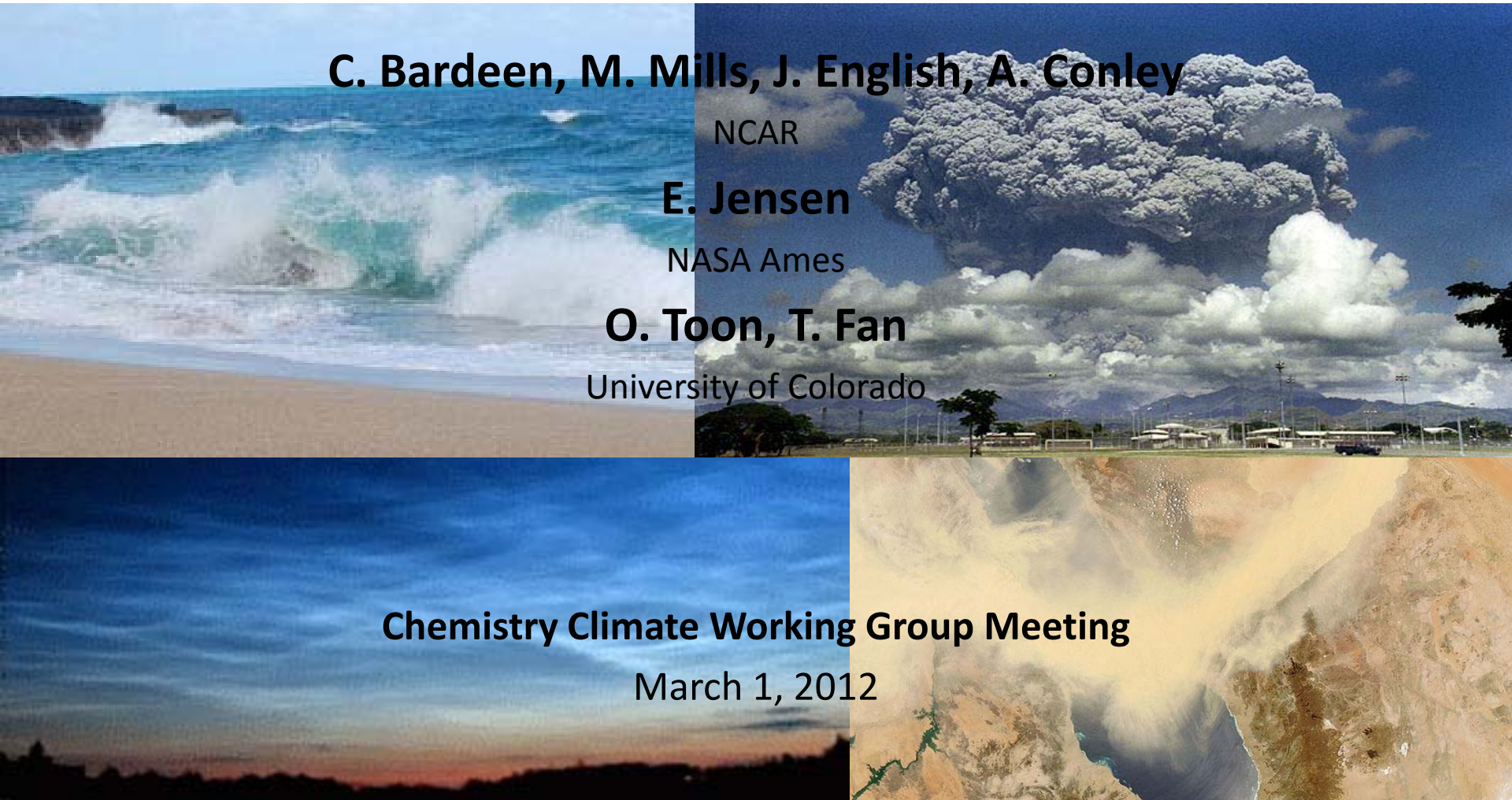
CARMA implementation in CAM



C. Bardeen, M. Mills, J. English, A. Conley

NCAR

E. Jensen

NASA Ames

O. Toon, T. Fan

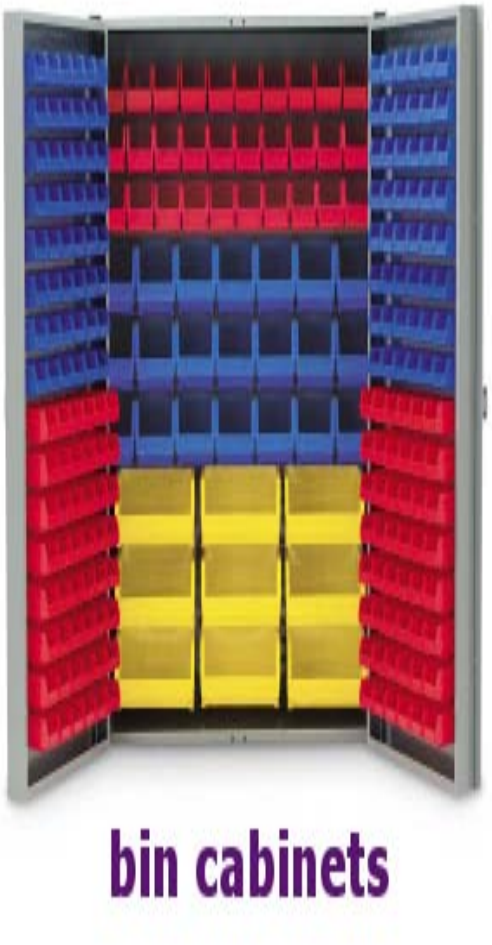
University of Colorado

Chemistry Climate Working Group Meeting

March 1, 2012

CARMA

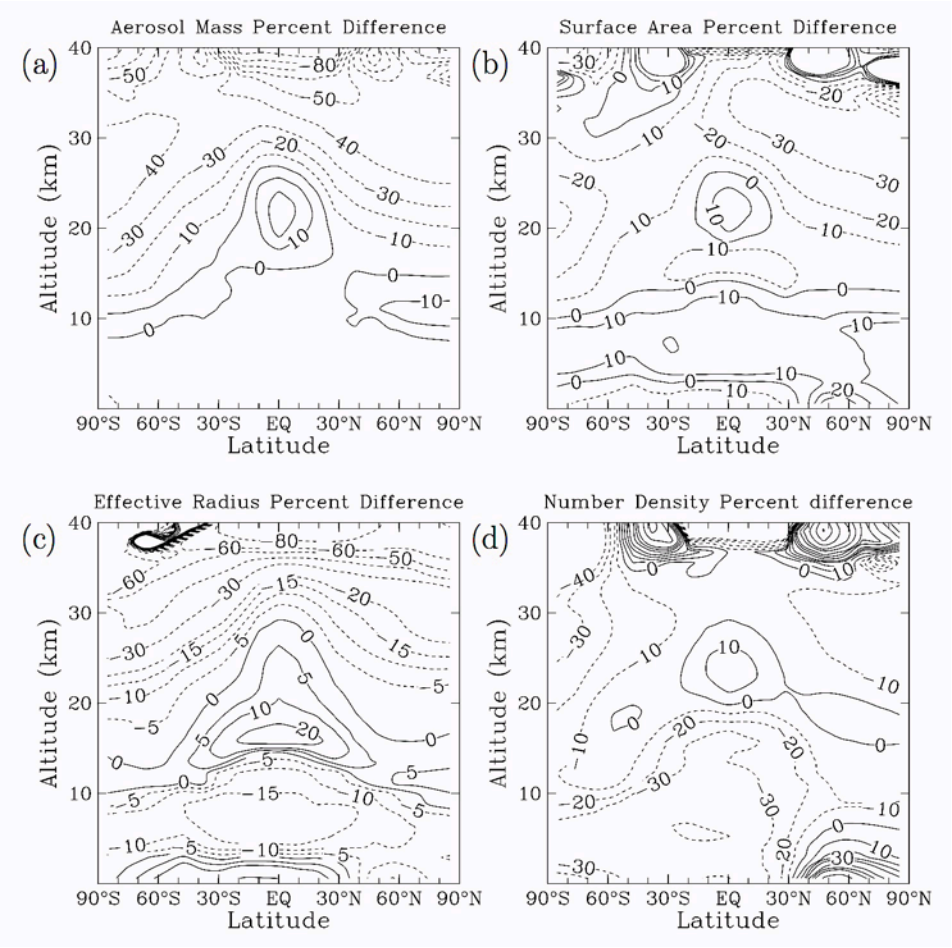
Community Aerosol and Radiation Model for Atmospheres

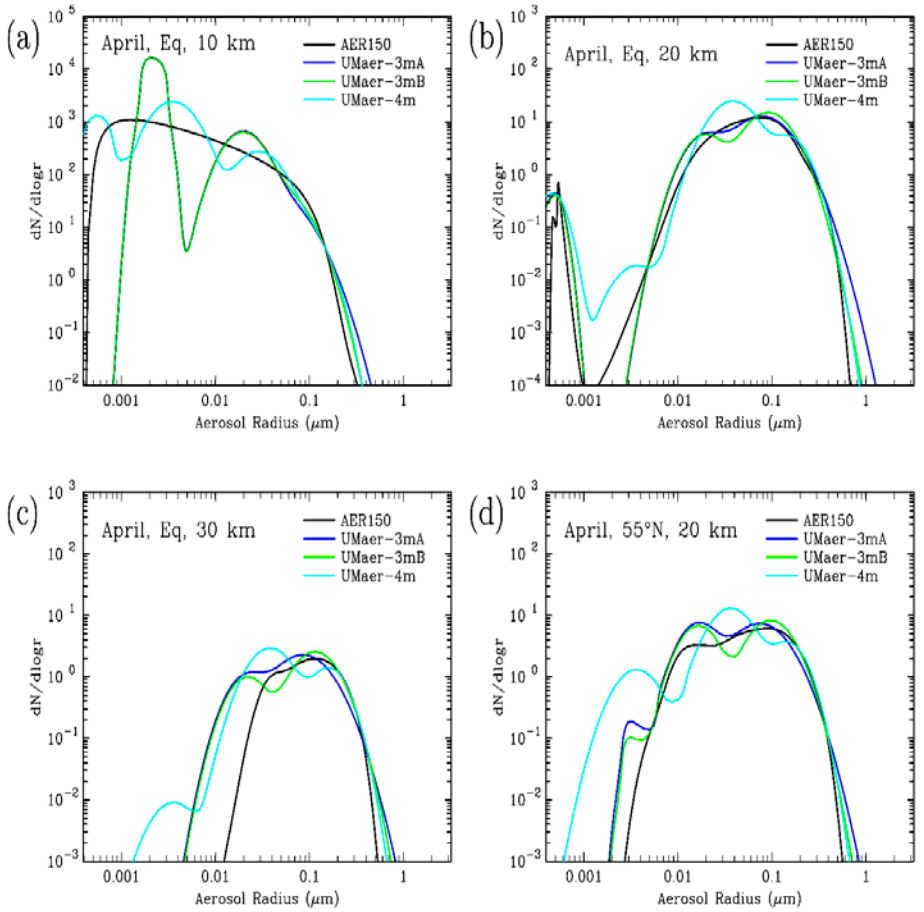


