SEASONAL ALBEDO CHANGES ON MARS FROM MOLA RADIOMETRY AND TES: SEEKING AN EXPLANATION FOR APPARENT "SUMMER SNOW". Rongrong Lu[1], Shane Byrne[2] and Maria T. Zuber[3]; [1]Department of Earth, Atmospheric and Planetary Sciences, E34-370, Massachusetts Institute of Technology, Cambridge, MA 02139; lurr@mit.edu, [2]Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139; Now at: University of Arizona, Tucson, AZ 85721. shane@quake.mit.edu, [3]Department of Earth, Atmospheric and Planetary Sciences, 54-918, Massachusetts Institute of Technology, Cambridge, MA 02139; zuber@mit.edu.

Introduction: Radiometry data from the Mars Orbiter Laser Altimeter (MOLA) have identified an anomalous late summer brightening of the northern hemisphere of Mars. We investigate possible causes of this brightening – deposition of CO_2 or water frost. We have developed a surface mixing model to attempt to match the observed albedo increase and simultaneous surface temperature data. Our results indicate water frost is the most likely brightening agent.

Motivation: MOLA radiometric observations of the northern mid- and high- latitude regions have identified an unexplained increase in brightness during late summer when CO_2 frost would not be expected to be present [1]. This is at odds with the standard paradigm for the behavior of the Martian CO_2 cycle [2], where CO_2 frost would not be expected.

Fig. 1a shows the temporal coverage of the MOLA radiometry dataset. In this figure each pixel represents a zonal average of which falls into a 1 degree in solar longitude by 2 degrees in latitude (centered at grid) bin. Some small gaps in this coverage can be seen and are mostly due to solar conjunctions, along with occasional spacecraft glitches. The end of altimetry operations in June 2001 created a longer gap in coverage as the instrument was tested and ultimately reprogrammed to act exclusively as a radiometer. From this figure, we can see that the overall pattern of albedo change on Mars is approximately repeatable from year to year. Fig. 1d shows albedo changes at specific latitudes, In this figure, each point represents the zonal average of data that falls into a 1 degree (in L_S) by 10 degree (in latitude, centered at 40°N, 60°N, 70°N, and 80°N) bin. The first day of fall (at solar longitude L_S=180°) denotes the expected onset of CO_2 frost deposition in the northern hemisphere. However, the data show a consistent increase in brightness initiating earlier than the first day of autumn (circled in black). Fig. 1d shows that the late summer brightening phenomena can also be seen in previous years (despite some data gaps). This repeatability indicates that the apparent phenomenon that we seek to explain is not due to instrumental effects.

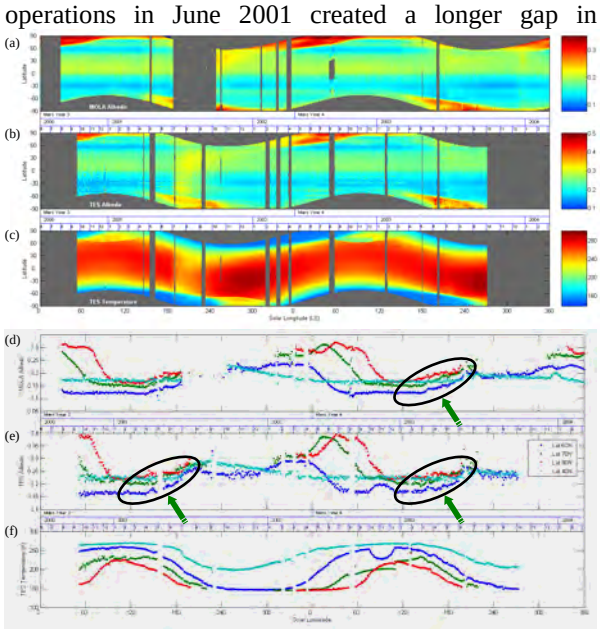

Figure 1: Observations of albedo and temperature collected by MOLA and TES.

Fig. 1b and 1c show the temporal coverage of radiometry and temperature datasets from the Thermal Emission Spectrometer (TES), together with zonal-averaged plots in Fig. 1e and 1f showing repeatable albedo and temperature fluctuations over two years. Unsurprisingly, the TES albedo data confirm the existence of the late summer brightening.

Possible Explanations: We developed a fractional frost model, assuming the Martian surface can be partially frosted during the late summer. The surface is represented by a mixture of bare ground and ice. Both the albedo and the temperature measurements are an average due to the mixture of radiance reflected and emitted from terrain which is either bare or frosted.

