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The atmospheric iron cycle: Relevant WMO research programmes and recent modelling examples

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World Weather Research Programme

Atmospheric Research and Environment Programme

World Meteorological Organization, Geneva

GESAMP 36th Annual Meeting, 28 April – 1 May, Geneva Switzerland

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WMO-WWRP Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS)

SDS-WAS Mission

To enhance the ability of countries to deliver timely sand and dust storm forecasts, observations, and knowledge to users through international partnership of research and operational communities

SDS-WAS and GESAMP

GESAMP has advised WMO to enhance the ability of countries to deliver timely sand and dust storm forecasts, observations, and knowledge to users through international partnership of research and operational communities

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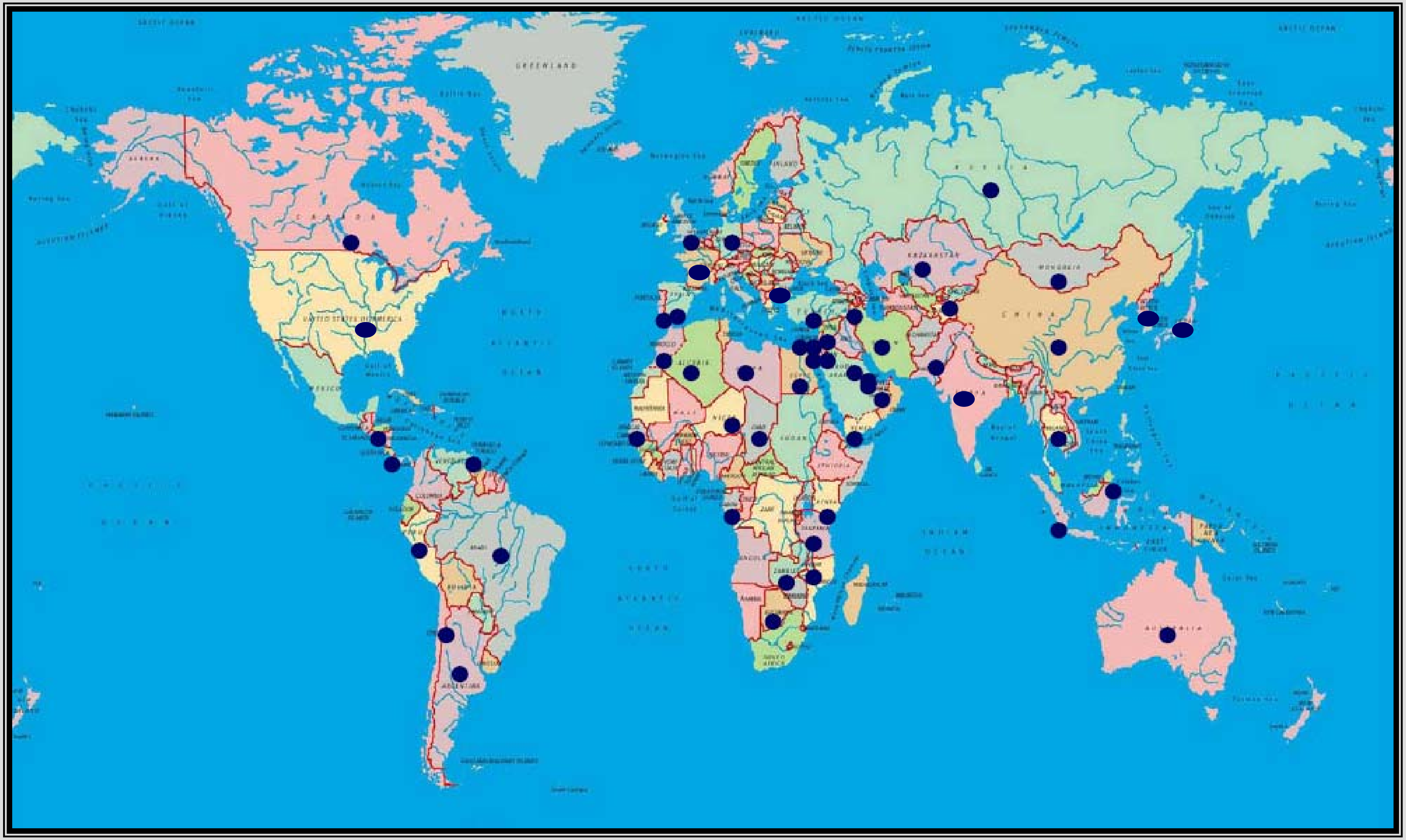
Many SDS Countries



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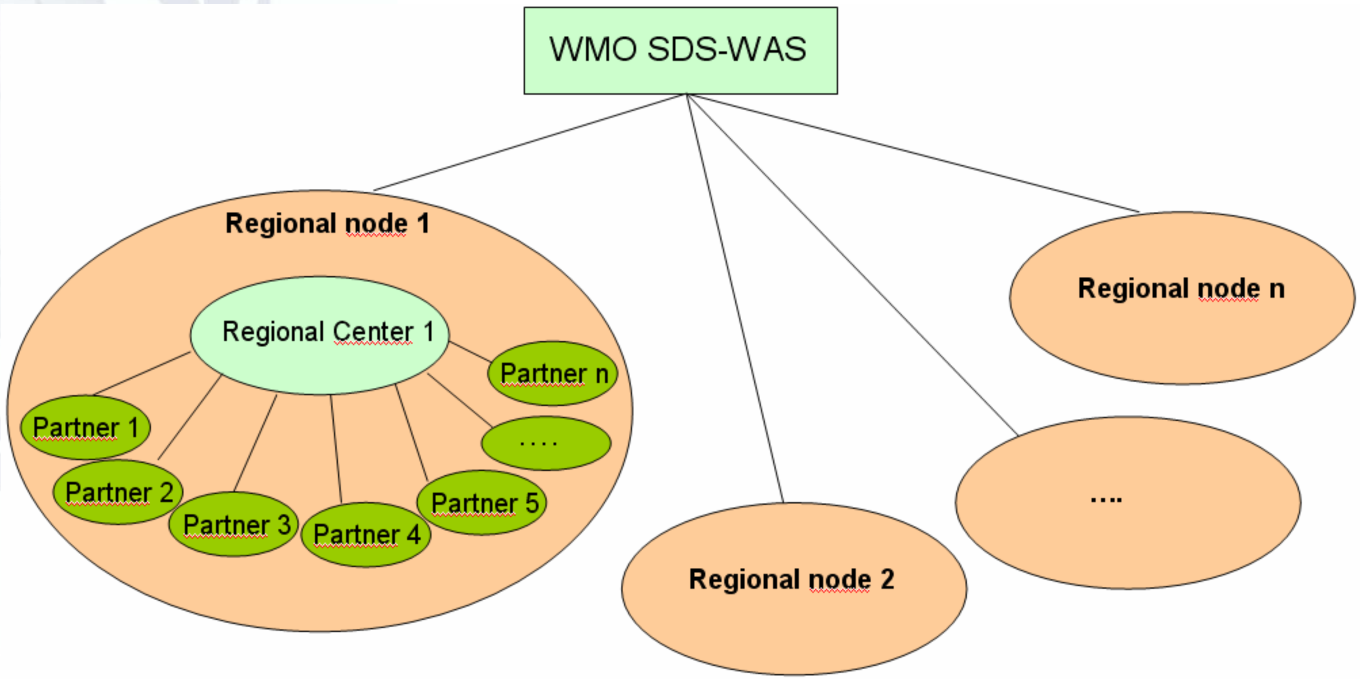
The SDS-WAS network consists of federated nodes assisted by regional centres

