1.1. The project summary

Project Number [1]	641727	Project Acronym [2]	PRIMAVERA

One form per project	
General information	
Project title [3]	PRocess-based climate sIMulation: AdVances in high resolution modelling and European climate Risk Assessment
Starting date [4]	01/11/2015
Duration in months [5]	57
Call (part) identifier [6]	H2020-SC5-2014-two-stage
Topic	SC5-01-2014 Advanced Earth-system models
Fixed EC Keywords	Climatic research
Free keywords	High-resolution; Global Climate Models; Climate Variability; Understanding European Climate Risk

Abstract [7]

The goal of PRIMAVERA is to deliver novel, advanced and well-evaluated high-resolution global climate models (GCMs), capable of simulating and predicting regional climate with unprecedented fidelity, out to 2050. This capability will deliver innovative climate science and a new generation of advanced Earth System Models. Sector-specific end-users in policy and business will be identified and engaged individually, with iterative feedback, to ensure that new climate information is tailored, actionable and strengthening societal risk management decisions.These goals will be achieved through the development of coupled GCMs from seven groups across Europe, with sufficient resolution to reproduce realistic weather and climate features (~25km mesh size), in addition to enhanced process parameterisation. Thorough assessment will use innovative process-based metrics and the latest observational and reanalysis datasets. Targeted experimental design will reduce inter-model spread and produce robust projections, forming the European contribution to the CMIP6 High-Resolution Model Intercomparison Project, led by PRIMAVERA. It is the first time that high-resolution coupled GCMs will be used under a single experimental protocol. Coordination, and the underlying process-understanding, will significantly increase the robustness of our findings. Our new capabilities will be used to improve understanding of the drivers of variability and change in European climate, including extremes, since such regional changes continue to be characterised by high uncertainty. We will also explore the frontiers of climate modelling and of high performance computing to produce simulations with a reduced reliance on physical parameterisations. These will explicitly resolve key processes such as ocean eddies, and will include new stochastic parameterisations to represent sub-grid scale processes. These “frontiers” simulations will further our understanding of the robustness of climate projections.

1.2. List of Beneficiaries

Project Number [1]	641727	Project Acronym [2]	PRIMAVERA

List of Beneficiaries

No	Name	Short name	Country	Project entry date[8]	Project exit date
1	MET OFFICE	MET OFFICE	United Kingdom		
2	THE UNIVERSITY OF READING	UREAD	United Kingdom		
3	KONINKLIJK NEDERLANDS METEOROLOGISCH INSTITUUT-KNMI	KNMI	Netherlands		
4	SVERIGES METEOROLOGISKA OCH HYDROLOGISKA INSTITUT	SMHI	Sweden		
5	CENTRE EUROPEEN DE RECHERCHE ET DE FORMATION AVANCEE EN CALCUL SCIENTIFIQUE	CERFACS	France		
6	MAX-PLANCK-GESELLSCHAFT ZUR FORDERUNG DER WISSENSCHAFTEN EV	MPG	Germany		
7	UNIVERSITE CATHOLIQUE DE LOUVAIN	UCL	Belgium		
8	BARCELONA SUPERCOMPUTING CENTER - CENTRO NACIONAL DE SUPERCOMPUTACION	BSC	Spain		
9	FONDAZIONE CENTRO EURO-MEDITERRANEOSUI CAMBIAMENTI CLIMATICI	CMCC	Italy		
10	ALFRED-WEGENER-INSTITUT HELMHOLTZ-ZENTRUM FUR POLAR- UND MEERESFORSCHUNG	AWI	Germany		
11	THE CHANCELLOR, MASTERS AND SCHOLARS OF THE UNIVERSITY OF OXFORD	UOXF	United Kingdom		
12	CONSIGLIO NAZIONALE DELLE RICERCHE	CNR	Italy		
13	EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS	ECMWF	United Kingdom		
15	UNIVERSITY OF LEEDS	UNIVLEEDS	United Kingdom		
16	STOCKHOLMS UNIVERSITET	SU	Sweden		
17	UNITED KINGDOM RESEARCH AND INNOVATION	NERC	United Kingdom		
18	PREDICTIA INTELLIGENT DATA SOLUTIONS SL	PREDICTIA	Spain		
19	DEUTSCHES KLIMARECHENZENTRUM GMBH	DKRZ	Germany		

1.2. List of Beneficiaries

No	Name	Short name	Country	Project entry date[8]	Project exit date
20	ADMINISTRATIA NATIONALA DE METEOROLOGIE R.A.	NMA	Romania	01/09/2016	

1.3. Workplan Tables - Detailed implementation

1.3.1. WT1 List of work packages

WP Number[9]	WP Title	Lead beneficiary[10]	Person-months[11]	Start month[12]	End month[13]
WP1	Development and application of metrics for process-based evaluation and projections	8 - BSC	196.00	1	57
WP2	The added value of high-resolution in the atmosphere and ocean	4 - SMHI	329.00	1	57
WP3	The role of model physics	1 - MET OFFICE	282.00	1	57
WP4	Frontiers of Climate Modelling	1 - MET OFFICE	240.00	1	57
WP5	Drivers of variability and change in European climate	5 - CERFACS	197.00	1	57
WP6	Flagship simulations	3 - KNMI	136.00	1	57
WP7	Project Management of PRIMAVERA	1 - MET OFFICE	40.00	1	57
WP8	Scientific coordination of PRIMAVERA	2 - UREAD	47.00	1	57
WP9	HPC and Data management	1 - MET OFFICE	142.00	1	57
WP10	Climate Risk Assessment	3 - KNMI	90.00	1	57
WP11	User Engagement and Dissemination	8 - BSC	147.00	1	57
WP12	Ethics requirements	1 - MET OFFICE	N/A	1	57
		Total	1,846.00		

1.3.2. WT2 list of deliverables

Deliverable Number[14]	Deliverable Title	WP number[9]	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D1.1	First examples of common process-based metrics application	WP1	7 - UCL	Report	Public	18
D1.2	Tools for assessment of climate experiments	WP1	9 - CMCC	Other	Public	40
D1.3	Strategy and metrics for PRIMAVERA and CMIP6 experiments analysis	WP1	8 - BSC	Other	Public	48
D1.4	Report on strategy for integrating metrics software	WP1	1 - MET OFFICE	Report	Public	12
D2.1	Assessment of benefits of increased ocean resolution	WP2	7 - UCL	Report	Public	14
D2.2	Quantification of benefits of increased atmosphere resolution	WP2	13 - ECMWF	Report	Public	24
D2.3	Quantification based on WP2 findings and initial sensitivity experiments in WP3	WP2	9 - CMCC	Report	Public	40
D2.4	Assessment of processes benefitting from increased resolution	WP2	12 - CNR	Report	Public	51
D2.5	Conclusions on minimum requirement for resolution	WP2	3 - KNMI	Report	Public	56
D3.1	Quantification of aerosol-radiation-cloud interactions.	WP3	2 - UREAD	Report	Public	24
D3.2	Quantification of land-atmosphere coupling strength response	WP3	2 - UREAD	Report	Public	48
D3.3	Quantification of effect of improved sea ice processes	WP3	9 - CMCC	Report	Public	40
D3.4	Quantification of benefits of enhanced upper ocean mixing processes	WP3	17 - NERC	Report	Public	46
D4.1	Quantification of the relative cost/ performance of	WP4	8 - BSC	Report	Public	53

Deliverable Number[14]	Deliverable Title	WP number[9]	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
	different approaches to going beyond simple parameterisation					
D4.2	Datasets from all model integrations: fully documented with appropriate meta-data	WP4	1 - MET OFFICE	Other	Public	42
D4.3	Assessment of improved representation of atmospheric processes	WP4	15 - UNIVLEEDS	Report	Public	52
D4.4	Assessment of representation of convection influences	WP4	11 - UOXF	Report	Public	55
D4.5	Quantify impact of resolution on European climate change	WP4	6 - MPG	Report	Public	56
D5.1	Document protocol for forced and coupled sensitivity experiments	WP5	5 - CERFACS	Report	Public	9
D5.2	Document impacts of AMV and IPV	WP5	2 - UREAD	Report	Public	51
D5.3	Document impact of sea ice and snow changes	WP5	4 - SMHI	Report	Public	55
D5.4	Documenting scenarios for 2015-34 European climate	WP5	5 - CERFACS	Report	Public	56
D6.1	Model configurations for Stream 1 integrations	WP6	3 - KNMI	Report	Public	4
D6.2	Stream 1 historical AMIP runs	WP6	3 - KNMI	Other	Public	12
D6.3	Stream 1 future AMIP runs	WP6	3 - KNMI	Other	Public	42
D6.4	Stream 1 control and historic coupled runs	WP6	6 - MPG	Other	Public	40
D6.5	Stream 2 historical AMIP runs	WP6	3 - KNMI	Other	Public	47
D6.6	Stream 2 future AMIP runs	WP6	5 - CERFACS	Other	Public	47
D6.7	Stream 2 control and historic coupled runs	WP6	8 - BSC	Other	Public	47
D7.1	Quarterly Reports for EC	WP7	1 - MET OFFICE	Report	Confidential, only for members	3

Deliverable Number[14]	Deliverable Title	WP number[9]	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
					of the consortium (including the Commission Services)	
D7.2	PRIMAVERA Public website	WP7	17 - NERC	Other	Public	4
D7.3	Project Media and Communications Plan	WP7	1 - MET OFFICE	Report	Confidential, only for members of the consortium (including the Commission Services)	6
D7.4	Project Dissemination and Exploitation Plan	WP7	1 - MET OFFICE	Report	Confidential, only for members of the consortium (including the Commission Services)	6
D7.5	Final Project Dissemination and Exploitation Report	WP7	1 - MET OFFICE	Report	Confidential, only for members of the consortium (including the Commission Services)	57
D7.6	Ethics Documentation	WP7	1 - MET OFFICE	Report	Confidential, only for members of the consortium (including the Commission Services)	2
D8.1	Progress summary following review of WPs	WP8	2 - UREAD	Report	Public	43
D8.2	Comparison case study for Government	WP8	2 - UREAD	Report	Public	56
D8.3	Final summary and synthesis of results	WP8	2 - UREAD	Report	Public	57
D8.4	PRIMAVERA Review paper	WP8	2 - UREAD	Report	Public	57
D8.5	Policy briefings for government target audience	WP8	2 - UREAD	Websites, patents filling, etc.	Public	57
D9.1	Data Management Plan	WP9	1 - MET OFFICE	Report	Public	6
D9.2	Initial training for JASMIN users	WP9	3 - KNMI	Other	Public	12

Deliverable Number[14]	Deliverable Title	WP number[9]	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D9.3	Tools for data conversion to CMOR format	WP9	1 - MET OFFICE	Other	Public	12
D9.4	Publication of PRIMAVERA Stream 1 data set	WP9	1 - MET OFFICE	Report	Public	44
D9.5	Publication of PRIMAVERA Stream 2 data set	WP9	1 - MET OFFICE	ORDP: Open Research Data Pilot	Public	55
D9.6	Review of DMP and lessons learnt for future projects	WP9	1 - MET OFFICE	Report	Public	57
D9.7	Exploitation of project data by the climate research community	WP9	1 - MET OFFICE	Report	Public	45
D10.1	Description of use cases identified	WP10	3 - KNMI	Report	Public	12
D10.2	Statistics and representation of events in CMIP5, CORDEX and first PRIMAVERA output.	WP10	4 - SMHI	Report	Public	24
D10.3	Physics of extreme and compound events from PRIMAVERA output.	WP10	2 - UREAD	Report	Public	51
D10.4	Scientific input for risk assessment	WP10	2 - UREAD	Report	Public	56
D11.1	End-user Dissemination and Communication plan	WP11	8 - BSC	Report	Public	3
D11.2	PRIMAVERA User Interface Platform	WP11	18 - PREDICTIA	Websites, patents filling, etc.	Public	20
D11.3	Sector specific case studies and climate projection factsheets	WP11	3 - KNMI	Websites, patents filling, etc.	Public	42
D11.4	Energy sector visual prototype	WP11	8 - BSC	Demonstrator	Public	51
D11.5	Evaluation report of project outcomes by end-users	WP11	8 - BSC	Report	Public	57
D11.6	Report on end-user requirements	WP11	1 - MET OFFICE	Report	Public	12
D11.7	Document detailing where PRIMAVERA	WP11	8 - BSC	Report	Public	57

Deliverable Number[14]	Deliverable Title	WP number[9]	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
	outcomes have been presented to end-users					
D12.1	H - Requirement No. 2	WP12	1 - MET OFFICE	Ethics	Confidential, only for members of the consortium (including the Commission Services)	2
D12.2	H - Requirement No. 1	WP12	1 - MET OFFICE	Ethics	Confidential, only for members of the consortium (including the Commission Services)	2

1.3.3. WT3 Work package descriptions

Work package number [9]	WP1	Lead beneficiary [10]	8 - BSC
Work package title	Development and application of metrics for process-based evaluation and projections		
Start month	1	End month	57

Objectives

•Develop process-based metrics to assess the impact of model improvements in the atmosphere (including those related to the changes in atmospheric composition), ocean, land, cryosphere, and the interactions between the different components, with special emphasis on the simulation of the European climate.
•Develop combinations of metrics to be used in order to improve climate models by using present-day performance to attempt to reduce uncertainty in climate projections.

Description of work and role of partners

WP1 - Development and application of metrics for process-based evaluation and projections [Months: 1-57]
BSC, MET OFFICE, UREAD, KNMI, SMHI, CERFACS, MPG, UCL, CMCC, CNR, NMA
This WP is led by F.J. Doblas-Reyes, BSC (lead) and Panos Athanasiadis, CMCC (co-lead)

Description of work
Process-based metrics to assess the impact of increased model resolution (WP2), improved model physics (WP3) and novel representation of sub-grid processes (WP4) on the simulation of the key mechanisms that govern European climate variability at a range of time scales (seasonal, interannual, decadal and longer) will be developed. These will build on the work performed in relevant FP7 related projects (e.g. EMBRACE), national efforts (AutoAssess) and the metrics effort carried out by the WGNE/WGCM Climate Model Metrics Panel (http://www-metrics-panel.llnl.gov/wiki) towards CMIP6, but with increased emphasis on understanding variability and extremes due to better resolved processes. This will also require access to the most recent observational and reanalysis datasets together with their uncertainties.
In addition to using the above metrics to assess model reliability over past climate, metrics addressing how strengths in feedbacks and the seasonal cycle relate to sensitivity to anthropogenic forcing, will also be developed. These will enable an increased understanding of inter-model spread in future projections and potentially ways in which this may be understood and constrained.
A specific set of metrics will be identified for each individual component of the GCMs (atmosphere, ocean, cryosphere and land surface), together with additional cross-cutting metrics focusing on processes that cannot be ascribed to one specific sub-system – such as coupled processes and important feedbacks involving the interplay between different constituents of the climate system.
Consideration will be given to metrics appropriate to both forced-atmosphere and coupled integrations, where the former can be more of a quantitative measure (comparing with past climate), while the latter will be process and statistically based.

The following rules will be applied in the development of the metrics:
a) The metrics will be included in a package and will be directly applicable to all participating models, creating a platform for the common interpretation of the model results obtained in other WPs.
b) Observational uncertainty will be taken into account.
c) Appropriate output lists will be elaborated and discussed with WP9.
d) Statistical inference should be applied specifically to each metric without exception.
e) The metrics developed within PRIMAVERA will complement (and integrate with) pre-existing tools/packages developed in the framework of national initiatives (AutoAssess), EU-funded FP7 (EMBRACE) or G8-funded (Exarch) projects, and/or at PCMDI (ESMVal). This implies avoiding repetition and fostering synergies. They will be designed as a European contribution to the CMIP6 effort targeting, in particular, HighResMIP.

This WP will coordinate the different metric development efforts that will take place across the project and integrate the large diversity of metrics that have been included to create a roadmap for European CMIP6 efforts and to efficiently analyse the simulations while they are running, increasing the added value of the demanding computing resources available to the climate modelling community. Metrics will be tested, as they are developed, on CMIP5 simulations and on any simulation performed in the period between the end of CMIP5 and the start of the project, especially if they are of high resolution. As the PRIMAVERA core and frontier simulations are being produced, partners involved in other

WPs will use them and provide feedback to WP1 to ensure an efficient development, in particular for the comparison of model results (by using the same metric across all the models). In parallel, WP1 will design a strategy to make use of the metrics to 1) reduce the uncertainty in the simulations by better constraining model with observations and increasing the robustness in process representation across models, 2) increase the efficiency of European climate modelling groups by quickly comparing their experiments on an equal basis, and 3) raise the confidence in climate projections to provide action- and policy-relevant climate information. Metrics will be combined to assess present-day climate, and then used in an attempt to understand and constrain future projections.

T1.1 [M1-M57] Process-based metrics for single components (Lead: UREAD. Participants: CERFACS, CMCC, CNR, BSC, MET OFFICE, MPG, SMHI, UCL, KNMI, NMA)
Metrics will be developed to quantify the representation of processes that involve mainly one component of the climate system when considering their impact on European climate. These will include both aspects of the basic mean state (e.g. mid-latitude jet, storm track, ocean heat content) together with weather-related variability and extremes (storm clustering, atmospheric moisture transport, sea ice variability). Metrics will be combined to enable assessment of present day climate, and then used in an attempt to understand and constrain future projections (D1.1, D1.2, D1.3).

T1.2 [M1-M57] Process-based coupled and multi-component metrics (Lead: UCL. Participants: CERFACS, CMCC, BSC, MET OFFICE, MPG, SMHI, UREAD, NMA)
Metrics will be developed to quantify the representation of coupled processes and those processes that involve more than one component of the climate system and their impact on European climate. These will include coupled modes of variability and teleconnections (North Atlantic Oscillation (NAO), Atlantic Meridional Overturning Circulation (AMOC), troposphere-stratosphere coupling), local coupled feedbacks and indices of climate extremes. Metrics will be combined to enable assessment of overall present-day performance, and be used to understand and constrain future projections (D1.1, D1.2, D1.3).

T1.3 [M1-M57] Metrics for final model synthesis and evaluation, and contribution to CMIP6 (Lead: MET OFFICE. Participants: CMCC, BSC, MPG)
This task aims at providing a framework to integrate all the diagnostics developed to address the metrics described in tasks 1.1 and 1.2 and to develop a long-term solution for the process-based analysis of the PRIMAVERA and CMIP6 European experiments (including HighResMIP). The solution will be based on existing national and international initiatives to develop metrics and will encompass the main developments in metrics performed in PRIMAVERA. In particular this task entails the conversion of AutoAssess to Python, the analysis of the common functionalities of the EMBRACE and WGNE/WGCM diagnostic packages including the necessary adaptations for a special focus on Europe and the design of a strategy for common metrics and diagnostics for the analysis of the CMIP6 experiments performed by European climate modelling institutions (D1.3, D8.3).

Interactions with other work packages:
This work package provides to:
WP2,3,4,5,6 (Metrics to assess model processes, impact of resolution and model physics, teleconnections via MS1)
WP10 (Metrics for assessment of processes for input to climate risk assessment) - D10.2
This work package receives from:
All WPs (Ideas to exploit the simulations to analyse a specific process and develop the general-purpose metric, via MS1, and observational-based datasets required for model assessment)
WP9 (Data management issues related to the implementation of the metrics at the different institutions and adding metrics to open repository) - D9.2

Participation per Partner

Partner number and short name	WP1 effort
1 - MET OFFICE	15.00
2 - UREAD	24.00
3 - KNMI	6.00
4 - SMHI	17.00
5 - CERFACS	18.00
6 - MPG	18.00

Partner number and short name	WP1 effort
7 - UCL	24.00
8 - BSC	30.00
9 - CMCC	24.00
12 - CNR	18.00
20 - NMA	2.00
Total	196.00

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D1.1	First examples of common process-based metrics application	7 - UCL	Report	Public	18
D1.2	Tools for assessment of climate experiments	9 - CMCC	Other	Public	40
D1.3	Strategy and metrics for PRIMAVERA and CMIP6 experiments analysis	8 - BSC	Other	Public	48
D1.4	Report on strategy for integrating metrics software	1 - MET OFFICE	Report	Public	12

Description of deliverables

D1.1: First examples of the application of common process-based metrics to existing climate experiments with a focus on European climate variability and change (M18)
D1.2: Tools for the process-based assessment of the PRIMAVERA climate experiments (M40)
D1.3: Strategy and package of metrics, in project repository coded using freely available software, for the analysis of the PRIMAVERA and CMIP6 experiments, with a focus on European climate variability and change (M48)
D1.4: Report for distribution to WP leaders on strategy for integrating metrics software into different partner institutions (M12)

D1.1 : First examples of common process-based metrics application [18]

First examples of the application of common process-based metrics to existing climate experiments with a focus on European climate variability and change

D1.2 : Tools for assessment of climate experiments [40]

Tools for the process-based assessment of the PRIMAVERA climate experiments

D1.3 : Strategy and metrics for PRIMAVERA and CMIP6 experiments analysis [48]

Strategy and package of metrics, in project repository coded using freely available software, for the analysis of the PRIMAVERA and CMIP6 experiments, with a focus on European climate variability and change

D1.4 : Report on strategy for integrating metrics software [12]

Report for distribution to WP leaders on strategy for integrating metrics software into different partner institutions

Schedule of relevant Milestones

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification
MS1	Observational/reanalysis/ CMIP5 datasets required for metrics development and model assessment, available on JASMIN in appropriate format, with documentation	4 - SMHI	6	Means of verification: All data available and confirmed against checklist, coordinated by WPs 1 and 9
MS2	Strategy for integrating the metrics software available in the different partner institutions	1 - MET OFFICE	12	Means of verification: Strategy available to partners
MS3	Assess performance of metrics package for Stream 1 and WP3 integrations.	2 - UREAD	44	Means of verification: Report on Wiki with priorities for further development to meet WP requirements
MS6	Plan and tools for co-ordinated process-based analysis of the core-simulations.	4 - SMHI	12	Means of verification: Plan and tools available. Validated using representative data.

Work package number [9]	WP2	Lead beneficiary [10]	4 - SMHI
Work package title	The added value of high-resolution in the atmosphere and ocean		
Start month	1	End month	57

Objectives

• Provide a systematic assessment of the benefits of simultaneously increased atmospheric and oceanic resolutions and increased atmospheric resolution only in global coupled climate models for processes affecting European climate and its variability.
• Evaluate the robustness of the response across the PRIMAVERA model ensemble and implications for future projections.

Description of work and role of partners

WP2 - The added value of high-resolution in the atmosphere and ocean [Months: 1-57]
SMHI, MET OFFICE, UREAD, KNMI, CERFACS, MPG, UCL, BSC, CMCC, AWI, UOXF, CNR, ECMWF, NERC, NMA
This work package is led by: Torben Koenigk, SMHI (lead) and Virginie Guemas, BSC (co-lead).

Description of work
WP2 will focus on analysing the coordinated coupled and AMIP-type core experiments from the PRIMAVERA global climate models (WP6). In the first year of the project until the first core simulations are available, we will investigate the effect of higher resolution in already existing CMIP5 and CMIP6 DECK global model simulations from the PRIMAVERA partners. The high-resolution simulations will be evaluated over the historical period using the newest reanalyses and satellite based products such as ESA-CCI. The analysis in WP2 will be done in close collaboration with WP1 using both existing tools and metrics and the newly developed metrics in WP1.
The analyses will focus on the benefits of high resolution on processes with well-established links to European climate and will assess the robustness of these benefits across the PRIMAVERA models.
In the second half of the project, results from WP5 on large-scale drivers will be used to assess how these influence both the processes previously identified, as well as any additional processes found to be significant.

T2.1 [M1-M57] North Atlantic climate system processes (Lead: KNMI. Participants: SMHI, BSC, CMCC, ECMWF, MET OFFICE, UREAD, CNR, UOXF, MPG, CERFACS, NERC, AWI, NMA)
Focus will be on the representation of the North Atlantic ocean processes, dynamics and air-sea interactions, and atmosphere dynamics in the North Atlantic/European region. Processes will include ocean mixing, mid-latitude jets and blocking, eddy fluxes of heat, momentum and vorticity, and their combined effect on moisture and heat transports towards Europe, including the occurrence of extreme events such as droughts, heat waves and flooding (D2.1, D2.2, D2.3, D2.5).

T2.2 [M1-M57] Arctic processes (Lead: UCL. Participants: SMHI, BSC, CMCC, ECMWF, CNR, MPG, CERFACS, NERC, AWI, NMA)
Assess the added value of a resolution increase on Arctic sea ice processes including ice concentration, thickness and transport, and ocean-sea ice interactions such as ocean circulation and heat transports and the role of sea ice processes (e.g. melting and freezing) on ocean deep water formation and the AMOC (D2.1, D2.3, D2.5).

T2.3 [M13-M57] Tropical cyclones and their transition to the extra-tropics (Lead: CMCC. Participants: ECMWF, MET OFFICE, UREAD, KNMI, MPG)
Evaluate the benefits of high resolution on the representation of tropical cyclones (including formation and evolution), and their extra-tropical transition and impact on European climate, including associated heat and moisture transports and potential changes in the near future (D2.2, D2.5).

T2.4 [M24-M57] Processes impacted by large-scale drivers and implications for climate projections (Lead: CNR. Participants: ECMWF, UREAD, MET OFFICE, SMHI, UCL, MPG, CERFACS, NERC, CMCC, KNMI)

Based on WP5 analysis of large-scale drivers, focus on how European processes are affected by local drivers such as the Atlantic Multi-decadal Oscillation (AMO) and NAO, remote drivers such as the Pacific Decadal Variability (PDV), and hence compare and contrast the implications for processes of projected changes in large-scale drivers (WP5) with the actual change in processes diagnosed from the climate projections (D2.4, D8.3).

Interactions with other work packages:
This work package provides to:
WP1 (feedback for design and improvement of metrics and tools via MS1)
WP3 (comparison of the benefits from improved model physics and increased resolution on the same physical processes) - D2.3
WP4 (assessment methods to apply to frontier integrations)
WP5 (impact of the large-scale drivers on processes at different resolutions) - D5.2
WP6 (recommendations for the design of Stream 2 simulations) - D8.1
WP8 (minimum resolution requirements for an optimal representation of the North Atlantic, Arctic, and Pacific climate and their impacts on the European climate for the end of project deliverable) - D8.3
WP9 (provision of reference datasets used for assessment and validation) - MS1
WP10 (assessment of the benefits of high-resolution in capturing extremes) - D10.2

This work package receives from:
WP1 (metrics for process assessment via MS1)
WP3 (benefits from new model developments for comparison with the benefits from increased resolution on the same physical processes) - D3.1-D3.4
WP5 (assessment of impact of large-scale drivers)
WP6 (core simulation datasets) - D9.4-D9.5
WP9 (dataset formats and data management for provision to Open Access) - D9.4-D9.5

Participation per Partner

Partner number and short name	WP2 effort
1 - MET OFFICE	11.00
2 - UREAD	30.00
3 - KNMI	30.00
4 - SMHI	33.00
5 - CERFACS	15.00
6 - MPG	22.00
7 - UCL	22.00
8 - BSC	30.00
9 - CMCC	34.00
10 - AWI	12.00
11 - UOXF	4.00
12 - CNR	34.00
13 - ECMWF	30.00
17 - NERC	20.00
20 - NMA	2.00
Total	329.00

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D2.1	Assessment of benefits of increased ocean resolution	7 - UCL	Report	Public	14
D2.2	Quantification of benefits of increased atmosphere resolution	13 - ECMWF	Report	Public	24
D2.3	Quantification based on WP2 findings and initial sensitivity experiments in WP3	9 - CMCC	Report	Public	40
D2.4	Assessment of processes benefitting from increased resolution	12 - CNR	Report	Public	51
D2.5	Conclusions on minimum requirement for resolution	3 - KNMI	Report	Public	56

Description of deliverables

D2.1: Assessment of the benefits of increased resolution on the North Atlantic ocean dynamics and processes and the Arctic sea ice conditions and their robustness across the pre-PRIMAVERA multi-model ensemble listed in milestone MS1 (M15).
D2.2: Quantification of the benefits of increased resolution in the atmosphere only versus in the coupled system, as well as their robustness across the WP6 Stream 1 simulations, for processes which impact European weather and climate such as atmospheric blocking, ocean-sea-ice-atmosphere interactions in the Arctic region and for tropical cyclones and their extra-tropical transition (M24).
D2.3: Based on WP2 findings and initial sensitivity experiments performed in WP3, quantification of the relative merits of increased resolution and model developments on the North Atlantic, Arctic, Pacific and tropical climates and their robustness across the PRIMAVERA models to provide recommendations to WP6 for the Stream 2 design (M40).
D2.4: Assessment of the impact of large-scale drivers (from WP5) on processes that benefit from increased resolution across the multi-model ensemble, and their sensitivity to climate change based on the WP6 Stream 1 simulations (M51).
D2.5: Conclusions on the minimum requirements in terms of model resolution for a reliable representation of the North Atlantic, Arctic and Pacific climates, the tropical cyclones and their impact on the European climate and on their projected changes in future based on Stream 2 simulations from WP6 (M56).

D2.1 : Assessment of benefits of increased ocean resolution [14]

Assessment of the benefits of increased resolution on the North Atlantic ocean dynamics and processes and the Arctic sea ice conditions and their robustness across the pre-PRIMAVERA multi-model ensemble listed in milestone MS1

D2.2 : Quantification of benefits of increased atmosphere resolution [24]

Quantification of the benefits of increased resolution in the atmosphere only versus in the coupled system, as well as their robustness across the WP6 Stream 1 simulations, for processes which impact European weather and climate such as atmospheric blocking, ocean-sea-ice-atmosphere interactions in the Arctic region and for tropical cyclones and their extra-tropical transition

D2.3 : Quantification based on WP2 findings and initial sensitivity experiments in WP3 [40]

Based on WP2 findings and initial sensitivity experiments performed in WP3, quantification of the relative merits of increased resolution and model developments on the North Atlantic, Arctic, Pacific and tropical climates and their robustness across the PRIMAVERA models to provide recommendations to WP6 for the Stream 2 design

D2.4 : Assessment of processes benefitting from increased resolution [51]

Assessment of the impact of large-scale drivers (from WP5) on processes that benefit from increased resolution across the multi-model ensemble, and their sensitivity to climate change based on the WP6 Stream 1 simulations

D2.5 : Conclusions on minimum requirement for resolution [56]

Conclusions on the minimum requirements in terms of model resolution for a reliable representation of the North Atlantic, Arctic and Pacific climates, the tropical cyclones and their impact on the European climate and on their projected changes in future based on Stream 2 simulations from WP6

Schedule of relevant Milestones

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification
MS1	Observational/reanalysis/ CMIP5 datasets required for metrics development and model assessment, available on JASMIN in appropriate format, with documentation	4 - SMHI	6	Means of verification: All data available and confirmed against checklist, coordinated by WPs 1 and 9
MS3	Assess performance of metrics package for Stream 1 and WP3 integrations.	2 - UREAD	44	Means of verification: Report on Wiki with priorities for further development to meet WP requirements
MS4	List of existing past-CMIP5 global model simulations and of the available high-resolution observational datasets for validation of the simulations.	12 - CNR	2	Means of verification: List available and distributed within consortium.
MS5	Exchange of model outputs from the past-CMIP5 high-resolution simulations already available at the start of the project and of observational datasets for validation.	8 - BSC	4	Means of verification: Data available in the central repository in appropriate common formats.
MS6	Plan and tools for co-ordinated process-based analysis of the core-simulations.	4 - SMHI	12	Means of verification: Plan and tools available. Validated using representative data.

Work package number [9]	WP3	Lead beneficiary [10]	1 - MET OFFICE
Work package title	The role of model physics		
Start month	1	End month	57

Objectives

• Quantify the need for improved representation or levels of complexity of a range of physical processes within the atmosphere, ocean, land and sea ice in a high resolution environment.
• Develop and evaluate the impact of improved representations of key processes influencing European climate such as clouds and aerosols, land surface processes, Arctic sea ice and near-surface ocean mixing within the ensemble of high resolution simulations.

Description of work and role of partners

WP3 - The role of model physics [Months: 1-57]
MET OFFICE, UREAD, KNMI, SMHI, MPG, UCL, BSC, CMCC, ECMWF, UNIVLEEDS, SU, NERC
This work package is led by: Cath Senior (MET OFFICE, lead), and sub work packages led by (3A) Nicolas Bellouin, UREAD; (3B) Panos Athanasiadis, CMCC; (3C) Dorotea Iovino, CMCC and (3D) Adrian New, NERC

Description of work
Improved scientific understanding of processes that govern climate variability and change at regional spatial scales as well as extremes is needed to feed into model capability to reduce uncertainty in future projections. Models of relatively low resolution may not provide a suitable platform for testing new developments. Higher resolution models with improved characteristics of the regional scale circulation and better simulation of large-scale characteristics such as the water cycle can enable more detailed representation or greater complexity of important processes to be employed. We will evaluate key processes in existing CMIP5 simulations and within the Stream 1 core multi-model ensemble from WP6 (as it becomes available) and incorporate, test and evaluate new developments in the parameterisation of processes within the atmosphere, land, sea ice and oceans in our global models at enhanced resolutions (~25 km scale) and/or at even higher resolution (<10km in the atmosphere or ocean in conjunction with WP4) to investigate the impact on the regional climate of Europe. Focus will be on physical processes known to particularly impact European climate such as clouds and aerosols, land surface processes, Arctic sea ice and near surface ocean mixing. The latest available observations will be used for process-level evaluation wherever possible. A second set of core experiments (Stream 2) will be performed in WP6 incorporating improvements suggested from testing in WP3 with the goal of delivering improved modelling capability for Europe. The benefits of including the additional physics in the Stream 2 experiments will be evaluated against the Stream 1 experiments. Because of the diverse nature of the work involved, this work package comprises four sub-work packages associated with the different components of the climate system as follows:

3A: Clouds and Aerosols
Changes in aerosol concentrations and cloudiness exert a forcing of top-of-atmosphere and surface radiative fluxes, which in turn modifies surface temperature and the hydrological cycle. In PRIMAVERA, aerosol concentrations are prescribed in a consistent way in all core simulations (WP6), thus partly suppressing the inter-model diversity in aerosol and cloud radiative forcing, trends, and climate response. The PRIMAVERA ensemble will therefore be uniquely suitable to:
- Assess whether prescribed (rather than interactive) aerosols can produce realistic radiative forcing and responses in spite of a lack of consistency with the modelled clouds and precipitation;
- Compare core simulations to additional European simulations of aerosol-radiation-cloud interactions at convection-permitting scales to identify potential biases introduced by lower resolution dynamics and microphysics complexity;
- Quantify the robustness of aerosol-radiation-cloud interactions and their effect on European Climate across models, resolutions, and Stream 1 and 2 simulations;
Findings will guide future model developments (WP4) and the specification of Stream 2 simulations.

T3A.1 [M8-M40] Quantify the importance of interactive aerosol-radiation-cloud coupling. (Lead: SU. Participants: SMHI, UREAD, UNIVLEEDS)
Quantify the impact of introducing interactive aerosol-radiation-cloud couplings on the quality of simulated European climate as measured by WP1 metrics. The analysis will be based on Stream 1 AMIP, Hansen-like, and coupled simulations (WP6), complemented by shorter simulations with interactive aerosol schemes (D3.1).

T3A.2 [M8-M40] Explore the relationship between resolution and parameterization complexity. (Lead: UNIVLEEDS. Participants: SMHI, SU, UREAD)
Cloud microphysics schemes of greater complexity than those used in Stream 1 simulations may be required to accurately represent aerosol-radiation-cloud interactions, however these simulations may not resolve dynamics sufficiently well enough to drive these sophisticated cloud schemes that represent droplet activation and ice nucleation from aerosols. To explore and quantify these potential shortcomings, high-complexity, high-resolution simulations of the European domain with the convection-permitting (~kilometre-scale) regional MetUM with advanced cloud and aerosol interacting microphysics schemes will be compared to observations and coarse-grained for comparison to prescribed (Stream 1) and interactive (T3a.2) aerosol simulations (WP4) (D3.1, D4.3).

T3A.3 [M8-M57] Quantify the need for improved representation of clouds and aerosols in a high resolution environment. (Lead: UREAD. Participants: SMHI, SU, UNIVLEEDS)
Analyse the robustness of aerosol and cloud radiative forcing, their fast adjustments and climate response across AMIP and coupled CMIP5 and Stream 1 simulations. The analyses will be informed by the quantification of the added value of cloud and aerosol complexity by Tasks T3a.1 and 2, and will focus specifically on radiative and cloud processes and convective and stratiform cloud regimes to identify those processes and regimes that are most sensitive to complexity in a high-resolution context. The analysis will then be repeated using Stream 2 simulations to assess whether the added value has been achieved (D3.1 and D8.3 via Stream 2 assessment).

3B: Land surface-atmosphere coupling
We start with the hypothesis that an overly wide range of land-atmosphere coupling strength54 plays a significant role in causing model divergence in CMIP4 and 5 projections. For instance, it has been suggested that the land-atmosphere coupling can determine a significant portion of the summer climate variability and extremes in the European region primarily through the soil moisture-evapotranspiration feedback55. Soil moisture has been shown in modeling studies to act as a precursor of extreme maximum temperature and drought in the European region56,57. Vegetation seasonality, the evaporation-cloud feedback, and the surface soil temperature-circulation feedback, can also amplify heat waves58,59,60,61. WP3B will therefore adapt and homogenise the use of some key physical packages in the land surface (LS) – Planetary Boundary Layer (PBL) system and will then systematically test and compare the sensitivity to improvements in model resolution and improvements in model physics. The PBL physics was also recently identified as a key factor involved in the dynamics of heat waves, explaining their persistence60. We will make use of both uncoupled (LS-only) and coupled (LS GCM) simulations under different configurations of physical complexity (other parts of WP3 and WP4), as well as over a range of resolutions (from WP2 and WP4). After determining the degree of LS-atmosphere coupling for each configuration, we will apply other WP1 metrics to understand feedbacks with the rest of the climate system, e.g. ocean and sea ice, including their impacts on regional predictability. WP3B will also develop methods and data sets suitable for the computation of key metrics in WP1.

T3B.1 [M12-57] Quantifying the contribution of land-atmosphere biogeophysical processes to European regional predictability. (Lead: UREAD. Participants: CMCC, KNMI)
This task will attribute land-atmosphere coupling strength to constraints and processes that emerge with resolution. In particular, by combining off-line and coupled LS simulations, we will investigate how the LS-atmosphere coupling strength depends, for the key resolutions adopted in PRIMAVERA simulations (core and FCM), on the representation (parameterisation) of:
• Terrestrial surface albedo and its dependence on:
- landscape composition/state, including effects of elevated terrain (rock, snow, ice)
- snow and vegetation seasonal dynamics, including black carbon deposition on snow.
•Plant response to:
- surface radiation changes (direct/diffuse) caused by aerosol loading and cloud.
- surface temperature and root-zone water stress via photosynthesis and transpiration.
•Runoff generation: simplified (excess) vs. complex (e.g. TOPMODEL)
•PBL (particularly Surface Layer) turbulent transfer:
- Vertical stability adjustments suitable for ~25km and ~5km atmospheric grids
- Influence of coherent circulations and their enhancement of surface fluxes

We will confront full LS models response against simplified models, (e.g. calibrated regression of evaporation dynamics and idealised experiments in Task T3B.3). Focus for the attribution of the coupling strength will be on land surface skin temperature, plant transpiration and runoff (via river discharge) (D3.2, D8.3).

T3B.2 [M18-40] River routing schemes for high-resolution GCMs. (Lead: CMCC. Participants: KNMI)
This task will produce and apply, in common to all LS models in PRIMAVERA:
• ancillary files (e.g. terrain height/variability/slope aspects, soil mineral composition, vegetative cover)

• hydrological catchment masks for all major global rivers64,65
• global river network at the two key resolutions (~25km in WP2 and ~5km in WP4).
• These configurations will support T3B.1 and strengthen the consistency of:
- River routing and discharge into the ocean.
- Catchment-level discharge for metrics in WP1.
Delivers to D3.2 and D8.3.

T3B.3 [M24-50] Idealised and sensitivity experiments around the theme of hydrological supply/demand and its impacts on the surface energy balance. (Lead: CMCC. Participants: UREAD, UNIVLEEDS)
For Stream 1 of the core integrations, and starting from off-line simulations, we will undertake idealised studies, to be contrasted with T3B.1 and using tools from T3B.2:
• Alter Europe-wide terrain to coarse/low-elevation mountains and consistent land cover.
• Alter Europe-wide vegetation water use intensity towards:
- Hydro-ecologic equilibrium, consistent with potential vegetation
- High-intensity, consistent with intensive agriculture and forestry

For Stream 2 of the core integrations, we will undertake sensitivity experiments:
• Implement a selected combination of the most important changes from T3B.1 and Stream 1.
• Apply-Europe-wide nudging of low-level cloud (contrasting with analyses in WP2,4) and perform Koster-type studies54 of soil moisture pre-conditioning in Spring and its impact on (intra-)seasonal memory.
Assess impacts on Europe-wide atmospheric circulation, surface temperature, boundary layer dynamics etc., as well as evaporative and runoff efficiencies, all the way to land-atmosphere coupling. (D3.2, D8.3)

T3B.4 [M36-57] Land surface – atmosphere coupling at resolutions that permit explicit convection. (Lead: UREAD. Participants: CMCC, ECMWF)
By exploiting the results of T3B.1,T3B.3 and guided by the metrics in WP1, we will recompute the land-atmosphere coupling strength for the convection-permitting simulations in WP4 (D3.2, D4.4, D8.3) to quantify the impact of:
• Better simulated diurnal cycle of convection and precipitation, as well as their propagation.
• Emergence of low-level jets and seasonal dynamics of mesoscale soil moisture fronts
• Shifting of convection triggers from wet land patches to dry land patches (62)

3C: Sea ice
Shortcomings in the representation of sea ice processes in CMIP5 models contribute to a wide spread in historical and projected sea ice change. All CMIP5 models capture the observed reduction in September Arctic sea ice extent, but still show considerable range in their projections over the coming decades. There is no consensus yet among models on the rate of decline in Arctic sea ice or on when ice-free Arctic conditions will be reached. This suggests that improved representation of key sea ice processes will be required to both better simulate the observed sea ice behavior and to advance our understanding of the predictability of sea ice conditions. To address this, WP3C will assess the impact of more complex sea ice parameterisations in the high-resolution environment. Three sea ice models will be used, namely LIM, GELATO and CICE, and to improve robustness, changes will be tested in more than one model wherever possible. Changes will be validated within the coupled model context of present day and the recent past through comparison with available observational-based data sets and satellite products. We will also investigate the interaction of sea ice physics and model resolution (from 1 degree to ¼ degree).

T3C.1 [M1-M57] Sea ice dynamics and thermodynamics. (Lead: CMCC. Participants: ECMWF, BSC, MET OFFICE, SMHI, UCL)
This task will assess the impact of developments available in sea ice dynamics and thermodynamics such as rheology, multi-category ice and multi-layer thermodynamics, on Arctic sea ice variability and trends. The new parameterisations will be tested and evaluated in the three models. We will evaluate the impact of improved representation of Arctic sea ice properties on European Climate (D3.3, D8.3).

T3C.2 [M1-M57] Surface schemes and interactions with atmosphere and ocean. (Lead: BSC. Participants: CMCC, ECMWF, SMHI, UCL)
This task will investigate the response of Arctic sea ice variability to improved surface schemes. The effect of new representations of snow processes, melt ponds and spatial distribution of ice albedo will be tested and evaluated. This will aim towards a better representation of heat fluxes at the sea ice – atmosphere interface, hence potentially affecting heat exchanges at the sea ice – ocean bottom interface. The impact of changes in Arctic sea ice on large-scale ocean and atmosphere circulation will be assessed (D3.3, D8.3).

3D : Upper Ocean Mixing
Mixing in the upper ocean affects the ocean mixed-layer depth, sea-surface temperature (SST), and air-sea interactions, and therefore has the potential to affect European climate variability. The SSTs in the North Atlantic are known to affect

the North Atlantic Oscillation both directly and through the ocean re-emergence mechanism, whereby water masses which form during one winter can be covered over during the seasonal cycle of the mixed layer, and re-exposed to the atmosphere during the following winter. There is also evidence that SSTs in the tropical Atlantic affect local air-sea exchanges and, through teleconnections, could impact on European climate variability. This task will investigate the impact of upper ocean mixing processes on European climate variability. It will require additional short (decadal timescale) simulations parallel to those in Stream 1 of the core runs in WP6, and use the metrics from WP1 to assess the benefits of the additional physics. The task will provide recommendations on the optimal way to include these processes into Stream 2 of the core runs (at M24), as well as assessing their impact in those (multidecadal) Stream 2 runs (M25-45). The larger part of the effort will be in M1-24, though significant effort will also be needed in M25-45.

The specific processes which will be included fall into two categories, as follows:

T3D.1 [M1-57] Impact and optimal representation of Langmuir turbulence. (Lead: NERC. Participants: KNMI, MET OFFICE)
Langmuir turbulence is a process through which the surface wave field drives vertical diffusive fluxes of momentum and tracers in the ocean mixed layer. We will investigate the impact of interactive wave fields (through the use of coupled wave models) as compared with prescribed wave fields, and the impact of a new advanced scheme for Langmuir turbulence (based on a second order turbulence closure model informed by extensive Large Eddy Simulation modelling, from the OSMOSIS project in the UK) as compared with the existing (simpler) scheme in the NEMO ocean model (D3.4, D8.3).

T3D.2 [M1-57] Impact and optimal representation of internal mixing processes. (Lead: MPG. Participants: MET OFFICE, NERC)
We will evaluate the representation of internal processes which act to modify the mixed layer structure either through (i) restratification by sub-mesoscale eddies within the mixed layer, as described by enhanced implementations of the Fox-Kemper63 scheme, and (ii) mixing generated by near-inertial and internal waves at the base of, and within, the mixed layer (D3.4, D8.3).

Interactions with other work packages:
This work package provides to:
WP1 (methods and datasets suitable for the computation and improvement of key metrics via MS1)
WP2 (benefits from increased resolution on the same physical processes) - D2.3
WP4 (developed version of interactive cloud aerosol coupling and complexity scheme) - D4.3
WP6 (model code for inclusion of new physics in Stream 2 of the core integrations) - D6.5-D6.7
WP8 (recommendations on additional physics for design of Stream 2 of the core integrations and conclusions on the overall benefits of model improvements) - D8.1

This work package receives from:
WP1 (metrics needed to evaluate the impact of the improved model physics via MS1)
WP2 (comparison of the benefits from improved model physics and increased resolution on the same physical processes) - D2.3
WP4 (convection-permitting atmospheric simulations, with advanced cloud-aerosol interacting microphysics schemes and for land-atmosphere coupling assessment) - D4.3-D4.4
WP6 (configuration of Stream 1 models as baseline for improved model physics implementation, and core simulations for comparison) - D6.1

Participation per Partner

Partner number and short name	WP3 effort
1 - MET OFFICE	34.00
2 - UREAD	49.00
3 - KNMI	12.00
4 - SMHI	26.00
6 - MPG	18.00
7 - UCL	16.00

Partner number and short name	WP3 effort
8 - BSC	18.00
9 - CMCC	32.00
13 - ECMWF	12.00
15 - UNIVLEEDS	29.00
16 - SU	16.00
17 - NERC	20.00
Total	282.00

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D3.1	Quantification of aerosol-radiation-cloud interactions.	2 - UREAD	Report	Public	24
D3.2	Quantification of land-atmosphere coupling strength response	2 - UREAD	Report	Public	48
D3.3	Quantification of effect of improved sea ice processes	9 - CMCC	Report	Public	40
D3.4	Quantification of benefits of enhanced upper ocean mixing processes	17 - NERC	Report	Public	46

Description of deliverables

D3.1: Quantification of robustness of aerosol-radiation-cloud interactions across models and resolutions (M36).
D3.2: Quantification and attribution of land-atmosphere coupling strength response to atmospheric resolution, forcing (including the temporal distribution of precipitation), land surface physics and robustness across multi-model resolution ensemble (M48).
D3.3: Quantification of the effect of improved sea ice processes on representing Arctic sea ice and the impact on European climate and robustness across multi-model resolution ensemble (M40).
D3.4: Quantification of the benefits of enhanced upper ocean mixing processes on the European climate system and robustness across the multi-model resolution ensemble (M46).

D3.1 : Quantification of aerosol-radiation-cloud interactions. [24]

Quantification of robustness of aerosol-radiation-cloud interactions across models and resolutions

D3.2 : Quantification of land-atmosphere coupling strength response [48]

Quantification and attribution of land-atmosphere coupling strength response to atmospheric resolution, forcing (including the temporal distribution of precipitation), land surface physics and robustness across multi-model resolution ensemble

D3.3 : Quantification of effect of improved sea ice processes [40]

Quantification of the effect of improved sea ice processes on representing Arctic sea ice and the impact on European climate and robustness across multi-model resolution ensemble

D3.4 : Quantification of benefits of enhanced upper ocean mixing processes [46]

Quantification of the effect of improved sea ice processes on representing Arctic sea ice and the impact on European climate and robustness across multi-model resolution ensemble

Schedule of relevant Milestones

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification
MS1	Observational/reanalysis/ CMIP5 datasets required for metrics development and model assessment, available on JASMIN in appropriate format, with documentation	4 - SMHI	6	Means of verification: All data available and confirmed against checklist, coordinated by WPs 1 and 9
MS3	Assess performance of metrics package for Stream 1 and WP3 integrations.	2 - UREAD	44	Means of verification: Report on Wiki with priorities for further development to meet WP requirements
MS7	Deliver recommendations and model configurations with improved physics for Stream 2 of the core integrations.	1 - MET OFFICE	24	Means of verification: Report delivered to WP8, models verified by groups. Metadata and descriptions delivered to WP6,9
MS8	Assessment of impact of improved physics and robustness across all PRIMAVERA models in Stream 2 as compared with Stream 1, and dependencies of robustness on model resolution	9 - CMCC	55	Means of verification: Assessment documented and provided to WP8

Work package number [9]	WP4	Lead beneficiary [10]	1 - MET OFFICE
Work package title	Frontiers of Climate Modelling		
Start month	1	End month	57

Objectives

• Develop the next generation of coupled models by exploring the concept of 'Beyond simple parameterisation' by testing different approaches to the representation of sub-gridscale processes.
• Assess the relative benefits and costs of each approach, and provide recommendations for future development.

Description of work and role of partners

WP4 - Frontiers of Climate Modelling [Months: 1-57]
MET OFFICE, CERFACS, MPG, BSC, AWI, UOXF, CNR, ECMWF, UNIVLEEDS, NERC, DKRZ
This work package is led by: Malcolm Roberts, MET OFFICE (lead) and Jin-Song von Storch, MPG (co-lead).

Description of work
The lack of representation of sub-grid scale variability and the uncertainty in model parameters mean that the parameterisation process is a large source of error in climate simulations. Three different approaches to the representation of sub-grid scale processes will be investigated:

1. Uniformly increasing global model resolution in order to resolve or better represent the processes explicitly, such as ocean eddies or atmospheric convection;
2. Increase sea ice-ocean model resolution in regions in which important, otherwise unresolved processes are very likely to occur by using unstructured mesh methods;
3. Use stochastic parameterisations to represent the variability of sub-grid scale processes, including allowing some uncertain parameter values to vary in a stochastic manner.

By comparing with observations relevant to the processes studied, the strengths and problems of each of the three approaches in simulating the present-day European climate and its variability will be assessed.

Most of the simulations required will be made as scientifically parallel as possible and for the same period as those of the core integrations, so that complementary analysis can be achieved, and therefore giving an extra dimension in the model hierarchy. However the integrations used to study atmospheric convection will only be 5-10 years in length.

The timing of the main integrations here will be deliberately offset compared to the initial core integrations to allow time for the required technical development of these ambitious models and to reduce multiple commitments for key personnel and HPC.

T4.1 [M1-M56] Eddy-resolving ocean and impact on Europe. (Lead: MET OFFICE. Participants: MPG, BSC, CERFACS, NERC, AWI, DKRZ)
Develop coupled models with an eddy-resolving ocean component (requiring 1/10° to 1/12° resolution) including a spin-up strategy for the ocean, and investigate the impact that this has on European climate and its variability. Specific aspects of the analysis proposed in WP2 Task2.1 will be performed using WP1 metrics to investigate aspects likely to be influenced by the ocean resolution, such as the Atlantic Meridional Overturning Circulation (AMOC, through Arctic sea ice, deep water formation and overflow processes as well as Southern Ocean influences) and Atlantic ocean biases, storm tracks and atmospheric blocking. Emphasis will also be placed on the representation of the Mediterranean Sea with its fundamental importance for Southern European climate (D4.1, D4.2, D8.3).

T4.2 [M1-M54] Novel approaches to enhanced regional resolution (Lead: AWI. Participants: MPG)
Use an unstructured mesh ocean/sea ice model coupled to a traditional atmospheric model to investigate the impact of enhanced resolution (1/10° to 1/12°) in particular regions of the ocean – such as the North Atlantic/Arctic or the Mediterranean – and standard resolution elsewhere (1/4°) on European climate, including the impact on teleconnections from less well-resolved regions. This model will be compared to a coupled model using the same atmosphere but a different, more traditional ocean model (D4.1, D4.2).

T4.3 [M1-M54] Novel approaches to sub-grid scale representation (Lead: UOXF. Participants: CNR, MET OFFICE, BSC, ECMWF)
Use atmosphere-land and fully coupled models which include stochastic physics, at different resolutions comparable to the core simulations, together with shorter, very high resolution simulations (~5km), to investigate how including

a representation of sub-grid scale variability affects the resolved scale variability of the models and land-atmosphere fluxes. Contrast the approaches used in different models and compare model integrations with and without stochastic schemes (D4.1, D4.2, D4.4).

T4.4 [M1-M57] Next generation atmospheric microphysics development (Lead: UNIVLEEDS. Participants: MET OFFICE)
Assess the impact over Europe of two new cloud microphysics schemes implemented in one global model (MET OFFICE) at sufficiently high resolution (~5km) to enable use of explicit rather than fully parameterised convection, in comparison to the ECMWF model at similar resolutions. The first approach is based on a single moment scheme but with the addition of a new graupel species and a physically based lightning scheme. The second approach will introduce a new cloud-aerosol interacting double moment multi-aerosol species scheme that explicitly represents the initiation of hydrometeors from aerosol. Methods to translate this scheme to other models will also be explored (D4.3, D4.4, D3.2).

T4.5 [M20-M57] Impact of sub-gridscale representation on the future European climate, and a novel measure of climate uncertainty (Lead: MPG. Participants: BSC, MET OFFICE, AWI, CERFACS, NERC, DKRZ)
Investigate the impact that an eddy-resolving ocean or representation of sub-gridscale variability has on European climate change by comparing the projected European changes obtained from all three approaches (T4.1, T4.2, T4.3) with those obtained from the core runs, and deliver a novel measure of climate uncertainty or robustness. Particular emphasis will be placed on changes in the AMOC and atmosphere-ocean interactions and the resulting impact on changes in European climate such as storms and extremes (using metrics developed in WP1 and in cooperation with WPs 5, 6, 10 and 11) (D4.5).

Interactions with other work packages:
This work package provides to:
WP1 (feedback for design of common metrics, and recommendations for observational datasets and metrics for the diurnal cycle and land-atmosphere coupling relating to the explicit convection model via MS1)
WP3 (T3B.1 model datasets for assessment of impact of explicit convection on land surface-atmosphere interactions)
WP5 (assessment of impact of improved resolution of ocean fronts and consequences for air-sea interaction and European climate drivers) - D5.2
WP6 (contribution to HighResMIP datasets, subsetting or resampling data to reduce volumes as necessary)
WP8 (assessment of novel modelling techniques for end of project assessment) - D8.3
WP10 (changes in risk of extremes from next-generation modelling techniques, including representation of electrical storms and land surface extremes over Southern Europe) - D10.3

This work package receives from:
WP1 (use of metrics) - D1.2
WP2 (use of coordinated analysis techniques for climate processes) - MS3
WP3 (3A will provide developed version of interactive cloud aerosol coupling and complexity scheme) - D3.1
WP6 (experience gained on methods for ocean spin-up used in core runs and methods for model initialisation, and core simulation datasets) - D6.1, D6.4
WP9 (model diagnostics, dataset formats and data management for provision to Open Access, HPC requirements) - D9.3

Participation per Partner

Partner number and short name	WP4 effort
1 - MET OFFICE	38.00
5 - CERFACS	6.00
6 - MPG	24.00
8 - BSC	28.00
10 - AWI	38.00
11 - UOXF	33.00
12 - CNR	16.00
13 - ECMWF	15.00
15 - UNIVLEEDS	24.00

Partner number and short name	WP4 effort
17 - NERC	12.00
19 - DKRZ	6.00
Total	240.00

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D4.1	Quantification of the relative cost/performance of different approaches to going beyond simple parameterisation	8 - BSC	Report	Public	53
D4.2	Datasets from all model integrations: fully documented with appropriate meta-data	1 - MET OFFICE	Other	Public	42
D4.3	Assessment of improved representation of atmospheric processes	15 - UNIVLEEDS	Report	Public	52
D4.4	Assessment of representation of convection influences	11 - UOXF	Report	Public	55
D4.5	Quantify impact of resolution on European climate change	6 - MPG	Report	Public	56

Description of deliverables

D4.1: Quantify the relative cost/performance of the different approaches to going beyond simple parameterisation (making use of the simulated historical period and comparing with observations), the relative strengths and weaknesses of each approach, the consequences for representing particular climate extremes, their impacts on climate risks and sectors considered in WP10,11 (M53).
D4.2: Datasets from all model integrations, fully documented with appropriate meta-data, available in standard data format, together with methods for accessing from the central JASMIN platform to comply with Open Data Access requirements and for HighResMIP contribution (suitably subsetted or regridded as necessary) (M51).
D4.3: Assessment of an improved representation of atmospheric microphysical processes at km-scales, thereby permitting a direct representation of lightning, and the impacts on European climate via cloud-aerosol-microphysics-precipitation interactions. Implications for climate risk due to changes in electrical storms in present day and future climate (M52).
D4.4: Assess the representation of convection influences on the diurnal cycle phase and its impacts on land-surface–atmosphere fluxes, with potential implications for climate change impacts over Southern Europe. Use standard models with parameterised atmospheric convection, stochastic physics models and models with ~5km atmosphere resolution (M55).
D4.5: Quantify and further consolidate the impact of resolution on future European climate change (including changes in extreme and compound events in cooperation with WP2,10) obtained from all three approaches, and develop a novel measure of European modelling uncertainty by comparing the spread in climate projections from the ensemble of core integrations with that obtained from the multi-model runs performed here (M56).

