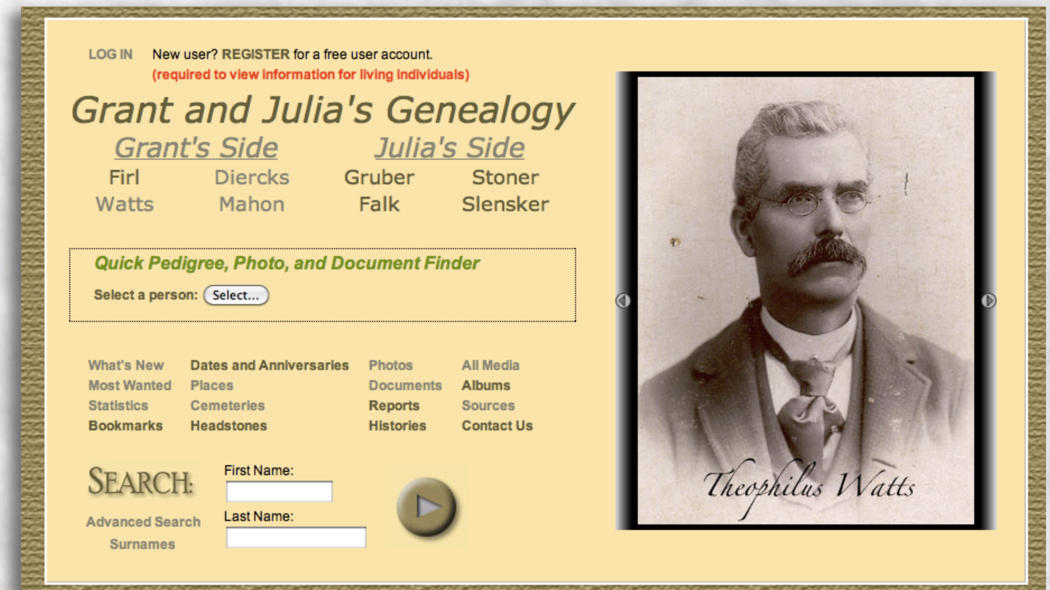
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(required to view information for living individuals)
Grant and Julia's Genealogy
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Flying Under the Radar:

Why Boundary Layer Clouds Are Important and How We're Representing Them

Grant J. Firl

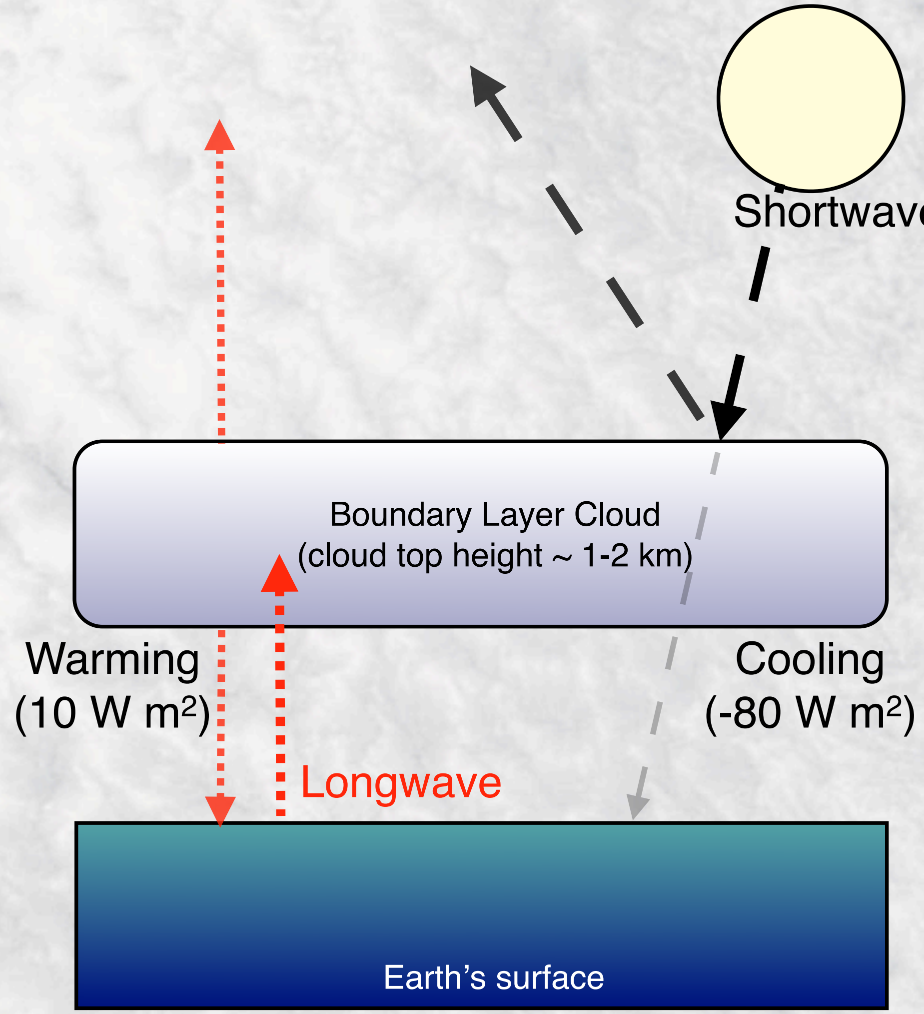
Research Overview
August 3, 2011

Colorado State University
Department of Atmospheric Science
CMMAP
Reach for the sky.

