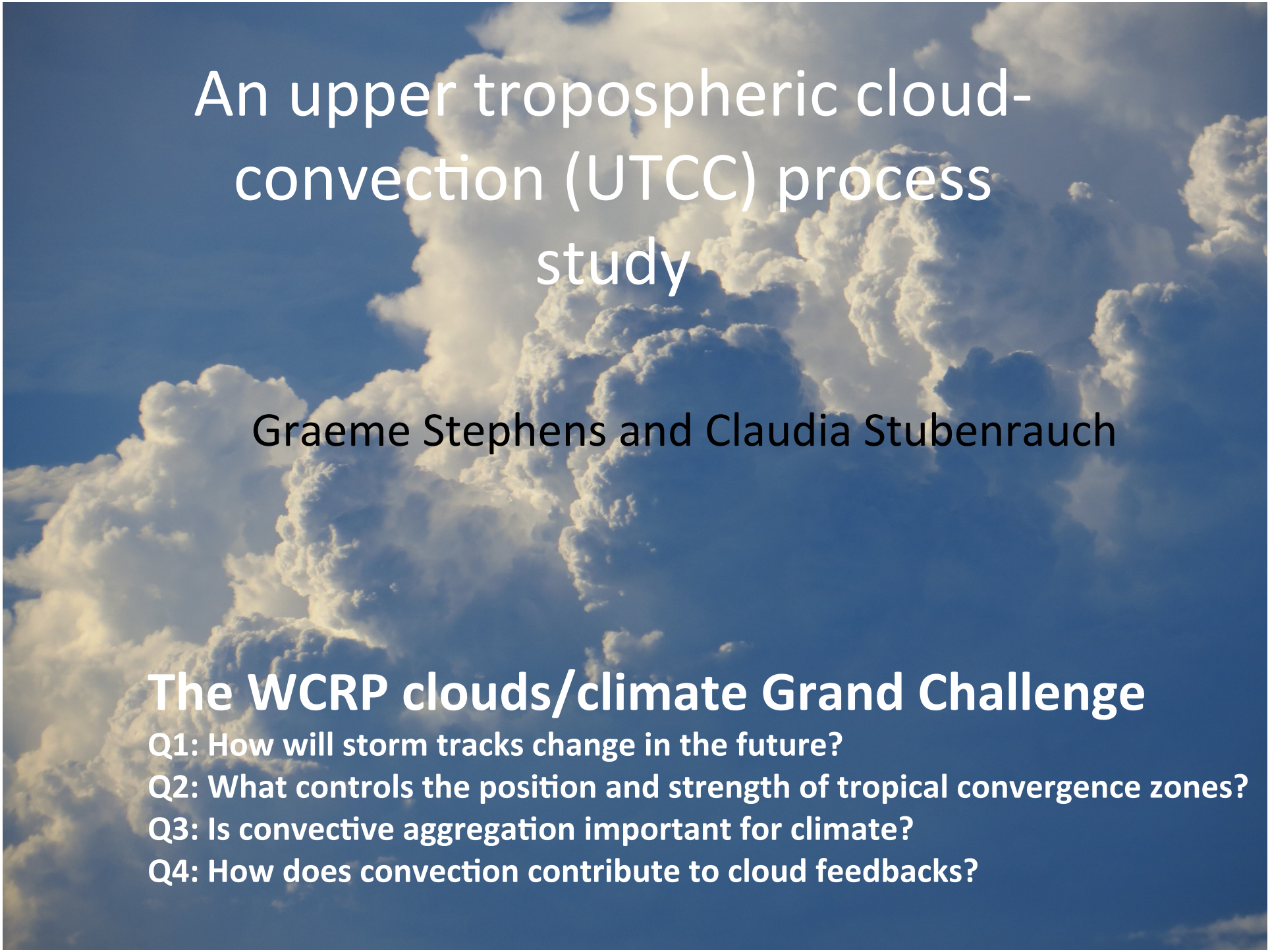
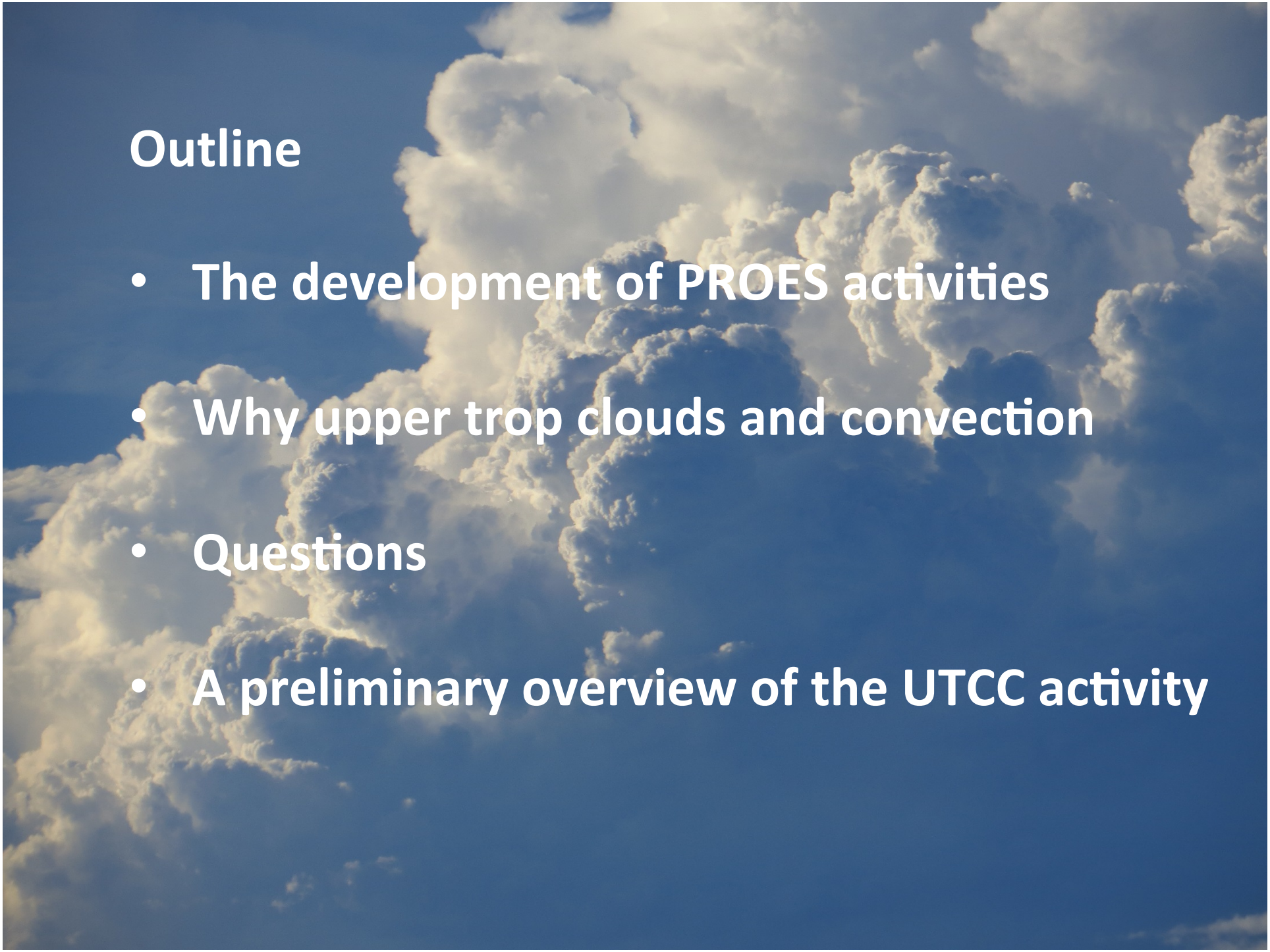


An upper tropospheric cloud-convection (UTCC) process study

Graeme Stephens and Claudia Stubenrauch

The WCRP clouds/climate Grand Challenge

Q1: How will storm tracks change in the future?
Q2: What controls the position and strength of tropical convergence zones?
Q3: Is convective aggregation important for climate?
Q4: How does convection contribute to cloud feedbacks?


Outline
• The development of PROES activities
• Why upper trop clouds and convection
• Questions
• A preliminary overview of the UTCC activity

GEWEX PROES - Process Evaluation Studies underdevelopment

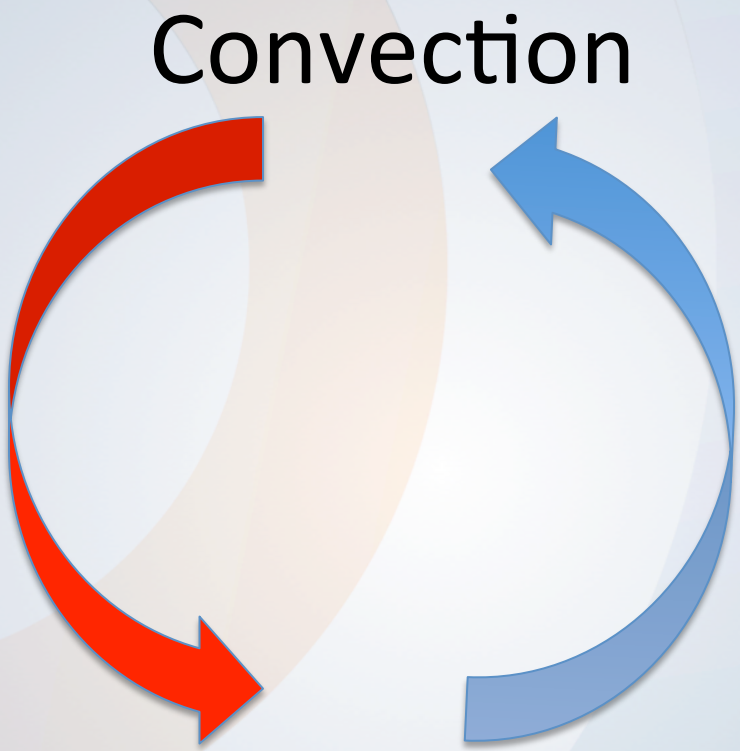
This grew out of the obs4mip meeting where participants felt the issue of using obs more intelligently to probe process understanding was missing in obs4mip II

