CLIMATE DYNAMICS OF ATMOSPHERIC COLLAPSE ON ANCIENT MARS

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Introduction: Global energy balance models of the Martian atmosphere have predicted that early in Martian history, for a range of initial total CO_2 inventories, the atmospheric CO_2may be unstable relative to surface condensation[1, 2]. This is commonly referred to as atmospheric collapse. A collapsed state may limit the amount of time available for physical and chemical weathering [3].

The global energy balance models that predict atmospheric collapse represent the atmospheric heat transport, which controls atmosphere collapse, in terms of a single, globally uniform parameter. This assumption requires reconsideration since at high CO_2inventories atmospheric heat transport may be significant and variable with respect to obliquity, surface pressure, and other factors. Using a general circulation model (GCM), we investigate the details of the three-dimensional, time varying climate dynamics at the threshold for atmospheric collapse.

An important constraint on the evolution of the Martian atmosphere is the partitioning of the Martian CO_2inventory into the atmosphere and surface. When the solar and thermal energy that arrives at the surface of Mars is low enough, the resulting surface temperature can be below the condensation temperature of CO_2. For a given total inventory of CO_2, the atmosphere either completely condenses onto the surface or achieves a thermodynamic balance between the atmosphere and surface reservoirs of CO_2. When the martian atmosphere achieves a thermodynamic balance, the CO_2partitions between the atmosphere and the surface ice, and thus the global mean atmosphere pressure is determined by this balance.

Simulations: To simulate an ancient Martian climate, we use the Mars Weather Research and Forecasting (MarsWRF) GCM [4]. We simulated the Martian climate under the current solar luminosity for a range of total CO_2inventories: ∼6 mb, ∼60 mb, ∼30 mb, ∼600 mb, ∼1200 mb, and ∼3000 mb, in terms of the equivalent global mean surface pressure. The orbital obliquities were simulated for a range from 0° to 45° in 5° increments. Zero eccentricity was used for all simulations. For each inventory, the simulation began with all of the CO_2in the atmosphere. The formation of CO_2ice was then dependent on the local surface energy balance and the atmospheric transport of heat. The model, however, lacks a complete CO_2microphysics scheme nor CO_2clouds. The simulations ran for five years, which was sufficient to reach quasi-steady state and to determine if the atmosphere was collapsing for a given CO_2inventory.

Results: The lower right hand corner of Figure 1 shows how the interaction of polar surface temperature, polar surface pressure, and condensation temperature results in different climate states. The solid black line represents a condensation curve for CO_2. The dashed black line represents the modeled polar surface temperature assuming atmospheric heat transport and a greenhouse effect. Point A and B are the transition points between a non-collapsed atmosphere (red region) and a collapsed atmosphere (blue region). When the polar surface temperature is below the vapor pressure curve, then runaway condensation of CO_2will occur at the poles and the atmosphere will collapse. Thus, the Martian atmosphere can experience three types of climate: first, an inflated, ice-free climate that occurs above point B in Figure 1, second, a vapor pressure balance climate where atmospheric $CO_2$and ice coexist at point A, and third, a collapsed climate where the only atmospheric constituents are the non-condensable gases, such as argon and nitrogen, and where the CO_2consists of surface CO_2ice.

The other plots in Figure 1 show the results from the simulations. Each plot corresponds to the labeled orbital obliquity and the various CO_2inventories are represented by the circles, as explained in the caption. At 0° obliquity all of the surface temperatures lie on the condensation curve for all CO_2inventories. These are collapsing simulations, and as such lie between points A and B shown in the lower right hand plot. At 15° obliquity, some of the measured annual mean

