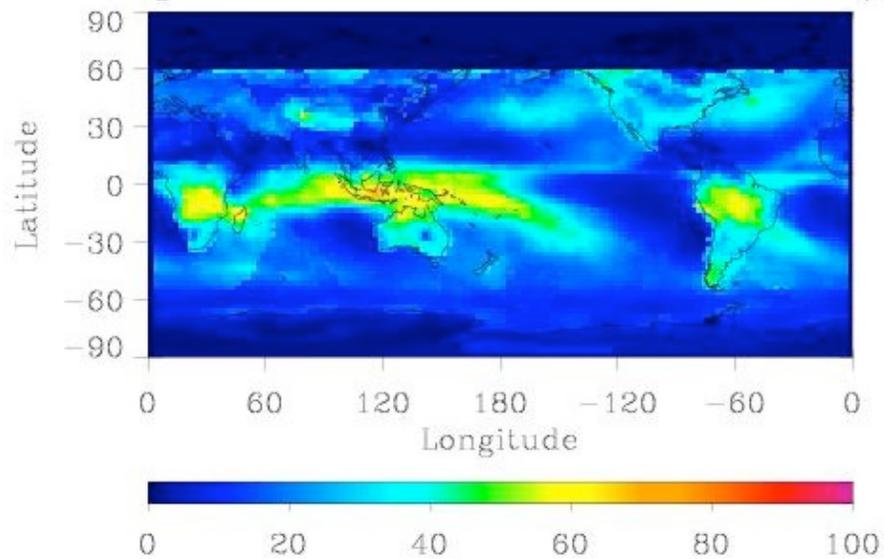


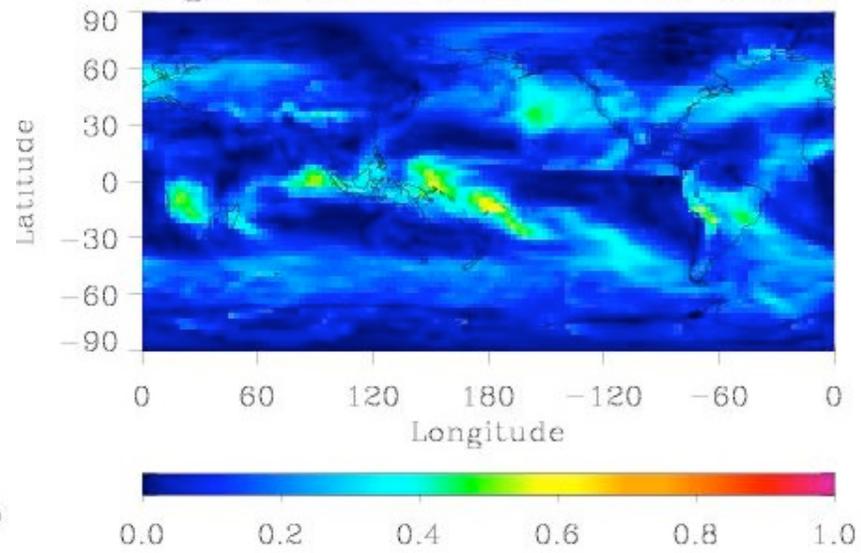
Super-parameterization and Cloud-Climate feedbacks

Multi-scale Modeling of Atmospheric Processes (MMAP)

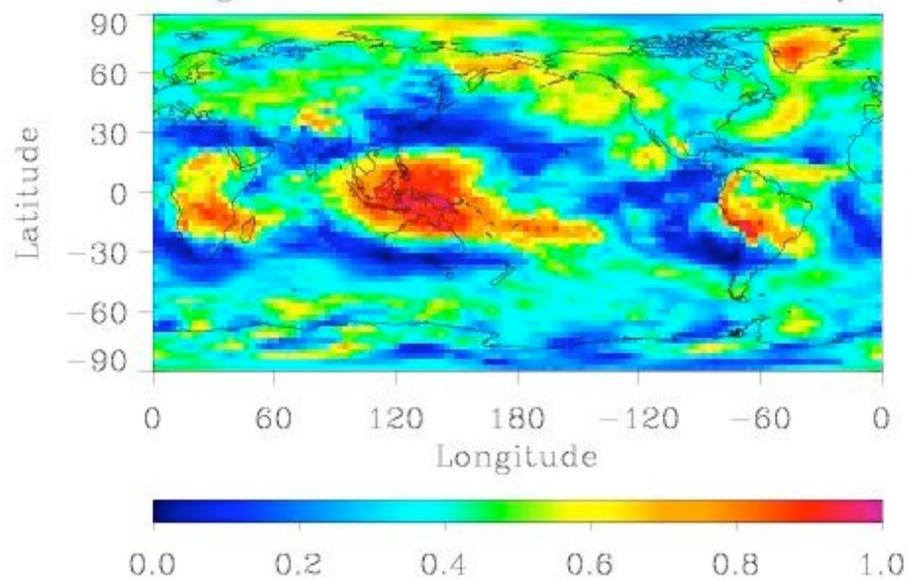
High Cloud Fraction- ISCCP Mean January



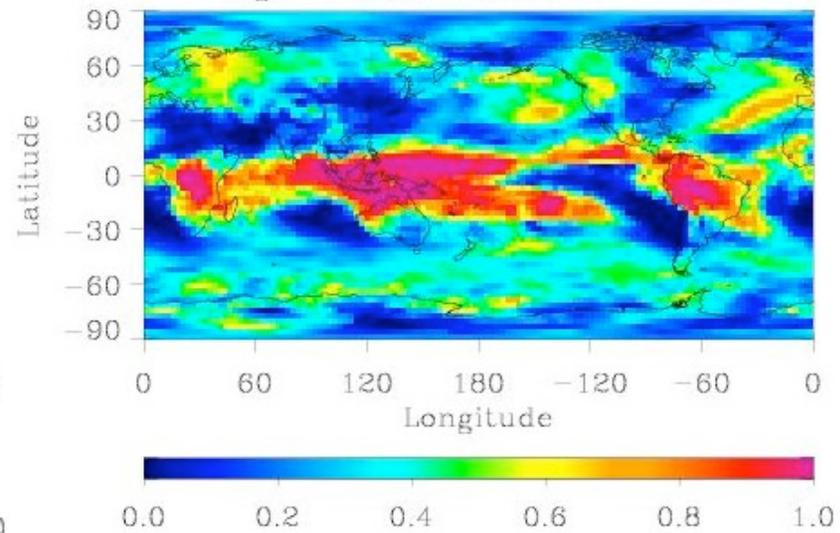
High Cloud Fraction- Interactive



High Cloud Fraction- Fixed January



High Cloud Fraction- GCM



'water vapor, confessedly the greatest thermal absorbent in the atmosphere, is dependent on temperature for its amount, and if another agent, as CO₂, not so dependent, raises the temperature of the surface, it calls into function a certain amount of water vapor which further absorbs heat, raises the temperature and calls forth for more vapor....'

T.C. Chamberlain in his 1905 correspondence to G.G Abbott

On a molecule by molecule basis, the 'thermal absorbent effects' of water in condensed phase >1000 times that of water in gaseous phase

While it is (reasonably) clear what is meant by water vapor it is less clear for clouds – amount, height, water/ice amount, optical properties, microphysics, etc .

The dependence of 'clouds' on temperature and surface temperature specifically is not well understood and to first order is governed by large scale fluid motions of the atmosphere

Unlike water vapor, clouds impart an almost equal effect of solar energy balance. This adds to the complexity of the problem.

Clouds and water vapor are intimate (inseparable?) components of the hydrological cycle and couple to other of processes and thus contribute to other climate feedbacks

There are two perspectives to the climate change problem, one of energy and one of water.

Perhaps the umbrella theme of MMAP concerns the atmospheric branch of the water cycle

Perhaps then one of the goals of MMAP is towards understanding and (eventually) quantifying the climate sensitivity

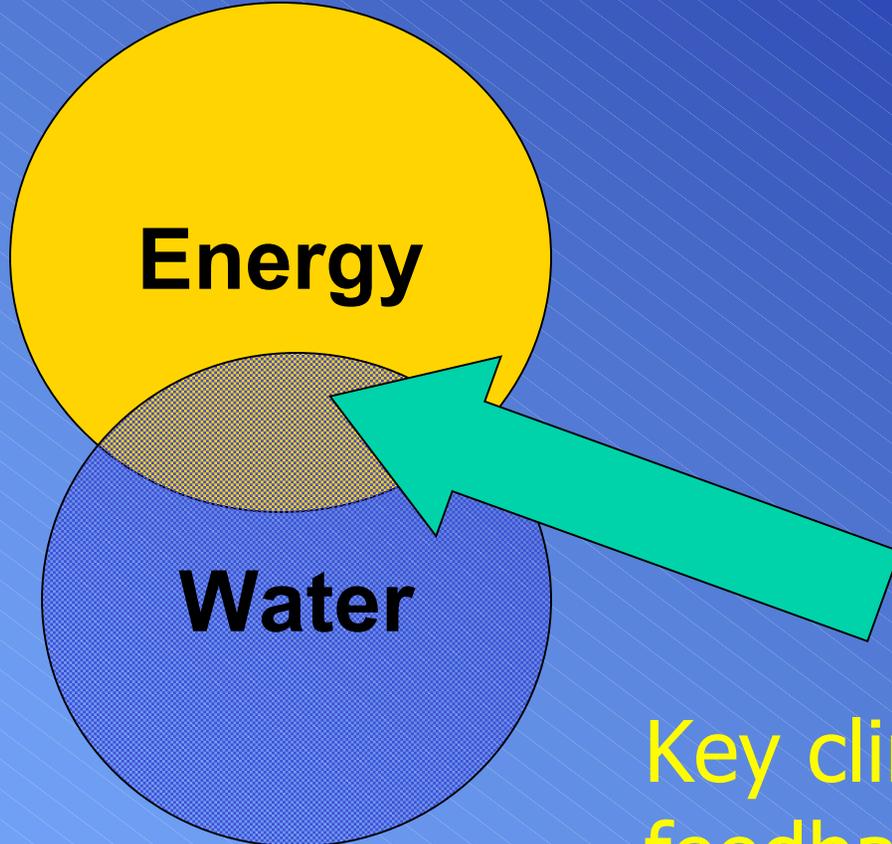
MMAP (perhaps) also provides an organizing principle for addressing/ formulating the science under this perspective

The energy/water perspective of climate change

Examples of 'feedback' systems that exemplify the multi-process nature of the problem and issues

The convection/stratiform conundrum

Key Issues, steps forward and journey with MMAP



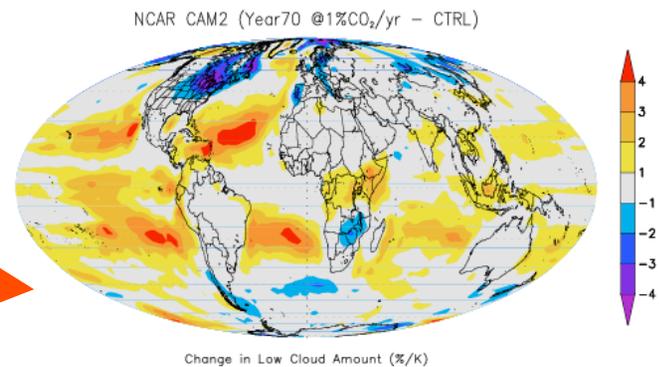
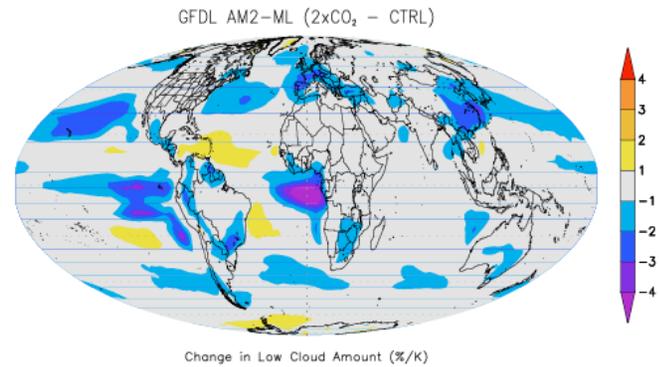
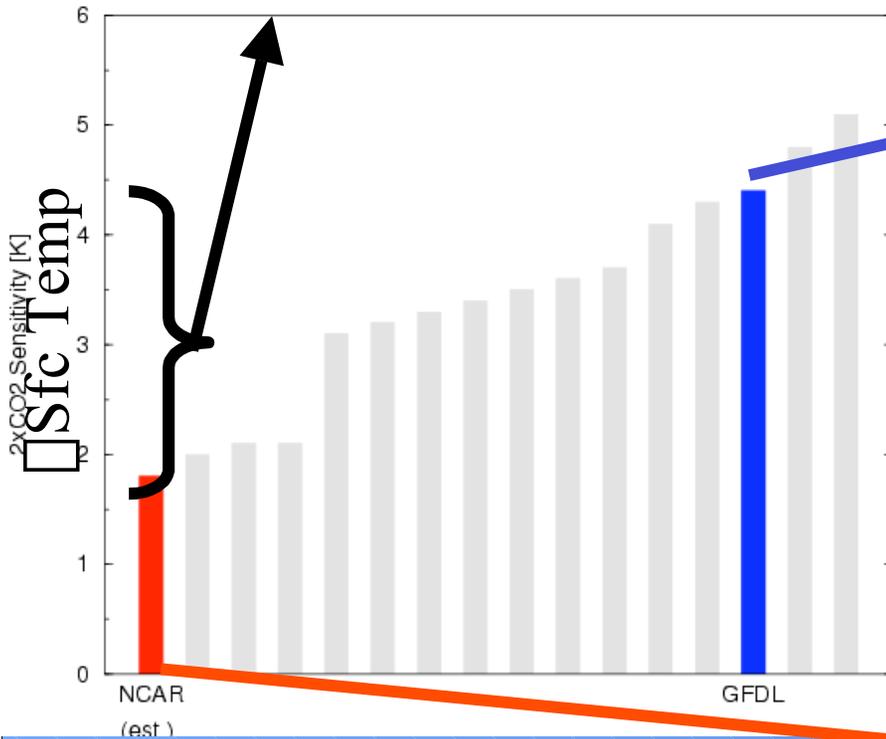
Energy