Outline

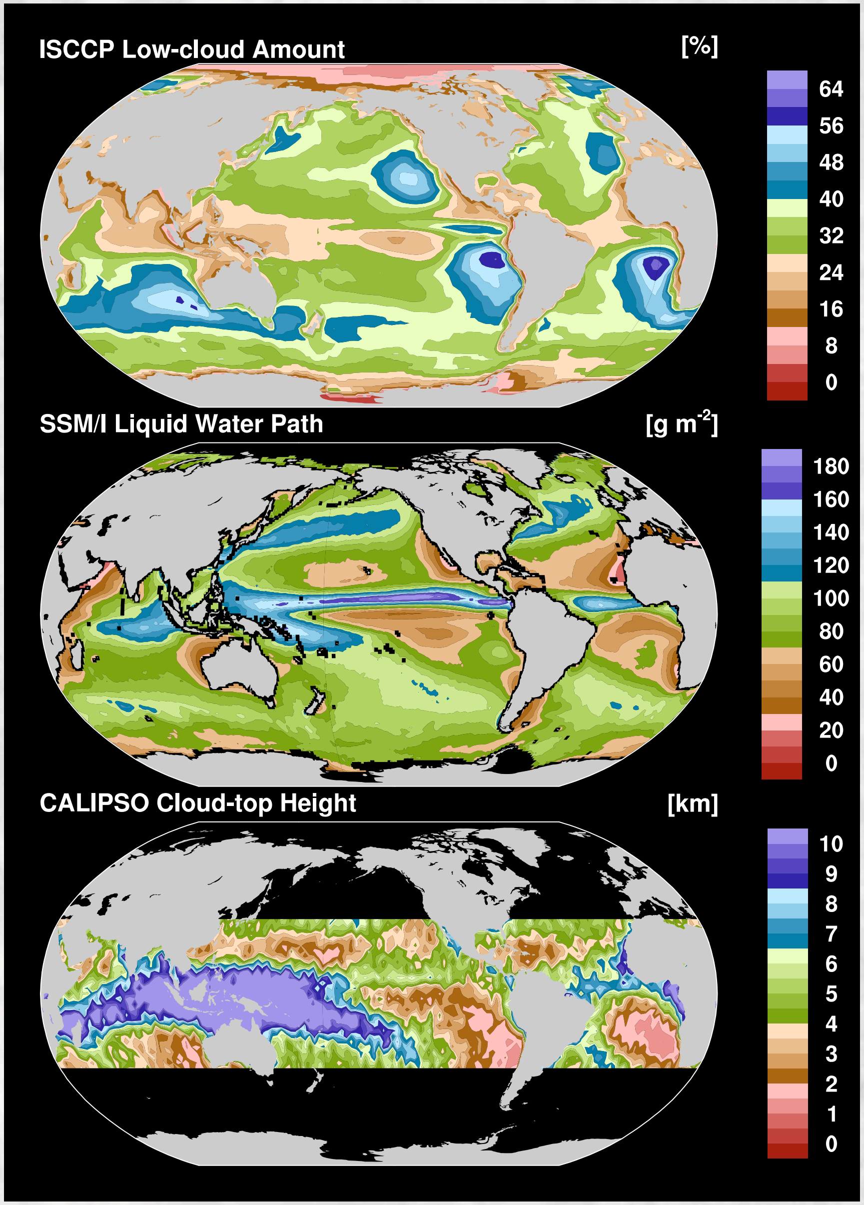
I. Role of boundary layer clouds in climate system
II. Why climate models misrepresent them
III. A potential solution - better turbulence param.
IV. Expected benefits

Low Clouds and Earth's Radiation Budget



Net Cloud Radiative Forcing ~ -70 W m^2 (Cooling)

Low Clouds are Common!



=> abundant (~1/4 of Earth's surface in annual mean)

Low clouds contribute 16 W m^{-2} of cooling (Hartmann et al. 1992)

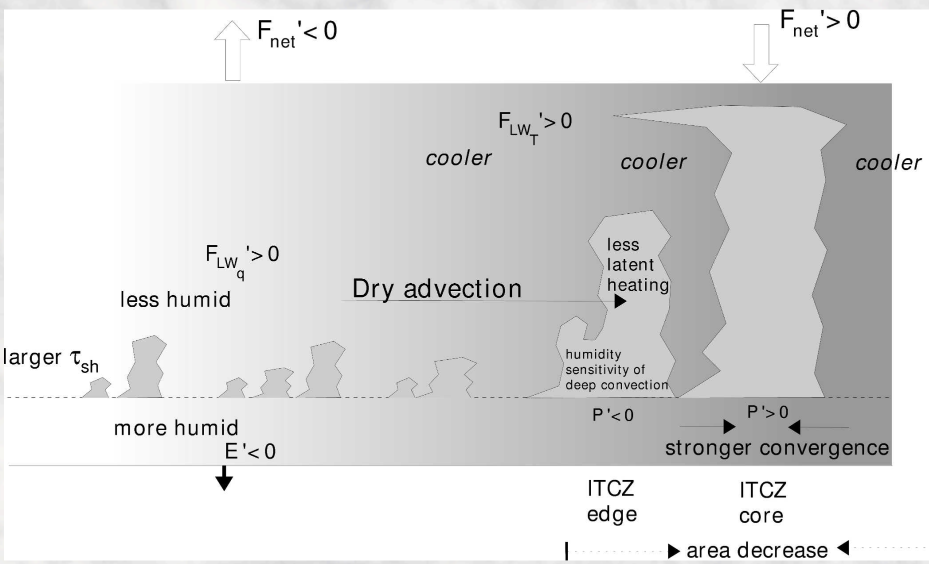
=> shallow, optically thin (compared to deep conv.)

