PDF-Based Cloud Schemes in Conventional and Super-Parameterized GCMs

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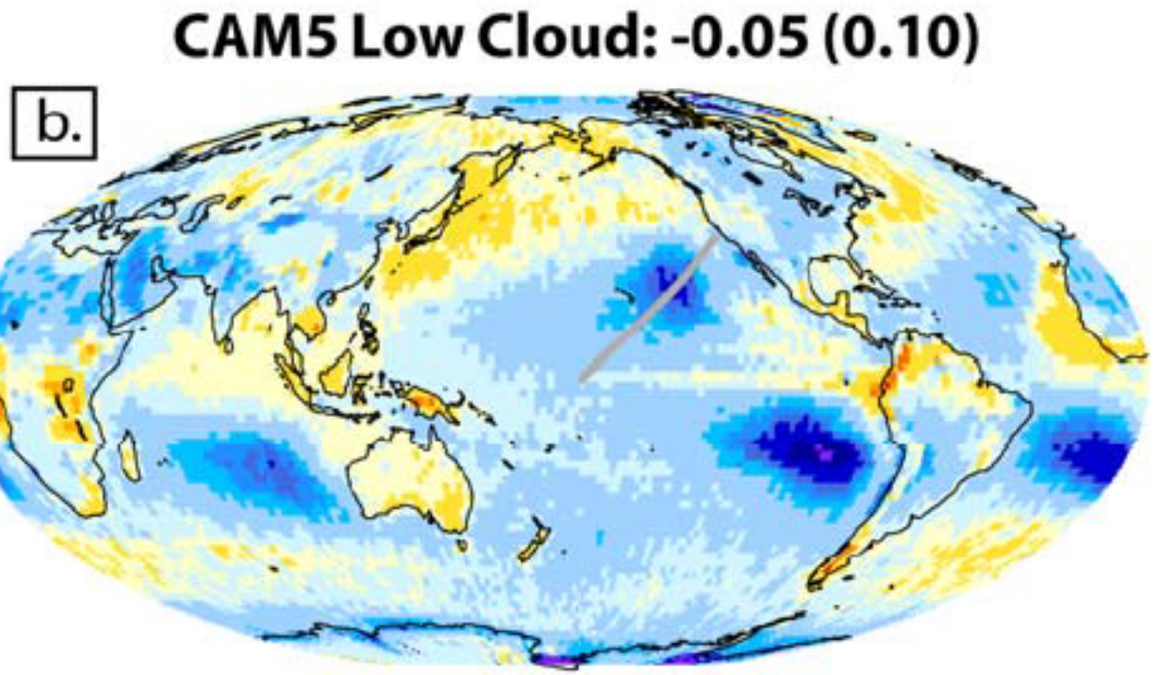
Outline

- Conventional GCM
  - CAM5
  - Implementation of CLUBB (Cloud Layers Unified by Bi-normals, Golaz et al. 2002a,b)
- Super-parameterized GCM
  - SP-CAM
  - Implementation of SHOC (Simplified Higher-Order Closure, Bogenschutz and Krueger 2013)

CAM5

- Kay et al. (2012) shows that CAM5 improves cloud representation compared to CAM4 mostly due to new stratiform and shallow convection schemes

- However, stratocumulus to cumulus transition is still poorly represented...



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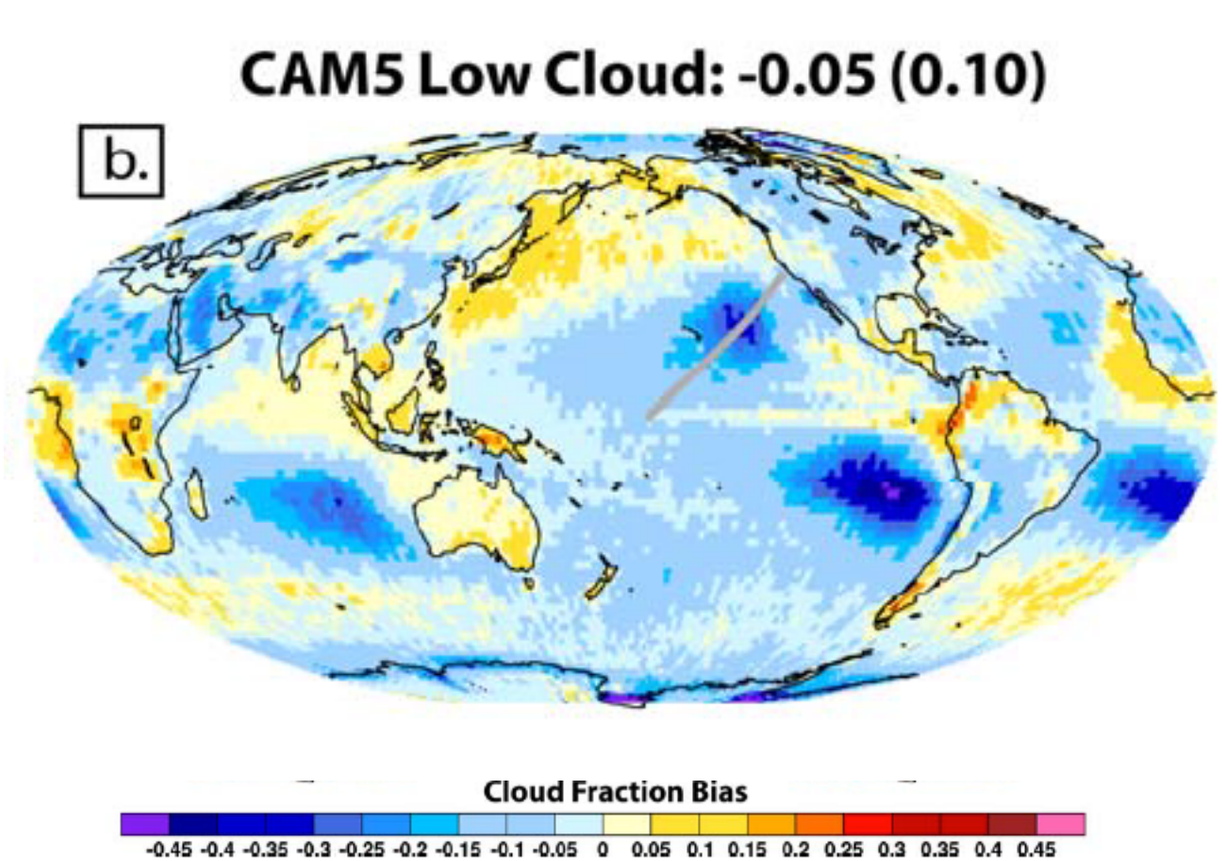

