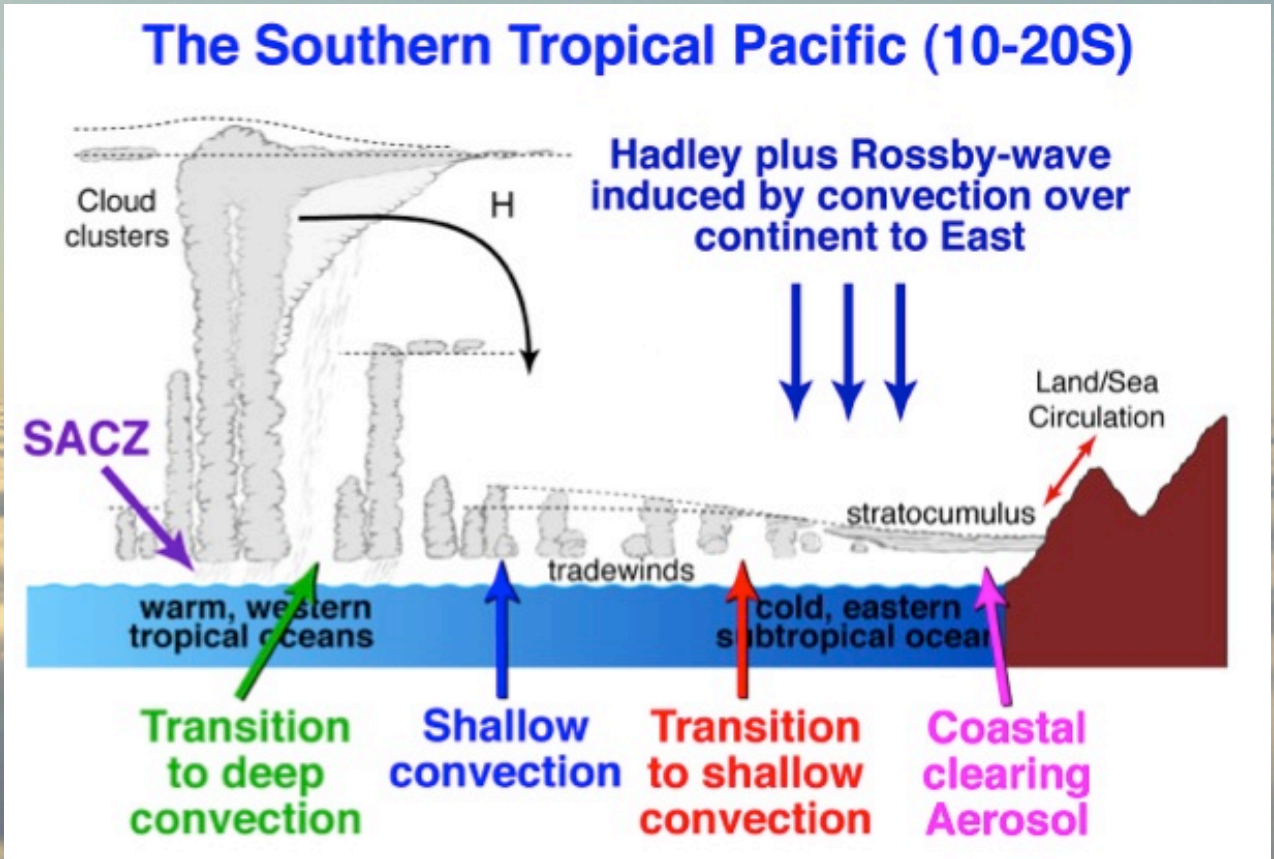
Stratocumulus to Cumulus Transition CPT



NCEP H. Pan (PI), J. Han, R. Sun

NCAR S. Park (PI), C. Hannay

JPL J. Teixeira (CPT lead PI), M. Witek

U. Washington C. Bretherton (PI), J. Fletcher, P. Blossey

UCLA C. R. Mechoso (PI), H. Xiao

LLNL S. Klein (PI), P. Caldwell

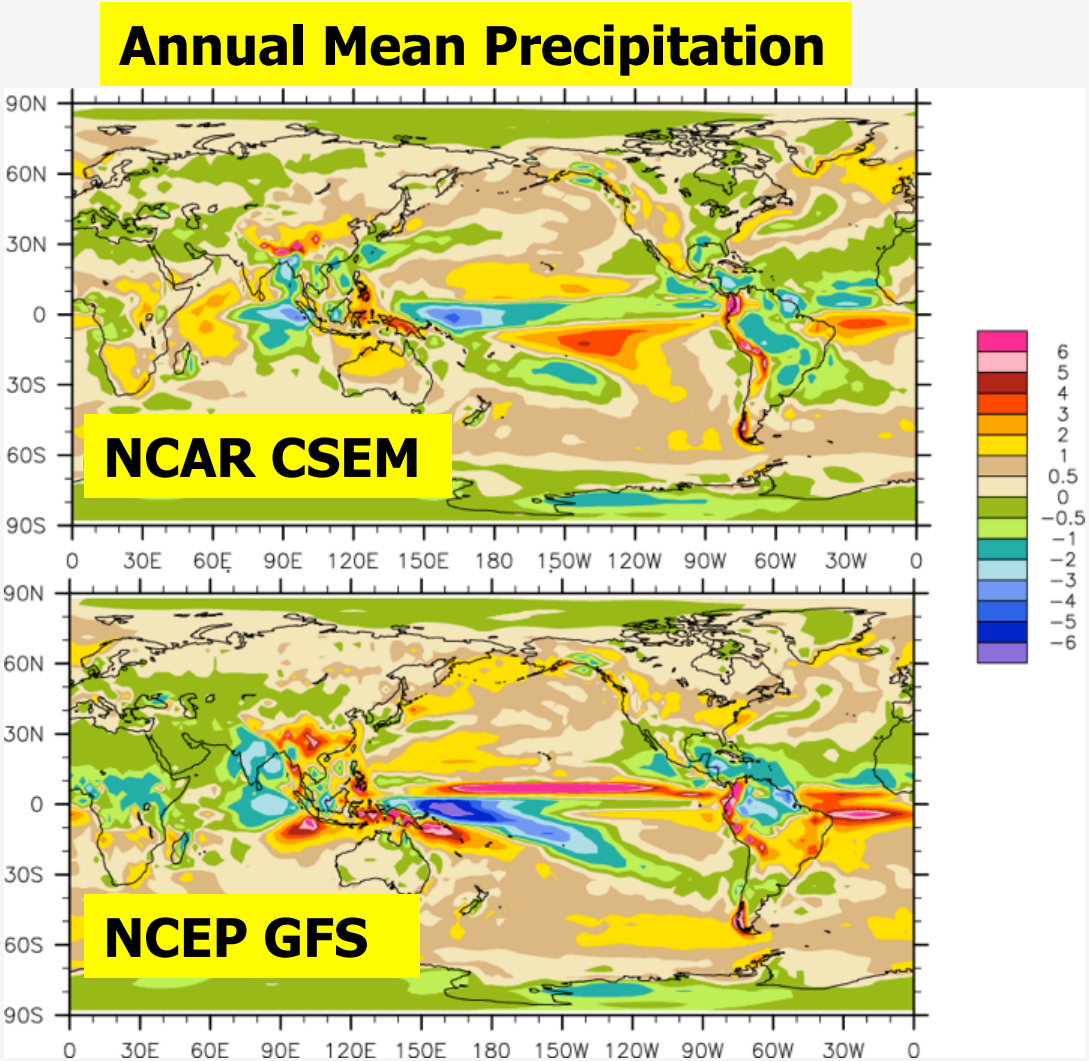
NOAA funded Aug. 2010 - 2013

(additl internal JPL and DOE funds)

The CPT goal is to 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.

