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An examination of Mars' north seasonal polar cap using MGS: Composition and infrared radiation balance

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ABSTRACT

A detailed analysis of data from one revolution of the Mars Global Surveyor (MGS) is presented. Approximately 80% of this revolution observes the mid-winter northern seasonal polar cap, which covers the surface to <60°N, and which is predominantly within polar night. The surface composition and temperature are determined through analysis of 6–50 μm infrared spectra from the Thermal Emission Spectrometer (TES). The infrared radiative balance, which is the entire heat balance in the polar night except for small subsurface and atmospheric advection terms, is calculated for the surface and atmospheric column. The primary constituent, CO_2 ice, also dominates the infrared spectral properties by variations in its grain size and by admixtures of dust and water ice, which cause large variations in the 20–50 μm emissivity. This is modified by incomplete areal coverage, and clouds or hazes. This quantitative analysis reveals CO_2 grain radii ranging from ~100 μm in isolated areas, to 1–5 mm in more widespread regions. The water ice content varies from none to about one part per thousand by mass, with a clear increase towards the periphery of the polar cap. The dust content is typically a few parts per thousand by mass, but is as much as an order of magnitude less abundant in "cold spot" regions, where the low emissivity of pure CO_2 ice is revealed. This is the first quantitative analysis of thermal spectra of the seasonal polar cap and the first to estimate water ice content. Our models show that the cold spots represent cleaner, dust-free ice rather than finer grained ice than the background. Our guess is that the dust in cold spots is hidden in the center of the CO_2 frost particles rather than not present. The fringes of the cap have more dust and water ice, and become patchy, with warmer water snow filling the gaps on the night side, and warmer bare soil on the day side. A low optical depth (<1 in the visible) water ice atmospheric haze is apparent on the night side, and appears with smaller optical depth on the day side. The infrared radiative balance at the surface is typically 20–25 W m^{-2} in the central polar cap, with ~25% dips in the regions of dust-free CO_2. The atmospheric radiative terms are typically 1–3 W m^{-2}.

1. Introduction

The seasonal polar caps of Mars are composed primarily of solid carbon dioxide condensed from the thin ~6 mbar atmosphere, which was predicted by simple thermal balance models (Leighton and Murray, 1966), and which was confirmed by early measurements (Neugebauer et al., 1969; Herr and Pimentel, 1969; Larson and Fink, 1972). The conventional seasonal measure for Mars is given by the areocentric longitude of the Sun, L_S, with 0° defined as the vernal equinox in the northern hemisphere. The seasonal caps occur from about fall equinox (L_S = 180° in the north, L_S = 0° in the south) to summer solstice (L_S = 90° in the north, L_S = 270° in the south). Although the optical properties of CO_2 dominate the surface spectrum of, and the outgoing radiation from, the polar caps, water ice/snow and dust also play a role. CO_2 has very different properties from dust and water ice in the thermal infrared (Hansen, 1999), so the overall spectral properties depend mainly on the grain size of CO_2 and the amount of intimately or spatially mixed water snow or dust. Here I will show results from the analysis of the north seasonal cap in mid-winter, using data from one revolution of the Mars Global Surveyor (MGS). The analysis of infrared spectra from the Thermal Emission Spectrometer (TES) includes the determination of composition, grain size, and thermal radiative balance. The analysis is aided by surface elevation and morphology from the Mars Orbiter Laser Altimeter (MOLA).

I will present a brief overview of previous work on composition and radiative balance of the seasonal polar caps. A more comprehensive review is presented in Hansen (1999). The amount of non-CO_2 contaminants (dust, H_2O ice) in the seasonal caps in the literature is discussed first. Larson and Fink (1972) found abundant CO_2 in the southern cap at $L_S \approx 213°$, and determined an upper limit for water ice contamination of about 1%. Near-infrared spectra of the southern seasonal cap at $L_S \approx 200°$ were acquired in 1969 by Mariner 7. The solar reflection spectrum below 4 μm was studied by Calvin and Martin (1994), who found variation across the cap in surface coverage near the edge, in water ice contamination,