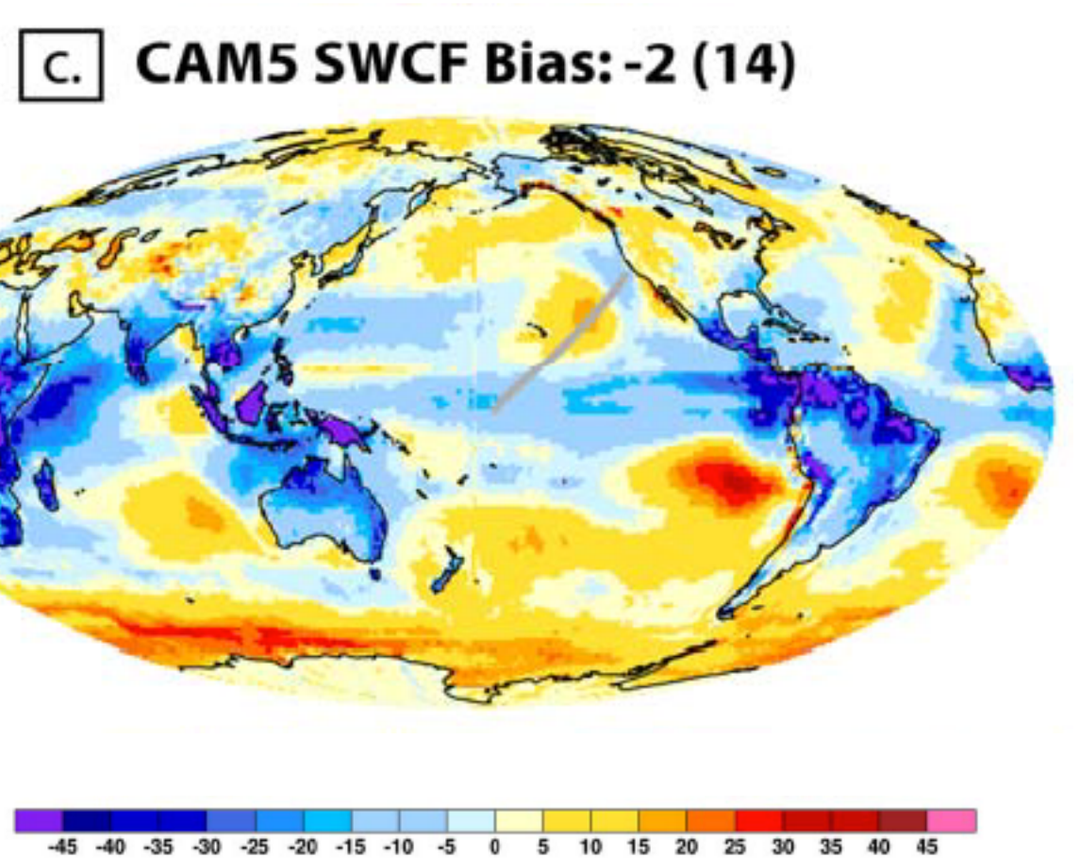

Figs from Kay et al. (2012)

Coupling CAM with CLUBB

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Physics	CAM5	
Deep Convection	Zhang and McFarlane (1995)	
Boundary Layer	Bretherton and Park (2009)	
Shallow Convection	Park and Bretherton (2009)	
Cloud Macrophysics	Park (2012)	
Cloud Microphysics	Morrison and Gettelman (2008)	
Radiation	RRTMG (Iacono et al. 2008)	
Aerosols	Modal (Liu et al.2012)	

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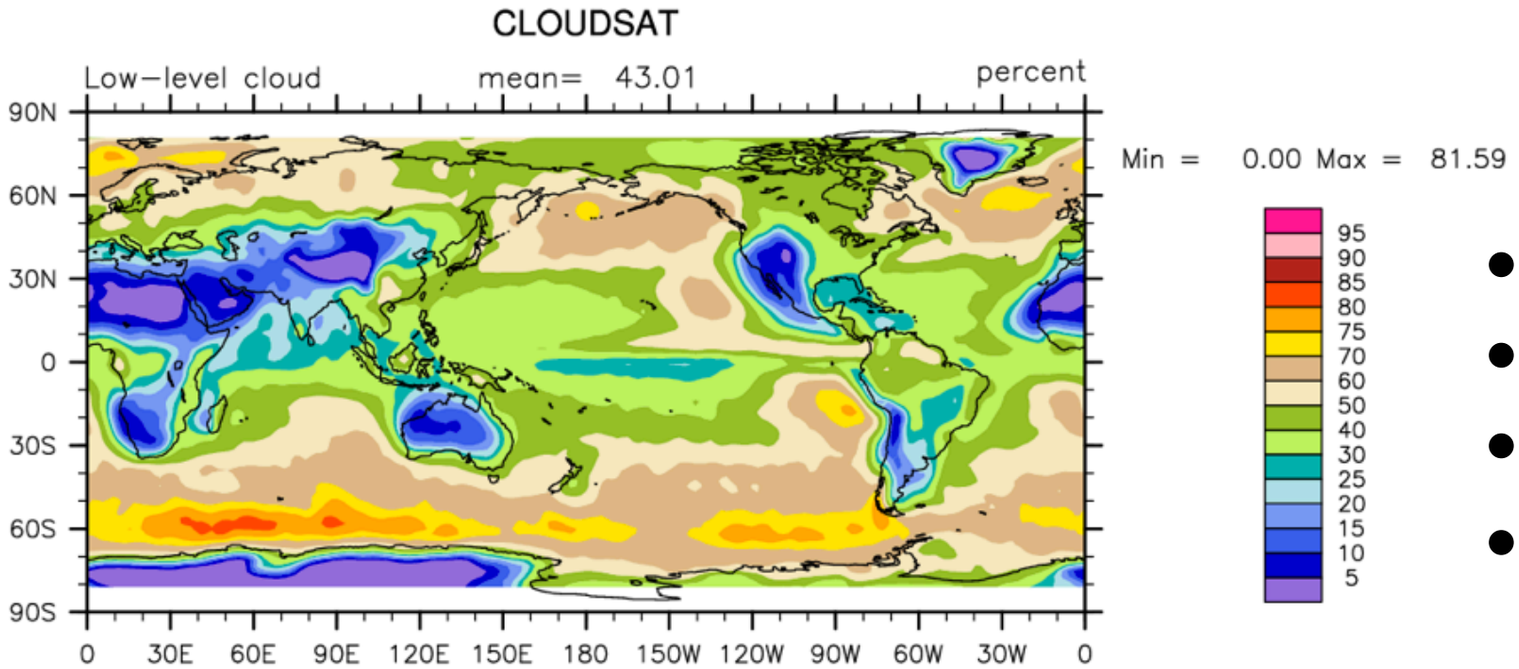
- CLUBB time step is 5 minutes
- CLUBB called directly after deep convection and directly before microphysics
- Predicted vertical velocity variance used for aerosol activation
- Series of two papers Bogenschutz et al (2012, 2013 (submitted)) documents CAM-CLUBB
- Future versions of CAM-CLUBB may allow CLUBB to provide deep convective tendencies

