DISTINGUISHING ORBITAL SIGNALS FROM STOCHASTIC VARIABILITY IN THE MARTIAN POLAR LAYERED DEPOSITS
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Introduction: Ice cores on Earth record past climate changes that are thought to be partially due to orbitally driven changes in the planet's insolation over time. Layered strata of dusty water ice exposed in the walls of spiraling troughs in the Martian polar ice caps (Figure 1) have similarly been hypothesized to reflect climate change resulting from Milankovitch cycles [1]. It seems probable that an orbital signal in Martian stratigraphy would be stronger relative to a terrestrial analogue, given the simpler climate system and larger obliquity variations on Mars. However, the relationships between insolation and deposition of ice and dust in the Martian polar layered deposits (PLD) are poorly constrained, and therefore the relationship between time and depth in the deposits is unknown. Given the possibility of a nonlinear insolation-composition relationship, a nonlinear time-depth relationship, and the presence of random noise in the PLDs, we model PLD formation to determine whether an orbital signal could be detected with a high degree of certainty, even if present.

Orbital Forcing of Martian PLDs: Quasi-periodic changes in Earth's orbital eccentricity, precession, and obliquity necessarily cause changes in insolation, and are major factors driving terrestrial climate change over tens of thousands of years [2]. Similarly, it has been proposed that these Milankovitch cycles result in important changes in Martian climate, such as the presence of global dust storms [3, 4].

Previous work has explored the relationship between insolation (determined by orbital characteristics) and formation of the PLDs through models [5, 6]. Some previous studies have allowed for a nonlinear time-depth relationship and have adopted the strategy of tuning the PLD record to match an assumed orbital forcing [7]. We seek to explore a wide variety of models and to continue this tuning approach, but with the important addition of applying a statistical test [8] to assess the level of confidence that a match obtained by tuning is not spurious [9].

PLD Formation Model: Since PLD formation is poorly understood, we consider various mechanisms for how insolation affects deposition rates of ice and dust, starting with simple models and then considering cases of increasing complexity. Figure 2 shows a sample case in which dust deposition rate is constant, and ice deposition rate is inversely proportional to insolation. Using the insolation record for the past 5 Myr, we construct a synthetic PLD deposit – dust concentration as a function of depth – by integrating the ice and dust deposition rates forward in time (Figure 2). We assume that the observed brightness variations in PLD sequences are primarily controlled by variations in dust concentration. The mechanisms we consider include cases in which the deposits experience ablation at high insolation.

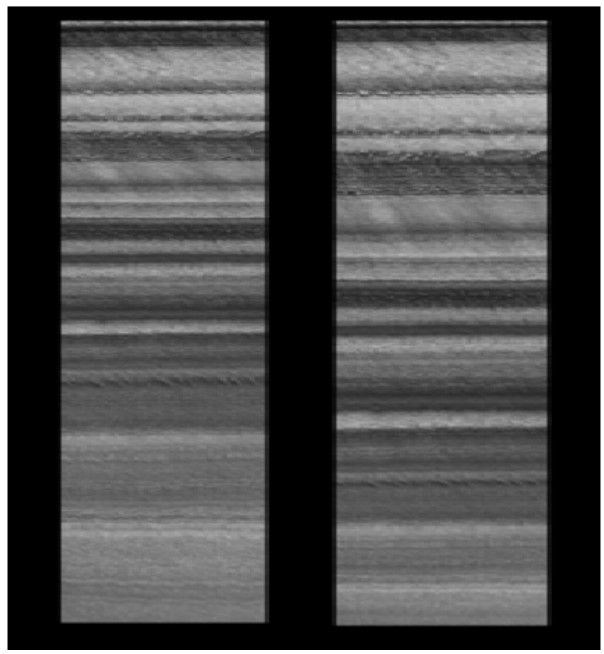

Figure 1: Images of a PLD sequence, before (left) and after (right) the image is corrected for underlying topography. Images taken from the Mars Orbiter Camera (MOC).

Statistical Analysis: When dealing with time-uncertain series like the PLDs, there is a possibility that two unrelated records can be made to appear to covary by time adjustment. The dynamic time warping algorithm MCTEST [8] addresses this issue by using theory of order statistics to determine the probability of obtaining a given covariance from randomly realized time-uncertain series. For each mechanism, we use MCTEST to determine how well we can extract an orbital signal from the model PLD. Figure 3 shows an output of MCTEST for the case of constant dust depo sition rate and linearly decreasing ice deposition with respect to insolation.

