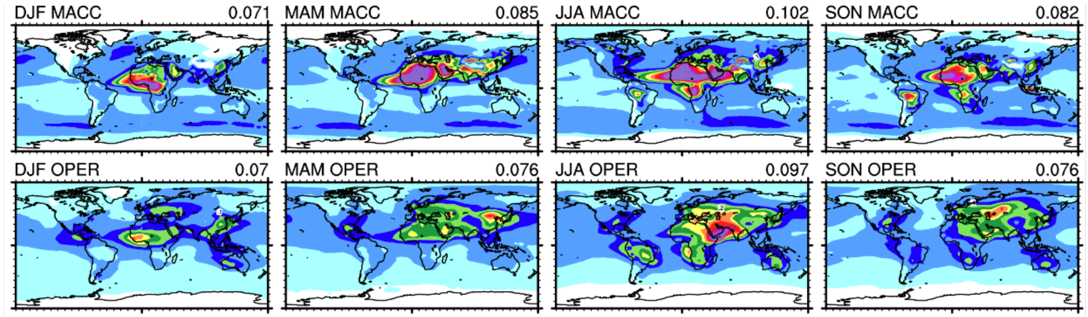
Aerosols, diurnal convection cycle and tropical waves

P. Bechtold, A. Bozzo, M. Herman, Ž. Fuchs and C. Birch

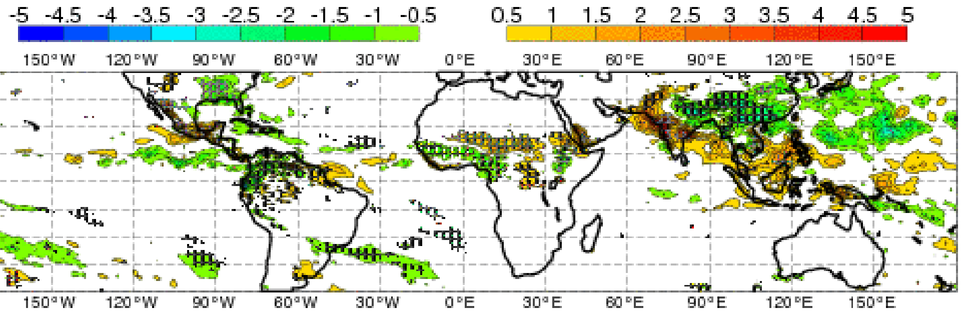
New MACC Aerosol climatology and impact on radiation and Asian Monsoon

1.



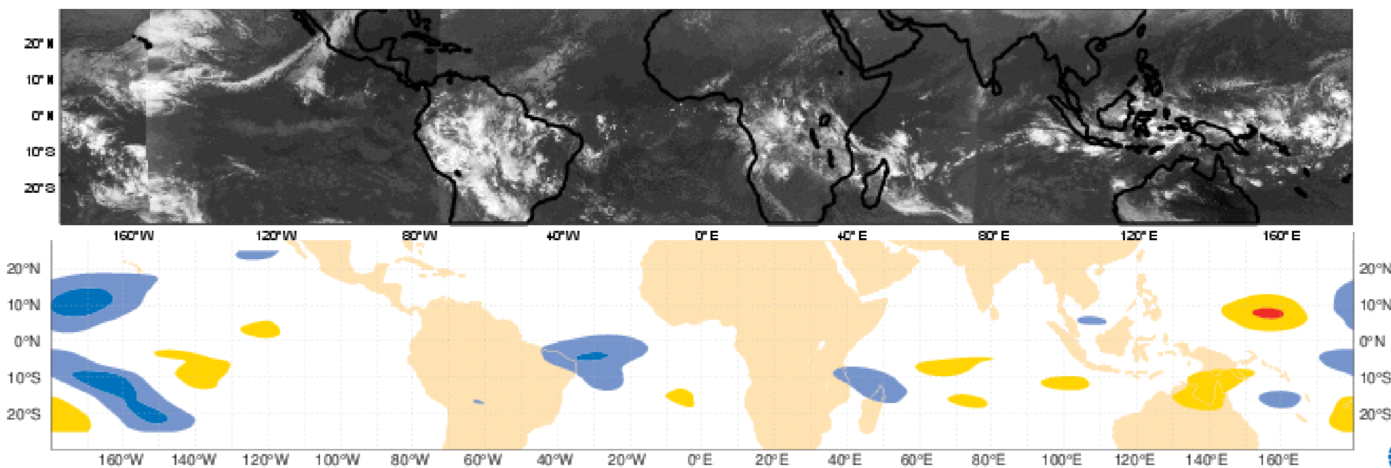
Diurnal cycle of convection with impact on moist static energy gradient and Monsoon

2.



Tropical wave filtering and explaining the convection Kelvin wave interaction

3.



EMBRACE

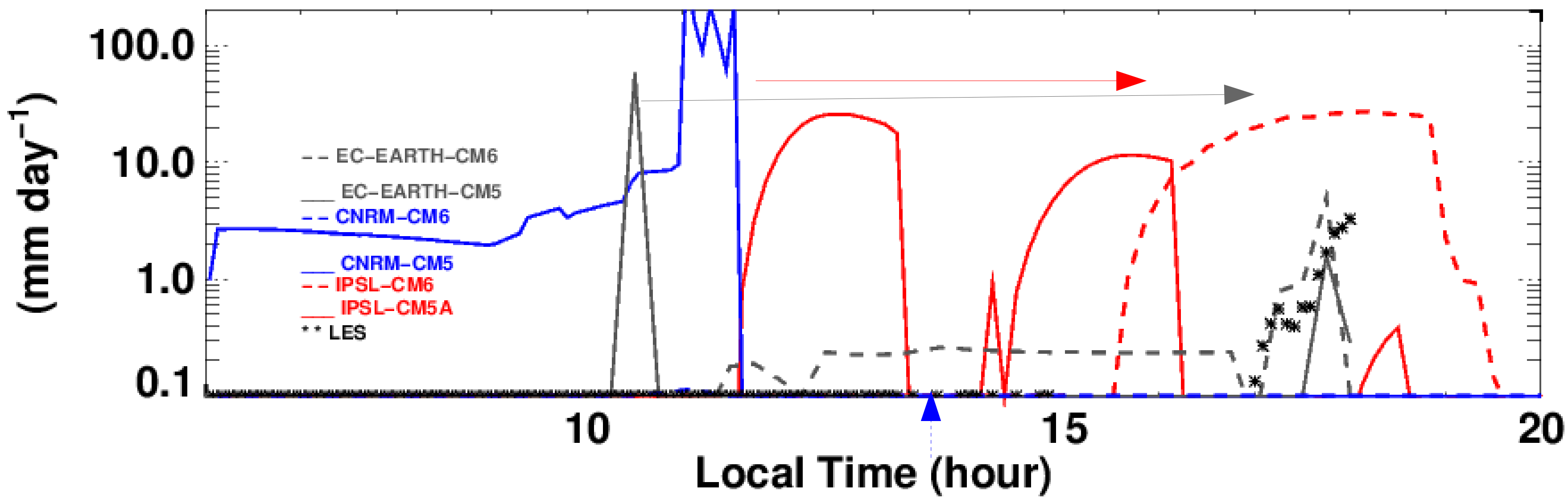
ECMWF

Representation of daytime moist convection over the semi-arid Tropics by parametrizations in CMIP6 models - Couvreux et al *poster n°2 in Session 2*

- the diurnal cycle of convection = **a long-standing bias** in climate models

- Framework : intercomparison of Single Column Model version of ESMs to LES for a case of daytime moist convection in the Sahel

Objectives : to analyse the different processes at play and to test the hypothesis underlying convective parametrizations



For more results come and see my poster !

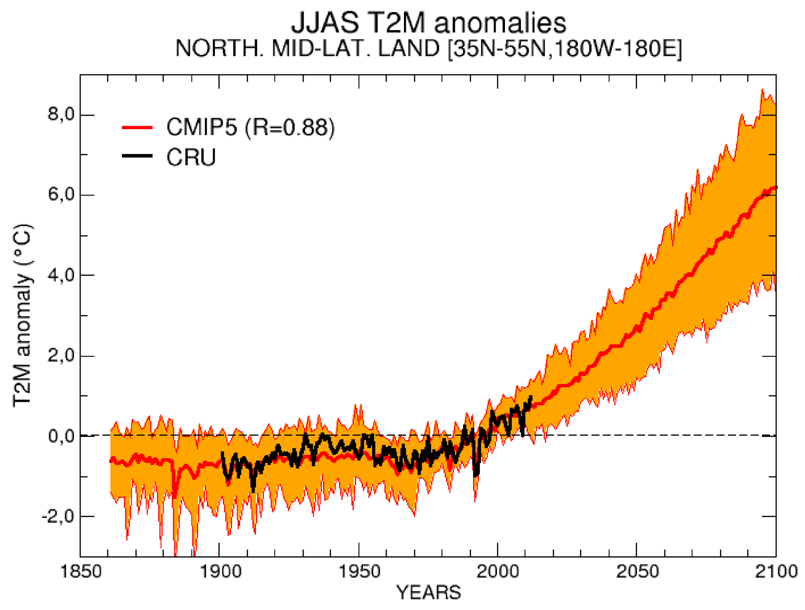
What are we MIPing for?

What is the roadmap for narrowing regional uncertainties in global climate projections?

Hervé Douville, J. Cattiaux, F. Chauvin, J. Colin, B. Decharme, C. Delire, A. Ribes, R. Roehrig
CNRM-GAME (Météo-France and CNRS)
herve.douville@meteo.fr

1. Motivations

- WGCM has recently endorsed about 20 model intercomparison projects (MIPs) whose ultimate common objective is to better understand and possibly constrain the most relevant climate drivers and feedbacks in order to narrow regional uncertainties in global climate projections.
- While all MIPs are potentially useful, we need to define both priorities and synergies to achieve this overarching objective.
- Beyond mean climate, we also need to pay attention to the response of high-impact weather and climate events.
- We here illustrate this issue by proposing a multi-MIP strategy to constrain the northern mid-latitude summer climate response in global projections.

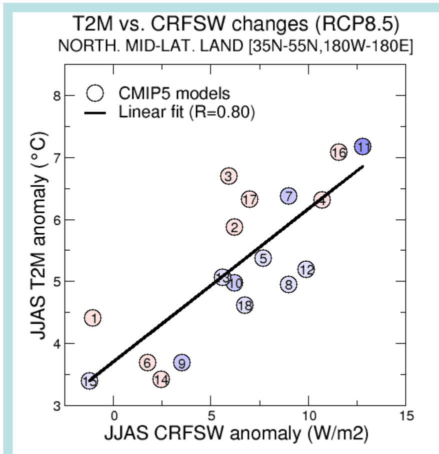


Ensemble mean and range of summer mean near-surface temperature anomalies relative to the 1979-2008 climatology in a subset of 20 CMIP5 models (historical + RCP8.5 scenario).

- While the ensemble mean multi-decadal variability looks reasonable over the last century, the projections remain highly model-dependent.
- Beyond mean climate, what are the uncertainties in the response of temperature (and precipitation) extremes?
- How well do they scale on climate sensitivity? What are the most relevant feedbacks? Can we constrain them with observations?

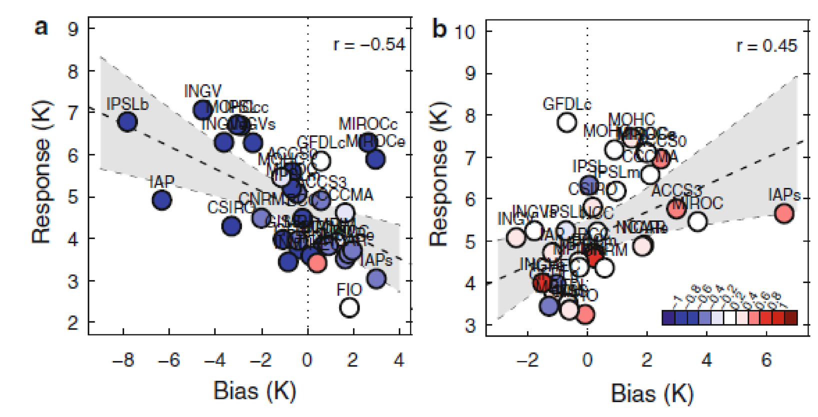
2. Cloud processes (CFMIP)

- CFMIP has emphasized the dominant role of cloud feedbacks on global climate sensitivity and on regional climate change, especially for temperature, for understanding the inter-model spread in CMIP5 projections.
- Yet, changes in cloud radiative forcing (CRF) at the land surface do not explain the pattern of temperature anomalies within each model.
- The inter-model spread in regional temperature anomalies is not dominated by changes in large-scale circulation, but rather by regional radiative and non-radiative processes (e.g., Cattiaux et al. 2013, Cheruy et al. 2014).
- The scaling with climate sensitivity is even worse for extreme temperatures.
- Biases in radiative feedbacks and/or in temperature do not represent strong constraints on the projected regional temperature anomalies.



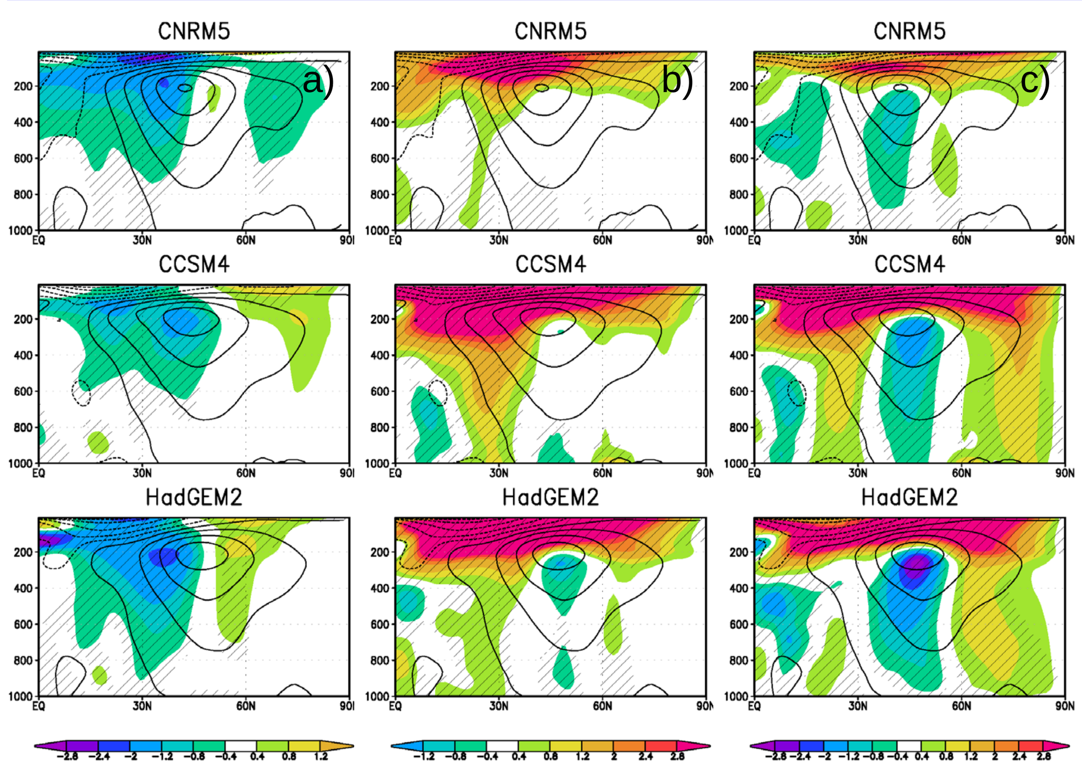
Scatterplot of changes in surface air temperature (t2m) vs. changes in surface shortwave cloud radiative forcing (crfsw) in RCP8.5 projections. Symbols denote the late 21st century JJAS anomalies averaged over the Northern mid-latitude land areas among a subset of CMIP5 models, while symbol colours denote the spatial correlation between t2m and crfsw anomalies within each model.

