From AR5 to AR6 Priorities for modelling (Physical system)

John Mitchell, MetOffice Hadley Centre

CRESCENDO/PRIMAVERA meeting, Exeter 24-25th November,2015

PRIMAVERA AIMS

a. To develop a new generation of global **high-resolution** climate models.
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.
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.
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).
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.
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.
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.
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.

-Climate research with high resolution models

CMIP5 resolution

- **Atmosphere**

  Typically 200 – 100km

  Highest 25, 20km atmosphere only

  Typically 40-50 levels (from 19 to 95)

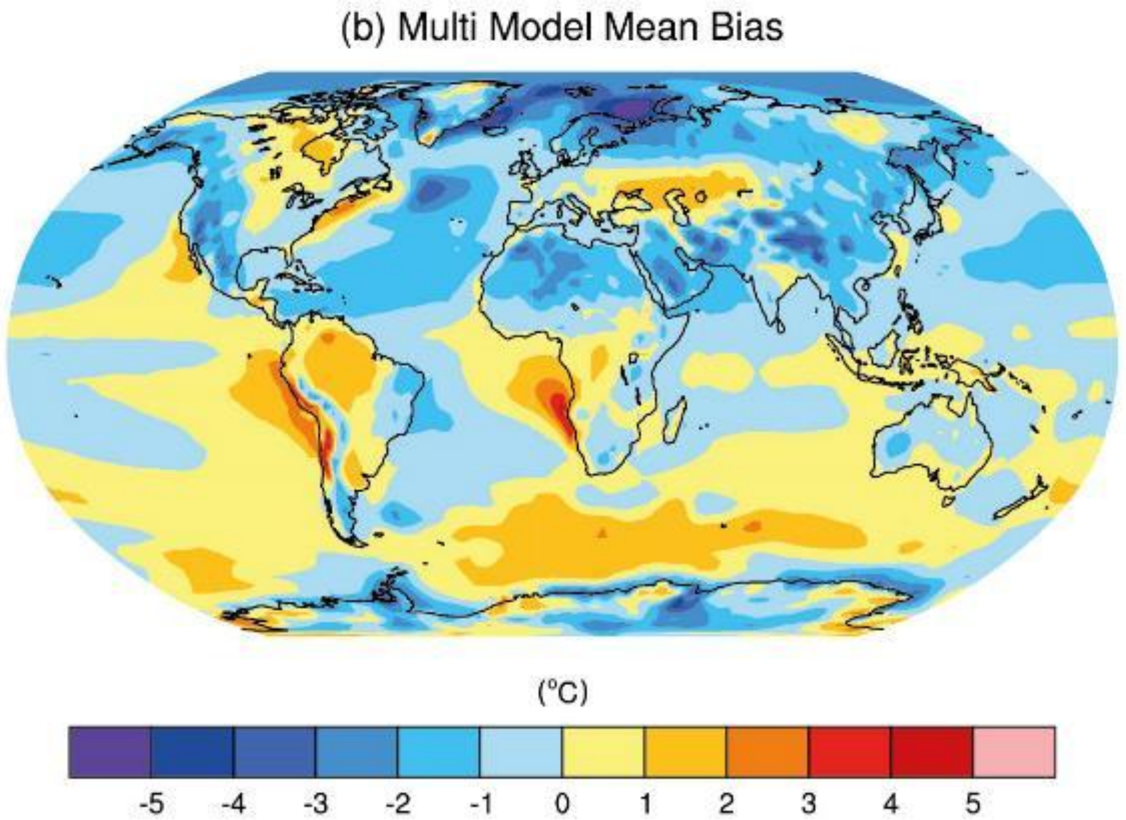
- **Ocean**

  Typically 1^0, down to $1/3^0$ in tropics

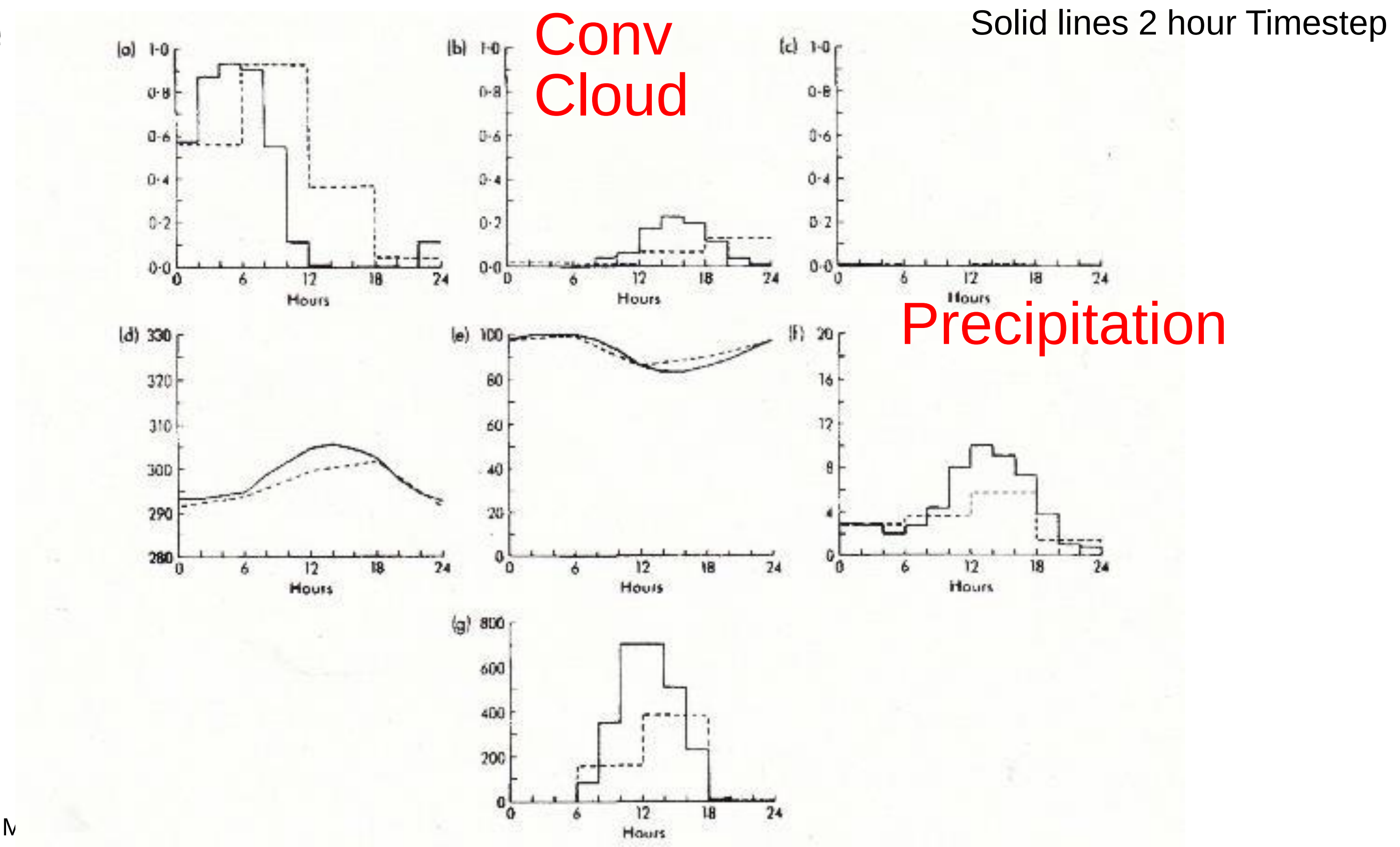
  Highest $1/4^0$x $1/6^0$

  Typically ~40 levels

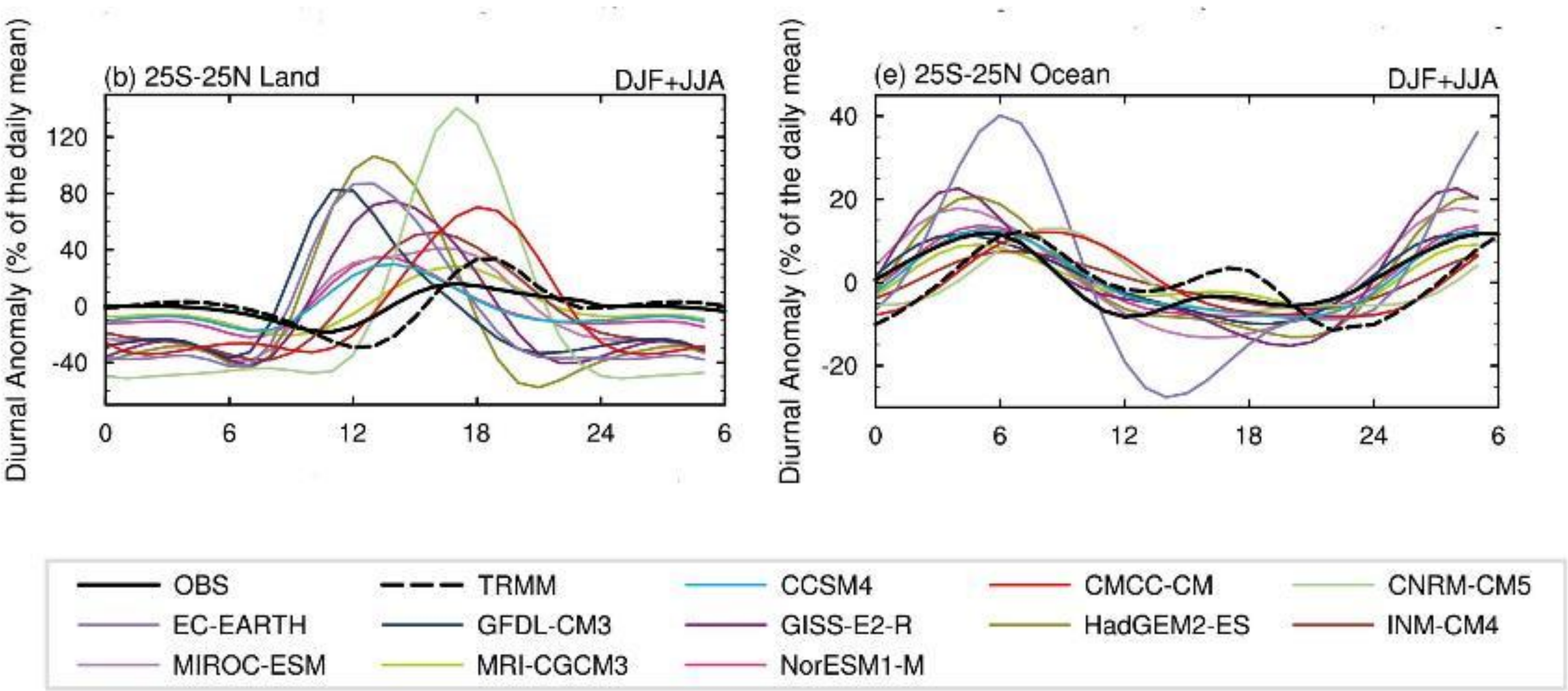
Modelling for AR5
Systematic Errors in CMIP5 - examples



