SUBLIMATION KINETICS OF CO_2 ICE AND EVOLUTION OF THE MARTIAN POLAR CAPS. D.G. Blackburn[1], K. Bryson[1], V. F. Chevrier[1], L. A. Roe[1] and K. F. White[2], [1]Arkansas Center for Space and Planetary Science, University of Arkansas, Fayetteville, AR 72701, USA, [2]Department of Physics & Astronomy, Ball State University, Muncie, IN 47306, USA <dgblackb@uark.edu>.

Introduction: The south martian polar cap is predominately composed of CO_2 ice [1,2]. Early modeling of the polar caps suggested that they were in equilibrium with the ~6 mbar CO_2 atmosphere [2], and various observations have shown a cyclicity of growth and retreat, following martian seasons [3]. Other studies show that CO_2 ice is only a thin veneer on the surface of a probably much thicker ice layer [4]. This veneer is too small for the caps to be in equilibrium with the atmosphere [5,6], suggesting that the polar caps are very young [7]. Therefore, larger unidentified CO_2 reservoirs in the martian subsurface are required, possibly adsorbed CO_2 in the regolith [8,9], to buffer the much larger atmosphere. Or the total budget of CO_2 is present in the atmosphere, and Mars today has much less CO_2 than other telluric planets.

The majority of dynamic models of the polar caps are based on CO_2 ice sublimation, lacking laboratory confirmation. We report the experimentally measured sublimation rate of pure CO_2 ice under simulated martian conditions, and compare them to data from MOLA, MOC, HiRISE and CRISM.

Methods: Dry ice was packed into a beaker with a thermocouple above and below the surface of the dry ice. Our planetary environmental chamber was evacuated to less than 0.09 mbar, filled with dry gaseous CO_2 (g) to atmospheric pressure, and cooled to between 0 and -10ºC. Once stable, the chamber was opened and the sample was placed on a top loading analytical balance inside the chamber. The chamber was evacuated to 7 mbar and once stable mass, pressure, and temperature were recorded every minute for ~1 hour. Pressure and atmospheric temperature were maintained between 6.5 and 7.5 mbar and -11 to -1ºC, respectively.

Results: The mass loss of CO_2 is very linear, with R^2 coefficients above 0.99. The mass loss in g min^{-1} is converted into sublimation rate in mm h^{-1}. The average value for CO_2 ice is 1.20 ± 0.27 mm h^{-1}. These results are less than one order of magnitude higher than measurements of polar caps retreat, 0.13-0.19 mm h^{-1} [3] and 0.36 mm h^{-1} [5], suggesting a common process for the sublimation on Mars and in our chamber.

Discussion:

Heat transfer process: The CO_2 sublimation process is governed by heat transfer between the chamber and the ice, and by diffusion of the sublimated molecules from the surface. The temperature below the ice surface is measured to be constant, 148-153 K, indicating that conduction has caused the ice to reach internal thermal equilibrium. As a result, the surface and interior of the ice are at the same temperature, eliminating conduction into the ice as a heat transfer model. Therefore sublimation occurs because the atmosphere is too warm compared to the cold ice surface (263 to 273K against 150K). Thermal conduction in the CO_2 atmosphere is too low to be an efficient process in the chamber. Therefore, sublimation of CO_2 ice is controlled by radiation from the walls. Our calculations show that radiative energy from the walls and conduction from the atmosphere gives a sublimation rate of 0.97 mm hr^{-1}, a value close to experimental results, 1.2 mm hr^{-1}.

Application to Mars: Our experiments show that the behavior of CO_2 ice on Mars is largely dependent on the intensity of surface insolation. Based on this we predicted sublimation rates at latitudes 86.5º N and S. By integrating the sublimation rates over a martian year, we predicted the changes in CO_2 thickness in the martian polar regions and compared them to the MOLA observations of surface altitude variations, averaged at constant latitude [3]. Both the model and MOLA altitude variations show a net transfer of 0.32 cm from the south to the north polar caps over a year. The agreement between our purely sublimational model and the MOLA data indicates that there is a loss in CO_2 from the south polar cap, which is in agreement with the eccentricity of the martian orbit which causes the intensity of irradiance for the southern hemisphere summer to be larger than for the northern hemisphere.

In order to better understand the precise dynamics of the polar caps, we focused on HiRISE images. Smoother surfaces are observed at higher elevations than layers presenting an irregular surface (Fig. 1). CRISM observations of these features show that the top flat features are composed of CO_2 ice while the lower irregular layers are composed of water ice (Fig. 1). The water ice layer is visible only during the summer (L_S = 332º), being covered by seasonal CO_2 during the winter. This demonstrates the presence of a seasonal cap of CO_2 on top of a perennial cap composed

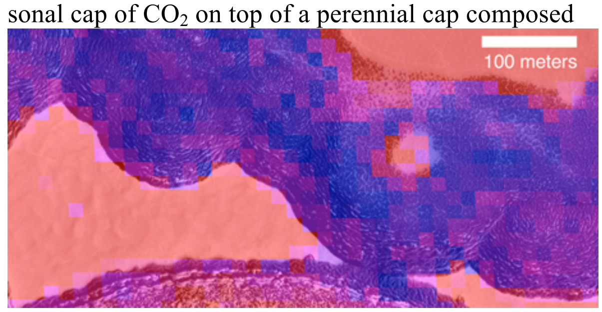

Figure 1. *Summer observation at L_S 331.8º, a subframe of HiRISE image PSP-005728-0935 with a superimposed CO_2/water ice indicator from infrared CRISM observation FRT000083f2_07. Red indicates CO_2 ice and blue water.*

