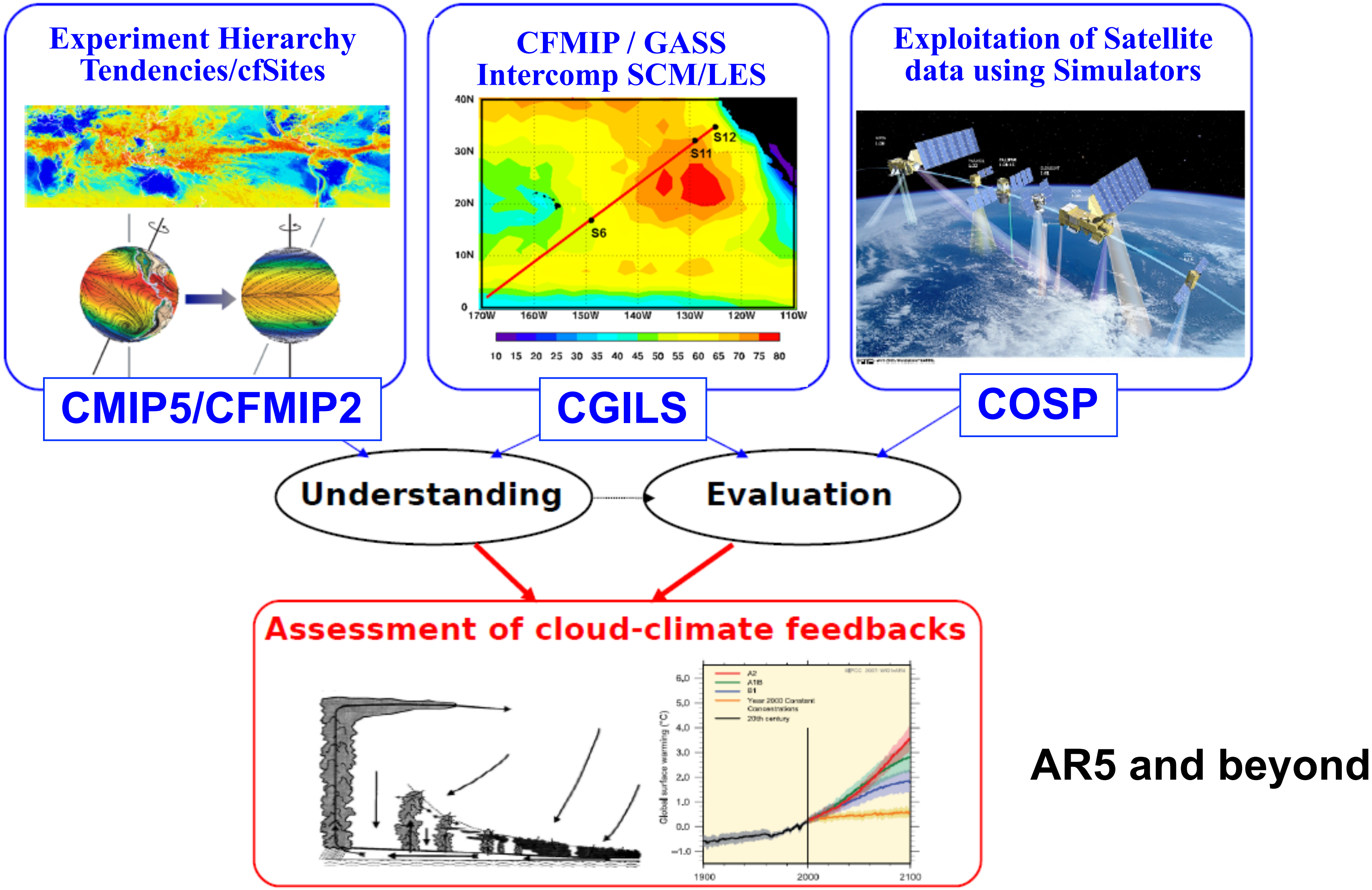
The Cloud Feedback Model Inter-comparison Project

A WGCM project in collaboration with GEWEX/GASS

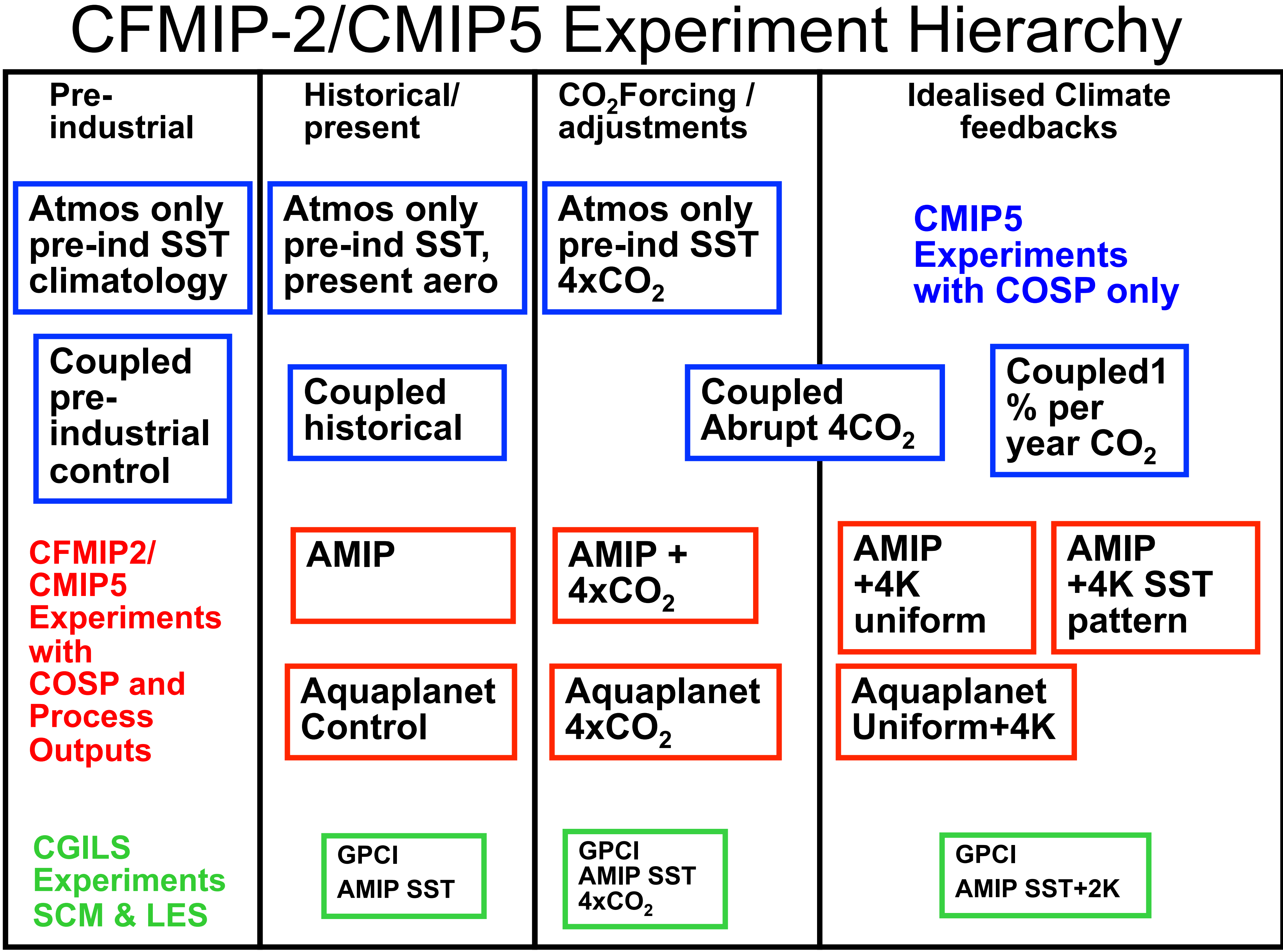
Mark Webb and Chris Bretherton, CFMIP co-chairs

CFMIP Coordination Committee:
Sandrine Bony, Jen Kay, Steve Klein, George Tselioudis,
Pier Siebesma, Bjorn Stevens, Masahiro Watanabe

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



Objective:To inform assessments of climate change cloud feedbacks by improving evaluation of clouds simulated by climate models and understanding of cloud-climate feedback processes.