Water

Key climate
feedbacks lie here

An energy perspective

Smagorinsky 1975 NRC report,
range of uncertainty 1.5-4.5K



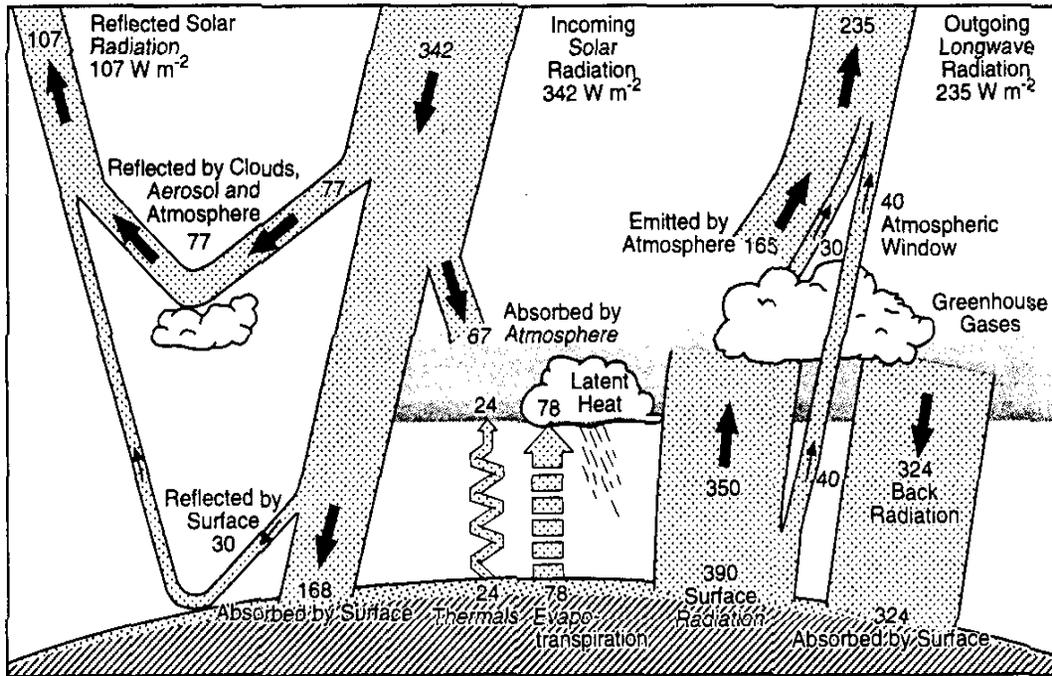
← Model →

Same prescribed forcing
(Courtesy, B. Soden)

To First Order

Atmos energy loss $\sim 100 \text{ Wm}^{-2}$

\sim in balance with latent heating $\sim 80/90 \text{ Wm}^{-2}$

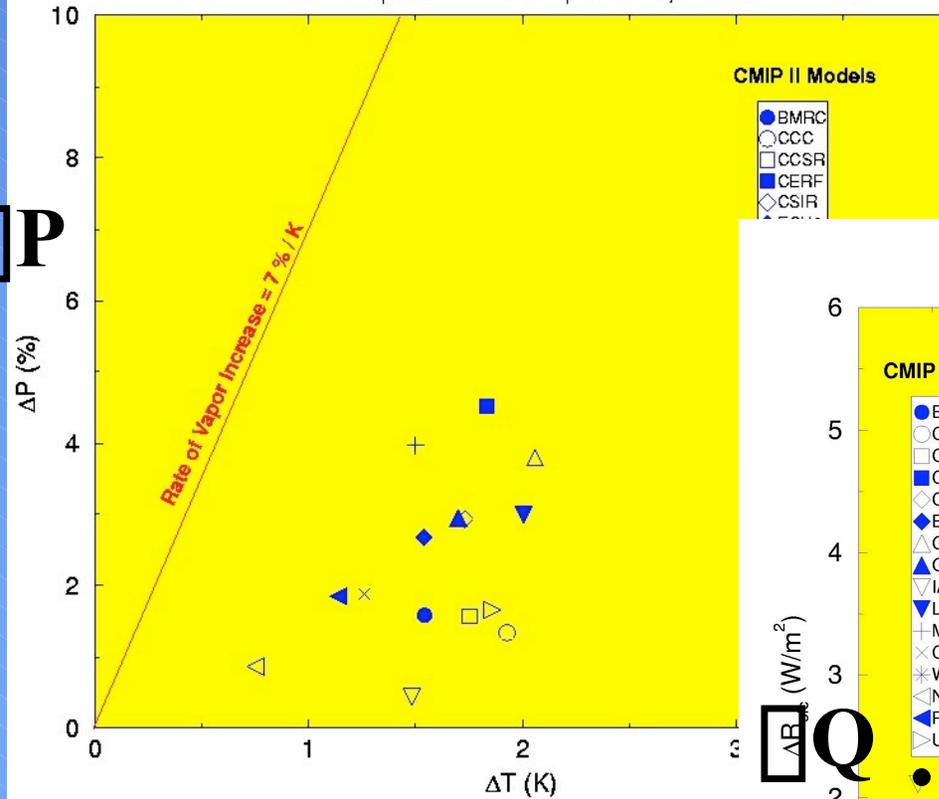


Thus changes to atmospheric radiative heating \square
changes in precipitation
Clouds are the principal modulator of this heating

CMIP analyses, B. Soden

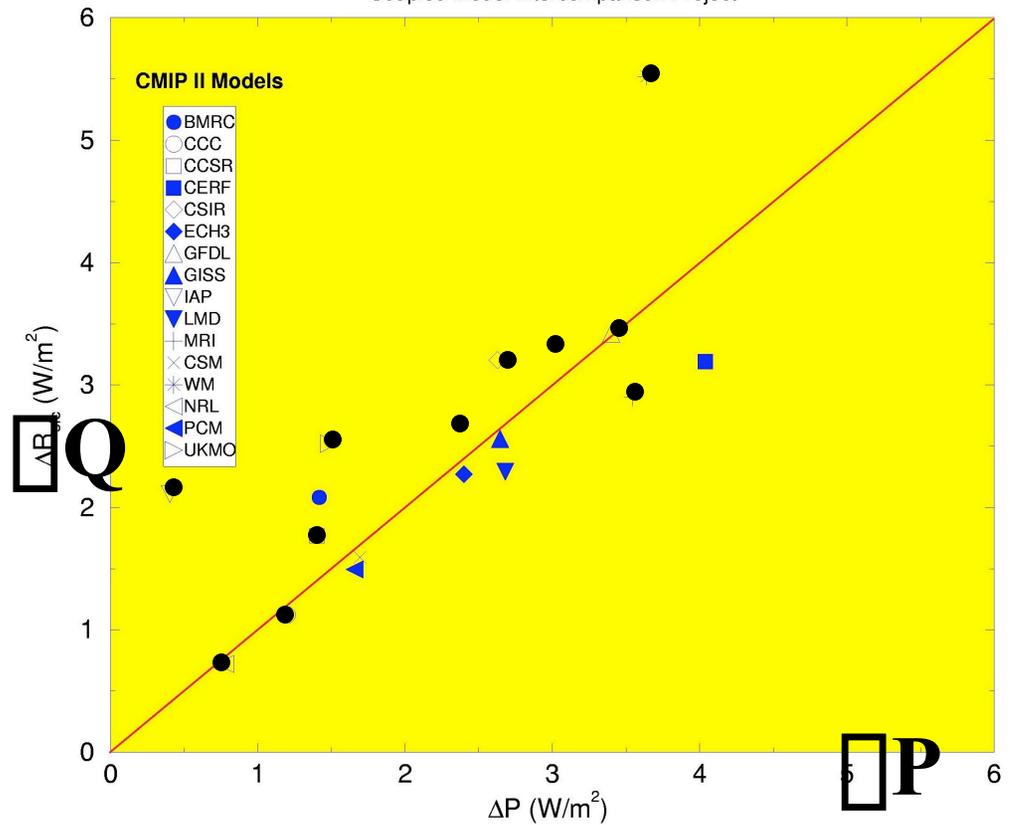
Global-Means (year 61-80 @ 1% CO₂ per year)

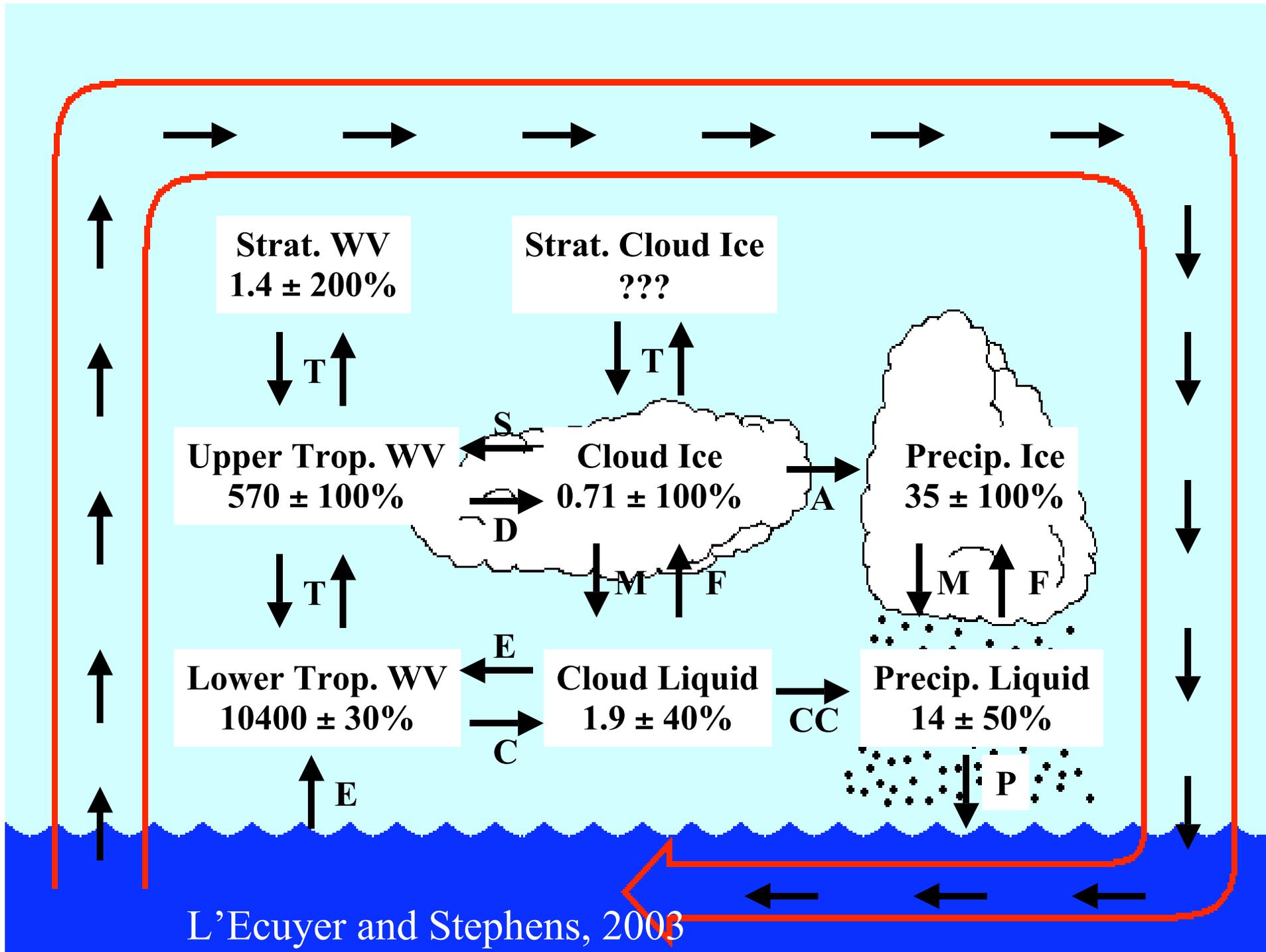
Coupled Model Intercomparison Project



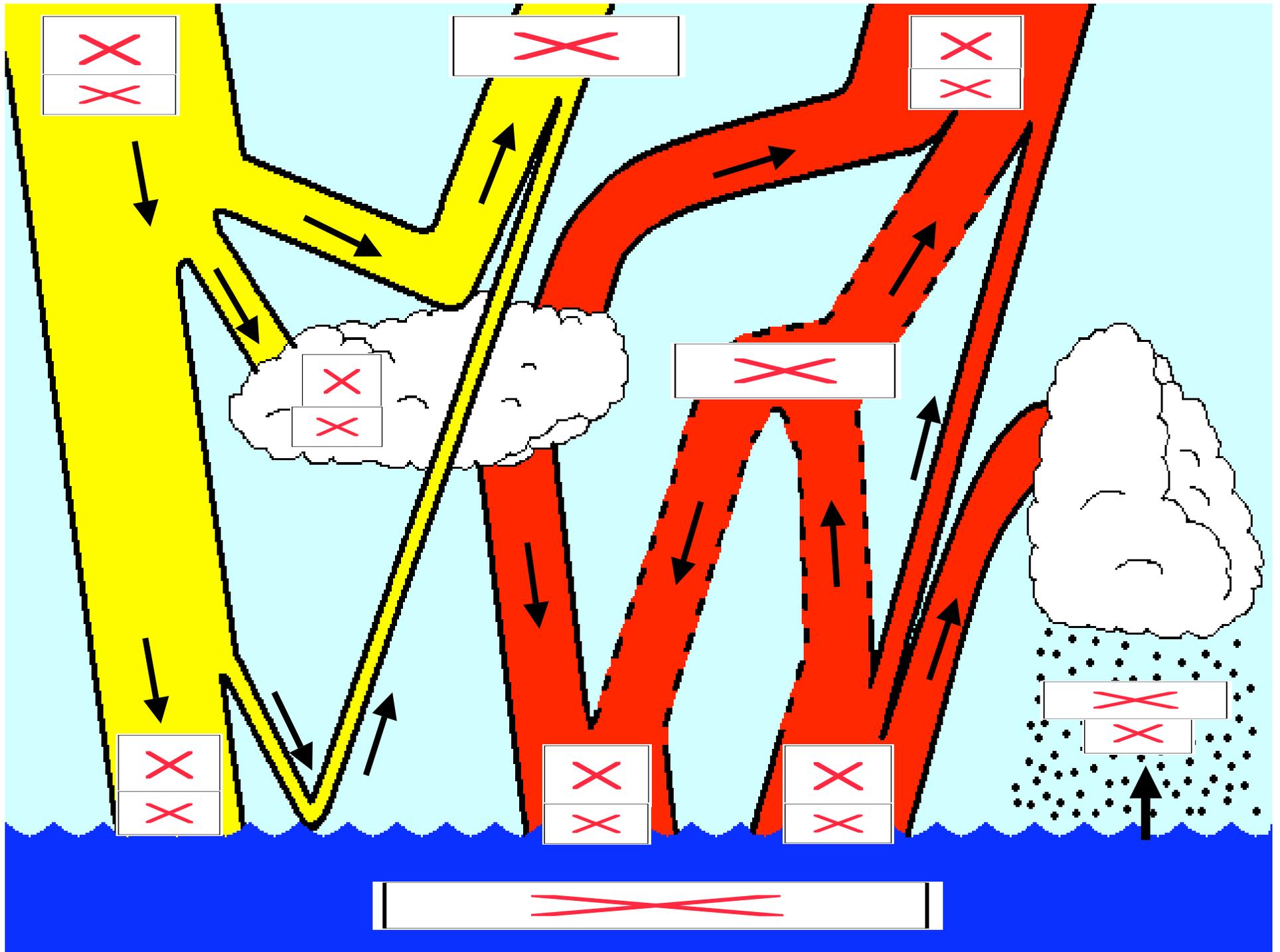
Global-Means (year 61-80 @ 1% CO₂ per year)

