Detection of Mineral Dust Aerosols

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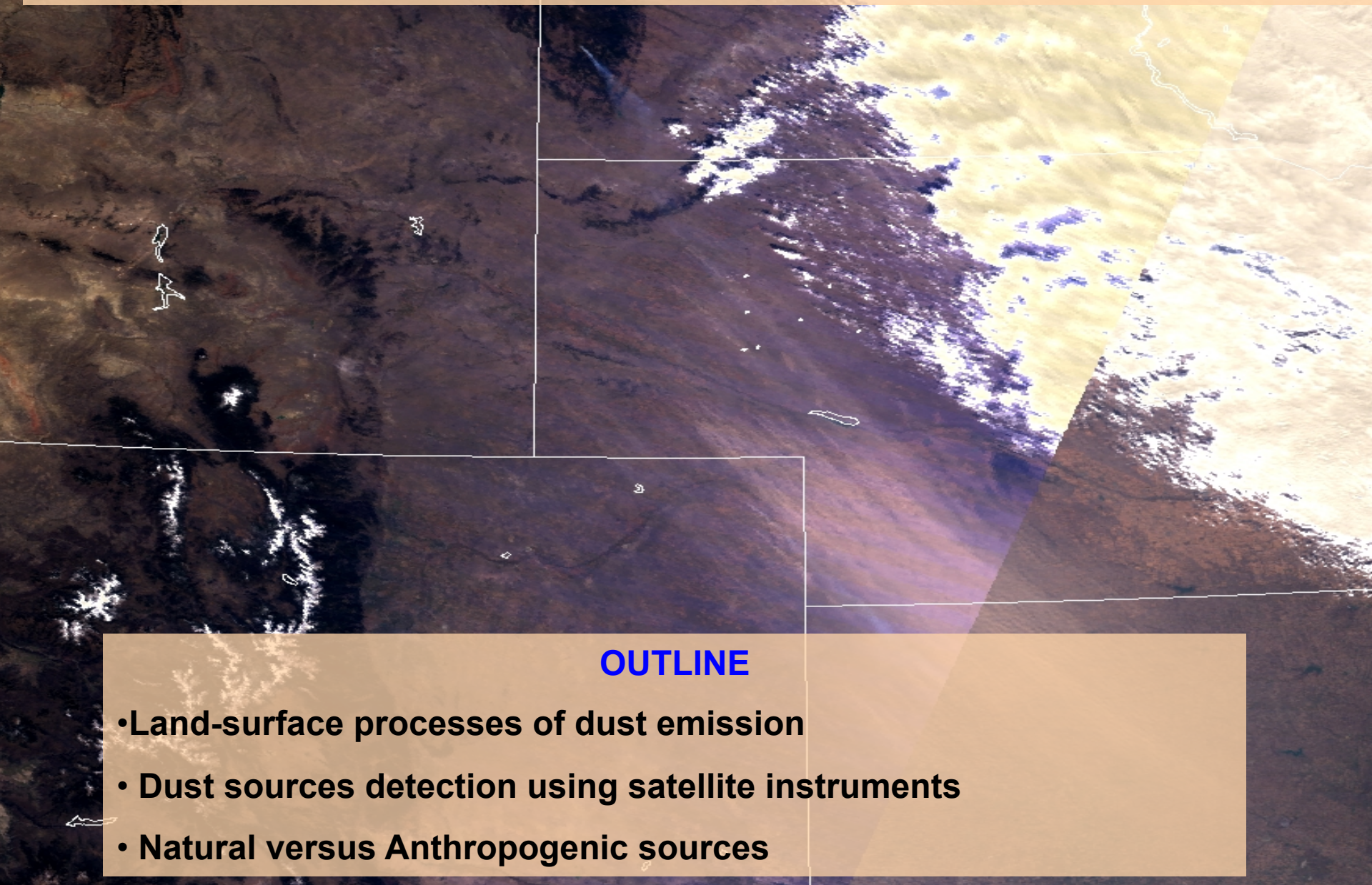


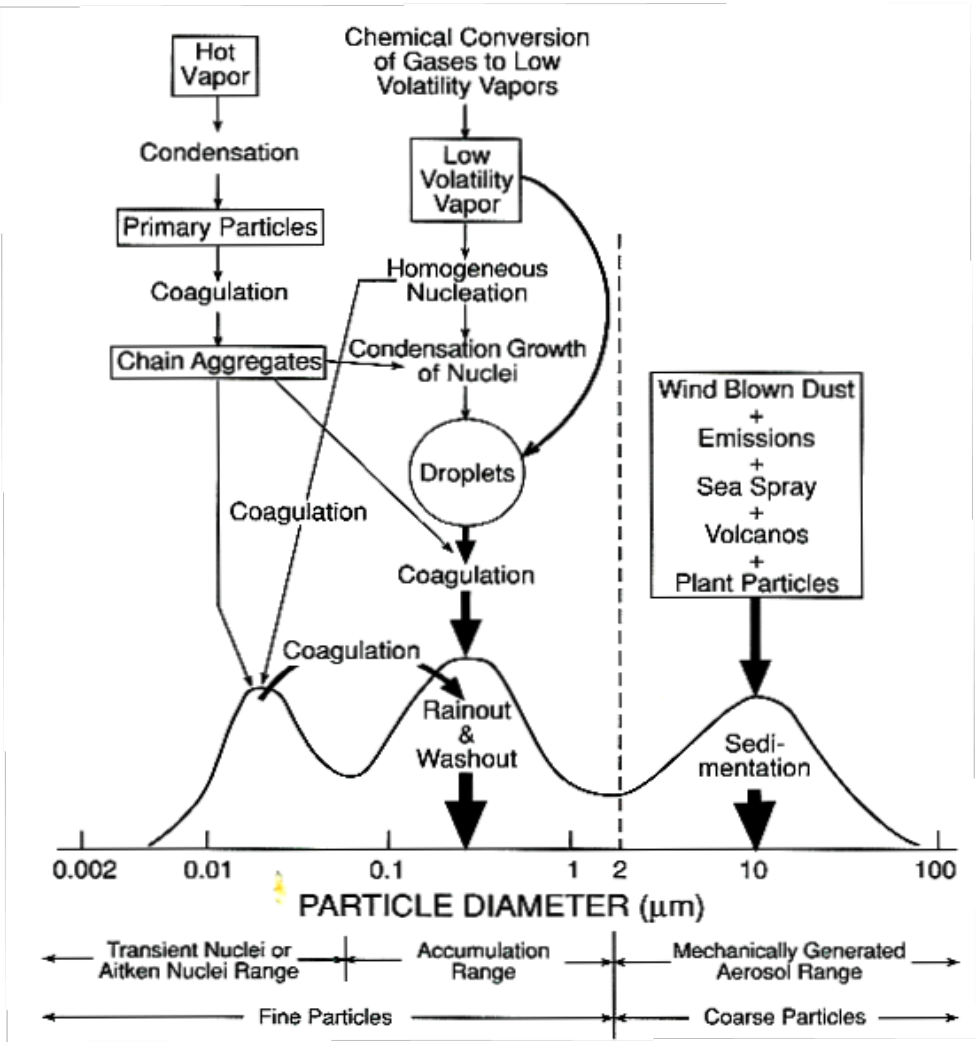
OUTLINE

- Land-surface processes of dust emission
- Dust sources detection using satellite instruments
- Natural versus Anthropogenic sources

Introduction

- Definitions:
  - **Aerosol** designates a suspension of particles, either solid or liquid, in a gaseous environment. Example: aerosol from spray canister
  - **Atmospheric aerosol**: particles staying in suspension in the atmosphere for at least several hours, excluding cloud droplets and ice crystals.

Intro cont'd: Particle size



Aerosol modes: particles are grouped within 3 diameter subranges (modes): **nucleation** or **Aitken** (diam< 0.1um), **accumulation** (0.1< diam < 2), **coarse** (diam > 2).

Aerosol size fractions: **Fine** (diam <2 um), and **Coarse** (diam>2um)

Loss Processes: Aitken = **coagulation** with larger particles by diffusion; Coarse = **sedimentation** by gravitational settling; Accumulation : weak diffusion and sedimentation -> particles aggregate in this mode until removed by **wet deposition**

Source Processes: Primary: mechanically produced (e.g. dust, sea salt), **Secondary**: gas-to-particle conversion (e.g. sulfate)

Aerosol Lifetime a few hours up to 2 weeks

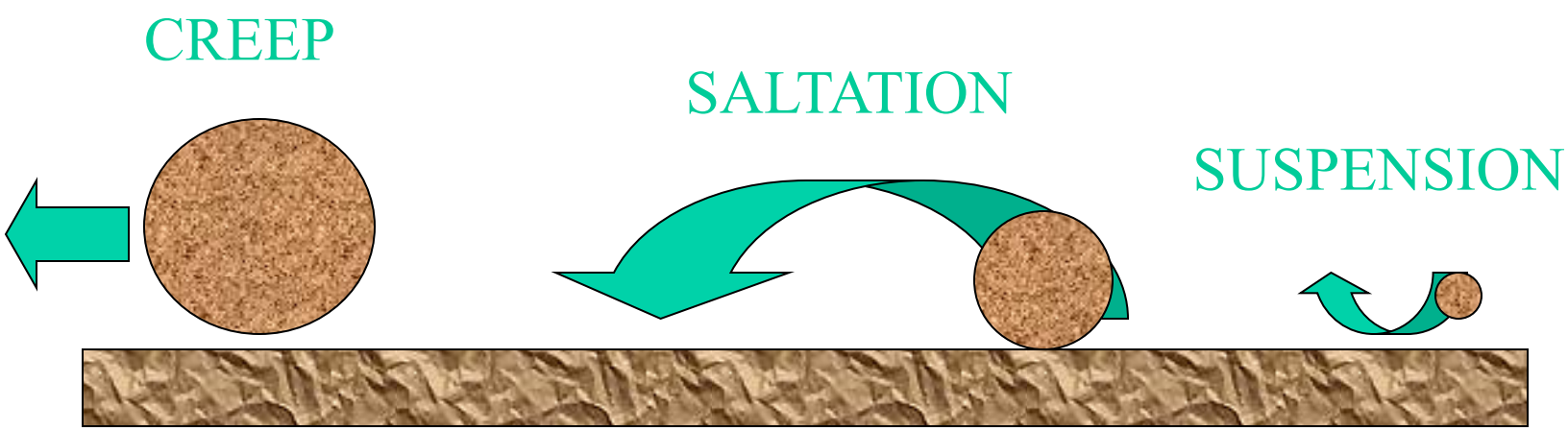
Introduction cont'd: Aerosol effects

- Air quality:
  - Respiratory distress, eyes irritation
  - Reduction of visibility
  - Acid rain
- Climate:
  - Direct: scattering and absorption of solar and infrared radiation
  - Indirect: modify clouds properties
    - 1st : brighter clouds
    - 2nd : decrease precipitation efficiency

Mineral Dust Aerosols: Physical Processes: *Particle motion*

Three modes of particle motions:

1. Creep : rolling motion of largest particles (> 500um)
2. Saltation: hopping motion of sand (50-500um)
3. Suspension: wafting motion of silt and clay (0.1-50um)

