THE EARTH INSTITUTE
COLUMBIA UNIVERSITY

An online mineral dust forecast model from meso to global scales: description, validation and applications

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Earth Institute - NASA GISS - IRI

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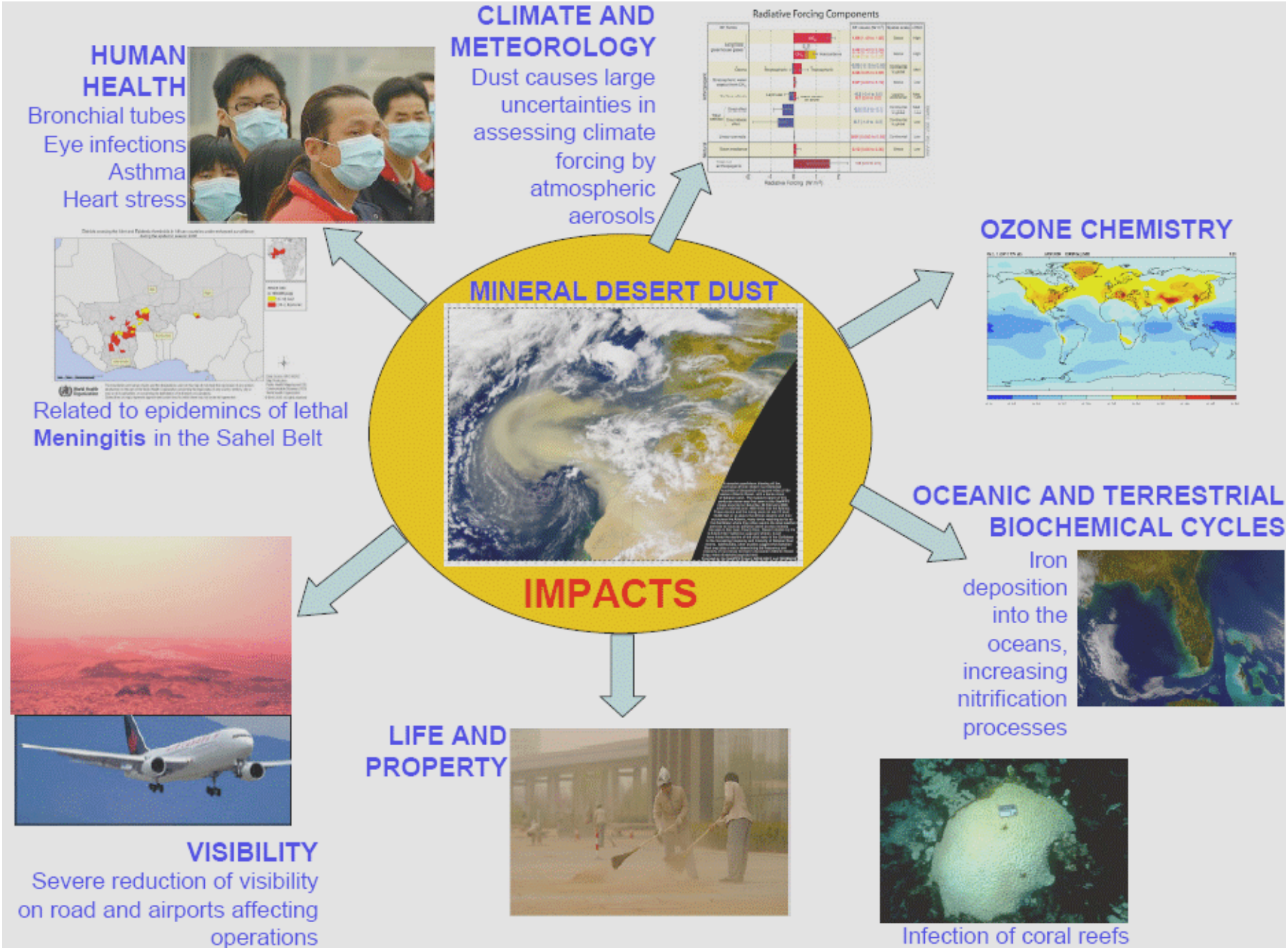
- Model description
- Model validation
- An application: long term simulations in support of meningitis studies in Sub-Saharan Africa


HUMAN HEALTH
Bronchial tubes
Eye infections
Asthma
Heart stress
Related to epidemincs of lethal **Meningitis** in the Sahel Belt
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Iron deposition into the oceans, increasing nitrification processes
LIFE AND PROPERTY
VISIBILITY
Severe reduction of visibility on road and airports affecting operations
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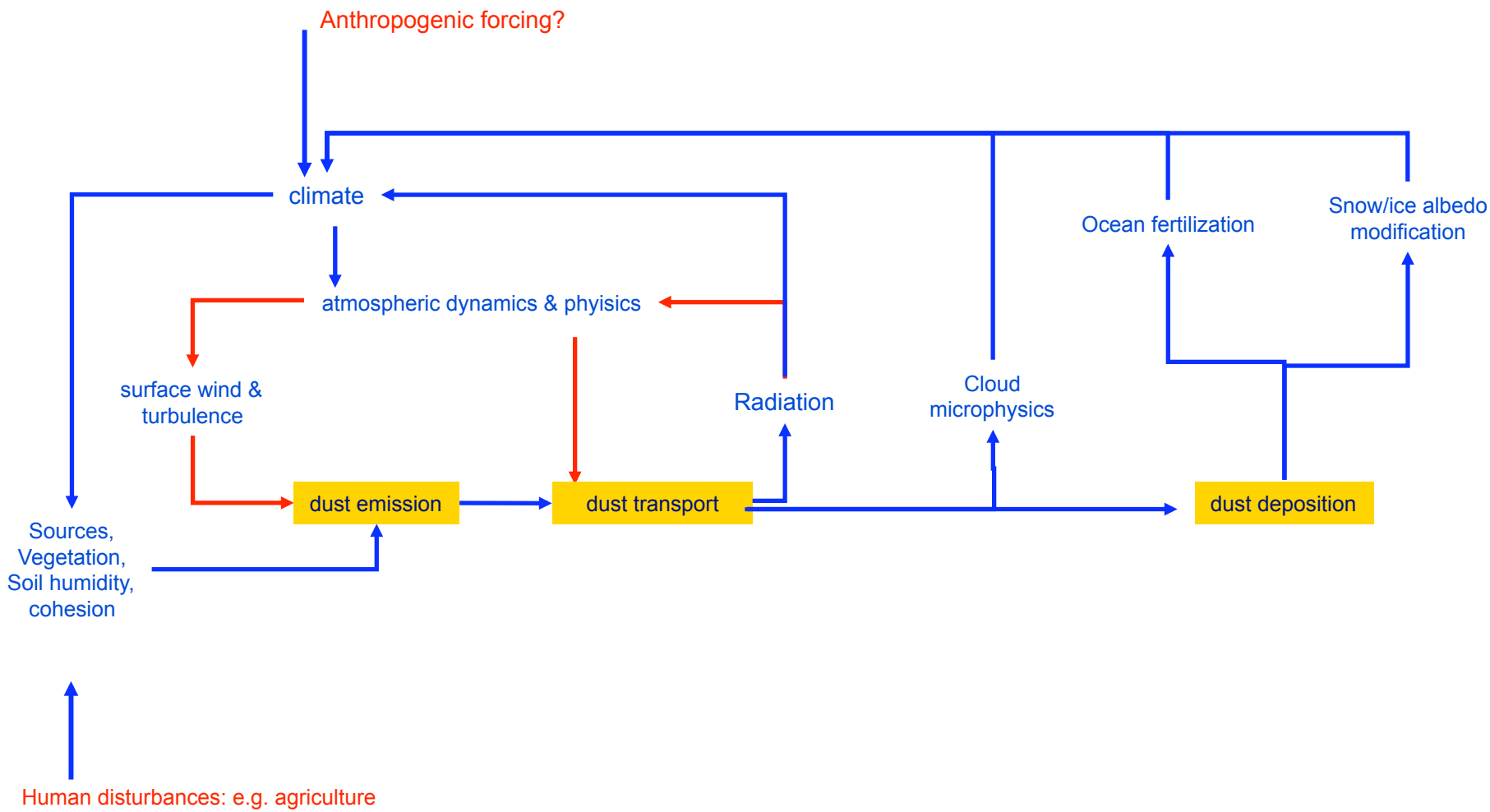
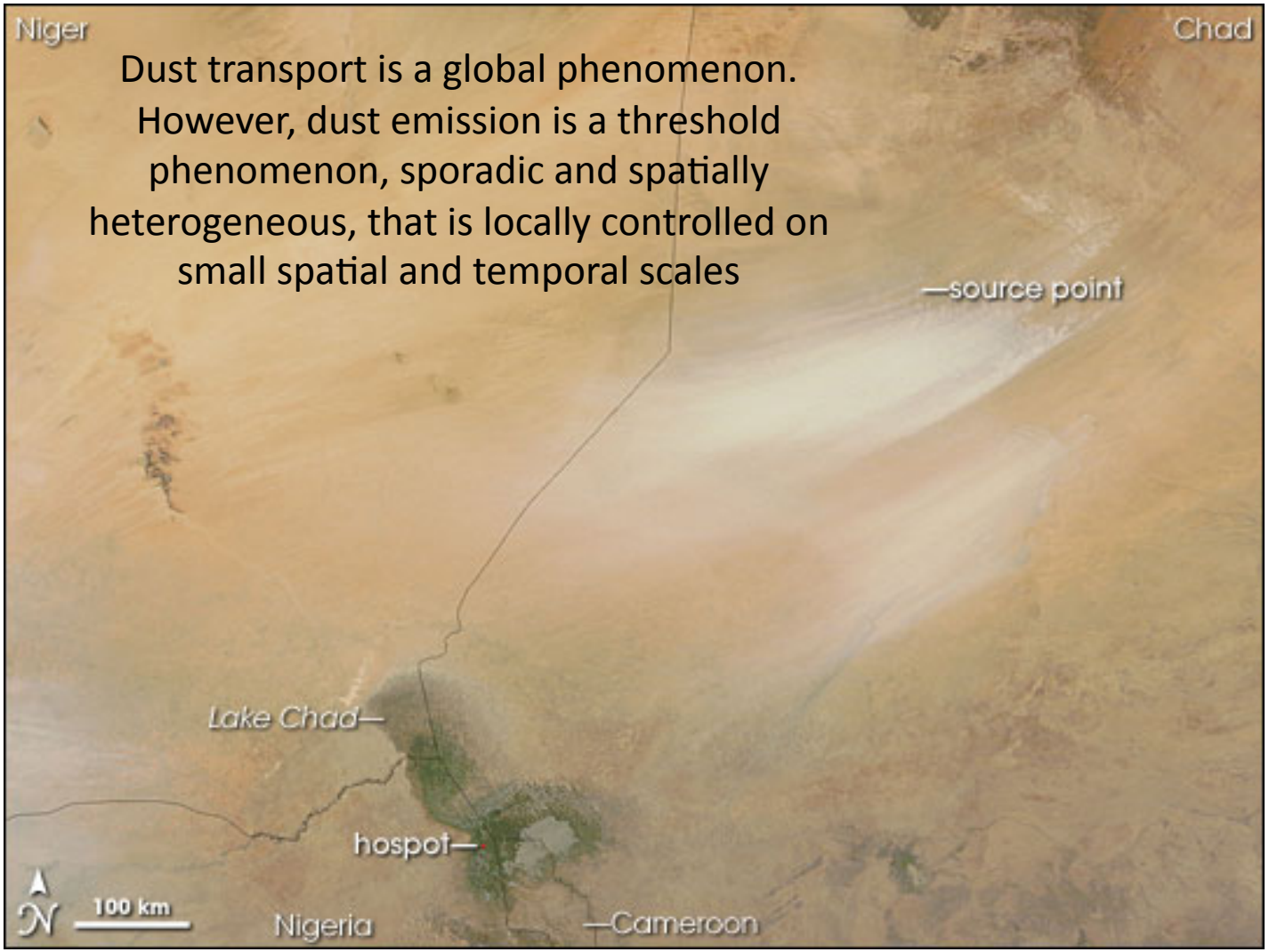
Mineral dust interactions with meteorology and climate



Dust emission



Dust transport is a global phenomenon. However, dust emission is a threshold phenomenon, sporadic and spatially heterogeneous, that is locally controlled on small spatial and temporal scales

NMMb/BSC-Dust

GOALS

✓ Implement a common 'on-line' dust module for regional and global domains

✓ Global dust forecasts up to 7-8 days at sub-synoptic resolutions and nested regional domains at high resolution (5-10 km).

✓ Intermediate complexity dust emission scheme

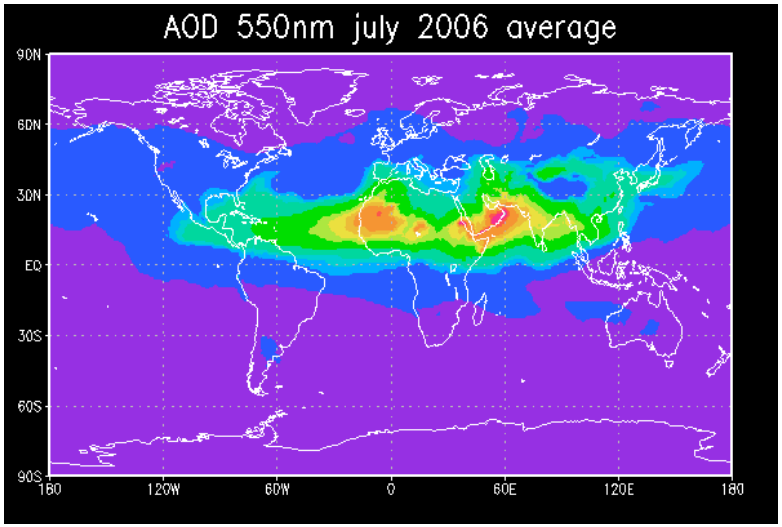
✓ Include new high resolution databases for soil textures and vegetation fraction.