First task
NCAR AMWG diagnostic package adapted to GFS output

- NCAR CESM 1.0 (coupled version of CAM 5.0, 200-yr run)
- NCEP GFS (coupled to MOM ocean model, 50-yr)
- Too low precip in western equatorial Pacific
- Too high precip south of equator in Atlantic
- GFS avoids double-ITCZ bias



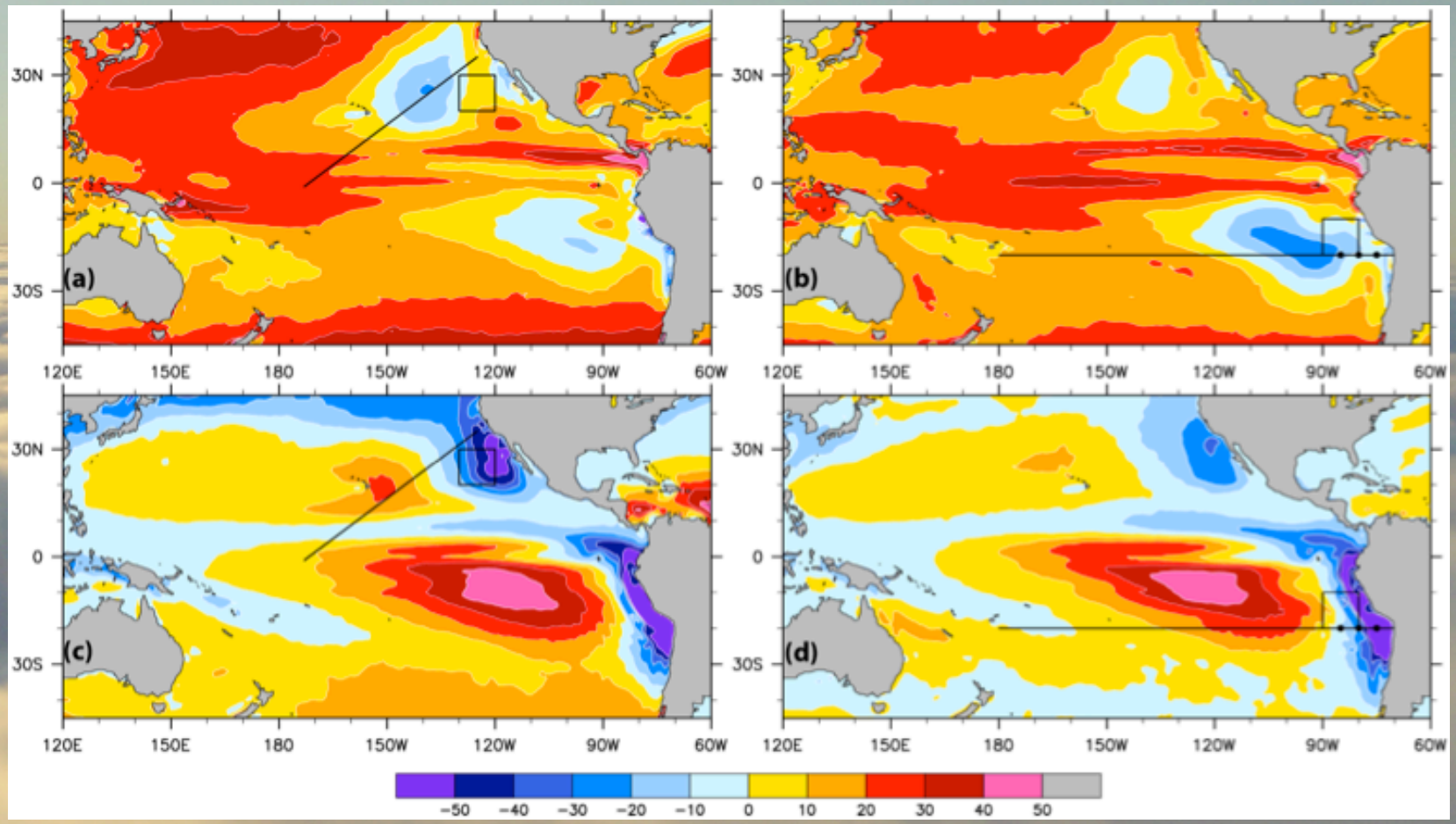
Biases in Low-Clouds (%)

June - August

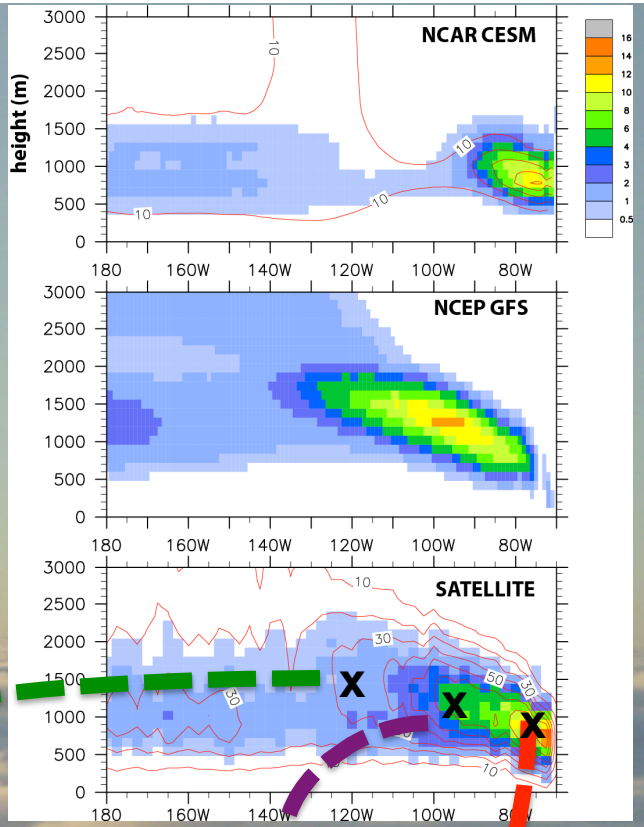
September - November

NCAR CSEM

NCEP GFS



The vertical distributions of cloud water and cloud fraction (contours) along 20°S (VOCALS) simulated by the two models have clear differences with satellite observations …