Coupled Model Intercomparison Project





L'Ecuyer and Stephens, 2003



Example 1: The Cloud Optical Depth Feedback

Optical depth \propto LWP (Stephens, 1978)

LWP \propto Optical depth \propto cloud albedo
(Stephens, 1978)

T \propto LWP \propto cloud albedo \propto cloud albedo \propto T

Paltridge, 1980; Charlock,
1982; Sommerville &
Remer, 1984;.....

TABLE 1. Measured Mean Annual Cloud Liquid Water Content Over the U.S.S.R as a Function of Temperature Range [from Feigelson, 1978]

Temperature Range, °C	Water Content, 10^{-3} kg m $^{-3}$
-20 to -25	0.09
-15 to -20	0.12
-10 to -15	0.15
-5 to -10	0.17
0 to -5	0.21
5 to 0	0.26
10 to 5	0.28
15 to 10	0.25

Our procedure is extremely simple. We note that cloud optical thickness is to a good approximation proportional to cloud liquid water content [Stephens, 1978]. Defining f by

$$f = \frac{1}{L} \frac{\partial L}{\partial T} \quad (1)$$

where L is cloud liquid water content and T is temperature, we estimate that the observational data (Table 1) suggest $f = 0.04$ to 0.05 for temperatures between -25°C and $+5^{\circ}\text{C}$, which is approximately the temperature range of the cloud-containing levels in our model. If cloud liquid water content L scaled as saturation vapor pressure, as given by the Clausius-Clapeyron equation, we would expect $f = 0.08$ for temperatures near 263 K, for example. Our results are presented compactly in Table 2. The surface temperature warming

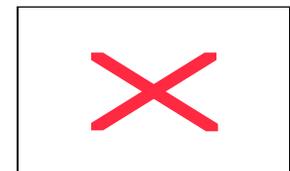


TABLE 2. Model Surface Temperature Warming ΔT Due to Doubling CO_2 Concentration as a Function of Cloud Liquid Water Content Dependence on Temperature f

f, deg^{-1}	$\Delta T, ^\circ\text{C}$
0	1.74
0.01	1.34
0.02	1.12
0.03	0.96
0.04	0.85
0.05	0.75
0.06	0.67
0.07	0.62
0.08	0.56
0.09	0.51
0.10	0.48

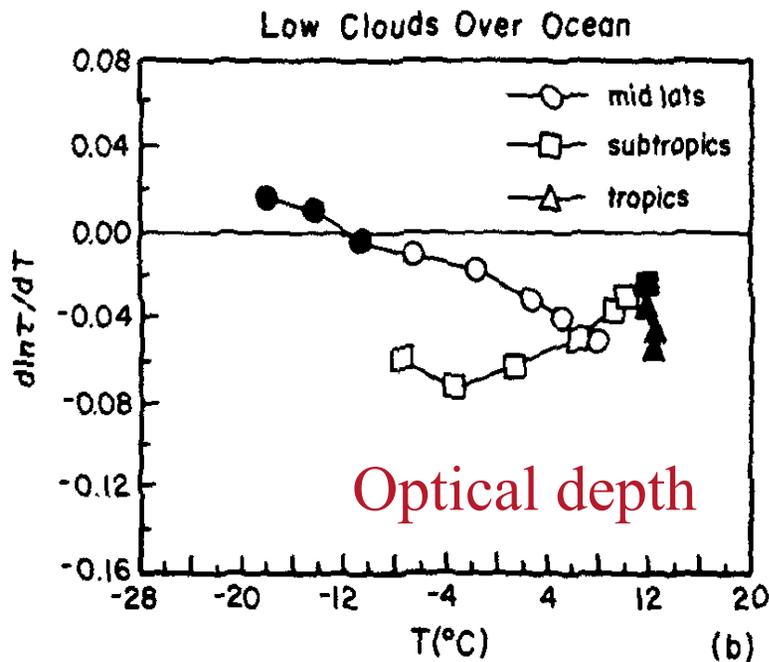
L is cloud liquid water content, T is temperature, and $f = (1/L)(\partial L/\partial T)$.

From this perspective the main result of our research is that temperature-dependent cloud optical thicknesses may act as a thermostat and provide a substantial negative feedback

BUT.....

Many speculated cloud feedbacks ignore the contribution of term A (effects of changing circulation on clouds).

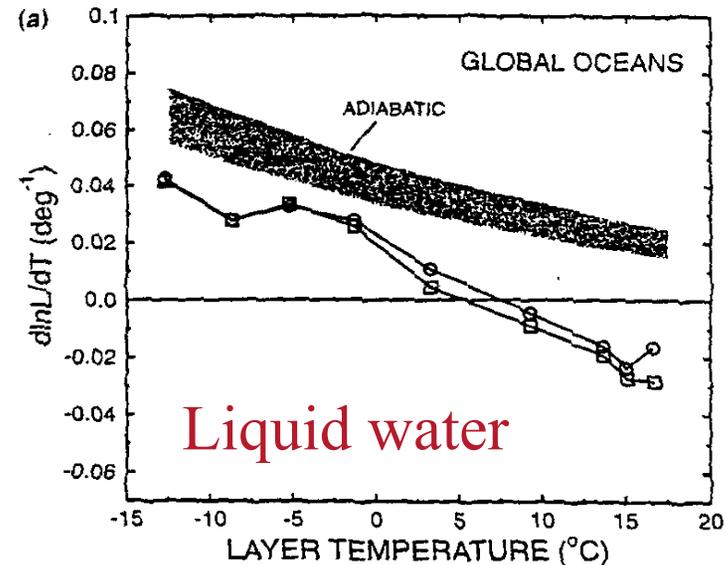
This has led to substantial confusion and debate on the relevance of the given feedback



Tselioudis et al., 1992

Others since: Del Genio and Wolf, 2000

Consideration of circulation feedback



Example2: Regulation of Tropical SSTs

In the paradigm of simple RCE, The tropical atmosphere acts like runaway GH system

A negative feedback occurs to constrain tropical SSTs

Large-scale wind-driven
Priestly, 1964; New

Enhanced emission to space
regions Pierrehumbert, 2000

Convection-radiation interaction
Ramanathan and Collins,
Lindzen et al., 2000

(i) Increasing SST

□ Increasing Convection

(ii) Increasing Convection

□ Increasing/decreasing
cirrus/CsCu

(iii) Increasing cirrus □

decreasing SST (R&C-
negative feedback)

Decreasing cirrus □

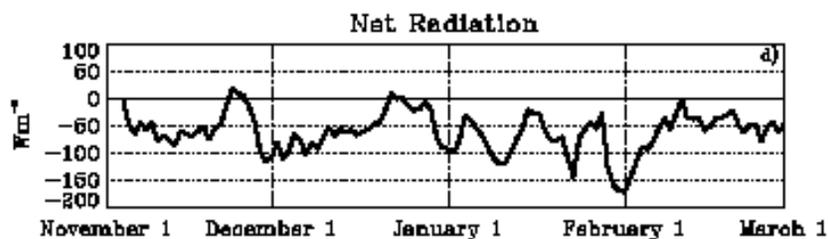
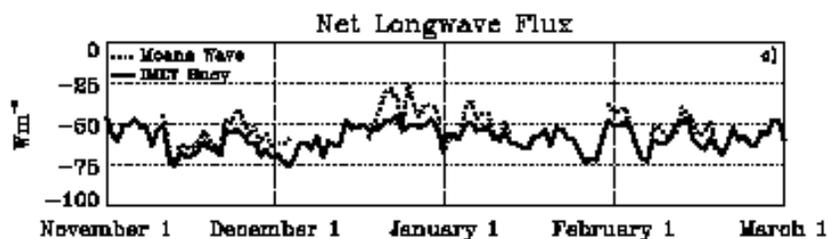
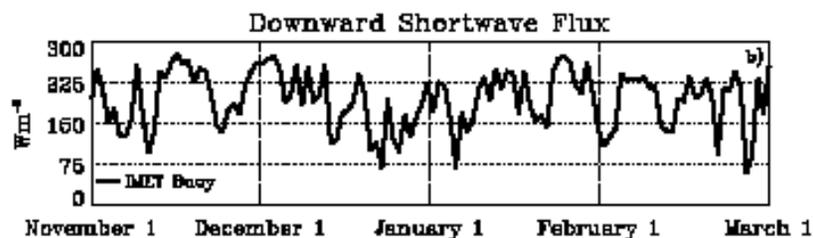
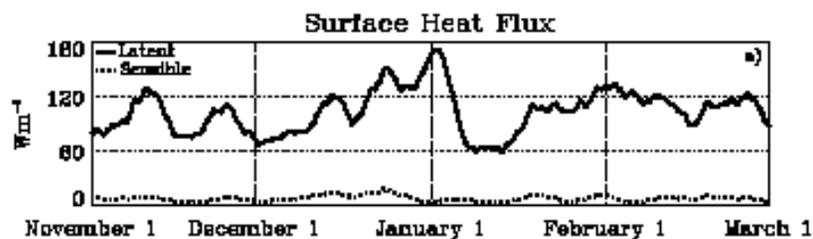
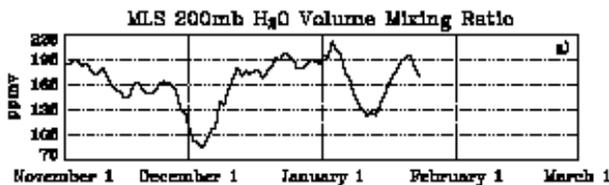
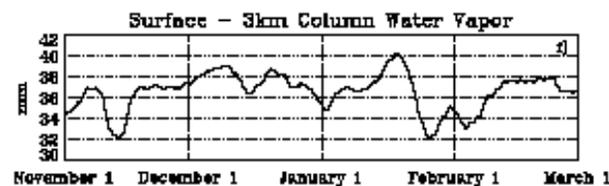
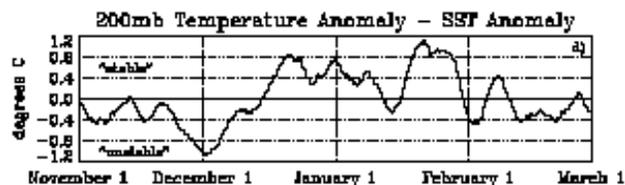
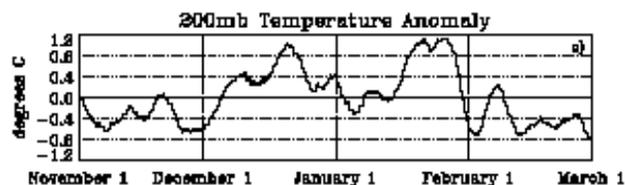
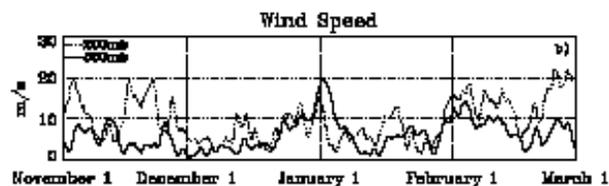
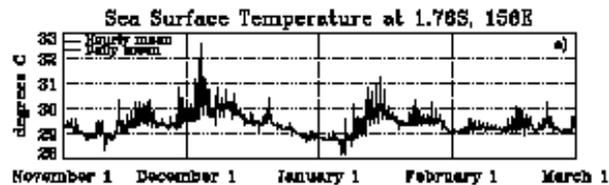
decreasing SST (L et al-

A lesson here is that analyses of feedbacks probably
cannot be quantified from observations alone – it has to
involve a valid ‘theory’ - is SP-CGM such a theory?

