Global shortwave aerosol direct radiative forcing from MODIS measurements for mineral dust, marine aerosol, biomass-burning and industrial pollution.

Nicolas Bellouin, Olivier Boucher, and Jim Haywood

November 2004

The shortwave direct aerosol radiative forcing

What is needed?

1. The aerosol optical thickness for each type
2. The aerosol optical properties for each type
3. The surface albedo

Step 1

Get the optical thickness for mineral dust, marine aerosol and anthropogenic aerosols

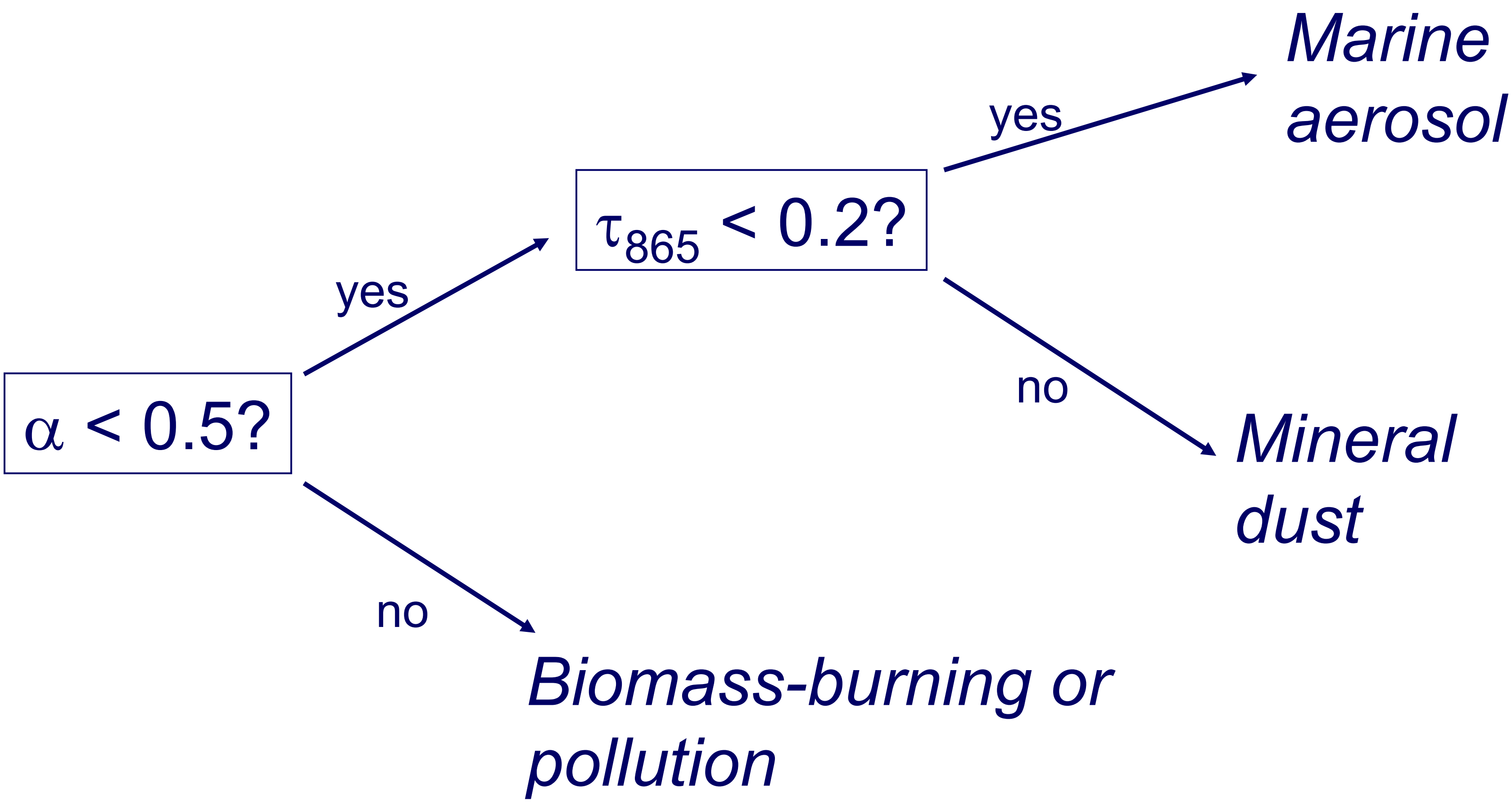
Splitting the total aerosol optical thickness

Solve $\tau_{total} = \tau_{dust} + \tau_{marine} + \tau_{biomass/pollution}$

Help wanted!

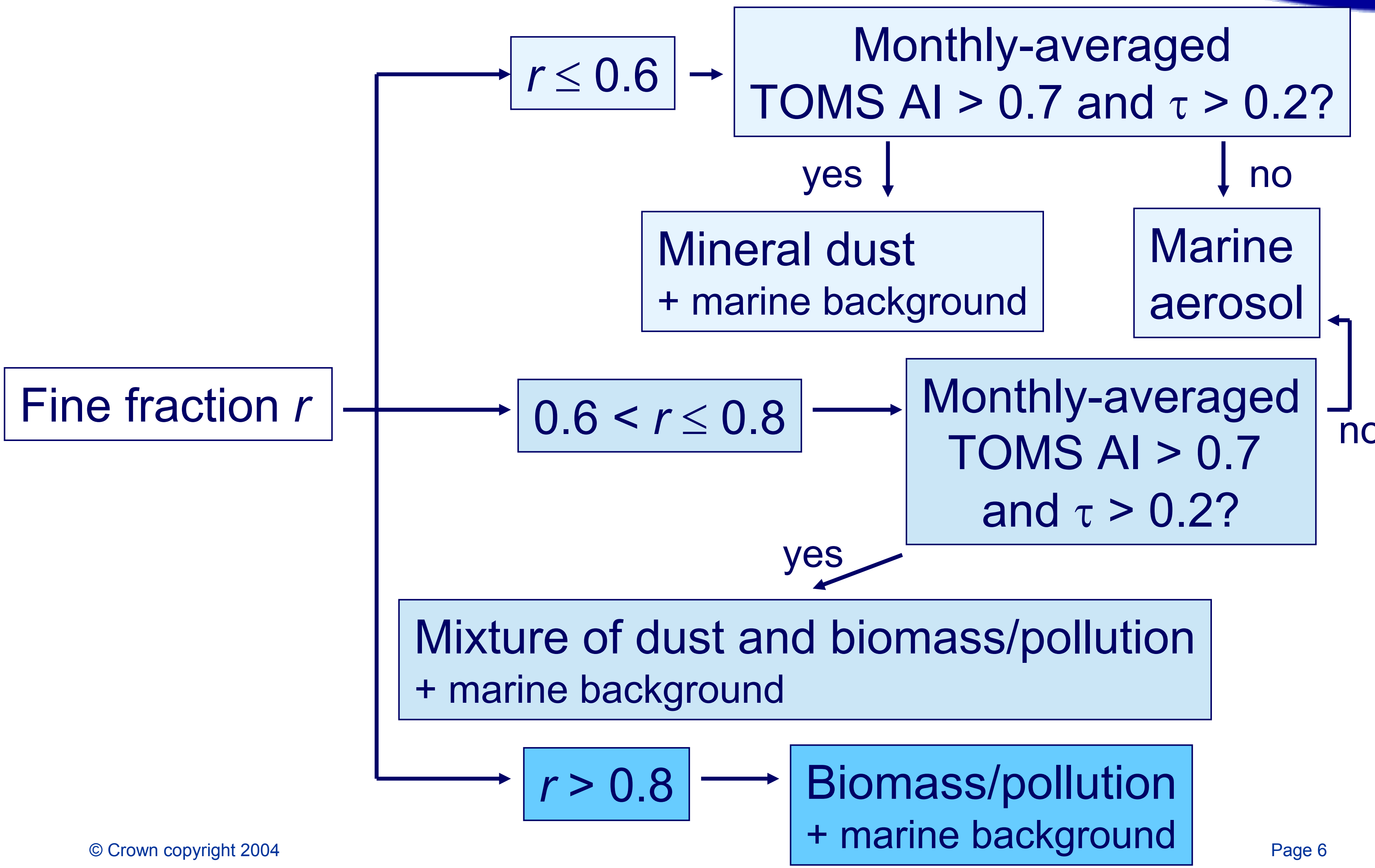
- Ångström exponent α
  spectral dependence of the extinction
- Fine fraction r
  fraction of the OT due to the accumulation-mode particles
- Surface wind speeds
  give a rough estimate of the marine aerosol OT
- TOMS aerosol index
  detects UV-absorbing aerosols (i.e. dust and biomass-burning)

