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Seasonal flows on dark martian slopes, thermal condition for liquescence of salts

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ABSTRACT

RSLs are narrow, dark albedo features on relatively steep slopes that appear during warm seasons and fade in the cold ones. So far they have only been observed in mid-latitudes where surface temperature is too high, periodically exceeding 300 K, for the presence of shallow ground ice. We attempt to determine what conditions are needed for the liquescence of salt to occur exactly when the RSLs are observed. If the eutectic temperature is exceeded, and humidity is high enough, salts may produce liquid brines through absorption of water vapor and liquescence. We calculate regolith temperature as a function of time and depth, for different macroscopic distributions of salt, for two different microphysical models of the distribution of salt on the regolith grains. Model parameters which are varied include surface albedo, thermal inertia of the dry regolith, the depths at which salt is present, and the salt content. We find that it is possible, for liquescence of magnesium perchlorate to occur where and when RSLs have been observed, but only within a very narrow range of parameters.

1. Introduction

Recurring slope lineae (RSL) are seasonally growing long, narrow dark features on Mars surface (McEwen et al., 2011). These features were found in the images taken with the High Resolution Imaging Science Experiment on the Mars Reconnaissance Orbiter (McEwen et al., 2010). RSLs are found mostly on equatorward inclined steep dark slopes, in the south hemisphere and in mid-latitudes. The RSLs are typically 0.5–5 m wide and up to 40% darker than the average local surface. They are observed year after year in the same locations, on the slopes inclined by more than 25°. RSLs start growing at $L_s \sim 240$ and disappear at $L_s \sim 20$, parameters of the observed RSLs are summarized in McEwen et al. (2011) and Ojha et al. (2012). Terrestrial analogos for RSLs were presented by Levy (2012). The fact that RSL are observed only on areas of steep slopes needs further explanation. It is important, that RSL are observed not just on any steep slope, but on dunes of east–west orientation. This implies, that close to the very warm slopes inclined toward equator are very cold slops facing poles. Our calculations indicate, that at these slopes ground ice could be close to the equilibrium. Possibly, dunes were formed of a material containing salt and the ice accumulated at the cold sides. The uppermost part of a warm slope is close to the reservoir of ice at the cold side. This could explain, why the RSL start developing close to the top of the slopes.

Several scenarios have been proposed for the formation of RSL. One of the potential processes is the surface flow of brines (e.g. Schaefer et al., 2012). Another possibility are avalanches (Martinez and Renno, 2013). This assumes salt deposits in a near surface layer throughout the slope in question or at least near the top. Indeed RSLs usually extend downslope from bedrock outcrops (McEwen et al., 2011). The proposed explanation for formation of RSL is simply that during warming of the ground in spring temperature raises above the salt eutectic temperature producing brines which flow down the slope wetting and darkening the surface. In fall as temperature falls, brines are no longer produced and surface water sublimates leaving dry surface with restored higher albedo. There are two strong arguments against the brines hypothesis. One of them is the to date unsuccessful detection of water absorption bands in the CRISM-MRO data. This problem may be however resolved in the future as indicated by preliminary results of laboratory measurements of IR spectra of hydration and dehydration of perchlorates (Massé et al., 2012). Another problem is the need of sufficiently high humidity. Surface temperature of the slopes, where RSLs were so far identified is very high, at noon it seasonally exceeds 300 K. Thus, presence of pure water ice at small depth is

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unlikely. The necessary humid may only diffuse from a ground ice reservoir beneath the cold slope.

Properties of brines or more precisely cryobrines (brines with eutectic temperature below 0 °C) have been recently reviewed by Moehlmann and Thomsen (2011) and Moehlmann (2011). In our work, the critical parameters are: the eutectic temperature and the deliquescence relative humidity (DRH), characteristic of each salt but typically >40%. The DRH is the lowest value of the relative humidity, RH, required for a changing the phase from solid salt crystals into liquid brines. Thus, we have two necessary conditions for the formation of brines from salt: (1) RH > DRH, and (2) $T > T_{eutectic}$. We try to answer the question at what depths can we expect seasonal temperature to rise above eutectic temperature of magnesium perchlorate ($Mg(ClO_4)_2$). We consider this salt, because it has very low eutectic temperature of 212 K and is present on Mars, as indicated by the in situ measurements by Phoenix Mars Lander (Hecht, 2009). Many other salts are possible.

2. Model

We assume the regolith has layered structure. This is because: (i) the low thermal inertia (McEwen et al., 2011) indicates low thermal conductivity of the material, at least in the diurnal thermal skin layer, while (ii) some ice reservoir is needed to keep humidity in the pores sufficiently high to allo formation of brines. We do not know, at what depth salt becomes present, if it is present at all. Thus, we considered several possibilities. The depth to the potential reservoir of the ground ice is also unknown. However, if it is larger than few meters, it is unlikely to maintain high humidity in the pores at a depth of tens of centimeters.

