Modal Aerosol Treatment in CAM4

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Scientific Discovery through Advanced Computing
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Benchmark 7-Mode Modal Aerosol Model (MAM)

Aitken
- number
- sulfate
- ammmonium
- secondary OM
- sea salt

Accumulation
- number
- sulfate
- ammonium
- secondary OM
- hydrophobic OM
- BC
- sea salt

Fine Soil Dust
- number
- soil dust
- sulfate
- ammonium

Fine Sea Salt
- number
- sea salt
- sulfate
- ammonium

coagulation
condensation

Primary Carbon
- number
- hydrophobic OM
- BC

Coarse Soil Dust
- number
- soil dust
- sulfate
- ammonium

Coarse Sea Salt
- number
- sea salt
- sulfate
- ammonium

All modes log-normal with prescribed width.

Total transported aerosol tracers: 31

Cloud-borne aerosol and aerosol water predicted but not transported.

Computer time is ~100% higher than BAM

Simplified 3-mode version of MAM

Assume primary carbon is internally mixed with secondary aerosol.
Sources of dust and seasalt are geographically separate
Assume ammonium neutralizes sulfate.

Aitken
number
sulfate
secondary OM
sea salt

→ coagulation, condensation →

Accumulation
number
sulfate
secondary OM
primary OM
black carbon
soil dust
sea salt

Coarse
number
soil dust
sea salt
sulfate

Total transported aerosol tracers: 15

Computer time is 30% higher than BAM

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New Processes

- New particle formation (in UT and BL)
- Coagulation within, between modes
- Dynamic condensation of trace gas (H_2SO_4, NH_3) on aerosols
- Aging of primary carbon to accumulation mode based on sulfate coating from condensation & coagulation
- Ultrafine sea salt emissions from Martensson et al.
- A new secondary organic aerosol treatment: reversible condensation of SOA (gas)
- Aerosol optics from Ghan and Zaveri (JGR 2007)

CAM Simulations (camdev23_CAM3.6.28)

- Double-moment MG cloud microphysics
- RRTMG shortwave and longwave radiative transfer
- Modal aerosol module (MAM)
- UW PBL + shallow Cu + cloud macrophysics

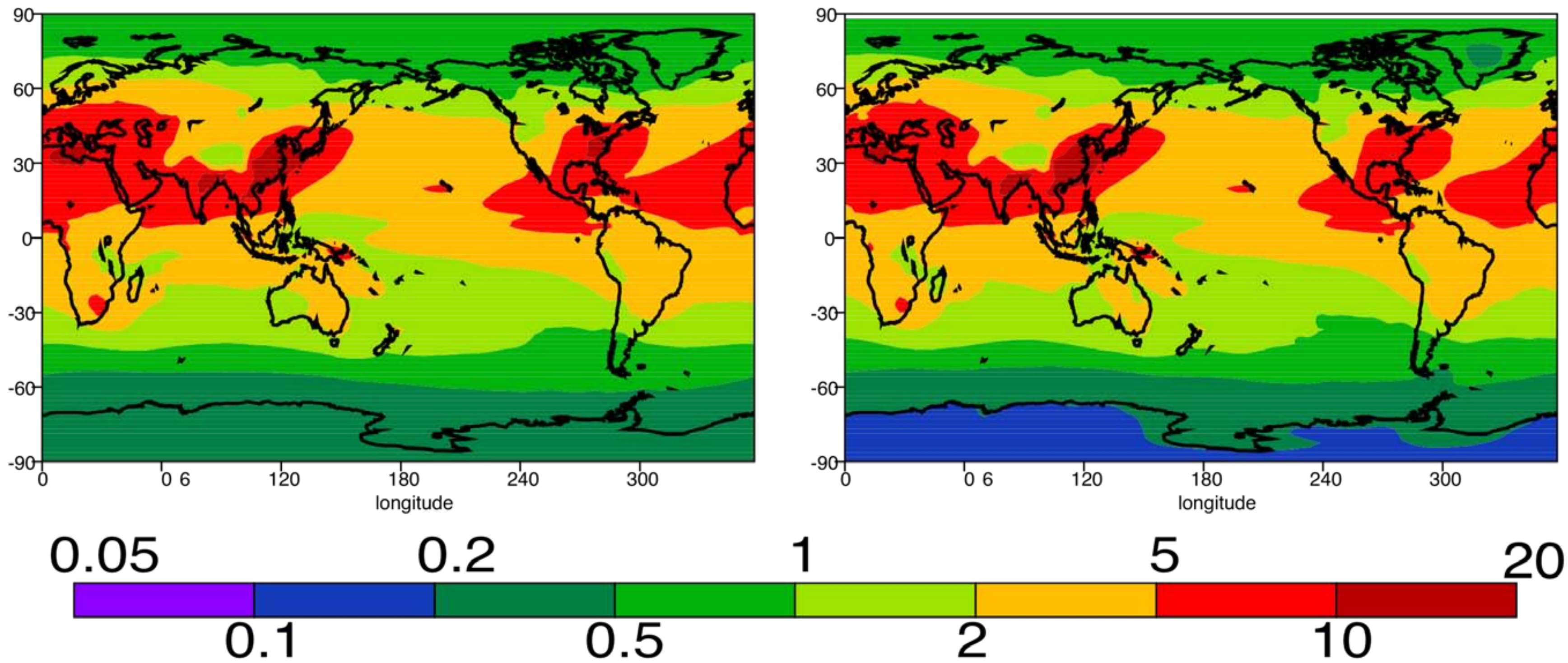
- 3-mode and 7-mode
- 5 years at 1.9° x2.5° resolution

- IPCC AR5 emissions for anthr. OM, BC, SO2, SO4 (Lamarque)
- AEROCOM emissions for natural DMS, SO2, SO4, injection heights and primary particle sizes
- Biogenic SOA(g) emission: apply yields on MOZART VOCs emissions

