Evaluation of Aerosol Properties with GFDL Atmospheric Model, Satellite and Ground-based Data

by

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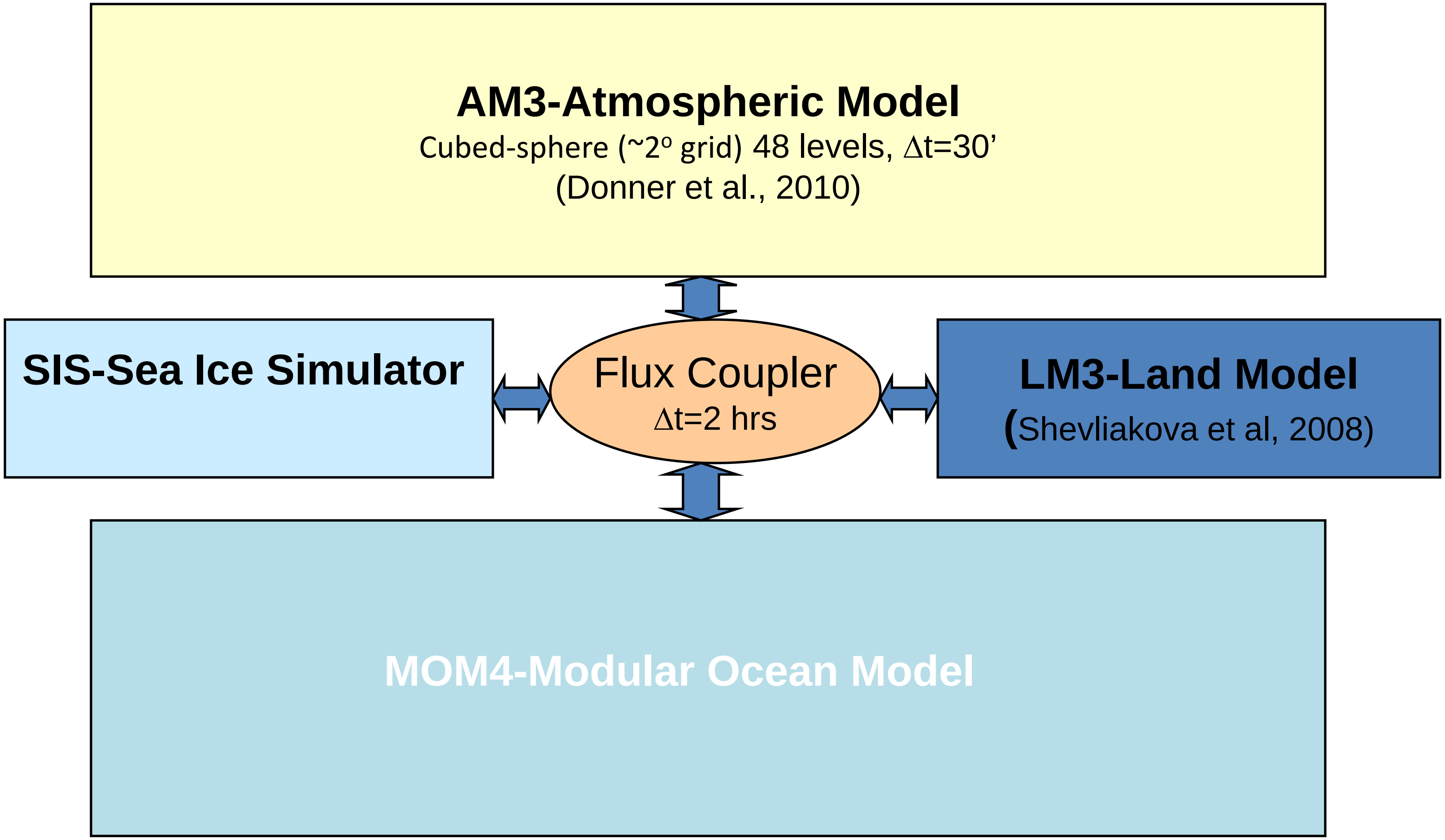
Outline

- GFDL AM3: description of aerosol model
- Global evaluation of aerosol properties
- Analysis of aerosol properties in Midwest
- Conclusions

GFDL Coupled Climate Models



AM3 configurations

1. Fully coupled with ocean model (CM3)
2. Fixed BC: “observed SST”
3. Nudging of u, v, T, p_s: relaxation technique using observed meteorology to force the evolution of transport in the course of time.
   - Advantages:
     - Separate errors associated with dynamics (u, v, p_s), hydrology (q) or thermodynamics variables (T) from chemistry (production/loss) and optical properties
     - Allow direct comparison with observation on daily time scale

GFDL Atmospheric Model AM3

- **Dynamical core:** Finite volume on cubed-sphere grid (~ 2^0 grid, 48 vertical levels) by Putman and Lin (2007)
- **Convective Clouds:** Deep convection scheme of Donner (1993), Shallow convection scheme of University of Washington (Bretherton and Park, 2008).
- **Cloud Droplet Number:** Prognostic equation for cloud droplet number using parameterization of activation (Ming et al. ,2006).
- **Full tropospheric and stratospheric chemistry online** (Horowitz et al., 2003)
- **Aerosol types:** prognostic equation for mass of sulfate (SU), organic carbon (OC), black carbon (BC), dust (DU), and sea-salt (SS). Secondary organic aerosol (SOA) production based on Tie et al. (2005). Sulfate production using full tropospheric chemistry.

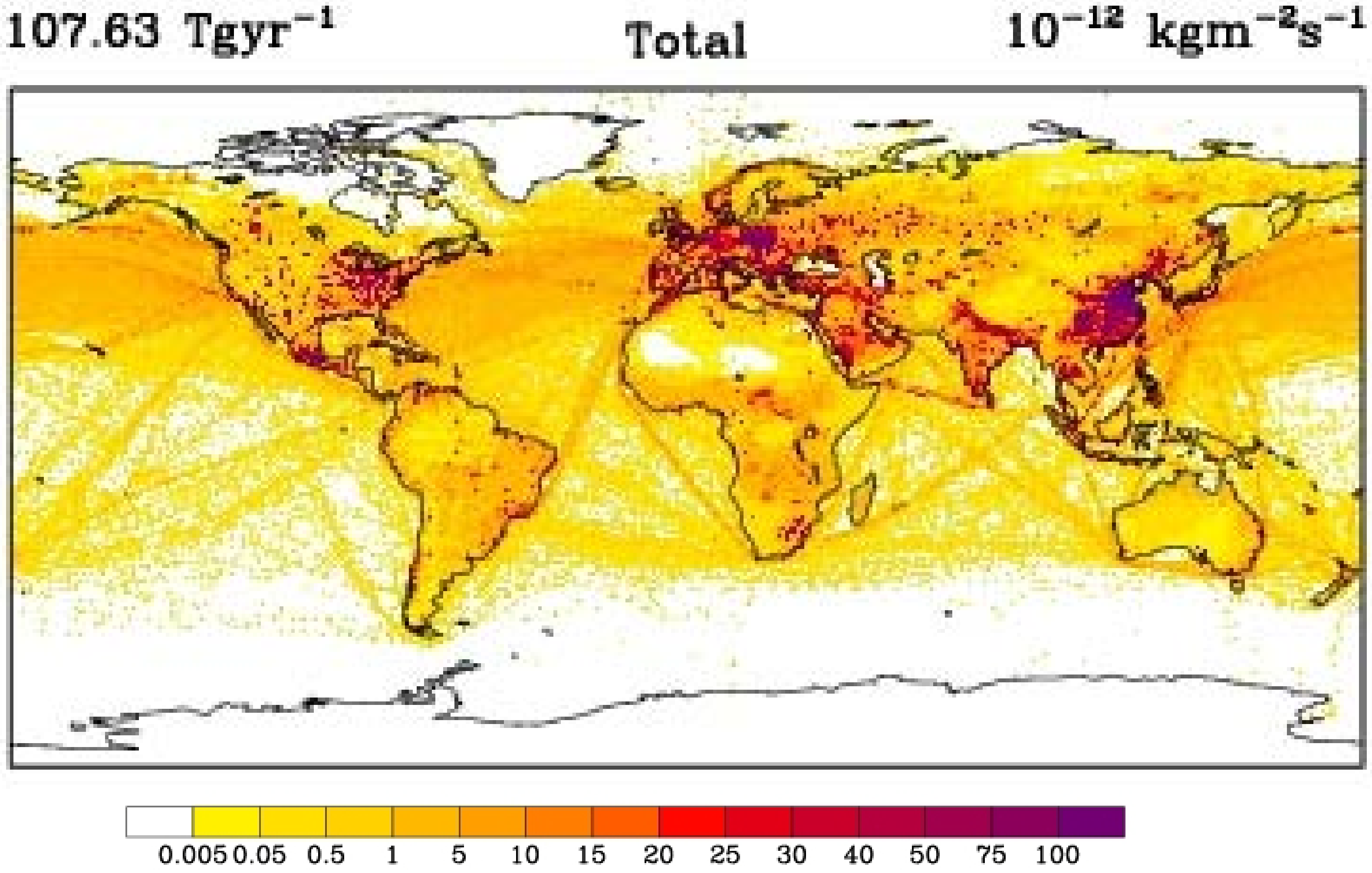
Aerosols in AM3

	Sources	Transport	Sinks
	Depends on w_{10m}	Advection Convection Diffusion	Depends on rain 3D, u_*
Dust	Size = 5 classes 0.1 – 10 mm $\Phi = \alpha\ S\ w_{10m}^3$ α= 10% clay, 90% silt S= topographic lows (Ginoux et al., 2001)		Gravitational settling of dry particle Turbulent deposition Wet removal
Sea salt	Size = 5 classes 0.1 – 10 μm $\Phi = S\ f\ (r, w_{10m}^{3.4})$ of dry particle S=open ocean (Monahan et al., 1986)		Gravitational settling of wet particle Turbulent deposition Wet removal
DMS	Dimethylsulfide (CH3SCH3) $\Phi = S\ f(w_{10m}, S_c)$ (Chin et al., 1998) S=phytoplankton (Kettle, 1999)		Turbulent deposition and Wet removal Oxidation by OH and NO_3
SO2	Anthropogenic + Biomass burning (Lamarque et al., 2010) Continuous volcanic degassing(Andres&Kasgnoc98) Oxidation of DMS by OH and NO_3		Turbulent deposition and Wet removal Oxidation by OH, and H_2O_2 and O_3 in aqueous phase
SO4	Oxidation of SO_2 by OH and Aqueous reaction with H_2O_2 and O_3		Turbulent deposition and Wet removal
H2O2	$HO_2 + HO_2 \rightarrow H_2O_2 + O_2$		Turbulent deposition and Wet removal Aqueous reaction with SO2, Oxidation by OH, Photo-dissociation
BC/OC	Anthropogenic + Biomass burning (Lamarque et al., 2010) Biogenic OC emission: plants (Gunther et al., 1995)+ ocean (O'Dowd et al., 2008) Secondary organics: C_4H_{10} oxidation		Aging (τ_{OC}= 2.88, τ_{BC}=1.44 days) Turbulent deposition Wet removal of hydrophilic OC/BC

