The Cloud Feedback Model Intercomparison Project (CFMIP) Progress and future plans

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Sandrine Bony, Majolaine Chiriaco (IPSL/LMD)

and CFMIP contributors (BMRC,GFDL,UIUC,MPI,NCAR)

CERES/GERB meeting October 2006

CFMIP: Cloud Feedback Model Inter-comparison Project

- Set up by Bryant McAvaney (BMRC), Herve Le Treut (LMD)
- WCRP Working Group on Coupled Modelling (WGCM)
- Systematic intercomparison of cloud feedbacks in GCMs
- +/-2K atmosphere only and $2xCO_2$ ‘slab’ experiments
- Aim to identify key uncertainties
- Link climate feedbacks to cloud observations
- ISCCP simulator required (Klein & Jakob, Webb et al)
- Now have data for 13 GCM versions from 8 groups
- Website shows data available, publications, plans, etc.
- http://www.cfmip.net

cfmip homepage - Mozilla Firefox

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http://www.cfmip.net/

CFMIP

Cloud Feedback Model Intercomparison Project

- Project Overview
- Detailed Project Description
  - Diagnostic Subprojects
  - Experimental Protocols
    - Data Requirements
    - The ISCCP simulator
  - Project Extensions
- Participating Groups
- Data Available
- FAQ
- Publications
- Change History

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News

This section contains announcements about the CFMIP project and website. Please email keith.williams@metoffice.gov.uk or mark.webb@metoffice.gov.uk if you wish to add anything.

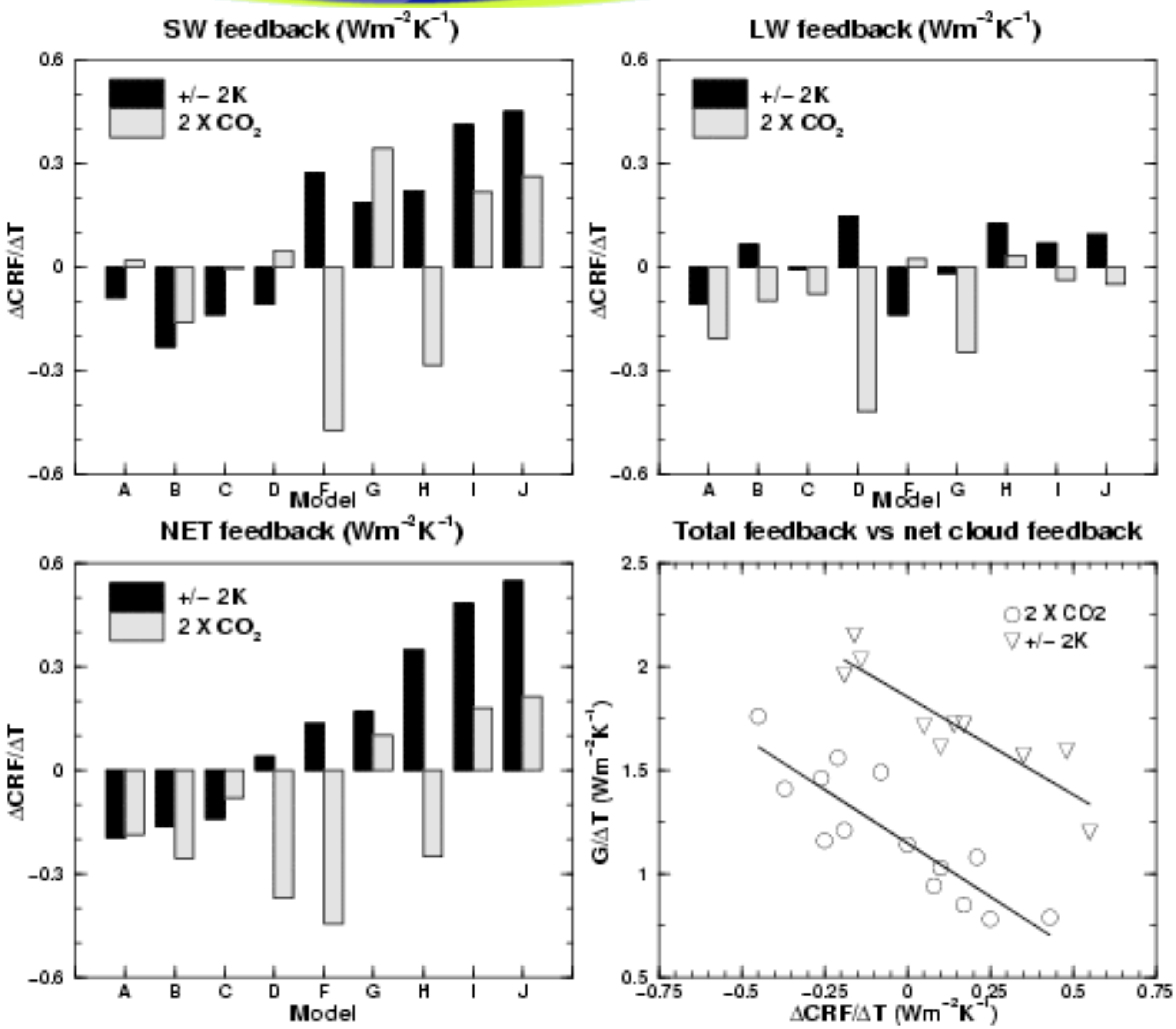
June 2006 - CFMIP Publications

Work under various CFMIP subprojects is now appearing in the literature. Please see our new publications section. *Mark Webb*

April 2006 - CFMIP Phases I and II

By the time of the fifth IPCC Scientific Assessment we hope that the ISCCP simulator will be required as standard in the IPCC experimental protocol. When this happens the current CFMIP experimental protocol will be redundant. With this in mind we are now thinking about what CFMIP could do in future to develop and apply new techniques for understanding and evaluating cloud climate feedbacks. These ideas will eventually form CFMIP Phase II. It is expected that CFMIP Phase I will continue until the time when daily ISCCP simulator diagnostics are required as standard in the AMIP and CMIP experimental protocols. Further daily data are expected from IPSL, NCAR, and Environment Canada by the end of 2006. *Mark Webb*

Comparison of +/- 2K and slab model experiments
Ringer et al, GRL 2006



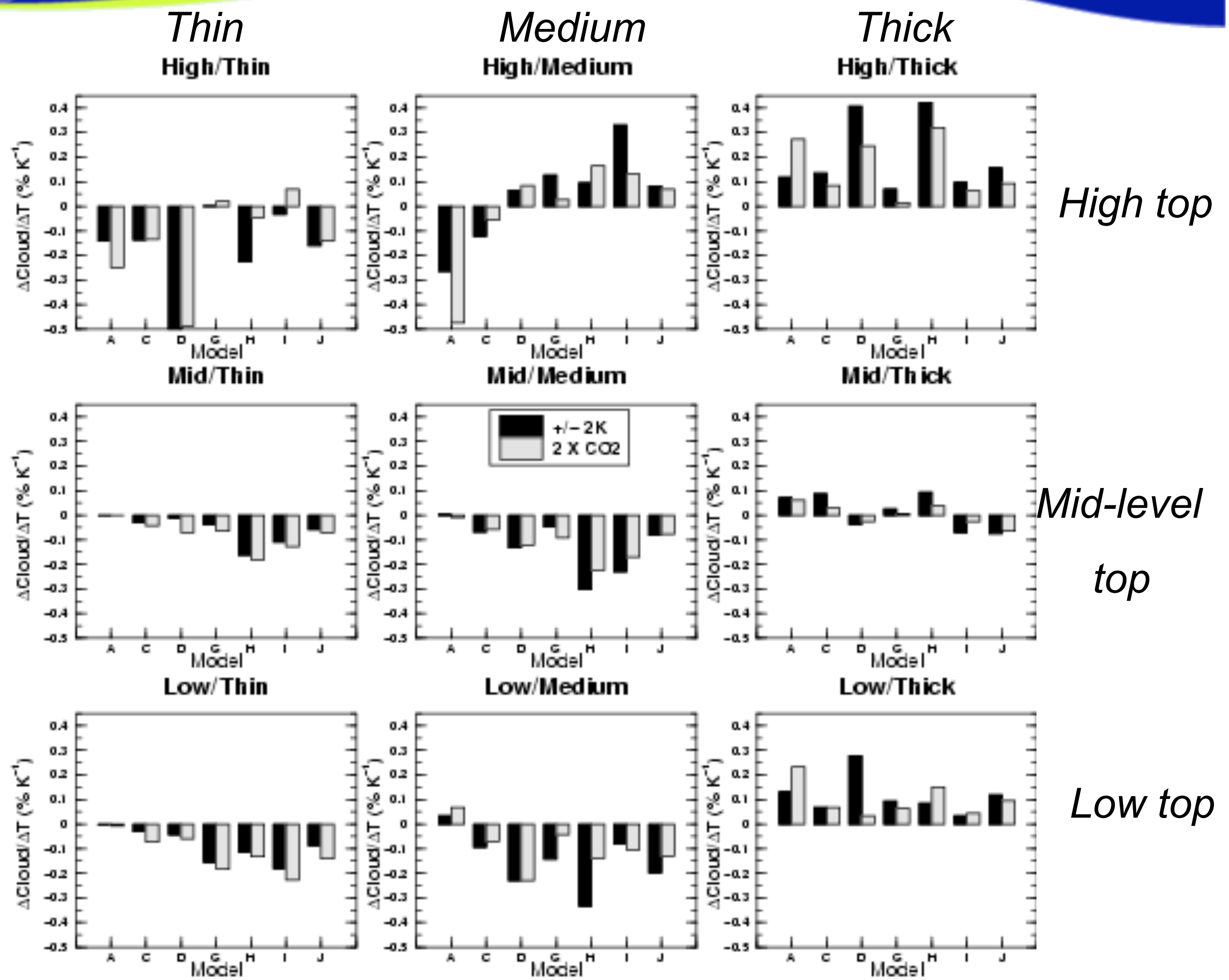
Cess experiments capture the spread in cloud feedback from slab experiments.

Offset due to suppressed clear-sky feedbacks in slab vs Cess

Values are global mean changes in NET, SW and LW CRF per degree of warming ($Wm^{-2}K^{-1}$)

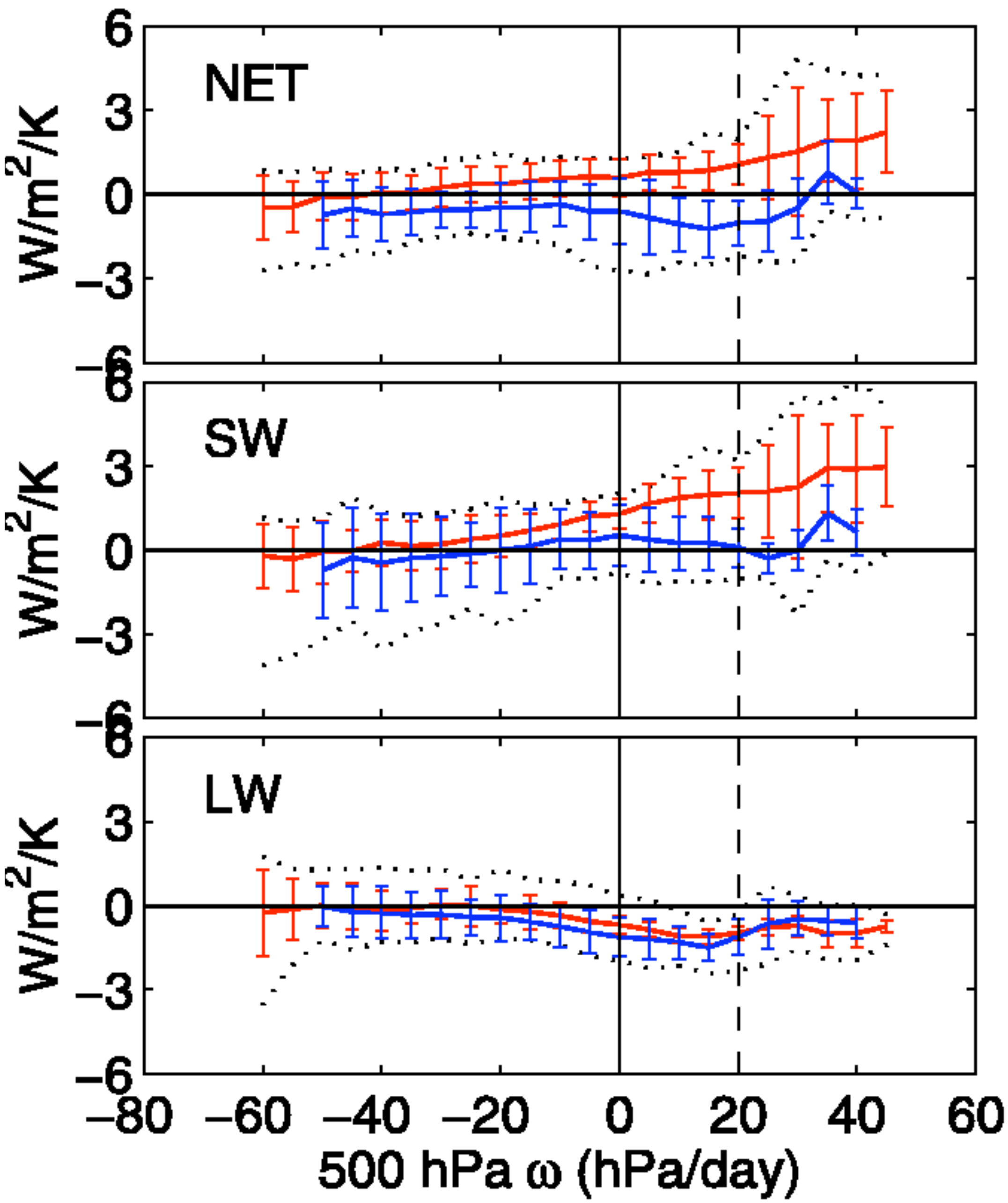
Changes in ISCCP cloud types slab vs +/-2K
Ringer et al, 2006

Values are global mean change in each cloud type per degree of warming (% / K)



