PRESERVATION OF ORBITAL SIGNALS IN THE MARTIAN POLAR LAYERED DEPOSITS: A STATISTICAL APPROACH Michael Sori[1], Taylor Perron[1], Peter Huybers[2], and Oded Aharonson[3], [1]Dept. of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology (mms18@mit.edu), [2]Dept. of Earth and Planetary Sciences, Harvard University, [3]Dept. of Geological and Planetary Sciences, California Institute of Technology.

Introduction: Terrestrial climate changes caused in part by orbitally-induced variability in insolation are recorded in ice cores [1]. Similarly, Martian polar layered deposits (Figure 1) have been hypothesized to reflect climate change resulting from Milankovitch cycles [2, 3, 4]. However, deposition rates of the PLDs are poorly constrained, and thus the time-depth relationship in the stratigraphy is unknown and possibly non-linear.

Previous work has explored the relationship between insolation (determined by orbital characteristics) and formation of the PLDs through models [5, 6]. Some previous observational 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]. As with comparisons of terrestrial climate proxies to established records, however, there is a danger of successfully tuning unrelated records to match.

We seek to explore a variety of models for PLD formation and to extend the tuning approach, with the important addition of a statistical test [8] to assess the level of confidence that a match obtained by tuning is not spurious [9]. In a previous report [10], we described a simple model for the formation of PLDs in response to orbitally induced insolation variability, and suggested a statistical method for evaluating the significance of the tuned match. Here, we report the results of applying this statistical procedure to different PLD formation scenarios, and discuss the conditions in which such a procedure could identify an orbital signal in spite of the uncertainties in the PLD chronostratigraphy.

Modeled PLD Formation Scenarios: The first study to consider in detail how different PLD formation mechanisms influence the resulting stratigraphy [5] used highly simplified models, but revealed how sensitive the modeled stratigraphy was to factors such as ice deposition rates and thresholds, and thus hinted at the difficulty of detecting an orbital signal. Since PLD formation is poorly understood, we consider various mechanisms for how insolation affects ice deposition rate. In one class of models, we assume ice deposition rate is negatively correlated with insolation; in a second, we assume it is negatively correlated with insolation but goes to zero above a certain insolation threshold (i.e., contains hiatuses); in a third class of models, we assume ice deposition rate is negatively correlated with insolation but is negative (i.e., ablates away) above a certain insolation threshold. Figure 2 shows an example of a resultant synthetic PLD for each model class We assume that the observed brightness variations in PLD sequences are primarily controlled by variations in dust concentration. We note that models that include hiatuses and ablation are missing information about the planet's insolation history; we aim to discover how much information must be preserved to allow us to distinguish the quasi-periodic orbital signal from random records.

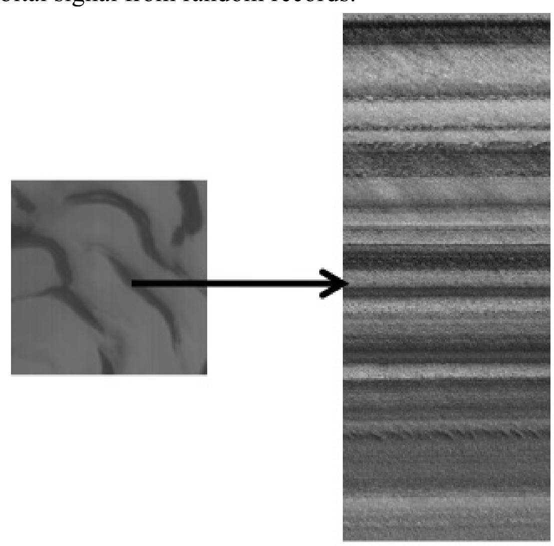

Figure 1: Image of a PLD sequence (right) inset into a trough on the northern Martian ice cap (left). Image has been corrected for topography to give the appearance of a vertical stratigraphic section.

Evaluating the Statstical Significance of Tuning: Conventional time-series analysis is limited by the assumption of a linear time-depth relationship, but the alternative tuning approach introduces a risk of identifying matches in unrelated records. We address this issue by using a dynamic time warping (DTW) algorithm and a Monte Carlo procedure. The DTW algorithm attempts to match an assumed forcing (an insolation time series) to a synthetic PLD record via tuning, as seen in Figure 3. The Monte Carlo exercise estimates the confidence level at which we can say that such a match was not spurious. We estimate this confidence level by attempting to match 200 randomly generated records with the insolation record, and noting the percentage of matches with a covariance less than or equal to the covariance of the insolation time series with the synthetic PLD.

