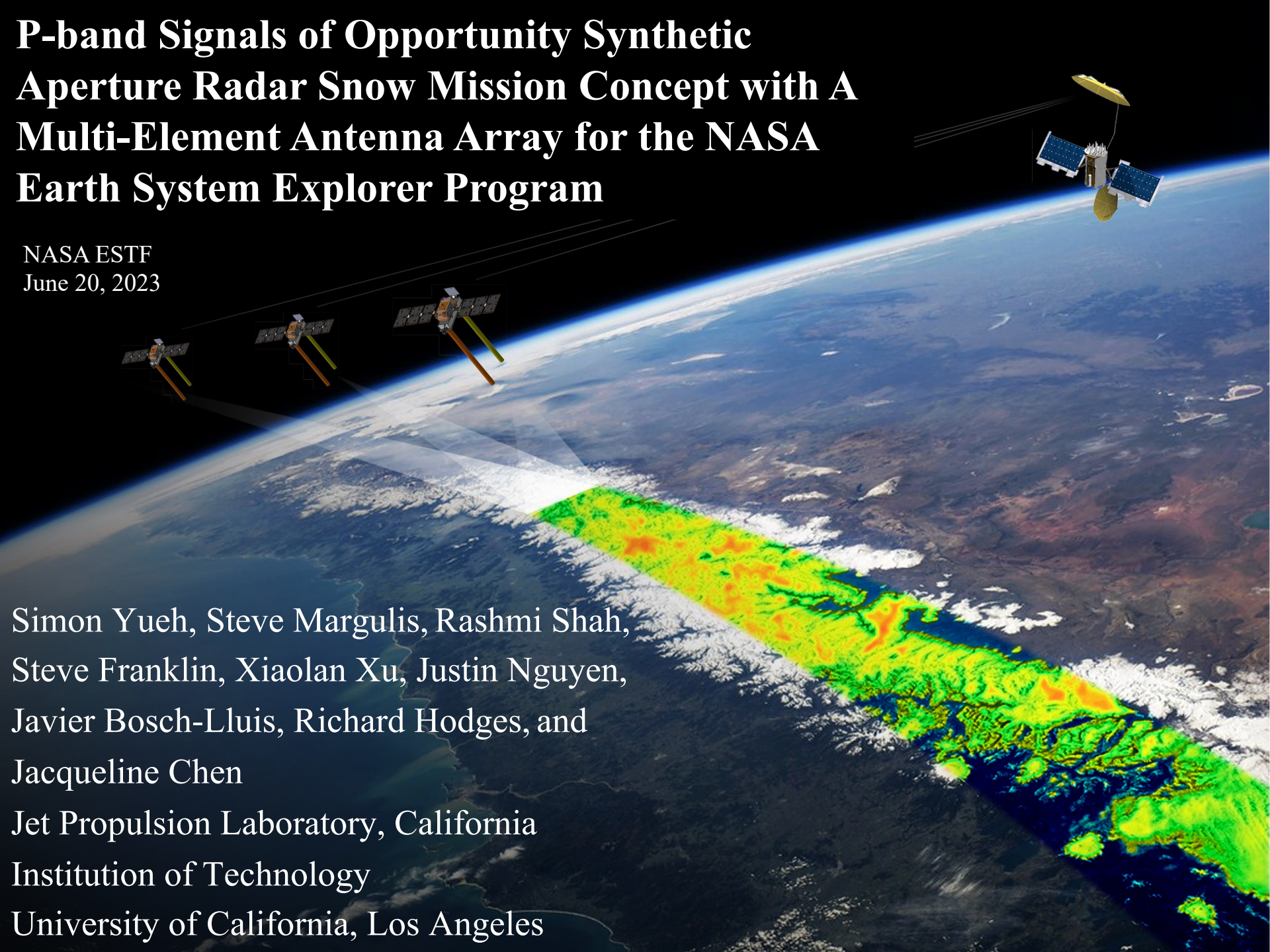
P-band Signals of Opportunity Synthetic Aperture Radar Snow Mission Concept with A Multi-Element Antenna Array for the NASA Earth System Explorer Program

NASA ESTF
June 20, 2023



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Javier Bosch-Lluis, Richard Hodges, and
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Using P-band Signals of Opportunity (SoOp)

MUOS Signal of Opportunity

- Four geosynchronous communication satellites: global coverage up to +/- 60 deg. latitude
- UHF (P-band: 240-400 MHz): designed for all-weather, all-terrain, and penetration through dense foliage
- Stable long-term signal (since 1978)

