Clouds, Circulation and Climate Sensitivity

A WCRP Grand Challenge coordinated by WGCM
in close collaboration with GEWEX, SPARC and WGNE

Lead coordinators :
Sandrine Bony (LMD/IPSL) & Bjorn Stevens (MPI)
with
Christian Jakob, Masa Kageyama, Robert Pincus, Ted Shepherd,
Steven Sherwood, Pier Siebesma, Adam Sobel, Masahiro Watanabe and Mark Webb

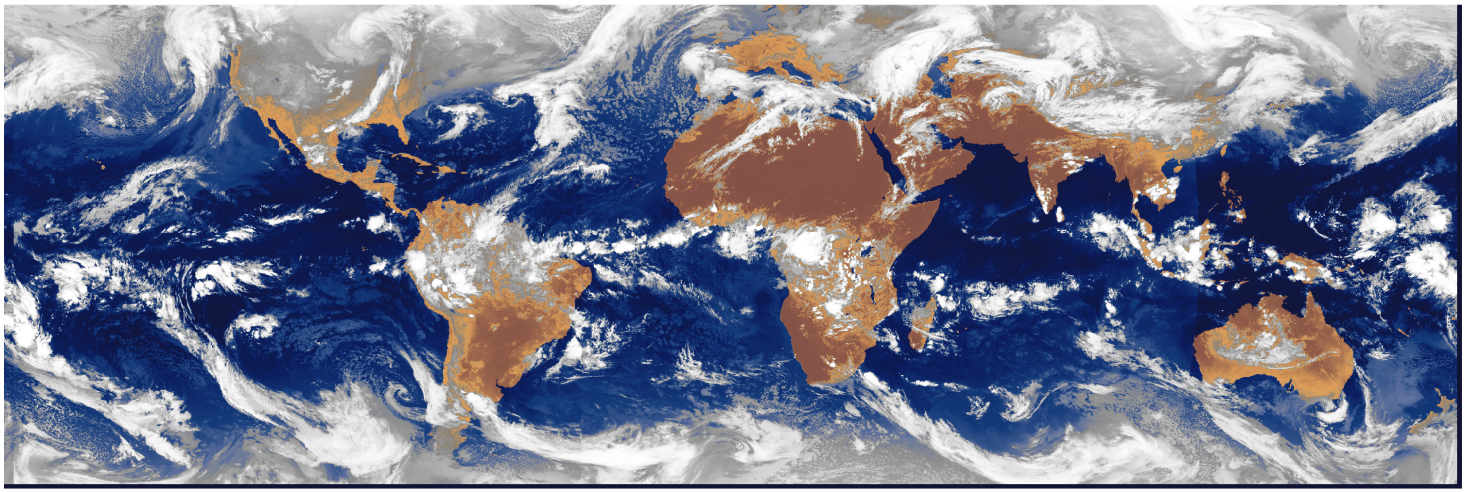
WCRP
World Climate Research Programme

WCRP White Paper

Clouds, Circulation and Climate Sensitivity:

How the interactions between clouds, greenhouse gases and aerosols affect temperature and precipitation in a changing climate

Led by WGCM, in collaboration with GEWEX, WGNE and SPARC



http://www.wcrp-climate.org/index.php/gc-clouds

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* There are many WCRP groups and individuals who have contributed to this document. The authors wish to thank in particular the WGCM and GEWEX/GASS steering committees for their input and the WCRP Joint Scientific Committee for its support and encouragement. Specific and extensive comments from Alessio Bellucci, Pascale Braconnot, Christopher Bretherton, Veronika Eyring, Christian Jakob, Masa Kageyama, Stephen Klein, Natalie Maholwald, Teruyuki Nakajima, Jon Petch, William Rossow, Adam Scaife, Cath Senior, Ted Shepherd, Philip Stier, Kevin Trenberth, Mark Webb and Steve Woolnough also helped sharpen and broaden the articulation of this grand challenge.

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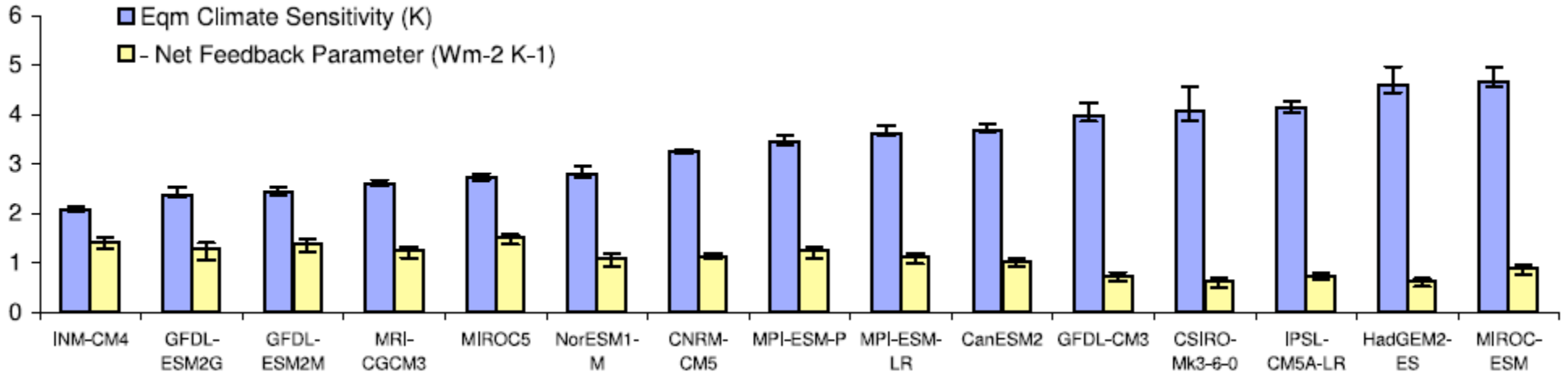
GC on Clouds, Circulation and Climate Sensitivity

- The challenge
- Opportunities
- Initiatives
- Status and perspectives

CMIP5 Climate Sensitivity Estimates



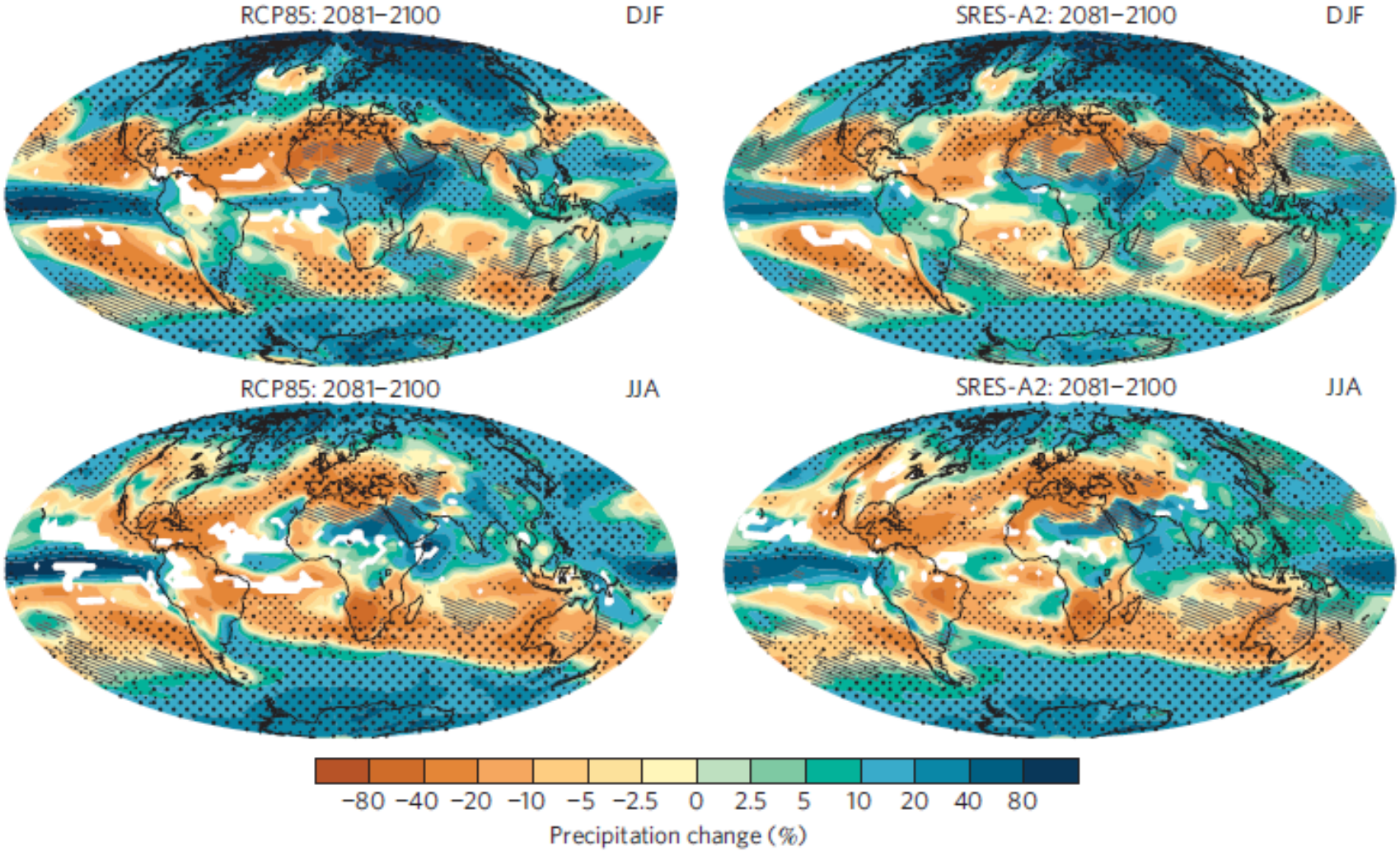
Range : 2 K – 4.6 K

Andrews et al., GRL, 2012

Precipitation projections

CMIP5 (RCP8.5)

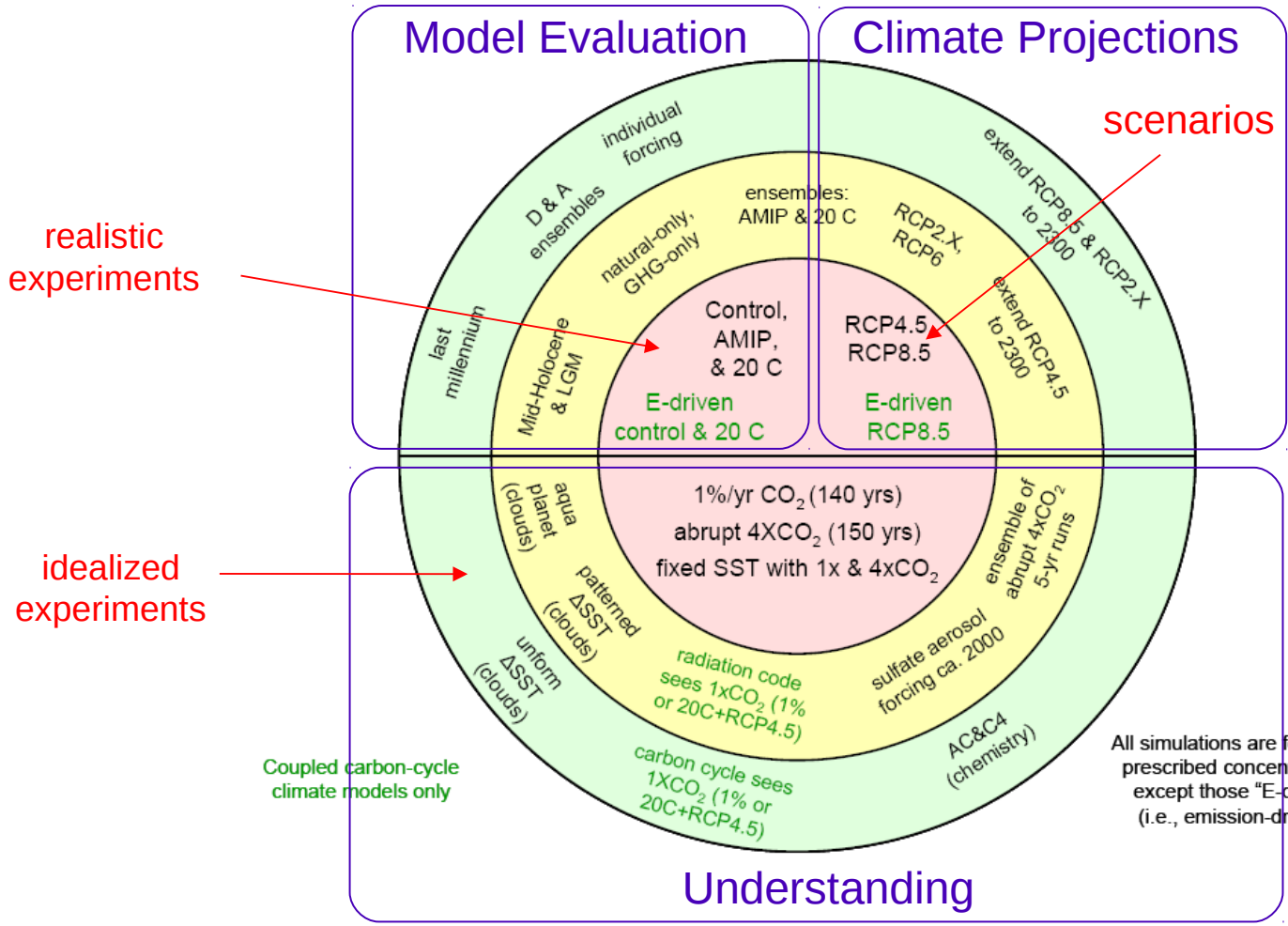
CMIP3 (SRES-A2)



Knutti & Sedlacek, Nature Climate Change 2012

CMIP5

A hierarchy of models, experiments, configurations
(coupled ocean-atmosphere, atmosphere-only, aqua-planet..)



