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Simulation of the Martian water ice clouds, frosts, and surface ices with General Circulation Model

A.V. Rodin (1,2), A.V. Burlakov (1,2), A.A.Fedorova(2), N.A.Evdokimova(2), R.O.Kuzmin(3,2), and R.J.Wilson(4)

(1)Moscow Institute of Physcis and Technology, Russia (Alexander.Rodin@phystech.edu/ Fax: +7-495-408-5233), (2)Space Research Institute, Russia, (3)Vernadsky Institute for Geochemistry and Analytical Chemistry, Russia, (4)Geophysical Fluid Dynamics Laboratory, USA

Introduction

The connection of the Martian atmospheric water cycle with surface and subsurface reservoirs has been a serious challenge for comprehensive climate models during last decade. A number of Mars general circulation models have been developed to reproduce the observed column amounts of water vapour in the atmosphere. Despite the variety of adopted approximations, model results show that simulated water cycle behaviour depends both quantitatively and qualitatively on the rates of water removal from the atmosphere, storage in the condensed phase and return. Recent spacecraft missions have resulted in strict constraints on the seasonal water cycle in the atmosphere as well as surface and subsurface inventories. This work is aimed to study the microphysics of water phase transitions and its impact on the global water cycle, based on the GFDL Mars general circulation model [1]. The model employs a hydrostatic dynamical core, aerosol block with full cloud microphysics, radiation block coupled with aerosol and cloud microphysics, and surface block including a simple model of surface and subsurface frost, with thermal inertia dependent on ice storage in the regolith. Model setup used in this work has spatial resolution 1°×1.2° and 28 layers in vertical σ-coordinates.

Microphysics of water ice clouds

The microphysical model is based on the hybrid two-moment approach, with size distribution of water ice crystals defined on the coarse logarithmic grid by two independent values – number density and mass mixing ratio. Ice particles are assumed to nucleate on condensation cores provided by atmospheric dust and change their size due to condensation and sublimation processes as well as coagulation. Integration in time is carried out using Jacobson’s semiimplicit scheme[2].

Size distribution of water ice clouds demonstrates narrow, regular peaks with typical radii of 1-2 μm. In some cases multimodality occurs due to dynamical supply of small particles from higher altitudes, where broad, smooth distribution with typical size of 0.2-0.3 μm is formed, consistent with observations[3]. In turn water vapour profile at high altitudes may allow for significant supersaturation, resulting in enhanced poleward transport of water by the Hadley cell. Near-surface nighttime fogs are characterized by broader distribution with typical sizes 2-10 μm. Subsequent growth of large particles by coagulation may increase the rate of the atmospheric water deposition from saturated boundary layer.

Regolith microphysics

Soil model includes diffusion of water vapour, adsorption, hydration and fractal deposition of frost both on the surface and inside the porous regolith. The dependence of surface thermal inertia on the amounts of frost provides feedback between sinks and sources of the atmospheric water and surface reservoirs [4]. Along with buffering of water by the regolith on the seasonal timescale, assumed fractal nature of frost patches damps the loss of surface water to the atmosphere on the daily basis and finally shift the resulting water cycle to a dry side.

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Planetary waves revealed by the water cycle

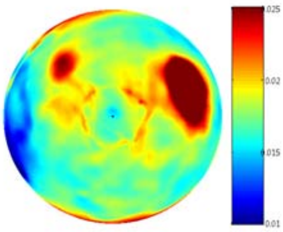

Figure 1: Combination of wave-2 and wave-3 features in the water vapour column in the South hemisphere triggered by Hellas and Argyre. L_s=235°.

The detailed description of microphysical processes in clouds provide accurate evaluation of sedimentation and sublimation rates, which in turn allows to calculate horizontal transport of water in both vaporized and condensed phases by the atmospheric circulation. Strong zonal modulation of the water vapour distribution, with wave 2 feature dominating in the tropics and extratropics, and wave 1 feature in the polar regions, reflect the effect of atmospheric stationary waves whose phases are controlled by topography and surface thermal inertia. However, it is wave 3 transient feature that provides most effective meridional transport. MGCM simulations show that during late solstice seasons, water flux out of the subliming polar caps substantially increases during short periods near L_s≈125° and L_s≈145° in the North hemisohere, and near L_s≈225° and L_s≈275° in the South, when wave 3 transients occur. The nature of transients is likely an inertial instability of the zonal flow triggered by decreasing meridional wind shear. MGCM predicts the occurrence of wave-3 feature in water vapour zonal distribution during these periods, and compact annular clouds in the North circumpolar region residing near the channels of water meridional transport.

MGCM predicts enhanced deposition of water onto the surface along the ‘wet corridor” between 90°E and 180°E and two antipodal maxima near Arabia and Memnonia, where maximal amount of bound water is observed in the subsurface layer. In the Southern hemisphere, dominating is wave-1 feature connected with Hellas regional weather system.

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