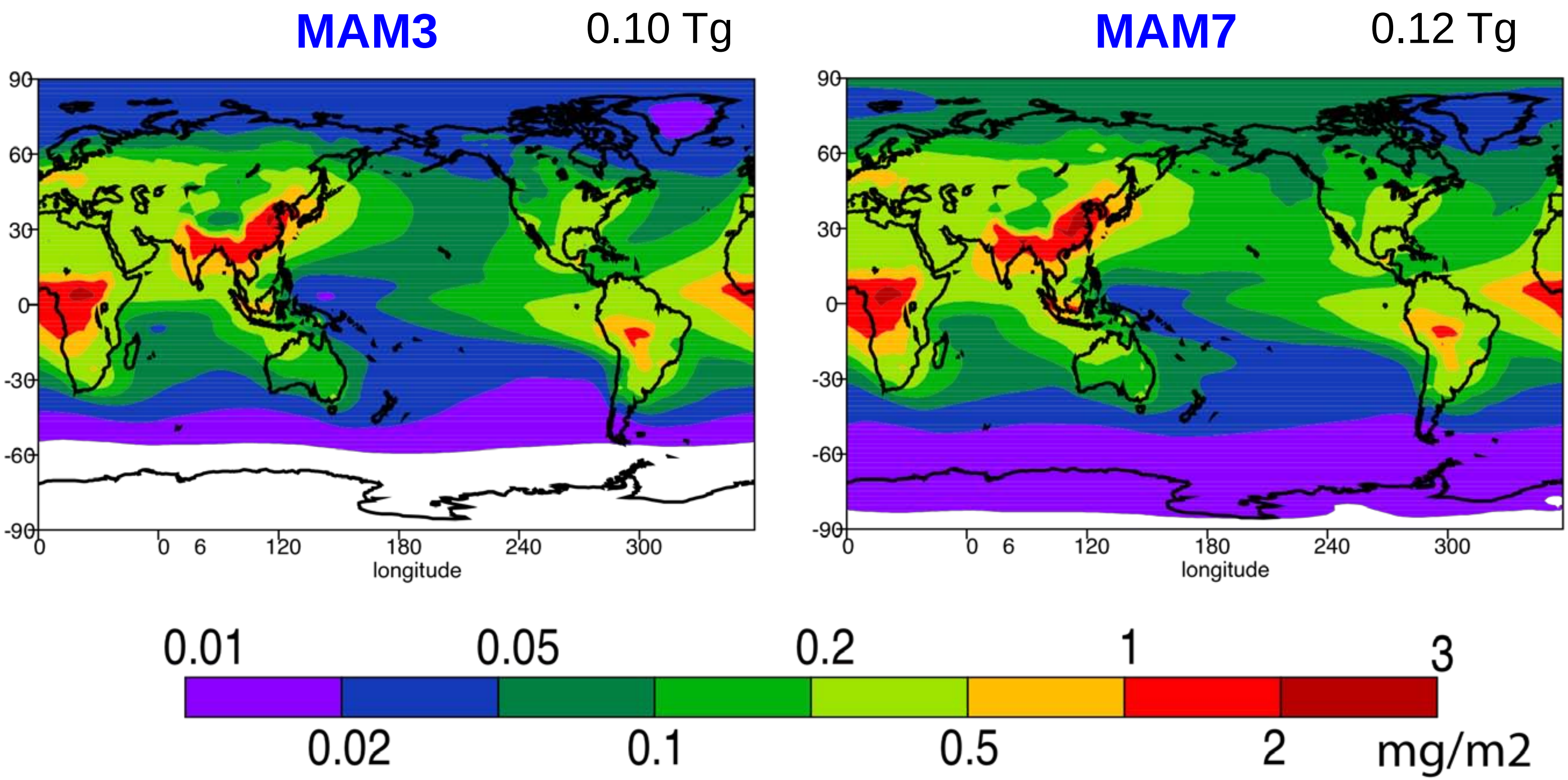
Sulfate Column Burden

MAM3 0.52 TgS

MAM7 0.50 TgS



BC Column Burden



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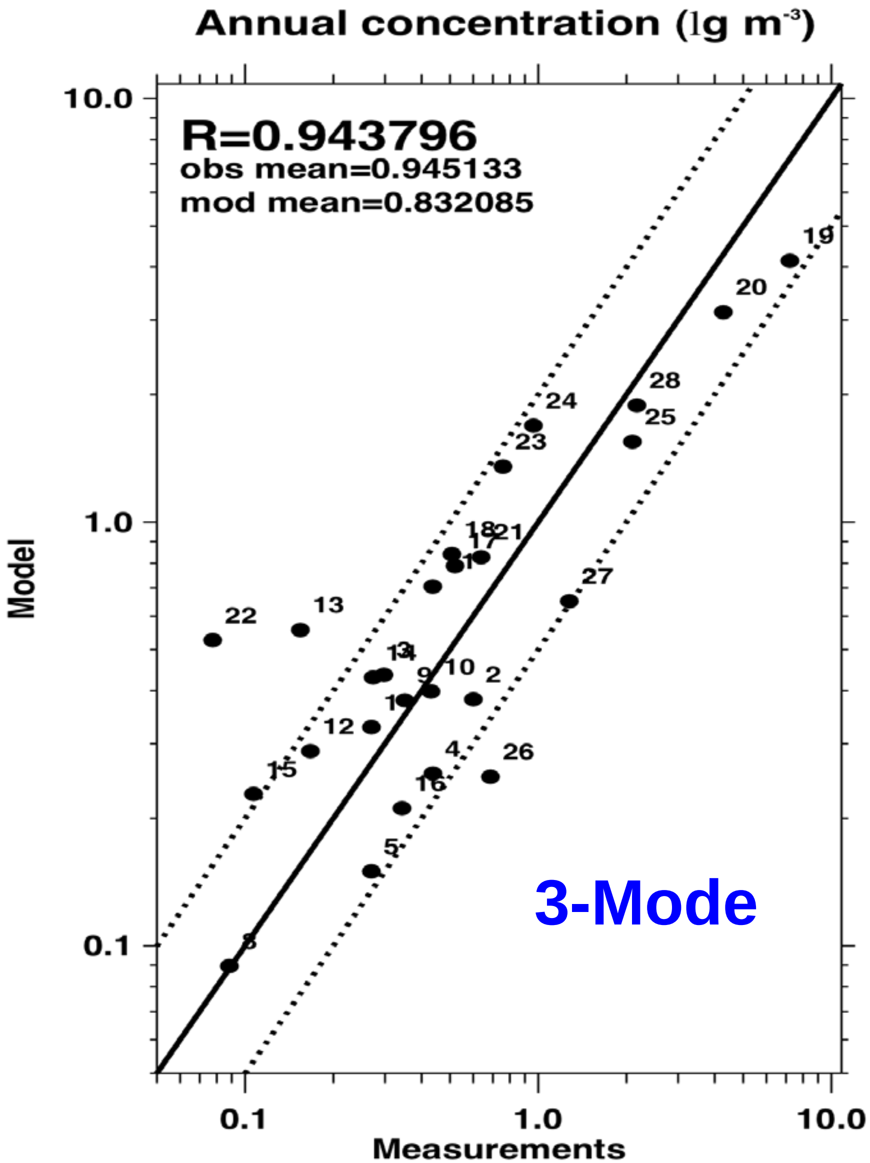
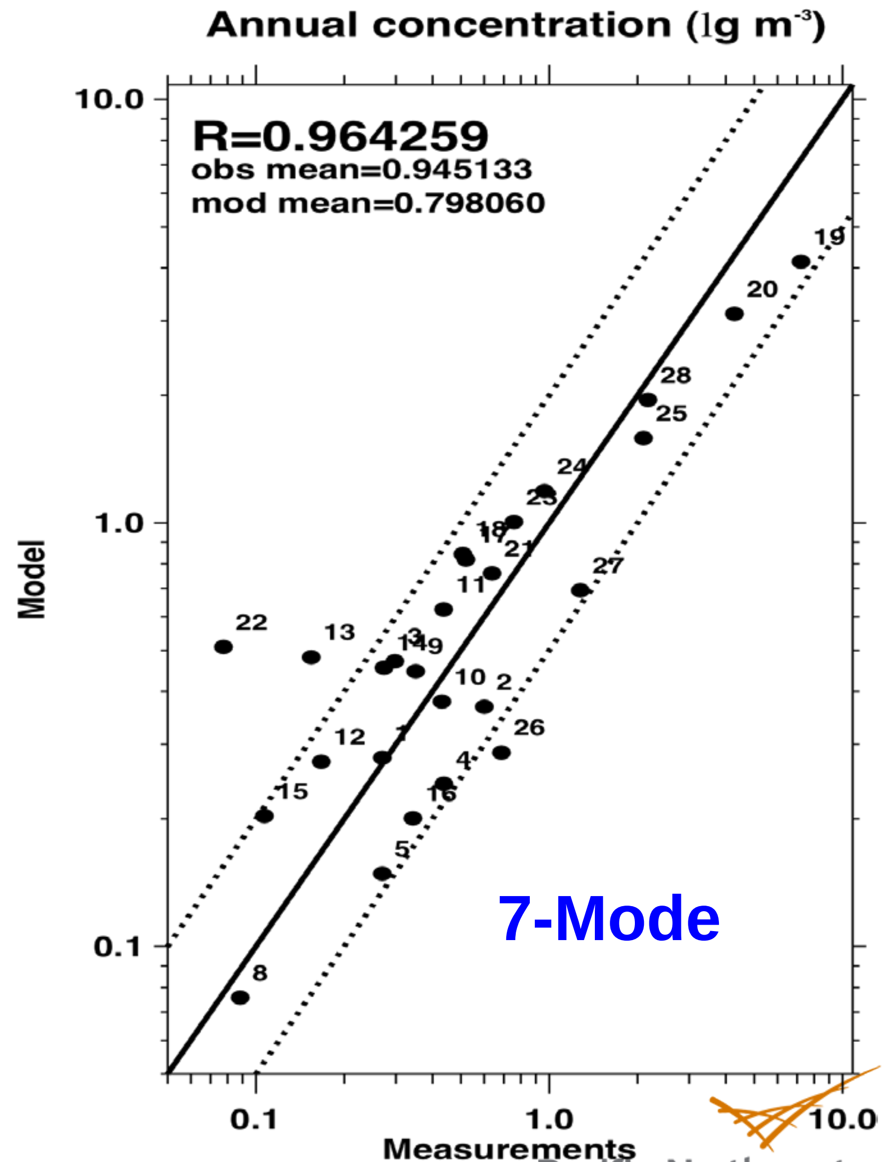
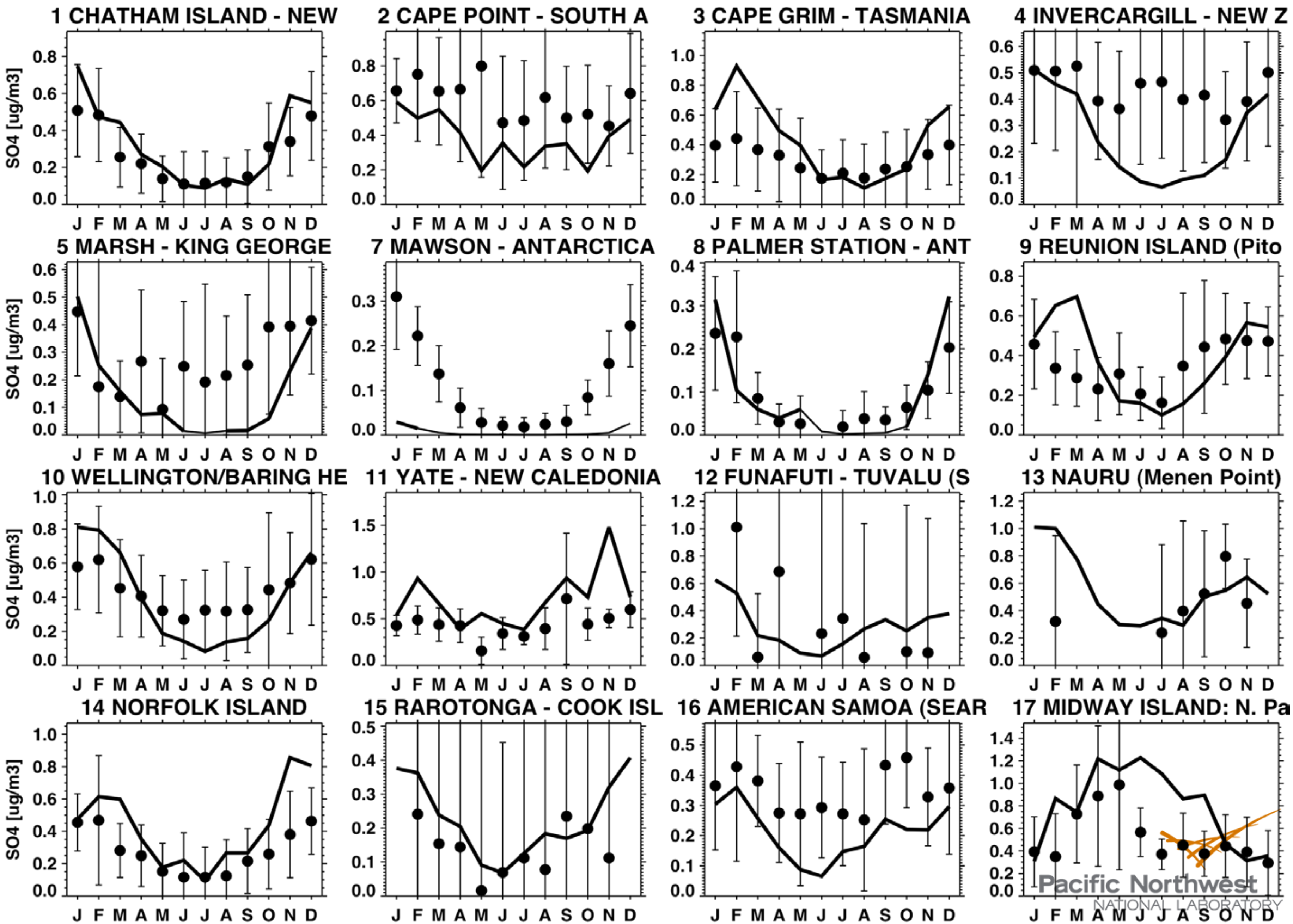
SO_4 compared with RSMAS data

