An overview of recent CAM developments

**Contributors: Chris Bretherton, Bill Collins, Andrew Conley,
Brian Eaton, Andrew Gettelman, Steve Ghan, Cécile Hannay,
Mike Iacono, Xiaohong Liu, Hugh Morrison, Rich Neale,
Sungsu Park, Phil Rash, Joe Tribbia, and many others**

**National Center for Atmospheric Research, Boulder
Pacific Northwest National Laboratory, Richland
Atmospheric and Environmental Research, Lexington
University of California, Berkeley
University of Washington, Seattle**

AMWG Meeting, Boulder, March 2-4, 2009

Outline

- What happens since the last CCSM meeting ?
  - Changes in the CAM trunk since Breckenridge
  - New datasets for tuning and evaluation
- CAM standalone simulations
  - CAM3.5
  - Microphysics scheme
  - Radiation scheme
  - Aerosol model
  - PBL/ShCu/Macrophysics schemes (“cloud package”)
- Conclusions

Changes in the CAM trunk since Breckenridge

- **June 2008 (Breckenridge): Trunk = CAM3.5**
- **August 2008: New default microphysics (MG)**
- **Nov 2008: New default radiation (RRTMG)**
- **Feb 2009: New default aerosol model (MAM)**
- **Feb 2009: Completed merge between MAM and the cloud branch (UW PBL, shallow convection, macrophysics) => "CLAM branch"**

New datasets for tuning

- **Tuning** = adjusting parameters (weakly constrained by obs) to achieve agreement of the TOA radiative balance with observations.

TOA radiative balance: Net SW - Net LW ~ 0

- **CAM3.5 ⬄ ERBE dataset**

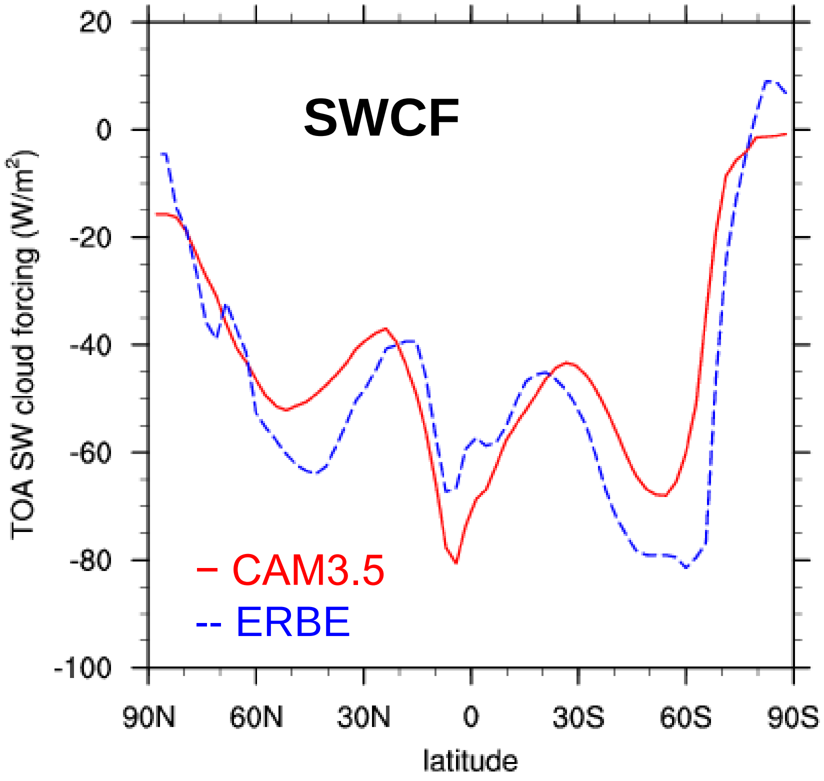
- **CERES-EBAF dataset (global net TOA flux ~0.9 Wm-2)**

Comparison of ERBE, CERES and CERES-EBAF TOA fluxes

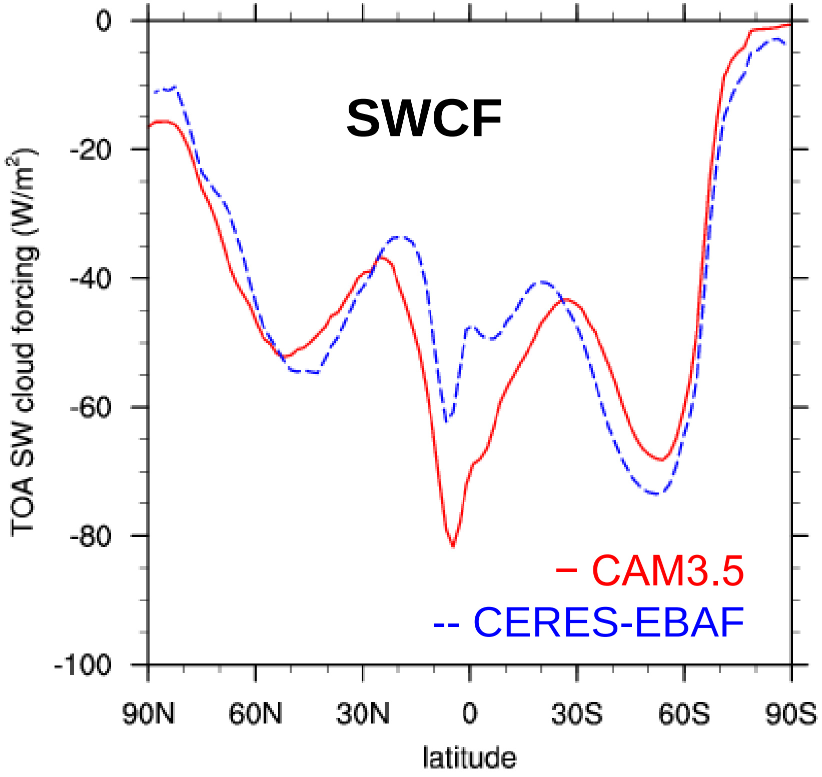
	ERBE Adjusted (Trenberth, 1997)	**CERES**	**CERES-EBAF** (Loeb et al., 2008)
Solar Irradiance	341.3	341.3	340.0
LW (All-Sky)	234.4	237.1	239.6
SW (All-Sky)	106.9	97.7	99.5
Net (All-Sky)	0.0	6.5	0.9
LW (Clear-Sky)	264.9	264.1	269.5
SW (Clear-Sky)	53.6	51.1	52.5
LWCF ($LW_{Clear-sky-}LW_{All-sky}$)	30.5	27.0	29.9
SWCF ($SW_{Clear-sky-}SW_{All-sky}$)	-53.3	-46.6	-47.1