- *Turco et al.* [1979] – 1D
- *Toon et al.* [1988] – 3D
- *Jacobson et al.* [1994] – Coagulation
- Sectional (Bin) Microphysics Framework
- Flexible & Extensible
  - Sedimentation
  - Coagulation
  - Nucleation
  - Growth & Evaporation
  - Brownian Diffusion
  - Dry Deposition
  - Particle Swelling
  - Optical Properties (Mie)

*blue means new or modified in CARMA 3.0

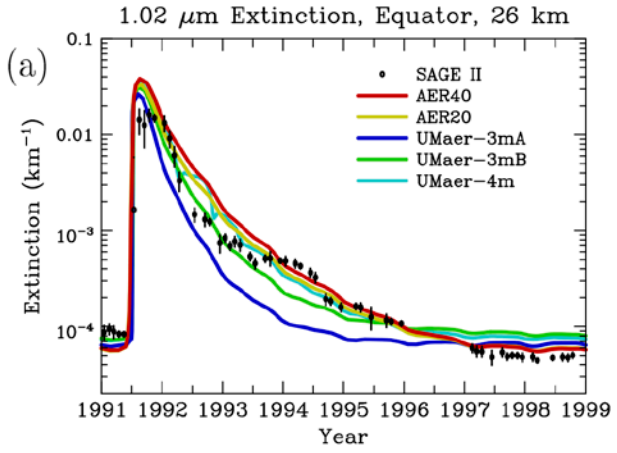
Why Sectional Aerosols?

