Process based model evaluation

George Tselioudis
Academy of Athens, Centre for Atmopspheric Physics and Climatology
NASA/GISS – Columbia University

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Two branches of '**Process based model evaluation**' studies:

B1. ***Feedback process evaluation*** **-** looks at processes as a proxy for climate feedback

- T – dependencies, ω – dependencies, ω-θ – joint dependencies
- Seasonal variability, decadal variability
- Cloud-defined weather states

Observations: Global satellite retrievals, reanalysis datasets

Models: GCMs

B2. ***Cloud process evaluation*** – looks at process as a means to improve cloud parameterization

- GCSS regional case-studies – cloud-type specific
- Extended regional studies (GPCI, CGILS) – aiming at local feedbacks

Observations: Field study data, global satellite retrievals, reanalysis datasets

Models: CRM, LES, SCM

Criteria to evaluate Process based evaluation methods:

B1. Need to prove climate feedback relevance – can use theoretical arguments, agreement in model projections (?), or occurring climate shift

B2. Need to prove parameterization relevance – can use theoretical arguments and sensitivity studies.

Ways to utilize Process based evaluation methods

B1:
Quantitative: Derive metrics for methods fulfilling the criteria – use successful models to derive sensitivity magnitude
Qualitative: Use successful models to understand feedback mechanisms not resolved by observations

B2: Upscale successful LES-CRM simulations to cloud parameterization scales.

A 'Process based – Feedback process' evaluation study: Cloud, radiation, and precipitation changes with midlatitude storm strength and frequency.

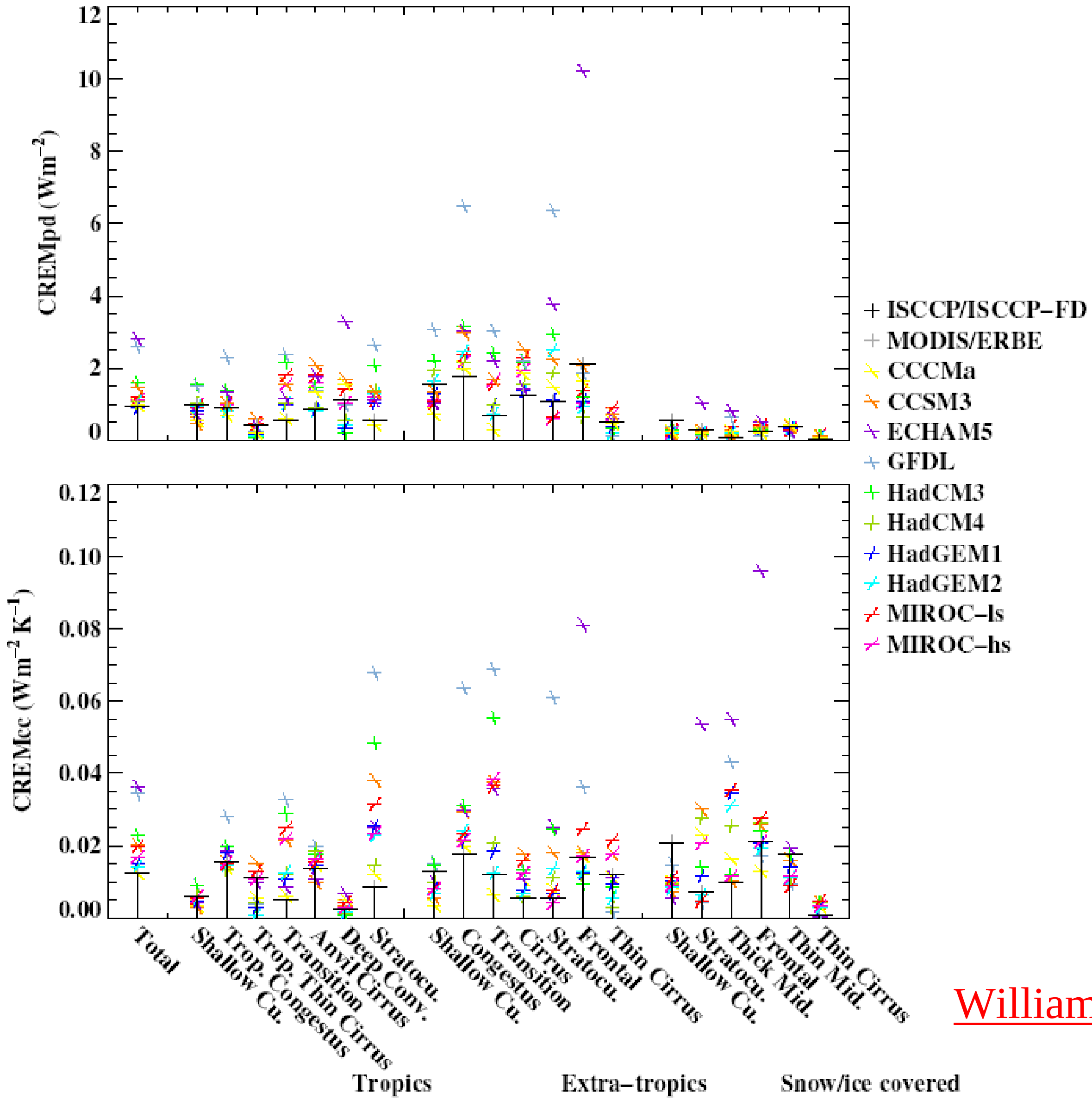
Feedback relevance criteria:

- Theoretical arguments: Baroclinic storm strength and frequency depend on Meridional Temperature Gradient and in-storm Latent Heat release, both predicted to experience consistent (decrease-increase) changes with climate warming

- Model projections: Overall agreement for fewer but stronger storms with climate warming.

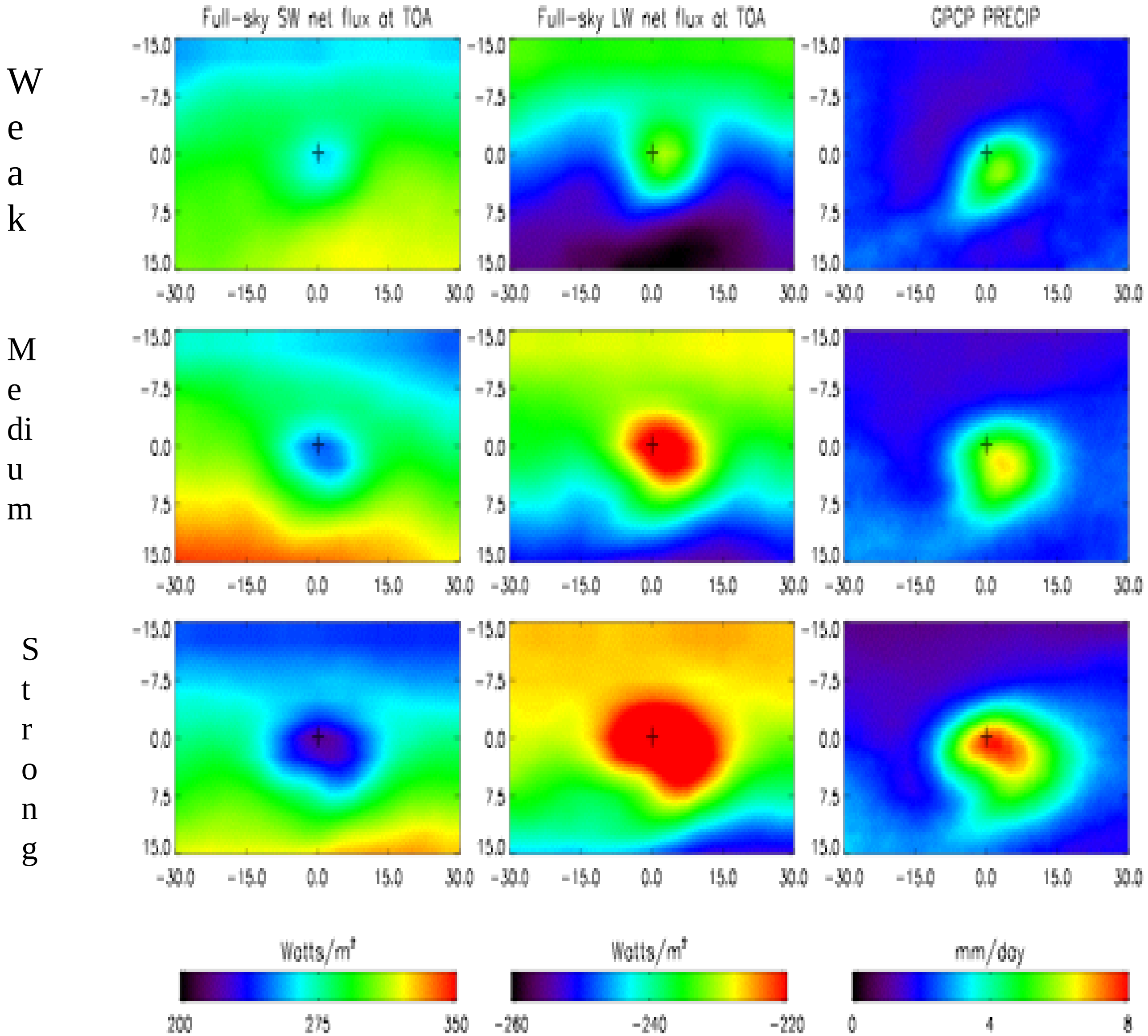
- Observational trend: Similar trend is derived for the last 50 years from reanalysis data.

Extratropical clouds, contrary to popular belief, produce the largest spread among GCM cloud radiative signatures



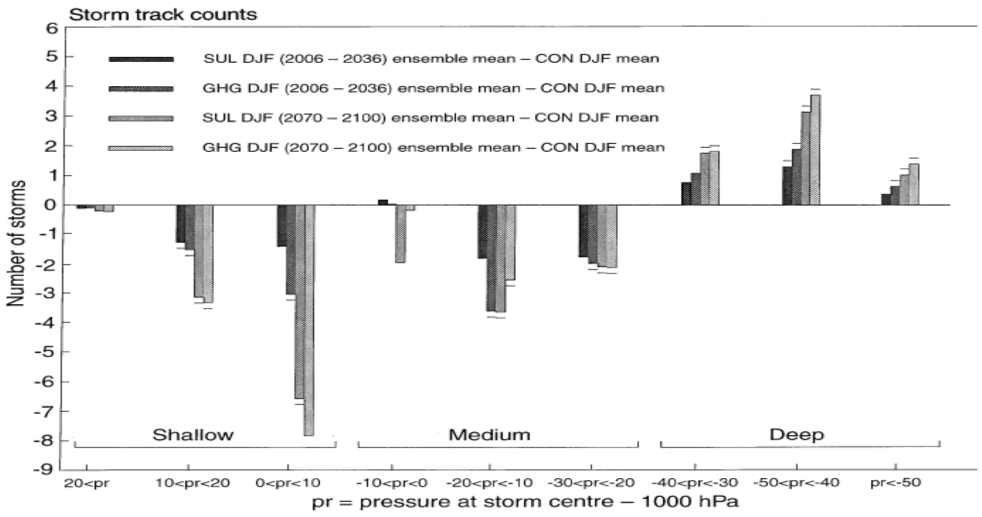
Williams and Webb 2008

How do radiation and precipitation fields change with storm strength and frequency?