Impact of the new datasets on the tuning

CAM3.5 versus ERBE



CAM3.5 versus CERES-EBAF



The two datasets gave a different picture of where the deficiencies are

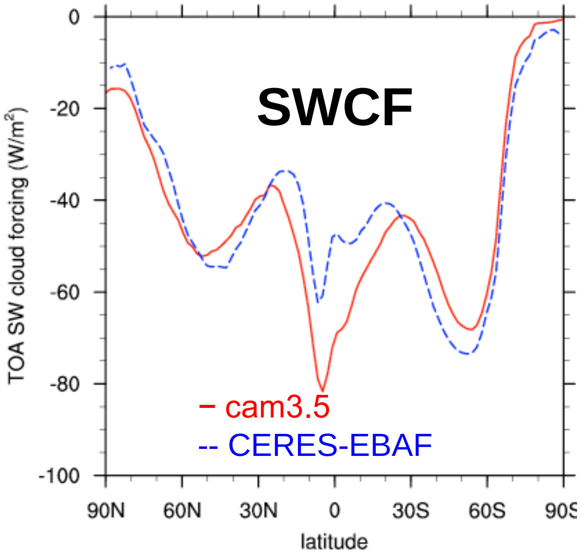
Outline

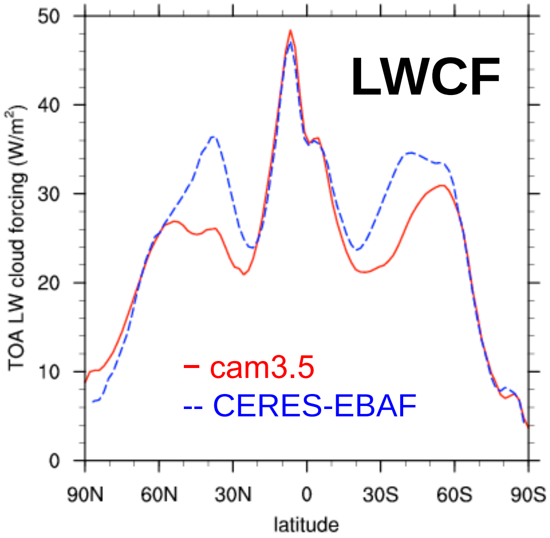
- What happens since the last CCSM meeting ?
  - Change in the CAM trunk since Breckenridge
  - New datasets for tuning and evaluation
- **CAM standalone simulations**
  - **CAM3.5**
  - **Microphysics scheme**
  - **Radiation scheme**
  - **Aerosol model**
  - **PBL/ShCu/Macrophysics schemes ("cloud package")**
- Conclusions

cam3.5: parameterizations

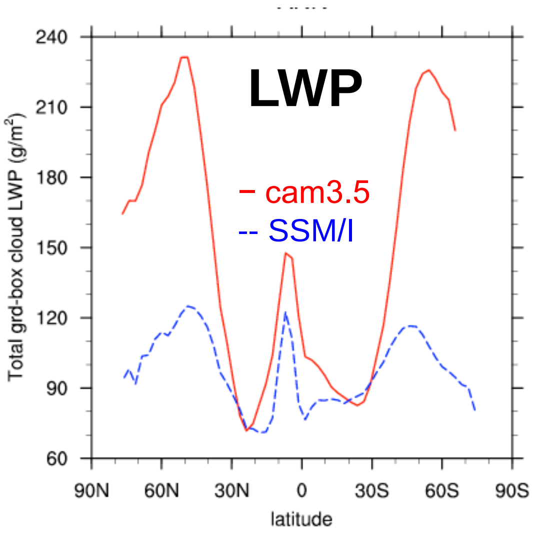
- **Deep convection: Neale-Richter (2008)**
- **Microphysics: Rasch-Kristjansson (1998)**
- **Boundary layer: Holtslag-Boville (1993)**
- **Shallow convection: Hack (1993)**

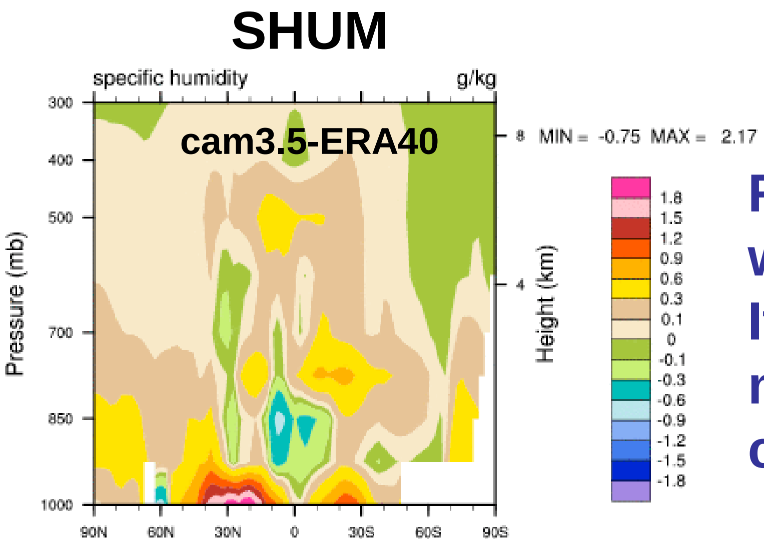
Where were we in cam3.5 ?





- Too much SWCF in the tropics
- Not enough LWCF at mid latitudes
- LWP is overestimated
- atmosphere is too moist (especially near the sfc)





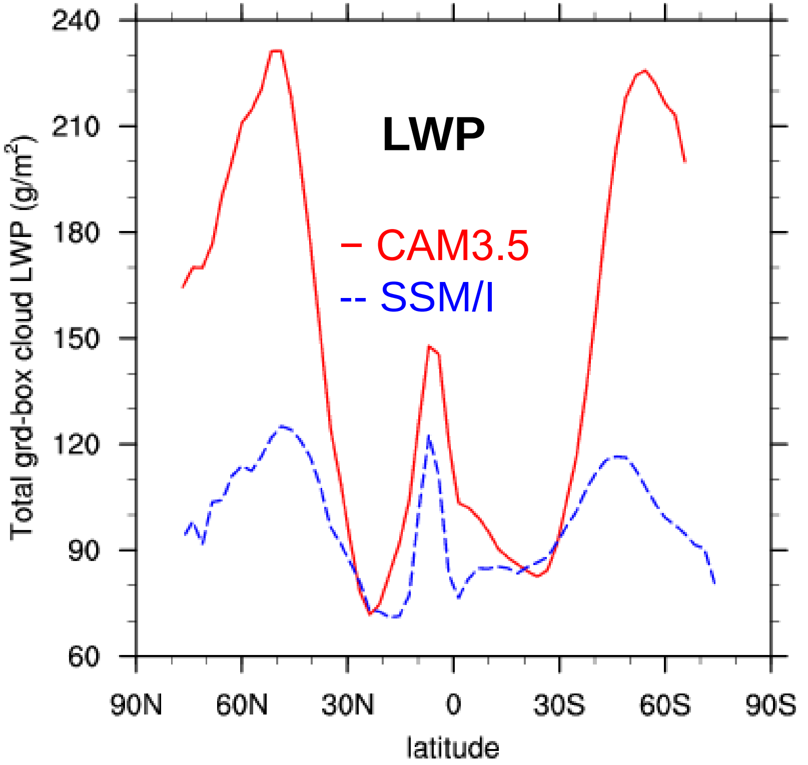
Reminder: cam3.5 was not well tuned. It was a guinea pig model for the carbon cycle

Morrison-Gettelman microphysics

- **2-moment scheme: prognostics variable for cloud mass and number concentration (liquid + ice).**
- **Microphysical processes: hydrometeor collection, condensation/evaporation, freezing, melting, and sedimentation.**
- **Explicit treatment of subgrid cloud water variability for calculation of the microphysical process rates.**
- **Diagnostic treatment of rain and snow number concentration and mixing ratio.**

