EUCLIPSE

FP7 EU Cloud Intercomparison and Evaluation Project

“Understanding Low Cloud feedbacks”

2010-2014

www.euclipse.eu

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The EUCLIPSE Challenge

To determine, understand and reduce the uncertainty in Earth System Models (ESMs) due to cloud-climate feedback

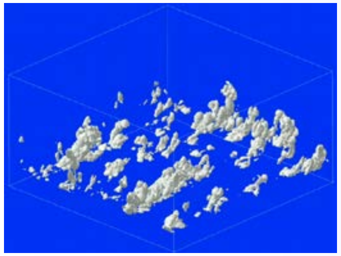
Objectives:

1. **Evaluation** and **Analysis** of cloud-related processes in ESM's.
2. Develop **physical understanding** of how these cloud-related processes respond and **feedback** to climate change.
3. Developing **metrics to measure the relative credibility** of the cloud feedbacks produced by the different ESM's thereby demonstrating a reduction of the uncertainty in model-based estimates of climate change.
4. **Improve the Parameterizations** of cloud-related processes in the current ESM's

How?

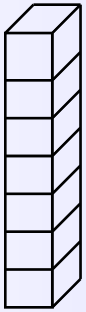
……..Use the full hierarchy of models and observations

Process studies

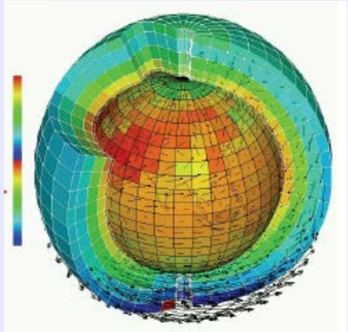


Large Eddy Simulation

Evaluation



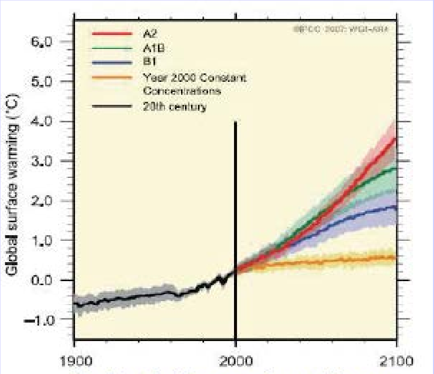
Single Column Models



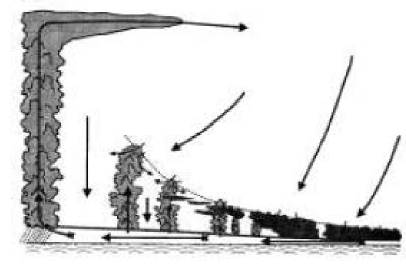
Climate Models

NWP Models

Analyses



Model Projections



Analysis & Understanding cloud feedbacks

Field Campaigns

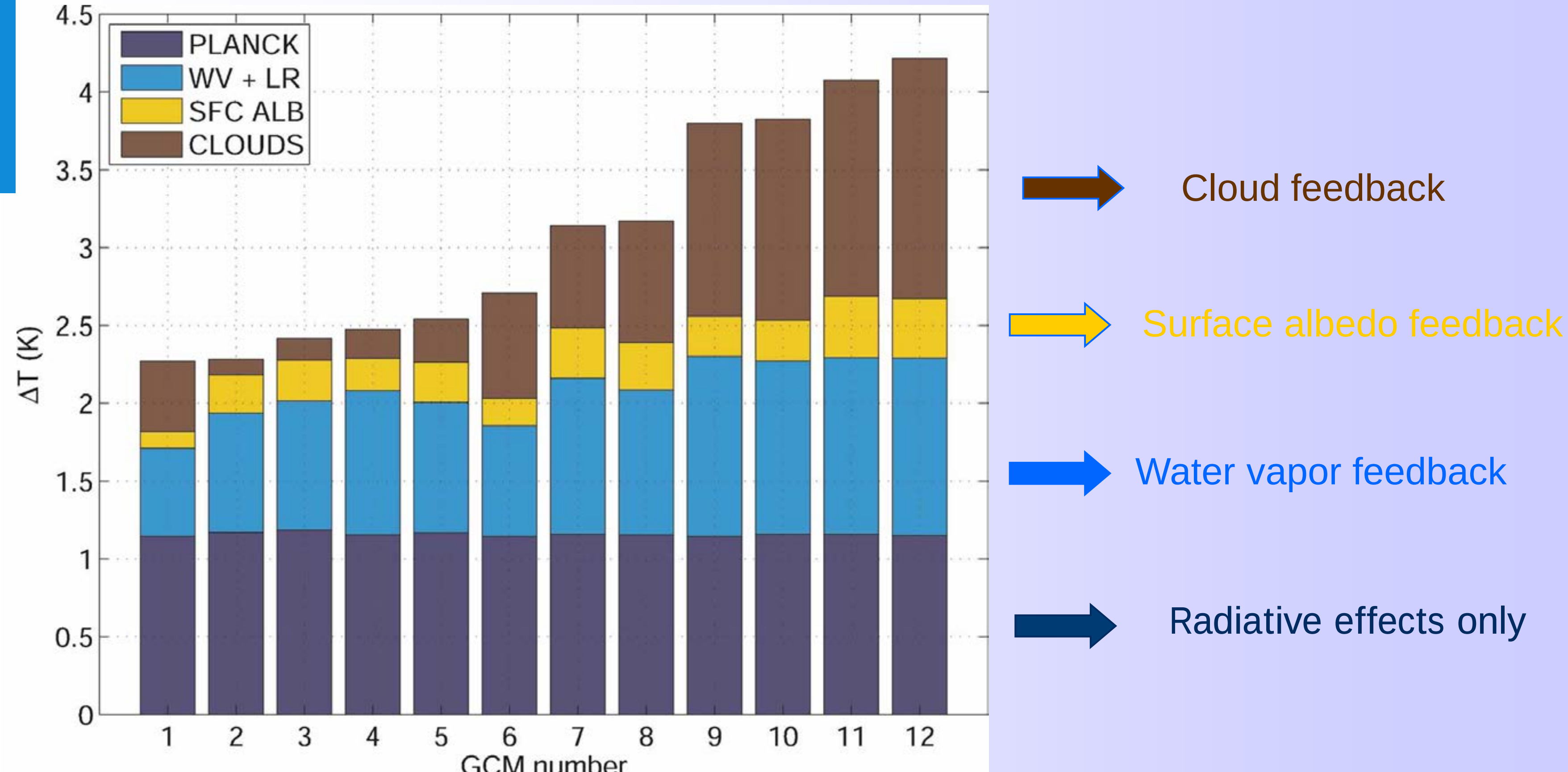
Instrumented Sites

Global Observational Data sets

1.

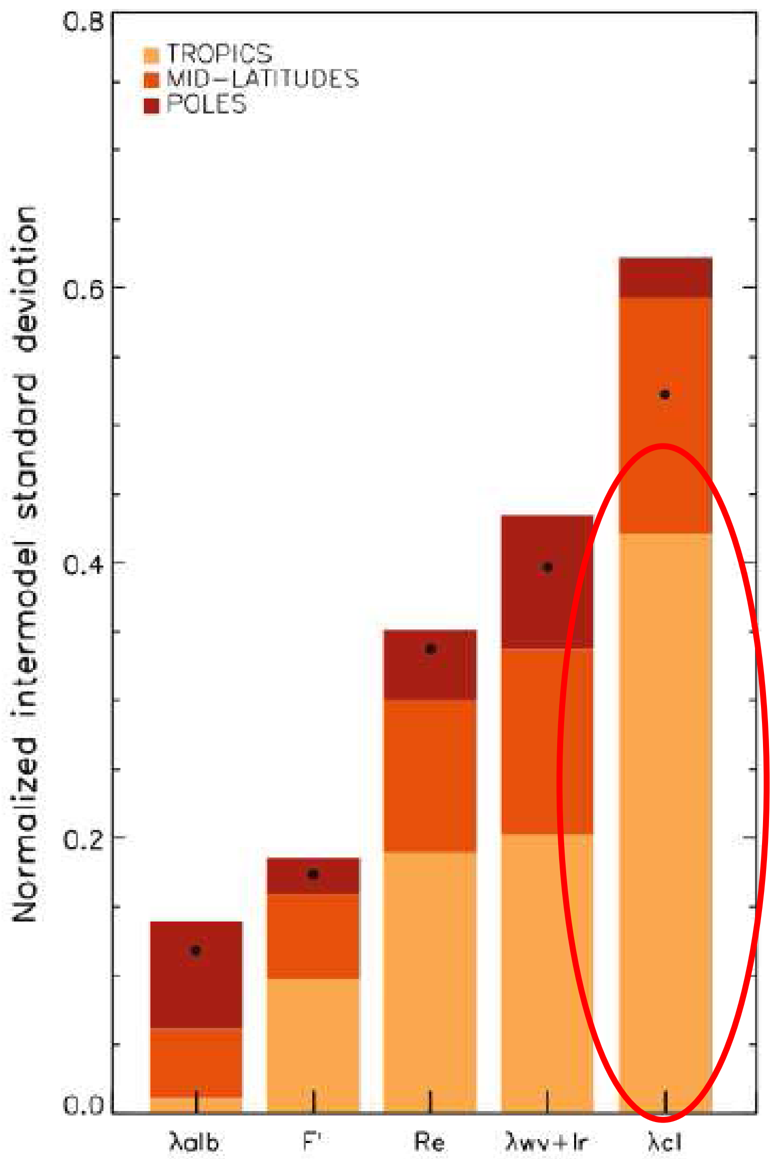
Where Were We (in 2010) ?