With this model, we first convert the albedo-time function into a fractional frost coverage as a function of time. We assume linear mixing (appropriate for spatially segregated mixtures) and obtain the end-member ice and bare ground albedo from the zonally-averaged MOLA albedo curve during mid-winter and summer (Fig. 1d).

Then we relate the fractional frost coverage to the temperature variation. The bare-ground temperature variation was simulated using a thermal model with appropriate thermophysical parameters [3]. The temperature of ice was set to be a free parameter within a range from 148K to 240K. The modeled

effective temperature, which TES would measure, was calculated using a forth order combination of the two-end-member temperatures in the ratio previously derived from the albedo data. Using a grid search algorithm, we found the best-fit ice temperature by minimizing the difference between the modeled mixed-surface temperature and the TES measured temperature. The temperature of the unknown frost can tell us whether the frost is CO_2 ice or water ice.

Results and Discussion: Our approach and results are summarized in Fig. 2 and Fig. 3 for latitude 60°N and 70°N, respectively. Fig. 2a and 3a show the effective albedo observed by MOLA versus L_S in Mars year 3 and 4 respectively. We calculated the corresponding fraction of frost coverage, shown in Fig. 2b and 3b. Fig. 2c and 3c show the best-fit modeled surface temperature, in which the green dashed line shows the bare ground temperature variation obtained from a thermal model, the blue dotted line shows the surface temperatures predicted from fractional frost coverage, and the red dotted line shows the TES-measured surface temperatures. The figures show close agreement between the model results and measured

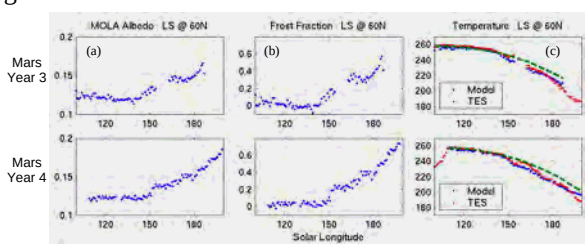

Figure 2: Fraction frost model result on latitude 60°N.

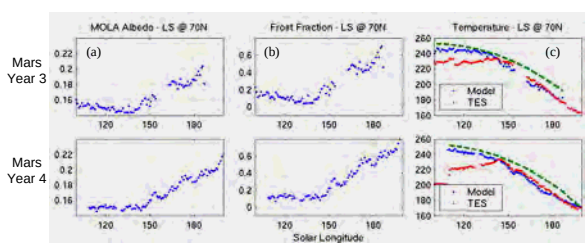

Figure 3: Fraction frost model result on latitude 70°N.

temperature data. The best-fit frost temperature is 195K in Mars year 3 and 201K in Mars year 4 for latitude 60°N. Similarly, the best-fit frost temperature is 170K in Mars year 3 and 172K in Mars year 4 for latitude 70°N.

This approach has several limitations (such as not including atmospheric scattering of radiation) which limit its ability to predict temperatures at all times of year. An obvious temperature valley in the 60°N TES temperature curve can be seen (Fig. 1f and Fig. 2c bottom) during Mars year 4 between L_S=75 and 105. There is also another temperature anomaly in the 70°N TES temperature shown as a temperature discontinuity at about L_S=105 of Mars year 4. The reason for these temperature anomalies is still unknown and is possibly due to atmospheric effects (especially clouds).

As we discussed above, the temperature of the unknown frost may shed some light on its composition. Our results confirm that, if the brightening is caused by some fractional frost deposit on the surface, then this frost is most likely condensed water ice as these ice temperatures are too high for stable carbon dioxide ice.

Conclusion: In this analysis we provide a possible explanation as to why the Martian surface is observed to start brightening during the late-summer/early-fall, before the sun sets when CO_2 frost is expected to condense. We conclude the most likely reason is that H_2O frost from atmospheric vapor starts to accumulate during the late summer on part of the Martian surface. The fractional frost model indicates that the best fit between observed albedo and temperature data occurs by choosing frost temperatures of about 170K~200K, which is the range that water vapor can condense. Although the water content in the present day Martian atmosphere is small (~10 precipital micrometers) condensation of even a fine layer can be detected from orbital remote sensing. Our model shows that up to 60% of the Martian surface could be covered by frost during the transition time from late summer to early fall.

References: [1] Zuber M. T. and Smith D. E. (2003) *Third Mars Polar Conf.*, Banff, Canada. [2] Leighton R. B. and Murray B. C. (1966) *Science*, 153, 136-144. [3] Putzig et al. (2005) *Icarus*, **173**, 325-341.