Solving the Cloud Feedback Problem

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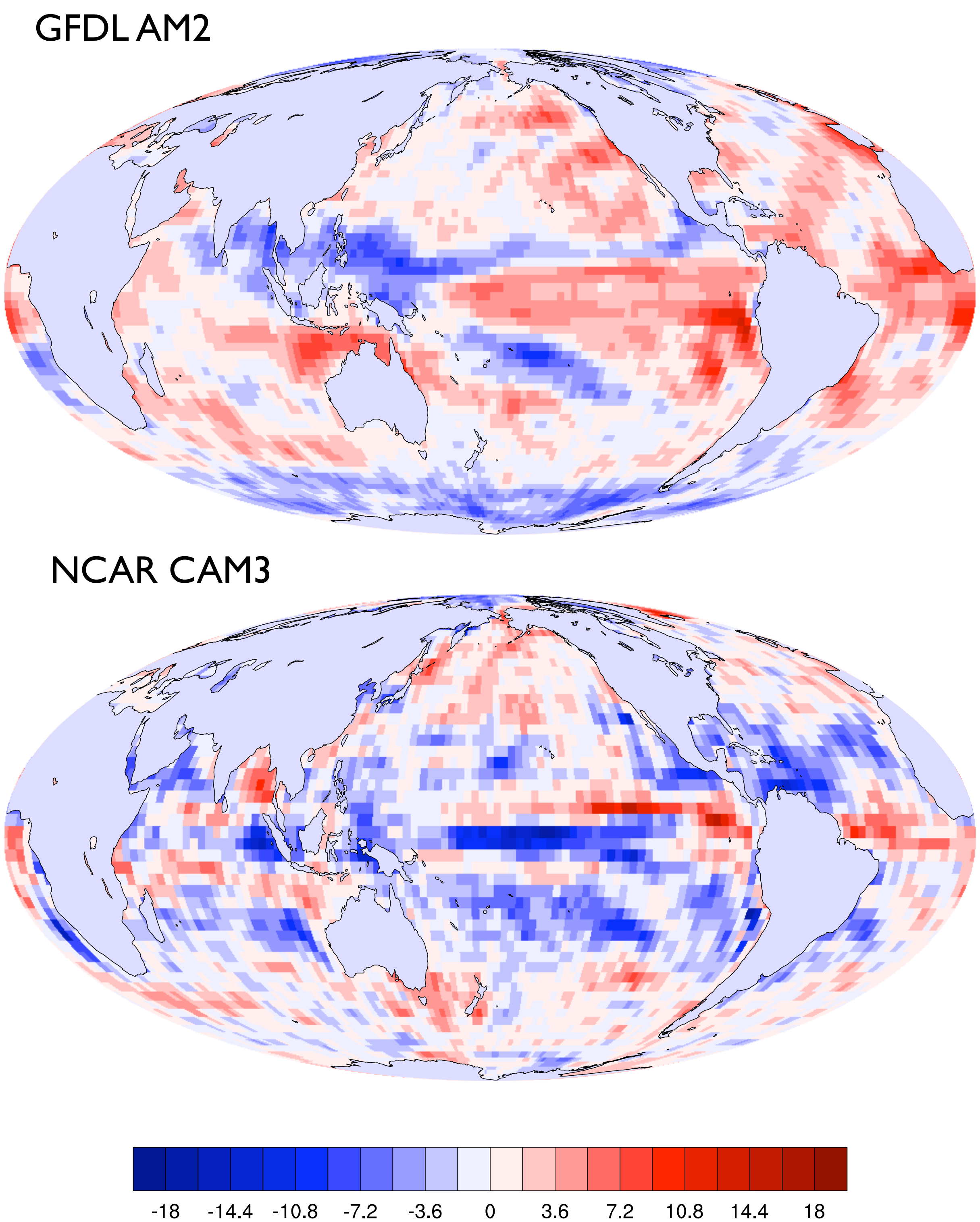
clouds & climate change



clouds act to enhance the warming (positive feedback)

clouds act to mitigate the warming (negative feedback)

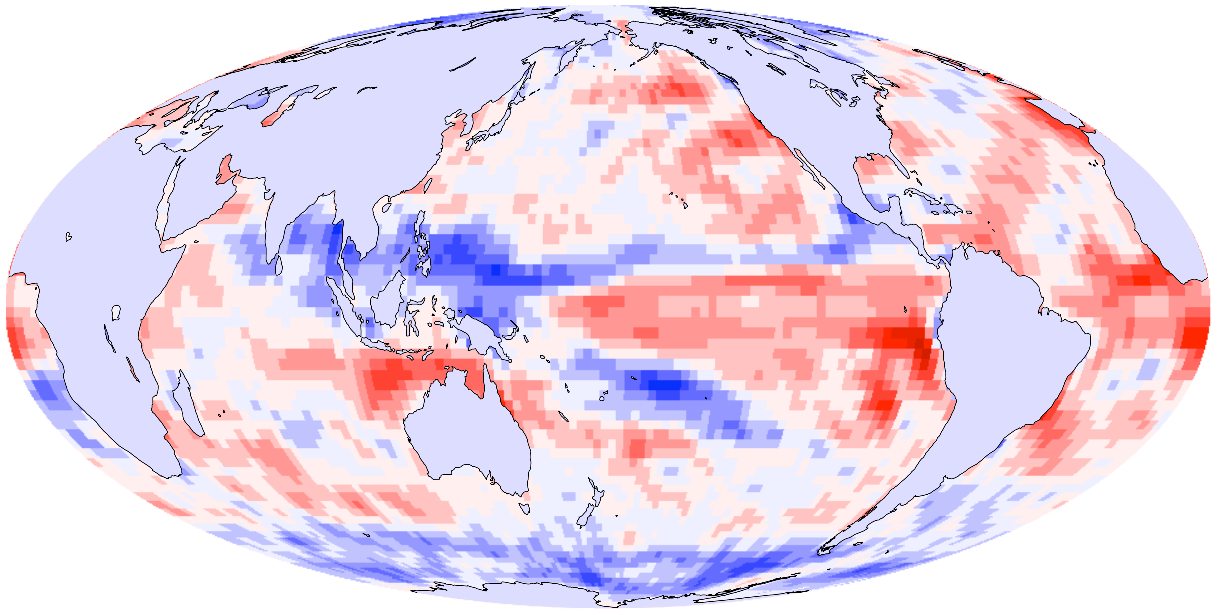
positive cloud feedback, larger climate sensitivity