Scatterplot of changes (RCP8.5 scenarios) vs. biases (historical simulations) in surface air temperature over Europe during a) winter and b) summer among CMIP5 models. Symbol colours denote the spatial correlation between anomalies and biases over Europe. [Cattiaux et al. 2013]



CMIP6 objectives

- Understand and constrain uncertainties in global climate sensitivity and in the response of large-scale atmospheric circulation and precipitation (Tier 1 experiments).
- Isolate the contribution of direct (radiative & biophysical) vs. indirect (climate-mediated) CO2 effects on regional climate change (also using Tier 2 proposed by Chadwick and Douville).
- Understand the role of SST biases and anomaly patterns as a source of uncertainty for regional climate change (using Tier 2 proposed by Chadwick and Douville).

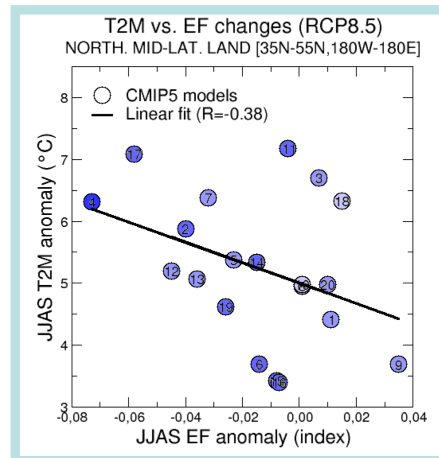


Changes in boreal summer zonal mean zonal wind (m/s) as a response to a) the radiative-only, b) the SST-mediated, and c) both effects of 4xCO2 in three AGCMs. [Douville et al., in preparation]

- How to bridge the gap between understanding and narrowing uncertainties?
- Can we use the interannual variability to constrain the SST-mediated response?

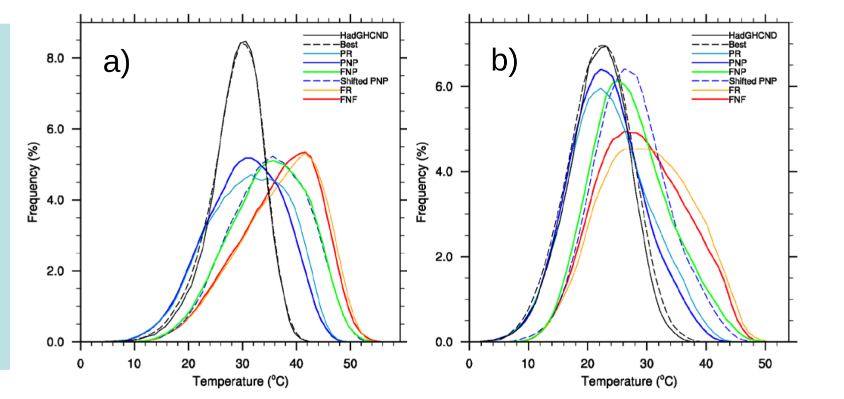
3. Land surface processes (LS3MIP)

- Despite their major potential influence on the energy, water, and carbon budgets, land surface processes have received little attention in CMIP5.
- Beyond the well known and relatively well constrained snow albedo feedback in spring (Qu and Hall 2014), soil moisture is also likely to amplify temperature (and precipitation) anomalies in summer (Seneviratne et al. 2013).
- While the response of the evaporative fraction, EF=LE/(LE+H), is not the main source of inter-model spread in surface temperature projections over land, it is worth of further investigation and connects more strongly to the pattern of temperature anomalies within each model.
- The soil moisture feedback dominates changes in the shape of the daily temperature distribution in the summer mid-latitudes (Douville et al. 2015)].



Scatterplot of changes in surface air temperature (t2m) vs. changes in surface evaporative fraction (ef) in RCP8.5 projections. Symbols denote the late 21st century JJAS anomalies averaged over the Northern mid-latitude land areas among a subset of CMIP5 models, while symbol colours denote the spatial correlation between t2m and ef anomalies within each model.

Empirical distribution of daily Tmax (K) for present-day (Pxx) and future (Fxx) climates over a) central US and b) eastern Europe. Results demonstrate the lack of change in the shape of the distribution when the SMF is suppressed (green curve for future climate nudged towards present-day soil moisture). [Douville et al. 2015]



CMIP6 objectives

- Evaluate and attribute land surface model biases in a hierarchy of configurations (land only GSWP runs, land-atmosphere only AMIP runs, and fully coupled historical runs).
- Quantify land surface feedbacks in AMIP and/or CMIP runs with prescribed land surface boundary conditions. [NB: what is the required ensemble size for CMIP runs?]
- Narrow uncertainties in land surface feedbacks and regional climate change through model assessment at shorter (seasonal, interannual, multi-decadal) timescales.

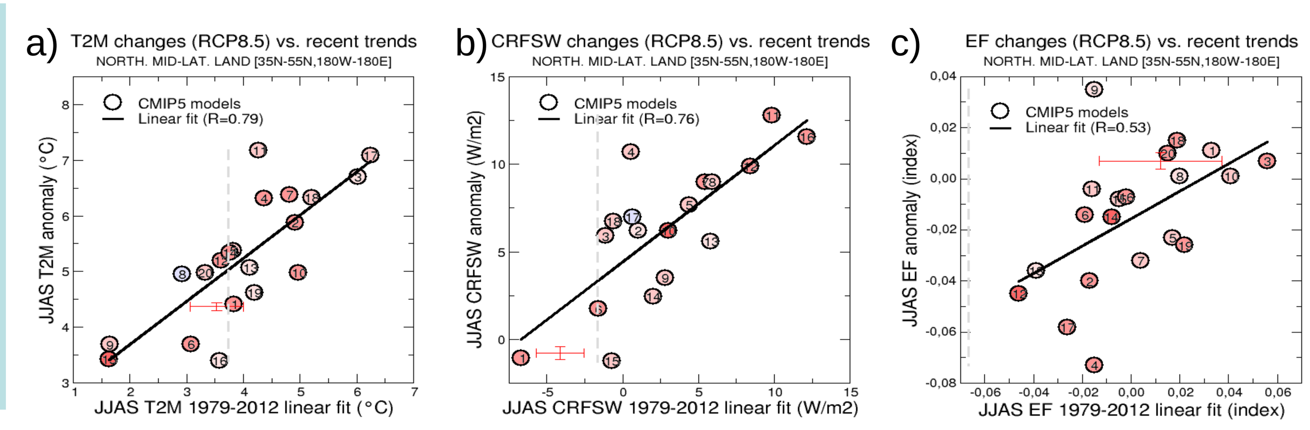
4. Detection and attribution (DAMIP)

- The "International Detection and Attribution Group" (IDAG) is a group of specialists on climate change detection and attribution, who have been collaborating on assessing and reducing uncertainties in the estimates of climate change since 1995.
- Despite the role of non-GHG radiative forcings and of internal climate variability, recent trends in spatially aggregated climate indices already emerge as potential constraints on long-term projections.

CMIP6 objectives

- Isolate the contribution of the GHG radiative forcings vs. internal climate variability and other (more heterogeneous) radiative forcings in the observed climate multi-decadal variability.
- Develop new D&A algorithms which allow the assumption of perfect model response patterns to be relaxed [Ribes et al. 2015].
- Apply D&A not only to temperature and precipitation, but also to land surface variables using the multi-model GSWP3 archive as a surrogate for observations [e.g., Douville et al. 2012].

Scatterplot of changes vs. recent trends (per century) for 3 averaged climate indices in a subset of CMIP5 models. Symbol colours denote the spatial correlation between anomalies and trends within each model. Dashed grey lines show observational trend estimates using CRU_TS3.22, SRB and ERAI respectively. Red crosses denote the mean and range of a 5-member ensemble with CNRM-CM5



5. A roadmap for CMIP6 and beyond?

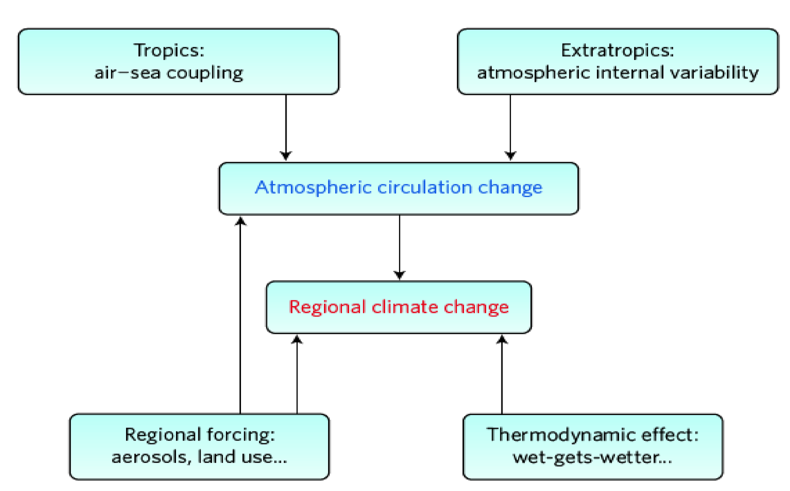
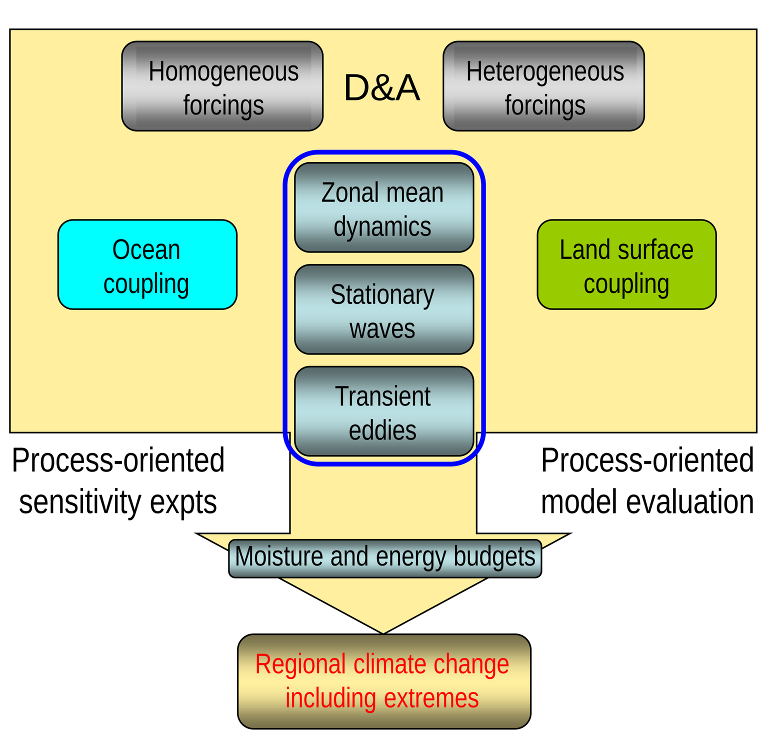


Figure 5 | Schematic of physical origins of regional climate change.

- "In the tropics, where atmospheric internal variability is small (…), advancing our understanding of the coupling between long-term changes in upper-ocean temperature and the atmospheric circulation will help most to narrow the uncertainty."
- "In the extratropics (…), large ensemble simulations are essential to estimate the probabilistic distribution of climate change on regional scales."
- "The current priority is to understand and reduce uncertainties on scales greater than 100 km to aid assessments at finer scales."

[Xie et al. 2015: Towards predictive understanding of regional climate change]



A complementary rather than alternative schematic

- Can we draw robust conclusions about the real climate system from idealized sensitivity experiments and/or more or less arbitrary breakdown between dynamical vs. non dynamical contributions to climate change?
- How large ensembles of historical simulations do we need for developing efficient emerging constraints?
- Are there important gaps [e.g., small ensembles of full ESM simulations with nudged atmospheric dynamics and/or land surface boundary conditions] or missing model outputs [e.g., more statistics than only the mean for sub-daily precipitation] in CMIP6?

