SIMULATION OF THE MESOSPHERIC CO_2 ICE CLOUDS ON MARS USING A GENERAL CIRCULATION MODEL

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Introduction:

It is a well-known phenomenon that the CO_2 atmosphere on Mars condenses in winter polar regions to form CO_2 ice polar caps. In addition, the condensation of CO_2 atmosphere can also be expected in the mesosphere (above ~60km) of low- and mid-latitudes, because the temperature there can be as cold as in the winter polar regions near the surface. Due to the condensation, CO_2 ice clouds can likely form there.

The formation of CO_2 ice clouds in lower latitudes was first suggested from observations of mesospheric temperature in the previous century. The descending Mars Pathfinder [1] and ground-based microwave telescope [2] indicated that the equatorial mesospheric temperature could be lower than the CO_2 condensation level. However, there was very few observational data for mesospheric temperature, and the existence of CO_2 ice clouds had not been confirmed.

Recently, SPICAM onboard Mars Express first observed CO_2 ice clouds in the mesosphere [3]. Stellar occultations with the UV wavelengths detected the 'detached layers' at around 100 km as well as the cold temperature. It points to a supersaturation of CO_2 in the southern winter subtropical latitudes. The estimated radius of particles at the 'detached layer' was ~100 nm. Additionally, OMEGA and HRSC onboard Mars Express have observed the equatorial CO_2 ice clouds at 60-85 km in visible and near-infrared wavelengths [4,5]. They estimated the particle size of the clouds as 1-2 μm at ~80 km. The clouds are mainly seen during two periods before and after the aphelion, Ls=330-60° and 90-135°. THEMIS onboard Mars Odyssey observed also the clouds in northern midlatitudes during autumn and winter [6]. The observations of CO_2 ice clouds were used for estimations of wind velocities in mesosphere by tracking clouds [5,6].

Here we report on an introduction of a CO_2 cloud formation scheme into our MGCM, present results of simulations, and discuss the comparison with the available observations.

Description of the MGCM:

The DRAMATIC (Dynamics, RAdiation, MAterial Transport and InteraCtions between them) MGCM, previously known as CCSR/NIES or CCSR/NIES/FRCGC MGCM, is based on a spectral solver for the three-dimensional primitive equations. In this simulation the horizontal resolution is set at about 5.6°×5.6° (~333 km at equator), the vertical grid consists of 49 σ-levels with the top of the model at about 100 km. Realistic topography, albedo and thermal inertia 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. The amount of atmospheric dust varies with season and latitude, imitating the observations in MY24.

We changed the condensation/sublimation scheme of CO_2 atmosphere from the previous version [7,8], in which the condensed CO_2 ice falls to the surface instantaneously. Now we account for the finite velocity of the gravitational sedimentation, and consider the formation of CO_2 ice clouds if the forecasted temperature in the MGCM is lower than the CO_2 condensation level. The sedimentation velocity of the CO_2 ice clouds depends on their size and density. The particle size of the clouds r_0 is estimated as a function of height z:

$$r_o(z) = r_{z0}\exp(-z/h)$$

where r_{z0} is the radius at z=0 km, and h is the particle density scale height. Here we set r_{z0} to 50 μm, and h to 20 km. Under this estimate, the cloud radius is ~1 μm at ~78 km. The density of CO_2 ice clouds is set to 1000 kg m^{-3}.

Model results:

Figure 1 compares the simulated zonal-mean daily-averaged atmospheric temperature with observations by Mars Climate Sounder onboard Mars Reconnaissance Orbiter (MRO-MCS) [9,10] at the corresponding seasons of MY29. The MGCM overestimates the mesospheric (0.1-1 Pa) temperature of low- and mid-latitudes by ~10K at the northern summer solstice (L_s=90°) and autumn equinox (L_s=180°), while is consistent with the observations in northern winter solstice (L_s=270°). Figure 2 shows the MGCM results for seasonal changes of zonal-mean thickness of the CO_2 ice cap on the surface, and the surface pressure at 47° N, 225° W, which corresponds to the landing site of Viking Lander 2 (VL2). VL2 observations for the year without global dust storm (MY13) are superimposed in Figure 2. It is seen that the MGCM reproduces the seasonal changes of the surface pressure well, thus validating the new CO_2 condensation/sublimation scheme.