Immediately beneath the surface, down to the depth z_1 the regolith is free of ice and salt (Layer 1). In the second layer (Layer 2) of thickness d the volume fraction of salt linearly increases with depth and in Layer 3, for $z_1 + d < z < z_2$, the volume fraction of salt is constant with the value v. In the Layer 4, for $z > z_2$ regolith is free of salt, but contains water ice. Salt, where present, uniformly mantles the whole regolith grains (Model 1), or only the necks between adjacent grains (Model 2). Identification of RSLs mostly at relatively low latitudes indicates, that water ice is not likely to be present within first meters below surface. However, presence of deep ice formed during period of colder climate is possible. When some ice is present, it should affect humidity in the regolith. We assume, that the volume concentration of ice in Layer 4 is the same as the volume concentration of salt in Layer 3. Thus, thermal properties of the Layers 3, and 4 are similar.

Our thermal numerical model has been developed over many years to simulate evolution of the regolith temperature, as well as condensation and sublimation of H_2O and CO_2 ices in the regolith and on the surface. It was used among others to investigate: the possibility of seasonal ice melting in martian gullies (Kossacki and Markiewicz, 2004), the escape rate of subsurface ice (Kossacki et al., 2006), possible frost formation in small trenches dug during the Phoenix Mars Lander mission (Kossacki and Markiewicz, 2009), formation of water film between the regolith grains and the water ice mantling the grains, as well as evolution of fresh exposed ice in craters on Mars (Kossacki et al., 2011). In the present work we used simplified version of the model, for a flat, but inclined, surface without trenches, or craters.

The model includes warming of the surface due to absorption of the direct solar light, as well as the IR radiation emitted by the atmosphere toward surface. The seasonal and diurnal variations of atmospheric pressure, atmospheric humidity and atmospheric opacity can be taken either from the results of a general circulation model (GCM) such as LMD/Oxford GCM (Forget et al., 1999; Lewis et al., 1999), available at http://www-mars.lmd.jussieu.fr, or parameterized. In this work, dealing with the long term temperature evolution of the dry regolith we consider smoothed GCM profiles of the atmospheric pressure and humidity. These profiles include seasonal effects, but not diurnal cycles.

The equations, except the formula for the instantaneous thickness of the liquid water film described below, were described in detail in our previous papers (Kossacki and Markiewicz, 2004; Kossacki et al., 2006). The main equations are those describing the diffusion of heat in the regolith, and the local energy input at the surface.

2.1. Parameters

McEwen et al. (2011) observed the RSLs at latitudes 32°S–48°S, on slopes inclined by 25°–40°. The albedo and the thermal inertia of these slopes are low, <0.2, and 200–340 J m^{-2} K^{-1} s$^{-1/2}$ respectively. We consider slopes located at the latitude 40°, inclined by 32.5°. We vary albedo A in the range 0.15–0.2 and the thermal inertia of the regolith, when free of salt, I_{dry} is within the range 200–340 J m^{-2} K^{-1} s$^{-1/2}$. Our standard value is 230 J m^{-2} K^{-1} s$^{-1/2}$. The observed width of RSLs, 0.5–5 m, suggests, that some liquid should appear seasonally at a depth about a meter, or even less. Thus, the depth z_1 of the boundary between Layers 1 and 2 is within the range 0.4–4 m. The transient Layer 2 has thickness $d = 0.2$ m. Thickness of Layer 3 is determined by the depth to the bottom of the numerical grid. The latter is chosen large enough, that the temperature oscillations at the bottom are smaller than 0.1 K. We performed tests and decided to consider: 8 m thick layer of the regolith when the volume fraction of salt is 0.05, and 16 m when the amount of salt is larger.

The initial temperature of the regolith T_0 is 212 K, the eutectic temperature for $Mg(ClO_4)_2$. This makes quickly visible whether the average temperature is lower, or higher than the eutectic temperature. The simulations were performed until the temperature at the bottom of the grid reached steady state. The necessary period for this was 10–40 martian years, depending on the model parameters. The results presented are for the last year of simulations.

3. Results

3.1. Thermal properties of the regolith

Fig. 1 shows to what extent the regolith temperature depends on the model describing micro-distribution of salt in the regolith. We presented profiles of the temperature at local noon versus

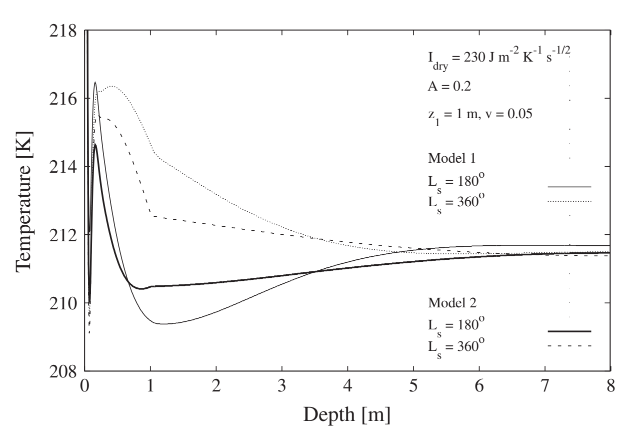

Fig. 1. Seasonal changes of the regolith temperature: influence of the microscopic distribution of salt in the regolith. Plotted are profiles of the temperature versus depth at two different seasons. Values of the model parameters are given in the legend.