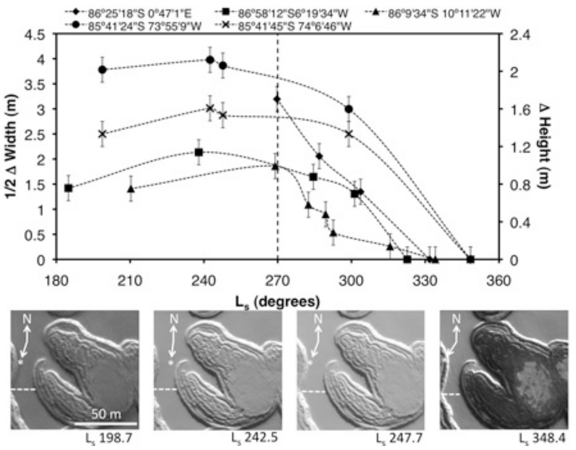

Figure 2. *Summer evolution of the south polar cap on HiRISE images. Measured 1/2 Δ width of the tops of CO_2 features at 5 different locations as a function of season. Subframes of HiRISE images at 85°41'S, 74°6'W (left to right: PSP_002922_0945, PSP_003832_0945, PSP_003937_0945, PSP_006126_0945), with dashed lines indicating where a feature width was measured. Arrows indicate direction toward the north (N) and the Sun (*).*

of CO_2 and water ice.

Since there is good agreement between our model and MOLA results on a global scale, we want to verify its applicability at local scale. Therefore, we studied the evolution of the width of the south perennial CO_2 features (Fig. 2) at latitude ~86ºS by comparing HiRISE images of the same region, obtained between that the local CO_2 ice layer features undergo significant decrease in width by 3 ± 1 m (Fig. 2), which is also observed in the ripples (Fig. 3). Using a ~30º slope [6], this corresponds to a local elevation decrease of ~1.5 m during the summer, similar to longitudinally averaged MOLA observations of ~1.8 m and our model prediction of ~1.4 m.

All previous observations focused on annual or shorter timescales, while trends should also be observed in longer timescales. To determine the net perennial variation of the CO_2 caps, we compared MOC images and HiRISE images of the southern polar cap, during the summer (L_S 285.6º and 289.5º) separated by three martian years. We observed a retreat of the CO_2 slab at low sun declination, we determined the average thickness of the CO_2 perennial cap to be 2.3 ± 0.4 m in MOC images and 1.03 ± 0.14 m in HiRISE images of the same features. The thickness difference gives an average sublimation rate of 0.43 ± 0.04 m y^{-1}, near the model prediction, 0.32 m y^{-1}.

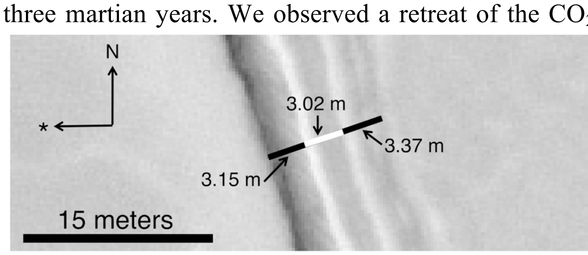

Figure 3. *Ripples moving away from the pit walls are remnants of the seasonal sublimation cycle. The spacing of the ripples is on average 3.2 ± 0.2 m, similar to the total annual retreat of the seasonal cap from Fig. 2 of ~ 3 m. The image at 86º8S, 10º15' W is a subframe of HiRISE image PSP-004792- 0940.*

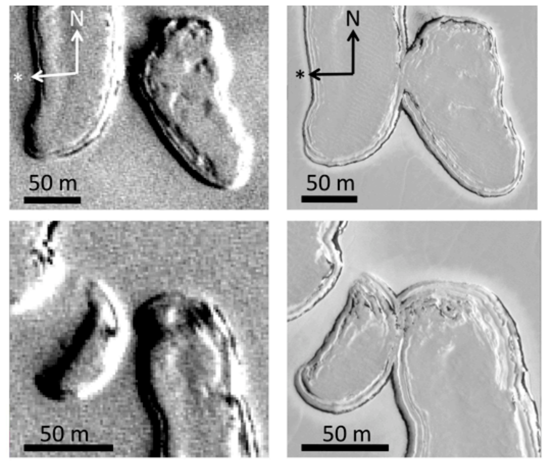

Figure 4. *Comparison between MOC (E11-00955) (left) and HiRISE (PSP-004792-0940)(right) images of the same region, during the same season, L_S 285.57º and 289.5º, respectively, indicating sublimation of CO_2 features over a 3 martian years. Arrows indicate direction toward the north (N) and the Sun (*), respectively.*

Conclusions: Our study demonstrates that the dynamics of the polar caps are predominately controlled by the irradiance of the sun. We show that the southern CO_2 seasonal cap, about 1 to 1.5 m thick, covers presently a 1 meter thick CO_2 perennial cap, both on top of a layer of water ice. Furthermore, the eccentricity of the martian orbit produces higher sublimation rates in the south hemisphere than in the north, resulting in a transfer of CO_2 from the south pole. If the flux of CO_2 remains the same (0.3 – 0.4 m y^{-1}), then the perennial CO_2 cap should disappear in approximately 3 martian years. The migration of CO_2 from the south polar cap, will leave the south pole entirely composed of water ice. If this water ice starts to sublimate, then higher humidity in the martian atmosphere should be expected. Alternatively, if progression of the south polar cap occurs in this timescale [10], then this suggests a short timescale climatic cycle.

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