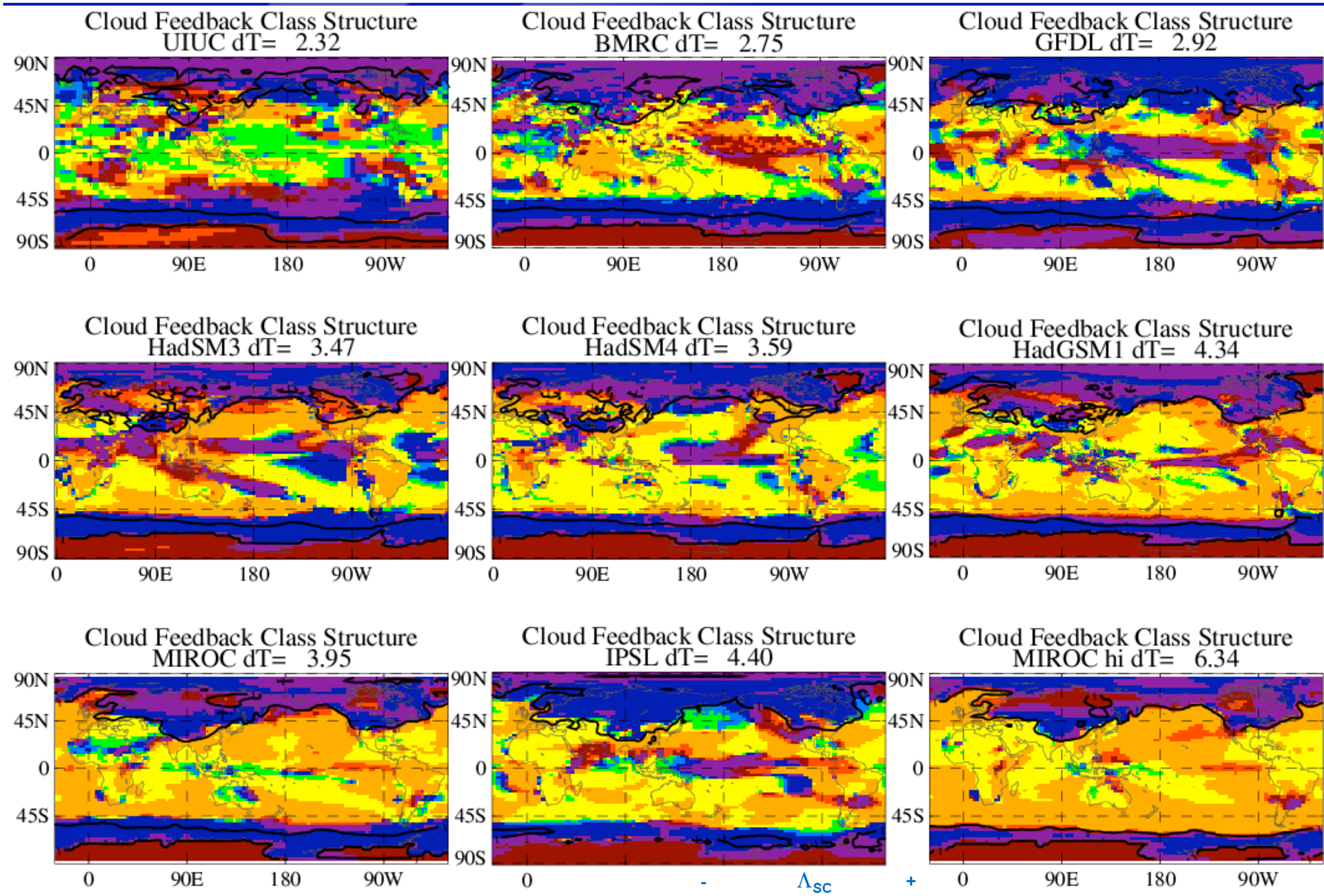
Ringer et al, 2006

Bony and Dufresne GRL 2005

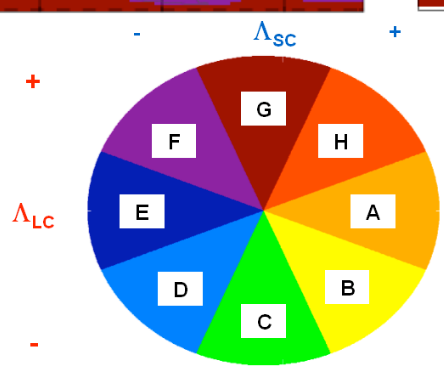


Cloud radiative forcing (CRF) climate response in vertical velocity bins over tropical oceans (30N-30S) from 15 coupled climate models
8 higher sensitivity and
7 lower sensitivity

Net CRF spread largest in subsidence regions, suggesting low clouds are ‘at the heart’ of cloud feedback uncertainties



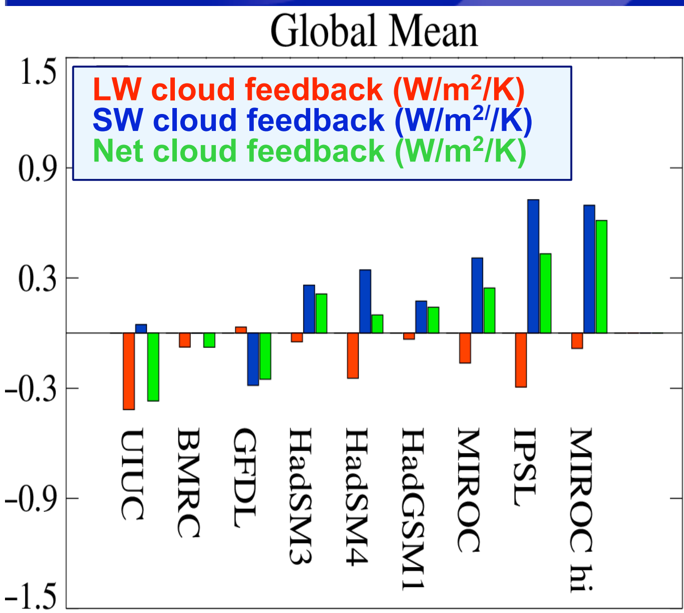
CFMIP cloud feedback "classes"

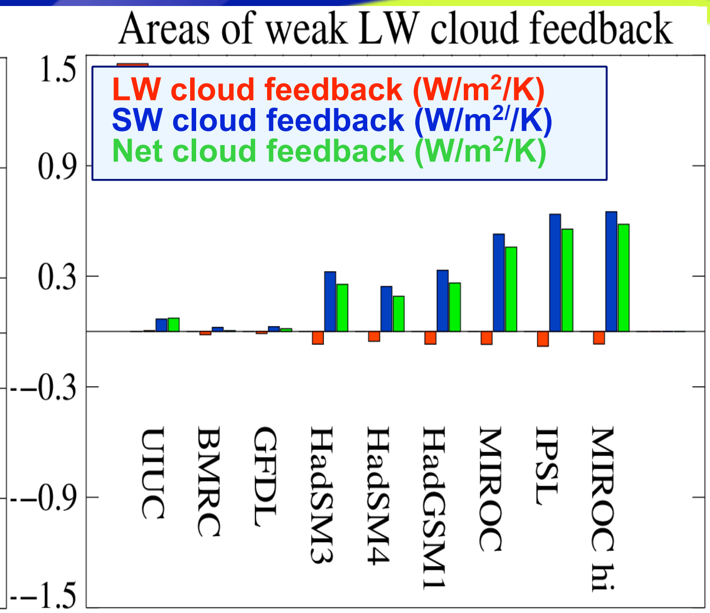


Models with positive low cloud feedback over larger areas have higher sensitivity

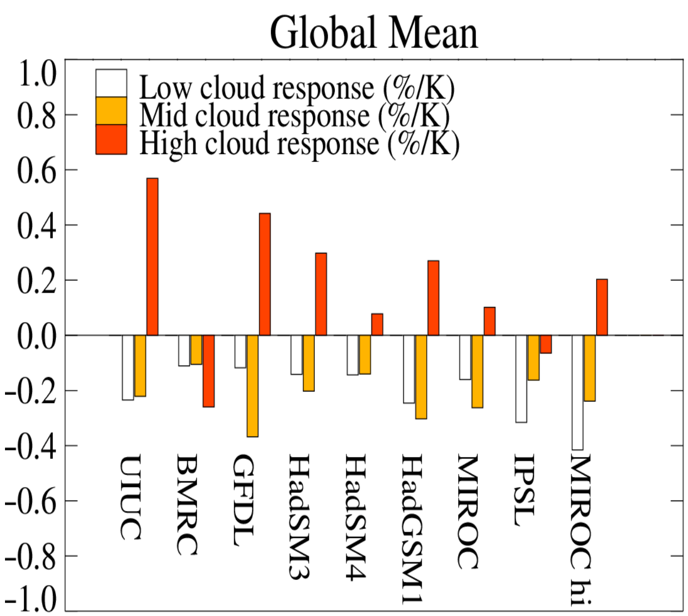
Webb et al 2006

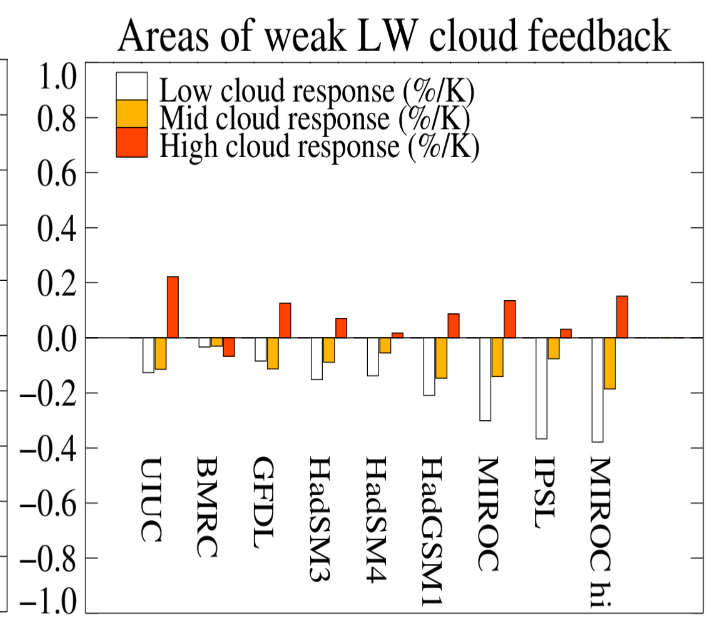
Webb et al Climate Dynamics 2006 – CFMIP models



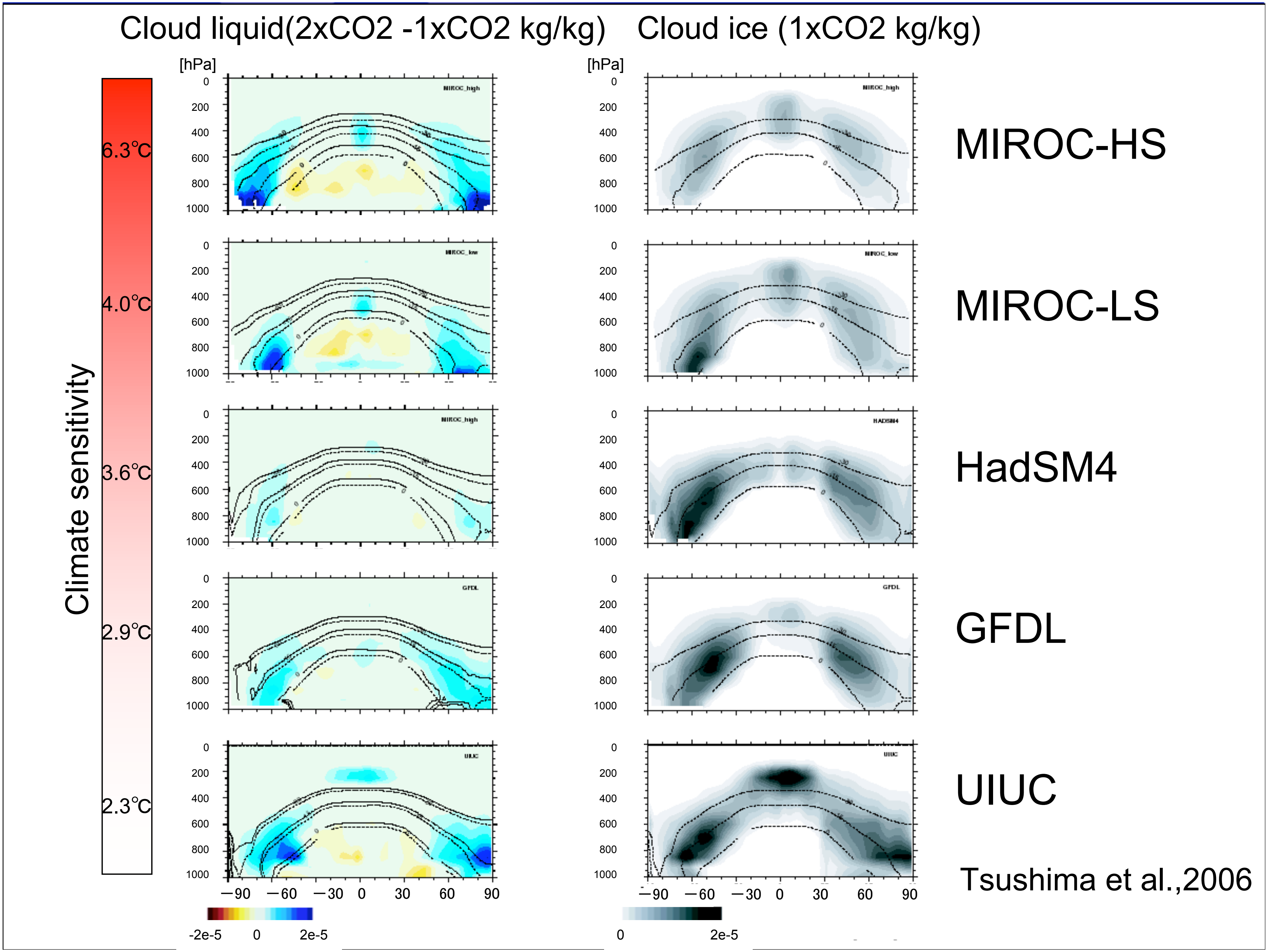


Areas with small LW cloud feedbacks explain 59% of the NET cloud feedback ensemble variance

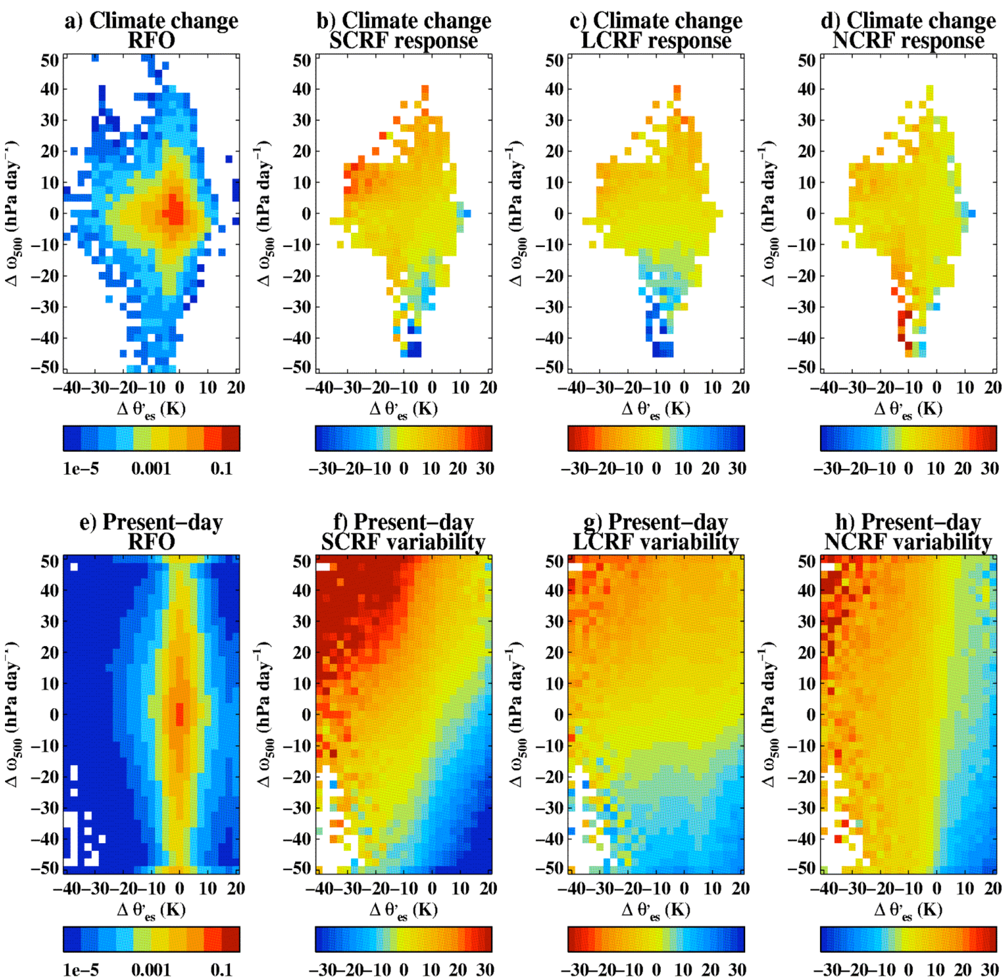




Cloud feedbacks in these areas are indeed dominated by reductions in low level cloud amount (shown with ISCCP simulator)


Cloud liquid(2xCO2 -1xCO2 kg/kg)
Cloud ice (1xCO2 kg/kg)
Climate sensitivity
6.3℃
4.0℃
3.6℃
2.9℃
2.3℃
[hPa]
MIROC-HS
MIROC-LS
HadSM4
GFDL
UIUC
-2e-5
0
2e-5
Tsushima et al.,2006