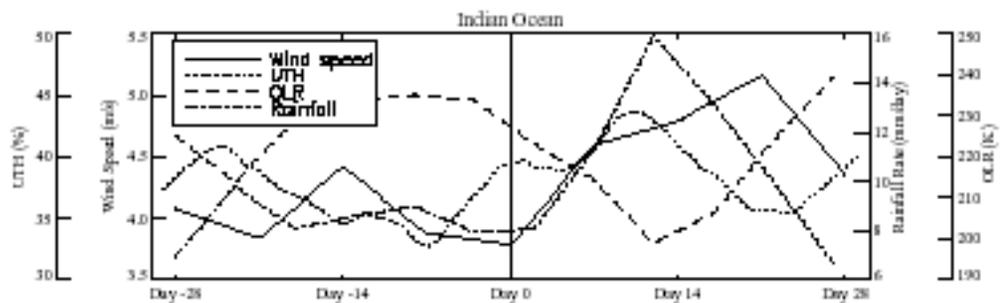
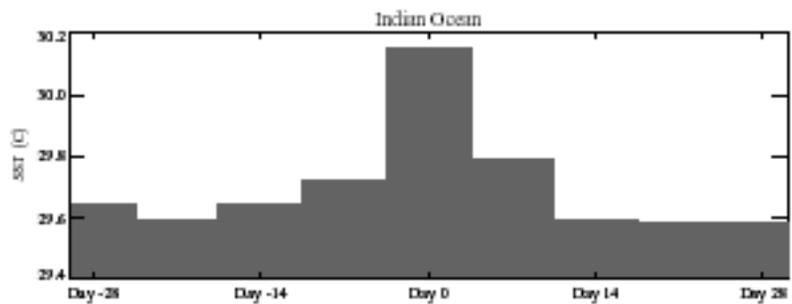
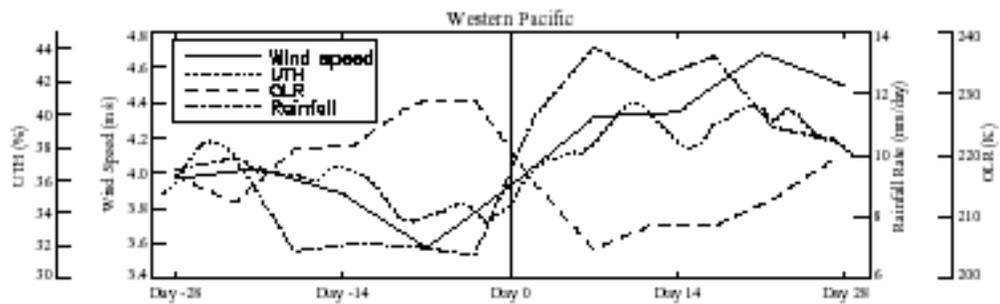
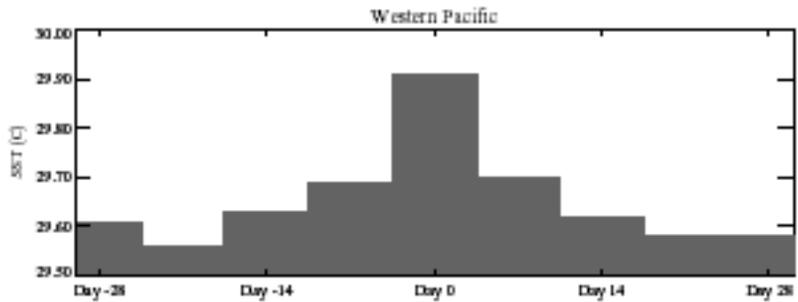
????

The MJO example of a cloud-radiation- climate feedback system?

The Madden Julian Oscillation is a fundamental mode of variability –
A mode neither well understood nor well represented in models

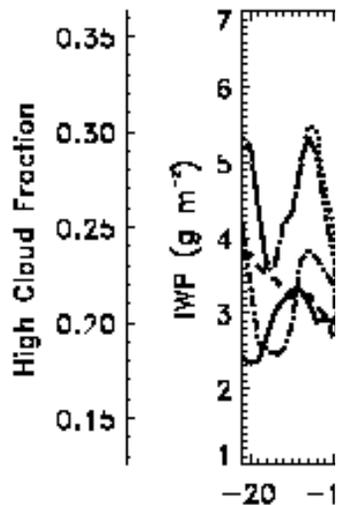


TOGA-COARE

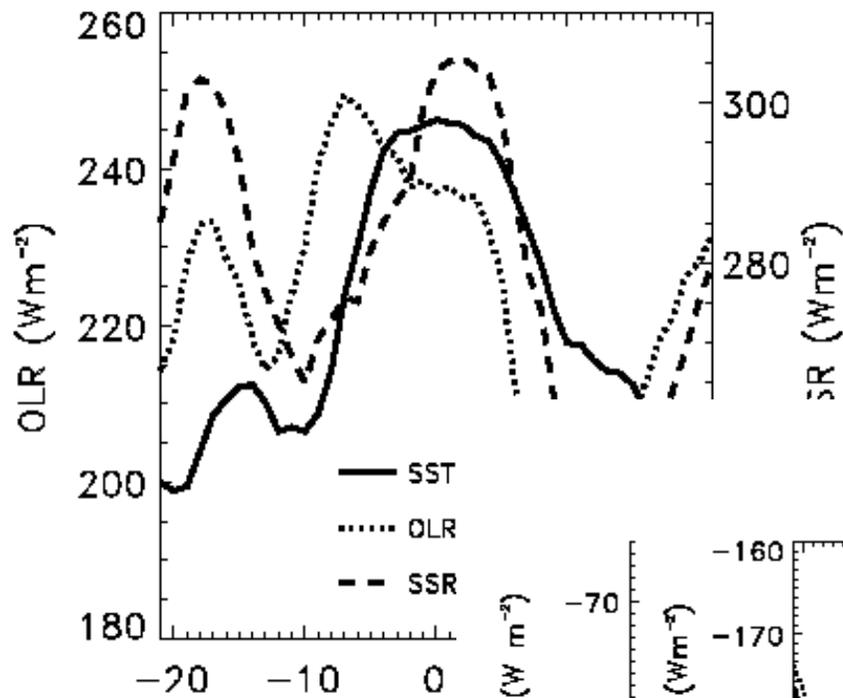


Satellite climatology

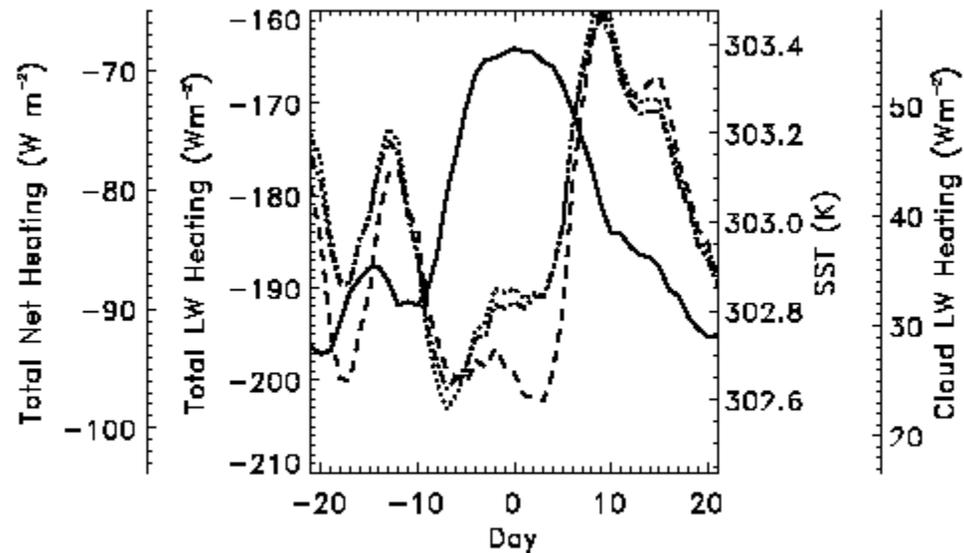
TOVS
 GPCP
 Reynolds SST
 ERS1



— S
 R
 --- G

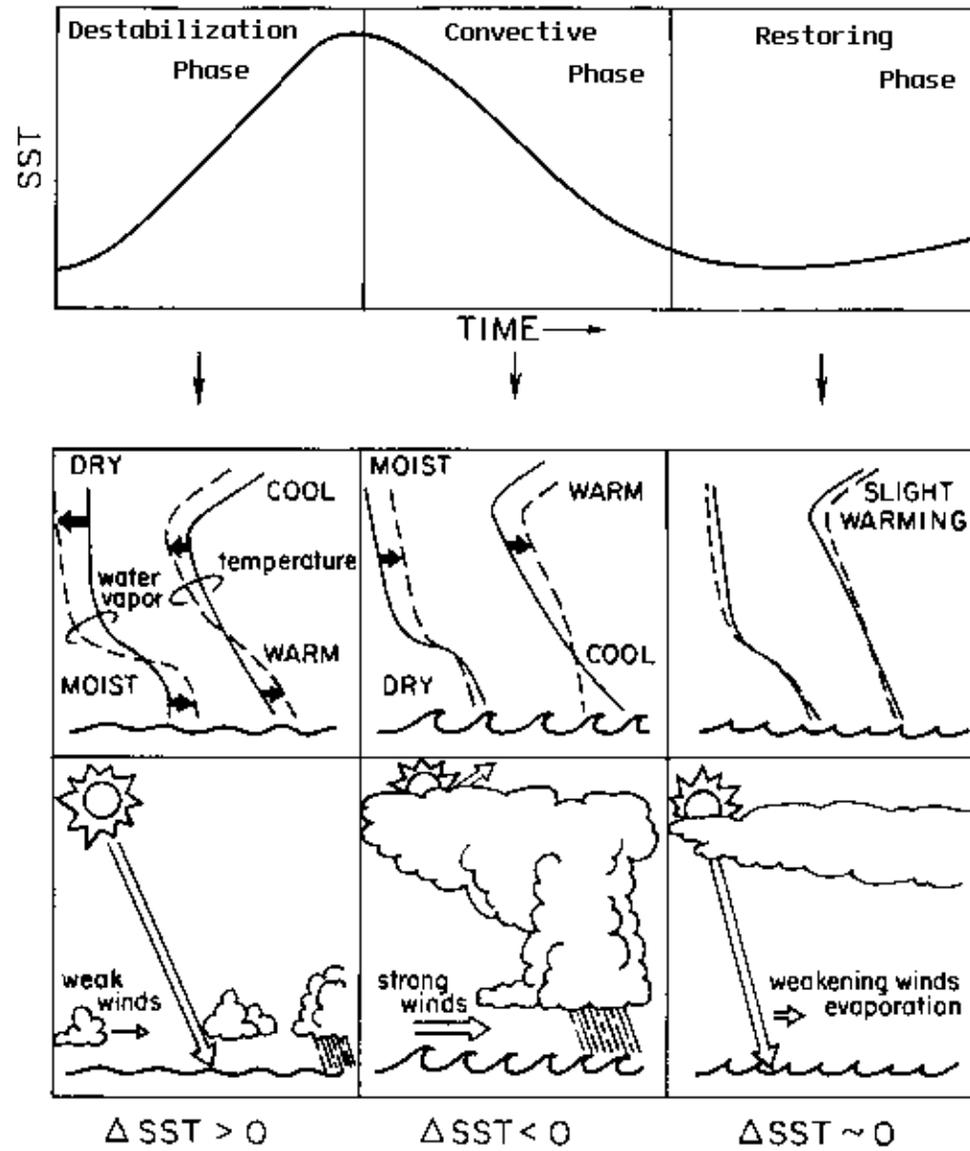


— SST
 OLR
 --- SSR



— SST
 Total LW Heating
 - · - · Cloud LW Heating
 --- Total Net Heating

TRMM composite
 data



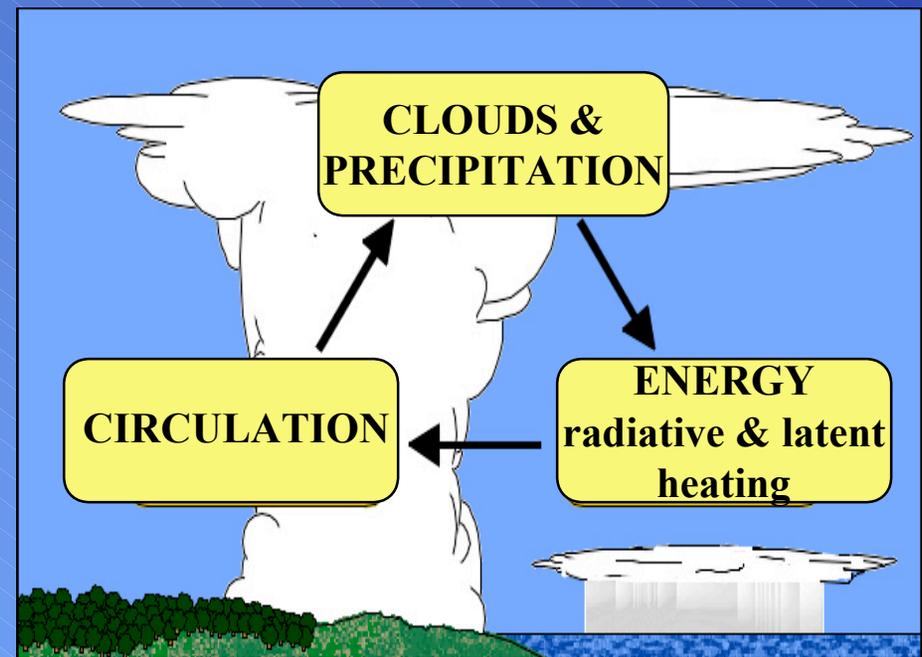
Stephens et al., 2003

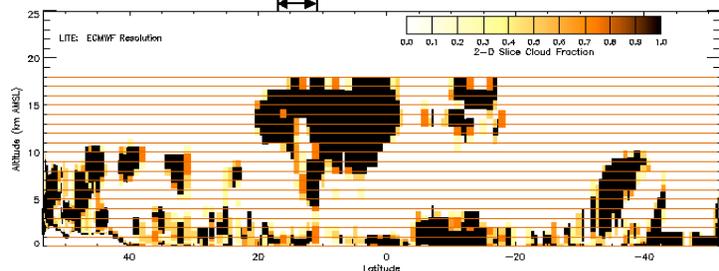
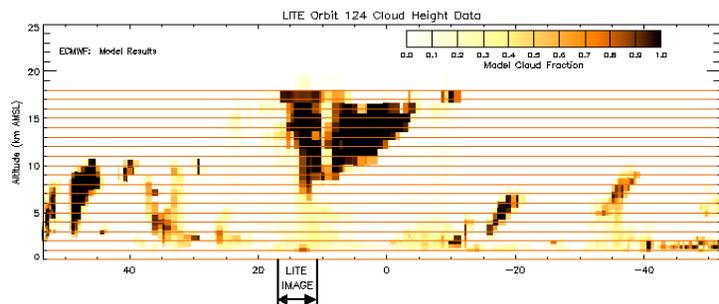
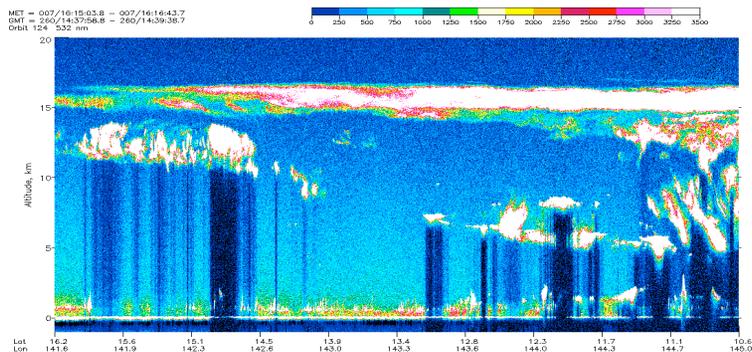
Summary comments:

The cloud climate problem is complicated by the fact that there are many processes and associated parameters that potentially give rise to a complicated system of intertwined feedbacks

But there is much yet to understand at a very gross level

Progress in the cloud parameterization problem is absolutely necessary if we are to demonstrate future progress in the cloud-climate problem





gather an understanding
 ve a *demonstrated* ability to

ly orchestrated marriage
 ration.

ery' (assimilation, forecast
 , etc) has to play a

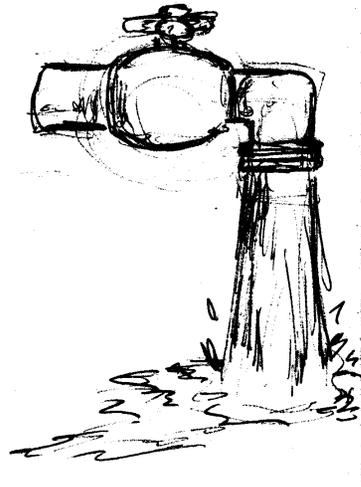
critical/seminal role

Therefore the ties between super-
 parameterization/climate modeling with
 NWP have to be strongly linked and clearly
 articulated.

