NORTH POLAR SPRINGTIME REMOVAL OF COLD-TRAPPED H_2O ICE THROUGH INSOLATION-INDUCED BASAL SUBLIMATION OF CO_2.

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Introduction: The H_2O and CO_2 cycles on Mars are coupled processes, and conditions in the north polar springtime seasonal ice cap demonstrate how these volatiles modify each other's condensation and sublimation rates.

Background: Both modeling [1-3] and observations [4-9] support the theory that a sublimation lag of H_2O ice is left behind when the edge of the seasonal CO_2 ice cap retreats. As the surface continues to warm, the H_2O ice lag also sublimes and some of that H_2O vapor is transported over the CO_2 ice cap edge where it is cold-trapped within the cap interior. This process acts like a conveyor belt transporting the water poleward until all of the CO_2 ice has sublimed.

Observations: The retreating north polar seasonal cap has been observed by numerous spacecraft instruments over a wide spectral range. Mars Global Surveyor Thermal Emission Spectrometer (TES) [10], Mars Express Mars Observatoire pour la Minéralogie, l'Eau, les Glaces et l'Activité (OMEGA) [11], Mars Reconnaissance Orbiter (MRO) Compact Reconnaissance Infrared Spectrometer for Mars (CRISM) [12] and the Mars Odyssey THermal EMission Imaging System (THEMIS) [13] are the focus for this study although several other instruments provide corroborating observations.

TES. Observations of both solar (albedo) and thermal spectral regimes enabled the tracking of seasonal ice cap edges. Temperature observations can be used to determine whether bright materials are CO_2 ice or are being thermally buffered by CO_2 ice [5,7].

OMEGA/CRISM. Both OMEGA and CRISM had short-wave infrared (SWIR) subsystems with the ability to spectrally distinguish between volatile types. Unlike TES, SWIR observations only sense the top few micrometers of the surface, such that an optically thick layer of one type of volatile (even if physically thin), can obscure the spectral signature of underlying materials. It is these observations that show H_2O ice is removed while CO_2 ice is still present.

THEMIS VIS. Observations of clouds over the early morning seasonal cap (Fig. 1) suggest a southward airflow in the bottom few kilometers of the atmosphere [14-15]. The presence of lee clouds and cloud streets shows the presence of H_2O vapor at a temperature near the dew point with little to no vertical mixing. The afternoon observations show a lack of lee clouds and cloud streets, suggesting either a warmer or more turbulent lower atmosphere. In both times of day, what appears to be ice-fog is prevalent.

The Model:

Getting the water in: There are two theories as to how the water ice that is observed in the cap interior is transported: (1) prior to the seasonal cap formation [12] and (2) after the seasonal cap formation [1-3,10-11].

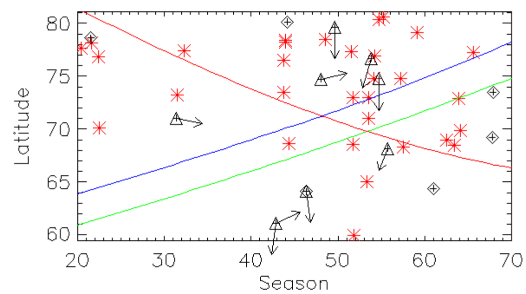

Figure 1: MY 33 northern spring morning clouds observed by THEMIS VIS. Red asterisks indicate ice-fog. Triangles indicate lee clouds. The arrow indicates the direction the cloud is moving based on a 360-degree azimuth. Diamonds indicate cloud streets. The red line indicates the edge of polar day. The blue line indicates the average CO2 cap edge latitude while the green line indicates the average H2O cap edge [16].

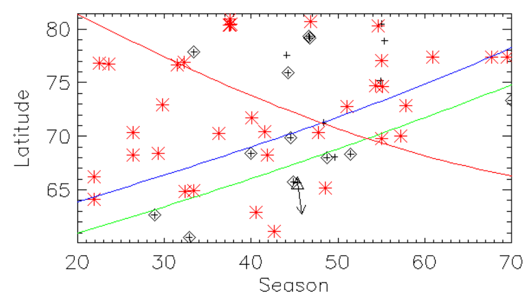

Figure 1: MY 33 northern spring afternoon clouds observed by THEMIS VIS. Legend is the same as in Fig. 1. The "+" signs indicate stratocumulus clouds.

