THE MARTIAN NORTH POLAR WATER CYCLE.
A. J. Brown[1] and W.M. Calvin[2] , P. Becerra[3], S. Byrne[3], [1]SETI Institute, 189 N. Bernardo Ave, Mountain View, CA (abrown@seti.org), [2]Geological Sciences, University of Nevada, Reno, [3]Lunar and Planetary Laboratory, University of Arizona, Tucson.

Introduction: We have used observations from the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) of the north polar cap during late summer for four Martian years, to monitor the summertime water cycle in order to place quantitative limits on the amount of water ice deposited and sublimed in summer. We have identified regions and periods of 'net deposition' and 'net sublimation' on the summer north polar cap. Regions of the cap undergo a 'mode flip' from sublimation to deposition mode and the timing of mode flips is latitude dependent. We show how this process explains late summer brightening of the north polar cap.

Methods: The Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) is a visible to near-infrared spectrometer on the MRO spacecraft that is sensitive to near infrared (NIR) light from ~0.39 to ~3.9μm [1]. The MARs Color Imager (MARCI) is a super wide angle, fish eye lens camera with 1024 pixels-wide CCD [2]. As in previous studies of the springtime recessions of the north and south poles [3,4] we produced 1000x1000 pixel mosaics of all the CRISM mapping data available for each summer two week period (equivalent to one period in the MRO planning cycle). We used MARCI images to track visual changes and cloud activity during the summer period to ensure atmospheric effects did not affect our observations.

H_2O index: We tracked the variations in the H_2O index [4-6] over the parts of the cap that received CRISM coverage throughout the summer period over four Mars Years. The index is based on the depth of the water ice 1.5μm absorption band. It is high when water ice is present, and grows with the water ice grain size. When deposition of fine grained ice occurs, the H_2O index decreases, because finer grained ice scatters light back to the observer more readily and in turn decreases the depth of the 1.5μm H_2O absorption band [7].

Previous work on brightening of the north polar cap albedo: A long standing problem of the Martian climate is the summer brightening of the north polar cap. This was first reported by Kieffer [8] using IRTM data, and subsequently observed with TES by Titus and Kieffer [9]. Bass and Paige [10] used Viking IR thermal mapper (IRTM) and Mars Atmospheric Water Detector (MAWD) measurements to determine the peak amount of water vapor above the north polar cap. They found that the lowest visible albedo was observed between L_s=93-103 and water vapor was released after L_s=103. They found the visible albedo increased after L_s=103, and the temperatures were too warm for re-de

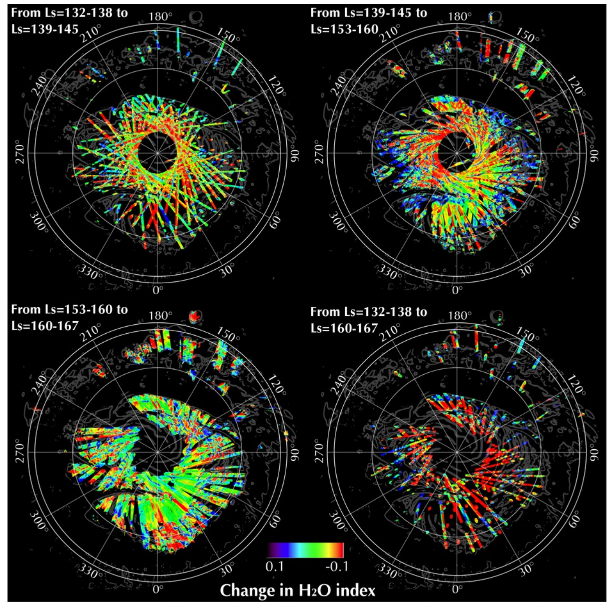

Figure 1 – Changes in H_2O index for MY28 showing net deposition in red colors and net sublimation in blue. The bottom right image is a summary of the whole period from L_s=132 to L_s=167.

position of CO_2 ice. They suggested that the center of the cap would be an area of preferred deposition of H_2O ice because it was colder than the rest of the cap. They presented a model of the NPRC ice cap as a cold trap for water vapor. Under this model, sublimation of water ice during spring and summer builds up water vapor in the atmosphere until L_s=103, after which time the water vapor is deposited as fine grained H_2O ice accumulated on top of the cap, as temperatures cool in late summer.

Results: Using the comprehensive, multiple year visible and near infrared mosaic dataset supplied by the MRO spacecraft, we have been able to confirm and extend the Bass and Paige model for water deposition on the North polar cap. We have also established for the first time the summer cycle of water ice absorption band signatures on the north polar cap.

Variations in H_2O index: Figure 1 shows four H_2O mosaics from Mars Year 28 that show the deposition or sublimation of water ice for that two week period as tracked by changes in the H_2O index. Regions in red show decreases in H_2O index due to condensation of fine grained ice while regions in blue show increases in H_2O index due to net sublimation. The bottom right image summarizes water ice deposition for the late summer (L_s=132-167) period, showing blue around the periphery where water ice is undergoing net sublimation and red in the interior where the cap is undergoing net deposition of water ice over this time period.

