

WATER CYCLING IN THE NORTH POLAR REGION OF MARS. L. K. Tamppari¹, M. D. Smith², A. S. Hale³, and D. S. Bass³, ¹NASA Jet Propulsion Laboratory (4800 Oak Grove Drive, Pasadena, CA 91109 leslie.k.tamppari@jpl.nasa.gov), ²NASA Goddard Space Flight Center (Michael.D.Smith.1@gsfc.nasa.gov), ³NASA Jet Propulsion Laboratory (MS 264-235, 4800 Oak Grove Drive, Pasadena, CA 91109 amy.s.hale@jpl.nasa.gov), ⁴NASA Jet Propulsion Laboratory (MS T1722, 4800 Oak Grove Drive, Pasadena, CA 91109 deborah.s.bass@jpl.nasa.gov).

Introduction: The Martian water cycle is one of the three annual cycles on Mars, dust and CO₂ being the other two. Despite the fact that detailed spacecraft data, including global and annual coverage in a variety of wavelengths, have been taken of Mars spanning more than 25 years, there are many outstanding questions regarding the water cycle.

There is very little exposed water on Mars today, in either the atmosphere or on the surface [1] although there is geological evidence of catastrophic flooding and continuously running water in past epochs in Mars' history [2] as well as recent (within about 10,000 years ago) evidence for running water in the form of gullies [3]. While there is little water in the atmosphere, water-ice clouds do form and produce seasonal clouds caused by general circulation and by storms [5-8]. These clouds may in turn be controlling the cycling of the water within the general circulation [e.g., 6].

The north polar cap region is of special interest as the residual cap is the main known reservoir of water on the planet today. The south polar residual cap may contain water, but presents a CO₂ ice covering, even during southern summer. This hemispheric dichotomy is unexplained and is especially puzzling due to the fact that the Martian southern summer is much warmer (due to Mars' eccentricity) than the northern summer. Recently, water has been found in the top meter of the surface in both the northern and southern high latitude regions [e.g. 8-9] indicating an even greater amount of water on Mars than previously known.

Background: In order to better understand the current climate of Mars, we seek to understand atmospheric water in the north polar region. Our approach is to examine the water transport and cycling issues within the north polar region and in/out of the region on seasonal and annual timescales. Viking Mars Atmospheric Water Detector (MAWD) data showed that water vapor increased as the northern summer season progressed and temperatures increased, and that vapor appeared to be transported southward [10]. However, there has been uncertainty about the amount of water cycling in and out of the north polar region, as evidenced by residual polar cap visible brightness changes between one Martian year (Mariner 9 data) and a subsequent year (Viking data). These changes were originally thought to be interannual variations in the amount

of frost sublimed based on global dust storm activity [10-12]. However, Viking thermal and imaging data were re-examined and it was found that 14-35 μm of water-ice appeared to be deposited on the cap later in the summer season [14], indicating that some water may be retained and redistributed within the polar cap region. This late summer deposition could be due to adsorption directly onto the cap surface or due to snowfall. The possibility that some of the water is seasonally sequestered in water-ice clouds and may allow later precipitation had not been previously considered. We address these issues by examining water vapor and water-ice clouds in the north polar region of Mars during the north spring and summer period.

Method:

Water-ice clouds. Water-ice clouds, in the north polar region, have previously been tentatively identified in the Viking era using the Infrared Thermal Mapper (IRTM) data [14] and in the Mars Global Surveyor (MGS) era using the Thermal Emission Spectrometer (TES) data ([15] and M. Smith, pers. comm., 2001). The Viking data provides only nadir pointed data, which necessitates separating the surface contribution from the atmospheric contribution. The technique used relies on the water-ice absorption feature at 11-microns. Specifically, it uses the 11- and 20-micron channels of the IRTM instrument along with a surface model to accurately remove the surface contribution [4]. For the Viking time frame, we are restricted to ice free surfaces and therefore do not see the entire north polar cap region throughout the spring and summer season.

With the MGS TES data, there exist both limb- and nadir-pointed data. The nadir-pointed data retrievals are currently performed for water ice clouds only over surfaces above 220 K (M. Smith, pers. comm.). The surface is colder than 220 K northward of 60° N at $L_s=0^\circ$, but this latitude limit moves gradually northward as spring progresses, reaching the pole just before $L_s=90^\circ$. The TES limb data do not have any complications due to cold surface temperatures. Therefore, water-ice clouds can be identified throughout the Martian season, even over the seasonal and residual polar cap.

MGS TES data over the poles are taken much more frequently than over other areas of the planet due to the nature of the orbit. The nominal TES observing sequence has limb-geometry observations taken every 10 degrees in latitude. The orbit of MGS is such that over a 2-sol period (approximately 1 degree of L_s), approximately 24 orbits of Mars are made with tracks spaced roughly evenly every 15 degrees in longitude. Therefore, in the polar region, while not as dense as the nadir-geometry observations, the limb-geometry observations help to fill out the data set and provide an additional cut through the atmosphere from which to identify clouds and vapor. The limb data also offer the possibility to detect the cloud heights as there are multiple spectra over the vertical range.