CFMIP-2/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 $4xCO_2$
GPCI AMIP SST+2K

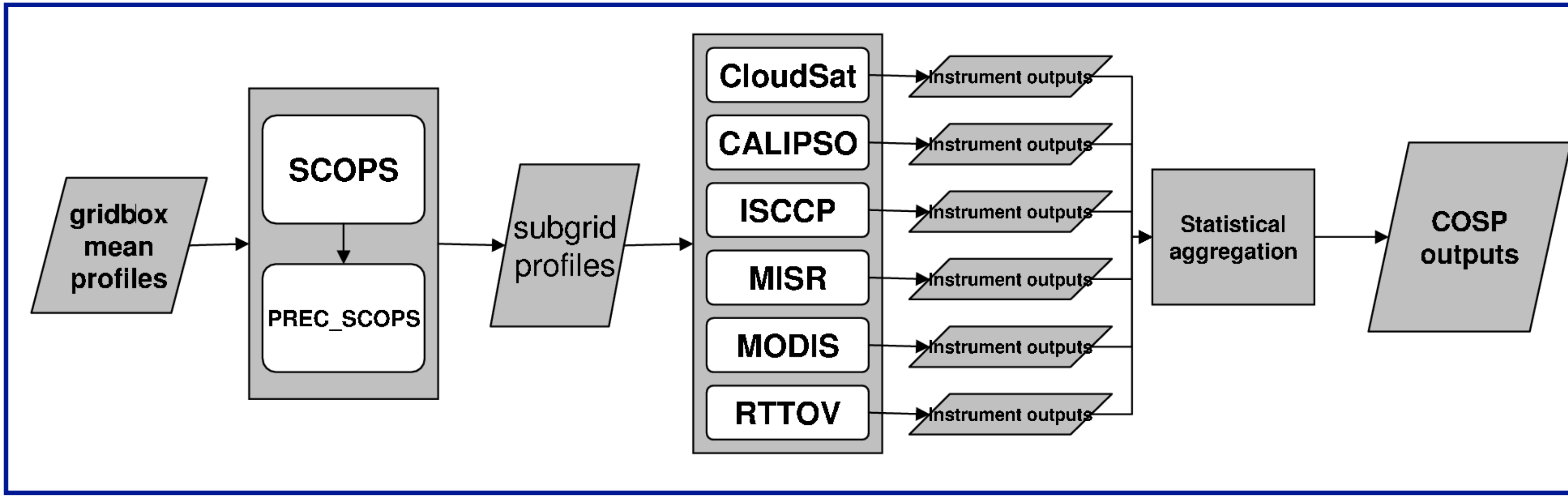
CFMIP-2 Data available on the Earth System Grid

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	12	12	7	5	4	4
amip4K	13	12	12	10	10	6	5	4	
amip4xCO2	13	12	12	11	11	5	5	4	
amipFuture	12	10	10	9	10	5	3	4	
aquaControl	10	7	8	6	8	4	1		
aqua4xCO2	9	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	31	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

Stable release COSP 1.4 for CMIP6 available since Nov 2013

Future developments (See Alejandro Bodas-Salcedo's talk on Thursday)

Recent model evaluation studies using COSP:

Zhang et al 2015: Simulations of Stratus Clouds over Eastern China in CAM5 (J. Climate)

Mason et al 2015: A hybrid cloud regime methodology used to evaluate Southern Ocean cloud and shortwave radiation errors in ACCESS (J Climate)

English et al 2015: Arctic Radiative Fluxes: Present-day biases and future projections in CMIP5 (J Climate)

Ban-Weiss et al 2014: Evaluating clouds, aerosols, and their interactions in three global climate models using satellite simulators and observations, (JGR)

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)

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

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Please see http://www.cfmip.net for full publication list

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

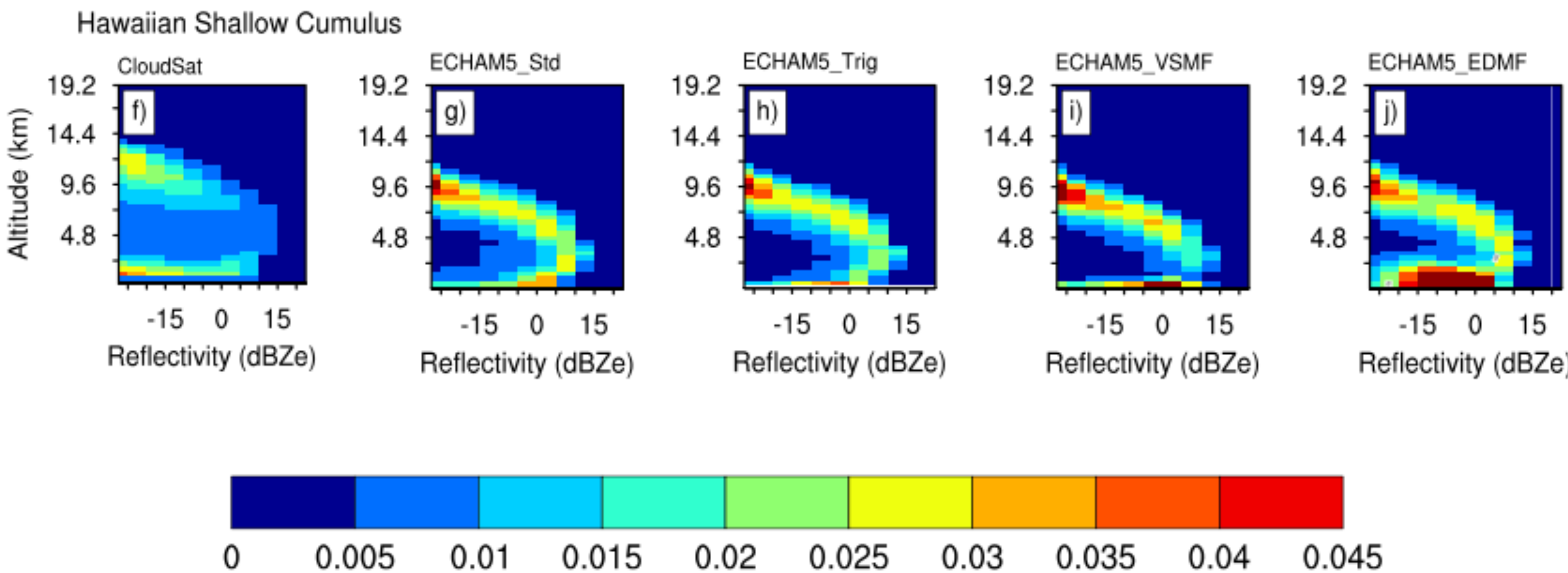
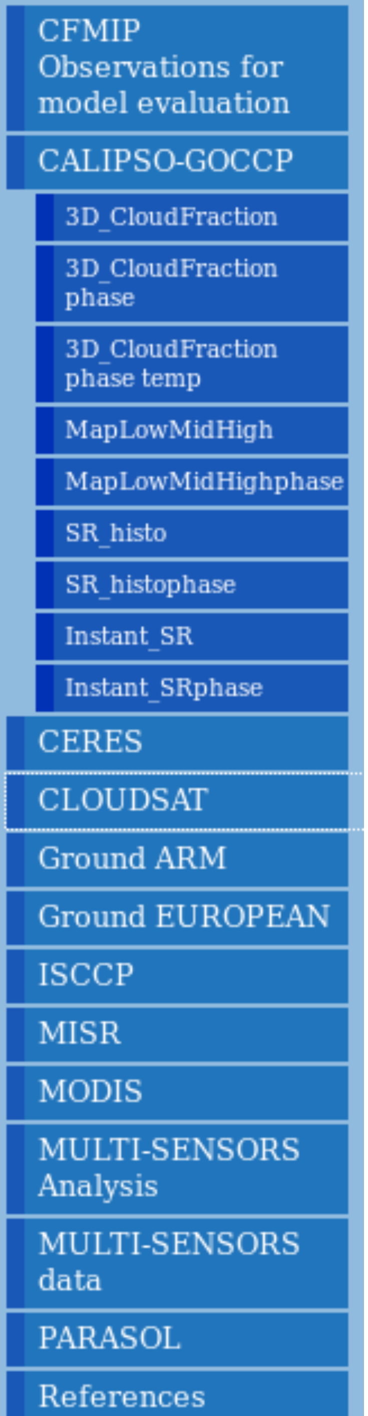


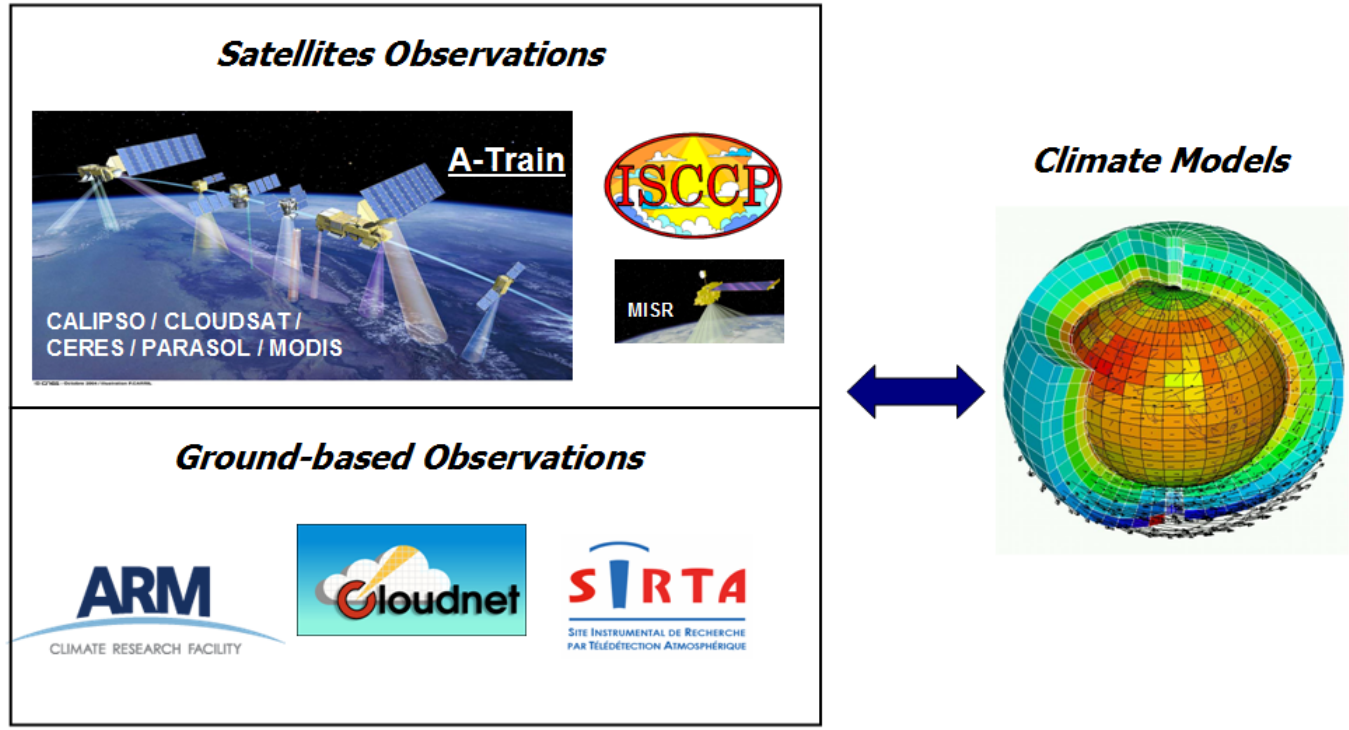
Figure 4. Cloud Altitude-Reflectivity Histogram for the Californian Stratocumulus and Hawaiian Trade Cumulus Cloud Regimes for JJA 2007.