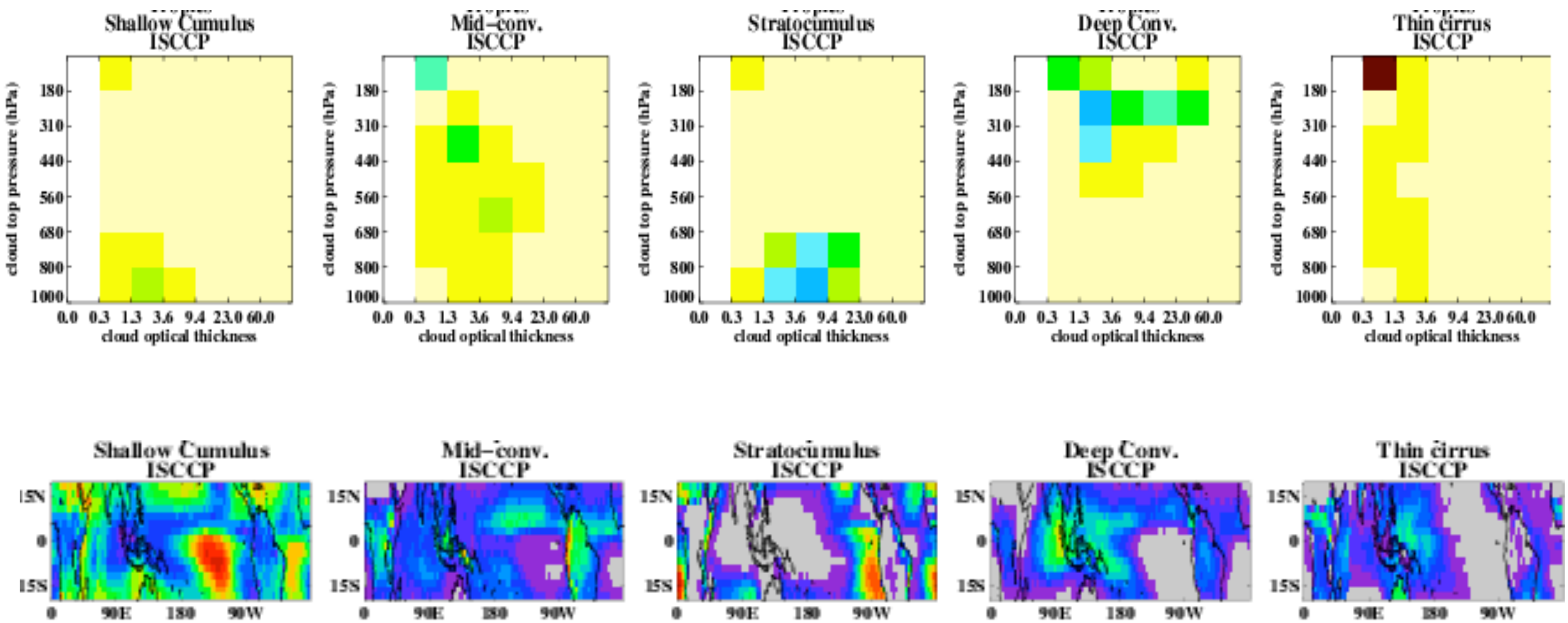
Williams et al Climate Dynamics 2006 (CFMIP)



ERBE /ERA SW	ERBE /ERA LW	ERBE/ NCEP SW	ERBE/ NCEP LW	Avg RMS	Avg Climate Sens.& Range
1.2	1.0	1.6	0.9	1.2	3.8K
1.3	1.2	1.3	1.1	1.2	
1.5	1.0	1.9	1.0	1.4	2.9
1.8	1.2	2.1	1.1	1.5	-4.4K
1.7	1.1	2.2	1.2	1.5	
2.1	1.1	2.3	1.0	1.6	3.0K
2.4	1.0	3.0	1.0	1.9	
1.7	1.6	2.2	1.9	1.9	2.3
2.2	1.4	2.8	1.5	2.0	-3.5K
3.4	1.3	3.7	1.1	2.4	

RMS-differences of present-day variability composites against observations for 10 CFMIP/CMIP model versions. The five models with smallest RMS errors tend to have higher climate sensitivities. (Consistent with Bony & Dufresne 2005)

Williams and Tselioudis (Climate Dyn in revision)



ISCCP observational cloud cluster regimes (20N-20S)

Williams and Tselioudis

In the cloud regime framework, the mean change in cloud radiative forcing can be thought of as having contributions from:

•A change in the RFO (Relative Frequency of Occurrence) of the regime

•A change in the CRF (Cloud Radiative Forcing) within the regime (i.e. a change in the tau-CTP space occupied by the cluster/development of different clusters).

$$\overline{\Delta CRF} = \sum_{i=1}^{nclusters} CRF_i \, \Delta RFO_i + \sum_{i=1}^{nclusters} RFO_i \, \Delta CRF_i + \sum_{i=1}^{nclusters} \Delta RFO_i \, \Delta CRF_i$$

Model	Difference in $\overline{\Delta NCRF}$ (Wm^{-2}/K)	Model λ (Wm^{-2}/K)	Obs. constr. λ (Wm^{-2}/K)	Model clim. Sens. (K)	Obs. constr. Clim. Sens. (K)
ECHAM5	0.49	1.21	0.72	3.3	5.6
HadSM3	0.17	1.06	0.89	3.5	4.2
HadSM4	0.03	1.00	0.97	3.7	3.8
HadGSM1	-0.11	0.83	0.94	4.6	4.1
MIROC-lo	-0.12	0.79	0.91	3.9	3.4
MIROC-hi	-0.19	0.48	0.67	6.5	4.7
Range		0.73	0.30	3.2	2.2
Std. dev.		0.25	0.12	1.2	0.8

CFMIP Phase I continues…

Daily cloud diagnostics to be hosted by PCMDI

To be made available as a community resource

UKMO, MIROC, MPI, NCAR data currently in transit

IPSL, Env Canada promised later this year

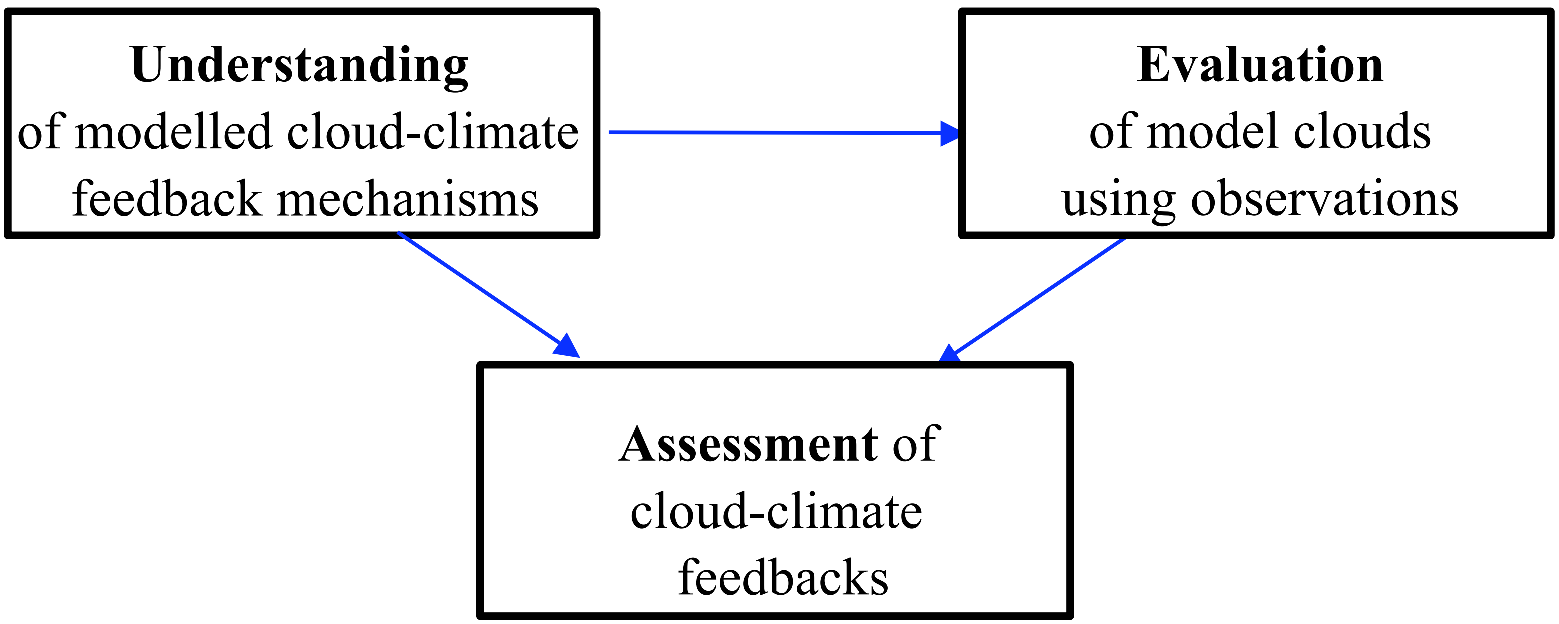
Will allow many ISCCP cloud studies to be applied to a representative selection of climate models

Will become part of standard IPCC diagnostic protocol by time of AR5 (agreed by WGCM Sep 06)

CFMIP Phase II – looking further ahead

Co-ordinators: Mark Webb, Sandrine Bony, Rob Colman
Project advisor: Bryant McAvaney

Main objective : A better assessment of modelled cloud-climate feedbacks for IPCC AR5



CFMIP Phase II – planned approach

Develop improved cloud diagnostic techniques in climate models :

- CFMIP CloudSat/CALIPSO simulator
- Cloud water budget / tendency terms
- 3 hourly data at key locations (ARM sites, GPCI)

Explore the sensitivities of cloud feedbacks to differing model assumptions using idealised climate change experiments

Demonstrate the application of these techniques to the understanding and evaluation of cloud climate feedbacks via pilot studies

Organise a systematic cloud feedback model comparison with the next generation of climate models (ideally by embedding suitable cloud diagnostics in the AR5 experimental protocol.)

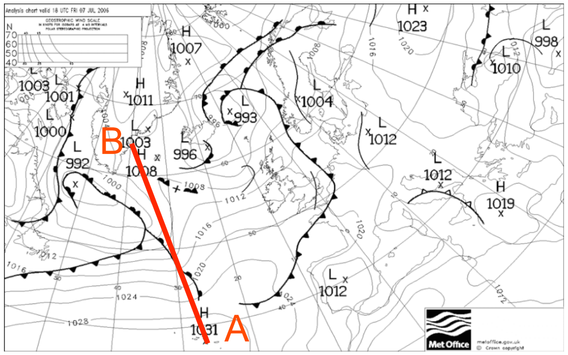
CFMIP CloudSat/CALIPSO simulator (C3S)

This is a modular cloud simulator framework which will allow a number of cloud simulator modules to be plugged into climate models via a standard interface.

This is currently under development in collaboration with various groups:

- Hadley Centre (Alejandro Bodas-Salcedo, Mark Webb, Mark Ringer)
- LLNL (Steve Klein, Yuying Zhang)
- LMD/IPSL (Marjolaine Chiriaco, Sandrine Bony)
- CSU (Johnny Lyo, John Haynes, Graeme Stephens)
- PNNL (Roger Marchand)

C3S/CloudSat comparison with UK NWP model (Alejandro Bodas-Salcedo)

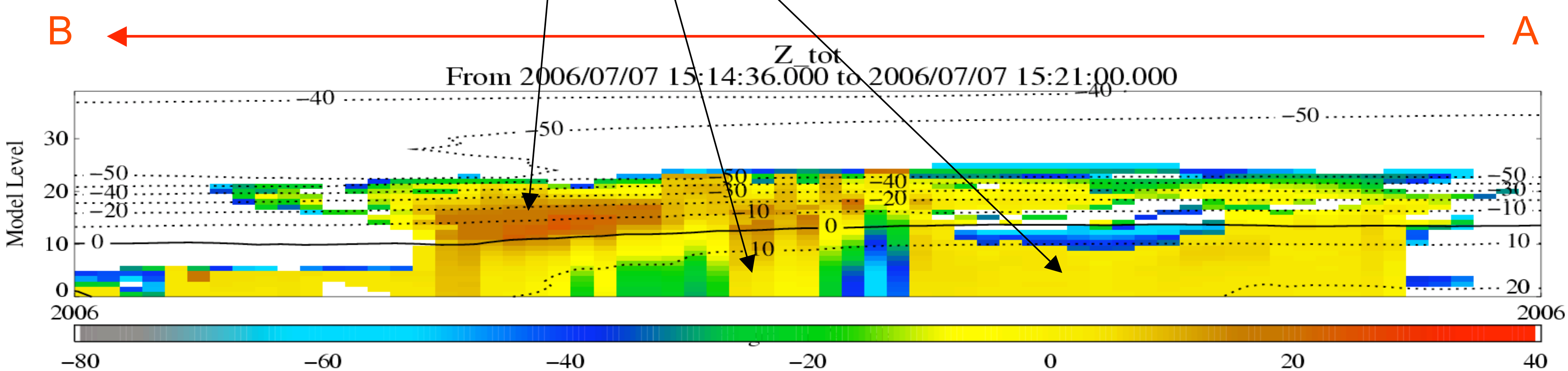


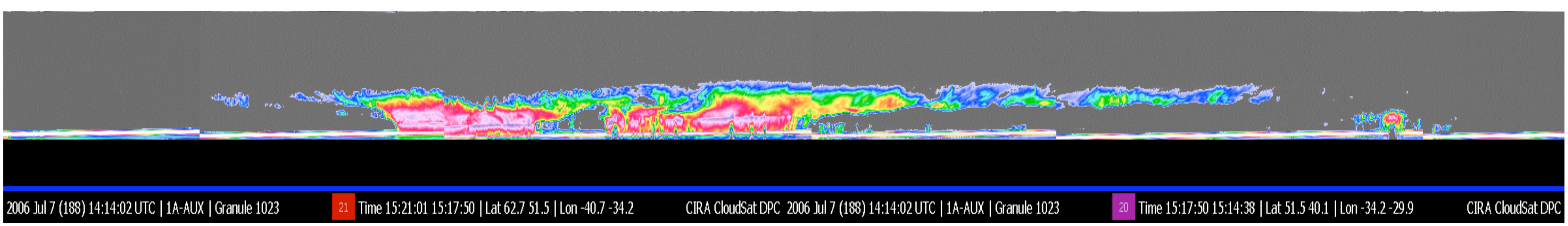
Transect trough a mature extra-tropical system