WMO established two SD-WAS Regional Centres: China and Spain



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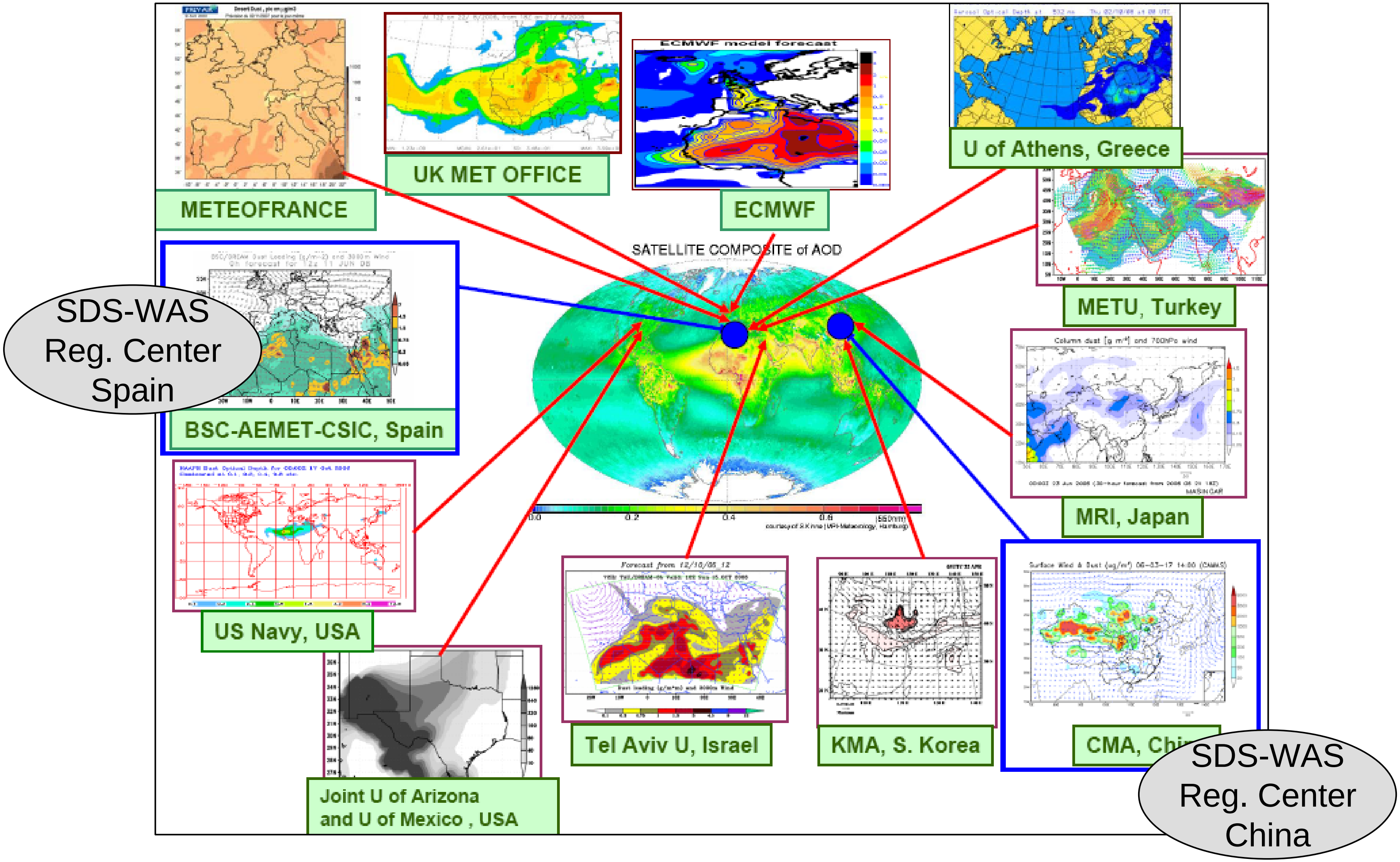
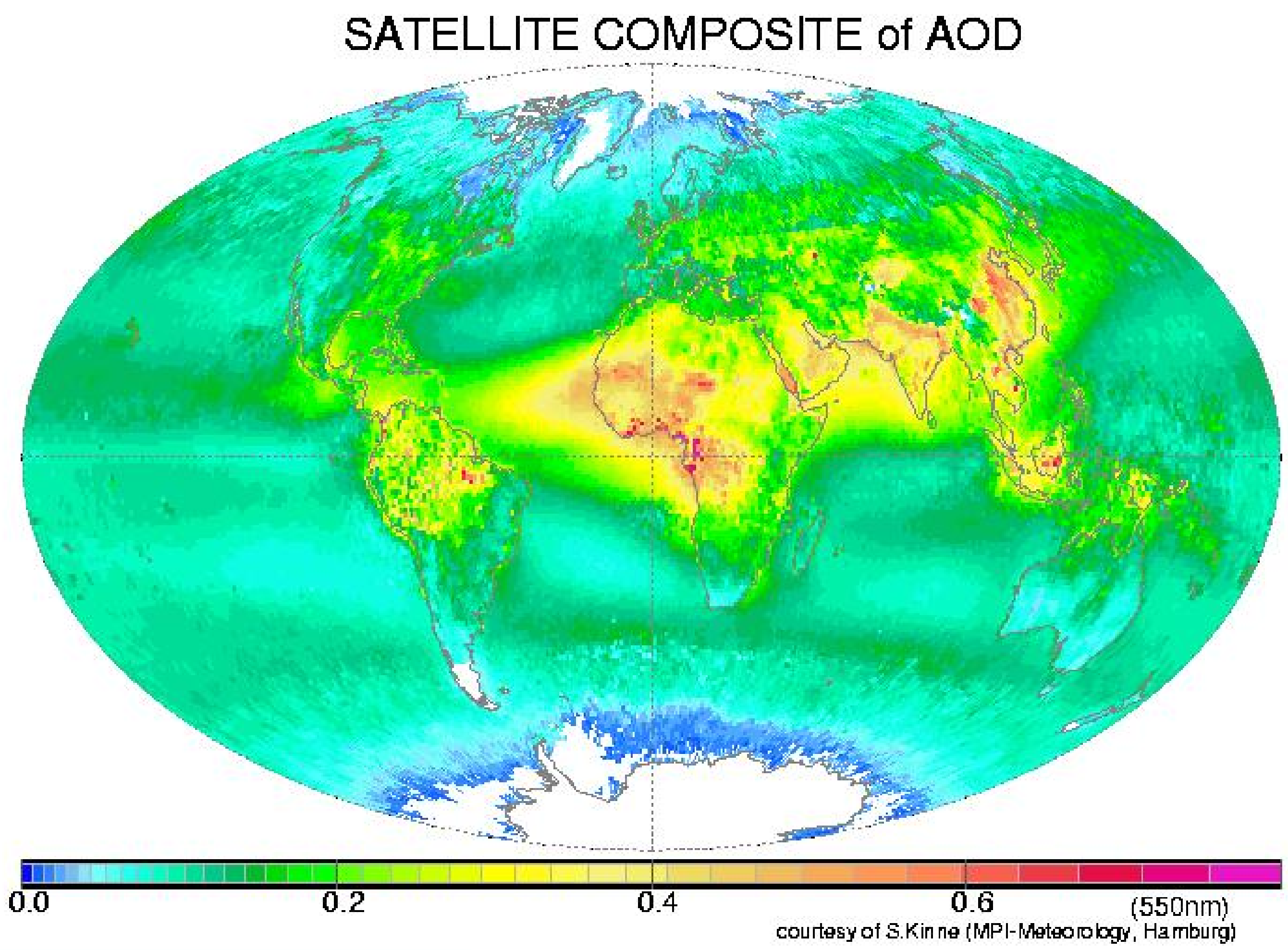
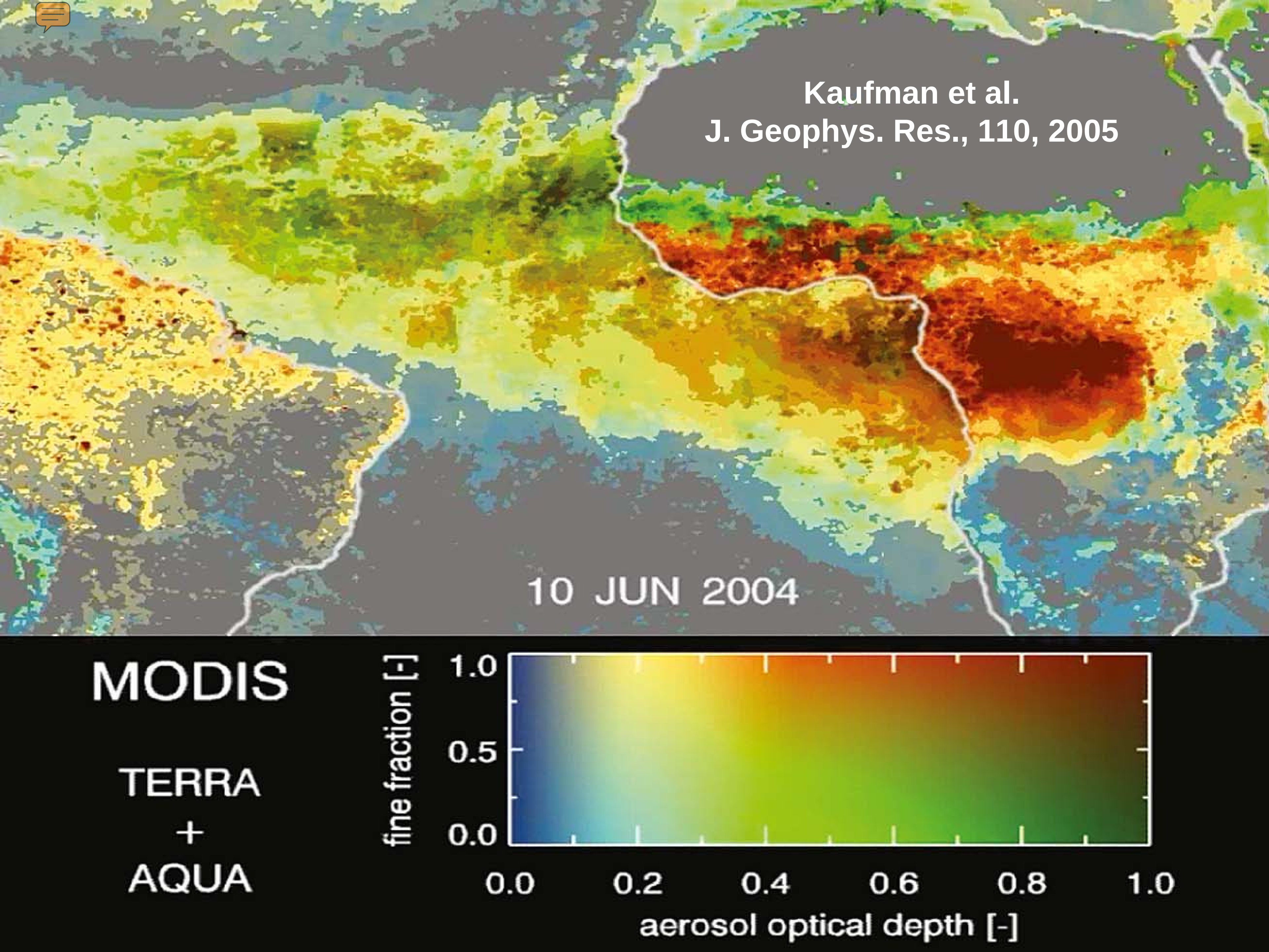
Sand and dust models performing daily forecasts as of July 2008