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



CFMIP-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 and quantify cloud feedbacks / adjustments

Tsushima at al (submitted) Robustness, uncertainties, and emergent constraints in the radiative responses of stratocumulus cloud regimes to future warming (Climate Dynamics)

Chepfer et al 2014: Where and when would a space born lidar observe cloud changes due to climate warming? (GRL)

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)

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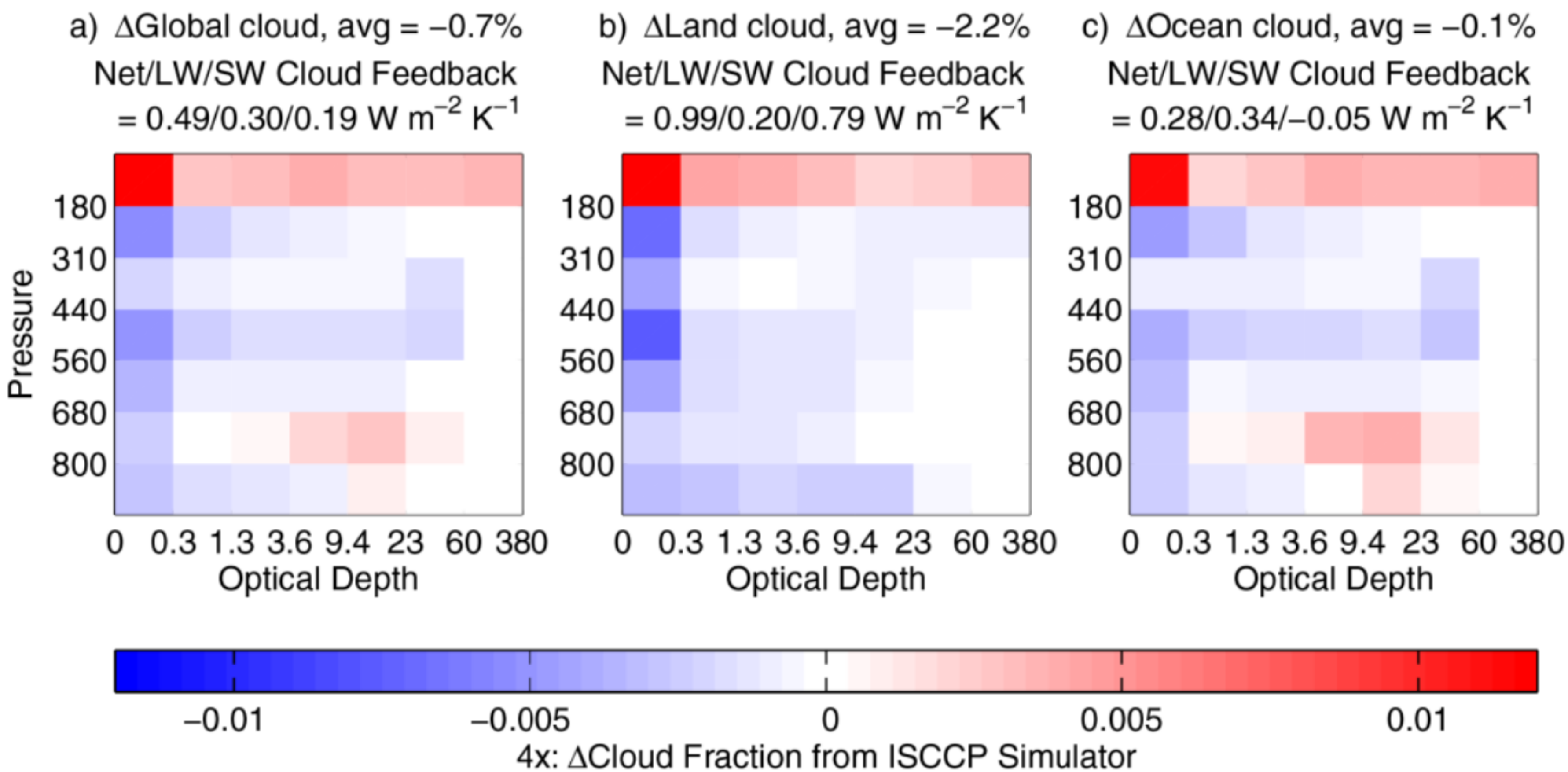
Please see http://www.cfmip.net for full publication list

Using COSP to examine and quantify cloud feedbacks/adjustments



Bretherton et al 2014: Cloud feedbacks on greenhouse warming in the super-parameterized climate model SP-CCSM4 (JAMES)

Understanding forcings and feedbacks using idealised CFMIP5/CFMIP-2 experiments / process diagnostics (AMIP, aqua, abrupt4xCO2)

Brient et al submitted: Shallowness of tropical low clouds as a predictor of climate models' response warming (Climate Dynamics)

Ceppi et al submitted: Mechanisms of the negative shortwave cloud feedback in mid to high latitudes (J Climate)

Webb et al 2015: The diurnal cycle of marine cloud feedback in climate models (Climate Dynamics)

Qu et al 2014: The strength of the tropical inversion and its response to climate change in 18 CMIP5 models (J Climate)

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)

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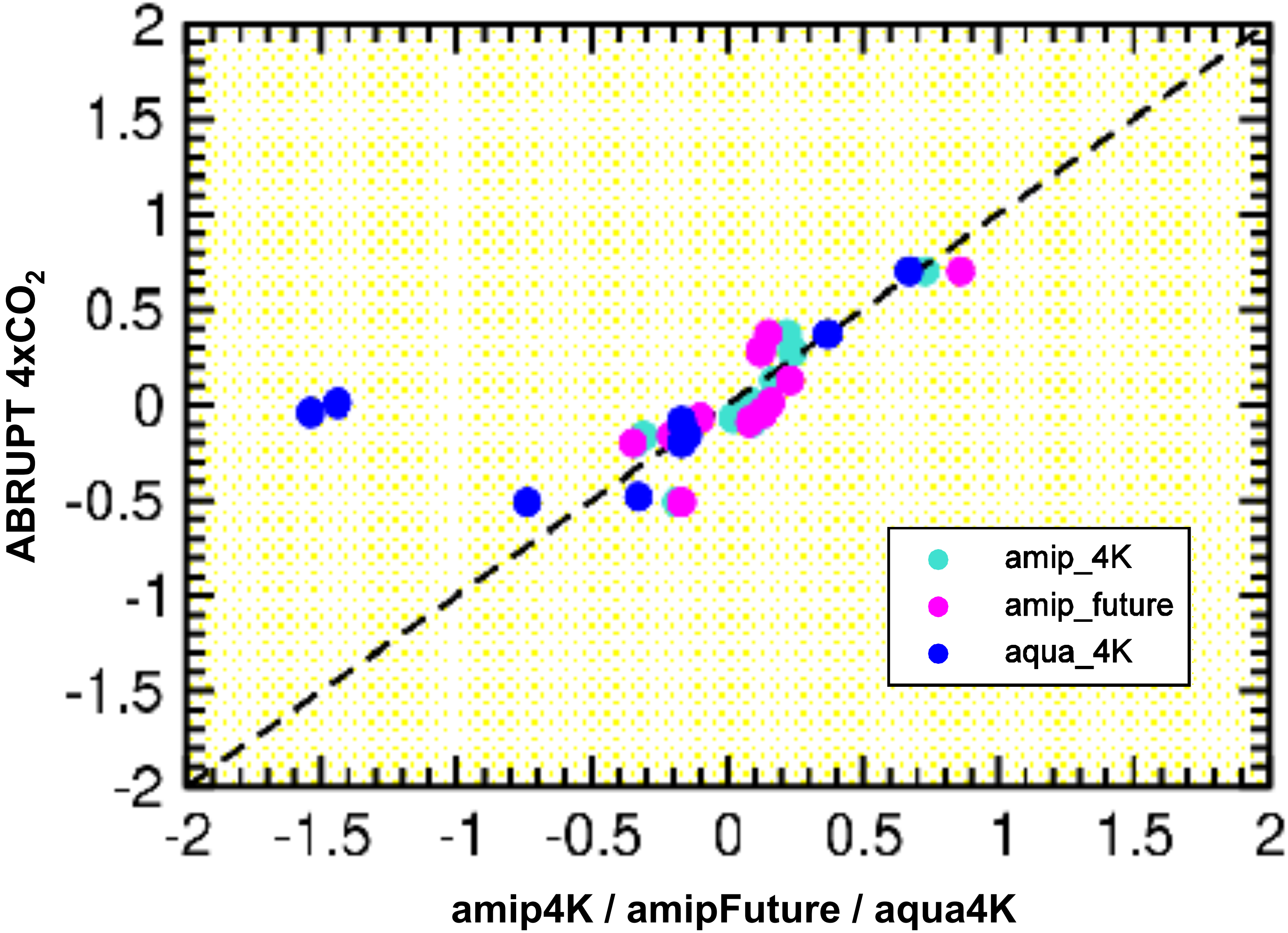
CFMIP atmosphere-only experiments capture cloud feedbacks in AOGCMs