Aerosol Properties

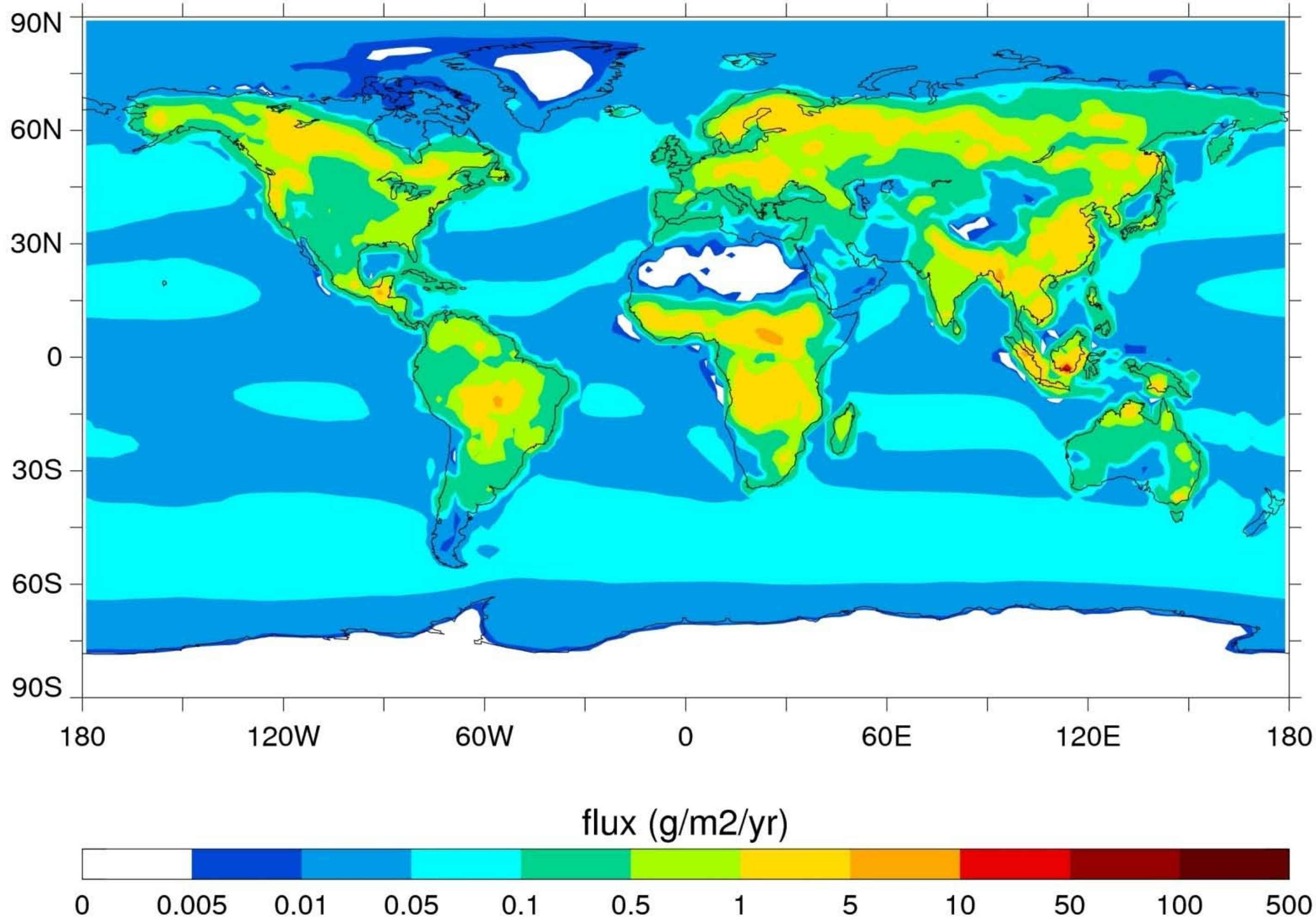
	SU	OC	BC	DU	SS
Size	n=logn(r), r_{geom}=0.05 μm, σ=2	n=Logn(r), r_{geom}=0.085 μm σ=1.5	n=Logn(r), r_{geom}=0.018 μm σ=2	dN/dlnr=a/r^3, 5 bins: 0.1-10 μm	dN/dlnr=a/r^3 5 bins: 0.1-10 μm
Shape	Sphere	Sphere	Sphere	Sphere	Sphere
Growth	Yes, as $(NH_4)_2SO_4$ Tang and Munkelwitz (1994)	Yes for phylic (Ming, 2004) No for phobic	No	No	Yes as mixture of salts
Composition	Mixture with NH_3	Mixture of acids (Ming et al., 2005); Aging	Elemental carbon Aging	Alumino-silicate, mostly illte+2.7% hematite	Mixture of salts Tang et al., 1997
Refractive index	Tang and Munkelwitz (1994)	Hess et al. (1999)	WCP (1986)	SW: Balkanski et al., 2007 LW: Volz,1973	Tang et al., 1997
Mixing	Internal with BC (volume weighted)	external	Internal with sulfate	external	external
Density (dry) kg/m^3	1769	1800	1000	Clay: 2500 Silt: 2650	2160

SO_2 annual mean emission (2000)



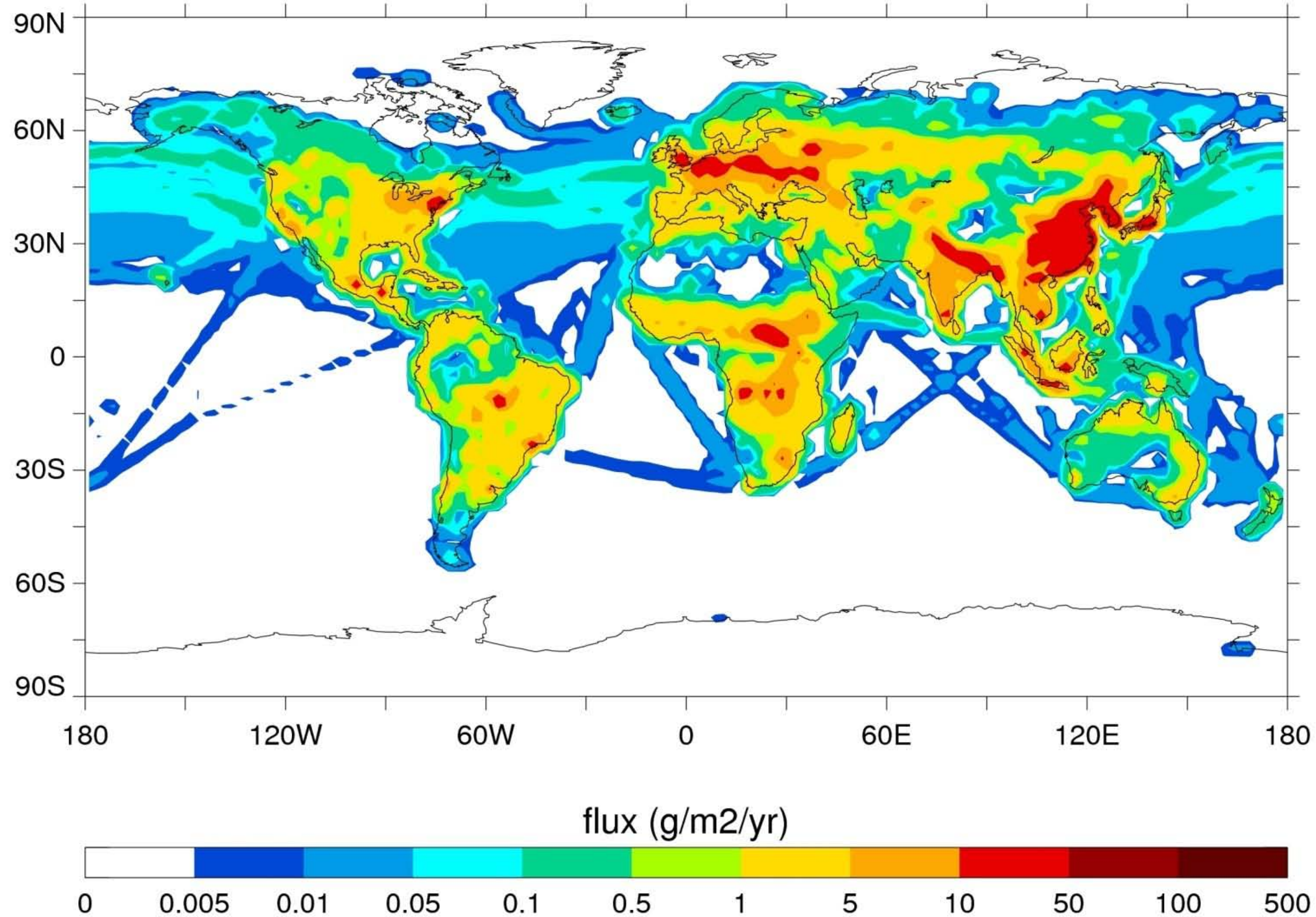
Lamarque et al., 2010

OM annual mean emission (1990-2000)



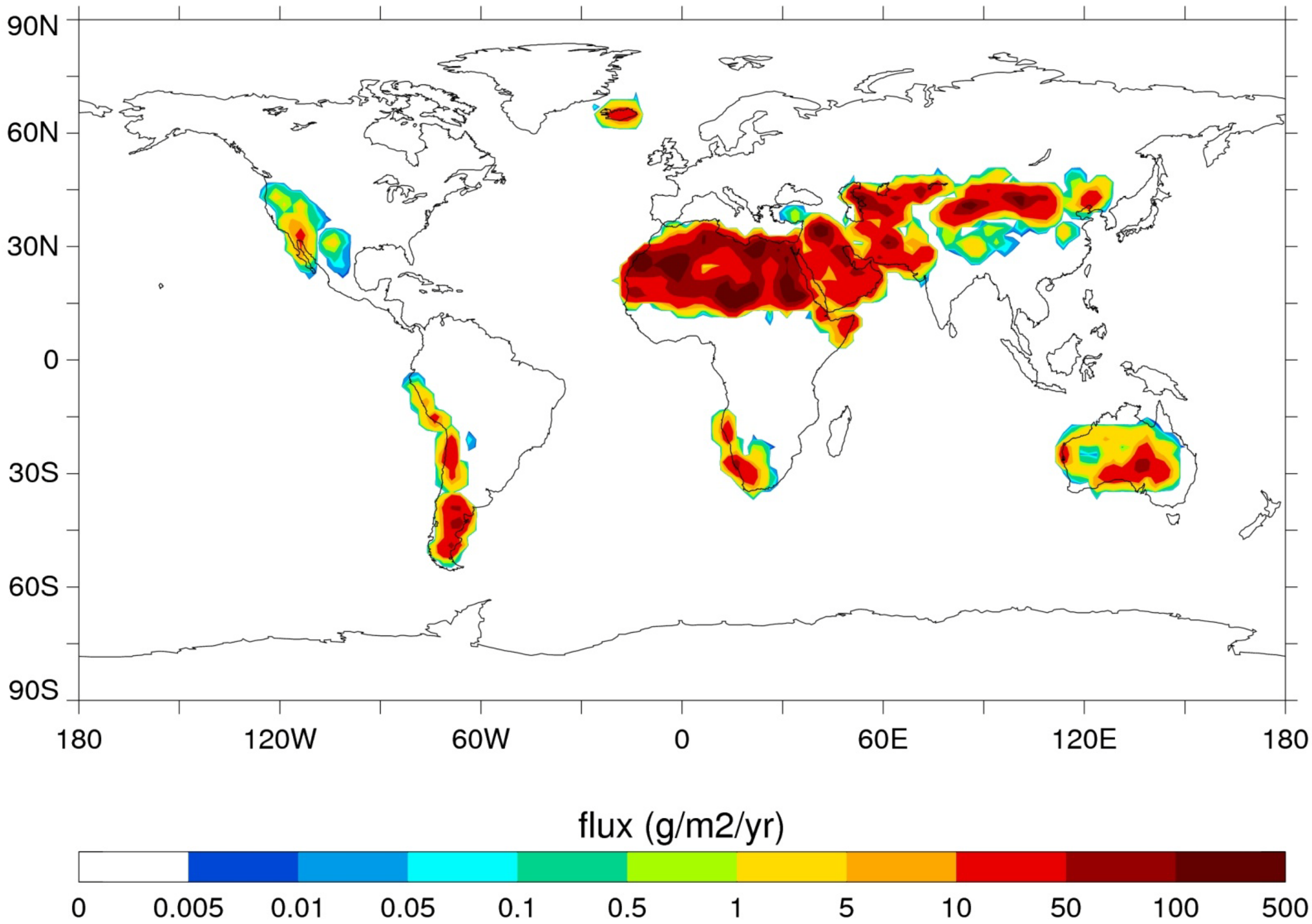
Anthro: Lamarque et al., 2010

BC annual mean emission (1990-2000)



