Future CFMIP Experiments in CMIP6 and elsewhere

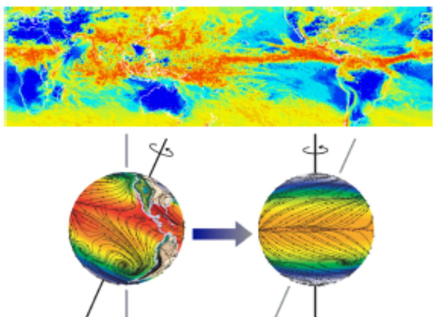
CFMIP Committee: Mark Webb, Chris Bretherton, Sandrine Bony, Jen Kay, Steve Klein, Pier Siebesma, Bjorn Stevens, George Tselioudis, Masahiro Watanabe
Additional contributions: Timothy Andrews, Robin Chadwick, Hervé Douville, Peter Good, Alejandro Bodas-Salcedo and the COSP PMC

CFMIP Meeting, Monterey, June 2015

Cloud Feedback Model Inter-comparison Project CFMIP3/CMIP6
http://www.cfmip.net

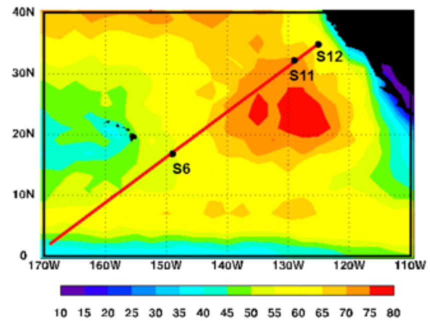
Objective 1: Inform improved assessments of climate change cloud feedbacks by:
a) Improving our understanding of cloud-climate feedback mechanisms.
b) Improving evaluation of clouds and cloud feedbacks in climate models.

CFMIP3/CMIP6 Hierarchy
T/q budgets, cfSites



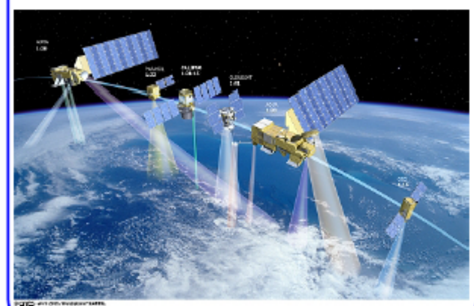
CMIP6/CFMIP3

CFMIP Intercomparison
of SCM/LES



CGILS

Exploitation of Sat Obs
via Simulators in CMIP

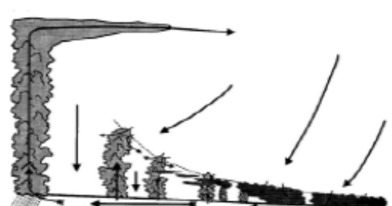


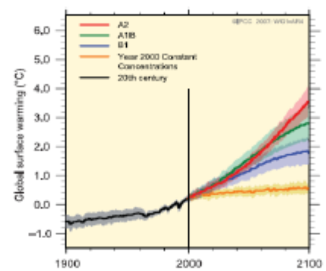
COSP

Understanding

Evaluation

Assessment of cloud-climate feedbacks



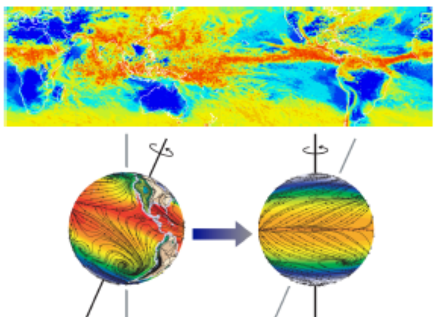


AR6
WCRP Assessment

Cloud Feedback Model Inter-comparison Project CFMIP3/CMIP6
http://www.cfmip.net

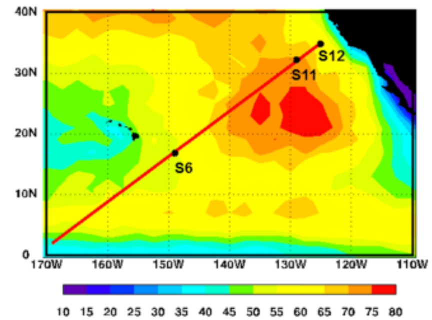
Objective 1: Inform improved assessments of climate change cloud feedbacks by:
a) Improving our understanding of cloud-climate feedback mechanisms.
b) Improving evaluation of clouds and cloud feedbacks in climate models.

CFMIP3/CMIP6 Hierarchy
T/q budgets, cfSites



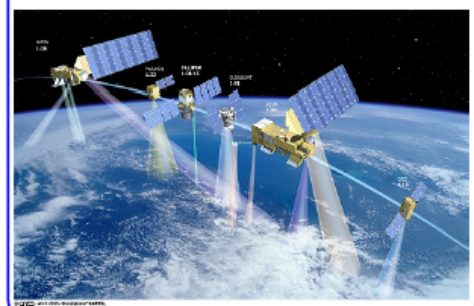
CMIP6/CFMIP3

CFMIP Intercomparison
of SCM/LES



CGILS

Exploitation of Sat Obs
via Simulators in CMIP



COSP

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

Three Categories of GCM Experiments relevant to CFMIP Phase 3

- **CMIP 'DECK' + CMIP6 Historical Experiments - AMIP, preindustrial control, 1% CO2, abrupt 4xCO2, CMIP6 Historical**
  - CFMIP/COSP PMC have proposed COSP + process diagnostics for these.
- **CFMIP experiments in CMIP6**
  - Various experiments proposed – soon to be endorsed by the CMIP panel?
  - Includes COSP + process diagnostics
  - Modelling groups participate via CMIP6 activity on CMIP6 timescales (2016-)
  - Hosted on the Earth System Grid as part of CMIP6 activity
  - Required Tier 1 experiments and optional Tier 2 experiments
- **Other CFMIP3 experiments outside of CMIP6**
  - Coordinated by CFMIP on a case by case basis
  - Hosted on Earth System Grid or via ad hoc data transfer/hosting
  - Can start at any time
  - May form pilot studies for future CMIP experiments

CFMIP CMIP6 Experiments (Tier 1)

A compact set of Tier 1 (entry level requirement) experiments are proposed address the question:

"What are the physical mechanisms underlying the range of cloud feedbacks and cloud adjustments predicted by climate models, and which models have the most credible cloud feedbacks?"

Tier 1 experiments retain CFMIP-2/CMIP5 idealized experimental hierarchy (amip, amip4K, amip4xCO2, amipFuture, aquaControl, aqua4xCO2 and aqua4K 174 yrs AGCM) Lead coordinator: Mark Webb

These experiments will continue to include outputs from the CFMIP Observational Simulator Package (COSP) to support quantitative evaluation of modelled clouds with observations and to relate cloud feedbacks to observed quantities.

Process diagnostics including 'cfSites' high frequency outputs at selected locations and temperature and humidity budget terms from radiation, convection, dynamics, etc. are also retained from CMIP5.

These support continuity with CFMIP-2/CMIP5 and application of the CFMIP approach to a larger number of models.

CFMIP CMIP6 Experiments (Tier 2)

How do responses in the climate system due to changes in solar forcing differ from changes due to CO_2, and is the response sensitive to the sign of the forcing?

- Abrupt +/-4% Solar Forcing (abruptSp4 abruptSm4 300 yrs AOGCM)
- Chris Bretherton, Roger Marchand, Bjorn Stevens

To what extent is regional climate change per CO_2 doubling state-dependent (nonlinear), and why?

- Abrupt 2x and 0.5x CO_2 (abrupt2xCO2,abrupt0-5xCO2 300yrs AOGCM)
- Peter Good (NonLinMIP)

Are cloud feedbacks symmetric when subject to climate cooling rather than warming, and if not, why not?

- AMIP minus uniform 4K SST (amipMinus4K 36yrs AGCM)
- Mark Webb (Link to PMIP)

Are climate feedbacks during the 20th century different to those acting on long term climate change and climate sensitivity?

- AMIP with preindustrial forcing 1870-present (amipPIforcing 145yrs AGCM)
- Timothy Andrews

CFMIP CMIP6 Experiments (Tier 2)

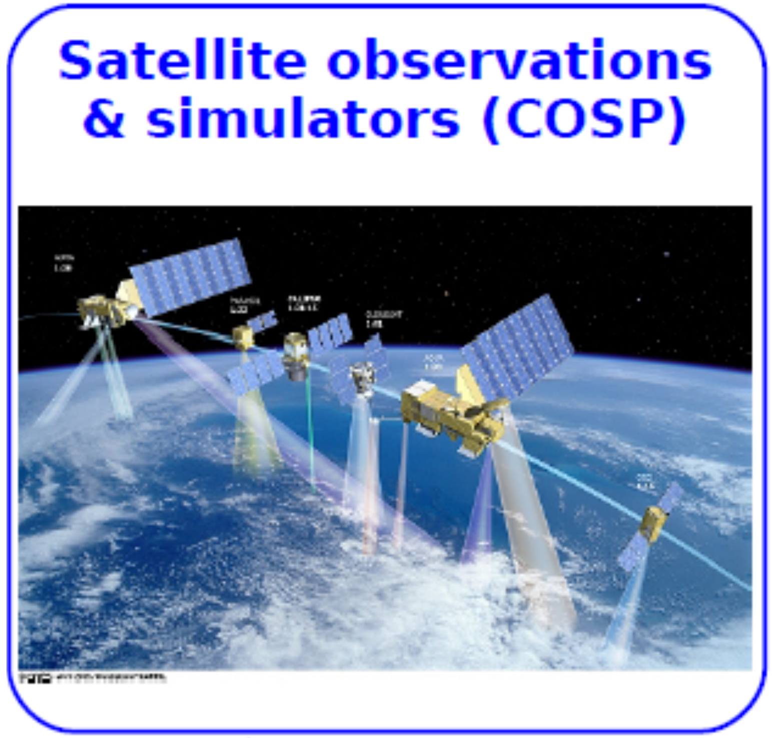
How do regional climate responses (e.g. in precipitation) in coupled models arise from the combination of different aspects of CO_2 forcing and warming?

- Timeslice experiments forced with SSTs from preindustrial and abrupt4xCO2 (sstPi, sstPi4K, sstPi4xCO2, sstPi4xCO2Veg, sstPiFuture, sstPiTot, amipTot 156 yrs AGCM)
- Robin Chadwick, Hervé Douville

How do cloud-radiative effects impact the structure, the strength and the variability of the general atmospheric circulation in the present-day climate?

- Atmosphere-only experiments with clouds transparent to longwave radiation (offlwamip, offlwamip4K, offlwaquaControl, offlwaqua4K 92 yrs AGCM)
- Sandrine Bony

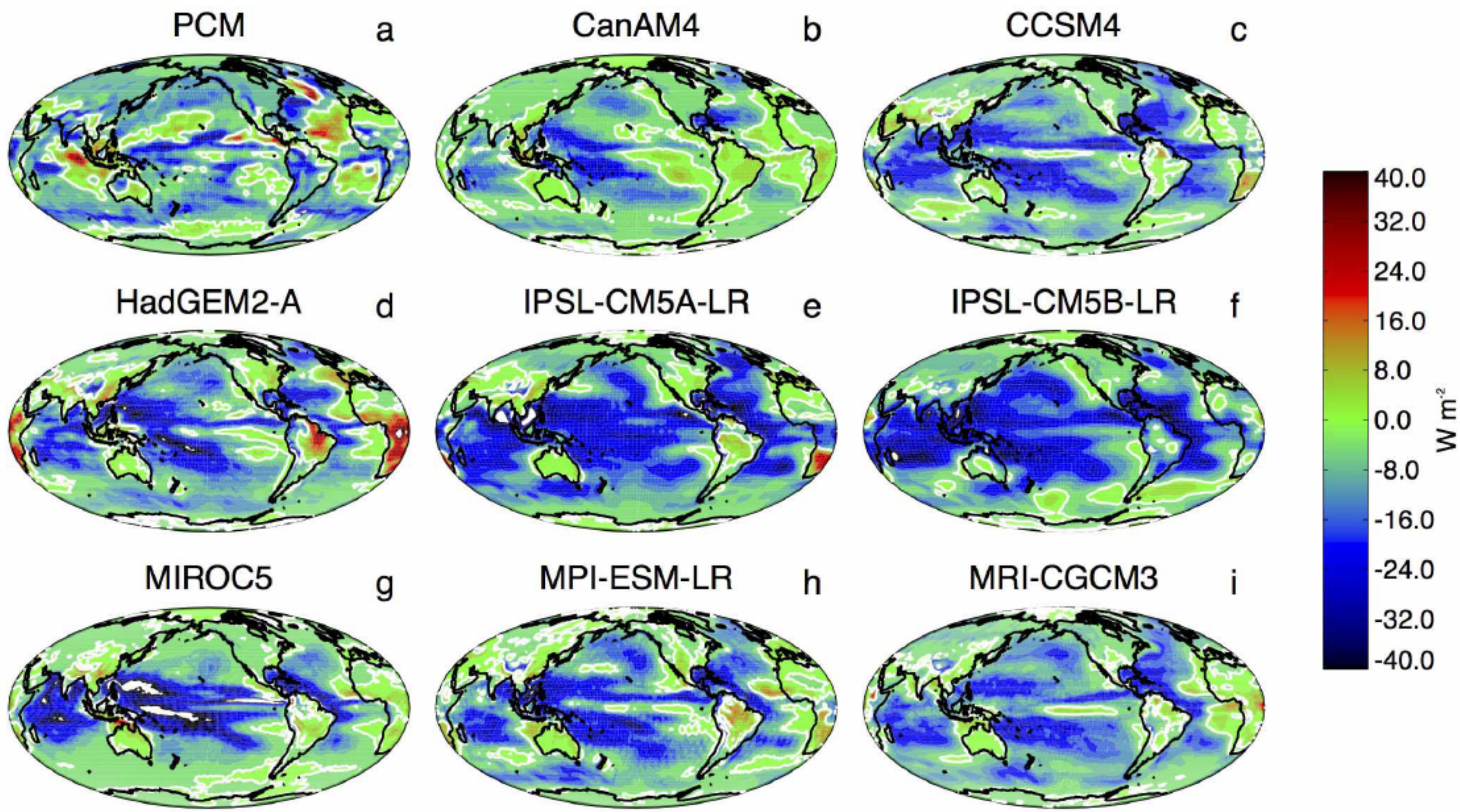
For full details see http://www.cfmip.net -> CFMIP Strategy and Plans



To evaluate present day clouds in the models, COSP simulator outputs for various instruments (ISCCP, CALIPSO, PARASOL, CloudSat, MODIS, MISR) and simulator inputs for one year (2008) are requested in the AMIP DECK experiment

A lighter set of ISCCP and CALIPSO simulator outputs are also requested to interpret and assess the credibility of cloud feedbacks:
PIcontrol abrupt4xCO2 1pctCO2 CMIP6Historical abruptSp4 abruptSm4 amip amip4K amip4xCO2 amipFuture aquaControl aqua4K aqua4xCO2 amipMinus4K offlwamip offlwamip4K offlwaquaControl offlwaqua4K

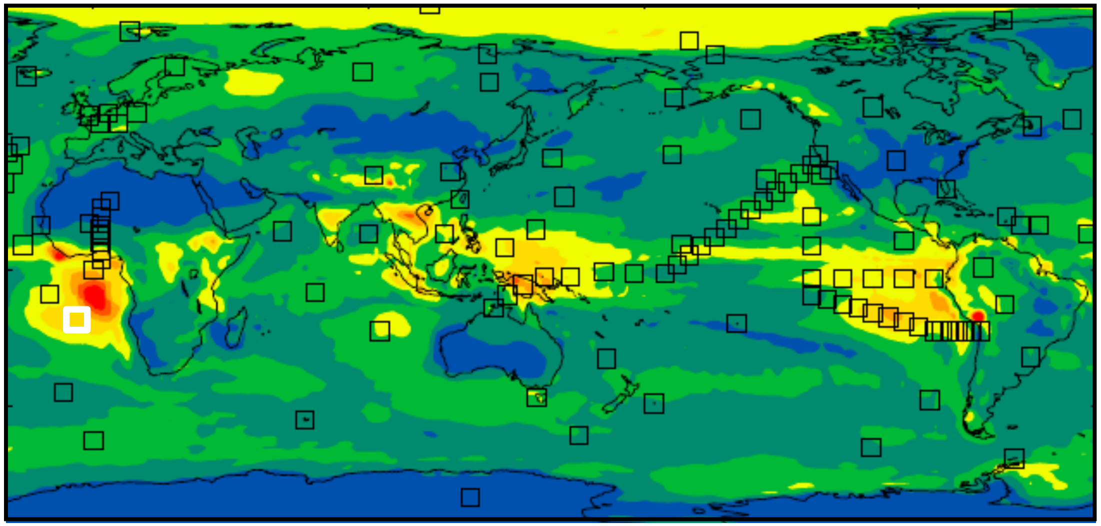
Use of Temperature and Humidity Tendency terms to understand cloud feedback mechanisms (e.g. Sherwood et al 2014)



Extended Data Figure 5 | Response of small-scale, low-level drying to warming. Change in convective moisture source M_{small} below 850 hPa upon a +4 K warming in eight atmosphere models and one CMIP3 coupled model; units are W m^{-2}, with negative values indicating stronger drying near the surface. Zero contours are shown in white (a few off-scale regions also appear white). The models used for calculating M_{large} are the eight shown here plus two for which M_{small} data were unavailable: CNRM-CM5 and FGOALS-g2.

Proposed for Picontrol abrupt4xCO2 amip amip4K amip4xCO2 amipFuture aquaControl aqua4K aqua4xCO2 amipMinus4K abruptSp4 abruptSm4 offlwamip offlwamip4K offlwaquaControl offlwaqua4K

Instantaneous high frequency outputs at ‘cfSites’ locations



At the request of the US CLIVAR Eastern Tropical Ocean Synthesis Working Group we have added St. Helena to the increasing the total number of locations to 121.

cfSites will be requested in amip, amip4K and amip4xCO2

Possible CFMIP3 Experiments

What processes control the dependence of cloud and climate feedbacks on the pattern of SST change?
- amip4K experiments with different patterns + process diagnostics (amip4Kfast, amip4Kslow, amip4K20C - 108 yrs AGCM)
- Timothy Andrews

What processes contribute to inter-model spread in cloud feedback?
Further SPOOKIE experiments:
- Simplify PBL schemes?
- More targeted sensitivity experiments?
- Mark Webb

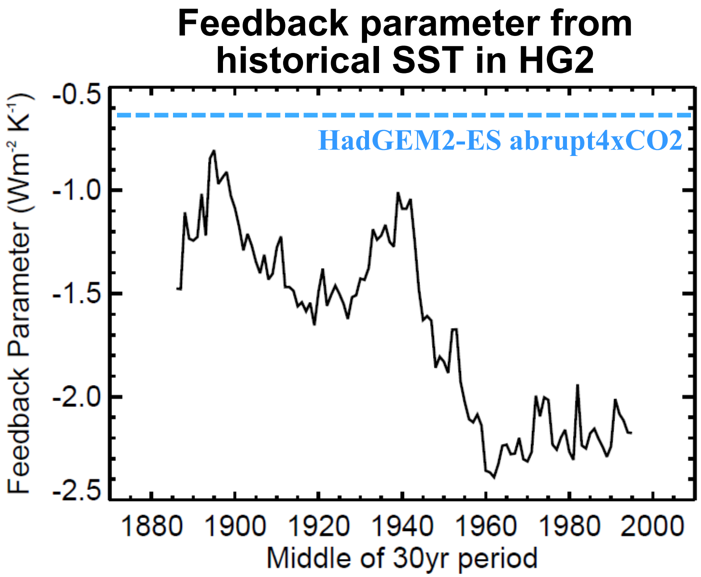
What role does convective aggregation play in cloud feedback?
- Non-rotating rotationally symmetric Radiative Convective Equilibrium experiments with varying resolutions up to cloud resolving
- aquaRCEcontrol, aquaRCE4K (2-10 yrs AGCM)
- Bjorn Stevens

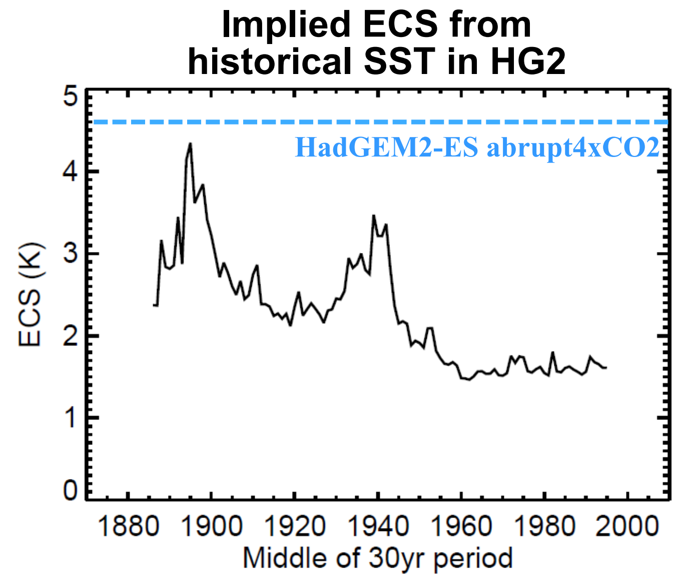
Please contact CFMIP co-chairs if you have a proposal and we can put you in touch with the relevant modelling groups contacts.

