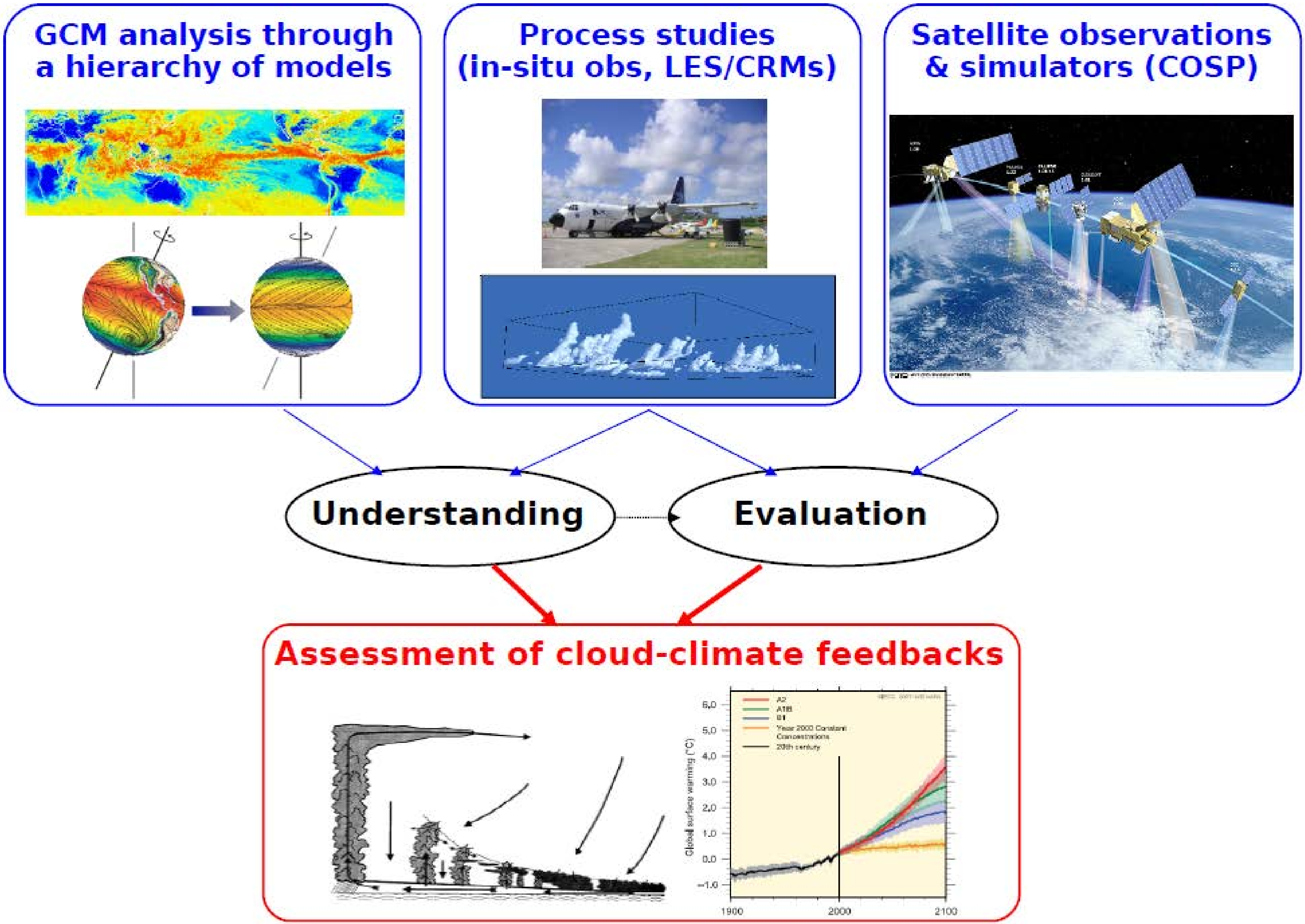
World Climate Research Programme

CMIP6 Recommendations from The Cloud Feedback Model Inter-comparison Project

CFMIP Committee members Mark Webb, Chris Bretherton, Sandrine Bony, Steve Klein, Masahiro Watanabe, Bjorn Stevens + input from Steve Sherwood and members of the COSP Project Management Committee

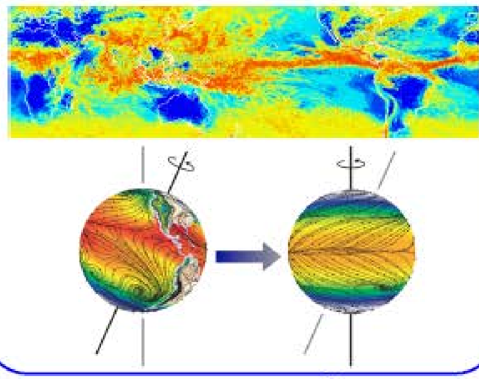
Cloud Feedback Model Inter-comparison Project Phase-2
CFMIP-2 (www.cfmip.net)



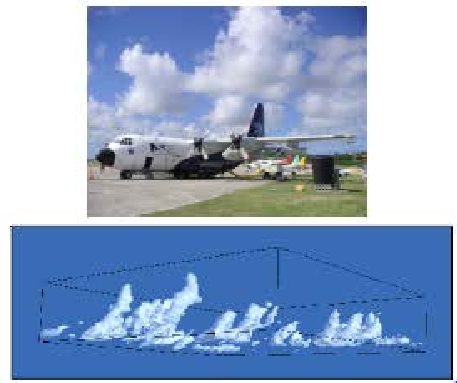
The objective of CFMIP-2 is to provide a better assessment of climate change cloud feedbacks by improving the evaluation of clouds simulated by climate models and the understanding of cloud-climate feedback processes.

Cloud Feedback Model Inter-comparison Project Phase-2
CFMIP-2 (www.cfmip.net)

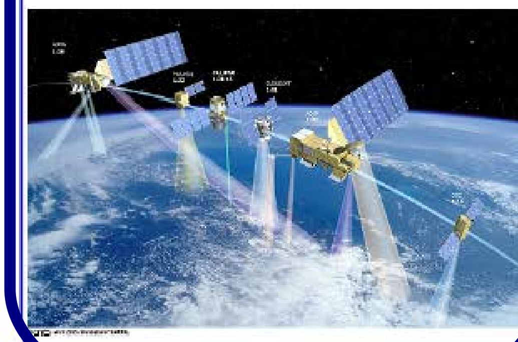
GCM analysis through a hierarchy of models



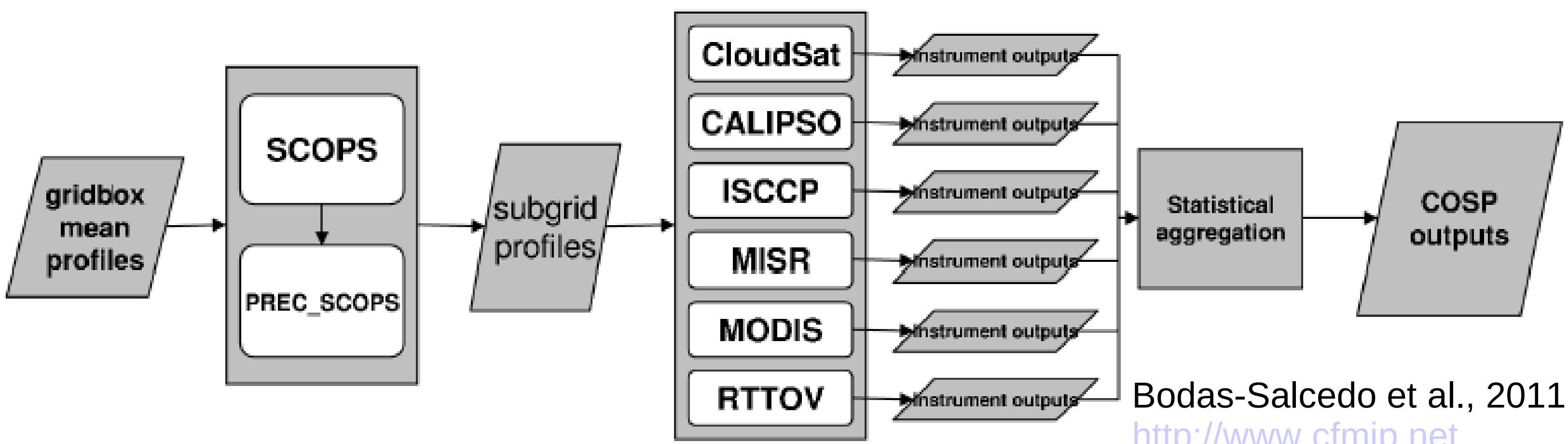
Process studies (in-situ obs, LES/CRMs)



Satellite observations & simulators (COSP)



CFMIP Observation Simulator Package (COSP)



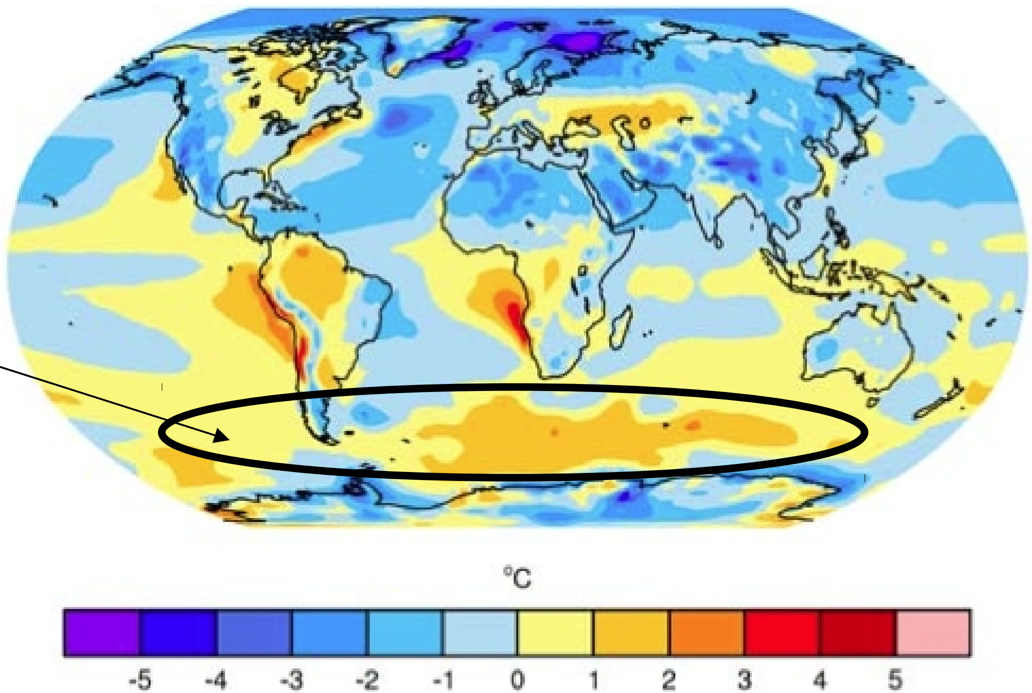
Bodas-Salcedo et al., 2011
http://www.cfmip.net