PROES is likely to grow into a WCRP cross cut activity

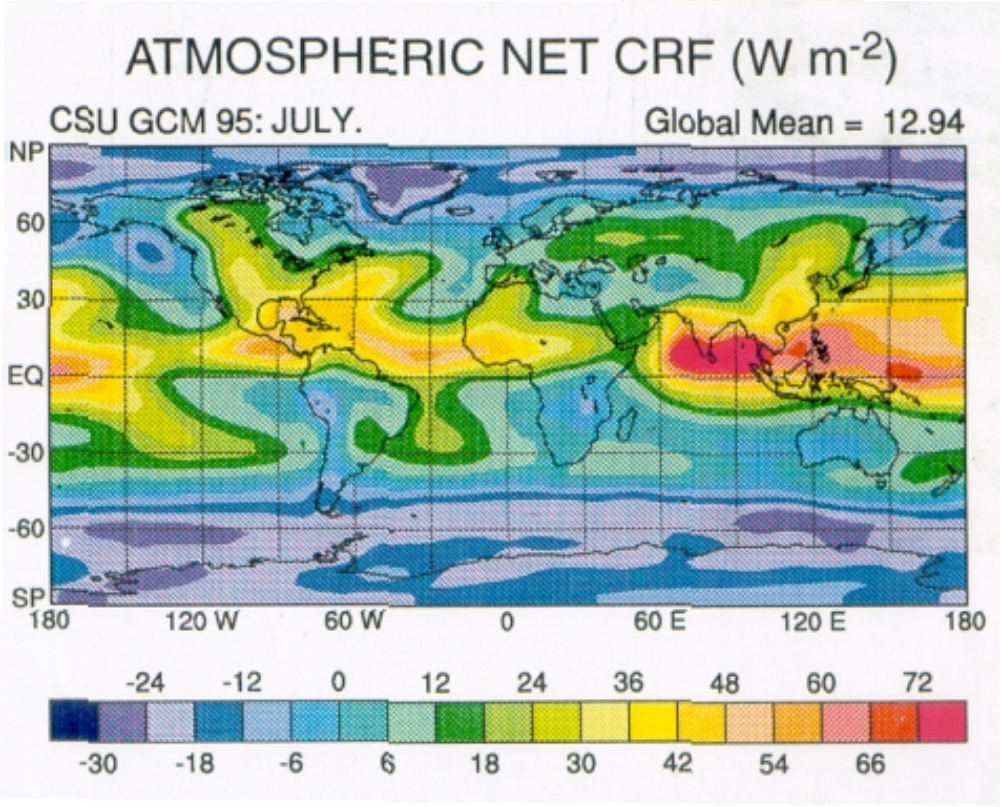
Five GEWEX-related PROES activities developing, one led by CliC

- Upper Tropospheric Clouds & Convection (UTCC) lead Stubenrauch and Stephens
- Ice mass balance (lead Larour, Sophie Nowicki), GEWEX with CLiC
- Radiative Kernels for Climate (lead Soden)
- Mid-lat storms (lead Tselioudis, Jakob)
- Soil moisture climate (lead Sonia Seneviratne)

Why UTCC? Cloud/radiation/convection feedbacks

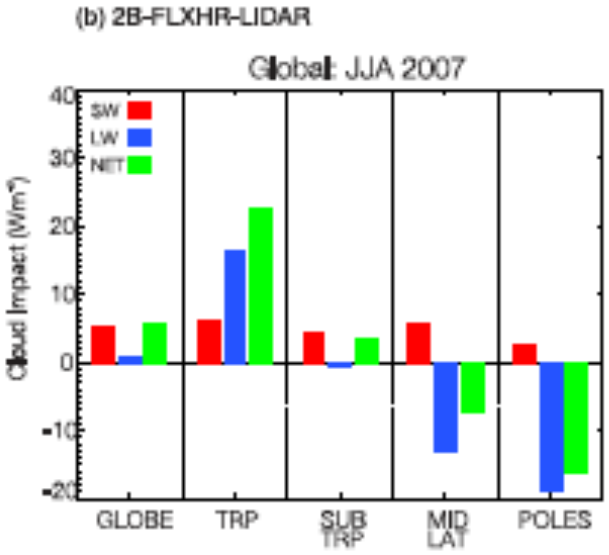


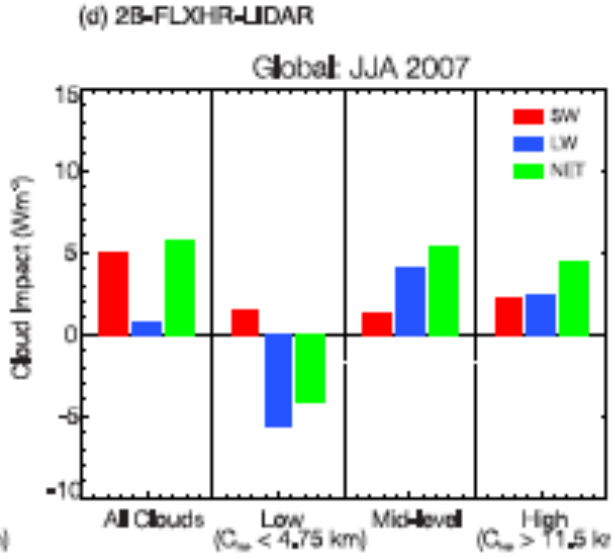
Cloud influences on atmospheric radiative heating



The radiative effects of high clouds dominate the heating at low latitudes, and low clouds largely determine the cooling at high latitudes

A-Train observations





Climate sensitivity and the IRIS effect

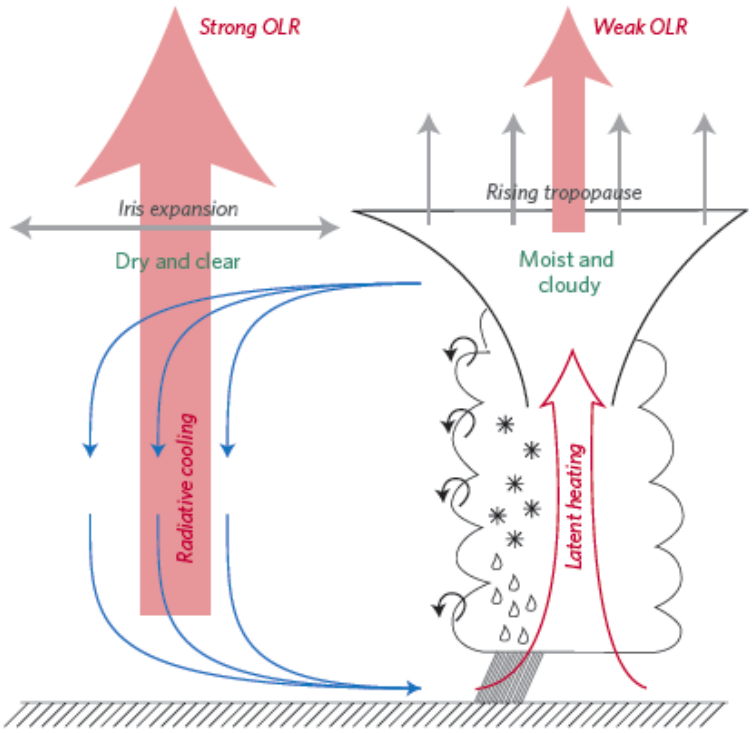
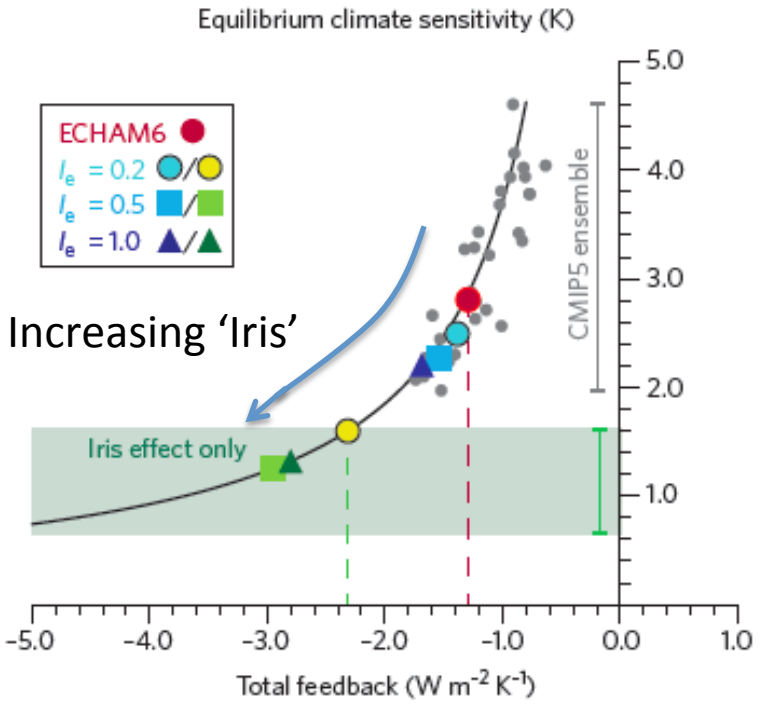


Figure 1 | Illustration of the tropical atmospheric circulation.