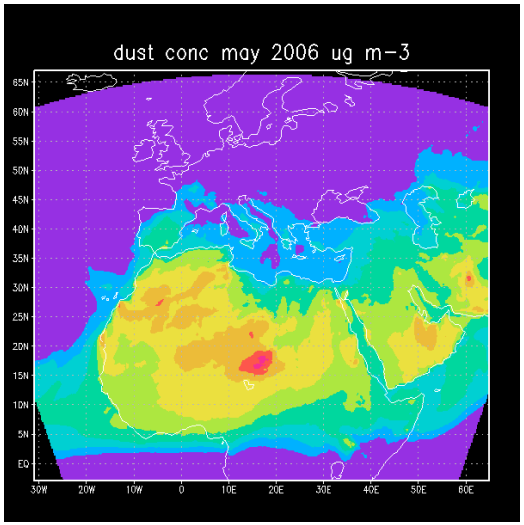
✓ Update deposition schemes

✓Radiative feedbacks between dust and meteorology

NCEP Nonhydrostatic *Multiscale* Model on B grid (NMM-b) (Zavisa Janjic)

- Further evolution of WRF NMM (Nonhydrostatic Mesoscale Model)
- Intended for wide range of spatial and temporal scales, from meso to global, and from weather to climate
- The nonhydrostatic option as an add–on nonhydrostatic module
- Global lat-lon, regular grid ; Regional rotated lat-lon
- Arakawa B grid (in contrast to the WRF-NMM E grid) and Pressure-sigma hybrid



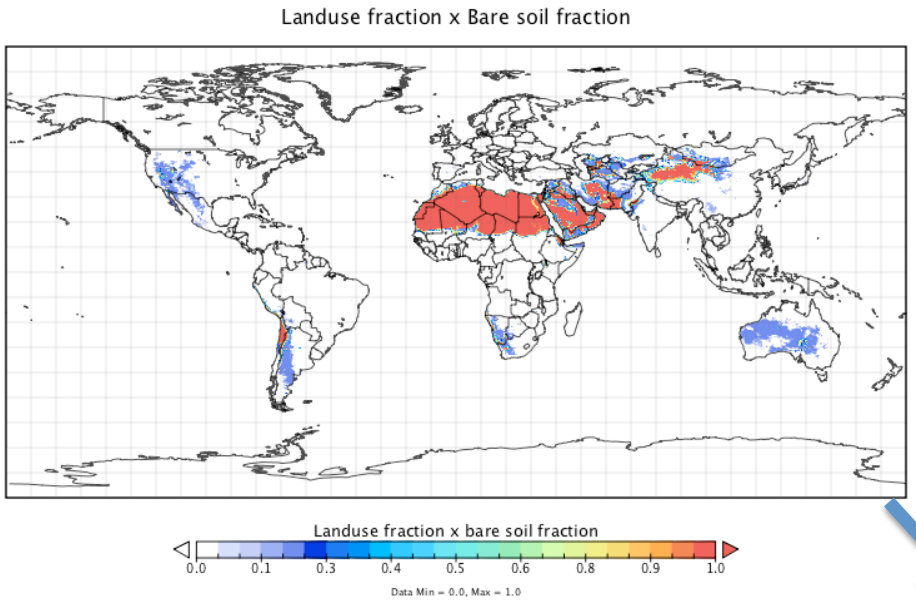


NCEP Nonhydrostatic *Multiscale* Model on B grid (NMM-b) (Zavisa Janjic)

- ✓ NCEP's WRF NMM "standard" physical package (more options will be available)
  - Mellor-Yamada-Janjic (MYJ) level 2.5 turbulence closure for the treatment of turbulence in the planetary boundary layer (PBL) and in the free atmosphere (Janjic, 2001)
  - Surface layer scheme based on the Monin- Obukhov similarity theory (Monin and Obukhov, 1954) with introduced viscous sublayer over land and water (Zilitinkevich, 1965; Janjic, 1994)
  - The NCEP NOAH land surface model (Ek et al., 2003) or the LISS model by Janjic
  - The GFDL longwave and shortwave radiation (Fels and Schwarzkopf, 1975; Lacis and Hansen, 1974) UPGRADED
  - Ferrier gridscale clouds and microphyisics (Ferrier et al., 2002)
  - Betts-Miller-Janjic convective adjustment scheme (Betts, 1986; Betts and Miller, 1986; Janjic, 1994, 2000).

- ✓ Recent upgrades
  - New Eulerian tracer advection scheme (Janjic)
  - Gravity wave drag (Janjic)
  - RRTM radiation with aerosols (implemented by C. Perez)
- ✓ Regional version planned to replace the WRF NMM as the NOAA/NCEP regional operational forecasting model for North America (NAM) this year

dust sources



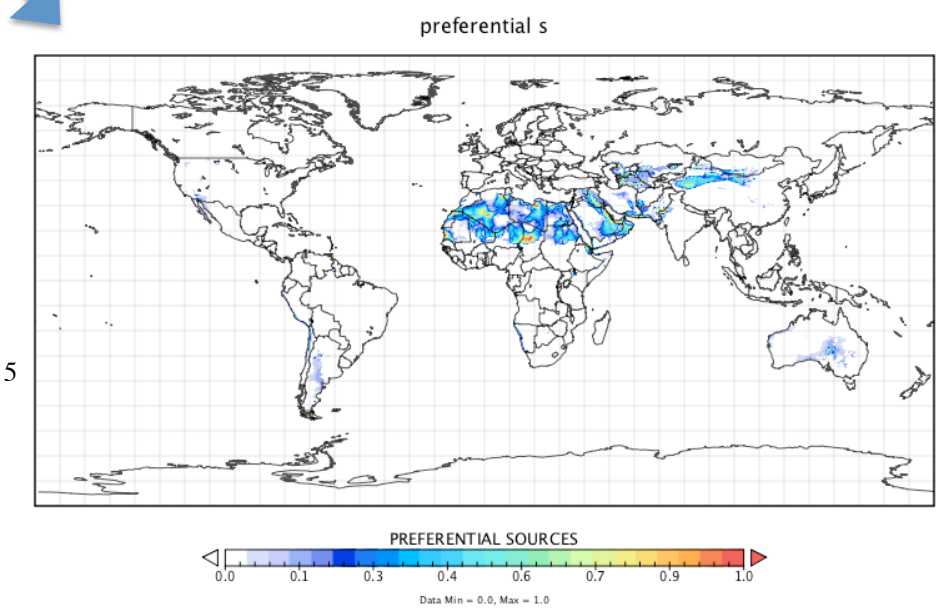
Based on USGS-wrf vegetation/surface type

19: Barren or sparsely vegetated (1)
8: Shrubland (0.3)

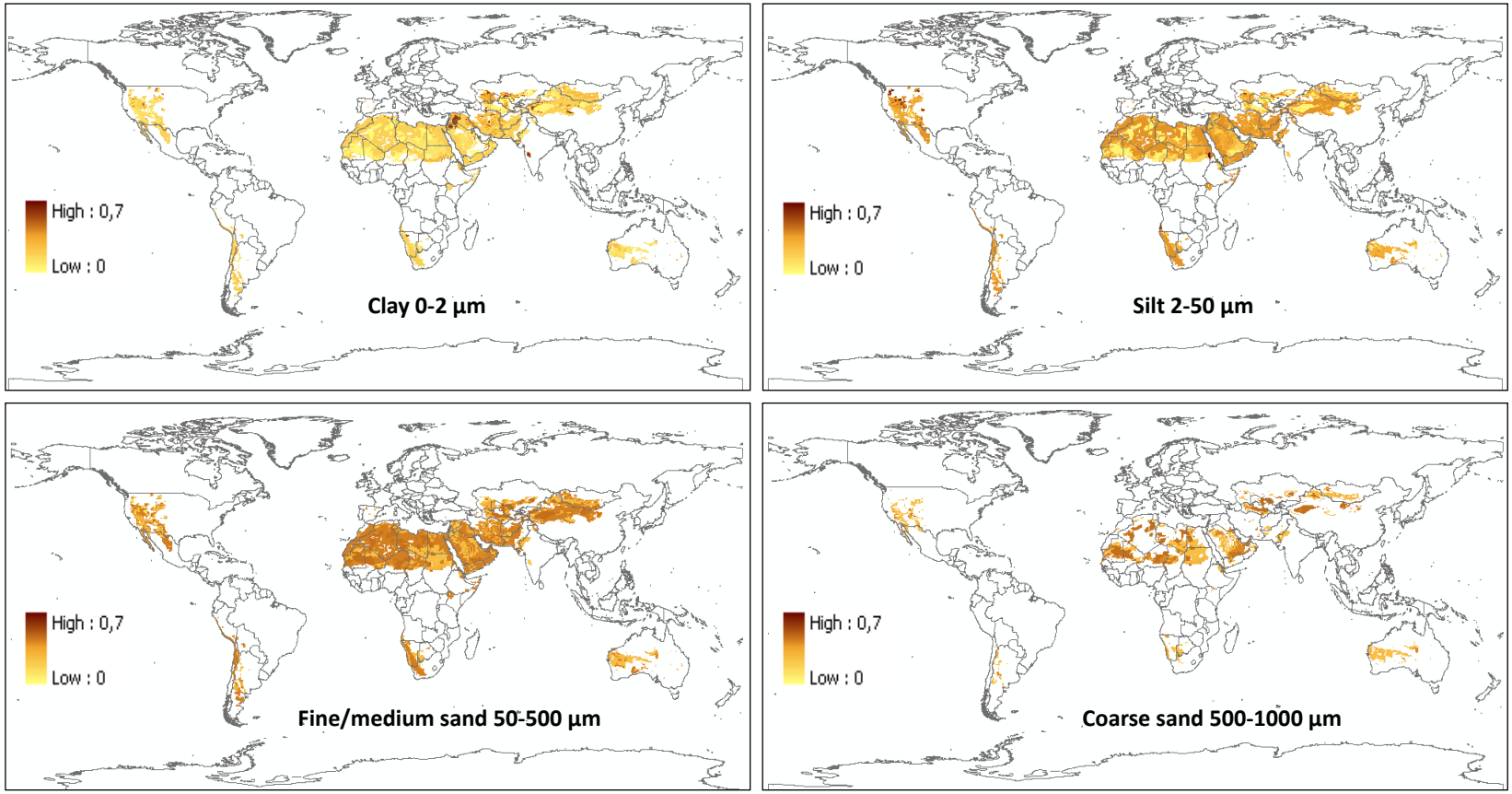
P: probability to have accumulated sediments in the grid (Ginoux et al., 2001)

Best fit with the sources identified by Prospero et al. 2000

$$P = \left(\frac{z_{\max} - z_i}{z_{\max} - z_{\min}} \right)^5$$



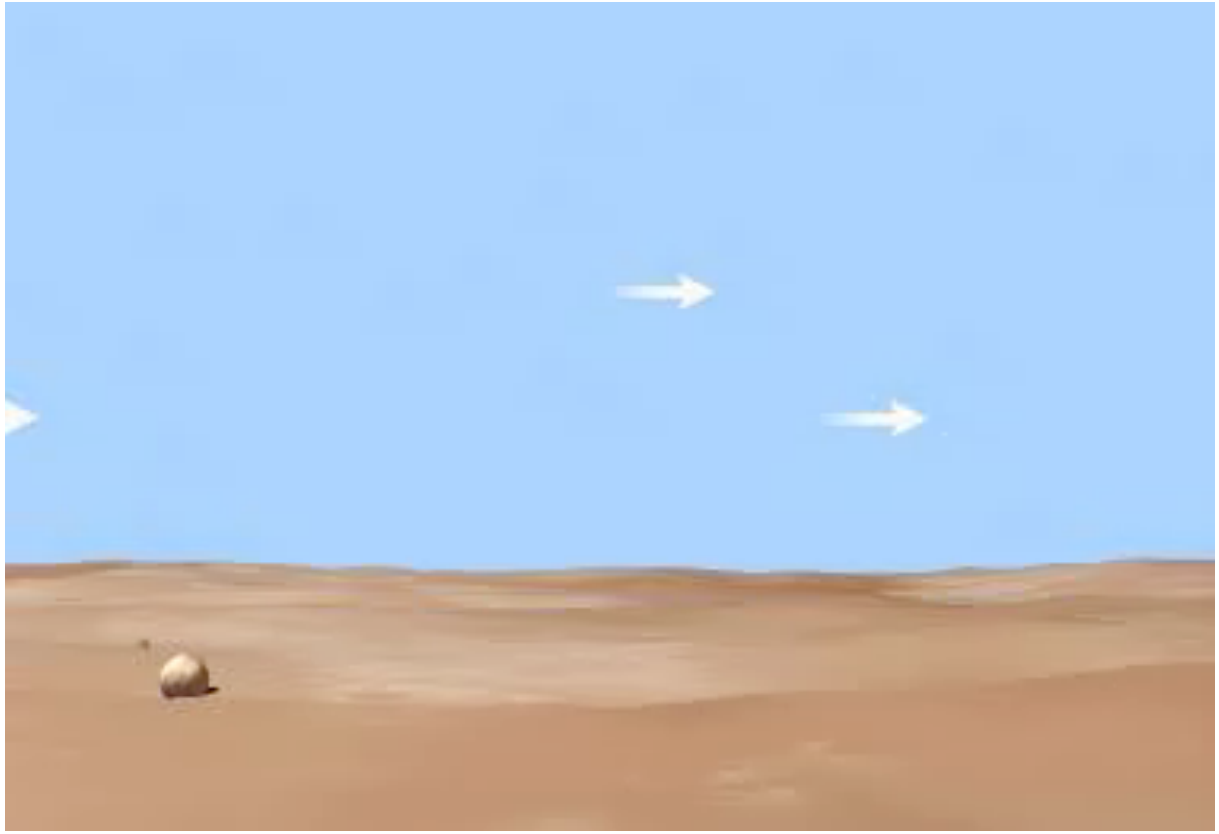
parent soil size distribution



Soil texture classes according STASGO-FAO 1km database are converted to 4 parent soil size

They are used to calculate ***horizontal flux***

Modes of particle motion



Movie from the COMET program at http://meted.ucar.edu/ of the University Corporation for Atmospheric Research (UCAR)

- Creep or rolling motion of the largest particles (> 500 um)

- Saltation or horizontal motion of large soil grains (sand) (50-500um)