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

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

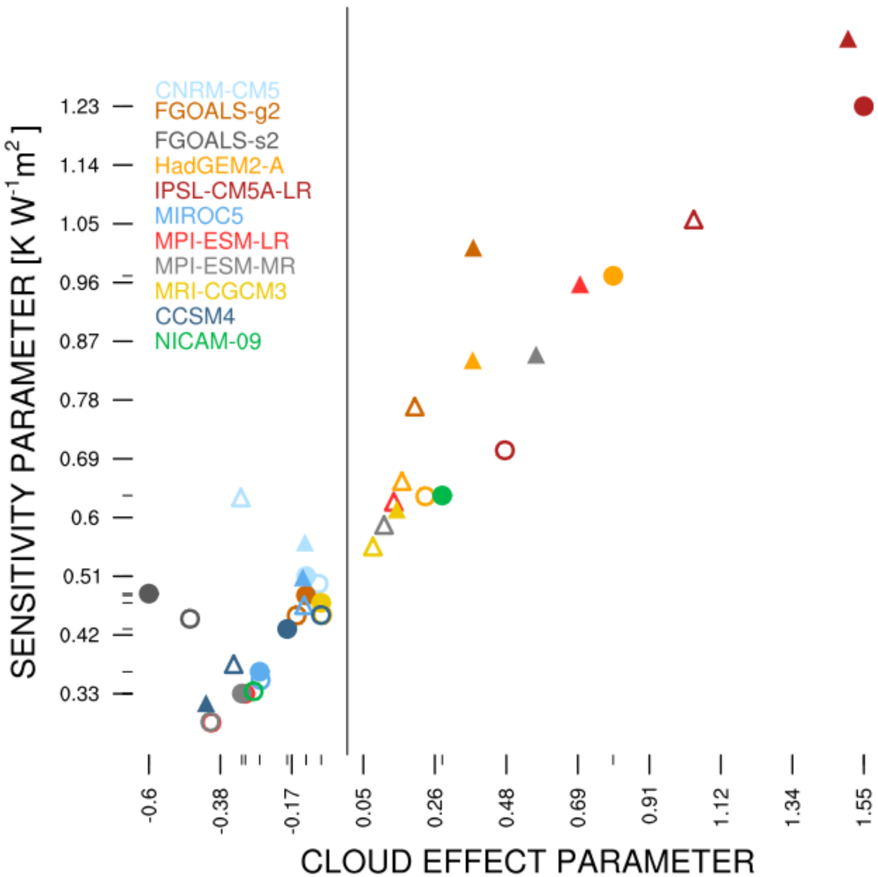


Fig. 3 Sensitivity versus cloud effect parameter for SST+4K warming experiments. *Triangles* show the AMIP experiments, *circles* show the aquaplanets. *Solid symbols* are the tropical values, while *unfilled symbols* are the global values. *Color* varies by model

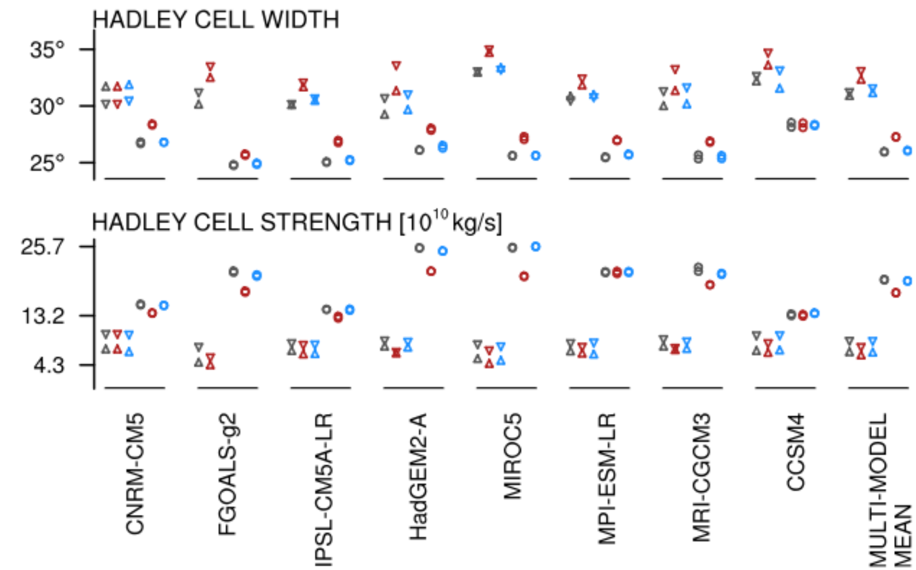
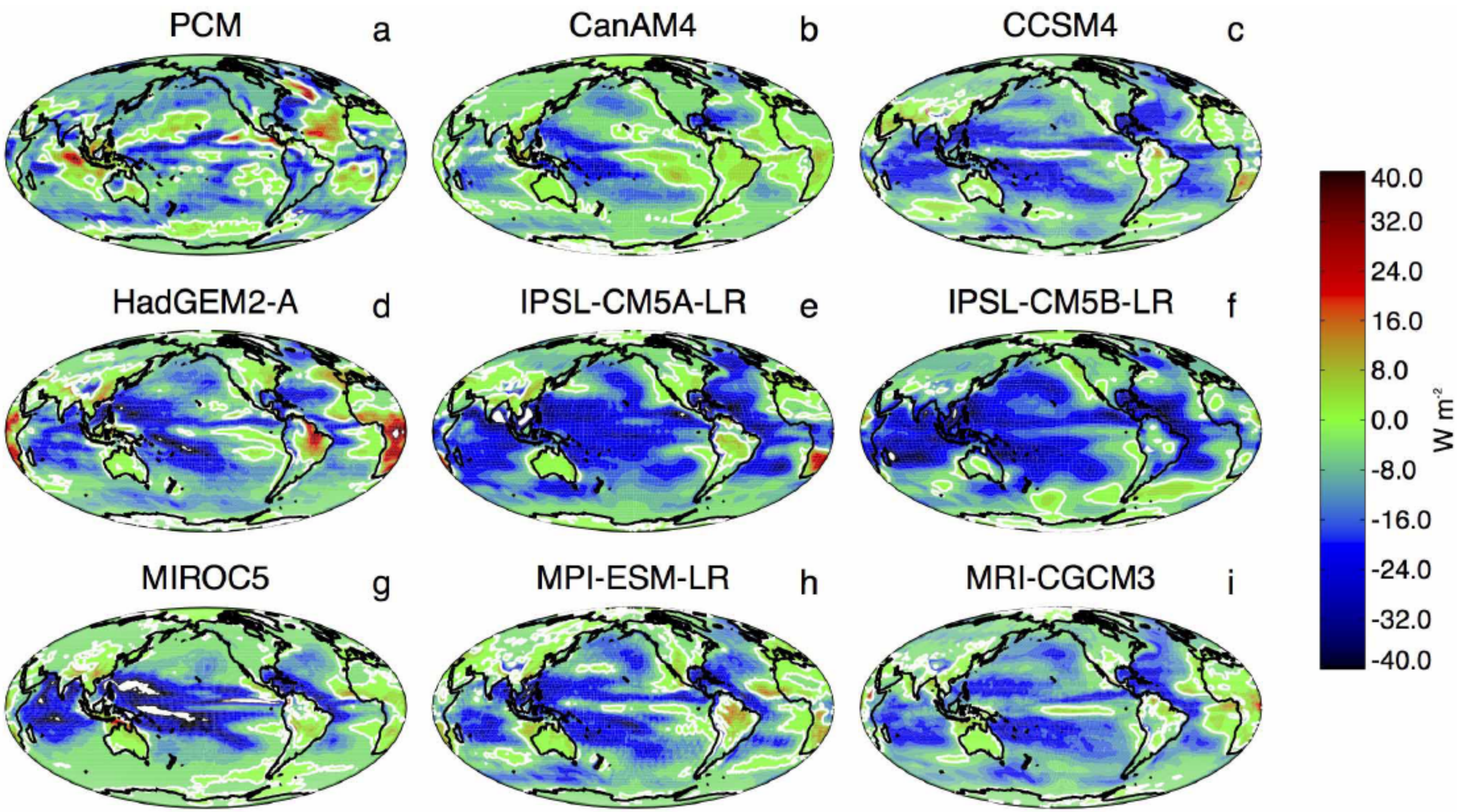


Fig. 5 Hadley circulation width (*top*) and strength (*bottom*) for each model and the multi-model mean (*far right*). *Triangles* denote the AMIP simulations (*upward* and *downward pointing* for northern and southern hemisphere, respectively) and *circles* the AQUA simulations. *Gray markers* show 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)

Use of CFMIP amip4K tendency terms to understand cloud feedback mechanisms:



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.