The POLDER-1 algorithm over clear-sky oceans



Bellouin et al., *GRL*, 2003

The MODIS algorithm over clear-sky oceans



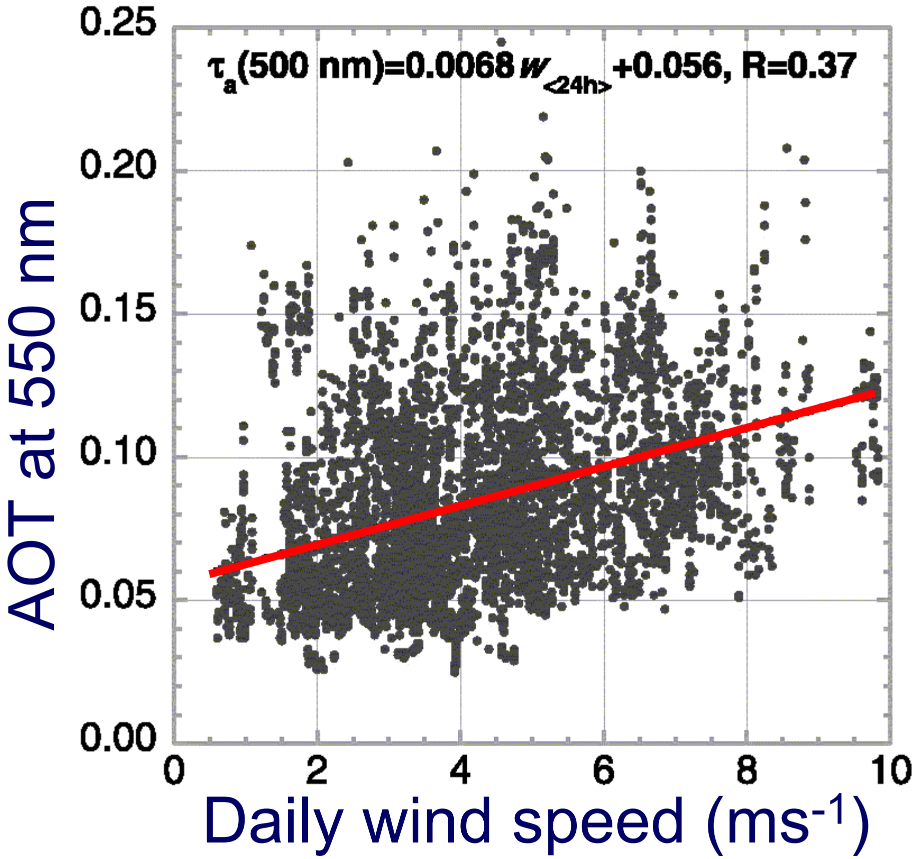
In-situ measurements of *r*

Measurements from the Met Office C-130
Osborne and Haywood, *Atmos. Res.*, 2004

Experiment	**Aerosol type**	***r***
SHADE	Mineral dust	0.67
SAFARI 2000	Aged biomass-burning (over ocean)	0.97
	Fresh biomass-burning (over land)	0.95
TARFOX	Industrial pollution	0.88
ACE-2	Industrial pollution, mixed with marine aerosol	0.60
---	Marine aerosol	0.16

The marine aerosol background

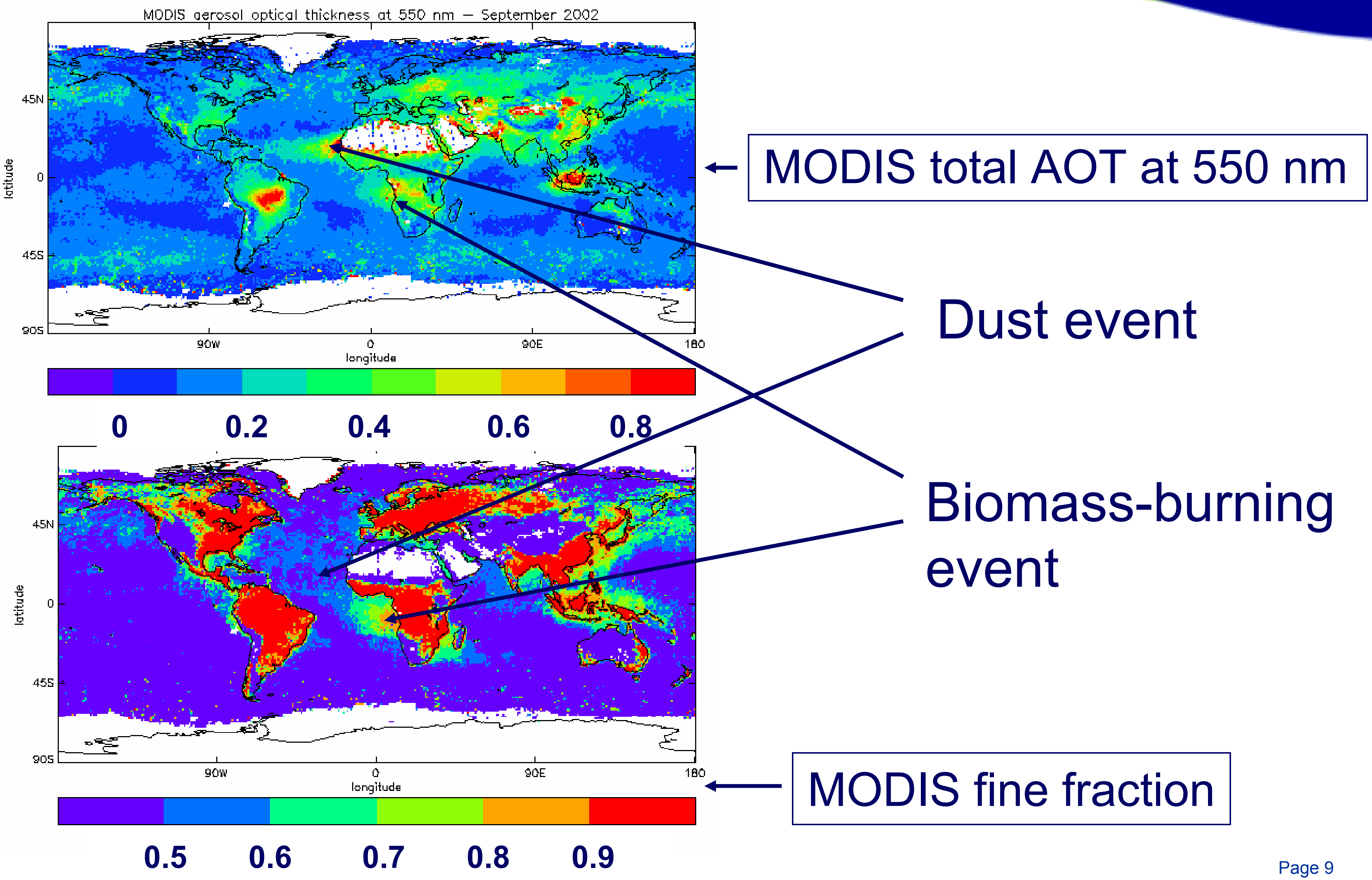
Get a *sensible* estimate of the marine aerosol OT when dust or biomass/pollution is identified.