$2XCO_2$ Scenario for 12 Climate Models



Dufresne & Bony, Journal of Climate 2008

Cloud effects "remain the largest source of uncertainty"
in model based estimates of climate sensitivity IPCC 2007

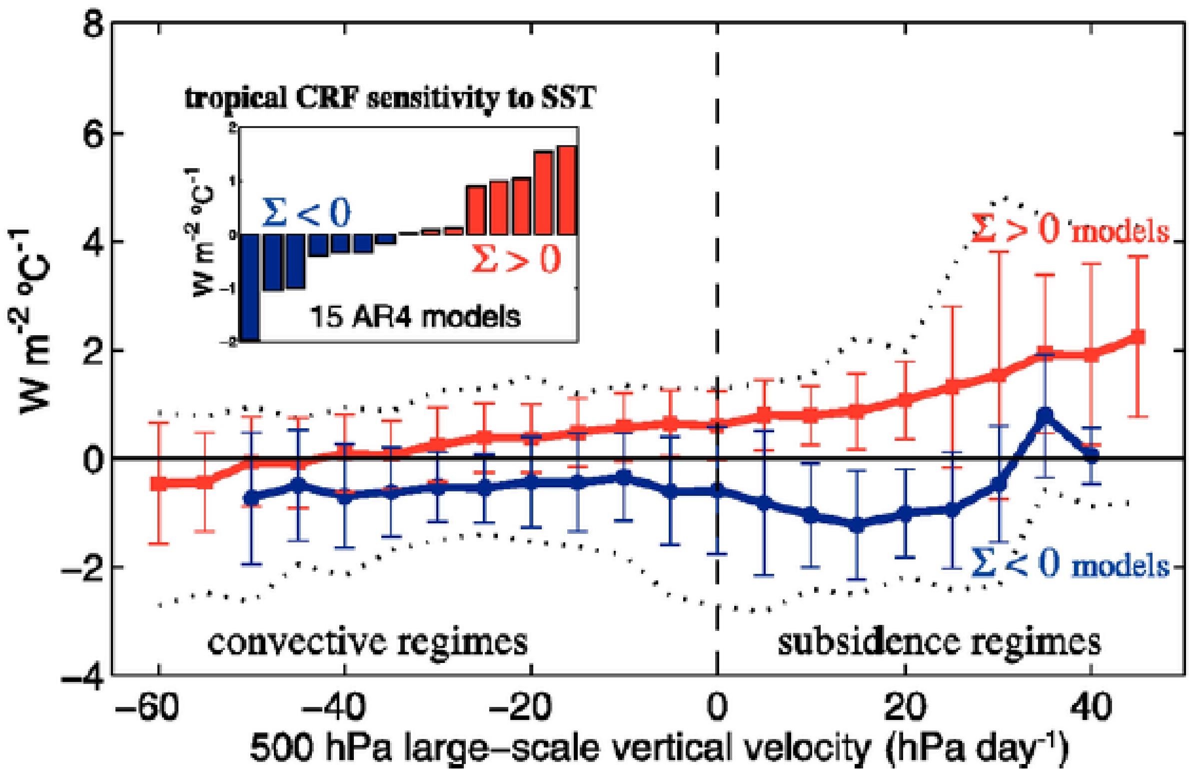


Still true in CMIP5

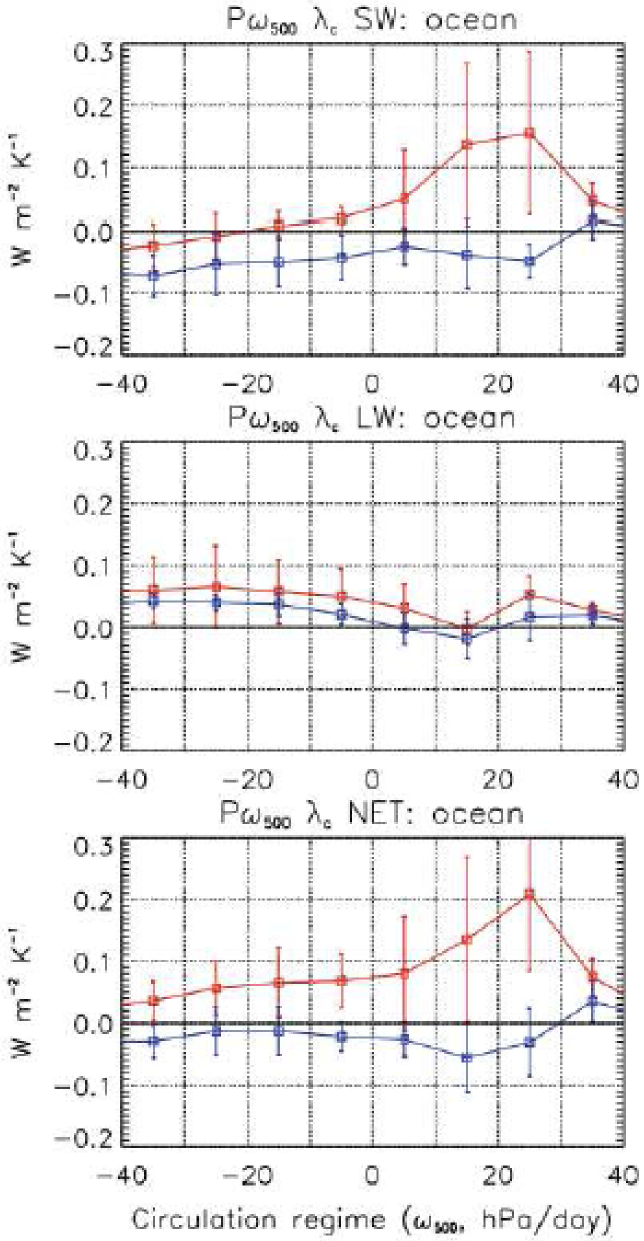
"Largest spread in climate sensitivity due to clouds in the tropics"

Vial et al (2013)

"Marine boundary layer clouds are at the heart of tropical cloud feedback uncertainties in climate models"
(duFresne&Bony 2005 GRL)



IPCC report, 2007

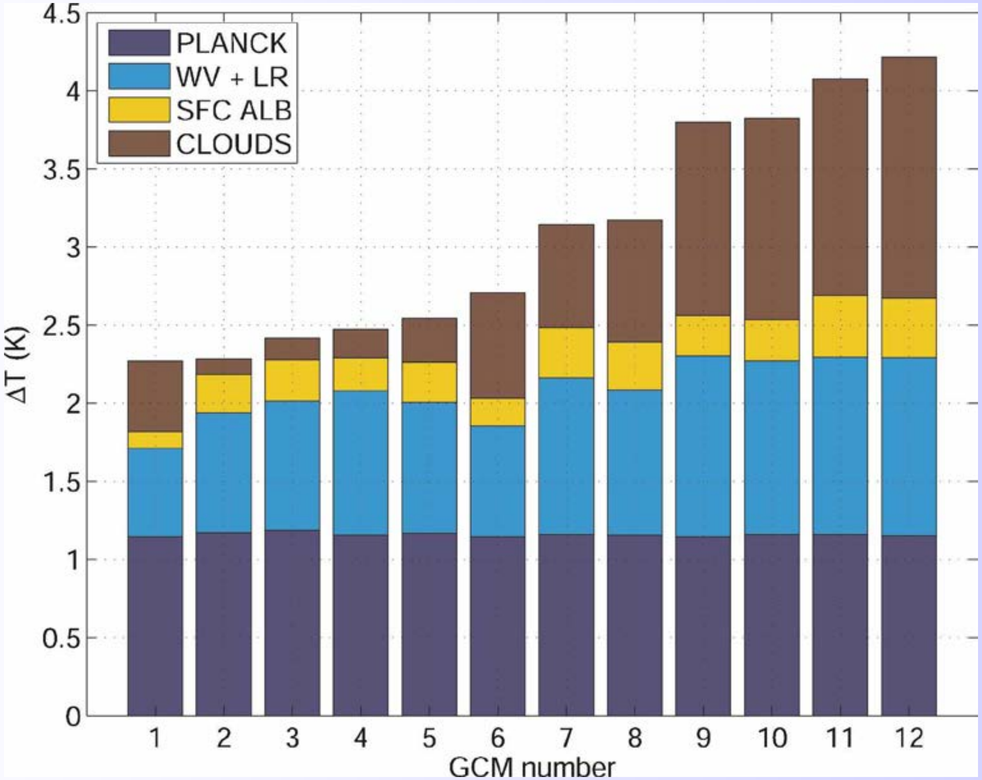


Still true in CMIP5

Vial et al (2013)

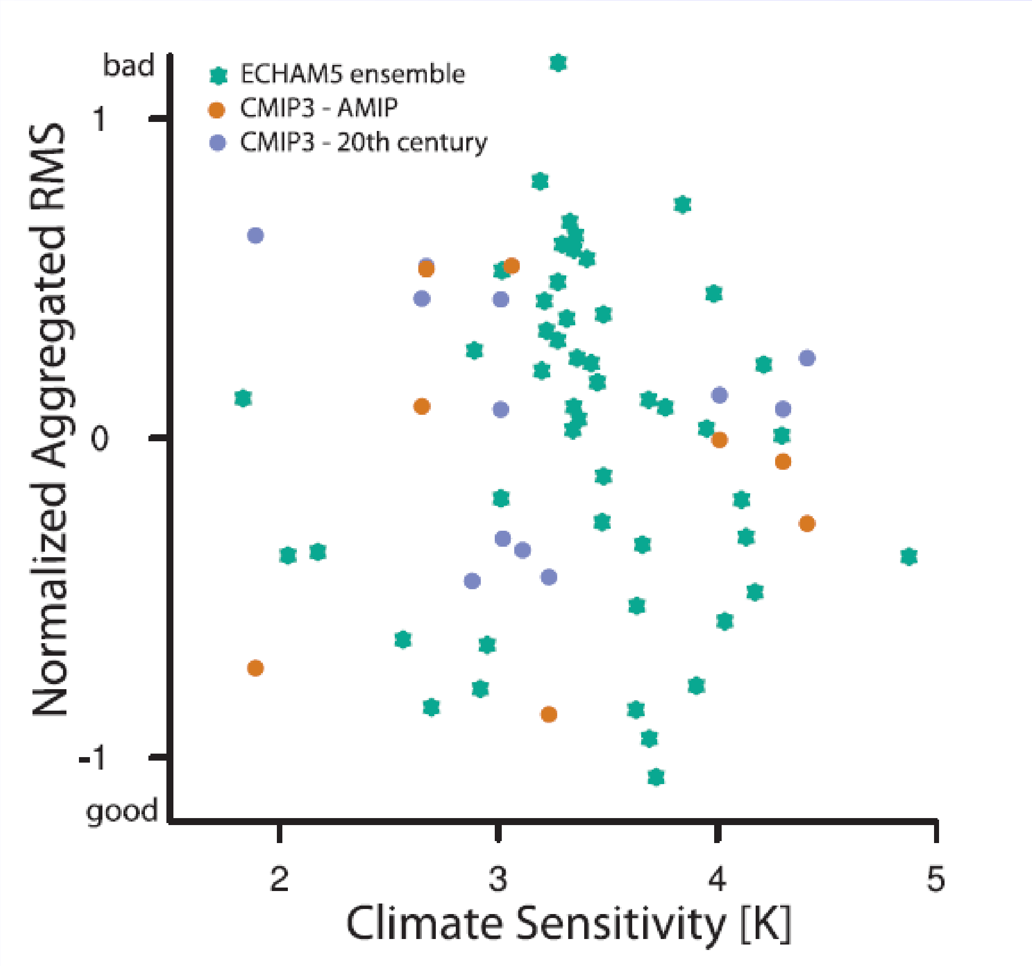
Developing Metrics

Relation between model skill and model sensitivity?