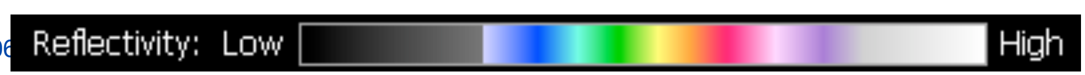
Strong signal from ice clouds

Strong signal from precipitation

Cloud and precip not present in obs



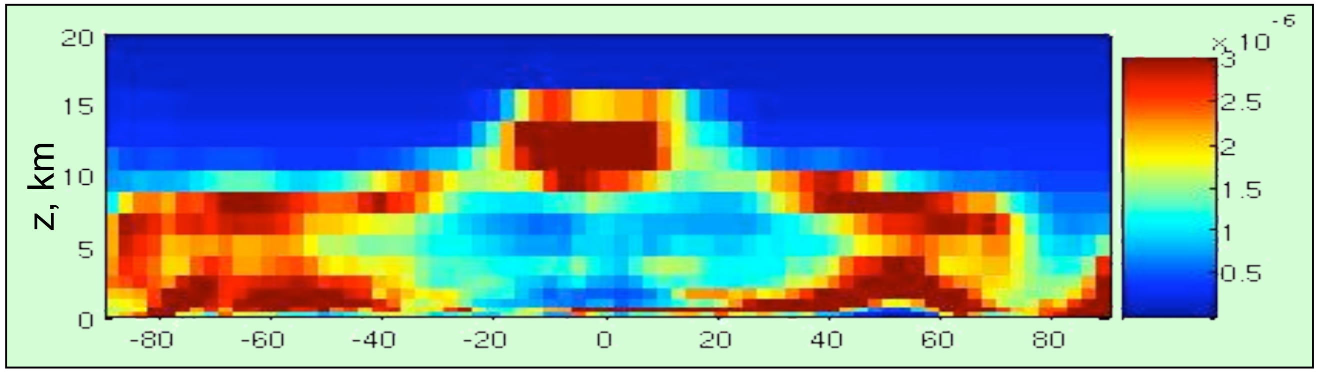




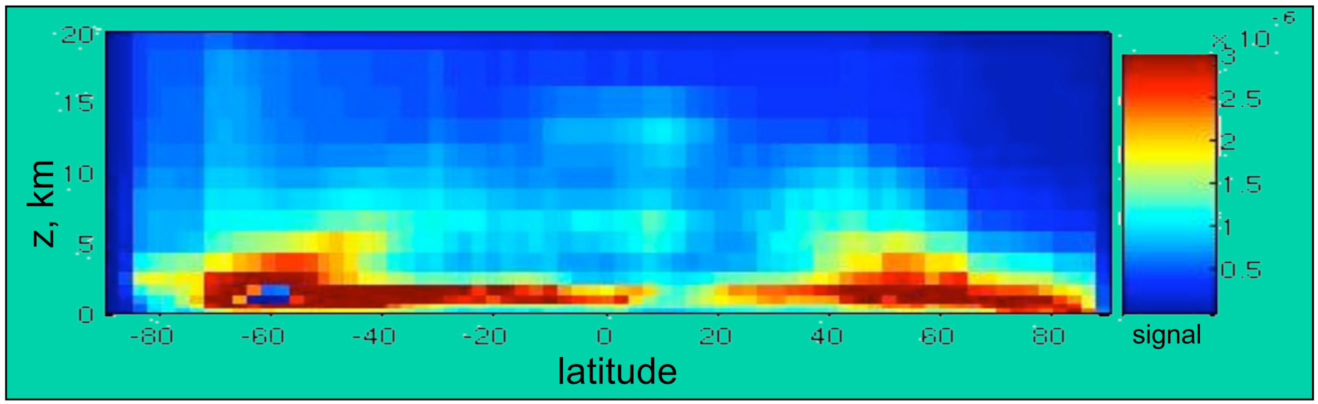
ACTSIM LIDAR comparison with GLAS / ICESat data

(M. Chiriaco LMD/IPSL)

Lidar signal **simulated** from LMDZ outputs



Lidar signal **observed** from GLAS spatial lidar



➔Evaluation of the vertical structure of the atmosphere in models, at global scale

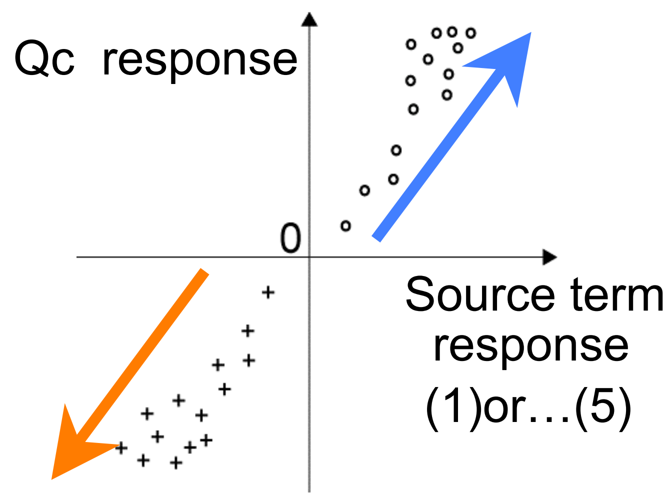
Indicates excessive reflectivities from cloud ice in this climate model

Cloud water budget / process diagnostics (Tomoo Ogura NIES Japan)

$$\frac{\partial Qc(\mathrm{liq}+\mathrm{ice})}{\partial t} = \underbrace{\text{Condensation} + \text{Precipitation}}_{(1)} + \underbrace{\text{Ice-fall-in} + \text{Ice-fall-out}}_{(2)}$$

$$+ \underbrace{\text{Advection}}_{(3)} + \underbrace{\text{Cumulus mixing}}_{(4)} + \underbrace{\text{Conv. adjustment}}_{(5)}$$

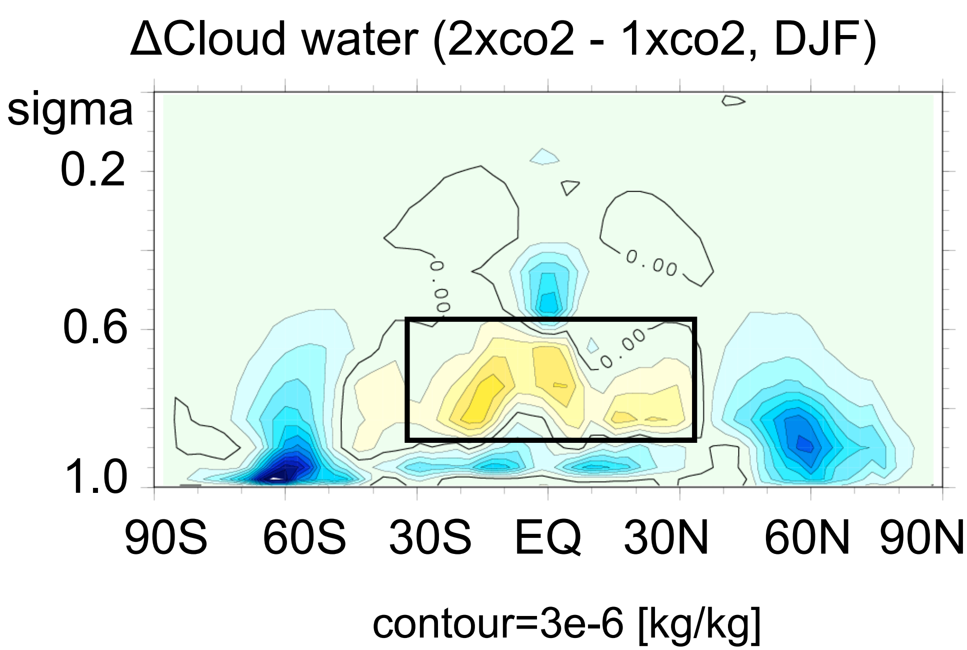
- Transient response of terms (1)…(5) to CO2 doubling is monitored every year.
- Terms showing positive correlation with cloud water response contribute to the cloud water variation.

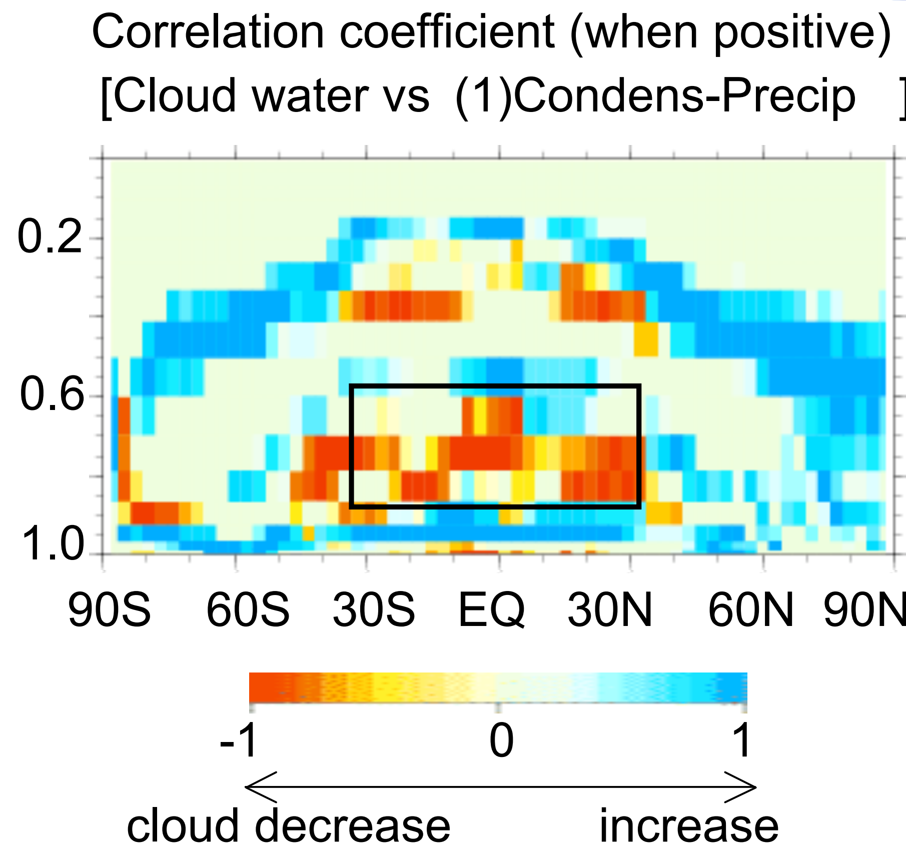


Qc increase related to the source term

Qc decrease related to the source term

Cloud water budget diagnosis in MIROC (Tomoo Ogura NIES Japan)



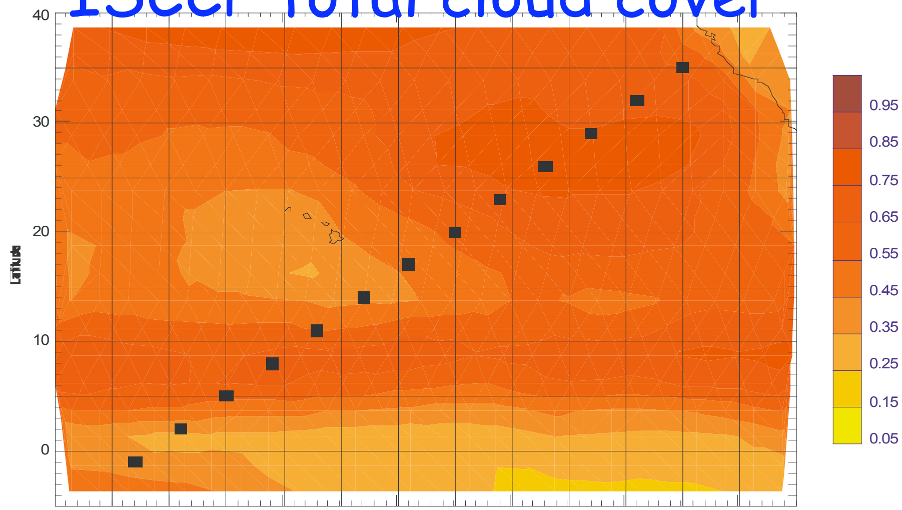


Decrease in mid-low level sub-tropical cloud water correlates with decrease in large-scale condensation

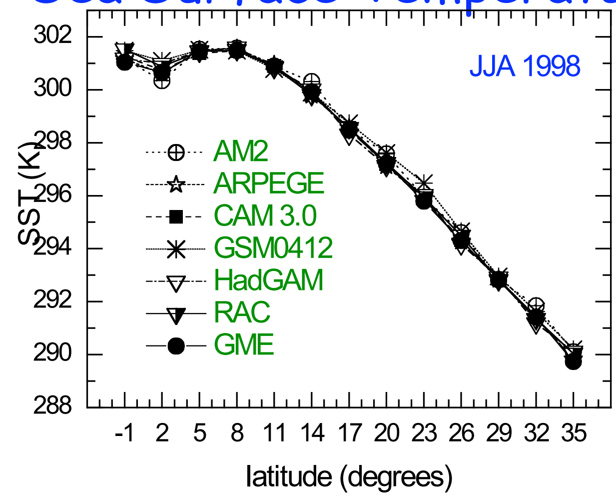
GCSS/WGNE Pacific Cross-section Intercomparison (GPCI)

Joao Teixeira teixeira@nurc.nato.int

ISCCP total cloud cover



Sea Surface Temperature



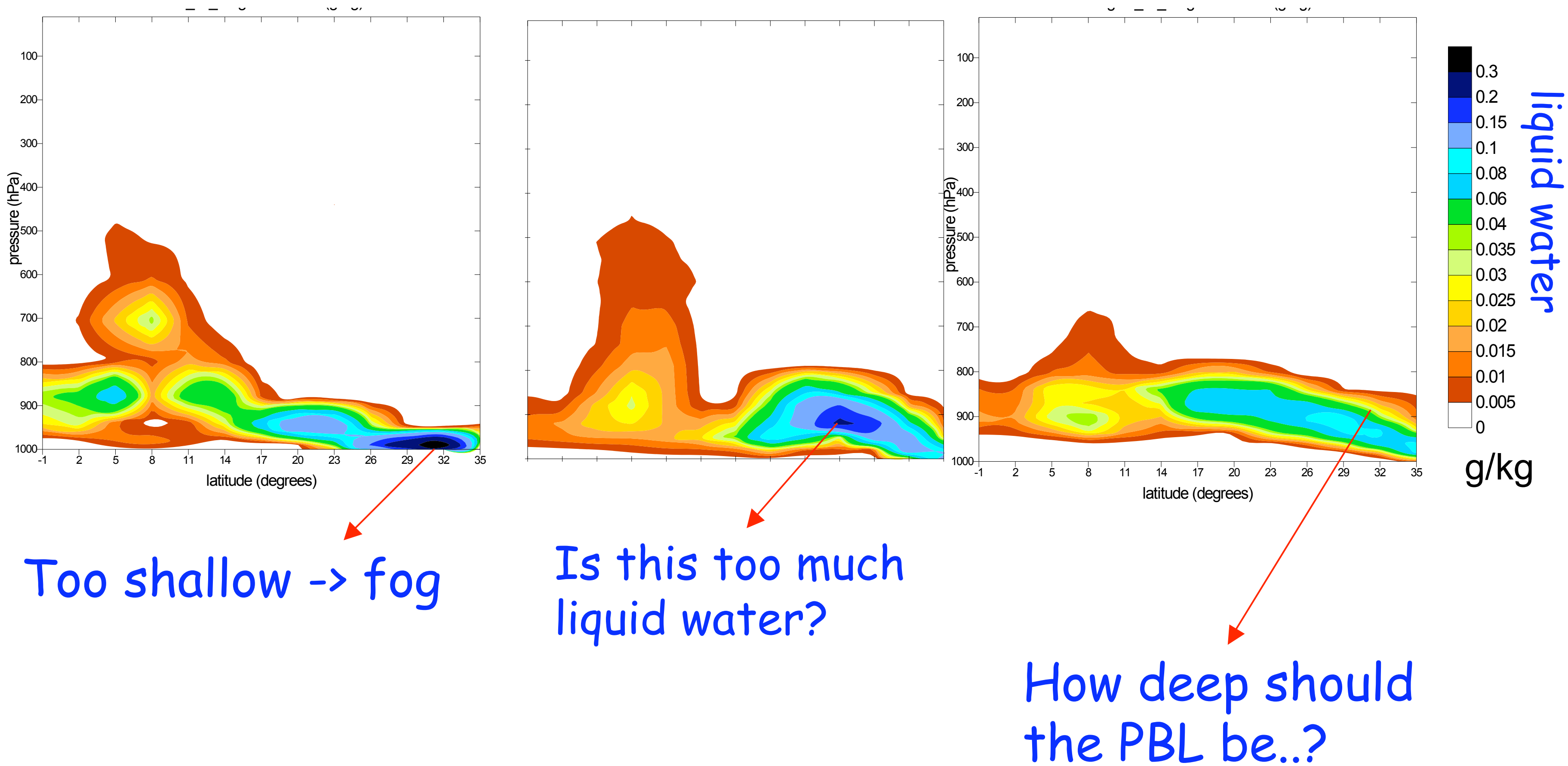
GPCI is a working group of the GEWEX Cloud System Study (GCSS)

