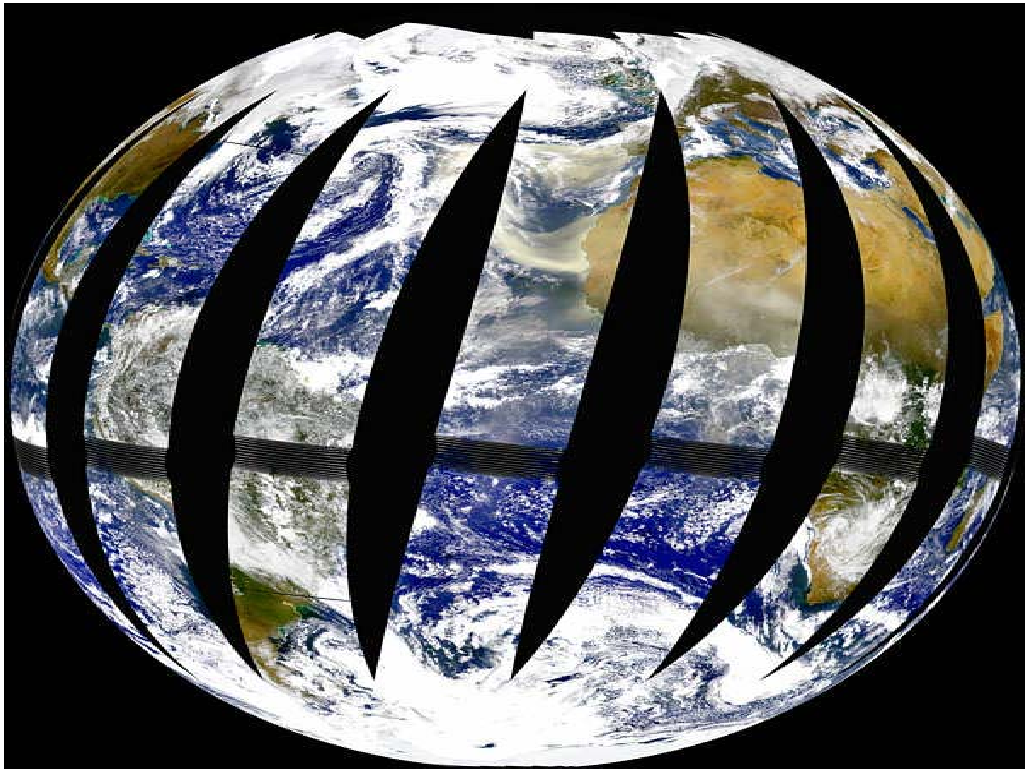
20^{th} Century Dust Emission



Paul Ginoux

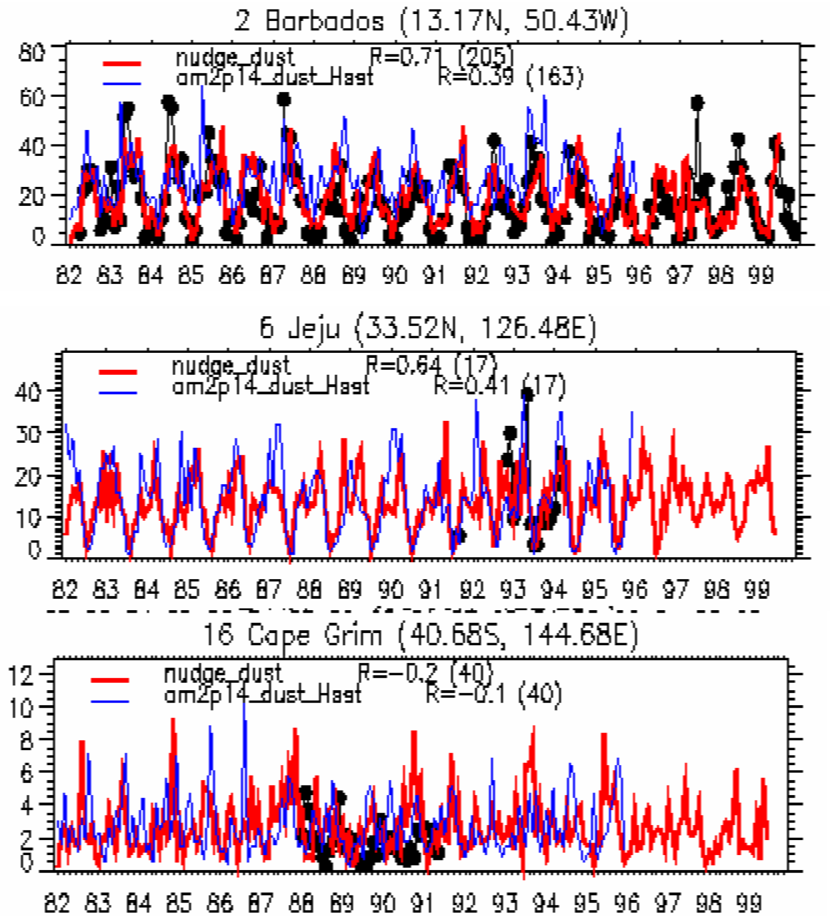
In collaboration with L. Horowitz, Y. Ming, V. Ramaswamy, D. Schwarzkopf, E. Shevliakova

NOAA-GFDL & Princeton U.

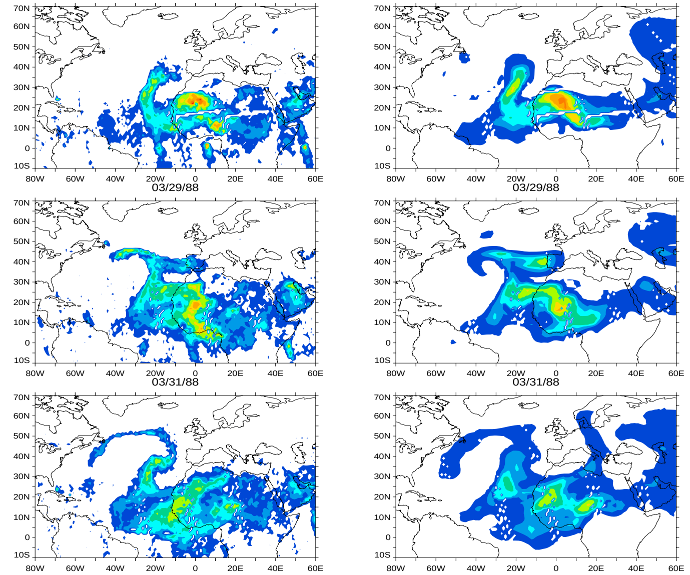
5^{th} AeroCom Workshop
Virginia Beach, VA
October 17-19, 2006

Simulation of dust for the last two decades

Comparison of dust concentration at Barbados, Jeju, and
Cape Grim measured by U. Miami and GFDL GCM with on-line dust



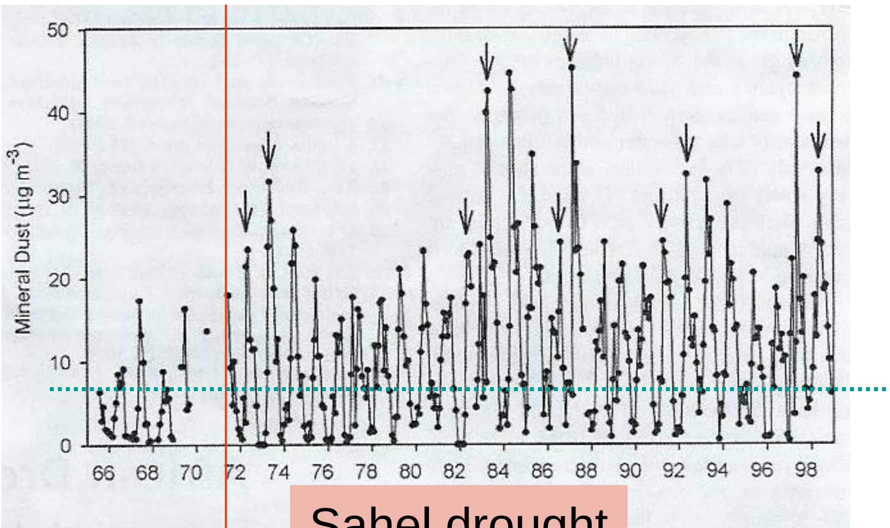
Comparison TOMS and GOCART AI for March 1988
(Ginoux et al., 2004)



Dust models can simulate reasonably well the daily, seasonal and inter-annual distributions of dust for the last 2 decades.