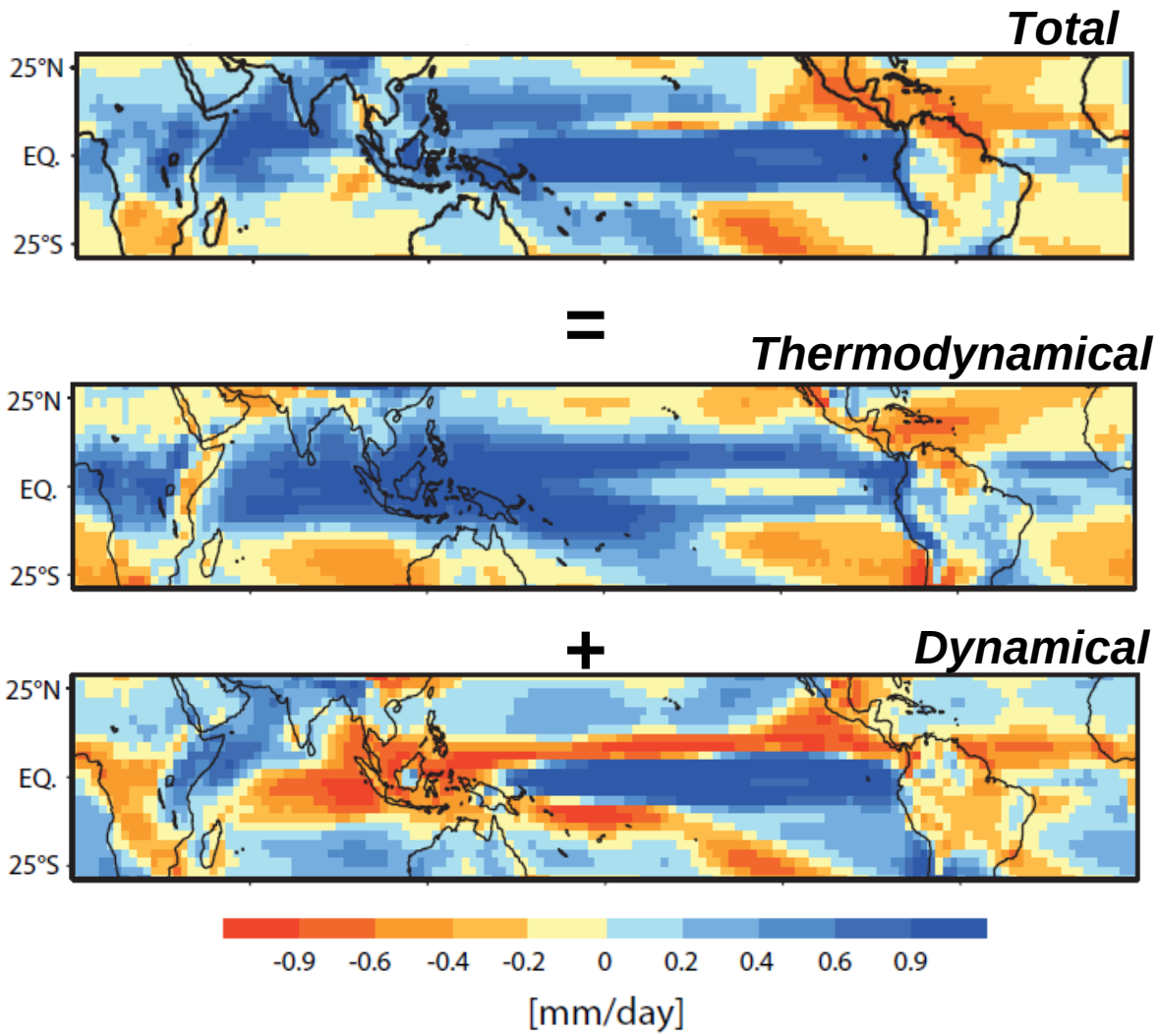
Models :
ESM
OAGCM
AGCM
Aqua-planet

Experiments :
realistic
idealized
partial forcings

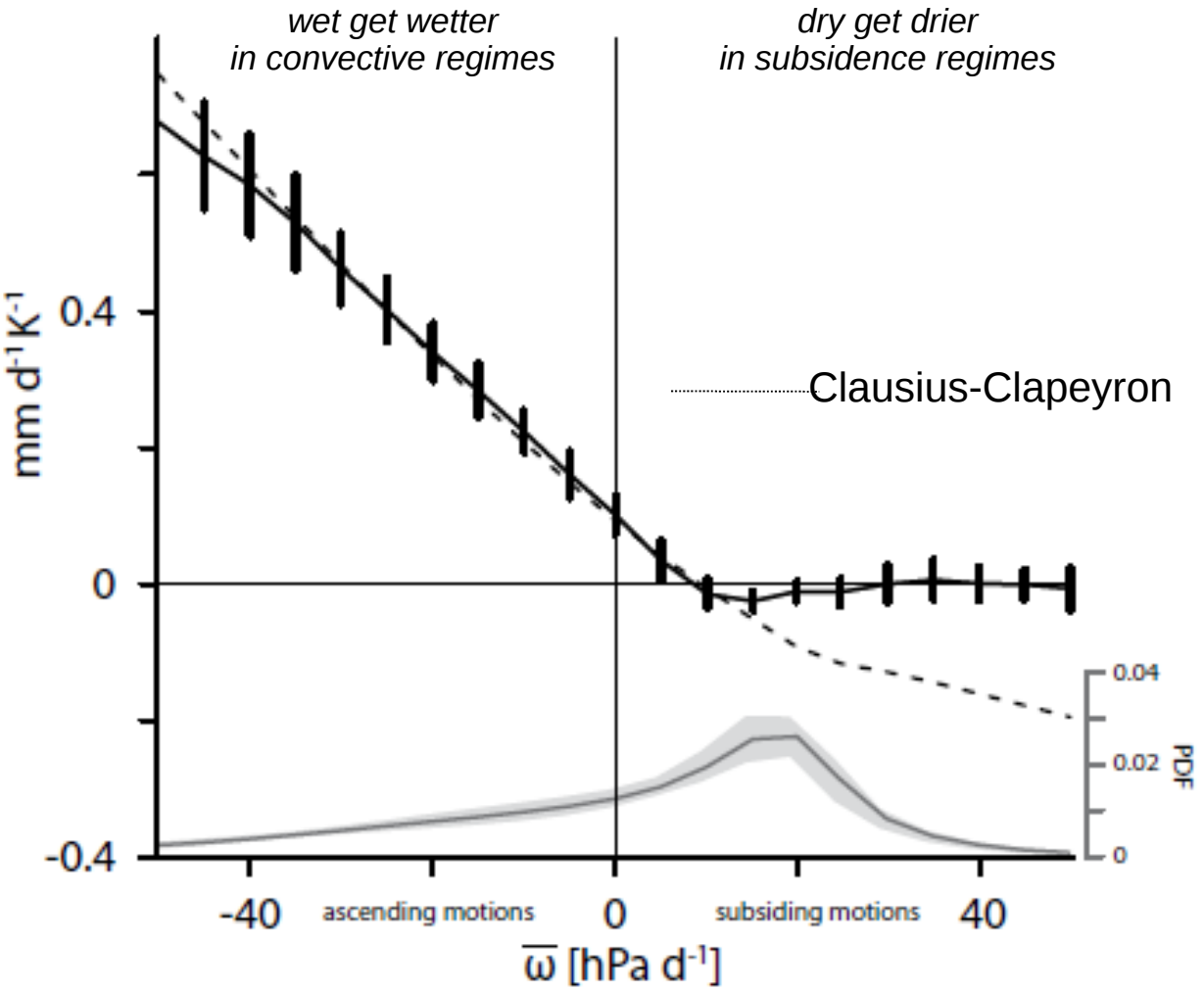
-> Helps decompose complex, long-standing problems into (more tractable) pieces

Regional pattern of tropical precipitation projections

$$\Delta P = \Delta P_{\mathrm{dyn}} + \Delta P_{\mathrm{ther}}$$



Precipitation response to warming conditioned on large-scale vertical velocity



Bony et al., Nature Geoscience, 2013 in press

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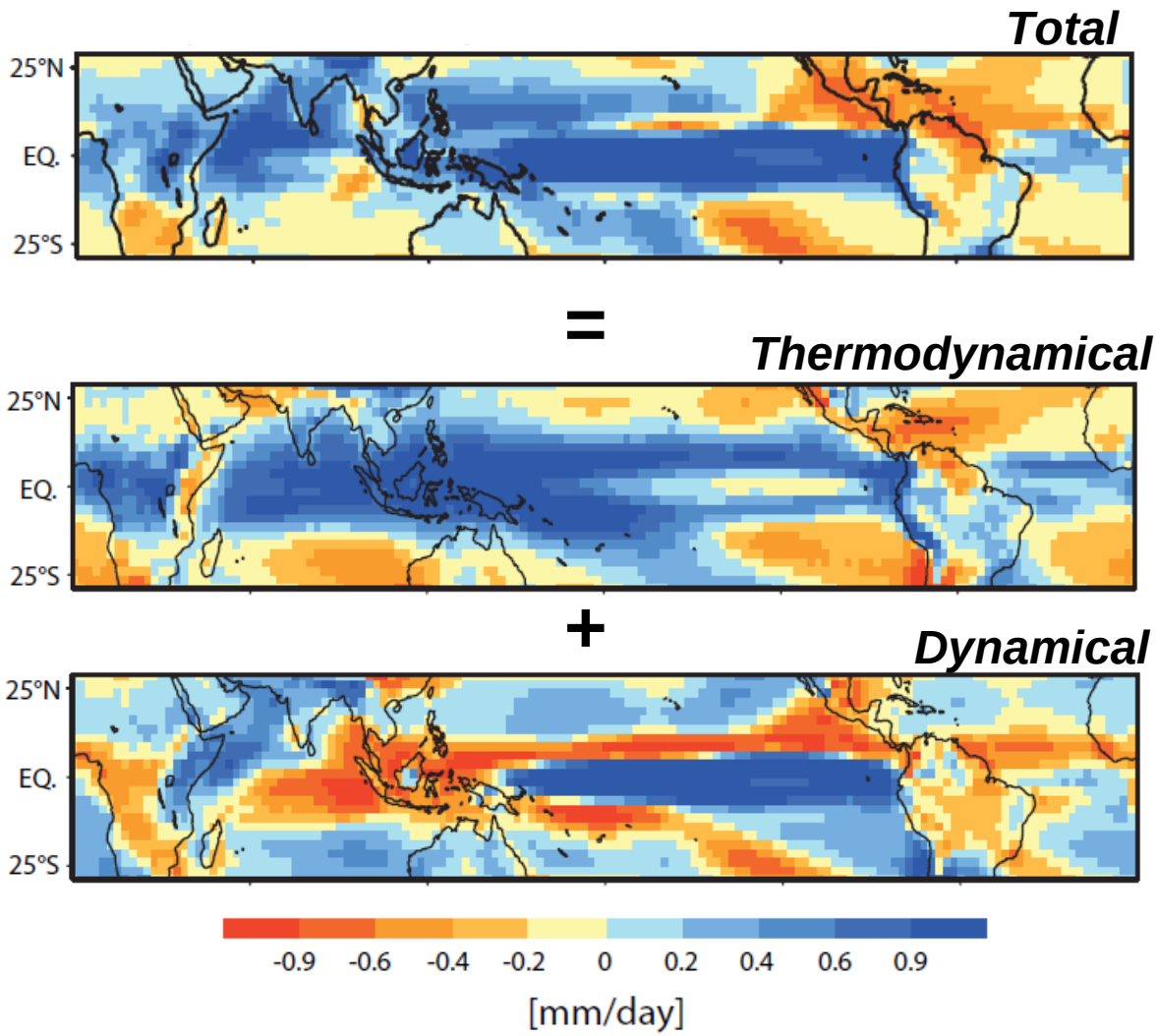
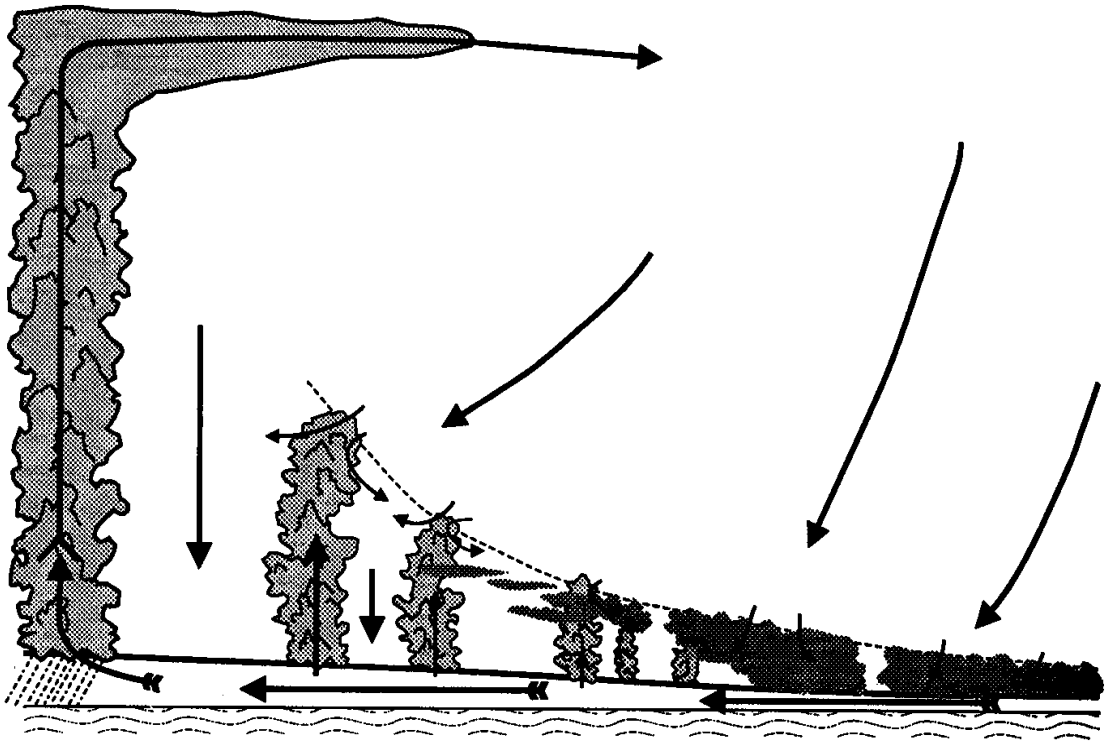


depends on climatology
+
scales with climate sensitivity

Bony et al., Nature Geoscience, 2013 in press

Tropical circulation response to increased CO_2



CMIP5 :