Operational Global Aerosol Observations



Global annual average distribution of aerosol optical depth (AOD), a composite from six satellites. (courtesy of S. Kinne MPI, Hamburg, Germany)


Kaufman et al.
J. Geophys. Res., 110, 2005
10 JUN 2004
MODIS
TERRA
+
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fine fraction [-]
1.0
0.5
0.0
0.0
0.2
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0.6
0.8
1.0
aerosol optical depth [-]

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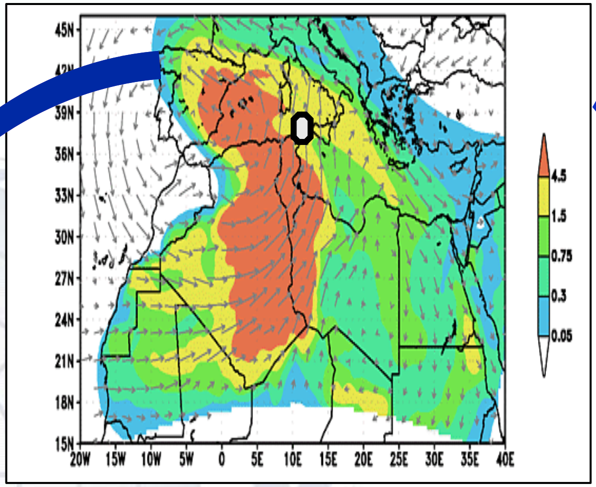
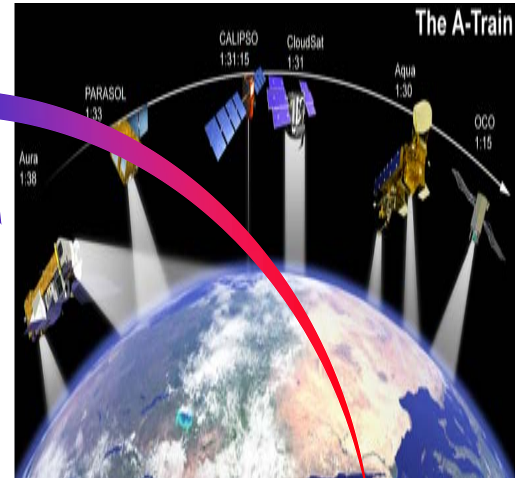
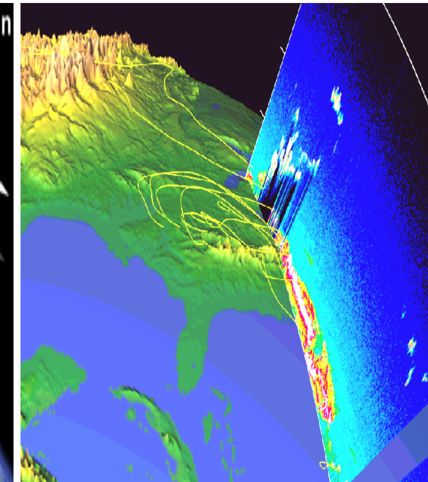
SDS integrated observation-modelling approach

