SPECTRAL ANALYSES AND GRAIN SIZE DETERMINATION IN MARE BOREUM ICE CAPS FROM CRISM

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Introduction:

Identification and mapping of Martian polar caps can potentially answer many questions related to climate cycles on Mars. During the fall and winter seasons at high latitudes, the local surface and atmospheric temperatures become very cold to reach the frost point of CO_2 [5]. The north polar deposits are dominated by water-ice and the south polar deposits are covered by a thin Carbon-Di-Oxide Veneer [1]. Understanding the CO_2 cycle can provide suggestions on Mass transfer and heat transfer from the sublimating cap toward the region of forming polar cap[2]. The dark layered deposits in Martian Polar regions can help us to a large extent in understanding the transport of Dust. This work presents an extended classification of different types of Ice forms present in Mare Boreum Region of Mars from the images obtained by Compact Reconnaissance Imaging Spectrometer for Mars (CRISM), aboard the Mars Reconnaissance Orbiter. Spectral measurements were used to derive indices for Carbon-di-Oxide Ice and Water-Ice. Normalized Indices were developed to detect the water-Ice, Co2-Ice and dust. At places where Dust covered the water-ice, water-Ice to dust index was determined to estimate the percentage of Water-Ice. Using these Indices, an extended classification of these Ice forms was performed. Further, the water equivalent of polar ice cap region on Mars was also found.

Keywords: CRISM, Nomalised Indices, CO_2 Ice,Water-Ice.

Spectral analyses of Ice forms: The water-Ice spectra shows distinct absorption features near 1.3 µm, 1.5µm and 2µm. The absorptions features for CO2-ice were found near 1.3µm, 1.4µm, 1.5µm and 2µm. The difference between water-Ice and CO2-Ice occurs near 1.4-1.5 µm. The doublet which is found in case of CO2 ice is absent in water-ice. It is clear that there exists a mixture of CO2-Ice and Water-Ice in CRISM's resolution of 200m. Hence we are in need of indices to improve the classification of these ice forms. The water-Ice index was developed from the peak reflectance in the visible region and the absorption at 2µm. The 2µm absorption is the key feature which is found in all three forms water Ice;
But their properties like the band depth, band area differs from one form to other form. The CO2 index was developed by considering the reflectance at 1.4 µm and absorption at 2 µm.

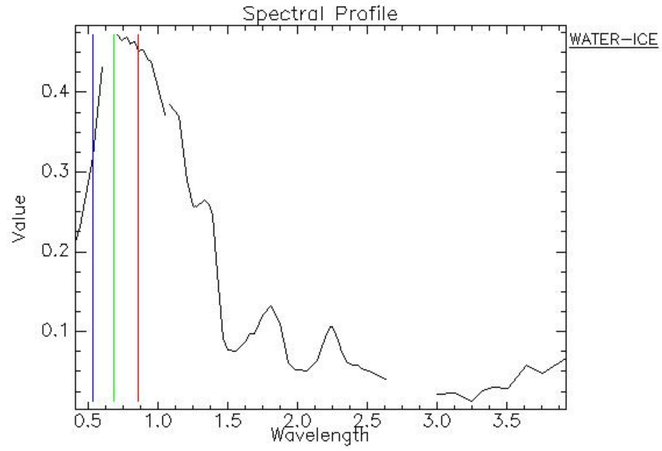

Figure 1. Water-Ice spectrum from CRISM.

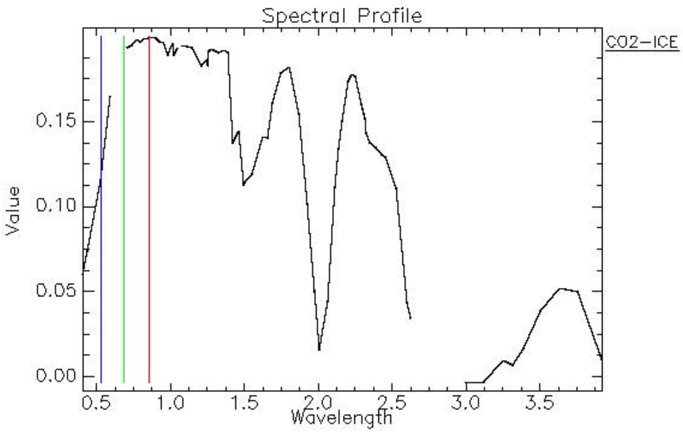

Figure 2. CO2-Ice spectrum from CRISM.

