GLOBAL MARTIAN SAND TRANSPORT AS PREDICTED BY THE GDFL MARS GCM. L. K. Fenton and M. I. Richardson, Caltech, MS 150-21, Pasadena, CA 91125, lori@gps.caltech.edu, mir@gps.caltech.edu

Introduction: Aeolian erosion is most likely the dominant geologic process currently operating on Mars. Unfortunately little is known about either the timescale over which these processes take place or the sources and sinks of the materials they move.

Sand dunes on Mars are located in three distinct settings. The majority of the dunes are located in large ergs partially surrounding the northern polar ice cap. Several smaller dunefields occur in craters in the mid southern latitudes. Although Mariner 9 and Viking images clearly show these dark northern and southern dunefields, new MOC images show that smaller brighter dunes are almost ubiquitous on the surface.

The sources of the sand dunes on Mars are poorly understood. Several researchers have inferred that the northern polar ergs may be derived from sand transported from northern mid latitudes [1,2,3]. Alternatively, Thomas and Gierasch [4] concluded that the dark dune material originated in the northern polar ice cap and has subsequently become latitudinally trapped by winds "generated by their own low albedo".

According to Thomas and Gierasch [4] the southern mid latitude dunes were derived from the southern polar cap like their northern counterparts, but that rough topography has prevented a confining polar wind, allowing the dunes to move farther from the pole.

Little is known about the small brighter dunes found by the MGS MOC. Thomas et al. [5] propose that because the dunes appear to be located near outcroppings of bright materials, the outcroppings are the source regions of nonresistant particles that break down rapidly. Thus the bright dunes may be made of a soft material such as gypsum.

Using wind velocity output from a Mars Atmospheric General Circulation Model (GCM), a sand transport model can aid in determining not only whether the features were formed under the current or an ancient wind regime but also whether or not the aeolian process is still active. Thomas and Gierasch [4] employed an analytic "sea breeze" model, in which winds are enhanced by albedo contrast between the dark northern polar dunes and the bright polar ice, to determine how winds affect the surface distribution of dunes. Few global sand transport studies have been undertaken. Anderson et al. [1] used the Ames Mars GCM to predict sand movement using several different threshold shear values for up to 1500 years. They concluded that the northern polar ergs could form within 50,000 years with source regions generally in the northern mid latitudes.

Dune shape and orientation is determined by wind modality. Barchan and transverse dunes are formed by unidirectional winds, linear dunes are formed by bidirectional winds, and star dunes are formed by multidirectional winds [6]. The wind modality is quantified by RDP/DP, the ratio of the RDP (resultant drift potential, the vector sum of the sand fluxes) to the DP (drift potential, the scalar sum of the sand fluxes). Values near unity imply unidirectional winds; smaller values imply bidirectional and multidirectional winds. Therefore, dune shapes indicate the wind regime in which they were formed. On Mars, the abundance of barchan and transverse dunes coupled with the scarcity of linear and star appears consistent with unidirectional wind predicted by GCM's [7], leading to the conclusion that dunes have been active during the current wind regime.

There are a number of reasons to proceed with numerical modeling of sand transport at this time. Most importantly, the wind regime near the surface is strongly influenced by topography, and the first accurate map of global topography from MGS MOLA has only recently become available. Mars GCM's now appear to adequately simulate the circulations during dust storm periods, which produce some of the strongest surface winds [8]. Finally, Mars GCM's now have the flexibility to examine wind regimes from different epochs. We have used surface wind output from the GDFL Mars GCM to build a global sand transport model for Mars. Several parameters have the same values used by Anderson et al. [1] in order to directly compare the Ames GCM output with that of the GDFL GCM. We compare the resulting sand distribution with the known sand dunes on the Martian surface. We also compare our results with those of Anderson et al. [1]. The RDP/DP is also calculated along with the sand transport, and these values are compared with known dune forms and orientations as well as to the results found by Lee and Thomas [7] with the Ames GCM.

