TRI-FREQUENCY SYNTHETIC APERTURE RADAR FOR THE MEASUREMENTS OF SNOW WATER EQUIVALENT

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ABSTRACT

A new airborne synthetic aperture radar (SAR) system was recently developed for the estimation of snow water equivalent (SWE). The radar is part of the SWESARR (Snow Water Equivalent Synthetic Aperture Radar and Radiometer) instrument, an active passive microwave system specifically designed for the accurate estimation of SWE. The dual polarization (VV, VH) radar operates at three frequency bands (9.65 GHz, 13.6 GHz, and 17.25 GHz), with bandwidths of up to 200 MHz. The radar flew its first flight campaign in November 2019, along with SWESARR's -already operational – radiometer. The radar collected comprehensive data sets over various terrains that show a successful system performance. The instrument is slated to participate in future SnowEx campaigns.

***Index Terms*—** Snow, SAR, SWE

1. INTRODUCTION

Snow is an important source of fresh water in many areas of the world. One-sixth of the world's population (1.2 billion people) rely on seasonal snowpack and glaciers as a source of fresh water [1][2]. With rising global temperatures, the world's snow resources are predicted to change [3]. Snow water equivalent (SWE), the measurement of how much water is present as snow, is thus an important parameter for water resource management and climate studies. Developing the tools to remotely measure SWE is one of NASA's priorities. To that end, SnowEx, a multi-year airborne snow campaign, allow us to test the performance of various instrument to get a better understanding of how much water is stored in the Earth's terrestrial snow. The ultimate goal of these studies is to develop robust remote sensing techniques by collecting multi-sensor datasets that will advance the science needs. SWESARR (Snow Water Equivalent Synthetic Aperture Radar and Radiometer) is an airborne instrument designed to measured co-located active and passive microwave signatures from snow. The instrument's unique measurement approach can provide critically needed data for the accurate estimation of SWE and make a valuable contribution to future SnowEx efforts. Furthermore, SWESARR will provide a test-bed for measurement techniques that can be extended to satellite observation, setting a path for future spaceborne snow missions. In addition, the Canadian Space Agency is conducting phase 0 snow mission concept study for dual band Ku band SAR. SWESARR could serve as an airborne simulator for that mission concept

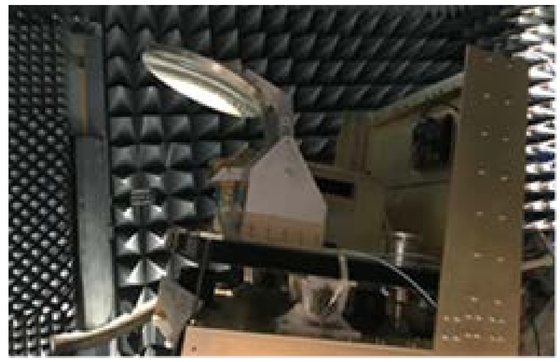

Figure 1. SWESARR, a tri-band radar and radiometer airborne system designed to retrieve snow water equivalent (SWE), during testing at NASA GSFC's anechoic chamber.

SWESARR's radar and radiometer systems (fig. 1) were developed at the NASA Goddard Space Flight Center (GSFC). The radar development was completed in Oct 2018, while the radiometer has been operational since 2013 and has been flown several campaigns. The radar conducted its first test flights over the Grand Junction area in Colorado between December 1st and 4th, 2018. The area covered during the flights included the Grand Junction airport, where corner reflectors were deployed for radar calibration, and the Grand Mesa, a large flat top mountain which has been selected as test site for SnowEx campaigns. SAR images acquired at 9.65 GHz over the Grand Junction airport are shown in figure 2.

2. RADAR SCPECIFICATION

The radar system is made up of three independent radar units that operate at 9.65 GHz, 13.6 GHz, and 17.25 GHz, respectively, with bandwidths up to 200 MHz, utilizing the maximum ITU allocations. The three radars transmit vertically (V) polarized waveforms and receive returns with vertical and horizontal (VV, VH) polarizations (dual-

