Aerosol-Cloud Interactions in Climate Models

Leo Donner, Huan Guo, Chris Golaz
GFDL/NOAA, Princeton University

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Overview

- Physically based treatments of aerosol-cloud interactions included in some IPCC AR5 models (e.g., GFDL CM3, NCAR CAM5)
- 20th century warming reduced in CM3 and CAM5, relative to earlier models without aerosol-cloud interactions
- Interactions among aerosols, precipitation, and cloud dynamics limit cooling by aerosol-cloud interactions and could improve realism of climate models including aerosol-cloud interactions

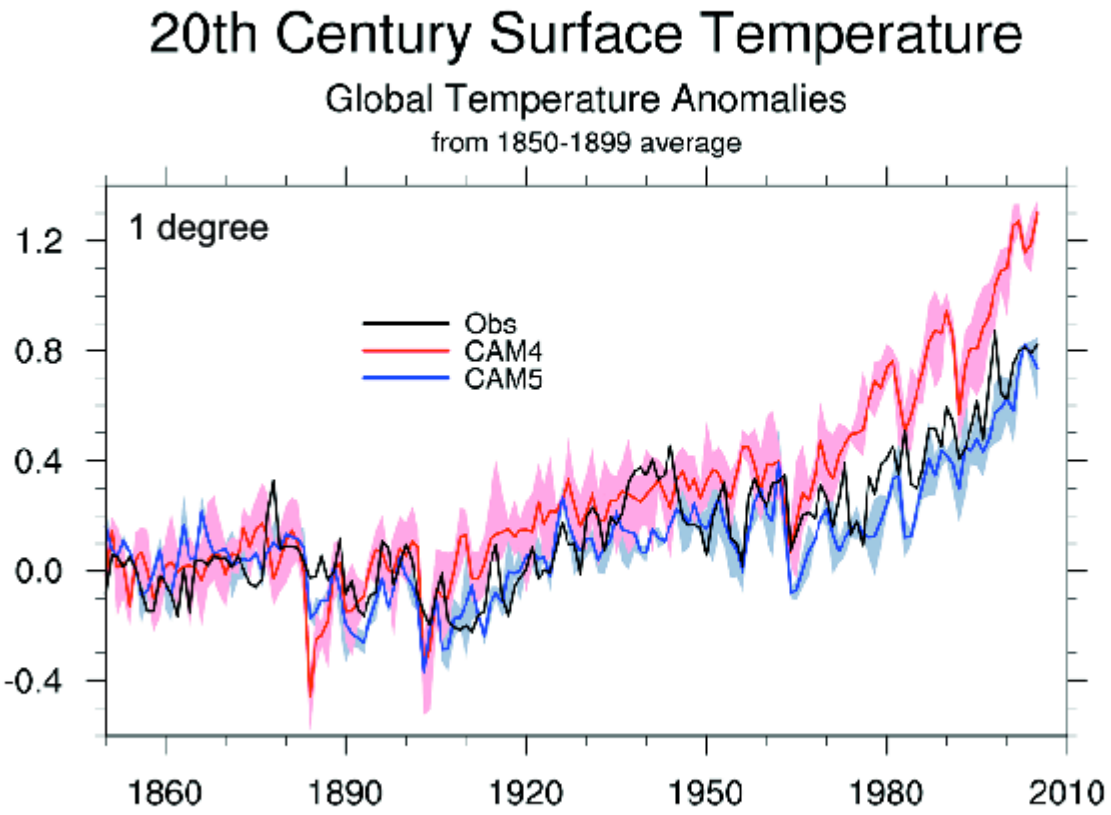
CM3: First GFDL Climate Model with Indirect Aerosol Effects

Globally Averaged Temperature Change
(1980-2000) minus (1881-1920)
(5-member ensembles for models)
(from Donner *et al.*, 2011, *J. Climate*)

