Long-Term Climate Projections : Perspectives on a Scientific Assessment

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Co-Chair of the WCRP Working Group on Coupled Models (WGCM)

With the Writing Team of our Position Paper :

(available on the WCRP Open Science Conference website)

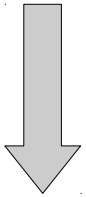
Jean-Louis Dufresne, Kerry Emanuel, Pierre Friedlingstein,
Stephen Griffies, Isaac Held, John Mitchell,
Cath Senior and Bjorn Stevens

WCRP Open Science Conference, Denver, Oct 24-28 2011

Climate Modelling Challenge

Climate change projections are increasingly used

to support climate-related decision making and planning.



The need to provide reliable assessments of future climate changes
has never been so high :

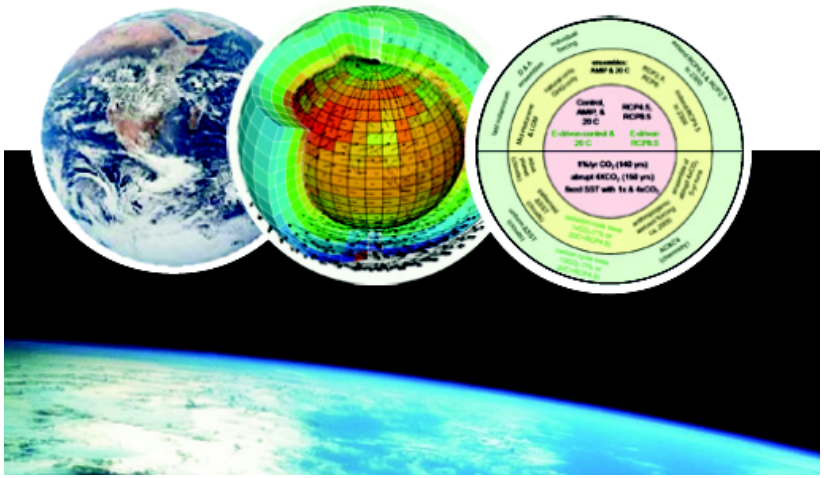
How to improve scientific assessments ?

By developing more realistic models
but this is not sufficient....

Modelling Long-Term Climate Change

- The WCRP Working Group on Coupled Models (WGCM) promotes and coordinates global climate simulations to :
  - **evaluate** climate models on recent and longer past (incl. paleo)
  - **provide projections** of future climate change
  - **assess and understand uncertainties** associated with projections

WCRP Coupled Model Intercomparison Project - Phase 5 - CMIP5 -



CLIVAR Exchanges – CMIP5 Special Issue May 2011

- Currently, these efforts are deployed within the so-called CMIP5 project,

- designed in collaboration with many scientific commnunities
- within WCRP and beyond (*e.g.* IGBP).

- CMIP5 simulations will be assessed by the 5th Assessment Report of the IPCC.

CMIP5 results becoming available on the "Earth System Grid"
Multi-model analyses starting...

CMIP5 participating modelling groups

50+ models from 23 groups (15 countries)

As of 17 Oct 2011: about half is already available

Primary Group	Country	Model
CAWCR	Australia	ACCESS
BCC	China	BCC-CSM1.1
GCESS	China	BNU-ESM
CCCMA	Canada	CanESM2, CanCM4, CanAM4
CCSM	USA	CESM1, CCSM4
RSMAS	USA	CCSM4(RSMAS)
CMCC	Italy	CMCC- CESM, CM, & CMS
CNRM/CERFACS	France	CNRM-CM5
CSIRO/QCCCE	Australia	CSIRO-Mk3.6
EC-EARTH	Europe	EC-EARTH
LASG, IAP	China	FGOALS- G2.0, S2.0 & gl
FIO	China	FIO-ESM
NASA/GMAO	USA	GEOS-5
GFDL	USA	GFDL- HIRAM-C360, HIRAM-C180, CM2.1, CM3, ESM2G, ESM2M
NASA/GISS	USA	GISS- E2-H, E2-H-CC, E2-R, E2-R-CC, E2CS-H, E2CS-R
MOHC	UK	Had CM3, CM3Q, GEM2-ES, GEM2-A, GEM2-CC
NMR/KMA	Korea / UK	HadGEM2-AO
INM	Russia	INM-CM4
IPSL	France	IPSL- CM5A-LR, CM5A-MR, CM5B
MIROC	Japan	MIROC 5, 4m, 4h, ESM, ESM-CHEM
MPI-M	Germany	MPI-ESM- HR, LR
MRI	Japan	MRI- AGCM3.2H, AGCM3.2S, CGCM3, ESM1
NCC	Norway	NorESM1-M, NorESM-ME, NorESM1-L

Courtesy Karl Taylor (PCMDI)

Early results presented in Parallel and Poster sessions of the OSC

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Multi-model analyses starting...

Workshop Announcements :

CMIP5

Model Analysis Workshop

March 5-9, 2012

IPRC, University of Hawaii, Honolulu

Check WGCM website

for upcoming announcement:

http://www.clivar.org/organization/wgcm/wgcm.php

PMIP

Using paleo-climate model-data comparisons to constrain future climate projections