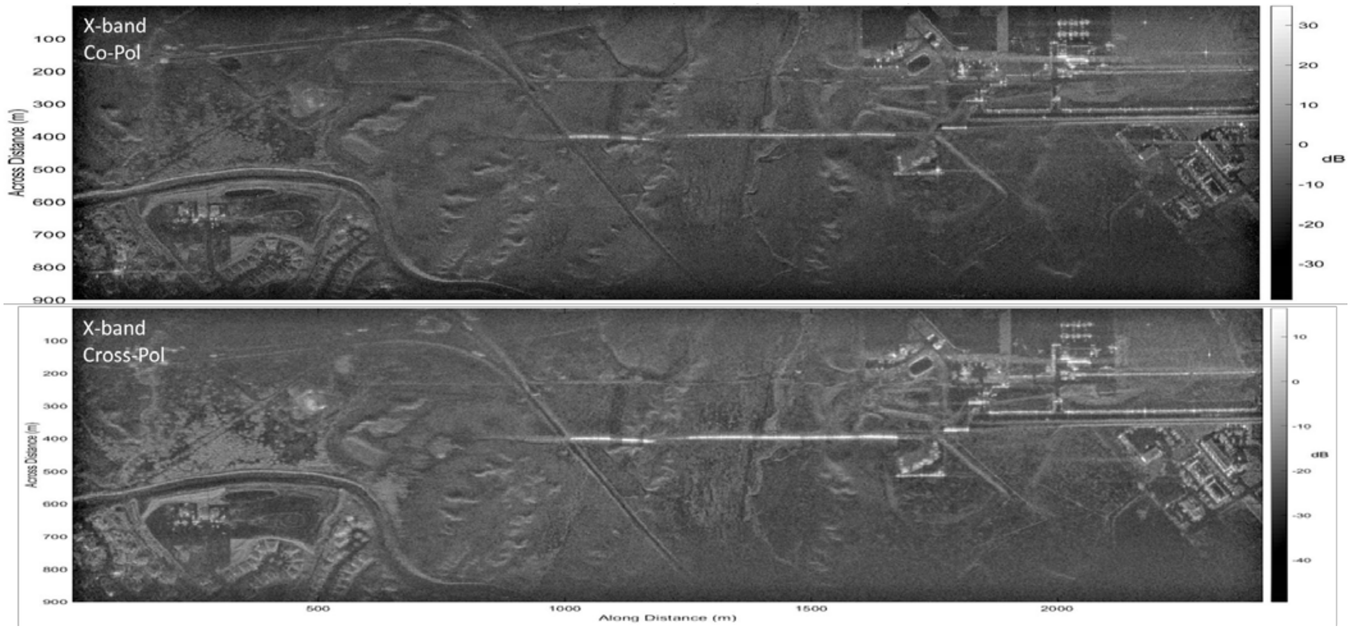

Figure 2. SWESARR's dual polarization (VV, VH) images acquired at 9.65 GHz over the Grand Junction airport from an altitude of 2 km.

polarization mode). The radar can operate at all three frequency bands simultaneously or interleaving them, depending on the application. The radiometer operates at 10.6 GHz, 18.7 GHz, and 36.5 GHz. Table 1 lists the radar nominal characteristics and a block diagram illustrating the radar architecture is shown in fig. 3.

SWESARR's waveform generation and data acquisition is performed by a multi-channel Radar Digital Unit (RDU) developed for EcoSAR [4]. The RDU, capable of arbitrary waveform generation, data acquisition, and onboard processing, generates the transmit waveforms and coherently acquires all six radar returns.

The radar and the radiometer share an offset-fed reflector antenna (fig. 1), making the acquisition of collocated active/passive measurements possible. The reflector, designed by Harris Corporation [5], is fed by a "current sheet array" feed, designed by Nuvotronics, that operates from 8 to

Table 1 SWESARR's radar main characteristics

Frequency (GHz)	9.65	13.6	17.25
Aircraft Height (km)	2	2	2
PRF (kHz)	1	1	1
Look Angle (degrees)	45	45	45
Pulse Width	10	10	10
Max Bandwidth (per ITU)	200	200	100
Slant Range Resolution (m)	0.75	0.75	1.5
NESO (dB)	-32.6	-30.8	-29
Swath (m)	446	316	249

40 GHz [6]. The antenna is nominally pointed at 45 degree depression angle and perpendicular to the flight track.

3. PERFORMANCE

The radar flew on board a Twin Otter International (TOI) aircraft (fig. 3) at three altitudes (1.5 km, 2 km, 3 km) above ground. The flights were spread over several days and about a total of 8 hours of data were acquired at different bandwidths and acquisition modes. Four trihedral corner

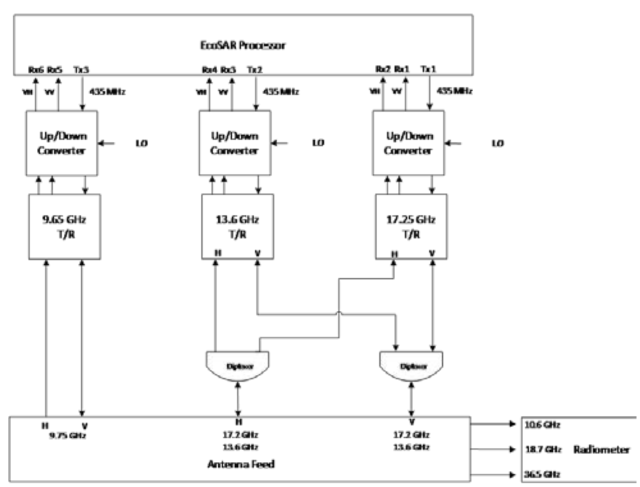

Figure 2 Architecture of the SWESARR instrument that operates at three radar bands, and three radiometer bands, using a shared an offset fed reflector antenna.

Figure 3. The SWESARR instrument during integration to the Twin Otter aircraft prior to the radar's first test flights.

reflectors (CRs) were deployed adjacent to the airport runway for calibration. The CRs were 0.9 m, 0.5 m, 0.2 m, and 0.16 m in size. Figure 4 shows an expanded area of figure 2 where the corner reflectors were deployed.