Figure 3 presents the simulated zonal-mean daily-averaged CO_2 ice cloud mixing ratio, and temperature at ~1 Pa (~64 km height) and ~0.5 Pa (~70 km height). It shows that the equatorial CO_2 ice clouds

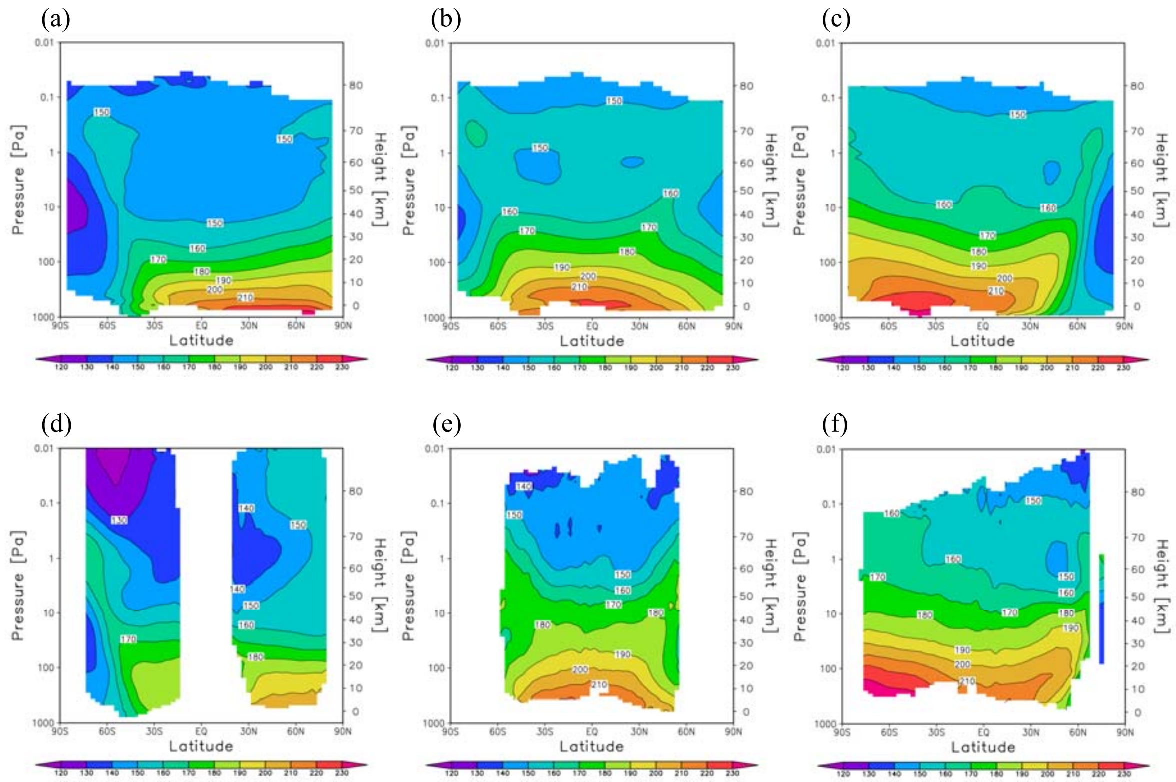

Figure 1: Zonal-mean daily-averaged temperature: the upper plots show the simulations by DRAMATIC MGCM, and the lower plots present the observations by MRO-MCS. L_s=90° (northern summer solstice) for (a) and (d), L_s=180° (northern autumn equinox) for (b) and (e), and L_s=270° (northern winter solstice) for (c) and (f).

