Clouds in CMIP5: How can ASR/ARM influence IPCC-class models?

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Program for Climate Model Diagnosis and Intercomparison

Lawrence Livermore National Laboratory

ASR 2012 Science Team Meeting

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PCMDI

Program for Climate Model Diagnosis and Intercomparison

LLNL-PRES-537593

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Outline

- IPCC and CMIP5
- First Glimpses of Clouds in CMIP5

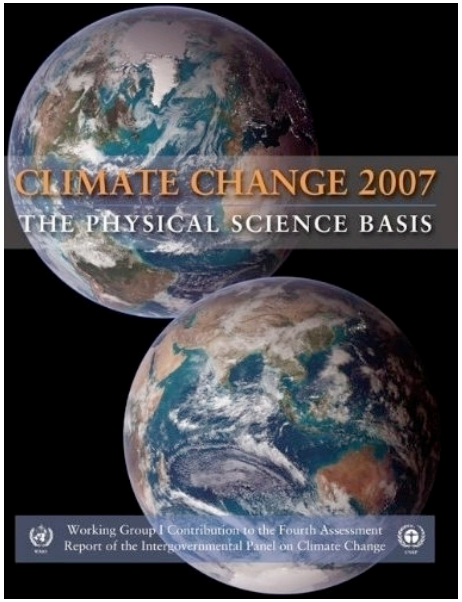
  Are climate model simulations of clouds and radiation for today's climate improving?

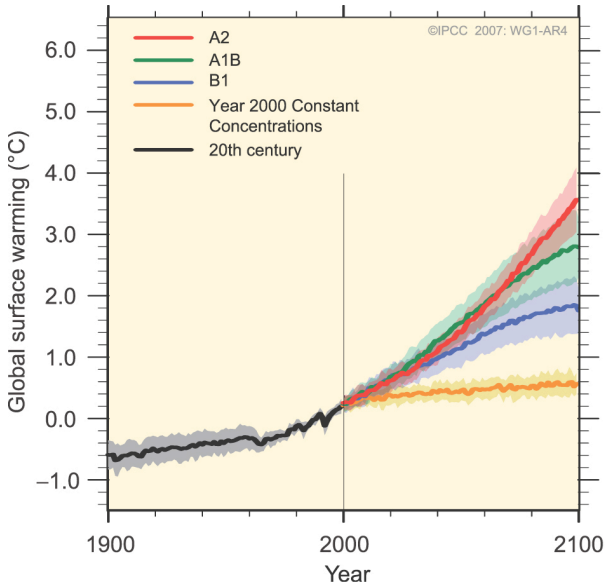
  Is the inter-model spread in climate-change predictions of clouds and climate sensitivity reducing?

- In what new ways can ASR/ARM influence the development and improvement of IPCC-class climate models?
- Conclusions

Intergovernmental Panel on Climate Change (IPCC)

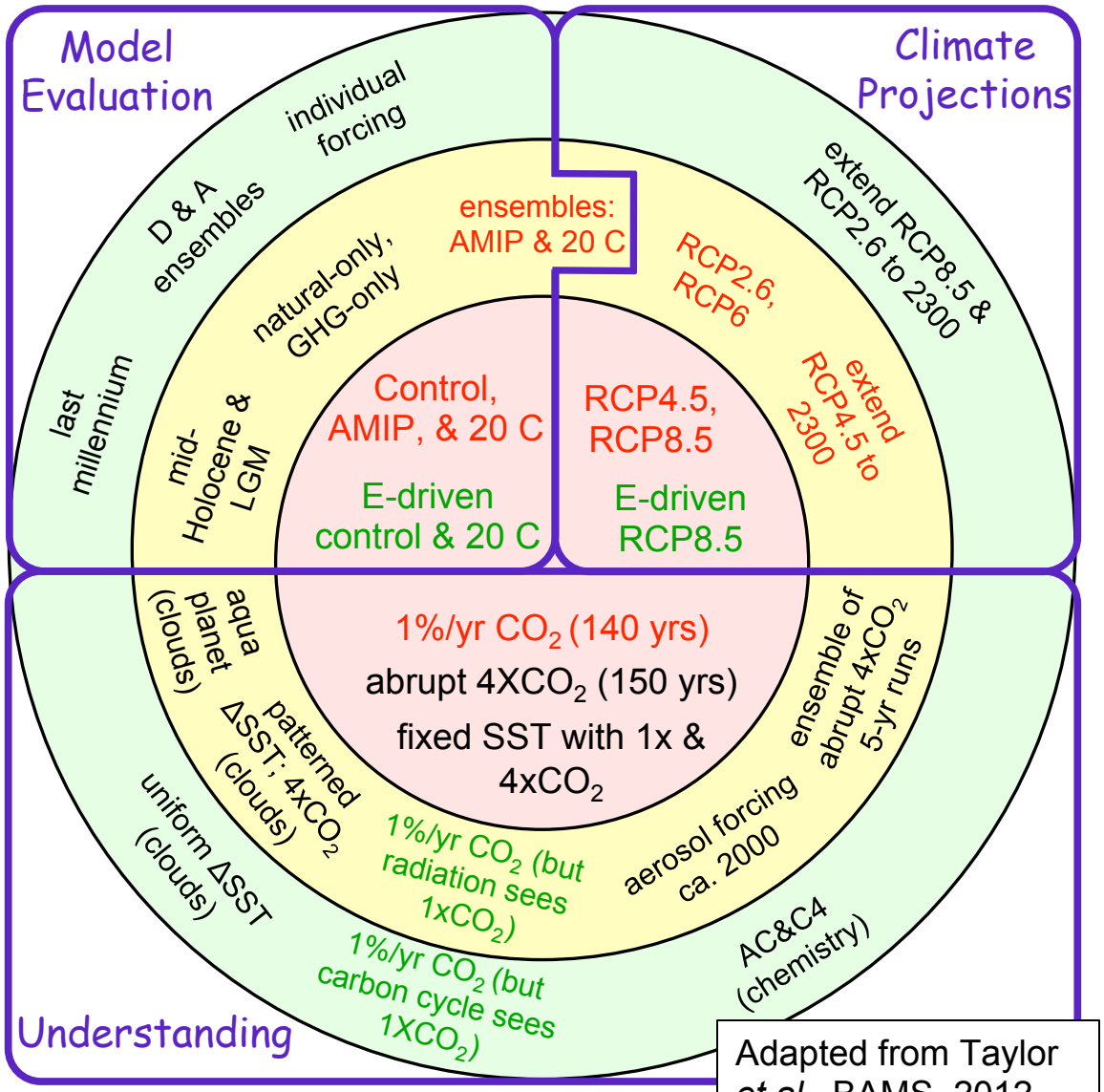
- IPCC assesses climate change science
- 5th report is currently being written
- 4th report (2007):
  - Increased evidence for human impact on warming since pre-industrial times primarily through increases in well-mixed greenhouse gases such as CO_2
  - Largest uncertainty in equilibrium warming due to a doubling of CO_2 (equilibrium climate sensitivity) is due to clouds (basis in part for ARM program)
- IPCC assesses climate model simulations are organized by World Climate Research Program





Coupled Model Intercomparison Project (CMIP)

- Coupled Model Intercomparison Project 3 (2005) was assessed in 4th assessment report
- CMIP5 is the new project whose output is just now becoming available
- CMIP5 is very ambitious



Adapted from Taylor *et al.*, BAMS, 2012

CMIP5 participating groups (24 groups; 50+ models; 3 Mar 2012: 41 models available from 20 centers)

Primary Group	Country	Model
CSIRO-BOM	Australia	ACCESS 1.0
BCC	China	BCC-CSM1.1
GCESS	China	BNU-ESM
CCCMA	Canada	CanESM2, CanCM4, CanAM4
DOE-NSF-NCAR	USA	CESM1, CCSM4
RSMAS	USA	CCSM4(RSMAS)
CMCC	Italy	CMCC- CESM, CM, & CMS
CNRM/CERFACS	France	CNRM-CM5
CSIRO/QCCCE	Australia	CSIRO-Mk3.6
EC-EARTH	Europe	EC-EARTH
LASG-IAP & LASG-CESS	China	FGOALS- G2.0, S2.0 & gl
FIO	China	FIO-ESM
NASA/GMAO	USA	GEOS-5
NOAA GFDL	USA	GFDL- HIRAM-C360, HIRAM-C180, CM2.1, CM3, ESM2G, ESM2M
NASA/GISS	USA	GISS- E2-H, E2-H-CC, E2-R, E2-R-CC, E2CS-H, E2CS-R
MOHC	UK	Had CM3, CM3Q, GEM2-ES, GEM2-A, GEM2-CC
NMR/KMA	Korea / UK	HadGEM2-AO
INM	Russia	INM-CM4
IPSL	France	IPSL- CM5A-LR, CM5A-MR, CM5B-LR
MIROC	Japan	MIROC 5, 4m, 4h, ESM, ESM-CHEM
MPI-M	Germany	MPI-ESM- HR, LR, P
MRI	Japan	MRI- AGCM3.2H, AGCM3.2S, CGCM3, ESM1
NCC	Norway	NorESM1-M, NorESM-ME, NorESM1-L
NCEP	USA	CFSv2-2011

Courtesy of Karl Taylor (LLNL)

Data Delivery

- Earth System Grid (ESG) is a distributed archive
- Current volume in last 6 months: 1 Petabyte (10^{15}), 2,000,000 files
  - Final volume expected to be 3 Pb, ~100x bigger than CMIP3