Models and data are analyzed along a Pacific Cross section from Stratocumulus, to Cumulus and to deep convection

Period: June-July-August 1998 and 2003

Time resolution: 0, 3, 6, 9, 12, 15, 18, 21 UTC

Mean GPCI liquid water cross section - JJA98 from three climate models

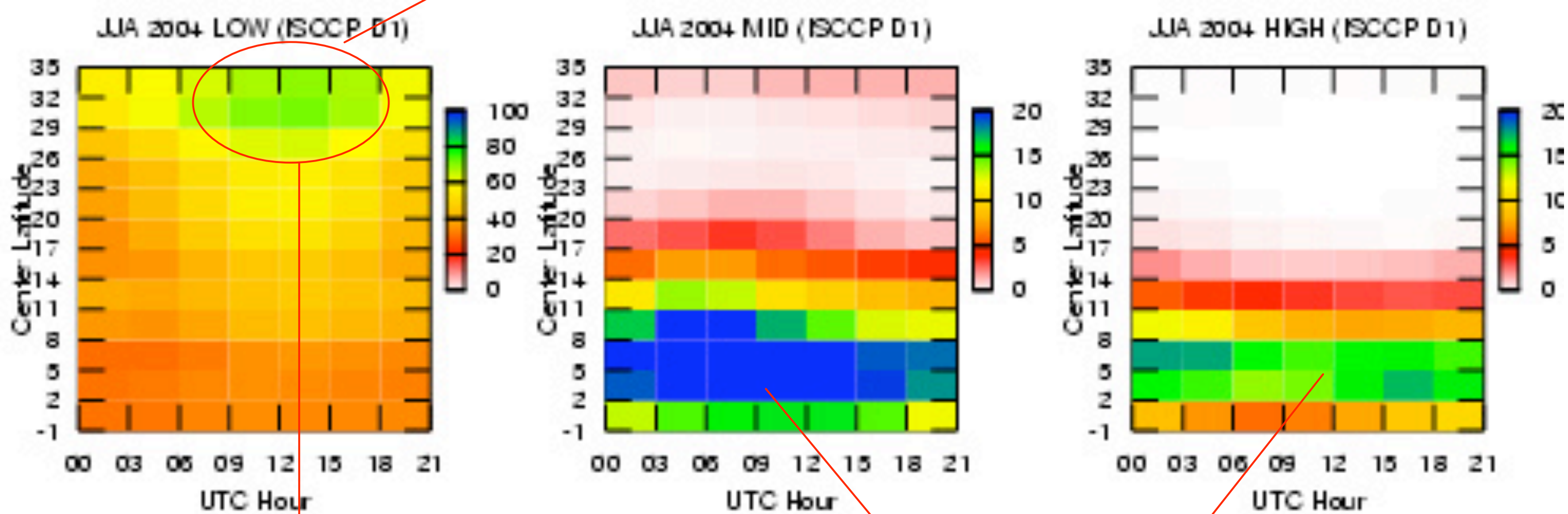


Joao Teixeira teixeira@nurc.nato.int

Mean diurnal cycle: ISCCP cloud cover

Joao Teixeira teixeira@nurc.nato.int

peak values of Sc cloud cover around 32-35 N

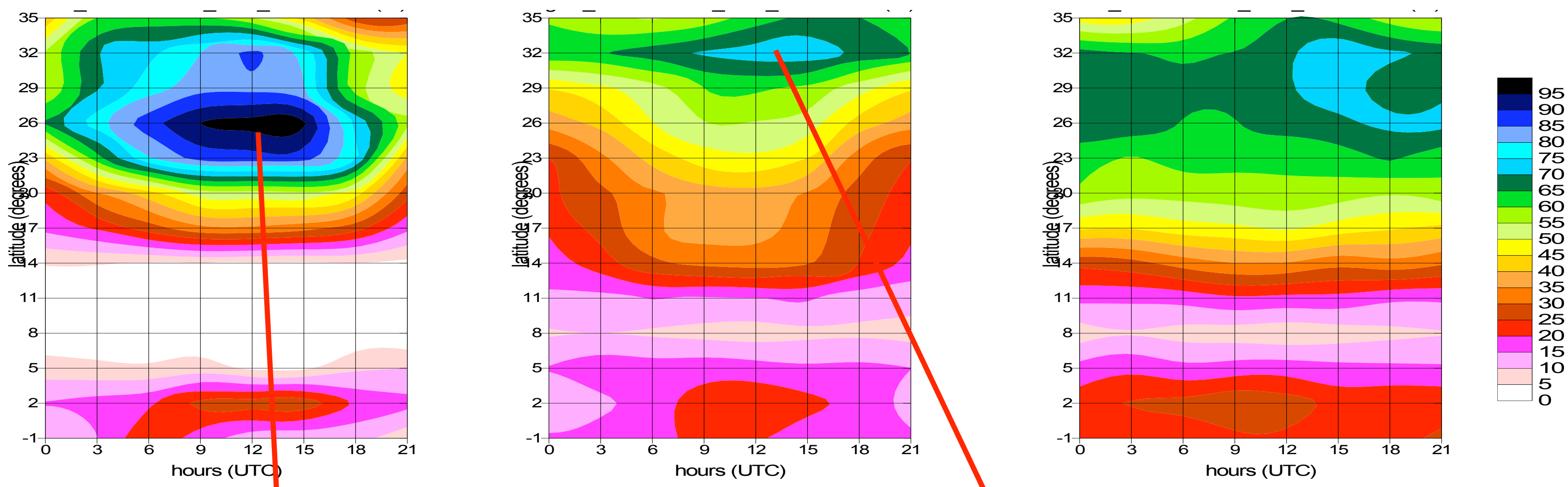


Diurnal cycle: max in (early) morning local time

peak values of mid/high clouds close to ITCZ

JJA98 mean diurnal cycle: model low cloud cover

Joao Teixeira teixeira@nurc.nato.int



peak values too far to
the south (around 26 N)

realistic diurnal
cycle: morning max

Proposed point diagnostics for CFMIP Phase II

- 3 hourly instantaneous model data
- 10-20 years of data to give stable statistics
- on a grid of locations covering the GPCI and TWP
- additional key locations (e.g. ARM sites, high latitudes)
- in AMIP and idealised climate change experiments

The aim is to align climate model diagnostics with those in use in GCSS/ARM to encourage a wider group of people to examine and criticise cloud feedbacks in climate models

For example this would give insight into the impact of diurnal cycle errors on cloud-climate feedbacks

CFMIP Phase II physics sensitivity tests

Sensitivity tests are proposed using the idealised climate change experiments developed by Brian Soden:

i.e. AMIP and AMIP + composite CMIP SST anomaly

The aim is to quantify the impact of certain differences in model formulation on cloud-climate feedbacks by implementing consistent treatments across models

Possible examples include:

- fixed liquid cloud water content and radiative properties
- consistent precipitation & mixed phase partitioning
- consistent boundary layer resolution
- consistent simple shallow convection scheme?

CFMIP Phase II timescales

Concrete project proposal by Jan 2007

Aim for endorsement by WGCM and GEWEX SSG in early 2007

Joint CFMIP/ENSEMBLES meeting Paris April 2007

Development of diagnostics / pilot studies 2007-2008

Systematic model inter-comparison with new model versions 2008- (preferably as part of AR5 models)

Use of CERES/GERB products in CFMIP PII

Met Office

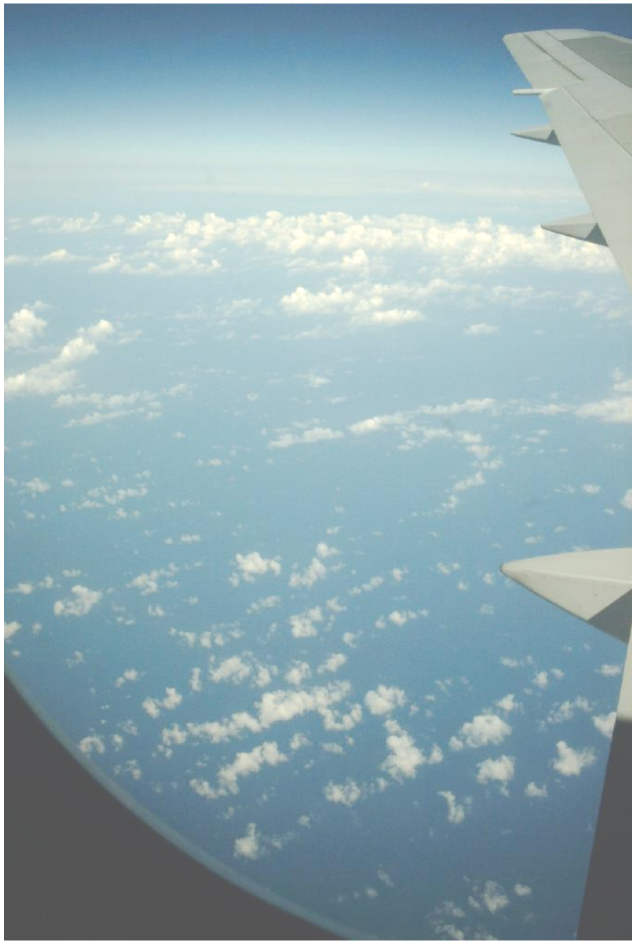
CFMIP Phase I – mostly ISCCP/ERBE/ISCCP_FD

All of the following will benefit CFMIP Phase II:

- CERES SRBAVG GEO, SYN/AVG/ZAVG products
- CERES/MODIS cloud retrievals
- CloudSat/CALIPSO/CERES merged products
- Surface + ATM + TOA products (e.g. SARB)
- Diurnal cycle GEO/GERB data

The barriers are often in bringing the sampling and statistical summaries from satellite products and GCM diagnostics into line – e.g. providing ISCCP D1-like tau-Pc histograms

Hawaii – California transect: March 2005



mark.webb@metoffice.gov.uk

Cleaner separation of SW feedbacks
Taylor et al (in revision)

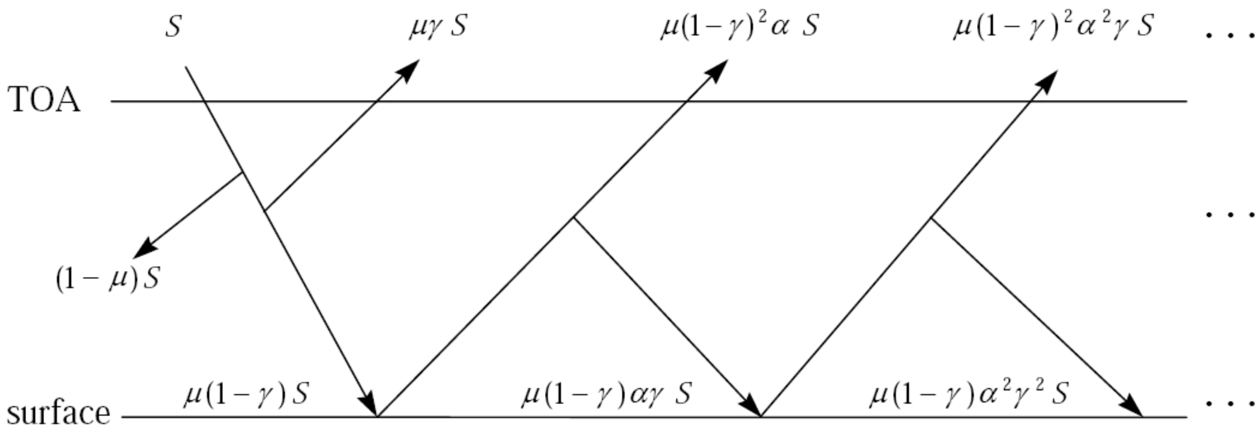


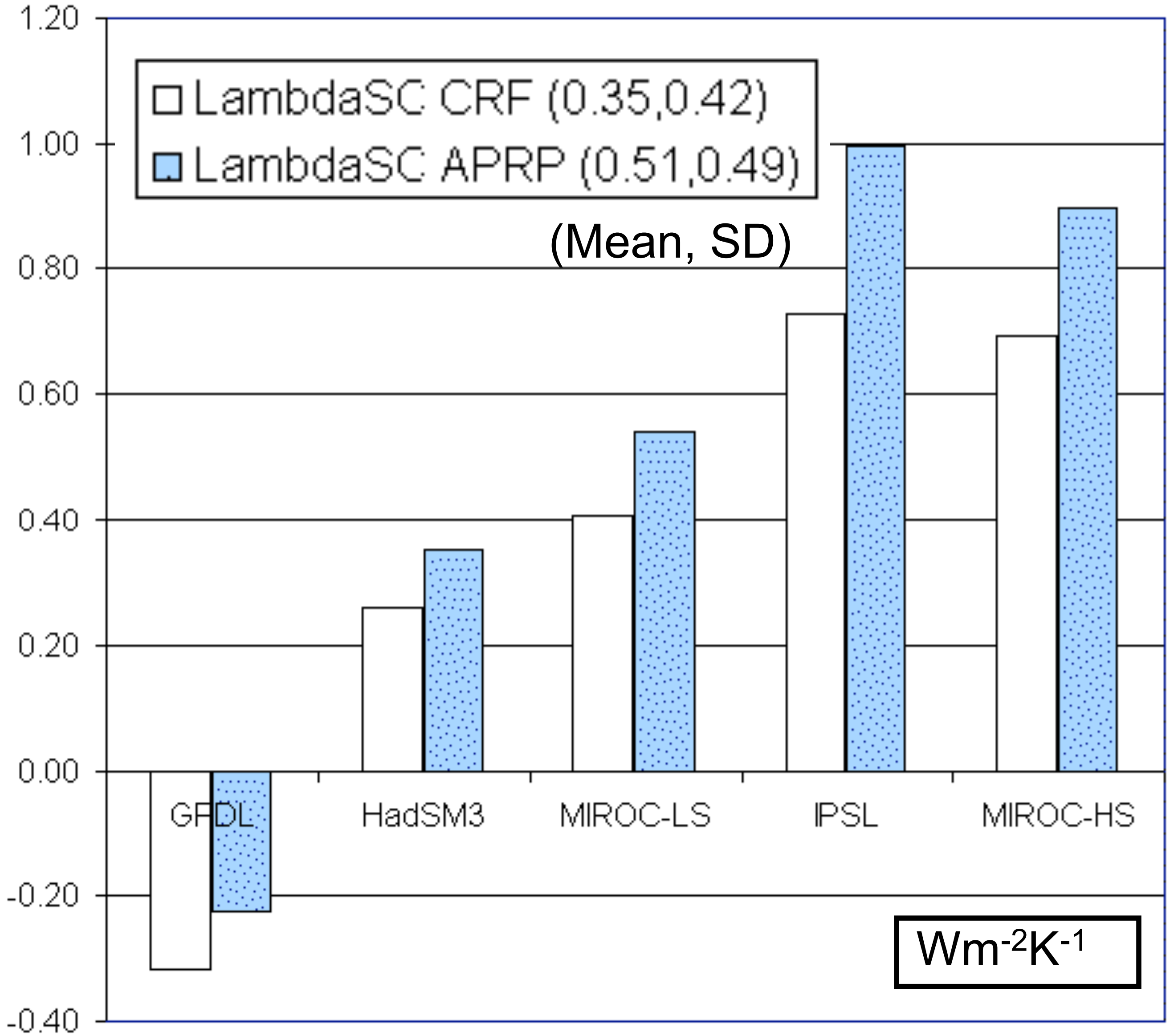
Fig. 1: Schematic representation of a simple shortwave radiation model showing fluxes passing through the atmosphere and being partially reflected on each pass, where S is the insolation, α surface albedo, and γ and μ are the atmospheric scattering coefficient and transmissivity, respectively. Wavelengths that are readily absorbed by the atmosphere are assumed to be completely removed on the first pass, and the atmosphere is transparent to other wavelengths.

