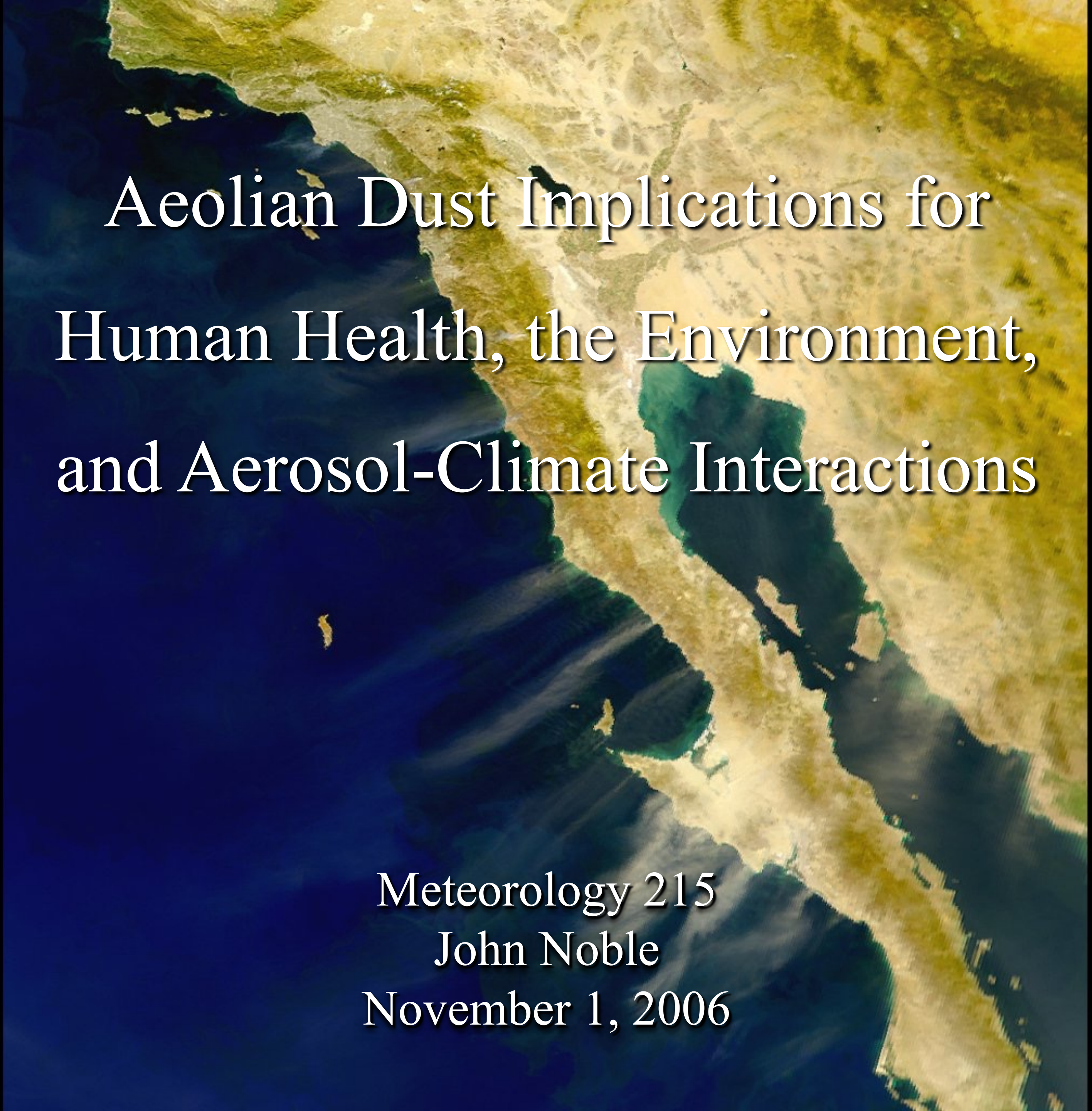

Aeolian Dust Implications for Human Health, the Environment, and Aerosol-Climate Interactions