CLUBB

- CLUBB = Cloud Layers Unified By Binormals
- First developed by Golaz et al. (2002), maintained by University of Wisconsin Milwaukee (Vincent Larson's group)
- "Incomplete" third-order turbulence closure (predicting 9 second and third order moments), centered around a trivariate assumed double gaussian PDF
- Should provide a unified treatment of PBL and shallow convection, that drives a single microphysics scheme
- Based upon the so-called "assumed PDF" approach
  - Assumed double Gaussian PDF $P(\theta_l, q_t, w)$

Low Cloud Amounts



- 5-year simulations
- FV dy-core
- 1 degree
- Present day emissions

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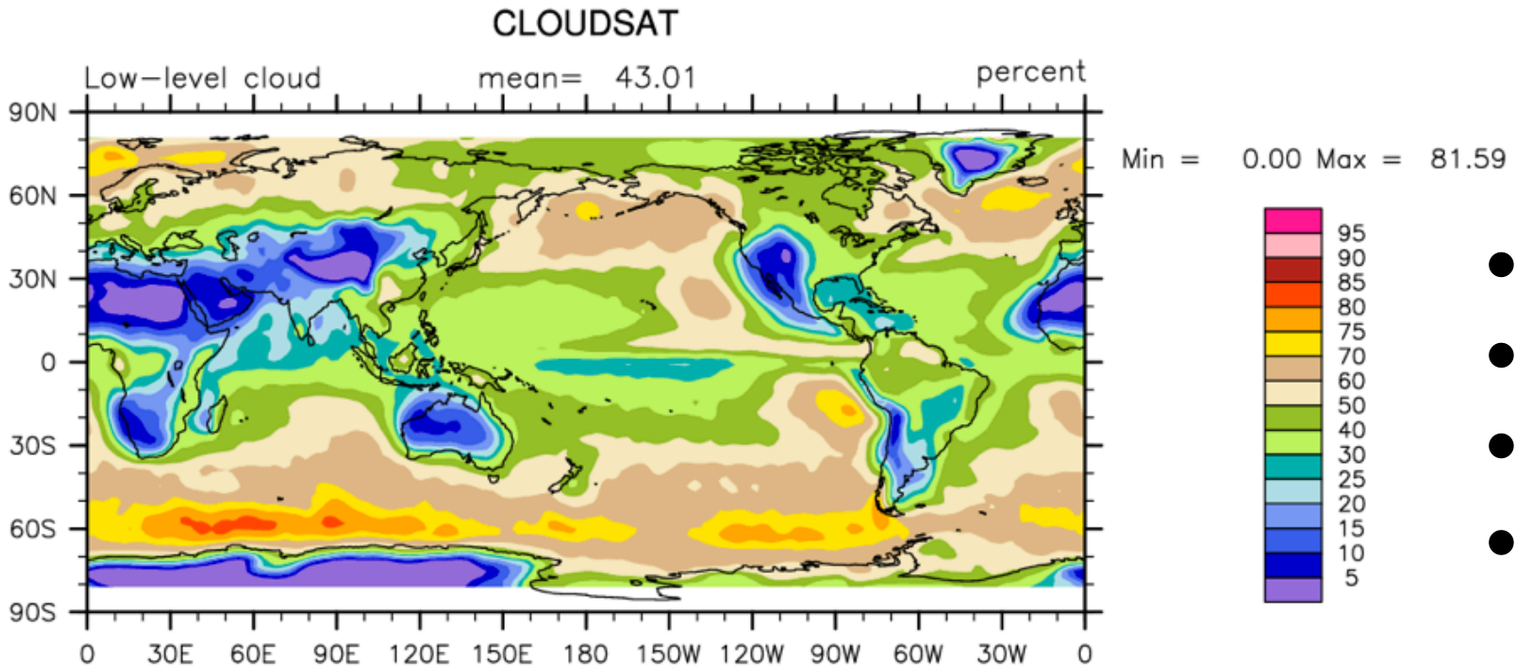

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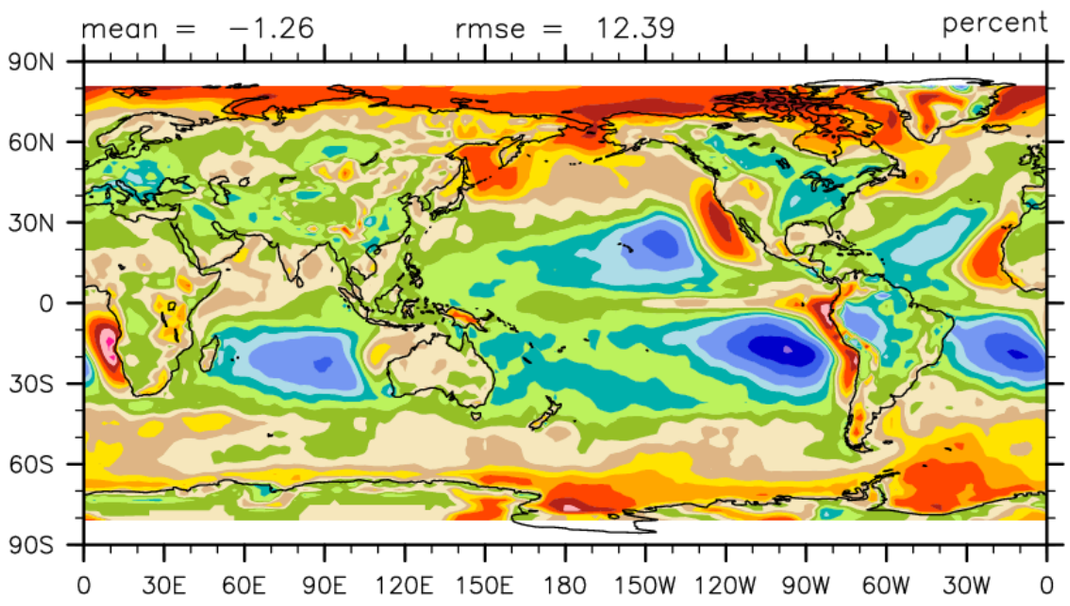
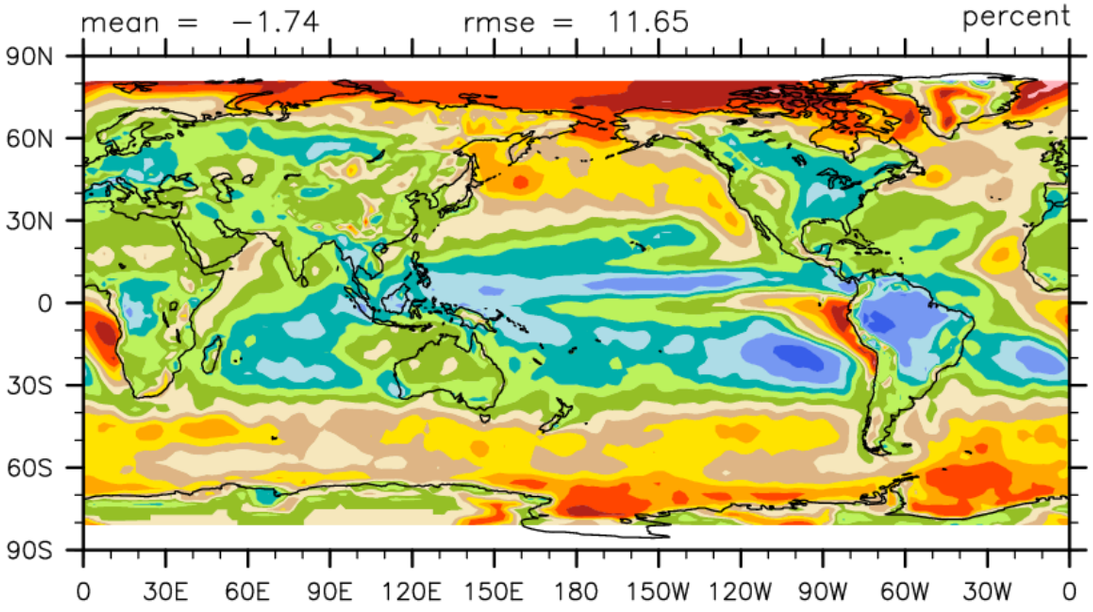
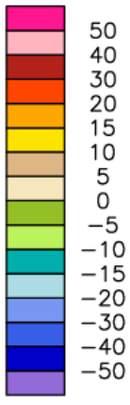
CAM5 - CLOUDSAT