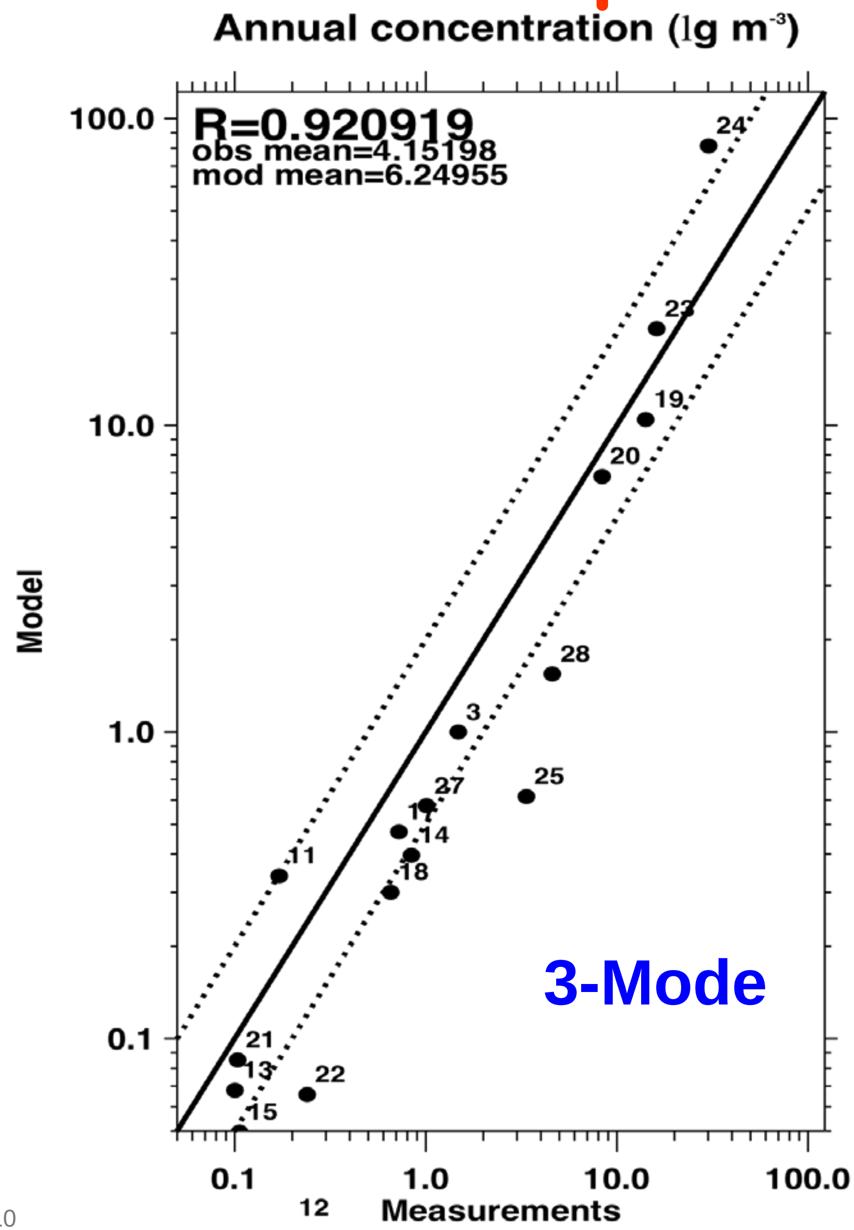


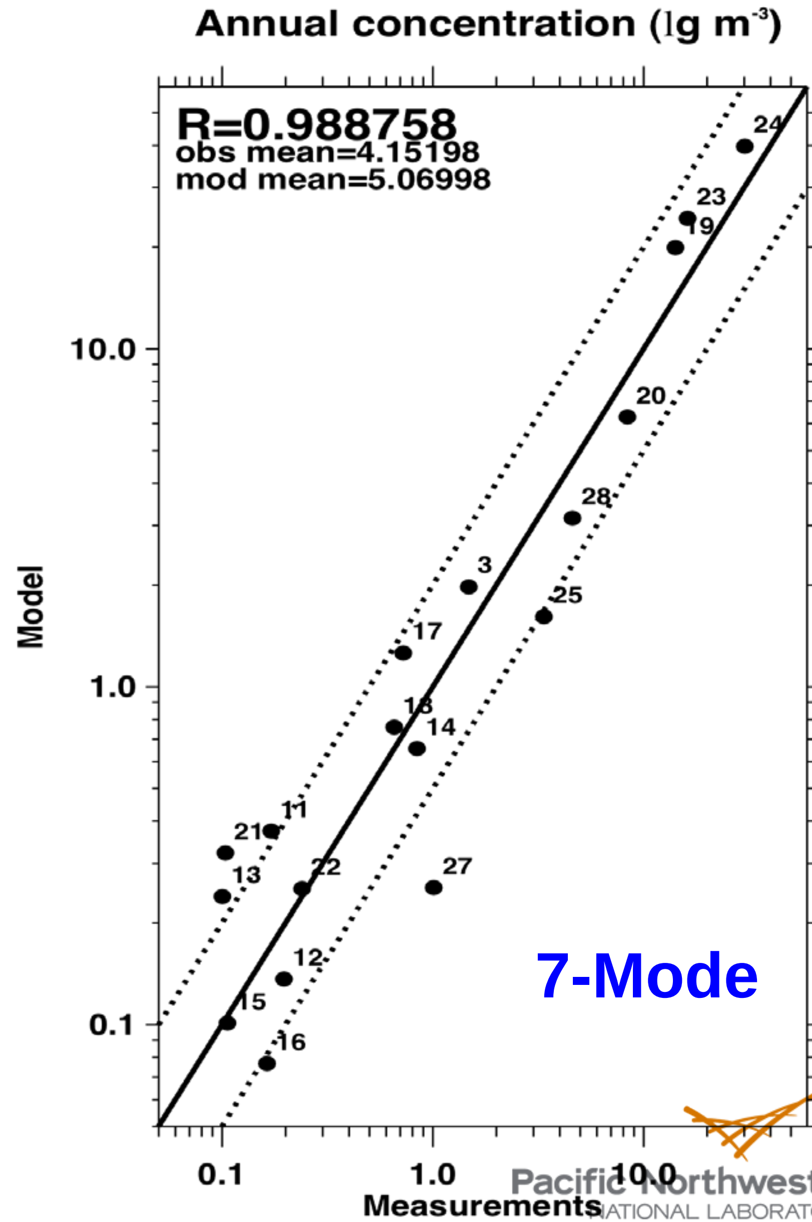


MAM3 - Compared with RSMAS SO4 Data

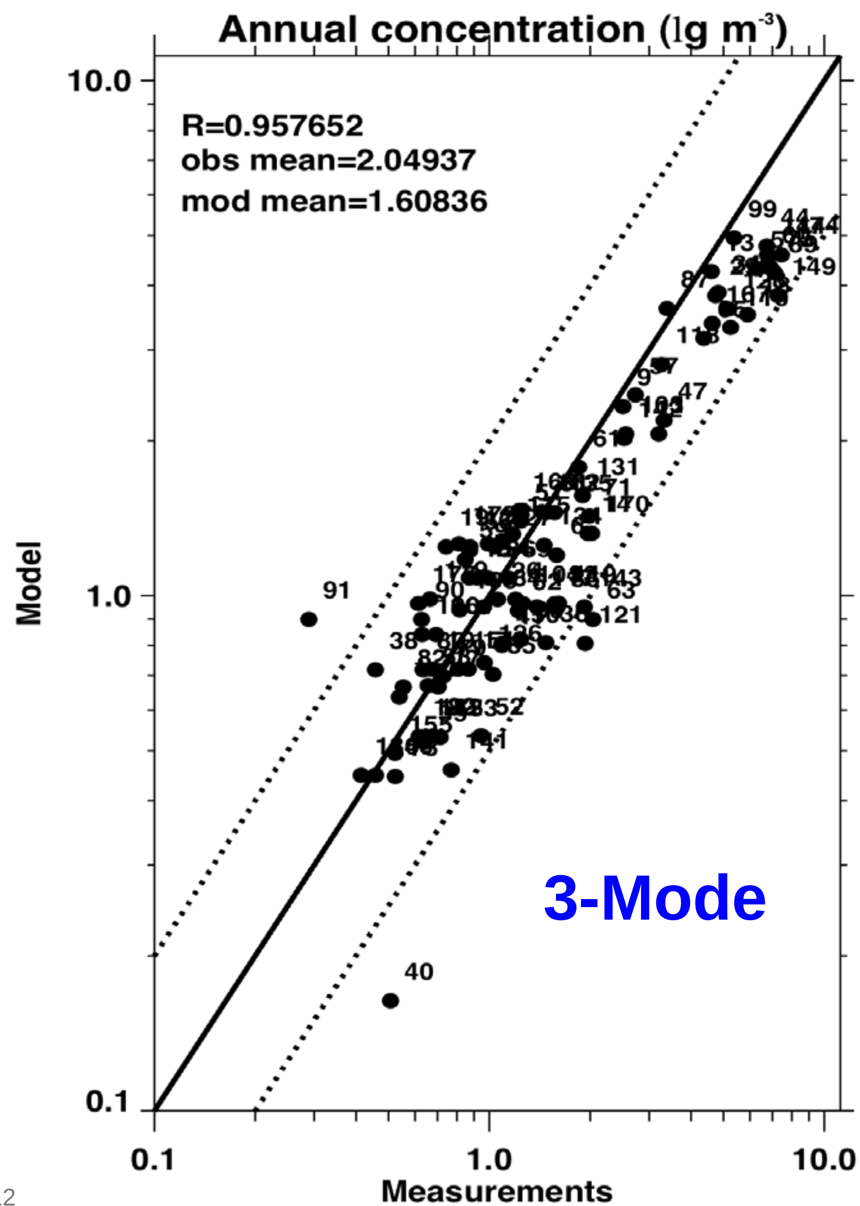


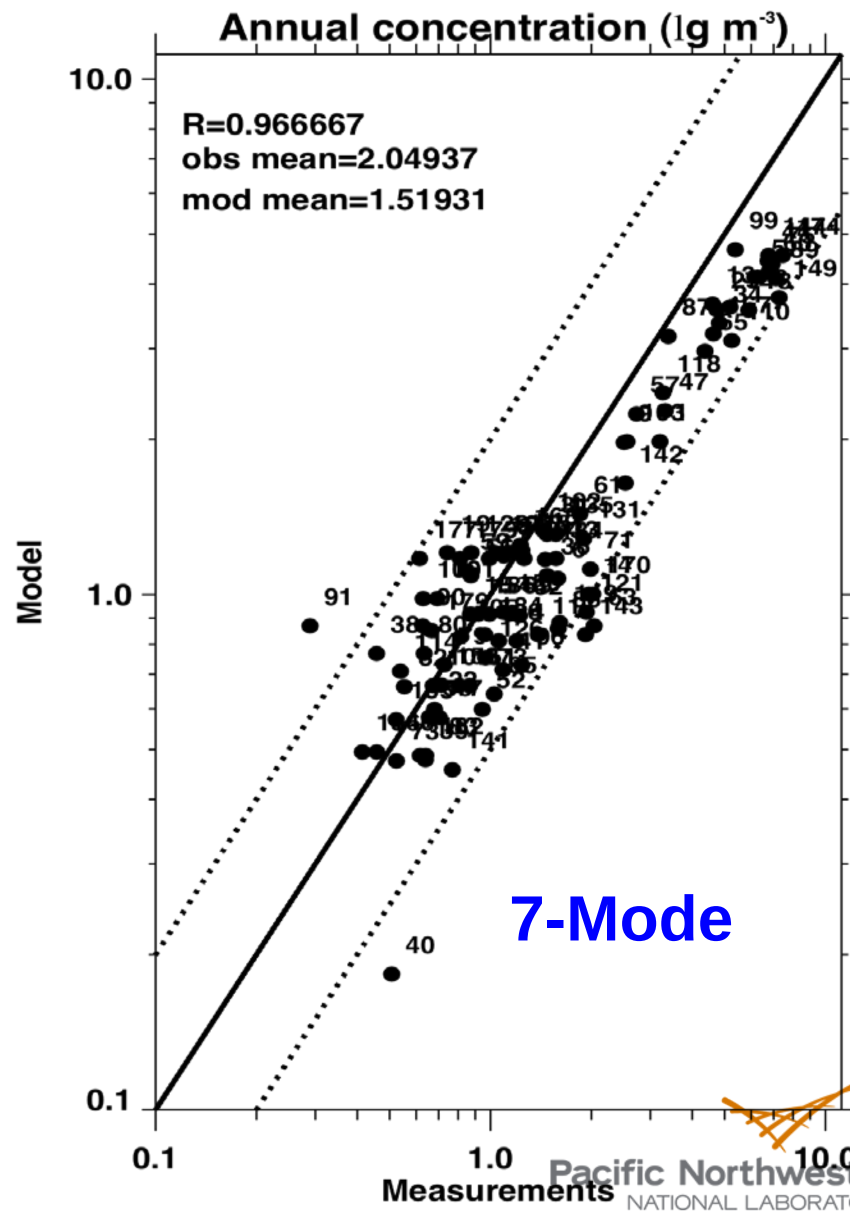
Dust compared with RSMAS data



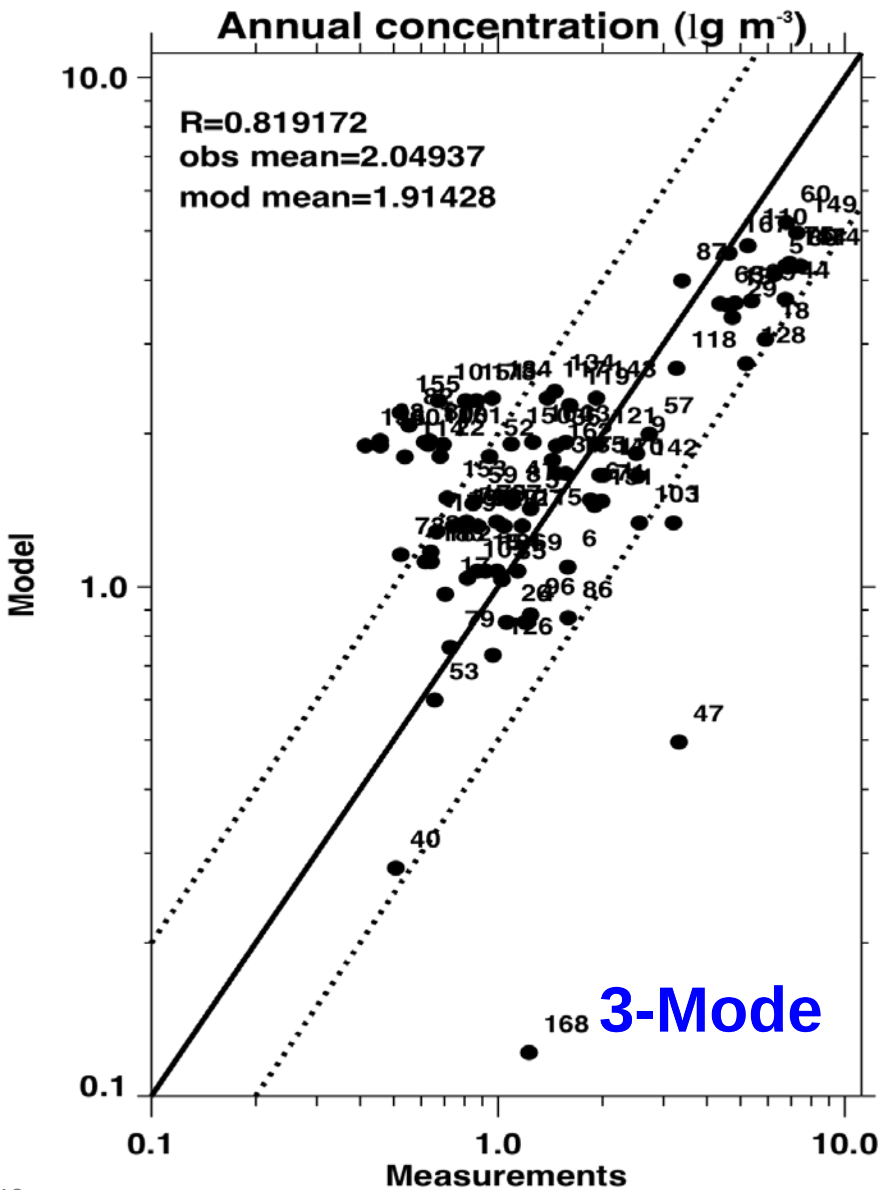


