Atmospheric CO_2 Depletion at the Surface in the Polar Regions of Mars. S. Piqueux[1], A. Kleinböhl[1], P. O. Hayne[2], D. M. Kass[1], N. Heavens[3], D. J. McCleese[5], M. I. Richardson[4], J. T. Schofield[5], J. Shirley[1], [1]Jet Propulsion Laboratory, California Institute of Technology, USA, [2]University of Colorado, Boulder, USA; [3]Hampton University, USA; [4]Aeolis Research, USA; [5]JPL Retired.

Introduction: The yearly waning and waxing of the seasonal polar caps represents one of the most dramatic expression of the CO_2 cycle on Mars, with massive amounts of carbon dioxide cyclically exchanged between the atmosphere and the surface [1]. As CO_2 condenses on the surface in the local Fall and Winter, non-condensable species remain and accumulate in the atmospheric column, resulting in a decrease of the CO_2 partial pressure and thus a lowering of the CO_2 frost point temperature T_{CO2} [2]. We determine the lowering of T_{CO2}, and discuss its impact on the polar energy budget and regional circulation.

Methods: To determine T_{CO2}, we bin Mars Climate Sounder (MCS) on Mars Reconnaissance Orbiter [3] retrieved surface temperatures acquired near 22 (T_{22}) and 12 µm (T_{12}) over the Polar Regions (10° in latitude and 10° Ls). In order to obtain kinetic surface temperatures, we perform a necessary emissivity correction [4] because CO_2 ice emissivity depends strongly on crytal size. The emissivity correction relies on the unique spectral properties of CO_2 ice at 12 and 22 µm (Fig. 1), resulting in a quasi linear relationship between T_{12} and $T_{12} - T_{22}$ (see [4], and Fig. 2). When $T_{12} = T_{22}$ (intercept of the regression line), the surface emissivity must approach 1, and the brightness temperature equals the kinetic temperature T_{CO2}.

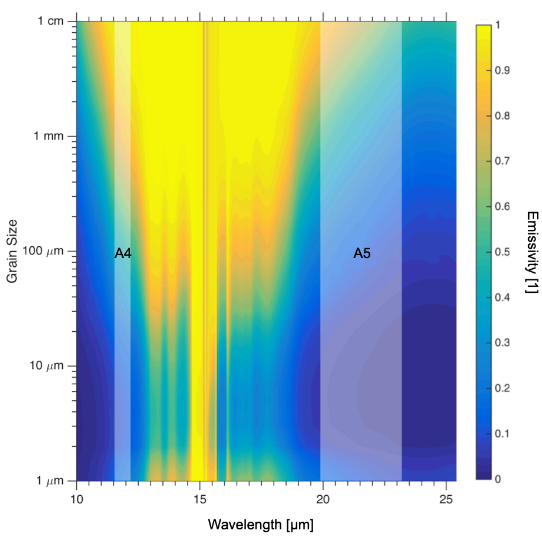

Fig. 1: Modeled CO_2 ice emissivity as a function of crystal size and wavelength (emission angle of 70°, typical of MCS). MCS Channels A4 (T_{12}) and A5 (T_{22}) are indicated in white.