- Suspension of dust (after sandblasting or saltation bombardment) (0.1-50 um)

dust emission I

H: Horizontal dust flux

$$H = c_s \frac{\rho_a}{g} u^{*3} \sum_{i=1}^{4} (1 + \frac{u^*_{t_i}}{u^*})(1 - \frac{u^{*2}_{t_i}}{u^{*2}}) s_i \quad \text{for } u^* > u^*_{t_i}$$

White (1979)

c_s : constant
s_i : relative surface area of each soil particle fraction
ρ_a : air density
g : gravitational constant
u* : friction velocity
u^*_t: threshold friction velocity

$$u^*_t = u^*_{tsd}(D) \frac{f_h}{f_e}$$

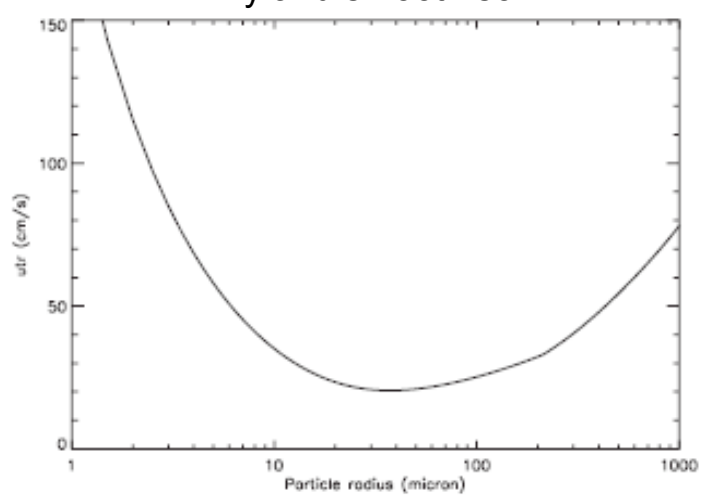
u^*_{tsd} : Iversen and White (1982)

f_e :Drag partition correction
Marticorena and Bergametti (1995)

$$F = \alpha \cdot H$$

f_h :Soil moisture effects.
Fecan et al. (1999)

Dry and smooth soil



dust emission II

F: Vertical dust flux

$$F = \alpha H$$

$$\alpha = \sum_{i=1}^{4} m_i \alpha_i$$

- Horizontal to vertical flux ratio (Tegen et al. 2002)

$$F_k = \sum_{i=1}^{3} F_i M_{i,j}$$

- We assume tri-modal size distribution of emitted dust in source regions (D'Almeida, 1987)

- Emitted dust in 3 source modes is distributed over 8 size transport bins (Zender et al., 2003)

$$F_k = CS(1-V)\alpha H \sum_{i=1}^{3} M_i M_{i,k}$$

C: Tuning parameter
S: Preferential source probability
V: Vegetation fraction
α: vertical to horizontal flux ratio

Advection and diffusion

- Eulerian advection; conservative, positive definite, monotone
  - Crank-Nicholson for vertical advection
  - Modified Adams-Bashforth for horizontal advection
- Vertical diffusion in the PBL and in the free atmosphere is handled by the NMMb surface layer scheme and by the boundary layer parameterization scheme (Janjic 1996a,1996b, 2002a, 2002b)
- The lateral diffusion is formulated following the Smagorinsky's non-linear approach (Janjic, 1990).

Sedimentation and dry deposition

- Terminal velocity of aerosol:

$$v_{gk} = \frac{d_k^2 g(\rho_k - \rho_a)Cc}{18\nu}$$

k: aerosol size bin number
dk: aerosol diameter
ρk: aerosol density
ρ: density of air
g: gravitational constant
v: dynamic viscosity of air
Cc: Cunningham correction factor

- Dry deposition velocity (Zhang et al. 2001):

$$v_{dk} = v_{gk} + \frac{1}{(R_a + R_s)}$$

$$R_a = \frac{\Psi(\zeta_2) - \Psi(\zeta_1) + \varphi(0) ln\left(\frac{z_1}{z_2}\right)}{\kappa u^*}$$

Aerodynamic resistance (z2 from viscous sublayer over land and ocean)

$$R_s = \frac{1}{3u^*(E_B + E_{IM} + E_{IN})}$$

Surface resistance (brownian diff., impaction, interception)

Scavenging from grid scale clouds

- Grid scale clouds (NMMb incorporates Ferrier microphysics for grid scale clouds)

$$F_k^w(L) = F_k^w(L-1)(1-\alpha_w f_{evp}(L)) + \Delta F_k^w(L)$$

  - In-cloud and below cloud scavenging for rain
    - In cloud is proportional to auto conversion of cloud water to rain

$$\Delta F_k^w|_{in} = \epsilon_k \left[f_{liq} \frac{P_{CR}}{QW} + f_{ice} \frac{P_{IR}}{QI} \right] M_k$$

    - Below cloud scavenging (Slinn, 1984) includes directional Interception, inertial Impaction and brownian diffusion

$$\Delta F_k^w|_{sub} = \frac{cP_l E_k^l(d_k, D)}{D} M_k$$

  - Below cloud scavenging for snow

$$\Delta S_k|_{sub} = \frac{rP_s E_k^s(d_k, \lambda)}{D_m} M_k$$

Convective scavenging and mixing

- Convective clouds (NMMb incorporates BMJ convective adjustment for convective clouds)
  - deep convective clouds
    - Dust mixing follows the postconvective moisture redistribution.

$$\Delta T = (T_{ref} - T^n)\frac{\Delta t}{\tau / F(E)} \qquad \Delta C = (C_{ref} - C^n)\frac{\Delta T}{\tau / F(E)}$$

$$\Delta q = (q_{ref} - q^n)\frac{\Delta t}{\tau / F(E)}$$

    - In-cloud scavenging is proportional to the release of moisture from the cloud

$$\Delta F_k^w|_{in} = -\epsilon_k \frac{DQ_{tot}}{Q_{tot}} M_k$$

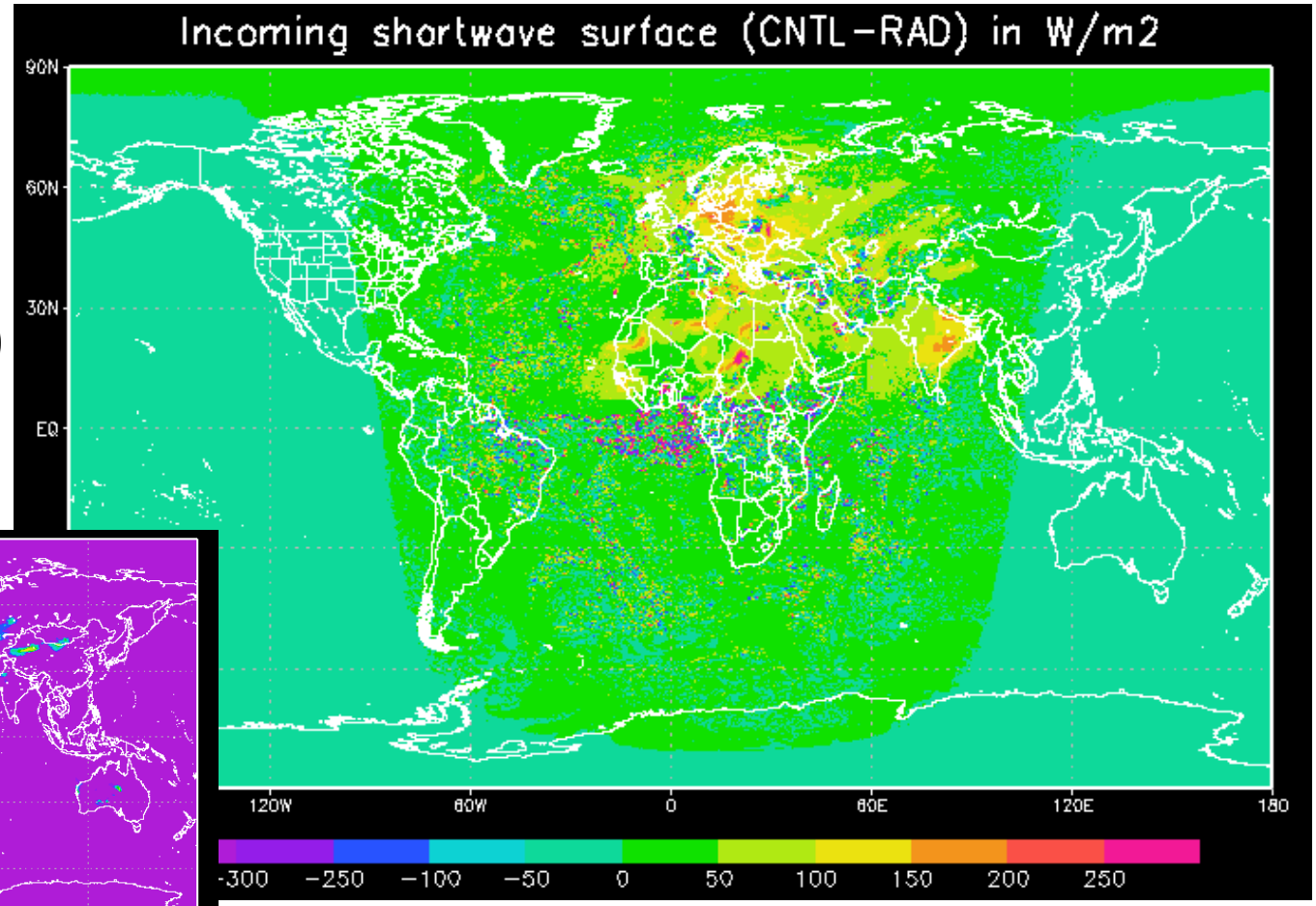
    - Below cloud scavenging is perfomed following Slinn 1984 assuming a typical raindrop diameter for convective clouds.

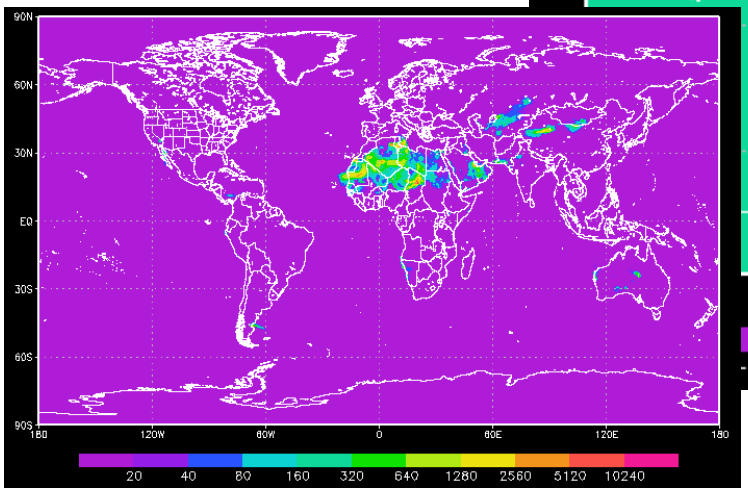
  - shallow convective clouds (no precipitation)
    - Dust is mixed homogeneously within the cloud

Dust and Radiation

- RRTM with aerosol implemented. Aerosol climatologies are available.

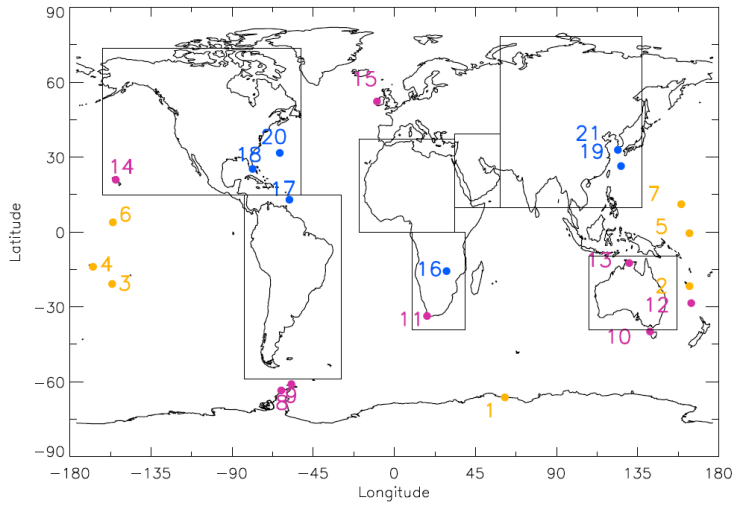
-Map shows effects on NMMb incoming shortwave at the surface of aerosol climatology (sea-salt, om, bc and so4) and forecasted dust