Forecast Models

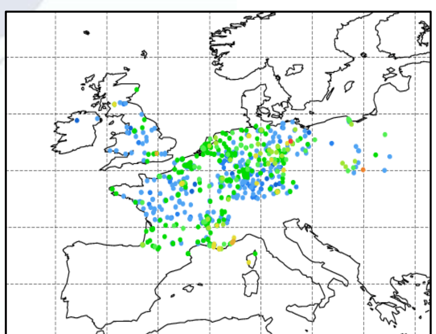


18 UTC, 7 May 2002 30-hr forecast



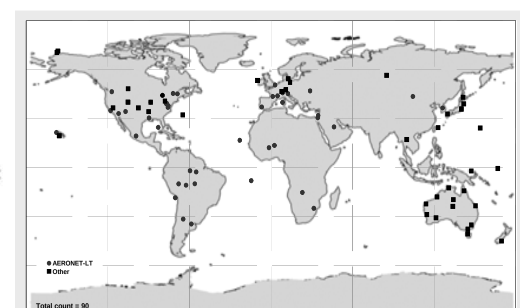


NASA A-Train MODIS CALIPSO; Geostationary Satellite IR Obs



European PM10

WMO GALION Surface-based LIDAR



GAW/AERONET/SKYNET Surface-based AOD

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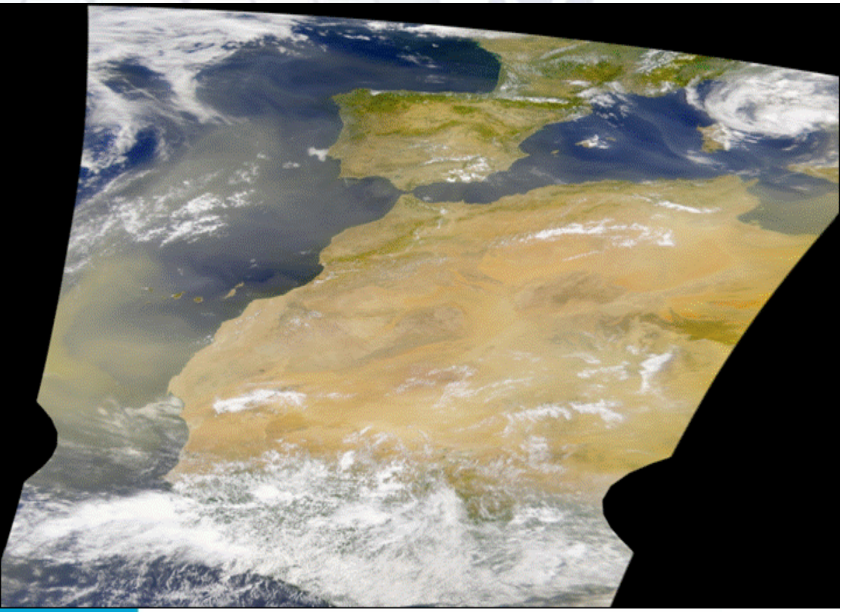
ATMOSPHERIC IRON

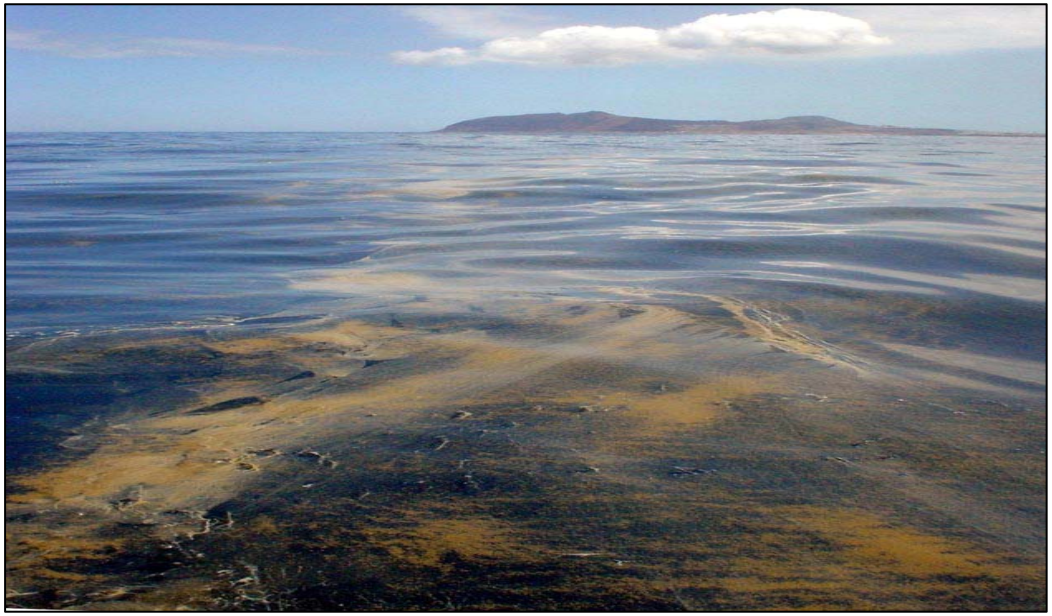
- Why dust?
- **Dust** is a carrier of the embedded nutrients such as Fe (and phosphorus)

- In remote oceans, input of iron in dust dominates other inputs

- Soluble iron is the essential micronutrient in marine environment



Dust over W Africa
July 2004



Bloom of Trichodesmium around Canary Islands
August 2004 (Ramos et al., 2008)

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Fe SOLUBILITY

- Fe - essential nutrient for phytoplanktons
- Fe very insoluble in seawater
- Lots of Fe added to the oceans from rivers, but very close to the coast
- Open ocean is ‘iron-limited’ –insufficient Fe available to ocean plant life
- Away from the coast, dust aerosol can be a very important source of Fe
- How much of Fe becomes available to phytoplanktons?

Yet unresolved issue!!

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OPEN SCIENTIFIC QUESTIONS

- Fe solubility - major uncertainty in marine biochemistry
- Lack of data on soil/dust mineralogy
- Fe chemical rate constant - one order of magnitude uncertainty
- Relative influence atmospheric Fe processing components not well known
- Fe transport models - too coarse to sufficiently resolve the process

