# SIMULATIONS OF THE MARTIAN DUST CYCLE WITH A GFDL MARS GCM

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The Martian seasonal dust cycle is examined with a General Circulation Model (GCM) that treats dust as a radiatively and dynamically interactive trace species. Dust injection is parameterized as being due to convective processes (such as dust devils) and model-resolved wind stresses. Size-dependent dust settling, transport by large-scale winds and sub-grid scale diffusion, and radiative heating in the visible and infrared due to the predicted dust distribution are treated. Multi-year Viking and Mars Global Surveyor air temperature data sets are used to quantitatively assess the quality of simulations. Varying the three free parameters for the two dust injection schemes (rate parameters for the two schemes and a threshold for wind-stress lifting), we find that northern spring and summer temperatures, which are observed to repeat very closely each year, can be reproduced by the model if the background dust haze is supplied by either convective lifting or by stress lifting with a very low threshold and a low injection rate. In order for either of these cases to yield dust storms, and specifically spontaneous and variable global storms, dust injection due to high threshold, high rate stress lifting must be added. The convective scheme is found unable to generate a dust storm (not to be confused with perennial high-opacity background haze) from which we conclude that dust devils do not initiate dust storms (in agreement with imaging observations). In order to supply the background haze, wide-spread and on-going lifting is required by the model. Imaging data provides a viable candidate mechanism for this lifting if it is convective, in the form of dust devils. Local storms and other observed, non-convective lifting systems appear insufficiently frequent and widespread to satisfy the role demanded by the model.

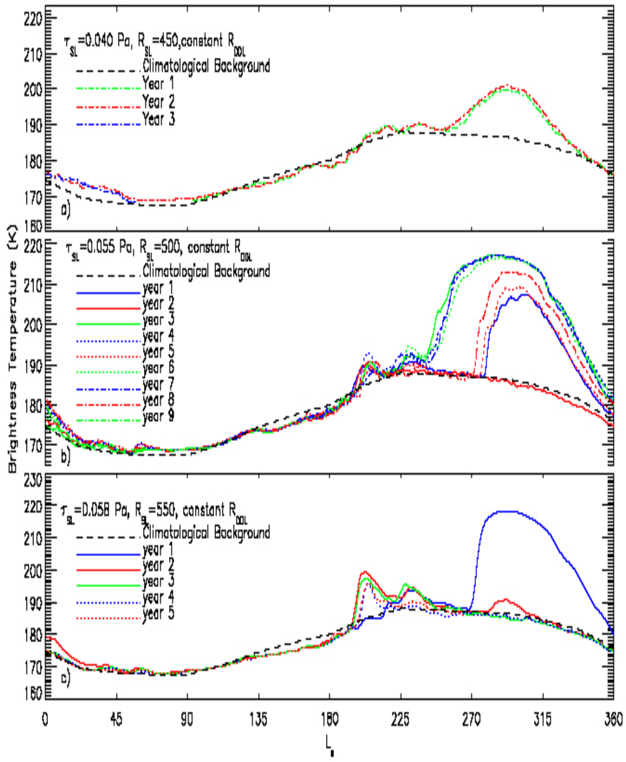


**Figure 1:** Multiyear globally averaged $T_{15}$ temperatures as a function of areocentric solar longitude. (a) Low threshold case of 0.04 Pa. (repeatable storms every year) (b) critical threshold case of 0.055Pa (inter-annually variable storms) (c) 0.058 Pa (early Hellas storm ~Ls=195 and late Hellas storm)

The high repeatability of northern spring and summer temperatures precludes slow fall-out of dust following global dust storms as important for maintaining the background haze. Further quantitative studies of dust lifting observations are needed to determine with confidence the nature of small-scale dust lifting. However, on the basis of the model results and inferences from thermal and imaging data, we suggest that the seasonal cycle of background dust haze on Mars is maintained by the action of convective processes, and specifically dust devils. The model predicts a spatial distribution of convective dust lifting, including a pronounced peak in the Amazonis region, where numerous dust devils have been observed. The annually integrated net dust erosion/deposition is predicted using the full dust cycle, yielding net erosion rates one-to-two orders-of-magnitude lower than if deposition is neglected.

Combining the convective scheme and high-threshold stress lifting, we obtain a "best fit" multi-year simulation, which includes simulation of both a realistic thermal state in northern spring and summer and, for the first time, the spontaneous generation of inter-annually-variable global dust storms [Figure 1]. This simulation predicts latitudinal and vertical distributions of air temperature that compare well with observations, and produces a variety of spontaneous local-to-global dust storms whose spatial and seasonal distribution compare reasonably well with orbiter camera observations. Our results support the idea that variable and spontaneous global dust storm behavior can emerge from a periodically forced system (the only forcing being the diurnal and seasonal cycles) when the dust injection mechanism involves an activation threshold. We obtain two main kinds of storms in these simulations. The first kind of storms evolves from the Hellas and Argyre basins. These are eastward propagating storms as the midlatitude westerlies advect the dust eastwards. The stresses in the Hellas basin (especially along the south-western rim of Hellas) have maximum variability ~Ls=180. This is when the traveling wave activity is also at its peak. In addition, the slope winds also help raise the stresses. However, the early Hellas storms are not able to spread globally as the Hadley cell circulation is weak at this early season. The simulated storms die soon after as the traveling waves weaken with polar ice cap retreat from the slopes of Hellas. The late Hellas storms that start from the northern rims of Hellas (where the subtropical jet prevails) are much bigger and go global (Figure 3). The dust gets entrained in the Hadley cell circulation and due to the positive feedback the circulation also becomes very strong. These storms spread in all directions and in both hemisphere. The decay of these storms is however purely seasonal i.e. when the Hadley cell becomes weaker with the season, these storms also stop.