Tselioudis and Rossow 2007

UKMO prediction for 2XCO2 storm changes (Carnell and Senior 1998)



What if the UKMO prediction materialized?

	30-65N DJF		30-65N JJA	
	SW (W/m²)	LW (W/m²)	SW (W/m²)	LW (W/m²)
Storm Strength ⬆	-3,7	+1.5	-1.9	+1.6
Storm Frequency ⬇	+2.6	-1.4	+1.9	-1.0
Total	-1.1	+0.1	0.0	+0.6
	30-65S JJA		30-65S DJF	
	SW (W/m²)	LW (W/m²)	SW (W/m²)	LW (W/m²)
Storm Strength ⬆	-4.9	+2.5	-3.7	+1.4
Storm Frequency ⬇	+1.4	-0.3	+1.9	-0.4
Total	-3.5	+2.2	-1.8	+1.0

Table 1: Net TOA shortwave and longwave flux changes with storm strength and frequency

	Precipitation (mm/day) 30-65N	
	DJF	JJA
Storm Strength ⬆	+0.10	+0.08
Storm Frequency ⬇	-0.02	-0.03
Total	+0.08	+0.05

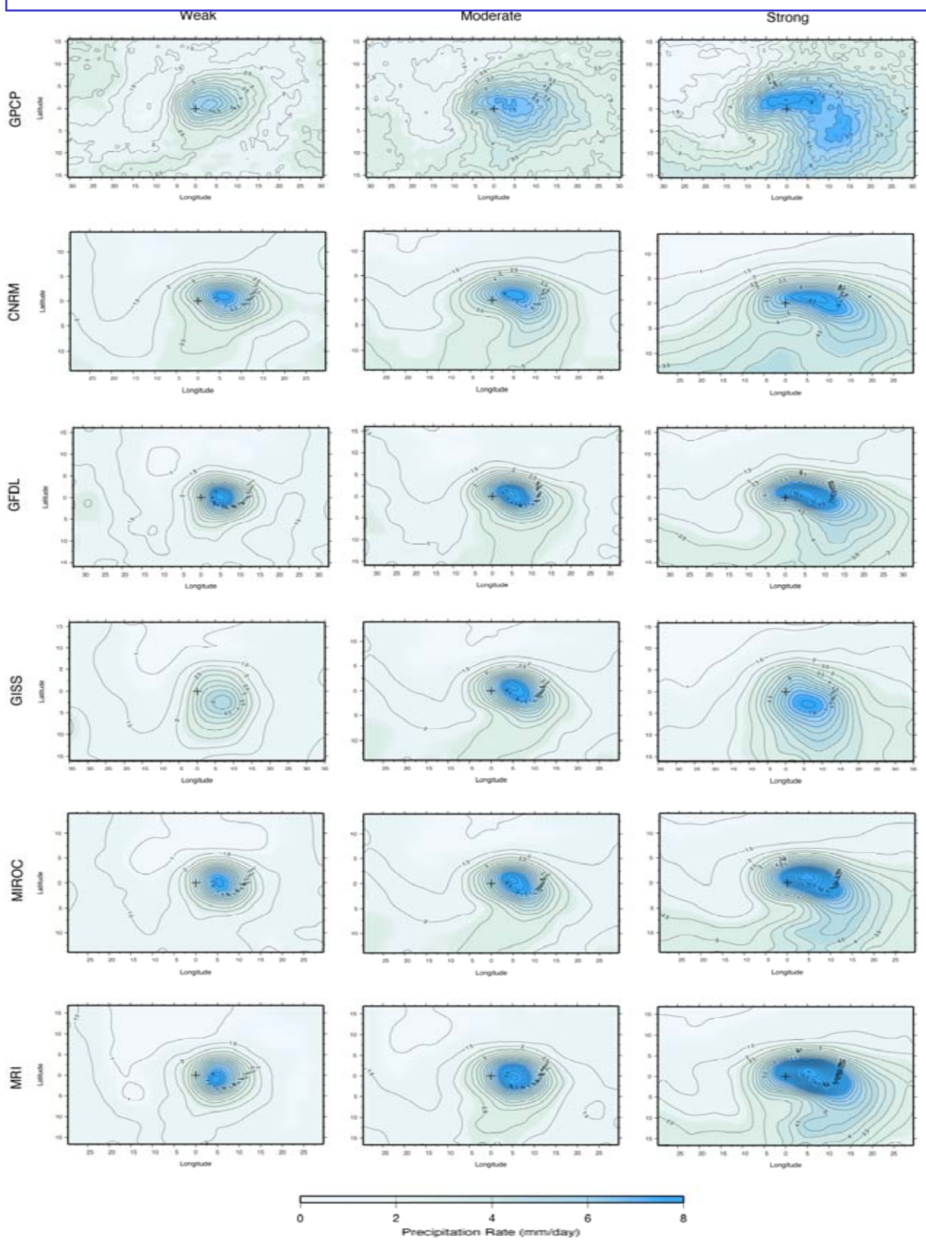
Table 1: Net precipitation changes with storm strength and frequency

GO → F

GCM → F

Tselioudis and Rossow 2007

Precipitation Changes with Storm Strength in Observations and in IPCC Models



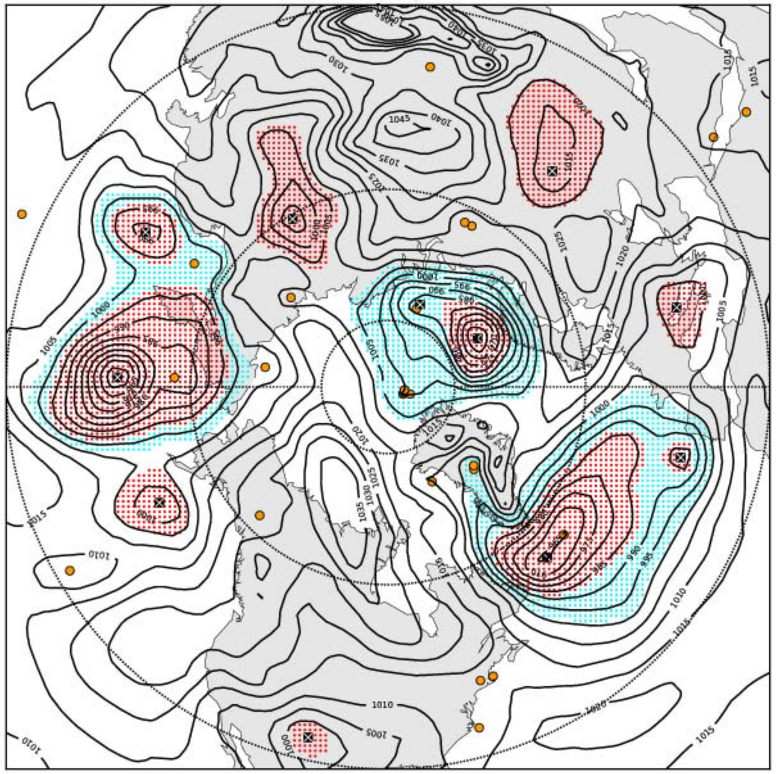
Why not use GCMs to derive F?

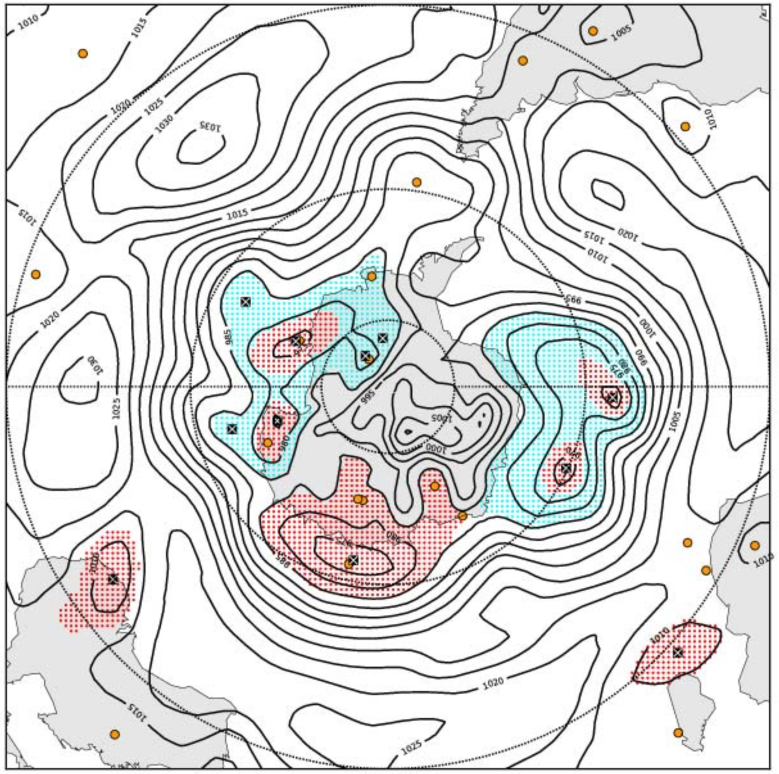
Calculation of midlatitude precipitation changes with climate assuming UKMO-predicted storm changes

	Storm Strength	Storm Frequency	Total
GPCP	+0.1 (mm/day)	-0.02 (mm/day)	+0.08 (mm/day)
CNRM	+0.08	-0.14	-0.06
GFDL	+0.08	-0.11	-0.03
GISS	+0.05	-0.10	-0.05
MIROC	+0.08	-0.11	-0.03
MRI	+0.10	-0.11	-0.01

- All models estimate correctly the increase in precipitation due to increasing storm strength but overestimate the decrease in precipitation due to decreasing storm frequency. This is because all models produce very little midlatitude precipitation outside storm events. As a result, models produce a negative rather than a positive precipitation feedback when the two UKMO-predicted storm changes are applied together

Tselioudis et al. 2008





Dynamic definition of storm area that allows better attribution of clouds/radiation/precipitation to storm influence
Feedback study is redone using the improved dynamic storm area definition.