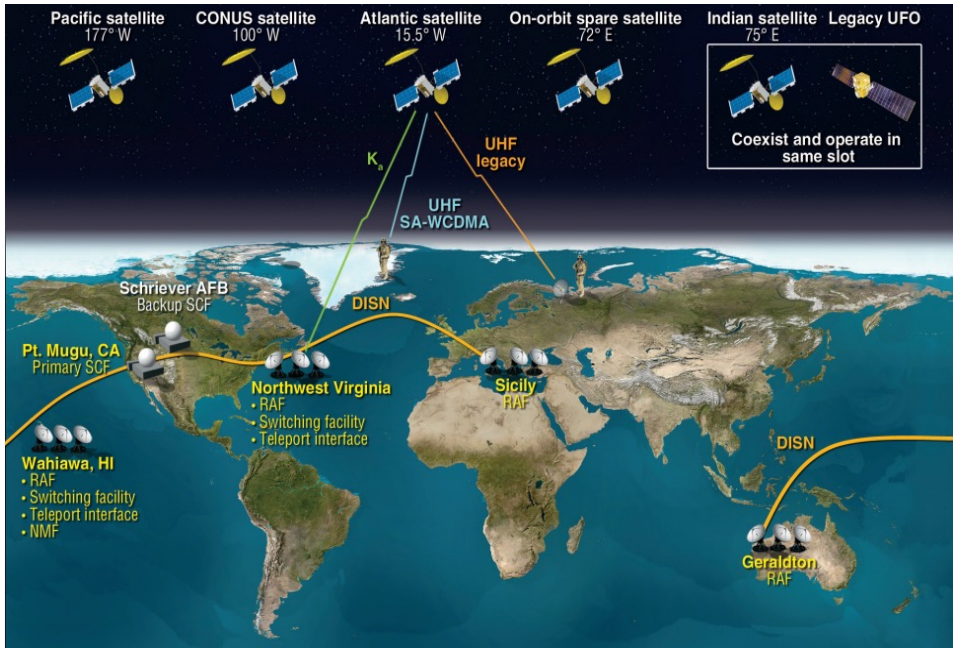


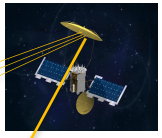
Image: JOHNS HOPKINS APL

- Provides a "free" transmitter with modulated signal in band that is otherwise difficult to use for earth science (RFI)
  - only need to fly receivers and use as bistatic RADAR

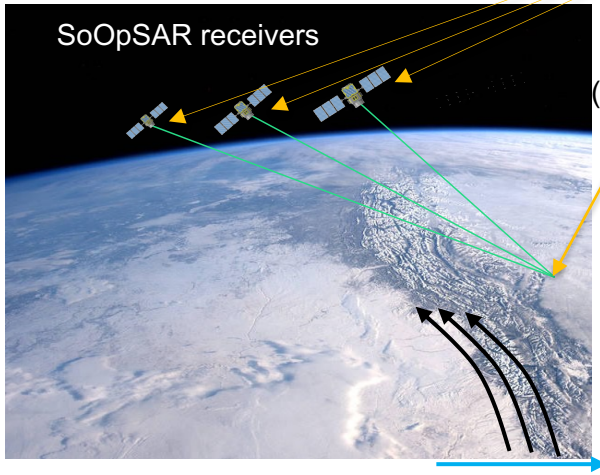
A Satellite Synthetic Aperture Radar Concept Using P-Band Signals of Opportunity

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

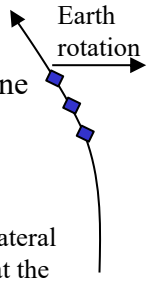
SoOpSAR is a bistatic interferometric SAR using transmit signals from US Govt. MUOS P-band communication satellites with receivers on a constellation of LEO SmallSats



MUOS
(Existing US Govt Asset)

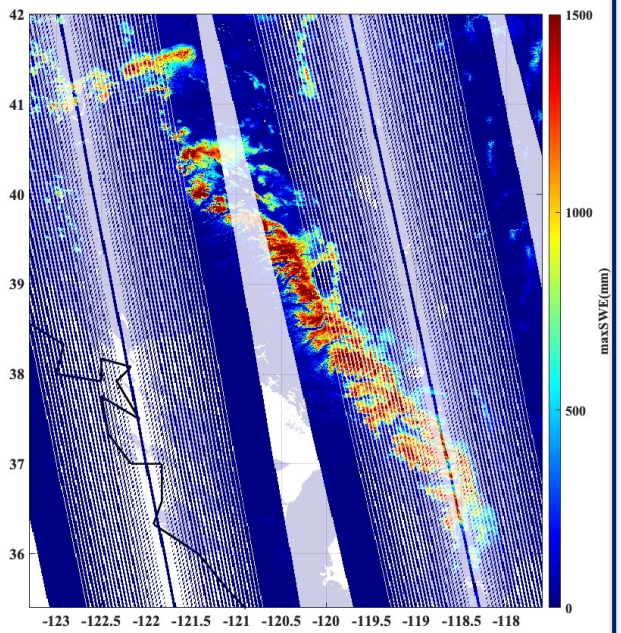


Earth rotation to create separate tracks



Train of smallsats on one orbit plane

Along track spacing: 1.4 km for a lateral ground tracking spacing of 100 m at the Equator



One SnowOp-SAR orbit pass can encompass the entire Sierra Nevada

Targeted Measurements:

