$$\frac{\partial C}{\partial t} + \frac{\partial UC}{\partial X_1} + \frac{\partial VC}{\partial X_2} + \frac{\partial WC}{\partial X_3} - \frac{\partial \rho^*}{\partial X_1} K_1 \frac{\partial C/\rho^*}{\partial X_1} - \frac{\partial \rho^*}{\partial X_2} K_2 \frac{\partial C/\rho^*}{\partial X_2} - \frac{\partial \rho^*}{\partial X_3} K_3 \frac{\partial C/\rho^*}{\partial X_3} = (P - L) VmHm_1 Hm_2$$

The "L" Part of the Story

Pete Colarco, NASA GSFC

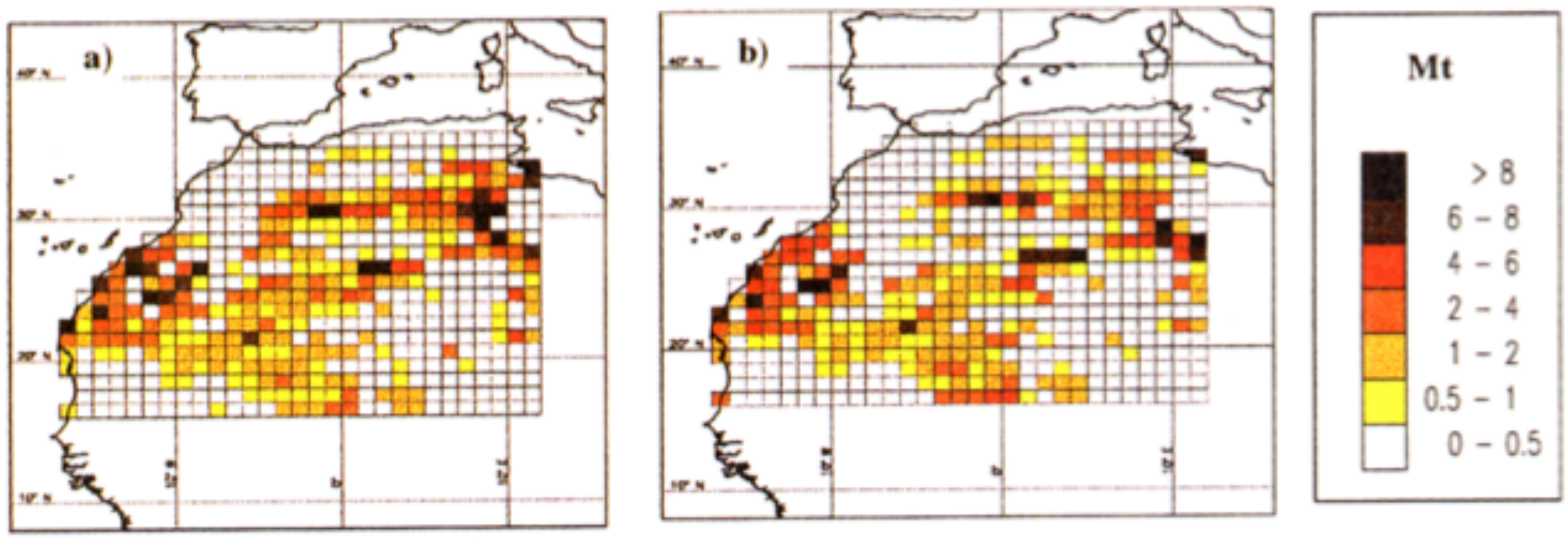
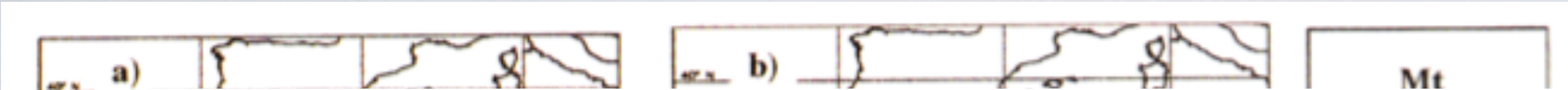


Plate 2. Dust Emissions over the Western Sahara for (a) 1991 and (b) 1992.

Marticorena et al. 1996

OK, First the "P" Part of the Story



Marticore

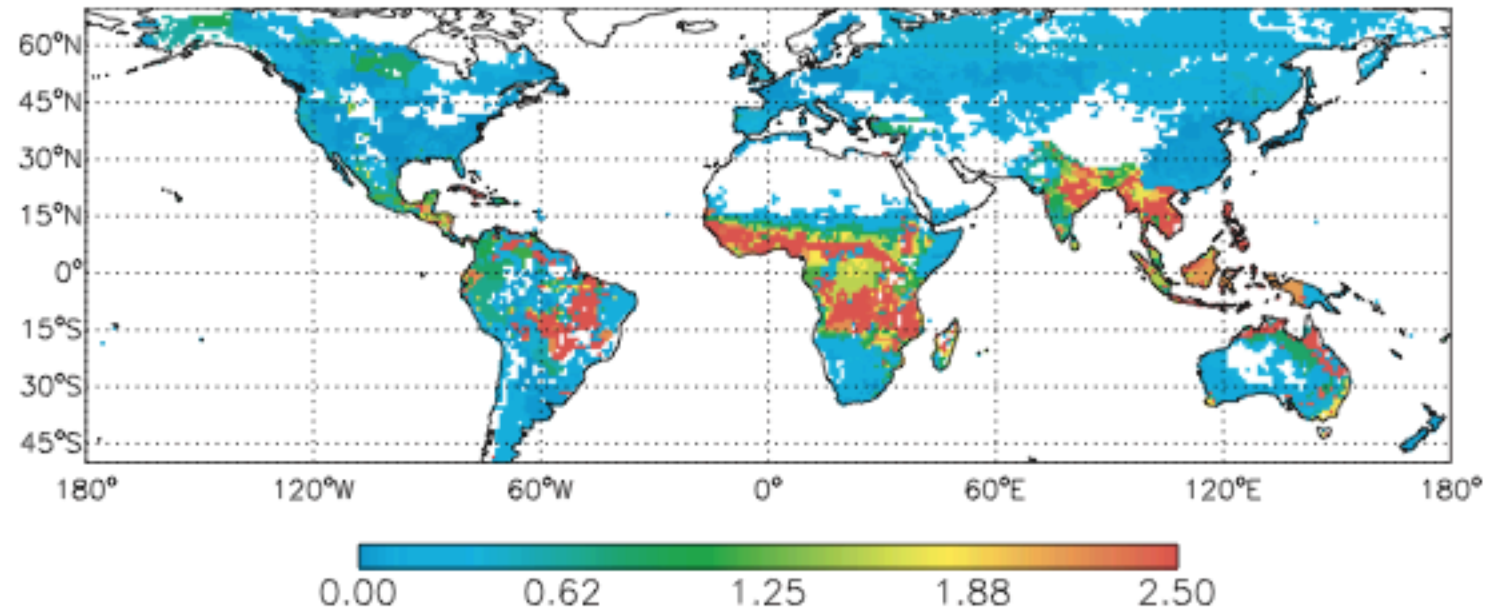


Figure 4. Spatial distribution of mean CO emissions from biomass burning ($\times 10^{19}$ molecules CO cm^{-2} yr^{-1}). There are data points higher than 2.5×10^{19} molecules CO cm^{-2} yr^{-1}, however, for clarity, the scale is capped.

Duncan et al. 2003

OK, First the "P" Part of the Story

Marticore

Duncan e

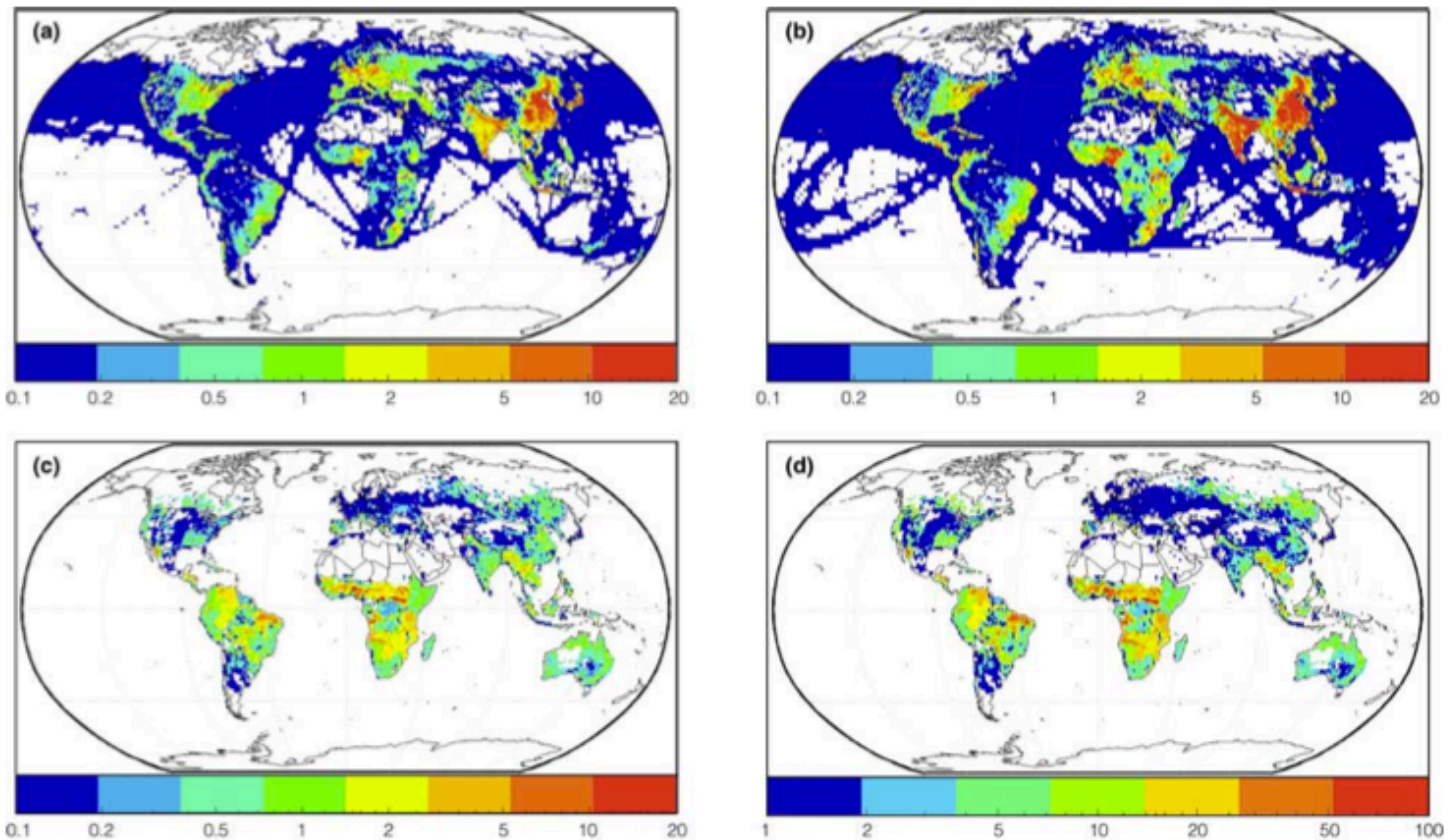


Figure 1. The 1996 emissions (ng m^{-2} s^{-1}) of carbonaceous aerosols: (a) BC emissions from energy-related combustion; (b) OC emissions from energy-related combustion; (c) BC emissions from open biomass burning; (d) OC emissions from open biomass burning.