6. References

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The cloud radiative effect on simulating the asymmetry in the strength of the two types of El Niño in CMIP5 models

Xiang-Hui FANG [1,2], Fei ZHENG [1] and Jiang ZHU[1]
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2. University of the Chinese Academy of Sciences, Beijing, China
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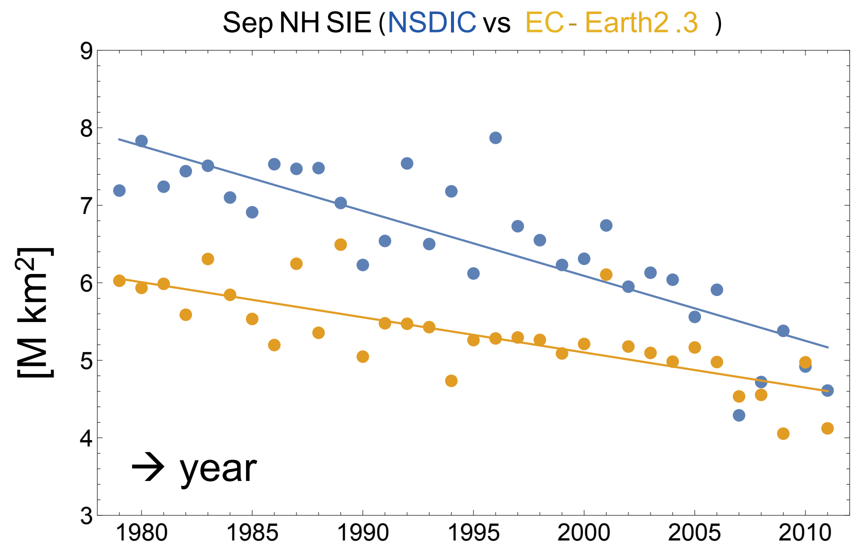
Contents

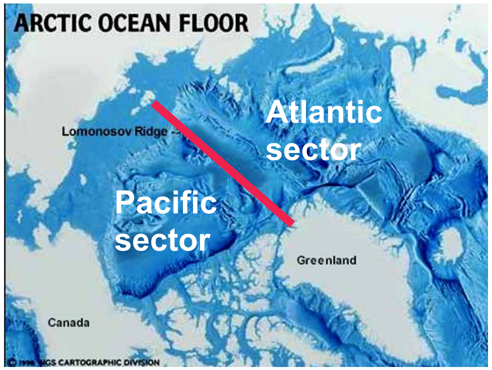
Climate Forecasting Unit

On the anatomy of the NH sea ice extent and impacts of different bias correction methods in a set of CMIP5 models

Neven S. Fučkar[1,7] (nevensf@gmail.com), Virginie Guemas[1,2,7], Matthieu Chevallier[2], Michael Sigmond[3], Felix Bunzel[4], Rym Msadek[5] and Francisco J. Doblas-Reyes[1,6,7]

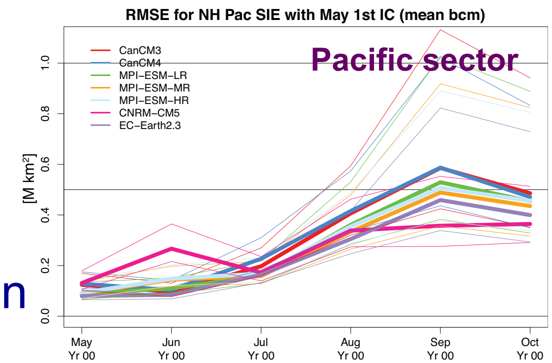
[1]Institut Català de Ciències del Clima (IC3), Barcelona, Spain, [2]Centre National de Recherches Météorologiques/Groupe d'Etude de l'Atmosphère Météorologique, Météo-France, CNRS, Toulouse, France, [3]Candain Center for Climate Modeling and Analysis, Victoria, British Columbia, Canada, [4]Max Planck Institute for Meteorology, Hamburg, Germany, [5]Geophysical Fluid Dynamics Laboratory, NOAA, Princeton, NJ, USA, [6]Instituciò Catalana de Recerca i Estudis Avançats (ICREA), Barcelona, [7]Earth Sciences Departments, Barcelona Supercomputing Center, Barcelona, Spain

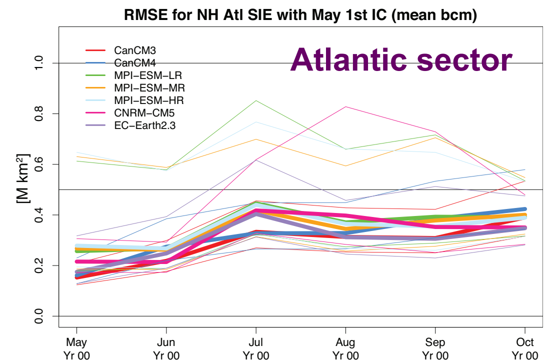




Sea ice extent in the Atlantic sector of the Arctic is more predictable than in the Pacific sector

Long-term and interannual differences ⇒ utilizing a hierarchy of bias correction methods can improve prediction skill



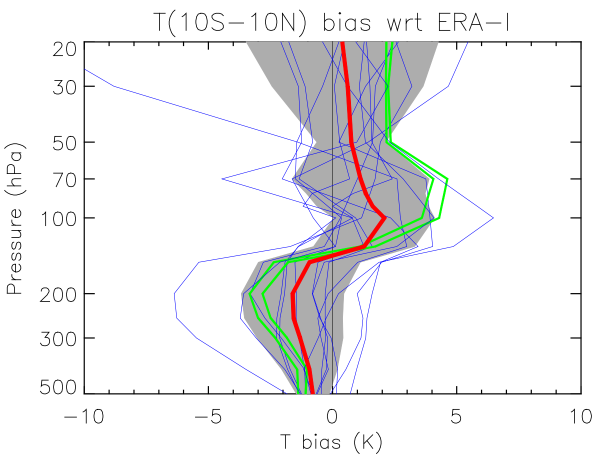


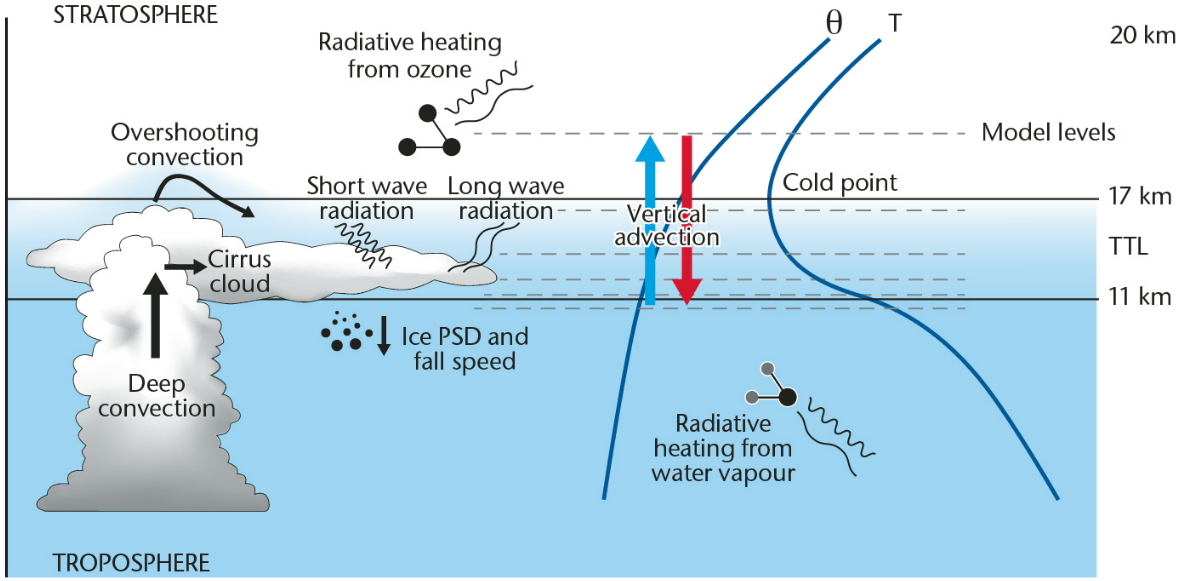
Workshop on CIMP5 Model Analysis and Scientific Plans for CMIP6, 20th - 23rd October 2015, Dubrovnik (Croatia)

Processes controlling tropical tropopause temperature and stratospheric water vapour in climate models

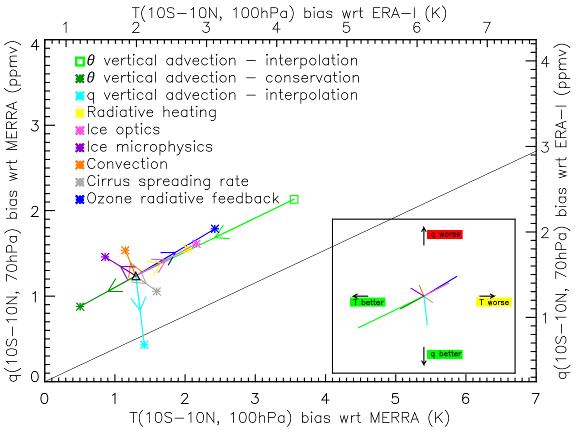
(Poster 6: Hardiman et al.)

Met Office
Hadley Centre





- Warm bias (average 2K) in ‘cold point’ temperature common across CMIP5 models
- Stratospheric water vapour can affect surface climate, atmospheric circulation, and stratospheric composition
- Processes in TTL can influence stratospheric water vapour either directly or through changing cold point T
- Aim to reduce biases whilst simultaneously improving model representation of the physical processes

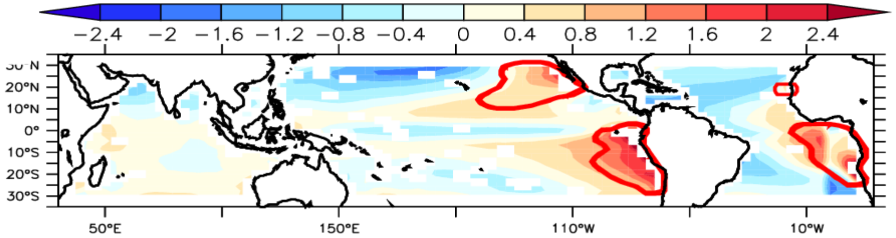


On the control of sea surface temperature and air-sea coupling variables by atmospheric boundary layer parameterizations

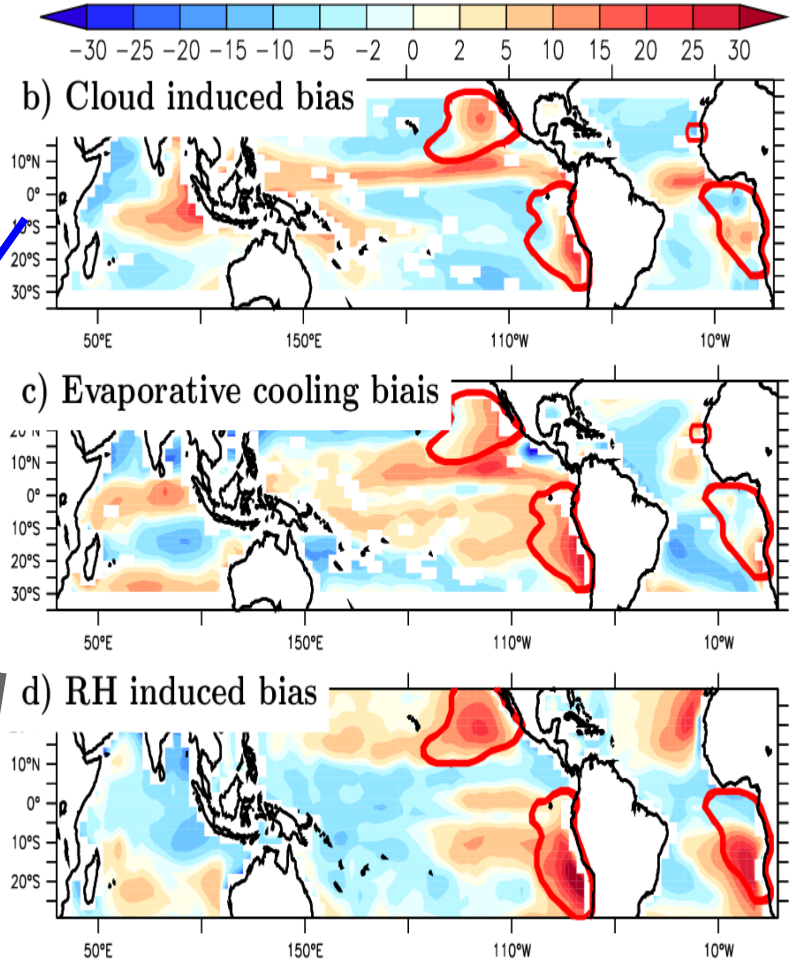
Hourdin, F., Gainusa-Bogdan, A., Braconnot, P., Dufresne, J.-L, Rio, C., Jam, A., Laboratoire de Météorologie Dynamique, IPSL/CNR/UPMC

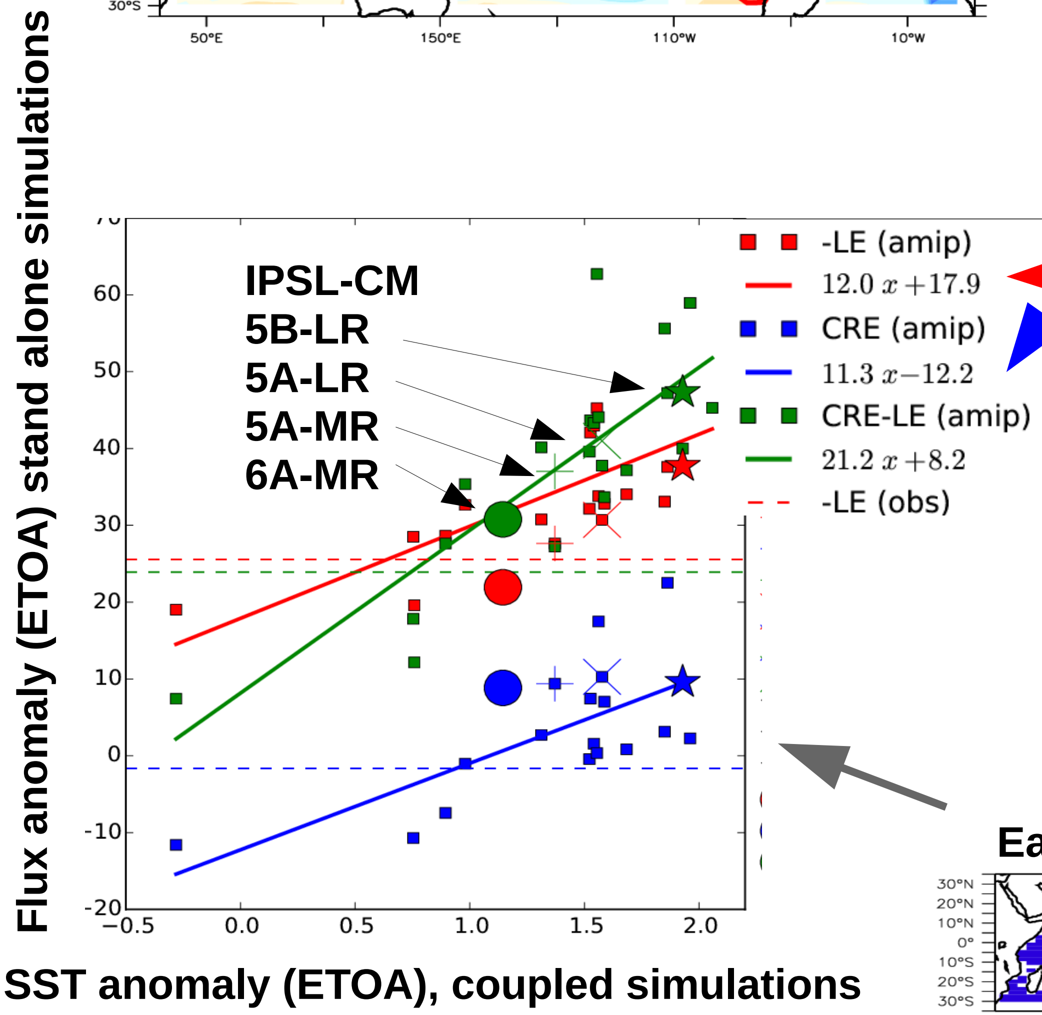
Eastern tropical ocean warm bias in CMIP5 simulations