D4.1 : Quantification of the relative cost/performance of different approaches to going beyond simple parameterisation [53]

Quantify the relative cost/performance of the different approaches to going beyond simple parameterisation (making use of the simulated historical period and comparing with observations), the relative strengths and weaknesses of each approach, the consequences for representing particular climate extremes, their impacts on climate risks and sectors considered in WP10,11

D4.2 : Datasets from all model integrations: fully documented with appropriate meta-data [42]

Datasets from all model integrations, fully documented with appropriate meta-data, available in standard data format, together with methods for accessing from the central JASMIN platform to comply with Open Data Access requirements and for HighResMIP contribution (suitably subsetted or regridded as necessary)

D4.3 : Assessment of improved representation of atmospheric processes [52]

Assessment of an improved representation of atmospheric microphysical processes at km-scales, thereby permitting a direct representation of lightning, and the impacts on European climate via cloud-aerosol- microphysics-precipitation interactions. Implications for climate risk due to changes in electrical storms in present day and future climate

D4.4 : Assessment of representation of convection influences [55]

Assess the representation of convection influences on the diurnal cycle phase and its impacts on land-surface–atmosphere fluxes, with potential implications for climate change impacts over Southern Europe. Use standard models with parameterised atmospheric convection, stochastic physics models and models with ~5km atmosphere resolution

D4.5 : Quantify impact of resolution on European climate change [56]

Quantify and further consolidate the impact of resolution on future European climate change (including changes in extreme and compound events in cooperation with WP2,10) obtained from all three approaches, and develop a novel measure of European modelling uncertainty by comparing the spread in climate projections from the ensemble of core integrations with that obtained from the multi-model runs performed here

Schedule of relevant Milestones

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification
MS1	Observational/reanalysis/ CMIP5 datasets required for metrics development and model assessment, available on JASMIN in appropriate format, with documentation	4 - SMHI	6	Means of verification: All data available and confirmed against checklist, coordinated by WPs 1 and 9
MS9	Requirements for completion of frontier integrations and how they might contribute to HighResMIP.	6 - MPG	6	Means of verification: Requirements documented and provided to WP8
MS10	Readiness of all modelling approaches (eddy-resolving and unstructured mesh, stochastic and atmospheric convection-permitting) assessed, in order to start planned long simulations	1 - MET OFFICE	12	Means of verification: Models tested over short integrations and output validated
MS11	Information to WP8 on quantifying the impact of different approaches to	10 - AWI	56	Means of verification: Model integrations completed, datasets available and validated using metrics

Schedule of relevant Milestones

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification
	simulation of European climate and risk of extremes			and assessment of different approaches completed and available

Work package number [9]	WP5	Lead beneficiary [10]	5 - CERFACS
Work package title	Drivers of variability and change in European climate		
Start month	1	End month	57

Objectives

• Improve understanding of the key oceanic physical and dynamical drivers and mechanisms leading to decadal variability of European climate.
• Assess the influences of regional climate phenomena such as the summer Arctic sea ice decline and Siberian autumn snow cover reduction on the decadal variability of European climate.
• Quantify the respective influence of oceanic modes and anthropogenic direct radiative factors for both recent observed (1979-2014) and near-future (2015-2034) atmospheric and continental changes in European climate.
• Assess the robustness of European climate responses to the range of considered drivers to atmospheric and oceanic model resolution as well as physics.

Description of work and role of partners

WP5 - Drivers of variability and change in European climate [Months: 1-57]
CERFACS, UREAD, SMHI, MPG, UCL, BSC, CNR, ECMWF
This work package is led by: Laurent Terray, CERFACS (lead) and Rowan Sutton, UREAD (co-lead).

Description of work
WP5 aims to improve the understanding of the influence of a selected range of European climate drivers at decadal time scale as well as the associated mechanisms and their robustness to climate model resolution and physics.
The first objective will focus on the two leading decadal modes of climate variability, namely the Interdecadal Pacific Variability (IPV) and the Atlantic Multidecadal Variability (AMV), and their influence/interaction on/with tropospheric and stratospheric variability (Northern annular mode (NAM) and North Atlantic European weather regimes). Research will also address inter and intra-basin connections (such as the Atlantic Meridional Overturning Circulation (AMOC)) and processes (e.g. vertical mixing, role of eddies) connecting the subsurface ocean to surface temperature anomalies and thus to AMV, which in turn can both force and respond to large-scale atmospheric changes. The second objective will concentrate on assessing the influences of regional changes such as the summer Arctic sea ice decline and Siberian autumn snow cover reduction, and mechanistically understand their combination and contribution to the decadal variability in European climate. The third objective is to quantify the respective influence of IPV/AMV modes and anthropogenic direct radiative effects both for recent observed (1979-2014, TS1 period thereafter) and near-future (2015-2034, TS2 period thereafter) atmospheric and continental changes in European climate. A specific focus will be placed on the past and future changes of the hydrological cycle and extreme events, namely droughts, heat waves, intense precipitation and mid-latitude storms. The fourth objective, in close collaboration with other WPs, is to assess the sensitivity of European climate responses to the range of considered drivers to atmospheric and oceanic model resolution and physics.

The analyses will mainly be based on WP5 dedicated and coordinated coupled and AMIP-type sensitivity multi-model ensemble experiments as well as on the core experiments from the PRIMAVERA global climate models (WP6). In the first months of the project, the protocol for the various WP5 sensitivity experiments (implementation of regional relaxation, partial coupling and mixed layer coupling, design of future SST and sea ice extent (SIE) evolution for forced atmospheric simulations, full or anomaly coupling, mixed layer coupling and flux restoring) will be refined and tested. New (compared to CMIP5) radiative forcings for TS1 and TS2 will be agreed in collaboration with relevant CMIP6 MIPs. The experiments will be used to interpret the first PRIMAVERA core simulations, when their results will become available, and to inform the PRIMAVERA projections (Task 5.3). Experiments will be repeated at different atmospheric model resolutions to assess the robustness of European climate responses.

T5.1 [M01-M54] AMV and IPV modes and their impact on European climate (Lead: UREAD. Participants: BSC, MPG, ECMWF, CERFACS, CNR)
We will first assess the influence of AMV and IPV modes on the observed climate during the 1979-2014 period. This period has seen a remarkable change from a climate state with positive IPV and negative AMV phases to a state characterized by a reversal of the two modes. Forced and coupled multi-model ensemble simulations will be performed for both TS1 and TS2 periods. These experiments will be used to identify and quantify the roles of changes in the ocean state (e.g. SST) and changes in direct radiative forcing for changes in European climate. Forced experiments with SSTs

from TS1 and TS2 will be performed jointly with the appropriate radiative forcing (RF1 and RF2). Complementary experiments will exchange constraints between periods to identify the relative importance of different factors: for instance performing TS2 with either SSTs from TS1 and RF2 or SSTs from TS2 and RF1. Coupled simulations will also be performed using different approaches: several groups will use an ocean mixed layer-atmosphere coupling (in which SSTs can respond to changes in radiative forcing), while others will focus on fully coupled models but using regional relaxation in some of the ocean basins (either by prescribing SSTs or upper ocean heat content) and comparing to a fully coupled reference simulation (D5.1, D5.2).

T5.2 [M01-M55] Influence of Arctic sea ice and Siberian snow cover on European climate (Lead: SMHI. Participants: UCL, BSC, MPG, ECMWF, CERFACS, CNR, UREAD)
This task will focus on the impact of recent Arctic sea ice and Siberian snow changes on European climate. Regarding the sea ice influence, similar experiments to those of task 5.1 will be performed with the objective to separate as much as possible the effects of the SIE and SST changes. Coupled model runs will also be performed with prescribed sea ice (and SSTs at the ice edge) and compared to simulations with fully interactive sea ice. To identify the sensitivity of European climate to local and regional sea ice changes and the relevant mechanisms and teleconnections, we will also systematically change sea ice not only in the entire Arctic but also separately in different key marginal ice zones. Specific experiments regarding the impact of snow changes will also be carried out. We will assess the role of snow variability by comparing standard AMIP simulations with interactive snow and AMIP ones in which snow properties are prescribed as the model climatology of interactive simulations (D5.3).

T5.3 [M18-M57] Scenarios for the European climate of the next decades (Lead: CERFACS. Participants: SMHI, MPG, CNR, UREAD, UCL)
The last task of WP5 will be to design a set of several coherent scenarios for the future evolution of the drivers studied in the first two tasks. We will focus on the 2015-2034 period as the future time slice. Combined with the effects of direct radiative forcing of greenhouse and aerosols projected evolution, a set of multi-model experiments will be designed to assess the possible influence and relative weight of oceanic modes and regional phenomena on the European climate changes of the next decades. Specification of the selected scenarios that will be explored (including deriving projected SST and SIE changes for forced simulations and relaxation parameters/regions for coupled simulations) will be defined based on the analysis and results of the core PRIMAVERA simulations as well as the experiments of tasks 5.1 and 5.2. Possibilities include scenarios of a strong MOC/AMV slowdown, summer Arctic sea ice free, long-lasting positive/negative IPV phase, all these combined with different anthropogenic forcing projections including aerosols (D5.4).

Interactions with other work packages:
This work package provides to:
WP1 (feedback for design and improvement of common metrics) - MS3
WP2, 6 (contribute assessment of impact of different large-scale drivers on European climate variability) - D2.4
WP11 (communicate its key results and methodology to users regarding the future of European climate and related uncertainties) - D11.3

This work package receives from:
WP1 (use of common metrics) - MS3
WP2, 6 (use of results as a reference for comparing the findings from the specific sensitivity experiments performed in T5.1 and T5.2, and from WP2 the impact of the drivers on climate processes) - D2.4
WP3, 4 (use of results to assess model structural uncertainty in specific processes key to European climate variability and change)
WP9 (model diagnostics, dataset formats and data management for provision to Open Access, HPC requirements) - D9.3

Participation per Partner

Partner number and short name	WP5 effort
2 - UREAD	27.00
4 - SMHI	20.00
5 - CERFACS	36.00
6 - MPG	20.00
7 - UCL	14.00

Partner number and short name	WP5 effort
8 - BSC	26.00
12 - CNR	26.00
13 - ECMWF	28.00
Total	197.00

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D5.1	Document protocol for forced and coupled sensitivity experiments	5 - CERFACS	Report	Public	9
D5.2	Document impacts of AMV and IPV	2 - UREAD	Report	Public	51
D5.3	Document impact of sea ice and snow changes	4 - SMHI	Report	Public	55
D5.4	Documenting scenarios for 2015-34 European climate	5 - CERFACS	Report	Public	56

Description of deliverables

D5.1: Report documenting the selected protocol for both forced and coupled sensitivity experiments in tasks 5.1 and 5.2 (M9).
D5.2: Report documenting the impacts of AMV and IPV, and changes in direct radiative forcing, on the European climate of the most recent period and sensitivity to resolution and physics choices (M51).
D5.3: Report documenting the impact of sea ice and snow changes on European climate of the most recent period and its sensitivity to resolution and physics choices (M55).
D5.4: Report documenting scenarios for European climate in 2015-34, taking into account the potential impacts of oceanic modes, regional phenomena, direct radiative effects due to anthropogenic forcing and the sensitivity of responses to resolution and physics choices (M56).

D5.1 : Document protocol for forced and coupled sensitivity experiments [9]

Report documenting the selected protocol for both forced and coupled sensitivity experiments in tasks 5.1 and 5.2

D5.2 : Document impacts of AMV and IPV [51]

Report documenting the impacts of AMV and IPV, and changes in direct radiative forcing, on the European climate of the most recent period and sensitivity to resolution and physics choices

D5.3 : Document impact of sea ice and snow changes [55]

Report documenting the impact of sea ice and snow changes on European climate of the most recent period and its sensitivity to resolution and physics choices

D5.4 : Documenting scenarios for 2015-34 European climate [56]

Report documenting scenarios for European climate in 2015-34, taking into account the potential impacts of oceanic modes, regional phenomena, direct radiative effects due to anthropogenic forcing and the sensitivity of responses to resolution and physics choices.

Schedule of relevant Milestones

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification
MS12	List of proposed protocols for forced and coupled model sensitivity experiments with pros and cons	13 - ECMWF	6	Means of verification: List available to WP8 and all partners
MS13	Exchange of model data outputs regarding sensitivity experiments performed in T5.1 and 5.2	8 - BSC	39	Means of verification: Data under correct format located in central repository
MS14	Protocol design for the multi-model scenarios that will be performed in T5.3	12 - CNR	43	Means of verification: Design available to WP8 and all partners
MS15	Exchange of model data outputs regarding scenario projections performed in T5.3	6 - MPG	54	Means of verification: Data under correct format and located in central repository

Work package number [9]	WP6	Lead beneficiary [10]	3 - KNMI
Work package title	Flagship simulations		
Start month	1	End month	57

Objectives

• To deliver the core PRIMAVERA flagship simulations at low and high resolution, both coupled and forced AMIP-style, conforming to the HighResMIP experimental design.
• Coordinate the delivery and availability of core model datasets and documentation to all partners with WP9.

Description of work and role of partners

WP6 - Flagship simulations [Months: 1-57]
KNMI, MET OFFICE, SMHI, CERFACS, MPG, BSC, CMCC, AWI, UOXF, CNR, ECMWF, DKRZ
This work package is led by Rein Haarsma (KNMI, lead) and Johan Jungclaus (MPG, co-lead).

Description of work
As described elsewhere in this proposal, there is now a huge body of evidence that demonstrates the added value of enhanced resolution. To take this research to the next stage of demonstration and impact, PRIMAVERA PIs have led the development of HighResMIP, a new high-resolution model intercomparison project for the international CMIP6 project. This CMIP6 activity is supported by most of the research centres active in high-resolution modelling worldwide. WP6 will provide the European contribution to HighResMIP, and the WP6 simulations will provide the foundation for analyses in other work packages.

The flagship integrations will consist of two streams:
1) In the first phase Stream 1, the simulations will be carried out with the model versions that are available at the start of the project. The output of these integrations will be analysed in other WPs [Tasks 6.3-6.5]. The Stream 1 runs involve both the high- and low-resolution simulations. Basic validation of integrations will be performed as they progress to maximize effective use of HPC resources and minimise delays in data delivery to the other work packages. To isolate the effect of increased resolution and to provide a reference frame under similar boundary conditions, the high-resolution Stream 1 simulations are repeated with a low-resolution version comparable to CMIP5. At the other end of the spectrum, WP4 will push the frontiers going to even higher resolution and locally refined grids.
2) In Stream 2 a smaller number of high-resolution runs will be made with the improved model components derived from WP2, 3 with input from WP11 from user requirements [Tasks 6.6-6.8]. Only a focused subset of integrations will be carried out. The main goal for the Stream 2 simulations is to demonstrate the impact of the model modifications recommended by WP2-4 and to provide input to WP10,11. A complete analysis of the Stream 2 simulations will not be feasible within the time frame of the project, and hence the analysis will focus on those aspects of the simulated climate that are expected to benefit most from the model improvements.

CMIP6 HighResMIP Protocol
The simulations in Stream 1 and 2 will be made following the detailed CMIP6 HighResMIP protocol, being led by PIs of PRIMAVERA. This protocol describes the scenarios, number of ensemble members, spin-up and initialization mechanism, boundary conditions, output format and data storage. The ensemble number will be a balance between available computing resources and the requirement to sample internal variability. The coupled model simulations are pairs of simulations, one using constant 1950's external forcings (CTL) and one using the historic forcing to 2012, and future forcings defined by a scenario such as RCP4.5 to 2050 (EXP).

T6.1 [M1-M24] Specification of model configurations (Lead: KNMI. Participants: MET OFFICE, CERFACS, SMHI, CMCC, MPG, DKRZ, CNR, UOXF, AWI, BSC, ECMWF)
Define the specification of the model configurations for the core integrations for both forced-atmosphere and coupled integrations, and all the external forcings required for the models (e.g. sea surface temperature, aerosol concentrations, greenhouse gas concentrations) (D6.1).

T6.2 [M1-M55] Coordination of delivery of data sets (Lead: AWI. Participants: MET OFFICE, CERFACS, SMHI, CMCC, MPG, DKRZ, CNR, UOXF, KNMI, BSC, ECMWF)
Agree (with WP9) on the methodology and tools needed for the delivery of data sets from Stream 1 and Stream 2 integrations to the common joint analysis facility. This will include metadata (full description of model

configuration, ensemble specification, and output data), standard diagnostic lists, methods for processing output, all to be communicated to all partners via the project web pages (D9.4, D9.5).

T6.3 [M1-M24] Stream 1 Historical AMIP runs (Lead: KNMI. Participants: MET OFFICE, CERFACS, SMHI, CMCC, MPG, DKRZ, CNR, UOXF, AWI, ECMWF)
Complete and deliver the AMIP-II ensemble of runs using historical forcings, observed SST and sea ice distributions as defined by HighResMIP for the period of integration 1950-2012. Monitor and publish on-going progress with simple verification on project web pages (for example an updated timeseries of top-of-atmosphere radiation budget) (D6.2).

T6.4 [M1-M44] Stream 1 Future AMIP runs (Lead: KNMI. Participants: MET OFFICE, CERFACS, SMHI, CMCC, MPG, DKRZ, CNR, UOXF, AWI)
Complete and deliver the AMIP-II ensemble of runs for future climate with forcings according to HighResMIP scenario for the period of integration 2013-2050 (D6.3).

T6.5 [M1-M44] Stream 1 Coupled pairs of runs (Lead: MPG. Participants: MET OFFICE, CERFACS, SMHI, CMCC, KNMI, DKRZ, CNR, UOXF, AWI, BSC)
Complete and deliver the pairs of coupled runs (CTL+EXP) using forcings according to HighResMIP scenario for the period of integration 1950-2050 (D6.4).

T6.6 [M38-M48] Stream 2 Historical AMIP runs (Lead: KNMI. Participants: MET OFFICE, CERFACS, SMHI, CMCC, MPG, DKRZ, CNR, UOXF, AWI, ECMWF)
Complete and deliver the AMIP-II runs using historical forcings, observed SST and sea ice distributions as defined by HighResMIP for the period of integration 1950-2012 using the updated model configurations for Stream 2. Compare the on-going evolution of these integrations with those of Stream 1 to verify that the changes in configuration have the expected impact (D6.5).

T6.7 [M24-M48] Stream 2 Future AMIP runs (Lead: CERFACS. Participants: MET OFFICE, KNMI, SMHI, CMCC, MPG, DKRZ, CNR, UOXF, AWI)
Complete and deliver the AMIP-II runs with forcings according to HighResMIP scenario for the period of integration 2013-2050. using the updated model configurations for Stream 2 (D6.6).

T6.8 [M24-M48] Stream 2 Coupled pairs of runs (Lead: IC3. Participants: MET OFFICE, KNMI, SMHI, CMCC, MPG, DKRZ, CNR, UOXF, AWI, KNMI)
Complete and deliver the pairs of coupled runs (CTL+EXP) with forcings according to HighResMIP scenario for the period of integration 1950-2050 using the updated model configurations for Stream 2. Compare the on-going evolution of these integrations with those of Stream 1 to verify that the changes in configuration have the expected impact (D6.7).

Interaction with other work packages
This work package provides to:
WP2,3 (core model datasets for model evaluation)
WP4 (experience of methods for ocean spinup)
WP9 (help in coordinating delivery of core datasets and metadata for access from JASMIN) - D9.4, D9.5
WP10 (Model datasets for input to climate risk assessment) - D10.2
WP11 (Stream 2 outputs for end-user requirements) - D11.5

This work package receives from:
WP1 (basic metrics to validate quality of model integrations both while simulations are ongoing and once finished) - MS3
WP2 (recommendations on the relative merits of increased resolution and improved model physics for the design of Stream 2 simulations (D2.3))
WP3 (updated model configurations for Stream 2 experiments) - via D8.1
WP9 (requirements for Data Management Plan, provision of data to HighResMIP) - D9.1
WP10,11 (user requirements from model integrations to contribute to defining Stream 2 model configuration) - D10.1

Participation per Partner

Partner number and short name	WP6 effort
1 - MET OFFICE	10.00
3 - KNMI	4.00

Partner number and short name	WP6 effort
4 - SMHI	12.00
5 - CERFACS	18.00
6 - MPG	12.00
8 - BSC	12.00
9 - CMCC	12.00
10 - AWI	18.00
11 - UOXF	12.00
12 - CNR	12.00
13 - ECMWF	8.00
19 - DKRZ	6.00
Total	136.00

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D6.1	Model configurations for Stream 1 integrations	3 - KNMI	Report	Public	4
D6.2	Stream 1 historical AMIP runs	3 - KNMI	Other	Public	12
D6.3	Stream 1 future AMIP runs	3 - KNMI	Other	Public	42
D6.4	Stream 1 control and historic coupled runs	6 - MPG	Other	Public	40
D6.5	Stream 2 historical AMIP runs	3 - KNMI	Other	Public	47
D6.6	Stream 2 future AMIP runs	5 - CERFACS	Other	Public	47
D6.7	Stream 2 control and historic coupled runs	8 - BSC	Other	Public	47

Description of deliverables

D6.1: Report on model configurations for Stream 1 integrations agreed by all partners and published on project website (M4).

Stream 1 Flagship runs
For each set of simulations, listed in the deliverables below, the following will be completed: Data is post processed and stored in coordination with WP9. Quality check has been performed with basic statistical analysis of main variables (coordination with WP1 on basic metrics). Both high and low resolution runs are completed, with any differences in model configuration documented.
A full description of these integrations (including metadata, HighResMIP, open data access), including basic comparison with the low-res simulations will be made available in a document (report) and published on the project website. MS16, MS17

D6.2: Historical AMIP runs completed at high and low resolution (M12)
D6.3: Future AMIP runs completed at high and low resolution (M42)
D6.4: Coupled runs, both control and historic, completed at both high and low resolution (M40)

Stream 2 Flagship runs
As for Stream 1, using updated model configurations recommended by WP2,3,11, and also with a basic comparison of Stream 1 and Stream 2 simulations.

D6.5: Historical AMIP runs completed at high and low resolution (M47)
D6.6: Future AMIP runs completed at high and low resolution (M47)
D6.7: Coupled runs, both control and historic, completed at both high and low resolution (M47)

D6.1 : Model configurations for Stream 1 integrations [4]

Report on model configurations for Stream 1 integrations agreed by all partners and published on project website

D6.2 : Stream 1 historical AMIP runs [12]

Future AMIP runs completed at high and low resolution

D6.3 : Stream 1 future AMIP runs [42]

Future AMIP runs completed at high and low resolution

D6.4 : Stream 1 control and historic coupled runs [40]

Coupled runs, both control and historic, completed at both high and low resolution

D6.5 : Stream 2 historical AMIP runs [47]

Historical AMIP runs completed at high and low resolution

D6.6 : Stream 2 future AMIP runs [47]

Future AMIP runs completed at high and low resolution.

D6.7 : Stream 2 control and historic coupled runs [47]

Coupled runs, both control and historic, completed at both high and low resolution

Schedule of relevant Milestones

Milestone number[18]	**Milestone title**	**Lead beneficiary**	**Due Date (in months)**	**Means of verification**
MS16	Stream 1 runs started	4 - SMHI	6	Means of verification: Metadata documented on Wiki and central analysis facility.
MS17	Stream 2 runs started	1 - MET OFFICE	30	Means of verification: Metadata documented on Wiki and central analysis facility.

Work package number [9]	WP7	Lead beneficiary [10]	1 - MET OFFICE
Work package title	Project Management of PRIMAVERA		
Start month	1	End month	57

Objectives

• Establish and maintain top-level project management of PRIMAVERA to enable the objectives and impacts to be efficiently and effectively achieved on time and within the resources budgeted.
• Establish and maintain an effective working relationship between PRIMAVERA and the European Commission (EC), which includes regular reporting on project progress.
• Coordinate and facilitate effective relationships and coordination between partners within PRIMAVERA, including sharing of information associated with all project management aspects.
• Manage the gender dimensions of PRIMAVERA within the project content and gender balance within the consortium.
• Establish and coordinate the dissemination, exploitation and communication strategies for PRIMAVERA.

Description of work and role of partners

WP7 - Project Management of PRIMAVERA [Months: 1-57]
MET OFFICE, UREAD, NERC
This work package is led by: Malcolm Roberts and Paul van der Linden, MET OFFICE (lead) and Pier Luigi Vidale, UREAD (co-lead).

Description of work
The management of PRIMAVERA is described in detail in Section 3.2, but is summarised here through six discrete tasks. These will primarily be the responsibility of the Coordinator and the Project Manager based at the Met Office, however they will also receive support from the Scientific Coordinator and will work closely with him to ensure effective overall management of the project.

T7.1 [M1-M57] Project management (Lead: MET OFFICE. Participants: UREAD)
Manage the project using effective management procedures based on PRINCE2 (Projects IN Controlled Environments) formal methodology. PRINCE2 is the de facto standard for project management used extensively by the UK Government and widely used in the UK and internationally. Managing the project includes the following (non exhaustive) activities:
(i) Implementation and maintenance of the Grant Agreement and of the preceding Consortium Agreement;
(ii) Overall legal, financial, administrative management and reporting, including:
• Designing and maintaining partner specific templates for collecting inputs to the required EC documents;
• Implementing and maintaining a project-specific process for reporting (Six monthly Project Periodic Reports, the Final Report and the Final Report on the EU Financial Contribution Distribution);
• Preparing for, and post-processing, the reviews from the EC including support in the implementation of recommendations;
• Handling of project correspondence and day-to-day requests from partners and external bodies;
• Adaptation of project and management structure after changes in the work plan and the consortium;
• Organisation of meetings relating to the management of the project; then executing, and post-processing, of major project meetings (i.e., agendas, invitations, locations, organisation of rooms/equipment etc – in support to the local organisers, preparation, distribution and archiving of material, minutes and action lists);
• Financial management – including transfer of project funds to partners (in compliance with directives from EC), providing clarification on any budget/financial issues, monitoring and controlling the budget.
(iii) Appropriate planning and operational management of intellectual property and risks (iv) Handling of/facilitating the resolution of any ethics issues, and any disputes/complaints in accordance with the Consortium Agreement;
(v) Implementation of competitive calls by the consortium for the participation of new beneficiaries.

T7.2 [M1-M57] Liaison with the European Commission (Lead: MET OFFICE. Participants: UREAD)
Maintain regular and comprehensive contact with the EC in Brussels. This will be partly fulfilled through the provision of short reports, provided to the EC every six months, outlining project progress and developments, in addition to other updates and reporting measures (D7.2).
This task will ensure the appropriate follow-up of project obligations from the Grant Agreement (formal reporting: of science results and finances, project reviews, communication, and management). The PRIMAVERA Coordinator will

ensure that the appropriate EC representative is invited to the General Assembly meetings and any other relevant project meetings.
If there are any major difficulties within the project that cannot be resolved using the appropriate management structure, the Coordinator will liaise with the EC to seek advice and a solution.

T7.3 [M1-M57] Facilitating internal communication (Lead: MET OFFICE. Participants: STFC)
Share knowledge as widely as possible across the project partners. The Project Office will ensure optimal internal information exchange through regular and routine communications. PRIMAVERA will also develop and use a dedicated internal, password-protected project Wiki, which will be designed and hosted by STFC (MS18). This will also host templates, documents and tools that the Project Office will develop that will aid the management and reporting of the project. This task will also ensure the implementing and maintenance of mailing lists for scientific contacts and administrative contacts.

T7.4 [M1-M57] Management of gender dimensions in PRIMAVERA (Lead: MET OFFICE. Participants: All)
Lead by the PRIMAVERA Coordinator with support from the Project Office, this will ensure that gender aspects of the project are fully considered within the research that is being undertaken, and that PRIMAVERA acts to promote gender equality wherever possible. This will be done with the aid of a Gender Strategy for PRIMAVERA that will be produced and maintained under this WP (MS19)

T7.5 [M1-M57] Communication activities (Lead: MET OFFICE. Participants: All)
A description of the communication measures for promoting the project and its findings during the period of the grant is provided in Section 2.2. Measures are proportionate to the scale of the project and to its objectives, and have been tailored to the needs of various audiences. A Media and Communications plan will be developed by month 6 of the project (D7.3) to establish how the project will manage communications.
Communication activities for the public and other identified target audiences will be performed under this task, as well as the development of the PRIMAVERA public website, which will be hosted by STFC and managed by the Project Office (D7.1). This WP will also be responsible for reporting on the communication activities of PRIMAVERA. The Project Office will provide the EC with a report of completed and planned communication activities together with the Project Periodic Reports and the final report. The report will comprise from all WPs. Additionally, the Project Office will be in charge of providing any information to EC which could help them to promote the project and European research, for example by notifying them of events, or before publishing press releases, and informing them of ways in which the project has been engaging with end-users and other audiences.

T7.6 [M1-M57] Exploitation, knowledge and innovation management (Lead: MET OFFICE. Participants: UREAD)
Prepare and oversee PRIMAVERA's exploitation, knowledge and innovation management activities. The Coordinator will take an overview of the WPs and the outcomes of PRIMAVERA to provide effective management and therefore exploitation both during and after the project. A Project Dissemination and Exploitation Plan (D7.4) will be produced, based on the principles explained extensively in Sections 2.2 and 3.2.10, with updates to this submitted in Project Periodic Reports to the EC. Towards the end of the project a Final Dissemination and Exploitation Plan (D7.5) will be written to ensure that effective management and exploitation continues beyond the end of the project. These will be consistent with the Data Management Plan (DMP), which is a deliverable (D9.1) in WP9.

Interactions with other work packages
This Work Package will coordinate closely with WP8 in order to ensure effective overall management of PRIMAVERA.
This Work Package provides:
• Support, guidance and management assistance to all Work Packages as required and to PRIMAVERA as a whole.

This Work Package receives:
• Regular summaries of the scientific progress of PRIMAVERA from WP8, for inclusion in the Short reports on project progress (D7.2) and other required reporting.
• Financial and administrative updates from all other WPs.

Participation per Partner

Partner number and short name	WP7 effort
1 - MET OFFICE	30.00
2 - UREAD	4.00
17 - NERC	6.00

Partner number and short name	WP7 effort
Total	40.00

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D7.1	Quarterly Reports for EC	1 - MET OFFICE	Report	Confidential, only for members of the consortium (including the Commission Services)	3
D7.2	PRIMAVERA Public website	17 - NERC	Other	Public	4
D7.3	Project Media and Communications Plan	1 - MET OFFICE	Report	Confidential, only for members of the consortium (including the Commission Services)	6
D7.4	Project Dissemination and Exploitation Plan	1 - MET OFFICE	Report	Confidential, only for members of the consortium (including the Commission Services)	6
D7.5	Final Project Dissemination and Exploitation Report	1 - MET OFFICE	Report	Confidential, only for members of the consortium (including the Commission Services)	57
D7.6	Ethics Documentation	1 - MET OFFICE	Report	Confidential, only for members of the consortium (including the Commission Services)	2

Description of deliverables

D7.1: PRIMAVERA Public website (M4)
D7.2: Short reports on project progress: A short summary report will be provided to the EC every three months (M4, 7, 10, 13, 15, 19, 22, 25, 28, 31, 34, 37, 40, 43, 46, 49, 52, 55, 57)
D7.3: Project Media and Communications plan (M6)
D7.4 Project Dissemination and Exploitation Plan: This will identify opportunities and pathways for exploitation that PRIMAVERA will explore. It will also outline the strategy for innovation and knowledge management in PRIMAVERA (M6)
D7.5 Final Project Dissemination and Exploitation Plan: This will identify opportunities and pathways for exploitation, and will outline effective innovation and knowledge management that is suitable following the formal completion of PRIMAVERA (M57)
D7.6 Ethics Documentation: This will detail the identification, recruitment and consent procedures that will be followed for participants in PRIMAVERA

D7.1 : Quarterly Reports for EC [3]

Short reports on project progress: A short summary report will be provided to the EC every six months (M6, 12, 18, 24, 30, 36, 42, 48)

D7.2 : PRIMAVERA Public website [4]

Public-facing website for PRIMAVERA, as part of project communications

D7.3 : Project Media and Communications Plan [6]

Plan which will detail the media and communications strategy for PRIMAVERA.

D7.4 : Project Dissemination and Exploitation Plan [6]

Plan which will detail how dissemination and exploitation will be undertaken during PRIMAVERA.

D7.5 : Final Project Dissemination and Exploitation Report [57]

Plan which will detail how dissemination and exploitation will be undertaken after PRIMAVERA.

D7.6 : Ethics Documentation [2]

Report detailing the procedures and criteria that will be used to identify and recruit research participants for PRIMAVERA, and detailed information on the informed consent procedures that will be implemented.

Schedule of relevant Milestones

Milestone number[18]	**Milestone title**	**Lead beneficiary**	**Due Date (in months)**	**Means of verification**
MS18	Wiki/ internal project website hosted by STFC, made available to all	17 - NERC	3	Means of verification: All partners verify that they can upload and download data
MS19	Gender Strategy for PRIMAVERA defined and adopted by the consortium	1 - MET OFFICE	6	Meand of verification: Strategy produced, agreed by consortium and published on the website.

Work package number [9]	WP8	Lead beneficiary [10]	2 - UREAD
Work package title	Scientific coordination of PRIMAVERA		
Start month	1	End month	57

Objectives

• Establish and maintain the scientific excellence and coordination of PRIMAVERA, to ensure that the scientific objectives and impacts of the project are achieved;
• Formulate high-level synthesis of scientific results and enable effective two-way PRIMAVERA knowledge exchange with the wider scientific community, Governments, and other target audiences.
• Ensure that the appropriate level of consultation with the External Expert Advisory Board (EEAB) is established and maintained, and that their advice is integrated into the project.

Description of work and role of partners

WP8 - Scientific coordination of PRIMAVERA [Months: 1-57]
UREAD, MET OFFICE, KNMI, SMHI, CERFACS, MPG, UCL, BSC, CMCC, AWI, UOXF, CNR, ECMWF, UNIVLEEDS, SU, NERC, PREDICTIA, DKRZ
This work package is led by: Pier Luigi Vidale, UREAD (lead) and Malcolm Roberts, MET OFFICE (co-lead).

Description of work
There are eight tasks within this work package. These will primarily be the responsibility of the PRIMAVERA Scientific Coordinator (Pier Luigi Vidale) who provides the scientific leadership for the project. The Coordinator (Malcolm Roberts) will work closely with the Scientific Coordinator at all times, to provide support and to ensure effective overall project leadership.

All WP leaders have been allocated 4 months within this WP, co-leaders have been allocated 2 months and all other partners have one month. This allocated time will enable all WP leaders to effectively oversee their WP, and will allow all relevant partners to contribute to the scientific coordination and communicate their relevant activities within the project.

The Scientific Coordinator and the Coordinator will also be supported by a Management structure outlined in Section 3.2, and will have full support from the Project Office.

T8.1 [M1-M57] Scientific coordination of PRIMAVERA (Lead: UREAD. Participants: All)
The Scientific Coordinator will carry out the coordination and monitoring of scientific excellence within the project, by regular discussion with the Coordinator and WP leaders and by scientific review of reports and deliverables to the EC. In addition, he will monitor contemporary results within the community relevant to the project, in conjunction with the EEAB and ensure that any necessary scientific aspects are incorporated into the project. WP leaders will ensure that the progress of milestones and deliverables is actively monitored and that they are delivered on time.

T8.2 [M1-M57] Synthesis of PRIMAVERA science (Lead: UREAD. Participants: All)
The Scientific Coordinator will take a holistic view of the ongoing work across all work packages in PRIMAVERA. A Progress Summary Report will be produced in M28 (D8.1) that will bring together results so far and assess the best approach for Stream 2 of the project. Prior to this, an Intra-Project workshop will be organised by the Scientific Coordinator with the relevant WPs and the EEAB in attendance, to agree appropriate next steps (MS20). A Final Summary Report will be produced at the end of the project, detailing and summarising the overall outcomes of PRIMAVERA (D8.3).

T8.3 [M1-M57] Coordinate interdisciplinary and cross-cutting activities (Lead: UREAD. Participants: All)
Coordination of the interdisciplinary and cross-cutting activities and themes within PRIMAVERA is necessary in order to maximise the benefits of the scientific and innovative research within the project, ensure it meets the needs of the users, avoid duplication of effort and identify any gaps. The Scientific Coordinator will organise meetings (utilising electronic remote methods wherever possible) with all the work package leaders, and other partners where beneficial, to facilitate this task.

T8.4 [M1-M57] External Expert Advisory Board (EEAB) management (Lead: UREAD. Participants: MET OFFICE)
This task will ensure the appropriate level of consultation with the EEAB. It is essential that the project receives independent advice and feedback from the EEAB, especially in relation to the direction of the scientific research and its user applications. This task will be led by the PRIMAVERA Scientific Coordinator to ensure that the consultations with the EEAB are organised and coordinated in an efficient and effective manner, and that advice given is reviewed

and acted on appropriately. The Scientific Coordinator will also ensure that the appropriate level of project information is provided to the EEAB. The EEAB is described further in Section 3.2.7.

T8.5 [M1-M57] Participation in PRIMAVERA General Assembly meetings (Lead: UREAD. Participants: All)
All beneficiaries will meet at the five planned General Assembly meetings. The purpose of these meetings will be to discuss progress of the project and any issues regarding the project (especially with respect to the project plans) and make any necessary consortium decisions.

T8.6 [M1-M57] Management of scientific risk (Lead: UREAD. Participants: All)
This will include resolving any conflict relating to scientific or technical issues. It will mean acting on unforeseen events and adapting work packages as required. It will also mean highlighting possible scientific risks early on in the project, and considering any necessary mitigation.

T8.7 [M1-M57] Participation in scientific decision making bodies and events, and co-ordination with other projects (Lead: UREAD. Participants: All)
PRIMAVERA will actively participate in scientific decision making bodies such as scientific advisory boards and panels (e.g. WGCM, GEWEX) executive and steering committees. This will be to provide specialist advice and to promote the project, its methodologies and results. The Scientific Coordinator will also promote PRIMAVERA at scientific events. These activities will ensure the continued awareness and exploitation of PRIMAVERA science during and after the project, meaning that it will be used in future decision making for contemporary and next-generation model development, as well as influencing model development and modelling practices at operational centres.
The Scientific Coordinator will provide overall coordination (including information exchange) and linkages with associated projects and programmes. Some of these projects are listed in Section 1.3.4. WP leaders and co-leaders will also use their knowledge and connections with other projects to assist in this task. All partners will ensure that any participation in events or links established with other projects are recorded and provided to the Project Office for their reporting on Communication activities.

T8.8 [M1-M57] Engagement with governments and public decision makers (Lead: UREAD, MET OFFICE. Participants: All)
PRIMAVERA will actively engage with governments and policy makers to communicate the impact and significance of PRIMAVERA results. A comparison case study will be produced (D8.2), as will policy briefings, which will be written specifically for this audience (D8.5). The Scientific Coordinator and other partners have long, well established engagement with governmental institutions (e.g. in the UK Government departments DECC and Defra) - with several partners also having strong links through operational weather and seasonal predictions roles, academic institutions (e.g. weather and climate centres worldwide) and industrial partners. These collaborations will ensure that PRIMAVERA science remains well aligned with international developments and requirements throughout the lifetime of the project.

Interactions with other Work Packages
This Work Package provides:
- Scientific guidance and leadership for all Work Packages and to PRIMAVERA as a whole.

This Work Package receives:
- Regular summaries of the scientific progress from each work package leader, so that the Scientific Coordinator can review progress and provide scientific guidance.
- WP1,2,3,4,5 (Assessment of impact of model resolution, model physics, novel techniques and climate drivers for review paper D8.4)

Participation per Partner

Partner number and short name	WP8 effort
1 - MET OFFICE	4.00
2 - UREAD	8.00
3 - KNMI	4.00
4 - SMHI	4.00
5 - CERFACS	4.00
6 - MPG	2.00

Partner number and short name	WP8 effort
7 - UCL	1.00
8 - BSC	4.00
9 - CMCC	4.00
10 - AWI	1.00
11 - UOXF	1.00
12 - CNR	1.00
13 - ECMWF	1.00
15 - UNIVLEEDS	1.00
16 - SU	1.00
17 - NERC	4.00
18 - PREDICTIA	1.00
19 - DKRZ	1.00
Total	47.00

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D8.1	Progress summary following review of WPs	2 - UREAD	Report	Public	43
D8.2	Comparison case study for Government	2 - UREAD	Report	Public	56
D8.3	Final summary and synthesis of results	2 - UREAD	Report	Public	57
D8.4	PRIMAVERA Review paper	2 - UREAD	Report	Public	57
D8.5	Policy briefings for government target audience	2 - UREAD	Websites, patents filling, etc.	Public	57

Description of deliverables

D8.1 Progress Summary Report: Following the Scientific Coordinators review of work package progress at M24, and the Intra-Project Workshop that will be held, they will produce a report detailing the progress of PRIMAVERA so far and the approach that will be taken for Stream2 of the project (M43)
D8.2 Comparison case study for Government of forms of climate information available from PRIMAVERA and from other sources (M56)
D8.3 Final Summary Report: This report will synthesise the results, and will quantify and assess the robustness of climate variability and change over Europe to the representation of small scales. This will combine the approaches used in WP2, 3, 4, 5, the metrics from WP1 and model integrations from WP4 and 6, to assess the consequent climate risks to sectors represented in WP10, 11 (M57)
D8.4 PRIMAVERA review paper describing the key findings of the project, the role of resolution, physics and sub-grid variability, to inform scientific community via HighResMIP and governments via IPCC AR6 process (M57)
D8.5 Policy briefings for governments, detailing the significance of PRIMAVERA results (M57)

D8.1 : Progress summary following review of WPs [43]

Progress Summary Report: Following the Scientific Coordinators review of work package progress at M24, and the Intra-Project Workshop that will be held, they will produce a report detailing the progress of PRIMAVERA so far and the approach that will be taken for Stream2 of the project.

D8.2 : Comparison case study for Government [56]

Comparison case study for Government of forms of climate information available from PRIMAVERA and from other sources

D8.3 : Final summary and synthesis of results [57]

Final Summary Report: This report will synthesise the results, and will quantify and assess the robustness of climate variability and change over Europe to the representation of small scales. This will combine the approaches used in WP2, 3, 4, 5, the metrics from WP1 and model integrations from WP4 and 6, to assess the consequent climate risks to sectors represented in WP10, 11.

D8.4 : PRIMAVERA Review paper [57]

PRIMAVERA review paper describing the key findings of the project, the role of resolution, physics and sub-grid variability, to inform scientific community via HighResMIP and governments via IPCC AR6 process

D8.5 : Policy briefings for government target audience [57]

Policy briefings for governments, detailing the significance of PRIMAVERA results

Schedule of relevant Milestones

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification
MS20	Intra-project Workshop	3 - KNMI	24	Means of verification: Workshop takes place at M24 General Assembly.

Work package number [9]	WP9	Lead beneficiary [10]	1 - MET OFFICE
Work package title	HPC and Data management		
Start month	1	End month	57

Objectives

• Produce a plan for the required HPC to cover the integrations needed by the whole project, on both national and potential PRACE resources.
• Produce and implement the Data Management Plan (DMP).
• Support the implementation of the Plan for Dissemination and Exploitation of the Project Results, and oversee participation in the Open Research Data Pilot

Description of work and role of partners

WP9 - HPC and Data management [Months: 1-57]
MET OFFICE, KNMI, SMHI, CERFACS, MPG, BSC, CMCC, AWI, UOXF, CNR, ECMWF, NERC
This work package is led by: Jon Seddon, MET OFFICE (lead) and Ag Stephens, STFC (co-lead).

Description of work
This work package will ensure that the PRIMAVERA dataset can be created and managed effectively, and will provide the facilities and structure needed to enable collaboration and the scientific exploitation of those data. Knowledge management and Open Data policy will be key considerations.

T9.1 [M01-M03] HPC plan (Lead: MET OFFICE. Participants: KNMI, SHMI, CERFACS, MPG, BSC, CMCC, AWI, UOXF, CNR, ECMWF, STFC)
Establish a plan for the computing resources required to perform all PRIMAVERA simulations in WP3-6. Identify any shortfalls and risks and indicate where additional resources (for example from PRACE) may be needed (MS2).

T9.2 [M01-M57] Data Management (Lead: MET OFFICE. Participants: STFC, KNMI, SHMI, CERFACS, MPG, BSC, CMCC, AWI, UOXF, CNR, ECMWF)
This task covers all activities necessary to arrange, support and manage the use of central data analysis facilities on the JASMIN platform (D9.2). This includes the following: i) The arrangement of central storage and analysis facilities on JASMIN and access for participants to project/reference data sets, and open source analysis tools (e.g. python, R); ii) Testing of data transfer routes from modelling centres and the automation of data transfer mechanisms. Several partners have more than 10 years of experience of transferring multi-terabyte data sets around the world; iii) On-going work to ensure compliance of the data set with the specification in the DMP and compliance with Open Research Data Pilot; iv) The support and training of users in the exploitation of the central analysis facilities.

T9.3 [M01-M06] Data Management Plan (DMP) (Lead: MET OFFICE. Participants: STFC, KNMI, SHMI, CERFACS, MPG, BSC, CMCC, AWI, UOXF, CNR, ECMWF)
Produce the first complete DMP (D9.1), in coordination with WPs 1-6,10,11, containing (a) the specification of the Required Inputs and Required Outputs, (b) the data format standards, (c) means of exploitation and (d) data curation policy. Revise the DMP as necessary throughout the remainder of PRIMAVERA. The specification of the Required Inputs and Outputs is a pre-requisite for all Stream 1 simulations in WP6 and will need to be arranged at the first opportunity. This specification will be based on CMIP5 standard diagnostic lists, but input will be required from all modelling groups to ensure completeness. The specification will include details of file-naming and metadata conventions building on the Data Reference Syntax (DRS) developed in CMIP5 and used for MIP-style projects in the Earth System Grid Federation (ESGF) (D9.1).

T9.4 [M01-M57] Data Conversion and Validation Procedures (Lead: STFC. Participants: MET OFFICE, KNMI, SHMI, CERFACS, MPG, BSC, CMCC, AWI, UOXF, CNR, ECMWF)
Establish the methodology and work flow for bringing the data from institutions involved in running simulations to the central data analysis facilities on JASMIN and converting to the standard format specified in the DMP. Much of this work will build upon the CMOR tools, with adaptations to allow for the level of throughput necessary. Data conversions will be carried out at both modelling institutes and on JASMIN depending on resource requirements. Validation of converted files will be carried out using STFC CEDA's quality control package (developed for CORDEX and FP7 SPECS projects) to ensure that the resulting files are compliant with the specification contained in the DMP (D9.3). Data will be published and validated (D9.4 and D9.5).

T9.5 [M01-M57] Support Dissemination and Exploitation of the Project Results (Lead: STFC. Participants: MET OFFICE, KNMI, SHMI, CERFACS, MPG, BSC, CMCC, AWI, UOXF, CNR, ECMWF)

Establish links between PRIMAVERA Public website (D7.1), internal Wiki (MS18) and source repositories for project documentation. Support the Open Research Data Pilot by enabling the PRIMAVERA data set to be freely available, as specified in the Plan for Dissemination and Exploitation (D7.4 and D7.5). The Required Outputs will be published to the BADC and ESGF archives making them accessible by a range of existing tools and international metadata portals/ catalogues. Explore extraction of non-core data sets across ESGF nodes at remote centres to central analysis facility on JASMIN to allow specialised data processing.
Obtain suitable persistent data identifiers (DOIs) for the data set and publish a description of it in a suitable data journal such as 'Earth System Science Data'. Technical workshops for project members on the use of facilities on JASMIN will be organised as required (D9.2).

T9.6 [M42-M48] Review data management strategy and methods (Lead: MET OFFICE. Participants: STFC, KNMI, SHMI, CERFACS, MPG, BSC, CMCC, AWI, UOXF, CNR, ECMWF)
Review the strategy and implementation of the DMP in order to document the experience for future big data projects such as CMIP6 and the associated MIPs (D9.6).

Interactions with other work packages:
This work package provides to:
WP 1,2 (Reference data sets for computation of metrics and model validation on JASMIN, repository for metrics code) - MS1
WP 3-6 (diagnostic lists for simulations from the DMP and tools for data format conversion) - MS21
WP 1-6,10,11 (Provision of central analysis facilities on JASMIN, training on how to use them and specification of methods for accessing model output data sets (T9.2). Tools/web portals to enable dissemination activities and support for Open Data Research Pilot. Some level of support on using JASMIN and open source analysis tools)

This work package receives from:
WP 1,2,3,4 (Specification of data sets for metrics and model validation) - MS1
WP 3-6 (HPC requirements and availability of computing resources) - MS22
WP 3-6 (PRIMAVERA data sets and full description of model specifications)
WP 1-6,10,11 (Specification of data required from core simulations including that needed for HighResMIP submission) - MS21
WP1-11 (Experience of use of data and facilities for review in T9.6/D9.4)

Participation per Partner

Partner number and short name	WP9 effort
1 - MET OFFICE	44.00
3 - KNMI	4.00
4 - SMHI	6.00
5 - CERFACS	3.00
6 - MPG	8.00
8 - BSC	12.00
9 - CMCC	6.00
10 - AWI	22.00
11 - UOXF	8.00
12 - CNR	12.00
13 - ECMWF	5.00
17 - NERC	12.00
Total	142.00

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D9.1	Data Management Plan	1 - MET OFFICE	Report	Public	6
D9.2	Initial training for JASMIN users	3 - KNMI	Other	Public	12
D9.3	Tools for data conversion to CMOR format	1 - MET OFFICE	Other	Public	12
D9.4	Publication of PRIMAVERA Stream 1 data set	1 - MET OFFICE	Report	Public	44
D9.5	Publication of PRIMAVERA Stream 2 data set	1 - MET OFFICE	ORDP: Open Research Data Pilot	Public	55
D9.6	Review of DMP and lessons learnt for future projects	1 - MET OFFICE	Report	Public	57
D9.7	Exploitation of project data by the climate research community	1 - MET OFFICE	Report	Public	45

Description of deliverables

D9.1: Data Management Plan (M6)
D9.2: Deliver initial training for users of the JASMIN platform, to include on-site training course and web-based documentation, the latter to also support Open Data Access (M6)
D9.3: Tools for data conversion to CMOR format and validation procedures for model datasets (M12)
D9.4: Publication of PRIMAVERA data set for Stream 1 through data DOIs and data description publication (M44)
D9.5: Publication of PRIMAVERA data set for Stream 2 through data DOIs and data description publication (M55)
D9.6: Review of outcomes of the DMP and document lessons for future EU and international big data projects (M57)

D9.1 : Data Management Plan [6]

Produce the data management plan document and post on the project website

D9.2 : Initial training for JASMIN users [12]

Deliver initial training for users of the JASMIN platform, to include on-site training course and web-based documentation, the latter to also support Open Data Access

D9.3 : Tools for data conversion to CMOR format [12]

Tools for data conversion to CMOR format and validation procedures for model datasets

D9.4 : Publication of PRIMAVERA Stream 1 data set [44]

Publication of PRIMAVERA data set for Stream 1 through data DOIs and data description publication

D9.5 : Publication of PRIMAVERA Stream 2 data set [55]

Publication of PRIMAVERA data set for Stream 2 through data DOIs and data description publication

D9.6 : Review of DMP and lessons learnt for future projects [57]

Review of outcomes of the DMP and document lessons for future EU and international big data projects

D9.7 : Exploitation of project data by the climate research community [45]

An important action for the PRIMAVERA project is to ensure the climate research community has access to project data for use in research in their areas of specialism. This Deliverable builds on the Data Policies devised for the Stream 1 and Stream 2 datasets and describes a management framework under which data can be disseminated,

climate researchers can engage to access data, and policies with respect to intellectual property rights of the data are in place. The success of PRIMAVERA depends on broader engagement with the extra-EU research community – many groups, with foci and expertise complementary to that in PRIMAVERA, would like to analyse PRIMAVERA data. A robust set of guidelines will be developed for how outsiders can collaborate substantively with PRIMAVERA beyond simply downloading the HighResMIP data from the ESGF. The guidelines will indicate points of contact, potential collaboration opportunities, and rules of engagement, including protection of intellectual property rights. The PRIMAVERA data use and engagement guidelines should remain valid beyond the end date of the project to ensure the outcomes endure.

Schedule of relevant Milestones

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification
MS1	Observational/reanalysis/ CMIP5 datasets required for metrics development and model assessment, available on JASMIN in appropriate format, with documentation	4 - SMHI	6	Means of verification: All data available and confirmed against checklist, coordinated by WPs 1 and 9
MS2	Strategy for integrating the metrics software available in the different partner institutions	1 - MET OFFICE	12	Means of verification: Strategy available to partners
MS21	Specification of model diagnostic outputs required for Stream 1 integrations.	3 - KNMI	1	Means of verification: Specification signed by all modelling groups delivered to WP8
MS22	Confirm that all centres have required HPC resources and models that can perform the core integrations	8 - BSC	3	Means of verification: Report signed by all modelling groups delivered to WP8
MS23	JASMIN central analysis facilities available to all project members	17 - NERC	3	Means of verification: Access verified for all project members.
MS24	Prototype data conversion procedures available and documented.	1 - MET OFFICE	6	Means of verification: Software tested on subset of model data and released for general testing.
MS25	Finalise and agree updated DMP for Stream 2 simulations	12 - CNR	23	Means of verification: DMP and details of revisions available to WP8

Work package number [9]	WP10	Lead beneficiary [10]	3 - KNMI
Work package title	Climate Risk Assessment		
Start month	1	End month	57

Objectives

• Assess the representation of the physics and statistics of meteorological hazards (e.g. extreme and compound events) relevant to end-users in global high resolution climate model simulations Develop scientifically based narratives as input for risk assessments related to extreme and compound meteorological events in Europe, as influenced by climate drivers, to inform the needs of end-users

Description of work and role of partners

WP10 - Climate Risk Assessment [Months: 1-57]
KNMI, MET OFFICE, UREAD, SMHI, BSC
This work package is led by: Ge Verver and Gerard van der Schrier, KNMI (lead) and David Brayshaw, UREAD (co-lead).

Description of work
In PRIMAVERA scientific input for risks assessments will be developed and disseminated for a number of sectors and end-users (see WP8, 11). The assessments will provide scientifically reliable, trustworthy and actionable information on extreme and compound meteorological events in Europe up to 2050 based on unprecedented high-resolution global climate models.

Current climate risk assessment applications rely on output from ensembles of relatively coarse resolution global models (e.g. CMIP5) and their downscaled products (e.g. CORDEX). In PRIMAVERA we will compare this already existing Bayesian approach, where large ensembles are used, to an approach where scientific narratives are constructed for end-users based on results from high resolution global models that resolve relevant physical processes (e.g. representation of blocking, extreme storms) while also including the remote drivers of climate variability and change. These meteorological conditions are related to hazards that expose vulnerability of society such as storm surges, flooding and drought. Moreover, by using global models in PRIMAVERA, consistency between large scale flow and regional climate is ensured as well as internal physical consistency of events that is hard to obtain with downscaling methods.

The narratives will contain a physical description of the hazards and their drivers, the potential changes of the events and, if possible, statistics of the events. They will include an assessment of how well events are simulated (using WP1 metrics) and a comparison to the data from traditional model ensembles. In this way PRIMAVERA will contribute to a new risk assessment approach where scientific information on the physics of events is central. The narratives are complemented by a description of the impact as obtained from WP11.

We will compare Stream 1 data (WP6) from high resolution global models with observational and reanalysis data and with CORDEX and CMIP5 simulation data, focussing on events relevant for user needs defined in WP8,11. For selecting relevant extreme events or compound events (e.g. floods and winds), we will draw on experience from earlier and ongoing Climate Services activities. Naturally, we will have special attention for events for which high resolution has a clear benefit compared to coarse resolution models. We will draw on experience gained in FP7 ECLISE, CLIMRUN and other projects. We will be aided by the results from WP5 on the drivers of variability and change, and WP1,2,3 on the impact of resolution and physics and their metrics. This is essential for trustworthy scientific assessments of climate variability and change in Europe.

T10.1 [M1-M24] Translate user needs obtained in WP11 to construct use cases based on vulnerability of end-users to climate (Lead: KNMI. Participants: BSC, SMHI, MET OFFICE)
WP11 will engage with end-users and provide information of their needs. We will also draw on experience from ongoing Climate Services activities, and from WP8 for needs of policymakers. Here, we will select on the order of 10 relevant extreme and/or compound meteorological events to be assessed and construct use cases, detailing meteorological information that needs to be derived from the models, for policymakers and each sector or end-user (D10.1).