shallow cumulus
puffy with small cloud fraction

broken stratocumulus
in transition to shallow cumulus

coastal stratocumulus
low-lying and uniform

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

Vertical distributions of cloud water and cloud fraction (contours) along 20°S

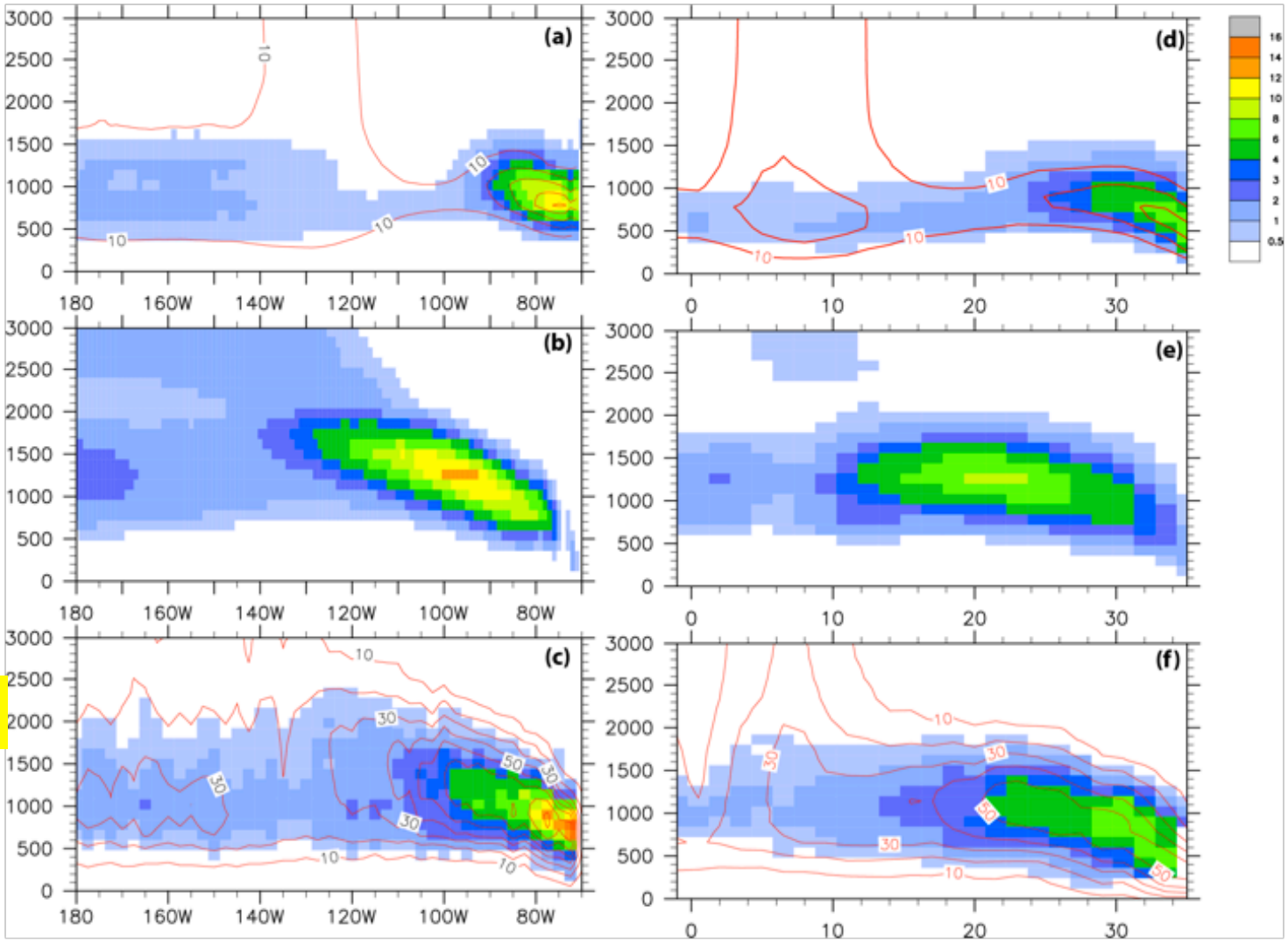
June - August

September - November

NCAR CSEM

NCEP GFS

Satellite



Xiao (UCLA), Sun (NCEP)

Foci for CPT Activities

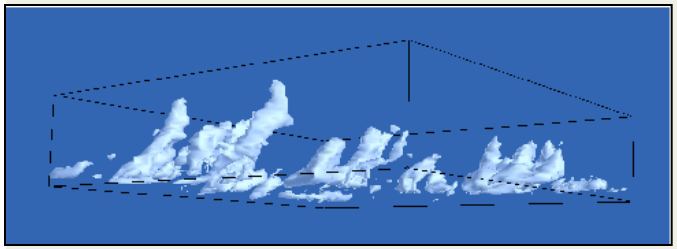
NCEP

- Diagnose and improve clouds in operational GFS
- Evaluate free-running coupled GFS with climate model metrics
- Use single-column GFS as testbed for upgrades in parameterizations

NCAR

- Impose consistency between processes in the new cloud physics parameterizations of the CESM/ CAM5. Interactions among those processes is inadequately understood and suboptimal.

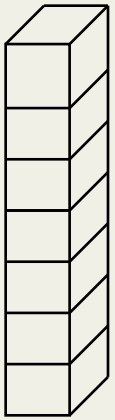
Single-column testing and improvement of GFS



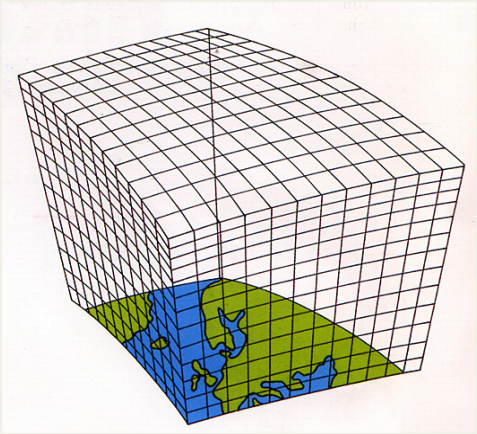
High-resolution model data:

Large Eddy Simulation (LES) models

Cloud Resolving Models (CRMs)



Testing in Single Column Model (SCM) Versions of Climate Models



3D Climate/Weather Models:

Evaluation and Diagnostics with satellite observations

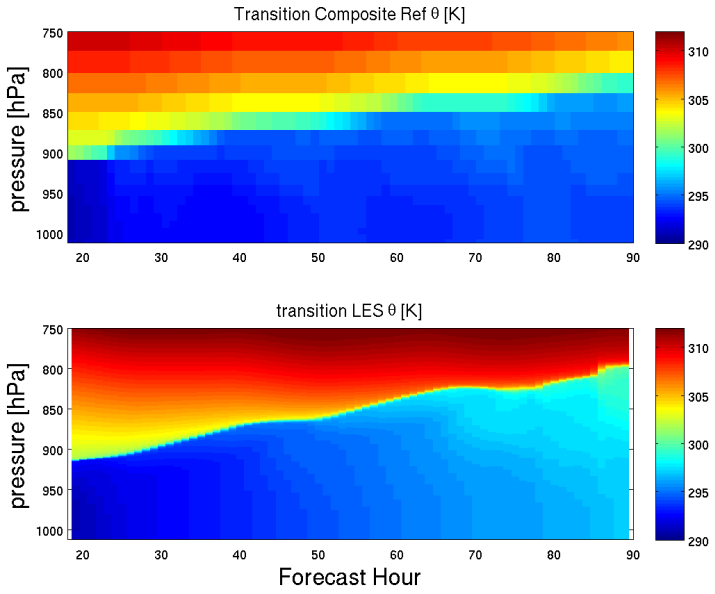
LES/CRM models provide unique information on small-scale statistics

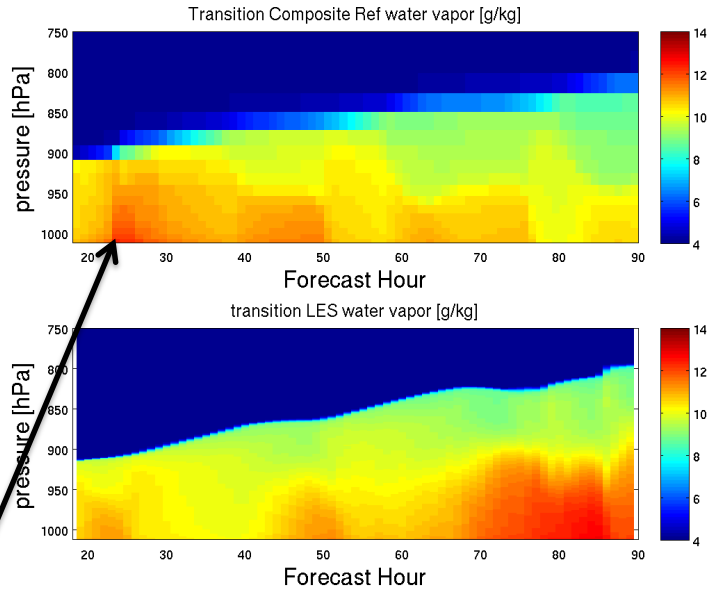
Idealized Lagrangian simulation of Scu-Cu transition

- Initialization and forcings generated from satellite and ERA---Interim data in the NE Pacific stretch from SW of California to Hawaii.
- See Sandu et al, 2010, ACP
- Simulation includes full radiation and diurnal cycle.
- Forcings include constant divergence profile, gradual ramping up of SST from 294 K to 299 K over 3 days.