negative cloud feedback, smaller climate sensitivity

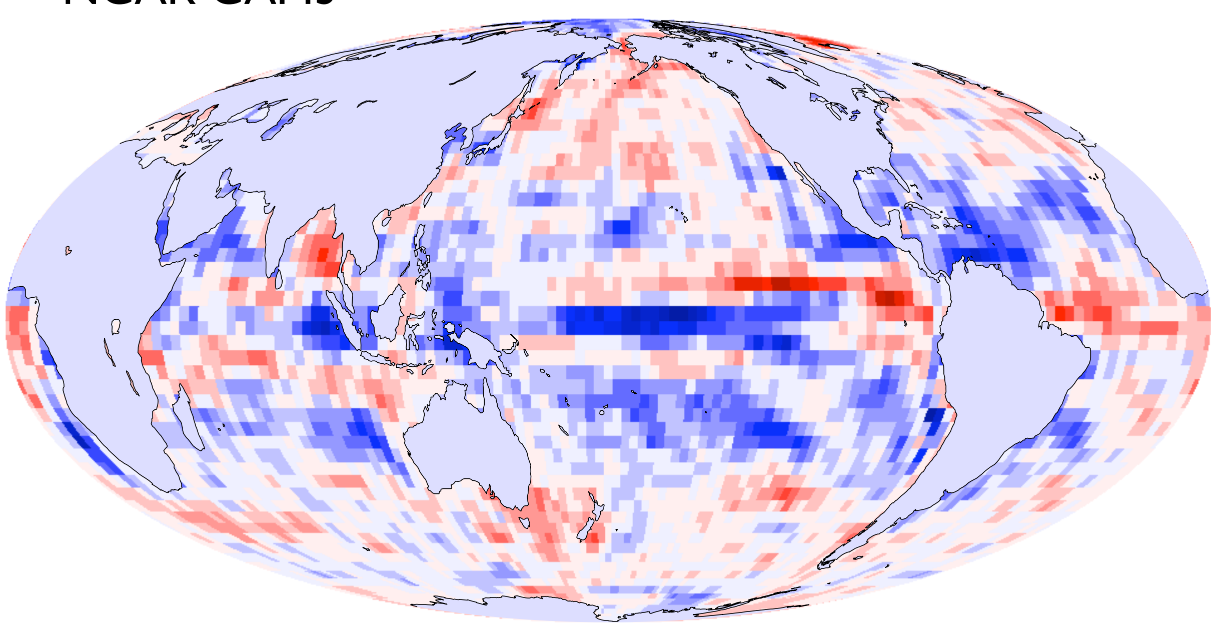
Following Stephens (2005,)

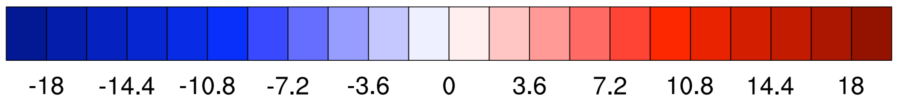
an old story

GFDL AM2



NCAR CAM3





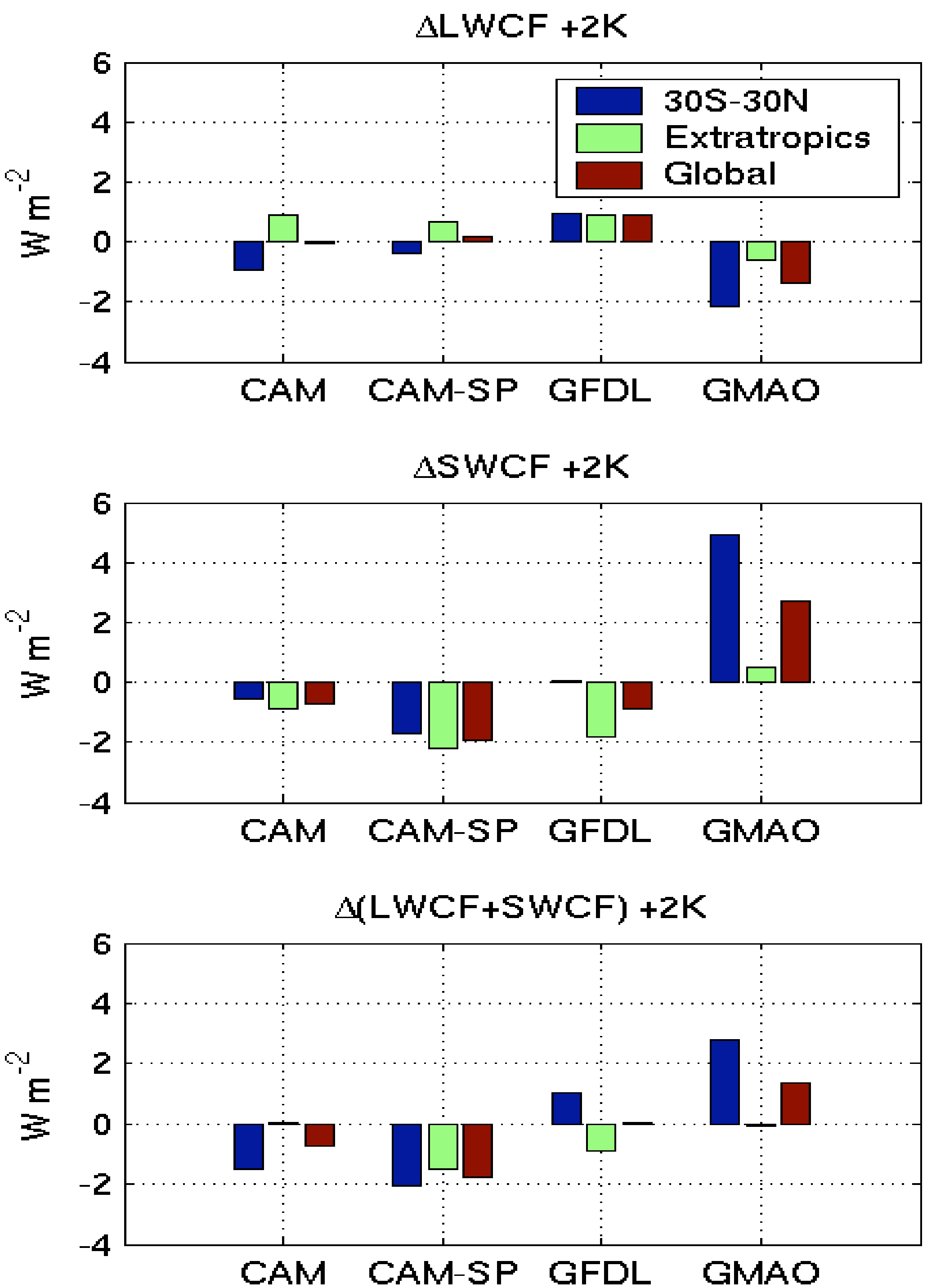
- "... the modelling of time dependent clouds is perhaps the weakest aspect of the existing general circulation models and may be the most difficult task in constructing any reliable climate model" --- Arakawa (WMO,1975)

- "It must thus be emphasized that the modeling of clouds is one of the weakest links in the general circulation modeling efforts" --- Charney (NRC,1979)

- "Probably the greatest uncertainty in future projections of climate arises from clouds and their interactions with radiation ... even the sign of this feedback remains unknown" --- IPCC (TAR 2001)

- "Cloud feedbacks are a primary source of inter-model differences in equilibrium climate sensitivity, with low cloud being the largest contributor" --- IPCC-draft language (2006)

CAM3-SP SST+2 climate sensitivity



Wyant et al. 2006 (GRL)
A Cloud CPT project

- Based on 3.5 yr ctrl, SST+2 runs
- Strong negative shortwave cloud feedbacks in tropics, extratropics, esp. from subsidence regimes.
- Mean BL cloud thickness and fraction both increase
- CAM3-SP λ = 0.41 K/(W m^{-2})

  vs. CAM3 λ = 0.54 K/(W m^{-2})
- Global CRM, DARE results similar to CAM3-SP.

Deep Convection as seen from the space shuttle

Shallow cumulus during RICO

Stratocumulus during DYCOMS-II

when will we know?