Streets et al. 2004

OK, First the "P" Part of the Story

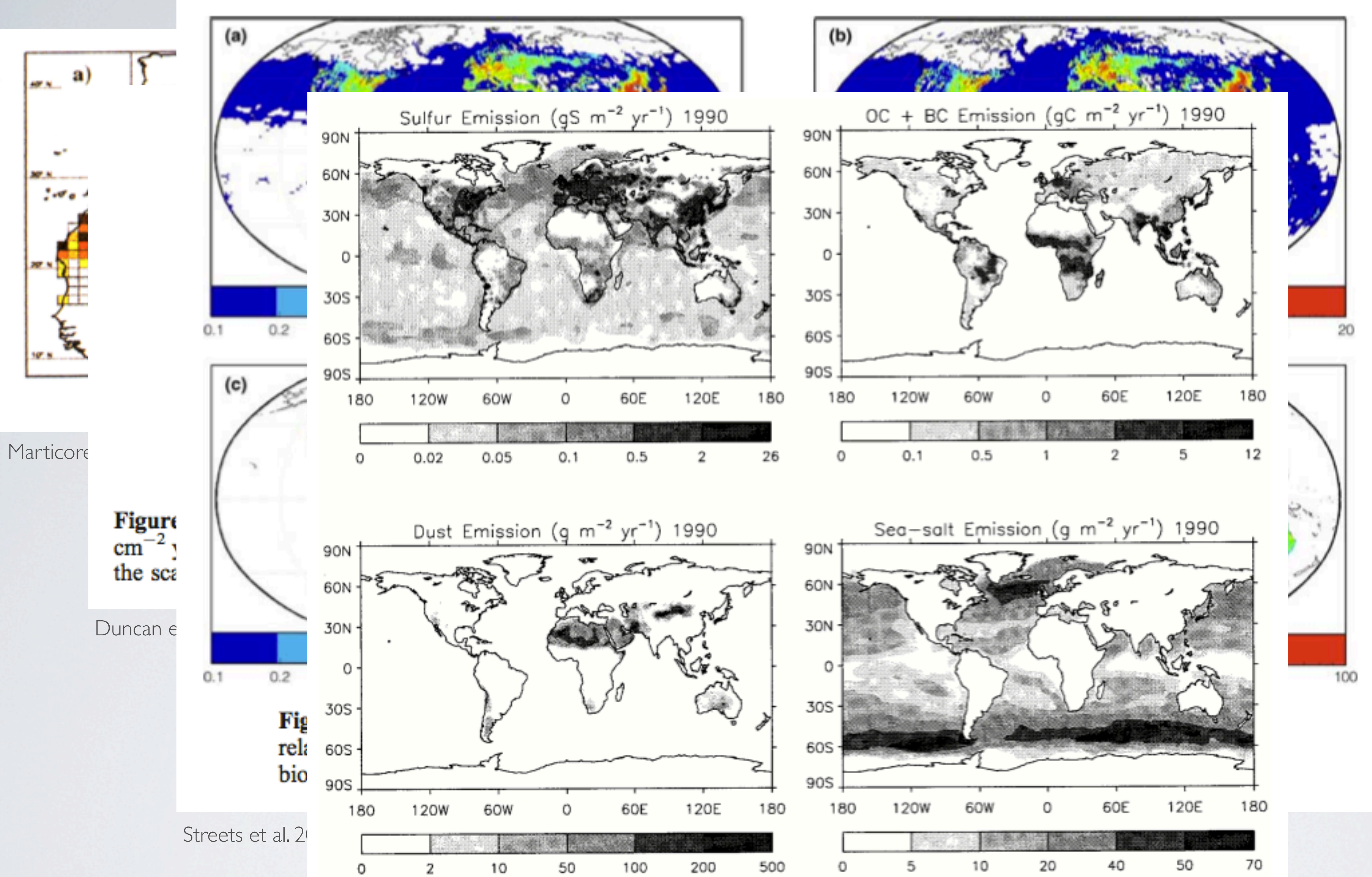


FIG. 1. Global annual emission rates for total sulfur (SO_2 + DMS) (g-S m^{-2} yr^{-1}), dust (g m^{-2} yr^{-1}), OC + BC (g-C m^{-2} yr^{-1}), and sea salt (g m^{-2} yr^{-1}) for 1990.

Chin et al. 2002

OK, First the "P" Part of the Story

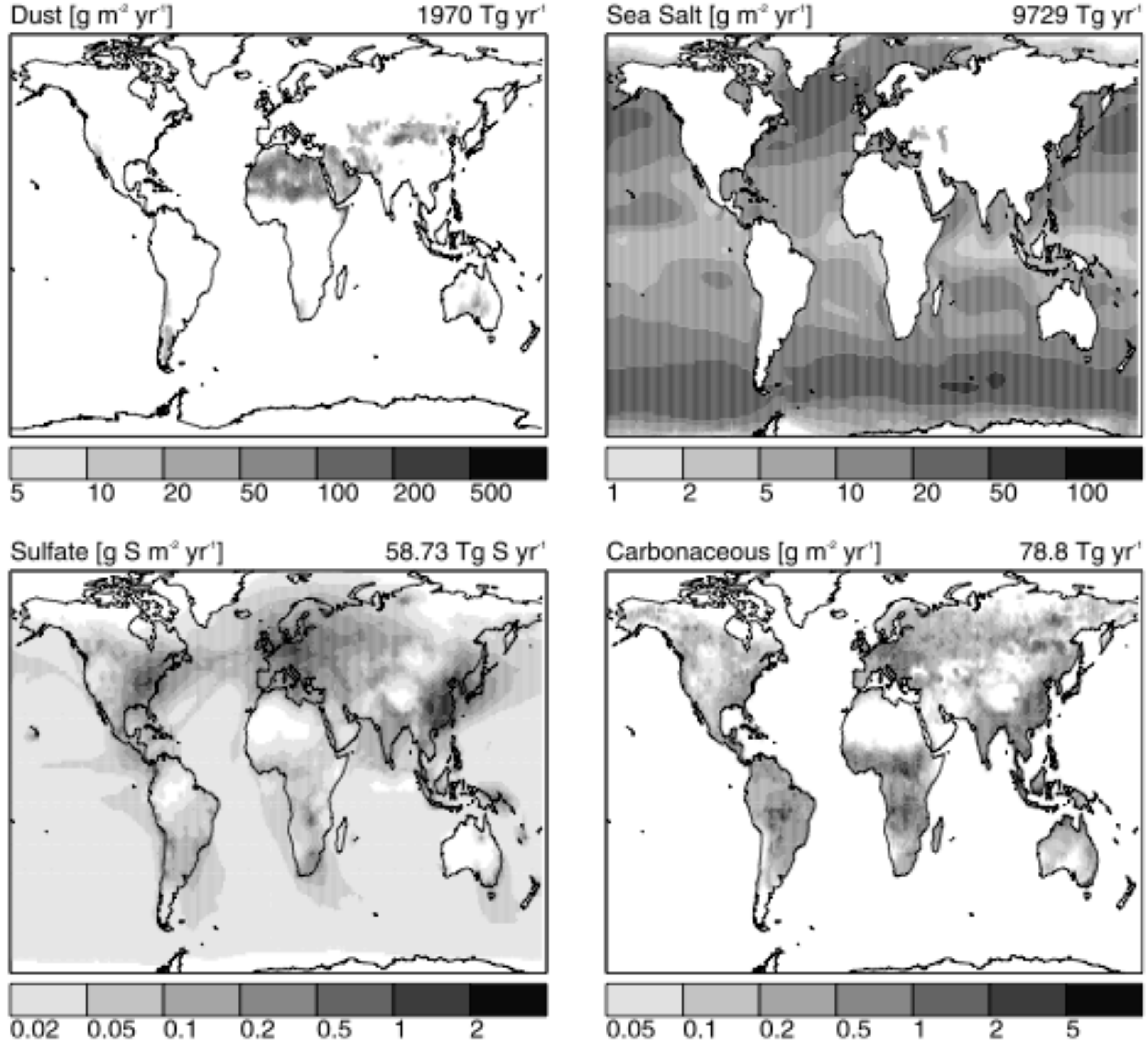


Figure 1. Annual average aerosol emissions over the period 2000–2006 used in our model. Results shown are for dust, sea salt (dry mass), sulfate (sulfur mass of direct emissions and chemical production from oxidation of SO_2), and carbonaceous (BC+POM) aerosol.

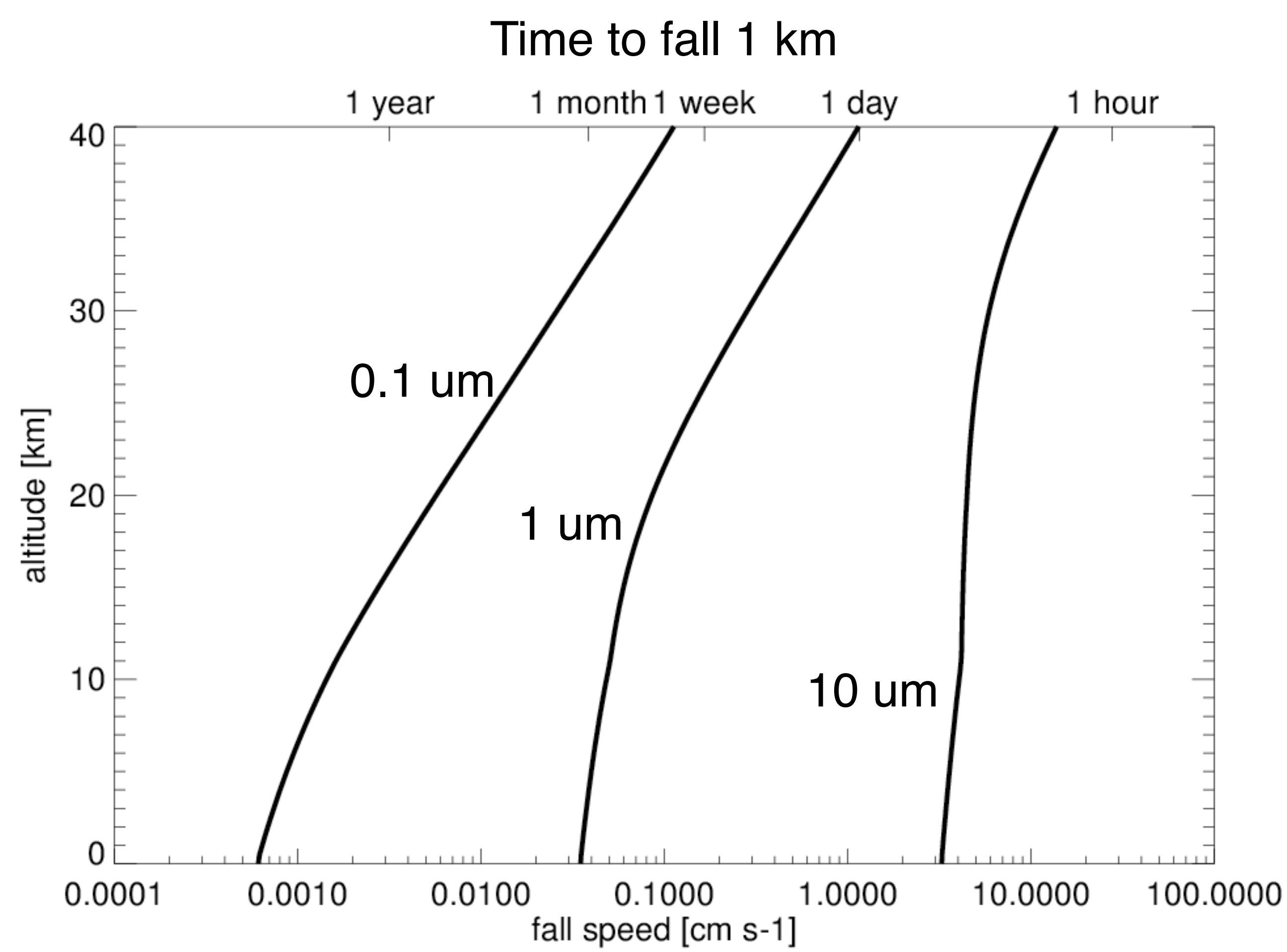
Colarco et al. 2010

Species	Emissions ($Tg\ yr^{-1}$)
Dust	**1970**
	3242
	1789
	(541–4036)
Sea salt	**9729**
	5056
	16407
	(2190–117949)
Black carbon	**10.06**
	10.11
	11.96
	(7.83–19.34)
POM	**68.76**
	86.21
	95.87
	(59.33–137.7)
Sulfate (sulfur amount only)	**58.73**
	46.12
	58.18
	(40.88–77.42)

Issues regarding sinks

- Three main processes: sedimentation, dry deposition, wet removal
- Processes are typically treated as separable (operator splitting)
- Not necessarily general, but the ICAP models tend to treat the aerosols as external mixtures

