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Remote sensing of dry snow masses with GNSS-R

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The use of GPS signals scattered off the Earth surface has been proved as a valid technique for remote sensing purposes. Working as a bistatic L-band radar, the concept of GNSS-R (GNSS-Reflectometry) or PARIS (Passive Reflectometry and Interferometry System) appeared in 1993 as a means toward sea surface altimetry. From then on and motivated by the availability of the GPS, GLONASS and future GALILEO and COMPASS constellations of navigation satellites, many other applications with GNSS reflections have been investigated, such as determination of ocean wind speed, soil moisture and sea surface state, as well as detection and classification of sea ice. We present in this paper another potential application of this approach: characterization of dry snow masses.

Radar waves with frequencies under 1000MHz have been widely used to investigate the internal properties of continental ice masses, sounding maximum depths of about 4000m in cold ice and about 1500m in temperate ice. The vertical structure or internal dielectric layering within the ice sheet is usually inferred from the time delay suffered by distinct echoes reflected off boundaries separating media with different dielectric properties. GPS signals, with frequencies between 1200 and 1500MHz, will have smaller penetration depth than lower frequencies. However, penetrations of around 100 meters are expected, which relate to millennium scale accumulation rate.

The GPS-SIDS project (funded by ESA and conducted by ICE-IEEC/CSIC, GFZ, IFAC/CNR, ADT), with the aim of investigating the viability of using GPS reflectometry to study sea-ice and dry snow properties from space, has been the frame of this work. During its second stage, an experimental campaign took place in the Italian-French base of Concordia (Dome-C), located in the middle of the East Antarctic plateau (75 deg. Latitude South). A dedicated GNSS-R receiver (GOLD-RTR) monitored a dry snow protected area continuously during one week of December 2009, generating the complex cross-correlation function (waveform) of reflected signals in real-time. The same scenario has been used for the DOMEX-2 (2008-2010) campaign, consisting of L- and C- band radiometric measurements to verify the stability of the snow emissions over long periods of time.

A first analysis of the collected data showed interferometric behavior under the surface level. This result motivated us to develope a model that reconstructs the received complex waveform as a sum of a finite number of multipath reflections (from different snow layers) separated both delay and phase. This forward model requires information of the snow layering (taken from in-situ measurements of snow density) and the geometry (incidence angle). In order to retrieve the interferometric information, we have performed an spectral analysis of time series of real and modeled (by taking the same geometry) waveforms. A FFT algorithm has been applied to each lag-sequence to generate lag-holograms. We have found that the frequency bands predicted by the model are in general consistent with the data, except for low elevation angles of observation. The repeatability of the lag-holograms from real waveforms has also been checked for different days. We will attempt a proper inversion of the collected data to determine the dominant layers of the dry snow profile at L-band. In addition, we will further analyze the possibility of a total inversion of the snow density of these layers.