March 1-3, 2012

Bishop Museum, Honolulu

Contact: G. Schmidt & V Masson-Delmotte

CFMIP

Assessing Cloud-Climate Feedbacks in CMIP5 models

May 28 – June 1, 2012

Paris, France

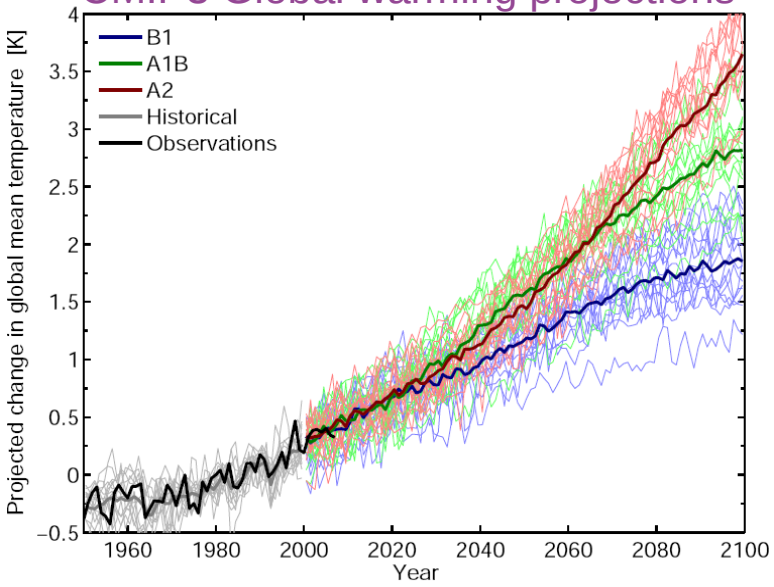
Check CFMIP website www.cfmip.net

for upcoming annoucement

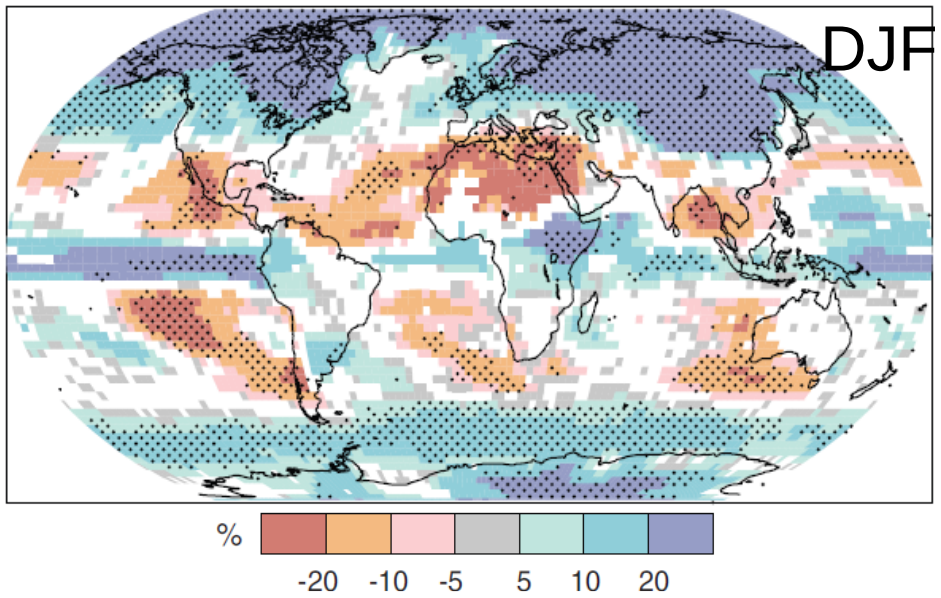
How to Assess our Confidence in Model Projections ?

- Long-standing characteristics of long-term projections from climate models :
  - Some aspects robust amongst models
  - Others associated with large inter-model differences

CMIP3 Global warming projections



CMIP3 Precipitation projections



- How to assess our confidence in climate projections ?
  - Are consensual results reliable ?
  - Reasons for inter-model differences ? Are some results more credible than others?

Key questions for long-term climate change assessments

An Early Assessment of Long-Term Climate Change : The “Charney Report” (1979)

Carbon Dioxide and Climate: A Scientific Assessment

Report of an Ad Hoc Study Group on Carbon Dioxide and Climate
Woods Hole, Massachusetts
July 23–27, 1979
to the
Climate Research Board
Assembly of Mathematical and Physical Sciences
National Research Council

Jule Charney
(1917-1981)

NATIONAL ACADEMY OF SCIENCES
Washington, D.C. 1979

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- Available material :
  - simple climate models (EBM, 1D..)
  - a few early general circulation models
  - very few global observations
- Amazingly prescient in its assessment :

... of the effects of increased CO_2 on climate :

- timing of doubling of CO_2 concentration
- 2 x CO_2 radiative forcing : ~ 4 W/m^2
- pattern of surface warming (land/ocean, polar)
- water vapor and sea-ice feedback estimates
- climate sensitivity estimates :
  range : 1.5 – 4.5 K ; likely value : 3 K
- etc

... of key uncertainties :

- cloud feedbacks
- role of the ocean in carbon and heat uptake
- regional precipitation changes
- etc

An Early Assessment of Long-Term Climate Change : The "Charney Report" (1979)

Carbon Dioxide and Climate :
Perspectives on a Scientific Assessment

Sandrine Bony[1], Bjorn Stevens[2], Isaac Held[3], John Mitchell[4],
Jean-Louis Dufresne[1], Kerry Emanuel[5], Pierre Friedlingstein[6],
Stephen Griffies[3] and Catherine Senior[4]

[1] *Laboratoire de Météorologie Dynamique / IPSL, CNRS, Paris, France*
[2] *Max-Planck Institute for Meteorology, Hamburg, Germany*
[3] *Geophysical Fluid Dynamics Laboratory, Princeton, NJ, USA*
[4] *MetOffice / Hadley Center, Exeter, United Kingdom*
[5] *Massachusetts Institute for Technology, Cambridge, MA, USA*
[6] *University of Exeter, Exeter, United Kingdom*

Position paper prepared for the
WCRP Open Science Conference to be held in Denver, Oct 24-28 2011

- What explains the prescience of the Charney report (1979) ?
- What progress have we made in assessing the effects of increased CO_2 on climate ?
- What lessons do we draw from 30 years of climate modelling and climate change research ?
- Recommendations for future progress

The insights of the “Charney Report” were not an accident

- They reflect the power of the scientific approach underlying the assessment :

“In order to assess the climatic effects of increased CO2, we consider first the primary physical processes that influence the climate system as a whole.”

“These processes are best studied in simple models whose physical characteristics may readily be comprehended.”

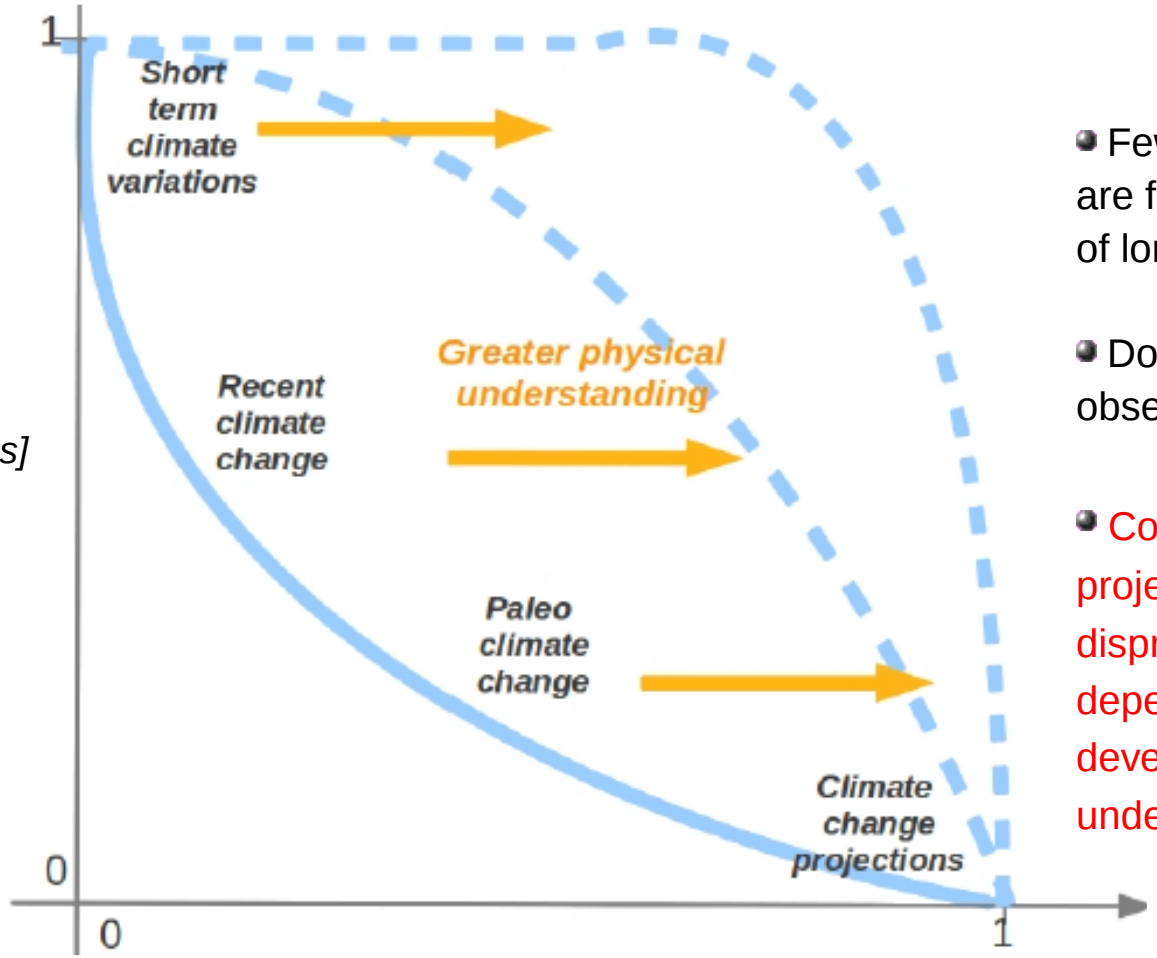
“The understanding derived from these studies enables one better to assess the performance of the 3D circulation models.“