Convection/stratiform separation

Convective hydrology

Large scale energy balance



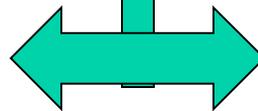
Circa, 1960/70s

Zonally averaged cloud
prescribed (fixed) properties

Circa, 1980s

Convective parameterizations
while physically intuitive contain
much empiricism

Cloud physics through
emergence of prognostic
schemes



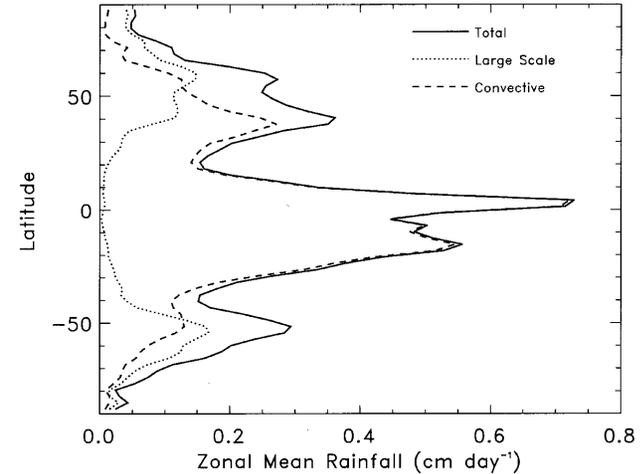
Historically, the artificial separation of convective & stratiform processes implies that energy balance and hydrological cycle are empirically decoupled

Intuitively, super-parameterization (extended) offers a consistent framework to bridge this separation.

Modern-'Classical' parameterization too can bridge the separation requiring the specification of an 'empirical' detrainment

Does SP move us more to a testable 'theory' that links convective with stratiform cloudiness?

CCM v3.10.11 Liquid Precipitation (Year 6, January)



Is MMAP intrinsically & demonstrably more accurate than comparative parameterization methods?

Use ARM data to quantify the stochastic component of cloud-radiation parameterization

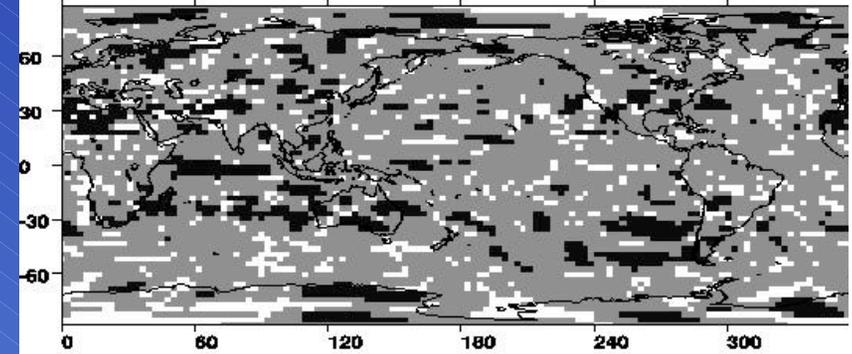
Include this noise in CAM2.0

Conduct ensemble integrations
With fixed SST

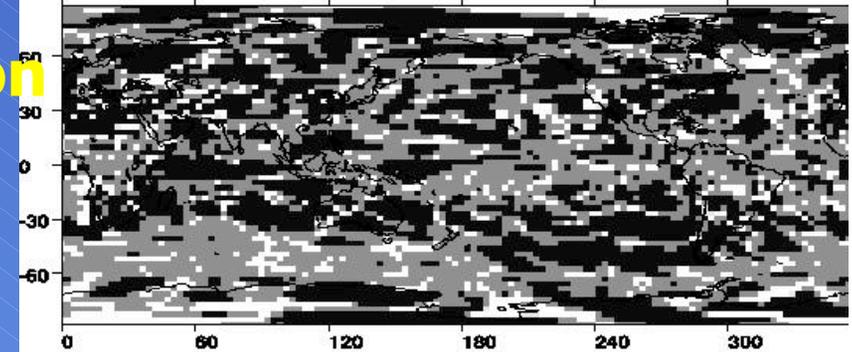
Compare ensemble to 'control'

Does MMAP lead to a reduction in the intrinsic parameterization noise of cloud parameterization?

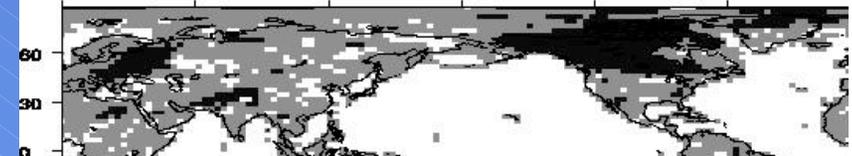
Total precip, 20% of control



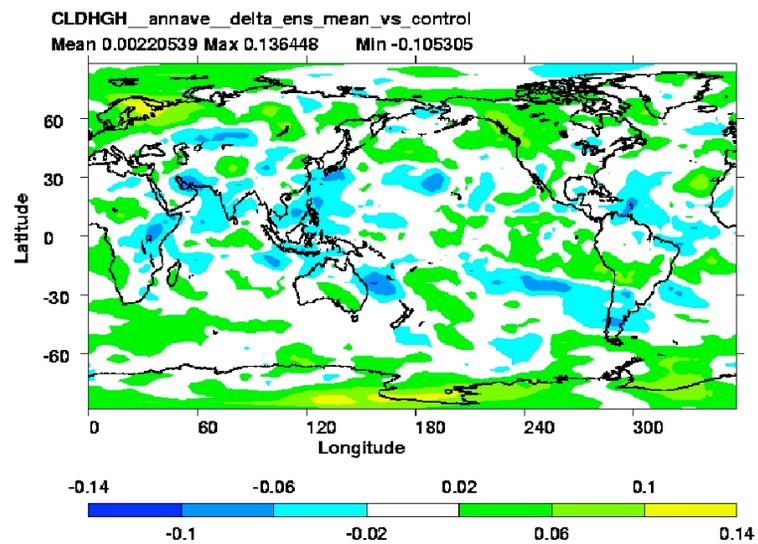
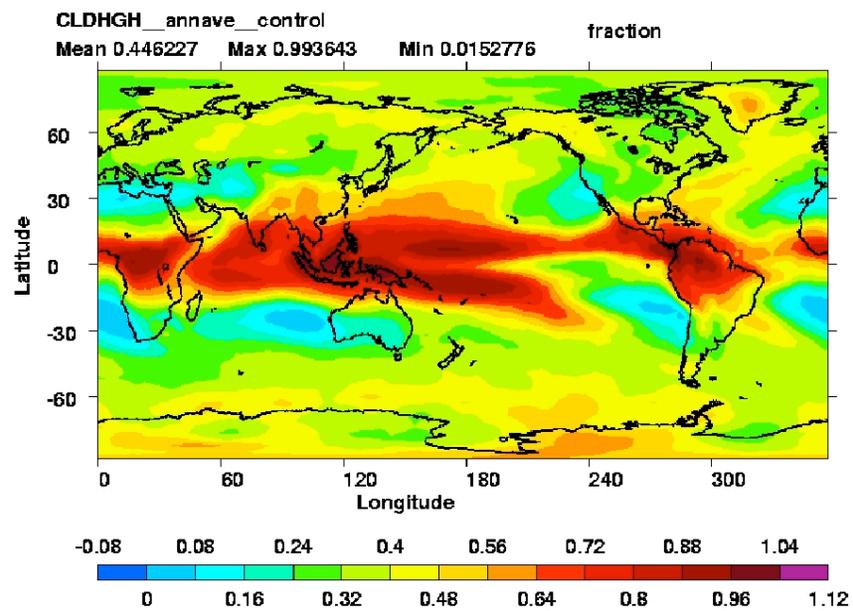
Total precip., 10% of control



Surface temperature, 1K vs. control



MMAAP science is central to modeling and understanding the atmospheric branch of the water cycle – it potentially offers an organizing principle for studying the water perspective of the climate system





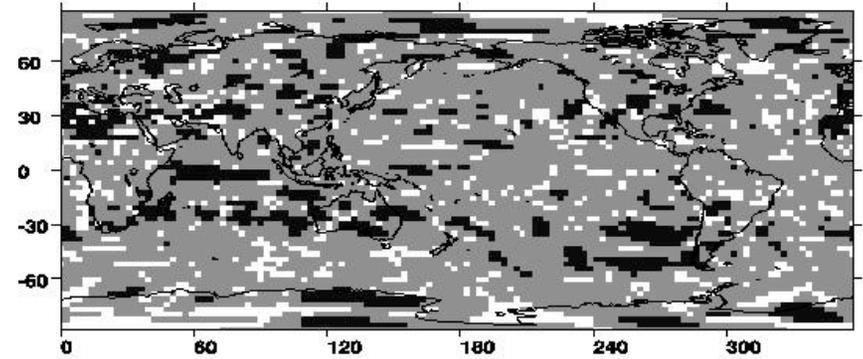
increasing statistical significance



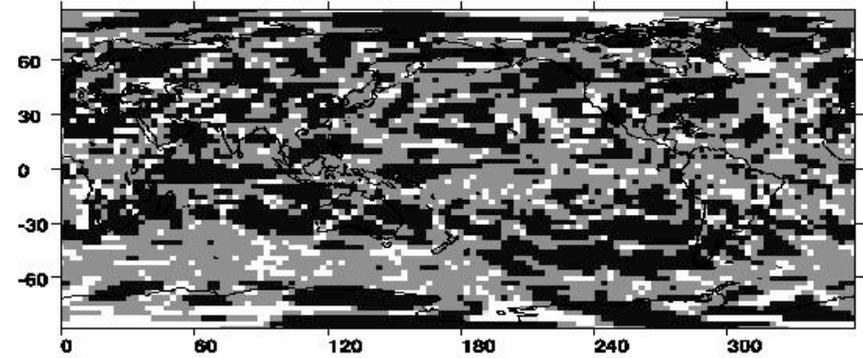
increasing relevance

$t < \#$ $\Delta_x < \sigma_x$ insignificant	$t > \#$ $\Delta_x < \sigma_x$ marginally significant
$t < \#$ $\Delta_x > \sigma_x$ marginally insignificant	$t > \#$ $\Delta_x > \sigma_x$ significant