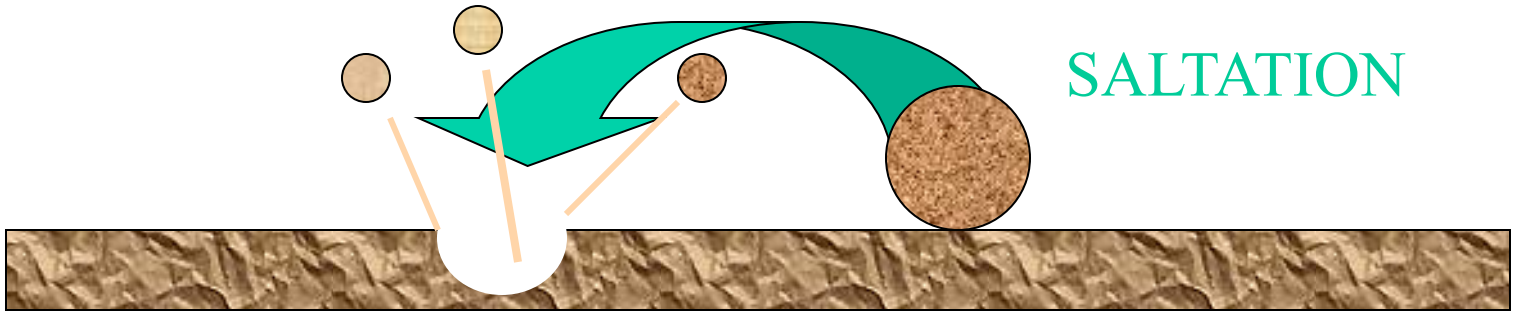


Mineral Dust Aerosols: Physical Processes: Dust uplift

Observations show that:

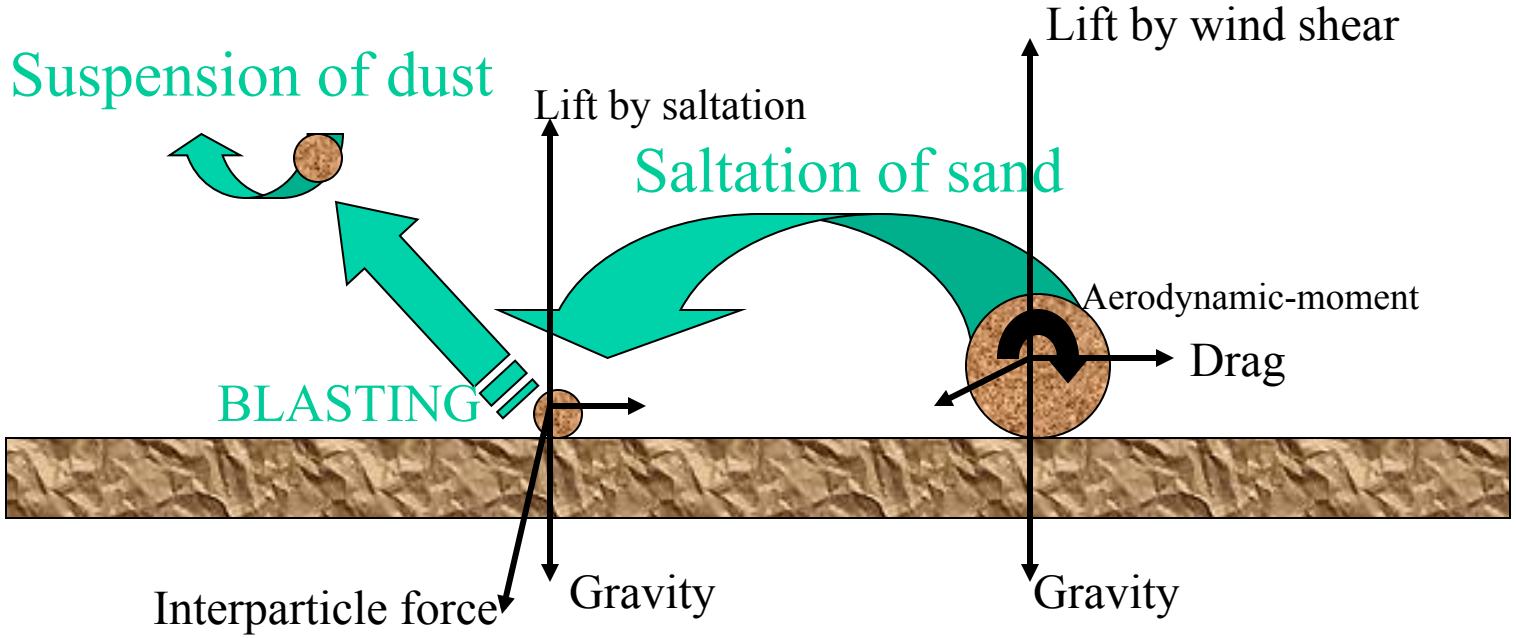
1. Saltating sand grains excavate ovoid-shaped micro-craters in loose fine particle surfaces (Rice et al., 1995 and 1996). A proportion of the material displaced is ejected into the flow.
2. Field and laboratory studies show that dust concentration is enhanced by orders of magnitude in presence of saltation. Without saltation impacts a surface of dust particles is remarkably stable (Bagnold, 1941).

These observations imply that dust uplifting is essentially determined by the saltation of larger particles.



Mineral Dust Aerosols: Physical Processes: *Sand blasting*

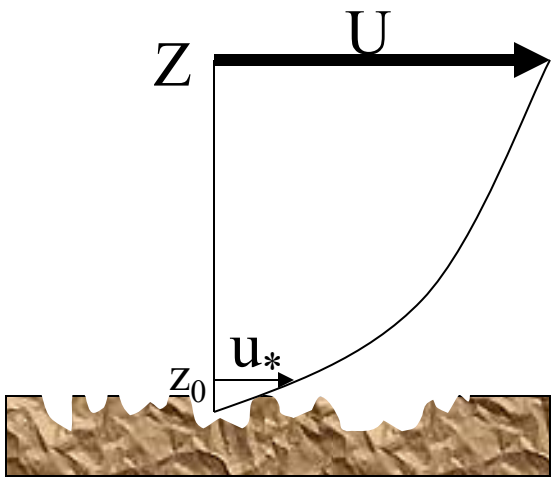
The primary mechanism for uplifting dust from the surface is through saltation bombardment by sand particles because the **interparticle cohesive forces** between dust particles are too strong to allow direct suspension. .



Mineral Dust Aerosols: Physical Processes: Friction velocity

The friction velocity, u_*, is the fundamental quantity determining dust emission, and is defined by $\tau = \rho u_*^2$

Within a constant-stress layer, the mean wind speed U(Z) is related to u_* by $U(Z) = \frac{u_*}{k} \ln(\frac{Z}{z_0}) \quad k \cong 0.4$



u_*: Friction velocity
z_0: roughness length
k: Von Karman constant

Saltation flux

The streamwise sand flux flux Q is given by Bagnold (1941):

Dimensionless constant

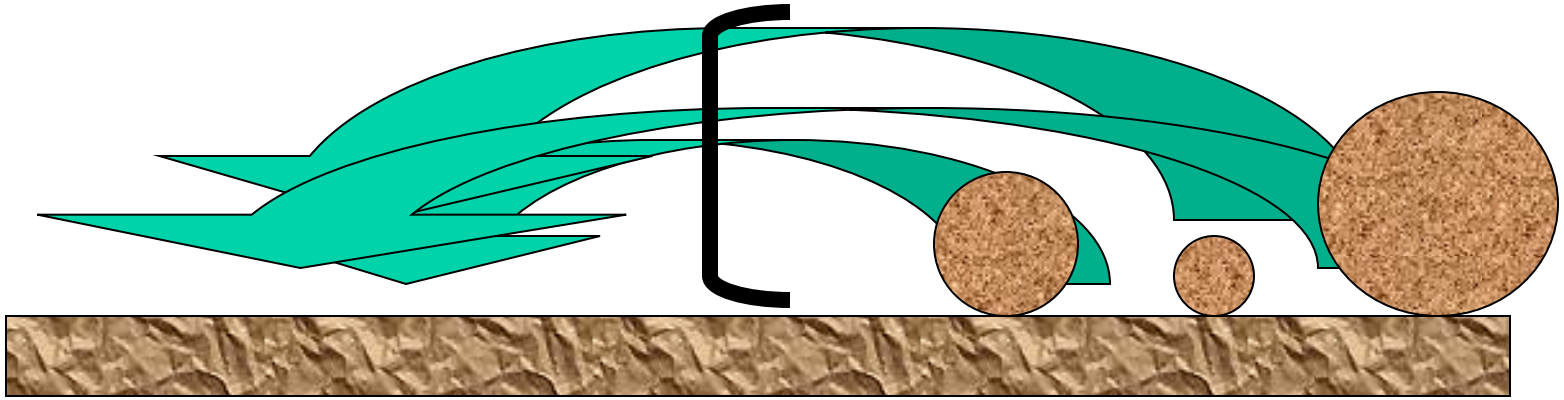
Friction velocity

$$Q = \int_0^\infty q(z)dz = \frac{c\rho_a}{g} u_*^3 \Phi\left(\frac{u_*}{u_{*t}}\right)$$

Air density

Function [0-1]

Threshold friction velocity



Function $\Phi(u_* / u_{*_t})$

Suppression of saltation when friction velocity below its threshold value

$$\Phi(u_* / u_{*_t}) = 0 \quad u_* < u_{*_t}$$

$$= 1 \quad u_* / u_{*_t} \rightarrow \infty$$

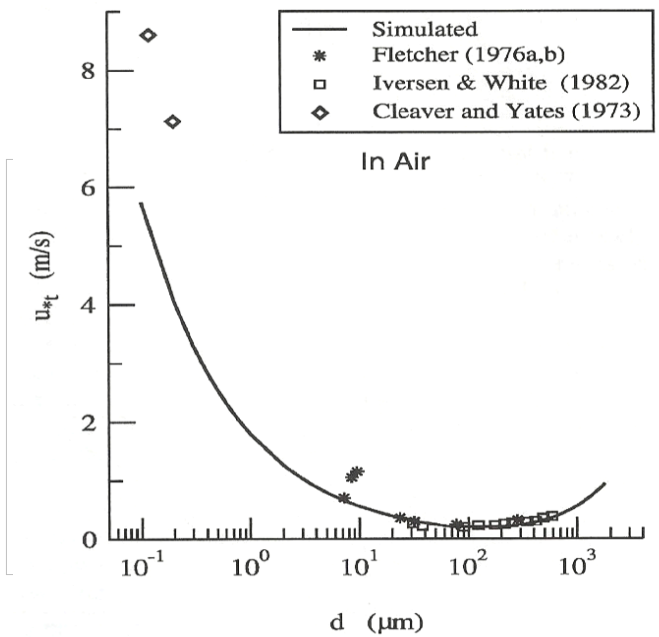
Forms: $\Phi = (1 - \frac{u_{*_t}}{u_*})(1 + \frac{u_{*_t}}{u_*})^2$

White, Soil transport by winds on Mars, J. Gephys. Res., 84(B9), 4643-4651,1979

$\Phi = (1 - \frac{u_{*_t}^2}{u_*^2})$

Shao et al., Effect of saltation bombardment on the entrainment of dust by wind, J. Geophys. Res., 98(D7), 12,719-12,726, 1993

Threshold friction velocity u_{*t}



$$u_{*t}(d_p) = \sqrt{a_n\left(\frac{\rho_p g d_p}{\rho_a} + \frac{\gamma}{\rho_a d_p}\right)}$$

With a_n=0.0123, γ=300 kg m^{-2}, ρ_p=2.65 10^3 kg m^{-3}, ρa=1.227 kg m^{-3}

Shao and Lu, A simple expression for wind erosion threshold friction velocity, J. Geophys. Res., 105, 22437-22443, 2000