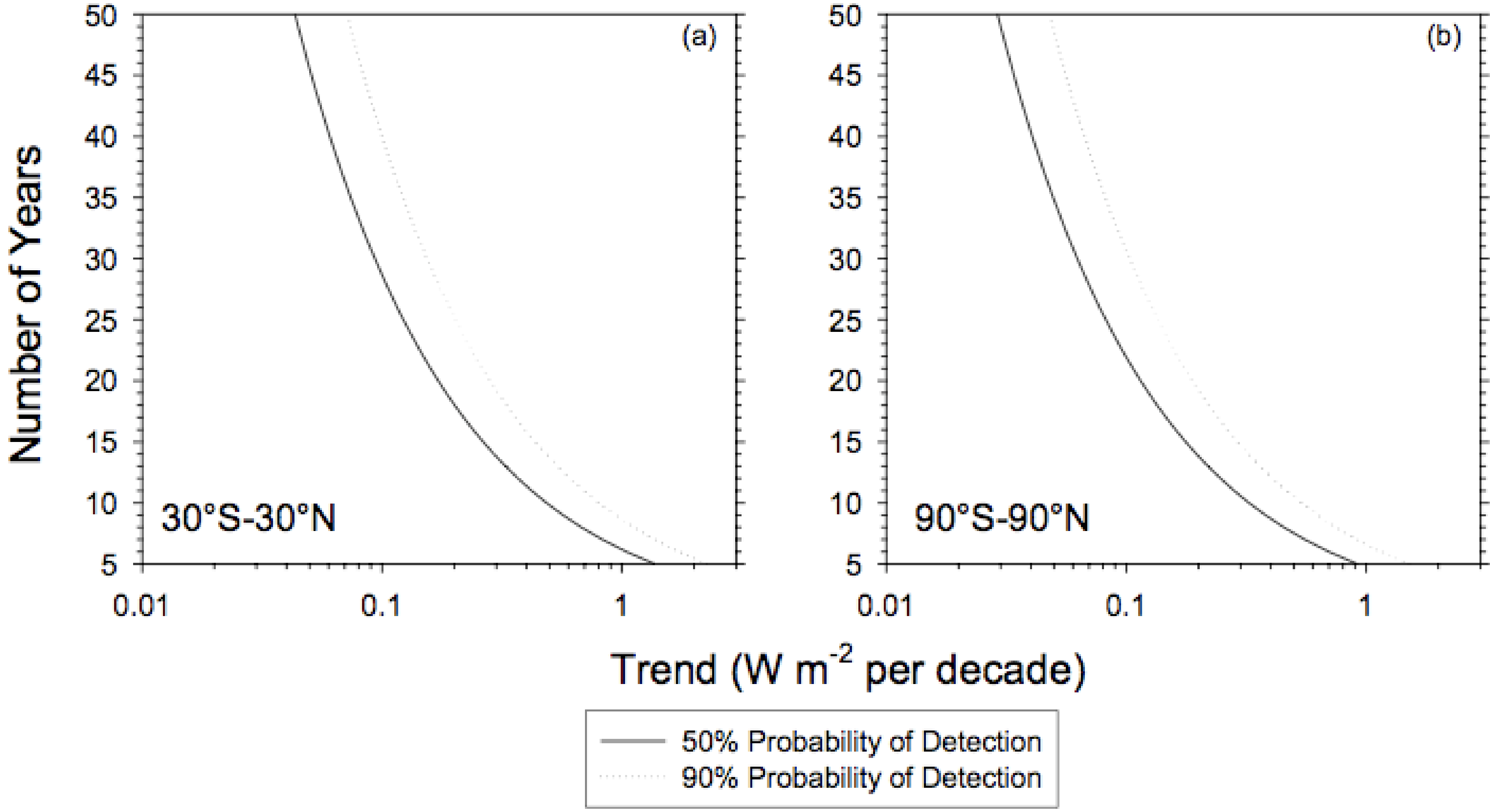


Figure 9 Number of years to detect a given trend in SW TOA flux anomaly with 50% and 90% probability for (a) 30°S-30°N and (b) 90°S-90°N.

Loeb, Wielicki et al., (2006, submitted)

remarks

- foremost the cloud feedback problem poses the question of how shallow moist convection responds to changes in the physical environment.

- the strengths of the MMF approaches explored to date do not naturally benefit the representation of shallow moist convection.

- our theoretical understanding and observational characterization of shallow moist convection is perhaps the most advanced, certainly trade-cumulus and stratocumulus are amongst the simplest forms of moist convection.

- theory and modeling will begin to feel qualitatively new types of observational constraints in the coming years.

the objective conditions

- GEWEX Cloud Systems Studies (**GCSS**) is just coming into its prime and many of us are part of it. It continues to provide unique bounds on cloud resolving models, a source of inspiration for theory and a rich framework for transforming insights and data from the field into forms capable of improving the representation of clouds in climate models.

- The Climate Process Teams (**CPT**) are winding down, but have helped better define the problem and teach us many things about how to work as a team. Many of us were part of this, and we need to absorb its momentum and lessons.

- Remote Sensing: **ARM**, **EOS**. We are in the midst of a data explosion that outpaces our computational advances. ISCCP is nearing 30, ARM is almost 20, Terra is almost 7, TRMM is even older CloudSat and CALIPSO are toddlers with rich imaginations.

- Computational maturity: **PetaFLOPS** (100,000 processors). A 24 hour simulation of shallow cumulus 512x512x100 points (57600 timesteps) takes 18 hours on 128 BlueVista processors. We can expect to do computational problems at tenfold this scale 4096x4096x512 in a similar timeframe within the next five years.

- Ackerman, **Arakawa**, Barker, Bretherton, Collins, Donner, Grabowski, Jakob, Khairoutdinov, Klein, Kreidenweis, Krueger, Miller, Moeng, Pincus, Randall, Rossow, Satoh, Schubert, Sommerville, Stephens, Tao, Wielicki, Xu.

