OBSERVATIONS AND MODELING OF THE MASS AND ENERGY BALANCE OF TERRESTRIAL SNOWPACKS TO CONSTRAIN MARTIAN SNOWPACK MODELS A. R. Dove[1], O. B. Toon[1], and J. L. Heldmann[2], [1]University of Colorado, Laboratory for Atmospheric and Space Physics, Boulder, CO (adrienne.dove@colorado.edu), [2]NASA Ames Research Center, Space Sciences and Astrobiology Division, Moffett Field, CA 94035.

Introduction: Gully-like features observed on the surface of Mars are likely the result of erosion by aqueous flow, although other processes, such as dry mass wasting [1] and CO_2 flow [2] have also been considered. The exact mechanism responsible for aqueous flow is uncertain; however, one proposed explanation is that gullies are a result of basal melting of snowpacks, which may currently be manifest as "pasted-on" deposits found along the edges of craters [3]. We are interested in determining if, in geologically recent history, Martian snowpacks could have melted, creating liquid water runoff available to carve the gully features we currently observe on the surface. When modeling terrestrial snowpacks, we have the advantage of being able to take accurate *in situ* measurements of meteorological conditions, of solar and terrestrial radiation, and of the conditions inside of snowpacks themselves. However, these detailed datasets are not available for Mars, where lower resolution Global Circulation Models have large uncertainty for parameters such as wind speeds and precipitation rates. Often, solar insolation is the most well understood parameter that can be used to drive energy balance within a snowpack, and past Martian snowpack models have considered this the dominant energy term [*e.g.* 4, 5]. Thus, it is important to understand how accurately these models can calculate melt amounts and timing when there are such large uncertainties in many of the energy balance terms.

Methods: In order to study the physical processes controlling terrestrial snowpacks and to complement our numerical modeling, *in situ* measurements were collected in an area of known deep snow occurrence, lasting from fall until late summer, in Lassen National Park, CA (40º28'25.7"N, 121º29'58.7"W). Instrumentation was first deployed at the field site in 2005 and has been revised and redeployed in subsequent years (2005-present). Data collected throughout the seasons includes incident solar radiation, snowpack temperature and light profiles, liquid water content as a function of snowpack depth, and seasonal runoff timing and amount.

To validate Martian snowpack models, it is useful to start with a model that has been validated using terrestrial field sites. Thus, we will use the data collected from Lassen to drive our SNTHERM models and attempt to reproduce the observed temperature profiles and depth variation. SNTHERM is a physically based, one-dimensional mass- and energy-balance model used for computing temperatures and energy flux profiles within a snowpack [6]. It is a widely-used, publicly distributed code that has been repeatedly tested and shown to produce accurate temperatures, energy fluxes, and melt timing [7]. By combining observations and modeling, we can also analyze the effects of various snow parameters (such as albedo and density) on snowpack metamorphism, as well as which energy terms are dominant in governing metamorphism and melt. Terrestrial analog experiments have shown that under most conditions the radiative energy fluxes are the dominant terms, but that turbulent fluxes can play an important role on cloudy, snowy, or rainy days [7].

Results: Our numerical simulations were run to model the snowpack growth and ablation, as compared with the observed burial and ablation at given heights. The final observed ablation of the snowpack took place over 23 days, and there was no precipitation during this timespan, so we estimate a linear ablation rate of about 8.6 cm/day. In order to reproduce these observations, we found it useful to simultaneously vary multiple parameters used in the SNTHERM simulations. The density of newly fallen snow and the albedo of the top snow layer can either be varied within the numerical model or held constant throughout the simulation; we found that changing these parameters had the greatest effect on the depth, lifetime, and ablation rate of the snowpack. We also varied the air temperature within a few degrees for different simulations, and this had a significant effect on the slope of the ablation curve. Our best-fit model utilized a constant albedo of 0.62 and a constant density of 325 kg/m^3 for newly fallen snow, and all temperatures were shifted by -1.7 K from the observations initially used. Model ablation of the snowpack occurred 7 days before the observed ablation at the highest sensor (1.96 m above the ground) and 7 days after that observed at the lowest sensor (0.02 m). This yields a linear ablation rate of about 5.4 cm/day as compared to the observed 8.6 cm/day. Depth variation of the best-fit model throughout the season is shown in Figure 1, compared with the observed depths. Temperature profiles produced by this model are compared with the observational data in Figure 2, and the contribution of radiative and turbulent energy terms throughout the season are shown in Figure 3.

Conclusions: We were able to produce a model that approximately matches the observations of snowpack depth, temperature profile, and liquid water content, but there is still much uncertainty in the choice of the snowpack physical parameters. Snowpack modeling can reproduce, with reasonable accuracy, the changes in a well-constrained terrestrial snowpack, such as that modeled in [7], for which the initial parameters of the snowpack itself were known. However, the internal conditions of potential Martian snowpacks will be almost entirely unconstrained. The results of this study indicate that in such a case, even a well-validated model has a large margin of error in simulating accurate snowpack metamorphosis and melt. Snowpack metamorphosis is strongly dependent on the interior conditions of the snowpack, as well as the driving external energy terms. It is clear from the simulations that the radiation is the dominant energy term involved in the heat transfer within the snowpack, and as such, it is important to accurately model the albedo, which will change over time due to snow grain metamorphosis and increasing melt content.