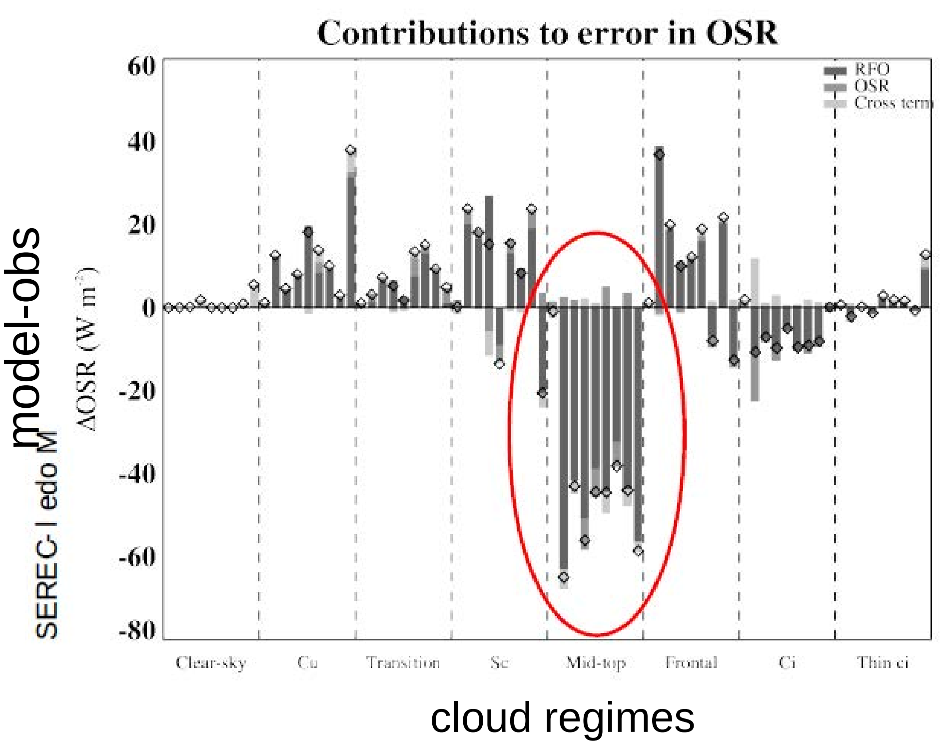
Quantitative evaluation of the 3D distribution of clouds and cloud properties in models
COSP is being used by all the major modelling groups in CMIP5 (& NWP)

Clouds and model systematic errors...

CMIP5 Multimodel Mean SST error

Over-estimate of
absorbed SW radiation
primarily due to mid-level
topped ISCCP cloud regime
(e.g. Bodas-Salcedo et al.,
submitted)





COSP also useful for :

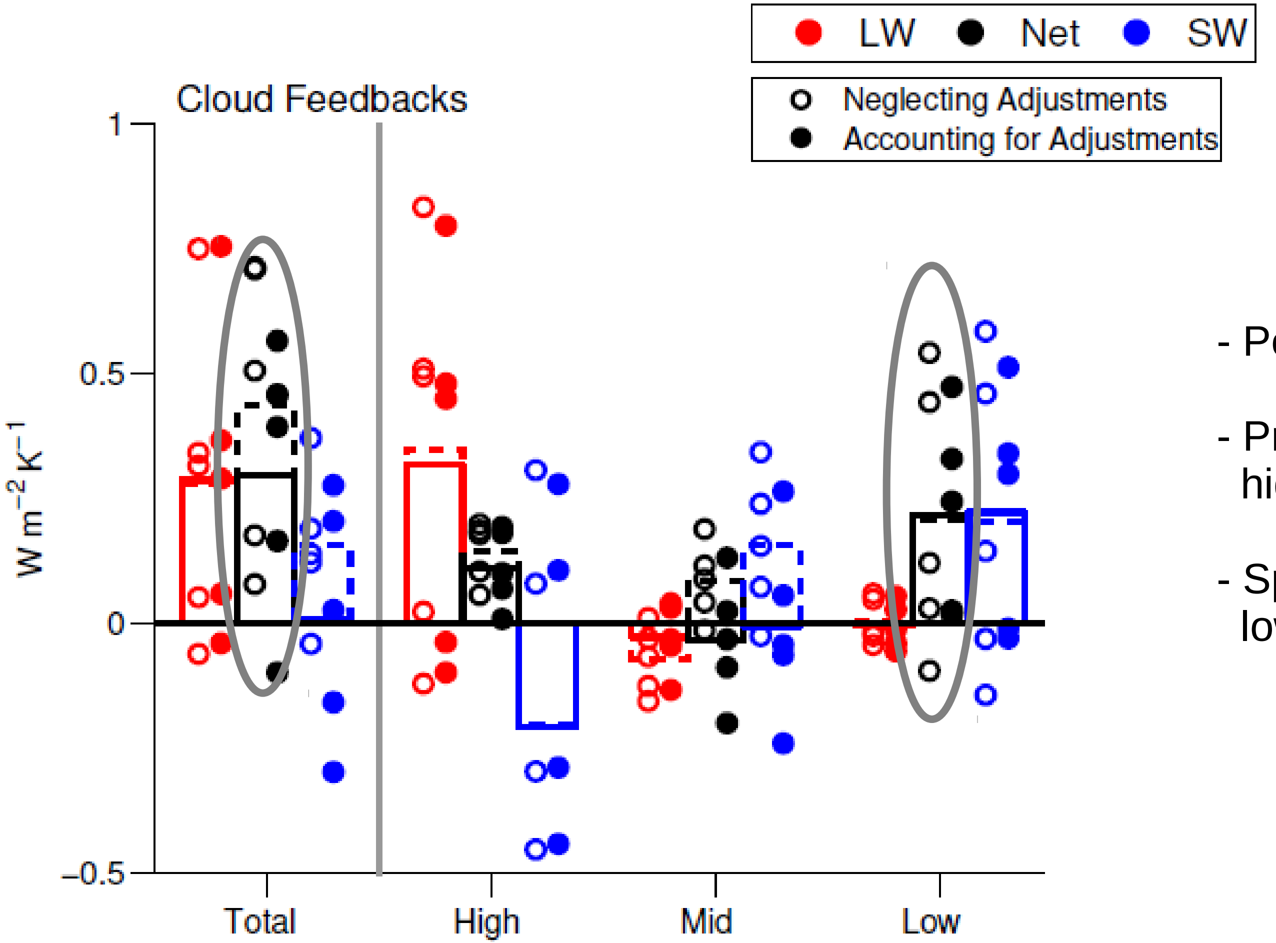
+ evaluation of polar clouds, etc

+ emerging constraints

+ analysis cloud feedbacks

CMIP5 cloud feedbacks analyzed in terms of cloud types & processes

COSP simulator outputs are not useful only for evaluating clouds but also for the understanding of cloud feedbacks



(using COSP simulator outputs)

- Positive cloud feedback
- Primarily arises from low-level and high-level cloud feedbacks
- Spread primarily arises from low-level cloud feedbacks

Zelinka et al., J. Climate, 2013

Cloud Feedback Model Inter-comparison Project Phase-2
CFMIP-2 (www.cfmip.net)

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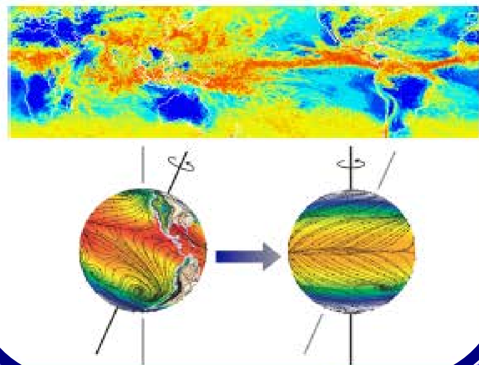

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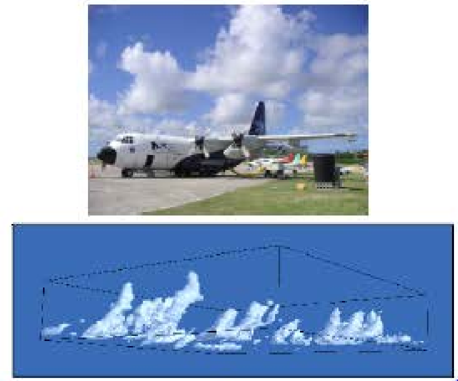
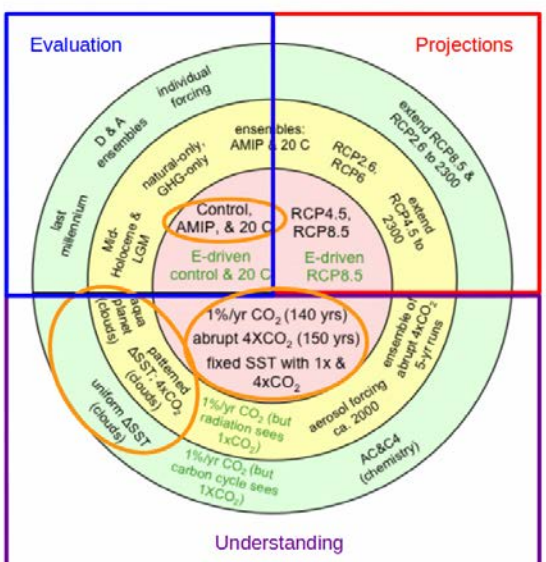