Observed Variability of Dust for the last 50 Years

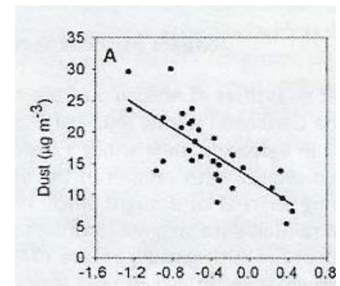
Dust concentration at Barbados (Prospero and Lamb, 2003)



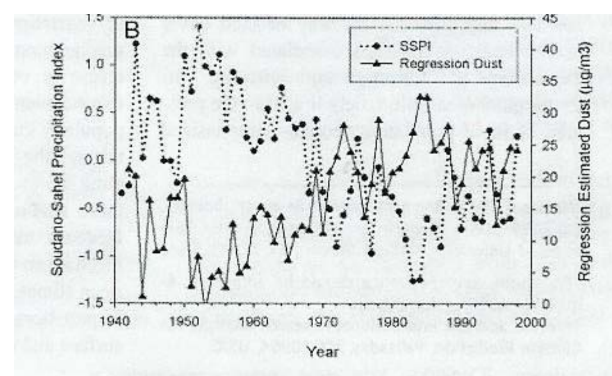
Sahel drought

Since 1970ies dust concentration in Caribbean (Prospero and Lamb, 2003) and dust deposition in French Alps (De Angelis and Gaudichet, 1991) have increased by a factor 4-5. This is much higher than the interannual variability for the last 2 decades

Barbados Dust

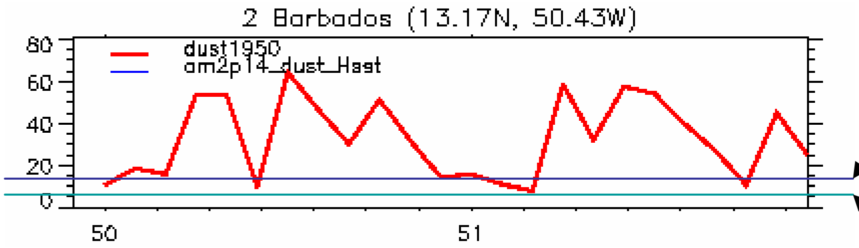


Sahel Precipitation Index (previous year)



Simulation of dust beyond the last two decades

Barbados dust with GFDL AM2 observed SST



1965 obs. dust

1950 obs. dust

Barbados dust with NCAR MATCH NCEP re-analysis could also not reproduce obs in 1960ies with existing dust sources (Mahowald et al., 2002)

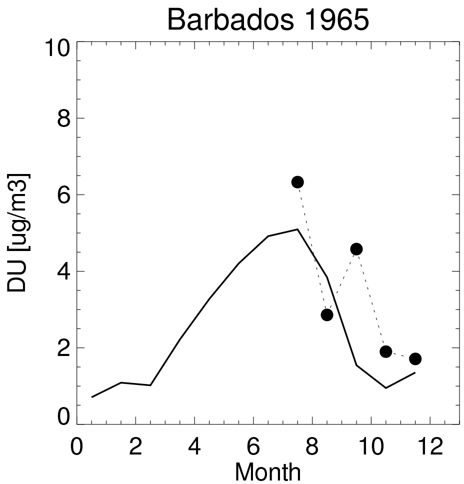
The models (transport and GCM) seem to be unable to simulate properly the jump of dust concentration at Barbados using existing dust source inventories.

Do we need to care about dust decadal variability?

Dust emission simulated with MOZART-2 (Horowitz, 2006):