T10.2 [M13-57] Comparison of statistics of selected meteorological events in CMIP5, CORDEX and in PRIMAVERA models (Lead: SMHI. Participants: KNMI, MET OFFICE)
Assess and compare statistics of selected extreme events by constructing distributions from observations, from climate model ensembles and from PRIMAVERA simulations Stream 1 and (early) Stream 2.

Assess possible changes of extreme events due to changes in external forcing as compared to natural variability as informed by WP5 on drivers (D10.2)

T10.3 [M13-57] Comparison of physics of selected meteorological events in CMIP5, CORDEX and in PRIMAVERA models (Lead: UREAD. Participants: KNMI, SMHI, MET OFFICE)
Assess the model biases and representation of physics of selected extreme events drawing from results of WP 1, 2, 3 as simulated by PRIMAVERA high resolution models (Stream 1 and 2) and compare them to the existing CMIP5 and CORDEX simulations. Focus will be on mechanisms controlling storm development and their tracks: tropical (intense rain, storm surge) and extra-tropical (intense rain, wind), as well as extra-tropical transition along changing storm tracks, particularly in the North Atlantic sector (D10.3).

T10.4 [M25-57]: Construct input for scientific risk assessments of meteorological hazards (Lead: BSC. Participants: KNMI, MET OFFICE)
For each use case construct a narrative, or storyline, of relevant meteorological events in current and future climate. These will include a statistical description and an underpinning scientific assessment on physical mechanisms causing the events and the ability of models to simulate those events. It will also include processing of output from PRIMAVERA models to user-relevant meteorological variables (for both policymakers and end-users). The information will be complemented by information on local vulnerability and impact of events from WP11. This will complement existing products from observation and reanalysis-based data such as the wind storms catalogue 49. (D10.4).

Interactions with other work packages
This work package provides to:
WP8,11 (scientific input for risk assessments to be used in the interaction and dissemination to policymakers and end users) - D8.5
WP1 (feedback on use of metrics package) - MS3
WP6 (diagnostics and model configurations required for Stream 2) - D8.1

This work package receives from:
WP1 (key metrics indicative of model trustworthiness) - D1.1
WP2,3,4 (model biases and representation of physics of extreme events)
WP5 (drivers of climate variability) - D2.4
WP6 (data from core runs to select the extreme events) - D6.2-D6.4
WP8,11 (use cases and requirements from sectors, end-users and policymakers) - D11.3

Participation per Partner

Partner number and short name	WP10 effort
1 - MET OFFICE	18.00
2 - UREAD	24.00
3 - KNMI	20.00
4 - SMHI	10.00
8 - BSC	18.00
Total	90.00

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D10.1	Description of use cases identified	3 - KNMI	Report	Public	12

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D10.2	Statistics and representation of events in CMIP5, CORDEX and first PRIMAVERA output.	4 - SMHI	Report	Public	24
D10.3	Physics of extreme and compound events from PRIMAVERA output.	2 - UREAD	Report	Public	51
D10.4	Scientific input for risk assessment	2 - UREAD	Report	Public	56

Description of deliverables

D10.1: Report describing the use cases, identified by policymakers and end-user needs for information on future extremes and compound events (M12)
D10.2: Report on statistics and representation of relevant extreme and compound events in CMIP5, CORDEX and from first PRIMAVERA output (M24)
D10.3: Report on physics of extreme and compound events from PRIMAVERA output (M51)
D10.4: Report with scientific input for risk assessments for policymaker and each end-user (M56)

D10.1 : Description of use cases identified [12]

Report describing the use cases, identified by policymakers and end-user needs for information on future extremes and compound events

D10.2 : Statistics and representation of events in CMIP5, CORDEX and first PRIMAVERA output. [24]

Report on statistics and representation of relevant extreme and compound events in CMIP5, CORDEX and from first PRIMAVERA output

D10.3 : Physics of extreme and compound events from PRIMAVERA output. [51]

Report on physics of extreme and compound events from PRIMAVERA output

D10.4 : Scientific input for risk assessment [56]

Report with scientific input for risk assessments for policymaker and each end-user

Schedule of relevant Milestones

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification
MS26	Provide first results of scientific assessments to WP11	8 - BSC	24	Means of verification: Results documented and available to WP11

Work package number [9]	WP11	Lead beneficiary [10]	8 - BSC
Work package title	User Engagement and Dissemination		
Start month	1	End month	57

Objectives

• To advance the communication of scientific information needed to develop climate risk response strategies for European businesses, and thus strengthen their competitiveness and growth.
• To engage with end-user groups from key economic sectors, to exploit new capabilities in high-resolution global climate modelling and understanding with a focus on European climate, towards the development of improved climate services.
• To ensure the project outcomes are disseminated and communicated effectively to business sector end-users.

Description of work and role of partners

WP11 - User Engagement and Dissemination [Months: 1-57]
BSC, MET OFFICE, UREAD, KNMI, PREDICTIA
This work package is led by: Dragana Bojovic, BSC (lead) and Erika Palin, MET OFFICE (co-lead).

Description of work
A common barrier to the use of climate information is a mutual lack of understanding between the capabilities of the "producers" of climate science and the needs of "end-users". To address this, engagement with business sector end-users will be performed from the start of the project. A co-production approach will be used (32) where information and ideas are exchanged between end-users and PRIMAVERA scientists in an on-going and bi-directional manner (primarily via workshops and individual meetings). WP11 will subsequently go beyond WP10 by carrying out an in-depth analysis of specific climate risks and potential impacts on these end-users.

Each partner will focus on specific end-users within key sectors (wind energy, transport, power system, and finance/ insurance) to ensure that the project outcomes are both useful and actionable. Product tools and communication materials (D11.3, D11.4) will be developed that translate existing GCM simulations, Stream 1 integrations (WP6) and sensitivity tests for decadal scale climate variability (WP5) into "usable" information to be exploited by end-users. The results of these interactions will inform the model configurations and experimental design for the Stream 2 core integrations (WP6).

Scientifically, the work will focus on near-surface climate properties (wind, temperature, precipitation, insolation) both individually and in joint occurrence, along with their underlying drivers both at the "weather" (e.g., storms, blocking) and "climate" timescales (e.g., low-frequency modes of variability including coupled processes), with a focus on extreme and compound events. This will be closely linked to climate risk assessments, in conjunction with WP10, and aims to facilitate the development of risk response strategies for the target sectors (e.g. power system response due to supply-demand imbalance and infrastructure damage, transport disruption risk response due to extreme heat, financial markets instability due to storm damage). This draws on three key strengths and research topics in PRIMAVERA; Better representation of certain weather extremes (using metrics from WP1); better representation of spatial differences in weather/climate (change) (from process based assessment in WP2), and more possibilities to quantify and present the various types of climate drivers, including those from natural variability and climate change (from WP5). A range of dissemination activities will be implemented throughout to make the project results available to end-users, in a format that is tailored and relevant to their specific needs. These methods are described in detail in Section 2.2.

T11.1 [M1-M57] End-user dissemination and communication plan (Lead: BSC. Participants: MET OFFICE, KNMI, PREDICTIA, UREAD)
This will detail the measures to be adopted during and after the project and illustrate how the proposed measures will achieve the expected impacts (Section 2.1), It will address the full range of potential "users and uses" as indicated in T11.2. Updates of this plan (D11.1) will be provided to the EC together with the Project Periodic Reports (every 18 months) and the final report (M 48).

T11.2 [M1-57] End user-engagement: Identifying their needs (Lead: MET OFFICE. Participants: UREAD, KNMI, BSC)
Meetings will be prepared and carried out to engage end-users of the climate projections [All]. Interactions will begin with initial "demonstration of principle" activities that translate outputs from climate models into first estimates of the

properties of interest to the target sector. These will inform and motivate end-users of the opportunities for exploiting near-term climate information. An evaluation of both their short-term (operational) and longer-term (planning) strategies that are affected by climate variability will be made. The potential risk of future variability (with a focus on the near-term 2020-2050 timescales) to their identified strategies, and the subsequent challenges this could bring will be explored with the end-user. Unique features of high-resolution GCM simulations, that can improve the representation of climate events of relevance to end-users, will be addressed specifically.

For the power (electricity) sector, [BSC and UREAD] will work together to address the 2013 IPCC AR5 WG2 conclusion that "much research is still needed to understand the implications of climate change and extreme weather on the energy sector" (Ch 10.2.5). BSC will take the lead in targeting wind farm owners/investors, national and international infrastructure operators, and energy policy makers whose operations are affected by large-scale wind-power integration (e.g. EDF, E.ON, Scottish Power, Iberdrola, Endesa, SSE, Centrica, UK National Grid). The outcomes of PRIMAVERA will help these end-users to evaluate and explore measures to manage the risk of future variations in wind power supply over their investment time-frames (which is known to affect initial loan rates and subsequent cash-flow)42 or for the planning of long-term strategies (where to site wind farms, how will future wind capacity vary, transmission requirements, storage and reserve requirements). UREAD will lead research taking a wider view of climate risk in the power sector, targeting individuals linked to policy-making for energy, energy system consultants, and operation and planning managers in the power sector (e.g., IEA; IAEA; power generators such as SSE, EDF, Centrica; transmission system operators such as UK National Grid; GE energy consulting; and the IPCC WG2 process). These climate risks take many forms, both acute (e.g., heatwaves and droughts posing risks to the operation of coal and nuclear generation plant and consequent electricity price spikes) and chronic (e.g., reduction of plant and transmission-line efficiency at higher temperatures; changes in water-availability for hydropower). These will be explored and evaluated, to help end-users respond to physical impacts (damage to infrastructure), compound/network interactions (e.g., loss of load during high-demand, low supply extremes), or economic (e.g., market price spikes) mechanisms. This work links with T8.7 with considerations of how regulation may be affected by end-user exposure.

For the transport sector [Met Office], the end-users will be the weather and climate change resilience and/or climate change adaptation experts at national and European rail companies. The outcomes of PRIMAVERA will help these end-users to evaluate and explore measures to respond to risks facing rail systems. Considering wind specifically, this includes the current operational management of high winds, and how wind-related risks (overturning trains, trees on lines, damage to overhead lines or bridges etc) also needs to be considered in the longer-term planning of the rail network. Other climate variables will also be considered, following feedback from initial user-interactions. For the finance and insurance sectors [KNMI], the end-users will be risk managers. The finance sector has links with many sectors that are influenced by extreme weather/climate through financing projects, (re)-insurances, for properly assessing the financial risks of (re)insurances and assets and the spreading of risks related to weather / climate, this sector needs representative information on the intensity of weather extremes, spatial distribution and variation (high spatial resolution) and whether or not extremes occur simultaneously. The outcomes of PRIMAVERA will help these end-users to evaluate possible climate trends, intra- and inter-annual variability, the spatial extent of extreme and/or compound weather events, and explore measures to evaluate optimal financing strategies and premiums.

The feedback (MS27 provided by the end user through meetings and individual interviews will be passed to WP1-6,10, M12), so that their climate research can be tailored to the identified needs.

T11.3 [M6-M12], [M24-M57] Answering user needs using CMIP5 and PRIMAVERA outcomes (Lead: UREAD. Participants: BSC, KNMI, MET OFFICE)
Iterative feedback will be provided to WP6, 10 (MS27) to ensure that their research answers and results can be incorporated within the end-user risk response strategies identified in T11.2 [All by M12].

In collaboration with these WPs, illustrations of climate projections, including an assessment of climate risk, will be created that responds to the end-user needs. Specific attention will be given to the visualisation and communication of the information to improve end-user understanding and use of the information. Similar examples currently available elsewhere will also be considered e.g. ECA&D website (http://eca.knmi.nl/).

For the wind energy and power system sector, climate projections will be communicated and disseminated building on the prototype concept developed in the FP7 project EUPORIAS for shorter timescales [UREAD, BSC, by M36]. The prototype will be a visual illustration and background information of climate projections and impacts up to 2050, communicated in an experimental, quasi-operational mode for this sector (D11.4).

T11.4 [M12-M57] Evaluating how the project outcomes strengthen the competitiveness and growth of companies (Lead: BSC. Participants: KNMI, UREAD, MET OFFICE)

Final meetings will be prepared and carried out with all end-users who were initially approached [All]. A full evaluation (D11.5) will be made of the value, relevance and usability of the project outcomes for the users (46). Any limitations in the results will be evaluated and areas for on-going research to address the identified gaps will be documented.

T11.5 [M6-M57] Web-based dissemination portal (Lead: PREDICTIA. Participants: BSC)
A separate user-oriented section of the PRIMAVERA website will be designed to maximise the dissemination of the project outcomes (D11.2). This will be developed as a User Interface Platform (UIP), as described in Section 2.2. Where possible, the PRIMAVERA UIP will build upon and connect to similar and related initiatives that have been developed in climate service projects, in particular the FP7 EUPORIAS sector specific microsites, which focus on shorter-term climate predictions.

T11.6 [M6-M57] Communication material (Lead: KNMI. Participants: BSC, MET OFFICE, UREAD, PREDICTIA)
Sector specific case studies (D11.3) for the end-users will be co-developed with WP10 around their strategies identified in T11.2. These describe the value and role of climate projections in the chosen sectors, and provide examples of how the results of PRIMAVERA contribute to a better understanding of the climate risk up to 2050. Specific guidance material will be included that describes how the project results can be used/interpreted, its limitations and its relation to other available climate projection data.

Climate projection factsheets (D11.3) will be created describing the basics behind climate projections up to 2050 to complement those coming from the FP7 SPECS project for seasonal-to-decadal predictions [Met Office]. All communication materials will be made available via the PRIMAVERA UIP developed in T11.5.

T11.7 [M24-M57] End-user workshop activities/link to complementary international initiatives (Lead: UREAD. Participants: MET OFFICE, KNMI, BSC, PREDICTIA)
Partners will participate in and/or deliver end-user workshops at relevant external events or initiatives organised by the target sectors. This will facilitate co-production and maximise exploitation and engagement. Events will include the annual European Wind Energy Association conference, the International Conference for Energy Meteorology, appropriate events held by the International Energy Agency and the International Council on Large Electric Systems, the UNEP-FI conference and the bi-annual TRA (Transport Research Arena). KNMI also co-host a weather and climate risk session, convened by SwissRe, at the annual EGU meeting where PRIMAVERA outcomes will be presented. From 2016, KNMI also plan to host a session at the annual "Understanding Risk" conference, which is very well attended by the end-user sectors identified in PRIMAVERA. D11.7 will provide information on the workshops that PRIMAVERA has been presented at, and which key end-users were present. This information will also be included as part of the projects Communication and Dissemination reporting.

Interactions with other work packages
This work package provides to:
- WP1,5,6,10 (user needs for climate information to inform research focus and outcomes) - MS27

This work package receives from:
- WP1-6, 10 (weather and climate metrics; climate projections to 2050: co-development of "demonstration of principal" activities on current climate status and capabilities, and a response to address the identified end-user requirements
- On-going feedback and interaction will occur between WP11 and WP10, as part of a co-production approach to develop climate information that can demonstrate the value of information in a specific context, and stimulate use elsewhere.

Participation per Partner

Partner number and short name	WP11 effort
1 - MET OFFICE	24.00
2 - UREAD	36.00
3 - KNMI	24.00
8 - BSC	48.00
18 - PREDICTIA	15.00
Total	147.00

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D11.1	End-user Dissemination and Communication plan	8 - BSC	Report	Public	3
D11.2	PRIMAVERA User Interface Platform	18 - PREDICTIA	Websites, patents filling, etc.	Public	20
D11.3	Sector specific case studies and climate projection factsheets	3 - KNMI	Websites, patents filling, etc.	Public	42
D11.4	Energy sector visual prototype	8 - BSC	Demonstrator	Public	51
D11.5	Evaluation report of project outcomes by end-users	8 - BSC	Report	Public	57
D11.6	Report on end-user requirements	1 - MET OFFICE	Report	Public	12
D11.7	Document detailing where PRIMAVERA outcomes have been presented to end-users	8 - BSC	Report	Public	57

Description of deliverables

D11.1: End-user Dissemination and Communication plan (M3)
D11.2: PRIMAVERA User Interface Platform (M20)
D11.3: Communication material: Online delivery of sector specific case studies and climate projection factsheets, via the UIP to a wide end-user cross-sectoral audience (M42)
D11.4: Answering user needs with a visual prototype: Online delivery of a sector prototype, via the UIP to a wide end-user audience (M51)
D11.5: Evaluation report of project outcomes by end-users: A user-driven evaluation to summarise a) the user needs for 2050 climate projections, their mode of delivery and their communication within the identified sectors, b) how PRIMAVERA 2050 projections advance CMIP5 2050 projections to answer the user needs and c) how the project outcomes strengthen the competitiveness and growth of companies/organisations and policy. Include in the annex minutes from meetings arranged with end-users. (M57)
D11.6: Report sent to WP leaders documenting end-user requirements for climate information and preferred delivery and visualisation methods (M12)
D11.7: Document on public web site detailing all meetings and workshops where PRIMAVERA outcomes have been presented and which key end-users were present (M57)

D11.1 : End-user Dissemination and Communication plan [3]

Initial plan for communication and dissemination with various user audiences.

D11.2 : PRIMAVERA User Interface Platform [20]

PRIMAVERA User Interface Platform

D11.3 : Sector specific case studies and climate projection factsheets [42]

Communication material: Online delivery of sector specific case studies and climate projection factsheets, via the UIP to a wide end-user cross-sectoral audience

D11.4 : Energy sector visual prototype [51]

Answering user needs with a visual prototype: Online delivery of a sector-specific prototype, via the UIP to a wide end-user audience

D11.5 : Evaluation report of project outcomes by end-users [57]

Evaluation report of project outcomes by end-users: A user-driven evaluation to summarise a) the user needs for 2050 climate projections, their mode of delivery and their communication within the identified sectors, b) how PRIMAVERA 2050 projections advance CMIP5 2050 projections to answer the user needs and c) how the project outcomes strengthen the competitiveness and growth of companies/organisations and policy. The annex of the report will also contain the minutes of meetings that have been conducted.

D11.6 : Report on end-user requirements [12]

Report for WP leaders documenting end-user requirements for climate information and preferred delivery and visualisation methods

D11.7 : Document detailing where PRIMAVERA outcomes have been presented to end-users [57]

Document on public web site detailing all meetings and workshops where PRIMAVERA outcomes have been presented and which key end-users were present (M48)

Schedule of relevant Milestones

Milestone number[18]	**Milestone title**	**Lead beneficiary**	**Due Date (in months)**	**Means of verification**
MS27	End-user requirements for climate information and their preferred delivery and visualisation methods documented	1 - MET OFFICE	12	Means of verification: Recommendations and feedback available to partners for WP1-6,10.

Work package number [9]	WP12	**Lead beneficiary** [10]	1 - MET OFFICE
Work package title	Ethics requirements		
Start month	1	**End month**	57

Objectives

The objective is to ensure compliance with the 'ethics requirements' set out in this work package.

Description of work and role of partners

WP12 - Ethics requirements [Months: 1-57]
MET OFFICE
This work package sets out the 'ethics requirements' that the project must comply with.

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D12.1	H - Requirement No. 2	1 - MET OFFICE	Ethics	Confidential, only for members of the consortium (including the Commission Services)	2
D12.2	H - Requirement No. 1	1 - MET OFFICE	Ethics	Confidential, only for members of the consortium (including the Commission Services)	2

Description of deliverables

The 'ethics requirements' that the project must comply with are included as deliverables in this work package.

D12.1 : H - Requirement No. 2 [2]
Detailed information must be provided on the informed consent procedures that will be implemented.

D12.2 : H - Requirement No. 1 [2]
Details on the procedures and criteria that will be used to identify/recruit research participants must be provided

Schedule of relevant Milestones

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification

1.3.4. WT4 List of milestones

Milestone number[18]	Milestone title	WP number[9]	Lead beneficiary	Due Date (in months)[17]	Means of verification
MS1	Observational/ reanalysis/CMIP5 datasets required for metrics development and model assessment, available on JASMIN in appropriate format, with documentation	WP1, WP2, WP3, WP4, WP9	4 - SMHI	6	Means of verification: All data available and confirmed against checklist, coordinated by WPs 1 and 9
MS2	Strategy for integrating the metrics software available in the different partner institutions	WP1, WP9	1 - MET OFFICE	12	Means of verification: Strategy available to partners
MS3	Assess performance of metrics package for Stream 1 and WP3 integrations.	WP1, WP2, WP3	2 - UREAD	44	Means of verification: Report on Wiki with priorities for further development to meet WP requirements
MS4	List of existing past-CMIP5 global model simulations and of the available high-resolution observational datasets for validation of the simulations.	WP2	12 - CNR	2	Means of verification: List available and distributed within consortium.
MS5	Exchange of model outputs from the past-CMIP5 high-resolution simulations already available at the start of the project and of observational datasets for validation.	WP2	8 - BSC	4	Means of verification: Data available in the central repository in appropriate common formats.
MS6	Plan and tools for co-ordinated process-based analysis of the core-simulations.	WP1, WP2	4 - SMHI	12	Means of verification: Plan and tools available. Validated using representative data.
MS7	Deliver recommendations and model configurations with improved physics for Stream 2 of the core integrations.	WP3	1 - MET OFFICE	24	Means of verification: Report delivered to WP8, models verified by groups. Metadata and descriptions delivered to WP6,9
MS8	Assessment of impact of improved physics and robustness across all PRIMAVERA models in Stream 2 as	WP3	9 - CMCC	55	Means of verification: Assessment documented and provided to WP8

Milestone number[18]	Milestone title	WP number[9]	Lead beneficiary	Due Date (in months)[17]	Means of verification
	compared with Stream 1, and dependencies of robustness on model resolution				
MS9	Requirements for completion of frontier integrations and how they might contribute to HighResMIP.	WP4	6 - MPG	6	Means of verification: Requirements documented and provided to WP8
MS10	Readiness of all modelling approaches (eddy-resolving and unstructured mesh, stochastic and atmospheric convection-permitting) assessed, in order to start planned long simulations	WP4	1 - MET OFFICE	12	Means of verification: Models tested over short integrations and output validated
MS11	Information to WP8 on quantifying the impact of different approaches to simulation of European climate and risk of extremes	WP4	10 - AWI	56	Means of verification: Model integrations completed, datasets available and validated using metrics and assessment of different approaches completed and available
MS12	List of proposed protocols for forced and coupled model sensitivity experiments with pros and cons	WP5	13 - ECMWF	6	Means of verification: List available to WP8 and all partners
MS13	Exchange of model data outputs regarding sensitivity experiments performed in T5.1 and 5.2	WP5	8 - BSC	39	Means of verification: Data under correct format located in central repository
MS14	Protocol design for the multi-model scenarios that will be performed in T5.3	WP5	12 - CNR	43	Means of verification: Design available to WP8 and all partners
MS15	Exchange of model data outputs regarding scenario projections performed in T5.3	WP5	6 - MPG	54	Means of verification: Data under correct format and located in central repository
MS16	Stream 1 runs started	WP6	4 - SMHI	6	Means of verification: Metadata documented on Wiki and central analysis facility.

Milestone number[18]	Milestone title	WP number[9]	Lead beneficiary	Due Date (in months)[17]	Means of verification
MS17	Stream 2 runs started	WP6	1 - MET OFFICE	30	Means of verification: Metadata documented on Wiki and central analysis facility.
MS18	Wiki/ internal project website hosted by STFC, made available to all	WP7	17 - NERC	3	Means of verification: All partners verify that they can upload and download data
MS19	Gender Strategy for PRIMAVERA defined and adopted by the consortium	WP7	1 - MET OFFICE	6	Meand of verification: Strategy produced, agreed by consortium and published on the website.
MS20	Intra-project Workshop	WP8	3 - KNMI	24	Means of verification: Workshop takes place at M24 General Assembly.
MS21	Specification of model diagnostic outputs required for Stream 1 integrations.	WP9	3 - KNMI	1	Means of verification: Specification signed by all modelling groups delivered to WP8
MS22	Confirm that all centres have required HPC resources and models that can perform the core integrations	WP9	8 - BSC	3	Means of verification: Report signed by all modelling groups delivered to WP8
MS23	JASMIN central analysis facilities available to all project members	WP9	17 - NERC	3	Means of verification: Access verified for all project members.
MS24	Prototype data conversion procedures available and documented.	WP9	1 - MET OFFICE	6	Means of verification: Software tested on subset of model data and released for general testing.
MS25	Finalise and agree updated DMP for Stream 2 simulations	WP9	12 - CNR	23	Means of verification: DMP and details of revisions available to WP8
MS26	Provide first results of scientific assessments to WP11	WP10	8 - BSC	24	Means of verification: Results documented and available to WP11
MS27	End-user requirements for climate information and their preferred delivery and visualisation methods documented	WP11	1 - MET OFFICE	12	Means of verification: Recommendations and feedback available to partners for WP1-6,10.

1.3.5. WT5 Critical Implementation risks and mitigation actions

Risk number	Description of risk	WP Number	Proposed risk-mitigation measures
1	Key staff assigned to project become unavailable for any reason (all)	WP1, WP10, WP11, WP2, WP3, WP4, WP5, WP6, WP7, WP8, WP9	All consortium members to have appropriate succession planning, with deputies for all key roles appointed. Coordinate between partners to ensure expertise is available.
2	Individual partners are unable to complete their assigned tasks (all)	WP1, WP10, WP11, WP2, WP3, WP4, WP5, WP6, WP7, WP8, WP9	Regular communications led by Coordinator and Project Manager between WPs to monitor progress, gain early sight of issues and manage/ reassign work/resources as required.
3	Severe damage to JASMIN platform (all)	WP1, WP10, WP11, WP2, WP3, WP4, WP5, WP6, WP7, WP8, WP9	STFC maintain JASMIN with a high level of rigour, as it is crucial UK infrastructure. Model output will be kept at partner institutes, and backups of web pages and code repositories maintained. Data analysis would continue more slowly at partner institutes.
4	Funding for JASMIN infrastructure or staff is severely reduced (all)	WP1, WP10, WP11, WP2, WP3, WP4, WP5, WP6, WP7, WP8, WP9	NERC has invested millions of GB pounds in expanding the JASMIN platform over the last two years to increase its capacity. This indicates a commitment to support the platform in the future, specifically with its planned use for CMIP6.
5	Late delivery of the process-based metrics assessment tools, impacting the synthesis assessment of the PRIMAVERA simulations (b, f)	WP1, WP10, WP11, WP2, WP3, WP4, WP5, WP6, WP7, WP8, WP9	Strategy for prioritised delivery of crucial tools to allow for assessment of the uncertainties in PRIMAVERA simulations and projections
6	Late delivery of the Stream 2 simulations from WP6 including physics improvements, potentially missing CMIP6 deadlines (c, f)	WP3, WP6	Deeper investigation of the PRIMAVERA Stream 1 simulations complemented by the analysis of the partially completed Stream 2 simulations and WP3 simulations assessing model physics improvements.
7	FCM integrations have fundamental technical problems -HPC availability, scalability, stability, ocean spin-up (d, c)	WP4	Seek and share experience between groups and from external sources; if necessary shorten integration period by limiting to present day. Seek PRACE resource for HPC if necessary.
8	Unable to assess the impact of different scenarios/climate drivers on European climate at high resolution (e, f)	WP1, WP10, WP2, WP5	Select a subset of contrasted scenarios to ensure delivery of reasonable uncertainty estimates for input to scientific risk assessment
9	AMIP and Coupled runs have technical problems leading to late delivery of simulations (HPC requirements, model scalability or stability, ocean spin-up) (a, c, e, f, g)	WP10, WP11, WP3, WP4, WP5, WP6, WP9	Ensure resource requirements are well understood by each centre. Produce outline document of the procedures for obtaining HPC resource at different centres, along with the timescales involved, possibly including PRACE. Seek and share experience between groups and help from vendors. Reduce number of ensemble members.

Risk number	Description of risk	WP Number	Proposed risk-mitigation measures
10	Utilities to enable on demand conversion of datasets to CMOR common format have severe problems, compromising the plan for central, common data analysis (b, e, f)	WP9	Engage with (MET OFFICE) experts in configuration and usage of the CMOR software. Invest significant resources in establishing very clear data specifications at the outset to avoid divergence and confusion in data conversions. Consider weakening strict format controls (implications for inter-comparison, software tools).
11	End-user fatigue leading to lack of engagement, inability to discover climate information required by users and hence unable to deliver it (g)	WP11	"Demonstrations of principle" activities will be created early in the project to translate PRIMAVERA's results into quantities meaningful to end-users, making the value of engagement with PRIMAVERA clear. These will be updated, extended and published regularly throughout the project, ensuring that there is ongoing engagement from the end-users. Joint workshops will also be organised with other end-users (for example Climate-KIC projects) to cross-fertilise ideas.
12	Resources to deal with large data flows, either at national centres or via PRACE machines, need in order to have model data available for analysis, becomes too demanding for various systems.	WP4, WP6, WP9	Prioritise particular diagnostics in time-critical order to reduce bandwidth needed. Take advice from PRACE and other experts about improving data transfer rates, including compressing data volumes more efficiently.

1.3.6. WT6 Summary of project effort in person-months

	WP1	WP2	WP3	WP4	WP5	WP6	WP7	WP8	WP9	WP10	WP11	WP12	Total Person/Months per Participant
1 - MET OFFICE	15	11	34	38	0	10	30	4	44	18	24		228
2 - UREAD	24	30	49	0	27	0	4	8	0	24	36		202
3 - KNMI	6	30	12	0	0	4	0	4	4	20	24		104
4 - SMHI	17	33	26	0	20	12	0	4	6	10	0		128
5 - CERFACS	18	15	0	6	36	18	0	4	3	0	0		100
6 - MPG	18	22	18	24	20	12	0	2	8	0	0		124
7 - UCL	24	22	16	0	14	0	0	1	0	0	0		77
8 - BSC	30	30	18	28	26	12	0	4	12	18	48		226
9 - CMCC	24	34	32	0	0	12	0	4	6	0	0		112
10 - AWI	0	12	0	38	0	18	0	1	22	0	0		91
11 - UOXF	0	4	0	33	0	12	0	1	8	0	0		58
12 - CNR	18	34	0	16	26	12	0	1	12	0	0		119
13 - ECMWF	0	30	12	15	28	8	0	1	5	0	0		99
15 - UNIVLEEDS	0	0	29	24	0	0	0	1	0	0	0		54
16 - SU	0	0	16	0	0	0	0	1	0	0	0		17
17 - NERC	0	20	20	12	0	0	6	4	12	0	0		74
18 - PREDICTIA	0	0	0	0	0	0	0	1	0	0	15		16
19 - DKRZ	0	0	0	6	0	6	0	1	0	0	0		13
20 - NMA	2	2	0	0	0	0	0	0	0	0	0		4
Total Person/Months	196	329	282	240	197	136	40	47	142	90	147		1846

1.3.7. WT7 Tentative schedule of project reviews

Review number [19]	Tentative timing	Planned venue of review	Comments, if any
RV1	24	Bologna	at the general assembly
RV2	40	Barcelona	at the general assembly
RV3	57	Brussels	

1. Project number

The project number has been assigned by the Commission as the unique identifier for your project. It cannot be changed. The project number **should appear on each page of the grant agreement preparation documents (part A and part B)** to prevent errors during its handling.

2. Project acronym

Use the project acronym as given in the submitted proposal. It can generally not be changed. The same acronym **should appear on each page of the grant agreement preparation documents (part A and part B)** to prevent errors during its handling.

3. Project title

Use the title (preferably no longer than 200 characters) as indicated in the submitted proposal. Minor corrections are possible if agreed during the preparation of the grant agreement.

4. Starting date

Unless a specific (fixed) starting date is duly justified and agreed upon during the preparation of the Grant Agreement, the project will start on the first day of the month following the entry into force of the Grant Agreement (NB : entry into force = signature by the Commission). Please note that if a fixed starting date is used, you will be required to provide a written justification.

5. Duration

Insert the duration of the project in full months.

6. Call (part) identifier

The Call (part) identifier is the reference number given in the call or part of the call you were addressing, as indicated in the publication of the call in the Official Journal of the European Union. You have to use the identifier given by the Commission in the letter inviting to prepare the grant agreement.

7. Abstract

8. Project Entry Month

The month at which the participant joined the consortium, month 1 marking the start date of the project, and all other start dates being relative to this start date.

9. Work Package number

Work package number: WP1, WP2, WP3, ..., WPn

10. Lead beneficiary

This must be one of the beneficiaries in the grant (not a third party) - Number of the beneficiary leading the work in this work package

11. Person-months per work package

The total number of person-months allocated to each work package.

12. Start month

Relative start date for the work in the specific work packages, month 1 marking the start date of the project, and all other start dates being relative to this start date.

13. End month

Relative end date, month 1 marking the start date of the project, and all end dates being relative to this start date.

14. Deliverable number

Deliverable numbers: D1 - Dn

15. Type

Please indicate the type of the deliverable using one of the following codes:

R	Document, report
DEM	Demonstrator, pilot, prototype
DEC	Websites, patent fillings, videos, etc.
OTHER	
ETHICS	Ethics requirement
ORDP	Open Research Data Pilot
DATA	data sets, microdata, etc.

16. Dissemination level

Please indicate the dissemination level using one of the following codes:

PU	Public
CO	Confidential, only for members of the consortium (including the Commission Services)
EU-RES	Classified Information: RESTREINT UE (Commission Decision 2005/444/EC)
EU-CON	Classified Information: CONFIDENTIEL UE (Commission Decision 2005/444/EC)
EU-SEC	Classified Information: SECRET UE (Commission Decision 2005/444/EC)

17. Delivery date for Deliverable

Month in which the deliverables will be available, month 1 marking the start date of the project, and all delivery dates being relative to this start date.

18. Milestone number

Milestone number:MS1, MS2, ..., MSn

19. Review number

Review number: RV1, RV2, ..., RVn

20. Installation Number

Number progressively the installations of a same infrastructure. An installation is a part of an infrastructure that could be used independently from the rest.

21. Installation country

Code of the country where the installation is located or IO if the access provider (the beneficiary or linked third party) is an international organization, an ERIC or a similar legal entity.

22. Type of access

VA	if virtual access,
TA-uc	if trans-national access with access costs declared on the basis of unit cost,
TA-ac	if trans-national access with access costs declared as actual costs, and
TA-cb	if trans-national access with access costs declared as a combination of actual costs and costs on the basis of unit cost.

23. Access costs

Cost of the access provided under the project. For virtual access fill only the second column. For trans-national access fill one of the two columns or both according to the way access costs are declared. Trans-national access costs on the basis of unit cost will result from the unit cost by the quantity of access to be provided.

PRIMAVERA

History of changes which modify the meaning of Annex 1:

Section	Details of changes made	Changes made by whom	Date
4.2	Description of ICREA and relationship to BSC added	Katie Herring	23/03/15
4.1	Description of IC3 replaced with description of BSC	Katie Herring	23/03/15
Throughout proposal document	Replace reference to IC3 with BSC	Katie Herring	23/03/15
3.2.11 and 5.1	Text amended to include reference to Ethics Documentation (D7.6) which PRIMAVERA will provide	Katie Herring	23/03/15
4.1	Additional information added to description of participant 7 (UCL) regarding staff involved in PRIMAVERA.	Katie Herring	24/03/15
3.2.7	Additional information added to description of External Expert Advisory Board	Paula Newton	08/04/15
4.2	Addition of description of sub-contract with the Netherlands e-Science Center	Paula Newton	08/04/15
Throughout proposal document	New partner NMA added	Paul van der Linden	01/03/17
Throughout proposal document	Nine months extension	Paul van der Linden	31/01/19

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1. EXCELLENCE

1.1 Objectives

The overarching goal of PRIMAVERA is:

> **To develop a new generation of advanced and well-evaluated high-resolution global climate models, capable of simulating and predicting regional climate with unprecedented fidelity, for the benefit of governments, business and society in general.**

Advanced, high-fidelity models

The concept of model fidelity[a] is central to PRIMAVERA, and its foundations are in process understanding. It is clear that many of the most pressing questions about regional climate change urgently require advances in process simulation. For example, to what extent are recent heat waves, floods and droughts in Europe attributable to natural variability or human influences on the global climate system? How will the risk of such high impact events change over the next few decades and beyond? The extent to which it is possible to provide robust answers to these questions relies fundamentally on the fidelity of the climate models that are used to address them. However, fidelity is insufficient in itself: we must be able to justify why a particular model produces a particular prediction at the process level.

Climate processes and high-resolution Global Climate Models (GCMs)

Many years of experience, first in numerical weather prediction and, equally albeit only recently, in climate simulation, have demonstrated that advances in the explicit simulation of key processes are essential to achieving sustained progress and to provide robust answers. High-resolution has been identified as one essential element of the development of GCMs to reproduce key climate processes with higher fidelity than conventional GCMs, thus enabling detailed process understanding.

PRIMAVERA draws on key scientific and technological advances in four cross-disciplinary areas: i) seamless weather and climate; ii) process-based assessment; iii) high-performance computing (HPC); iv) IT, networks and post-processing capacity for large datasets. Optimally combining these advances is a huge challenge and has never been attempted before. PRIMAVERA will, for the first time ever, make highly coordinated use of European high-resolution GCMs to provide trustworthy projections up to 2050.

The proposed consortium of European groups are uniquely placed to take up this challenge at this time, because they possess the skills required; they have a track record in successfully utilising HPC (PRACE-UPSCALE, PRACE-HiResClim, Athena), coordinated via IS-ENES2; they possess global, coupled climate models with shared components; the required HPC is now available, both from national and supra-national sources.

PRIMAVERA is a demonstrative project and its outputs will produce the essential scientific basis for future operational prediction and projection systems. In order to make the challenge tractable, we choose to impose a very specific focus:

- Concentrate on the physical climate aspects of model development and simulation
- Limit the period of integration to the near past and future, 1950-2050
- Limited use of ensembles, sufficient to interpret the output from ensembles generated by much lower resolution models and to support climate risk assessment, based on robustness of process-understanding compared to robustness from large data samples.
- Restrict the study to *horizontal* resolution increases – vertical resolution is also important and the stratosphere requires sufficient resolution, but this is currently the scope of specific national programmes

With these elements in place, we believe that PRIMAVERA will be a catalyst for a step change in capability for climate prediction and projection, providing a robust foundation for future climate services and climate policy at national and European levels.

Specific objectives of PRIMAVERA are (work packages addressing each objective are listed in parenthesis):

a. To develop a new generation of global high-resolution climate models. *(3, 4, 6)*

b. To develop new strategies and tools for evaluating global high-resolution climate models at a process level, and for quantifying the uncertainties in the predictions of regional climate. *(1, 2, 5, 9, 10)*

c. To provide new high-resolution protocols and flagship simulations for the World Climate Research Programme (WCRP)'s Coupled Model Intercomparison Project (CMIP6) project, to inform the Intergovernmental Panel on Climate Change (IPCC) assessments and in support of emerging Climate Services. *(4, 6, 9)*

[a] *Fidelity* expresses the accuracy with which a numerical simulation captures the behaviour of the real world.

d. To explore the scientific and technological frontiers of capability in global climate modelling to provide guidance for the development of future generations of prediction systems, global climate and Earth System models (informing post-CMIP6 and beyond). *(3, 4)*

e. To advance understanding of past and future, natural and anthropogenic, drivers of variability and changes in European climate, including high impact events, by exploiting new capabilities in high-resolution global climate modelling. *(1, 2, 5)*

f. To produce new, more robust and trustworthy projections of European climate for the next few decades based on improved global models and advances in process understanding. *(2, 3, 5, 6, 10)*

g. To engage with targeted end-user groups in key European economic sectors to strengthen their competitiveness, growth, resilience and ability by exploiting new scientific progress. *(10, 11)*

h. To establish cooperation between science and policy actions at European and international level, to support the development of effective climate change policies, optimize public decision making and increase capability to manage climate risks. *(5, 8, 10)*

1.2 Relation to the work programme

PRIMAVERA is designed to answer to the "SC5-1-2014: Advanced Earth-system models" call and to closely fulfil its ambitions. In the following text, the relevant PRIMAVERA objective is indicated in parentheses (e.g.: (a)).

PRIMAVERA will deliver "*a new generation of advanced and well-evaluated global climate models"* (a,b,c,e) at high-resolution (a,d) that will provide the foundational capability for future "*sophisticated climate related prediction systems*" (a,b,c,f). PRIMAVERA will focus particularly on improving the representation of "*relevant physical processes*", including "*anthropogenic drivers*", "*at the appropriate scale*" (a,b,e). "*New methods for representing uncertainties*" will be developed as part of the process-based evaluation (b) and frontiers research (d), and used "*to assess the reliability of regional responses and their impacts on key economic sectors"* (e,g). The advanced models will be used to achieve "*better understanding of past climatic variability and its causes and impacts*" (e,g), focussing particularly on the period since 1950. The models and scientific advances will also be used to produce "*novel climate scenarios*", focussing on the next few decades up to 2050 in order to provide more robust climate risk assessments for governments, business and society (f) and thus supporting decision making at private and public level (g,h). PRIMAVERA will support the post-AR5 IPCC process by using CMIP5 and CMIP6 DECK experiments to develop tools and assessment methods that will then be used to assess the project's simulations (which will themselves be delivered to CMIP6 and AR6) (c), further contributing to a solid scientific basis for future science cooperation at European and international level.

As part of the post-AR5 process PRIMAVERA investigators are already engaging with WCRP (through high profile participation in the October post-IPCC workshop in Bern) and, with HighResMIP, directly engaging the WGCM programme. PRIMAVERA goals and scientific questions are aligned with WCRP Grand Challenges, in particular with regard to the roles of clouds and circulation in the climate system; the relative roles of sea surface temperature and aerosol patterns in governing climate variability and change over seasonal to decadal time scales; the changes in the global hydrological cycle and in the regional availability of water. Improved and more rigorously assessed models, including co-design by end-users, will produce significant progress in all these areas.

1.3 Concept and approach

1.3.1 Concept

Improved climate projections are required by governments, businesses and society to manage, respond and adapt to the risks and opportunities associated with climate variability and change. Recently available projections delivered by the IPCC[1] have re-confirmed most aspects of climate change associated with global warming, regarding changes at global and continental scales, but are limited by the large uncertainties still remaining at the spatial scales relevant for society - regional and smaller - and extending to our understanding of high impact events[2]. With a backdrop of the six WCRP Grand Challenges, the WCRP Working Group on Coupled Models (WGCM) has identified three themes for particular focus for the next phase of CMIP[3]. These are: (1) Systematic Biases, (2) Response to Forcings and (3) Variability, Predictability and Future scenarios.

Meeting WCRP grand challenges thus requires that substantial progress is made in fundamental process-understanding, and the use of climate models can help interpret observations, and formulate and test hypotheses about mechanistic chains. While some progress can be made by enhancing the physical realism of parameterisations, it has been shown that increasing model resolution allows some of the key climate processes to be directly resolved.

The history of Numerical Weather Prediction (NWP) and, more recently, seasonal prediction[4] has shown that increases in model resolution are fundamental to improved credibility in simulating the atmosphere and ocean: NWP skill scores have improved nearly linearly in time over the last thirty years and, while this progress has relied on advancements in all aspects of the forecast system (observations, data assimilation, parameterisation, resolution,

ensemble size), analyses available from each of the operational centres show clearly that a step change was obtained when resolution passed critical thresholds. Equally, in climate modelling, it has been robustly demonstrated that increasing resolution leads to systematically more credible simulations of key phenomena, such as El Niño Southern Oscillation (ENSO)[5], Tropical Instability Waves[6], the Gulf Stream and its influence on the atmosphere[7,8], the global water cycle[9], extra-tropical cyclones and storm tracks[10,11], tropical cyclones[12,13], tropical-extratropical interactions[14] and Euro-Atlantic blocking[15,16,17]. The emergence of these processes has also been shown to have consequences for the simulation of the global climate system: this is the case, for instance, for extra-tropical cyclones and their atmospheric transports, or eddies in the ocean and the mixing of heat and salinity. The atmosphere is of course a continuum and resolution could be taken all the way to molecular scales, but a systematic, multi-model study of the relative roles of resolution, physical parameterisation and forcing can robustly establish some of the key priorities and opportunities in model development.

PRIMAVERA aims to combine the knowledge and expertise gained in the last decade to use, and further develop, the "fleet" of European high-resolution GCMs in order to meet the grand challenge of more credibly simulating the fundamental processes that govern global climate. There is a strong rationale in such ambition and enhanced resolution is particularly important for European climate, which is governed by the interaction of the eddy-driven North Atlantic jet with Europe's unique physiography[45]. A regional modelling approach that relies on downscaling is insufficient, because there is substantial evidence that a continuum of interactions exists between processes at scales from local to global that have a direct impact on European climate. For instance, it has been shown that the Indian monsoon has influence on Southern European summers[18]; that the Madden-Julian Oscillation affects the North Atlantic Oscillation[19]; that a significant number of Atlantic hurricanes undergo extra-tropical transition and morph into storms that impact Europe[14]; that European heat waves are influenced by processes in the Tropical Pacific ocean[20]. These issues can only be adequately investigated using a global modelling approach. Improving the simulation of the physical climate system also offers the opportunity to objectively assess more complex Earth System processes as they are introduced (e.g. those related to the carbon cycle[21]), since the consequent feedbacks may be in error otherwise.

A concrete example is provided in the recent KNMI study[14], using EC-Earth at high-resolution, showing how, in the future, more Atlantic hurricanes can be expected to travel north and affect the European region. More importantly, the study showed how it is the combination of tropical and extra-tropical phenomena that can give birth to some unprecedented weather and climate extremes, which will severely affect European society. Accurate simulation and prediction of phenomena such as the transition of a tropical cyclone into an extra-tropical cyclone (Fig. 1.3.1) requires global high-resolution,[12,13] as the underlying processes are as small as their individual clouds, yet governed by remote drivers. Traditional (IPCC-class) GCMs use too coarse resolution, so that these phenomena are entirely absent[12,13] and therefore estimates of future climate risk based on such models cannot be trusted.

Thus the **limited resolution of current climate models is a critical source of uncertainty in all applications of climate and Earth System modelling**, including to predictions, projections and risk assessments. However, the requirement for a multitude of multi-centennial simulations, including poorly constrained Earth System processes and feedbacks, has meant that model resolution within CMIP has progressed very slowly. In CMIP3 the typical horizontal resolution was 250km in the atmosphere and 1.5° in the ocean, while more than seven years later in CMIP5 this had only increased to 150km and 1° respectively. The benefits of higher resolution (~25km) have been abundantly demonstrated, but there has never been a systematic investigation of these benefits in the context of a multi-model assessment. PRIMAVERA will, for the first time, provide such an assessment. Furthermore, by forming a "European High-resolution Modelling Hub", and leading a new High-Resolution Model Intercomparison Project (HighResMIP) under CMIP6, PRIMAVERA will enable standardisation of experimental design for high-resolution simulations, which will galvanise the international community towards a more systematic exploration of the role of resolution in addressing these key issues. The output of PRIMAVERA models and the scientific advances in process understanding will provide a basis for Climate Service activities that are becoming operational under the Copernicus (European Earth observation programme) framework and the Global Framework for Climate Services.

1.3.2 Approach and Methodology

The approach of PRIMAVERA is to concentrate on delivering, evaluating and exploiting the best representation, at the highest horizontal resolutions possible, of the processes that are important for the evolution of climate on decadal timescales, with a specific focus on the period 1950-2050. To make this possible, we will focus on the physical climate system (atmosphere, ocean, sea ice, land) and their interactions. A key mediator of these interactions is the global hydrological cycle, which is so strongly constrained by the Earth's energy balance and general circulation. Understanding the transports and fluxes of water in all its phases, is crucial for any assessment of weather and climate

impacts at the regional scale. As such, processes important for European climate will be afforded particular attention,

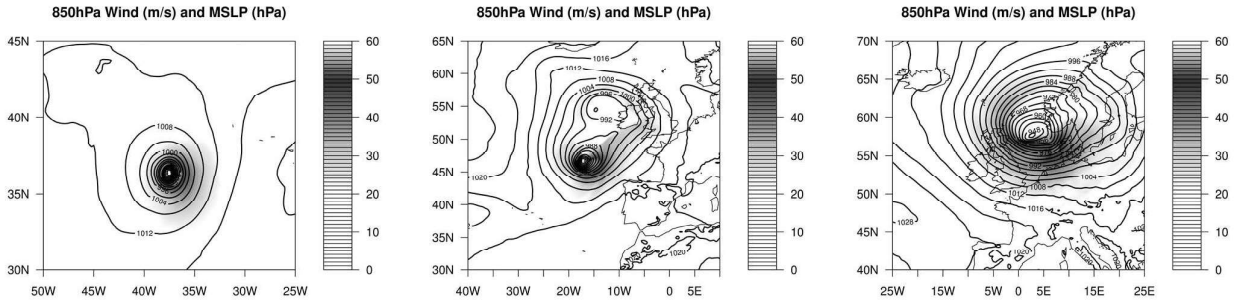

Figure 1.3.1. A Tropical Cyclone reaching Europe, as simulated by the high-resolution (~25km) EC-Earth Global Climate Model with a future climate scenario. Contours are isobars (hPa); shading represents wind speed (m/s). Panel 1 (left) shows the early stage (96h), as the hurricane emerges from the tropical Atlantic and is still axisymmetric; panels 2 (132h) and 3 (162h) show how it interacts and merges with a mid-latitude disturbance, growing into a severe extra-tropical windstorm. This type of tropical-extra-tropical interaction leads to the development of mid-latitudes storms bearing extreme amounts of water (thus high-impact precipitation). Traditional, low-resolution GCMs are unable to simulate such phenomenon. Adapted from Haarsma et al, 2013[14].

but our fundamental approach is global.

PRIMAVERA is organised around five major research themes, as illustrated in the Fig. 1.3.2 which will interact strongly and follow an iterative work flow. The three science themes - 1. Innovations in Modelling; 2. Process-based Assessment; 3. Drivers of European Climate - will primarily use the 4. Flagship Simulations for CMIP6 for input data, and 5. Climate Risk Assessment and User Engagement will then ensure robust interpretation of the scientific risks for policy and other users, as well as engaging specific end-users in the co-design of climate scenarios.

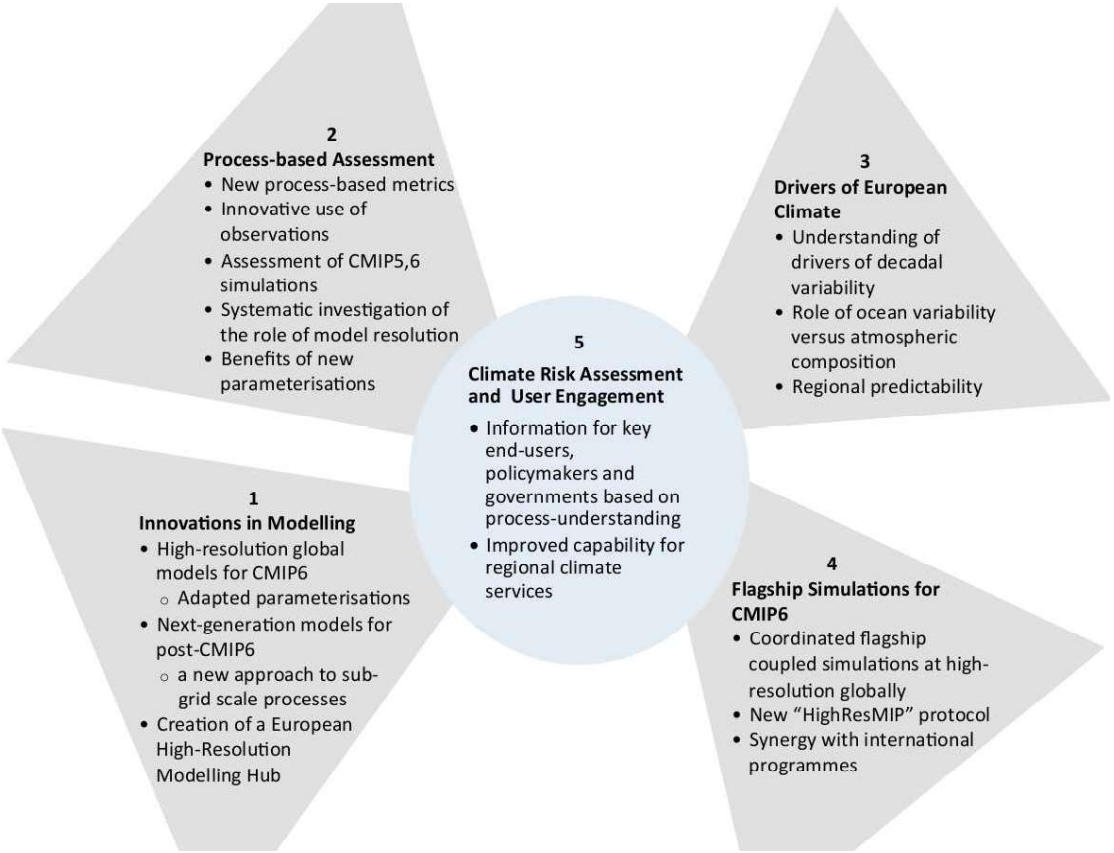

Figure 1.3.2: Schematic diagram of the interconnected research Themes of work addressed by PRIMAVERA

Table 1.3.1: Correspondence between Themes and work packages

	Corresponding work packages in the work plan
Theme 1 Innovations in modelling and exploring the frontiers of climate modelling	WP1 - Development and application of metrics for process-based evaluation and projections WP3 - The role of model physics WP4 - Frontiers of Climate Modelling WP6 - Flagship simulations
Theme 2 Process-based assessment of high-resolution global climate models	WP1, 3, 4 WP2 – The added value of high-resolution in components of the physical climate system WP5 - Drivers of variability and change in European climate
Theme 3 The drivers of European climate variability and change	WP2, 3, 5
Theme 4 Flagship simulations for CMIP6 and IPCC AR6	WP4, 6
Theme 5 Climate risk assessment and user engagement	WP8 – Scientific coordination WP10 - Climate Risk Assessment WP11 – End-user Engagement and Dissemination

At the centre of the project are seven General Circulation Models (GCMs), as described in Table 1.3.2. PRIMAVERA will develop, evaluate and exploit these models, with a major emphasis on assessing the benefits of substantial increases in atmosphere and ocean-sea ice resolutions. Model vertical resolution is typically 80-100 levels, is comparable across the ensemble and will remain fixed. Increasing model resolution to the extent indicated in Table 1.3.2 requires significant technical improvements to models, including working with High-Performance Computing (HPC) providers to efficiently use many 10,000s of supercomputer cores and manage many PetaBytes of data output and processing. The latter is a particular Big Data challenge to make these large datasets open access to any scientist within Europe for data mining and exploitation.

PRIMAVERA Partners	MET OFFICE UREAD NERC	KNMI BSC SMHI CNR	CERFACS	MPG	AWI	CMCC	ECMWF
Model names	MetUM NEMO CICE	IFS NEMO LIM, GELATO	Arpege NEMO GELATO	ECHAM MPIOM MPIOM	ECHAM FESOM FESOM	CAM NEMO CICE	IFS NEMO LIM, CICE
Atmosph. Res., core	60-25km	T255-799	T127-359	T63-255	T63-255	100-25km	T319-799
Atmosph. Res., FCM	10-5km	T799	T359	T511	T511		T1279-T3999
Oceanic Res., core	¼ º	1, ¼º	¼	0.4-¼º	1-¼ spatially variable	¼	¼
Oceanic Res., FCM	1/12º	1/12º	1/12º	1/10º	¼ -1/12º spatially variable		

Table 1.3.2: European GCMs that will be used in PRIMAVERA. A distinction is made between i) **core** and ii) **F**rontiers of **C**limate **M**odelling (**FCM**) integrations (see Theme 1).

Theme 1: Innovations in modelling and exploring the Frontiers of Climate Modelling

Objectives addressed: (a, b, c, d, e, f)

Major activities: i) develop GCMs so that they can perform coordinated experiments at high-resolution, including incorporating new physical parameterisations; ii) design and carry out core 1950-2050 experiments, and targeted

sensitivity experiments, to assess the benefits of increased resolution in the ocean and atmosphere; iii) explore the frontiers of climate modelling through experiments at ultra-high resolution and through novel approaches to parameterisation for high-resolution models.

The core and frontiers experiments are summarised in Figure 1.3.3 below. The PRIMAVERA core experiments comprise ensembles of both forced-atmosphere and coupled ocean-sea-ice-atmosphere-land integrations for the period 1950-2050 at both standard and high resolutions for each model. The high-resolution simulations will deliver a 4-5x[b] increase in resolution over typical CMIP5 models in both atmosphere and ocean. This will be a huge step forward enabling, for example, a greatly improved simulation of blocking in the atmosphere and the Gulf Stream in the ocean[7,8], and will form the basis of the HighResMIP contribution to CMIP6 (see Theme 4). This time period has been chosen since the uncertainties of climate change response up to 2050 are primarily due to model uncertainties and scenario uncertainties (in terms of the drivers of variability and change), both of which PRIMAVERA will address.

The core experiments will be completed in two phases, an initial phase (Stream 1) in which models will be used in their current formulation, and a final phase (Stream 2) which will benefit from lessons learned in WP2, 3, 4, 5 as well as the co-design process in WP11.

Preparatory work for HighResMIP will involve developing, testing and optimising parameterisations for targeted processes at these new resolutions, such as enhancements in the representation of sea ice albedo and rheology to improve simulated rates of Arctic sea ice decline and impacts on European climate[22,23,24].

PRIMAVERA will not only develop the next generation of high-resolution models for CMIP6, it will also carry out pioneering research to explore the potential for further improvements that will be staged post-CMIP6. Frontiers experiments will increase resolution a further 3-4x in the ocean and atmosphere, taking the models into entirely different simulation regimes. An eddy-resolving ocean (1/10-1/12 degree) in five coupled models will, for example, enable a step-change in the simulation of the Mediterranean Sea and its interactions with the surrounding complex physiography. This will enable, among many other processes, a credible simulation of moisture and energy transports that feed extreme precipitation and flooding and hence, for the first time, a process-based assessment of climate risk over Southern to Central Europe.

