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Dust activity over the Hellas basin of Mars during the period of southern spring equinox

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A B S T R A C T

Dust storms that last for more than one Martian day frequently occur in Hellas basin of Mars around southern spring equinox. The dynamics behind the formation of these “Hellas storms”, however, is still unclear. In this study, a ten-year climatology of Martian atmospheric dust is simulated with the MarsWRF global climate model. Results suggest that occurrence of Hellas storms during southern spring equinox is related to the abrupt increase in the surface temperature contrast between the southern edge of the Hellas basin and the carbon dioxide ice covered south polar cap. Significant dust lifting over the southern edge of the Hellas basin occurs mainly during night time, due to the particular strength of the prevailing downslope flows at the site.

1. Introduction

It has been reported (e.g., Martin and Zurek, 1993; Wang et al., 2015) that Hellas basin is a region on Mars where dust storms can be commonly observed. The basin is a huge crater region about 3000 km in diameter and 8 km in depth. The steep topography of the basin boundary likely generates a slope-wind circulation associated with the diurnal solar cycle. Observational studies (e.g., Strausberg et al., 2005; Cantor, 2007) have shown that the well-known planet-encircling dust event that occurred in 2001 was initiated in Hellas Basin around the time of the southern spring equinox ($L_S = 180°$). In particular, Strausberg et al. (2005) pointed out that in the initiation phase of this severe dust event, a sequence of dust storm events was observed between the southern edge of Hellas basin and the south polar ice cap edge. The dust was transported out of the basin and propagated to the east in later stage, and facilitated the development of a second dust lifting center over the Syria/Solis/Daedalia region.

The occurrence of dust storms over Hellas Basin around the southern spring equinox ($L_S = 180°$) period has been noted in some general circulation model simulations (e.g., Newman et al., 2002; Basu et al., 2006; Newman and Richardson, 2015). In those studies, the small-scale to regional-scale dust storms (“Hellas storms”) typically lasted for a few sols (a Martian solar day) and usually initiated at the southern or southwestern edge of the basin. Results of a high resolution mesoscale model by Toigo et al. (2002) were shown in Strausberg et al. (2005); in which a high-stress region in the southern edge of Hellas Basin was displayed around $L_S = 180°$. Furthermore, the numerical experiments of Ogohara and Satomura (2008) showed that dust injected at the southwestern edge of the Hellas basin during southern spring equinox may form a regional dust storm over the basin, similar to the Hellas storms simulated by Newman et al. (2002), Newman and Richardson (2015), and Basu et al. (2006).

In the modeling studies mentioned above, the occurrence of Hellas storms are believed to be due to the temperature difference between the basin and the southern region. However, there has been only limited analysis (e.g., Strausberg et al., 2005) to explain why the Hellas storms are initiated only during this particular short period, and in this particular region. Nevertheless, there were still some modeling and dynamical studies related to this topic. In Siili et al. (1997, 1999), a two-dimensional mesoscale model was used to study the circulation over a flat ice covered cap edge region. From the idealized numerical simulations, they found that if only the thermally driven circulation due to ice-land temperature contrast is present, the resulting surface stress may be insufficient for dust lifting. However, the stress may be sufficient if a sublimation flow due to the ice cap is present as well. They also found that the presence of an ice cover on the top edge of the valley may significantly enhance the downslope wind (referred as ice-edge forcing) and surface stress during the night time. In the day time, the enhanced temperature contrast between the ice-covered valley slope at the top and the ice free ground surface in the bottom may

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significantly weaken the upslope wind. The addition of sublimation flow over the edge of the valley may also substantially increase the downslope wind. In Toigo et al. (2002), a three-dimensional mesoscale model with realistic physics and nested with a Mars general circulation model was used to examine dust lifting over the ice cap edge during southern summer. In particular, the three major forcings related to dust lifting over cap edge: thermal contrast of cap edge, slope flow, and sublimation flow due to CO_2 ice were examined. With a more realistic simulation of the ice cap, they found that surface stress for dust lifting over the cap edge region is generally large during local afternoon. They also found that the sublimation flow is not important to dust lifting during the period considered in their study, and slope flow due to topography could be more important to dust lifting compared with the effect of thermal contrast over the cap edge region. In particular, their results presented in Strausberg et al. (2005) suggest that a high surface stress region can be found over the southern edge of the Hellas Basin during the period of the southern spring equinox, and the stress is at maximum during night time. In the afternoon, upslope wind is dominant over the western and northern rims of the basin. These previous studies provide some insight on the dynamics of dust lifting over the cap edge region. However, the effect of the above three forcing over the Hellas basin, particularly during the period of the southern spring equinox was basically not investigated in detail.

In the present study, the formation of Hellas storms has been investigated based on the results from a general circulation model for Mars. This study is attempting to address the question why Hellas storms are commonly initiated and active in the basin for a short period around the southern spring equinox, which could be related to the retreat of ice cap as will be discussed in this paper. This issue has not been addressed in the studies mentioned above (Silli et al., 1997, 1999; Toigo et al., 2002; Strausberg et al., 2005). We believe that a better understanding on the initiation of Hellas storms may help us understand more about the regular dust cycle, and hopefully may provide more insight into the initiation mechanism of the 2001 planet-encircling dust event occurred around the time of the southern spring equinox.