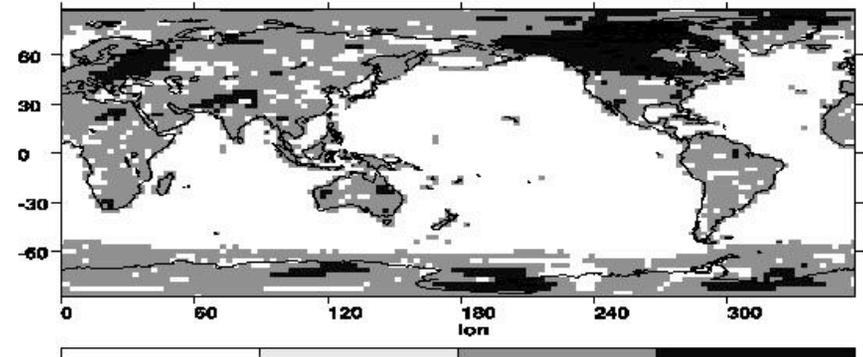
Total precip., 20% of control



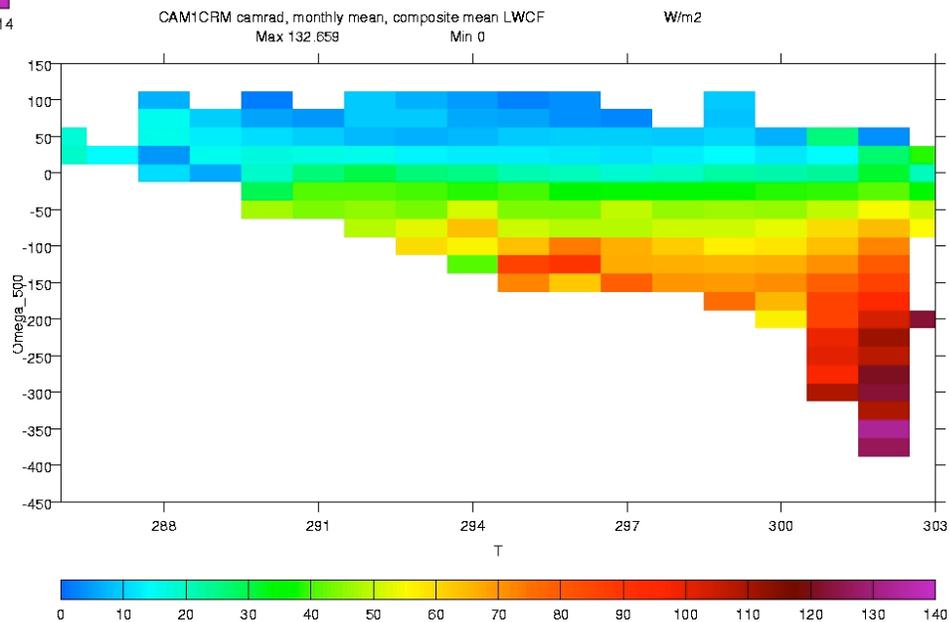
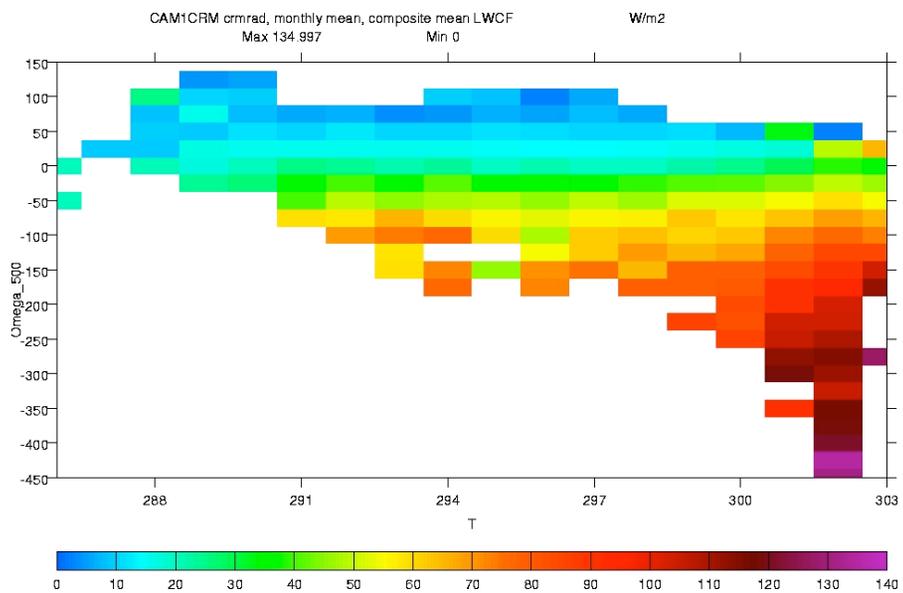
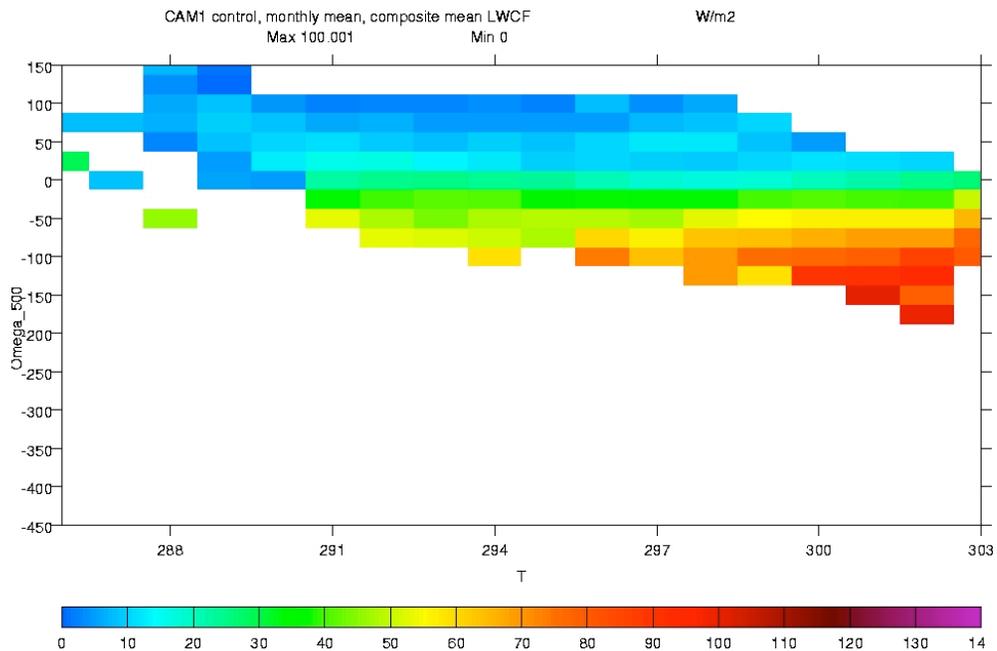
Total precip., 10% of control

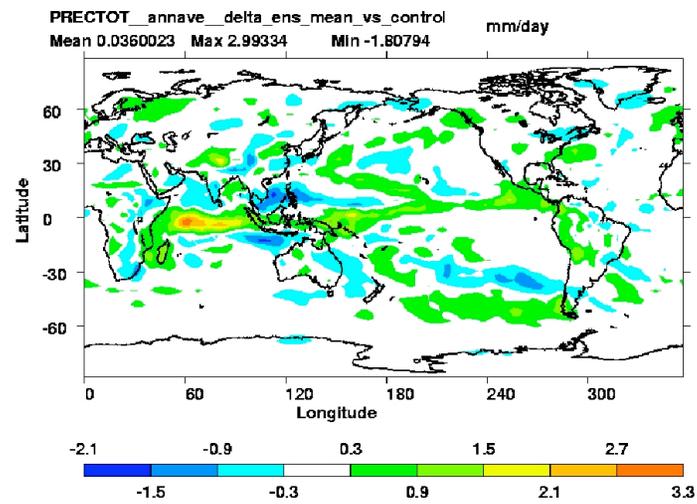
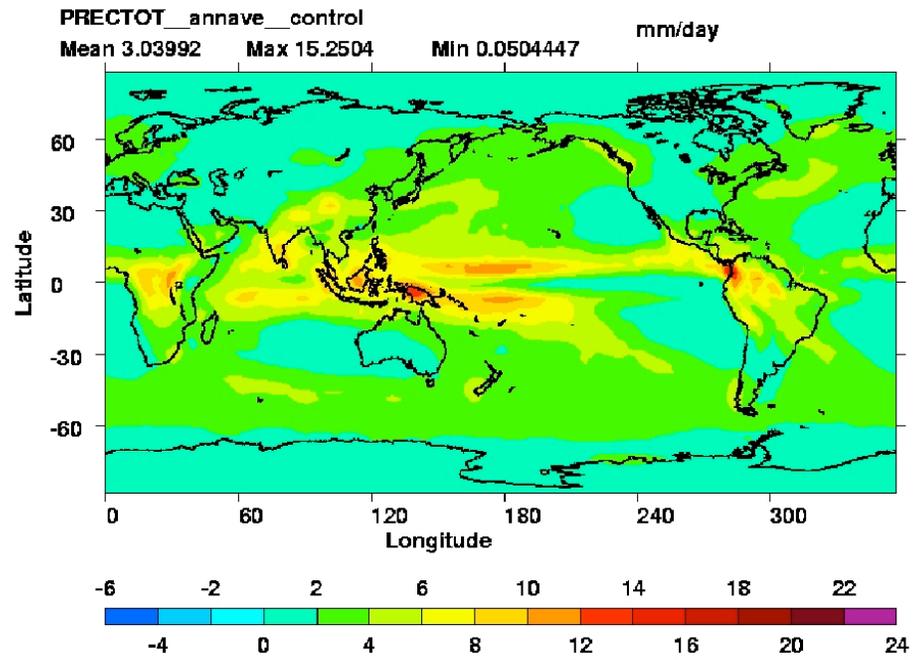


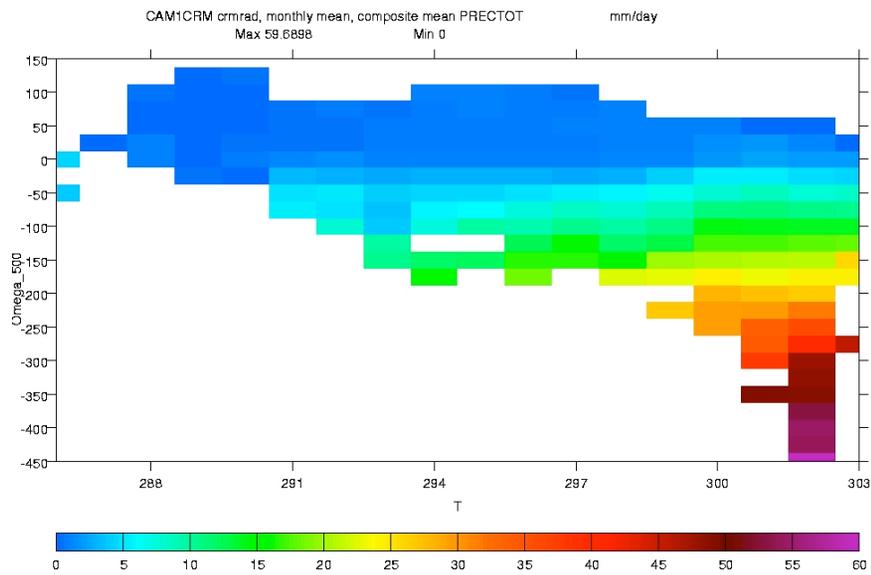
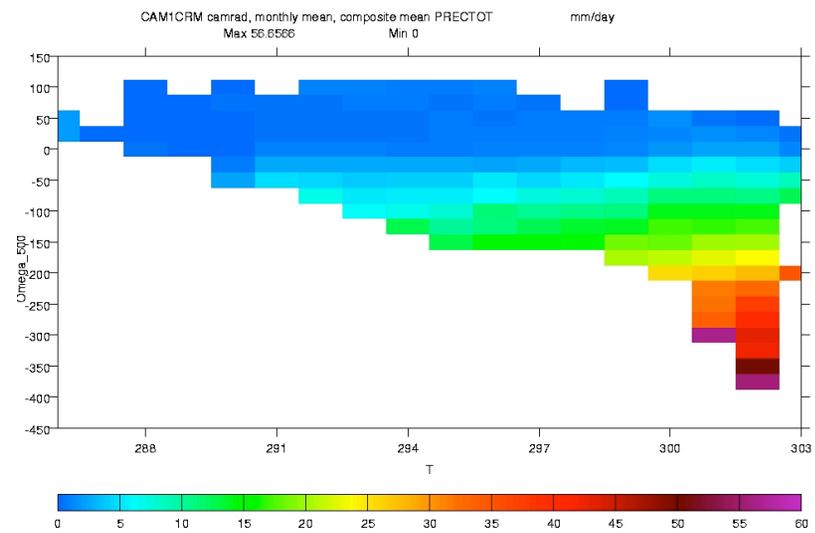
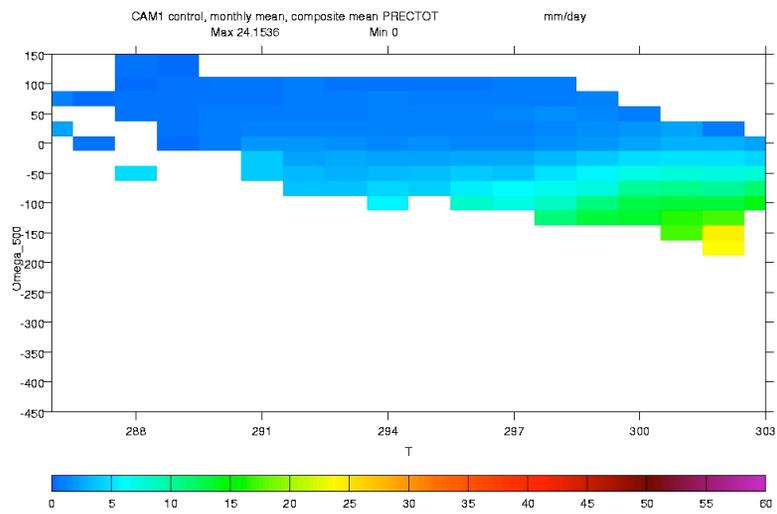
Surface temperature, 1K vs. control