from Brian Medeiros (2009)

It's Not Just Radiation: Transport

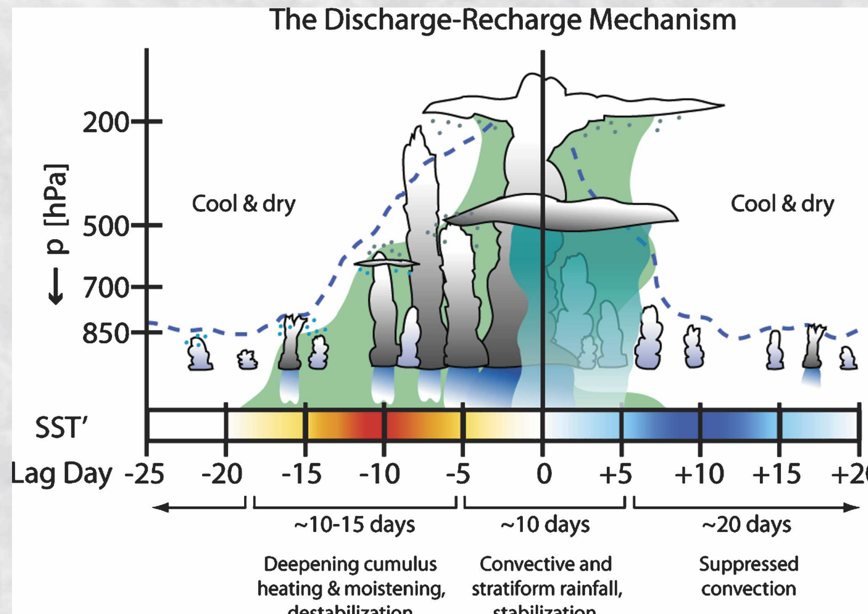
Boundary layer clouds transport heat, momentum, moisture, and chemical constituents from the PBL to the free troposphere...

1. Strength of shallow convection determines how much moisture is transferred from PBL to free atmosphere.
2. If weak, less moisture in mid-troposphere, less vigorous congestus on outskirts of ITCZ, but stronger surface convergence in core



from Neggers et al. (2007)

Shallow convection is thought to play an important role in the MJO, transferring heat and moisture from the PBL into the mid-troposphere, preconditioning it for deeper convection.



from Benedict and Randall (2007)

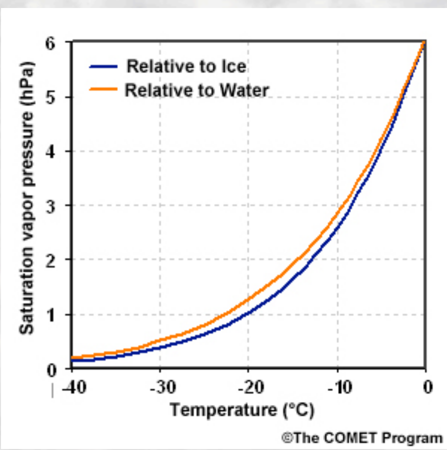
Climate Feedbacks

Clausius-Clapeyron Low Cloud Feedback
(Betts and Harshvardhan, 1987)

Mechanism

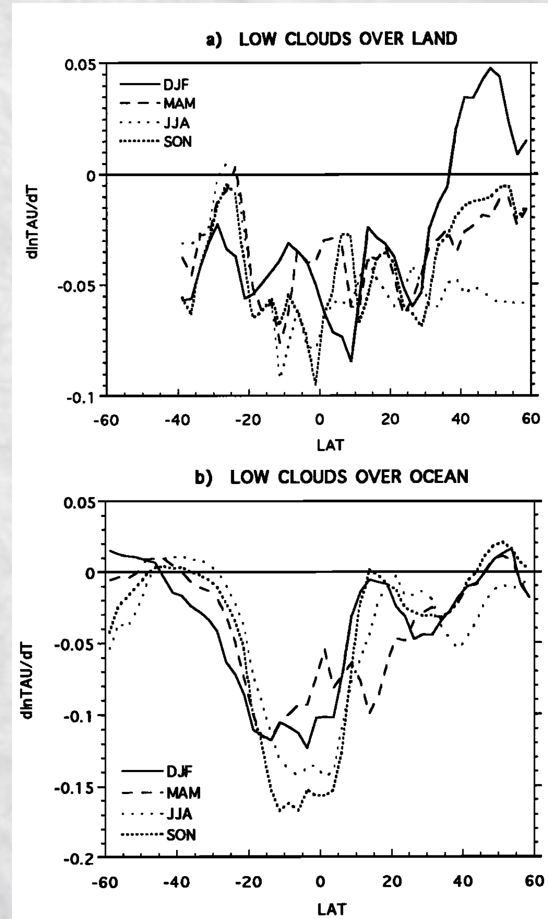
Driver: Warmer Surface

1. Increased PBL moisture
2. Higher vapor content => thicker PBL clouds (higher albedos)
3. Optically thicker clouds reflect more insolation
4. Cools surface (negates driver)



HOWEVER...

