National Aeronautics and Space Administration

Explorer Snow Depth and Snow Water Equivalent

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Program: FY22 R&TD Strategic Initiative

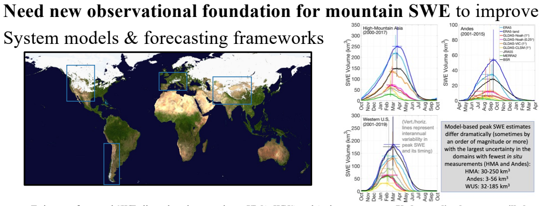
Strategic Focus Area: Earth System Explorer - Strategic Initiative Leader: Sabrina M Feldman

Objectives:

- The overarching goal of this Strategic Initiative is to mature snow-related science concepts, observing technologies and model studies needed for a JPL proposal to NASA Earth System Explorer (ESE) opportunities. The 2017 Earth Decadal Survey (DS) established the Explorer mission line (NAHEM, 2018), which calls for concepts in seven investigation categories (inc. Snow Depth/Snow Water Equivalent). DS2017 identifies Radar (Ka/Ku-band) altimeter or Lidar as candidate SD/SWE technologies. However, these approaches tend to be costly (~$1B-class), and may not fit within the ESE $310M FY24 cost cap.
- The objective this project is to advance the JPL P-band Signals of Opportunity Synthetic Aperture Radar (SoOpSAR) concept for remote sensing of terrestrial snow by carrying out airborne flights of the P-band SoOpSAR over mountainous terrains to acquire data for the development of science algorithms for SAR processing, snow water equivalent/depth retrieval, and mitigation of radio frequency interferences (RFI).

Science Significance:

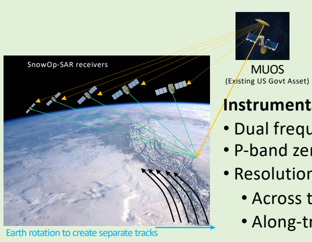
- **1 billion+ people depend on seasonal mountain snow** (water resources, food supply, hydropower, downstream economic activity).
- Water stored as snow is **fastest changing but least monitored component of terrestrial water cycle** (no current reliable remote sensing platforms for **mountain** snow water equivalent (SWE))
- **Need new observational foundation for mountain SWE** to improve Earth System models & forecasting frameworks



Estimates of seasonal SWE climatology integrated over HMA, WUS, and Andes water towers. **Understanding how snow will change in the future requires knowledge of how much water is stored in these regional snowpacks, where uncertainty is very large.**

SnowOp-SAR is a bistatic interferometric SAR using transmit signals from US Govt. MUOS P-band communication satellites with receivers on a constellation of LEO SmallSats

Yueh, Shah, Xu, Stiles, Bosch-Lluis, Feb 2021. IEEE JSTARS (Best paper of the Year)

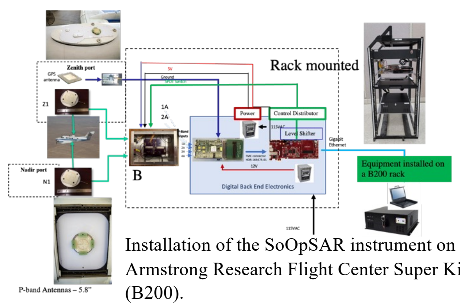


Targeted Measurements:

- Snow water equivalent (SWE)
- Root zone soil moisture (RZSM)

Instrumentation

- Dual frequency (240-270 MHz & 360-380MHz) SAR receivers
- P-band zenith (direct) and deployable nadir (reflected) antennas
- Resolution:
  - Across track (100 m to 1.4 km)
  - Along-track (50 m/10 m for 2/10 sec integration time)



Installation of the SoOpSAR instrument on the NASA Armstrong Research Flight Center Super King Air (B200).

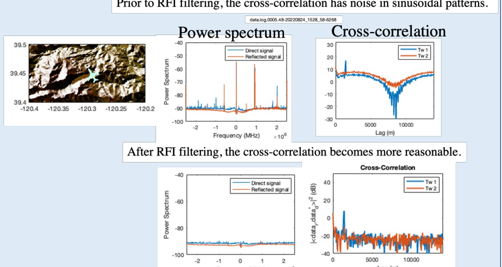
Approach and Results:

- Conduct airborne campaigns by leveraging the P-band SoOpSAR receivers developed under the support of the NASA Instrument Incubator Program.
- The airborne flights are designed to acquire data for snow-free and snow-on conditions so that the change of P-band reflected signals due to snow accumulation or depletion can be assessed.
- We have completed flights over selected sites in California and Colorado, which can provide varying snow conditions.

SoOpSAR was flown on the NASA AFRC Super King Air over the Wolverton Meadow, Tuolumne Meadow, Dana Meadow, Sagehen Creek, and Grand Mesa during August 22-26, 2022.

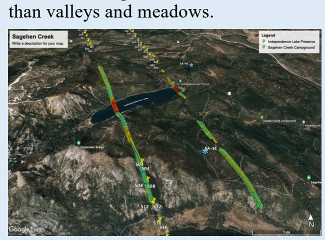
The SoOpSAR data sample acquired at the Sagehen Creek indicate the impact of radio frequency interference before (upper panels) and after filtering (lower panels)

Prior to RFI filtering, the cross-correlation has noise in sinusoidal patterns.



After RFI filtering, the cross-correlation becomes more reasonable.

The power of cross-correlation peak of data acquired the Sagehen Creek site indicates stronger reflections over lake than valleys and meadows.



Significance/Benefits to JPL and NASA:

- The maturation of the SoOpSAR technology for Snow Depth and Snow Water Equivalent (SD/SWE) by airborne campaigns. This aligns with JPL's and 8X's strategic plans for utilizing JPL's key capabilities and product lines for upcoming NASA ESE mission opportunities.
- The preliminary analysis of data from August 2022 campaign has already shed light on the impact of RFI and methods for mitigation and has also allowed us to start developing geolocation algorithms for the positioning of specular points.
- The developed airborne SoOpSAR instrument can also contribute to future NASA Earth Venture Suborbital program.

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Publications:

[A] Simon Yueh, Steve Margulis, Rashmi Shah, Julian Chaubell, Xiaolan Xu, Bryan Stiles, Xavier Bosch-Lluis, Mehmet Ogut, Devin Cody, Richard Hodges, Jacqueline Chen, And Yunjin Kim, "A P-Band Signals of Opportunity Synthetic Aperture Radar Concept for Remote Sensing of Terrestrial Snow," IEEE International Geoscience And Remote Sensing Symposium, Kuala Lumpur, Malaysia, July 2022.

[B] Steven Margulis, Simon Yueh, Rashmi Shah, Julian Chaubell, Xiaolan Xu, Bryan Stiles, Xavier Bosch-Lluis, Mehmet Ogut, Devin Cody, Richard Hodges, Jacqueline Chen, Yunjin Kim, Elias Deeb, Jeff Dozier, Kelly Elder, Dara Entekhabi, Manuela Girotto, Ethan Gutmann, Adrian Harpold, Mimi Hughes, Dennis Lettenmaier, Glen Liston, Jessica Lundquist, Keith Musselman, and McKenzie Skiles, "A mountain snow synthetic aperture radar mission concept using P-band signals of opportunity," AGU Frontiers in Hydrology Meeting (https://www.agu.org/FIHM), Puerto Rico, June 2022.

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