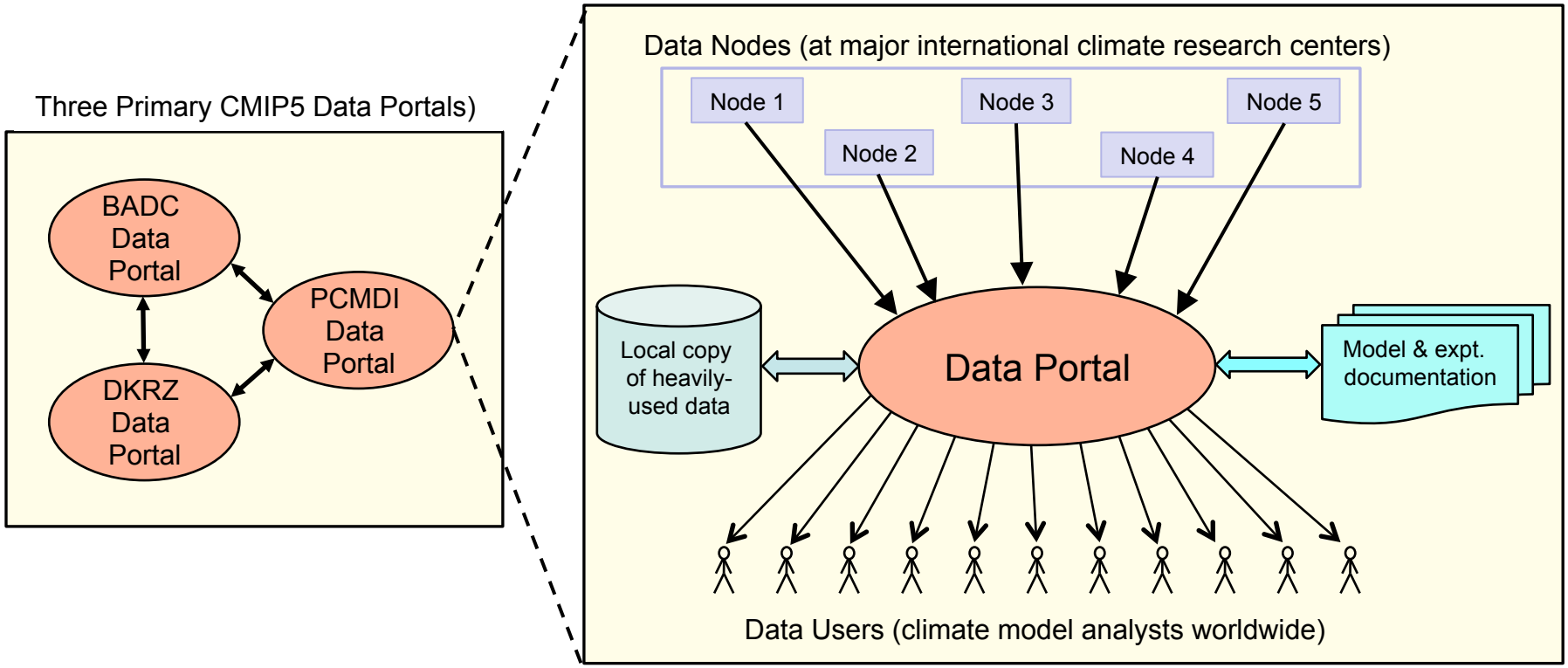


Figure courtesy of Karl Taylor (LLNL)

CMIP5 First Glimpses

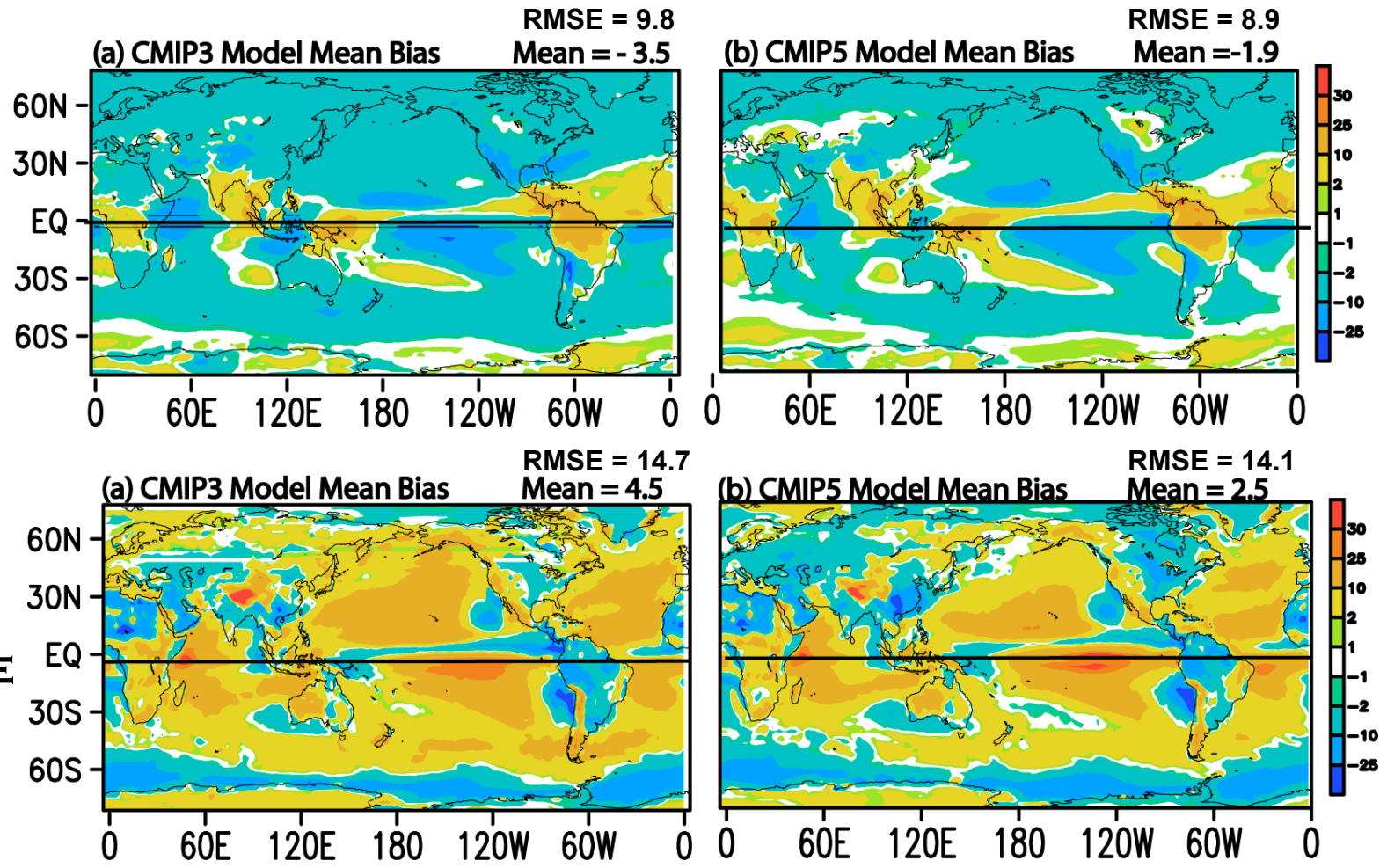
Preliminary results reported at the WCRP Workshop on CMIP5 Climate Model Analysis

March 5-9, 2012, University of Hawaii

Are climate model simulations of clouds and radiation for today's climate improving?

Yes, but improvement is moderate from the CMIP3 (ca. 2003)

Radiation Errors



observational source: CERES-EBAF

Figures courtesy of Frank Li (JPL)

Progress over time

Root Mean Square Errors for Outgoing Longwave Radiation

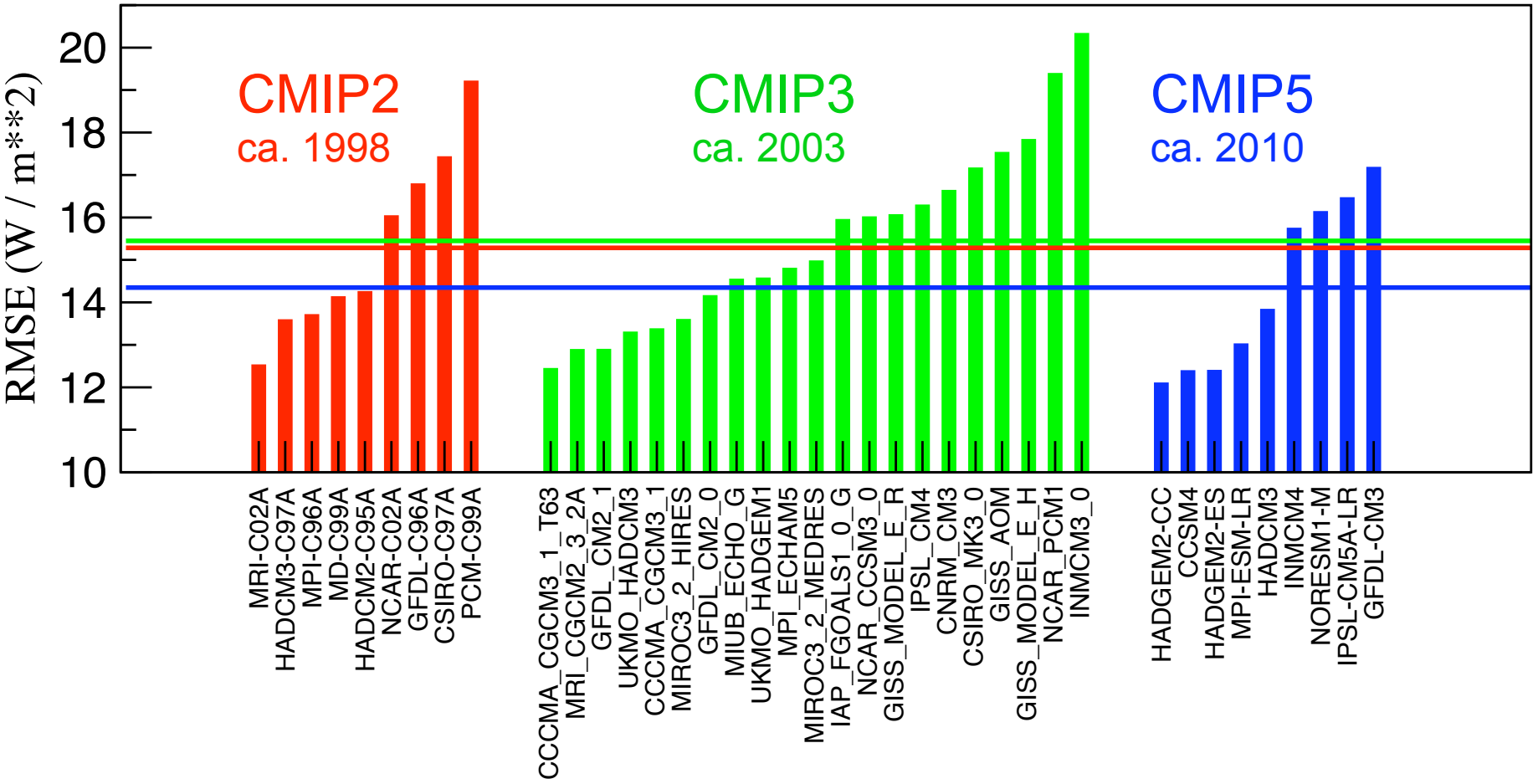
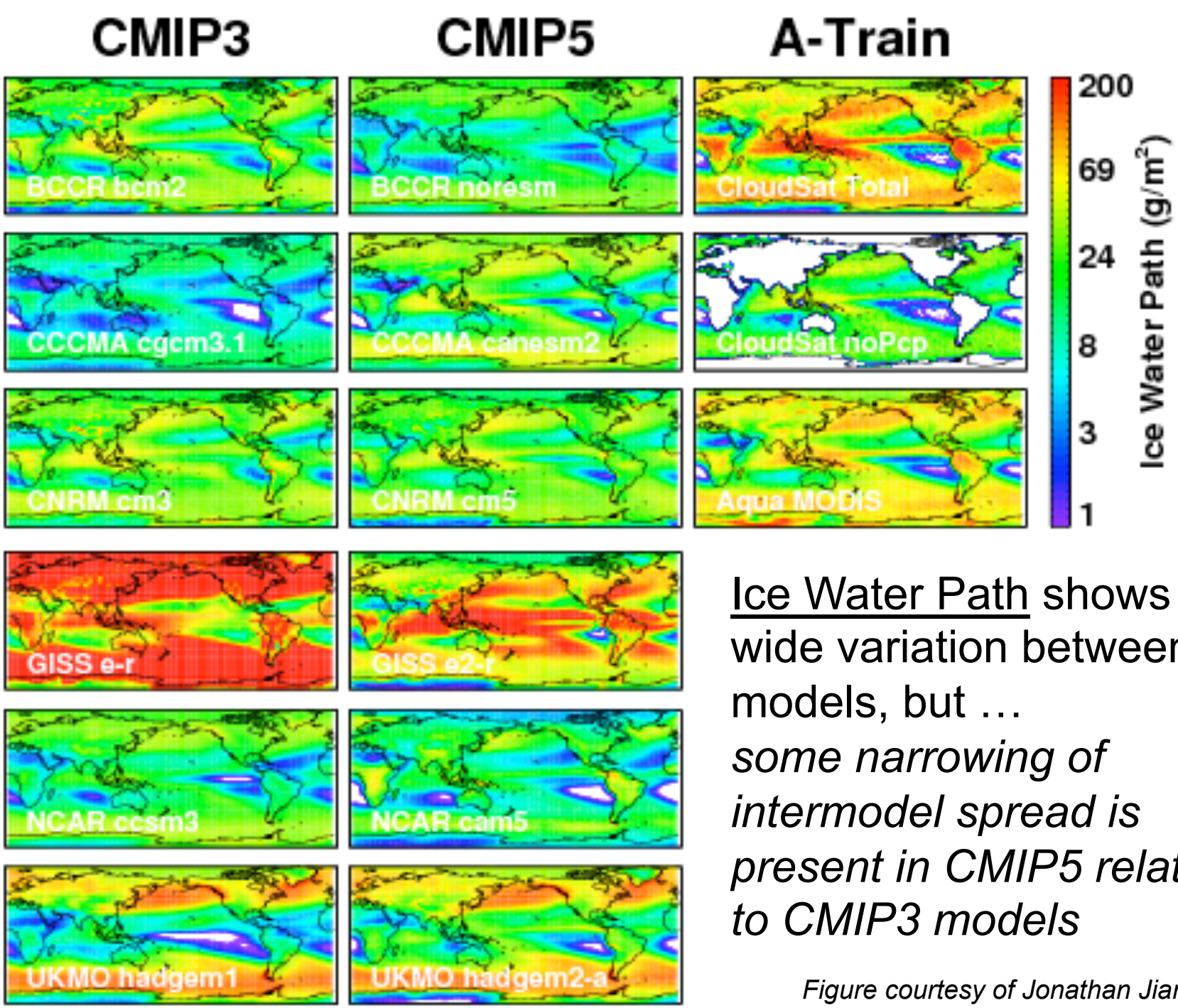


