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Water-ice clouds and dust in the north polar region of Mars using MGS TES data

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Abstract

Water-ice and dust optical depths in Mars' north polar region are mapped as function of season, latitude and longitude, and their characteristics and variability on a geographic, seasonal, and interannual basis are discussed. We use water-ice and dust optical depth data provided by the Mars Global Surveyor (MGS) Thermal Emission Spectrometer (TES), covering nearly three northern spring and summer periods. We find that interannual variability exists in both the water ice and dust behavior, although there are trends that repeat year to year as well. The optical thickness of the north polar hood (NPH) exhibits interannually varying longitudinal structure, both during springtime recession and late-summer onset. We define the characteristics associated with the transition to and from the NPH and find that the disappearance occurs near $L_s = 75^\circ$ and the reappearance near $L_s = 160$–165°. We find that the late spring to early summer time frame is characterized by very low water-ice optical depths and enhanced dust activity, with a preference for lower water-ice and higher dust optical depths in the 0–90°W quadrant. We see possible evidence for stationary wavenumber 2 systems in a few of the maps examined.

Keywords: Mars; Water ice; Clouds; Dust; North polar; MGS; TES; Mars atmosphere

1. Introduction

The behavior of water ice and dust in the Martian atmosphere is important for understanding the overall Martian climate system, which is characterized by three main cycles: water, dust, and CO_2. Understanding these cycles will lend insight into the behavior of the atmospheric dynamics; the atmosphere's ability to transport dust, water ice, and vapor to different parts of the planet; and how that ability changes as a function of dust and water ice loading.

Because the north polar region has the largest detectable source of water present on Mars today (e.g., Boynton et al., 2002; Feldman et al., 2002; Kieffer et al., 1976; Mitrofanov et al., 2003), examining water-ice clouds and their relationship to dust in this area is of interest. Furthermore, understanding the behavior of dust and water-ice clouds may provide insight into the differences in behavior between the polar caps and in the formation of the polar layered deposits.

North polar water-ice clouds are prevalent near the edge of the seasonal polar cap in the spring and late summer/early fall, forming the polar hood (e.g., Briggs and Leovy, 1974; James et al., 1994; Leovy et al., 1972). Another well-recognized water-ice cloud feature is the aphelion cloud belt that extends from approximately 10°–30°N from early spring through mid-summer (e.g., Clancy et al., 1996; Tamppari et al., 2000, 2003), a time when the polar water-ice cloud optical depths are quite low. The aphelion cloud belt and the southernmost edge of the polar hood can be seen clearly in longitudinally averaged maps such as those provided by Smith (2004, Fig. 5). Dust optical depths, on the other hand, tend to be higher in the north polar region during spring and summer than in the equatorial regions (e.g., Smith, 2004). This is due to increased frequency of cap-edge dust storms (James and Cantor, 2001).

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Previous studies of water-ice clouds and dust in the north polar region of Mars have typically focused on imaging data sets (e.g., Wang and Ingersoll, 2002; James and Cantor, 2001, Cantor et al., 2001) without optical depth estimates, or on longitudinally averaged infrared data sets that do provide optical depth estimates (e.g., Liu et al., 2003; Smith, 2004). Additionally, older data sets (pre-MGS) either did not have full spectral capability (e.g., Viking infrared thermal mapper [IRTM]) or did not have multi-year coverage (Mariner 9). Water-ice clouds can be detected in the Viking IRTM instrument (Tamppari et al., 2000, 2003), but have not yet been fully studied in the polar regions using this data set, although some preliminary latitude-, longitude-, and season-resolved studies using IRTM data have been performed (Tamppari and Bass, 2000). Dust retrievals have been performed from the IRTM data set (e.g., Martin and Richardson, 1993), including the poles, but the focus was on global mapping and used a lat/lon bin size of $4^\circ \times 6^\circ$. The MGS spacecraft provides, for the first time, a multi-year data set with both good resolution and good, consistent spatial coverage. This data set enables us to perform high spatial and temporal resolution studies of the north polar atmospheric water-ice and dust variability.