Ways to utilize the midlatitude storm 'Process based - Feedback process' evaluation method

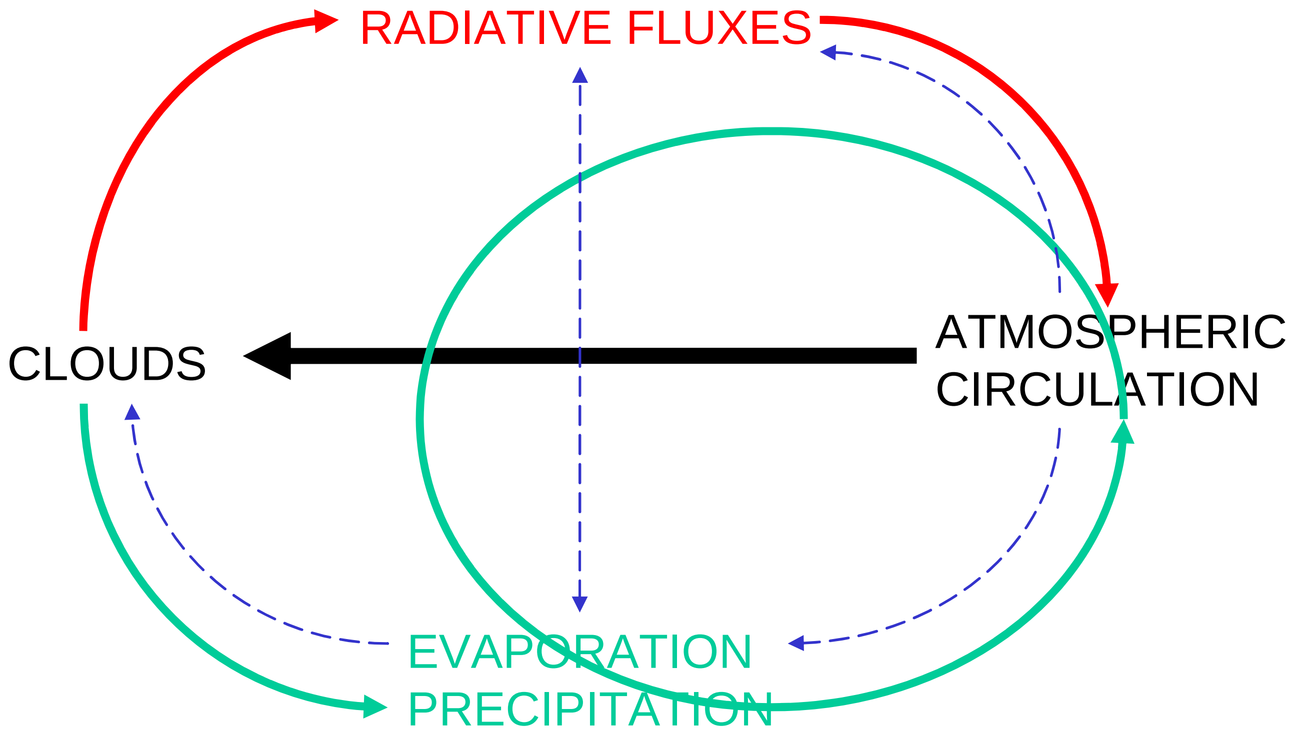
Quantitative:

- Derive quantitative metrics for the method – simulation of cloud/radiation/precipitation changes with storm strength and between storm-non storm regimes.
- Use successful models to derive feedback parameter

Qualitative:

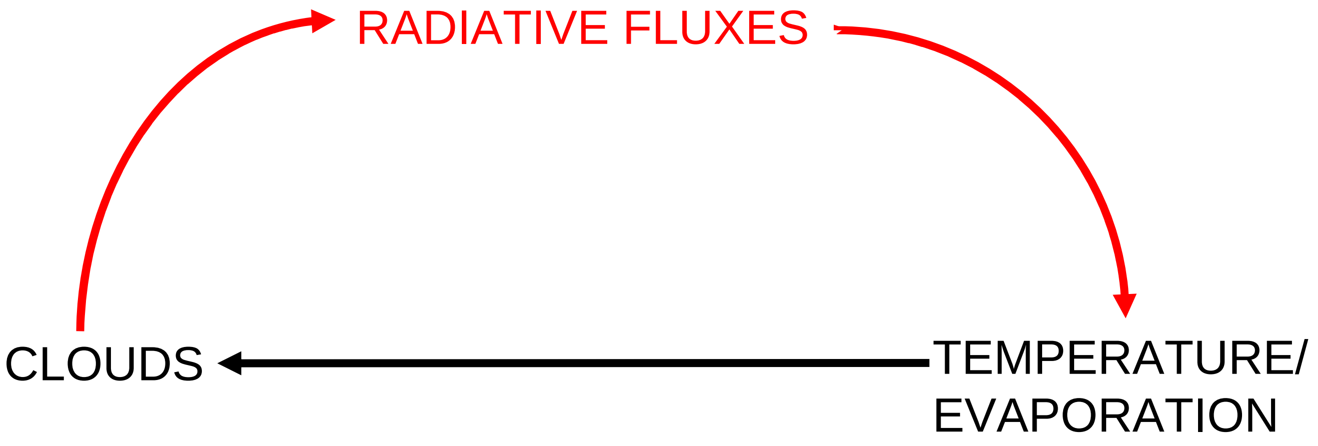
- Use successful models to understand feedback mechanisms not resolved by observations – e.g. effect of diabatic heating on storm cloud and precipitation formation mechanisms.

A CASE FOR MIDLATITUDE STORM FEEDBACKS



Atmospheric circulation influences on cloud properties, radiative fluxes, and precipitation distribution provide the potential for large climate feedbacks in the middle latitudes

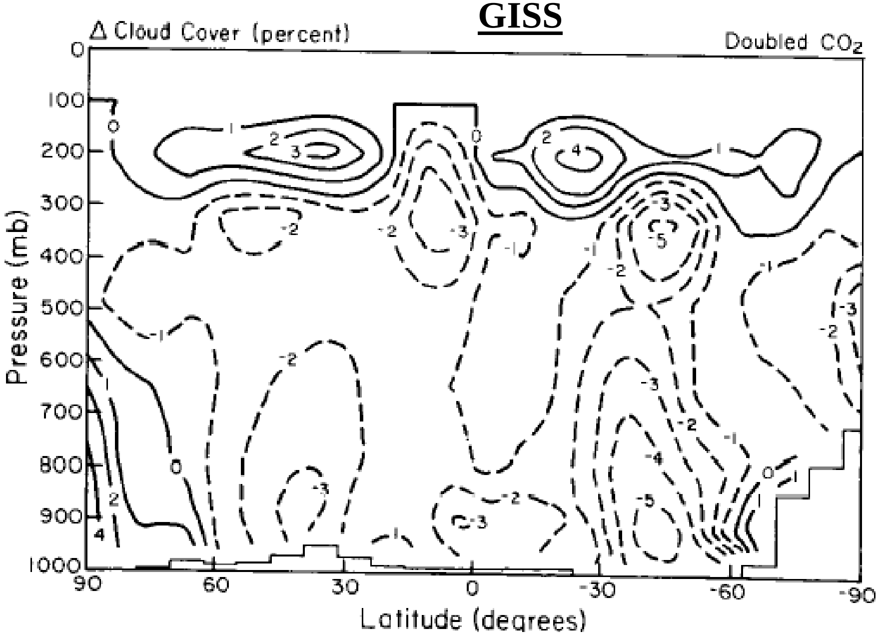
THE VIEW IN THE BEGINNING (1980s)



GCMs with RH-dependent cloud cover, fixed cloud optical thickness, and instantaneously precipitating cloud water

FIRST CLOUD CHANGE PROJECTIONS AND FEEDBACK ESTIMATES

GISS



CLIMATE SENSITIVITY: ANALYSIS OF FEEDBACK MECHANISMS

J. Hansen, A. Lacis, D. Rind, G. Russell

NASA/Goddard Space Flight Center, Institute for Space Studies
2880 Broadway, New York, NY 10025

P. Stone

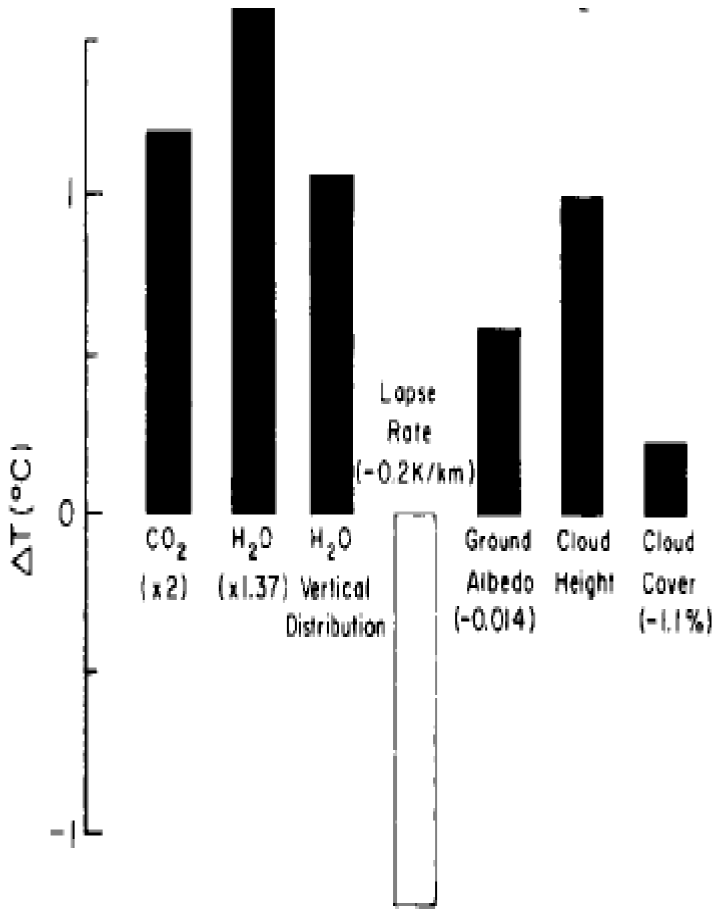
Center for Meteorology and Physical Oceanography
Massachusetts Institute of Technology, Cambridge, MA 02139

I. Fung

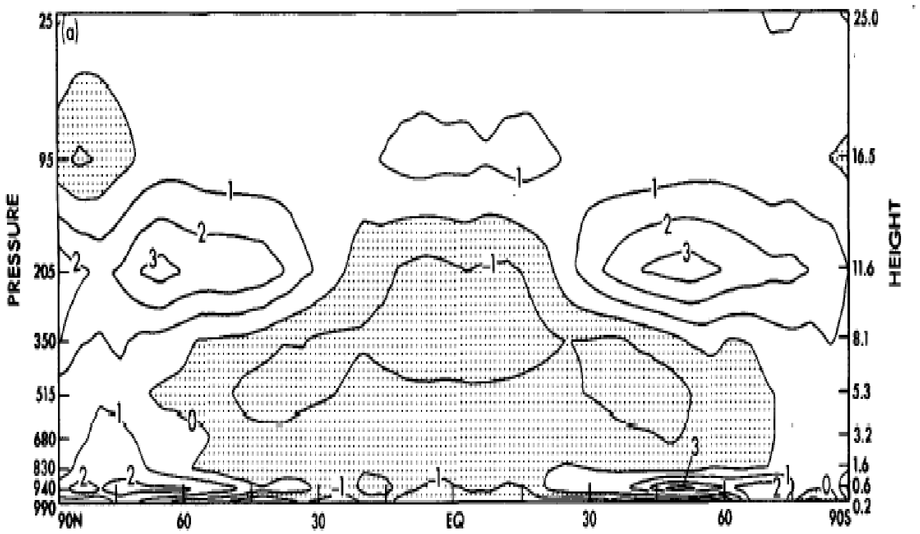
Lamont-Doherty Geological Observatory of Columbia University
Palisades, NY 10964

