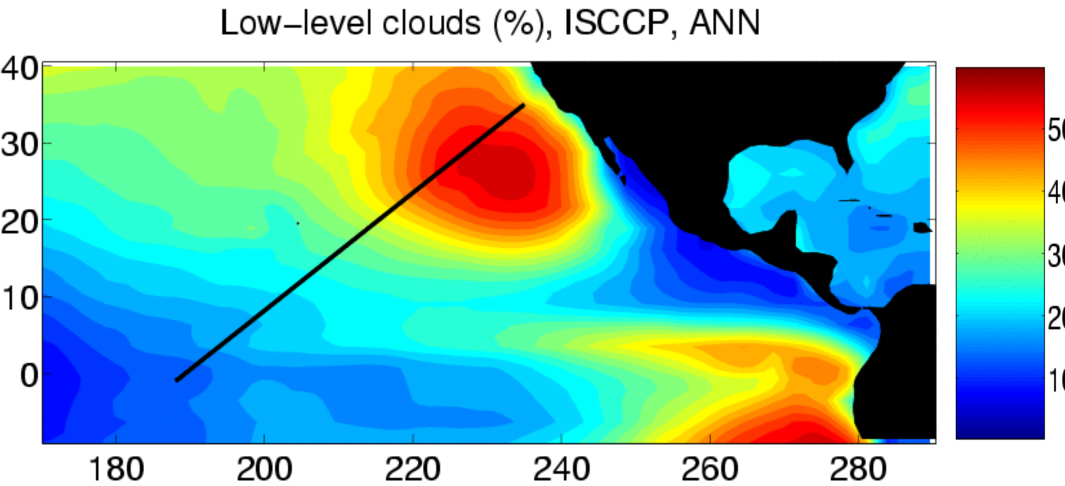
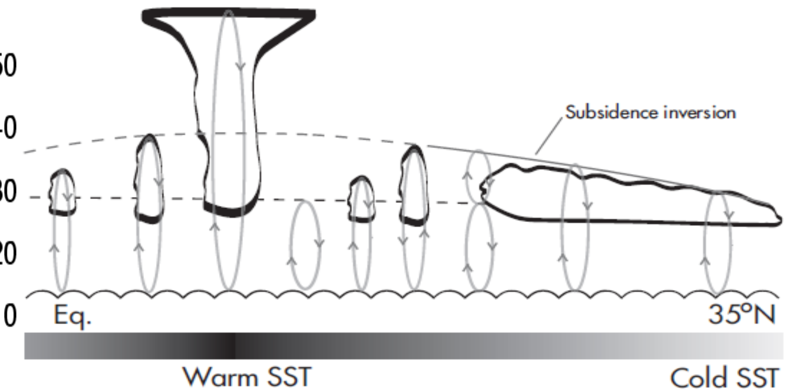
Stratocumulus to Cumulus transition CPT

Goal: Improve the representation of the cloudy boundary layer in NCEP GFS and NCAR CAM5 with a focus on the subtropical stratocumulus to cumulus (Sc-Cu) transition





Hypothesis: Sc-to-Cu transition plays key role in cloud-climate feedbacks (e.g. Teixeira et al, 2011)

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NCAR S. Park (PI), C. Hannay
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U. Washington C. Bretherton (PI), J. Fletcher, P. Blossey
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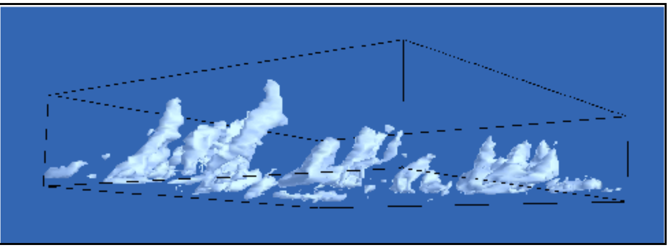
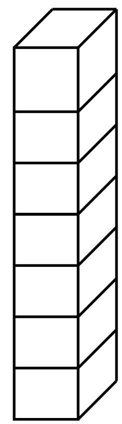
Strategy for climate model physics development

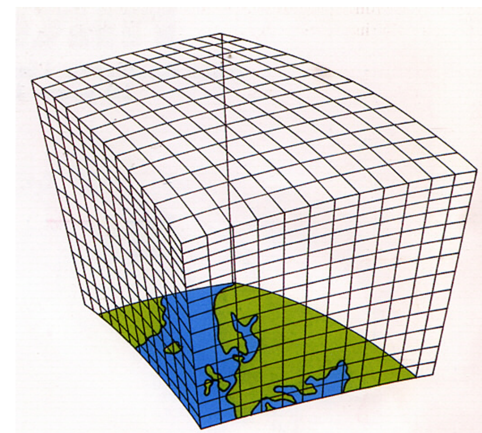


High-resolution model data:

Large Eddy Simulation (LES) models

Cloud Resolving Models (CRMs)





Testing in Single Column Models:

Versions of Climate Models

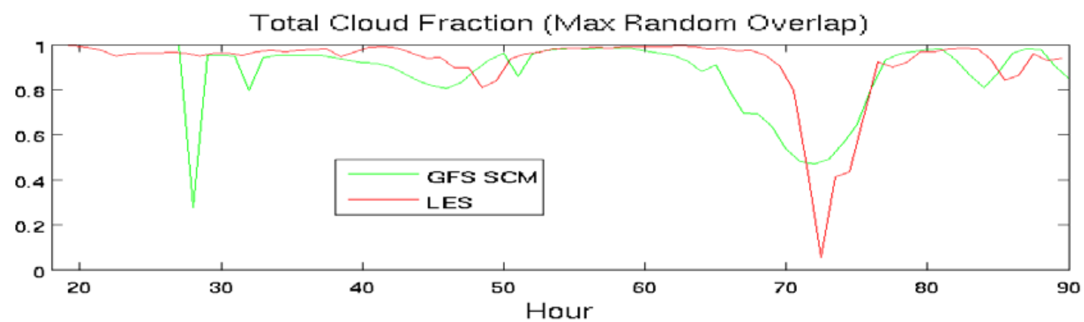
3D Climate/Weather Models:

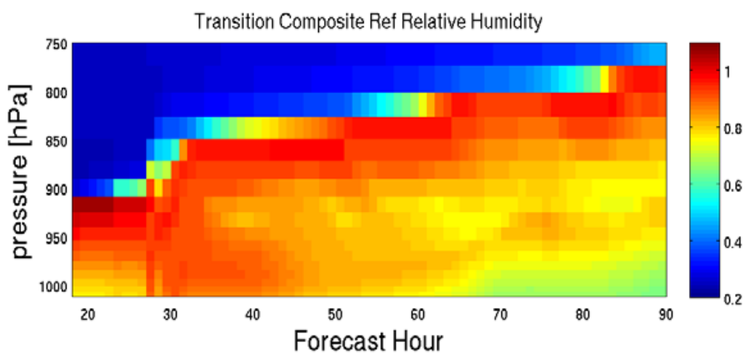
Evaluation and Diagnostics with satellite observations

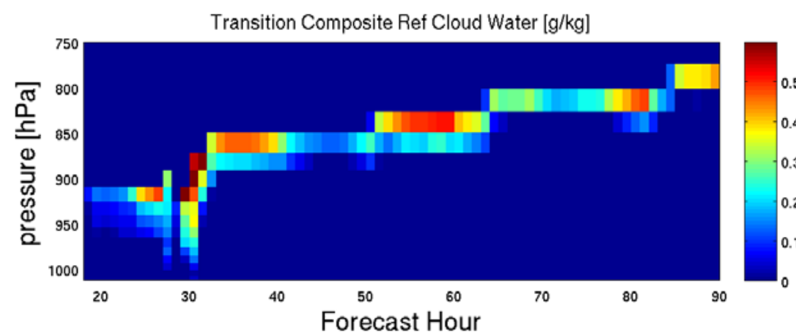
LES/CRM models provide unique information on small-scale statistics

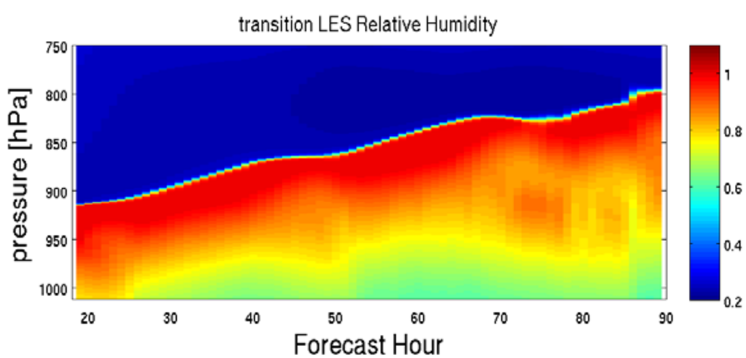
Sc-to-Cu composite transition case with NCEP SCM