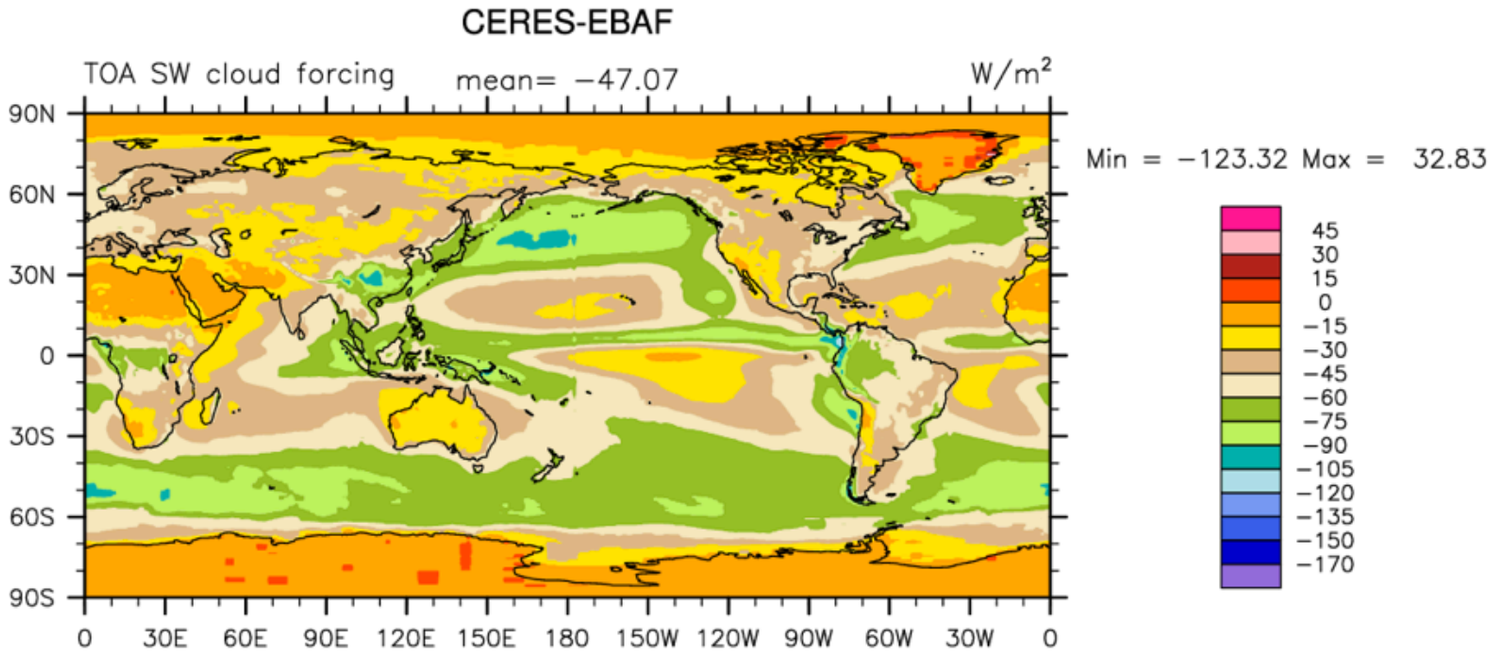


CAM-CLUBB - CLOUDSAT





Shortwave Cloud Forcing



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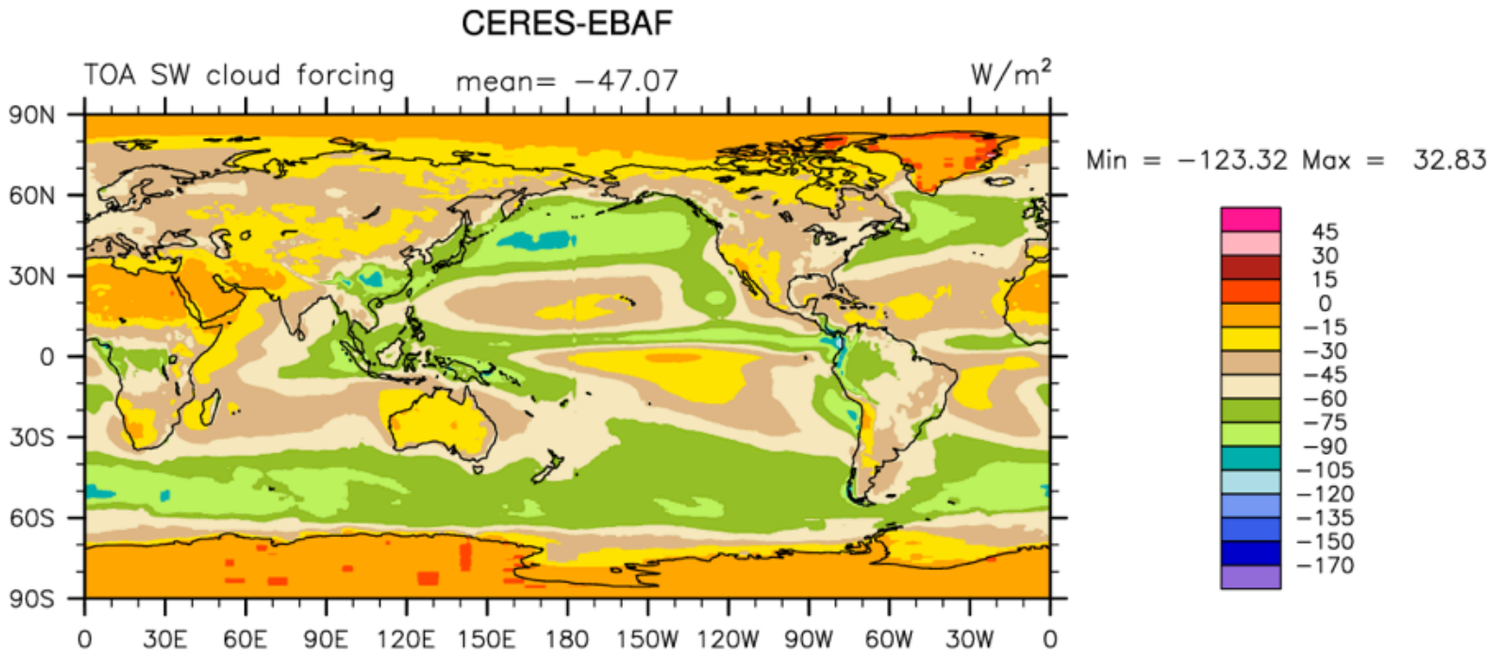
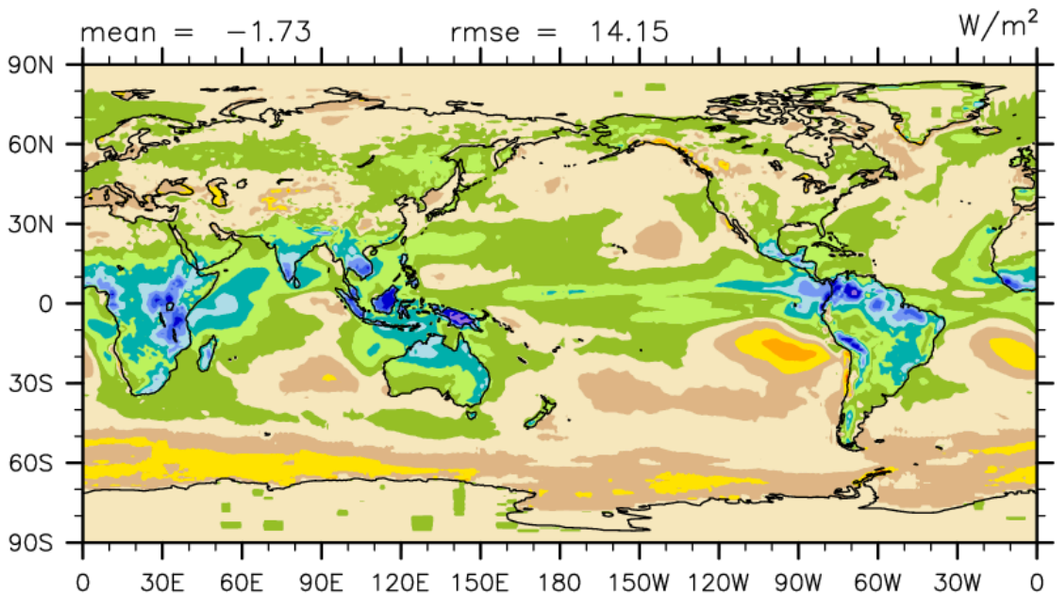


