Multi-step model of seasonal activity related to CO_2 ice basal sublimation in Martian polar areas

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Abstract

The model of processes involving basal sublimation of CO_2 described in [4] has been further refined by introducing a more precise calculation of available solar energy depending on local topography (inclination effects) and neighboring terrain shadowing using ray-tracing. This model is now being adapted to describe northern circum-polar area activity. The application of our model to the northern polar areas (in addition to the southern) is justified by recent observations by Mars Reconnaissance Orbiter instruments (HiRISE and CRISM). Both polar regions have been repeatedly monitored during several spring seasons and the results of these observation campaigns lead to the conclusion that basal sublimation is active in both hemispheres.

1. Introduction

Recent observations by HiRISE [2] showed that despite their major differences, the northern and southern seasonal caps share one exotic physical process: basal sublimation of a CO_2 ice layer which forms during winter. The sublimation occurs during the retreat of the seasonal polar caps, during local spring. Acting for a long period of time, this process has resulted in the creation of araneiforms terrain in the southern hemisphere. In the north it accelerates the process of modification of dunes.

1.1 CO_2 basal sublimation process

In this work we use the term "basal sublimation process" to describe the process playing the main role in Kieffer's model of araneiform formation [3]. It is also sometimes referred to as a type of solid-state greenhouse effect. The process occurs because of the specific optical properties of CO_2 ice: it is transparent in the visible part of spectrum and opaque at thermal emission wavelengths. The ratio of the transparencies in these wavelength ranges translates into the strength of the greenhouse effect – i.e. the rate of increase of temperature underneath the layer of material with these special properties when it is exposed to sunlight. In the case of the Martian CO_2

layer it leads to the sublimation between the substrate and the CO_2 ice layer. This in turn creates pressure growth and subsequent breaking of the ice plate.

1.2 HiRISE and CRISM observations

Our strategy for HiRISE observations in the polar areas is to obtain good temporal coverage of the selected areas of interest at HiRISE resolutions. In this way we get series of images showing temporal development of chosen locations while the CO_2 ice is subliming. High spatial resolution of HiRISE is accompanied by high spectral resolution of CRISM that provides us with the time dependence of CO_2 and water ice presence on the surface.
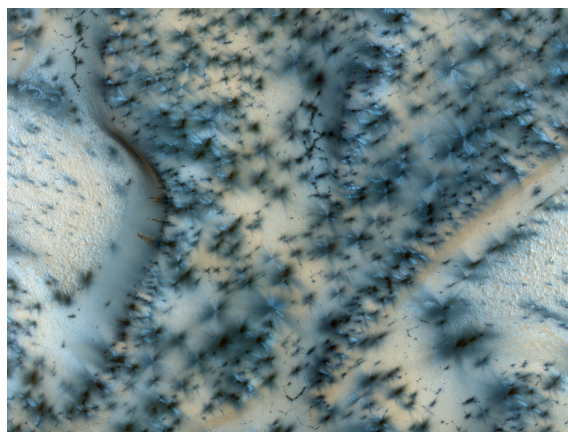

Figure 1: HiRISE image ESP_016520 sub-frame showing northern polar dunes covered by CO_2 ice layer. Seasonal activity manifests itself in an abundance of dark and bluish fans – results of jet-like phenomena created by basal CO_2 ice sublimation.

Both instruments show that activity levels strongly depend on local topography and/or surface properties. Active and inactive areas can be as close as hundreds of meters apart. There is not always an obvious correspondence of activity with directions of slopes or changes of substrate material properties. To distinguish between these two effects and narrow down the range of parameters that modify the rate of activity we decided to concentrate first on the best

known term - insolation. We modified our previous 'flat' model with the aim of taking into account possible influence of terrain inclination and shadowing during early spring in polar areas.

2. The model

The basic equations of the model are described in [4]. It allows the calculation of sublimation fluxes of CO_2 on top and underneath the ice layer specific to local topography. It also includes a calculation of stress produced in the ice sheet by this process. We list recent modifications to the model below. The model includes the following steps:

1. Calculation of the energy deposited in the lower boundary of the ice layer.
   It depends on Mars' orbital position, height of the Sun above the local horizon, the inclination of the local surface towards the instantaneous Sun position, the optical depth of the Martian atmosphere, and CO_2 ice sheet optical properties.
   Two improvements have been made to this part of the model: the precise position of the Sun relative to local topography was calculated using the SPICE system [1]. Local topography is taken either from MOLA topographical maps or (for smaller scale studies) from a HiRISE digital elevation model (DEM).   MOLA and/or DEM data also serve as an input to the ray tracing algorithm that allows us to calculate how long each point of the terrain was shadowed.
2. Calculation of the pressure growing underneath the ice plate in response to the ice sublimation from the lower plate surface.
   This was calculated with the ideal gas equations and has, as free parameters, the volume available for the gas to expand underneath the ice layer and the initial pressure in that volume. The volume is calculated from the packing properties of underlying regolith. In the present calculations we used the atmospheric surface pressure as the initial pressure of gas underneath the ice layer.
3. Calculation of the stress that is induced by the pressure in the ice plate.
   Unknown parameters are the mechanical properties of CO_2 ice and the size of the ice sheet that is able to bend and the area that is exposed to the pressure gradient.

3. Results

Fig. 2 shows an example of the calculation of stress induced in the ice plate by the pressure underneath it at a particular time of the day. The distribution of stress over the area changes during the day following the movement of the Sun. This sometimes allows the first fracturing of the ice to happen early in the season in one area but only after several sols in the neighbouring ones.

We will present the model results for various locations inside the southern and northern polar areas that possess distinctive topography and discuss its influence on the small scale variations of activity in those locations.
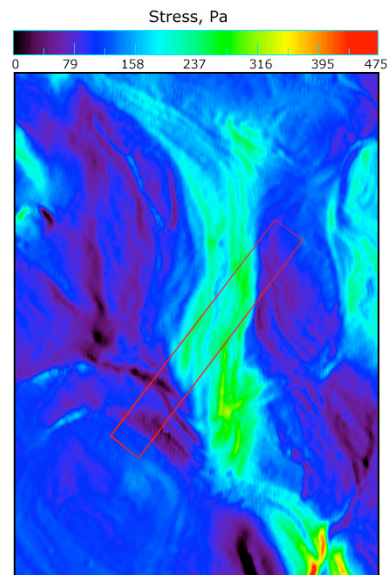

Figure 2: Stress produced in ice plate by basal sublimation at local noon of $L_s = 188^o$ in the area of Starfish (lat = 84.3^{o}S, lon=242.1^{o}E). Red lines outline the approximate position of the HiRISE imaging campaign in the area.

References

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