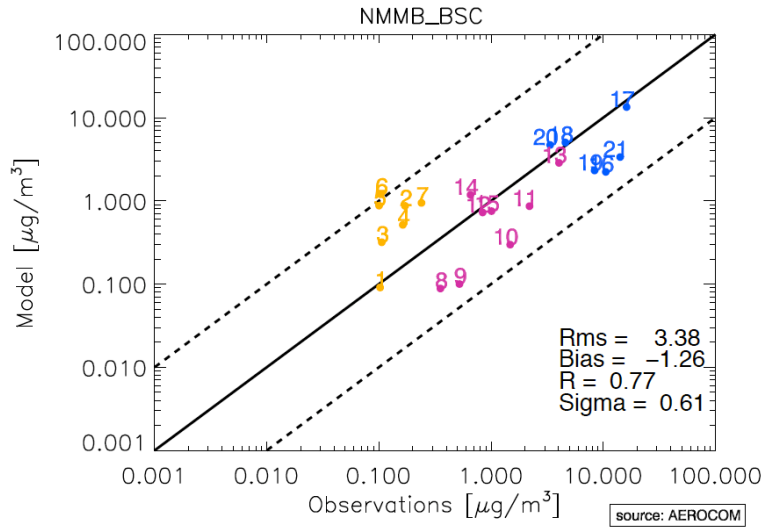


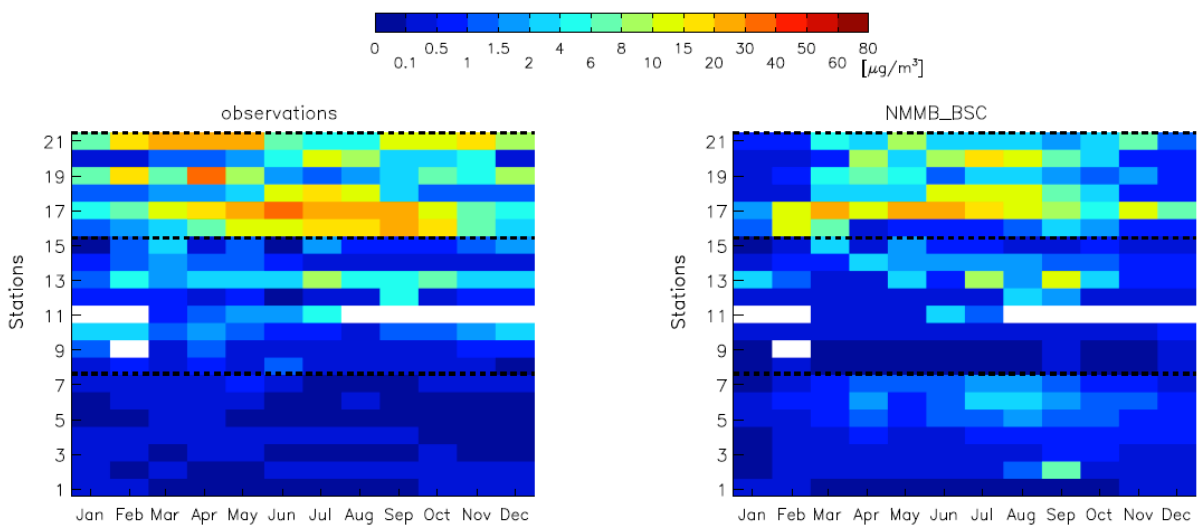


Surface concentration of forecasted dust

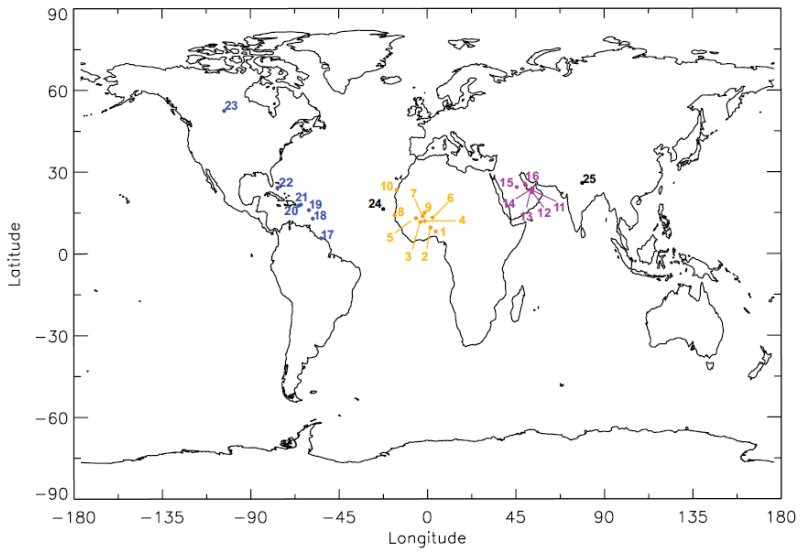
AEROCOM Year 2000: surface concentration

