Clouds and Cloud Microphysics in CESM2

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CESM2 Cloud changes

- Multivariate PDF scheme: CLUBB
  - Unified representation of boundary layer, shallow convection and stratiform macrophysics
  - Bogenschutz et al 2013; Golaz and Larson 2002
- Updated 2-moment microphysics
  - Prognostic Precipitation & Sub-stepping
  - Gettelman & Morrison 2015
- Mixed Phase Ice nucleation (Hoose et al 2010)
  - Replaces empirical scheme: IN=f(T)

The CAM family

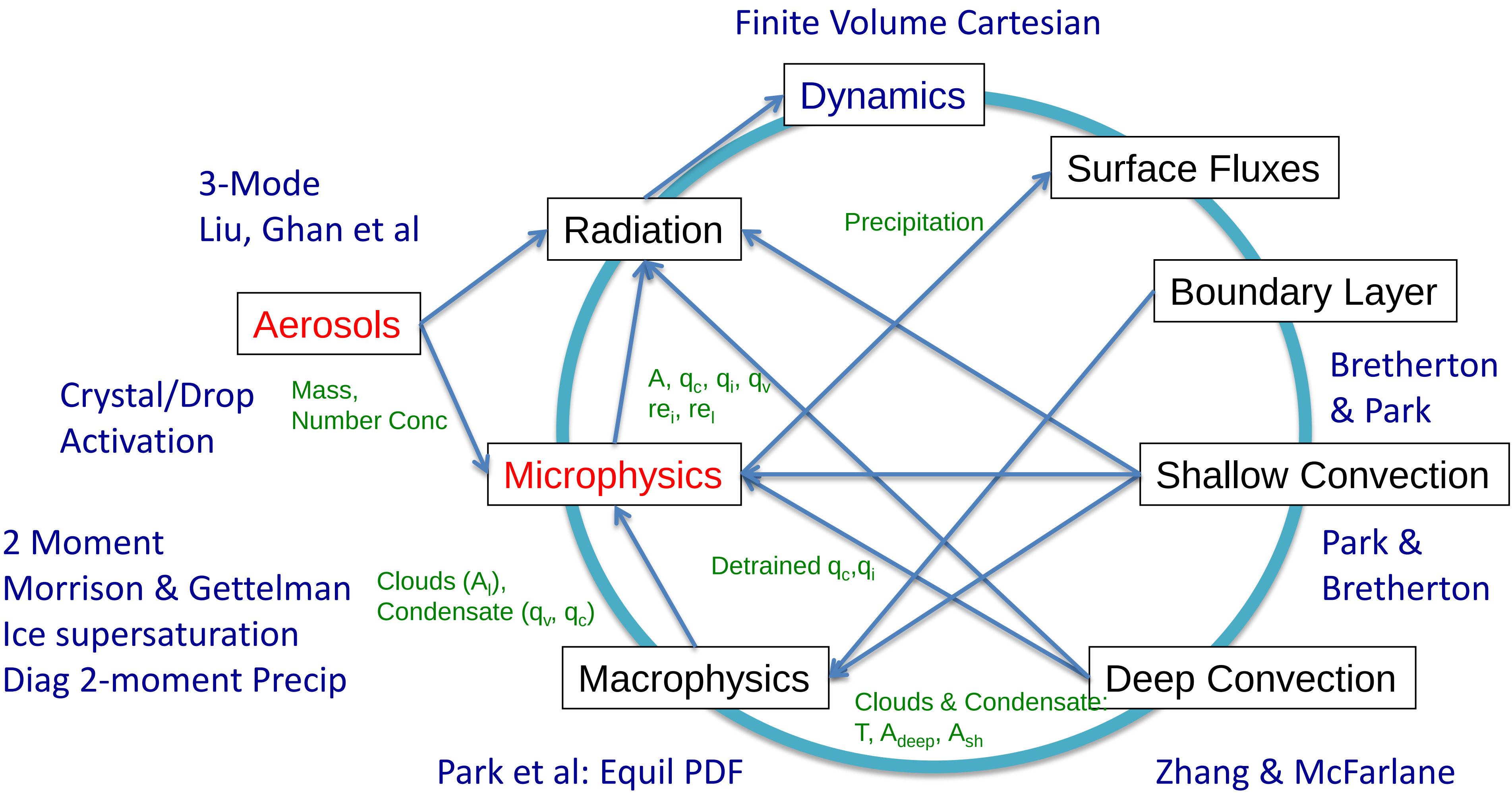
Model	CAM3 CCSM3	CAM4 CCSM4	CAM5 CESM1.0	CAM6 CESM2
Release	**Jun 2004**	**Apr 2010**	**Jun 2010**	**Mid 2016**
Deep Convection	Zhang-McFarlane (1995)	ZM + Neale et al (2008)	ZM+Neale	ZM+Neale
PBL	Holtslag-Boville (1993)	Holtslag-Boville (1993)	UW: Bretherton-Park (2009)	CLUBB
Shallow Convection	Hack (1994)	Hack (1994)	Park et al. (2009)	
Macrophysics	Rasch-Kristjansson (1998)	Rasch-Kristjansson (1998)	Park et al. (2011)	
Microphysics	Rasch-Kristjansson (1998)	Rasch-Kristjansson (1998)	Morrison-Gettelman (2008) MG1	MG2
Radiation	Collins et al. (2001)	Collins et al. (2001)	Iacono et al. (2008): RRTMG	RRTMG
Aerosols	Bulk Aerosol Model	Bulk Aerosol Model BAM	3 Mode Aerosol Model (MAM3) Ghan et al. (2011)	4 Mode Aerosol Model MAM4
Dynamics	Spectral	Finite Volume (FV)	Finite Volume	FV/Spectral element

= New parameterization/dynamics

= Modified Parameterization

Community Atmosphere Model (CAM5)

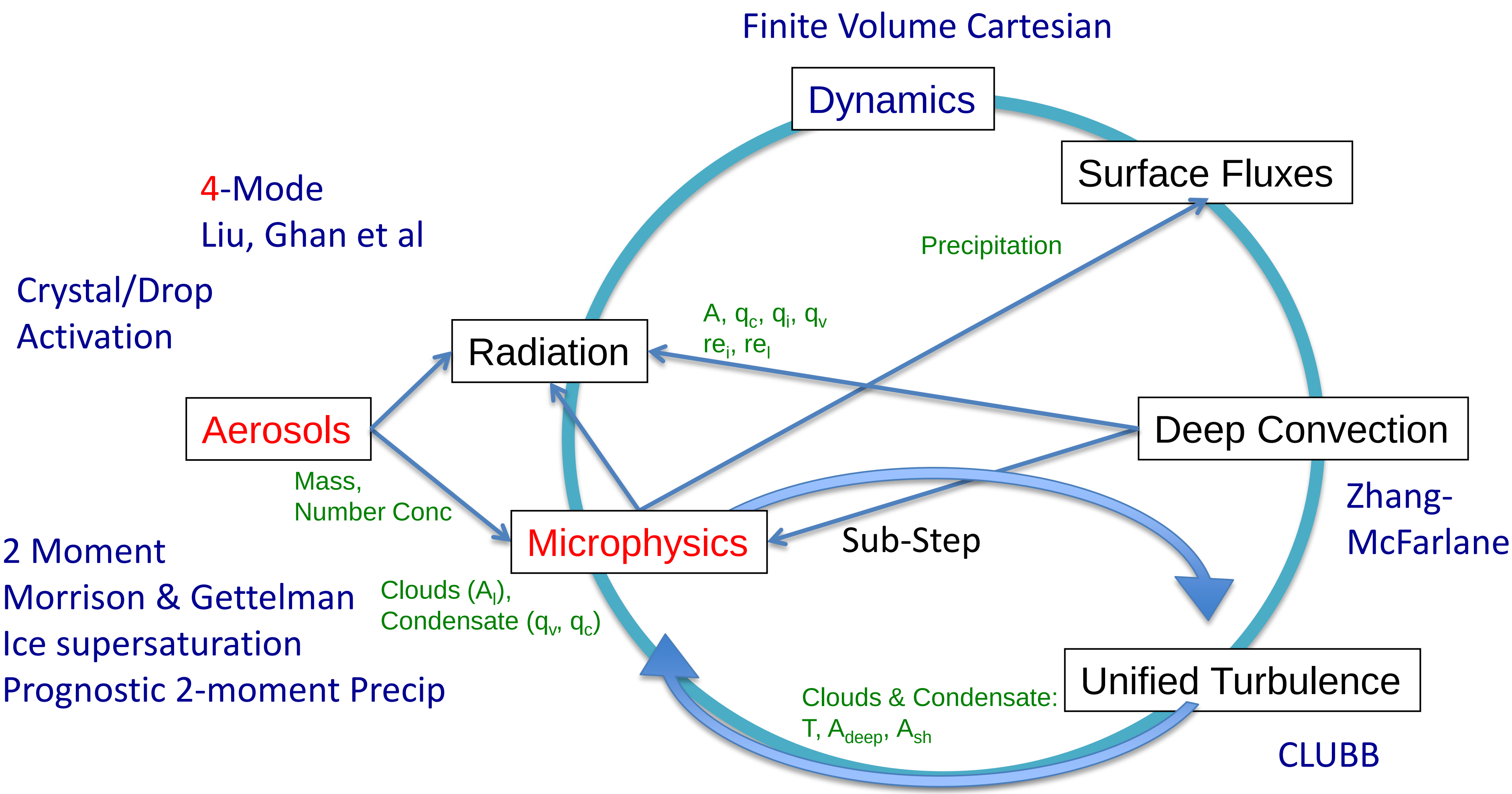
CAM5.1-5.3: IPCC AR5 version (Neale et al 2010)



A = cloud fraction, q=H_2O, re=effective radius (size), T=temperature
(i)ce, (l)iquid, (v)apor

Community Atmosphere Model (CAM5.5)

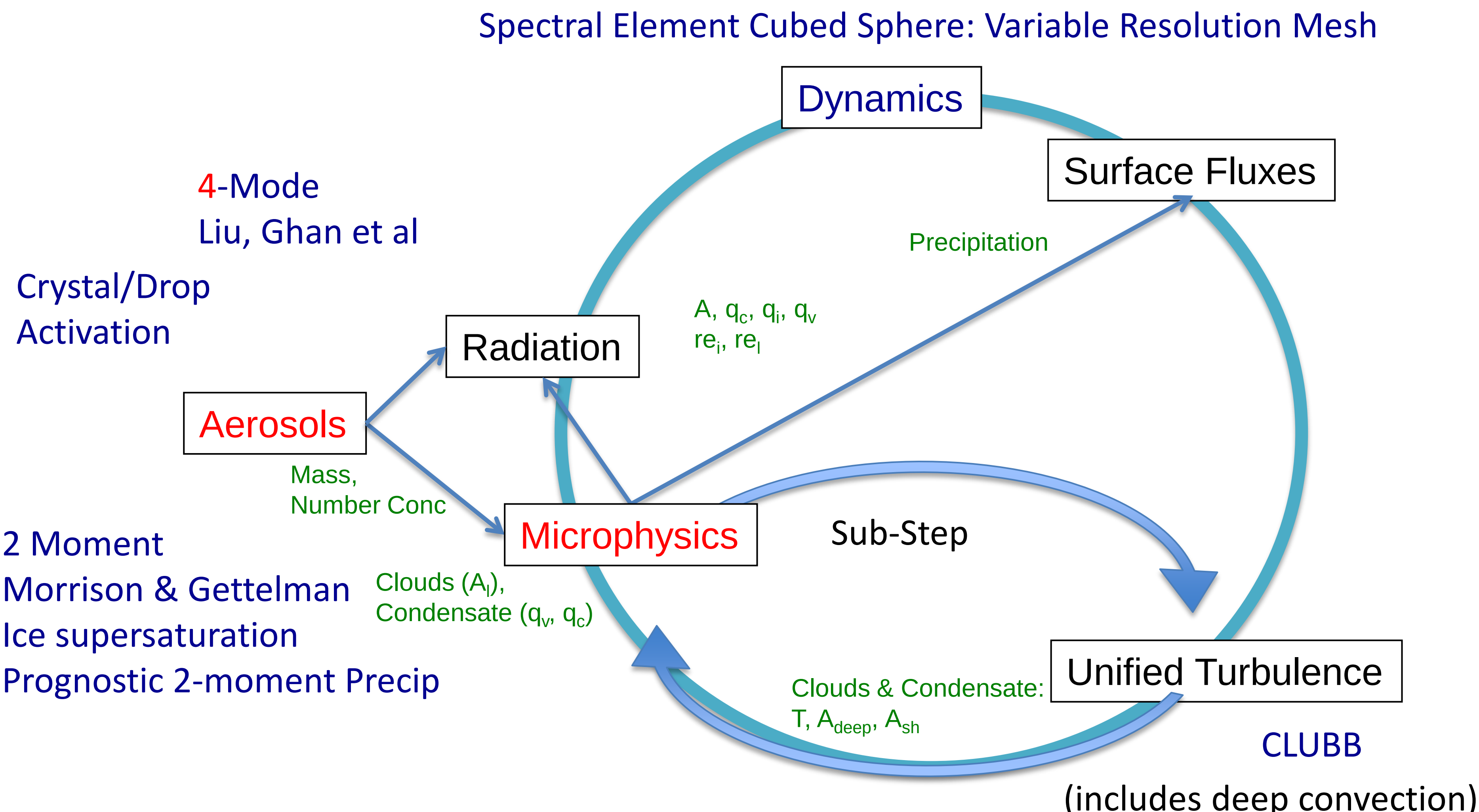
Baseline for CMIP6 model (CAM6)



