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PRIMAVERA

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PRocess-based climate sIMulation: AdVances in high resolution modelling and European climate Risk Assessment

Deliverable D*4.3*

Improved representation of atmospheric processes

Deliverable Title	Progress summary following review of WPs	
Brief Description	*Summarising work on atmospheric processes within WP4, in particular microphysics and lightning*	
WP number	4	
Lead Beneficiary	*ULEEDS*	
Contributors	*Paul Field, Daniel McCoy, Malcolm Roberts*	
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Nature of the Deliverable	R	*R - Report*
		P - Prototype
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		O - Other
Dissemination Level/ Audience	PU	*PU - Public*
		PP - Restricted to other programme participants, including the Commission services
		RE - Restricted to a group specified by the consortium, including the Commission services
		CO - Confidential, only for members of the consortium, including the Commission services

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1. Executive Summary

This report is a brief summary of work done within WP4 on the representation of atmospheric processes, specifically microphysics at km-scale and the direct representation of lightning, and the impacts on European climate via cloud-aerosol- microphysics-precipitation interactions. There are Implications for climate risk due to changes in electrical storms in present day and future climate

2. Project Objectives

With this deliverable, the project has contributed to the achievement of the following objectives (DOA, Part B Section 1.1) WP numbers are in brackets:

No.	Objective	Yes	No
A	To develop a new generation of global high-resolution climate models. *(3, 4, 6)*	X	
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)*	X	
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)*		x
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)*	y	
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)*	y	
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)*		n
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)*		n
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)*		n

3. Detailed Report on Progress

The University of Leeds (UoL) team utilized high-resolution simulations performed under the auspices of PRIMAVERA to publish work describing how model resolution impacts lighting, midlatitude weather and precipitation, aerosol-cloud interactions (aci), as well as future global and midlatitude climate via improved midlatitude cloud feedbacks.

3.1 Lightning and diurnal cycle of precipitation

For the high resolution convection permitting simulations (HadGEM3-GA7.1 Walters et al., 2019; N1280, dx~10km) a physically based lightning parametrization that uses information about the ice and graupel amounts was used to generate a lightning climatology (Field et al. 2018; Fig. 1). For the first time the global simulations capture the strong diurnal flash rate variation (see video in references) as well as the seasonal modulation.

Comparisons with observed ground-based (World Lightning Location Network) and satellite-based (LIS: Lightning Imaging Sensor & OTD: Optical transients detector) climatologies show that the model generally captures the temporal behavior and spatial distribution of the lightning over land, but appears excessive for the ITCZ over the ocean.

Using these same 10km simulation, with and without convective parameterisation, the phase of the diurnal cycle of precipitation over Europe was examined. Parameterisations of convection typically make peak rainfall occur too early in the day, particularly in tropical regions (Birch et al. 2015), which can also change the surface radiation budget and potentially soil moisture. The phase of the diurnal cycle is shown in Fig. 2 for observations and these two simulations. In summer over much of Europe there is a clear signal for rainfall to occur in late afternoon. The explicit convection simulation begins to capture some of this signal, while the parameterised simulation rains around midday. Further analysis was attempted on the surface radiation budget, but it was found that by switching off the convection parameterisation the global radiation budget is changed by a large amount (several W/m^2). We did not have resources to complete further tuned simulations, and hence the impact on the surface energy budget is left for future work.

3.2 Aerosol-cloud interactions

Investigation of aci by the UoL team focused on the effects of aerosol-cloud adjustments, which are not well-constrained in either magnitude or even in the expected sign of their radiative forcing on climate during the industrial era (Bellouin, Quaas et al. 2019). The team utilized convection-permitting resolution (Δx~7km midlatitude) simulations in the MetOffice Unified Model (UM) to examine the effect of resolved aerosol-cloud adjustments in midlatitude cyclones. These results are published in McCoy, Field et al. (2018) and show that when synoptic state is accounted for, increasing aerosol increases cyclone liquid content (a negative forcing during the industrial era, Fig. 1). In order to enable this analysis the UoL team needed to characterize uncertainty in measurements of cloud microphysical state. The team published a paper showing that remotely-sensed cloud droplet number concentration (CDNC) is robust and agrees well with data sources describing aerosol sources (McCoy, Bender et al. 2018). This allowed the UoL team to contrast the observed response of cloud macrophysics to cloud microphysics (aerosol-cloud adjustments) with simulations. One key result of the UoL team's analysis was that precipitation rate was a crucial factor that must be accounted for to unveil aerosol-cloud adjustments. Controls on extratropical cyclone (EC) precipitation are well-characterized by synoptic state. When not in a cyclone precipitation rate is low and difficult to predict. The UoL team developed a novel analysis methodology utilizing simulations in the UM to examine aerosol-cloud adjustments in the midlatitudes outside of ECs to allow a unified description of extratropical aerosol-cloud adjustments. These results are described in McCoy, Field et al. (2019) and demonstrate that aerosol-cloud adjustments in the outside of cyclone regime lead to a thickening of liquid cloud (a negative radiative forcing during the industrial era). These results are focused on the midlatitudes and thus provide a description of how changing aerosol in the NH has affects on weather systems and climate in the European region via the formerly poorly-constrained aerosol-cloud adjustment.