Figure courtesy of Peter Gleckler (LLNL)



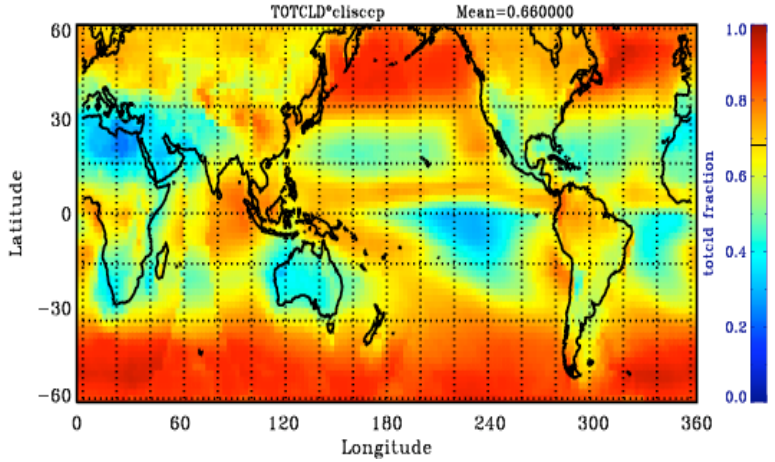
<u>Ice Water Path</u> shows wide variation between models, but …

some narrowing of intermodel spread is present in CMIP5 relative to CMIP3 models

Figure courtesy of Jonathan Jiang (JPL)

Satellite simulators for clouds provide a firmer basis for model intercomparison

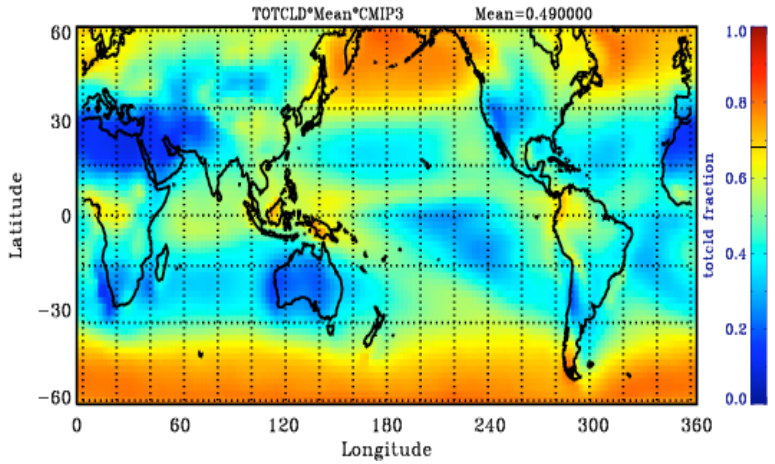
ISCCP Observations



CFMIP
Cloud Feedback Model Intercomparison Project

Total Cloud Cover shows little change between CMIP3 and CMIP5 wide variation between models, but …

Mean CMIP3 Model



Mean CMIP5 Model

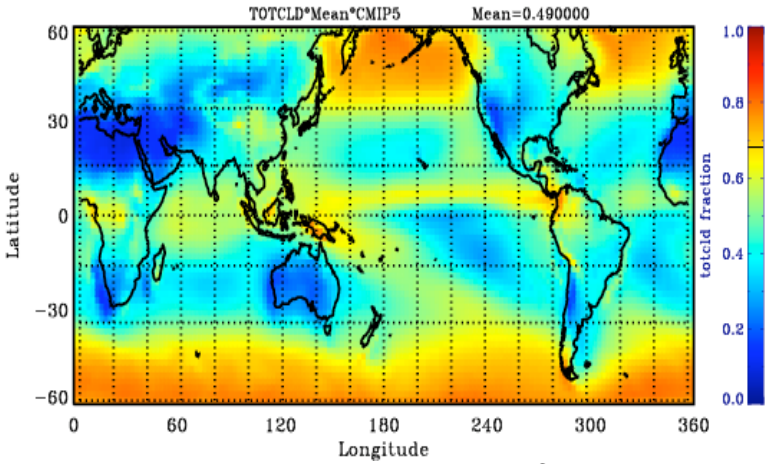
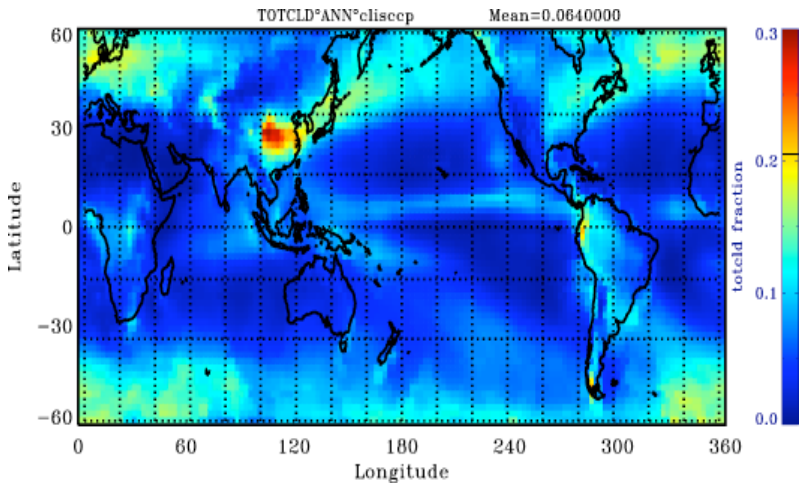


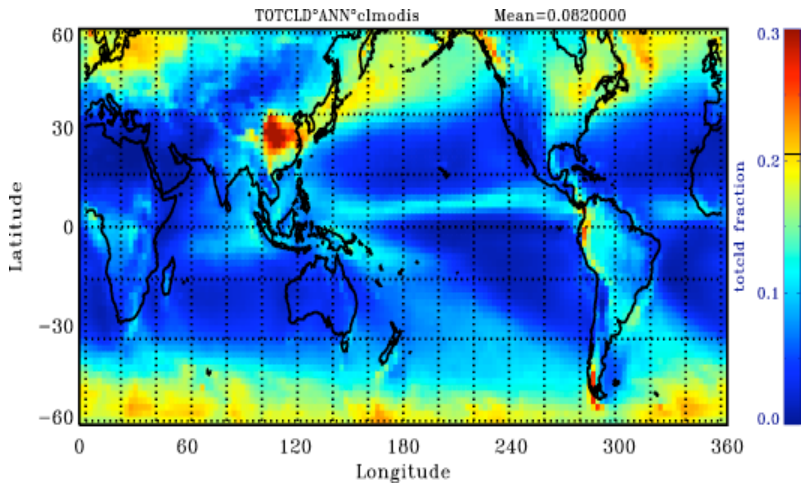
Figure courtesy of Yuying Zhang (LLNL)

The overestimate of highly reflective cloud cover ($\tau > 23$) is reduced by 40%