U_{*t} dependency on soil moisture

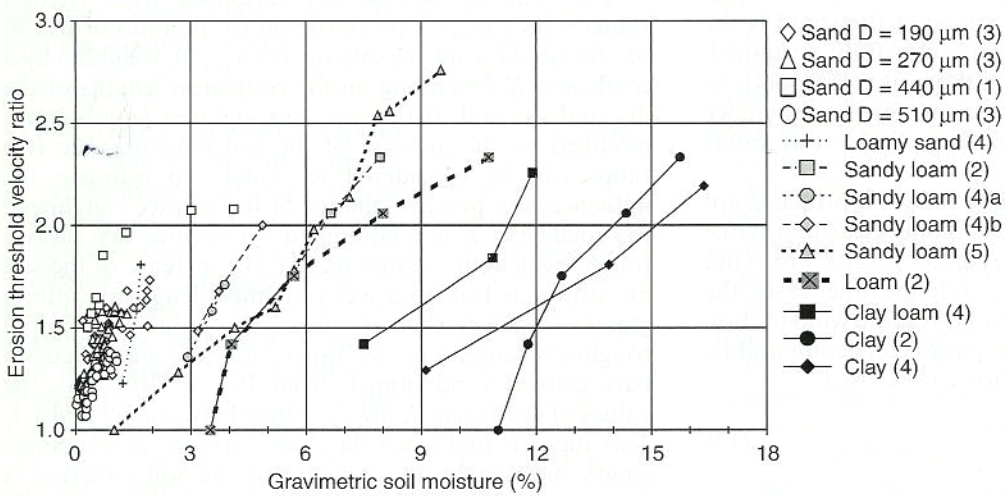
Wind erosion threshold increase with increasing soil moisture, due to interparticle forces

$$\frac{u_{*tw}}{u_{*td}} = 1 \qquad \text{for } w < w'$$

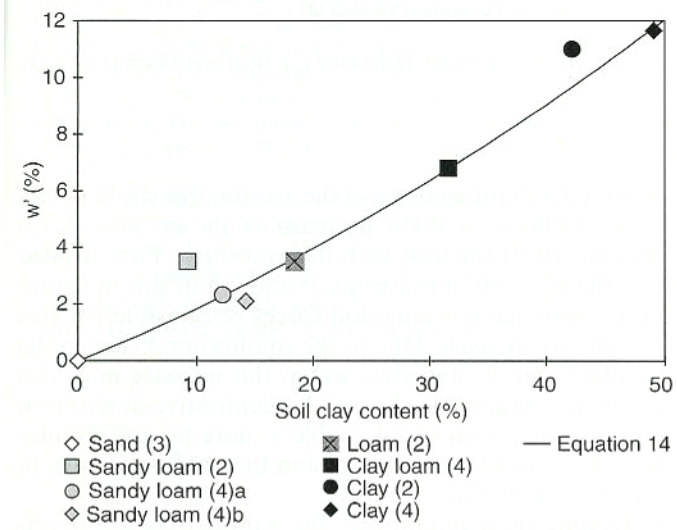
$$\frac{u_{*tw}}{u_{*td}} = \left[1 + 1.21(w - w')^{0.68}\right]^{0.5} \qquad \text{for } w > w'$$

$$\text{with } w' = 0.0014(\%\text{clay})^2 + 0.17(\%\text{clay})$$

Ratio of wet to dry threshold wind velocity



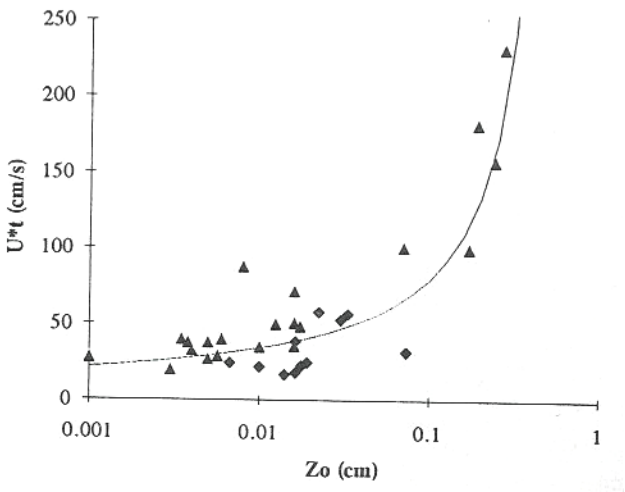
Maximum adsorbed water



Fean et al., Parameterization of the increase of the aeolian erosion threshold wind friction Velocity due to soil moisture for arid and semi-arid areas, Ann. Geophysicae, 17, 149-157, 1999.

U_{*r} dependency on roughness length

For an immobile surface the roughness length depends only on the surface morphology, but for a saltating surface it depends on u_*



For mobile surface, the effective roughness length is: $z_{0s} = (\frac{Au_*^2}{2g})^{1-r} z_0^r$

with $r = \min[\frac{u_{*t}}{u_*}, 1]$

U_{*r} dependency on other parameters

- Crusting:

  u_{*t} proportional to crust thickness

- Soil disturbance:

  u*t decrease significantly for disturbed soils

- Salt content:

  u*t double with 1% increase of salt content

- others

Vertical Dust Flux

Assuming dust uplift is mainly driven by saltation:
=> Vertical mass flux F proportional to saltation flux Q

Vertical Flux of clay and silt

Soil size distribution

Dimensional factor

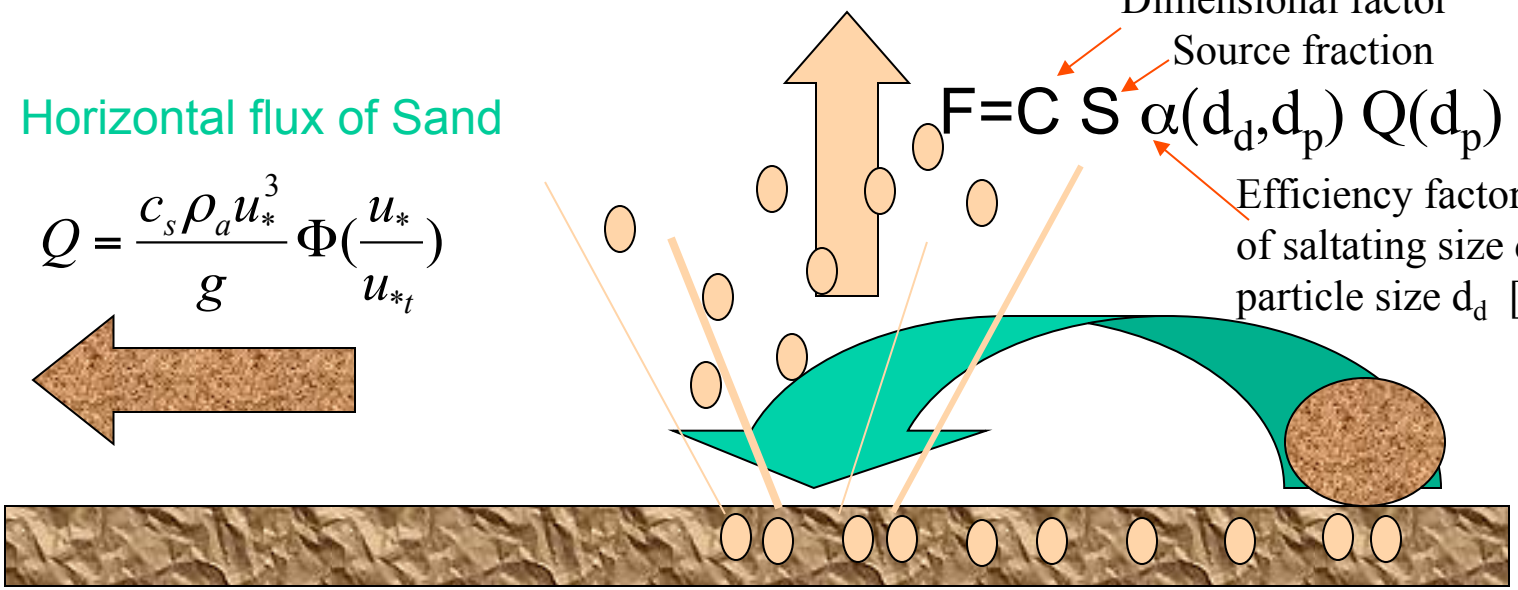
Source fraction

$$F = C\ S\ \alpha(d_d, d_p)\ Q(d_p)\ s(d_d, d_p)$$

Efficiency factor function of saltating size d_p and dust particle size d_d [m^{-1}]

Horizontal flux of Sand

$$Q = \frac{c_s \rho_a u_*^3}{g} \Phi\left(\frac{u_*}{u_{*t}}\right)$$

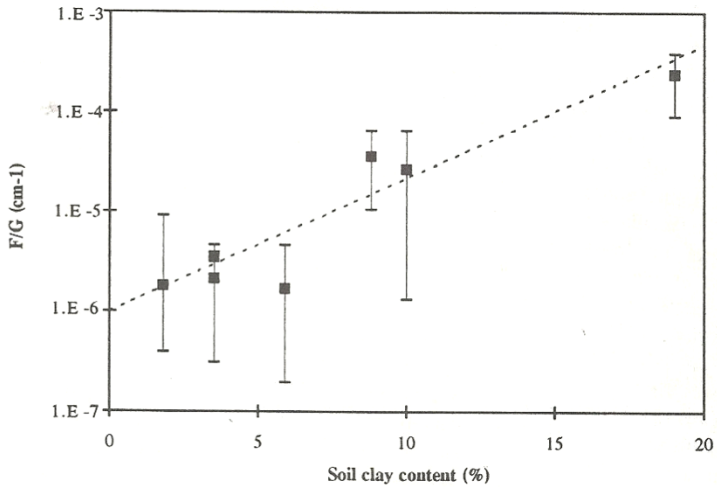


Alfaro et al., Modeling the size distribution of a soil produced by sandblasting, J. Geophys. Res, 102, 11239-11249, 1997