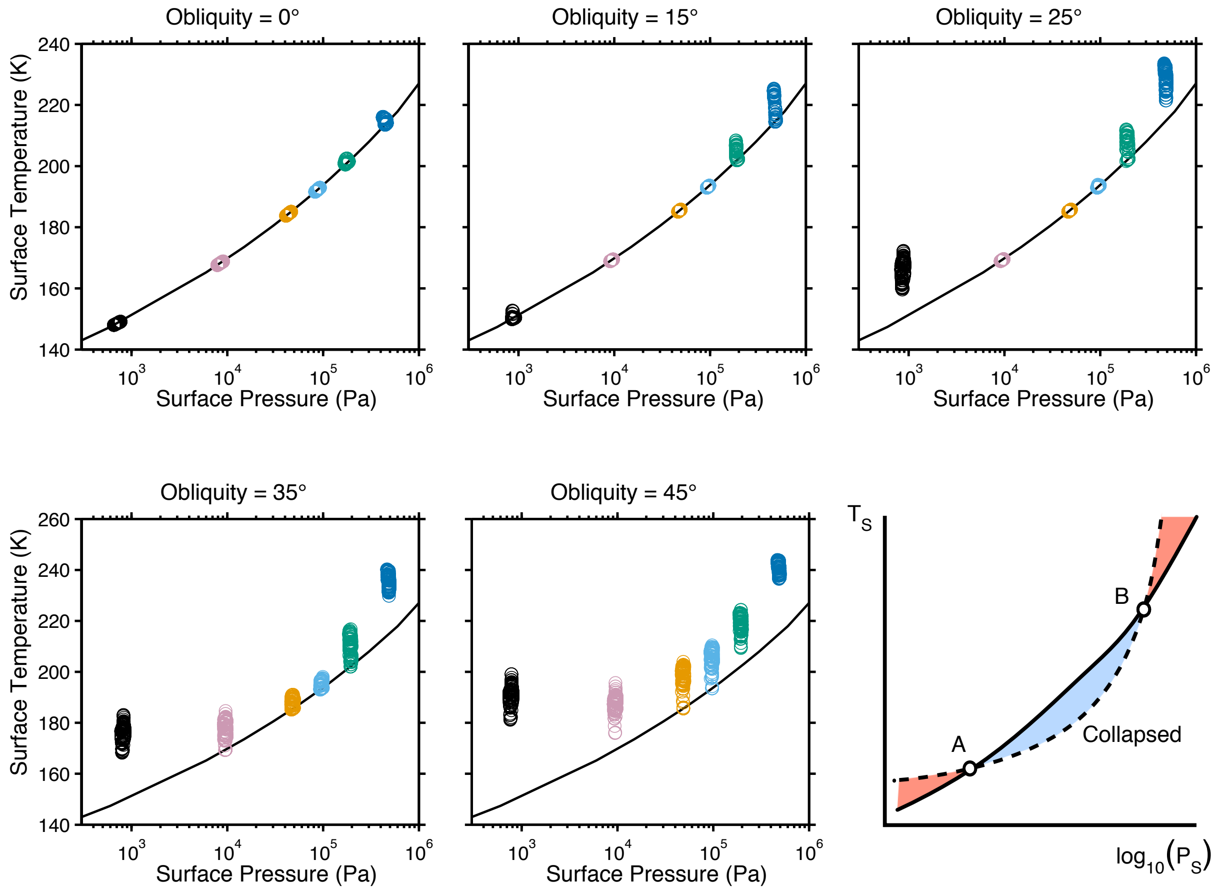

Figure 1: Annual mean surface temperature versus annual mean surface pressure for each longitude point along the 77.5° N latitude. The black circles are for the 6 mb simulation, the light red circles are for the 60 mb simulation, the orange circles are for the 300 mb simulation, the light blue circles are for the 600 mb simulation, the green circles are for the 1200 mb simulation, and the dark blue circles are for the 3000 mb simulation. The solid black line is the condensation curve for CO_2. The lower right hand figure shows a schematic representation of the simulation results, as explained in the text.

surface temperatures are above the condensation curves at the highest CO_2inventory. This 3000 mb simulation is still collapsing, since some of the polar regions lie on the condensation curve, but the existence of temperatures above the curve demonstrate that the location of transition points A and B with respect to surface pressure changes with changing obliquity. By 25° obliquity both the lowest and highest CO_2inventories are no longer collapsing and their polar surface temperatures are above the condensation curve, which resembles our schematic in the lower right hand corner of Figure 1. This process continues in 35° obliquity and 45° obliquity plots, where the separation between the transition points A and B narrows in terms of surface pressure.

Conclusion: These results show a weaker meridional transport of heat than estimated by previous energy balance modeling [5, 6]. This weaker meridional transport is dominated by the large scale circulation with little contribution from transient and stationary eddies, especially at higher CO_2inventories. The weaker meridional heat transport leads to a wider range of CO_2inventories for which the atmosphere will collapse.

References: [1] R. R. Leighton, et al. (1966) *Science* 153:136. [2] R. M. Haberle, et al. (1994) *Icarus* 109:102. [3] O. B. Toon, et al. (1980) *Icarus* 44(3):552 . [4] M. I. Richardson, et al. (2007) *Journal of Geophysical Research* 112(E09001). [5] P. J. Gierasch, et al. (1973) *Journal of the Atmospheric Sciences* 30(8):1502. [6] C. P. McKay, et al. (1991) *Nature* 352(6335):489.