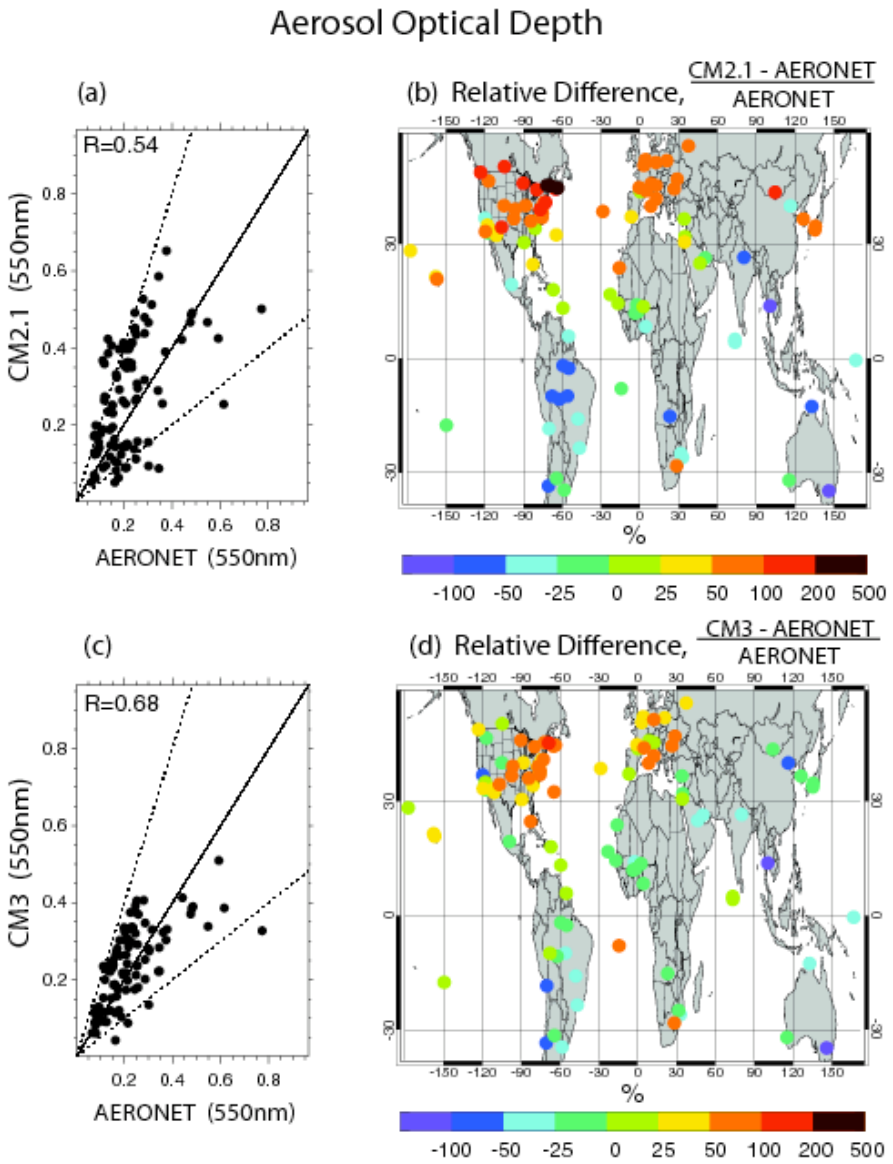
CM2.1 (no indirect effect)	0.66°C
CM3 (includes indirect effect)	0.32°C
GISS Observations	0.52°C
CRU Observations	0.56°C

CM3 cloud-aerosol interactions from physically based aerosol activation driven by sub-grid PDFs of vertical velocity in shallow cumulus and stratiform clouds (Ming *et al.*, 2006, *JAS;* Golaz *et al.*, 2011, *J. Climate*).