For the first time PRIMAVERA will explore the benefit of using ocean models based on unstructured mesh methods in high-resolution global climate modelling. This will help to address the question of whether the advantages of mesh flexibility that come with multi-resolution modelling will outweigh technical overheads. The use of stochastic parameterisations to represent the variability of sub-grid processes will also be investigated, since through non-linear feedbacks, they can reduce model biases[25,26], and improve the representation of European weather regimes[25,27]. Contrasting these two sub-grid approaches –ultra-high-resolution modelling versus stochastic parameterisation– is entirely novel. New processes such as graupel, hail and lightning will also be introduced. The "Frontiers" work is obviously very challenging, and only a handful of climate modelling groups worldwide have capability in this area, but it represents a key opportunity to capitalise on recent developments in high-resolution at a small number of European institutions and to combine them to further establish our international leadership. The addition of Prof. Jablonowski to the EEAB (see Section 3.2.7) will give the project valuable links to the community building and assessing these next-generation models.

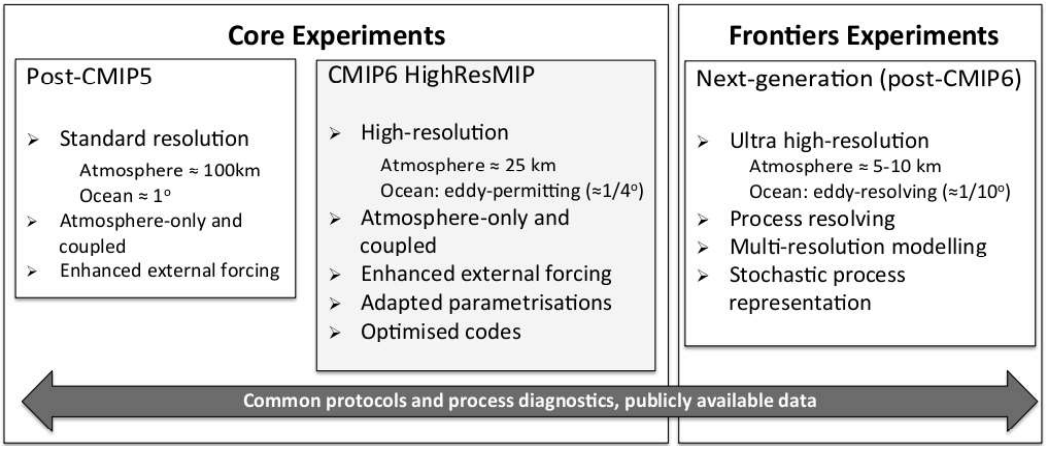

Figure 1.3.3: Schematic diagram of the proposed model simulations to be performed by PRIMAVERA.

[b] The proposed 4x increase in horizontal resolution requires ~30x more computational capacity

Theme 2: Process-based assessment of high-resolution global climate models

Objectives addressed: (b, d, e, f)

Major activities: i) develop new metrics for the process-based evaluation of high-resolution climate models, using diverse observational datasets; ii) apply metrics to assess systematically and objectively the benefits of higher resolution; iii) explore the potential for metrics that can be used to narrow the uncertainty in projections of European climate for the next few decades.

Enhancing resolution is, by itself, insufficient and the benefits of resolution must be rigorously assessed at a process level. PRIMAVERA will take advantage of new diagnostic approaches to evaluate the simulation of fundamental processes in the climate system, such as the lifecycles of extratropical cyclones[11], the position of the Gulf Stream[7], and of processes that govern high impact events such as heat waves and droughts[28,20]. Processes that affect European climate (e.g. cyclones and storm tracks, clouds and aerosols, land surface processes, near-surface ocean mixing, Arctic sea ice) will be a particular focus. The assessment will be applied individual climate components, as has been typical previously, but in addition, metrics assessing the fidelity of coupling processes between components and related feedbacks will be implemented, paving the way for more physically-based model evaluation. Aligned with the process-focussed philosophy of CMIP6, new strategies and tools will be developed to evaluate these processes including their individual responses to natural and anthropogenic drivers of climate. The new tools will be applied systematically to the integrations carried out in Theme 1 to assess the benefits of higher resolution, and the degree of robustness across the PRIMAVERA model ensembles. Emergent relationships between climate projections and observable climate parameters will be sought, and their potential to constrain uncertainty in projections will be explored. The work will build on related FP7 projects (e.g. EMBRACE), national efforts and the metrics effort carried out by WGNE (Working Group on Numerical Experimentation) and WGCM Climate Model Metrics Panel (http://www-metrics-panel.llnl.gov/wiki).

Theme 3: The drivers of European climate variability and change

Objectives addressed: (b, e, f)

Major activities: i) Analysis of core integrations with a focus on identifying natural and anthropogenic drivers of European climate; Design, carry out and analyse coordinated multi-model sensitivity experiments to ii) identify the causes of recent changes in European climate, and iii) to assess future changes in European climate over the next few decades.

Theme 3 will exploit the new capabilities in high-resolution modelling to improve fundamental understanding of the drivers of variability and change in European climate, including high impact events. Understanding the drivers of change in atmospheric circulation will be a key priority because such changes are characterised by high uncertainty and low understanding (IPCC AR5 WG1). Theme 3 will analyse the core simulations of Theme 1 and carry out specific sensitivity studies to identify the roles of different drivers in explaining past changes in European climate since 1950. The roles of both internal drivers (e.g. decadal variability in the Atlantic and Pacific Oceans[29] or changes in Arctic sea ice[22]) and external forcings will be considered. Amongst the external forcings, better understanding the roles of greenhouse gases and aerosols will be a particular priority. Aerosols, in particular, still represent a major source of uncertainty due to the difficulty in representing their interactions in climate models[30,31]. An important goal will be to extract the fingerprint of the various drivers' influence on climate, and mechanistically to understand their combination and contribution to the decadal variability of European climate.

Theme 4: Flagship simulations for CMIP6 and IPCC AR7

Objectives addressed: (a, c, d, f)

Major activities: i) Define protocol for HighResMIP as a flagship contribution to CMIP6; ii) Perform HighResMIP simulations using the PRIMAVERA models; ii) Coordinate and execute analysis of these simulations using Theme 2 metrics.

High-resolution simulations in the past have been carried out typically by individual modelling centres on an ad-hoc basis. HighResMIP will, for the first time, provide the opportunity to assess systematically the benefits of unprecedented increases in resolution in the ocean-sea ice and atmosphere across a global multi-model ensemble. Previous CMIP activities, most recently CMIP5, provide outstanding examples of the value and success of such a coordinated approach, with the multi-model mean often proving to be superior to individual models and significant scientific understanding gained from analysing inter-model spread. Initial work on defining the protocol for HighResMIP has already begun, led by PRIMAVERA Principal Investigators (PI), and has already garnered support from modelling groups around the world (e.g. USA – GFDL, NCAR; China – IAP; Japan – MRI and NICAM groups; Brazil - CPTEC). PRIMAVERA will provide the European contribution to HighResMIP, which will provide a flagship contribution to CMIP6, led by Europe. The results will provide a unique coherent multi-model dataset, which will enable assessment and understanding of the role of resolution in climate model simulation for Europe and other regions.

Theme 5: Climate risk assessment and user engagement

Objectives addressed: (b, f, g)

Major activities: i) Identify user needs and ii) provide novel risk assessments based on improved climate information associated with hazardous meteorological events tailored to end-users needs.

At European level, PRIMAVERA can count on the support[c] of the JPI Climate, EuroGOOS, the European Climate Research Alliance (ECRA) and the German Consortium for Marine Research, as well as the UK Committee on Climate Change. All these institutions either involve governmental bodies directly, or are important interlocutors for the support of decision-making in the climate field at European level, and engagement with them will allow PRIMAVERA to establish the robust scientific base upon which policy decisions are made.

PRIMAVERA identifies specific end-users in policy and business from four key sectors (energy, power systems transport and finance/insurance) whose decisions are influenced by climate information. Scientific input for risk assessments for hydrometeorological extreme events will be made, such as floods, droughts, heat waves, extreme winds and compound events, over regions of interest to the end-users. As an example of the latter, high temperatures and droughts may not be extreme themselves, but the combination of both is shown to have a large impact on managing the balance between energy supply and demand across Europe[48].

The end-user needs for climate information, related to their vulnerability and exposure, and the associated risk that will affect decision-making processes, will be evaluated via individual meetings and iterative feedback processes with the end-users. This is one of the best strategies identified in other international initiatives and is based on the concept of co-design of the climate information[32]. PRIMAVERA will then provide scientific information derived from the simulations and new scientific insights targeted to end-user needs. To this end PRIMAVERA will compare the new climate information to that from existing data from model ensembles at coarse resolution and regionally downscaled data (CMIP5 and the Coordinated Regional Climate Downscaling Experiment, CORDEX) and observations. Narratives will be constructed based on evidence from Themes 1-4, consisting of quantitative information on extreme events that include scientific assessments of their magnitude, plausibility, as well as their expected future changes. These narratives will also be integrated into the scenarios that will be applied in Theme 3 to produce projections.

PRIMAVERA partners have a well established history of collaboration with end-users that will be enhanced in the user engagement activities and these are detailed in WP11.

1.3.3 Positioning of the project

PRIMAVERA covers a whole spectrum of innovation, from scientific insight and ideas (climate model improvement by resolution enhancement and process representation, Theme 1) through to delivery of well-assessed and robust climate model projections using scenarios in which Theme 1-4 science and Theme 5 narratives are fully integrated by co-design. It extends the timescales considered by two FP7 projects, EUPORIAS and SPECS, from seasonal to multi-decadal at higher model resolution. It seeks to retain the more physical aspects of global climate modelling and to a more constrained approach to initialising and forcing models, to simplify understanding of the climate system. For instance, in the ocean, given the abundant evidence that initialisation does not have a large impact for lead times beyond a few years, we will impose decadal SST patterns rather than applying data assimilation. In the atmosphere, given the evidence from CMIP5 models that large spread in radiative forcing results from inter-model differences in aerosol concentrations and transports, we will impose aerosol loadings, rather than aerosol emissions. Finally, given the relatively short PRIMAVERA time scale, up to 2050, we will sharply focus on enhanced understanding and simulation of the physical climate processes, rather than attempting to include long-term biogeochemical feedbacks, e.g. dynamic biosphere, carbon and nutrient cycles.

The project is expected to reach Technology Readiness Level (TRL) 4-5 for both Research and Engagement with Users activities. The Research involves testing our process understanding of climate variability and change using a multi-model ensemble of uninitialized models ("laboratory environment") – this is a necessary first step to operational use such as seasonal forecasting. For Users, it will produce prototypes of products for specific sectors to meet the requirements for decision-making derived from end-user engagement, to be delivered via a User Interface Platform, and which post-project and with interaction with other organisations (such as Climate-KIC) will be brought up and disseminated to a broader European business community.

1.3.4 National or international research and innovation activities linked to PRIMAVERA

PRIMAVERA will work in full coordination with a number of on-going and new international programmes:

- CMIP6 HighResMIP: PRIMAVERA PIs are currently leading the definition and implementation of a high-resolution CMIP protocol and the project will provide flagship simulations to both CMIP6 and more specialised

[c] support and endorsement from organisations stated within the text mean that letters of support have been received and are available upon request

Model Intercomparison Projects (MIPs).

- WCRP: PRIMAVERA's aim to improve understanding and simulation of climate variability, in particular processes affecting Europe on decadal timescales, is aligned with the main objectives of the WCRP WGCM[3]. PRIMAVERA will seek synergies with new ground-breaking efforts in WCRP Grand Challenges such as *Regional Climate Information*. PRIMAVERA scientists will also further develop relationships with WCRP working groups such as WGCM and WGSIP (Working Group on Seasonal to Interannual Prediction) as well as WCRP projects such as GEWEX (Global Energy and Water Exchanges) and CliC (Climate and Cryosphere), and provide leadership where appropriate. The Scientific Coordinator, has already been invited by the pan-GEWEX panel to expose the PRIMAVERA concept and help design the GEWEX core modelling programme. Finally PRIMAVERA will also provide ideal boundary conditions for very-high resolution dynamical downscaling carried out in the context of CORDEX2.
- World Meteorological Organization (WMO)'s Global Framework for Climate Services (GFCS): PRIMAVERA will contribute to the scientific underpinning of future climate services by developing and running the most advanced climate models and by co-designing climate information with a targeted set of end-users. Furthermore, the model output will be aligned with requirements of WMO's GFCS to ensure that PRIMAVERA outputs will include relevant metrics and diagnostics suitable for driving impacts models. The model data will be openly accessible and communication measures will ensure awareness among the communities working on the development of climate services and adaptation. Similar synergies will be exploited for European activities such as Copernicus and the Climate Service Partnership.
- PRIMAVERA will build strong links with the groups developing new datasets for model validation. The Observations for Model Intercomparison Projects (Obs4MIPs) initiative, which aims to make the National Aeronautics and Space Administration (NASA) products more readily available for model evaluation, will be incorporated into metrics developed within the project, with Graeme Stephens a key link as an EEAB member. Involvement with the European Space Agency (ESA)'s Climate Change Initiative (CCI) and their Climate Model User Group (CMUG) will be ensured by having an ESA representative from these activities on the External Expert Advisory Board.

PRIMAVERA will also build on many existing and new activities at the European level:

- The second InfraStructure for the European Network for Earth System Modelling (IS-ENES2): In order to overcome challenges associated with technical infrastructure for high-resolution climate modelling on petascale HPC, PRIMAVERA will work closely with IS-ENES2. Expected benefits of this collaboration include further development of modelling systems and deployment of technologies that will enable fast and robust analysis of PRIMAVERA results across the consortium and for end-users.
- PRIMAVERA will work in full synergy with existing EU projects. Collaboration with the FP7 projects, EUPORIAS (European Provision Of Regional Impacts Assessments on Seasonal and Decadal Timescales) and SPECS (Seasonal-to-decadal climate Prediction for the improvement of European Climate Services) for example, will help to exploit the growing knowledge about the mechanisms responsible for improved regional prediction and the role of increased global resolution in a climate service context. PRIMAVERA will also benefit from cooperation with the FP7 NACLIM project (from which support has been received). The North Atlantic Ocean is one of the most important drivers for the global ocean circulation and its variability on time scales beyond inter-annual. Knowledge of these drivers and processes is of paramount importance for society and key economic sectors, which have to base their planning and decisions on robust climate information
- PRIMAVERA will benefit from existing and future global and regional reanalysis efforts. Planned high-resolution reanalysis projects for the atmosphere (e.g. the new ECMWF reanalyses of the satellite era, ERA-SAT), ocean and coupled system (e.g. the FP7 European Reanalysis of Global Climate Observations, ERA-Clim2) will provide unique opportunities to evaluate high-resolution PRIMAVERA simulations on a global scale. Regional reanalysis efforts for Europe such as those carried out in the European Reanalysis and Observations for Monitoring project (EURO4M) and its follow-on project UERRA (Uncertainties in Ensembles of Regional Re-Analyses) provide unique data, including extremes, with which PRIMAVERA models can be confronted.
- Carrying out the PRIMAVERA simulations will strongly benefit from the use of supra-national facilities and the PIs will work with the Partnership for Advanced Computing in Europe (PRACE) and IS-ENES2 to establish multi-year access to PRACE facilities for running the frontier models and analysing / transferring data, as was successfully done in past PRACE projects (e.g. UPSCALE and HIRESCLIM).

PRIMAVERA will also build on many existing and new national activities. Examples include:

- The UK Joint Weather and Climate Research Programme (JWCRP), a strategic partnership between the Natural Environment Research Council and the Met Office, will continue to provide core resources, both human and computational, for sustaining and advancing the UK high-resolution climate model development programme.
- The Nordic Top-level Research Initiative project (GREENICE) and the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning project (ADSIMNOR) provide valuable insights into the simulation of Arctic processes and their interactions with mid-latitude climate.
- PRIMAVERA will benefit from the German consortium project (STORM), which carried out pilot coupled runs with an eddy-resolving ocean GCM and established a platform for advancing high-resolution climate simulations in Germany.

In the Future Weather projects as part of the Dutch Knowledge for Climate and National Computing Facilities Program, high-resolution global atmospheric model data were generated and applied in use cases for water management. This work is currently supported by the Ministry of Infrastructure and Environment.

1.3.5 Sex and/or gender dimension

SC5-1-2014 does not have a gender dimension explicitly integrated into it, however careful thought has been given to how gender considerations are applicable to the project. The nature of the work within the research themes of PRIMAVERA is considered to be gender neutral. The consortium does recognise, however, that gender considerations can be highly relevant when engaging with end-users and other target audiences, and when designing information and services that will have a societal impact. Gender aspects will be considered within the context of the end-users that will be targeted, the range of sectors that may have an interest in the project results, and in the project Dissemination, Exploitation and Communication measures. A Gender Strategy (MS19) will detail how PRIMAVERA will manage gender considerations (see Section 3.2.11)

1.4 Ambition

1.4.0 State-of-the-art

While typical IPCC-class GCMs use grid lengths of O(100)km, to produce decadal to centennial simulations, the most advanced GCMs used for climate science are now starting to be run at weather-resolving scales (~20km in the atmosphere and ¼ degree in the ocean). Currently, the high-resolution efforts are carried out in a rather uncoordinated way and without a systematic assessment of the robustness of all benefits. There is growing potential for a seamless[d] approach to weather, seasonal and decadal prediction and projection, a strategy that has in fact been adopted by a few modelling groups in Europe and in the USA[33,34] and is the theme of other projects (such as EUPORIAS, CLIMRUN, ECLISE) in a climate service context. Targeting substantially longer time scales and larger spatial scales while retaining a seamless strategy offers the opportunity for a better understanding of underlying processes at all scales and for making better use of new observations, alongside analyses and re-analyses, to further develop climate models and related services[35].

1.4.1 Beyond the state-of-the-art: advancements and benefits

1.4.1.1 **Improving our understanding of model prediction and of inter-model divergence (Themes 1,2):** PRIMAVERA will test the role of better-defined constraints (model formulation, resolution, forcing) and then systematically measure inter-model divergence. The development of new metrics, suitable for high-resolution climate models and for their assessment at the process level, can help us to objectively discriminate between models that present credible mechanisms and those that lack internal consistency. PRIMAVERA will apply process understanding to identifying model outliers, indicating either poor reliability, or else the fingerprint of a process previously missing in state-of-the-art models. The consequent improvement in understanding of the causes of regional variability and change is then a crucial factor to better represent the impacts of climate variability and change. The assessment (and subsequent reduction) of model errors will also feed back into the development of sub-seasonal forecast systems, which are expected to run at resolutions comparable to the PRIMAVERA experiments in the next few years. Therefore, PRIMAVERA will generate valuable synergies with research activities carried out under the joint World Weather/Climate Research Programmes (WWRP/WCRP) Sub-seasonal-to-Seasonal Prediction project[e] and take an unprecedented step in bridging the gap between predictions of climate variability on short and long time scales. This synergy will also enable an assessment of remote causes of European climate anomalies and high impact events, as influenced by the Madden-Julian Oscillation, ENSO and other Pacific variability on both short and long timescales.

[d] A modeling strategy in which either the same model is used across all applications and all scales; or a strategy that seeks to build traceability and intercomparability of the science derived from different modeling streams.

[e] http://www.wmo.int/pages/prog/arep/wwrp/new/S2S_project_main_page.html

1.4.1.2 **Reducing our reliance on physical parameterisations (Theme 1):** by relying less on empirical, uncertain physical parameterisations, it is expected that future high-resolution models will slowly converge in their simulation of the physical climate system, and for the first time capture the crucial physical processes. It has been suggested that this may even apply to regional scales, for reasons that we can trace to the underlying processes (for instance the relative importance of large scale transports and local processes in the chain of models[9]) but these findings must urgently be confirmed in a multi-model context. This should lead to more reliable models and more robust future projections. Going further, it is, in fact, now starting to be possible to operate global models without convective parameterisation, reaching into the grey zone[36], and without meso-scale eddy parameterisation in the ocean, two major sources of uncertainty in climate simulations[37]. It is the ambition of PRIMAVERA to develop, exploit and fully evaluate this new class of models in a concerted effort by partners that have such capability. The knowledge gained by running models at these unprecedented scales will be used to further develop existing models, recognising that the most complete (combining best resolution and most advanced parameterisations) models will still be too expensive for multi-centennial, and longer, applications.

1.4.1.3 **Exploration of the frontiers of model capability (Theme 1):** the 2008 World Modelling Summit for Climate Prediction[38] declared that climate models were very much behind their NWP counterparts in terms of process-representation and reliability. Six years on, it is now true that a number of flagship climate models have been developed and run (simulation length order 1-10 years per ensemble member) at resolutions that in some cases exceed the state-of-the-art in global weather forecasting. In the USA, the National Center for Atmospheric Research operate the CESM model at 10km; in Japan, MRI operate their GCM at ~20km and several teams operate the NICAM model at sub-10km resolution; in the UK, the HadGEM3 model is run at 12km; in mainland Europe the EC-Earth model is run at T799 (~25km). There is now an opportunity to coordinate these pioneering model capability efforts, using common platforms (PRACE) and protocols (e.g. Open Data Access), to learn common lessons from the exercise, extend model resolutions to sub-10km, based on a rigorous assessment of its benefits and to make more efficient use of human and computational resources for generating actionable climate information.

1.4.1.4 **Exploiting petascale high performance computing and preparation for exascale (Theme 1)**: the set of simulations planned in PRIMAVERA is extremely ambitious, because it will require sustained HPC and success depends on a step change in European and international coordination, simplification of protocols for forcing models and continuing to expand our capability to exploit petascale HPC at the supra-national level for the consortium as a whole. Several of the partners in the consortium have pioneered the use of petascale HPC for climate science (Athena, PRACE) to produce ground-breaking simulations, demonstrating how climate research in particular can make effective use of such levels of HPC[15,39]. However, although ambitious we estimate that the required HPC resources for the Stream 1 simulations in WP6 are in the range of 400-500 million core hours across a range of different platforms, equating to between 2.5-3% of the total time available each year across the 26 existing supercomputers around Europe that are suitable and potentially available. These figures do not take into account known substantial upgrades scheduled to take place during 2015 and 2016 to several facilities that we have experience of using, including Archer (EPCC, UK) Hornet (HLRS, GER) and at the Met Office (UK), which will increase the HPC resources available to PRIMAVERA.

1.4.1.5 **Exploiting new observations and reanalyses (Themes 2,3,4):** the high resolution used in the core PRIMAVERA runs will be comparable to the resolution range of next-generation re-analyses, allowing a detailed validation of phenomena such as cyclones, tropical organized convection, flow in ocean straits. The ESA-CCI is working with Copernicus and the Global Earth Observation System of Systems (GEOSS) to deliver the most complete and consistent set of Essential Climate Variables (ECVs) available to date including key information for Europe such as driving SSTs, sea ice, clouds and aerosols. These will be used within PRIMAVERA to develop novel metrics; to assess processes and trends; as constraints for future projections and as boundary conditions for model simulations. Several PRIMAVERA groups are involved in CCI, and comparisons can be made between models driven using the core experimental protocol and sensitivity studies using CCI products (which will be delivered too late to use in the initial integrations). Other datasets such as the NASA Gravity Recovery And Climate Experiment (GRACE) mission to retrieve water transports will be used to validate the model variability, for example by examining how ENSO processes change water transports over Europe via global teleconnections.

1.4.1.6 **Strengthening the competitiveness and growth of key European businesses by enhancing their resilience to increasing exposure to weather and climate risk (Themes 5,2,3,4):** while the focus of the hazard themes in PRIMAVERA is the European region, European businesses have an increasing global exposure, because of an increasingly interconnected market chain. In fact, most of the PRIMAVERA partners currently working with European industry are asked attribution questions about phenomena that occur in remote regions of the planet, particularly in the tropics. PRIMAVERA will provide a broader range of metrics and co-design new climate information tools that are suitable to drive industry risk models (see also Section 2.1) and quantitatively answer these risk-related questions. In the mid and long-term these newly developed and improved tools will allow key European

business sectors to become more competitive at a global scale, providing chances for growth and improved resilience

1.4.1.7 **Informing governmental climate change policy and decision-making (Themes 3,4,5):** Engagement in advising governmental climate policy on both national and European/international levels will be through contribution to IPCC AR6 (via HighResMIP, and by comparing PRIMAVERA results with lower resolution CMIP6 Earth System Models). Specific national climate advisory groups, such as the UK Committee on Climate Change, and the German Konsortium Deutsche Meeresforschung, have endorsed the project. Within Europe, support from the Joint Programming Initiative (JPI) Climate (representing 14 Member States in Europe) and the European Climate Research Alliance (ECRA, representing 8 European countries) will act as multiplicators in the dissemination of PRIMAVERA science-based climate outputs. Speakers will be sent to specific events of JPI Climate and ECRA, and targeted policy briefings written in appropriate language will be made available to open up a dialogue with policy makers at national and European level.

1.4.2 Challenges, approach and mitigation

Scientific challenges include i) the spin-up of the coupled system at high resolution, because of the long timescales involved in the ocean; ii) attempting to use a more constrained design for the external forcing for the models to reduce avoidable model spread; iii) interpretation of scientific results requiring high resolution datasets, long time periods and robust methodologies; and iv) the efficient co-design of relevant climate information for better risk assessment.

We will explore several techniques to reduce spin-up costs, such as reducing the resolution of atmosphere (and/or ocean) models for part of the period, and/or using fixed 1950's forcings rather than full spin-up via pre-industrial forcing. We will use recent techniques[50,51] in WP3 to diagnose the effect of different forcing agents (greenhouse gases, aerosols and volcanoes) in efficient ways to ensure that these protocols are robust and trustworthy compared to using aerosol emissions. We will attempt to characterise extreme events (for example extended blocking events) in statistically robust ways, taking into account the relatively short observational datasets available. End-user engagement is likely to indicate that a wide range of climate information is of interest, and some prioritisation could be required to supply a sufficiently detailed view of specific climate risk assessments.

The central role of *technological advances* is a critical dimension of the new opportunities that underpin PRIMAVERA. Fulfilling the ambitions and meeting the respective challenges is achievable through the exploitation of increasingly available and affordable HPC. However, sustaining the current, fast-pacing trend requires complementary, highly coordinated programmes of research and development, to produce a new generation of GCMs that can scale up to tens-hundreds of thousands of cores and to manage their data flow efficiently in order to effectively operate in climate mode. PRIMAVERA will leverage many recent breakthroughs in the use of PRACE resources[f], particularly important for FCM integrations, with the full support and endorsement of IS-ENES2. The requirement for multi-machine, coordinated, multi-year access to PRACE resources, together with the need for scientific equivalence on different machines, will pose challenges, together with data volumes of many TeraBytes per day. We will make use of experience developed in Athena, PRACE-HiResClim and PRACE-UPSCALE[9,39], as well as new capability within IS-ENES2 and at the facilities developed within, in support of the CMIP exercise.

Trans-disciplinary aspects: PRIMAVERA will be at the nexus of capability in scientific understanding and interpretation for users, model development, challenging IT and HPC resources. PRIMAVERA will include new methods for processing and analysing the huge datasets produced by the inter-model ensemble in novel ways, e.g. exploiting new parallelism paradigms, so that the relevant science can be extracted in from PetaBytes of data reasonable timescales, in cooperation with the new global initiative, BDAC (Big Data Analytics: Challenges and Opportunities). The multi-model datasets will live in archives accessible by a common platform (JASMIN) and share formats, so that the Horizon 2020 Data Policy can be upheld, enabling scientists from throughout Europe to have simple and effective access to the datasets. Also, recognising that climate model data is not the same as actionable climate information, this stream of efficiently processed climate simulations will be the source of an ambitious activity to co-design climate narratives with end-users.

1.4.3 Innovation potential

The developments provided by PRIMAVERA will help to enhance prediction capabilities at major operational centres, including Met Office (UK), ECMWF (International), KNMI (NL) and SMHI (SE). It will provide the underpinning science for more skilful and reliable regional and extended weather forecasting, seasonal to multi-decadal prediction (WP2, 3, 4, 6), new understanding of the drivers of decadal predictability for Europe (WP1, 5), as well as the tools, for both modelling and analysis of weather and climate data (WP1, 9). In addition to the existing evidence for increased resolution from seasonal prediction[4], evidence from research models indicates that increased

[f] There may also be a need for a small subset of the most cutting-edge integrations proposed here to use PRACE computing resource, since these models require such Tier 0 architectures since they are so far ahead of current modelling requirements.

mid-latitude variability is driven by the ocean when its resolution is enhanced[40], and that there may be potential for increased forecast predictability skill.

PRIMAVERA will also address the three priority areas discussed by ECOMS (European Climate, Observations, Modelling and Services board): EUCP20, trust in climate models and EUCP30. The core multi-model ensemble and assessment using timescales relevant for adaptation decisions will inform the first two areas (WP2, 3, 6), while the Frontiers integrations will give early information for next generation modelling systems (WP4). The output from the unprecedented PRIMAVERA global modelling ensemble could also be used to drive regional convection-permitting models at kilometre scales[41] and impacts models. Such models are able to represent local extremes in a much more realistic way, and examination of sub-hourly rainfall extremes and river catchment flooding would then become possible, as would threats from changes in hail and lightning frequency (WP3, 4). However, it is absolutely essential that before those levels of detail are achieved, the large-scale, global climate must be better simulated than it is currently, and this will not be possible without an ambitious undertaking such as PRIMAVERA.

The open availability of the unique PRIMAVERA climate data, corresponding to more realistic climate simulations, will provide the foundations for a new approach in the assessment of climate risk on multi-decadal timescales using the lessons learned in recent climate services and adaptation collaborative projects (WP9, 10). The higher resolutions and ensemble size will allow improved interpretation of the wealth of new observational information collected by operational centres, as well as the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) and WMO. In addition, recently developed reanalysis products such as from the EURO4M and follow-on UERRA projects[42] will enable us to put observed high-impact weather and extreme events in a long-term historical context, such as the co-variability of cyclones and moisture transports leading to extreme events (WP10). This will be of great value for many sectors including renewable energy, insurance, and transport.

2. IMPACT

2.1 Expected impacts of PRIMAVERA

2.1.1 Impacts in the work programme

The objectives developed for PRIMAVERA (Section 1.1) are designed to answer the expected impacts of the call. These impacts are listed below and the corresponding PRIMAVERA objectives are given in parenthesis.

i) "Improved science based foundation to better assess the impacts of climate variability and change at decadal to centennial time scales" (b,d,e,f)

PRIMAVERA will deliver an improved science based foundation by delivering a coordinated, multi-model ensemble of climate integrations at unprecedented horizontal resolutions (25km and beyond) for the 1950-2050 period, using a new generation of global, coupled climate models. This is set to revolutionise our understanding of the climate system by providing robust simulations of high impact weather events with fidelity to address key European risks as highlighted by IPCC AR5 WG2. The envisioned outputs will be included in CMIP6 and are likely to be exploited post-CMIP6. PRIMAVERA will evaluate the value of new capabilities in simulating these events through process-based assessment of results and a set of metrics that will be made openly available. To ensure the credibility of the results, PRIMAVERA will confront its results with Essential Climate Variables that are being collected by COPERNICUS, EUMETSAT and ESA projects.

ii) "S*upport the development of effective climate change policies and optimize private decision-making" (a-e)*

At present, policy and private decision-making is based on information that has little or no reference to future predictions of climate variability or change. This is true for the majority of "catastrophe models" used in the insurance industry to assess risk, as well as renewable energy resource assessments. Climate service projects have started to address this discrepancy (e.g. FP7 EUPORIAS, SPECS and ECLISE) and PRIMAVERA will build upon these. It will address the needs of identified key sectors by providing high resolution, decadal to centennial information on mean, variability and extremes up to 2050, further translated into risk management information. Innovative user-engagement techniques will be used to ensure that the science is both relevant and actionable. A user-orientated, open access web interface that engages and guides the decision maker through the climate information and narratives that describe the relevance and impact of climate projections to their decision making processes will be developed. Crucially, training support on the use of these services and tools will also be provided.

The new understanding of past and future climate risk within Europe, both from improved physical process modelling and from the isolation of climate drivers, will enable more informed and appropriate decisions to be made by Governments and policy makers around risk, climate change adaptation and mitigation. PRIMAVERA will engage directly with energy policy makers through WP11 and with governments through WP8, where a case study and targeted policy briefings will be written for this audience. PRIMAVERA will also support the development of effective climate change policies on both national and European/international levels through contribution to IPCC AR6 (via HighResMIP, and by comparing PRIMAVERA results with lower resolution CMIP6 Earth System Models).

iii) "Robust, credible and trustworthy climate predictions and projections to make in the medium- and long-term European business sectors more resilient and competitive at global scale" (f, g)

The PRIMAVERA experimental design is achieved by specifying the appropriate levels of complexity and including the best process representation currently available, including process assessment using metrics developed to help constrain projections. The integrations will enable a much improved representation of the Mediterranean Sea, a shallow basin that provides the evaporation controlling a significant portion of the hydrological cycle in Southern Europe, a region which is thought to be particularly vulnerable to water stress and drought in coming decades (IPCC AR5 WG2).

For the insurance and reinsurance industries, understanding the risk of extreme winters in Europe (2009-2010, 2010-2011) or storms such as Hurricane Sandy[47] reaching Europe and their subsequent impact on transport management will be developed during the project and delivered alongside the improved metrics. For the energy management sector, joint frequency events of high wind, high temperature during winter months can destabilise the power network, as occurred in December 2013 over Central Europe. New climate adaptation measures within a smart grid design can be explored to minimise such impacts in the future. For solar power forecasting, the improved cloud microphysics in both core and FCM integrations will give a greatly improved representation of surface solar energy in model projections. Together with insight into European climate drivers from Theme 3 and new reanalysis products, the relationship between present day weather regimes and sector-specific impacts into the future can be assessed. This new information will strengthen end-user decisions and enable them to minimise the risk and subsequent impact of such meteorological events within their sectors. The inclusion of Dr. Soares on the EEAB will further improve the links with the impacts and user communities.

Major climate information operators in Europe are partners in PRIMAVERA: MET OFFICE, KNMI, ISAC-CNR, SMHI, ECWMF and CMCC. They are involved in building a complete supply chain that can deliver the best climate information at the European level for private businesses. The models and techniques developed in PRIMAVERA are a basis for their services.

European business is no longer confined to Europe, and the international, interconnected nature of business means that developing an understanding of the impact of global climate on global supply chain risk, could make European business sectors more resilient and competitive at the global scale. Global events can have huge financial consequences. For example, the Thai floods in 2011 closed over 10,000 factories, and paralysed the global supply of hard drives. The flooding cost Lloyd's of London $2.2bn. The Thai floods were exacerbated by the effect of La Niña, part of the large-scale ENSO mode of climate variability, the further understanding of which requires *high-resolution global* climate modelling. The development of risk management solutions will be driven by the end-users´ ability to inform and advance their decision-making using PRIMAVERA climate information, creating a new opportunity to make their sectors more resilient to climate variability and therefore more competitive over future timescales. Although specific end-users will be targeted, the application of advanced and credible science for climate services strengthens other areas of policy and business. For example, the requirement for robust predictions of changes in hail and lightning occurrence by the insurance industry can also be of benefit to aviation.

iv) "*Support the post-AR5 IPCC process and other relevant international scientific assessments"* (c, d, e)

Many of the open questions from AR5 WG1 and WG2 reports are the starting point of analysis for the project. PRIMAVERA will initially use data and outputs from both CMIP5 and CMIP6 DECK experiments as a bridge while they set up and coordinate HighResMIP as part of CMIP6, together with international collaborators. A common experimental protocol between these groups will allow further understanding of model structural uncertainty and novel diagnoses, as well as extending the outreach of PRIMAVERA and European expertise to the global scientific community. PRIMAVERA will even work post-CMIP6 with next-generation flagship eddy resolving and synoptic resolving global coupled simulations. These simulations will resolve coupled climate processes not simulated before in climate models and likely revolutionize climate science. The inclusion of Prof. Kimoto on the EEAB will further increase our links with the IPCC and CMIP process.

v) "*Provide a solid scientific basis for future science cooperation and policy actions at European and international level*" (a, b, c, f, g)

By bringing together the leading climate modelling groups in Europe, under the "European High-resolution Modelling Hub", PRIMAVERA will provide a significant advancement in the capability of European climate modelling, with at least seven European groups further establishing high resolution capability competitive with the leading world groups. The CMIP6 HighResMIP common protocol will entrain other world-leading groups and generate a set of constrained model ensembles suitable for strong global science cooperation in their analysis. Specifically this will include new co-ordinated metrics for evaluating and constraining models at a process level delivering more robust, well understood projections of regional climate change and extremes. Europe can lead the way for the International community through engagement with the CMIP metrics activity, co-ordinated by WGCM. This well-evaluated global multi-model dataset will be a unique resource and basis for international policy and

industry risk management strategies that are vulnerable to the effects of climate variability and change and also as a springboard for future European collaboration on delivering risk-based advice through a probabilistic modelling approach. The UK's national climate programme undertaken at the Met Office is organised around a set of Government policy requirements that help to inform UK and international adaptation and mitigation policy. Key to the delivery of the science and built into the programme is direct and regular contact with its Government customers; strong collaborations with UK and international universities, and collaboration with a large number of national meteorological and climatological centres around the world. For example, findings from the AVOID project, using combined expertise from the Met Office and other UK institutes, feed directly into UK Government negotiations at the UNFCCC negotiations.

2.1.2 Innovation capacity and integration of new knowledge

Throughout the project, an integral part of PRIMAVERA is the engagement with end-users from identified sectors (wind energy, transport, power and insurance). Through this engagement PRIMAVERA will configure the experimental design so that the project outputs are in a format required by these end-users. This will enable these sectors to integrate this new knowledge efficiently into their decision making processes during and beyond the lifetime of the project.

The outcomes of PRIMAVERA will be based on models with higher fidelity than have ever been used before. They are very likely to be incorporated into thee prediction systems of partner operational centres within five years of the project start, with deliverables from the project providing the evidence for likely improvements in predictive skill set against the increased cost of such systems at enhanced resolutions. For instance, EuroGOOS (European Global Ocean Observing System) have endorsed PRIMAVERA and have confirmed that the work in WP4 with an eddy-resolving ocean is a crucial first step that must be taken before implementation in their prediction systems. This illustrates where PRIMAVERA results provide the opportunity for increasing innovation capacity within Europe, and where results can be integrated for improved outcomes.

Through engagement with other European organisations (for example Climate-KIC, Europe's largest public-private innovation partnership on climate change, and its Climate Data Factory project, have both endorsed PRIMAVERA), the project outputs can be widened both in sectors and in applications, enabling more European and global companies to benefit from improved climate projections, risk assessments and other outcomes. Such groups will be invited to project meetings and workshops to encourage exchanges of ideas and methods.

The improved representation of high impact events that PRIMAVERA will provide is also important for the work that the ECRA (European Climate Research Alliance) has planned, specifically under their proposed "High Impact Events and Climate Change" collaborative programme, and they have endorsed the project. In addition partners in both HighResMIP and the PREMISE proposal (H2020-WATER-2a-2014) intend to use the global model output to drive regional models at the convection-permitting scale. Such models are demonstrably better at representing local impacts (e.g. extreme convective rainfall[41]) but require systematic understanding and robustness of the driving model to obtain reliable projections of impacts. PRIMAVERA will offer this and other projects and modelling groups will be able to build upon the advances made by PRIMAVERA, which will strengthen the innovation capacity of Europe.

PRIMAVERA will further contribute to the integration of new knowledge by training the next generation of climate scientists (currently PhDs or Post-Docs) accordingly. They will have the opportunity to participate in project meetings, workshops and general assemblies, present their results, prepare discussions and chair sessions. Involving the younger generation in PRIMAVERA will guarantee a safe transfer of knowledge and prepare the ground for even more ambitious projects in a near future.

PRIMAVERA will also contribute to the integration of new knowledge through its participation in two Summer Schools. The PRIMAVERA Scientific Coordinator is currently the Director of two Summer Schools which help to train this next generation of climate scientists;

- The UK "Climate Modelling Summer School", which has been held bi-annually since 2007. The MET OFFICE have been heavily involved in each one, together with UOXF, UNIVLEEDS, ECMWF, NERC. Other partners within the PRIMAVERA consortium will contribute to future schools.

- The EU-level E2SCMS "Earth System Modelling Summer School". MPG co-lead this and it is funded by ENES/ENES-2

Both schools attract students from around the world and will seek to make PRIMAVERA science a prominent ingredient of future Schools, by engaging PRIMAVERA scientists as teachers and demonstrators and by using all PRIMAVERA open access resources as teaching material, leading to enhanced knowledge sharing.

2.1.3 Any other environmental and socially important aspects

PRIMAVERA will also ensure that it is open to public scrutiny through transparent working practices. Information on methodologies, uncertainties and results will be made available with the hope of engendering trust in the research

carried out by the project. This is particularly important because PRIMAVERA is under a Societal Challenge call, and so the purpose and benefits of the project should be widely understood. The research will be communicated with the public, raising awareness of scientific process and outcomes. This has the potential to improve the relationship between science and society.

This transparency will be further enhanced by following the Open Data Access Pilot, to include not only project data but as many other forms of output as possible. The multi-model ensemble data will be openly accessible with all the appropriate metadata to fully understand the integrations and post-processing methods. All analysis tools will use freely available open source software and these, together with all scientific reports and publications, will be held within an open repository. This will ensure that PRIMAVERA is doing everything possible to foster collaboration between research groups and reduce the need for duplication of effort.

2.2 Measures to maximise impact

In order for PRIMAVERA to realise its full potential, and achieve all of the expected impacts, considerable effort will be made to enable effective engagement with all relevant target audiences, ranging from governments at national and European level to specific end-users. Appropriate methods of dissemination, communication and exploitation of the project results to these target audiences have been identified. Making these things integral to the way in which PRIMAVERA will be run will ensure maximum benefit for society.

Four work packages across the project will have responsibility for establishing processes for:

- Engagement with business sector end-users (WP11), specialist research community, wider scientific community, Government and policy makers (WP8) and the public (WP7).
- Dissemination and Exploitation of the project results to business sector end-users (WP11), to Government and scientific communities (WP8) and to the public and other target audiences (WP7). WP7 will oversee the project strategies and WP9 leads on Data Management for PRIMAVERA.
- Communicating the overall project and the results to business sector end-users (WP11), to Government and scientific communities (WP8) and to the public and other target audiences (WP7).

2.2a Dissemination and Exploitation of Results

The draft 'Plan for the dissemination and exploitation of PRIMAVERA results' is given below. During the project, this draft plan will be used as the basis on which to develop four separate plans. These individual plans will be consistent with each other, and will be overseen ultimately by the Coordinator and the Scientific Coordinator. They are as follows:

1. End-user Dissemination and Communication plan (WP11, Task, 11.1, D11.1)
2. Data Management Plan (WP9, Task 9.3, D9.1)
3. Project Dissemination and Exploitation plans and reports (WP7, Task 7.6, D7.4 and D7.5)
4. Project Media and Communications plan (WP7, Task 7.5, D7.3)

Within these updated plans, much more detail will be given about specific requirements, target audiences, deadlines, methods, procedures and evaluation measures. These will then be used as working documents to ensure effective management of these activities and their integration into the project as a whole.

PRIMAVERA is participating in the Open Research Data Pilot, and will make the results of PRIMAVERA as open and accessible as possible to all interested parties. The updated Data Management Plan will be provided in month 6 of the project (D9.1), and relevant aspects are described in the plan below.

Plan for the dissemination and exploitation of PRIMAVERA results

1. **Metrics, tools and software generated by PRIMAVERA**

A coordinated metric calculation suite D1.1-D1.3 will be developed in WP1, starting from existing tools in participating centres and extended with new metrics developed throughout the project. Data will be stored in CMOR compliant standard form, as used in CMIP5, the metric suite will be applicable to data from other CMIP6 MIPs. As part of the Open Research Data Pilot the source code will be written using open source tools and made publicly available, including through the WGNE/WGCM metrics panel for CMIP6.

Dissemination

The core resource for exploiting the data within PRIMAVERA is the JASMIN platform, managed by STFC.
JASMIN will be the central facility for access to and analysis of the data set and will allow project members to collaborate effectively across the different centres. JASMIN provides computer and storage capability for big-data projects and consists of 13 Pbytes of parallel high-performance disk, 6 Pbytes of tape storage and hosted and cloud computing services. The LOTUS batch compute cluster attached to JASMIN has over 3,000 processing cores, providing a step change in the ability of scientists to rapidly analyse large data sets. In addition generic scientific

processing servers provide access to a range of common open source software packages and project-specific servers can be provided on request.

Working documentation for the project, including interim results, working logs and tool documentation will be held on an Internal project wiki hosted by STFC (MS18), with all material of use to a more general audience published/mirrored on the counterpart PRIMAVERA public website (D7.1) once it has been reviewed. In parallel to the documentation, source code will be lodged in a repository with versions made publicly available either at the point of delivery or by the end of the project. Project members will be encouraged to post information on their activities within the project and link to relevant external resources where appropriate.

Exploitation –during and after the project
The metric suite will be made publicly available (D1.3) through the project website and source repositories. Using the CMIP data conventions, this suite could provide the basis for a common comparison suite that can be used by the scientific community. Training materials, based upon existing STFC documentation, developed to enable project members to make good use of the JASMIN data analysis and storage platform (described above and in WP9) and associated computing resources will also be made publicly available, allowing the wider scientific community to make best use of JASMIN and to provide examples for other similar facilities.

As part of the Open Research Data Pilot PRIMAVERA is committed to publishing the analysis scripts used to generate all figures and results in scientific publications. These analysis scripts will be published on a public source code repository and may also be submitted as part of journal publications as appropriate. Tools and code produced within WP10,11will be made publicly available at the end of the project, to allow maximum end-user exploitation first.

Improvement to model physics will be developed in WP3-4, and fed into Stream 2 simulation runs. These improvements will be fed back into model development programmes within each centre for both climate and weather applications, and to the wider modelling community via publications. The Scientific Coordinator will liaise with the relevant projects and organisations to ensure that PRIMAVERA results are synthesised and can be exploited within the relevant working groups.

How these measures help achieve the expected impacts of PRIMAVERA
The dissemination and exploitation activities described above will ensure that PRIMAVERA metrics, software and tools are available for the scientific community to use (specifically the WGNE/WGCM metrics panel for CMIP6), and will ensure that they know how to use them. This will contribute to the achievement of impacts 2.1.1 (i and iii).

2. **Datasets and related metadata**

From WP6 two phases of core integrations will be delivered, the first with existing AMIP and coupled climate configurations, the second using scientific improvements generated by WP3. In addition the FCM simulations in WP4, and sensitivity tests in WP5 will produce data of interest to the scientific community, and trials of model improvements in WP3 will also generate data.

Dissemination
Initial data will be archived within each partner institution since the storage volumes preclude full storage at CEDA/JASMIN. The maintenance of full metadata specifications is important, as it will describe the content and context of data (from experimental design, model implementation and monitoring, data output, formatting and post-processing), to ensure that it is used appropriately in analysis and publication. The Data Management Plan (D9.1) will provide a template for the information that should accompany each data set generated by the project. Data submitted to long term public archives will require more detailed descriptive metadata suitable for data discovery and usage beyond the lifetime of the project. These metadata specifications and procedures for gaining access to project data sets will be available from the public PRIMAVERA website, with examples of data analysis methods and links to the documentation on JASMIN training.

PRIMAVERA PI's have already been asked to provide a journal paper describing the experimental design of HighResMIP, which will provide a unified framework for comparing high resolution climate simulations, allowing collaborations to extend to international modelling groups. PRIMAVERA will produce publications in data journals, such as Earth System Science Data, where corresponding Digital Object Identifiers (DOIs) will describe the results from each stream of PRIMAVERA simulations (D9.5).

Exploitation –during and after the project
The data set will be available for exploitation by project members via JASMIN through the life of the project, and core data will be maintained for a period (at least 3 years) after the end of PRIMAVERA. A subset of the full data set will be made available through data portals hosted by STFC CEDA, including the Earth System Grid Federation (ESGF) services, with limitations on the scope of the data made available applied due to technical considerations such as data volumes.

In addition access to the data stored on or accessible via JASMIN will be made available to external scientists for exploitation following the production of data description publications (D9.4 and D9.5) at the end of each simulation cycle (M24, M46). Limits on the number of users and the resources available to them will only be applied if there is a significant impact on project activities. The link between PRIMAVERA and HighResMIP will also ensure valuable information and data will be maintained beyond the end of the project via interaction with CMIP6.

How these measures help achieve the expected impacts of PRIMAVERA
A clear understanding of the data allows well-structured planning of scientific analysis, and the common standards used will allow scientists working in climate/weather science to rapidly exploit the data set alongside other sources such as the CMIP5 archive. This will help to achieve the impact of *2.1.1(i)* in particular, as well as all of the impacts associated with improving innovation capacity and integration of new knowledge.

Further Data Management considerations

Types of data that the project will generate
Simulation runs performed in WP3-6 will produce a large volume of multi-dimensional primary output data. Additional secondary (derivative) data, produced through post processing in WP1-5, will be generated consisting of a wide variety additional data fields describing particular phenomena, such as atmospheric blocking indices, and catalogues of events including tropical cyclones and weather extremes. Where secondary output is sufficiently difficult to regenerate or particularly valuable for further exploitation, these will be retained along with full documentation within the project and will be made publicly available following a suitable embargo period.

Data standards that will be used
CMOR-compliant netCDF format will be used for the primary simulation data used within the project, and equivalent specifications will be encouraged for secondary (i.e. derivative) results where possible. Specifications of the standards used for secondary data will be maintained on the internal project wiki and published externally along with the data, following any embargos. Data sets provided to the long term CEDA archives will be associated with ISO19115 metadata records that are exported to publicly searchable catalogues (such as data.gov.uk).

How will this data be exploited and/or shared/made accessible for verification and re-use? If data cannot be made available, explain why.
As stated above, the data will initially be accessible to project participants via the JASMIN platform. The main data set will also be made publicly available through existing portals and catalogue services, subject to practical limitations due to data volumes.

Curation and preservation of the data
Curation of the primary simulation data sets will be the responsibility of individual partners, while metadata and other secondary data will be stored in a long-term archive managed by STFC CEDA. The lifetime of the data in national archives will be finite, and set to a minimum of 3 years from the end of the project by agreement between the project partners. Throughout the project links and automated systems will be developed to allow data to move between national archives and JASMIN. These connections will need to be maintained, in some form and level of functionality, following the end of project to allow continued exploitation of the PRIMAVERA data set.

3. **User documentation, project reports and peer reviewed literature**

A number of different documentation types will be produced, each with a different purpose and intended for different target audiences.

Dissemination

PRIMAVERA Public Website: PRIMAVERA will have a website which will be hosted by STFC and managed by the Project Office (D7.1). This will act as the central hub of information for PRIMAVERA, allowing dissemination and communication of project progress and results, as well as being the portal through which all target audiences can engage with PRIMAVERA. It will be regularly updated and will be suitable for public users. It will contain;

- Project description and member profiles
- Published reports (i.e. all deliverable reports marked public)
- Specification of the PRIMAVERA data set once it is published.
- Links to all open access journal publications and any other relevant articles.
- Source code repository permitting open access to code based deliverables (metrics suite D1.1, D1.2)
- Source code repository permitting open access to analysis tools used for all journal publications.
- Descriptions of, and code to generate, secondary/derivative data sets. This will be embargoed until associated publications have been accepted.
- Links to user guides and introductory material on how to make use effective use of JASMIN
- Instructions for external scientists wanting to access primary project data

- Connection to the User Interface Platform for specified users

User Interface Platform (UIP): A separate user-oriented section of the PRIMAVERA website (D11.2) will be designed to maximise the dissemination of the project results to this target audience. This UIP will be used to host any communication material that is sector-specific, and will facilitate the ongoing engagement amongst end users and between end-users and the work packages. This will also build on KNMI's successful climate data atlas.

Case studies and factsheets: Case studies (D11.2) and use cases (D10.1) will be developed for end-users and tailored to the sector specific needs identified in T11.2. A case study will also be developed for use with Governments (D8.2). Climate projection factsheets (D11.3) suitable for a range of target audiences will also be created, explaining how climate projections up to 2050 are created and what their purpose in industry and policy is.

Climate projection visualisations: Following engagement with end-users and a review of visualisations already available, these will be generated as another method to disseminate and communicate climate projections and their related uncertainty (D11.4). Advanced animations suitable for a public audience will also be developed for use in project communication materials.

Scientific narratives for Climate Risk Assessments: These will be constructed based on the high resolution global models that will be run within PRIMAVERA. User engagement in WP11 will determine the meteorological events that are most significant for each sector, and so will determine which narratives will be most useful and should be produced in WP10 (D10.4).

Policy Briefings for Government: policy relevant synthesis of the results will be made available during the lifetime of the project (D11.5). This is a short document (2-4 pages) that presents the findings and recommendations of a research project to a non-specialized audience, exploring an issue and distilling lessons learned from the research and providing policy advice. The Scientific Coordinator also regularly meets with government institutions (e.g. the UK DECC, Defra), academic institutions (e.g. weather and climate centres worldwide) and industrial partners and will continue to ensure that PRIMAVERA science is strongly aligned with international developments and requirements throughout the lifetime of the project.

User guides and training materials: In WP9, documentation describing the PRIMAVERA data set and accompanying meta data will be produced (D9.1 and D9.5) along with training materials for making efficient use of JASMIN and working with Big Data (D9.2). The UIP and material produced in WP11 (D11.2, D11.3, D11.4) will give an interpretation of results, including uncertainties and limitations, along with the relationships to other climate projections.

Internal project Wiki: This will be established (MS18) to ensure that information relevant to partners is effectively disseminated, kept up to date and available to all. This will be where internal documentation, information on management of tasks and progress is stored. This wiki will be hosted by STFC and will also be integrated with the code repository.

Project reports: There are 33 deliverables that are in report format and will contain useful results and conclusions from PRIMAVERA. All of these reports will be made openly accessible and will be placed on the project website, except for those in WP7.

Papers for peer-reviewed literature: All project partners will contribute to a set of scientific and technical papers that will be published in open access peer-reviewed literature. These will be aimed at an expert audience, and cover a wide range of the innovative aspects of PRIMAVERA. The Scientific Coordinator and other partners will attend conferences and give presentations to disseminate the progress of the project and results to the scientific community, for instance the annual EGU conference, where PRIMAVERA PIs convene a high-resolution modelling session, and at Summer Schools. These include: WCRP (WGNE/WGCM) meetings, to report on HighResMIP progress; GEWEX conferences to engage the remote sensing community in advanced model assessment; US-CLIVAR meetings that regularly gather international scientists working on related topics; IS-ENES2 bi-annual workshops, to leverage EU-wide expertise; PRACE workshops to continue to learn about exploiting HPC for Grand Challenge simulation.

Exploitation – during and after the project

Much of the documentation outlined above will be developed in conjunction with its intended target audiences, and will be in the most suitable format and repositories for these audiences. Communication measures that are outlined in Section 2.2b will ensure that audiences remain informed.The PRIMAVERA public website will greatly aid exploitation as it will allow ongoing engagement and dissemination. It will connect all information and be usable by all target audiences.

Case studies will be directly related to sector requirements that have been defined during PRIMAVERA that will ensure their ongoing usefulness and exploitation. A case study developed for Government will illustrate the information available from PRIMAVERA that will be applicable to their decisions (D8.2). Factsheets will not be tailored specifically for expert users and will be written is an accessible way, therefore enabling exploitation and

understanding of the results by a wider audience. The advanced animations will also be produced for a public audience.

Through WP11, partners will deliver and/or participate in end-user workshops at relevant external events. These will bring together users from the same sector, enabling them to consider ways to jointly exploit the results.

How these measures achieve the impact of PRIMAVERA

Through the measures described above, PRIMAVERA will have a significant and ongoing impact, as the results of the research will be fully documented and explained. The variety of dissemination methods means that PRIMAVERA will be visible to a wide audience, and the breadth of information that will be made available means that it will be an open and transparent project.

In particular these measures will ensure that PRIMAVERA achieves its stated impacts 2.1.1 (ii, iii). Through information targeted and made available specifically for end-users it will act to strengthen the competitiveness and growth of companies in these sectors. Information aimed at Governments will enable them to optimize their decision making.

2.2a.2 Outline strategy for knowledge management and protection

Knowledge management

PRIMAVERA will adopt a strategy for knowledge management that encapsulates the guiding principles of H2020 on Intellectual Property (IP) management and will define a range of effective management protocols.

WP9 – HPC and Data Management is designed specifically for the management of research data, and will work directly with WP7 which has overall responsibility for knowledge management. A strategy for innovation and knowledge management will be produced in WP7 within the Project Dissemination and Exploitation plan (D7.4) by month six of the project. A final version of this will be produced in month 48 of the project as a report (D7.5) to outline how innovation and knowledge management will be done following the end of the project. The Project Office will ensure that PRIMAVERA complies fully with the Grant Agreement and fulfils any requirements with regards to knowledge management and protection.

Achieving PRIMAVERA's objectives will involve accessing a number of different existing data sources. Some of these have already been identified, and are listed in this proposal, for example model datasets (e.g. CMIP5, CORDEX), observational and reanalysis datasets (e.g. OBS4MIP, HadISST[53], GRACE, EURO4M). An internal catalogue of these data sources will be formally created as soon as the project commences. Details will include the licenses for each of these data sources, and a statement as to any restrictions of their use and subsequent incorporation within any knowledge generated by PRIMAVERA.