'Mode flips': We also show that in a key region in the interior of the north polar cap, the absorption band depths grow until L_s=130, as reported in [5], followed by a period when they begin to shrink, until they are obscured at the end of summer by the north polar hood (Figure 2). This behavior is transferable over the entire north polar cap, where in late summer regions 'flip' from being net sublimating into net condensation mode as the weather cool (Figure 3). This transition or 'mode flip' happens earlier for regions closer to the pole, and later for regions close to the periphery of the cap. For some parts of the periphery of the cap, there are regions where water ice absorption band depths have not been observed to decrease over the time we have observed them, suggesting that they may remain in net sublimation mode during the entire summer season and only go into condensation mode in winter.

Figure 2 shows individual spectra at 'Point B', a region on Gemini Lingula, the 'tongue' of the north polar cap. These spectra show that this region undergoes a 'mode flip' around L_s=130.

Total deposition of water ice during summer. Under the assumption that the shrinking of grain sizes is all due to the deposition of fine grained water ice, we have approximated the total amount of water ice deposited on the cap each summer, which equates to 70 microns of deposition over the L_s=132-168 late summer period. This amount is considerably more than the ~6 microns of deposition of water ice on the south polar cap during the summer period as reported in [11].

Conclusions: We have used CRISM mapping observations of the Martian north polar cap to quantify the deposition of water ice in summer. We have analyzed changes in albedo and water absorption band maps for the entire north polar region as a function of space and time. We identify 'net deposition' and 'net condensation' regions and periods and present a unified model of how these regions change over the course of an entire Martian boreal summer. These two identified modes are illustrated in Figure 3.

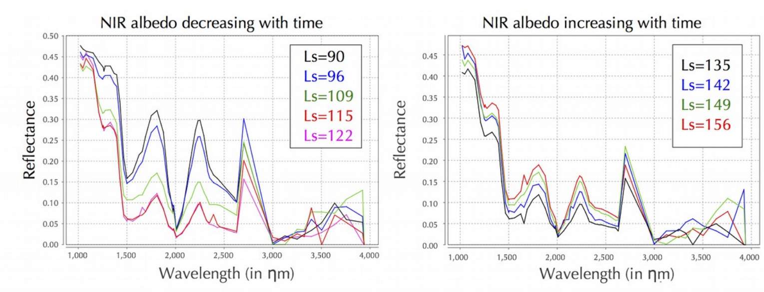

Figure 2 – CRISM MSP spectra over L_s=90-156 period on Gemini Lingula, showing a 'mode flip' reversing the NIR albedo decrease to increasing after L_s=130.

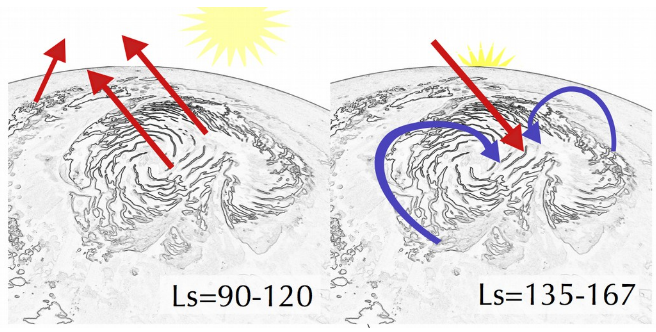

Figure 3 – Cartoon representation of deposition/sublimation 'mode flips'. Dates given are relevant for the Gemini Lingula region (where the arrows point in the right image).

Take home messages: 1. We have identified regions and periods of 'net deposition' and 'net sublimation' on the Martian summer north polar cap.

2. Regions of the cap undergo a 'mode flip' from sublimation to deposition mode and the timing of mode flips is latitude dependent. Subtle discrepancies between the expected and observed latitudinal dependence remain for future investigation and will be discussed at the conference.

3. Studies such as this one have revealed the path forward for science studies into the transport of water in the Martian climate cycle. Using CRISM and MARCI, we have now quantified the annual spring and summer amounts of water ice deposition for both poles by direct observation. These figures are crucial to our understanding of the construction and ongoing stability of the caps under today's climate. However, there is a clear and pressing need to understand the fall and winter 'dark side' of the Martian polar region that is impenetrable to passive instruments like CRISM and MARCI and instead requires multi-wavelength lidar instruments such as the recently proposed *ASPEN* concept [12].

References: [1] Murchie, S. et al (2007) *JGR* **112** doi:10.1029/2006JE002682 [2] Malin, M.C. et al. 2001 *JGR* **106** 17651 [3] Brown A. J. et al. (2010) *JGR,* **115**, doi:10.1029/2009JE003333. [4] Brown A. J. et al. (2012) *JGR,* **117**, doi:10.1029/2012JE004113. [5] Langevin, Y. et al. (2005) *Science* **307**, 1581. [6] Appere, T. et al. *JGR* **116** doi:10.1029/2010JE003762 [7] Bohren, C. (1983) *JOSA A* **73** 1646 [8] Kieffer (1987) *MEVTV Workshop*, LPI, Houston, p. 72-73. [9] Titus, T.N. and Kieffer, H. (2001) *Icarus* **154** 162-180 [10] Bass D.S. and Paige, D.A. (2000) *Icarus,* **144** 397-409. [11] Brown, A.J. et al. (2014) EPSL, 406, 102 doi:10.1016/j.epsl.2014.08.039 [12] Brown, A.J. et al. (2015) *JQSRT* **153**, 131-143 doi:10.1016/j.jqsrt.2014.10.021