Sandblasting Mass Efficiency

$$F = C\ S\ \alpha(d_d, d_p)\ Q(d_p)\ s(d_d, d_p)$$

Based on field data,

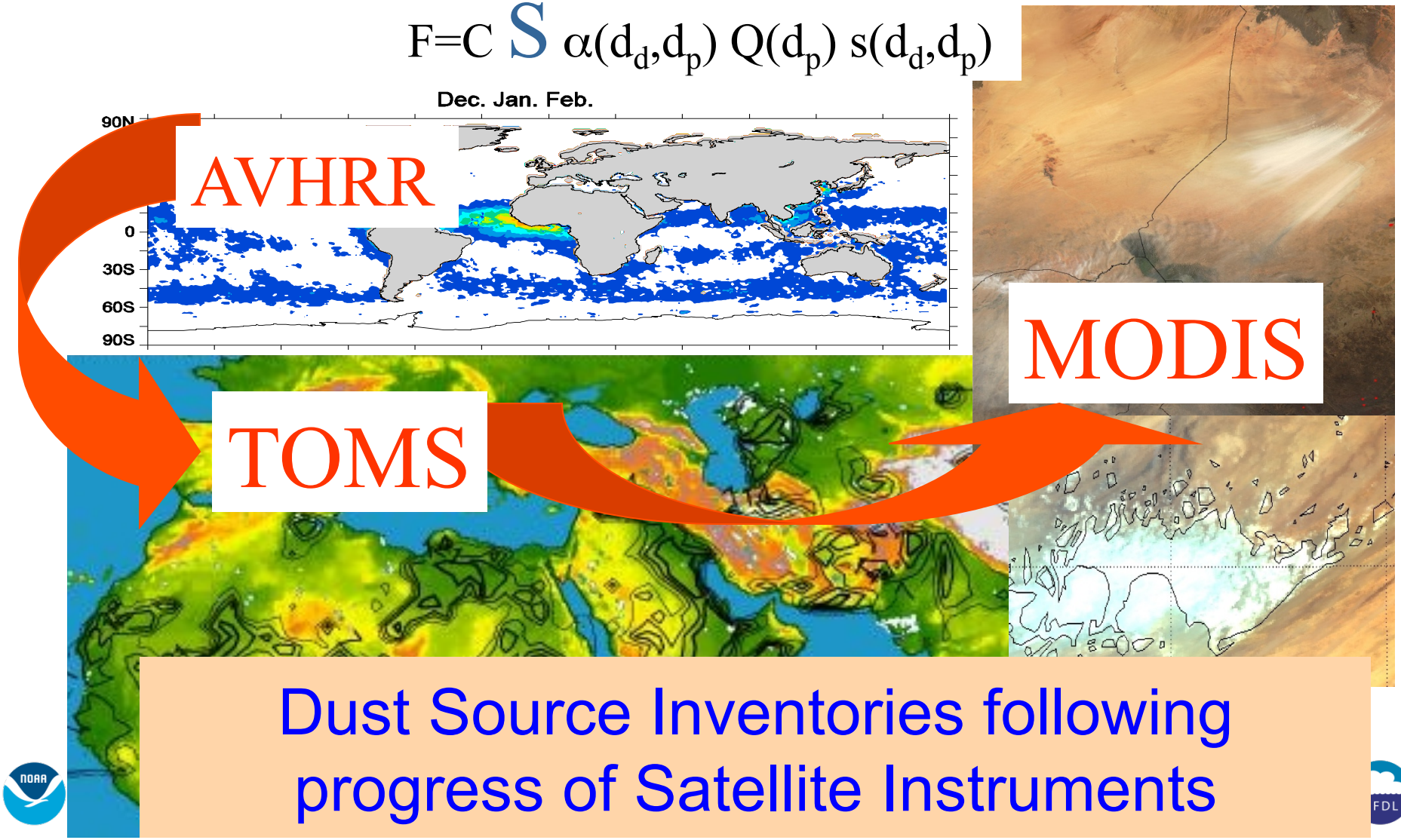


$$\alpha = 0.01\, e^{(0.308 f_{clay} - 13.82)}$$

with $f_{clay} < 0.2$

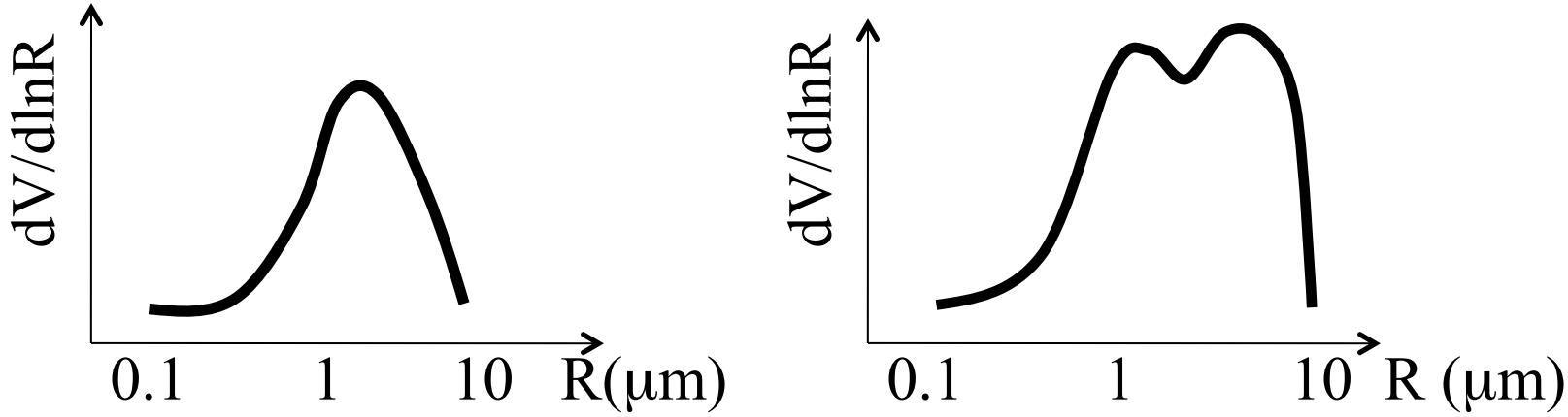
Dust source fraction S from remote sensing data

$$F = C\, S\, \alpha(d_d, d_p)\, Q(d_p)\, s(d_d, d_p)$$



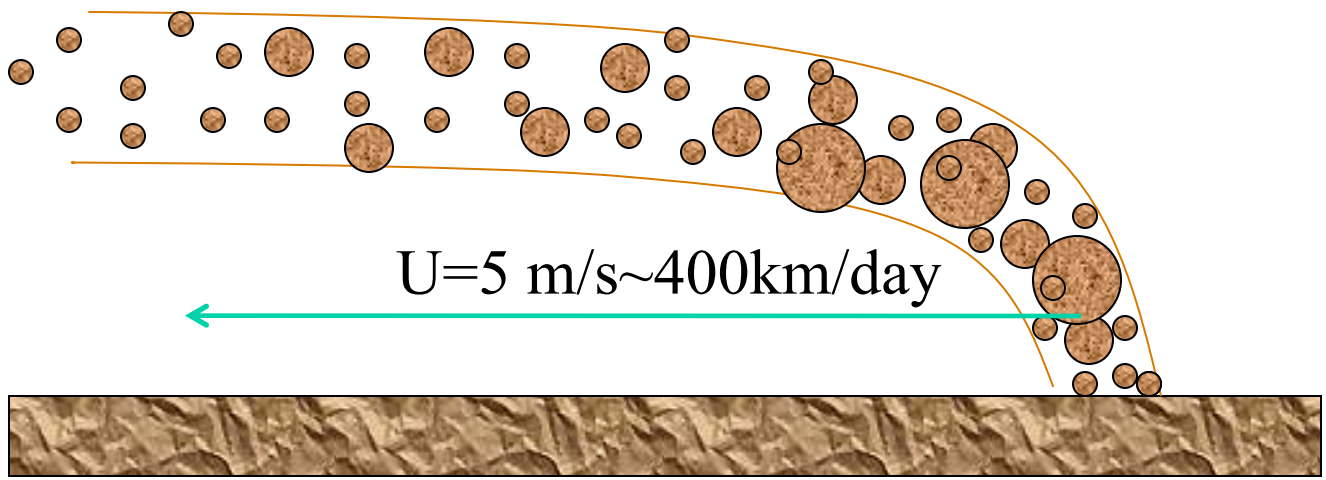
Dust Source Inventories following progress of Satellite Instruments

Change of dust size distribution along dust plume

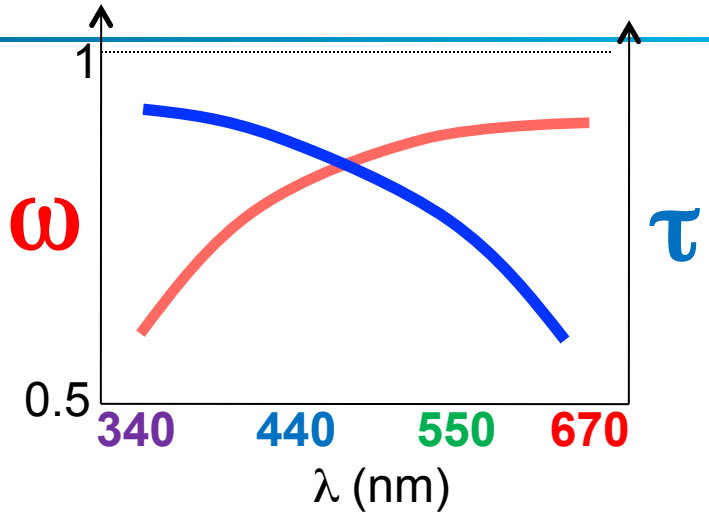


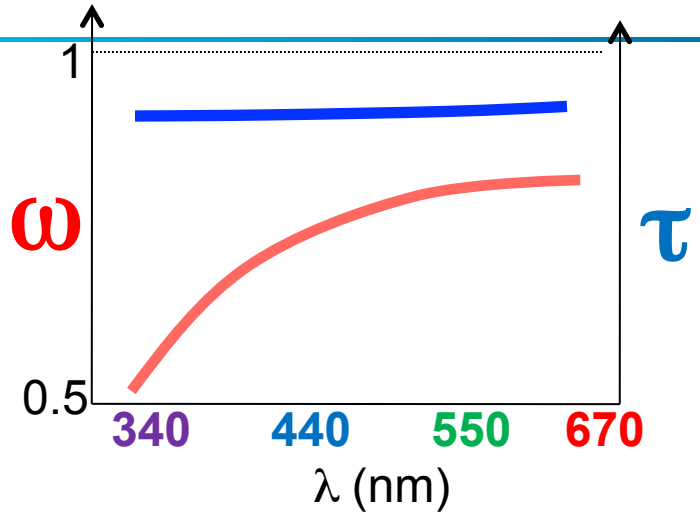
$$V_g = \frac{2\rho g R^2}{9\mu}$$

1 100 1000 m/day



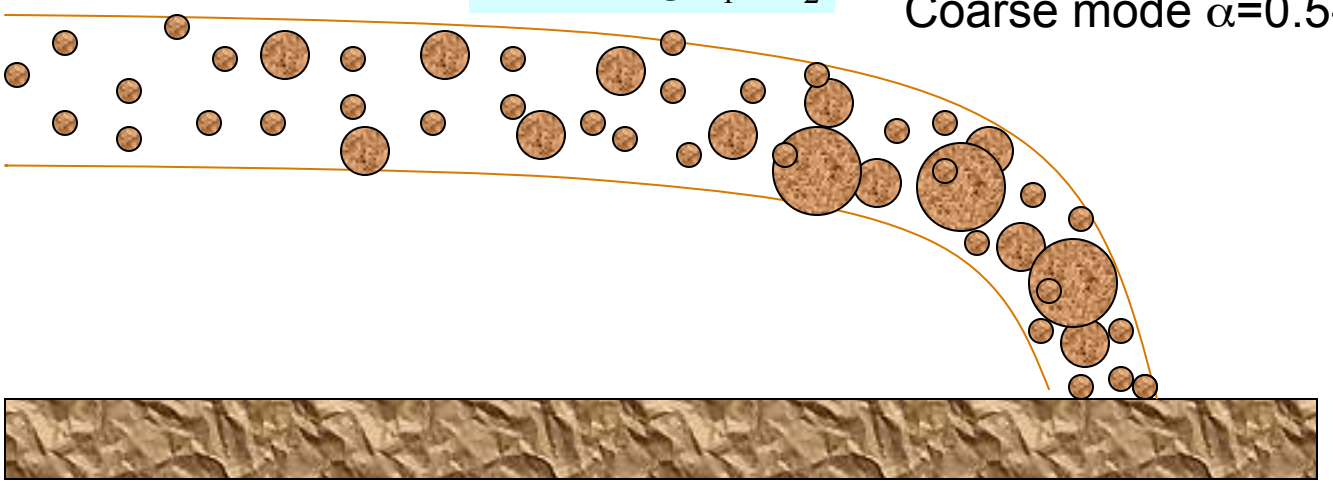
Change of dust optical properties along dust plume





Angstrom exponent $\alpha = -\dfrac{\log \tau_1 / \tau_2}{\log \lambda_1 / \lambda_2}$