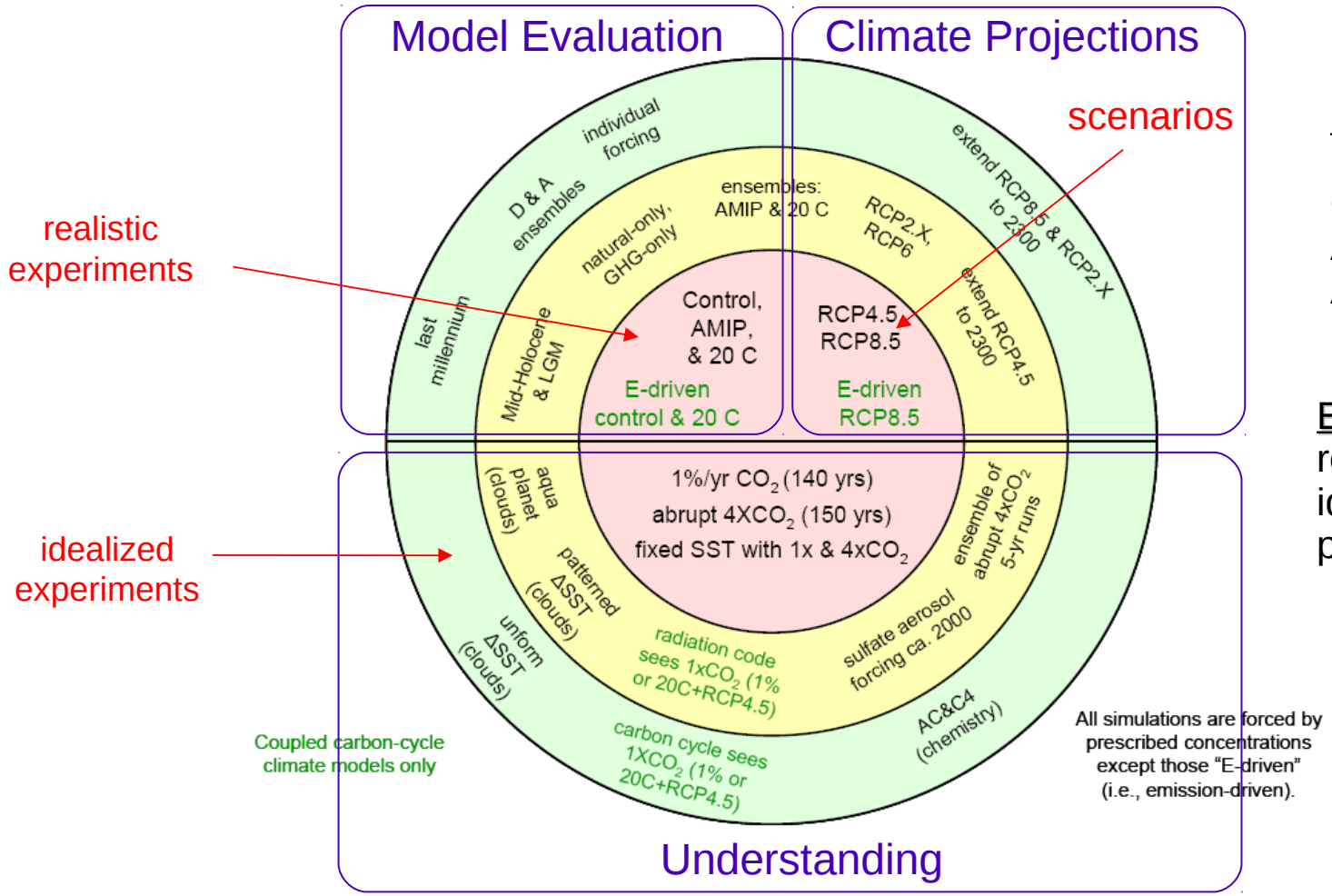
Weakening of the circulation in response to global warming (Ts and WV changes)

+

Direct effect of carbon dioxide on the strength of the Hadley-Walker circulation

CMIP5

A hierarchy of models, experiments, configurations
(coupled ocean-atmosphere, atmosphere-only, aqua-planet..)



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Experiments :
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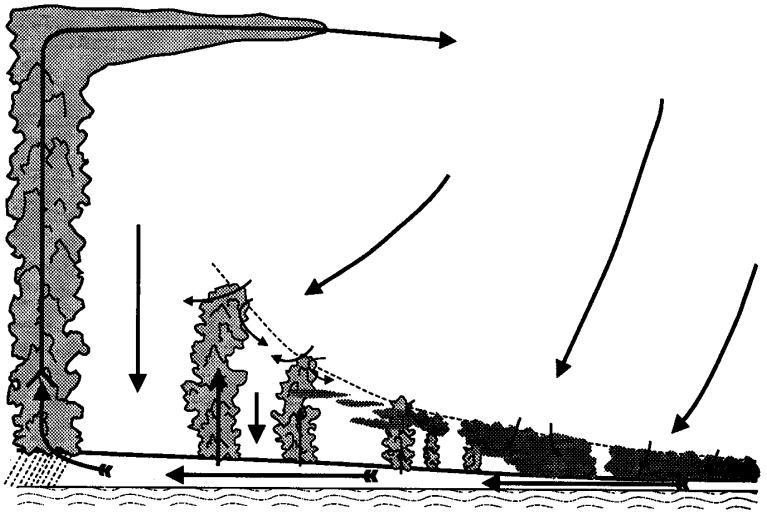
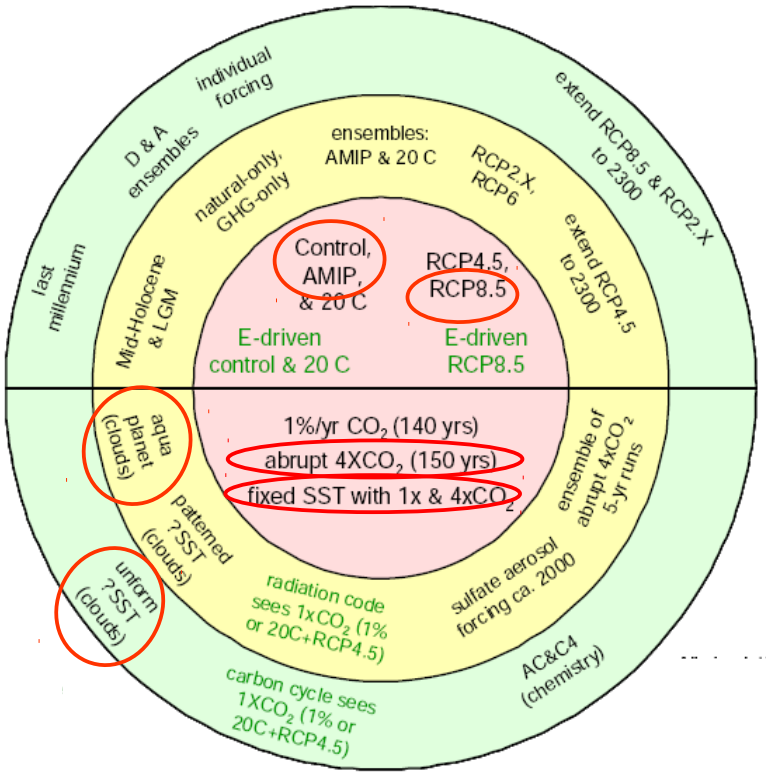
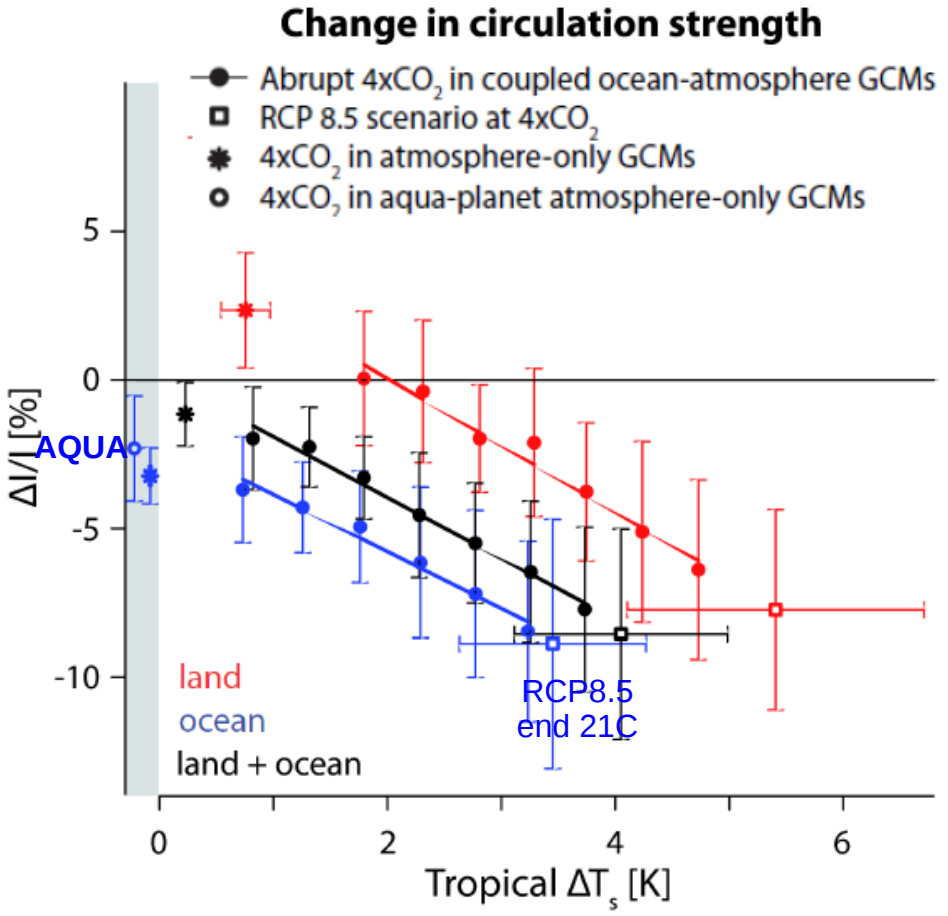


- Weakening of the tropical overturning circulation in response to increased CO2
- Even in the absence of surface temperature changes and land-sea contrasts (robust direct effect)
- Significant fraction of long-term changes, especially in convective regions