Lower credibility? Higher credibility?

No relationship………



(Klocke, Pincus & Quaas J. Climate 2011)

Physical Understanding of the tropical low cloud feedbacks

Stratocumulus

Shallow cumulus

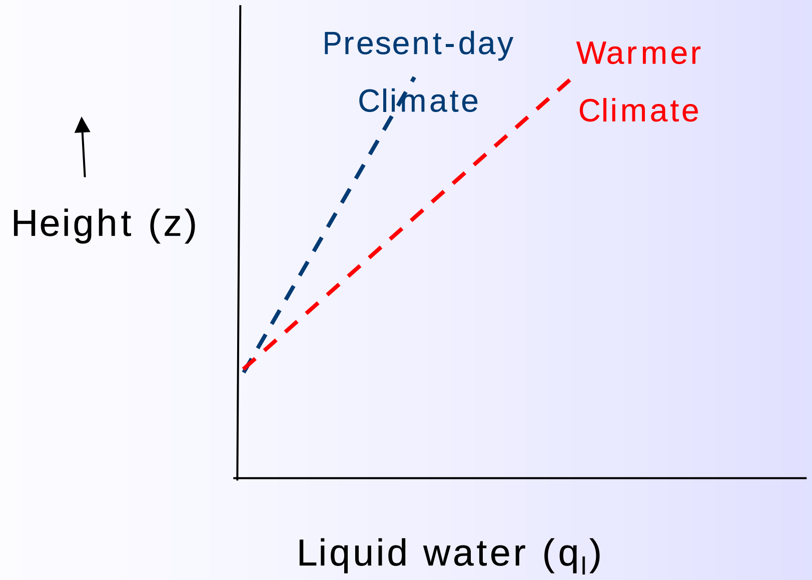
- Which are the physical mechanisms for the low cloud feedbacks?

- The reasons for intermodel differences in (low level) cloud response (e.g. cloud physics vs large scale forcings)

- Which of the model cloud feedbacks are the more credible ?

Only one existing physical mechanisms/hypotheses for low cloud feedback (Paltridge 1980)

- adiabatic lapse rate of liquid water increases with temperature
- So in a warmer climate even under constant RH conditions, clouds will contain more liquid water.....
- Which make them more reflective (i.e. higher albedo)....
- which supports a negative cloud feedback.

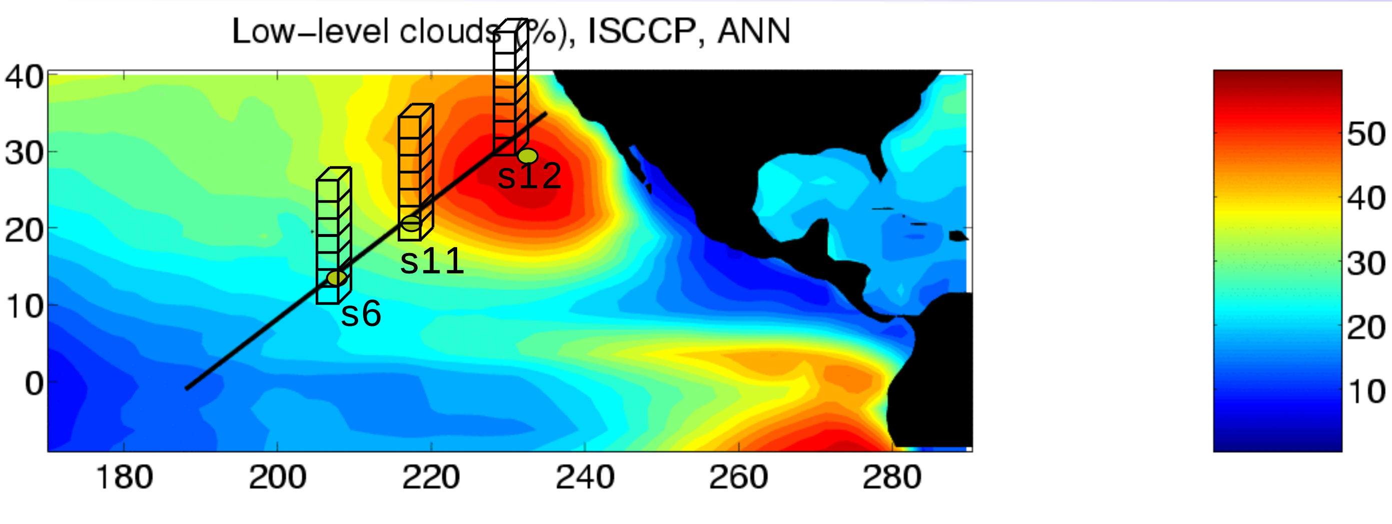


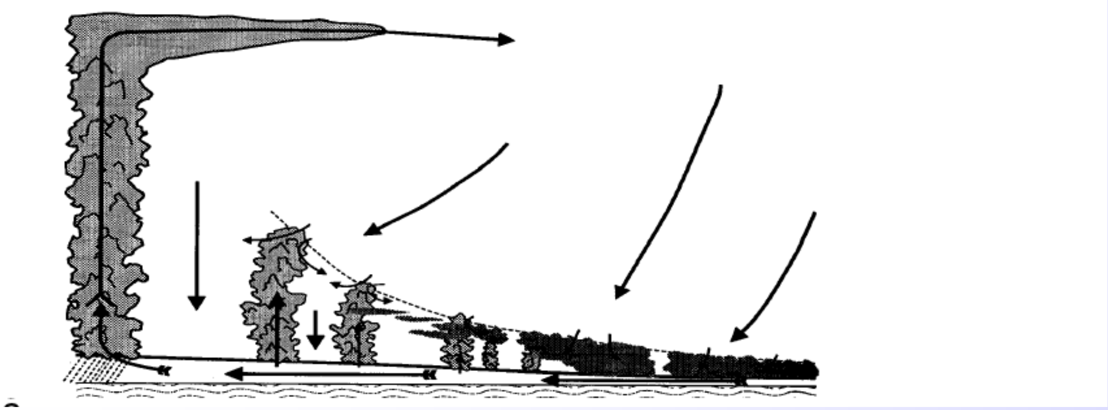
2.

Process Studies and Hypotheses

Process Studies with Large Eddy Simulations and Single Column Models for present and an idealized future climate (CGILS)

Zhang et al . 2013 (JAMES), Blossey et at 2012 (JAMES)

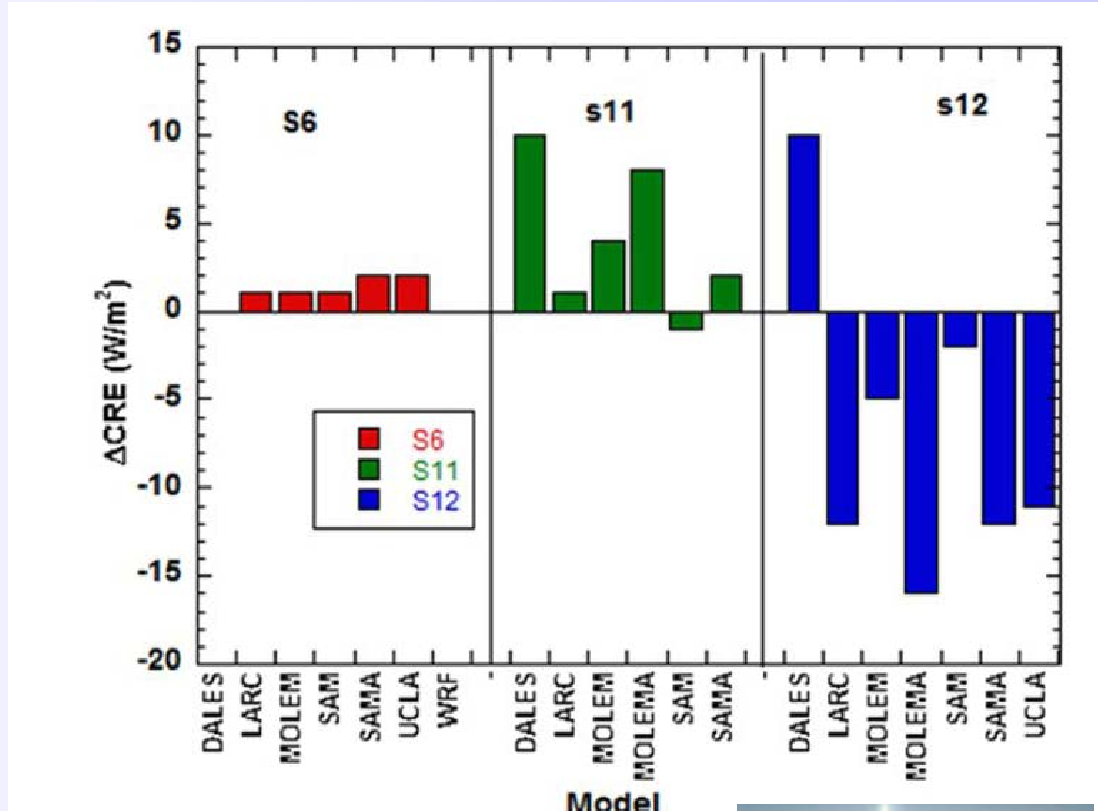




Perturbed climate:

- Warmer SST (+2K)
- Constant RH
- moist adiabatic profiles free atm
- Weaker subsidence

Shallow cu   Shallow cu under Scu   Scu



LES Results:

- Shallow cu (S6) and Shallow cu under Scu (S11) :

Cloud thinning => Pos feedback

- Scu (S12)

Cloud thickening => Neg feedback

Corollary:

- for constant subsidence:

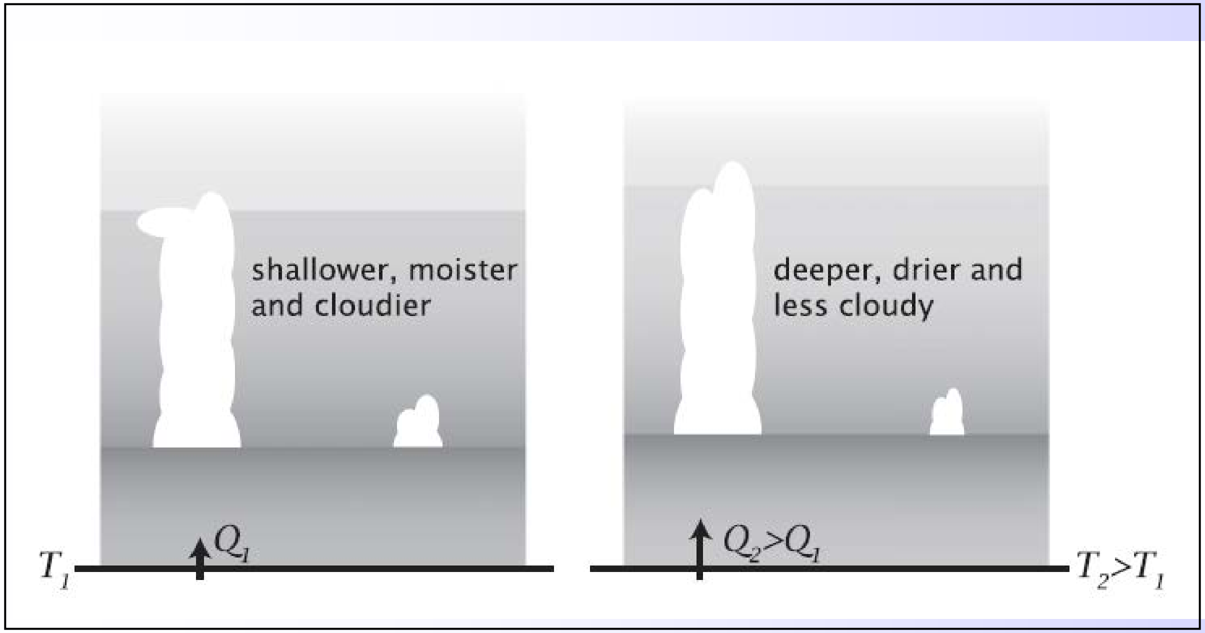
All cases: **Cloud thinning => Pos feedback**

Blossey et al 2012 ; Zhang et al 2013

Shallow Cu Feedback: (turbulent mixing based hypothesis)

(Rieck et al Jas 2012)

- Increased SST leads to larger surface evaporation
- Just enough to sustain a constant RH if the cloud topped BL would not grow
- But increased surface evaporation drives deeper boundary layers
- which cannot be kept at the same RH
- So RH decreases and the BL becomes less cloudy => **positive cloud feedback**

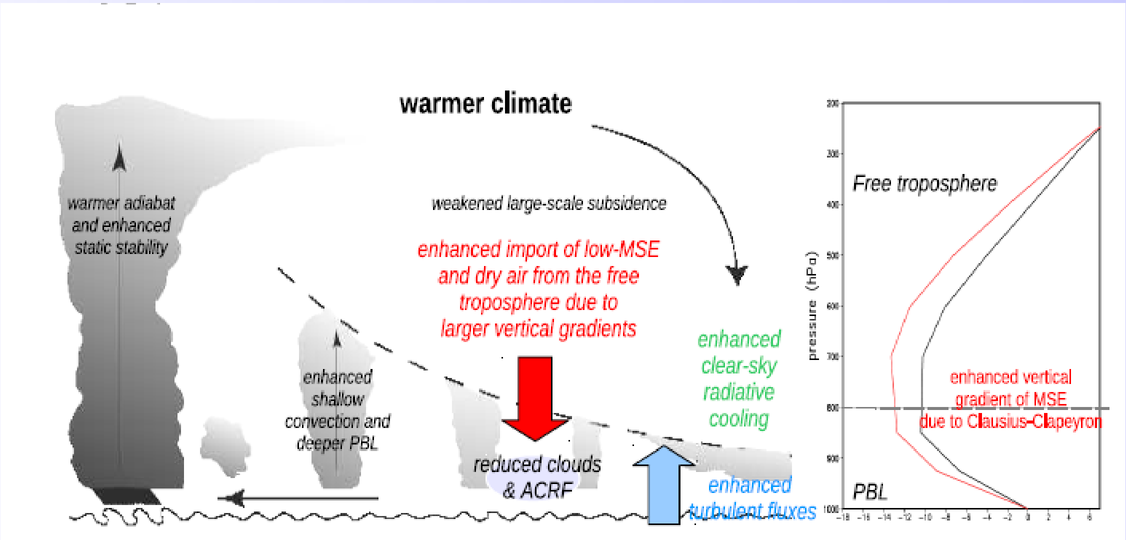


Supported by LES

Shallow Cu Feedback: Moist Static Energy (MSE)-balance based hypothesis

(Brient & Bony, Clim. Dyn, 2012)

In a warmer climate :



MSE deficit

- Larger Surface Fluxes
- More clear sky rad. cooling
- More drying due to vert. adv of MSE (in pbl)

So that less cooling due to clouds is required

↓

Less ACRF

↓

Lesser clouds (positive feedback)

$$(LH+SH)+[R_0]-\left[w\frac{\partial h}{\partial z}\right]+ACRF=0$$

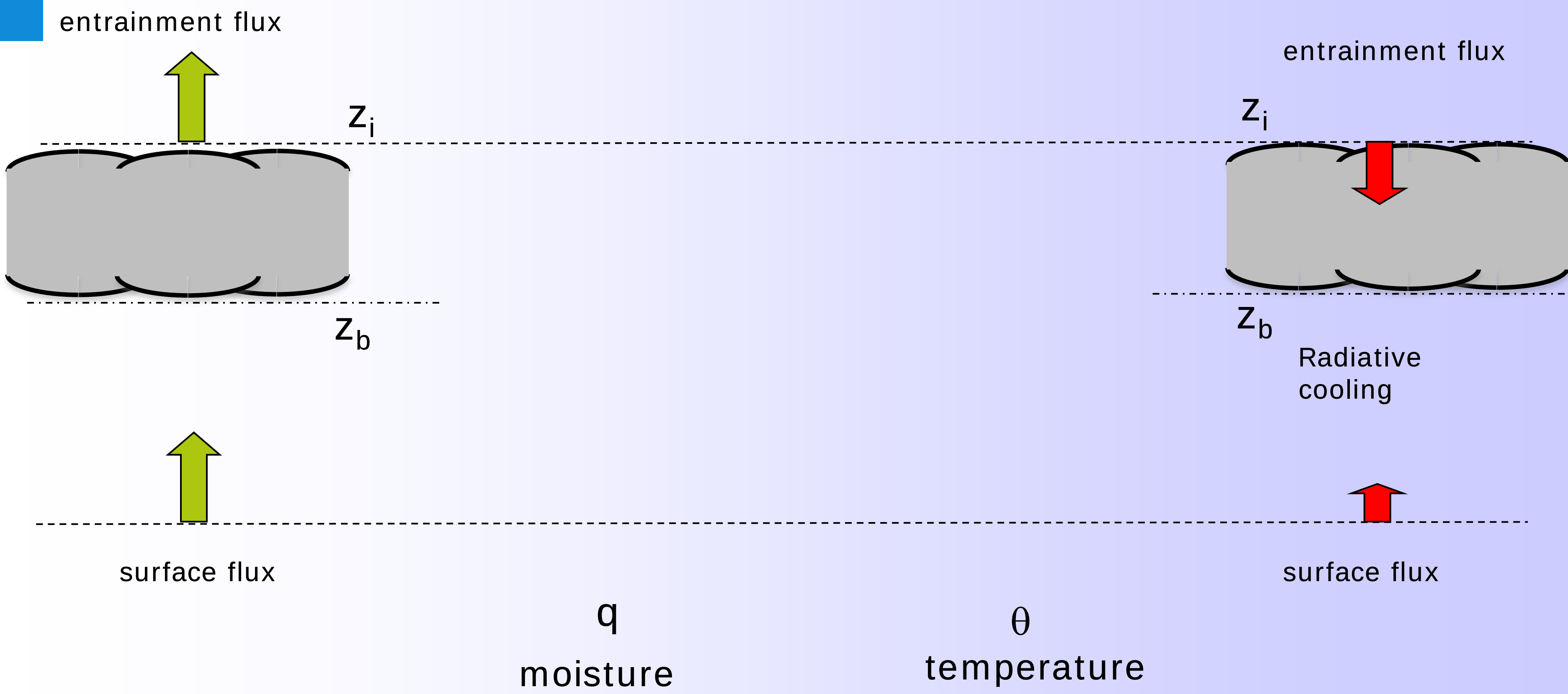
>0 $\quad <0 \quad <0 \quad <0$

Further explored in Spooky-experiments

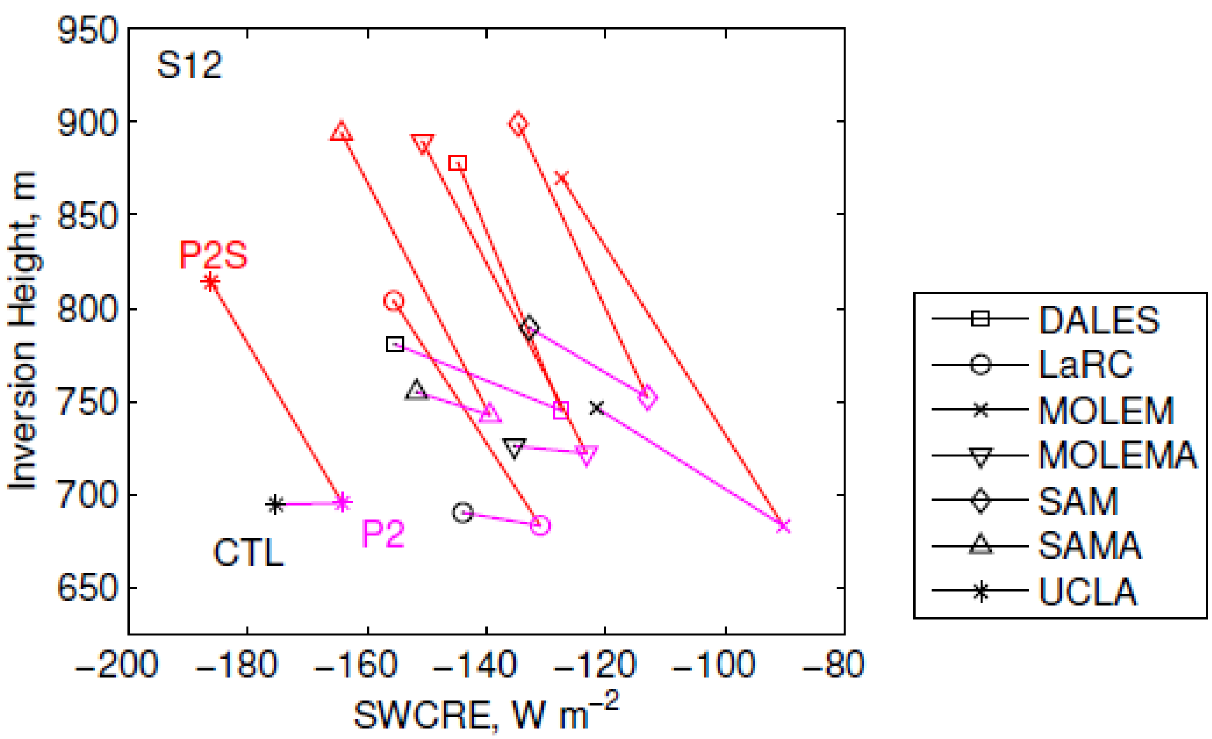
Scu Feedback: Physical Mechanism: more complicated