Water vapor. Smith *et al.* [17] have performed retrievals for the column-integrated abundance of water vapor using the rotational water vapor bands at 220–360 cm^{-1} . Atmospheric temperatures are first retrieved using the 15- μm CO_2 band (Conrath *et al.*, 2000). Next, a forward radiative transfer computation is used to find the column-integrated water abundance that best fits the observed water vapor bands. At this time water is assumed to be well-mixed up to the condensation level and then zero above that. A total of six water vapor bands between 220 and 360 cm^{-1} are observed in TES spectra and the widths and relative depths of all six bands are very well fit by the synthetic spectra. Because the spectral signature of water vapor is spectrally very distinct from those of dust and water-ice, we can easily separate the relative contributions from each component (dust, water-ice, and water vapor) on a spectrum-by-spectrum basis.

Recent analysis with MGS TES data has shown evidence for water vapor "pulses" as the seasonal north polar cap sublimates [15]. This could be linked to the previous late-summer season deposition, discussed above. Additionally, there may be some differences in the details of the water vapor as a function of latitude and season between the Viking era and the current era. Any such differences would help identify and characterize the degree of interannual variability in the water vapor. There is also indication of latitudinal water vapor transport as a function of season seen through longitudinally averaged water vapor [16 and Figure 1]. We will present our latest results on water vapor transport, spatially and temporally.

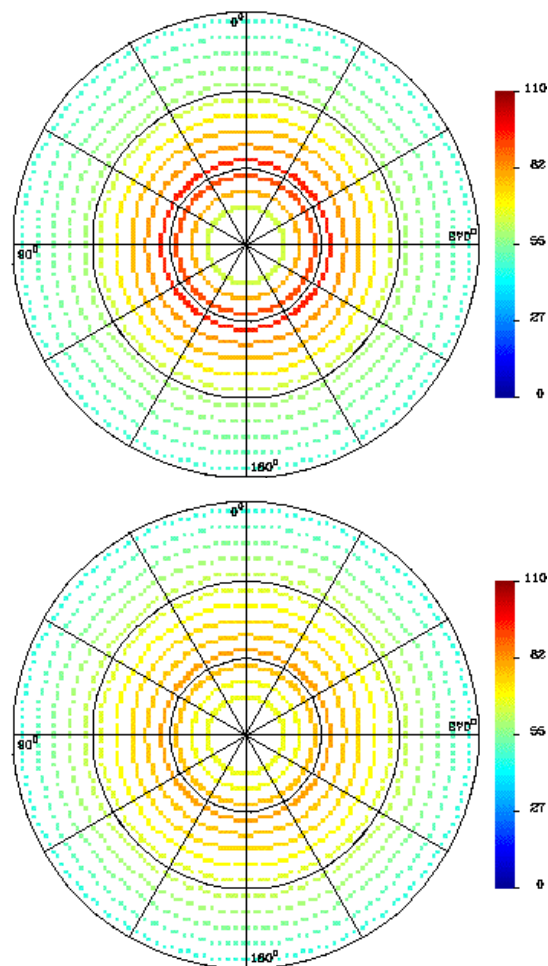


Figure 1. Longitudinally averaged water vapor as a function of latitude for $L_s=115^\circ$ (top) and $L_s=117^\circ$ (bottom). The amount of water vapor in the centermost ring (highest latitude ring) shows about a 15 pr micron enhancement in $2^\circ L_s$, while the 3rd and 4th rings from the center show a decrease in vapor amount.

Dust. Dust in the north polar region can play an important role in the water cycling story in a couple of ways. One, by acting as cloud condensation nuclei, dust may allow water-ice clouds to form and could potentially cause gravitational settling and sequestering of the water. Two, dust may be sufficiently radiatively active to prohibit clouds from forming and potentially allowing a greater degree of water vapor transport out of the polar region. The MGS TES instrument also spans the wavelength region over which Martian dust is absorbing, allowing its retrieval.

Surface Temperature. The north polar region surface temperature during the northern polar season can be compared to the Viking era to further elucidate potential interannual differences and to understand the vapor, water-ice, and dust retrievals. MGS TES is also

capable of measuring the surface temperature. Surface temperatures can confirm that carbon dioxide is not present on the cap surface, implying that any brightening is likely water ice.

Intercorrelation of data: To date, there has been no comprehensive study to understand the partitioning of water into vapor and ice clouds, and the associated effects of dust and surface temperature in the north polar region. Ascertaining the degree to which water is transported out of the cap region versus within the cap region will give much needed insight into the overall story of water cycling on a seasonal basis. In particular, understanding the mechanism for the polar cap surface albedo changes would go along way in comprehending the sources and sinks of water in the northern polar region. We approach this problem by examining TES atmospheric and surface data acquired in the northern summer season and comparing it to Viking data when possible. Because the TES instrument spans the absorption bands of water vapor, water ice, dust, and measures surface temperature, all three aerosols and surface temperature can be retrieved simultaneously. This presentation will show our latest results on the water vapor, water-ice clouds seasonal and spatial distributions, as well as surface temperatures and dust distribution which may lend insight into where the water is going.

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