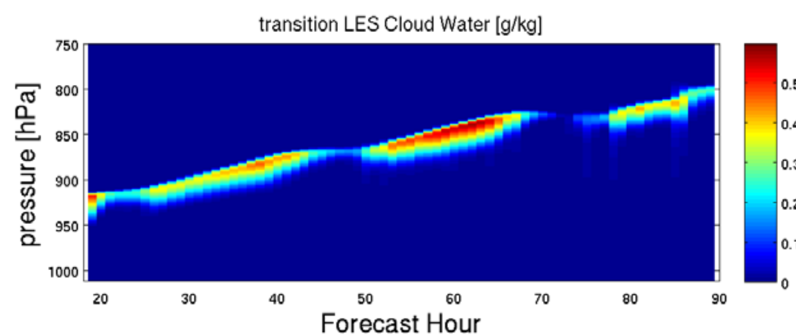
Fletcher et al, UW







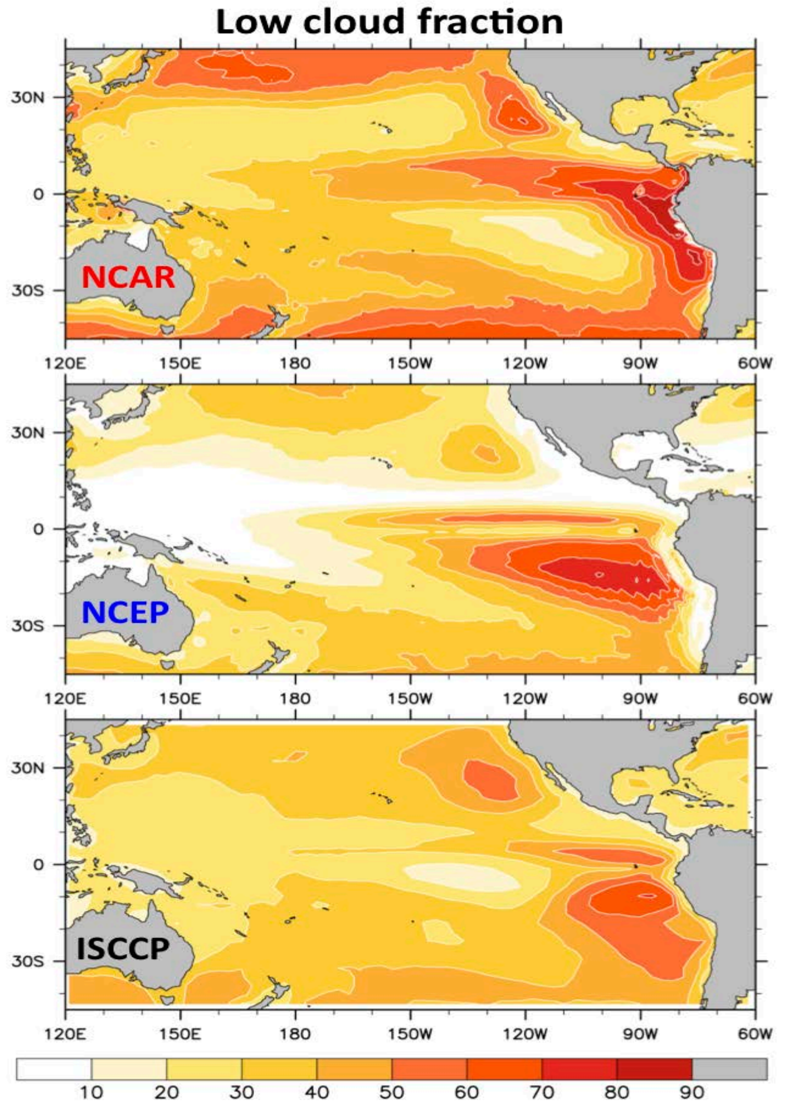




NCAR and NCEP SCM results will be submitted soon
JPL LES results will be submitted soon

NCEP Model Diagnostics

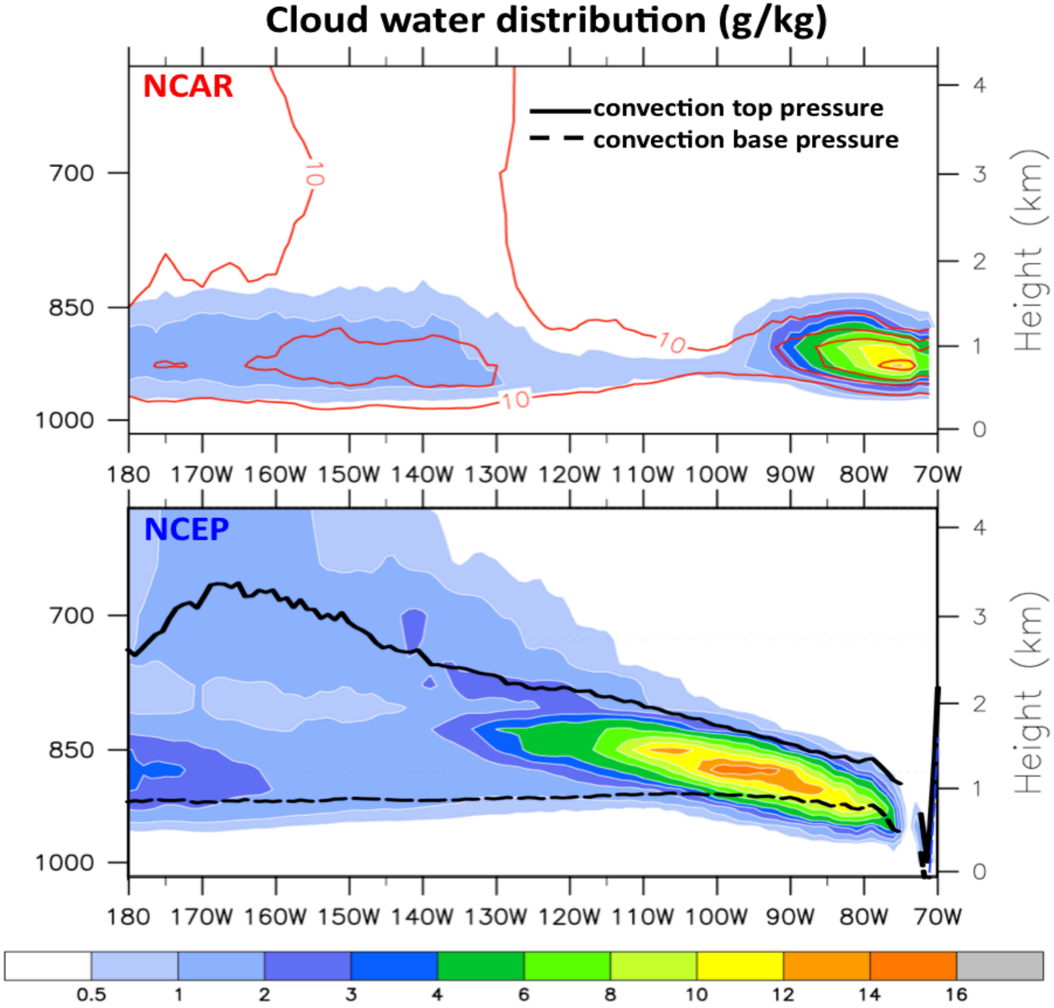
- NCAR CESM 1.0 (coupled version of CAM 5.0, 200-year run)
- NCEP CFS (coupled version of operational GFS, 20-year)
- Modified NCAR AMWG diagnostic package to add NCEP GFS output
- NCEP has TOA energy imbalance
- Both models reproduce global circulation patterns
- Both models have cloud biases