1. Control: 1994 with NCEP re-analysis
2. Perturbed: 0.2 x emission from West Africa

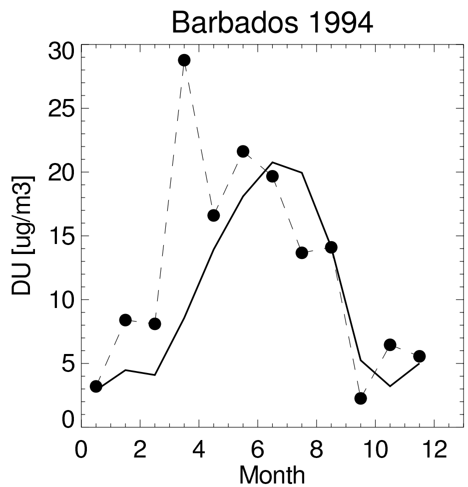
Perturbed



Emission / 5

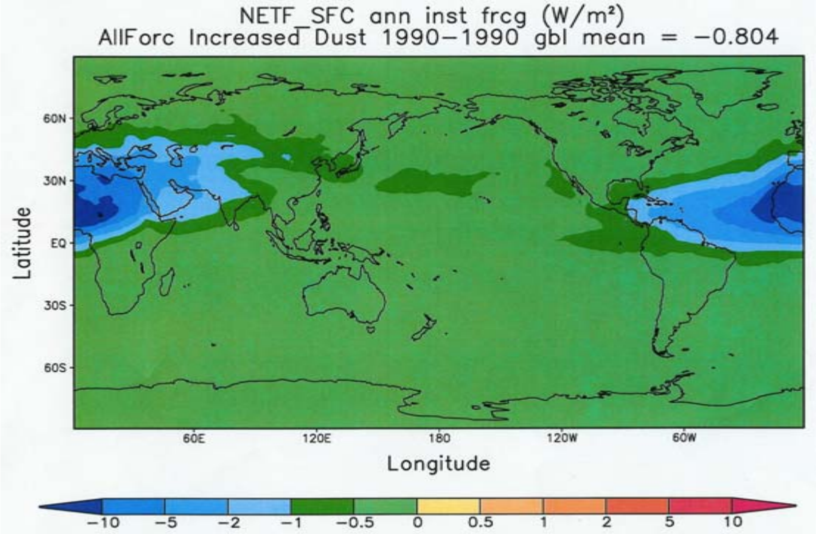
Concentration/4

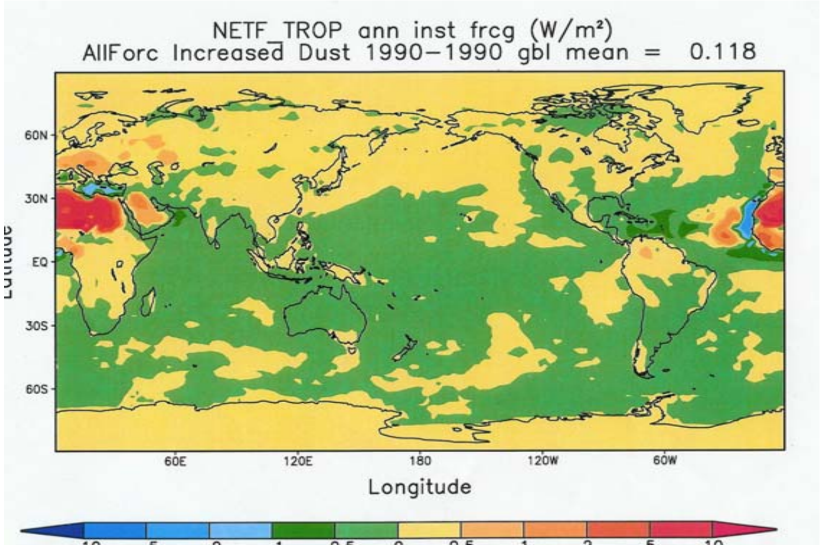
Control



Instantaneous Dust Forcing

Forcing (Control-Perturbed) at surface and tropopause



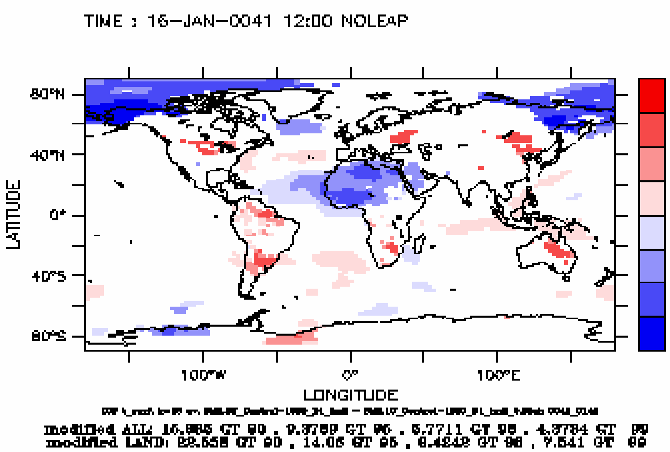


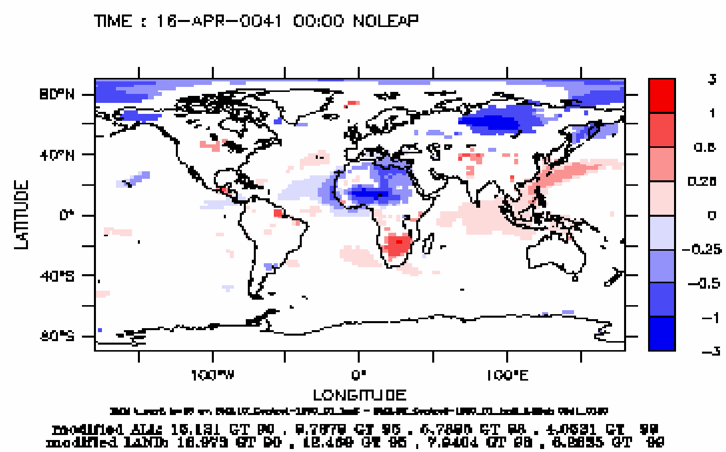
W/m²	SW	LW	Net
Old optics	-0.9	0.1	-0.8
New optics	-0.6	0.2	-0.4

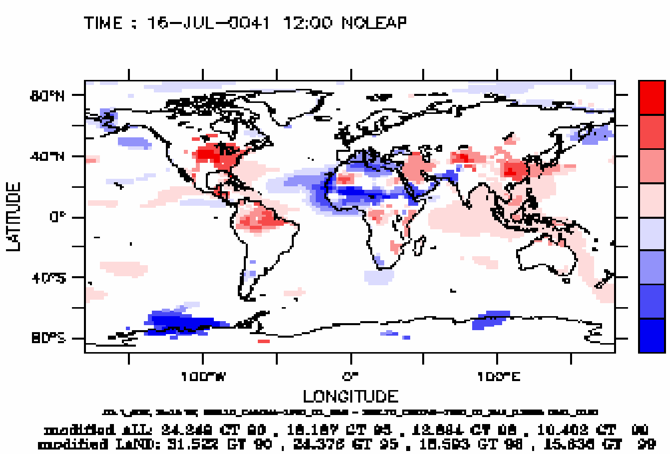
W/m²	SW	LW	Net
Old optics	0.08	0.04	0.12
New optics	-0.1	0.11	0.01