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

Constraining Cloud Feedbacks and Climate Sensitivity:

Tsushima at al submitted: Robustness, uncertainties, and emergent constraints in the radiative responses of stratocumulus cloud regimes to future warming (Climate Dynamics)

Brient et al submitted: Shallowness of tropical low clouds as a predictor of climate models' response warming (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)

Qu et al 2014: On the spread of changes in marine low cloud cover in climate model simulations of the 21st century (Climate Dynamics)

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

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Please see http://www.cfmip.net for full publication list

‘Emergent Constraint’ on cloud feedback and climate sensitivity

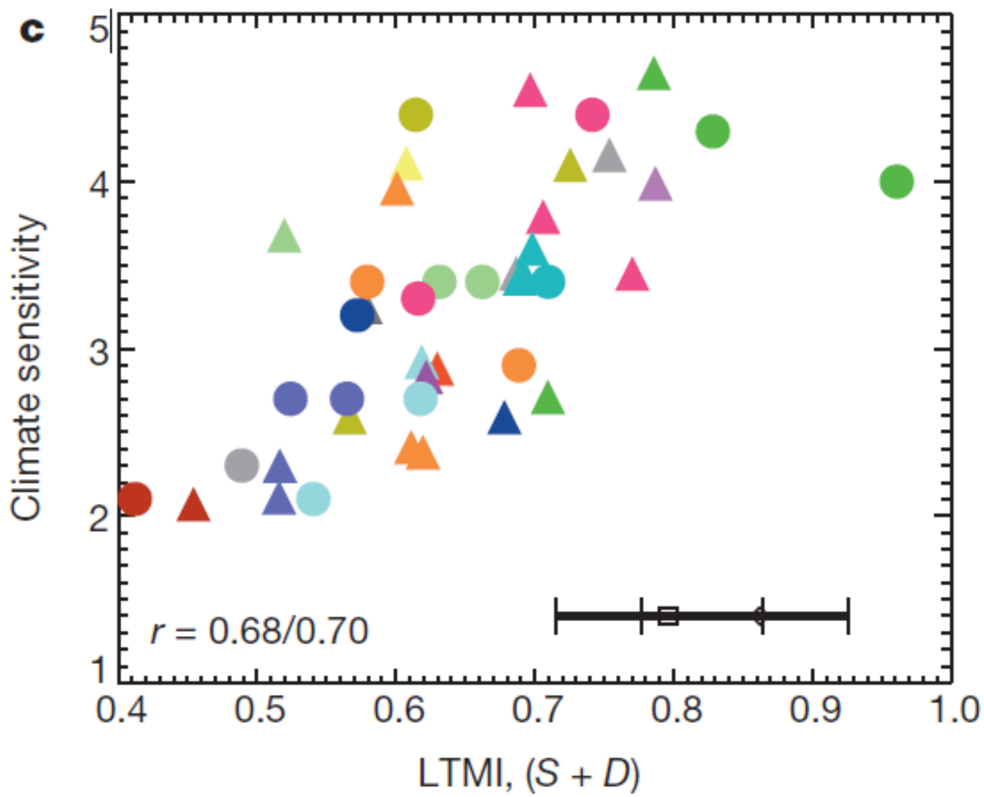

Figure 5 | Relation of lower-tropospheric mixing indices to ECS. ECS versus S (**a**), D (**b**) and LTMI = $S + D$ (**c**) from the 43 coupled models with known ECS. Linear correlation coefficients r are given in each panel

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

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

Bretherton et al (submitted): Insights into low-latitude cloud feedbacks from high-resolution models (Phil Trans A)

van der Dussen et al 2015: An LES model study of the influence of the free tropospheric thermodynamic conditions on the stratocumulus response to a climate perturbation (QJRMS)

Dal Gesso et al 2015: A Single-Column Model Intercomparison on the stratocumulus representation in present-day and future climate (JAMES)

De Roode et al 2014: A mixed-layer model study of the stratocumulus response to changes in large-scale conditions (J. Climate)

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)

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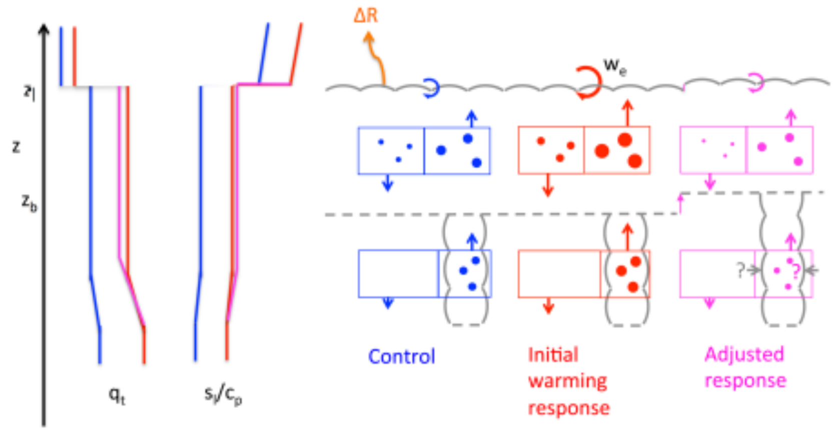
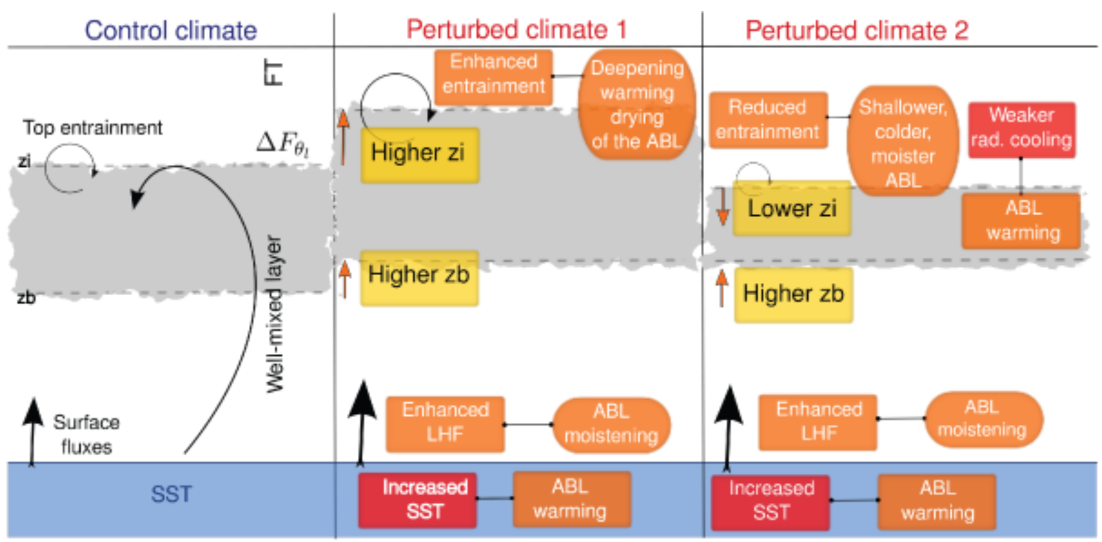
New cloud feedback mechanisms are being identified in CGILS studies:

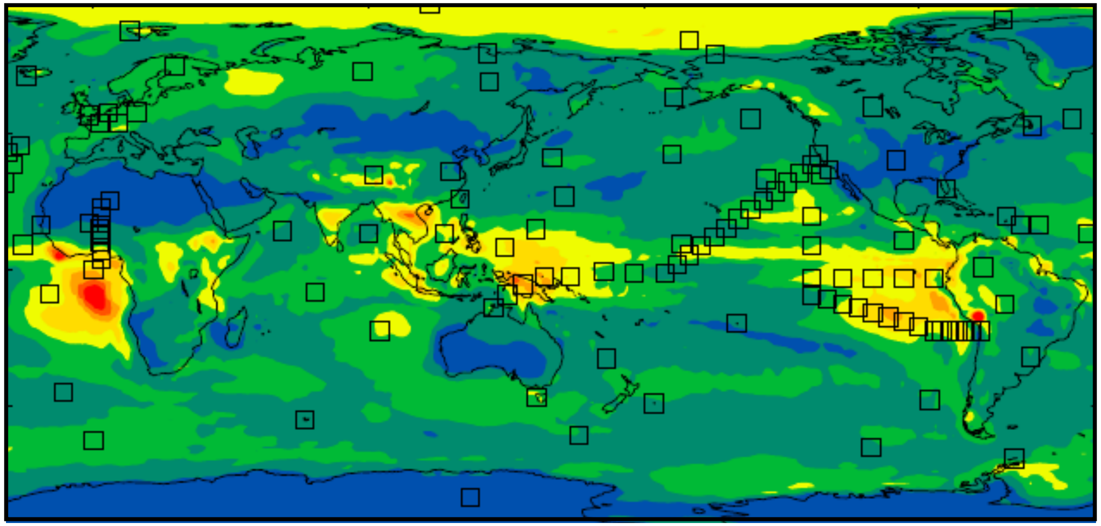


Bretherton and Blossey 2014: Low cloud reduction in a greenhouse warmed climate: Results from Lagrangian LES of a subtropical marine cloudiness transition (JAMES)