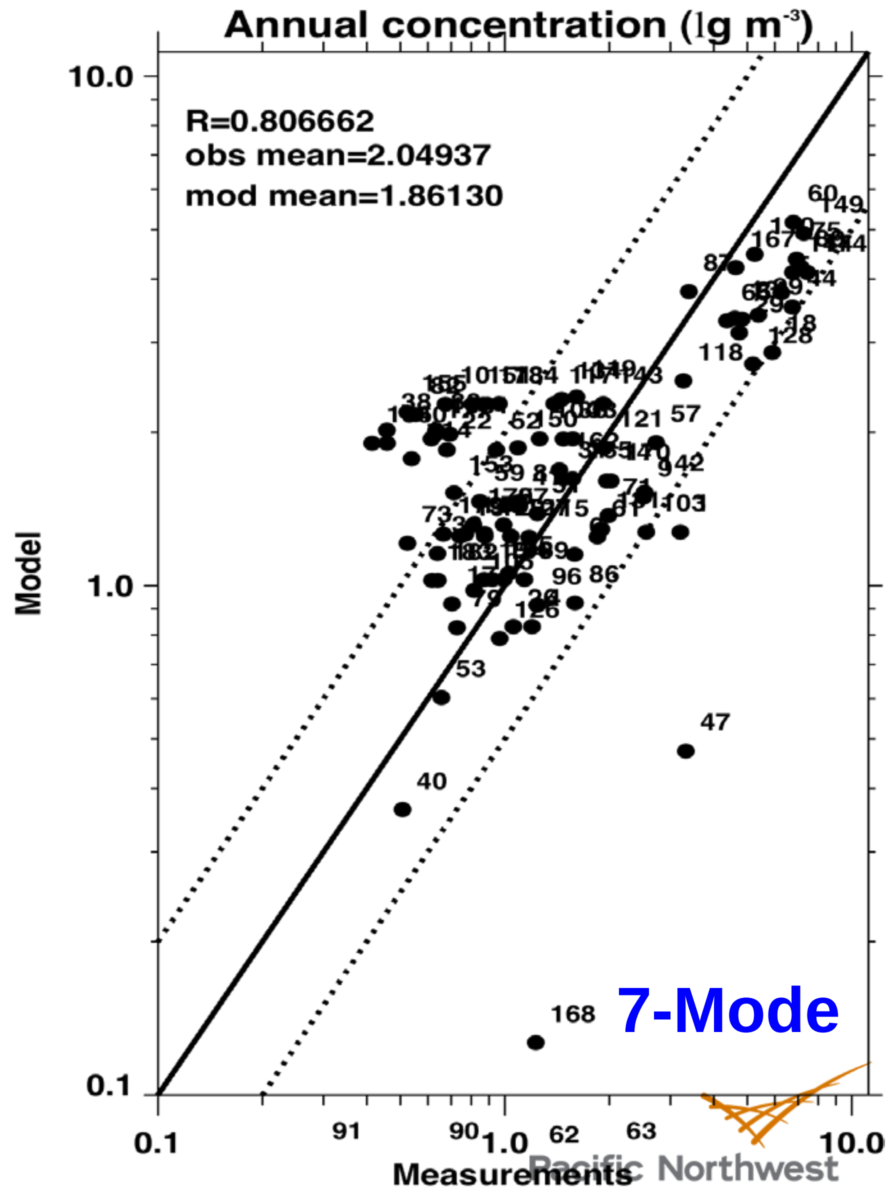
SO_4 compared with IMPROVE data



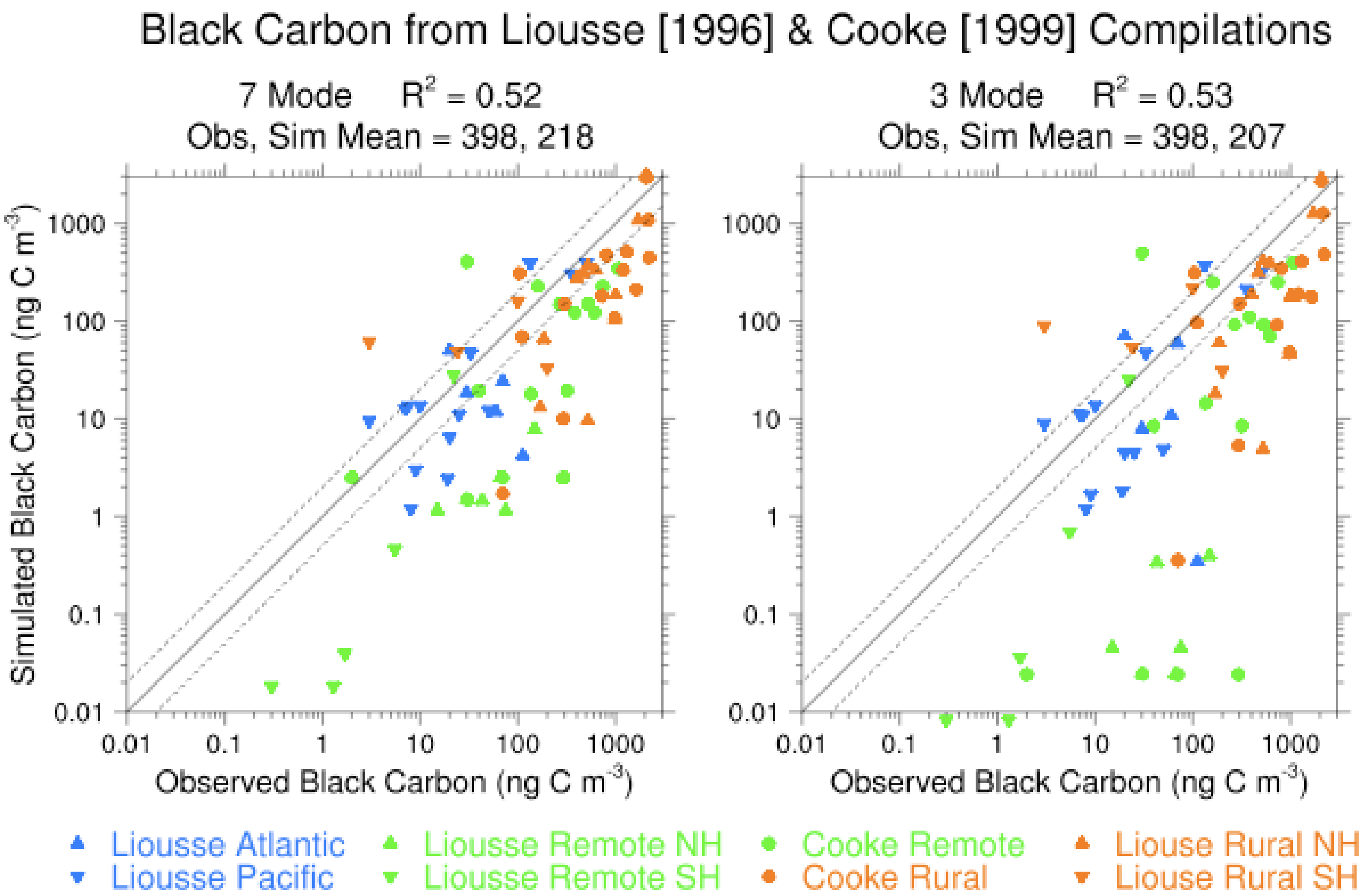


OC compared with IMPROVE data





BC compared with global data



7-Mode **3-Mode**

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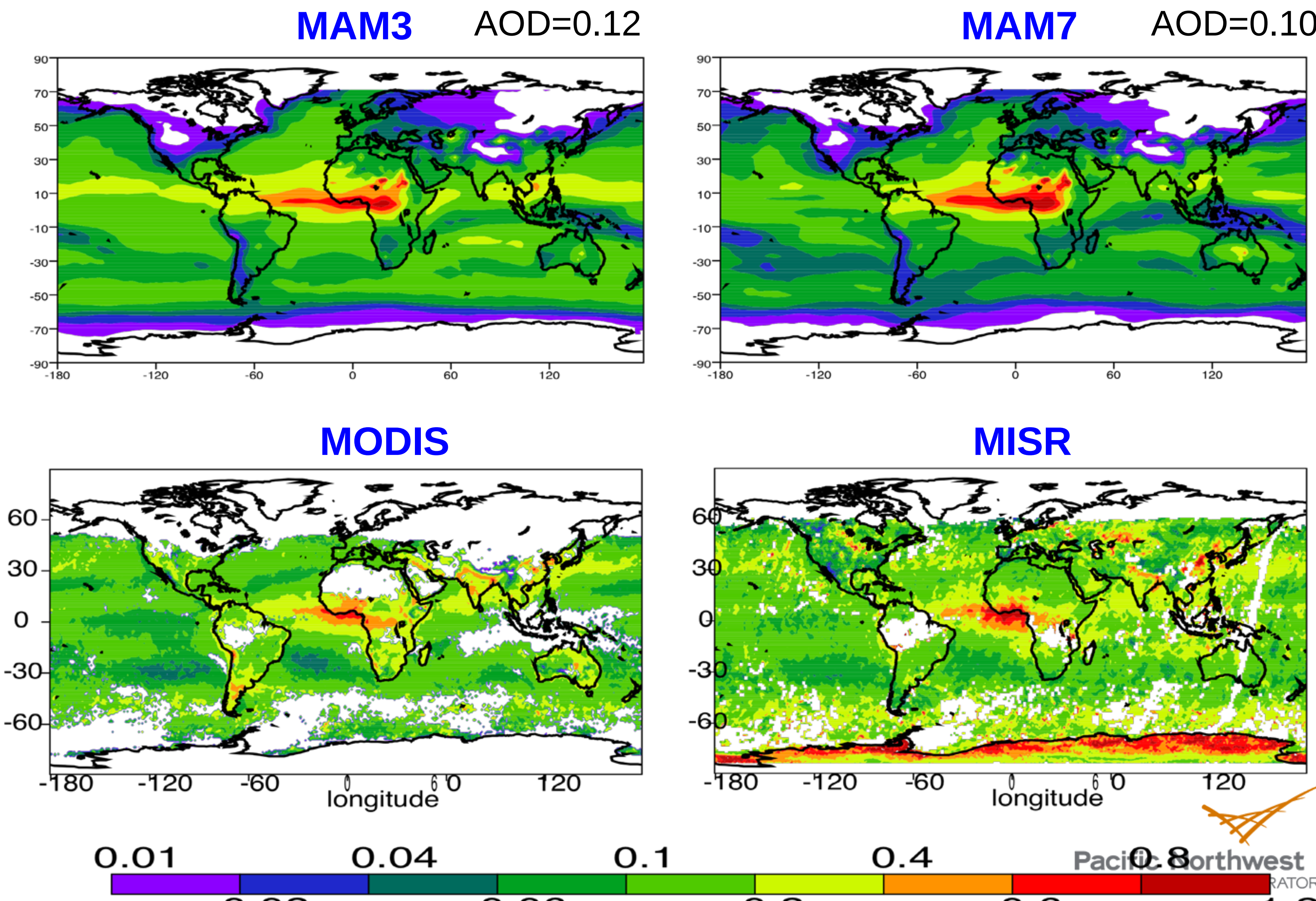
