Stratocumulus to Cumulus Transition CPT

Main Goal: To improve the representation of the cloudy boundary layer in global weather/climate models with a focus on the subtropical stratocumulus to cumulus (Sc-Cu) transition

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(with additional internal JPL and DOE funds)

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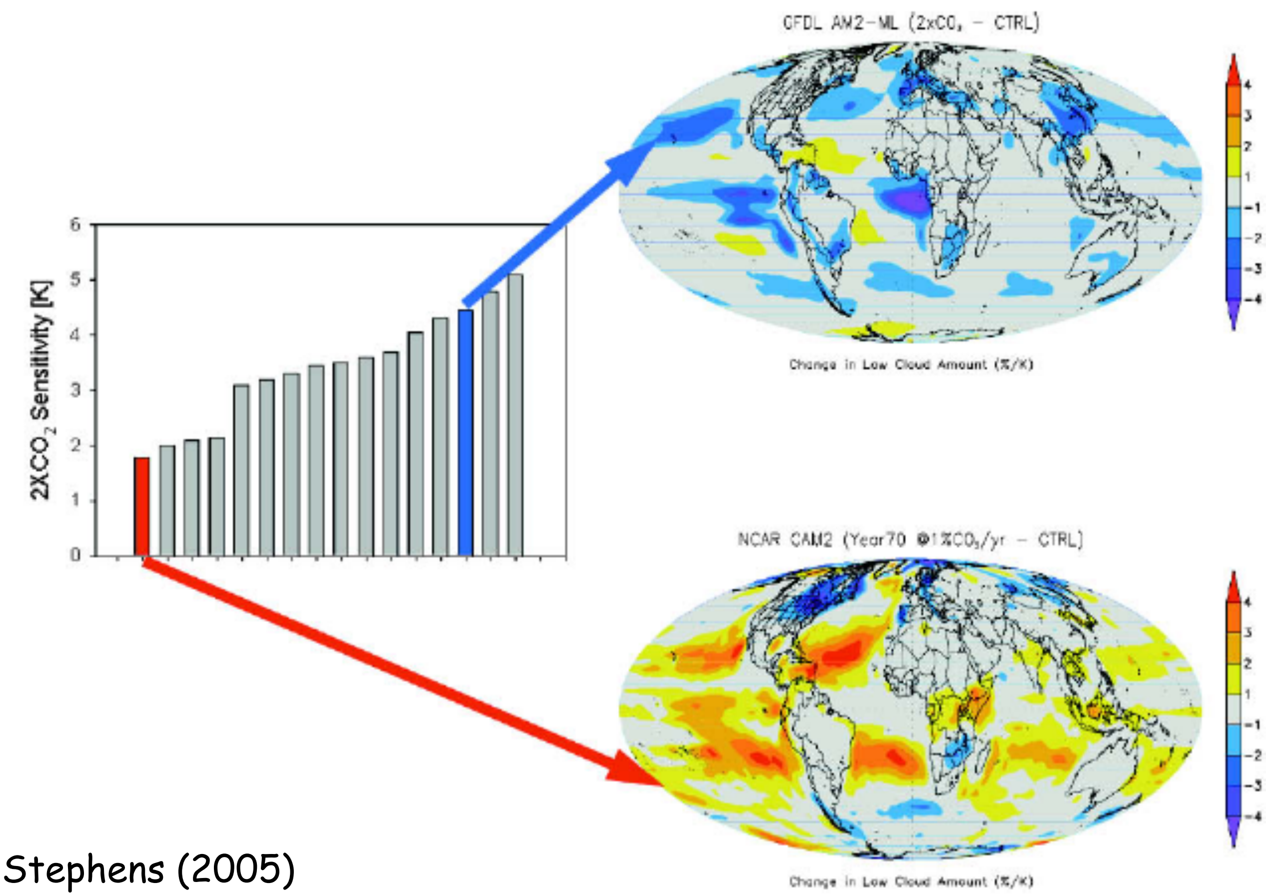
Climate is changing … YET there is large uncertainty in climate prediction

IPCC 2007: "Cloud feedbacks remain the largest source of uncertainty"