Simulated Diurnal cycle 19.5N 0W July

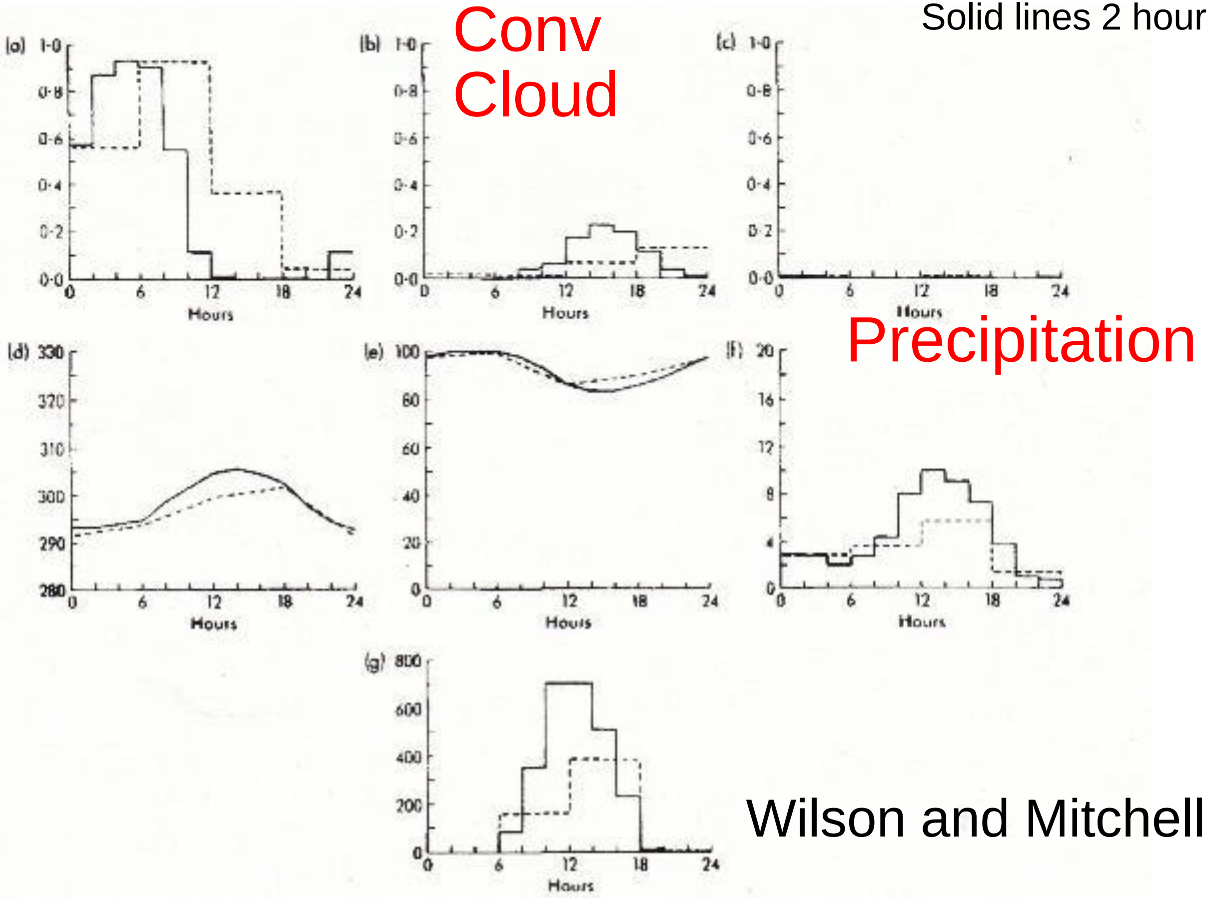


Diurnal cycle of precipitation



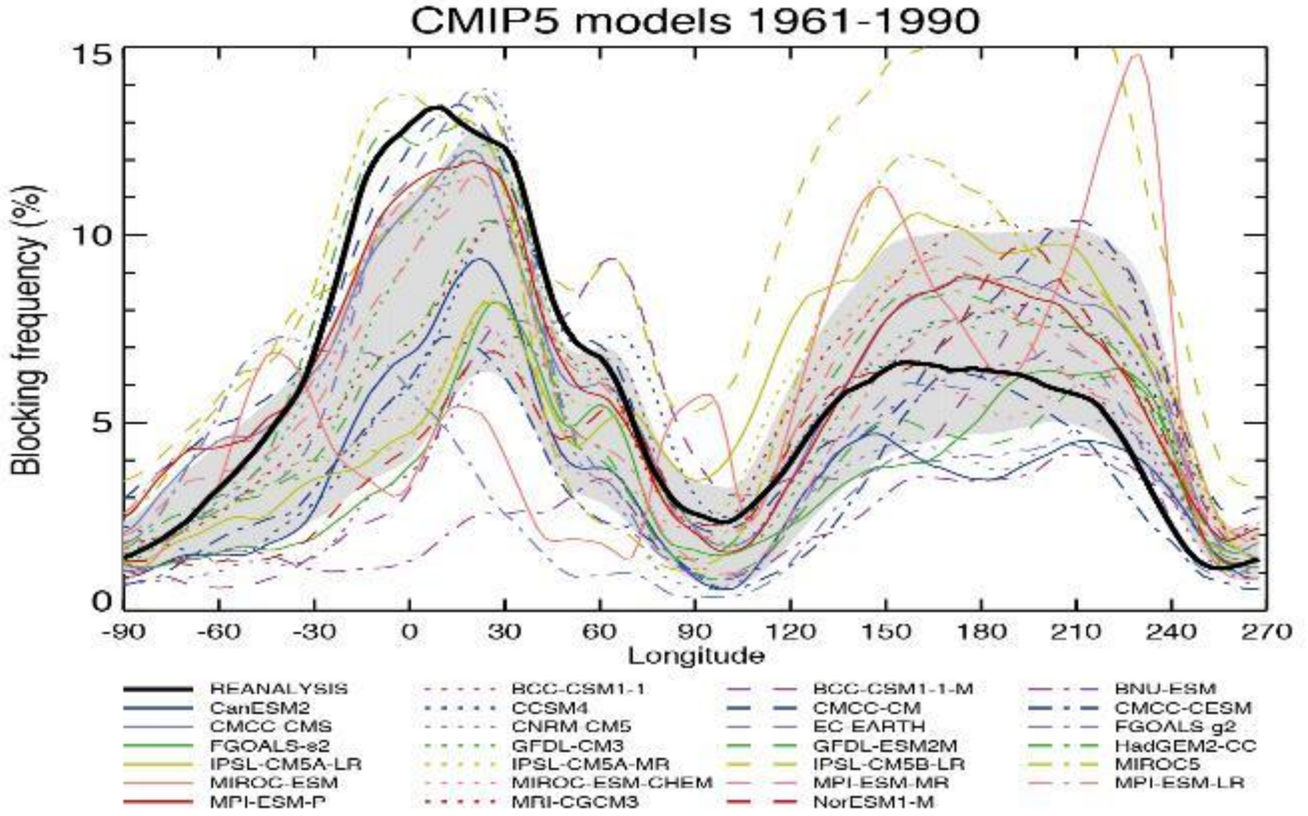
Simulated Diurnal cycle 19.5N 0W July

Solid lines 2 hour Timestep

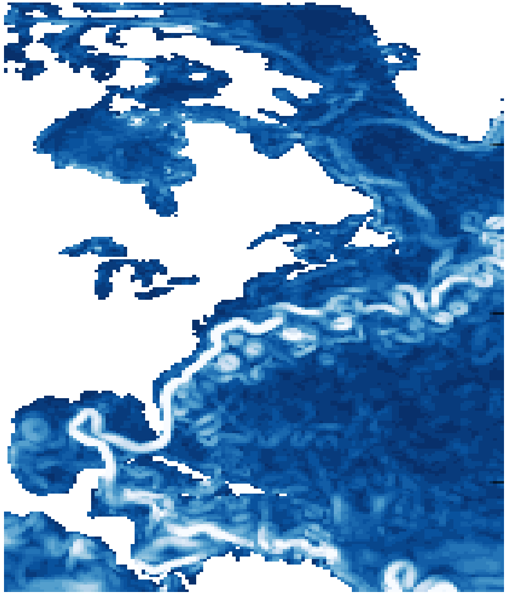


Wilson and Mitchell,1986

Blocking Frequency



CMIP6, PRIMAVERA and high resolution modelling

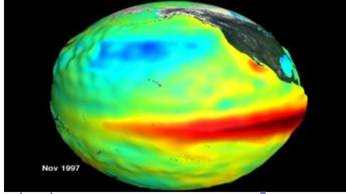


Why higher resolution?

- Improved representation of key weather and climate processes

  - Blocking
  - Tropical cyclones
  - Convective storms
  - Land-surface feedbacks

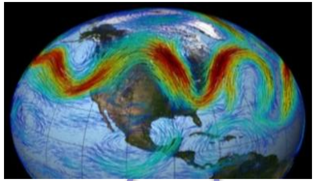
- Local processes contribute to large scale circulation and local impacts
- Vital for understanding and constraining regional climate variability and change

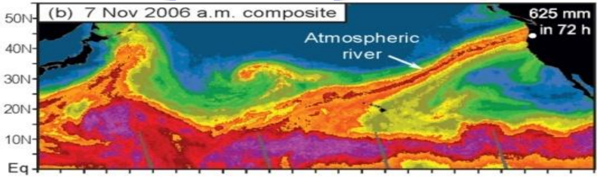


Global drivers

Regional variability

Feedbacks to large scale



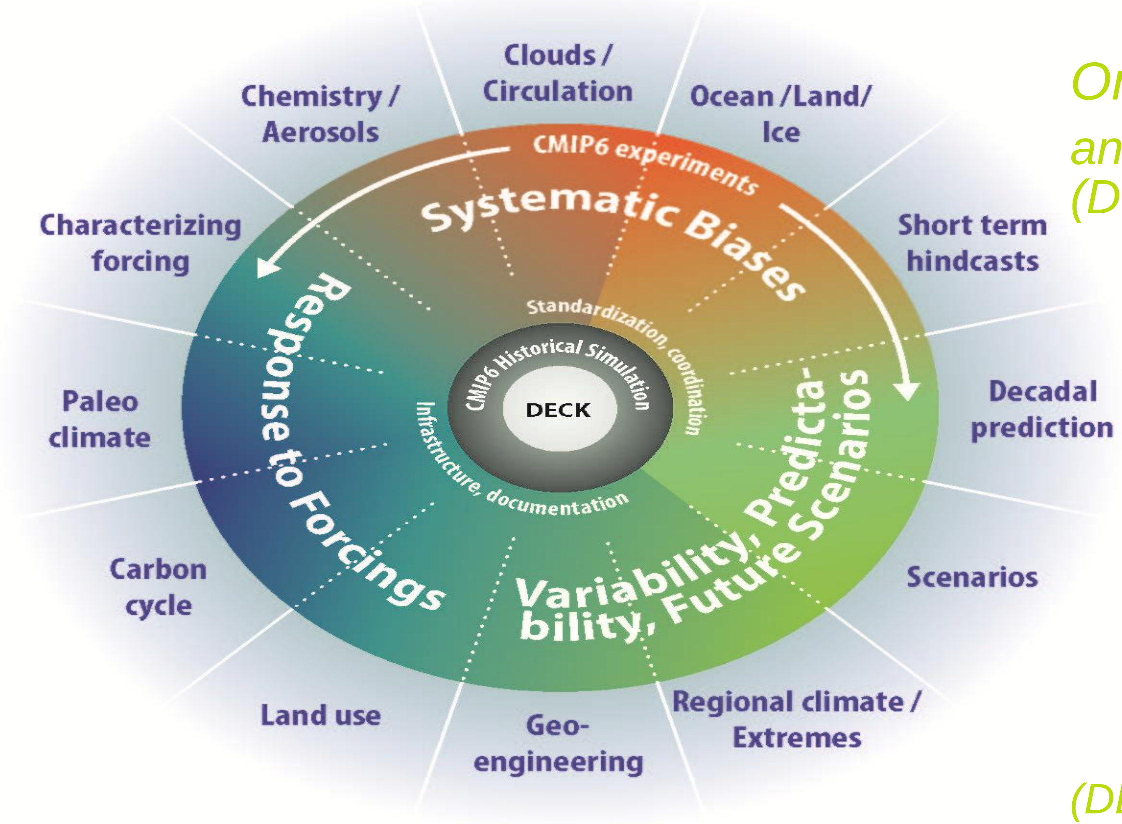


Local processes

Impacts, extremes

From L Kendon

WCRP Grand Challenges: (1) Clouds, circulation and climate sensitivity, (2) Changes in cryosphere, (3) Climate extremes, (4) Regional climate information, (5) Regional sea-level rise, and (6) Water availability, plus an additional theme on "Biogeochemical forcings and feedbacks"