“ ***Our confidence in our conclusion*** *that a doubling of CO2 will eventually result in significant temperature increases and other climate changes* ***is based on the fact that the results*** *of the radiative-convective and heat-balance model studies* ***can be understood in purely physical terms and are verified by the more complex GCMs.****”*

Likely to remain a productive approach in the future

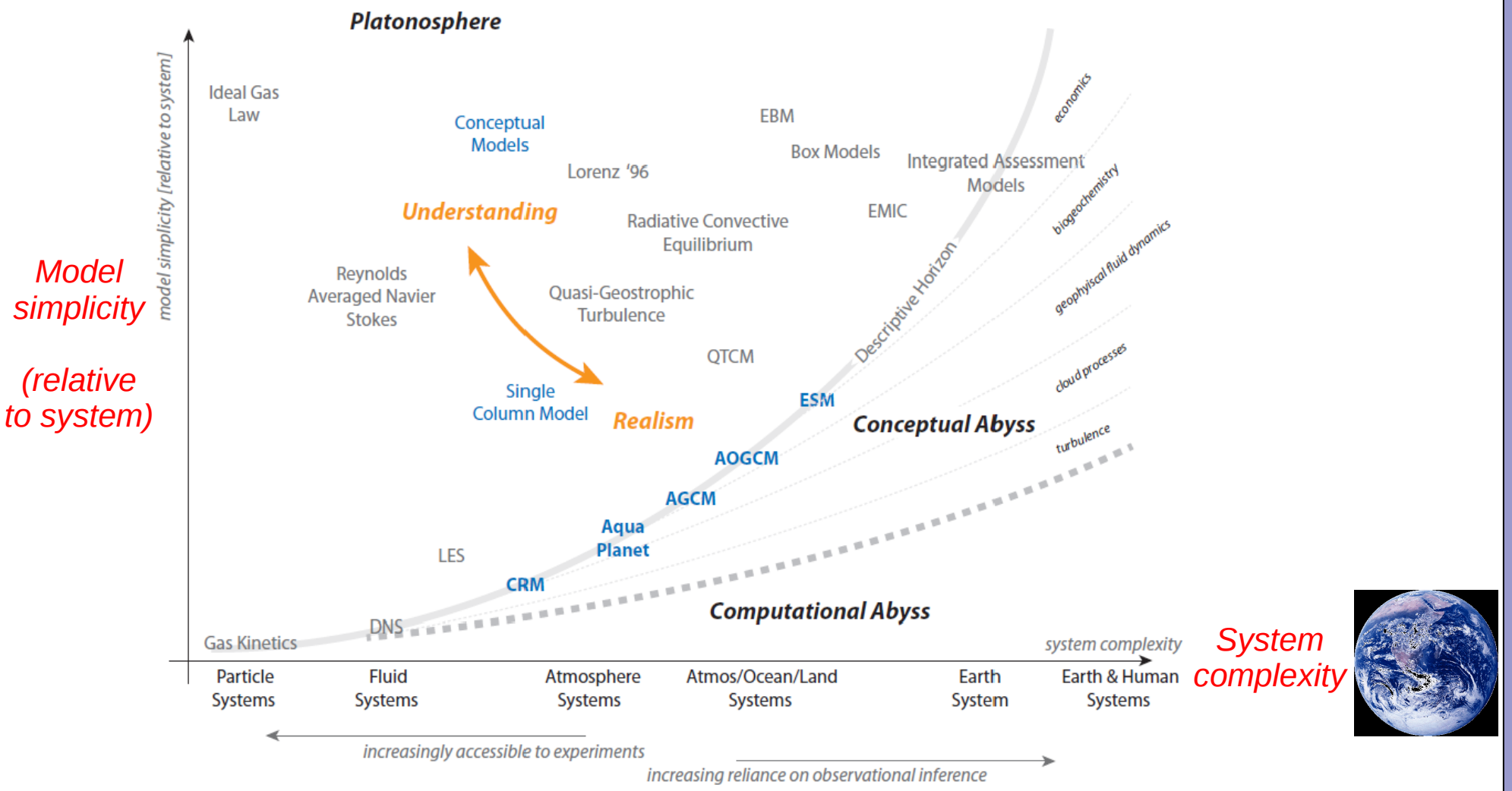
Model predictive capabilities for long-term climate change

- Unlike in weather prediction, the reliability of model predictive capabilities for long-term climate change can not be established in a straightforward way... but *only through indirect routes*.



- Few observational tests are fully discriminating of long-term projections.
- Do we apply relevant observational tests ?
- Confidence in climate projections thus remains disproportionately dependent on the development of understanding

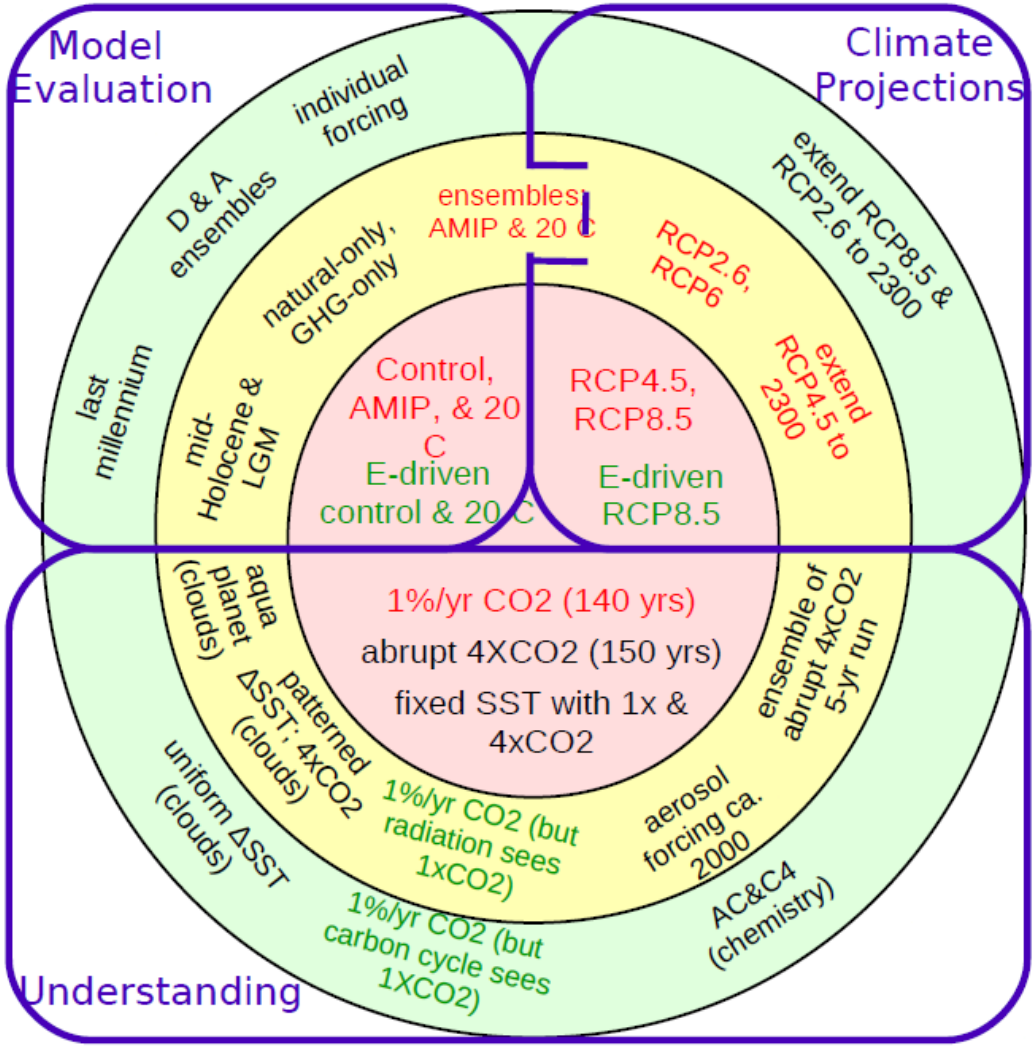
Our physical understanding of the climate system relies on a spectrum of models and theories