Xiao et al, UCLA

NCEP/NCAR diagnostics of cloud transition

October climatology along 20 S cross-section



NCAR and NCEP results are significantly different

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 $a_u \ll 1$ and $w_e \sim 0$ leads to

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

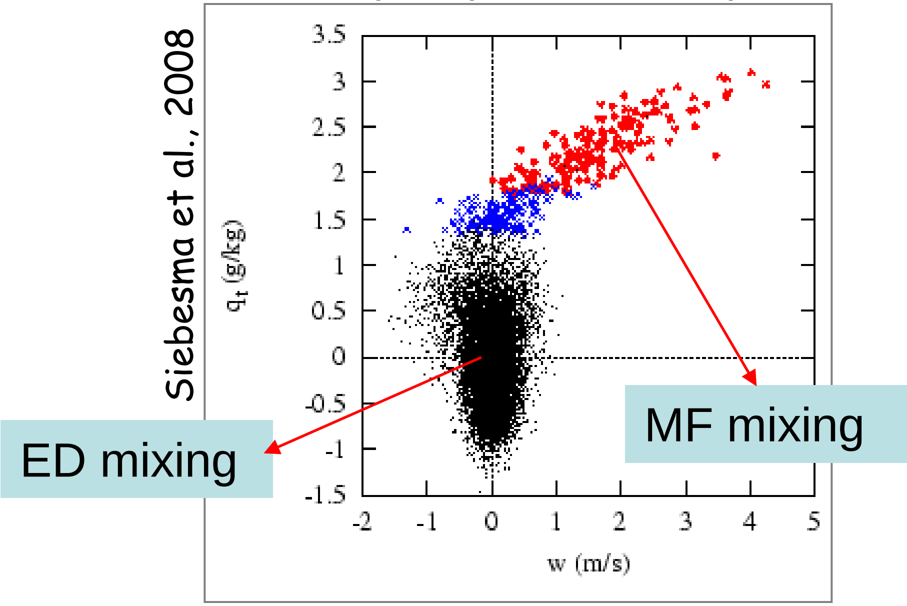
ED closure: assuming ED for 1st term and neglecting 2nd term