Summary and proposed allocation to DECK, CFMIP/CMIP6 and CFMIP3 coordinated experiments

Proposal	DECK	CMIP6/CFMIP3	CFMIP3
Include COSP and temperature and humidity budget tendency terms in selected DECK / CMIP6 Historical runs.	X		
Retain amip,amip4xCO2, amip4K, aquaplanets with COSP+process diagnostics in CMIP6 (Lead Mark Webb)	X	Tier 1	
AMIP minus uniform 4K (Mark Webb)		Tier 2	
AMIP with pre-industrial forcings amipNoForcing (Tim Andrews)		Tier 2	
+/- 4% Abrupt solar forcing AOGCM experiments (Chris Bretherton/Roj Marchand/Bjorn Stevens)		Tier 2	
abrupt 4CO2 and 0.5 CO2 experiments to understand non-linear changes in precipitation (Peter Good)		Tier 2	
Timeslice experiments for understanding regional climate change (Rob Chadwick & Hervé Douville)		Tier 2	
COOKIE sensitivity experiments with clouds made transparent to radiation (PI Sandrine Bony)		Tier 2	
Sensitivity of atmospheric feedbacks to ‘fast’, ‘slow’ and 20C SST response patterns (Tim Andrews)			X
Develop SPOOKIE approach in CFMIP (Mark Webb)			X
Develop an inexpensive global RCE experiment (Bjorn Stevens)			X

Are climate feedbacks during the 20th century different to those acting on long term climate change?





CFMIP & CMIP6 proposal: amipPI*forcing* (1870-2015) (PI Tim Andrews)

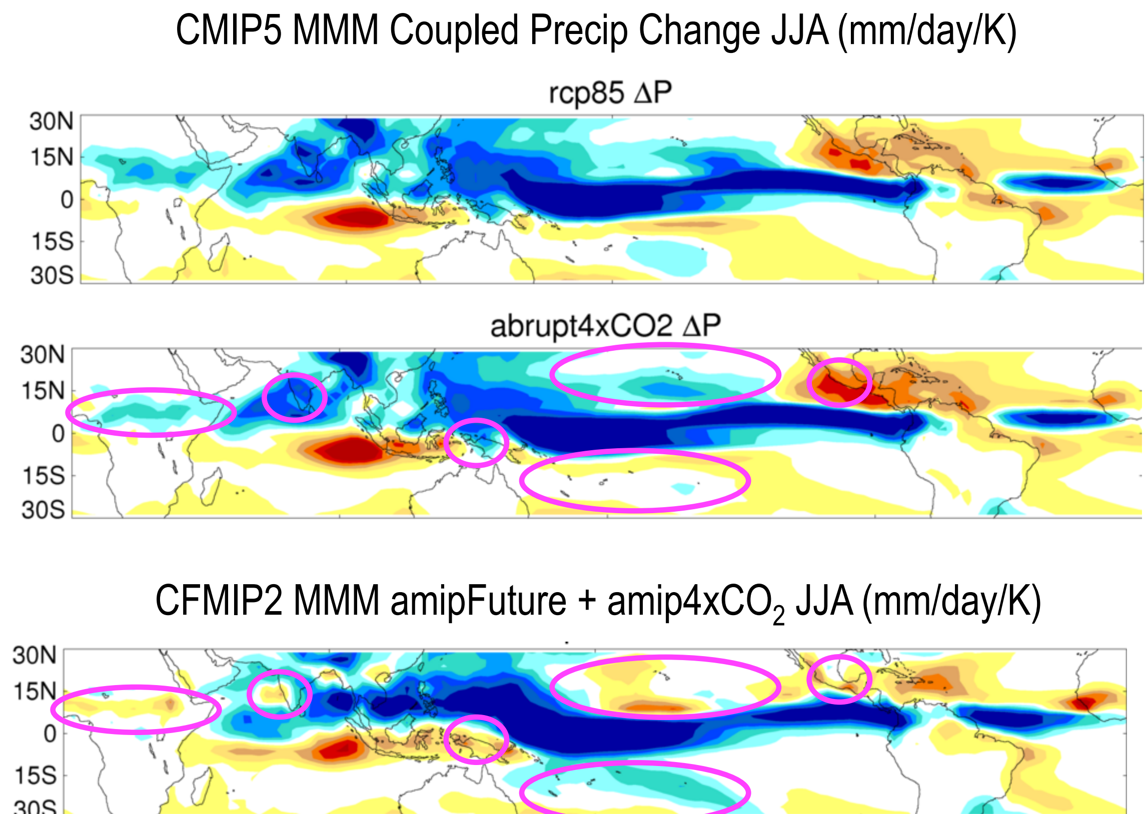
- Same as standard amip experiment (i.e. monthly varying observed SST & sea-ice boundary conditions) but with pre-industrial forcing conditions and covering a longer period (1870-2015).

- Readily allows diagnosis of time-varying feedbacks to observed SST change over the 20th century in models.

- Pilot study (Gregory & Andrews) suggests substantial time-variation in feedbacks, undermining fixed feedback assumptions in observational ECS estimates

Idealised experiments to understand uncertainty in regional climate projections - Rob Chadwick/Hervé Douville

- Large inter-model differences remain in the simulation of regional climate change.
- Current amip, amip4K etc... expts are useful, but do not linearly sum to give the coupled AOGCM response in many regions, particularly over land.
- We propose decomposing the abrupt4xCO2 coupled expt into a number of timeslice (TS) AGCM-only runs with each model's own SSTs as a baseline, and own future SSTs used in a future pattern expt.



- Besides a better understanding of processes and uncertainties in the full coupled response another benefit is that comparison of these expts with CFMIP2-style amip expts will give information about the effect of model SST biases on future projections

CFMIP Proposal #8 Proposed time-slice (TS) experiments

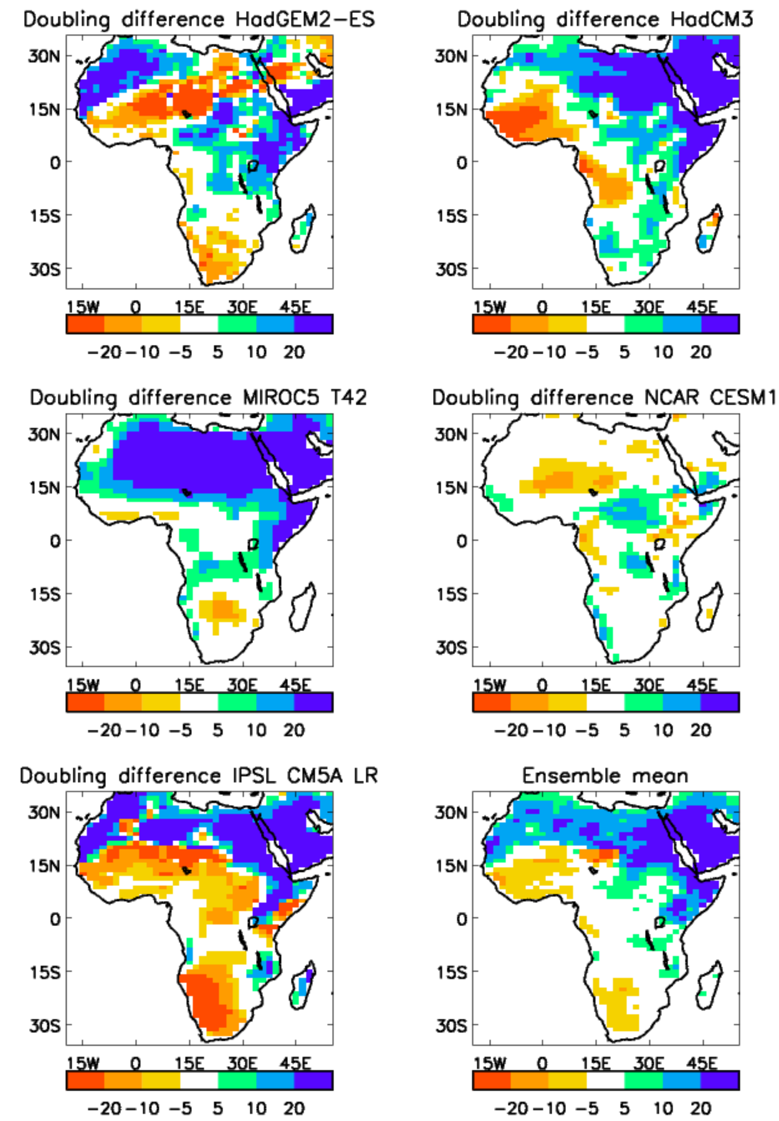
Experiment	Description
TSpiControl	SSTs from model's own control run (*varying or climatological?*). Pre-industrial atmospheric constituents. Similar to, and replacing CMIP5 SSTClim experiment.
TS4K	TSpiControl with a uniform global 4K SST perturbation
TS4xCO_2	TSpiControl with quadrupled CO_2 concentrations. Similar to, and replacing CMIP5 SSTClim4xCO_2 experiment.
TSFuture	TSpiControl with pattern of future SST anomalies, taken from each model's own abrupt4xCO_2 expt, normalised to have a global mean perturbation of 4K.
TSTot	Combination of TSFuture and TS4xCO_2, to test for linearity of response.
amipTot	As TSTot but with amip baseline SSTs. Used to test influence of model SST biases on future projections. Possibly replacing amipFuture.

- 3 CMIP5 experiments replaced with alternatives plus 3 new additional experiments.
- Allows a detailed inter-model comparison of the regional climate response to different aspects of forcing. To improve our understanding of the inter-model spread, and guide the development of observational constraints.
- Comparison of Clim and amip experiments provides information on the effect of model SST biases on future projections. Perhaps guide the development of improved bias correction techniques.

Large non-linear precipitation responses to CO_2 – in 5 GCMs

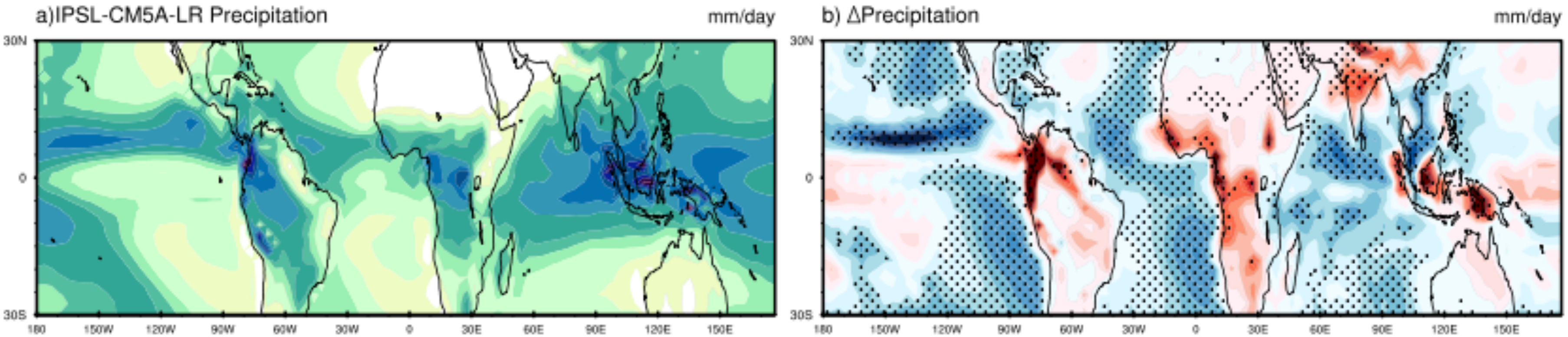
- Large regional non-linearities across Africa from nonlinMIP pilot study (Peter Good)

- 'Doubling difference' :
  - Second CO2 doubling minus first CO2 doubling
  - First doubling: ~rcp4.5 at 2100
  - Second doubling: 'mitigation benefits'



- Good et al., 2012: A step-response approach for predicting and understanding non-linear precipitation changes. Clim Dyn
- Chadwick, R. and Good, P., 2013. Understanding non-linear tropical precipitation responses to CO2 forcing. *GRL*
- Good, Peter, et al. "Nonlinear regional warming with increasing CO2 concentrations." Nature Climate Change 5.2 (2015): 138-142.
- Bouttes, N., et al. "Nonlinearity of ocean heat uptake during warming and cooling in the FAMOUS climate model." Geophysical Research Letters 42.7 (2015): 2409-2416.

CFMIP Proposal #5: COOKIE sensitivity experiments with clouds made transparent to radiation



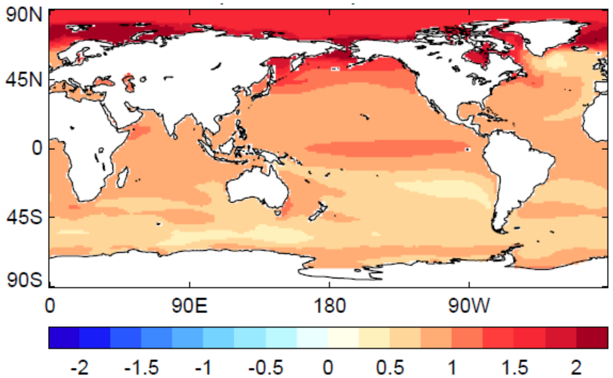
Impact on precipitation of making PBL clouds transparent to radiation: Fermepin and Bony 2014

- These would comprise offAMIP, offAMIP4K, offAMIP4xCO2 and equivalent aquaplanet experiments.
- Also PBLoff equivalents where PBL clouds are made transparent.
- PI Sandrine Bony

What processes control the dependence of cloud and climate feedbacks on the pattern of SST change?

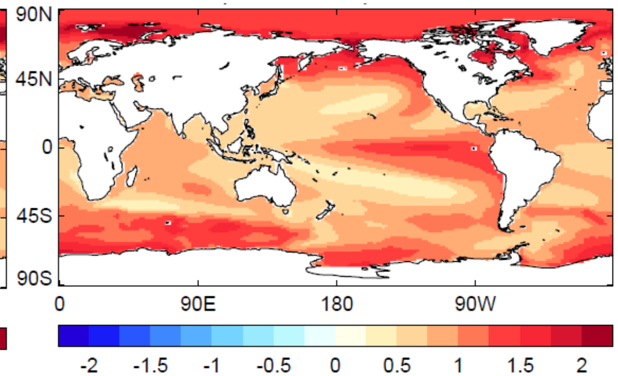
Met Office

$4xCO_2$ fast SST pattern



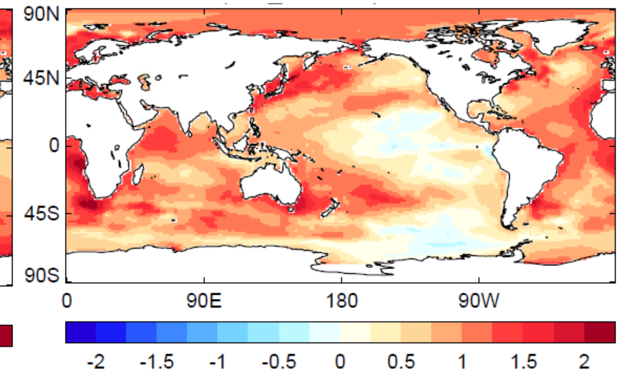
HG2 ECS ~ 3.3K

$4xCO_2$ slow SST pattern



HG2 ECS ~ 5K

Observed 20^{th}C SST pattern



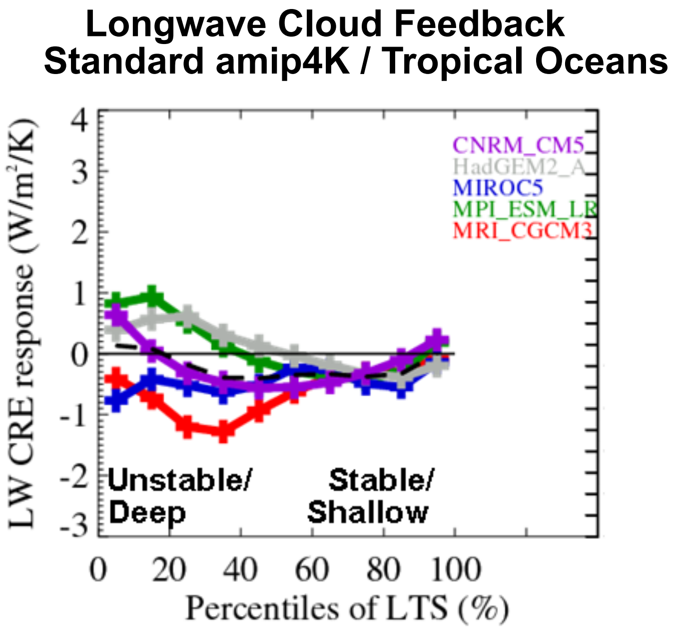
HG2 ECS ~ 2.3K

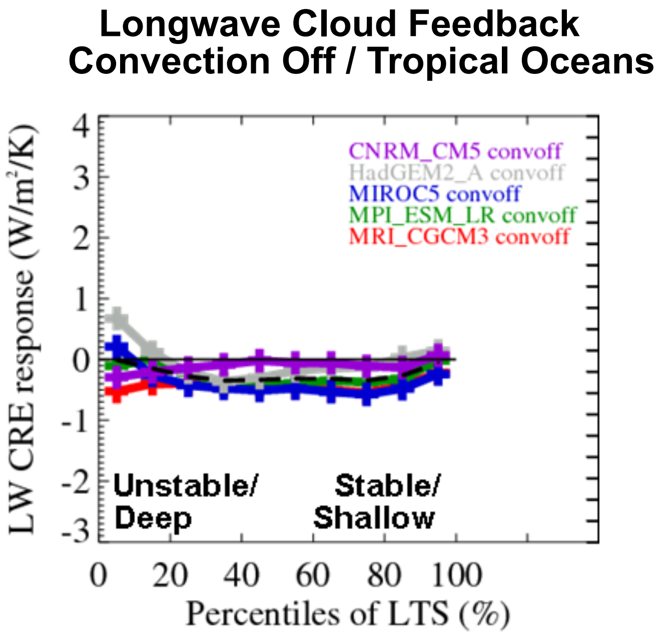
CFMIP3 proposal: amip4K*fast*, amip4K*slow* & amip4K*20C* (PI Tim Andrews)

- Equivalent to the CFMIP amip4K uniformed & patterned experiments but with patterns of SST change derived from the transient behaviour of AOGCMs and observations
- Allows us to readily determine atmospheric feedbacks to any given SST pattern with process diagnostics to identify the mechanisms and processes involved across models
- Allows us to test whether observed 20^{th} century warming generates feedbacks of relevance to long term climate change and climate sensitivity.
- Can be used as a platform for further sensitivity experiments (e.g. to test which regions are the most important) which are hard to do with AOGCMs.

Proposal #6: Develop SPOOKIE approach in CFMIP

- Extend amip/amip4K/amip4xCO2 and aqua equivalents without parametrized convection to more models
- Investigate the contributions of different entrainment/detrainment and precipitation efficiency (entrainmentOff, convectivePrecipitationOff)
- Investigate the relative importance of remote vs local changes in convection (deepConvOff SST > 300K) and subtropicsConvOff (SST 290-300K)
- PI Mark Webb

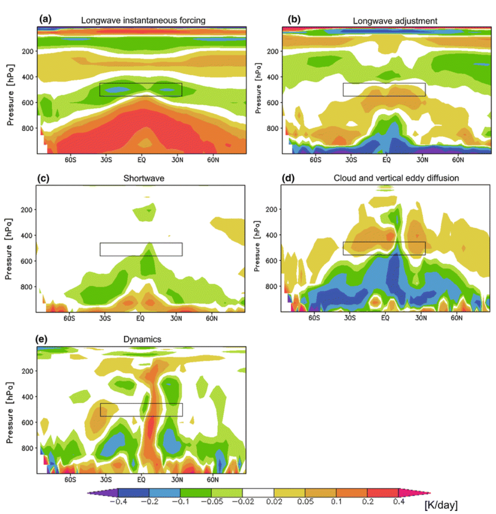




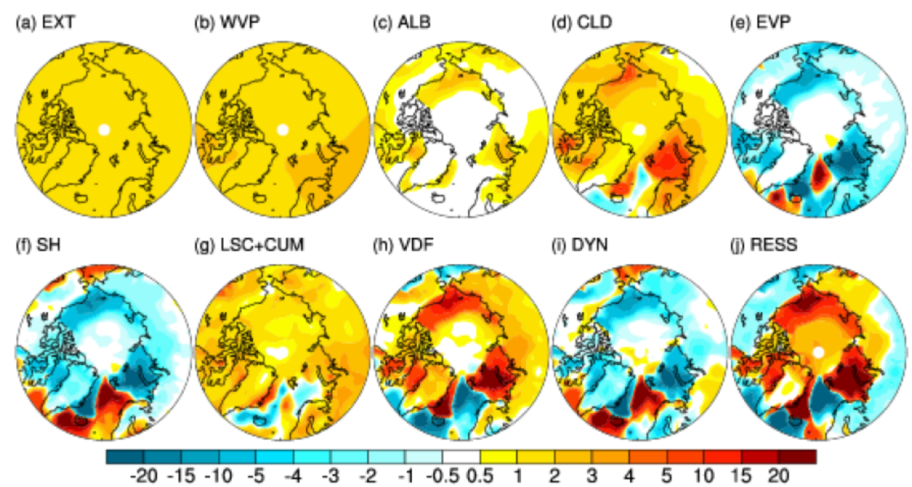
CMIP5 Science Gap: Difficulty in interpreting physical feedback mechanisms in coupled model experiments due to lack of process diagnostics

- Temperature and humidity tendency terms have been demonstrably useful for understanding the roles of different parts of the model physics in cloud feedbacks and adjustments Williams et al 2013, Webb and Lock 2013, Kamae and Watanabe 2012, Demoto et al 2013, Sherwood et al 2014, Ogura et al 2014.