Ongoing Diagnosis, Evaluation, and Characterization of Klima (DECK) Experiments

DECK (entry card for CMIP)

i. AMIP simulation (~1979-2014)
ii. Pre-industrial control simulation
iii. 1%/yr CO_2 increase
iv. Abrupt 4xCO_2 run

CMIP6 Historical Simulation (entry card for CMIP6)

v. Historical simulation using CMIP6 forcings (1850-2014)

***Note:** The themes in the outer circle of the figure might be slightly revised at the end of the MIP endorsement process*

(DECK & CMIP6 Historical Simulation to be run for each model configuration used in the subsequent CMIP6-Endorsed MIPs)

CMIP6 - HiResMip

Institution	MO/NCAS/ NOCS	KNMI/SMHI/ IC3/CNR	CERFACS	MPI	CMCC	ECMWF	AWI	
Model names	UM / NEMO	ECEarth / NEMO	Arpege / NEMO	ECHAM / MPIOM	CCESM / NEMO	IFS / NEMO	ECHAM/ FESOM	**Typical CMIP5**
Atmospheric resolution	60-25km	T239-T799 ~60-20km	T359 ~45km	T255 ~60km	25km	T239-T799 ~60-20km	T255 ~60km	~200-100km
Oceanic resolution	¼-1/12 ^{o}	¼^o-1/12 ^{o}	¼-1/12^o	¼-1/10^o	¼	¼	¼ - 1/12 spatially variable	~1-1/3^0 in tropics

HiResMip at June 2015

Global high resolution climate modelling
Atmosphere

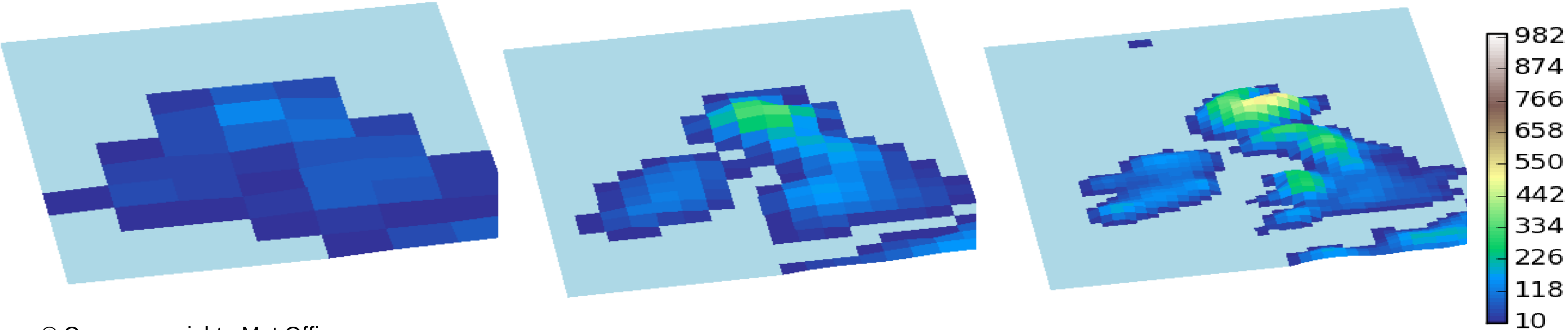
UK-Japan Climate Collaboration 2004-7 & UK HiGEM

- N96 (130km) atmos, 1˚ ocean (HadGEM1) a lot of Earth Simulator nodes...
- Finished with N216 (60km) – 1/3˚ ocean – HiGEM model, still used today

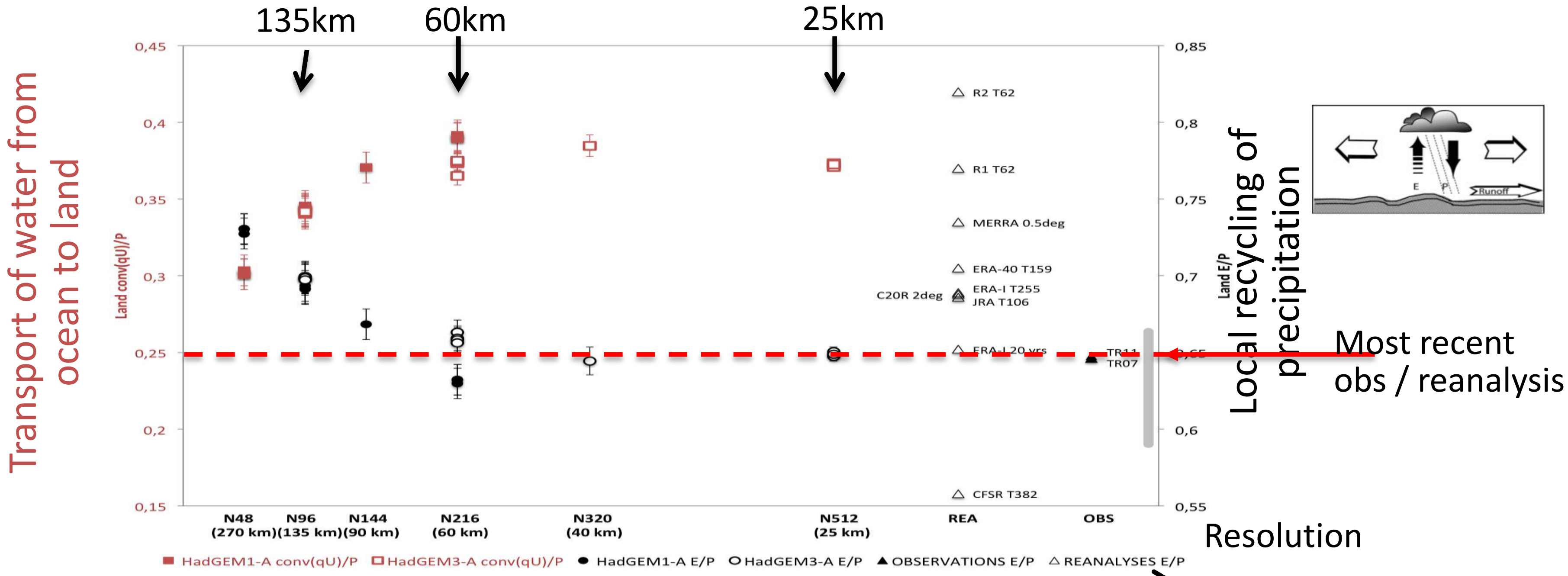
UPSCALE project 2012

- N512 (25km) atmosphere, 3-5 ensemble members, 1985-2011

N96 orography | N216 orography | N512 orography



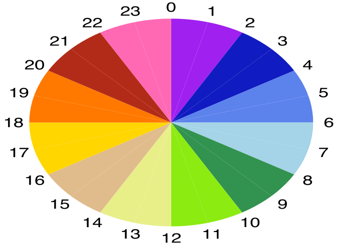
The atmosphere: Convergence of land moisture transport with increasing resolution