All products and results of PRIMAVERA will be openly disseminated at the appropriate time. There are several levels of information and knowledge derived from the outputs of the model integrations (core from WP6 and frontier from WP4), combined with these other data sources, which require management:

a) Data sets and related metadata from the core and frontier integrations will be submitted to HighResMIP/CMIP6 database after verification and validation (plus any appropriate data downsizing) are complete
b) Scientific analysis and understanding using tools and software developed within the project – this will be stored in the internal repository until publication of results at which point the derived data and tools will be made available on the public repository together with the paper/report
c) Code to improve model physics developed within WP3 will be communicated to code owners through existing relationships within each partner institution
d) Derived analysis products used for further project outputs (e.g. inputs to scientific risk assessment, extreme event catalogues) will remain internal to the project until external publication of the analysis has completed.
e) Derived information used for the User Interface Platform (WP11) and to communicate to engaged end-users will be protected until at least the end of the project to allow these users to fully exploit it

The PRIMAVERA partners will also bring their own pre-existing knowledge (e.g. analysis software, existing metrics code, model configurations). This will be included in the catalogue referenced above, along with the appropriate protection level. All records detailed above will be maintained electronically, providing reconcilable audit trails, such as documented proof of ownership, if necessary.

Methodologies, product designs and newly generated datasets will be developed in collaboration between the PRIMAVERA partners. Here, it is important that there is a clear strategy for joint ownership, which may subsequently include joint ownership agreements. The methodologies and product designs will be documented in peer-reviewed papers generated by PRIMAVERA. Datasets will be documented with appropriate metadata to capture their provenance and derivation.

Open access to peer-reviewed scientific publications

PRIMAVERA will adopt the "gold" model for open access to peer-reviewed journal articles where possible, and funding is provided specifically for this. In parallel, "green" open access will also be adopted by using the institutional and subject-based repositories made available through the partners. Authors will avoid entering into any copyright agreements with publishers that will not allow them to fulfil the EC Open Access requirement. The Project Office will be involved in the process, and these publications will be advertised and logged through the project website. All published material will contain an acknowledgement to the research funding from the European Union and Horizon 2020.

Protection

The protection of the knowledge/intellectual property (IP) that the partners bring to the project and then the subsequent knowledge generated (i.e., methodologies, datasets, results) will be regulated through the project Consortium Agreement (CA), and aligned with the specific requirements from the H2020 Model Grant Agreement. Specific procedures for governing access and use of IP, plus the type of IP right, will also be included in the CA.

Each of the partners will have the right to exclude specific pre-existing knowledge (background IP) from the other partners' access, as far as the restrictions are announced before the signature of the Grant and Consortium Agreements or before the effective joining of a new partner.

Foreground intellectual property will be identified at the point of creation and steps taken to ensure its protection. Partners will respect their own, and each other's, protection protocols/IP Rights. In the event the creation of a new piece of knowledge as a result of the work of a single partner of the project and solely the result of individual intrinsic skills rather than shared knowledge, this partner will be the exclusive owner of the results, subject to granting access rights to the other partners where necessary for their execution of the project or to the use of their own results. For the case in which the designated owner of the results waives its option to start registration proceedings the coordinator will follow a procedure outlined in the CA to allow other project partners the opportunity to obtain or maintain such protection.

Access rights will be considered on a case by case basis and where appropriate after consultation with the partners concerned, to ensure that a partner's legitimate interests are not compromised. IP awareness training will be available through the Met Office for personnel working on the project; and the partners' legal teams will be engaged to provide support and advice on IPR matters. However, the overall aim of the knowledge management strategy and protection will be to maximise the chances of effective exploitation of the project's research results.

2.2b Communications activities

In order to successfully promote PRIMAVERA, and its progress, results and achievements, it is important to identify suitable measures for communication. Not only will this be beneficial for the project, but it will also illustrate what successful collaboration across Europe has achieved, and will highlight how European research is relevant to society. Initially a number of distinct target audiences have been identified and the proposed communication activities are outlined below.

WP7 will provide an update to the outline below by producing a Project Media and Communications plan (D7.3) and WP11 will take responsibility for providing the communications plan specifically for our identified end-users (D11.1). These updated plans will contain more detail about activities, and will include monitoring and evaluation measures. Those measures will then be reported against when updates are provided to EC as part of the periodic reports. The results are likely to be of interest to the media, and so in co-ordination with the Press Offices of the partner institutions and in line with Open Data principles, the project will decide how to manage ad hoc media enquiries, FOI requests, routine communication of research results and negative media coverage, amongst other things. The Coordinating institute (MET OFFICE) also has an experienced Communications department who will be able to support PRIMAVERA with social media and other public communication activities. Another part of the plan will specifically focus on successful communications with Governments. This is a specific task under WP8 (T8.7).

Table 2.2.1 PRIMAVERA Communication measures

Target Audience	Objective	Material/content	Method/Communication Measures	Frequency	Responsibility
PRIMAVERA partners	• Ensure an effective and integrated project	• Progress and results of Work Package tasks • Risks/benefits/issues • Queries/questions	• Internal project wiki (D7.xx) • General Assemblies (GAs) • Work Package meetings • Email • Web and teleconferencing	• Regular updates of wiki • Five project GAs • Annual WP meetings • Quarterly scientific coordination Skype	• WP7 and WP8 • Co-ordinator and Project Office • All partners • Scientific coordinator
EEAB	• Inform of progress and receive useful information	• Progress and results of project • Risks/benefits/issues • Queries/questions	• Internal project Wiki • General Assemblies (GAs) • Targeted communications • Email and teleconferencing	• Regular updates of Wiki • Five project GAs • Other contact as required	• WP7 and WP8 • Scientific Coordinator • Project Office
EC project officer	• Ensure EC is fully informed of progress	• Overall project progress • Issues • Deliverable progress	• One page progress reports/summaries • Deliverable reports • Periodic reports	• Six monthly throughout project • As per deliverable dates • As per reporting periods	• Co-ordinator • Project office
Business Sector End-user – wind energy, power system, transport, insurance/finance	• Ensure maximum societal benefit • Ensure project design delivers useful results	• Project progress • Derived products and relevant user documentation	• User Interface Platform (UIP) • Newsfeed and blog on UIP • Case studies and factsheets • Climate visualisations • User guides and training materials • Workshops and presentations	• Regular updates of the project website • Regular activity on newsfeed and blog	• WP11 • Scientific coordinator
National and European governments and policy makers (via IPCC, institutional links, UK CCC and German KDM)	• Greater understanding of climate risk, impacts and uncertainty	• Project results • Contribution to IPCC AR6 via HighResMIP	• Policy briefings • UN Conference of Parties (COP) brochures • Inclusion of published papers, reports in IPCC AR6 • Presentations to government departments • Workshops and conferences	• In line with publications timetable • To be organised as appropriate	• WP8 • Coordinator • Scientific Coordinator
Specialist research communities	• Share knowledge between projects	• Project progress and results	• UIP and public website	• Regular updates of the project website	• WP7 and WP8 • All

(IPCC, CMIP6 via HighResMIP, GEWEX and Earth System Modelling community)	• Maximise impact and exploitation • Integration of PRIMAVERA with other projects	• Comparisons with standard CMIP6 model results	• WGCM development meetings, HighResMIP, GEWEX, IPCC,AR6 • Scientific conferences • Joint workshops with each community • Peer-reviewed journal articles • User guides and training materials	• Regular publication and dissemination of user documentation	• Scientific Coordinator • EEAB
Wider scientific community	• Share knowledge • Maximise impact and exploitation • Integration with other projects	• Project progress and results	• Public website • WGCM development meetings • Sessions in scientific conferences (e.g. High Resolution session at EGU2013 onwards) • CMIP6/HighResMIP workshops • Peer-reviewed journal articles	• Regular updates of the project website • Regular publication and dissemination of user documentation	• WP7 and WP8 • All • EEAB
Public and wider society	• Ensure project is visible to public • Provision of credible climate information • Engagement with scientific process	• Relevant results and their implications • FAQs	• Project website • Press releases and media contacts • Advanced animations • Public lectures and presentations • Links through other web portals • Project newsletters and flyers • Twitter and LinkedIn groups	• Regular updates of the project website • Regular and proactive media activity and newsletters/flyers publication	• WP7 • Project Office • All
Media	• Ensure project is visible to public • Ensure project is reliably communicated	• Project progress and results • Methodologies of PRIMAVERA • Significance of results and impacts	• Public website • Press releases and media contacts • Advanced animations • Public lectures and presentations • Project newsletters/flyers	• Regular updates of the public website • Regular press releases, as required • Invitations to relevant events	• WP7 • Project Office • Scientific Coordinator
Education/ training	• Ensure knowledge is passed on through education	• Project progress and results • Methodologies of PRIMAVERA • Results and impacts	• Public website • Factsheets • Summer schools • Conferences • Lectures	• Regular updates of the public website • Factsheets when available • At Summer schools	• WP7 • Scientific Coordinator • All
Other EU bodies and projects	• Shared understanding of	• Progress and results	• Public website • EU project meetings	• Regular updates of the public website	• WP8 - Scientific Coordinator

	project and results	• Understanding of specific user requirements	• Scientific conferences and presentations	• Meetings, conferences and presentations	• All

3.IMPLEMENTATION

3.1 Project Overview

Aligned with the objectives in Section 1, the PRIMAVERA programme will be delivered by 11 Work Packages, organised under the five Themes introduced in Section 1. The first six work packages deliver model development, process-based assessment and flagship simulations. Two work packages (10,11) address decision-making and end-user engagement. Three management work packages (7,8,9) guarantee that the project will run in a coordinated way and deliver effectively to Governments, decision makers and the rest of the scientific community.

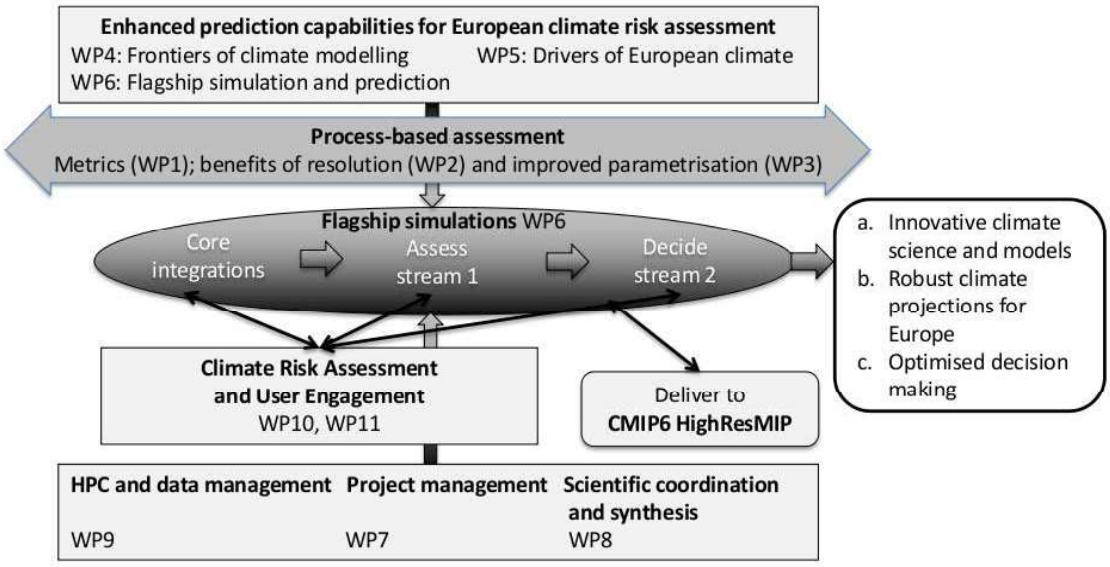

Figure 3.1.1: graphical presentation illustrating how Work Packages and crucial activities inter-relate

Core and frontiers integrations, and sensitivity experiments: WPs 3-6 are primarily concerned with model development and simulation, which will happen in two Streams, providing the ability to re-formulate and re-assess models half-way through the project, based on lessons learned from assessment of core, frontiers and sensitivity experiments. WP2 will systematically assess the role of model resolution across the multi-model ensemble, while WP3 will develop and assess physical parameterisations specifically designed for use in combination with high-resolution. WP4 will develop global climate models at unprecedented resolutions, including reaching into the so-called "greyzone" to better understand the potential for direct simulation of key processes; at the same time it will experiment with stochastic parameterisation, which present an alternative to ultra-high resolution. WP5 will investigate the key drivers that govern European climate variability and change, making use of a number of sensitivity experiments to isolate their individual influence on key processes. WP6 is dedicated to the production of flagship simulations that will be studied by all other work packages, but also delivered to CMIP6 as HighResMIP.

Evaluating the benefits of resolution and improved parameterisations: WPs 1-3 will produce process-based metrics and assessment that are specifically designed for the resolutions developed in PRIMAVERA. Combining evidence from WP2, WP3 and WP4, it will be possible to point out if and how different modelling strategies are beneficial to the simulation of key processes and how they contribute to governing European climate variability and change.

Projections, scenarios and risk assessment: WP5 and WP6 will both produce predictions based on a number of scenarios, ranging from idealised (WP5) to CMIP-quality (WP6). WP10 will make use of results from WPs 1-6 to contribute to climate risk assessments, as well as the tools that will enable scientists to interrogate PRIMAVERA outputs and support decision-making. WP11 will engage end-users and enable targeted knowledge exchange, as well as co-design scenarios for the projections produced in WP5 and WP6 Stream 2.

Project Coordination: WPs 7-9 coordinate the project from the point of view of managing the collaboration (WP7) and the computational aspects (WP9), but, equally importantly, enabling the flow of scientific ideas and producing synthesis for collaboration with the rest of the scientific community and for dissemination (WP8).

Interaction between work packages and project milestones: interaction between the work packages and individual teams is key to the success of PRIMAVERA. The project is organised around two Streams of model development and experimentation, with key milestones at month 24, when Stream 1 results are exchanged between WPs and decisions will be taken about model formulation and the experimental design for Stream 2. The timing of events and exchange of information will be very carefully managed, by WPs 7,8 and 9.

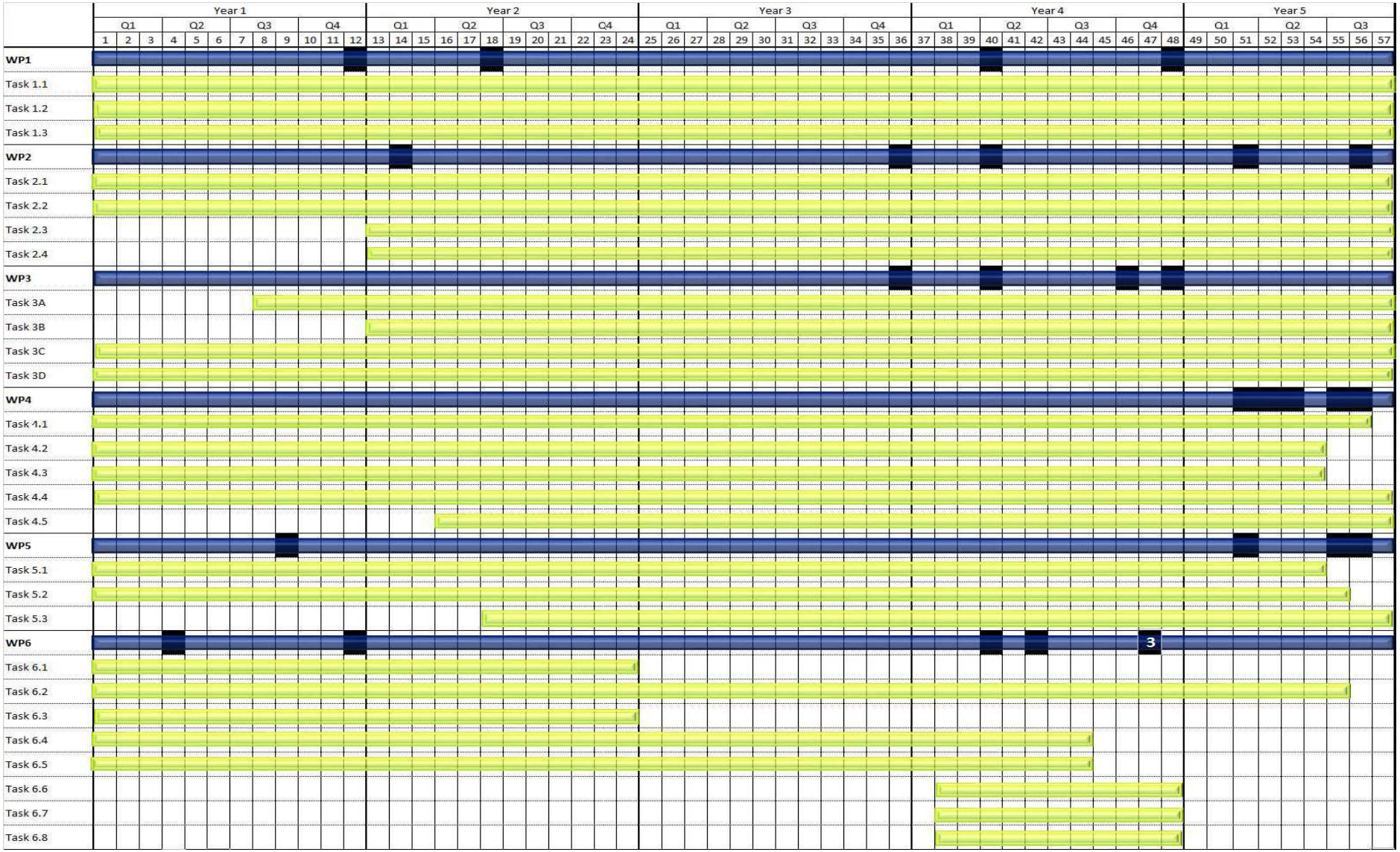

Figure 3.1.2a: Timing of the work packages and their components.

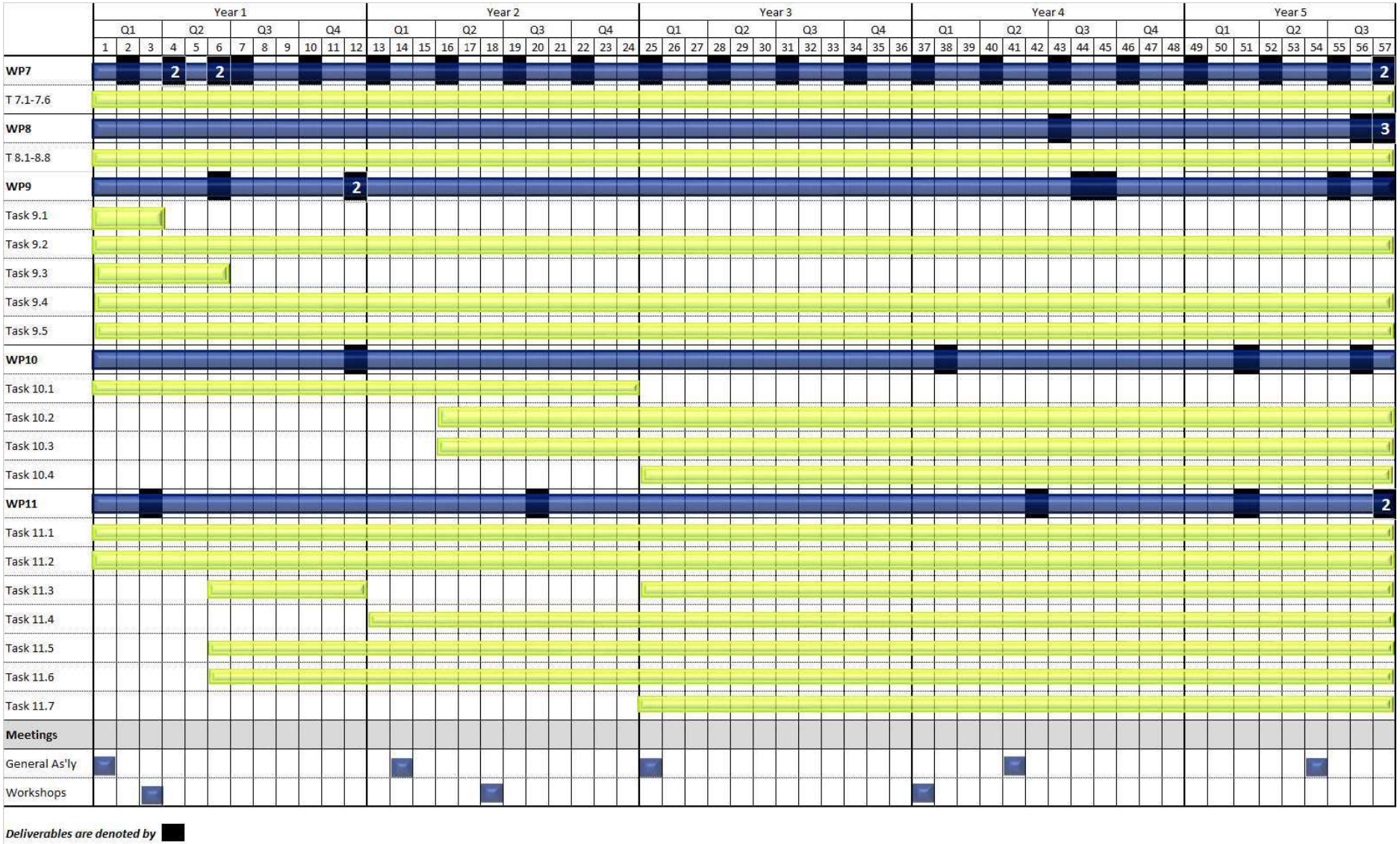

Figure 3.1.2b: Timing of the work packages and their components. Dark and light lines represent the duration of the planned activities at the WP level and task level respectively. Black squares represent the timing of deliverables. Other marks represent when events such as General Assembly meetings and User Workshops are planned.

Details of the Work Packages and deliverables can now be found in Part A of the Description of Action.

3.2 Management structure and procedures

PRIMAVERA brings together 19 partners from across Europe, including National Met Services, academic institutions and an SME. The project is organised around five research themes, made up of eleven work packages (see Section 3.1). Each work package is expected to produce distinct deliverables. As control points in the project, we have defined a number of milestones to be attained (see Table 3.2.1).

PRIMAVERA is considered to be a large project, as defined by the DESCA framework. It therefore requires and will have a highly effective management structure, and efficient decision making processes, allowing flexibility in the management and implementation of the activities at all levels.

There are two distinct Work Packages (WPs) – WP7: Project Management and WP8: Scientific Coordination, which will ensure that this management structure is established. These WPs will allow the Coordinator and Scientific Coordinator to maintain a holistic view of the project, but each WP also has distinct responsibilities. WP7 will ensure the efficient day to day management of the project, whereas WP8 will ensure that the science of PRIMAVERA is fully synthesised and is working in conjunction with external projects, meaning that the objectives and potential impacts are fully realised. The Coordinator and the Scientific Coordinator will be supported by the Project Manager. Since the Project Office will be based at the Met Office, the project will also be able to draw on in-house expertise such as Legal, Finance and Communications, and will be included in their public engagement activities.

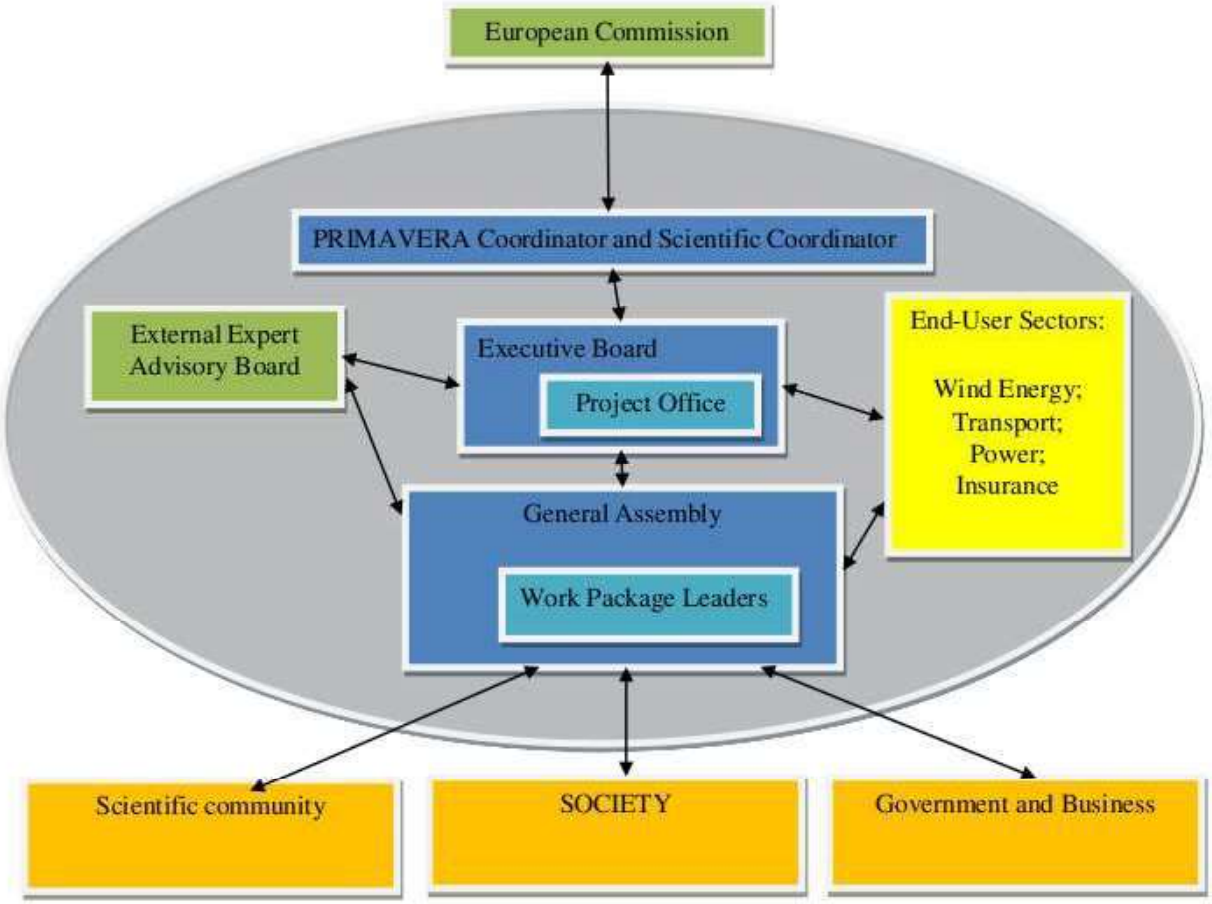

Figure 3.2.1: PRIMAVERA Management Structure

3.2.1 Overview of structure and decision-making bodies/mechanisms

The structure that has been adopted for PRIMAVERA follows the DESCA Model Consortium Agreement for Horizon 2020 projects (the model favoured by the Coordinator's Institution), and specific roles and decision making responsibilities have been assigned accordingly. Further detail about these, and all of the components illustrated in Figure 3.2.1 are given below.

In summary:

- The **General Assembly** is the ultimate decision making body for PRIMAVERA. This will be chaired by the Coordinator and will consist of all the partner organisation.
- The **Executive Board** will be the supervisory body ensuring successful execution of the project, and will be accountable to the General Assembly. This will be chaired by the Coordinator.
- The **Coordinator** is responsible for the overall coordination of the project and will act as the point of contact for the European Commission (EC). The Coordinator has ultimate responsibility for ensuring that the project delivers what is expected.
- The **Scientific Coordinator** is responsible for overseeing the scientific content of the project and ensuring that all work packages are contributing to the outcomes and scientific excellence of PRIMAVERA.
- The **Project Office will co**nduct the routine management of PRIMAVERA on behalf of the General Assembly.
- The **Work Package Leaders** (**and their co-leaders**) have a responsibility to ensure delivery of their Work Pa**ckage objectiv**es and deliverables, working closely with the Coordinator and Scientific Coordinator to support the outcomes of PRIMAVERA as a whole.
- The **External Expert Advisory Board** is a group of independent experts, whose role is to provide advice on project progress and plans.
- The **End-users** will influence the direction of research and advise on project activities and priorities from a end-user perspective. They will be represented on the General Assembly by WP11 partners.

3.2.2 General Assembly (GA)

The General Assembly consists of all the partner institutions. It will be chaired by the PRIMAVERA Coordinator. The purpose of the General Assembly will be to:

- Act as the overall decision-making body for the project;
- Discuss the progress of the project and plans for the future of the project;
- Oversee the political and strategic orientation of the project;
- Advise the Executive Board on any matters relating to the work plan.

There will be five ordinary GA meetings; the first at project inception and then annually thereafter until the project end.

3.2.3 Executive Board (EB)

The EB provide overall management and oversight for the project. In particular the purpose of the EB will be to:

- Execute and implement the decisions made by the GA
- Prepare the meetings and agenda of the GA, and propose decisions for their consideration
- Ensure all Work Packages are fully integrated and contributing to the overall work plan and objectives
- Assist with communicating knowledge as widely as possible across and beyond the project (e.g. by agreeing press releases and project publications)
- Agree the work plan and monitor its implementation
- Recommend resolutions for any dispute between partners
- Ensure proper operation of the consortium, including financial management, reporting and liaison with the EC.
- Deliver the objectives, deliverables and milestones of PRIMAVERA.
- Manage the risks, issues and benefits of PRIMAVERA.

In the event of changes to the Consortium plan or specified content, financial or IPR issues the EB will make recommendations for the GA to approve.

Membership of the Executive Board is as follows: PRIMAVERA Coordinator (Chair of the EB); Project Manager (Reports to the EB); Scientific Coordinator; all Work Package leaders. The WP11 leader will represent the end-users on the EB and ensure that their requirements are fully taken into consideration.

The EB will meet at project inception, and then quarterly thereafter. Annually, this will coincide with the General Assemblies. For the intermediate meetings, methods such as teleconferences will be used, to reduce the travel costs and the carbon footprint of PRIMAVERA.

3.2.4 Project Coordination and Project Office

Project Office

At the delegation of the General Assembly, all administrative, financial and management aspects of PRIMAVERA will be coordinated by the Met Office. Specific day-to-day management tasks are listed in WP7 (Section 3.1).

Coordination

The overall coordination of the project is provided by the Coordinator, Malcolm Roberts (MET OFFICE) and the Scientific Coordinator, Pier Luigi Vidale (UREAD). In 2004, together they pioneered high-resolution UK climate

research at the Earth Simulator Centre in Yokohama, Japan. Since then they have individually lead national and international projects, but their collaboration has also continued over these ten years, and they have worked together on numerous large scale climate projects. Currently they manage a research team under the umbrella of the UK's Joint Weather and Climate Research Programme (JWCRP). They jointly coordinate a dedicated team of four senior research scientists, two project scientists, and a number of PhD students. Together, they have published over twenty peer-reviewed papers.

PRIMAVERA Coordinator: Malcolm Roberts (MET OFFICE)
Responsible for the overall coordination of the project; acting as the intermediary between the European Commission (EC) and PRIMAVERA for all aspects of the project, including communicating any required information or deviations from agreed plans; coordinating and monitoring PRIMAVERA's Gender strategy (MS19); coordinating and monitoring communication, knowledge and innovation management tasks; establishing and managing the project Dissemination and Exploitation plan and report (D7.4 and D7.5).

PRIMAVERA Scientific Coordinator: Pier Luigi Vidale (UREAD)
Responsible for monitoring scientific progress of the research themes and work packages; providing scientific leadership for the project; synthesising the results of PRIMAVERA to maximise benefit and impact (D8.1 and D8.2); coordinating the scientific work of PRIMAVERA; engaging with the EEAB; identifying potential gaps/shortfalls in work; managing the scientific risks within the project; communicating the project and its results to Government, external bodies and other projects (D8.3 and D8.4).

PRIMAVERA Project Manager (PM)
Responsible for facilitating internal communication within PRIMAVERA; providing support and planning tools for WP management; scheduling and organising meetings for the project; maintaining regular communication with the EC and the PRIMAVERA Coordinator; managing, monitoring and reporting of project finances and budget; management of risks, benefits and issues registers; reporting on Gender strategy, dissemination, exploitation and communication; providing administrative support to PRIMAVERA Coordinator. The Project Manager will report to the General Assembly. Specialist support will be provided to the Project Office by the relevant Met Office departments (who have the benefit of extensive experience of European Research Programmes) and other partners where required.

3.2.5 Work Package leaders (WPL)
Work Package Leaders (WPL) and Co-Leaders have been appointed. WPLs will have autonomous responsibility for coordinating the tasks within their WP, which contribute to the delivery of PRIMAVERAs objectives and impacts. The WPLs will support the scientific coordination of the project as a whole. They will ensure that: the planned work at WP level is carried out according to plan and budget and that the deliverables are produced and milestones are attained on time; a link is established with PRIMAVERA project coordination and that the decisions taken at steering level are implemented at WP level; they assist with exchanges with other projects and the scientific community. To achieve these aims, the WPLs will arrange one annual face to face, and other more regular teleconference meetings between those involved in their WP, and will communicate regularly with the Scientific Coordinator. They will make sure that the progress of their WP is monitored and reported on, including highlighting any departure from the work plan, disputes or difficulties as early as possible.

3.2.6 End-users
The end-users will work with PRIMAVERA through WP11. Meetings and interviews will be arranged with these end-users at the start of the project in order to establish how they use climate information in their decision making processes. These end-users will be central to the work done in PRIMAVERA, and will provide the expert sector knowledge which will determine the way in which PRIMAVERA will develop. They will assist in determining the most effective dissemination and communication methods for their groups, enabling maximum exploitation. They will be represented at the GA by the partner working most closely with them through WP11, ensuring that their feedback is incorporated at the decision making level.

3.2.7 External Expert Advisory Board (EEAB)
This independent group will be formally established by the Coordinator and the Scientific Coordinator at the beginning of the project. Terms of reference for the EEAB will be agreed prior to the start of the project by the Executive Board and published on the project website. It will consist of five experts in the areas immediately relevant to PRIMAVERA. These experts have already been identified and have agreed to form the EEAB:

Christiane Jablonowski (Female) - University of Michigan; is an expert in numerical methods and in atmospheric dynamics, particularly in the field of tropical cyclones. She is internationally recognised for her leading role in creating a number of novel, standardised tests for assessing current and next-generation dynamical cores – particularly those supporting the use of irregular and adaptive meshes– used in GCMs.

Graeme Stephens (Male) - Jet Propulsion Laboratory; leads the international GEWEX global water and energy project and is a world-renowned expert in remote sensing, and the PI of a number of key satellite missions in the last two decades, e.g. CloudSat, which have revolutionised the way we assess GCMs.
Masahide Kimoto (Male) - University of Tokyo; has extensive expertise in high resolution climate modelling and process-based assessment, and has played key roles in a number of past IPCC and CMIP programmes.
Marta Bruno Soares (Female) - University of Leeds; has expertise in end-user needs across different sectors, and works within FP7 EUPORIAS project for climate services.
Hilppa Gregow (Female) – Finnish Meteorological Institute; is an expert in climate change impacts research, the assessment of climate/weather extremes and risks and climate service and service co-creation.

Shoshiro Minobe (Male) Laboratory of Physical Oceanography and Climatology, Hokkaido University; is an expert on the climate processes of air-sea interaction, decadal variability, upper ocean dynamics, and ENSO.

They will provide independent evaluation and assessment of the project work plan, progress and techniques, making recommendations for improvement on the project's scientific approach and orientation where appropriate, ensuring scientific evaluation of the project and links to other programmes. The EEAB will also provide an assessment of the project's outputs in terms of quality and impact in the community. These assessments till be included in the regular project reporting (i.e., through D8.1). Consulting with the EEAB will increase awareness of PRIMAVERA through the members' involvement in communities such as IPCC, CMIP6, GEWEX, use of observational data for model validation (ESA-CCI and CMUG), climate services (through EUPORIAS), and hence will ensure that it will achieve maximum impact.

The EEAB will be invited to attend each of the General Assembly meetings. Prior to each General Assembly meeting the views of the EEAB on research progress and plans will be sought, which will contribute to the agenda of those meetings. General Assembly attendance will be in person where possible, but arrangements will be made for remote participation if required. The Coordinator and the Scientific Coordinator will also maintain more regular contact with the EEAB. The EEAB will routinely be provided with information on project progress and results.

3.2.8 How the organisational structure is appropriate to PRIMAVERA

Due to the number of partners contributing to PRIMAVERA, the consortium considers itself to be a large project by the DESCA definition. Therefore, having two management bodies within the project is appropriate and will ensure that PRIMAVERA is well governed.

The Coordinator and the Scientific Coordinator of PRIMAVERA have worked together on successful projects in the past, and whilst they will communicate and work together constantly, they also have well defined areas of responsibility to ensure that the project is coordinated effectively.

It is vital that PRIMAVERA does not work independently of all interested parties who are external to the project, which is why there is much importance placed on ensuring that end-users are represented at all levels. Similarly, the consortium will be able to ensure its connections and relevance to the wider scientific community through the involvement of the EEAB.

The WPLs play a key role in the scientific management at the WP level, which allows the Scientific Coordinator to use their feedback to successfully take the overview of the project. WPLs will also be supported by their Co-Leaders, Task Leaders and deliverable leaders, to make sure that all deliverables are provided according to the work plan.

Management of specific areas of importance such as gender, ethics and IPR will be done centrally through the Project Office. The Project Office will be at the centre of coordination, meaning that they will have visibility of all project activities and will be able to liaise effectively with the EC.

3.2.9 List of PRIMAVERA milestones

To help the decision making bodies chart progress, the following **control points** (milestones) have been identified and can be found in part A of the Description of Action.

3.2.10 Innovation Management in PRIMAVERA

Effective innovation management within this project will require an overview of the project in its entirety and for this reason the Coordinator will be responsible for the process of innovation management. The management of innovation activities is integral to PRIMAVERA, as already indicated in Sections 1.4.3 and 2.1. By nature of the structure of the consortium and the work packages within the project, both the technical and market aspects of innovation are addressed and combined. There is both technical expertise, and end-user engagement expertise within the consortium. Through the Coordinator, within the management structure already identified above, these elements will be brought together and will ensure that innovative products are developed and exploited as a result of the research.

The Coordinator, with support from the Scientific Coordinator where appropriate, will take an overview of the WPs and the outcomes of PRIMAVERA to provide effective management and therefore exploitation of these both during and after the project (D7.4 and D7.5). At each stage of the project, the tasks associated with the innovation management will be slightly different. At the beginning of the project the focus will be on the definition of a credible strategy and "route to market" for potential research outcomes. The potential pathways of market-oriented exploitation, converting or transforming knowledge will be identified, together with key factors for successful innovation management. These will form an integral part of the Dissemination and Exploitation Plan (D7.4). At a more mature stage of the project, the Plan will be adapted to take into account best practice methods of maximising the value of Intellectual Property (IP), for dealing with technology transfer/exploitation/protection, and with the assessment of IP/research results, and patent information. Finally, the focus will be on defining a strategy for the Intellectual Property exploitation after the project (D7.4).

WPs 2,3,5,6,10 and 11 form an iterative loop incorporating end-user feedback into the project. To ensure that the project responds to end-user feedback in the most efficient way, the timings of the deliverables and milestones of the work packages have been planned to allow sufficient time to incorporate feedback and development. In this way the project will be responsive to any external opportunities that are identified. The Scientific Coordinator will also ensure that any internal opportunities (those identified by other work packages) are addressed and incorporated if necessary.

The Met Office has established innovation management processes and PRIMAVERA will be able to draw on the experience that it has in successfully integrating new concepts and cutting edge research into user products.

3.2.11 Further management considerations

Gender balance within PRIMAVERA

In PRIMAVERA, 23 of the 67 (34%) scientists named by the partners to work in the research teams are female, and 6 of these 23 are WP leaders or co-leaders. 40% of those on the EEAB are female, as indicated in Section 3.2.7. By signing the Grant Agreement, the Consortium will commit to promoting equal opportunities during the implementation of the project, and makes a commitment to aim to achieve gender balance at all levels of staff assigned to the project, including at supervisory and management levels (Art. 33.1 Grant Agreement). The Consortium is aware of the importance of attracting, retaining and advancing more high quality female scientific researchers and PRIMAVERA will ensure that where applicable it works to satisfy the Horizon 2020 objectives of gender balance and integration. As an example, the School of Mathematical and Physical Sciences at the University of Reading is twice the winner of the Athena SWAN award for commitment to advancing women's careers in science. All partners will be encouraged to stay up to date with gender training. PRIMAVERA is aware that this can now be listed as an eligible direct cost under Horizon 2020 however has chosen not to access this resource, as it is thought that such training will be encouraged by individual institutions separately to this project.

Gender Strategy

The promotion and monitoring of gender equality throughout the project will be the responsibility of the PRIMAVERA Coordinator. A Gender Strategy (MS19) will be produced by month 6 of the project, and will be updated during the project. With support from the Project Office, the Coordinator will ensure that the Strategy is applied throughout the project, and that a process is followed for monitoring gender equality. The Strategy will encompass both internal and external participants.

A section of the Periodic Progress Reports for PRIMAVERA, produced by the Project Manager, will be dedicated to reporting on the Gender Strategy and will contain information on the *Specific Performance Indicators for Horizon 2020* needed by the European Commission for monitoring the gender equality in the new programme.

Ethics

The project has considered the Ethics criteria in Annex A. The nature of the research proposed by PRIMAVERA means that there are few ethical issues. PRIMAVERA will be required to submit Ethics Documentation (D7.6) to detail how participants will be identified and recruited to take part in PRIMAVERA, and what informed consent procedures will be in place.. The Project Office will monitor this and any other potential ethics issues throughout the duration of the project, and ensure that all of them are identified and appropriately handled.

Knowledge Management

The partners have a collective responsibility to ensure that any knowledge generated through the project is appropriately protected and shared. STFC and the Met Office will play key roles in this through WP9. The Coordinator is responsible for the project's knowledge management strategy, ensuring it is kept up to date and that the associated protocols are adhered to.

3.2.12 PRIMAVERA Critical risks for Implementation

The GA will be responsible for dealing with risks, issues and benefits realisation of the project. The Scientific Coordinator will be responsible for management of the risks within the project (WP8, T8.6), and day-to-day maintenance of the risk registers will be undertaken by the Project Office.

Critical risks to project implementation, which have the potential to impact the project objectives being achieved, have been identified and described in Table 3.2.2 below. They are risks that have been considered and that will be actively managed and monitored throughout the project. Where there are risks that exist specifically within individual WPs, these have been identified already and the design of the WPs has taken account of preventative measures for each.

Table 3.2.2: Critical risks for implementation

This can now be found in Part A of the Description of Action.

3.3 Consortium as a whole

PRIMAVERA is timely, in that it joins the wisdom of the post-IPCC AR5 synthesis of climate science with a number of opportunities from breakthroughs in model development and technology across Europe. The PRIMAVERA consortium is a cutting-edge combination of scientific and technical excellence, climate modelling and HPC expertise, with developed links to end-users. It therefore has the unique capability to produce ambitious and innovative climate science and deliver a new generation of advanced Earth System Models. This will enable an improved understanding of European climate variability and change, and will develop products jointly with the end-user sectors to strengthen their competitiveness and growth. Only a select few groups can do this, and PRIMAVERA has all of them as partners.

The consortium members bring previously demonstrated expertise in: i) developing new generations of global high resolution climate models (MET OFFICE, UREAD, KNMI, SMHI, CERFACS, MPG, ECMWF, CNR, AWI, CMCC, who were also leading participants in the 2008 Global Modelling Summit); ii) experience of delivering climate simulations to IPCC CMIP exercises (MET OFFICE, UREAD, KNMI, SMHI, CERFACS, MPG, CNR, CMCC) and the enabling technology for scalable data access (STFC, DKRZ); iii) exploring scientific and technical frontiers of modelling and analysis, for example via European PRACE or international HPC projects (MET OFFICE, UREAD, SMHI, BSC, KNMI, MPG). This work has demonstrated that we can now run our models efficiently on tens to hundreds of thousands of cores, in conjunction with (equally scalable) process-based model assessment.

Understanding and improving the representation of important climate processes, and hence produce robust projections, requires expertise from groups who have model components in common to enable testing in a multi-model sense. NERC, MET OFFICE, CERFACS are key developers in the European NEMO consortium, the ocean model used by 10 of the PRIMAVERA partners, in which the standard sea ice model (LIM) is developed by UCL. AWI and MPG share the same atmospheric model, and EC-Earth and ECMWF share the same dynamical core in the atmosphere and also multiple sea ice model options. Other processes require more specialised understanding. UNIVLEEDS and SU bring aerosol and microphysics expertise; UREAD and CMCC are land surface model developers; UOXF pioneer the use of stochastic physics and AWI bring novel unstructured mesh approaches to the ocean and sea ice modelling.

Many of the consortium members have worked together for many years on other projects. The use of common model components amongst many partners (ocean and sea ice as above, atmosphere within the EC-Earth group of three) demonstrates the effective working relationships for coordinated model development. The capability of the PRIMAVERA modelling groups to deliver ensembles of high-resolution global climate integrations has substantially increased, coordinated by European IS-ENES and IS-ENES2 projects in which 13 PRIMAVERA partners are involved. Europe is itself well-placed for this project, with high bandwidth networks using GÉANT and the ESGF nodes maintained by STFC and DKRZ. This high-speed connectivity makes it possible to use the central analysis platform, JASMIN, to which the multi-model ensembles can be extracted from national data archives (as done in PRACE-UPSCALE). This will make development, sharing and use of analysis tools much simpler. In addition the involvement of STFC is vital in providing the infrastructure for common model post-processing and analysis (JASMIN), together with hosting of the project web pages and hub for communication. STFC have in fact played a key role in Europe as regional hub for the CMIP archives and have a long history of collaborating across Europe and worldwide. They have provided the key capabilities in data transfer, serving and curation that have enabled the UK high-resolution team to exploit unprecedented levels of HPC for climate science in Japan, the USA and Germany since 2004.

Exploiting this next generation simulation and analysis capability most effectively requires expertise both in capturing the requirements of the user community, and the proven ability to present this information in a clear and

understandable way. BSC have much experience in engagement with end-users and enabling this information to be used to shape project design. A number of partners (BSC, KNMI, UREAD, MET OFFICE) have strong existing links with commercial organisations that will be fully utilised within PRIMAVERA. Partners will also be able to use their contacts to establish new relationships with other commercial organisations, for the benefit of the project. Delivery of climate information relevant to users is a strong component of two successful FP7 consortia in which many PRIMAVERA partners are involved: SPECS, which aims to improve seasonal prediction skills, and EUPORIAS, which aims to investigate the potential for decadal predictability. PREDICTIA provides the project with expertise on the presentation and delivery of climate information to end-users. During PRIMAVERA they will build on the work that they have previously done in FP7 EUPORIAS and will be integral to the project, offering a depth of experience in this area that the consortium would not have otherwise.

The majority of PRIMAVERA partners have also been involved in past IPCC assessments, but have always cultivated the ambition to drive the IPCC process with better and more trustworthy models. Joining our capability under the umbrella of a new CMIP protocol, HighResMIP, can effectively influence future IPCC exercises and make sure that the role of high-resolution is systematically tested and reported to the entire global climate modelling community, as well as to decision-makers and end-users.

Coordination and Scientific Coordination of PRIMAVERA

The PRIMAVERA Coordinator (Dr. Malcolm Roberts) and Scientific Coordinator (Prof Pier Luigi Vidale) have been working together since 2004, as described in Section 3.2.4. A substantial aspect of this collaboration is seamlessly managing the relationship with the model development teams at the Met Office and at NERC centres, as well as with international research groups (e.g. six invited visitor exchanges and ten keynote talks worldwide in 2014). Roberts and Vidale also hold research and HPC grants –nationally and internationally– and coordinate numerous exploitation projects with teams in the UK and overseas, including industry partners (e.g. Willis, Network Rail, EDF), analysing high-resolution experimental outputs. For instance, the PRACE-UPSCALE campaign currently counts on the coordinated efforts of thirty teams in six countries and has already seen the submission/publication of eight papers in its first year of existence. For these reasons they are perfectly placed to jointly lead this consortium and deliver the objectives of PRIMAVERA.

3.4 Resources to be committed

The total requested EC contribution for PRIMAVERA is 14,967,970 €. The 19 partners have offered 1844 person months to the project.

3.4.1 Financial planning approach

The majority of the funding for PRIMAVERA is required for personnel costs, as the project will rely on the skills and many years of expertise of the partner organisations involved. Therefore it was key that the budget was calculated using an estimation of the costs associated with the experts that have been identified to deliver the project's objectives. The budget has increased from 14,261,663 € primarily due to increases in the PMs in WPs 10 and11 in order to increase the number of end-user sectors involved and the effort in climate risk assessment (for both these end-users and Government) and hence increase the impact of the proposal.

Table 3.4.1: Summary of staff effort

This information can now be found in Part A of the Description of Action.

3.4.2.1 Personnel costs

Personnel costs (including associated indirect costs) represent 89.3% of the overall direct costs budget. Table 3.4.1 shows the amount of staff effort broken down by beneficiary and work package.

As coordinating partner, the Met Office has the most PMs. In addition to coordinating, they are also leading three WPs and so these PMs will allow them to oversee the success of these. BSC have a large number of PMs due to their substantial involvement in a number of WPs in which they have particular expertise, specifically in WP11 where they have 48 PMs dedicated to end-user engagement and dissemination. AWI have relatively large resource in several WPs due to the novelty of the unstructured mesh approach and the new data challenges.

WP2 is has the largest number of PMs dedicated to it because it is a core activity to assess the impact of model resolution on European climate that almost all groups are engaged with, and is likely to contribute to most of the influential scientific peer-reviewed publications expected from PRIMAVERA.

Resources required for dissemination activities

All partners have been given time within WP8 to allow them to undertake dissemination and communication activities for PRIMAVERA. Partners who are leading or co-leading WPs also have additional time to enable them to work with the Scientific Coordinator to synthesise all results for dissemination and communication. The Scientific Coordinator has dedicated time available to promote PRIMAVERA at scientific events, and to engage with other

projects and government in order to maximise impact and exploitation. In addition to this, WP11 has 147 PMs dedicated specifically to engagement, dissemination and communication with end-users.

Management activities
87 PMs are allocated for the Project Management, Coordination and Scientific Coordination (WP7 and WP8) of PRIMAVERA. Of this, 24 PMs are to allow the Met Office to fulfil its project management activities. Time for partners to prepare for and attend the GAs is included in WP8.

3.4.2.2 Other direct costs

Travel budget - A travel budget was prepared centrally by the Project Office then reviewed and agreed by all the partners. The Project Office has avoided any unnecessary travel and promoted the use of alternative forms of communication wherever practicable. 6.4% of the total project budget has been put aside for travel costs. This is to cover the partners' travel costs, 48,000 € (direct cost) will be available to cover travel associated with the end-user interviews in WP11, and 27,600 € to cover the travel costs of the EEAB to attend the General Assemblies.

Others - Other costs are relatively small, however each partner except for DKRZ, have been given 5000 € (direct cost) to cover open access publications. STFC require 28,500 € for the cost of digital tapes for backup of essential PRIMAVERA data sets and will be used as a stage data sets from disk. This will allow project scientists to manage data most effectively so that the priority data sets are available on disk at any point in time. BSC require 40,000 € to purchase disks for sharing project output data with partners, since although BSC obtains substantial amounts of competitive computing time this does not provide associated long-term storage.
Met Office and BSC have 25,000 € between them to cover the cost of end-user workshops to assist with exploitation of PRIMAVERA results. Thirteen of the partners will require external audits (for certification of financial statements) at the end of the project, accounting for 0.4% of direct cost. Five partners have other direct costs that are greater than 15% of their personnel costs. Table 3.4.2 provides the details of these other direct costs.

Table 3.4.2: Summary of other direct costs for five partners

8/BSC	**Cost (€)**	**Justification**
Travel	108,200	Travel for end-user interviews WP meetings (WP 1,2,3, 4, 5, 6, 9, 10,11: 9 WPs x four meetings per WP = 36 meetings) Five General Assemblies
Equipment	-	None
Other goods and services	3,500 10,000 15,000 40,000	Audit costs Publication/Open Access charges End-user workshops Purchase of disks for use during PRIMAVERA
Total	176,700	
16/SU	**Cost (€)**	**Justification**
Travel	15,400	WP meetings (WP3 = four meetings) Five General Assemblies
Equipment	-	None
Other goods and services	5,000	Publication/Open Access charges
Total	20,400	
17/STFC	**Cost (€)**	**Justification**
Travel	15,400	WP meetings (WP9 = four meetings) Five General Assemblies
Equipment	-	None
Other goods and services	5,000 28,500	Publication/Open Access charges Digital tapes
Total	48,900	
18/PREDICTIA	**Cost (€)**	**Justification**
Travel	15,400	WP meetings (WP11 = four meetings) Five General Assemblies
Equipment	-	None
Other goods and services	5,000	Publication/Open Access charges
Total	20,400	

19/DKRZ	Cost (€)	Justification
Travel	21,000	WP meetings (WP4 = four meetings and WP6=four meetings) Five General Assemblies
Equipment	-	None
Other goods and services	-	None
Total	21,000	

Large research infrastructure – None of the project participants will be declaring costs of large research infrastructure under Article 6.2 of the General Model Grant Agreement.

Sub-contracts – KNMI are planning to sub-contract an element of the PRIMAVERA work. See Section 4.2 for further details.

3.4.3 Contributions from beneficiaries

The 'in kind' contributions to PRIMAVERA are technical and computational resources that will be used within the project, but for which no project costs will be charged. They will provide the size and complexity necessary to complete this innovative and ambitious work. Details of the contributions of each beneficiary are given in Section 4. A considerable amount of resource has been committed and project members have a strong track record of securing significant HPC resources from both national and pan-European funding bodies. With support from IS-ENES2, we expect to obtain the required resources for the planned integrations.

The substantial costs for data storage within national archives and access to the high bandwidth network links within Europe will also be provided by the consortium. The JASMIN platform, run by STFC, will provide the central computing facilities for PRIMAVERA with up to a Petabyte of storage available along with archive space and the LOTUS analysis cluster currently comprising over 3,000 compute cores. In addition STFC will provide access to ESGF nodes and long term archives.

Extracts from selected letters of support

The following are verbatim extracts from a selected sample of the support letters received for PRIMAVERA. All letters are available upon request.

Sylvie Joussaume, CNRS/Institut Pierre Simon Laplace

I express this interest as coordinator of the Infrastructure for the European Network for Earth System modelling (ENES) project, IS-ENES2 and also as Chair of the ENES Scientific Board. PRIMAVERA's intention to deliver a new generation of high resolution climate tools and models to advance understanding and facilitate adaptation to regional climate variability up to 2050, with a focus on compound and extreme climate events is of high relevance and value to the climate modelling community. IS-ENES2 has in its main objectives to support the preparation of high-end experiments and coordinates the collaboration with PRACE. This objective follows the ENES infrastructure strategy elaborated during the IS-ENES phase 1 project, which emphasizes global climate model simulations at very high resolution (towards 1 km) as a grand challenge. PRIMAVERA will be instrumental to support the science program of this development and provide key steps in this direction, whereas IS-ENES2 aims at supporting its infrastructure development. PRIMAVERA will therefore benefit from the technical preparation of tools and models provided by IS-ENES2. Moreover, IS-ENES2 development and service activities support the international database of the WCRP international coordinated experiments (CMIP) to which PRIMAVERA will contribute. PRIMAVERA will therefore also benefit from the expertise of IS-ENES2 on data and metadata standards and setting of data nodes.

Prof. Christiane Jablonowski – University of Michigan

I am very enthusiastic about the opportunity to serve as a member of the External Expert Advisory Board for your proposed project "PRocess-based climate sIMulation: AdVances in high resolution modelling and European climate Risk Assessment (PRIMAVERA)".

Today, global climate modeling is at a crossroads. The recent advances in computing technology and our ever increasing understanding of the climate system allow us, for the first time, to ask detailed scientific questions about the impact of small-scale / meso-scale phenomena on the global climate system, such as the impact of tropical cyclones on the global hydrological cycle. High-resolution climate modeling enables us to answer these questions, and furthermore fosters our understanding of climate processes and their improved representation in climate models. PRIMAVERA is based on this premise, and furthermore uses powerful multi-model ensemble techniques to gain an understanding on model uncertainties at unprecedented scales.

There is an urgent need for multi-scale high-resolution climate simulations from public, economic and academic stakeholders. Our future-generation models must provide climate projections that are reliable and trustworthy at the local, regional and global scales. The proposed research and broad multi-institutional collaborations in PRIMAVERA are paramount steps to systematically tackling this challenge. PRIMAVERA will greatly accelerate the scientific progress, and has the potential to fundamentally change the way we build, evaluate and improve climate models, and communicate their outcomes to the wide spectrum of stakeholders and decision makers.
I am looking forward to lively discussions with the PRIMAVERA team. As you know, my own research pushes the frontiers of high-resolution global climate modeling, and I am excited about interacting with PRIMAVERA researchers and establishing international collaborations.

Prof. Masahide Kimoto – The University of Tokyo
We have seen many attempts at just increasing the number of computational grids gave a degraded performance at higher resolution. These physical processes are often represented in models by what we can subgrid-scale parameterization, a semi-empirical, therefore imperfect, method to represent under-resolved processes in numerical models. Into the higher resolution, it becomes more and more important that we understand and represent those processes in the model. I therefore highly appreciate that you explicitly included the words "process-based" in your project to emphasise this important aspect in the high resolution modelling. In the same token, involvement of many research groups, not only modelling centres but also groups that have strengths in physical processes, should be another important aspect for the success of the project. Hard work of single modelling centre only may not be sufficient to obtain a good model. Multiple views and approaches should be important. I am happy to have heard that you have already 20 European institutions and are asking for international collaborations. I believe that this scale of research collaboration should bring your project an unprecedented success.