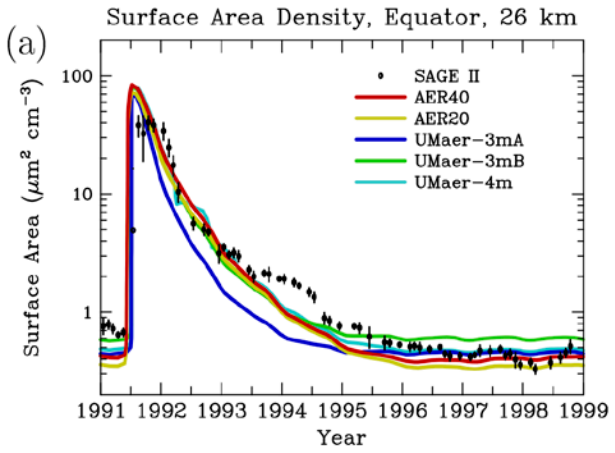


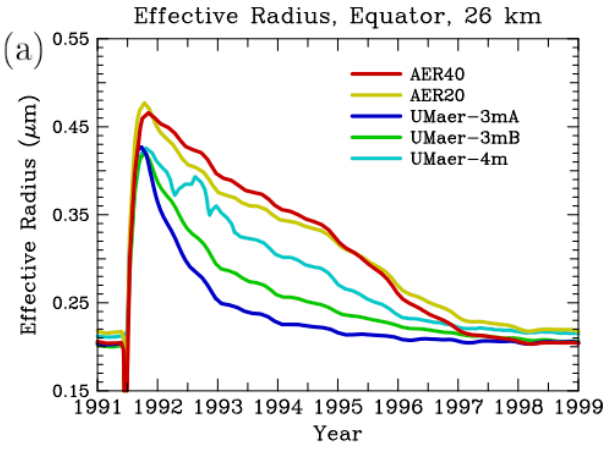


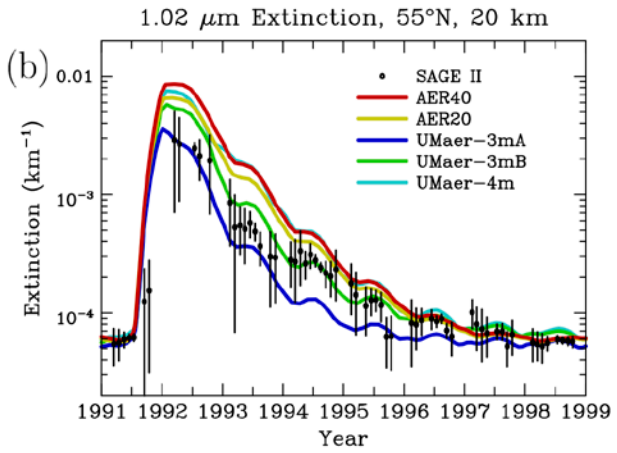
[Weisenstein et al. 2007]

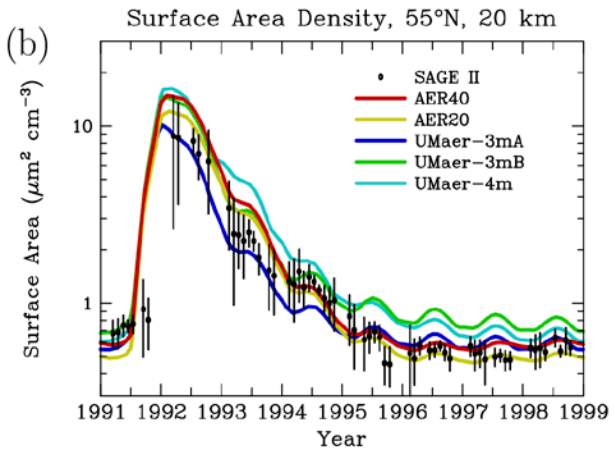
Volcanic Eruption: Mt. Pinatubo

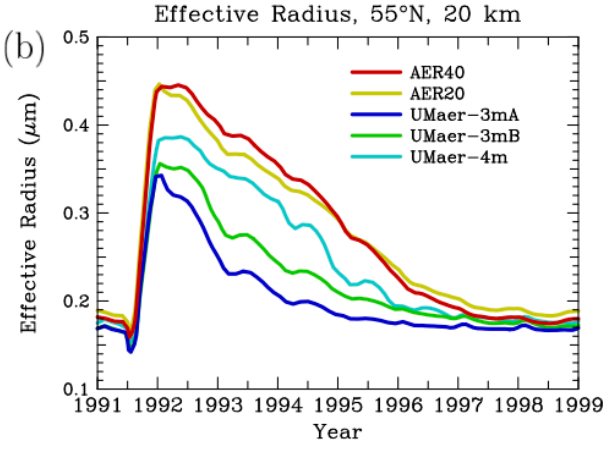






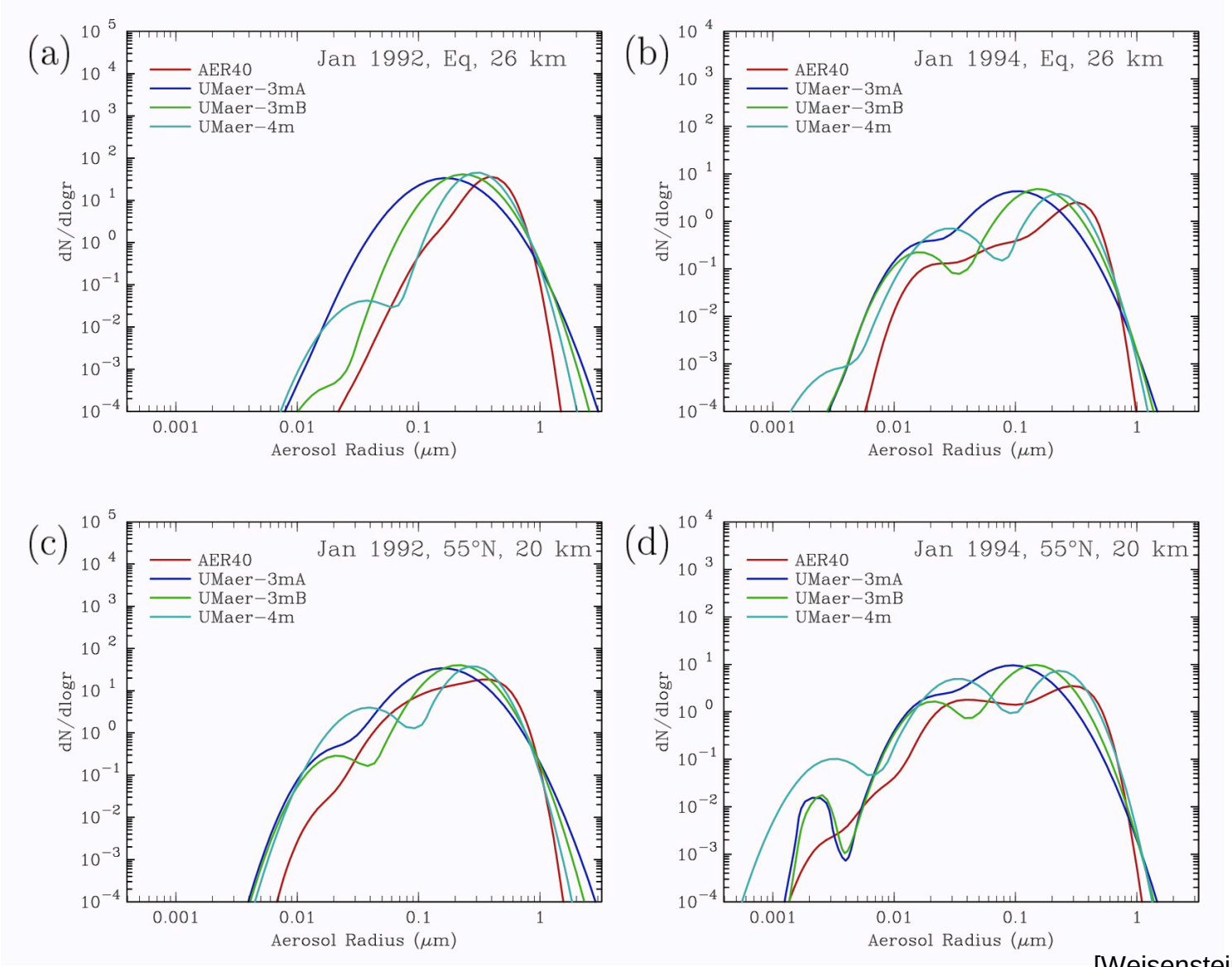






[Weisenstein et al. 2007]