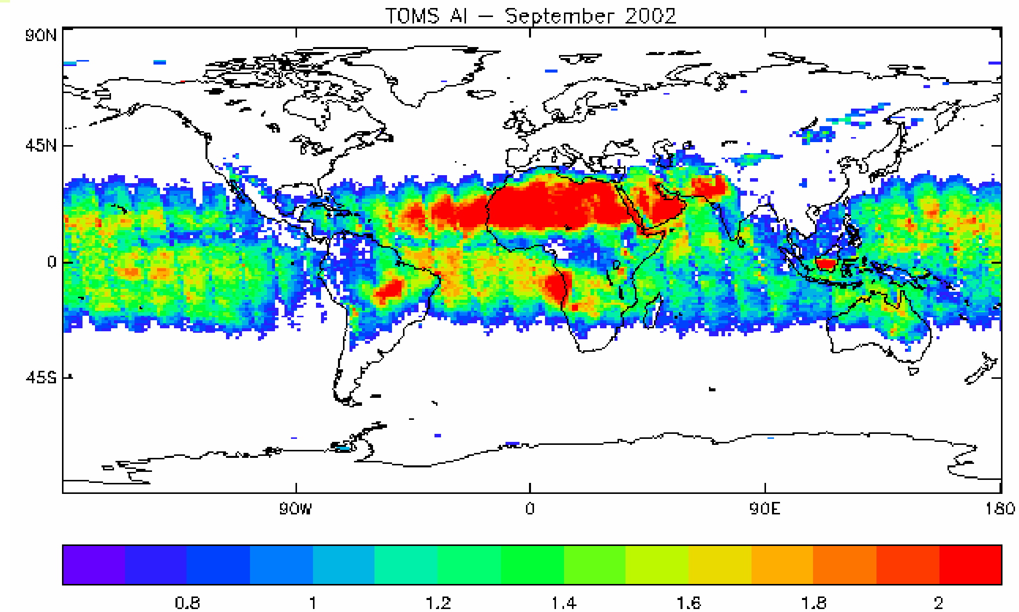
Linear relationship from Smirnov et al., *JGR, 2003*

In the algorithm, wind speeds are provided by SSM/I.

The MODIS algorithm: Data for September 2002

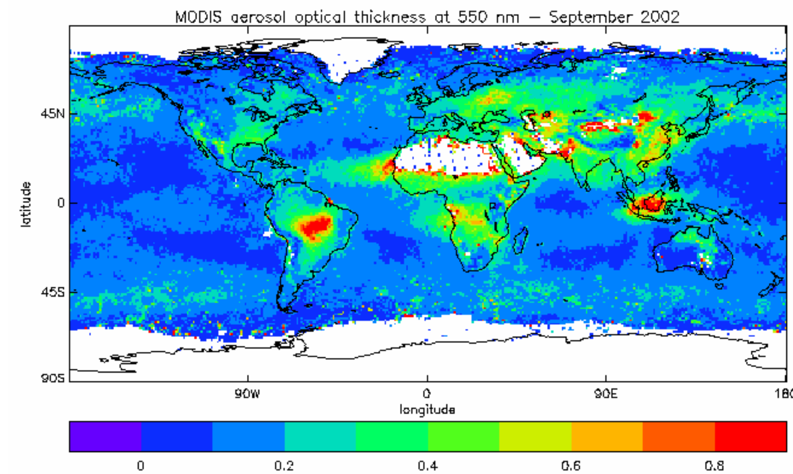


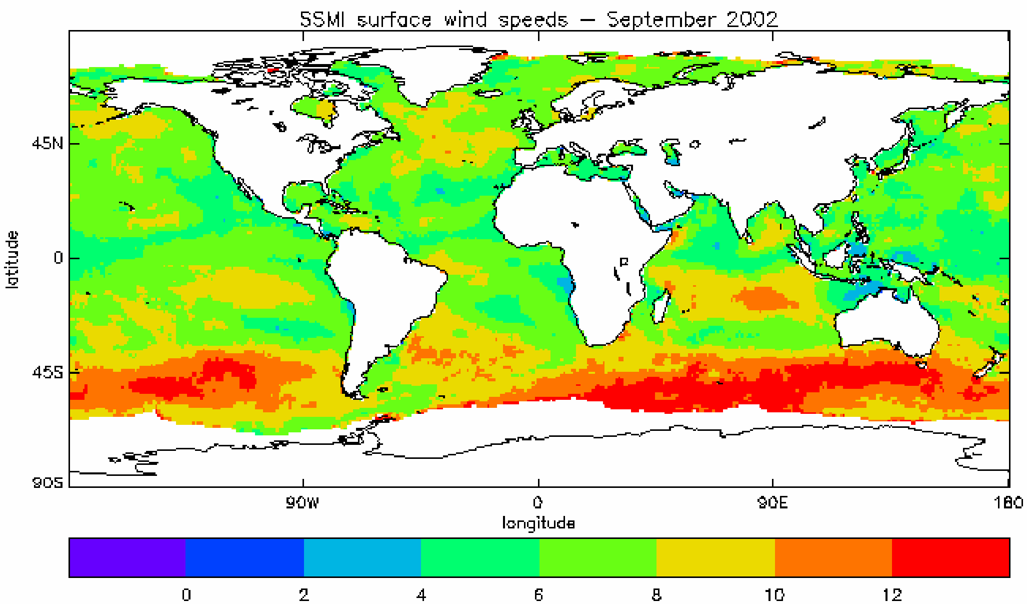
The MODIS algorithm: Data for September 2002