Meteorology 215
John Noble
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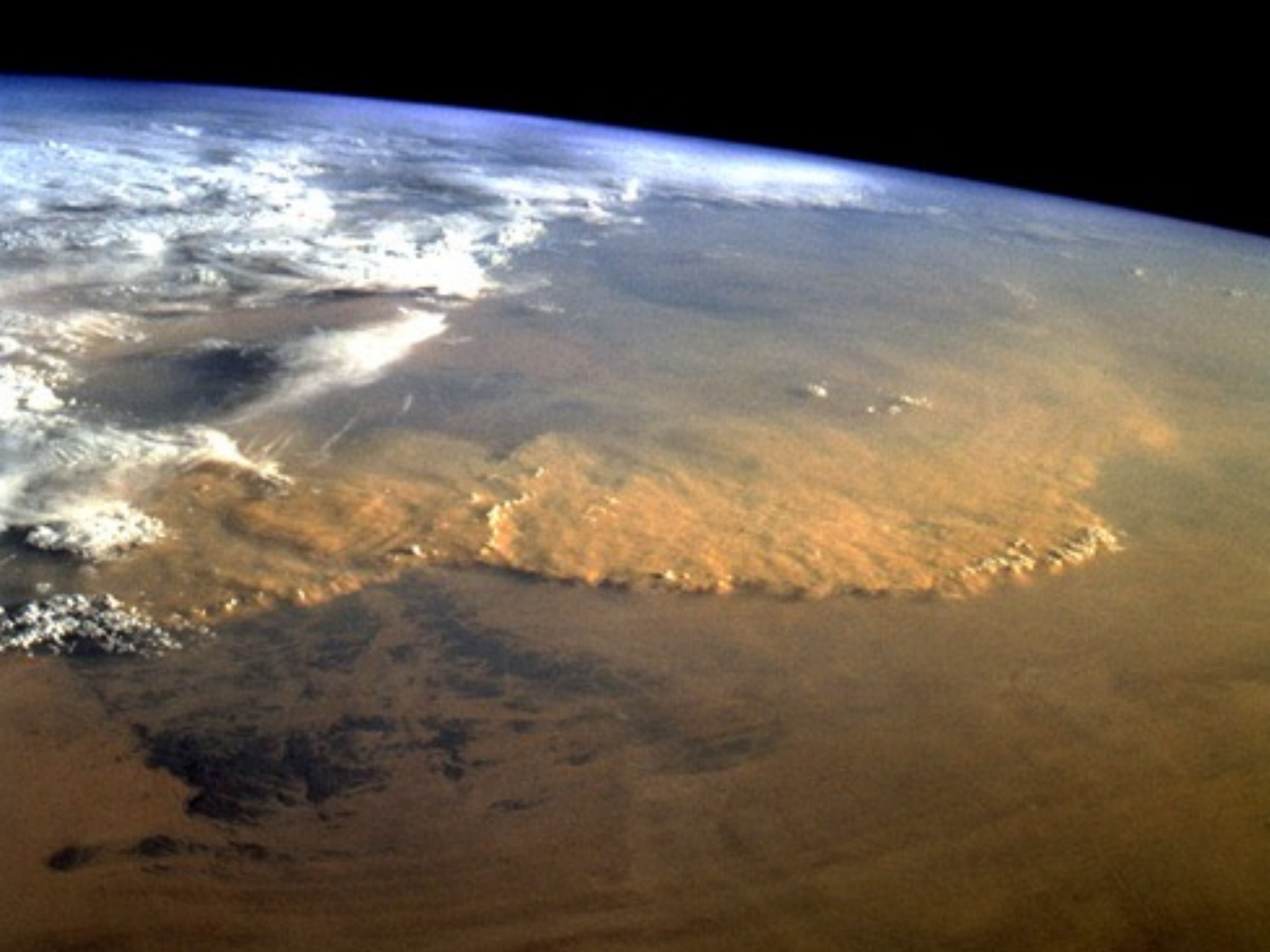
Outline

- Temporal and spatial variability of aeolian dust events
- Aeolian dust characteristics
  - Optical properties
    - Scattering coefficient (σ_{sp})
    - Absorption coefficient (σ_{ab})
    - Single scattering albedo (ϖ)
    - Radiative Forcing Efficiency (*RFE*)
  - Composition
  - Coagulation
  - Transport
  - Implications

Temporal & spatial variability of aeolian dust events

- Frequency increases with increasing desertification.
- Wide temporal and spatial variability. Two of the largest sources of globally transported dust are the Sahara and Gobi deserts.
- Millions of tons of dust are carried each year from the Sahara and Sahel regions of Africa to the Caribbean and Southeastern United States.
- A similar and larger system transports dust from the Gobi Desert in Western China across the Northern Pacific and sometimes into the Pacific Northwest and beyond.