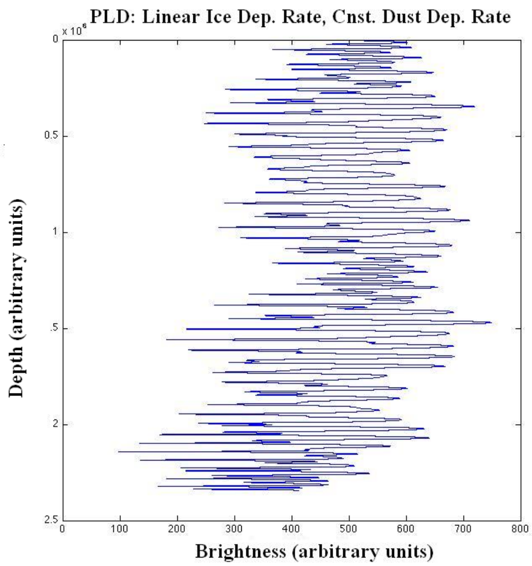

Figure 2: Plot of brightness against depth for a synthetic PLD sequence spanning the past 5 Myr for the case in which dust deposition rate is constant and ice deposition rate is inversely proportional to insolation.

Discussion and Future Work: Our analysis continues to explore models for increasingly complex formation mechanisms. Preliminary results indicate that it is possible to identify matches between an orbital signal and a synthetic PLD record when the formation mechanism contains a linear or constant relationship of ice or dust deposition rate with insolation. However, we find it is difficult to find a match with a high degree of confidence for more complex cases, like those that include ablation of ice. We will also apply MCTEST to images of actual PLD stratigraphy reconstructed from spacecraft images and topography. If significant matches between insolation and tuned PLD sequences can be identified, applications of this statistical procedure will constrain formation mechanisms of the PLDs, and thus Martian climate history.

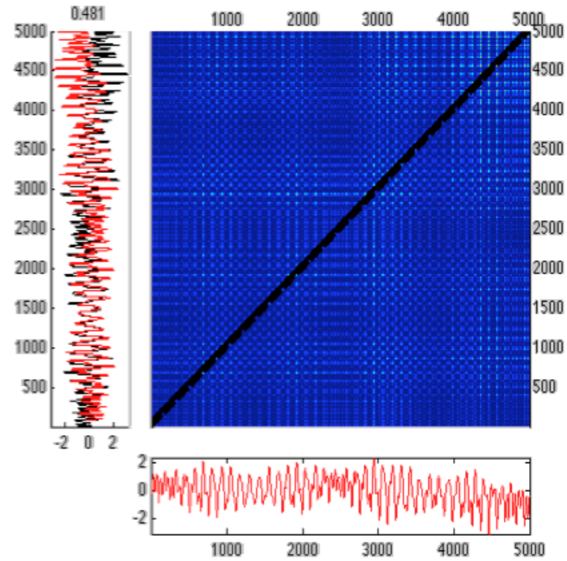

Figure 3: Example output of the dynamic time warping algorithm MCTEST. This compares the synthetic PLD model from Figure 3 with the record of Martian insolation history over the past five million years, and determines with what level of confidence we can say that the synthetic record was in fact driven by insolation. The center graph is that of a "cost matrix" that MCTEST uses to attempt to match records, and the side graphs show normalized plots of the insolation (black) and synthetic PLD (red) against units of time, in thousands of years.

References: [1] Murray, B.C. et al (1972), *Icarus 17,* 328-345 [2] Hayes, J.D. et al (1976), *Science 194* [3] Ward, W.R. (1973), *Science 181* 260-262. [4] Toon, O.B., et al (1970), *Icarus 44* 552-607. [5] Cutts, J.A., and B.H. Lewis (1982), *Icarus, 50,* 216-244. [6] Levrard, et al (2007) *J. Geophys. Res. 112*. [7] Laskar, J. et al. *Nature, 419,* 375-377 [8] Haam, E. and Huybers, P. (2010), *Paleoceanography 25*. [9] Perron, J.T. and Huybers, P. (2009), *Geology 37,* 155-158.