A = cloud fraction, q=H_2O, re=effective radius (size), T=temperature
(i)ce, (l)iquid, (v)apor

Community Atmosphere Model (0.25°)

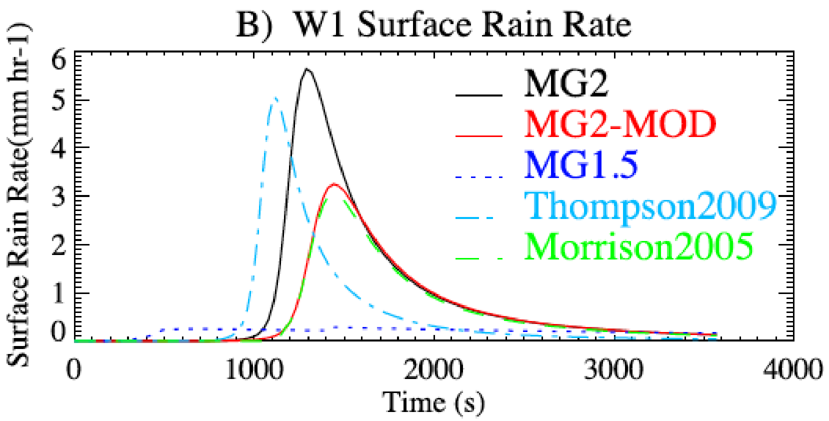
Working on this as an option



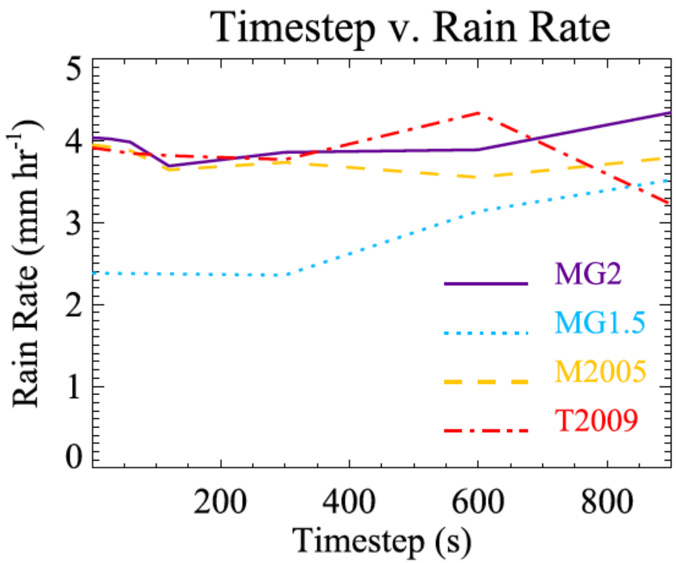
A = cloud fraction, q=H_2O, re=effective radius (size), T=temperature
(i)ce, (l)iquid, (v)apor

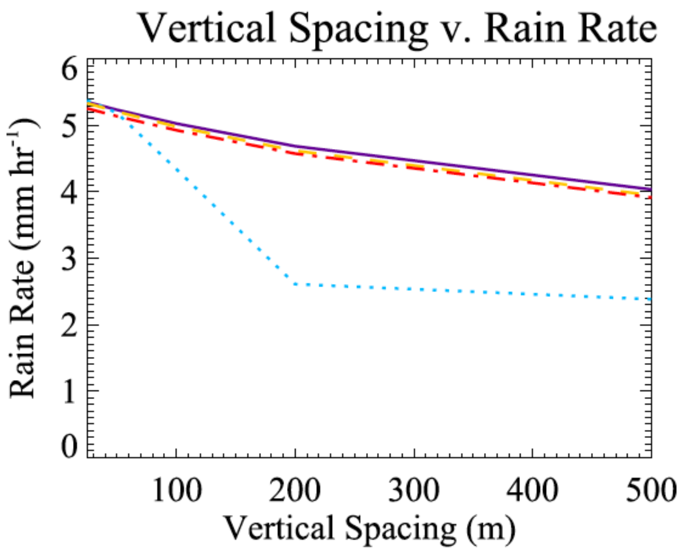
Where are we now: Microphysics

Warm rain: Benchmarks against 2-moment bulk schemes used in mesoscale models



Numerical Stability: Rain rates nearly constant with Timestep and Vertical grid

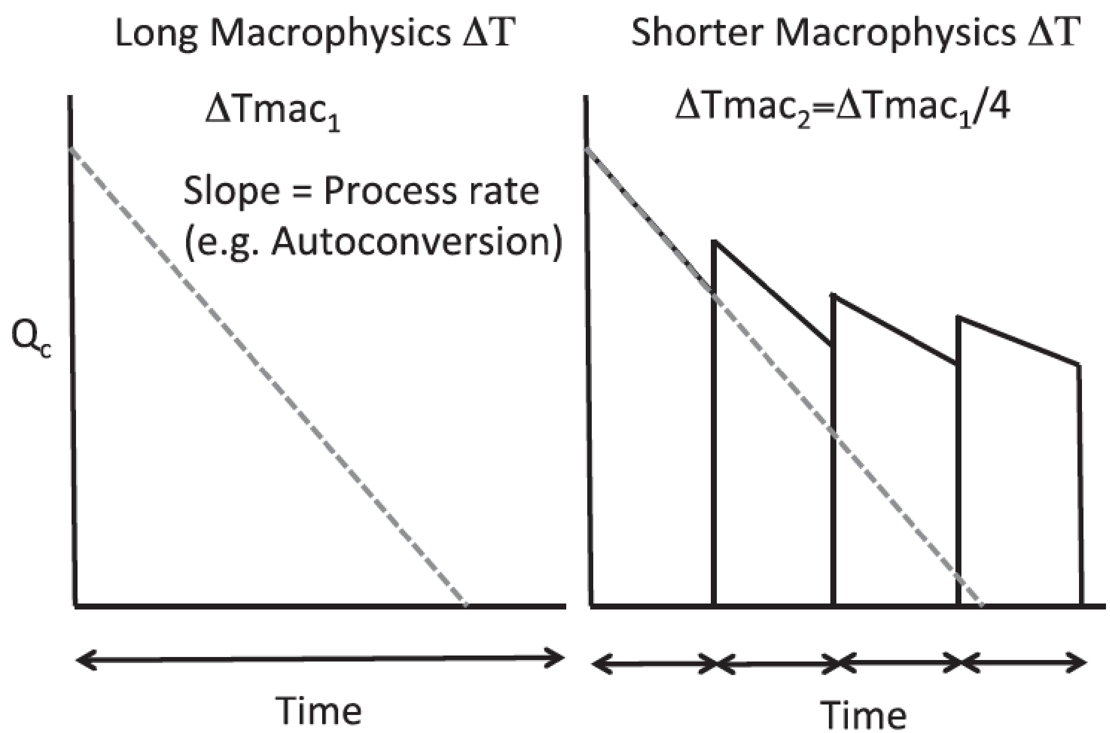




Gettelman & Morrison 2015, J. Climate

Where we are now: Macrophysics

Couple Macrophysics (CLUBB) with microphysics (MG2) on a 5 minute timestep



Gettelman et al 2015, J. Climate

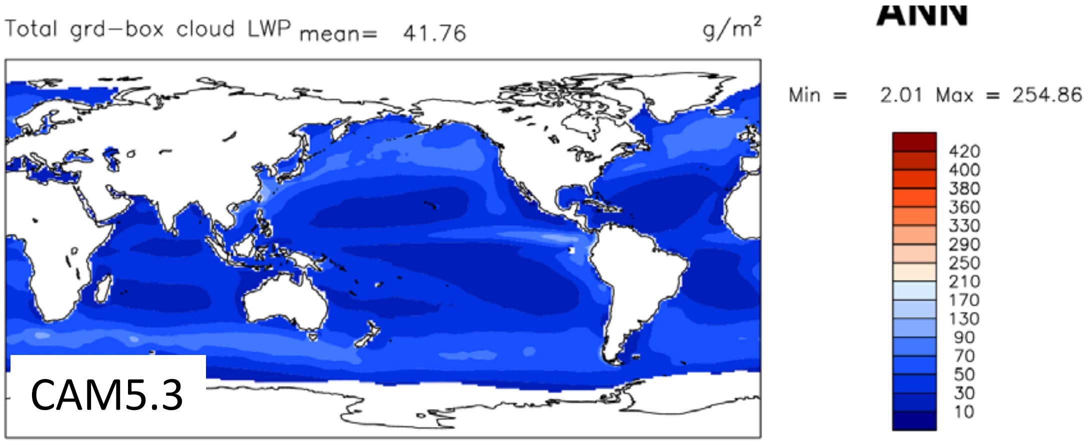
Bias Reductions in CESM1.5

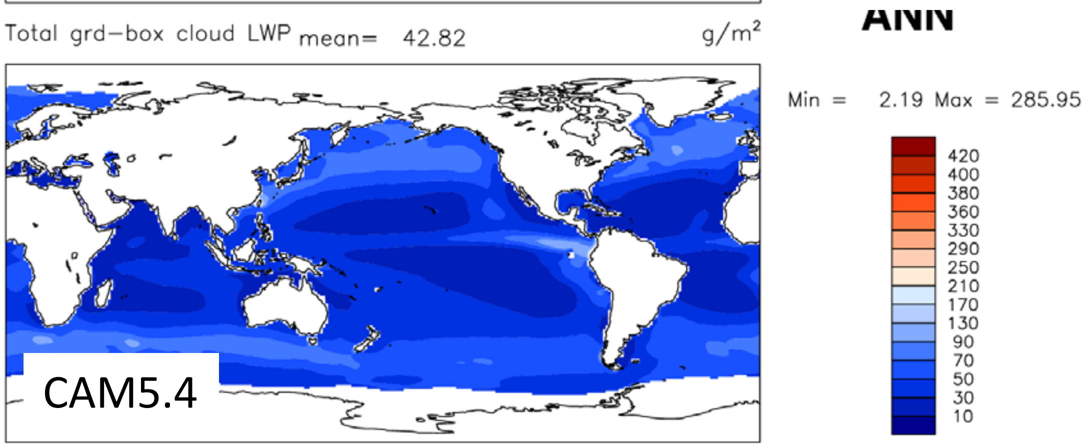
Focus: consistent features (others subject to tuning)