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

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

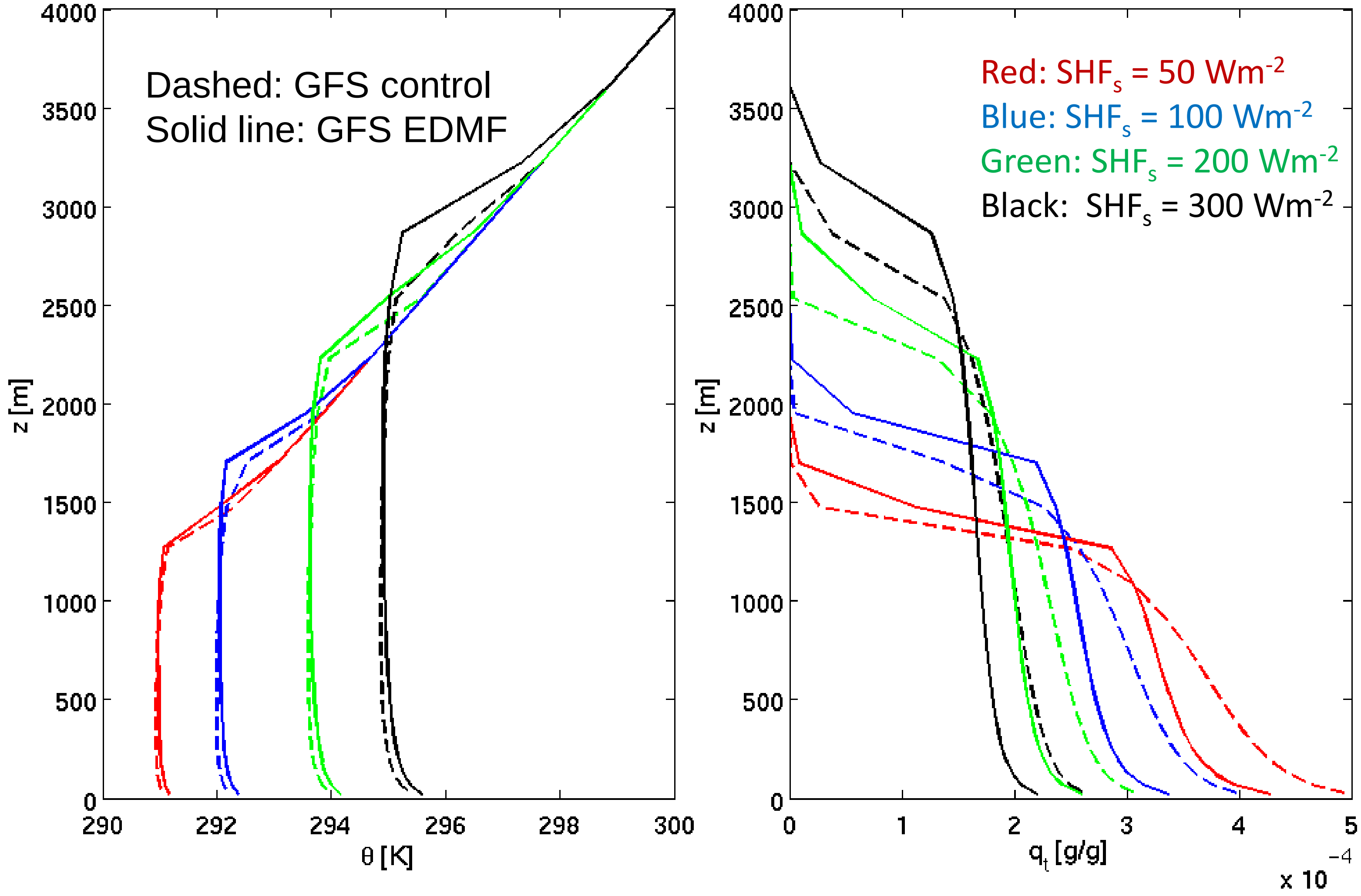
Siebesma & Teixeira, 2000

Bimodal joint pdf of w and qt



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

Implementation of EDMF in GFS SCM
Dry convective boundary layer



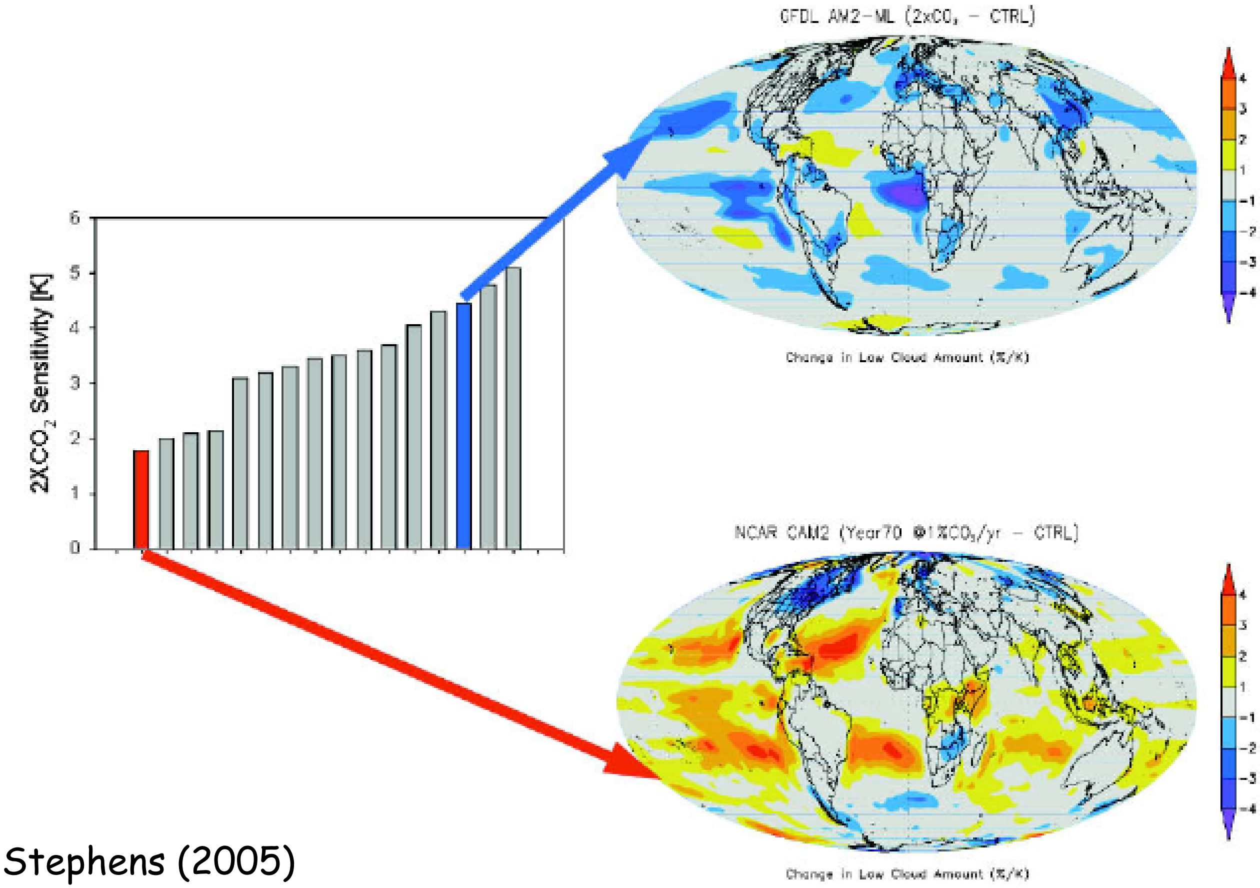
EDMF improves dry convective boundary layer in GFS