freedom & necessity

Main Entry: **free·dom**

Pronunciation: `'frE-d&m`

Function: *noun*

1 : comprehended necessity

Main Entry: **ne·ces·si·ty**

Pronunciation: `ni-'se-s&-tE, -'ses-tE`

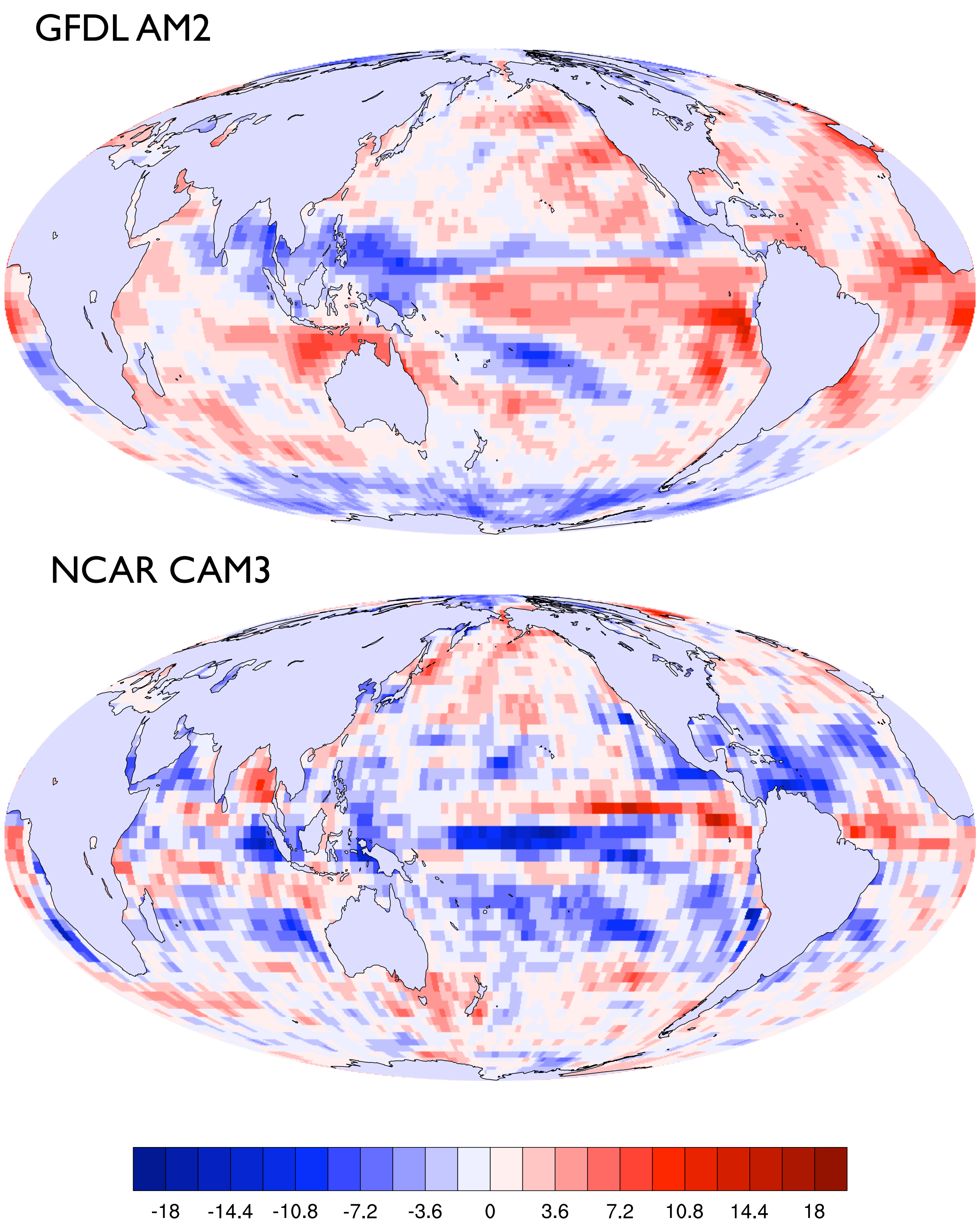
Function: *noun*

1 : solving the cloud feedback problem

strategies

- Phase 1: model problems - (not problems for models) lets pick a few and work on them together.
- Phase II: the mmf & beyond - lets see where our understanding from phase I gets us.

back to our future



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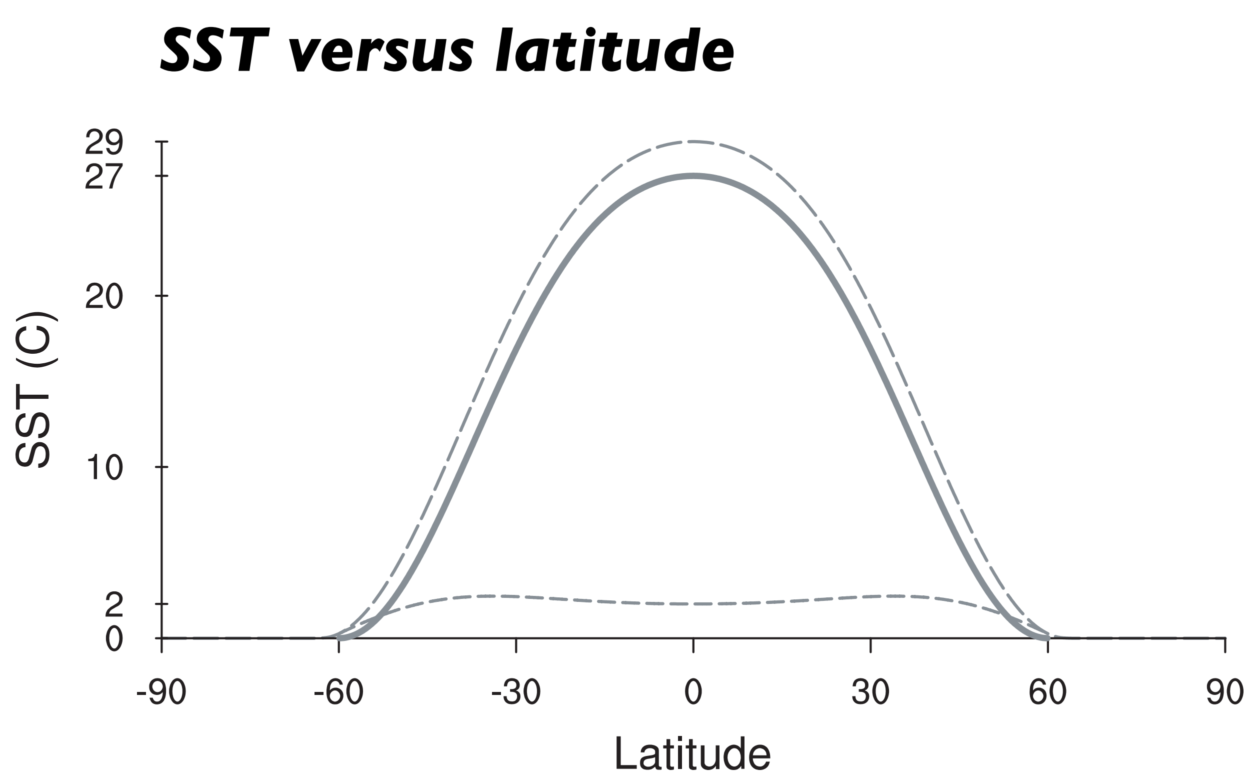
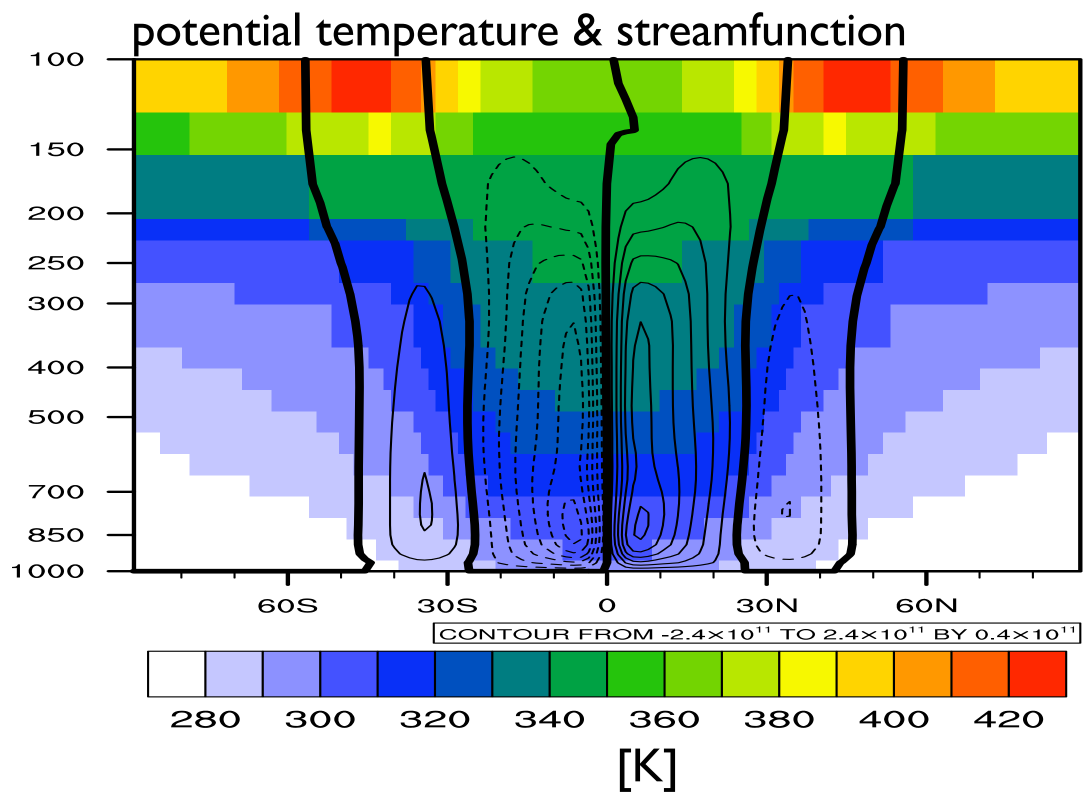
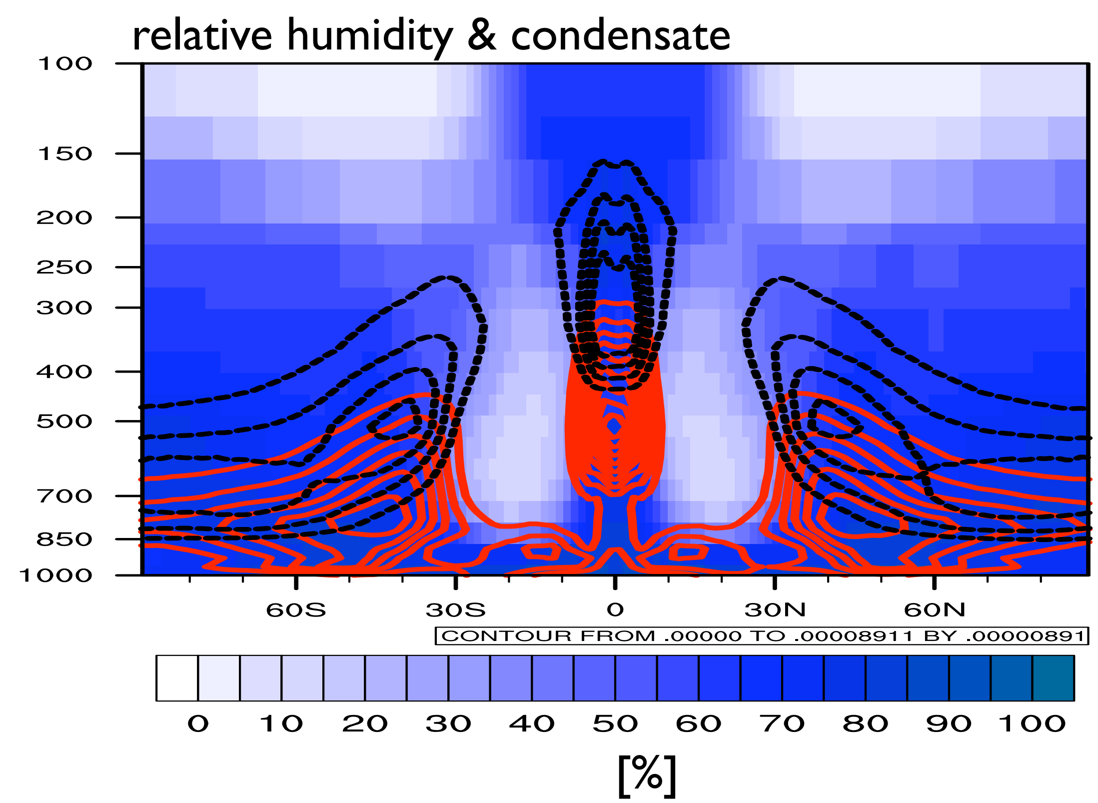
circulation or cloud differences?