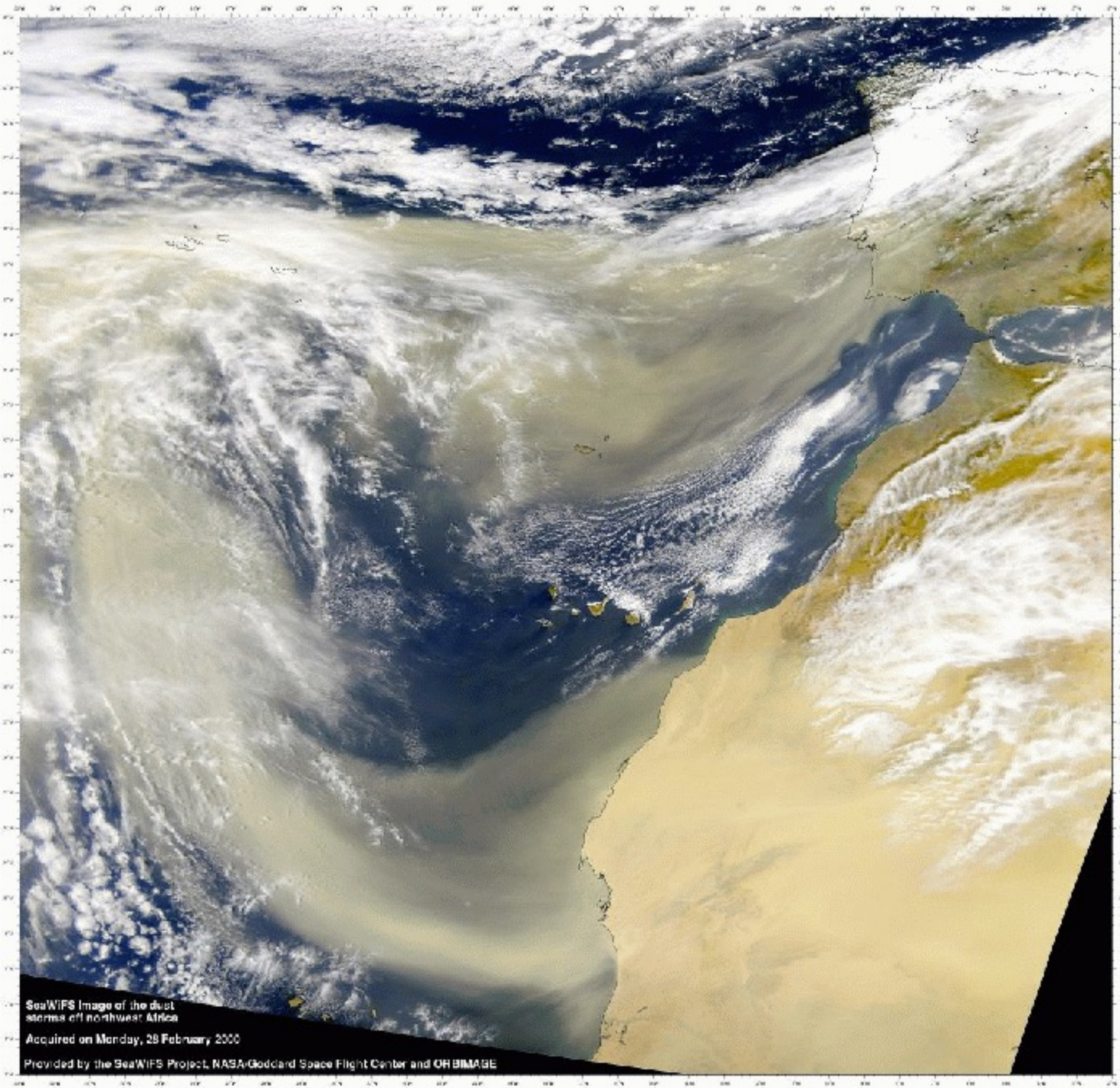



SAGMA


A TYPICAL WESTERN DUST STORM, TAKEN NEAR HUGOTON, KANS.
PORTER DRUG CO. HOUGTON, KANS.


DUST STORM APPROACHING SPEARMAN, TEXAS.
APRIL 14. 1935


12. 11. 2002


SeaWiFS Image of the dust
storms off northwest Africa
Acquired on Monday, 28 February 2000
Provided by the SeaWiFS Project, NASA/Goddard Space Flight Center and ORBIMAGE

Aeolian dust optical properties

- Scattering coefficient (σ_{sp}) defines the amount of aerosol-induced cooling.
- Absorption coefficient (σ_{ab}) defines the amount of aerosol-induced warming.
- Single scattering albedo:

$$\varpi \equiv \frac{\sigma_{sp}}{\sigma_{sp} + \sigma_{ab}}$$

These properties were investigated in Greece and Turkey during a severe Saharan dust event in April 2000. (Vrekoussis *et al*. 2005).

- Ambient light σ_{sp} had a mean value 50 ± 23 Mm^{-1}.
- σ_{sp} values as high as 5000 Mm^{-1} were encountered during dust events.
- The average calculated ϖ for the total period was 0.89, with lower and upper limits of 0.74 and 0.98.

Aeolian dust optical properties

- Radiative forcing efficiency (RFE) is the amount of the radiative forcing that increases the optical thickness by one unit.

- Vrekoussis *et al.* (2005) calculated RFE using the following equation (Haywood *et al.* 1995):

$$RFE = SD\left(1 - A_c\right)T^2\left(1 - R_S\right)^2\left[2R_S\frac{1-\varpi}{\left(1-R_S\right)^2} - \beta(b)\varpi\right]$$

where S is the solar constant 1370 W m^{-2}, D the daylight fraction, A_c the mean fractional cloud, T the atmospheric transmissivity (0.76), R_S the surface albedo (0.07 for sea and 0.34 for land), $\beta(b)$ the average upscatter fraction derived from the backscatter ratio (~ 13%).

Aeolian dust optical properties

- *RFE* is irreversibly correlated to ϖ and thus positively correlated to absorption.

- *RFE* mean summer minimum of –73 W m^{-2} was multiplied by the aerosol optical thickness* to obtain the *RFE* at the top of the atmosphere: –12.6 W m^{-2}.

- This value is up to five times greater (but opposite in sign) than the forcing induced by greenhouse gases, estimated to be 2.4 W m^{-2} (Vrekoussis *et al.* 1995, Houghton *et al.* 1995)

*Provided by NASA's AERONET (AErosol RObotic NETwork) program

Transport and coagulation

Analysis of 1994 Saharan dust regional transport with the ETA model (Vukmirović *et al.* 2003).

- Sampling was performed by an automatic wet/dry collector.
- Determination of trace metal content was performed in a “clean room” by differential pulse stripping voltammetry.
- Determination of morphology, size distribution and semi-quantitative chemical composition, was performed with a scanning electron microscope. The adjusted range of electron microscope analysis was 0.1–100 μm.
- Samples were covered with thin AuPd film and observed at magnification ranging between 600 and 2000. The composition of particles was determined by X-ray analysis.