CESM(CAM5.1) 20th Century

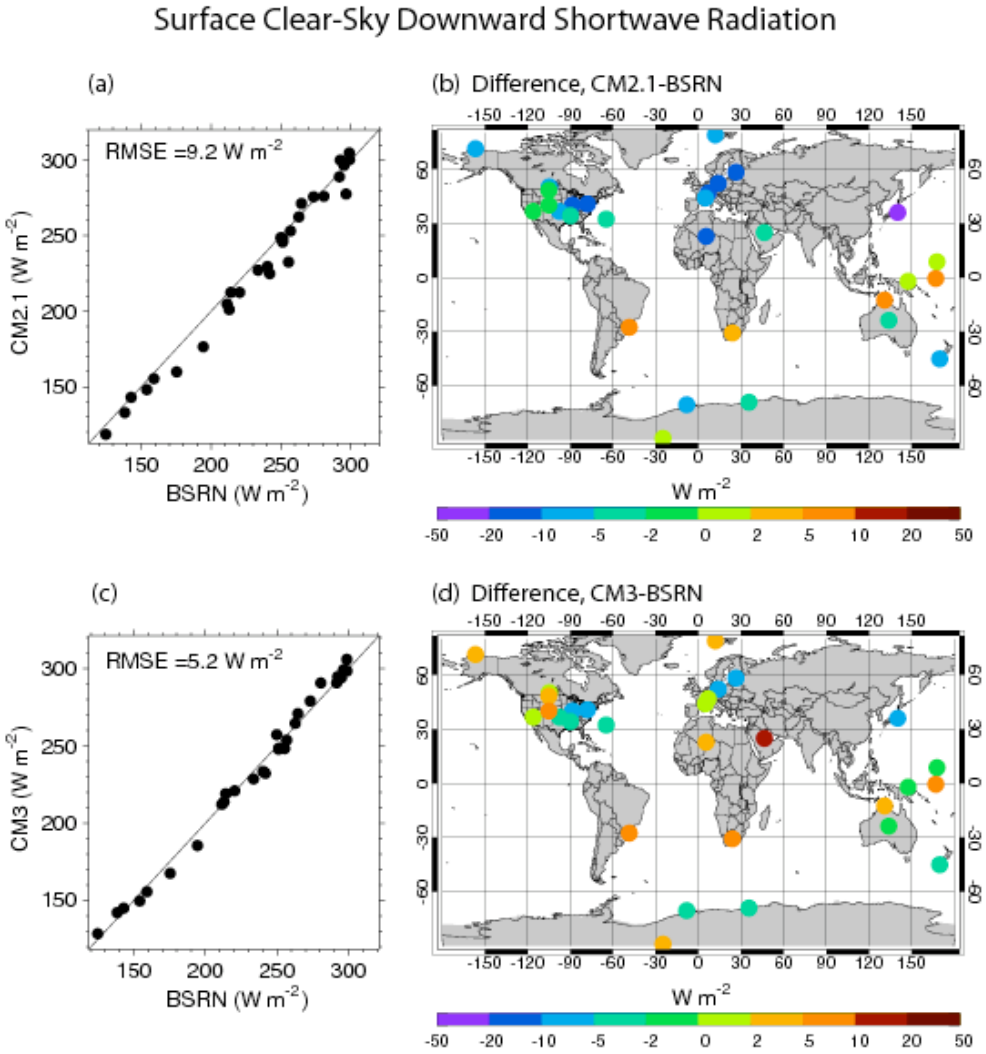


from Rich Neale, NCAR



GFDL CM3 has more realistic aerosol distribution than GFDL CM2.1

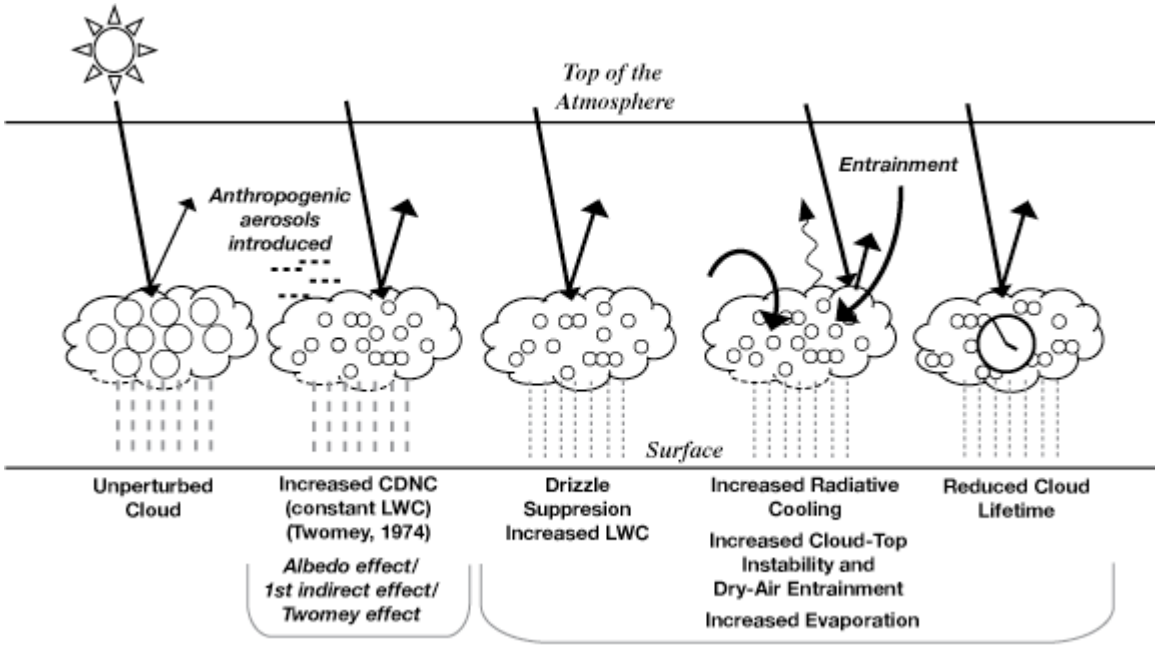
from Donner *et al.* (2011, *J. Climate*)