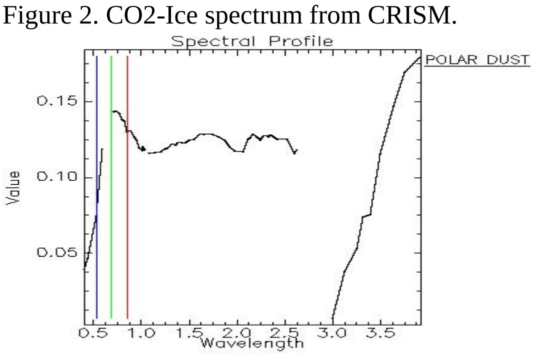

Figure 3 . Dust spectrum from CRISM in Mare Boreum North Polar Ice Cap.

It was found from the band depths that when the dust is mixed with water-Ice, the absorption feature is reduced by 0.42%. But when dust is mixed with CO2-ice, the absorption feature of CO2-Ice is reduced by 0.55%. Thus the spectral absorption of Water-Ice is relatively resistant to band depth changes when mixed with dust.

Normalized Difference Water ice Index: It is clear that there exists a mixture of CO2-Ice and Water-Ice in CRISM's resolution of 200m. Hence we are in need of indices to improve the classification of these ice forms. Water-Ice index was developed from the peak reflectance in the visible region and the reflectance at 2µm. The 2µm absorption is the key feature which is found in all three forms water Ice, CO2 ice and dust. The CO2 index was developed by considering the reflectance at 1.4 µm and absorption at 2 µm.

$$NDWII = (R_{0.7} - R_2)/(R_{0.7} + R_2)$$

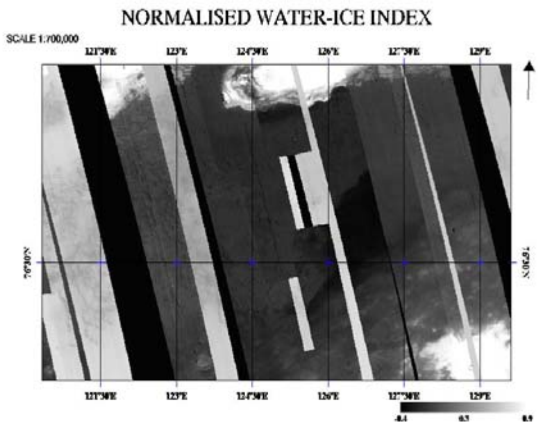

Figure 4. Map showing the water-ice index ranging from -0.4-0.9 in Mare Boreum North Polar Ice cap.

The bright regions show the water-Ice. The grey areas represent the dust mixed with Water-Ice. The dark areas represent the thick cover of dust enveloping the polar ice caps.

Normalized Difference CO2-Ice Index: The Normalized difference CO2 index is obtained by the following algorithm.

$$NDCII = (R_{1.4} - R_2)/(R_{1.4} + R_2)$$

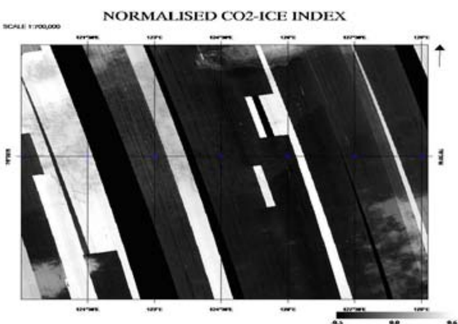

Figure 5. CO2 index map showing the bright areas occupied by CO2 ice in Mare Boreum.

Polar Dust: The polar dust can be identified by a very less visible reflectance. Since the particles are of basaltic origin, they can be mapped by framing an index consisting of reflectance at 0.75 µm and 0.95 µm. The areas having the maximum layer of thick dust cover is shown in Black and those areas having least dust cover are represented in white.The Normalized difference dust index (NDDI) was computed using the ratio

$$NDDI = (R_{750}-R_{950})/R_{750}+R_{950})$$

Where R_i = Reflectance at wavelength 'i'. Wavelength 'i' is in nanometers).