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

Instantaneous high frequency outputs at 120 'cfSites' locations

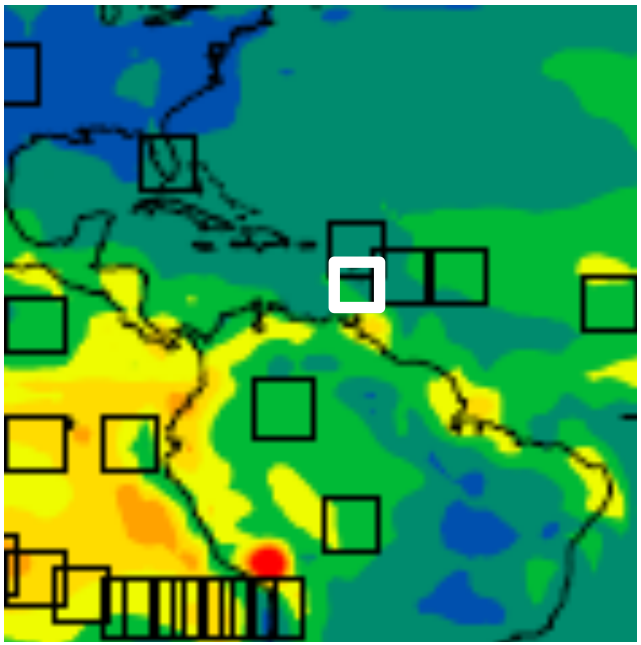


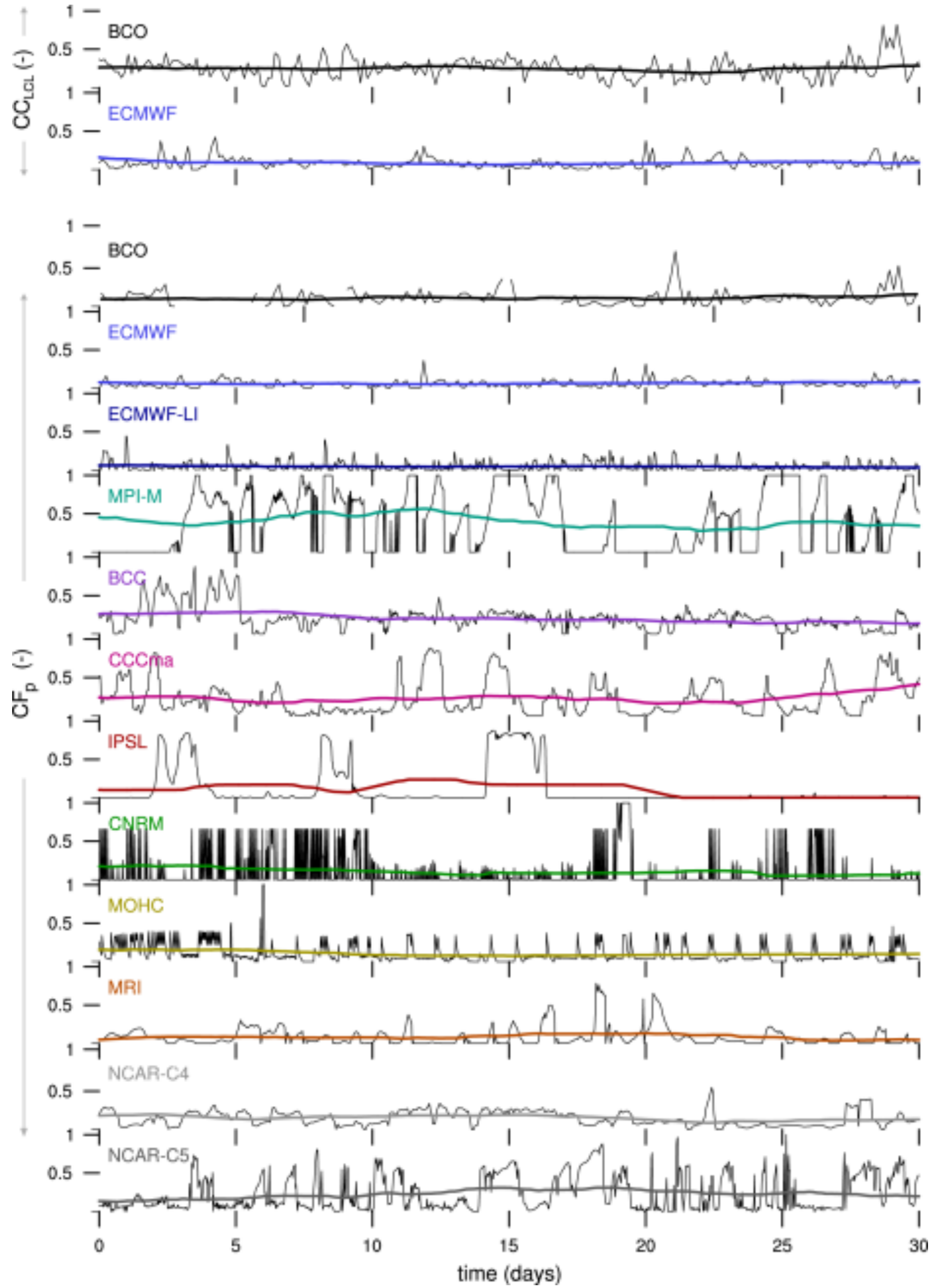
Nuijens et al submitted: Observed and modeled patterns of co-variability between low-level cloudiness and the structure of the trade-wind layer. (JAMES)

Neggers at al in preparation: Attributing the behavior of low-level clouds in large-scale models to sub-grid scale parameterizations.

Webb et al 2015: The diurnal cycle of marine cloud feedback in climate models (Climate Dynamics)

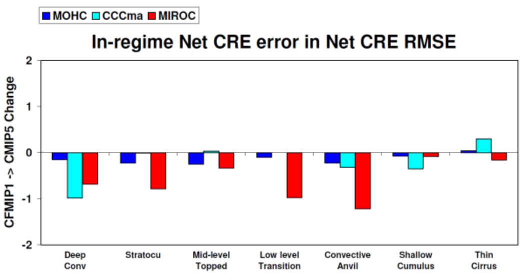
Nuijens et al (2015) The behavior of trade-wind cloudiness in observations and models: The major cloud components and their variability (JAMES) cfSites model output comparison with radar/lidar observations at the Barbados Cloud Observatory.



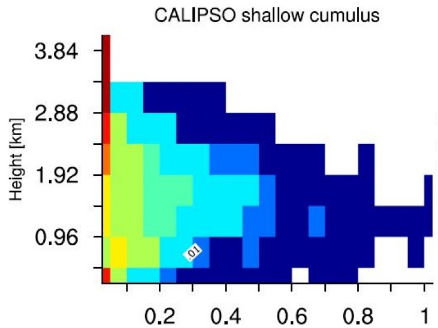


Nuijens et al (2015) The behavior of trade-wind cloudiness in observations and models: The major cloud components and their variability (JAMES)

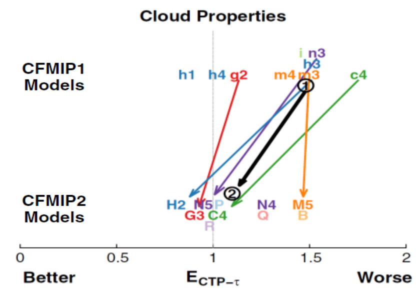
CFMIP Metrics/Diagnostics Repository



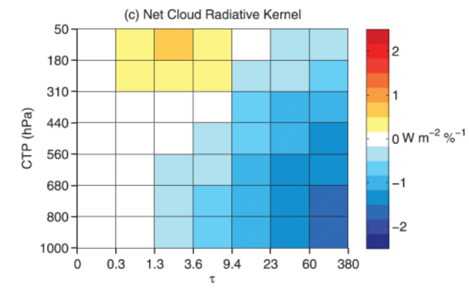
Williams and Webb 2009
Tsushima et al. 2012



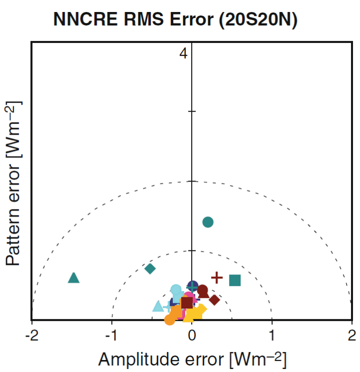
Nam et al., 2012



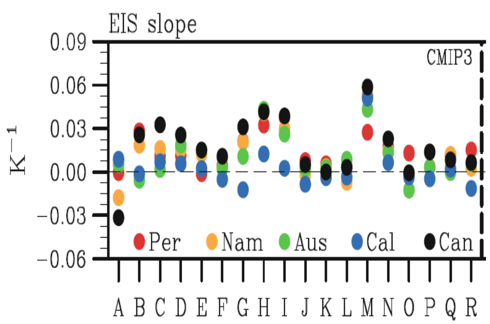
Klein et al. 2012



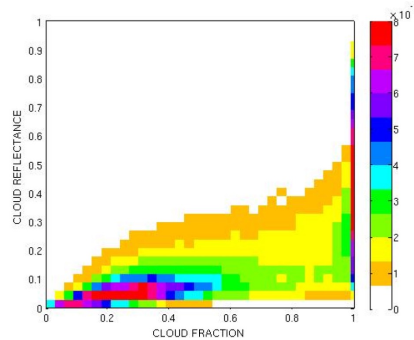
Zelinka et al. 2012



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 community – widening interests….