Fletcher (UW) and Bretherton (UW)

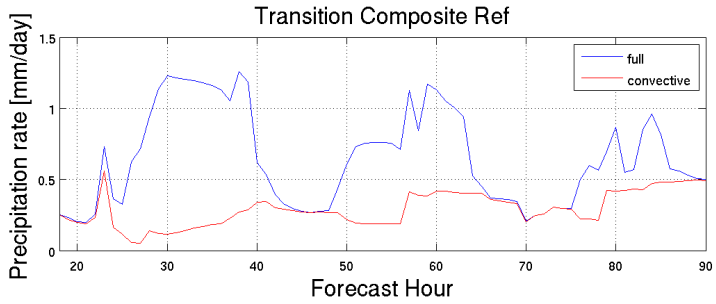
Transition: Basic Thermodynamics Profiles





LHF ~ 400 W/m^2 at this point! Afterward it steadily drops to ~40 W/m^2. LES LHF steadily increases from ~80 to ~160 W/m^2

- GFS successfully simulates the deepening and decoupling of the PBL.
- However, the GFS boundary layer stays cooler and dryer than the LES, particularly in the latter part of the simulation.
- As with other cases, GFS produces too much precipitation.



Fletcher (UW) and Bretherton (UW)

Short development runs with the CFS

SR1

In this one-year run, the tunable coefficient controlling rain conversion rate is reduced to half the original value; the updraft lateral entrainment rate is increased three times.

SR2

This one-year run includes additional modifications:

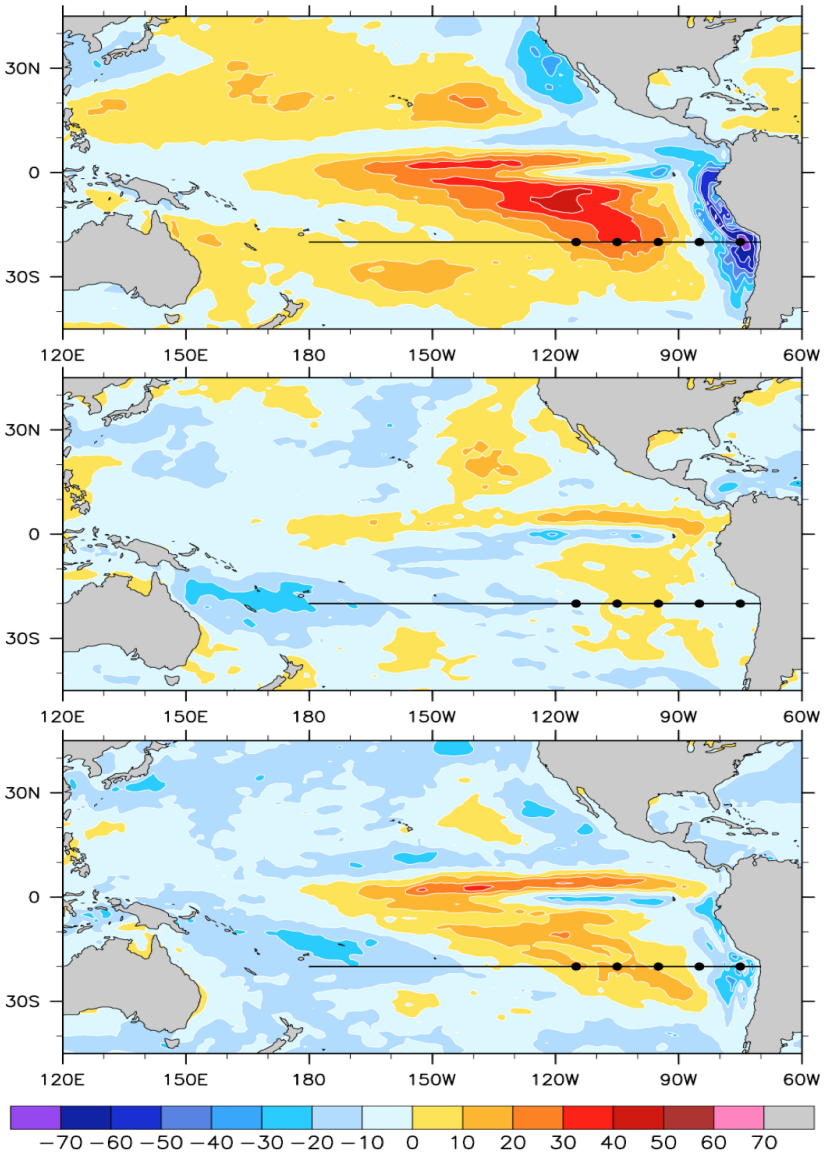
- A diagnostic equation is added to calculate the updraft vertical velocity in the shallow convection parameterization and is used to calculated convective overshooting.
- The tunable coefficient controlling cloud water detraining rate is reduced to half.
- Shallow convection is turned off when the diagnosed convective cloud layer is shallow or below the diagnosed PBL top.
- Background diffusion in the PBL is reduced.
- Convective cloud fraction associated with shallow convection plumes is directly used by the radiation scheme.
- Heating associated with TKE dissipation in the surface layer is added.

Mean Low-Cloud Fraction Errors (Sep-Nov)

Control

Control – SR1

Control – SR2



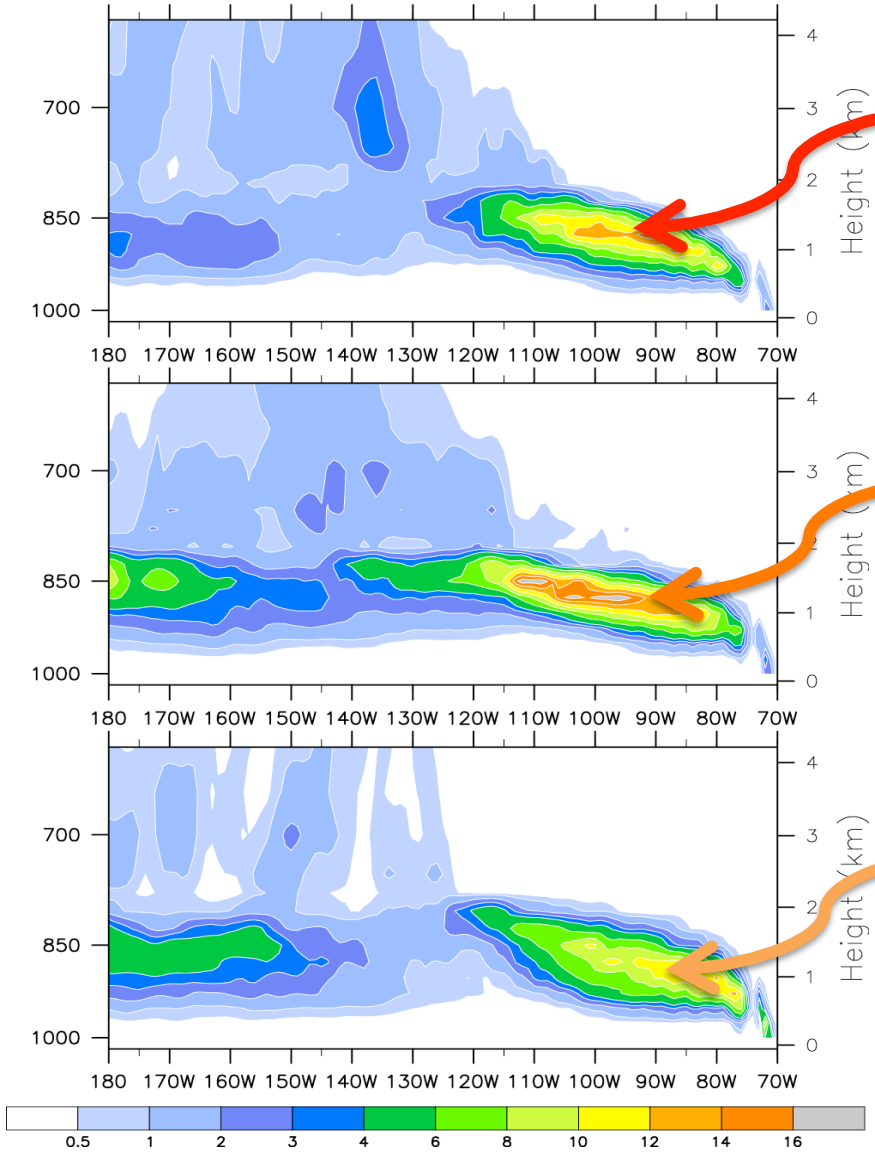
Xiao (UCLA), Sun (NCEP)