Transport and coagulation

- Initially "clean" particles absorbed and adsorbed toxic matter after passing over heavily polluted areas.
- Turbulent flow enhanced the coagulation process of Saharan dust with lead (Pb) and Cadmium (Cd).
- The coagulation and scavenging processes below and in clouds increased deposition rates of Pb and Cd.
- Pb concentration of 312 $\mu g\ L^{-1}$ was found in a weekly wet-sample collected in Belgrade during the episode.
- Cd dry deposition rate of 17 $\mu g\ m^{-2}\ d^{-1}$ was measured two weeks after the episode. (Vukmirović *et al.* 2003)

Transport and coagulation

- The efficiency of coagulation in turbulent flow is significant for radius >1 μm.
- The mean diameter of Saharan dust transported to Belgrade was 3.7 μm and the 98 percentile reached 9.8 μm, indicating a high probability of coagulation processes in the Saharan air mass with small particles (< 1 μm) transported 1000 km away from sources. (Vukmirović *et al.* 2003)

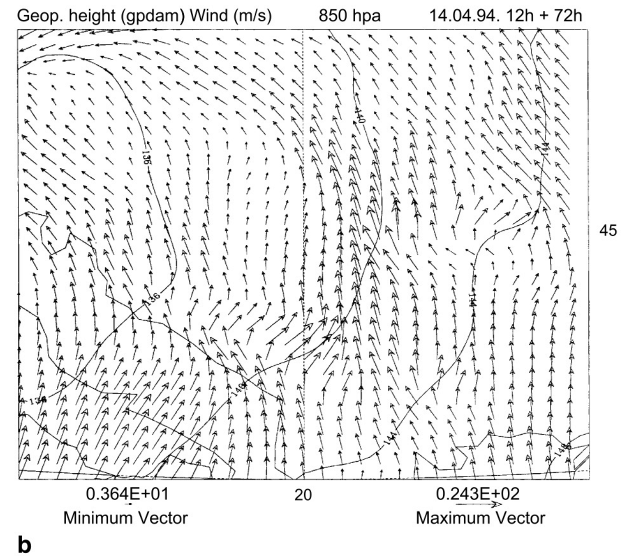
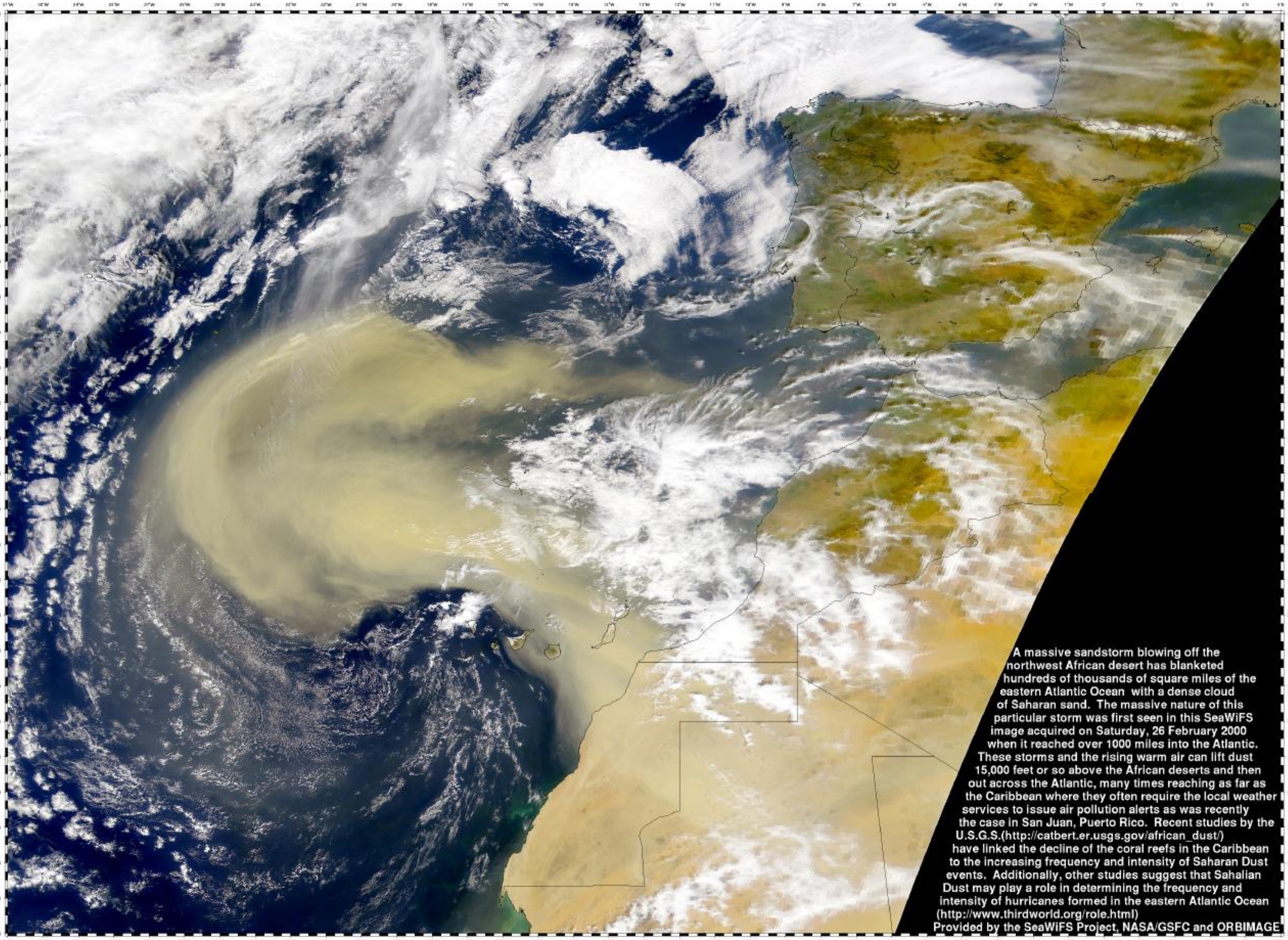