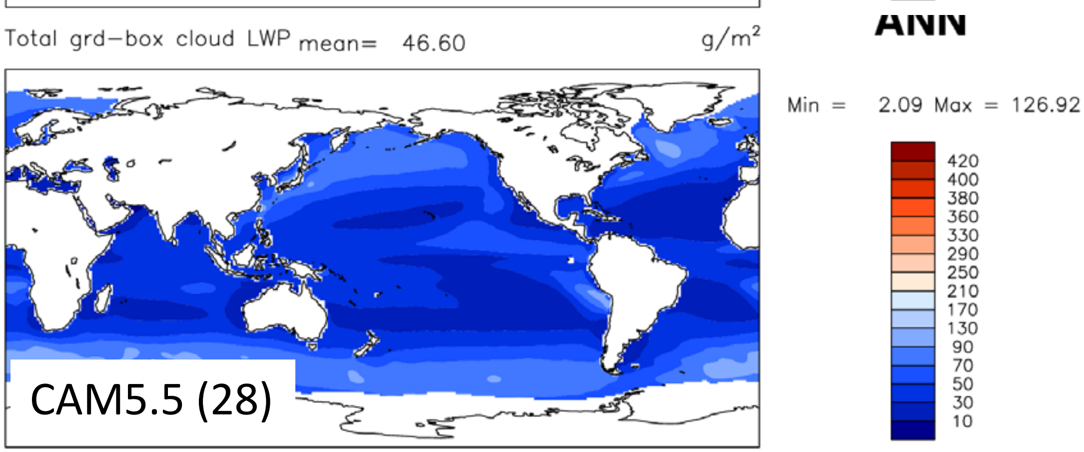
- Better diurnal cycle of precipitation (CLUBB)
- Reduction of SH Absorbed Solar Radiation (ASR) bias:
  - More mixed phase clouds: (Hoose & MG2)
  - Also helps Greenland SMB
- Better strato-cumulus clouds (CLUBB)
- Still issues with ice phase

LWP

(annual mean)





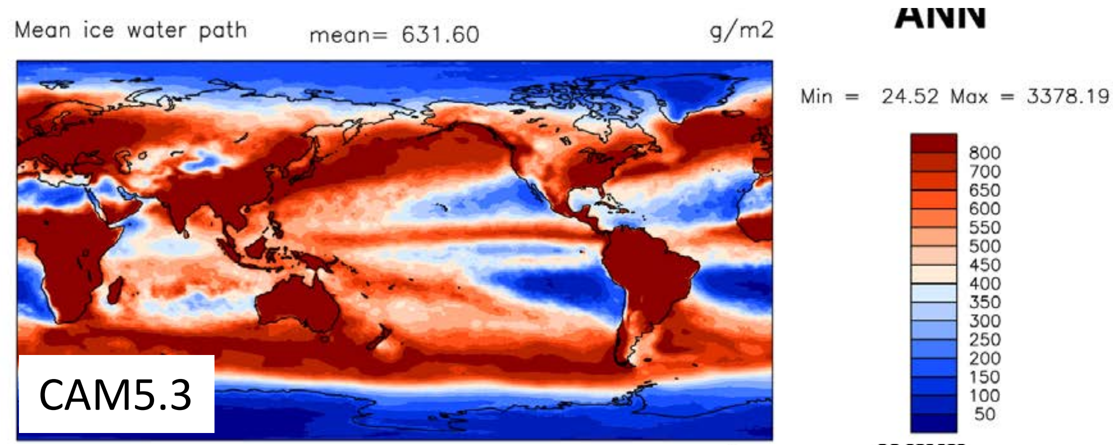


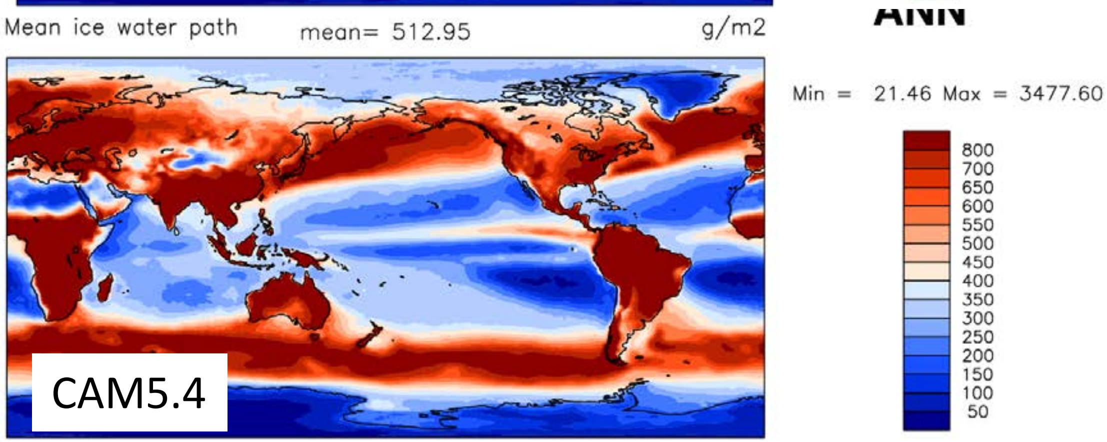
LWP Has not changed much.

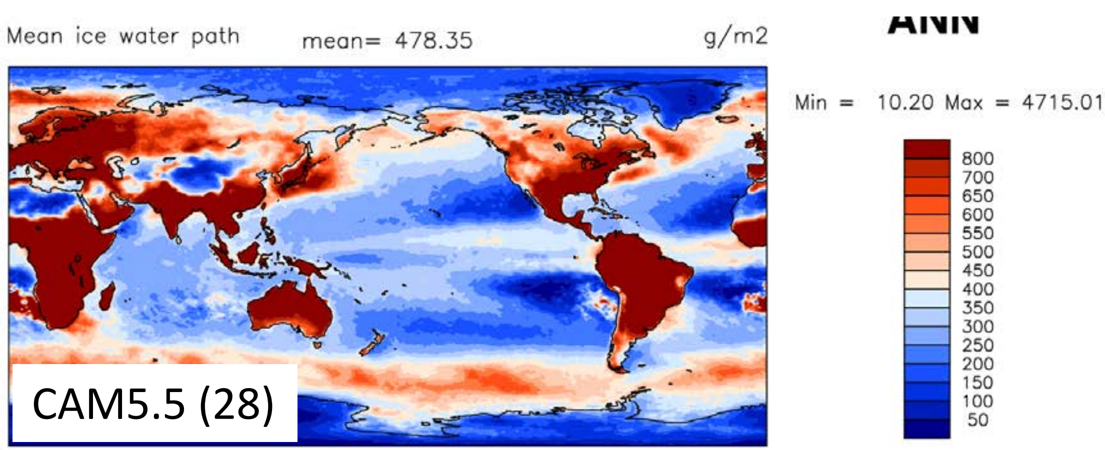
Increases in tropics , storm tracks

Note: not showing comparisons v. observations: measuring different things.

IWP: MODIS-COSP







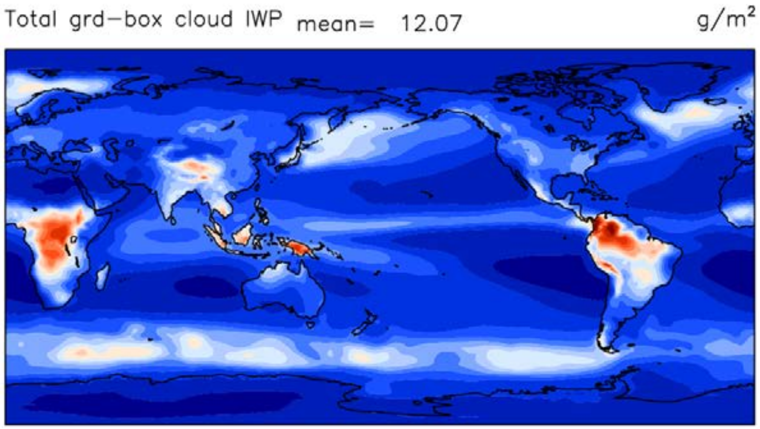
Note: this includes ‘snow’

Lower Ice + Snow Water Path in CAM5.5 Particularly High Latitudes

Why? Tuning to accommodate CLUBB

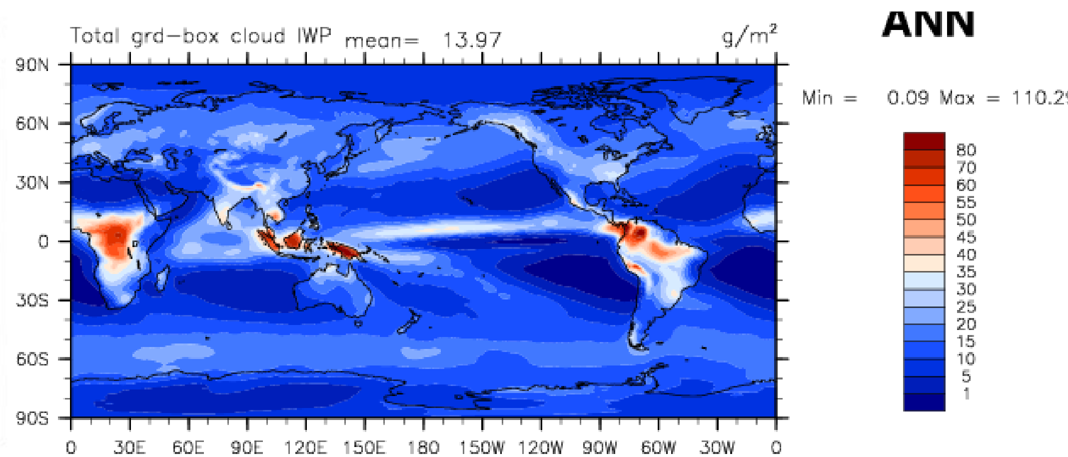
IWP: Annual Mean

CAM5.4

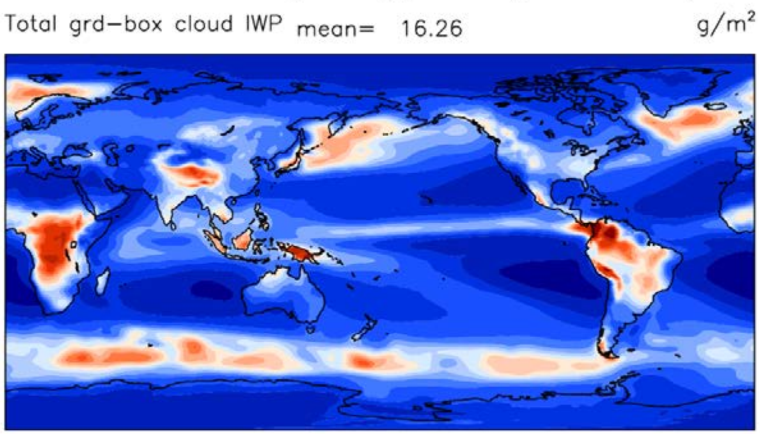


f.e12.FAMIPC5.f09_f09.amip_L30.001 (yrs 1980-2004)

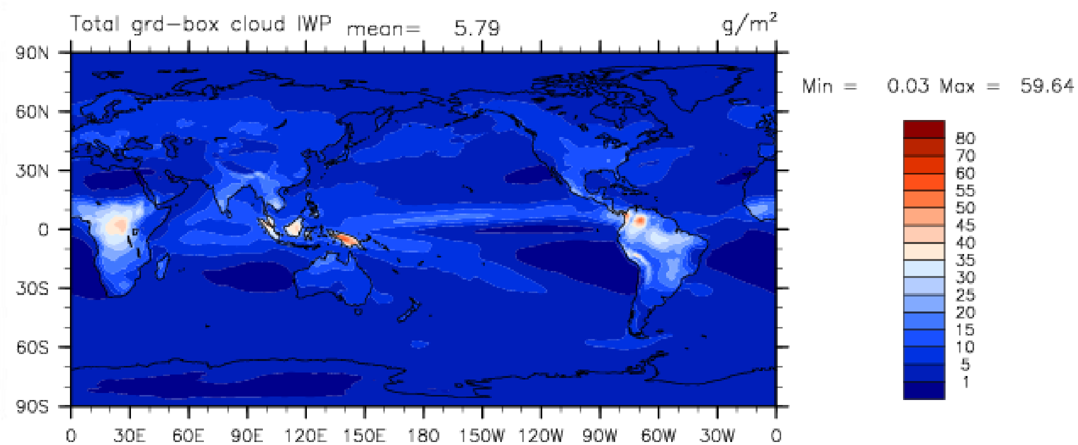
CAM5.5-SB2001



cam55_FC5_f09f09_cam5_4_22_001 (yrs 2-6)