Sedimentation



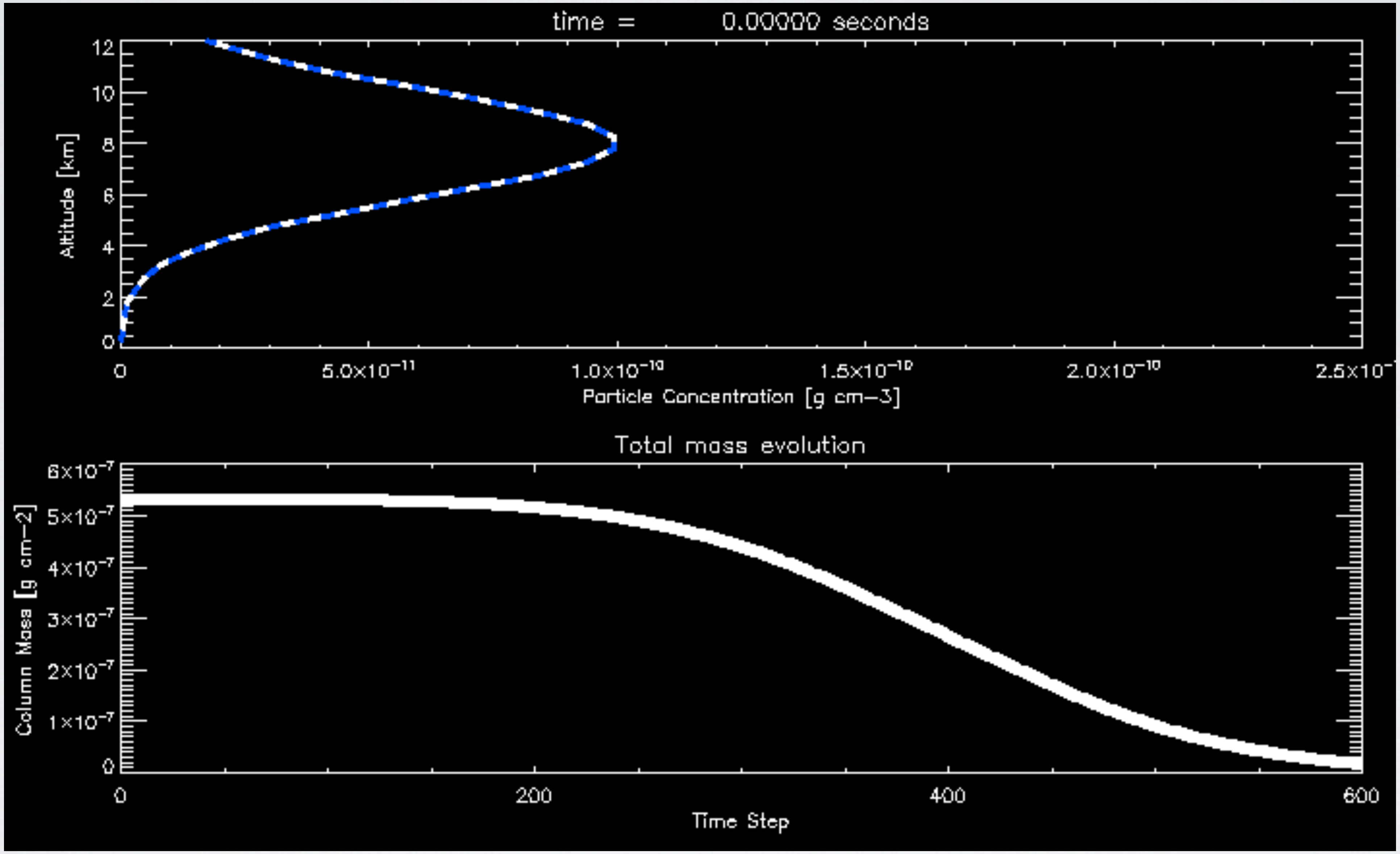
- Stokes fall velocity

  $v_f = 2/9 \cdot \mu^{-1} \cdot (\rho_{particle} - \rho_{air}) \cdot g \cdot r^2$

- Apply corrections for
  - slip correction - enhance fall speed for particles small compared to mean free path in air
  - drag effects - tend to slow fall down at high Re (i.e., large particles wrt viscosity)
  - shape effect

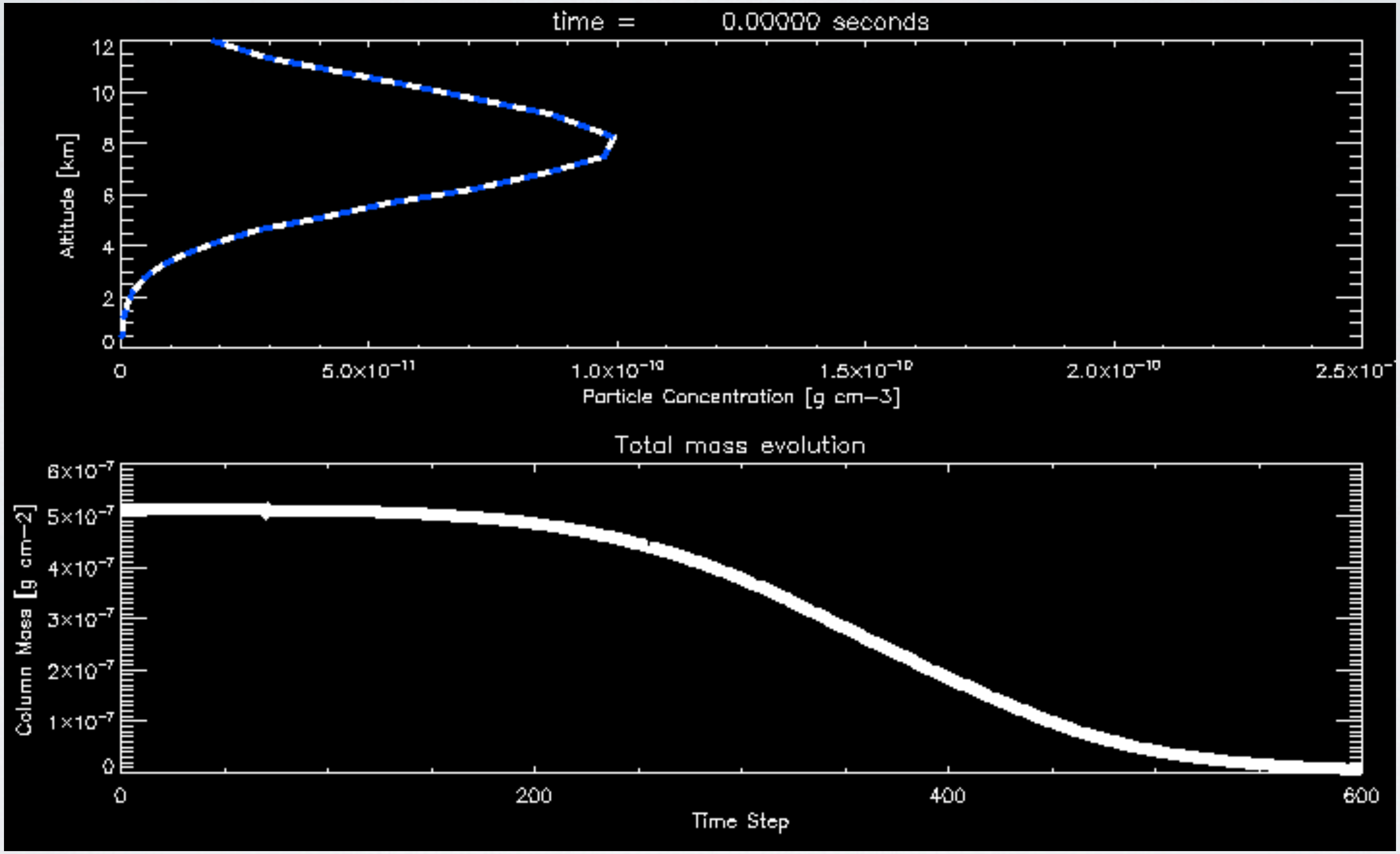
- Possible error in models: particles treated as external mixtures might assign small fall speeds to, e.g., carbonaceous particles that might be internally mixed with larger particles

Sedimentation



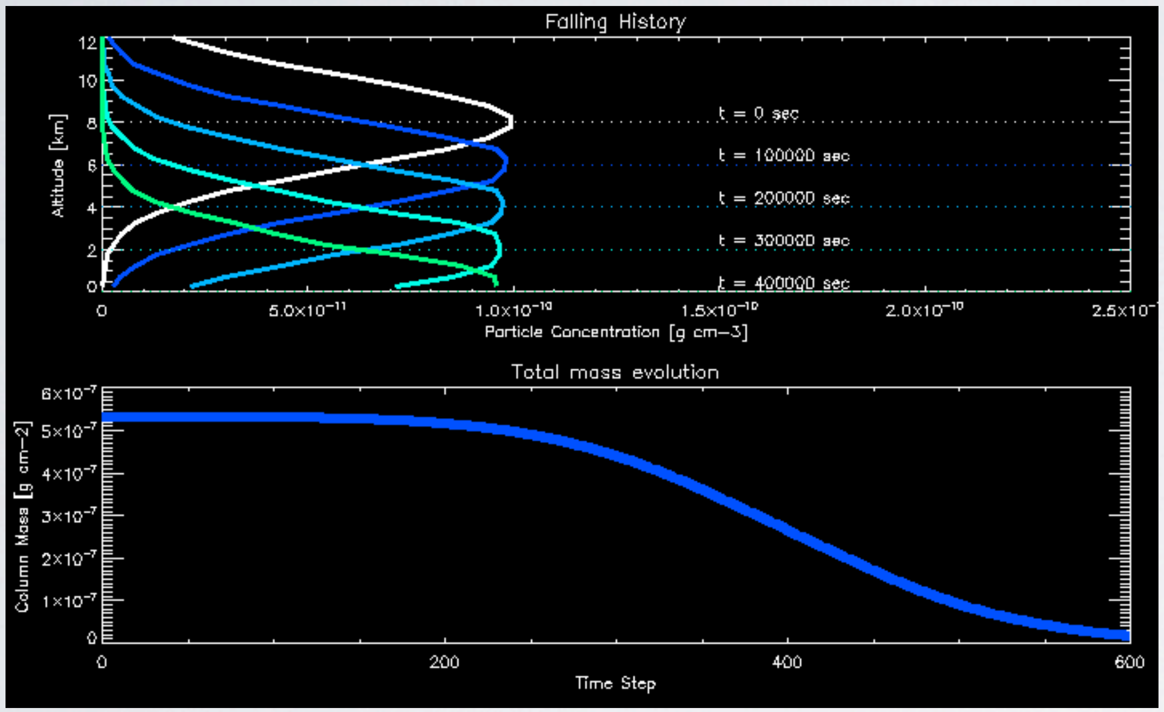
Cartesian Grid

Sedimentation

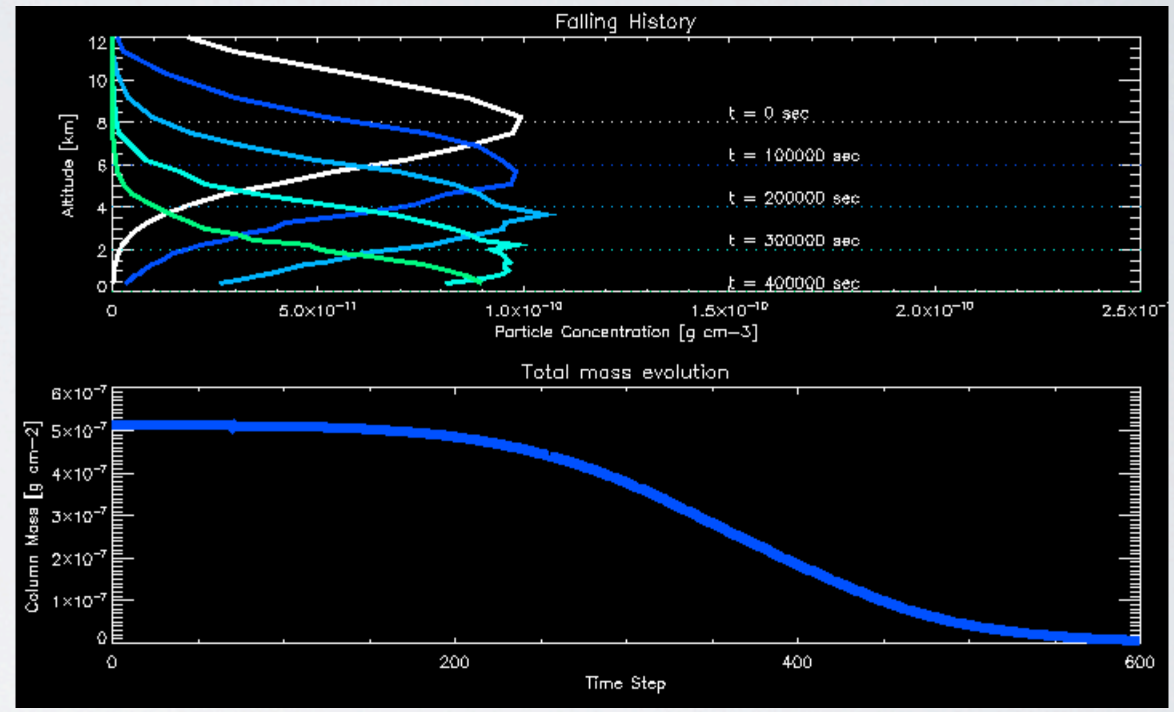


Sigma Grid

Sedimentation



Cartesian Grid



Sigma Grid

Dry Deposition

- Dry removal of particles from lowest model level
- Often parameterized in terms of a deposition velocity (e.g., Zhang et al. 2001)

$$v_d = v_f + 1/(R_a+R_s)$$

- v_f is the sedimentation velocity discussed previously
- Residual deposition velocity is due to turbulent processes
- Approach here is so called "resistance in series" approach
- Terms depend on atmosphere, surface, particle properties