- Our confidence in modelling results depends on our ability :
  - to connect robust behavior across a spectrum of relevant models
  - to connect this behavior both to basic physical principles and to observations

CMIP5 is part of our current “descriptive horizon”

Long-Term Set of Climate Experiments :



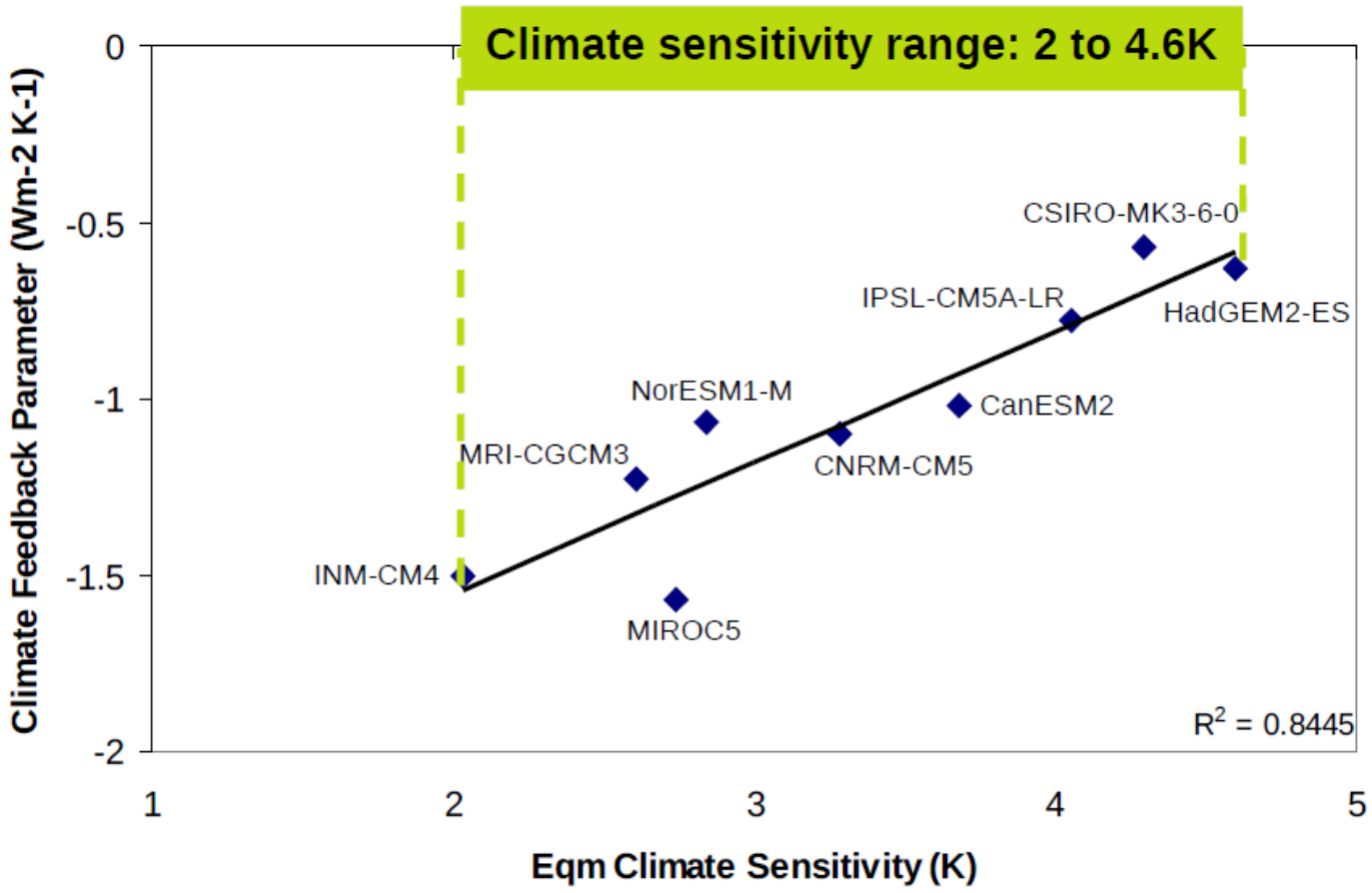
CMIP5 compared to previous CMIPs :

- Wider spectrum of models, configurations and experiments (e.g. ESM, AOGCM, AGCM Aqua-planet AGCM..)
- More (idealized) experiments aiming at better understanding the model results
- More comprehensive set of model output
- Originally independent MIPs into a single MIP

→ Synergistic opportunities for greater scientific understanding

Climate Sensitivity

Subset of CMIP5 models :



Courtesy
Tim Andrews,
Karl Taylor et al.
(cf Session B12)

Preliminary analyses suggest that inter-model differences in cloud feedback, once again, remain a primary contributor to this uncertainty

What Progress in our Understanding of Climate Change Cloud Feebdacks ?

Charney Report (1979) :

- Clouds response recognized as a key source of uncertainty
- But only a vague idea as to why clouds should change... + no evaluation of model clouds

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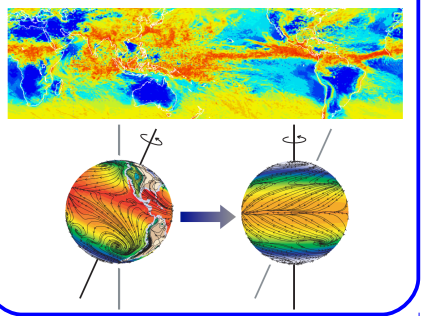
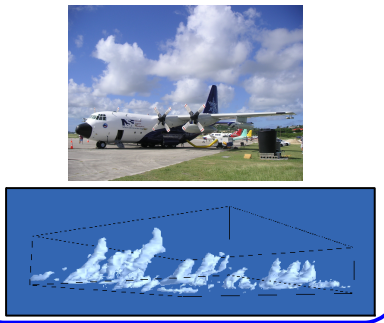
Since then :

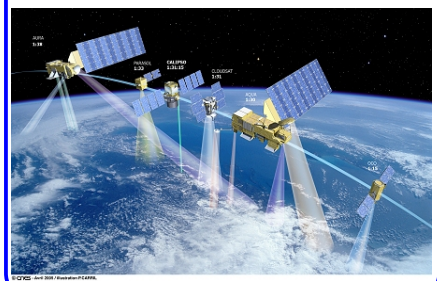
GCM analysis through a spectrum of models



Process studies (in-situ obs, LES/CRMs)