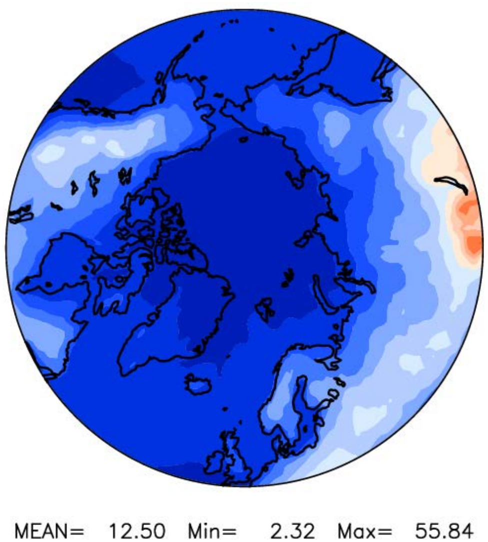
CAM5.3



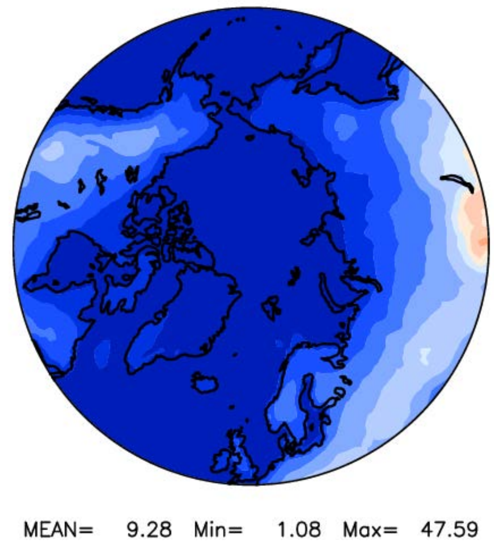
CAM5.5

JJA Ice Water Path (no snow)

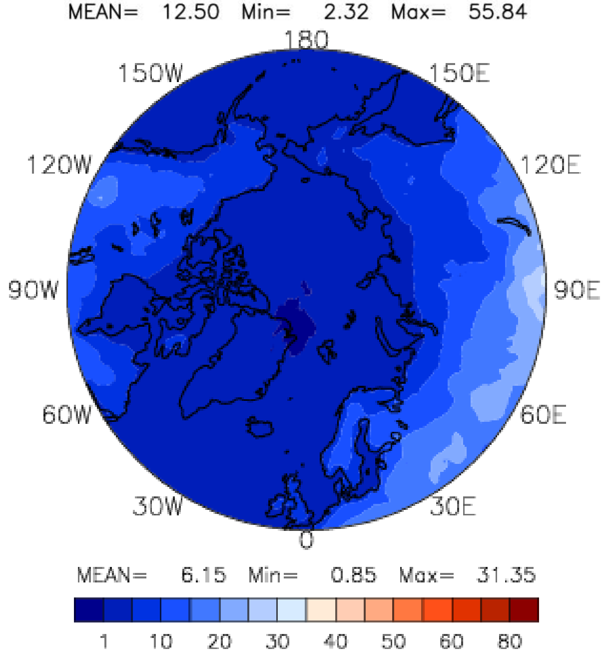
CAM5.3



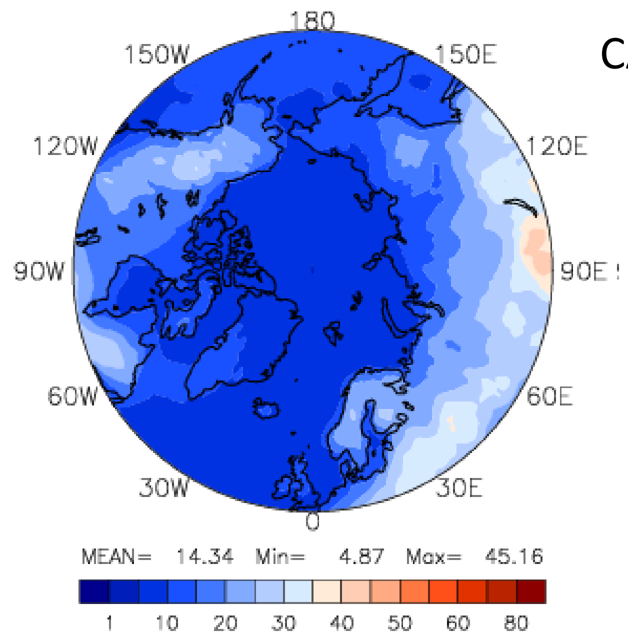
CAM5.4



CAM5.5 (28)

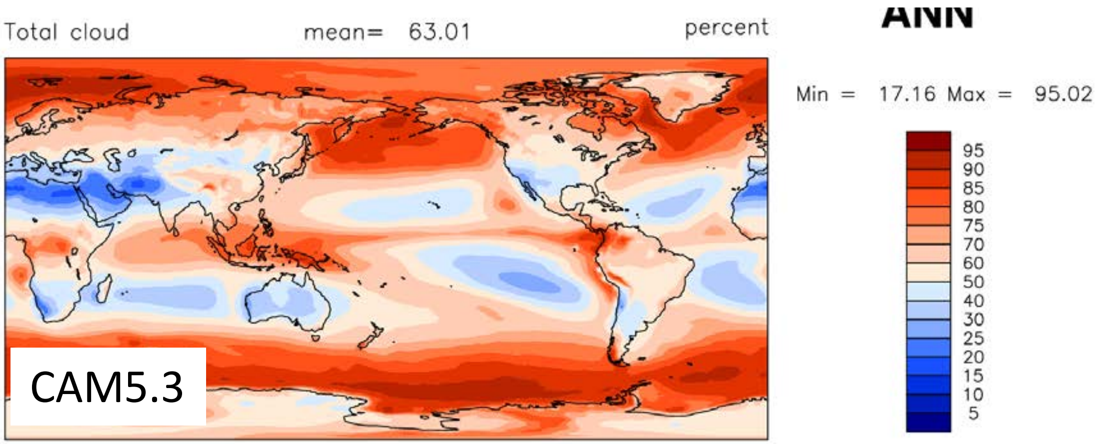


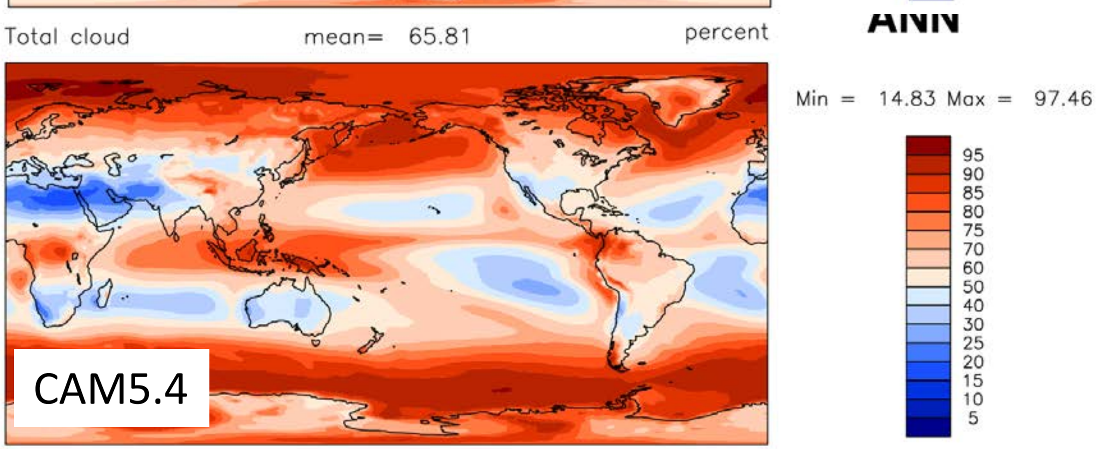
CAM5.5: SB2001

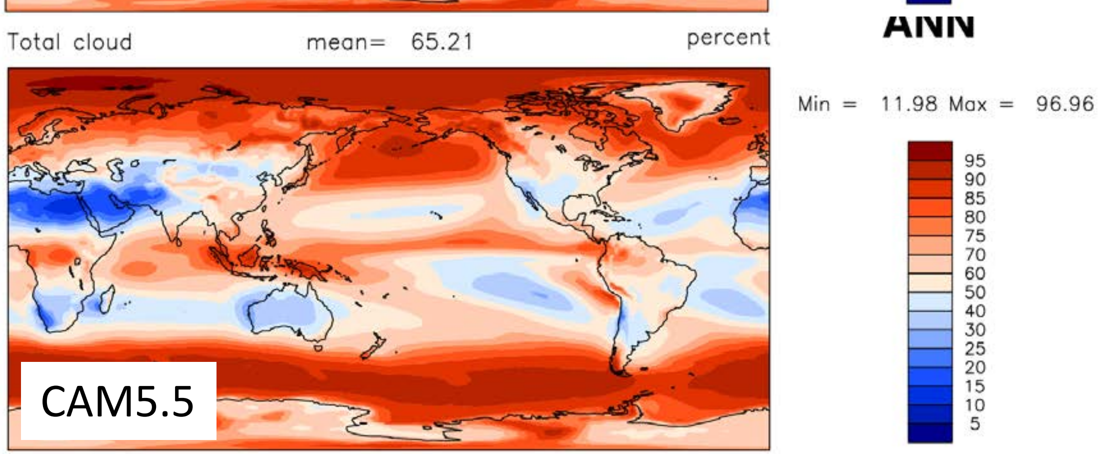


(g/m2)

Cloudiness







Total Cloud fraction Similar
A bit less (current tuning)

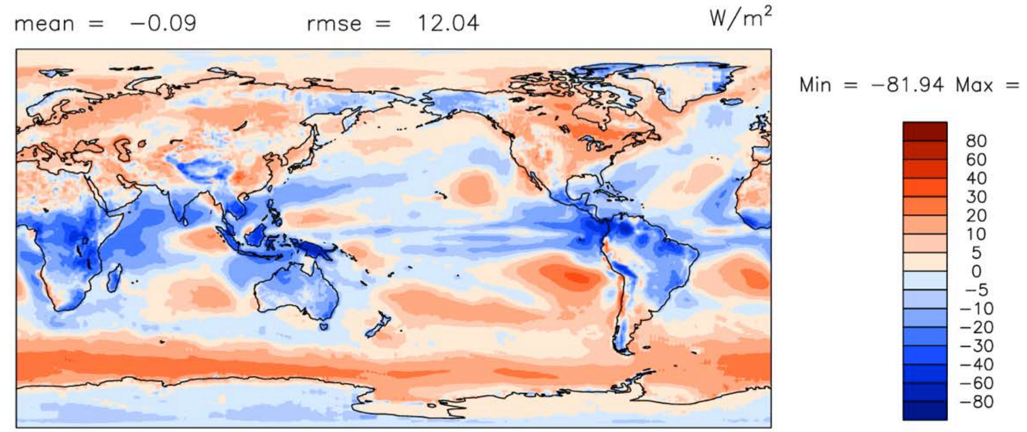
Notes:

- Pacific Strato-cu better
- S. Ocean better

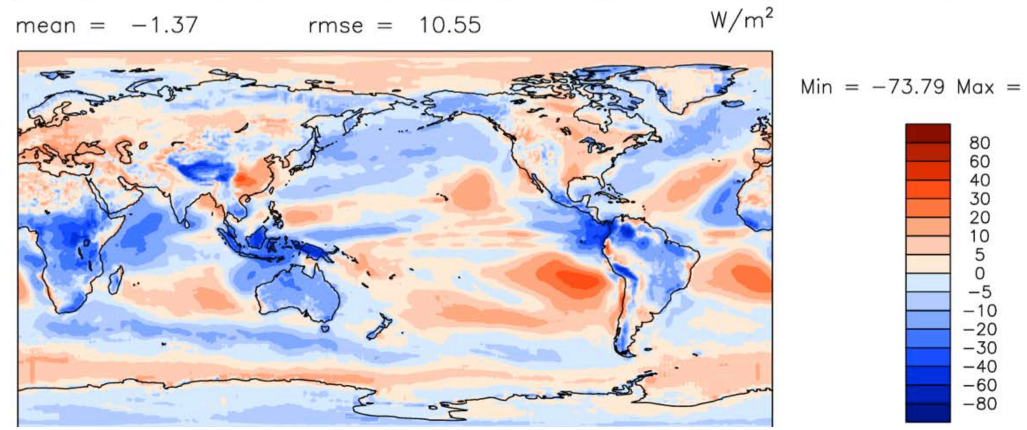
Mean State: TOA SW radiation

Ann SW TOA
Bias v. Satellite (CERES)
Bias = too much Absorbed Solar (ASR)
Free running (Fixed SST) simulations

