QUANTIFICATION OF A PROCESS OF MULTI-YEAR, POLE-WIDE, SUMMERTIME H_2O ICE DEPOSITON ON THE CO_2 ICE CAP OF THE SOUTH POLE OF MARS. A.J. Brown[1] , S. Piqueux[2] and T. N. Titus[3] [1]SETI Institute, 189 N. Bernardo Ave Mountain View, CA 94043, abrown@seti.org, [2]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dve, Pasadena, CA 91109, [3]USGS Astrogeology Science Center, Flagstaff, AZ, 86001. Author website: http://abrown.seti.org

Introduction: The Martian southern cap has been thought to be composed of relatively pure CO_2 ice until minor water ice signatures were observed in 2004 [1]. However, temporal and spatial variations of these water ice signatures have remained unexplored, and the origins of these water deposits remains an important scientific question. To investigate this question, we have used observations from the Imaging Spectrometer instrument (CRISM) on the Mars Reconnaissance Orbiter (MRO) spacecraft of the southern cap during austral summer over four Martian years to search for variations in the amount of water ice. We report below that an as-yet-undetermined process causes the magnitude of H_2O ice signatures on the southern cap to rise steadily throughout summer, particularly on the west end of the cap.

This study deepens our understanding of the Martian water cycle, which is crucial for astrobiology and future human exploration. This process may also play a significant role in the climate budget of modern day Mars.

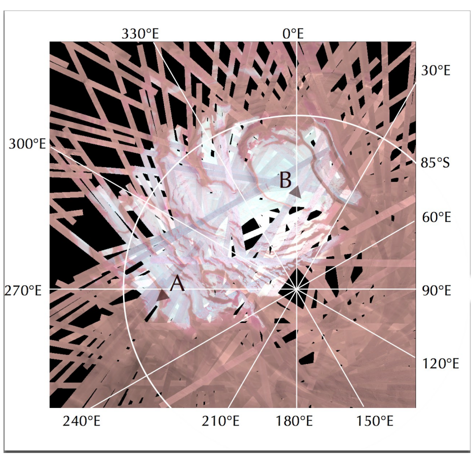

Figure 1 - CRISM mosaic of south polar residual cap (SPRC) in Mars Year 28,511 compiled during aerocentric longitude Ls=304-319 (mid summer). The locations of Point A (265.5E, 86.1S) and Point B (1.0E, 87.0S) are shown.

Methods: Our primary means of quantification of the south polar residual cap (SPRC) summer water ice cycle comes from mosaics and spectra constructed of the CRISM global mapping data during Mars Year (MY) 28-31. CRISM is a visible to near-infrared spectrometer onboard the MRO spacecraft that is sensitive to near infrared (NIR) light from ~0.39 to ~3.9 µm and is operated by the Applied Physics Laboratory at Johns Hopkins University. We used the multispectral (MSP and HSP) TRR3 I/F data that are available from the Planetary Data System. In CRISM mapping mode 10x on-instrument binning is employed in the cross-track direction. Consequently the mapping swathes we use are 60 pixels across, covering approximately 10.8 km on the surface [2] with a down and cross track resolution of ~182 m. The length of each swathe is controlled by exposure time and is variable depending on commands sent to MRO.

Results: We discuss two lines of evidence for pole-wide H_2O ice deposition here. The first line of evidence for H_2O ice deposition is the residual cap ice identification maps in Figure 2. Following previous studies [3,4] we use a H_2O index threshold of 0.125 to indicate that surficial H_2O is present. CO_2 ice is detected using a band analysis routine described [5]. Positive identification of CO_2 ice is indicated by a threshold 1.435 µm band depth of 0.16.

The ice identification maps show almost complete coverage of the residual cap in CO_2 ice (shown in red) and little to no H_2O ice in the early summer period (L_s=310). The cap presents an excellent ***witness plate*** for summertime deposition at this point. On the right of Figure 2, however, we have ***superposed*** the CRISM observations in the L_s=310-330 time period. These show strips of cyan where CRISM has detected small but significant increases in the 1.5 H_2O µm band. As can be seen from the CRISM mosaics in Figure 2, the effect is not just around the edges of the cap, as report-

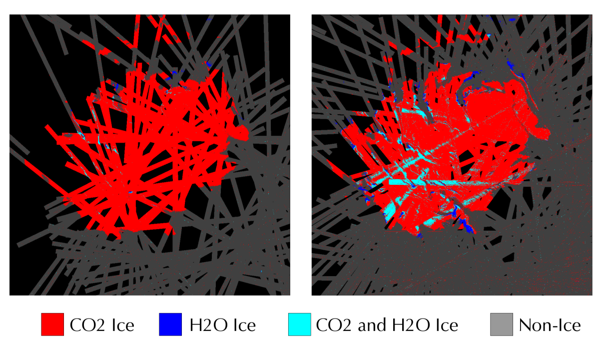

Figure 2 - Martian Year 28 southern summer ice identification mosaics. On left is the mosaic containing images from L_s=304-311. Note the almost complete coverage by CO_2 ice (in red). On right is the mosaic constructed images spanning L_s=320-342 overlain on the left image. NOTE that this water ice signature is not just constrained to the edges of the CO_2 ice cap but covers the entire cap where CRISM obtained observations.

ed, for example in [7], but covers the entire cap where CRISM has observations. The red areas of the map are largely regions that do not have CRISM coverage, and so retain their red colour from the left image.

