CO_2 Glaciers on the South Polar Layered Deposits of Mars. I. B. Smith[1,2] (ibsmith@yorku.ca); N. Schlegel[3]; E. Larour[3]; Ignacio Isola[1]; P. Buhler[2]; N. E. Putzig[2]; R. Greve[4];, [1]York University, Toronto, Ontario, [2]Planetary Science Institute, Denver, Co; [3]Jet Propulsion Laboratory, Pasadena, Ca; [4]Hokkaido University, Sapporo, Japan

Introduction: A thin unit of CO_2 ice, called the south polar residual cap (SPRC), overlies the south polar layered deposits (SPLD) of Mars. This unit, capping a domed-shaped ice deposit, has inspired several studies concerning the glacial-like flow of CO_2 ice under martian conditions [1-3]. Furthermore, evidence of moraines at the north pole have led to interpretations that CO_2 ice was once prevalent there and that it flowed [4]. However, prior to 2011, no known and present day deposits were thick enough to flow.

After 2011 data from the Shallow Radar (SHARAD) instrument on Mars Reconnaissance Orbiter were used to determine that massive CO_2 deposits are buried beneath the surface of the SPRC [5]. Using geophysical arguments and layer geometry, [5] and then [6 and 7] determined that CO_2 ice up to 1000 m thick had been deposited in the spiral depressions of the SPLD before being buried. A total of 16,500 km^3 is likely stored there, having been deposited in three distinct periods. This interpretation re-opened the door for the massive CO_2 deposits to undergo viscous flow.

Laboratory experiments have determined that CO_2 ice can be much less viscous than water ice at similar temperatures (150-170 K) [1,2], and therefore it must flow much more readily. More recent experiments have been conducted over a wider range of temperatures and grain sizes, and while the stiffness of CO_2 has been refined upward (making it more viscous), the stress exponent is makes dry ice flow much faster than H_2O ice on slopes [8]. Thus, the thick CO_2 ice deposits are likely to flow when met with slopes.

Model Input: We use geometry of the current surface [9] and mapping by the SHARAD instrument [7] to provide geometric inputs that feed the model. Additionally, we use physical constants of CO_2 ice (Table 1), including the newly obtained flow law parameters [8], as inputs into a three dimensional glacial model. For our simulations, the surface temperature is locked at ~150 K (the sublimation temperature of CO_2 at Mars' pressure), and a very high friction coefficient was chosen to prevent basal sliding because CO_2 glaciers are dry based.

Table 1: Model Inputs.

Heat Capacity CO_2	700 J/K
Thermal Conductivity	0.4 W/m/K
Geothermal Flux	0.020 W/m^2
Current Surface Temp	150 K

Modeling: To assess the current flow and the circumstances that caused the ice deposits to reach their present state, we employ the Ice Sheet System Model (ISSM) [10]. ISSM successfully simulates glaciers and ice sheets on Earth and can be adapted to Mars by changing parameters for the planet (e.g. geothermal flux, gravity) and for the type of ice (eg. rheological parameters, thermal conductivity) (Table 1). Full thermal conduction and advection is included with the model. This provides a foundation to run a steady state simulation that calculates the vertical temperature profile of the deposits and then all of the stresses and strains of the present-day features.

Following [3], we choose a Glen's law behavior using this equation and inputs from [8]:

$$\dot{\varepsilon} = A\sigma^n e^{(-Q/RT)}$$

Where $\varepsilon^{\cdot}$ is strain rate, A is a material constant (A= $10^{13.4}$ MPa^{-n}/s), Q is the activation energy (Q = 68.2 kJ/mol), R is the gas constant ($R_{(gas)}$ = 8.3144598 J/K/mol), and n is the laboratory derived stress exponent (n=8). 8 is much higher than that of water ice (3), and so the CO_2 responds more quickly on slopes.

To evolve the CO_2 deposits, we begin with the basal topography [7] and no ice. During a forward run (transient) that begins at 600 kya before present we supply the volume of ice each year as modeled by [11] and deposit it equally over the accumulation zone.

Results: We find that during 600 kyrs of alternating accumulation and sublimation, the ice accumulates everywhere and flows fastest on the higher slope regions. These regions point into basins, where the ice accumulates to thicknesses of 100s of meters. During sublimation periods corresponding to higher obliquity, all of the ice in thin regions moves to the atmosphere; however the pooled ice remains, enduring until the following accumulation period. Over the full run, there are multiple accumulation periods that aggregate to make deposits that rival the thickness of our SHARAD measurements (Figure 1).

Discussion: After 600 kyr, our forward, transient simulations result in surface topography and glacier thickness similar to that observed with radar, supporting the hypothesis that the CO_2 deposits reached their present state in large part because of flow. An important component of remaining stable even during periods of sublimation is that the ice has to pool in basins, where the thicker column (up to 500 m) can withstand several meters of sublimation that would not persist if the ice didn't pool (Figure 2).

The resulting volume of ice matches that measured by SHARAD, providing a quick check of the hypothesis, but the real value comes with the predicted stratigraphy. Our model, following the accumulation and sublimation patterns of [11], would generate three distinct units of CO_2 ice, separated by a lag of H_2O, that resembles the true stratigraphy as mapped by [5-7], supplying an excellent test of CO_2 flow.