Inversion height zi : $w_e = w_{subs}$

Cloudbase height zb : depends on RH



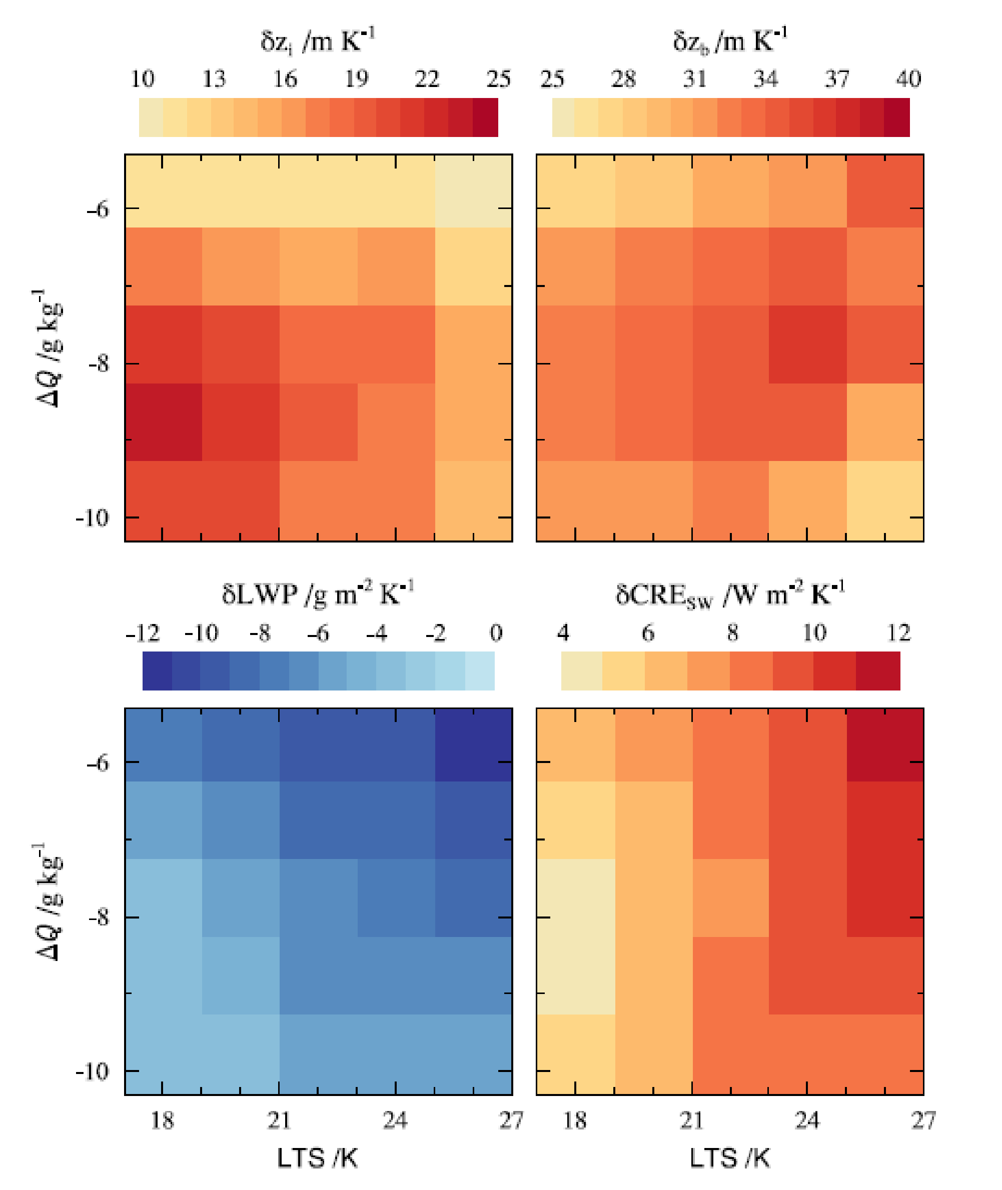
- SST increase only : decrease zi : thinner cloud => positive feedback
- weakened subsidence : increase zi : thicker clouds => negative feedback



LES results for perturbed climate:

Consistent with CGILS findings:

- CC=1 present & future
- Increase of inversion height
- Decrease of RH in mixed layer
- Increase of cloud base height
- Decrease in LWP
- Positive cloud feedback



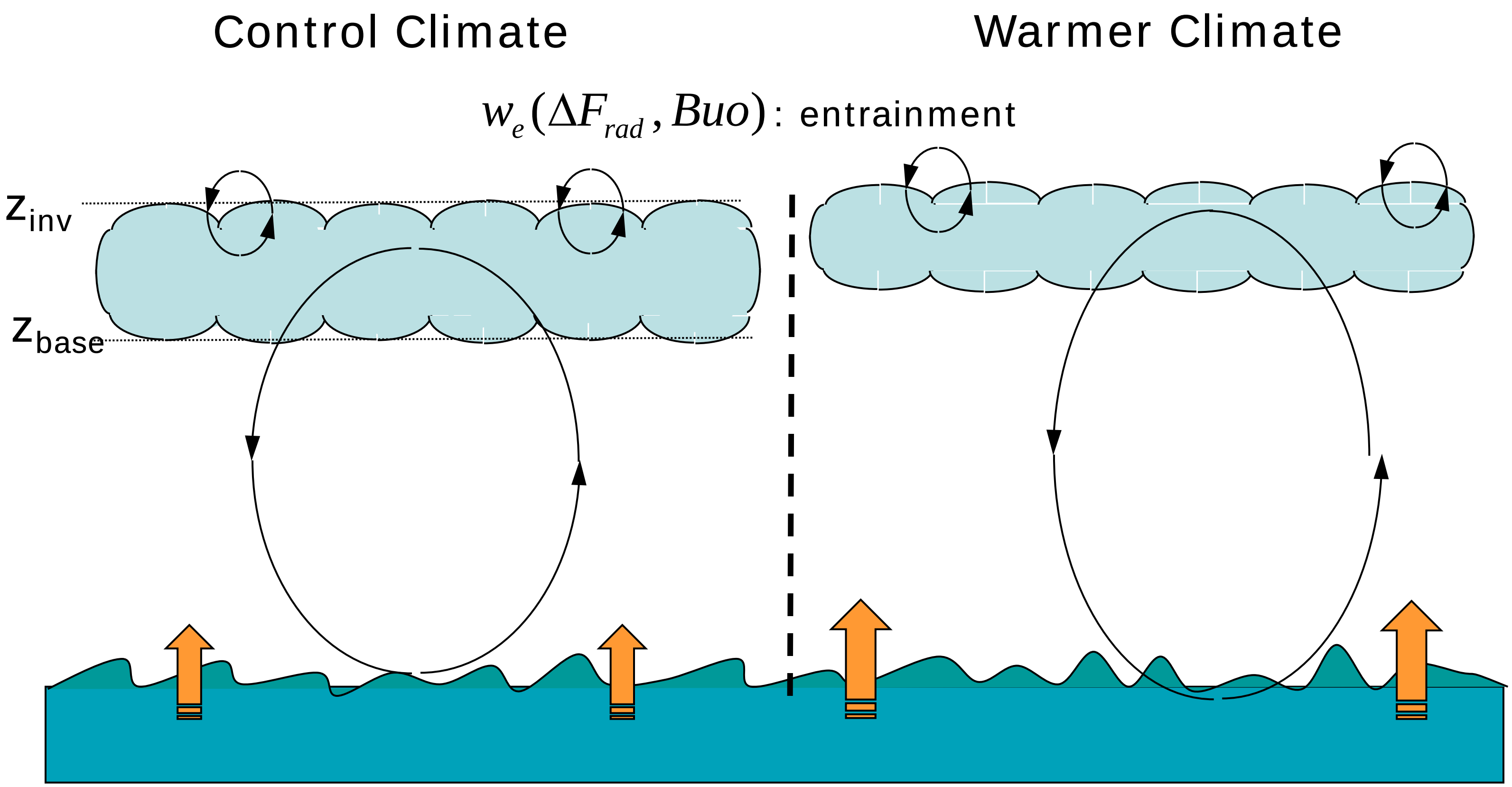
Dussen et al subm. to JAMES (2014)

Warmer Climate

- Increased surface fluxes
- Leading to increased entrainment

- Weaker radiative cooling
- Leading to decreasing entrainment

→ Deeper BL → Lower RH in BL → Higher cloud base → Less LWP → Pos feedback



Summary Feedbacks: based on LES,MLM and Theory

SST increase:

Scu : Cloud thinning => positive cloud feedback

Shallow Cu : Less Clouds => positive cloud feedback

SST increase plus weakened subsidence:

Scu : Cloud thickening => negative cloud feedback

Shallow Cu : Less Clouds => positive cloud feedback

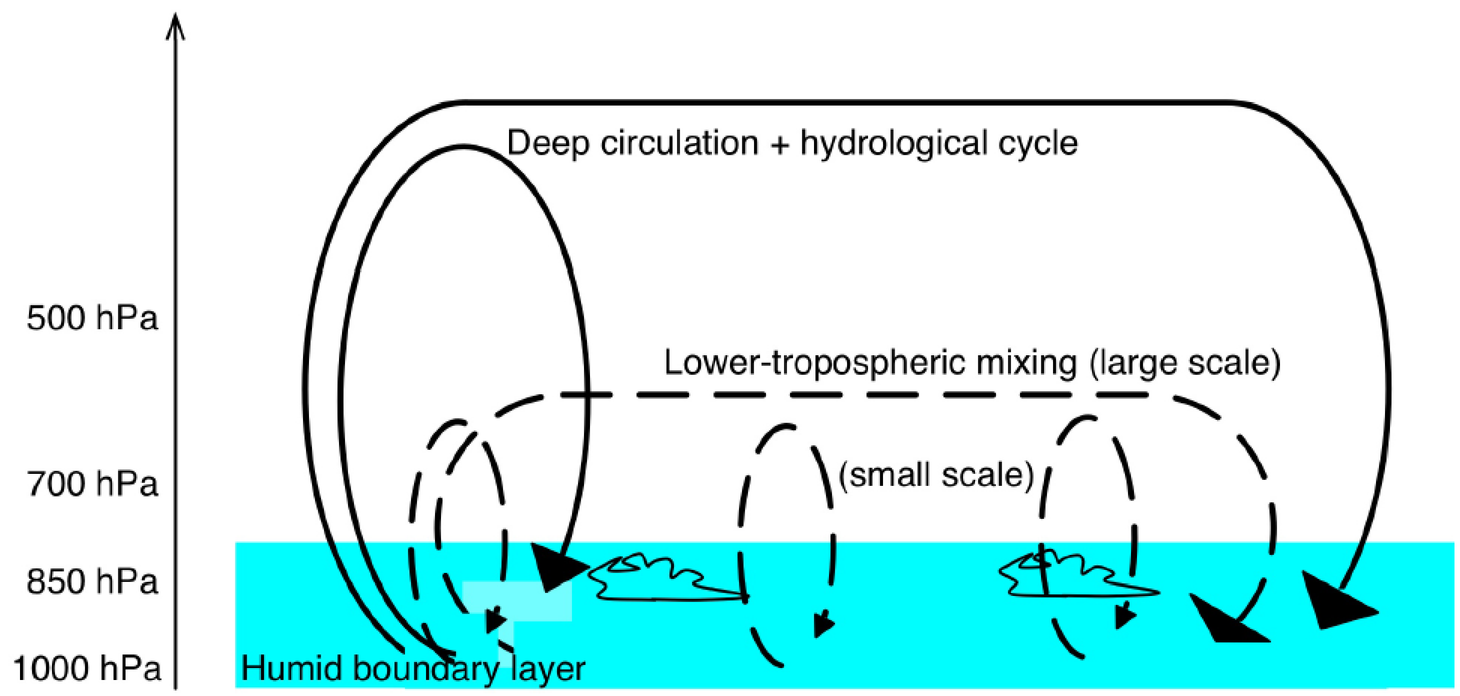
3.

Emerging Constraints

Spread in model climate sensitivity linked to atmospheric convective mixing

Sherwood, Bony & Dufresne Nature (2014)

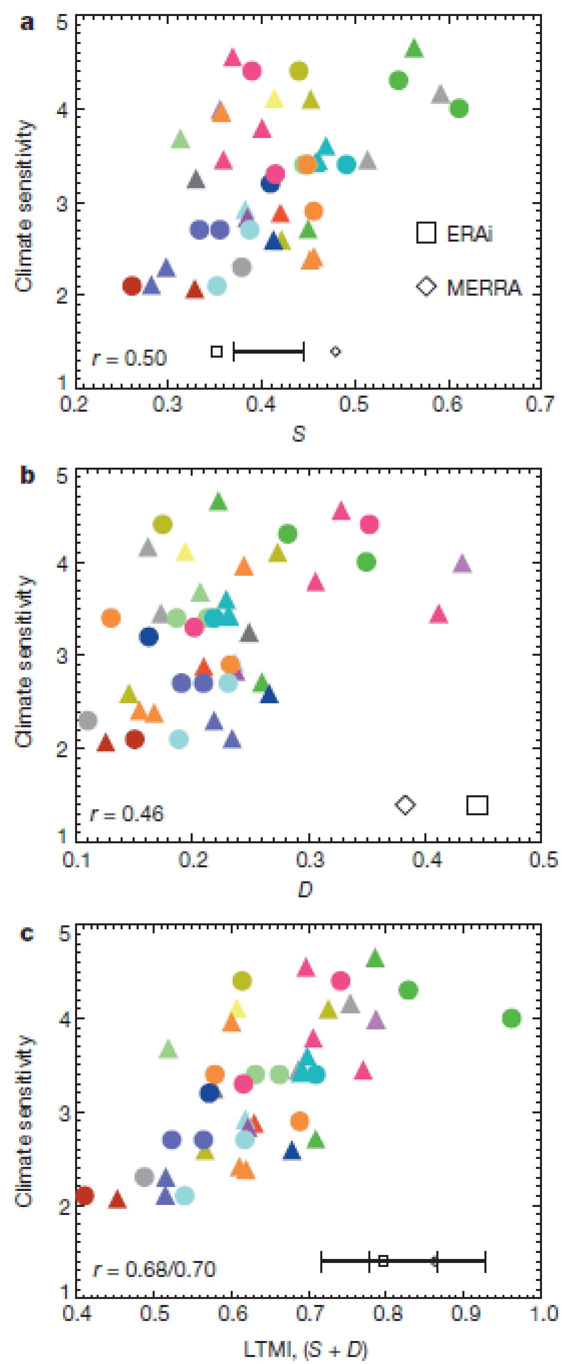
- Lower tropospheric mixing occurs through i) small scale shallow cumulus mixing and ii) explicitly resolved circulations.
- Hypothesis: moisture transport increases in a warming climate at a rate that appears to scale with the initial lower-tropospheric mixing



• Equilibrium Climate Sensitivity (ECS) vs small scale low tropospheric mixing

• Equilibrium Climate Sensitivity (ECS) vs large scale low tropospheric mixing

• Equilibrium Climate Sensitivity (ECS) vs total large scale tropospheric mixing

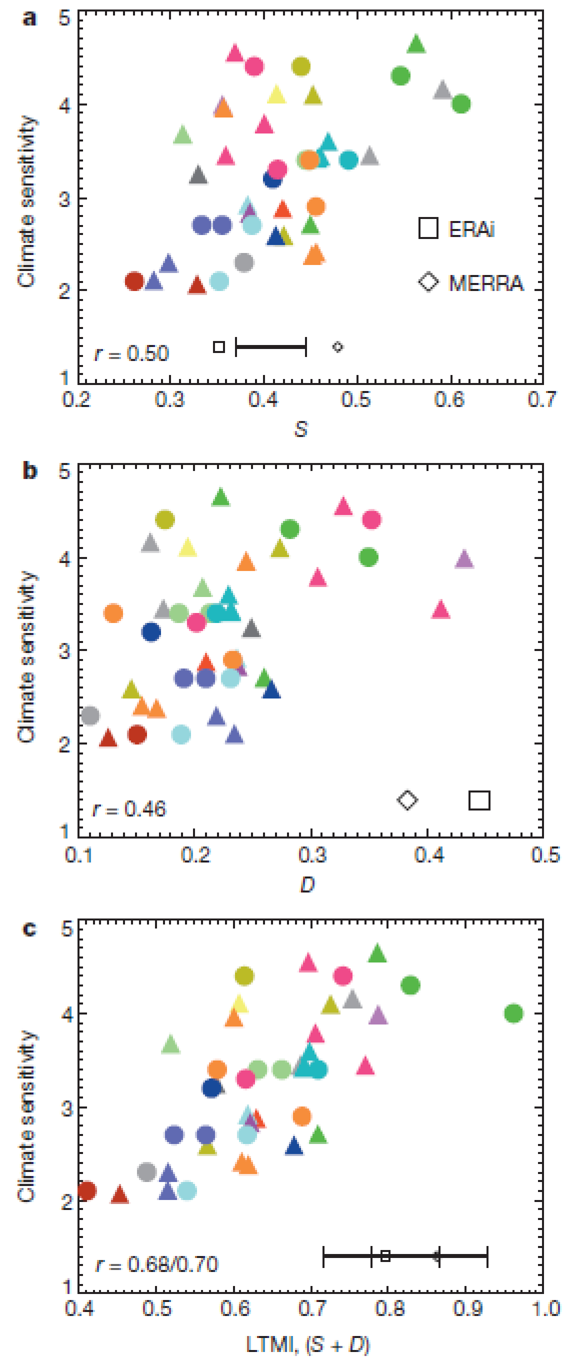


Remarks:

- Reanalysis results suggest that the high sensitivity models are more credible

- Lower tropospheric mixing depends strongly on the competion between shallow and deep convection so understanding and realistically representing this competition is key for making more accurate climate projections.

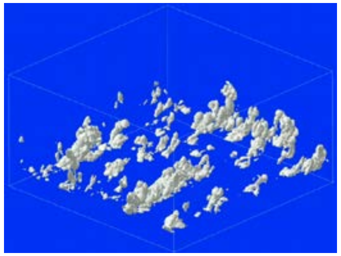
- Lower tropospheric mixing is to a large extend a process that is unconstrained in GCMs



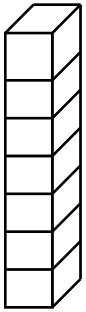
4.