Medeiros, Stevens et al., (2006, in preparation)

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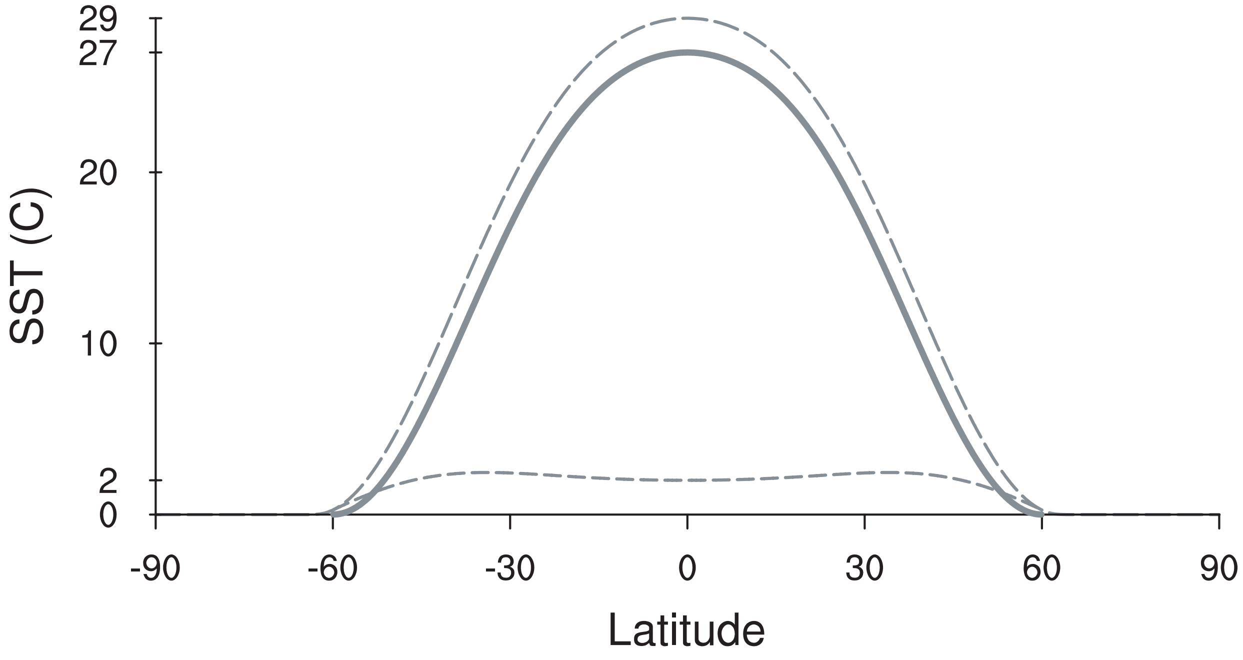
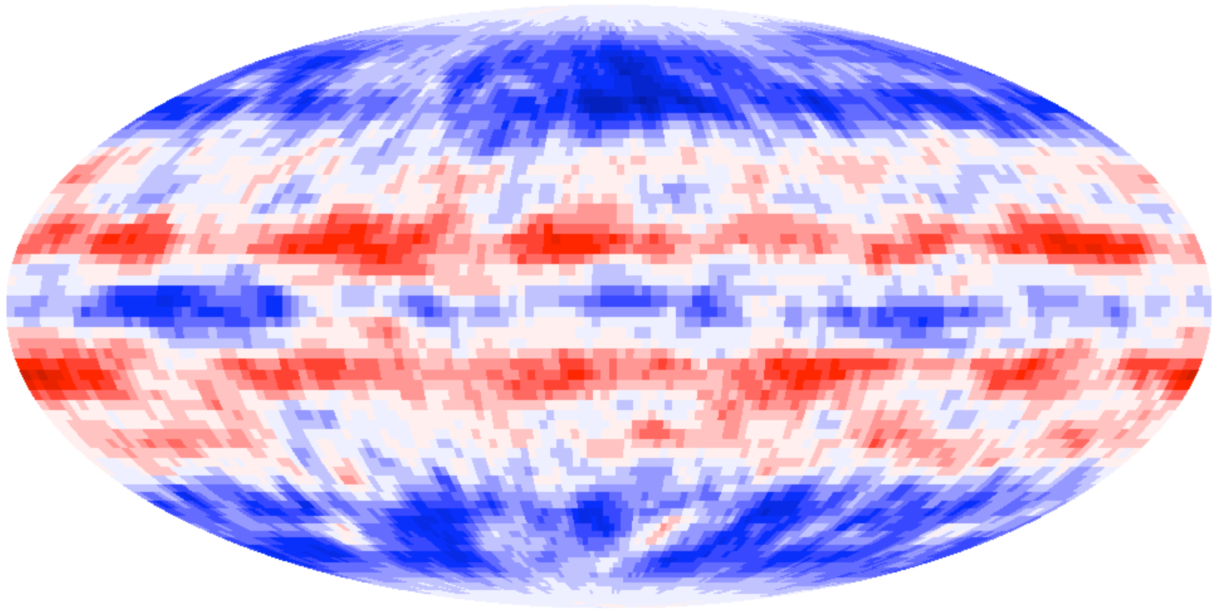