Mean Cloud Liquid Water (Sep-Nov) along 20S

Control

SR1

SR2



Erroneous Maximum

Error Remains

Error Reduced

Xiao (UCLA), Sun (NCEP)

Eddy-diffusivity/mass-flux parameterization scheme

In the EDMF framework, the fluxes of moist conserved variables (total water mixing ratio and liquid water potential temperature) are written as

$$\overline{w'\varphi'} = -K_H \frac{\partial \varphi}{\partial z} + \sum_i M_i \left(\varphi_{ui} - \varphi\right)$$

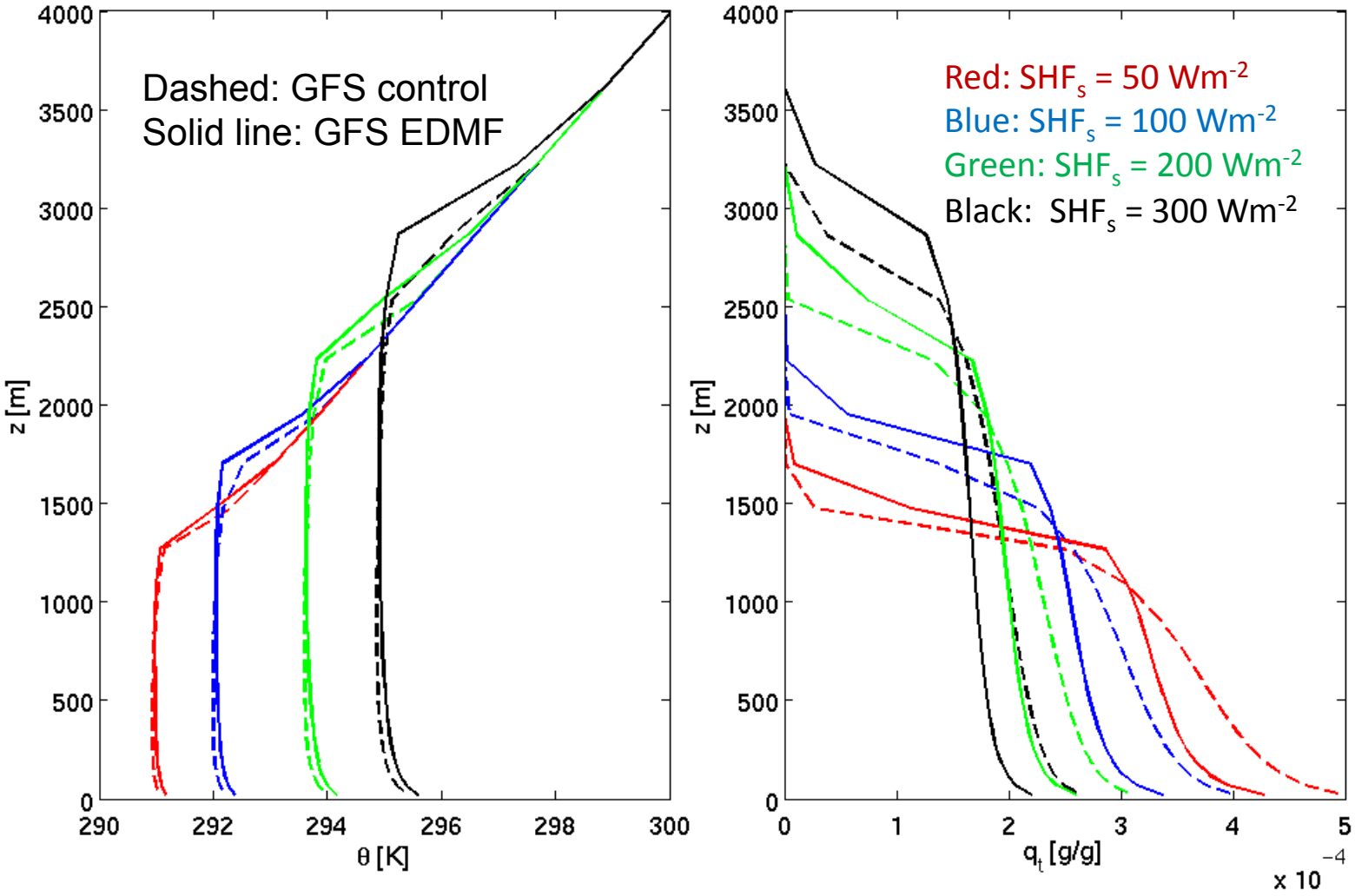
The sum is over all updrafts at a specific level, where M_i is mass flux and φ_{ui} is the value of φ in the i-th updraft.

To complete the parameterization, K_H, M, and φ_u, are determined based on other equations and LES-derived relationships.

The cloud cover and mean liquid/ice water content can be consistently determined given the joint PDFs of relevant thermodynamic variables within each grid box.

Teixeira (JPL)

EDMF in GFS SCM: Dry convective boundary layer



EDMF improves dry convective boundary layer in GFS

Teixeira (JPL)

CAM5 Stratiform Cloud Development

Improvements made:

1. Fixed inconsistency between number and mass of newly formed cloud droplets
2. Expanded substepping to include macro- in addition to microphysics, which reduces splitting errors.
3. Created new macrophysics = unified PDF-based liq cloud fraction and condensation schemes
4. Imposed consistent subgrid-scale assumptions for both macro- and micro-physics