- They have also been used to understand regional warming patterns such as polar amplification in coupled models (e.g. Yoshimori et al 2013,2014)



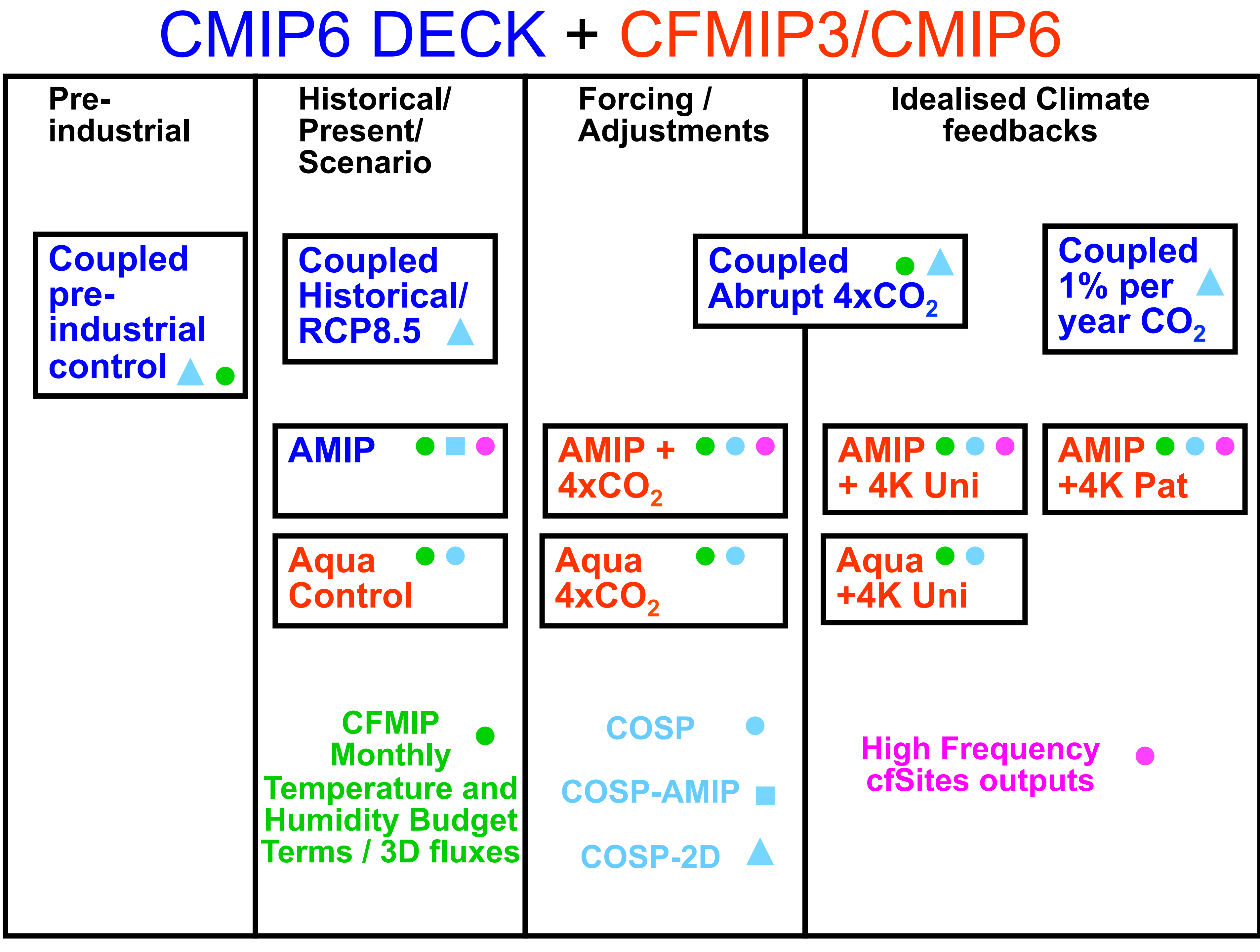
Ogura et al 2014



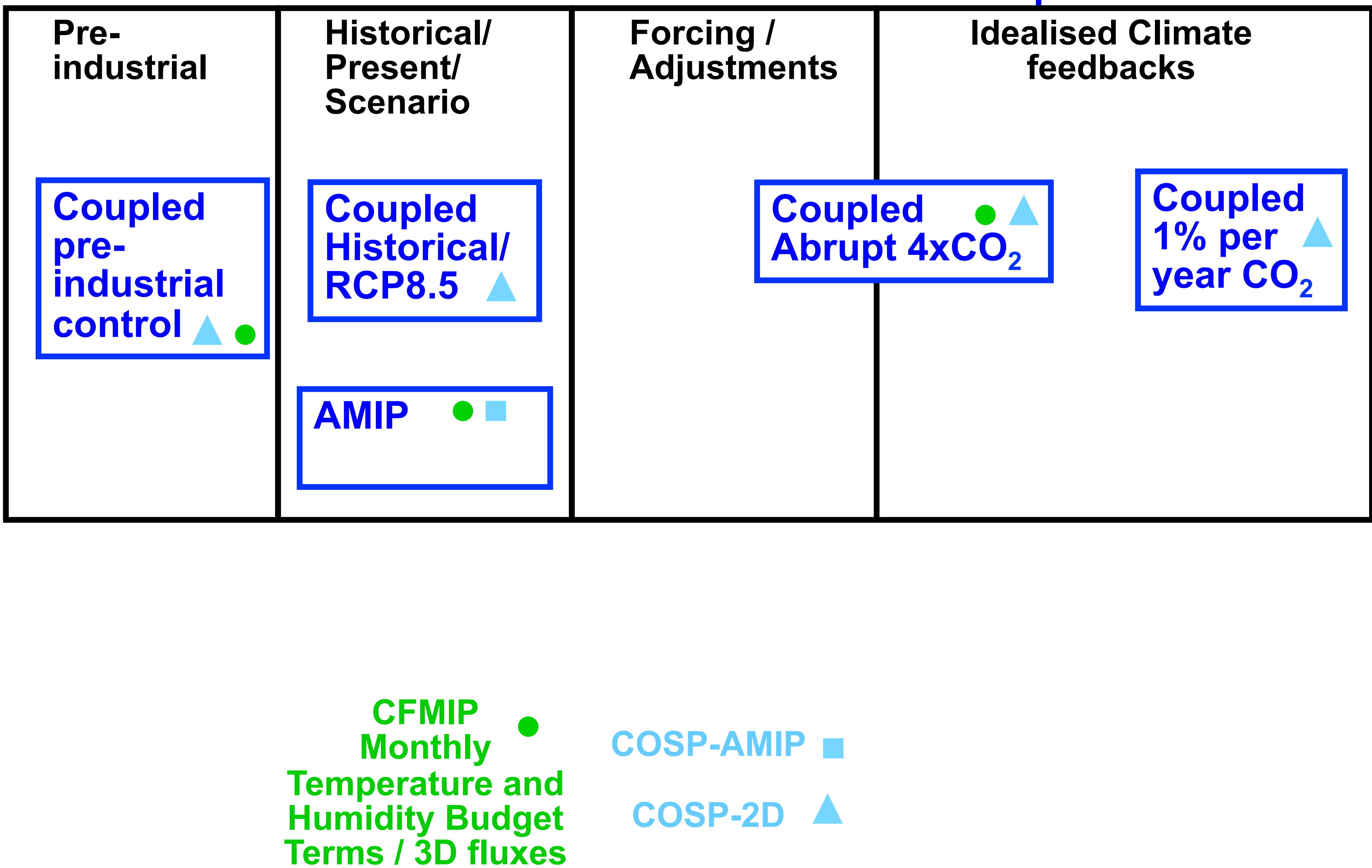
Yoshimori et al 2014

CFMIP/CMIP6 Tier 1 experiments:

- **Science Question:** What are the physical mechanisms underlying the range of cloud feedbacks and cloud adjustments predicted by climate models, and which models have the most credible cloud feedbacks?
- The value of CFMIP-2 amip/amip4K/amipFuture/amip4xCO2 + aquaplanet experiments and COSP+process diagnostics has been demonstrated in CMIP5.
- However not all modelling groups have participated to date, limiting the insights gained to a subset of models which may not capture the full diversity of the overall CMIP ensemble.
- Hence we proposed to continue the well established CFMIP-2 experiments as Tier 1 experiments in CMIP5.


CMIP6 DECK + CFMIP3/CMIP6
Pre-industrial
Historical/ Present/ Scenario
Forcing / Adjustments
Idealised Climate feedbacks
Coupled pre-industrial control
Coupled Historical/ RCP8.5
Coupled Abrupt 4xCO2
Coupled 1% per year CO2
AMIP
AMIP + 4xCO2
AMIP + 4K Uni
AMIP +4K Pat
Aqua Control
Aqua 4xCO2
Aqua +4K Uni
CFMIP Monthly Temperature and Humidity Budget Terms / 3D fluxes
COSP
COSP-AMIP
COSP-2D
High Frequency cfSites outputs

CMIP DECK + CMIP6 Historical Experiments



CFMIP Science Gap #4: Understanding the role of cloud and precipitation CO_2 adjustments in coupled model response patterns

- Rapid adjustments in clouds and precipitation in response to CO_2 forcing are now widely recognized as important.
- While they can easily be separated from conventional feedbacks in SST forced experiments, such a separation in coupled models is complicated by various issues, including the response of the ocean on decadal timescales (see for example Andrews et al 2012).
- A number of studies have examined cloud feedbacks in coupled models subject to a solar forcing, which is generally associated with much smaller cloud and precipitation adjustment, due to a smaller atmospheric absorption for a given top of atmosphere forcing – e.g. (Gregory et al 2004, Andrews et al 2012, Cao et al 2012).
- Would provide a useful complement to the abrupt4xCO2 experiment, and would support our understanding of regional responses of the coupled system with and without CO_2 adjustments.

CFMIP Proposal #4: +/- 4% Abrupt solar forcing AOGCM experiments

- A +4% solar experiment would be equivalent to the abrupt4xCO2 experiment but would increase the solar constant abruptly by 3 percent, resulting in a radiative forcing of a similar magnitude to that due to CO_2 quadrupling.
- This is very straightforward to perform, well tested previously and could qualify for the CMIP6 experiment set.
- A complementary -4% abrupt solar forcing experiment would allow the examination of feedback symmetry under climate cooling, and would also help with the interpretation of model responses to geo-engineering scenarios and volcanic forcing.
- PI's Chris Bretherton and Roj Marchand

CFMIP Science Gap #5: Understanding of impact of clouds and cloud changes on regional temperatures, circulation and precipitation

- CMIP5 does not currently provide experiments which support an understanding of the impact of clouds and cloud changes on other aspects of the climate, for example regional temperature, circulation and precipitation biases and responses.

- This area of research is central to the initiative on coupling of clouds to the circulation in the Grand Challenge on Clouds, Circulation and Climate Sensitivity.

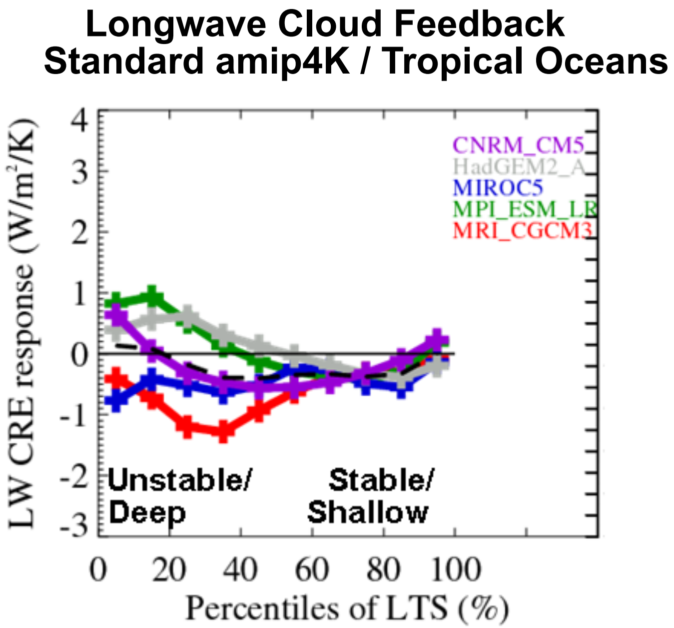
- COOKIE (Clouds On/Off Klima Intercompariton Experiments) provide a wealth of information on this by making the clouds transparent to radiation in AMIP, AMIP+4K, AMIP4xCO2 and equivalent aquaplanet experiments.

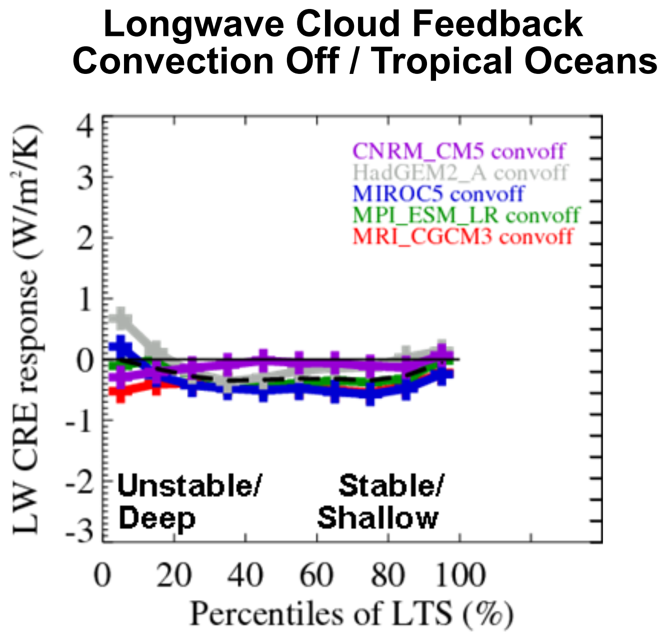
- Variants that switch off the radiative properties of low or high clouds separately are also possible (e.g. Fermepin et al 2014)

- For more information, see EUCLIPSE COOKIE website http://www.euclipse.eu/wp4/wp4.html

CFMIP Science Gap #6: Identifying which parts of model physics contribute most to inter-model differences in cloud feedbacks and how – e.g. How important is convection for cloud feedback? (GC)

- The Selected Processes On/Off Klimate Experiment (SPOOKIE) approach is to switch off or fix various key processes in turn to understand which processes control cloud feedback.
- Pilot study has switched off parametrized convection in five models and shown strong convergence in longwave cloud feedback





CFMIP Science Gap #7: The gap in the experimental hierarchy between global GCM experiments and cloud resolving model/super-parametrization experiments is still large.

- The CFMIP/CMIP5 experimental hierarchy still struggles to bridge continuously between coupled GCMs to cloud resolving models.
- Global Radiative Convective Equilibrium (RCE) experiments are full GCM experiments with a slab ocean, but without land-surface processes, spatial gradients in solar insolation or rotation.
- These have the potential to run GCMs cloud feedback experiments with very simple global forcings which are easier to relate to idealized experiments with cloud resolving models.
- They also support the investigation of the importance of convective aggregation in climate change (a question from the GC)
- e.g Popke et al 2013: Climate and climate change in a radiative-convective equilibrium version of ECHAM6 (JAMES)

CFMIP Proposal #7: Develop an inexpensive global RCE experiment which sits within the CMIP/CFMIP experimental hierarchy.

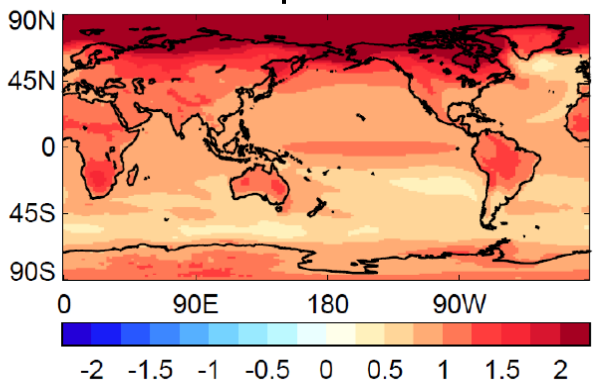
- Current experiments of this type are run with a slab ocean, but these require quite long runs compared to the existing CFMIP aquaplanet experiments.
- Development of an SST forced version might fit more neatly into the existing CFMIP/CMIP5 hierarchy, and would be more computationally tractable for those groups with global CRMs.
- Additionally, the impact of model resolution on model results is known to be important but has never been carefully assessed across models. Models could be run with consistent horizontal and more importantly vertical grids to assess the impact of model resolution on model biases and projections.
- This would be much more straightforward to do in RCE mode than in more realistic configurations.
- PI Bjorn Stevens

Science Gap #9: Process understanding of the dependence of cloud feedback on the pattern of SST change seen in AOGCMs

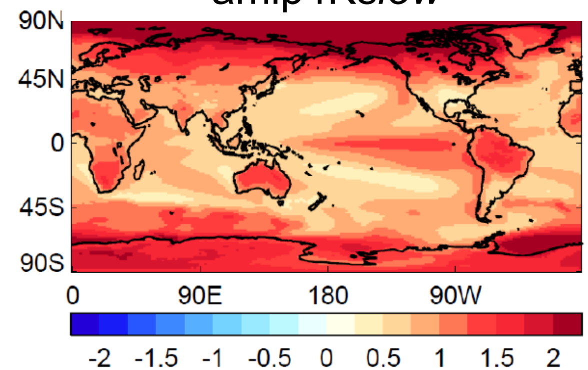
- The CFMIP2 design is unable to investigate why cloud feedback is so sensitive to evolving SST patterns in AOGCMs since the amip4K experiments (uniform and patterned) are not sufficiently different.

- **CFMIP proposal #9:** targeted experiments to investigate the sensitivity of atmospheric feedbacks to the *'fast'* and *'slow'* SST response patterns:

amip4K*fast*



amip4K*slow*



- Using the AGCM design to reproduce the time-varying feedbacks then gives us a basis to better understand the physical processes (better signal-to-noise, process diagnostics etc.)

- Can then be used as a platform for further sensitivity experiments (e.g. to test which regions are the most important) which are hard to do with AOGCMs

- PI Tim Andrews

Science Gap #10: CFMIP-2 had no experiments on cooling climates or link to PMIP

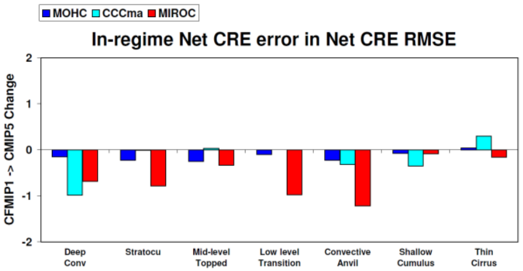
Met Office

- PMIP has found cases where cloud feedbacks behave asymmetrically between cooler and warmer climates (e.g. Yoshimori et. al., J. Climate, 2009).
- CFMIP-1 had +2K and -2K experiments, but these were not included in CFMIP-2

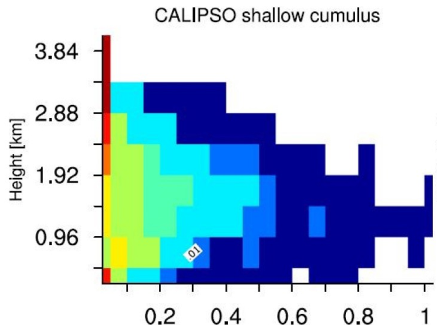
CFMIP proposal #10

- Re-introduce SST forced uniform cooling experiments amipMinus4K to complement amip4K CFMIP-3 CMIP6 experiments.
- Trivial to set up, but CFMIP process diagnostics may help to explain causes of cloud feedback warming/cooling asymmetry
- PI Mark Webb

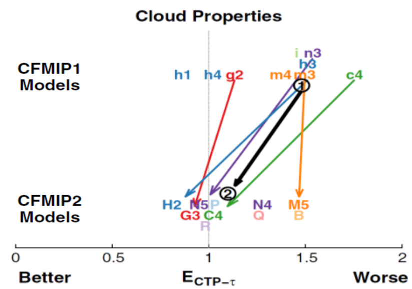
CFMIP Metrics/Diagnostics Repository



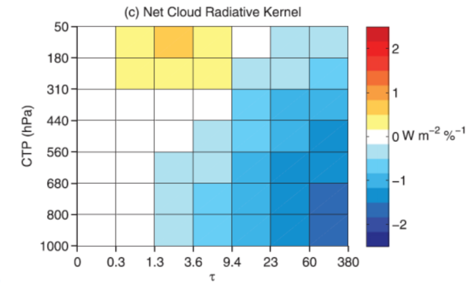
Williams and Webb 2009
Tsushima et al. 2012



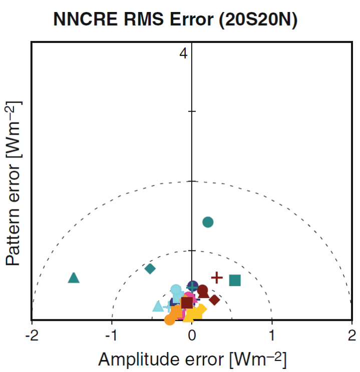
Nam et al., 2012



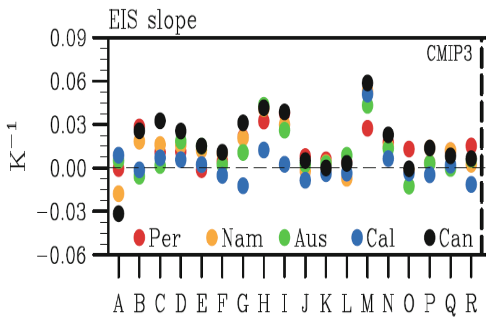
Klein et al. 2012



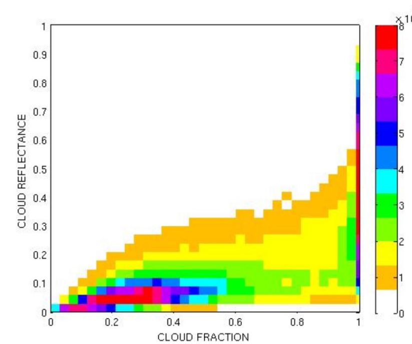
Zelinka et al. 2012



Tsushima et al., 2012



Qu et al., 2012



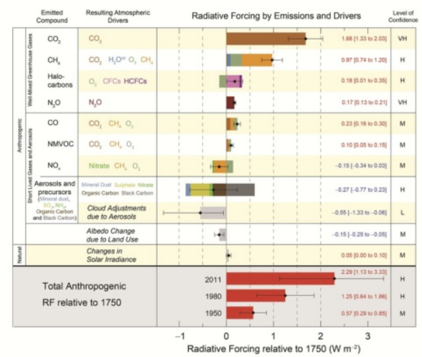
Konsta et al., 2012

Any metrics/diagnostics related to clouds whose multi-model analysis results are published are welcome.