TOMS Aerosol Index

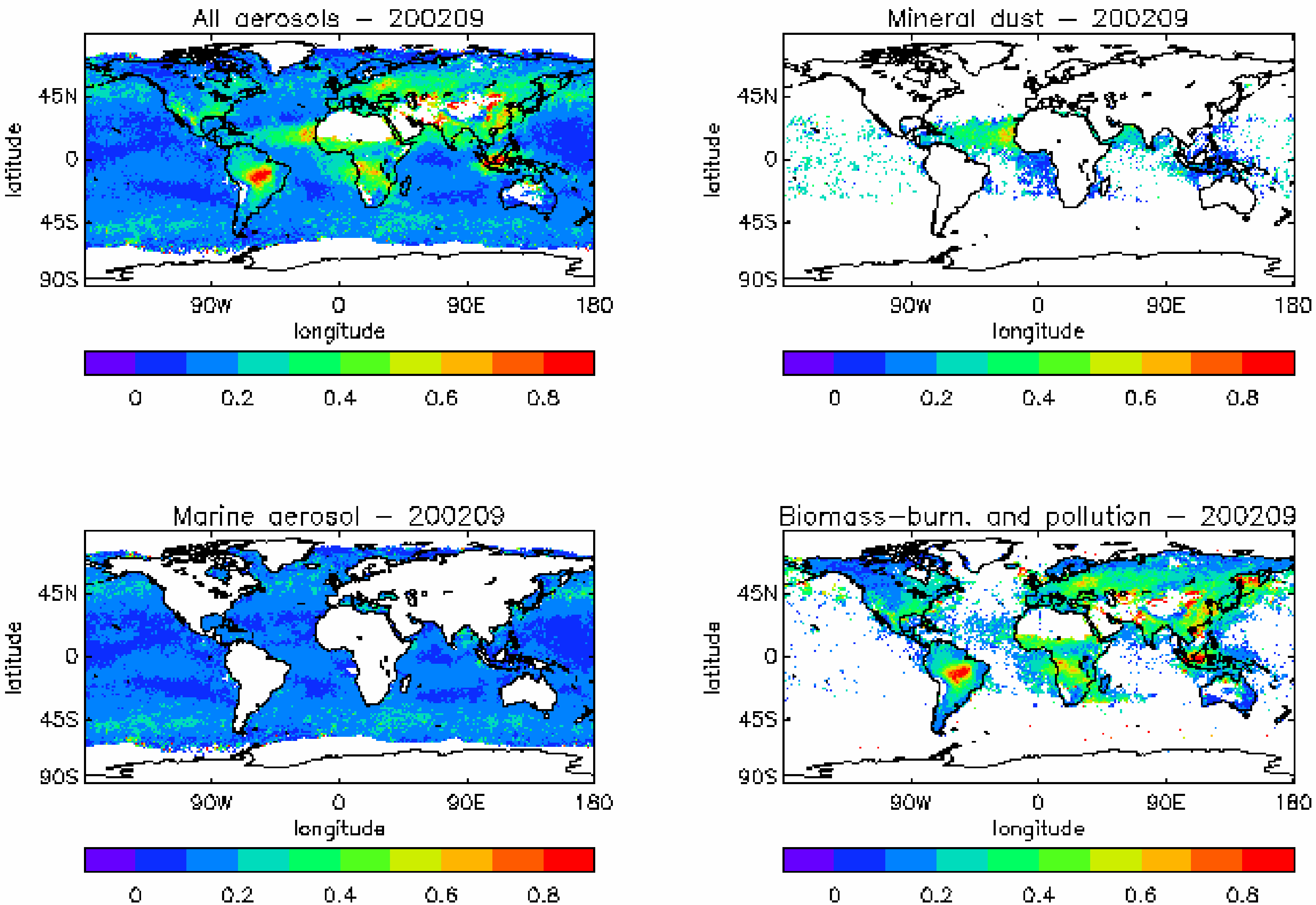
MODIS τ_{550}



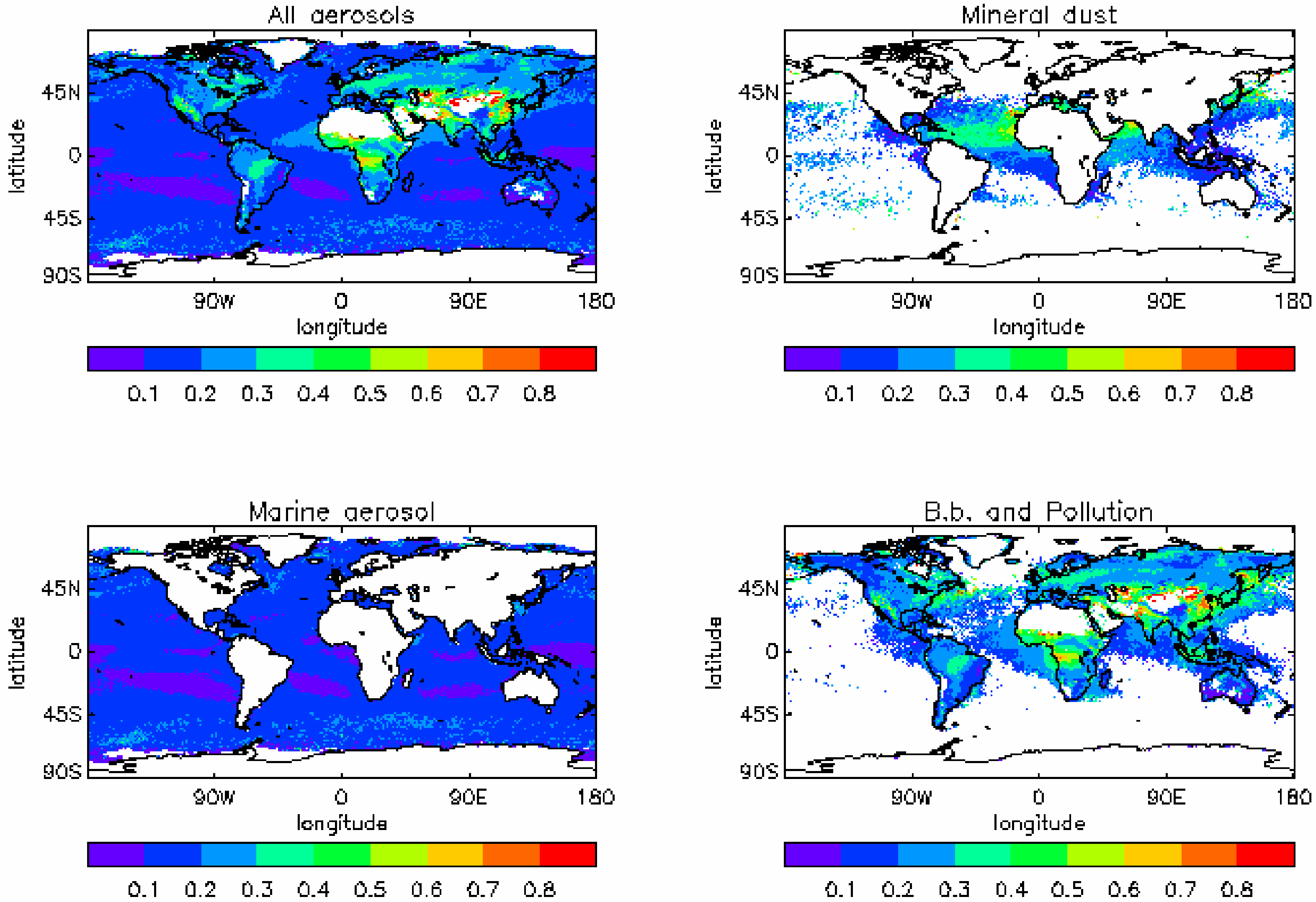


SSM/I wind speeds

The MODIS algorithm: Results for September 2002



Distributions of optical thicknesses for 2002



Step 2

Estimate the radiative forcing from the discriminated optical thicknesses

From the optical thickness to the radiative forcing

Aerosol model:
- size distribution
- refractive index
(from AERONET)

Mie theory, 24 λ

$\tau(\lambda)$, $\omega_0(\lambda)$, $P(\Theta,\lambda)$

Aerosol optical thickness of a given aerosol type (from MODIS or POLDER)

radiative transfer code

Surface albedo (VIS & near IR)

DARF ΔF
- instantaneous or daily-averaged
- at the TOA or surface

Met Office

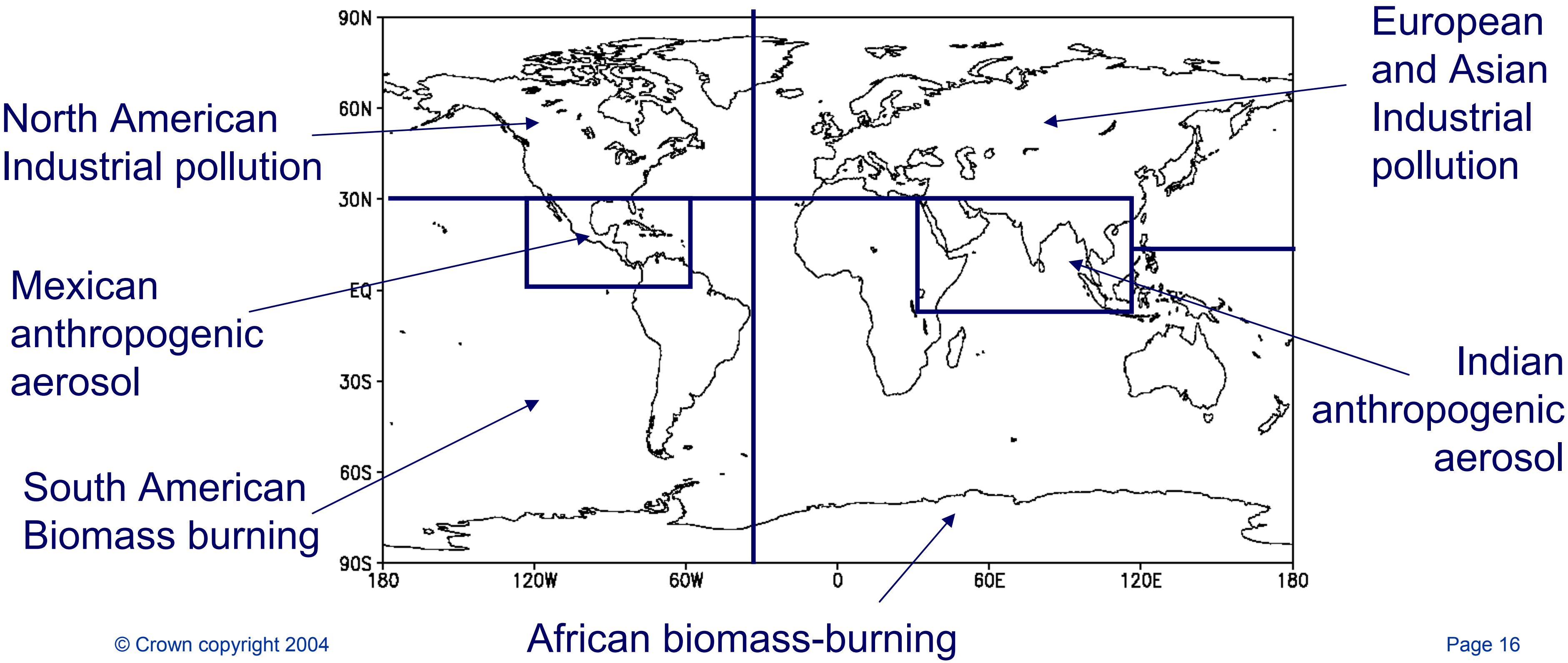
Aerosol optical properties

Dubovik et al., *JAS*, 2002

Aerosol	AERONET site	ω_0 at 550 nm
Dust	Cape Verde	0.97
Marine aerosol	Hawaii	0.98 **(0.99)**
Industrial pollution	Greenbelt, USA	0.97
Industrial pollution	Créteil, France	0.93
Industrial pollution, biomass-burning	Mexico City, Mexico	0.88
Industrial pollution, biomass-burning	Maldives (INDOEX)	0.89
Biomass-burning	Brazil	0.90
Biomass-burning	Zambia	0.86