APRP (Approximate Partial Radiative Perturbation) method for separation of SW cloud and non-cloud feedbacks.

Validated against full GFDL PRP calculations courtesy of B. Soden.

Similar to Yokohata et al method but with subtle differences.

Taylor et al SW APRP on CFMIP model data



APRP method gives a more positive SW cloud feedback and larger spread than CRF method

This is because it makes a cleaner separation between surface albedo and cloud feedbacks

Michel Crucifix, Karl Taylor, Mark Webb

Summary

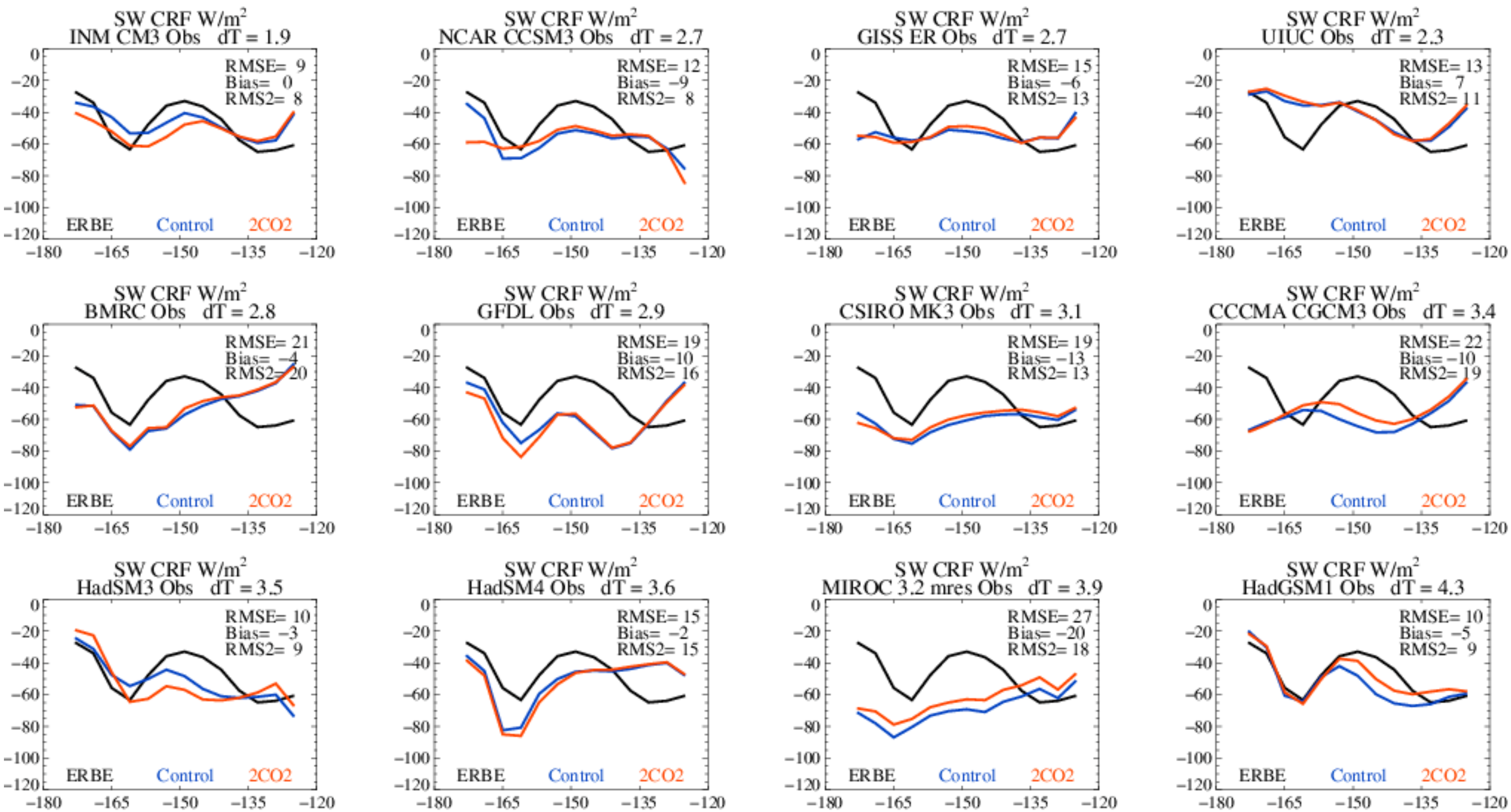
A number of studies now point to low cloud feedbacks being a key uncertainty in climate models

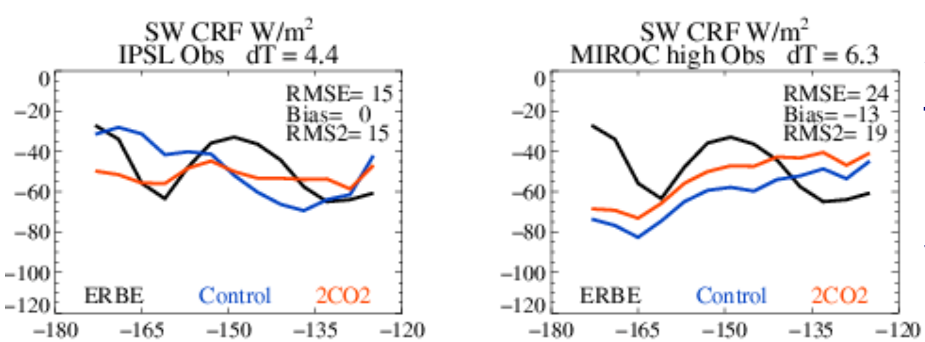
Daily cloud/radiation/ISCCP simulator diagnostics from CFMIP Phase I will be available from PCMDI by the end of the year

Reductions in uncertainty due to cloud feedbacks will require links to observations and also understanding and criticism of feedback mechanisms in models

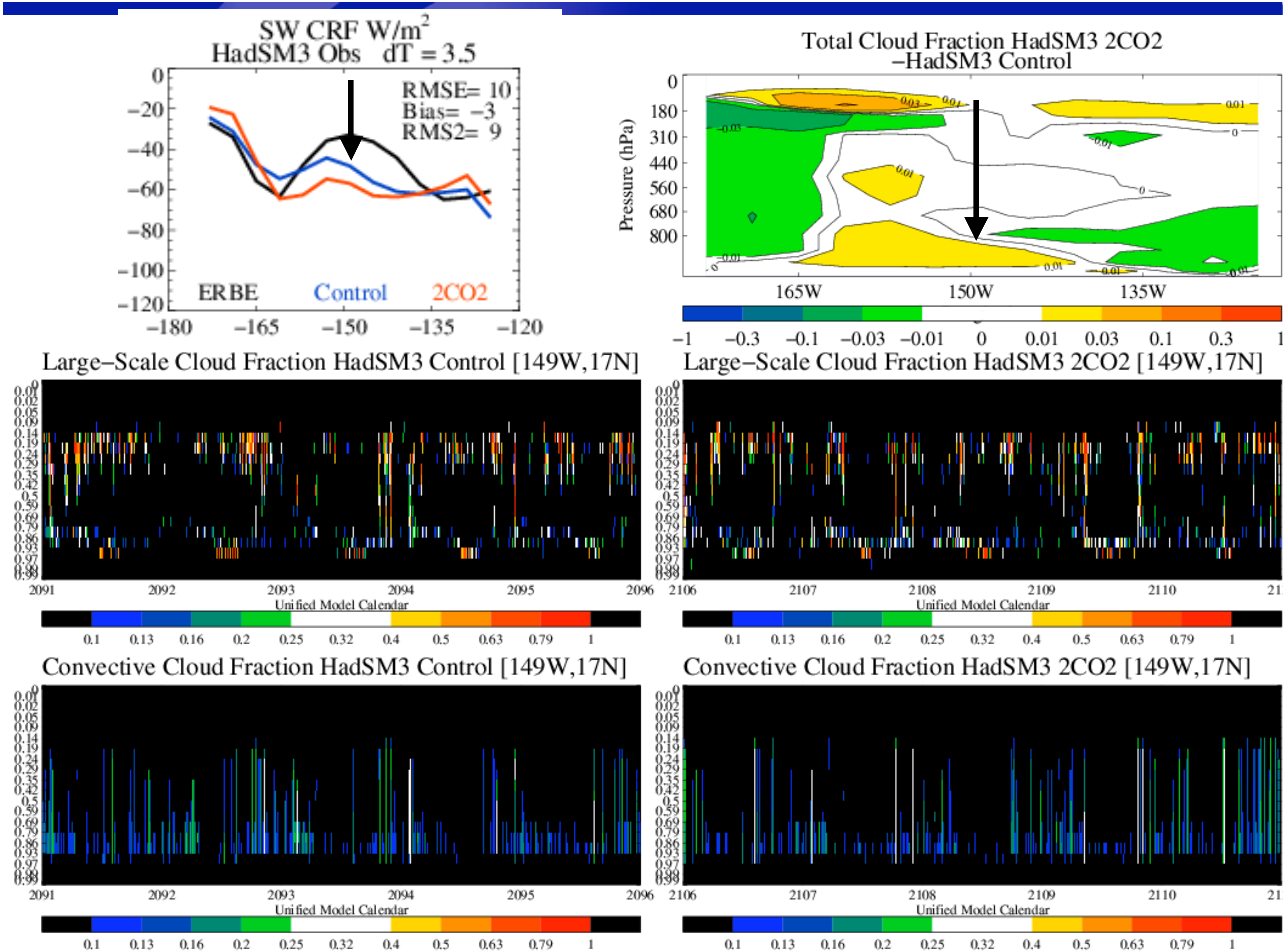
CFMIP Phase II is an opportunity to align diagnostics in a range of models with those in use in GCSS/ARM/CPT

We hope to formalise our plans by the end of this year.

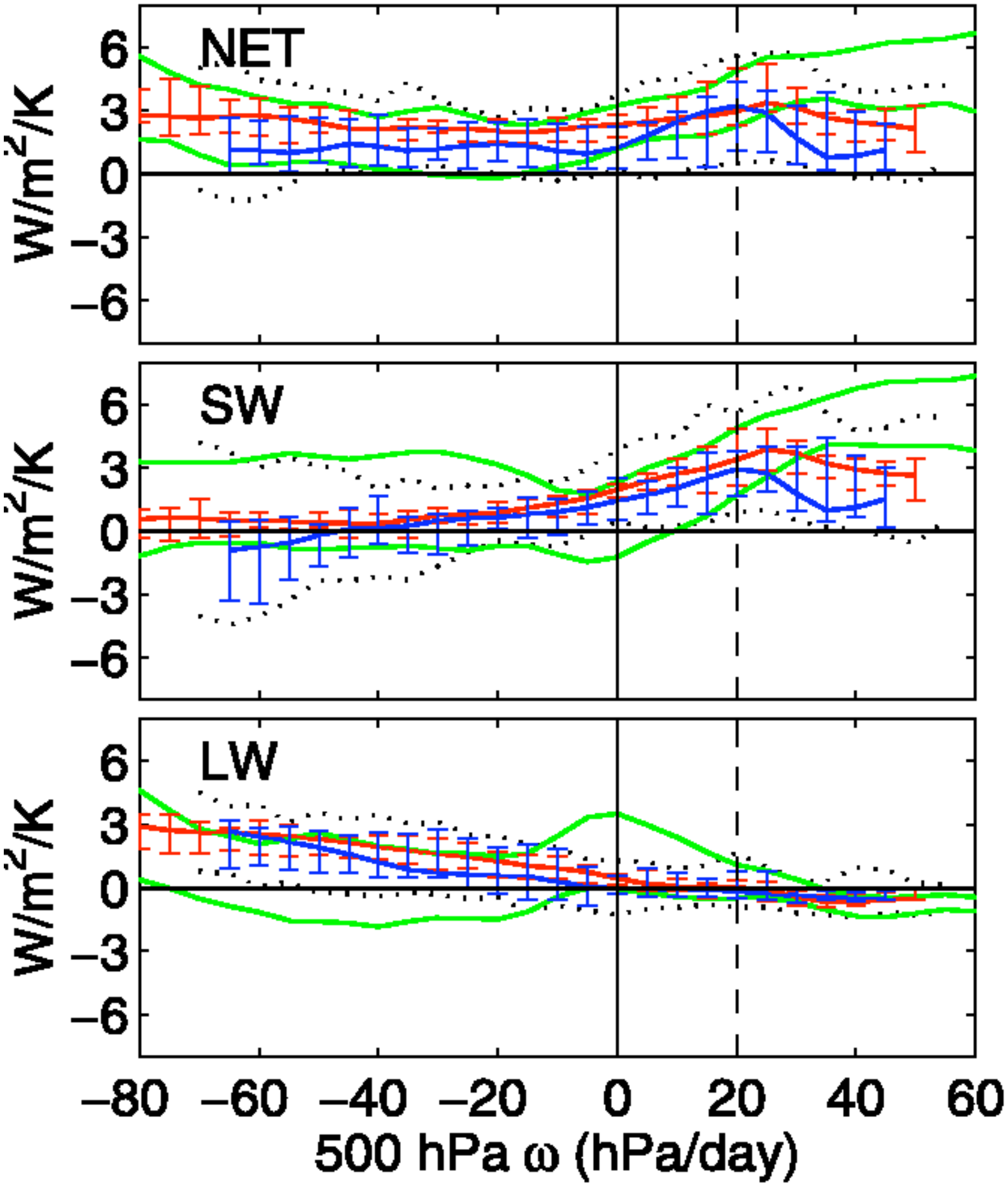




SW CRF response along Pacific transect in CFMIP and AR4 slab models. Cloud feedbacks are typically smaller than model biases. No clear relationship between bias and feedback


SW CRF W/m2
HadSM3 Obs dT = 3.5
RMSE= 10
Bias= −3
RMS2= 9
ERBE
Control
2CO2
0
−20
−40
−60
−80
−100
−120
−180
−165
−150
−135
−120
Total Cloud Fraction HadSM3 2CO2
−HadSM3 Control
Pressure (hPa)
0
180
310
440
560
680
800
165W
150W
135W
−1
−0.3
−0.1
−0.03
−0.01
0
0.01
0.03
0.1
0.3
1
Large−Scale Cloud Fraction HadSM3 Control [149W,17N]
Large−Scale Cloud Fraction HadSM3 2CO2 [149W,17N]
2091
2092
2093
2094
2095
2096
2106
2107
2108
2109
2110
Unified Model Calendar
0.1
0.13
0.16
0.2
0.25
0.32
0.4
0.5
0.63
0.79
1
Convective Cloud Fraction HadSM3 Control [149W,17N]
Convective Cloud Fraction HadSM3 2CO2 [149W,17N]
Unified Model Calendar

Bony and Dufresne (2005)

