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Depth, volume and density of Mars' seasonal polar caps

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Abstract

We have revisited the laser altimeter data obtained by the Mars Orbiter Laser Altimter (MOLA) [1,2] on the Mars Global Surveyor spacecraft between March 1999 and June 2001 to re-estimate [3] the depth of the accumulated CO_2, its variation with latitude and solar longitude, Ls, estimate its volume and infer the density of the deposited CO_2.

1. Introduction

The atmosphere of Mars is composed primarily of carbon dioxide, CO_2. During the winter seasons some of the CO_2 condenses onto the polar regions of the planet; in the summer season the precipitation sublimes back into the atmosphere. As winter approaches in the opposite hemisphere a very similar process of condensation followed by sublimation occurs creating a seasonal cycle in which 30% of the CO_2 atmosphere moves from one pole to the other with significant changes in atmospheric pressure. This process of exchanging atmospheric CO_2 with the polar caps has been well represented in Mars climate models and the seasonal change in the albedo of the surface has been observed photometrically for many decades.

2. Altimetry Data

The dataset was composed of MOLA altimeter residuals with respect to the best-fit global shape of Mars [4]. The total dataset was ~150 million measurements of elevation residuals referenced to the latitudes 50N & 50S. These elevation residuals are shown in Figure 1.

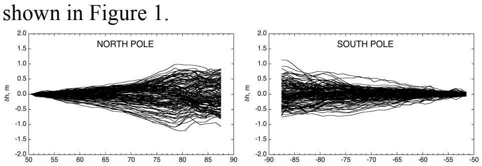

Figure 1: Elevation residuals referenced to 50N & S.

The figure shows ~160 profiles in each hemisphere of the mean residual in each 1 degree latitude band.

3. Depth of Precipitation

The residuals increase with latitude towards the pole with a full range of ~2 meters. Figure 2 shows the maximum depth with latitude independent of when the maximum depth occurs. The residuals were reference to latitude 50 because it is approximately the lowest latitude of seasonal deposition.

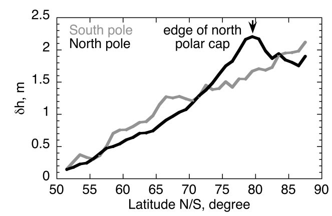

Figure 2: Maximum accumuation of CO_2 vs latitude. The average increase in depth is ~5 cm/degree. The maximum depth in the northern hemisphere occurs at the edge of the permanent cap. In the southern hemisphere the precipitation appears to increase almost linearly with latitude and may reflect the irregularity of the southern highlands and the lack of an identfiable polar cap boundary.

Sublimation begins as the planet warms in the Spring and Summer starting at latitudes nearest the equator and moving towards the pole. A northern hemisphere example is shown in Figure 3.

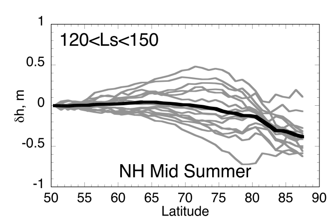

Figure 3: Example of northern mid-summer sublimation for 120<Ls<150. The larger positive values are for Ls<~135 and the larger negative values are for Ls> ~135. The black line is the average for the period.

4. Volume of Precipitation

We have used the average depth of the precipitation and the surface area of each 1-degree of latitude to estimate the volume of deposited material as a function of Ls. Figure 4 is an example of the southern hemisphere volume for late Spring.

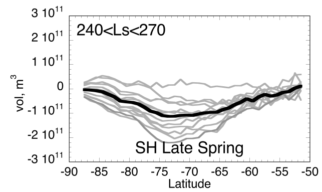

Figure 4: Change in volume during sublimation during the late Spring, 240<Ls<270. The black line is the average for the period. The curves above the avaerage are for Ls<~255; those below the average are for Ls>~255.

The data suggest sublimation in the north does not appear to be complete until the end of summer, particularly at high latitudes. In the south, sublimation is complete by the end of spring suggesting that the phasing of the seasons is not symmetric, probably as a result of the eccentricity of Mars' orbit and consistent with the longer winter and shorter summer in the southern hemisphere.

Figure 5 shows the total volume of precipitated material throughout the Mars year.

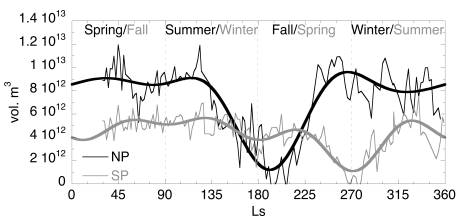

Figure 5: The total volume of precipitation on the surface during a single Mars year for latitudes ±50 and the N&S poles.

The volume in the north is remarkably constant except for the period mid summer through early Fall when sublimation seems to be greatest. In the south the minimum volume occurs around vernal equinox and overall the southern hemisphere has about half the volume of the northern hemisphere even though the winter season is actually longer in the south suggesting a more concentrated deposition, eg. ice or frost rather than snow.

5. Density Implications

Using estimates of the masses of the seasonal caps from gravity [5] and from Mars climate models [6] we can derive the average precipitation density. Since the northern hemisphere mass is estimated to be about half of the mass of the southern hemisphere and considering the volume of the north is about twice that of the south we obtain a significantly higher maximum density in the south of ~1200 kg/m^3 compared ~400 kg/m^3 in the north. This difference, if true, must indicate a different form of the precipitation in the south from the north. The most likely cause is significant block CO_2 ice in the south compared to snow like deposition in the north.

The density is very sensitive to errors in the volume of the precipitation and considering the probability of orbital errors we can only be confident that the densities of the seasonal precipitation are very different. In addition, we must remember that we only have altimeter data for 1 Mars year and it my not be typical.

References

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