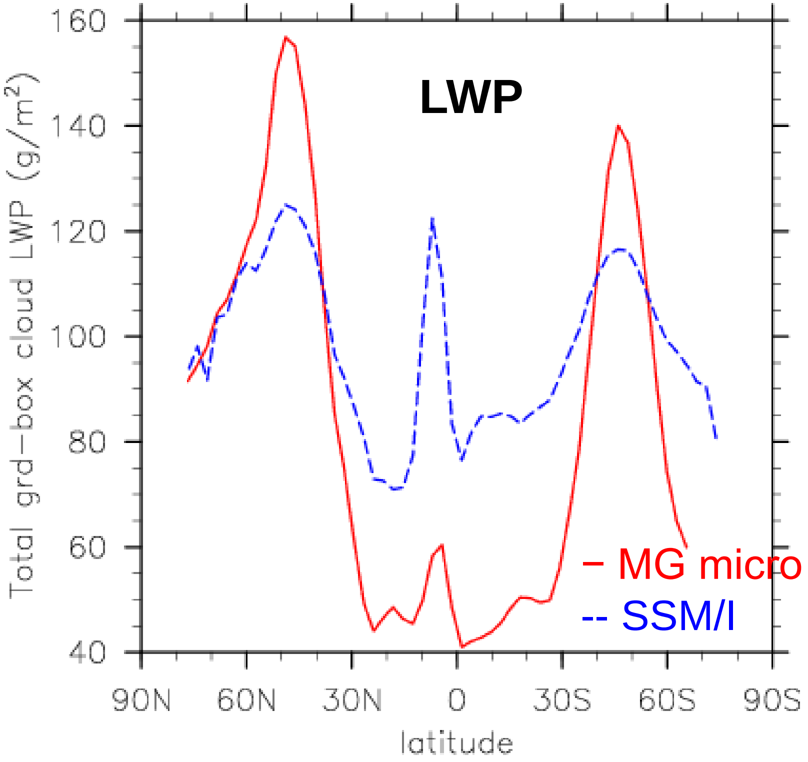
MG microphysics: LWP is reduced

CAM3.5



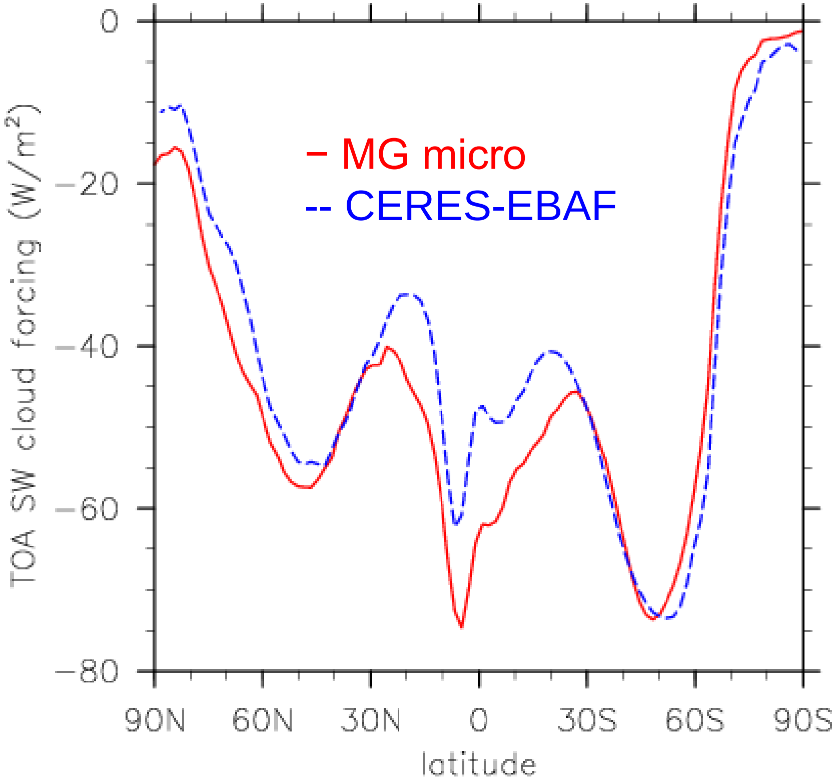
cam3.5 overestimates LWP at mid latitudes

MG microphysics

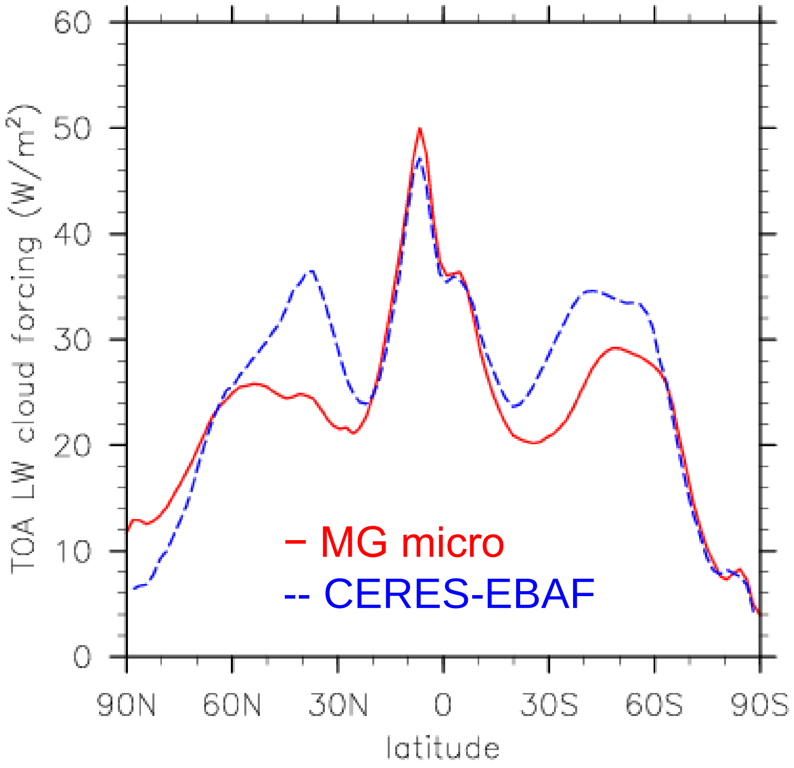


- **LWP improves at mid latitudes**
- **LWP too low in the tropics (but no contribution of convective clouds)**

MG microphysics: cloud forcings



SWCF, ANN



LWCF, ANN

Despite low values of LWP, the cloud forcings are reasonable
MG microphysics allows smaller cloud droplets => brighter clouds

Precipitable water

Model or observations	**Precipitable water (mm)**
NVAP	24.6
JRA25	24.3
ERA40	24.9
cam3.5	25.3
MG microphysics	25.9

(+1.0 compared to cam3.1)

(+0.6 compared to cam3.5)

Atmosphere is too moist compared to obs and analysis

=> Impact on the clear sky LW at the TOA
Atm too moist => clear sky LW at the TOA is too low

RRTMG (Conley, Collins, Iacono et al.)

- Correlated-k code for gases in LW and SW
- Monte Carlo Independent Column Approximation for clouds
- New liquid and ice cloud optics
- Greater accuracy than CAMRT relative to LBL calculations

RRTMG: TOA clear-sky longwave bias

Dataset/model	Clear-sky LW (W/m2)	Diff with ERBE (W/m2)	Diff with CERES (W/m2)
ERBE	264.4	0	-5.1
CERES-EBAF	269.5	5.1	0
cam3.1	264.3	-0.1	-5.2
cam3.5	263.1	-1.3	-6.4
MG micro	262.3	-2.1	-7.2
RRTMG	258.3	-6.1	-11.2