Harilaos Loukos - Climate Data Factory project leader within Climate-KIC
I express this interest as coordinator of the Climate Data Factory Project, an innovation project supported by the Climate-KIC. The goal of the Climate Data Factory project is to distribute user-friendly climate projections data to facilitate adaptation strategies and to design a climate service offer in order to facilitate and accelerate the diffusion of climate data to society. This will help reduce time to action for climate change adaptation for many potential users in specific business sectors (energy, building sector, insurance, agriculture, local authorities).

The PRIMAVERA outcomes and research data will benefit the Climate Data Factory project by providing open access to new and innovative climate datasets for the 1950-2050 period, together with in-depth analysis of climate information over relevant planning timescales. In particular, we are very interested in supporting the research teams of WP1 "Development and application of metrics for process-based evaluation and projections", WP10 "Climate Risk Assessment" and WP11" User Engagement and Dissemination" for the period of time when Climate Data Factory and PRIMAVERA overlap (2015-2017). As such, the Climate Data Factory project consortium is keen to count the PRIMAVERA project as an official project supporter.

Dr. Jan-Stefan Fritz, Head Brussels Office, Konsortium Deutsche Meeresforschung (KDM)
KDM is the representative body of Germany's major marine research centres and is acknowledged by the German federal government as a national contact for marine research strategy. The KDM Brussels Office is engaged in an ongoing dialogue with decision-makers of all EU Institutions and other global international organisations on the future of ocean research and policy. Amongst our many activities, we have developed a successful tradition of organizing scientific briefings to policy-makers in Brussels. I would be very interested to support the PRIMAVERA project in communicating its results to appropriate policymakers, for example, through the organization of one or more scientific briefings.

Kathryn Humphrey, Senior analyst, UK Committee on Climate Change

I express this interest as the lead analyst managing the development of the statutory UK Climate Change Risk Assessment (CCRA). PRIMAVERA's intention to deliver a new generation of high resolution climate tools and models to advance understanding and facilitate adaptation to regional climate variability up to 2050, with a focus on compound and extreme climate events will be highly relevant to future cycles of the CCRA process, which is required by law every five years. A further evaluation of the associated regional climate risks will be of high interest to our ability to evaluate the effectiveness of adaptation strategies for the UK.

Gil Lizcano, Research and Development Director, Vortex

As R&D Director at Vortex, PRIMAVERA's intention to deliver a new generation of high resolution climate tools and models that advance understanding and facilitate adaptation to climate variability up to 2050 is of high relevance to my organisation. In particular, an evaluation of the associated risks facing the energy sector will be of great interest to our clientèle, many of whom are small to large companies operating within this sector. The enhanced communication protocol and user-led approach will help us to establish a continual feedback process with the project team.

Hélène Galy, Managing Director, Global Analytics, Willis Group

The project outcomes will benefit Willis Group and our clients by providing access to in-depth analysis of climate information over the investment and strategic planning timescales of insurance and reinsurance contracts and facilitating key pricing and market positioning decisions in relation to past, present and future climates. The analysis of climate information can allow validation and calibration of industry catastrophe models, by adjusting or supporting established views and offering alternative and robust guidance on climate variability on a variety of spatial scales. The extra information that can be potentially offered by high resolution climate modelling regarding changes in severity of climate events (and associated impacts), can be useful in assessing the non-stationarity of past climate data and therefore the most appropriate view for the future. We see a lot of potential in collaborating with PRIMAVERA as a stakeholder: regularly informed of the progress of the project, we could validate the products of the project, provide guidance on appropriate application of the products of the project for our industry, and be consulted about the impact of new developments.

Dickie Whitaker, Managing Director, Oasis Loss Modelling Framework

As co-founder and managing director of Oasis LMF we are strongly supportive of
PRIMAVERA's intention to deliver a new generation of high resolution climate tools and models to advance understanding and facilitate adaptation to regional climate variability up to2050,with a focus on compound and extreme climate events is of high relevance and value to my organisation. A further evaluation of the associated regional climate risks will be of high interest to our community of users globally.
The project outcomes will benefit Oasis and the Insurance industry in particular by providing access to new and innovative climate datasets for the 1950-2050 period, together with in-depth analysis of climate information over relevant planning timescales.

Dr Peter Craig, Acting CAWCR Director, The Centre for Australian Weather and Climate Research

The Centre for Australian Weather and Climate Research (CAWCR) is pleased to provide you with a letter of support for your 'PRIMAVERA' project proposal. We recognize the valuable lead that your project would take to develop and evaluate high-resolution climate models, a task that is largely beyond the resources of CAWCR and many other groups worldwide. We are consequently keen to learn from your experience as we assess our ability to move to higher resolution coupled climate modelling with the Australian Community Climate and Earth System Simulator (ACCESS).

Heikki Mannila, Chair JPI Climate Governing Board

The project outcomes will benefit JPI Climate by providing access to new and innovative climate datasets for the 1950-2050 period, together with in-depth analysis of climate information over relevant planning timescales

JPI Climate is the European platform where the policies of 14 EU member states, responsible for a large amount of climate research funding in Europe, can be aligned. JPI Climate provides a platform where coordinated and large-scale European efforts can be made to understand and respond to climate change according to a jointly agreed Strategic Research Agenda (SRA) with the aim of complementing and supporting initiatives at the European level.

JPI Climate overcomes fragmentation in climate change research while maintaining creative diversity. Collaboration shall be pursued with other research programmes, networks and initiatives at member state or European level.

Dr. Erik Buch, European Global Ocean Observing System (EuroGOOS) Chair

The overarching goal of PRIMAVERA – "*to develop a new generation of advanced and well-evaluated high-resolution global climate models, capable of simulating and predicting regional climate with unprecedented fidelity"* – is extremely challenging. It will however highly improve our understanding of the climate system and thereby our ability to predict and provide information and warnings on extreme events to the benefit of the society.
EuroGOOS acknowledge that the model improvements that will be an outcome of this project will be highly valuable for the operational community and will thereby have a positive impact on our ability to forecast event on a shorter time scales than the climatic ones.

Selected references (full list available upon request)

[1] IPCC (2013). Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., et al. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[2] Kirtman, B., et al. (2013). Near-term Climate Change: Projections and Predictability. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., et al. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[3] Meehl, G. A., et al. (2014). Climate Model Intercomparisons: Preparing for the Next Phase, Eos Trans. AGU, 95(9), 77.

[4] Scaife, A. A., et al. (2014). Skilful long range prediction of European and North American winters. Geophys. Res. Lett. (in press), doi: 10.1002/2014GL059637.

[5] Shaffrey, L. C., et al. (2009). U.K. HiGEM: the new U.K. High-Resolution Global Environment Model-model description and basic evaluation. J. Clim., 22,1861-1896.

[6] Roberts, M. J., et al. (2009). Impact of Resolution on the Tropical Pacific Circulation in a Matrix of Coupled Models. J. Clim., 22, 2541-2556.

[7] Chassignet, E.P., and D. P. Marshall (2008). Gulf stream separation in numerical ocean models. In: Hecht, M., Hasumi, H. (eds.), Eddy-Resolving Ocean Modeling, AGU Monog. Ser., 39-62.

[9] Demory, M.-E., et al. (2014). The role of horizontal resolution in simulating drivers of the global hydrological cycle. Clim. Dyn., 42, 2201-2225.

[11] Hodges, K. I., et al. (2011). A comparison of extratropical cyclones in recent re-analyses ERA-Interim, NASA MERRA, NCEP CFSR, JRA-25. J. Clim., 24, 4888-4906.

[12] Zhao, M., et al. (2009). Simulations of Global Hurricane Climatology, Interannual Variability, and Response to Global Warming Using a 50km Resolution GCM. J. Climate, 33, 6653-6678.

[14] Haarsma, R. J., et al. (2013). More hurricanes to hit Western Europe due to global warming. Geophys. Res. Lett., 40, 1783-1788.

[15] Jung, T., et al (2012). High-resolution global climate simulation with the ECMWF model in project Athena: Experimental design, model climate, and seasonal forecast skill. J. Clim., 25, 3155-3172.

[18] Rodwell MJ, Hoskins BJ (1996) Monsoons and the dynamics of deserts. Q J Roy Meteorol Soc, 122, 1385-1404.
[19] Cassou, C. (2008). Intraseasonal interaction between the Madden-Julian Oscillation and the North Atlantic Oscillation. Nature, 455, 523-527.
[22] Yang, S. and J. H. Christensen (2012). Arctic sea ice reduction and European cold winters in CMIP5 climate change experiments. Geo. Res. Lett., 39, L20707.
[31] Stevens, B. (2013). Climate science: Uncertain then, irrelevant now.Nature,503,47-48.
[32] Cash D.W. et al. (2003). Knowledge system for sustainable development. Proc. Nat. Acad. Sciences, 100, 8086-8091.
[34] Brown, A., et al. (2012). Unified Modeling and Prediction of Weather and Climate: A 25-Year Journey. Bull. Amer. Meteor. Soc., 93, 1865-1877.
[35] Hoskins, B. (2013). The potential for skill across the range of the seamless weather-climate prediction problem: a stimulus for our science. Q.J.R. Met. Soc., 139, 573-584.
University of Cambridge Institute for Sustainability Leadership (2014). IPCC Briefings on the implications of climate change for business as a vital resource for companies wanting to plan for the future. www.cisl.cam.ac.uk/ipcc
[42] Bakker, A. and B. van den Hurk (2012). "Estimation of persistence and trends in geostrophic wind speed for the assessment of wind energy yields in Northwest Europe". Climate Dynamics 39.3-4. doi:10.1007/s00382-011-1248-1 (in press), pp. 767–782. doi: 10.1007/s00382-011-1248-1.
[46] Hulme M, Dessai S. 2008. Negotiating future climates for public policy: a critical assessment of the development of climate scenarios for the UK. Environ. Sci. Policy 11:54–70.
[47] Thomas J. Galarneau Jr., Christopher A. Davis, and Melvyn A. Shapiro, 2013: Intensification of Hurricane Sandy (2012) through Extratropical Warm Core Seclusion. Mon. Wea. Rev., 141, 4296–4321.
[48] Rübbelke, D, and S. Vögele, (2011). Impacts of climate change on European critical infrastructures: The case of the power sector. Environmental Science and Policy, 14, 53–63
[49] J. F. Roberts, A. J. Champion, L. C. Dawkins, K. I. Hodges, L. C. Shaffrey, D. B. Stephenson, M. A. Stringer, H. E. Thornton, and B. D. Youngman, The XWS open access catalogue of extreme European windstorms from 1979–2012. Nat. Hazards Earth Syst. Sci. Discuss., 2, 2011-2048, 2014
[50] Hansen, J., et al. (2005). Efficacy of climate forcings. J Geophys Res 110:D18104. doi:10.1029/2005JD005776
[51] Andrews, T., et al. (2012). Cloud adjustment and its role in CO2 radiative forcing and climate sensitivity: A review. Surveys in Geophysics, 33, 619-635.
[52] Kinter, III, J. L., et al. (2013). Revolutionizing Climate Modeling with Project Athena: A Multi-Institutional, International Collaboration. Bull. Amer. Meteor. Soc., 94, 231–245.
[53] Rayner, N. A., et al. (2003). Global analyses of SST, sea ice and night marine air temperature since the late nineteenth century. J. Geophys. Res., 108.
[54] Koster, R. D., et al. (2011). The Second Phase of the Global Land–Atmosphere Coupling Experiment: Soil Moisture Contributions to Subseasonal Forecast Skill. J. Hydrometeor, 12, 805–822. doi: 10.1175/2011JHM1365.1
[55] Seneviratne, S.I., et al. (2006): Land-atmosphere coupling and climate change in Europe. Nature, 443, 205-209
[56] Zampieri, M, et al. (2009). Hot European Summers and the role of soil moisture in the propagation of Mediterranean drought. Journal of Climate, 22, 4747–4758, doi: 10.1175/2009JCLI2568.1.
[57] Quesada, B., et al. (2012). Asymmetric European summer heat predictability from wet and dry Southern winter/springs. Nature Climate Change, 2, 736-741.
[58] Zampieri M, Lionello P, (2011). Anthropic land use causes summer cooling in Central Europe. Clim Res 46:255-268.
[59] Lorenz R., et al. (2013). How Important is Vegetation Phenology for European Climate and Heat Waves? J. Climate, 26, 10077–10100
[60] Miralles D. G., et al. (2014). Mega-heatwave temperatures due to combined soil desiccation and atmospheric heat accumulation. Nature Geoscience, 7, 345–349
[61] Schubert, S. D., et al. (2014). Northern Eurasian Heat Waves and Droughts. J. Climate, 27, 3169–3207. doi:10.1175/JCLI-D-13-00360.1.
[62] Taylor, C. M., et al. (2012). Afternoon rain more likely over drier soils. Nature, 489, 423-426.
[63] Fox-Kemper, B., et al. (2008). Parameterization of mixed layer eddies. Part I: Theory and diagnosis. Journal of Physical Oceanography, 38(6):1145-1165.
[64] Hirschi, M., et al. (2007). Analysis of seasonal terrestrial water storage variations in regional climate simulations over Europe. J. Geophys. Res., 112, D22109, doi: 10.1029/2006JD008338
[65] Materia, S., et al. (2010). The Sensitivity of Simulated River Discharge to Land Surface Representation and Meteorological Forcings. J. Hydrometeor, 11, 334–351. doi: 10.1175/2009JHM1162.1

4. Members of the consortium

4.1. Participants (applicants)

Participant 1: Met Office (Met Office)

The Met Office is one of the leading centres for weather and climate research and has been heavily involved in all of the Intergovernmental Panel on Climate Change (IPCC) and associated Coupled Model Intercomparison Project (CMIP) climate model inter-comparison projects. There are over 500 people actively involved in all areas of weather and climate science, including observational research, weather/climate model development and assessment on all timescales from days to centuries, as well as climate impacts and consultancy for both governmental and industry partners. It is involved in a wide range of European Union projects under FP7. There is also significant expertise in the Information Technology and supercomputer areas, with over 40 staff directly involved.

The Met Office Hadley Centre (MOHC), based at the Met Office's Exeter HQ, provides world-class guidance on the science of climate change and is the primary focus in the UK for climate science. MOHC staff will be involved in many aspects of this proposal, with significant experience and expertise beyond the staff named here.

The Met Office will project manage the project. There is a team of experienced project managers, who hold formal project management qualifications. This team has much experience in managing projects involving multiple partners and users. The Met Office has co-ordinated projects such as the FP6 ENSEMBLES project, and is currently coordinating and managing ongoing FP7 collaboration projects such as EUPORIAS. The Met Office will call upon this wealth of experience when appointing a project manager for PRIMAVERA.

It will also provide the coordination and contribute to the scientific coordination of PRIMAVERA – Malcolm Roberts has significant previous experience in project and scientific coordination related to high resolution model development and assessment (see relevant projects below). The Met Office also has established links with numerous important projects and has strong, influential relationships, for example WGCM as a leading contributor to CMIP assessments, GEWEX and its strategy for a high resolution modelling and observational datasets.

The High Resolution Climate Modelling (HRCM) group, a joint Met Office-NCAS-Climate (University of Reading) group, will form the core team for producing the model integrations for both the core and frontiers parts of PRIMAVERA, as well as the data management aspects. This group ran the UPSCALE project (see below) and, together with the expertise in both organisations, are well qualified to ensure the successful implementation of the proposed integrations. Expertise in model assessment will be brought in from the relevant groups, for example from the Met Office Seasonal-to-Decadal group for understanding global teleconnections to European weather and climate, and the Ocean, Cryosphere and Dangerous Climate Change group for developing an innovative ocean freshwater metric.

Short profile of key personnel involved:

Dr Malcolm Roberts (Male) [PRIMAVERA Coordinator and Work Package 4 Leader] – Manager, High Resolution Climate Modelling, Met Office Hadley Centre, has 23 years experience working at the Met Office Hadley Centre on a wide variety of projects involving ocean, atmosphere and coupled high resolution global climate modelling (Co-managing UJCC, and Co-Investigator of UPSCALE, see relevant projects below), both on the technical and scientific aspects. He was a Panel Member of the CLIVAR WGOMD (Working Group on Ocean Model Development), 2000-2004, and is a current member of the US CLIVAR Hurricane Working Group. He manages the high resolution climate modelling group, which encompasses both model development and assessment, with key input into the Met Office model development strategy as part of the INTEGRATE (ImproviNg model error, TEleconnections, and predictability Globally and Regionally Across TimEscales) project. He is also the deputy leader of the proposed CMIP6 High Resolution Model Intercomparison Proejct (HighResMIP).

Catherine Senior (Female) – [Work Package 3 Leader] – Head of Understanding Climate Change at the Met Office Hadley Centre, has over 28 years experience in understanding climate change, climate feedbacks and model development. In her role at the Met Office she leads a team of scientists working to understand and improve model simulations of present day and future climate. The foci of the group include understanding the global water cycle and the role of high resolution modelling. She has a proven delivery record as Theme Leader for numerous projects, recently including; Themes on Climate model development and understanding climate processes (Met Office Hadley Centre Climate Programme MOHCCP funded by UK Government Departments DECC and Defra) including pioneering work to investigate the role of high resolution in both global and regional modelling; The Africa Climate Science Research Partnership (CSRP funded by UK Government Department DFID) including resolution sensitivity of African rainfall. She has published over 40 peer-reviewed articles (h-index 22) including articles in Nature and

Science, and has been lead author of on the 3rd Assessement report of the IPCC and involved as a contributing author on all other IPCC reports. She is Co-chair of WCRP Working Group on Coupled Models (WGCM) and plays a key role in Met Office-UK Academic partnerships including chairing the High Resolution Implementation Group which provides strategic guidance and an International perspective to the HRCM.

Dr Matthew Mizielinski (Male) [Work Package 9 Leader] – Senior Scientist, High Resolution Climate Modelling, Met Office Hadley Centre, has five years experience of running, managing and analysing high resolution coupled and uncoupled HadGEM3 climate models. As the technical lead of the UPSCALE project Matthew managed the porting and running of simulations on the HERMIT supercomputer at HLRS, Germany, and the transfer of the 400TB data set to the JASMIN super-data-cluster in the UK. In addition he has several years of experience of working with JASMIN, managing data sets, supporting other scientists in their analysis and exploring the potential of the facilities available using open source data analysis tools. Matthew has also worked on the porting to, and running of, HadGEM3 on a variety of HPC facilities around the world.

Dr Erika Palin (Female) [Work Package 11 Co-leader] – Applied Science Manager: Surface Transport & Utilities. Erika has worked in the climate consultancy team at the Met Office since 2008. Her role involves working closely with government and commercial customers in order to further their understanding of potential climate change impacts on their operations and infrastructure. She has developed strong engagement with the transport and utilities sectors, and now manages a team of scientists applying the Met Office's world-class science to addressing customer needs in these sectors. She currently leads the Met Office science input to the "Tomorrow's Railway and Climate Change Adaptation" (TRaCCA) consortium project (led by Arup), for the UK Rail Safety and Standards Board (RSSB); has contributed to a European Environment Agency report on adaptation in the transport sector; and leads a task in FP7 EUPORIAS which will produce a seasonal forecast prototype for use by UK transport stakeholders.

Relevant publications, and/or products, services, achievements:

L. Shaffrey, I. Stevens, W. A. Norton, M. J. Roberts, P.-L. Vidale, J. Harle, A. Jrrar, D. Stevens, M. Woodage, M.-E. Demory, J. Donners, D. Clarke, A. Clayton, J. Cole, S. Wilson, W. Connolley, T. Davies, A. Iwi, T. C. Johns, J. King, A. New, J. Slingo, A. Slingo, L. Steenman-Clark, G. M. Martin, 2009: UK-HiGEM: the new UK high resolution global environment model. Model description and basic evaluation. J. Climate, 22 1861-1896. http://dx.doi.org/10.1175/2008JCLI2508.1

Mizielinski, M. S., M. J. Roberts, P. L. Vidale, R. Schiemann, M.-E. Demory, J. Strachan, T. Edwards, A. Stephens, B. N. Lawrence, M. Pritchard, P. Chiu, A. Iwi, J. Churchill, C. Del Cano Novales, J. Kettleborough, W. Roseblade, P. Selwood, M. Foster, M. Glover, and A. Malcolm, 2014: High resolution global climate modelling; the UPSCALE project, a large simulation campaign. Geosci. Model Dev., 7, 1629-1640, doi:10.5194/gmd-7-1629-2014

Roberts, J. F., Champion, A. J., Dawkins, L. C., Hodges, K. I., Shaffrey, L. C., Stephenson, D. B., Stringer, M. A., Thornton, H. E., and Youngman, B. D.: The XWS open access catalogue of extreme European windstorms from 1979–2012, Nat. Hazards Earth Syst. Sci. Discuss., 2, 2011-2048, doi:10.5194/nhessd-2-2011-2014, 2014

Kendon, E. J., N. M. Roberts, M. J. Roberts, S. Chan, H. J. Fowler, C. A. Senior: Heavier summer downpours with climate change revealed by weather forecast resolution model. Nature Climate Change, doi:10.1038/nclimate2258, 2014

Roberts, M. J., P. L. Vidale, M. Mizielinski, M.-E. Demory, R. Schiemann, J. Strachan, K. Hodges, J. Camp, R. Bell: Tropical cyclones in the UPSCALE ensemble of high resolution global climate models. J. Clim special issue on Hurricanes

Relevant previous projects or activities:

UK-Japan Climate Collaboration (UJCC) 2004-7 (Co-manager Malcolm Roberts): Collaboration with the Earth Simulator Centre in Japan to develop and apply the HiGEM (UK high resolution global environmental model) model for climate research, to understand the impact of model resolution on climate simulation. There have been more than 30 peer-reviewed papers published based on this project so far.

UPSCALE project 2012-present (Co-Investigator Malcolm Roberts, Technical Lead Matthew Mizielinski) – UK on PRACE: weather-resolving Simulations of Climate for globAL Environmental risk. This proposal was granted the largest award of HPC resource for a single project under the Partnership for Advanced Computing in Europe (PRACE) framework, to run ensembles of 25km resolution global atmosphere integrations, each of 27 years in length, for present and future climate, along with lower resolution ensembles. These are being analysed to further quantify the impact of model resolution on weather and climate simulation. The outputs

from this project are currently supporting more than 25 projects and have contributed to 10 submitted or published papers to date.

The Met Office is an active member of WP9 of the **IS-ENES2** project, the second phase project of the distributed e-infrastructure of models, model data and metadata of the European Network for Earth System Modelling (ENES). This involves many European modelling groups and aims to develop both the scientific and technical aspects of Earth System Models.

The Met Office has contributed to each of the IPCC-related **CMIP projects**, which involves strong coordination between many aspects of climate science (IT systems, model development, delivery of model integrations and their assessment), which are all important aspects of this proposal.

An example of Met Office engagement with industrial partners is its leading role in the development of the **Extreme Wind Storms catalogue** (http://www.europeanwindstorms.org/) for the recent past climate based on observations, reanalyses and modelling. This is the first freely available digitised catalogue of European windstorms, and as such is a valuable resource for both academia and the (re)insurance industry.

Any significant infrastructure and/or any major items of technical equipment:

High performance supercomputer IBM Power 7 (with a planned upgrade 2015-2017 producing around 10 times the capacity compared to present) – this will be used to complete a subset of the core integrations (UK integrations are split between Met Office and NCAS-University of Reading). It will also be used for some of the frontiers/next generation integrations.

The Met Office MASS data archive – IBM HPSS (High Performance Storage System) to provide hierarchical storage management of IBM disk and tape hardware and services for very large storage requirements, together with interfaces for easy data extraction.

Fast link to Centre for Environmental Data Archival (CEDA) JASMIN platform for data retrieval and analysis – JASMIN will be our central analysis platform, there is a link with speed in excess of 20MB/s direct from the Met Office MASS archive, and it hosts multi-petabyte disk arrays and both fast processors and a high performance cluster for dedicated parallel post-processing.

Participant 2: University of Reading (UREAD)

The department of Meteorology at the University of Reading (UREAD) is world-renowned for its pioneering research on weather, climate and earth observation (75% of its research graded as world leading or internationally excellent, it is the third department in the country in "Earth Systems & Environmental Science", and highest-graded department on fundamental science of weather and climate since 2008). This is reflected in the long-standing presence of staff from the UK Met Office, and the presence of the Natural Environment Research Council (NERC) funded National Centre for Atmospheric Science (NCAS) and the National Centre for Earth Observation (NCEO). The department also works closely with the European Centre for Medium-Range Weather Forecasts (ECMWF), which is located close to the University. The Department strongly contributed to the IPCC Fifth Assessment Report (AR5): in total 33 scientists were involved as review editors, lead authors, contributing authors, or expert reviewers.

UREAD is, with the Met Office, one of the two main coordinating organisations of PRIMAVERA. It is involved in the management of the project (WP7), and leads the scientific coordination of the project (WP8), for which it has much experience, as described by the key personnel and projects sections below. UREADs main scientific tasks are to develop process-based metrics for model evaluation of the atmosphere and land surface components (WP1); to evaluate the added value of increasing resolution in climate models (WP2); to quantify the need for improvement in the complexity of models parametrisation regarding the interactions between clouds, aerosols and radiation, and interactions between the land surface and the atmosphere (WP3); to improve the understanding of key drivers of the European climate variability (WP5); to assess the representation of the physics of extreme events over Europe relevant to stakeholders (WP10). There are several teams from UREAD whose expertise are particularly relevant to the project: 1) the global HRCM team, who have 10 years experience in the development of high-resolution models, metrics and process-based model evaluation regarding the role of resolution in atmospheric and land-surface processes: energy and water cycles, mean and extreme precipitation, tropical and extra-tropical cyclones, blocking events, heat waves and droughts; 2) the climate variability and change group who specialise in decadal climate variability and predictability, the role of the Atlantic Ocean in the global climate system, and climate sensitivity to radiative forcing; 3) the climate processes group on aerosols-atmosphere interactions who aim to identify and quantify the uncertainties in radiative forcing and climate change due to changes in aerosols. Each of these teams is composed of research scientists, post-docs and PhD students based at UREAD.

UREAD also hosts the Walker Institute for Climate System Research, which brings together the expertise that exists within UREAD and works closely with business, governments and research organisations across the world to enhance understanding of the risks and opportunities from the changing climate. The strong links between the department of Meteorology, NCAS-Climate and the Walker Institute will be particularly important for the UREADs involvement in the user engagement, dissemination and communication of the project (WP8 and WP11).

Short profile of key personnel involved:

Professor Pier Luigi Vidale (male) [PRIMAVERA Scientific Coordinator] is the Willis Chair of Climate System Science and Climate Hazards, Director of the Weather and Climate Hazards Laboratory at UREAD Department of Meteorology, and Senior Scientist at NCAS in Reading. He has over 18 years international experience in the development of weather and climate models, focused on high-resolution and land surface modelling. Prof. Vidale has led, in partnership with Dr. M. Roberts (Met Office), four global high-resolution climate modelling programmes in the UK, Europe and Japan: UK-HiGEM, UJCC, Partnership for Advanced Computing in Europe (PRACE)-UPSCALE, and Joint Weather and Climate Research Programme (JWCRP) in Global High-Resolution Modelling. He currently leads a large consortium project, PAGODA, within NERC's Changing Water Cycle programme, and is a co-I in the EU's IS-ENES2 project. Before joining UREAD, he was co-I in two European regional climate programmes (MERCURE and PRUDENCE) from which he has published highly-cited papers on changes in the variability of European summers. Prof. Vidale is currently a member of the Gung-Ho Exec, monitoring the development of the next-generation dynamical core for UK Earth System Models.

Professor Rowan Sutton (male) [Work Package 4 Co-leader] is Director of Climate Research for NCAS. He has over 20 years experience in climate research, focused especially on the use of global climate models as tools for understanding the climate system. His specific research interests address understanding natural climate variability and anthropogenic climate change, with an emphasis on the role of the oceans and the Atlantic/European region. He was a Lead Author of Chapter 11 ("Near term climate change: projections and predictability") of the Working Group 1 Contribution to IPCC AR5. Prof. Sutton has won more than 20 research grants and contracts. Two of them include FP7 EUCLEIA (European Climate and weather Events: Interpretation and Attribution project) and FP7 SPECS (Seasonal-to-Decadal Climate Prediction) that are particularly relevant to PRIMAVERA with their focus on drivers of European climate variability (WP5).

Dr Nicolas Bellouin (male) joined UREAD in 2012 as a Lecturer in Climate Processes, specialising in the role of aerosols in the climate system. He has published 45 peer-reviewed papers, which have attracted 2000 citations. He is a Contributing Author of the IPCC AR5 WG1 (Chapter 7 "Clouds and Aerosols"). Dr Bellouin was highly involved in the development of the Met Office Hadley Centre Earth System Model (HadGEM2-ES). He was involved in two major European projects under FP7 on atmospheric composition (MACC-II) and air quality climate impact (ECLIPSE) and is the Reading PI of a large UK project on clouds and aerosol radiation impacts and forcing (CLARIFY-2016). His knowledge of aerosol forcing mechanisms and of aerosol schemes in global climate models is particularly relevant to this proposal.

Dr David Brayshaw (male) [Work Package 10 Co-leader] is the Willis Lecturer in Weather and Climate Hazards at UREAD Department of Meteorology and Research Scientist at NCAS. He has expertise in large-scale atmospheric dynamics and its impacts on human and environmental systems (including flooding, power systems, telecommunications and insurance). Dr Brayshaw leads the interdisciplinary energy-meteorology research group at UREAD. His work has included several industry-partnered research projects on weather and climate risk management, and he has provided bespoke consultancy and training services to the commercial sector. Dr Brayshaw contributed to a major 2013 report by the International Energy Agency ("Redrawing the Energy Climate Map"), and currently serves on the scientific committee for the International Conference on Energy Meteorology (2013, 2015).

Relevant publications, and/or products, services, achievements:

Roberts, M. J., P. L. Vidale, M. Mizielinski, M.-E. Demory, R. Schiemann, J. Strachan, K. Hodges, J. Camp, R. Bell: Tropical cyclones in the UPSCALE ensemble of high resolution global climate models. J. Clim special issue on Hurricanes

Demory, M.-E., P. L. Vidale, M. J. Roberts, P. Berrisford, J. Strachan, R. Schiemann, M. S. Mizielinski, 2014: The role of horizontal resolution in simulating drivers of the global hydrological cycle. Clim. Dyn., 42, 2201-2225, doi: 10.1007/s00382-013-1924-4.

Ely, C. R., D. J. Brayshaw, J. Methven, J. Cox and O. Pearce, 2013: Implications of the North Atlantic Oscillation for a UK–Norway renewable power system. Energy Policy, 62. pp. 1420-1427, doi: 10.1016/j.enpol.2013.06.037.

Sutton, R. and B. Dong, 2012: Atlantic Ocean influence on a shift in European climate in the 1990s. Nature Geoscience, 5, 788-792, doi: 10.1038/ngeo1595.

Bellouin, N., J. Rae, A. Jones, C. Johnson, J. Haywood, and O. Boucher, 2011: Aerosol forcing in the Climate Model Intercomparison Project (CMIP5) simulations by HadGEM2-ES and the role of ammonium nitrate. J. Geophys. Res., 116, D20206, doi:10.1029/2011JD016074.

Relevant previous projects or activities:

a) **UPSCALE** led by UREAD in 2012, is a one year project that aimed to increase the fidelity of global climate simulations and our understanding of weather and climate risk, by representing fundamental weather and climate processes, their variability and teleconnections, more completely. UPSCALE was allocated 144 million core-hours on a TIER-0 supercomputer located at HLRS in Germany. This was, at the time, the largest allocation ever made to one team worldwide. UPSCALE has a major impact worldwide on the climate and climate risk communities (more than 30 collaborations so far). The simulation data will be used during the first stage of PRIMAVERA.

b) The **JWCRP** is an on-going major collaborative project between the UK Met Office and NERC that aimed to ensure that the UK maintains and strengthens its leading international position in climate science, and hence in weather and climate forecasting and provision of advice for climate policy. Among specific JWCRP research topics are high-resolution modelling, Indian monsoon, seasonal and decadal prediction, aerosol and cloud processes.

c) The "**Joint Weather and Climate" High-Resolution Climate Modelling (HRCM) programme**, co-led by UREAD and the Met Office, is a 10-year programme that has its foundations in the UK-Japan Climate Collaboration (UJCC) and the UK High-Resolution Global Environmental Modelling project (HiGEM). HiGEM (2003-2007) brought together expertise from NERC, the UK academic community and the UK Met Office to develop a coupled climate model with increased horizontal resolution. UJCC (2004-2008) exploited the power of the Earth Simulator in Japan to produce world-leading climate simulations. This expertise was used to develop the next generation of the UK high-resolution global climate model, which will be used for IPCC-AR6 and will be the basis of further development in PRIMAVERA and HighResMIP.

d) **HadGEM2** family of climate models (2005-2009) represent the Met Office climate prediction models, in the **development** of which UREAD was majorly involved. HadGEM2 represents the second generation of the Hadley Centre Global Environment Model configuration. HadGEM2 includes a coupled atmosphere-ocean configuration, with or without a vertical extension in the atmosphere to include a well-resolved stratosphere, and an Earth-System configuration (HadGEM2-ES), which includes dynamic vegetation, ocean biology and atmospheric chemistry. HadGEM2 and HadGEM2-ES were used in the IPCC-AR5, and were the basis for the development of the third configuration HadGEM3 on which the Met Office seasonal forecasting system (GloSea5) is based.

e) The **European Climate and weather Events: Interpretation and Attribution** (**EUCLEIA**) project is a 3-year (2014-2016) European project focussing on understanding the drivers, including aerosol forcings, of weather and climate events in Europe. The UREAD's role is to understand how attribution studies can be affected by the representation of oceans in the climate models by performing experiments with atmosphere-only and coupled atmosphere-ocean mixed-layer climate models, to develop indices to determine the role of sea surface temperatures, sea ice and aerosol in extreme events, and to assess the role of sea surface temperatures and sea ice in specific extreme events. The expertise and outputs developed within this project will be particularly relevant to PRIMAVERA.

Any significant infrastructure and/or any major items of technical equipment:

UREADs Department of Meteorology hosts the High Performance Computing and Numerical Modelling group of the NCAS Computational Modelling Services (CMS) that provides information services and support for modelling in the UK Academic Atmospheric Science community. The expertise of that group will be highly used in PRIMAVERA.

For model development and core and sensitivity experiments, UREAD will make use of the national supercomputer ARCHER (~1PFlop) and the JWCRP Met Office - NERC joint supercomputer MONSooN, both of which will be significantly upgraded in 2015. In 2014, the HRCM team has been awarded 62 million core hours on ARCHER by NERC, and equivalent amounts are expected for the duration of the project. The team will also bid for resources through the European PRACE call, as they did in 2012.

For data analyses and storage, UREAD has worked with the UK Centre for Environmental Data Archival (CEDA, previously BADC) for ten years. They host a super-data-cluster (JASMIN) for petascale storage and cloud computing for big data in environmental science.

Participant 3: Koninklijk Nederlands Meteorologisch Instituut (KNMI)

KNMI is the Dutch national data and knowledge institute for climate science. As an agency of the Ministry of Infrastructure and the Environment, KNMI advises the Dutch government on climate change. Being a scientific institute, KNMI contributes to international climate research and represents the Netherlands on the Intergovernmental Panel on Climate Change (IPCC). KNMI is constantly optimizing the measuring network and refining climate models, which run on the KNMI super-computer. Calculations carried out using these models form the basis of the KNMI climate scenarios for the Netherlands, which provide an applied product to policy advisors and other professionals, to help them make appropriate decisions for a safe and sustainable Netherlands in a changing climate. The KNMI modelling group consists of about 50 researchers. It is involved in many FP7 EU projects (SPECS, EUPORIAS, IS-ENES, EMBRACE, PREFACE, and EUCLEIA). KNMI plays an active role in the EC-Earth consortium. In PRIMAVERA, KNMI will lead WP6 which coordinates the core runs, and WP10 which will assess the climate risks. KNMI is well suited to cover the chain from high resolution modelling to climate risks assessments and the dissemination to end-users and other target audiences.

Short profile of key personnel involved:

Dr. Reindert Haarsma (male) – [Work Package 6 Leader] is a member of the modelling division of the KNMI. He has a background in large scale atmospheric dynamics and profound experience in coupled atmosphere-ocean modelling. He has worked on the development of coupled climate models and is now involved in the EC-EARTH project. He was PI in the EU FP7 project COMBINE. A recent research focus is the extra-tropical transition of tropical cyclones; the possible changes in these under a future warmer climate and the ensuing consequences for western Europe. He is leader of the CMIP6 HighResMIP.

Prof. Dr. B.J.J.M. Van der Hurk (male) –is a permanent staff member at KNMI. He is heavily involved in the KNMI global modelling project EC-Earth, and is co-author of the land surface modules of the European Centre for Medium Range Weather Forecasts (ECMWF). He occupies the chair "Climate Interactions with the Socio-Ecological System" at the Institute for Environmental Studies at Amsterdam Vrije Universiteit. He is editor for Hydrology and Earth System Science (HESS). In summer 2014 he was appointed Head of the Weather and Climate model Research Division at KNMI.

Dr. G. Verver (male) - [Work Package 10 Leader] is a senior researcher in the Climate Services department of KNMI. He is manager of the EUMETNET Climate Programme, in which 27 European Meteorological Services collaborate to better serve the European user community with climate products and services for the benefit of environment, safety, economy and health. He is also involved in the FP7 projects EURO4M, CHARMe and EUPORIAS. He is a key member of the project team developing the European Climate Assessment & Dataset (ECA&D) that provides information on changes in European weather and climate extremes, as well as the daily data needed to monitor and analyse these extremes.

Dr. Andreas Sterl (male) is a member of the modelling division of the KNMI. He has worked on different aspects of climate, ocean and wave modelling. He was member of the ERA-40 steering team. He is now active in the development of EC-Earth. He is the leader of the Dutch ARGO Project, which is part of the International ARGO project and he is a member of the Argo steering team. He is a member of the WCRP working group of surface fluxes. He is topic editor of Ocean Science.

Dr. Jannette Bessembinder (female) is a member of the Climate Services division of KNMI. Since 2005 she has worked at KNMI as a project member and leader, specialising in the tailoring of climate data for a large variety of sectors (e.g. water management, agriculture, energy, and infrastructure) and target audiences, ranging from researchers to policy makers. She is involved in the inventory of users' requirements and much of the communication and guidance around the KNMI climate scenarios to professional users (the KNMI'06 ad KNMI'14 scenarios). Besides this, she is also active in JPI-Climate (module 2 on Climate Services).

Dr. Michiel van Weele (male) is an experienced researcher whose interests centre around 'chemistry-climate interactions', with a focus on the ozone layer, air pollution, and the parameters that determine the oxidising (or 'cleansing') capacity of the atmosphere. Returning activities are: (1) Contributions to the long-term monitoring of the global distributions of atmospheric trace gases and aerosols and surface UV radiation by means of satellite observations. (2) The interpretation of observations with global chemistry transport models.

Relevant publications, and/or products, services, achievements:

Haarsma, R.J., W. Hazeleger, C. Severijns, H. de Vries, A. Sterl, R. Bintanja, G.J. van Oldenborgh and H.W. van den Brink, *More hurricanes to hit Western Europe due to global warming.* Geophys. Res. Lett., 2013, doi:10.1002/grl.50360

Hurk, B.J.J.M. van den, G.J. van Oldenborgh, G. Lenderink, W. Hazeleger, R. Haarsma and H. de Vries, *Drivers of mean climate change around the Netherlands derived from CMIP5.* Clim. Dyn., 2014, 42, 1683-1697, doi:10.1007/s00382-013-1707-y

Berkhout, F., B. Vd Hurk, J. Bessembinder, J. De Boer, B. Bregman and M. Van Drunen: Framing climate uncertainty, socio-economic and climate scenario's in vulnerability and adaptation assessments. Reg. Eviron. Change, doi: 10.1007/s10113-013-0519-2. 2013

Schrier, G. van der, E.J.M. van den Besselaar, A.M.G. Klein Tank en G. Verver, Monitoring European averaged temperature based on the E-OBS gridded dataset J. Geophys. Res., 2013, 118, doi:10.1002/jgrd.50444.

Mel, R., A. Sterl en P. Lionello, High resolution climate projection of storm surge at the Venetian coast, Natural Hazards and Earth System Sciences, 2013, 13, 1135-1142, doi:10.5194/nhess-13-1135-2013.

Relevant previous projects or activities:

COMBINE (www.combine-project.eu) is an FP7 project that ended in 2013. It brought together research groups to advance Earth system models (ESMs) in order to provide more accurate climate projections and reduce uncertainty in the prediction of climate and climate change in the next decades. COMBINE contributed to better assessments of changes in the physical climate system and of their impacts in the societal and economic system, and strengthened the scientific base for environmental policies of the EU for the climate negotiations, and provided input to the IPCC/AR5 process. **Dr. Haarsma** was PI of the WP that coordinated the simulations of the partners for the decadal predictions.

SPECS is an FP7 funded EU-project that aims to deliver a new generation of European climate forecast systems, with improved forecast quality and efficient regionalisation tools, in order to produce reliable, local climate information over land at seasonal-to-decadal time scales. The improved understanding and seamless predictions will offer better estimates of the future frequency of high-impact, extreme climatic events and of the prediction uncertainty. New services to convey climate information and its quality will be used. KNMI lead the work package that focuses on sources of skill in seasonal to decadal forecasts and KNMI will assess the role of the initial state and the radiative forcing from the greenhouse gases and aerosols on the skill.

EUPORIAS (www.euporias.eu) is an FP7-funded project whose vision is to improve the ability to maximise the societal benefit of recent developments in future environmental predictions, specifically focussing on seasonal to decadal timescales. Working closely with over 70 European stakeholders, this project is developing fully working prototypes of climate services addressing the need of specific users and stakeholders. EUPORIAS aims to increase the resilience of the European Society to climate change by demonstrating how climate information can become directly usable by decision makers in different sectors. KNMI specifically work on the seasonal to decadal predictions of user-oriented climate indices. KNMI also lead the development of an interface that will allow for the effective delivery of the climate scenarios developed within EUPORIAS to the end users, who range from the general public through to relevant decision makers.

EMBRACE is an FP7 funded EU-project. EMBRACE brings together the leading Earth System Models (ESMs) in Europe around a common set of objectives to improve our ability to (i) simulate the Earth System and (ii) make reliable projections of future global change. The project has a number of key goals; (i) to reduce the main, known biases in existing European ESMs, (ii) to fully evaluate ESM simulation capabilities and improvements made in the project, (iii) to increase the realism of, and interactions between, the physical and biogeochemical components of ESMs, (iv) to assess the risks of abrupt or irreversible changes in key components of the Earth system, in response to the most recent greenhouse gas, aerosol and land-use scenarios proposed for the IPCC AR5.

KNMI performs dedicated runs with the ESM EC-Earth. Also, KNMI contribute with analyses and improvement of the parameterized moist convection though the use of the Single Column Version of EC-Earth; analysing and

improving biases in mixing in the Southern Ocean, by coupling the ocean to a wave model and investigating the role of sub-mesoscale eddy parameterizations; and then assessing all the associated improvements.
IS-ENES2 is the second phase project of the distributed e-infrastructure of the European Network for Earth System Modelling (ENES). IS-ENES2 combines expertise in Earth system modelling, in computational science, and in studies of climate change impacts. IS-ENES2 will provide a service on models and model results both to modelling groups and to the users of model results, especially the impact community. Joint research activities will improve the efficient use of high-performance computers, model evaluation tool sets, access to model results, and prototype climate services for the impact community. Networking activities will increase the cohesion of the European ESM community and advance a coherent European Network for Earth System modelling.

Relevant significant infrastructure and/or any major items of technical equipment:

High performance super computer BullX B500 that will be used for the core integrations. Successful high resolution runs of EC-Earth have already been performed with it.

Participant 4: Sveriges Meteorologiska Och Hydrologiska Institut (SMHI)

SMHI is a government agency under the Swedish Ministry of Environment. SMHI offers products and services that provide organisations with important environmental information to support decision making. The main areas of expertise include weather and climate forecasts/projections, industry-specific services, simulations and analyses. SMHI has a strong Research and Development focus, with climate research involving all six research sections, including the Rossby Centre that is responsible for the development and application of regional and global climate models. SMHI will host the International Project Office for CORDEX, decided in June 2014 by a selection board established by the WCRP Joint Planning Staff (JPS), in close consultation with the CORDEX Science Advisory Team (SAT). The Rossby Centre is a leading partner in the development of EC-Earth. Currently, the Rossby Centre is involved in nine FP7-EU-projects.

In PRIMAVERA, SMHI will lead WP2 where the benefits of increased resolution in global coupled climate models for processes affecting European climate and its variability will be assessed. SMHI will contribute to WP1 with the development of process based metrics for ocean, atmosphere and cryosphere. In WP3, SMHI will work on interactive aerosol-radiation-cloud coupling and improve the sea ice component. SMHI will contribute to WP5, using its considerable expertise in high latitude climate processes to identify the main drivers for European climate variability and change. SMHI will also contribute to the core atmosphere and coupled climate simulations in WP6. In WP10, SMHI will use its outstanding knowledge in high weather impact events and regional climate modelling in the CORDEX context.

Short profile of key personnel involved:

Dr Torben Koenigk (male) – [Work Package 2 leader] – Senior Research Scientist at Rossby Centre/ SMHI. He has 13 years experience of global and regional coupled climate modelling. His major research focuses on Arctic climate variability and future change, sea ice-ocean-atmosphere interactions and exchanges between mid and high latitudes. He is leading the Arctic climate modelling activities at Rossby Centre. He is strongly involved in the development of the EC-Earth model and is chairing the EC-Earth working group on ocean and sea ice modelling. He has contributed to a number of EU-projects (DAMOCLES, COMBINE, EMBRACE and SPECS).

Dr Klaus Wyser (male) – Senior Research Scientist at the Rossby Centre. He has much experience of global climate modelling and works with the development of EC-Earth. He specialises in the parameterization of clouds and radiation. He led the CMIP5 working group within the EC-Earth consortium and leads a work package in the EU project EMBRACE developing diagnostics and metrics.

Dr Ralf Döscher (male) – Scientific Leader at the Rossby Centre. He has more than 20 years experience in climate modelling. He is the chair of the international EC-Earth consortium. He has been involved in many national and international projects, and was a joint co-cordinator and a WP-leader for the EU-project DAMOCLES.

Dr Mihaela Caian (female) – Research Scientist at the Rossby Centre. She has experience in global and regional climate modelling and works presently on decadal climate prediction. She is involved in both the SPECS project and the EMBRACE project.

Dr Grigory Nikulin (male) - Research scientist at the Rossby Centre. His main research area is analysis of both global and regional climate models. Involved in analysis of climate information in many European and international projects (IMPACT2C, HEALTHY FUTURES, EUPORIAS, SPECS, SIDA-ESCWA, and CORDEX) his current focus is on providing climate information for impact studies. He is WP leader on 'calibration and downscaling' in the FP7 project EUPORIAS and a member of WRCP CORDEX Science Advisory Team.

Ulrika Willén (female) – Research Scientist at the Rossby Centre. She works on regional and global climate modelling with a focus on the parameterization and evaluation of clouds and radiation. She has been involved in many EU-projects, evaluating climate models using ground based and satellite obsverations. She is on the review board for the CM-SAF project and is involved in the ESA-CCI initiative.

Relevant publications, and/or products, services, achievements:

Koenigk, T, U. Mikolajewicz, J. Jungclaus, A. Kroll, 2009: Sea ice in the Barents Sea: seasonal to interannual variability and climate feedbacks in a global coupled model. Clim Dyn 32: 1119-1138, doi:10.1007/s00382-008-0450-2

Nikulin, G., Kjellström, E., Hansson, U., Jones, C., Strandberg, G. and Ullerstig, A., 2011: Evaluation and Future Projections of Temperature, Precipitation and Wind Extremes over Europe in an Ensemble of Regional Climate Simulations. Tellus, 63A(1), 41-55. DOI: 10.1111/j.1600-0870.2010.00466.x

Koenigk, T., L. Brodeau, R. Grand Graversen, J. Karlsson, G. Svensson, M. Tjernström, U. Willén and K. Wyser, 2013**:** Arctic Climate Change in the 21st Century in an Ensemble of AR5 Scenario Projections with EC-Earth. Clim Dyn 40:2719-2743, doi:10.1007/s00382-012-1505-y.

Döscher, R. and T. Koenigk, 2013: Arctic Rapid Sea Ice Loss Events in Regional coupled Climate Scenario Experiments. Ocean Science, os-2012-65.

Koenigk, T., A. Devasthale, K.-G. Karlsson, 2014: Summer Sea Ice Albedo in the Arctic in CMIP5 Models. Atmos Chem Phys 14, 1987-1998, www.atmos-chem-phys.net/14/1987/2014/, doi:10.5194/acp-14-1987-2014.

Relevant previous projects or activities:

EMBRACE (www.embrace-project.eu) is an FP7 funded EU-project coordinated by SMHI. EMBRACE brings together the leading Earth System Models (ESMs) in Europe around a common set of objectives to improve our ability to (i) simulate the Earth System and (ii) make reliable projections of future global change. SMHI is co-leading WP4 (Evaluation of combined improvements in coupled Earth System Models) and contributes to WP1 (Improving atmospheric moist convections and tropical climate), WP2 (Ocean and cryospheric processes) and WP5 (Abrupt and irreversible changes). Amongst several tasks, SMHI is exploring the effect of different atmospheric resolutions on synoptic variability.

The EU FP7 collaborative project **SPECS** aims at the improvement of seasonal to decadal (s2d) predictions. SMHI focuses mainly on the benefits of increased horizontal and vertical resolution for decadal predictions and leads WP41 "Impact of increased horizontal resolution". In addition, SMHI contributes to WP21 "Forecast quality of s2d systems", WP22 "Sources of skill", WP31 "Impact of improved initialization and sample size", WP32 "Improvements in ensemble generation", WP42 "Impact of improved climate-vegetation representation and BML vertical resolution", WP43 "Stratosphere and changing radiative forcing", WP61 "Pilot applications" and WP62 "Forecast visualization and outreach."

EU FP7 project **HELIX** investigates the impacts of higher-end warming scenarios and extremes. SMHI leads WP3 "High resolution specific warming timeslices and regional downscaling" and also collaborates with project partners in WP1 "Stakeholder engagement and outreach", WP7 "Regional focus: Europe", WP8 "Regional focus: sub-Saharan Africa", WP9 "Regional focus: South Asia" and WP10 "Risk management of tipping points".

IS-ENES2 is the second phase project of the distributed e-infrastructure of models, model data and metadata of the European Network for Earth System Modelling (ENES). SMHI co-leads WP9 (Multi-model, multi-member high resolution Earth System Models) and contributes to WP5 (Data Networking), WP6 (Innovating on climate modelling) and WP11 (developing software infrastructure for data archive services).

The "**HighResClim: High Resolution Ensemble Climate Modelling**" project is funded in repsonse to the 7th PRACE Project Access Call. The main objective is to further the ENES preparations for efficient use of PRACE Tier-0 and other large-scale HPC systems. SMHI contributes by providing and supporting the EC-Earth Earth System Model at the MareNostrum HPC system (BSC, Barcelona, Spain) as well as by running and monitoring a share of the high-resolution climate model experiments

Relevant significant infrastructure and/or any major items of technical equipment:

SMHI is a leading partner in the EC-Earth consortium and is deeply involved in the development of the components of the EC-Earth model and in the codes, scripting and infrastructure. SMHI closely cooperates with NSC, the National Supercomputing Centre in Linköping, and the PDC Center for High Performance Computing at the KTH Royal

Institute of Technology in Stockholm. SMHI also has resources at the European Centre for Medium-Range Weather Forecasts (ECMWF, United Kingdom). Furthermore, SMHI has its own ESGF data node at NSC.

Participant 5: Centre Europeen de Recherche et de Formation Avancee en Calcul Scientifique (CERFACS)

CERFACS (http://www.cerfacs.fr), established in 1987 in Toulouse (France), is currently one of the world's leading research institutes working on efficient algorithms for solving large-scale scientific problems. The CERFACS Climate Modelling and Global Change (GLOBC) team (about 20 researchers and engineers) conducts fundamental scientific research and leads high-level technical developments in the field of climate studies. In particular, the team develops the OASIS coupler which is currently used by more than 35 climate-modelling groups in Europe and around the world. Significant resources are devoted to develop and offer user support for this community software.

CERFACS activities in high performance computing encompass assembling high-resolution coupled climate based on state-of-art component models, porting and optimising them on a variety of platforms, including PRACE tier-0 machines such as those of TGCC and BSC. CERFACS is also getting involved in building new approaches to deal with large data volumes produced in climate science together with large data centres in Europe. This is through its participation in EU-FP7 projects such as EUDAT, CLIPC and IS-ENES2.

CERFACS undertakes research activities aimed at better understanding world climate variability, predictability and change at regional to global spatial scales and seasonal-to-decadal time scales. CERFACS researchers have made pioneering contributions to a better understanding and description of European climate variability and change with a specific focus on the ocean influence at various time scales. CERFACS in partnership with CNRM/Météo-France ,develops the CNRM-CM suite of global coupled models such as CNRM-CM5 that was used for the CMIP5 exercise.

CERFACS/GLOBC is currently involved in 6 FP7 projects (SPECS, EUDAT, IS-ENES2, PREFACE, CLIPC and ERACLIM), many nationally-funded projects (MORDICUS, OCCIPUT and CONVERGENCE) and two computing projects granted by PRACE (HighResClim and SPRUCE), focusing on high-resolution climate predictions at decadal and seasonal time scales.

CERFACS will lead WP5 where it will exploit its expertise in climate variability studies over Europe, in particular related to the influence of low frequency modes such as the Atlantic and Pacific multidecadal Variability (AMV/PDV) and detection/attribution of climate change signals relative to internal variability. CERFACS will contribute to WP1, developing new process-based metrics tailored for a robust assessment of climate model structural uncertainty. CERFACS will contribute to WP4 where it will be producing and analysing ground-breaking high-resolution climate simulations within the framework of the HighResClim and subsequent PRACE-funded projects. CERFACS will also contribute to WP6 and to the HighResMIP WCRP initiative.

Short profile of key personnel involved:

Dr. Laurent Terray (male) – [Work Package 5 Leader] is a worldwide expert in the study of climate variability and change, and is the head of the GLOBC Climate group. He was involved in the initial development of the OASIS coupler since its inception. He is an IPCC contributor and reviewer (Fourth and Fifth Assessment Report), served in numerous national and WCRP scientific panels, has participated in a large number of FP4 to FP7 projects, and is author of more than 70 peer-reviewed papers. He is shaping CERFACS's plans for the development of a Mediterranean climate service and contributes to the International Climate Services Partnership.

Dr Sophie Valcke (female) holds a "highly qualified" research engineer position at CERFACS. Dr Valcke is currently leading a team of four engineers working on developing the OASIS coupler further. Through the user support provided for the OASIS coupler, Dr Valcke has established working relationships with many climate-modelling groups in Europe. Dr Valcke is CERFACS Principal Investigator for the current IS-ENES2 project and was CERFACS PI in the METAFOR project. These projects also favor Dr Valcke's interaction with other groups developing coupling framework internationally, such as the USA-led ESMF project, the USA NCAR Community Earth System Model 1 (CESM1), and Earth System Grid (ESG).

Eric Maisonnave (male) started working as a research engineer at CERFACS in 1999. Involved in several EU projects like DEMETER, PREDICATE, ENSEMBLES and DYNAMITE, he has enabled the configuration and use of several OASIS-based coupled models. He is involved in the European project IS-ENES2 where he works on Earth System Model assembling and where he is providing support on OASIS coupling to several European laboratories. He has a broad range of experience in code porting and optimization on both vector (like Earth Simulator) and scalar machines (like massively parallel IBM Blue Gene and Bull machines). He is also very active in code performance analysis and model improvement. Currently his main interests are code coupling, optimization for massively parallel platforms, set up and technical validation of high-resolution climate models.

Relevant publications, and/or products, services, achievements:

Boé J. and Terray L., 2013: Land-sea-contrast, soil-atmosphere interactions and cloud-temperature interactions : interplays and roles in future summer European climate change. Climate Dynamics, 42, 683-699. doi10.1007/s00382-013-1868-8

Valcke S., 2013: The OASIS3 coupler: a European climate modelling community software, Geosci. Model Dev., 6, 373-388, doi:10.5194/gmd-6-373-20-13. http://www.geosci-model-dev.net/6/373/2013/gmd-6-373-

Terray L, 2012: Evidence for multiple drivers of North Atlantic multi-decadal climate variability. Geophys. Res. Lett, 39, L197-12, doi:10.1029/2012 GL053046.

Boé J., L. Terray, C. Cassou and J. Najac, 2009: Uncertainties in European summer precipitation changes: role of large scale circulation. Clim. Dyn., 33, 265-276, doi10.1007/s00382-008-0474-7.

Cassou, C., 2008: Intraseasonal interaction between the Madden-Julian Oscillation and the North Atlantic Oscillation. Nature, 455, doi:10.1038/nature07286, 523-527.

Relevant previous projects or activities:

Within the EU FP7 **SPECS**, CERFACS will perform cutting-edge high-resolution dynamical decadal forecast experiments using a high resolution version of the ARPEGE-OASIS-NEMO coupled GCM and sets of sensitivity experiments to estimate the advantages of improving the model representation of air-sea interaction including air-sea fluxes and accounting of the diurnal cycle in the coupling. The improved understanding and seamless predictions will offer better estimates of the future frequency of high-impact, extreme climatic events and of the prediction uncertainty.