Theory 1 requires H_2O ice to condense onto the polar surfaces in early autumn, and be sufficiently rough that it protrudes above the seasonal CO_2 ice as early as L_s=11°. At this season, the CO_2 ice in the interior of the seasonal cap may exceed a meter in depth [5,17]. Additional modeling is needed to determine if intimately mixed H_2O ice that condensed with the CO_2 ice during the fall can account for this early detection of H_2O absorption features.

Theory 2 (Fig. 3) requires the existence of either a Mars polar cell or that the baroclinic waves penetrate deep into the cap interior. Observations of early morning lee clouds and cloud streets favor the Theory #2 scenario [14-15], as their formation indicates high concentrations of water vapor in the bottom few kilometers of the atmosphere.

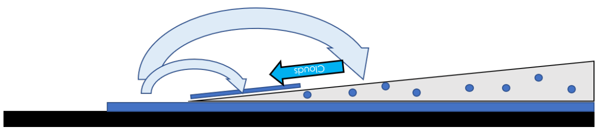

Figure 2: General movement of water vapor near the cap edge. The water vapor that forms the low-altitude water-ice clouds (dark blue arrow) are from the same vapor source that results in the cold-trapped water ice on the surface.

Getting the water out: As pointed out by Brown et al. [9], removing a thin cold-trapped layer of H_2O ice that is in direct contact with CO_2 ice through sublimation of the top layer is not plausible. We propose that the same process that has been used to explain spots and fans on the southern seasonal cap[18-21] and spots on defrosting northern dunes [22] can be scaled to the north polar seasonal cap. In this scenario, insolation induces basal sublimation of a semi-transparent slab of CO_2 ice, just as in the south. However, instead of the CO_2 gas being concentrated and then released at vents, the escape of gas is widely distributed – more akin to seepage than jets. The seeping CO_2 gas may initially levitate the optically thick, but physically thin, layer of cold-trapped H_2O ice. The H_2O ice layer quickly fractures where the smaller fragments are lofted into suspension and the larger fragments are pushed aside to form ring-shaped micro-piles. The tops of these micro-piles are no longer in direct contact with the underlying CO_2 ice, possibly enhancing sublimation during the warmer parts of the day. (Fig. 4) These micro-piles could also be eroded into blowing H_2O snow as suggested by Brown et al. [9], by katabatic winds. The ice fogs observed by THEMIS-VIS could be blowing H_2O snow.

Summary: The conceptual model presented here explains many of the observations of the northern springtime seasonal cap. Water vapor is transported into the interior of the seasonal cap either through deep penetrating baroclinic waves or by a Mars polar cell. The vapor transported is the source for both clouds and observed cold-trapped water ice. Seepage of CO_2 gas from insolation-induced basal sublimation fractures cold-trapped water ice on the CO_2 ice surface, thus removing the H_2O ice from direct thermal contact with the underlying CO_2 ice. Smaller fragments can be lofted – either subliming, being carried away in suspension, or falling back on the surface as snow-like material. Larger fragments are pushed aside into concentric piles, which can either be eroded or sublimate.

The solid greenhouse effect may be a widespread process on the springtime seasonal caps – the morphology of the process may be determined by the pressure and volume of the escaping gas, e.g. seepage vs. jets.

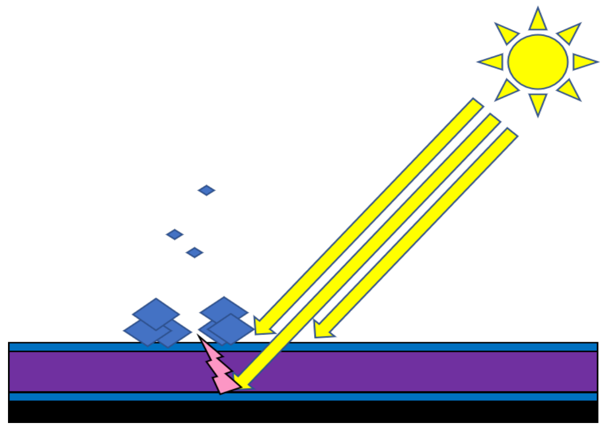

Figure 3: Insolation induced basal sublimation causes CO_2 gas to seep through the CO_2 ice slab. When the gas reaches the surface, the pressure fractures the H_2O cold trapped layer, where large fragments are pushed aside into micro-piles and small pieces are carried away in suspension.

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