CAM5 - CERES-EBAF



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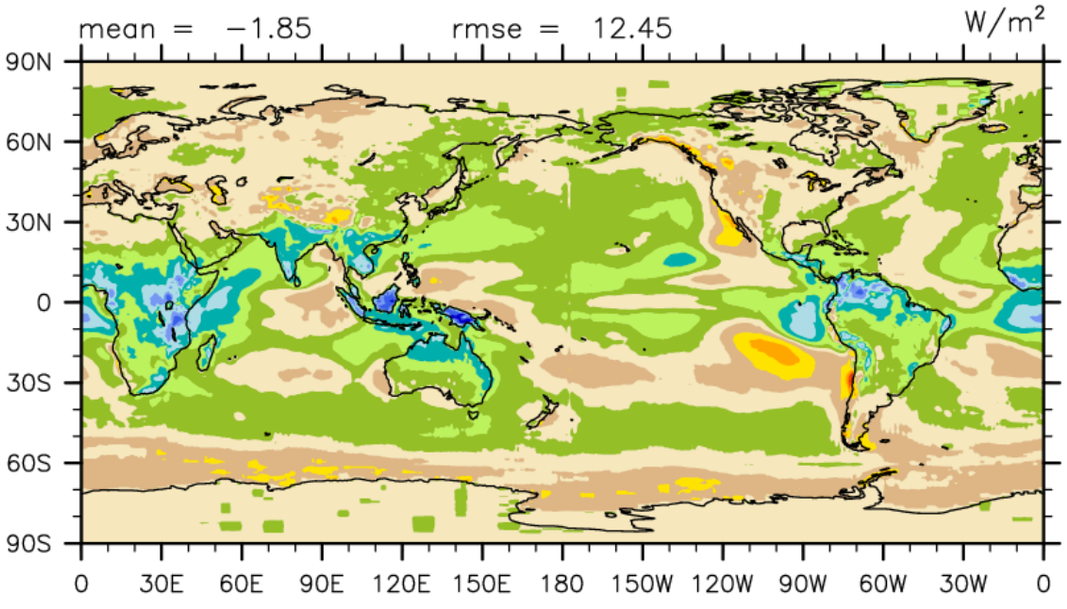
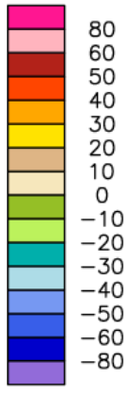
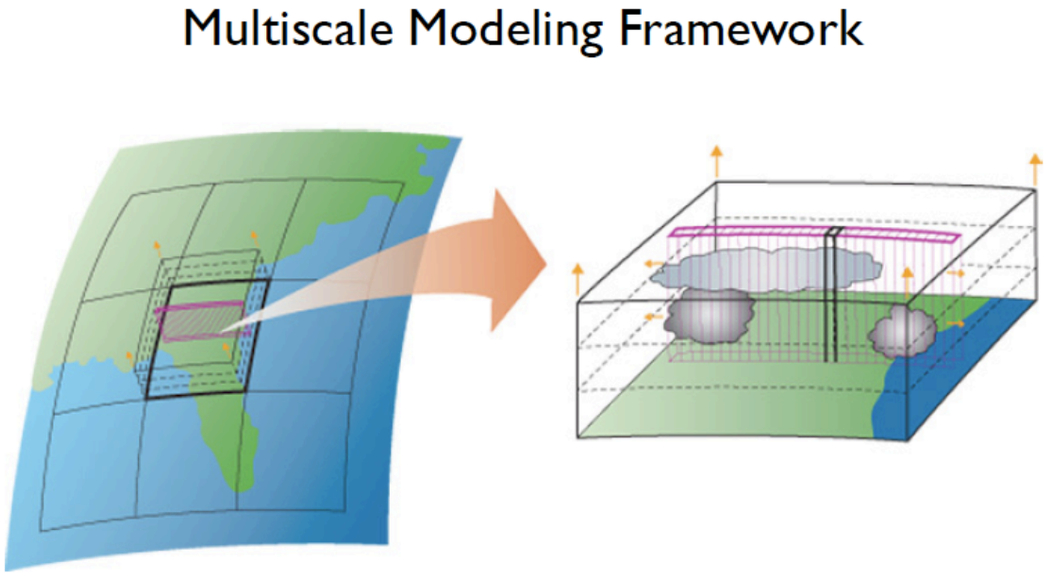