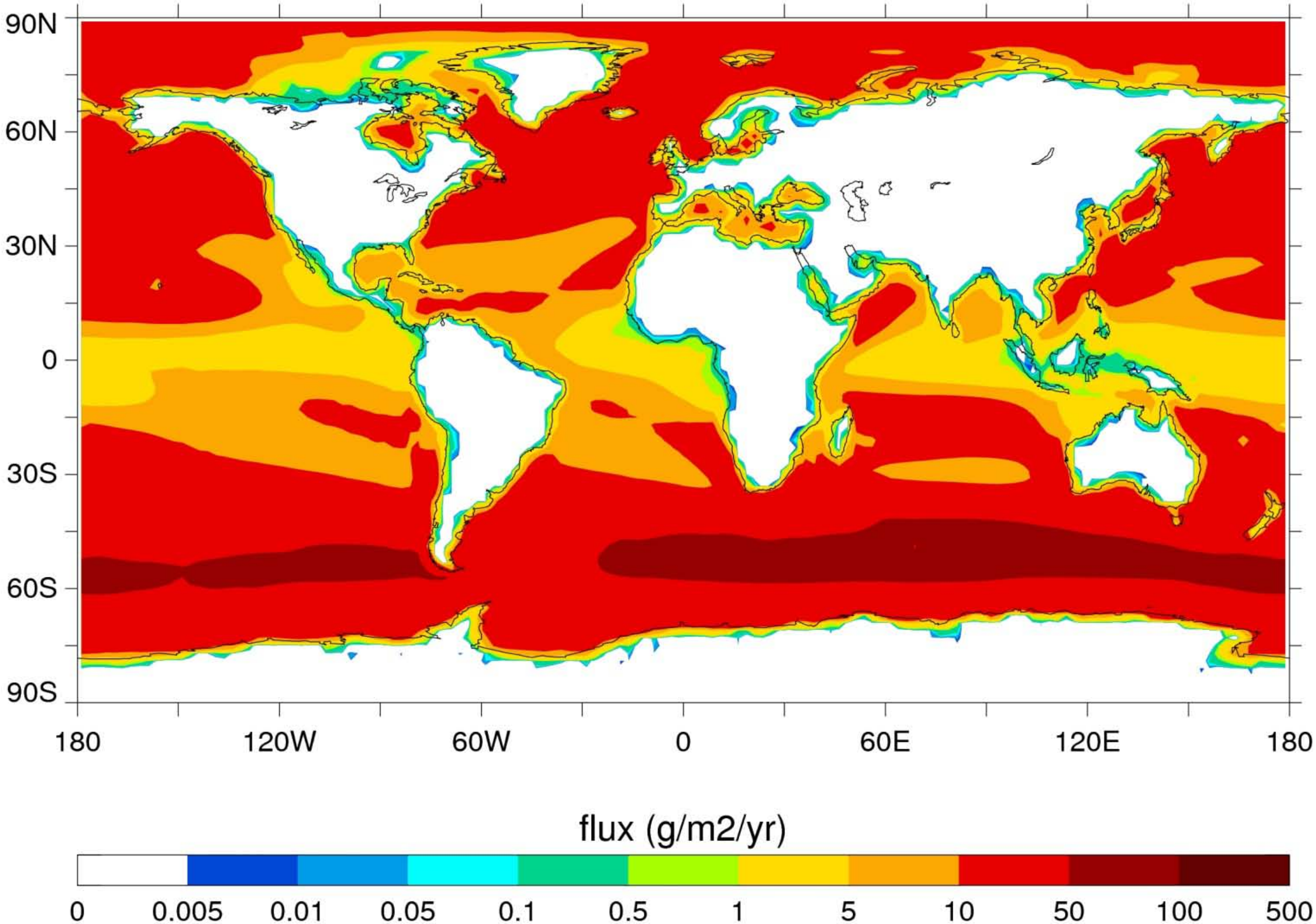
Lamarque et al., 2010

Dust annual mean emission (1990-2000)



Ginoux et al., 2001

Sea-salt annual mean emission
(1990-2000)



Monahan et al., 1986

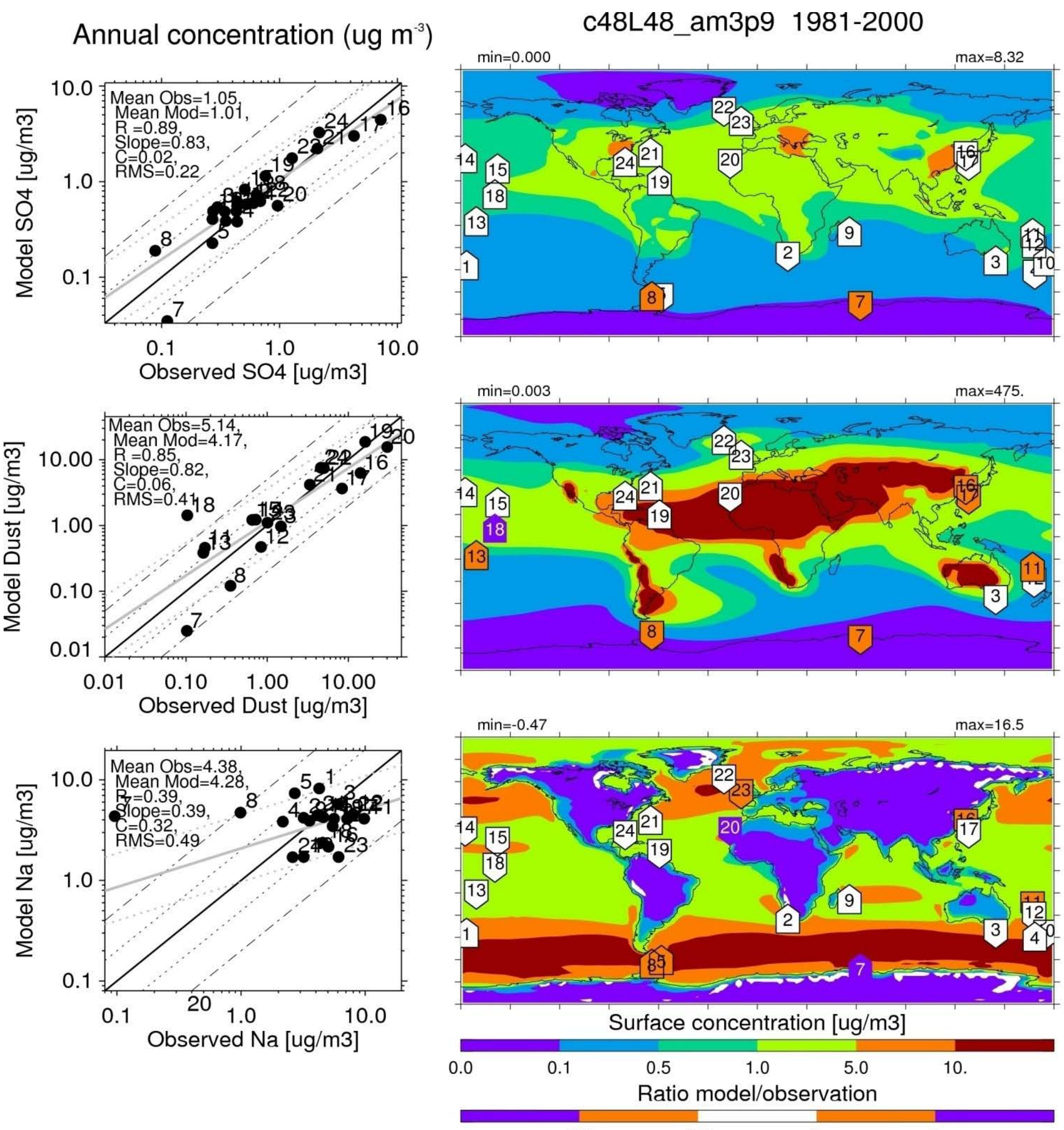
Global annual mean emission (1990-2000) [Tg/year]

Species	anthro	biobur	biog	ocean	soil	volc	ships	aircraft	total
SO2	113	1.7	0	0	0	7.3	11.1	0.1	133.2
OM	20+11*	35.9	31.5	22	0	0	0.18	0	98.6
BC	4.9	2.6	0	0	0	0	0.1	0.005	7.6
Sea-salt	0	0	0	6445	0	0	0	0	6445
Dust	0	0	0	0	1324	0	0	0	1324

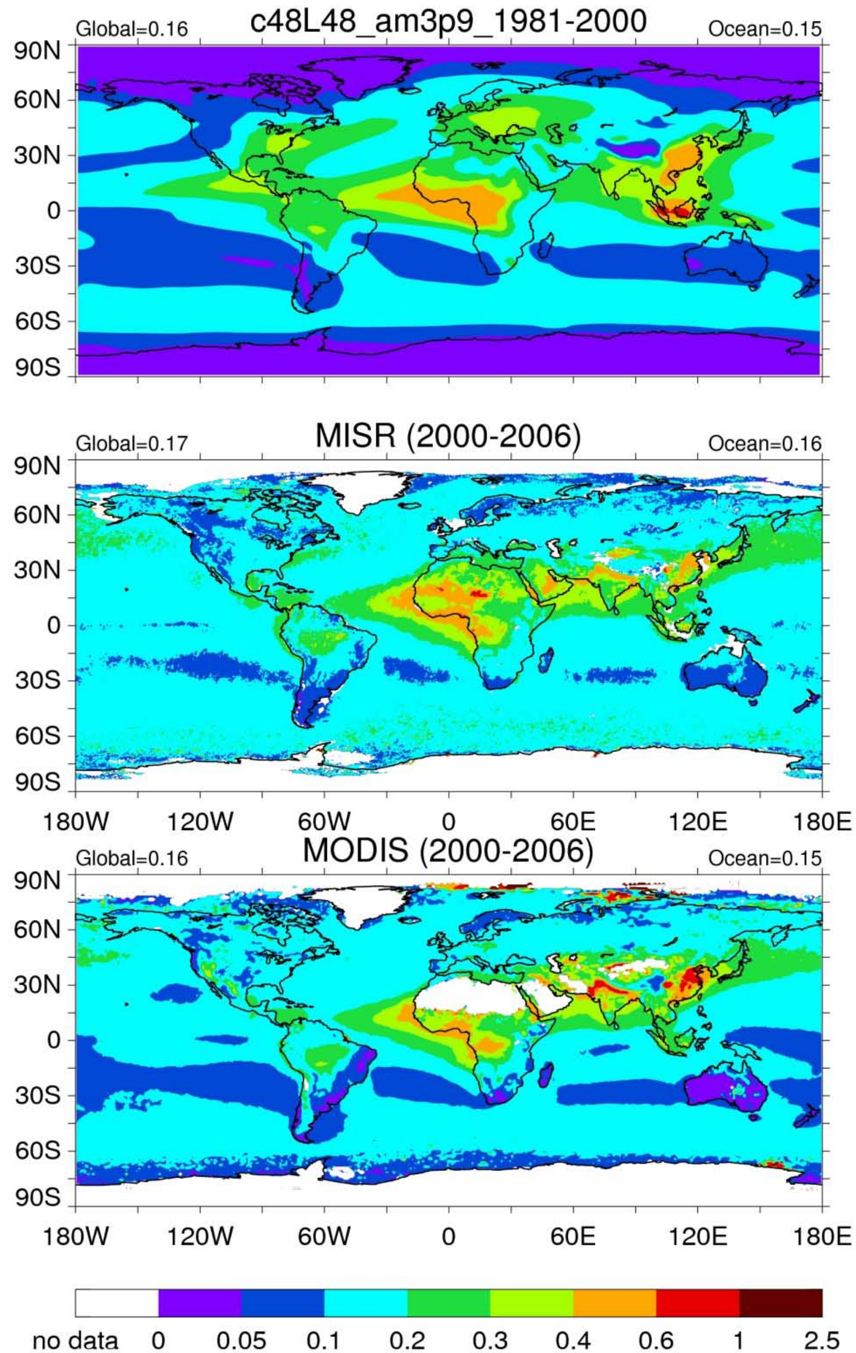
* *Production of secondary organics*

II. Global scale evaluation

- Surface concentration: U. of Miami data (Savoie and Prospero, 2001)
- Aerosol optical depth:
  - MODIS (Levy et al., 2005) and MISR (Khan et al., 2005)
  - AERONET sunphotometers (Holben et al., 1999)
- Aerosol co-albedo: AERONET retrieval (Dubovik et al., 2002)
- Aerosol extinction profile: MPLNet (Welton et al., 2001)