R. Ruedy, J. Lerner

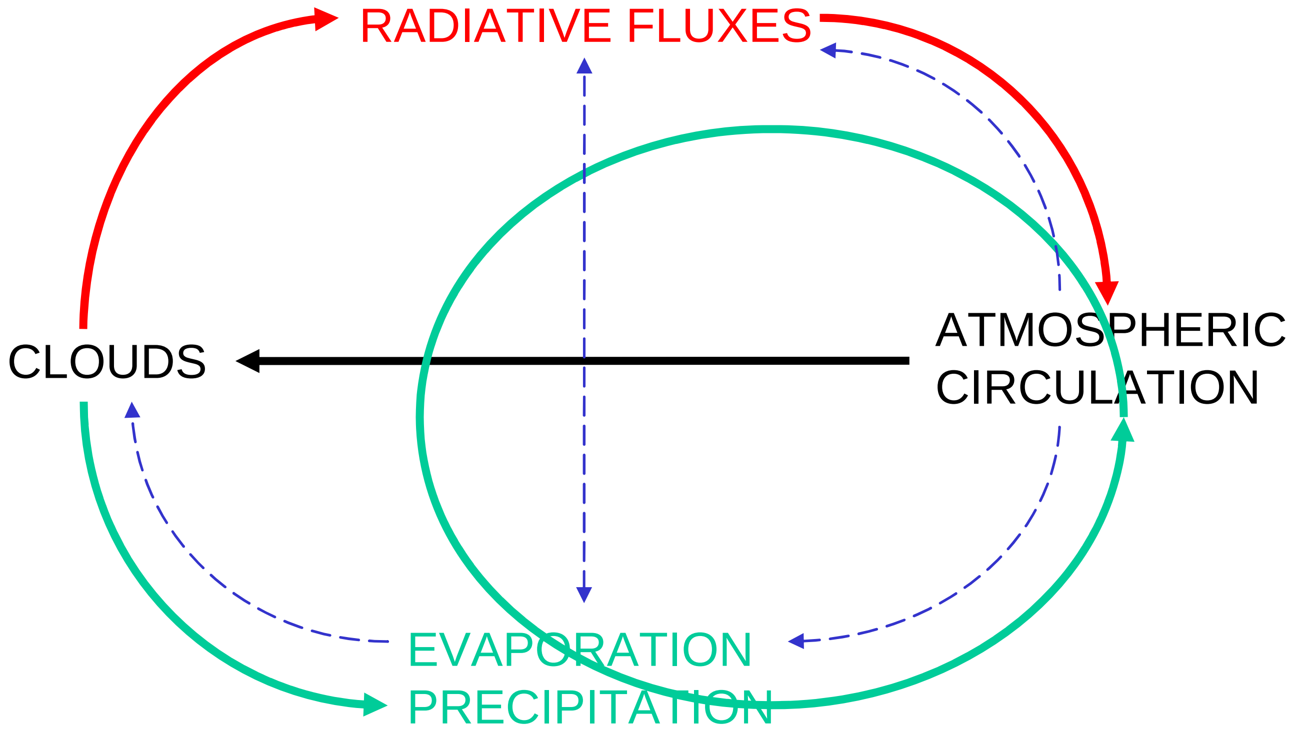
M/A COM Sigma Data, Inc.
2880 Broadway, New York, NY 10025



15 April 1988 **GFDL** R. T. WETHERALD AND S. MANABE 1403



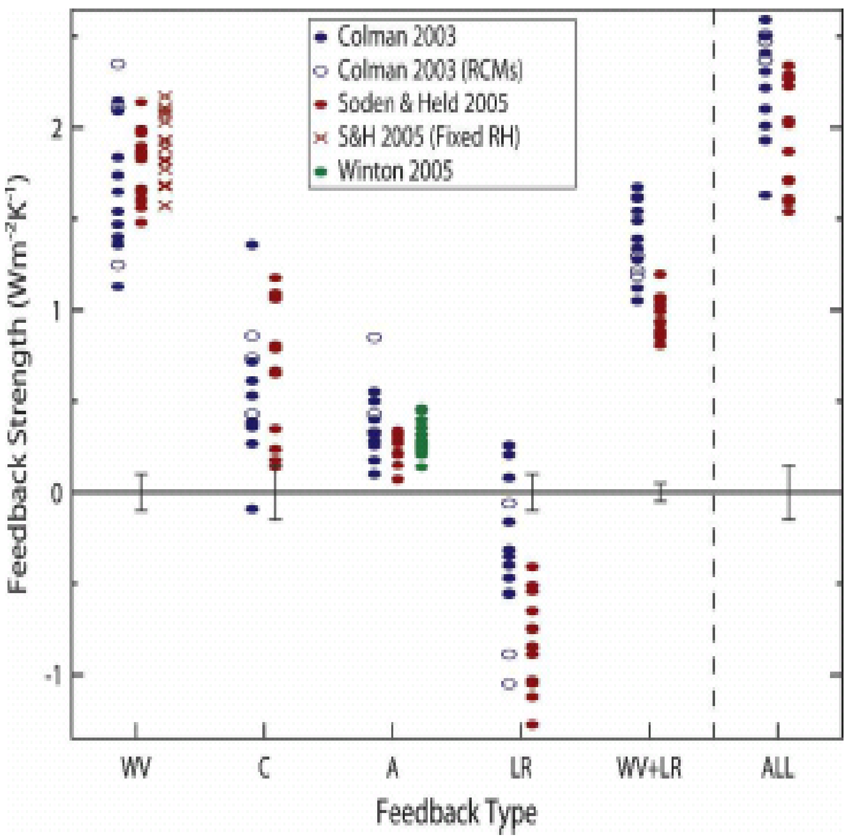
THE VIEW NOW: THE COMPLETE ENERGY AND WATER CYCLES OF CLIMATE



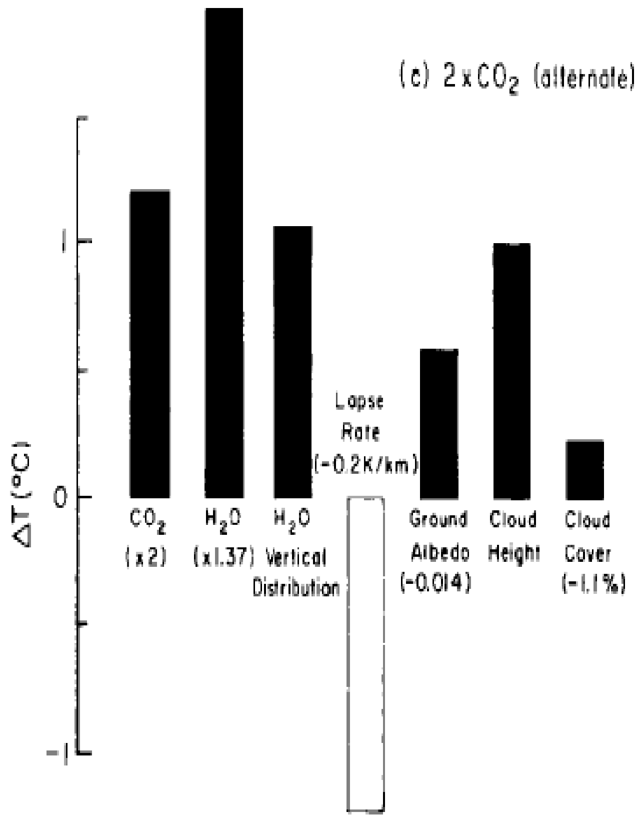
ESMs with fully interactive cloud water/ice cycles

The more things change………. ………..the more they stay the same

Bony et al., 2006

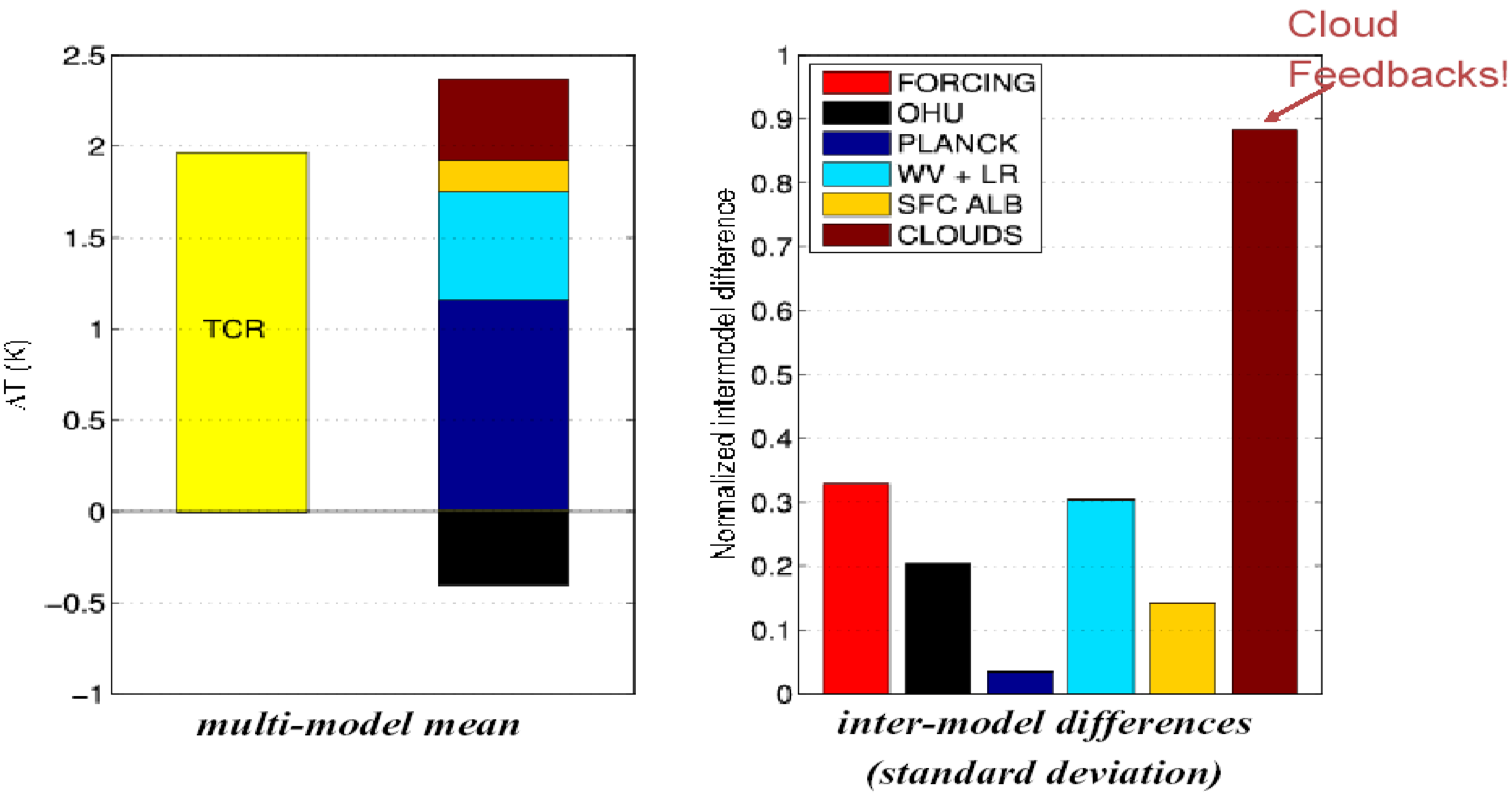


Hansen et al. 1984



Why then put an emphasis on cloud feedbacks?

