DARK SPOTS AND COLD JETS IN POLAR REGIONS: NEW CLUES FROM MODELS.

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Introduction: Observations of the southern and northern seasonal caps have revealed the presence of dark spots and fans. These exotic features with no equivalent on Earth could result from the characteristics and behavior of solid CO_2 on Mars. A proposed explanation is that the solar flux penetrates into the CO_2 ice and heats the regolith. Once the sublimation temperature is reached at the bottom of the slab, gas forms and tries to escape. When a path to the surface is created, CO_2 gas and dust are ejected, which forms these dark spots [1].

The full model that we developed solves conduction, radiation and mass evolution equations in the CO_2 ice as well as in the underlying regolith.

In this paper, we present some simulations results aiming at better understanding these exotic features. We first investigate on the validity of the scenario previously described on the "Manhattan Island" region example and then try to understand why dark spots appear at some places and not another on Mars.

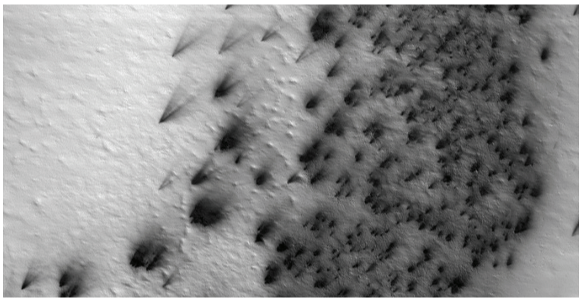

Figure 1: *HiRISE picture of the South part of the Manhattan Island region (99.0°E, -87.0°S) at Ls=188.2°.*

Modeling CO_2 polar caps evolution: Our model is a 1D, time-marching model aiming at simulating the details of the physical processes controlling the thermodynamics of surface CO_2 ice on Mars.

Its vertical computational grid is a dynamic layer grid where layers have their own thermal and optical properties. The vertical resolution is 1cm. Two models have been used to simulate the solar flux penetration into the CO_2 ice: a radiative transfer code, which allows us to simulate different scenarios, with different CO_2 ice properties (CO_2 grain radius, amount of dust, dust grain radius), and a translucent slab model derived from [1] model.

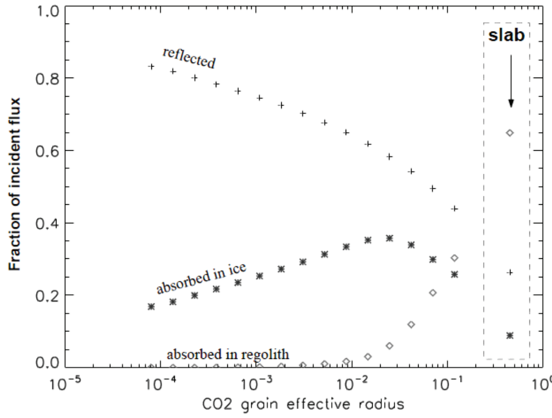

Figure 2: *Evolution of the interaction between the CO_2 ice layer and the solar flux as a function of CO_2 grain radius in meters. Ice thickness=0.6 m; incident solar angle=60°; ground albedo=0.24; no dust content. As the effective grain radius increases, the reflected part decreases and the part absorbed in the ice increases. However, photons are not yet able to reach the regolith until the effective radius is higher than about 1 mm. As the effective radius continues to increase, photons can go through the ice more easily and the part absorbed in the ice begins to decrease.*

Our model takes into account the solar flux (0.1−5μm), the thermal flux, the thermal emission, the sensible heat flux, the geothermal heat flux, and the latent heat flux when there is a phase transition. In a case of running simulations on a slope, another term related to the thermal emission and reflexion from surrounding terrains is added [3].

The radiative model is coupled to a complete parametrization of heat conduction and storage by CO_2 and regolith. We also took into account the modification of the thermal and optical behavior of the layers in case there were gas between the CO_2 ice and the regolith.

Different scenarios can be therefore very easily simulated

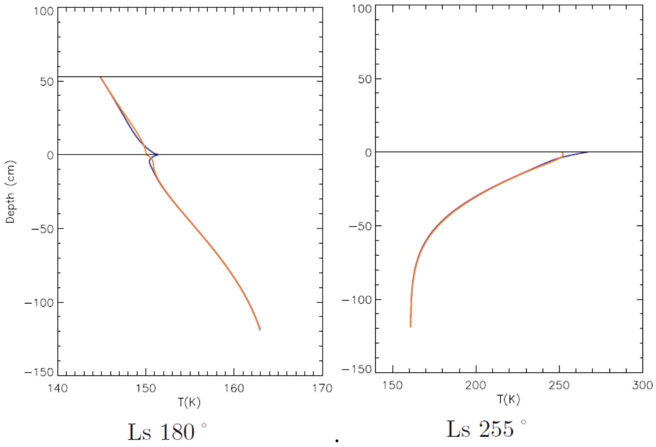

Figure 3: *Temperature profile at local 12AM (blue) and 12PM (orange) for a clean CO2 ice slab on a flat terrain at -85°. Energy storage in the slab can be noticed. Furthermore, the largest temperature difference between 12AM and 12PM occurs at the regolith interface. When CO2 ice has disappeared, we have the usual daily thermal waves.*