Impact of CAM5 Improvements

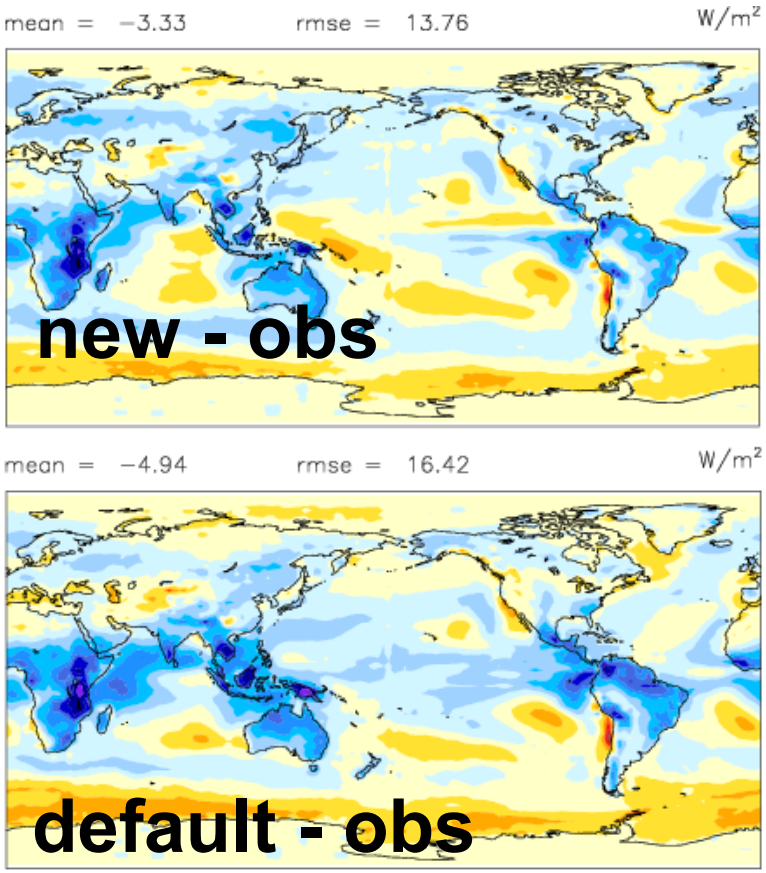
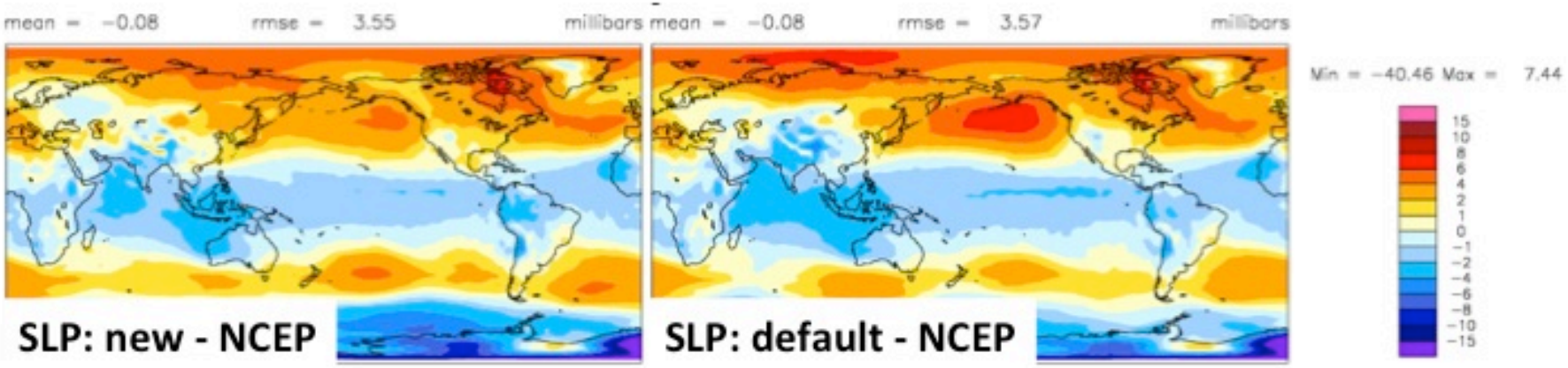


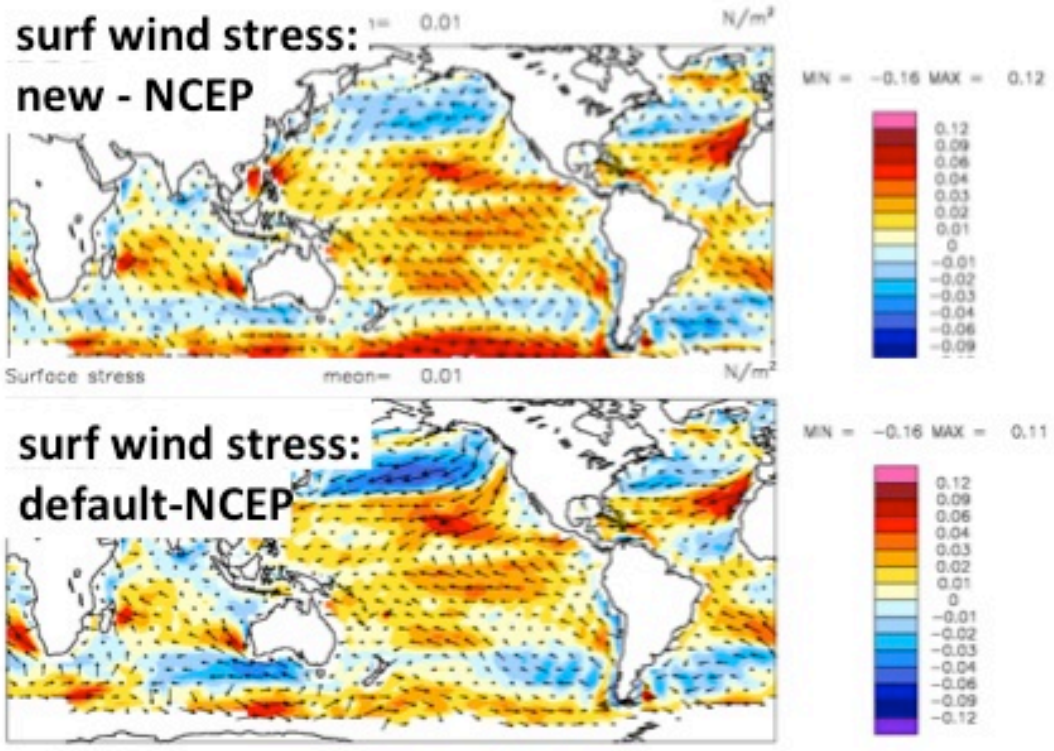
Fig: Shortwave Cloud Forcing bias from default and new runs. Obs = CERES-EBAF

- LWP, SWCF, OLR and Scu-Cu transition improved
- Overall model skill is ~ unchanged.

Caldwell (LLNL)

Impact of CAM5 Improvements





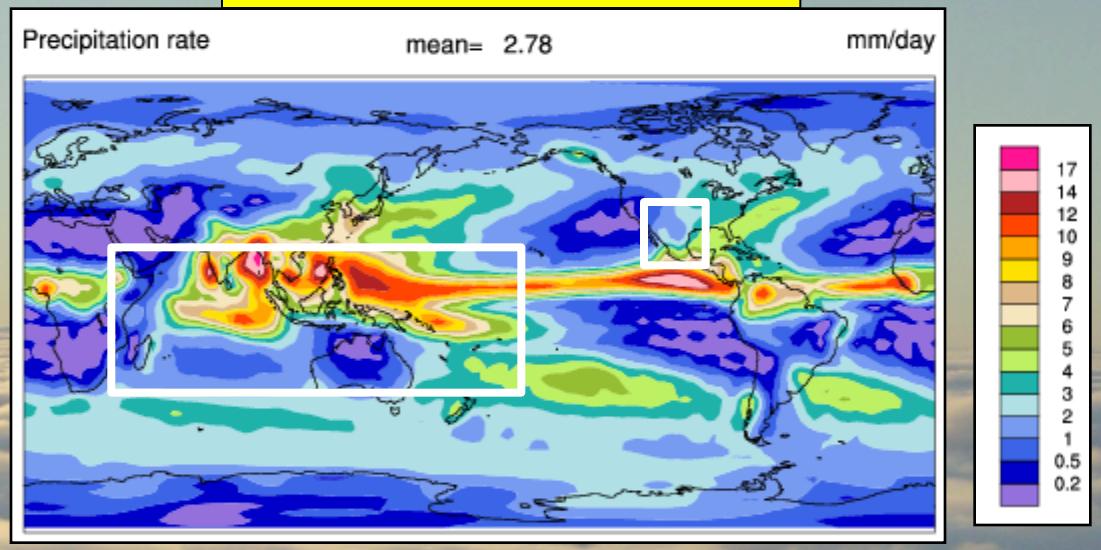
- SLP slightly better, particularly the Aleutian Low
- Surface stress slightly better
- LWP, SWCF, OLR and Scu-Cu transition improved

Caldwell (LLNL)