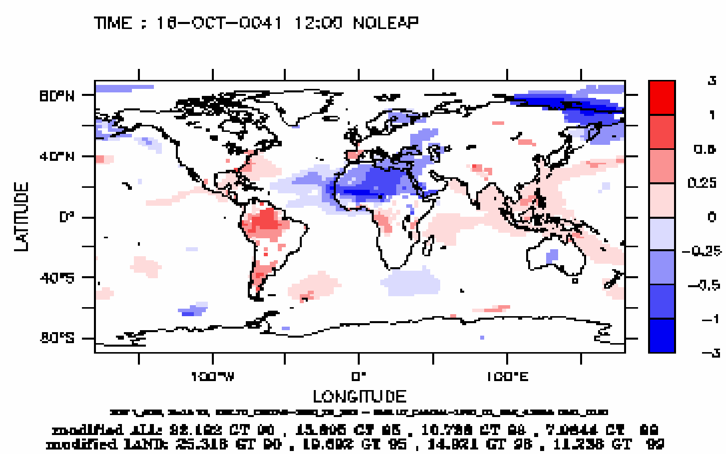
Difference of surface temperature

Sm2.1 Control-perturbed (mean years 41-100) with 95% confidence level



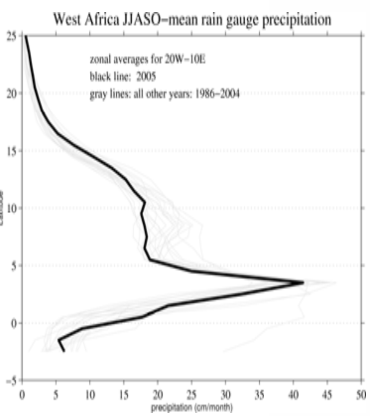


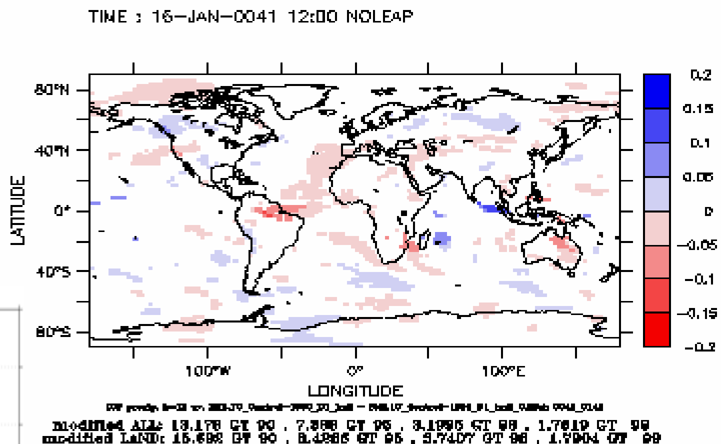


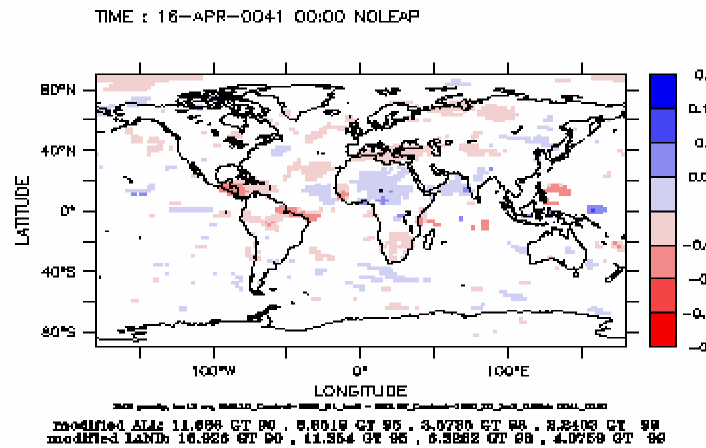


Difference of precipitation

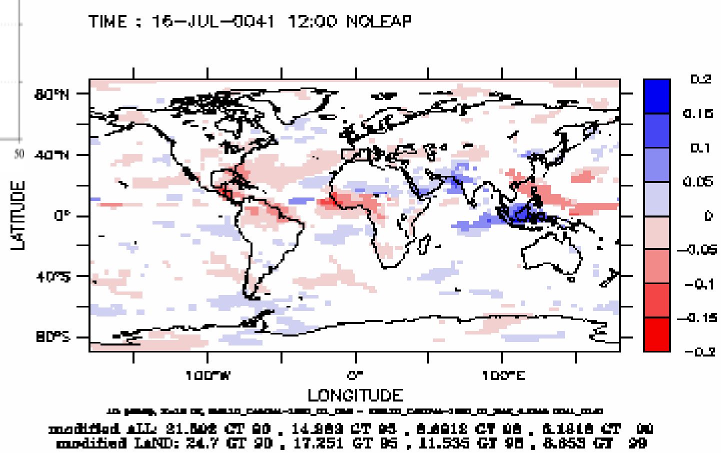
Sm2.1 Control-perturbed (mean years 41-100) with 95% confidence level

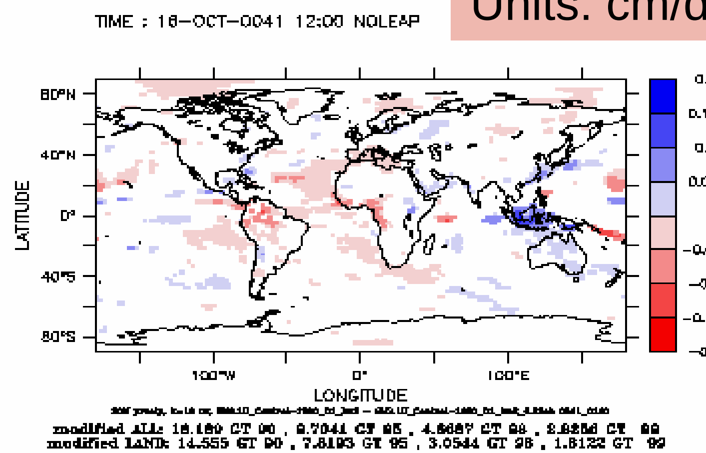






Units: cm/day



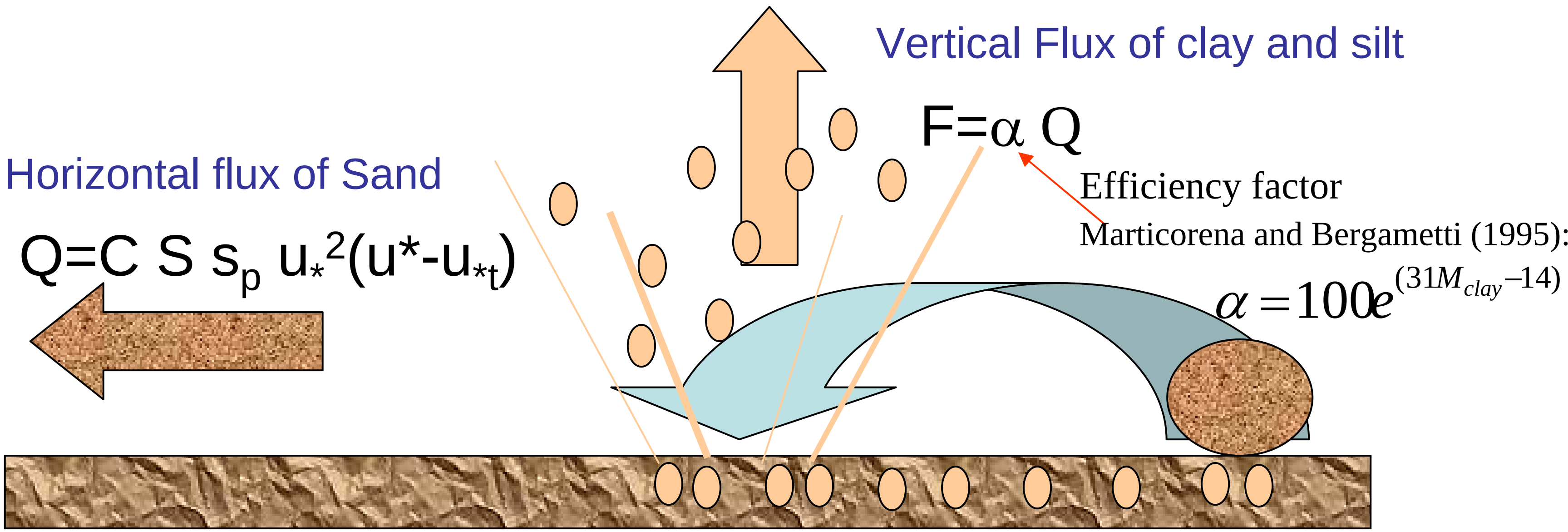


Implications of a 5 x emission increase

- Surface forcing of $1W/m^2$ globally
- Reduced precipitation over Sahel, Amazon, Mediterranean basin
- Reduced SST over eastern part of North Atlantic
- Increased SST over western part of North Atlantic