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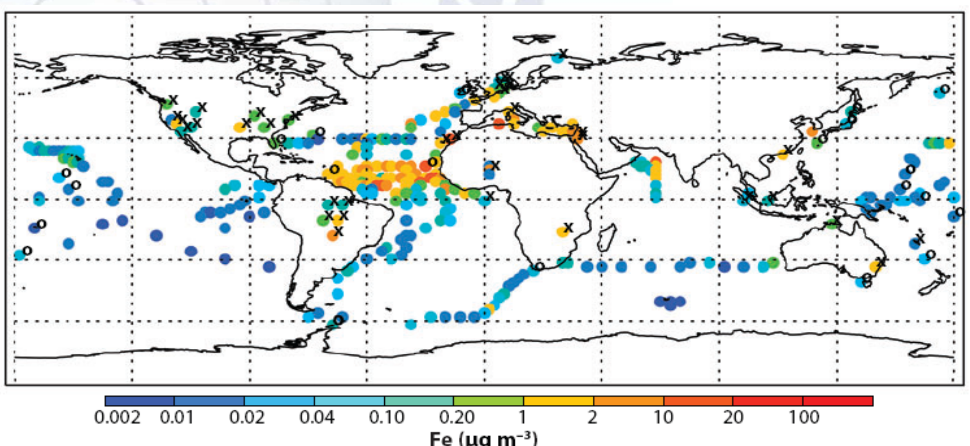
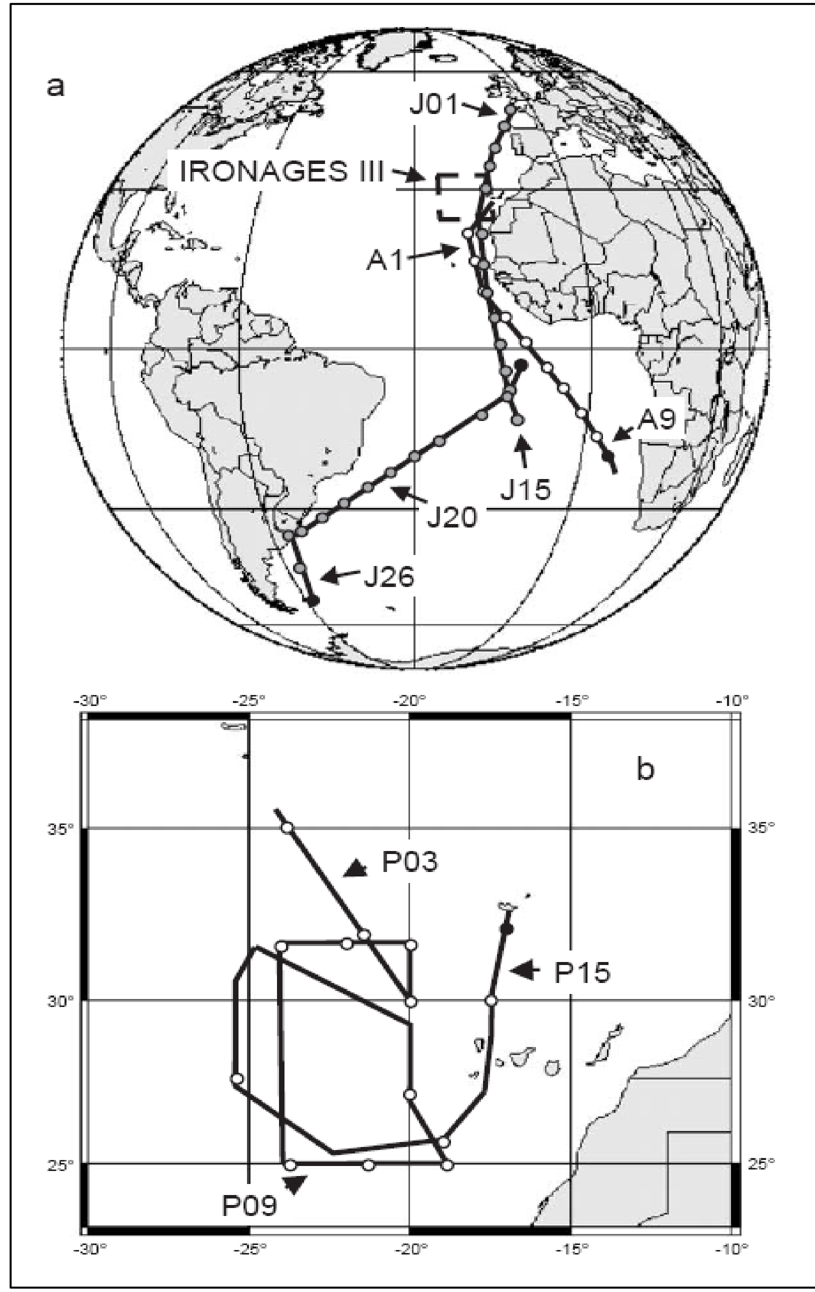
OBSERVATIONS

- No systematic observations
- Cruises data
  - – major source of measurements information



Measured solubility (Mahowald et al., 2008)



Cruise paths (Baker and Jickells, 2006)

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ATMOSPHERIC Fe MODELLING

Complementary way to learn more about the Fe atmospheric processing

Iron solubility:

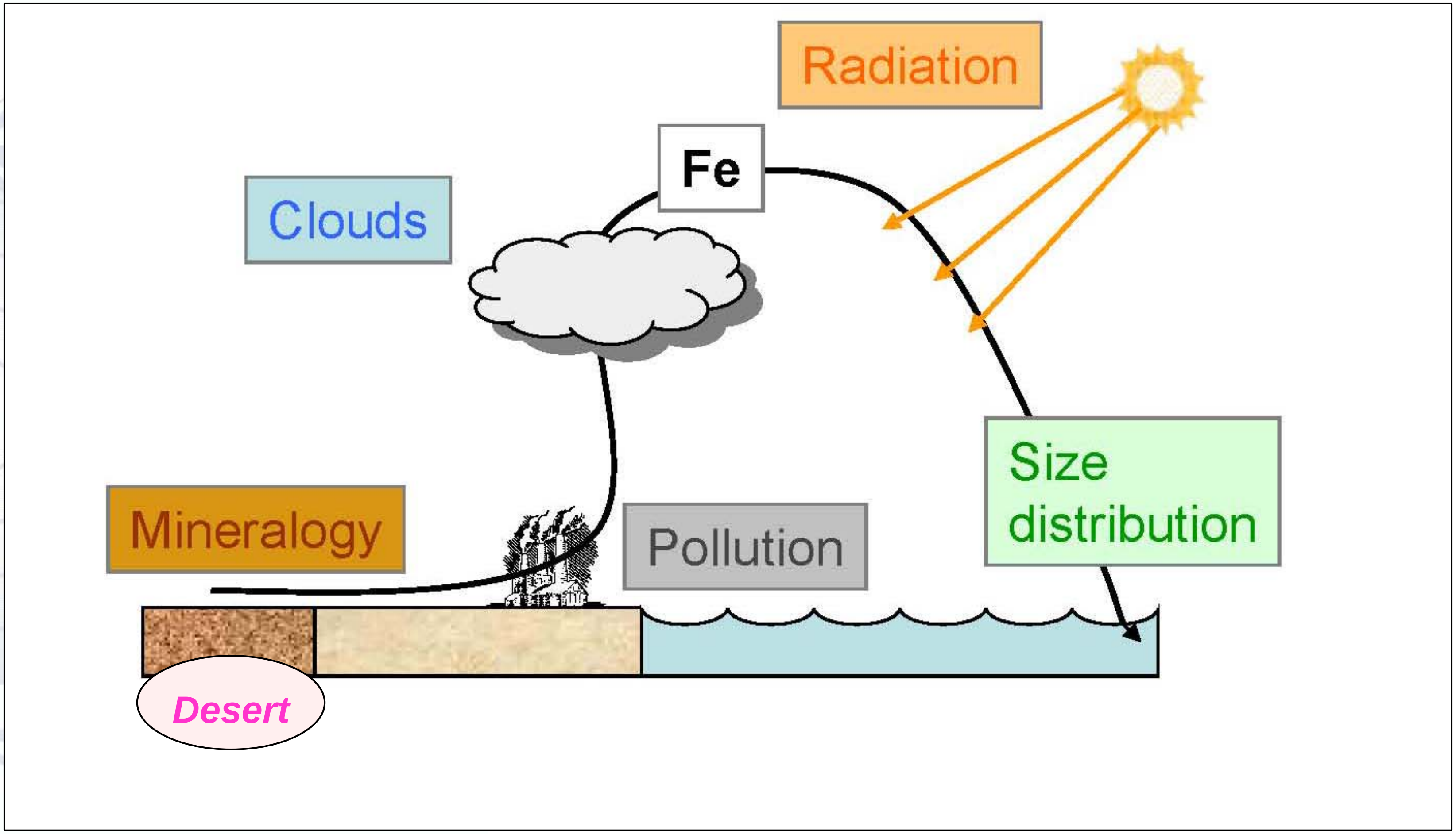
- low at sources
- on average, desert dust aerosols contain 3.5% iron (*Duce and Tindale, 1991*)
- high in ocean deposit

Not well known why!