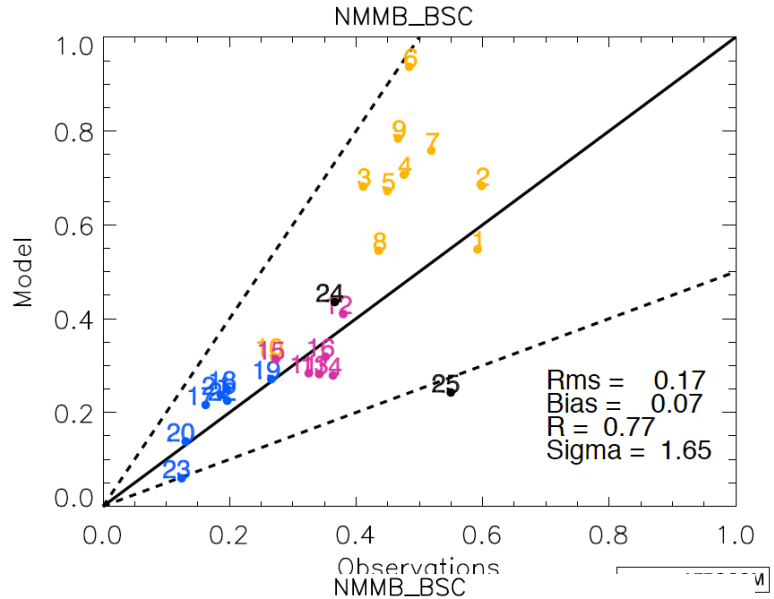


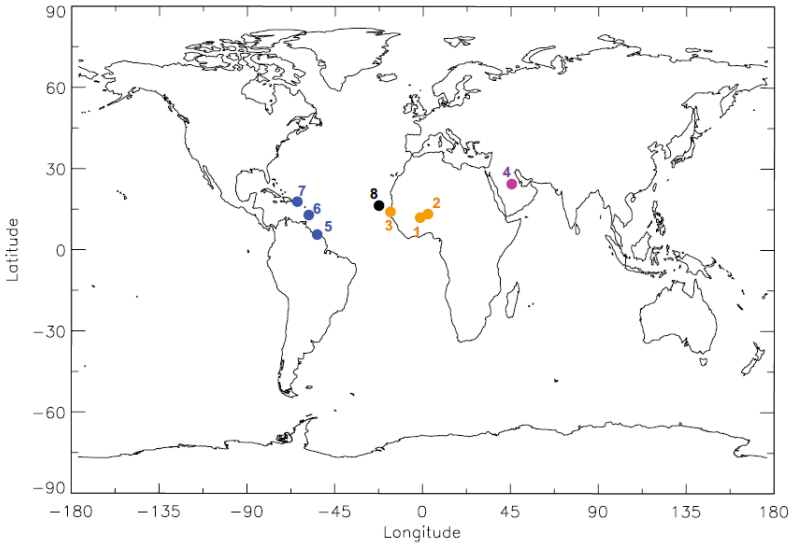


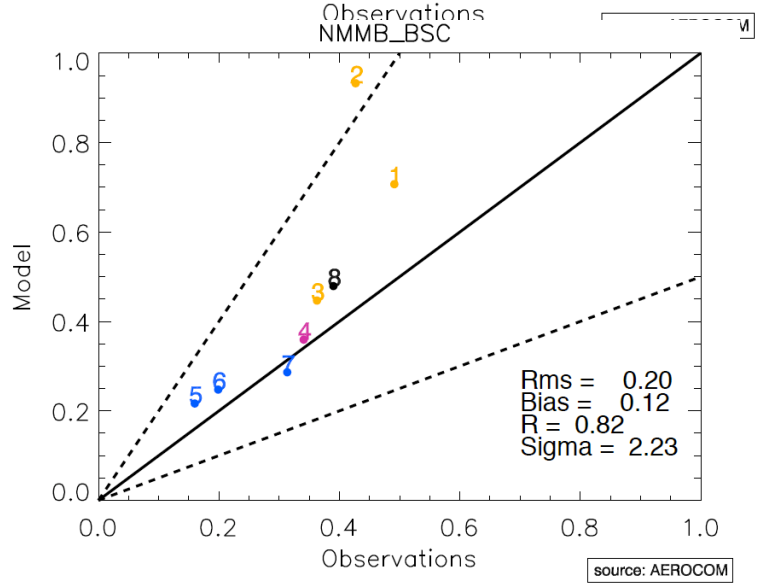


AEROCOM Year 2000: optical depth

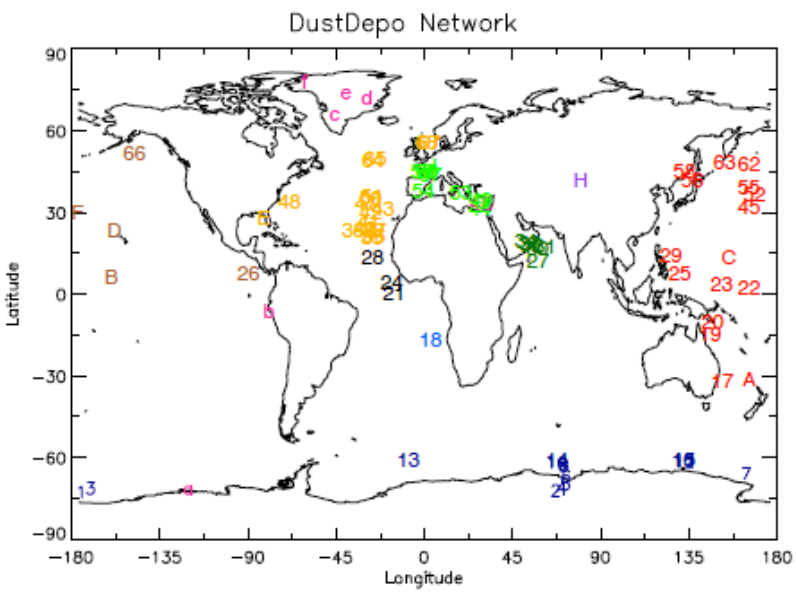


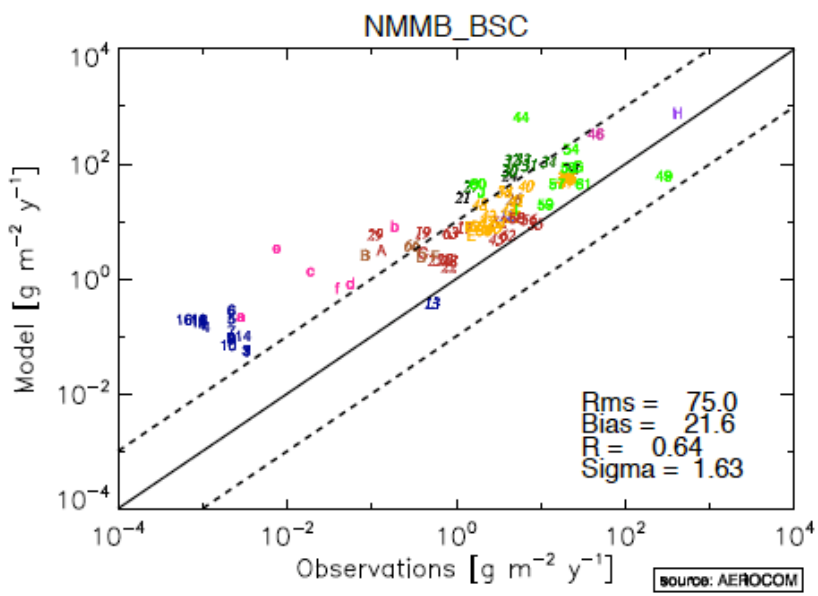




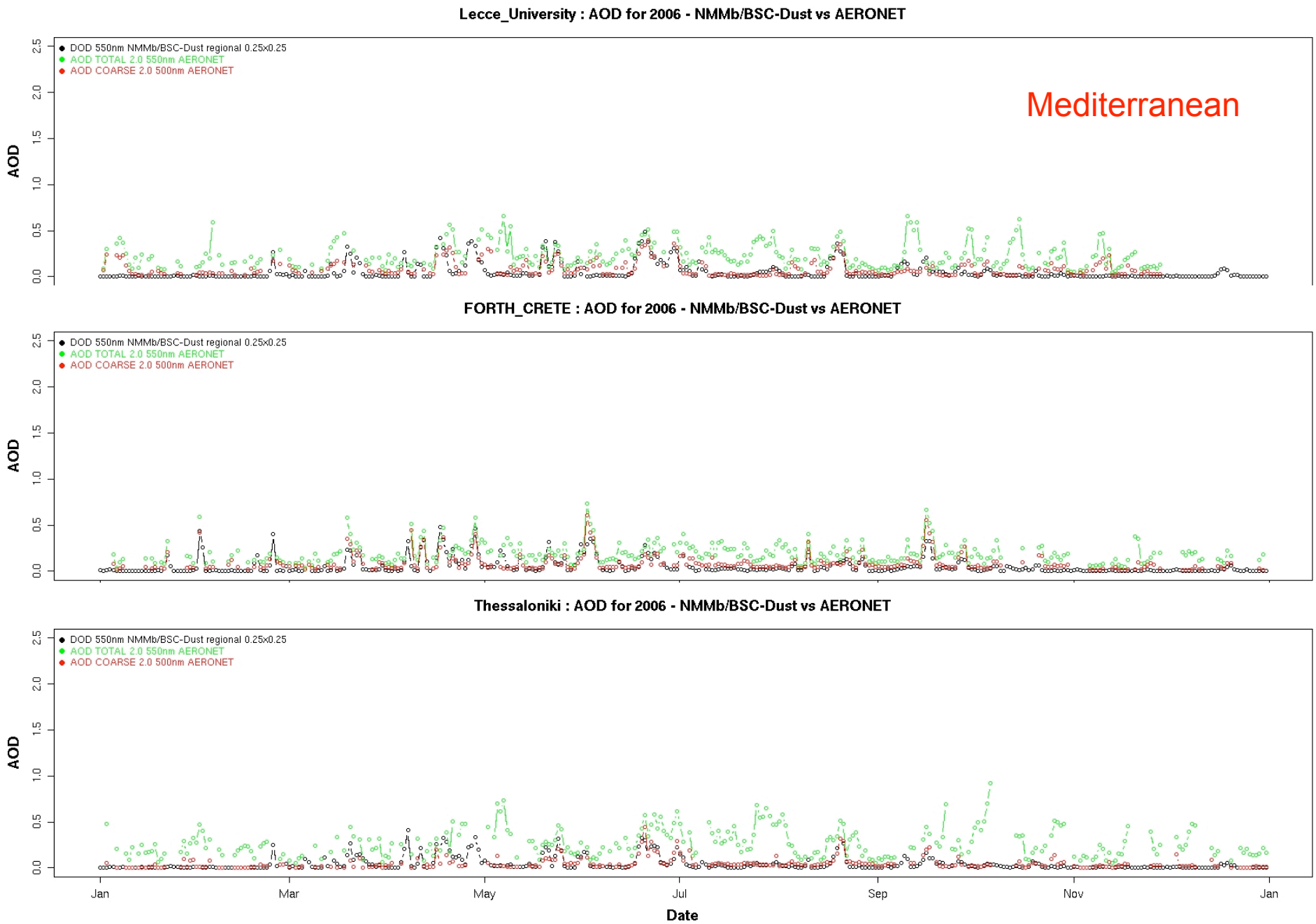


AEROCOM Year 2000: deposition





Regional simulation 0.25ºx0.25º for 2006 vs AERONET AOD daily averages



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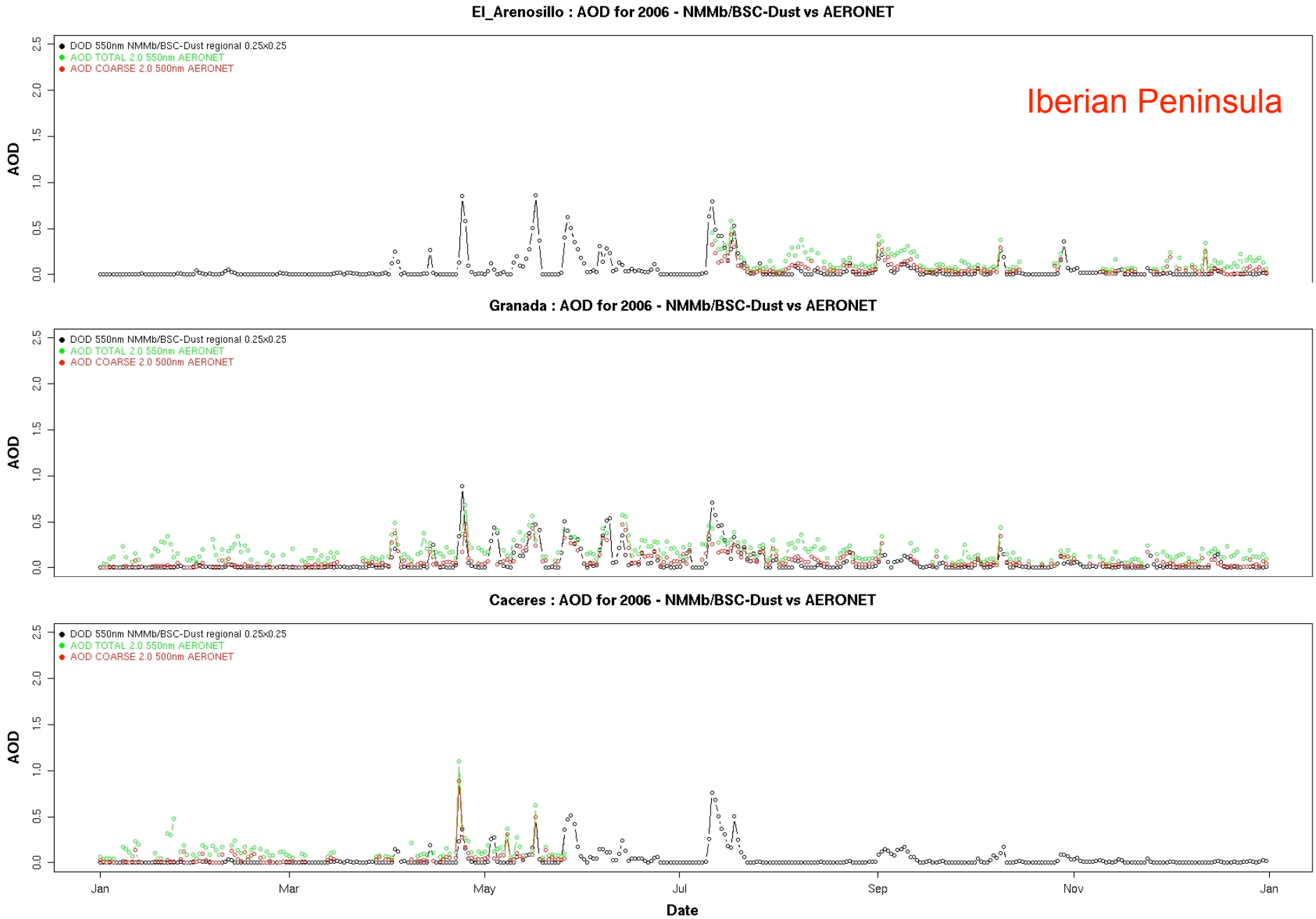

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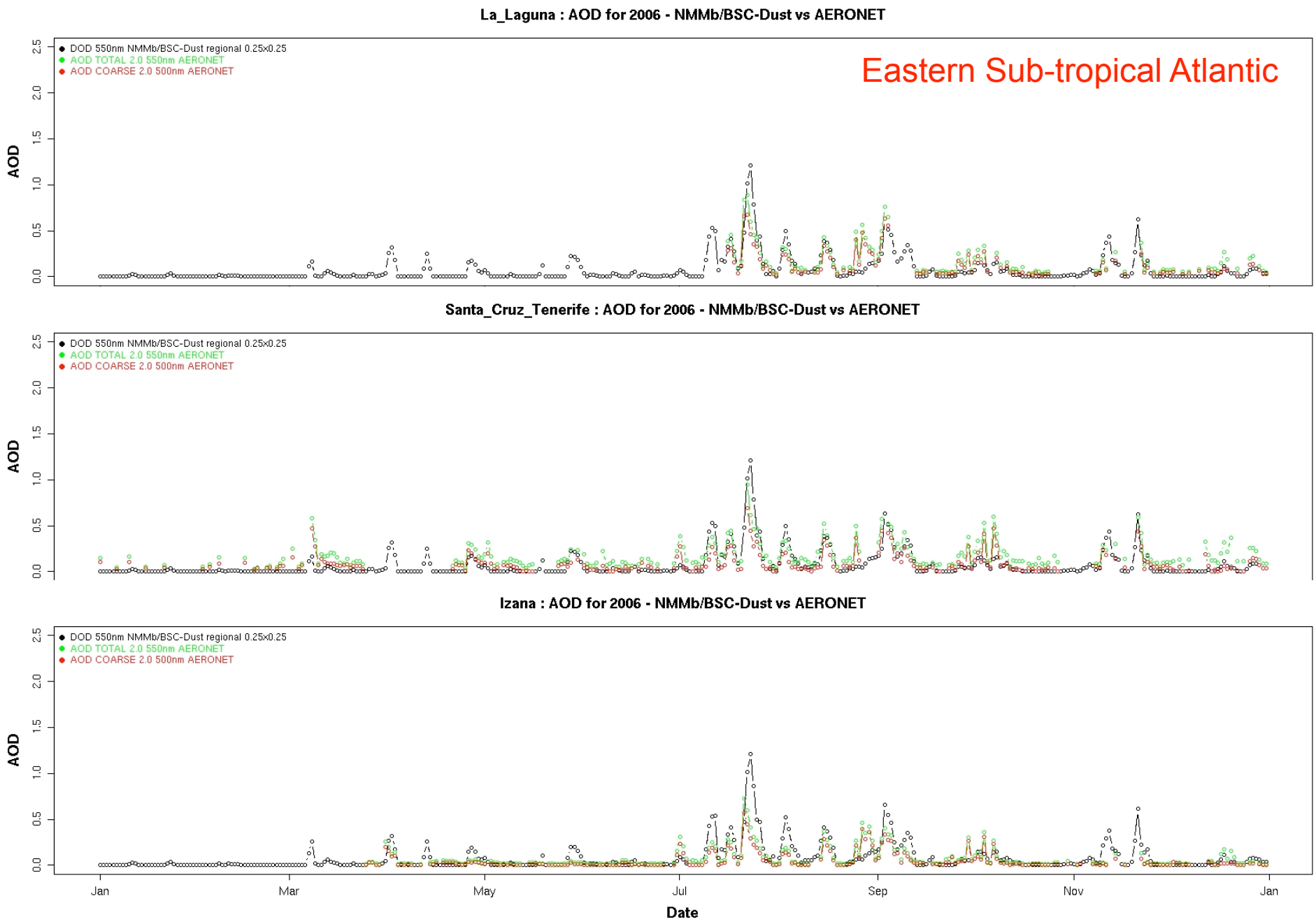

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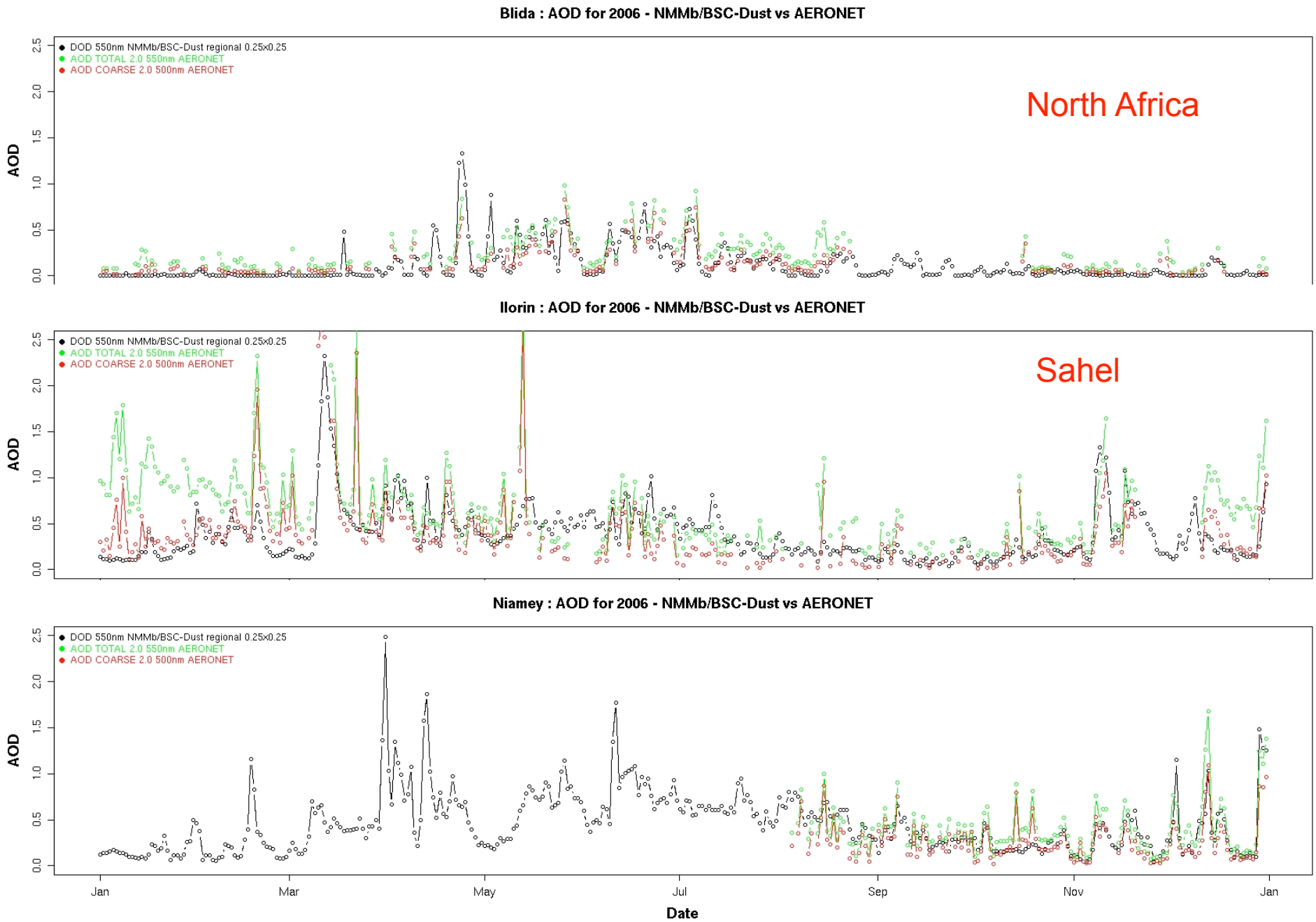

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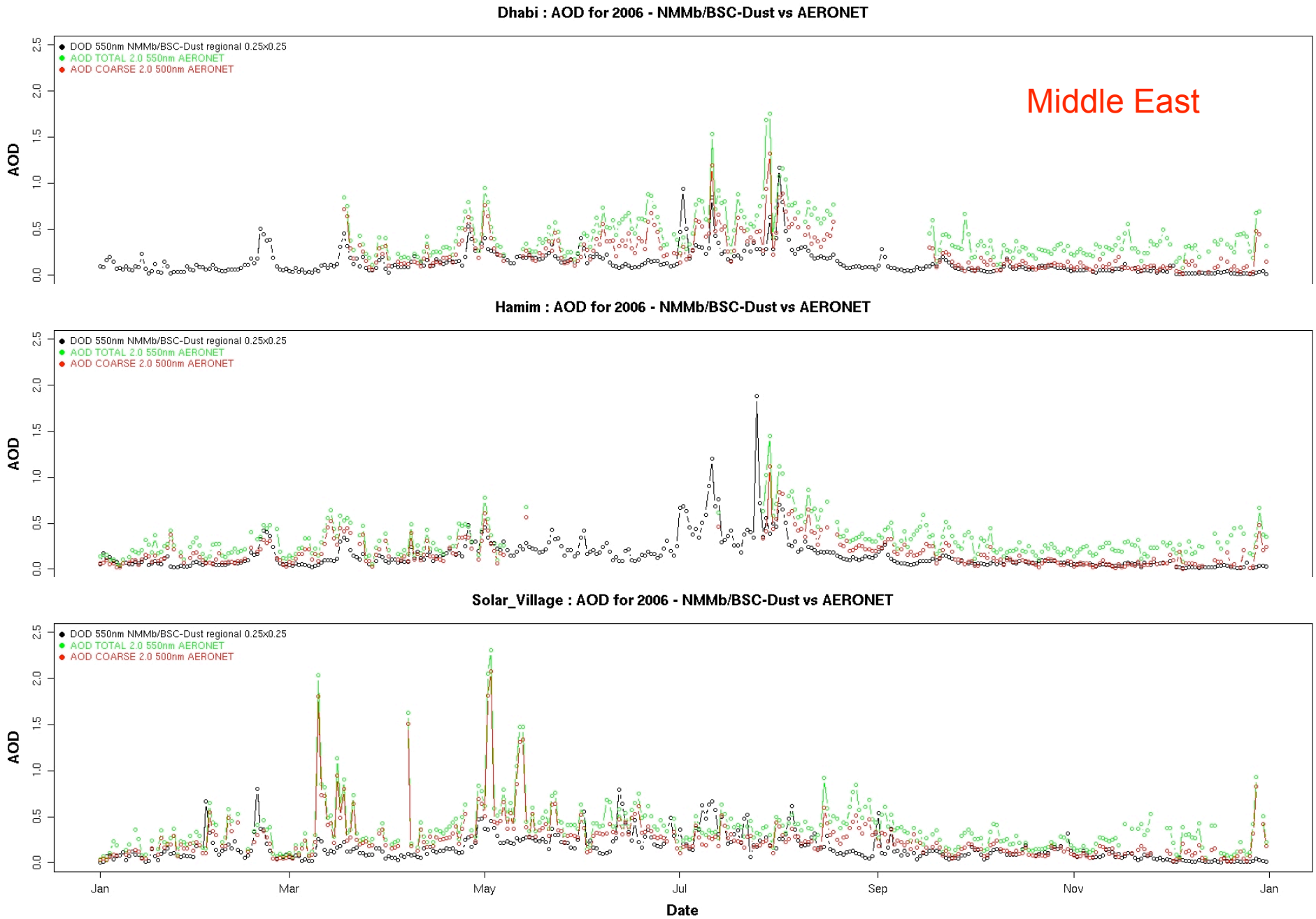