IS-ENES2 https://verc.enes.org is the second phase project of the distributed e-infrastructure of the European Network for Earth System Modelling (ENES). IS-ENES2 combines expertise in Earth system modelling, in computational science, and in studies of climate change impacts. IS-ENES2 will provide services based on models and model results both to modelling groups and to the users of model results, especially the impact community. Joint research activities will improve the efficient use of high-performance computers, model evaluation tool sets, access to model results, and prototype climate services for the impact community. Networking activities will increase the cohesion of the European ESM community and advance a coherent European Network for Earth System modelling.

CLIPC http://www.ceda.ac.uk/projects/clipc/ will provide access to climate information of direct relevance to a wide variety of users, from scientists to policy makers and private sector decision makers. Information will include data from satellite and in-situ observations, climate models and re-analyses, transformed data products to enable impacts assessments and climate change impact indicators. The platform will complement existing GMES/Copernicus pre-operational components, but will focus on datasets which provide information on climate variability on decadal to centennial time scales from observed and projected climate change impacts in Europe, and will provide a toolbox to generate, compare and rank key indicators.

EUDAT http://www.eudat.eu/ is a three-year project that will deliver a Collaborative Data Infrastructure (CDI) with the capacity and capability for meeting future researchers' needs in a sustainable way. Its design will reflect a comprehensive picture of the data service requirements of the research communities in Europe and beyond. This will become increasingly important over the next decade as we face the challenges of massive expansion in the volume of data being generated and preserved (the so-called 'data tsunami') and in the complexity of that data and the systems required to provide access to it.

PREFACE http://preface.b.uib.no/ is a bold and ambitious project that targets one of the regions that will be more affected by climate change and its consequences. The project will provide the first comprehensive assessment of the Tropical Atlantic climate, from observations to predicting its socio-economic impacts. This is expected to lead to a number of high impact results for this region such as improved climate modelling and prediction capabilities, better understanding of the function of marine ecosystem so that socio-economic impacts can be better predicted and enhanced cooperation between European and African researchers working on Tropical Atlantic climate and its impacts.

Any significant infrastructure and/or any major items of technical equipment:

CERFACS develops the OASIS coupler https://verc.enes.org/models/software-tools/oasis that allows climate models to be coupled on a wide range of platforms in a uniform and highly parallel way. CERFACS has its own computing platform based on Bull, HP and IBM clusters delivering 80 TeraFlops/s.

Participant 6: Max Planck Gesellschaft zur Foerderung der Wissenschaften E.V. (MPG)

The Max Planck Institute for Meteorology (MPG) is an institute funded by the Max Planck Society. MPG is one of the leading institutions developing Earth System Models (ESM). The institute made major contributions to the simulation and analysis of a human influence on climate, including contributions to the fifth phase (and previous phases) of the Coupled Model Intercomparison Project (CMIP5). Particular attention is given to near-term predictions and research on the limits of predictability. MPG is presently involved in two FP7 projects (NACLIM and SPECS), three nationally funded projects (BMBF-MiKlip, BMBF-HDCP2, and BMBF-RACE) focusing on near-term prediction and high-resolution, process-oriented modelling.

In PRIMAVERA, MPG will co-lead WP4 and WP6 building on experience in setting-up, conducting, and evaluating complex model systems at high resolution, as well as the distribution of data. MPG contributes to WP1 providing knowledge in metrics describing processes in the ocean and atmosphere. In WP2, MPG will assess the added-value of high resolution core simulations. MPG will contribute to WP3 providing expertise in the parameterisations of mixing processes in the ocean and the assessment of their relevance in simulations of the North Atlantic/European climate. In WP5, MPG will contribute its outstanding expertise in climate variability and predictability on annual to decadal time-scales and the identification of drivers and teleconnections.

Short profile of key personnel involved:

Dr. Jin-Song von Storch (female) - [Work Package 4 Co-leader] is a senior scientist and research group leader at MPG. She is author and co-author of more than 50 peer-reviewed publications. She led, in cooperation with CliSAP cluster of excellence of University Hamburg, the German consortium project STORM which provided high-resolution climate change simulations. Her recent experience in STORM, in particular regarding eddy-resolving ocean modeling and analysis of high-resolution simulations, will be extremely valuable for PRIMAVERA. She has contributed to the EU project THOR and acts as principle investigator within the BMBF-founded program MiKlip.

Dr. Johann Jungclaus (male) - [Work Package 6 Co-leader] is a senior scientist and research group leader at MPG. He is author and co-author of more than 80 peer-reviewed publications and has served on WCRP scientific panels and steering groups. He played a key role in the development of the MPI-ESM and has long standing expertise in North Atlantic/Arctic Ocean studies and in modelling oceanic processes. He has contributed to several EU projects. In the FP7 project NACLIM, he coordinates Core Theme 1 **"**Predictability of key oceanic and atmospheric quantities related to the North Atlantic/Arctic ocean surface state". He is principle investigator of projects dealing with near-term predictions within the BMBF-funded programs MiKlip and RACE.

Dr. Jürgen Kröger (male) is a climate scientist (with a strong background in physical oceanography) and with more than 12 years experience working with several different coupled climate models. In the field of near term climate prediction and predictability, his focus lies in ensemble and initialisation strategies. He has contributed to the FP7-EU projects THOR and COMBINE and is currently involved in the German BMBF-project MiKlip.

Dr. Katja Lohmann (female) is a climate scientist (with a strong background in physical oceanography) and with almost 10 years of experience working with several different coupled climate models. Her focus lies in studying the climate variability and change in the North Atlantic/European sector. She has contributed to the EU projects DYNAMITE (FP6) and THOR (FP7) and is currently contributing to the EU FP7 project NACLIM.

Dr. Daniela Matei (female) is a climate scientist (with a strong background in atmospheric physics and climate dynamics) with over 10 years of experience in climate variability and predictability, and a focus on the North Atlantic/European and the tropical Pacific sectors. She played a key role in the MPG CMIP5 decadal prediction experiments and has contributed to the EU projects DYNAMITE and THOR. Currently she is contributing to the EU FP7 projects NACLIM and APPOSIT, and the BMBF-funded RACE program.

Relevant publications, and/or products, services, achievements:

Exarchou, E., J.-S. von Storch, and J.H. Jungclaus, 2013: Sensitivity of transient climate change to tidal mixing: Southern Ocean heat uptake in climate change experiments performed with ECHAM5/MPIOM. Climate Dynamics, published online, doi: 10.1007/s00382-013-1776-y

Kröger, J., W. Müller and J.-S. von Storch, 2012: Impact of Different Ocean Reanalyses on Decadal Climate Prediction. Climate Dynamics, doi: 10.1007/s00382-012-1310-7

Li, H. and J.-S. von Storch, 2013: On the Fluctuations of Buoyancy Fluxes Simulated in a 1/10o OGCM. J. Phys. Oceanogr., 43, 1270-1287

Matei, D., J. Baehr, J.H. Jungclaus, H. Haak, W.A. Müller, and J. Marotzke, 2012: Multiyear prediction of monthly-mean Atlantic Meridional Overturning Circulation at 26.5°N. Science, 355, 76-79, doi:10.1126/science.1210299

Von Storch, J.-S., C. Eden, I. Fast, H. Haak, D. Hernandez-Deckers, E. Maier-Reimer, J. Marotzke, D. Stammer, 2012: An estimate of the Lorenz energy cycle for the world ocean based on the 1/10° STORM/NCEP simulation. J. Phys. Oceanogr. 42, 2185-2205

Relevant previous projects or activities:

NACLIM (www.naclim.eu) is a project funded by the EC under FP7, aiming to quantify the predictability of the climate in the North Atlantic/European sector related to North Atlantic/Arctic Ocean surface state variability. MPG leads the Core Theme 1 "Predictability of key oceanic and atmospheric quantities", which includes coordinated model analysis requiring common metrics. NACLIM builds on the multi-model decadal prediction experiments as part of the CMIP Phase 5 (CMIP5) in combination with observations of key oceanic quantities in the North Atlantic.

THOR (www.eu-thor.eu) was an FP7 project with the aim of establishing an operational system that monitors and forecasts the development of the North Atlantic THC on decadal time scales, and assesses its stability, and the risk of a breakdown in a changing climate. MPG has led Core Theme 1 "Quantifying and modeling THC variability using palaeoclimate observations and simulations" and coordinated simulations and collaborative analyses. MPG was involved in all sensitivity studies in Core Theme 4 "Predictability of the THC".

COMBINE was an FP7 project (2009-2013) coordinated by MPG that brought together research groups to advance Earth system models (ESMs) by including key physical and biogeochemical processes. Coordinating COMBINE required substantial effort in planning the simulations, data-exchange and archiving. Like PRIMAVERA, COMBINE was based on two streams of simulations, the second incorporating model improvements and new components. The project led to considerable improvements in climate models developed in Europe and strengthened their position in the international context.

MIKLIP is a program funded by the German Federal Ministry of Education and Research (BMBF) and is coordinated by MPG. MPG develops the central systems for quasi-operational decadal predictions and further contributes to the development of initialization schemes for decadal predictions.

RACE is a BMBF-funded programme that includes six major marine research institutions in Germany, where MPG leads two sub-projects. The main goal of RACE is to create regional high-resolution simulations of future Atlantic circulation changes as a part of global change.

One of the MPG-led sub-projects aims at decadal predictions using an ocean model at eddy-resolving resolution. MPG provides a high-resolution regional coupled climate model and has developed a dynamical downscaling approach coupling the global model to regional simulations.

MPG has participated in each of the IPCC-related CMIP projects continuously improving on model capabilities, data management and work flow together with the climate computing center. MPG scientists serve at WCRP and other international planning boards coordinating the next round of model intercomparison projects.

Any significant infrastructure and/or any major items of technical equipment:

MPG provides the MPI-ESM and is the developer of its component models for atmosphere, ocean, sea-ice, land-surface and ocean biogeochemistry. MPG provides the codes, scripting infrastructure and educational activities (e.g. summer schools on earth system modelling). MPG closely cooperates with DKRZ, the German Climate Computing Center in Hamburg. MPG is the largest shareholder of DKRZ and both institutions share many projects on code optimization and infrastructure-adaptation. MPG has substantial computing resources at DKRZ. In summer 2015, DKRZ will install a new BULL computing system that will deliver six times the application performance compared to its predecessor (IBM-Power6). In 2016, when the new computing system will finally be completed with more than 60,000 processor cores on the basis of B700 DLC Blades distributed over 60 Racks, it will achieve a peak performance of about 3 petaflops.

Participant 7: Université catholique de Louvain (UCL)

The research conducted at UCL-TECLIM (Georges Lemaître Centre for Earth and Climate Research; around 80 staff members) aims at understanding the functioning of the Earth system, with focus on its climate component, and the interactions between human activities and their natural environment. The current research activities concern (1) past environmental and climate changes, (2) the current state of the Earth and solar systems, (3) human-environment interactions and (4) modelling tools. The positive reputation of UCL-TECLIM in the area of global climate modelling

is well established. The sea ice model (LIM) it has built is considered to be essential within the community of climate and ocean modellers, and is used in many countries. A large number of original process studies were performed with this model coupled to various oceanic general circulation models. These studies have notably highlighted the key role played by sea ice–ocean interactions in controlling the World Ocean's circulation. Members of UCL-TECLIM have also developed a hierarchy of ESMs, one of them (LOVECLIM) being utilized worldwide. The group has carried out seminal studies focusing on the last glacial-interglacial cycles, the abrupt climate change that occurred 8,200 years ago, climate variability and changes during the Holocene (including the last millennium), inter-annual climate variability over the last decades and future climate changes.

With a wealth of experience in sea ice modelling behind it, UCL-TECLIM will actively contribute to WP1, WP2, WP3 and WP5 of PRIMAVERA by (1) developing and using sea ice process-based metrics for model evaluation, (2) assessing the impact of an enhanced model resolution on the simulation of Arctic and North Atlantic sea ice and ocean processes, and on their links with the European climate, (3) determining how more comprehensive representations of Arctic sea ice processes in models contribute to improve the simulation of the Arctic and European climates, and (4) thoroughly investigating the influence of Arctic sea ice variability and change on the European climate.

Short profile of key personnel involved:

Two postdoctoral researchers with expertise in global climate modelling and sea ice modelling will be recruited to carry out the work for PRIMAVERA. Staff listed below will also provide expertise and guidance to the project.

Dr. Thierry Fichefet (male) is a Full Professor at UCL. He has 30 years experience in global climate modelling, with a focus on climate-cryosphere interactions. He was principal investigator for around 30 research projects funded by UCL, the Belgian National Fund for Scientific Research, the French Community of Belgium, the Belgian Science Policy Office, several French agencies and the European Commission. He is author or co-author of around 180 scientific papers, most of them published in international peer-reviewed journals or books. He is frequently invited to give talks and chair sessions at international scientific meetings, and to give popular conferences on climate change in schools and societies. He is also deeply involved in national and international research programmes and organizations. In particular, he was member of the Scientific Steering Group of the Climate and Cryosphere (CliC) programme of the World Climate Research Programme (WCRP) up to 2008. He was Lead Author of the Fourth and Fifth Assessment Reports of Working Group 1 (WG1) of the IPCC.

Dr. Hugues Goosse (male) is Senior Research Associate with the Belgian National Fund for Scientific Research, Part-time Professor at UCL and Invited Professor at the Universiteit Gent. He has around 20 years experience in global climate modelling and his research interests are presently focused on decadal-to-centennial climate variability in mid- and high latitudes, and on the evolution of climate over the last millennia. He is Theme Leader of the WCRP Polar Climate Predictability Initiative and member of the Steering Committee of the PAGES (Past Global Changes) programme. He is author or co-author of more than 125 papers published in international refereed journals and was Contributing Author of the IPCC WG1 Fourth and Fifth Assessment Reports.

Dr. François Massonnet (male) is Postdoctoral Research Fellow with the Belgian National Fund for Scientific Research. He has 5 years experience in climate model evaluation and data assimilation in climate models, with focus on high latitudes. He is author or co-author of 9 scientific papers, all of them published in international peer-reviewed journals. He was heavily involved in the FP7 project COMBINE and was a Contributing Author to the IPCC WG1 Fifth Assessment Report. His current research deals with the linkages between high and mid-latitude climates, and the impact of sea ice on seasonal-to-decadal climate predictability.

Relevant publications, and/or products, services, achievements:

Arzel, O., T. Fichefet, and H. Goosse, 2006: Sea ice evolution over the 20th and 21st centuries as simulated by current AOGCMs. Ocean Modell., 12, 401-415

Lecomte, O., T. Fichefet, M. Vancoppenolle, F. Domine, F. Massonnet, P. Mathiot, S. Morin, and P.-Y. Barriat, 2013 : On the formulation of snow thermal conductivity in large-scale sea ice models. J. Adv. Mod. Earth Syst., 5, 542-557, doi : 10.1002/jame.20039

Massonnet, F., T. Fichefet, H. Goosse, M. Vancoppenolle, P. Mathiot, and C. König Beatty, 2011: On the influence of model physics on simulations of Arctic and Antarctic sea ice. The Cryosphere, 5, 687-699, doi: 10.5194/tc-5-687-2011

Massonnet, F., T. Fichefet, H. Goosse, C. Bitz, G. Philippon-Berthier, M. Holland, and P.-Y. Barriat, 2012: Constraining projections of summer Arctic sea ice. The Cryosphere, 6, 1383-1394, doi: 10.5194/tc-6-1383-2012

Vancoppenolle, M., T. Fichefet, H. Goosse, S. Bouillon, G. Madec, and M.A. Morales Maqueda, 2009: Simulating the mass balance and salinity of Arctic and Antarctic sea ice: I. Model description and validation. Ocean Modell., 27, 33-53

Relevant previous projects or activities:

ENSEMBLES (www.ensembles-eu.org) was an EU FP6 project (2004-2009). Its overall objective was to maintain and extend European pre-eminence in the provision of policy relevant information on climate and climate change and its interactions with society. This was achieved by (1) developing an ensemble prediction system based on the principal European state-of-the-art, high-resolution, global and regional ESMs to produce, for the first time, an objective probabilistic estimate of uncertainty in future climate at the seasonal-to-decadal and longer timescales, (2) quantifying and reducing the uncertainty in the representation of physical, chemical, biological and human-related feedbacks in the Earth system, and (3) maximising the exploitation of the results by linking the outputs of the ensemble prediction system to a range of applications, including agriculture, health, food security, energy, water resources, insurance and weather risk management. UCL-TECLIM participated to WP2A.3 (Creation of multi-model change scenarios for the 21st century that exploit the probabilistic nature of the multi-model ensemble system) by (1) contributing to the climate change scenarios that were performed with the Institut Pierre Simon Laplace ESM and (2) by making a thorough comparison of the sea ice changes simulated by the ENSEMBLES ESMs over polar regions. It was also deeply involved in WP4.1 (Feedbacks and surprises). In particular, it explored the effects of non-linear feedbacks related to sea ice in some of the ENSEMBLES ESM runs.

EU FP7 project **COMBINE** brought together research groups to advance ESMs for more accurate climate projections and for reduced uncertainty in the prediction of climate and climate change in the next decades. UCL-TECLIM was responsible for several important tasks and was an active member of WP4 (Cryosphere), WP5 (Initialization), WP6 (Climate prediction) and WP7 (Climate projections and feedbacks). More specifically, it significantly improved LIM3 by implementing a multi-layer snow scheme, a representation of newly-formed ice and a comprehensive melt pond formulation. It also carried out a hindcast simulation of Arctic and Antarctic sea ice over the last decades that included sea ice data assimilation. Outputs were subsequently used by SMHI to initialize climate predictions at the decadal time scale with EC-Earth and the impact of this new initialization was assessed. In addition, UCL-TECLIM was in charge of assessing feedbacks of new sea ice processes in control runs and 1% CO_2 simulations conducted with the Institut Pierre Simon Laplace ESM.

PAST4FUTURE (www.past4future.eu) is an EU FP7 project (2010-2014) that uses paleo-environmental data and simulations of past climates to advance our understanding of the Earth system, with the ultimate objective to improve our ability to project potential future changes. It focusses on the present and last interglacial periods in order to address four key questions: what is the risk of abrupt changes during interglacial periods, can we understand the greenhouse gas records of the interglacial periods, what is the risk of rapid collapse of the ice sheets, and did ocean circulation change significantly during the interglacial periods? UCL-TECLIM co-leads WP1.3 (Integrating climate models and paleoclimate data) and WP4.2 (Sea ice and its links to climate changes). Its main tasks are (1) to develop a data assimilation technique adapted to paleoclimate studies, (2) to apply this technique to study the last millennium and key periods of past interglacials, and (3) to reconstruct past sea ice changes in order to better understand the causes of those variations.

EMBRACE is an EU FP7 project (2011-2015). UCL-TECLIM actively contributes to WP2 (Ocean and cryosphere processes in ESMs) by implementing an elasto-brittle rheology for sea ice in NEMO-LIM3 and by assessing the performance of this rheology at high resolution.

ASICM (Antarctic Sea Ice in Climate Models) is a single-partner research project funded by the Belgian National fund for scientific research (2014-2018). Its goal is to improve the representation of Antarctic sea ice in climate models by gaining a better understanding of the processes governing its mean state and variability. This is done by (1) investigating a number of diagnostics from current climate models in order to determine which processes are mainly responsible for the model biases and the wide range of model behaviours with respect to Antarctic sea ice, (2) systematically determining the impact of modifications to these processes in the sea ice–ocean model NEMO-LIM3 to improve the Antarctic sea ice representation in this model, and (3) assessing the influence of the combination of these model improvements on the simulation by a particular climate model (EC-Earth) of the mean state and variability of the Antarctic sea ice cover as well as on the model response to perturbations.

Any significant infrastructure and/or any major items of technical equipment:

CISM (Centre de Calcul et de Stockage de Masse; www.uclouvain.be/cism) is a high-performance computing facility integrated inside the UCL structure. It offers researchers access to high-computing power and mass storage. The whole infrastructure consists of four clusters containing up to 3860 CPU core, corresponding to a total peak performance of 39.7 Tflops, and 261 TB of secure mass storage. CISM is also member of CECI (Consortium des Equipements de Calcul Intensif; www.ceci-hpc.be) sharing computing infrastructures of five universities in the French Community of Belgium and providing together up to 7600 CPU core.

Participant 8: BSC

The Barcelona Supercomputing Center - Centro Nacional de Supercomputación (BSC), created in 2005, has the mission to research, develop and manage information technology in order to facilitate scientific progress. At the BSC, more than 350 people from 40 different countries perform and facilitate research into Computer Sciences, Life Sciences, Earth Sciences and Computational Applications in Science and Engineering. The BSC is one of the four hosting members of the European PRACE Research Infrastructure as well as one of the first eight Spanish "Severo Ochoa Centre of Excellence" awarded by the Spanish Government. The Earth Sciences Department of the BSC (ES-BSC) was established with the objective of carrying out research in Earth system modelling. The ES-BSC conducts research on emissions, air quality, mineral dust and global and regional climate modelling and prediction.

It also undertakes research on the development of dynamical and statistical methods for the prediction of global and regional climate on time scales ranging from a few weeks to several years, with a special focus on technologies that allow high-resolution modelling. The formulation of the predictions includes the development and implementation of techniques to statistically downscale, calibrate and combine dynamical ensemble and empirical forecasts to satisfy specific user needs in the framework of the development of a climate service.

Making progress in dynamical global climate modelling with a focus on monthly-to-decadal climate prediction is one of the main objectives of the ES-BSC, for which it uses EC-Earth and develops initialization methods that lead to improvements in different aspects of the forecast quality. The assessment of the sources of predictability and the limitations of current climate prediction systems to exploit them, especially over Europe, inspires many of the publications by the unit.

The department operates the high-resolution air quality forecasting system CALIOPE for Europe and Spain; it also maintains the BSC-DREAM8b model for daily operational mineral dust forecasts for the Euro-Mediterranean region, collaborates with the WMO and the Spanish Meteorological Agency (AEMET) to host the Regional Centre for Sand and Dust Warning System (SDS-WAS) covering Europe, Northern Africa and the Middle East and is an active member of the EC-Earth consortium, whose global climate model is widely used at ES-BSC for research and teaching purposes.

Over the years, the department has been active in numerous European Projects including, including MEDSPA-91, INCO, EUREKA, EARLINET, DEISA, EC-EARTH, EARLINET-ASOS, ACTRIC, IS-ENES and FIELD_AC ,DENFREE (2011), IS-ENES 2 (2013), PREFACE (2013), EUCLEIA (2014) and EUPORIAS (2012). and two computing projects granted by PRACE (HighResClim and SPAITAC) focusing on high-resolution climate predictions. The Earth Science department is the coordinator of the European project SPECS (2012). We also participate and receive grants from the Spanish Government for various R&D projects: RUCSS, PICA-ICE, RESILIENCE.

The ES-BSC has coordinated the renewable energy case study in CLIMRUN, and has started the Climate Service Alliance for the Renewable Energy Sector, as part of the Climate Services Partnership.

In PRIMAVERA, ES-BSC will lead WP11, which will manage and facilitate the engagement with end-users who will shape and make use of the outcomes of PRIMAVERA. This relies on the strong experience of the climate service group within ES-BSC, who have undertaken much successful work like this in previous projects. This group was created in 2011 during one of the first EU climate service projects, CLIM-RUN, to provide a link between climate scientists and end users in the energy sector, and to develop, tailor and exploit emerging climate research in line with their specific needs.

BSC also lead WP1 where it will exploit its expertise in developing new process-based metrics tailored for a robust assessment of climate forecast skill, and will extend this expertise to control simulations and projections. BSC will co-lead WP2 and contribute to WP4 where it will utilise its past experience in producing and analysing ground-breaking high-resolution climate forecasts within the framework of the HighResClim and SPAITAC PRACE-funded projects. ES-BSC will contribute to the sea ice model development and assessment within WP3 and to the analysis of its role on the European climate within WP5. The variability and predictability of the Arctic sea ice cover is a core area of expertise of ES-BSC, with the PICA-ICE project being fully dedicated to this topic. BSC will also contribute

to WP5 bringing its past experience on investigating the Atlantic Multidecadal Variability and the Interdecadal Pacific Variability.

Short profile of key personnel involved:

Prof. Francisco Doblas-Reyes (male)- [Work Package 1 Leader] is a world renowned expert in the development of seasonal-to-decadal climate prediction systems and is the head of the CFU. He is involved in the development of the EC-Earth ESM, and has been since its inception. He is an IPCC lead author (Fifth Assessment Report), serves in WCRP and WWRP scientific panels, has participated in a number of FP4 to FP7 projects, is coordinator of the FP7 collaborative SPECS project, and is author of more than 90 peer-reviewed papers. He is shaping BSC's plans for the development of a Mediterranean climate services and contributes to the International Climate Services Partnership.

Ms Melanie Davis (female) – [Work Package 11 Leader] leads the climate services group within the Climate Forecasting Unit at BSC. She has eleven years' experience in renewable energy business and policy, and more recently in climate research. Her core role has been the translation of technical science to end-users and decision makers. This diverse background enables her to bridge the gap between different communities to develop actionable services from end-user driven research. Melanie has contributed to the development of the first European-funded climate services projects, where she leads various work packages. She is also coordinating a national climate and energy project, funded by the Spanish Ministerio de Economía y Competitividad. She is actively collaborating with climate research institutions and private companies worldwide, and is a member of the International and European Climate Services Partnership (CSP) and European Energy Research Association (EERA).

Dr Virginie Guemas (female) - [Work Package 2 Co-leader] is lead researcher for the Arctic climate activities within CFU. She is PI of the nationally-funded PICA-ICE project. She is author of 26 published peer-reviewed articles, including 15 where she is first author, and one published in Nature Climate Change. She was awarded the 'Prix Adrien Gaussail' from the Académie des Sciences de Toulouse in 2010, for her PhD 'Role of the marine surface in the summer intraseasonal variability in the North-Atlantic/Europe region'.

Relevant publications, and/or products, services, achievements:

- Guemas, V., E. Blanchard-Wrigglesworth, M. Chevallier, J.J. Day, M. Déqué, F.J. Doblas-Reyes, N. Fučkar, A. Germe, E. Hawkins, S. Keeley, T. Koenigk, D. Salas y Mélia and S. Tietsche (2014). A review on Arctic sea ice predictability and prediction on seasonal-to-decadal timescales. Quarterly Journal of the Royal Meteorological Society, doi:10.1002/qj.240
- Guemas, V., J. García-Serrano, A. Mariotti, F.J. Doblas-Reyes and L.-P. Caron (2014). Prospects for decadal climate prediction in the Mediterranean region. Quarterly Journal of the Royal Meteorological Society, doi:10.1002/qj.2379
- Guemas, V., F.J. Doblas-Reyes, I. Andreu-Burillo and M. Asif (2013). Retrospective prediction of the global warming slowdown in the past decade. Nature Climate Change, 3, 649-653, doi:10.1038/nclimate1863.
- Doblas-Reyes, F.J., I. Andreu-Burillo, Y. Chikamoto, J. García-Serrano, V. Guemas, M. Kimoto, T. Mochizuki, L.R.L. Rodrigues and G.J. van Oldenborgh (2013). Initialized near-term regional climate change prediction. Nature Communications, 4, 1715, doi:10.1038/ncomms2704

Relevant previous projects or activities:

SPECS (http://www.specs-fp7.eu/) is a project funded by the European commission under FP7 and is coordinated by **Prof. Francisco Doblas-Reyes**. SPECS aims to deliver a new generation of European climate forecast systems, with improved forecast quality and efficient regionalisation tools; therefore producing reliable, local climate information over land at seasonal-to-decadal time scales. The improved understanding and seamless predictions will offer better estimates of the future frequency of high-impact, extreme climatic events and of the prediction uncertainty. New services to convey climate information and its quality will be used.

EU FP7 project **EUPORIAS** aims to develop end-to-end climate impact prediction services, operating on seasonal to decadal timescales, and demonstrating their value in informing decision making. Working closely with several European stakeholders, including those from the energy sector, EUPORIAS is developing prototype climate services, thus the project will have many social and economic benefits for regional and national authorities and businesses. Melanie Davis leads the energy sector user engagement activities, which are linked to the Resilience project referenced below.

PICA-ICE (http://www.ic3.cat/detail_project.php?menu=180&project=18) is a nationally-funded project coordinated by **Dr Virginie Guemas**. This project aims to produce reconstructions of the Arctic sea ice cover over the past 50 years, investigate the mechanisms explaining its variability and predictability and its impact on the European climate.

RESILIENCE (http://www.euporias.eu/prototype/resilience-energy) is a nationally-funded project coordinated by **Melanie Davis.** This project aims to secure the provision of energy to society. The rapidly evolving energy system is in an increasingly vulnerable position due to the growth of highly variable wind power contributing to the total energy supply, and unusual temperatures affecting demand. Temperature and wind speed as a function of energy demand and supply are the focus.

HighResClim is a PRACE project which aims to produce high-resolution climate simulations to deliver a significant improvement in our ability to simulate key modes of climate and weather variability and, thereby provide reliable estimates of future changes in this variability. The project involves representatives of BSC, SMHI, KNMI and CERFACS.

Any significant infrastructure and/or any major items of technical equipment:

The BSC hosts MareNostrum III, a Tier-0 PRACE system with 1.1 Pflop/s capacity as well as other High-Performance Computing (HPC) resources, which will be used by ESRs during their training in climate modelling to conduct their experiments. The BSC also coordinates the Spanish Supercomputing Network, which is the main instrument to grant competitive computing time to Spanish research institutions. The BSC is located within a university campus, and has special agreements to use the university residence and other university facilities (libraries, EDUROAM network, etc).

ES-BSC develops the powerful Autosubmit tool, which allows them to configure, submit and run climate simulations on a wide range of platforms in a uniform and highly automated way. This tool has made IC3 a leader in the development of user-friendly tools and a very flexible partner in the efficient use of any kind of computational resources.

The ES-BSC has substantial in-kind computing resources obtained from their own cluster, the European Centre for Medium-Range Weather Forecasts (ECMWF, United Kingdom) and Parallell dator centrum (PDC, Sweden). These resources relate to a total value of approximately €0.5M/yr.

Participant 9: Centro Euro-Mediterraneo sui Cambiamenti Climatici S.c.a.r.l (CMCC)

The Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC) is a non-profit research institution (www.cmcc.it). CMCC's mission is to investigate and model our climate system and its interactions with society to provide reliable, rigorous, and timely scientific results, which will in turn stimulate sustainable growth, protect the environment, and develop science driven adaptation and mitigation policies in a changing climate. CMCC collaborates with experienced scientists, economists, and technicians, who work together in order to provide full analyses of climate impacts on various systems such as agriculture, ecosystems, coasts, water resources, health, and economics. CMCC also supports policymakers in setting and assessing costs, mitigation, and adaptation policies.

CMCC benefits from the extensive applied research experience of its consortium members: Istituto Nazionale di Geofisica e Vulcanologia (INGV); Università del Salento; Centro Italiano di Ricerche Aerospaziali (CIRA S.c.p.a.); Università Ca' Foscari Venezia; Fondazione Eni Enrico Mattei (FEEM), Università di Sassari, Università della Tuscia, Università degli Studi del Sannio. CMCC research activities are distributed among six research divisions that share different knowledge and skills in the field of climate science: The Numerical Applications and Scenarios (ANS) Division; The Climate Impacts and Policies. An Economic Assessment (CIP) Division; The Impacts on Agriculture, Forest, and Natural Ecosystems (IAFENT); The Impacts on Soil and Coast (ISC) Division; The Scientific Computing and Operations (SCO) Division; The Climate Services Division (SERC).

CMCC's portfolio of research projects includes 125 funded projects: two funded projects in FP6, 35 funded projects in FP7 and 88 funded projects under other EU and international research grants (tot. of ca. 43 M €). For about half of these implemented projects, CMCC has acted as the coordinator.

Since 2011, CMCC has been a member of the NEMO Consortium and, through the consortium's Systems Team and Steering and Development Committees, collaborates to set the strategic direction of the NEMO framework.

CMCC will contribute to several WPs in PRIMAVERA, with co-leading roles in WP1 and WP3. In WP1, expertise on several aspects of climate dynamics, including land-atmosphere coupling, Atlantic blocking, mid-latitude

variability and extreme events, will be exploited to develop a set of process-based metrics which will contribute to set up a robust evaluation tool for PRIMAVERA core integration. Within WP2, CMCC will contribute to assessing the effect of resolution on global models performance, leveraging their in-house expertise on sea-ice processes and polar oceanography, blocking, tropical cyclones and their connection with the high-latitudes. CMCC will also contribute to WP3, testing the impact of improved physics parameterization relevant for the land-atmosphere coupling and Arctic sea-ice processes.

Short profile of key personnel involved:

Silvio Gualdi (male) is Senior Scientist at the Istituto Nazionale di Geofisica e Vulcanologia (INGV) and at CMCC, where he leads the "Climate Service" Division (SERC). He holds a degree in Physics from the University of Modena (Italy), a PhD in Geophysics from the University of Hamburg (Germany) and has more than 10 years experience in climate modelling and simulations. During this period, he has contributed to the development of a several climate models (e.g. SINTEX, CMCC-Med) and has performed a number of climate scenario simulations and projections (CMIP3, CMIP5). During the past 12 years, he has been partner in several international projects, such as the EU-Project SINTEX, DEMETER (INGV principal investigator), ENSEMBLES (INGV principal investigator and WP leader), CIRCE (WP leader) and COMBINE (WP leader). He is a Member of the International Scientific Steering Committee of HyMex (Hydrological Cycle in the Mediterranean Experiment), and a member of the MedCLIVAR Programme. Along with other colleagues, in 2006 he received the Norbert Gerbier-MUMM International Award. Since February 2008 he has convened the AW4 Session ("Large scale air-sea interaction processes and their influence on the Euro-Mediterranean climate) at the Annual Meeting of the European Meteorological Society (EMS).Since 2007, he has lectured on "Climate Dynamics" for the "Science and Management of the Climate Change" Doctorate Programme at the Cà Foscari University of Venice. Furthermore, he has been co-tutor to several PhD and Degree students at the University of Bologna. He is an author of more than 30 peer-reviewed publications.

Alessio Bellucci (male) - [Work Package 1 Co-leader] holds a PhD in physical oceanography from the University of Southampton/NOCS and is a climate modeller. His major field of expertise is climate variability and predictability at decadal and interdecadal timescales. He is currently coordinating the activities of the Climate Variability and Prediction group at CMCC, working on seasonal-to-decadal predictions. He has been involved in the 5th Coupled Model Intercomparison Project (CMIP5) as the CMCC reference person for decadal prediction experiments. He has been involved in several EU-funded FP projects, including ENACT, ENSEMBLES, CIRCE, COMBINE (as WP-leader) and CLIM-RUN. As of 2010, he is a lecturer in Geophysical Fluid Dynamics and (since April 2014) member of the scientific board for the PhD Programme in Science and Management of Climate Change, at the University of Venice.

Dorotea Iovino (female) – [Work Package 3 Co-leader] holds a PhD in physical oceanography and specialises in studying the dynamics of sea ice and polar regions with a focus on dense water formation, thermohaline circulation (THC) and the role of sea-ice processes in climate. She has almost 10 years experience working on ocean and sea ice modelling, both on the technical and scientific aspects. She is currently involved in high-resolution ocean modeling within ENS4OCEAN, a PRACE-funded project and is coordinator and principal investigator of a nationally funded project, CATARSI, which aims to investigate the mechanisms explaining Antarctic sea ice variability and its role on global THC. She is the NEMO Officer for CMCC within the NEMO System Team.

Matteo Zampieri (male) [Work Package 3 Co-leader] holds a PhD in physics and he is a weather and climate modeller. His major field of expertise is turbulence and land-surface modelling and the analysis of various aspects of atmospheric circulation, climate variability and change, and interactions with the land-surface, with particular focus on the European and Mediterranean regions.

Enrico Scoccimarro (male) holds an MSc in Marine Environmental Sciences. He has contributed to the development of a several fully coupled climate models (e.g., SINTEX-G, CMCC-Med, CMCC-CM) and has performed a number of climate scenario simulations and projections (CMIP3, CMIP5). Currently his main area of research is investigating the relationship between Tropical Cyclones and Climate.

Relevant publications, and/or products, services, achievements:

Bellucci, A., R. Haarsma, S. Gualdi, P. Athanasiadis, M. Caian, C. Cassou, E. Fernandez, A. Germe, J. Jungclaus, J. Kroeger, D. Matei, W. Moeller, H. Pohlmann, D.Salas y Melia, E. Sanchez, D. Smith, L. Terray, K. Wyser and S. Yang (2014) An assessment of a multi-model ensemble of decadal climate predictions. Climate. Dynamics. doi:10.1007/s00382-014-2164-y

Gualdi S., Scoccimarro E., Navarra A.: Changes in Tropical Cyclone Activity due to Global Warming: Results from a High-Resolution Coupled General Circulation Model (2008), J Climate, doi:10.1175/2008JCLI1921.1

Walsh K., Lavender L., Scoccimarro E., Murakami H. Resolution dependence of tropical cyclone formation in CMIP3 and finer resolution models (2013), Climate Dynamics, Volume 40, Issue 3-4, pp 585-599, doi: 10.1007/s00382-012-1298-z

Zampieri M., Scoccimarro E. and S. Gualdi, Atlantic influence on spring snowfall over the Alps in the past 150 years (2013) Environ. Res. Lett., doi:10.1088/1748-9326/8/3/034026

Eldevik T., J. Nilsen, D. Iovino, K. Anders Olsson, A. Sandø and H. Drange (2009) Observed sources and variability of Nordic seas overflow. Nature Geoscience 2, 406–410. doi:10.1038/ngeo518

Relevant previous projects or activities:

CIRCE (www.circeproject.eu/) was an integrated project funded under the EU's FP6 Programme, coordinated by CMCC. CIRCE aimed at understanding impacts and possible adaptation actions of the climate change in the Mediterranean region, that includes Europe, North Africa and Middle East. Specific objectives included: predicting and quantifying physical impacts of climate change in the Mediterranean area; evaluating the consequences of climate change for the society and the economy of the populations located in the Mediterranean area; developing an integrated approach to understand combined effects of climate change; identifying adaptation and mitigation strategies in collaboration with regional stakeholders.

Within EU FP7 **COMBINE**, the CMCC played a key role, co-leading two work packages and contributing to several activities in the project. These included: the development of a well-resolved dynamical stratosphere in ESMs and production of historical simulations (WP3; CMCC co-leader), development of improved initialisation techiniques and ocean analyses (WP5), production and analyses of decadal prediction experiments (WP6; CMCC co-leader), and production and analysis of centennial scenario simulations with the carbon cycle (WP7).

IS-ENES2 – Infrastructure for the European Network for Earth System modelling – Phase 2. This project integrates the European climate modelling community, stimulates common developments of software for models and their environments, fosters the execution and exploitation of high-end simulations and supports the dissemination of model results to the climate research and impact communities.

Within IS-ENES2, CMCC is involved in several networking and joint research activities. These include future models and exascale (WP3/NA2), model environment (WP4/NA3), data and metadata networking (WP5/NA4), innovation for climate modelling (WP6/NA5), multi-model multi-member high-resolution simulations for PRACE machines (WP9/JRA1), performance benchmarks for coupled climate models (WP10/JRA2) and software development for data archives (WP11/JRA3).

ERA-CLIM2 (European Reanalysis of Global Climate Observations 2) is a collaborative research project funded by the European Union, with the goal of preparing input data and assimilation systems for a new global coupled reanalysis of the 20th century.

CMCC will contribute to ERA-CLIM2 by developing and testing hybrid variational and ensemble ocean data assimilation systems and exploring the impact of coupled ocean-atmosphere model error covariances to correct near-surface meteorological fields through ocean data assimilation.

ENS4OCEAN is a **PRACE** project coordinated by CMCC, that aims to produce a simulation of an eddy-resolving global ocean (1/16° horizontal resolution and 98 vertical levels), which will be the base for a real-time forecasting system able to provide forecasts of global oceanographic parameters for the following 10 days, on a daily basis. Starting from the hindcast for a few selected dates, an ensemble of perturbed forecasts will be also produced. This ensemble will form the basis for short-range predictability studies and for estimating ensemble-derived background-error covariances for further use in variational data assimilation experiments.

Any significant infrastructure and/or any major items of technical equipment:

CMCC operates its own Supercomputing Center (located in the "Ecotekne" Campus in Lecce) whose HPC facilities have been ranked, since 2008, in the 500 most powerful supercomputing systems in the world (316th at November 2013). The CMCC HPC infrastructure is the third most powerful computational facility in Italy.

Participant 10: Alfred-Wegener-Institut, Helmholtz-Zentrum für Polar- und Meeresforschung (AWI)

The Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research (AWI) is one of the world´s leading polar and marine research organisations, and delivers significant contributions to international research on climate,

marine and coastal issues. It coordinates German polar research within an international framework and provides the national and international science community with polar and marine infrastructure. The AWI belongs to the Helmholtz Association, Germany's largest scientific organization and is the central German research facility for the Polar Regions. AWI is the national management and implementation agency of the National German Arctic and Antarctic Programme. The AWI has a staff of approximately 1000 people. The annual budget is the equivalent of 114 million Euros, 90 % of which is provided from the Federal Ministry of Education and Research (BMBF) and 10 % of which is from provincial sources. The institute operates the ice-going polar research and supply vessel POLARSTERN, the regional research vessel HEINCKE and several smaller vessels, two research airplanes, and permanent research stations in Antarctica and on Spitsbergen.

Through memberships, the AWI is embedded in a number of European Research initiatives, such as the European Polar Board, the European Marine Board and the European Climate Research Alliance. Overall, the AWI has been involved in international projects for 30 years and has participated in numerous FP5, FP6 and FP7 projects. AWI hosts two ERC Starting Grants (PHYTOCHANGE and PETA-CARB), one ERC Advanced Grant (ABYSS) and several Marie Curie Fellowships. Additionally AWI-coordinates the two FP7 collaborative project PAGE21, which started in November 2011 and StratoClim, which started in December 2013, as well as the Marie Curie IRSES project IMCONet, which started in February 2013.

AWI has more than ten years of experience in the development and use of sea ice-ocean models on unstructured meshes. More recently, the first global climate model with a sea ice-ocean component based on unstructured mesh methods has been developed at AWI. AWI will contribute to WP4 by exploring the value of unstructured mesh methods in climate modelling. Furthermore, contributions will be made to WP6 by carrying out core integrations with ECHAM6-FESOM.

Short profile of key personnel involved:

Prof Thomas Jung (male) is a full professor of Physics of the Climate System, is an expert in climate modelling, climate prediction, climate analysis and NWP, with more than 50 peer-reviewed publications to his name. He is head of the Climate Dynamics section at AWI; he serves as the spokesperson for AWI's entire research programme; he acts as the chair of the Polar Prediction Project of WMO's World Weather Research Programme; and since 2012 he has been co-chair of the Arctic programme of the European Climate Research Alliance (ECRA). Prof. Jung published numerous papers on the role of resolution and parameterisation of sub grid-scale processes in weather prediction and climate modelling. Following his arrival at the AWI in December 2010 he worked to increase existing modelling efforts, which culminated in the development of the first climate model with a sea ice-ocean representation on unstructured meshes.

Dr Sergey Danilov (male) is principal scientist at AWI and leads the modelling group within the Climate Dynamics section. He has published more than 80 papers and is a renowned expert in the field of ocean dynamics and modelling, who has developed the world's first sea ice-ocean model for large-scale climate applications based on unstructured mesh methods – the Finite Element Sea Ice-Ocean Model (FESOM).

Dr Tido Semmler (male) is senior scientist in the Climate Dynamics section at AWI with more than 29 publications in peer-reviewed literature. He is an expert in regional and global climate modelling and has contributed to the development of EC-Earth and ECHAM6-FESOM. He has also made substantial contributions to setting up and running the CMIP5 integrations with EC-Earth.

Dr Dimitry Sidorenko (male) works as a scientist in the Climate Dynamics section at AWI. He has a strong track record in ocean modelling on unstructured meshes using FESOM. Despite being at a relatively early stage of his career, he has 17 papers published in peer-reviewed literature. Furthermore, he took a pivotal role in the development and implementation of the first climate model that employs an unstructured sea ice-ocean component – ECHAM6-FESOM.

Relevant publications, and/or products, services, achievements:

Sidorenko, S., T. Rackow, **T. Jung**, T. Semmler, D. Barbi, **S. Danilov**, K. Dethloff, W. Dorn, K. Fieg, H. F. Goessling, D. Handorf, S. Harig, W. Hiller, S. Juricke, M. Losch, J. Schroeter, D. Sein, and Q. Wang: Towards multi-resolution global climate modelling with ECHAM6-FESOM. Part I: Model formulation and mean climate. *Climate Dynamics*, accepted

Danilov, S., 2012: Two finite-volume unstructured mesh models for large-scale ocean modeling, *Ocean Modelling*, **47**, 14—25

Wang, Q., **S. Danilov**, **D. Sidorenko**, R. Timmermann, C. Wekerle, X. Wang, **T. Jung**, and J. Schröter, 2014: The Finite Element Sea ice-Ocean Model (FESOM): Formulation of an unstructured-mesh ocean general circulation model. *Geosci. Mod. Dev*., **6**, 3893—3976

Jung, T., M.J. Miller, T.N. Palmer, P. Towers, N. Wedi, D. Achuthavarier, J.D. Adams, E.L. Altshuler, B.A. Cash, J.L. Kinter III, L. Marx, C. Stan, and K.I. Hodges, 2012: High-resolution global climate simulations with the ECMWF model in Project Athena: Experimental design, model climate and seasonal forecast skill. *J. Climate*, **25**, 3155—3172

Hazeleger, W., C. Severijns , **T. Semmler**, S. Ştefănescu, S. Yang, X. Wang, K. Wyser, E. Dutra, J.M. Baldasano, R. Bintanja, P. Bougeault, R. Caballero , A.M.L. Ekman, J.H. Christensen, B. van den Hurk, P. Jimenez, C. Jones, P. Kållberg, T. Koenigk, R. McGrath, P. Miranda, T. Van Noije, T. Palmer, J.A. Parodi, T. Schmith, F. Selten, T. Storelvmo, A. Sterl, H. Tapamo, M. Vancoppenolle, P. Viterbo, and U. Willén, 2010: EC-Earth: A seamless Earth-system prediction approach in action. *Bull. Amer. Meteor. Soc.*, 91, 1357—1363

Relevant previous projects or activities:

Athena is an international project in which Prof. Jung has played a key role. In the *Athena project* the sensitivity of climate simulations to horizontal resolutions up to 10 times higher than contemporary climate models (i.e. ≈12 km) has been explored on a dedicated supercomputing facility (Cray XT-4 operated by the University of Tennessee's National Institute for Computational Science and hosted by Oak Ridge National Laboratory ORNL).

Miklip is a project that is funded through the Federal Ministry of Education and Research in Germany (BMBF). Miklip aims to create a model system that can provide reliable decadal forecasts on climate and weather, including extreme weather events. Funding from the Miklip project has contributed to the development of ECHAM6-FESOM used in this proposal.

REKLIM (REgionale KLIMaänderungen/Regional climate change) is a consortium of nine research centres within the Helmholtz Association in Germany. REKLIM is using its unique combination of competence in regional observations and process studies (in situ observations, airborne and satellite remote sensing), coupled with model simulations to improve regional and global climate models, which provide a solid basis for climate-related decision support. Funding from the REKLIM has contributed to the development of ECHAM6-FESOM used in this proposal.

Any significant infrastructure and/or any major items of technical equipment:

In 2015 AWI will obtain a new supercomputing system (Tier-3 with approx. 15.000 computational cores) for model development and tuning purposes.

AWI is a shareholder at the Deutsche Klimarechenzentrum (DKRZ) in Hamburg, Germany, holding 9% of the shares. Through its shareholder position AWI has access to the supercomputing resources and data storage facilities.

Participant 11: The Chancellor, Masters and Scholars of the University of Oxford (UOXF)

The University of Oxford is relatively unusual on the national and international scene, in focusing on atmospheric and climate research within a world-class Physics department. The traditional strength of the Atmospheric, Oceanic and Planetary Physics (AOPP) department is in atmospheric measurements, including the development of sensors and instrumentation, data analysis and inverse theory. These activities are complemented by a flourishing research programme in theoretical climate dynamics, physical oceanography, and climate modelling. The University of Oxford has designated Physical Climate Science as a key area for expansion and investment, within which AOPP is taking a leading role alongside the Departments of Earth Sciences and Mathematics.

AOPP has strong links both within the UK and internationally, collaborating with centres as diverse as the European Centre for Medium Range Weather Forecasts (ECMWF), the NERC National Centre for Atmospheric Science (NCAS), the Oxford Martin School (http://www.oxfordmartin.ox.ac.uk/) and the Smith School for Enterprise and the Environment (http://www.smithschool.ox.ac.uk/). In addition, Oxford University has recently formalised a partnership with the UK Met Office – the Met Office Academic Partnership (MOAP) – and has also recently signed an MOU with the Australian Research Council's Centre of Excellence for Climate System Science, in order to better leverage existing relationships with a range of Australian partners in stochastic physics and model parameterisations.

AOPP employs 14 lecturers and 35 post-doctoral researchers across 10 research groups. Within AOPP, the Predictability of Weather and Climate group, the research group involved in this proposal, consists of 8 postdoctoral researchers headed by Royal Society Research Professor, Tim Palmer, and Senior NCAS Research Fellow, Antje Weisheimer. The key focus of the group is the reliable quantification of uncertainty in weather and climate predictions, together with the reduction of current levels of forecast uncertainty. Within these areas, the group is involved in a wide range of research projects. In particular, the group's expertise in high resolution modelling,

through its involvement with the ATHENA project (partly funded by the National Science Foundation), will be utilised in PRIMAVERA's WP2 to assess the benefits of increasing model resolution on the representation of European weather regimes. The group also has significant experience in the area of stochastic parametrisation: the first operational stochastic scheme was co-developed by Prof. Tim Palmer for use in the ECMWF numerical weather prediction model, and several members of the group are currently involved in developing stochastic parametrisation schemes for use in the ocean, land surface and atmospheric components of the ECMWF model. In WP4, the group will play a leading role in investigating the use of stochastic parametrisation schemes as a novel representation of sub-grid scale variability.

Short profile of key personnel involved:

Prof. Tim Palmer (male) is a Royal Society Research Professor in Climate Physics at Oxford University. He is a Professorial Fellow at Jesus College, Oxford, Co-Director of the Oxford Martin Programme on Modelling and Predicting Climate, and Senior Consultant at ECMWF. He was lead author and review editor of IPCC WG1, and President of the Royal Meteorological Society (2010-2012). His expertise lies in dynamics and predictability of weather and climate. He has several national and international awards. He had a leading role in Project ATHENA (Kinter et al. 2013): High Resolution Global Climate Simulations, as well as several EU funded projects.

Dr. Antje Weisheimer (female) holds a joint position at AOPP Oxford as a Senior NCAS Research Fellow and as a research scientist in the Ensemble Prediction section at ECMWF. Her interests are mainly model-based weather and climate forecasts and the uncertainties associated with them. She has been involved in several EU and NERC funded research projects on seasonal-to-interannual predictability with a focus on studying the impact of different methodologies to address model error in complex climate and weather models. Antje is a Research Fellow at Wolfson College Oxford.

Dr. Hannah Christensen (female) is a postdoctoral researcher in AOPP and Junior Research Fellow at Corpus Christi College Oxford. Her areas of expertise include developing, testing and implementing stochastic parameterisation schemes in global numerical weather prediction models using HPC environments. In particular, she has experience of working with the IFS model, which forms the atmospheric component of EC-Earth. She has papers on the development of stochastic parameterisation schemes, verification of probabilistic forecasts, and evaluation of models using regime diagnostics. She is a principle investigator in the ECMWF Special Project SPGBTPUC.

Relevant publications, and/or products, services, achievements:

Christensen, H. M., Moroz, I. M. and Palmer, T. N. (2014). Simulating weather regimes: impact of stochastic and perturbed parameter schemes in a simple atmospheric model. Clim. Dynam. (in press). DOI: 10.1007/s00382-014-2239-9

Dawson, A. and Palmer, T. N. (2014). Simulating weather regimes: impact of model resolution and stochastic parameterization. Clim. Dynam. (in press). DOI: 10.1007/s00382-014-2238-x

Weisheimer, A., Corti, S., Palmer, T. N. and Vitart, F. (2014). Addressing model error through atmospheric stochastic physical parametrizations: impact on the coupled ECMWF seasonal forecasting system. Phil. Trans. R. Soc. A, 372, 20130290

Palmer, T. N. (2012). Towards the probabilistic Earth-system simulator: A vision for the future of climate and weather prediction. Q. J. Roy. Meteor. Soc., 138, 841-861

Berner, J., Jung, T. and Palmer, T. N. (2012). Systematic Model Error: The Impact of Increased Horizontal Resolution versus Improved Stochastic and Deterministic Parameterizations. J. Climate, 25, 4946-4962

Relevant previous projects or activities:

PROVOST was a project funded by the European Commission under the 4th framework programme, co-ordinated by **Prof. Tim Palmer**. The project, which ran from 1997 to 1999, was a programme involving 11 European partners that aimed to quantify the scientific basis for seasonal prediction. The insight gained was then used to develop the science of predicting climate anomalies on seasonal to interannual timescales. The study resulted in many peer-reviewed papers, including a special issue of the Quarterly Journal of the Royal Meteorological Society (volume 126, issue 567).

DEMETER was a project funded by the European Commission under the 5th framework programme, co-ordinated by **Prof. Tim Palmer**. The objective of the project, which involved 12 partners and ran from 2000-2003, was to develop a well-validated European coupled multi-model ensemble forecast system for reliable seasonal to interannual

prediction. There was a particular focus on ensuring the system would produce useful, practical output for the health and agriculture industries.

ENSEMBLES was a project funded by the European Commission under the 6th framework programme from 2004 to 2009. This was an ambitious project involving 68 partners, which built on the work carried out in DEMETER: **Prof. Tim Palmer** and **Dr Antje Weisheimer** were research co-ordinators of RT1 – Development of the Ensembles Prediction Systems – with the key aim of quantifying and reducing uncertainty in Earth System models. A range of different approaches were considered (multi-model ensembles, stochastic parametrisation schemes and perturbing physical parameters), and their impacts on seasonal to interannual timescales analysed.

THOR was a project funded by the European Commission under the 7th framework programme, which ran from December 2008 to November 2012 involving 21 partners. **Prof Tim Palmer** and **Dr Antje Weisheimer** were involved in CT4 – Predictability of the Thermohaline Circulation (THC). The primary aim of this theme was understanding and assessing decadal climate predictability by focusing on producing reliable forecasts of the THC.

EU FP7 **SPECS** intends to develop the new generation of European operational seasonal-to-decadal climate forecast systems for the production of reliable, local climate information at the global scale. **Dr Antje Weisheimer** and **Prof. Tim Palmer** lead WP 4.4 – Addressing Model Inadequacy, which will develop methodologies to address model uncertainty as part of the "seamless prediction" programme, incorporating developments from numerical weather prediction into the climate arena. The main focus here is on developing and testing representations of model uncertainty in the land surface scheme.

Any significant infrastructure and/or any major items of technical equipment:

The Predictability of Weather and Climate group at UOXF use computer resources on their own cluster, which consists of one master and four compute nodes, each of which has two quad-core Intel Xeon E5630 processors and 48GB of RAM. The group also have access to the UOXF supercomputer, ARC, as well as the HPC resources, file storage and infrastructure at ECMWF.

Participant 12: Consiglio Nazionale delle Ricerche (CNR)

The Italian National Research Council (CNR) is the largest public research institution in Italy. Its duty is to carry out, promote, disseminate and improve research activities within its main areas of interest - knowledge growth and its applications for the scientific, technological, economic and social development of Italy and Europe. To this end, the activities are divided into macro areas of interdisciplinary scientific and technological research and CNR has seven corresponding departments. The Institute of Atmospheric Sciences and Climate (ISAC) belongs to the Earth and Environmental Department, whose research activities cover the full range of Earth science, including some of this century's key environmental issues as the Climate Change, Natural Hazards and Sustainability of Natural Resources.

ISAC employs over 200 members of staff who conduct pure and applied research on atmospheric sciences and the climate system. The objectives of the Climate Dynamics and Variability Group (DIVAC), the research unit involved in this proposal, include the characterization of Earth's climate and of its past, present and future variability (reconstructions and scenarios), the estimate of environmental risks induced by climate change, and the analysis of (some of) the fundamental processes of climate dynamics. In particular, the research group undertakes research in: Climate downscaling and upscaling with dynamical, statistical and stochastic methods; Sub-seasonal to decadal climate predictions, also in the framework of climate services; High resolution climate reconstructions and future scenarios; Climate predictability; Sources (and limitations) of climate predictability; Role of the stratospheric dynamics in climate variability at seasonal to multi-decadal time-scales.

The DIVAC group is currently involved in three FP7 projects (ECLISE, StratoClim and ICE-ARC), four nationally funded projects (NextDATA, HR-CIMA, PRIN1 and PRIN2) and two super-computing projects (the Gauss Super-computing project EXPRESS-Hydro and the national ISCRA project). The DIVAC group is also running a Special Project at ECMWF which aims to systematically investigate the sensitivity of multi-annual forecasts to model resolution.