More realistic aerosol distribution in CM3 improves downward surface clear-sky shortwave fluxes.

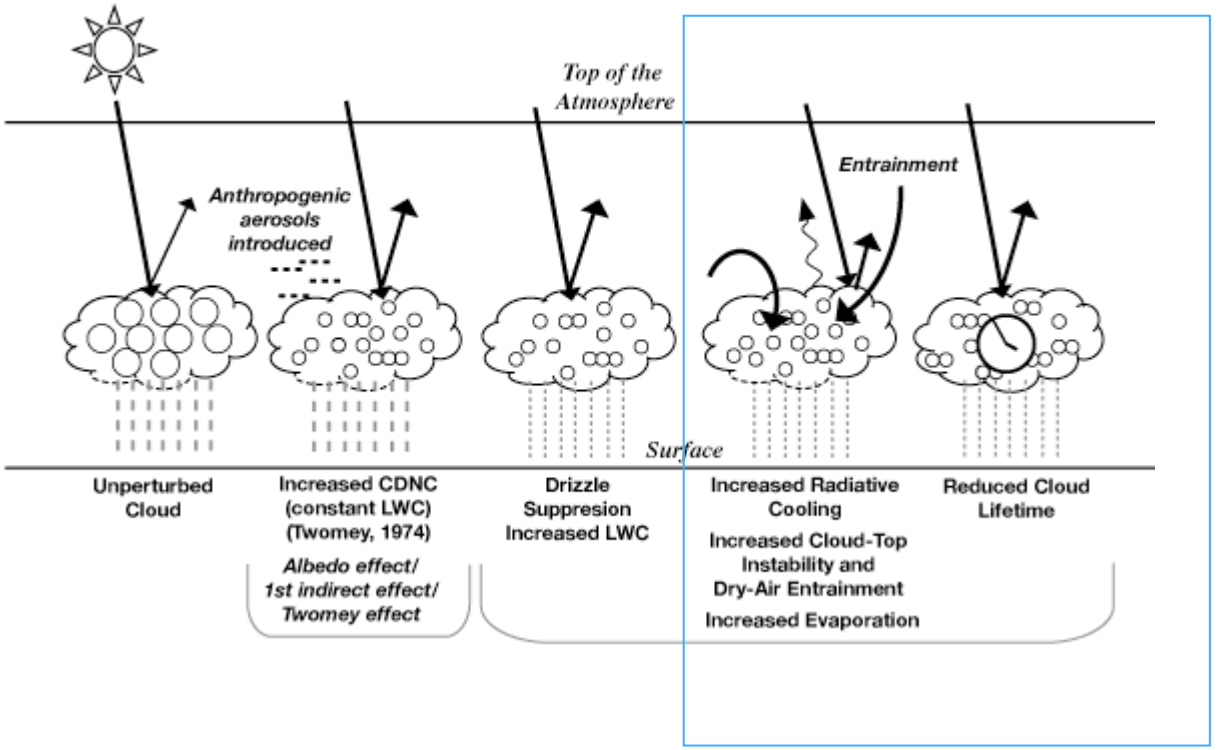
from Donner *et al.* (2011, *J. Climate*)

