MARS ICE CONDENSATION AND DENSITY ORBITER. T.N. Titus[1], T.H. Prettyman[2], A. Brown[3], T.I. Michaels[4] and A. Colaprete[5], [1]U.S. Geological Survey (2255 N. Gemini Dr., Flagstaff, AZ 86001), [2]Planetary Science Institute (1700 E. Ft. Lowell, Suite 106, Tucson, AZ 85719), [3]SETI Institute (515 N. Whisman Rd., Mountain View, CA 94043), [4]Southwest Research Institute (Boulder, CO), [5]NASA Ames Research Center (MS 245-3, Moffett Field, Mountain View, CA)

Introduction: The seasonal polar caps of Mars consist primarily of CO_2 that condenses from the atmosphere to form surface ice at high latitudes following the autumnal equinox in both hemispheres. The seasonal caps are prominent features on Mars that were first described by Herschel in 1784. They extend equatorward as far as 40º S in the southern hemisphere and 55º N in the northern hemisphere. Approximately 25% of the Martian atmosphere is cycled annually into and out of the seasonal caps. Consequently, the seasonal CO_2 cycle plays an important role in the planet's atmospheric general circulation.

Questions about the seasonal caps that remain unresolved concern local cap properties (e.g., column mass, density, thickness, grain size, dust and water ice fraction), energy-balance terms (e.g., wavelength dependent albedo and emissivity) and CO_2 condensation mechanisms. The rate of seasonal deposition and sublimation of CO_2 ice is determined by the local energy balance, which depends on solar insolation, atmospheric properties (such as dust optical depth), emissivity and albedo of the surface, advection of energy by the atmosphere and energy storage within the regolith.

The pursuit of detailed knowledge regarding the polar energy balance continues to be an important aspect of understanding Mars and its polar regions. Without the understanding of the present-day Mars processes and climate, especially in the polar regions, it will be difficult to accurately extrapolate to past climates when Mars may have been a warmer, wetter planet.

CO_2 Ice Density: What are the densities, column abundance and areal coverage of the CO_2 ice that compose the seasonal and residual polar caps?

Investigation: Measure the spatial and temporal evolution (thickness) of the seasonal polar caps with centimeter vertical resolution sampled at approximately every 10º of L_s.

Investigation: Measure the topography of the south polar residual cap at 20 meter (horizontal) and centimeter (vertical) resolutions.

Investigation: Measure the column mass abundance of the CO_2 ice in the seasonal and residual polar caps with accuracy of 50 kg/m^2 sampled at approximately every 10º of L_s.

Discussion: Surface CO_2 ice emplacement can occur either as direct deposition onto the surface or as precipitation (snow) from the atmosphere aloft. The time evolution of these two modes of ice emplacement and subsequent grain growth primarily determines the seasonal cap density. Spatial and temporal density variations of the seasonal CO_2 ice are expected, but cannot be easily measured with present day observations. For example, an estimate of the volumetric density of seasonal CO_2 ice has been determined by combining MOLA altimetry (cm precision over ~120 m footprints) (e.g., [1]), gravity measurements (radio science) [2], and nuclear spectroscopy (e.g., [3-5]). Unexpectedly, the results are consistently much lower than the density of solid CO_2 ice, and may indicate either measurement bias or the effects of physical processes that are currently not understood. Similar results were obtained for the density of the residual polar ice. To determine CO_2 ice density as a function of space and time, we recommend two specific measurements: vertical changes in the cap height (and thus depth, given the substrate topography) during the fall, winter, and spring seasons, and a simultaneous determination of the CO_2 ice column abundance.

The changes in elevation could be monitored by either a laser altimeter or by interferometric synthetic aperture radar (InSAR). The second measurement could be accomplished with a collimated, thermal neutron detector, designed to exploit the relative motion of the spacecraft and the neutrons to localize surface emission sites. Since CO_2 surface ice is a very bright source of thermal neutrons and thermal neutrons are readily absorbed by thin layers of material (e.g., Cd or Gd), it would be possible to build a compact CO_2 ice imaging system with high spatial resolution (e.g., able to resolve spatial variations in the cap on a scale of 50-100 km), close to an order of magnitude improvement over that presently achieved by Mars Odyssey instrumentation (600 km resolution) [6].

Absorption of thermal neutrons by atmospheric noncondensable gas (N_2 and Ar) would be corrected using microwave data (using CO as a proxy for Ar and N_2) or using measurements of epithermal neutrons. The column abundances would be determined to better than 50 kg/m^2, and coupled with thickness measurements accurate to 0.01 m, which would enable the determination of density to within 3.3% (for a 1 m thick solid slab). This level of precision allows for the testing of different theories on the physical form of the ice (e.g., snow vs. slab-ice vs. hoar frost) and how ice properties change with time (e.g., compaction, dust loading). Determining the thickness of the residual CO_2 ice cap to the nearest centimeter may also assist in the assessment of long term climate change.