Biomass-burning and pollution properties

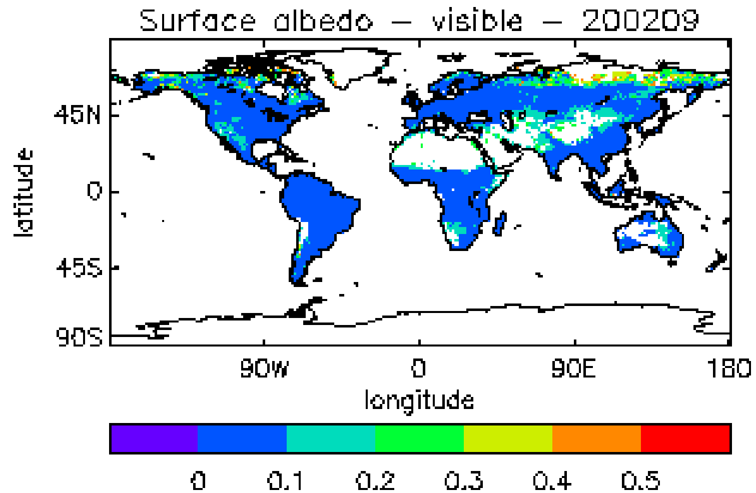
- The optical thickness is derived in the same way for all biomass-burning and pollution aerosols.
- But optical properties differ according to geographic location, using regional boxes.

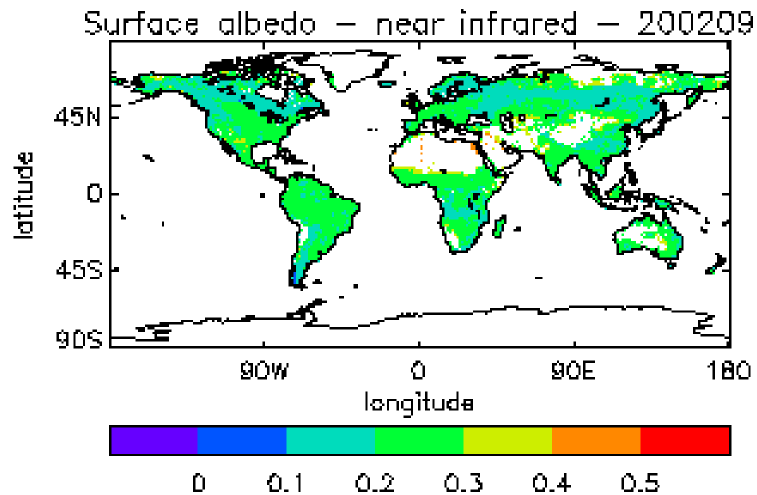


Surface albedo

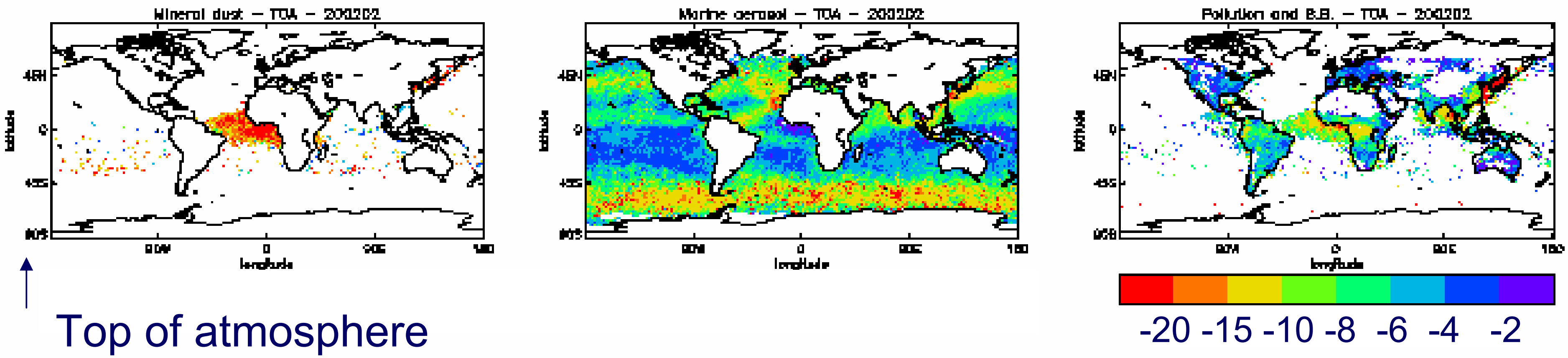
Over ocean, the albedo is computed using *Cox and Munk* [1954]

Over land, the albedo is derived from MODIS measurements (products MOD43B3, *Schaaf et al.*, 2002) and corrected for aerosol effects.





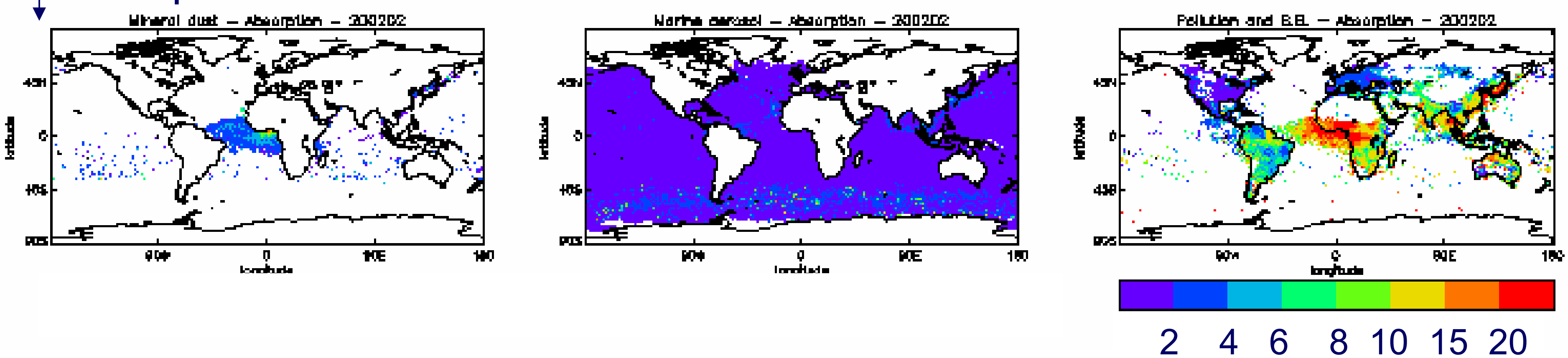
MODIS: Monthly average for February 2002



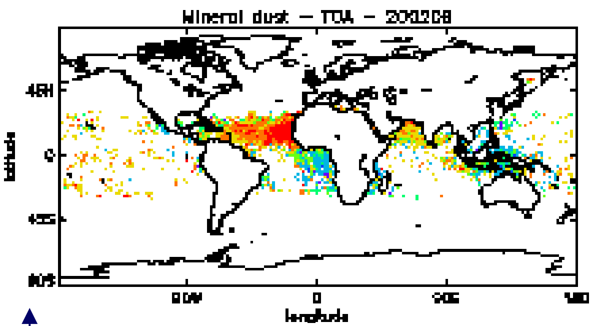
Top of atmosphere

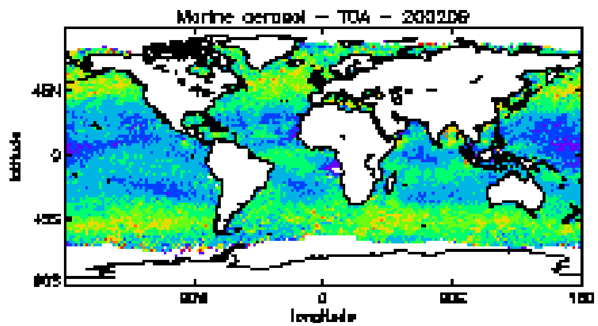
Mineral dust | Marine aerosol | Biomass+Poll.