Molecules α=4
Accumul mode α=2-1
Coarse mode α=0.5-0



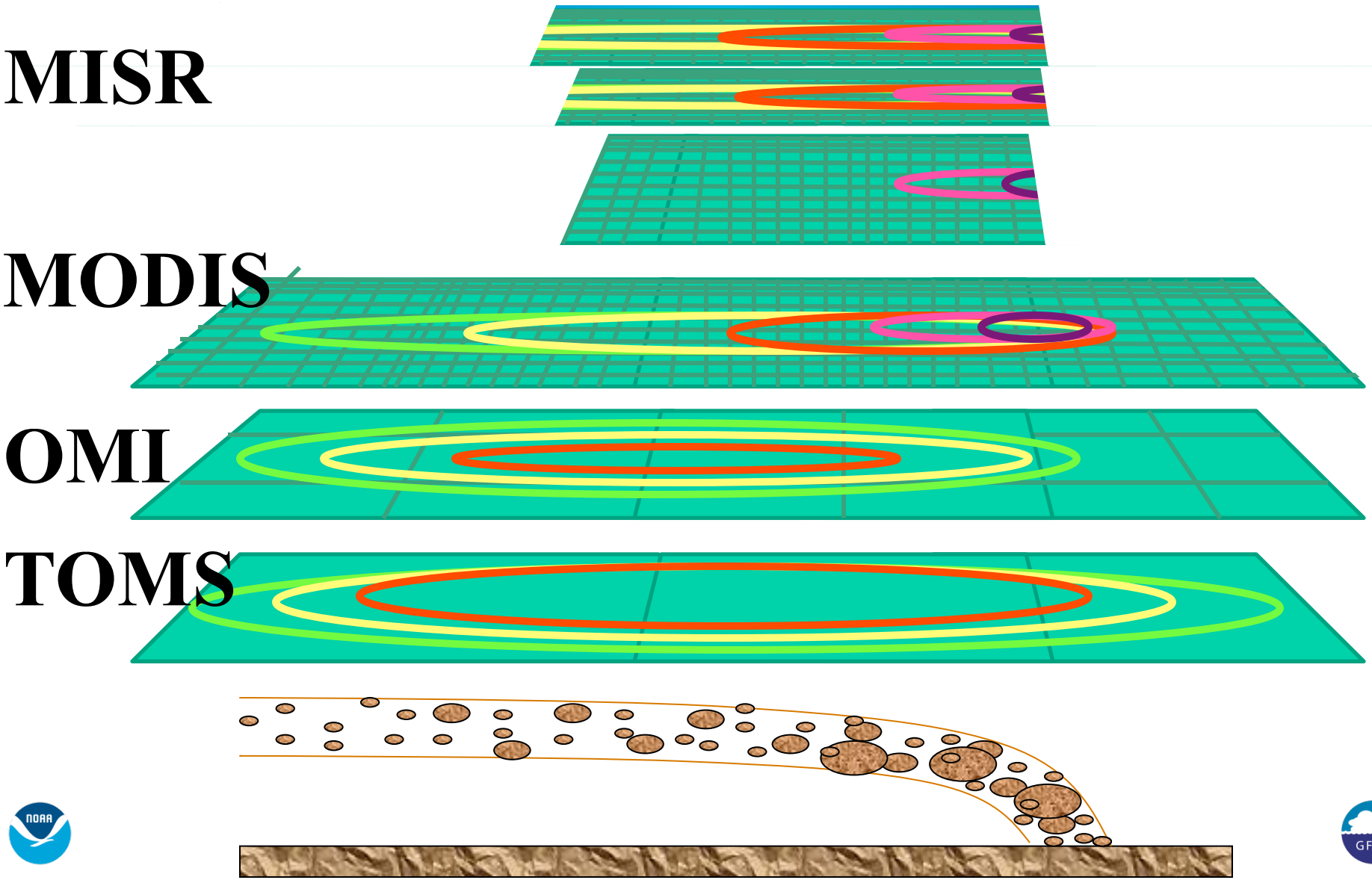
Dust detection from space

- Knowing spectral variation of ω and τ, specially between nUV and visible, allows separation of dust from other aerosol components.
- Knowing α allows screening off aged dust from freshly emitted aerosol.

Satellite products w global coverage

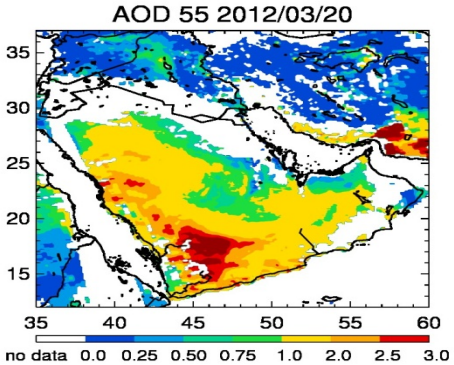
Instrument	Platform	Dates	Eq LT	Swath (km)	L2 Resol (km)	λ (nm)
TOMS	Nimbus-7	1979-1993	11:30AM	2300	50x50 100x250	AIv7: 340, 380 AIv8: 331, 360
TOMS	Earth-Probe	1996-2001	11:16AM	2300	50x50 100x250	AI(v8): 331, 380
OMI	Aura	2004-present	1:38PM	2600	13x24 28x150	AI(v8): 331, 360 τ, ω: 354, 388
MISR	Terra	2000-present	10:30AM	360	17.6x17.6	τ, ω: 446, 558, 672, 867
MODIS DB	Aqua	2002-present	1:30 PM	2330	10x10 20x48	τ, ω: 412, 470, 670
CALIOP	CALIPSO	2006-present	1:30AM 1:30PM	0.07	0.333x0.06	Bck, mask, s

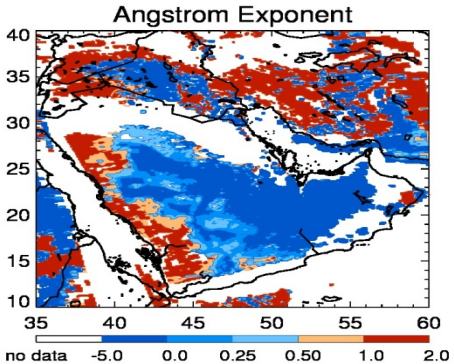
Satellite resolution and swath

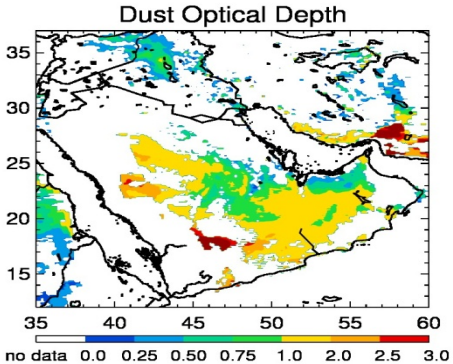


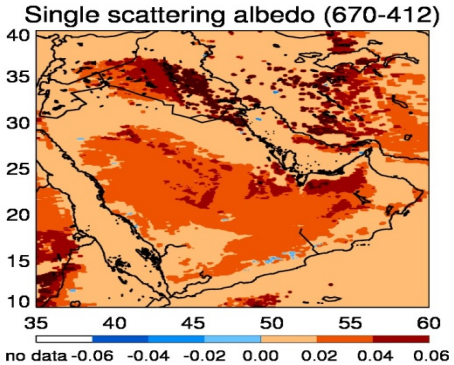
Dust Sources detection using MODIS

MODIS Aqua Level 2
AOD on March 20, 2012







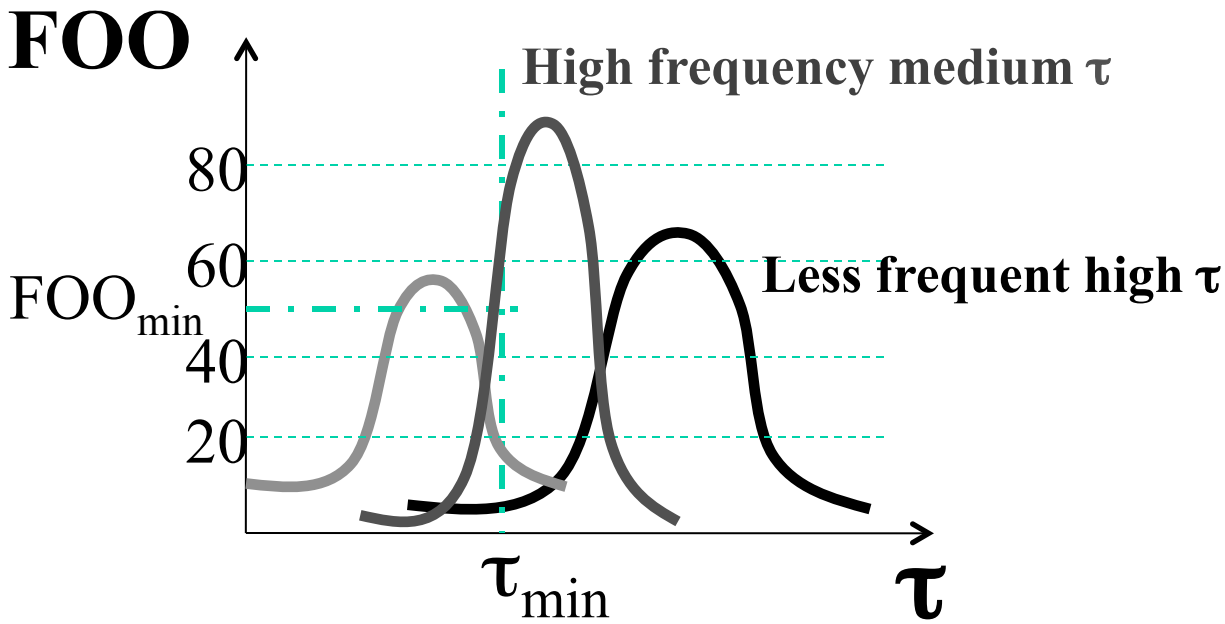


Fine mode aerosol
Coarse mode aerosol

Decreased absorption with wavelength

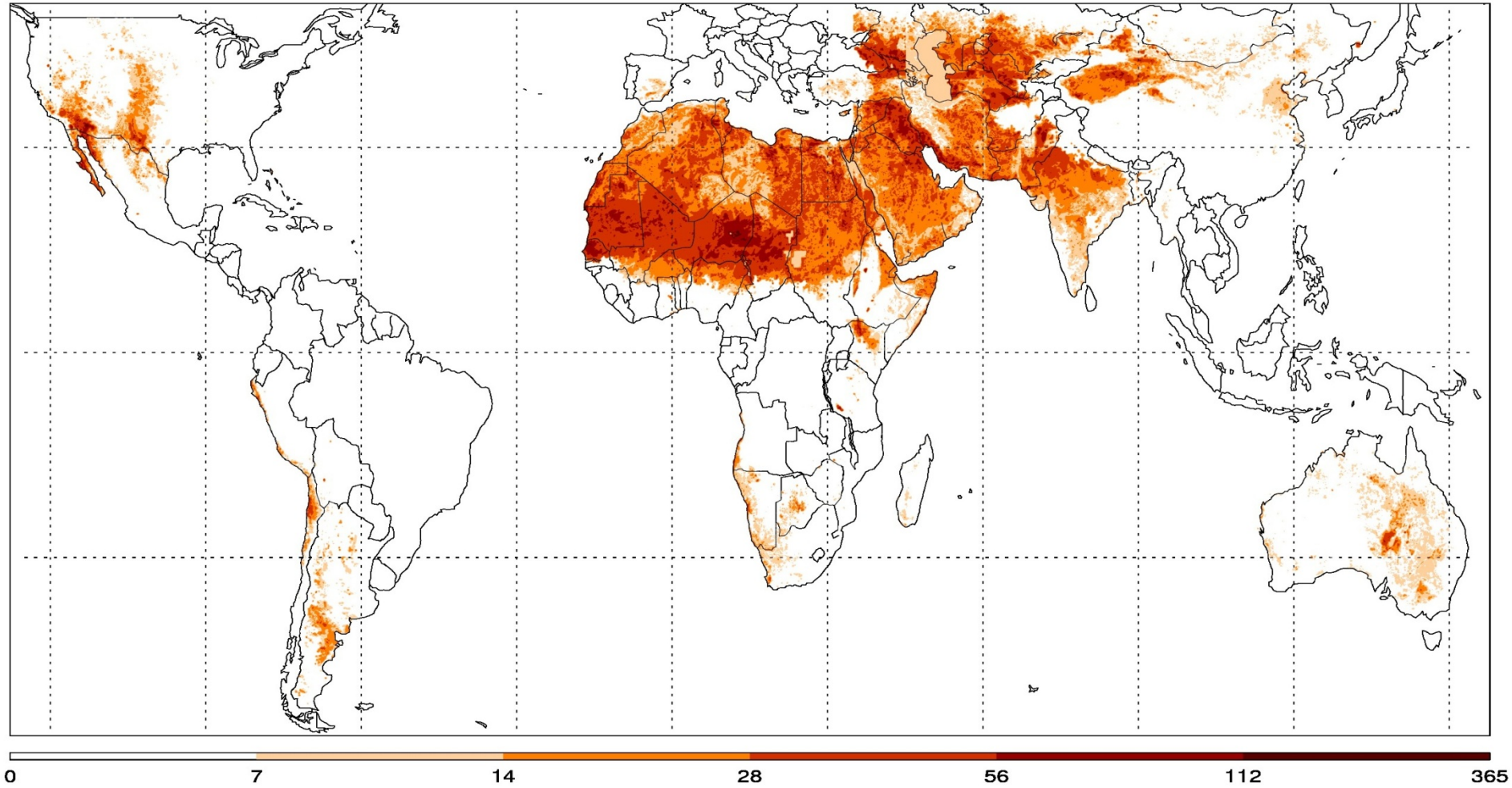
Increased absorption with wavelength

Frequency Of Occurence



Active sources are locations with $\tau > \tau_{min}$ and FOO > FOO_{min} over many years.