Decomposition of the Transient Climate Response (TCR) simulated by CMIP3/AR4 OAGCMs :



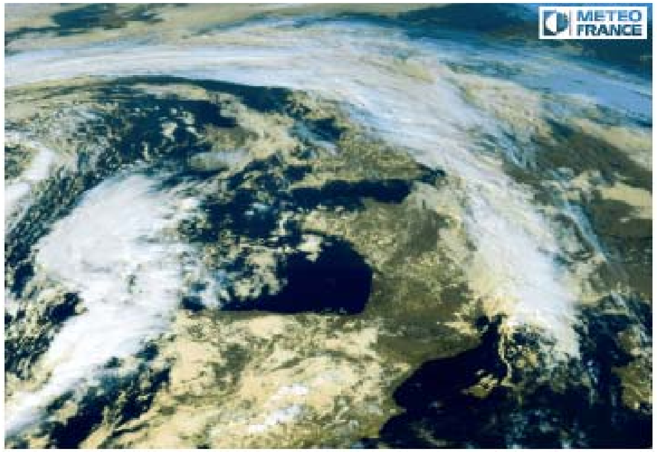
[Dufresne and Bony, 2007]

Why then put an emphasis on cloud feedbacks?

1. Reduce spread in climate model sensitivity
2. Understand and quantify the processes involved in the energy and water budgets

Where does the spread of cloud feedbacks come from ?

deep convective activity



baroclinic activity & frontal clouds

boundary-layer turbulence and clouds

What if all models simulated the same current climate cloud properties?

$$\overline{\Delta CRF} = \sum_{r=1}^{nregimes} CRF_r \Delta RFO_r + \sum_{r=1}^{nregimes} RFO_r \Delta CRF_r + \sum_{r=1}^{nregimes} \Delta RFO_r \Delta CRF_r$$

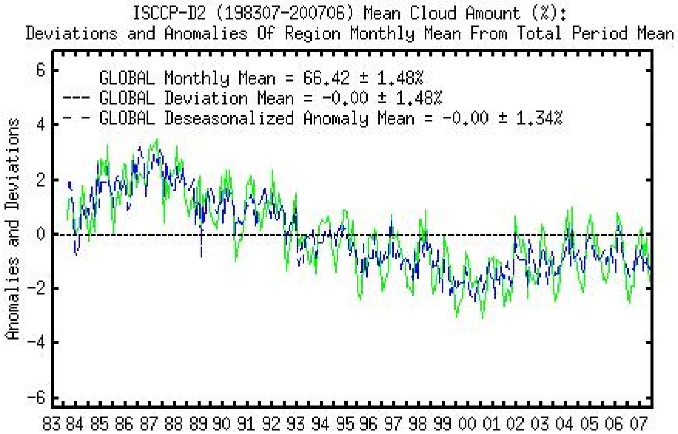
Model	Difference in $\overline{\Delta NCRF}$ (Wm^{-2}/K)	Model λ (Wm^{-2}/K)	Obs. constr. λ (Wm^{-2}/K)	Model clim. Sens. (K)	Obs. constr. Clim. Sens. (K)
ECHAM5	0.49	1.21	0.72	3.3	5.6
HadSM3	0.17	1.06	0.89	3.5	4.2
HadSM4	0.03	1.00	0.97	3.7	3.8
HadGSM1	-0.11	0.83	0.94	4.6	4.1
MIROC-lo	-0.12	0.79	0.91	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

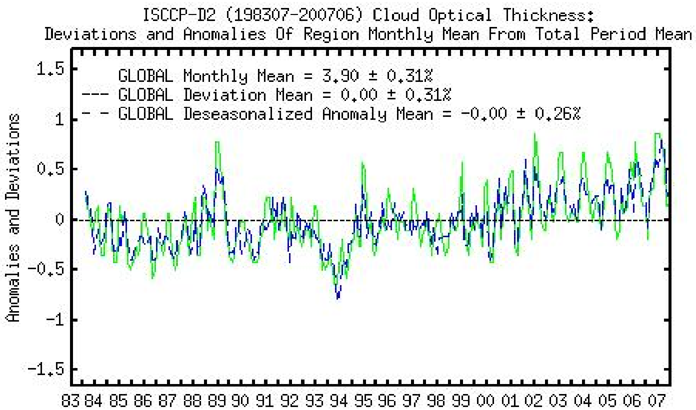
The spread in climate sensitivity would be cut by ~30%

Williams and Tselioudis 2007

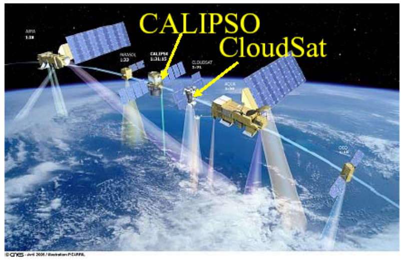
The time to make progress is now!

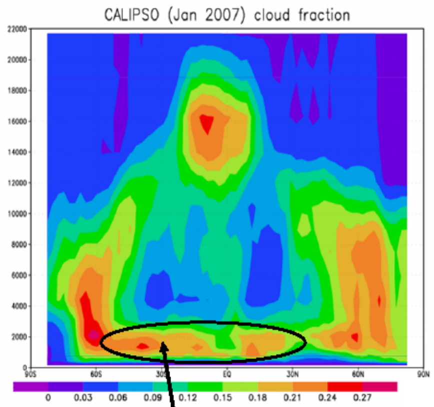
Long climatologies of critical cloud/rain properties





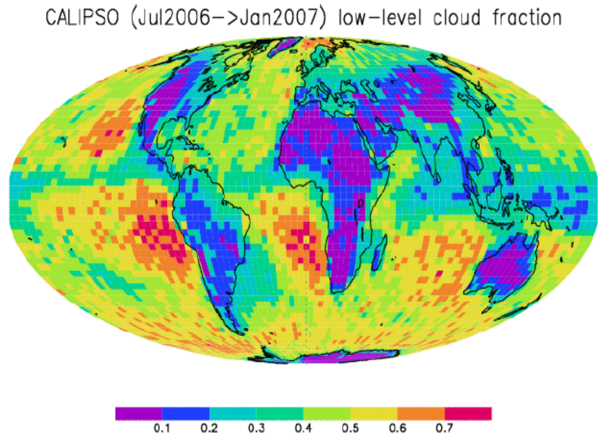
Detailed retrievals of vertical cloud/rain structure





CALIPSO lidar measurements :
Towards a near-global view of the 3D structure of clouds from space

low-level cloud fraction derived from CALIPSO



(Chepfer et al. 2007, submitted)

The story of low cloud optical thickness variations with temperature

Analysis of field observations showed reductions in low cloud optical thickness with temperature implying a negative feedback

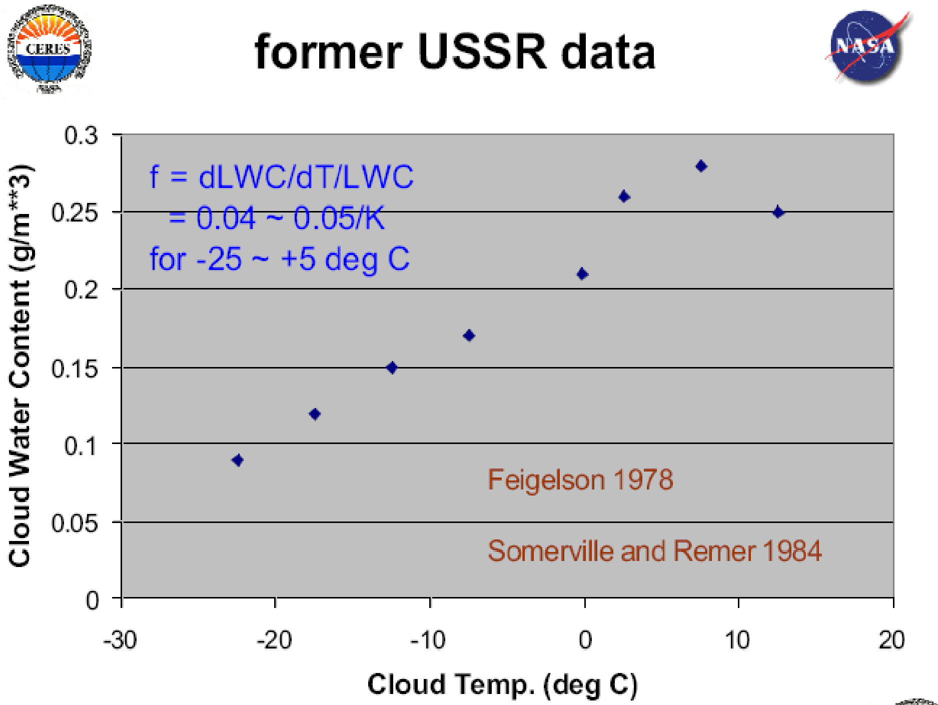
Analysis of global observations showed consistent opposite patterns of variation in the optical thickness-temperature relationship

Global model output analysis provided information on the atmospheric processes that produce the relationship in the model and on the climate effects of the low cloud optical thickness changes

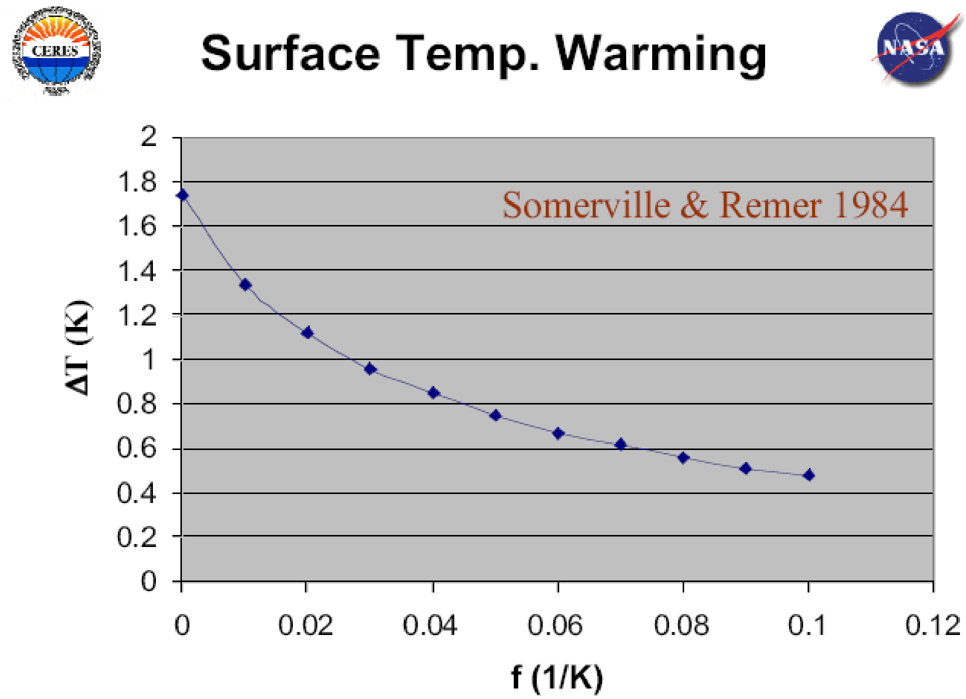
Field study data analysis provided microphysical and dynamical explanations for the relationship at the field study location