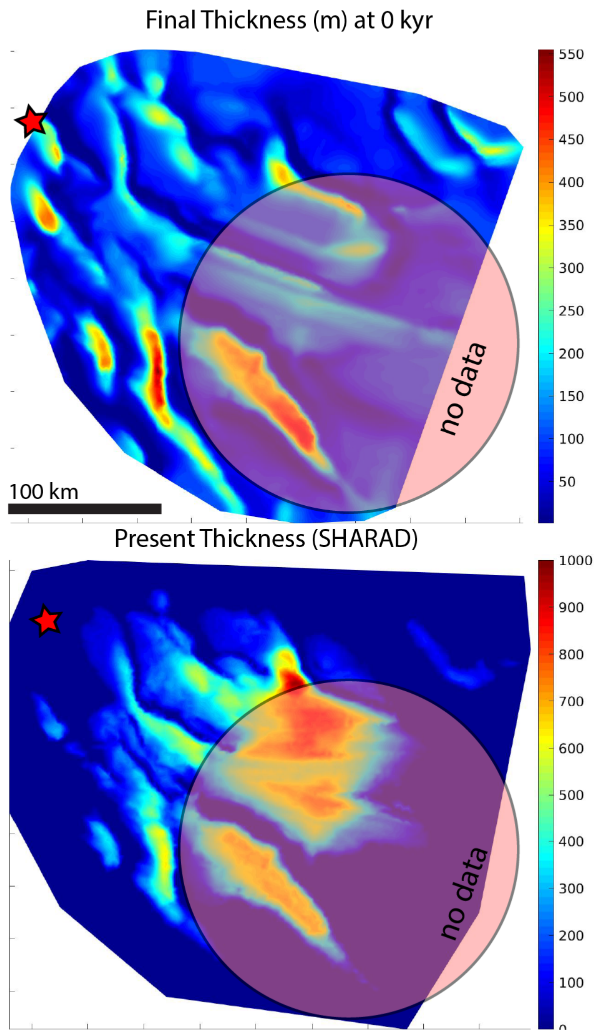

Figure 1: *Comparison of the model thickness against present thickness for a uniform accumulation pattern (provided by [11]) over the entire region. Ice flowed into the topographic basins, where it persisted during sublimation periods. The final volume is a near perfect match to the measured, even if the final distibution is not exactly the same. "No data" region is where neither SHARAD nor MOLA have data.*

Future Work: Our current modeling results match the gross stratigraphy, volume, and distribution of ice, giving a compelling story of flow to first order. Several details will complete the study, starting with including the stratification and alternating flow laws of H_2O and CO_2. We also intend to determine the influence of surface crevasses (as mapped by [5]on flow velocity.

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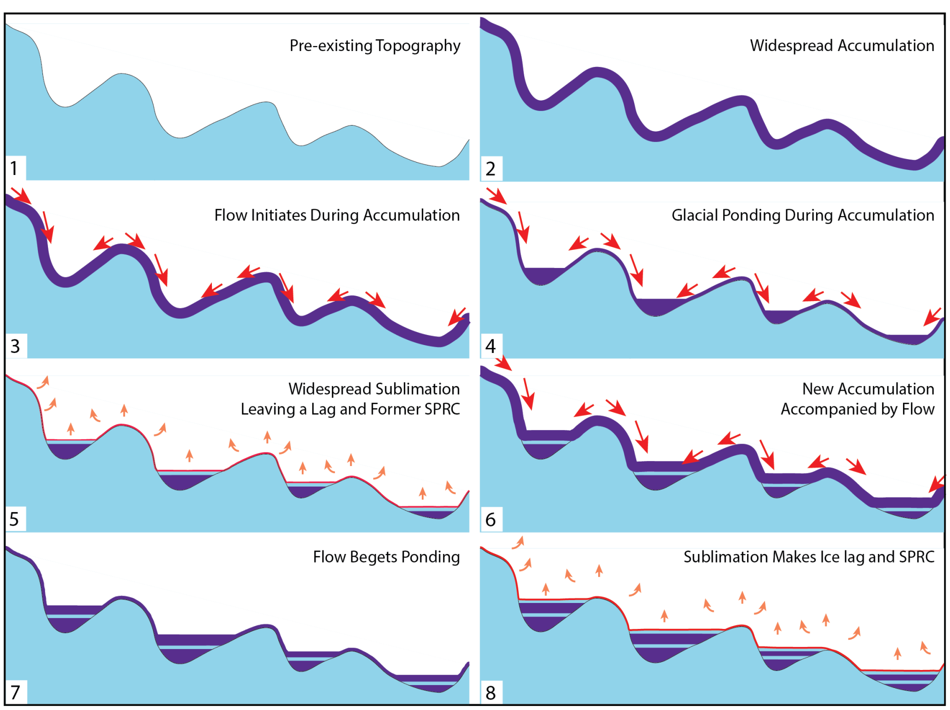

Figure 2: *Heuristic model of the deposition of CO2 ice on the south polar layered deposits of Mars during a cyclical pattern of accumulation and sublimation. The key is that ice accumulated on steep slopes flows into basins where it pools and becomes thicker enough to withstand warmer periods with high sublimation. Between each cycle, a lag layer of H_2O forms [11], leaving stratigraphy by which we can test this hypothesis.*