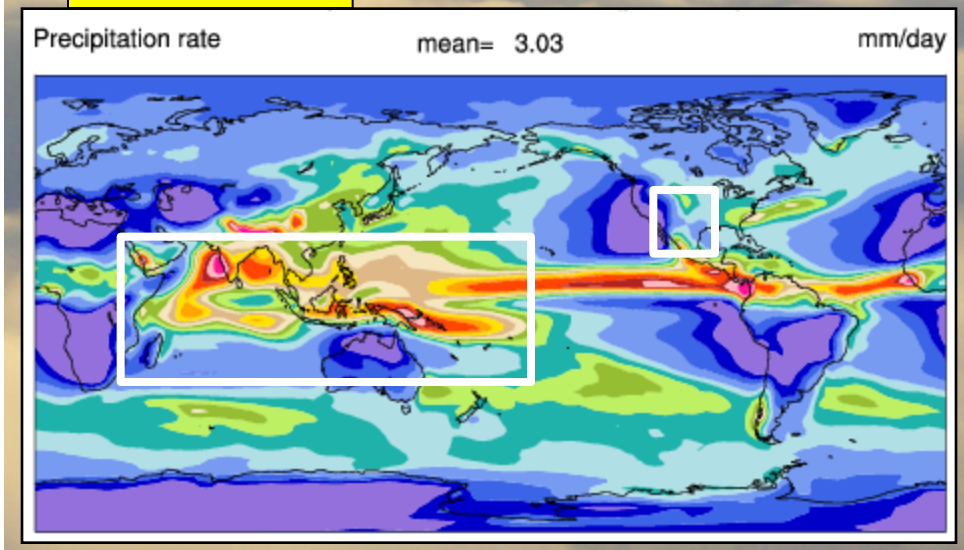
Precipitation Climatology JJA

Park (NCAR)

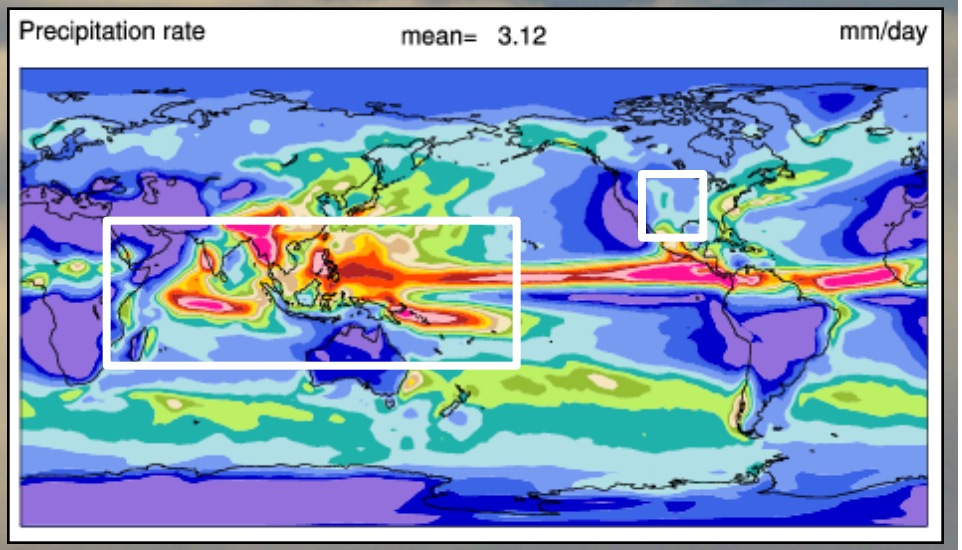
OBSERVATION



CAM5



UNICON



Summary

- AMWG diagnostic package adapted to GFS output
- Diagnosis of marine clouds simulation by the NCEP GFS and NCAR CSM completed
- GFS SCM developed with recent physics
- GFS SCM has been adapted to several GCSS cases (Sc, shallow Cu, Sc-Cu transition) for which LES and observations exist
- SCM work suggested several adjustments in GFS parameterizations
- SCM used to implement EDMF scheme in GFS
- Consistency among CAM5 parameterizations enhanced

On-going Research

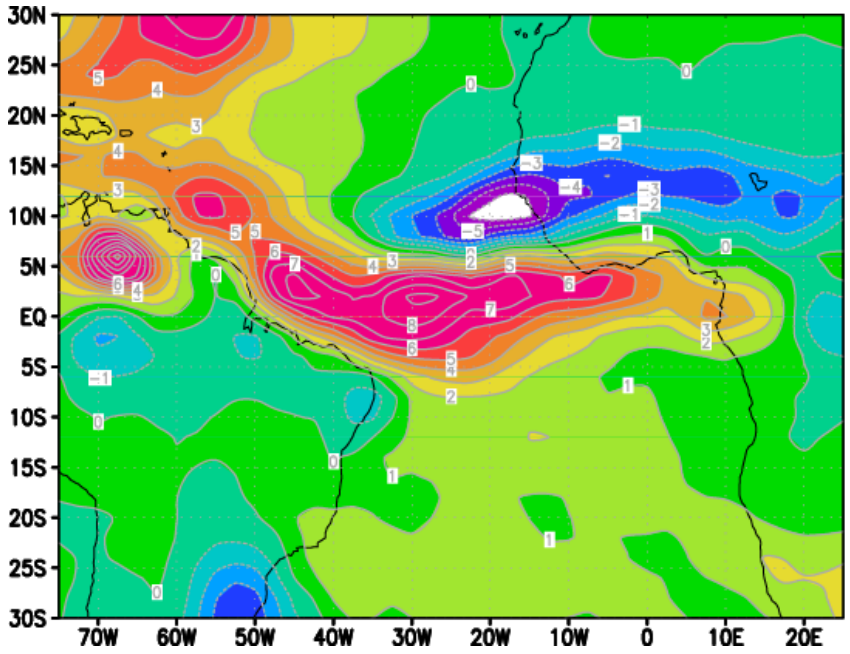
- More analysis of GFS and CAM5 climate simulation biases and their impact on the simulated Sc-Cu transition
- Improve microphysics to increase deep cloud
- Improve Sc entrainment formulation to enhance coastal Sc
- Test EDMF turb. for cloud-topped boundary layers.
- Detailed evaluation of new PDF-based cloud macrophysics and mixing schemes, and interactions with other schemes in CAM5

CGCM and Experiments

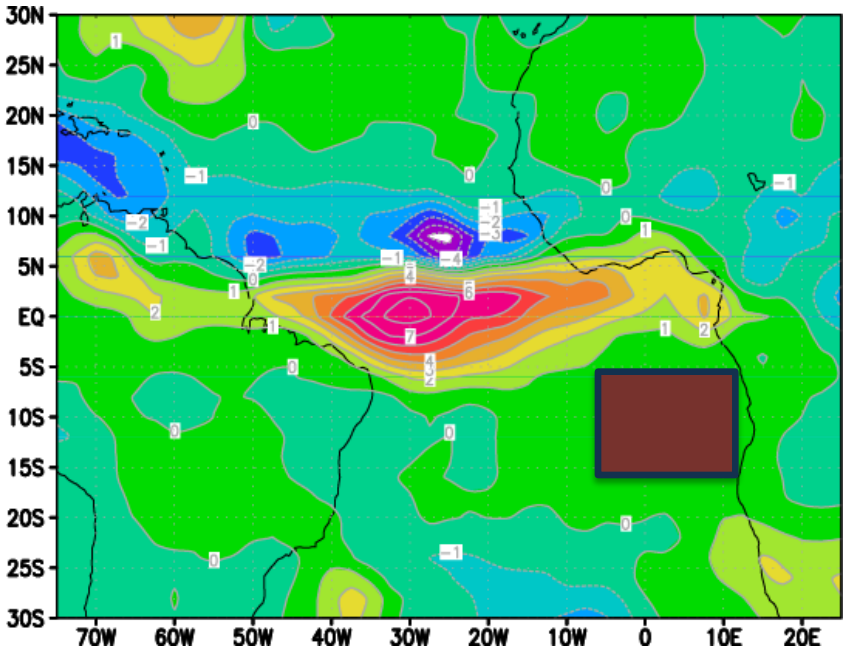
- UCLA AGCM (7.1) (2.5x2x29 levels) coupled to MIT OGCM (1x1/3-to-1x46 levels)
- **Control** is a two-year period in a 120-year long simulation, in which interannual anomalies in either the tropical Atlantic or Pacific are negligible.
- In **Experiment**, a seasonally varying Scu fraction that approximates the observation is prescribed in SEA regions in the radiation calculation only.
- In locations where Scu fraction is prescribed, liquid water path is set to 75 g/m^2.