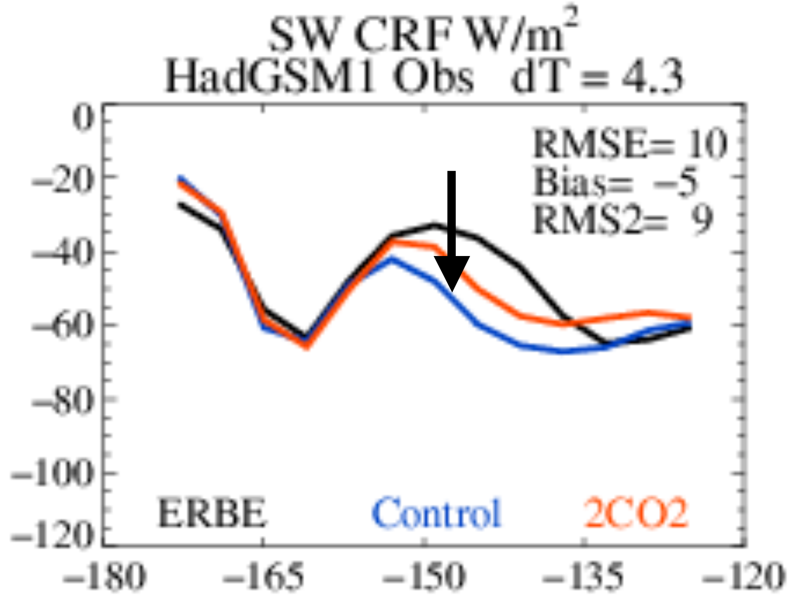


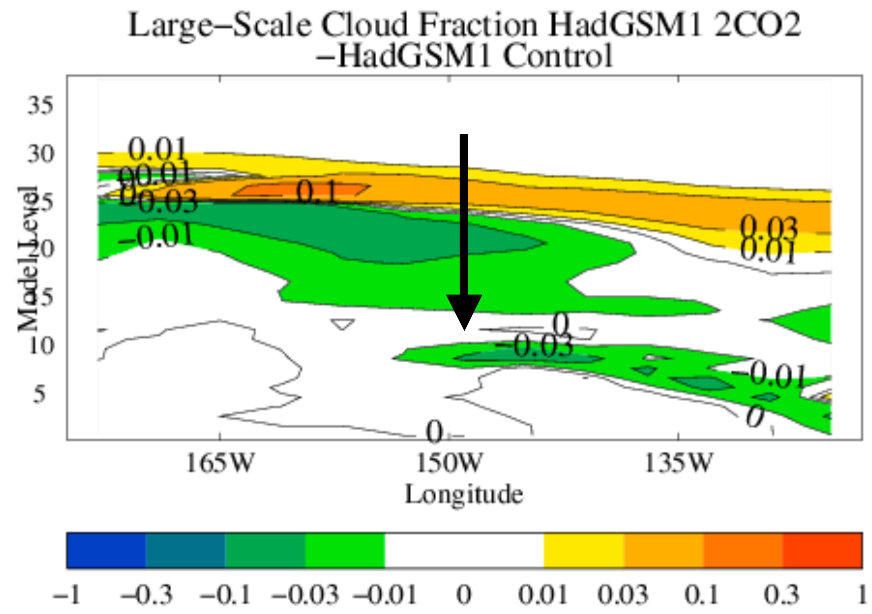
Interannual sensitivity of CRF to SST in vertical velocity bins over tropical oceans (30N-30S) from 15 coupled climate models
8 higher sensitivity and
7 lower sensitivity and
observed (ISCCP FD)

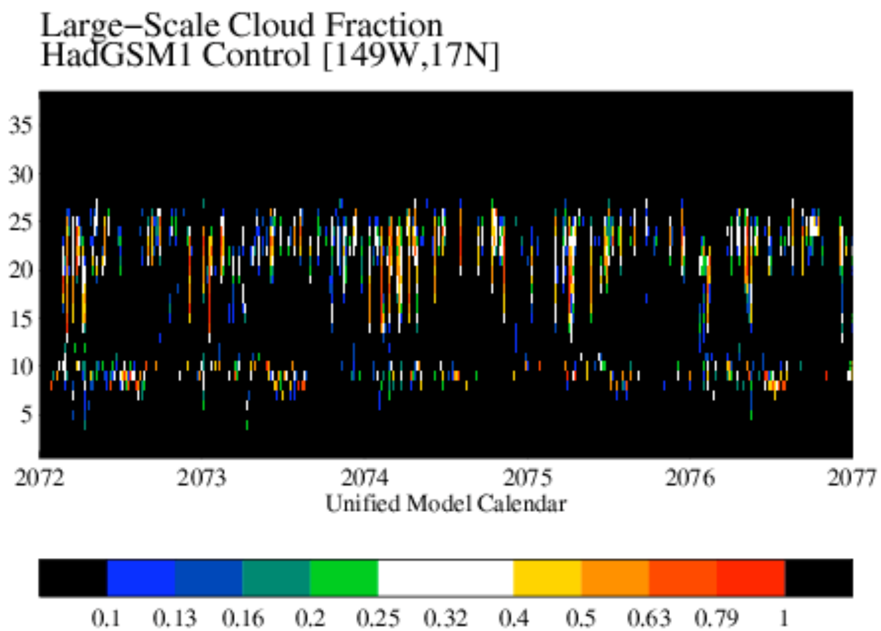
Models underpredict low cloud sensitivity, but higher sensitivity models less so.

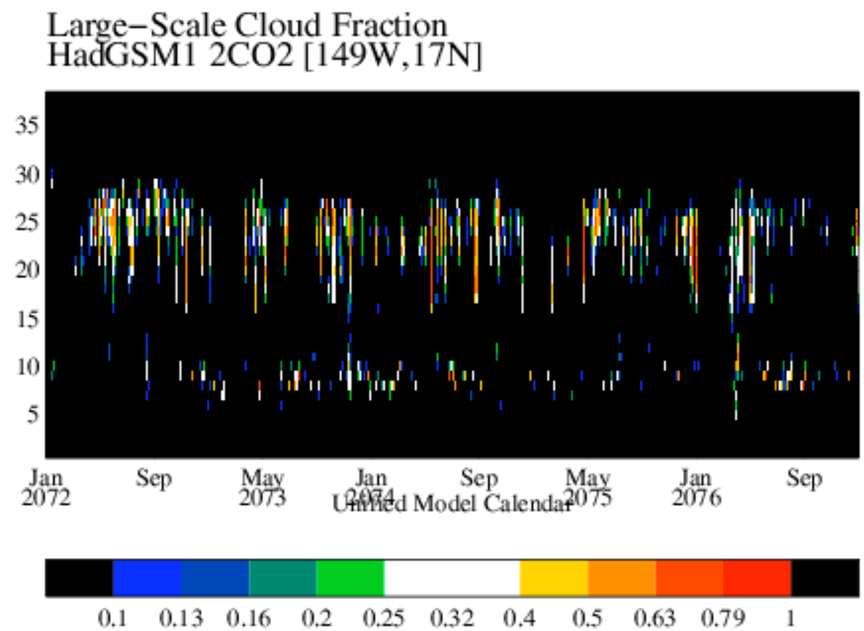
Low cloud response in HadSM3 transition regions

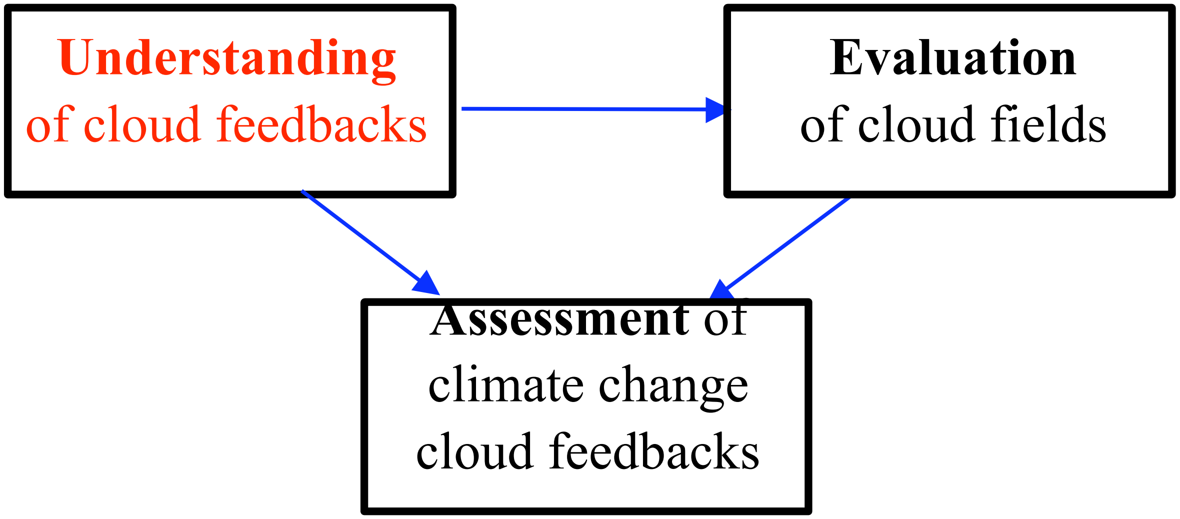
- Deep and shallow convection weaken in the warmer climate (consistent with Held and Soden 2006)
- Shallow convection typically detrains into two model layers in present day, but one level in the warmer climate
- If a certain amount of water vapour is detrained into a single layer it will moisten that layer more than would be the case if it was spread over two layers
- May explain why HadSM3 stratiform cloud fraction increases with weakening shallow convection
- Hence the negative low cloud feedback in HadSM3 may be due to poor vertical resolution and so not credible


SW CRF W/m2
HadGSM1 Obs dT = 4.3
RMSE= 10
Bias= -5
RMS2= 9
ERBE
Control
2CO2


Large-Scale Cloud Fraction HadGSM1 2CO2
-HadGSM1 Control
Model Level
Longitude
165W
150W
135W


Large-Scale Cloud Fraction
HadGSM1 Control [149W,17N]
Unified Model Calendar


Large-Scale Cloud Fraction
HadGSM1 2CO2 [149W,17N]
Unified Model Calendar



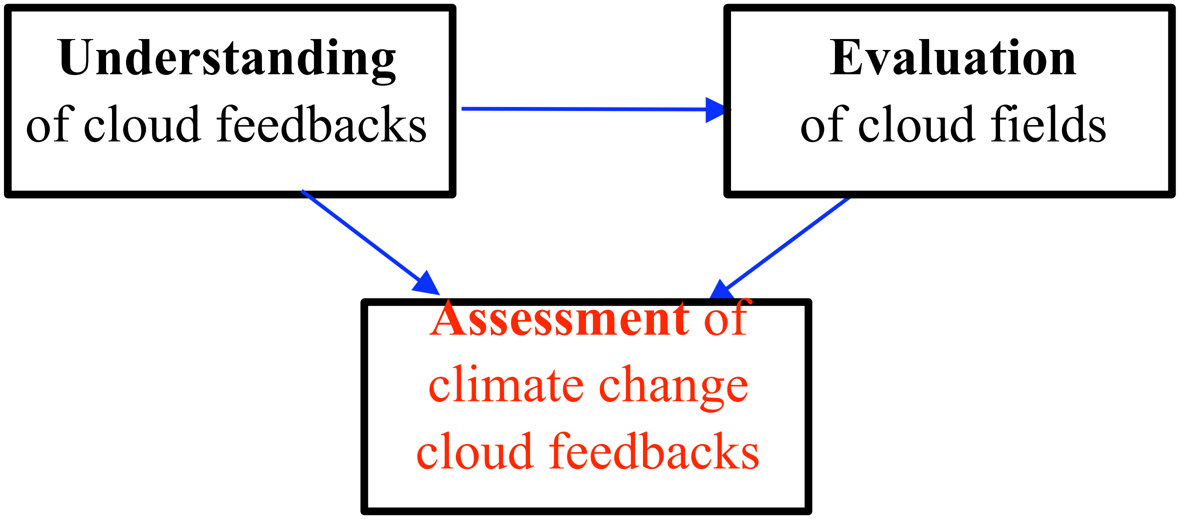
Requires: more cloud diagnostics from GCMs + enhanced scrutiny

CFMIP-II:

→Encourage the analysis of cloud feedback processes by a wider community !

- make cloud diagnostics more easily accessible to the community (daily cloud diagnostics from CFMIP-1 to be available from PCMDI)
- strengthen the link between CMIP and CFMIP (e.g. by increasing the number of cloud diagnostics in the outputs of coupled models, by running the ISCCP simulator)

→Organize climate physics sensitivity experiments + consistent implementation of simplified physics (e.g. mixed-phase cloud feedback)



How may we use our *physical understanding* of climate change cloud feedbacks and the available *model-data comparisons* to define a "metrics" for cloud feedbacks?

CFMIP-II:

→Explore relationships between cloud evaluation tests and cloud-climate feedbacks based on a wide diversity of diagnostics and approaches + a large number of GCMs

→Discuss the issue during a joint CFMIP/ENSEMBLES workshop in Paris (11-13 April 2007).

CFMIP Phase II

CFMIP Phase II will aim to reduce uncertainty in cloud feedbacks and climate sensitivity by developing further links between feedbacks and observations and improving our understanding of cloud feedback mechanisms by:

1. Developing better cloud diagnostics for models:
   - CloudSat/CALIPSO simulator
   - GCSS Pacific Cross Section (diurnal cycle, …)
   - Cloud budget/tendency diagnostics

2. Applying
2. Exploring sensitivities of feedbacks to model physics
   e.g. low clouds, convective entrainment

3. Collaboration with Gewex/GCSS community
   - GCSS Pacific Cross Section (diurnal cycle, …)

Alternative experimental setups

Cess +/-2K fixed season experiments are not a quantitative guide to coupled model feedbacks
- no seasonal cycle
- no high latitude amplification of warming

Alternative options include:
- continuing use of mixed layer experiments
- re-running sections of AR4 coupled experiments with extra diagnostics
- ‘patterned SST perturbation’ experiments as developed by Brian Soden (possibly AMIP+)

Proposed new diagnostics for CFMIP Phase II

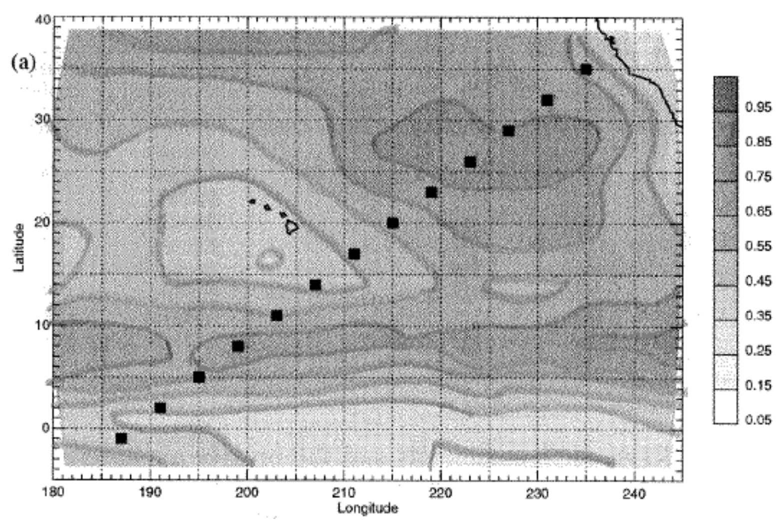
CFMIP Cloudsat/CALIPSO Simulator (C3S)

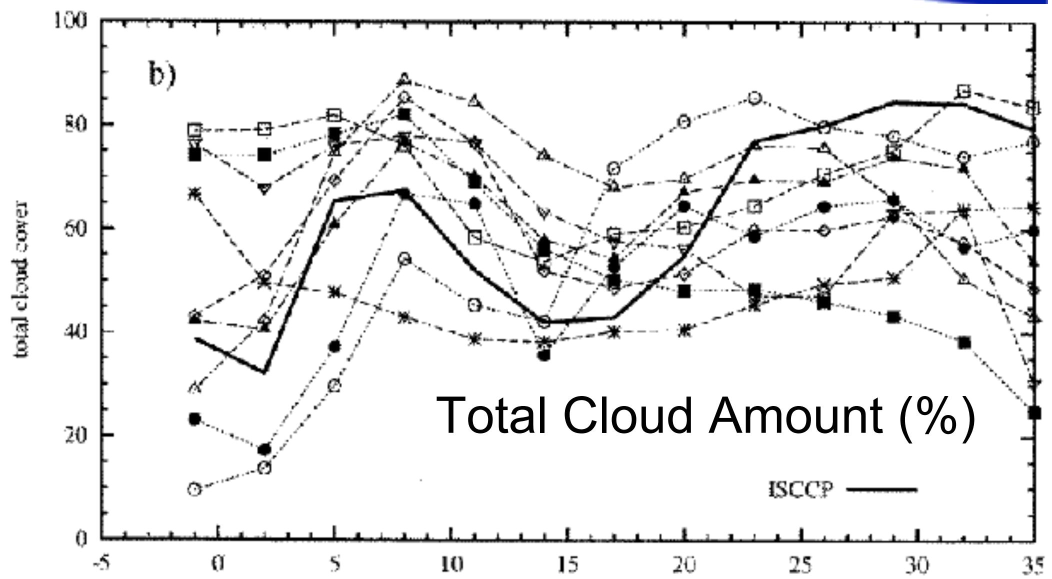
Sub-timestep information
- Cloud condensate budget terms
- Physics increments for temperature, humidity, etc