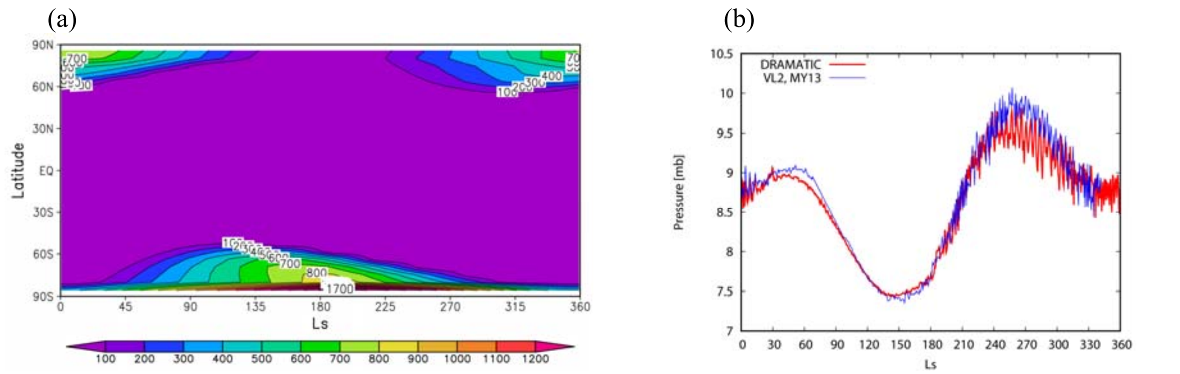

Figure 2: (a) Season-latitude cross-section of surface CO_2 ice thickness simulated by DRAMATIC MGCM. (b) Seasonal changes of daily-averaged surface pressure at 47° N, 225° W: (red) simulations by DRAMATIC MGCM and (blue) Viking Lander 2 observations.

are simulated at ~1 Pa around northern spring equinox and summer solstice, consistently with the HRSC observations [5], when the simulated atmospheric temperature is colder than at other seasons. At this height, the clouds exist also in northern midlatitudes during the autumn and winter, which is consistent with the THEMIS observations [6]. Higher, the mixing ratio is larger, except over the equator around the northern summer solstice.

Figure 4 displays the season-altitude cross-sections of the CO_2 ice cloud mixing ratio and temperature above the equator (averaged between 10°N and 10°S). The formation of clouds is strongly related to the atmospheric temperature, and occurs down to ~2 Pa (~60 km height) around northern spring equinoxes and summer solstices.