Doubling CO_2 ➔ less low clouds in GFDL ➔ 4 K global warming

Doubling CO_2 ➔ more low clouds in NCAR ➔ 2 K global warming

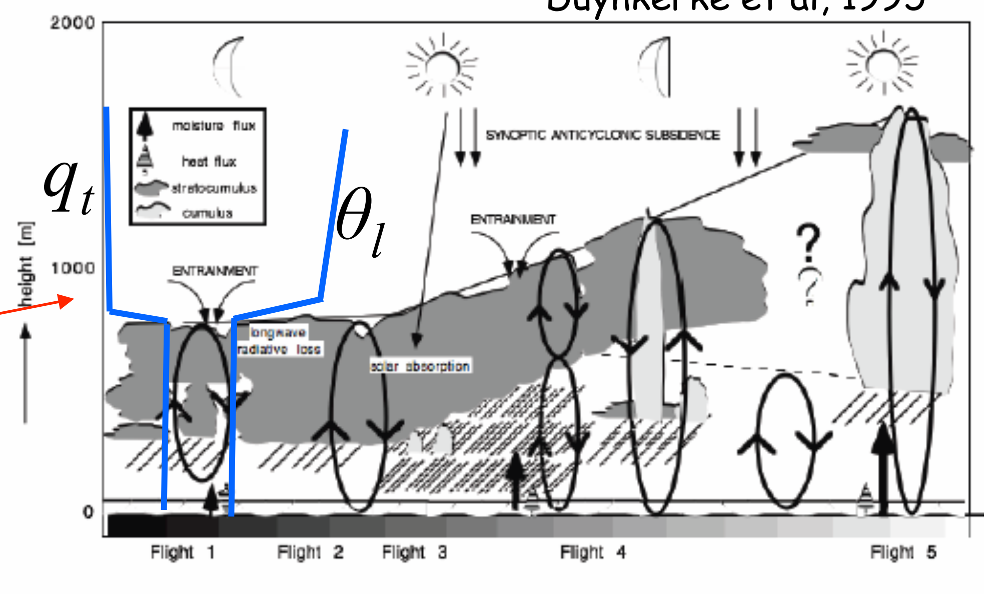
Stephens (2005)

Major uncertainty is in the stratocumulus to cumulus regions

GEWEX Cloud Systems Study (GCSS): Two new Sc-Cu transition case-studies

ASTEX
Lagrangian 1992

Duynkerke et al, 1995



SST=290K	SST=293K	SST=295K
CA =100%	CA = 100%	CA = 60%
LWP=50 gm^{-2}	LWP=140 gm^{-2}	LWP=40 gm^{-2}

GCSS Working Group 1 will spend next 3 years evaluating LES and SCMs for two new Sc-Cu transition case-studies

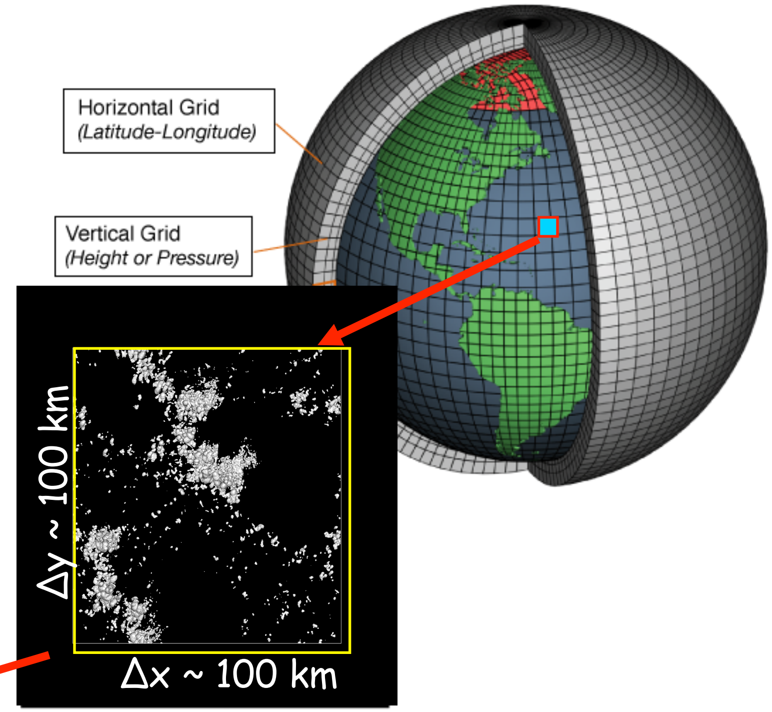
Optimal period to develop and test new parameterizations for Sc-Cu transition in NCEP and NCAR models