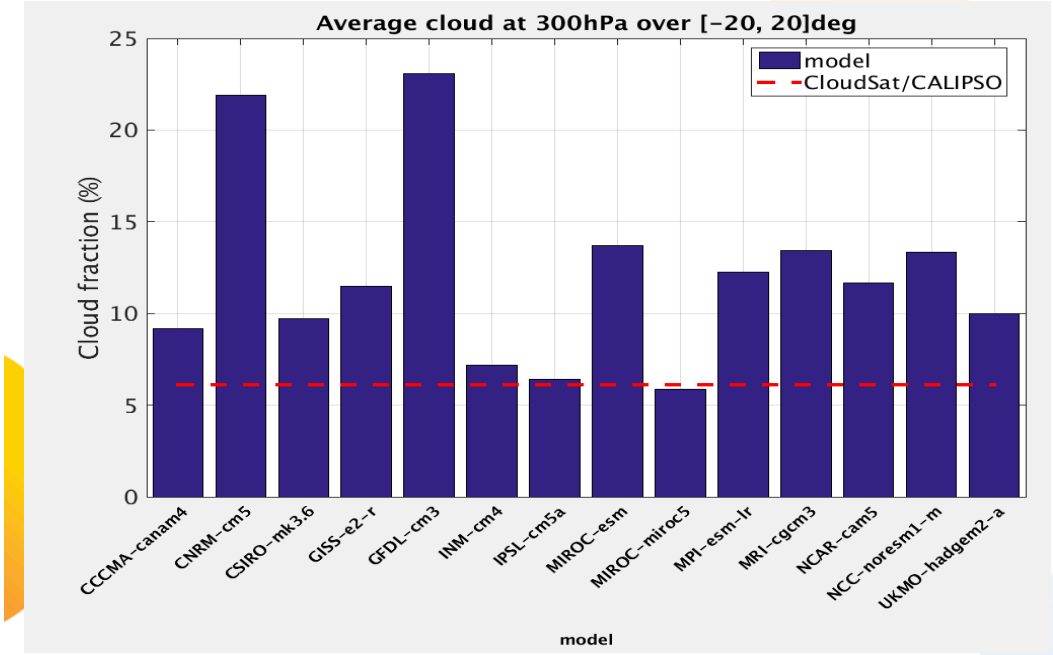
Mauritsen and Stevens, 2015

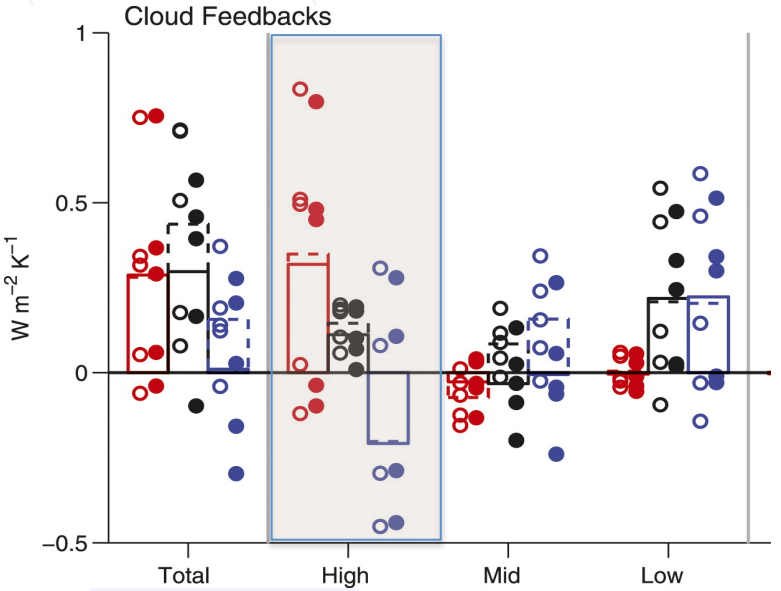


Clearly the convectively produced high clouds can effect both the climate and hydrological sensitivities – increasing strength of the IRIS effect lowers the ECS but enhances the hydrological sensitivitiy

High Clouds – the climate modeler's canary

"High clouds are the modeling communities last line of defense against top-of-atmosphere observations of energy fluxes", A DelGenio, 2002, ECMWF, Reading UK.





CloudSat/CALIPSO

Two concepts Clouds -radiation → convection feedbacks

Differential heating/cooling: I horizontal

Gray 1973

(i) Disturbed-undisturbed radiative heating; Gray and Jacobsen, 1977; Raymond, 2000; Mapes, 2002

Think of this as a self-sustaining of the convectively disturbed regions and reinforcing of the clear sky – a positive feedback (+). This is a key aggregation mechanism

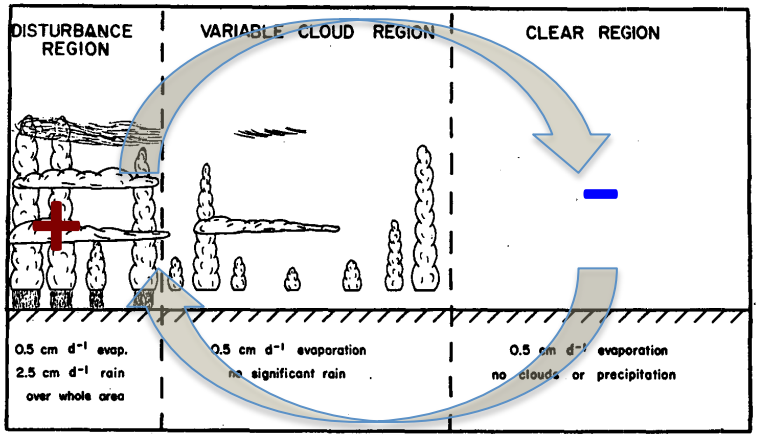


FIG. 2. Schematic of cloudiness in the cloud cluster disturbance and its environment.

Differential heating/cooling: II vertical

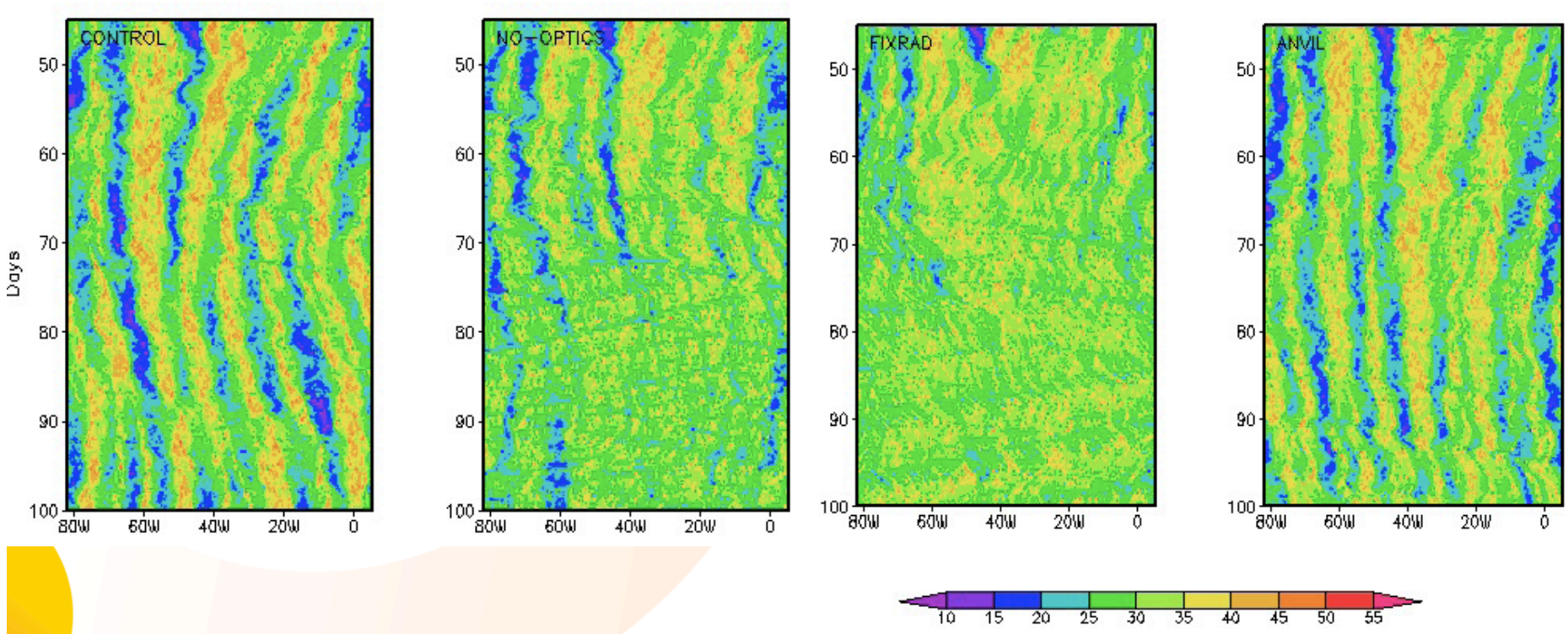
(i) Destabilization by strong cloud top radiative cooling over regions of deep convection– Webster and Stephens, 1980; Tao 1996; Xu and Randall, 1995 (positive feedback)

(ii) Stabilization by upper tropospheric heating of cirrus anvils – Fu et al., 1995; Stephens et al., 2003; Slingo and Slingo, 1988;Lebsock et al., 2010 (negative feedback)

Large domain CRM Radiative-convective equilibrium expts

Stephens et al., 2008

Column water vapor



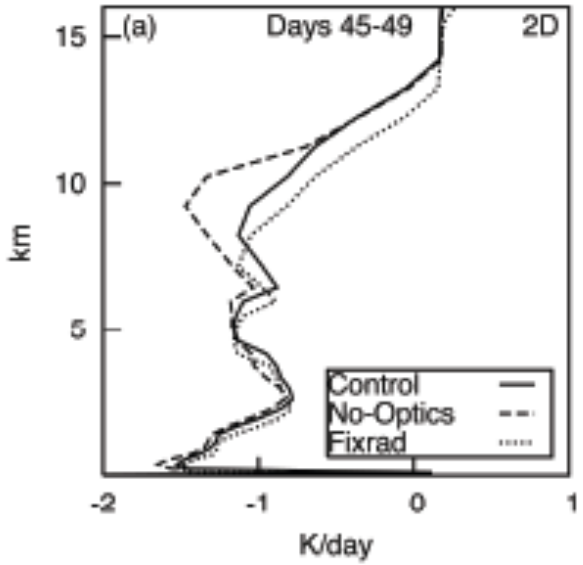
Control

Water vapor only

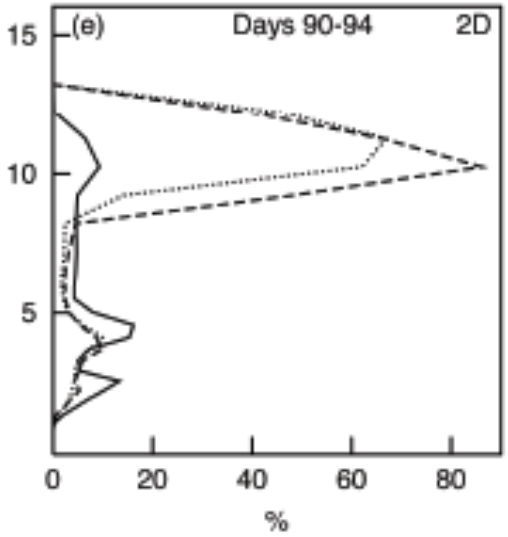
Uniform radiative cooling

Water vapor plus anvils

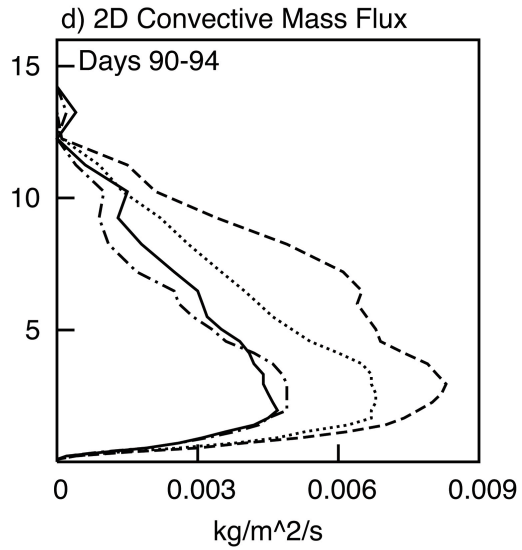
Vertical heating and feedbacks on convection & clouds