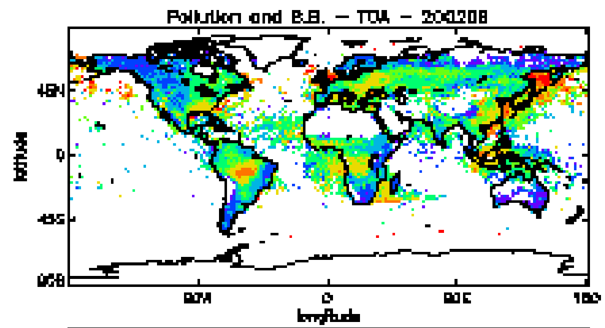
Absorption

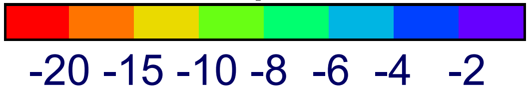


MODIS: Monthly averages for September 2002









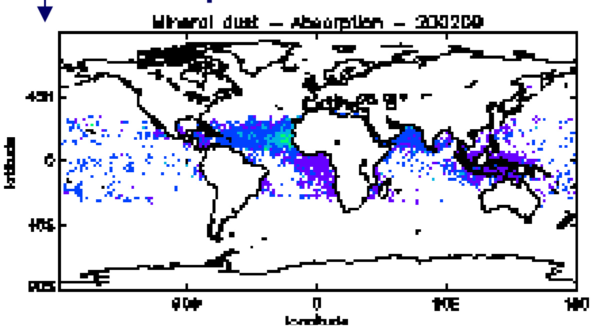
Top of atmosphere

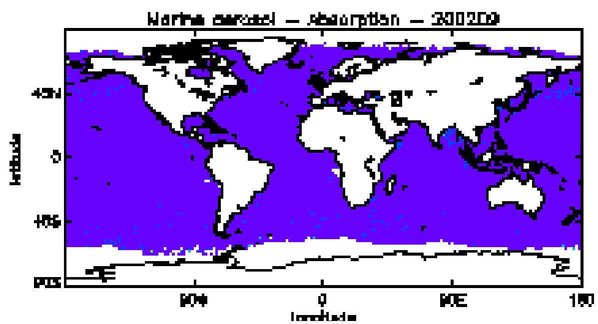
Mineral dust

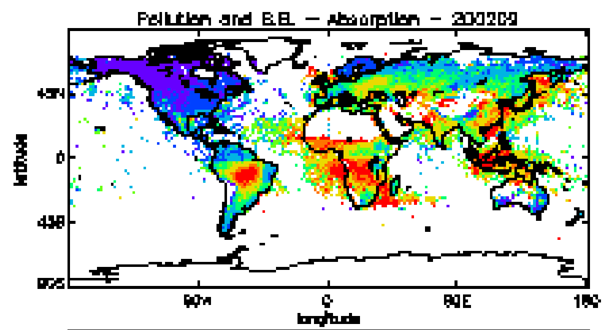
Marine aerosol

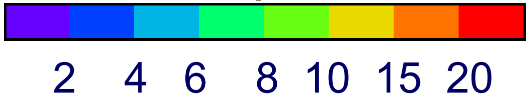
Biomass+Poll.

Absorption









MODIS: Global clear-sky averages for 2002

Met Office

Mineral dust	TOA (Wm^{-2})	Surface (Wm^{-2})	Abs. (Wm^{-2})	τ (550 nm)	E (Wm^{-2} / unit τ)
Global	-0.48	-0.57	0.09	0.009	-56
Ocean	-0.71	-0.85	0.14	0.013	-56
Marine aerosol					
Global	-3.61	-4.25	0.64	0.076	-47
Ocean	-5.35	-6.31	0.95	0.113	-47
bb + poll					
Global	-2.39	-5.43	3.04	0.093	-26
Ocean (+)	-0.52	-1.18	0.66	0.014	-37
Land (-)	-6.18	-14.06	7.88	0.255	-24

(+) lower bound of anthropogenic RF (-) upper bound of anthropogenic RF

Conclusion

- Our algorithm applied to MODIS data does a good job distributing the total optical thickness to mineral dust, marine aerosol, and biomass-burning and pollution aerosols.

- Choosing realistic aerosol properties from AERONET measurements improves the confidence in the estimated radiative forcings.

- Paper to be submitted soon.

Radiative forcing efficiency

Olivier Boucher
LOA (CNRS/USTL, France)

Contributions from
Nicolas Bellouin
Shekar Reddy
Jim Haywood

The concept of radiative forcing efficiency (RFE) has been introduced to decouple uncertainties on aerosol burden/OD from uncertainties in other inputs and RT and to allow intercomparaison.

Clear-sky RFE of a particular aerosol type depends on:
- aerosol single scattering albedo & aerosol upscattering
- surface albedo
- diurnal and seasonal distribution of SZA at a particular location / region
- histogram of AOD (for a given average AOD).
+ small uncertainty on RT scheme (assuming RT is done properly!)

All-sky RFE depends additionnally on:
- vertical distribution of aerosol and cloud
- cloud fraction.
+ it may be more sensitive to the RT scheme used.

Moreover RFE will depend critically on
- RH growth factor if reported by unit of dry mass (sulfate, OM, sea-salt)
- radius cut size if reported by unit of mass for sea-salt and dust

Clear-sky and all-sky TOA SW RFE from our GCM calculations:

	clear-sky	all-sky
sulfate	RFE = -235 and	-145 $W\ (g\ sulfate)^{-1}$

sulfate: RFE = -235 and -145 W $(g\ sulfate)^{-1}$
per mass of sulfate, but also includes ammonium & water
fairly constant since B&A [1995], on the low side?
fairly constant for different SRES sulfate distributions

BC: RFE = +1200 and +1400 W $(g\ BC)^{-1}$
BC single scattering albedo = 0.2
BC density is low (1 g cm^{-3})

OM: RFE = -132 and -87 W $(g\ OM)^{-1}$
slightly absorbing, less hygroscopic than sulfate

Needs to be intercompared in AEROCOM B & PRE
Weighted by the sophistication of the RT procedure.

Global RF and RFE from MODIS/AERONET aerosol properties and RT calculations

Mineral dust	TOA (Wm^{-2})	Surface (Wm^{-2})	Abs. (Wm^{-2})	τ (550 nm)	E (Wm^{-2} / unit τ)
Global	-0.48	-0.57	0.09	0.009	~~-56~~
Ocean	-0.71	-0.85	0.14	0.013	-56
Marine aerosol					
Global	-3.61	-4.25	0.64	0.076	~~-47~~
Ocean	-5.35	-6.31	0.95	0.113	-47
bb + poll					
Global	-2.39	-5.43	3.04	0.093	-26
Ocean	-0.52	-1.18	0.66	0.014	-37
Land	-6.18	-14.06	7.88	0.255	-24

Bellouin, Boucher & Haywood

Clear-sky TOA SW RFE (@550 nm) from the GCM calculations:

			"MODIS"
dust ocean	RFE = -21 W m^{-2} tau^{-1}	vs	-56 W m^{-2} tau^{-1}
sea-salt ocean	RFE = -25 W m^{-2} tau^{-1}	vs	-47 W m^{-2} tau^{-1}
anthropogenic ocean	RFE = -12 W m^{-2} tau^{-1}	vs	-37 W m^{-2} tau^{-1}
anthropogenic land	RFE = -10 W m^{-2} tau^{-1}	vs	-24 W m^{-2} tau^{-1}
anthropogenic globe	RFE = -11 W m^{-2} tau^{-1}	vs	-26 W m^{-2} tau^{-1}

BUT GCM clear-sky <> MODIS clear-sky (sampling issue) !