Origins of Dust Decadal Variability

Processes involved in dust emission

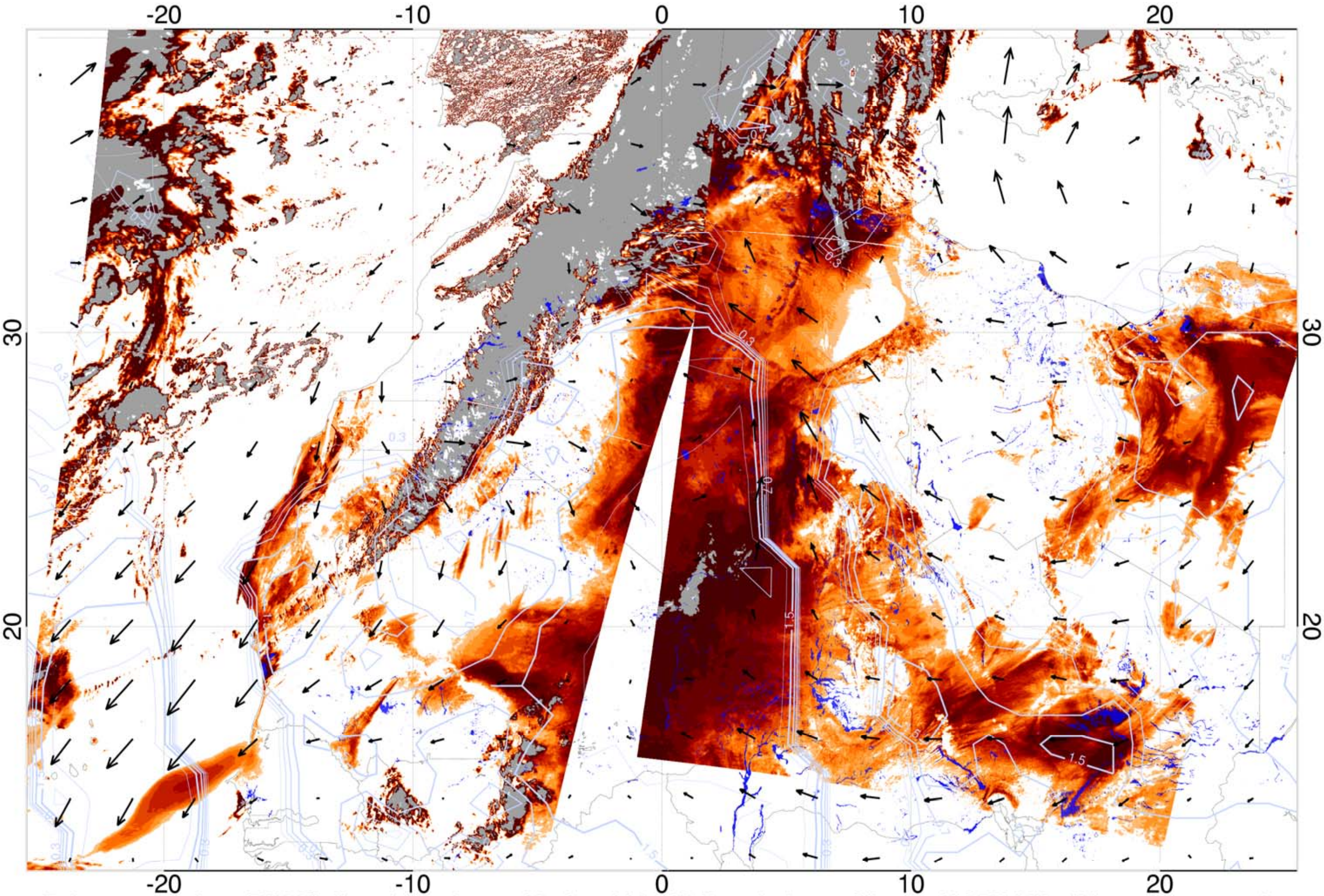


The threshold velocity u_{*t} is a function of particle radius, surface roughness height, temperature, and surface wetness

Threshold velocity for dust emission

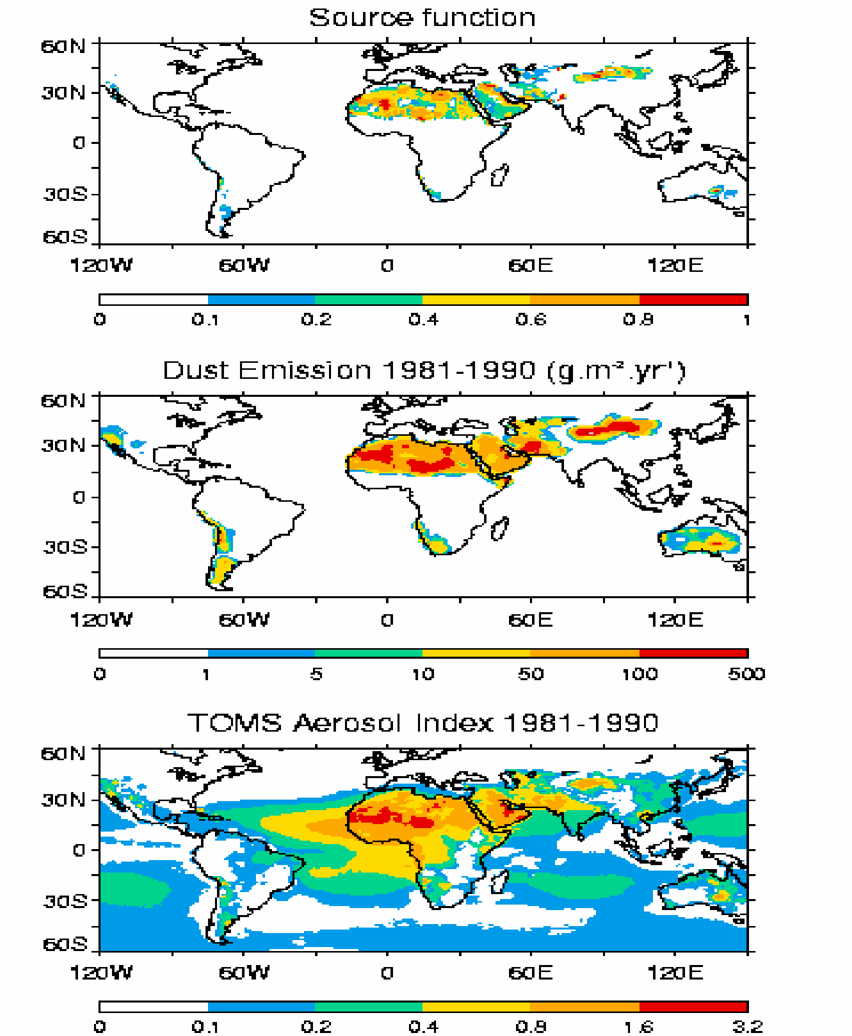
Laboratory and field measurements show that (*Nickling*, 1984; *Marticorena et al.*, 1997; *Fecan et al.*, 1999; *Shao*, 2000; *McKenna Neuman*, 2003; *Gillette; …*):

1. U*t is a nearly quadratic function of particles diameter with a minimum for D= 10 to 100 um
2. U*t is controlled primarily by the local soil roughness z0m
   ⇨ Dust sources = bare surface, preferentially flat as lake bed
3. Other important parameters are:
   1. Temperature: u*t decreases by 30% from 30C to -10c
      ⇨ Important for LGM simulations
   2. Soil moisture: u*t(M)=g(M)u*t(dry) where g is an empirical exponential function ⇨ only dry surface can emit dust
   3. Crusting by salts: u*t double with 1% increase of salt content
      ⇨ only disturbed soils would be expected to be erodible in normal wind storms



Ephemeral Lakes, TOMS Absorbing Aerosol Index, MODIS Dust Index & Clouds, NCEP Wind Vectors at 965mb
April 30, 2003