Domain average Radiative column

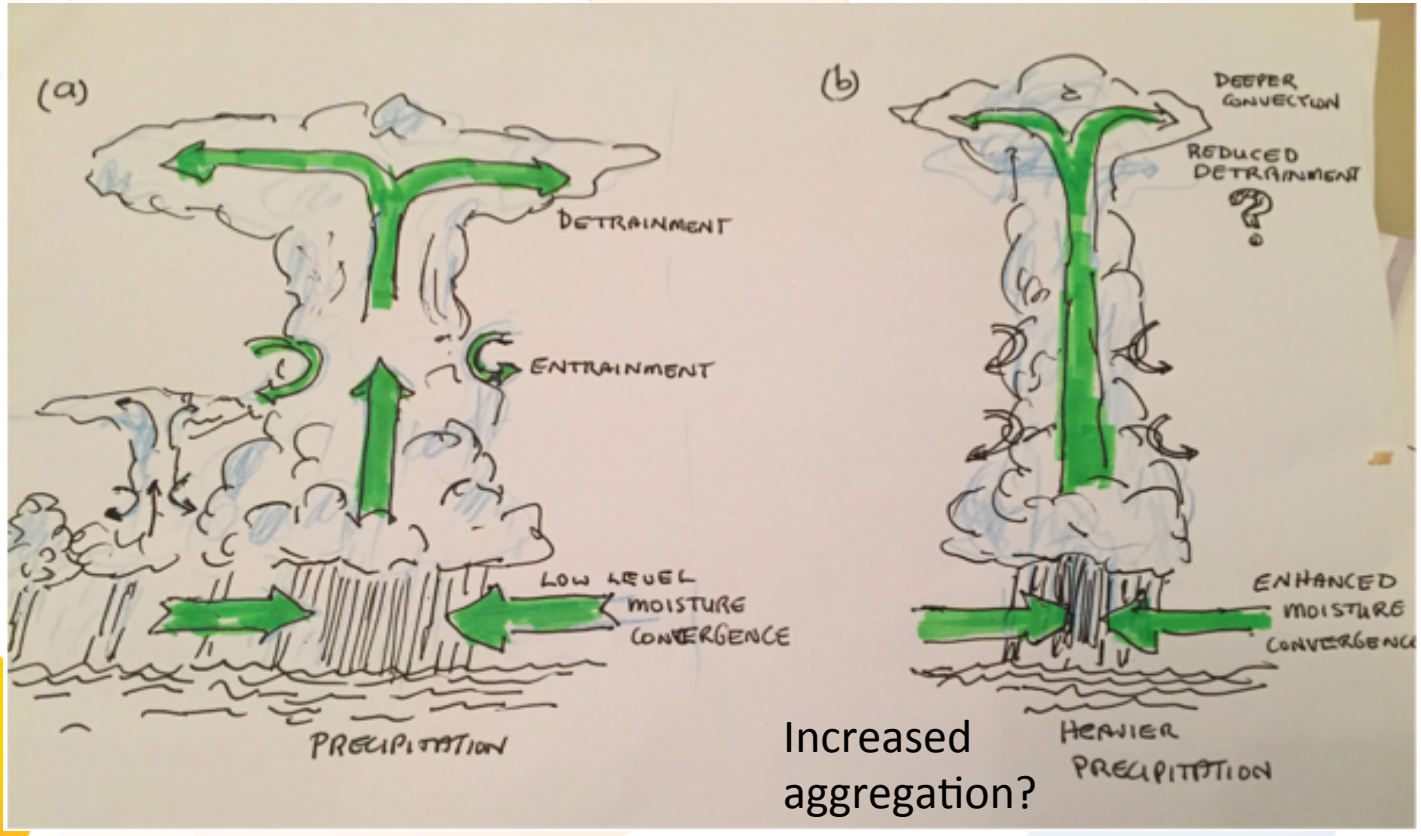


Domain average cloudiness



Domain average convective mass flux

Questions



Present

Increased aggregation?

Future

Reduced high cloud???- (IRIS),

less IR heating,

strengthened convection and precipitation,

reduced cloud greenhouse effect

Moisture Supply 7%/K

Precipitation super CC; >7%/K?

GEWEX PROES UTCC (Stubenrauch (LMD) and Stephens)

1) Scientific Motivation: How does convection affect UTC ? And how does UTC affect convection?

2) Goal: To understand the relation between convection, UTC and the radiative heating , & provide observational based metrics of these relationships as a way of evaluating detrainment processes in models

relate convective strength to properties of high clouds
Test hypothesis that majority of UT heating is from thinner (anvil) clouds

Tools & steps:

- **Develop/study proxies of convective strength from the A-Train (**e.g. colocate **CloudSat** *(Takahashi & Luo 2012, 2014),* **AIRS**)
- **determine horizontal extent & cloud types** (convect core, CiAnvil, thin Ci) **from AIRS, IASI**

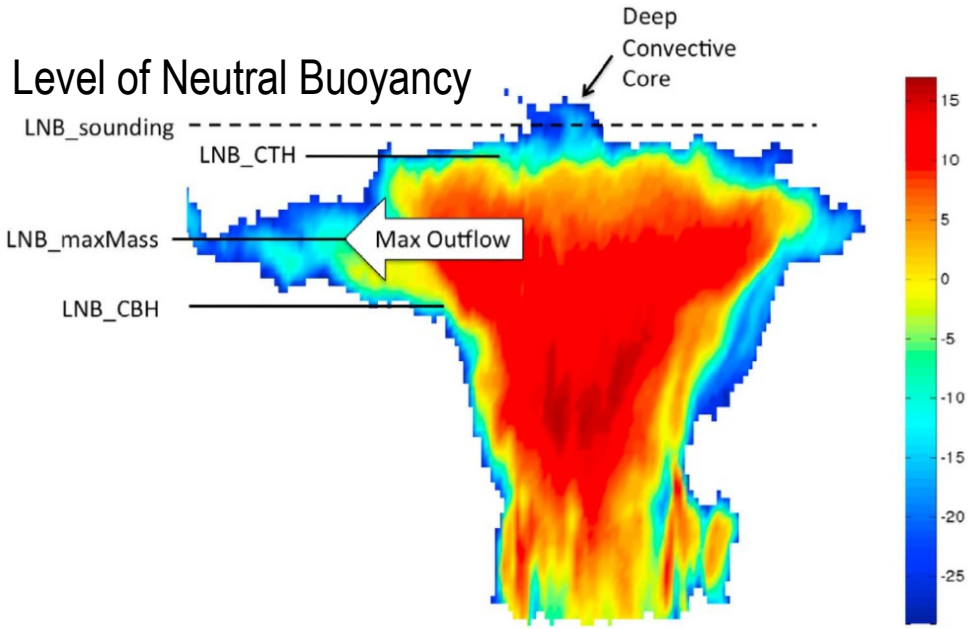
& study multi-layering from CALIPSO-CloudSat per cloud type

study life cycle of convective systems (MeghaTropiques, geostationary, AIRS-IASI)

Add large scale cirrus to study

GEWEX UTCC PROES (Process Evaluation Study) -> 1. meeting 16 Nov 2015, Paris
(coord. Stubenrauch & Stephens)

Illustrating the idea - proxies of convective strength:



Radar reflectivity profile of deep convective cloud over Amazon

Takahashi & Luo 2012

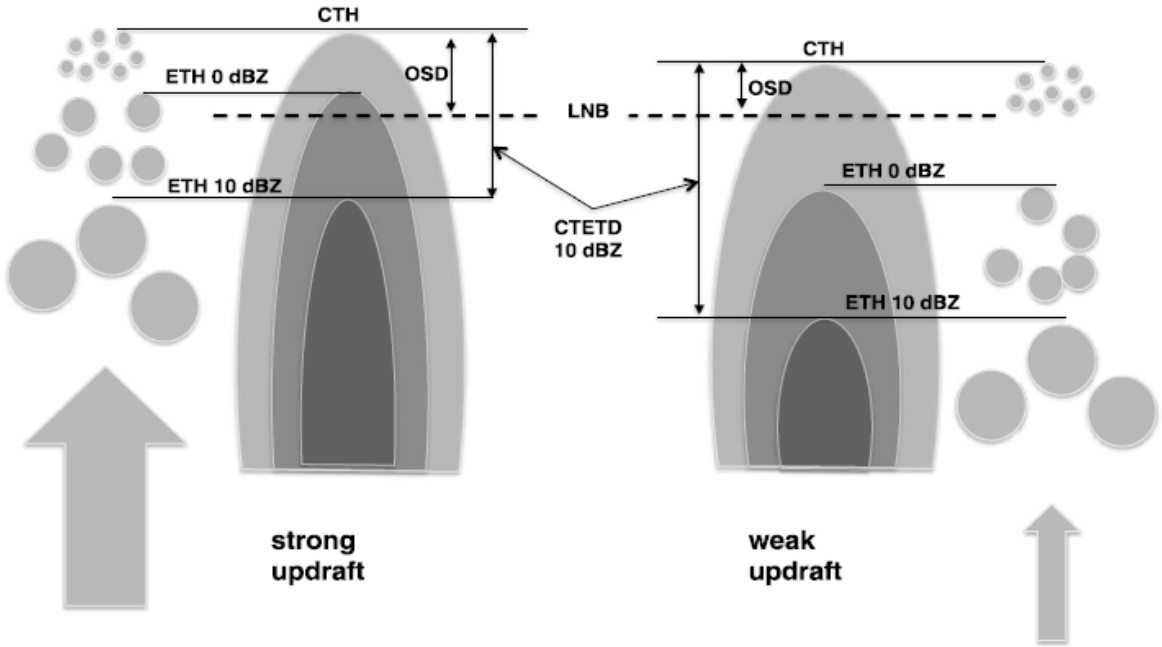
1) Radar Echo Top Height (ETH) of large echos