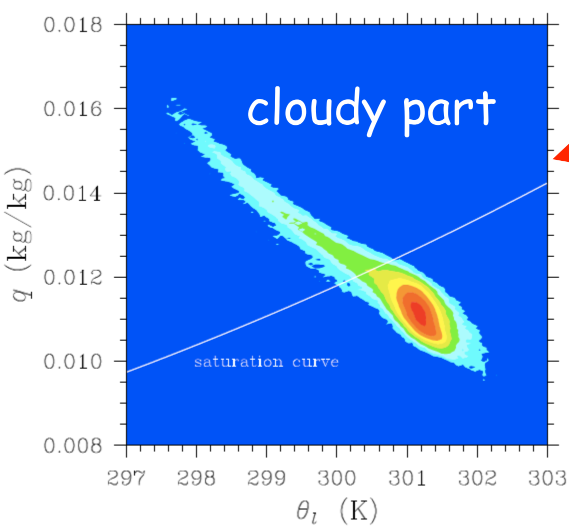
Parameterization of subgrid turbulence and clouds in climate models

3) <u>3D Climate Models</u>:

Large-scale dynamics +
1D dimensional physics

➔ Interaction between boundary layer clouds and large scale

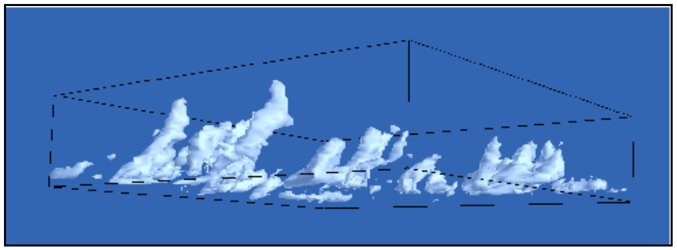




If PDF shape is known ➔ it is possible to compute cloud fraction and liquid water

In essence: 'cloud problem' is a question of representing small-scale turbulence/mixing

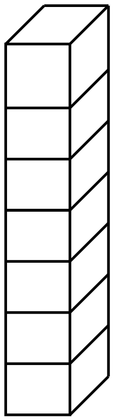
Strategy for climate model physics development

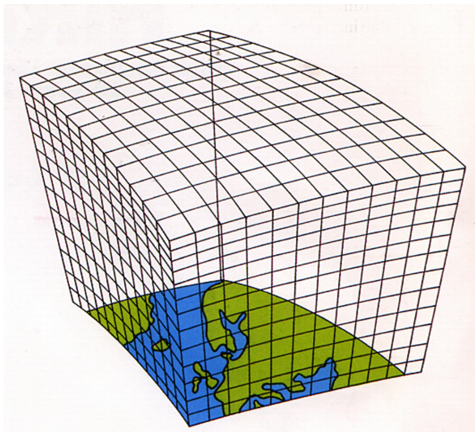


High-resolution model data:

Large Eddy Simulation (LES) models

Cloud Resolving Models (CRMs)





Testing in Single Column Models:

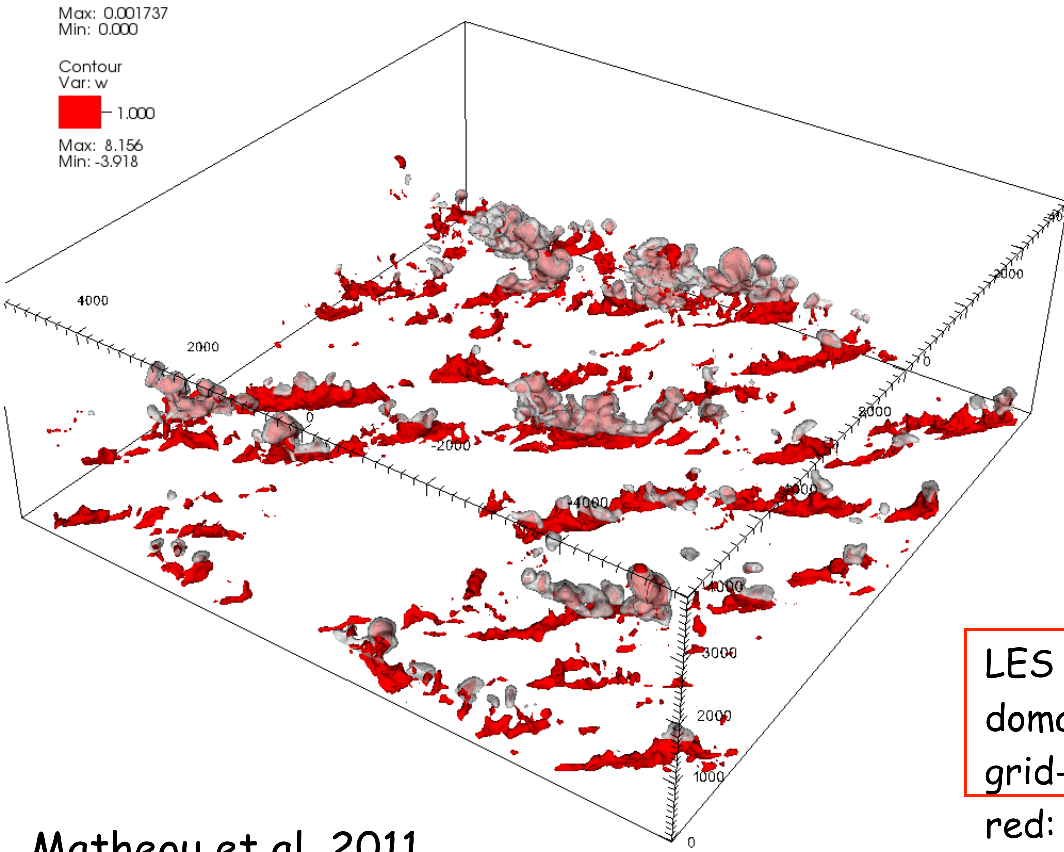
Versions of Climate Models

3D Climate/Weather Models:

Evaluation and Diagnostics with satellite observations

LES/CRM models provide unique information on small-scale statistics

Large Eddy Simulation (LES) models and Cumulus convection



detailed clouds and vertical velocity

Matheou et al, 2011

LES of Cumulus case
domain: 12 × 12 x 4 km
grid-size: 20 m
red: vertical velocity = 1 m/s

LES models solve fluid dynamics equations with resolutions of order 10 m

LES models explicitly resolve most atmospheric turbulence/convection

Eddy-Diffusivity/Mass-Flux (EDMF)

Dividing a grid square in two regions (updraft and environment) and using Reynolds decomposition and averaging leads to

$$\overline{w'\varphi'} = a_u \overline{w'\varphi'}_u + (1-a_u)\overline{w'\varphi'}_e + a_u(1-a_u)(w_u - w_e)(\varphi_u - \varphi_e)$$

where a_u is the updraft area. Assuming a_u<<*1* and w_e~*0* leads to

$$\overline{w'\varphi'} = \overline{w'\varphi'}_e + a_u w_u(\varphi_u - \overline{\varphi})$$