High local recycling
Low transport

Lower local recycling
Higher transport

Demory et al, Clim. Dyn., 2013

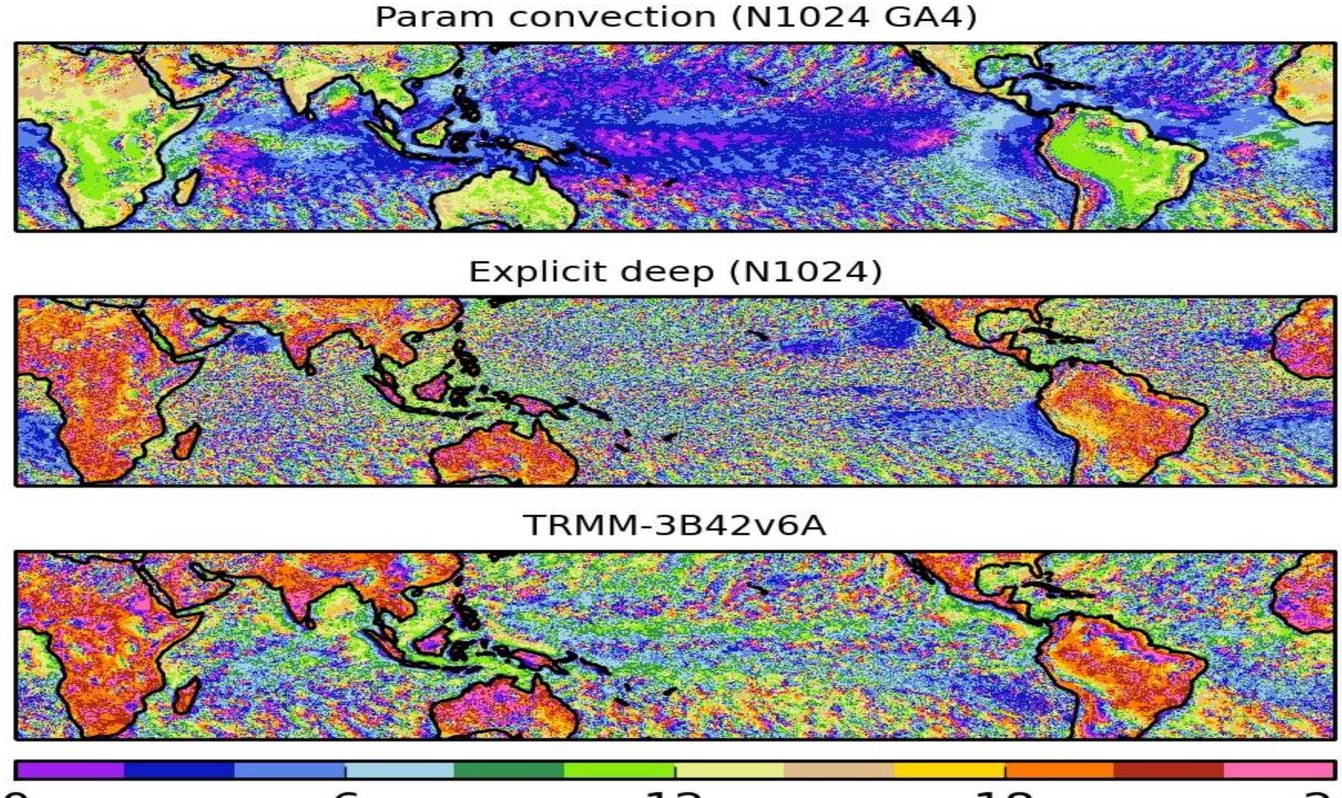


Precipitation diurnal cycle at different resolutions

Parametrized convection

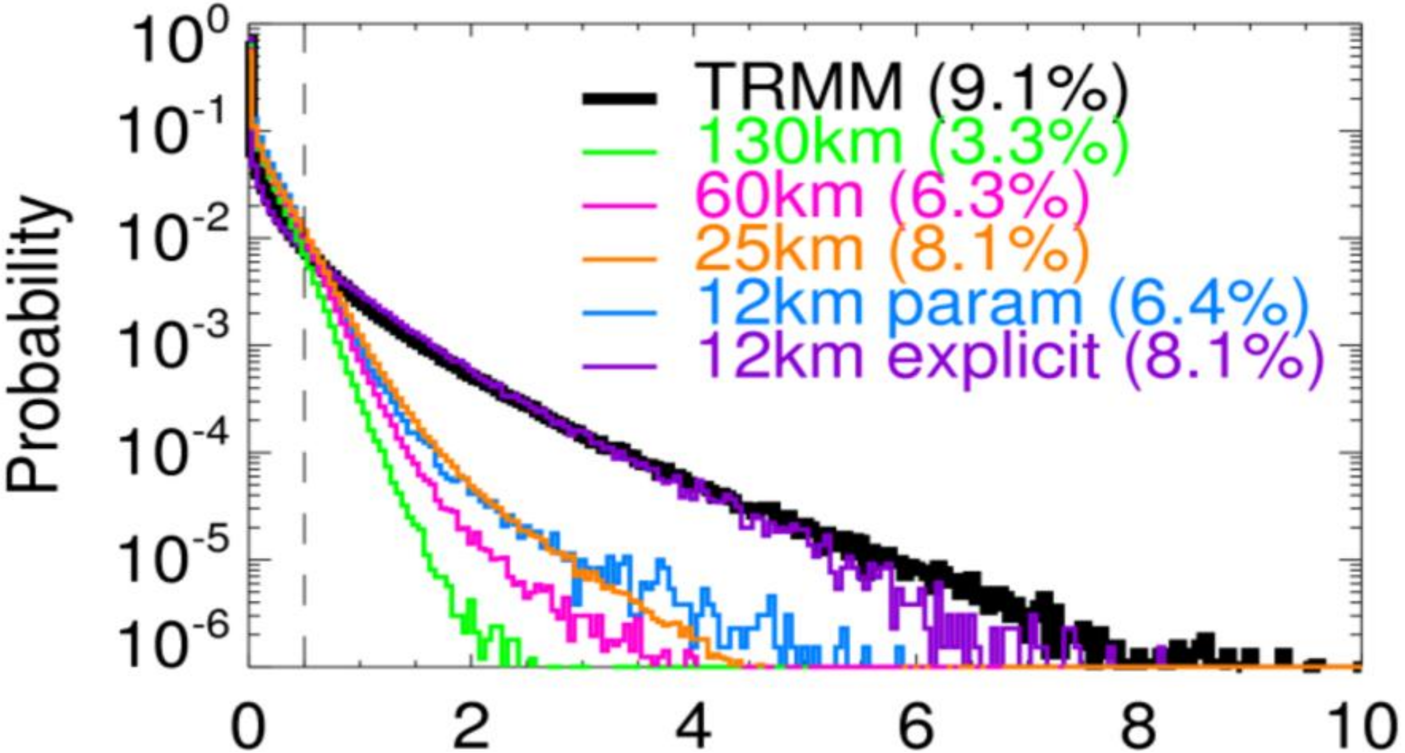
Explicit deep convection

Observations



Birch et al. 2015

Probability of precipitation rate exceeding a given threshold: Sahel

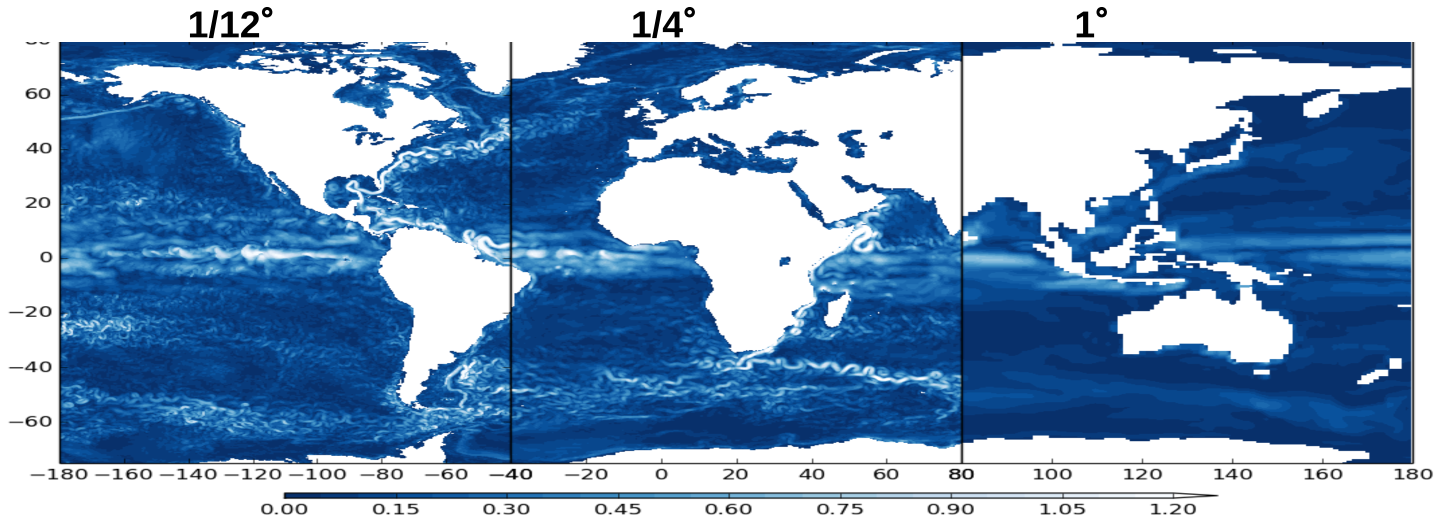


Frequency/intensity of precipitation(mm/hr)

Vellinga et al. 2015

The ocean:Spanning the eddy regime

Met Office



H Hewitt

Eddy resolving

Sub-mesoscale not resolved

Not eddy resolving at high latitudes or on the shelf

Eddy permitting

Eg, GloSea5

Parameterise eddies?

Under estimate eddy KE Boundary currents not fully resolved

Eddy parameterising

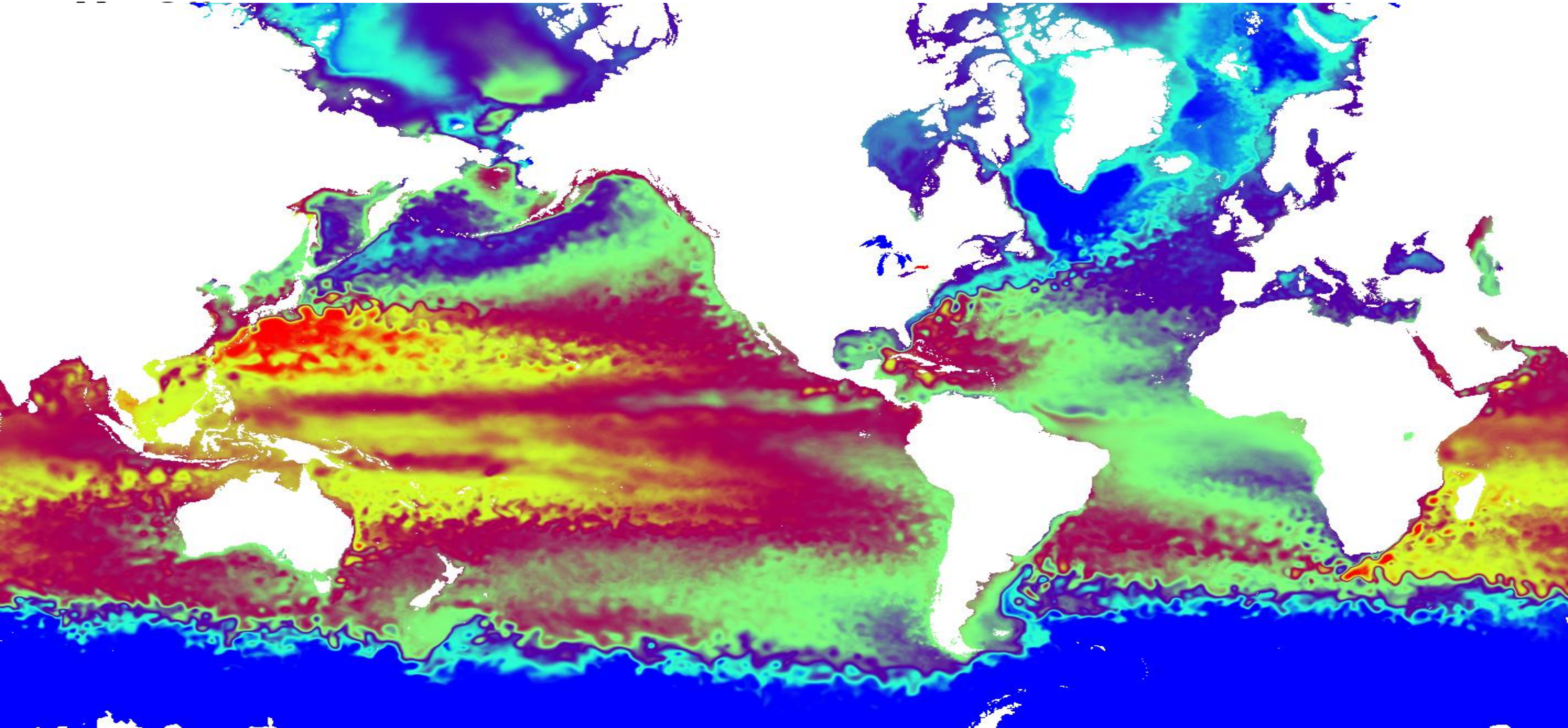
Eg, HadCM3, CMIP5 models

Diffusie rather than intertial boundary currents

Starting to resolve ocean eddy field …

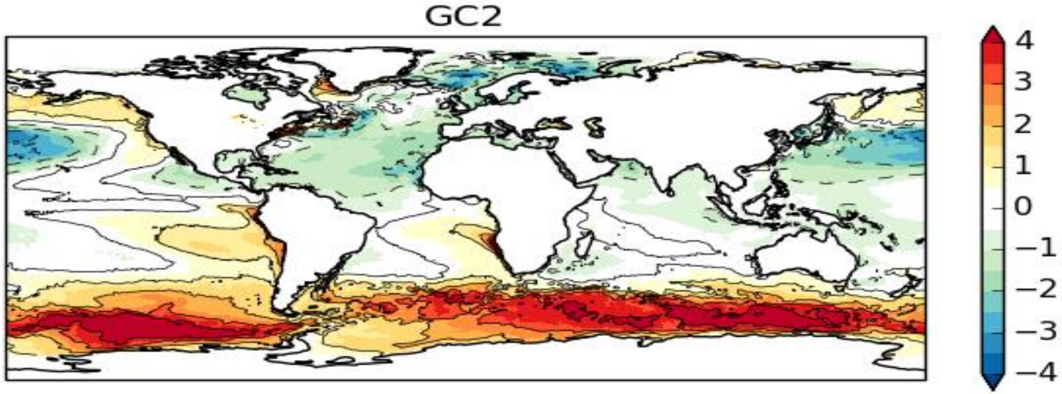
Coupled ORCA1/12˚ sea surface height

H Hewitt

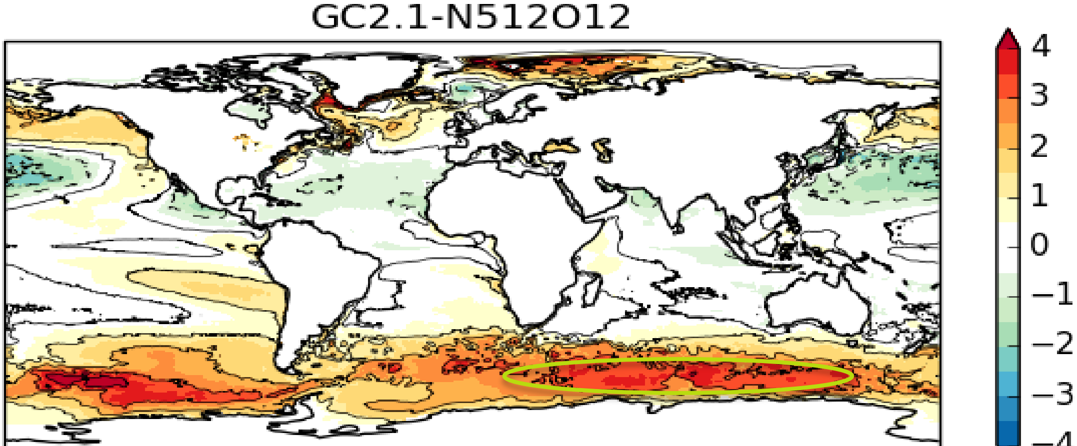


SST Biases

N216
ORCA025



N512
ORCA12



- **Reductions in**

  Southern Ocean warm bias (~20%)