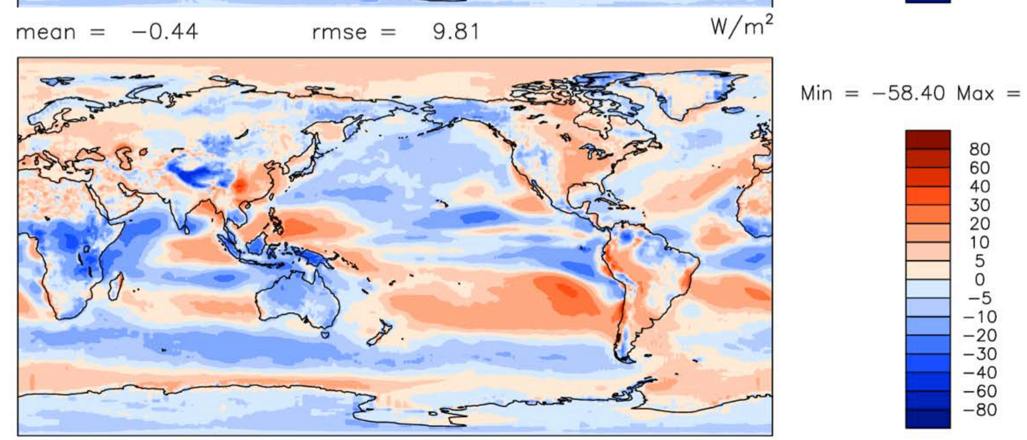
CAM5.3 (CESM1.2)



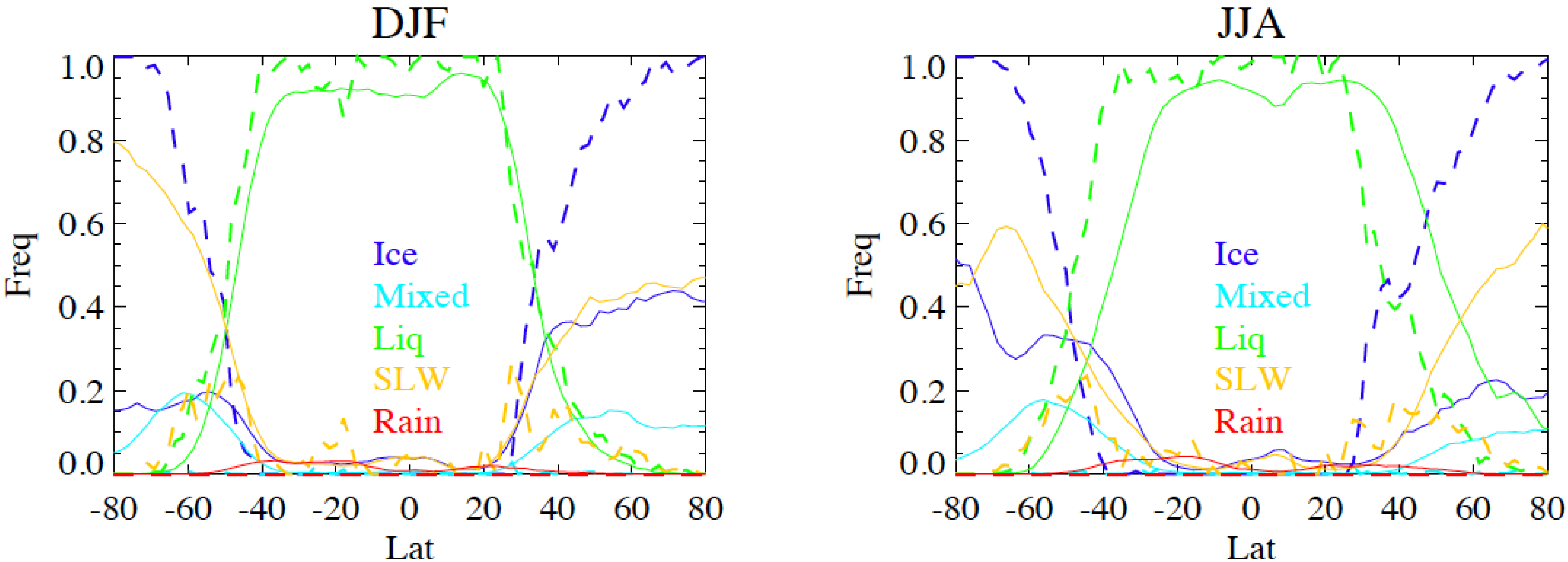
CAM5.4 (+ice nuc & MG2)

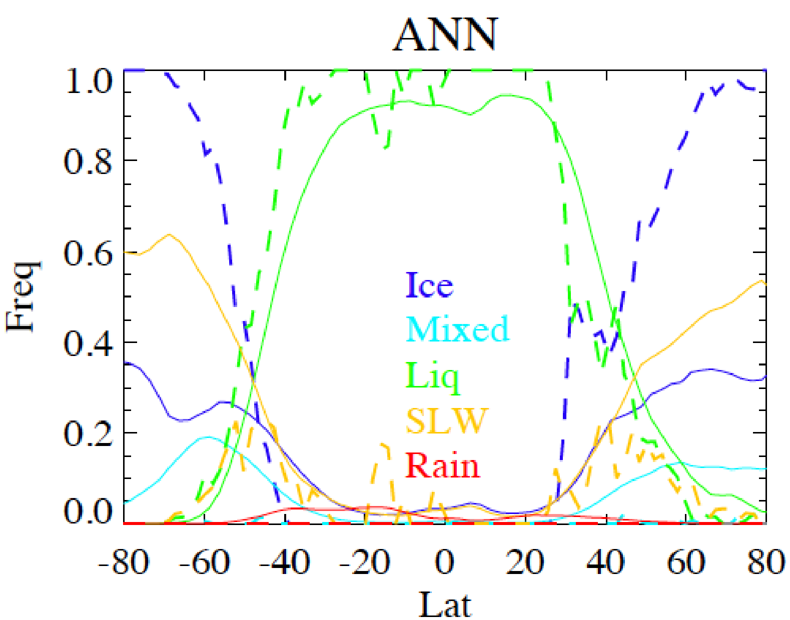


CAM5.5 (+CLUBB)



Supercooled liquid in CESM





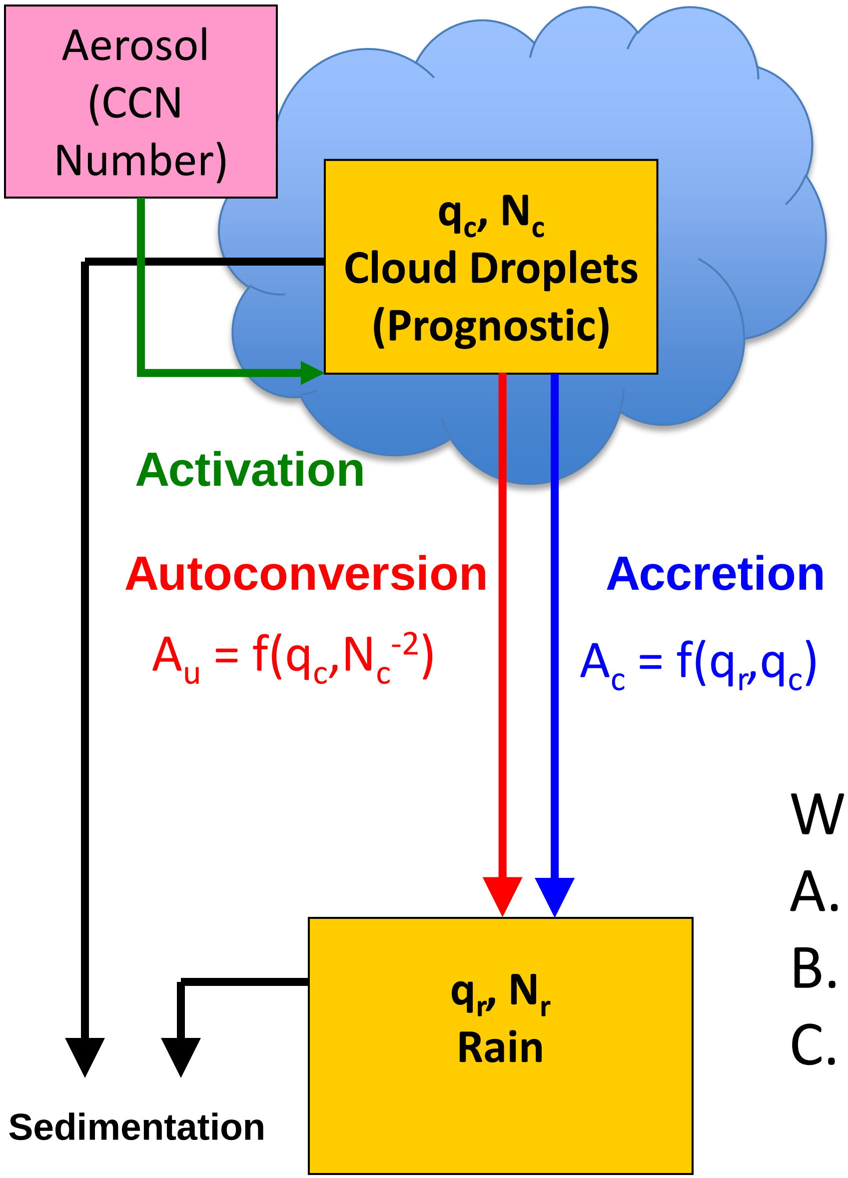
Frequency of occurrence of different hydrometeors at cloud top.
Solid = Satellite observations. (DARDAR)
Dashed = CAM5.4

Getting some super-cooled liquid water (SLW), not quite enough
Liquid looks good (too much Ice)

Aerosol Forcing

- Changes to Aerosol Cloud Interactions
  - MG2: Prognostic Precipitation
  - MAM4 now (add BCmode): SO_2 lifetime different
  - Mixed Phase Ice nucleation
  - CLUBB Macrophysics: includes shallow convection
- Impacts
  - MG2 decreases ACI
  - MAM4 increases ACI (more SO_4)
  - CLUBB increases ACI: now in shallow convective regimes
- Additional Proposed Change
  - Replace Autoconversion and Accretion in MG2 (SB2001)