==> sample MODIS clear-sky in model nudged 2002 run

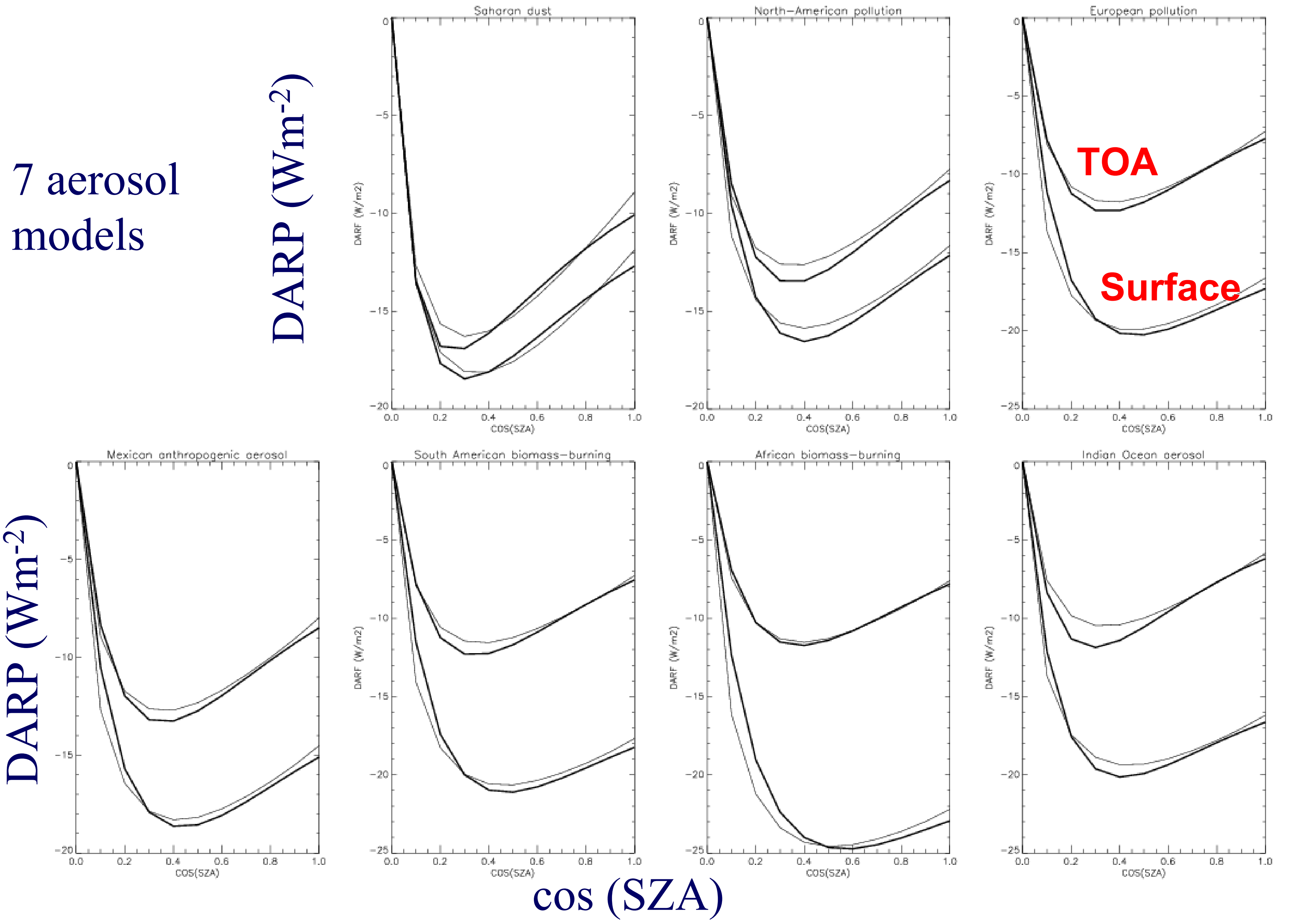
==> intercompare in AEROCOM B&PRE to see if LMDZ is an outlier

* RT scheme ?
* aerosol SSA ?
* surface albedo ?
* our GCM dust and sea-salt calculations are done in the presence of other (absorbing) aerosols, which shifts RFs to less negative values.

Shortwave 24-stream 24-waveband versus 2-stream 2-waveband RT codes

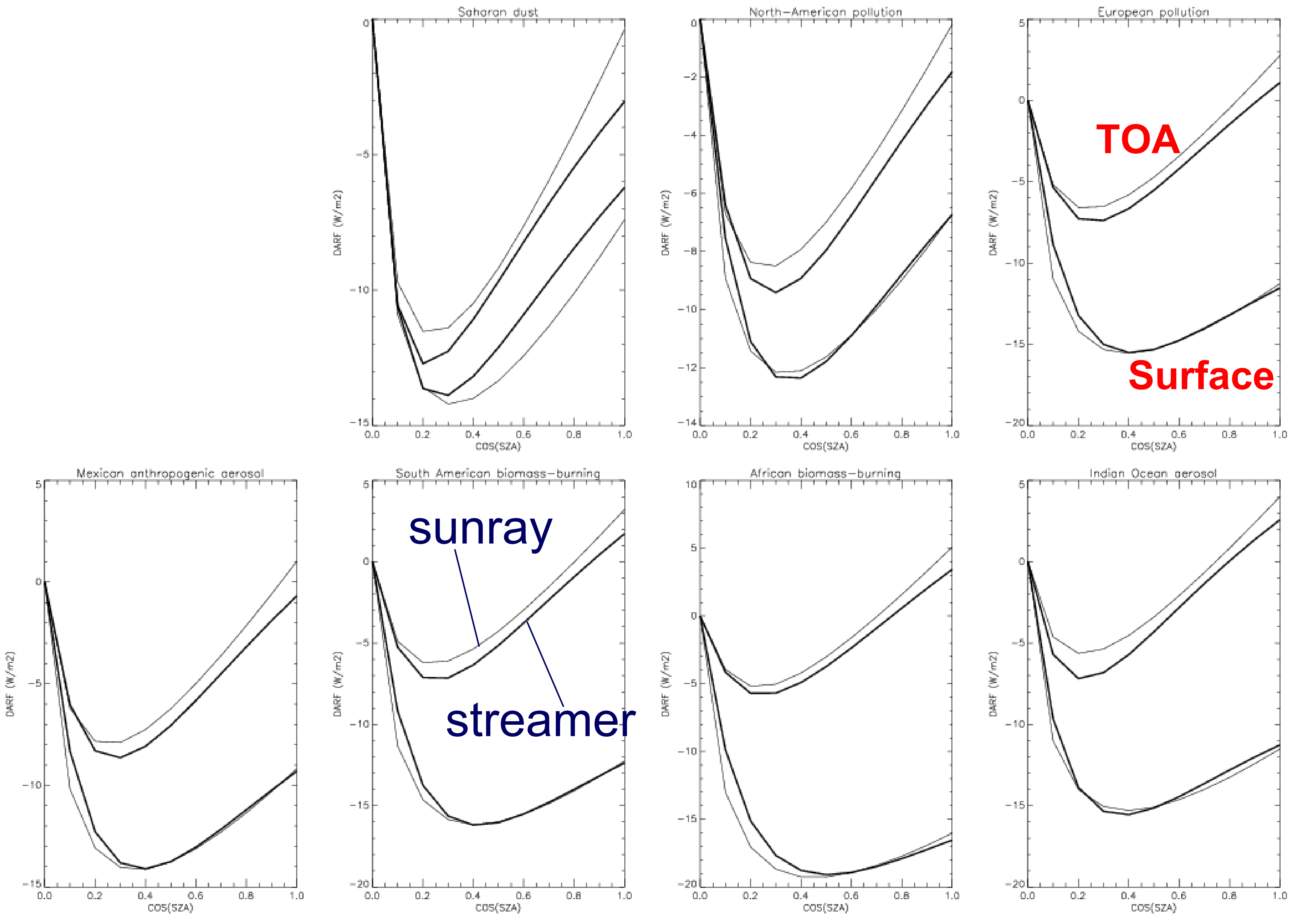
Aerosol optical depth = 0.1 Surface albedo = 0.0

