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CO_2 Snowfalls and Baroclinic Waves in the Northern Winter Polar Atmosphere of Mars

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Abstract

CO_2 snow forms in the high-latitude atmosphere of Mars in regular patches coinciding with passages of baroclinic planetary waves (periodic oscillations of temperature and other meteorological fields). Our simulations using a Mars general circulation model (MGCM) show that about a half of the snow cover on the northern polar cap is created by such snowfalls. This discovery would allow to forecast snow storms in future robotic and manned missions to Mars [1].

1. Introduction

The seasonal CO_2 polar cap is formed from ice particles that have fallen from the atmosphere as well as those condensed directly on the surface. The possible occurrence of CO_2 snowfall in the winter polar regions have been observed, and previous simulation studies have indicated that the longitudinal irregularities of CO_2 ice clouds in the northern polar region seemed to be linked to local weather phenomena. Transient planetary waves are the prominent dynamical feature during northern winters in the martian atmosphere, and this study focuses on revealing the mechanism of how the dynamical influence of transient planetary waves affects the occurrences of CO_2 ice clouds, snowfalls and formations of seasonal CO_2 polar cap in high latitudes during northern winters.

2. Outline of the MGCM

The DRAMATIC (Dynamics, RAdiation, MAterial Transport and their mutual InteraCtions) MGCM is based on a spectral solver for the three-dimensional primitive equations [2]. In this simulation the horizontal resolution is set at about 5.6° × 5.6° (~333 km at equator), the vertical grid consists of 69 σ-levels with the top of the model at about 100 km. Realistic topography, albedo, thermal inertia and roughness data for the Mars surface are included. Radiative effects of CO_2 gas (considering only LTE) and dust, in solar and infrared wavelengths, are taken into account.

We have implemented a simple scheme representing the formation and transport of CO_2 ice clouds into our MGCM, and investigated snowfall in high latitudes during northern winters.

3. Results

Figure 1 compares the observed and simulated zonal mean temperature and aerosol mass mixing ratios in the northern hemisphere averaged over the winter season between L_s = 255° and 285° during relatively low-dust conditions. Observations represent the MRO–MCS Derived Data Version 2 [3] for MY29, and the dust signals in retrievals in winter polar regions are likely to be caused by CO_2 ice clouds [4]. We consider such dust signals as the evidence for CO_2 ice clouds. Figure 1a demonstrates the presence of atmospheric ice particles northward of 70° N between 10 and 100 Pa (15–40 km). Simulations of temperature and mass mixing ratios of CO_2 snow, shown in Figure 1b, are in good agreement with the observations, at least in the case of the zonal mean values.

Figure 2 shows the composite features of the simulated mixing ratio of CO_2 ice clouds, atmospheric temperature at 15 and 30 km altitudes, and CO_2 ice deposition rate on the surface at 80° N around winter solstice. It is apparent that the occurrence of CO_2 ice clouds is very much aligned with cold phases of the baroclinic waves with zonal wavenumber of 1 and 5–6 sols period. Although the amplitudes of wave-induced variations in temperature are of the order of a few degrees Kelvin, they are sufficient enough to modulate the CO_2 cloud formation by dropping the local air temperature below the condensation threshold.

It takes ~0.2 sols for particles to descend from 25 km to the surface, which is much shorter than the periods of the transient waves. Thus, the fate of ice particles during sedimentation depends on the thermal structure below. Regions where the warmer and colder anomalies alternate vertically, which results in the sublimations of CO_2 clouds formed in upper atmosphere, except at 30° W–60° E where the deposition rate is at its largest. At 30° W–60° E, CO_2 ice particles formed below ~20 km can reach the surface. Calculations show that about 42 % of the ice cap is created due to the snowfalls, while the rest is by direct condensation.

4. Summary and Conclusions

Our simulations using a MGCM showed that the CO_2 ice clouds are formed at altitudes of up to ~40 km in the northern polar region during winter, and their occurrence correlates to a large degree with the cold phases of transient planetary waves. Ice particles formed up to ~20 km can reach the surface in the form of snowfall in certain longitude regions, while in others these particles likely sublimate in the lower warmer atmospheric layers. Given the regular nature of such waves, this suggests that statistics of the occurrence of such snow events in high latitudes may be reliably predicted.

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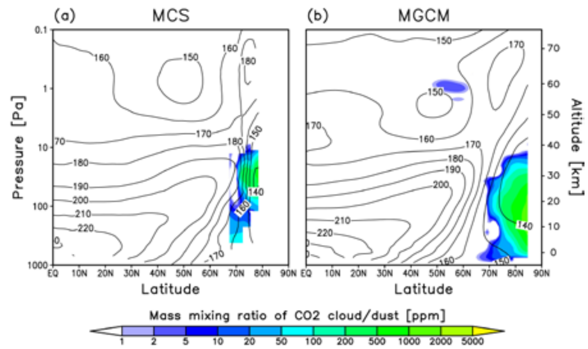

Figure 1: (a) MRO–MCS observations of the zonal mean temperature (contours) and dust (snow) mass mixing ratio (color-shaded, only north of 65° N) averaged between L_s = 255° and 285° of MY29. (b) Same as in (a), except for the simulation with the MGCM. Shades of color represent the mass mixing ratio of CO_2 ice.

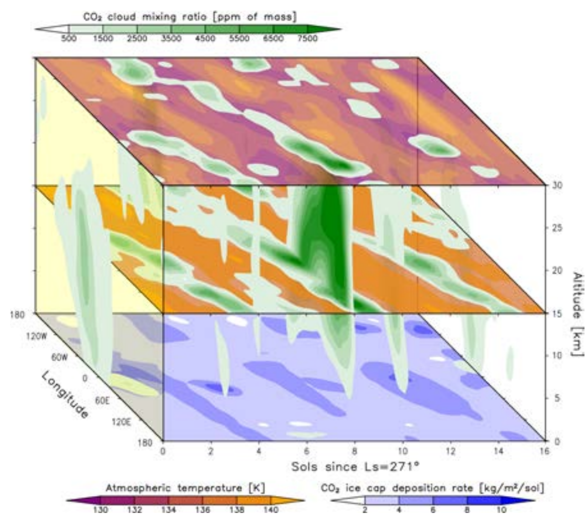

Figure 2: Composited features at 80° N simulated by the MGCM: Mass mixing ratio of CO_2 ice clouds (Hovmöller diagrams at 0, 15 and 30 km altitudes and longitude-altitude cross-sections for every 4 sols since L_s = 271°), atmospheric temperature at 15 and 30 km altitudes, and CO_2 ice cap deposition rate on the surface. All values represent as daily-averaged.