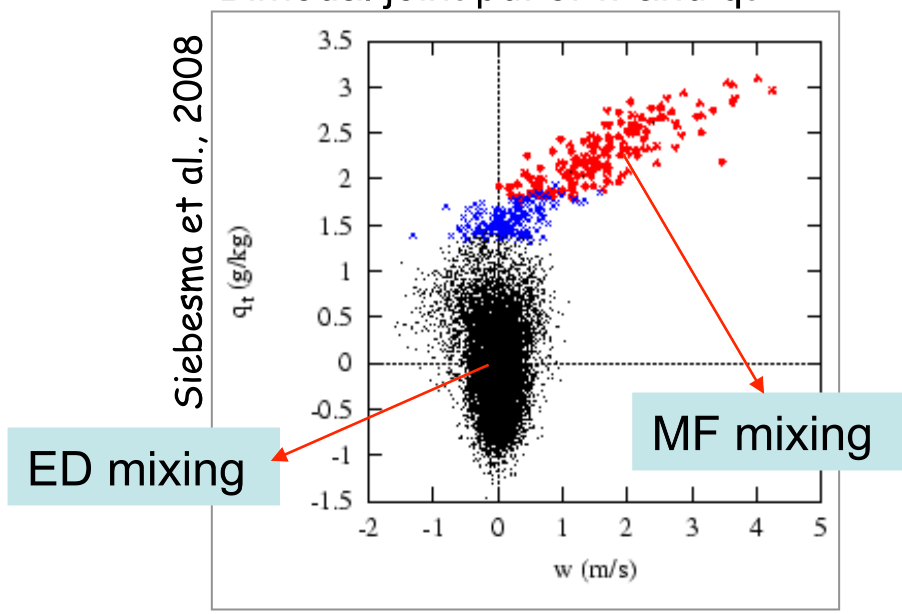
ED closure: assuming ED for 1st term and neglecting 2nd term

MF closure: neglecting 1st term and assuming $M=a_u w_u$

EDMF: $$\overline{w'\varphi'} = -k\frac{\partial\overline{\varphi}}{\partial z} + M(\varphi_u - \overline{\varphi})$$

Siebesma & Teixeira, 2000

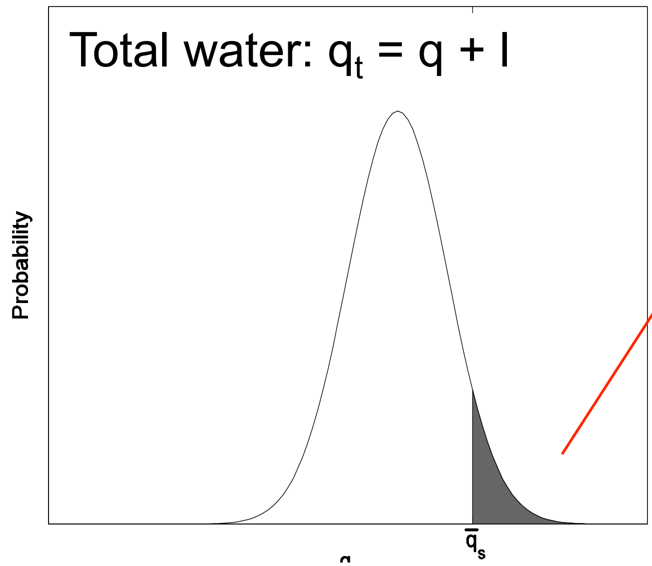
Bimodal joint pdf of w and qt



EDMF may be able to reproduce the mixing for the entire Sc-Cu transition

PDF-based Cloud Parameterization

PDF cloud parameterizations are based on the pdf of q_t (in this simple example) or on the joint pdf of q_t and θ_l



Values larger than saturation are cloudy

$$a = \int_{q_s}^{+\infty} p(q_t)\,dq_t$$

a = cloud fraction

$$\bar{l} = \int_{q_s}^{+\infty} (q_t - \overline{q_s})\,p(q_t)\,dq_t$$

Mellor, 77; Sommeria & Deardorff, 77

With Gaussian distribution we obtain cloud fraction and liquid water as a function of Q:

$$a = \frac{1}{2} + \frac{1}{2} erf\left(\frac{Q}{\sqrt{2}}\right)$$

$$\frac{l}{\sigma} = aQ + \frac{1}{\sqrt{2\pi}} e^{-Q^2/2}$$

$$Q = \frac{q_t - q_s}{\sigma}$$

CPT Current Main Tasks

GCSS Sc-Cu cases with NCAR and NCEP SCMs, and LES
(UW, NCAR, NCEP, JPL)