2) OverShooting Distance (OSD)

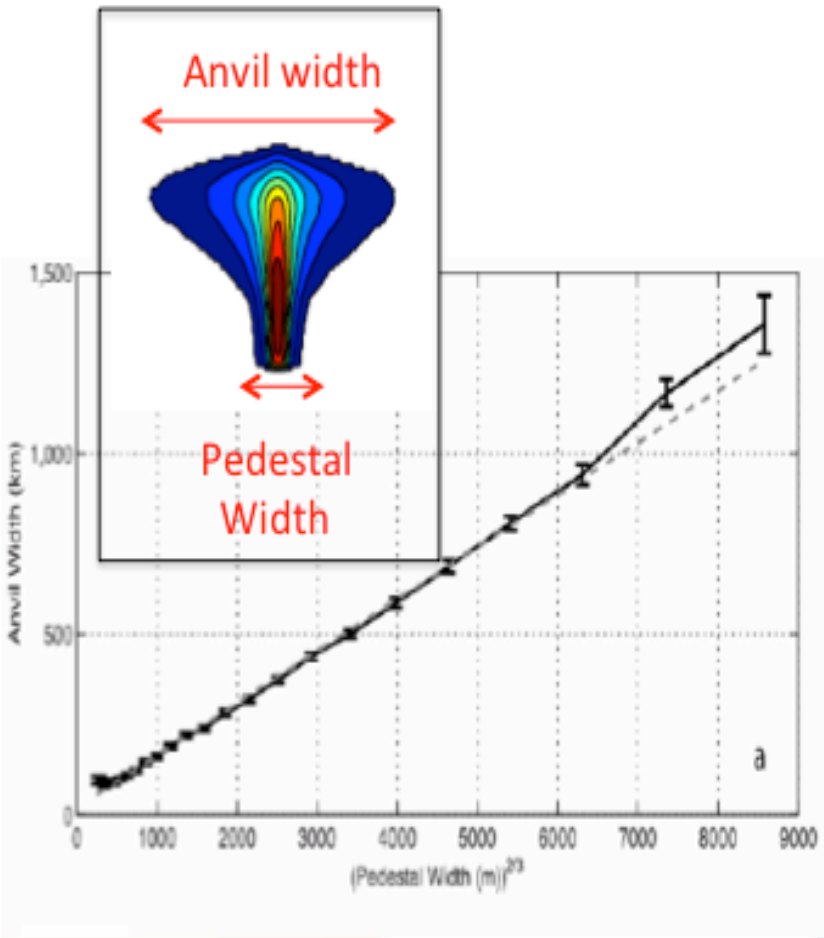
3) Cloud Top Height (CTH) - ETH

Takahashi & Luo 2014

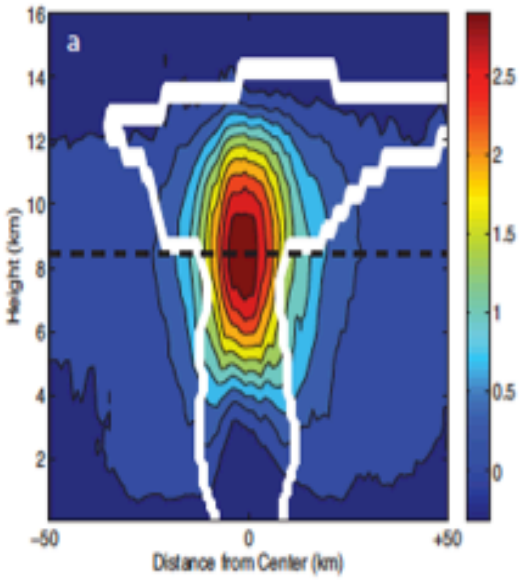
Overshooting Deep Convection:
0.7% in 15N-15S



Anvil width

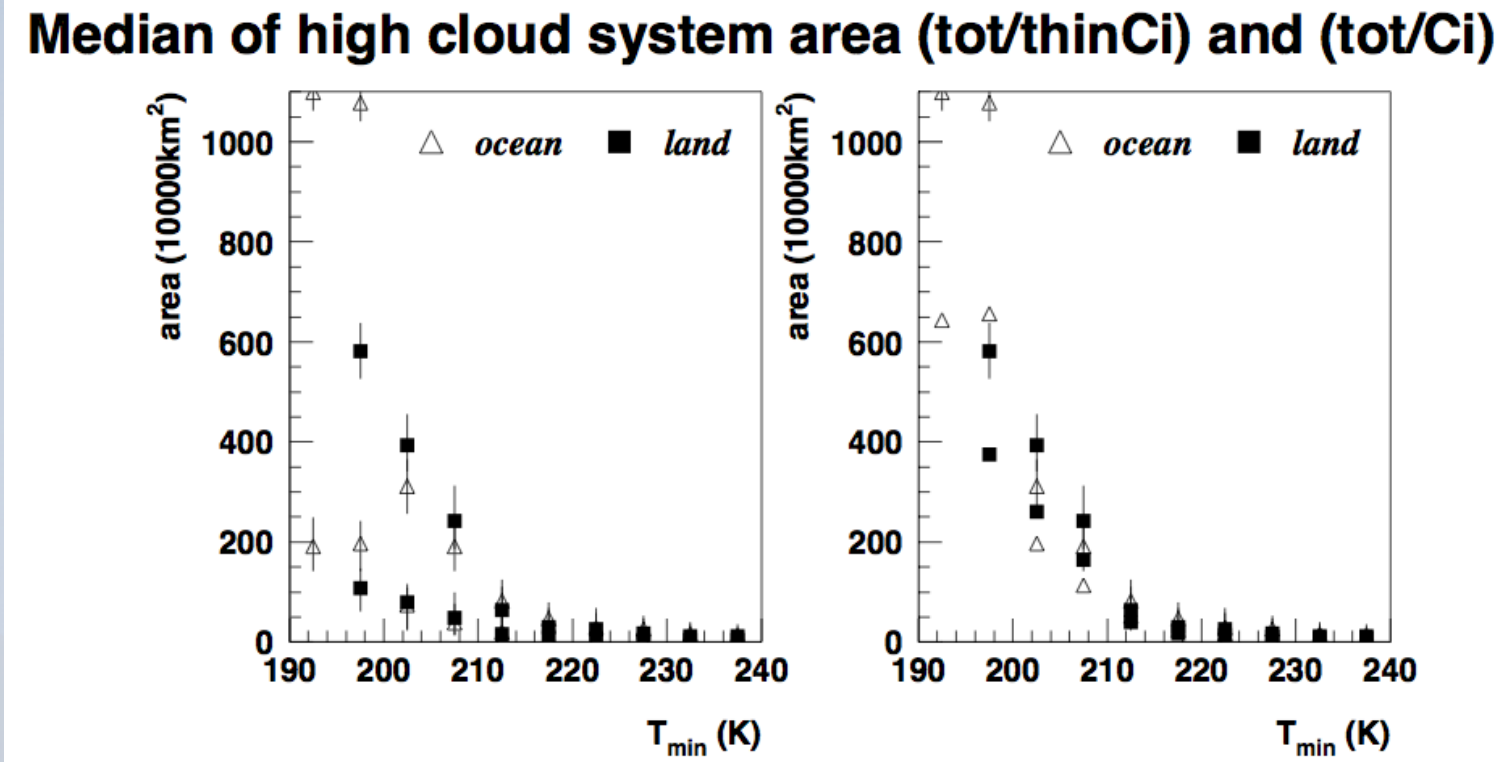


Core width



Igel et al., 2015

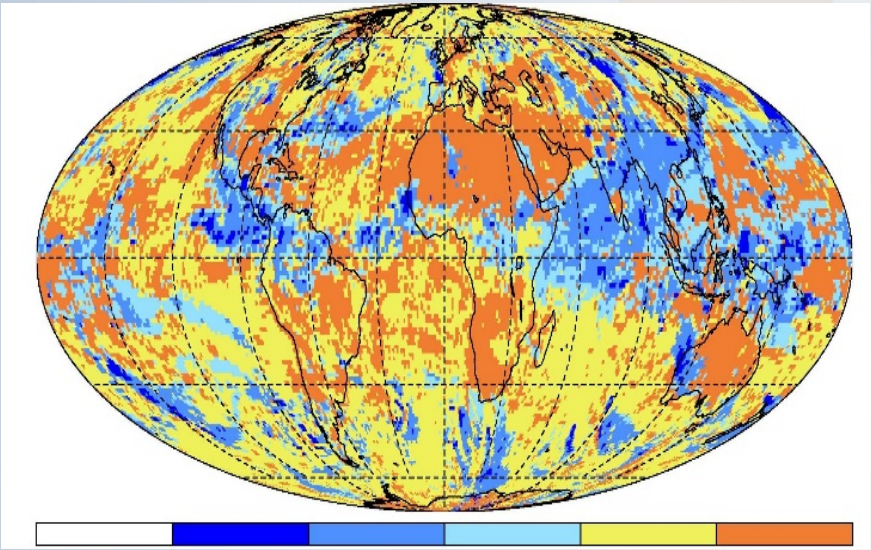
Preliminary example from TOVS for mature systems



anvil size increases continuously **with decreasing T_{min} within convective core *proxy for convective strength?***

Preliminary Example from AIRS data

AIRS 2 Jul 2009 1h30PM



Cb Ci thinCi mid/low clr

Cb (ε>0.95),
Ci (0.95>ε>0.5)
thin Ci (0.5>ε>0.3)