Tselioudis and Rossow (1994)



change in cloud optical depth with temperature from ISCCP observations

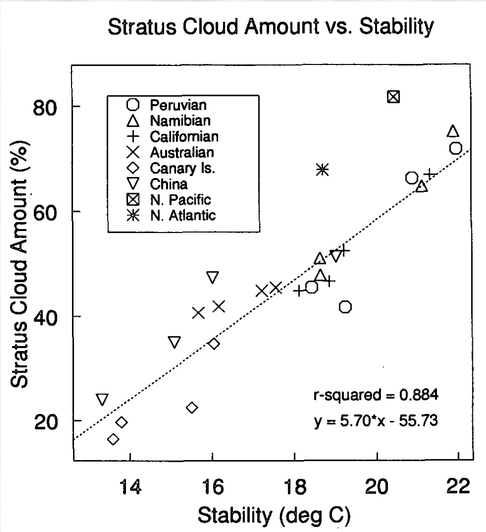
Climate Feedbacks

Lower Tropospheric Stability Feedback
(Klein and Hartmann, 1993)

Mechanism

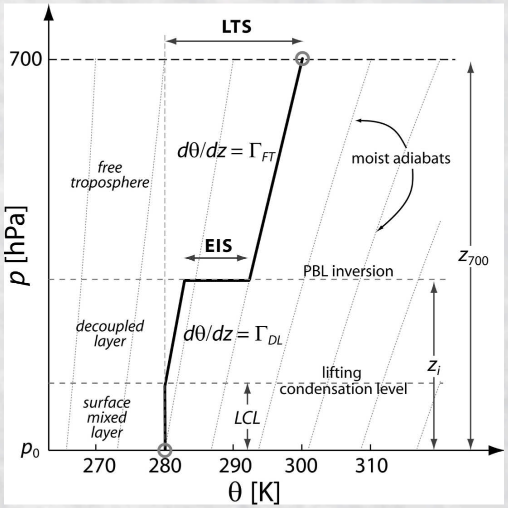
Driver: Warmer Surface

1. Increased PBL moisture
2. More latent heat released in mid, upper troposphere from deep convection
3. Deep convective profile dominates Hadley Cell region, including subtropics
4. Mid-troposphere warming is greater than surface warming in subtropics => greater LTS
5. Stronger LTS associated with more PBL clouds
6. More PBL clouds, more reflection, surface cools



HOWEVER...

Wood and Bretherton (2006)