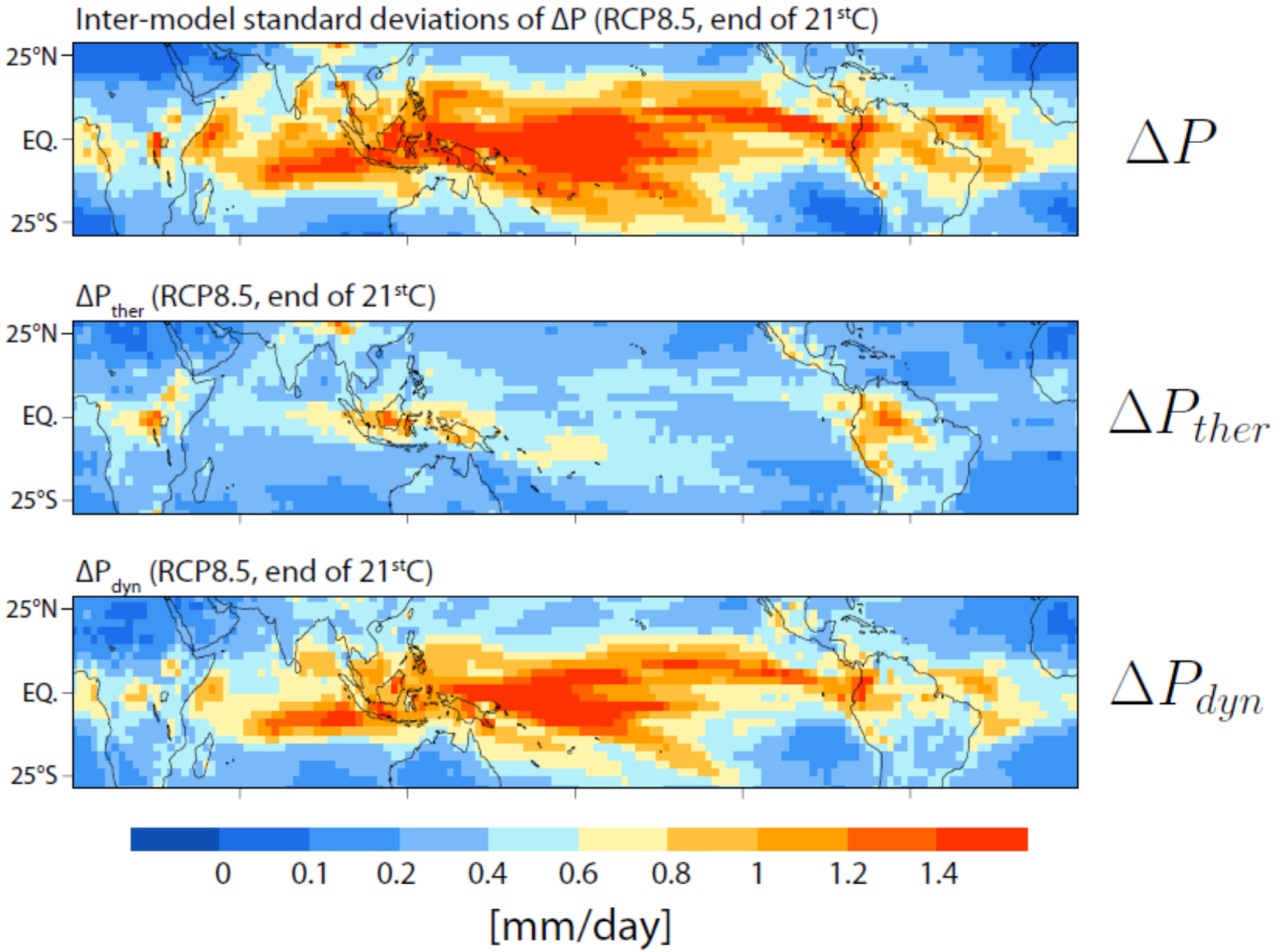




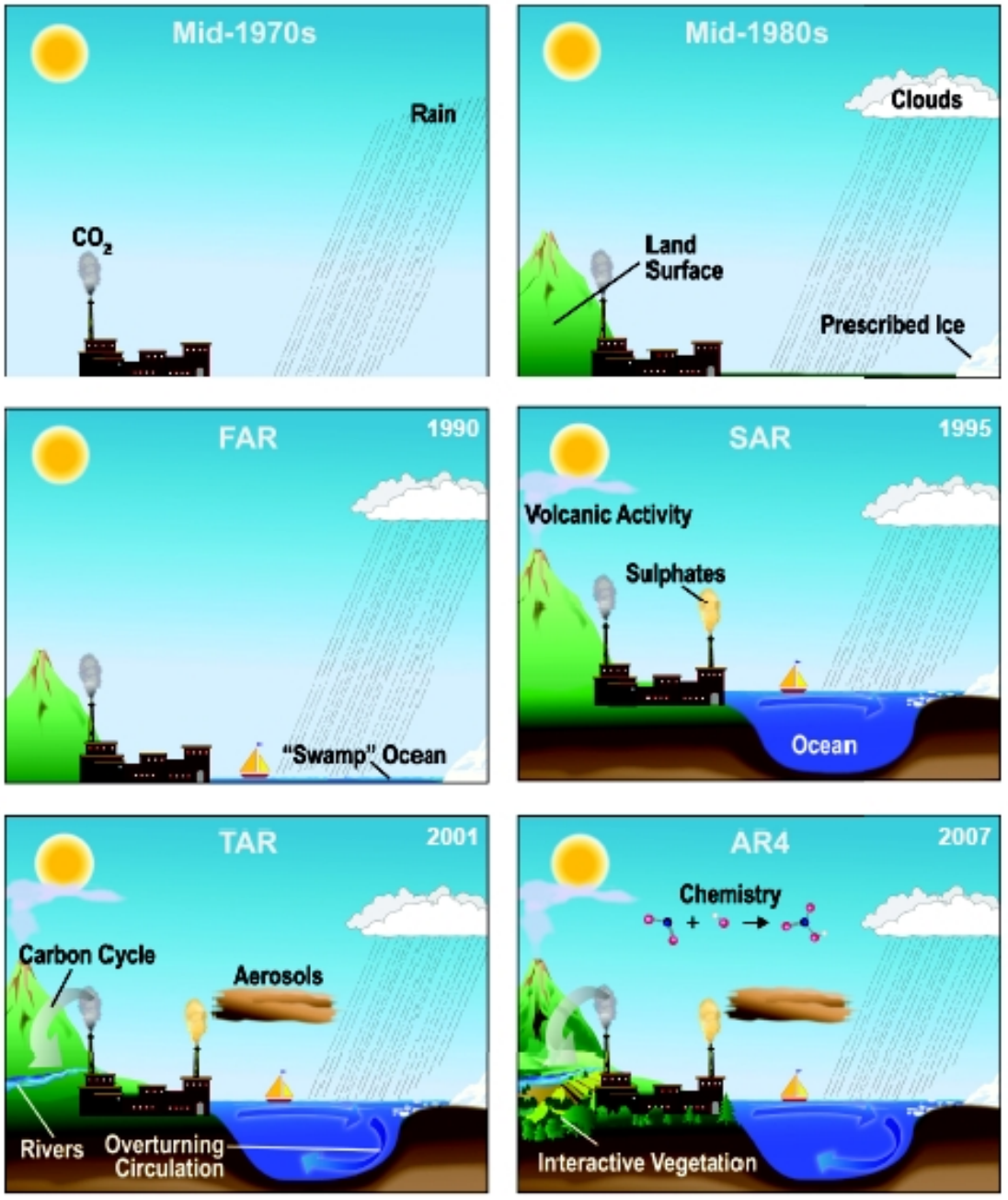
Bony et al., Nature Geoscience, 2013 in press

Sources of inter-model spread at regional scale

$$\Delta P = \Delta P_{\mathrm{dyn}} + \Delta P_{\mathrm{ther}}$$



From GCMs to OAGCMs to ESMs...



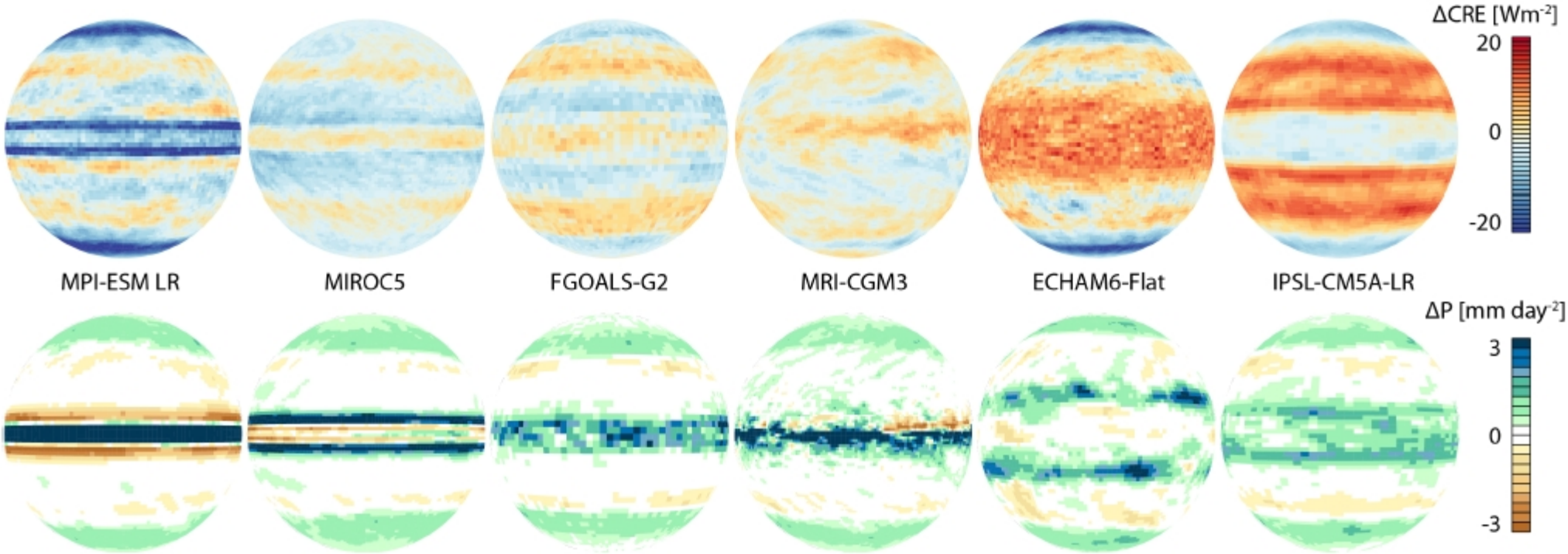
IPCC AR4

- GCMs have become more and more complex (aerosols, interactive vegetation, carbon cycle, chemistry, etc)
- The drive to complexity has greatly extended the scope of questions that can be addressed with GCMs...

  but has not reduced key uncertainties
- These uncertainties affect many aspects of climate projections, including biogeochemical responses

Something aqua planets make painfully evident

Response of Cloud Radiative Effects and Precipitation
to a uniform +4K in **CMIP5 aqua-planets**



- Uncertainties related to basic physical processes :
  interactions atmospheric water / temperature / circulation

- Critical limitation for mitigation and adaptation studies

Stevens & Bony, Science, 2013 in press

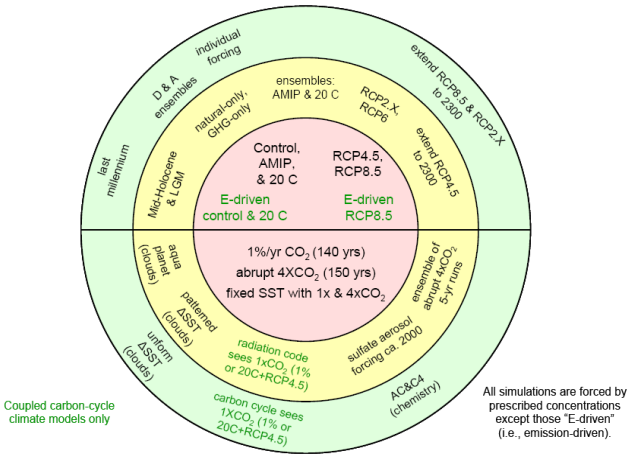
Much of what we know, and even more of what we don't know, about Earth's climate and its propensity to change is linked to our understanding of the interplay between water and air circulation.

WCRP Grand Challenge on
Clouds, Circulation and Climate Sensitivity

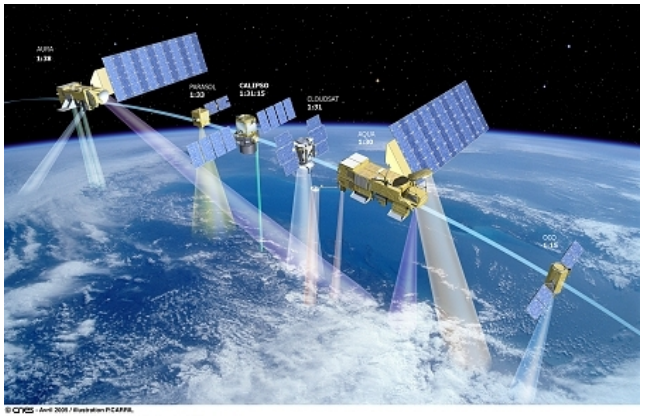
WCRP Organization

Opportunities

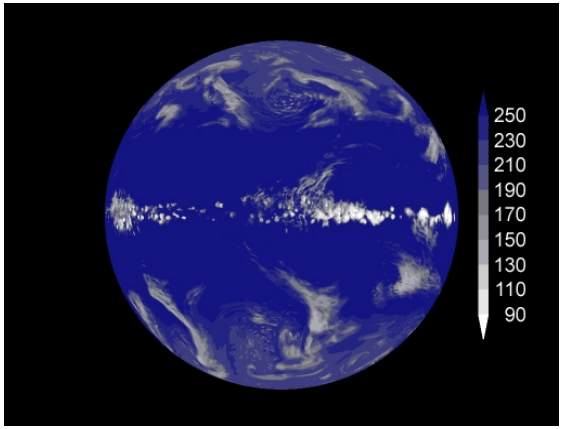
CMIP5 and associated MIPs



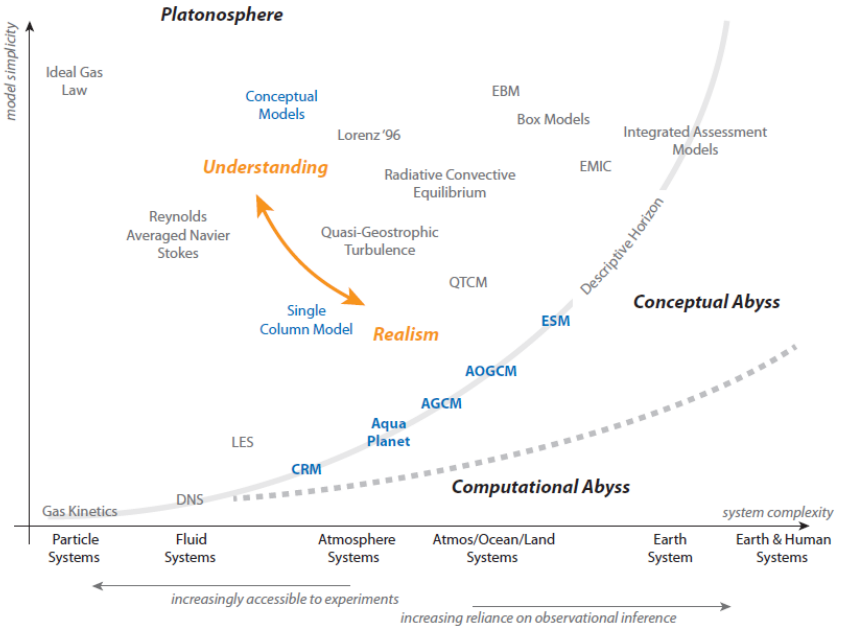
A golden age of Earth observations



Qualitatively new types of models



Lessons from experience



An interconnected research community

WCRP
World Climate Research Programme

WCRP Grand Challenge on Clouds, Circulation and Climate Sensitivity

Centered around five initiatives :

1. Climate and hydrological sensitivity
2. Coupling clouds to circulations
3. Changing patterns
4. Leveraging the past record
5. Towards more reliable models