Process rates: Essence



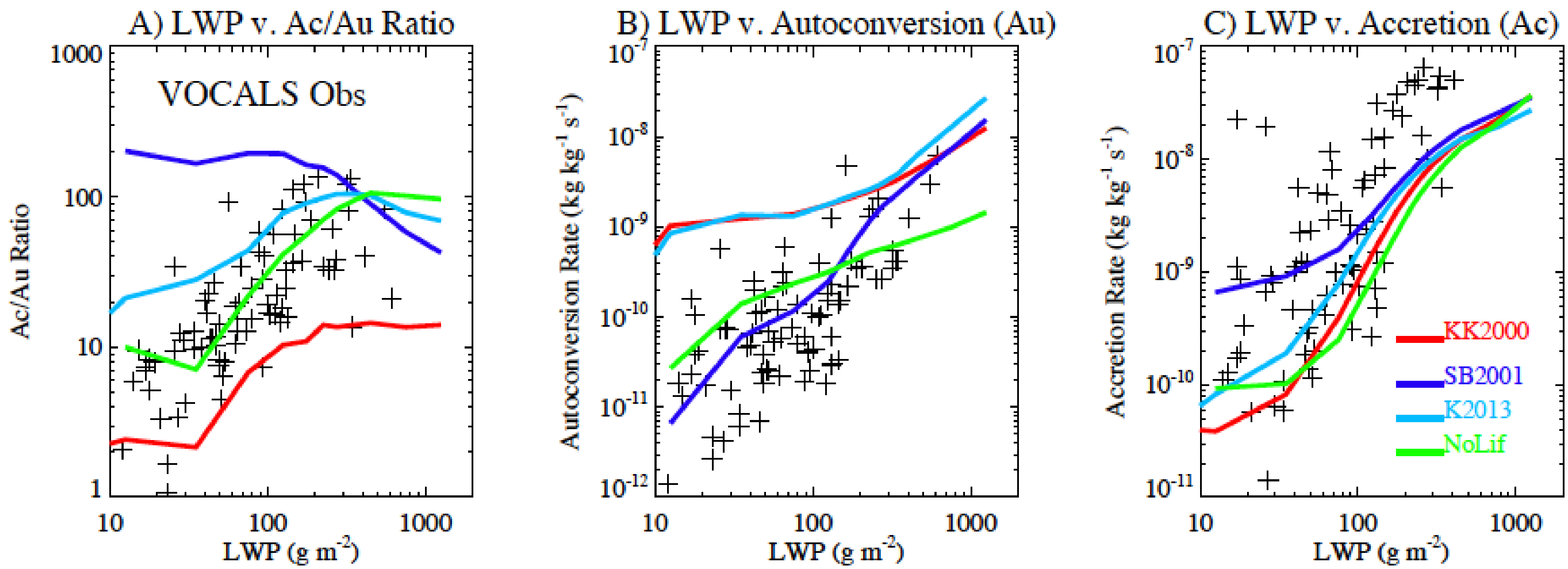
1. Activation (CCN) = f(RH,w)
   W at cloud scale is critical
2. Autoconversion (loss process) is a function of N_c^{-2} (=ACI)
3. Accretion depends on q_r

With Prognostic rain & Autoconversion:

A. Better representation of q_r
B. Increase in A_c / A_u
C. Reduced ACI (reduced N_c effect)

Gettelman 2015, ACP

Process Rates: Autoconversion Effects

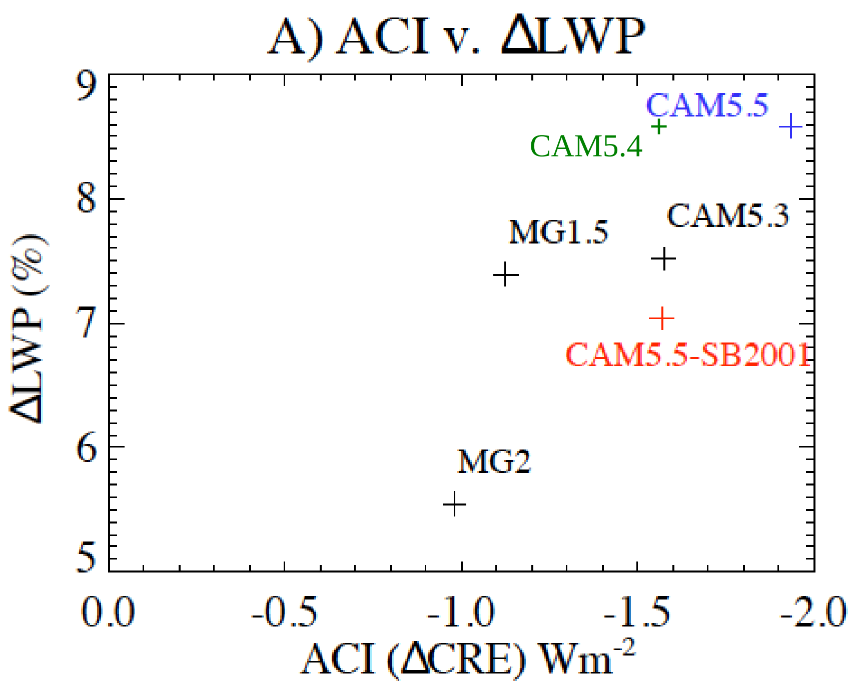


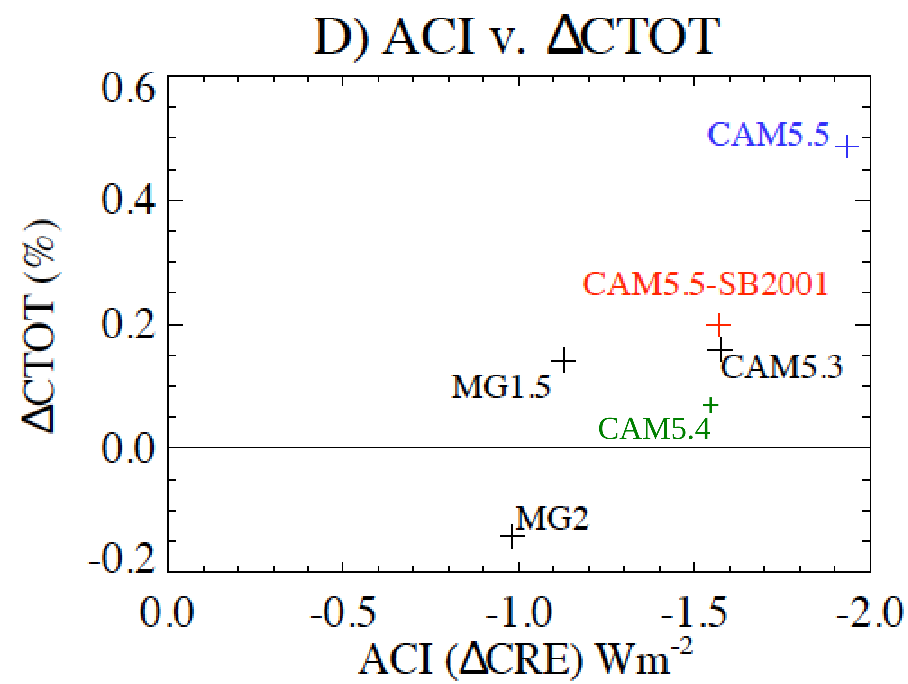
Observations = Calculations with detailed model and observed size distributions from S. E. Pacific (Terai and Wood)

Current Autoconversion, Alternative Schemes, No Lifetime Effects

ACI

ACI Definition following Ghan 2013

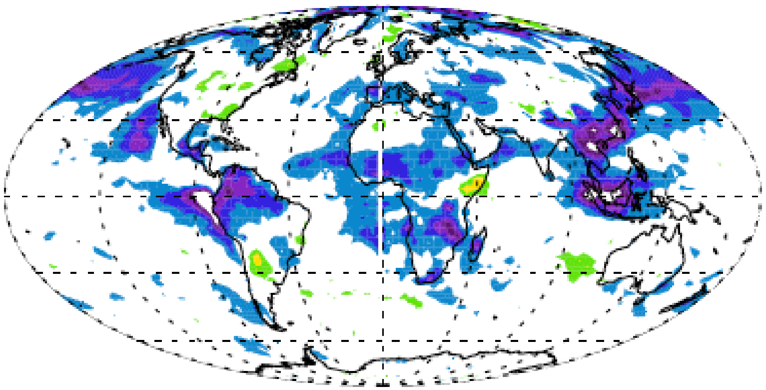




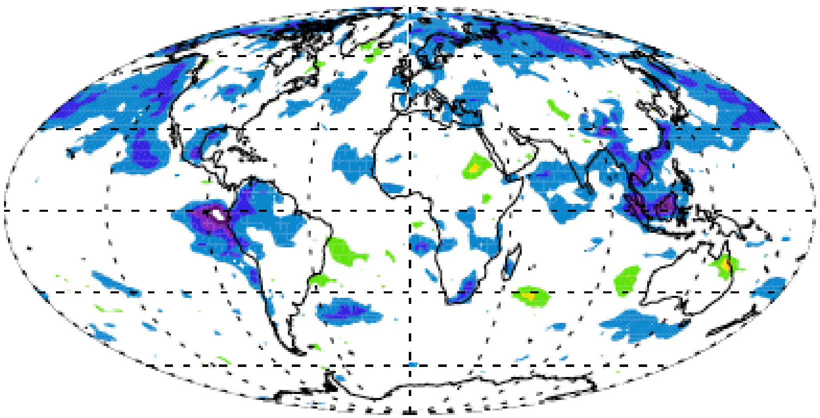
- Started (CAM5.3) with ACI about -1.5 Wm^{-2}
- Decrease with MG1.5 and MG2
- Increase with CAM5.4 (mixed phase ice nucleation+ MAM4)
- Increase with CAM5.5 (shallow convective regime)
- Can Decrease with new Autoconversion (SB2001)

TOA Flux Anomalies

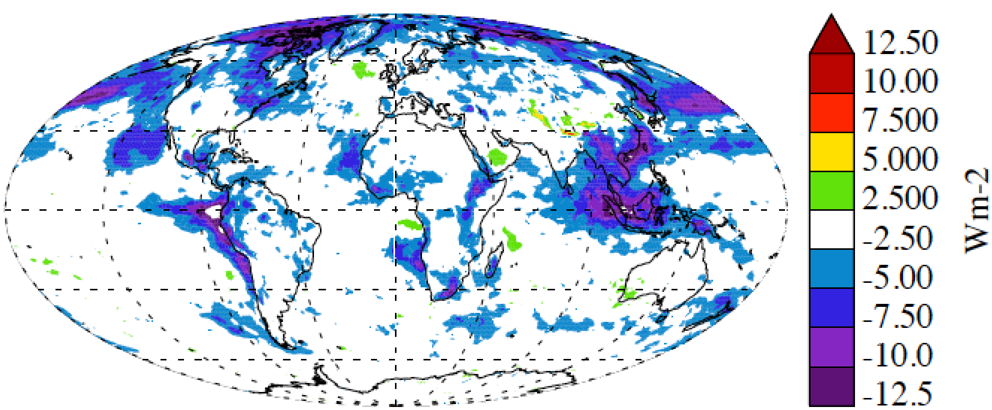
CAM5.3



CAM5.3-MG2



CAM5.4



Mid & High Latitudes:

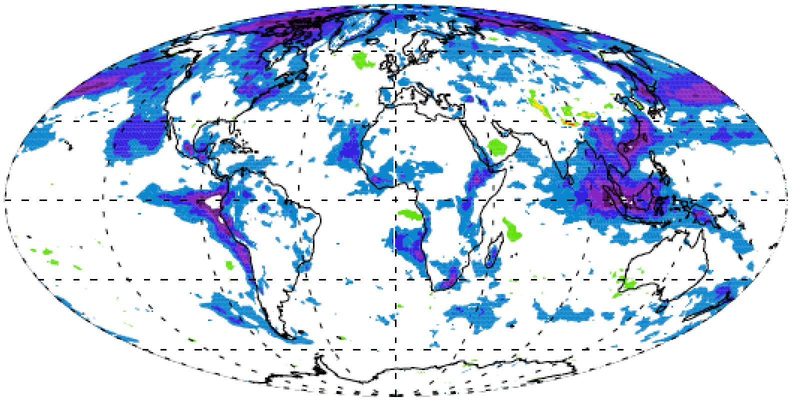
Mixed Phase ice Nucleation

Low Latitudes:

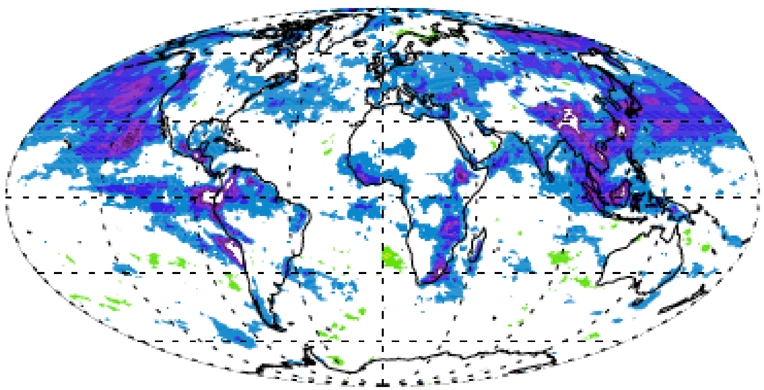
Aerosols: SO_2 lifetime change with new mode widths (higher SO_4)

TOA Flux Anomalies (2)