Dry Deposition

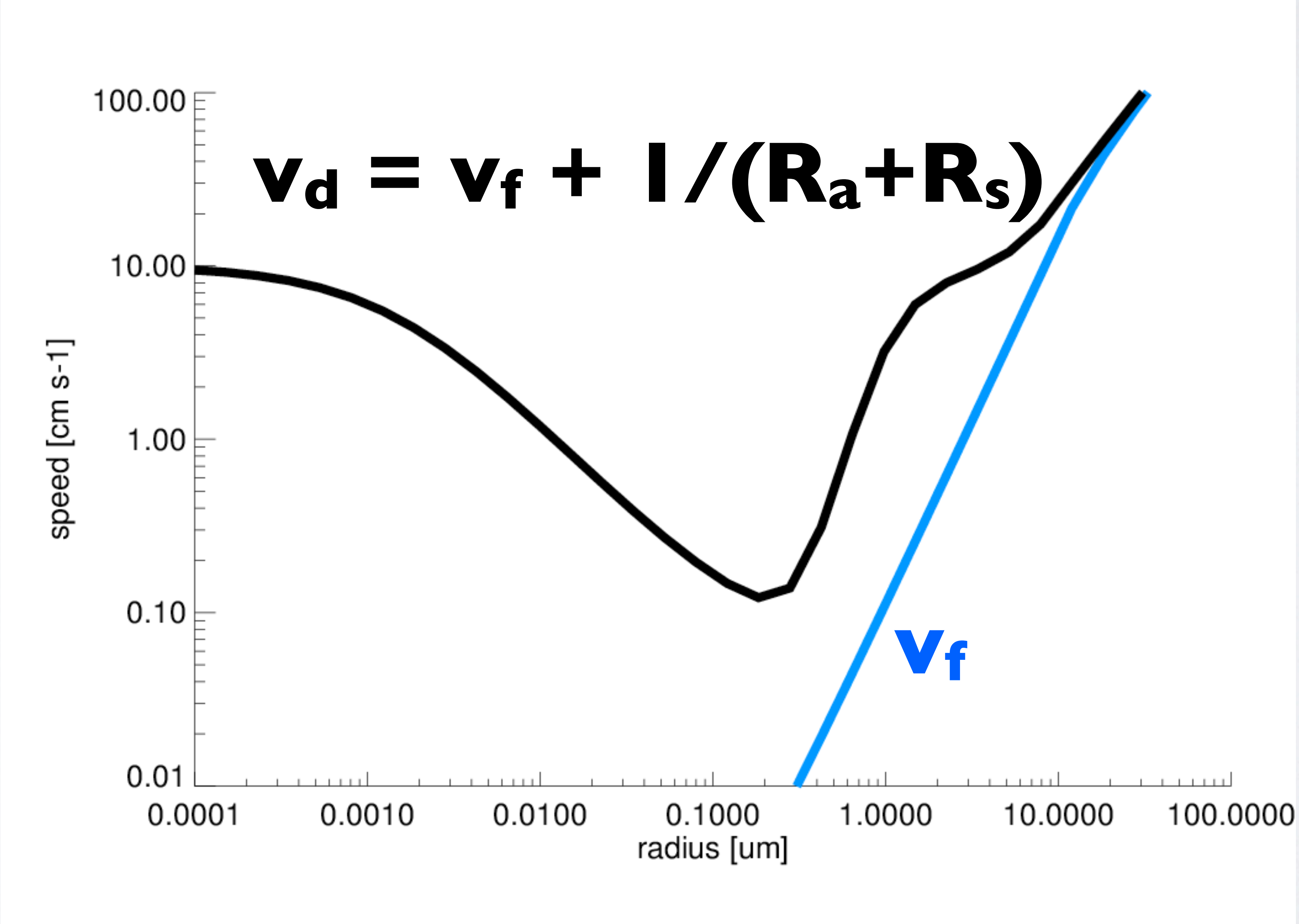
- R_a = aerodynamic resistance (depends on atmospheric stability)
- R_s = surface resistance

$$R_s = f(E_B, E_{IM}, E_{IN})$$

- E_B = Brownian diffusion efficiency (depends on particle size and air viscosity)
- E_{IM} = Impaction efficiency (eddies impacting surface, depends on surface collector characteristics)
- E_{IN} = Interception efficiency (flow distortion around objects, also depends on particle and surface collector size)
- For gases may also add sub-layer resistance term for molecular diffusivity

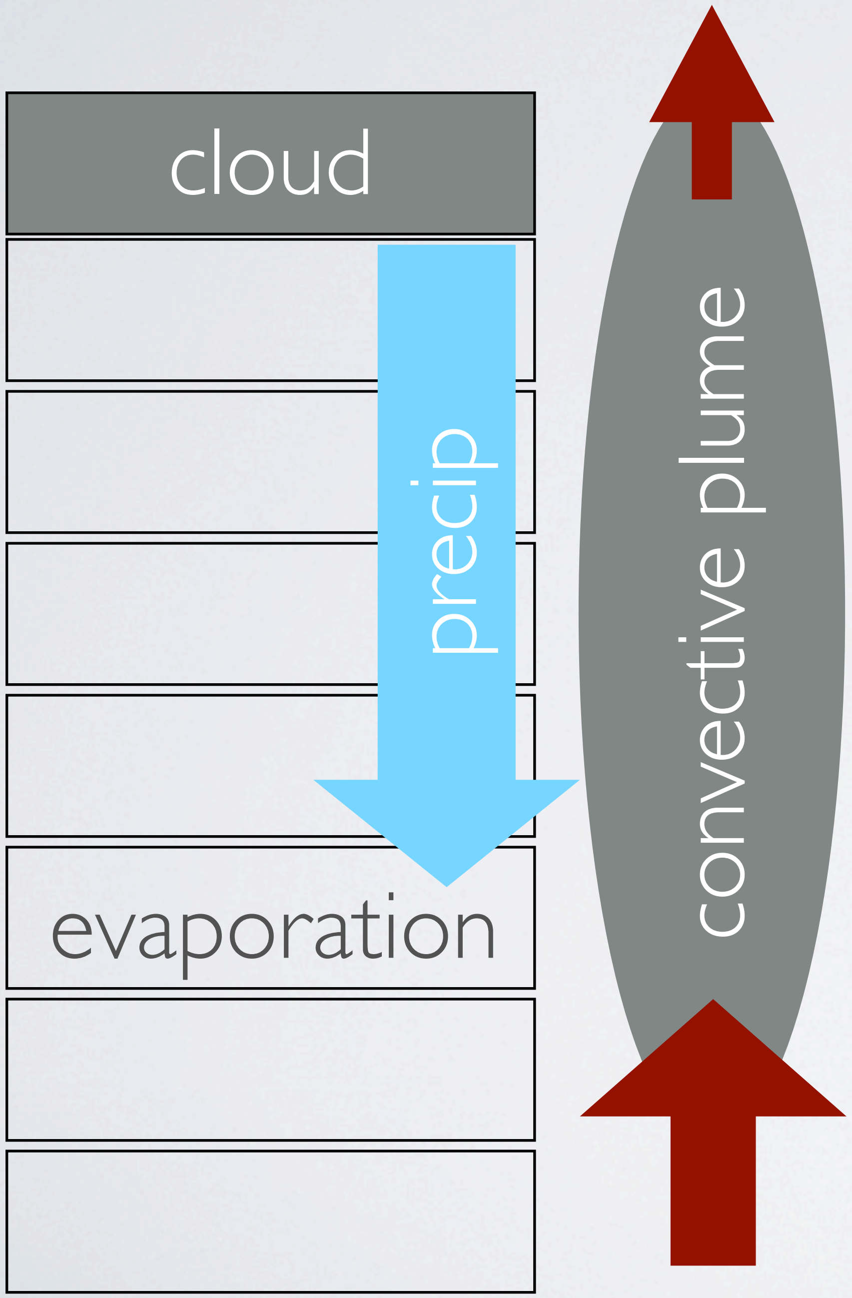
Dry Deposition

- Depending on model, v_d may be decoupled from v_f
- That is $v'_d = 1/(R_a+R_s)$
- And $c = c_0 \cdot [1\text{-}\exp(-v_d / \Delta z \cdot \Delta t)]$



Wet Removal

- Wet removal generally partitioned between *large scale* and *convective scale* processes

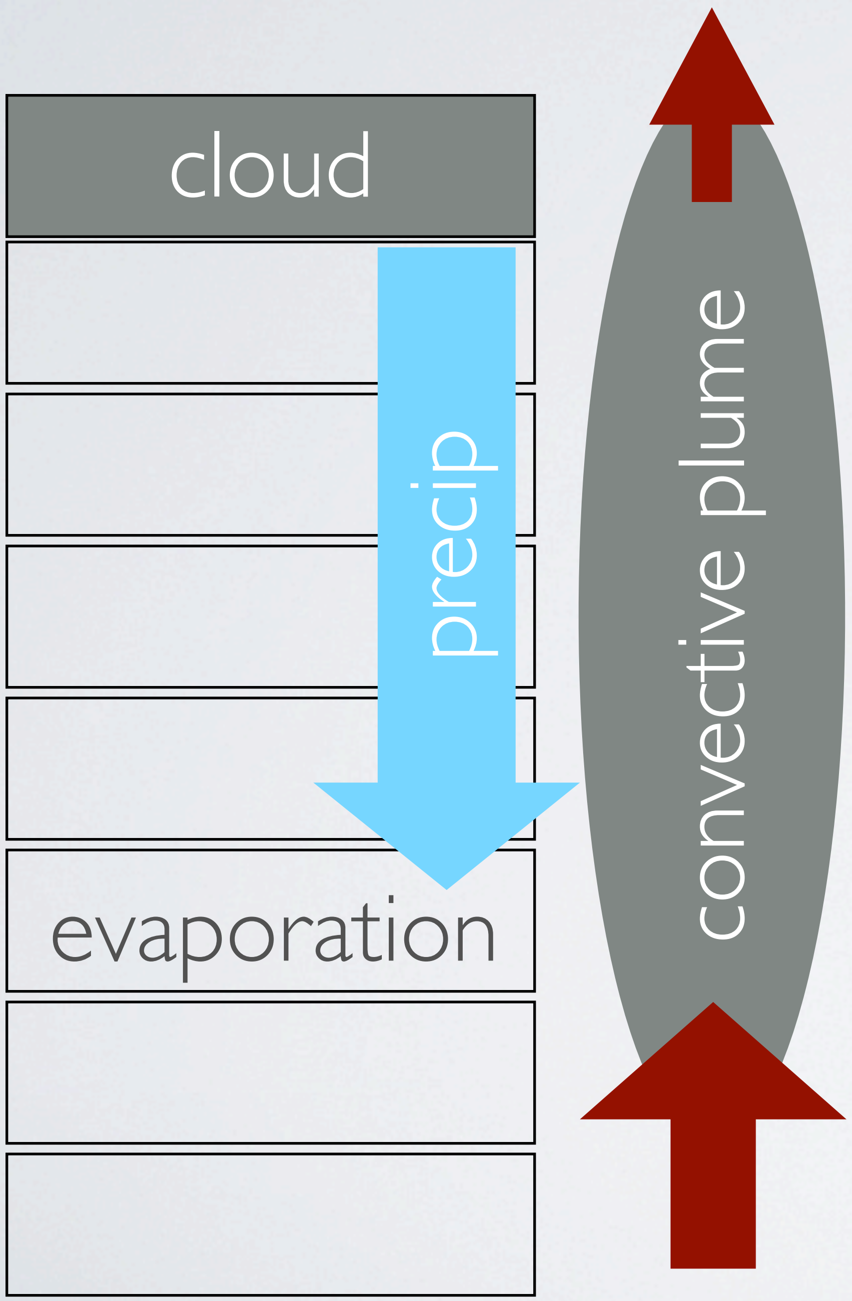


Large scale

- Assume some portion of aerosol entrained in condensates formed in time step
- Remove that fraction that precipitates
- Sweep up aerosol from precipitation from above
- Possibly release through evaporation

