Introduction: The Martian polar regions have layered deposits of ice and dust. It has been the overall goal of Mars polar research to determine whether these deposits preserve an interpretable record of climate and geological history on Mars[1]. In this work, we consider physical processes influencing the polar deposition rates of ice and dust and discuss how these processes can be expressed in terms of the solar insolation record. We further discuss how different processes influence the formation of layers and the expression of the solar insolation cycles in the stratigraphy, and how the resulting stratigraphy is constrained by observations[2].

Background: The stratigraphy of the North Polar Layered Deposits on Mars (NPLD) has been observed from orbit by radar and visual images. Radar imaging shows that the NPLD are several km thick with internal layering extending continuously over hundreds of km across the NPLD[3], and high-resolution images of equator-facing polar trough walls show a complex stratigraphy of dark and bright layers[4]. The layering is thought to be related to variations in dust content and modulated by solar insolation cycles.

The solar insolation record has been reliably calculated back to 20 Ma before present and shows large variations in orbital parameters over time[5]. Obliquity cycles of 120 ka and 2.4 Ma have resulted in dramatic changes of summer temperature at the poles and are thought to be reflected in the stratigraphy of the NPLD[1,6]. Understanding the stratigraphic imprint of solar insolation cycles is key to dating the NPLD and to derive a record of climate change from the layers, but the link between stratigraphy and these cycles has not been clear.

Methods: Our approach is to consider the physical processes controlling polar deposition of ice and dust and the resulting stratigraphy. We assume that deposition rates vary according to the solar insolation record and that the stratigraphy is a result of relative variations in polar ice and dust deposition over time. We assume that ice deposition rate is controlled by solar insolation at the North Pole, similar to suggested by previous work[7]. We assume a simplified parameterization of ice deposition rates in terms of solar insolation. We consider how different processes influence the deposition rates, and how they can be expressed in a simplified way. One important step is to distinguish between accumulation processes and ablation processes. Our formulation allows the possibility of negative deposition rates (formation of a lag deposit) at high obliquity.

We also derive a simplified parameterization of dust deposition rate in terms of surface temperature on Mars inspired by climate modelling results [8]. Dust deposition rates are not well understood, and the relative importance of dust devils in the polar deposition rate of dust at other epochs is poorly understood.

Constraints by observations: We compare our deposition rates and resulting stratigraphy against a high-resolution stratigraphic column[2] from a trough at 87.1°N, 92.6°E constructed from a stereo pair of images PSP_001738_2670 and PSP_001871_2670 from the High Resolution Imaging Science Experiment (HiRISE) (Fig. 1). The stratigraphic column identifies marker beds and sections of thin layers. Marker beds are erosionally resistant layers with a distinctive visual morphology and a thickness that was measured on a digital elevation model (DEM) constructed from the stereo pair.

With a set of parameterization constants, we are able to model the build up of layers in the NPLD over time as a function of the solar insolation record. We assume that marker beds form when the relative dust content exceeds a threshold value. Our method allow marker beds to be forming by two different processes, either because of low ice deposition rates or because of high dust deposition rates.

We compare our model stratigraphy with the observed stratigraphic column, and determine the set of parameters that provide the best fit to the observations. We discussed what matching criteria are necessary and what results of the best fit are well constrained.
Figure 1. Climate forcing and an example of model deposition rates over the last 2 mill. years. Obliquity (a), Maximum monthly average summer temperature over the North Pole (b), Monthly average temperature at the Equator during northern summer (c), Model ice deposition rates (d), model dust deposition rates (e), model fractional dust (d). Red lines mark marker beds formed by low ice deposition rates, gray lines mark marker beds formed by high dust deposition rates.