An Ill Wind, Bringing Meningitis

Crippling epidemics of meningococcal meningitis sweep across Africa with the onset of the dry season and harsh harmattan winds. An affordable, effective vaccine in the works could change that

OUAGADOUGOU, BURKINA FASO; BAMAKO, MALI; GENEVA, SWITZERLAND—The dust is inescapable, burning your eyes, clogging your nose, penetrating into your lungs, and making breathing ragged. In March, on the road to Koudougou, some 100 km west of Ouagadougou, the landscape is moonlike. In the cratered bottom of a lakebed, dust-caked men, barely distinguishable from their surroundings, fashion bricks from the mud. The bricks will dry quickly in the baking heat, which tops 45°C each day.

It is the dry season in Burkina Faso. And with the dust and the hot, dry wind, known as the harmattan, that blasts across the Sahel come meningococcal meningitis epidemics, caused by the bacterium *Neisseria meningitidis*. What, exactly, about these conditions triggers the epidemics remains mysterious, but they come like clockwork, hitting Burkina Faso every year and engulfing the entire "meningitis belt," which runs from Ethiopia in the east to Senegal and The Gambia in the west, every 6 to 12 years.

The last big one, in 1996–97, sickened hundreds of thousands and killed more than 25,000 in 10 countries. In 2007, the death toll climbed alarmingly high again, prompting the World Health Organization (WHO) to warn that another huge epidemic was likely in 2008. But this season turned out to be relatively quiet, with some 9400 cases in Burkina Faso and 27,000 across the entire belt. As always, the epidemics in Burkina Faso stopped suddenly with the first rains in May, as the population in this country, one of the poorest in the world, braced for the inevitable onslaught next year.

Koudougou district officially passed the epidemic threshold in mid-March, and scarce supplies of the meningitis vaccine were made available to try to curb the epidemic's spread. At a rudimentary health center there, hundreds of people—mostly women and children—queue up for vaccinations, seeking shade by the buildings or under a scrawny tree. Most have been waiting patiently for hours, but some occasionally surge to the front of the line only to be pushed back by the men in charge of crowd control.

At best, this reactive vaccination strategy, as it is called, is a "Band-Aid," says Rosamund Lewis, a physician and meningitis expert at the GAVI Alliance (formerly the Global Alliance for Vaccines and Immunization). The reason is that the vaccine being used, a 1960s design using a polysaccharide from the bacterium's coat and still the only affordable one in Africa, doesn't work very well. Although this vaccine prevents those carrying the bacterium from getting sick, it doesn't stop them from passing it on to others; immunity lasts only a few years; and the vaccine has minimal effect on children under age 2. Because of these limitations, WHO has long recommended that it be used only to control epidemics, not to prevent them—a strategy that has its critics. "The epidemic is sometimes over by the time vaccine arrives," concedes William Perea, a Colombian-born epidemiologist who leads Epidemic Readiness and Interventions at WHO and who nonetheless supports the strategy for lack of a cost-effective alternative.

F. Marc LaForce wants to change all that. He is heading an innovative public-private partnership known as the Meningitis Vaccine

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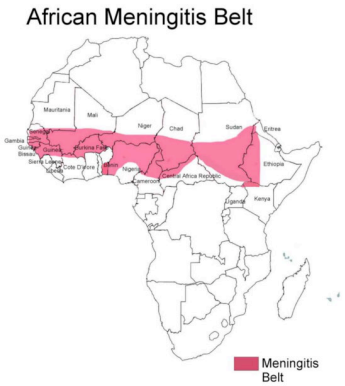
Published by AAAS

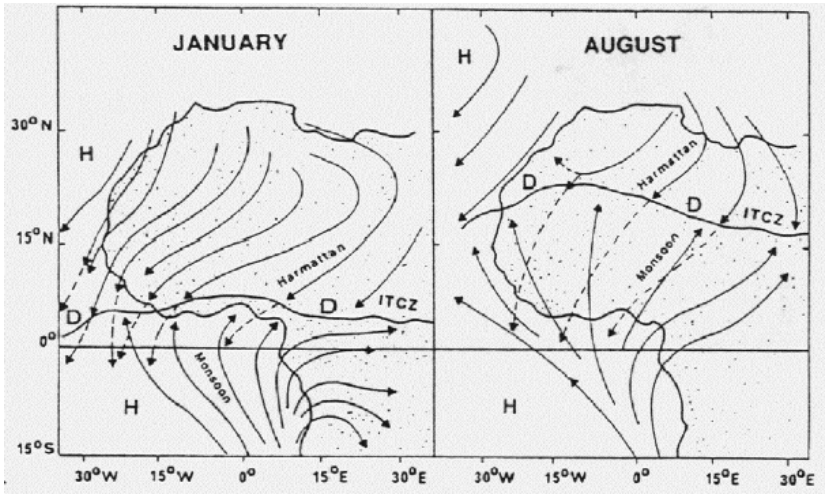
Meningoccocal meningitis key facts

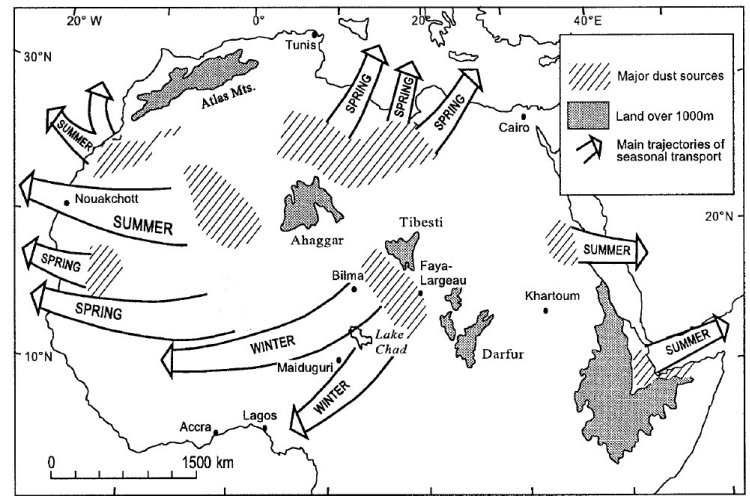
- Bacterial form of meningitis, a serious infection of the thin lining that surrounds the brain and spinal cord
- Direct transmission, person to person, respiratory droplets
- 12 serogroups. 4 in Africa: A, C, W135, X
- Highest rates of the disease in the so-called "meningitis belt" in sub-Saharan Africa stretches from Senegal in the west to Ethiopia in the east (80 % of the global burden)
- 21 countries and 300 million people at risk
- 700 000 cases in the past 10 years, 10-50 % fatality rates, 10-20 % of survivors suffer permanent brain damage
- Meningococcal polysaccharide vaccines are available for reactive vaccination
- A new meningococcal conjugate A vaccine developed specifically for Africa should be available by the end of 2010

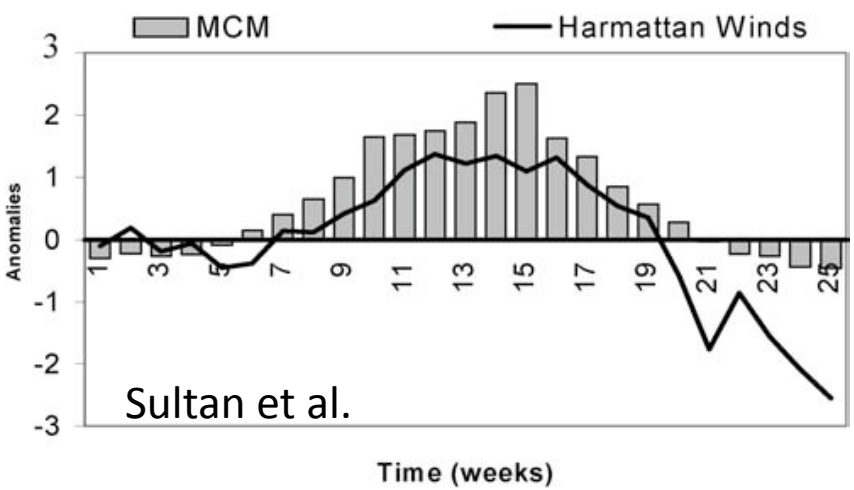


Climate and dust

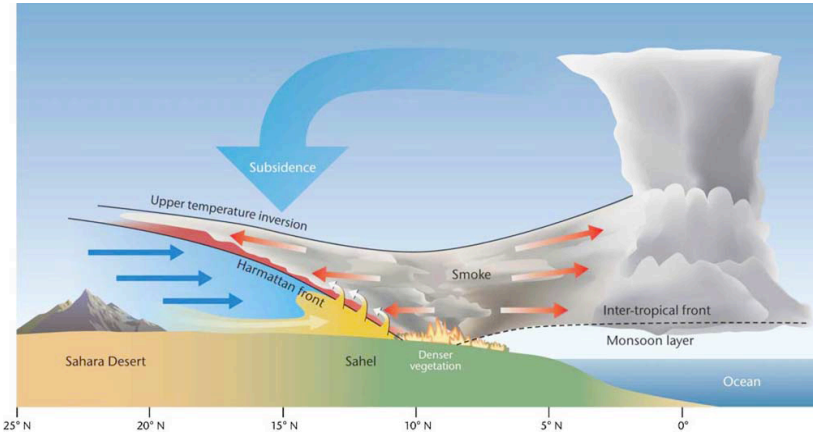
Seasonality of MM outbreaks related to climate dynamics in the region



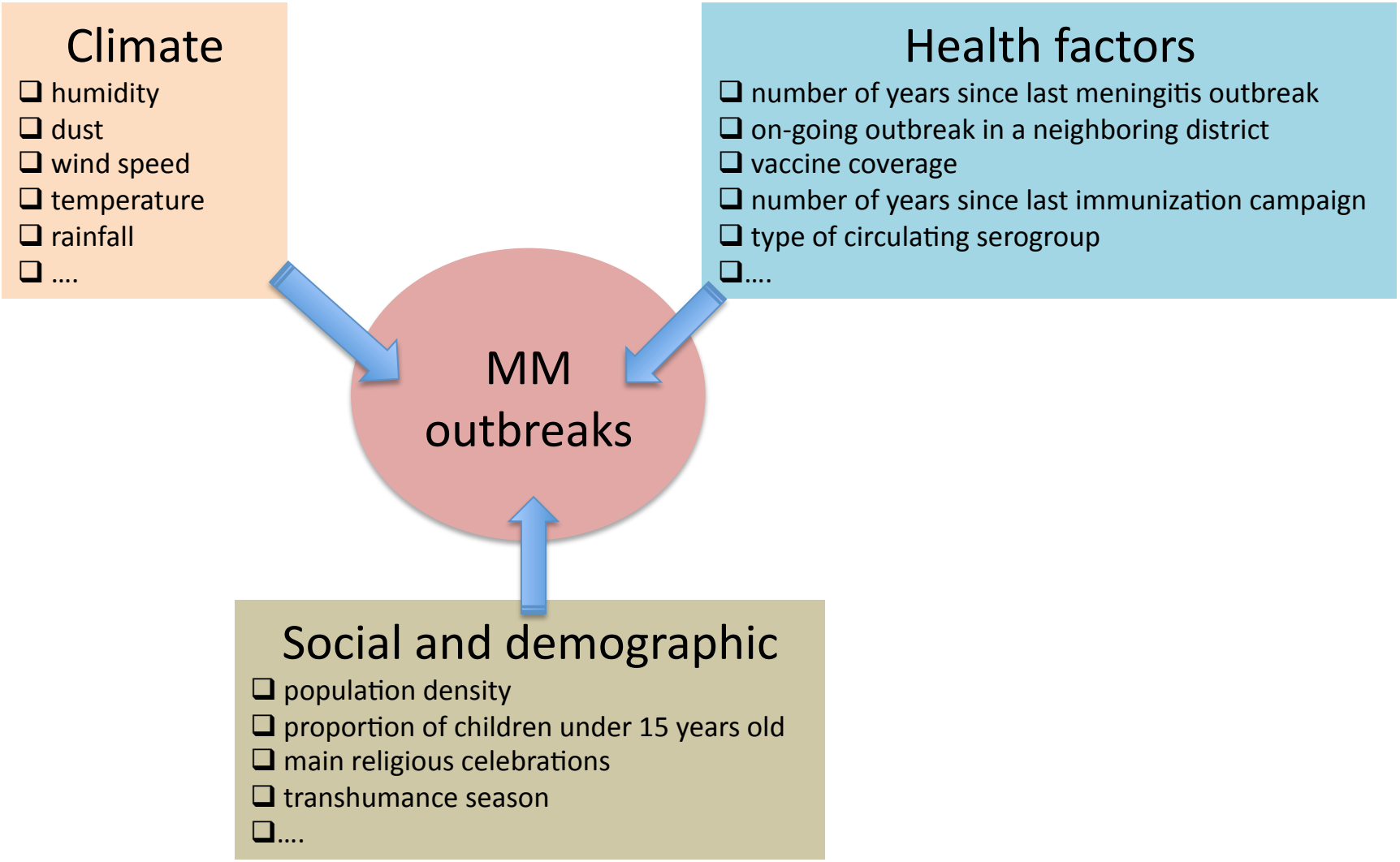




Sultan et al.