A cloud feedback estimate derived from local aircraft observations

former USSR data

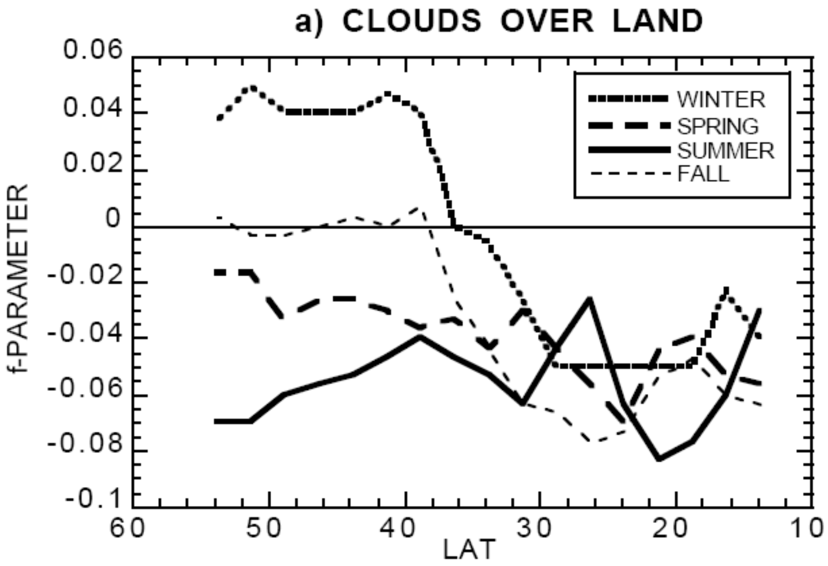


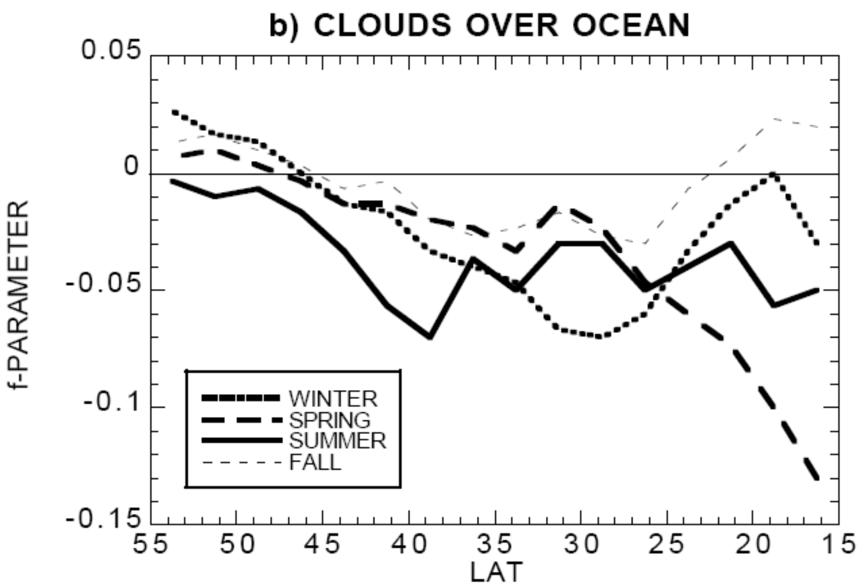
Surface Temp. Warming



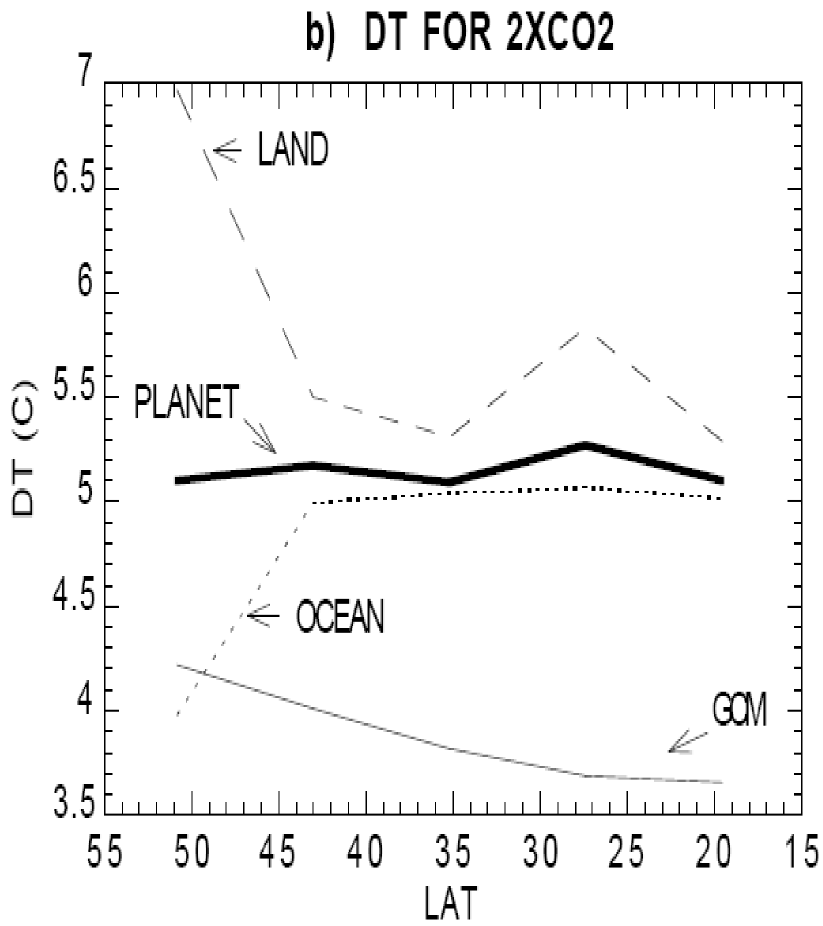
FO ⟶ RCM ⟶ CS

(supported by theoretical assumptions)



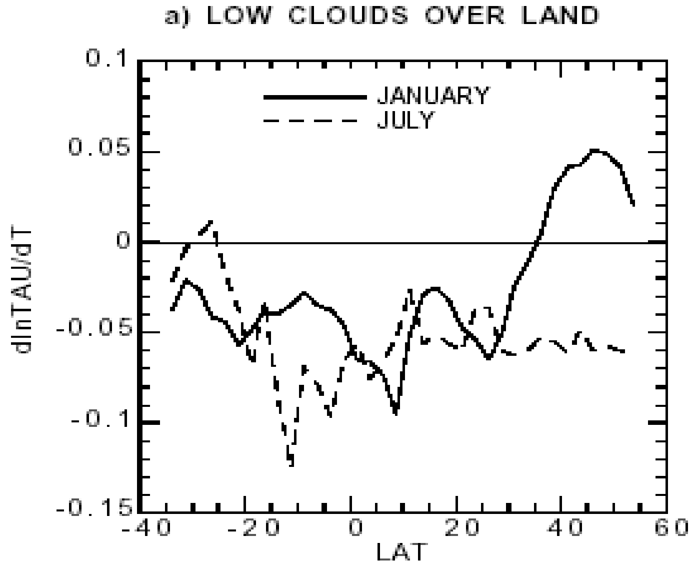


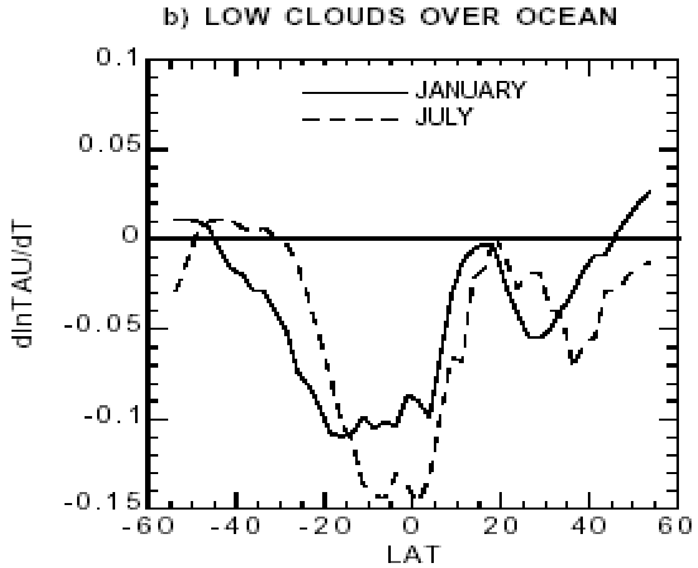
A corrected view derived from satellite observations



GO → RCM → CS

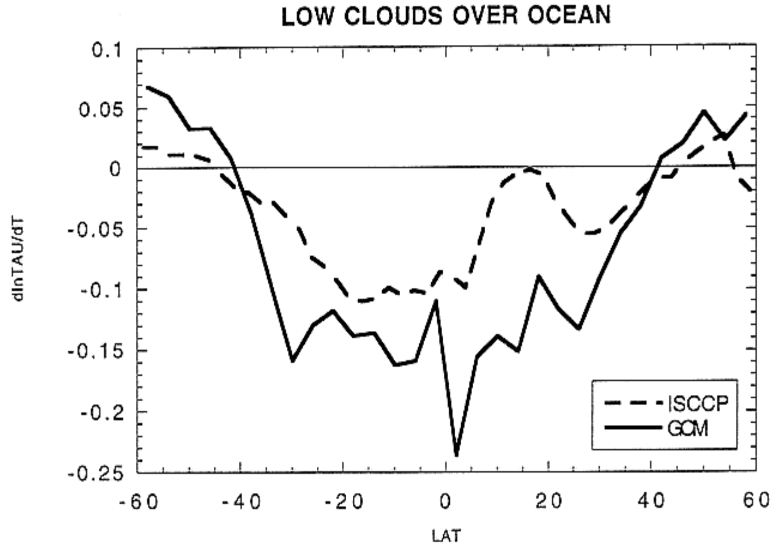
Satellite observations showed consistent patterns of change of low cloud optical thickness with temperature