Fig. 2. 14–17 April 1994: high horizontal grid resolution of wind and geopotential height at 850 hPa; **a** initial conditions, and **b** 72 h forecast

Table 1. Mineralogical composition of single particles (Belgrade) and bulk dust (Arjeplog)

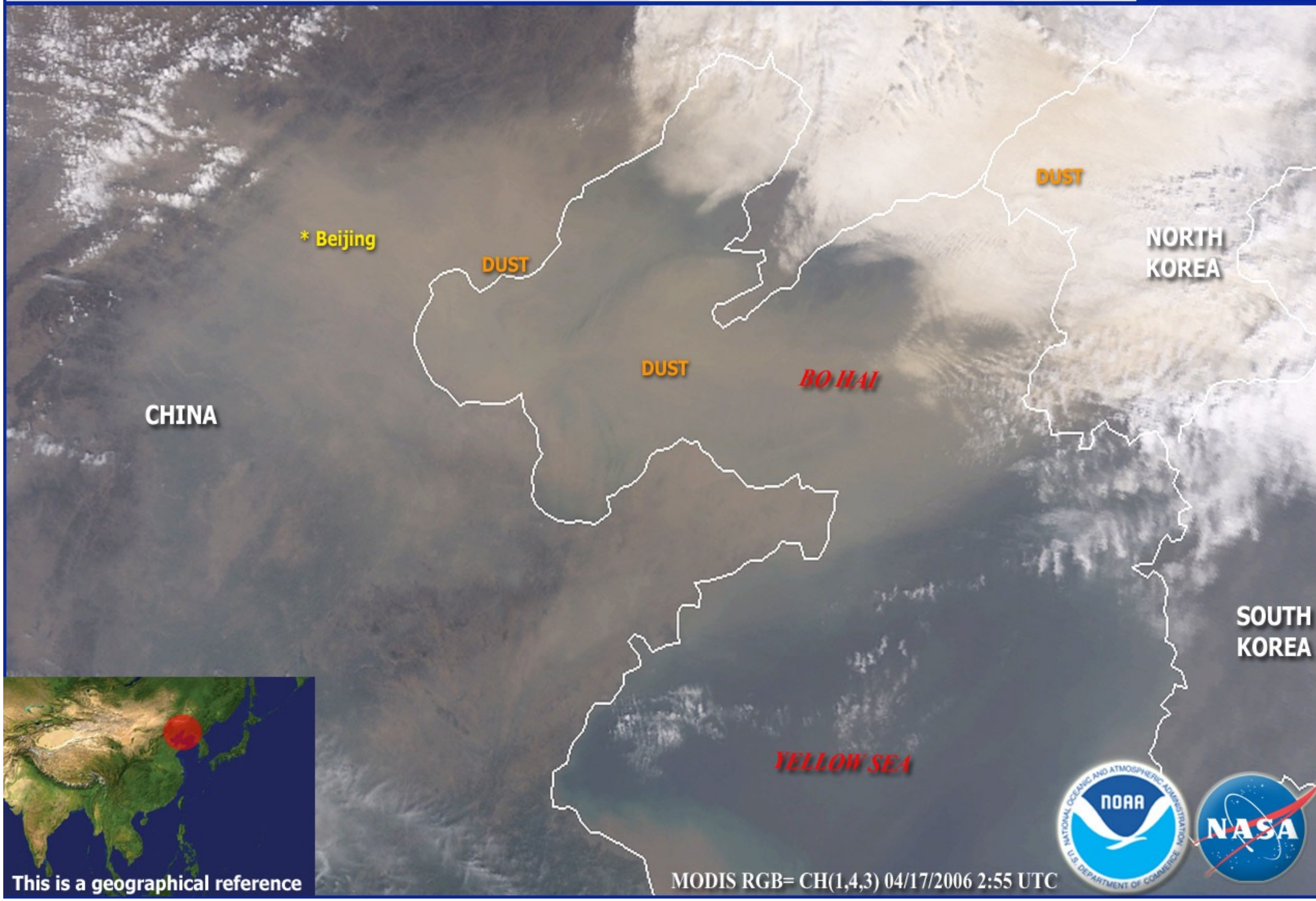
Element, at.%	Particle (Belgrade), 17 μm	Particle (Belgrade), 30 μm	Bulk dust (Arjeplog), 2.7 μm mean diameter
Mg	6.5	3.0	3.4
K	2.9	/	5.7
Al	27.8	7.5	20.7
Fe	14.4	11.2	12.3
Si	48.4	55.6	47.1
Si/Fe	3.4	5.0	3.8