Our second line of evidence stems from spectra extracted from extracted through summers from several test points, one of which we discuss here. Figure 3 shows a set of individual CRISM MSP spectra (no averaging or binning has been done) prior to H_2O ice deposition (starting at L_s=261) and throughout summertime (finishing at L_s=337) from 265.5 deg E, 86.1 deg S (marked as Point A on Figure 1). The spectra show a marked decrease in the 1.5 µm band that causes a decrease in the shoulder of the CO_2 ice absorption band at 1.4 µm. We attribute this change in band depth to the presence of increasing amounts of H_2O ice through the summer season.

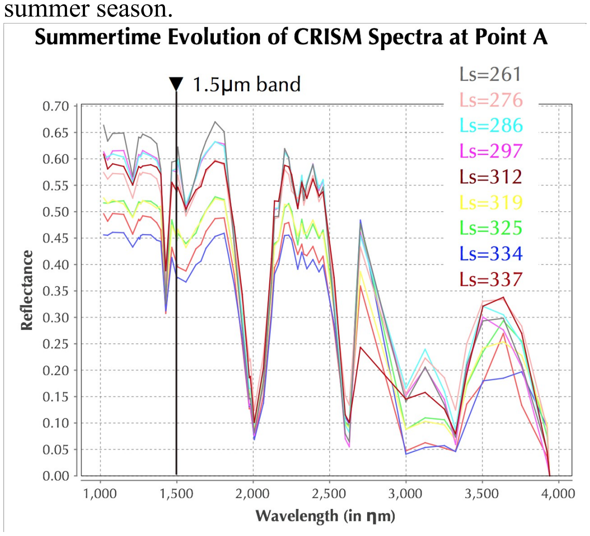

Figure 3 - CRISM summertime MSP spectra (from Point A in Figure 1) showing increase in H_2O ice absorption band for Mars Year 28 in late summer (pixels are ~180m across). The spectra were all taken close to Point A (265.5E, 86.1S; see Figure 1). Note overall decreasing albedo and increase in strength of H_2O absorption band at 1.5 µm.

Quantification: In order to estimate the amount of water ice deposited, we make the simplest assumption that the thickness of the water ice layer is a minimum of the derived grain size diameter (dH_2O=0.2mm or $0.2x10^{-6}$km) from a radiative transfer calculation. The only physical justification for this is that the water ice must be optically detectable and therefore at least one optical pathlength should be available for passage of vertically propagating photons. The true situation will be far more complex. We make the obviously simplified assumptions that: 1.) the residual SPRC has an approximate area of 200,000 sq. km [3], 2.) the SPRC is uniformly covered in summertime by a layer of water ice layer 3.) and that the H_2O ice is distributed in a "checkerboard" fashion (see Figure 4) and occupies 0.3 * 0.05 = 0.015% of this area. With these assumptions, the amount of water ice deposited would have a volume of $2x10^5$*0.3*0.05*0.2x10-6=$6x10^{-4}$ km^3. This is the volume of 240 terrestrial Olympic swimming pools. We regard this as a minimum estimate because it is likely that the deposit could be as thick as 10 grain diameters (10.dH_2O). This must be balanced with the fact that it is not clear from our present observations that the entire SPRC is covered by the same amount of water ice. Nevertheless, assuming an atmospheric Martian water ice budget of ~0.1 km^3 [8], the amount of water ice participating in this process will make up as much as 0.6% (at minimum, for 0.2mm thick ice deposit) to 6% (at maximum, for 2mm thick ice deposit) of the atmospheric Martian water budget. We consider this a first order approximation and hope that it will spur future research to further refine this estimate.

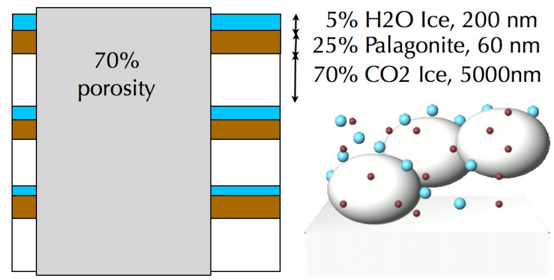

Figure 4 – Current layered (Shkuratov) model of the Martian ice pack and (bottom right) a more realistic future model using non-overlapping spherical grains.

CO_2 "re-coating": For each Martian year observed, the CO_2 residual cap has been "re-coated" during winter with CO_2 ice. This may have taken place by snowfall and/or direct surface condensation during the austral winter [9-10]. We find "relatively pure" CO_2 ice at the start of each austral summer in our CRISM mosaics (Fig. 2). This shows the "re-coating" process is cyclic and at least stable on observable time scales [11].

Acknowledgements: We would like to thank the entire CRISM Team, particularly the Science Operations team at JHU APL. Piqueux's contribution was carried out at the Jet Propulsion Laboratory, under a contract with NASA.

References: [1] Bibring, J-P. et al (2004), *Nature* 428 627-630. [2] Murchie, S. et al. (2007) *JGR* 112 [3] Brown, A.J. et al., (2010) *JGR* 115, E00D13 doi:10.1029/2009JE003333 [4] Brown, A.J. et al. (2012) *JGR* 117, doi:10.1029/2012JE004113 [6] Brown, A.J. (2006) *TGARS* 44, 1601-1608 [7] Langevin, Y. et al. (2007) JGR 112, E08S12 [8] Christensen, P.R. (2006) *Geosci. Elements* 2 151-155 [9] Forget, F. (1998) *Icarus* 131, 302-316 [10] Hayne, P. (2013) *Icarus* 231, 122-130 [11] Haberle, R. and Jakosky, B. (1990) *JGR* 95, 1423-1437