INTERPRETING MARTIAN PALEOCLIMATE WITH A MARS GENERAL CIRCULATION MODEL.

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Introduction: The Geophysical Fluid Dynamics Laboratory (GFDL) Mars GCM has been used extensively to study the evolution of martian climate over recent obliquity timescales. A variety of results are discussed here exploring the range of capabilities of this model. In particular, the GCM has been used to investigate orbital change as a cause of surface wind changes, the cycles of CO2 and water, and variations in the spatial distribution of net dust deposition / erosion.

Over the model's evolution, significant capabilities have been added, including the incorporation of dust and water cycles, an active regolith and radiatively active clouds.

Surface Winds: An in-depth discussion of the utility of the GFDL GCM for putting spacecraft results in context can be found in [1]. It has been observed [*e.g.* 2] that current wind-direction patterns and long-term wind indicators do not coincide, suggesting a change in long-term wind direction over time. Obliquity or orbital element change had long been suggested as a possible cause. However, for the range of obliquities obtaining in the past few million years (15°-35°), the surface wind patterns do not change significantly. The insensitivity of the overall wind direction to changes in these orbital parameters suggests that orbital change (at least for the range applicable in the recent past) are not responsible for the generation of geological indicators of wind direction, such as the ventifacts seen at the Pathfinder landing site.

Water Stability: We have explored the effect of both orbital changes and atmospheric pressure changes on the (transient) stability of water on the martian surface, similar to [3]. We find a significant variation in the spatial distribution of liquid water sites depending on the particular orbital parameters. However, the elevated nature of the southern highlands means that regardless of obliquity or orbital parameters (and provided the available climatic CO_2 is held constant), transient liquid water is not generally possible. Currently, transient liquid water is not possible in the northern mid- and high-latitudes – constrained by maximum temperatures. If the argument of perihelion is rotated by 180°, the majority of the northern mid- and high-latitude experience some days per year with conditions above the triple point and below boiling (though never with liquid water fully stable, since the partial pressure of water vapor in the atmosphere is always much less than 6.1mbar).

If the mean surface pressure is increased from present-day values to 4x and 16x (~24mb and 96mb respectively) while at 45° obliquity (Figure 1), we find interesting, if unexpected behavior. As surface pressure is slowly increased, the total area at which surface conditions are capable of sustaining transient liquid water increases, as would be expected. The southern hemisphere in particular now yields transient stability. However by the time we reach the 16x simulation, we find very little of the surface is actually capable of sustaining liquid water. This is, at first, perplexing, as increased surface pressure should only make boiling more difficult, and the "greenhouse" effect of the extra CO_2 heats the surface. However the key factor is the increased atmospheric circulation that comes with the increased surface pressure, which more effectively transports heat from the warmer to the cooler locations on the planet. This tendency to smooth temperature variations across the surface reduces the "maximum" temperatures and pulls the majority of the surface below the triple point. At very high pressures, sufficient greenhouse warming can exist to make liquid water truly stable at the surface – this is the "warm, wet Mars" problem and involves the question of whether than much CO_2 ever existed in the Martian atmosphere. The implication of our finding is that as surface pressure decrease from this early, putative state (few bars), Mars passes though a "dead zone" at moderate surface pressure (~0.1bar) where even transient liquid water is inhibited. Finally, as pressure falls even further, inability of the atmosphere to effectively cool portions of the surface leads to increase likelihood of transient liquid water. In short, the story of liquid water may not be linear.

Dust Cycle: Prognostic simulation of the full annual atmospheric dust cycle allows us to examine the fluxes of significance for the Martian surface dust deposits in a manner that has not been possible to date. For this study, our dust lifting scheme incorporates dust devil lifting and wind stress lifting and has been carefully validated against observations. Particularly satisfying, the model is now able to generate spontaneous and interannually-variable global dust storms without *ad hoc* forcing. This had long been a cause for concern over the validity of GCM's in application to longer term climatic problems, and the dust cycle, specifically.