Super-Parameterized GCMs

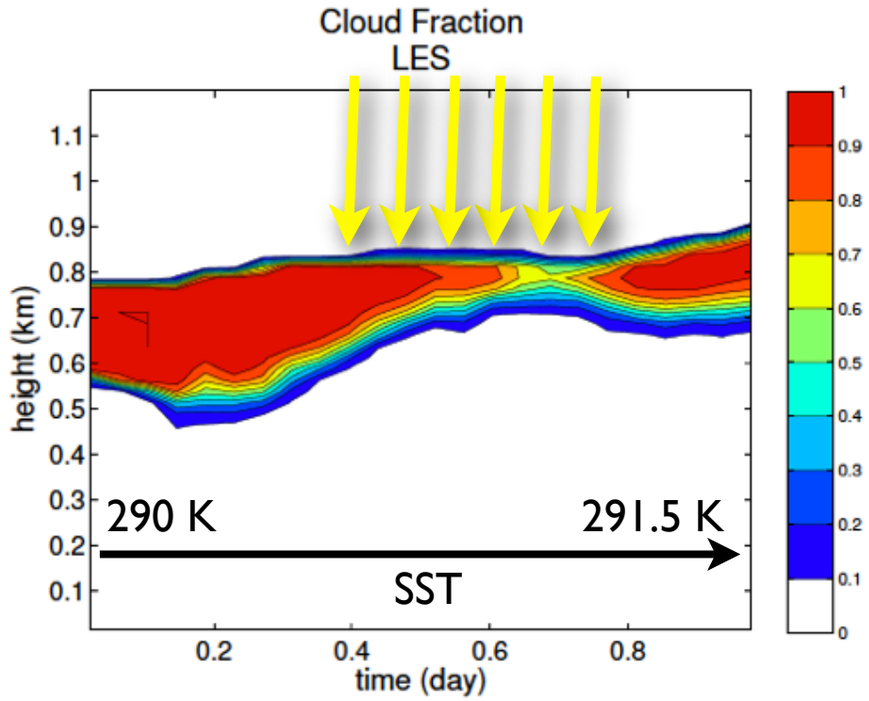
- SP-CAM
- Embedded CRMs use grid size ~4 km
- Adequate to permit deep convection but not shallow convection or turbulence
- Currently simple Smagorinsky closure is used, in conjunction with "all-or-nothing" condensation scheme
- Result: Under and mis-representation of boundary layer cloud
- MMFs (and especially GCRMs) are expensive



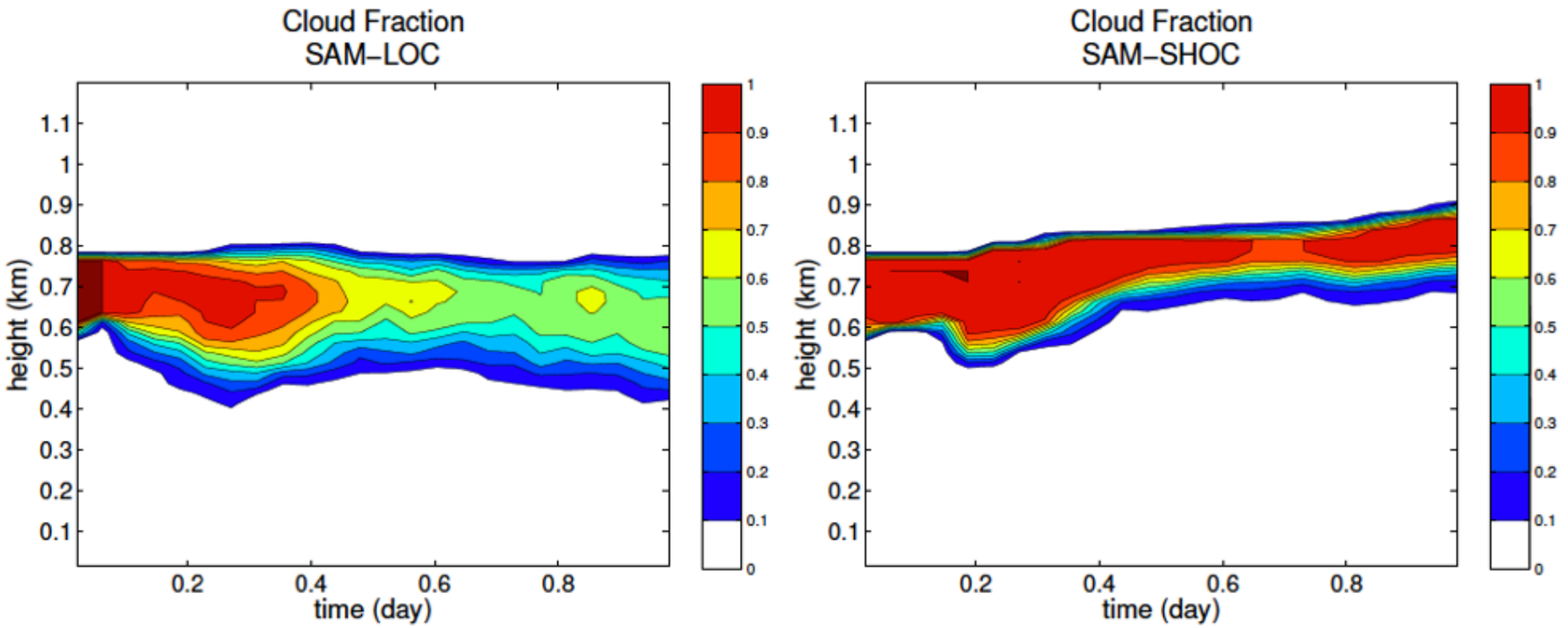
SHOC

- SHOC = Simplified Higher-Order Closure (Bogenschutz and Krueger 2013)
- Compared to similar assumed PDF-based schemes which predict anywhere from 8-13 higher-order moments, SHOC predicts only one (TKE)
- Other higher-order moments are diagnosed
- Uses assumed double-gaussian PDF for clouds and turbulence closure
- Computational cost of GCSS boundary-layer cases is only ~5-9% more than standard SAM
    - Currently SP-CAM-SHOC is 20-25% more expensive than SP-CAM (I need to work to bring this down a bit)