2. The numerical model

The general circulation model (GCM) MarsWRF (Richardson et al., 2007; Toigo et al., 2012) is used in this study to simulate the climate of Mars. MarsWRF is the Mars version of the PlanetWRF model (Richardson et al., 2007), which was developed by the National Center for Atmospheric Research (NCAR) Weather Research and Forecasting (WRF) model for Earth (Skamarock and Klemp, 2008). It has been illustrated in Richardson et al. (2007) and Toigo et al. (2012) that MarsWRF is capable of realistically reproducing climate features such as the large-scale general circulation and temperature field on Mars. In this study, the global domain of the MarsWRF model has been set to 36 latitude × 72 longitude grid points (horizontal spatial resolution of about 5° or 300 km in the equatorial region). There are 52 vertical levels in terrain-following hydrostatic-pressure vertical coordinate (Skamarock and Klemp, 2008), and the model top is set at 0.0057 Pa (about 80 km in altitude). Half of these 52 levels are located between the model top and the pressure level of 100 Pa. Hydrostatic dynamics is used for the model runs, and traditional Rayleigh damping is applied to the dynamical variables at the top three vertical layers. The radiation scheme for short- and long-wave radiation employed in these simulations is the "wide band model" scheme as described in Richardson et al. (2007), Toigo et al. (2012) and Newman and Richardson (2015). This scheme considers the heating/cooling effects of dust and carbon dioxide (CO_2). The planetary boundary layer scheme and land surface scheme were largely adapted from existing schemes in WRF forf Earth, as described in Richardson et al. (2007) and Toigo et al. (2012).

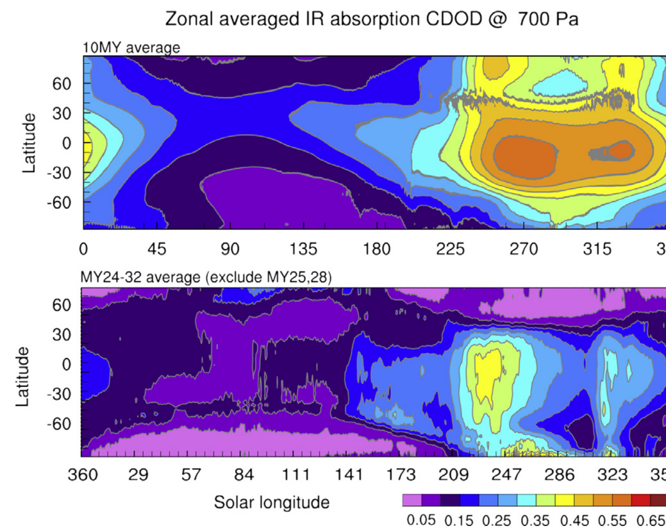

Fig. 1. Seasonal evolution of annually average zonal-mean column dust optical depth at 9.3 µm (normalized to a 700 Pa surface) from the ten-year average climatology of model simulation results (upper panel) and the re-constructed observational data (Montabone et al., 2015) averaged for the six Martian years of observations that do not contain a global-scale dust storm (lower panel).

The model also includes other physical process parameterizations specific to Mars, such as the carbon dioxide cycle (Guo et al., 2009) and the dust cycle (Newman and Richardson, 2015). However, no parameterization of the water cycle is included in these simulations.

The parameterization of dust processes in the model includes two interactive dust schemes similar to those used in Newman and Richardson (2015), and dust is assumed to be available everywhere and at all times over the whole planet surface except those surfaces with ice cover. The first scheme is similar to usual dust models on Earth, in which the lifting of dust is proportional to the surface wind stress. Dust lifting occurs over the surface when the local near-surface stress exceeds a particular threshold value (constant value 0.042 N m^{-2} in this study). The second scheme provides most of the background dust, which is parameterized as dust lifting by dust devils. The amount of dust lifting is dependent on the temperature difference between the surface and the air above, as well as the sensible heat flux. The radiation scheme in the model is interactive with dust so that the suspended dust may change the atmospheric radiation and thus the circulation.

The model was run for eleven Martian years, initially starting from the time of northern spring equinox ($L_S = 0°$). The first year is considered as a spin-up period. Therefore, only ten years of simulation results are used in this study and their ensemble mean is defined as the climatology of the model results.

Some important model parameters such as the threshold stress of dust lifting and lifting rate of dust devils were tuned to simulate the regular climate of Mars. When comparing the annual variation of the zonal-mean column dust optical depth (CDOD) from the ten-year averaged model climatology with the 6-year averaged observational data (described below), the model simulation is able to reproduce the essential features of the climatological dust distribution of Mars (Fig. 1), particularly the significant increase in global dust opacity after $L_S = 135°$, and the two episodes of increased dust opacity around $L_S = 240°$ and $L_S = 320°$ (although there is a certain time shift of the episodes). However, the simulation overestimates the dust opacity over the northern winter polar region, and during the observed winter “solsticial pause” period (e.g.,