WATER VAPOR RETRIEVALS OVER NORTH POLAR CRATERS WITH ICE MOUNDS: CONSTRAINTS ON SUBLIMATION RATES.

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Introduction

Craters with ice-covered floors dot the landscape of Mars's north polar region. Garvin et al. 2000 showed that orbital topographic measurements of several of these "ice-associated" craters reveal interior mounds, whose topologies are indicative of thick deposits of ice, rather than central peaks associated with the impact event. Only craters among those with diameters > 9.5 km, and northwards of 70°N are found to contain such mounds (Conway et al., 2012).

The lower latitudes, with respect to the polar cap, of many of these craters implies that their environments are more sensitive to seasonal changes, in terms of temperature variations and the effects associated with the movement of the seasonal CO_2 and H_2O caps. Furthermore, the spatial isolation of the craters from the polar cap comes with the possible implication that these ice mounds form and evolve in a process independent from that of the cap itself (Brown et al., 2008; Conway et al., 2012). Thus, ice-mound bearing craters provide an opportunity for studying Martian cryospheric processes responding to substantially different boundary conditions from those of the polar cap.

Multiple formation mechanisms for these ice mounds have been proposed. These include the mounds as (1) remnants after retreat of a previously more extensive polar cap, (2) formed by material from the radial ice deposits around the polar cap transported via saltation, (3) being frozen remnants of hydrothermal circulations initiated by the crater impact event, (4) the result of the tapping of deep aquifers via sub-surface faults beneath the crater, and (5) formed by deposition of atmospheric water vapor (Brown et al., 2008; Conway et al., 2012). Scenario 1 is considered unlikely because layered ice drapes the existing topography for a majority of the mounds, suggesting growth from a central core rather than as an eroded polar cap remnant (Conway et al., 2012). 2 has been discounted on the basis of the craters typically being separated from radial ice deposits by hundreds of kilometers, a distance that would require millions of years (spanning radically different climatic conditions at the pole over orbital cycles) to traverse via saltation (Werner and Kocurek, 1997; Brown et al., 2008).

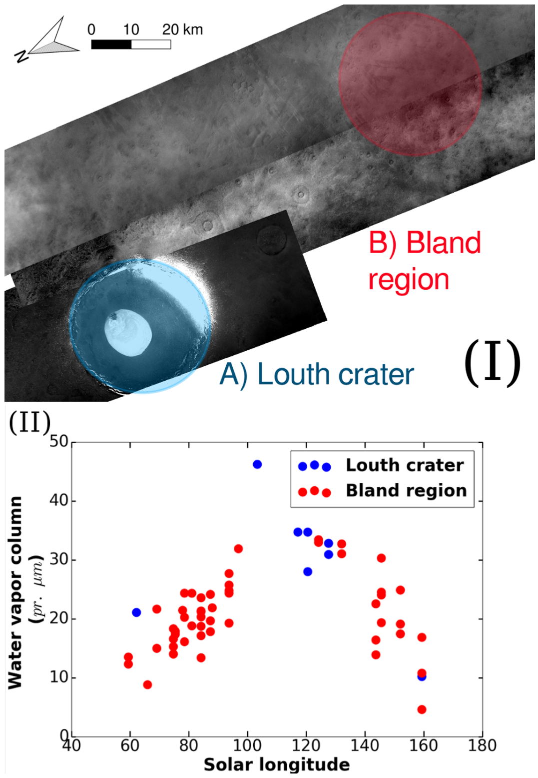

Fig. 1*. (I) CTX images of Louth crater ($103.2°E$, $70.2°N$) and surrounding region. The area over which water vapor retrievals were performed are shown for Louth crater and a nearby "bland" region without exposed ice visible in imagery and denoted in blue and red respectively. (II) Retrievals of water vapor over Louth crater and the nearby bland region as a function of solar longitude for Mars years 24-27.*

3 and 4 are considered inconsistent with the smooth, unfolded, unfaulted and regular layers that make up the mounds (Conway et al., 2012). Simply by exclusion, formation of the ice-mounds via atmospheric deposition is currently favored. Nevertheless, several observations also support atmospheric deposition as responsible for mound formation. Armstrong et al. 2005 observed that Korolev crater's ($164.5°E$, $72.8°N$) mound is consistently ~10 K cooler than the surrounding ice-free terrain throughout the year, remaining close to the water frost point and thereby enabling deposition. Al-

though initiation of this temperature depression likely requires a preexisting ice deposit of several meters or more, it enables growth of such a deposit into a larger mound. Furthermore, the aforementioned smooth and regular layering of the mounds observed in HiRISE (the High Resolution Imaging Science Experiment aboard Mars Reconaissance Orbiter) imagery is most consistent with a regular and continuous formation mechanism such as atmospheric deposition (Conway et al., 2012). The higher atmospheric pressure inside craters relative to surrounding regions is also thought to reduce sublimation resulting from free convection. (Ingersoll, 1970). Finally, craters on Mars are expected to have inward flowing katabatic winds, based on both mesoscale modeling (Toigo, 2003) and observations of "bullseye" dune morphologies within craters in the south polar region (Fenton and Hayward, 2010). These winds would facillitate transport of atmospheric water vapor into the crater.