Summary

GEWEX PROES - Process Evaluation Studies are under construction

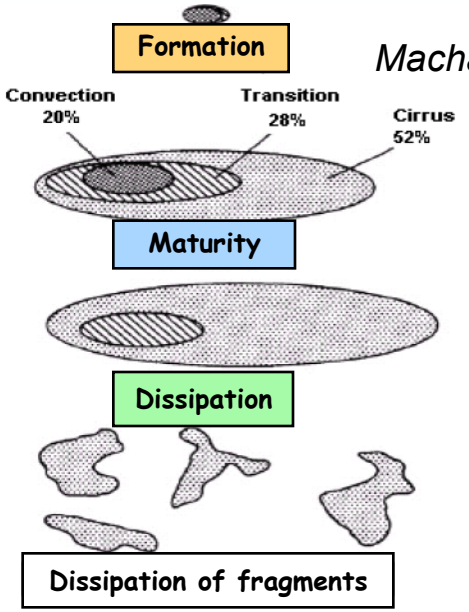
Grew out of a desire to use obs for process evaluation
PROES is likely to grow into a WCRP cross cut activity

Some motivation to study high-cloud related feedbacks

Describe aspects of the Upper Tropospheric Clouds & Convection (UTCC) lead Stubenrauch and Stephens

GEWEX UTCC PROES (Process Evaluation Study) -> 1. meeting 16 Nov 2015, Paris *(coord. Stubenrauch & Stephens)*

Proxies for life stage of convective system: TOVS



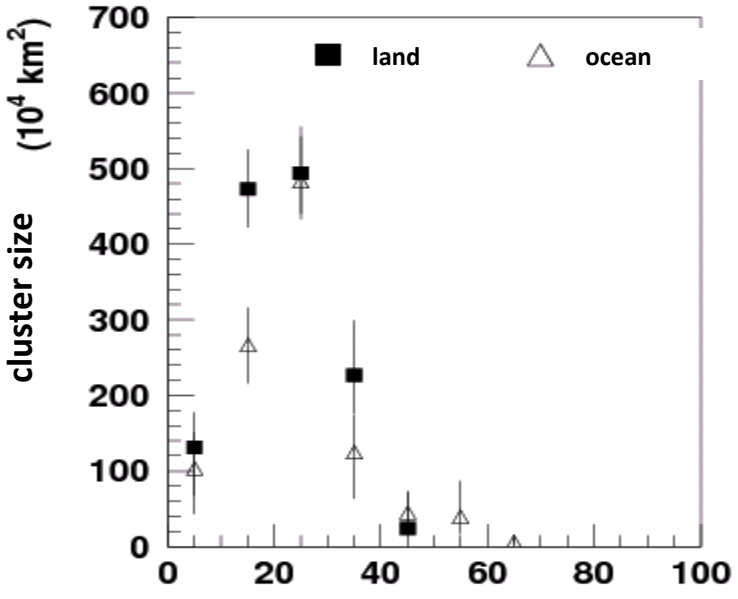
Machado & Rossow 1993

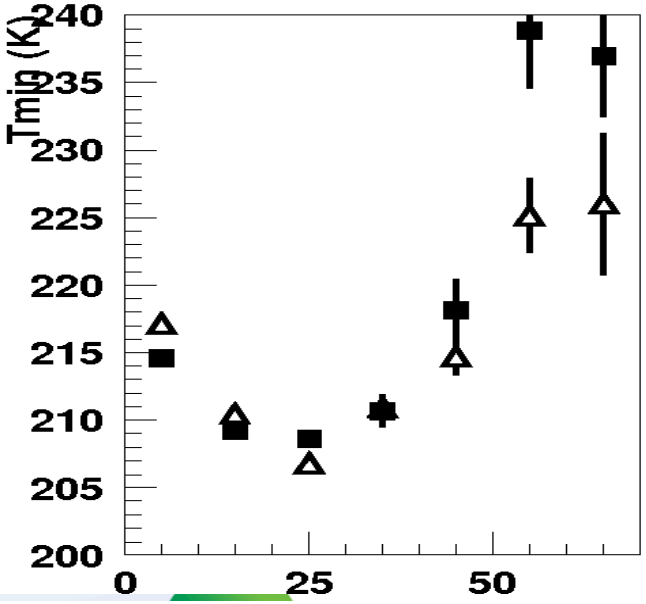
Formation (Cb>40%): ***small size, warm***

Maturity (10-30% Cb): ***max size, min temperature***

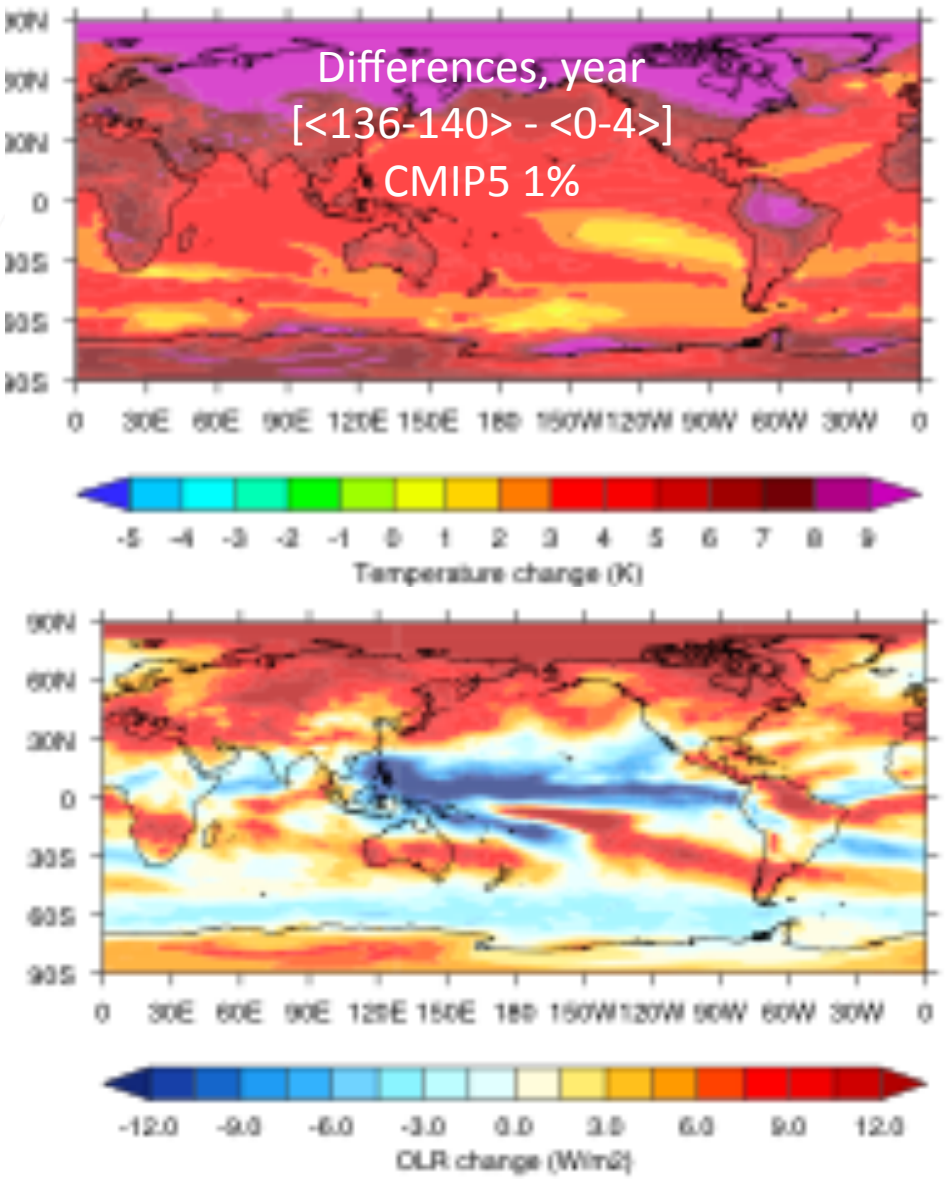
Dissipation (Cb<10%): ***small size, slightly warmer***

in agreement with *Futyan & DelGenio 2007* over Africa





Convection and the moistening of the upper troposphere

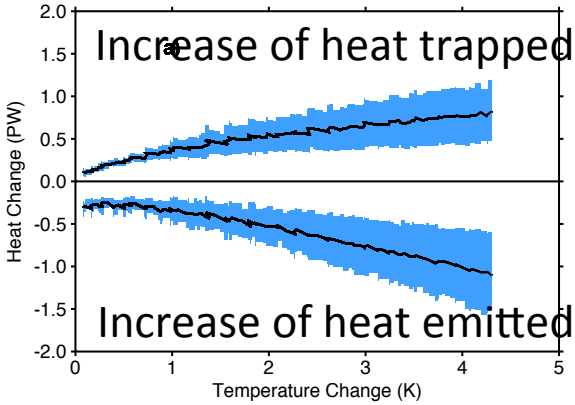


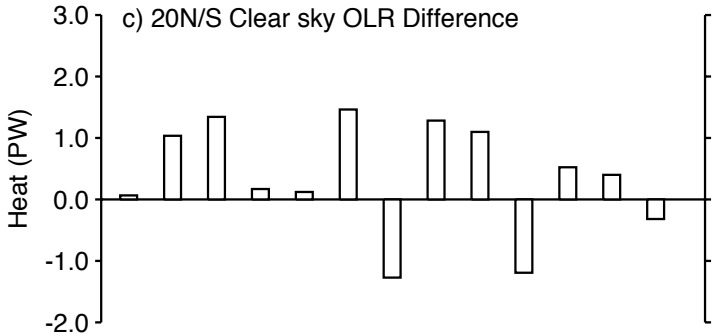
$$G = \sigma(SST)^4 - OLR$$

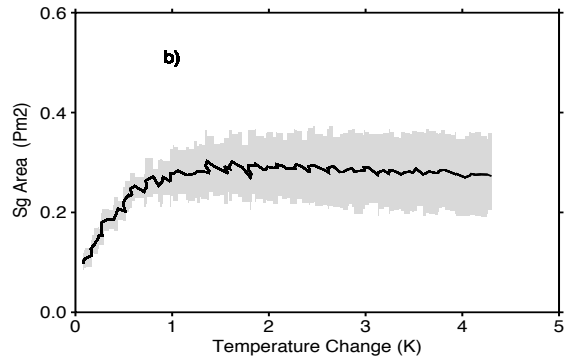
$$\frac{dSGE}{dSST} > 4\sigma SST^3$$

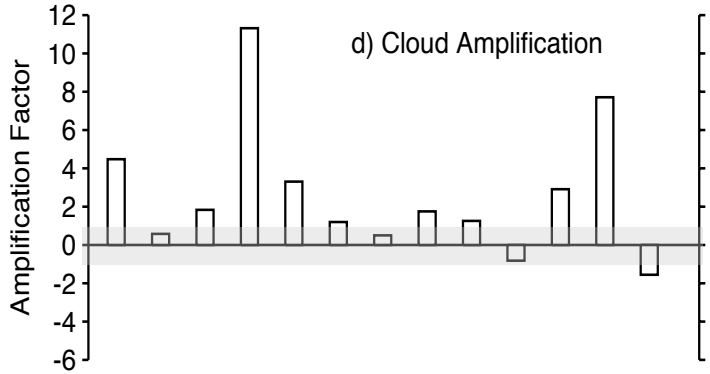
$$\frac{dOLR}{dSST} < 0$$

(e..g. Valero et al., 1997)









$$-\left[OLR_{end} - OLR_{begin} < 0\right]$$

$$-\left[\frac{OLR_{all,end} - OLR_{all,begin}}{OLR_{clr,end} - OLR_{clr,begin}}\right]$$

- Super greenhouse effect (SGE) is a term used here to refer to those regions of the planet that trap increasingly more heat than can be radiated to space as warming occurs.
- This places an onus on horizontal transport to move heat away from these regions in order to maintain a stable climate.
- The clear-sky SGE is a dominate source of heat build up in tropical latitudes in climate change experiments and is dominated by processes that moisten the low latitude upper troposphere associated with deep convection.
- the radiant energy exchange that defines it is strongly associated with emission in the far IR.