In developing novel constraints on aerosol-cloud adjustments in the midlatitudes (see above) the UoL team developed an improved characterization of extratropical cloud and precipitation variability. The UoL team utilized these insights to work with convection-permitting resolution simulations in the UM, in PRIMAVERA models, and in convection-permitting simulations provided by other partner institutions to predict changes in cyclone cloud and precipitation in warmed climates. These results are published in McCoy, Field et al. (2019). Cloud liquid content in extratropical cyclones is predicted to increase in response to warming (a negative cloud feedback) and precipitation is predicted to increase. The primary factor controlling these effects was found to be increased moisture convergence driven by increased atmospheric water vapor. It was found that higher-resolution simulations trended to more realistic behaviour in terms of cloud feedback on warming compared to low-resolution (Δx~100 km) simulations.

These results were leveraged to create a unified description of response in midlatitude cloud cover to warming in McCoy, Field et al. (2020). The results in this submitted study show that the extratropical shortwave cloud feedback is confidently negative and is primarily driven by changes in extratropical cyclones (a summary is shown in Fig. 1). Constraining the extratropical shortwave cloud feedback is important because it is the primary source of increased climate sensitivity between CMIP5 and CMIP6 (Zelinka, Myers et al. 2020). Results from McCoy, Field et al. (2020) suggest that extratropical cloud feedback in CMIP6 is more realistic. The characterization of midlatitude cloud feedback and precipitation changes in these studies is of broad relevance to the European community because it is important to regional and global climate change.