Risk factors for meningitis outbreaks in sub-saharan Africa



Temporal and spatial scales

Decadal/regional scale

- ❑ Could climate variability at these scales explain past meningitis large scale waves (8-12 years)?
- ❑ What will happen on the coming decades?

Interannual/sub-regional scale

- ❑ Prediction 1 year ahead for vaccine production planning?
- ❑ Seasonal forecasts are available but skills for the dry season must be assessed

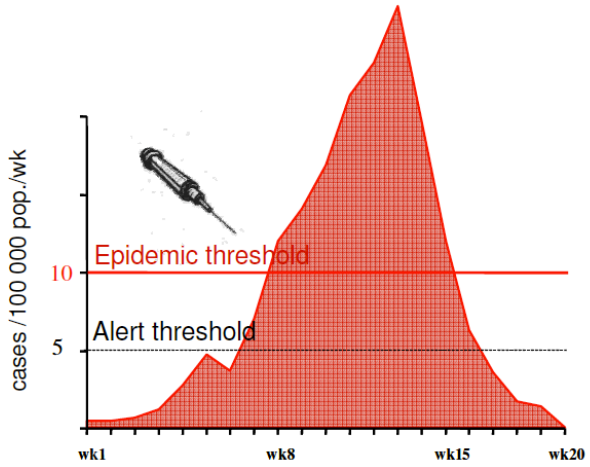
Operational/district scale

- ❑ Adding climate criteria in the reactive vaccination decision process at the district scale?

Reactive vaccination

- ❑ Polysaccharide vaccines
- ❑ Poorly immunogenic in children < 2yr
- ❑ Immunity short lived
- ❑ Does not protect from carriage
- ❑ Routine immunization not feasible in the Belt
- ❑ Limited supply, affordability

***CHALLENGE*: timely vaccination to optimize the control of the epidemics**



Dust & Meningitis: hypothesis

Possible mechanisms by which the dust could influence the development of the disease

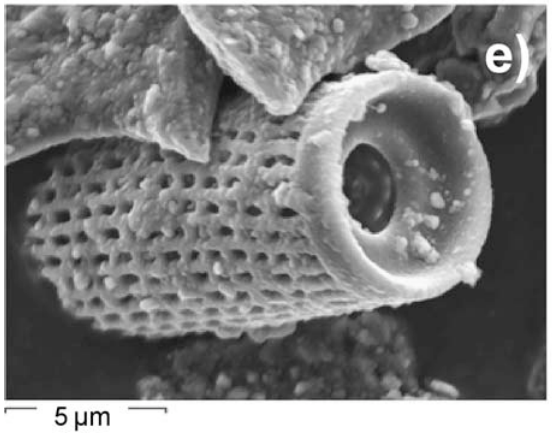
1. Irritation and disruption of the epithelial lining of the upper respiratory tract, allowing bacterial penetration

2. Enhancing bacterial survival via iron content of dust

3. High dust levels affecting human behaviour, including crowding and reduced ventilation (e.g. blocking windows)

4. (More controversially) serving as carriers for bacteria

People caught in a dust storm in Mali



FESEM image showing the morphology and particle size of a typical airborne diatome from the Chad Basin (Moreno et al., 2006)

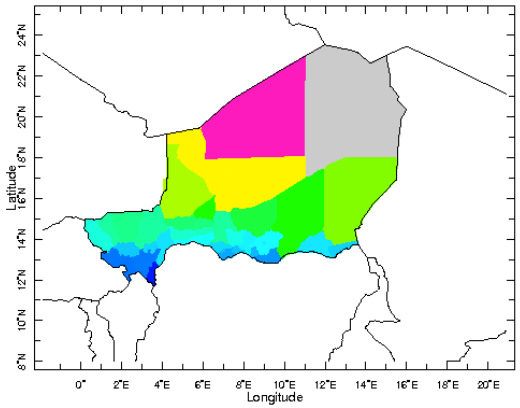
Ongoing work

- 30 year simulation (February 1979- March 2010) within a domain that covers Northern Africa, Middle East and Europe
- Resolution of the model was set to 0.5º x 0.5º
- The simulation was reinitialized every 24 hours with Reanalysis-2 for atmosphere and GLDAS for soil.
- 3 hourly output of climate (humidity, temperature, winds, precipitation) and dust respirable concentrations

- Comparison with weekly cases at distrct levels in Niger

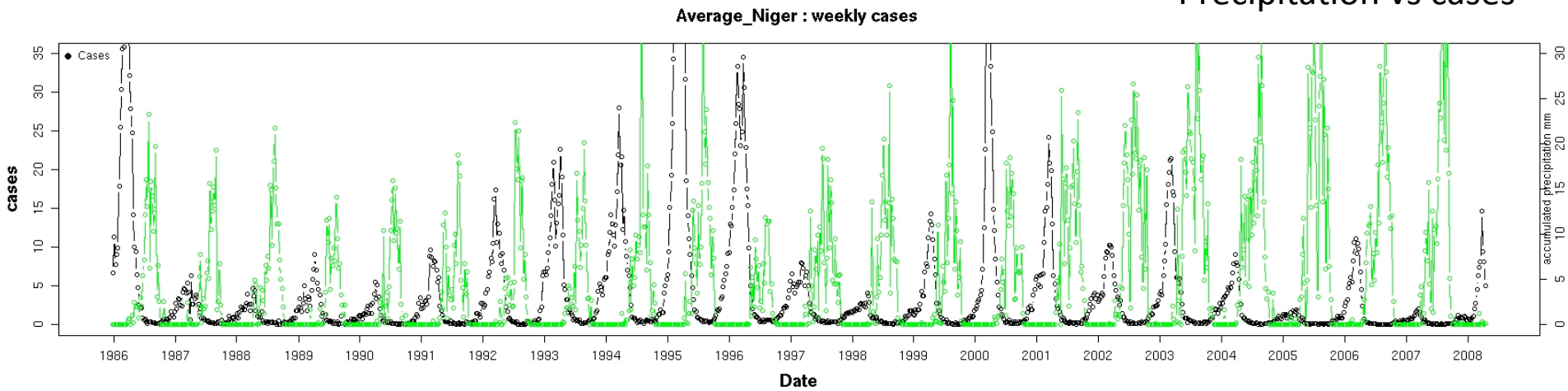
  Goals:

  - undestand the influence of climate and dust on epidemics
  - Build statistical predictive tool to help reactive WHO vaccination strategy

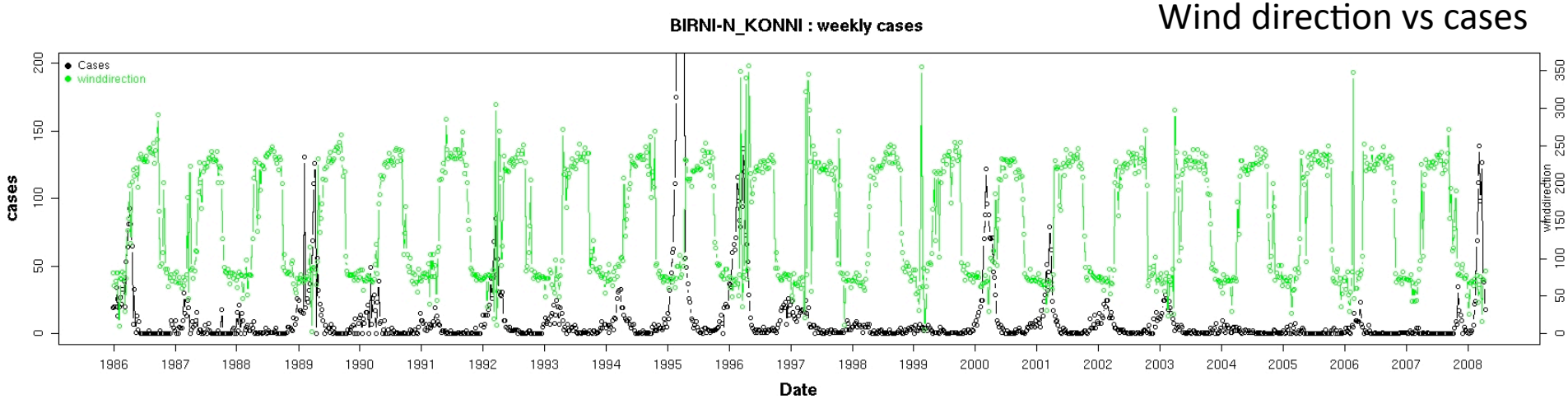


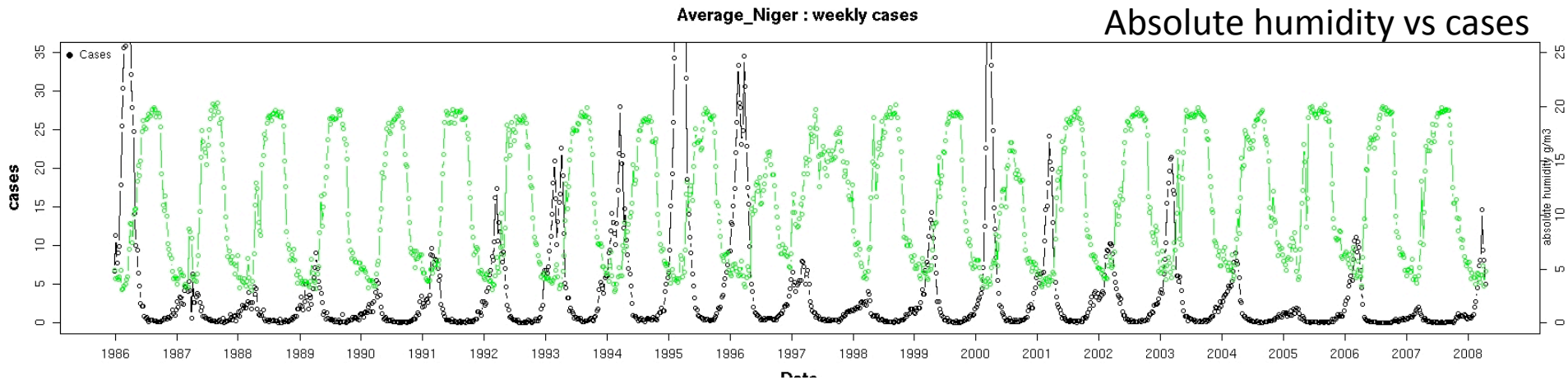
Preliminary results for Niger
1986-2008 weekly cases vs climate and dust