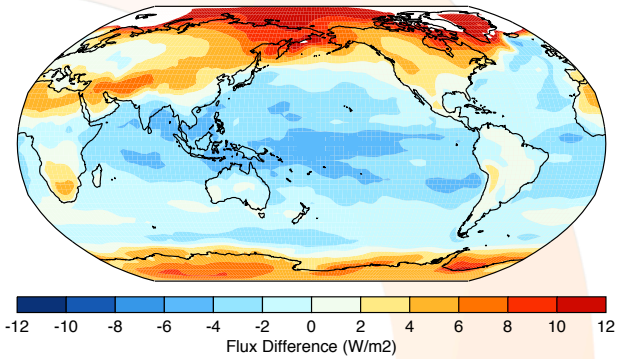
Summary

- Global -Energetic controls on precipitation & role of cloud radiative processes
- Regional - wet wetter/dry drier paradigm
- Storm-scale –superadiabatic
- Cloud radiation/convection/precipitation feedbacks involving high clouds (e.g. IRIS and other concepts) & the focus of the GEWEX PROES UTCC
- Upper tropospheric moistening by deep convection and enhanced heat trapping via the Super Greenhouse Effect

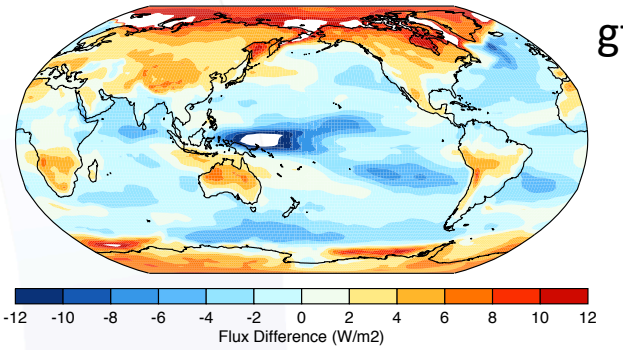
The SGE in CMIP5 1%/yr experiments
Clear-sky OLR differences [<136-140> - <0-4>]

CMIP5 1%/yr experiments

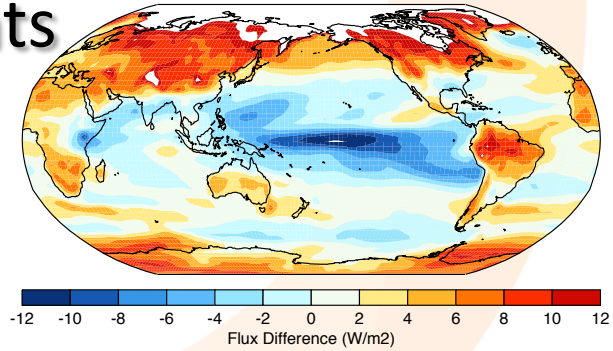
bcc



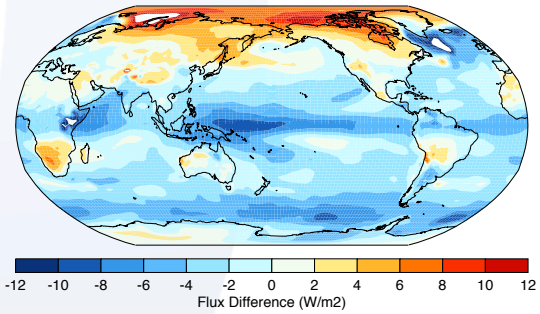
gfdl



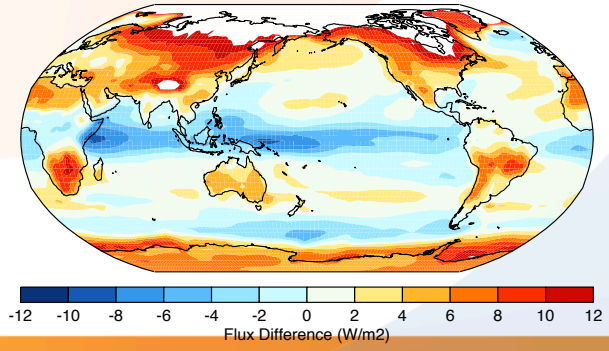
cnrncm5



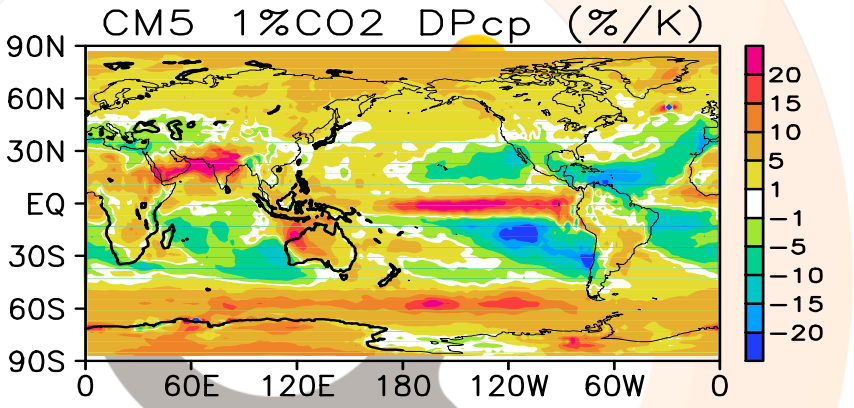
HadGEM

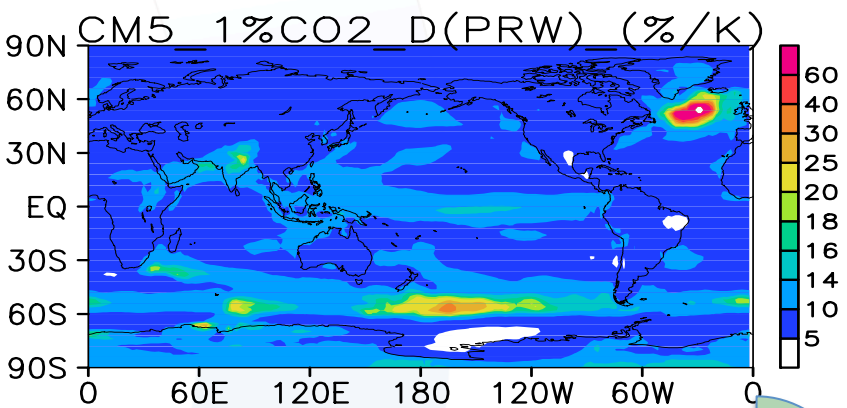


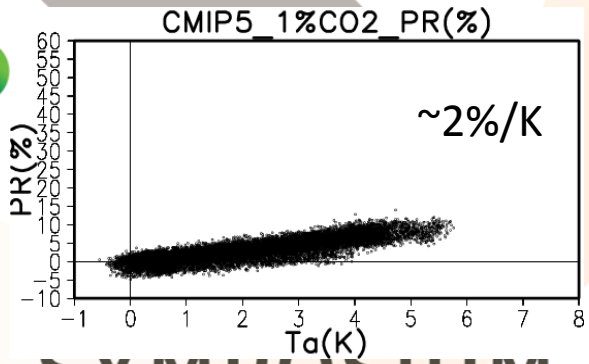
mpi

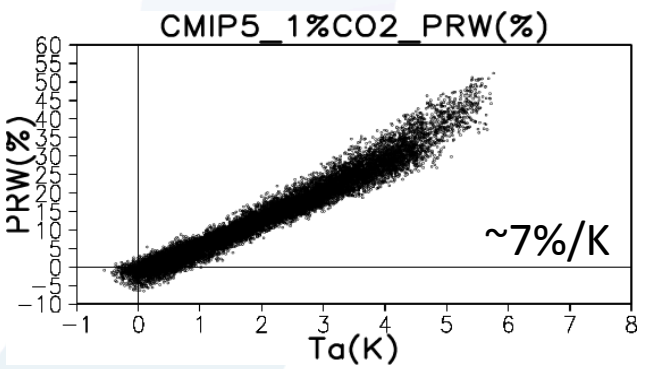


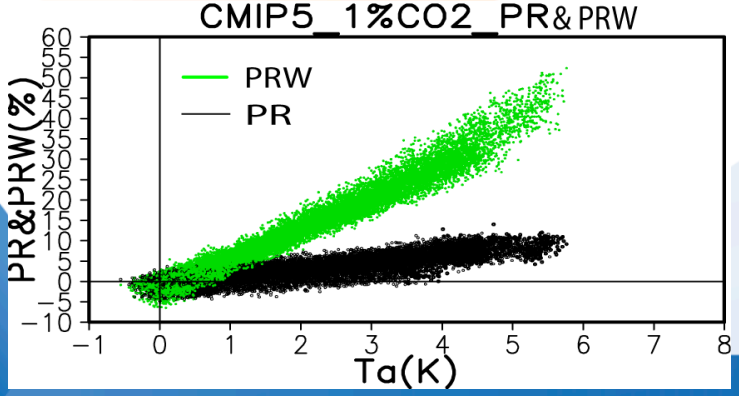
Here we consider the regions of SGE as where OLR decreases in a warming world. These regions aren't simply defined by a fixed SST threshold