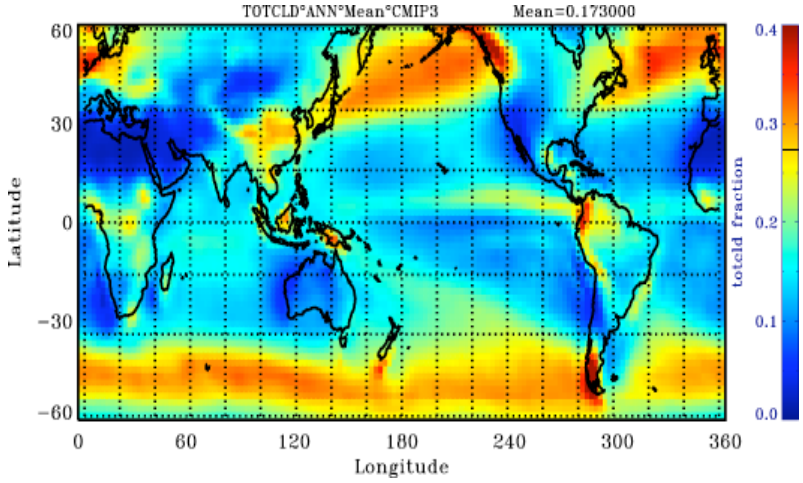
ISCCP Observations



MODIS Observations



Mean CMIP3 Model



Mean CMIP5 Model

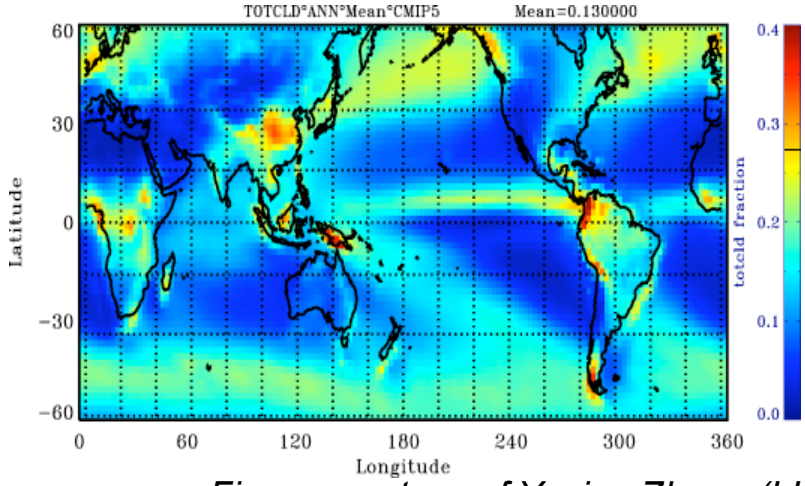
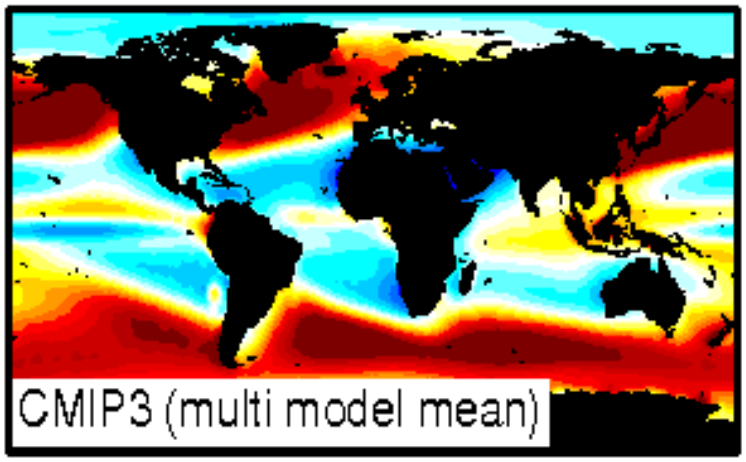
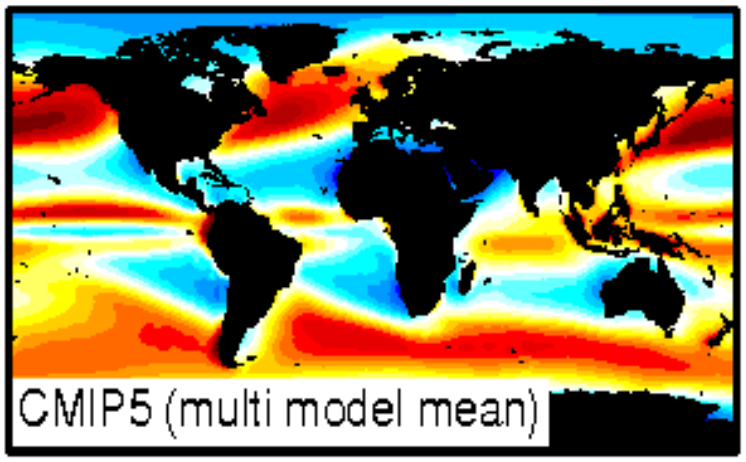
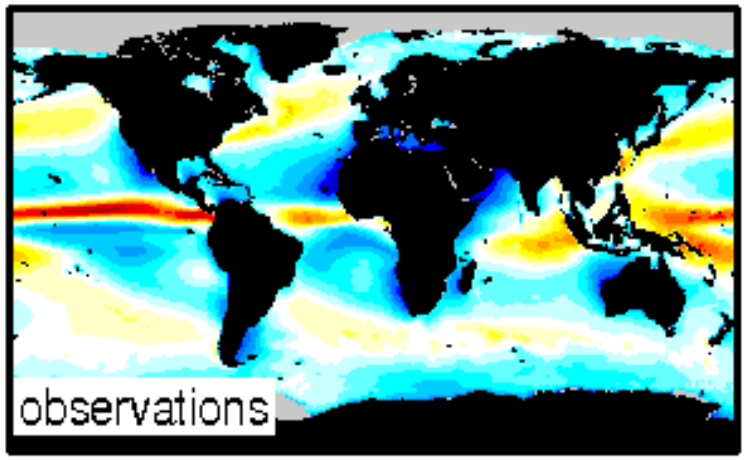


Figure courtesy of Yuying Zhang (LLNL)

This improvement is associated with a decrease in liquid water path







Liquid Water Path shows significant reduction in the midlatitude storm tracks (but there is still too much)

observational source:
SSM/I LWP (O'Dell et al. 2008)

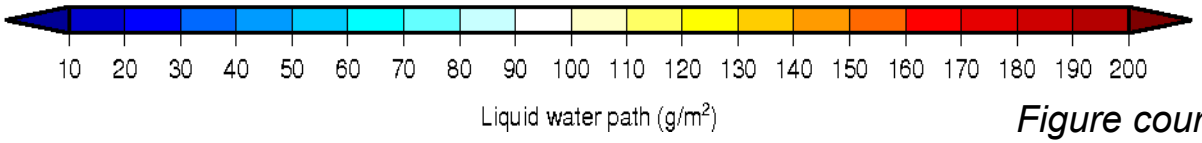
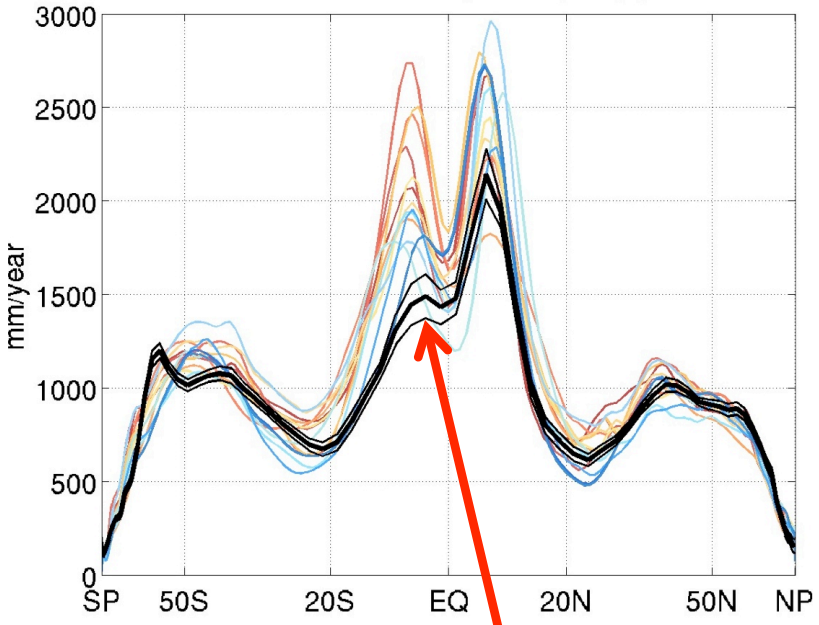


Figure courtesy of Axel Lauer (IPRC)

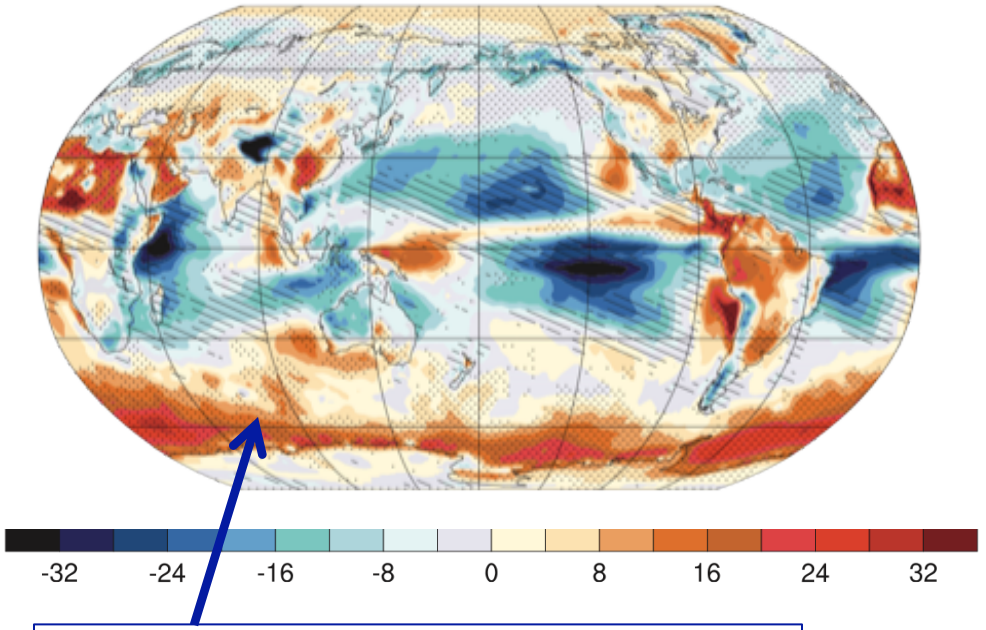
Multi-model studies help point to the causes of model errors

CMIP5 Zonal Mean Precipitation



Double-ITCZ Error

CMIP3 Mean Bias in Absorbed Shortwave



Too Much Shortwave Absorption

Are these two problems related?