Global Circulation Model: In this study we have used winds derived from the Mars GCM developed by John Wilson at the Geophysical Fluid Dynamics Laboratory (GFDL) [9]. The model is based on the terrestrial grid-point GFDL "skyhi" GCM, but is modified in several ways: 1) The basic planetary and atmospheric properties have been set to Martian values. 2) The Martian diurnal and seasonal cycles of insolation are applied. 3) Atmospheric heating rates are determined by a broadband radiative scheme that treats CO_2 gas and atmospheric dust aerosols. 4) A cycle of CO_2 between the atmosphere and surface ice has been implemented which matches the observed Viking Lander seasonal pressure cycles. 5) The radiatively active dust aerosols are injected into the model where they are self-consistently transported by the model winds and gravitational settling. The surface boundary uses MOLA data to describe topographic elevation, and fully global maps of albedo and thermal inertia [10,11].

For the work described here, the model has been run at a resolution of 5° of latitude and 6° of longitude, with 20 levels between the surface and roughly 85 km. A time step of roughly 5 minutes has been used, with output from each time step contributing to the calculation of sand transport. In the non-dust storm years, a temporally uniform dust injection rate has been used. The injection rate used was chosen to force the model air temperatures at 0.5 mbar to agree with observations. For the dust storm years, a 5-fold increase in injection occurs at Ls = 255° between 40°S — 60°S. The injection is exponentially relaxed back to non-dust storm values with a time constant of 7 sols (Mars days).

The surface layer mixing scheme used in the model is based on the work of Hicks (1976). This scheme is a Monin-Obukhov surface drag model, which has been tested against terrestrial field observations. In the Mars GCM, the scheme is run with a globally uniform value of surface roughness of 16.62 cm. It is the Reynolds stress derived from this parameterization that is used to calculate the sand transport flux.

Sand Transport Model: The sand transport model determines where winds blow sand particles under the current wind regime. The movement of sand is derived by using the mass flux relation experimentally determined by White [13]. In the manner of Anderson et al [1] we begin with a uniform 4-mm distribution of 100-µm quartz grains over the Martian surface.

With each successive timestep, mass is transported into or out of each 6° by 5° cell depending on the GCM output sand fluxes. In addition, a yearly and seasonal value for both the RDP and the DP are calculated.

Simulations: We have undertaken a number of sand transport model runs, each with 1000 - 10,000 year time spans. For the current climate, we have undertaken three cases to examine the impact of dust storms. In the first case we use non-dust storm years every year (for the definition of dust storm and non-dust storm, see the model section above), in the second we insert a dust storm every 5 Mars years, while in the third case we run dust storms every year (this is most analogous to the Anderson et al. [1] study). In each case, evolving distributions of sand for six different threshold stress have been calculated (stress = 0.0125, 0.01875, 0.025, 0.033, 0.04, 0.055 N/m^2). A plot of RDP/DP for the lowest threshold case is shown in Figure 1. These simulations show rapid movement of sand in regions such as Hellas and the northern edge of Tharsis. Transport decreases significantly as the threshold stress is increased.

An important statement in previous studies is that the rough agreement between winds and dune orientations suggests active dunes. However, the degree of agreement with winds predicted for differing obliquity or passage-of-perihelion timing has not been examined. We will show transport simulations from cases where the obliquity has been set to 45° and the atmospheric mass has been increased appropriately [14].

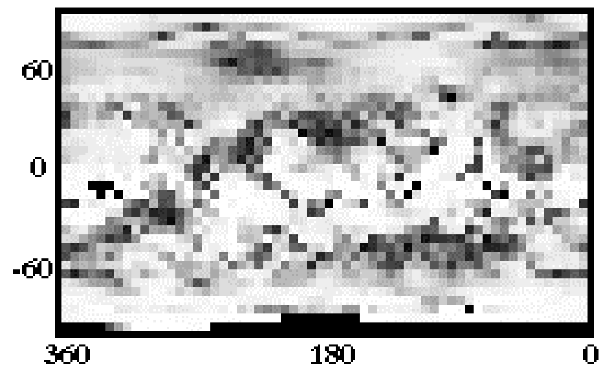

Fig. 1 RDP/DP calculations for a full Martian year. White corresponds to RDP/DP values of unity, implying directionally uniform winds. Darker regions correspond to areas with bi- or multidirectional winds. The black areas at high southern latitudes contain no data. The general unidirectionality of the winds appears to be in agreement with observed dune forms [7].

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