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

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

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

GESAMP 36th Annual Meeting, 28 April – 1 May, Geneva Switzerland
SDS integrated observation-modelling approach

Forecast Models

18 UTC, 7 May 2002 30-hr forecast

NASA A-Train MODIS CALIPSO; Geostationary Satellite IR Obs

WMO GALION Surface-based LIDAR

GAW/AERONET/SKYNET Surface-based AOD

European PM10
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

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**Dust over W Africa**
*July 2004*

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

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

Measured solubility (Mahowald et al., 2008)

Cruise paths (Baker and Jickells, 2006)
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

Desert

Mineralogy

Pollution

Clouds

Radiation

Size distribution
GLOBAL MODEL STUDIES

Hand et al (2004):
Solubility due to radiation and cloud processing
  - annual average
  - model underestimates S

Global approach:
  - advantage – a global prospective
  - disadvantage – too coarse model resolution
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
Fe Solubility and mineralogy (Journet et al., 2008)

Conclusion...

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

Fe solubility is strongly driven primarily dust physical properties

(Baker and Jickells, 2006)
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

\[
\frac{\partial C}{\partial t} + \vec{V} \cdot \nabla_h C + (w - w_g) \frac{\partial C}{\partial z} + \nabla_h \cdot \left( K_H \nabla_h C \right) + \nabla \cdot \left( K_z \frac{\partial C}{\partial z} \right) = \frac{\partial C^{\text{SOIL}}}{\partial t}
\]

\[
\frac{\partial T}{\partial t} + t \vec{V} \cdot \nabla_h C + t(w - w_g) \frac{\partial C}{\partial z} + \nabla_h \cdot \left( t K_H \nabla_h C \right) + \nabla \cdot \left( t K_z \frac{\partial C}{\partial z} \right) = t \frac{\partial C^{\text{SOIL}}}{\partial t}
\]

\[
t = \frac{T}{C}
\]

\[
\frac{\partial S}{\partial t} + k(S - T) = 0
\]
REGIONAL MODEL RESULTS

Solubility

Concentration

Vertical

Horizontal
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.