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Numerical Approaches to the Simulation of Wind Elevation of Polydispersional Particles from Land Surface to the Atmosphere

A contribution to subproject AEROSOL

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Introduction

Long-range transport of dust is one of the important environmental problems. Two main sources of atmospheric dust are wind erosion of soils and anthropogenic emissions. Natural dust is elevated by strong winds during storm episodes and from long-range atmospheric transport. An example of this effect is the impact of Saharan desert to the Mediterranean. Anthropogenic dust is mainly emitted to the atmosphere from industry. Some part of the emitted dust is deposited locally, the rest can be transported over long distances. Under certain conditions the deposited particles can be elevated by wind and then return to the atmosphere.

A numerical model was developed for simulation of the dust lifecycle as a whole; emissions (natural/anthropogenic), atmospheric transport and deposition and further re-emission. The model (see Fig. 1) consists of a unit for calculations of wind erosion of soils and dust elevation, a unit for the re-suspending simulation, and atmospheric long-range transport and deposition units. The module for re-suspending evaluation is currently under development.

Natural dust emission and re-suspending of deposited particles

The soil erosion calculations are based on Gillette and Passi (1988). It is assumed that in the case of wind speeds lower than a boundary value, large scale dust elevation does not take place. If the wind is stronger then there is a 4-th power dependence upward flux, G, of the dust on the wind velocity u (or friction velocity u_*):

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$$G(u) = Cu_*^4\left(1 - u_{*0}/u_*\right) \qquad u_* > u_{+0} \tag{1}$$

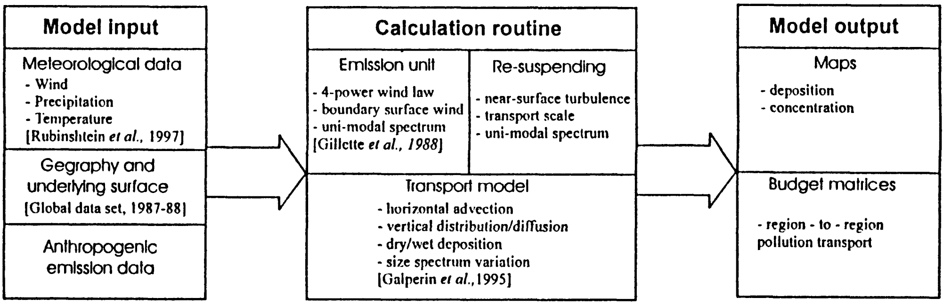

Fig. 1: Scheme of model simulations

Contrary to that, re-suspending of previously deposited particles does not necessarily imply destroying of soil surface. It can start when turbulence penetrates into the roughness layer. It can occur if Reynolds number exceeds a critical value:

$$\mathrm{Re} = \frac{u_* z_0}{\nu} \geq \mathrm{Re}_{crit} = \frac{u_{*crit}\, z_0}{\nu} \tag{2}$$

where u_* is the threshold friction velocity, z_0 is roughness length, and ν is the kinematic air viscosity.

The boundary values for friction velocity in (1) and (2) are similar with the exception for regions with large roughness length - cities, forest, *etc.* In these areas erosion is almost impossible but re-suspension can easily take place.

Transport unit

The transport model is based on a 3-D Eulerian scheme with variable time step. This scheme was originally developed and tested on long-range acid pollution transport and deposition (Erdman *et al.* 1994; Galperin *et al.* 1995). The particle spectrum is described by Pearson Γ-distribution which allows a

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calculation of the mean dry deposition intensity $\bar{x}$ over the whole spectrum range (Galperin and Sofiev, 1995).

It is assumed that during transport the dust is subject to dry and wet deposition and vertical redistribution caused by diffusion and gravitational scavenging. Because of these processes the original spectrum of particles (up to 20 μm ∅) changes with a tendency for coarse and very fine particles to be swiftly removed. This trend leads to a spectrum shape close to the known Junge spectrum (0.1–1 μm ∅) for distant areas.

Calculation results and discussion

The model (without anthropogenic emission and re-suspending units) was applied to long-term calculations 1967–1988, 1995 of a dust emission and transport in the northern hemisphere. Examples of the model output are presented in Figs. 1 to 4. One evident specific of Fig. 2 is a variation of frequency of dust episodes in the early 1970s and 1980s which can probably be explained by a non-uniformity of the meteorological data in the archive.

The bottom two charts in Fig. 2 show the model-measurement comparison results for two stations in Italy (Grigoryan and Erdman, 1996). The model shows accurately the moment the dust arrives at the location of the site. Fairly good agreement with measured values shows qualitatively that the model reproduces the main features of scavenging processes.