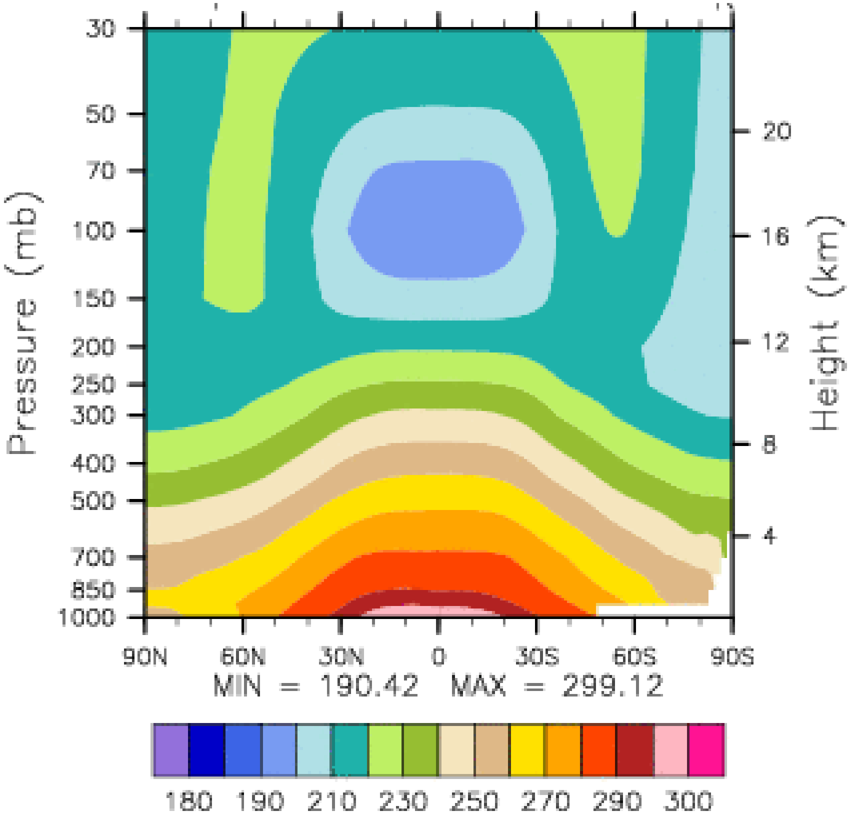
Dataset/model	LWCF (W/m2)
CERES-EBAF	29.9
cam3.1	30.6
cam3.5	27.1
MG micro	26.8
RRTMG	22.4

Because of the clear-sky bias, we will have a low LWCF (to achieve the TOA balance)

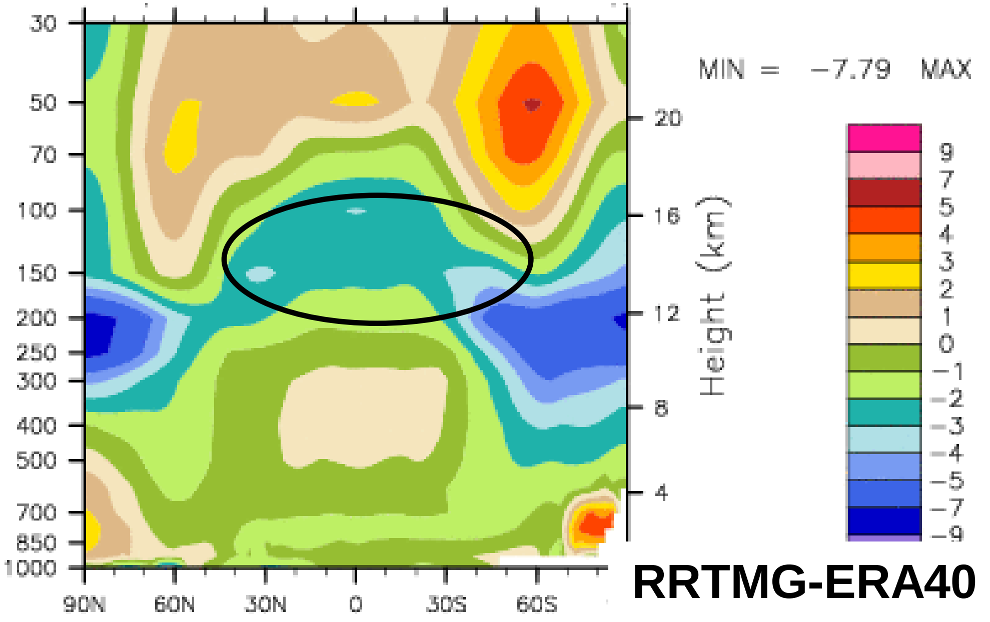
$$\begin{cases} LW_{All\text{-}sky} + SW_{All\text{-}sky} = 0.9 \\ LWCF = LW_{Clear\text{-}sky}-LW_{All\text{-}sky} \end{cases}$$

RRTMG: Temperature

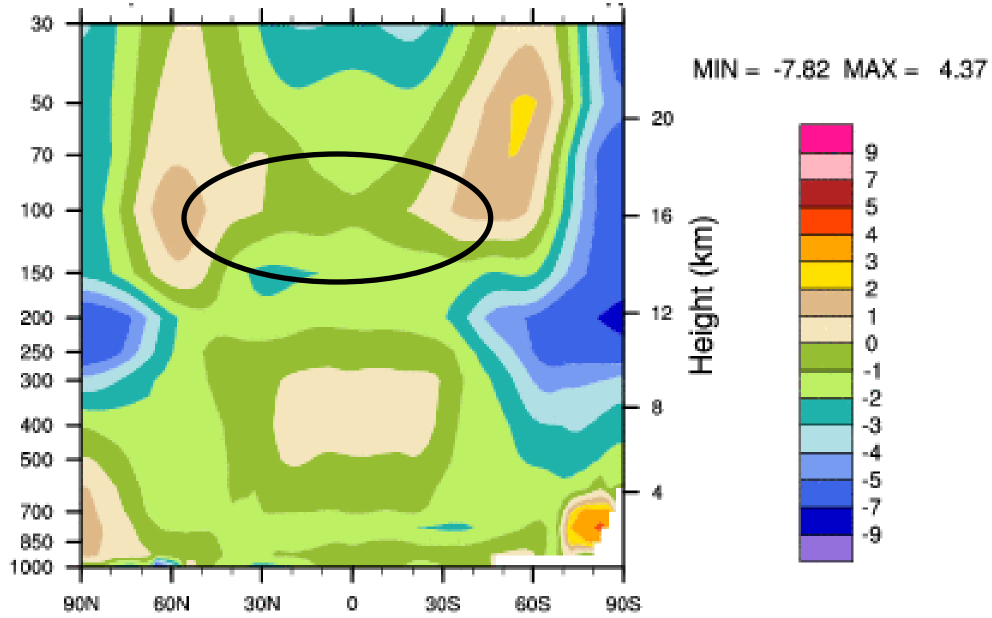
ERA40



MG-ERA40



RRTMG-ERA40



RRTMG reduces cold T bias at the tropopause

Modal Aerosol Model (Ghan, Liu et al.)

- Prognostic modal aerosol treatment (with 3 modes)
- Predicts aerosol mass and number, and internal mixing between aerosols.
- New processes: new particle formation (upper troposphere and BL), coagulation within and between aerosol modes, condensation of water vapor and trace gas on aerosols, aging of primary carbon to accumulation mode, secondary organic aerosol formation, and aerosol activation.
- More realistic representation of aerosol properties and more accurate estimation of aerosol direct and indirect forcing