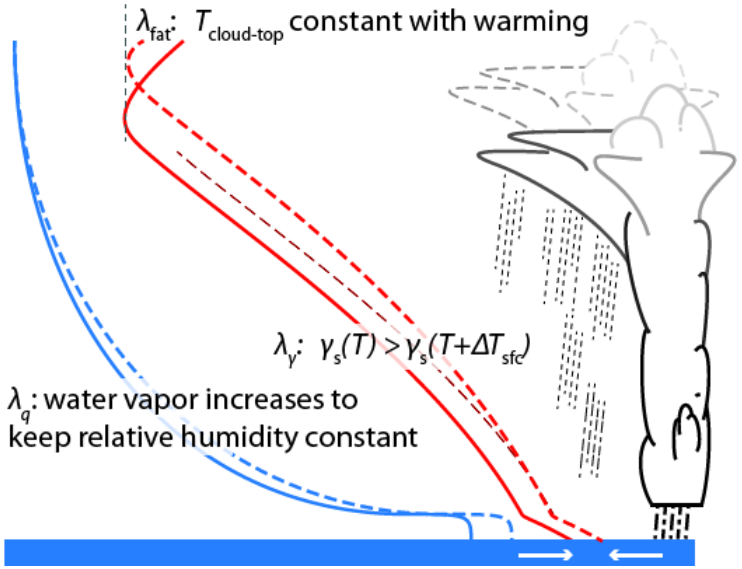
1. Climate and Hydrological Sensitivity

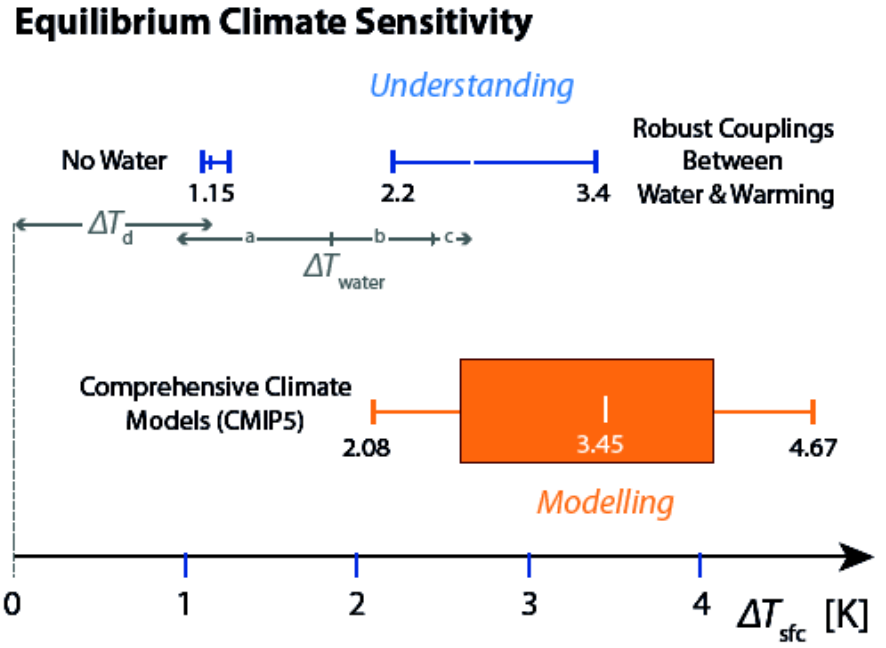
Led by Steven Sherwood (CCRC, Australia) & Mark Webb (MetOffice, UK)

Aim : Design critical tests for climate models, whose application will help assess the most likely estimates of climate and hydrological sensitivity.

Focus : Intensify efforts to identify causes of inter-model differences in sensitivity ; Interpret robust features ; Explain extreme behaviours ; Unravel uncertainties and propose strategies to tackle them

Connections : WGCM/CMIP5/CFMIP (e.g. CGILS project), GEWEX/GASS, PMIP + link GC on water availability

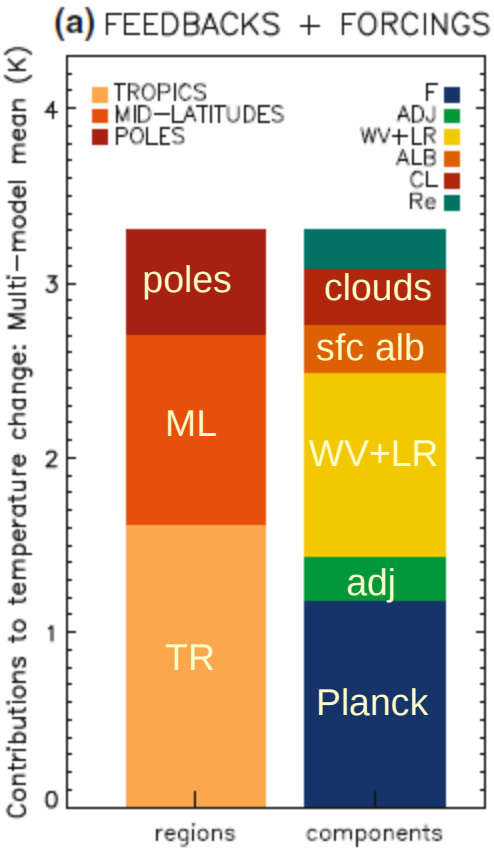




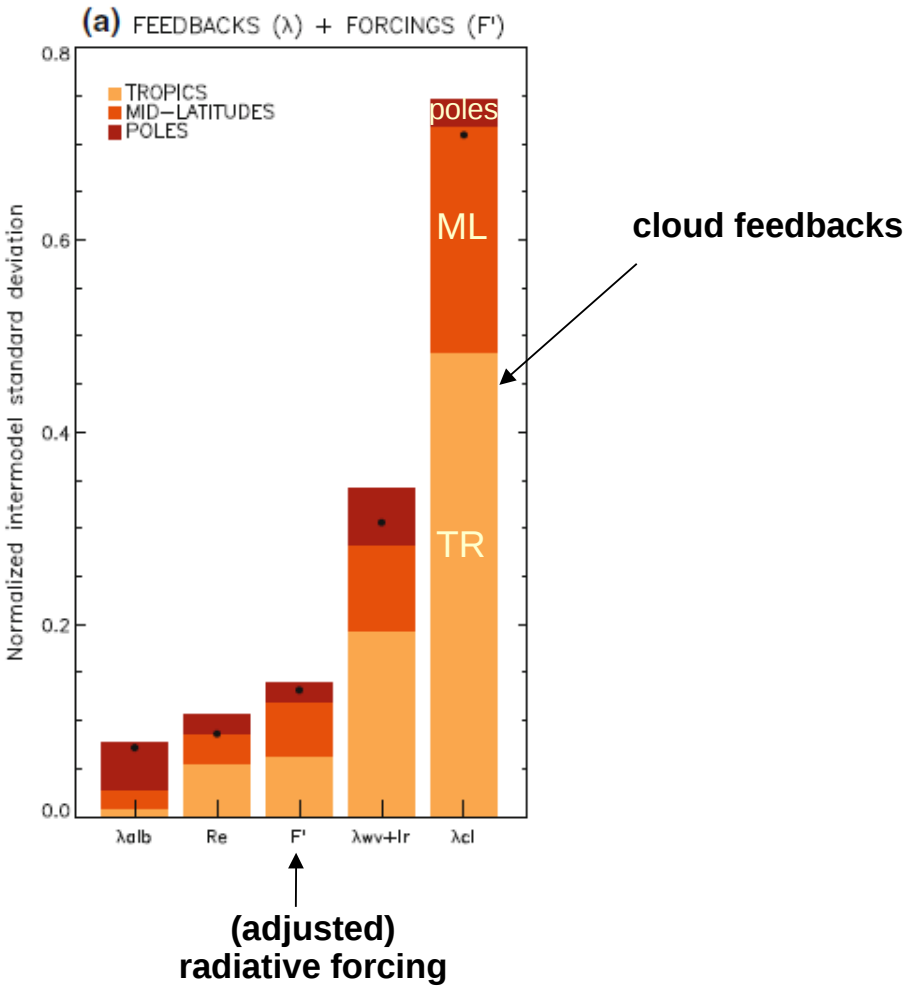
Stevens & Bony, Physics Today, 2013 in press

Analysis of CMIP5 Climate Sensitivity Estimates

Multi-Model Mean



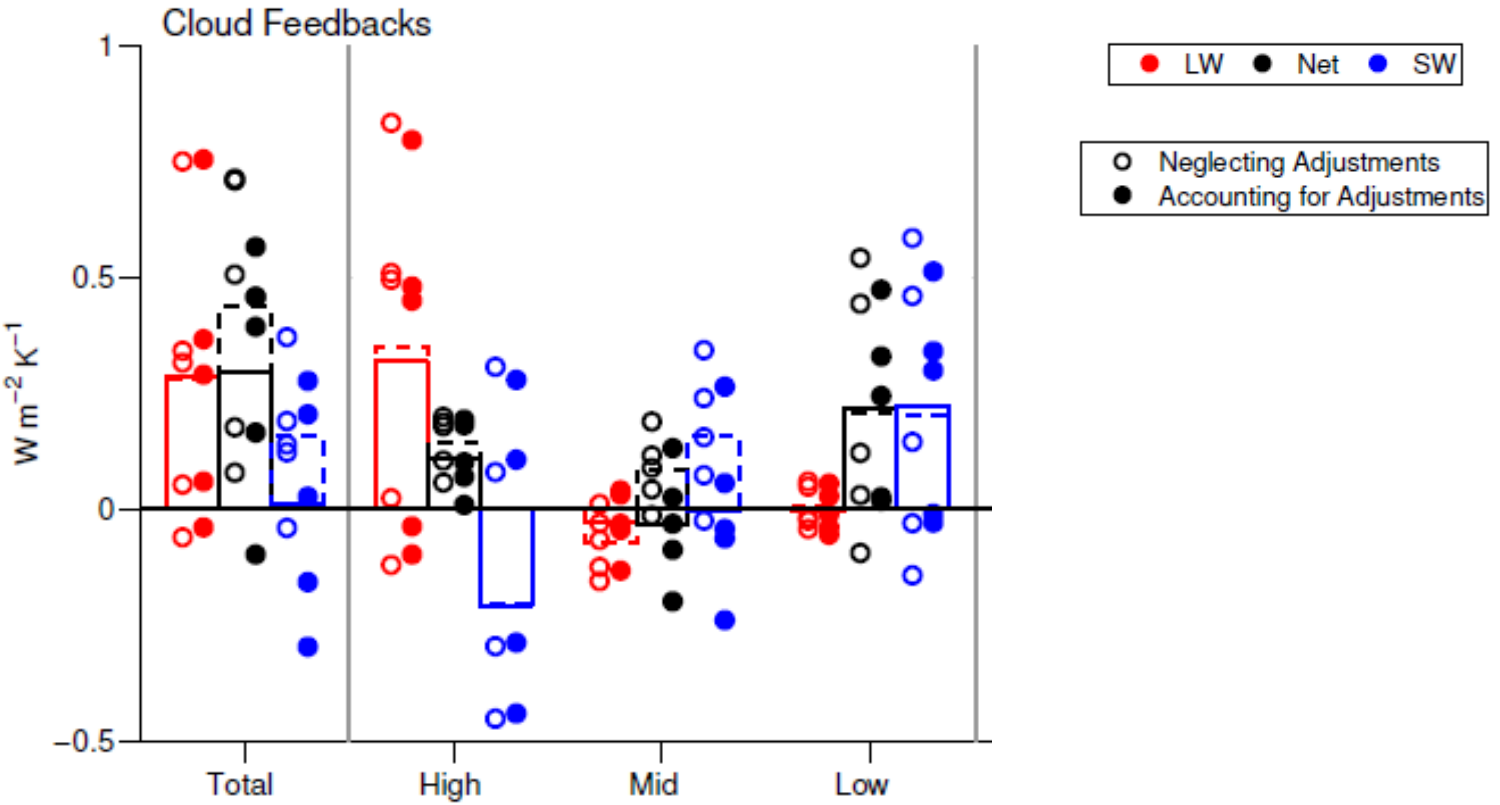
Inter-Model Spread



Cloud feedbacks remain the leading source of uncertainty.

Vial et al., Clim. Dyn., 2013

Climate change cloud feedbacks in CMIP5 models



- As the planet warms, clouds become fewer, higher and thicker.
- Global mean net cloud feedback positive in all but one model.
- Low-cloud changes are the largest contributor to the mean and spread in net cloud feedback.

NB : CFMIP/GASS CGILS project : understanding low-cloud feedbacks through a spectrum of models

Zelinka et al., J. Climate, 2013 in press

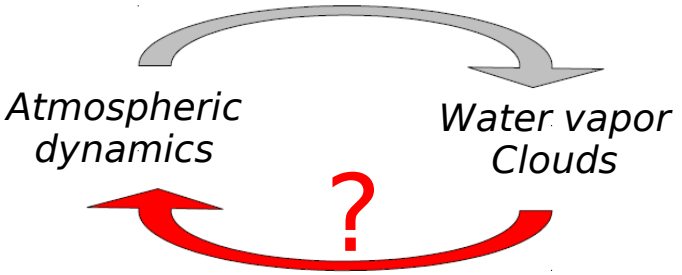
2. Coupling Clouds to Circulation

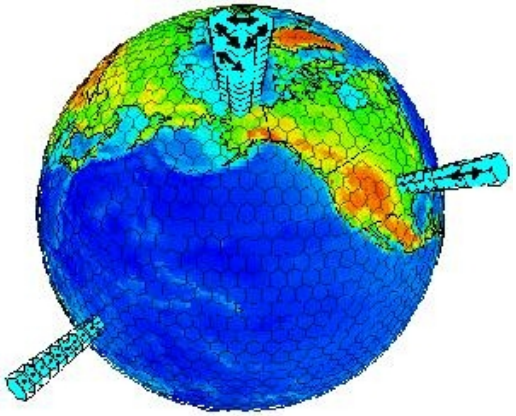
Led by Pier Siebesma (KNMI, Netherlands) & TBD

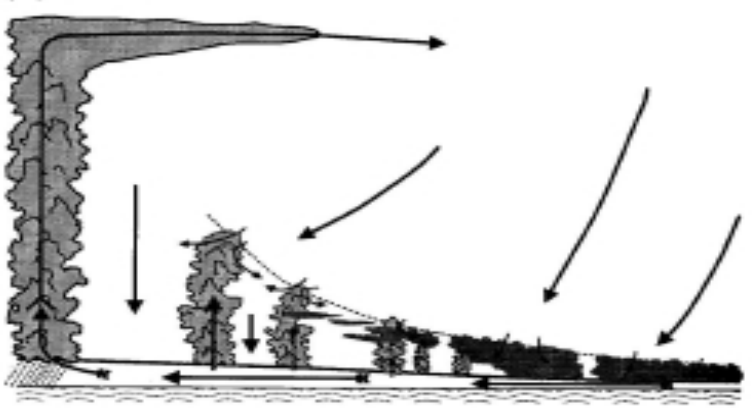
Aim : Tackle the parameterization problem through a better understanding the interaction between cloud / convective processes and circulation systems