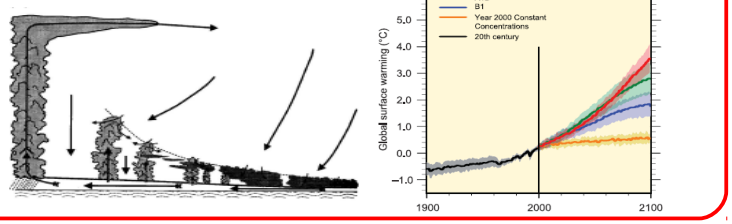


Satellite observations & simulators (COSP)



Understanding ⋯▸ Evaluation

Assessment of cloud-climate feedbacks



CFMIP (Cloud Feedback Model Intercomparison Project)

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Since then :

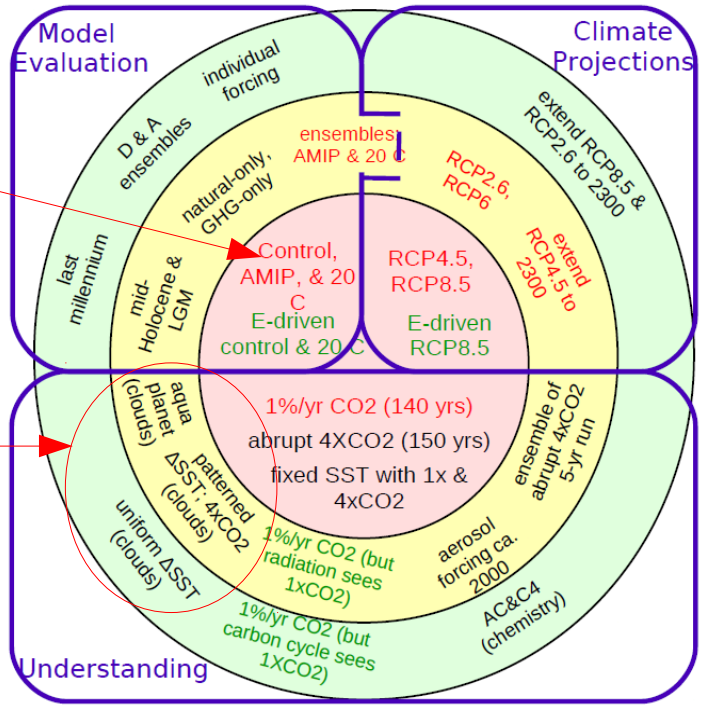
- A variety of physical mechanisms have been proposed, such as :

- upward shift of cloud layers
- poleward migration of extratropical storm tracks
- thermodynamical controls on CWP
- fast response to CO2 radiative forcing
- changing PBL stability, depth and structure
- changing profiles of moist static energy

CMIP5

satellite simulator + process diagnostics

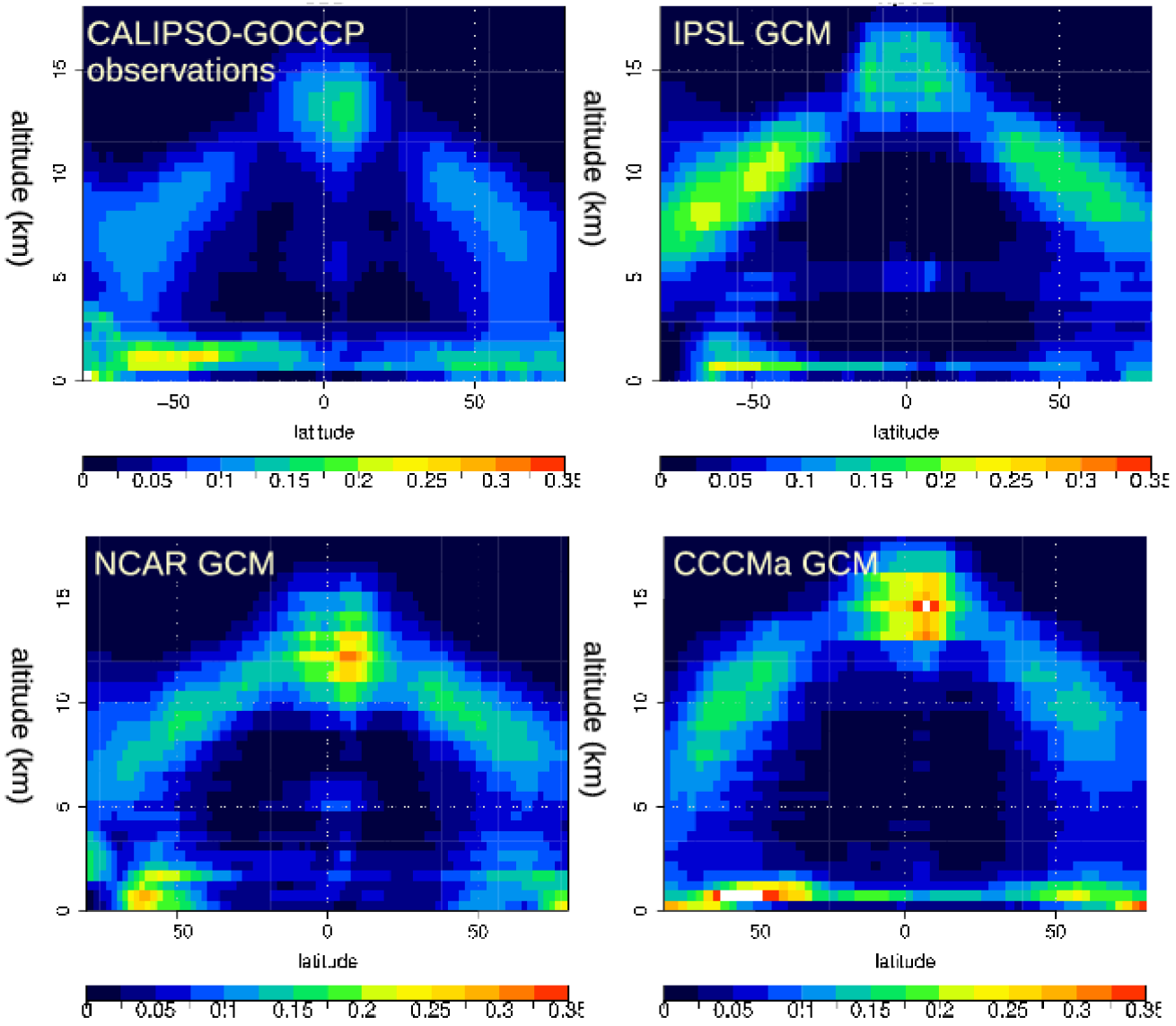
idealized experiments



Opportunities to better assess cloud feedbacks in CMIP5 models

First evaluations of the 3D distribution of clouds simulated by climate models

CALIPSO lidar



Other satellite observations considered : ISCCP, CloudSat, Parasol, MODIS, MISR..