Aerosol Optical Depth - January



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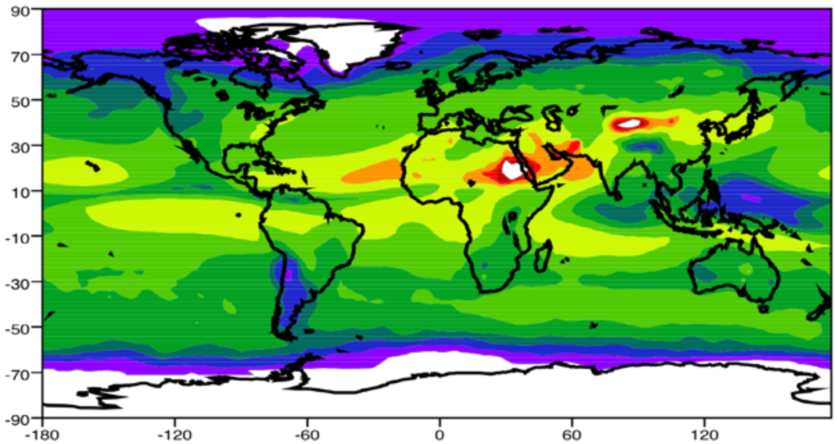
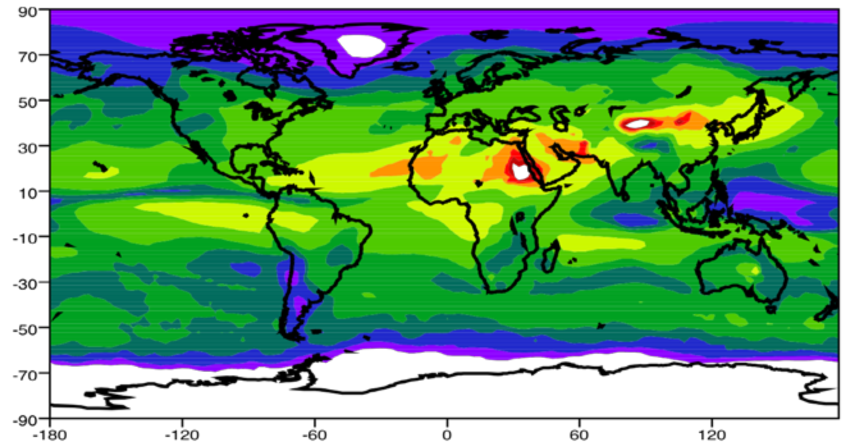
Aerosol Optical Depth - July

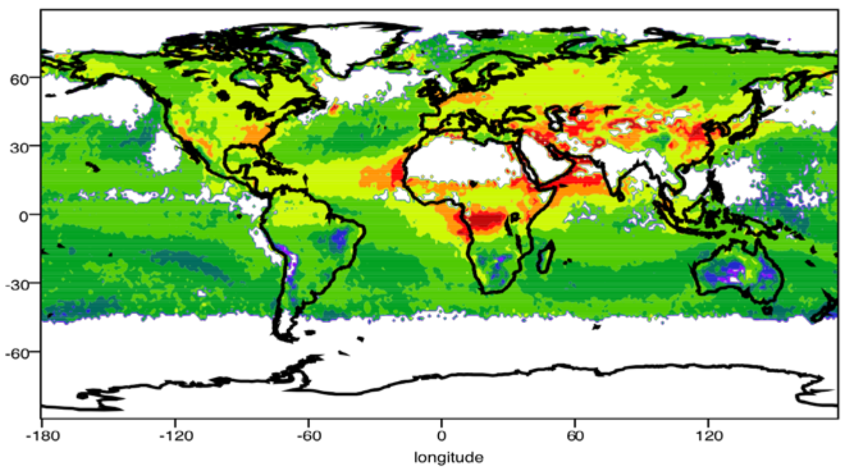
MAM3 AOD=0.13



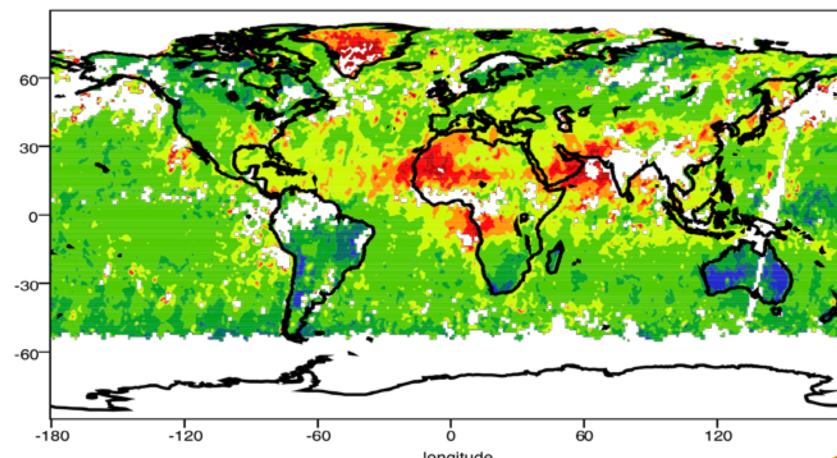
MAM7 AOD=0.11



MODIS



MISR



Anthropogenic Indirect Effect

- Aerosol effects on liquid and ice clouds
- Reformulate droplet activation: modify Abdul-Razzak and Ghan to have droplet activation in cloud layers by assuming a cloud lifetime of 3 hours
- And/or add low bound on CNDC (10 cm^{-3} or 20 cm^{-3})