SST bias pattern (K), coupled O/A simulations

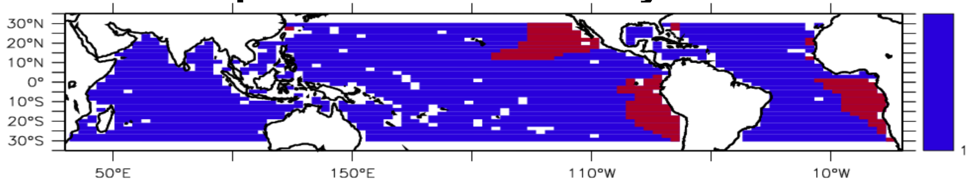


Heat flux bias pattern (K), atmosphere alone



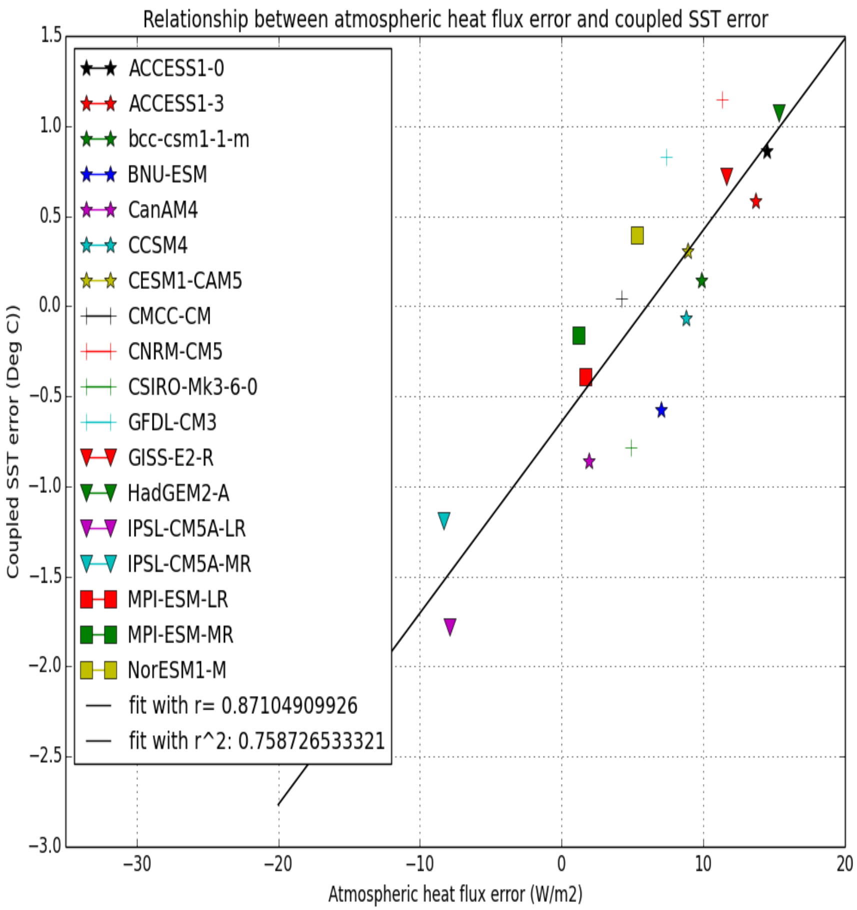


East Tropical Ocean Anomaly : ETOA index



Understanding Southern Ocean sea surface temperature biases

Colin Jones, Pat Hyder et al

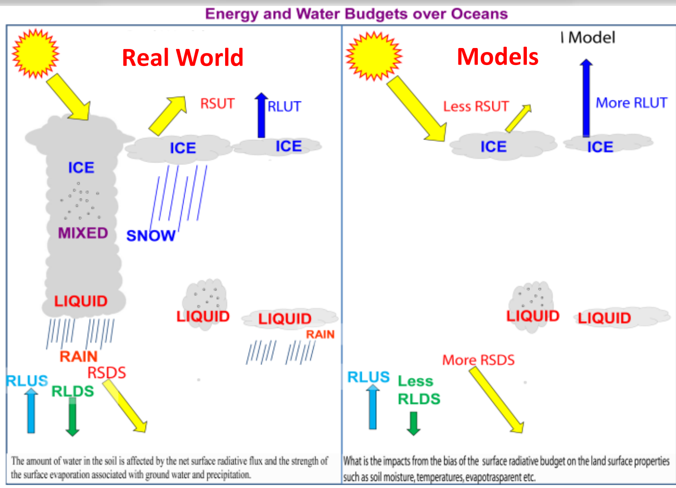


- Many CMIP5 coupled climate models have warm Southern Ocean SST biases.
- Net flux errors in atmosphere only simulations explain ¾ of the variance in coupled SST biases (fig).
- Hence, in combination, ocean model and atmosphere only wind & freshwater forcing errors contribute to <¼ of spread in SST biases.
- Some planned changes to our current atmospheric configuration reduce the 40-60ºS net flux bias by ~40%, and coupled SST biases by ~60%.

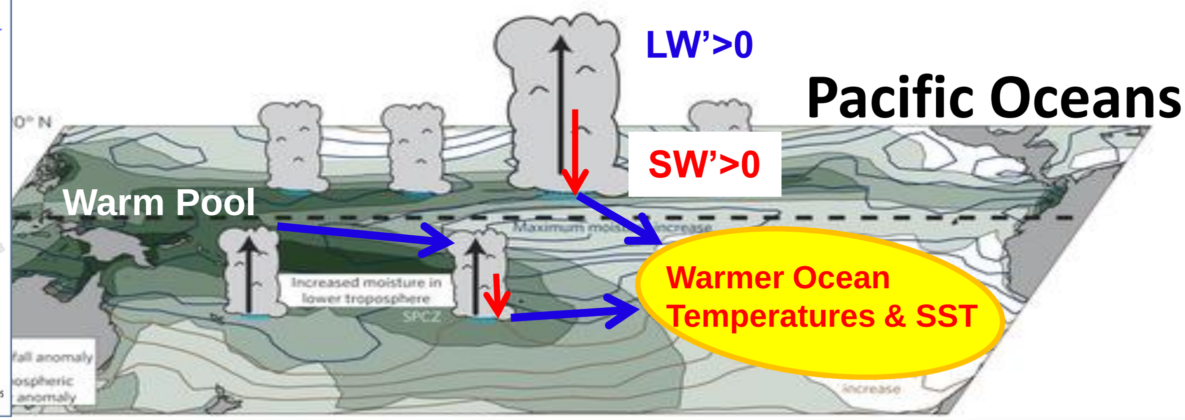
Quantification of Systematic Biases of Cloud, Radiation, Water Vapor and their Impacts on Land/Ocean Surface Processes in CMIP3/CMIP5 Simulations using NASA Observations

Jui-Lin (Frank) Li

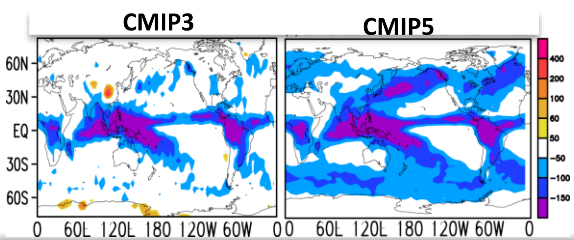
W.-L Lee, Duane Waliser, T. Lee, E. Fetzer, Graeme Stephens, D. Neelin, J.-Y. Yu, Y-J Chen, Y-H Wang, Q. Yue, S. Wong



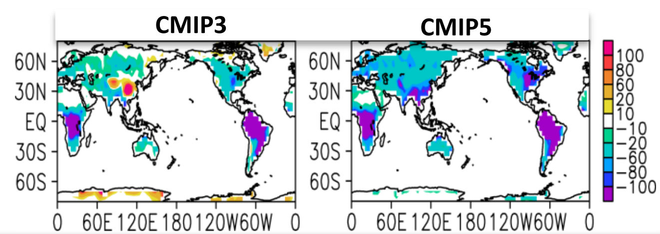
The Common Biases in CMIP3/CMIP5



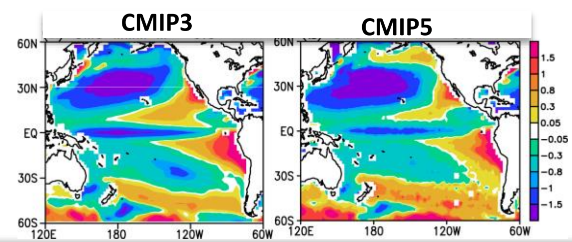
Total Ice Water Path Bias



Total Ice Water Path Bias - Land



Sea Surface Temperatures Bias



Problem: The *radiative effects of snow* have been ignored in most global climate models (CGCMs) – **CMIP3/CMIP5**.

To what extent snow-radiative effects contributes to the CGCMs' biases in key climate indicators (H2O, SST and LST)?

Result: Using NASA observations, we identify systematic biases in CMIP models (no snow-radiation effects):

- Too weak trade winds; too moist & excessive precipitation; warmer ocean temperatures in the Tropical Pacific Ocean.
- Too cold land surface temperatures (LST) in winter seasons and too warn LST in summer seasons.

Significance: With snow-radiation included, most systematic errors in CGCM reduced with improved climate mean state and variability. **We suggest that the snow-radiative effects should be implemented in CMIP6 CGCMs.**

Kelvin and Rossby gravity wave packets in the lower stratosphere of CMIP5 models

François Lott and 13 co-authors (Poster 10, Wednesday Afternoon)

Motivations:

How well are represented
the eq. Waves in CMIP models
What makes the differences between
models

Methodology :

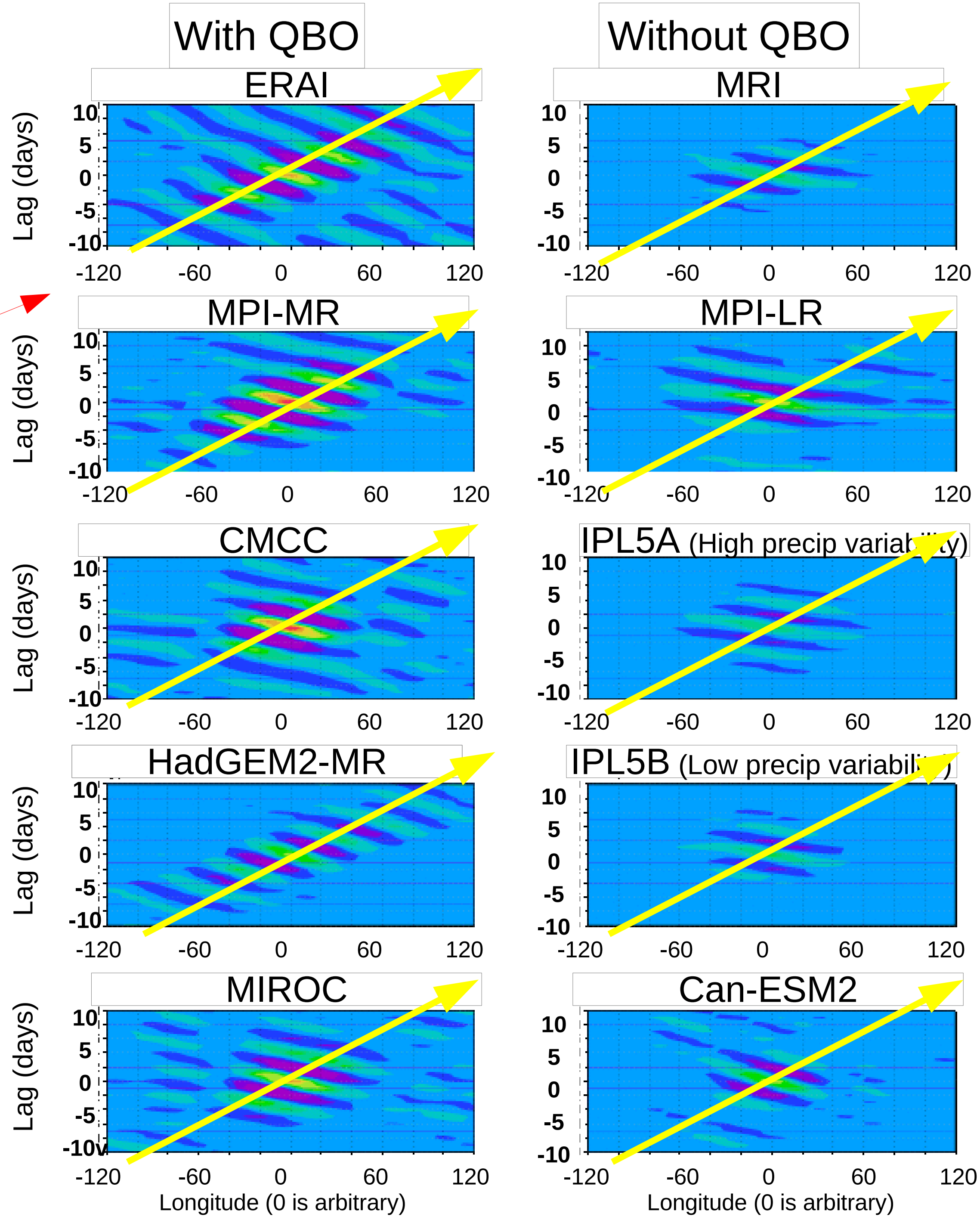
Rossby Gravity wave composites
at 50hPa Hovmoller of V at equator

Results :

Pronounced differences : For RGWs
model with QBO
do better because of wind filtering

Models with QBO also have better Kelvin
wave although wind filtering
is not favorable :
effect of vertical resolution

Convection parameterizations do not
play a Role as large as the dynamical
and numerical filtering do

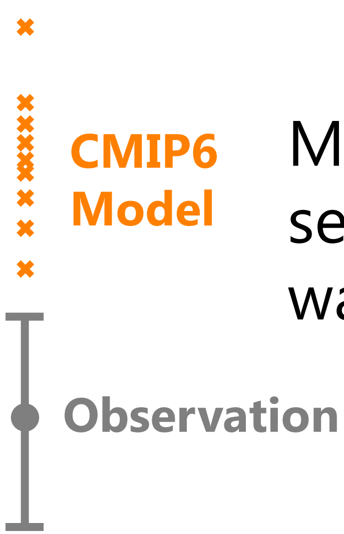


The next generation of Arctic sea ice metrics

F. Massonnet, M. Vancoppenolle, D. Ivanova, O. Lecomte, P. Hezel, T. Fichefet

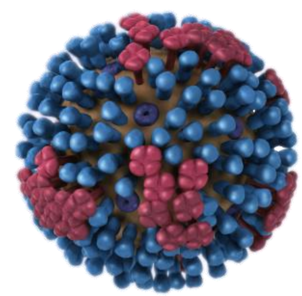
SYMPTOMS

You have a strong headache

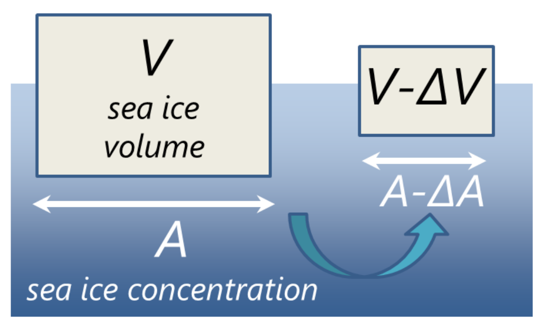


Modelled Arctic sea ice extent is way too large

DISEASES



You suffer from a bad flu



Sea ice albedo feedback is not well simulated

National Science Challenges

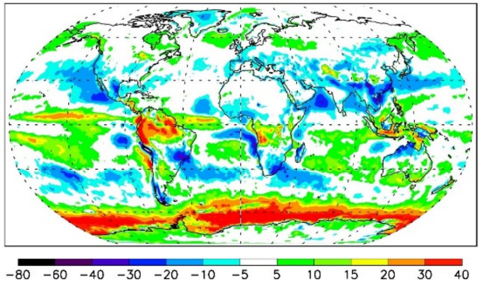
THE DEEP SOUTH | Te Kōmata o Te Tonga

The Deep South National Science Challenge: Reducing Persistent Climate Model Biases in the Southern Hemisphere

O. Morgenstern[1], S. M. Dean[1], D. Frame[1,2], et al.

[1]NIWA, New Zealand [2]Victoria U., Wellington, New Zealand

- Persistent biases affect SH climate projections.
- Problems with southern high-latitude processes (clouds, sea ice, Antarctic bottom water formation)
- New Earth System Model (NZESM) to address these issues
- New observations and new modelling approaches
- New or updated composite data sets for model validation
- Associate partner in CRESCENDO



Cloud-radiative forcing bias in DJF (W/m^2) in a GCM.