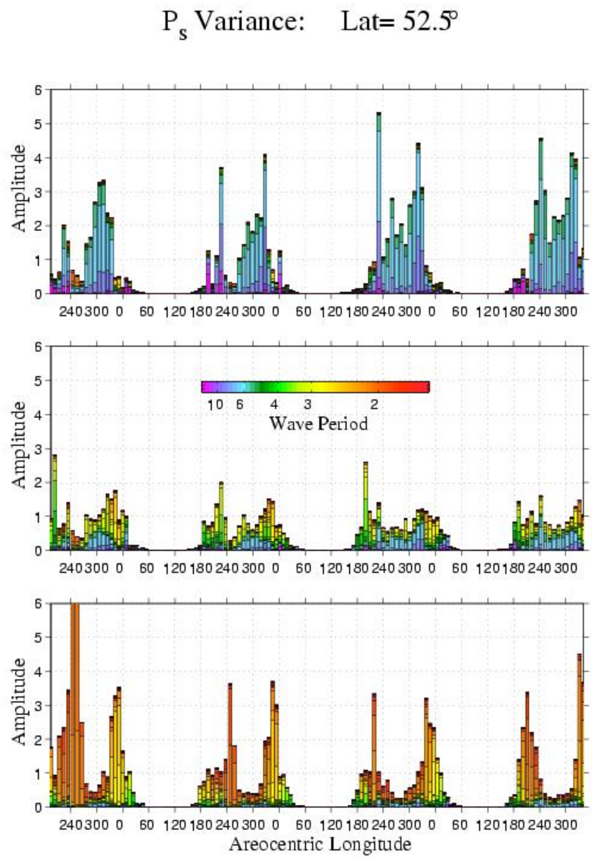


**Figure2:** The seasonal variation of eastward propagating zonal waves 1, 2 and 3 (top, middle, and bottom) derived from simulated surface pressure. At each $L_s$ , the contributions to the total variance are represented in color. Zonal wave 3 with a period of 2-3 sols is most important for the evolution and development of the cross equatorial flushing storms in the Northern Hemisphere.

The second kinds of storms are the baroclinic storms simulated in the northern hemisphere. These are cross equatorial storms that occur in the three lowland channels of Arcadia, Acidalia and Utopia. These are triggered by high stresses due to traveling waves in the pre and post solstice season. These waves have a periodicity of 2-3 days as also has been observed (Figure 2).

The general circulation model is also used to evaluate changes to the circulation and dust transport in the Martian atmosphere for simulations with a finite supply of dust on the surface. The focus is on changes to atmospheric temperatures and dust-related surface features, as these may potentially be verified by observations. In this work, the use of a finite surface dust supply increases the amount of interannual variability the system is capable of producing. This is due to a new set of initial conditions, in the form of available surface dust, being present at the beginning of each storm season. The important thing in these simulations is to let the few 'most' rapidly expiring points disappear. Then the realism of the simulations becomes not due to the source regions switching back and forth, but due to the remaining source regions (that were previously secondary) being more representative of those that are probably most important on Mars itself.

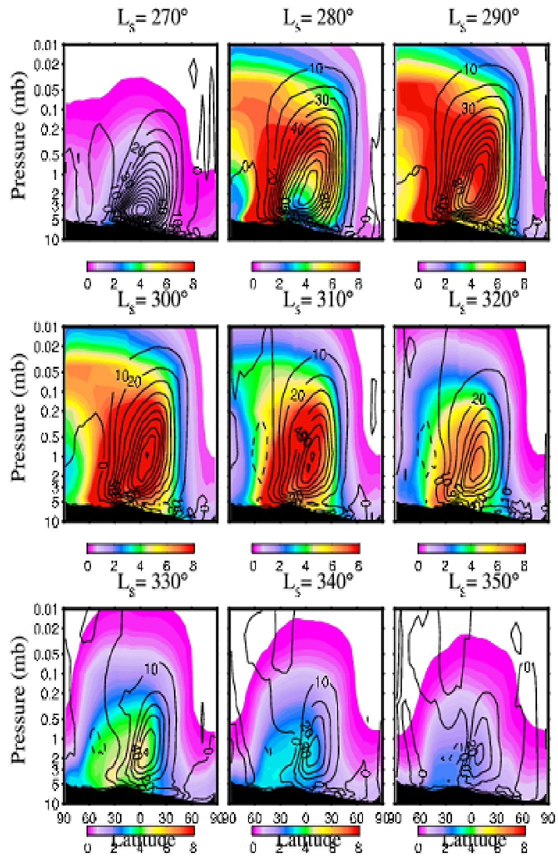


**Figure 3**. Latitude-height section of dust distribution and mass streamfunctions for a Hellas storm. The dust storm starts out in Hellas basin where the dust is lifted into lower levels of the atmosphere. It spreads into the northern hemisphere predominantly through higher levels in the atmosphere ~ 25 km. The explosive development of the global dust storm occurs when dust lifting in Hellas is sufficient to intensify the Hadley Cell Circulation and wind stresses in a portion of the southern tropical convergence zone exceed $\tau_{SL}$. This activates the secondary lifting centers and the dust storm becomes global.