CFMIP has up to now mostly focused on the evaluation of clouds using satellite observations and the understanding of cloud feedbacks and adjustments:

However, the CFMIP-2 experiments are now being applied to other questions:

- Understanding of precipitation and circulation responses to climate change
- The role of cloud processes in atmospheric dynamics and variability

The WCRP Grand Challenge is a further development of these widening interests

This is also reflected in a broader scope for CFMIP3/CMIP6

Understanding changes in precipitation and the circulation:

Kent et al 2015: Understanding Uncertainties in Future Projections of Seasonal Tropical Precipitation. (J. Climate)

Voigt and Shaw 2014: Circulation response to warming shaped by radiative changes of clouds and water vapour (Nature Geoscience)

Huang et al 2014: Regional response of annual-mean tropical rainfall to global warming. (Atmospheric Science Letters)

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)

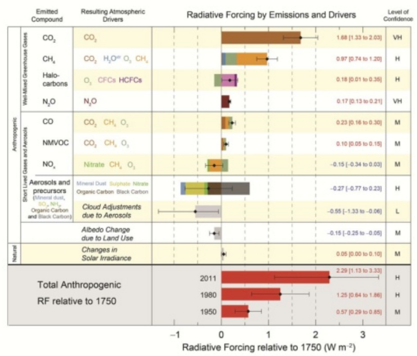
Thorpe and Andrews 2014: The physical drivers of historical and 21st century global precipitation changes (ERL)

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

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

Please see http://www.cfmip.net for full publication list

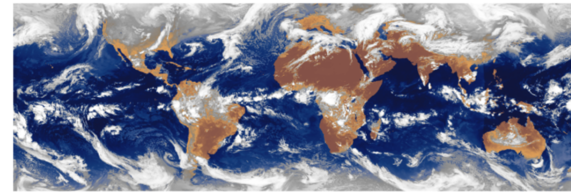
CFMIP Future Plans and Related Activities Thursday



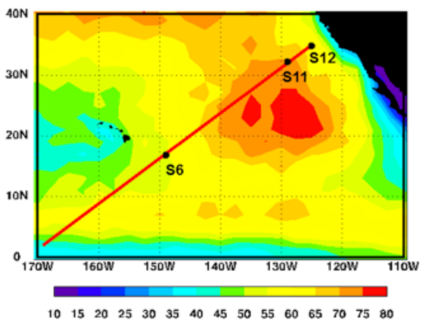
RFMIP

WCRP Grand Challenge on

Clouds, Circulation and Climate Sensitivity

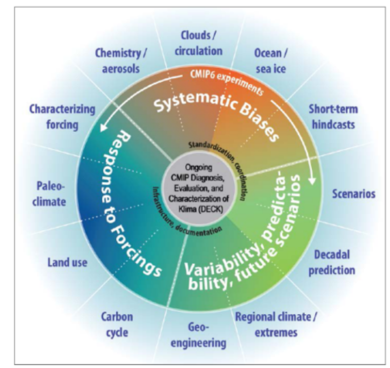


http://www.wcrp-climate.org/index.php/gc-clouds



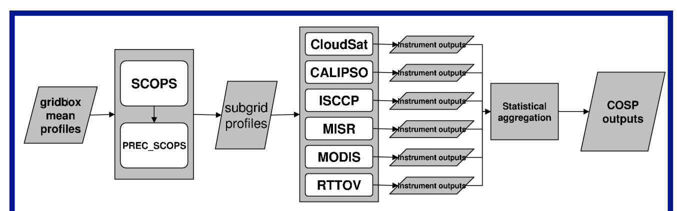
CGILS

CFMIP-3



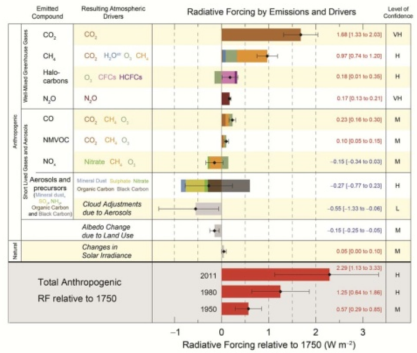
CMIP6

GASS GEWEX WCRP Global Atmospheric System Studies



COSP

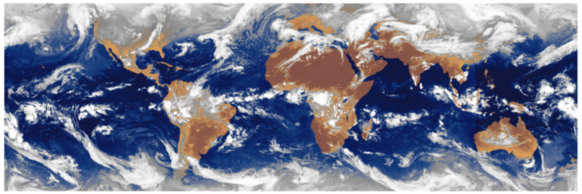
CFMIP Future Plans and Related Activities Thursday



RFMIP

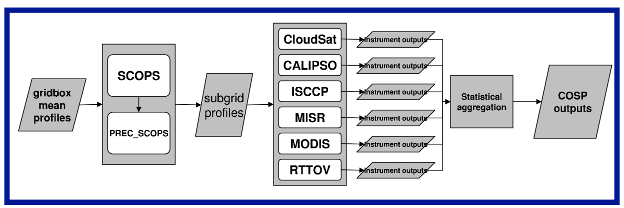
WCRP Grand Challenge on

Clouds, Circulation and Climate Sensitivity



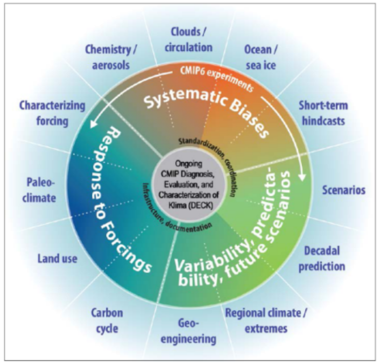
http://www.wcrp-climate.org/index.php/gc-clouds