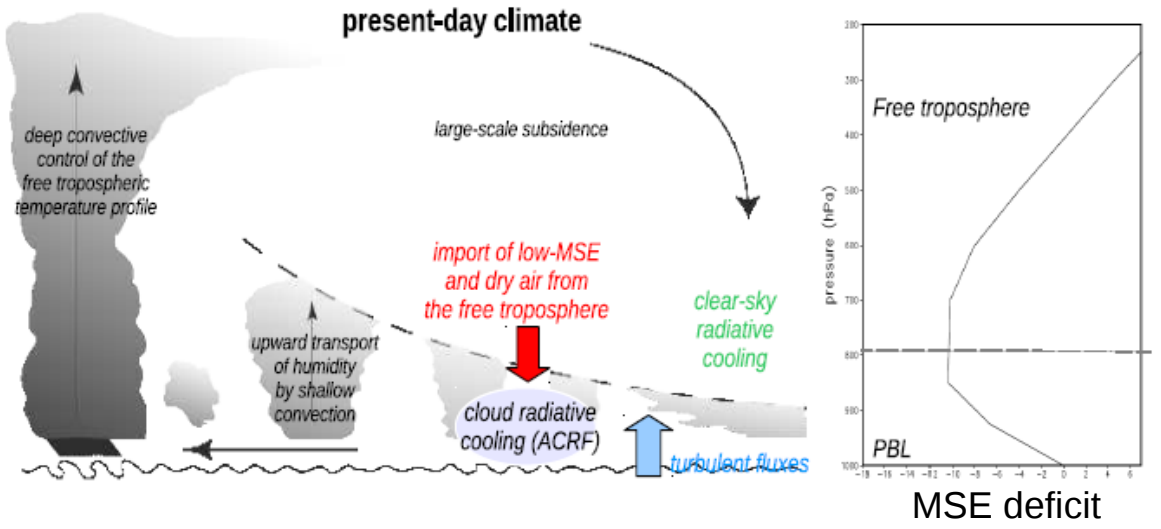
Understanding the response of low-level clouds through a spectrum of models

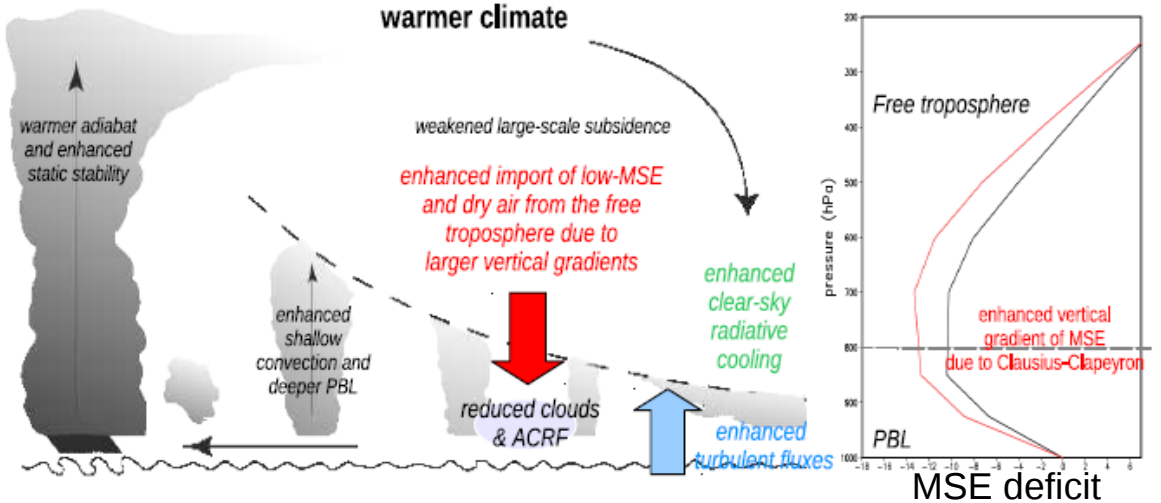
In a CMIP5 General Circulation Model (IPSL-CM5A)

- Positive low-cloud feedback analyzed through a range of CMIP5 experiments and configurations (OAGCM, AGCM, aqua-planet, 1D)

- Primary physical mechanisms controlling the feedback identified (e.g. vertical gradient of MSE at the top of the PBL)

(Talk by Florent Brient in B12 session)



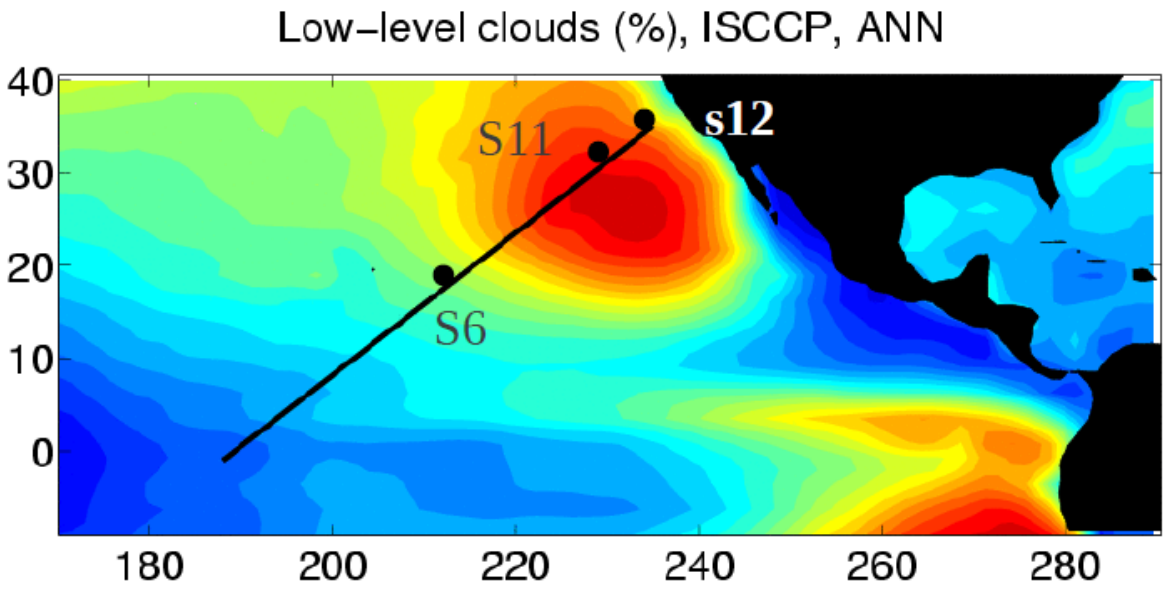


(Brient & Bony, Clim. Dyn, submitted)

Understanding the response of low-level clouds through a spectrum of models

In multiple Large-Eddy Simulation (5 LES) models and
Single-Column Model versions of CMIP5 GCMs (16 SCM)
[CFMIP-GCSS CGILS project]

What are the primary physical processes controling the formation and response of low-level clouds to (idealized) climate change ?