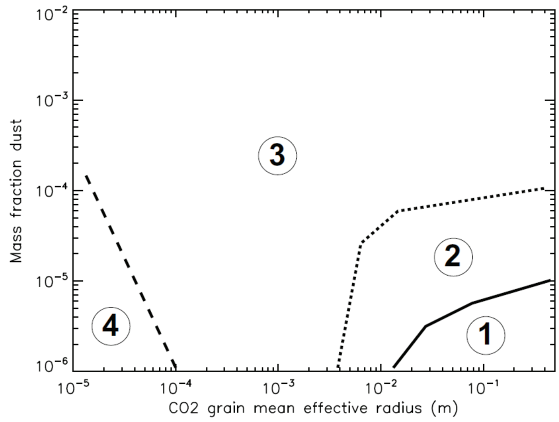

Figure 4. *Different behaviors of the CO2 ice depending on effective grain size and dust content. Zone 1 represents the zone where both surface and basal sublimation occur ; zone 2, is the same as zone 1 but here sublimation temperature is reached within the ice before being reached at the base ; zone 3, the zone where only surface sublimation occurs ; zone 4 the zone where CO2 ice accumulates year after year. Simulations were run on a flat terrain at -85°.*

Simulating the "Manhattan Island" region conditions: "Manhattan Island" region is centered at 99°E, -86.25°S and follows the classic TES "cryptic" behavior of low albedo while remaining near the CO_2 ice temperature [4]. Dark spots can be seen on THEMIS images at Ls=176° [5] and might even appear sooner.

We simulated the behavior of the seasonal cap in this region. Our results show that basal sublimation is possible if we consider large pathlengths and very little dust content within the ice. Moreover, the model can explain how dark spots can appear very early after the end of the polar night at high latitudes. Contrary to what was suggested by theoretical models, the role of seasonal thermal waves is found to be limited. Solar radiation alone can initiate basal sublimation, which therefore only depends on the CO_2 ice properties.

Investigating on dark spots formation requirements on Mars: For different places at the same latitudes, simulations results tend to prove that only CO_2 ice properties have a major impact on the sublimation process. Other parameters mostly have an impact of the time on the first gas ejection but do not determine if sublimation at the bottom of the ice will occur or not. This would suggest that dark spots formation highly depends on the condensation process during winter (atmospheric CO_2 condensation, dust and water ice deposition, etc.) [5][6].

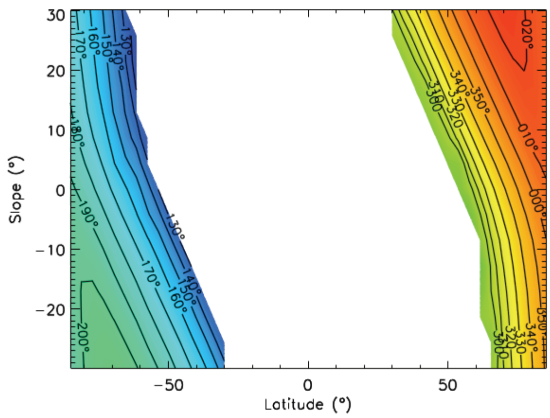

Figure 5: *Evolution of the solar longitude Ls (deg) of the first gas ejection with respect to the latitude (slab model). Surface pressure* was *set to 400 Pa in the southern hemisphere and to 1000 Pa in the northern*

hemisphere. Results show that the venting process can also occur in the northern hemisphere.

As for the impact of latitude, many questions were arisen. Dark spots can be observed on the polar caps at many northern and southern latitudes. [7] mentions the presence of a northern dark region which could have the same nature as the "cryptic" sector in the south polar cap. Still, fewer seasonal and perennial features are observed in the north compared to the south [8]. We tried to better understand this feature by running simulations at different northern and southern latitudes. The main result is that as long as we have similar conditions (ice properties, albedo, regolith thermal inertia, etc.), gas ejections are as likely to occur in the north as in the south. However, water ice is much more abundant in north polar regions and certainly plays a role, even at southern mid-latitudes and in some areas in the southern high latitudes. Adding water ice inclusions in our model should allow us to investigate more deeply dark spot formation in these regions.

Conclusion: The model that we developed gives some interesting clues to better understand the dark spots formation process. Simulations results show that the Kieffer et al. [1] model is plausible and that for certain CO_2 ice properties (like the one that are observed by OMEGA for instance) sublimation of the CO_2 ice slab from the bottom occurs. More precisely:

1. Only in the case of very large CO_2 grains and very little dust contamination, a large fraction of solar radiation can reach the regolith. In this latter case, the model shows that regolith surface can heat and sublimation temperature at the base of the CO_2 ice can be reached, what is consistent with Kieffer (2007)
2. Simulations results show that the occurrence of basal sublimation during spring only depends on the CO_2 ice properties, considering that the substrate on which the CO_2 ice lies has an albedo lower than 0.3. Other parameters (thermal inertia, slope angle) have however a significant impact on the starting date of the jet activity.
3. Early dark spots formation in Manhattan Island region (-85°) can not be explaine by seasonal thermal waves. However, our results show that venting process can be under certain conditions initiated very early by solar radiation penetration and that dark spots could form as early as Ls 174°.
4. We suggest that the venting process also occurs around the dunes. However, substrate material nature make them certainly difficult to observe compared to the dark spots on the dunes
5. We suggest that the decrease of the CO_2 ice effective grain radius observed during spring in the some of the southern polar regions could be caused by cracks in the ice, which would be the result of sublimation within the ice.

The article describing these results in more details will be published in Icarus [9]

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