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The role of vertically propagating stationary waves in the Martian atmospheric water cycle

A.V.Rodin (1,2), A.S.Medvedev (3) and N.A.Evdokimova (2,1)
(1) Moscow Institute of Physics and Technology, Dolgoprudny, Russia, (2) Space Research Institute, Moscow, Russia, (3) Max Planck Institute for Solar System Research, Katlenburg-Lindau, Germany (alexander.rodin@phystech.edu)

Abstract

Numerous evidences suggest that seasonal meridional migration of water in the Martian climate system reveals regular zonal modulation associated with mesoscale and planetary-scale wave activity. Based on GCM simulations, we concluded that the intensity of this activity, dominant zonal wavenumbers and their seasonal evolution are determined by conditions on vertical propagation of orographic stationary waves, implied by mean zonal flow. Such waves, penetrating deeply in the Martian troposphere during onset and decay of the polar vortex in the summer hemisphere, provide efficient corridors for meridional transport of tracers, including water vapor and aerosols.

1. Introduction

Continuous monitoring of the Martian climate has revealed the detailed picture of the planet's water cycle driven by atmospheric motion and exchange of water between the atmosphere and surface reservoirs. Major feature of the atmospheric water transport is meridional migration from the summer polar region to midlatitudes and tropics with further cross-equatorial migration to the opposite hemisphere and deposition in the polar cap during the spring. Several mechanisms taking into account the detailed of such meridional transport have been proposed to explain the apparent asymmetry of water cycle between the North and South hemisphere[1,2]. Both observations and GCM simulations suggest that the meridional water transport reveals distinct zonal structure characteristic of planetary-scale atmospheric waves with zonal wavenumbers varying from 1 to 3. For instance, during the Northern summer, water vapor migrates from the North polar cap primarily through two channels at longitudes 60°-120°E and 240°-300°E. Late in the aphelion season, the decay of the tropical cloud belt and transition from solstitial to equinoctial Hadley circulation is accompanied by a development of strong transient wave-3 feature and sudden displacement of significant mass of water vapor to the tropics and South hemisphere. This work is aimed at studying of the nature of these phenomena based on GCM simulations of the Martian water cycle.

2. The model

We applied MAOAM Mars general circulation model (MGCM) with spectral dynamical core and detailed treatment of radiative forcing [4]. The model domain extends to 110 km, typical integration time step is 30 sec. In order to simulate water cycle, fully conservative tracer transport scheme has been developed and implemented for water vapor, several size categories of dust and water ice particles. Surface model reproduces Martian topography and thermal inertia, with thermal model taking into account the internal soil structure and composition and extending to 1.5 m deep. After spinup and equilibration, model result on the full Martian year have been analyzed.

3. Results

MGCM simulations suggest that strong stationary wave features with zonal wavenumber 1-3 are developing during specific seasons associated with onset and decay of the polar vortices and with transitions between solstitial and equinoctial types of the meridional circulation. These features are topographically induces stationary waves propagating upwards providing westerly mean zonal flow. As the conditions for vertical wave propagation require the reversal of the zonal flow and hold for limited periods of time determined by seasonal evolution of the Hadley cell circulation, these features have transient character and provide remarkable enhancement of water meridional transport. The efficiency of deep stationary waves in tracer transport, especially for water vapor, is a consequence of their penetration above the boundary layer where strong diurnal temperature cycle requires most of atmospheric water vapor to freeze out and be deposited to the surface. Wave transport channels in the altitude range with minor diurnal temperature variability may provide 'wet corridors' observed by remote sensing techniques.

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