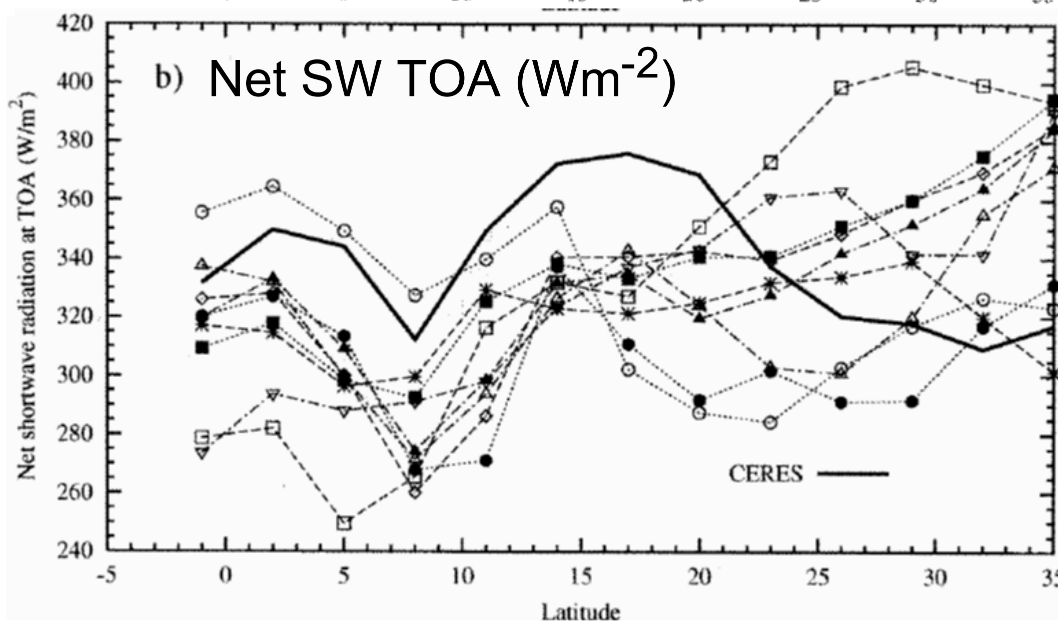
Detailed diagnostics at key locations as used in GCSS/ARM studies (e.g GPCI)

European Cloud System study (EUROCS)
Pacific Cross Section

A. P. SIEBESMA *et al.*



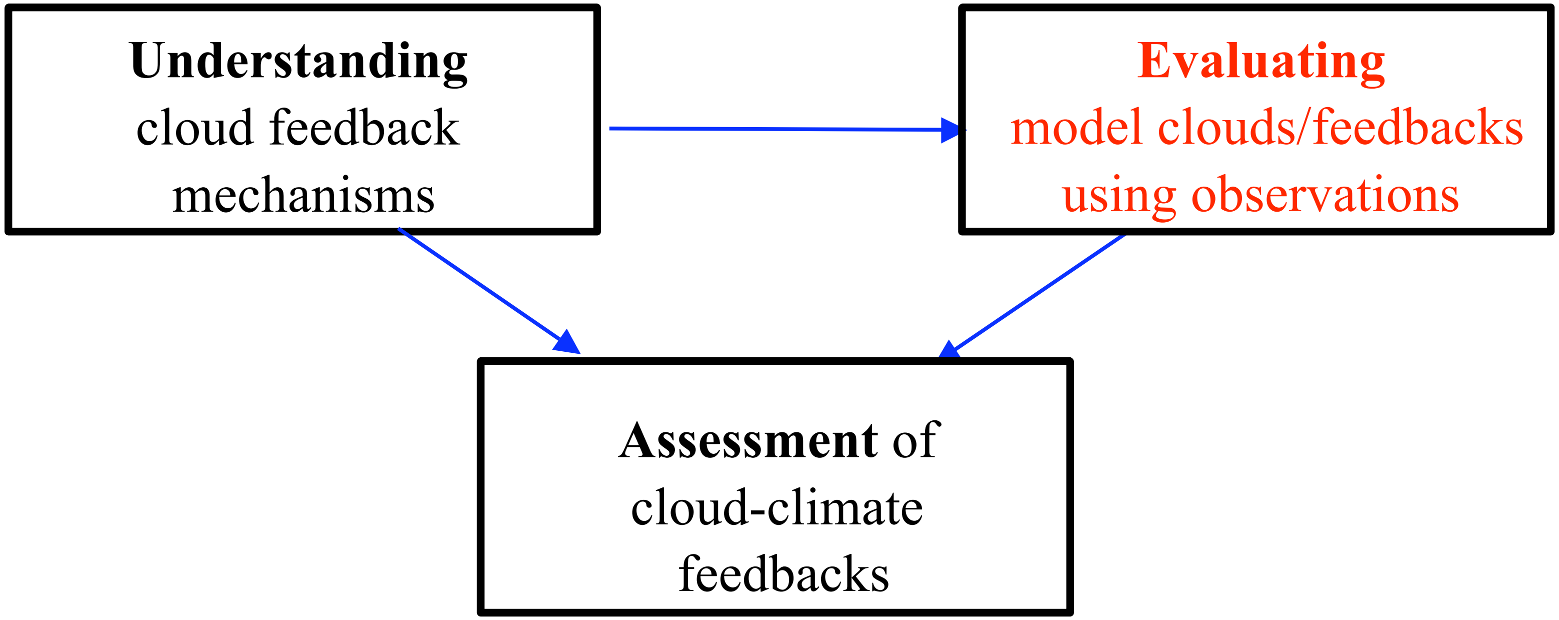




Siebesma et al 2004

Pacific Transect
California/trades/ITCZ

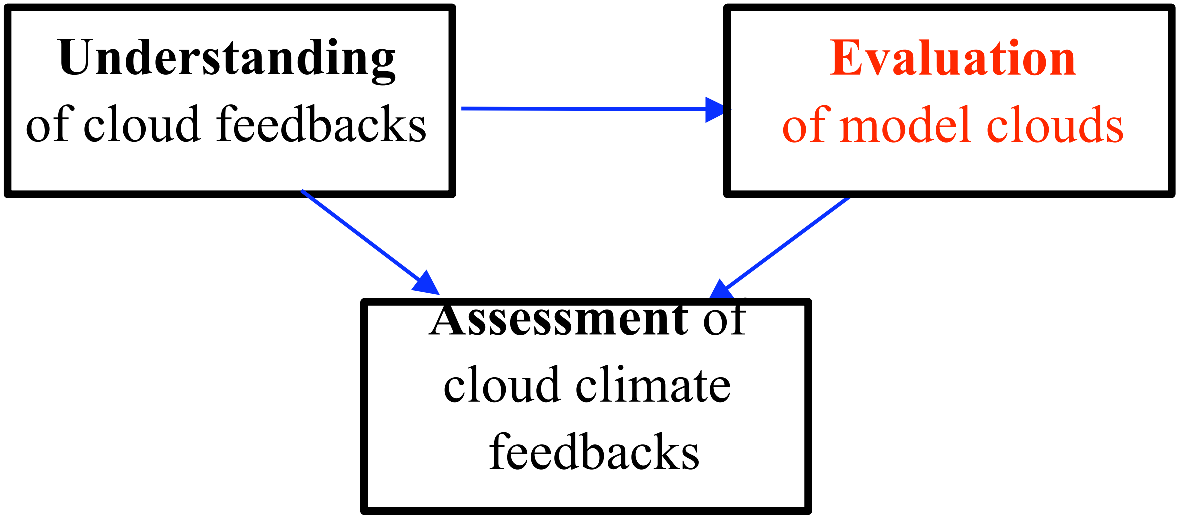
9 regional, NWP and climate models compared, JJA 1998



Develop better cloud diagnostics for climate models:

High frequency instantaneous diagnostics along WGNE/GCSS GPCI and at ARM sites

CFMIP CloudSat/CALIPSO Simulator (C3S)



Requires: process-level studies + model-data comparisons + new satellite data

→Embed GCSS (e.g. high-frequency diagnostics at ARM sites, GEWEX Pacific Cross-Section; evaluation of some specific cloud processes)

→Development of a CFMIP CloudSat/CALIPSO Simulator (C3S) (including eventually an A-train orbital simulator) -> will favor interactions with obs people!

→We would like the AR5 models to be run with the ISCCP/radar/lidar simulator, and the CFMIP cloud diagnostics to be included into the list of standard outputs

Reducing uncertainty by understanding feedbacks

1/ Try to understand how physical cloud climate feedback processes are operating in models

2/ Ask ‘Is this behaviour credible?’

3/ Develop new schemes with more credible cloud-climate feedback behaviour in mind

4/ Differences between model feedbacks may reduce in the longer term

5/ Can help to focus attention on key physical processes for cloud feedbacks

Further links between feedbacks and observables

New diagnostics will provide opportunities for new links

e.g. CloudSat/CALIPSO data may constrain models with strong mixed-phase cloud feedbacks due to excessive amounts of cloud ice

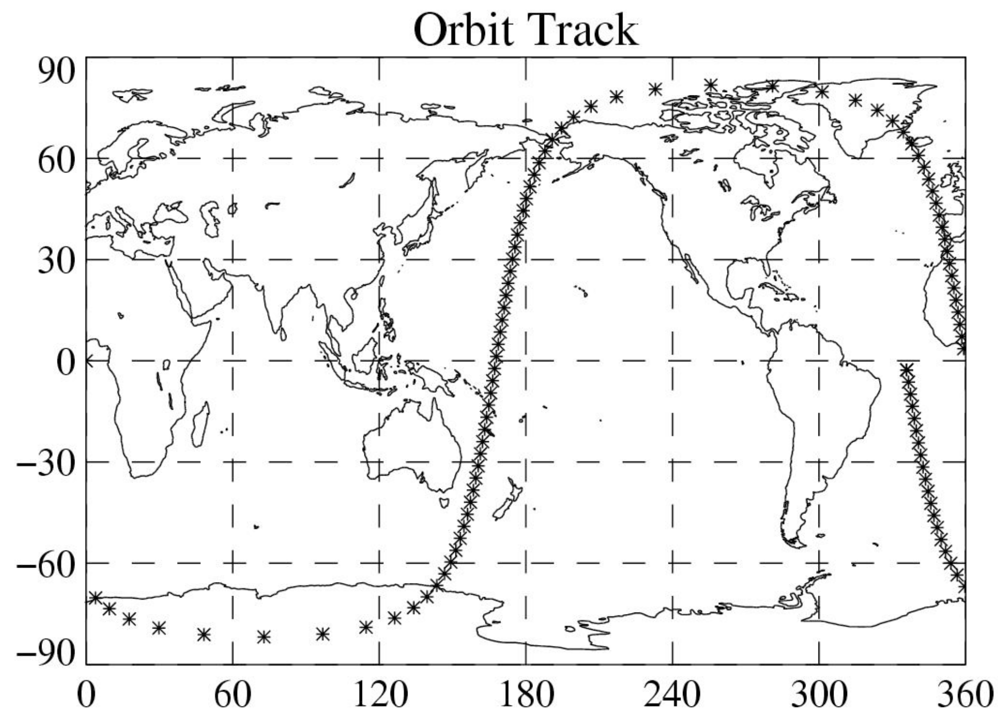
This will be an ongoing area of research, and the focus of a joint ENSEMBLES/CFMIP meeting in Paris 11^{th}-13^{th} April 2007

CFMIP CloudSat/CALIPSO simulator (Alejandro Bodas-Salcedo)

Simulated CloudSat reflectivities from UKMO forecast model

The simulator consists of 5 steps:

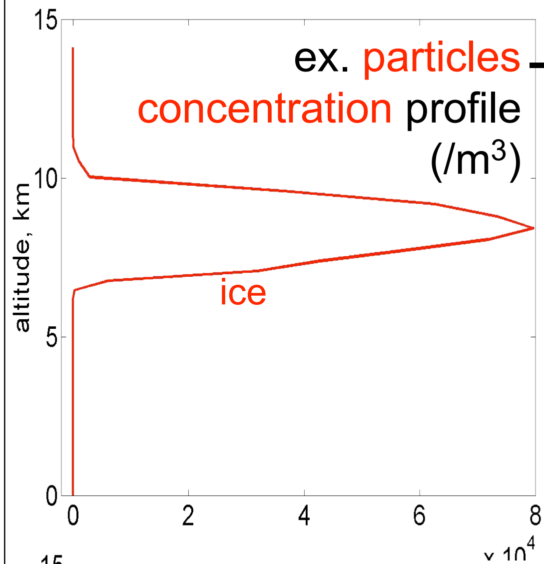
1. Orbital simulation
2. Sampling
3. Preprocessing
4. Subgrid sampling of cloud overlaps
5. Radar reflectivity calculated using code provided by Matt Rogers (CSU)

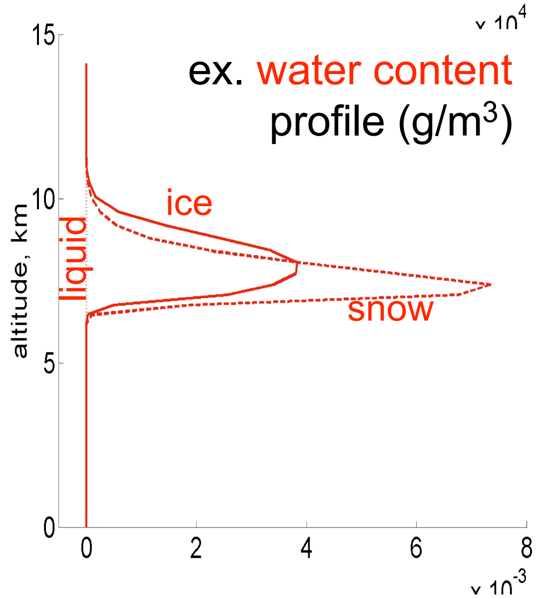


Outputs:

- Reflectivity from clouds and precipitation (without attenuation)
- Total reflectivity, accounting for attenuation by gases, clouds and precipitation
- Products obtained from inputs at gridbox and subgrid scales

ACTSIM CALIPSO simulator – Marjolaine Chiriaco (LMD/IPSL)

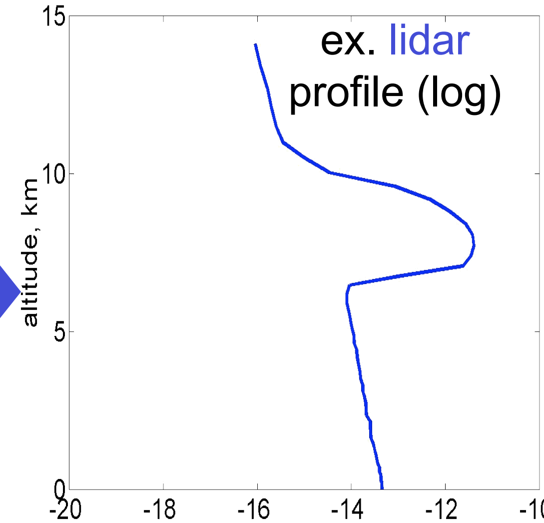




ACTSIM

Lidar Equation

- Optical properties: $P(\pi,z)$, $Q_{sca}(z)$, $Q_{abs}(z)$ *(532 nm)*
- Lidar calibration
- Multiple scattering



CFMIP Phase II C3S inter-comparison

Initially we will provide an A-train orbital simulator to allow climate modellers to save model cloud variables co-located with CloudSat/CALIPSO overpasses

Initially sampled data would be submitted to CFMIP and both simulators run centrally

As the approach matures we plan to integrate this package with the ISCCP simulator so that it can be run in-line as part of the model development cycle