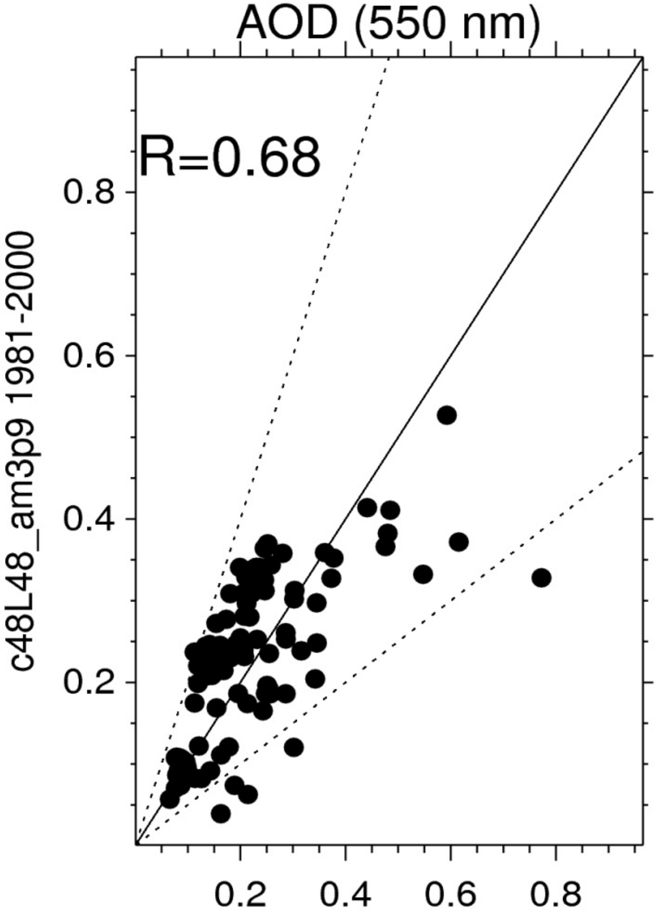


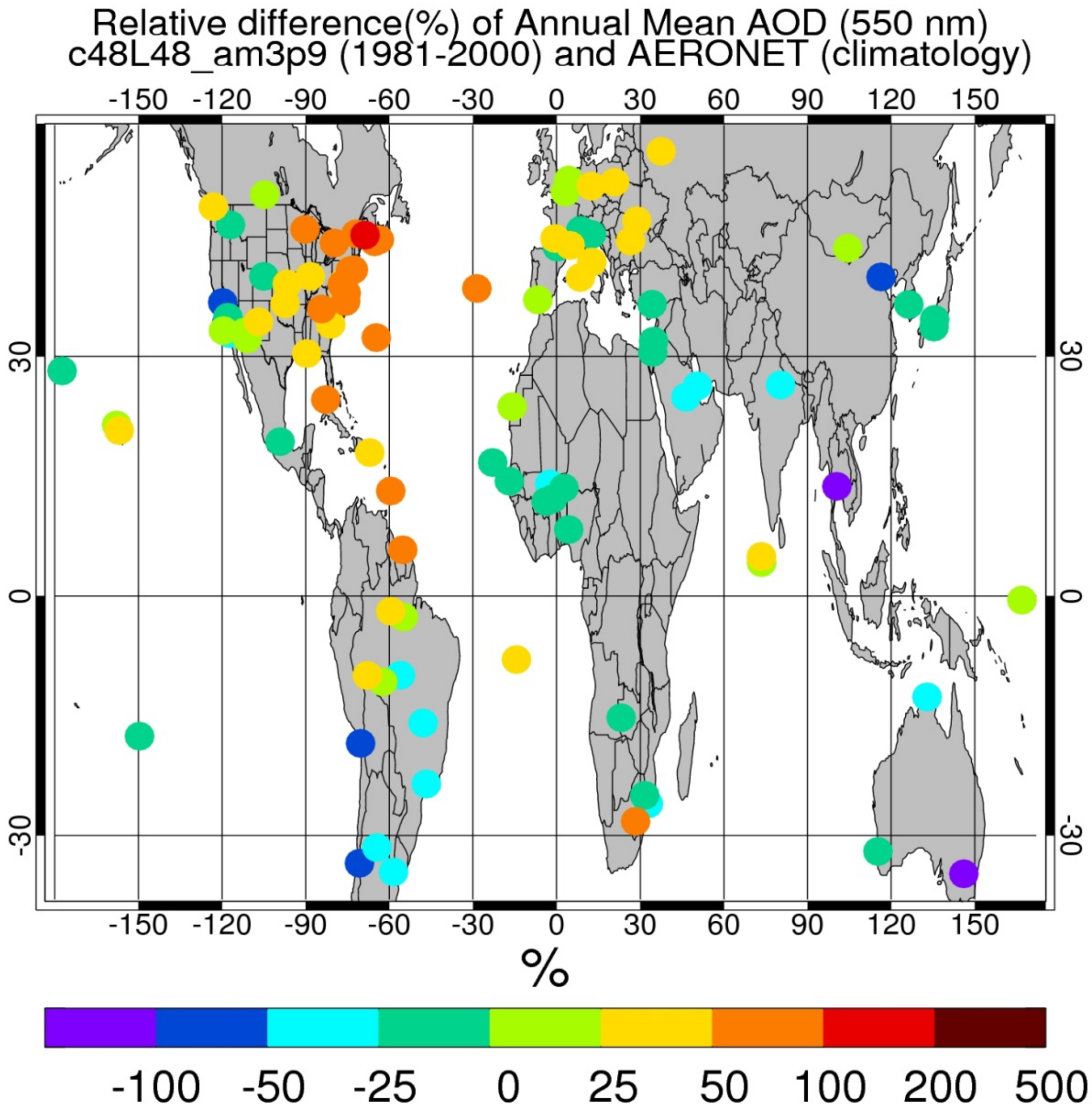
Annual concentration (ug m-3)
c48L48_am3p9 1981-2000
Mean Obs=1.05,
Mean Mod=1.01,
R =0.89,
Slope=0.83,
C=0.02,
RMS=0.22
Model SO4 [ug/m3]
Observed SO4 [ug/m3]
min=0.000
max=8.32
Mean Obs=5.14,
Mean Mod=4.17,
R =0.85,
Slope=0.82,
C=0.06,
RMS=0.41
Model Dust [ug/m3]
Observed Dust [ug/m3]
min=0.003
max=475.
Mean Obs=4.38,
Mean Mod=4.28,
R =0.39,
Slope=0.39,
C=0.32,
RMS=0.49
Model Na [ug/m3]
Observed Na [ug/m3]
min=-0.47
max=16.5
Surface concentration [ug/m3]
0.0 0.1 0.5 1.0 5.0 10.
Ratio model/observation
0.2 0.5 2 5



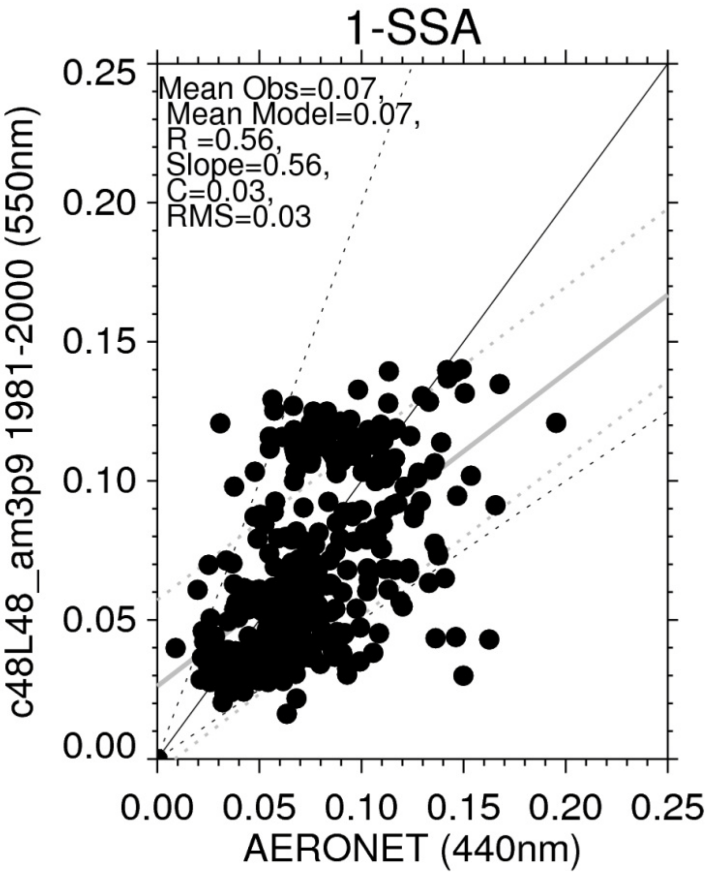
c48L48_am3p9_1981-2000
Global=0.16
Ocean=0.15
MISR (2000-2006)
Global=0.17
Ocean=0.16
MODIS (2000-2006)
Global=0.16
Ocean=0.15
90N
60N
30N
0
30S
60S
90S
180W
120W
60W
0
60E
120E
180E
no data
0
0.05
0.1
0.2
0.3
0.4
0.6
1
2.5

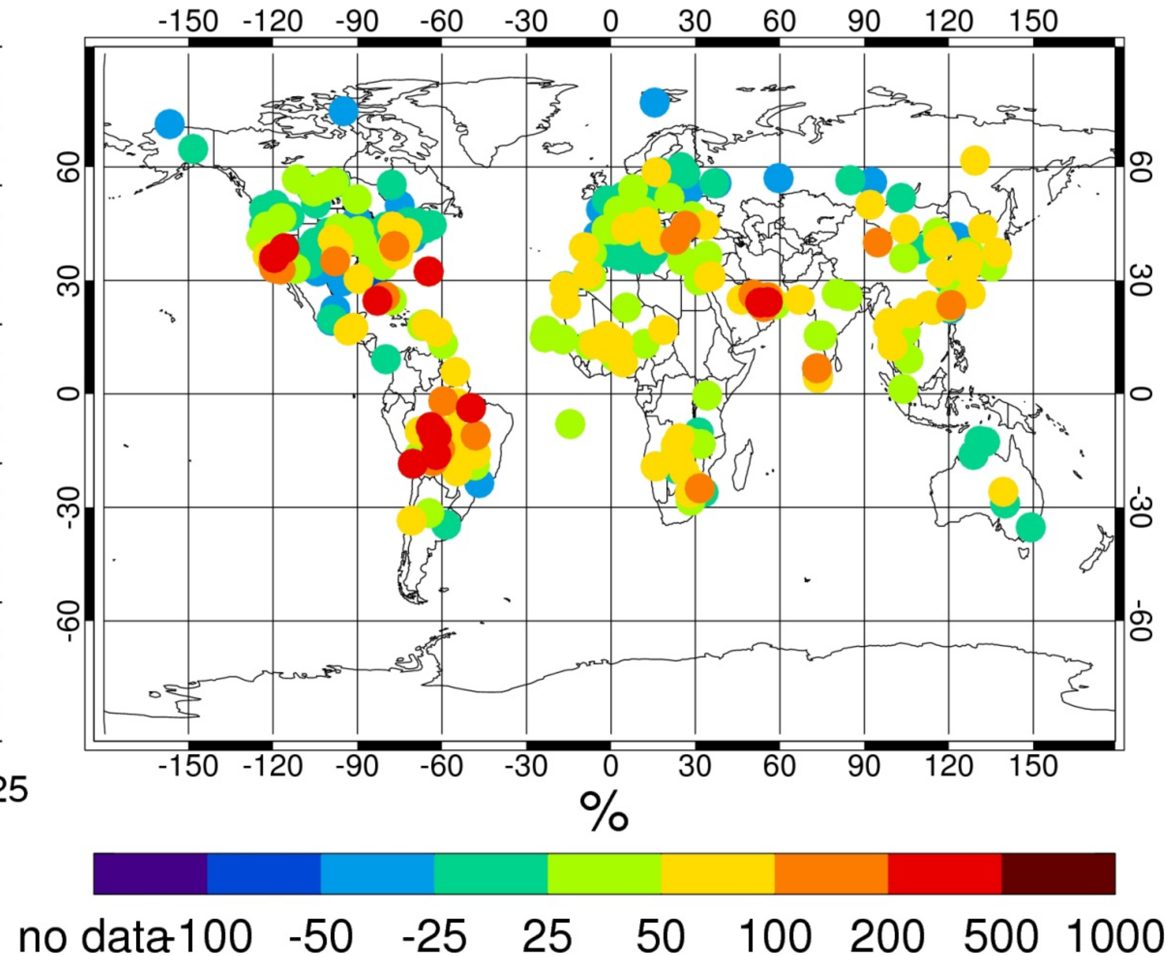
AERONET AOD (550nm)



