MODELING ICE STABILITY WITH TOPOGRAPHY ON A LOCAL SCALE, MARS. P. S. Russell[1], A. Lefort[1], N. Thomas[1], [1]Div. Planetary Sciences, Physikalisches Institut, Univ. Bern, Sidlerstrasse 5, 3012 Bern, Switzerland (patrick.russell@phim.unibe.ch).

Introduction. Models addressing the stability of ice on a global scale have been put forth by several authors [e.g., 1-6]. General circulation models [e.g., 7-10] are inherently large in scale and take into account general elevation, but not specific topographic geometry, in determining energy balances and ice stability. In this study, we seek to assess the stability of ice on a more local scale: a scale at which the effects of topography will potentially cause spatial variation in ice stability by differentially modifying the energy balance at the ice's surface.

It is on these smaller scales that, according to both theory [11] and observation [12], the stability and activity of water and ice act to shape local geomorphology and ice deposits themselves. Hecht [11] considered the affects of local topographic geometry on local ice stability with the goal of constraining whether or not particular, yet realistic, physical configurations and atmospheric conditions could lead to the melting of ice to form gully features [12] common on crater and canyon walls. He concluded that geometry could have substantial effects, theoretically producing conditions under which ice could even melt. In previous work, we have adapted general ice stability models [11,13] to the setting of a crater interior, to investigate the variation in ice stability conditions over the interior surface and to model the morphological evolution of a crater-interior ice deposit [14]. Due to the topographic effects on energy balance near the crater walls, ice stability is decreased proximal to the crater walls. Modeling of the morphological evolution of an interior ice deposit over time reasonably reproduced the central plug and surrounding annular trough morphology of crater interior ice deposits observed in martian circum-polar regions. Geologic observations of such circum-polar craters in the south, in combination with an understanding pf physical processes gained from modeling, led to the recognition of a sequence of morphologies strongly correlated with distance from the south polar layered terrain [15]. This morphological sequence and its spatial distribution is interpreted to be the result of latitudinally migrating zones of ice stability due to changing orbital parameters [15], as predicted by recent climate models [16,17]. Another small-scale environment in which ice stability has been modeled for Mars is that of a linear trench. Studies with the goal of predicting where frost would likely form in a trench on the scale of that dug by a lander [18] and of determining the physical processes and local ice stability in polygons [19], have focused both on the stability of frost ice on the surface of the regolith and on the regions of ice stability within the upper tens of centimeters of regolith.

Ice Stability Model with Local Topography. We build on the above works in developing a numeric model of ice stability within the upper regolith and particularly on its effects on local-scale landscape evolution. We eventually hope to test model predictions in specific areas with the high resolution imaging capabilities of the HiRISE instrument on MRO, to be launched in August, 2005.

Several additional terms must be taken into account in a model of ice stability on local scales with significant topography relative to those models considering flat plains or a regional or global scale.

1) Shadowing. If the direct line to the sun is blocked by topography, the local surface receives no direct insolation but still receives diffuse light scattered by the atmosphere (as do sun-lit surfaces). The amount of scattered light depends on the solar zenith angle and atmospheric dust opacity [e.g., 20], and may be a relatively high percentage of the amount of direct light when the sun is near the horizon. This suggests that when shadows are the longest, they also cause the least difference in insolation from directly lit areas. For a surface to be greatly affected by shadowing, it must therefore be relatively close to a relatively steep slope in order to be in shadow during mid-day.

2) Reflection. If two surfaces are oriented within 180° from another, there is the potential for incident light on one to be reflected to the other. The fraction of original insolation reaching the martian surface (I_1) that is reflected and absorbed by a second surface (I_2) is:

$$\frac{I_2}{I_1} = \frac{\cos(i_1) A_1 \cos(e_1) \cos(i_2)(1 - A_2)}{\pi d^2}$$

where, i_1 is the incidence angle of sunlight on surface 1, e_1 is the emission angle at which light leaves surface 1 towards surface 2, i_2 is the incidence angle of light from surface 1 onto surface 2, d is the distance between the two surfaces, and A_1 and A_2 are the albedos of the respective surfaces.

3) Modified Emission. In an environment without topography, a surface emits radiation proportional to the fourth power of its temperature to the entire hemisphere of sky. However, with topography, some of this emitted radiation is emitted to neighboring surfaces, roughly analogous to the above case of reflection. Thus, a given surface may be considered to lose energy to an entire hemisphere, but also to gain some energy back from emission from parts of that hemisphere that are occupied with near-by topography.

4) Slope. By definition, in areas of significant topography, the local slope of the surface is important in determining radiation balance, a concept which has been used by many authors [e.g., 21].

We first quantify the relative effect of each of these factors in a given situation to assess their relative importance in determining ice stability through an energy balance. Slope can have a major effect on insolation, on the order of that of surface albedo and latitude, while the role of the others is strongly dependent on the distance of a given surface to the obstructing topography. We then include these effects in a 2-D thermal model of a profile through a given topography, such as a scarp. The temperature of the surface and upper regolith is tracked over time. We are interested in not only in where ice is stable within the subsurface [18,19], but how the resulting sublimation, or disappearance, of ice -rich material changes the morphology of the original profile, which in turn effects the energy balance at each point in a feedback cycle in which the change in morphology depends on the morphology [14,22]. The case of pure ice is considered first, with modeling of water migration within the subsurface and removal of desiccated regolith to be considered in future work.

Model Applications. Many features on Mars have been proposed as examples of ice-rich materials that have been modified by sublimation. Previously we have modeled complex circum-polar craters on the order of 10s of km across with interior deposits [14], and [23] modeled ice stability analytically over bowl-shaped craters. It was demonstrated in [14] how the effects of topography increase with decreasing crater radius or increasing wall height. Modeling of small ~ km scale craters may explain why some of the smaller craters do not contain fill material while the larger ones do, especially in the northern subpolar region. In a study of MOC images, [24] found several latitude-dependent classes of features interpreted to represent successive degrees of desiccation of an ice-dust mantle that blankets high latitudes up to ~10 m thick. These textures, on the scales of 10s of meters, could be modeled under conditions of changing obliquity to better understand the processes and conditions of their formation. The same is true of diverse polar terrains [e.g., 22], as well as the layered terrain and its troughs. In particular, there is a latitudinal band of scalloped-shaped depressions on Amphritites and Peneus Paterae on the southern rim of Hellas [25] that may represent degredation of a volatile-rich layer, resulting in scarps on the order of 10s of meters high and possible instances of coalescence of neighboring initial sublimation sites [25,26].

In modeling the evolution of such features with significant topography, it is important to include the related effects on energy balance as outlined above. In this research, we are modeling on a scale to understand the processes involved in the formation of individual features rather than regional or global patterns. It is at this scale that high resolution data in a regional context, such as from HRSC on Mars Express or HiRISE on MRO, will be essential in validating our models.

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