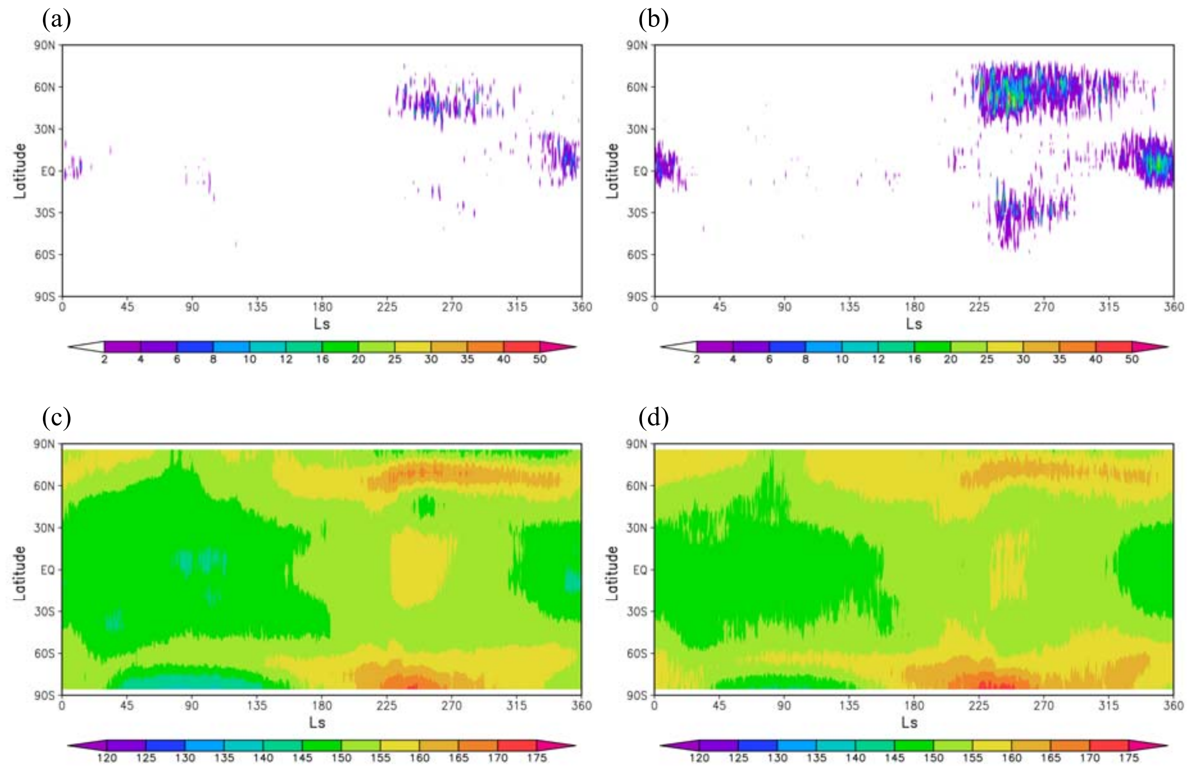

Figure 3: The upper plots show the season-latitude cross-sections of the simulated zonal-mean daily-averaged CO_2 ice mixing ratio [ppm]. The lower plots present the same as in the upper plots but for temperature [K]. The results are given at 1 Pa (~64 km height) for (a) and (c), and at 0.5 Pa (~70 km height) for (b) and (d).

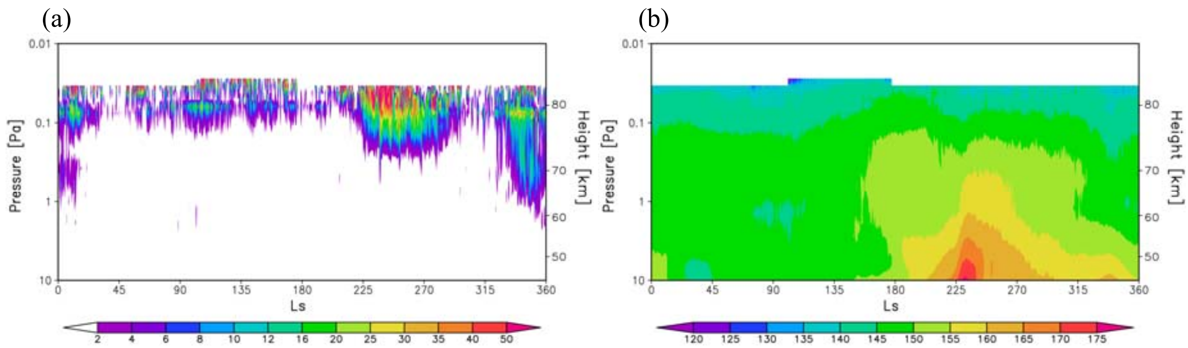

Figure 4: (a) Season-altitude cross-section of the simulated zonal-mean daily-averaged CO_2 ice cloud mixing ratio [ppm] averaged between 10°N and 10°S. (b) Same as in (a), but for temperature [K].

Summary:

We present simulations of mesospheric CO_2 ice clouds with a MGCM. The simulated cloud formations occur above the equator around northern spring equinoxes and summer solstices, in addition to mid-latitudes in the northern hemisphere during autumn and winter, down to the height of ~60 km. These results are consistent with the recent observations by OMEGA, HRSC and THEMIS.

References:

[1] Schofield J.T. et al. (1997) *Science, 278,* 1752-1758. [2] Clancy R.T. and Sandor B.J. (1998) *GRL, 25,* 489-492. [3] Montmessin F. et al. (2006) *Icarus, 183*, 403-410. [4] Montmessin F. et al. (2007) *JGR, 112,* E11S90. [5] Määttänen et al. (2010) *Icarus, 209,* 452-469. [6] McConnochie T.H. et al. (2010) *Icarus, 210*, 545-565. [7] Kuroda T. et al. (2005) *J. Meteorol. Soc. Japan, 83*, 1-19. [8] Kuroda T. et al. (2008) *Third workshop on the Mars Atmosphere: Modeling and Observations,* 9049. [9] McCleese D.J. et al. (2008) *Nature Geosci.,* 1, 745-749. [10] Kleinböhl A. et al. (2009) *JGR, 114,* E10006.