Cloud Feedback and Single Column Modelling (Scu)

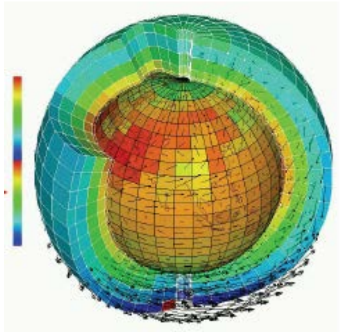
……..Use the full hierarchy of models and observations



Large Eddy Simulation

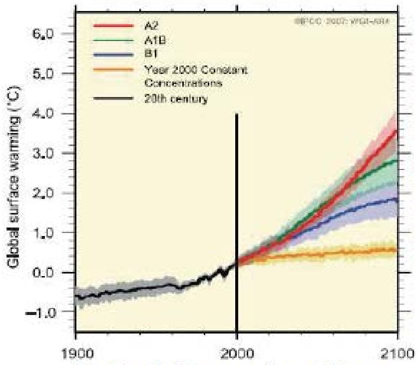


Single Column Models

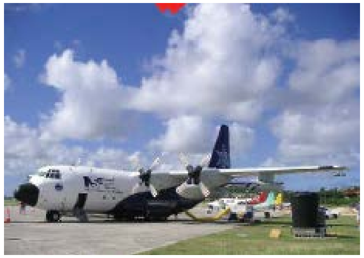


Climate Models

NWP Models



Model Projections



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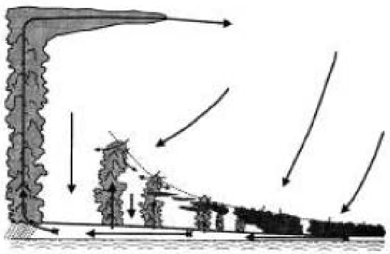
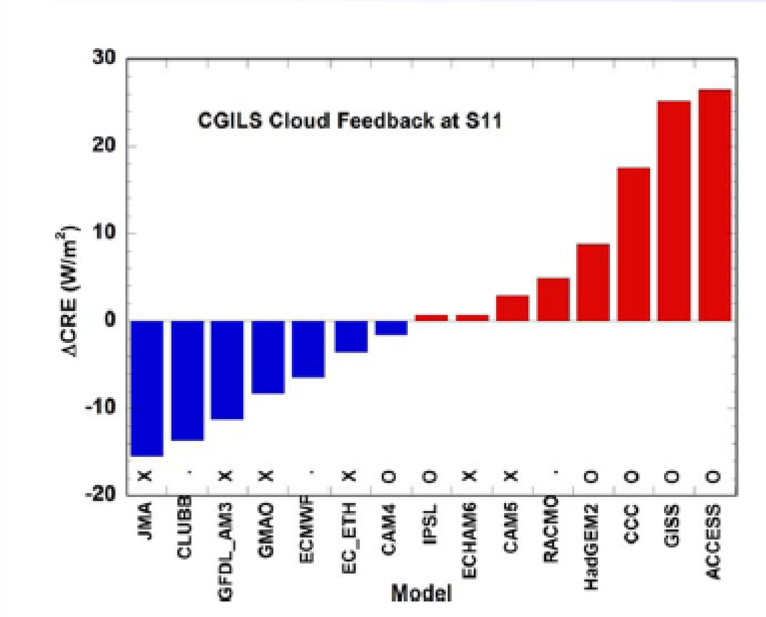
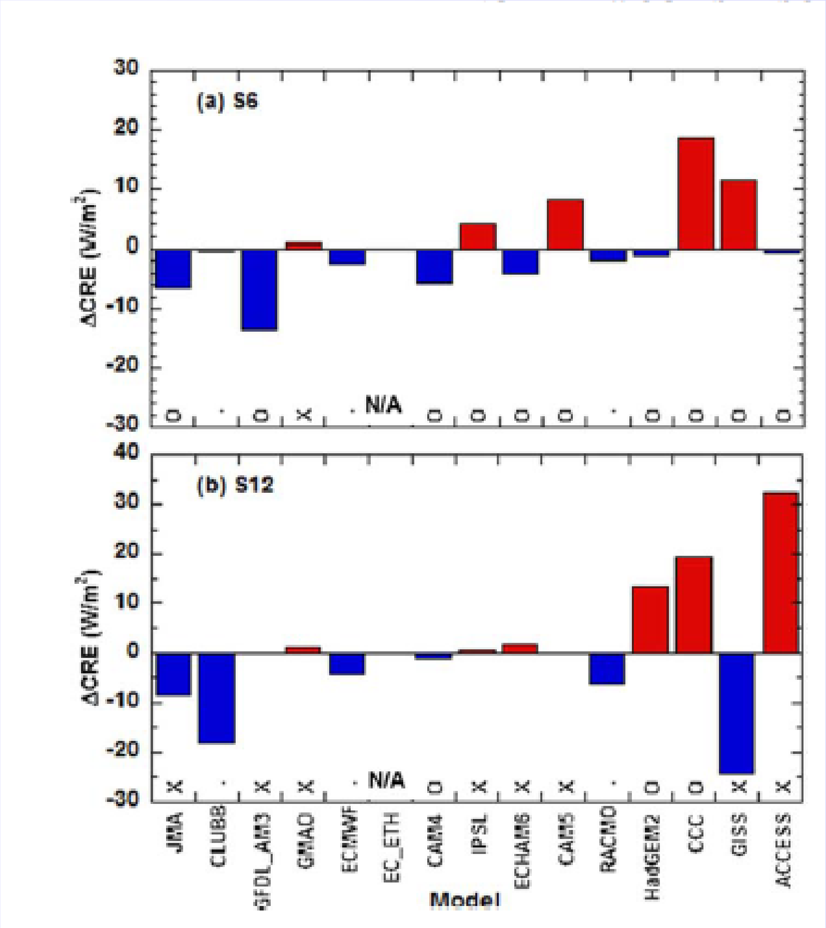


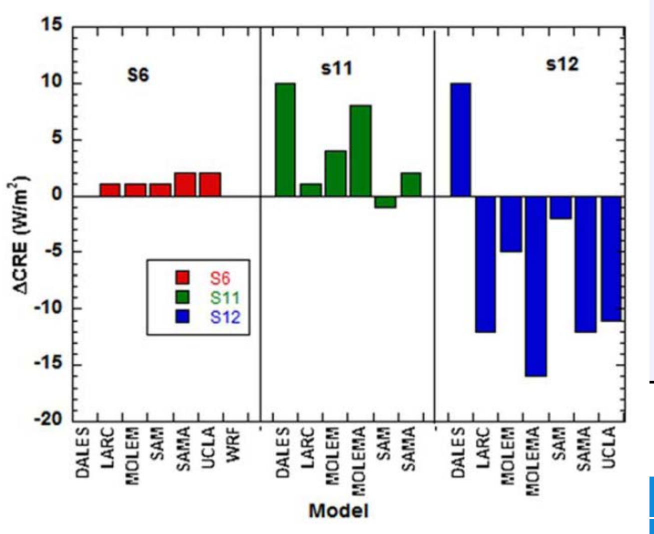
Analysis & Understanding cloud feedbacks

SCM Response (Inconsistent with too high amplitudes)

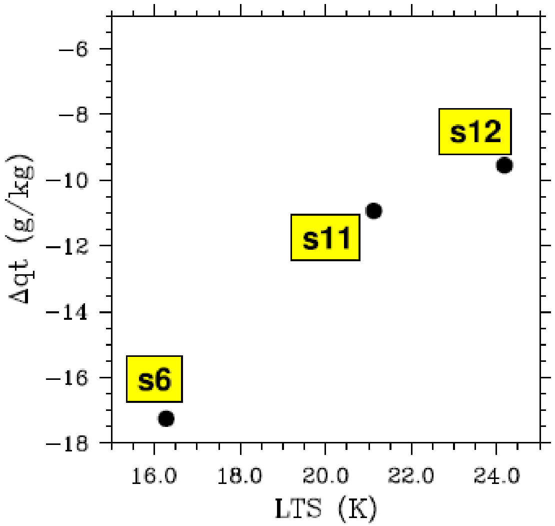




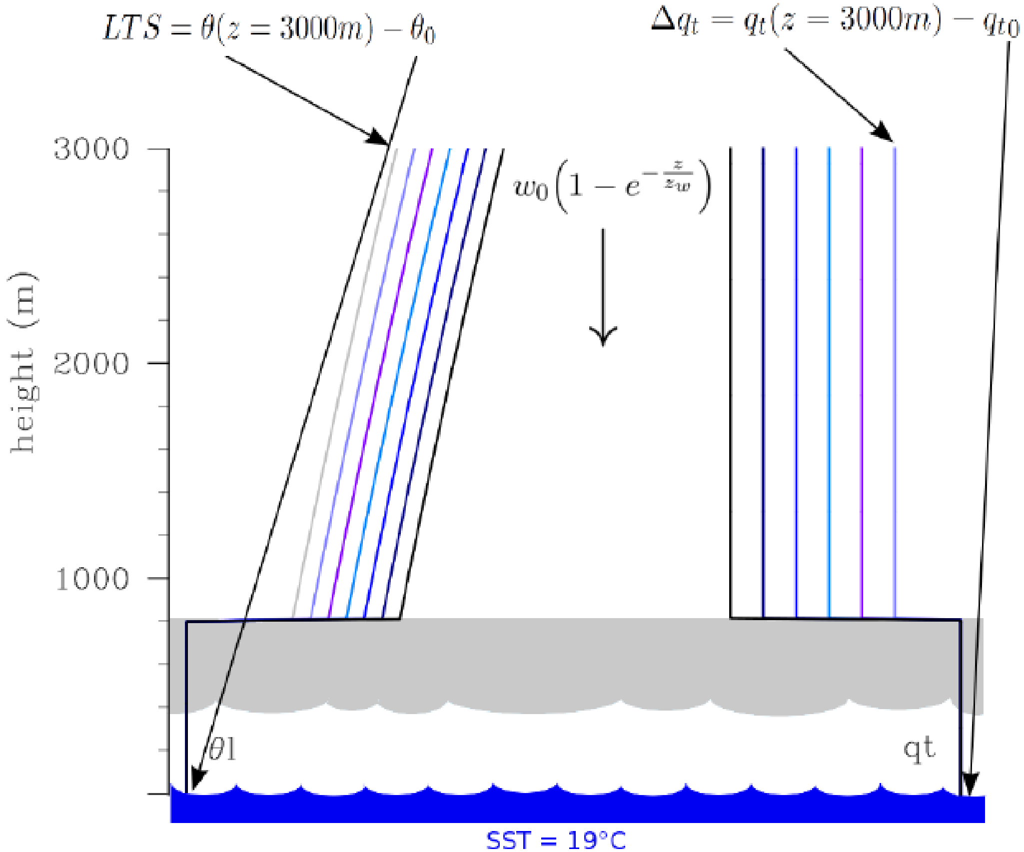
LES



(Zhang et al 2013)