Wet Removal

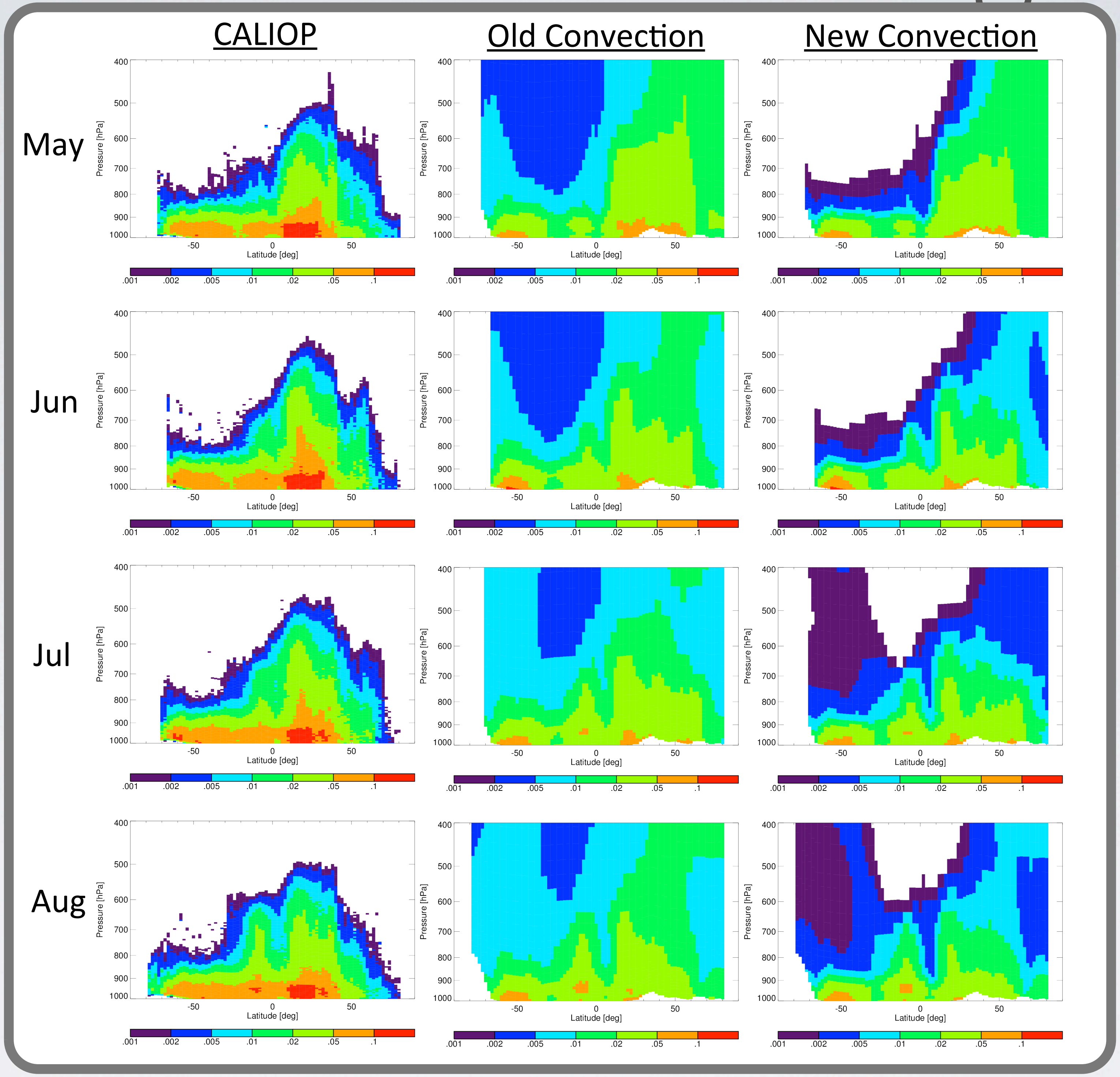
- Wet removal generally partitioned between *large scale* and *convective scale* processes



Convective Scale

- Convection not explicitly resolved in models
- Remove some fraction of aerosol entrained in updrafts
- More sophisticated might follow water cycle of convective plumes
- Convective transport becomes major mechanism of vertical transport

Update to Convection Algorithms



- Comparison of offline and online instances of GOCART revealed discrepancies in implementation traced to online convective scavenging

Sensitivity to Model Variables

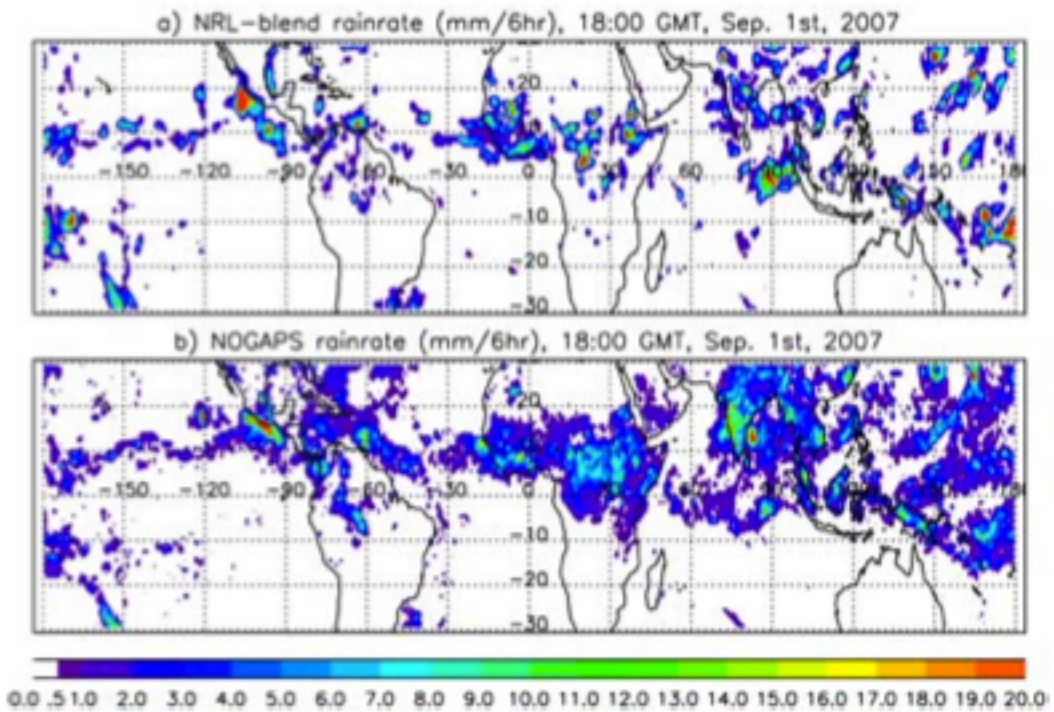
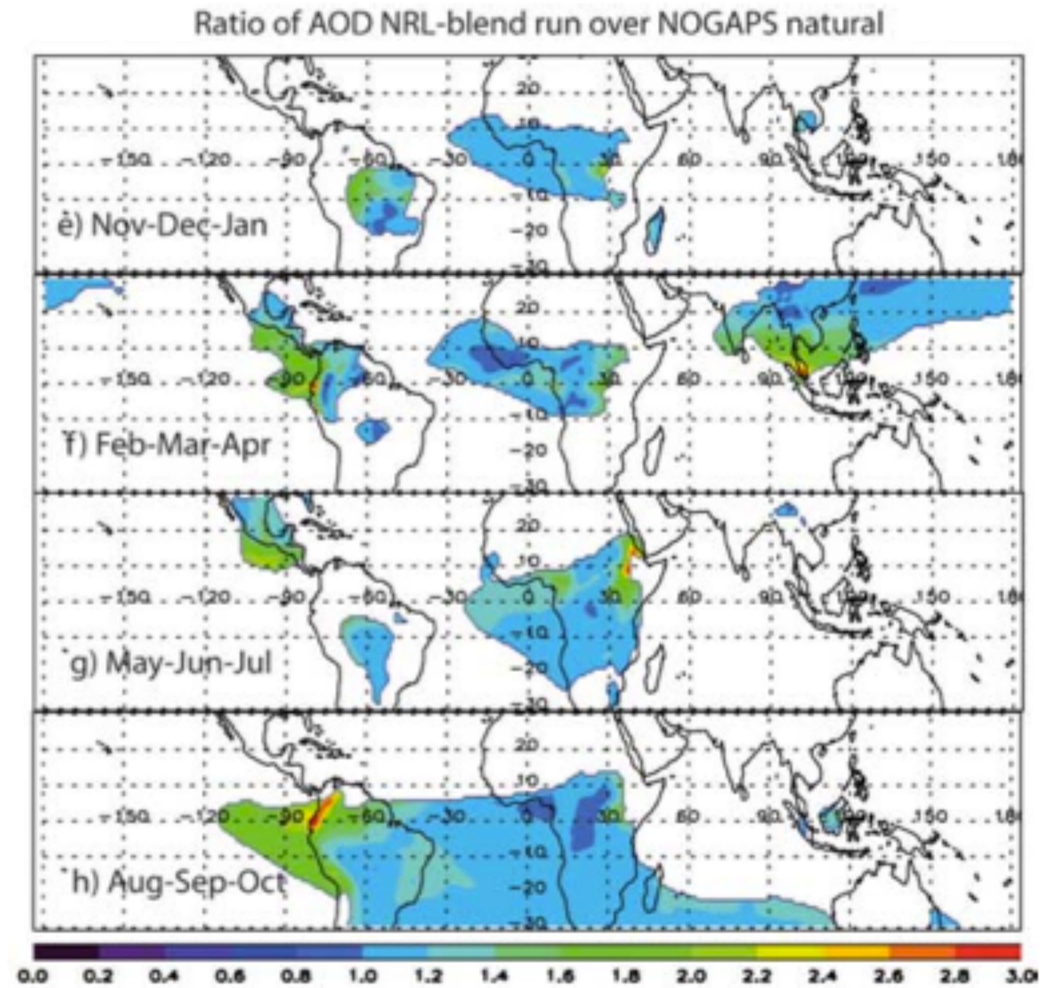


Figure 1. Comparison of NOGAPS precipitation with the NRL-blended precipitation valid at 1800 GMT on 1 September 2007. The total number of precipitation grids within the tropics is 7641 in the NRL-blend, 13770 in NOGAPS, and 6365 for the overlapping area of the two precipitation fields. The tropical average rain rate is 0.7 mm/6hr in the NRL-blend, and 0.9 mm/6hr in NOGAPS.



- Precipitation in model is generally tuned to give a decent regional averages
- Actual precipitation is more isolated
- This has implications for aerosol lifecycle

ICAP Models

- Very preliminary stuff
- Look at loss budgets in three ICAP models: GEOS-5, NAAPS, and MACC (*my apologies to MASINGER*)
- Period considered: April 2012
- Regrid all model fields to 1° x 1.25°

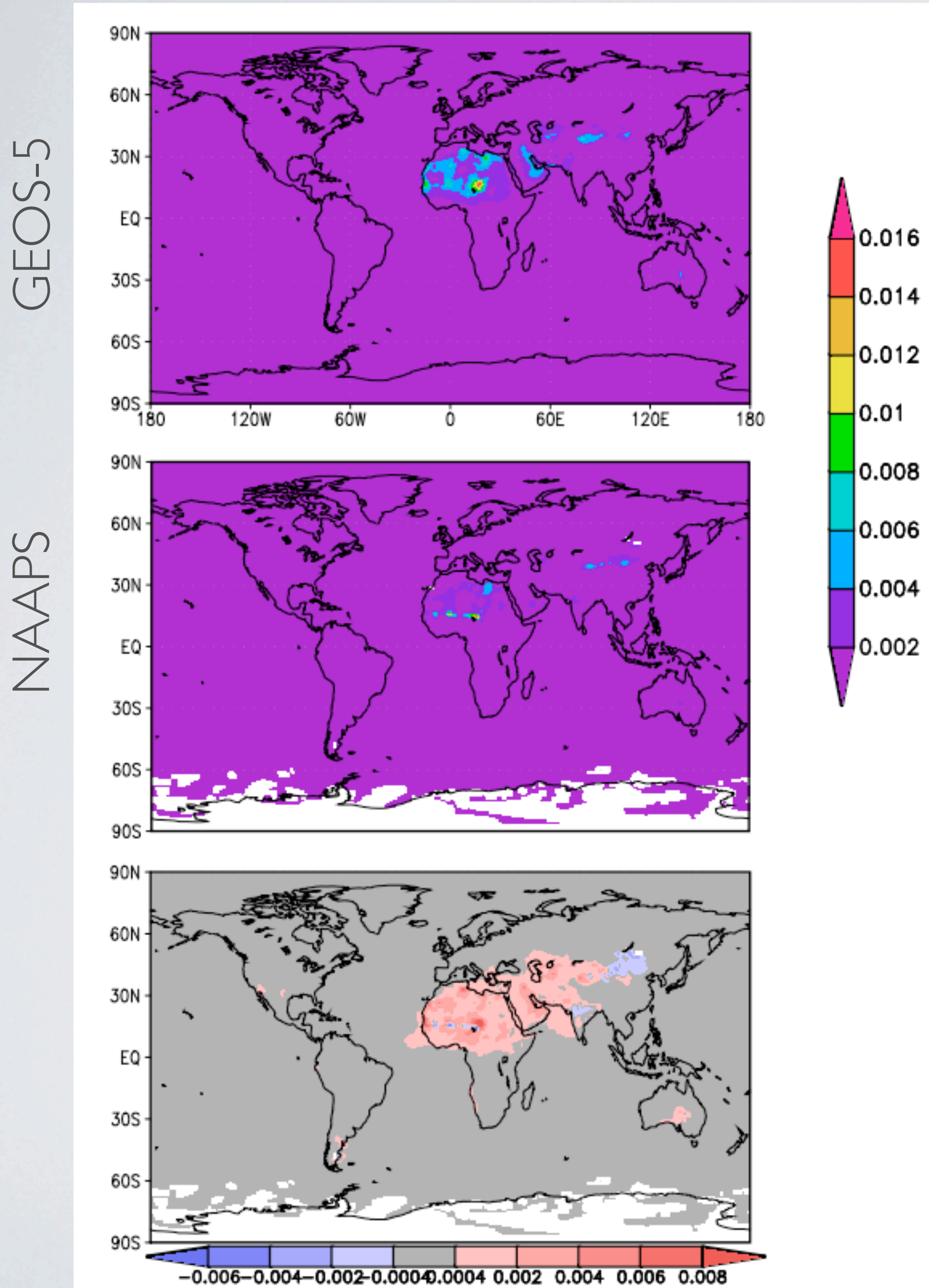
lifetime τ = load / total sink = [days]