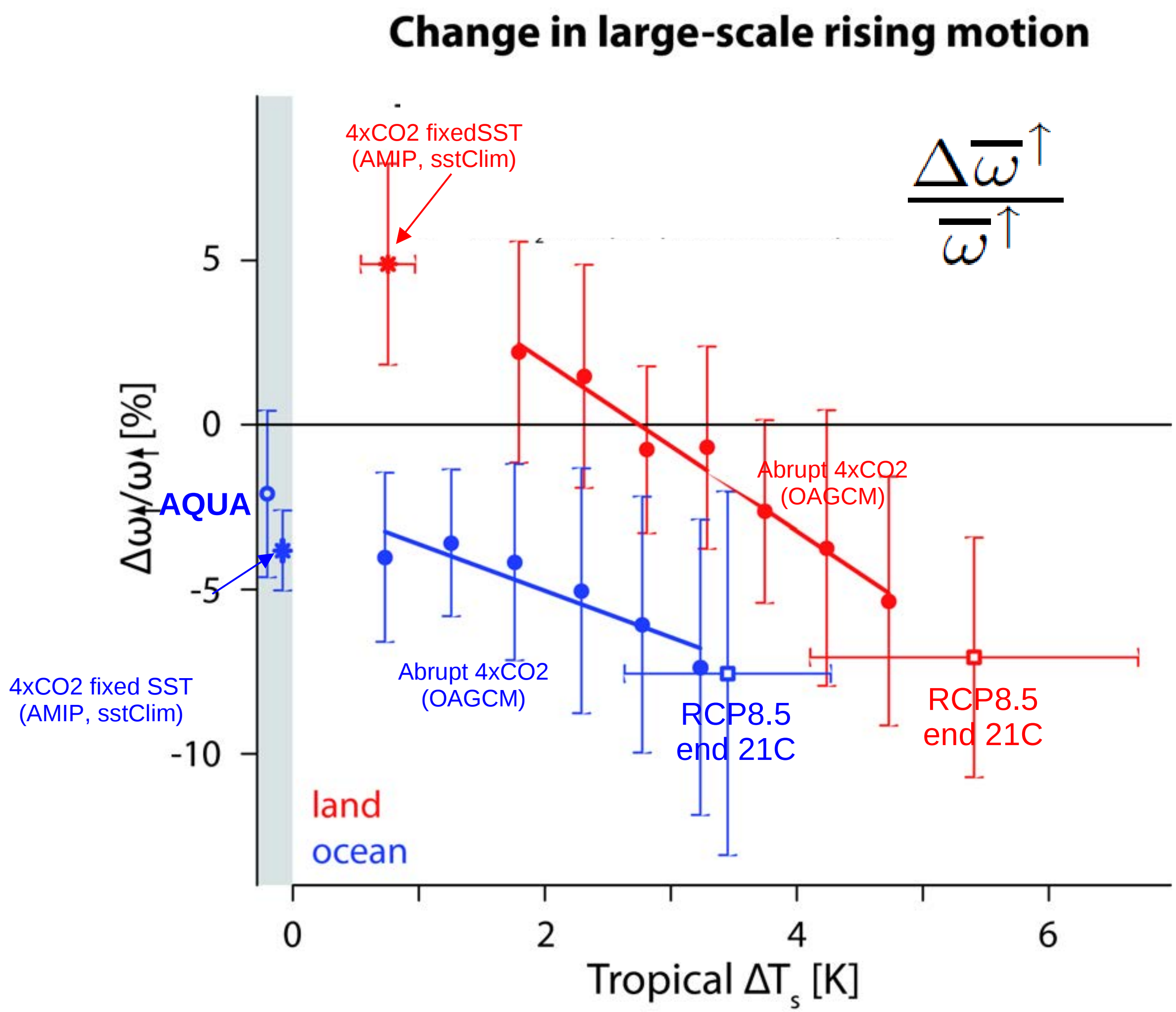
Satellite observations & simulators (COSP)

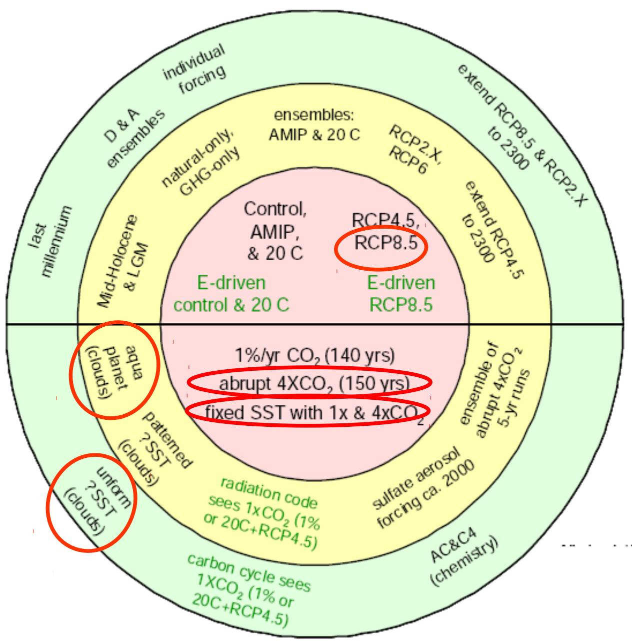
CFMIP2/CMIP5 Experiment Hierarchy



Pre-industrial	Historical/ present	CO_2 Forcing / adjustments	Idealised Climate feedbacks
Atmos only pre-ind SST climatology	Atmos only pre-ind SST, present aero	Atmos only pre-ind SST $4xCO_2$	CMIP5 Experiments with COSP only
Coupled pre-industrial control	Coupled historical	Coupled Abrupt $4CO_2$	Coupled1 % per year CO_2
CFMIP2/ CMIP5 Experiments with COSP and Process Outputs	AMIP	AMIP + $4xCO_2$	AMIP +4K uniform; AMIP +4K SST pattern
	Aquaplanet Control	Aquaplanet $4xCO_2$	Aquaplanet Uniform+4K
CGILS Experiments SCM & LES	GPCI AMIP SST		GPCI AMIP SST+2K

CMIP5 models also predict fast adjustments of the atmospheric circulation to increased CO2





Robust direct effect of CO2 on the strength of the overturning atmospheric circulation in the tropics

Bony et al., NGS, 2013

Cloud Feedback Model Inter-comparison Project Phase-2
CFMIP-2 (www.cfmip.net)

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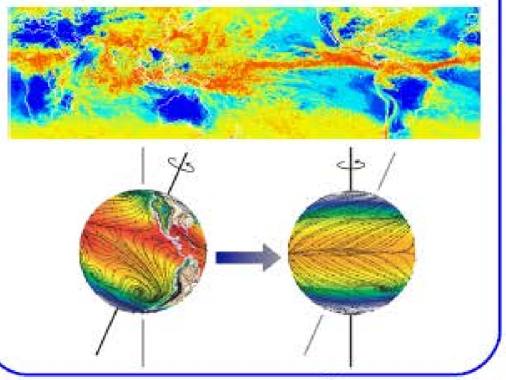

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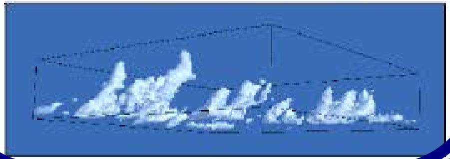

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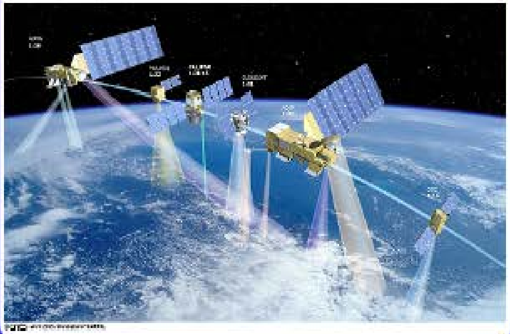


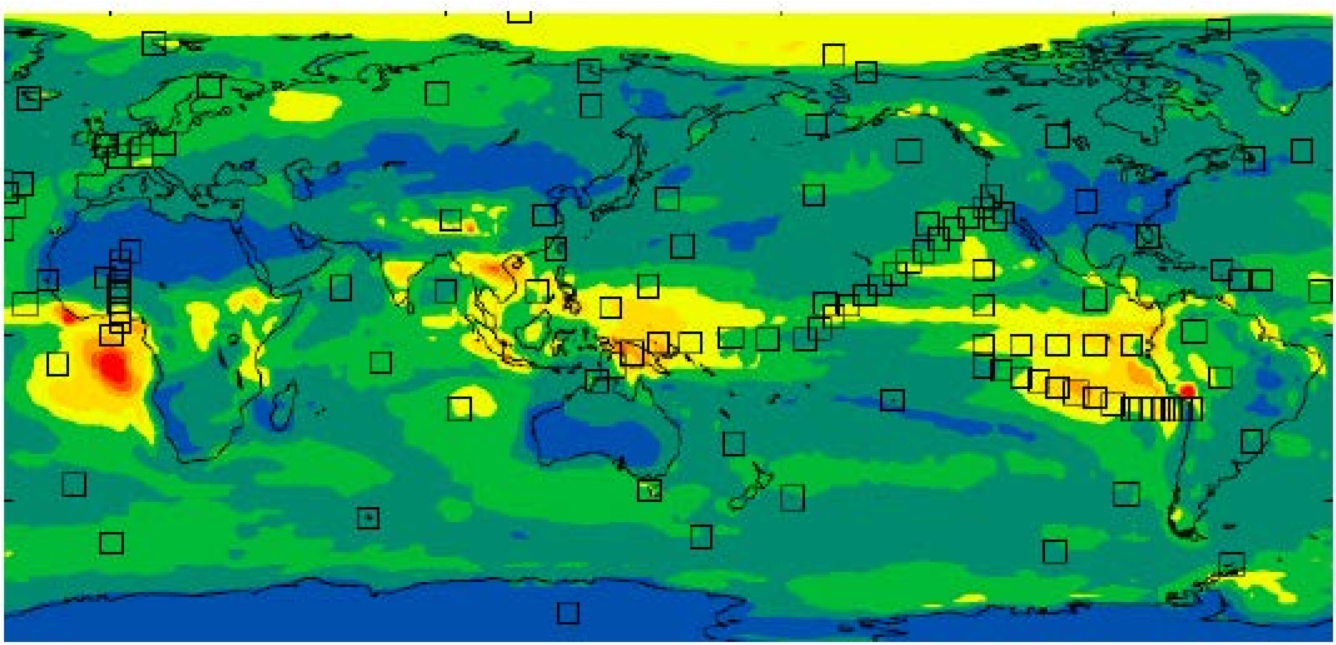
High frequency 'cfSites' outputs at site locations

- Timestep level (e.g. 30 minute) frequency outputs at 120 locations

- Clouds, radiation, precipitation and environmental variables

- Temperature/humidity tendencies for advection, convection, PBL, …

-> diurnal cycle, analysis of cloud feedback processes, etc



CMIP5 / CFMIP2 : What went well ?

- A fair number of groups submitted CFMIP experiments, including simulator and process outputs.

	Monthly CFMIP	Monthly ISCCP/ CALIPSO	Daily CFMIP	Daily ISCCP/ CALIPSO	Timestep cfSites Outputs	COSP Orbital CloudSat/ CALIPSO	Gridded Orbital CloudSat/ CALIPSO	3 Hourly COSP Inputs
amip	12	11	11	11	7	4	3	4
amip4K	10	10	10	10	6	4	3	
amip4xCO2	11	12	11	11	4	4	3	
amipFuture	10	10	9	10	4	2	3	
aquaControl	6	7	8	7	4	1		
aqua4xCO2	6	6	7	6	4	1		
aqua4K	6	6	7	6	4	1		
piControl	6	9	10	9				
1pctCO2	4	8	9	8				
abrupt4xCO2	4	8	9	8				

- A large number of studies with COSP
- CFMIP provides computationally inexpensive experiments which have led to new insights into cloud feedback and adjustment mechanisms, and precipitation responses to climate change... and have formed the basis for additional CFMIP experiments (e.g. COOKIE or SPOOKIE).
- Analysis of CFMIP-2 outputs are ongoing and we are still receiving data from some modelling groups, so the full value of the CFMIP experiments is yet to be realised.