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

Instrumentation

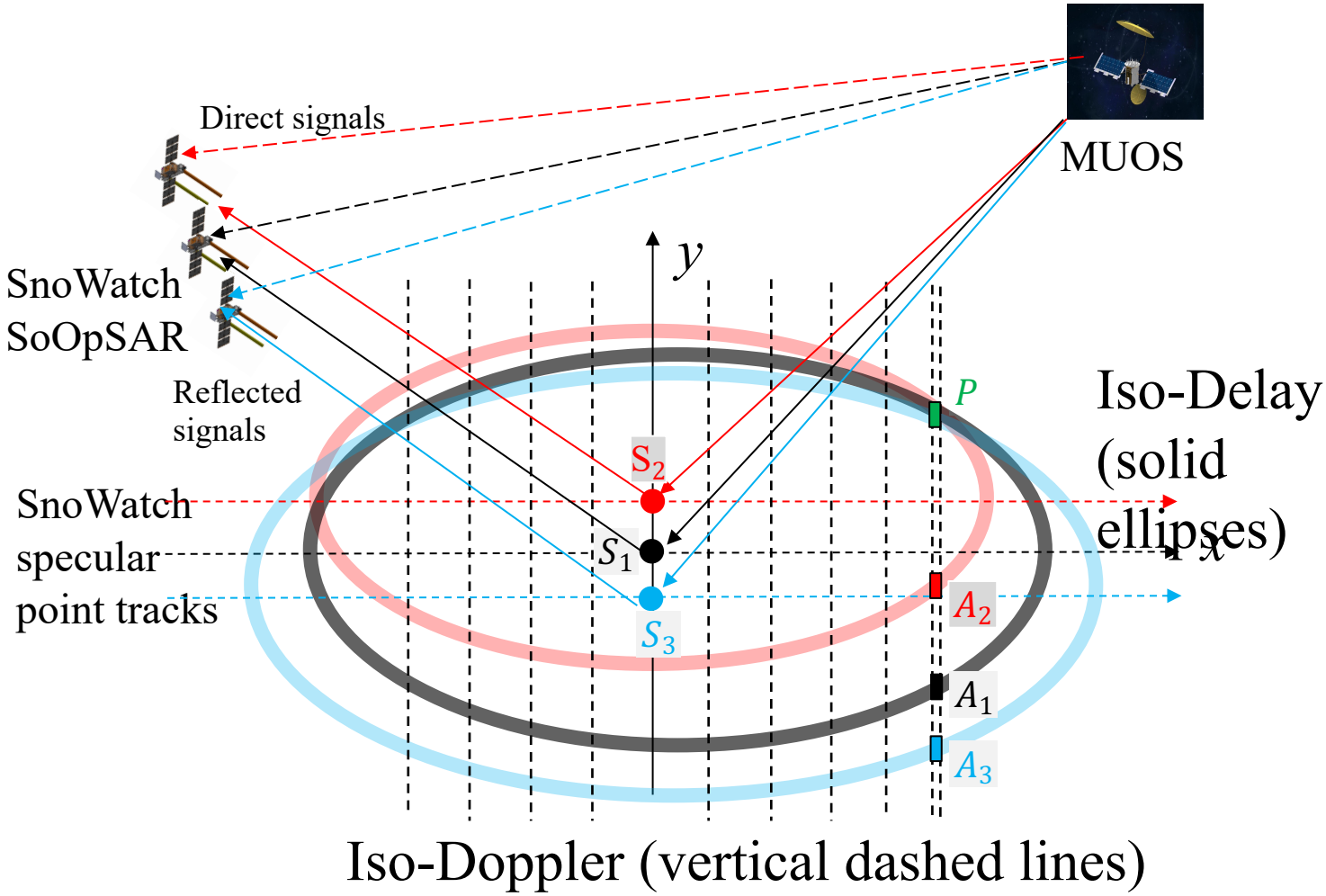
- Dual frequency (240-270 MHz reflectometer & 360-380MHz SAR)
- P-band zenith (direct) and deployable nadir (reflected) antennas

Science Mission

- 3 water-years for science mission
- 6 day repeat
- Resolution:
- Across track (100 m to 2 km)
- Along-track (50 m/10 m for 2/10 sec integration time)

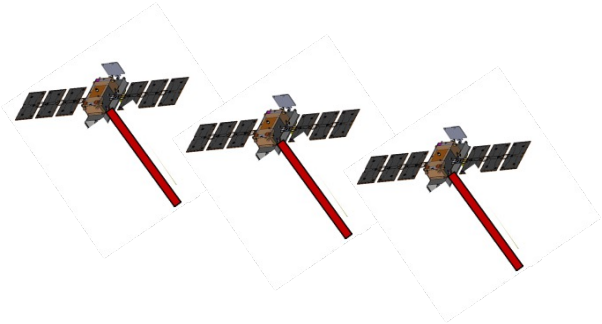
SoOpSAR Measurement Geometry

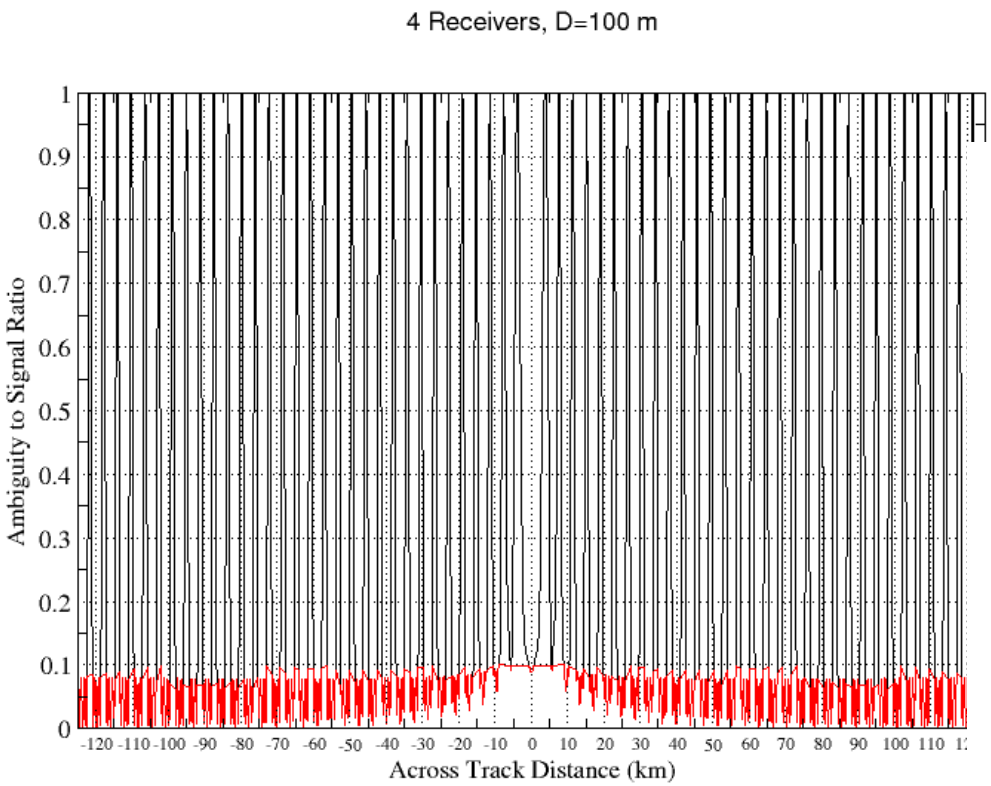
Data from multiple satellites with an offset on ground tracks can allow the reduction of reflection from iso-Doppler/range ambiguities