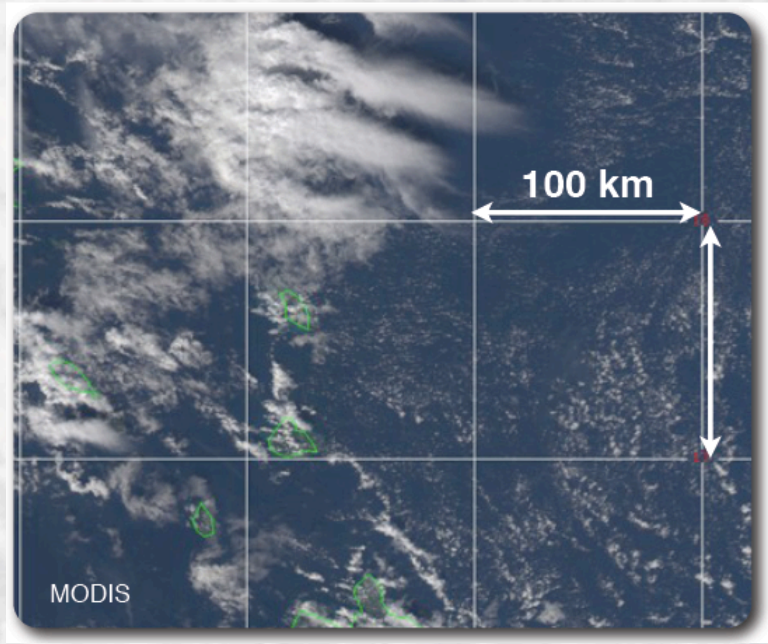


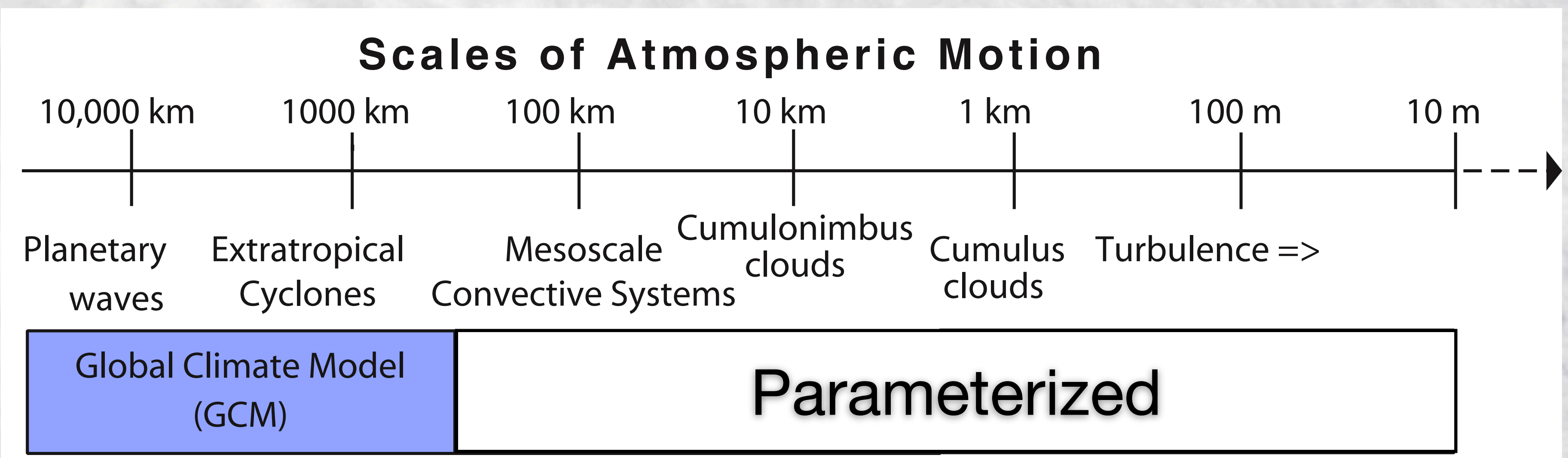
1. LTS is "gross" measure of inversion strength
2. Inversion strength is better predictor of PBL clouds
3. In warming climate, most of the increase in LTS is associated with lapse rate above the inversion

=> This negative feedback might be overestimated

Problem: GCMs and PBL clouds

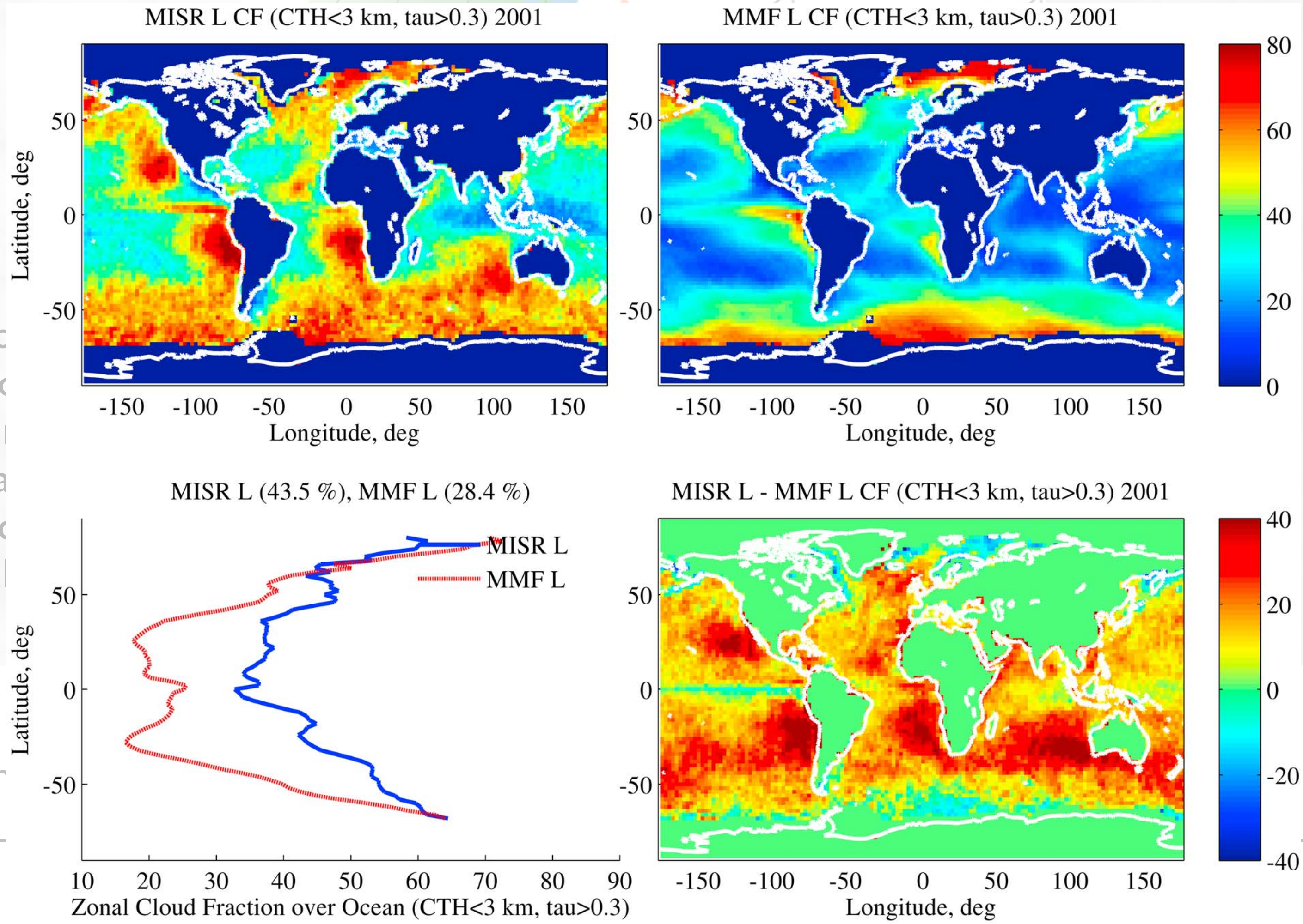
Cloud feedbacks (especially low clouds) are a huge source of uncertainty for modeled climate sensitivity (IPCC- Randall et al., 2007) - Why?