Possible `suspects` affecting Fe processing (*Luo et al., 2006*)

- radiation
- clouds
- pollution
- surface-to-volume ratio (*Baker and Jickells, 2006*)
- mineralogy (*Journet et al, 2008*)

ATMOSPHERIC Fe PROCESSING



GLOBAL MODEL STUDIES

Hand et al (2004):

Solubility due to radiation and cloud processing

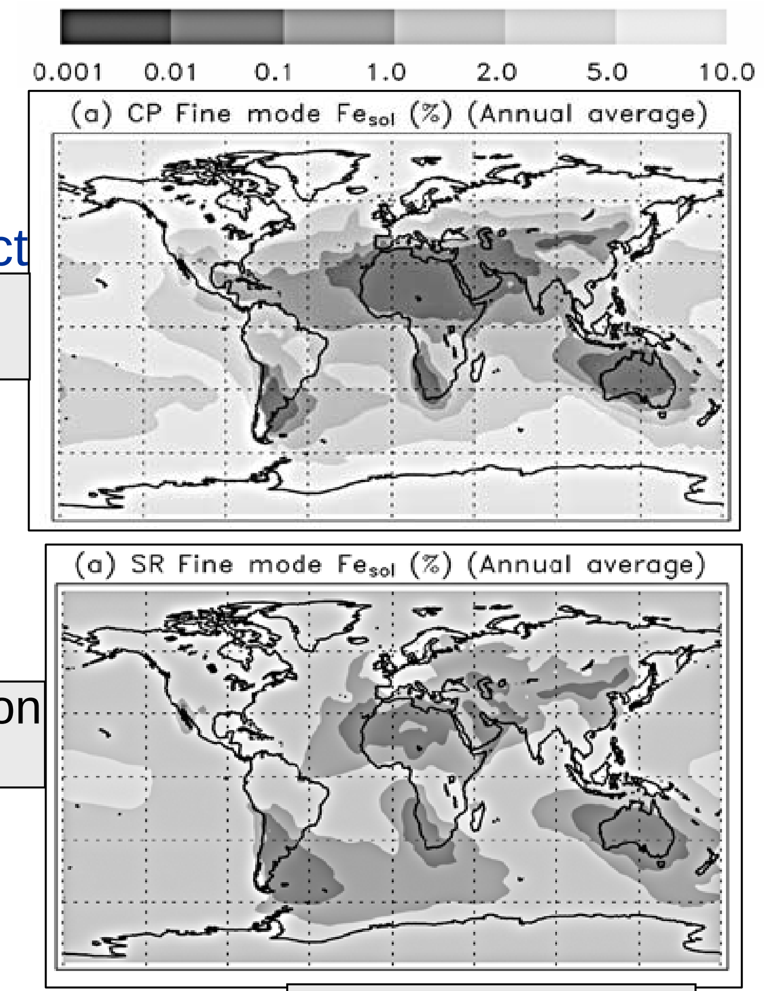
- annual average
- model underestimates S

Global approach:

- advantage – a global prospect

  disadvantage – too coarse model resolution

Cloud processing



Solar radiation processing

Fe solubility S (%)

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REGIONAL MODEL STUDIES

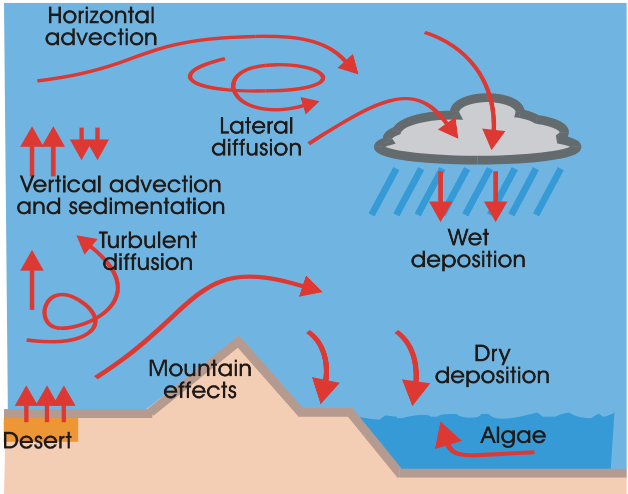
• Advantages of regional modelling:

- High resolution
- Studying particular cases

DREAM-IRON model (*Nickovic and Perez, 2008*)

• Iron module embedded into DREAM dust model (*Nickovic et al, 2001*)

• 8 particle bins, radius range (0.1 – 10 μm)

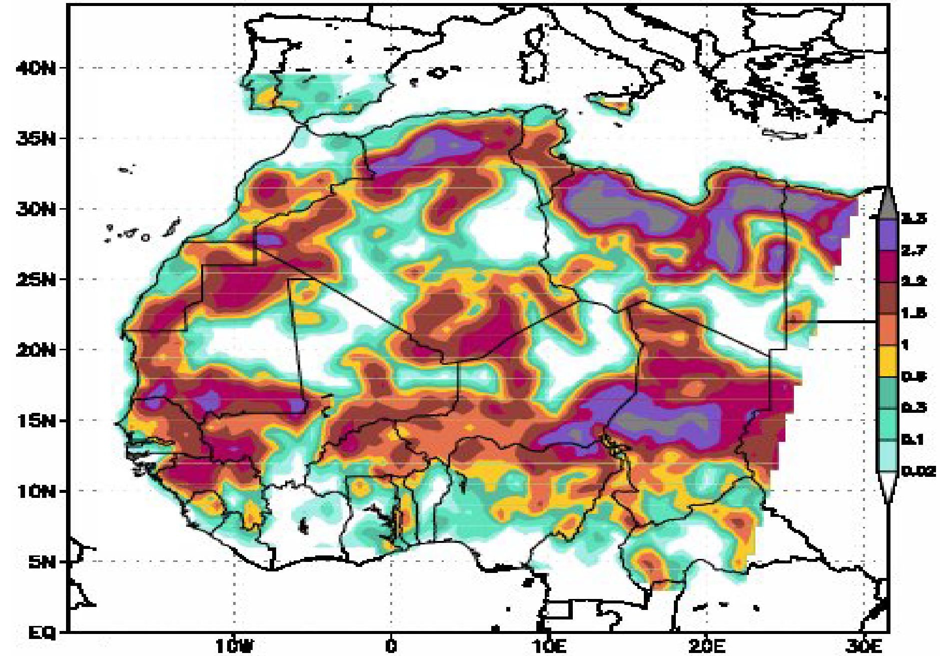


Iron mineralogy based on:

- FAO-UNESCO global 4’ soil type data
- Claquin et al. (1999) mineralogy evidence
- Journet et al. (2008) mineralogy data
- USGS global 1km land cover

5 minerals reach in Fe considered:

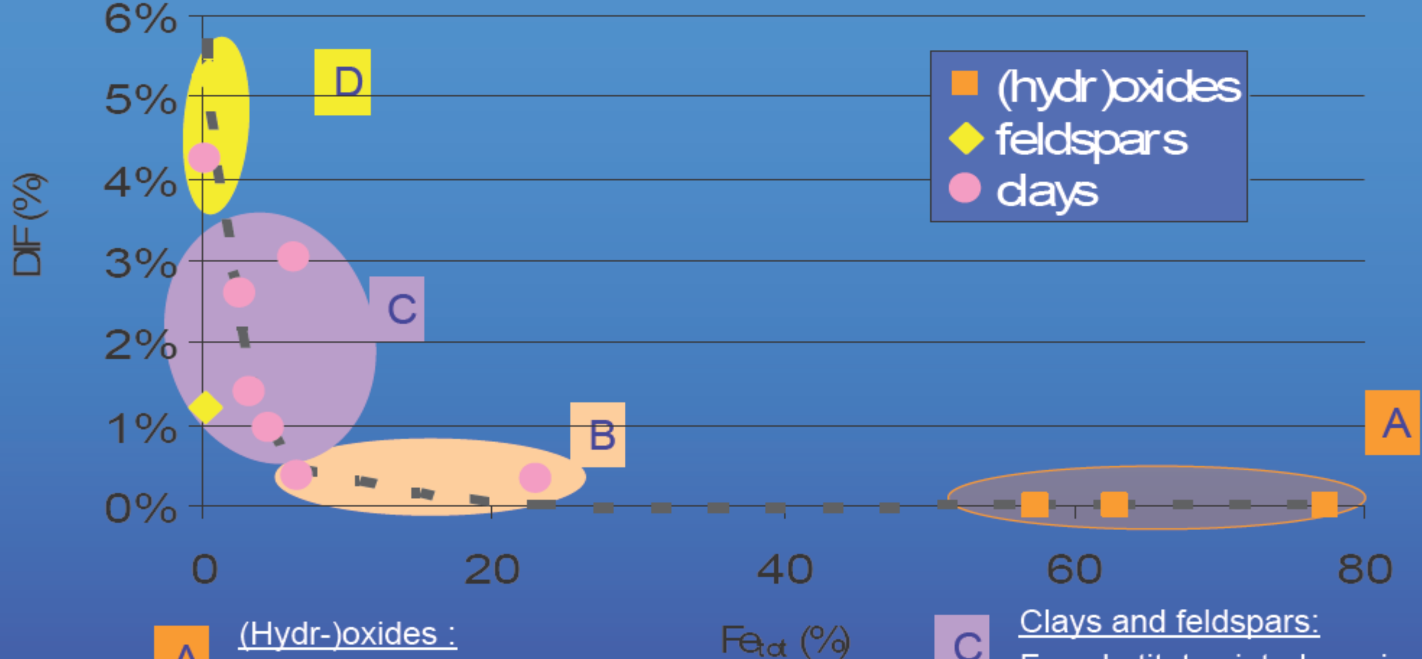
- Illite
- kaolinite
- smectite
- feldspars
- iron oxides



Total Fe fraction in Saharan soils

Fe Solubility and mineralogy (Journet et al., 2008)

% of dissolved Fe as a function of total iron content in %



A — (Hydr-)oxides : Covalent bonds Fe-O or Fe-OH

B — clays : Fe substitutes Al & Si

C — Clays and feldspars: Fe substitutes interlayer ions

D — Claiys & Feldspars: Fe = impurities

Conclusion…

The results of this study suggest that dissolved Fe from dust mainly comes from clay

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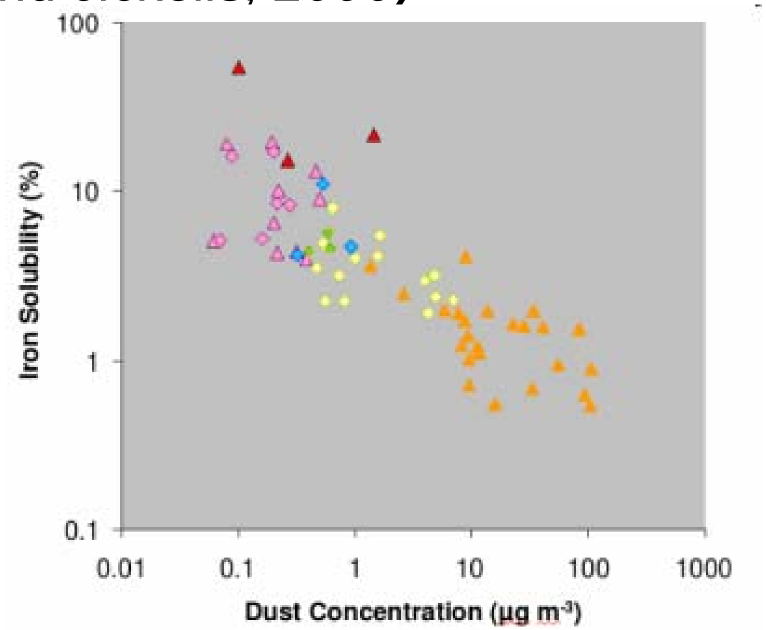
IRON SOLUBILITY cruise data *(Baker and Jickells, 2006)*



A possible explanation for this effect:

- Dust falls out of the air as it is transported.

- The larger dust particles - the higher gravitational settling rates → removed quickly.

- After long-range transport – only the smallest particles remain.

- These small particles have a high proportion of their iron content close to the surface to be released into seawater.

-Large particles have more of their iron locked away in the interior of the particle.

(http://www.uea.ac.uk/env/research/reshigh/ironsupply)

→ Fe solubility is strongly driven primarily dust physical properties

CAN MODEL SIMULATE *Baker and Jickells, 2006* RESULT?

DREAM–IRON DYNAMICS:

- Total Fe (**T**) = Soluble (**S**) + Non-soluble (**N**)
- By pseudo-first order chemical reaction: (**N**) → (**S**)
- Total Fe (**T**) :
  is *embedded in and* is *carried by* dust (**C**);

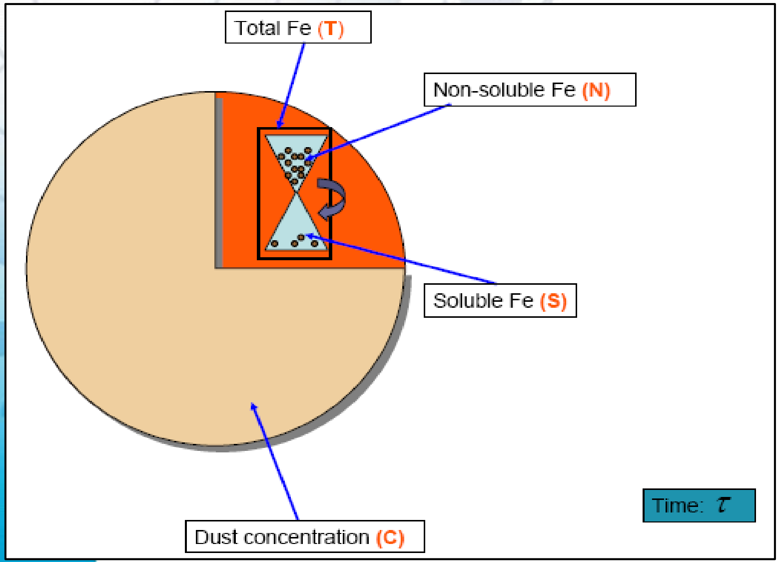
→ (**T**) is driven by (**C**) dynamics!!!