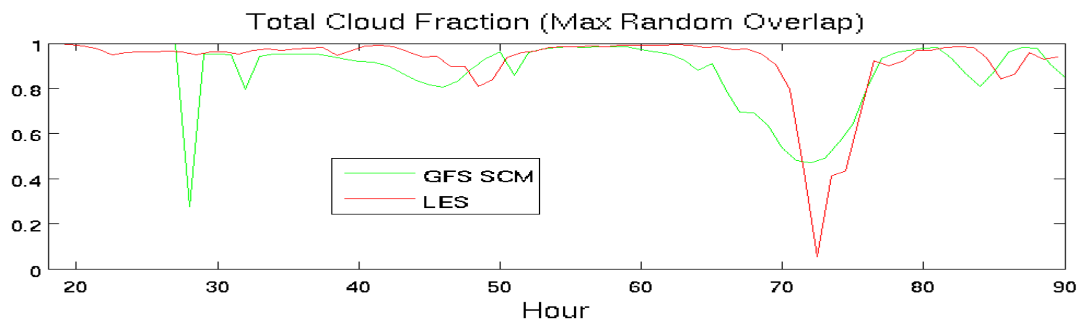
Detailed coupled/uncoupled diagnostics with NCEP/NCAR models
(NCEP, NCAR, UCLA)

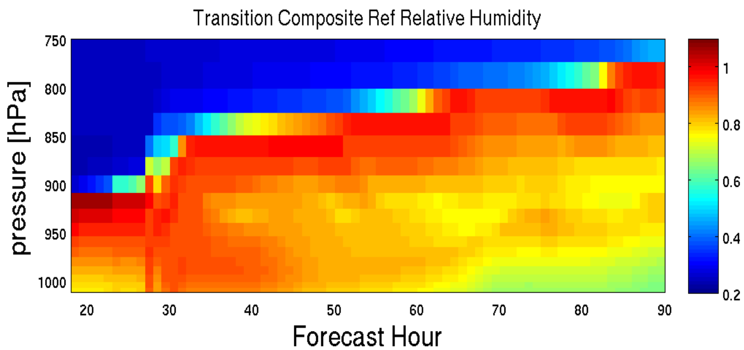
Development/testing of PDF cloud parameterization in NCAR
(LLNL, NCAR)

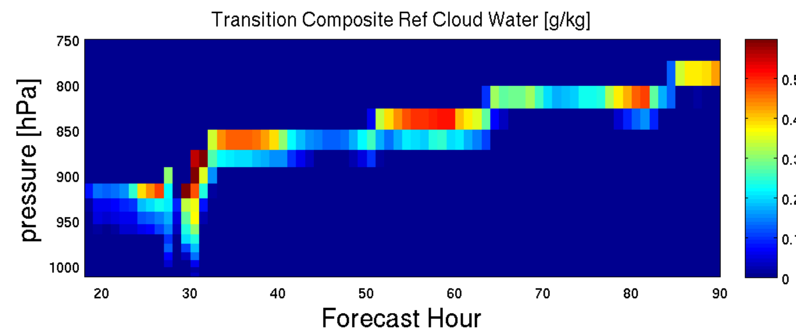
Development/testing of EDMF approach in NCEP and NCAR
(JPL, NCEP, NCAR, UW)

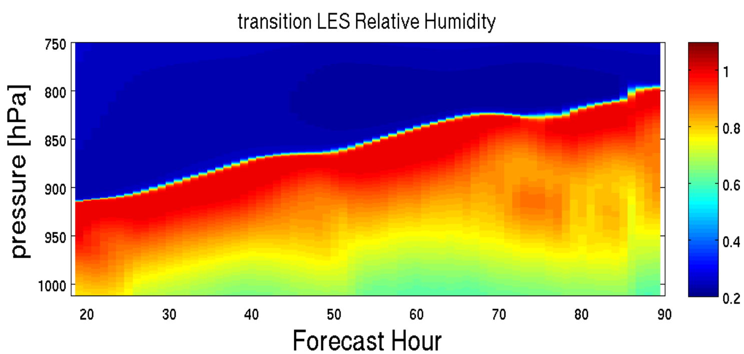
Sc-to-Cu composite transition case with NCEP SCM