Role of clouds, aerosols, and aerosol-cloud interaction in 20th century simulations with GISS ModelE2

Larissa Nazarenko, David Rind, Susanne Bauer, Anthony Del Genio

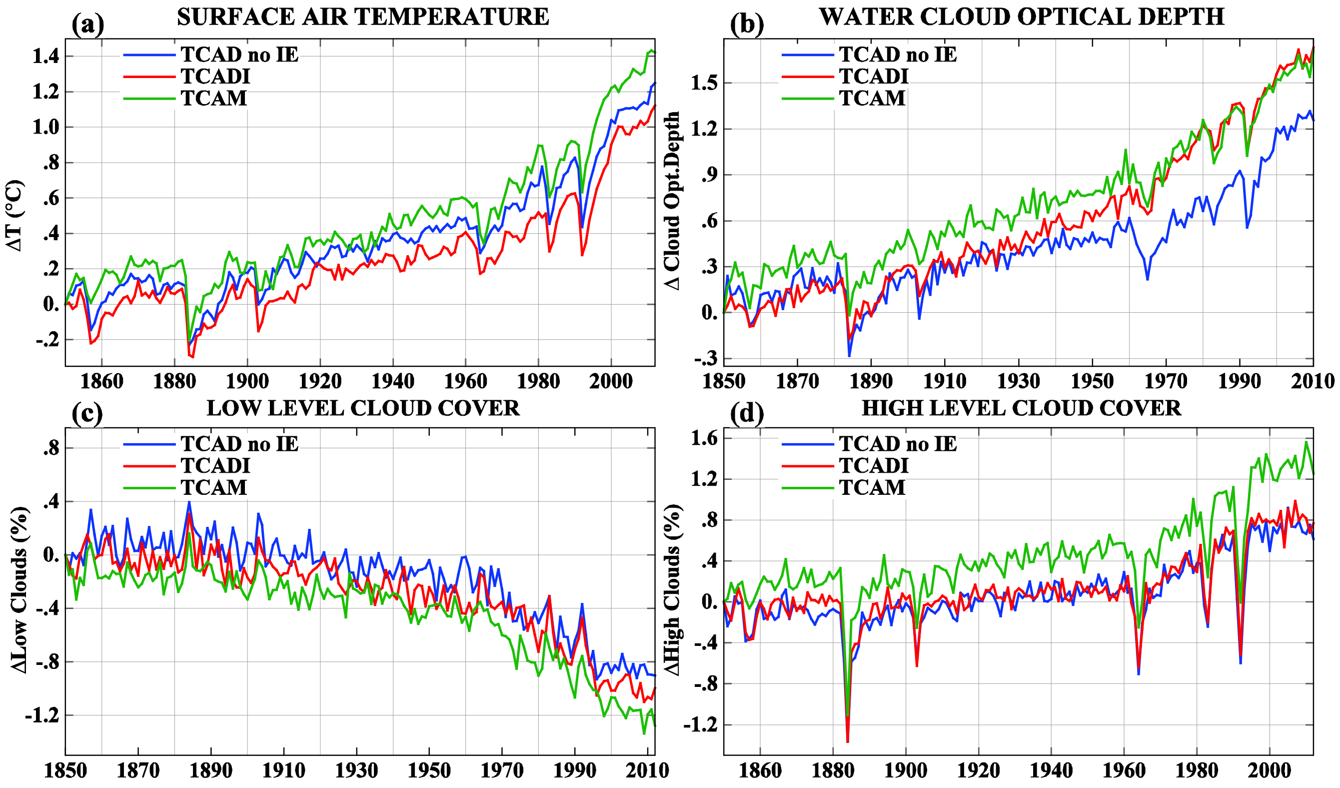
Columbia University/NASA Goddard Institute for Space Studies, New York, NY, USA

We use the new version of NASA Goddard Institute for Space Studies (GISS) climate model, modelE2 with 2º by 2.5º horizontal resolution and 40 vertical layers, with the model top at 0.1 hPa [*Schmidt et al.,* 2014].

We use two different treatments of the atmospheric composition and aerosol indirect effect: (1) TCAD(I) version has fully interactive Tracers of Aerosols and Chemistry in both the troposphere and stratosphere. This model predicts total aerosol number and mass concentrations [*Shindell et al*., 2013]; (2) TCAM is the aerosol microphysics and chemistry model based on the quadrature methods of moments [*Bauer et al*., 2008]. Both TCADI and TCAM models include the first indirect effect of aerosols on clouds [*Menon et al*., 2010]; the TCAD model includes only the direct aerosol effect.

We consider the results of the TCAD, TCADI and TCAM models coupled to “Russell ocean model” [*Russell et al.*, 1995], E2-R.

We examine the climate response for the “historical period” that include the natural and anthropogenic forcings for 1850 to 2012. The effect of clouds, their feedbacks, as well as the aerosol-cloud interactions are assessed for the transient climate change.



Anomalies relative to 1850: (a) global annual mean surface air temperature; (b) water cloud optical depth; (c) low level cloud cover; (d) high level cloud cover .

On the ability of NEMO-LIM3 to simulate sea ice dynamics using a Maxwell-elasto-brittle rheology

Jonathan Raulier, Thierry Fichefet, Vincent Legat, Véronique Dansereau, Jérôme Weiss

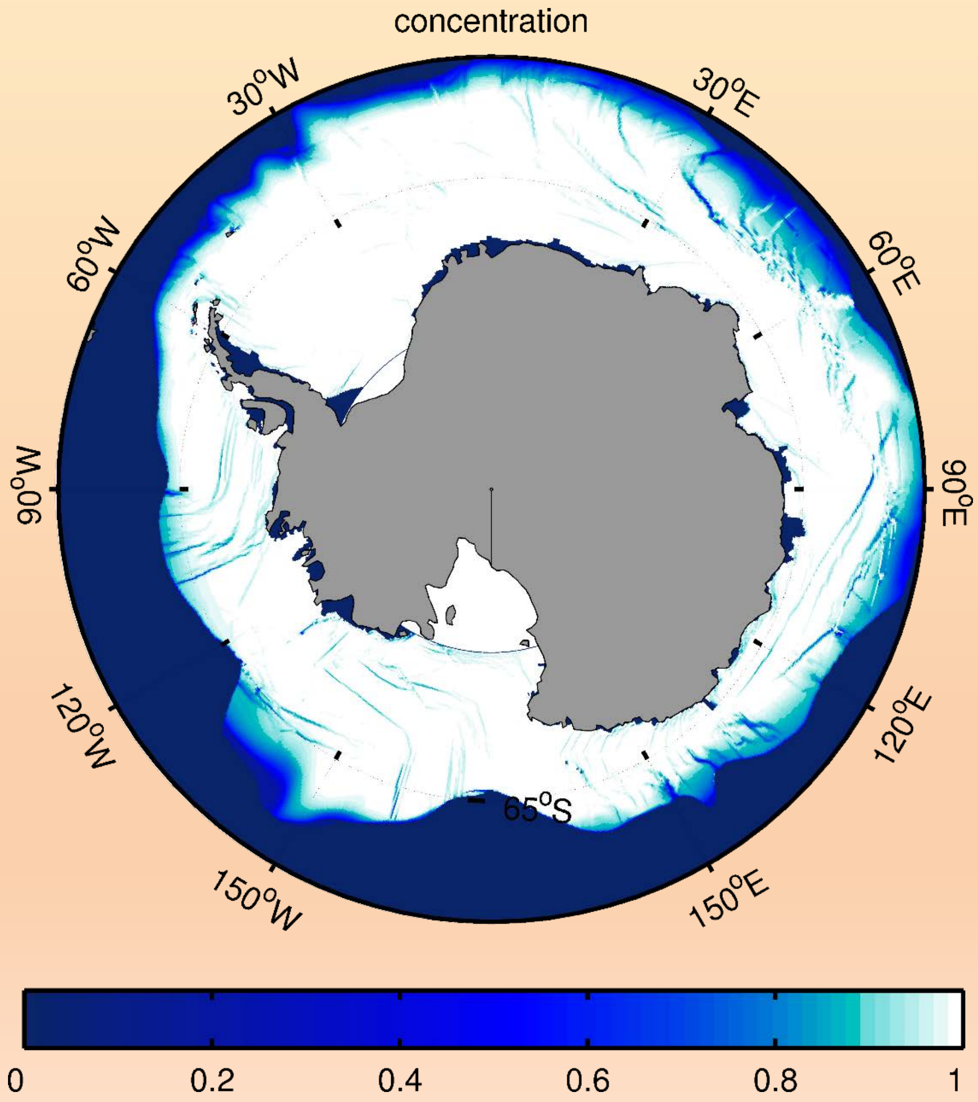
- A Maxwell-elasto-brittle rheology
  - Maxwell model :

    → **elastic** media + apparent **viscosity.**
  - Brittle behaviour :

    → **damaging** event;

    → **weakening** of sea ice.

- Purposes :
  - reproduce the **anisotropy** and **intermittency** of the deformation;
  - simulate the right degree of **localization** of the deformation;
  - reproduce the formation and evolution of **leads**.



Daily mean concentration of sea ice in the Antarctic for the beginning of August 1980 simulated with NEMO-LIM3

Missing pieces of the puzzle: understanding decadal variability of Sahel rainfall using CMIP5 and higher resolution models

Met Office | Natural Environment Research Council | National Centre for Atmospheric Science | UKaid | PRACE

Joint Weather & Climate Research Programme

M. Vellinga, **M.J. Roberts**, M.S. Mizielinski, P.L. Vidale, R. Schiemann, M.-E. Demory, J. Strachan, C. Bain

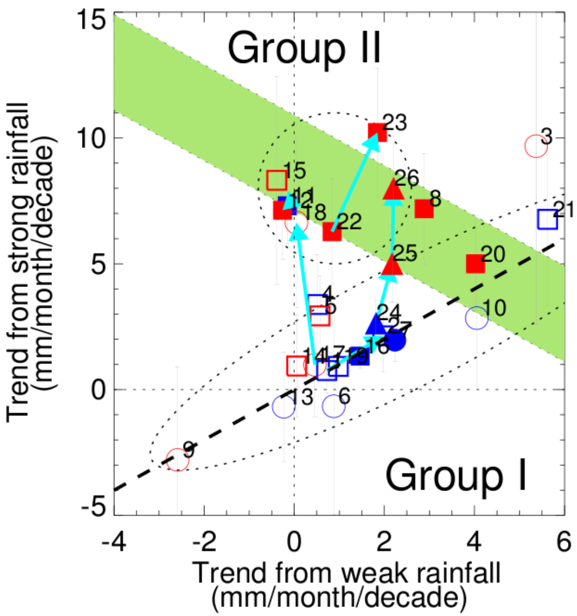
Significant low frequency Sahel rainfall fluctuations in 20th Century, causing:

- Devastating local drought
- Influence on downstream processes

Challenge for CMIP5-type models

- Does enhanced model resolution help?

Study using CMIP5 AMIP-II simulations + MetUM GA3 at 130km, 60km and 25km



Models with significant trend to match observed precipitation trend (green):

- typically have significant trend in the strong precipitation events (red)
- models with higher horizontal resolution have stronger trend (e.g. 24 → 25 → 26)
- models with trend in weak rainfall events (blue) do not typically match observed trend

Vellinga et al (submitted)

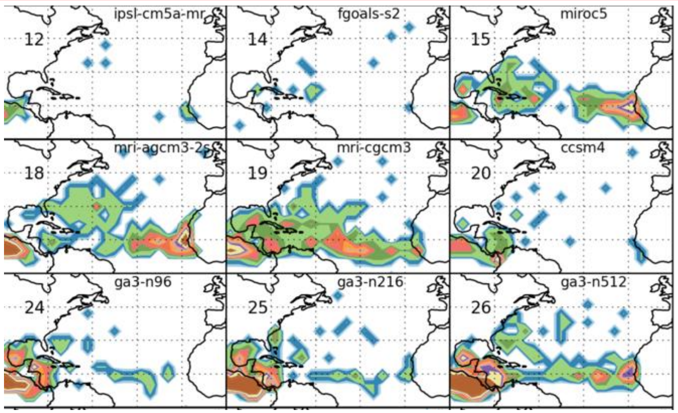
African Easterly Waves provide crucial link in chain of mechanisms:

- large-scale variability increases jet shear
- this produces more and stronger AEWs in higher resolution model (12% per decade)
- higher resolution models seem to extract more of converged moisture as rainfall
- lower resolution models have much weaker changes

Are there consequences for downstream processes such as Atlantic tropical cyclones?