Focus : Lessons from observations and cloud-resolving modelling over large domains ; Interaction between diabatic heating and large-scale dynamics

Connections : WGCM/GEWEX/WGNE (e.g. CFMIP, T-AMIP, global CRM/LES models), WWRP/GEWEX/CLIVAR (MJO-diabatic), SPARC



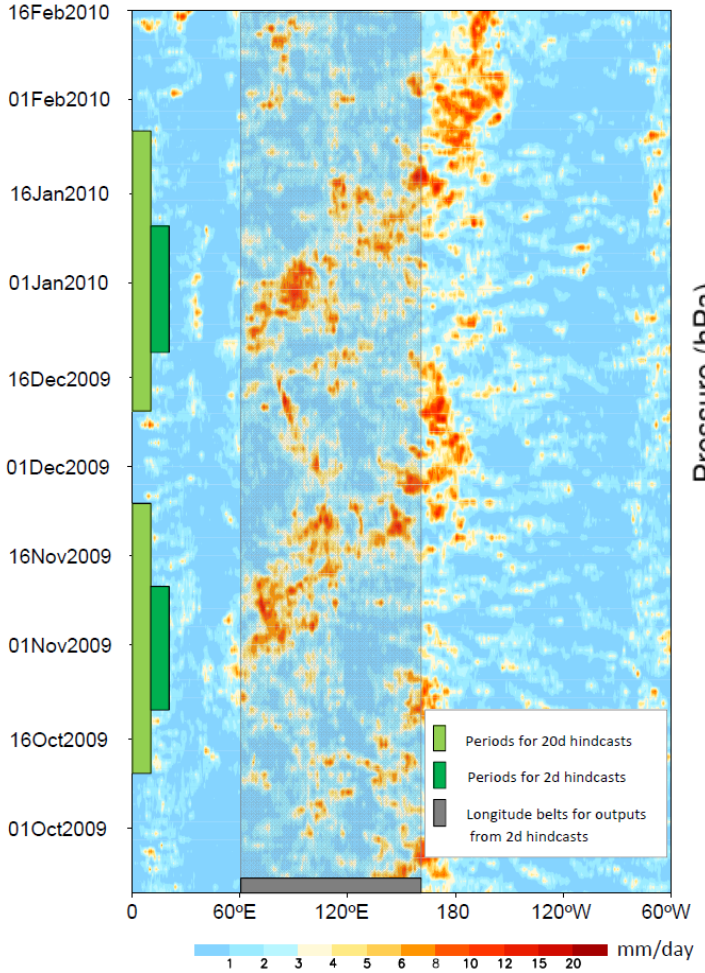


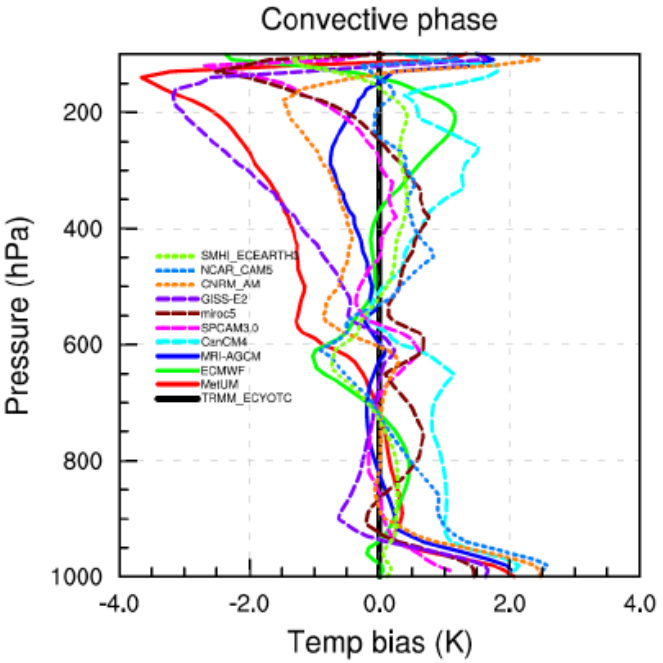


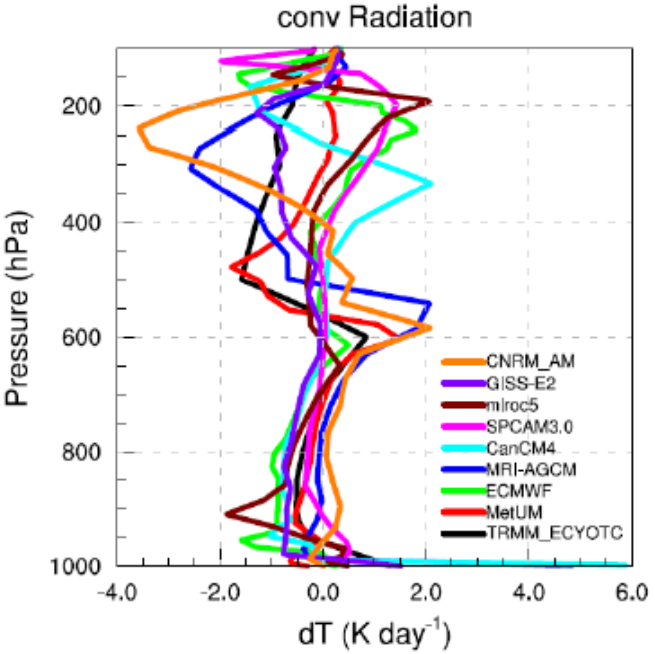
Vertical Structure and Diabatic Processes of the MJO :

Global Model Evaluation Project

2-day forecasts from climate models







Courtesy Prince Xavier & Jon Petch (MetOffice)
WGNE workshop on systematic errors

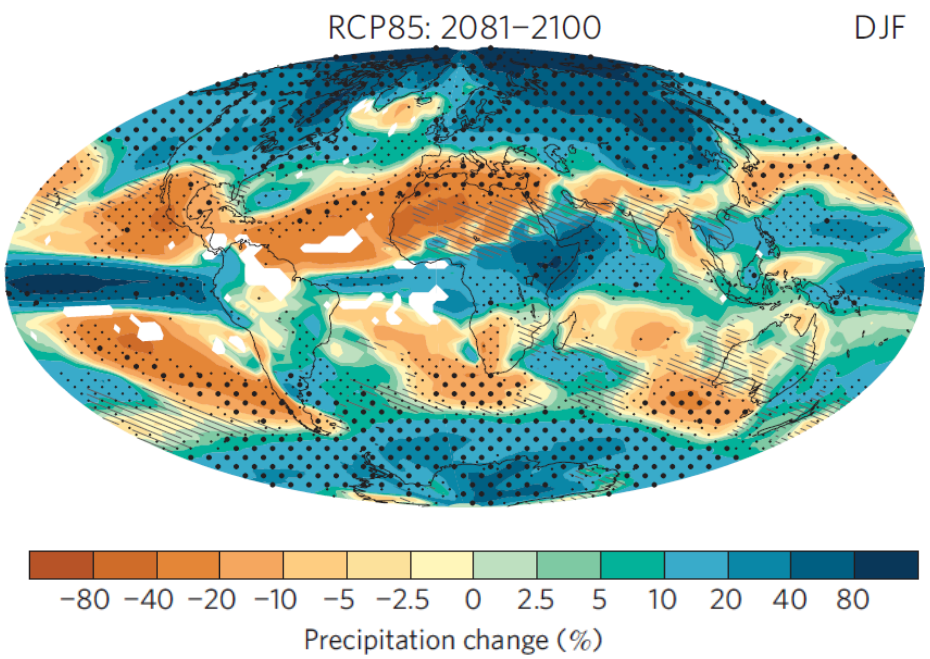
3. Changing Patterns

Led by Ted Shepherd (Univ. Reading, UK) & Adam Sobel (Columbia Univ., USA)

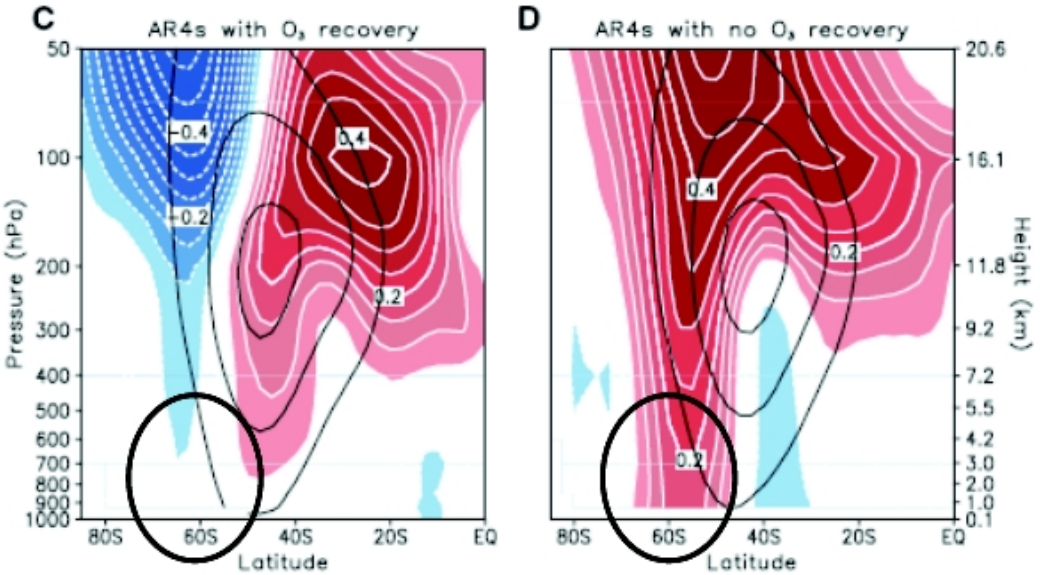
Aim : Better anticipate how the large-scale atmospheric circulation will respond to anthropogenic forcings (GHG, aerosols, ozone).

Focus : Role of local vs large-scale or remotely forced changes in driving regional changes ; Identify robust responses ; Interpret uncertain components ; Assess the impact of model biases or shortcomings on regional responses

Connections : GEWEX/GASS (e.g. WTG), AEROCOM, SPARC

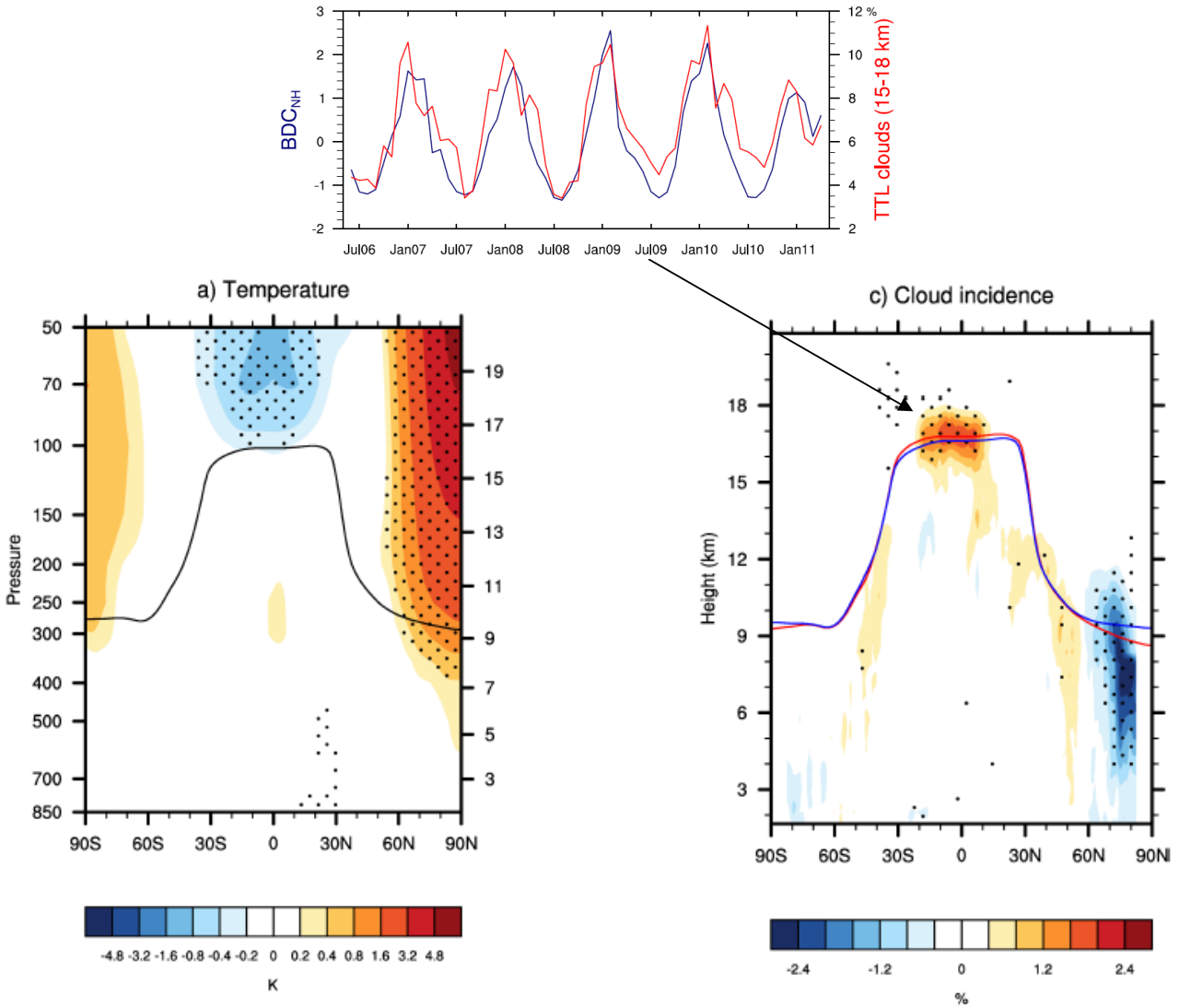


Knutti & Sedlacek (2012)



Son et al. (2008)

Signature of the Brewer-Dobson circulation in tropospheric clouds



- Robust linkage between the BDC and clouds in the TTL and Arctic troposphere.
- Robust increase in the strength of the BDC in response to increased greenhouse gases
- What influence on long-term cloud changes and climate ?

