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Stability of Subsurface Carbon Dioxide Ice over the Obliquity Cycle.

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Carbon dioxide (CO_2) ice does not remain stable at the surface of Mars for long periods of time over the obliquity cycle. We use the UK version of the LMD Mars Global Circulation Model (MGCM) [1] with a newly integrated subsurface scheme to investigate how the timescales for the stability of CO_2 ice are affected by overlying regolith at different obliquities within the range expected for Mars over the last 4 Myrs [2].

Introduction: Martian subsurface ice studies have focused on the distribution of water ice, because the amount of subsurface CO_2 ice present has been considered insignificant. This is because present day surface and subsurface temperatures are only temporarily low enough for the presence of CO_2 ice.

The large variability of martian obliquity significantly impacts surface and subsurface temperatures [3], affecting the timescale and distribution of CO_2 ice stability at the surface. At low obliquities, mean surface temperatures drop and the perennial CO_2 polar caps extend equatorward [e.g. 4, 5]. Conversely, at high obliquities, higher surface temperatures mean the CO_2 polar cap sublimates, revealing the water ice below which migrates equatorwards [e.g. 5, 6]. In all obliquity cases, it has been assumed CO_2 only occurs as either surface ice at the poles, vapour within the atmosphere or adsorbed in the regolith, ignoring the potential for subsurface CO_2 ice.

Investigations into the South Polar Layered Deposits (SPLD) using data from the Shallow Radar (SHARAD) on the Mars Reconnaissance Orbiter revealed the presence of buried CO_2 ice deposits interspersed with layers of water ice [7]. The amount of CO_2 ice stored within these deposits has been estimated to be enough to nearly double the present day atmospheric pressure if released [7, 8].

One suggested mechanism for the formation of the SPLD is that surface CO_2 ice slabs form during obliquity minima and are then buried under a water ice layer that accumulates in the south when perihelion occurs during northern summer and while the obliquity is still low enough for the CO_2 ice to remain stable [9]. Another possibility is the CO_2 ice deposits could form within the subsurface, and when the obliquity changes, these deposits would persist for longer due to the effect of the overlying regolith reducing the sublimation rate, as has been demonstrated for water ice [e.g. 10]. We investigate how the stability of CO_2 ice is affected by a thin layer of regolith compared to at the surface boundary layer that exchanges with the atmosphere over a range of obliquities.

Method: The subsurface scheme integrated into the MGCM comprises of three sets of interdependent calculations (temperature, water and CO_2). The equations used throughout the subsurface scheme are from experimental work at Mars relevant temperatures and pressures.

The thermal scheme uses a finite volume discretization of the heat conduction equation, with a thermal conductivity that varies with depth and both water and CO_2 ice content. The thermal conductivity of the empty regolith uses the method of [11], the water ice thermal conductivity is from [12] and CO_2 ice thermal conductivity is from [13].

The water scheme was developed using mostly the same water properties as in the previous subsurface scheme of the MGCM [14]. The main differences between the two schemes are a finite volume method is used to discretise the vapour diffusion equation and different equations of state have been used [from 15]. Adsorption effects have also been ignored in the new scheme because the inclusion of an adsorption isotherm has been shown to have a negligible effect on long term ice accumulation [16].

The CO_2 scheme uses the same methods as the water scheme, but with equations appropriate for CO_2. The diffusion coefficient used is from [17], the equations of state are from [18] and a variable density of CO_2 ice is used [19].

Preliminary Results and Discussion: We present results from a series of simulations with different initial amounts of both water and CO_2 at three different obliquities (15°, 25° and 35°). Figures 1 and 2 show examples of the results from these simulations, using an initial condition of 50% of the pore space filled with water ice and 50% with CO_2 ice. The initial global coverage of both ices gives an idea of where CO_2 ice could survive in the subsurface at each obliquity if already present. This is useful because the exact amount and distribution of subsurface CO_2 ice in the present day is unknown and has never been investigated, so the results from this study will be used to inform where CO_2 could be present for the initial conditions for future investigations.