Modellers and analysts are encouraged to use and add to the repository – documentation and help/advice are available.

For details see http://www.cfmip.net -> CFMIP Diagnostic Codes
or email yoko.tsushima@metoffice.gov.uk

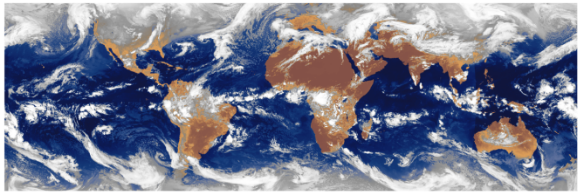
CFMIP Links to other Projects



RFMIP (Radiative Forcing)

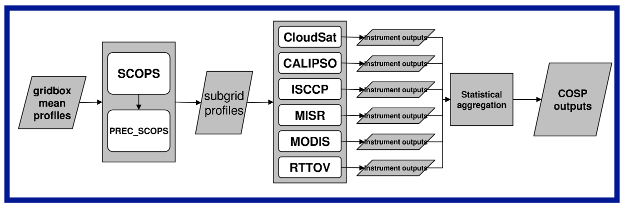
WCRP Grand Challenge on

Clouds, Circulation and Climate Sensitivity



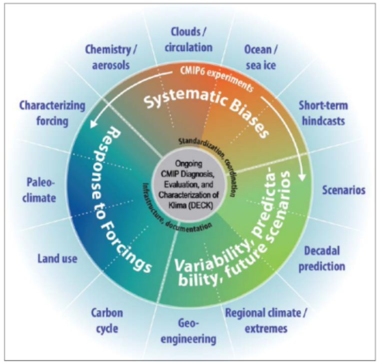
http://www.wcrp-climate.org/index.php/gc-clouds

WCRP
World Climate Research Programme

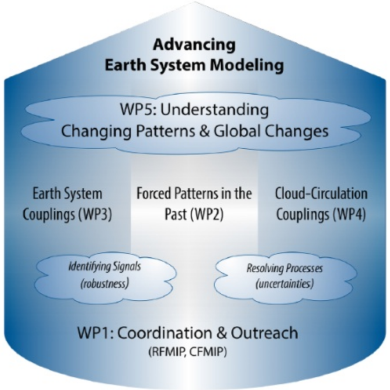


COSP

CFMIP3



CMIP6



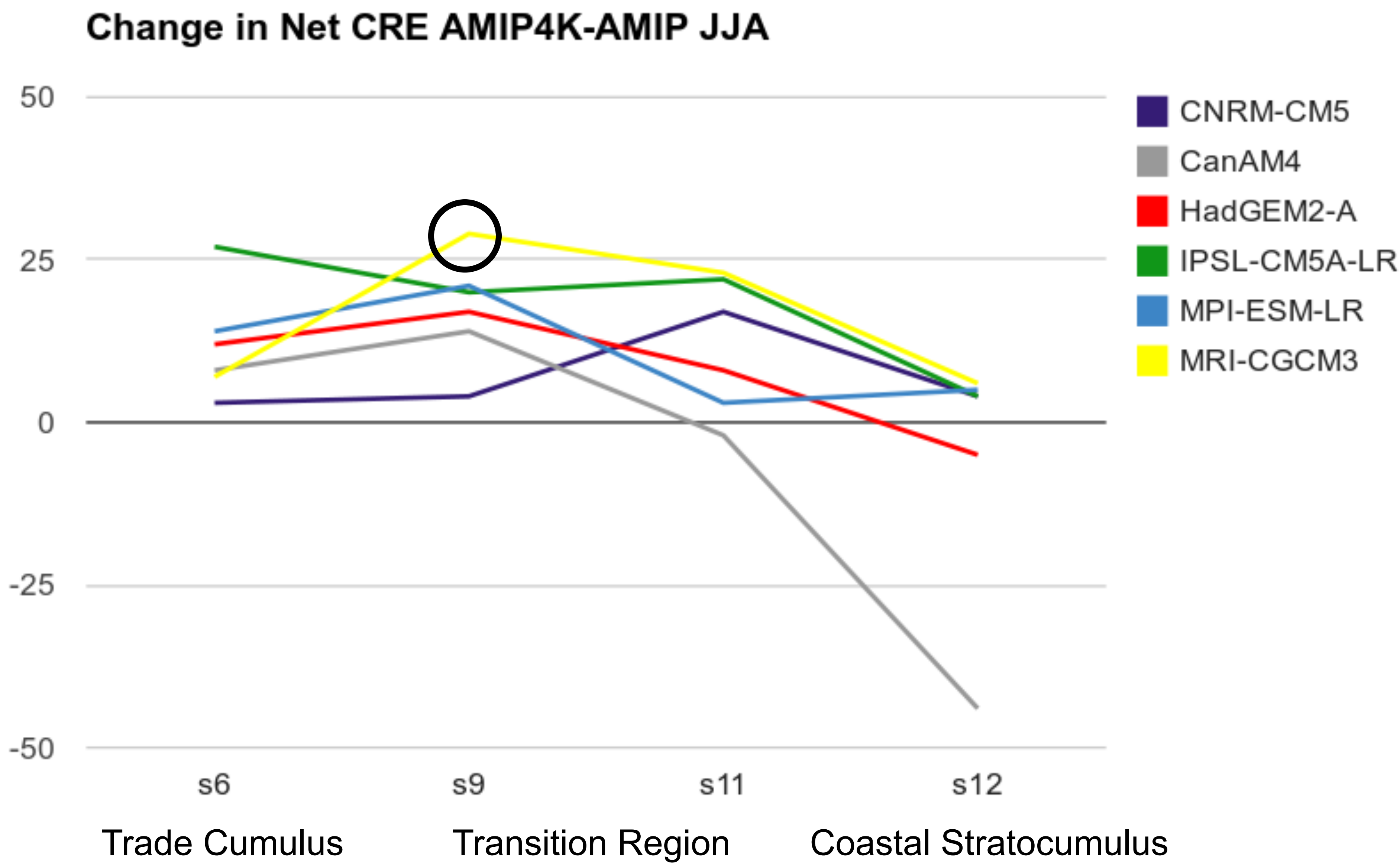
IMPULSE

GASS GEWEX WCRP
Global Atmospheric System Studies

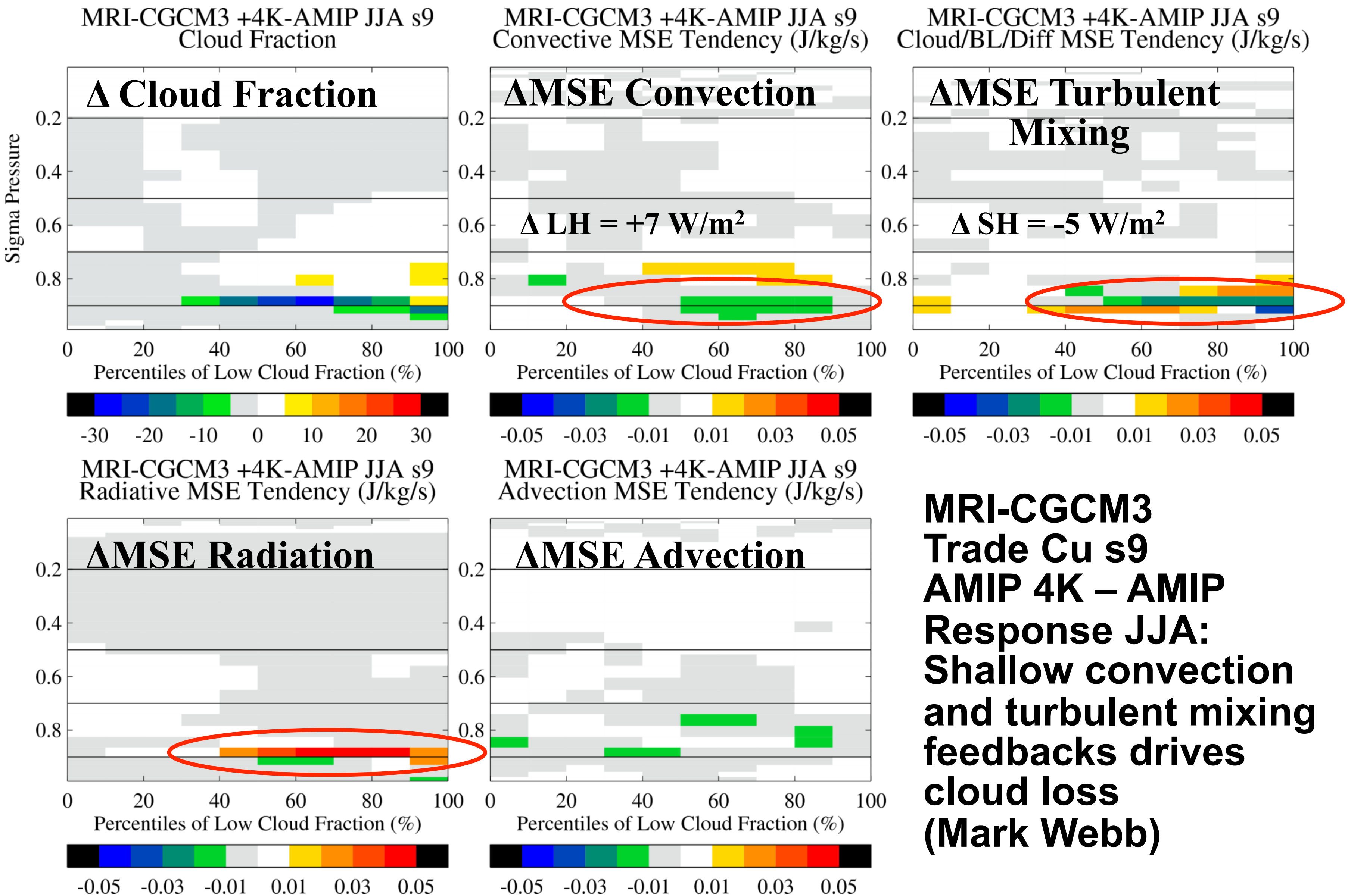
Paleoclimate Modelling
PMIP
Intercomparison Project

Additional slides providing more detail if required

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

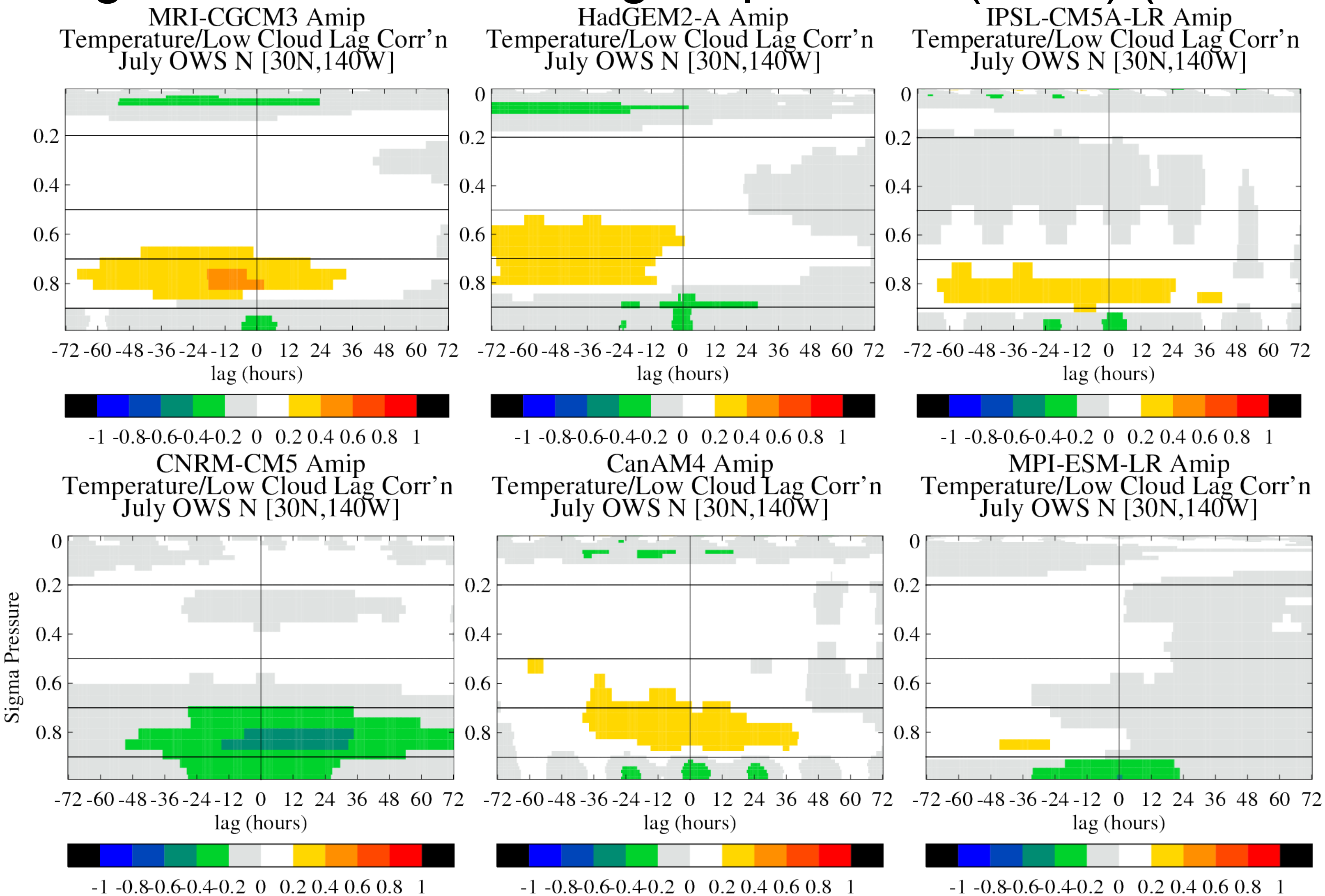


cfSites: Moist Static Energy Budget Approach following Brient and Bony 2013, Webb and Lock 2013

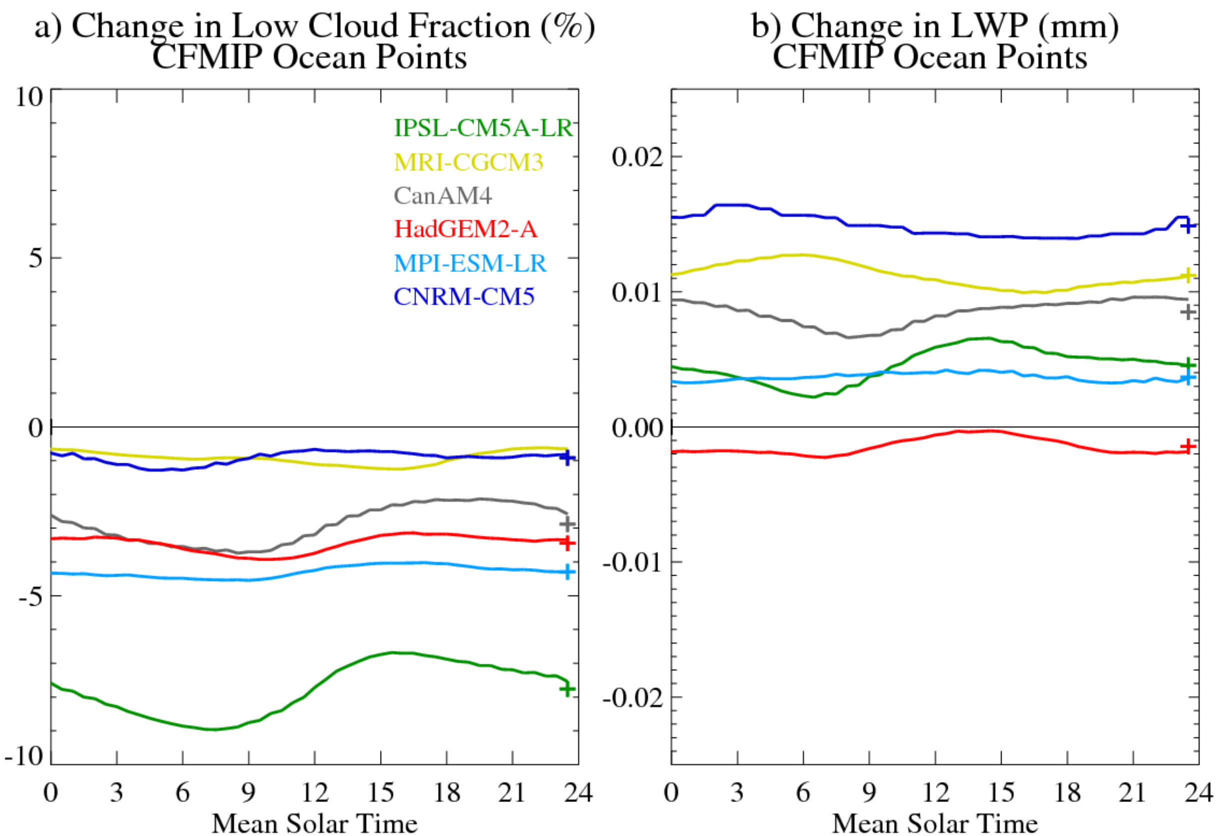


MRI-CGCM3 Trade Cu s9 AMIP 4K – AMIP Response JJA: Shallow convection and turbulent mixing feedbacks drives cloud loss (Mark Webb)

cfSites data: Identifying causal relationships between clouds and other variables using temporal precedence: Lag correlations following Mapes et al (2008) (Mark Webb)



How important is the diurnal cycle for cloud feedback?

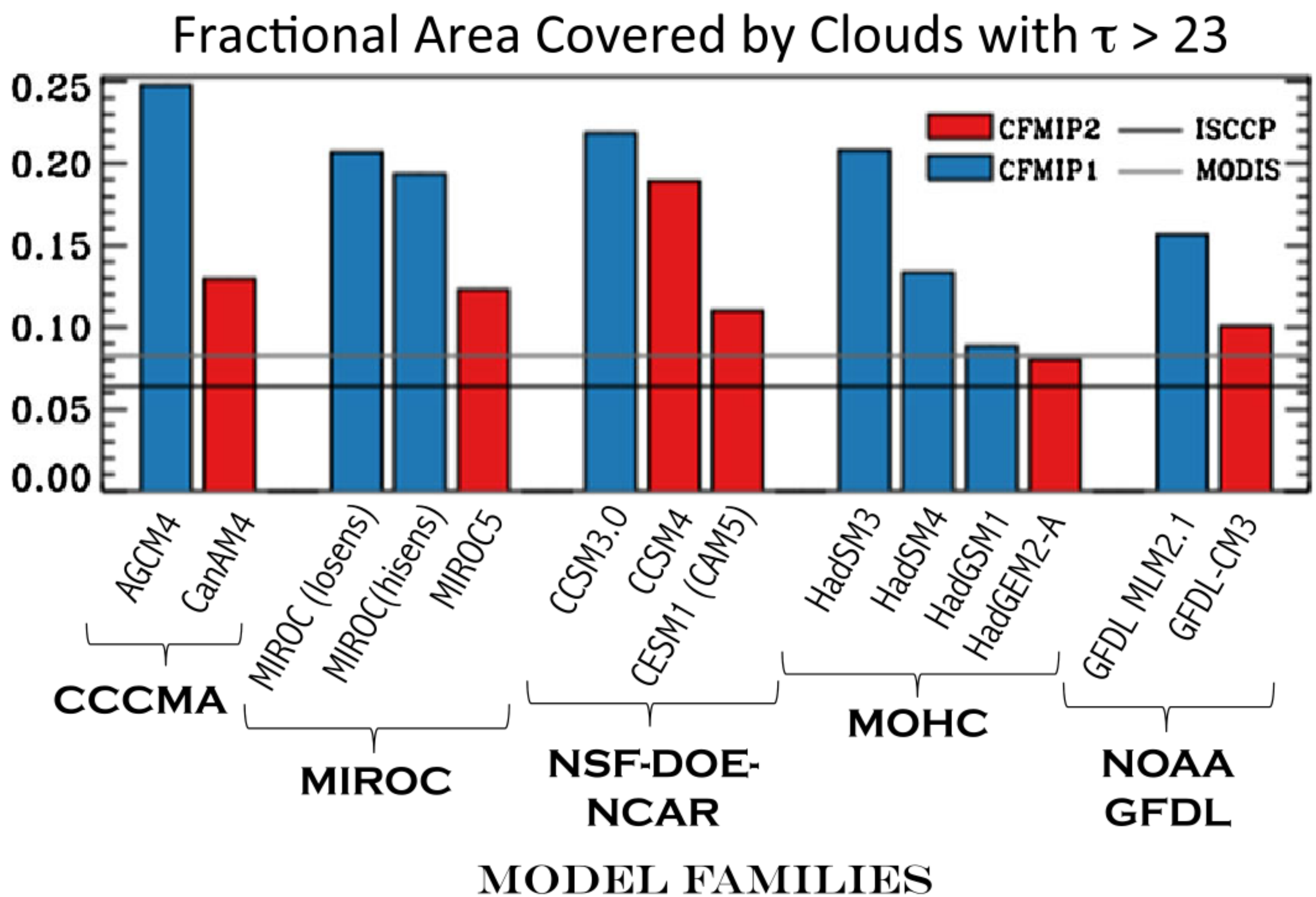


Low cloud and Liquid Water Path (LWP) response to uniform +4K SST perturbation over Ocean cfSites Points

Diurnal amplitudes of the responses are small compared to inter-model differences.