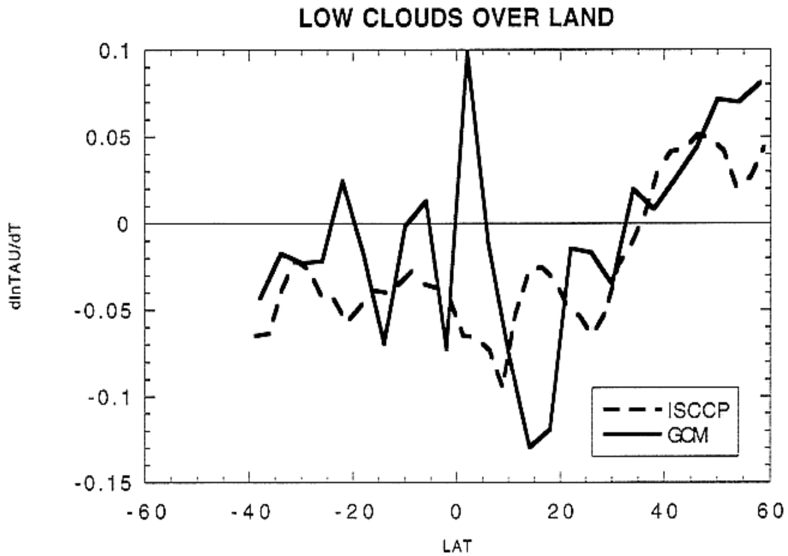




Tselioudis and Rossow 1994

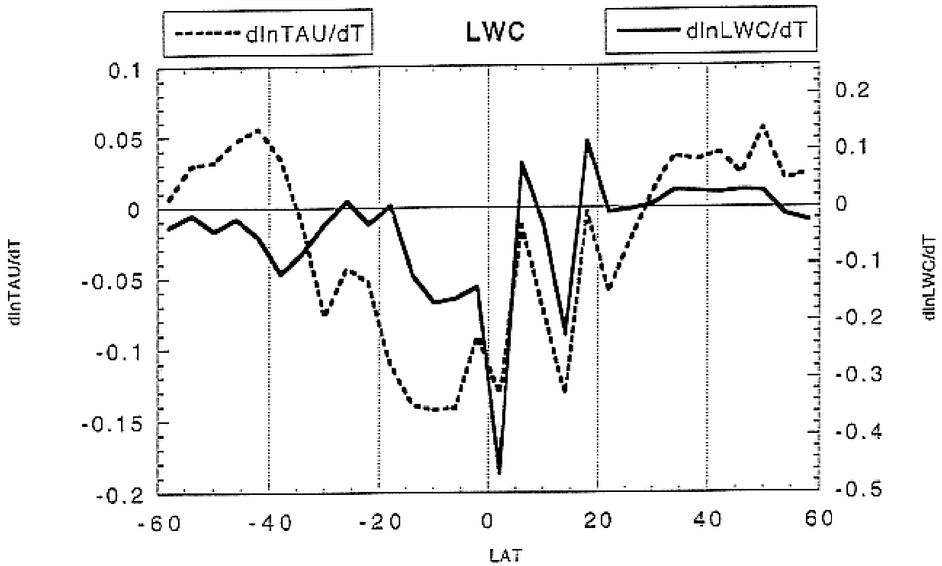
The GISS GCM reproduced to a large extent the observed behavior (especially for clouds over ocean)

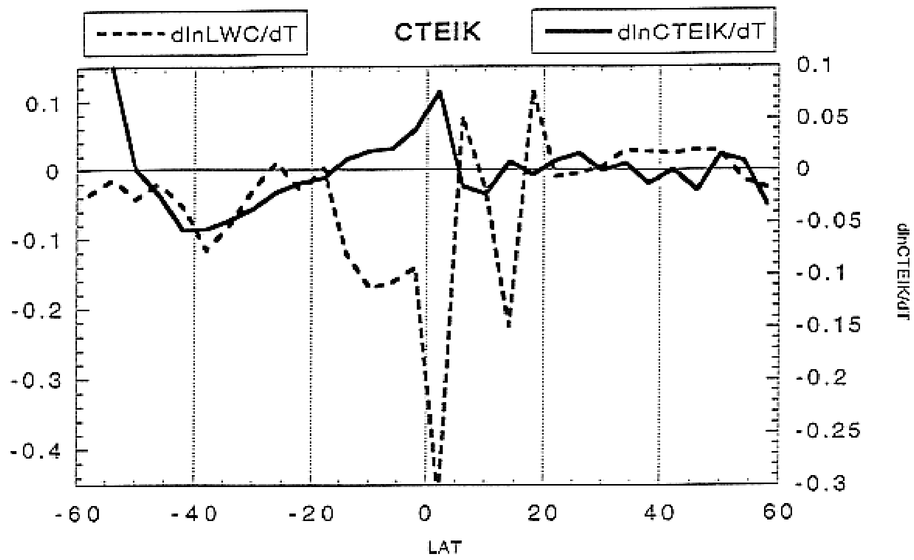


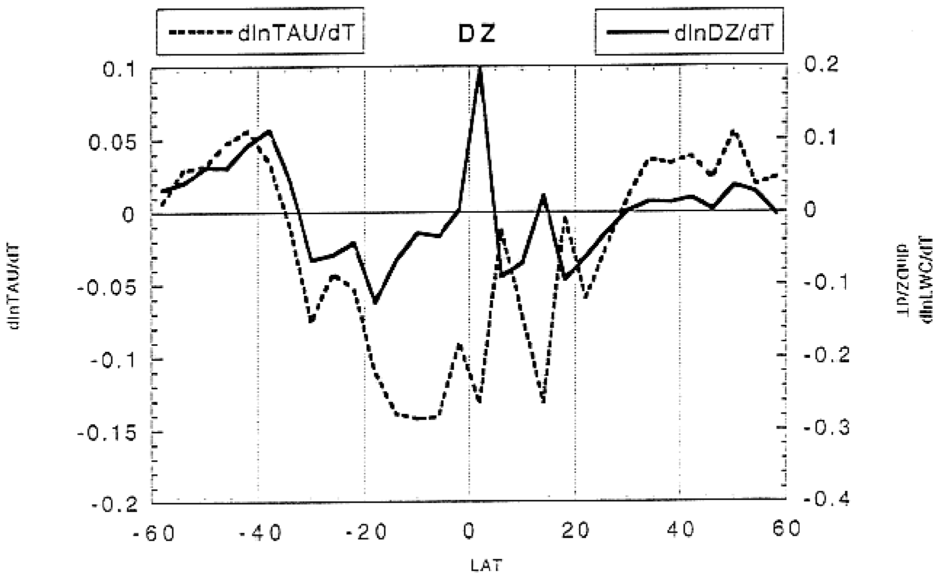


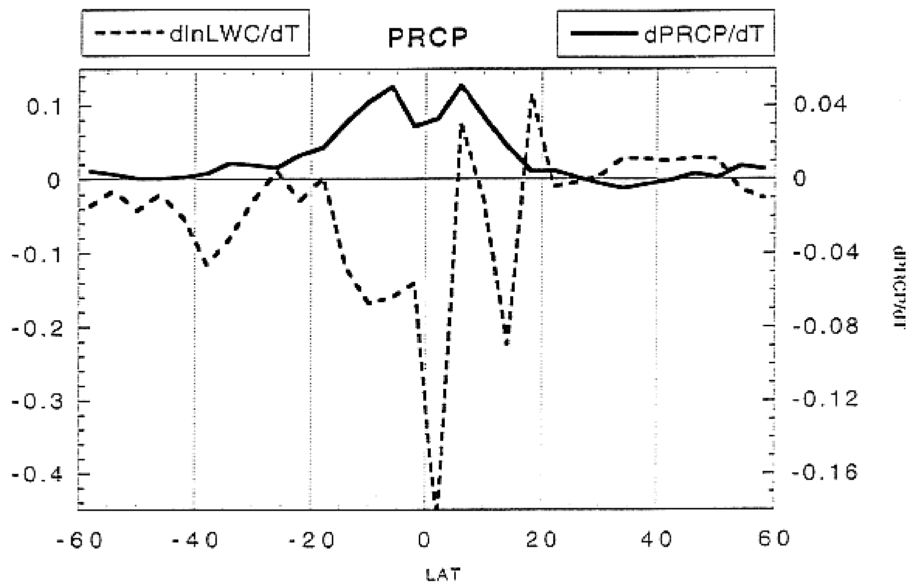
Tselioudis et al. 1998

The GCM could then be used to understand the cloud properties and physical processes that are responsible for the optical depth-temperature relationship in the model atmosphere