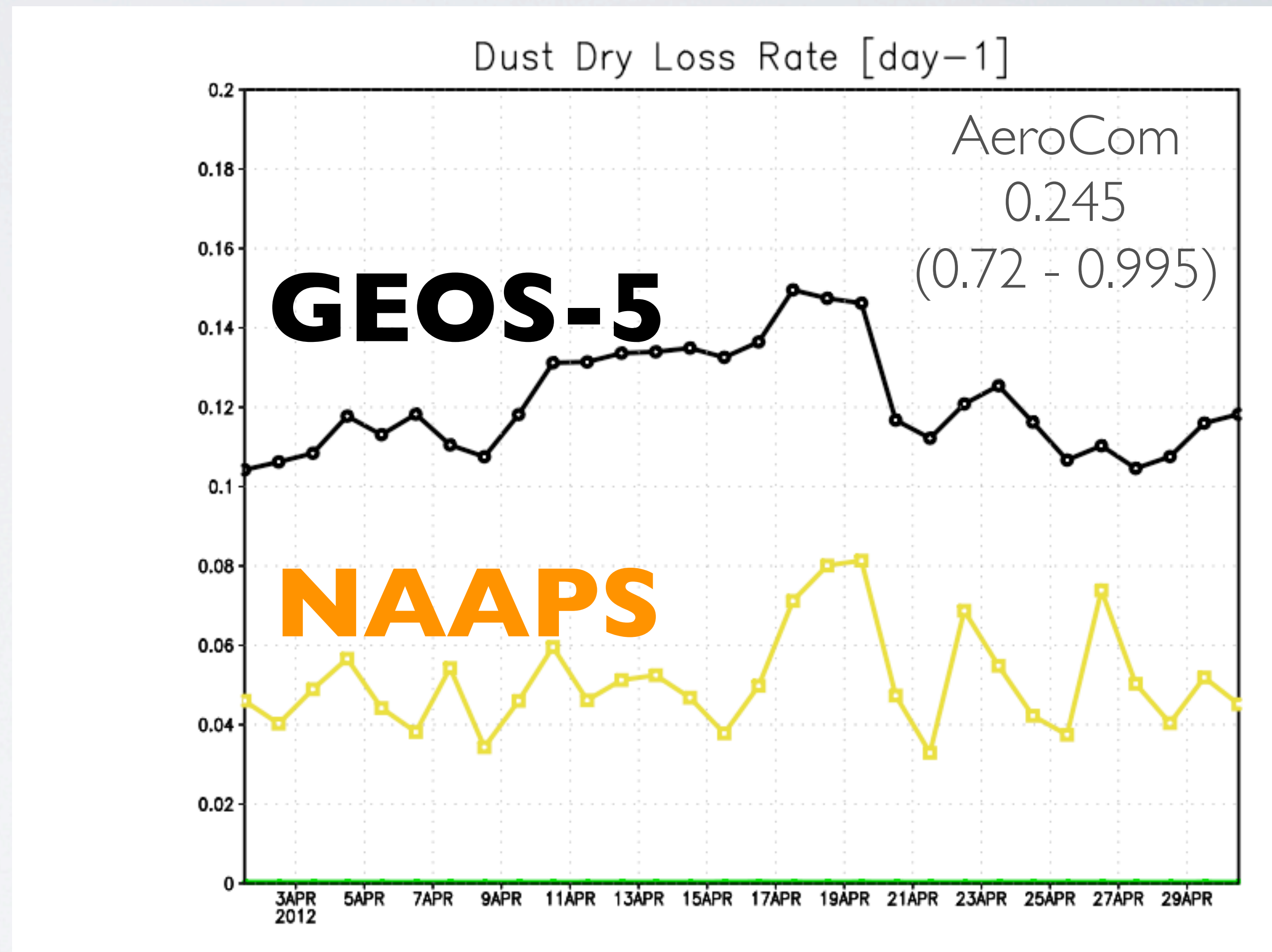
loss rate $k_{loss} = (1/\tau) \cdot sink_{wet\ or\ dry}$ / total sink [$days^{-1}$]

	Lifetime (days)	kwet ($days^{-1}$)	kdry ($days^{-1}$)
DU	**5.85**	**0.055**	**0.116**
	4.33	*0.056*	*0.176*
	4.22	0.084	0.245
	(0.92–18.4)	(0.027–0.169)	(0.072–0.995)
SS	**0.88**	**0.45**	**0.69**
	0.77	*0.40*	*0.90*
	0.48	0.73	1.60
	(0.03–1.59)	(0.11–2.45)	(0.06–2.94)
BC	**8.82**	**0.078**	**0.036**
	8.62	*0.079*	*0.037*
	6.91	0.128	0.028
	(5.15–15.3)	(0.055–0.175)	(0.005–0.046)
OC	**6.90**	**0.104**	**0.041**
	6.56	*0.109*	*0.044*
	6.07	0.137	0.033
	(4.12–8.08)	(0.107–2.445)	(0.006–0.094)
SU	**4.42**	**0.194**	**0.033**
	5.78	*0.146*	*0.028*
	4.14	0.224	0.030
	(2.56–6.36)	(0.115–0.340)	(0.003–0.074)