GFDL AM2



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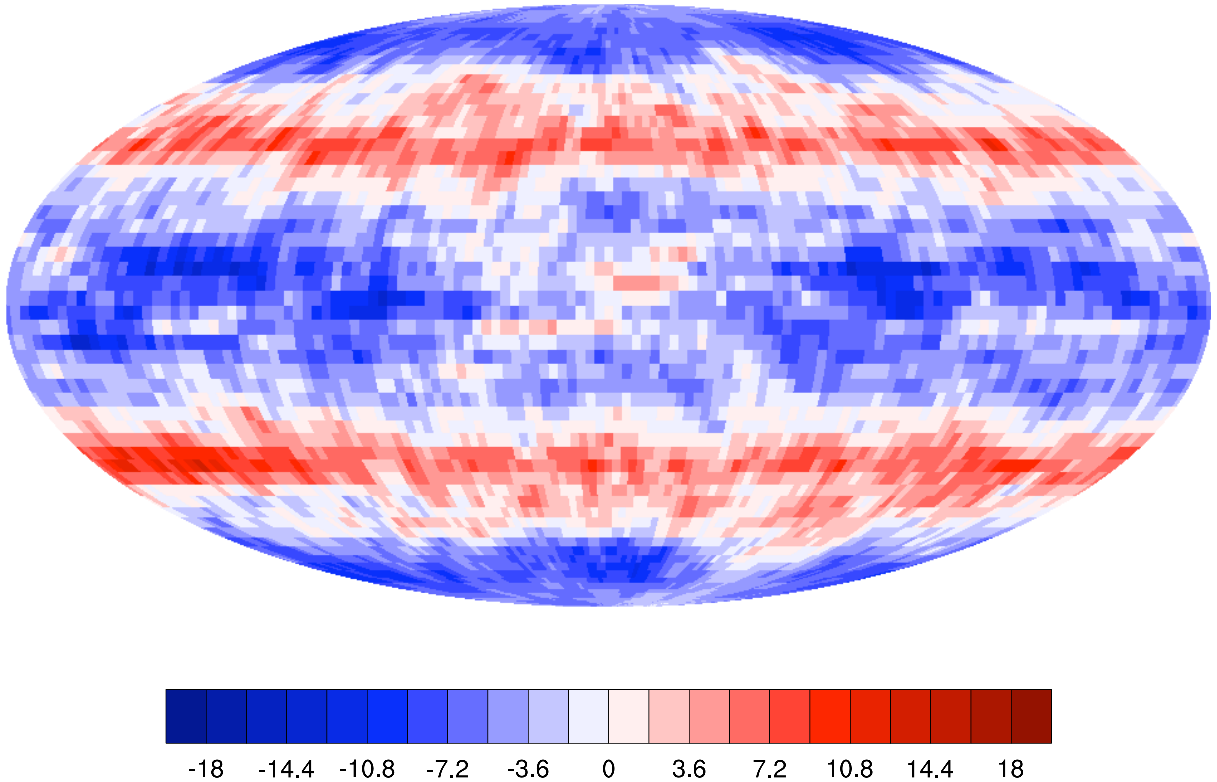

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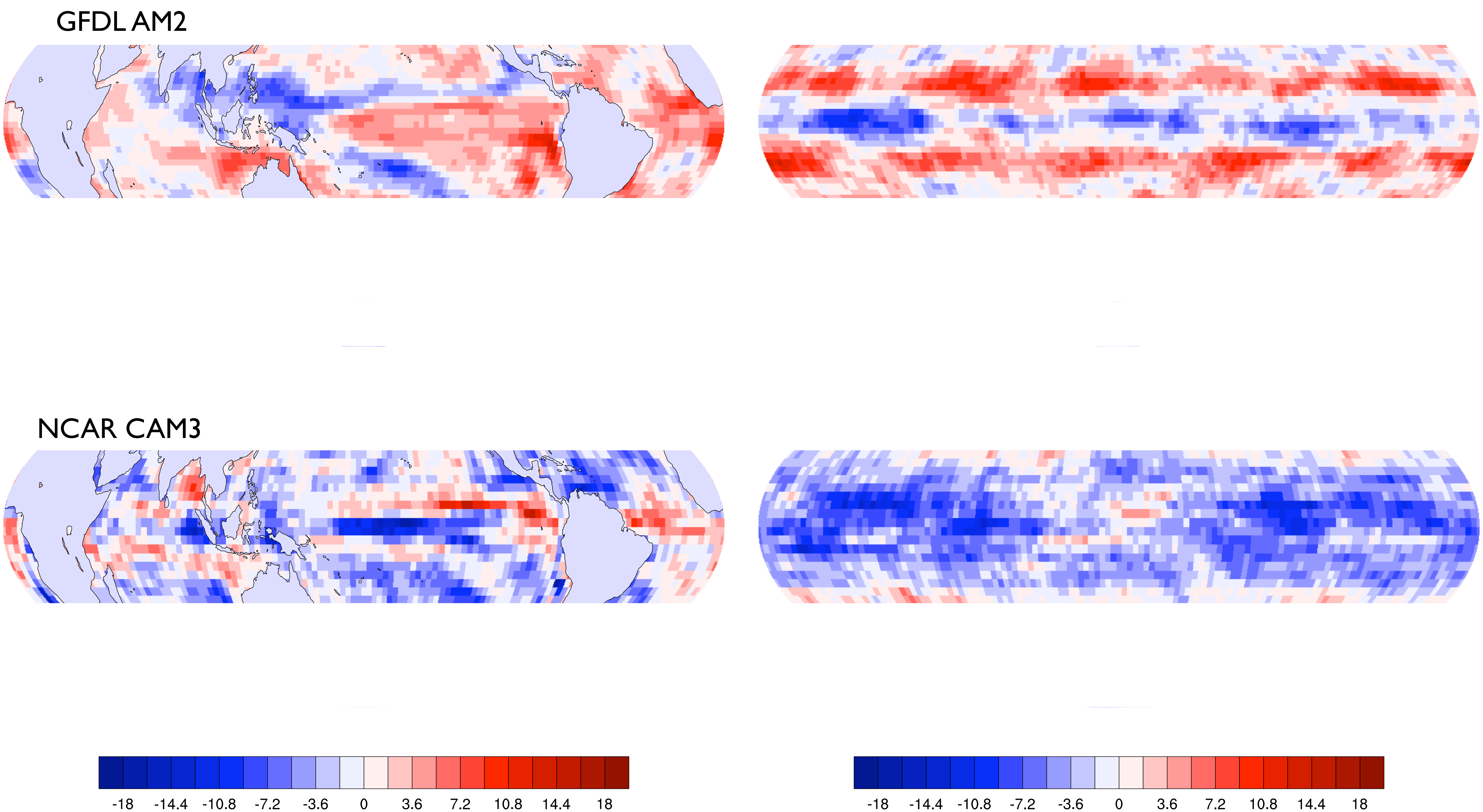
cloud differences