CMIP5 / CFMIP2 : Science questions

- **How well do climate models simulate clouds ?**
  (in the vertical, from the tropics to the poles)

- **What is the role of fast adjustments to CO2 ?**
  (diagnostic forcing/feedbacks, uncertainties in climate sensitivity)

- **What are the physical processes underlying cloud feedbacks ?**
  (and the inter-model spread)

- **How well do we understand precipitation changes ?**
  (including regional patterns)

CMIP5 / CFMIP2 : Publications

Already a large number of CFMIP-2/CMIP5 studies and related publications;

see http://www.cfmip.net -> "CFMIP Meetings" for presentations

http://www.cfmip.net -> "CFMIP publications" for a full list, including :

- **Many COSP papers on CMIP5 models**: Klein et al 2013; Tsushima et al 2013; Bodas et al 2013; Konsta et al 2013; Lacagnina et al (submitted); Zelinka et al 2013; Cesana and Chepfer 2013; Stevens et al 2013; Xie et al 2013; Franklin et al 2013; John et al 2013; von Salzen et al 2013;Wang and Su 2013; Nam et al 2013

- **Quantifying forcings and feedbacks in idealised CFMIP5/CFMIP-2 experiments:** Zelinka et al 2013; Andrews et al 2012; Vial et al 2013; Geoffroy et al, 2012 Parts 1&2; Shiogama et al 2013; Yoshimori et al 2013; Webb et al (in preparation); Tsushima et al (in preparation)

- **Demonstration that aquaplanets reproduce a large inter-model spread :** Stevens and Bony 2013; Medeiros et al (in preparation)

- **Understanding adjustment/feedback mechanisms in GCMs/SCMs:** Brient and Bony 2012; Kamae and Watanabe, 2012a,b; Brient and Bony 2013; Webb and Lock 2013; Ogura at al (in press); Zhang et al (submitted); Demoto et al (2013); Sherwood et al (submitted).

- **Understanding cloud feedback/adjustment mechanisms in LES/MLMs:** Rieck et al 2012; Zhang et al 2012; Blossey at al 2013; Bretherton et al 2013; De Roode et al (submitted); Dal Gesso et al (submitted); Bretherton et al (submitted)

Towards CFMIP3/CMIP6 :

Proposals for Filling Science Gaps (1)

To strengthen, develop and generalize the findings of CFMIP2/CMIP5 (role of cloud processes in model biases and response to forcings) :

- **Favor the continuity with CFMIP2/CMIP5** to encourage the implementation of CMIP experiments and COSP/process outputs in more models than in CMIP5.

To better assess and understand cloud feedbacks and adjustments in *coupled* models :

- Propose experiments aiming at **diagnosing the time-varying radiative forcing** in historical experiments

- Propose **+/- 3% abrupt solar forcing AOGCM experiments** to examine coupled feedbacks without CO_2 adjustments

- Request **process outputs** (3D tendencies, cfSites) in sections of piControl & abrupt4xCO2

Towards CFMIP3/CMIP6 :

Proposals for Filling Science Gaps (2)

To understand the impact of clouds and cloud changes on regional temperatures, circulation and precipitation :

- Propose sensitivity experiments with **clouds made transparent to radiation** (Clouds On/Off Klimate Experiments, **COOKIE**)

- Promote idealized experiments in **simplified frameworks** (e.g. aquaplanets, global RCE)

To test physical hypotheses (and observational constraints) about the link between processes, model formulation (e.g. parameterizations) and cloud responses :

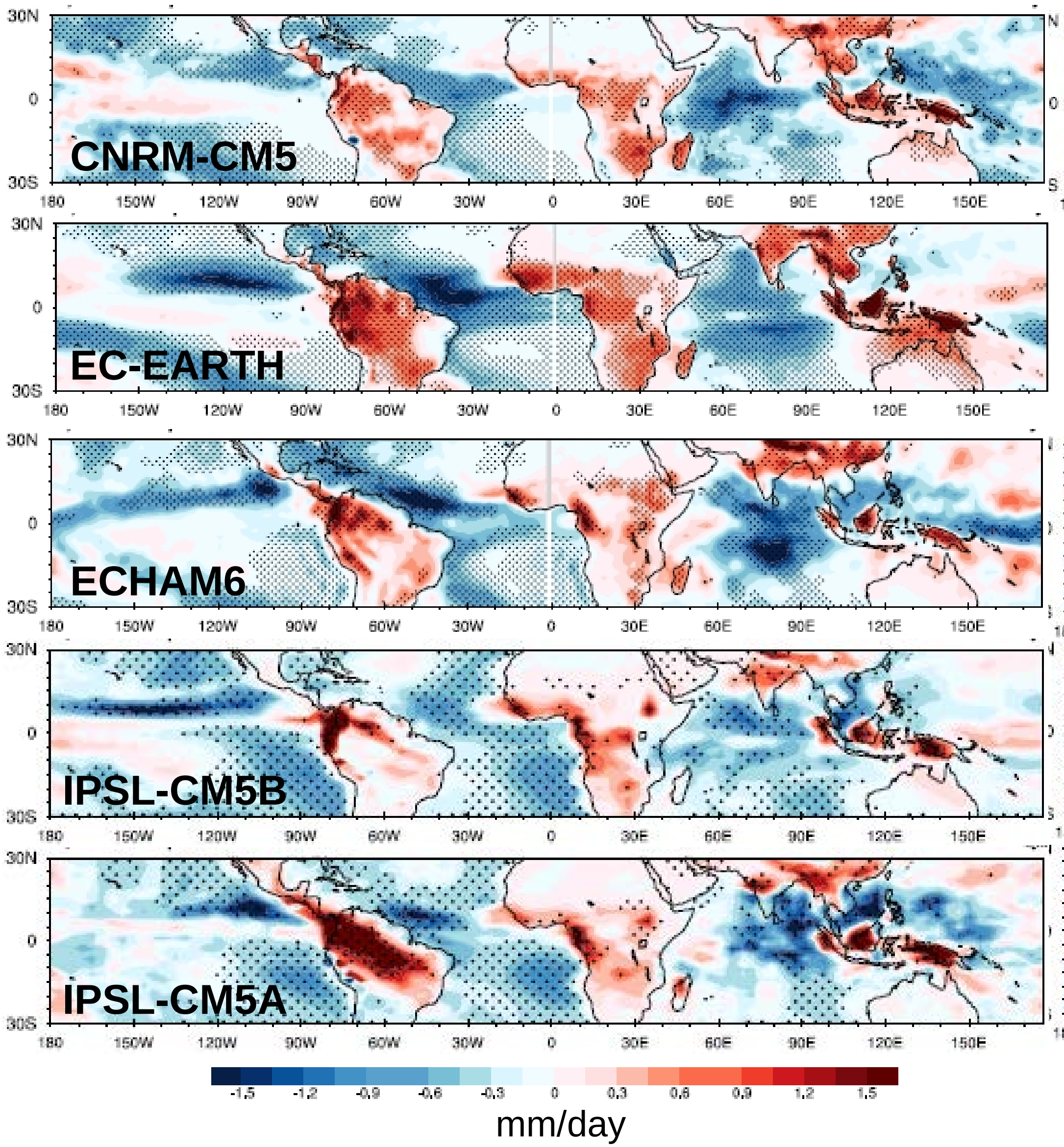
- Propose a hierarchy of **short-term T-AMIP experiments** (4xCO_2, +4K) to examine timescales and identify causal links between cloud-controlling factors and cloud responses.

- Encourage **sensitivity tests to parameterizations** based on CFMIP experiments (e.g. Selected Processes On/Off Klimate Intercomparison Experiment, **SPOOKIE**)

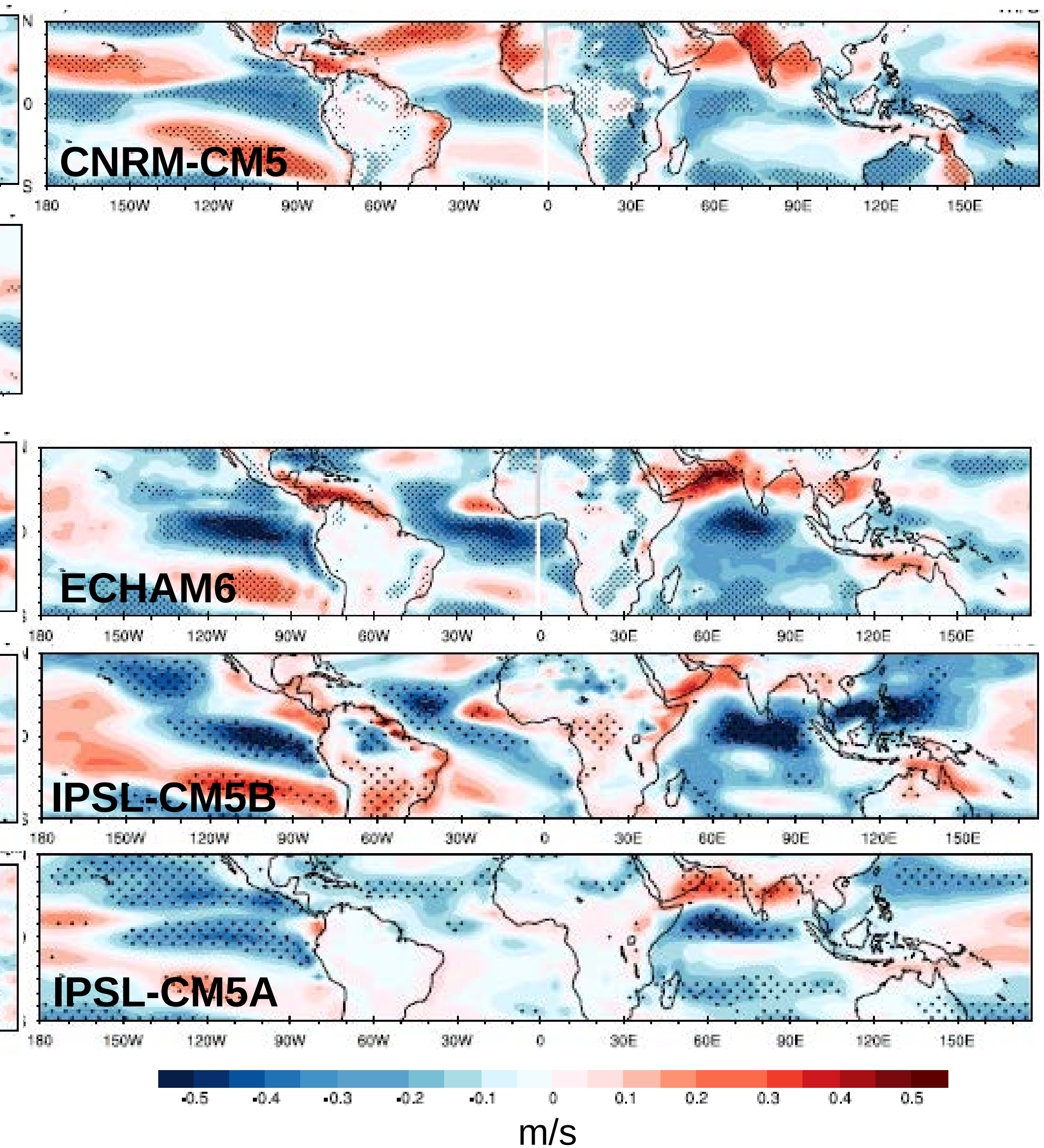
- Propose **inexpensive idealized experiments** (e.g. aquaplanets, global RCE) to fill the gap between CMIP models and Cloud-Resolving models (global CRM, SP-GCMs)