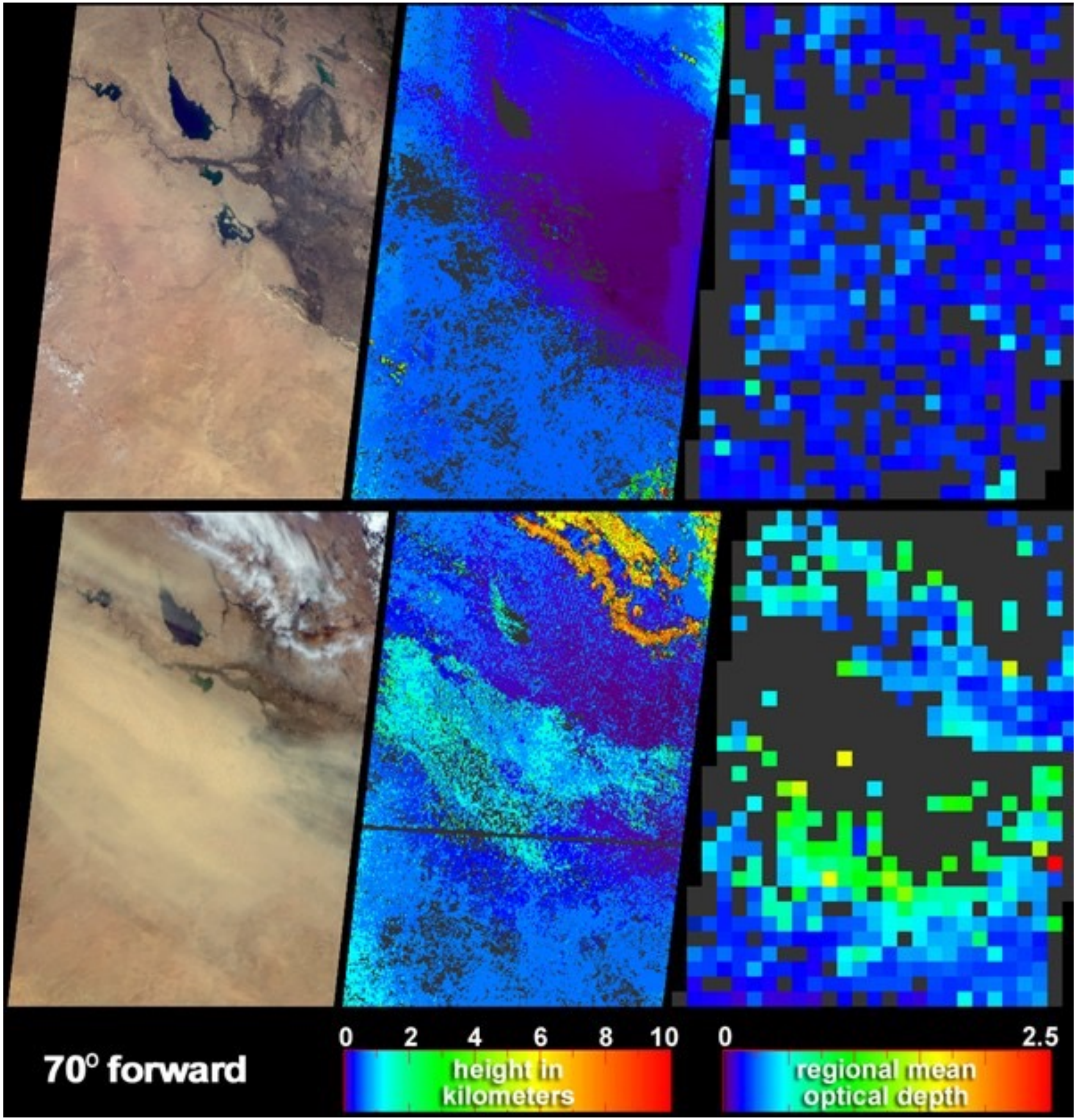
(Vukmirović *et al.* 2003)


A massive sandstorm blowing off the
northwest African desert has blanketed
hundreds of thousands of square miles of the
eastern Atlantic Ocean with a dense cloud
of Saharan sand. The massive nature of this
particular storm was first seen in this SeaWiFS
image acquired on Saturday, 26 February 2000
when it reached over 1000 miles into the Atlantic.
These storms and the rising warm air can lift dust
15,000 feet or so above the African deserts and then
out across the Atlantic, many times reaching as far as
the Caribbean where they often require the local weather
services to issue air pollution alerts as was recently
the case in San Juan, Puerto Rico. Recent studies by the
U.S.G.S.(http://catbert.er.usgs.gov/african_dust/)
have linked the decline of the coral reefs in the Caribbean
to the increasing frequency and intensity of Saharan Dust
events. Additionally, other studies suggest that Sahalian
Dust may play a role in determining the frequency and
intensity of hurricanes formed in the eastern Atlantic Ocean
(http://www.thirdworld.org/role.html)
Provided by the SeaWiFS Project, NASA/GSFC and ORBIMAGE

A huge dust storm is over Northeast China and North Korea. BBC NEWS reported that the Chinese capital, Beijing, has been hit by its eighth - and worst - sandstorm of the year.

Credit: NOAA/NASA




70° forward
0 2 4 6 8 10
height in kilometers
0 2.5
regional mean optical depth

Implications for the environment

- Changes in global climate, regional meteorological conditions, and land use in northern and western Africa resulted in severe droughts in the Sahara and Sahel of Africa starting in the 1970s.

- Hundreds of millions of tons of African dust are transported annually from the Sahara and Sahel to the Caribbean and southeastern U.S.

- Although these global atmospheric systems have been transporting fine soil particles for hundreds of thousands of years, the quantities of dust vary annually as a result of global climate, local meteorology, geomorphology of source areas, and human activities (Prospero and Nees 1986).