Figures 1 and 2 show the number of sols CO_2 ice is stable for in the surface layer and at a depth of 0.012 m, respectively. The CO_2 ice in the surface layer equilibrates with the atmosphere near instantaneously from the changes in temperature associated with a change in obliquity, whereas CO_2 ice in the subsurface would take longer to respond to this change. The longer response time is because subsurface ice is not in direct contact with the atmosphere and vapour needs to diffuse through the overlying regolith before equilibrating with the atmosphere. The diffusion coefficient

[16] controls the rate of this diffusion and has a range of 0.00018 m/s to 0.11 m/s when the porosity ranges from 0.01 (when ice nearly fills the pore space) to 0.5 (with no ice) at 150 K.

The observed effect of the overlying regolith on the rate of sublimation in these simulations demonstrates that subsurface CO_2 ice could remain stable for longer periods than surface ice after a change in obliquity. This allows enough time for a water ice layer to deposit over the CO_2 ice, trapping it within the subsurface. Future investigations will involve running simulations with more realistic initial CO_2 ice distributions, such as using the resulting distribution at one obliquity as an initial condition for a different obliquity

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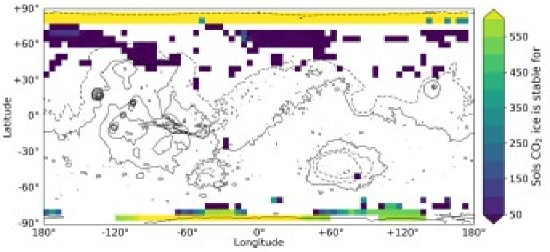
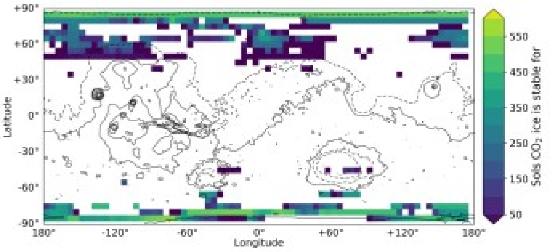


(a) Obliquity = 15°



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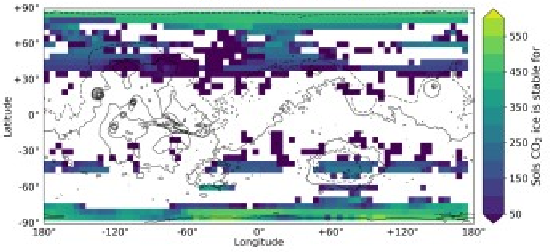
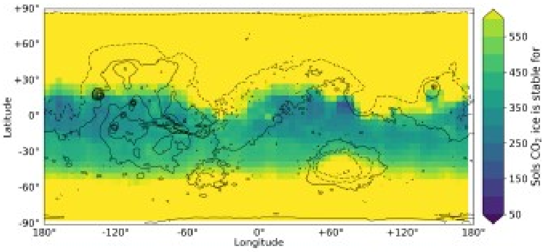


(c) Obliquity = 35°

Figure 1: Number of sols CO_2 ice remains stable at the surface for the entire day at an obliquity of (a) 15° (b) 25° (c) 35°. The plots show the results for the second year of a simulation with an initial condition of 50% of the pore space filled with water ice and 50% with CO_2 ice.



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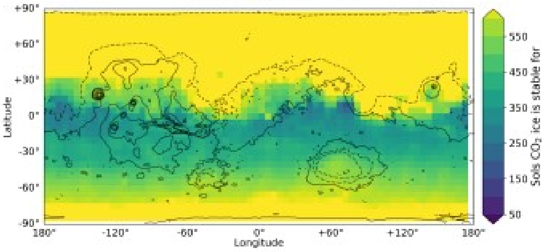
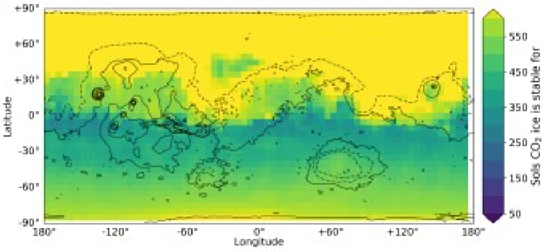


(b) Obliquity = 25°



(c) Obliquity = 35°

Figure 2: Number of sols CO_2 ice remains stable at a depth of 1.2 cm for the entire day at an obliquity of (a) 15° (b) 25° (c) 35°. The plots show the results for the second year of a simulation with an initial condition of 50% of the pore space filled with water ice and 50% with CO_2 ice.