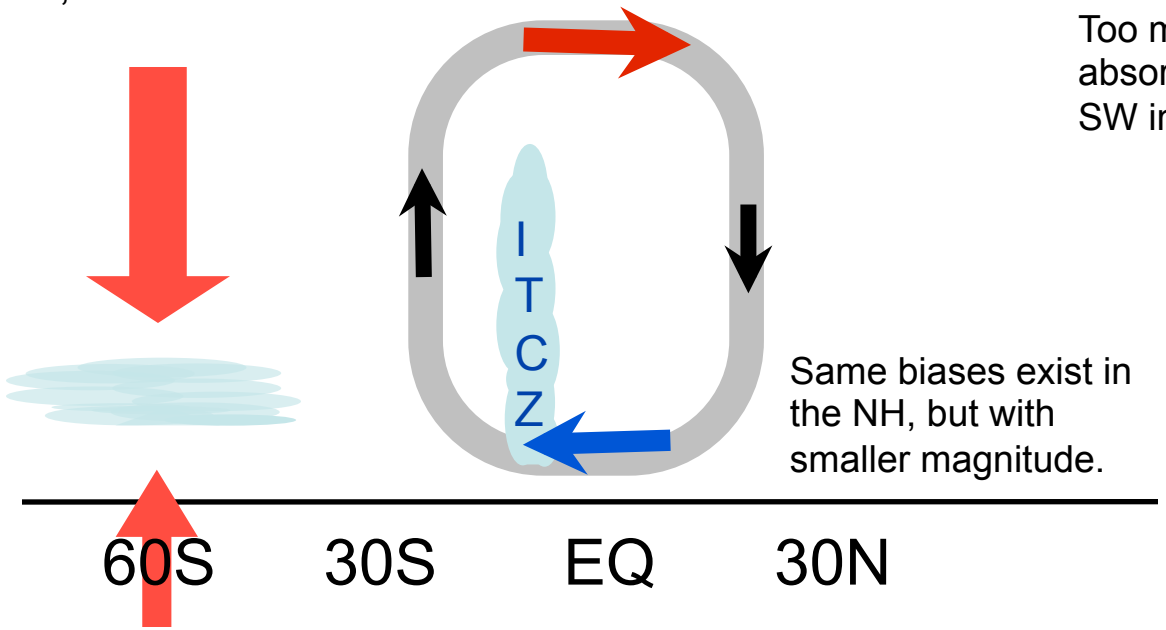
Figure courtesy of Yen-Ting Hwang (U. Wash.), Dargan Frierson (U. Wash.) and John Fasullo (NCAR)

Biases in clouds in extra-tropics lead to double ITCZ in GCMs?

Should ARM make an effort to observe these clouds?

too little SW reflection due too little clouds, or clouds being too thin, too dark

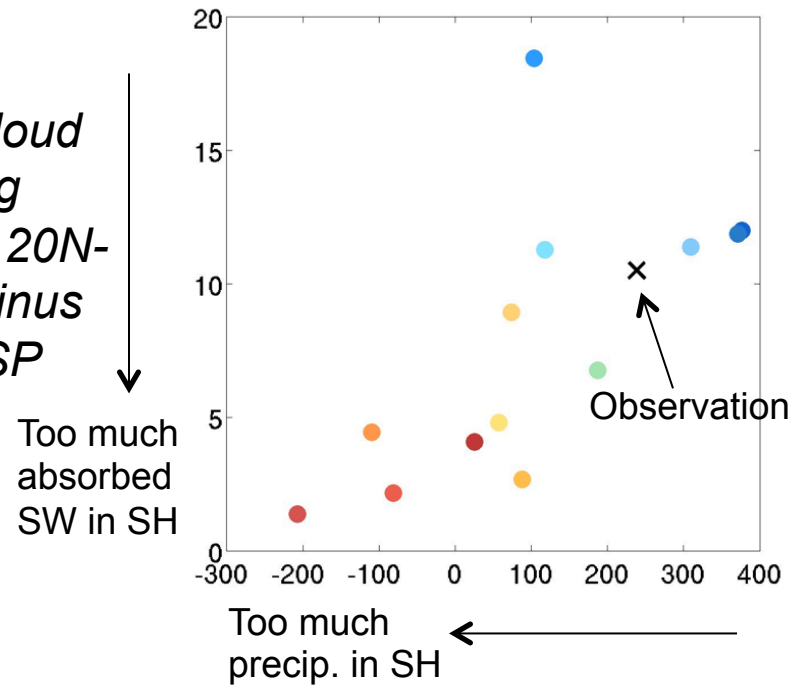
The Hadley cell responds by transporting excess energy from the southern hemisphere to the northern hemisphere



Same biases exist in the NH, but with smaller magnitude.

too much upward surface flux in high latitudes

CMIP5 Multi-Model Scatterplot



Precipitation Asymmetry

Figure courtesy of Yen-Ting Hwang (U. Wash.)

CMIP5 First Glimpses

Is the inter-model spread in climate-change predictions of clouds and climate sensitivity reducing?

No, but…

Emerging evidence suggests that the average cloud changes predicted by models are starting to be observed in the climate system, and

Significant progress has been made in understanding how different cloud systems should respond to climate change

Equilibrium Climate Sensitivity in CMIP5

- Equilibrium Climate Sensitivity among CMIP5 models ranges from 2.1 to 4.7 K indicating no reduction in inter-model spread from earlier estimates

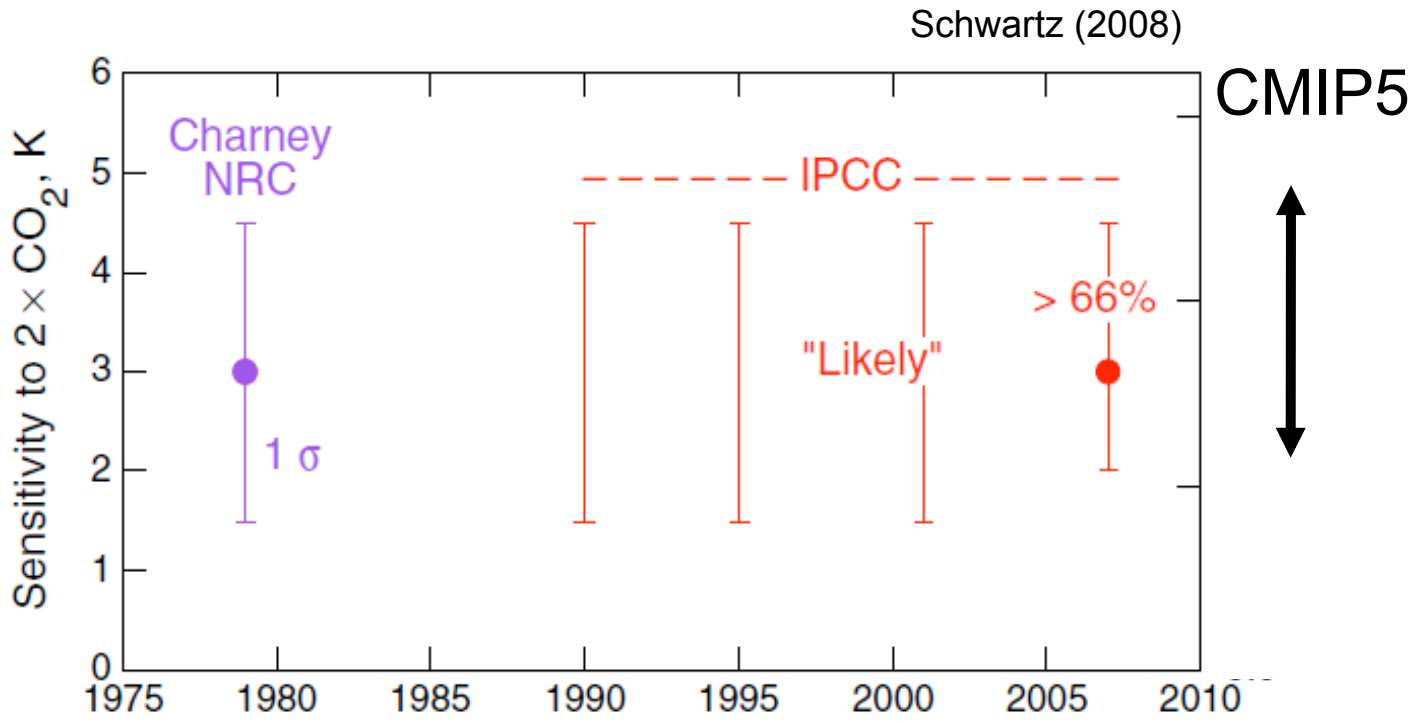


Figure courtesy of Tim Andrews (UKMO)

The contribution of clouds to inter-model spread in climate feedbacks

- Differences in cloud feedback continue to be the largest, but not the only, source of uncertainty in feedbacks

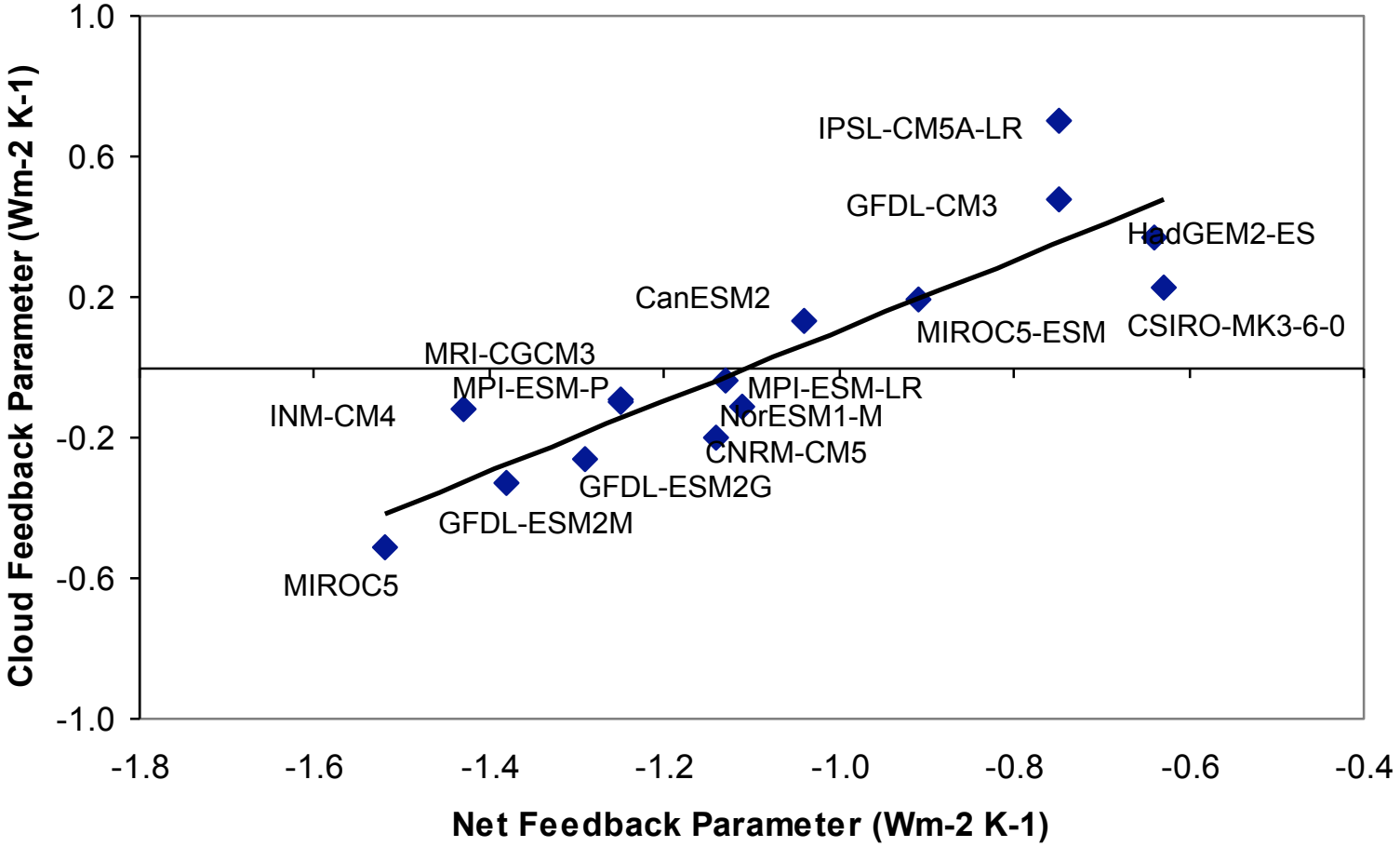


Figure courtesy of Tim Andrews (UKMO)