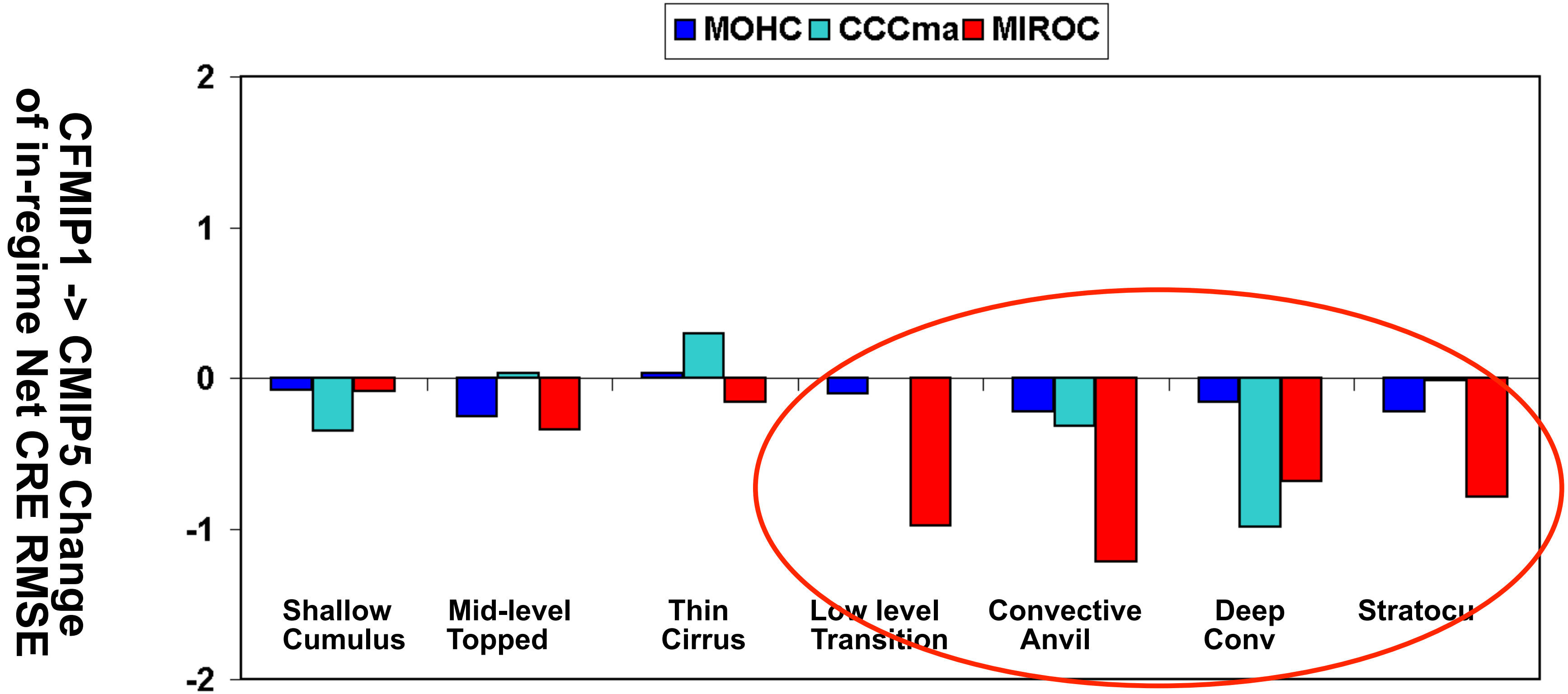
Webb et al (in preparation).

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)

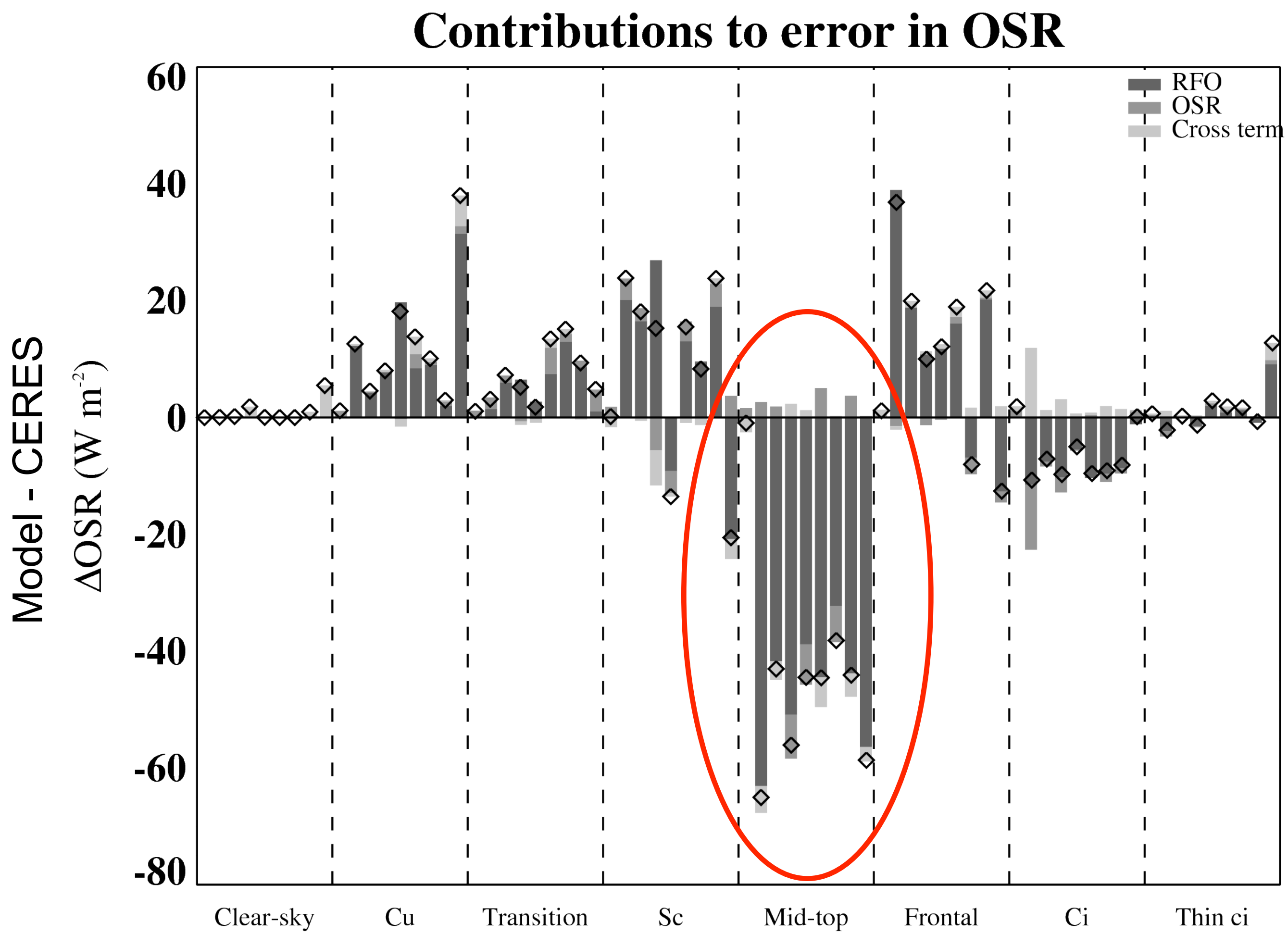
Improvements are seen in mainly in the radiative properties of optically thicker low and high topped cloud regimes rather than frequency of occurrence.



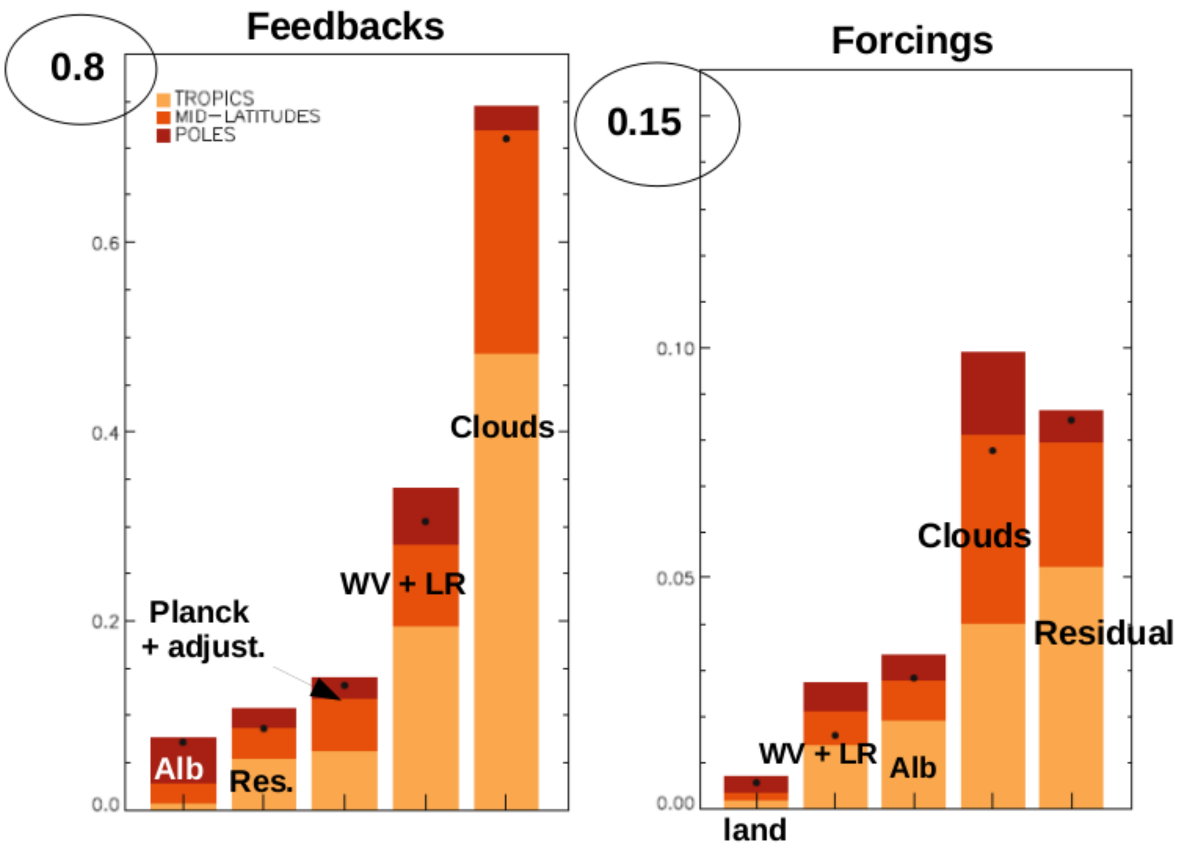
Change between CFMIP-1 and CMIP5 of in-regime Net Cloud Radiative Effect (Net CRE) RMSE within daily ISCCP simulator cloud regimes in the tropics

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

The mid-level topped ISCCP cloud regime dominates Outgoing Solar Radiation (OSR) errors over the Southern Ocean in CMIP5 models



Origins of the solar radiation biases over the Southern Ocean in CFMIP2 models. Bodas et al, Submitted to J. Climate



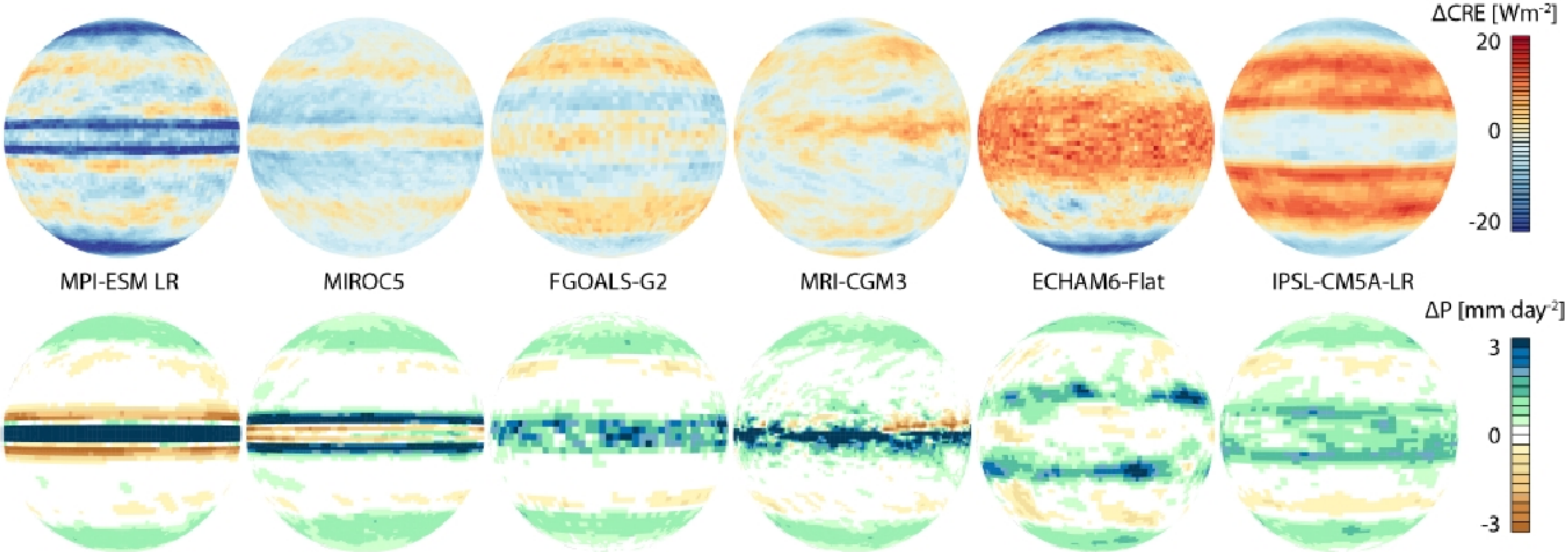
- Cloud feedback represents 70% of the total spread; the spread is the largest in tropics
- WV+LR feedback is the second most important source of spread (30%); largest spread in tropics
- The residual is the largest source of spread among all forcing terms (< 10%, less than for any feedback)

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**

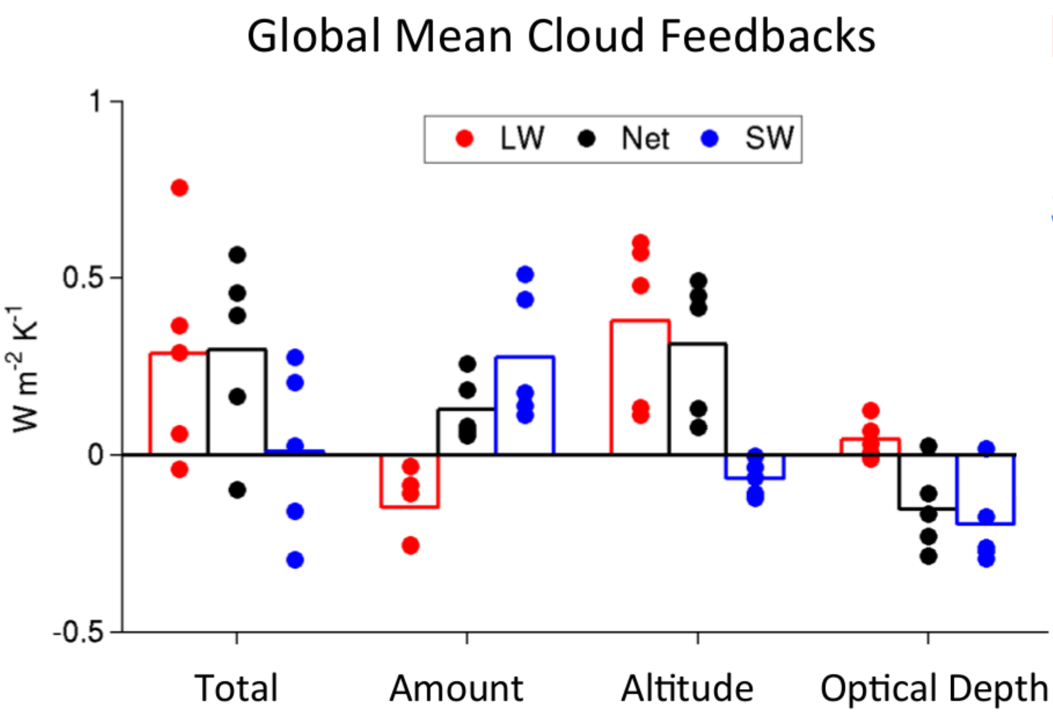


- Uncertainties related to basic physical processes

- 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 ↑

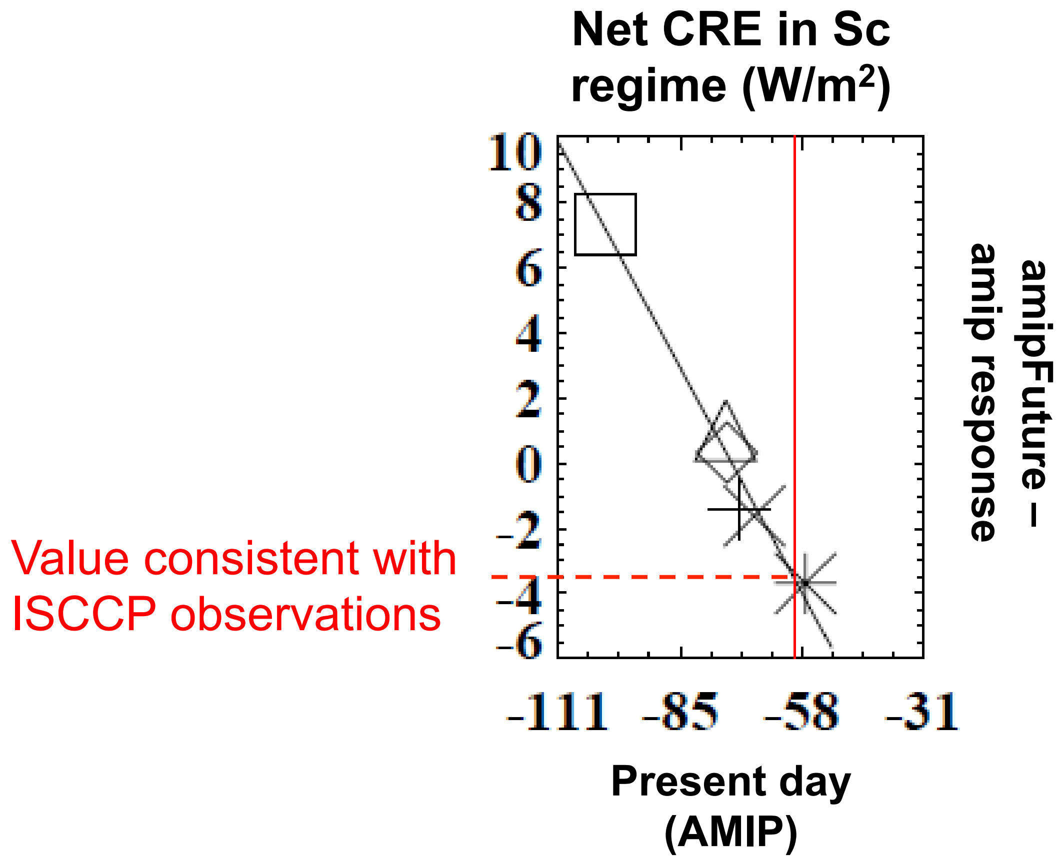
Shortwave feedbacks variable

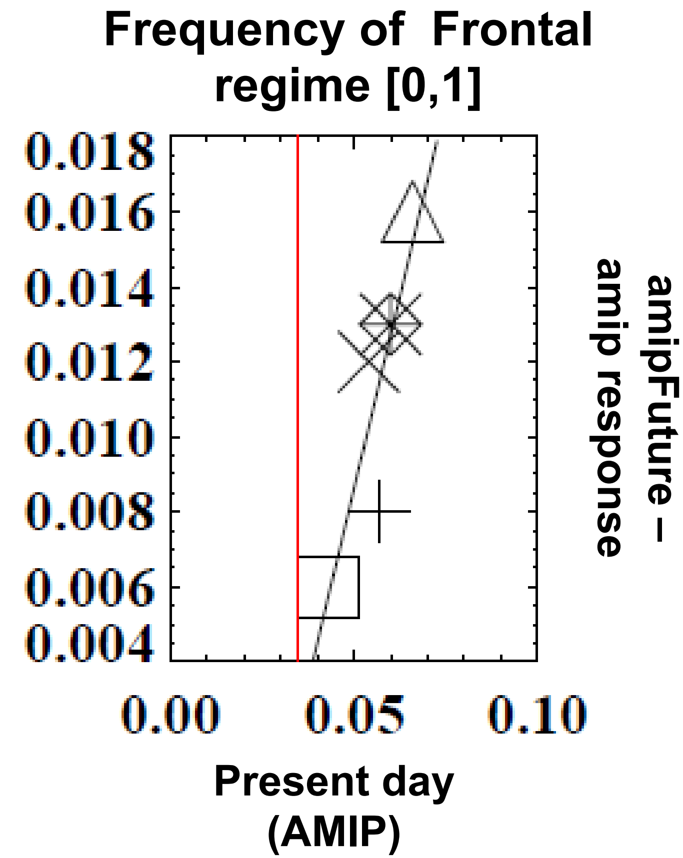
– cloud amount ↓ (+)

– 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.