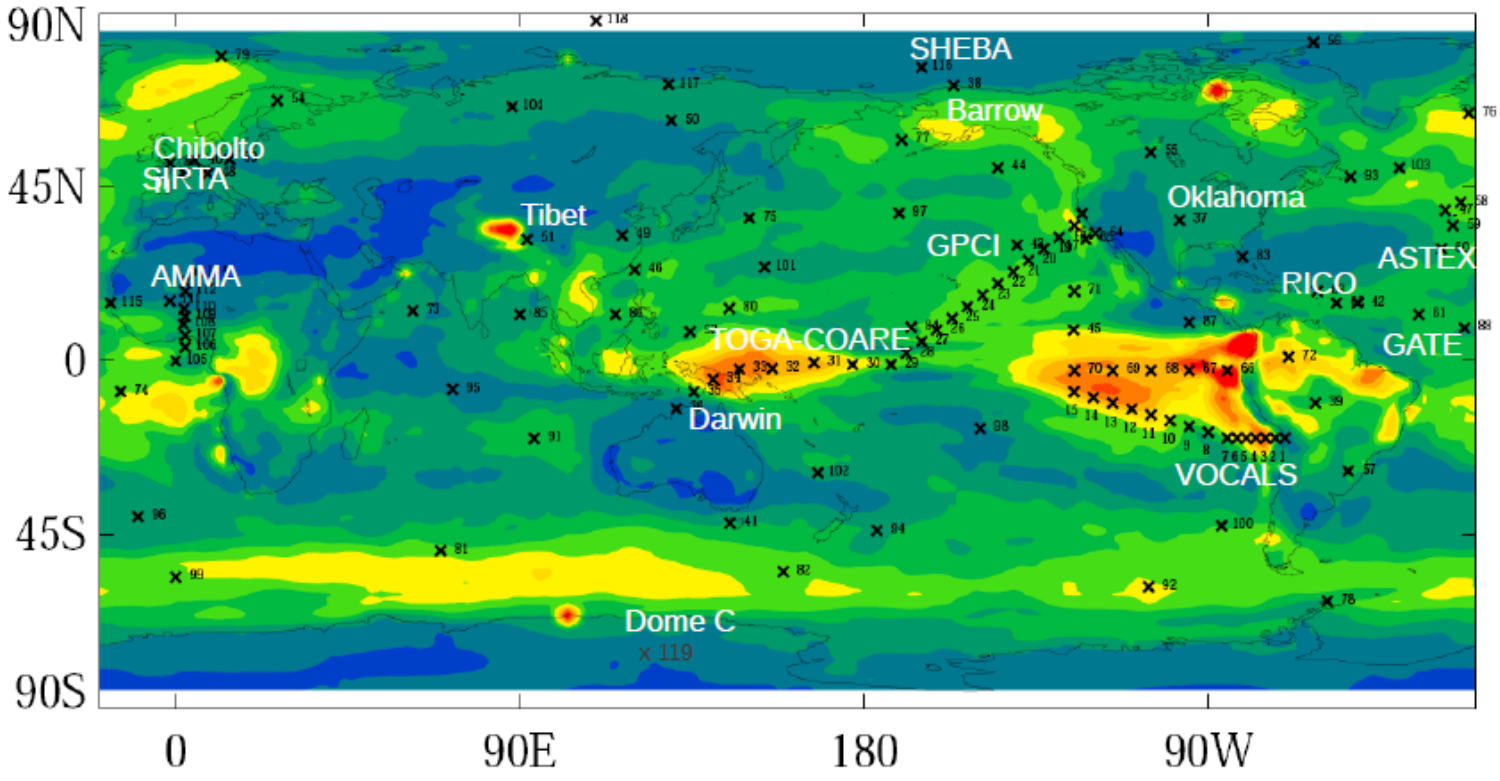


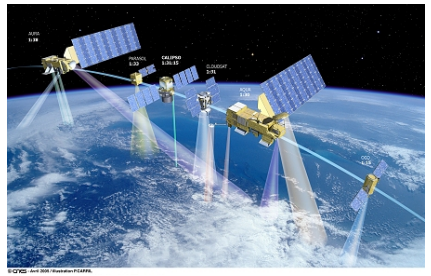
Talk in B6 session by Chris Bretherton, Peter Blossey, Minghua Zhang et al.

Observational opportunities to test processes critical for CMIP5 model cloud feebdacks

High-frequency (half-hourly) detailed model outputs from CMIP5 models over 120 sites where cloud feedbacks are particularly uncertain, or for which observations facilities (ARM, CloudNet..), field experiments and/or satellite observations are available

CFMIP sites with detailed CMIP5 outputs





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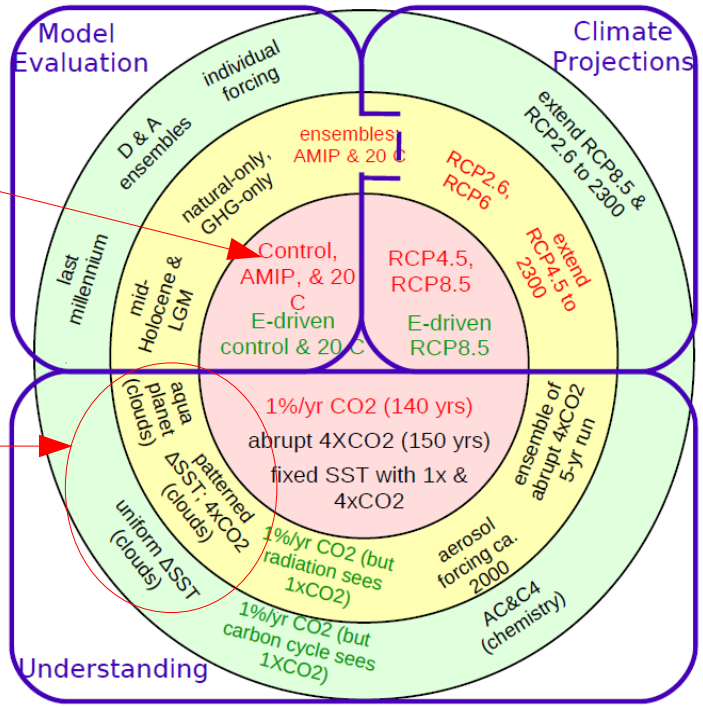
CMIP5

satellite simulator + process diagnostics

idealized experiments



Opportunities to better assess cloud feedbacks in CMIP5 models

Conclusions

Our ability to anticipate long-term climate changes primarily relies on our physical understanding of how the climate system works

Therefore, to better assess predictive capabilities of models and improve our assessment of future climate changes :

- Developing more realistic climate models (more comprehensive, complex, higher-resolution) and better quantifying uncertainty in projections : **NECESSARY...BUT NOT SUFFICIENT**

- Of equal importance : Need to physically interpret model results in terms of processes or basic principles, and to connect them to simpler models, concepts, theories and observations.

We should strive do as well as the Charney Report did for global to zonal scales, but for global to regional scales

A key for :

- Assessing our relative confidence in different aspects of the projections
- Determining how available observations might help to assess projections
- Communicating with the public and society

"Actionable Science" is needed, i. e.
sufficiently predictive, accepted and understandable to support decision-making " (David Behar)

Recommendations to WCRP

- Recognize that progress in climate change assessments does not only rely on the growth in complexity of the models upon which they are based, but primarily relies on our ability to better understand how the climate system works.

  The science of climate and climate change is not done!

- Be pro-active in encouraging the community to tackle long-standing, difficult problems in addition to new uncharted problems (e.g. model errors, influence of cloud and moist processes on large-scale circulation, ocean mixing, land hydrology)

- Promote the physical understanding of CMIP5 results and projections by facilitating connections between communities dealing with theory, simple/complex modelling, processes & observations.

→ A strategy may include *Climate Process Teams* (or *Climate Projection Understanding Teams*) and organizing Workshops on "Understanding climate change through a hierarchy of models".