In order to better constrain observations of the snowpack, and produce more useful data for driving the snowpack simulations, updated instrumentation should be installed at the fieldsite. Precipitation, relative humidity, wind speed, downwelling and upwelling solar radiation, and terrestrial radiation sensors are all needed in order to drive the meteorological parameters used by SNTHERM. These sensors must be placed well above the ground surface so that they are not buried by snow. Finally, in order to learn more about the internal conditions within the snowpack, core snow samples need to be obtained throughout the season. These samples should measure the snow density, grain size, and temperature profiles throughout the depth of the snowpack.

Even with these constraints, however, it is problematic to apply this model to the Martian case, as Martian models cannot be initialized with a well-measured snowpack and full meteorological conditions. Global Circulation Models can be used to predict meteorological parameters, but have many uncertainties in the current Martian climate and are even less refined for the past, when snowpack deposition is likely to have occurred. Thus, while speculation into the past and present existence of snow on the surface of Mars can provide insight into the formation of features such as gullies, further constraint of these models is beyond our current capabilities.

References: [1] Treiman, A. (2003) *JGR, 108, 8031*. [2] Musselwhite, D., Swindle, T. and Lunine, J. (2001) *GRL, 28, 1283–1285*. [3] Christensen, P. (2003) *Nature, 422, 45-48*. [4] Clow, G. (1987) *Icarus, 72, 95–127*. [5] Williams, K. and Toon, O. (2008) *Icarus, 196, 565–577*. [6] Jordan, R. (1991) *U.S. Army Cold Reg. Res. and Eng. Lab., Special report 91-16*. [7] Cline, D. (1997) *Water Resources Research, 33, 689-701*. Cline, D. (1997) *J. App. Met., 36, 32-51*.

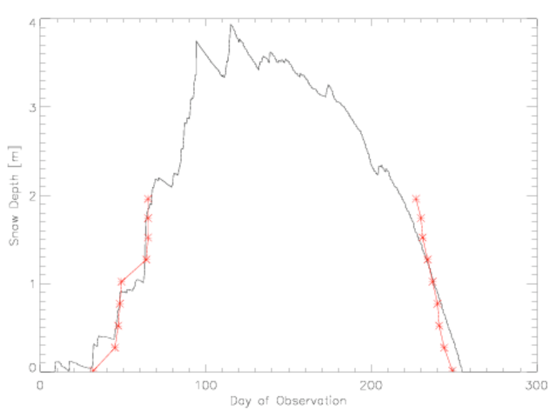

Figure 1. SNTHERM modeled depth of the snowpack throughout the 2007-2008 season. Day 1 corresponds to November 1, 2007. Observed snow depths are indicated by red asterisks.

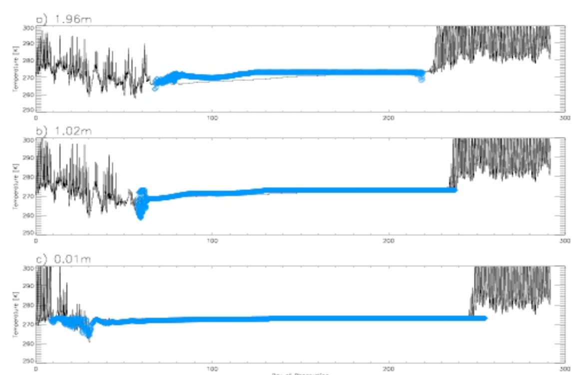

Figure 2.

Figure 2. Temperature measurements from observations at three heights (black lines) and corresponding predicted temperatures from the best-fit SNTHERM simulation (blue diamonds).

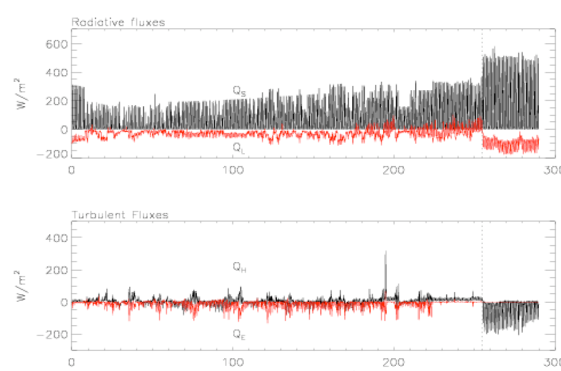

Figure 3.

Figure 3. Radiative (top) and turbulent (bottom) flux terms predicted by the best-fit SNTHERM simulation. Q_S is the net solar flux, Q_L is the net longwave flux, Q_H is the sensible heating term, and Q_E is the latent heating term.