Volcanic Eruption: Mt. Pinatubo

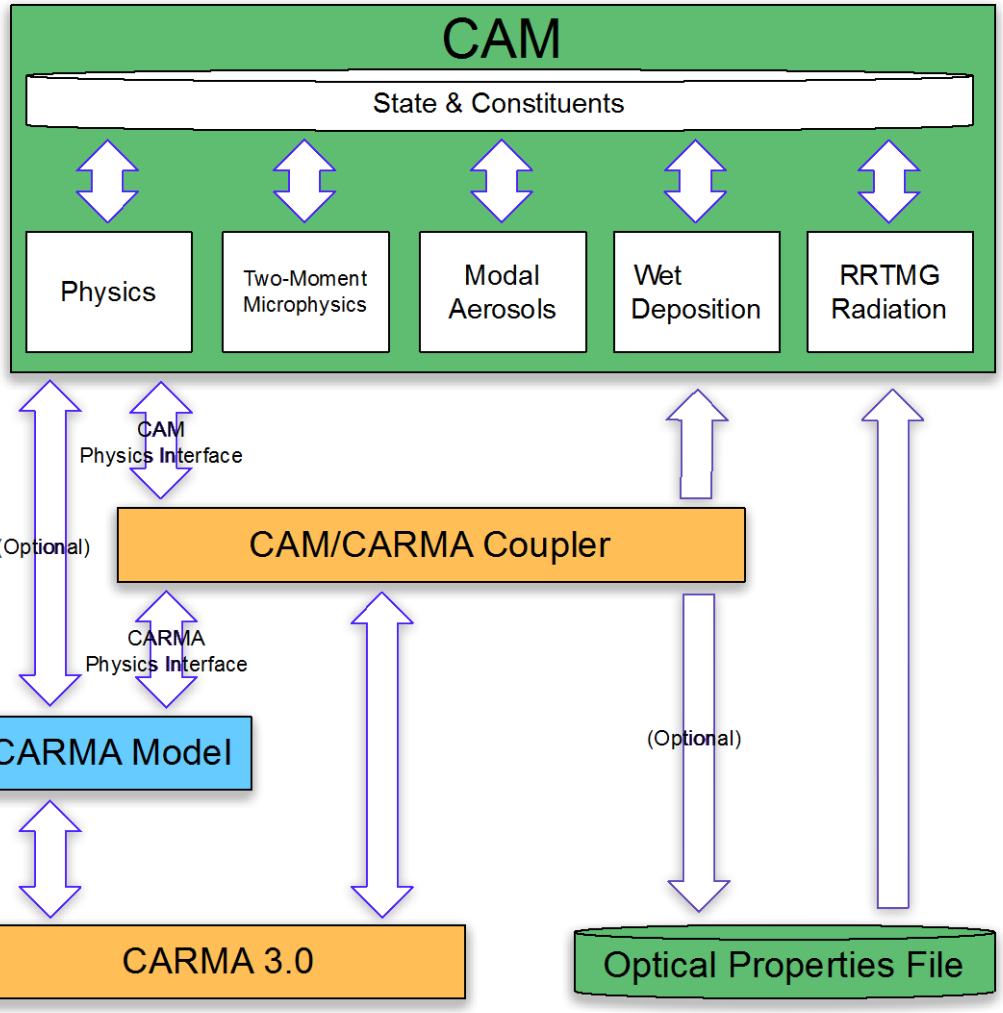


[Weisenstein et al. 2007]

CARMA 3.0 Design Goals

- Embed as cloud and/or aerosol component in other 3D models (GCMs)
  - F77 -> F90
  - Common Blocks -> Modules, Defined Types, Dynamic Allocation
  - Thread Safe
  - Implicit None
  - 3-D -> 1-D (Remove horizontal advection, fewer dimensions in arrays)
  - Constants from parent model
  - Conserve mass and energy
  - Radiative Transfer -> Optical Properties
  - Use from many models (e.g. CAM, WACCM, GEOS5, WRF)
  - Generalized interface to configure the model definition (no direct CARMA field access from parent model)
- Keep code familiar to CARMA 2.3 users
  - Use #define to map common block names to field names
  - Keep files names for core routines the same
- Additions
  - Bug Fixes
  - New/Updated Physics Parameterizations
  - Standalone Test Cases

CAM/CARMA



Unique to each science problem

CESM/CARMA Models

CAM/CARMA

- Sea Salt (Fan)
- Dust (Su)
- Cirrus (Bardeen)
- Soot (Yu, Smith)
- Sulfate (Fan)

WACCM/CARMA

- Sulfate (Mills, English, Fan, Neely)
- Soot (Mills)
- Polar Stratospheric Cloud (Zhu)
- Early Earth Haze (Wolf)
- Meteor Smoke (Bardeen)
- Polar Mesospheric Cloud (Bardeen)
- Meteor Impact (Bardeen, Mills, Garcia)

General Changes

Software Engineering

- OPEN/MP and hybrid modes
  - Thread safe
- Same result independent of decomposition and restarts
  - Initialize CARMA every timestep or once against a reference temperature profile
- Allow multiple CARMA models in the same source tree

Science

- Bug fixes
- Radiatively active particles via RRTMG
- Brownian diffusion
- Use updated CAM wet deposition code
- CARMA dry deposition

Changes for Cirrus

- Diagnostic & prognostic particles
- Cloud (before coupling) & aerosol (after coupling) CARMA models
- Substep retry mechanism for more efficient nucleation & growth
- Cloud fraction & subgrid scale saturation (Wilson & Ballard 1999)
- Detrainment of cloud condensate
- Detrainment of ice as a size distribution (Heymsfield et al. 2010)
- Variable particle density and projected area (Heymsfield et al. 2010)
- Ice sedimentation (Heymsfield & Westbrook 2010)
- Saturation vapor pressure of water (Murphy & Koop 2005)
- Aerosol freezing (Koop et al. 2000, Mohler et al. 2010)
- Heterogeneous nucleation of glassy aerosols (Murray et al. 2010)
- Particle radiative heating (from RRTMG) effects on growth

Changes for Sea Salt & Sulfates

- Sulfur Chemistry
- Sulfuric acid saturation vapor pressure (Kulmala & Laaksonen 1990)
- Binary homogeneous nucleation (Zhao & Turco 1995)
- Particle Swelling (Wet Radius)
  - Sea Salt, f(relative humidity) (Fitzgerald 1975, Gerber 1985)
  - Sulfate, f(sulfate weight percent) (Tabazadeh et al. 1991)
- Van der Waals forces for coagulation (Chan & Mozurkewich, 2001)