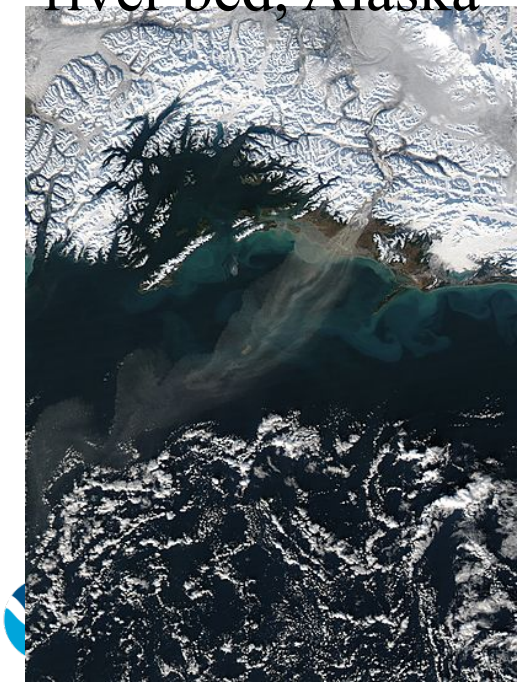
Number of days per year, in average, MODIS DB Dust Optical Depth > 0.2



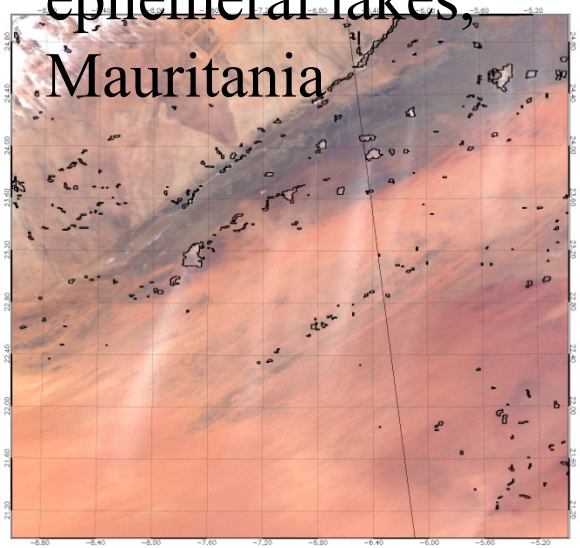
Natural Sources

bare and dry surfaces with fine soil texture (clay, silt or alluvium) = dry river, lake or sea bed

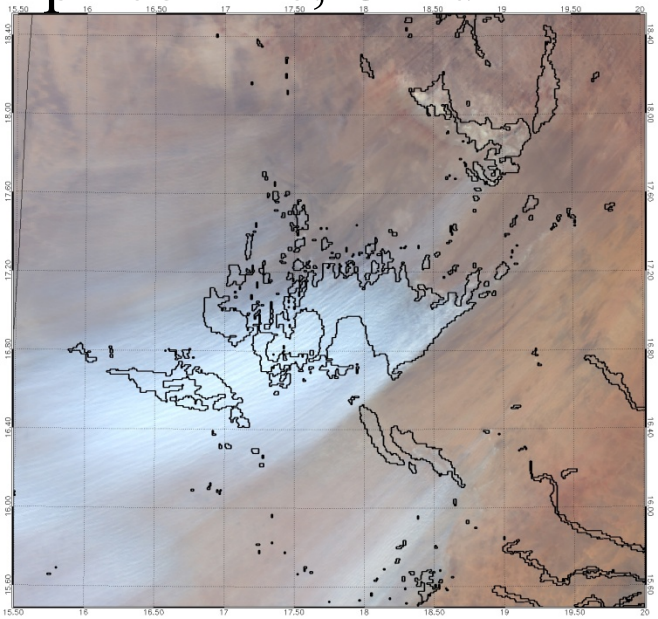
Dust from dry river bed, Alaska



Dust from ephemeral lakes, Mauritania



Bodele depression, paleo-lake, Chad



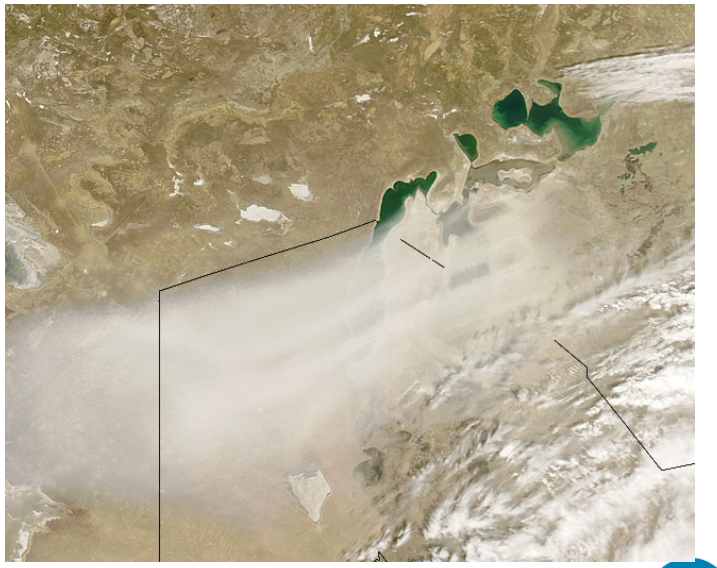
Anthropogenic dust sources

- Disturbed soil due to agriculture, overgrazing
- Dry sea or lake bed by excessive irrigation
- Construction, mining, etc.

Agriculture

Mining, Ohio valley

Dry lake from irrigation in Uzbekistan



Attribution of a natural/anthropogenic/hydrologic origin to dust sources

Dust sources are attributed a natural, anthropogenic or hydrologic origin based on the fraction of

1. **Land use**:
   - agriculture + pasture
   - Dataset: 10x10km Klein Goldewijk, GBC, 2001

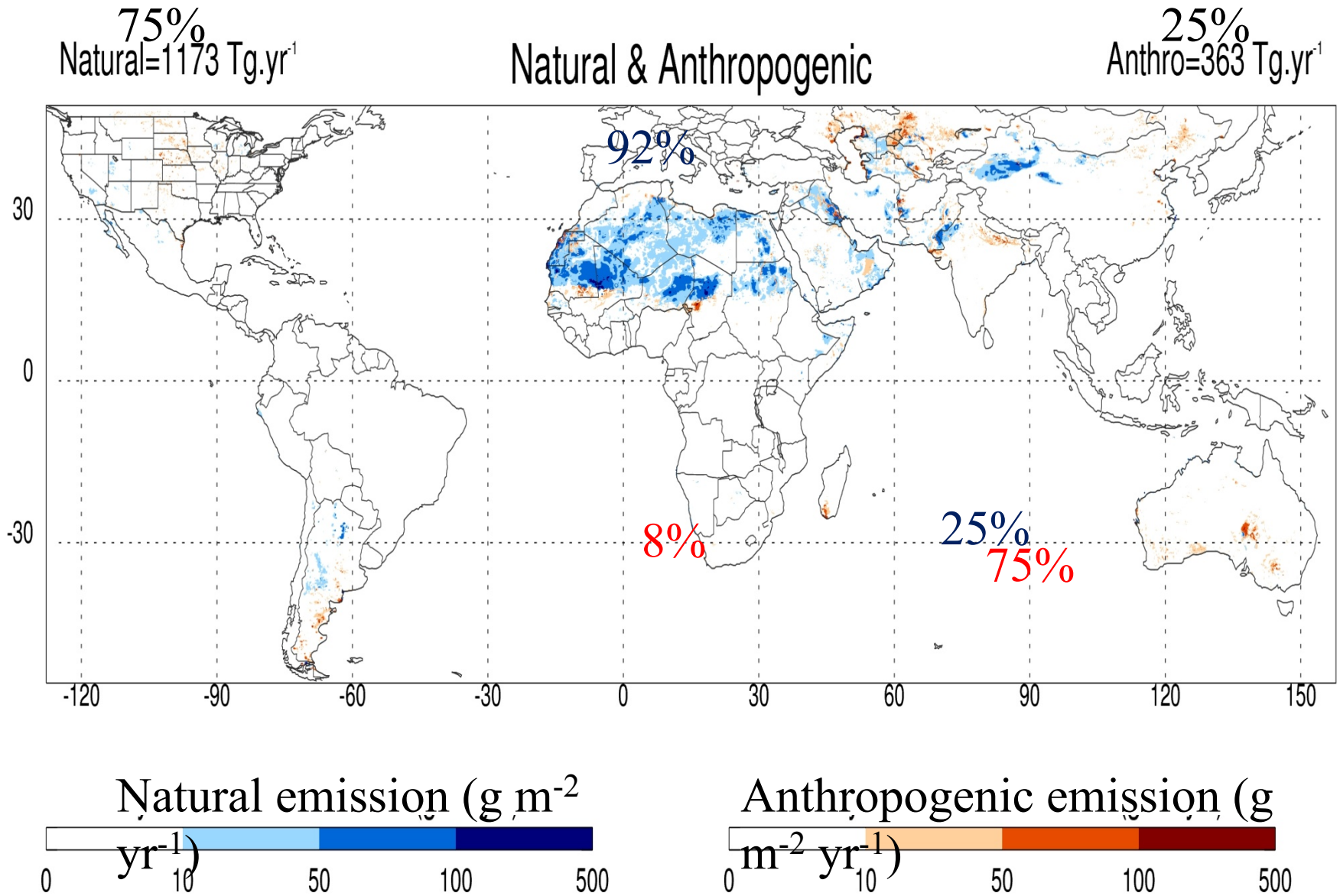
   Anthropogenic if land use > 30%

   Natural if land use < 30%

2. **Ephemeral water bodies**:
   - ephemeral lakes and wadis
   - dataset: 1x1km MODLAND

