PARAMETERIZATION OF CAP-EDGE DUST LIFTING OVER THE SOUTHERN POLAR REGION

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Introduction:

While the dust climate on Mars has certain variability such as the rare but severe global or planet-encircling dust activities, it appears to have a certain regular variation over a Martian year as indicated in some observational studies (Montabone et al. 2015; Kass et al. 2016). Occurrence of southern high-latitude dust activities (SHLDA) around the southern solstice period have been observed for many Martian years (e.g. Toigo et al. 2002; Imamura and Ito 2011; Douté 2014), and is named as "B storm" in Kass et al. (2016). These dust events occur near the southern cap-edge region and play an important role in the observed dust climate. However, they generally cannot be simulated in the existing Mars general circulation models. In this study, an approach of parameterization has been proposed in which the dust lifting threshold stress is adjusted in according to the surface temperature difference between the regolith and the ice in the southern polar region.

The above setting of threshold stress over the cap-edge grid points is based on the following two reasons. First, the ground temperature difference in the southern cap-edge region is significantly strong in the period between Ls 230° and 270°. It can be anticipated that the wind stress over the cap-edge region due to thermal forcing as well as the sublimation flow as mentioned above will also be significant in this period. Second, some recent studies proposed a so-called "thermal creep" process on Mars (e.g., de Buele et al. 2014, 2015; Küpper and Wurm 2015); which suggests that when solar radiation is strong over the Martian regolith without ice cover, the CO_2 gas condensed in the porous subsurface before (e.g. at night) will sublimate and burst out to the surface. This may facilitate the erosion of soil particles over the ground surface by wind stress and so may decrease the threshold stress for dust lifting.

Setup of Simulations:

The Mars GCM used is the MarsWRF model (Richardson et al. 2017). The global domain has ~ 5° resolution (~ 300 km in the equatorial region). The vertical grid has 52 levels with a model top of 0.0057 Pa (~ 84 km). The basic configuration of the model is similar to that in Chow et al. (2019), with the "wide band model" for evaluating the radiation, and the approach of "interactive dust" is used in all the simulations.

In the interactive dust approach, dust in the atmosphere is provided by dust lifting over the surface. Two types of dust lifting parameterization are included in the model. One is to parameterize dust lifting associated with dust devils, and dust lifting is dependent on the surface sensible heat and the temperature difference between surface and the boundary layer top. Another type is the wind stress dust lifting. Dust lifting occurs when the surface wind stress exceeds a certain threshold stress value, which is everywhere constant at 0.044 N m^{-2} in the control simulation (EXP_CTRL).

The dust schemes consider dust particles having two sizes of 1 and 2.5 μm in diameter. Supply of dust particles is assumed to be unlimited over the surface.

In EXP_CTRL, the model with the above configuration was tuned such that it can reasonably reproduce the observed time series of dust optical depth (e.g. Montabone et al. 2015). To simulate the SHLDA, another simulation (EXP_CAP) was performed. This simulation is similar to EXP_CTRL except the threshold stress for dust lifting at the cap-edge grid point is reduced to about 0.007 N m^{-2} (16 % of the constant threshold stress) when the temperature difference across the cap edge is greater than a particular threshold value (115 K).

Results:

When the parameterization of cap-edge dust is implemented, occurrence of SHLDA can be seen (Fig. 1b) between Ls 230° and 270°. The effect of the parameterization is mainly in the dust season. The column dust optical depth (CDOD) is slightly higher in the dust season in almost all latitudes.

The SHLDA simulated in EXP_CAP can have a significant effect on the temperature field (Fig. 2)). In particular, around Ls 270° the temperature near the southern polar region is significantly increased below the altitude of 20 km in EXP_CAP (Fig. 2c). The higher temperature in the southern polar region around the southern summer solstice in EXP_CAP is generally more consistent with observation such as MCS. It is worth noting that temperature increase in EXP_CAP is not limited to the southern high-latitude region, certain increase can also be seen in the northern mid- to high-latitude region at higher altitudes (Fig. 2c).