The Co-pol image in figure 2 was used here for a preliminary performance assessment. The impulse response of the 0.9 m CR is shown in figure 5 where a Kaiser smoothing window (2.5 beta value) has been used in both range and azimuth dimensions. The impulse response shows the radar resolution is 0.35 m and 2 m in azimuth and range, respectively, as expected with the use of a Kaiser smoothing window. The ISLR (Integrated Sidelobe Ratio) is -14 dB and -16 dB in azimuth and range, respectively. The larger ISRLR in azimuth is likely caused by errors in the focusing of the image due to aircraft motion. An improvement of the motion correction algorithm is under way which should yield a lower ISLR.

The PSLR (Peak-to-Siledlobe Ratio) is -13 db and -16 dB in azimuth and range, respectively. The higher PSLR in azimuth is also due the motion errors and is expected to decrease with the more robust motion correction algorithm.

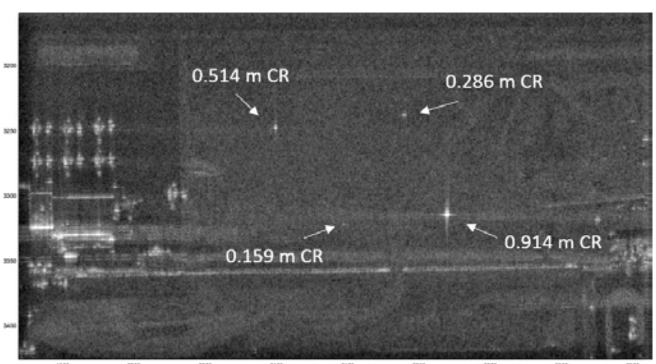

Figure 4 Four corner reflectors were deployed adjacent to the airport for radar calibration and performance analysis.

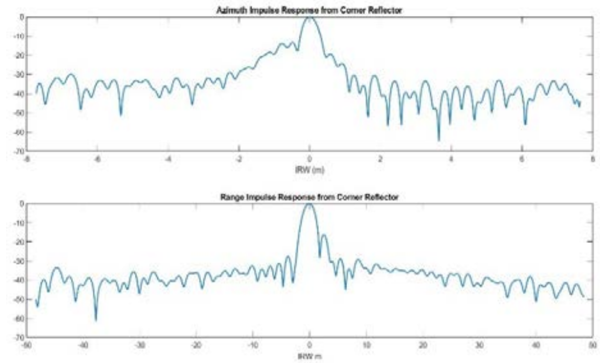

Figure 5 Impulse response of the radar at 9.65 GHz using the 0.9 m Corner Reflector.

The large sidelobe in range, which has also been observed in loop back calibration data, is likely caused by artifacts in the waveform introduced by the digital waveform generator. These issues will be addressed prior to the next SWESARR flight. The noise equivalent sigma naught is better than – 30 dB, as expected.

4. CONCLUSION

The new airborne synthetic aperture radar (SAR) designed for the SWESARR instrument demonstrated its dual polarization operation at 9.65 GHz, 13.6 GHz, and 17.25 GHz. Analysis of the radar data acquired during its first flight campaign indicated the radar operated successfully meeting the design performance metrics. The radar will fly again in 2019 as part of the SnowEx campaigns when the radar will be expected to operate at optimum performance.

4. REFERENCES

[1] National Aeronautics and Space Administration, "Got Snow", https://neptune.gsfc.nasa.gov/uploads/images_db/Got_SnowSM.pdf

[2] J. S Mankin, D. Viviroli, D. Singh, A. Y. Hoekstra, N. S. Diffenbaugh, "The potential for snow to supply human water demand in the present and future", November 2015. doi.org/10.1088/1748-9326/10/11/114016.

[3] Räisänen, J. Clim Dyn (2008) 30: 307. https://doi.org/10.1007/s00382-007-0289-y.

[4] R. Rincon, T. Fatoyinbo, K. Ranson, B. Osmanoglu, G. Sun, M. Deshpande, M. Perrine, C. Du Toit, Q. Bonds, J. Beck, and D. Lu, "The ecosystems sar (EcoSAR) an airborne P-band polarimetric InSAR for the measurement of vegetation structure, biomass and permafrost," Proc. 2014 IEEE Radar Conference, pp. 1443–1445, May 2014, Cincinnati OH, USA.

[5] T. E. Durham, K. J. Vanhille, C. R. Trent, K. M. Lambert and F. A. Miranda, "Design of an 8–40 GHz antenna for the wideband instrument for snow measurements (WISM)," *2015 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting*, Vancouver, BC, 2015, pp. 1999-2000. doi: 10.1109/APS.2015.7305389.

[6] J. W. Jordan *et al*., "PolyStrata® X/Ku/K/Ka-band, Dual-Polarized, Tightly Coupled Dipole Scannable Focal Plane Array," *2018 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting*, Boston, MA, 2018, pp. 817-818. doi: 10.1109/APUSNCURSINRSM.2018.8608507.