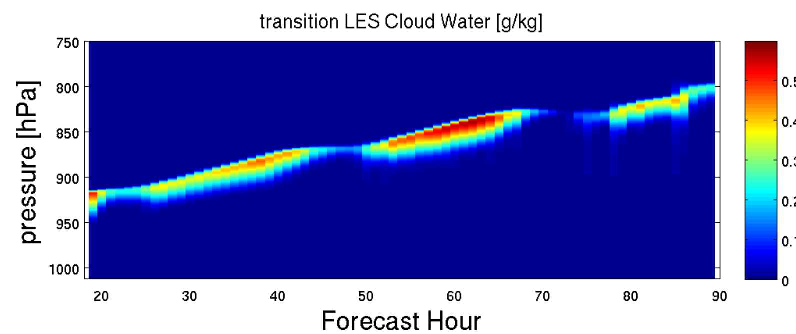
Fletcher et al, UW







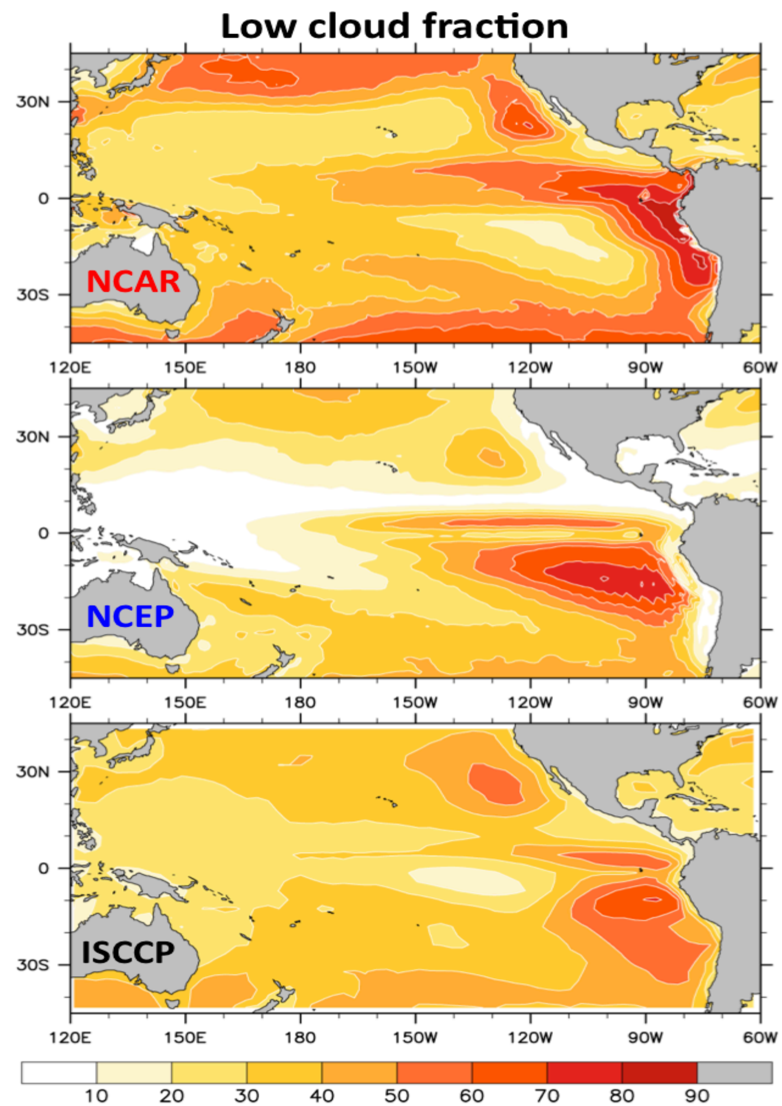




NCAR and NCEP SCM results will be submitted soon
JPL LES results will be submitted soon