Preliminary COOKIE results: Impact of PBL cloud-radiative effects on tropical circulation and precipitation

Precipitation (offpblamip-amip)



Surface wind (offpblamip-amip)

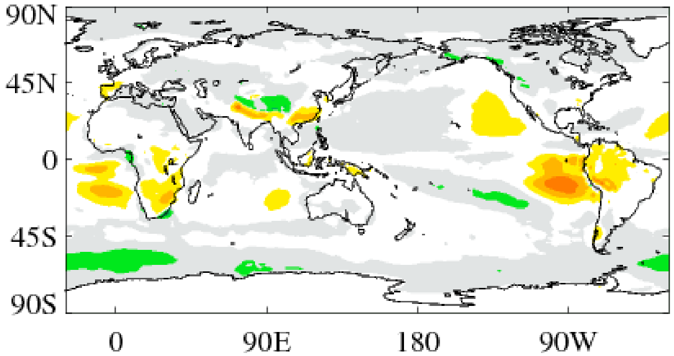


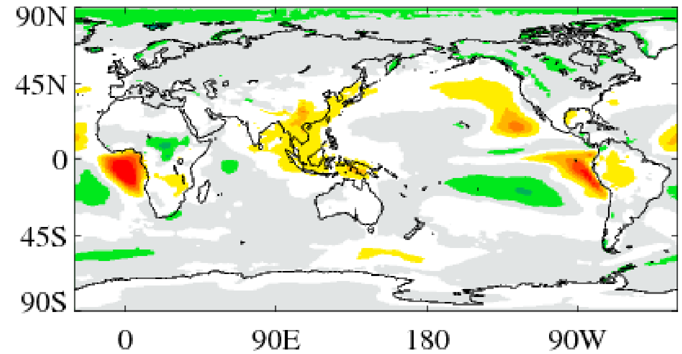
Solange Fermepin and the EUCLIPSE/COOKIE participants

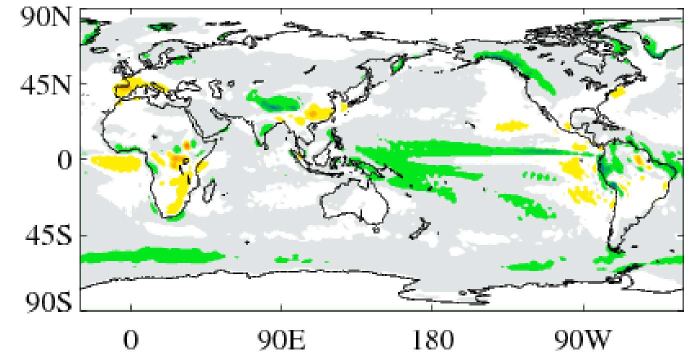
Preliminary SPOOKIE results: Impact of switching off convective parametrization on net cloud feedback in amip/amip4K

HadGEM2-A Standard 0.25 Wm^{-2}K^{-1} **MRI-CGCM3 Standard 0.10 Wm^{-2}K^{-1}** **MIROC5 Standard -0.22 Wm^{-2}K^{-1}**

Range = 0.47 Wm^{-2}K^{-1}

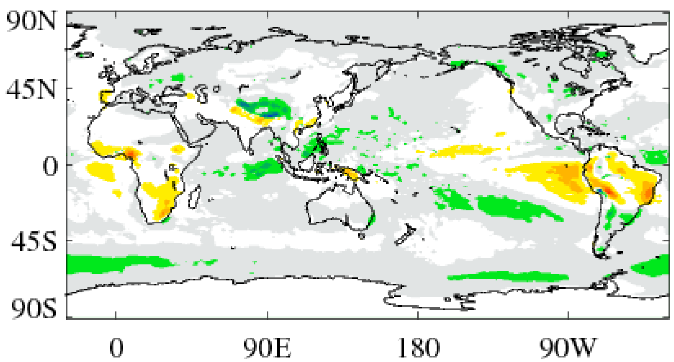


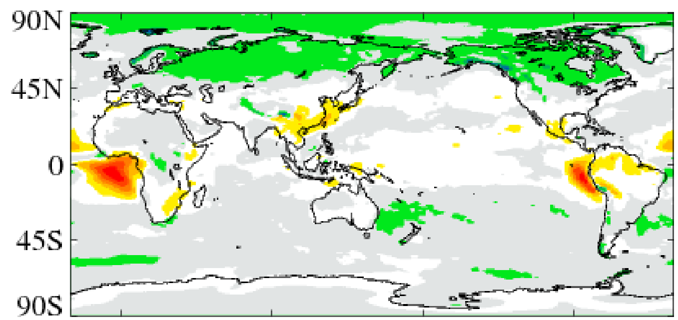


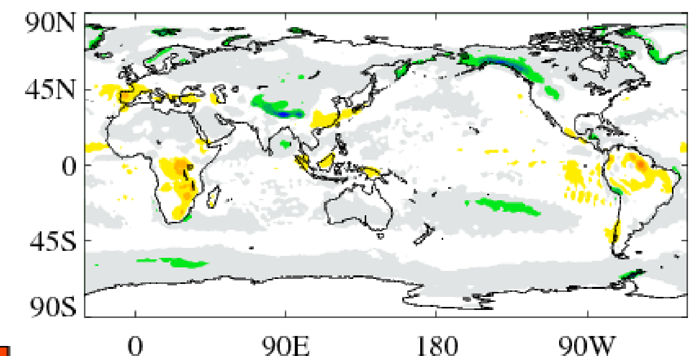


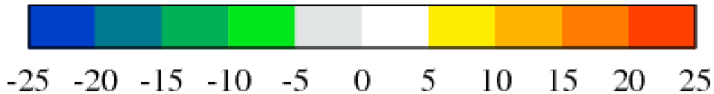
HadGEM2-A ConvOff -0.05 Wm^{-2}K^{-1} **MRI-CGCM3 ConvOff -0.08 Wm^{-2}K^{-1}** **MIROC5 ConvOff 0.18 Wm^{-2}K^{-1}**

Range = 0.26 Wm^{-2}K^{-1}





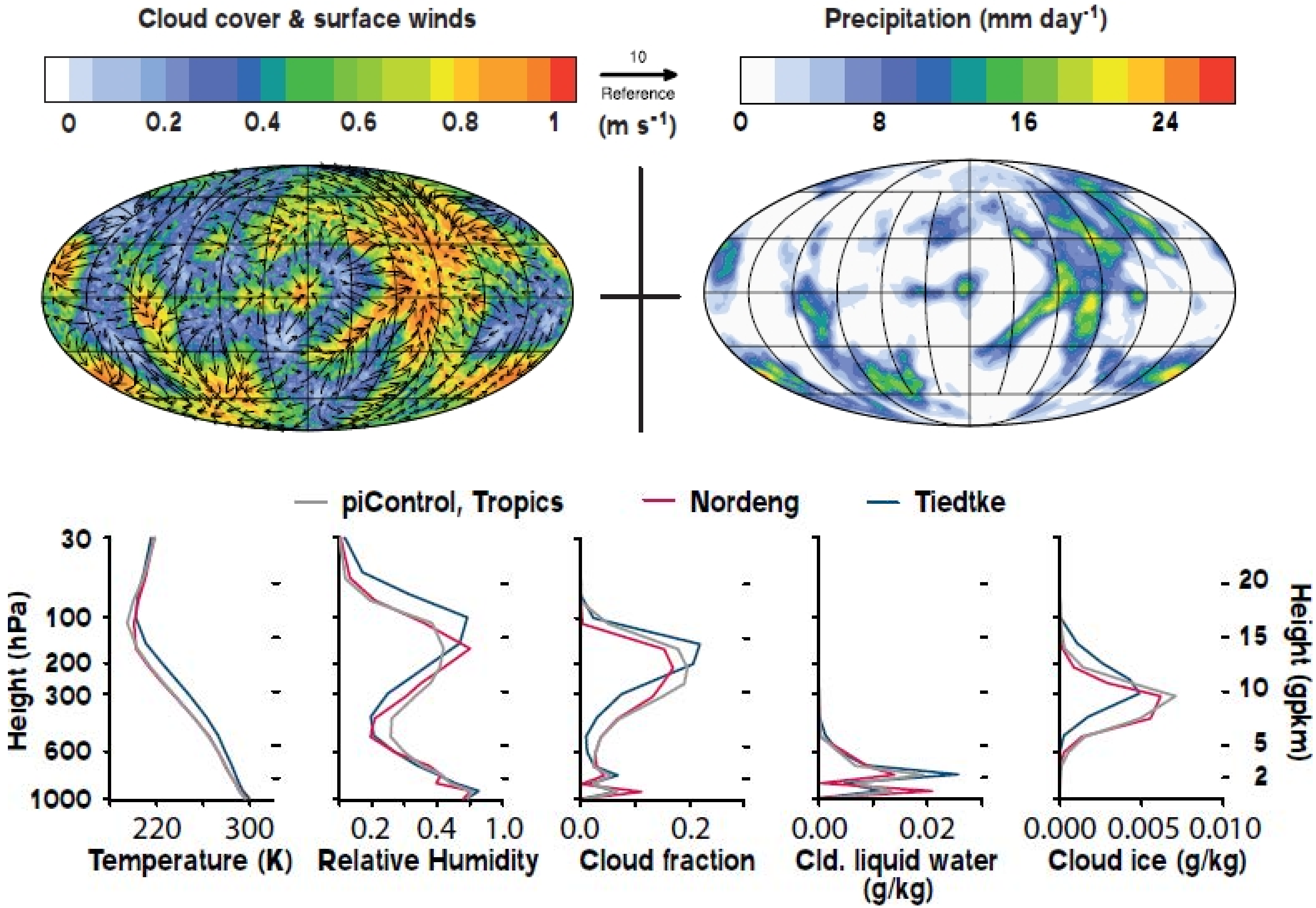




Mark Webb, Adrian Lock, Masahiro Watanabe, Hideaki Kawai, Tsuyoshi Koshiro, Thorsten Mauritsen

Towards CGILS RCE :

Global Radiative-Convective Equilibrium simulations



Popke, Stevens and Voigt, JAMES, 2013

Towards CFMIP3/CMIP6 :

Main CFMIP Recommendations

- **Favor the continuity with CFMIP2/CMIP5 :** CMIP6 should be an opportunity for modeling groups to provide the experiments and outputs they did not provide at the time of CMIP5.
- **Communicate better rationale for experiments and outputs** to tackle science gaps, in connection with WCRP Grand Challenges (e.g. COSP = evaluation + feedback diagnostics)
- **Raise priority of inexpensive idealized experiments** (e.g. amip4xCO2, amip4K and aquaplanets) which isolate the influence of basic physical processes on climate change uncertainties.
- **Make a limited set of key simulator and process diagnostics ‘core/high priority’** (e.g. temperature and humidity tendency terms, ISCCP and CALIPSO simulator outputs.