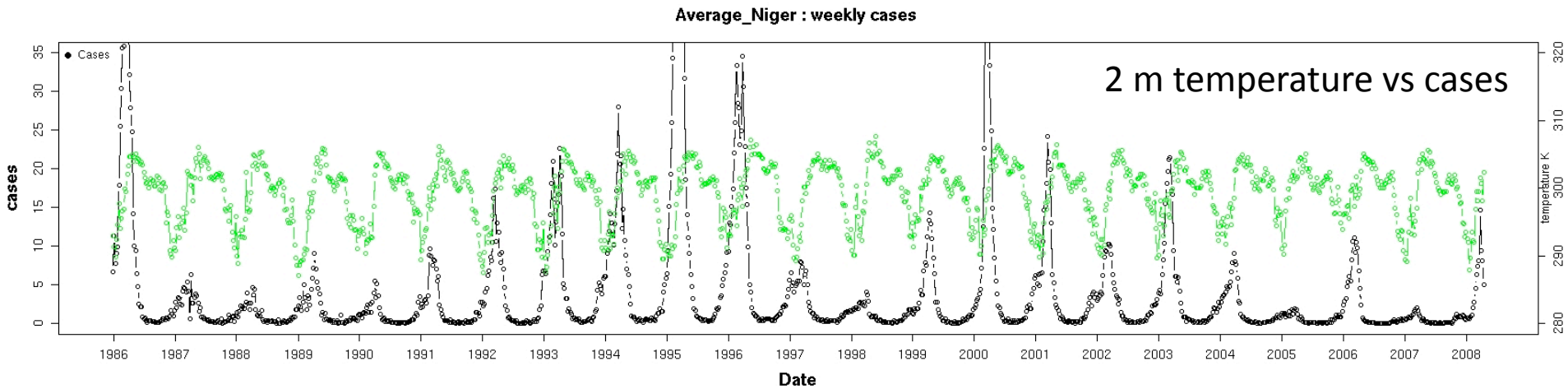
Precipitation vs cases

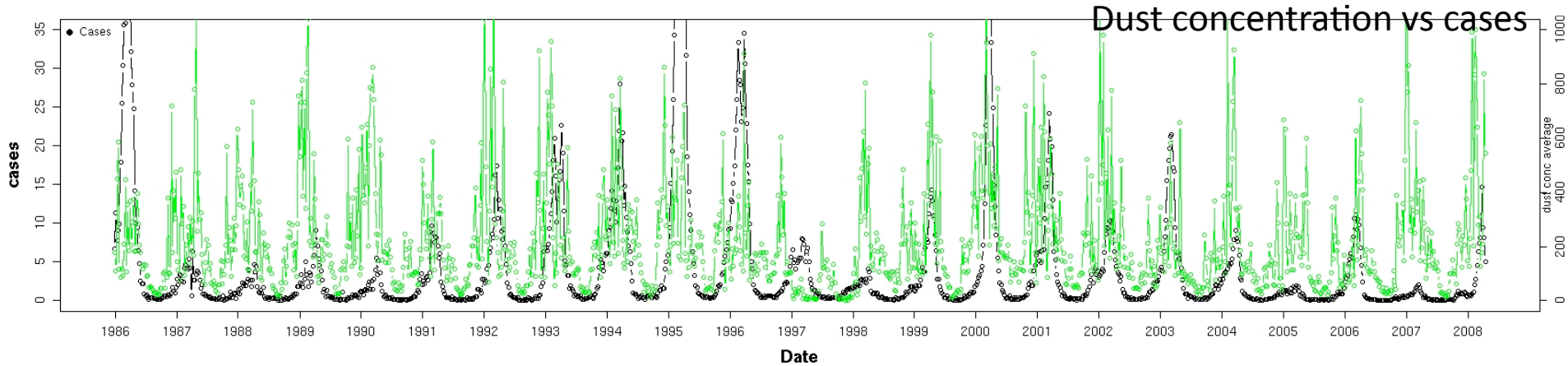


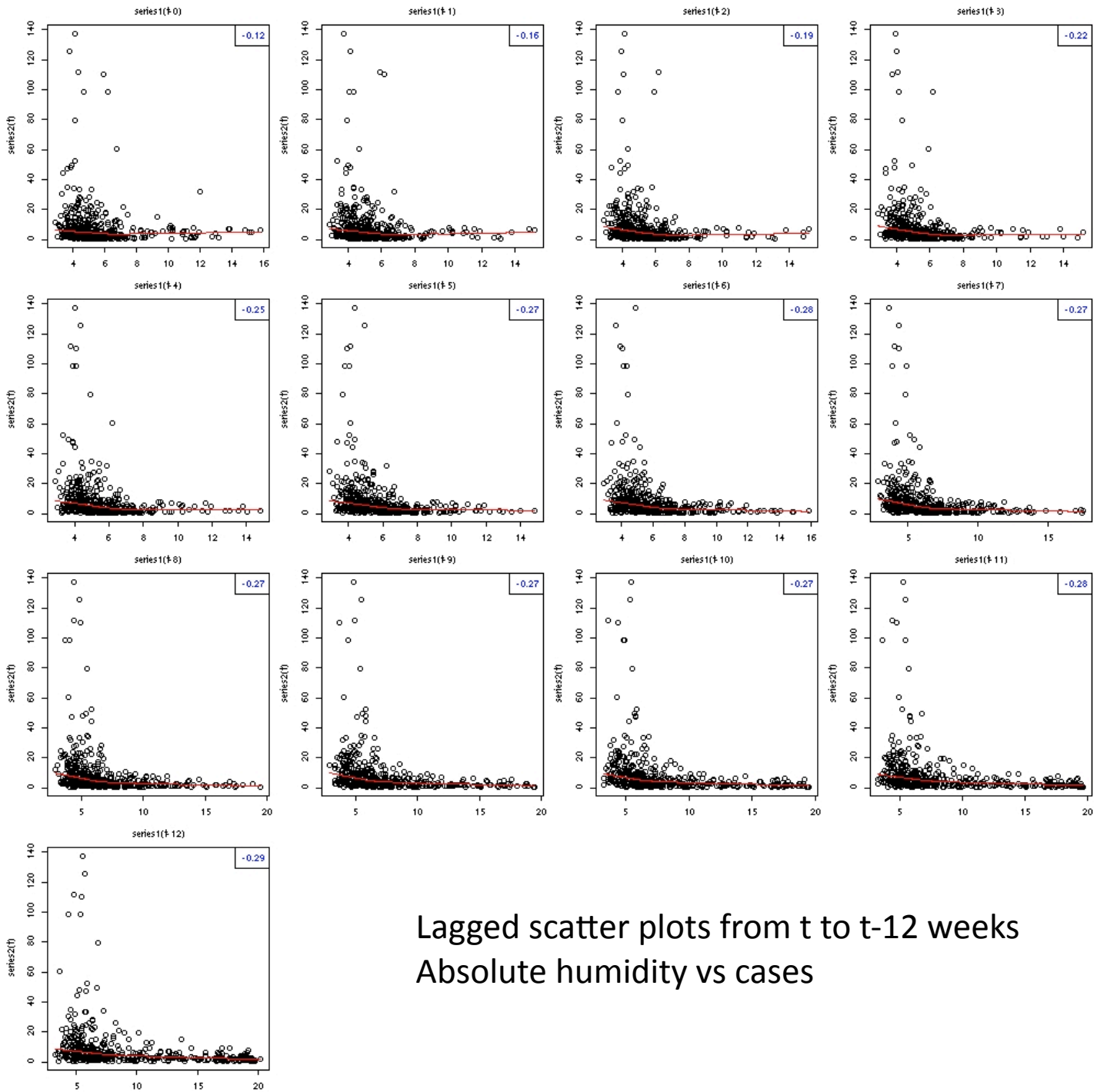
Wind direction vs cases



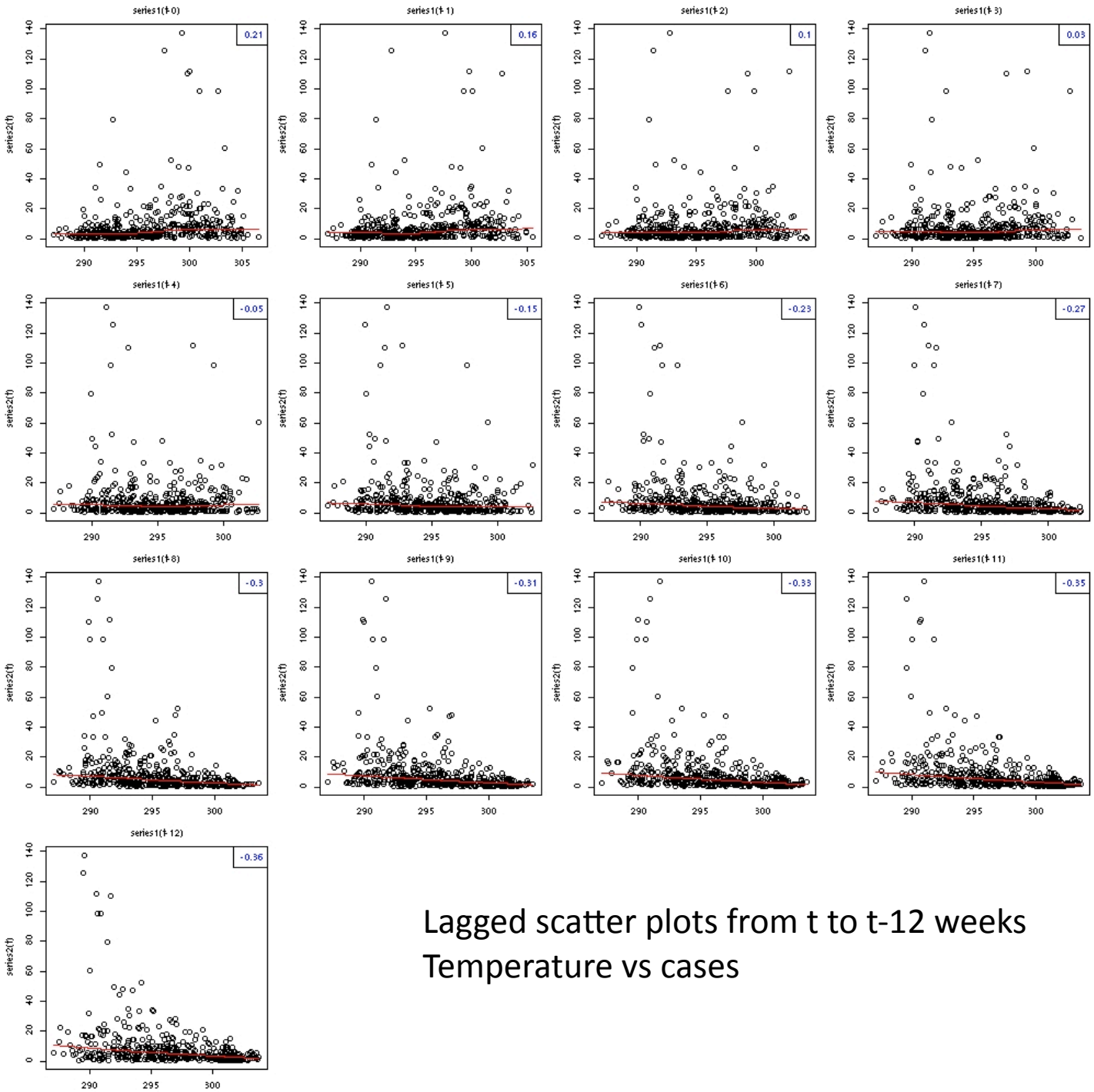

Average_Niger : weekly cases
Absolute humidity vs cases
Cases
cases
absolute humidity g/m3


Average_Niger : weekly cases
2 m temperature vs cases
Cases
cases
temperature K
Date

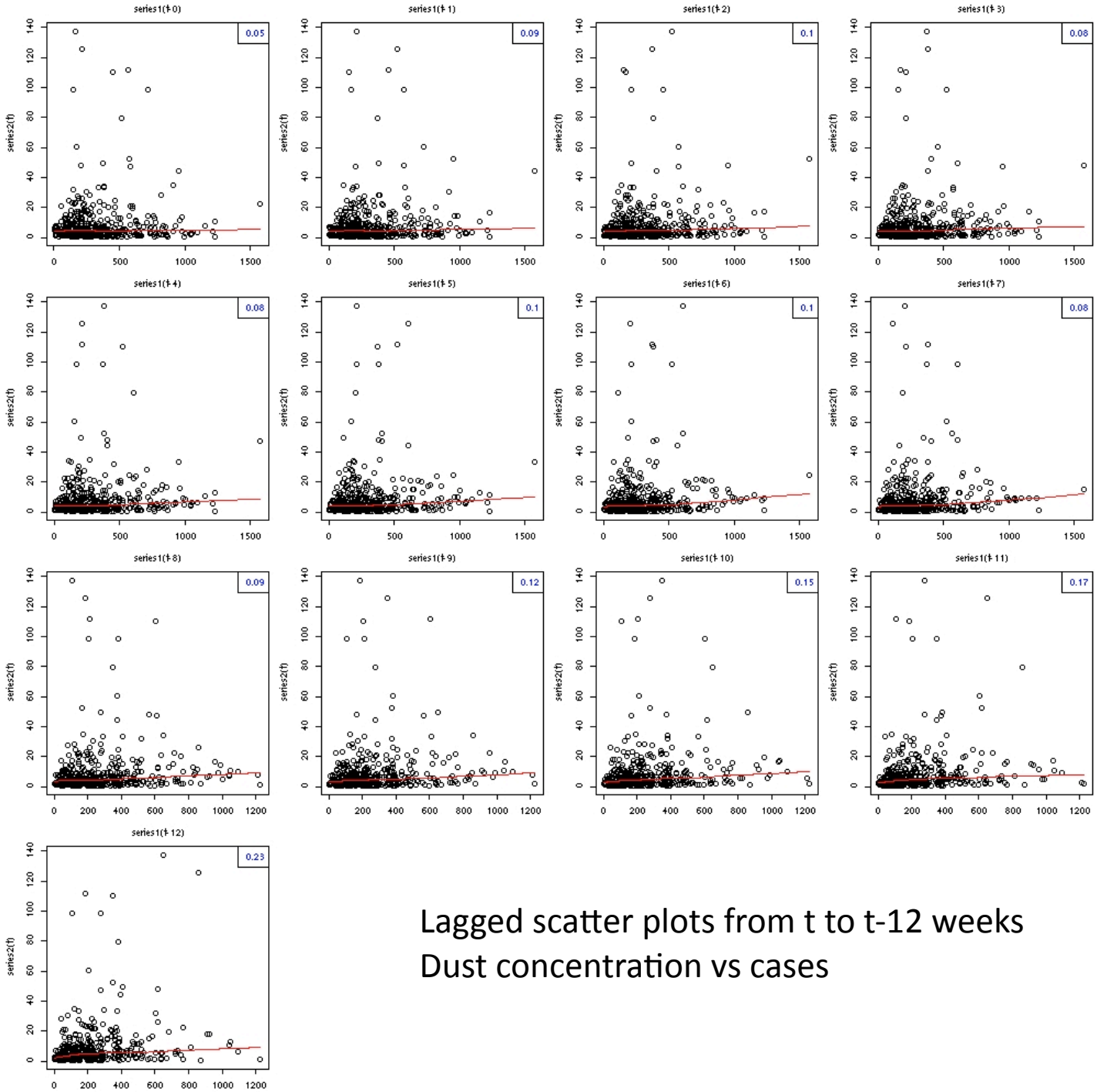

Dust concentration vs cases
Cases
cases
dust conc average
Date



Lagged scatter plots from t to t-12 weeks
Absolute humidity vs cases



Lagged scatter plots from t to t-12 weeks
Temperature vs cases



Lagged scatter plots from t to t-12 weeks
Dust concentration vs cases

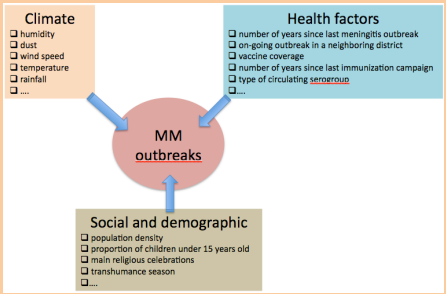
projects

FRAMEWORK: Meningitis Environmental Risk Information Technologies (MERIT)

On-going projects

NASA ROSES:

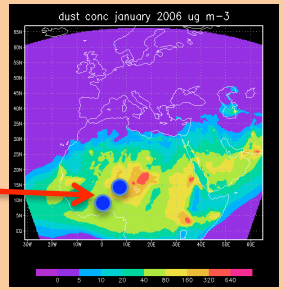
Towards improved control of meningitis outbreaks in sub-Saharan Africa'
PI: S. Trzaska



NIEHS: *The role of airborne dust and climate in meningococcal meningitis outbreaks in the Sahel*

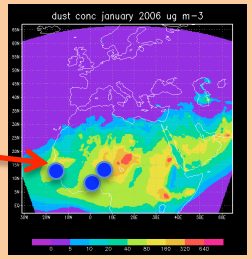
PI: S. Trzaska

Dust measurements of concentration and composition
2 stations: Niger and Ghana



2010

CCI: *Atmospheric aerosol impacts on health in sub-Saharan Africa*

PI's: C. Pérez Garcia-Pando, S. Trzaska

Additional dust measurements of concentration and composition in Senegal