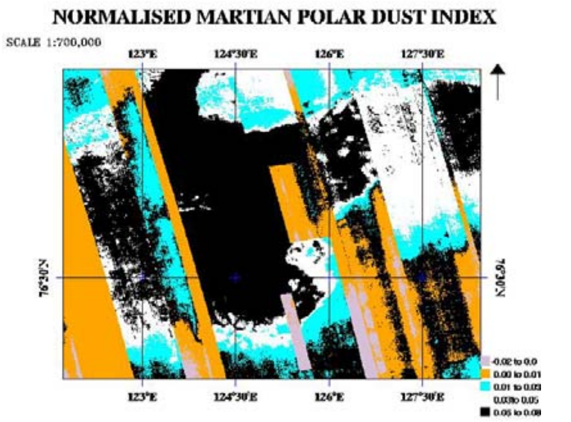

Figure 6. Map showing the polar dust index in Mare Boreum.

The dust was found to accumulate either away from the thick polar ice cap or in the rim of craters housing thick water-Ice. The maximum amount of dust cover in this region was 8%. Most of the dust particles contribute to dark dust clouds which hinder the monitoring of the surface. One such occurrence was witnessed in Mare Boreum region in North Polar Ice cap.

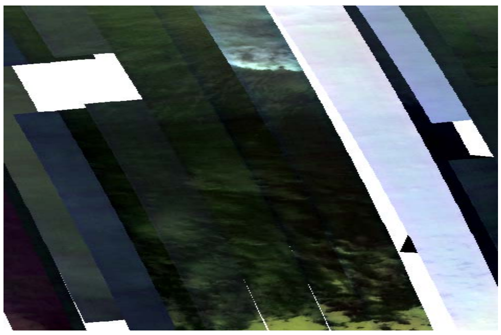

Figure 7. Dust cloud in Mare Boreum North polar region.

The dust covering the Polar Ice caps are capable of rising the temperatures and thus melting the Ice Caps. The radiative forcing of Dust storms can be one of the methods for melting Ice on Mars in future. Hence it becomes a prime objective to determine the water-Dust ratio[4]. Finally the water-Equivalent of Martian Polar Ice caps must be analyzed in order to know the quantity of water which will be obtained when the Polar Ice caps are melted.

Water ice-Dust Ratio: Water-Dust ratio is calculated from the normalized indices maps of water-Ice and Dust.

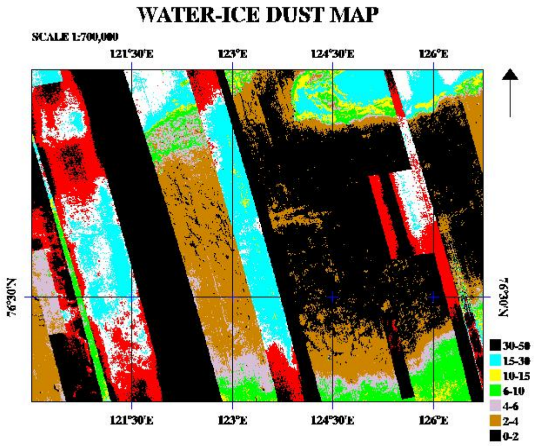

Figure 8. Water-Ice to dust Map in Northern Polar Ice caps of Mars.

Water Equivalent: The water-Equivalent of Polar Ice caps can be retrieved from the snow depth and snow density. Snow depth can be calculated from snow fraction in each pixel. Snow fraction can be determined as follows

$F=(R-R_L)/(R_S-R_L)$

Where R = Observed visible Reflectance of the pixel.

R_L = Reflectance of snow free terrain.

R_S = Reflectance of Snow.

Snow Depth = $e^{(aF)}-1$

Where a = 0.0333 for non forested areas

F= Snow fraction.

The water equivalent is then calculated from the product of snow density and snow depth. The visible albedo was less and hence it can be concluded that the density of the Ice Pack must have been high. This suggests that the Ice crystals were not fresh. Since the visible reflectance resembled more of a one year old ice pack, the density was assumed to be 550Kg/m^3 . The water equivalent was found to range between 20-21% (This refers to only one scene of CRISM data in Mare Boreum).

The water-Equivalent value was found to be high in those areas covered by dust. This proves that a thick layer of Ice lies beneath the layer of dust which when melted can contribute to surplus amounts of water. Hence future attempts to melt Ice in Martian Polar Caps can be performed in these areas with the suitable conditions required for radiative forcing of dust.