Towards CFMIP3/CMIP6 :

Proposed Experiment Hierarchy

Pre-industrial	Historical/ present	Forcing / Adjustments	Idealised Climate feedbacks	
	AMIP+ preindustrial forcings		Coupled Abrupt $4xCO_2$	Coupled1 % per year CO_2
Coupled pre-industrial control	Coupled historical		Coupled +/-3% Abrupt Solar	
CORE CMIP experiments	AMIP	AMIP + $4xCO_2$	AMIP +4K uniform	COSP only
Potential CFMIP Experiments Under Discussion	Aquaplanet Control	Aquaplanet $4xCO_2$	Aquaplanet Uniform+4K	COSP and CFMIP Process Outputs
	RCE Control	RCE $4xCO_2$	RCE Uniform +4K	
	T-AMIP Control	T-AMIP $4xCO_2$	T-AMIP Uniform +4K	
CGILS-2 Experiments SCM & LES	GPCI/Lagrangian AMIP SST	GPCI/Lagrangian AMIP SST+$4xCO_2$	GPCI/Lagrangian AMIP SST+4K	

A concern about CFMIP diagnostics in CMIP

- **Scientific benefits from CFMIP** are **as much due to COSP and process diagnostics as** additional **experiments** (e.g. amip4K, amip4xCO2, aquaplanets)
- These diagnostics **need to be in core CMIP (or DEC) experiments** (e.g. amip, piControl, abrupt4xCO2)
- If CMIP core experiments are frozen in advance of other MIPs, it is crucial that the CFMIP process diagnostics are included in the CMIP core experiments
- This will also be **an issue for other MIPs** which depend on diagnostics in the core CMIP experiments

- **-> CFMIP will do its best to :**
  - **define the CFMIP design and output requirements early**
  - **communicate the rationale of CFMIP experiments and diagnostics to modeling groups**

Close Connection between CFMIP and the WCRP Grand Challenge on Clouds, Circulation and Climate Sensitivity

CFMIP closely associated with each initiative of this Grand Challenge :

- Climate and Hydrological Sensitivtiy
- Coupling Clouds to Circulation
- Understanding Changing Patterns
- Leveraging Observational Records
- Developing Mode Reliable Models

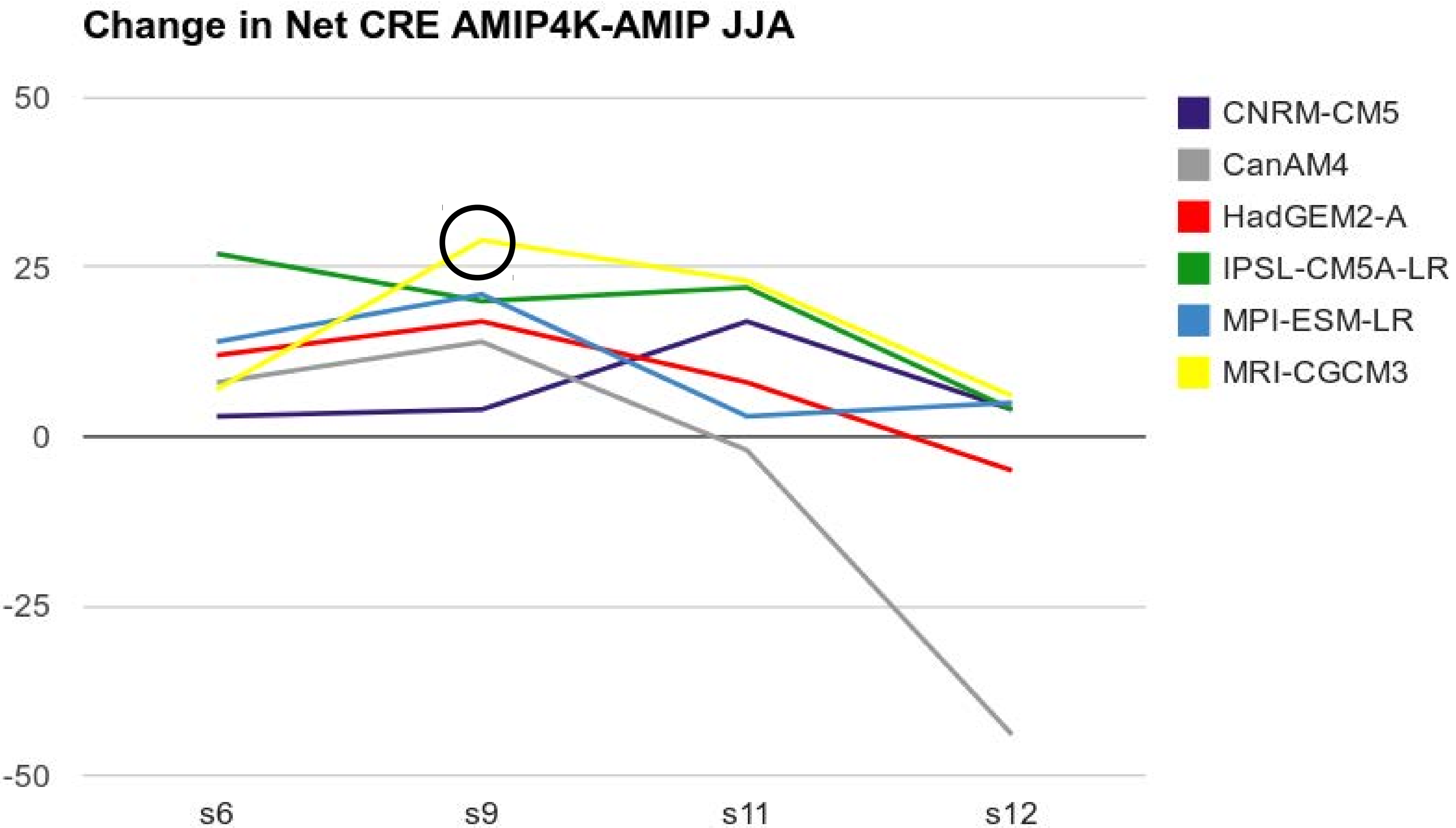
As part of this Grand Challenge, CFMIP will :

- widen its focus and interests (e.g. coupling clouds, convection – circulation)

- develop stronger connections to PMIP (paleo), GASS (processes), SPARC (dynamics), WGNE (model biases) and observations.

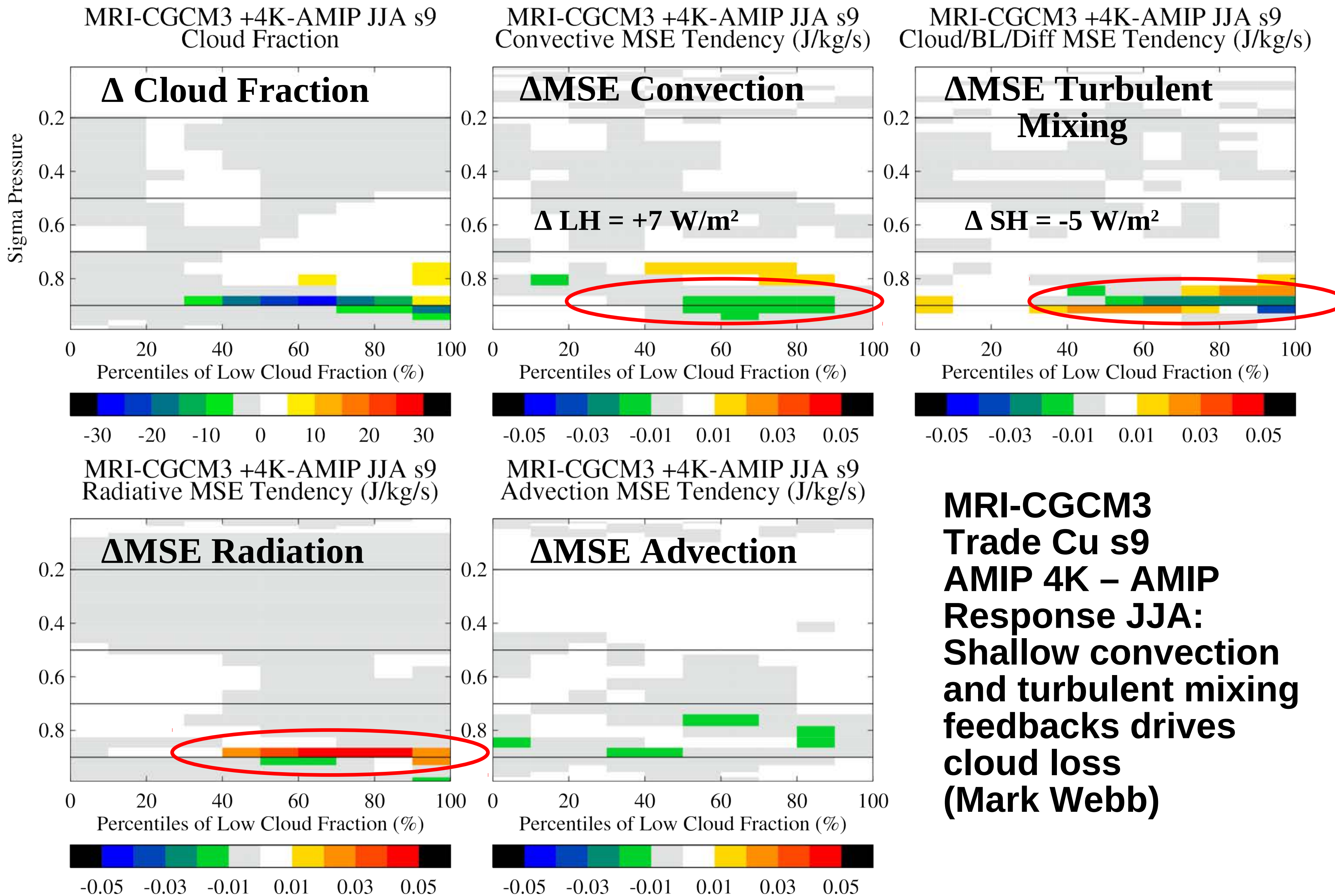
Additional slides

Amip4K Net Cloud Feedback along GPCI from models with cfSites data (Mark Webb)