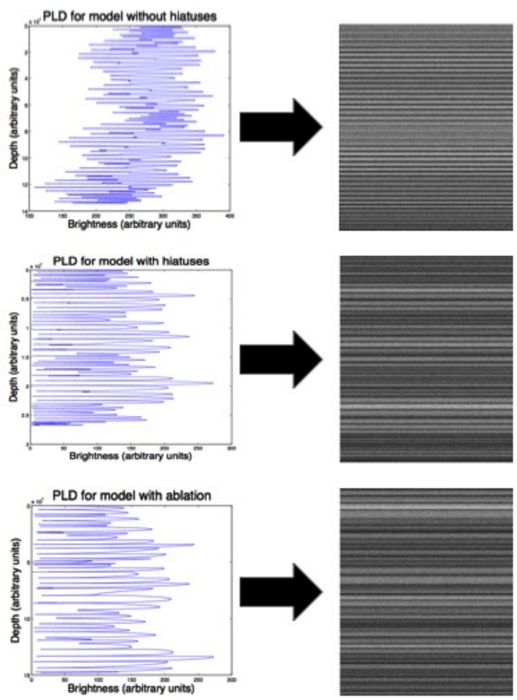

Figure 2: Model outputs showing, from top to bottom, instances of a model with neither hiatuses nor ablation, a model with hiatuses but not ablation, and a model with ablation. Figures on the left are plots showing brightness as a function of depth in arbitrary units; figures on the right show simulated images of the stratigraphy created by adding Gaussian noise to the model output.

Our 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 relationship between ice deposition rate and insolation. However, for formation mechanisms with ablation or hiatuses, our confidence level is more variable, and depends on model parameters such as the insolation threshold at which hiatuses or ablation begin occurring during ice deposition. If Martian polar ice begins ablating at an insolation of 243 W/m^2 or less, detection of an orbital signal is infeasible. If polar ice begins ablating at an insolation of 269 W/m^2 or higher, detection of an orbital signal is probably realistic, but confidence levels should be interpreted as upper limits due to model simplifications. The confidence level correlates positively with the fraction of time preserved in the stratigraphy, and negatively with insolation threshold values. Improved constraints on ice and dust deposition rates on Mars would indicate whether detection of an orbital signal in the PLDs is feasible, but statistical analysis does not reveal the problem to be necessarily intractable at our current state of knowledge. Our results should help constrain Martian climate history by providing a guide for interpreting actual images of PLD stratigraphic sequences, as reconstructed from orbital images or other future data.

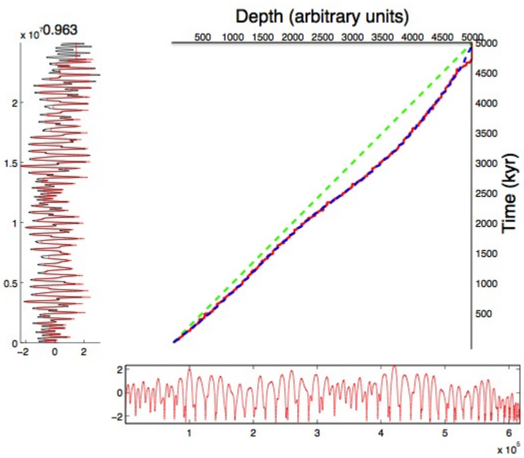

Figure 3: An output from our dynamic time warping algorithm. A PLD model output is compared with the past five million years of Martian insolation history. The DTW algorithm determines the best tuning of the PLD to the insolation history. The center graph is that of a cost matrix that the algorithm uses to make such a tuning, and the side graphs show normalized plots of the insolation (black) and synthetic PLD (red) against units of time and depth.

References: [1] Hayes, J.D. et al (1976), *Science 194*
[2] Murray, B.C. et al (1972), *Icarus 17,* 328-345
[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. [10] Sori, M. M. et al, (2011) 42nd LPSC.