Stratocumulus Diurnal Cycle



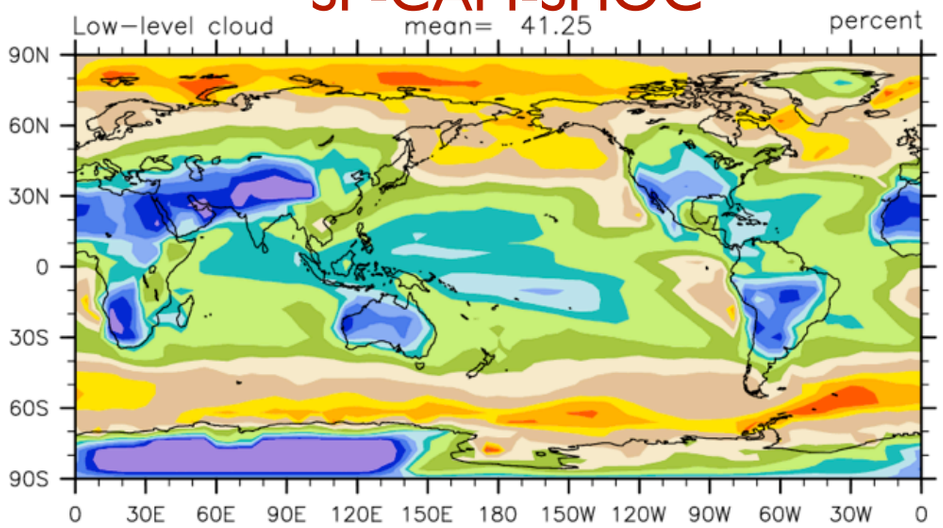
dx = 50 m



dx = 3.2 km

Fig from Bogenschutz and Krueger (2013)

SP-CAM-SHOC



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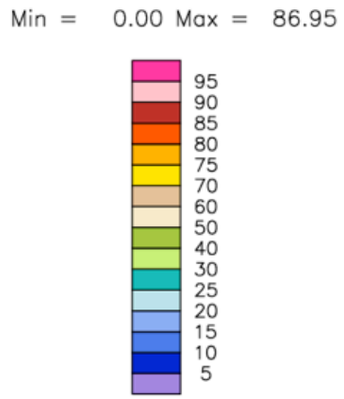
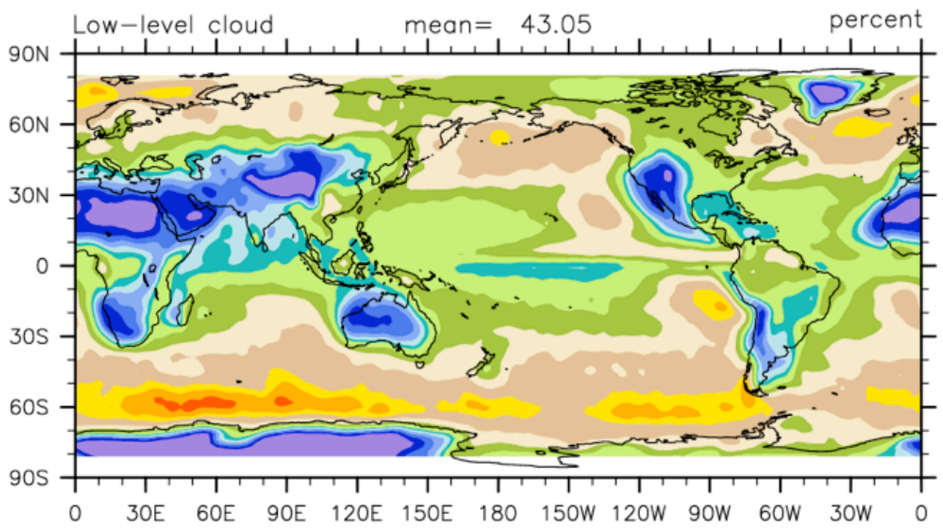
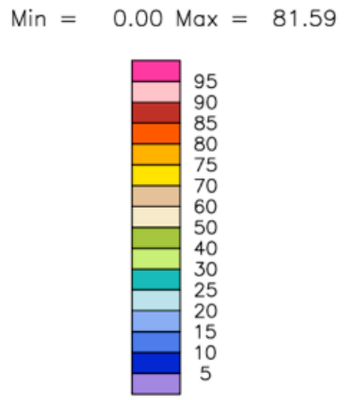
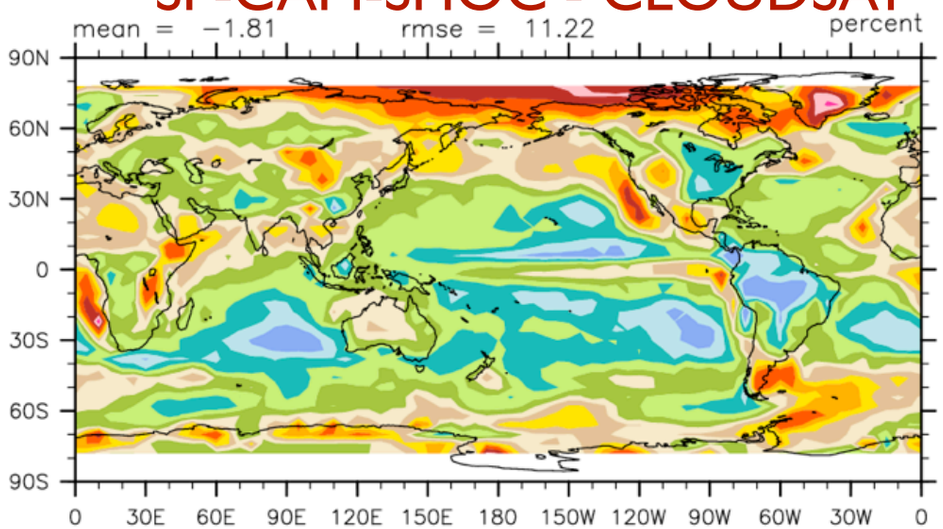