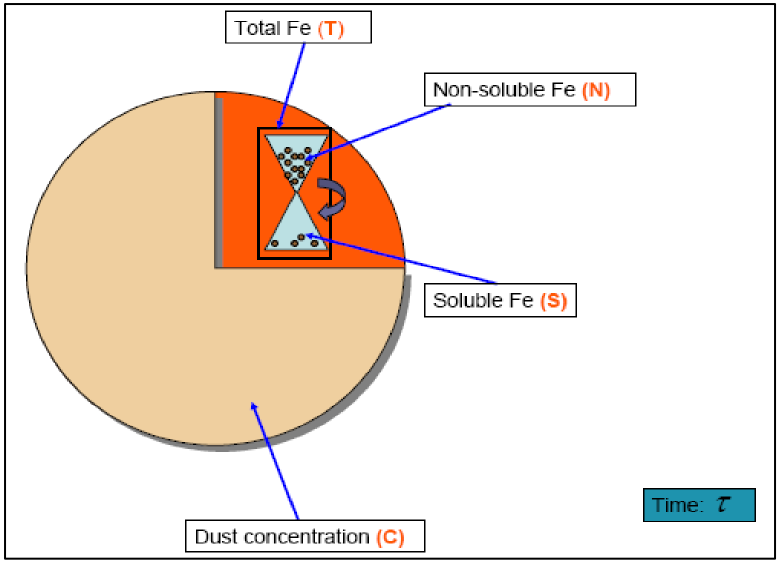
GOVERNING EQUATIONS

$$\frac{\partial C}{\partial t}+\vec{V}\cdot\nabla_h C+(w-w_g)\frac{\partial C}{\partial z}+\nabla_h\cdot(K_H\nabla_h C)+\frac{\partial}{\partial z}\left(K_Z\frac{\partial C}{\partial z}\right)=\frac{\partial C^{SOIL}}{\partial t}$$

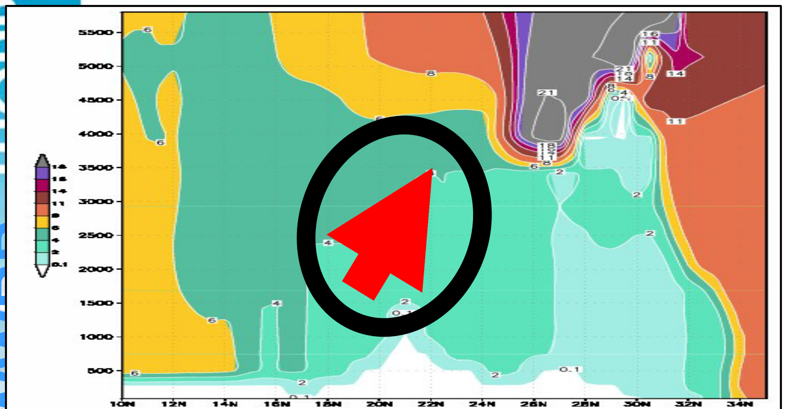
$$\frac{\partial T}{\partial t}+t\vec{V}\cdot\nabla_h C+t(w-w_g)\frac{\partial C}{\partial z}+\nabla_h\cdot(tK_H\nabla_h C)+\frac{\partial}{\partial z}\left(tK_Z\frac{\partial C}{\partial z}\right)=t\frac{\partial C^{SOIL}}{\partial t}$$

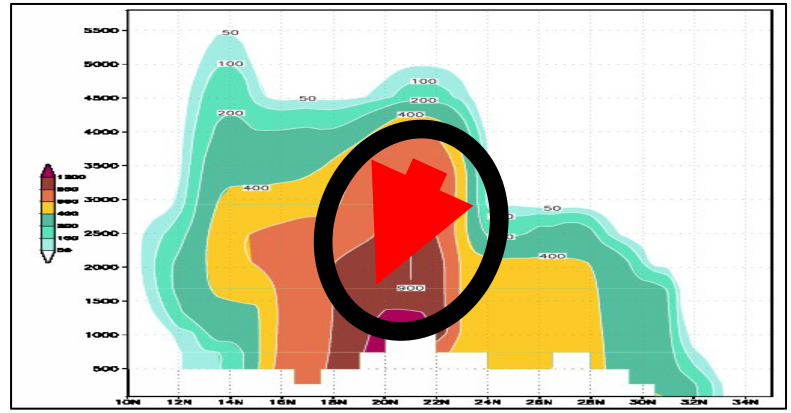
$$t=\frac{T}{C} \qquad \frac{\partial S}{\partial t}+k(S-T)=0$$



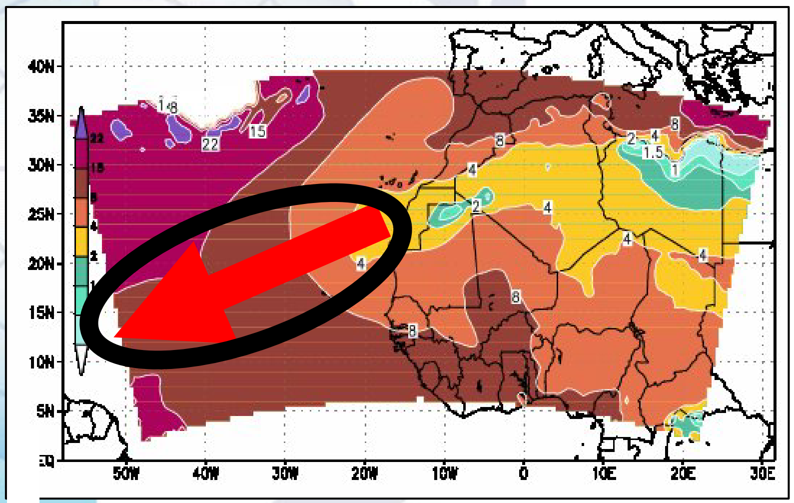


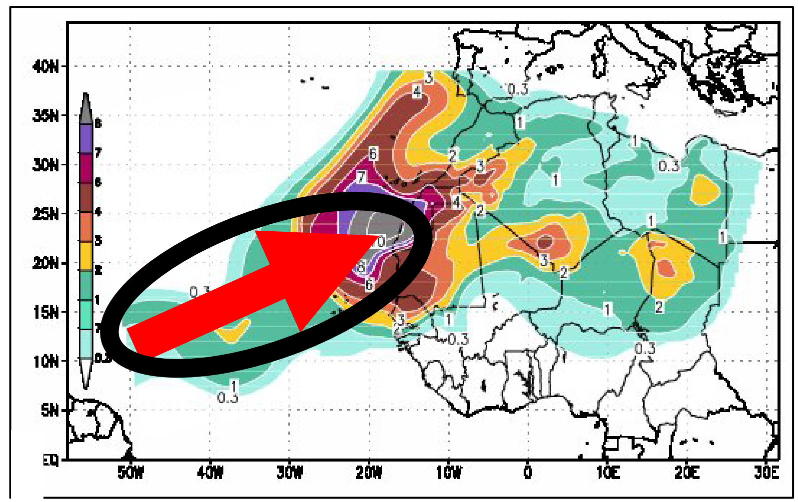
REGIONAL MODEL RESULTS





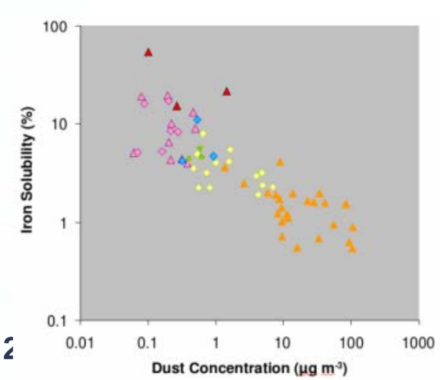
Vertical





Horizontal

Solubility



Concentration

REGIONAL MODEL RESULTS

• The model simulates the increase of Fe solubility with increased distance from soil sources **in horizontal**, concentration decreases

• In **vertical** – similar behavior:

- at higher elevations, solubility is high, concentrations are low

• Obtained results - consistent with *Baker and Jickells (2006)* and *Journet et al (2008)*