7 aerosol models

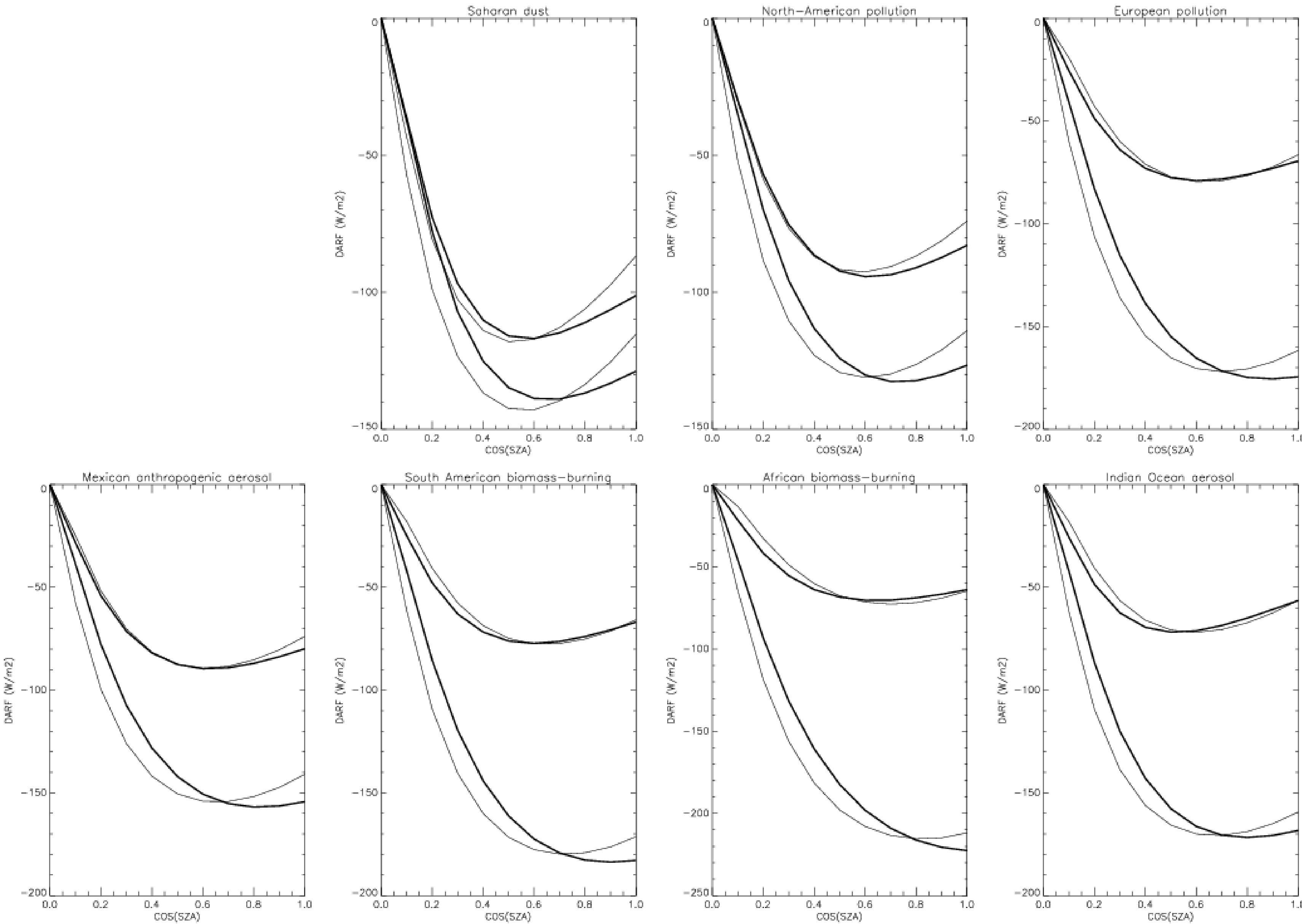


Broadband 24-stream 24-waveband versus 2-stream 2-waveband RT codes

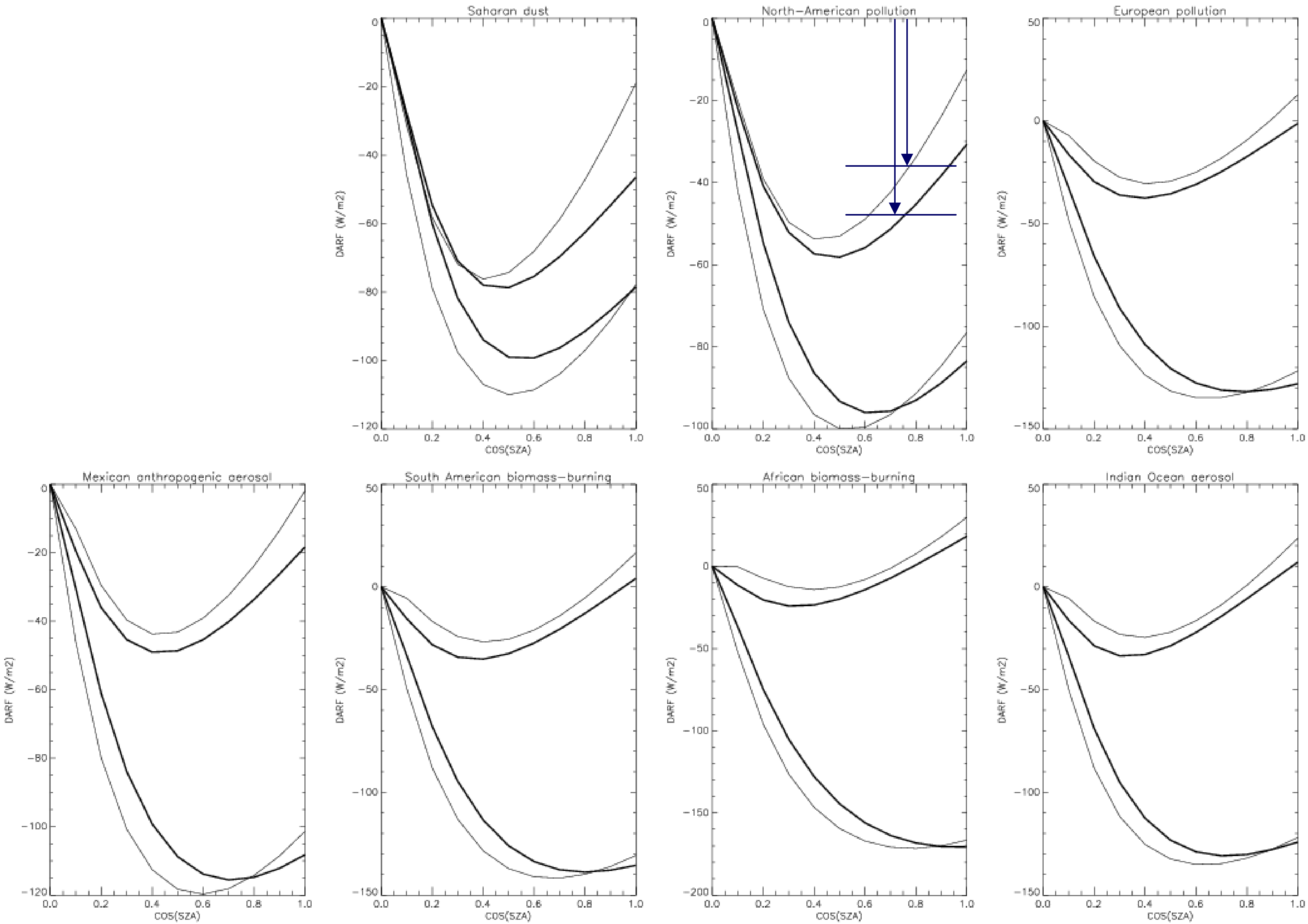
Aerosol optical depth = 0.1   Surface albedo = 0.2



Broadband 24-stream 24-waveband versus 2-stream 2-waveband RT codes
Aerosol optical depth = 1.0   Surface albedo = 0.0



Broadband 24-stream 24-waveband versus 2-stream 2-waveband RT codes
Aerosol optical depth = 1.0   Surface albedo = 0.2



The direct aerosol RF is not as linear as we may think!

$DF_{dust} + DF_{bb}$ <> $DF_{dust+bb}$

Implication is that $F_{dust+bb} - F_{bb} > F_{dust} - F_0$