Sc-to-Cu Transition CPT - Summary

- GCSS Sc-Cu cases with NCAR and NCEP SCMs, and LES performed and submitted (UW, NCAR, NCEP, JPL)
- Detailed coupled diagnostics with NCEP and NCAR global models performed (NCEP, NCAR, UCLA)
- PDF cloud parameterization implemented and tested in NCAR global model (LLNL, NCAR)
- EDMF parameterization implemented and tested in SCM mode in NCEP GFS (JPL, NCEP, NCAR, UW)

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

<u>IPCC 2007:</u> "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)

Hypothesis: Sc-to-Cu transition plays key role in cloud-climate interaction (Teixeira et al, 2011)

Comparison of NCAR CESM1 and NCEP GFS

Model	NCAR CESM1	NCEP GFS
Atmosphere	CAM5 (2x2.5, L30)	GFS (T126 L64)
Boundary Layer Turbulence	Bretherton-Park (09) UW Moist Turbulence	Han and Pan (11)
Shallow Convection	Park-Bretherton (09) UW Shallow Convection	Han and Pan (11)
Deep Convection	Zhang-McFarlane Neale et al.(08) Richter-Rasch (08)	Han and Pan (11)
Cloud Macrophysics	Park-Bretherton-Rasch (10) UW Cloud Macrophysics	Zhao and Carr (97)
Stratiform Microphysics	Morrison and Gettelman (08) *Double Moment*	Zhao and Carr (97)
Radiation / Optics	RRTMG Iacono et al.(08) / Mitchell (08)	RRTM
Aerosols	Modal Aerosol Model (MAM) Liu & Ghan (2009)	Climatology
Dynamics	Finite Volume	Spectral
Ocean	POP2.2	MOM4
Land	CLM4	NOAH
Sea Ice	CICE	MOM4

7-year C-GFS vs. 100 yr CESM1 climo: AMWG metrics

cor coef: Space-Time	cam3_5_fv1.9x2.5	b40_20th_c02c_76jpf	NCEP
	ANN	ANN	ANN
Sea Level Pressure (ERA40)	0.949	0.959	0.962
SW Cloud Forcing (CERES2)	0.707	0.714	0.413
LW Cloud Forcing (CERES2)	0.820	0.769	0.792
Land Rainfall (30N-30S, GPCP)	0.785	0.811	0.766
Ocean Rainfall (30N-30S, GPCP)	0.802	0.757	0.748
Land 2-m Temperature (Willmott)	0.876	0.876	0.913
Pacific Surface Stress (5N-5S,ERS)	0.872	0.797	0.856
Zonal Wind (300mb, ERA40)	0.967	0.960	0.940
Relative Humidity (ERA40)	0.900	0.874	0.900
Temperature (ERA40)	0.912	0.932	0.208

C-GFS better than CESM1 for

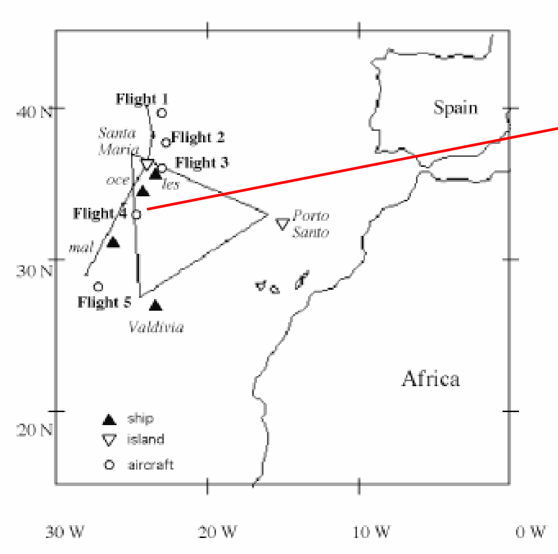
Pac surface stress, land surface temperature, 3D RH field,