Time independent dust sources



Ginoux et al. (2001) prescribed the dust sources based on topography

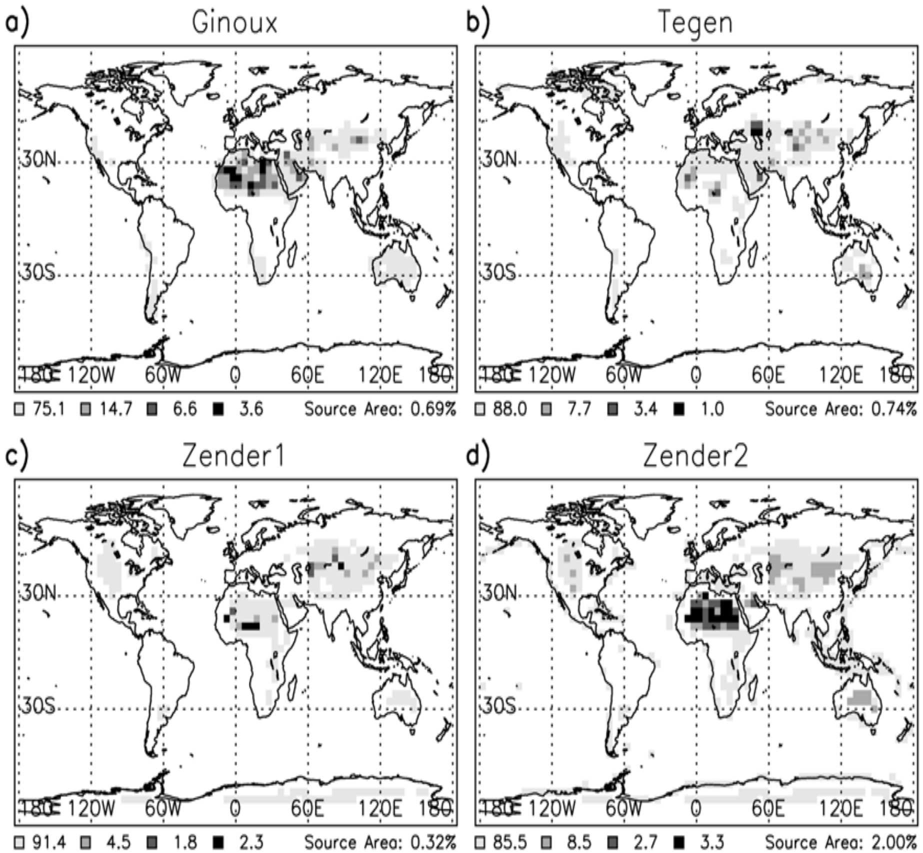
$$S = \left(\frac{z_{\max}^{10x10} - z}{z_{\max}^{10x10} - z_{\min}^{10x10}} \right)^5$$

and vegetation (bare surface from AVHRR 1x1 degree) assumed constant

→ GOCART, GFDL models, KARMA, GEOS-CHEM, US Army, several regional models, IPCC 2001, AEROCOM.

Comparison of Dust Source Inventories

Comparison of Ginoux et al (2001), Tegen et al. (2002), Zender et al. (2003) inventories with AOD from AERONET, AVHRR, TOMS, and concentration from U. of Miami, deposition rates, size distribution from AERONET (Cakmur et al., 2005)



EXP.	AERO	AVHRR	TOMS	SURF	DEPO(G)	DEPO(D)	SIZE	TOTAL
				RELEVANT				
Ginoux	0.50	0.59	0.59	0.47	0.18	0.23	0.82	0.51±0.22
Tegen	0.70	0.57	0.65	0.47	0.85	0.49	0.98	0.69±0.21
Zender1	0.73	0.56	0.64	0.66	0.74	0.89	0.95	0.77±0.13
Zender2	0.55	0.56	0.56	0.48	0.69	0.60	0.86	0.64±0.15
				ALL				
Ginoux	0.53	0.57	0.54	0.72	0.53	0.40	0.76	0.62±0.13
Tegen	0.69	0.57	0.58	0.74	0.80	0.62	0.91	0.75±0.13
Zender1	0.72	0.56	0.58	0.81	0.62	0.87	0.88	0.77±0.11
Zender2	0.55	0.55	0.52	0.71	0.59	0.65	0.77	0.66±0.09
				EQUAL				
Ginoux	0.66	0.69	0.65	0.68	0.26	0.51	0.79	0.63±0.16
Tegen	0.63	0.69	0.66	0.63	0.73	0.37	0.82	0.66±0.13
Zender1	0.59	0.63	0.62	0.63	0.71	0.47	0.80	0.66±0.10
Zender2	0.56	0.63	0.63	0.59	0.61	0.39	0.78	0.62±0.12

Limitations of actual dust source inventory

- Resolution is relatively coarse(1º x1º): does not characterize ephemeral lakes
- No dynamic vegetation (bare surface is assumed constant): its usage is limited to 1980-present.
- Land use changes are not include: it cannot be used to evaluate anthropogenic contribution

Solution I: By-pass the sources characterization

Dust emission as a function of Sahel precipitation index (SPI) of previous year

Methodology:

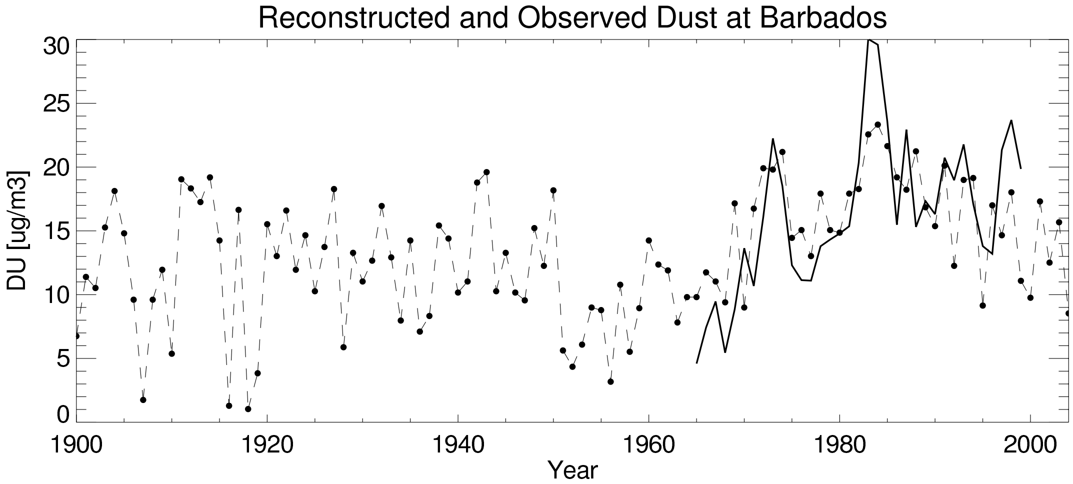
•Dust at Barbados is correlated with the SPI of the previous year (Prospero and Lamb, 2003).

•Dust at Barbados is correlated with its emission from West Africa

$\Rightarrow$Dust emission = f(SPI)

•The scaling factor is assumed constant all year long.

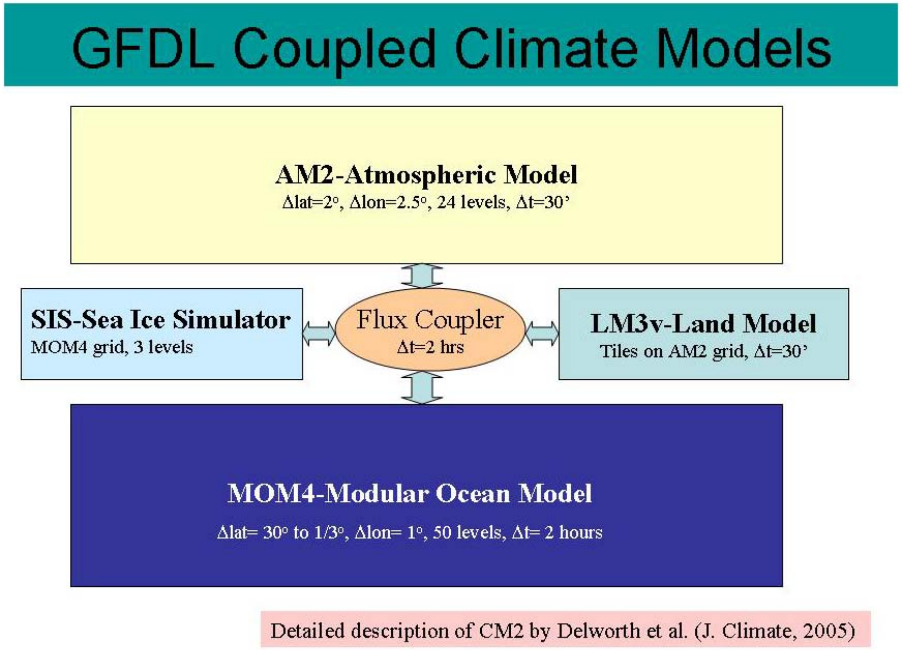
N.B. Lowest obs. dust supposed in 1950ies but not data. To be conservative, minimum emission (factor 5 reduction) is associated with 1950.