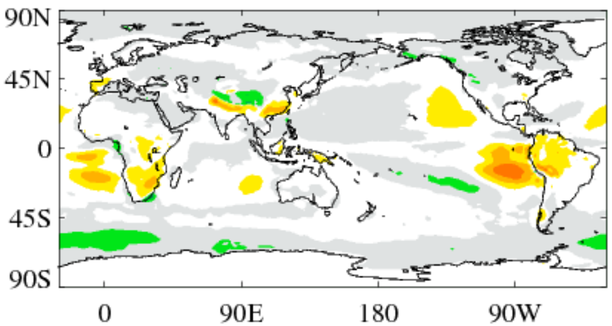


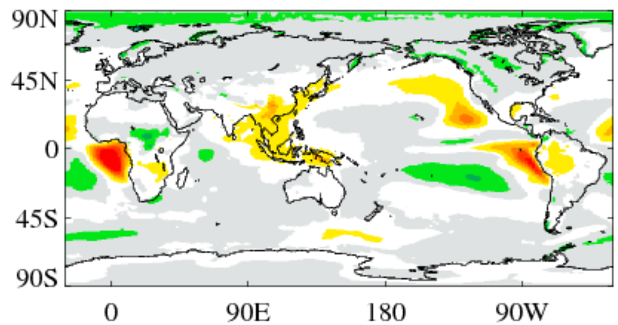
Yoko Tsushima, Met Office Hadley Centre

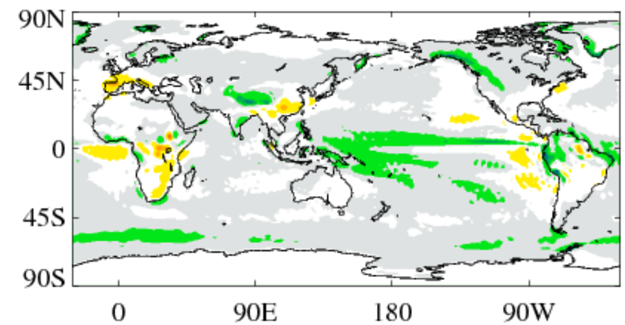
Preliminary SPOOKIE results: Impact of switching off convective parametrization on net cloud feedback in amip/amip4K

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}

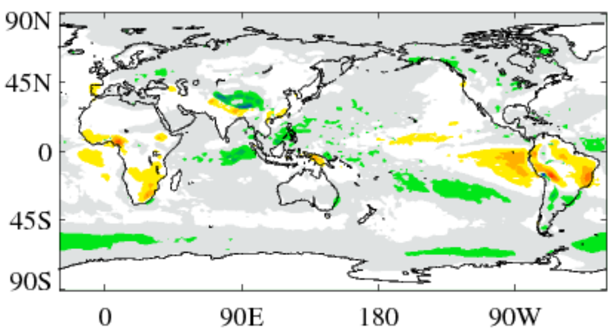


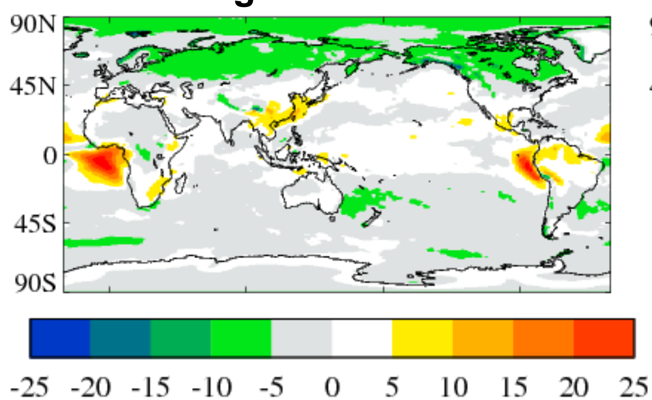


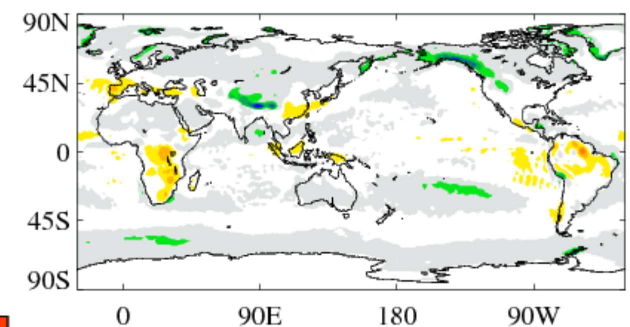


HadGEM2-A ConvOff -0.05 Wm^{-2}K^{-1} **MRI-CGCM3 ConvOff -0.08 Wm^{-2}K^{-1}** **MIROC5 ConvOff 0.18 Wm^{-2}K^{-1}**

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







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

CFMIP Science Gap #7: A CMIP approach to developing and testing physical hypotheses and observational constraints using sensitivity experiments.

Another initiative proposed by the GC is as follows:

- Modelling groups could use sensitivity tests to develop and test hypotheses to explain physical mechanisms underlying a climate model behaviours (e.g. subtropical feedbacks as in Webb and Lock, 2013, LW/SW cancellation in deep convection, hemispheric albedo symmetry).
- Another key issue is understanding why models are unable to do certain things that we see observational evidence for. Examples include strong polar amplification and flat tropical temperatures in early Pliocene (Fedorov et al. 2013, Barriero and Philander 2008), and the underestimates of poleward shifts of the general circulation (Johansson and Fu 2008, Allen et al. 2012).
- Experiments which push conventional models outside their usual modes of behaviour may help us to understand the causes of model shortcomings.
- New idealized experiments could be developed as a bridge between CFMIP and PMIP activities.

CFMIP Science Gap #7: A CMIP approach to developing and testing physical hypotheses and observational constraints using sensitivity experiments.

- Additionally, in recent years a number of so-called 'emergent constraints' have appeared in the literature. These are relationships between cloud feedbacks or climate sensitivity and observable quantities which 'emerge' from the multi-model ensemble.

- Examples include those proposed by Trenberth and Fasullo (2010), Trenberth and Fasullo (2012) and Sherwood, Bony and Dufresne et al (submitted)).

- If we are to have confidence in such observational constraints it is important that we understand the physical mechanisms which underly them.

- Such emergent constraints can be tested in individual models using sensitivity experiments.

CFMIP Proposal #7: Encourage creative use of sensitivity experiments based on the CFMIP/CMIP protocol

- These experiments do not need to be coordinated necessarily, but it is worthwhile pointing out that the presence of the relevant CMIP/ CFMIP experimental protocol provides an opportunity in this regard.
- CMIP/WGCM should we argue encourage and take some credit for spinoff activities such as these which would not be possible without the presence of the CMIP/CFMIP experimental framework.

Science gap #8: Identifying causal links between cloud controlling factors and cloud responses to climate forcings and warming.

- This is currently difficult to do because we typically analyse feedbacks in a state of atmospheric equilibrium - e.g 30 year mean response in amip4K etc.
- Transpose AMIP + 4CO2 / +4K experiments would allow us to examine the differing response timescales of clouds and potential cloud controlling factors in the days following abrupt SST/CO2 increases.
- Kamae and Watanabe (2012) show that CO2 adjustments in shortwave cloud radiative effect in MIROC5 respond on timescales consistent with the shoaling of the boundary layer, but not with those of the circulation change.
- Similarly, Demoto, Watanabe and Kamae (2013) show that the MIROC5 +4K feedback is associated with a reduction in low cloud which occurs in the first 10 days in TAMIP when the marine boundary layer (MBL) is destabilized because of contrast between fast and slow warming in the marine boundary layer and aloft.
- They also show that enhanced evaporation from the surface is suppressed by a reduced surface wind speed associated with a slowdown of the Walker circulation.

CFMIP Proposal #8: Develop CFMIP/CMIP6 protocol for ensembles of short experiments to examine timescales of responses to SST and CO2 forcing

- One approach could be to bring a cloud-focused version of Transpose AMIP into CFMIP/CMIP6 and use this as a control for 4CO2 and +4K perturbation experiments.
- An advantage of this would be that CFMIP be would be able to utilize the Transpose AMIP experiments for present day cloud evaluation.
- A disadvantage might be that initializing from analysis would require extra work from groups not participating in Transpose AMIP.
- Any decision would depend on the future plans for Transpose AMIP within CMIP/CFMIP.
- A simpler approach would be to propose an ensemble of short experiments, say a month each in length, and initialize these from various points in time during the standard AMIP experiments.
- Such experiments have so far been run with only one model and so would be quite experimental – hence we propose these for Tier 2.

Some recent papers using COSP:

Klein et al 2013: Are climate model simulations of clouds improving? An evaluation using the ISCCP simulator. (JGR) **CMIP5 models**

Tsushima et al 2013: Quantitative evaluation of the seasonal variations in climate model cloud regimes. (Climate Dynamics) **CMIP5 models**

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

Bodas et al (submitted) Origins of the solar radiation biases over the Southern Ocean in CFMIP2 models. (Submitted to J. Climate) **CMIP5 models**

Konsta, Chepfer and Dufresne (2013): Evaluation of Cloud Description in General Circulation Models Using A-Train Observations. (Advances in Meteorology, Climatology and Atmospheric Physics) **CMIP5 models**

Grégory and Chepfer: Evaluation of the cloud thermodynamic phase in a climate model using CALIPSO-GOCCP. (JGR, in press) **CMIP5 model**

Stevens et al, 2013: Atmospheric component of the MPI-M Earth System Model: ECHAM6. (JAMES) **CMIP5 model**

Xie et al 2013: Sensitivity of CAM5 Simulated Arctic Clouds and Radiation to Ice Nucleation Parameterization. (J. Climate, in press) **CMIP5 model**

More recent papers using COSP:

Franklin et al 2013: Evaluation of clouds in ACCESS using the satellite simulator package COSP. Part 2: Regime-sorted tropical cloud properties. (JGR, in press) **CMIP5 model**

Franklin et al 2013: Evaluation of clouds in ACCESS using the satellite simulator package COSP: Global, seasonal, and regional cloud properties. (JGR) **CMIP5 model**

John et al (2013): Analysis of upper-tropospheric humidity in tropical descent regions using observed and modelled radiances. (Atmos. Chem. Phys. Discuss) **CMIP5 model**

von Salzen et al, 2013: The Canadian Fourth Generation Atmospheric Global Climate Model (CanAM4). Part I: Representation of Physical Processes. (Atmosphere-Ocean) **CMIP5 model**

Wang and Su, 2013: Evaluating and understanding top of the atmosphere cloud radiative effects in Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5). (JGR) **CMIP5 models**

Nam et al, 2012: The ‘too few, too bright’ tropical low-cloud problem in CMIP5 models. (GRL) **CMIP5 models**

Quantifying forcings and feedbacks in idealised CFMIP5/CFMIP-2 experiments:

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

Andrews et al 2012: Forcing, feedbacks and climate sensitivity in CMIP5 coupled atmosphere-ocean climate models. (GRL) **CMIP5 models**

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

Geoffroy et al, 2012: Transient climate response in a two-layer energy-balance model. Part I: analytical solution and parameter calibration using CMIP5 AOGCM experiments. (J. Climate) **CMIP5 models**

Geoffroy et al, 2012: Transient climate response in a two-layer energy-balance model. Part II: representation of the efficacy of deep-ocean heat uptake and validation for CMIP5 AOGCMs. (J. Climate) **CMIP5 models**

Shiogama et al al 2012: Perturbed physics ensemble using the MIROC5 coupled atmosphere–ocean GCM without flux corrections: experimental design and results. (Climate Dynamics) **CMIP5 experiments**

Adjustment/feedback mechanisms in GCM/SCMs:

Brient and Bony 2012: How may low-cloud radiative properties simulated in the current climate influence low-cloud feedbacks under global warming? (GRL) **CMIP5 model**

Kamae and Watanabe, 2012: Tropospheric adjustment to increasing CO2: its timescale and the role of land-sea contrast. (Climate Dynamics) **CMIP5 model**

Kamae and Watanabe, 2012: On the robustness of tropospheric adjustment in CMIP5 models. (GRL) **CMIP5 models**

Brient and Bony 2013: Interpretation of the positive low-cloud feedback predicted by a climate model under global warming. (Climate Dynamics) **CMIP5 model**

Webb and Lock 2013: Coupling between subtropical cloud feedback and the local hydrological cycle in a climate model. (Climate Dynamics) **CMIP5 model**

Ogura at al (submitted): Importance of instantaneous radiative forcing to tropospheric adjustment. (Submitted to Climate Dynamics) **CMIP5 models**

Zhang et al (submitted): CGILS: First results from an international project to understand the physical mechanisms of low cloud feedbacks in general circulation models. (Submitted to JAMES) **SCM versions of CMIP5 models**

Understanding cloud feedback/adjustment mechanisms in LES/MLMs:

Rieck, Nuijens and Stevens 2012: Marine Boundary Layer Cloud Feedbacks in a Constant Relative Humidity Atmosphere. (J. Atmos Sci)

Zhang et al 2012: The CGILS experimental design to investigate low cloud feedbacks in general circulation models by using single-column and large-eddy simulation models. (JAMES)

Blossey at al 2013: Marine low cloud sensitivity to an idealized climate change: The CGILS LES intercomparison. (JAMES)

Bretherton, Blossey and Jones 2013: Mechanisms of marine low cloud sensitivity to idealized climate perturbations: A single-LES exploration extending the CGILS cases. (JAMES)

De Roode et al (submitted): The stratocumulus response to a single perturbation in cloud controlling factors. (Submitted to J. Climate)

Dal Gesso et al (submitted): A mixed-layer model perspective on stratocumulus steady-states in a perturbed climate. (Submitted to QJRMS)

A concern about CFMIP diagnostics in CMIP core

- Scientific benefits from CFMIP are as much due to COSP and process diagnostics as additional CFMIP experiments (e.g. amip4K, amip4xCO2, aquaplanets)
- These need to be in core CMIP experiments (amip, pre-industrial control, abrupt4xCO2) as well, because:
  - a) Many CFMIP SST forced experiments use AMIP as their control
  - b) We need to understand feedback processes in coupled experiments as well
- 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
- Ideally they would be listed as part of the standard model output requirements, rather than an ‘extra’ CFMIP list
- Obviously this would not be a concern if the timescales for the CFMIP and CMIP experiments were tightly coupled, as was the case for CMIP5/CFMIP-2.
- From the CFMIP perspective we can probably define our requirements as we expect the CFMIP experimental design or output requirements to change radically.
- This will also be an issue for other MIPS which depend on diagnostics in the core CMIP experiments

CFMIP-3/CMIP6 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	

CMIP5/CFMIP-2 GCM Experiments: What went well

- Many COSP studies e.g. Lacagnina et al 2014, Nam et al 2014, Zelinka et al 2014, Bodas-Salcedo et al 2013, Cesana et al 2013, Franklin et al 2013, Klein et al 2013
- Insights into cloud feedback and adjustment mechanisms using CFMIP experiments, tendency terms and cfSites outputs– e.g. Brient and Bony 2012,2013, Webb and Lock 2013, Kamae and Watanabe 2014, Ogura at 2014, Sherwood et al 2014, Roehrig et al 2013, Webb et al (in press).
- Aquaplanets capture many key features of feedbacks and adujstments in full models – Stevens and Bony 2013, Medeiros et al 2014, Ringer at al 2014
- The CMIP5/CFMIP-2 experiments have proven useful in interpreting precipitation responses in the climate system (e.g. Bony et al 2013, Chadwick et al 2013, He et al. 2014, Fermepin et al 2014, Thorpe and Andrews 2014)
- CFMIP experiments have also formed the basis for other pilot intercomparison projects (e.g. COOKIE Clouds Off and SPOOKIE convection off experiments)
- Analysis of CFMIP2 outputs are ongoing and we are still receiving data from some modelling groups, so the full value of the CFMIP2 experiments is yet to be realised.
- For relevant publications see http://www.cfmip.net -> ‘Publications’
- For work in progress see presentations from CFMIP meetings http://www.cfmip.net -> ‘CFMIP Meetings’

Some recent model evaluation studies using COSP:

Chepfer et al (submitted): Where and when would a space born lidar observe cloud changes due to climate warming? (Submitted to GRL)

English et al 2014: Contributions of clouds, surface albedos, and mixed-phase ice nucleation schemes to Arctic radiation biases in CAM5 (J Climate)

Wang et al 2014: Evaluation of cloud vertical structure simulated by recent BCC AGCM versions through comparison with CALIPSO-GOCCP data (Advances in Atmospheric Sciences)

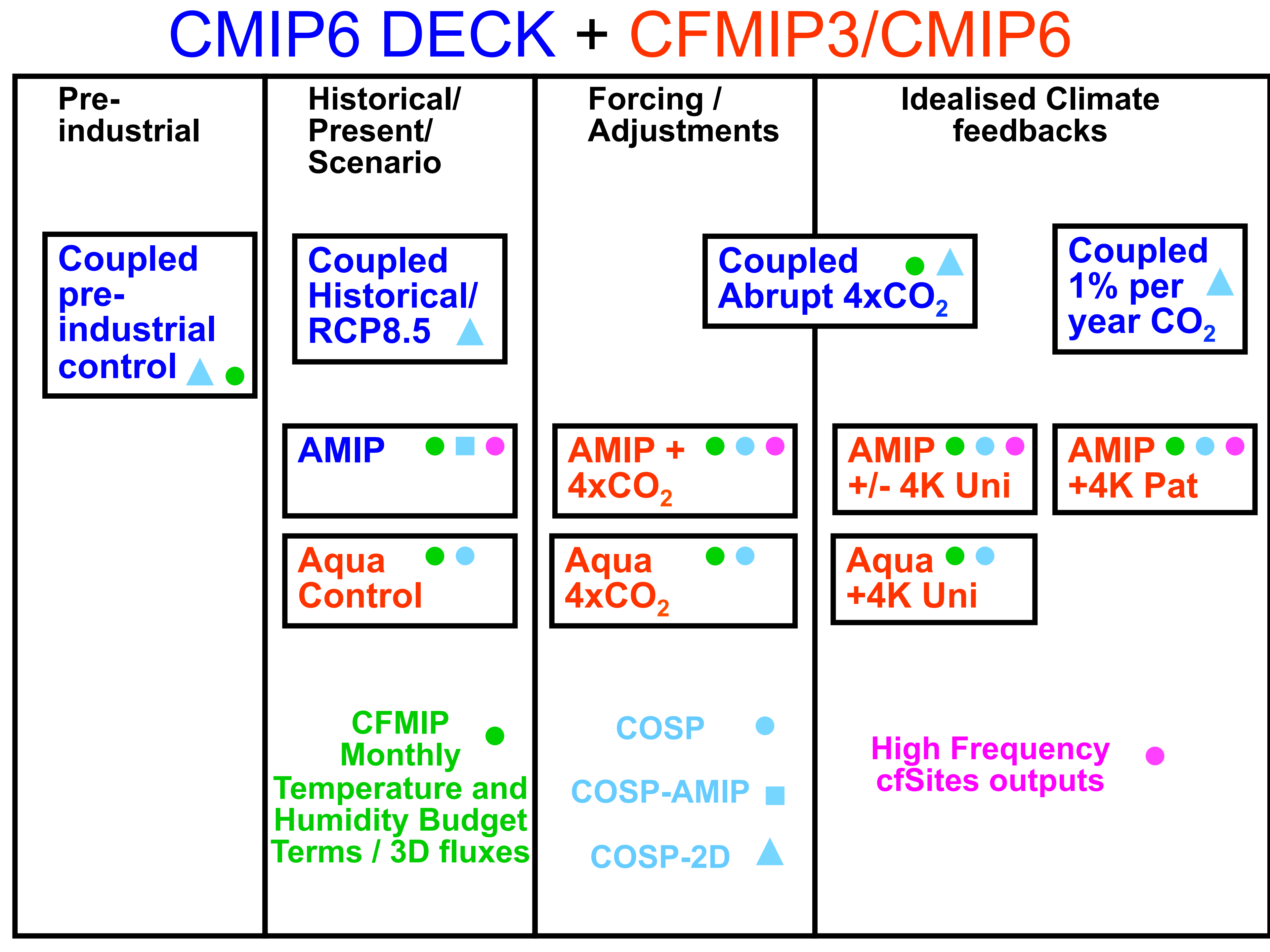
Lacagnina and Selten 2014: Evaluation of clouds and radiative fluxes in the EC-Earth general circulation model (Climate Dynamics)

Ma et al 2014: On the correspondence between mean forecast errors and climate errors in CMIP5. (J. Climate)

Lin et al 2014: Stratocumulus Clouds in Southeastern Pacific Simulated by Eight CMIP5–CFMIP Global Climate (J. Climate)

Grise and Polvani 2014: Southern Hemisphere cloud-dynamics biases in CMIP5 models and their implications for climate projections. (J. Climate)

Radley et al 2014: Uncertainties in radiative balance changes in response to ENSO in observations and models (J. Climate)


CMIP6 DECK + CFMIP3/CMIP6
Pre-industrial
Historical/ Present/ Scenario
Forcing / Adjustments
Idealised Climate feedbacks
Coupled pre-industrial control
Coupled Historical/ RCP8.5
Coupled Abrupt 4xCO2
Coupled 1% per year CO2
AMIP
AMIP + 4xCO2
AMIP +/- 4K Uni
AMIP +4K Pat
Aqua Control
Aqua 4xCO2
Aqua +4K Uni
CFMIP Monthly Temperature and Humidity Budget Terms / 3D fluxes
COSP
COSP-AMIP
COSP-2D
High Frequency cfSites outputs

CFMIP-2 Data available on the Earth System Grid as of June 2014

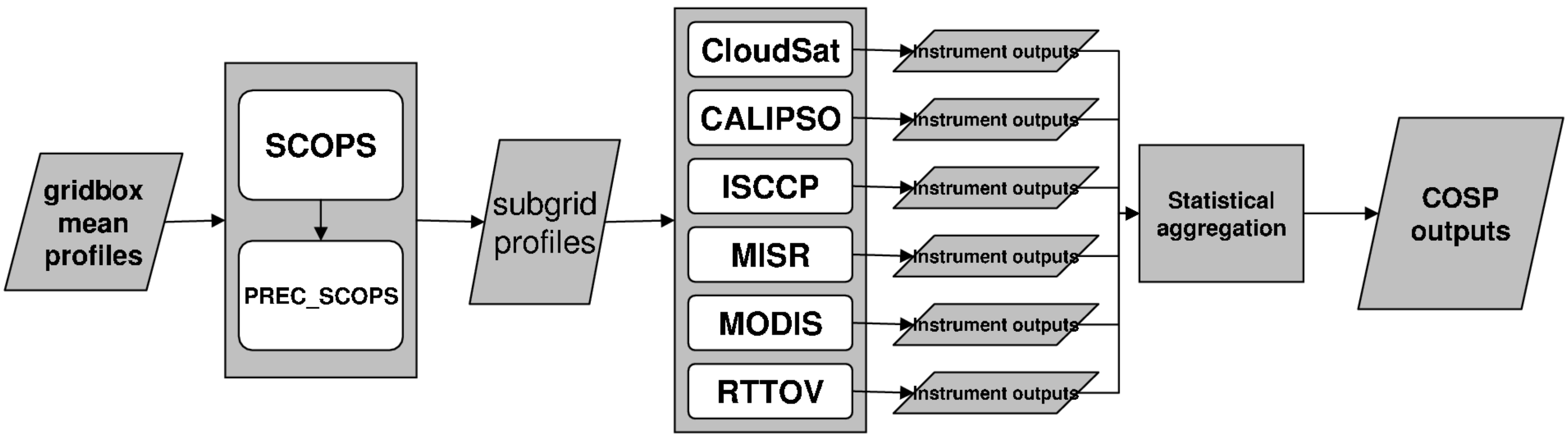
Met Office

Number of models with each type of data available for each experiment:

	Monthly Amon	Monthly cfMon	Monthly ISCCP/ CALIPSO	Daily CFMIP	Daily ISCCP/ CALIPSO	Timestep cfSites Outputs	COSP Orbital CloudSat/ CALIPSO	Gridded Orbital CloudSat/ CALIPSO	3 Hourly COSP Inputs
amip	30	12	11	11	11	7	5	4	4
amip4K	12	11	11	10	10	6	5	4	
amip4xCO2	15	12	12	11	11	5	5	4	
amipFuture	12	10	10	9	10	5	3	4	
aquaControl	9	7	8	6	8	4	1		
aqua4xCO2	8	7	7	8	7	4	1		
aqua4K	9	4	7	8	7	4	1		
piControl	45	6	9	10	9				
1pctCO2	34	4	8	9	8				
abrupt4xCO2	30	4	8	9	8				

Please see http://www.cfmip.net -> Data Availability
Please also check the data errata page:
http://cmip-pcmdi.llnl.gov/cmip5/errata/cmip5errata.html

CFMIP Observation Simulator Package (COSP)
Bodas-Salcedo et al, 2011 (BAMS)
http://www.cfmip.net -> COSP



COSP is being used by all of the major modelling groups in CMIP5.