Help is on the way: the MMF

No more cc
List of impro
1.global hyd
2.TOA radia
3.diurnal cyc
4.equatorial
5.MJO



10,000 km

10 m

Planetary waves

Extratropical Cyclones

Mesoscale Convective Systems

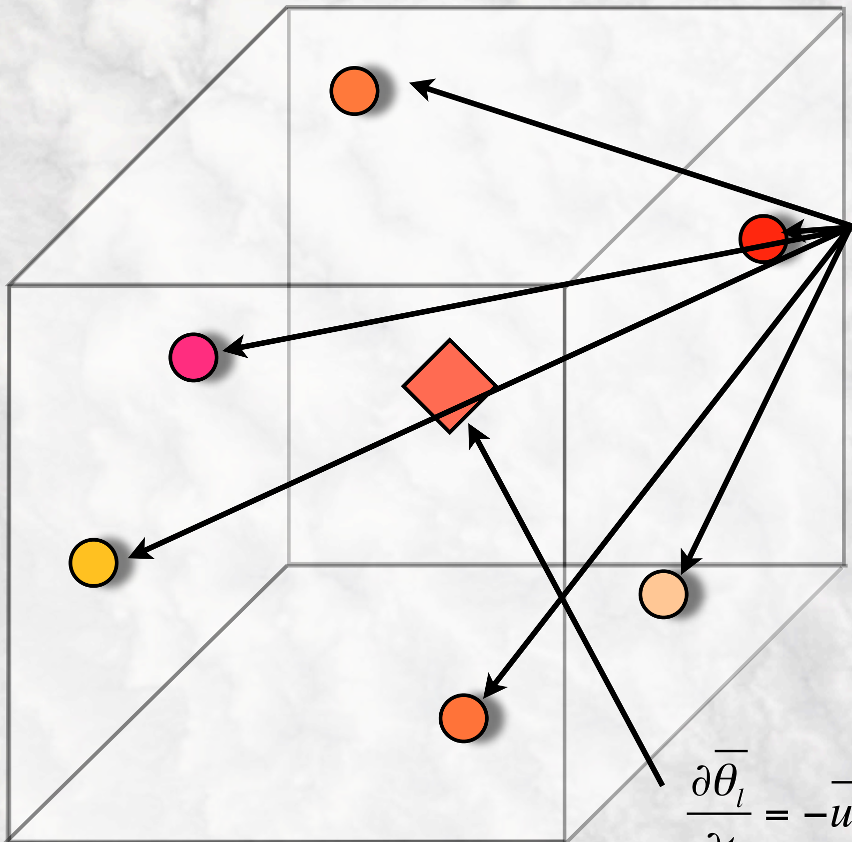
clouds

Cumulus clouds

Turbulence =>

Global Climate Model (GCM)	Cloud System Resolving Model (CSRM)	Parameterized

Why do you need a turbulence parameterization and what does it do?



"Ab Initio"

$$\frac{\partial \theta_l}{\partial t} = -u_j \frac{\partial \theta_l}{\partial x_j} + \nu_{\theta_l} \frac{\partial^2 \theta_l}{\partial x_j^2} - \frac{1}{\rho_0 c_p} \frac{\partial F_j}{\partial x_j} - \frac{L_v}{c_p}\left(\frac{p_0}{p}\right)^{\kappa} \frac{1}{\rho_0} \frac{\partial P}{\partial x_j}$$

Reynolds Averaging

$$\theta_l = \overline{\theta_l} + \theta_l'$$

$$\frac{\partial \overline{\theta_l}}{\partial t} = -\overline{u_j} \frac{\partial \overline{\theta_l}}{\partial x_j} - \frac{\partial \overline{u_j' \theta_l'}}{\partial x_j} + \nu_{\theta_l} \frac{\partial^2 \overline{\theta_l}}{\partial x_j^2} - \frac{1}{\rho_0 c_p} \frac{\partial \overline{F_j}}{\partial x_j} - \frac{L_v}{c_p}\left(\frac{p_0}{p}\right)^{\kappa} \frac{1}{\rho_0} \frac{\partial \overline{P}}{\partial x_j}$$

Levels of Parameterization

Complexity, Cost, Skill

1. First-order Closure

$$\overline{u_j'\theta_l'} \approx -K \frac{\partial \overline{\theta_l}}{\partial x_j}$$