Feedbacks are sensitive to the response of low-clouds but …

- The inter-model spread in low cloud responses at low-latitudes is correlated with the inter-model spread in warming, *but …*

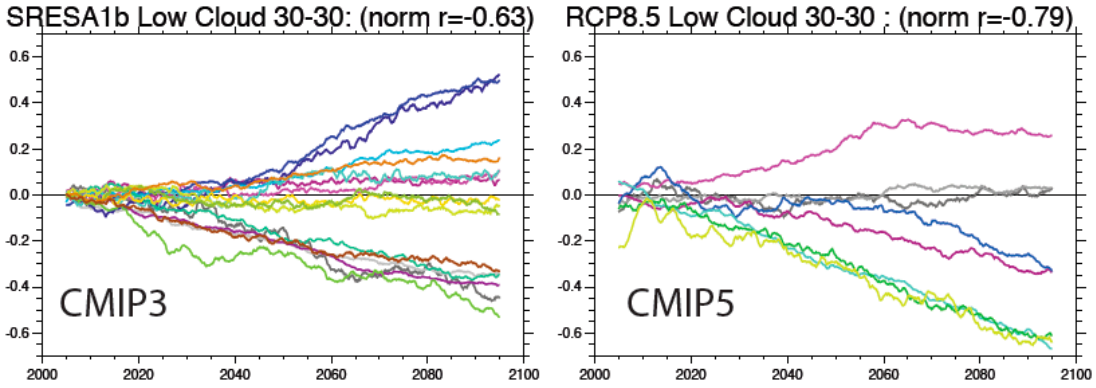
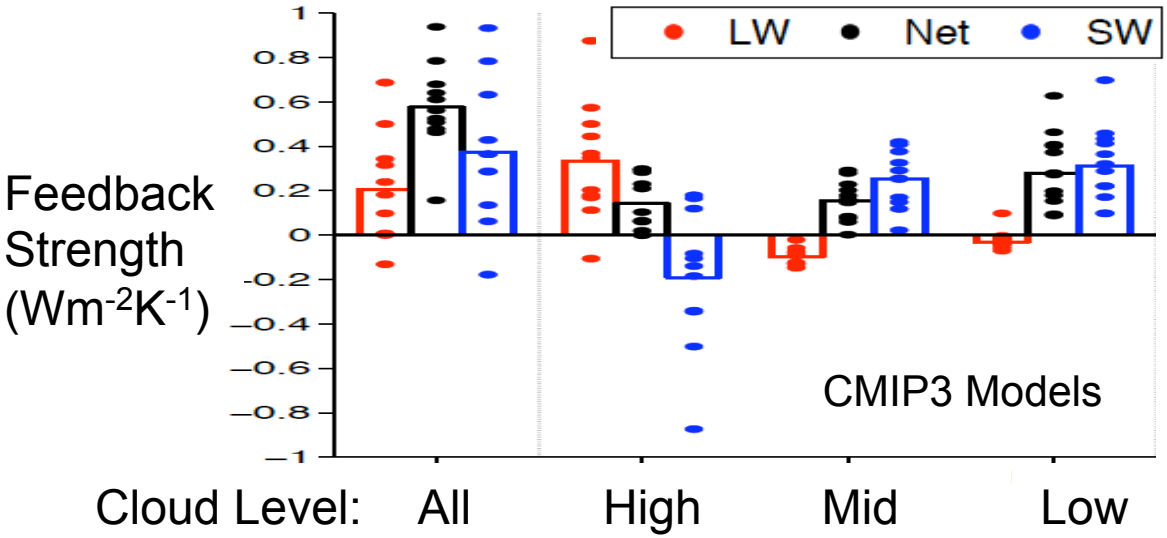


Figure courtesy of John Fasullo (NCAR)

- The spread in feedbacks from other cloud types is also significant and should not be ignored



Zelinka et al. (2012)

Reasons for optimism

- The spread of cloud feedback masks the fact that there are robust cloud changes that every model produces
- These robust cloud changes include:
  - Rise in the altitude of high clouds (positive feedback)
  - Expansion of the tropics (positive feedback)
  - Increase in cloud optical depth at high latitudes (negative feedback)
- An analysis of trends in (*corrected*) satellite cloud records (~1980 to present) suggests that all of these predicted cloud changes are occurring
- If one attributes the observed changes to greenhouse gas forcing, then one could have greater confidence that the estimates of cloud feedback are centered about the true value

(Relative) Cloud Trends In Satellite Observations and CMIP3 Models

Satellite Observations

Climate Models

Figures Removed

Figure courtesy of Joel Norris (UCSD) from Norris et al. (2012, in preparation)

In what new ways can ASR/ARM influence the development and improvement of IPCC-class climate models?

CMIP5 (and CFMIP2) provide new opportunities to use ARM data in model evaluation

“Obs4MIPs”

- The Observations for Model Intercomparison Projects is an effort, jointly organized between LLNL/DOE and JPL/ NASA, to put observational data into the same format (file type, variable names, etc.) as all of the climate model data (which are CF- and CMOR-compliant)

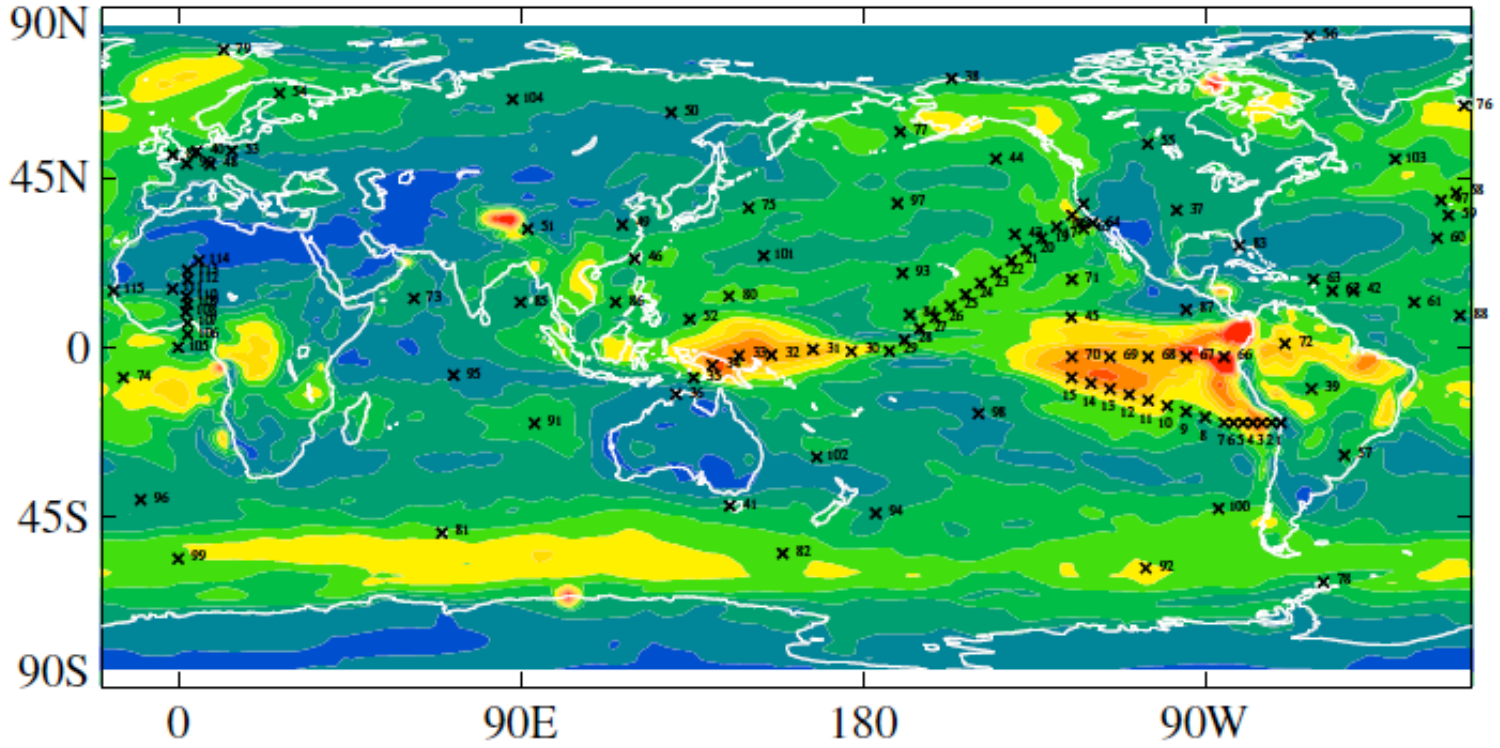
- ARM-observations, as well as CloudNet data from similar sites in Europe, has been reformatted and is being put into the Earth System Grid so that researchers can access observational data just as they do model data
  - ARM is contributing the ARM Best Estimate (formerly Climate Model Best Estimate) data product which contains hourly averages of high-quality basic quantities with direct model equivalents

New Opportunity

CFMIP
Cloud Feedback Model Intercomparison Project

PCMDI
Program for Climate Model Diagnosis and Intercomparison

- The CFMIP project has requested high-time frequency (~1 hour) output for a collection of sites from climate model simulations of the current and future climate
  - The sites include all ARM sites as well as sites deemed to be important to cloud feedbacks



Transpose-AMIP

- The Transpose-AMIP project will collect model output (including point data) from a series of weather hindcasts
  - Facilitate evaluation with point observations
  - Separate which climate errors arise from fast processes or require interactions of fast processes with the slower components of the climate system

Cloud Fraction profiles at the SGP site from ARM observations and the 5-day hindcasts of 5 climate models