Despite these observations, which all serve to support the notion that deposition of atmospheric water vapor to form the ice mounds is indeed a possibility, none can actually confirm that this is the actual formation mechanism. We perform retrievals of atmospheric water vapor over these mound-bearing craters to directly constrain any surface-atmosphere interactions, with emphasis on quantifying the sublimation rate. If the sublimation occurring during the warmer seasons is found to be less than the expected deposition during the winter months, this would indicate that the mound could indeed grow via atmospheric deposition (Conway et al., 2012), providing strong support for this being the formation mechanism.

Methods

We retrieve column abundances of water vapor using nadir observations by the Thermal Emission Spectrometer (TES) aboard Mars Global Surveyor. TES is a fourier-transform spectrometer with a spectral range of ~ 200 - $1700\ cm^{-1}$ ($\sim 6-50\mu m$) and two spectral resolutions of either 6.25 or 12.5 cm^{-1}. The TES instrument has 6 independent detectors (Christensen et al., 2001), each with a spatial resolution on the ground of $\sim 3 \times 3$ km.

Our retrievals of water vapor use five absorption bands between 240 and 360 cm^{-1}. The data are matched to iterated model radiances computed using a plane-parallel atmosphere. Water vapor absorption in the model is calculated using the correlated-k method with lines from the GEISA database (Jacquinet-Husson et al., 2011), which have been corrected, in approximation, for broadening by CO_2 rather than air. Scattering is ignored, while the surface thermal emission, haze and ice extinction, and absorption due to water vapor are all considered. Water vapor is assumed to be uniformly mixed. The retrievals from each detector are averaged to yield an observation footprint of 12×9 km (including "smear" from the two second integration time).

Retrievals are carried out over Louth ($103.2°E, 70.2°N$) and Korolev craters, which are selected for being the two lowest latitude mound-bearing craters, resulting in higher surface temperatures which facillitate retrievals. The water vapor column as a function of season are compared between the craters and neighboring regions, where ice deposits are not seen in imagery from the Contextual Camera (CTX) aboard the Mars Reconnaissance Orbiter. The water vapor column is expected to be dominated by ambient atmospheric water vapor, to which any sublimation would be added, and thus cannot be used to directly constrain the sublimation rate. Nevertheless, by comparing the crater mounds to adjacent areas without exposed ice, any enhancement in sublimation over the crater would become apparent, assuming negligible variations in the ambient atmospheric water vapor content over these ~ 100 km scale distances. The regions over which the retrievals are performed are seen in **Fig. 1-I** and **Fig. 2-I**, with the seasonal evolution of the water vapor columns shown in **Fig. 1-II** and **Fig. 2-II**. The data encompass multiple Mars years. Retrievals are only performed during the summer months, when the surface temperature is warm with respect to the atmosphere, and thus the atmosphere is oberved in absorption.

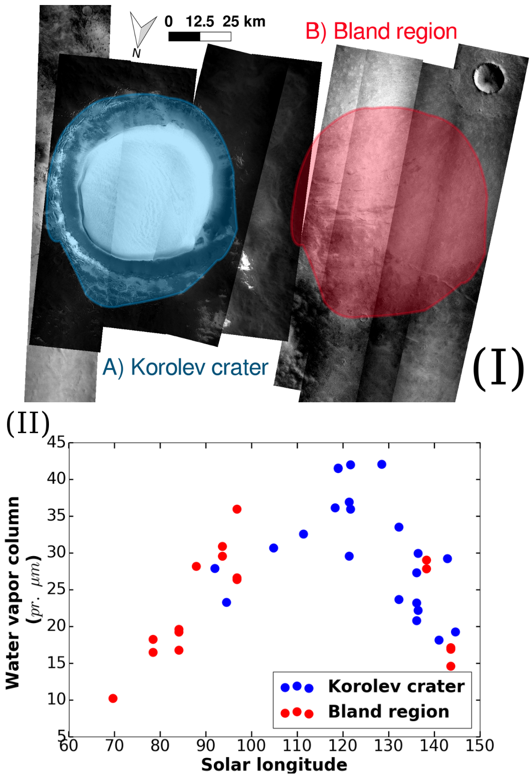

Fig. 2. *Same as Fig. 1, except for retrievals over Korolev crater ($164.5°E, 72.8°N$) during Mars years 24-27.*

Results and discussion

The water vapor column as a function of the season over the mound-bearing craters and their neighboring regions seen within **Fig. 1-II** and **Fig. 2-II** are largely indistinguishable upon inspection. As such, any consistent enhancement in the water vapor column over the craters due to sublimation of the mounds is not immediately apparent. Nevertheless, several aspects of the retrievals warrant further investigation.

Firstly, there is an outlier of a high water vapor column of 47 $pr.\mu m$ at $L_s \cong 105$ over Louth crater **(Fig. 1-II)**. As there is not a contemporaneous retrieval over the neighboring bland region, it is unclear whether this could be a result of mound sublimation during the times of high surface temperatures associated with the summer solstice. Studies of the seasonal behavior of the water vapor column have shown that there is a pronounced peak in the north polar regions around solstice (Smith, 2002), thus it is quite possible that this value is simply representative of this general region during this time. However, evaluating additional "bland" regions in the surrounding area will shed light on this.