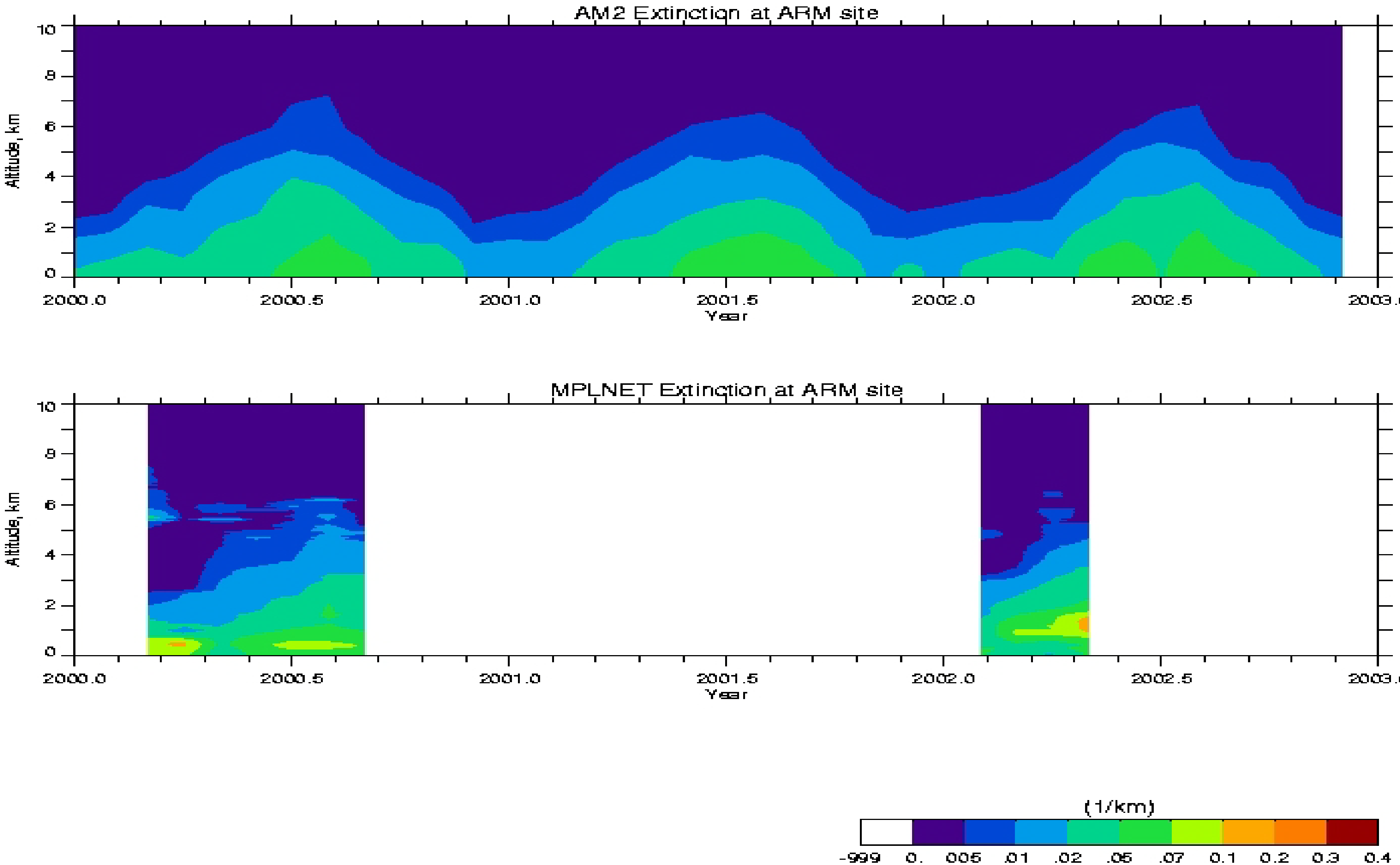


AERONET co-albedo (440nm)



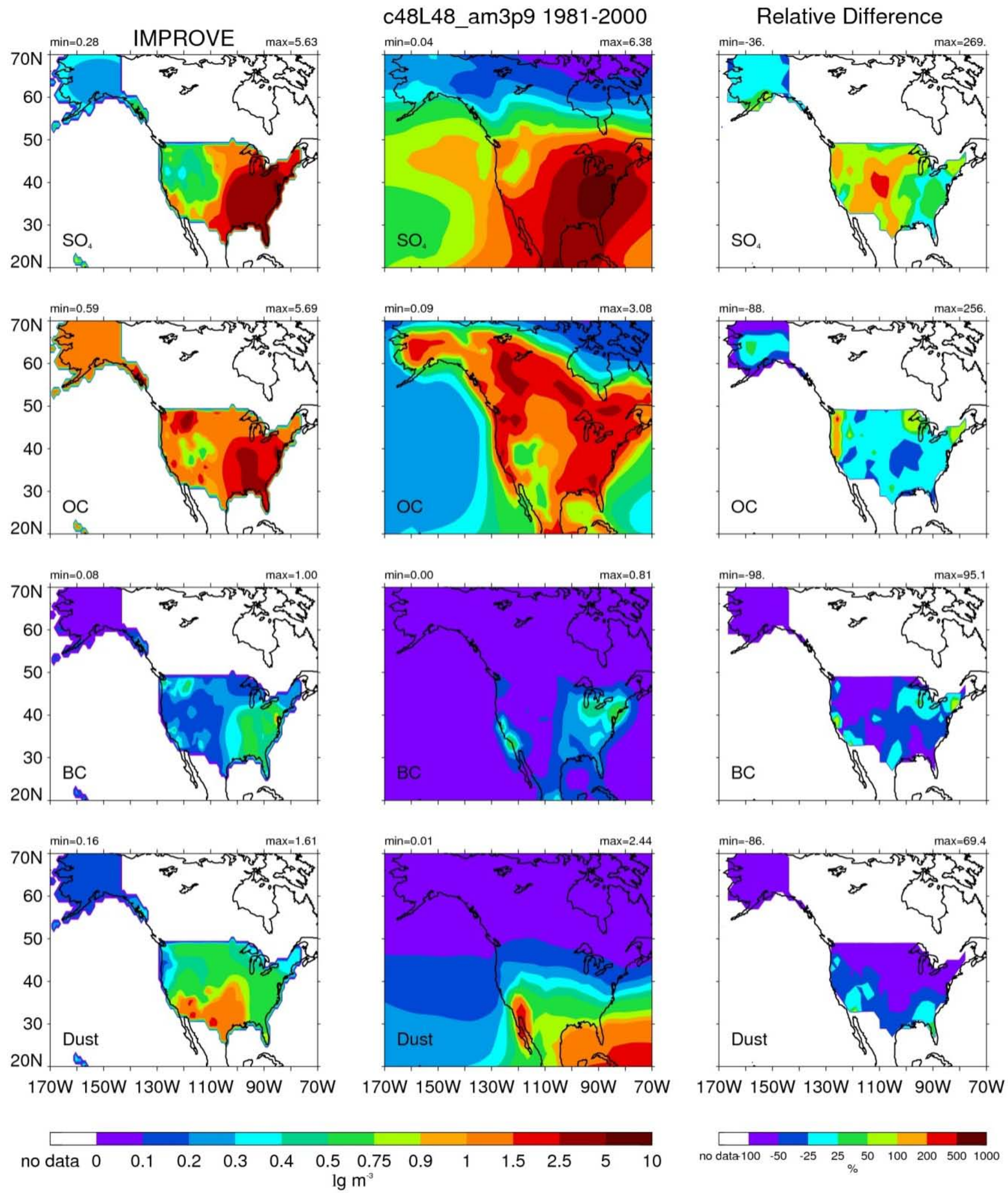


MPLNET $\varepsilon_{ext}(z)$ ARM site



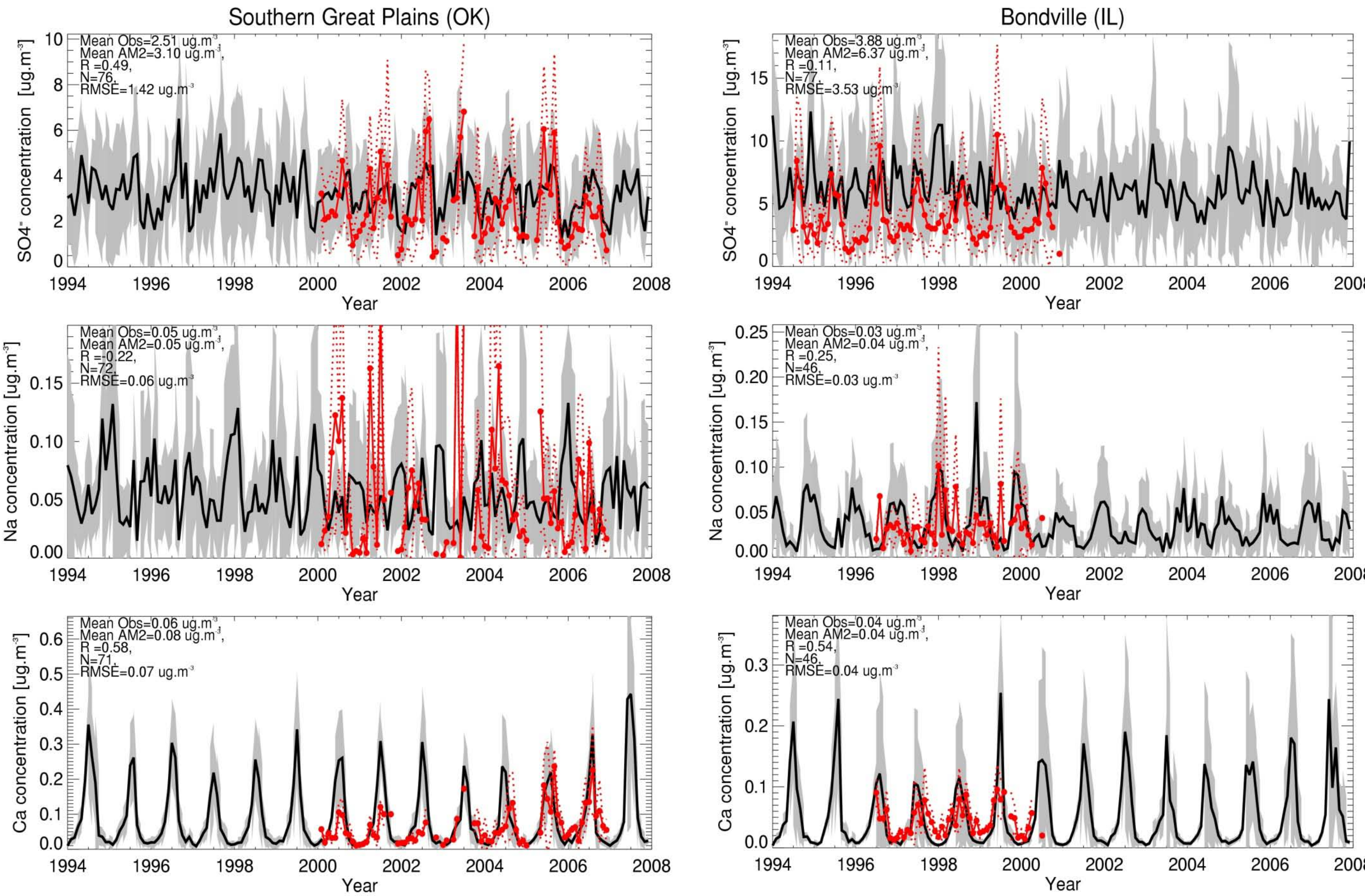
III. Aerosol properties over Midwest

- Surface concentration:
  - IMPROVE (Malm et al., 1994),
  - NOAA PMEL (Patricia Quinn)
- Scattering and Absorption: NOAA ESRL (Sheridan et al., 2001)
- Aerosol optical depth: MODIS (Levy et al., 2005)