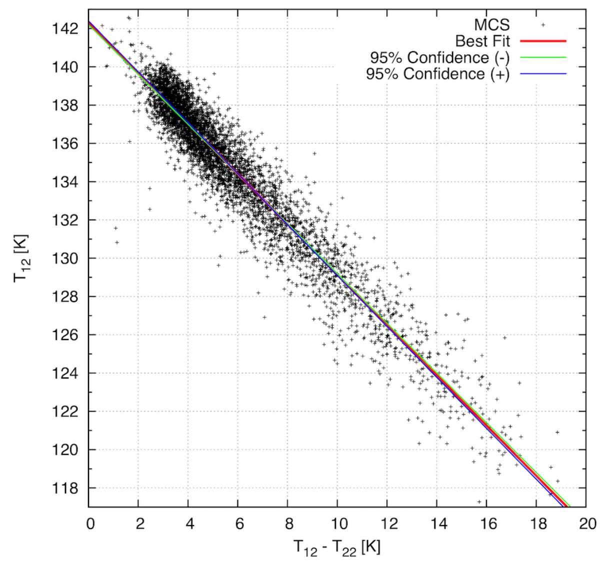

Fig. 2: Example of derivation for T_{CO2} for data at 110°<Ls<120°, -90°<Latitude<-80°. Where $T_{12} = T_{22}$, the surface emissivity is 1 and $T_{12} = T_{CO2}$. In this example, the 95% confidence is very small, < 0.1K

Surface CO_2 ice contamination by dust and H_2O ice do not measurably interfere with a successful derivation of T_{CO2} because they yield emissivities around 1 at 22 and 12 µm. Uncertainties are determined by fitting 95% confidence regression lines (Fig. 2). We then compare T_{CO2} with the theoretical surface frost point temperature calculated using the output of a General Circulation Model and Clapeyron's law [5], and convert the temperature depression to an equivalent CO_2 partial pressure. From here, we calculate the enrichment in non-condensable gases, expressed here as the Ar enhancement factor EF_{Ar} (Fig. 3 and 4).

Results: In the South (Fig. 3), near-surface non-condensable gasses enhancement peaks at ~5.5 (Ls~90°) a value indicative of static instability and likely vertical mixing of the entire atmospheric column [6]. Indeed, column integrated Ar concentrations display similar values, e.g, $5<EF_{Ar}<6$ based on data analysis from the Mars Odyssey Gamma Ray Spectrometer (GRS) [7], confirming the expected vertical diffusion. Surface depletion poleward of 50°S are homogenous, in contrast with GRS data that found modest depletion in the 75°S to 60°S latitude band, and no detectable depletion equatorward of 60°S.

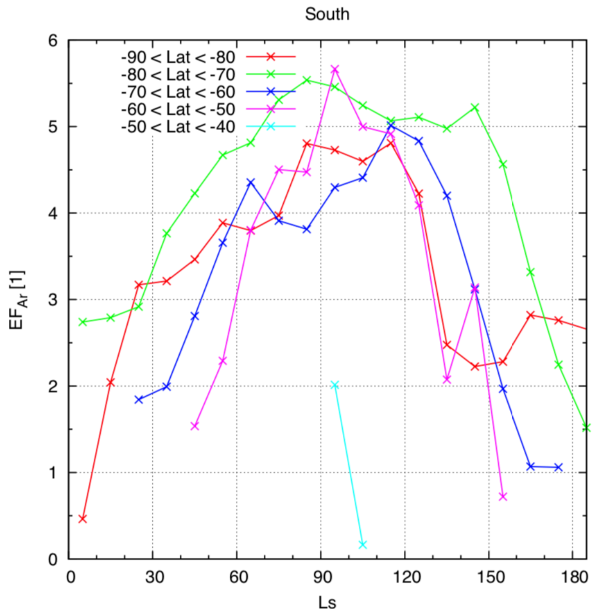

Fig. 3: Surface CO_2 depletion expressed as the equivalent Ar enhancement factor (EF_{Ar}) over the South seasonal cap. Error bars are not shown for clarity, but generally correspond to ± 1 EF_{Ar} unit.

In the North, we find even higher enrichment values (Fig. 5, up to ~7 near Ls~240°) in contrast with the quasi-absence of noticeable Ar enrichment reported [7] or modeled [8], e.g., $0<EF_{Ar}<2$derived from a ~3K depression of the frost point.. This difference suggests a depleted layer confined near the ground by an unmodeled atmospheric configuration, for example the presence of a near-surface inversion layer.

