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MINERAL DUST IN SAHELIAN AFRICA: (I) RATIONALE FOR THE AMMA FIELD EXPERIMENT

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AMMA offers the unique opportunity to address specific questions related to mineral dust in western Africa, where it accounts for a large – at times the largest – fraction of the regional aerosol burden by mass, and where the mineral dust cycle is strongly linked to the alterning Monsoon/Harmattan regimes. The quantification of mineral dust emissions in the Sahel remains questionable, especially due to human and climatic disturbances to their natural levels. Such disturbances are expected to increase in the next future, so their influence on mineral dust emissions must be assessed right now. Furthermore, the radiative impact of dust emitted from disturbed soils is considered as an anthropogenic forcing to the natural climate system. Because of its size distribution ranging from fractions to tenths of microns, dust has multiple impacts on the land-ocean-atmosphere system, and on human health.

In this presentation, the major features and impacts of mineral dust in western Africa are illustrated. The specific observational/modelling strategy deployed during AMMA, and expected scientific outcomes, are described in a related poster.

Content

Mineral dust is the second largest aerosol species by mass at the global scale. To date, it is estimated that 1 to 5 billions tons of mineral dust are emitted annually from arid and semi-arid areas [*Duce*, 1995; *IPCC*, 2001]. The emission of mineral dust is a natural phenomenon due to aeolian erosion in arid and semi-arid régions. This is a natural phenomenon, but its intensity can be altered by changes in soil use (agriculture, pasture…) and in climatic conditions in semi-arid areas [*Tegen et Fung*, 1995; *Nicholson*, 2000]. The contribution of disturbed areas to mineral dust emissions is not precisely known to date, but this dust is considered of anthropogenic origin, therefore accounts among the aerosol species exerting a radiative forcing on the atmosphere *IPCC* [2001].

The above considerations apply to the Sahara/Sahel region, the largest source area in the world. As a matter of fact, high aerosol concentrations are observed in the Sahelian part of Western Africa. The aerosol optical thickness in this region exhibit a clear seasonal cycle, with a maximum in winter, when the "Harmattan", a northeastern dry cold wind, is responsible for intense dust emissions and very efficient transport. At contrary, during summer, due to the northern displacement of the InterTropical Convergence Zone (ITCZ), the Sahel experiences the dry and wet Monsoon flow from SouthWest. This monsoon flow is responsible precipitations thus for a minimal aerosol load. This is due to the scavenging of aerosol transported from remote sources and to the development of the annual vegetation preventing local aeolian erosion. Beside this pronounced seasonal cycle, the mineral dust amount over western Africa is characterized by a high variability from the daily to the interannual time scale.

On a longer time scale, a continuous increase of the dust load in the Sahelian region has been observed in correspondence with the successive drought periods of the seventies and the eighties. At the meteorological station of Gao (16°N, Niger), the annual precipitation was of the order of 300-400 mm yr^{-1}. at the beginning of the 50^{th}'s, but it dropped down to 100-200 mm yr^{-1} during the eighties. Simultaneously, the number of days with dust haze has increased from a few days to about 300 d/yr [N'Tchayi et al., 1994]. Similarly, the mineral dust concentrations measured between the sixties and the eighties at Barbados in the Carribean Sea, have increased of a factor of 4 [Prospero and Nees, 1986]. These two simultaneous increases (dust haze in the Sahel, concentration of long range transported dust) have been interpreted as being due to an increase of the local dust emissions by additional Sahelian sources generated by the decrease of the vegetation cover rate. The contribution of the Sahelian belt to the mineral dust emission from North Africa has been further questioned based on numerical simulations of the mineral dust cycle performed with a global transport model [Tegen and Fung, 1995], showing that a correct simulation of dust concentrations over the Northern Tropical Atlantic Ocean and of the seasonal pattern of the Saharan plume requires the inclusion of Sahelian sources with a contribution of 30–50 % of the global dust emissions. These Sahelian emissions were attributed to regions affected by climatic changes and/or anthropogenic disturbance. From these results, some authors concluded that the Sahel was the major source of mineral dust in North Africa [Nicholson, 2000]. However, recent modelling studies tend to estimate to only 10 to 15% of the total dust emissions the contributions of anthropogenic sources over the Sahel [Tegen et al., 2004; Yoshioko et al., 2005].

All emitted mineral dust both of natural and anthropogenic origin, affects the radiative budget of the atmosphere: mineral dust contributes in average to 20% of the aerosol optical depth at the global scale, reaching up to 90% upwind the major source regions [*Li et al.*, 1996; *Chiapello et al.*, 1999]. The evaluation of this effect is complex, as, due to their size distribution and mineralogical composition, mineral dust can scatter and absorb both the solar and the terrestrial radiations.