The pattern of temperature increase in the southern high-latitude region in EXP_CAP (Fig. 2c) is generally consistent with the increase in dust mixing ratio over this region (Fig. 3). The increase in dust over this region is significant up to the altitude of 10 km. The increase in dust mixing ratio can extend from the southern hemisphere to the northern subtropical region through the Hadley circulation (Fig. 3).

The distribution of the corresponding dust lifting flux by wind stress in Ls 240° - 250° (Fig. 4b) approximately shows a wave-number-2 feature, generally with larger flux in the sector 0° E - 90° E where the mass of CO_2 ice is more. Considering the polar distributions of wind-stress dust lifting flux and the prevailing westward surface wind field, the distributions of optical depth (Fig. 4a) appear to be in the downstream of the dust lifting regions, i.e., westward advection of dust from the dust lifting region.

Conclusion:

By applying the present approach of parameterization, dust events in the southern cap-edge region have been simulated around the southern solstice period. As a result, the simulated temperature in the southern high-latitude region is increased and the resulting vertical temperature profile is closer to that from observation.

Despite its simplicity, the approach of parameterization has considered the effect of two major forcing (thermal forcing and sublimation flow) on the cap-edge wind. The strength of these two forcing is basically proportional to the temperature difference across the cap edge.

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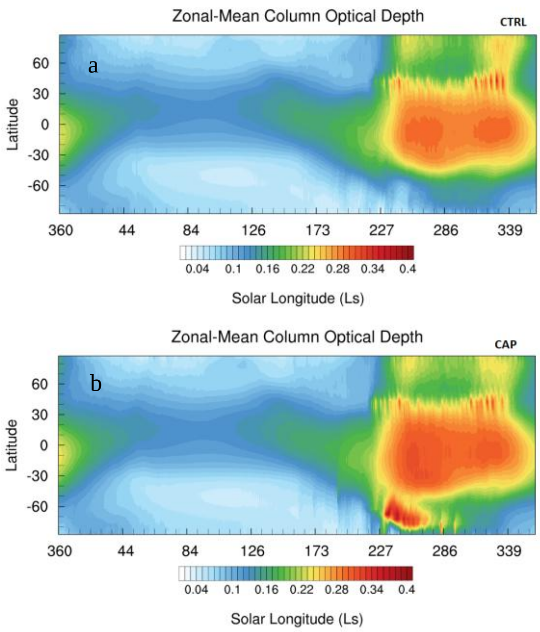

Fig. 1 Time series of MarsWRF simulated zonal-mean CDOD. (a) Control simulation (EXP_CTRL). (b) Simulation with parameterization of cap-edge dust in the southern polar region (EXP_CAP).