Dust Dry Removal

Dust dry removal sink normalized by GEOS-5 loading

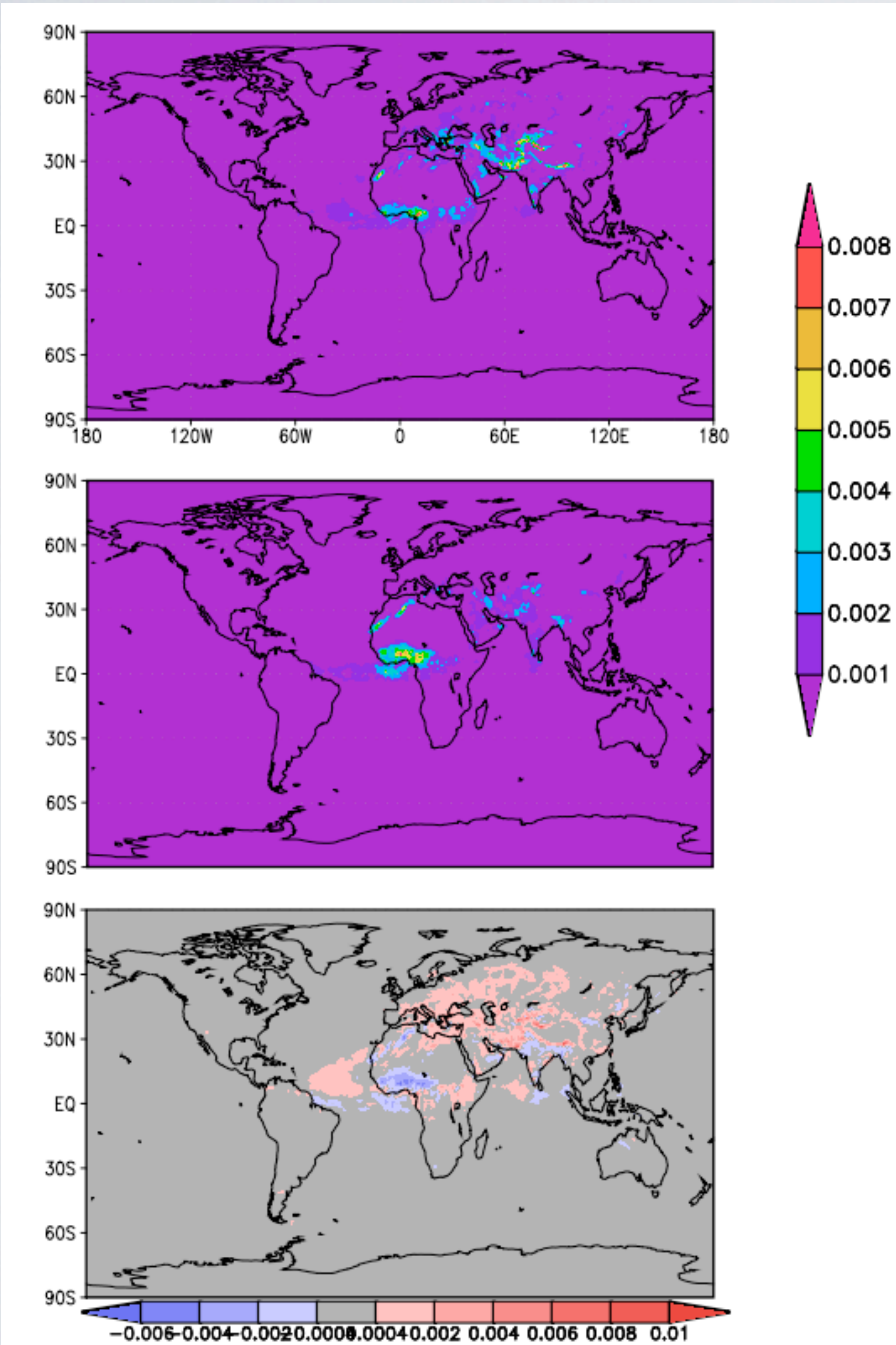




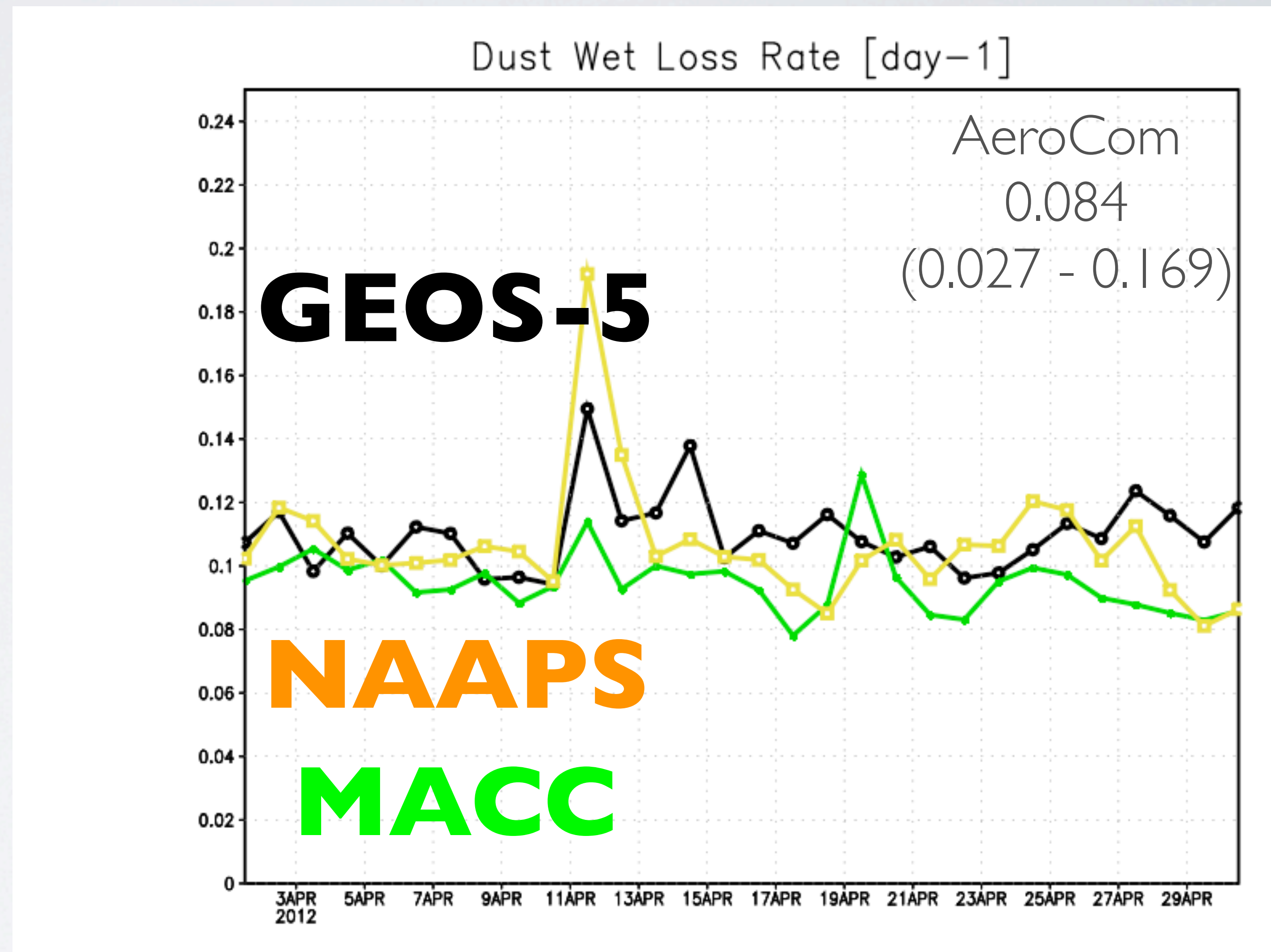
Dust Wet Removal

GEOS-5

NAAPS



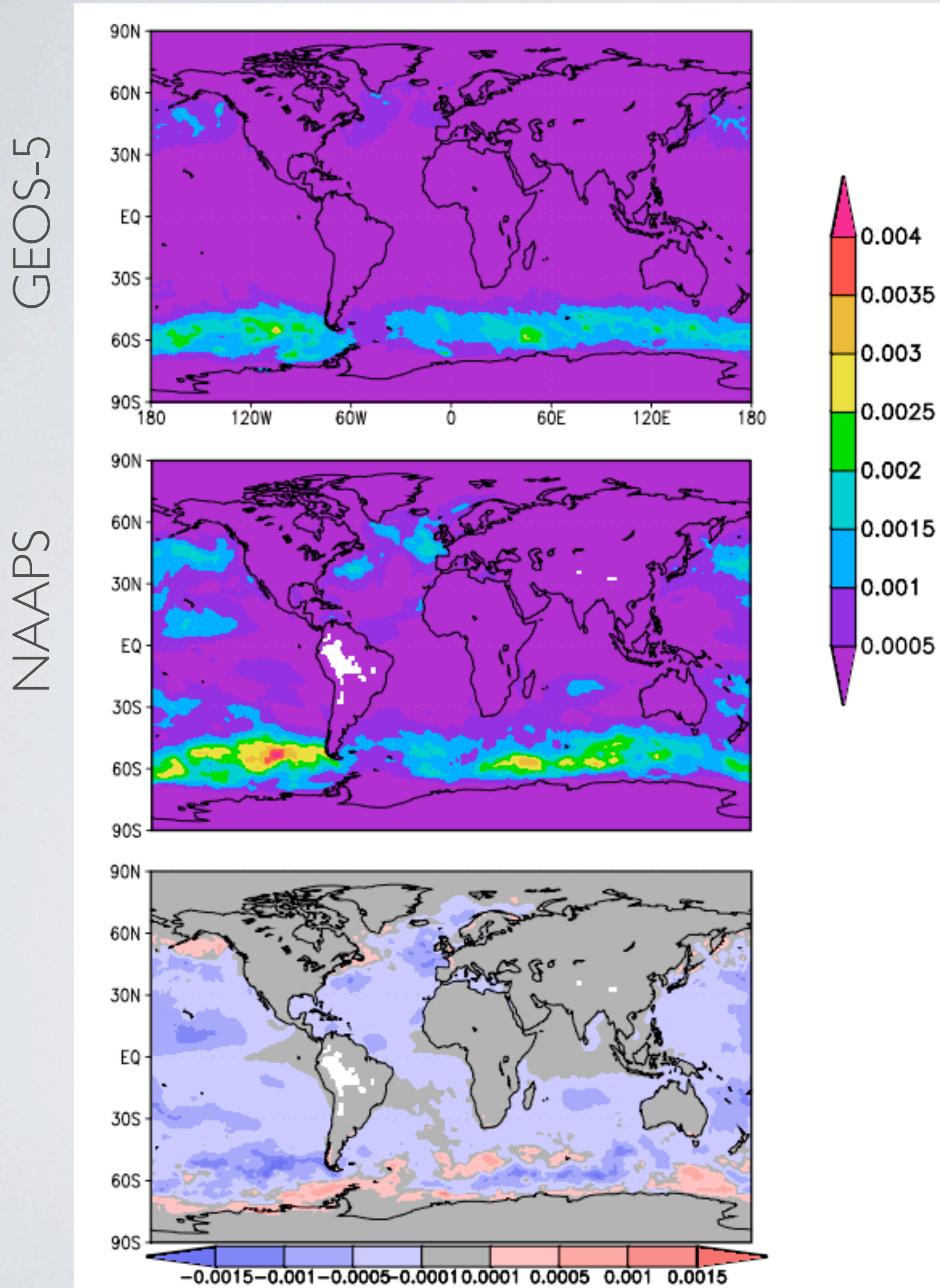
Dust wet removal sink normalized by GEOS-5 loading



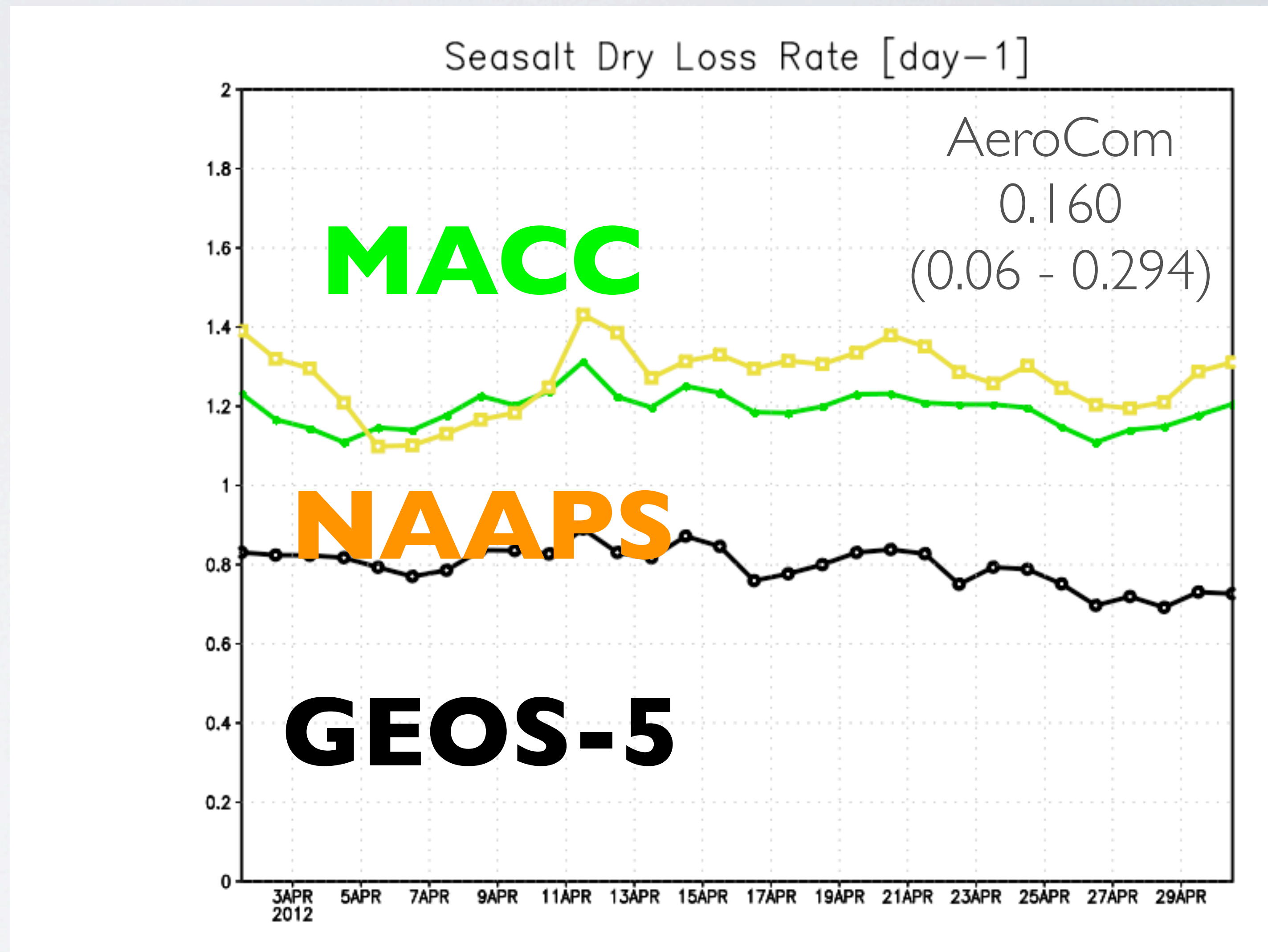
$\tau_{\text{GEOS-5}}$ ~ 4 days

τ_{NAAPS} ~ 6 days

Seasalt Dry Removal



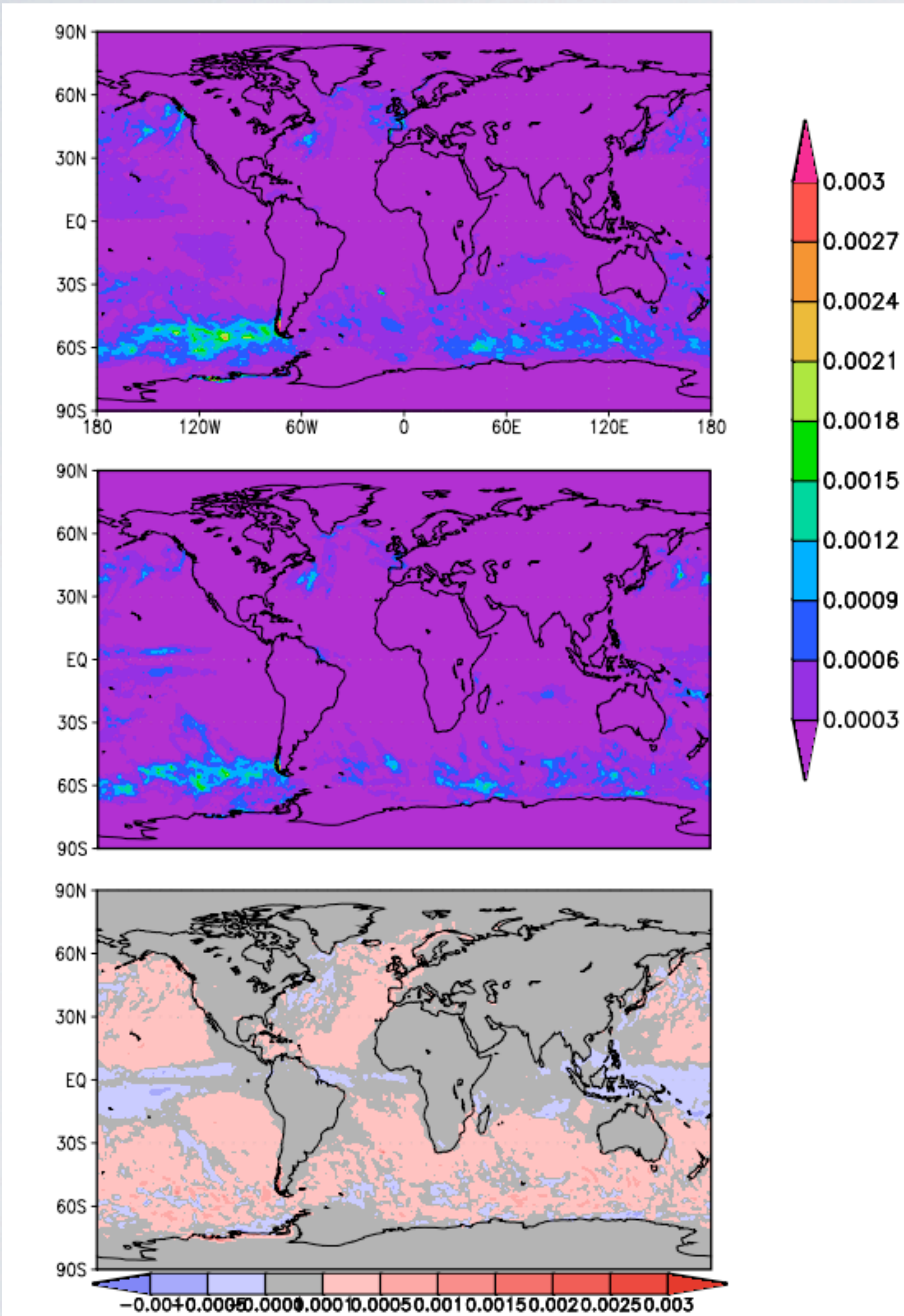
Seasalt dry removal sink normalized by GEOS-5 loading