Aerosol: direct and indirect effect

Direct effect

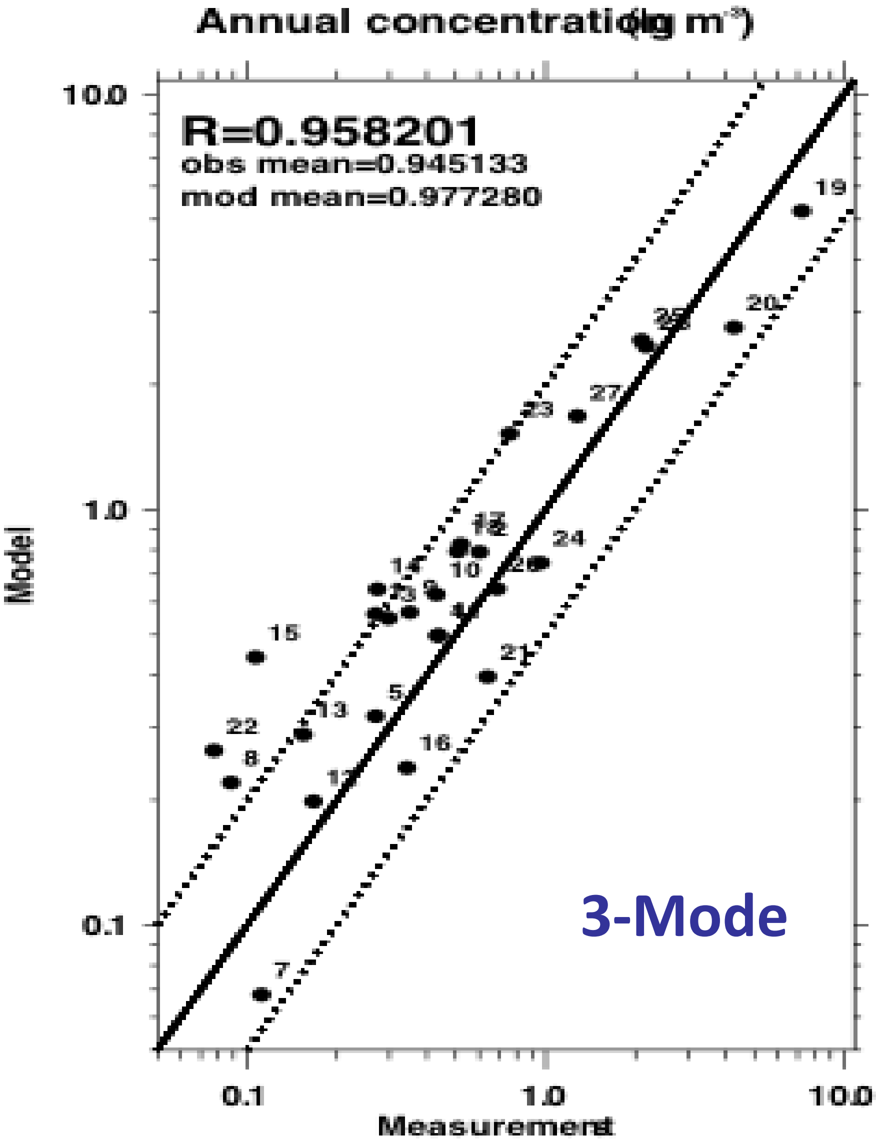
- aerosols scatter and absorb solar and infrared radiation

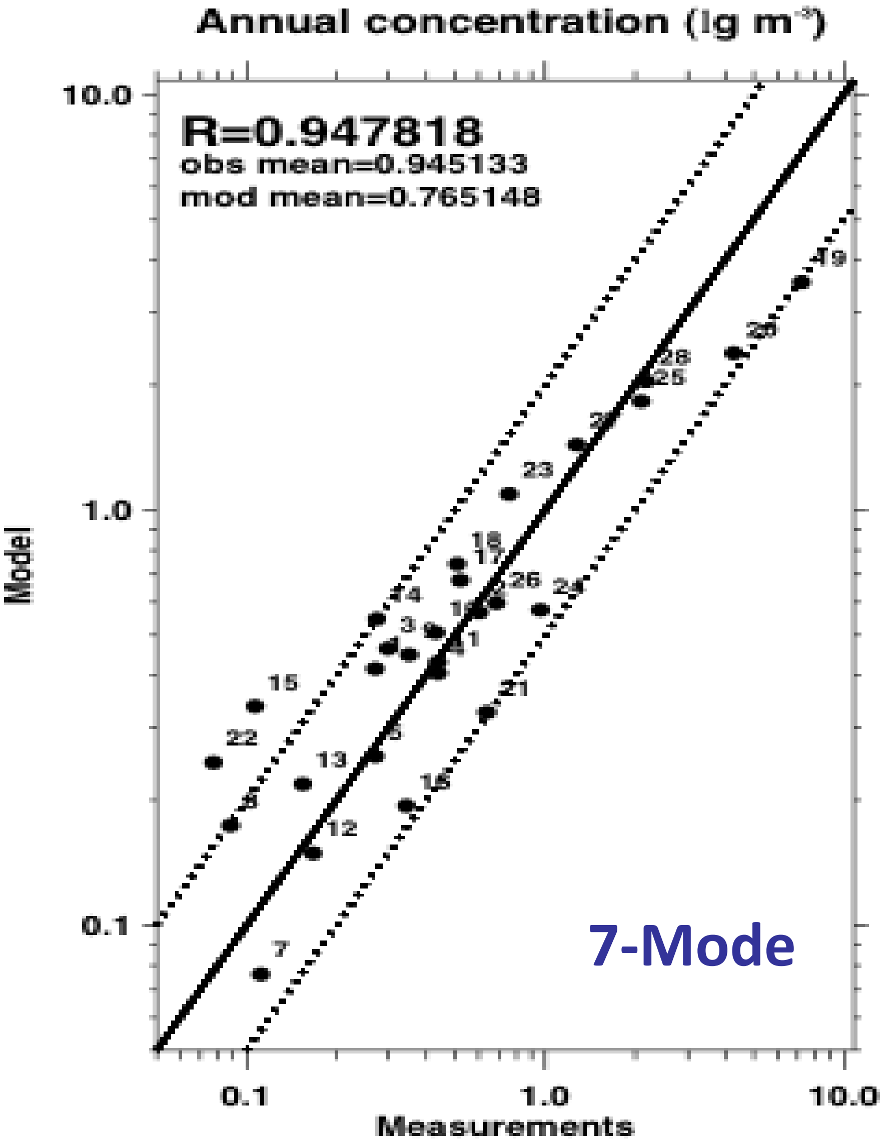
Indirect effect

- If aerosols increase => number of cloud droplets increase
=> droplet size decrease
=> for same LWP, clouds are brighter

	Direct effect W/m2	**Indirect effect W/m2**
MAM	-0.56	-1.2
MAM + droplet # limiter	-0.49	-0.6
IPPC values	-0.5 [-0.9 to -0.1]	-0.7 [-1.8 to -0.3]

SO_4 compared with RSMAS data





(Courtesy Xiaohong Liu)

UW PBL, shallow convection, macrophysics (Park and Bretherton)

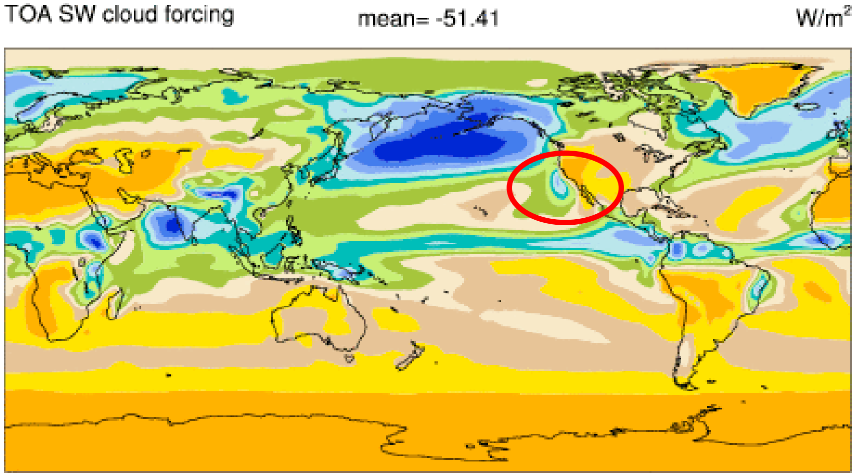
“UW scheme” or “Cloud branch”

- Turbulence scheme includes explicit entrainment at the top of the PBL and explicit interaction between cloud, radiation and turbulence.
- Shallow convection: cloud-base mass flux based on surface TKE and convection inhibition near cloud base
- New macrophysics treatment