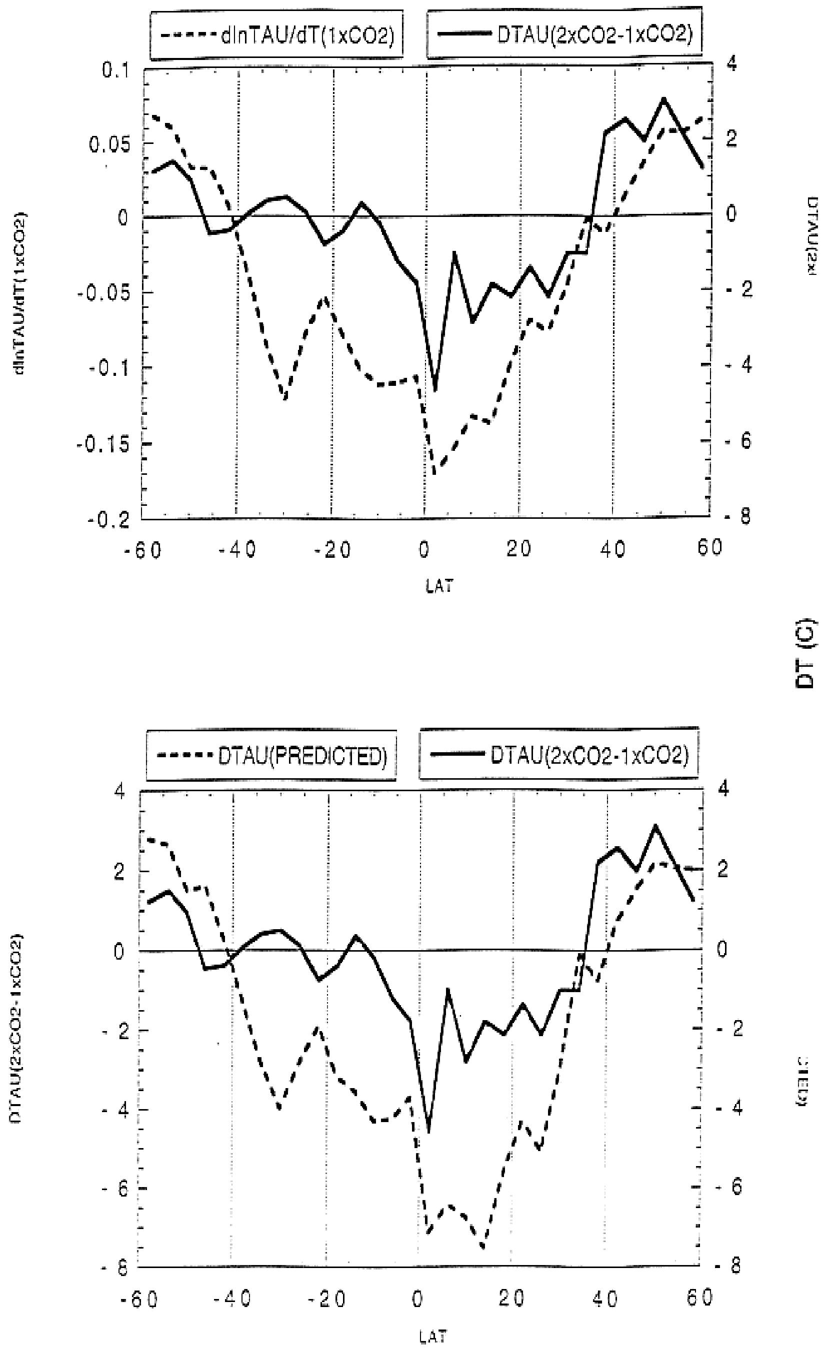


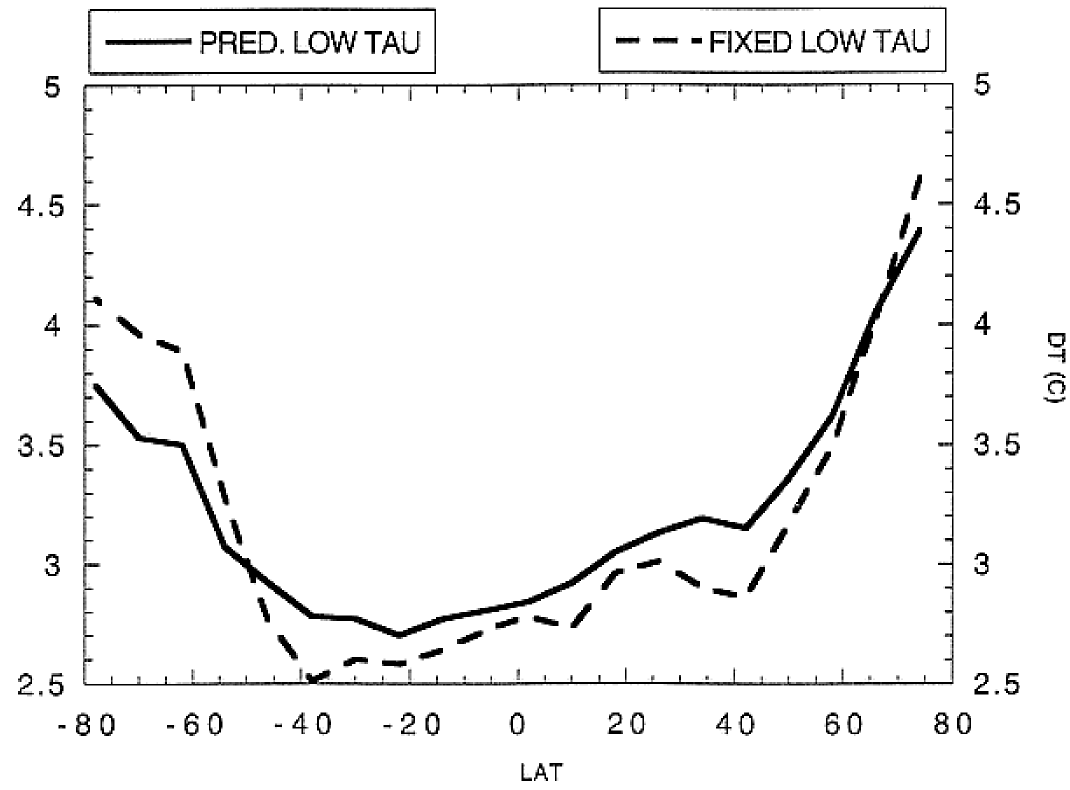






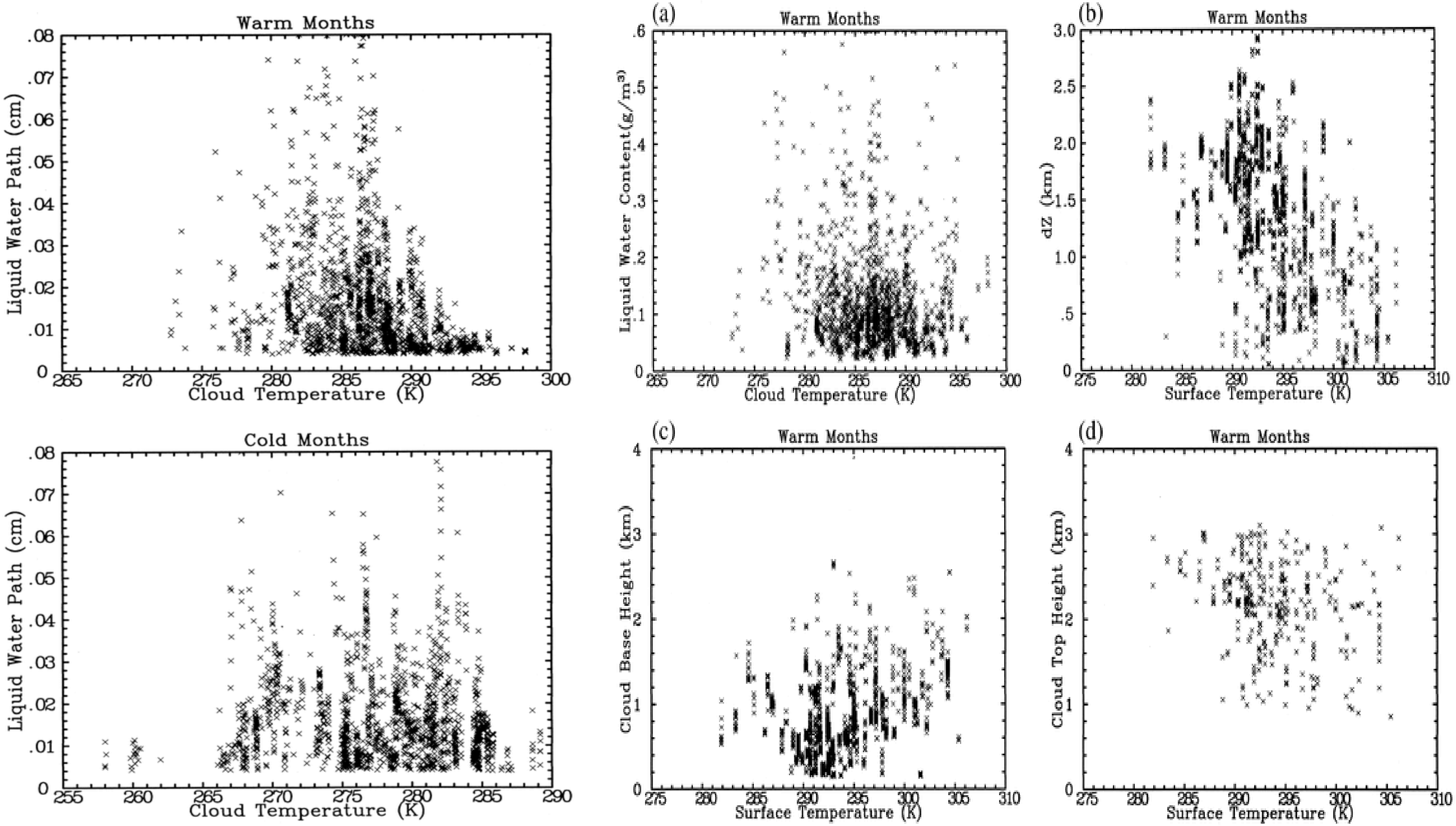
The GCM could also be used to examine the relevance of the current-climate TAU-T relationship to climate change and to quantify the effect of low cloud optical thickness changes on the model's climate sensitivity





GO →GCM →CS →FM

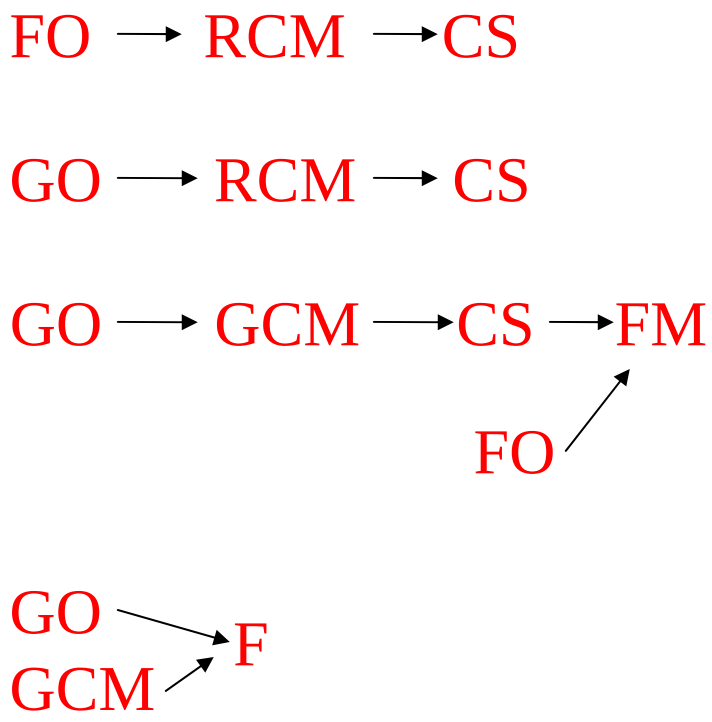
Long-term ARM field observations were used to derive statistical relationships between cloud microphysics and atmospheric dynamics and thermodynamics



DelGenio and Wolf 2000

FO → FM

ULTIMATE METHOD TO DERIVE/UNDERSTAND CLOUD FEEDBACK?



Or a combination of the above!

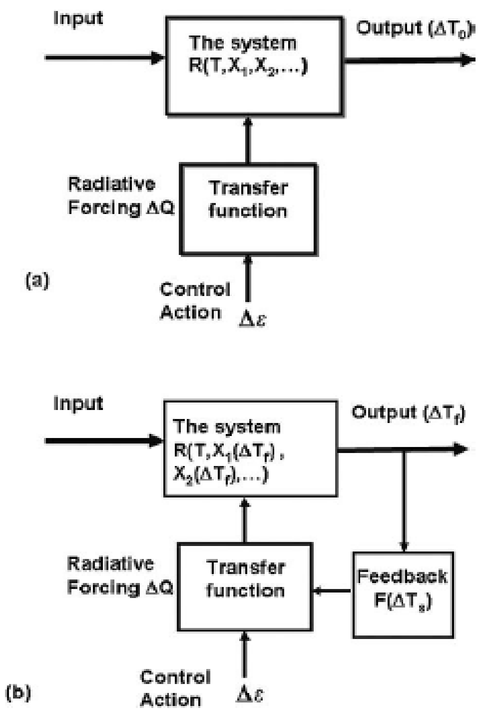


FIG. 10. (a) The main elements of an open (energy balance) climate system, where X is independent of output ΔT_o. The climate forcing involves the transfer function mapping from the control action to a change in radiative budget. (b) The control action modulates the output ΔT_f and feedback is established by a loop connecting the output to input.

$$R_{\mathrm{TOA}}[\epsilon, T, X_j(T), j = 1 \ldots n] = 0,$$

$$f = \frac{1}{\lambda_o}\sum_{j=1}^{n}\frac{\partial R_{\mathrm{TOA}}}{\partial X_j}\frac{dX_j}{dT} = f_1 + f_2 + f_3 + \ldots$$

$$R_{\mathrm{TOA}} = \frac{Q_o}{4}\{1 - \alpha[\mathrm{LWP}(T_s)]\} - \sigma T_p(T_s)^4,$$

$$f = -\frac{1}{\lambda_o}\frac{Q_o}{4}\frac{\partial \alpha}{\partial \mathrm{LWP}}\frac{d\mathrm{LWP}}{dT_s}.$$

Investigating Climate Feedbacks: The Tools

Global observations : Current-climate parameter relationships
(+) Global coverage, Large data ensembles
(-) Few parameters, Retrieval uncertainties,
Low space and time resolution

Global Models: Current and future climate feedback processes
(+) Fully resolved process definitions
(-) Model uncertainties, Low Resolution

Local (field) observations: Current climate parameter relationships
(+) Multiple parameters, Subgrid scale resolution
(-) Local coverage, Small data ensembles

Radiative Convective Models: Useful tools to translate atmospheric parameter changes into temperature/radiation changes