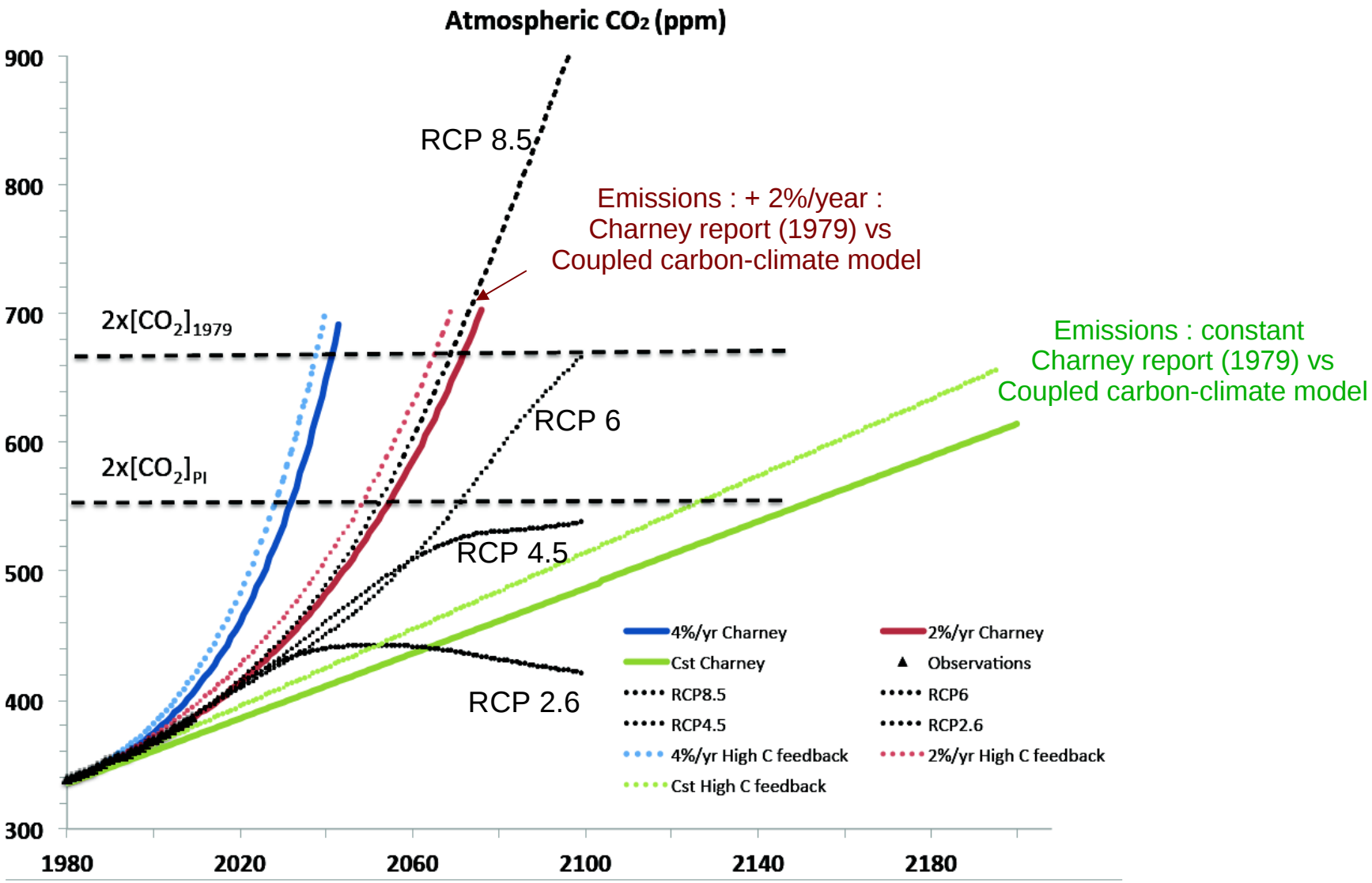
→ Consider organizing a series of bottom-up community assessments about specific aspects of climate projections (*cf* SPARC) to complement and facilitate IPCC assessments.

Your feedback on our position paper will be welcome :

Carbon Dioxide and Climate : Perspectives on a Scientific Assessment

http://conference2011.wcrp-climate.org/documents/LongTermClimateChange_Bony.pdf

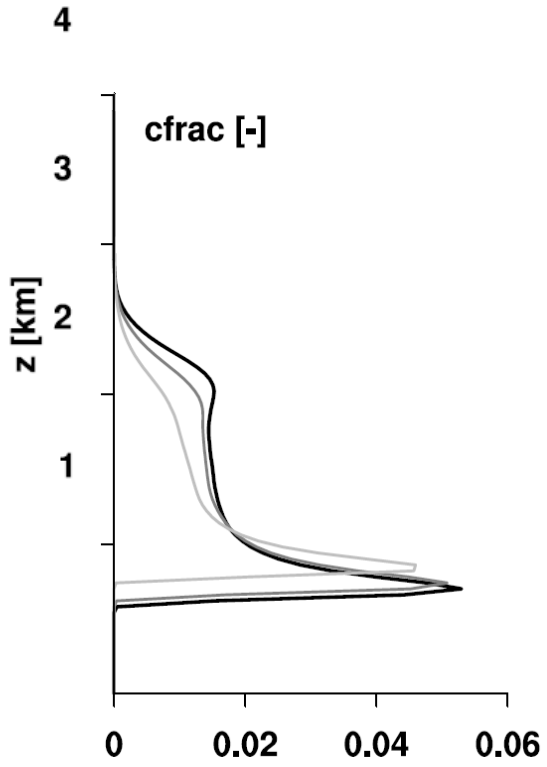
Evolution of Atmospheric CO2 Predicted for Different Emission Scenarios

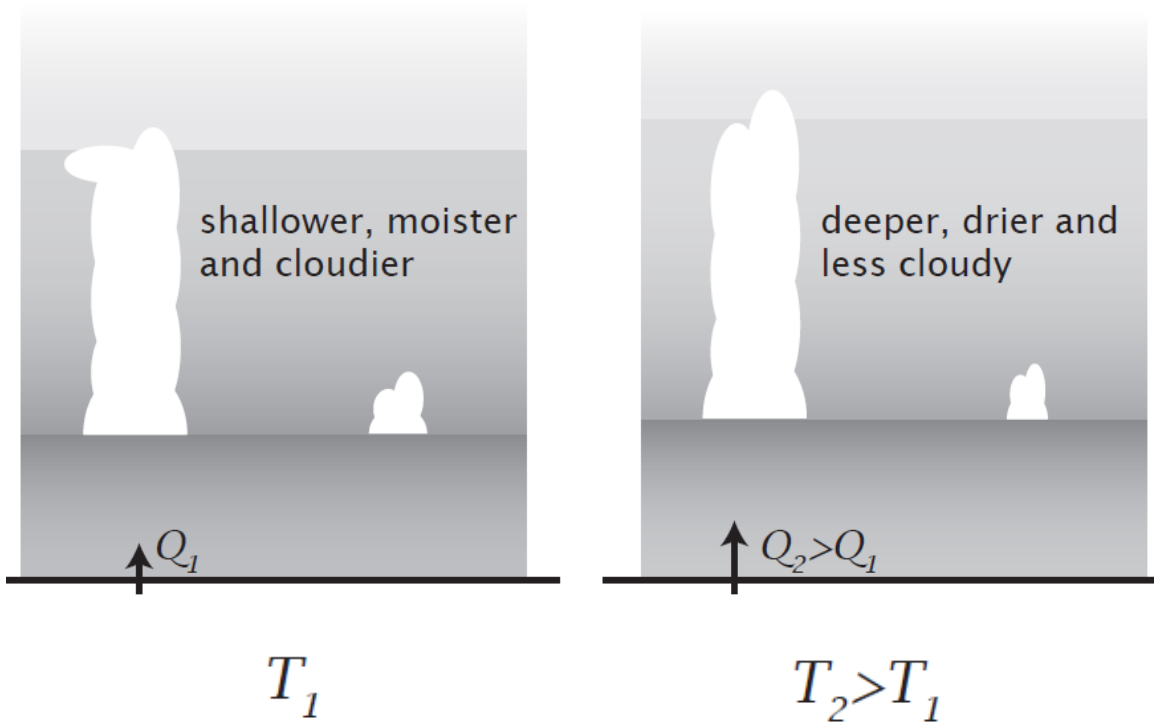


Understanding the response of shallow cumulus clouds through a spectrum of models

In a Large-Eddy Simulation (LES) model

- Idealized experiment assuming a nearly unchanged relative humidity atmosphere





(Rieck, Nuijens and Stevens, submitted)