WCRP
World Climate Research Programme



COSP

CFMIP3



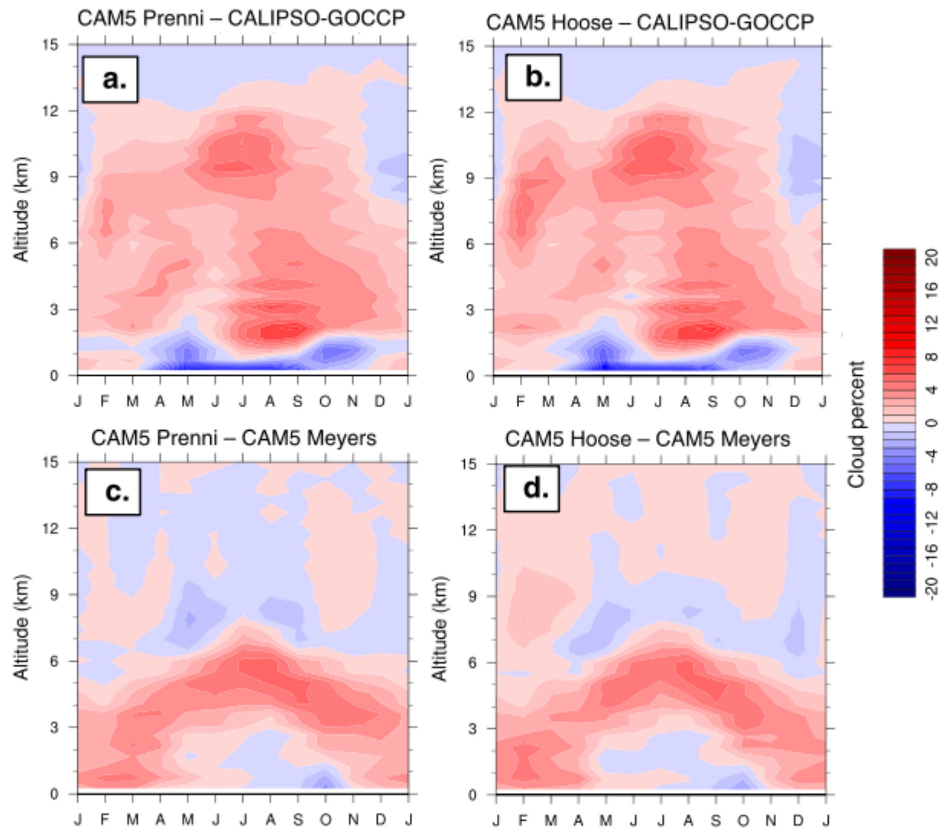
CMIP6

GASS GEWEX WCRP Global Atmospheric System Studies

Paleoclimate Modelling PMIP3 Intercomparison Project

Supplementary slides

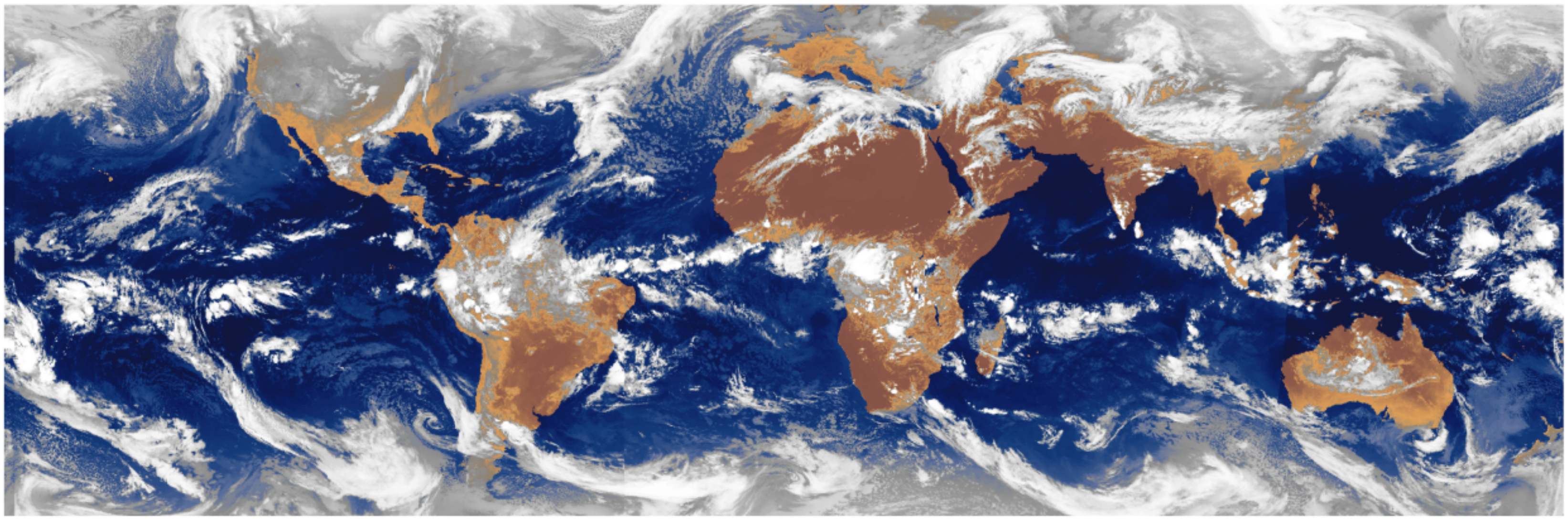
Evaluation of the seasonal cycle in Arctic cloud profiles using COSP and GOCCP in different versions of CAM5



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

WCRP Grand Challenge on

Clouds, Circulation and Climate Sensitivity

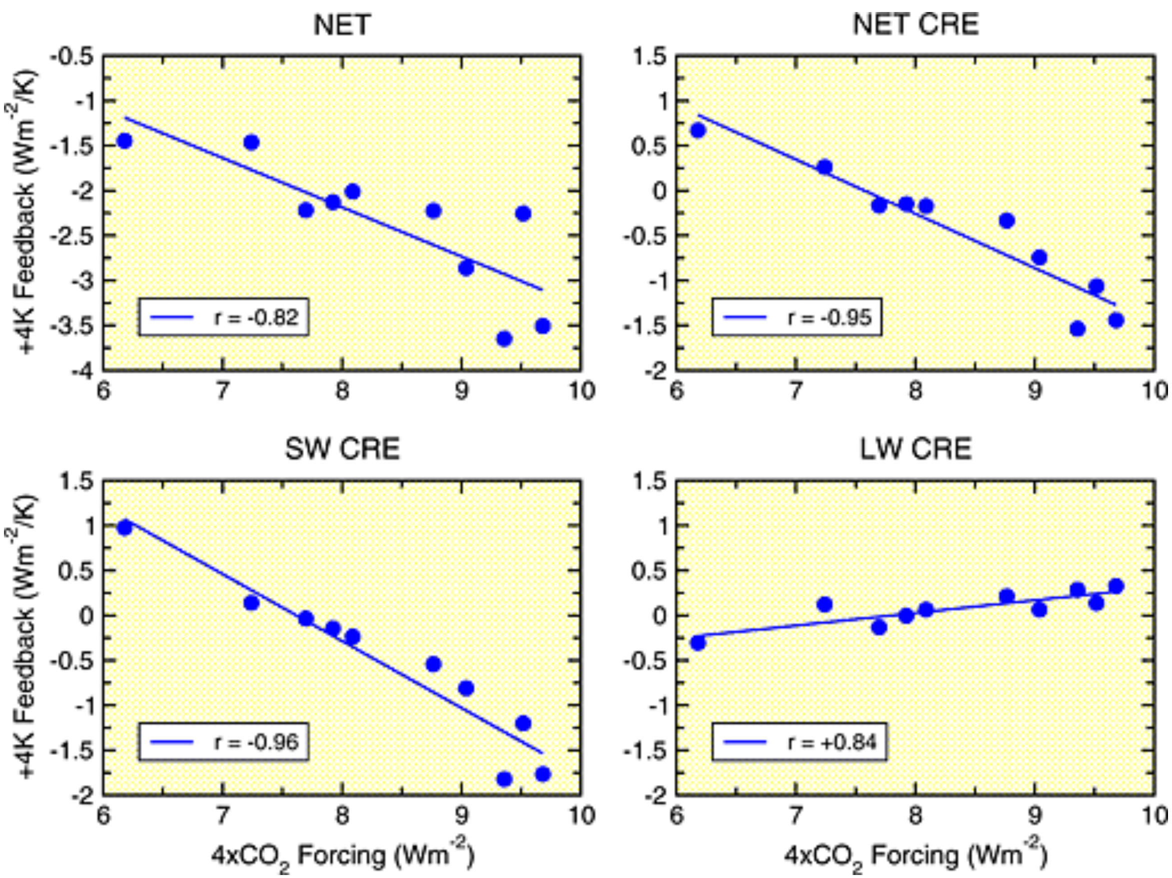


http://www.wcrp-climate.org/index.php/gc-clouds

Discussion led by Sandrine and Bjorn on Friday

World Climate Research Programme

They also reproduce the anti-correlation between forcing and feedback previously documented in coupled models



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

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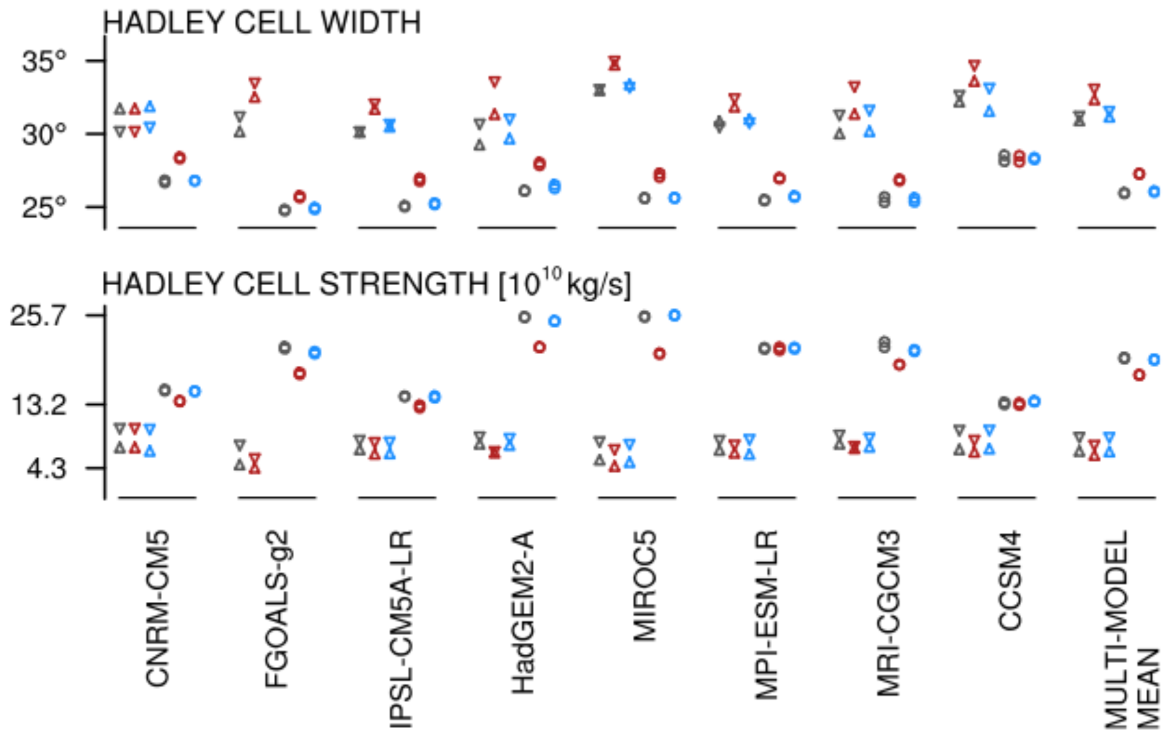

Fig. 5 Hadley circulation width (*top*) and strength (*bottom*) for each model and the multi-model mean (*far right*). *Triangles* denote the AMIP simulations (*upward* and *downward pointing* for northern and southern hemisphere, respectively) and *circles* the AQUA simulations. *Gray markers* show the control simulations, *red* the SST+4K, and *blue* the $4 \times CO_2$.

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

CFMIP-2 strategy

Better exploitation of ISCCP / CloudSat / CALIPSO in CMIP5:

- Adoption of CFMIP Observational Simulator Package (COSP) by modelling groups to evaluate 3D properties of cloud and precipitation

Understand and assess the physical credibility of cloud feedback mechanisms in climate models based on:

- CFMIP/GASS Intercomparison of LES and SCMs (CGILS)
- A hierarchy of experiments in CMIP5 (AOGCM/SST forced/aquaplanet)
- 3D rad fluxes/tendency terms for temperature, humidity, cloud water
- Instantaneous high frequency outputs at fixed ‘cfSites’ locations