  Cold biases in Northern Hem

  also warm bias in upwelling regions

at the expense of

large warming in Arctic

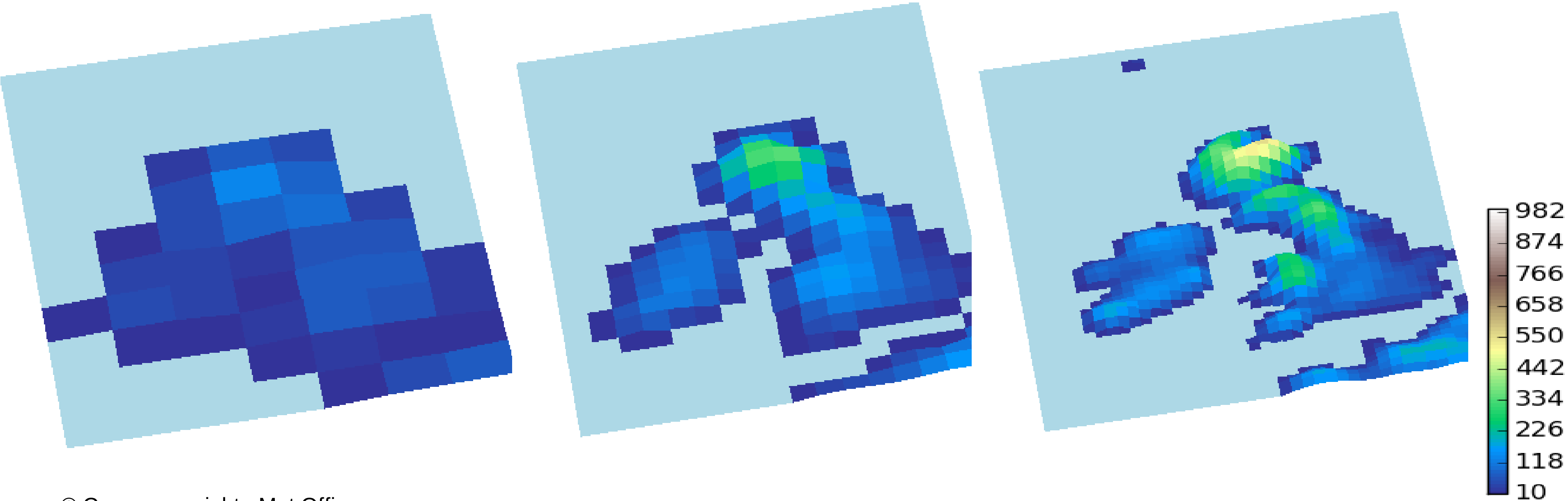
H Hewitt

Climate change and resolution

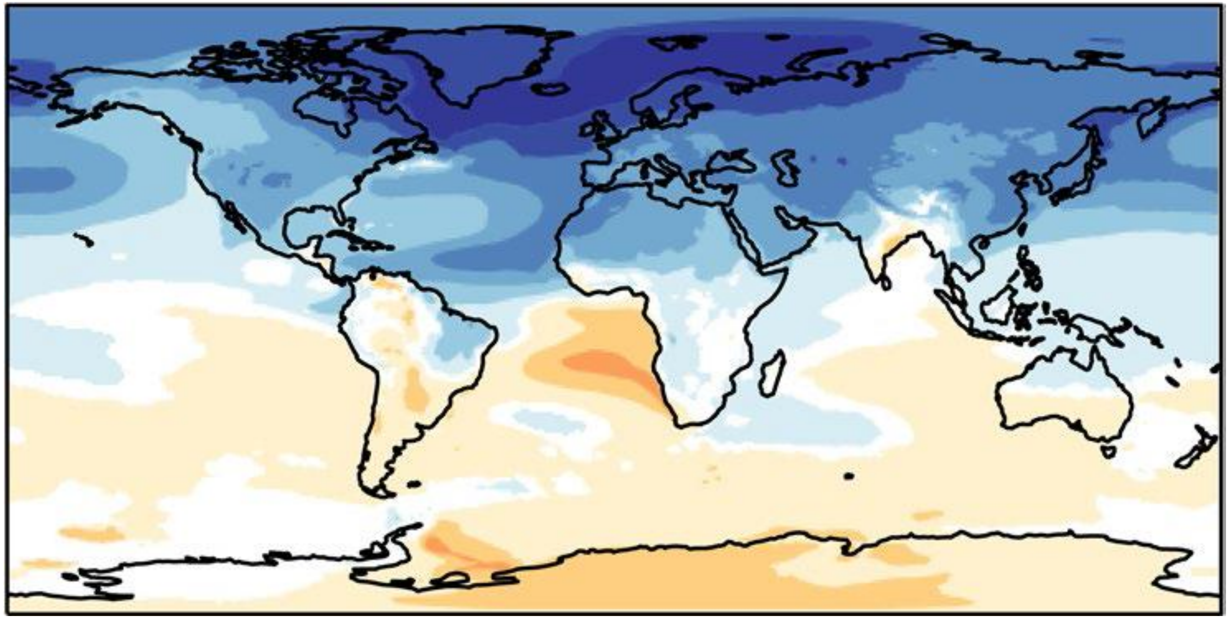
N96 orography

N216 orography

N512 orography



Regional changes-
Effect of slowdown in AMOC

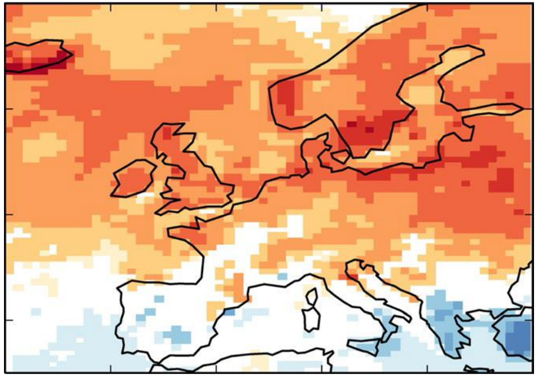


Change in annual mean surface temperature

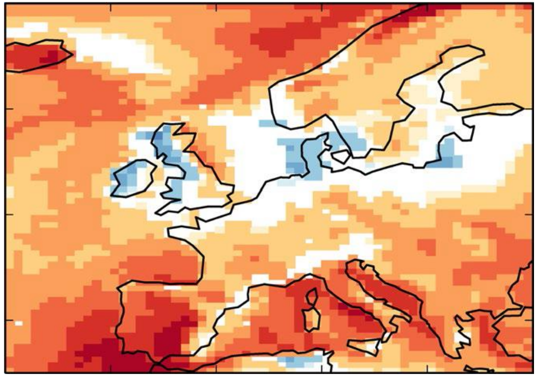
N216 Atmos
¼^0 Ocean

Jackson et al, 2015

JJA



DJF



Change in precipitation

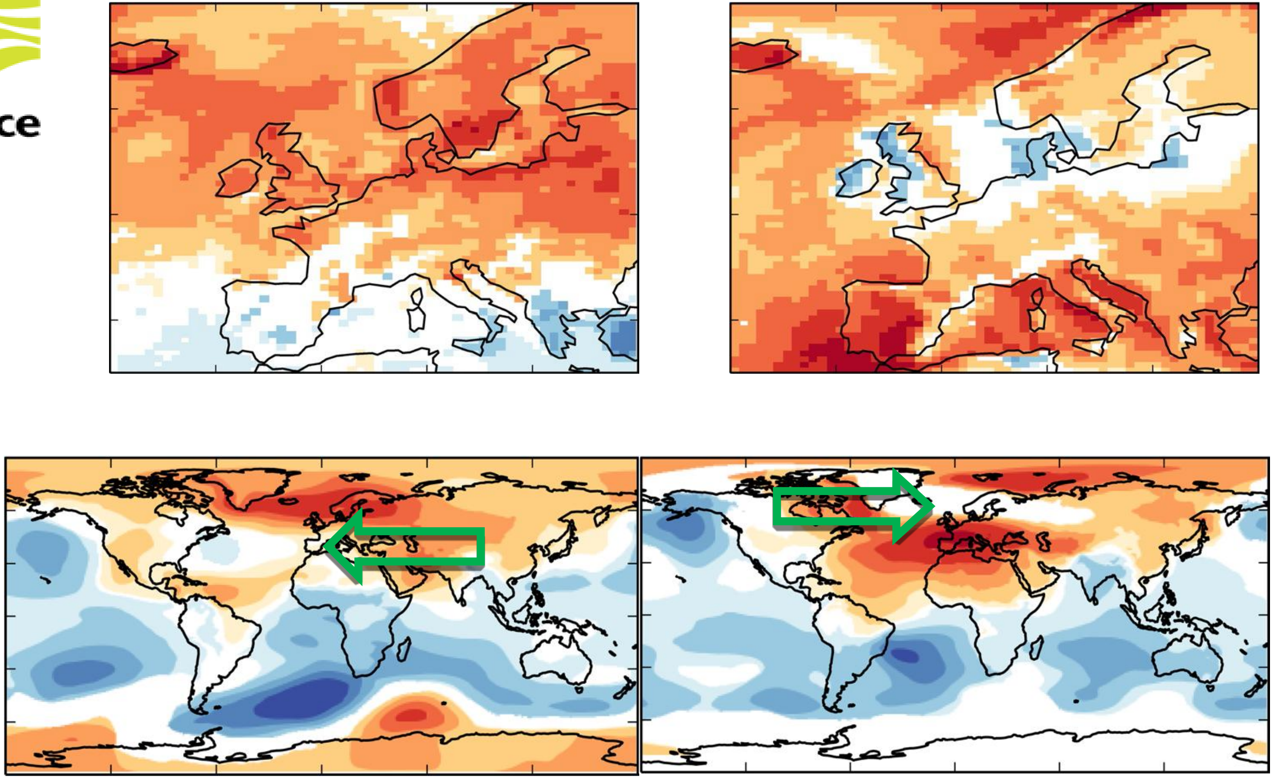
Decrease

Jackson et al 2015

Effect of weakening AMOC

Met Office

JJA DJF



Change in precipitation

Decrease

Wind anomaly over British Isles

Change in surface pressure

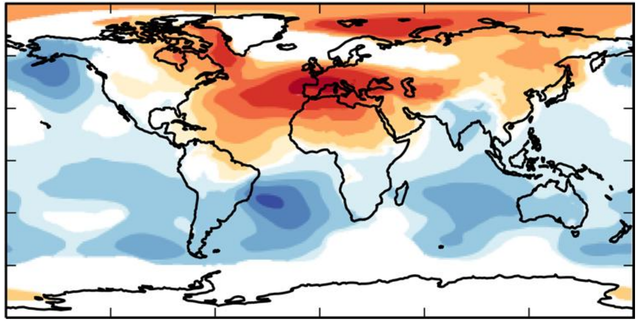
Decrease

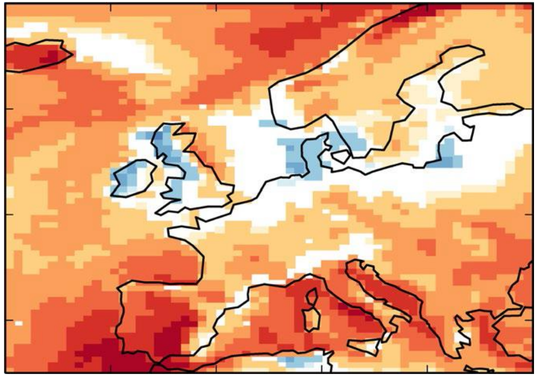
Jackson et al 2015

Effect of weakening AMOC

DJF

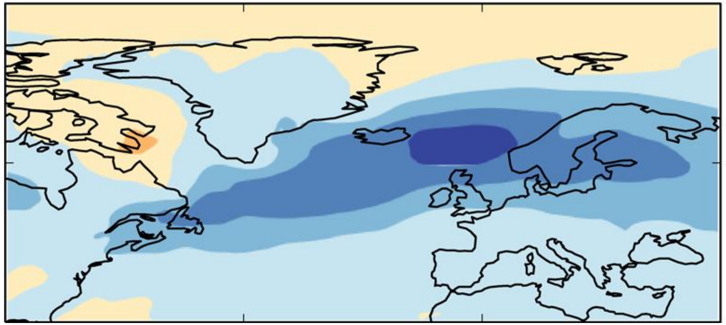
Change in surface pressure



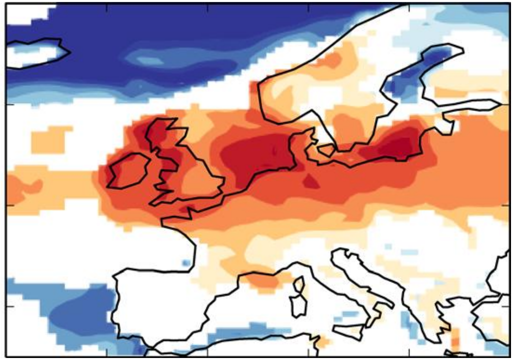


Change in precipitation

Decrease



Increase



Decrease

SLP filtered variance

Wind speed anomaly

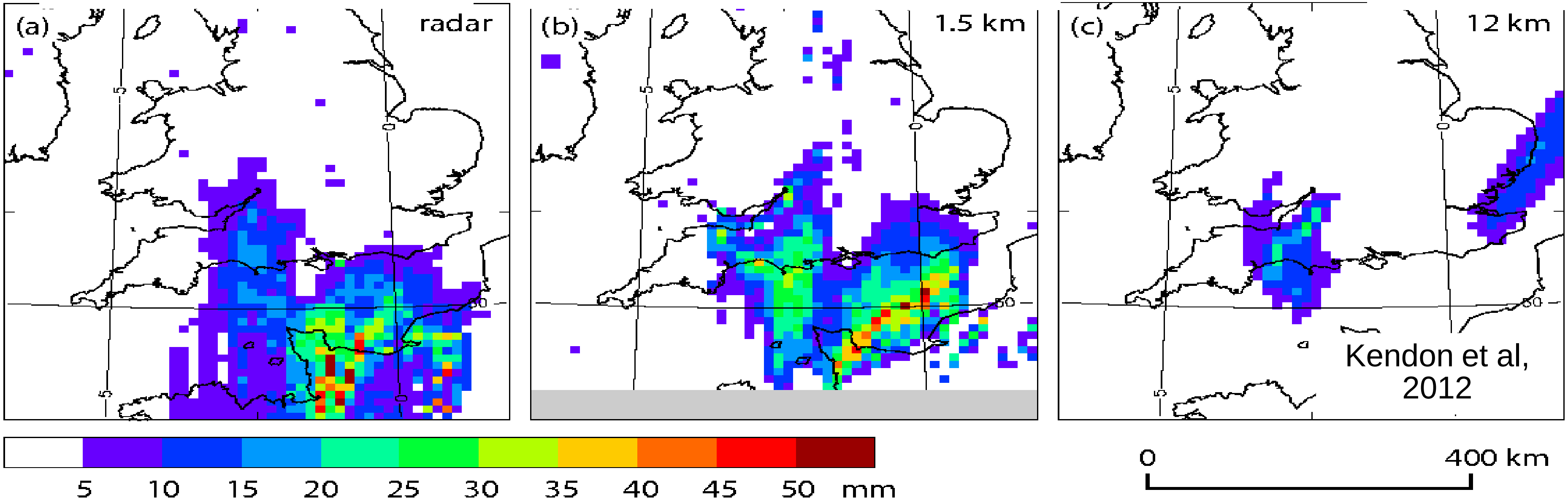
Jackson et al 2015

Effect of weakening AMOC

Convergence with resolution?

Convective scale modelling. ERA driven

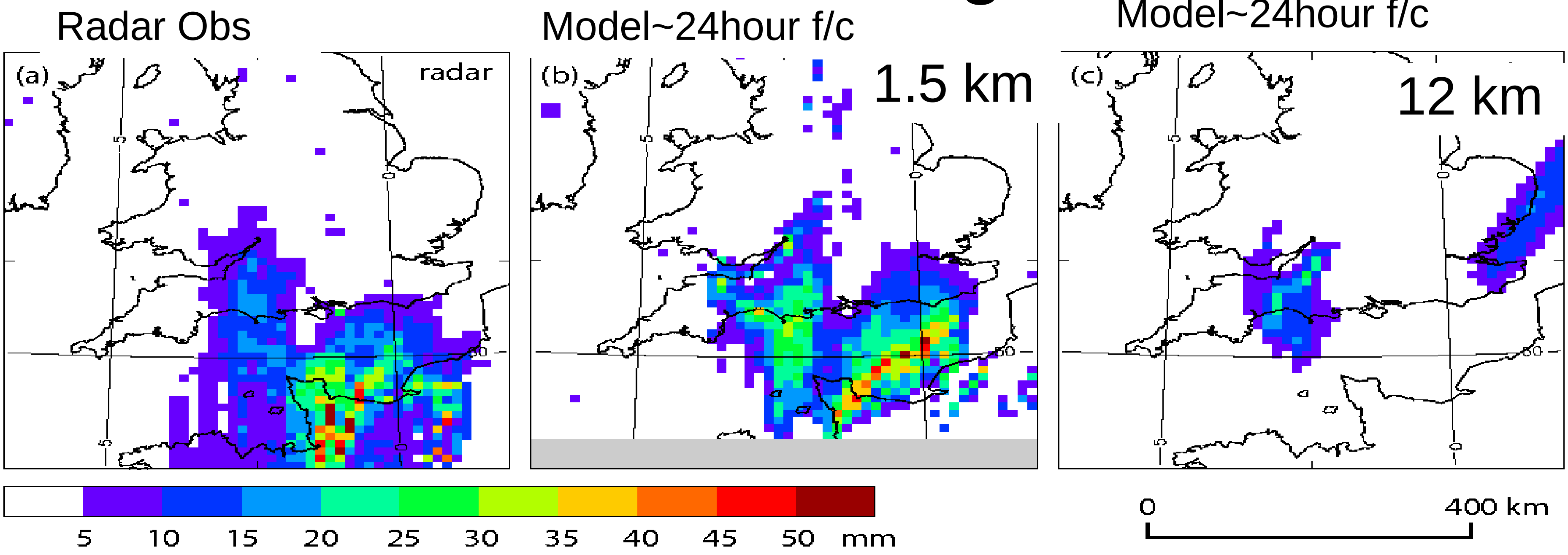
Radar Observations   Model~24hour f/c 1.5 km   Model~24hour f/c 12 km



L Kendon

Convective scale modelling,

kendon et al, 2012



Climate: -needed for realistic hourly rainfall
-potentially urban temp., severe wind gusts, hail, fog, lightning

To date only: -long simulations for single model realisations (small domains)
-seasonal-length simulations (larger domains)