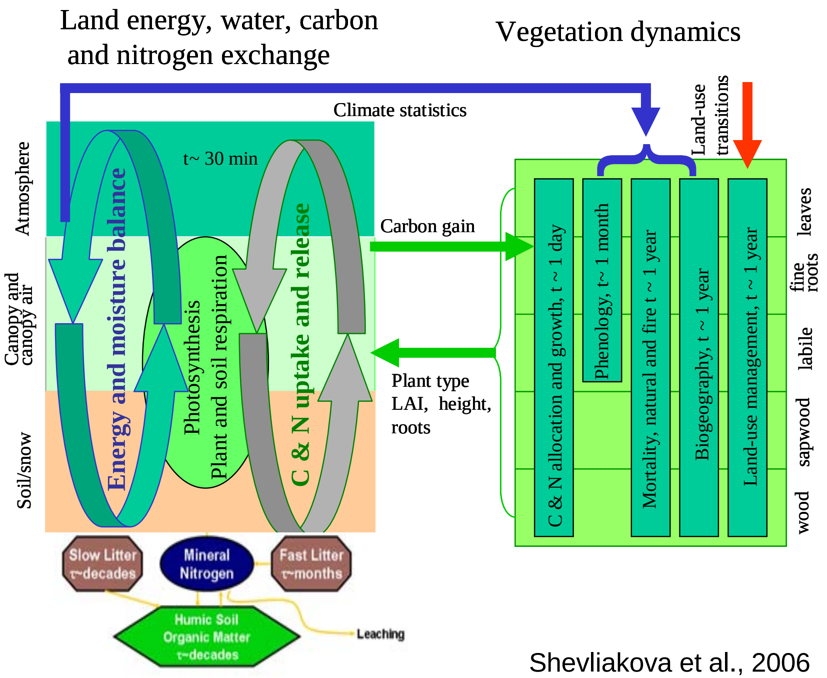


Similar Method: Moulin and Chiapello (2006) have also related Barbados dust with SPI but add a contribution from NAO index and a continuously increasing anthropogenic emission.

Solution 2: Solve dynamically the dust source and emission

Dust source characteristics (roughness length, soil moisture, land use changes) are simulated by the GFDL LM3v model part of the GFDL coupled models.





Shevliakova et al., 2006

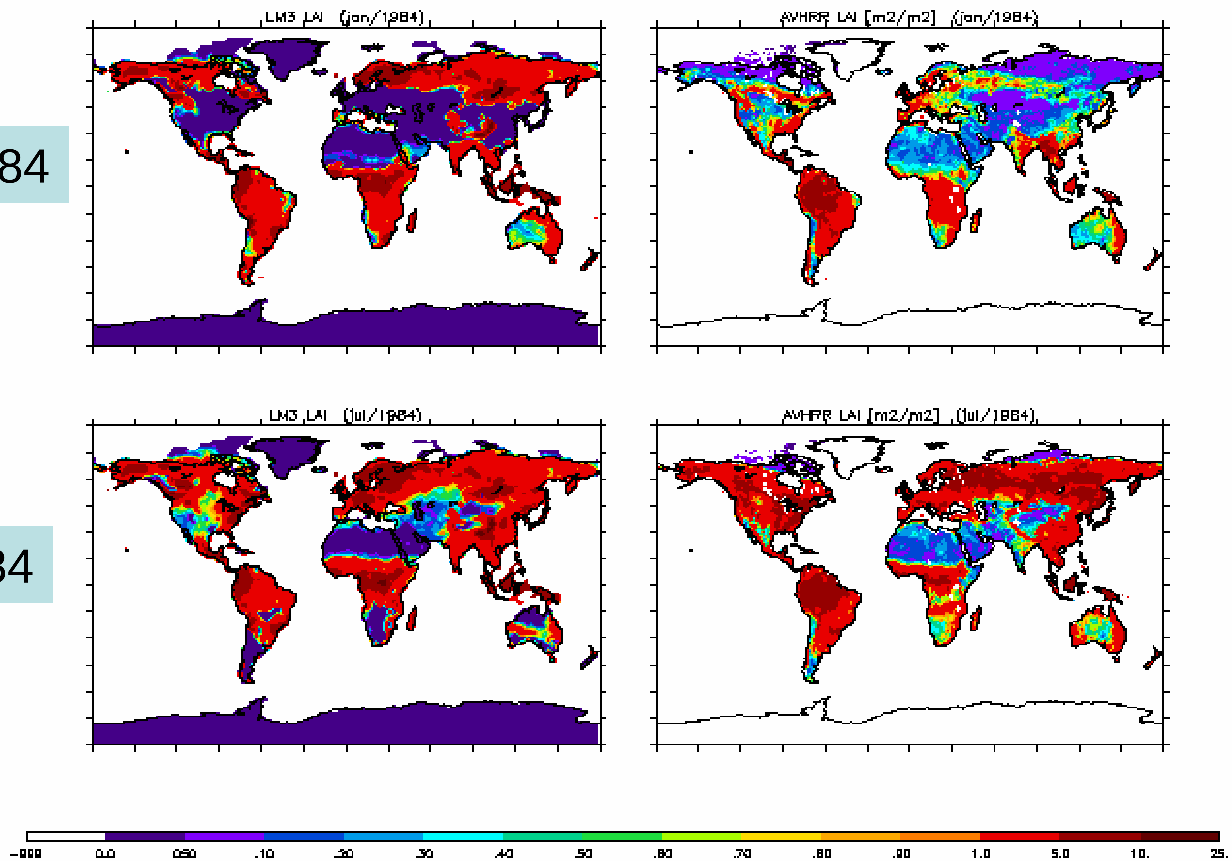
Comparison Leaf Area Index (LAI) simulated with LM3v and retrieved from AVHRR data