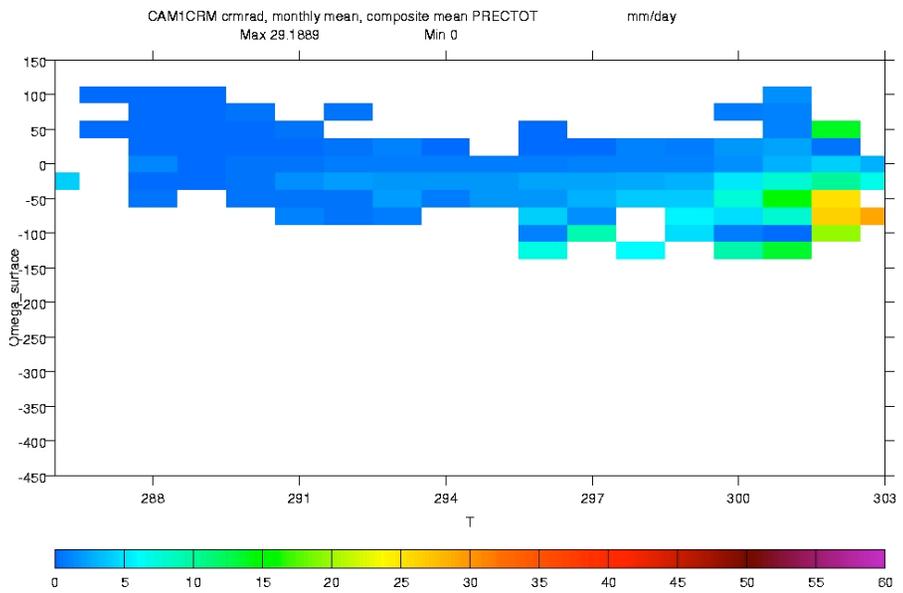
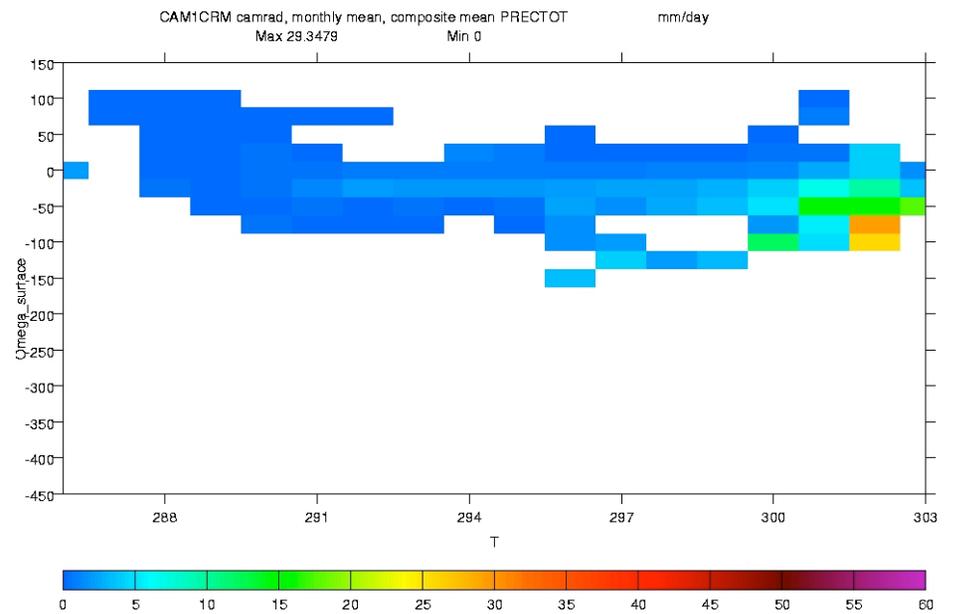
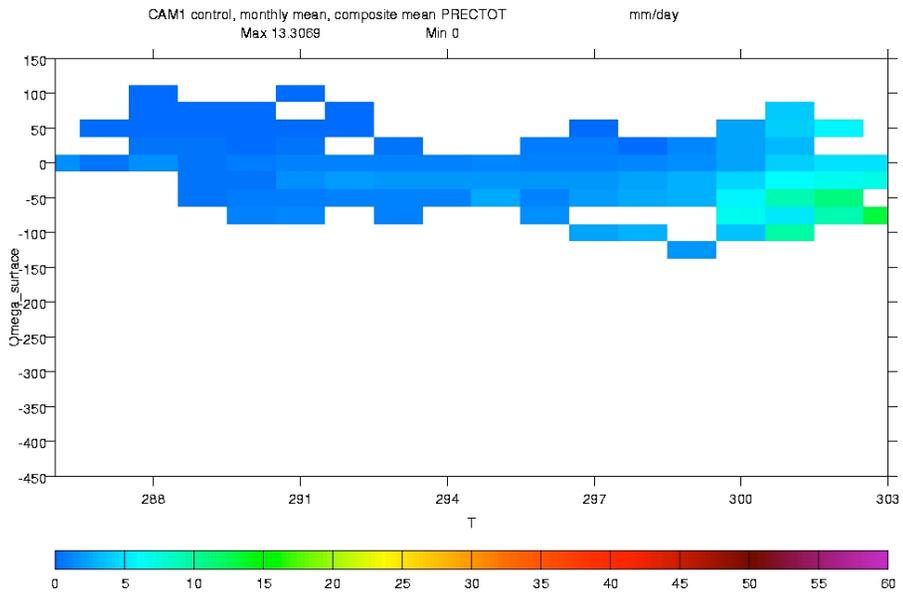


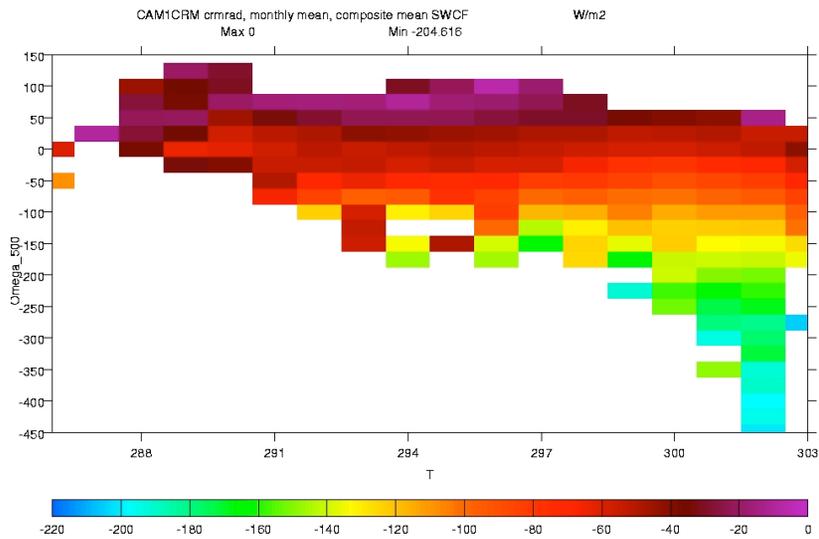
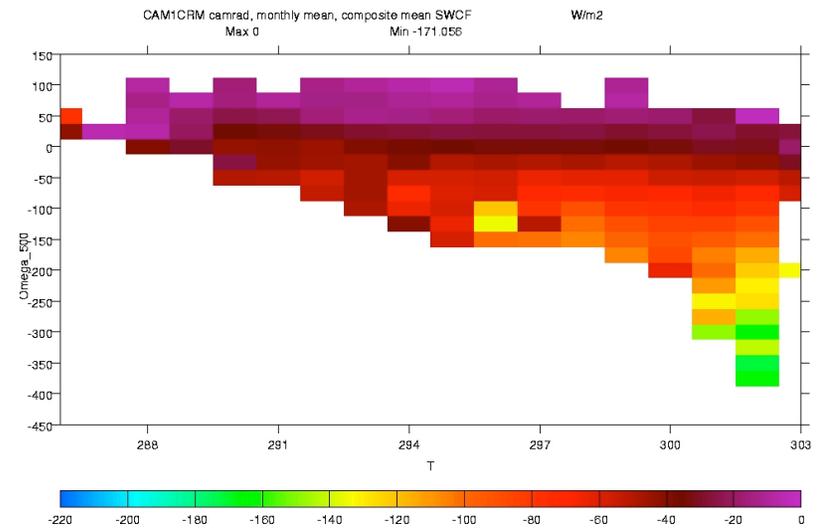
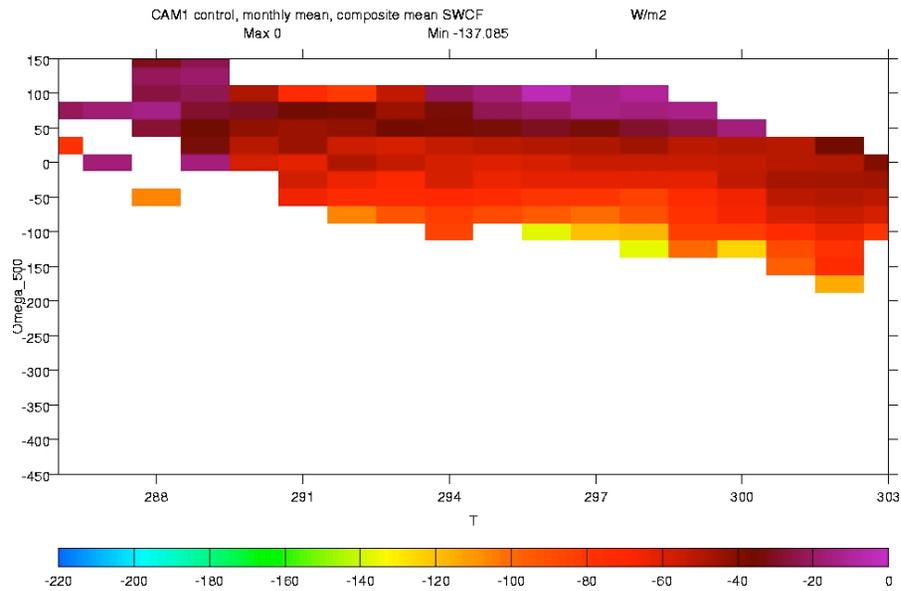
Insignificant
Marg. Insignificant
Marg. Significant
Significant

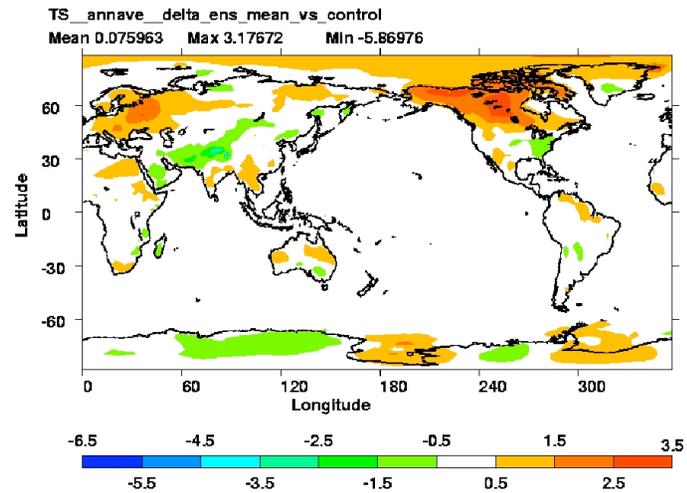
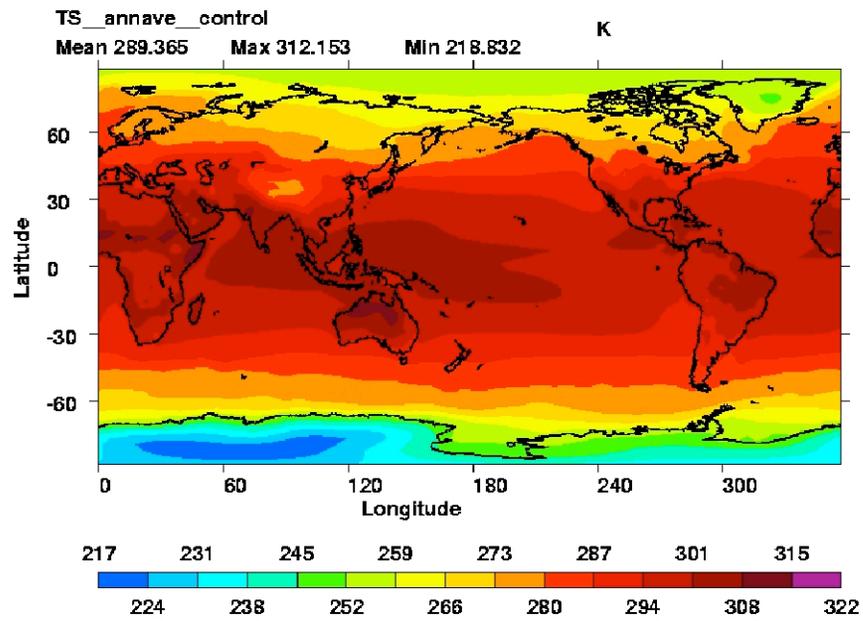












Super-parameterization

The cloud climate problem is complicated by the fact that there are many processes and associated parameters that potentially give rise to feedback

Processes these are inevitably coupled to other processes and hence other feedbacks of the system.

Two key themes:

1. The way forward is to thoroughly test models and the representation of key processes- this requires a carefully created liason between models and observation

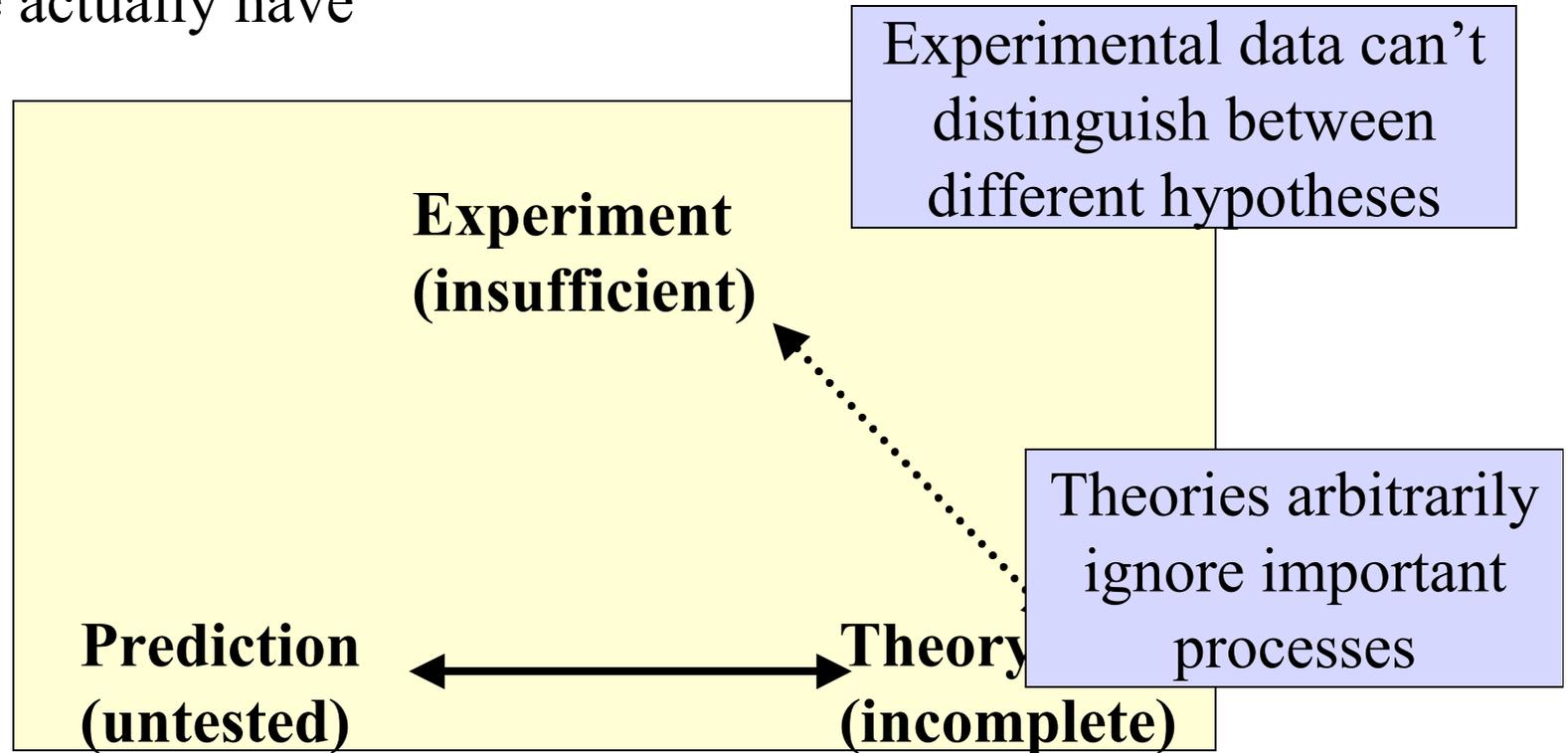
2. The way forward is develop models that have a *demonstrated* ability to represent reality

This requires a carefully orchestrated liason of models and observation.