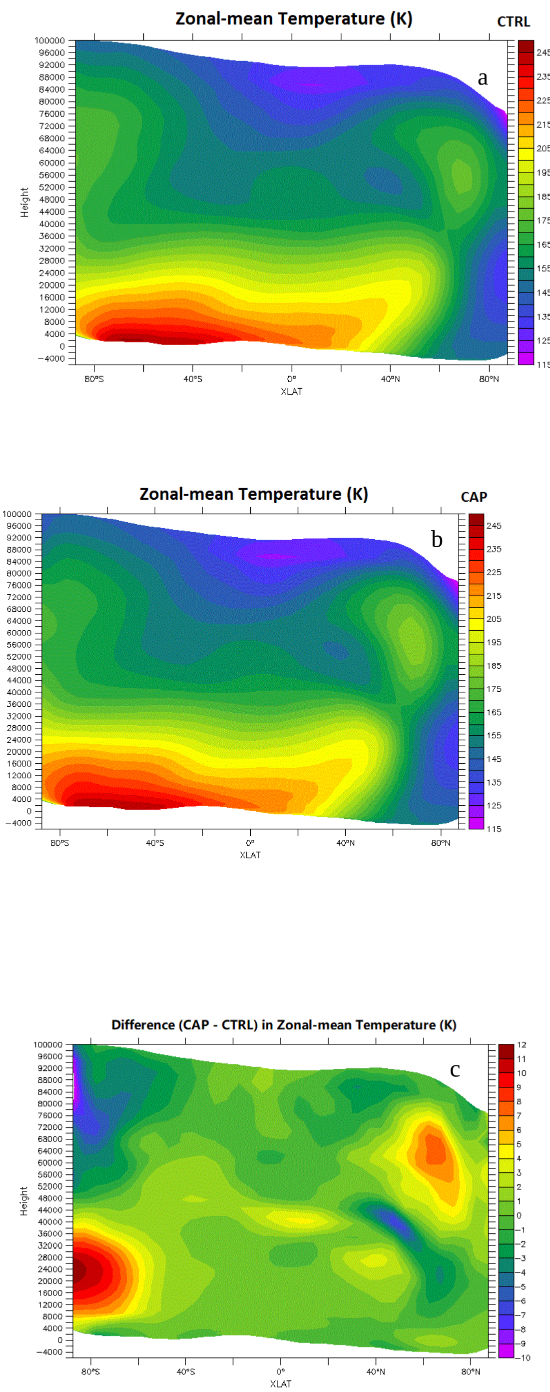

Fig. 2 Height-latitude profile of zonal-mean temperature (K) averaged for 5 sols around Ls 270°. (a) Control simulation (EXP_CTRL). (b) Simulation with the parameterization of cap-edge dust in the southern polar region (EXP_CAP). In (a) and (b) shading intervals are 5 K. (c) Difference between EXP_CAP and EXP_CTRL (interval 1 K).

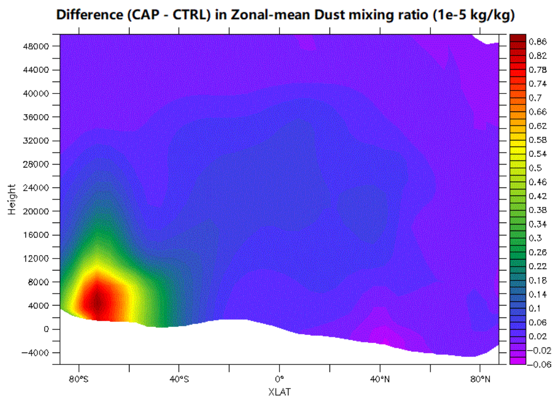

Fig. 3 Vertical profile of difference (EXP_CAP - EXP_CTRL) in zonal-mean dust mixing ratio (10^{-5} kg kg^{-1}) averaged from Ls 240° to Ls 270°.

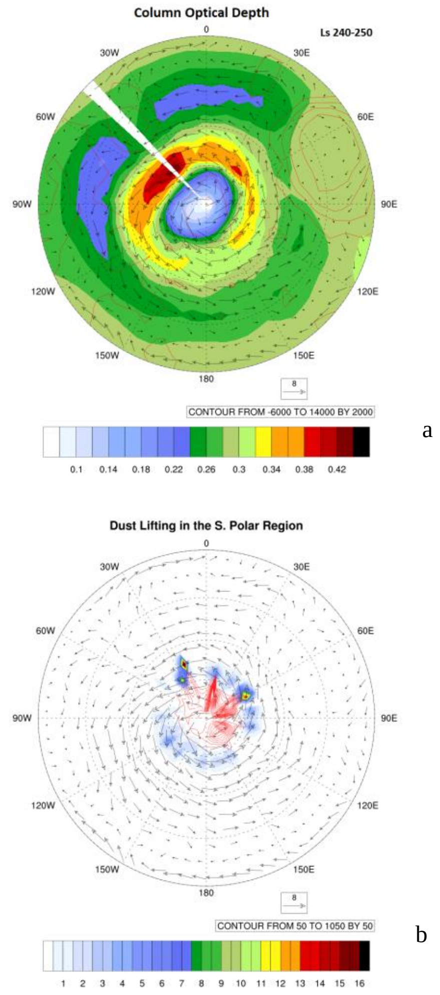

Fig. 4 Polar projection at Ls 240° - 250° in EXP_CAP; outermost circles at 30° S. (a) CDOD (shadings) and topography (contours). (b) Dust lifting flux (10^{-4} kg m^{-2} per Sol, shadings) and CO_2 ice (kg m^{-2}, contours). Vectors are surface wind (m s^{-1}).