Ice Nucleation

- Allow ice super-saturation
  - Ice does not form at RHi = 100% (super-sat required)
  - Ice nuclei (IN) can change the super-saturation
- Add ice nucleation link to aerosol (Liu et al 2007)
  - Homogenous & heterogeneous nucleation
    - Dust, sulfate. black carbon (soot) turned off
  - Competition between homogenous & heterogeneous nucleation
  - More IN -> Freezing at lower super-saturation -> Some crystals form earlier -> FEWER crystals

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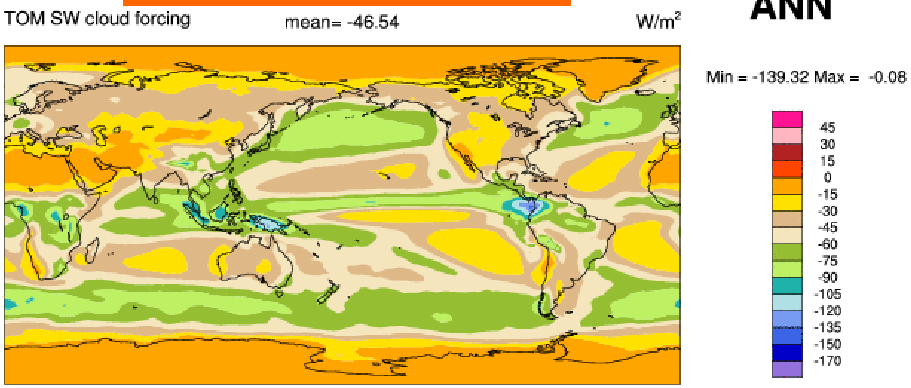
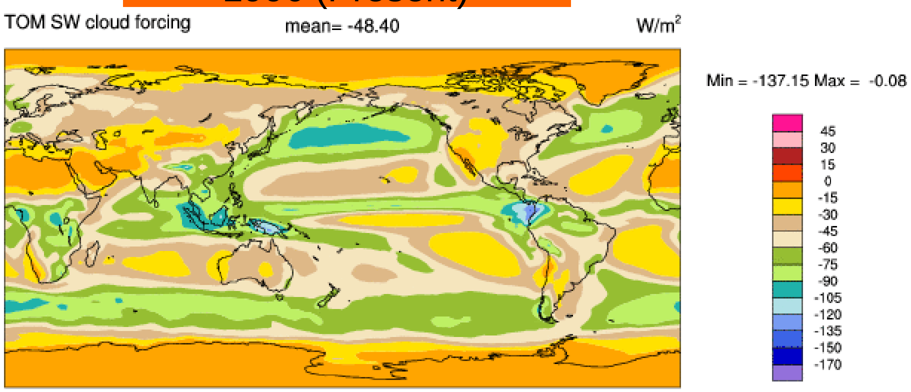
Experiment Description	Num	AIE
Base	u33	AIE = -2.2 W/m2 d(SWCF) (pd-pi) = -3.2, d(LWCF) = 1.0, d(FSNTC) = -0.44, d(LWP) = 4.9
Min CDNC = 20/cm3	u34	AIE = -2.0 W/m2 d(SWCF) (pd-pi) = -2.8, d(LWCF) = 0.83, d(FSNTC) = -0.3, d(LWP) = 3.8
Modify Drop Activation	u37	AIE = -1.4 W/m2 d(SWCF) (pd-pi) = -2.3, d(LWCF) = 0.86, d(FSNTC) = -0.36, d(LWP) = 3.2
Coupled model tuning	u49	AIE = -1.6W/m2 d(SWCF) (pd-pi) =-2.4 , d(LWCF) =0.8 , d(FSNTC) =-0.35 , d(LWP) = 3.3
IPCC Emissions	u50b	AIE = -1.2W/m2 d(SWCF) (pd-pi) =-1.9 , d(LWCF) =0.7 , d(FSNTC) =-0.6 , d(LWP) = 2.9
Better Ice Cloud Fraction	u60	AIE = -1.0W/m2 d(SWCF) (pd-pi) =-1.36 , d(LWCF) =0.37 , d(FSNTC) =-0.55 , d(LWP) = 2.6
PDF Liquid clouds	u66	AIE = -0.9W/m2 d(SWCF) (pd-pi) =-1.34 , d(LWCF) =0.48 , d(FSNTC) =-0.51 , d(LWP) =2.5
Retune ice nucleation	u67	AIE = -0.6W/m2 d(SWCF) (pd-pi) =-0.87 , d(LWCF) =0.27 , d(FSNTC) =-0.3 , d(LWP) = 2.2
Retune for coupled	u98b	AIE = -0.8W/m2 d(SWCF) (pd-pi) =-1.1 , d(LWCF) =0.3 , d(FSNTC) =- , d(LWP) =
Drop limiter = 10/cm3	u98	AIE = -1.25W/m2 d(SWCF) (pd-pi) =-1.75 , d(LWCF) =0.5 , d(FSNTC) =- , d(LWP) =
Remove Drop Limiter (=0)	u83	AIE = -1.5W/m2 d(SWCF) (pd-pi) =-2.1 , d(LWCF) =0.6 , d(FSNTC) =-0.58 , d(LWP) = 4.3
Latest good coupled run	u110	AIE = -1.3W/m2 d(SWCF) (pd-pi) =-1.8 , d(LWCF) =0.5 , d(FSNTC) =- , d(LWP) =

Aerosol Indirect Effect

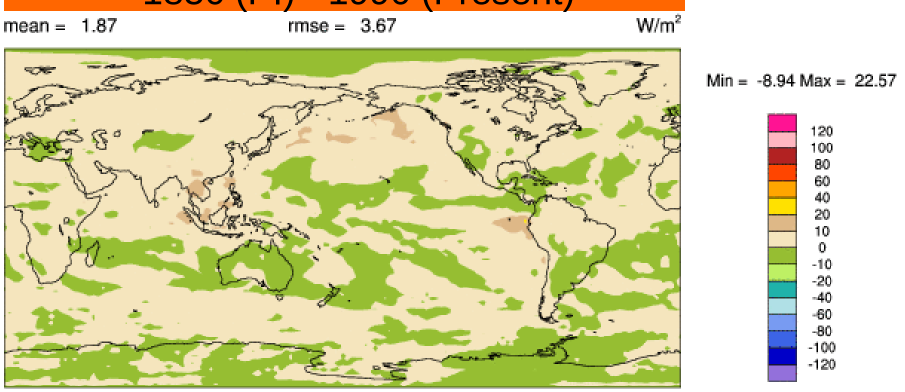
1850 (Pre-Industrial)



1990 (Present)



1850 (PI) - 1990 (Present)



1990-1850:

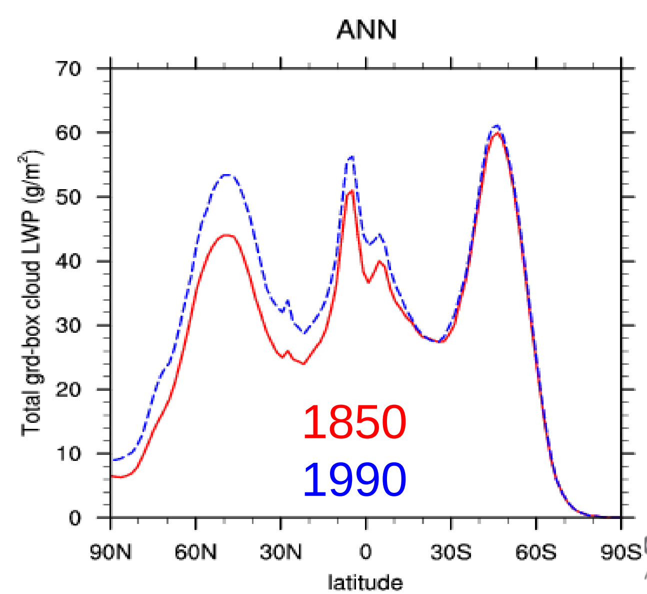
ΔTOA = -1.8 W/m2

AIE = -1.3 W/m2

Δ(SWCF) (pd-pi) =-1.8

Δ(LWCF) = 0.5

Δ(LWP) =+4.0 (g/m2) (10%)