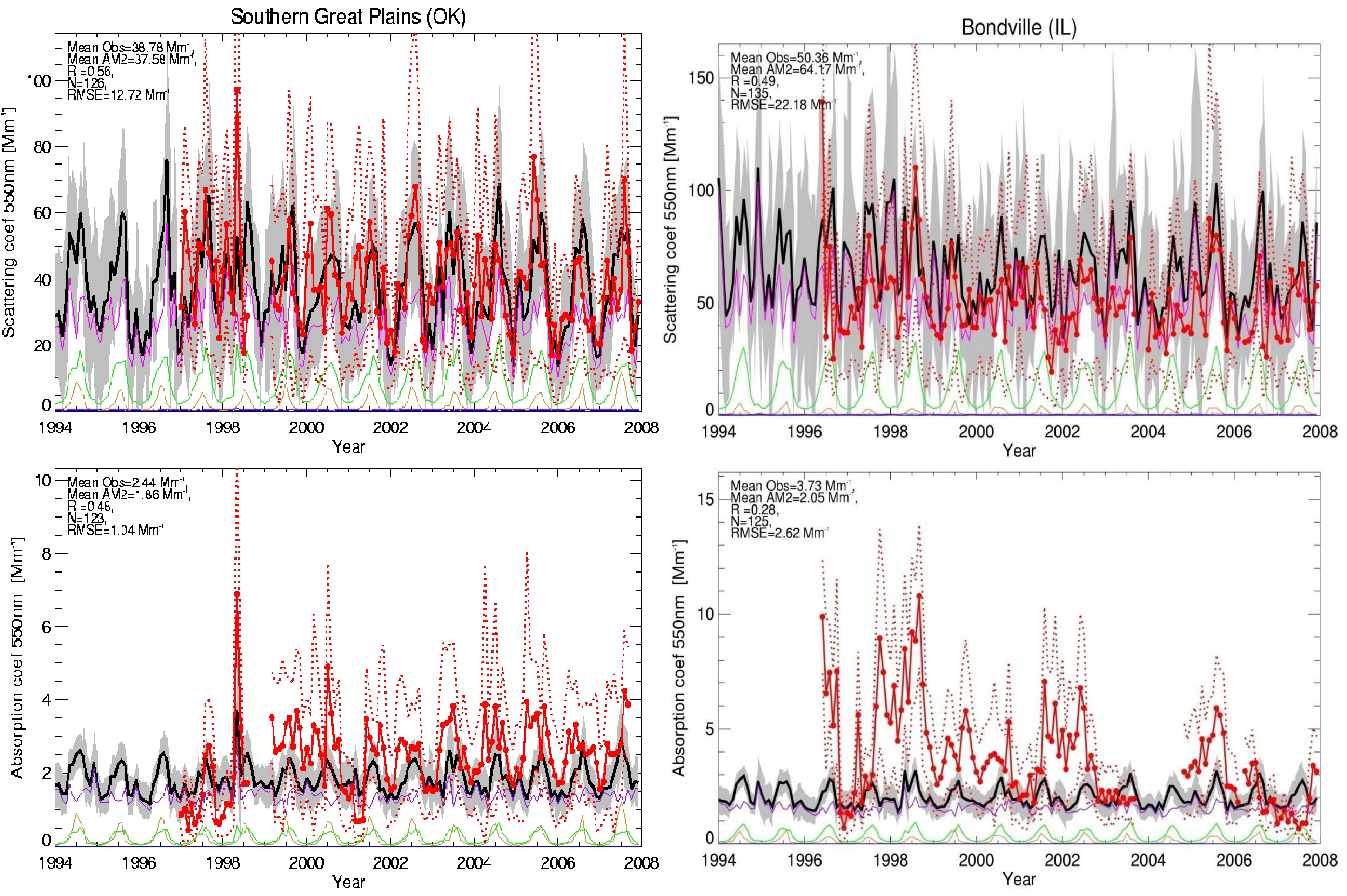


IMPROVE
c48L48_am3p9 1981-2000
Relative Difference
min=0.28
max=5.63
min=0.04
max=6.38
min=-36.
max=269.
SO4
OC
BC
Dust
min=0.59
max=5.69
min=0.09
max=3.08
min=-88.
max=256.
min=0.08
max=1.00
min=0.00
max=0.81
min=-98.
max=95.1
min=0.16
max=1.61
min=0.01
max=2.44
min=-86.
max=69.4
70N 60 50 40 30 20N
170W 150W 130W 110W 90W 70W
no data 0 0.1 0.2 0.3 0.4 0.5 0.75 0.9 1 1.5 2.5 5 10
lg m-3
no data -100 -50 -25 25 50 100 200 500 1000
%

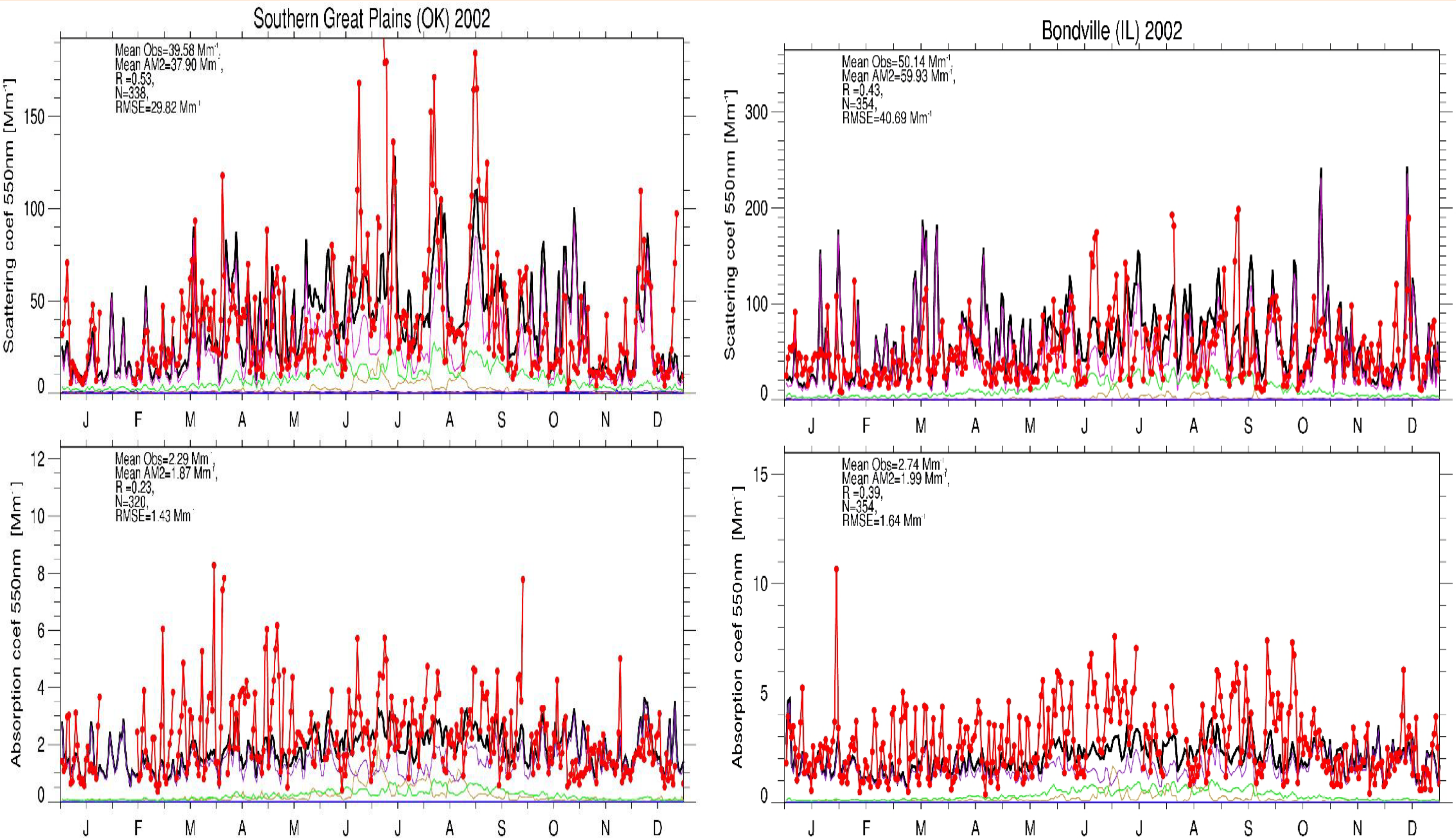
Sulfate, Sodium, Calcium surface concentration SGP (OK) and BND (IL)