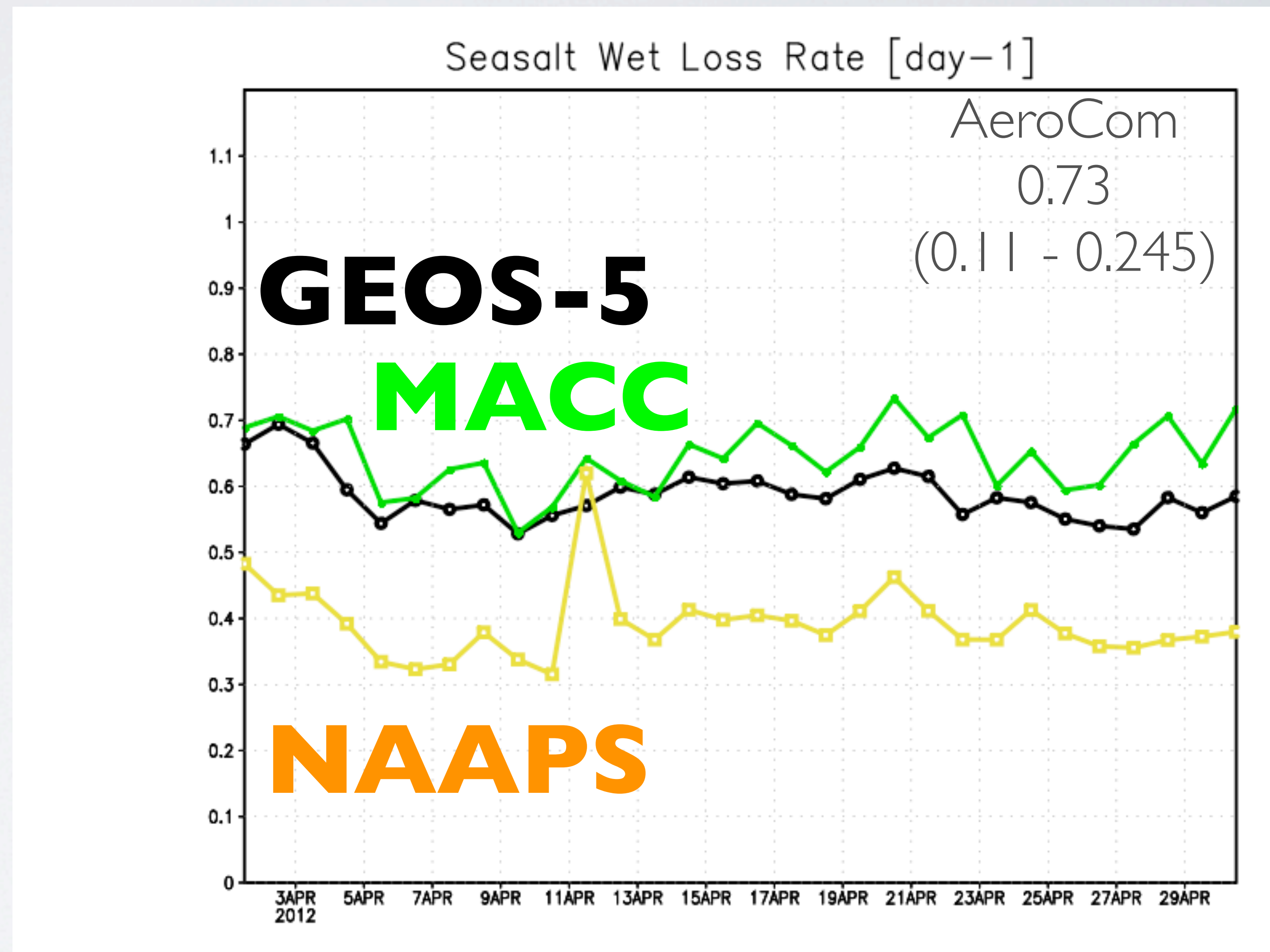
Seasalt Wet Removal

GEOS-5

NAAPS



Seasalt wet removal sink normalized by GEOS-5 loading



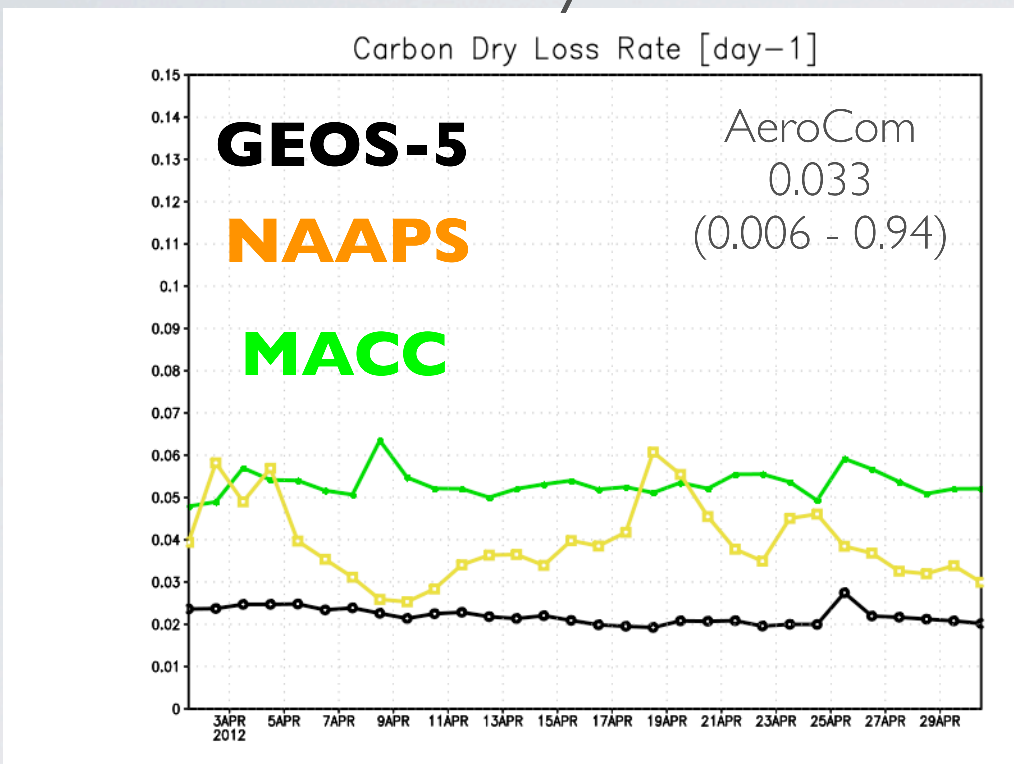
$\tau_{GEOS-5} \sim 0.7$ days

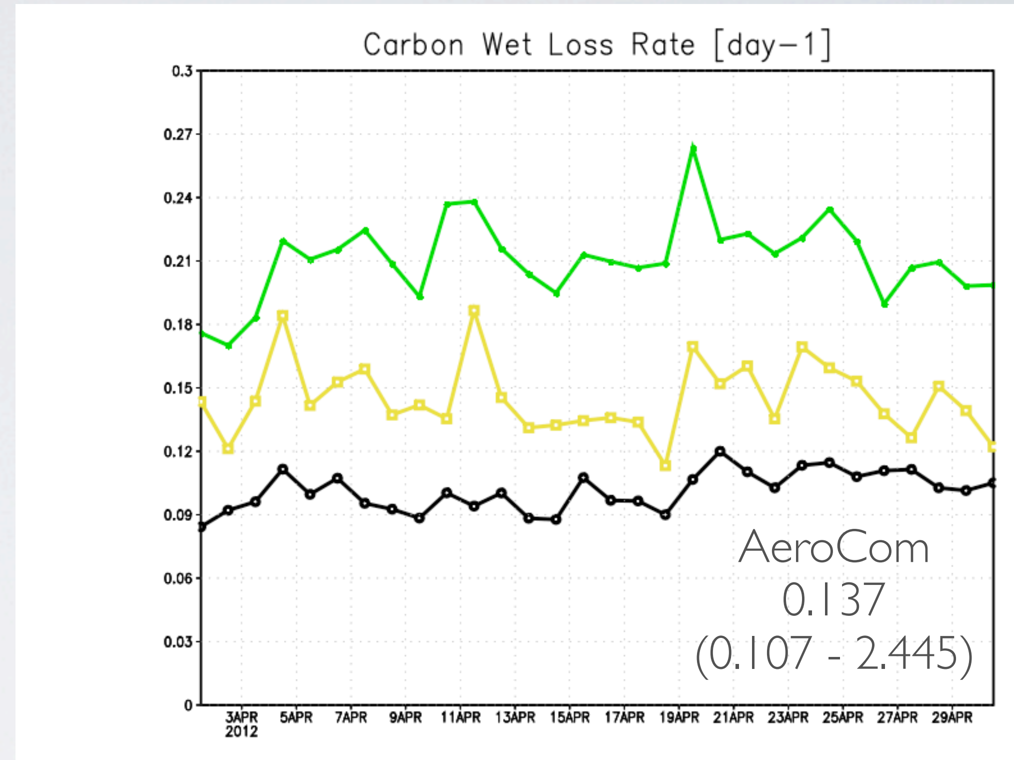
$\tau_{NAAPS} \sim 0.6$ days

Carbon and Sulfate

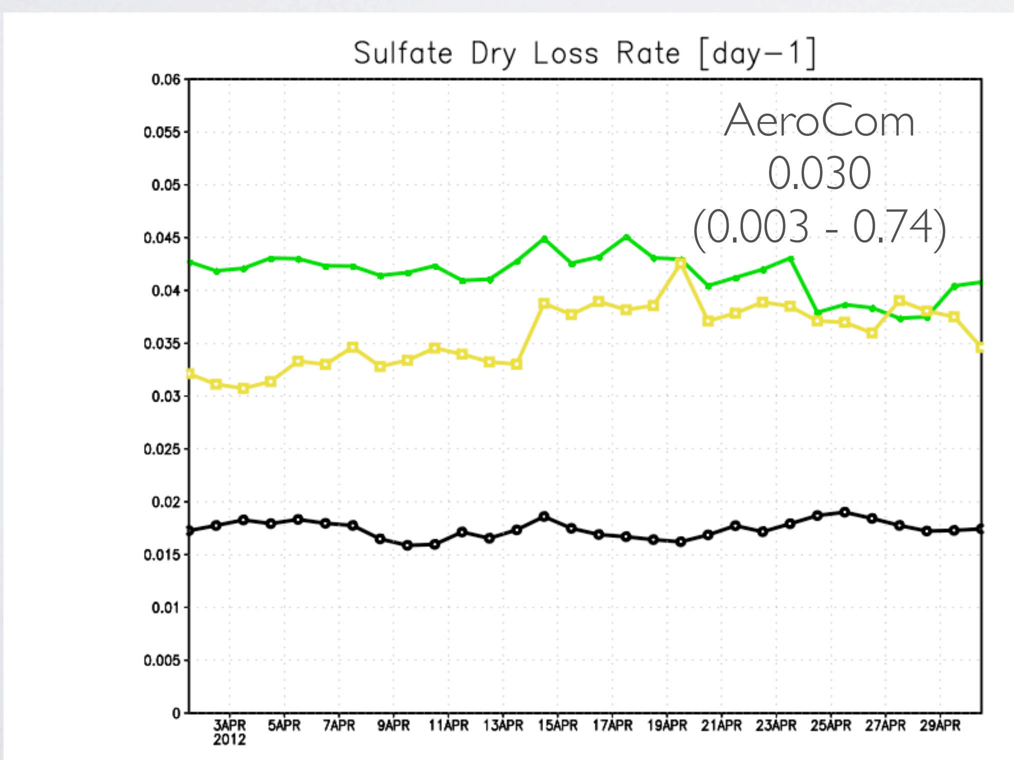
Dry | Wet

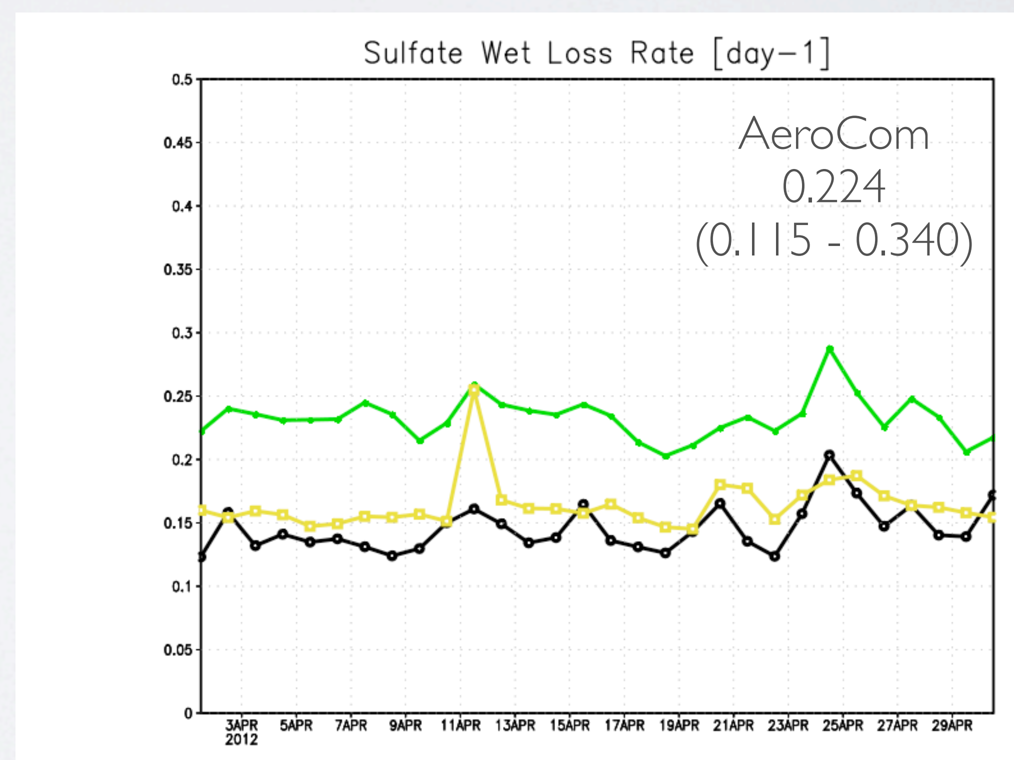
Carbonaceous





Sulfate





Conclusion and Questions

- Except for dust, GEOS-5 tends to have longest lifetimes
- GEOS-5 sedimentation is most aggressive (operator order?)
- Dry and wet loss processes may compensate (dust and seasalt)
- What are scale dependencies of needed model variables?
- What is sensitivity of algorithms to model space?
- What is role of external vs. internal mixing in loss processes?
- How physically realistic are assumptions for, e.g., carbonaceous wet removal?