Tropical cyclone genesis density from CMIP5 models shows large spread in performance in eastern Atlantic

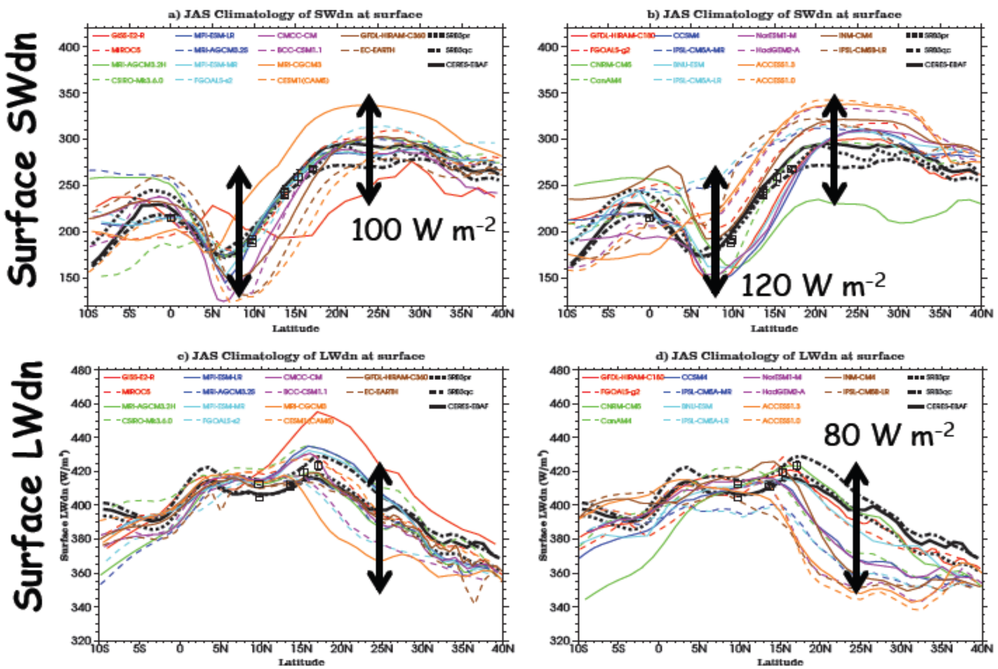
- understanding relationship with AEWs and circulation ongoing



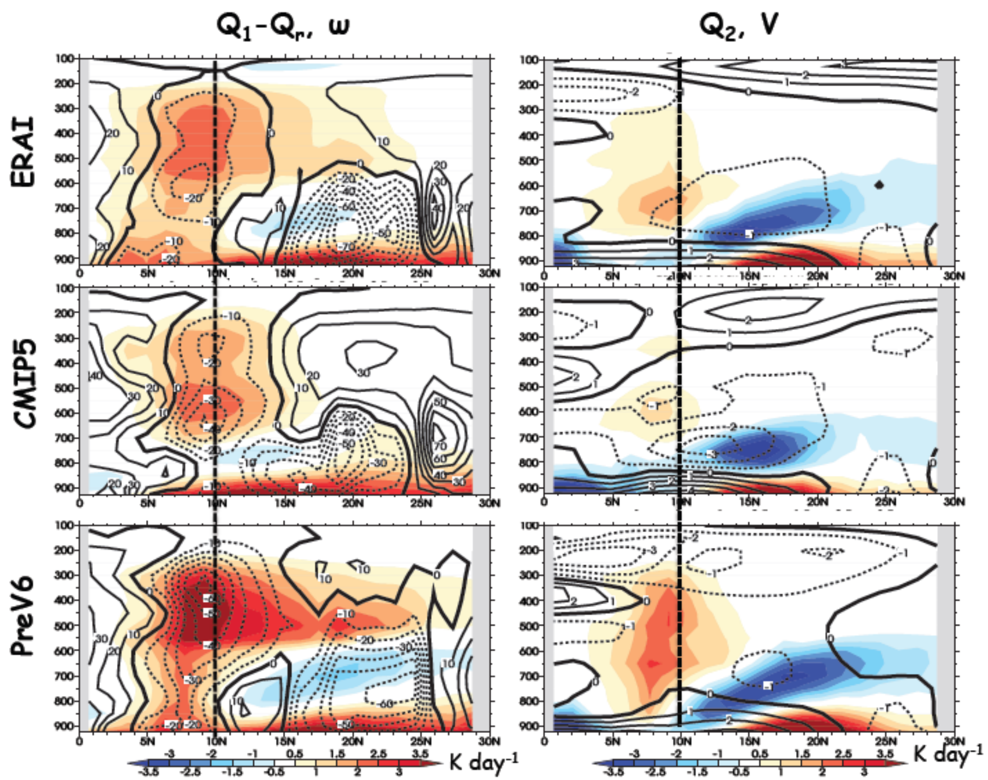
Overview of the West African monsoon in CMIP5 and in the updated CNRM model

Roehrig et al.

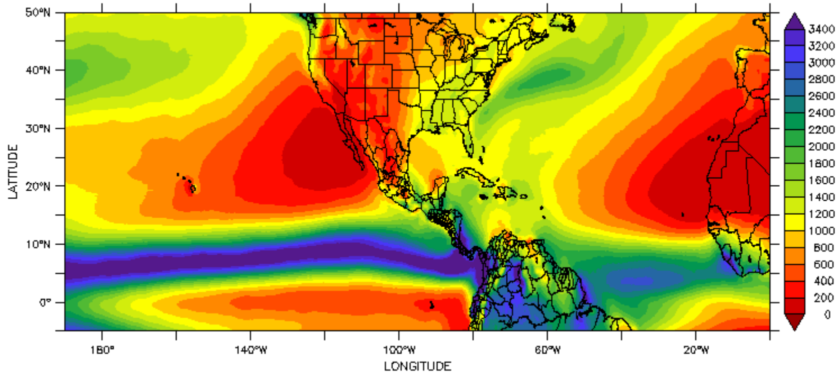
- Discuss the representation of the West African Monsoon in CMIP5 models

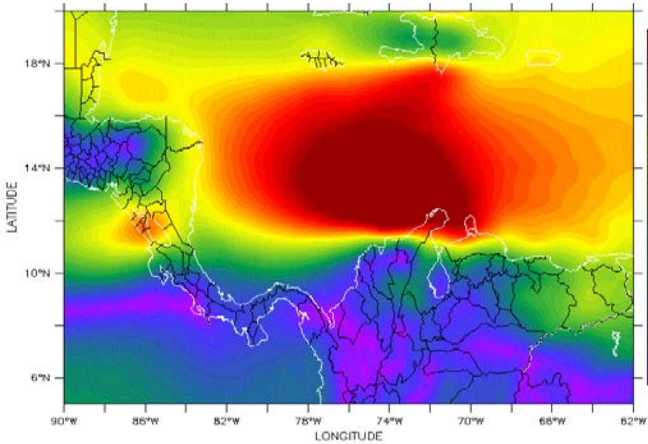


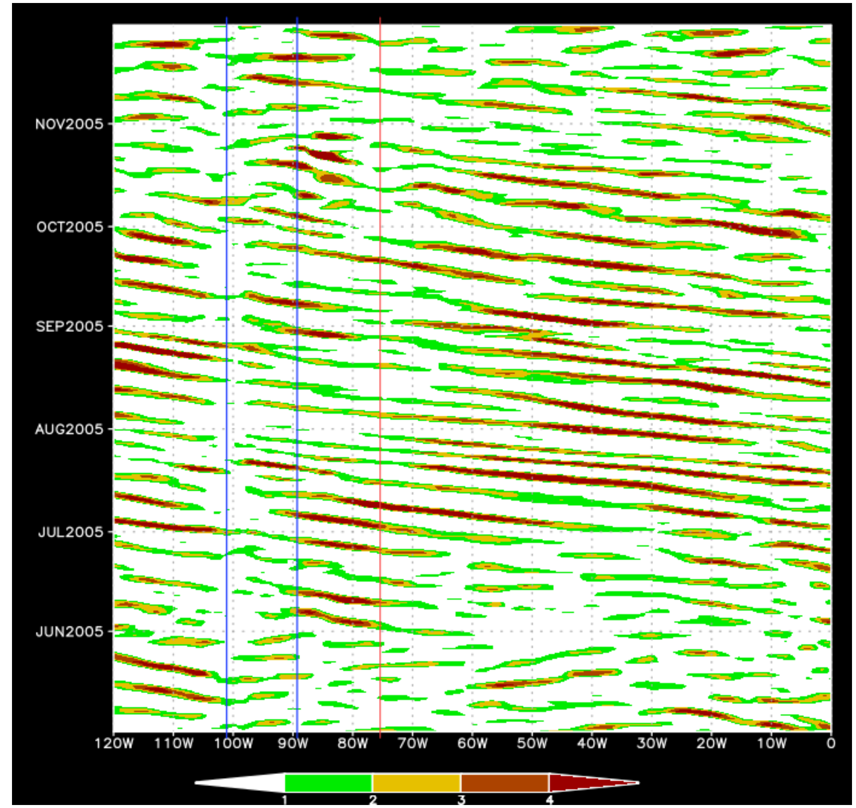
- Improvements (and new biases) in the new CNRM climate model

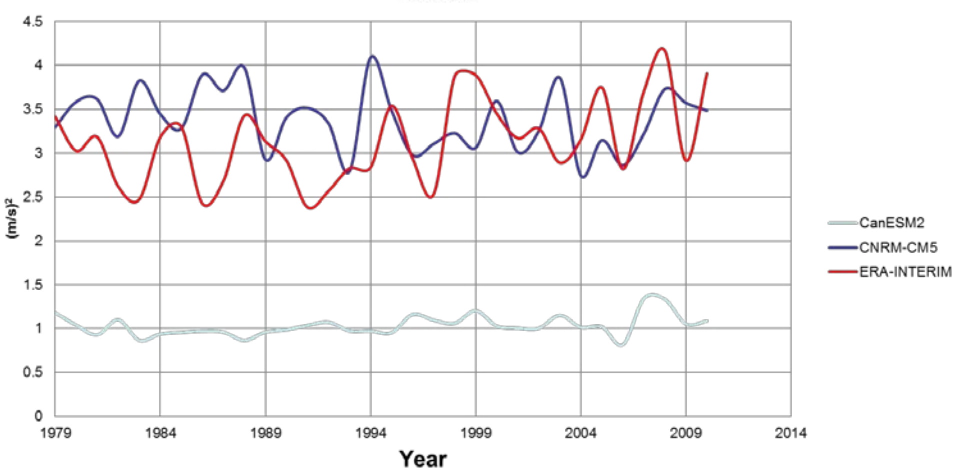


GOAL: To analyze the reproduction of the regional atmospheric dynamics: high and low frequency events.









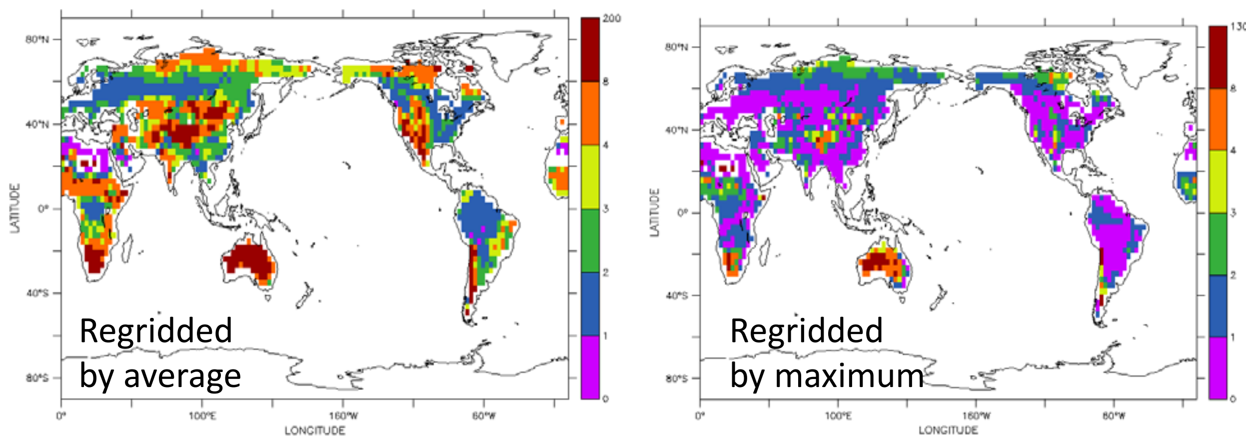
- Easterly waves
- Cold fronts

- ITCZ
- Low level Caribbean jet.
- High level Pacific jet.

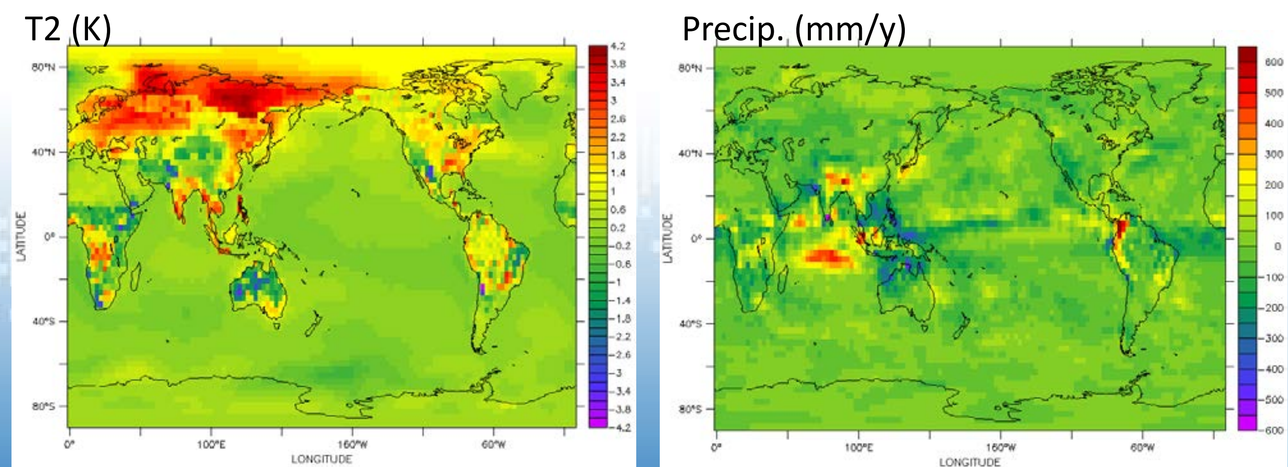
Reproducibility of the present-day Leaf Area Index by CMIP5 Earth System Models

Tachiiri. K., Hajima, T. and Kawamiya, M.
(Japan Agency for Marine-Earth Science and Technology)

- *LAI in most land surface models is defined for the vegetated part only, while remote sensing LAI is for the total area (vegetated and nonvegetated).* [Ge, 2009, JC].
- Experiment using MIROC-ESM shows replacement of modelled LAI with remote sensing LAI makes significant impact.