NWP and its 'machinery' (assimilation, forecast verification, analysis, etc) should play a critical/seminal role

Therefore the ties between super-parameterization/climate modeling with the more operational global modeling of NWP have to be strongly linked.

What we actually have

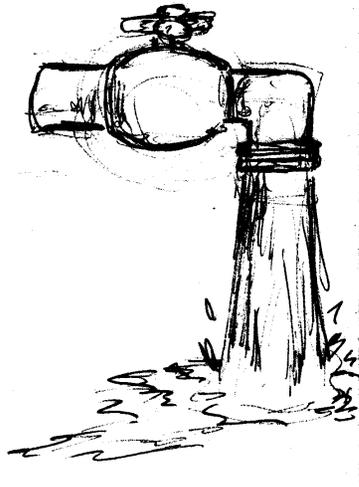


Hypotheses deal with large, complex coupled systems that do not necessarily obey simple laws – must be wary of over-reliance of lack of simplicity for exclusion of hypotheses 'simple is just simple'.

2. The GCM perspective

Convective □ hydrology

Large scale □ energy balance



Circa, 1960/70s

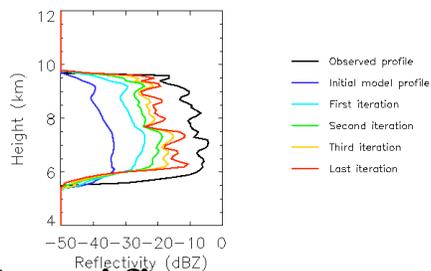
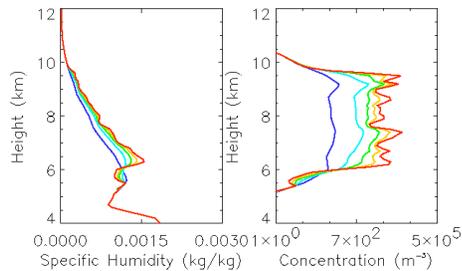
Zonally averaged cloud
prescribed (fixed) properties

Circa, 1980s

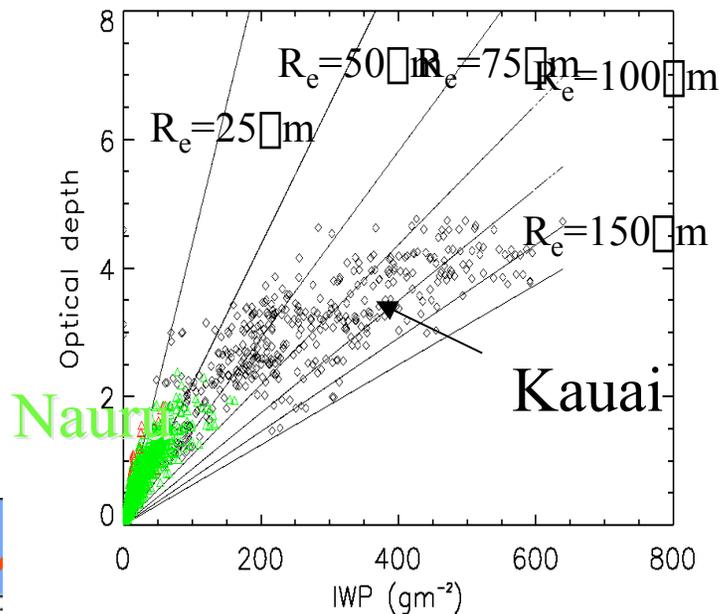
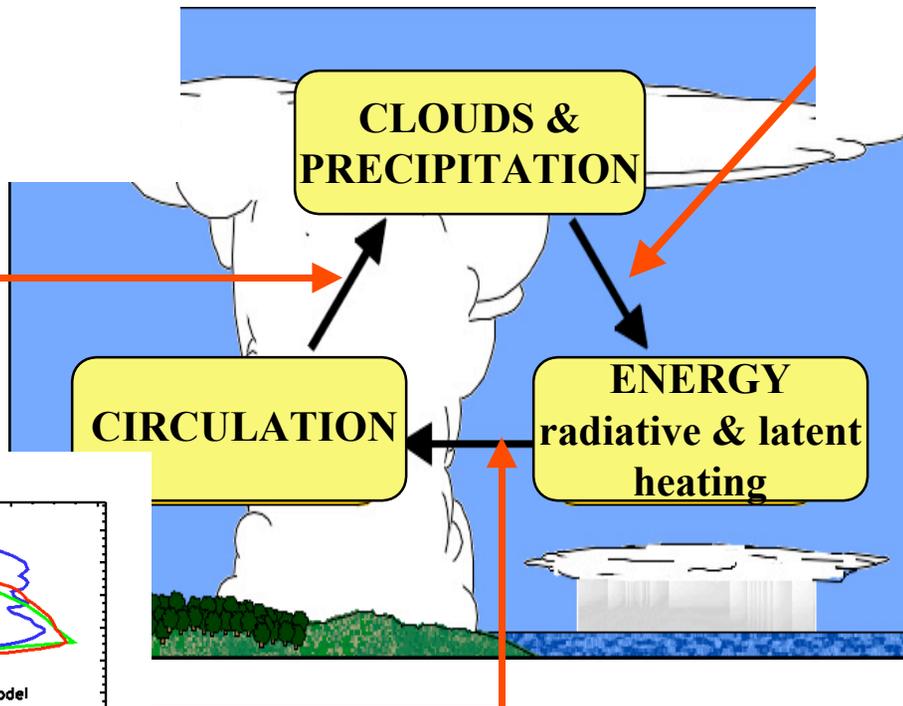
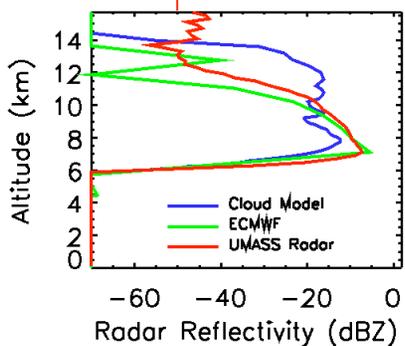
Convective parameterizations
remain largely empirical

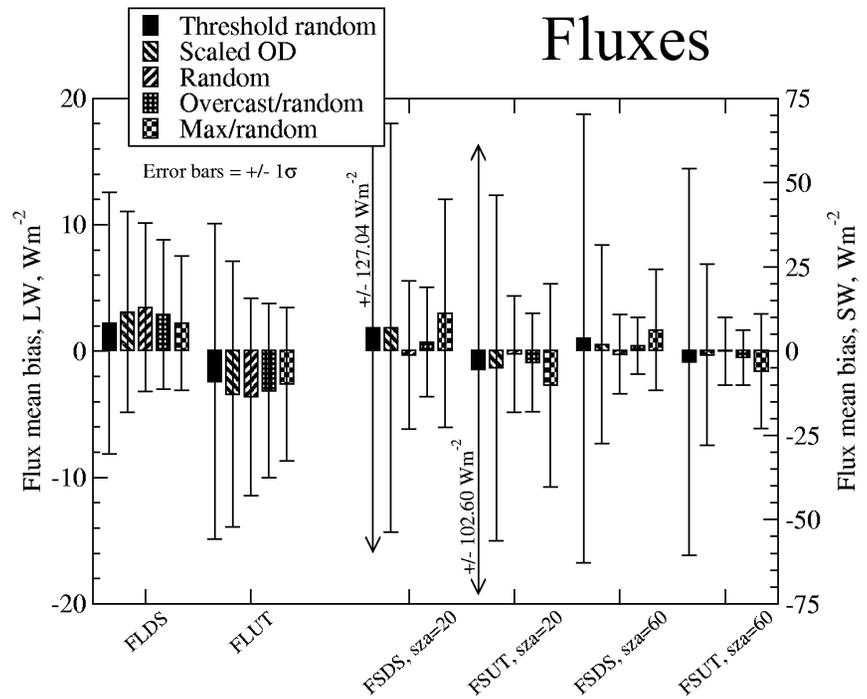
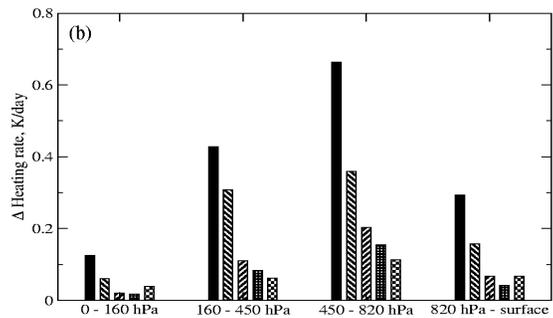
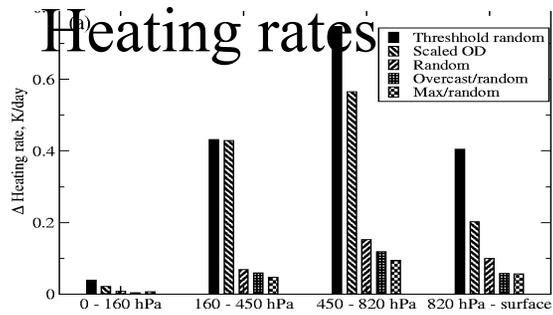
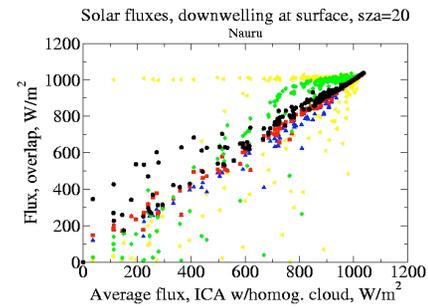
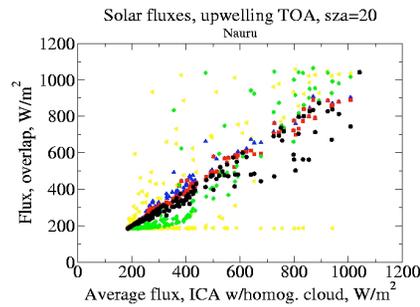
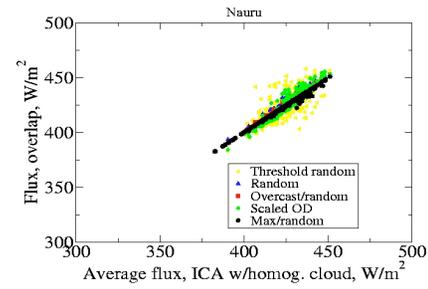
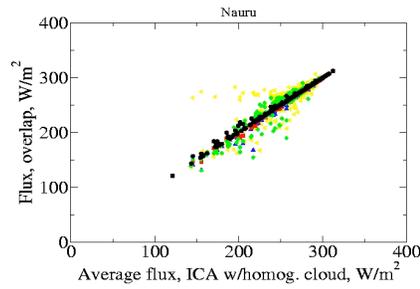
Cloud physics through
emergence of prognostic
schemes

Little connection between convective and large
scale clouds – little connection precipitation and
large scale cloudiness – precipitation efficiency



Specific Humidity as a control





“The researches of many commentators have already thrown much darkness on this subject, and it is probable that, if they continue, we shall soon know nothing about it...” *Mark Twain*

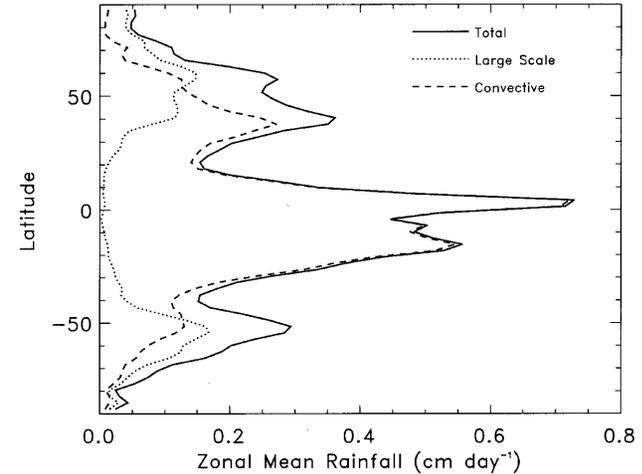
Historically, the artificial separation of convective & stratiform processes implies that energy balance and hydrological cycle are effectively decoupled

Intuitively, super-parameterization (extended) offers a consistent framework to bridge this separation.

Modern-'Classical' parameterization too can bridge the separation requiring the specification of an 'empirical' detrainment

Does SP move us more to a testable 'theory' ?

CCM v3.10.11 Liquid Precipitation (Year 6, January)



2. The way forward is to gather an understanding using models that have a *demonstrated* ability to represent reality

This requires a carefully orchestrated marriage of models and observation.

NWP and its 'machinery' (assimilation, forecast verification, analysis, etc) has to play a critical/seminal role

Therefore the ties between super-parameterization/climate modeling with the more operational aspects of NWP have to be strongly linked and clearly articulated.