Schematic View of Aerosol-Cloud Interactions in Boundary-Layer Clouds



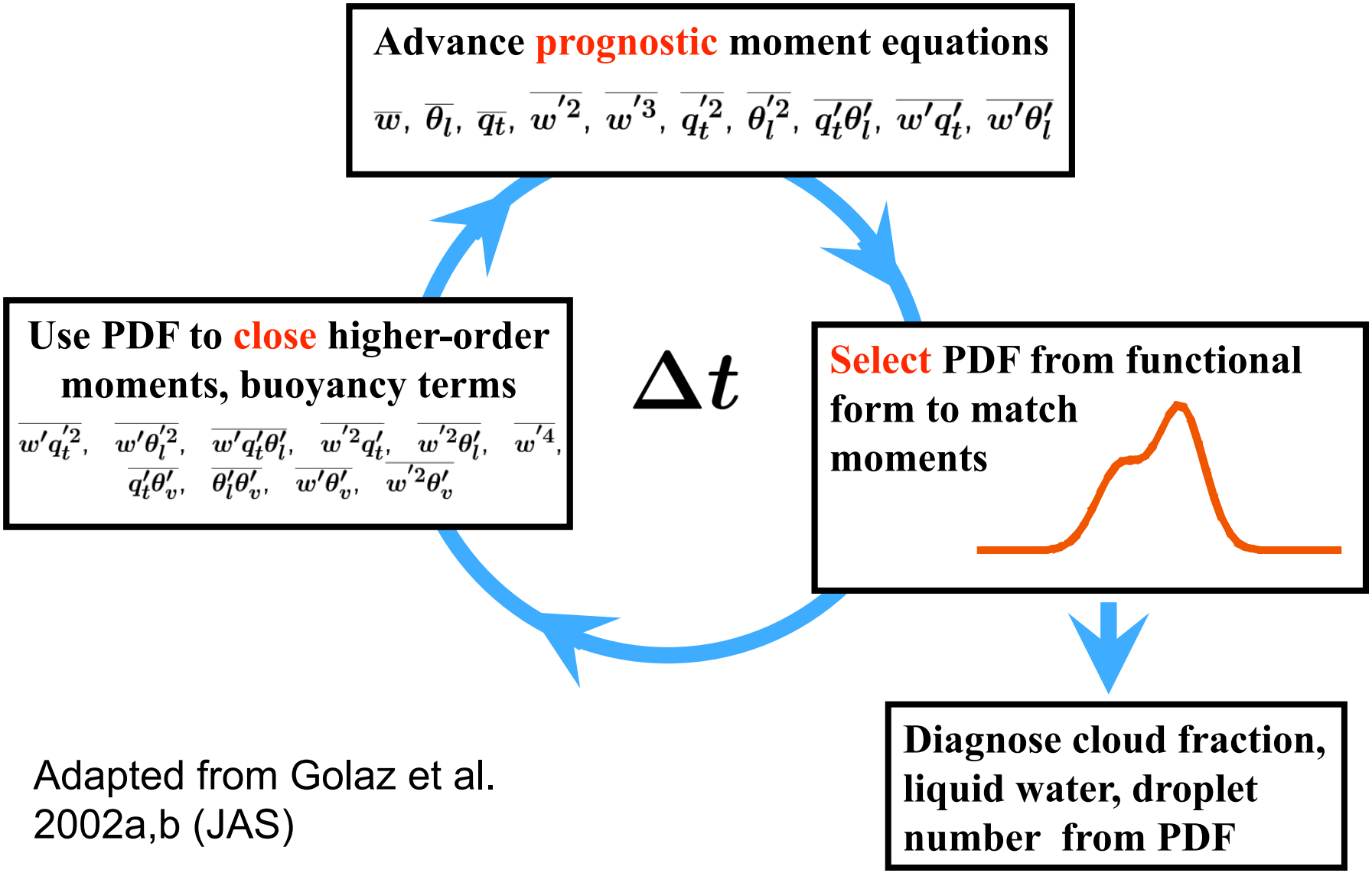
from Haywood et al. (2009, *Clouds in the Perturbed Climate System*)

GFDL CM3 cloud macrophysics does not treat cloud-top instability and dry-air entrainment realistically.



from Haywood et al. (2009, *Clouds in the Perturbed Climate System*)

Cloud macrophysics based on multi-variate probability distribution functions with dynamics (MVD PDFs), based on LES, proposed to treat cloud-top entrainment and dry-air mixing.