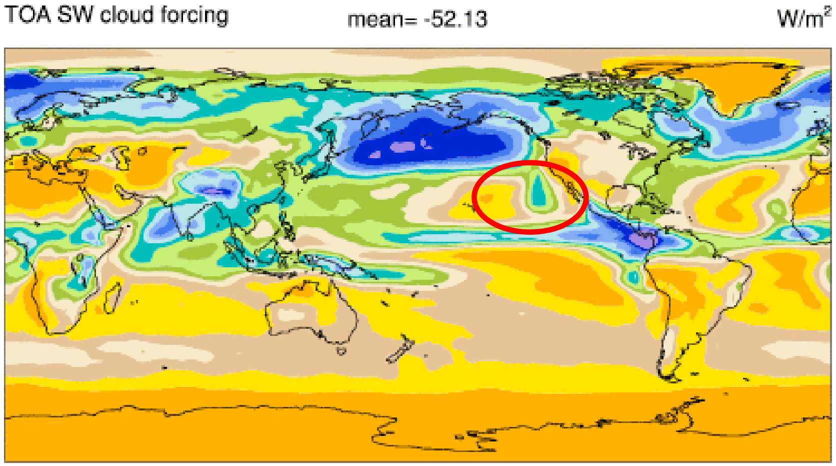
Cloud + MAM = CLAM branch

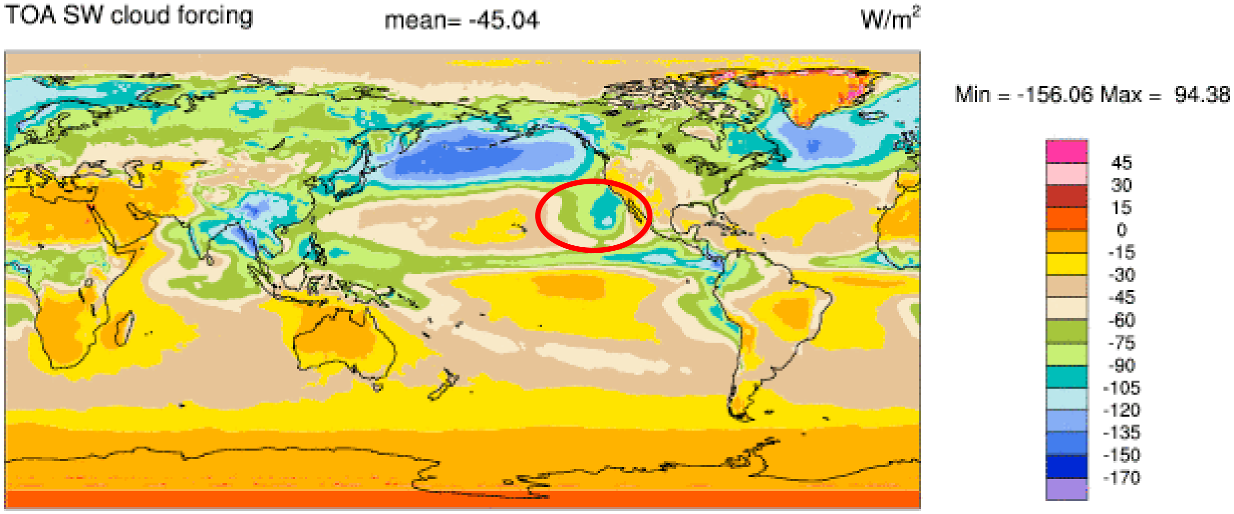
UW scheme: SWCF, JJA

cam3.5



UW PBL/ShCu/Macrophysics

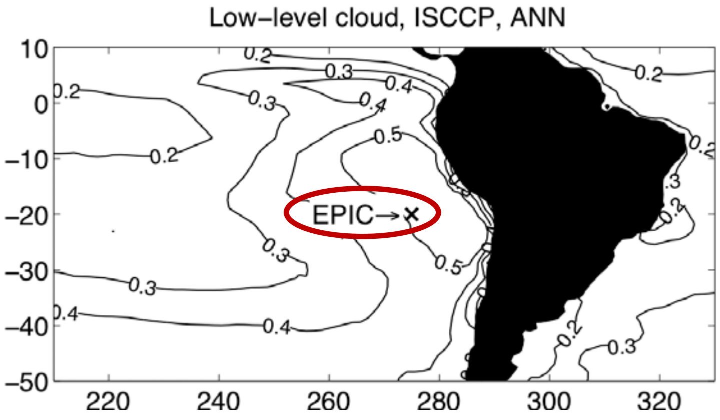




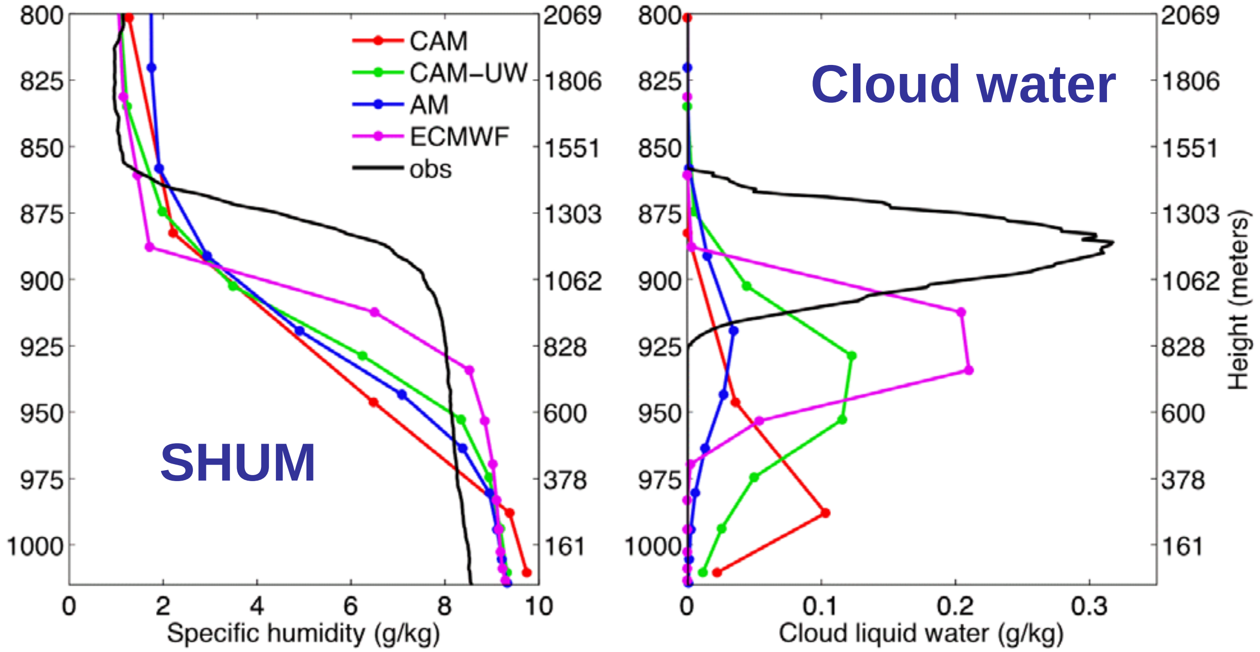
CERES-EBAF

UW scheme:
- Improves SWCF in stratocumulus deck (magnitude and location)
- doesn’t use “Klein line”

PBL in stratocumulus regions



UW scheme:
better representation of the PBL
in stratocumulus region
(here: compared to EPIC 2001
cruise)

