DARK SPOTS AND GULLIES FORMATION PROCESSES AS A RESULT OF CO_2 ICE SUBLIMATION ON MARS: NEW CLUES FROM MODELS. . C. Pilorget[1,α], F. Forget[2], P.-Y. Meslin[3], M. Vincendon[1]. [1]Institut d'Astrophysique Spatiale, Universite de Paris Sud 11, 91405 Orsay, France, [2]Laboratoire de Meteorologie Dynamique, CNRS/UPMC/IPSL, 4 place Jussieu, BP99, 75252 Paris Cedex 05, France, [3]Institut de Recherche en Astrophysique et Planétologie, Université Paul Sabatier, 9 avenue du Colonel Roche, BP 44346, 31028 Toulouse Cedex, [α]Email: cedric.pilorget@ias.u-psud.fr

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].

Gullies observed recent activity could also be related to the CO_2 ice cycle on Mars [2,3]. Changes indeed seem to have occurred as the CO_2 ice was present. More recently, HiRISE observations shown new alcoves after CO_2 ice removal [4].

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 and allows us to test a large variety of scenarios [5].

In this paper, we present some simulations results aiming at better understanding these CO_2 ice related processes. We first describe the last results concerning dark spots formation and then evaluate to what extent similar processes could be at stake for the gullies.

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 [6].

Its vertical computational grid is a dynamic layer grid where layers have their own thermal and optical properties. 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 and water ice inclusions, dust and water ice grain radius), and a translucent slab model derived from [1] model.

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 [7].

The radiative model is coupled to a complete parametrization of heat conduction and storage by CO_2 and soil.

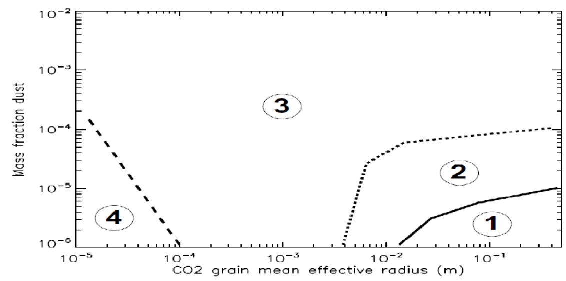

Figure 1. *Different behaviors of the CO_2 ice depending on effective grain size and dust content. Zone 1 represents the zone where both surface and basal sublimation occur ; zone 2, is the same as zone 1 but here sublimation temperature is reached within the ice before being reached at the base ; zone 3, the zone where only surface sublimation occurs ; zone 4 the zone where CO_2 ice accumulates year after year. Simulations were run on a flat terrain at -85°.*

Simulating a typical case: the "Manhattan Island" region: "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 [8].

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 on the time on the first gas ejection but do not determine if basal sublimation occurs 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.) [9][10].

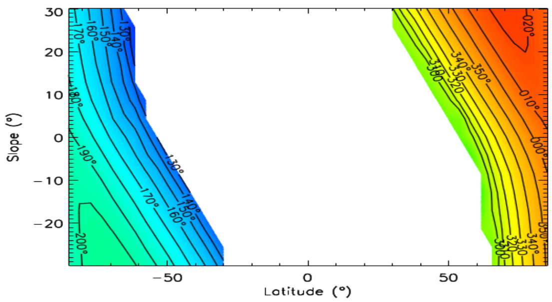

Figure 2: *Evolution of the solar longitude Ls (deg) of the beginning of basal sublimation with respect to the latitude (slab model). Surface pressure* was *set to 400 Pa in the southern hemisphere and to 1000 Pa in the northern hemisphere. Results show that the venting process can also occur in the northern hemisphere.*

As for the impact of latitude, many questions have arisen. Dark spots can be observed on the polar caps at many northern and southern latitudes. [11] 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 [12]. We tried to better understand this feature by running simulations at different northern and southern latitudes. The main result is that as we have similar conditions (ice properties, albedo, soil 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 plays a role, even at southern mid-latitudes and in some areas in the southern high latitudes. Simulations show that adding water ice inclusions in the CO_2 ice has a variable impact on the occurrence of basal sublimation, depending on their size and amount. Smaller inclusions for instance tend to limit more the solar flux penetration into the slab.

Gullies recent activity: Similarly to dark spots formation that involves material ejection, alcoves formation may result from processes that destabilize the first tens of centimeters of the soil, like the sublimation of CO_2 ice present within the pores of the soil for instance. Formation of CO_2 ice highly depends on pressure. A higher pressure increases the condensation temperature which makes the condensation easier in the soil. However, gas pressure in the pore space may not equal the cryostatic pressure exerted by the overlying ice slab. Temperatures in the regolith remain above the condensation temperature of CO_2, which inhibits condensation of CO_2 gas in the pore space, until enough gas is eventually liberated in the pore space to increase the condensation temperature above regolith temperature and thus lead to ice formation in the pore space. Work on this specific questions is ongoing and preliminary results will be presented.

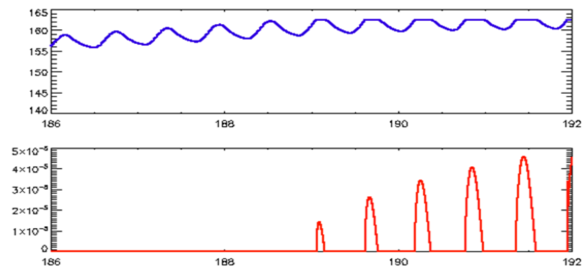

Figure 3: *Top: Evolution of the temperature at the base of the slab with Ls(°). Bottom: Evolution of the sublimation rate (kg.m^{-2}.s^{-1}) at the base of the slab with Ls(°). Simulations are made for a flat terrain at 85°S, soil albedo=0.24, soil thermal inertia=200SI.*

Conclusion: The model that we developed gives important clues to better understand CO_2 ice related features. Simulations results show that the Kieffer et al. [1] model is plausible for dark spots formation and that for certain CO_2 ice properties, sublimation of the CO_2 ice slab from the bottom occurs. More precisely:

1. Only in the case of very large CO_2 grains, very little dust contamination and a small amount of water ice inclusions, depending on their size, 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 CO2 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. Gullies recent activity, but also formation could also result from basal sublimation occurrence which would act as a CO_2 gas source and would allow the pressure to increase within the pores of the soil.

References: [1] Kieffer (2007) *JGR*, *112*, E08005. [2] Diniega et al. (2010) *GRA*, *38, 11*, 1047-1050. [3] Dundas et al. (2010) *GRL, 37,* L07202. [4] Hansen et al. (2011) *Science, 331*, 575-. [5] Pilorget et al. (2011) *Icarus, 213*, 131-149. [6] Forget et al. (1999) *JGR*, *104*, 155-176. [7] Spiga and Forget (2008) *GRL, 35, 15*. [8] Kieffer et al. (2006) *Nature*, *442*, 793-796. [9] The OMEGA team et al. (2009), *Icarus*, *200*, 374-394. [10] Colaprete et al. (2005), *Nature*, *435*, 184-188. [11] Kieffer and Titus (2001), *Icarus*, *154*, 162-180. [12] Piqueux and Christensen (2008), *JGR*, *113*, E06005.