[ESMs' LAI (average of 18 models)] / [RS LAI]

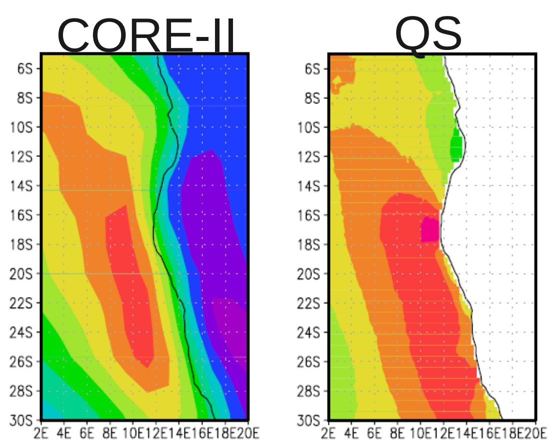


Difference in 20 year average in control run [RS LAI – modelled LAI]

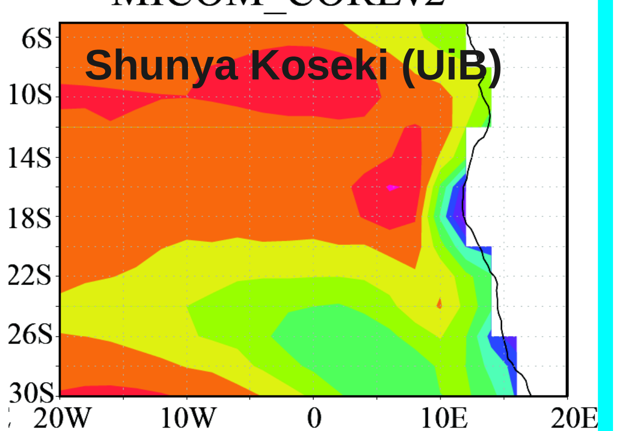
FP7 PREFACE collaboration: science objective for CT3+4

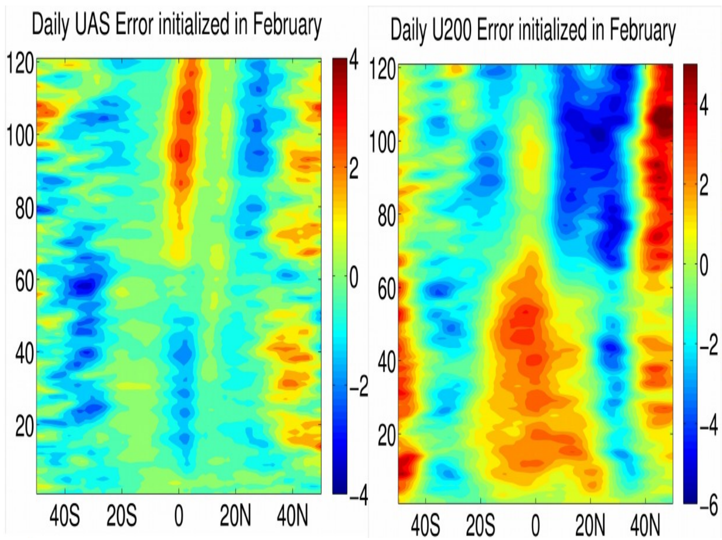
Presenter: Thomas Toniazzo (Bjerknes)

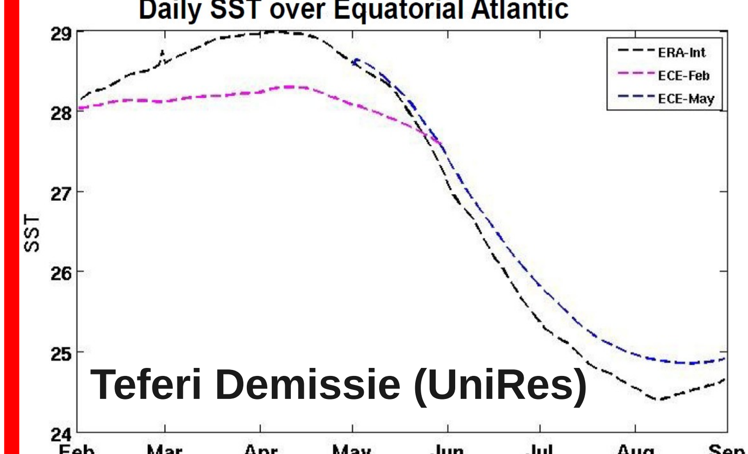
Improve the **accuracy** of **numerical simulations** of Tropical Atlantic coupled climate with **global GCMs** for
- ➔ s2d forecasting
- ➔ climate simulation and projections



MICOM_QS minus MICOM_COREv2







Marta Martin del Rey (UCM)

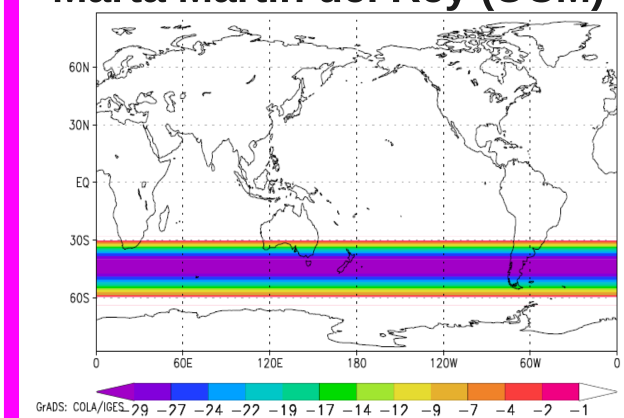
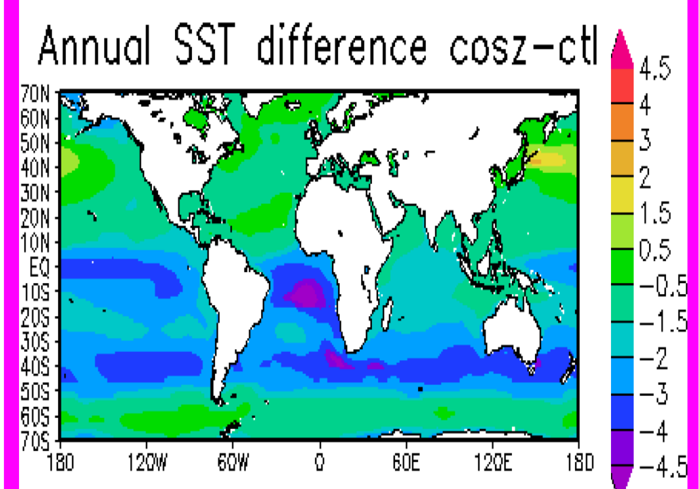


Figure 1: Reduction of SWD at TOA in IdExp.

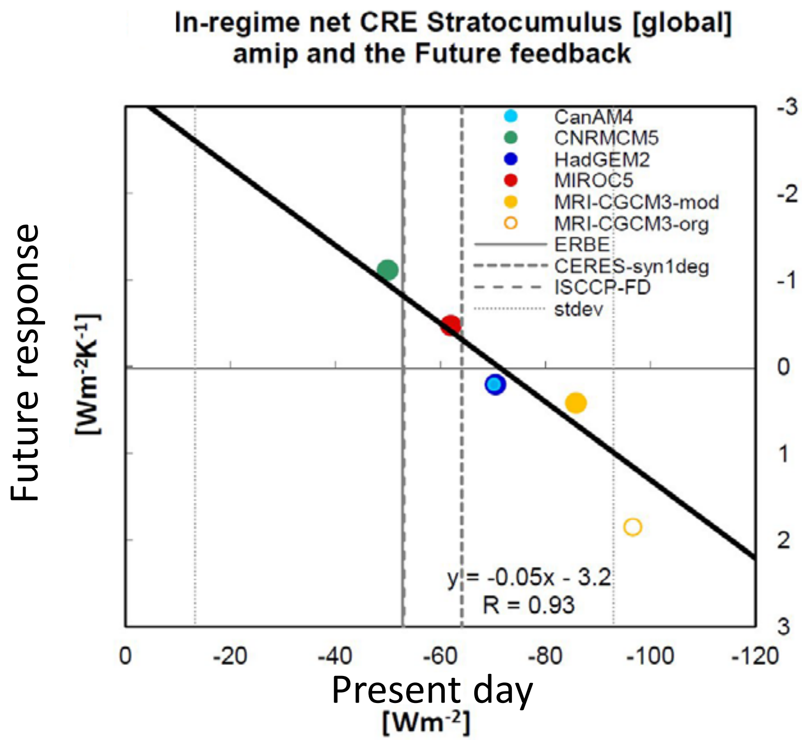


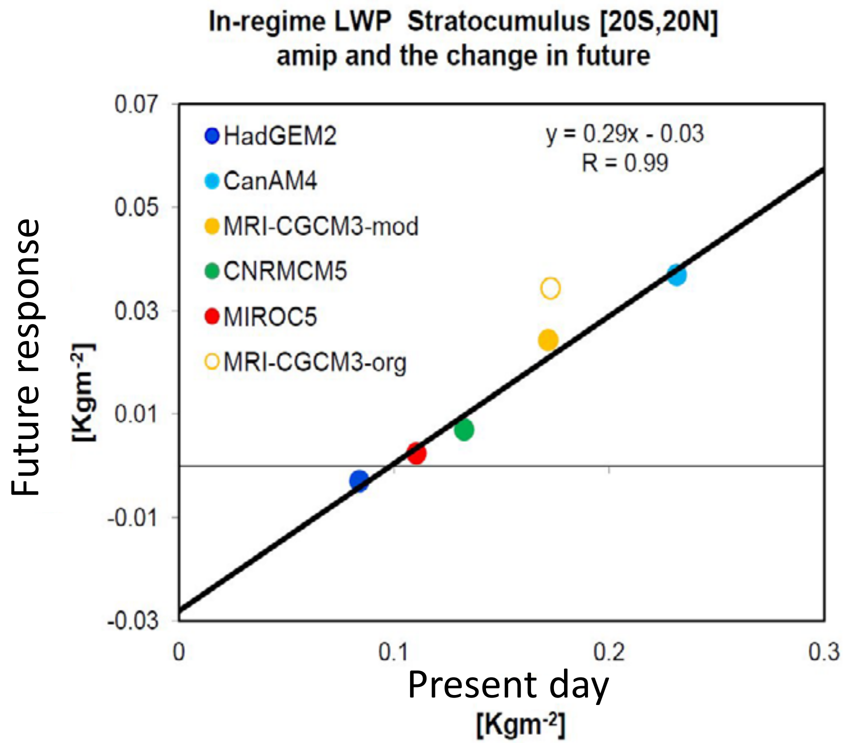
Robustness, uncertainties, and emergent constraints in the radiative responses of stratocumulus cloud regimes to future warming

Yoko Tsushima[1], Mark A. Ringer[1], Tsuyoshi Koshiro[2], Hideaki Kawai[2], Romain Roehrig[3], Jason Cole[4], Masahiro Watanabe[5], Tokuta Yokohata[6], Alejandro Bodas-Salcedo[1], Keith D. Williams[1], and Mark J. Webb[1]

1 Met Office, Hadley Centre, UK, 2. Meteorological Research Institute (MRI), JMA, Japan
3. Centre National de Recherches Météorologiques, France, 4. Canadian Centre for Climate Modelling and Analysis, Canada,
5. Atmosphere and Ocean Research Institute (AORI), University of Tokyo, Japan, 6. National Institute for Environmental Studies, Japan

- A correlation is found for bulk radiative properties in Stratocumulus regimes
- A correlation in a physical property emerges from more detailed analysis





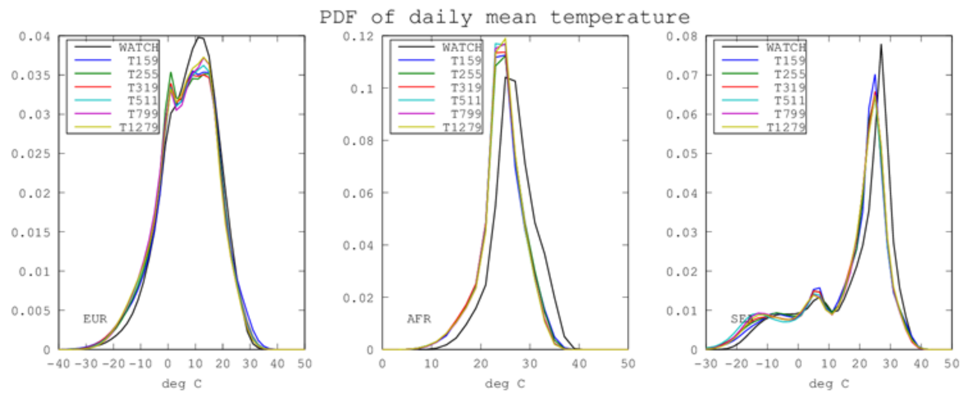
- But the better agreement with observations is found to result from compensation of errors
- A possible observational constraint?

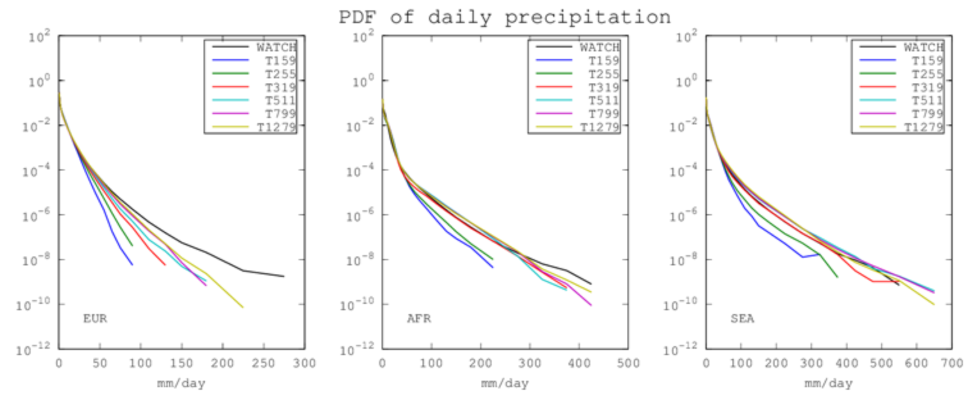
Tsushima et al.,2015 Clim Dyn

Sensitivity of AMIP simulations to model resolution and the temporal resolution of the forcing

Klaus Wyser, Rossby Centre, Swedish Meteorological and Hydrological Institute

Current GCMs suffer from a lack of variability compared to observations. We try to improve the variability of the EC-EARTH model by changing the resolution, and by increasing the forcing frequency in AMIP-type simulations.