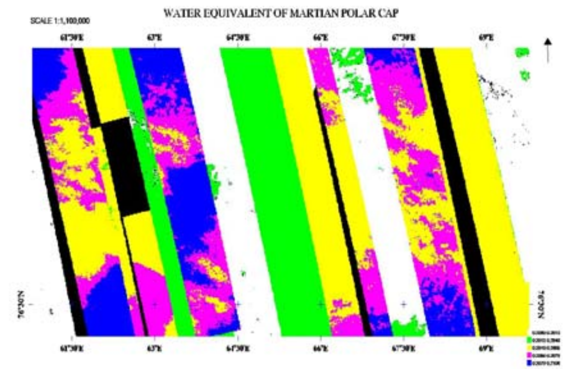

Figure 9. Water-Equivalent of Ice in North Polar region of Mars.

Grain size of ice crystals in mare Boreum: The grain sizes of Ice Crystals were reckoned from the thermal inertia data available from Viking Infrared Thermal Mapper [3]. The thermal inertia represents the ability of a material to resist thermal changes. Particle size was reckoned from thermal inertia by using a relation derived from laboratory studies [3],

Thermal conductivity = $(CP^{2/3})\, d^{(0.52-k.P)}$

Where *k is the constant k=0.01,*

C=0.0014,

d is the particle diameter,

P is atmospheric pressure

Throughout the study the average atmospheric pressure on Mars 5.25 torr (7 mb) was utilized. Usually Ice Crystals have high thermal inertia. The size of water-Ice crystals was found to be 3.35-3.48cm. The water crystals build by iterative sublimation and finally grow into snow pack covering large areas. These snow packs have wide range of sizes due to the agglomerated ice-crystals. The size of CO2 ice crystals was found to be 1.05-1.08cm. The dust particle size was found to be ~0.61-0.66cm. This proves that the dust particles are found to be mixed with Ice Crystals. If the crystals were of larger size, it would have been difficult to transport those particles by saltation. The pressure of Mars is very low and hence the wind speed required to lift the particles becomes very large even for those particle sizes in µm. These dust particle sizes were determined at places where the dust cover was very thick. Hence the dust particles are strongly bound with Ice-Crystals. This helps us to conclude that the Ice crystals must have formed first and the dust must have covered it after the formation of Ice. Moreover the Ice-Crystals found in this region resemble those of one year old Ice Pack in terms of visible reflectance. So this is one of the clear evidences that the Aeolian processes are still active in Mars.

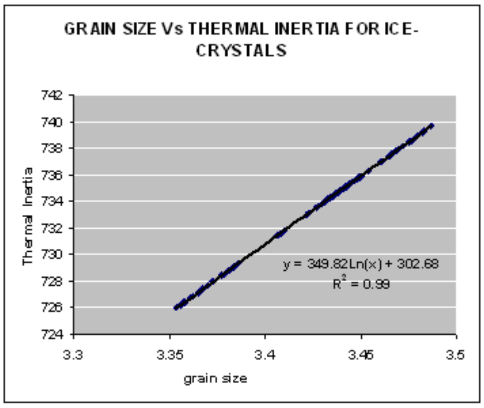

Figure 10. Scatter plot showing the correlation between the grain size of water-Ice crystals in cms (in X axis) and the thermal inertia in Y axis.

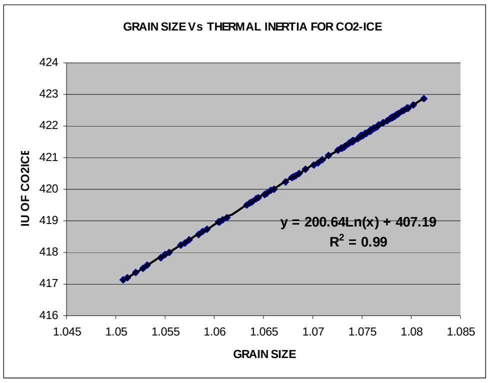

Figure 11. Scatter plot showing the correlation between the grain size of CO_2-Ice crystals in cms (in X axis) and the thermal inertia in Y axis.

Conclusion: Thus, evidences for two distinct kinds of Ices are clearly found in Martian Polar Regions. Water-Ice and CO_2-Ice also vary in their grain size composition. Also it has been found that the radiative forcing of heat has a prominent role in melting the Ice. This causes the formation of transient Liquid water which again freezes to form Ice. The emissivity of both Water-Ice and CO_2-Ice was very high. The waxing and waning of Ice in Martian polar caps greatly describe their seasonal characteristics. The results obtained in Martian Polar regions can be widely used in studying the climate cycles in mars. This can provide valuable conclusions on the puzzle if Mars is currently undergoing the Ice-Age.

References

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