- not applicable for all situations

2. Second-order Closure

$$\frac{\partial \overline{u_j'\theta_l'}}{\partial t} = \dots$$

- problems with convective boundary layers

3. Third-order Closure

$$\frac{\partial \overline{u_j'\theta_l'}}{\partial t} = \dots$$

$$\frac{\partial \overline{u_i'u_j'\theta_l'}}{\partial t} = \dots$$

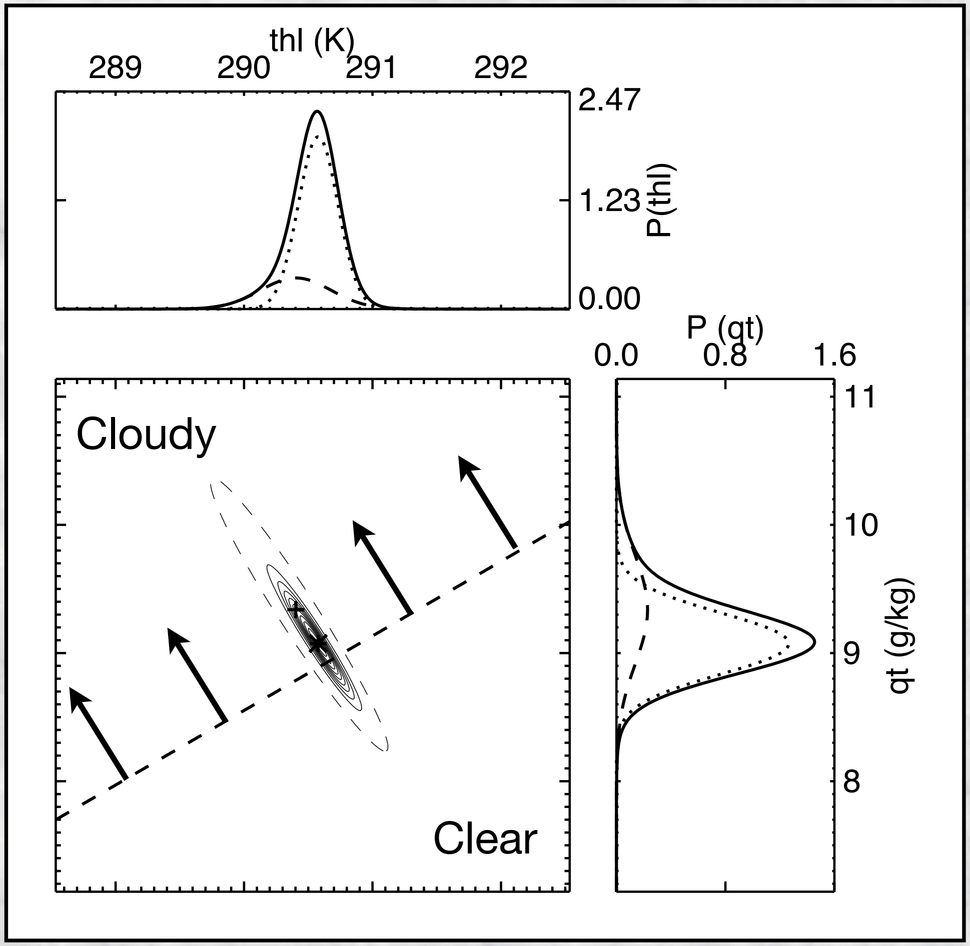
- more expensive, but best skill

★ My scheme: “quasi-third-order closure”

Subgrid-scale Cloudiness

Remember stats class... $\overline{\theta_l'^2}, \overline{\theta_l' q_t'}, \overline{q_t'^2}$ are variances/covariances.

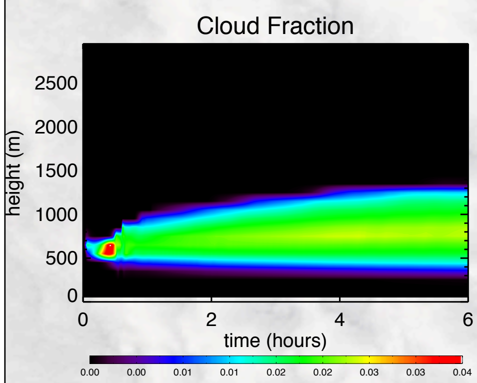
Assume the shape of the variability follows a double joint Gaussian PDF.
(Larson et al., 2002)



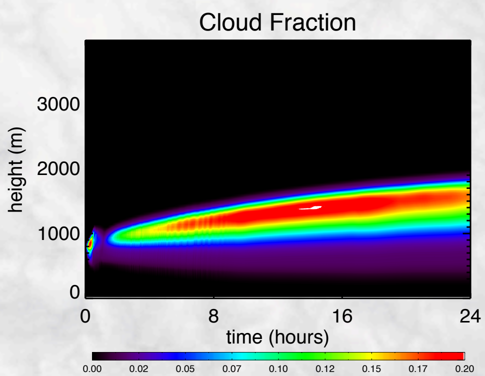
Testing the New Scheme

1. A variety of test cases were run, representing the range of boundary layer regimes and results compared favorably with observations and LES.