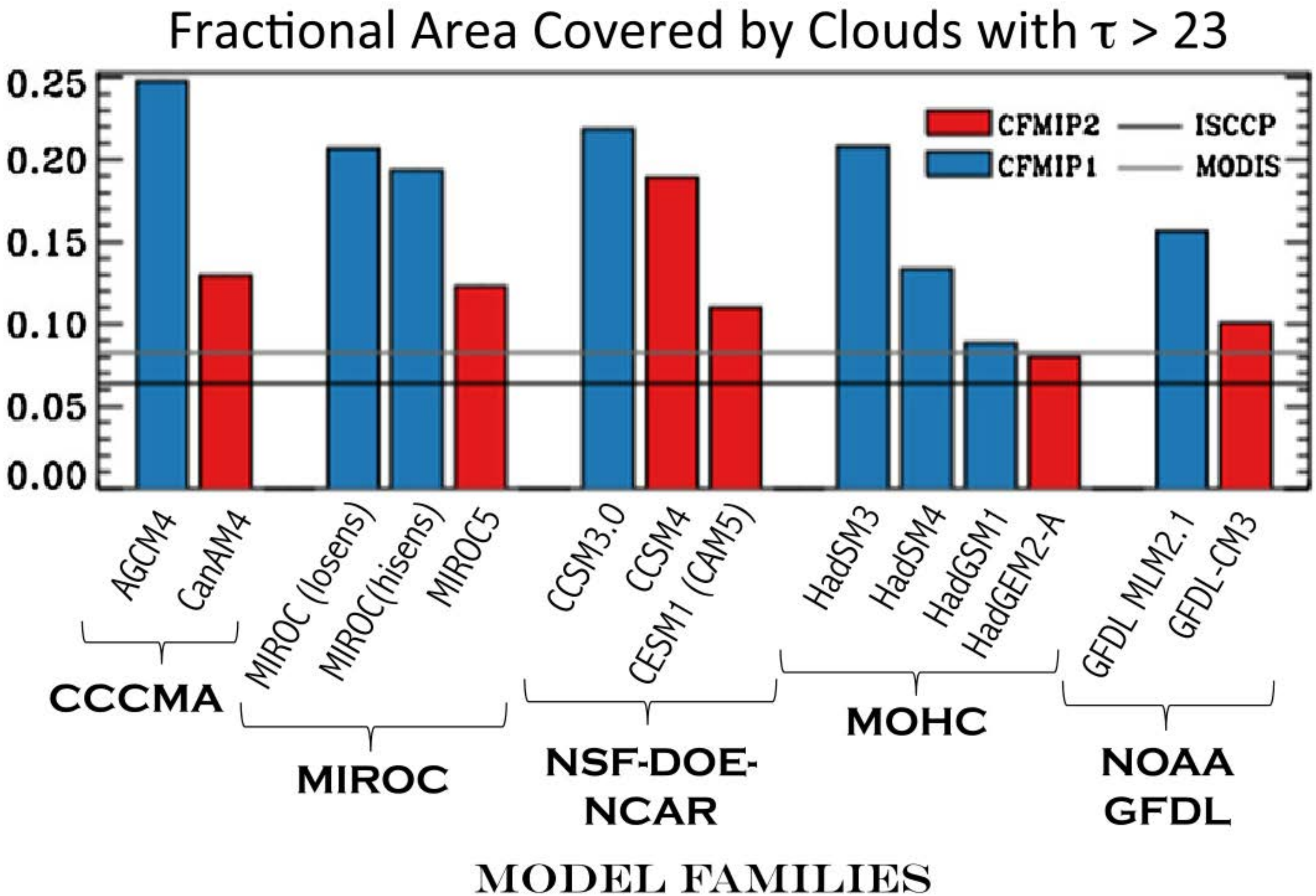
Trade Cumulus   Transition Region   Coastal Stratocumulus

cfSites: Moist Static Energy Budget Approach following Brient and Bony 2013, Webb and Lock 2013



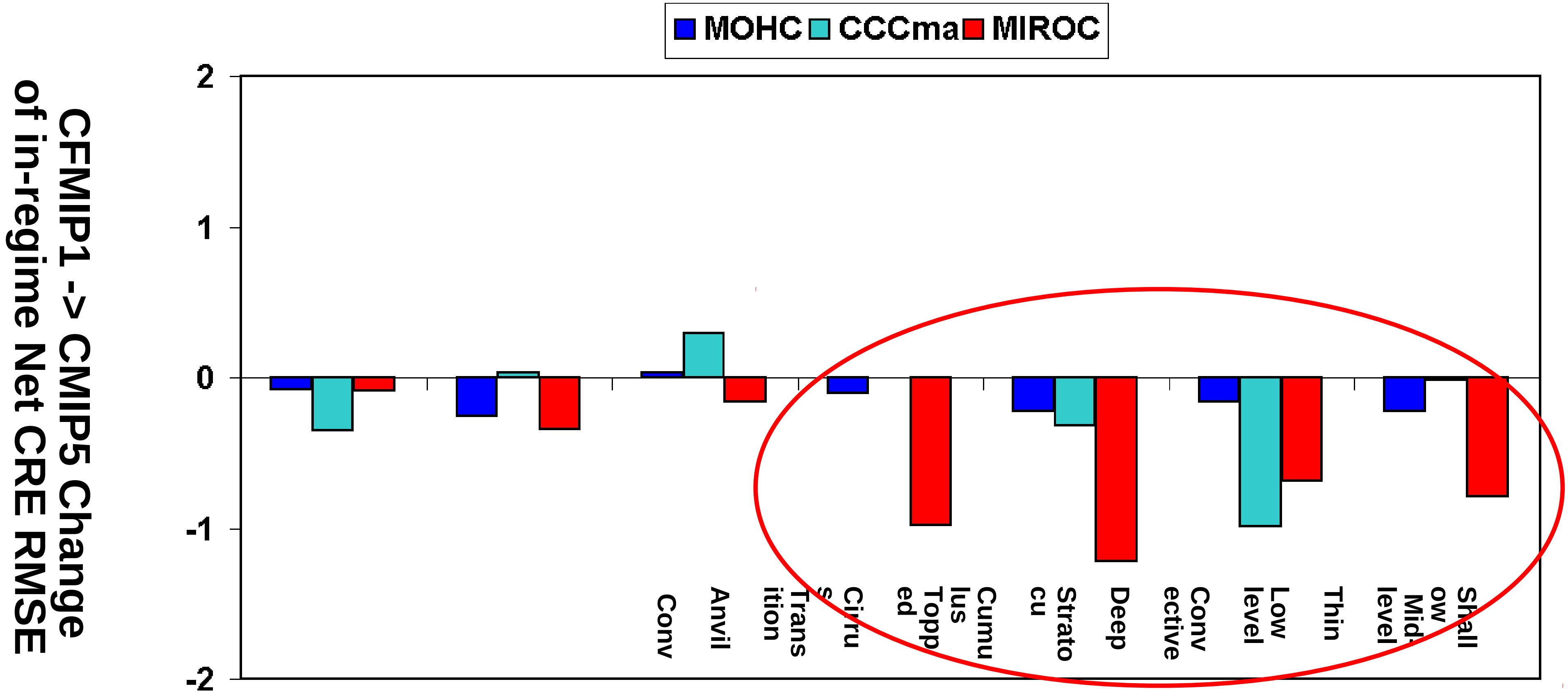
MRI-CGCM3
Trade Cu s9
AMIP 4K – AMIP
Response JJA:
Shallow convection and turbulent mixing feedbacks drives cloud loss
(Mark Webb)

Clouds have improved in CMIP5 models compared to those in CFMIP-1 – particularly optically thick clouds:



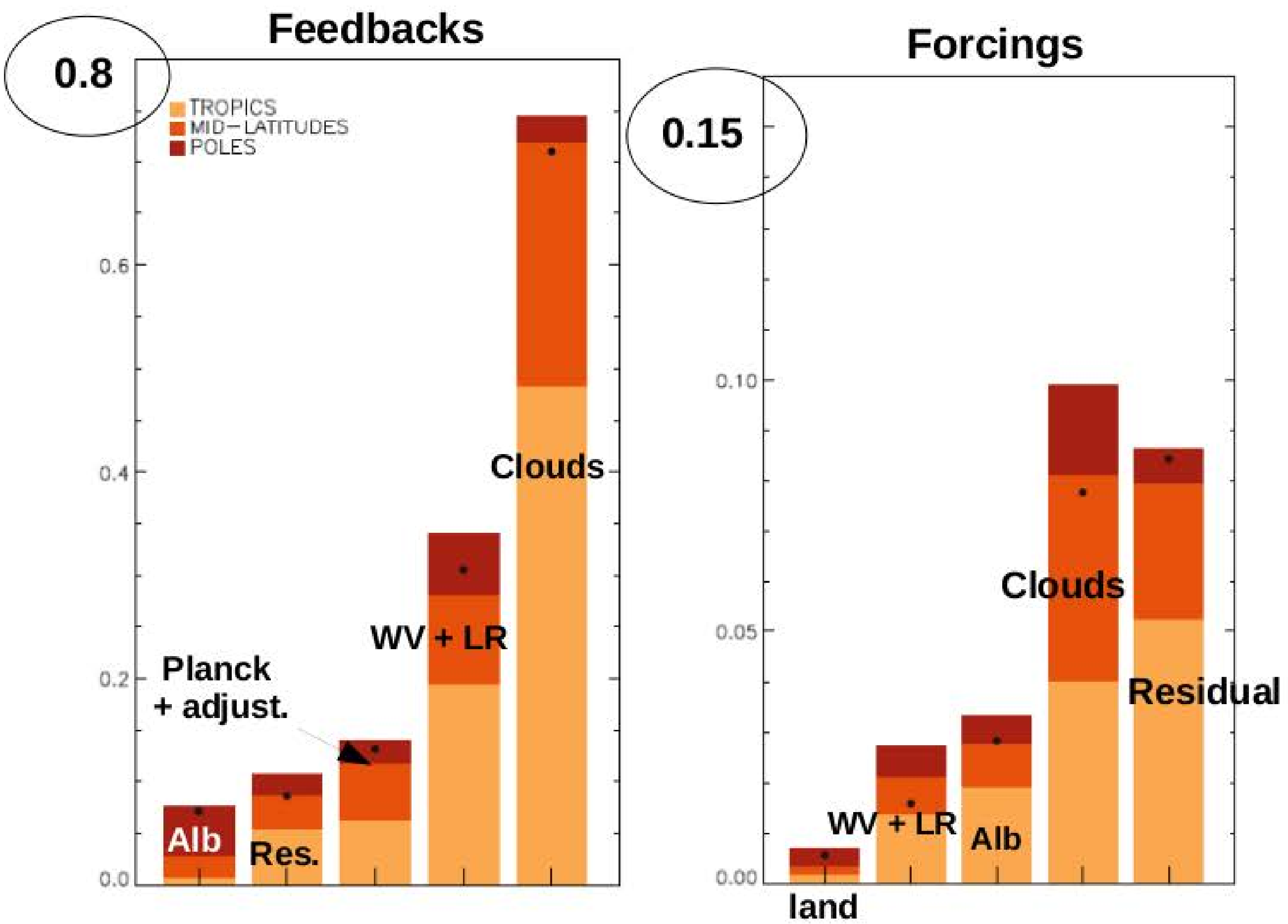
Klein et al 2013: Are climate model simulations of clouds improving? An evaluation using the ISCCP simulator. (JGR)

Improvements are seen in mainly in the radiative properties of optically thicker low and high topped cloud regimes rather than frequency of occurrence.