L Kendon

Convective scale modelling Climate

12 km

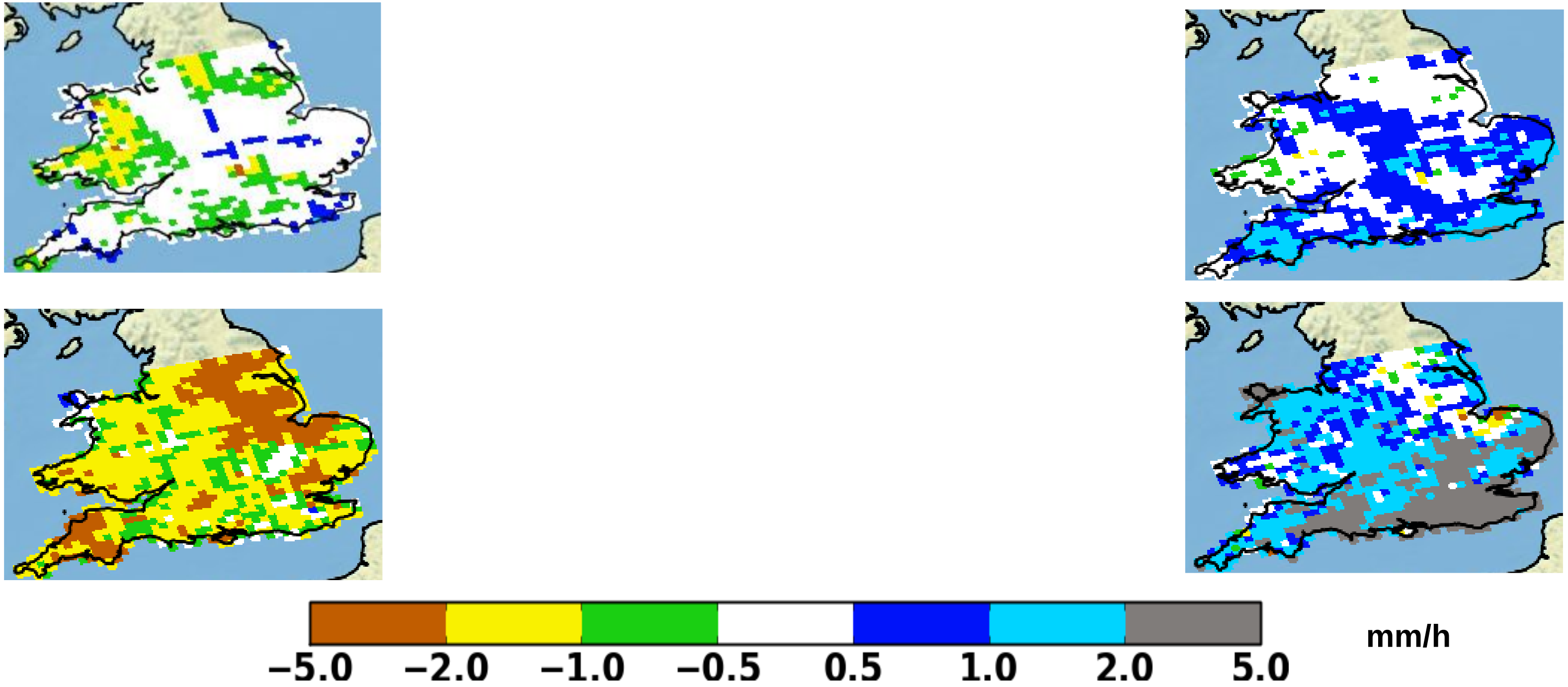
1.5km

Model bias

Model bias

DJF

JJA



mm/h

Based on Kendon et al, 2014

Convective scale modelling Climate

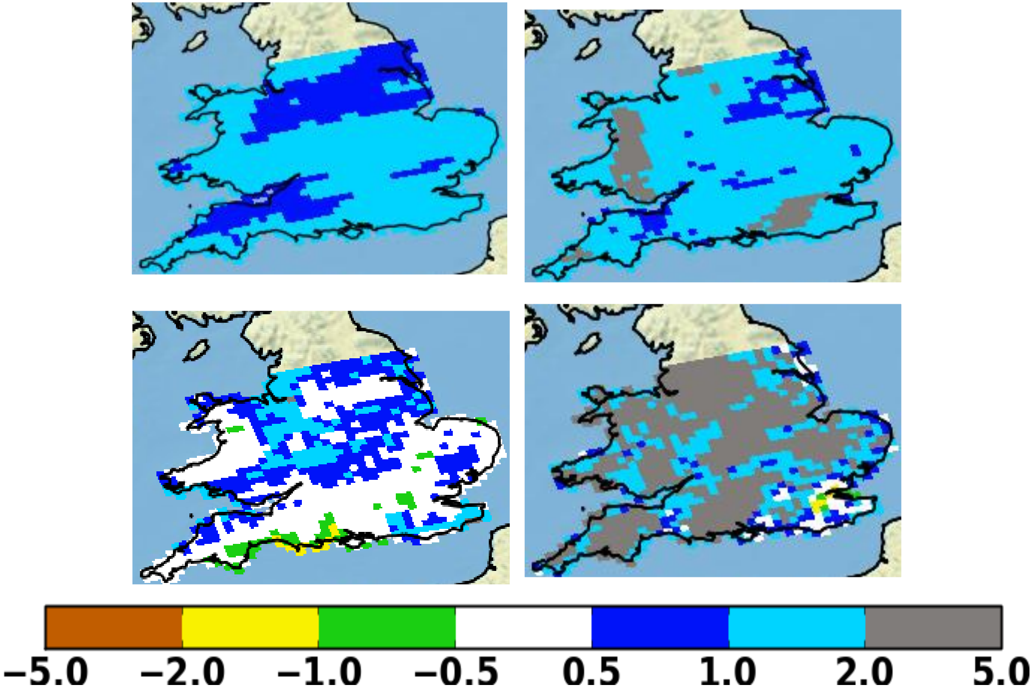
12 km

Future change (RCP8.5)