Realistic Planet | **Aqua Planet**



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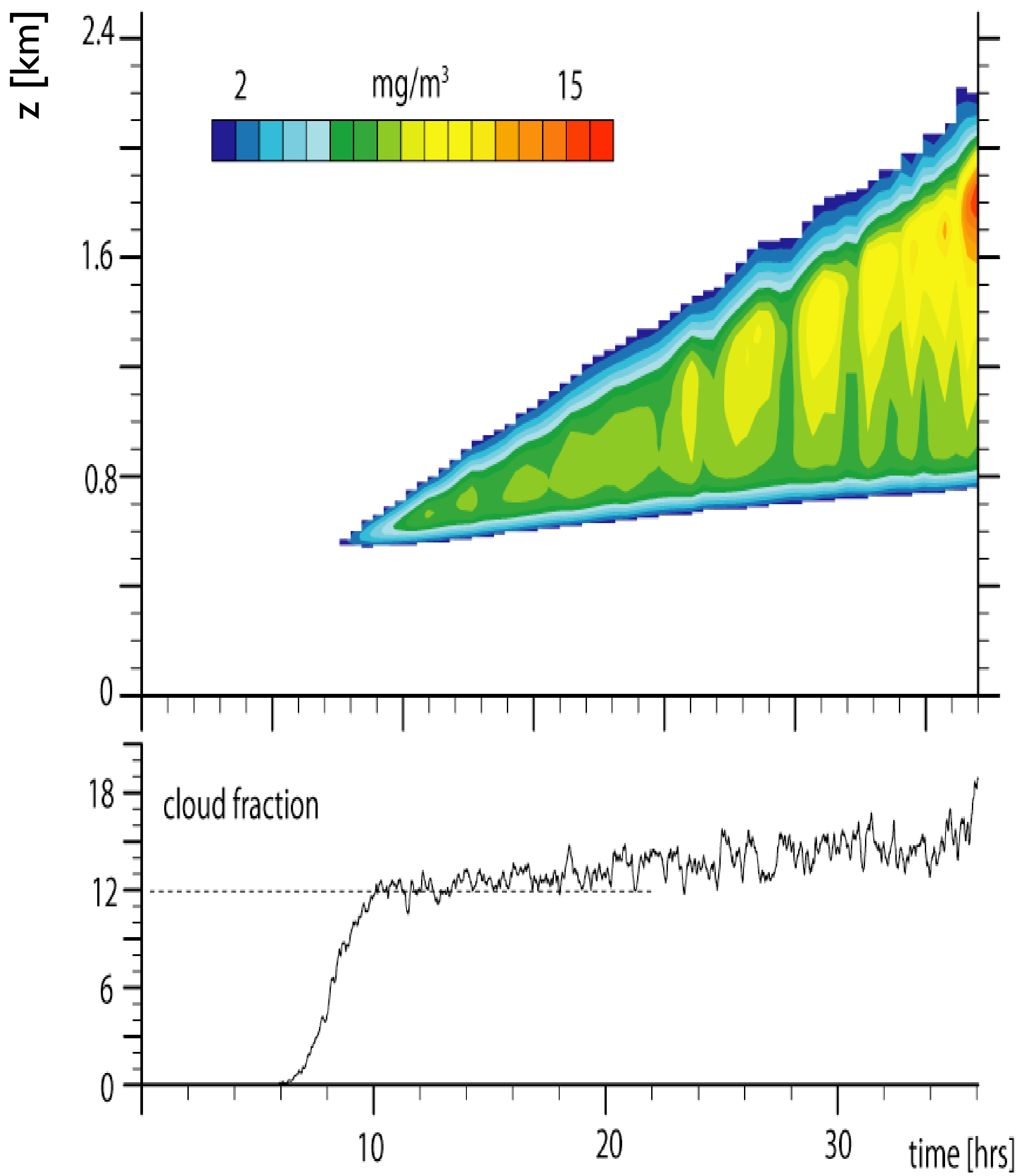
remarks

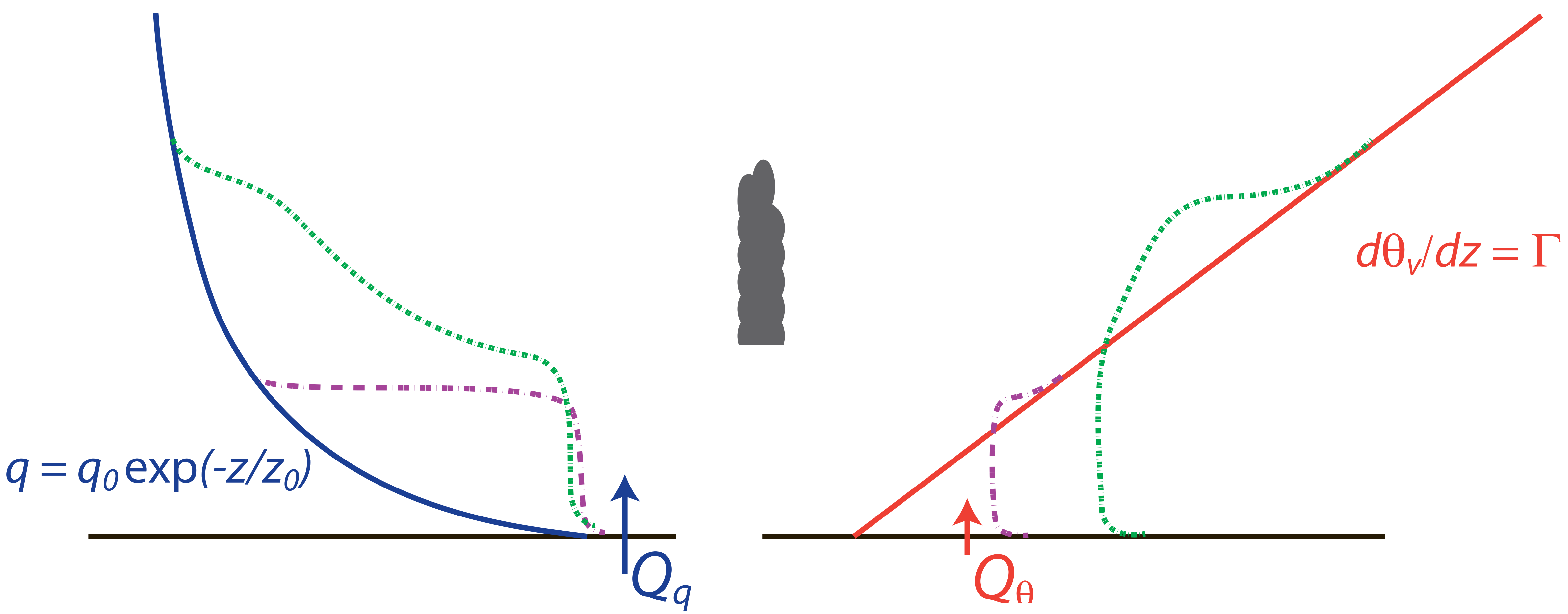
- this problem is much simpler, but apparently relevant.
- by working harder can we characterize the nature of the changes in the environment to which the parameterized clouds are responding.
- if so we can bring data and finescale simulation to bear on the problem to help decide the appropriate response.
- parameterizations designed to represent this response can then be used back in the original problem.