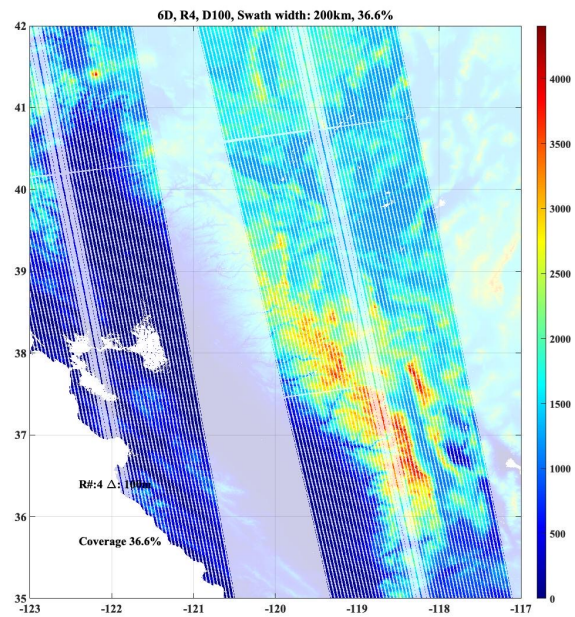


Ambiguity to Signal Ratio with One Antenna on Each Satellite

- 4 satellites with one antenna one each
- High level of ambiguities are distributed across the entire swath

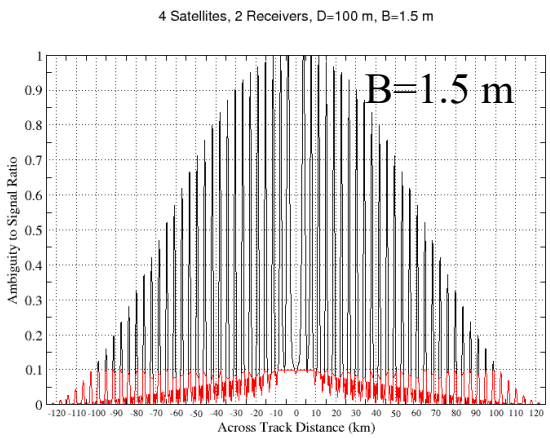


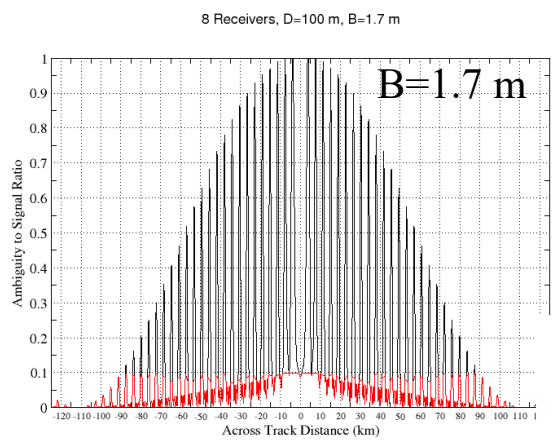




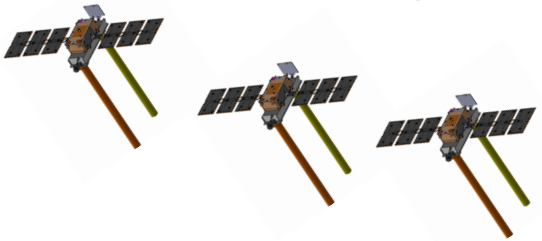
SoOpSAR Spatial Coverage
Ambiguity to Signal Ratio with One Antenna on Each Satellite

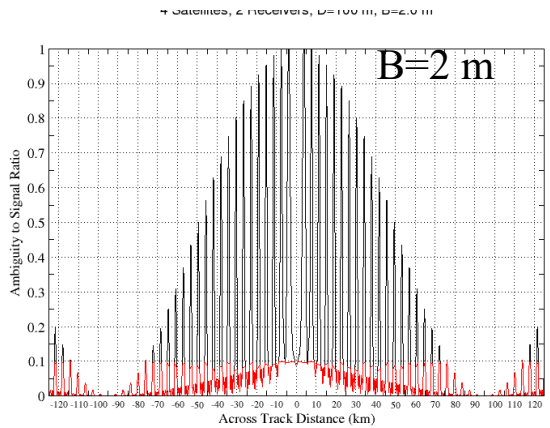
- 4 satellites with two antennas one each
- The level of ambiguity is greatly reduced at the outer edge of swath