In the solar spectrum, mineral dust mainly scatters radiation. Their absorbing power is more controversial, depending on the wavelength of the incoming radiation and on the mineralogy of the source region [*Sokolik and Toon*, 1999; *Lafon*, 2004]. The net radiative effect is cooling at the surface and at the top of the atmosphere [*IPCC*, 2001]. Conversely, absorption dominates in the infrared spectrum, where dust aerosols absorb the terrestrial radiation and act as a greenhouse gas, warming the atmosphere. Absorption in the infrared depends on the mineralogical composition and it is mainly due to super-micron particles. In conclusion, the net radiation budget (solar + infrared) may be negative or positive (cooling or heating of the atmosphere) depending on particle size and mineralogical composition [*Claquin et al.*, 1998; *Myhre and Stordal*, 2001]. As an example, the sensitivity study by *Myhre and Stordal* [2001] shows that the mean global radiative forcing (net, solar + infrared) varies between –0.40 W m^{-2} et +0.39 W m^{-2} depending on aerosol properties. These authors indicates that the spatial distribution, in particular the height of transport, the size distribution and the mineralogical composition are the most influent parameters in controlling the direct radiative effects, but also those affected by the largest uncertainties.

Besides affecting the radiative balance of the atmosphere by scattering and absorption, mineral dust can alter the physical and radiative properties of clouds (their lifetime and reflectance, respectively), therefore their precipitating capacity, by altering the size distribution of the cloud condensation nuclei [*Levin et al.*, 1996; *Wurzler et al.*, 2000; *Yin et al.*, 2002].

Also, mineral dust can provide the surface for hetereogeneous reactions for some trace gases such as HNO_3, SO_2, O_3, N_2O_5 [*Dentener et al.*, 1996]. As a consequence, the presence of mineral dust can locally alter the trace gas concentrations. Furthermore, is the gas is an aerosol precursor (as in the case of SO_2), the chemical composition and the size distribution of the resulting aerosols will be modified, and so their optical and radiative properties [*Dentener et al.*, 1996; *Li-Jones et al.*, 1998]. The measurements of *Chiapello* [1996] upwind North Africa in the Atlantic Ocean have shown that up to 100% of the mass of sulfur aerosols in the supermicron fraction result from the heterogeneous reaction of SO_2 and calcium carbonate ($CaCO_3$) of mineral origin. In the absence of this reaction, the SO_2 would have been photoxided and would have produced sulphate aerosols in the submicron fraction, more efficient in scattering radiating [*Li-Jones et al.*, 1998].

Dust outbreaks also provide a source of nutrients to the ocean, especially iron. Fe is important because it allows nitrogen fixation supplying nutrients to surface phytoplankton in the otherwise nutrient starved regions of the subtropical gyres (Mahaffey et al, 2003). Thus, the amount and location of dust deposition impacts biological productivity and subsequently the global carbon cycle – of fundamental importance to the climate system. Wet and dry deposition of Saharan dust in the North Atlantic region ensures that around 48% of the total Fe flux to the global oceans occurs to the North Atlantic (Gao et al, 2001).

Finally, mineral dust also has impact on human health. Over western Africa, it is suspected to be involved in the onset of meningococcal meningitis outbreaks. During the Harmattan season, the warm dry and dusty air may causes damage to the mucous membranes of the respiratory system and create conditions propitious to trigger meningitis epidemics. However, the quantitative relationships between the epidemic intensity and onset period and climatic conditions and mineral dust concentrations remain to be investigated.

The assessment of the different impacts of mineral dust required to precisely document the variability in space and time of the mineral dust load. This implies in particular (1) a high frequency sampling over long-time period; (2) a precise documentation of the vertical distribution of mineral dust and its physico-chemical properties, at least for intensive observation periods; and (3) an assessment of the budget of mineral dust emission and deposition over western Africa.

LES POUSSIERES MINERALES EN AFRIQUE SAHELIENNE : (I) JUSTIFICATION DES EXPERIENCES DE TERRAIN DANS LE CADRE D'AMMA

Le programme AMMA offre l'opportunité unique de traiter des questions spécifiques liées aux poussières minérales en Afrique de l'Ouest. Elles y elles représentent une fraction majeure, et souvent largement majoritaire, de la charge massique atmosphérique en aérosol. Le cycle de l'aérosol minéral en Afrique de l'Ouest est fortement contrôlé par l'alternance des régimes alternés d'Harmattan et de mousson. La quantification des émissions de poussières au Sahel pose toujours question, et notamment la perturbation des émissions que constituent les activités anthropiques et les variations climatiques. De telles perturbations sont attendues dans le futur proche, aussi leurs influences doivent être évaluée dès maintenant. De plus, l'impact radiatif des émissions par des sols perturbés doit être considéré comme un forçage radiatif du système climatique naturel. Du fait de leur distribution en taille, qui s'étend d'une fraction à une dizaine de microns, les poussières minérales ont des impacts multiples sur le système terre-océan-atmosphère et sur la santé humaine.

Au cours de cette présentation, les principales caractéristiques et impacts des poussières minérales en Afrique de l'Ouest seront illustrés. La stratégie d'observation et de modélisation déployée dans le cadre d'AMMA et les avancées scientifiques attendues sont décrites dans un poster associé.

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Convective wind system with aerosols, named “haboob”, Hombori in Mali, West Africa.