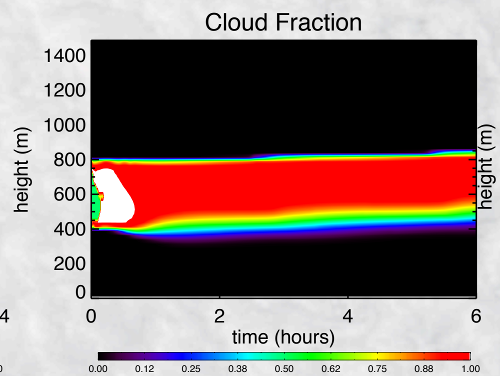
BOMEX
trade-wind cu



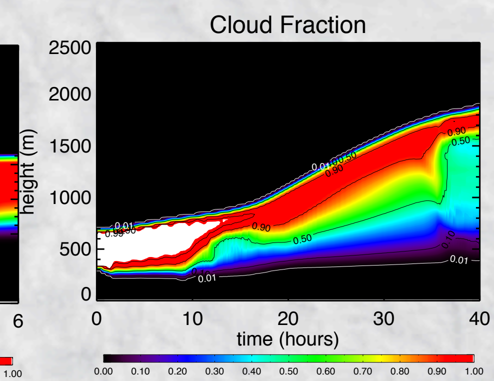
RICO
precipitating
trade-wind cu



DYCOMS
precipitating
nocturnal sc



ASTEX
precipitating
sc -> cu



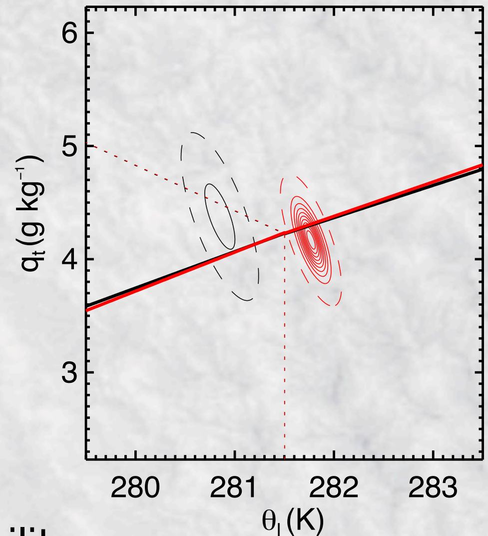
2. The new scheme was put into the VVM (cloud resolving model) and tested. Comparing the output to observations and LES intercomparison studies, the model with the new scheme performed much better than with the original scheme.

3. We are in the process of putting the new scheme in the MMF and have plans to use the scheme in thew new CSU global CRM.

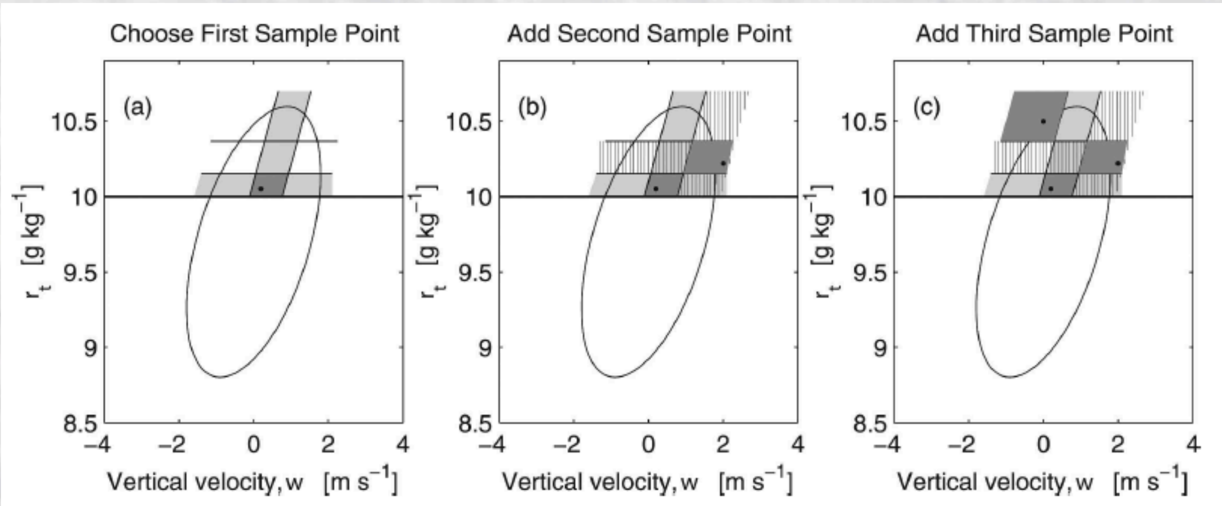
Current Work

Ongoing Development...

1. Adding Ice
   - need to consider saturation over liquid water and ice
   - integrate over nonstandard region
   - cloud ice depends on T, ice nuclei, etc.



2. Driving microphysics using subgrid variability
   - Latin-Hypercube sampling (Larson et al., 2005)



Expected Benefits

1.Modeling

- Works by Noda et al. (2010), Cheng and Xu (2010), and Bogenschutz and Krueger (2011) show that improving a GCM's turbulence parameterization and including SGS condensation can significantly improve the representation of boundary layer clouds
- We can expect similar improvements by including my new scheme into CSU's MMF and new GCRM
  - larger shields of stratocumulus off of western coasts and larger areas of shallow cumulus
  - improved representation of fluxes of heat, moisture, momentum, CO2, etc. throughout PBL (particularly in convectively active regions)
  - more accurate optical depths of PBL clouds => better radiative fluxes
  - better "shallow convective humidity throttle" for ITCZ and MJO
  - more accurate entrainment rates at the boundary layer top

2.Scientific Questions

- Better modeling of boundary layer clouds affords one to study the following questions:
  - To what extent do shallow cumuli control the areal extent and strength of deep convection in the ITCZ and MJO through vertical moisture redistribution?
  - What is the magnitude of the negative climate feedback associated with increased subtropical inversion strength?
  - What are the sign and magnitude of the low cloud feedback associated with the Clausius-Clapeyron relationship?