MONITORING OF CO$_2$ SEASONAL VARIATIONS AT THE MARTIAN POLAR ICE CAPS USING SHARAD DATA. M.C. Raguso$^1$, D.C. Nunes$^1$, $^1$Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA.

**Introduction:** During the course of a Martian year, the red planet cyclically exchanges up to a third of its atmospheric carbon dioxide (CO$_2$) with the surface [1]. The cycling of CO$_2$ into and out of ice on the surface produces active atmospheric dynamics and changes the atmospheric mass by tens of percent, resulting in a redistribution of $\sim$1x10$^{-6}$ of the total mass of Mars over the course of a Martian year.

This exchange between the atmosphere and the surface is intriguing and not yet well understood. Several attempts to investigate the dynamic behaviors of the CO$_2$ frost on the Martian surface involved radio science data [1], laser altimetry data [2,3], the Gamma Ray Spectrometer (GRS) [4,5] providing the first direct global-scale observations of the change in height of Mars’ seasonal ice caps and allowing the quantification of the column density (g/cm$^2$) respectively. Recent analyses established almost a Martian decade of observations for the seasonal cap cycle (MY 24-31) [6,7]. Until now, radar sounders have never been used to directly measure changes in CO$_2$ frost thickness on Mars. Several studies demonstrated that seasonal CO$_2$ accumulation affects radar sounder data [8,9] and [10] for the first time proposed to use a time delay technique to estimate the CO$_2$ accumulation using sounder data.

Herein, we seek to examine seasonal variations of CO$_2$ thickness at the Martian polar caps surface using radar sounder observations collected by SHALLOW RADar (SHARAD) on the Mars Reconnaissance Orbiter (MRO) over eight Martian Years (MY 28-35). Analysis of radar two-way delay between the surface reflections and reference subsurface reflectors is conducted over multiple orbital tracks at different seasons and over the same region, in order to estimate the change in the seasonal CO$_2$ frost thickness. The analysis gains by the application of recently developed SHARAD processing techniques able to increase the radar data quality in terms of range resolution and signal-to-noise ratio (SNR) to enable the detection of shallow subsurface layers.

**Dataset and General Methodology:** All the data used for this investigation were acquired by the SHARAD instrument on MRO. Using an 85µsec chirped pulse with a 10 MHz bandwidth centered at 20 MHz, it has a theoretical vertical resolution of 15m in free space (8.4 m in water ice) and an along-track resolution of 0.3–1 km achieved with synthetic-aperture processing techniques [11]. The proposed investigation is performed along multiple tracks acquired over the same area at cross-overs or in a closely adjacent-track configuration in order to look for variations in the seasonal CO$_2$ thickness of the caps.

Using advanced and dedicated processing techniques [12, 13] we are capable of re-processing the SHARAD data in a novel way in order to perform a more detailed, high-resolution examination of subsurface interfaces. After the sub-surface co-registration process, which allows the time realignment of radargrams using correlated stratigraphy signatures observed at different epochs but the same location, our work aims to estimate the seasonal accumulation using the time delay peak-to-peak difference of the first return to retrieve the delta-thickness at each cross-over.

**Explanation of the New Technique:** Our investigation focuses on detection of the change in SHARAD’s signal characteristic over seasonal cycles in the polar layered deposits, especially the solid CO$_2$ frost. The investigation requires high quality and reliable data. For this reason, a dedicated processing pipeline is applied to the entire SHARAD dataset. Using appropriate spectral analysis algorithms for radar sounder, known in literature as Bandwidth Extrapolation (BWE) techniques, we are able to reconstruct the radar bandwidth after electromagnetic interferences (EMI) suppression and to extend it over the conventional Rayleigh limits (see Figure 1). This produces a completely different datasets improving the range dynamic of about 3-5dB thanks to the removal of the low-frequency EMIs effects and increasing the nominal range resolution from 15 m to 5 m (in free space) and from 8.5 m to 2.8 m (in water ice). The thickness of the CO$_2$ seasonal deposits is evaluated via co-registration of the SHARAD tracks acquired in parallel or cross-over configuration over the same area in different seasons (see Figure 1).

Super-resolved products allows depth and thickness measurements with an accuracy never reached before. In addition, we will develop a SHARAD-like sounder multi-layer simulator in order to characterize the errors in the peak tracking, amplitude response of the slab, seasonal changes in backscattering and optimize the seasonal CO$_2$ thickness estimation by testing different tracking algorithms. Since the co-registration process is performed using internal layers as reference, our measurements will not be affected by ephemeris errors. However, the record of CO$_2$ seasonal variability present
in the radar echoes must be separated by ionospheric effects that occur during the summer. For this reason, further efforts to compensate ionospheric distortions on SHARAD data acquired during the summer will be required for the investigation.

**Expected Results and Future Works:** Data acquired from SHARAD spanning over almost 8MYs and properly processed with dedicated algorithms suited for radar sounders will be used for the first time to analyze SHARAD’s ability to record the seasonal pattern of CO₂ deposition and sublimation repeating every year. The analysis will provide information about the thickness of the seasonal CO₂ frost at the poles and thus a deeper understanding of phenomena (e.g. atmospheric temperature and dust loading) that drive the growth and the recession of the seasonal caps.

Results obtained by this analysis, compared and integrated with the information about seasonal CO₂ collected by previous studies, will be extremely valuable for characterizing the present-day seasonal behavior of CO₂ at the polar caps. In future works we propose to combine the time delay technique along with variation of the surface power return in order to estimate dielectric property of the CO₂ slab and derive the total volume of CO₂ exchanged between the polar caps and the atmosphere. This investigation will benefit the calibration of SHARAD data, allowing further investigation of different materials present on Mars. Layered ice deposits are also present outside the PLD themselves, notably in Korolev crater, as well as identification of Martian ice deposits at the mid-latitudes for future human explorations [14]. The SHARAD backscattering analysis at the polar ice caps would certainly benefit sonder data interpretation of future missions, such as Europa Clipper and JUICE, designed for the exploration of icy satellites.

**References:**