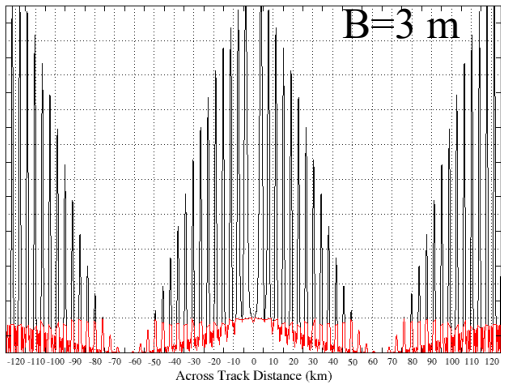


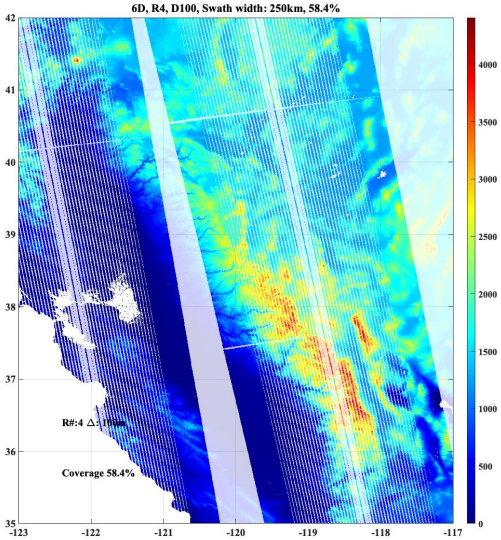


Antenna spacing: B





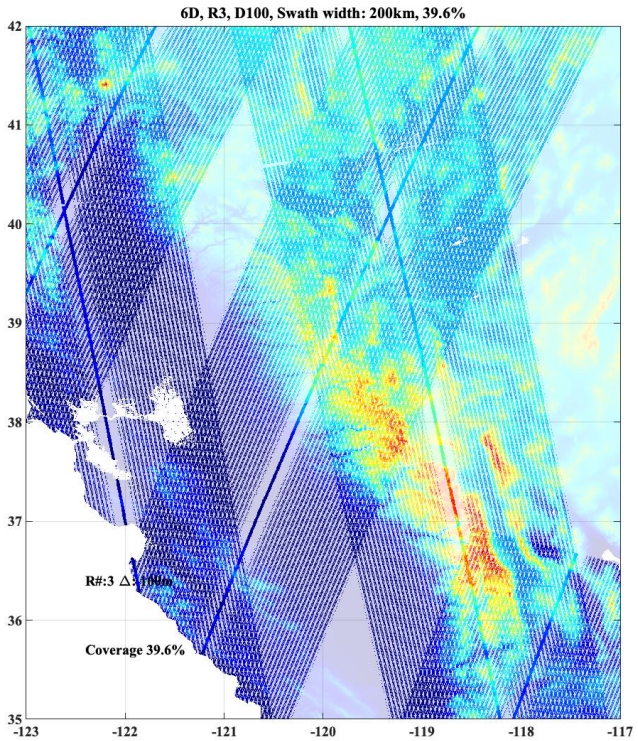




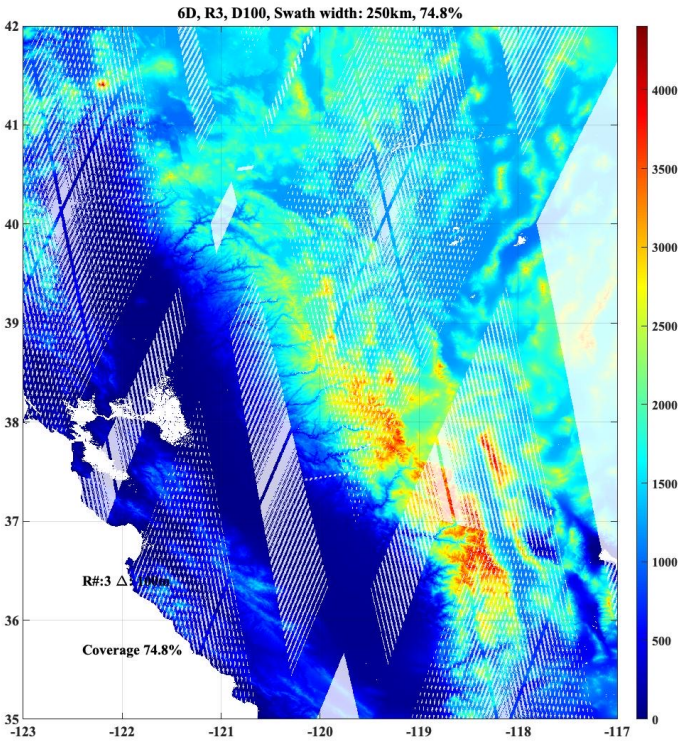
A baseline spacing (B) between 1.7 to 2 m appears to be optimal

Multiple Antenna Element Can Increase Swath Coverage (3 Satellites and 6 Day Repeat)