Effects of globally transported dust on coral reefs

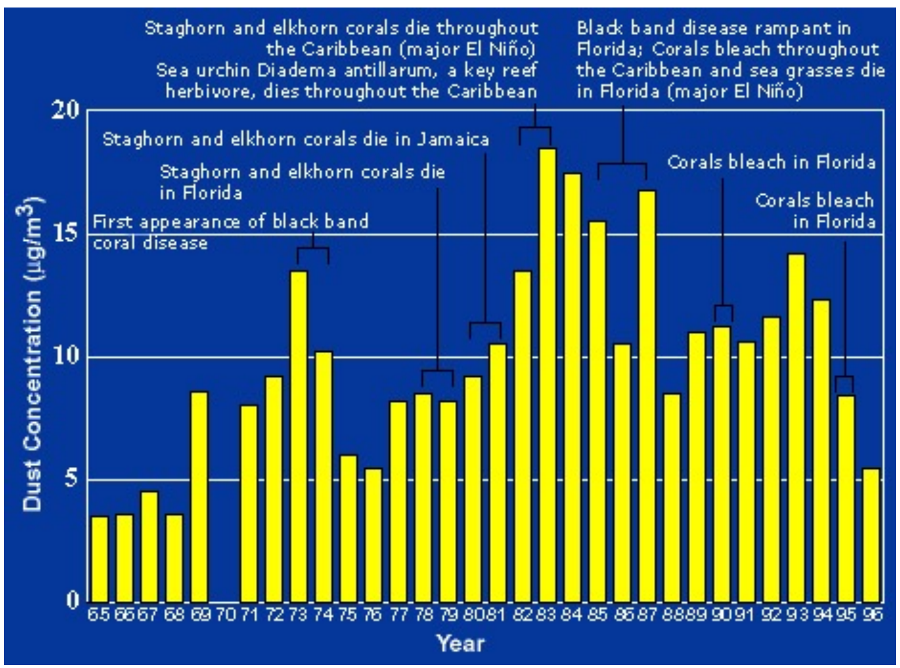
- Dust composition is a function of human-related changes in the source regions and areas over which the dust travels:
  - burning of biomass and waste
  - use of antibiotics, pharmaceuticals, and pesticides
  - increased industrialization

- Various peaks in the dust record in the western Atlantic coincide with benchmark events on reefs throughout the Caribbean.

- Saharan dust has been implicated as an efficient substrate for transporting disease-spreading spores that can cause Caribbean-wide epidemics that diminish coral reef vitality (Shinn *et al.* 2000).

Effects of globally transported dust on coral reefs

- Overall increase in African dust reaching the Caribbean island of Barbados since 1965.
- Dust deposition peak years were 1983 and 1987. These were also years of extensive environmental change on Caribbean coral reefs (Prospero and Nees 1986)



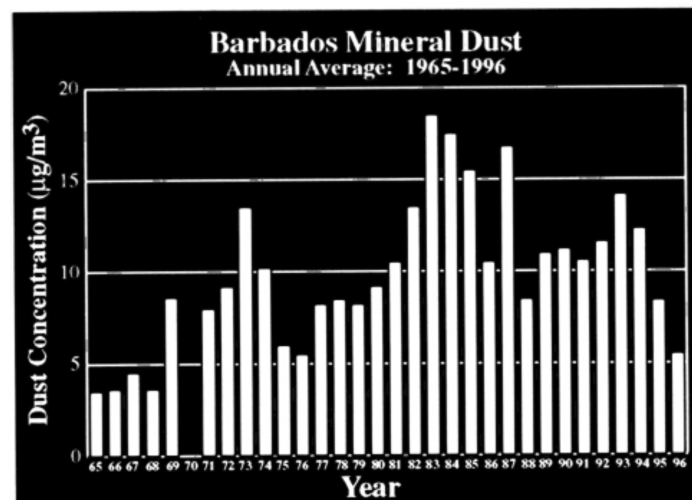


Figure 1. Annual averages dust flux at a station maintained on a bluff on the east side of Barbados Island since 1965, (Prospero et al. 1996). Note general increase beginning in the 1970s with peak fluxes in 1983 and 1987 coinciding with prolonged drought in the Sahel.

(Shinn *et al.* 2000)

Implications for human health

- African Dust is composed of clay minerals that are aggregated and held together by iron oxide. Toxic particles in the atmosphere readily coagulate with this dust.

- In dust, the mercury levels are four to a thousand-times higher than as in normal background in soils in the Southeastern United States.

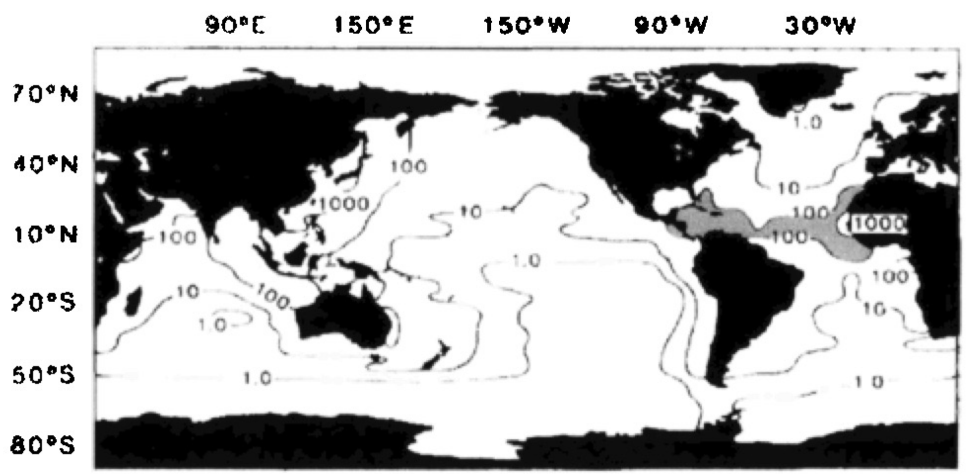


Figure 3. Map of world iron flux to oceans (modified from Duce and Tindale, 1991) with equatorial Atlantic Ocean highlighted in grey. Flux across the low-latitude Atlantic is approximately 100 times greater than at higher altitudes.