CO_2 Condensation Modes: What is the nature of CO_2 deposition (e.g., snow or direct frosting, continuous or sporadic) and sublimation (e.g., at some depth or at the ice surface, contribution of contaminant load) in space and time?

Investigation: Determine the mixing ratios of non-condensable gases within the polar night and during the polar sublimation phase.

Discussion: Mars Odyssey Gamma Ray Spectrometer (GRS) and Neutron Spectrometer (NS) data have shown that the wintertime atmosphere in the polar regions can become strongly enhanced with non-condensable gases (and are depleted in the springtime). This affects CO_2 condensation on the ground and in the atmosphere by changing the frost point, thus affecting the basic thermal structure of the atmosphere (and thereby affecting atmospheric circulation on a global scale). Because non-condensable gases are passive tracers, their time-dependent distribution can provide a great deal of information about the large-scale atmospheric circulation. It is thus very important that improved measurements of the enhancement/depletion of these non-condensable gases be made by future spacecraft. The GRS and NS Argon data have very low resolution in both space and time. Observation of trace gases other than N_2 and Ar may be feasible with spatial resolution higher than can be achieved by GRS or NS. Carbon monoxide is an obvious candidate because it can be measured very accurately at microwave wavelengths, enabling full coverage of the high latitude atmosphere, including regions in the polar night.

Investigation: Measure and monitor clouds in the polar night, ground fogs, and CO_2 precipitation (snow).

Discussion: Many of the physical expressions of the atmospheric portion of the polar energy balance on Mars occur on relatively small scales and are effectively unobservable by current passive spacecraft imagers (due largely to a lack of illumination or contrast, e.g., during the polar night). However, an active imaging instrument on an orbiting platform would enable a pioneering survey of these phenomena. An imaging LIDAR instrument, with lasers tuned to the continuum and spectral features of H_2O and CO_2 ices would allow observations of changes in H_2O and CO_2 discrimination in the snow pack and in the atmospheric clouds.

Grain sizes, shapes, and cloud thicknesses would also be accessible. Nocturnal cloud surveys elsewhere on the planet (also poorly observable at the present time) would also be accessible to such an instrument.

Implementation: The following orbital instrument combinations are suggested payloads that would be capable of answering questions about the nature of Martian CO_2 ice processes through synergy. These packages are meant to be relatively inexpensive and lightweight to facilitate their inclusion as an add-on to an existing mission concept or as a stand-alone discovery-class mission. Conceptually, these two packages could be combined into a single polar science orbiter.

CO_2 Density Instrument Package - laser altimeter or InSAR, high-resolution thermal neutron imager, microwave atmospheric sounder, and high-precision radio science (ultra-stable oscillator required).

CO2 Phase Change and Polar Night Instrument Package - Microwave atmospheric sounder, imaging LIDAR, and high-precision radio science (ultra-stable oscillator required). The new instrument in this package is an imaging LIDAR. This instrument would be a high-power pulsed LIDAR with multiple-wavelength near infrared (NIR) capability to measure the spectral intensity and polarization characteristics of backscattered radiation from the Martian surface (particularly the polar caps) and atmosphere (particularly CO_2 and H_2O ice clouds). The proposed instrument is ideally suited for a mission to Mars to investigate the nature and seasonal abundance of icy volatiles, provide insight into surface and cloud grain sizes and shapes, evaluate cloud particle microphysics and potentially also provide atmospheric column content constituent chemistry.

MICADO – Mars Ice Condensation And Density Orbiter: By combining these two packages, one creates a powerful polar and atmospheric observing orbiter. Most of the instruments would benefit from legacy technologies that have already been flown to Mars (e.g., MGS MOLA and Mars Odyssey Neutron Spectrometer). The only "new" instrument is the imaging LIDAR.

The MICADO satellite would have the ability to characterize and monitor the density of the seasonal ice caps, determine condensation modes, and determine composition and grain sizes of ices that compose both polar and non-polar clouds. Interannual changes in both residual polar caps could be monitored.

References: [1] Aharonson et al. (2004) JGR 109, CiteID E05004 [2] Smith et al. (2001) Sci. 294 2141-2146 [3] Feldman et al. (2003) JGR, 108, CiteID 5103 [4] Litvak et al. (2007) JGR 112, CiteID E03S13 [5] Prettyman et al. (2009) JGR 114, CiteID E08005 [6] Boynton et al. (2002) Sci 297, 81.