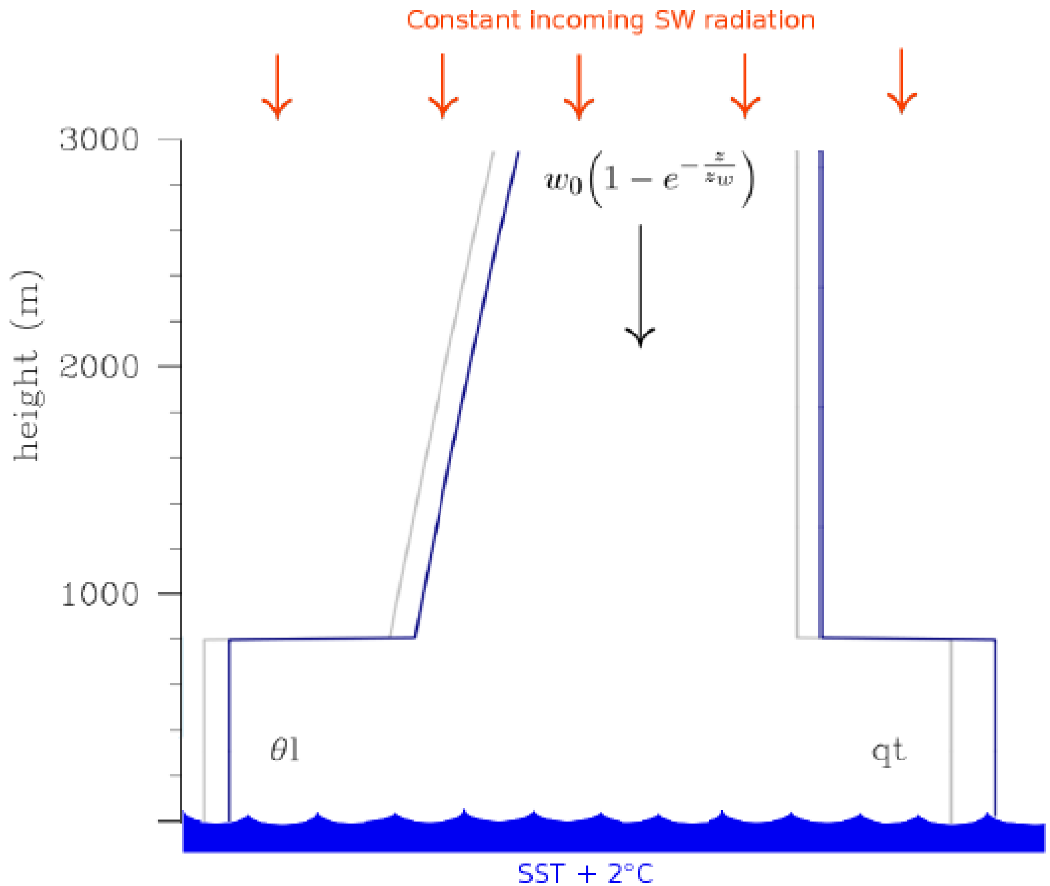
Idea: extending the CGILS framework in order to map a wider region of the phase space.

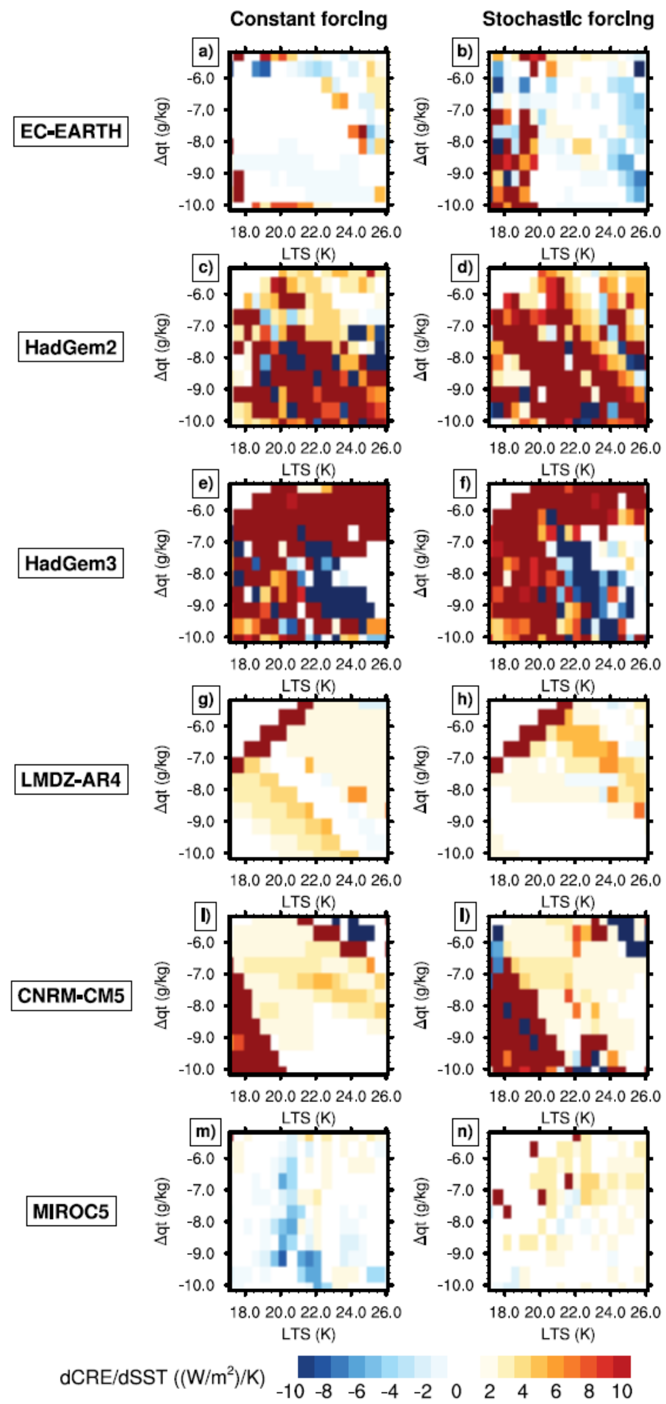


Dal Gesso et al QJRMS 2013

Dal Gesso et al QJRMS 2014

Perturbed climate (PC) set-up





SCM Results for Cloud Radiative Effect:

- Strong intermodel differences

- Different magnitudes mainly due to changes in cloud fraction rather than LWP.

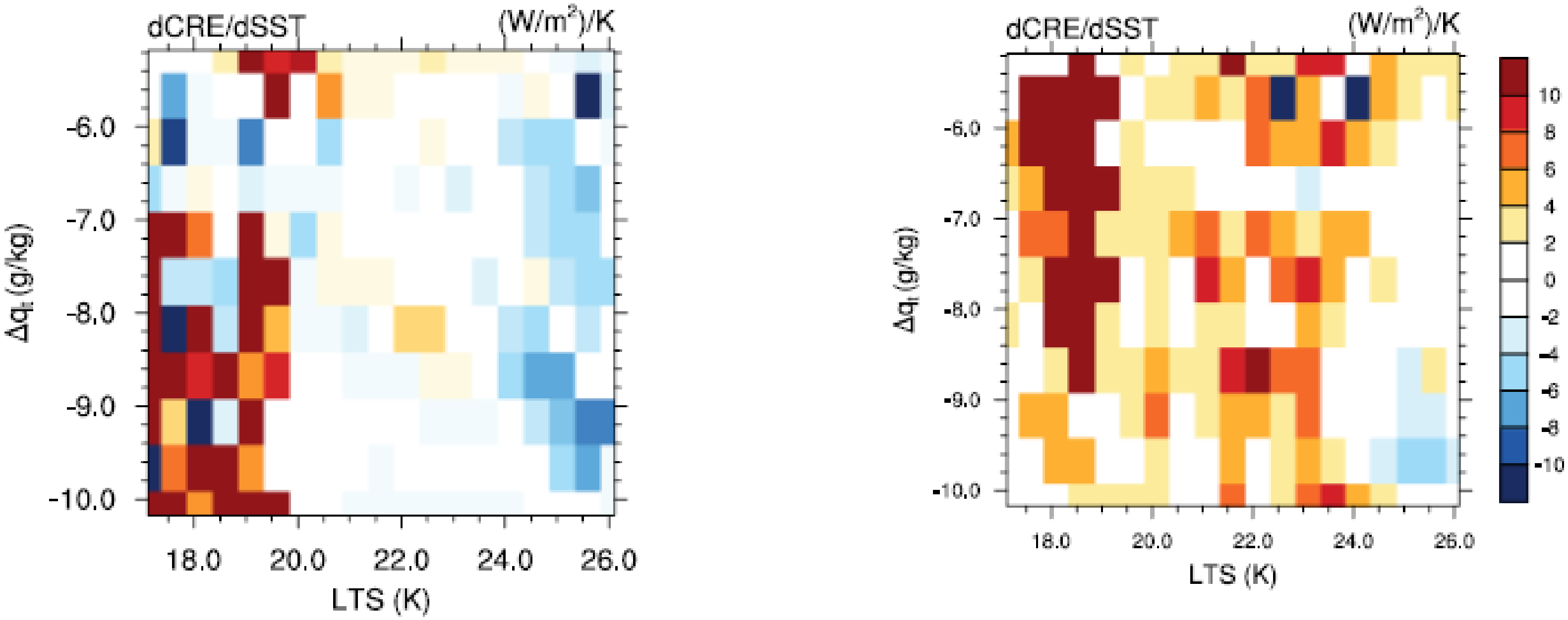
- Considering only a few cases can be misleading.

- Underlying reasons for spread partly resides in the physics as well as in the numerics.

Dependence on the vertical resolution

EC-EARTH SCM, SF experiment.

Standard resolution | High resolution



The vertical resolution alone can change the sign of the feedback.

Concluding Thoughts

- New hypotheses for low cloud feedback mechanisms have been put forward (and tested in turbulence resolving models and Mixed Layer Models)

- Pointing to (small but persistent) positive cloud feedback for shallow cu

- Emerging Constraints link the strength of the sh cu feedback to their present day intensity of lower tropospheric mixing.

•Emergent Constraints (like the sherwood et al) focusses the research.

- Situation is probably more subtle for Scu (both wrt to the forcing and the response)
- Both parameterizations and vertical resoltion are inadequate to make reliable staments over the cloud feedback strength in GCMs
- Due to the fact that mixing and cloud schemes in GCMs are far more unconstrained than in turbulence resolving models
- We need to do a similar excercise for shallow cumulus