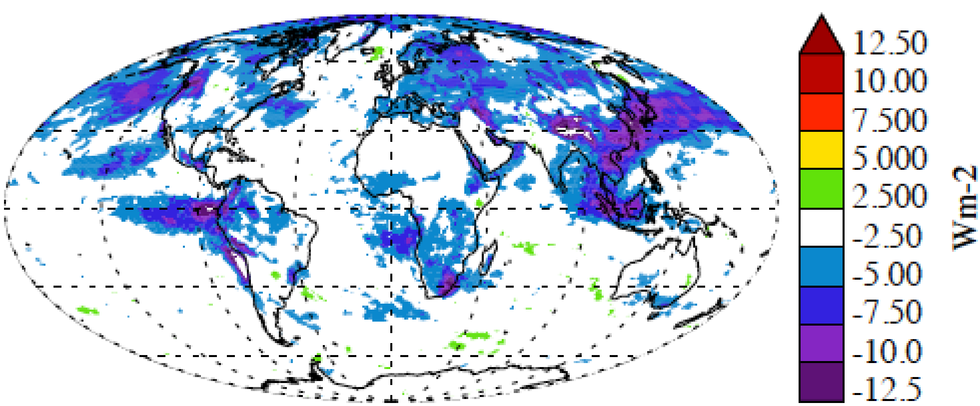
CAM5.4



CAM5.5



CAM5.5-SB2001



Subtropics and Middle Latitudes:

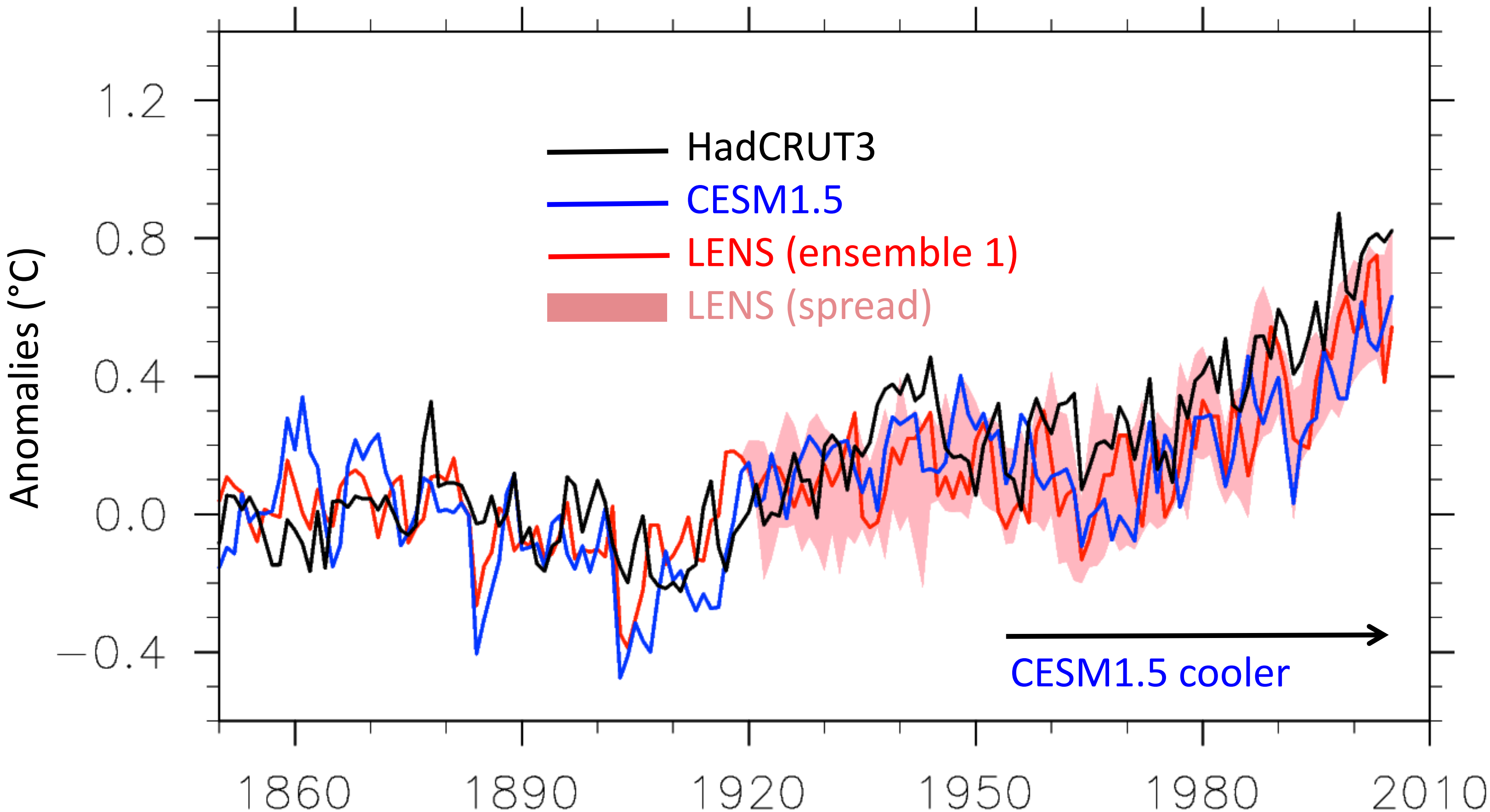
- Shallow convection Regime
- Arctic effects decrease (Robust?)

New Autoconversion reduces effects in Sub-Tropics

20th Century Global Surface Temperature

Temperature anomalies from 1850-1899 average

Thanks to: C. Hannay



➔ **Aerosol indirect effect is strong in CESM1.5**

➔ **Feedbacks: stay tuned for Wednesday**

Summary

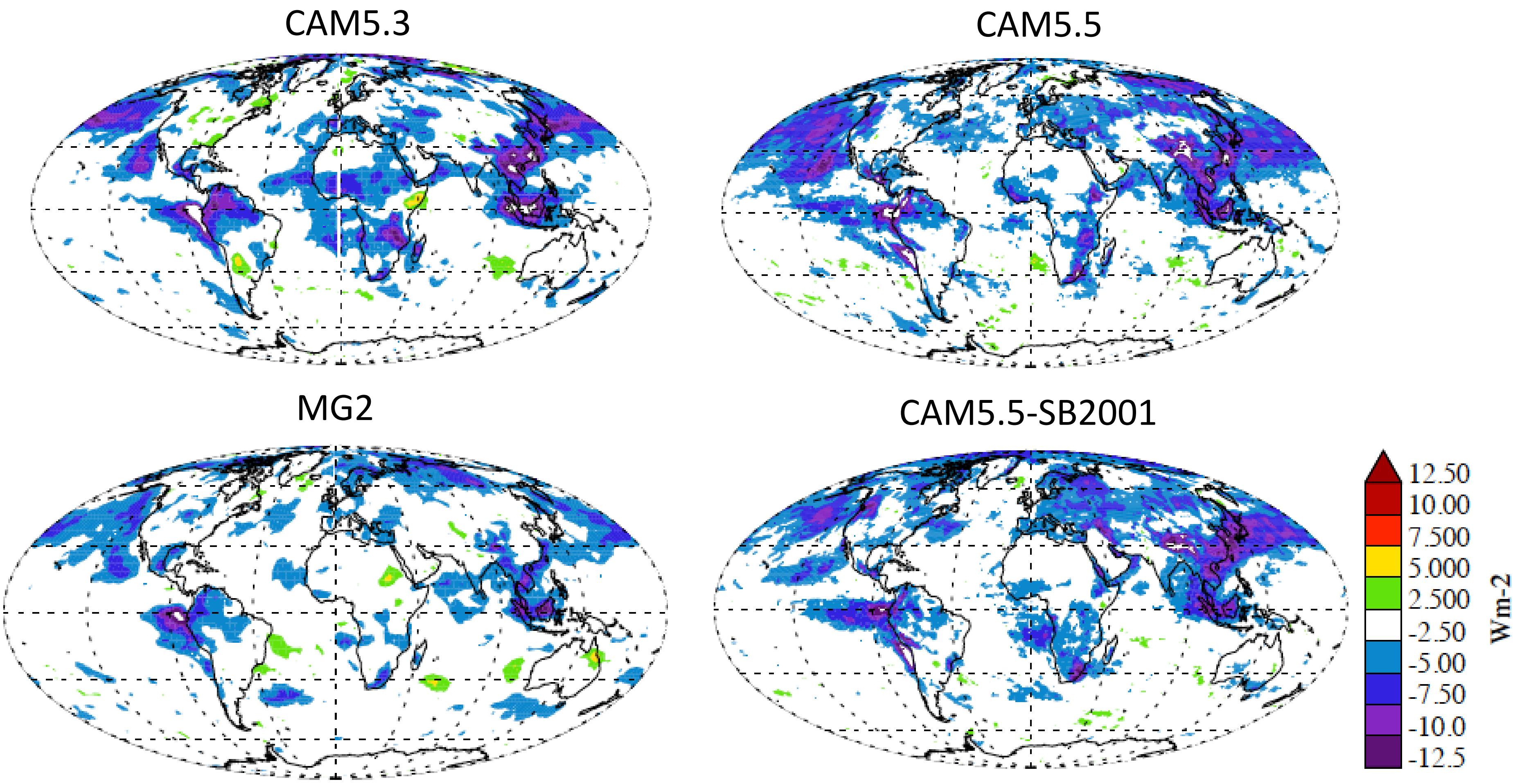
- Clouds in CESM now using a new approach
- Unified parameterization, fewer interactions
  - Designed to be less sensitive to scale
  - Towards one turbulence, one microphysics
- Improves some aspects of simulations
  - S. Ocean, Strato-cumulus
  - Cloud Radiative Forcing
  - Still working on ice clouds (more supercooled liquid better)
- Next steps: where we need to go….

Clouds Beyond CESM2

- Unify moist turbulence: stratiform + convective
  - CLUBB can probably do this
- Microphysical process rate formulations need to 'evolve'
  - Biggest climate impacts are on precipitation formation and aerosol cloud interactions (related)
  - Precipitation distribution is more important at finer scales
- Better treatment of ice
  - Unify snow and ice
  - Consistent description in Radiation Code
- 'Unified' microphysics for all clouds
  - Need to be able to do deep convective microphysics
  - Add graupel/hail
  - Use microphysics with sub-columns: force with sub-grid updrafts