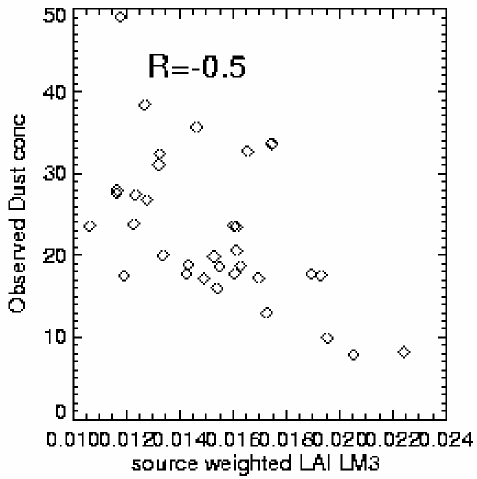
LM3v Model

AVHRR ISLSCP2

Jan 1984

Jul 1984





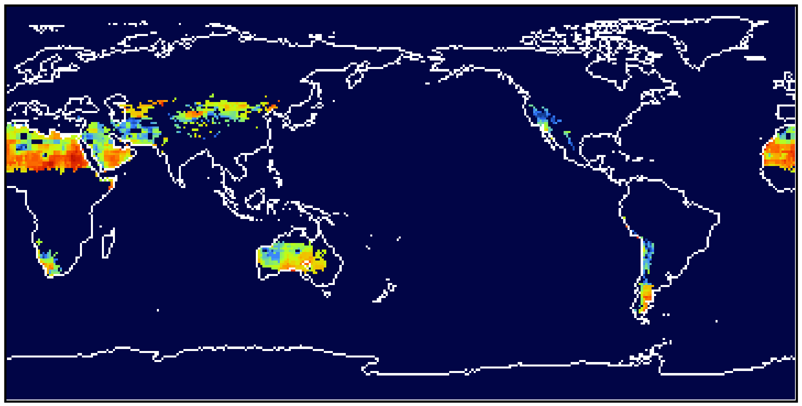
LM3v LAI is anti-correlated with observed dust at Barbados

Time dependent dust sources

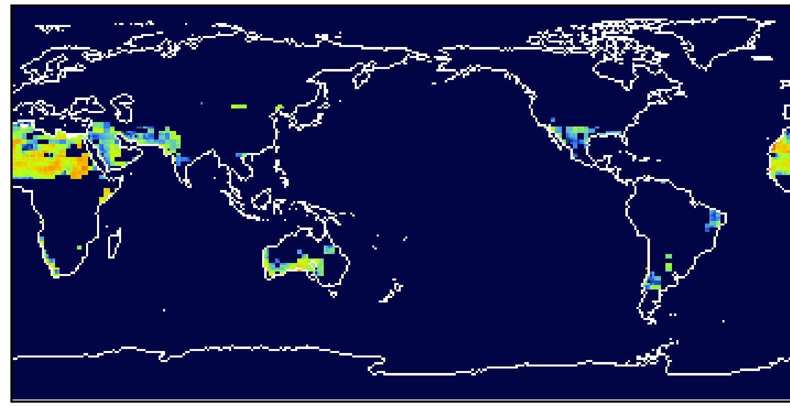
Dust emission from bare ground

Dust emission as a function of LAI, SAI, dead biomass, soil moisture, and snow as calculated dynamically by AM2-LM3v

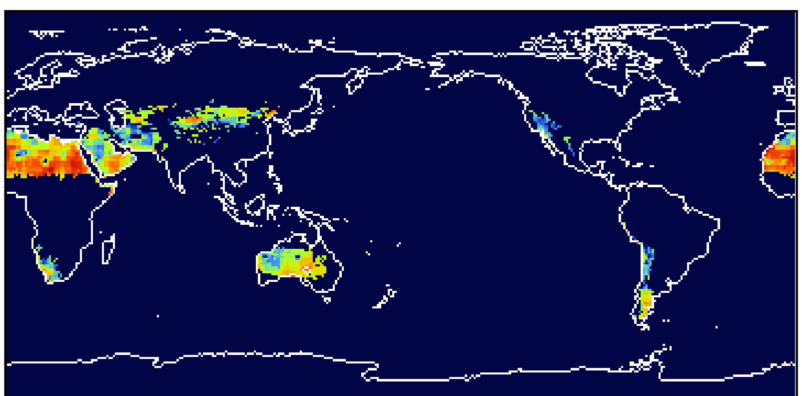
Dust emission without LAI 1965 (kg/m2/month)



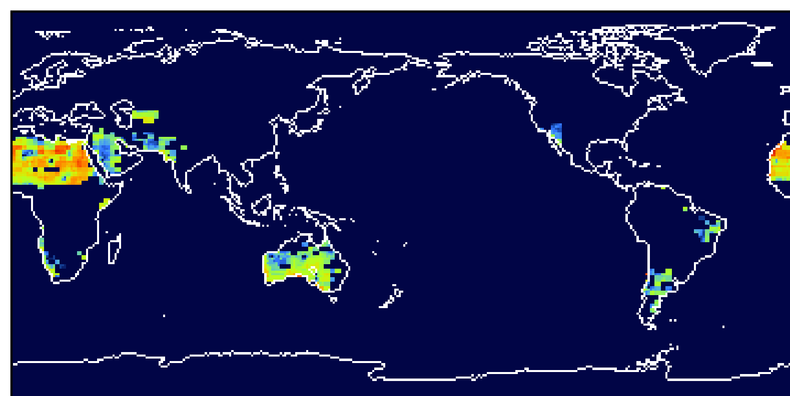
Dust emission with LAI 1965 (kg/m2/month)



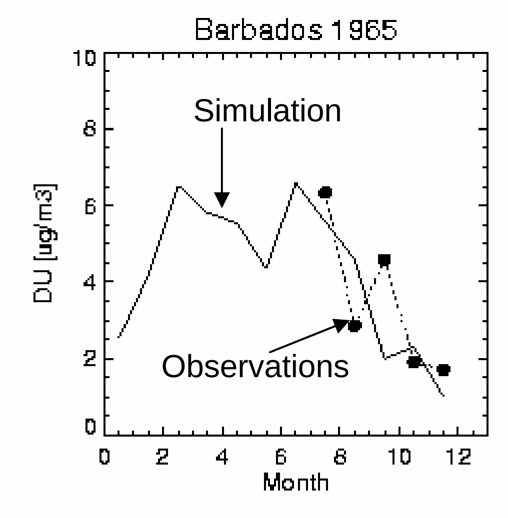
Dust emission without LAI 1990 (kg/m2/month)

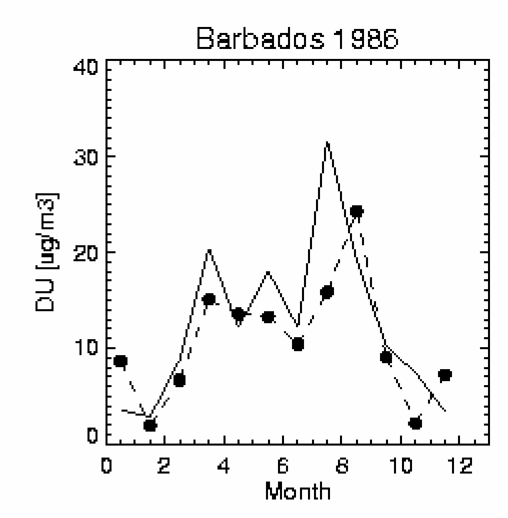


Dust emission with LAI 1990 (kg/m2/month)



Dust simulation by coupling dust emission with AM2-LM3v-observed SST





Dust concentration can be simulated for decades by constraining dust emission with land characteristics.

Conclusions

- Existing dust sources inventories allow to simulate reasonably well the daily, seasonal and inter-annual variability of dust for the last two decades, but fail to simulate previous decades
- The implications of large decadal variability seem important for climate studies (also O_3 chemistry, biogeochemistry, …)
- The origins of the decadal variability appear related to varying characteristics of dust sources
- These characteristics can be by-passed if we assume that dust emission is related to climatic indices (e.g. SPI for African emission).
- A more physical based approach consist to simulate dynamically these characteristics with a dynamic land model.
- An analysis of satellite data (MODIS-Land, MODIS Deep Blue, MISR, OMI, CALIPSO) over arid regions should be first performed to better constrain these characteristics, and evaluate the input and output fields of dynamic land models.