THE MARTIAN ATMOSPHERIC DUST CYCLE: INSIGHTS FROM NUMERICAL MODEL SIMULATIONS.

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Introduction: Suspended dust (or lack thereof) in the martian atmosphere is the most important determining factor regarding the thermal, and thus dynamical, state of the martian atmosphere. The observational history of martian atmospheric dust [1], including direct measurements at visible and infrared wavelengths and indirect inferences from microwave observations of atmospheric temperatures, indicate substantial variations in dust load during a given year and from year to year. The dust cycle is a manifestation of the interaction between near-surface atmospheric stability and dust available for lifting upon the martian surface. In this presentation, we address the role the large-scale atmospheric circulation can play in the dust cycle.

The NASA Ames Mars atmospheric General Circulation Model (GCM) [2, 3] has been modified to include a self consistently determined dust-lifting component dependent upon the calculated atmosphere-surface momentum exchange. This lifting scheme is based upon terrestrial observations and numerical modeling of Saharan dust storm [4]. Dust lifting rate (mass of dust per area per time) is dependent upon model calculated surface stress ($N\ m^{-2}$) for values greater than a threshold value ($0.0225\ N\ m^{-2}$) identified as producing realistic dust lifting rates for the Ls ~270 time period. Sensitivity studies indicate that threshold values 20% larger or smaller result in negligible and excessive dust lifting rates, respectively. In the experiments described herein, the surface dust source is assumed to be infinite, though no dust is lifted from locations covered by the seasonal CO_2 ice cap (no residual caps are present).

Nominal experiments initiated during northern summer from a spun-up low dust optical depth condition produce an annual cycle consisting of two prominent lifting maxima [Figure 1]. The first maximum occurs in early-mid northern autumn (Ls~220) and arises from enhanced dust lifting on the northern and eastern slopes of Tharsis (a northern hemisphere source). The second lifting maximum is based in the Hellas basin and occurs at Ls~275 (a southern hemisphere source). These dates seasonally coincide with the two significant lifting maxima observed during the first year of the Viking mission. Both Viking events had their genesis in the Solis Planum region (south and southeast of Tharsis), but the Hellas basin has been the observed genesis site of numerous dust-storm events [1]. Multiple year simulations provide almost identical cycles each year, indicating no interannual variability (which is at odds with observations).

There are preferred locations for lifting during these simulated years. The northern and southern internal slopes of Hellas are significant dust source regions (especially during northern autumn and early winter). There is little lifting at the 'bottom' of Hellas. The northern and northwestern slopes of Tharsis, well removed from the topographic peak (~10 km altitude with the model's resolution) are also prominent source regions, most active during northern autumn. A preferred equatorial source region is centered near 45^o West; this region connects with a pronounced source at southern subtropical latitudes centered between 0-60^o West longitude. The equatorial, exclusively active during northern autumn – early winter, coincides with the location of the enhanced meridional flow 'Western Boundary Current' identified by Joshi et al. [5]. The southern subtropical source corresponds to the region of enhanced eastward surface flow associated via Coriolis 'turning' with this boundary current. Northern middle latitudes (35^o- 60^o N) act as source regions during northern autumn, winter, and spring (but not summer); lifting in this region is related to the eastward travelling baroclinic waves which propagate throughout this region during these seasons. Several preferred longitudes (60^o W, 150^o E) correspond to the 'Storm Track' zones identified by Hollingsworth et al. [6].

One final source region is the area(s) bordering the seasonal polar cap edges (recall that no dust is lifted on ice-covered areas). Both the advancing and retreating cap-edge boundaries exhibit dust lifting in the northern hemisphere. In the southern hemisphere, the retreating cap edge exhibits dust lifting at its boundary, while the advancing cap is devoid of any coincident lifting. The longitudinal coverage of this apparent cap-edge lifting is not complete, and is much more longitudinally confined (centered near 0^o longitude) in the southern hemisphere.

Many of these source regions coincide with regions of large topographic slope, suggesting a strong connection. This is verified by simulations in which topographic variations are removed, wherein lifting is much more longitudinally uniform.