One antenna element

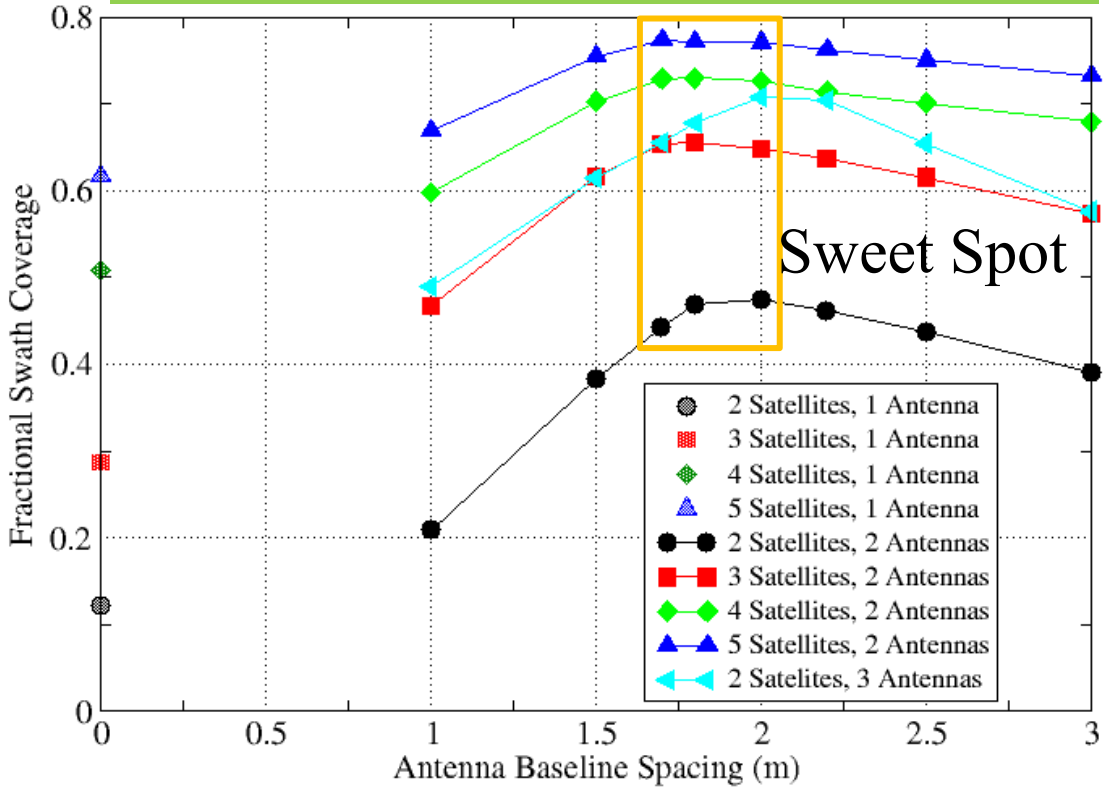


Two-element Array



Fractional Swath Coverage with Ambiguity to Signal Ratio (ASR) <0.1 for Multiple Satellites and Multiple Elements Configuration

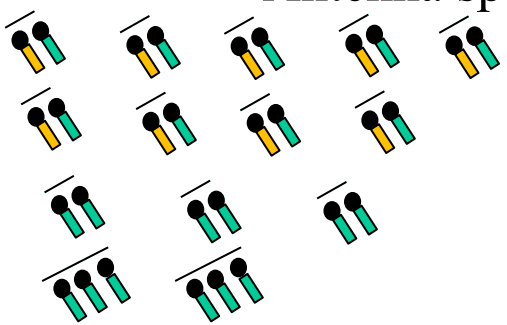
Optimal antenna spacing: 1.7 to 2 m



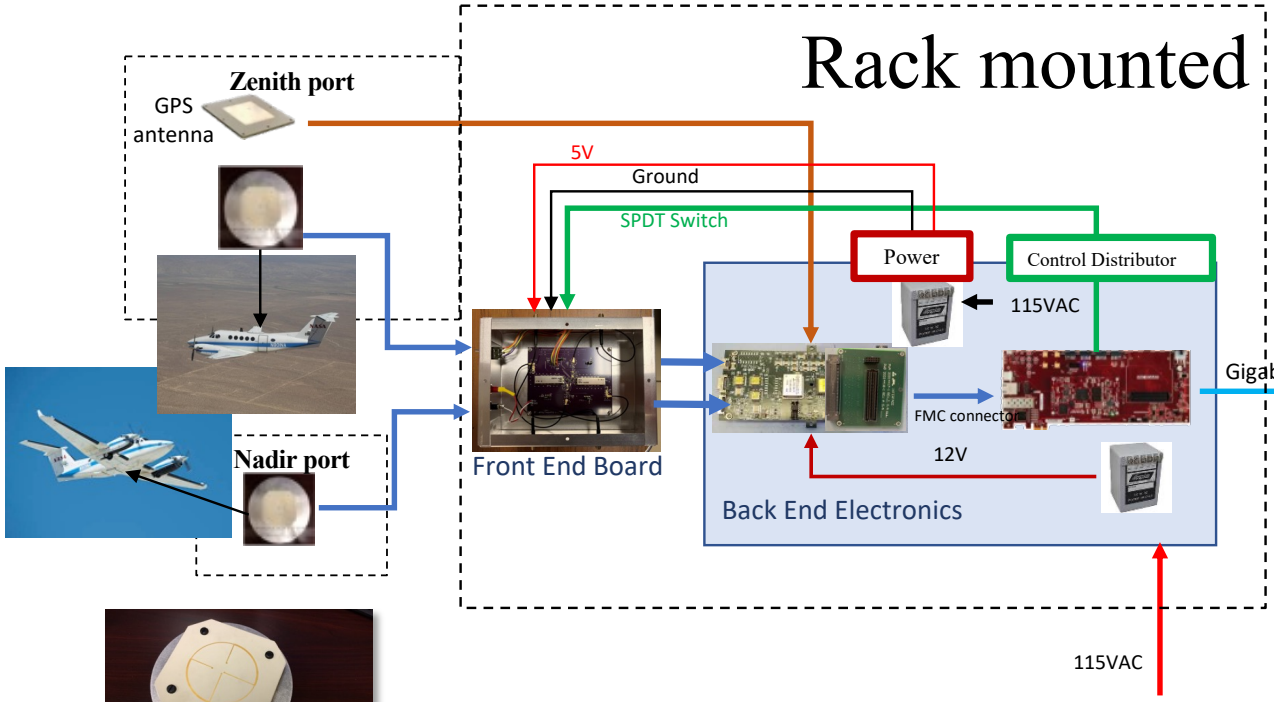
Intersatellite ground track spacing (D): 100 m

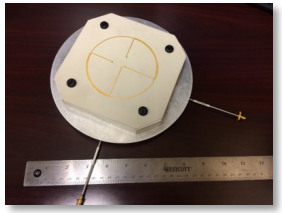
Antenna spacing: B

- Five satellites/2 elements
- Four satellites/2 elements:
- Three satellites/2 elements:
- Two satellites/3 elements:

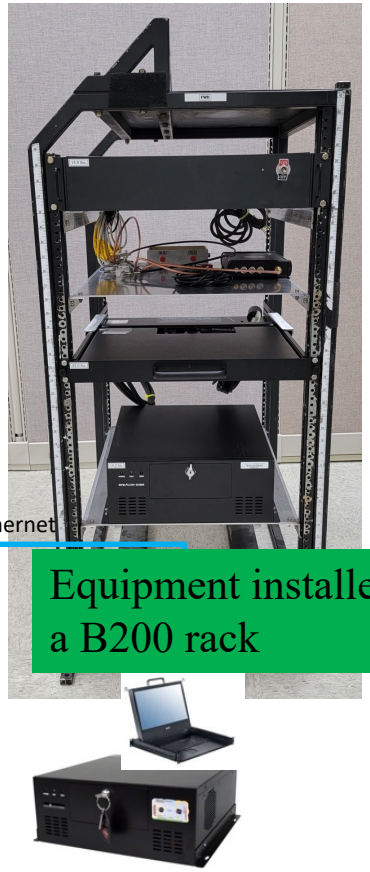


Airborne SoOpSAR





P-band Antennas



Equipment installed on a B200 rack

2022-2023 Airborne Campaign Summary

Aug 22-26, 2022:
- 4 Science flights
- 2 in Segehen Creek
- 2 in Grand Mesa

Jan 27, 2023:
Engineering Test Flight

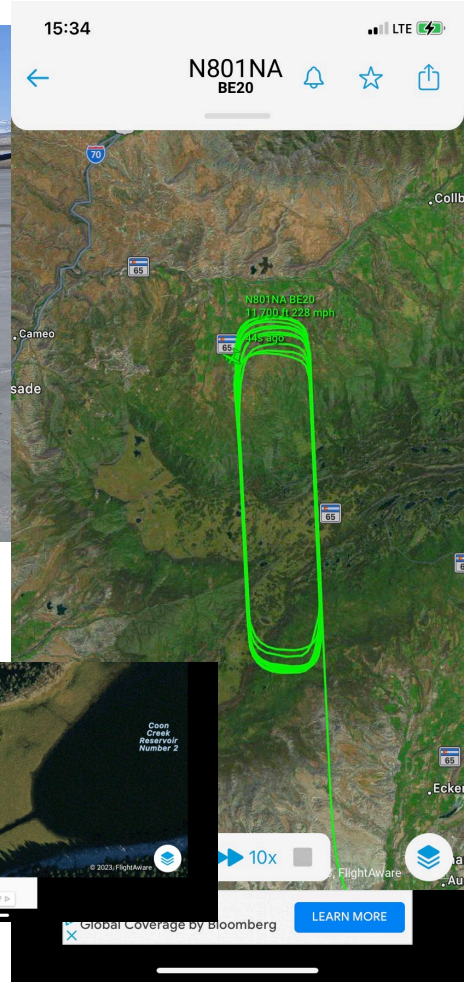
Feb 1-10, 2023:
- 4 science flights over Grand Mesa
- 3 science flights over Sagehen Creek and Central Sierra Snow Lab

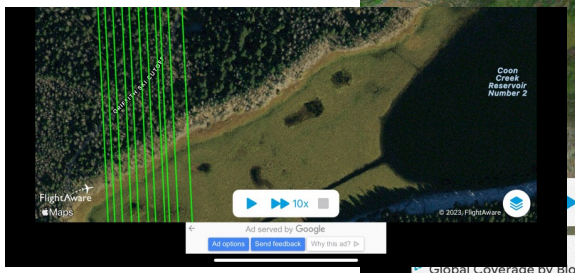
Mar 2-8, 2023:
- 6 flights over Grand Mesa in the AM & PM
- Poor weather delayed campaign and cancelled over Sagehen, CA

Ongoing data analysis
Produced preliminary, uncalibrated SAR images of Grand Mesa

AUGUST 2022 | JANUARY 2023 | FEBRUARY 2023 | MARCH 2023 | APRIL 2023

Airborne Science Flights:
Grand Mesa, CO; Feb 1-4, 2023

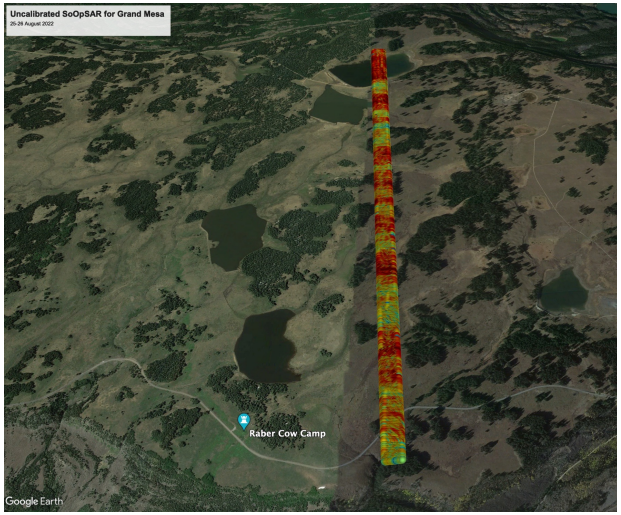




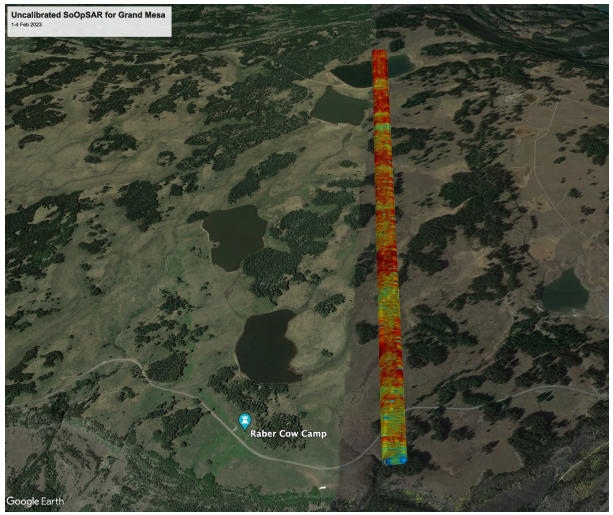
Preliminary Uncalibrated SAR Image for Grand Mesa: Consistency Among Three Periods