(Shinn *et al.* 2000)

Aerosol-climate interactions

Saharan dust modifies short-wave solar radiation transmitted through to the Earth's surface and long-wave IR radiation emitted to space.

The balance between these two tendencies determines whether this creates cooling or warming, and this in turn, depends in part upon such variables as the size distribution of dust particles and their chemical composition.

Can desert dust explain the outgoing longwave radiation anomaly over the Sahara during July 2003?

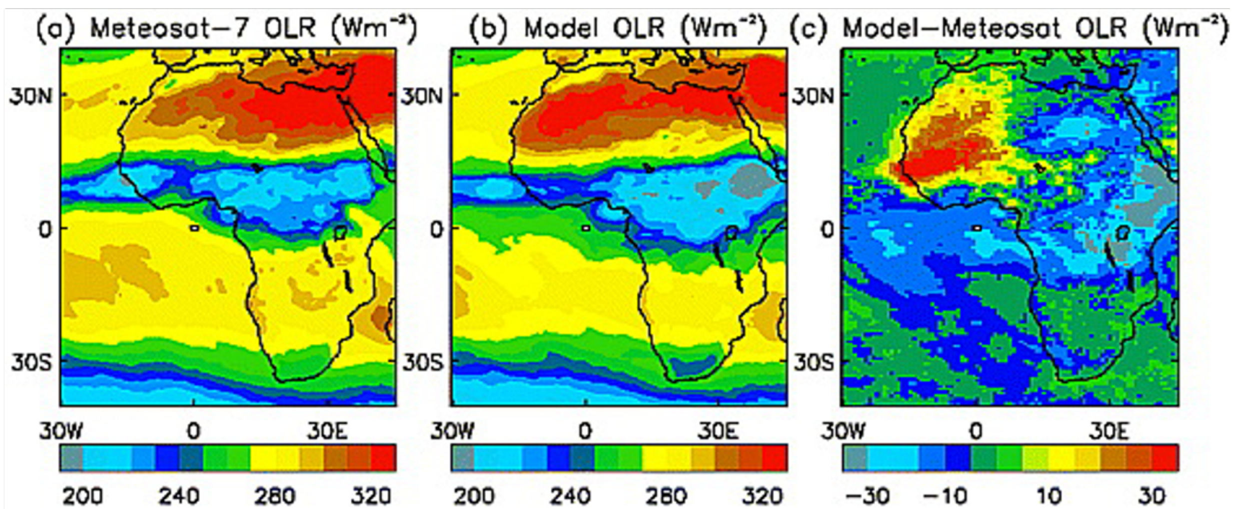


Figure 1. The July 2003 monthly mean for (a) OLR_{Met7}, (b) OLR_{model}, and (c) OLR_{model} – OLR_{Met7}. The monthly mean consists of the average of the monthly mean of the OLR diagnosed at 0000 UTC, 6000 UTC, 1200 UTC, and 1800 UTC. Units are Wm^{-2}.

(Haywood *et al.* 1995)

Aerosol-climate interactions

- Fouquart *et al.* (1987) found that either warming or cooling could take place in a Saharan dust event largely dependent upon the number/size distribution of the mineral particle population.

- Other important factors in this equation are cloud cover and the albedo of the underlying surface (Nicholson 2000). In the case of clouds, their altitude and optical depth are important determinants of the direct radiative impact of dust (Goudie 2001).

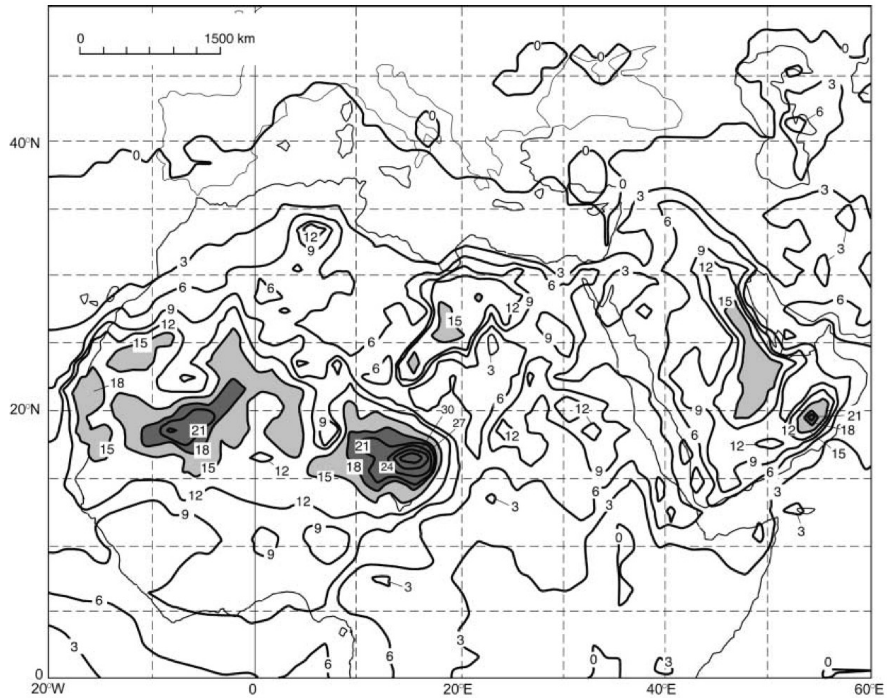


Fig. 1. Annual mean Aerosol Index for the Sahara, derived from TOMS.

(Goudie 2001)

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