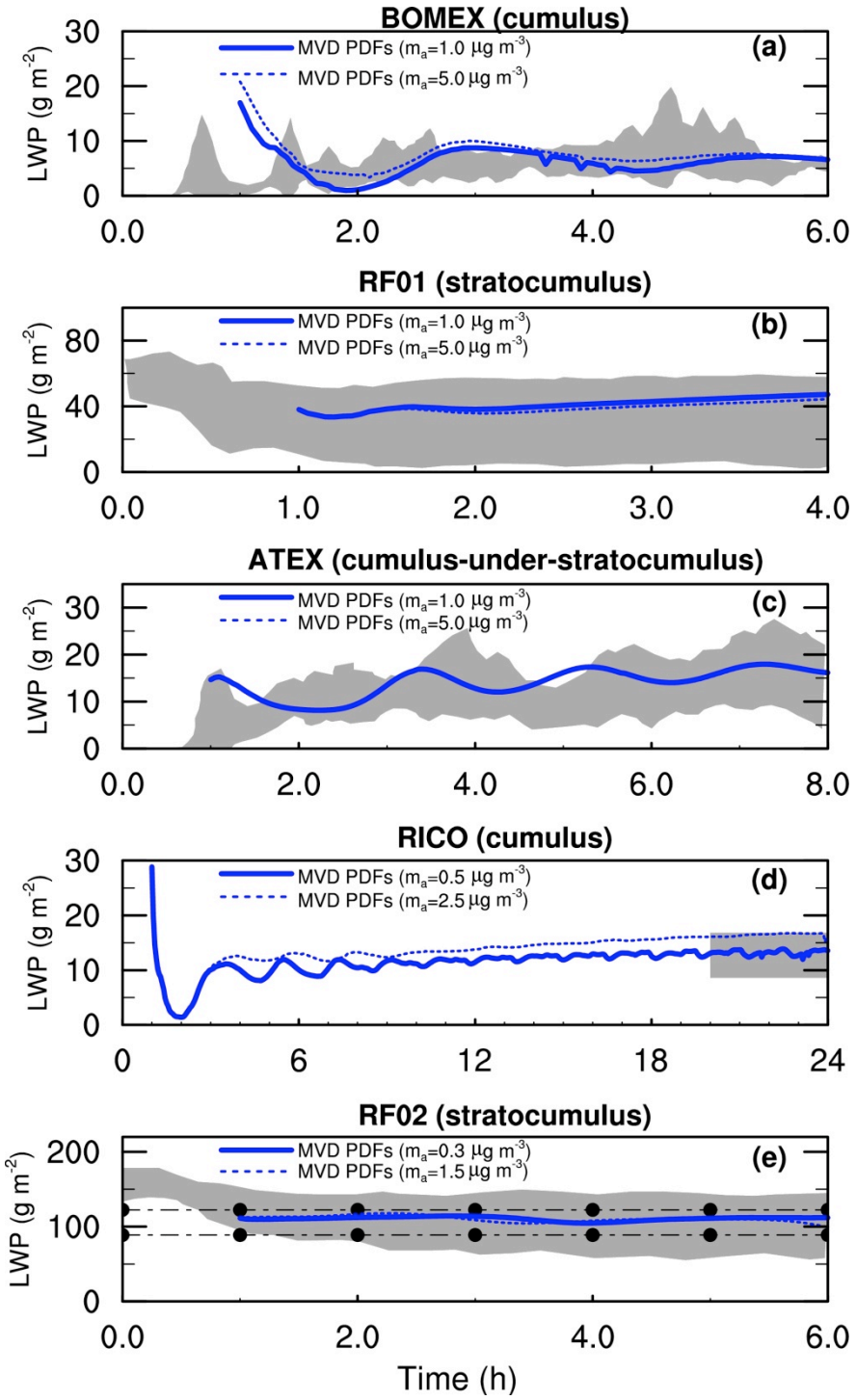
Adapted from Golaz et al. 2002a,b (JAS)

Five warm cloud cases

Non-precipitating
- BOMEX (cumulus)
- RF01 (stratocumulus)
- ATEX (cumulus-under-stratocumulus)

Precipitating
- RICO (cumulus)
- RF02 (stratocumulus)

AM3 Single Column Model using Multi-Variate Probability Density Function with Dynamics, Aerosol Activation, and Double-Moment Microphysics