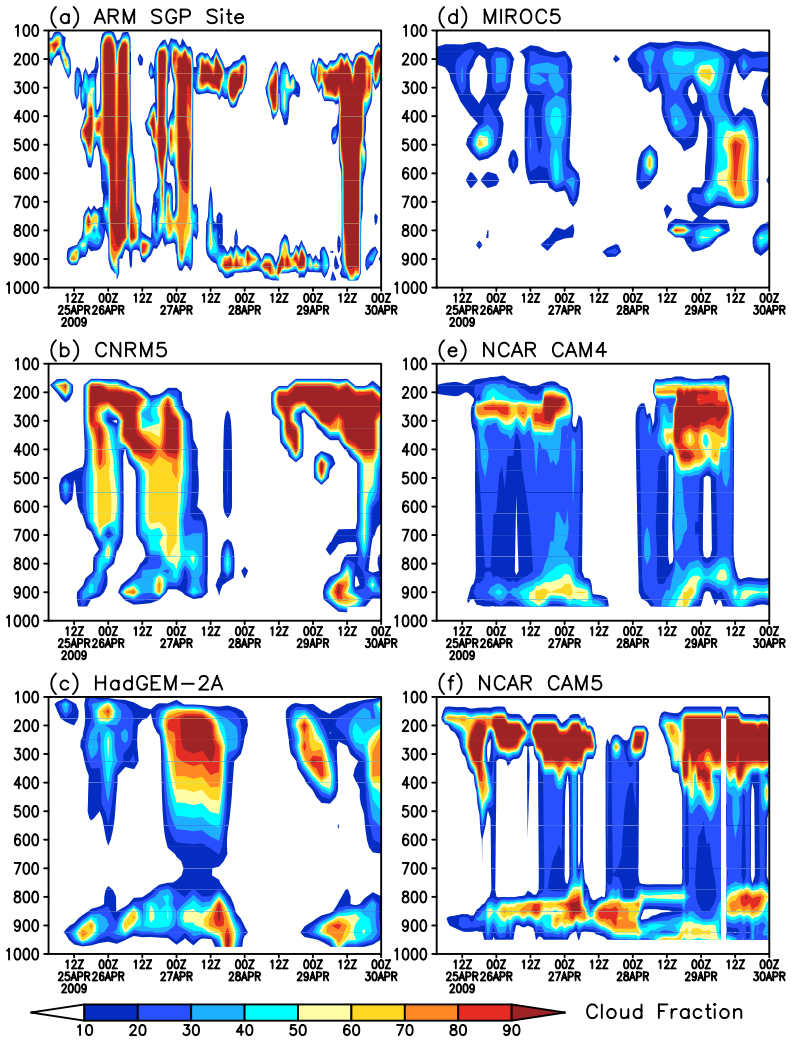


Figure courtesy of Hsi-Yen Ma (LLNL), Yunyan Zhang (LLNL), and Shaocheng Xie (LLNL)

Examples

- Qian et al. (2012) examined the relationship in ARM observations and CMIP3 models between surface shortwave transmissivity and mean cloud fraction at the SGP, NSA, and TWP (Manus) sites

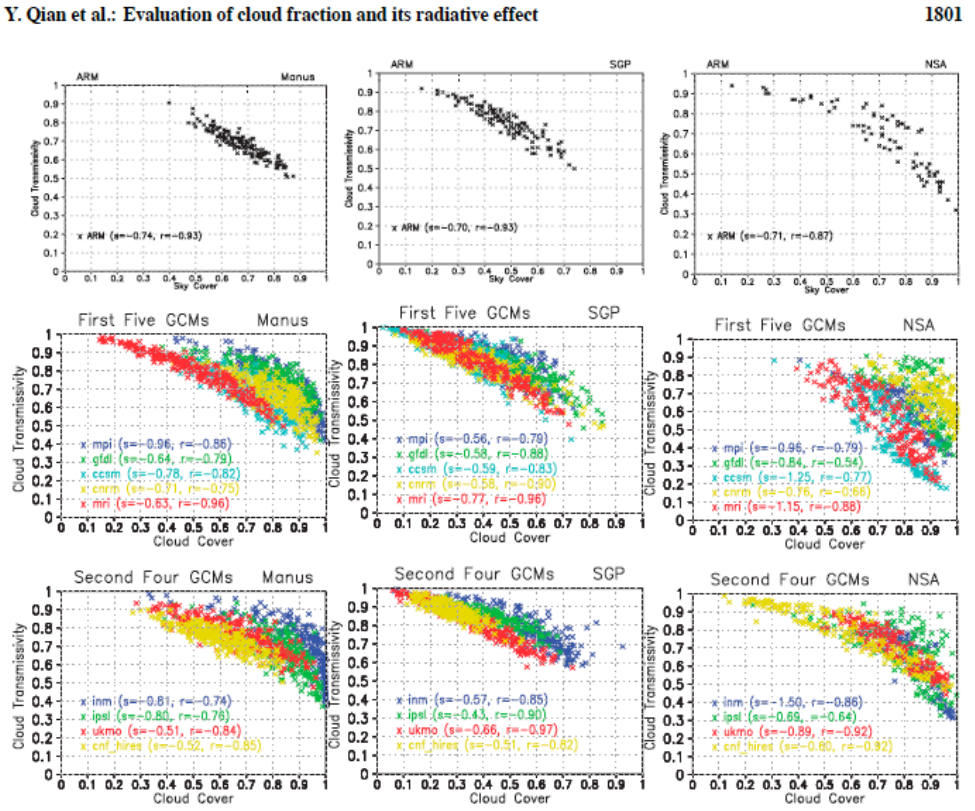


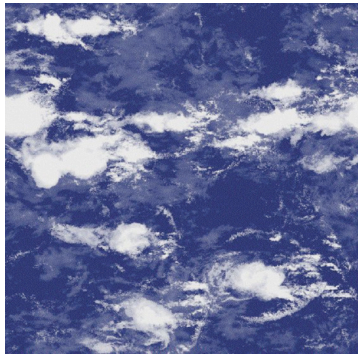
Fig. 8. The monthly mean SW transmissivity (Tsw) against their corresponding TCF for both observation and nine GCMs over three ARM sites. (a) Manus (left), (b) SGP (middle), and (c) NSA (right).

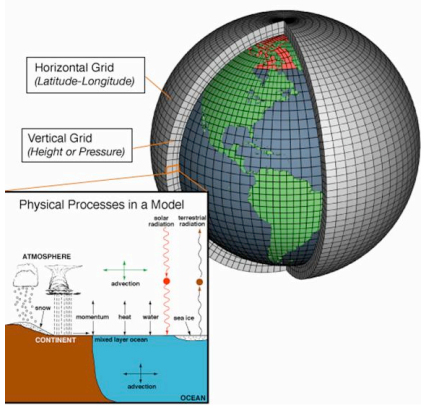
- Gero and Turner (2011) found a significant decreasing trend in downward longwave in the 14-year record from AERI at the SGP site

Is this a possible sign of the expected decrease in cloudiness that should occur between 30-40N due to tropics expansion?

Global Atmospheric Systems Study

- But process-based physical evaluation remains the central way ARM/ASR influences the development and improvement of cloud parameterizations in climate models
- Pan-GASS (formerly GCSS) (http://www.gewex.org/gass_panel.html) will have a meeting in Boulder on September 10-14, 2012
- GCSS has relied upon many ARM campaigns to provide observations need to constrain climate model parameterizations and cloud-resolving models
  - Summer 1997 ARM IOP, Summer 1999 ARM IOP, 2000 Cloud IOP, M-PACE, TWP-ICE, ISDAC, Sparticus





Conclusions

CMIP5 is a large multi-model project which provides new opportunities for ASR/ARM scientists to play a role in model evaluation

Are climate model simulations of clouds and radiation for today's climate improving?

Yes, but improvement is moderate from the CMIP3 (ca. 2003)

Is the inter-model spread in climate-change predictions of clouds and climate sensitivity reducing?

No, but progress is being made…

Why hasn't there been more progress?

- Modeling centers have focused on Earth System Model creation (i.e. interactive aerosols and carbon cycles)
  - Human effort devoted to cloud parameterization is limited
- Unrealistic expectations about how much effort is needed to actually reduce errors and feedback uncertainty
- Given the complexity added to models, it's amazing that they're not worse
  - Added complexity initially degrade simulations by allowing for more degrees of freedom
- Global mean cloud feedback is the sum over all of the changes in different cloud types
  - Small uncertainties in the size of individual feedbacks can add up to significant uncertainty in the global mean cloud feedback

The Glass Half-Full Side…

- Nobody at last week's meeting found degradation in model simulations of any phenomena between CMIP3&5
- Somethings show significant improvement (e.g. reduction of optically thick cloud) while others show less inter-model spread (e.g. IWP across models)
- The physical basis of parameterizations has been greatly improved in recent decades
  - We should have greater confidence in model results
- CMIP5 confirms conclusions based upon past modeling studies

Reproduction of results is a good thing in science

Do we thus have more confidence in model results?

Thank you!