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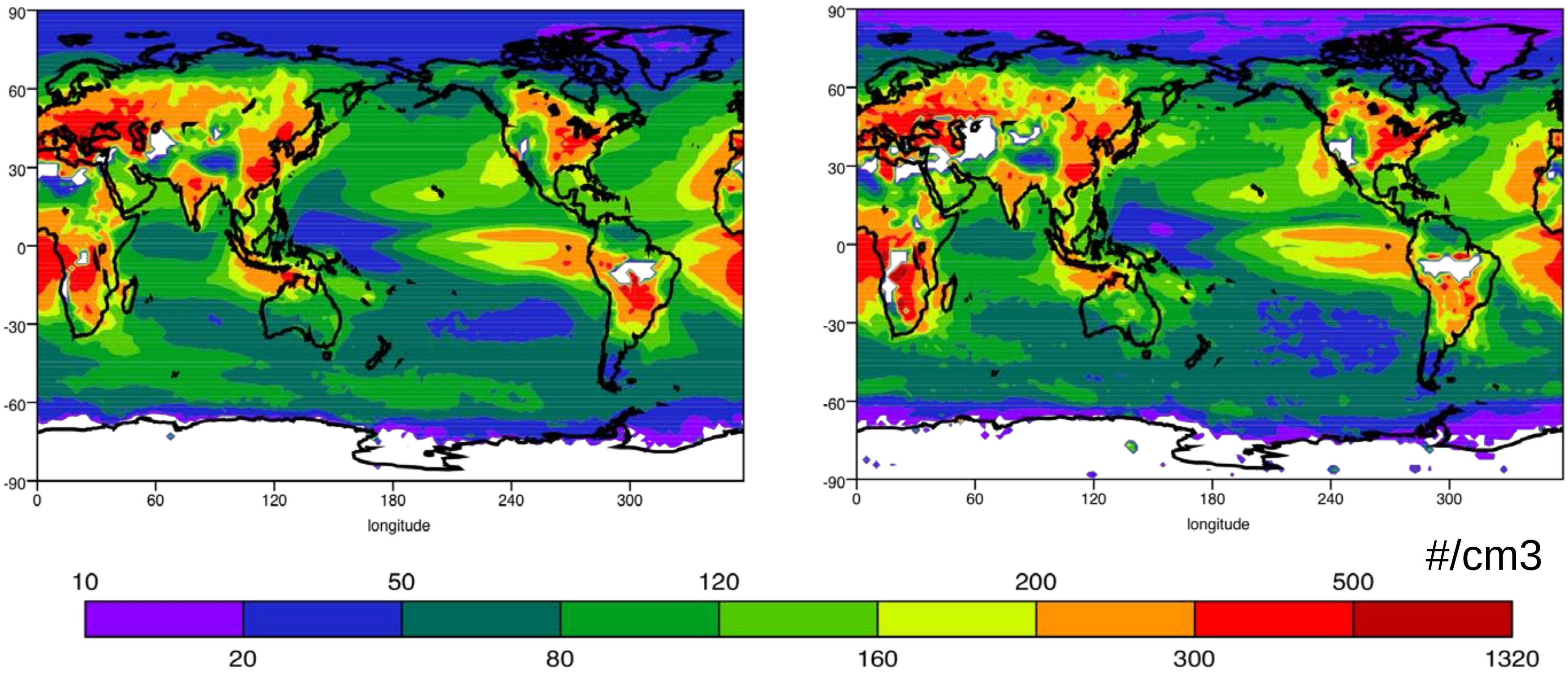
Effects of lower CNDC bound

PD in-cloud droplet number at 936 hPa in JJA



u83
b

u98 (CNDC limiter = 10 /cc)

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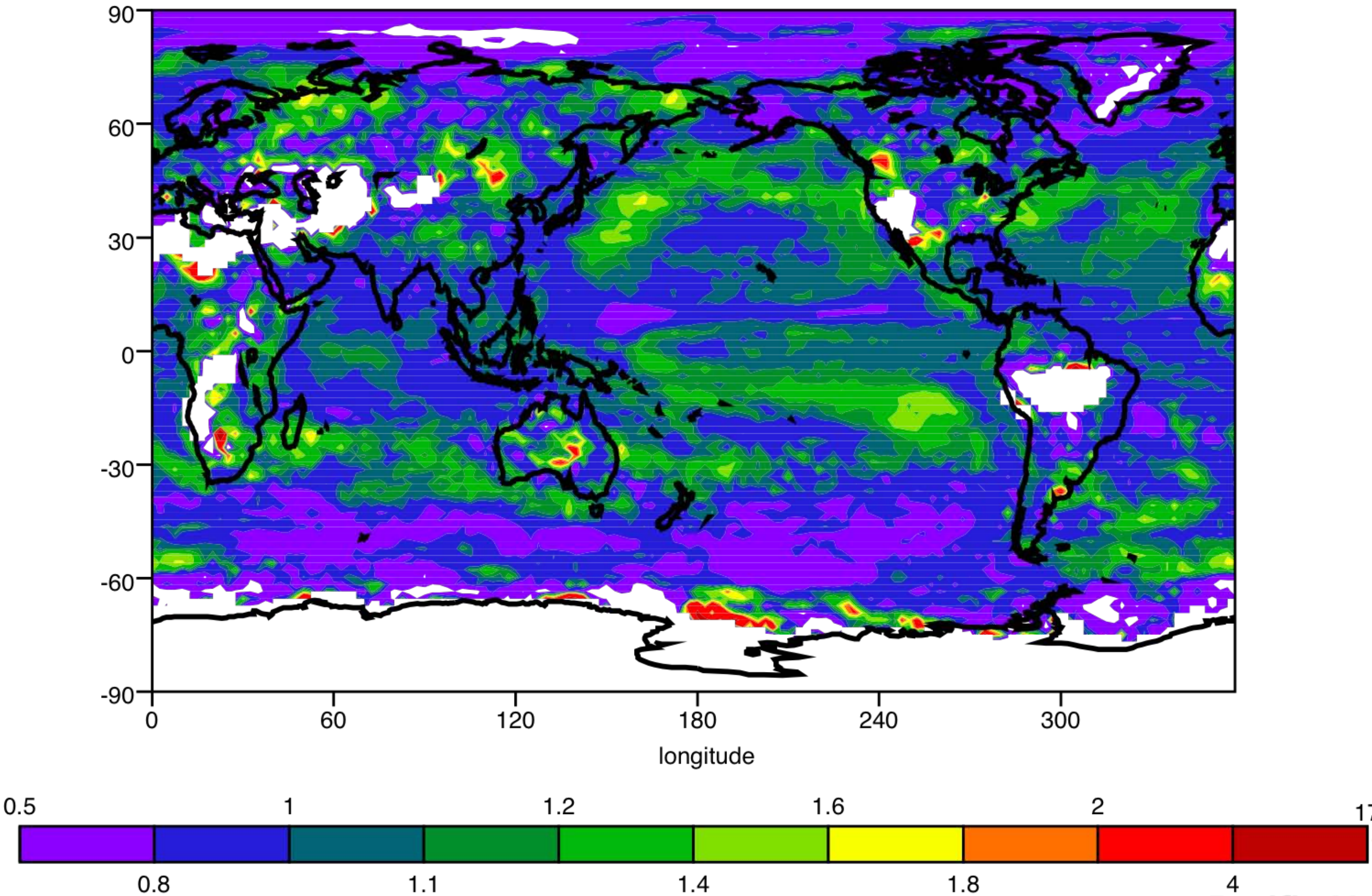
Ratio of PD droplet number, u98/u83b

936 hPa, JJA



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Summary

- MAM has many new physics with only a moderate increase in computer time (~30% compared to prognostic BAM)
- It has a good simulation of aerosol based on evaluation with observations
- SWCF is reasonable after we reformulated droplet activation scheme and/or add low bound on CNDC
- Anthropogenic AIE: -1.0 to -1.5 W/m^2;

  Δ(LWCF) = 0.3-0.8 W/m^2;

  Direct AE: ~0.5 W/m^2

THANKS!

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