Sensitivity studies highlight numerous aspects of the simulated dust cycle. If the lifted dust is radiatively inert (acts as a passive tracer), the resulting dust lifting cycle differs substantially from the nominal scenario. Rather than a double maximum in the lifting pattern, the modeled cycle consists of a single maximum situated in time (Ls~250) between the two maxima from the interactive-dust experiment. Thus, an early autumn lifting event acts has a negative feedback upon lifting during the latter half of autumn, and the early winter (interactive) lifting maximum can be viewed as a response to the decline of the dust load generated by the Ls~220 lifting event. Additional sensitivity simulations indicate that the atmospheric mass cycle itself (as it might impact surface densities and thus the momentum exchange between atmosphere and surface) does not play a significant role in the dust cycle, nor do minimal variations in the availability of surface dust available for lifting.

One notable shortcoming of the modeled dust optical depth cycle is the near complete loss of dust from the atmosphere during northern summer. This indicates that the large-scale circulation is insufficient itself of generating surface dust lifting capable of offsetting dust deposition which occurs during this time period. This result is inconsistent with atmospheric dust-content measurements obtained from martian surface stations (Viking, Pathfinder; [7, 8]) but is in general agreement with remotely sensed atmospheric temperatures at microwave [9] and IR wavelengths [10, 11] during this season. One possible remedy is dust lifting at a much smaller scale: the tens to hundreds of meters encompassed by a dust devil. Small-scale apparently convective vortices have been noted in martian meteorology data [12, 13] and possibly in surface images [14]. Inclusion of a 'dust devil' lifting mechanism, active within 15^o of latitude of the sub-solar latitude and during the hours from 1300-1500 local time ONLY at locations where the surface stress produced by the larger scale flow does not exceed the threshold, does result in an optical depth cycle at Viking-equivalent model locations in much better agreement with the observations. The resulting modeled 15-micron brightness temperatures agree well with Viking IRTM observations, but Wilson and Richardson's [10] results suggest that such agreement indicates too much atmospheric dust. T15 values at other seasons are in reasonable agreement, however the observed 1977B north polar warming is not reproduced.

The input particle size distribution evolves in both space and time. 'Larger' particles (> a few microns) generally remain confined vertically nearer to the surface and horizontally nearer to the described source regions. Thus, regions removed from the source regions will generally accumulate smaller particles.

Total northern hemisphere dust lifting exceeds that of the southern hemisphere. In fact, there is a net transfer of dust from the northern hemisphere to the southern hemisphere. This is an unexpected result. While this in fact might be an illustration of current conditions on Mars, other issues could offset this. These simulations assume an infinite source of dust at each model location. Therefore, no location can be 'swept clean' of liftable dust. High thermal inertia–low albedo locations are likely to be deficient in dust sized particles. Such regions include the northern middle latitudes, where the model predicts significant lifting during most seasons. Persistent lifting, with a net transfer of dust from the region of lifting, would over time lead to an exhaustion of dust. The lack of interannual variability in our modeled dust cycle thus could result from our as yet lack of a surface dust budget which would allow for the depletion of surface sources. Such work is ongoing.

Much work remains in order to understand the current martian dust cycle, and to then extrapolatesuch knowledge back in time to understand possible climatic implications (polar layered terrain, for example). Current modeling efforts, coupled with the growing cache of observational interpretations, offer great promise in the coming years.

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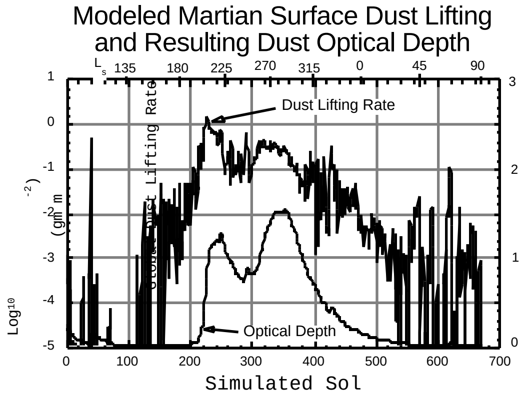

Figure 1. Modeled sol-integrated global dust lifting rate (gm m^{-2}) [upper curve] and globally averaged dust optical depth [lower curve] during the course of an annual model simulation including a self-consistent surface dust-lifting formulation in the NASA Ames Mars GCM.