Funding: IS-INES, NASA ROSES (Bodas-Salcedo, Pincus)

Developments: Stable release 1.4 for CMIP6

Recent model evaluation studies using COSP:

Chepfer et al (submitted): Where and when would a space born lidar observe cloud changes due to climate warming? (Submitted to GRL)

English et al 2014: Contributions of clouds, surface albedos, and mixed-phase ice nucleation schemes to Arctic radiation biases in CAM5 (J Climate)

Wang et al 2014: Evaluation of cloud vertical structure simulated by recent BCC AGCM versions through comparison with CALIPSO-GOCCP data (Advances in Atmospheric Sciences)

Lacagnina and Selten 2014: Evaluation of clouds and radiative fluxes in the EC-Earth general circulation model (Climate Dynamics)

Ma et al 2014: On the correspondence between mean forecast errors and climate errors in CMIP5. (J. Climate)

Lin et al 2014: Stratocumulus Clouds in Southeastern Pacific Simulated by Eight CMIP5–CFMIP Global Climate (J. Climate)

Grise and Polvani 2014: Southern Hemisphere cloud-dynamics biases in CMIP5 models and their implications for climate projections. (J. Climate)

Radley et al 2014: Uncertainties in radiative balance changes in response to ENSO in observations and models (J. Climate)

COSP is increasingly being used as part of the model development process:

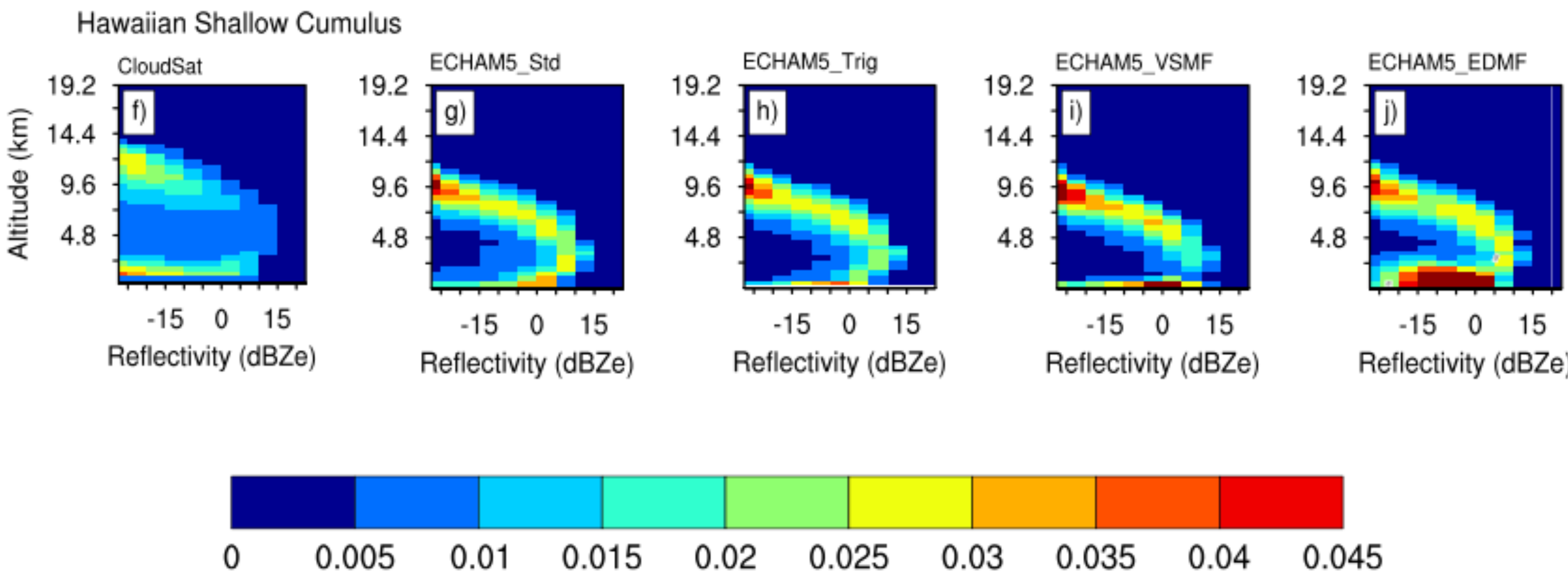


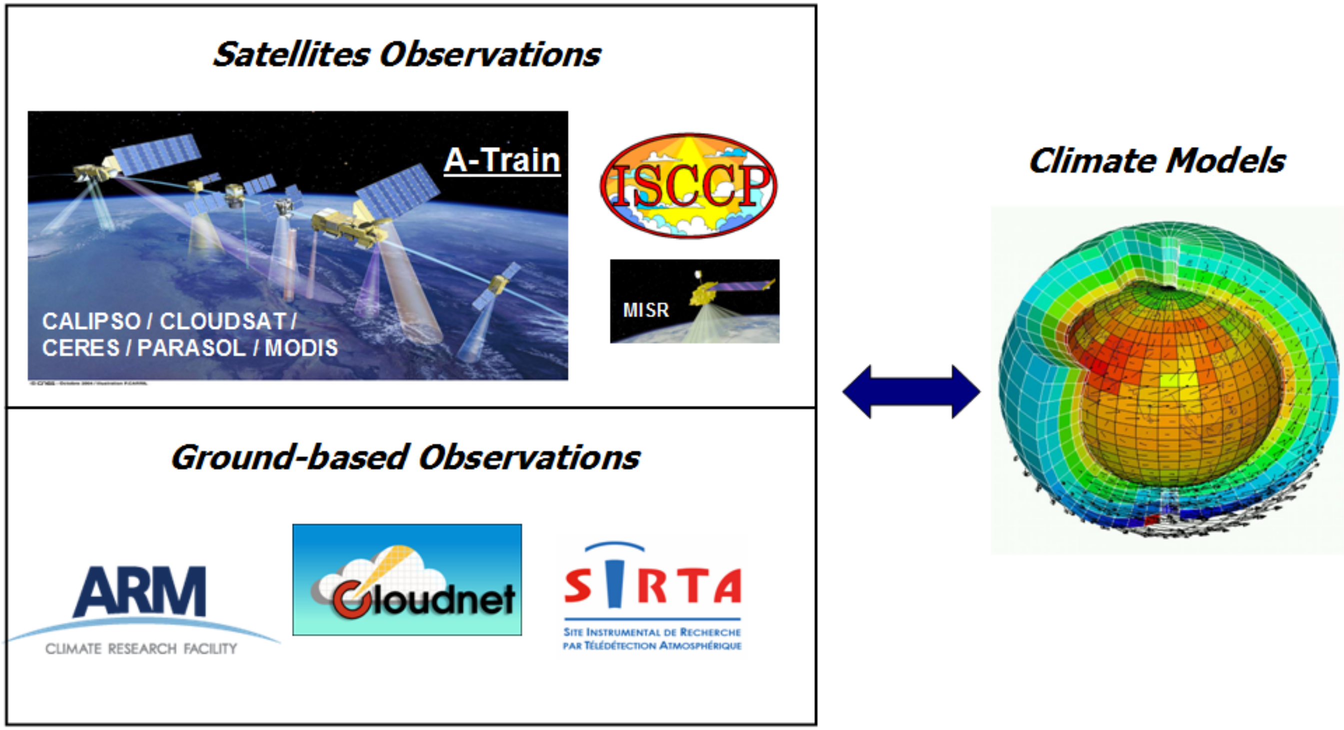
Figure 4. Cloud Altitude-Reflectivity Histogram for the Californian Stratocumulus and Hawaiian Trade Cumulus Cloud Regimes for JJA 2007.

Nam et al 2014: Evaluation of boundary layer cloud parameterizations in the ECHAM5 general circulation model using CALIPSO and CloudSat satellite data (JAMES)

- CFMIP Observations for model evaluation
- CALIPSO-GOCCP
  - 3D_CloudFraction
  - 3D_CloudFraction phase
  - 3D_CloudFraction phase temp
  - MapLowMidHigh
  - MapLowMidHighphase
  - SR_histo
  - SR_histophase
  - Instant_SR
  - Instant_SRphase
- CERES
- CLOUDSAT
- Ground ARM
- Ground EUROPEAN
- ISCCP
- MISR
- MODIS
- MULTI-SENSORS Analysis
- MULTI-SENSORS data
- PARASOL
- References

CFMIP-OBS

http://climserv.ipsl.polytechnique.fr/cfmip-obs



-Ongoing work to convert data into CMOR compliant NetCDF for ESGF via OBS4MIPS

-Preparation for future EarthCare Lidar/Radar Products with support from ESA

(Helene Chepfer, Gregory Cesana, Robert Pincus, Yuying Zhang, Roj Marchand)

Recent studies using COSP to examine cloud feedbacks/adjustments

Andrews and Ringer 2014: Cloud Feedbacks, Rapid Adjustments, and the Forcing–Response Relationship in a Transient CO2 Reversibility Scenario (J Climate)

Zelinka et al 2014: Quantifying Components of Aerosol Cloud Radiation Interactions in Climate (J. Climate)

Tsushima et al 2014: High cloud increase in a perturbed SST experiment with a global nonhydrostatic model including explicit convective processes. (JAMES)

Gordon et al 2014: Low cloud optical depth feedback in climate models (JGR)

Understanding forcings and feedbacks in idealised CMIP5/ CFMIP-2 experiments (amip, amip4xCO2, aqua, abrupt4xCO2)

Medeiros et al 2014: Using aquaplanets to understand the robust responses of comprehensive climate models to forcing (Climate Dynamics)

Ringer et al 2014: Global-mean radiative feedbacks and forcing in atmosphere-only and coupled ocean-atmosphere climate change experiments (GRL)

Kay et al 2014: Processes controlling Southern Ocean shortwave climate feedbacks in CESM (GRL)

Ogura at al 2014: Importance of instantaneous radiative forcing to tropospheric adjustment (Climate Dynamics)

Sherwood et al 2014: Spread in model climate sensitivity traced to atmospheric convective mixing (Nature)

Kamae and Watanabe (2012)

Aquaplanets capture many AMIP/coupled model responses of clouds, circulation and precipitation to warming and CO_2 quadrupling

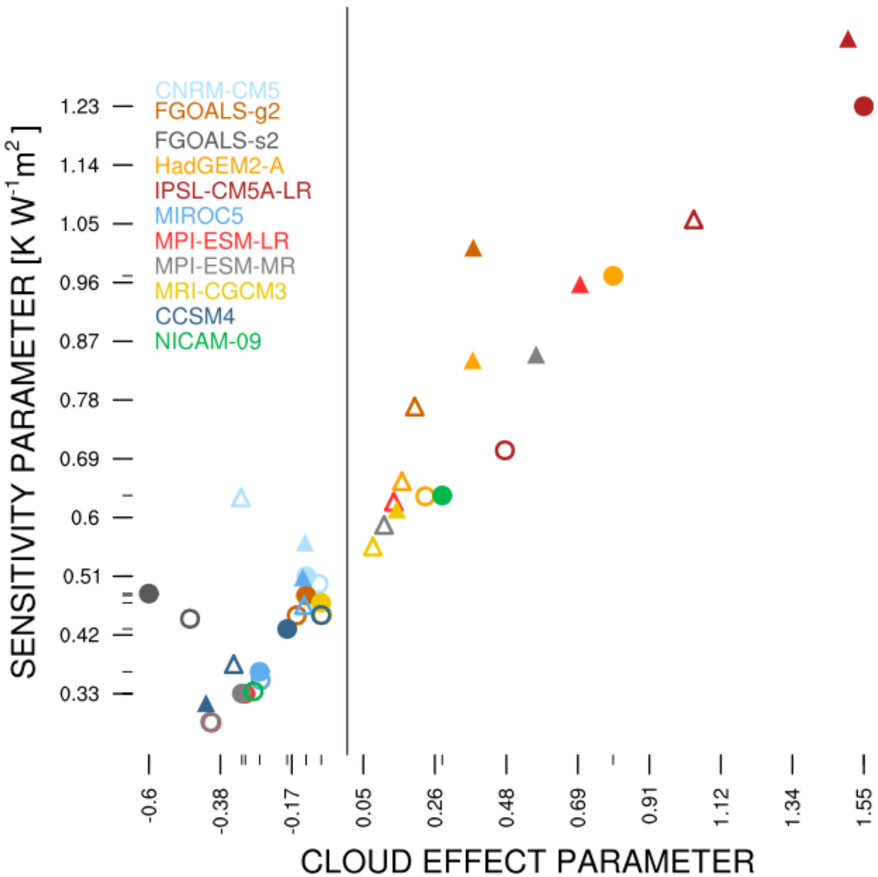


Fig. 3 Sensitivity versus cloud effect parameter for SST+4K warming experiments. *Triangles* show the AMIP experiments, *circles* show the aquaplanets. *Solid symbols* are the tropical values, while *unfilled symbols* are the global values. *Color* varies by model

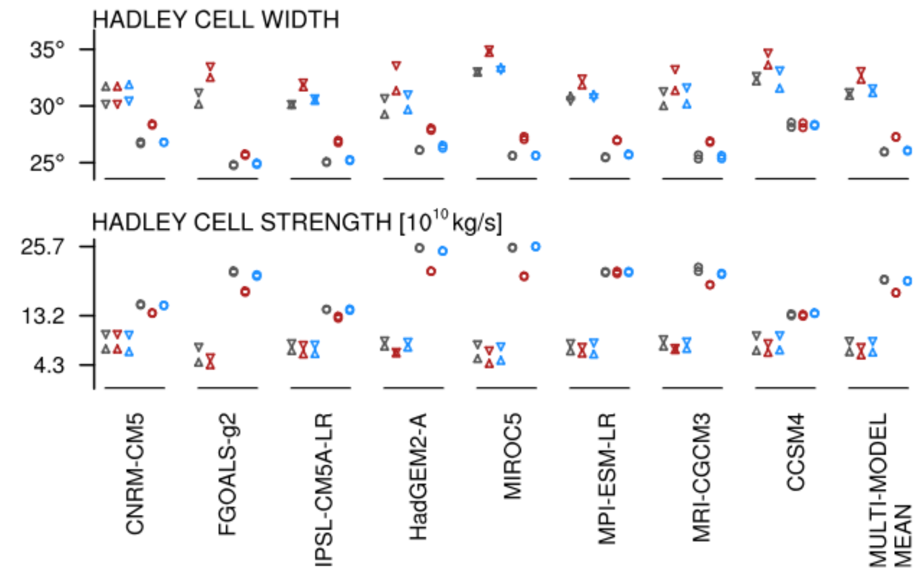


Fig. 5 Hadley circulation width (*top*) and strength (*bottom*) for each model and the multi-model mean (*far right*). *Triangles* denote the AMIP simulations (*upward* and *downward pointing* for northern and southern hemisphere, respectively) and *circles* the AQUA simulations. *Gray markers* show the control simulations, *red* the SST+4K, and *blue* the $4 \times CO_2$. The diagnostics are calculated using the meridional mass stream function vertically integrated between 700 and 300 hPa, $\hat{\psi}$. The width is determined as the most equatorward latitude where $\hat{\psi} = 0$ in each hemisphere, conditioned on being poleward of the absolute hemispheric maximum, $\hat{\psi}_{MAX}$, which defines the Hadley cell strength

Medeiros et al 2014: Using aquaplanets to understand the robust responses of comprehensive climate models to forcing (Climate Dynamics)

Constraining Cloud Feedbacks and Climate Sensitivity:

Caldwell et al 2014: Statistical Significance of Climate Sensitivity Predictors Obtained by Data Mining (GRL)

Qu et al: The strength of the tropical inversion and its response to climate change in 18 CMIP5 models. (Submitted to Climate Dynamics)

Gordon et al 2014: Low cloud optical depth feedback in climate models (JGR)

Su et al 2014: Weakening and Strengthening Structures in the Hadley Circulation Change under Global Warming and Implications for Cloud Response and Climate Sensitivity (JGR)

Sherwood et al 2014: Spread in model climate sensitivity traced to atmospheric convective mixing (Nature)

‘Emergent Constraint’ on cloud feedback and climate sensitivity

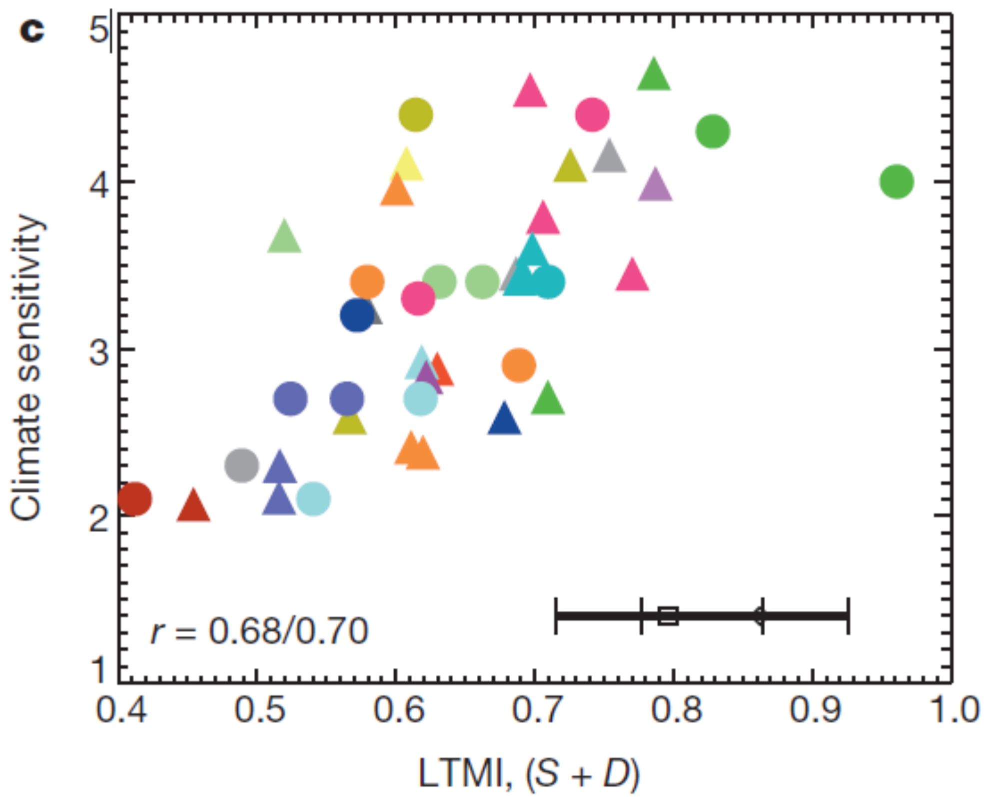


Figure 5 | Relation of lower-tropospheric mixing indices to ECS. ECS versus S (**a**), D (**b**) and LTMI = $S + D$ (**c**) from the 43 coupled models with known ECS. Linear correlation coefficients r are given in each panel.

