MELTING IN MARTIAN SNOWBANKS

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Introduction Precipitation as snow is an emerging paradigm for understanding water flow on Mars, which gracefully resolves many outstanding uncertainties in climatic and geomorphic interpretation [1].

Snowfall does not require a powerful global greenhouse to effect global precipitation. It has long been assumed that global average temperatures > 273K are required to sustain liquid water at the surface via rainfall and runoff. Unfortunately, the best greenhouse models to date predict global mean surface temperatures early in Mars' history that differ little from today's, unless exceptional conditions are invoked [2]. Snowfall however, can occur at temperatures < 273K; all that is required is saturation of the atmosphere. At global temperatures lower than 273K, H_2O would have been injected into the atmosphere by impacts and volcanic eruptions during the Noachian [3.4], and by obliquity-driven climate oscillations more recently [5,6]. Snow cover can accumulate for a considerable period, and be available for melting during local spring and summer, unless sublimation rates are sufficient to remove the entire snowpack.

We decided to explore the physics that controls the melting of snow in the high-latitude regions of Mars to understand the frequency and drainage of snowmelt in the high martian latitudes.

The surface mass and energy fluxes of the snow model are calculated by mass and energy balance with a one-dimensional radiative-convective boundary layer model [7]. The model predicts atmospheric temperatures caused by radiative (solar and infrared) and non-radiative (convection, turbulence, etc.) effects. Variations in surface winds caused by frictional mixing in the planetary boundary layer are also computed, in order to calculate turbulent energy fluxes to the snow interface. In the simulations described here, the optical depth of H_2O ice is assumed zero, although the code exists to explore these effects.

The code calculates the solar absorption by atmospheric CO_2. It considers separately infrared absorption by atmospheric CO_2 inside the strong 15 μm band. The model adjusts temperatures due to convection, and pases to the snowbank model the temperature of the air just above the surface, as well as the direct and diffuse solar insolation, and the downwelling IR radiative flux.

We use a one dimensional mass and energy balance model adapted from sntherm.89 [8]. which predicts the temperature and redistribution of snow. The transport of liquid water and water vapor are included in the model as necessary elements of the heat balance calculation. The model assumes that the Martian surface at the base of the snowbank is frozen and impermeable.

The snowbank is allowed to compact under the weight of the overburden. The overburden is augmented in polar winter by the mass of the seasonal ice cap (see the seasonal cap discussion). The compaction routine is taken from Anderson [9], and is a linear function of the overburden pressure. As the snow compacts, the finite difference grid on which it is calculated is allowed to compress, so that the volume elements continue to correspond with the original sample of snow. The density of water vapor and dry air are invariant during matrix deformation, and a portion of gas is expelled from the contracting volume, which is taken into account when defining fluxes for these constituents.

The snow energy balance equation accounts for the energy associated with the mass flux of liquid water, water vapor, thermal conduction, and radiative flux.

It is assumed that only the short-wavelength solar radiation penetrates the top node, and a maximum depth for solar penetration of 30 cm is assumed. The extinction coefficient is currently assumed to be that of pure snow, [9]. Although the introduction of snow/dust mixtures will be implemented in the next version of the model.

Latent heat changes, either due to movement of liquid water or phase change within an element are included. The apparent heat capacity method [10] is

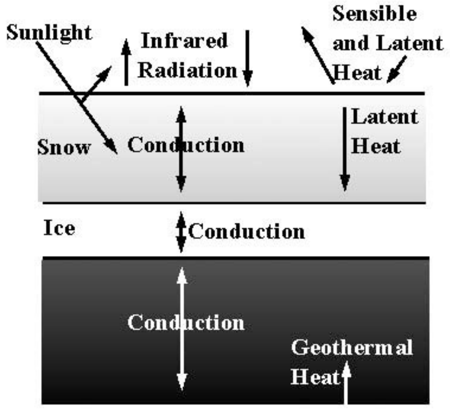

Fig. 1. The snowbank model solves energy and mass balance for the snow and overlying CO_2 cap.

used, where the total enthalpy change is expressed in terms of temperature through the definition of an apparent specific heat.

The surface energy balance of the snowbank is composed of the turbulent fluxes of sensible and latent heat, and the short and long wavelength components of the radiation. The turbulent exchange fluxes depend on surface roughness, wind speed and the atmpspheric gradients of temperature and humidity.

The radiation term is calculated by the coupled 1 dimensional radiative-convective Mars atmosphere code of [7]. The albedo of snow is taken as 0.34, as a basline the average value of the Martian polar caps. Relatively fresh, pure terrestrial snow has an albedo of around 0.78 [8], and snow albedo values between these extremes can be explored in the model.

At latitudes poleward of about 40 on Mars, the surface cools to the point that the major atmospheric component, CO_2, condenses during winter. In the event that CO_2 condenses, the surface energy balance is calculated as discussed below.

We use the surface temperature to establish stability for CO_2. As is common in these models, we calculate the condensation temperature of the atmosphere from the local pressure (700 Pa in all cases here). If the temperature falls below the condensation temperature, the mass of CO_2 that condenses is calculated by balancing the net radiation, the thermal emission, and the heat conducted upward into the cap from the underlying snow.

The assumed albedo of CO_2 is 0.4, which is consistent with the observations of the cap, although clearly the albedo of the cap is neither uniform nor fixed. We use 0.4 because it represents an average of the observations reported for the TES data [11]. The emissivity of the seasonal CO_2 cap is assumed to be 0.9.

Whenever the mass of CO_2 on the ground is > 0, we fix the wind speed (and hence the sensible and latent heat fluxes), experienced by the snowbank at zero. We also assume that the CO_2 ice is opaque, so that no solar insolation is absorbed by the snow once it is covered by CO_2. That is certainly a source of error when the seasonal cap is thin, particularly in the spring. Indeed, in the case of cryptic regions in the vicinity of the south pole, it appears that clear, transparent CO_2 ice is sitting over a darkish surface. It is not obvious however that clear CO_2 ice could form over snow.

References:

[1]. (Christensen, 2003).
[2]. (Haberle, 1998).
3]Segura et al., 2002,
[4]Hort and Weitz, 2002)
[5]Jakosky and Carr, 1985,
[6] Kieffer and Zent, 1992
[7] (Haberle et al., 1993)
[8](Jordan, 1991),
[9] Anderson (1976)
[10] Albert (1983)
[11] Kieffer and Titus (2000).

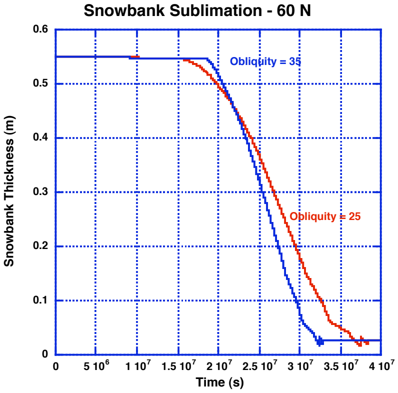

Fig. 2. Sublimation proceeds more rapidly at high obliquity, unless variations in atmospheric H_2O counteract this effect.

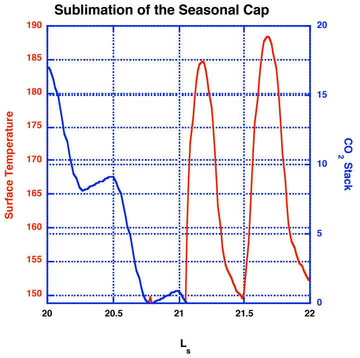

Fig. 3. The effects of recession of the seasonal cap from the snowbank are captured.