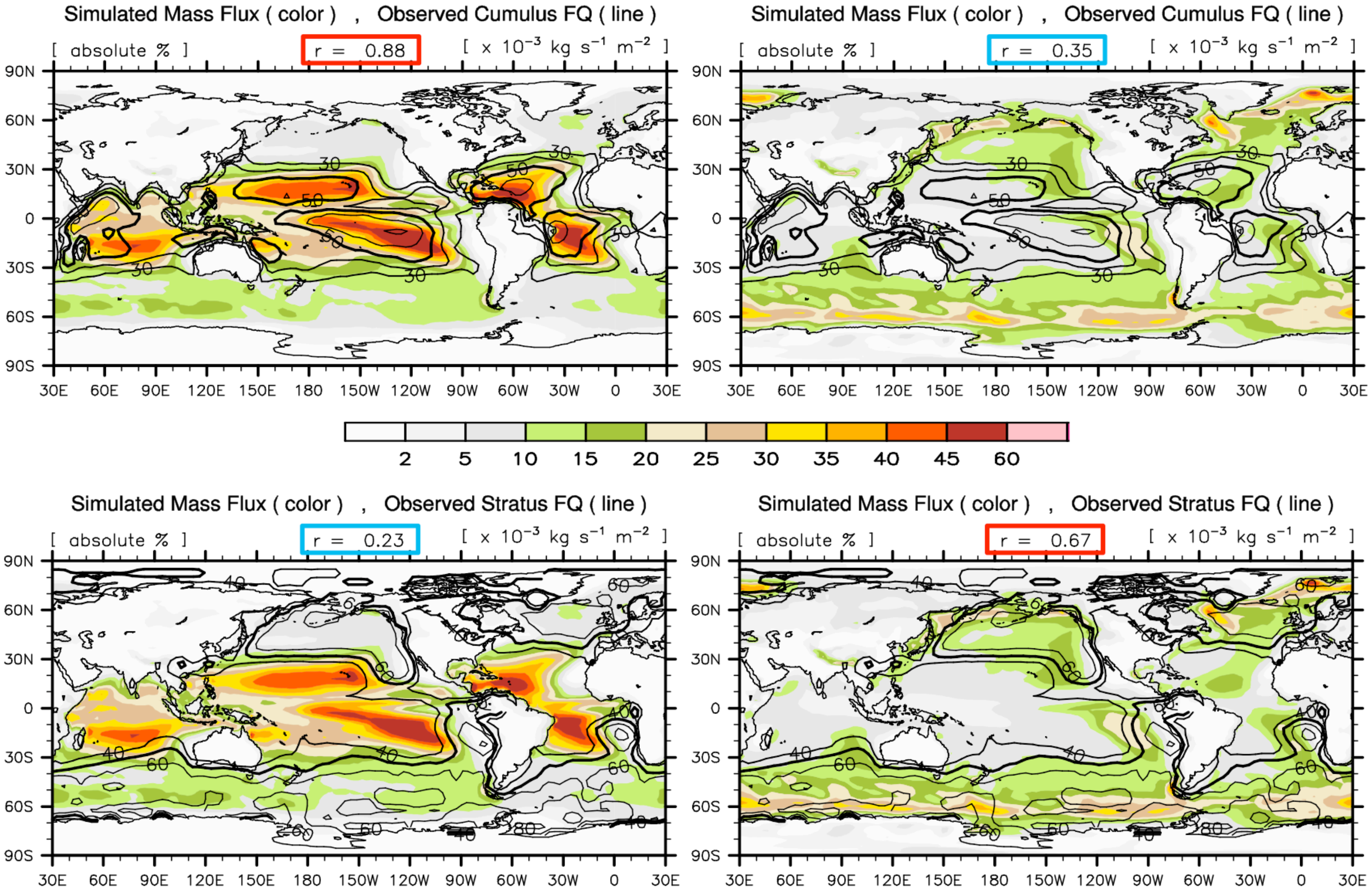


SHUM

Cloud water

(Hannay et al., J Climate, 2009)

Shallow convective mass flux at cloud base, ANN



UW Sh/Cu

Hack scheme

Cumulus

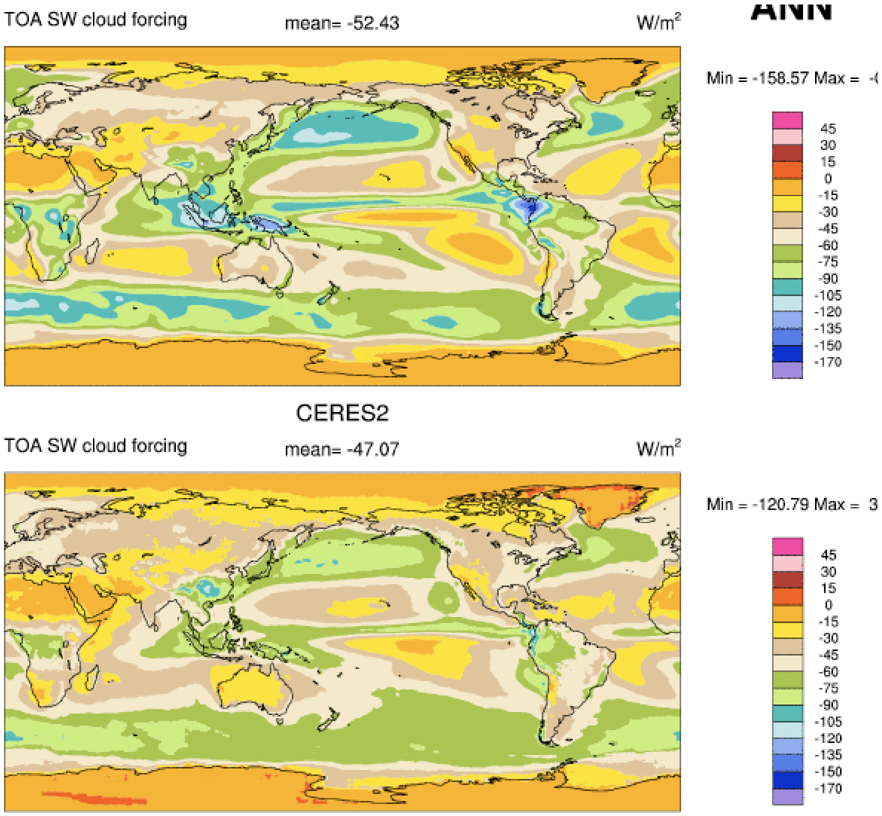
Stratus

(Courtesy Sungsu Park)

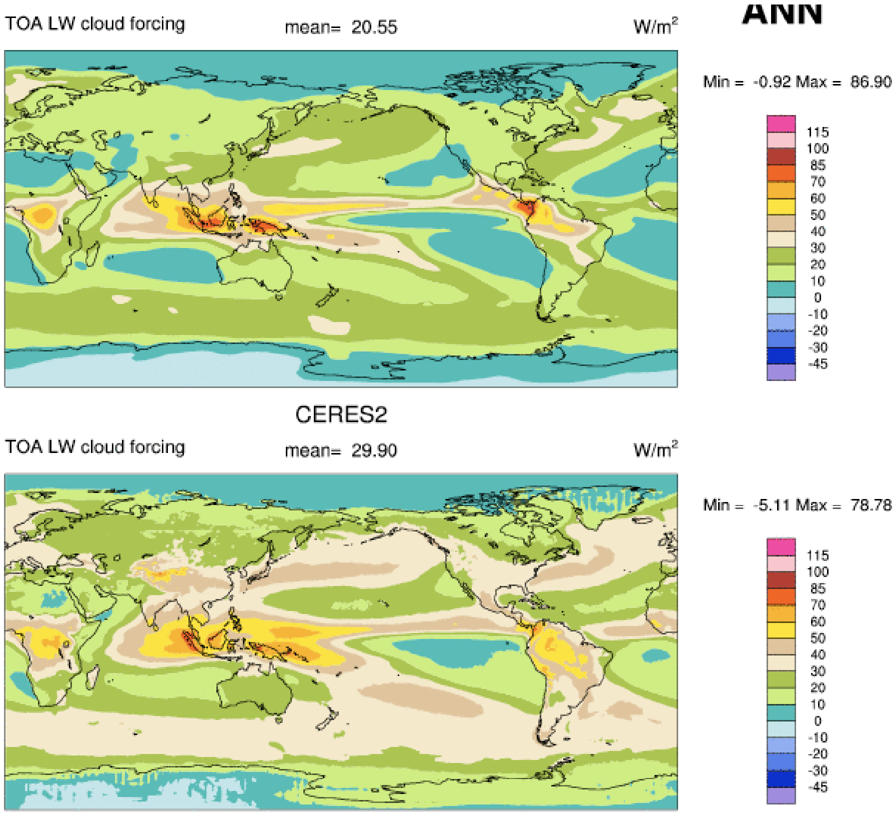
UW scheme: better representation of cumulus regions