1.5km

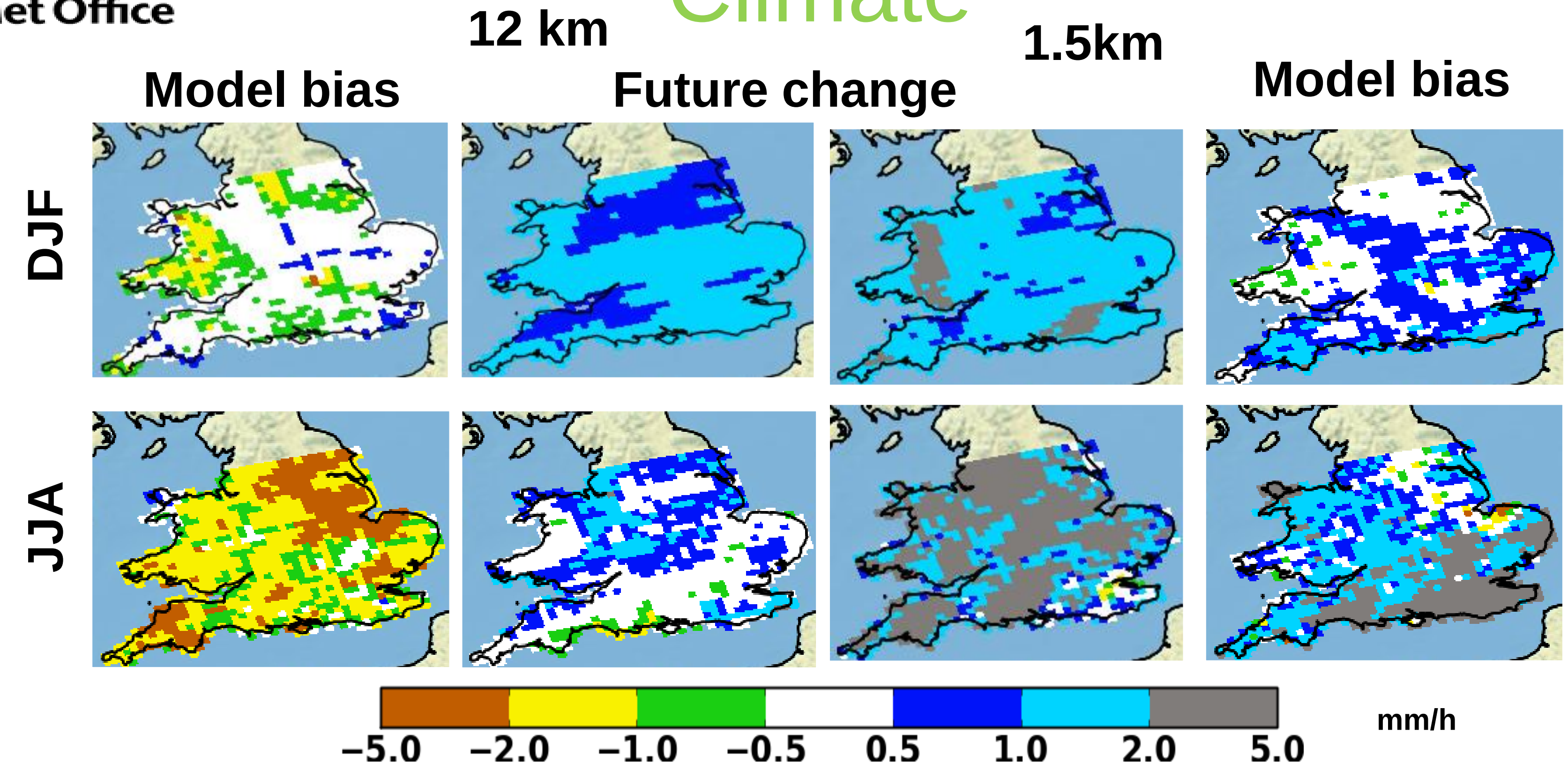
DJF

JJA



Based on Kendon et al, 2014

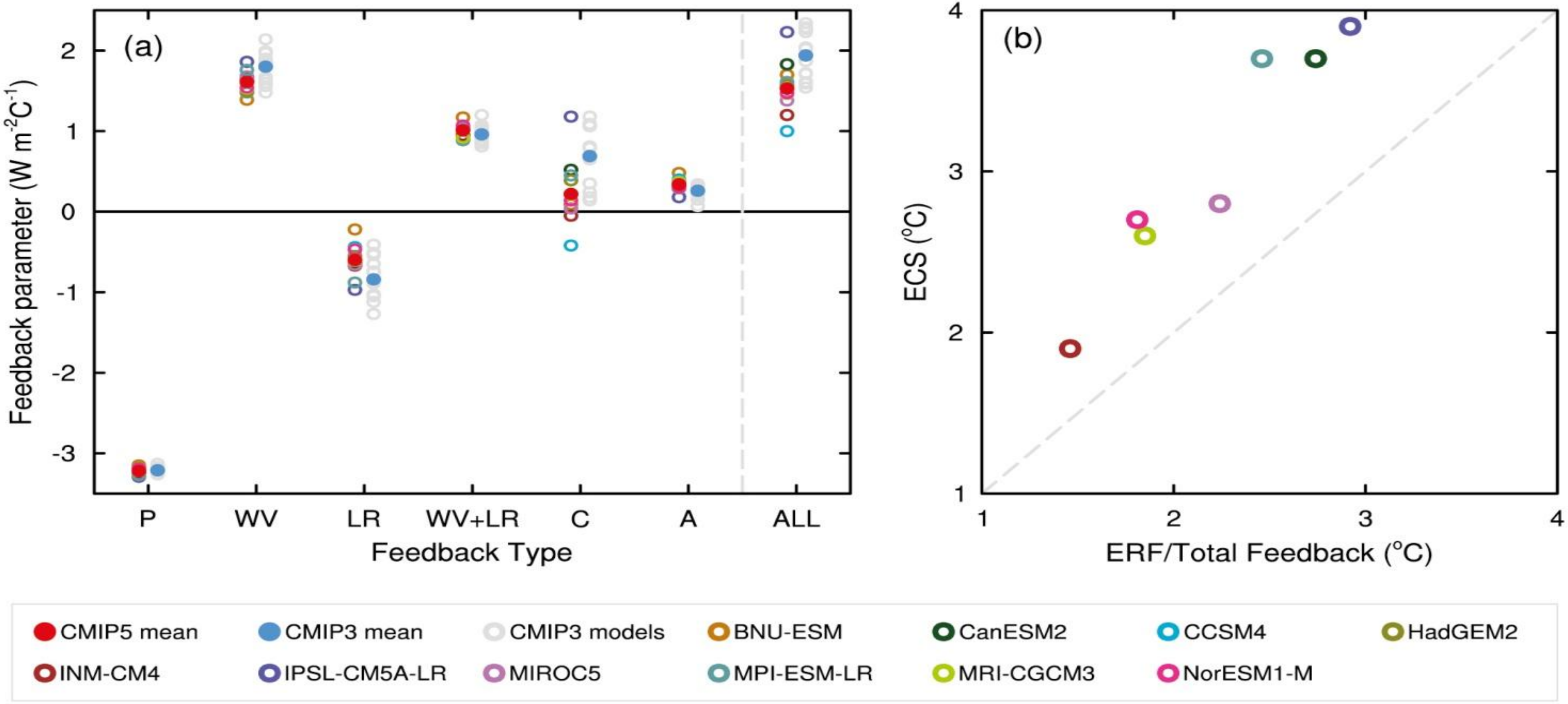
Convective scale modelling Climate



Based on Kendon et al, 2014

Higher resolution and processes

“Fast” feedbacks- AR5



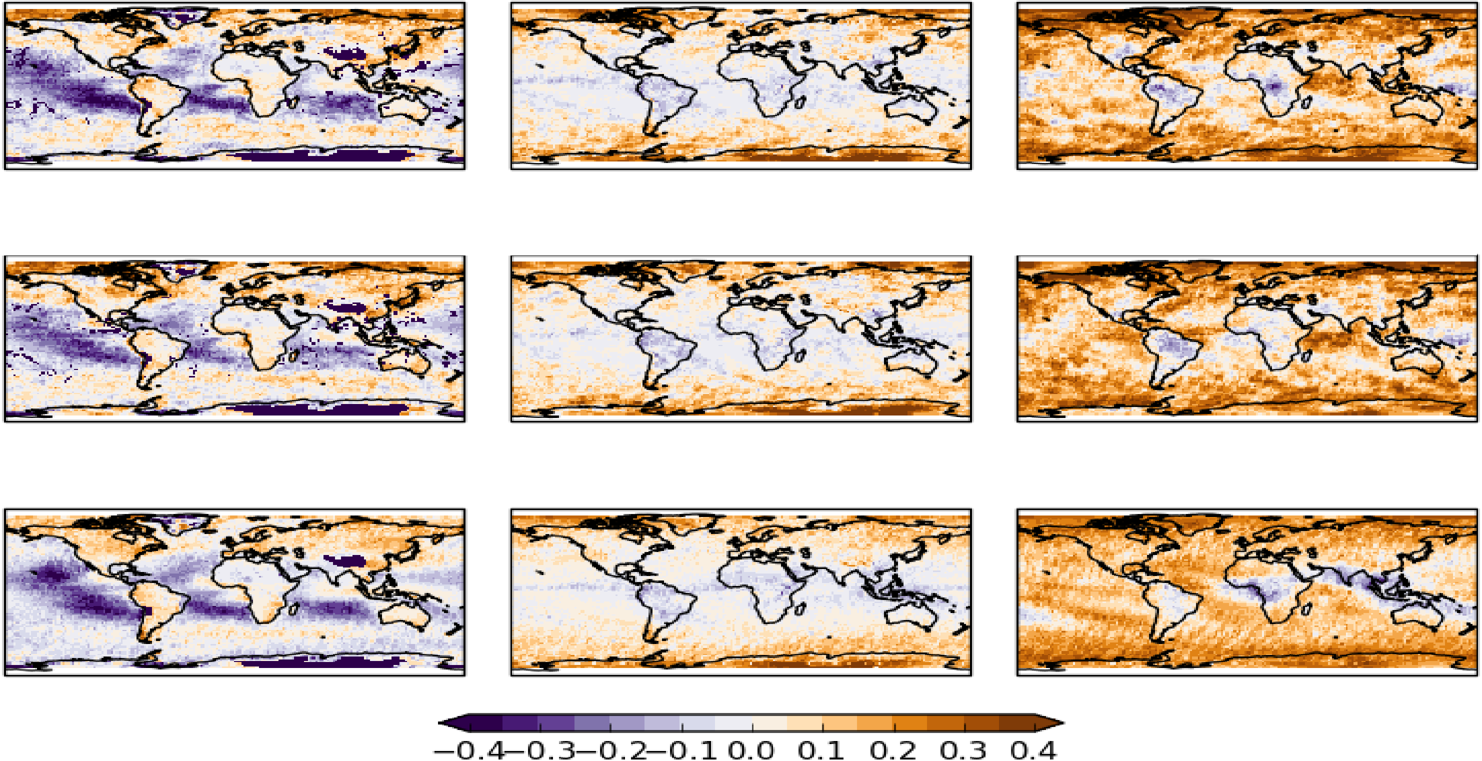
Bias in cloud cover

Low | Medium | High

1 Day N320 (NWP)

5 Days N320

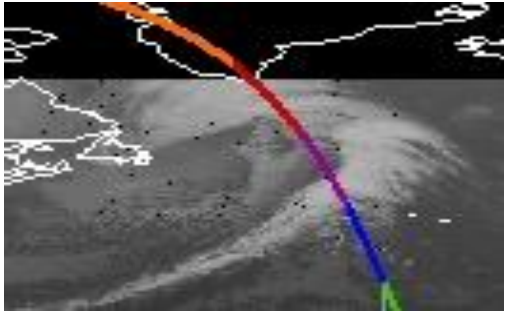
AMIP N96

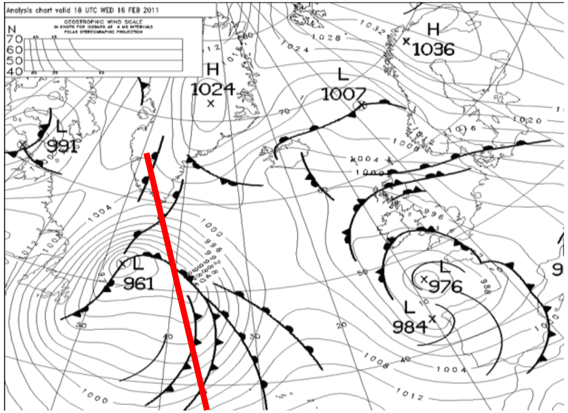


Case studies

VT: 15Z 16/02/2011 (T+27)

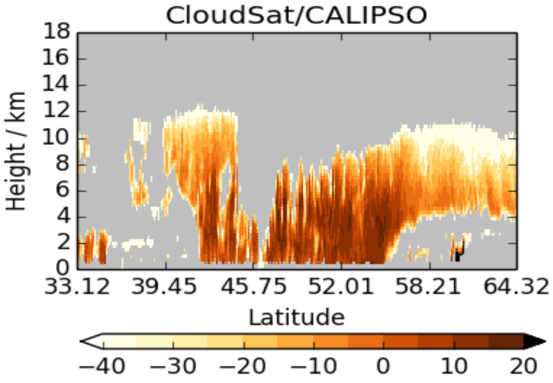
N320

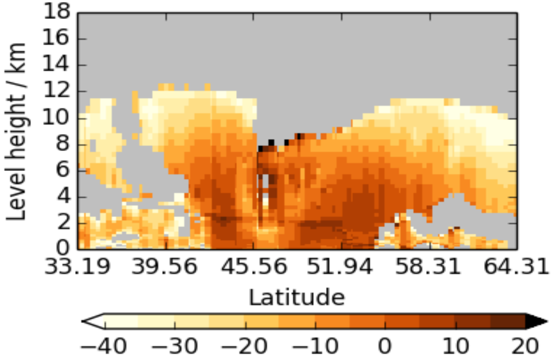




Radar

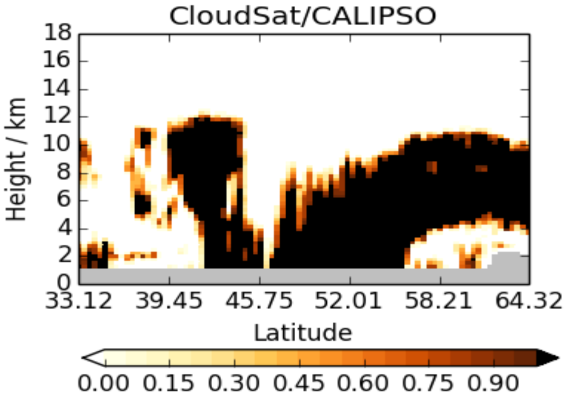
Model

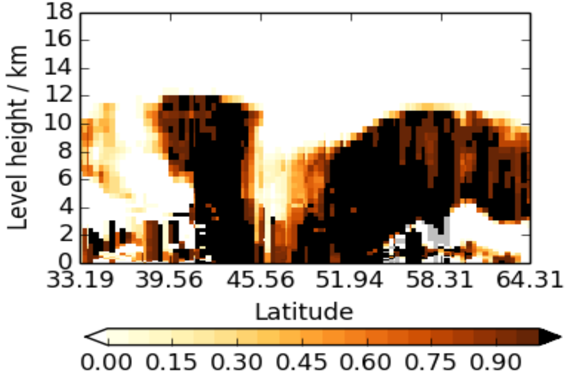




Cloud Amount

Model





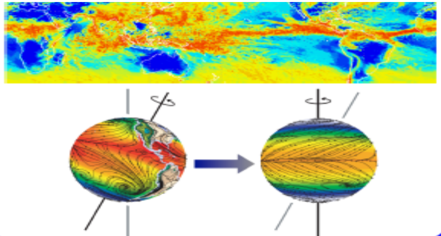
Process MIPs , for example: CFMIP3/CMIP6

Objective 1: Improved assessments of climate-cloud feedbacks by:

a) **Improving understanding of cloud-climate feedbacks.**

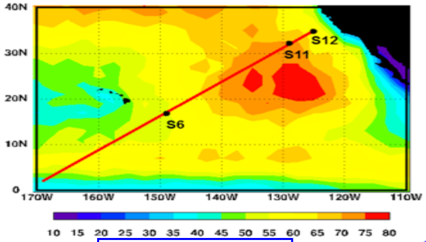
b) **Improving evaluation of clouds and cloud feedbacks in climate models.**

CFMIP3/CMIP6 Hierarchy
T/q budgets, cfSites



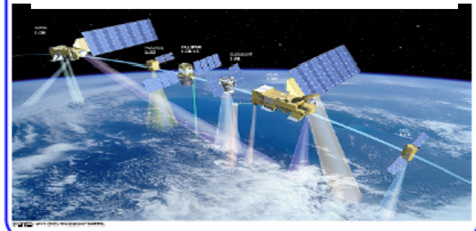
CMIP6/CFMIP3

CFMIP Intercomparison
of SCM/LES



CGILS

Exploitation of Sat Obs
via Simulators in CMIP

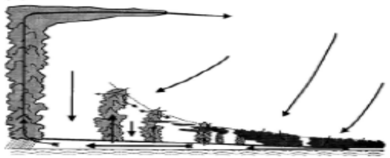


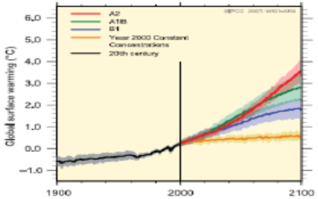
COSP

Understanding

Evaluation

Assessment of cloud-climate feedbacks





Adapted from
M Webb

AR6
WCRP Assessment

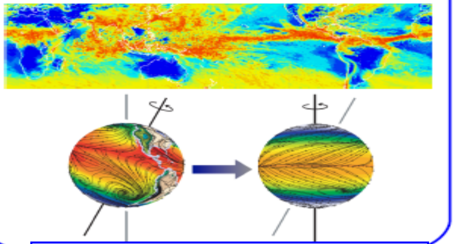