but much worse for

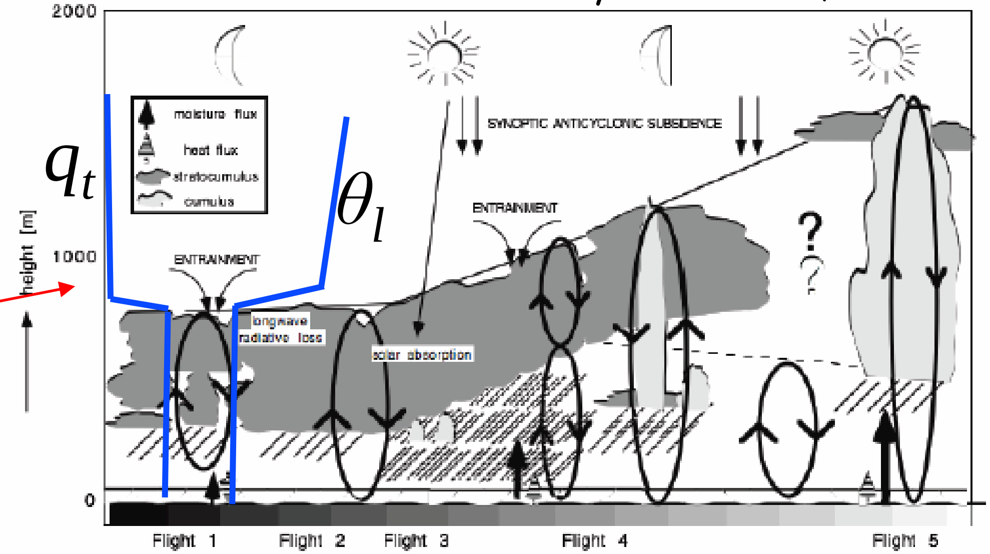
shortwave cloud forcing and land rainfall

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

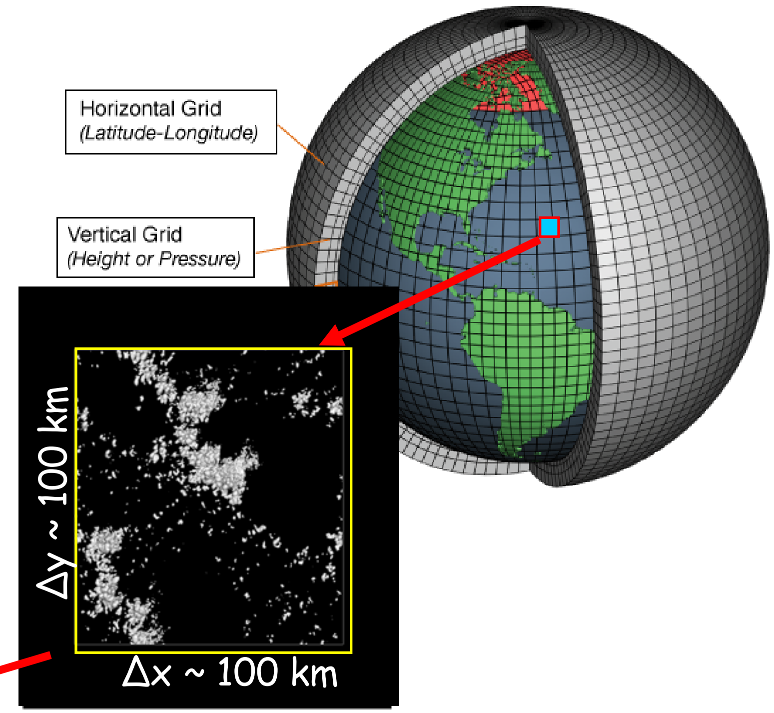
Optimal period to develop and test new parameterizations for Sc-Cu transition in NCEP and NCAR models

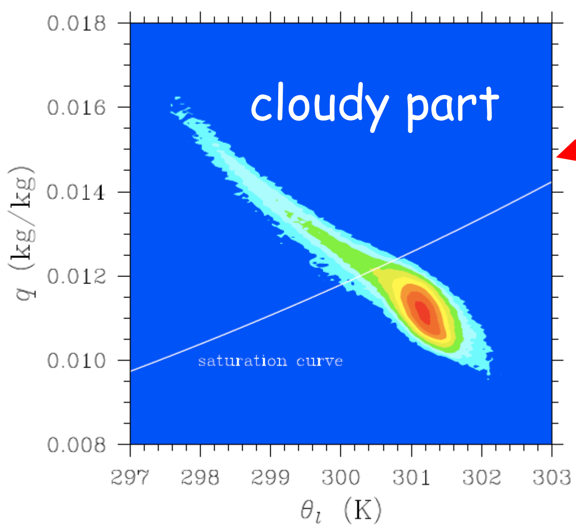
Parameterization of subgrid turbulence and clouds in climate models

