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Milankovitch-driven redistribution and fractionation of ice deposits on Mars.

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Abstract

The D/H isotopic ratio of polar ice deposits on Mars is modelled using GCM simulations. We predict variations at different orbital configurations and geographic locations that should be measurable by future missions.

1. Introduction

The North Polar Layered Deposits (NPLD) on Mars are thought to harbor a record of past climate [1-6]. Establishing a correlation between orbital element variation, climate, and the observed stratigraphy has remains an outstanding goal [1, 4-8]. Observation of layers and measurements of isotopic composition in ice cores on Earth reveal the past climate conditions and condensation temperatures [9], but additional effects exist due to factors such as distance from the shore, altitude and season [9]. Previous work [10] showed that on Mars temperature differences and the source reservoirs control the NPLD D/H ratio, thus the isotopic composition of an ice core reveals information not present in layer thicknesses alone. These findings motivate us to investigate and quantify processes that influence the D/H ratio in ice on Mars. We use the Laboratoire de Météorologie Dynamique (LMD) General Circulation Model (GCM) to study the effect of geography and past orbital elements on the fractionation coefficient via its temperature dependence.

2. Methods

Our GCM simulations track the full martian water cycle [11, 12]. Ice can precipitate from clouds or condense directly on the surface. The ice cap albedo is set to 0.4 to reproduce TES water vapor distribution. The model's spatial resolution is 64x64 (or 128x128 in select cases) with 28 vertical layers that span 100 km in altitude. The dust opacity is set 0.15, and we investigate variations with respect to this value. Ice is initially emplaced in the tropics and we allow the model run for 5 Mars years to reach steady state. The temperature dependent equilibrium fractionation coefficient [13] is given by:

$$\alpha = \exp(16288/T^2 - 0.0934) \qquad (1)$$

3. Results

Figure 1 shows a map of the surface temperature at the North polar region averaged during times of net ice accumulation. This "condensation temperature" varies in space. Condensation temperatures are generally lower for ice accumulating on top of the bright NPLD deposits compared with ice accumulating off the cap, and smaller variations are also seen across the cap. This variations are expected to be reflected in the fractionation coefficient at the time of deposition, and thus the D/H fluctuations.

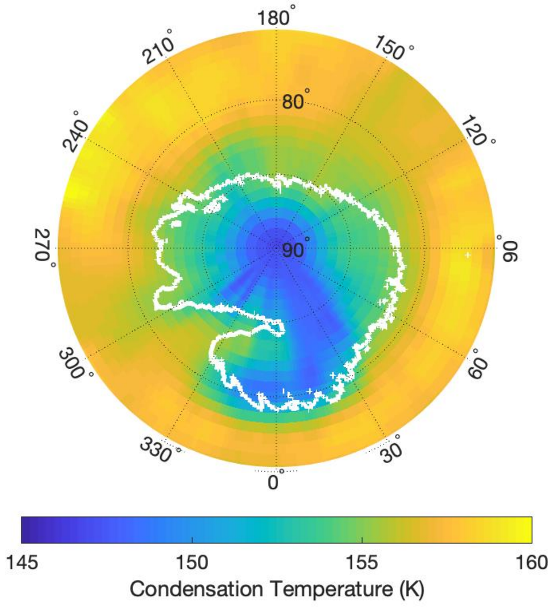

Figure 1: Average condensation temperature at times of ice accumulation in the North pole for an example past orbital configuration with $L_p = 90°, \epsilon = 20°, e = 0.093$. White contour indicates the approximate topographic boundary of the cap for reference. The GCM grid points have been interpolated to produce this smooth representation. Significant temperature variations are seen for ice accumulating at different locations.

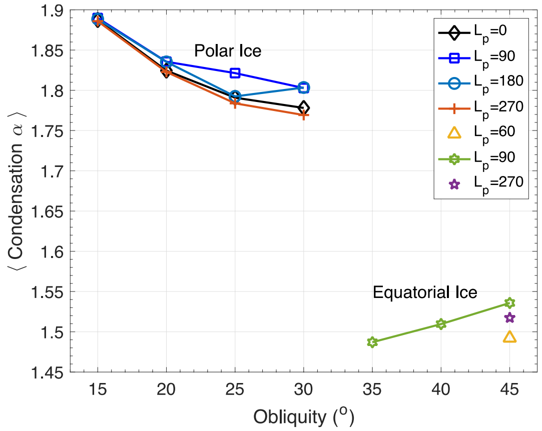

Figure 2: Average α at times of ice accumulation in the North Pole and in the equatorial region. Significant difference in α is seen between the two regimes, as well as variations within reservoirs deposited at different times.

At the relevant temperature, a 10° difference corresponds to approximately a 10% variation in α. The dependence of the surface fractionation coefficient α on obliquity is shown is Figure 2, for different perihelion positions parameterized by the solar longitude at perihelion, L_p. The typical values of α for ice depositing at the pole are higher by ~30% than that for ice accumulating in equatorial regions. The fractionation ratio depends strongly on the perihelion longitude, as well as on obliquity (and eccentricity, not shown). For lower obliquities and summer perihelion (longer, colder winters are coming) the value of α is larger. These effects may be understood because of both the reduction in polar temperatures due to reduced insolation, and the change in the season of condensation at different orbital configurations.

Figure 3 shows ice accumulation in the North Pole as function of L_p for different obliquities and constant eccentricity. This illustrates the significance of different solar longitudes at perihelion, as more ice accumulates during long winters distant from the Sun. Further variation with obliquity is seen.

4. Discussion

Our results indicate that in addition to source reservoir and average polar temperature effects as predicted previously by Vos et al. [10], more factors influence the D/H composition expected for NPLD ice. These effects include orbital elements configuration at time of deposition (particularly the perihelion season), as well as geographic location.

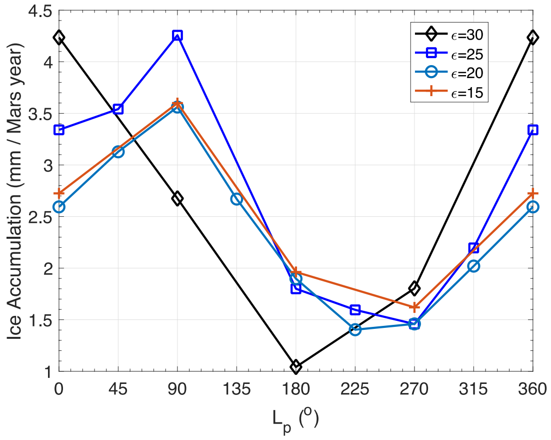

Figure 3: Ice accumulation at the North Pole as a function of L_p for different obliquities and $e = 0.093$. A dominant factor is the solar longitude at perihelion.

The polar ice is deposited at colder temperatures and hence with a substantially higher fractionation factor than that of equatorial deposits, reaffirming the assumptions of past models [10]. We also expect that condensation at the surface to differ from precipitation from clouds in its isotope composition, an effect which has not been studied here but should be included in future models. Variations in the D/H ratio of different reservoirs exchanging with atmosphere may also influence the atmospheric values observed on present-day Mars from both spacecraft and Earth.

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