Sherwood et al 2014: Spread in model climate sensitivity traced to atmospheric convective mixing (Nature)

rk

Understanding cloud feedback/adjustment mechanisms in LES/MLM/SCMs:

Bretherton and Blossey 2014: Low cloud reduction in a greenhouse warmed climate: Results from Lagrangian LES of a subtropical marine cloudiness transition (JAMES)

Jones et al 2014: Fast stratocumulus timescale in mixed layer model and large eddy simulation (JAMES)

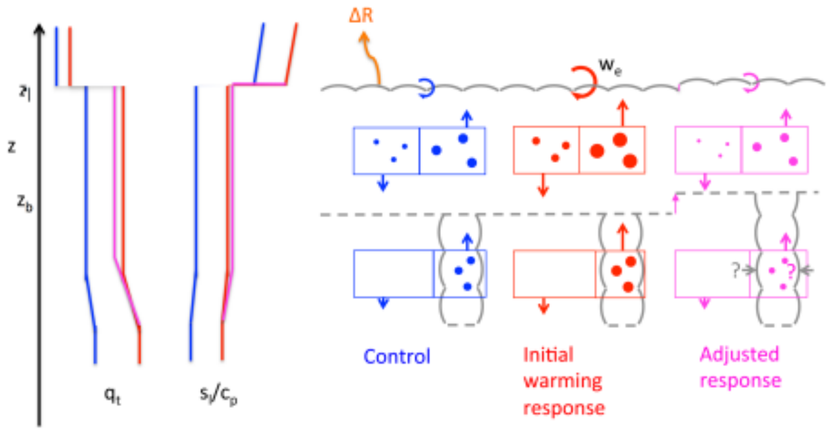
Dal Gesso et al 2014: Evaluation of low cloud climate feedback through Single Column Model equilibrium states (QJRMS)

Dal Gesso et al 2014: A mixed-layer model perspective on stratocumulus steady-states in a perturbed climate. (QJRMS)

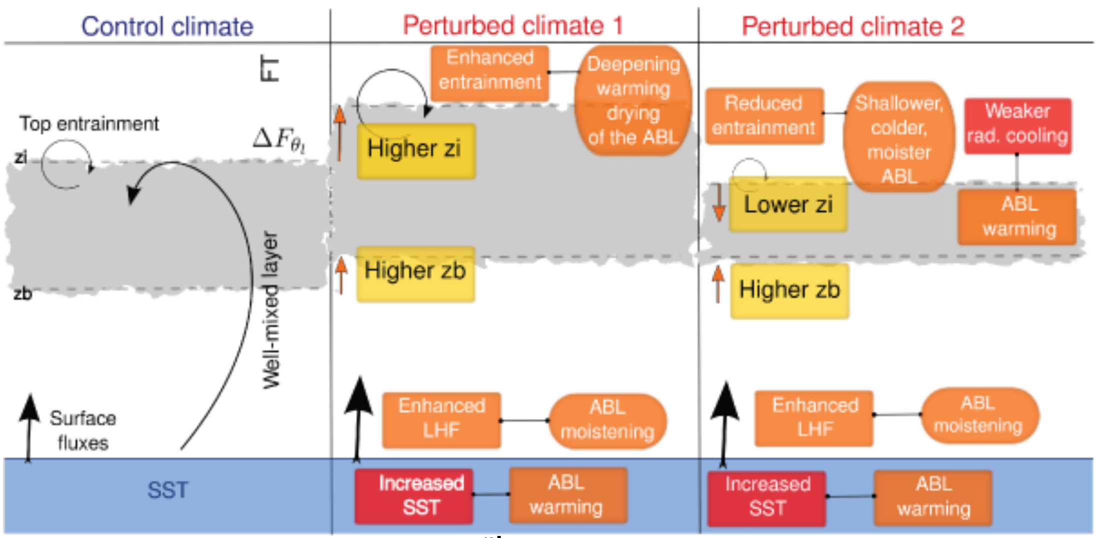
Dal Gesso et al (in preparation) A Single-Column Model Intercomparison on the stratocumulus representation in present-day and future climate

Zhang et al 2013: CGILS: First results from an international project to understand the physical mechanisms of low cloud feedbacks in general circulation models (JAMES)

New mechanisms are being identified in CGILS studies.



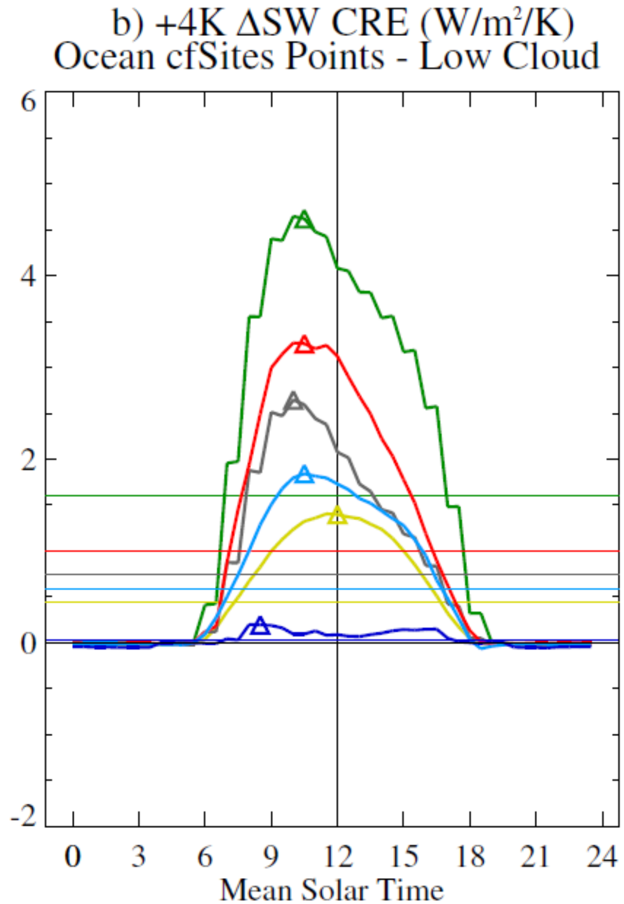
Bretherton and Blossey 2014: Low cloud reduction in a greenhouse warmed climate: Results fron Lagrangian LES of a subtropical marine cloudiness transition (JAMES)



rk

Dal Gesso et al 2014: A mixed-layer model perspective on stratocumulus steady-states in a perturbed climate. (QJRMS)

Diurnal cycle of marine cloud feedback: Inter-model spread is largest in the mornings.



Webb et al 2014: The diurnal cycle of marine cloud feedback in climate models (In press, Climate Dynamics)

Understanding changes in precipitation and the circulation:

Fermepin and Bony 2014: Influence of low cloud radiative effects on tropical circulation and precipitation (JAMES)

He et al 2014: The Robustness of the Atmospheric Circulation and Precipitation Response to Future Anthropogenic Surface Warming (GRL)

Kamae et al 2014: Summertime land–sea thermal contrast and atmospheric circulation over East Asia in a warming climate—Part II: Importance of CO2-induced continental warming (Climate Dynamics)

Thorpe and Andrews 2014: The physical drivers of historical and 21st century global precipitation changes (ERL)

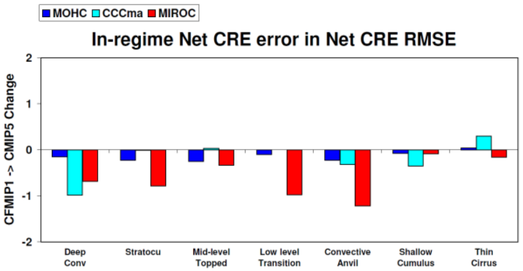
Lambert et al 2014: The cloud radiative effect on the atmospheric energy budget and global mean precipitation (Climate Dynamics)

Chadwick et al 2013: Surface Warming Patterns Drive Tropical Rainfall Pattern Responses to CO2 Forcing on All Timescales (GRL)

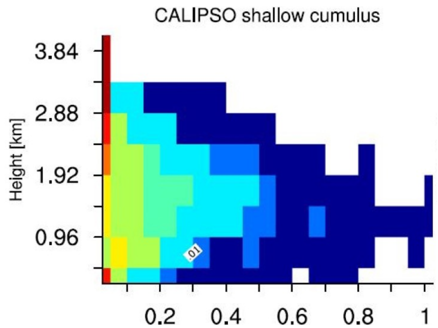
Grise and Polvani 2014: Is climate sensitivity related to dynamical sensitivity? A Southern Hemisphere perspective (GRL).

Ceppi et al: The Response of the Southern Hemispheric Eddy-Driven Jet to Future Changes in Shortwave Radiation in CMIP5 (Submitted to GRL)

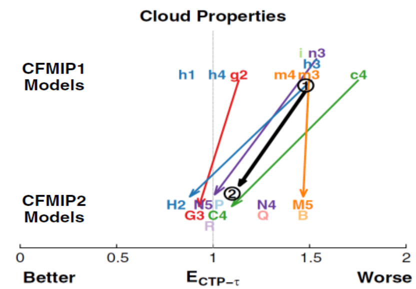
CFMIP Metrics/Diagnostics Repository



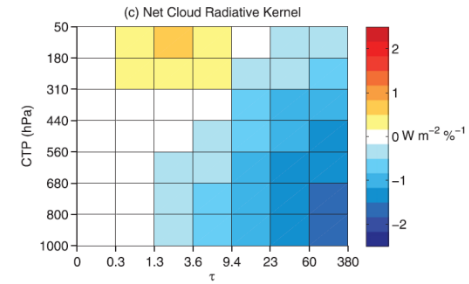
Williams and Webb 2009
Tsushima et al. 2012



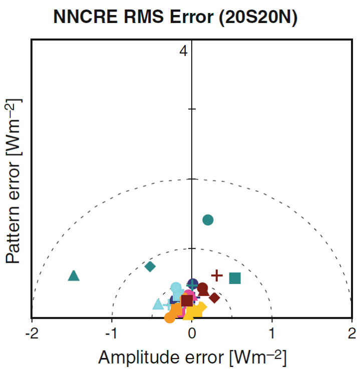
Nam et al., 2012



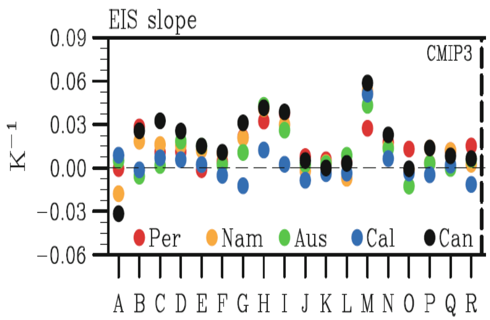
Klein et al. 2012



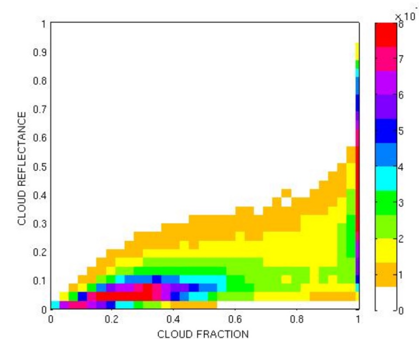
Zelinka et al. 2012



Tsushima et al., 2012



Qu et al., 2012



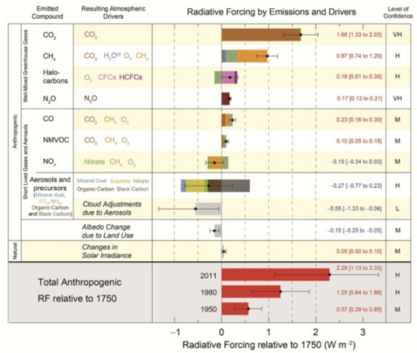
Konsta et al., 2012

Any metrics/diagnostics related to clouds whose multi-model analysis results are published are welcome.

Modellers and analysts are encouraged to use and add to the repository – documentation and help/advice are available.

For details see http://www/cfmip.net -> CFMIP Diagnostic Codes
or email yoko.tsushima@metoffice.gov.uk

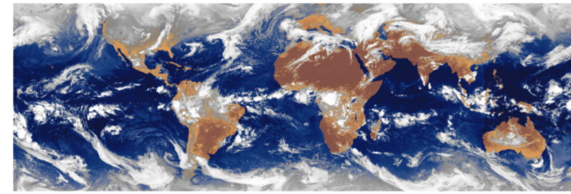
CFMIP Future Plans Friday



RFMIP (Radiative Forcing)

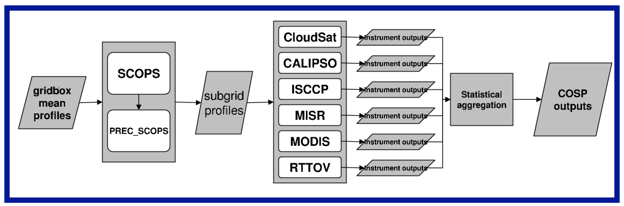
WCRP Grand Challenge on

Clouds, Circulation and Climate Sensitivity



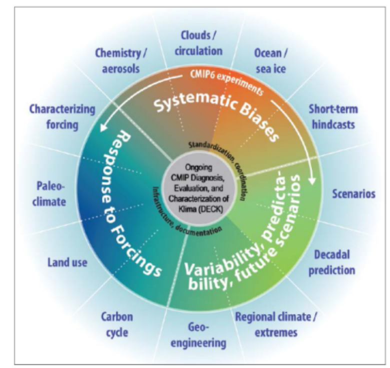
http://www.wcrp-climate.org/index.php/gc-clouds

WCRP World Climate Research Programme

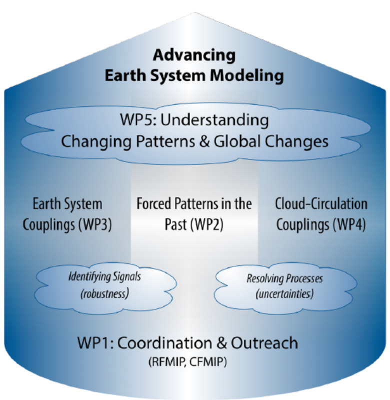


COSP

CFMIP3



CMIP6



IMPULSE

GASS GEWEX WCRP Global Atmospheric System Studies

Paleoclimate Modelling

PMIP

Intercomparison Project

CFMIP Future Plans - Friday

WCRP Grand Challenge on Cloud Feedbacks and Climate Sensitivity

COSP in CMIP6

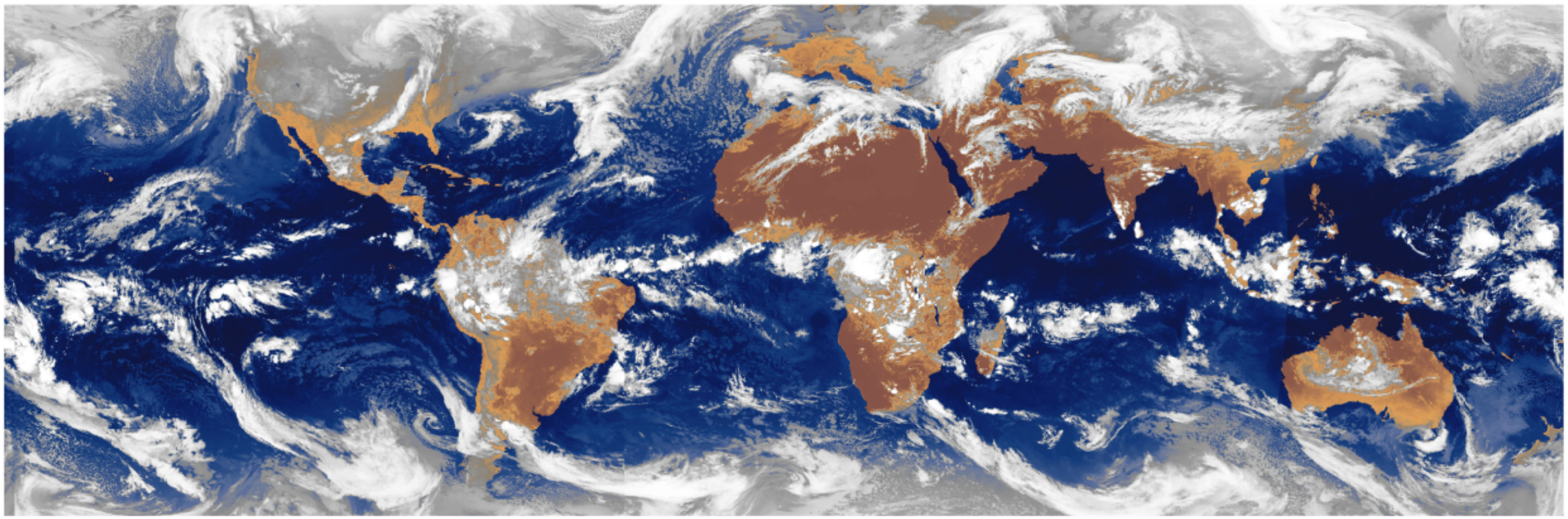
CFMIP Phase III and CMIP6

Links to other projects – GEWEX / GASS, PMIP, RFMIP, IMPULSE

Next CFMIP Meeting Summer 2015 - Offers to host very welcome!

WCRP Grand Challenge on

Clouds, Circulation and Climate Sensitivity

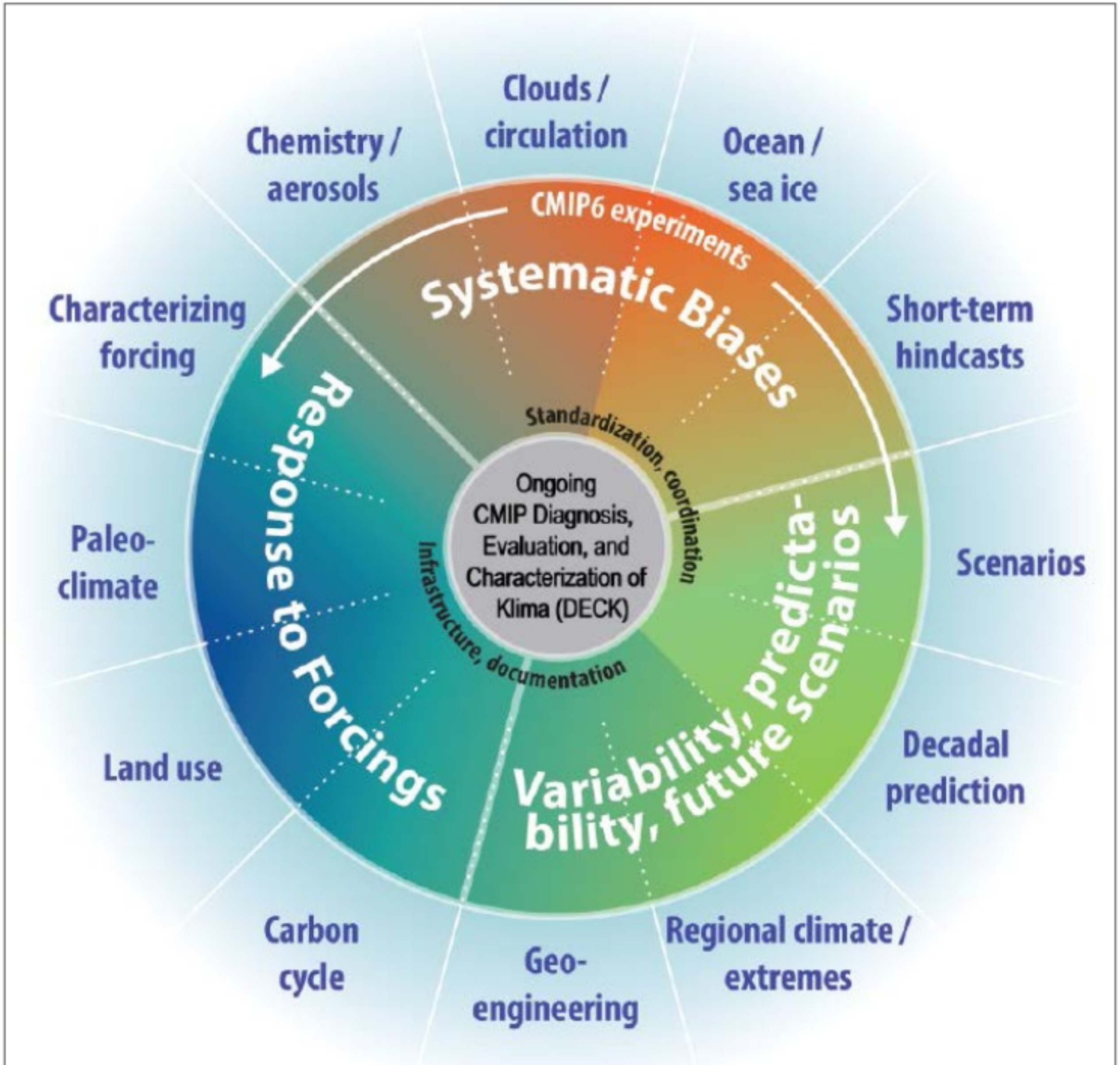


http://www.wcrp-climate.org/index.php/gc-clouds

Discussion led by Sandrine and Bjorn on Friday

World Climate Research Programme

CMIP6 Experimental Design (Meehl et al, *EOS*, 2014)



Proposed approach for CFMIP-3 Experiments

Avoid major changes to the CMIP6 experimental design compared to CMIP5/CMIP5.

Encourage more modelling groups to provide the CMIP5/CFMIP-2 idealised expts by retaining amip4xCO2, amip4K, amipFuture and aquaplanets in CMIP6

Also retain process outputs (temperature and humidity budget tendencies, cfSites outputs, ISCCP/CALIPSO/CloudSat simulator outputs) in CFMIP/CMIP6

Include simulator and process diagnostics in CMIP6 DECK experiments

Any new experiments in CMIP6 should be easy to implement. More complex experiments should be coordinated by CFMIP outside of CMIP6

Communicate more clearly the rationale for new experiments by linking to CMIP5 ‘science gaps’ and WCRP Grand Challenge on Clouds, Circulation and Climate Sensitivity

CFMIP3 experiments

The primary goal of CFMIP is to inform improved assessments of climate change cloud feedbacks.

This involves bringing climate modelling, observational and process communities closer together and providing better tools and community support for understanding and evaluation of clouds and cloud feedbacks simulated by climate models.

CFMIP supports ongoing coordinated model inter-comparison activities by recommending experiments and model output diagnostics for CMIP, designed to support the understanding and evaluation of cloud processes and cloud feedbacks in models.

The CFMIP approach is increasingly being applied to other aspects of climate change – circulation, regional-scale precipitation and non-linear changes.

CFMIP3 is proposing a number of experiments and model outputs for CMIP6, building on and extending the CFMIP experiments which were part of CMIP5.

Additional CFMIP3 experiments may be organised independently of CMIP6.

For full details see http://www.cfmip.net -> CFMIP Strategy and Plans