Wang and Ingersoll (2002) examined north polar water-ice clouds, dust, and the relationship between them with MGS Mars Orbiter Camera (MOC) images. They examined wide-angle images acquired between $L_s = 135$–360° (1998–1999), covering mid- to late-summer in Mars Year 24 (MY24; MY definitions per Clancy et al., 2000 with MY1 beginning in 1955), and between $L_s = 0$–111° (2000), covering the spring and early-summer in MY25. They distinguished water-ice and dust clouds by using MOC's blue and red filters, respectively, but did not provide a quantitative estimate of optical depth for either the water ice or dust. They examined the development and decay of the north polar hood (NPH) as well as provided a description of spiral and lee wave clouds. They concluded that the NPH began to grow between $L_s = 165$–185° through a series of baroclinic storms that occurred during that season. They also showed evidence for a wavenumber two (two maxima and two minima in 360°) pattern in the NPH in the autumn and winter seasons. The study presented here complements their paper by examining water ice and dust in the infrared data set, providing quantitative optical depths. Additionally, we will also extend the examination into MY26, providing two full Martian spring and nearly three full summer periods.

Cantor et al. (2002) examined 783 dust storm events, including those in the north polar region, from $L_s = 107$–274° in MY24 using the MOC data set. They found that dust storms occur on the edges of the receding polar cap, particularly between $L_s = 130$–159°. For 117 of these storms, they calculated an approximate optical depth (estimated 30% uncertainty). The data discussed in this paper are complementary in that we provide more precise optical depths, although the TES spatial coverage and resolution are not as high.

Water-ice and dust observations are important for the Phoenix Mars Scout mission, launched on August 4, 2007 and subsequently to land in the Mars north polar region between 65° and 72°N. The Phoenix mission carries two experiments that will observe water ice and dust in the atmosphere, a solid-state imager, developed by the University of Arizona, and an upward-looking LIDAR, contributed by the Canadian Space Agency. The Phoenix engineering team is also interested in water-ice and dust optical depths because both will affect the amount of sunlight impingent upon the solar panels, thus modifying the amount of solar energy present to power the spacecraft and instruments. Dust in the atmosphere will affect the surface and near-surface atmosphere temperatures, which in turn could affect the amount of heater power needed to keep the spacecraft warm (note that the lander is passively cooled). Finally, the spacecraft entry, descent and landing will be affected by atmospheric density that in turn depends upon the amount of atmospheric dust present and the atmospheric temperature profile. For these reasons, understanding the amount and variability of both water ice and dust is important for mission planning as well as scientifically.

In this paper, we use data from the MGS TES experiment (Christensen et al., 1992) to map the water-ice clouds in latitude, longitude, and season in the north polar region over three Mars years (March 1, 1999–May 5, 2003). We examine spatial, seasonal, and interannual differences in the water-ice cloud and dust amounts. In the following section, we describe the data used and its uncertainties. In Section 3, we will describe the method used for producing the water-ice and dust maps, and we will fully describe the maps. Section 4 contains a discussion of the results, followed by Section 5, in which we present our conclusions.

2. MGS TES data

The water-ice and dust optical depth mapping done in this study utilizes the data from the MGS TES instrument. TES is an infrared interferometer/spectrometer operating in the spectral range 6–50 μm (Christensen et al., 1992). In particular, the water-ice clouds are retrieved using the ~12-μm ($825\,\mathrm{cm}^{-1}$) water-ice absorption feature and the dust is retrieved using the ~9-μm ($1075\,\mathrm{cm}^{-1}$) dust feature (Pearl et al., 2001; Smith, 2004). The MGS spacecraft is in a Sun-synchronous, nearly polar orbit (Christensen, et al., 2001). The spacecraft orbits Mars 12 times every 1-sol period covering the globe with equally spaced strips once a day. The data are taken around the local time of 1400 and 0200 h. In this paper, we use the daytime data (varies between about 12:30 and 14:30 in the polar region). At this time of day, water-ice cloud formation is likely near a minimum since the diurnal temperatures will be near the maximum (e.g., Pathak et al., 2004). As such, water-ice