NCEP Model Diagnostics

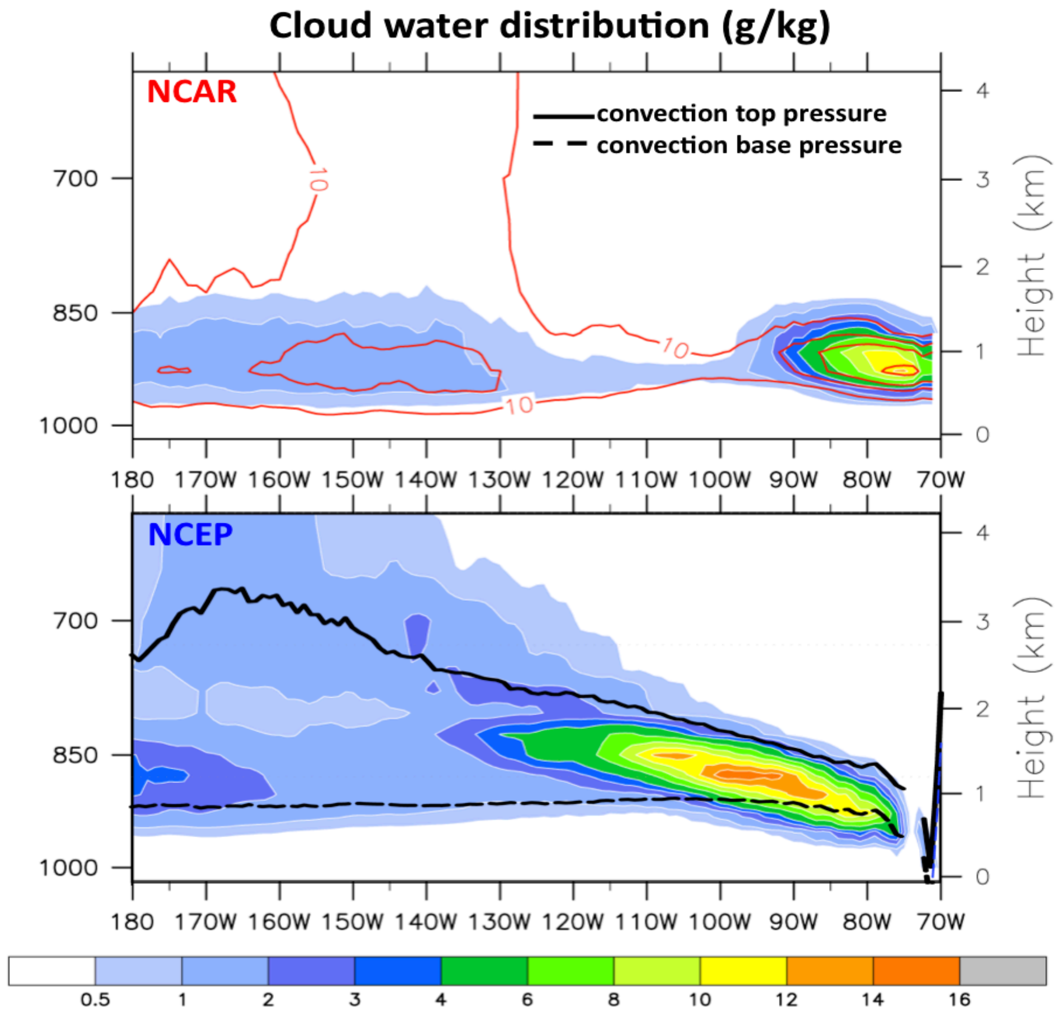
- NCAR CESM 1.0 (coupled version of CAM 5.0, 200-year run)
- NCEP CFS (coupled version of operational GFS, 20-year)
- Modified NCAR AMWG diagnostic package to add NCEP GFS output
- NCEP has TOA energy imbalance
- Both models reproduce basic global circulation patterns
- Both models have cloud biases



Xiao et al, UCLA

NCEP/NCAR diagnostics of cloud transition

October climatology along 20 S cross-section



NCAR and NCEP results are significantly different