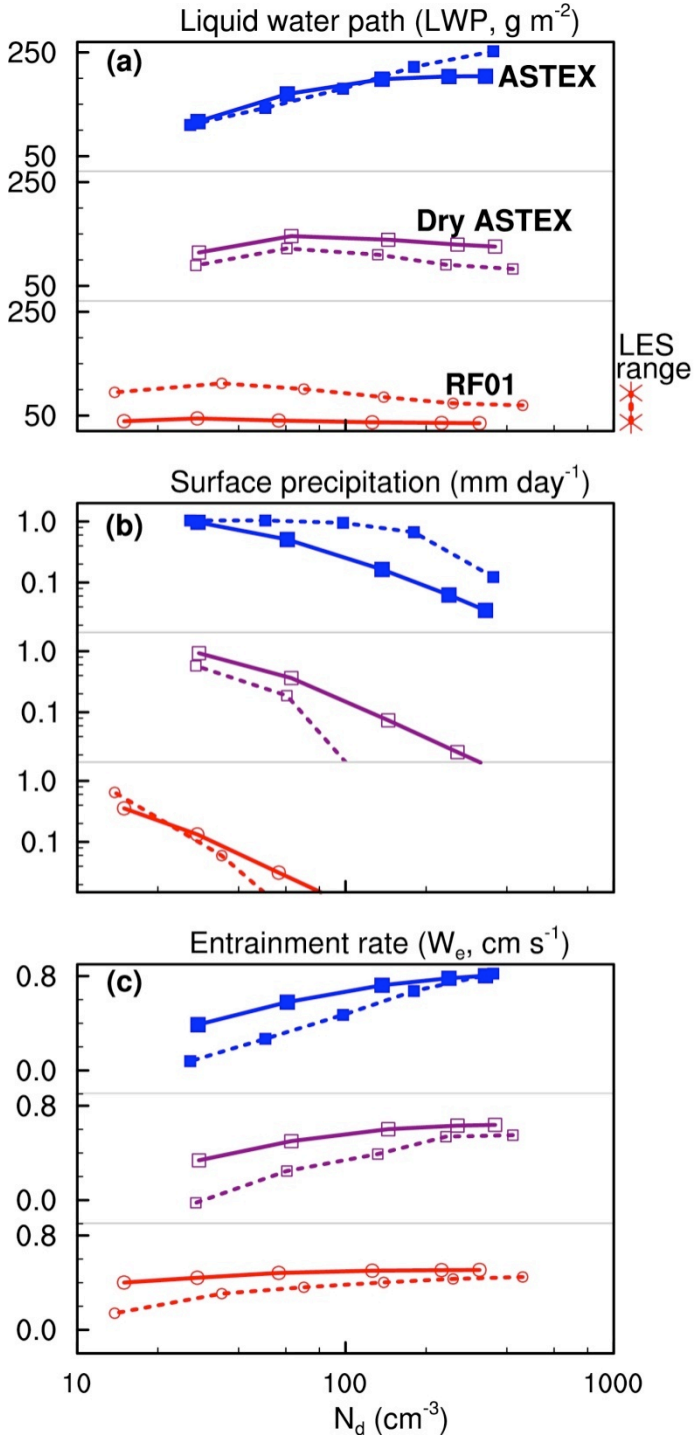
In some large-scale flows, cloud liquid *decreases* with increasing aerosol. Limits cooling by indirect effect.

from *Guo et al.* (2010, *Geosci. Model Dev.*)

Physics of entrainment-aerosol interaction similar in MVD PDFs and LES

Solid: MVD PDFs

Dashed: LES from Ackerman *et al.* (2004, *Nature*)



LES range from Guo *et al.* (2010, *GMD*)

cf., Guo *et al.* (2011, *GRL*)

Summary

- Aerosol-cloud interactions, using physically based activation dependent on super-saturation, have been incorporated in major IPCC AR5 models.
- CM3 and CAM5 warm somewhat less than observed over 20th century and corresponding earlier models, despite improved aerosol climatology in CM3.
- Too much cooling by aerosol-cloud interactions is a possible explanation.
- Aerosol-cloud interactions depend strongly on macrophysics of boundary-layer clouds, highly simplified in current climate models.
- Multi-variate PDFs for macrophysics are a promising alternate approach and may limit cooling by aerosol-cloud interactions.