Li & Thompson, JGR, 2013 in press

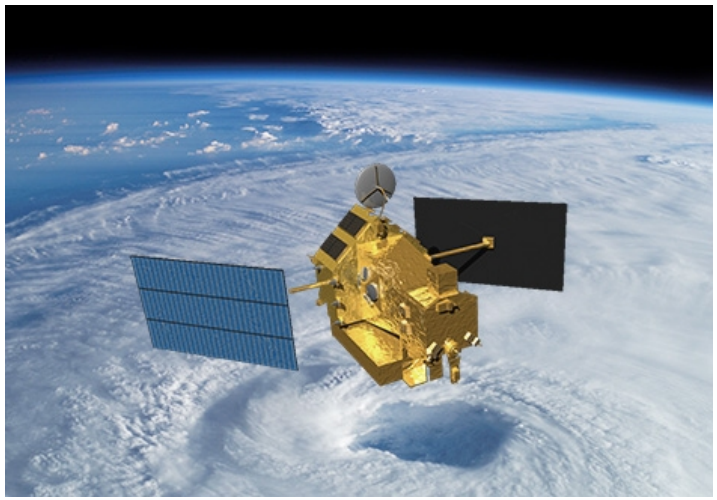
4. Leveraging Records of the Recent and Longer Past

Led by Masa Kageyama (IPSL, France) & Robert Pincus (CIRES, USA)

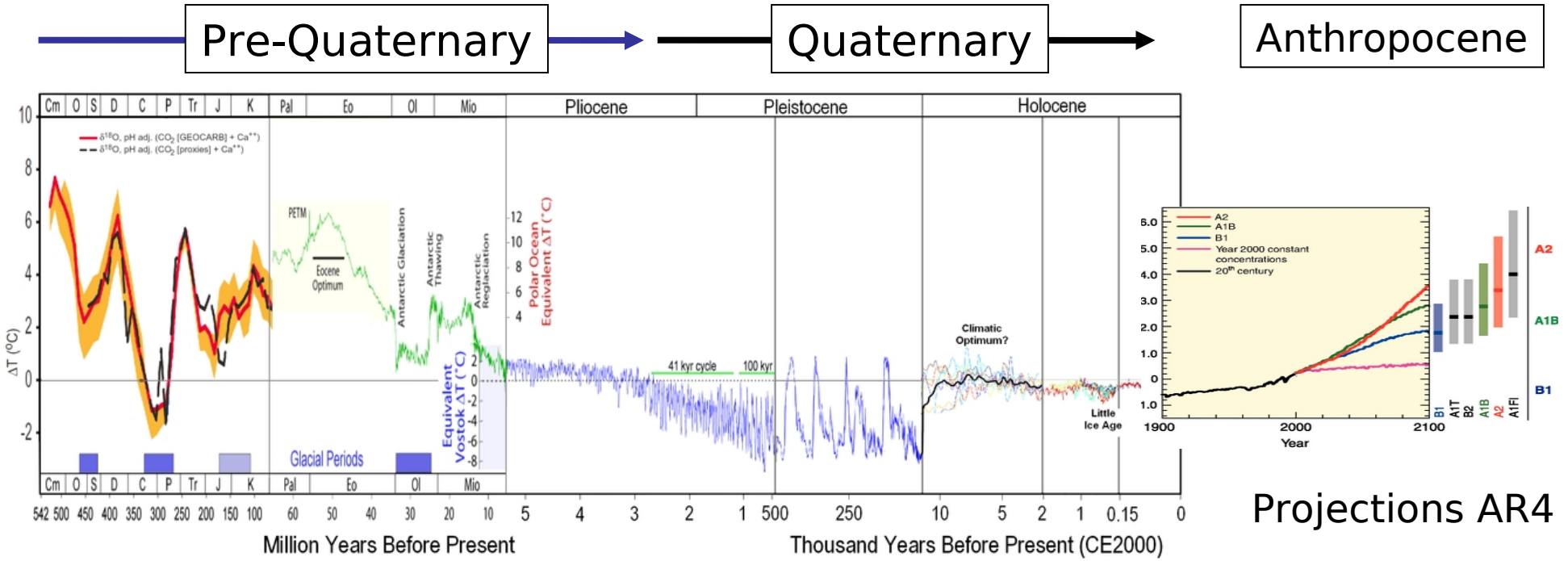
Aim : Exploitation of observations of the recent past, or proxies for longer-term changes, to better constrain cloud processes and feedbacks

Focus : Analysis of decadal/multi-decadal records from satellite and in-situ observations;
Improvement of paleo-climates reconstructions and syntheses ;
Comparisons of past vs future changes

Connections : GEWEX/GDAP, PMIP



How can paleo-data can help constrain future climate prediction ?



- The palaeo-record shows that the Earth has undergone a wide range of climates, but here are no perfect analogues for possible future climates
- However, we can use palaeo-climates to test our understanding of the mechanisms of climate change, as summarised in climate models

Courtesy Masa Kageyama

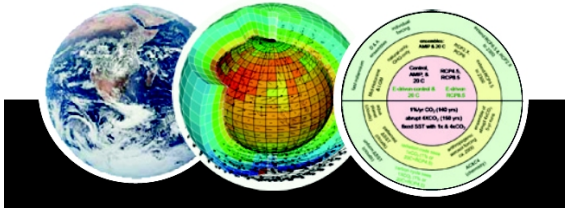
Paleoclimate Modelling

PMIP3

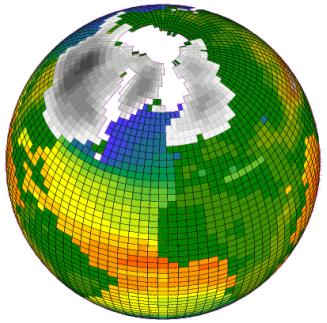
Intercomparison Project

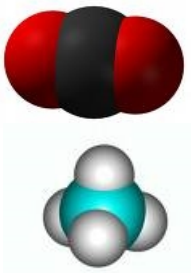
Last Glacial Maximum : Temperature reconstructions and comparison past vs future climate changes

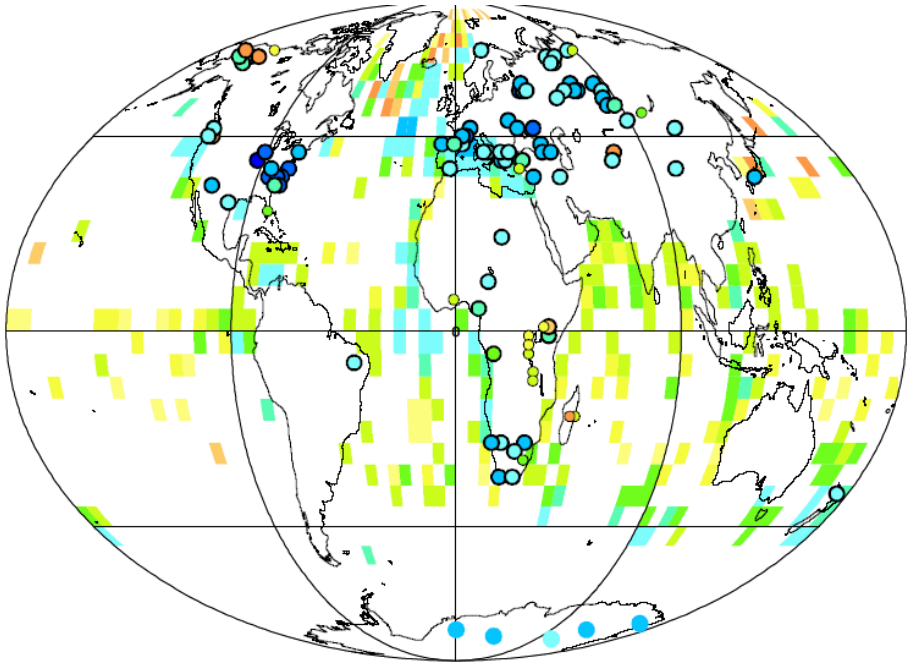
WCRP Coupled Model Intercomparison Project - Phase 5 - CMIP5 -



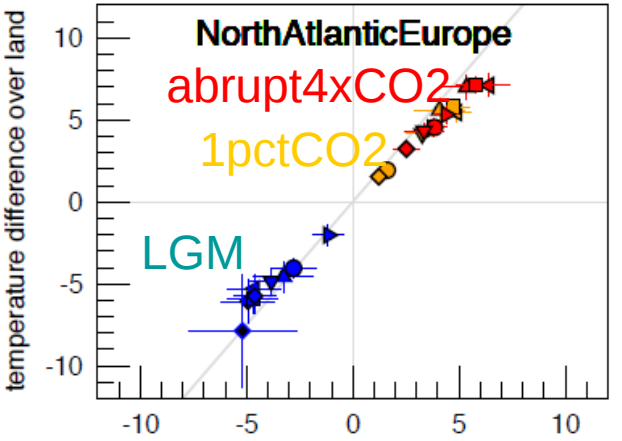
SOURCES:
Land data (pollen and plant macrofossils): Bartlein et al, Clim Dynam 2011
Ocean data (multi proxy): MARGO, NGS 2009
Ice-core data: Masson-Delmotte et al pers. comm

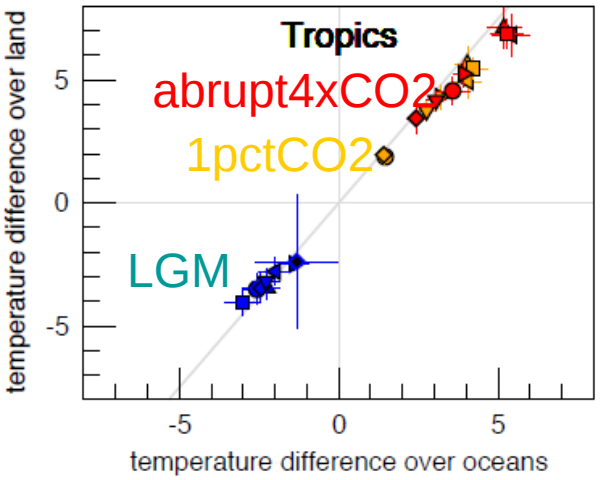






Land-Ocean contrasts





Schmidt et al, CPD 2013

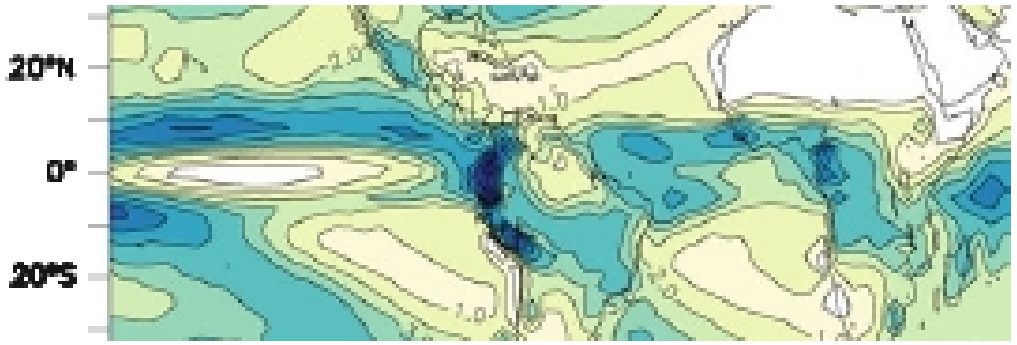
5. Towards more Reliable Models

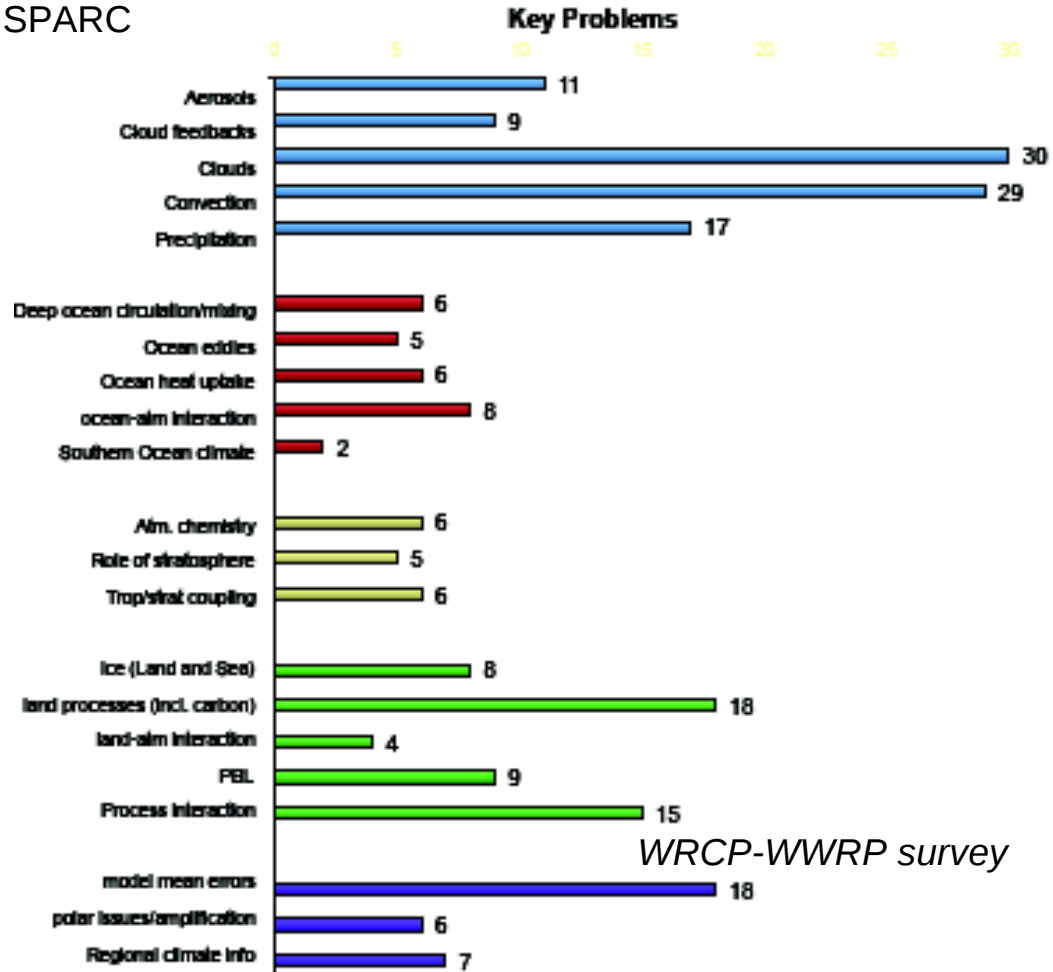
Led by Christian Jakob (Monash Univ., Australia) & Masahiro Watanabe (Tokyo Univ., Japan)