Conclusions

- Resolution has little impact on daily mean temperatures
- The variability of daily precipitation improves with model resolution

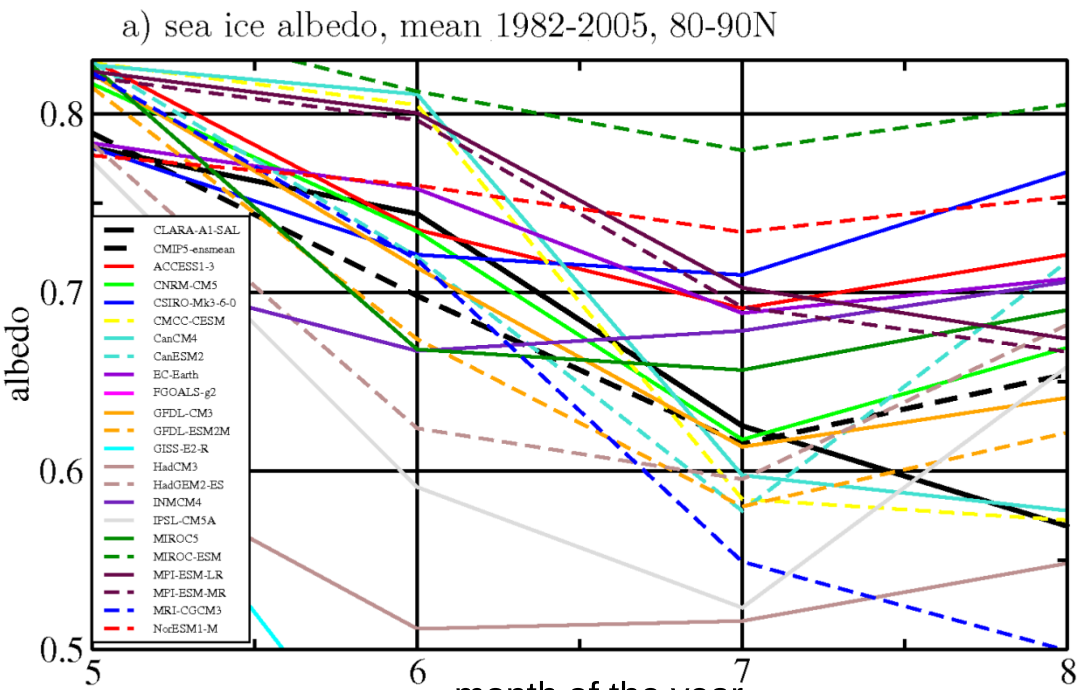
Summer Arctic sea ice albedo in CMIP5 models

T. Koenigk, A. Devasthale, K.G. Karlsson, K. Wyser

SMHI

Goal

The spatial and temporal variations of Arctic summer sea ice albedo across CMIP5 models are analyzed and compared to satellite observations (CLARA-A1-SAL). Potential causes for the different ice albedo in the models and the deviations from the observations are investigated.



Results:

We find a strong spread in ice albedo across CMIP5 models; variations in surface temperature and snow on ice are responsible for a large part of the albedo variations.

Temporal evolution of albedo throughout the summer is not well reproduced. Melting and refreezing start too early. Summer to summer variations are underestimated.

Spatial ice albedo patterns are too uniform and albedo too high along the ice edges
→ Underestimated ice-albedo feedback along ice edges in the models during summer

For more information: see poster #22

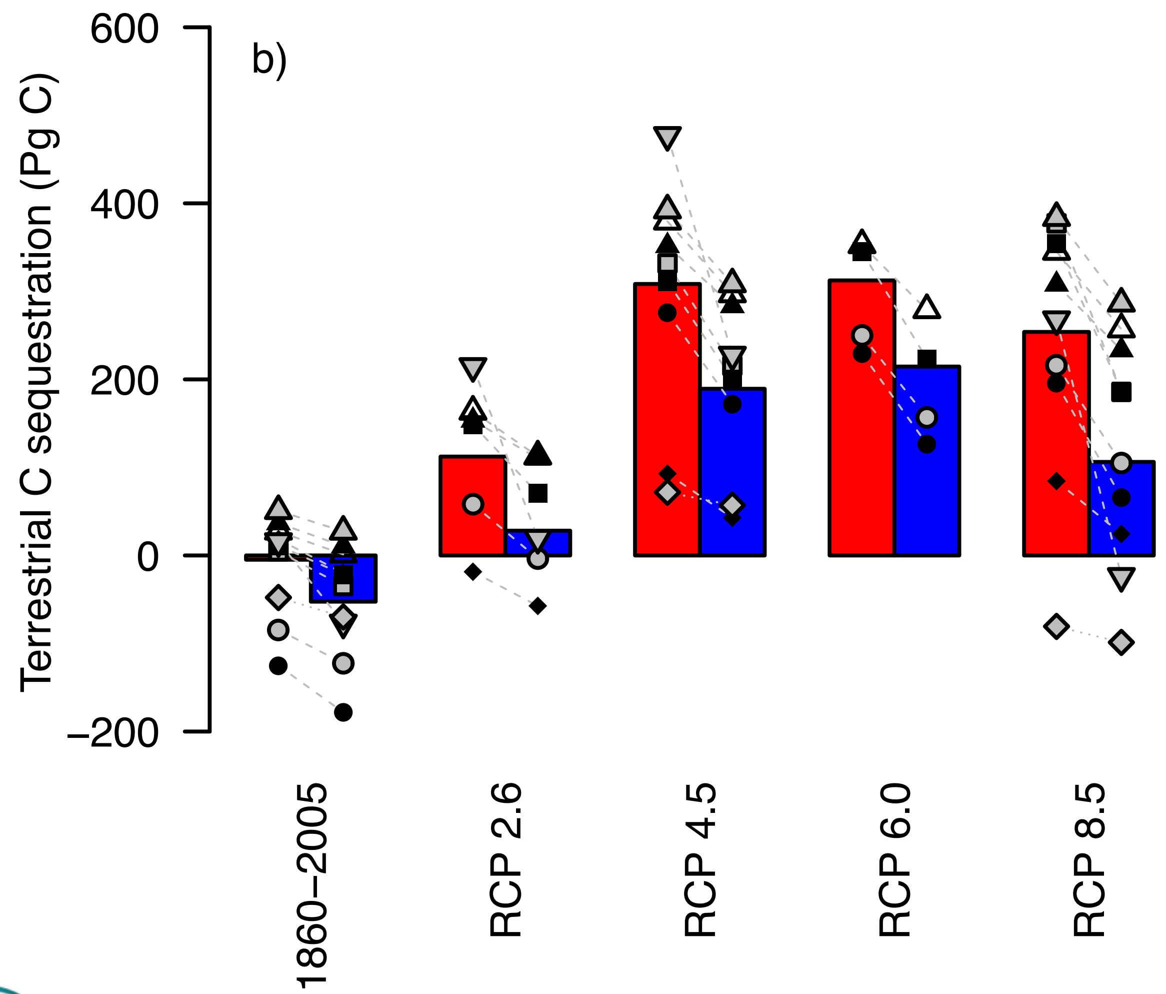
Poster 23: **Land carbon-nitrogen interactions in CMIP5/6**

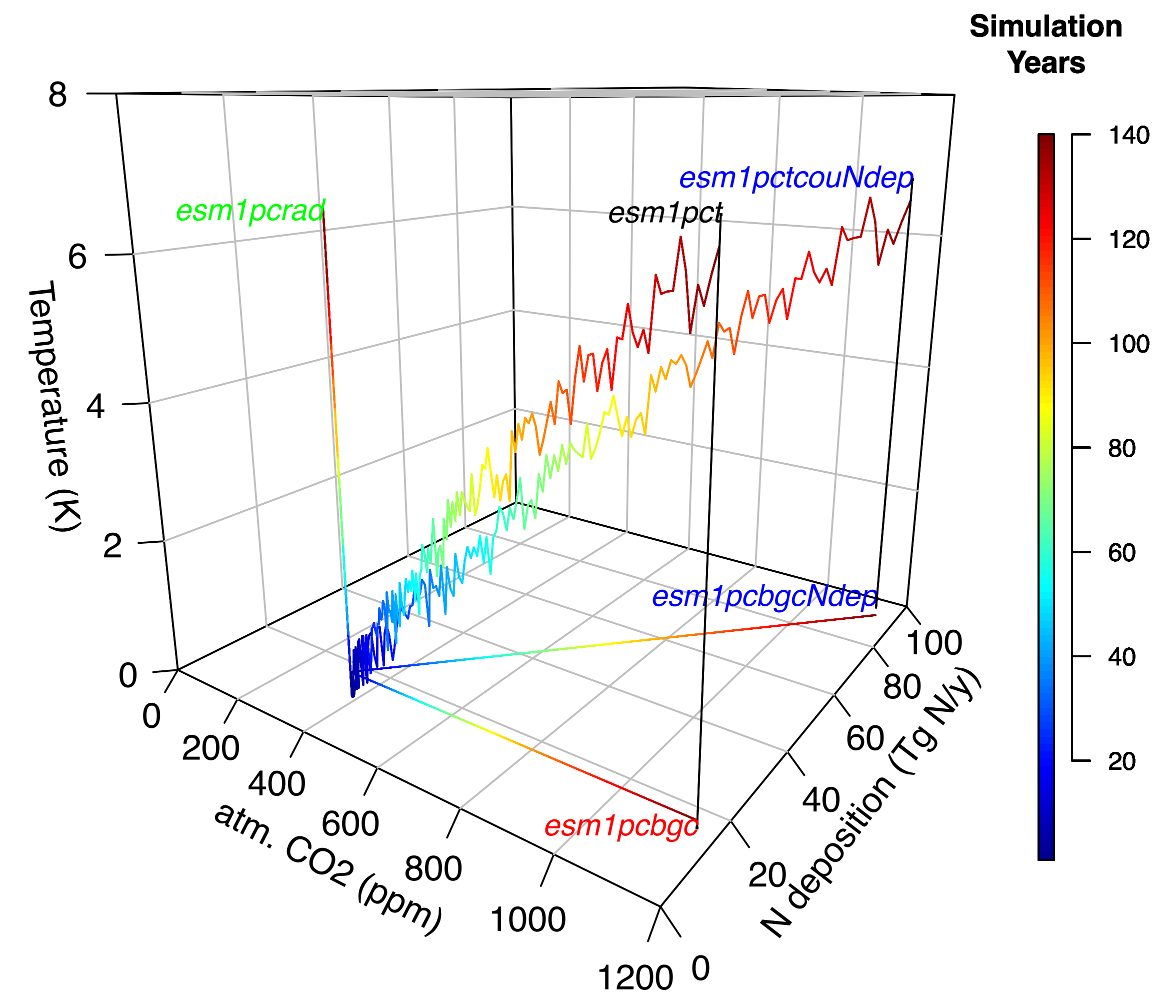
Sönke Zaehle, Chris D Jones

In CMIP5:
C-N interactions largely ignored.
A posteriori analyses suggest large overestimation of land C sequestration

In CMIP6:
Several models to include dynamic N cycle.
Requires a change in the experiment design.

Outline of experiment design
& likely consequences for projections of terrestrial carbon-climate feedbacks

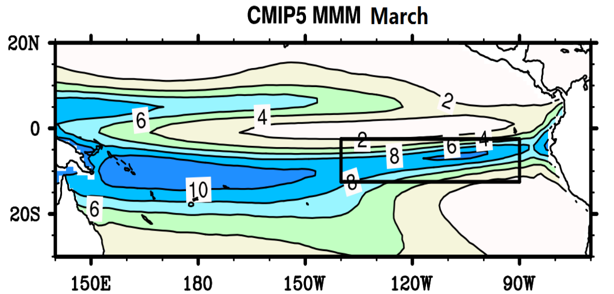




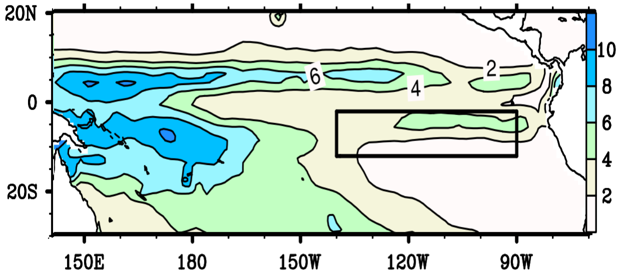
On the Double ITCZ Bias in CESM and CAS-ESM

Minghua Zhang[3,1], He Zhang[1], Xunqiang Bi[1], Duoying Ji[2], Xiaoxiao Zhang[1], Hailong Liu[1], Xin Xie[3]

[1]IAP/Chinese Academy of Sciences (CAS), [2]Beijing Normal University, [3]Stony Brook University

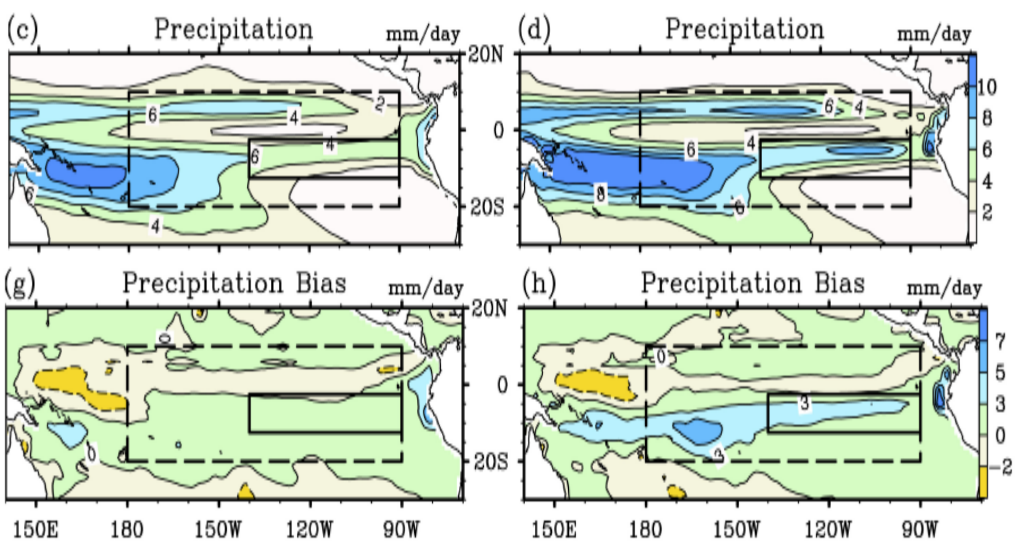


Precip CMIP5 MME (March)



Precip Obs (March)

CMIP3 Best Five **CMIP5 Best Five**



(Xiaoxiao Zhang et al. 2015 GRL)

Model	CESM1	CAS-ESM V1
AGCM	CAM5 (L30)	IAP5 (L30)
Dynamics	Finite Volume (Neale et al. 2013)	Finite Difference (Zhang He et al. 2013, MWR)
Shallow Convection	UW Shallow Convection (Park and Bretherton 2009)	Ensemble Convection (Xie et al. 2015)
Deep Convection	Zhang-McFarlane (95) Neale et al.(08) Richter-Rasch (08)	Ensemble convection (Xie et al. 2015)
Cloud Macrophysics	Park-Bretherton-Rasch (10)	Ensemble cloud macrophysics (CAR) (Zhang et al. 2013; Liang et al 2013)
Stratiform Microphysics	Morrison and Gettelman (08) *Double Moment*	Morrison and Gettelman (08) *Xie and Zhang (2015)*
Radiation / Optics	RRTMG Iacono et al.(08) / Mitchell (08)	Ensemble radiation (CAR) (Zhang et al. 2013; Liang et al 2013)
Aerosols	Modal Aerosol Model (MAM) Liu & Ghan (2009)	IAP Aerosol and Chemistry Model (AACM) (Cheng et al. 2015)
Ocean	POP2 (Smith et al. 2010)	LICOM2 + IAP OBGCM Liu et al. (2012), Xu et al. (2015)
Land	CLM4 (Lawrence et al. 2011)	CoLM+IAP DGVM (Ji and Dai, 2010; Zeng et al. 2014)