July mean rainfall biases (mm/day)

Control



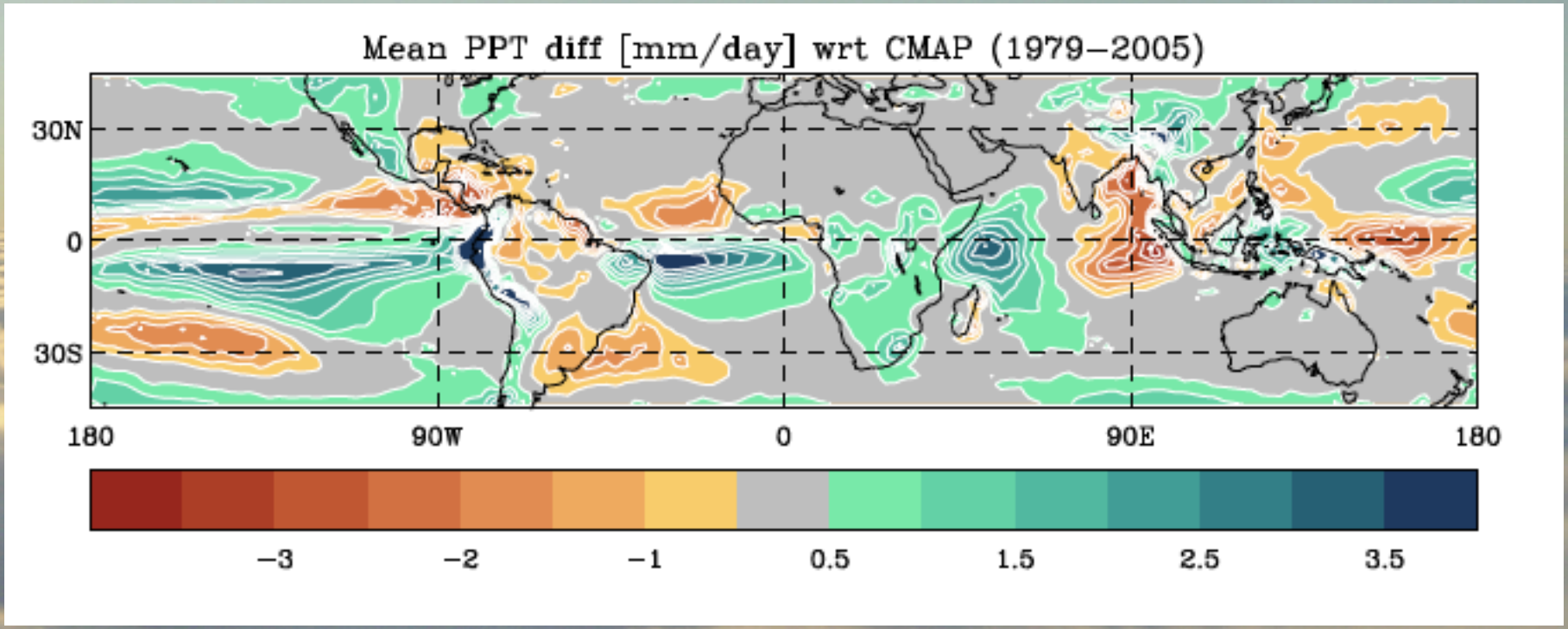
Control - Experiment



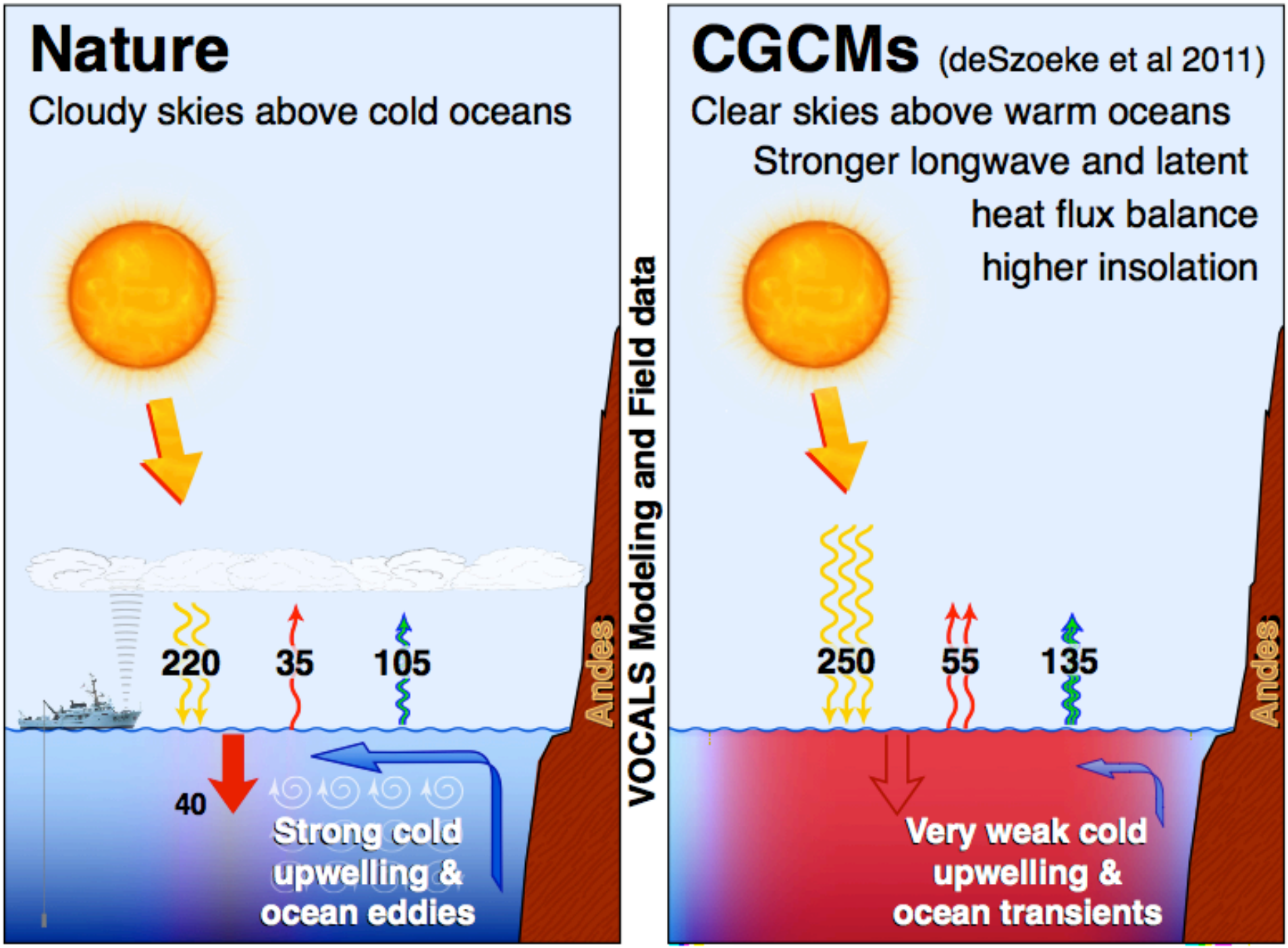
Artificially enhancing Scu in the Brown Square results in significantly decreased rainfall south of 5°N: Scu also matter in the southeastern Atlantic albeit their impact is weaker than in the southeastern Pacific

Mechoso and Xiao (UCLA)

Precipitation Errors in CMIP5 CGCMs



Courtesy T. Toniazzo, C34, #228B


Nature
Cloudy skies above cold oceans
220
35
105
40
Strong cold upwelling & ocean eddies
Andes
VOCALS Modeling and Field data
CGCMs (deSzoeke et al 2011)
Clear skies above warm oceans
Stronger longwave and latent heat flux balance
higher insolation
250
55
135
Very weak cold upwelling & ocean transients
Andes