Extra Slides

Tracking Progress by Modeling Center

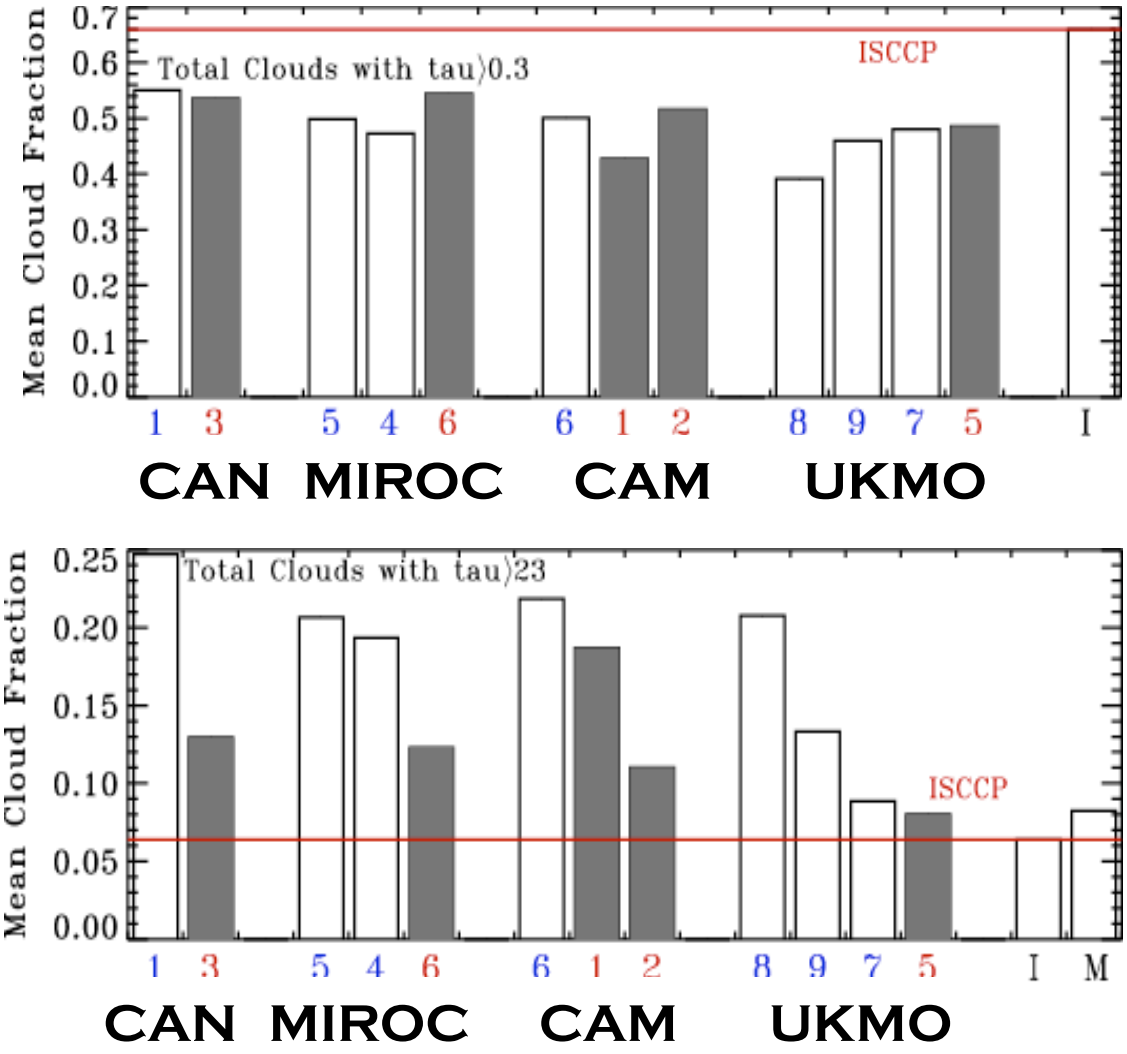


Figure courtesy of Yuying Zhang (LLNL)

Key

I – ISCCP
M - MODIS

Observations

1 - cccma_agcm4_0
2 - gfdl_mlm2_1
3 - ipsl_cm4
4 - miroc_hisens
5 - miroc_losens
6 - ncar_ccsm3_0
7 - ukmo_hadgsm1
8 - ukmo_hadsm3
9 - ukmo_hadsm4

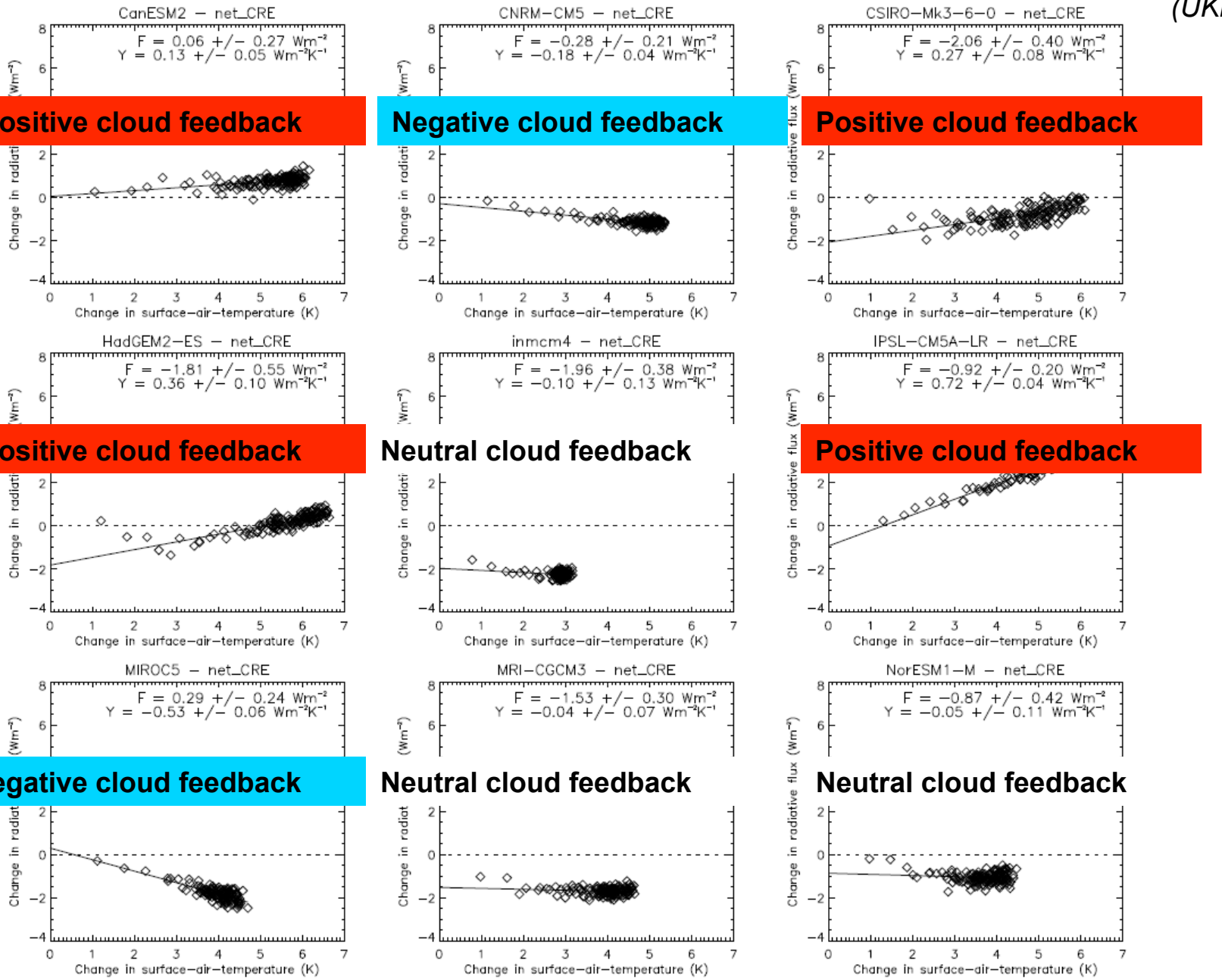
CMIP3 Models

1 - CAM4_amip
2 - CAM5_amip
3 - CanAM4_amip
4 - CNRM-CM5_amip
5 - HadGEM2-A_amip
6 - MIROC5_amip

CMIP5 Models

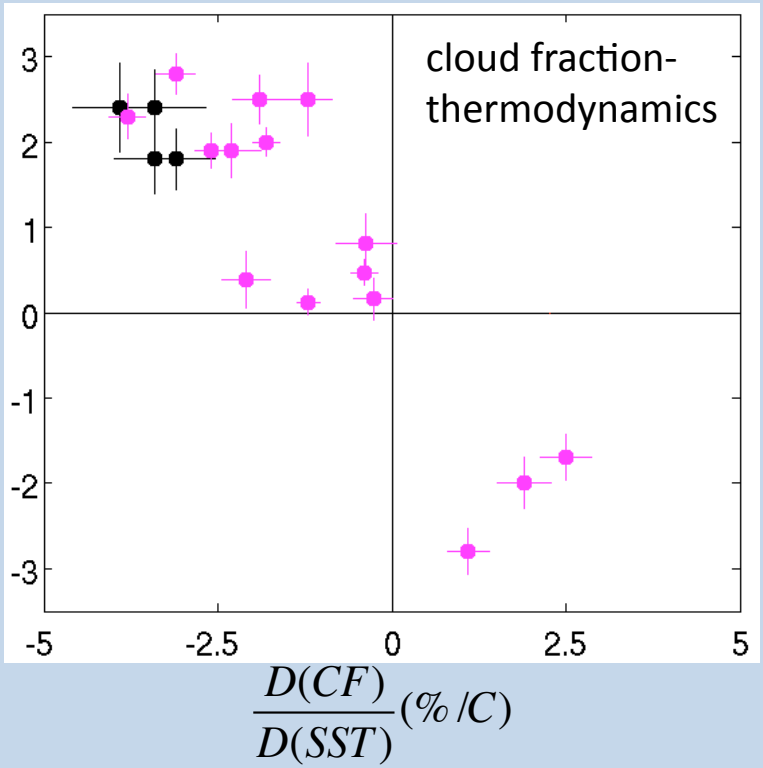
‘Long term’ Cloud Feedback

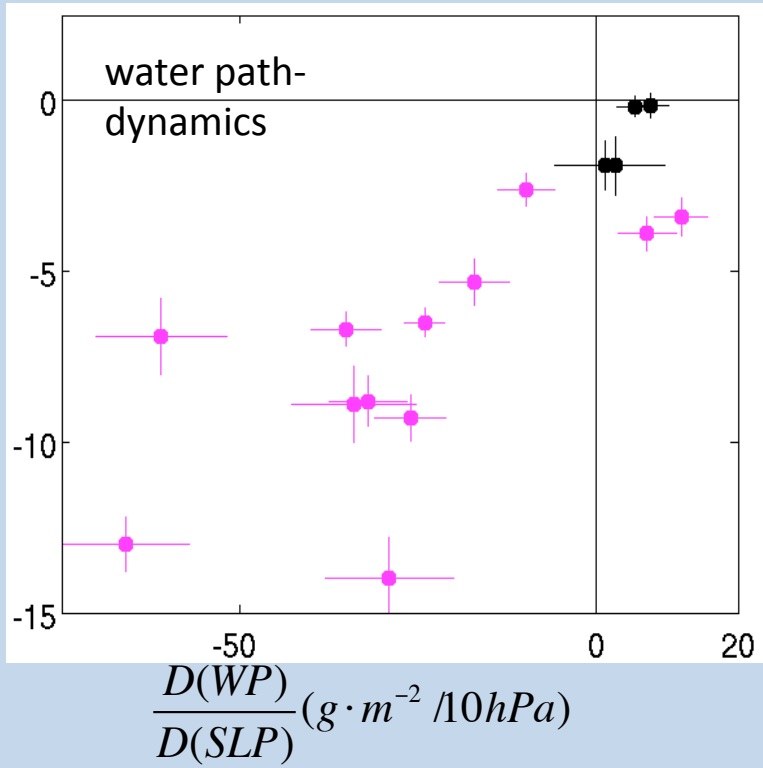
Figure courtesy of Tim Andrews (UKMO)



Evaluation of marine stratiform cloud simulation in CMIP5 models: Feedbacks, Trends, and Model Fidelity

Timothy Myers and Joel Norris
Scripps Institution of Oceanography





*Most models simulate the **correct signs** of the observed **CF-thermodynamic relationships**, while **WP** in the models is **excessively sensitive to large-scale dynamics** relative to observations*

LEGEND: ● observations ● models