CNR-ISAC will actively contribute to WP1 where it will collaborate to the development of a process-based metrics tailored for different regions and seasons. CNR-ISAC will also contribute to WP2, leading the assessment of the benefits of increasing model resolution on Pacific variability and its teleconnection to Europe. CNR-ISAC will collaborate with the University of Oxford and the Met Office to investigate novel stochastic approaches to represent sub-grid scale processes, which are among the new frontiers of climate modelling as described in WP4. Finally, in WP5 CNR-ISAC will bring its expertise on investigating the climate variability and predictability in the Extra-

Tropics in order to quantify the respective influence of Interdecadal Pacific Variabiliy, Atlantic Multidecadal Variability and anthropogenic forcing on recent and future changes in European climate.

Short profile of key personnel involved:

Dr. Susanna Corti (female) is a senior researcher at CNR-ISAC and executive Editor of Climate Dynamics. During the past three years she has worked as a consultant at ECMWF for the EU-funded project THOR (Thermohaline Overturning at Risk) performing decadal-scale coupled experiments in various configurations. Before joining CNR-ISAC she spent five years at the major Italian high-performance computing centre CINECA where she has contributed to a number of EU-funded projects on climate research. She has published peer-reviewed articles on atmospheric low-frequency variability, weather regimes (one as first author in Nature), seasonal forecasting, large-scale monsoon circulation, and near-term climate variability and predictability.

Dr. Chiara Cagnazzo (female) is a researcher at CNR-ISAC. She is an expert in stratosphere dynamics and composition. She collaborates in the SPARC DynVAR Activity of the WCRP, and she is involved in the Atmospheric Composition and the Asian Summer Monsoon (ACAM) Activity, in connection with CCMI (Chemistry-Climate Model Initiative). Before 2011 she was a Scientist at CMCC (Euro-Mediterranean Center on Climate Change) and was responsible for the CMIP5 simulations performed with a Stratosphere-resolving Earth System Model. She is author of 26 peer reviewed publications in the atmospheric and climate sciences.

Dr. Paolo Davini (male) is a post-doc researcher specialising in the study of climate variability in the extratropical region, with a special focus on the ability of coupled climate models to reproduce spatial and temporal modes of variability (as atmospheric blocking or the North Atlantic Oscillation). He is currently involved in the development of the EC-Earth Earth System Model and he is author of 9 peer-reviewed articles. Six of these are as a first author.

Dr. Antonello Provenzale (male) is Research Director and Head of the DIVAC Unit at CNR-ISAC, where he works on the interaction between climate and the hydrological cycle, climate-biosphere modelling, the assessment of the risks of climate change and climate downscaling. He participates in the consortium which develops the global Earth System model EC-Earth and coordinates the activities of the Collaborative Program "Changes in the Hydrological Cycle" of the European Climate Research Alliance (ECRA). He leads the Global Network for Observations and information in Mountain Environments of GEO-GEOSS (GEO-GNOME). He has published more than 150 scientific papers in international peer-reviewed literature and has received the Golden Badge Award of the European Geophysical Society.

Relevant publications, and/or products, services, achievements:

Davini, P., C. Cagnazzo, S. Gualdi, and A. Navarra (2012), Bidimensional diagnostics, variability and trends of Northern Hemisphere Blocking. J. Climate, 25, 6496–6509. DOI:10.1175/JCLI-D-12-00032.1

Davini, P. and C. Cagnazzo (2013); On the misinterpretation of the North Atlantic Oscillation in CMIP5 models, Clim. Dyn, DOI:10.1007/s00382-013-1970-y

Dawson, A., T. N. Palmer, and S. Corti (2012), Simulating regime structures in weather and climate prediction models, Geophys. Res. Lett., 39, L21805, doi:10.1029/2012GL053284

Palazzi, E., J. von Hardenberg, and A. Provenzale (2013), Precipitation in the Hindu-Kush Karakoram Himalaya: Observations and future scenarios, J. Geophys. Res. Atmos., 118, 85–100, doi: 10.1029/2012JD018697

Weisheimer A, Corti S, Palmer T, Vitart F. (2014) Addressing model error through atmospheric stochastic physical parametrizations: impact on the coupled ECMWF seasonal forecasting system. *Phil. Trans. R. Soc. A* 372: 20130290. http://dx.doi.org/10.1098/rsta.2013.0290

Relevant previous projects or activities:

THOR (http://www.eu-thor.eu/) was a project funded by the European commission under FP7. THOR aimed to establish an operational system for monitoring and forecasting the development of the North Atlantic THC on decadal time scales, and assess its stability, and the risk of a breakdown in a changing climate. Through the assimilation of systematic oceanic observations at key locations into ocean circulation models, the project provided a set of geo-observational products that were used to forecast the development of the system using global coupled ocean-atmosphere models.

EU FP7 **COMBINE**: **Dr. Chiara Cagnazzo** was a co-leader of the Stratosphere Work Package, whose overall goal was to improve the representation of the upper troposphere and stratosphere, by including dynamical stratospheric processes in Earth System Models, for better climate prediction and projections.

StratoClim (http://www.aerosols-climate.org/stratoclim.html) is an FP7-funded project which aims to produce more reliable projections of climate change and stratospheric ozone through a better understanding and improved representation of key processes in the Upper Troposphere and Stratosphere (UTS). This will be achieved by an integrated approach, bridging observations from dedicated field activities, process modelling on all scales, and global modelling with a suite of chemistry climate models (CCMs) and Earth system models (ESMs). **Dr. Chiara Cagnazzo** is co-leader of the of the Global Modeling working group.

NextDATA (http://www.nextdataproject.it/?q=en) is a nationally funded Project of Interest coordinated by Dr. Antonello Provenzale, head of DIVAC group at CNR-ISAC. This project aims to produce a national system for the retrieval, storage, access and dissemination of environmental and climate data from mountain and marine areas. The NextDATA Project has defined three Grand Challenges: (1) the construction of a system of archives and portals for distributing climate and environmental data on current conditions and ongoing changes in mountain regions; (2) the reconstruction of climate and its variability in Italy in the last two Millennia, with special focus on the last 100 years; and (3) the development of an ensemble of high-resolution temperature and precipitation fields from future climate scenarios over Italy for the next few decades.

SPITCORT is an ECMWF Special Project (http://old.ecmwf.int/about/special_projects/) coordinated by **Dr. Susanna Corti** which aims to investigate the sensitivity of multi-year forecasts to model resolution. Particular attention is devoted to the systematic investigation of the simulation of the main features of climate variability over the Euro-Atlantic sector.

Any significant infrastructure and/or any major items of technical equipment:

DIVAC group at ISAC-CNR has computer resources obtained from their own ISAC-CNR clusters (in Bologna, Turin and Rome), the Italian Super-Computing Centre (CINECA) and the European Centre for Medium Range Weather Forecasts (ECMWF).

Participant 13: European Centre for Medium-Range Weather Forecasts (ECMWF)

The European Centre for Medium-Range Weather Forecasts (ECMWF) is an international organisation supported by 34 States: 20 Members (Belgium, Denmark, Germany, Greece, Iceland, Spain, France, Ireland, Italy, Luxembourg, the Netherlands, Norway, Austria, Portugal, Switzerland, Finland, Slovenia, Sweden, Turkey, United Kingdom) and 14 Co-operating Members (Bulgaria, Croatia, Czech Republic, Estonia, the former Yugoslav Republic of Macedonia, Hungary, Israel, Latvia, Lithuania, Montenegro, Morocco, Romania, Serbia, Slovakia, Slovenia).

ECMWF's principal objectives are the development of numerical methods for medium-range weather forecasting; production of medium-range and long-range weather forecasts for distribution to the meteorological services of the Member States; scientific and technical research directed to the improvement of these forecasts; and the collection and storage of appropriate meteorological observations. ECMWF, through its partnerships with EUMETSAT, ESA, the EU and the European Science base, has established a leading position in Europe for operational numerical weather prediction, operational sub-seasonal and seasonal forecasting with coupled atmosphere-ocean-land models, exploitation of satellite data in data assimilation, and climate reanalysis.

Since November 2013, ECMWF has also run medium-range ensemble predictions with a coupled ocean-atmosphere model, and is currently developing a prototype system for coupled data assimilation in collaboration with European partners. They have great expertise in very high resolution modelling, process understanding and model physics development which will be invaluable to PRIMAVERA.

Short profile of key personnel involved:

Dr Franco Molteni (male) is Head of the Ensemble Prediction Section of ECMWF, with responsibility for the development and implementation of the ensemble systems used to produce medium-range, sub-seasonal and seasonal predictions. He has been at the forefront of research on ensemble and long-range predictions at ECMWF since its beginning in 1984, and played a major role in the development of the first ECMWF operational ensemble system in the early 1990's. He re-joined ECMWF in 2006 as Head of the Seasonal Forecast Section, after being co-leader of the Earth System Physics Section at the Abdus Salam International Centre for Theoretical Physics in Trieste. Over the last two decades, F. Molteni has managed research teams of up to 20 scientists, and co-ordinated their contributions to nine EU-funded research projects. He has been a member of the Scientific Steering Group of the CLIVAR (Climate Variability and Predictability) Core Project of the World Climate Research Programme, and a

member of the CLIVAR Pacific Panel. His scientific interests include atmospheric and climate predictability, geophysical flow regimes, numerical modelling of the climate system.

Dr Sarah Keeley (female) joined ECMWF in August 2011 as a Scientist in the Predictability Division and Education Officer. Her research work is focussed on developing the dynamic sea ice model in the ECMWF coupled system, and maintaining and developing the sea surface temperature and sea ice analysis. Previously, she has been a Research Fellow at the University of Reading, and carried out an Arctic scoping study (Identifying Uncertainties in Arctic Climate Change) for the Natural Environment Research Council, to provide guidance for their Arctic Research programme. She also co-wrote a successful funding proposal for Arctic Predictability and Prediction On Seasonal to Inter-annual Timescales. Dr. Keeley will be involved in research on sea-ice modelling and predictability within PRIMAVERA.

Dr Sylvie Malardel (female) is a Senior Research Scientist in the Numerical Aspects Section of ECMWF. She has much experience with numerical modelling of the atmosphere at synoptic and mesoscale resolutions. She has been working with the ECMWF global model IFS and the limited area codes derived from the IFS (i.e. ALADIN and AROME at Meteo-France, and HARMONIE in the HIRLAM consortium) for more than 20 years, both on the numerical and physical aspects of the system. She is now working at ECMWF on the transition towards convection permitting resolutions for the global IFS. She has contributed in the past to several inter-comparison projects and she is currently involved in the Grey Zone Project CONSTRAIN. Dr. Malardel will co-ordinate the ECMWF contribution to WP4.

Relevant publications, and/or products, services, achievements:

Tietsche, S., J. J. Day, V. Guemas, W. J. Hurlin, S. P. E. Keeley, D. Matei, R. Msadek, M. Collins, and E. Hawkins (2014), Seasonal to interannual Arctic sea ice predictability in current global climate models, Geophys. Res. Lett., 41, 1035–1043

Molteni, F., T.N. Stockdale, M. A.Balmaseda, G. Balsamo, R. Buizza, L. Ferranti, L. Magnusson, K. Mogensen, T.N. Palmer, and F. Vitart, 2011: The new ECMWF seasonal forecast system (System 4). ECMWF Technical Memorandum no. 656

Magnusson L., M. Alonso-Balmaseda, S. Corti, F. Molteni and T. Stockdale, 2012: Evaluation of forecast strategies for seasonal and decadal forecasts in presence of systematic model errors. *Climate Dyn.,* doi: 10.1007/s00382-012-1599-2

Stockdale, T.N, D.L.T. Anderson, M. A.Balmaseda, F. Doblas-Reyes, L. Ferranti, K. Mogensen, T.N. Palmer, F. Molteni and F. Vitart, 2010: ECMWF Seasonal Forecast System 3 and its prediction of Sea Surface Temperature. *Climate Dyn.,* **37,** 455-471, doi: 10.1007/s00382-010-0947-3

Balmaseda, M, L. Ferranti, F. Molteni and T. N. Palmer, 2010: Impact of 2007 and 2008 Arctic ice anomalies on the atmospheric circulation: Implications for long-range predictions. *Q. J. R. Meteorol. Soc.*, **136**, 1655–1664, doi: 10.1002/ qj.661

Relevant previous projects or activities:

The role of ECMWF in the EU FP7 project **SPECS** is focussed on land-surface and stratospheric processes and interactions, and on the development of calibrated multi-model products.

THOR (http://www.eu-thor.eu/) was an FP7 project funded by the European commission. Through the assimilation of systematic oceanic observations at key locations into ocean circulation models, the project provided a set of geo-observational products that were used to forecast the development of the system using global coupled ocean-atmosphere models. ECMWF has contributed to the assessment of decadal predictability.

EU FP7 **COMBINE**: Within this project, ECMWF delivered an ocean re-analysis used by COMBINE partners to initialise decadal simulations, and carried out research on different methods for initialisation and bias correction in multi-year coupled experiments.

ATHENA brought together an international team of over 30 people from six institutions, including climate scientists and modellers, and experts in high-performance computing (HPC), to determine the feasibility of using dedicated HPC resources to rapidly accelerate progress in simulating climate variability and change. Computationally-intensive experiments with two different atmospheric models made use of the entire 18,048-core Athena Cray XT-4 supercomputer at the University of Tennessee's National Institute for Computational Sciences, based at the Oak Ridge National Laboratory, with support from the U.S. National Science Foundation. The numerical experiments were designed to determine whether increasing model resolution to accurately resolve mesoscale phenomena in the

atmosphere can improve the fidelity of the models' climate simulations. Experiments were run with the ECMWF Integrated Forecast System (IFS), and the Non-hydrostatic ICosahedral Atmospheric Model (NICAM) global atmospheric model from the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) and the University of Tokyo.

MINERVA is a project co-ordinated by the Centre for Ocean-Land-Atmosphere Studies (COLA), currently in Fairfax (Virginia, USA), with the collaboration of ECMWF, and supported by the Accelerated Scientific Discovery program of the U.S. National Center for Atmospheric Research (NCAR). A version of the ECMWF coupled system used for seasonal prediction was installed on NCAR's Yellowstone HPC, and used to produce a set of seasonal-scale ensemble historical forecasts spanning the period 1981 to 2010. Simulations were run with an atmospheric horizontal resolution of about 64, 32 and 16 km, using more than 28 million core-hours for the whole project. MINERVA was designed to re-evaluate the issues explored in ATHENA, using a coupled model.

Any significant infrastructure and/or any major items of technical equipment:

ECMWF's computer facility includes supercomputers, archiving systems and networks. ECMWF operates one of the largest supercomputer facilities of its type in Europe and holds the largest meteorological data archive in the world. Member and Co-operating States can access ECMWF's basic computing facilities, the meteorological archive, and temporary tape storage. Member States also have access to the supercomputers and permanent tape storage.

The recently installed Cray supercomputer at ECMWF is designed for operational resiliency, featuring two Cray XC30 systems and a multi-petabyte Cray Sonexion storage system. The system comprises two independent sub-systems located in separate halls. Each subsystem consists of 19 Cray XC30 cabinets equipped with Intel Ivy Bridge processors and around 3500 dual-socket compute nodes per system, a number of Cray Development and Login (CDL) nodes and approximately 3PB of Lustre storage with the ability to cross mount the Lustre file systems between the halls.

Participant 14: Natural Environment Research Council (NERC)

The Natural Environment Research Council (NERC) is the UK's largest funder of independent environmental science, covering the physical, chemical and biological processes on which life depends, with an emphasis on better understanding and predicting how our planet works. The National Oceanography Centre (NOC) is a component body of NERC and has a world-leading reputation for marine and earth sciences, undertaking global-scale ocean research, observations, modelling and technology development. NOC plays a major role in influencing scientific, environmental, and maritime policy in both the UK and Europe, and is also involved in a wide range of European Union projects under FP7, both as partners and coordinators.

The Marine Systems Modelling (MSM) group at NOC will undertake the work proposed in PRIMAVERA. The group has world-class expertise in high-resolution global ocean modelling with NEMO, providing direct effort into its international development as the leading European ocean model, and working in close partnership with the Met Office on its implementation into the UK coupled climate models which will be used in PRIMAVERA. The group's scientific research focuses on the dynamics of ocean circulation and mechanisms of variability for the Atlantic and Arctic sectors, in both ocean-only and coupled climate models, on the development of enhanced physical processes for inclusion into NEMO, and on air-sea interaction. The group's tasks in PRIMAVERA focus on the analysis of the Atlantic and Arctic sectors of the high resolution (NEMO) ocean components in the UK coupled models at 1/4° (WP2) and 1/12° (WP4) resolutions, on the impact of additional physics in the upper ocean to better represent specified mixing processes (WP3), and assessments of how such increases in resolution and enhanced physics will benefit the representation of European climate and its variability. The group is therefore ideally positioned to undertake these tasks in PRIMAVERA. Moreover, the group is large, comprising 32 staff members, and has a considerable depth of experience and expertise in the above-mentioned areas beyond the staff named below.

Short profile of key personnel involved:

Prof. Adrian New (male) – [Work Package 3 Co-Leader] is Associate Head of the MSM group at NOC (which consists of 19 staff). He is the NERC representative on the NEMO Steering Committee for the international development of NEMO, is a coordinator of the DRAKKAR project (see below), and leads the interaction of NOC with the Met Office (through activities associated with the JWCRP, Joint Weather and Climate Research Programme, strategic partnership between NERC and the Met Office). With 32 years of research experience, he has wide-ranging interests covering ocean general circulation and coupled climate modelling, decadal-timescale variability of the ocean and climate system, and internal waves and ocean mixing processes. He has published over 50 peer-reviewed scientific papers, and has an H-factor of 24.

Dr. Joel Hirschi (male) is the leader of the high-resolution ocean modelling subgroup of MSM at NOC (which consists of eight staff). His main research interests are the variability and monitoring of the meridional overturning circulation (MOC) of the Atlantic Ocean, and its underlying theory. His work, based on numerical ocean models, was central to the successful proposal for the pre-operational RAPID (a large NERC-funded project) MOC monitoring system deployed at 26° N in March 2004. He currently uses NEMO to study the intrinsic ("chaotic") variability in the MOC and other ocean currents. He also has interests in oceanic impacts on the atmosphere and in atmospheric teleconnections. He is (co)supervising five PhD students working on questions relating to the ocean-atmosphere circulation.

Dr. Bablu Sinha (male) is the leader of the Climate and Uncertainty subgroup of MSM at NOC (which consists of six staff). He is an experienced scientist with specialisms in geophysical fluid dynamics and climate science, and 44 published papers. He has conducted research into the predictability of modes of variability in the climate system (the El Nino Southern Oscillation, the North Atlantic Oscillation and the Atlantic Meridional Overturning Circulation) and has worked on teleconnections in models and observations. He was a key contributor to papers on Southern Ocean influences on equatorial surface temperatures, and on the impact of surface heat loss in the Greenland Sea on the Denmark Strait outflow. He has also recently worked on ocean and orographic forcing of atmospheric storm tracks, and leads the NOC contribution to JOMP (a joint Met Office-NERC initiative, see below).

Relevant publications, and/or products, services, achievements:

NOC personnel included in the below: A. New, J. Hirschi, A. Blaker, B. Sinha, A. Megann, Y. Aksenov, S. Alderson, J. Grist, S. Josey, A. Coward, B. de Cuevas, G. Madec, J. Harle, J. Buchan (PhD Student), F. Hunt (PhD Student).

UK Met Office personnel included in the below: D. Storkey, D. Calvert, T. Graham, P. Hyder, J. Siddorn, M. Roberts, J. Slingo, T. Johns.

Buchan, J., J. J.-M Hirschi, A.T. Blaker, B. Sinha, 2014. North Atlantic SST anomalies and the Cold North European weather events of winter 2009/10 and December 2010, Monthly Weather Review, 142, 922-932

Megann, A., D. Storkey, Y. Aksenov, S. Alderson, D. Calvert, T. Graham, P. Hyder, J. Siddorn, B. Sinha, 2014. GO5.0: the joint NERC–Met Office NEMO global ocean model for use in coupled and forced applications Geosci. Model Dev., 7, 1069-1092

Hunt, F., J.J.-M. Hirschi, B. Sinha, N.C.Wells, K. Oliver, 2013. Combining Point Correlation Maps with Self-Organizing Maps to Compare Observed and Simulated Atmospheric Teleconnection Patterns, Tellus, Series A-Dynamic Meteorology And Oceanography 65, Art. No. 20822

Grist, J. P, S. A. Josey, R. Marsh, S. A. Good, A. C. Coward, B. A. de Cuevas, S. G. Alderson, A. L. New, G. Madec, 2010. The roles of surface heat flux and ocean heat transport convergence in determining Atlantic Ocean temperature variability. Ocean Dynamics, 60, 771-790. Doi: 10.1007/s10236-010-0292-4

Shaffrey, L., I. Stevens, W. A. Norton, M. J. Roberts, P.-L. Vidale, J. Harle, A. Jrrar, D. Stevens, M. Woodage, M.-E. Demory, J. Donners, D. Clarke, A. Clayton, J. Cole, S. Wilson, W. Connolley, T. Davies, A. Iwi, T. C. Johns, J. King, A. New, J. Slingo, A. Slingo, L. Steenman-Clark, G. M. Martin, 2009. UK-HiGEM: the new UK high resolution global environment model. Model description and basic evaluation. J. Climate, 22 1861-1896. http://dx.doi.org/10.1175/2008JCLI2508.1

Relevant previous projects or activities:

JOMP (Joint Ocean Modelling Programme, Sinha, New, Hirschi) is an activity within the JWCRP between the Met Office and NERC, which started in 2010. It involves staff from NOC and the Met Office in the joint development and testing of the latest options for the NEMO ocean model on a shared supercomputer, and the implementation of agreed configurations in the UK/ Met Office climate models. The latest such version is the GO5.0 ocean model described in Megann et. al., 2014, referenced above. Its successor, GO6.0 (currently in development) will form the ocean component of the UK climate model used for the PRIMAVERA simulations.

DRAKKAR (New, Hirschi, Sinha) is a European consortium project (in which NOC has been involved since 2005) for the alignment, coordination, and scientific analysis, of high-resolution versions of the NEMO ocean model. It brings together users and developers of NEMO from major ocean modelling and operational centres in Europe, principally France, the UK, and Germany, and places emphasis on global versions of NEMO at 1/4° and 1/12° resolutions. The NEMO configurations used in PRIMAVERA simulations at both these resolutions will be strongly guided by the work of DRAKKAR.

UK-HiGEM (New) was a UK national programme (2003-2009) in 'Grand Challenge' High Resolution Modelling of the Global Environment between NERC, UK Universities, and the Hadley Centre (part of the Met Office). This developed a new and cutting-edge high-resolution climate model for the UK, including an ocean with a resolution of 1/3°, and allowed new insights into the role of air-sea interaction in climate dynamics (see Shaffrey et. al, 2009, referenced above). NOC personnel were primarily responsible for analysis of the ocean component and its interaction with the atmosphere. This work will form a basis for the analysis and understanding of the high resolution PRIMAVERA simulations.

DYNAMOC (Dynamics of the North Atlantic Meridional Overturning circulation and Climate predictions, NERC funded project, 2014-2018. NOC PI Hirschi, Co-I Sinha). The main objective of this project is to exploit the latest generation of seasonal and decadal forecasting models developed at the Met Office to study how the Atlantic ocean meridional overturning circulation affects weather and climate in the North Atlantic and European regions.

MESO-CLIP (Mesocale ocean eddies and Climate Predictions, NERC funded project, 2013-2016. Lead PI Hirschi, Co-I Sinha). The aim of this project is to investigate how much uncertainty mesoscale ocean eddies add to the ocean circulation and how strongly they feed back onto the atmosphere and affect its predictability in the latest generation of coupled climate models.

Any significant infrastructure and/or any major items of technical equipment:

Fast link to Centre for Environmental Data Archival (CEDA) JASMIN platform for data retrieval and analysis. JASMIN will be our central analysis platform, and it hosts multi-petabyte disk arrays and both fast processors and a high performance cluster for dedicated parallel post-processing.

High Performance Supercomputer on site at NOCS comprising 1152 cores of Intel Xeon processors (20 TeraFLOP peak performance) with 225 Tbyte of high performance disk, for further analysis of datasets locally as needed.

Participant 15: University of Leeds (UNIVLEEDS)

The University of Leeds, the lead organization for the Joint Research Unit (JRU) and host site for the National Centre for Atmospheric Science directorate, is a world-leading research intensive university. The Institute for Climate and Atmospheric Science (ICAS) within the School of Earth and Environment has 30 academic staff, about 50 postdoctoral scientists and 50 PhD students. The institute is one of the UK's most diverse atmospheric research institutes, making fundamental advances in climate change, weather, atmospheric composition, palaeo-climates, and impacts on our planet and society. Researchers develop advanced computer models, lead major field campaigns, analyse satellite data, and perform innovative laboratory experiments. Leeds hosts the NCAS Directorate and the Director of NCAS-Weather. Several NCAS staff are employed by Leeds to develop national capability models and to perform aircraft and field measurements in meteorology, cloud physics and aerosols.

The University of Leeds is capitalising on its expertise in cloud and aerosol microphysics and strong collaboration with the Met Office to develop a coupled cloud aerosol microphsyics scheme. In PRIMAVERA the University of Leeds will carry out explicit simulations of cloud-aerosol interactions and lightning prediction over Europe (WP3), and globally. This work will explore the relationship between resolution and parameterization complexity (WP4) that is key to quantifying the potential shortcomings of parametrizing these processes in global models.

Short profile of key personnel involved:

Prof Paul Field (male) has 18 years experience in cloud physics observations and modelling. He manages a group of three scientists at the Met Office, who are responsible for improving cloud microphysical representations in the Unified Model, and a PDRA and PhD students at University of Leeds and University of Manchester working on cloud-aerosol interactions. He has extensive experience with data analysis of aircraft observations and comparing those with modelling output in novel ways. In 2013 he was appointed to the University of Leeds at 30% FTE to develop a group exploring aerosol-cloud interactions and is an Affiliate Scientist at NCAR. He also helped to plan and lead the ICE-L and ICE-T NSF campaigns when working at NCAR and is Co-I and model facilitator for CLARIFY and the NERC funded ICE-D campaign.

Prof Ken Carslaw (male) - Director of ICAS. He has around 140 publications related to aerosol and cloud processes in the atmosphere, from the troposphere to the stratosphere. Carslaw specializes in the development of advanced numerical models of aerosol and cloud processes, notably the Global Model of Aerosol Processes (GLOMAP), which is now incorporated in the UK climate model (HadGEM) and the ECMWF Integrated Forecasting System. Carslaw has been an investigator in several major EU projects, including EUCAARI, PEGASOS and MACC. The University of Leeds aerosol team has a long track record of integrating measurements with models, leading to the creation of the NERC-funded Global Aerosol Synthesis and Science Project, which has so far brought together about 15 aerosol

observation groups to build a global dataset for model evaluation. Carslaw's team has pioneered the development of new emulator-based statistical techniques (Lee et al., 2013) to quantify the sources of uncertainty in global models. Carslaw's research achievements have been recognized by the Leverhulme Prize in 2001, the Royal Society Wolfson Merit Award in 2011 and the AGU Ascent Award in 2014. In 2014 Carslaw achieved ISI Highly Cited status.

Relevant publications, and/or products, services, achievements:

Mann, G. W.; Carslaw, K. S.; Spracklen, D. V.; et al. 2010: Description and evaluation of GLOMAP-mode: a modal global aerosol microphysics model for the UKCA composition-climate model. Geoscientific Model Development 3(2), 519-551.

Thompson, Gregory; Field, Paul R.; Rasmussen, Roy M.; et al. 2008. Explicit Forecasts of Winter Precipitation Using an Improved Bulk Microphysics Scheme. Part II: Implementation of a New Snow Parameterization. Monthly Weather Review, 136(12), 5095-

Field, Paul R.; Heymsfield, Andrew J.; Bansemer, Aaron, 2007: Snow size distribution parameterization for midlatitude and tropical ice clouds. Journal of the Atmospheric Sciences, 64(12), 4346-4365.

Field, P. R.; Moehler, O.; Connolly, P.; et al 2006: Some ice nucleation characteristics of Asian and Saharan desert dust. Atmospheric Chemistry and Physics, 6, 2991-

Cui, ZQ; Carslaw, KS; Yin, Y; et al. 2006: A numerical study of aerosol effects on the dynamics and microphysics of a deep convective cloud in a continental environment. Journal of Geophysical Research-Atmospheres, 111(D5).

Relevant previous projects or activities:

BACCHUS is an EU FP7 funded project. The project aims to bring together state of the art numerical modelling and observations to improve our understanding of key aerosol cloud interaction processes. The University of Leeds is carrying out aerosol-cloud interacting simulations of arctic stratus cloud.

DACCIWA is an EU FP7 funded project understanding how growing anthopogenic emissions will affect human health, ecosystems, food security and the regional climate in South West Africa. The University of Leeds will be carrying out biomass buring aerosol-cloud interacting simulations of warm cumulus and stratus of this region.

PEGASOS is an EU FP7 funded project that is aimed at quantifying European air pollution and understanding links to global circulation and climate change. The University of Leeds will identify the most important interactions between air quality and climate using GLOMAP.

EUCAARI was an FP6 EU funded project. The objective of the project was to quantify the effect of aerosols on cloud, and air quality interactions for the present and future climate. The University of Leeds used GLOMAP to investigate aerosol processes on the European and global scale, with a focus on particle formation and effects on CCN.

ICE-D is a NERC funded project. This project will sample and characterise the ice nucleating ability of dust from the Sahara. The University of Leeds will simulate interactions between the dust and other aerosols and the cloud systems around Cape Verde.

Any significant infrastructure and/or any major items of technical equipment:

The University of Leeds has a strong collaborative relationship with the Met Office. Joint development, testing and scientific use of the Cloud and AeroSol Interacting Microphysics (CASIM) is central to our contribution to PRIMAVERA. We will make use of the supercomputing facilities based at the Met Office for the simulations.

Participant 16: Stockholms Universitet (SU)

The Department of Meteorology (MISU) at Stockholm University is part of the Bert Bolin Center for Climate research, which brings together more than 70 senior and junior scientists from the fields of meteorology, physical geography, quaternary geology, geological sciences and applied environmental sciences. The role of the Bolin Centre is to "*conduct fundamental research on critical processes in the climate system"*. The Bolin Centre was formed in 2006 and has generated more than 500 scientific articles, including 16 publications in the high-impact journals of Nature and Science. The Bolin Centre, in collaboration with the Royal Institute of Technology and the Swedish Meteorological and Hydrological Institute (SMHI), recently received a Swedish strategic research grant of 18.3MSEK/year, to strengthen Swedish climate modeling research.

Bolin Centre scientists participate in several Nordic collaborations, such as the Nordic Top-level Research Initiatives CRAICC (www.atm.helsinki.fi/craicc)/ and DEFROST (www.ncoe-defrost.org). The Bolin Centre has also sustained

international collaboration with a number of American and European research groups and participates in a large number of international projects. Researchers within the Bolin Center are also contributing to the development of aerosol and cloud process parameterizations in the earth system models EC-Earth and NorESM.

MISU will mostly contribute to WP3 within PRIMAVERA, collaborating with SMHI, UNIVLEEDS and UREAD to identify the robustness of aerosol forcing estimates, the impact of model resolution on aerosol and cloud processes as well as the importance of the complexity of the representation of these processes. Within the Bolin Centre, there is a strong focus on research related to aerosol and cloud processes, with more than 40 junior and senior scientists working on these topics.

Short profile of key personnel involved:

Dr. Annica Ekman (female) is an associate professor in the Department of Meteorology at Stockholm University. She is an expert in numerical modeling of aerosol particles and cloud processes, with more than 13 years experience of applying and developing atmospheric models on different scales, exploring a wide range of scientific problems related to aerosol processes and aerosol-cloud interaction. She has 35 publications in peer-reviewed journals, and a *h*-index of 12 (obtained from ISI Web of Science on August 8th, 2014). Of particular relevance for this project is her expertise in: (i) numerical modeling of aerosol-cloud interaction on a global scale, developing aerosol and cloud parameterizations in EC-Earth and NorESM (ii) analysis of aerosol effects on radiation and clouds in a large number of global models (output from the CMIP5 archive). Prof. Ekman's research group presently consists of seven students and researchers. She is one of the co-leaders of the "Clouds, aerosols, turbulence and climate" research area within the Bolin Centre at Stockholm University. She has been elected to represent Swedish aerosol and cloud research interests within the Nordic Association for Aerosol Research (NOSA) and the International Commission on Clouds and Precipitation (ICCP).

Relevant publications, and/or products, services, achievements:

Ekman, A. M. L. Do sophisticated parameterizations of aerosol-cloud interactions in CMIP5 models improve the representation of recent observed temperature trends? Journal of Geophysical Research, 119, 817-832, 2014

Lewinschal, A.*), **Ekman, A. M. L.**, Körnich, H. The role of precipitation in aerosol-induced changes in northern hemisphere wintertime stationary waves. Climate Dynamics, 41, 647-661, 2013

Lohmann, U., Rotstayn, L., Storelvmo, T., Jones, A., Menon, S., Quaas, J., **Ekman, A. M. L.**, Koch, D. and Ruedy, R., 2010. Total aerosol effect: forcing or radiative flux perturbation? Atmospheric Chemistry and Physics, 10, 3235-3246

Engström, A*). and **Ekman, A. M. L**. Impact of meteorological factors on the correlation between aerosol optical depth and cloud fraction. Geophysical Research Letters, 37, L18814, 2010

Ekman, A. M. L. and Rodhe, H., 2004. Regional temperature response due to indirect sulfate aerosol forcing: impact of model resolution. Climate Dynamics, 21, 1-24

*) indicates former PhD student of A. Ekman

Relevant previous projects or activities;

CRAICC (http://www.atm.helsinki.fi/craicc/) is part of the Top-level Research Initiative (TRI), the largest joint Nordic research and innovation initiative to date, aiming to strengthen research and innovation on climate change issues in the Nordic Region. A particular focus is short-lived climate forcings, including natural and anthropogenic aerosols, and their role in the Arctic climate system.

SCAC (http://www.scac.se) is a project funded by the Swedish Environmental Protection Agency. The research in the program is focused on exposure and health effects, effects on ecosystems, and climate effects from short-lived climate pollutants, as well as the synergies and conflicts between air pollution and climate action. **Dr. Annica Ekman** is a co-leader of one of the work packages within SCAC focused on large-scale modelling of aerosol effects on climate and how air pollution mitigation may affect climate.

PEGASOS (http://pegasos.iceht.forth.gr) is an FP7-funded project aiming to quantify the magnitude of regional to global feedbacks between atmospheric chemistry and a changing climate, and to reduce the corresponding uncertainty of the major ones. The project also aims to identify mitigation strategies and policies to improve air quality while limiting their impact on climate change.

Any significant infrastructure and/or any major items of technical equipment:

The Department of Meteorology at Stockholm University (MISU) currently has access to supercomputing facilities at the National Supercomputing Center (NSC) in Sweden. In particular we have access to the cluster "Triolith" with a total of 19200 cores and a peak performance of 338 Tflops/s. MISU also has access to the storage and analysis facility "Vagn" at NSC which a Linux-based cluster with seven analysis nodes and a login node, and an attached disk storage system.

Participant 17: Science and Technology Facilities Council (STFC)

The Science and Technology Facilities Council is keeping the UK at the forefront of international science and tackling some of the most significant challenges facing society such as meeting our future energy needs, monitoring and understanding climate change, and global security. The Council has a broad science portfolio and works with the academic and industrial communities to share its expertise in materials science, space and ground-based astronomy technologies, laser science, microelectronics, wafer scale manufacturing, particle and nuclear physics, alternative energy production, radio communications and radar.

As part of STFC, the Centre for Environmental Data Archival (CEDA) serves the environmental science community through four data centres and involvement in a host of projects. Through these services we aim to further environmental data archival practices and develop new web technologies to bring increased usability to the data in our archives.

CEDA is responsible for the running of the following data centres:

- **The British Atmospheric Data Centre (BADC):** NERC's designated data centre for the UK atmospheric science community, covering climate, composition, observations and NWP data.
- **UK Solar System Data Centre**: The UK Solar System Data Centre, co-funded by STFC and NERC, curates and provides access to archives of data from the upper atmosphere, ionosphere and Earth's solar environment.
- **NERC Earth Observation Data Centre**: The NEODC is NERC's designated data centre for Earth Observation data and is part of NERC's National Centre for Earth Observation. The NEODC is now known as the *CEMS-Academic* archive.
- **IPCC Data Distribution Centre:** The Intergovernmental Panel on Climate Change (IPCC) DDC provides climate, socio-economic and environmental data, both from the past and also in scenarios projected into the future. Technical guidelines on the selection and use of different types of data and scenarios in research and assessment are also provided.

STFC CEDA has many years of experience in the management of atmospheric, and other scientific data sets. We have been heavily involved in the development of national and international standards on metadata and data formatting: including the INSPIRE data specifications and the CF-netCDF Standard Name vocabulary. With multi-petabyte data holdings, STFC CEDA is also equipped to support the requirements of big data projects such as UPSCALE. The JASMIN platform provides the infrastructure to deliver large collaborative disks and batch processing systems to the project team. The STFC CEDA data centres are tasked with curation of data sets and dissemination into the medium and long-term.

Short profile of key personnel involved:

Mr Ag Stephens (male) - [Work Package 9 Co-leader] - Head of Partnerships, CEDA, has coordinated the BADC and Met Office Hadley Centre efforts during the previous UK Government (Defra and DECC) contracts leading up to this proposal. Ag has ten years experience in data management, software development and project leadership. He coordinated, and co-developed, the data services that underpin the UK Climate Projections User Interface for the UK government. Working on a long-term secondment at the Met Office, Ag works closely with the Met Office Hadley Centre to ensure a high level of integration between these two partner organisations in PRIMAVERA. Ag has an MSc in Atmospheric Science.

Dr Charlotte Pascoe (female) -Senior Data Scientist (Models), CEDA, has experience of working as a climate scientist and data manager relating to climate models and simulations. As a key player in the EU FP7 METAFOR Project, Charlotte coordinated the effective delivery of the climate model metadata questionnaire that is currently deployed to capture detailed information about both climate models and the simulations that they output. She manages content in the IPCC DDC website, promotional literature, and has presented at IPCC TGICA meetings. Charlotte has a PhD in Meteorology.

Mr Andrew Harwood (male) - Infrastructure Manager, CEDA, has over a decade of experience in developing and managing operational software to deliver data and metadata services. He supports a variety of CEDA software

systems and oversees many user-facing web-tools provided by the BADC. Andrew has a degree in physics and an MSc in Medical Physics and Information Technology.

Dr Alison Waterfall (female) – Earth Observations Data Scientist, has a background in the remote sensing of atmospheric composition. Her responsibilities include supporting CEDA users via the CEDA and CEMS helpdesks, ingestion of Earth Observation datasets of relevance to the NCEO community, and involvement in the EU FP7 GMES-Pure project, which is developing a process for collecting user requirements for GMES services. She obtained a DPhil in Atmospheric Physics from the University of Oxford, and has 13 years of experience in the field of atmospheric remote sensing.

Relevant publications, and/or products, services, achievements:

Lawrence, B.N. , V.L. Bennett, J. Churchill, M. Juckes, P. Kershaw, S. Pascoe, S. Pepler, M. Pritchard, and A. Stephens. Storing and manipulating environmental big data with JASMIN. To appear in Proceedings of IEEE Big Data 2013. (http://home.badc.rl.ac.uk/lawrence/static/2013/10/14/LawEA13_Jasmin.pdf)

Lawrence, B.N., V. Bennett, J. Churchill, M. Juckes, P. Kershaw, P. Oliver, M. Pritchard, A. Stephens (2012). The JASMIN super-data-cluster. arXiv e-print: http://arxiv.org/abs/1204.3553

Lawrence, B.N., Bennett, V.L., Churchill, J., Juckes, M., Kershaw, P., Pascoe, S., Pepler, S., Pritchard, M. & Stephens, A. 2013 IEEE International Conference on Big Data. Publication Year: 2013, Page(s): 68 – 75, IEEE Conference Publications. DOI: 10.1109/BigData.2013.6691556

Stephens, A., James, P., Alderson, D., Pascoe, S., Abele, S., Iwi, A. & Chiu, P. (2011). The challenges of developing an open source, standards-based technology stack to deliver the latest UK climate projections. International Journal of Digital Earth. DOI: 10.1080/17538947.2011.571724

Relevant previous projects or activities:

InfraStructure for the European Network for Earth System Modelling - Phase 2 (IS-ENES2) – CEDA leads the "Developing software infrastructure for data archive services" work package, co-leads the "ENES Climate Data Services" work package, and is involved in networking activities, particularly those associated with development of the Common Information Model for model documentation.

Climate Information Portal for Copernicus (CLIPC) – Co-ordinator. The CLIPC platform will complement existing GMES/Copernicus pre-operational components by providing access on decadal to centennial climate variability data (i.e. satellite and in-situ observations, climate models and re-analyses, transformed data products) to a wide variety of users. Supporting data quality and related information will also be made available. As well as co-ordinating CLIPC, CEDA leads the access to climate data work package. This work package will provide the software infrastructure to create a single point of access for climate model data from various sources: climate model data, in situ and satellite observations, and re-analyses.

Intergovernmental Panel on Climate Change Data Distribution Centre (IPCC DDC) – The DDC provides climate, socio-economic and environmental data, both from the past and scenarios projected into the future. Technical guidelines on the selection and use of different types of data and scenarios in research and assessment are also provided. The DDC is designed primarily for climate change researchers, but materials contained on the site may also be of interest to educators, governmental and non-governmental organisations, and the general public. The DDC is overseen by the IPCC Task Group on Data and Scenario Support for Impact and Climate Analysis (TGICA) and jointly managed by the British Atmospheric Data Centre (BADC) in the United Kingdom, the CSU World Data Center Climate (WDCC) in Germany, and the Center for International Earth Science Information Network (CIESIN) at Columbia University, New York, USA. The data are provided by co-operating modelling and analysis centres. (see: http://www.ipcc-data.org/).

5th Coupled Model Intercomparison Project (CMIP5) - CEDA provides the UK "Data Node" for publishing and disseminating data sets for CMIP5. CEDA hosts an archive of around half a petabyte of data sets from around the world. CEDA participates in an international federation of Data Centres (known as the Earth System Grid Federation, or ESGF) that works collaboratively to develop and maintain a global infrastructure for data services and dissemination systems.

Any significant infrastructure and/or any major items of technical equipment:

PRIMAVERA proposes to use the STFC CEDA compute and storage platform known as JASMIN. The platform will provide a large collaborative "workspace" using high-performance disk, project-specific Virtual Machines and a large compute cluster (LOTUS) for parallel processing. Additionally, JASMIN/CEMS provides co-location with a

number of other important data sets (such as the CMIP5) for long-term data curation. Data management within PRIMAVERA will utilise this platform to provide an end-to-end capability for data transferral, processing, ingestion and dissemination. The project consortium will be provided with the following hardware and processing capability:

Facility/hardware	Provided to this project
Group Workspace	Read/write access to up to 1 Petabyte of high-performance disk available to project partners accessible to: hosted processing and transfer nodes.
Hosted processing	Project-specific Virtual Machines and access to the large LOTUS parallel processing cluster as required.
Transfer details	Access to the JASMIN transfer servers to put/get data to/from remote sites. Access to the Met Office MASS archive client on JASMIN.
Archival of final products	Facility to migrate core PRIMAVERA outputs into the long-term archives of BADC and ESGF.
Tape usage/media	Allocation of 100 Terabytes of tape media for managed backup and staging of datasets.

Participant 18: Predictia Intelligent Data Solutions SL (PREDICTIA)

Predictia is an SME that emerged as a spin-off from a data mining group at the Universidad de Cantabria (Spain). Its mission is to offer data management and mining solutions for problems in scientific disciplines that require specialised skills in storage, access, visualization, and non-standard data mining techniques for extracting relevant information from data.

Predictia offers software solutions based on web technologies, including the development of portals for data access, visualization and online data mining algorithms. The company has participated in several national and international research projects including FP7 Projects like METAFOR and EUPORIAS. Predictia maintains a core of R&D as a key driver of competitiveness of their products.

For PRIMAVERA, Predictia will use their expertise and past experience to create an effective User Interface Platform (UIP) under WP11. This novel deliverable will allow end-users to engage with each other, PRIMAVERA results and PRIMAVERA partners.

Short profile of key personnel involved:

Daniel San Martín (Male) studied Telecomunication Engineering at the University of Cantabria and has a Masters degree in Mathematics and Computation. He is a co-founder of Predictia where he currently works as CEO. Since 2006 he has been involved in the development of web based climate data management portals. Currently his main research interests are the development of innovative data visualization techniques in scientific sectors like climatology. He has participated in several European Projects such as ENSEMBLES, EUPORIAS and METAFOR.

Max Tuni (Male) studied Telecomunication Engineering at the University of Cantabria and has a Masters degree in Mathematics and Computation. He has worked at Instituto de Física de Cantabria involved in several national research programs. He has very high-end computing skills, specialising in database management and ETL processes.

Relevant publications, and/or products, services, achievements:

The Downscaling portal: In collaboration with the Universidad de Cantabria, Predictia has developed the current version of the Downscaling Portal. This portal provides a user-friendly web access to different statistical downscaling techniques, and works transparently with the observations, reanalysis and global climate simulations. The portal has been successfully used in several FP7 projects for studying climate change impact in fire (FUME) and health (QweCI).

Confiño, A. S., San-Martín, D. and Gutiérrez, J. M. (2007). "A web portal for regional projection of weather forecast using GRID middleware', Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), 4489 LNCS(82-89).

Gutiérrez, J.M., San-Martín, D., Herrera, S., Cofiño, A.S. (2013). "The Statistical Downscaling Portal. An End-to-End Tool for Regional Impact Studies". International Conference on Regional Climate - CORDEX 2013

Relevant previous projects or activities:
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FP7 **EUPORIAS**: Predictia is participating in this project and leads the stakeholder engagement work package, which aims to engage with EU citizens and businesses (including SMEs) about how seasonal to decadal information can be used in everyday decision making, facilitate clear communication and information exchange with the stakeholders and demonstrate ways in which a climate service can be developed to address specific users' needs. Within EUPORIAS, Predictia is working on the development of web user interfaces for climate information.

MOSAICC: is a system of models and utilities, developed by the FAO, designed to carry out inter-disciplinary climate change impact assessment on agriculture through simulations. Predictia has worked to adapt the Downscaling Portal in order to provide regional climate projections to MOSAICC models.

Value COST Action: Predictia is developing a Value Validation Portal to allow users to validate statistical downscaling techniques within a common framework.

Meteocantabria: Predictia developed this website for the Goverment of Cantabria (a Spanish autonomous community). It contains local meteorological and climate information for this region, from many different sources and makes it available for re-use.

Participant 19: Deutches Klimarechenzentrum GMBH (DKRZ)

The German Climate Computing Centre DKRZ is national centre dedicated to providing computer and data management services for climate research. DKRZ is leading partner in the FP7 project IS-ENES2, which fosters simulations with global earth system models and also in the German BMBF-HDCP2 project focusing on cloud resolving models. The institute made a major contribution to the execution, coordination and quality control of the German simulations for the Coupled Model Intercomparison Project especially CMIP5.

In PRIMAVERA, DKRZ will contribute to WP4 and WP6, building on its long standing expertise in the execution and tuning of the whole workflow of coupled climate model simulations.

DKRZ is a non-profit and non-commercial limited company with four shareholders. MPG (Partner 6) holds 55% and AWI (Partner 10) 9% of the shares of DKRZ (see http://www.dkrz.de/about-en/Organisation/gesellschafter for more references). The dependency relationship has been declared in the Part 2 –Administrative data of participating organisation of this application form.

Short profile of key personnel involved:

Dr. Joachim Biercamp (male) is physical oceanographer and has been leading the application department of DKRZ for more than 20 years. He is a principal investigator for the IS-ENES2 project and member of the steering committee of the BMBF-HDCP2 project. He is also coordinating acquisition and deployment of DKRZs high performance computers.

Irina Fast (female) is a climate scientist, with a strong background in meteorology and over 10 years experience in climate research. Most recently her focus has been on performance analysis and optimization of MPI-ESM at different horizontal resolutions. She played key role in configuration, running and analysis of high-resolution MPI-ESM simulations within German national project STORM. Currently, she is contributing to the EU FP7 project IS-ENES2.

Dr. Kerstin Fieg (female) is a climate scientist, with a strong background in meteorology and over 20 years experience in climate research. She played a key role in the realization of the German contribution of IPCC cmip5. Recently her research interests have moved from the development, configuration and execution of climate models (e.g. FESOM / ECHAM) to development and configuration of workflows for climate science as well as management of projects (e.g. BMBF-Scales & BMBF-HD(CP)2 work package lead / EU FP7 project IS-ENES2).

Relevant publications, and/or products, services, achievements:

Adamidis, P., I.Fast, and T.Ludwig, 2011: Performance Characteristics of Global High-Resolution Ocean (MPIOM) and Atmosphere (ECHAM6) Models on Large-Scale Multicore Cluster. In Parallel Computing Technologies - 11th International Conference, PaCT 2011, Kazan, Russia, September 19-23, 2011. Proceedings, Lecture Notes in Computer Science (6873), pp. 390–403, (Editors: V. Malyshkin), Springer, PaCT, Kazan, Russia, ISBN: 978-3-642-23177-3, DOI: 10.1007/978-3-642-23178-0

Hertwig, E., J.-S. von Storch, D. Handorf, K. Dethloff, I. Fast, and T. Krismer, 2014: Effect of horizontal resolution on ECHAM6-AMIP performance, submitted to Climate Dynamics

Von Storch, J.-S., C. Eden, I. Fast, H. Haak, D. Hernandez-Deckers, E. Maier-Reimer, J. Marotzke, and D. Stammer, 2012: An estimate of the Lorenz energy cycle for the world ocean based on the 1/10o STORM/NCEP simulation. J. Phys. Oceanogr. 42, 2185-2205

D. Sidorenko, T. Rackow, T. Jung, T. Semmle, D. Barbi, S. Danilov,K. Dethloff, W. Dorn, K. Fieg ,H. F. Goessling, D. Handorf, S. Harig, W. Hiller, S. Juricke, M. Losch, J. Schröter, D. V. Sein & Q. Wang (2014): Towards multi□resolution global climate modeling with ECHAM6–FESOM. Part I: model formulation and mean climate, Clim Dyn, DOI 10.1007/s00382-014-2290-6

Stevens, B., Giorgetta, M. A., Esch, M., Mauritsen, T., Crueger, T., Rast, S., Salzmann, M., Schmidt, H., Bader, J., Block, K., Brokopf, R., Fast, I., Kinne, S., Kornblueh, L., Lohmann, U., Pincus, R., Reichler, T., & Roeckner, E. (2013). Atmospheric component of the MPI-M Earth System Model: ECHAM6. Journal of Advances in Modeling Earth Systems, 5, 146-172

Relevant previous projects or activities:

SCALES: (http://www.dkrz.de/Klimaforschung/dkrz-und-klimaforschung/infraproj/scales/scales) The project aimed to identify and solve scaling problems common to many model codes in coupled climate modelling. A key objective was to establish a prototypical, flexible and highly scalable ESM of production quality. Furthermore, a special focus was the conception and implementation of generic library components that facilitate efficient use of climate models on modern HPC architectures, especially with respect to I/O and communication within highly parallel applications.

HD(CP)2 (http://hdcp2.zmaw.de) is a BMBF funded German-wide research initiative to improve our understanding of cloud and precipitation processes and their implication for climate prediction. HD(CP)2 intents to build and use a model capable of very high-resolution simulations, i.e., horizontal grid spacing of 100 m, and intends to run hindcast experiments to compare the results to observation data. The aim is to advance the parameterization of clouds and precipitation, and to reduce uncertainty in climate projections related to cloud and precipitation quantities.

IS-ENES2 (https://verc.enes.org/ISENES2/) is the second phase of the infrastructure project of the European Network for Earth System Modelling (ENES). Main tasks are fostering the integration of European climate and Earth System modeling community; enhancing the development of Earth System Models for the understanding of climate variability and change, supporting high-end simulations for better understanding and prediction of climate variations and change.

STORM (https://verc.enes.org/storm) is a German national project that dealt with development, tuning, performance and evaluation of first climate simulations with the global Earth System Model MPI-ESM at resolutions significantly higher than used in CMIP5. The project has produced a set of stand-alone and coupled simulations that are available to scientific community for analysis. Achievements and experiences made within the STORM project provide a valuable basis for work targeted in the PRIMAVERA project.

Description of any significant infrastructure and/or any major items of technical equipment:

In early summer 2015, DKRZ will install a new BULL computing system that will deliver six times the application performance compared to its predecessor (IBM-Power6). In spring 2016 the computing system will be upgraded to more than 60,000 processor cores on the basis of B700 DLC Blades distributed over 60 Racks. It will achieve a peak performance of more than 3 petaflops.

The system will be equipped with a world leading amount of more than 50 PByte of usable disc storage and a tape archive with a capacity of several 100 PByte.

Staff at DKRZ provide a full range of services (e.g. Porting, Tuning, Data Management, Visualisation) to the users of its systems.

Participant 20: National Meteorological Administration

The National Meteorological Administration (NMA) of Romania is a state funded institute dealing with weather and climate information and research in Romania. NMA has participated in EC funded climate research projects including the FP6 project ENSEMBLES.

In PRIMAVERA, NMA will conduct research previously allocated to SMHI in WPs 1 and 2, but which moved to NMA due to a change by the researcher named below.

Short profile of key personnel involved:

Dr Mihaela Caian (female) – Research Scientist at the Rossby Centre. She has experience in global and regional climate modelling and works presently on decadal climate prediction. She is involved in both the SPECS project and the EMBRACE project.

Section 4.2: Third parties involved in the project (including use of third party resources)
There are two third party arrangements involved in PRIMAVERA.

1. Third party (ICREA) and their relation to PRIMAVERA partner BSC has been described below.

BSC applies a Third Party modality where the third party is making its resources available to the beneficiary under *Article12 of the Grant Agreement - Use of in-kind contributions provided by third parties free of charge*.

According to this situation, the third party, the Institut Català de Recerca i Estudis Avançats (ICREA) will not carry out any part of the work and just lends resources to the beneficiary. These resources are directly used by the beneficiary, the work is performed in its premises and there is no reimbursement by the beneficiary to the third party. The third party makes available some of its resources to the beneficiary, which does not reimburse the cost to the third party, but which charges the costs of the third party as an eligible cost of the project. Its costs will be declared by the beneficiary in its Form C but must be recorded in the accounts of the third party. In that context, ICREA resources corresponding to dedicated time of Prof. Francisco J. Doblas-Reyes (ICREA personnel) will be available for the whole duration of the project, mainly for RTD activities.

Prof. Francisco J. Doblas-Reyes is the Director of the Earth Science Department which brings together around 50 people working on the prediction of global weather, climate and air quality, as well as in the analysis of the computational efficiency of Earth science codes

In accordance with the budget of the project, an indicative effort of 18PM is allocated to this arrangement. This represents about 8% of the total estimated personal efforts for BSC.

Description of Institució Catalana de Recerca i Estudis Avançats (ICREA)

ICREA, Catalan Institution for Research and Advanced Studies, is a foundation supported by the Catalan Government and guided by a Board of Trustees. It was created in response to the need to seek new hiring formulas that would make it possible to compete with other research systems on a similar if not an equal footing.

ICREA's aim is to recruit top scientists for the Catalan R&D system, scientists capable of leading new research groups, strengthening existing groups, and setting up new lines of research. It works closely with Catalan universities and research centres based in Catalonia by means of long-term agreements that allow ICREA researchers to integrate in research groups within these universities and centres.

2. Implementation of action tasks by sub-contractor to KNMI.

KNMI are planning to sub-contract an element of the PRIMAVERA work. The sub-contractor will carry out some of the experiments as described in WP6 (in particular against Tasks T6.3, T6.4, T6.5, T6.6, T6.7 and T6.8). This includes setting-up the experiments, running them, data storage and post-processing with quality control. These experiments are at the edge of present computing capabilities, therefore this requires deep knowledge of High Performance Computing (HPC) infrastructure and the optimal use of it. The sub-contractor would need this knowledge and would be supporting the design of the optimal experimental set-up and performing the experiments. The sub-contractor will also participate in WP3 which involves the technical modification of a model component by the inclusion of a routing scheme. The experiments will be done at KNMI using the KNMI HPC infrastructure.

KNMI has identified the Netherlands e-Science center as an appropriate organisation to carry out these tasks. The e-Science center has the specific skills for HPC computing and the processing of very large datasets. These are focus points of the e-Science center as it is a non-profit organisation with a mission to support universities and research centres in this area. However, KNMI will comply with the applicable national law on public procurement procedures and the rules for sub-contracting as laid out in the H2020 General Model Grant Agreement (Article 13). This includes awarding the subcontract under conditions of transparency and equal treatment and ensuring the best value for money.

Section 5: Ethics and Security

5.1 Ethics

The project has considered the Ethics criteria in Annex A. The nature of the research proposed under PRIMAVERA means that there are few ethical issues. Consideration has been given to the end-users who will be involved in the research, and only organisational data will be collected as opposed to any personal data. Where commercially sensitive data is concerned, this will be identified and the relevant information will be withheld accordingly. All research information will be gathered in accordance with guidelines laid down by the European Commission, and in accordance with the guidelines of the partner conducting the research (BSC).

In addition to this, PRIMAVERA will provide Ethics Documentation (D7.6) by Month 2 of the project which will describe in detail the procedures that it will adhere to for identifying and recruiting research participants and for informed consent. These processes will then be followed by WP11.

5.2 Security

Please indicate if your project will involve:

- activities or results raising security issues: NO
- 'EU-classified information' as background or results: NO