WACCM Sulfur Chemistry

- Additional Species
  - OCS, S, SO, SO_2, SO_3, HSO_3, H_2SO_4
- SO_2 from surface emissions
- OCS from lower boundary condition
- Additional Reactions

<u>Photolysis</u>

$H_2SO_4 + hv \rightarrow SO_3 + H_2O$

$SO_2 + hv \rightarrow SO + O$

$SO_3 + hv \rightarrow SO_2 + O$

$OCS + hv \rightarrow S + CO$

$SO + hv \rightarrow S + O$

<u>Gas Phase</u>

$OCS + O \rightarrow SO + CO$

$OCS + OH \rightarrow SO_2 + \{C\} + H$

$S + OH \rightarrow SO + H$

$S + O_2 \rightarrow SO + O$

$S + O_3 \rightarrow SO + O_2$

$HSO_3 + O_2 \rightarrow SO_3 + HO_2$

$SO_3 + H_2O \rightarrow H_2SO_4$

$SO + OH \rightarrow SO_2 + H$

$SO + O_2 \rightarrow SO_2 + O$

$SO + O_3 \rightarrow SO_2 + O_2$

$SO + NO_2 \rightarrow SO_2 + NO$

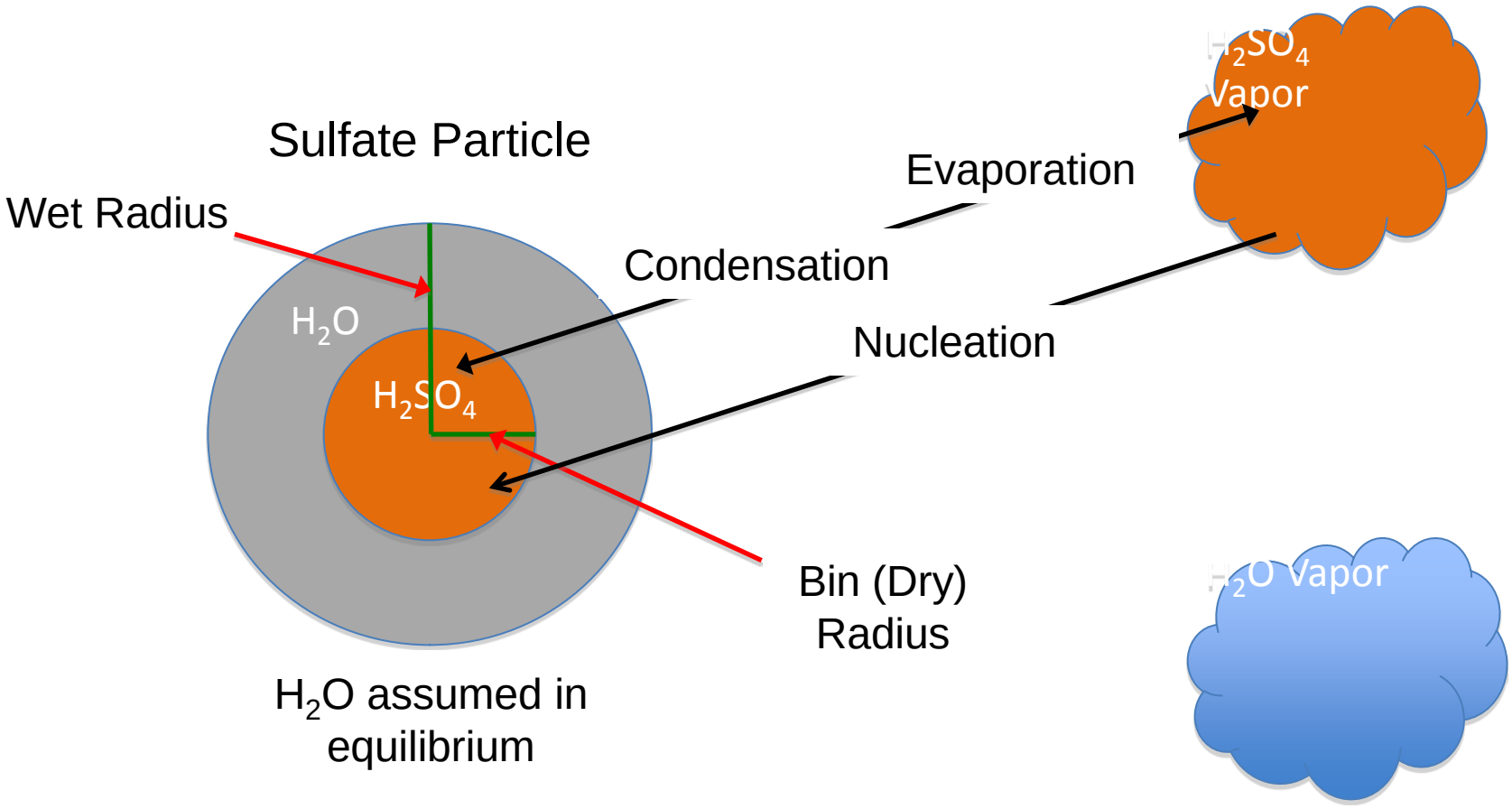
$SO + ClO \rightarrow SO_2 + Cl$

$SO + OClO \rightarrow SO2 + ClO$

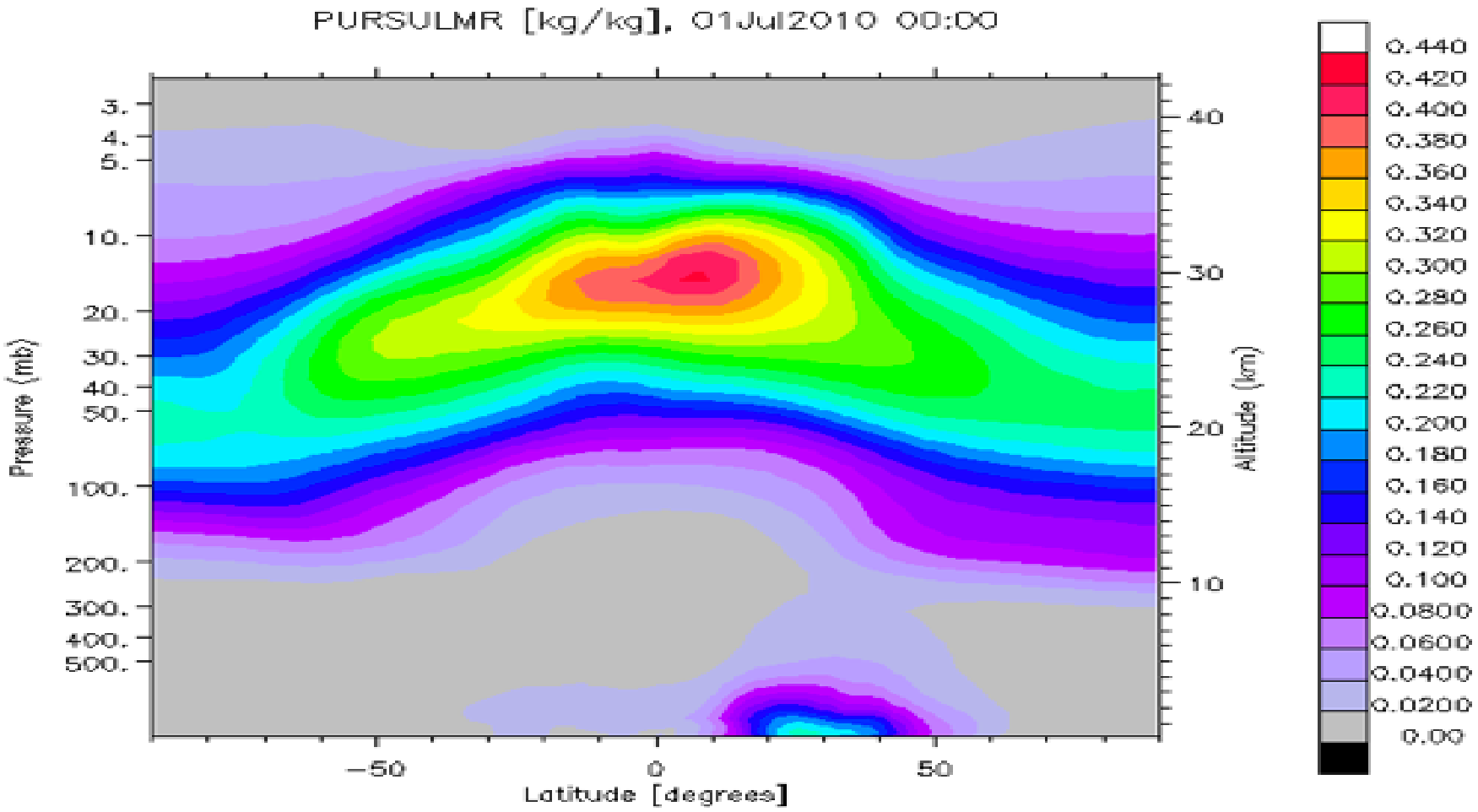
$SO + BrO \rightarrow SO_2 + Br$

$SO_2 + OH + M \rightarrow HSO_3 + M$

Sulfate Aerosols

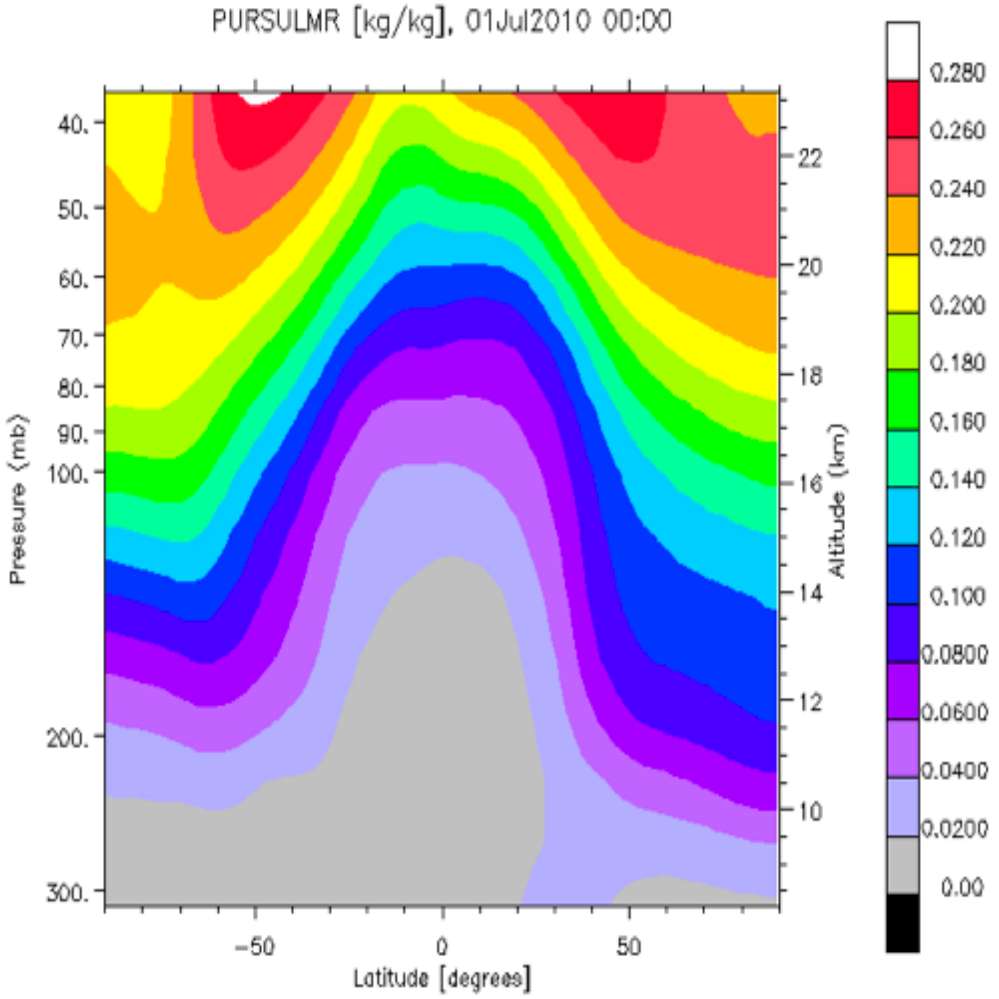


Sulfate Mass Mixing Ratio

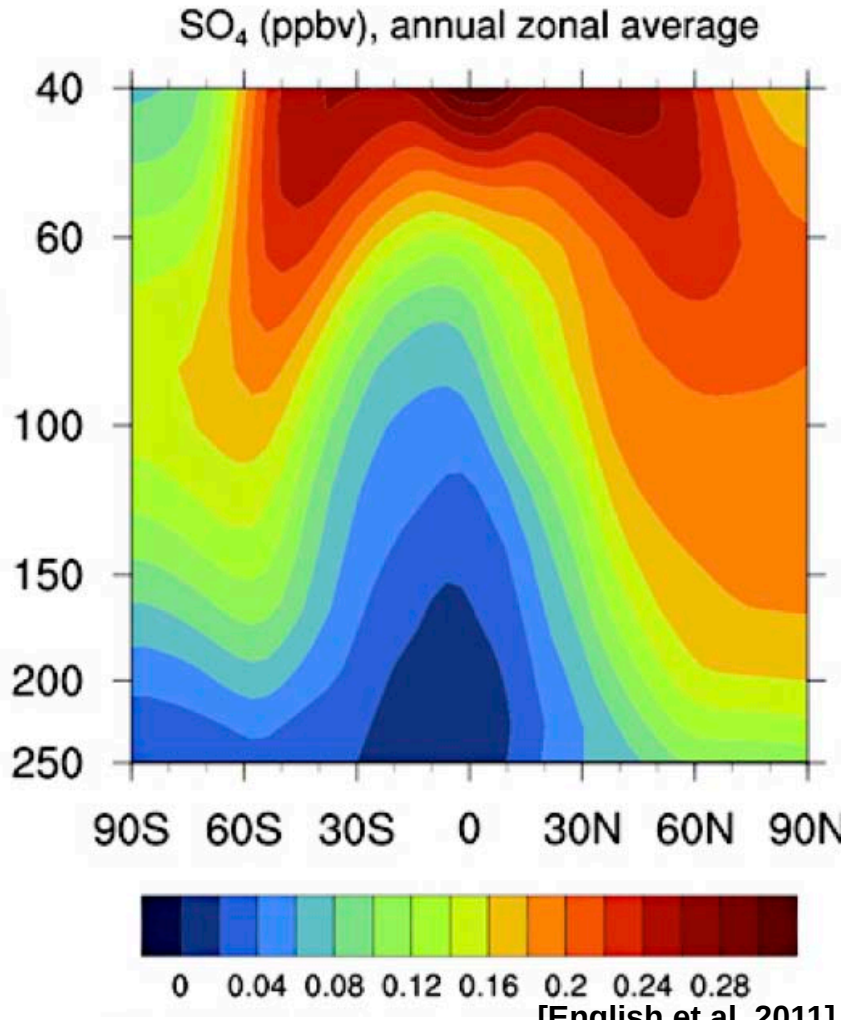


Sulfate MMR : UTLS

WACCM4/CARMA3