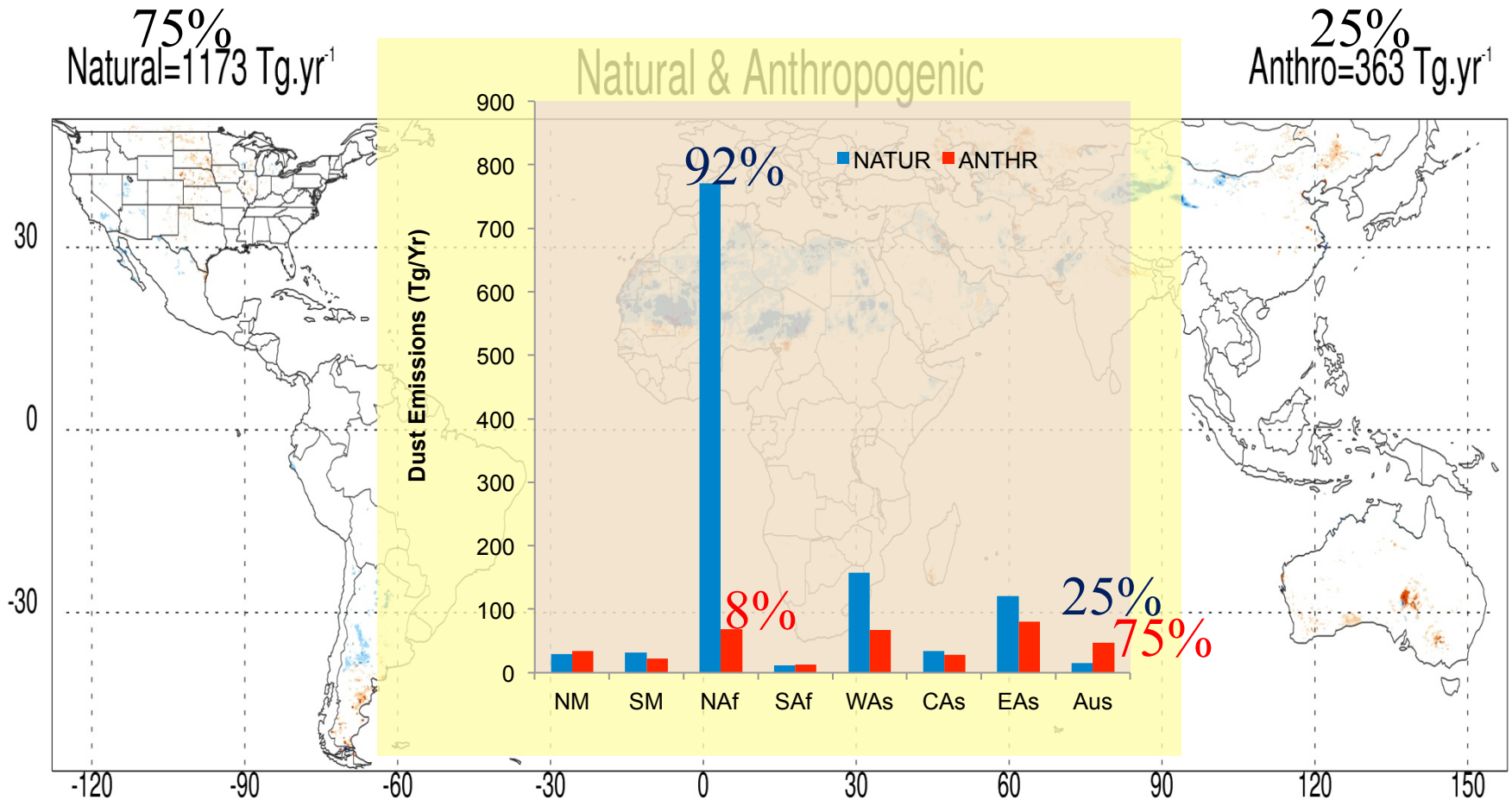
   Hydrologic if water body > 10%

Natural & Anthropogenic annual emissions



Ginoux et al., RoG,

Natural & Anthropogenic annual emissions



Natural emission (g m^{-2} yr^{-1})

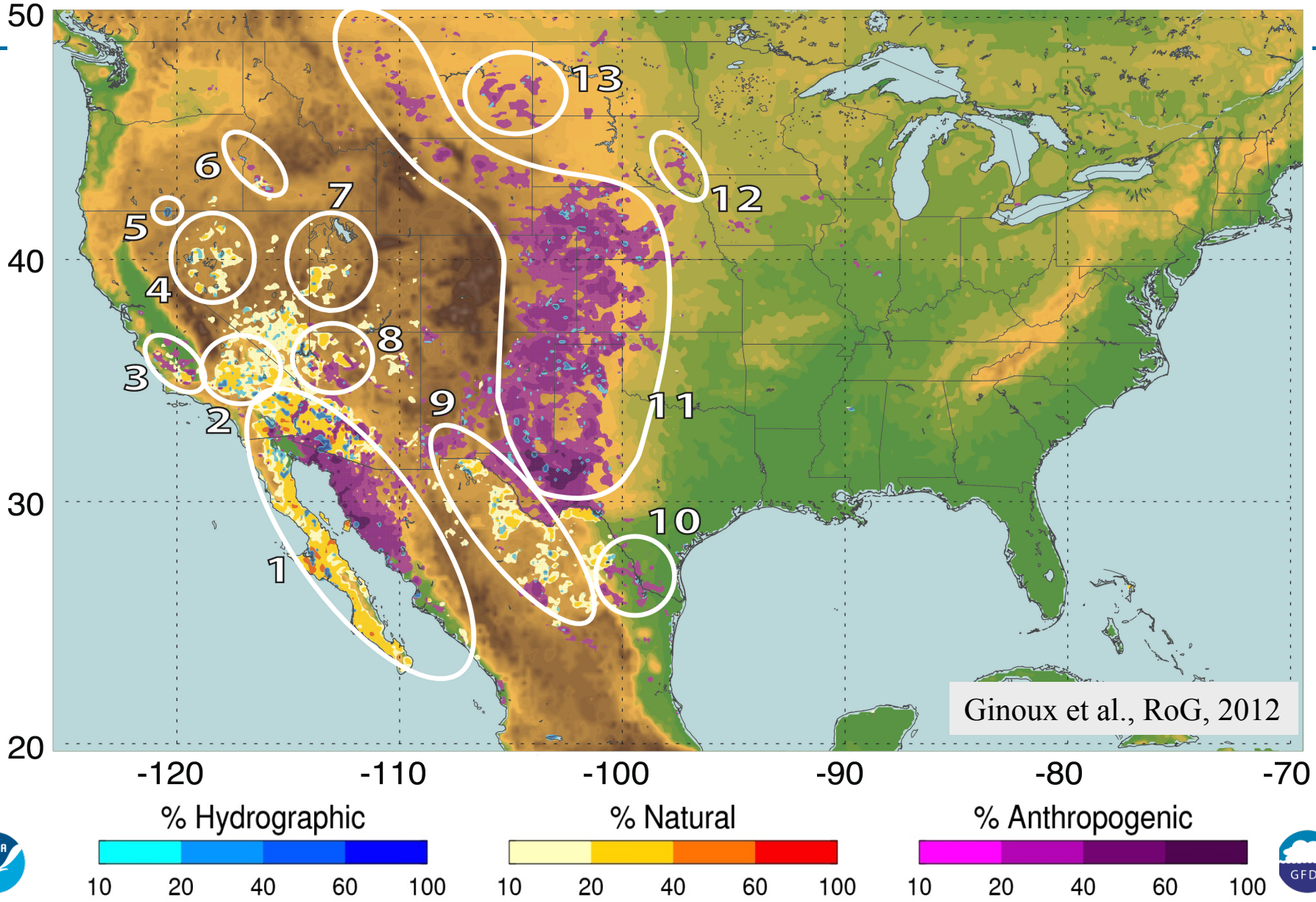
0 10 50 100 500

Anthropogenic emission (g m^{-2} yr^{-1})

0 10 50 100 500

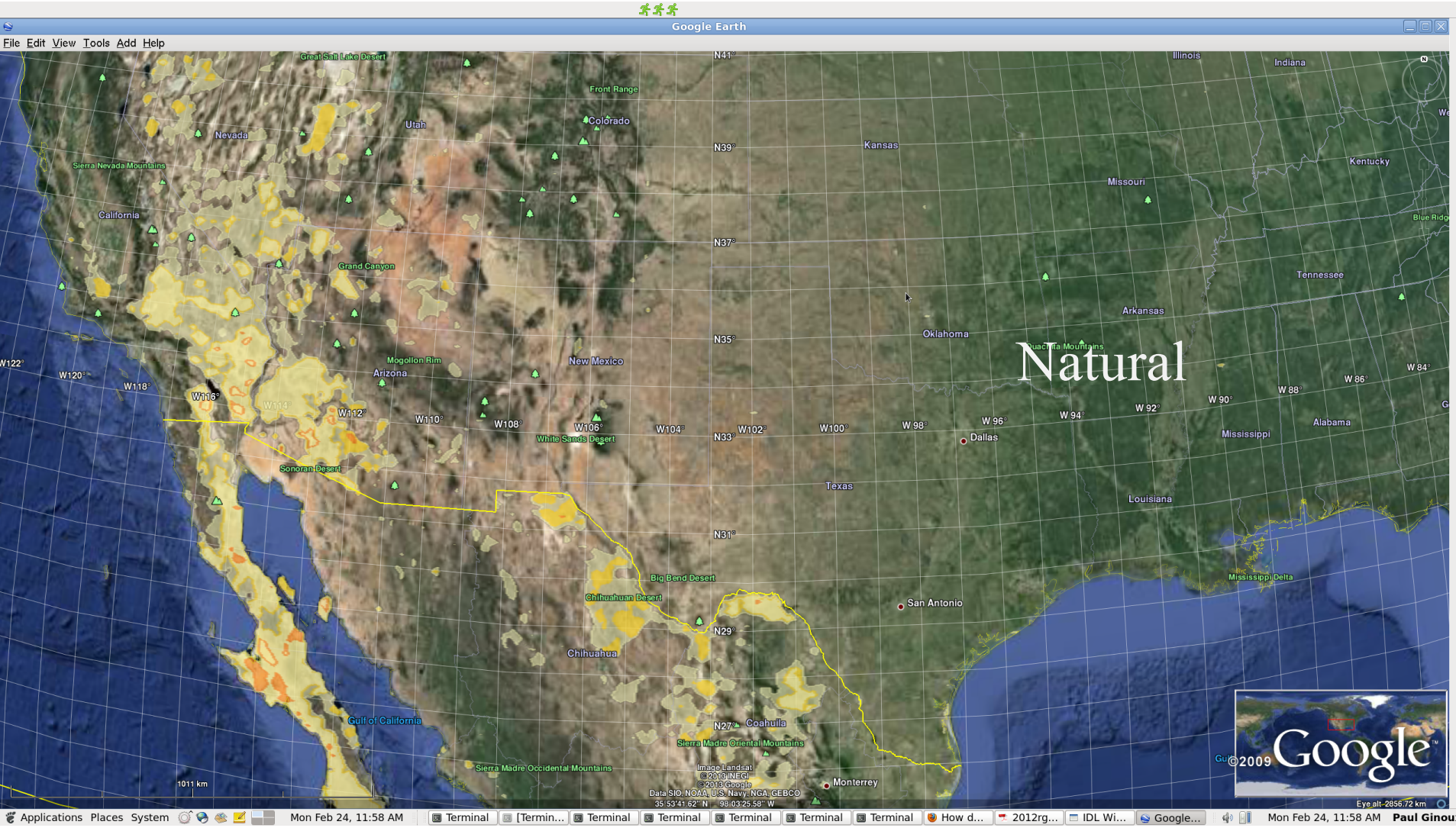
Ginoux et al., RoG,

Annual mean FoO M-DB2 DOD> 0.2



FoO for natural, anthropogenic, and hydrologic sources in kmz format:

http://www.gfdl.noaa.gov/atmospheric-physics-and-chemistry-data



FoO for natural, anthropogenic, and hydrologic sources in kmz format:

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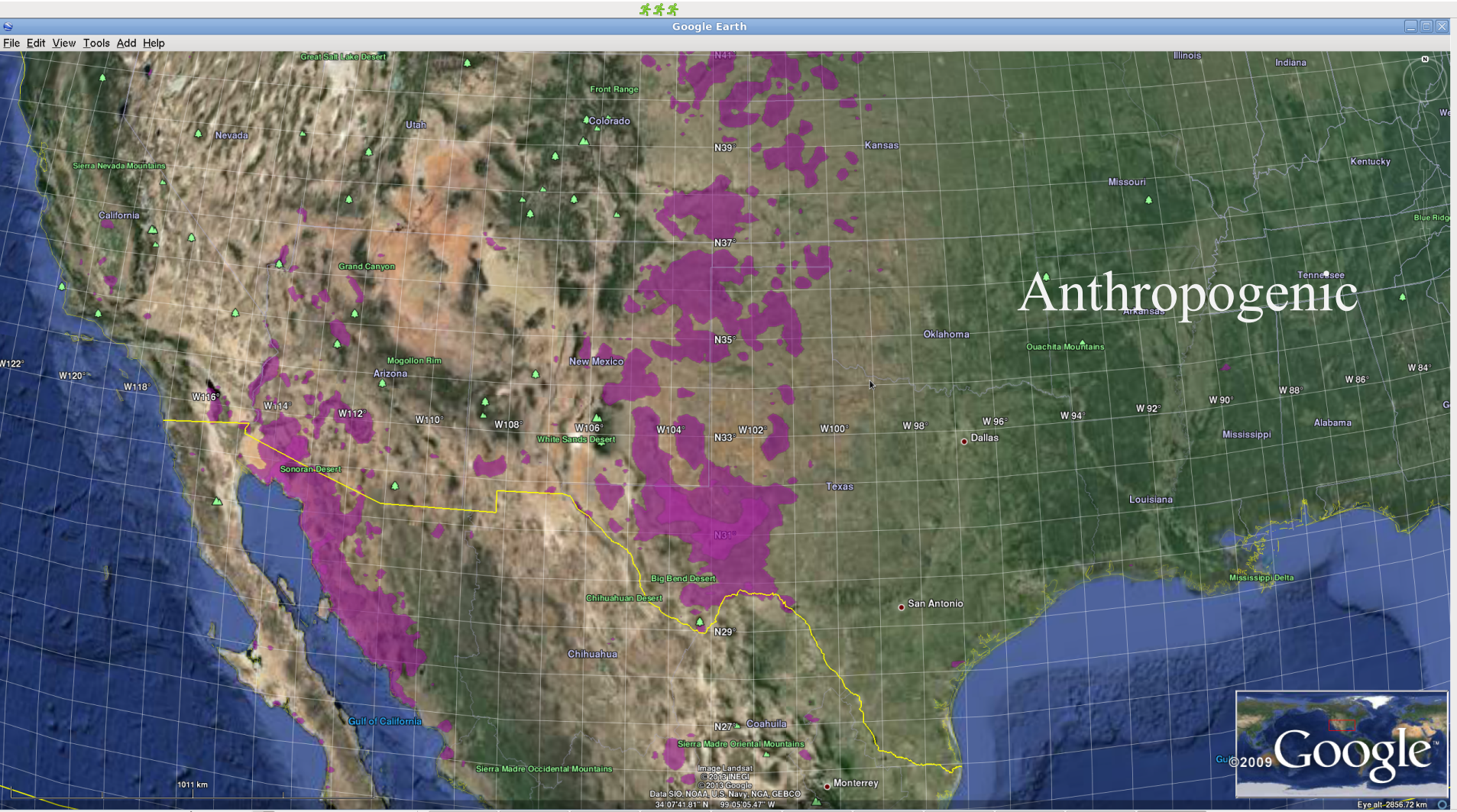

FoO for natural, anthropogenic, and hydrologic sources in kmz format:

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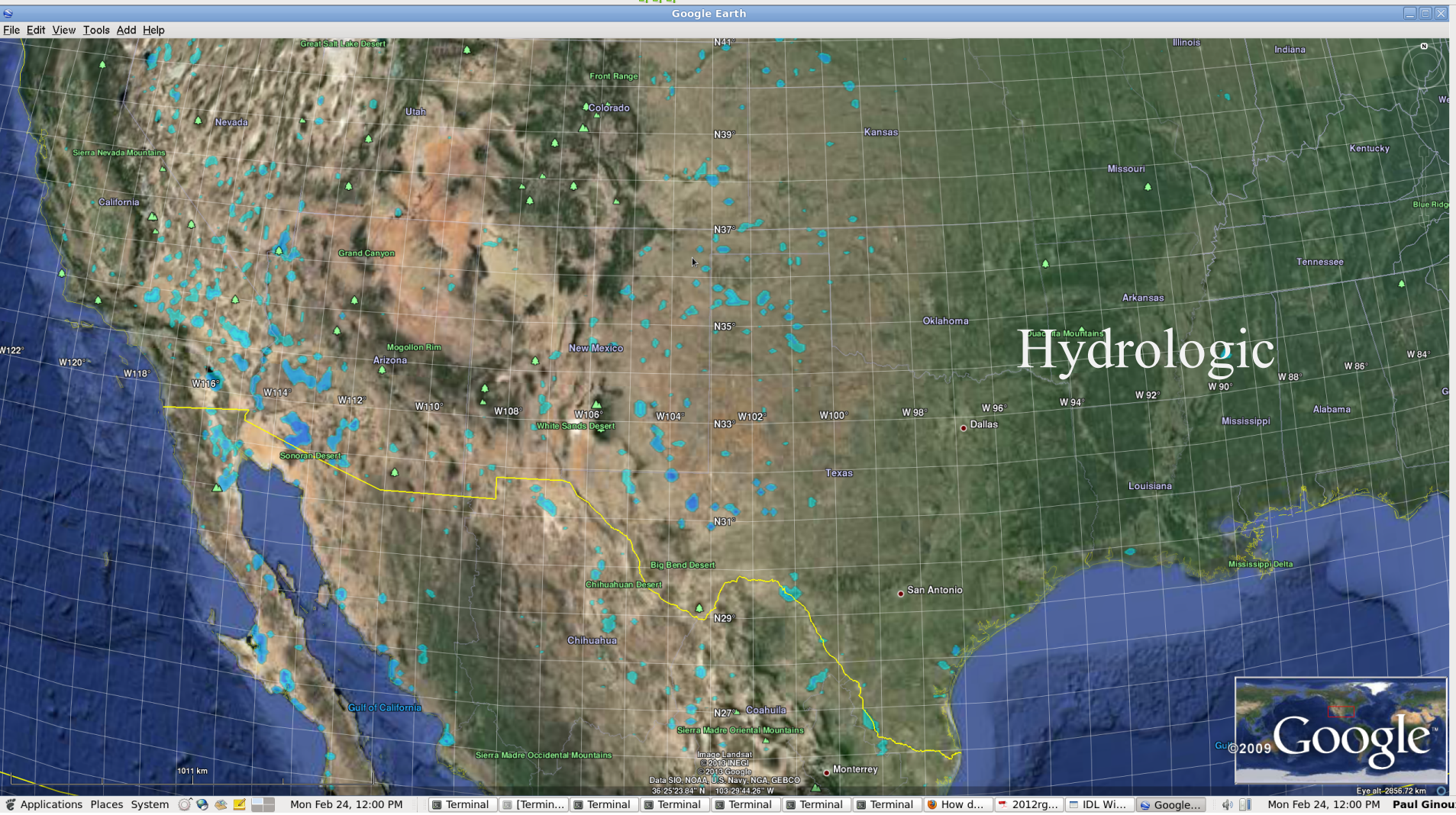

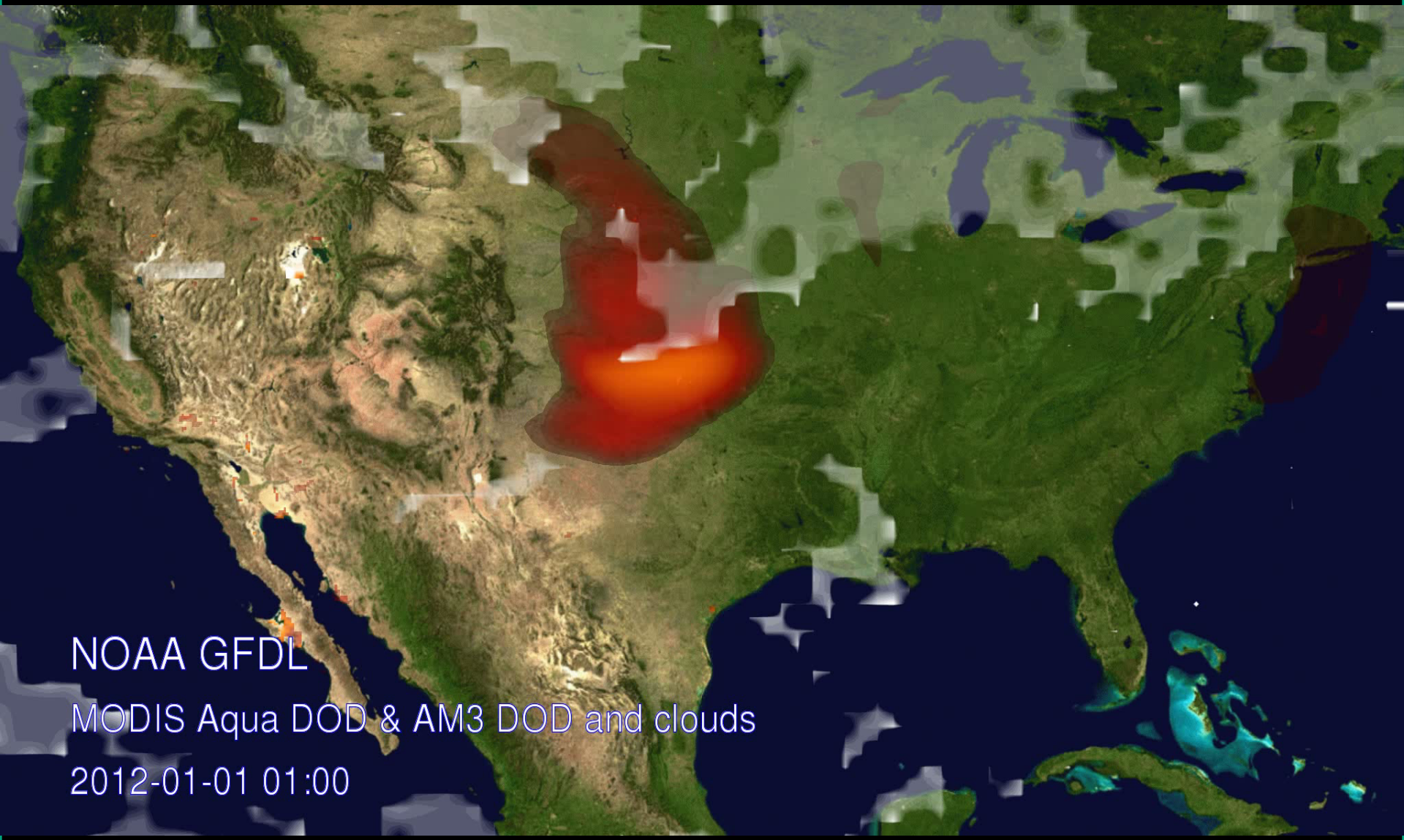
NOAA GFDL
MODIS Aqua DOD & AM3 DOD and clouds
2012-01-01 01:00