SNOWCUBE Mission Concept: P-Band Signal of Opportunity for Remote Sensing of Snow

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Snow-derived water supply is a vital component of the global water budget; it provides fresh water to approximately 2 billion people worldwide. Quantifying available water supplies for human activities, how they vary in space and time, and how they are changing are some of the biggest scientific issues of our time. The SNOWCUBE (Snow sigNals of Opportunity With CUBEsat) mission concept will use the passive P-band Signal of opportunity [1] and data assimilation tools to define Northern Hemisphere seasonal snowpack water storage and runoff for human applications.

The SNOWCUBE mission concept will sample SWE at scales consistent with moderate (orographic) to synoptic scales over a full seasonal cycle. To properly sample the synoptic-scale drivers, the mission concept will have a temporal sampling of approximately every 3 days. A between-track sampling of less than 100 km with spatial (pixel) resolution of 1-3 km will adequately sample the key synoptic and orographic impacts on SWE. The SNOWCUBE mission will assimilate the satellite observation-track SWE retrievals into a data assimilation model and produce spatially and temporally contiguous, high-resolution SWE products. We have conducted an Observing System Simulation Experiment (OSSE) to demonstrate the potential for the SNOWCUBE satellite concept to improve Northern Hemisphere SWE estimates. The results of OSSE will be reported.

The SNOWCUBE mission will retrieve SWE from coherent reflection of P-band (360-380 MHz and 250-270 MHz) radio signals from geostationary Mobile Use Objective System (MUOS) communication satellites. The SWE remote sensing

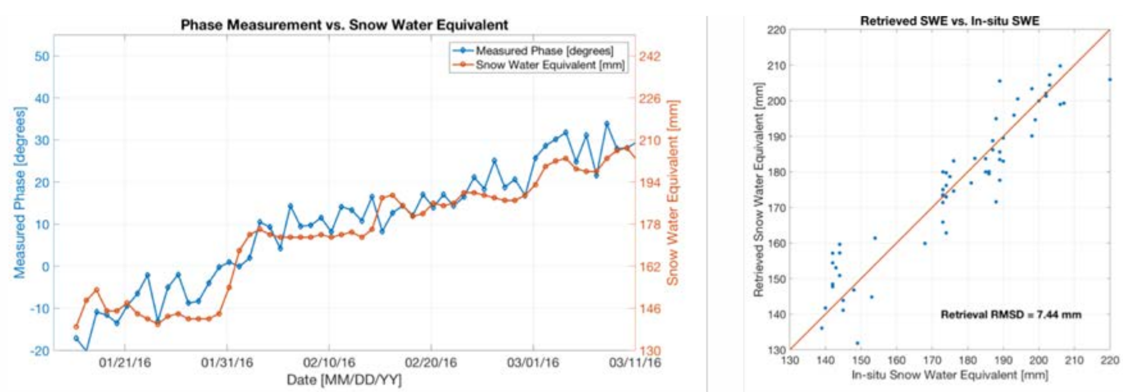

Figure 1. Excellent temporal correlation (left panel) between SWE and phase change of radio propagation (r=0.85) from the SNOWCUBE experimental data acquired at the Fraser Experiment Forest from January-March 2016 for a snowpack evolving through dry, melt, and refrozen conditions [2]. The RMSD of SWE retrieval with respect to in situ data is 7.4 mm (right panel). The radio receivers were mounted on the top of 50-foot tower with one antenna pointing toward the MUOS satellite and the other antenna toward the ground for reflected signal. The in situ data for SWE were acquired through weekly snowpit measurements and daily snow depth survey.

measurement principle is based on the propagation delay (or phase change) of radio signals through the snowpack. The refractive index or dielectric constant of snow is closely related to the snow density. The additional time delay of the reflected signal due to the snowpack with respect to snow-free conditions is directly proportional to the snowpack SWE. The SNOWCUBE mission measurement concept has been tested at the MUOS frequency during a field campaign in Colorado with the root-mean-square accuracy reaching 7.4 mm (Fig. 1).

The SNOWCUBE frequency bands, used by MUOS, were developed for U.S. Navy communication satellites and will be protected and hence free from external radio frequency interference. The P-band frequency also has the strength of nearly un-impeded propagation through most vegetation covers, thus allowing SWE measurements over most middle- and high-latitude landscapes.

Table I. SWE estimation error (σ_{SWE}) using dual-frequency technique to correct for ionospheric delay. f_1=360MHz, f_2=260 MHz, $\sigma_{\phi 1}$=6.8° (phase noise at f_1 for one 10 ms sample), $\sigma_{\phi 2}$=4.9° (phase noise for one 10 ms sample at f_2), spacecraft ground track velocity of V=6.7 km/s, and one sampling interval, T=10 ms

Number of samples for averaging	1	2	4	8
Effective smearing of spatial resolution (V*N*T) (m)	67	134	268	536
σ_{SWE} (cm)	2.23	1.71	1.38	1.18

To address the ionospheric delay at P-band frequencies, SNOWCUBE will use the signals from both MUOS bands (360-380 MHz and 250-270 MHz). This dual-frequency measurement method is a well-known technique used by GPS satellite systems and microwave synthetic aperture radar processing systems to mitigate ionosphere delay. From the phase data at two frequencies, we can solve for Slant Total Electron Content (STEC). Nominally, the phase measurements are performed with an integration time of about 10 ms for spaceborne instruments. As expected, there will be random noise in the phase data. If a noise reduction is necessary to reduce the error in the estimate of STEC, then averaging over multiple temporal samples can be carried out at the expense of spatial resolution of integrated footprints. We have conducted an analysis to trade off the spatial resolution and measurement accuracy (Table 1). The average over four samples will lead to an accuracy of about 1.4 cm for SWE, while only degrading the spatial resolution by about 270 m; this confirms that the residual effects will have a negligible impact on SNOWCUBE SWE observation accuracy and spatial resolution.

Reference

[1] Xiaolan Xu, Simon Yueh, Rashmi Shah, James Garrison, and Abi Komanduru, and Kelly Elder, "Multi-Frequency Reflectometry For Terrestrial Snow Cover Using Signals of Opportunity, Proc. IEEE Geoscience and Remote Sensing Symposium, Milan, 2015.

[2] Rashmi Shah, Simon Yueh, Xiaolan Xu, Chun Sik Chae, Marc Simard, and Kelly Elder, Snow Water Equivalent Retrieval Using P-Band Signals Of Opportunity, Proc. IEEE Geoscience and Remote Sensing Symposium, Beijing, 2016.