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The Penetration of Solar Radiation into Carbon Dioxide Ice and Snow

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Abstract

The depth to which solar radiation can penetrate through ice is important for understanding surface-atmosphere interactions across the surface of Mars. Related phenomena include cryoventing of CO_2 which creates dendritic troughs in the polar regions, and gully formation in the absence of liquid water. New light intensity measurements for calculating the e-folding scale, otherwise known as the absorption scale length, or penetration depth, of CO_2 slab ice are presented here, providing improved constraints on this parameter, which is vital for thermal models of the seasonal polar caps. In addition to this, the e-folding scale of both carbon dioxide snow and water snow has been measured, which has applications for modeling the volatile budget across the Martian surface.

1. Introduction

Icy surfaces behave differently to rocky or regolith-covered surfaces in response to irradiation because visible light can penetrate partially into the subsurface. Ices are transparent or translucent to visible and shorter wavelengths of light, while opaque in the infrared, which makes a solid state greenhouse effect possible [1]. This can result in significant differences in the shallow subsurface temperature profile when compared to rocky surfaces. Of particular significance for modeling the solid-state greenhouse effect is the e-folding scale of the ice. The e-folding scales of CO_2 slab ice [2], CO_2 snow and H_2O snow for the cumulative wavelength range 300 to 1,100 nm have been constrained. These are vital parameters in heat transfer models for the Martian surface, enabling us to better understand surface-atmosphere interactions at Mars' polar caps.

The permanent polar caps on Mars primarily consist of water ice. These are stable year round at both the northern and southern poles. However, as temperatures drop during autumn, CO_2 begins to condense out of the atmosphere at high latitudes to form the seasonal polar cap, containing around 25% of the atmospheric CO_2 at its maximum extent [3]. This can occur as both direct condensation or as precipitation: snow [4]. Whilst measurements have been made previously for water snow, e.g. [5, 6], no measurements for CO_2 snow have been published. Furthermore, there are several differences in sample preparation and experimental methodology in these previous studies which are considered during result analysis. With optical properties quite different to water ice, this could affect the thermal regime of the surface and shallow subsurface in these regions. Additionally, a widespread CO_2 frost cycle is now known to occur, with nighttime frosts frequently observed through to low latitudes [7]. As the presence of solid CO_2, either as slab ice or as snow/frost deposits, is widespread across the surface of Mars, having accurate models to describe how solar irradiation interacts with surface CO_2 ice could further our understanding of some of the unique surface processes observed today.

Such phenomena include active gully formation on mid-latitude slopes without the presence of liquid water [8]; spider formations in the Cryptic region in the south, which occur in consistent locations every spring [9]; and seasonal furrows in the northern hemisphere, which are similar to those in the south but tend to be smaller and ephemeral, occurring in different locations each year due to shifting sand dunes [10].

2. Methodology

Slab ice samples were prepared by condensing CO_2 directly from the gas phase within a pressure vessel cooled by liquid nitrogen. This forms large CO_2 ice blocks, which were then cut to size and polished smooth prior to experiment commencement [2].

CO_2 snow was made by decompression directly from a liquid CO_2 cylinder. The snow was sieved to <1 mm grain size, and stored in liquid nitrogen until use. This minimised sintering and contamination by water frost. Water snow was made by spraying deionised water into a dewar of liquid nitrogen, which was then sieved and stored in sealed containers at -85°C to avoid sintering of the samples.

Both the snow and slab ice experiments were undertaken in an argon-filled chamber, which was first cooled with liquid nitrogen. This both reduced the sublimation rate of the CO_2 ice, and minimised water frost deposition on both the sample and the glass plate the sample is held on.

3. Results

Table 1 E-folding scale results based on the minimum, maximum and mean light intensity measurements for each sample of CO_2 slab ice.

Sample No.	E-Folding Scale, ζ (mm)		
	Min Intensity	Max Intensity	Mean Intensity
1	40.00	28.57	32.58
2	43.48	30.30	33.33
3	35.71	58.82	47.62
4	35.71	71.43	47.62

The e-folding scale calculated using minimum light intensity measurements for samples 1 and 2 is higher than that calculated using the maximum data (see Table 1). This is due to the fact that these samples started out more opaque or ‘milky’, and so light penetration was lower than in the other samples. As measurements commenced, the minimum amount of light able to penetrate through the sample increased steadily. However, additional cracks would reduce the maximum light intensity, and so the rate of increase in light penetration was slower than that for the minimum results. In contrast, samples 3 and 4 were much more transparent at the beginning, and so any cracks forming would affect the minimum and maximum readings more equally than in samples 1 and 2. Consequently, we have more confidence in the results obtained from samples 3 and 4.

It is reasonable to give an e-folding scale value of ζ = 35.7 mm ± 7.7 mm for cracked, higher albedo CO_2 ice; for perfectly smooth, unblemished slab ice ζ = 65.1 mm ± 6.3 mm would be more applicable. However, we would urge caution with using the highest estimations of the e-folding scale, for in reality, any thermal variations, such as the diurnal insolation cycle, are likely to cause thermal cracking of the CO_2 slab ice. In addition, the e-folding scales of H_2O and CO_2 snow were calculated from light intensity measurements to give mean value of ζ = 11 mm ± 2 mm for both types of snow. Given the estimated errors, the e-folding scales can be considered identical. This suggests that light propagation through translucent ices at the grain sizes measured ($\leqslant$ 1mm) is determined by the number of scattering surfaces rather than the specific material’s optical properties.

We therefore recommend the use of 47.6 mm for modelling ‘normal’ CO_2 slab ice conditions on Mars, and 11 mm for snow or frost.

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