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A one-dimensional numerical model of H_2O cloud formation in Martian atmosphere

A.V. Burlakov (1), A.V. Rodin (2,1)

(1) Space Research Institute, Moscow, Russia, (2) Moscow Institute of Physics and Technology, Dolgoprudny, Russia (burlakov.alex@gmail.com)

Abstract

A one-dimensional numerical model with a size distribution of aerosol particles in Martian atmosphere is developed. The model incorporates detailed microphysics: the processes of heterogeneous nucleation (a primarily formation of a new phase germ on a solid surface), condensation and sublimation. As a liquid phase of water does not exist at Martian pressure, only two phases of water are considered – vaporous and crystal, with only hexagonal modification of ice being considered. The spatial component is described by the processes of sedimentation and turbulent diffusion. As the physical meaning of the eddy diffusion coefficient depends on a specific realization of the model, we have used various empirical dependences of a turbulent diffusion coefficient on height, which are set as external parameters of the model. In particular, the formalism of fractional diffusion is employed to describe simultaneous mass transfer by general atmospheric circulation, large eddies and small-scale turbulence.

The use of semi-implicit 2-moment scheme of integration of the kinetic equations describing microphysical processes in clouds [1] allows one to change a time step and the sparseness of a size grid in wide range, thereby selecting the necessary time resolution. Therefore, this model can be incorporated into a three-dimensional general circulation model of the Martian atmosphere as the microphysical block.

Diurnal cycle of condensational processes is obtained on the basis of GCM temperature profiles [2].

The time step, which is 0.1 second in the microphysical part, constitutes 10 second in the spatial part. At start, only water vapor and dust are present in the atmosphere, with the aerosol being formed in the nucleation and condensation processes. The initial mass concentration of water vapor in the atmosphere is 40 ppm, and the dust is distributed regularly in height.

No transport is allowed across either the top or bottom boundaries. Both dust and ice particles are allowed to settle into the lowest vertical layer but are not removed from the model entirely. Thus, the bottom boundary condition assumes it to be a surface in the form of water and dust sources, however an influence of this condition on the results is inconsiderable.

Depending on a turbulent diffusion coefficient, the system comes into a quasistationary diurnal cycle within 10-12 Martian days.

Within the limits of the one-dimensional model the profile of the water vapor has been calculated. It has a step character. According to the given temperature profile and initial concentration of water vapor, a saturation level is at height of 15-25 km depending on system parameters.

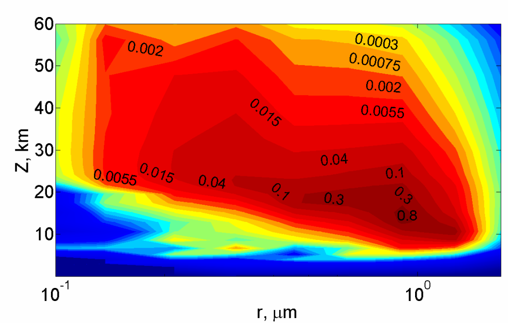

Figure 1: A size distribution of ice particles (ppm, cm^{-1}).

An effective radius of ice particles varies from 0.8 to 2 μm at lower layers of the cloud, with a concentration about 8-12 cm^{-3}. The effective radii vary within 0.2-0.3 μm at numerical concentration of 0.1-1 cm^{-3} above 50 km. An effective radius of dust particles is equal to 0.8 μm at saturation altitude, slightly increasing to 0.8-0.9 μm at the surface.

These results are consistent with solar infrared occultation observations by SPICAM experiment on Mars-Express [3].

In the lower part of troposphere, from the surface to 5 km, under specified conditions the model predicts fog rise in the morning hours, with the ice particles size distribution peaking near 1-1.5 μm.

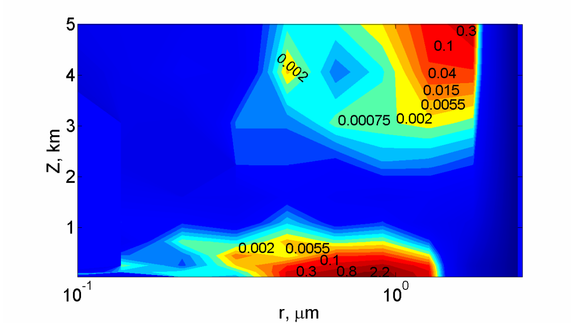

Figure 2: A size distribution of ice particles (ppm, cm^{-1}).

The dependence of condensational processes and macroscopic parameters on microphysical properties of aerosol particles is analyzed, particularly on the contact parameter of cloud condensation nuclei. Comparing model results at various $\cos\theta$ (the contact parameter), it is seen that larger ice particles are formed at smaller nucleation probability, also atmosphere becomes drier. The given result is in consistence with the experimental data obtained in laboratory conditions with the use of the new data about phase transitions at Martian parameters [4]. At small $\cos\theta$ the process of heterogeneous nucleation demands high supersaturations of water vapor that explains the concentrations of water vapor exceeding a saturation level by several times [5]. Thus, it is possible to conclude that at the values corresponding to the last experimental data, the model reproduces the distributions, consistent with experimental data, and in some cases allows one to explain the observed anomalous high concentrations of water vapor.

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