Cloud Feedback Model Inter-comparison Project CFMIP3/CMIP6

Objective 1: Improved assessments of climate-cloud feedbacks by:

a) Improving understanding of cloud-climate feedbacks.

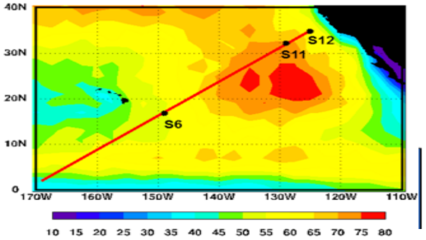
b) Improving evaluation of clouds and cloud feedbacks in climate models

CFMIP3/CMIP6 Hierarchy
T/q budgets, cfSites



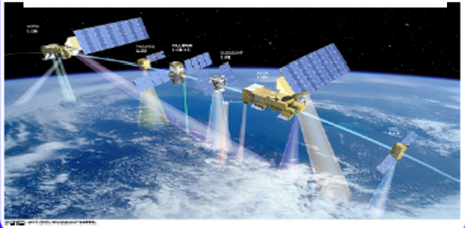
CMIP6/CFMIP3

CFMIP Intercomparison
of SCM/LES



CGILS

Exploitation of Sat Obs
via Simulators in CMIP



COSP

Objective 2: To use the CFMIP experimental hierarchy and process diagnostics to better understand other aspects of the climate response, such as changes in circulation, regional-scale precipitation and non-linear change.

Concluding remarks

- Higher resolution enables easier comparison with observations

- High horizontal resolution improves many aspects of circulation in its own right, and provides a better framework for investigating processes and simulating feedbacks.

Concluding remarks-continued

- We need to understand which changes are due to resolution, and which are due to other factors-not everything needs to be done at the highest resolution.
- Exploit the improved representation of processes and phenomena enabled by higher resolution- opportunity for new methods of analysis
- Don’t forget impact of vertical resolution
- Need to start to explore the consequences of resolving convection explicitly to support current findings, guide future model development