shallow cumulus convection

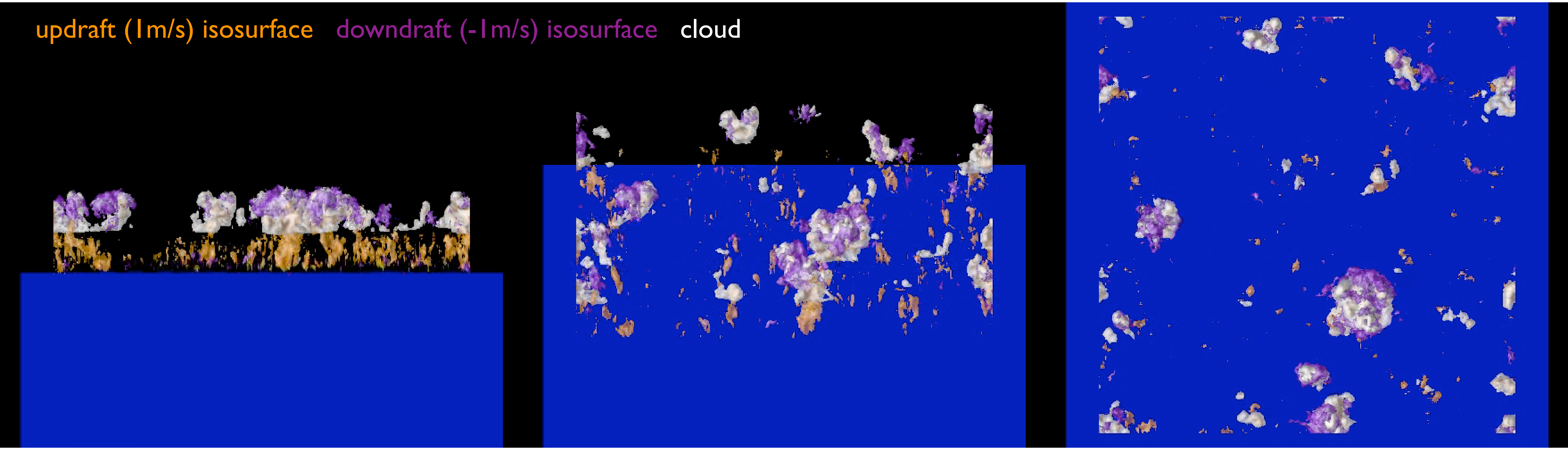


- what determines growth rate of layer?
- cloud fraction & mass flux?
- how does precipitation scale with the depth of the layer?
- how does rain affect the statistics of the layer?

a prototype problem for shallow moist convection.



flow visualization

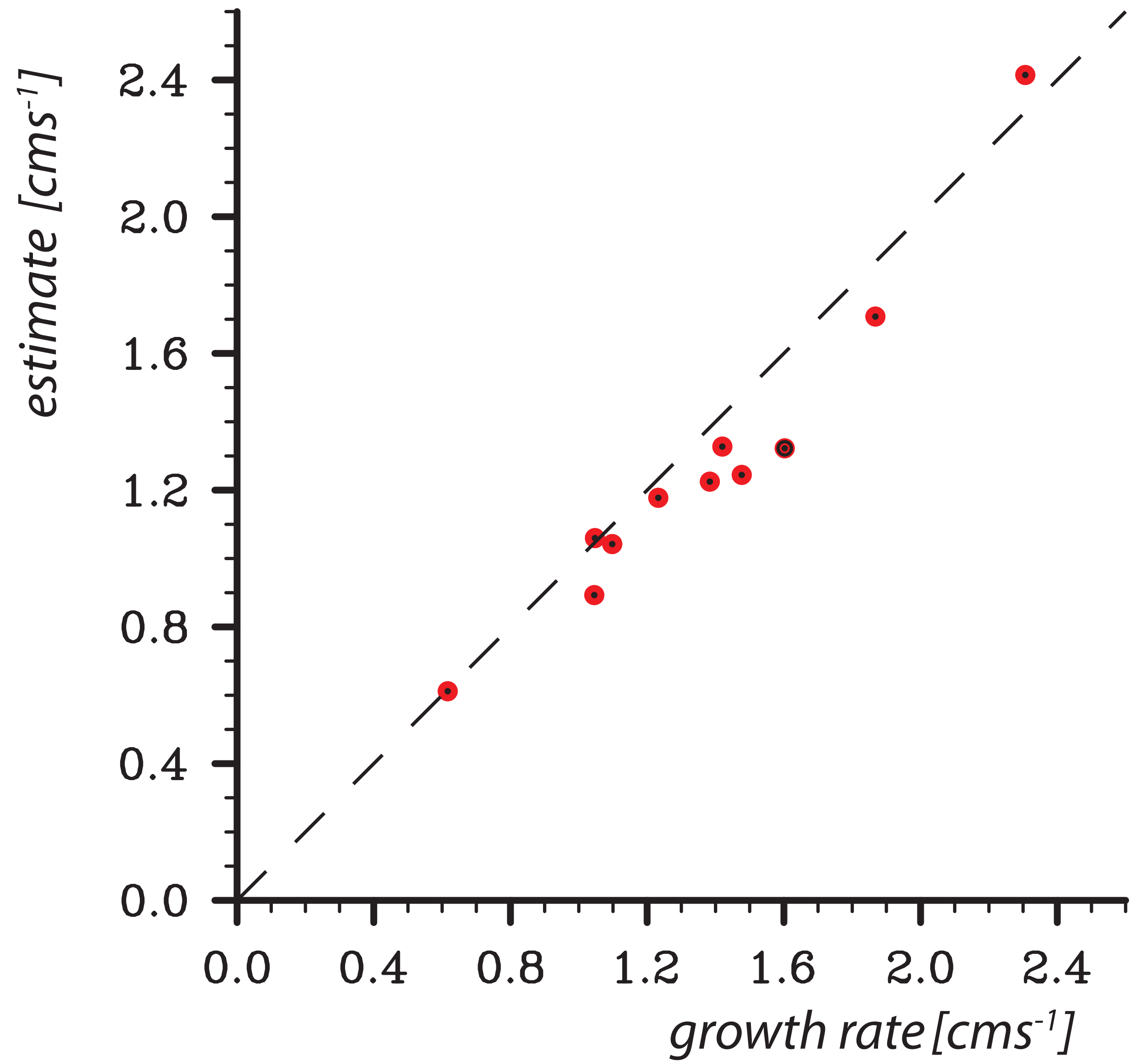


- ***Overview***
  - dx=dy=75m, dz=5m (stretched, 50m at 2km)
  - Nx=Nz=96, Nz=131
  - Simulated 24-36 hours
- ***Nine simulations***
  - Qv = 25 W/m2 (5,15,40)
  - Gamma = 6 K/km (4,8)
  - z0 = 1500 m (500, 1000,2000)
- ***Sensitivity experiments***
  - doubled domain
  - doubled resolution
  - varied q0

predicted versus actual growth rates

Three assumptions

- subcloud layer <=> dry cbl
- cloud water *in cloud layer* is stationary
- cloud layer density slaved to sub-cloud layer



remarks

- this problem is much simpler, but apparently relevant.
- it can be readily simulated and provides a laboratory for systematic parameter studies.
- results of predictions can be compared, in an aggregate sense, to data.
- it provides a framework for investigation simple parameterizations and improving the representation of cloud and boundary layer processes in climate models.

concluding statements

- we have to solve the cloud feed-back problem: are the trades dimming or brightening?
- the tools, resources, and people are in place.
- our greatest challenge is social and organizational.
- one step forward is to agree on the important problems that we wish to attack