The CLAM branch versus observation

SWCF



LWCF

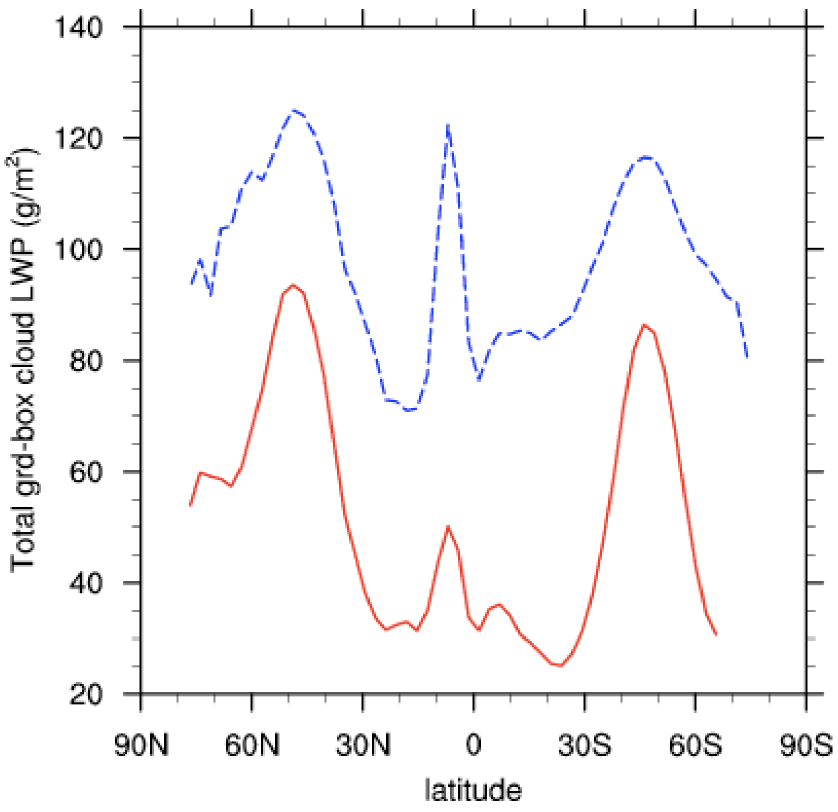


SWCF: too high (especially in deep convection)

LWCF: too low (especially at mid latitudes)

The CLAM branch

LWP



LWP is too low

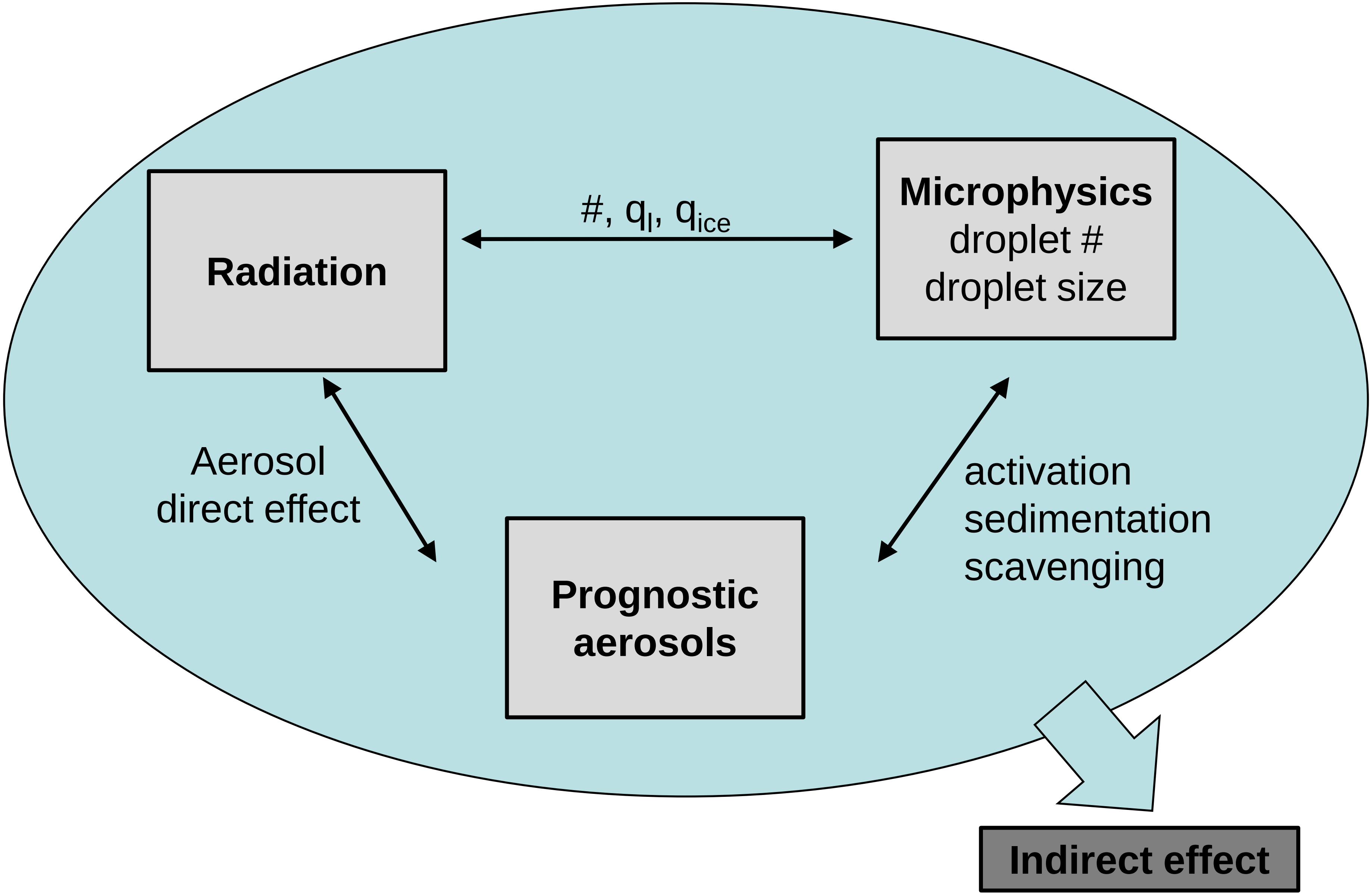
Example of trade-offs

In the CLAM branch, we reduced the SWCF in deep convective area

- by increasing the autoconversion of rain but this is also significantly reduced the LWP

- by decreasing the autoconversion size threshold for cloud ice to snow but this also reduced the LWCF

Tuning challenges



Conclusion

- **New dataset: CERES-EBAF**
  Significant change in the clear sky LW and SCWF

- **MG Microphysics:**
  MG improves LWP with realistic cloud forcing

- **Radiation (RRTMG)**
  greater accuracy relative to LBL calculations
  bias in the clear-sky LW

- **Modal aerosol (MAM)**
  realistic aerosol direct/indirect effect

Conclusion

- **UW PBL/ShCu/Macrophysics:**
  More realistic physics.
  Improves stratocumulus deck and cumulus area.

- **Challenging tuning because of feedbacks between radiation, aerosols and microphysics.**

Thanks !