Change between CFMIP-1 and CMIP5 of in-regime Net Cloud Radiative Effect (Net CRE) RMSE within daily ISCCP simulator cloud regimes in the tropics

Tsushima et al 2013: Quantitative evaluation of the seasonal variations in climate model cloud regimes. (Climate Dynamics)



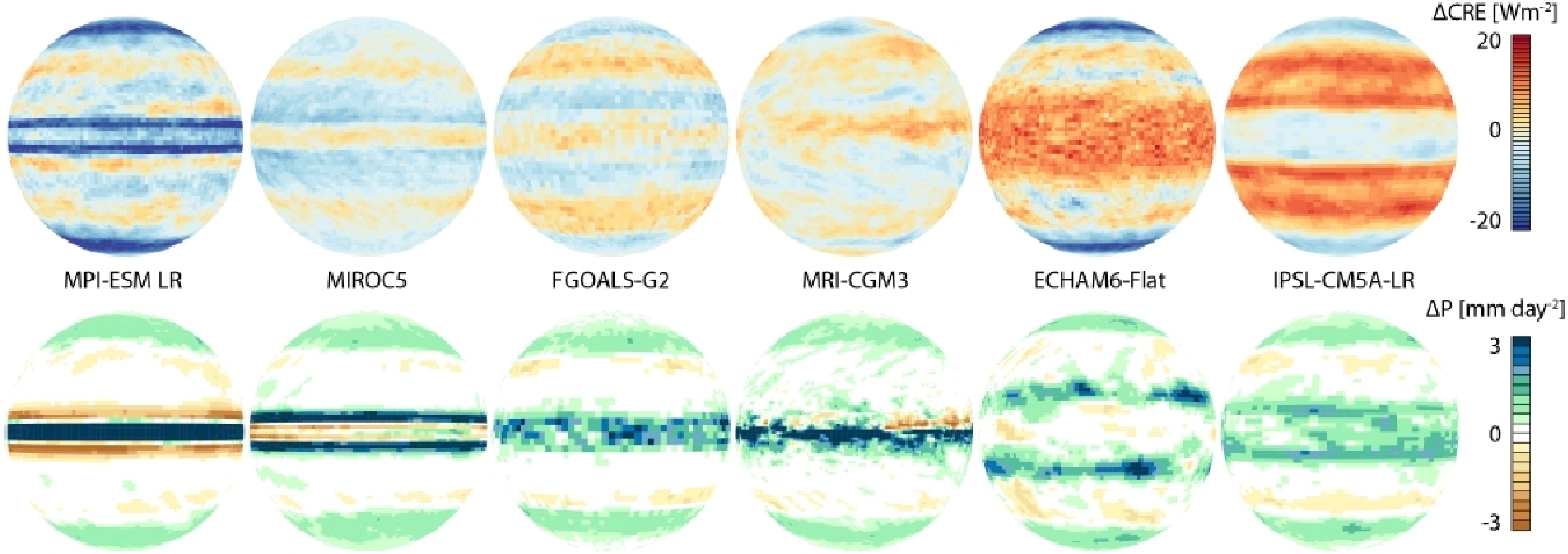
- Cloud feedback represents 70% of the total spread; the spread is the largest in tropics
- WV+LR feedback is the second most important source of spread (30%); largest spread in tropics
- The residual is the largest source of spread among all forcing terms (< 10%, less than for any feedback)

The inter-model spread of climate sensitivity arises primarily from the spread of feedbacks rather than adjustments, and particularly from the tropical cloud feedback.

Vial, Dufresne and Bony 2013: On the interpretation of inter-model spread in CMIP5 climate sensitivity estimates. (Climate Dynamics)

A (Really) Grand Challenge!

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

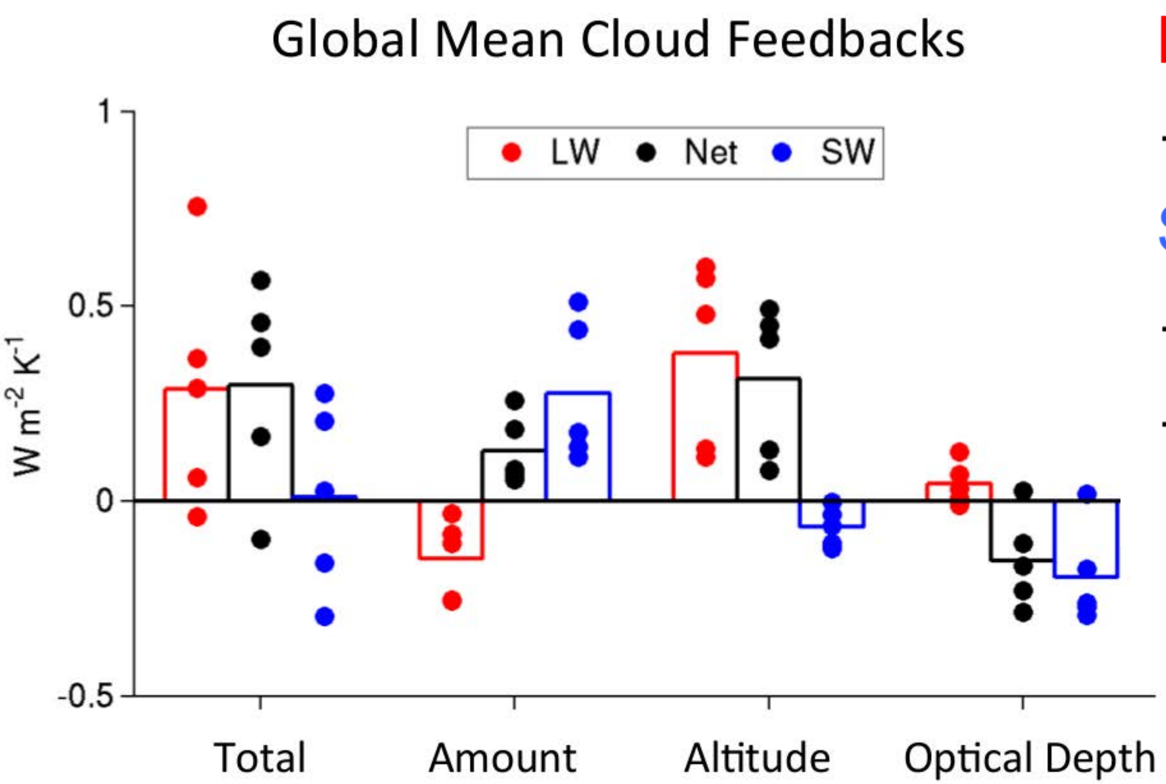


- Uncertainties related to basic physical processes

- Critical limitation for mitigation and adaptation studies

Stevens and Bony, 2013 (Science)

Use of ISCCP simulator to break down feedbacks into contributions from different cloud types:



Longwave feedbacks (+)

– cloud altitude ↑

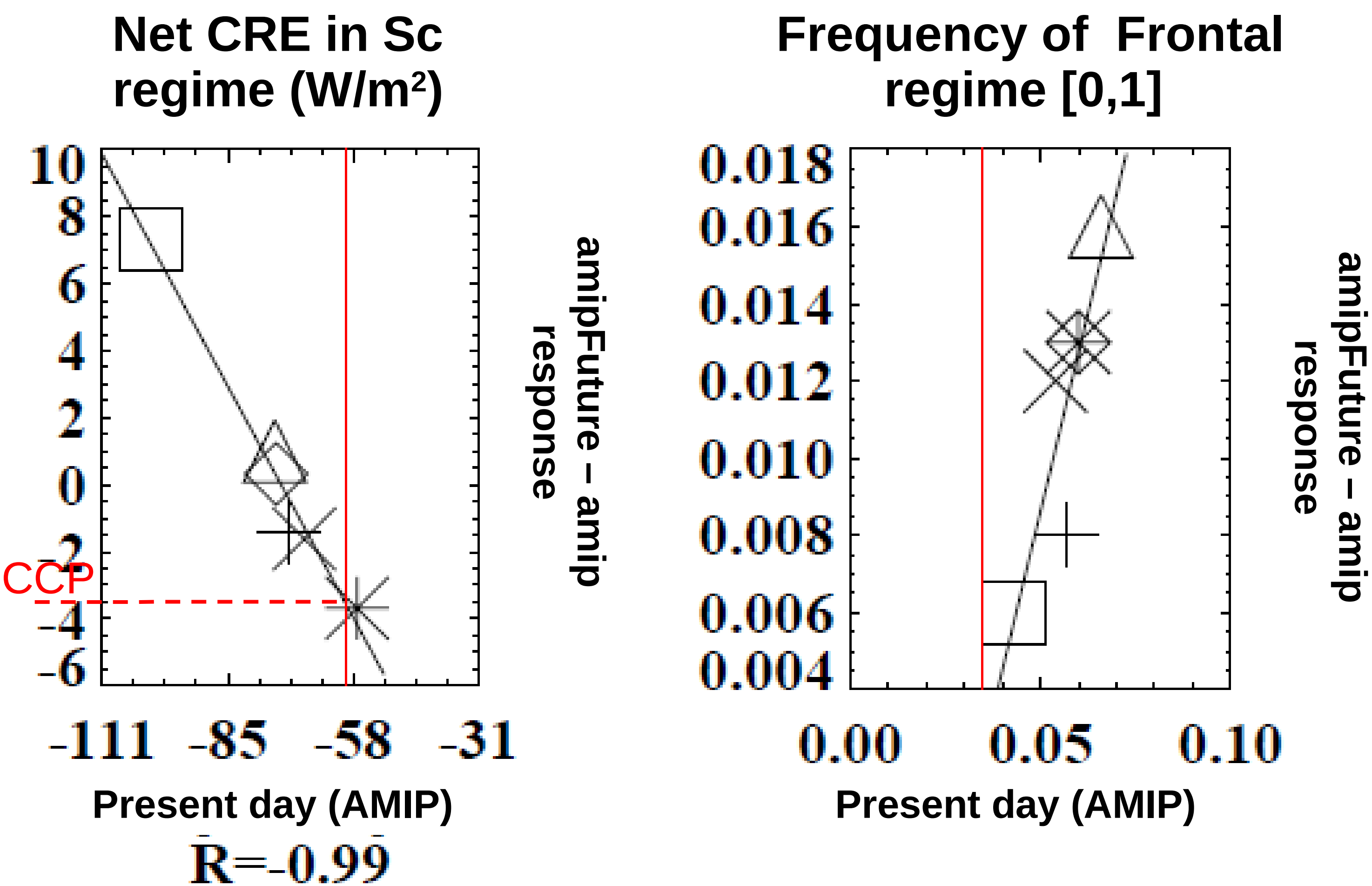
Shortwave feedbacks variable

– cloud amount ↓ (+)

– optical depth (τ) ↑ (-)

Zelinka et al 2013: Contributions of Different Cloud Types to Feedbacks and Rapid Adjustments in CMIP5. (J. Climate)

Observational constraints on responses of stratocumulus and frontal cloud regimes in amipFuture experiments.



Value consistent with ISCCP observations

Yoko Tsushima, Met Office Hadley Centre