With regards to the comparisons with neighboring regions, it will be useful to not only take the additional step of averaging the seasonal behavior of multiple surrounding regions for comparison with the mound-bearing craters, but also to confirm with spectra from either TES or CRISM (Compact Reconaissance Imaging Spectrometer on MRO) that these areas are indeed "bland" in terms of lacking exposed ground ice. Even if there is no exposed ice in these regions, it is likely that the entire area has shallow ground ice just centimeters below the regolith. In turn, the sublimation expected from exposed ice may not be significantly higher than that from ice several centimeters below the surface. We are estimating the sublimation rates that can be expected given the surface temperatures and pressure conditions for the region as retrieved by TES.

Finally, we are working to quantify the inherent errors of the water vapor retrievals. Even if no statistically significant differences in the water vapor column are found between the mound-bearing craters and their surrounding regions, we would be able to place upper limits on sublimation rates of the mound such that the water vapor would not be observed within the error of the retrievals. Whether the sublimation rate can be directly inferred, or an upper limit is placed on it, we will provide valuable constraints on the feasibility of atmospheric deposition as a formation mechanism for these mounds.

References

Armstrong, J. C., Titus, T. N., Kieffer, H. H., 2005. Evidence for subsurface water ice in Korolev crater, Mars. Icarus 174 (2 SPEC. ISS.), 360–372.

Brown, A. J., Byrne, S., Tornabene, L. L., Roush, T., 2008. Louth crater: Evolution of a layered water ice mound. Icarus 196 (2), 433–445.

Christensen, P. R., Bandfield, J. L., Hamilton, V. E., Ruff, S. W., Kieffer, H. H., Titus, T. N., Malin, M. C., Morris, R. V., Lane, M. D., Clark, R. L., Jakosky, B. M., Mellon, M. T., Pearl, J. C., Conrath, B. J., Smith, M. D., Clancy, R. T., Kuzmin, R. O., Roush, T., Mehall, G. L., Gorelick, N., Bender, K., Murray, K., Dason, S., Greene, E., Silverman, S., Greenfield, M., 2001. Mars Global Surveyor Thermal Emission Spectrometer experiment: Investigation description and surface science results. Journal of Geophysical Research 106871 (23), 823–23823.

Conway, S. J., Hovius, N., Barnie, T., Besserer, J., Le Mouélic, S., Orosei, R., Read, N. A., 2012. Climate-driven deposition of water ice and the formation of mounds in craters in Mars' north polar region. Icarus 220 (1), 174–193.
URL dx.doi.org/10.1016/j.icarus.2012.04.021

Fenton, L. K., Hayward, R. K., 2010. Southern high latitude dune fields on Mars: Morphology, aeolian inactivity, and climate change. Geomorphology 121 (1-2), 98–121.
URL dx.doi.org/10.1016/j.geomorph.2009.11.006

Garvin, J., Sakimoto, S., Frawley, J., Schnetzler, C., 2000. North Polar Region Craterforms on Mars: Geometric Characteristics from the Mars Orbiter Laser Altimeter. Icarus 144 (2), 329–352.

Ingersoll, A. P., 1970. Mars: Occurrence of Liquid Water. Science 168 (3934), 972–973.

Jacquinet-Husson, N., Crepeau, L., Armante, R., Boutammine, C., Chédin, A., Scott, N. A., Crevoisier, C., Capelle, V., Boone, C., Poulet-Crovisier, N., Barbe, A., Campargue, A., Chris Benner, D., Benilan, Y., Bézard, B., Boudon, V., Brown, L. R., Coudert, L. H., Coustenis, A., Dana, V., Devi, V. M., Fally, S., Fayt, A., Flaud, J. M., Goldman, A., Herman, M., Harris, G. J., Jacquemart, D., Jolly, A., Kleiner, I., Kleinböhl, A., Kwabia-Tchana, F., Lavrentieva, N., Lacome, N., Xu, L. H., Lyulin, O. M., Mandin, J. Y., Maki, A., Mikhailenko, S., Miller, C. E., Mishina, T., Moazzen-Ahmadi, N., Müller, H. S. P., Nikitin, A., Orphal, J., Perevalov, V., Perrin, A., Petkie, D. T., Predoi-Cross, A., Rinsland, C. P., Remedios, J. J., Rotger, M., Smith, M. A. H., Sung, K., Tashkun, S., Tennyson, J., Toth, R. A., Vandaele, A. C., Vander Auwera, J., 2011. The 2009 edition of the GEISA spectroscopic database. Journal of Quantitative Spectroscopy and Radiative Transfer 112 (15), 2395–2445.

REFERENCES

Toigo, A. D., 2003. Meteorology of proposed Mars Exploration Rover landing sites. Journal of Geophysical Research 108 (E12), 1–19.

Werner, B. T., Kocurek, G., 1997. Bed-form dynamics: Does the tail wag the dog? Geology 25 (9), 771–774.