Aim : Interpret and reduce model errors to gain confidence in projections and predictions

Focus : Long-standing model biases (at least a few of them);
Understand how model errors or shortcomings impact projections and predictions ;
Gain physical understanding of the climate system through model development

Connections : WGNE, WGCM, GEWEX/GASS, SPARC

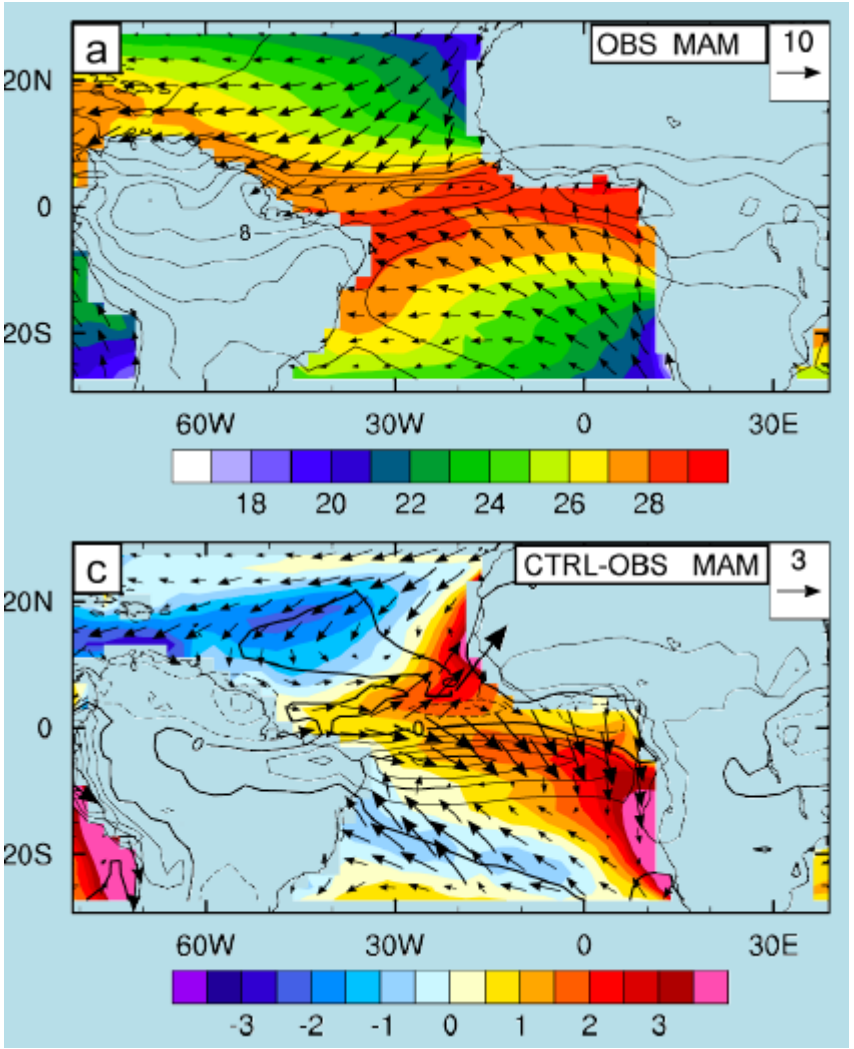


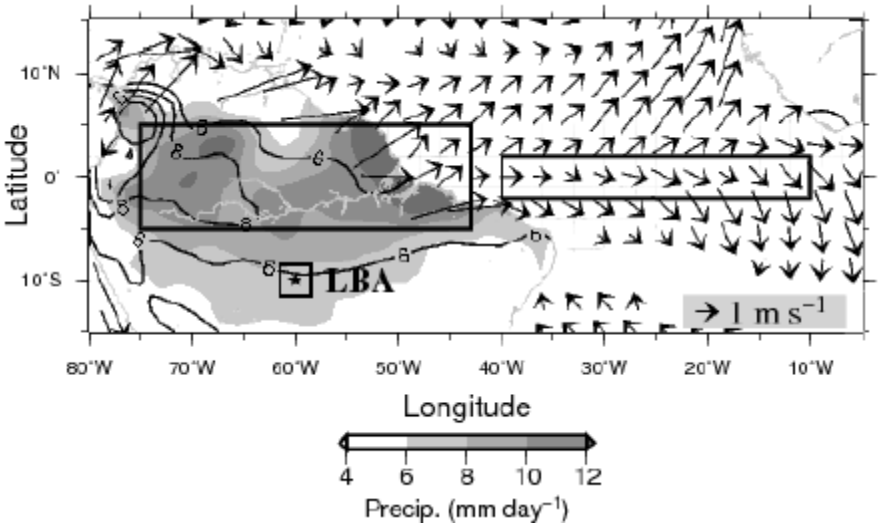


WRCP-WWRP survey

Interpretation of (long-standing) model biases

e.g. : The westerly bias over the equatorial Atlantic





There are two possible root causes of the westerly bias over the equatorial Atlantic in global climate models:

(a) insufficient low-level diabatic heating over the Amazonia, and

(b) insufficient momentum entrainment across the top of the boundary layer.

Zermeno & Zhang, J. Climate, submitted

WGNE workshop on systematic errors

Coordination

GC led by WGCM, in close collaboration with GEWEX/GASS, WGNE and SPARC

Many of the initiatives leverage on-going or planned WCRP projects.

GC Steering Committee

To ensure progress, coordination and integration of the different initiatives

Lead coordinators: **Sandrine Bony** (France) & **Bjorn Stevens** (Germany)	WGCM/CFMIP/GASS
Initiative #1: Climate and hydrological sensitivity **Steven Sherwood** (Australia) & **Mark Webb** (UK)	SPARC, CFMIP
Initiative #2: Leveraging the past record **Masa Kageyama** (France) & **Robert Pincus** (USA)	WGCM/PMIP, GEWEX
Initiative #3: Coupling clouds to circulations **Pier Siebesma** (Netherlands) & TBD	GEWEX/GASS/WGNE
Initiative #4: Changing patterns **Ted Shepherd** (UK) & **Adam Sobel** (USA)	SPARC, GEWEX/GASS
Initiative #5: Towards more reliable models **Christian Jakob** (Australia) & **Masahiro Watanabe** (Japan)	WGNE, CFMIP

Next steps : an outline

Grand Challenge :

Can help through collective priority setting, by maintaining focus on critical problems, by promoting activities within our community.

Next steps : an outline

First step (2013) :

To sharpen each initiative by highlighting key science questions and
by identifying opportunities (e.g. on-going projects) and gaps (e.g. missing connections)

- For this purpose, take advantage of (already planned) meetings. For instance *:*

WGNE workshop on systematic errors (Exeter, Apr 2013)
-> encourage the development of diagnostic methods that are specifically aimed at linking dynamical and physical processes in models. A special workshop in this area might be helpful to organize the community.

ISCCP 30th Anniversary (New-York, Apr 2013)
-> identified key questions for our GC (with a particular focus on the observational component) such as :
** How does convective organization influence to the large-scale circulation? What observational network would help investigate this issue ? Might convection organize differently in a warmer world ?*
** How do clouds mediate the coupling between the atmosphere and the surface ? (land sfc temp, arctic sea ice)*
** How do extratropical clouds interact with the general circulation (e.g. position and strength of the jets) ?*

And soon :
How to constrain climate sensitivity through process studies ? (CFMIP workshop)
How do aerosols affect large-scale atmospheric circulations ? (Aerocom workshop)
How robust is the large-scale circulation response to climate change ? (Royal Soc workshop)

- But also organize new meetings

Next steps : an outline

Next :

Motivate the community to work on GC initiatives, e.g. through high-profile papers
(a few examples in press, more to come),

and implement them through :

* on-going projects (e.g. CFMIP/GASS, WGNE, SPARC, PMIP, AEROCOM)

* workshops, summerschools
  - e.g. « *On the role of clouds in climate* » (Les Houches, France, July 2013)

* CMIP6 design

* The identification of new projects

Carbon Dioxide and Climate: Perspectives on a Scientific Assessment

Sandrine Bony, Bjorn Stevens, Isaac H. Held, John F. Mitchell, Jean-Louis Dufresne, Kerry A. Emanuel, Pierre Friedlingstein, Stephen Griffies, and Catherine Senior

...

4 Lessons from Past Experience and Recommendations to WCRP

Looking back at the Charney report and at the progress (or lack of progress) in climate research and modeling achieved over the last few decades, several key lessons for the future can be drawn. A selection of them are highlighted below.

...

G.R. Asrar and J.W. Hurrell (eds.), *Climate Science for Serving Society: Research, Modeling and Prediction Priorities*, DOI 10.1007/978-94-007-6692-1_14,

WCRP OSC Position Paper, 2013, in press

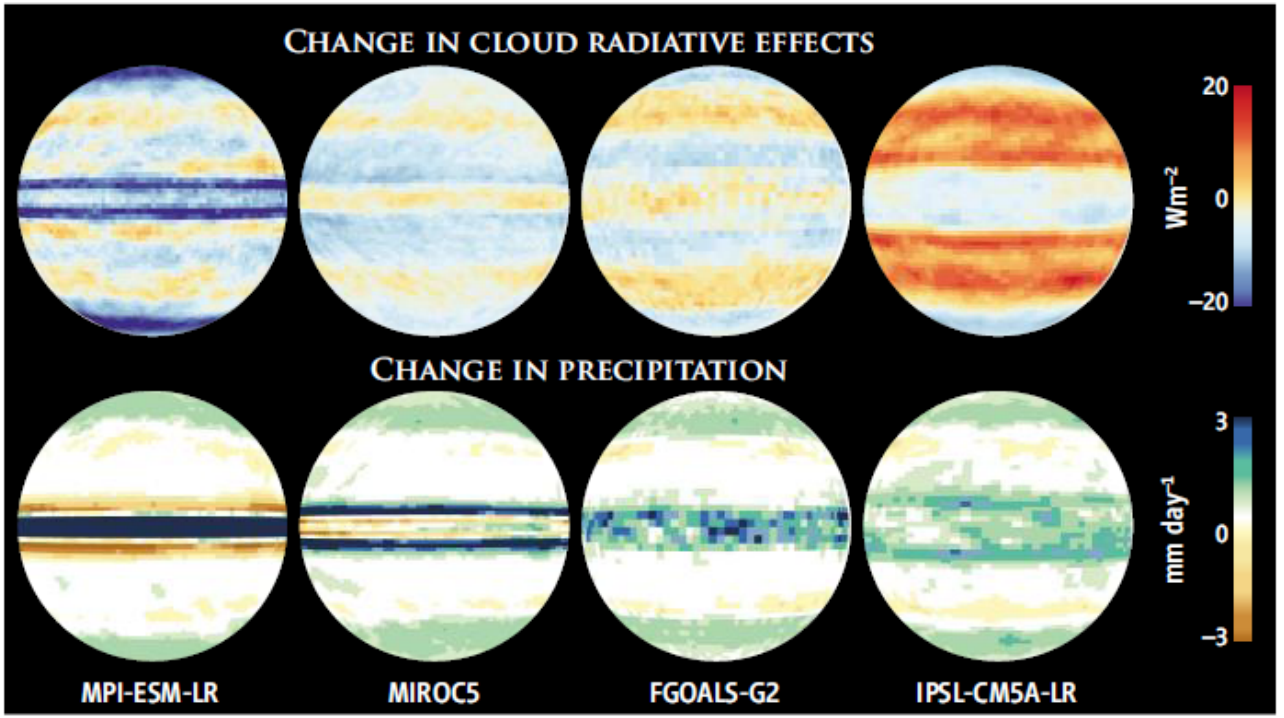
CLIMATE CHANGE

What Are Climate Models Missing?

A better representation of the coupling between atmospheric water and circulation is necessary to reduce imprecision in climate model projections.

Bjorn Stevens[1] and Sandrine Bony[2]

PERSPECTIVES



Wide variation. The response patterns of clouds and precipitation to warming vary dramatically depending on the climate model, even in the simplest model configuration. Shown are changes in the radiative effects of clouds and in precipitation accompanying a uniform warming (4°C) predicted by four models from Phase 5 of the Coupled Model Intercomparison Project (CMIP5) for a water planet with prescribed surface temperatures.

responses also influence ocean circulations, and hence how oceans take up heat, as well as patterns of precipitation, and hence how the land biosphere takes up carbon.

Back to Basics

A deeper understanding and better representation of the coupling between water and circulation, rather than a more expansive representation of the Earth System, is thus necessary to reduce the uncertainty in estimates of the climate sensitivity and to guide adaptation to climate change at the regional level. This knowledge should help focus efforts and lead to progress in reducing the imprecision of climate models in the next 50 years. Here, Numerical Weather Prediction (NWP) provides a good example. By focusing on key limitations in the model initialization, spatial resolution, and the representation of key parameterized processes, NWP has improved forecast skill substantially over the past 30 years (*15*).

Science, 2013 in press

Water in the Atmosphere

Bjorn Stevens and Sandrine Bony

Much of what we know, and even more of what we don't know, about Earth's climate and its propensity to change is linked to our understanding of the interplay between water and air circulation.

Physics Today, 2013 in press

Next steps : an outline

Next :

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Thank you for your attention