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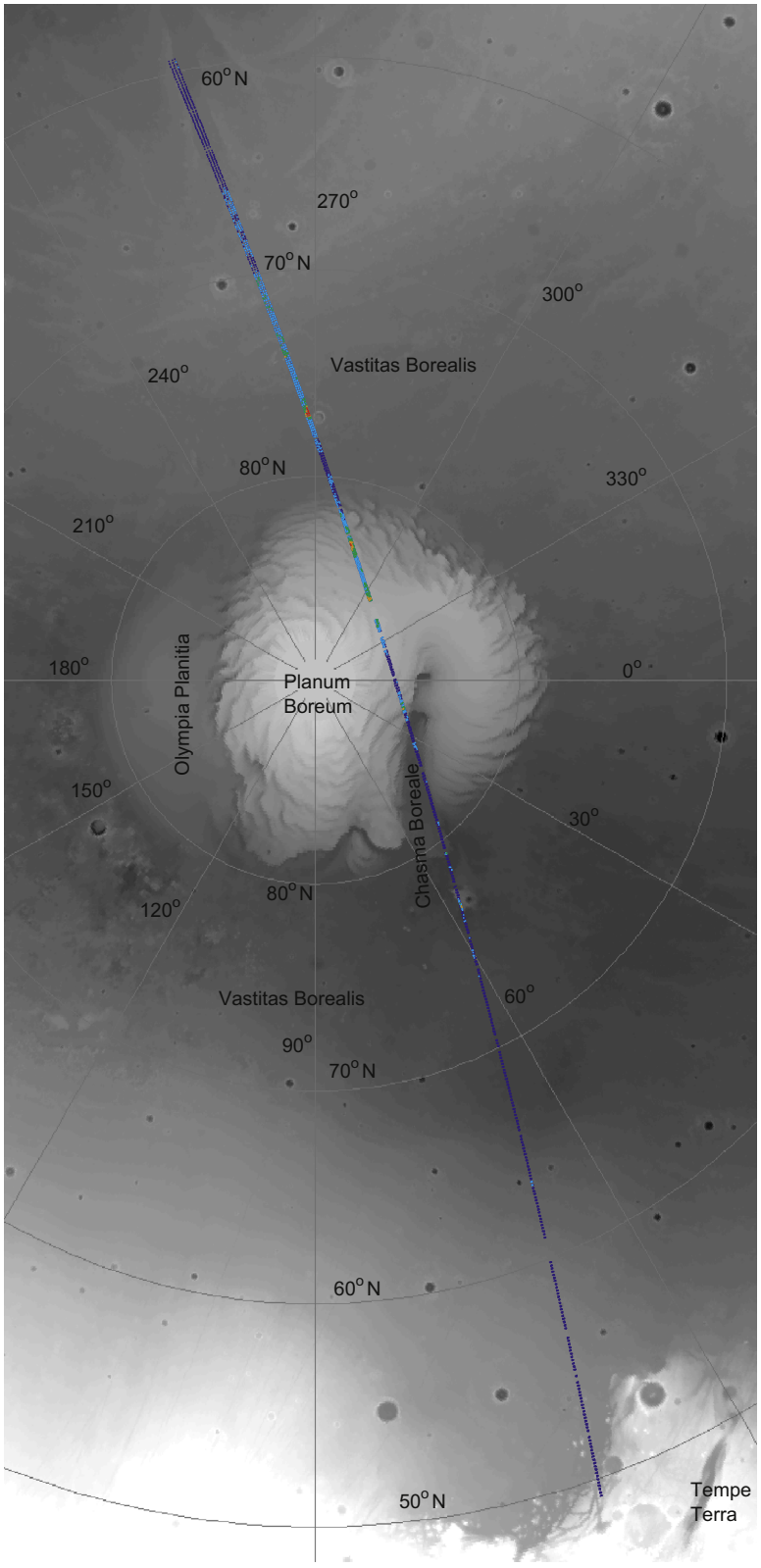

Fig. 1. Map of the orbit data analyzed here. The base map is a MOLA mosaic in polar stereographic projection. Each spectrum is a small point, three wide across the track. The cold spots, defined by brightness temperature differences between 25 and 12–18 μm (see Fig. 2), are colored red (>20 K), orange (15–20 K), green (10–15 K), and cyan (5–10 K), with the rest of the measurements in blue implying <5 K.

and in effective CO_2 particle size. The water ice concentration was estimated at 0.1–0.2% and was somewhat larger at the edge and some places in a more central region. Hansen and Martin (1993) modeled two of the Mariner 7 spectra and determined similar numbers for the grain size and water ice contamination, but the inclusion of a small amount of dust was also found necessary. An example Mariner 9 infrared spectrum (10–50 μm) of the north seasonal cap in mid-winter was modeled in Forget et al. (1995),