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

Large-scale dynamics +
1D dimensional physics

➔ Interaction between boundary layer clouds and large scale

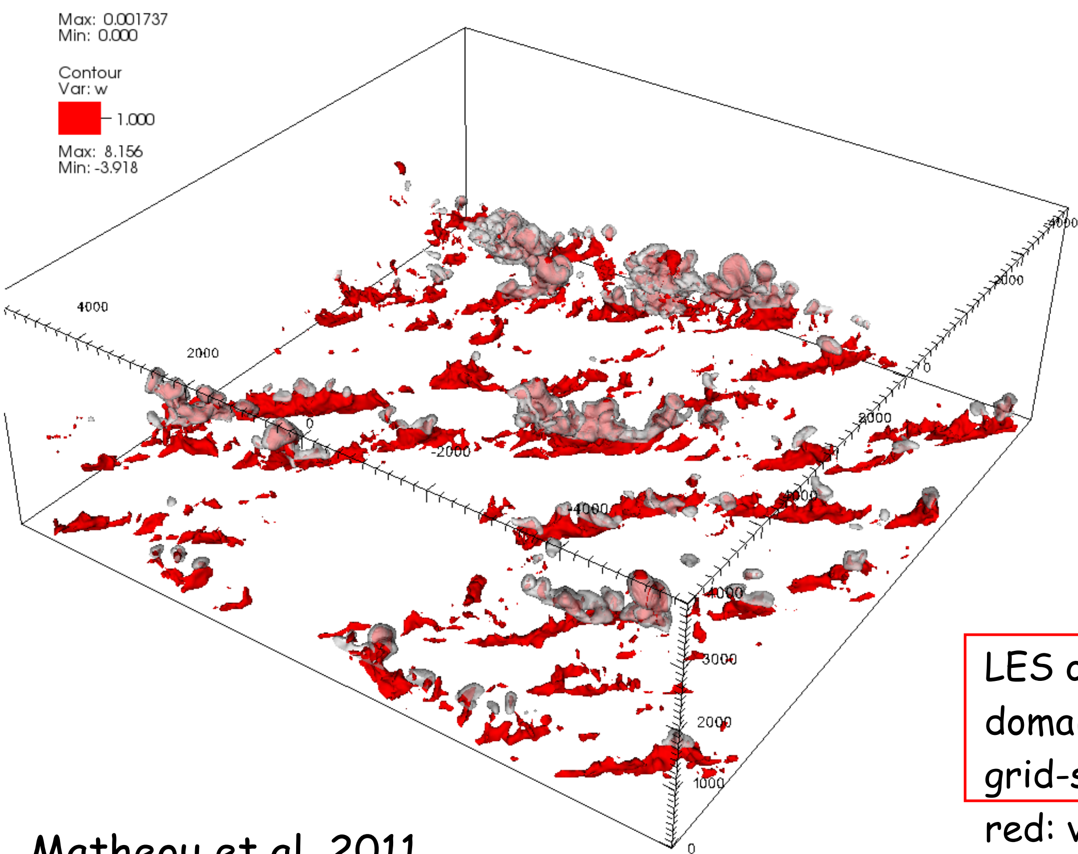




If PDF shape is known ➔ it is possible to compute cloud fraction and liquid water

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

Large Eddy Simulation (LES) models and Cumulus convection



Matheou et al, 2011

detailed clouds and vertical velocity

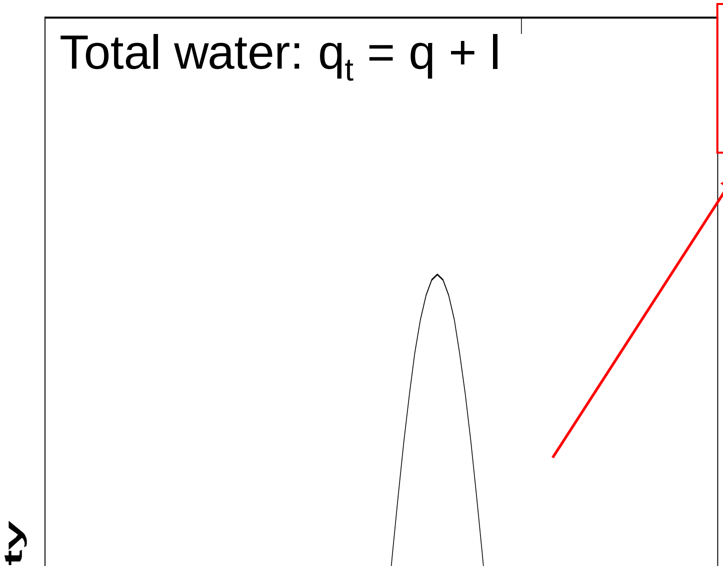
LES of Cumulus case
domain: 12 × 12 x 4 km
grid-size: 20 m
red: vertical velocity = 1 m/s

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

LES models explicitly resolve most atmospheric turbulence/convection

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

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

Mellor, 77; Sommeria & Deardorff, 77

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

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

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

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

Implementation of EDMF in GFS SCM
Dry Convective boundary layer