Change in annually-integrated dust erosion / deposition as a function of obliquity up to 60° is examined, with net deposition at the poles decreasing as obliquity increases (to 2-5μm/Martian year at 60°) (Figure 2). This non-intuitive result is due to an increased ability of convective and resolved winds to remove dust in the high latitudes at high obliquity, despite the fact that dust opacities and fall-out at the poles increase. Previous simulations with this GCM suggest that polar ice sheets are unstable at high obliquity, and thus even with these reduced deposition rates, polar dust sheets of several tens of centimeters thickness could be generated in a single obliquity cycle. Consistent with previous results from this GCM, the circulation patterns - and hence dust deposition/erosion patterns - do not change sufficiently with spin/orbital elements to allow a significant obliquity-driven cycle of surface dust sheets.

Regolith: The GCM has recently been augmented with an active regolith which allows for the uptake of water vapor from the atmosphere and redistribution within the pore spaces as either vapor or adsorbate. Adsorbate density is based upon previously published values representative of martian soil [8]. In the event the vapor pressure within the regolith exceeds the saturation pressure, ice forms within the pore spaces and is restricted in abundance to the available pore space. Once the regolith is filled by ice (or choked off), ice will continue to deposit upon the surface in thick ice layers, as found in [9].

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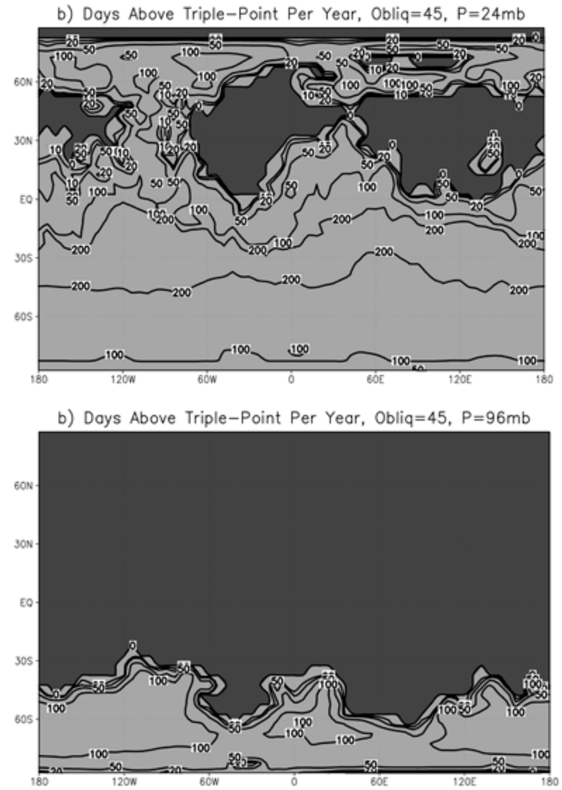

Figure 1: (a) (top) Number of days with temperature above the triple point and below the boiling point (at some point during the day) for a 4 times the current climatic (atmosphere plus seasonal cap) CO_2. (b) same as a, but for 16 times current inventory

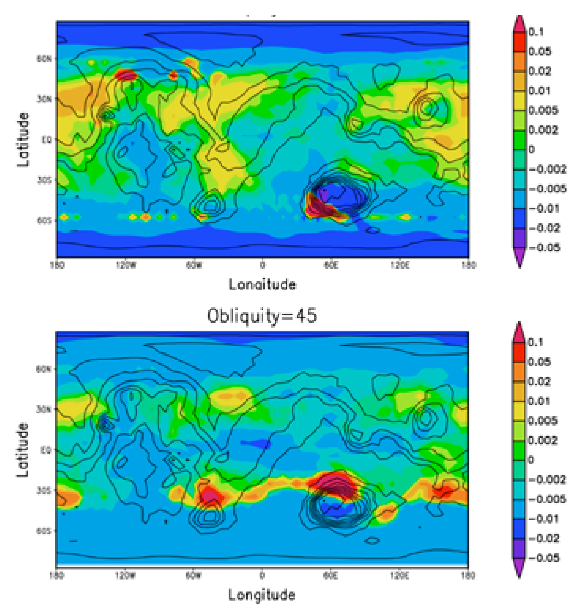

Figure 2: Annual net erosion / deposition with fully-interactive dust cycle. Units on color bar are in cm/Martian year. Warm colors are erosion and cold colors are deposition. A small net transport to the poles from the rest of the planet is found.