EXTRA SLIDES

TOA Flux Anomalies



Tropics and Sub Tropics: Shallow Convection

Autoconversion: Reduces magnitude in cleaner regions & Sub tropics

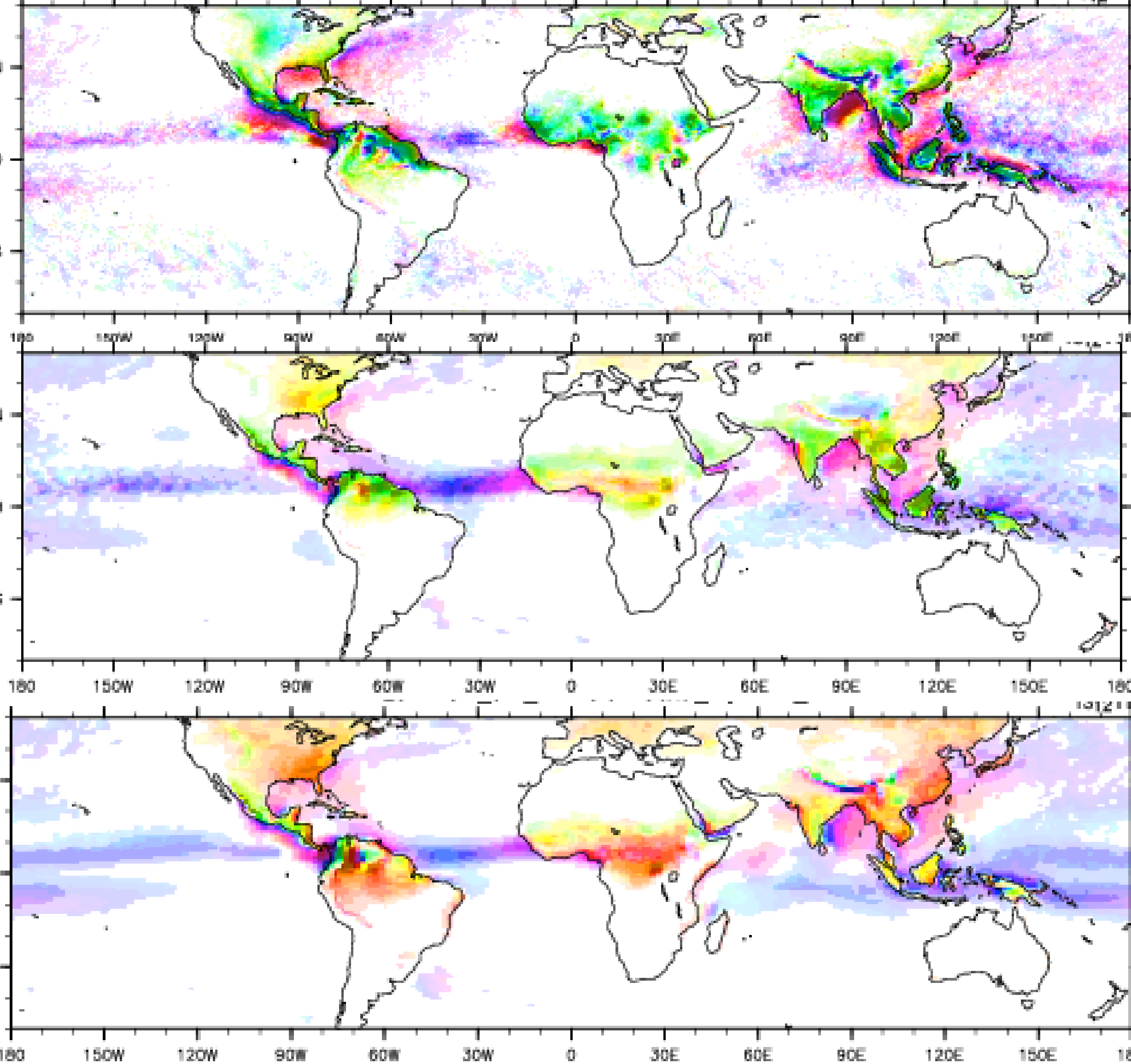
Variability: Diurnal Cycle of Precip

JJA Precipitation Rate

TRMM: OBS

CAM5.5 (new)

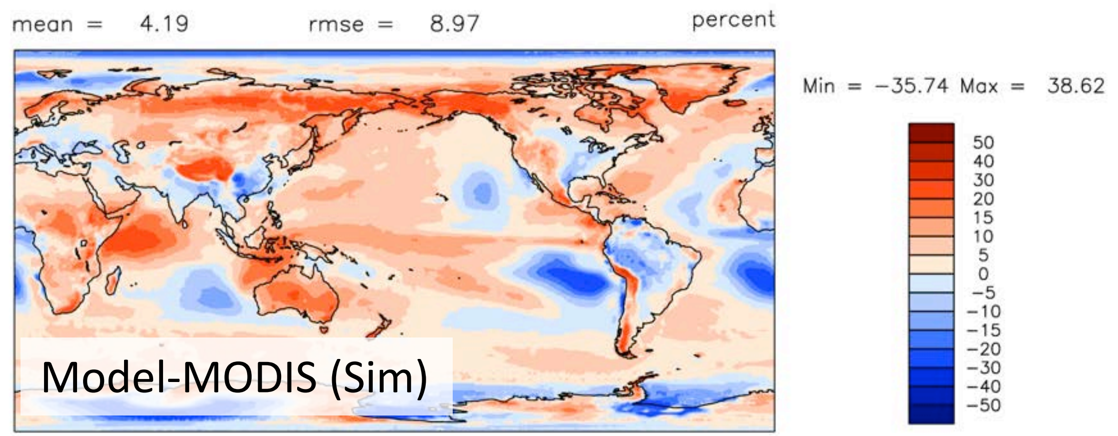
CAM5.3 (Old)

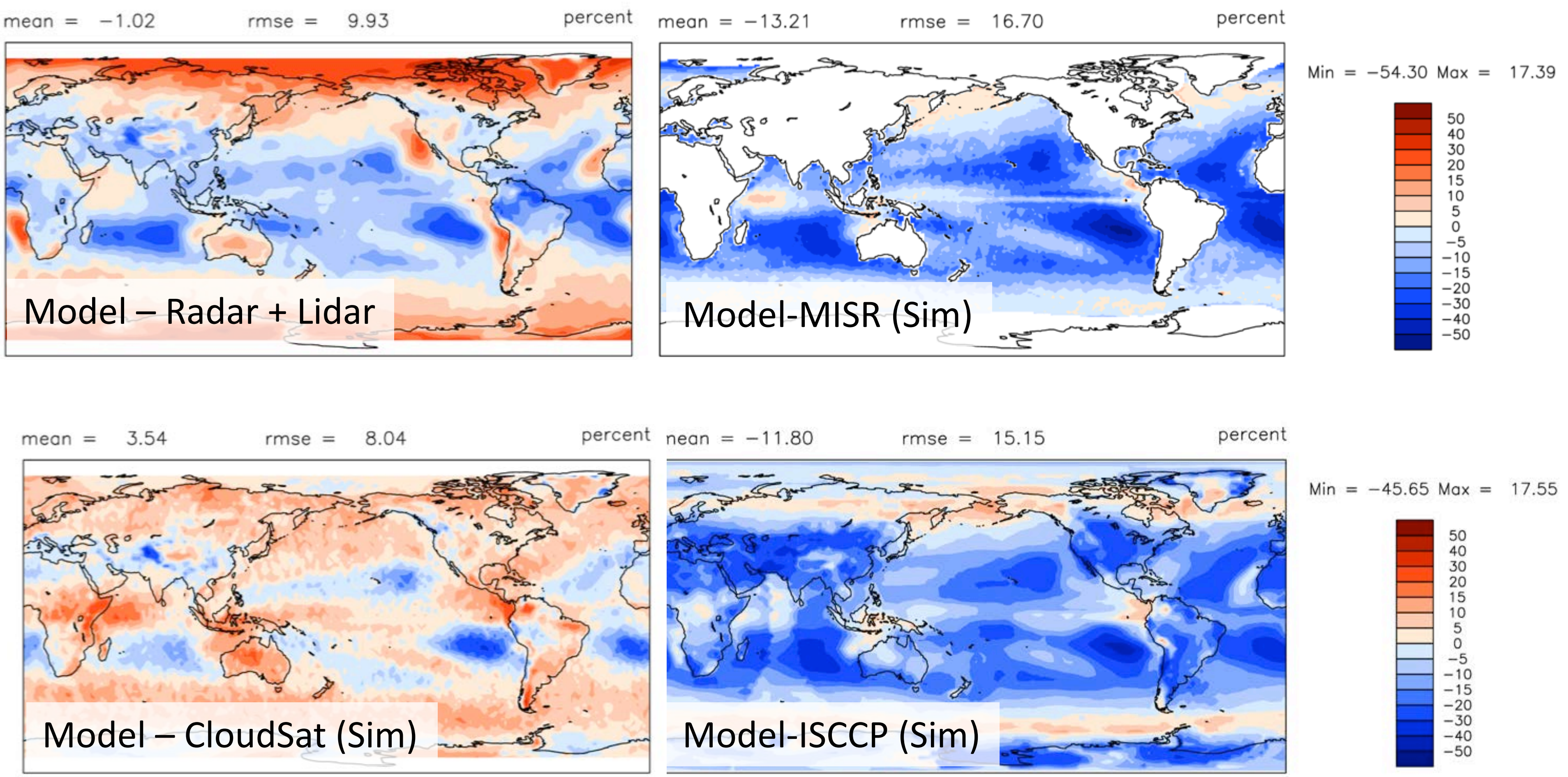


Thanks to R. Neale, C-C. Chen

Cloud Fraction Differences

Different bias against different instruments

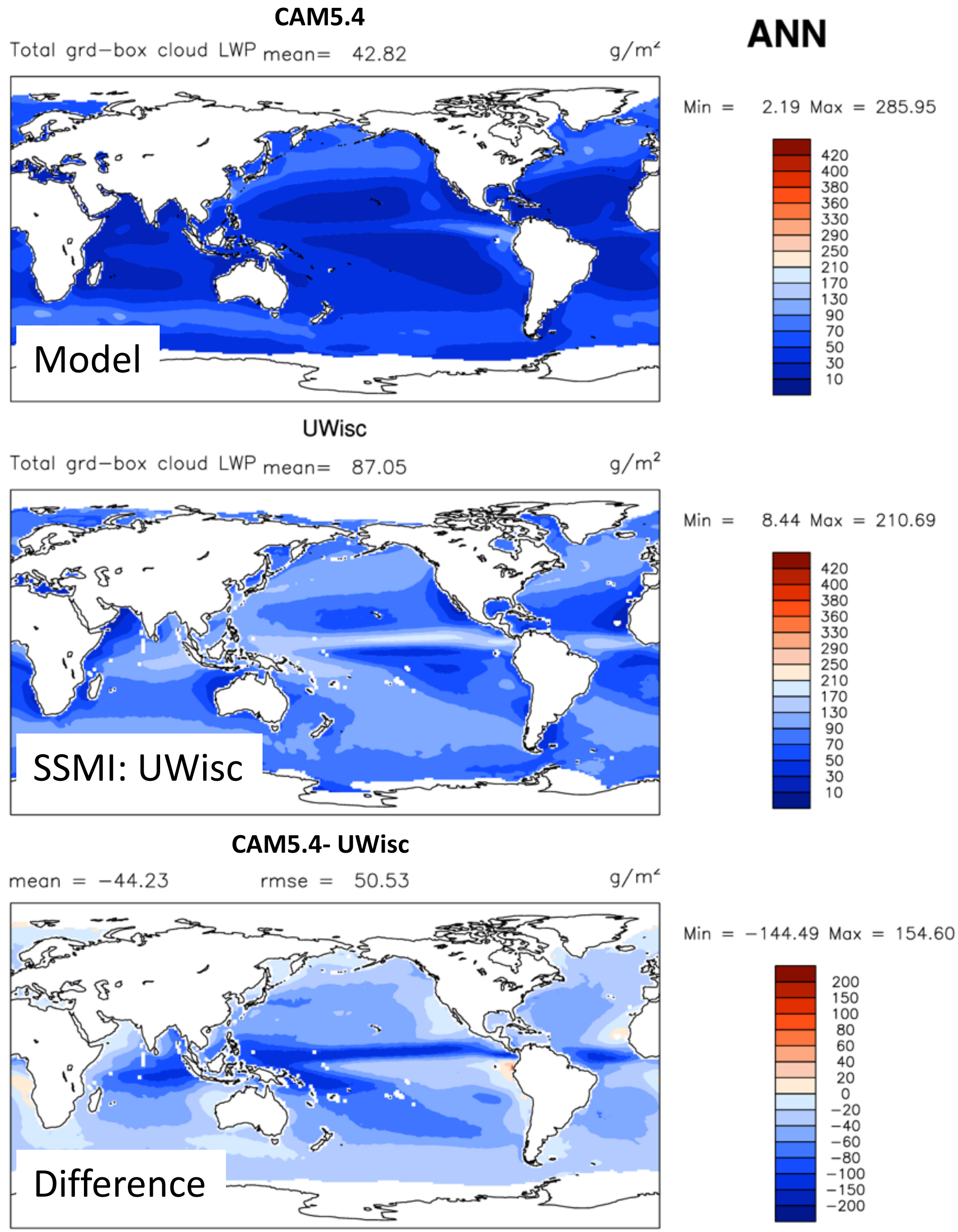




LWP: Wrong Message

Traditional comparison of Model LWP field against Microwave Satellite Observations of LWP. Model is low. But cloud forcing looks okay, and the cloud fraction looks okay. What is going on?

Same problem with comparison with MODIS LWP retrievals…



LWP: Correct Message

Use of the COSP MODIS satellite simulator for LWP: implies an Adiabatic assumption for low clouds. The model is not Adiabatic, but assuming it is Adiabatic increases LWP, especially over land and storm tracks

Now the model is slightly HIGHER than observations (+20%) rather than -50% LOW. Even over oceans