The maps in Figs. 4 and 5 show that in addition to the Sahara there are powerful sources from the Caspian region, the northern part of China and Mongolia and central regions of America. These sources are located close to regions with dense population or powerful industry or agriculture. Calculations show that in central Russia (about 1000 km to the North of the Caspian Sea) the annual dust deposition accounts for several grams per square metre, which can affect considerably the environment and human beings.

Figs. 3 and 4 also highlight the specific meteorological conditions in 1995 in the eastern part of Europe. The main transport direction was from south to north, which is different from the generally prevailing winds (from West to East). This anomaly was connected with abnormal anti-cyclone activity during the spring and summer of 1995.

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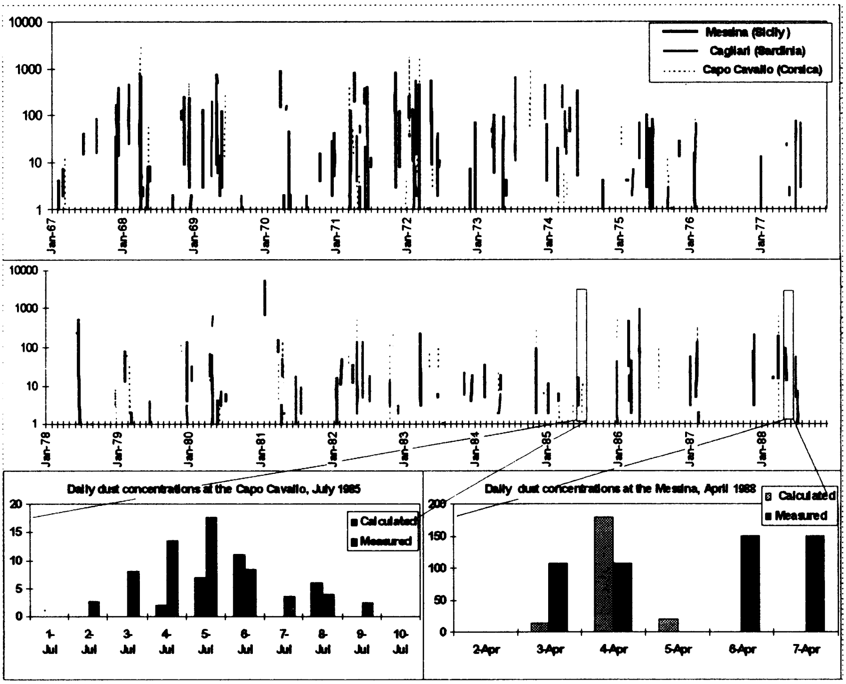

Fig. 2: Calculated daily dust concentrations at Mediterranean stations for 1967 - 1988. Unit = μg of dust m^{-3}

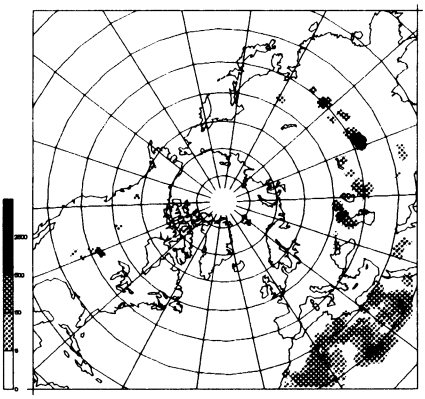

Fig. 3: Annual dust emission from sand deserts for 1995. Unit = kt dust $year^{-1}$

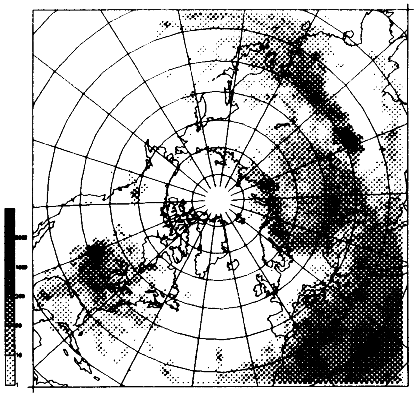

Fig. 4: Annual dust deposition for 1995. Unit = 10 mg dust m^{-2} $year^{-1}$

Conclusions

The model presented is based on simplified approaches but demonstrates qualitative agreement with available measurements. There is an underestimation of the transport distance of Saharan dust. This is probably connected with limitations of the Gaussian approach to vertical profile simulations. The first results for long-term model applications show very considerable variations in frequency of storm episodes from year to year. It is shown that dust deposition onto industrial and agricultural regions from sources located a distance away is quite considerable and potentially may have an influence to human health and agriculture production.

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