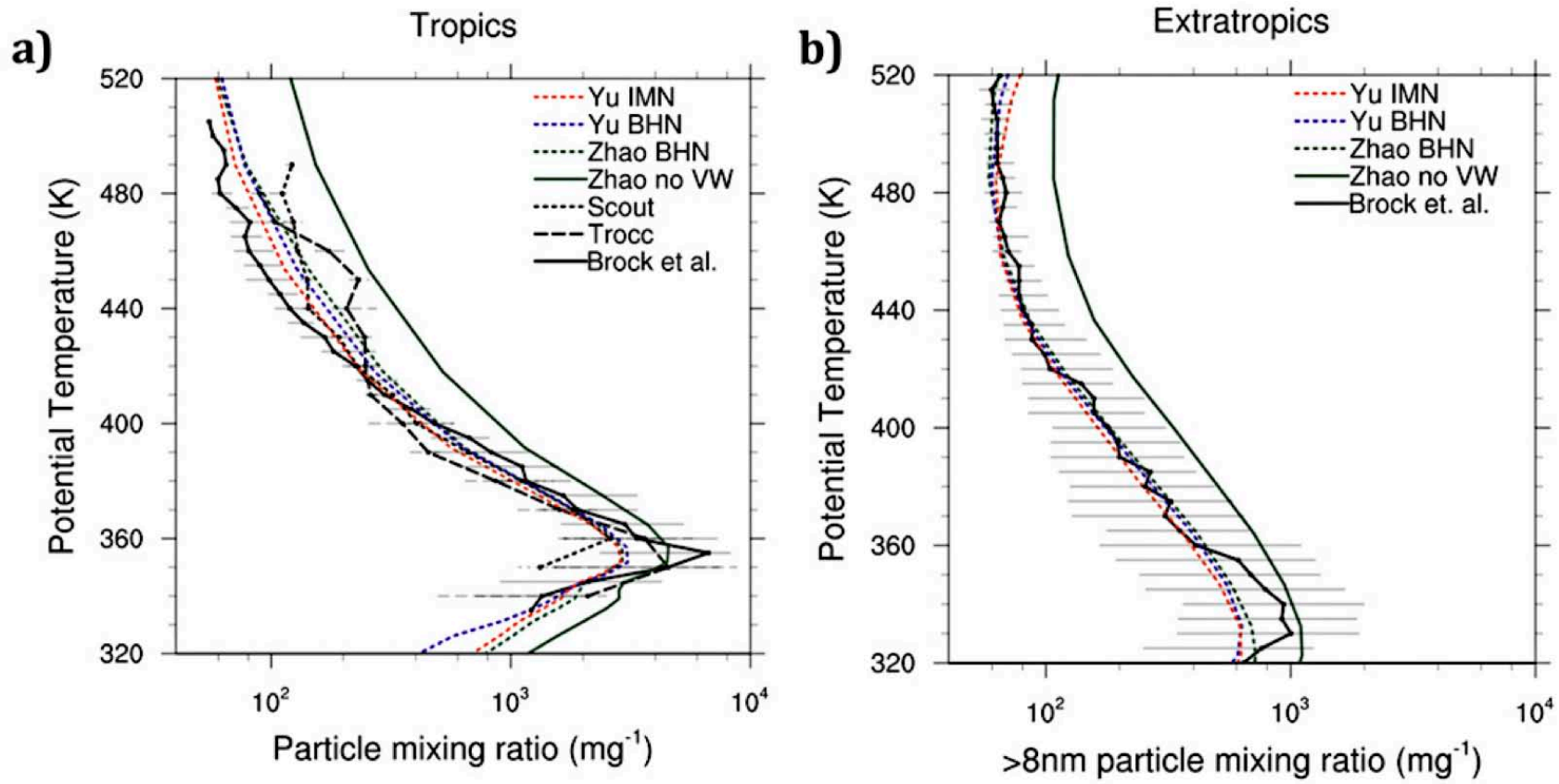


WACCM3.1.9/CARMA2.3



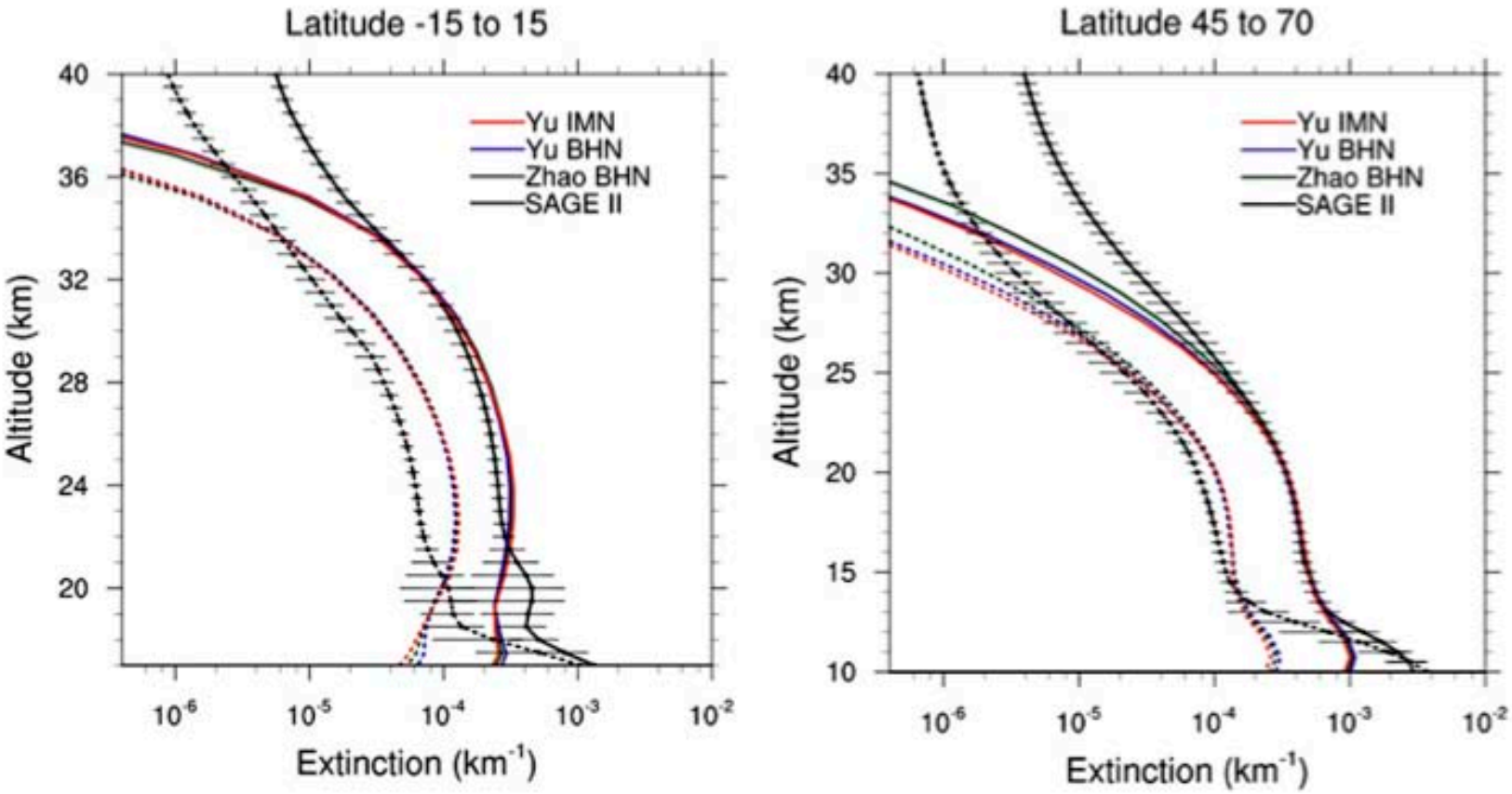
[English et al. 2011]

Sulfate MMR vs. Aircraft



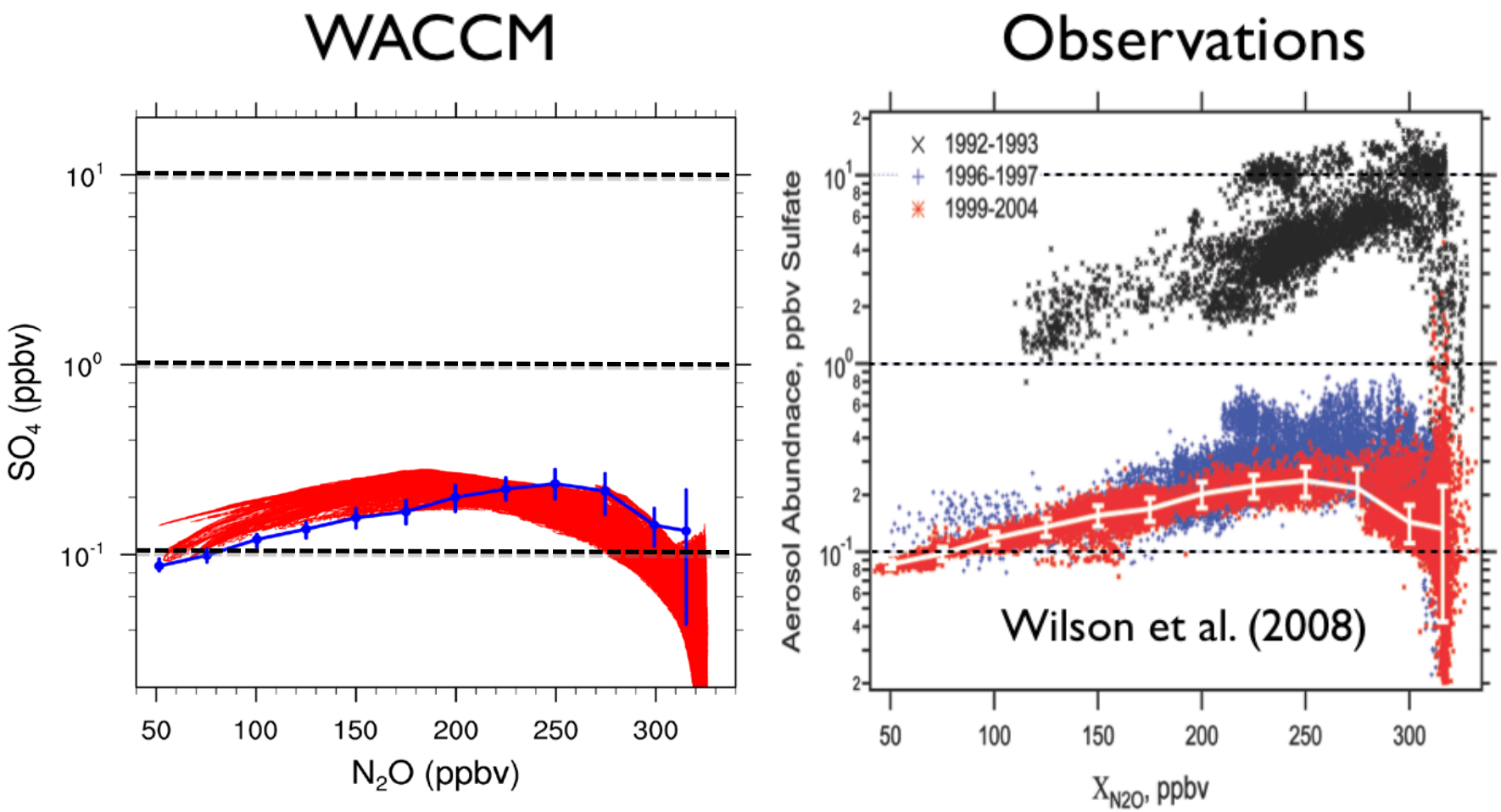
[English et al. 2011]

Sulfate Extinction vs. Sage II



[English et al. 2011]

Lower Stratospheric SO_4 & N_2O



Sulfate Futures

- Include Kelvin Effect in sulfate weight percent calculation
  - Different weight percent per bin
- Sulfate optical properties by weight percent
- Use CARMA sulfate for SAD for heterogeneous chemistry
- Add DMS chemistry
- Integrate CARMA sulfates with modal aerosols
- Add meteor smoke as sulfate condensation nuclei
- Interactive consumption of water vapor by sulfates?

Summary

- Sectional models can be used to help tune modal models, and may be more appropriate for experiments with large perturbations.
- CARMA 3.0 provides enhancements over CARMA 2.3 and was designed to be embedded in GCMs.
- CARMA sectional microphysics is been used successfully in CAM and WACCM for both cloud and aerosol models.
- Initial support for sulfate aerosols has been added to WACCM/CARMA, with more to come.