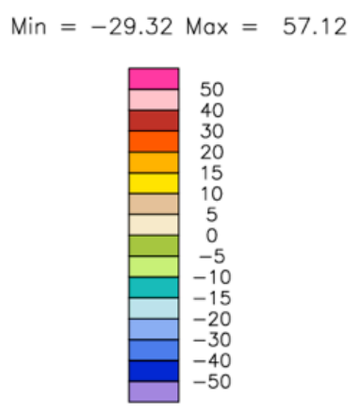
CLOUDSAT





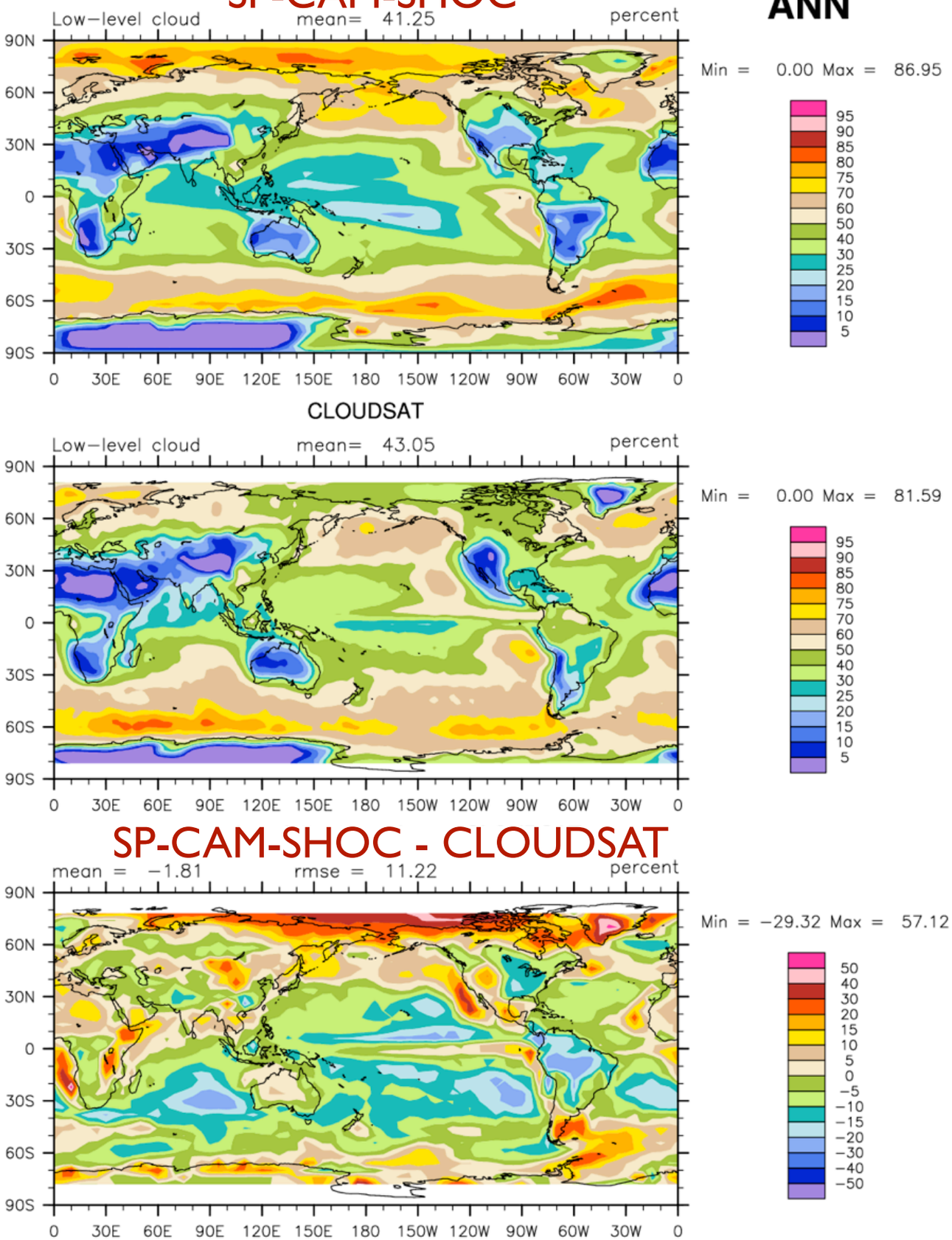
SP-CAM-SHOC - CLOUDSAT





- SP-CAM-SHOC still in training
- Presented here from a coarse (4.5 degree) FV simulation
- 2 degree currently running
- Initial simulations have been reasonably balanced and conserving energy
- Evidence of improved low cloud simulation compared to standard SP-CAM in these initial simulaitons

SP-CAM-SHOC



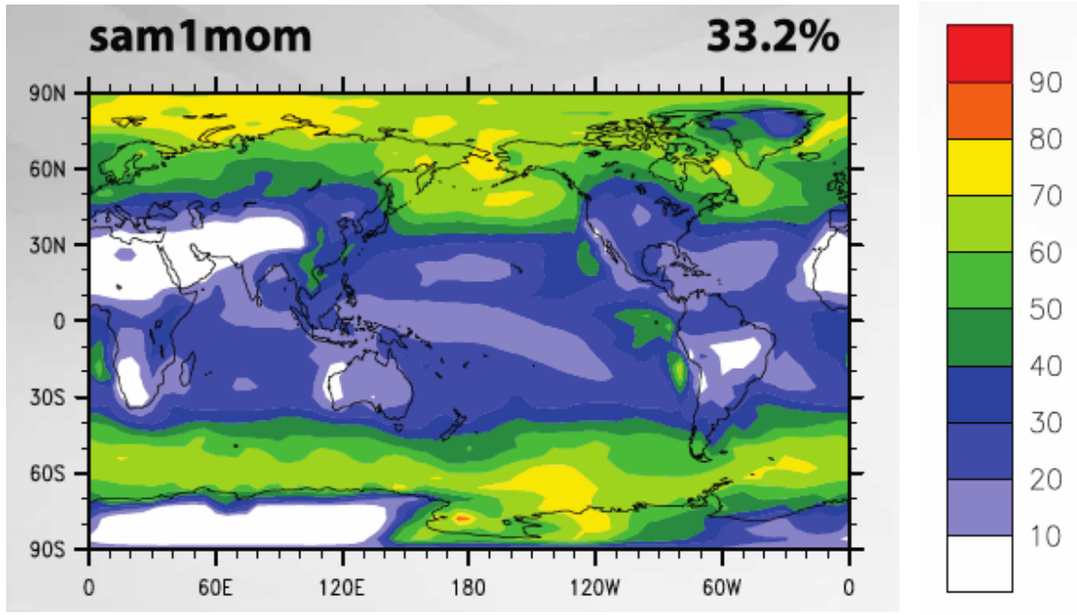


Fig courtesy of M.Wang

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Summary

- PDF-based cloud schemes and HOC for turbulence provide promising results for both conventional and super-parameterized GCMs
- CAM-CLUBB represents a more unified parameterization suite of atmospheric processes
  - Potential to be fully unified once it returns deep convective tendencies
- SAM-SHOC represents a low-cost PDF-based alternative, could be useful for weather models and GCRMs
  - Future work will test SAM-SHOC with double-moment microphysics, while further reducing SHOC comp cost