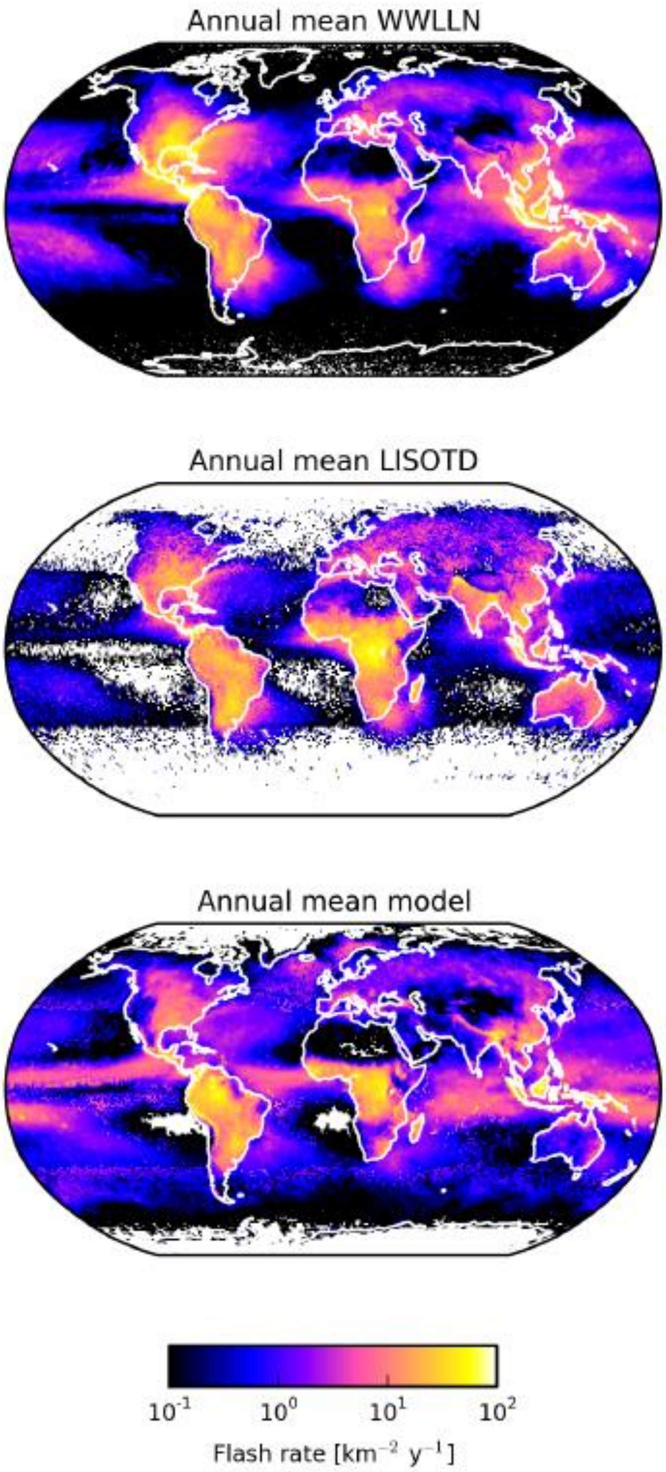

Figure 1 Annual flash rate from (top) radio time of arrival World Wide Lightning Location Network, (middle) optical satellite based detection (LIS-OTD) and (bottom) from the convection permitting global model.

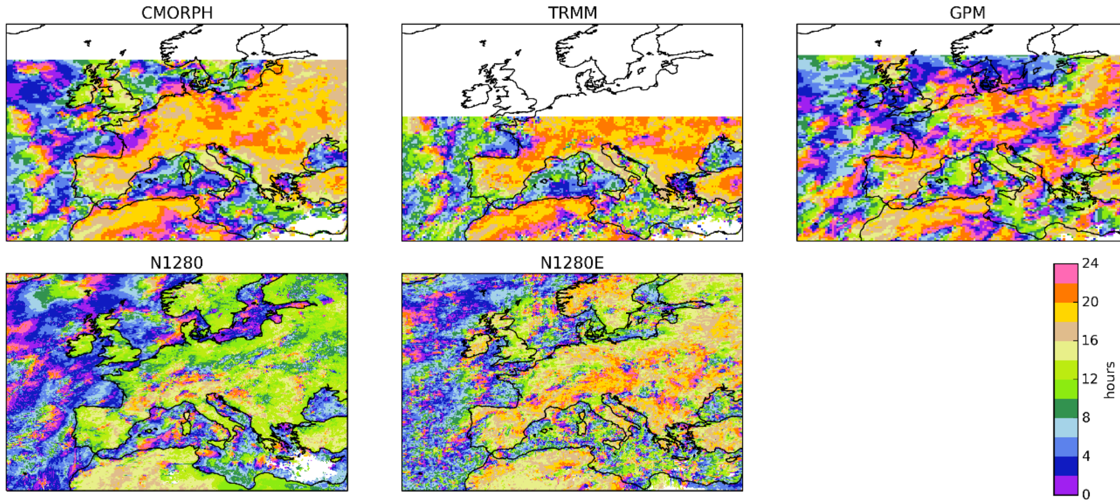

Fig. 2: Phase of diurnal cycle of precipitation over Europe during June-July-August (hours, local solar time) from three observational/satellite products (CMORPH, TRMM and GPM), together with two model simulations at ~10km resolution with convective parameterisation (N1280), and with explicit convection (N1280E).