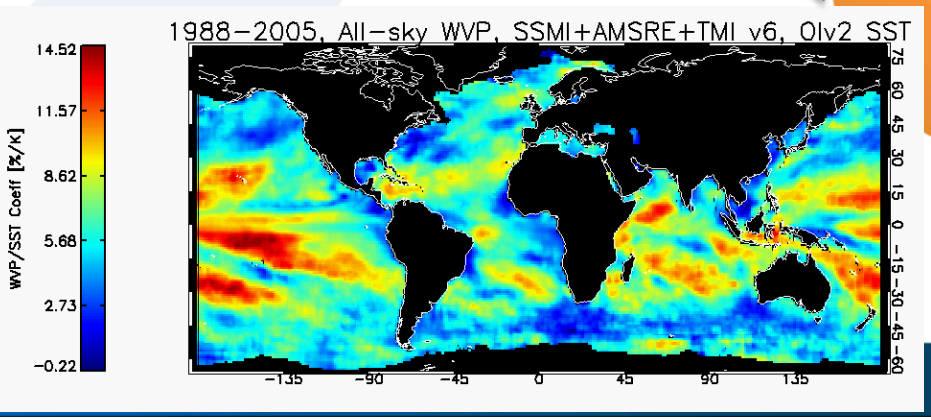

CM5 1%CO2 DPcp (%/K)
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0
20
15
10
5
1
−1
−5
−10
−15
−20


CM5 1%CO2 D(PRW) (%/K)
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0
60
40
30
25
20
18
16
14
10
5


CMIP5_1%CO2_PR(%)
PR(%)
Ta(K)
~2%/K


CMIP5_1%CO2_PRW(%)
PRW(%)
Ta(K)
~7%/K


CMIP5_1%CO2_PR& PRW
PR&PRW(%)
PRW
PR
Ta(K)


1988−2005, All−sky WVP, SSMI+AMSRE+TMI v6, OIv2 SST
WVP/SST Coeff [%/K]
14.52
11.57
8.62
5.68
2.73
−0.22
−135
−90
−45
0
45
90
135

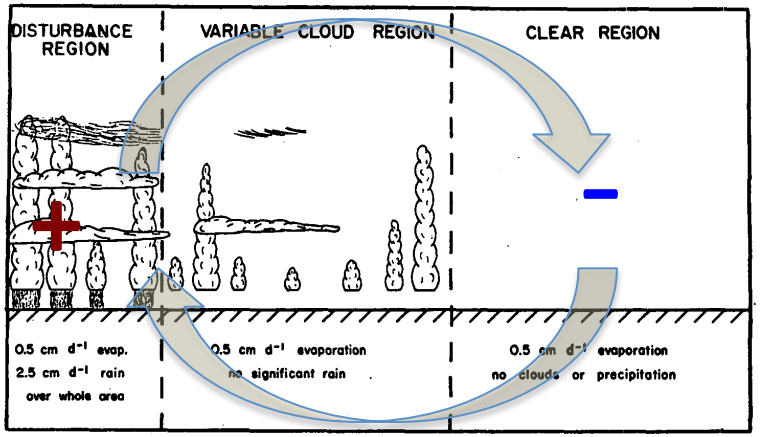
Two concepts Clouds -radiation ➔ convection feedbacks

Differential heating/cooling: I horizintal

Gray 1973

(i) Disturbed undisturbed radiative heating; Gray and Jacobsen, 1977; Raymond, 2000; Mapes, 2002

Think of this as a self-sustaining of the convectively disturbed regions and reinforcing of the clear sky – a positive feedback (+)



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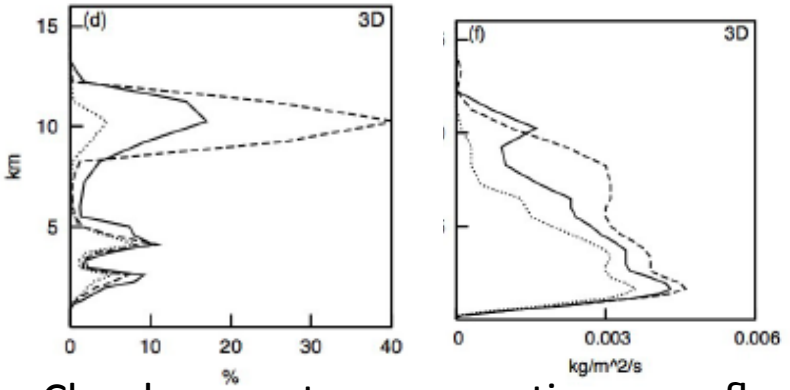
Differential heating/cooling: II vertical

(i) Destabilization by strong cloud top radiative cooling – Webster and Stephens, 1980; Tao 1996; Xu and Randall, 1995 (positive feedback)

(ii) Stabilization by upper tropospheric heating of cirrus anvils – Fu et al., 1995; Stephens et al., 2003; Slingo and Slingo, 1988;Lebsock et al., 2010 (negative feedback)

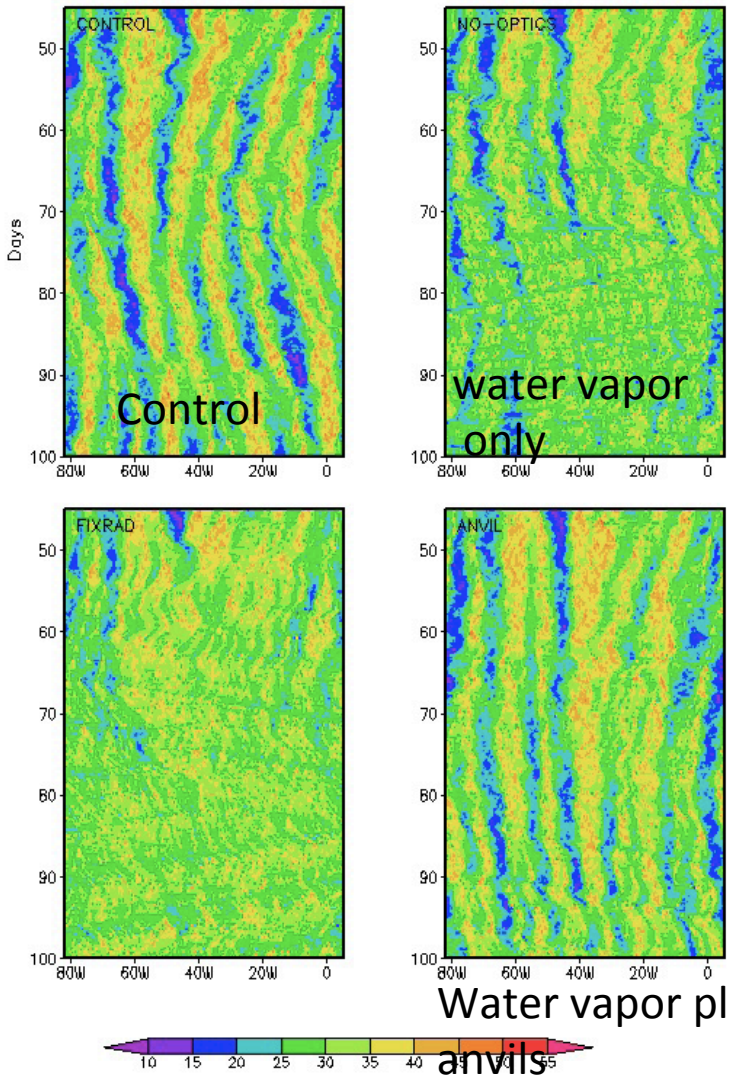
RCE CRM experiments - dashed is where U radiative heating turned off



Cloud amount convective mass flux

Radiative-convective equilibrium expts with CRM

Column water vapor

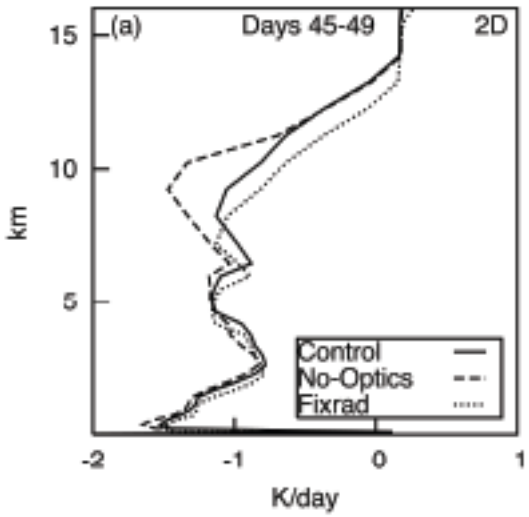


Control

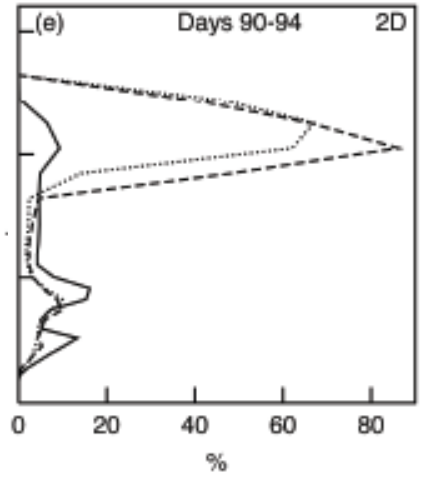
water vapor only

Water vapor plus anvils

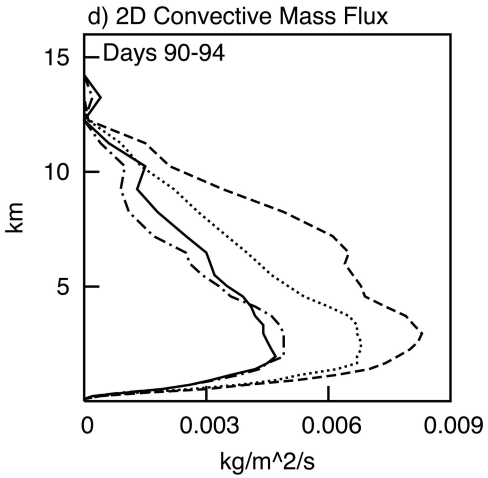
Uniform radiative cooling



Domain average Radiative column



Domain average cloud fraction



Domain average convective mass flux

Stephens et al., 2008