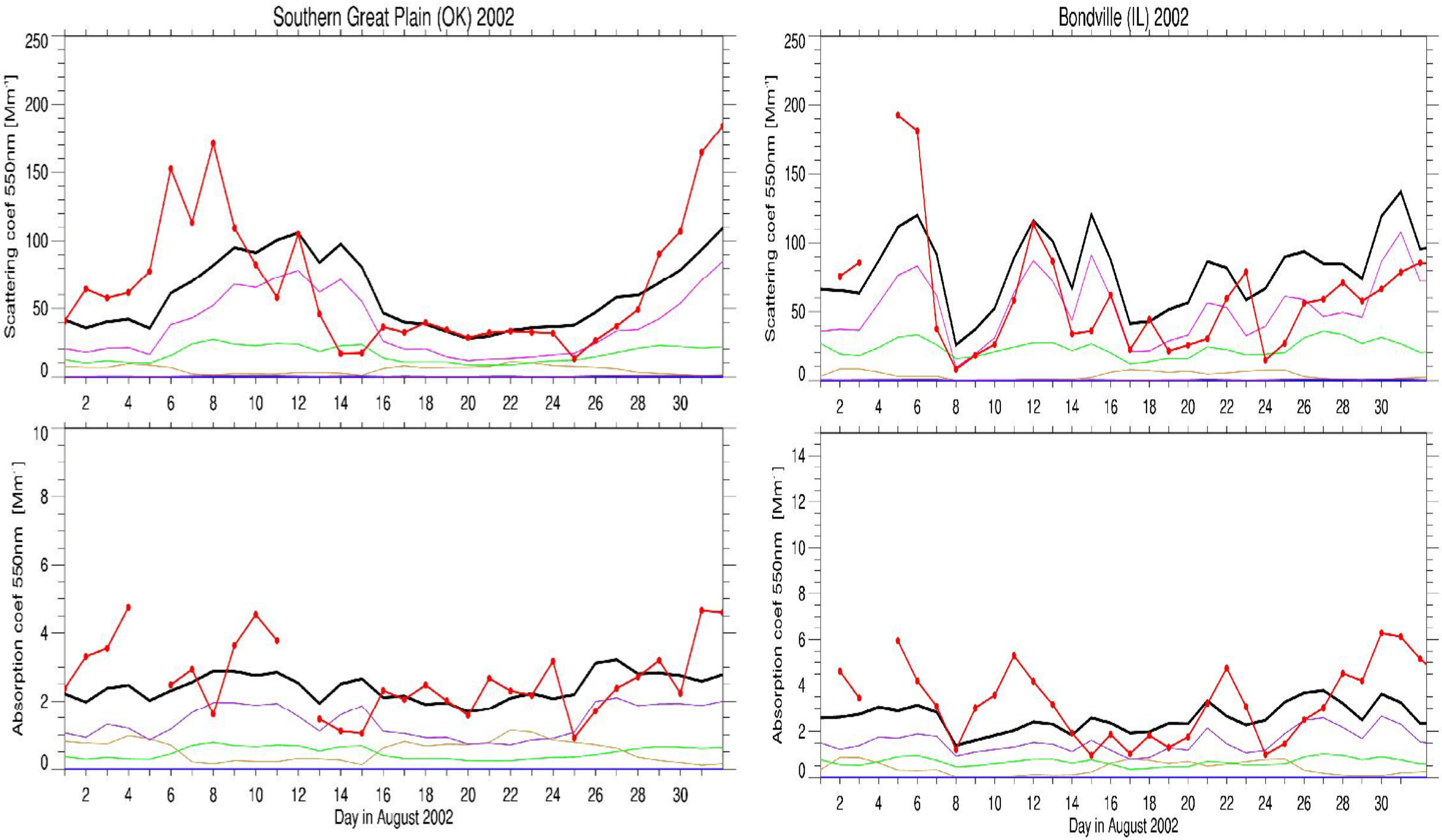
Monthly $\varepsilon_{scat}+\varepsilon_{abs}$ SGP (OK) & BND (IL)



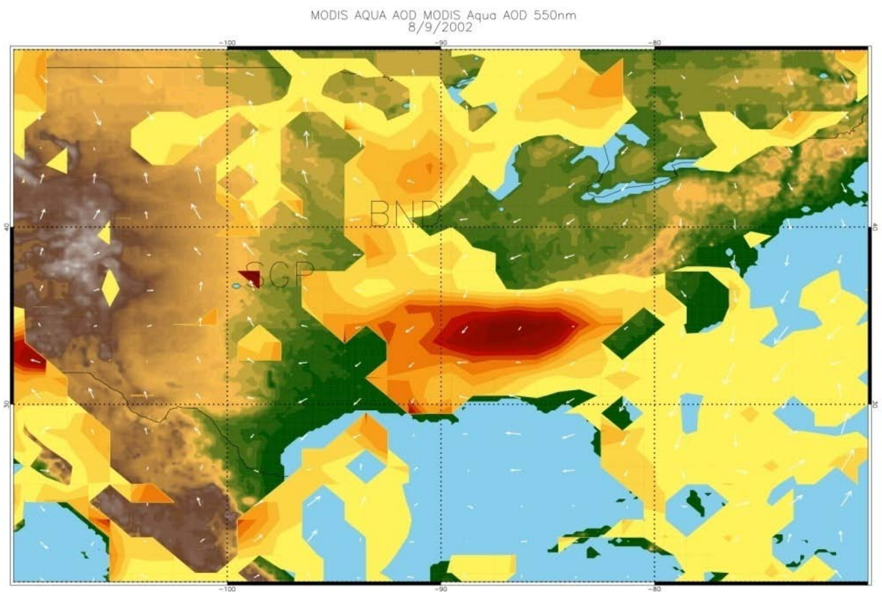
Daily (2002) $\varepsilon_{scat}+\varepsilon_{abs}$ SGP (OK) & BND (IL)

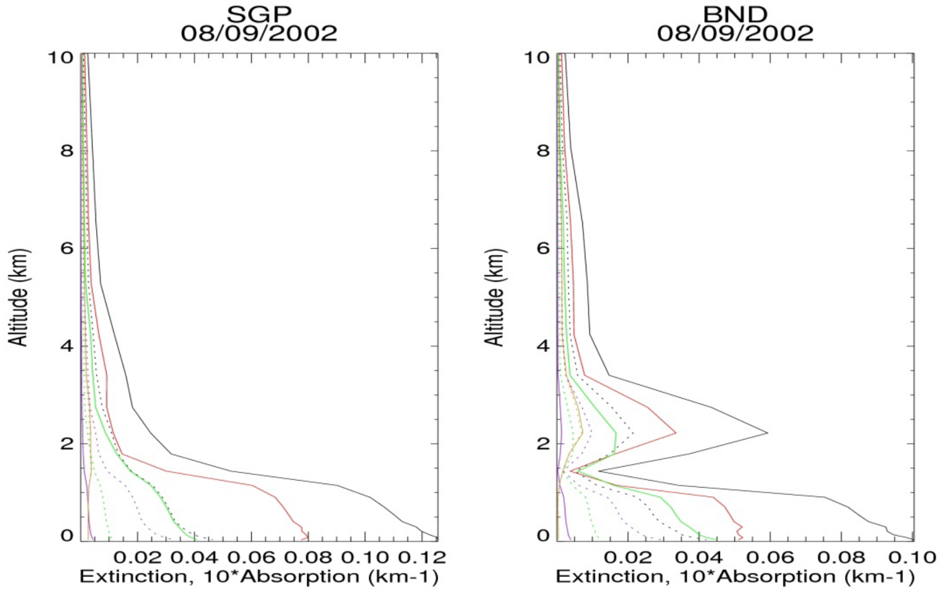


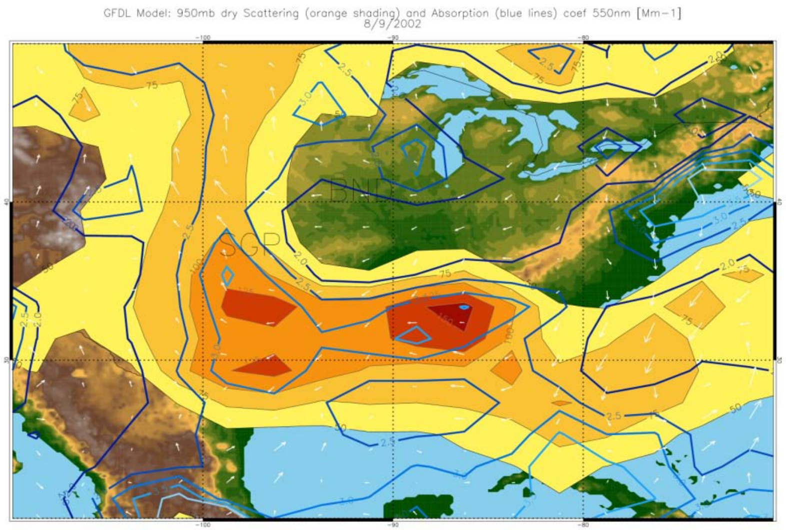
Daily (Aug 2002) ε_{scat} and ε_{abs} SGP & BND