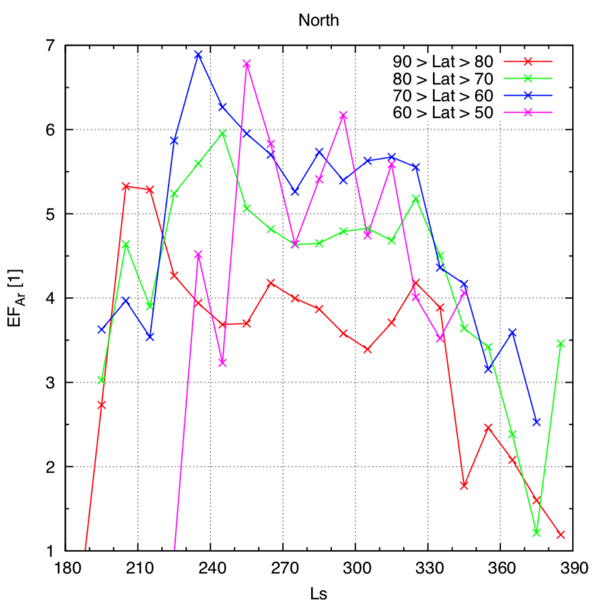

Fig. 4: Same as Fig. 3, but for the North.

Conclusions: The kinetic temperature of the North and South seasonal ice caps is derived, and shown to be depressed by up to ~3 K. This depression is interpreted as an enrichment of non-condensable gasses by factors up ~7 EF_{Ar}. While surface enrichments are similar to column integrated concentrations in the South [7], a strong near-surface depletion in the North is consistent with confinement near the ground. A simplistic two layer atmospheric model shows that the depleted surface layer cannot exceed a few km in thickness (Fig. 5) without driving the column integrated depletion values above observed numbers [7]. The presence of an un-modeled lower atmosphere phenomenon/configuration prevents buoyant depleted gas from rising away from the surface layer.

The measured ~3 K surface temperature decrease due to non-condensable enrichment has a modest effect on the CO_2 frost radiative balance, only decreasing the emission by ~9%. Other factors affecting the cooling to space (e.g., low CO_2 ice emissivity associated with snowfalls, clouds, etc.) will have a larger impact.

Acknowledgments: Work at the Jet Propulsion Laboratory is performed under a contract with NASA.

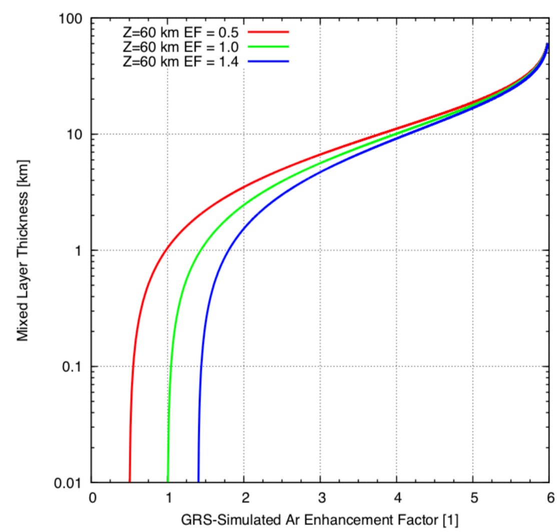

Fig. 5: Near-surface depleted layer thickness vs. column integrated (GRS-simulated, i.e., well mixed enrichment) EF_{Ar} for a 2 layer atmosphere model, three upper layer enhancement cases (EF_{Ar} =.5, 1., 1.4).

References: [1] Leighton and Murray, 1966, *Science*, 153; [2] Kieffer et al., 1976, *Science*, 193; [3] McCleese et al., 2007, *JGR*, 112; [4] Hayne et al., 2012, *JGR*, 117; [5] James et al., 1992, *Mars*, 934-968; [6] Hess et al., 1979, *JGR*, 84; [7] Nelli et al., 2007, *JGR*, 112; [8] Lian et al., 2012, *Icarus*, 218.