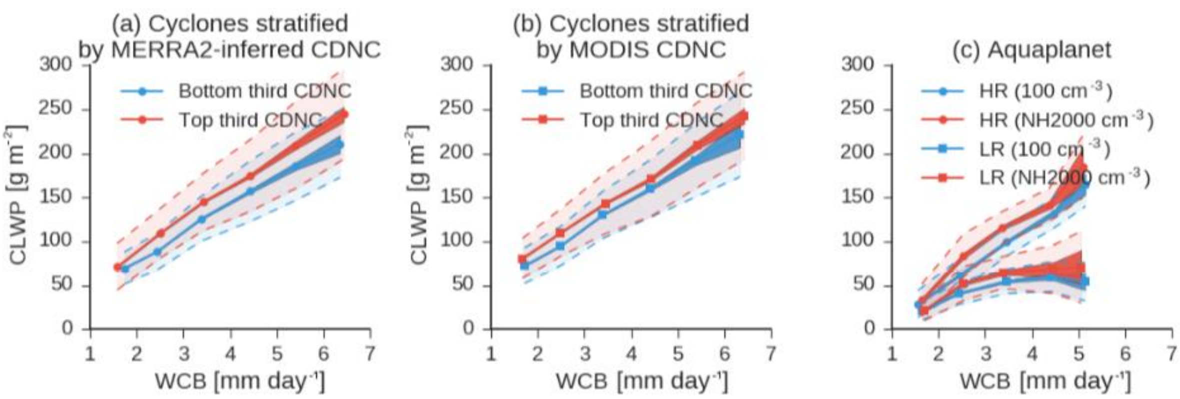

Fig. 3 Results from McCoy, Field et al. (2018) demonstrating stratification between polluted (high CDNC) and pristine (low CDNC) cyclones as a function of warm conveyor belt moisture flux (WCB). Stratification of observations by reanalysis sulfate mass is shown in (a), by observed CDNC is shown in (b), and in high- and low-resolution instances of the UM is shown in (c). These results demonstrate improved agreement between observationally-inferred aerosol-cloud adjustments and model predictions at convection-permitting resolution.

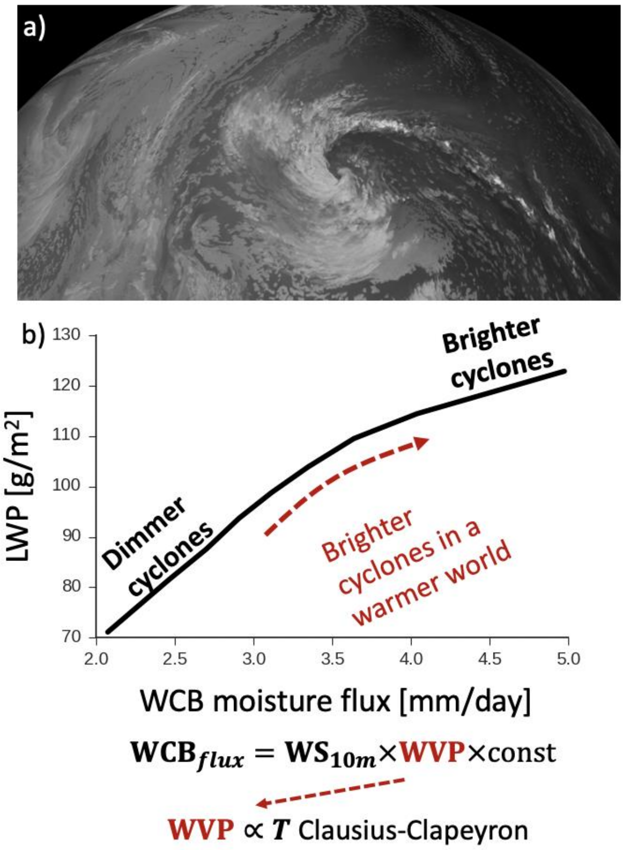

Fig. 4 An illustration of insight into extratropical cloud feedbacks based on convection-permitting model output (model output is shown in a). The moisture flux along the warm conveyor belt (WCB) of a cyclone plays a central role in determining cyclone cloud liquid water path (LWP) (b). Because WCB scales with water vapor path (WVP) and surface wind speed, WCB moisture flux increases following Clausius-Clapeyron and predicts a negative extratropical cloud feedback.

4. Future directions

The additional physics complexity used in some of the simulations described above currently requires both very high horizontal resolution (such that the convective parameterisation can be switched off and hence enable additional hydrometeors such as graupel, required for lightning), and very expensive microphysics scheme (CASIM). There is work ongoing at the Met Office and the University of Leeds to incorporate some of these features into lower resolution models which retain the convective parameterisation. An ambition is that these will be incorporated into simulations for CMIP7.

Further analysis of explicit convection simulations, when it is possible to keep the global radiation budget better balanced, is required to assess the impact on surface energy, soil moisture and other variables. Rainfall later in the day may be able to keep soil wet at night and have an impact on night-time temperatures. However, current models are tuned for the convection parameterisation so this analysis is compromised. In addition, once better simulations are possible without convective parameterisation (or with a more scale-aware scheme which is able to switch itself off when resolution is sufficient), it would be interesting to produce future timeslice simulations to examine the impact of improved diurnal cycle on future climate in a global configuration.

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