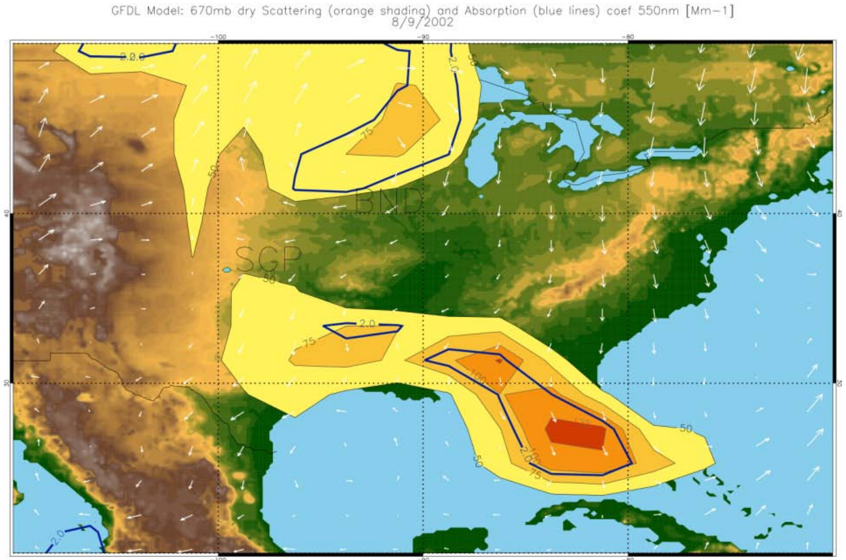


August 9, 2002









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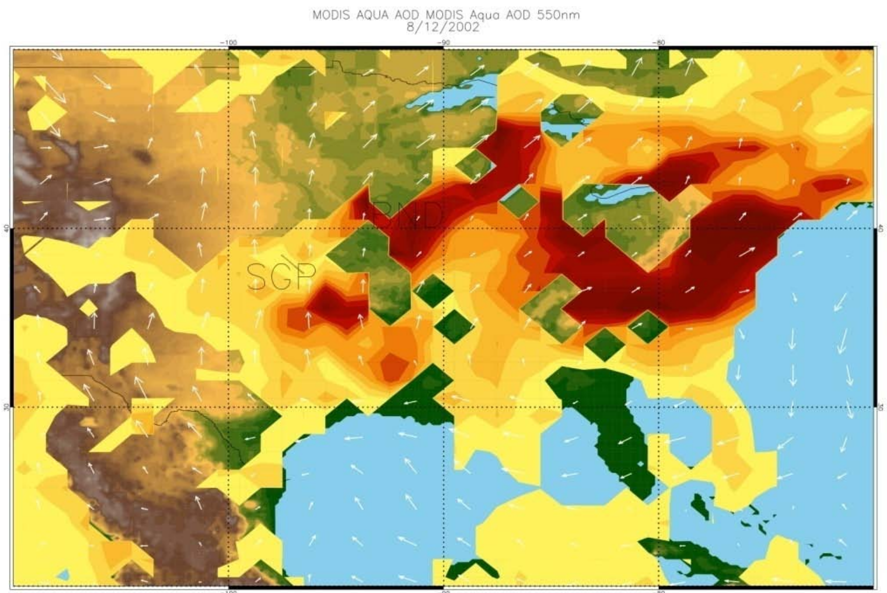
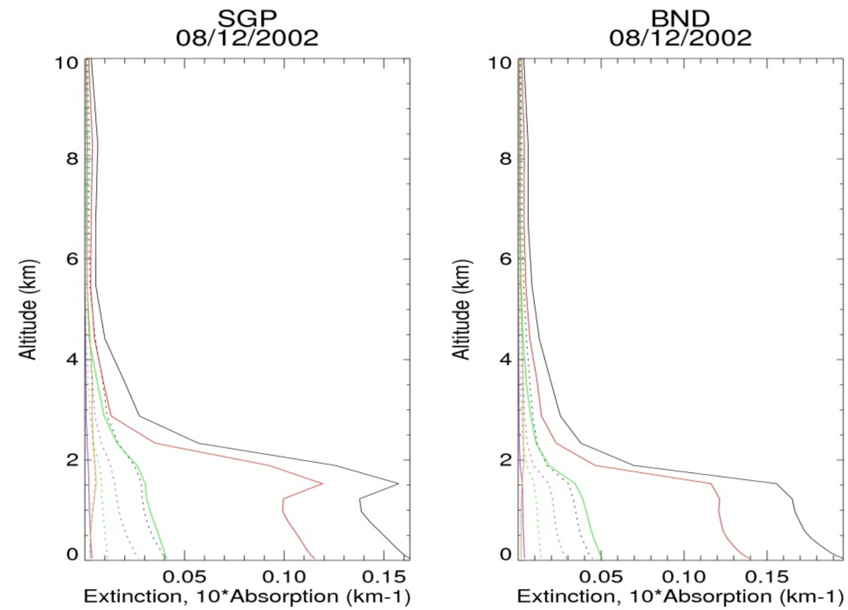
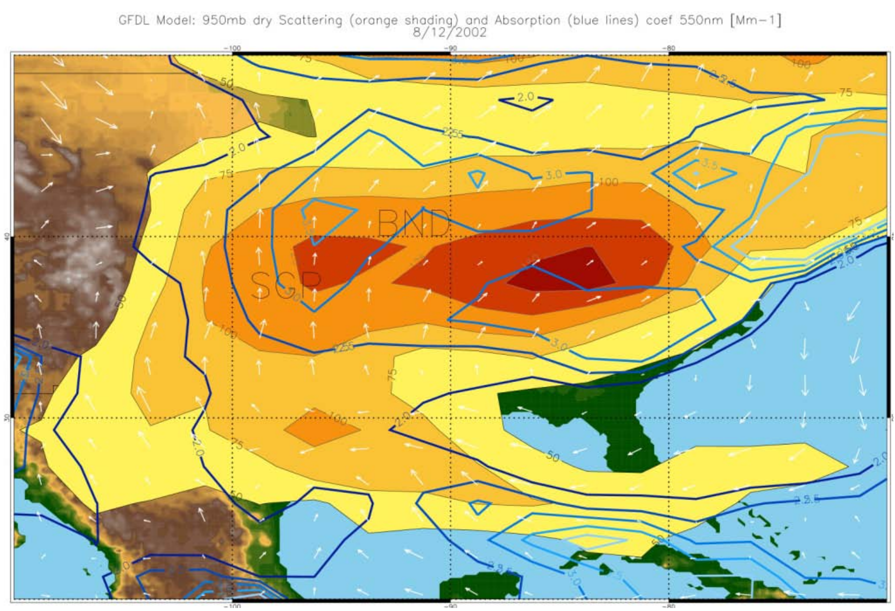
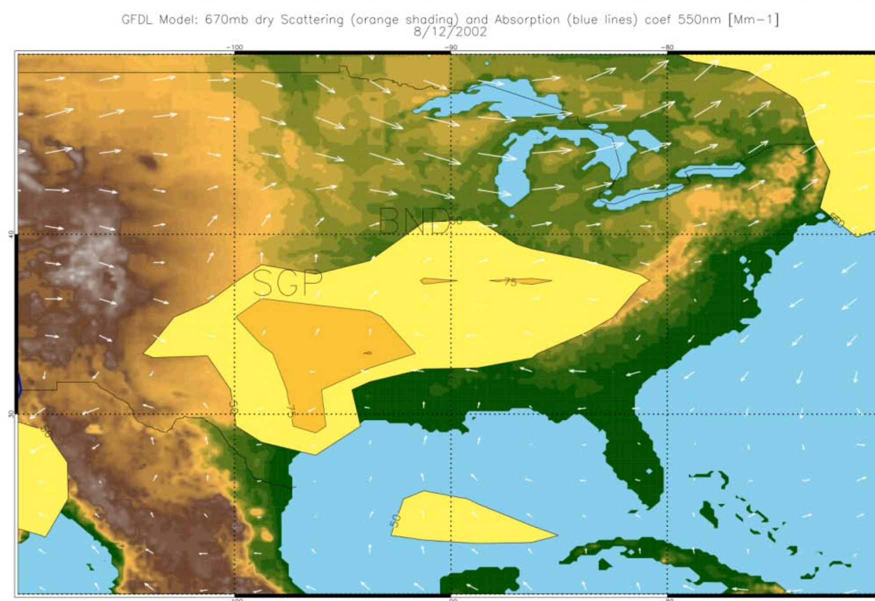
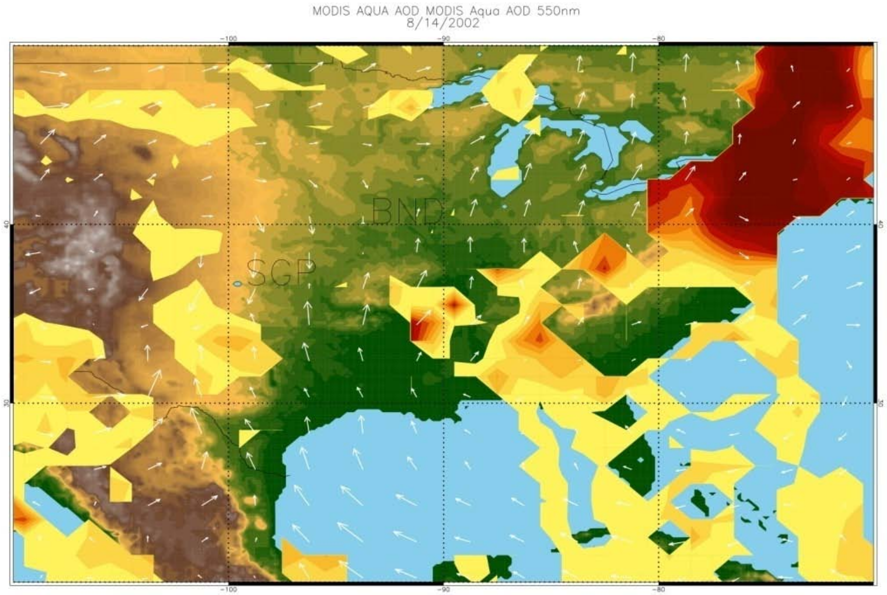


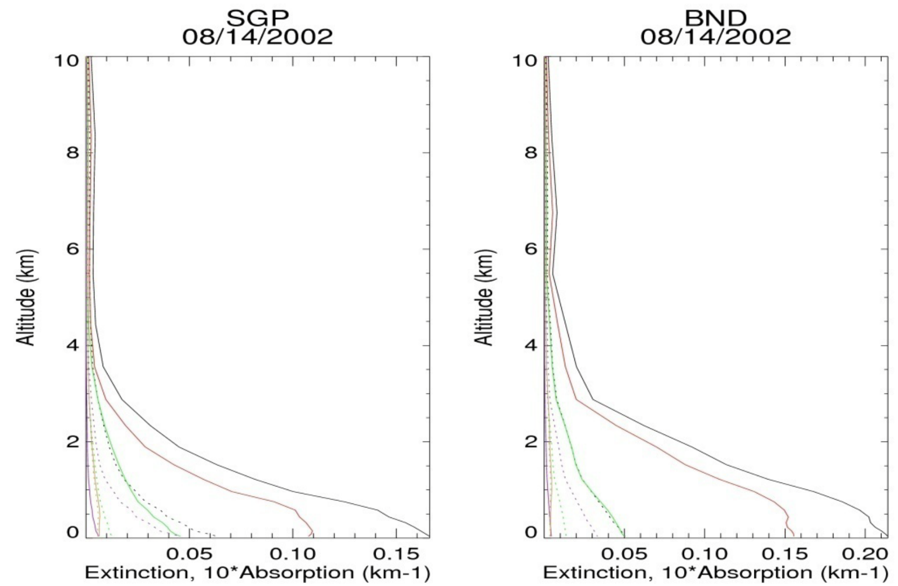


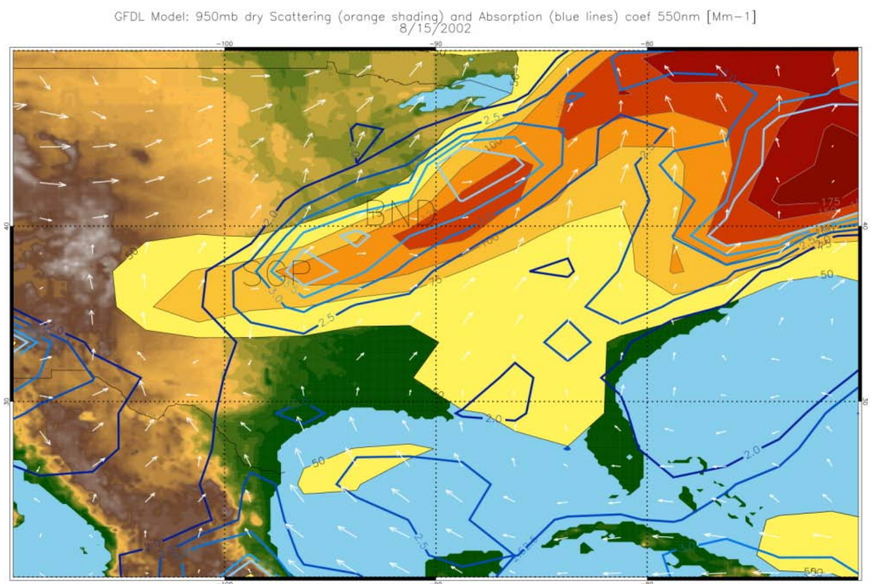


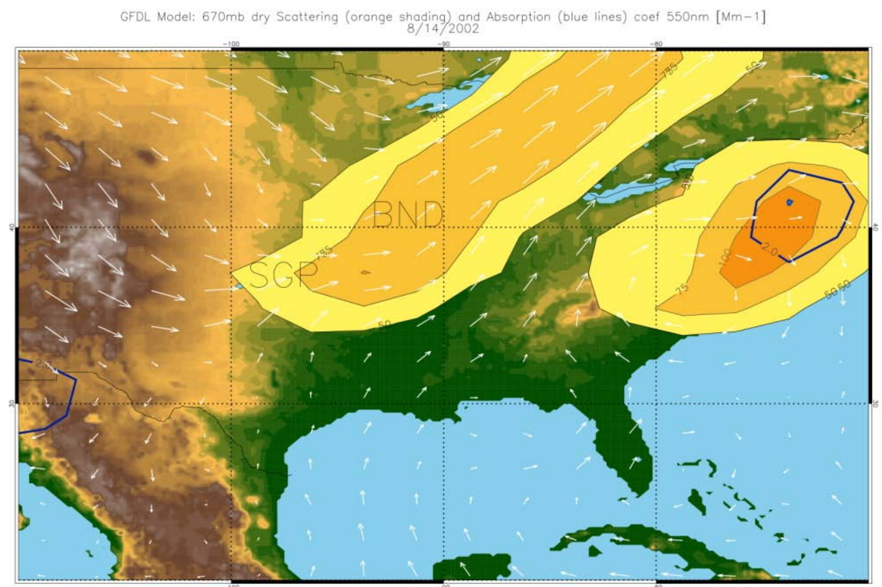


August 14, 2002









IV. Conclusions

- New developments in GFDL atmospheric model includes aerosol with full chemistry
- Evaluation with data shows satisfactory results globally but with regional discrepancies:
  - AOD underestimate in polar region (BC/OC aging, drizzle?)
  - AOD overestimate in polluted regions (f(RH)?)
- Nudging of u, v, T, ps is used to analyze synoptic variability over Midwest in conjunction with data at SGP and BND.
  - Model shows much larger discrepancy in scattering and absorption in BND than SGP.
  - Layering with different aerosol composition: difficulty to assess results without lidar data
  - Internal mixing of $BC/SO_4^{=}$: sensitivity analysis

Acknowledgments

- GFDL GMDT: John Austin, Leo Donner, Stuart Feidenreich, Chris Golaz, Larry Horowitz, S-J Lin, Chris Milly, Yi Ming, Dan Schwarzkopf, Elena Schevliakova, John Wilson, Ming Zhao
- ESRL data: John Ogren and Betsy Andrews
- PMEL data: Patricia Quinn
- AERONET: PIs of each sunphotometer, Oleg Dubovik
- MODIS and MISR: science teams