Promising consistency: Spatial patterns of reflections from three operational periods largely agree with each other

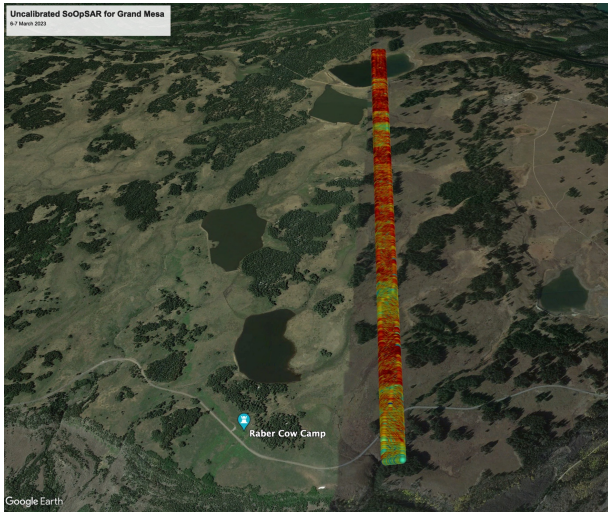
25-26 Aug 2022



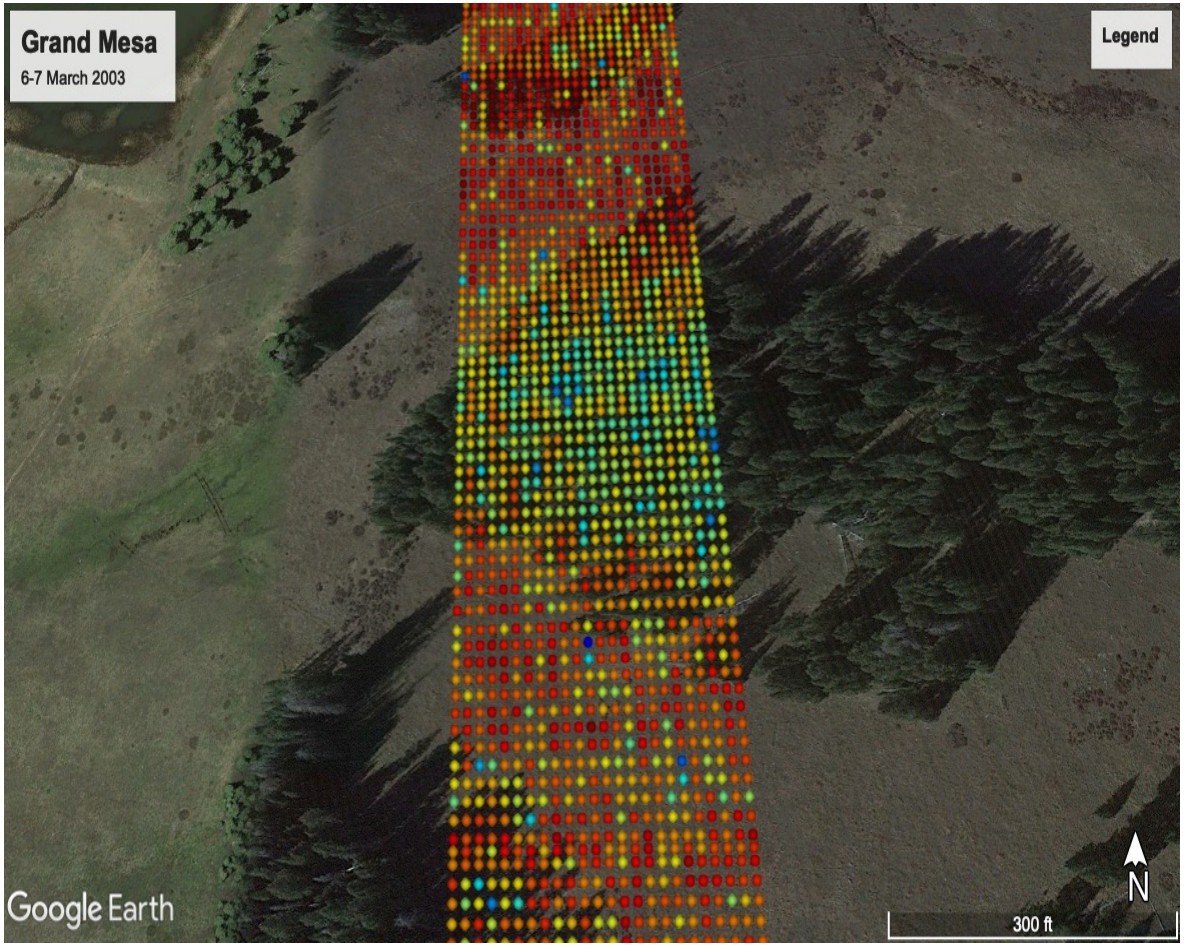
1-4 Feb 2023



6-7 March 2023



Preliminary Uncalibrated SAR Image for Grand Mesa: Trees



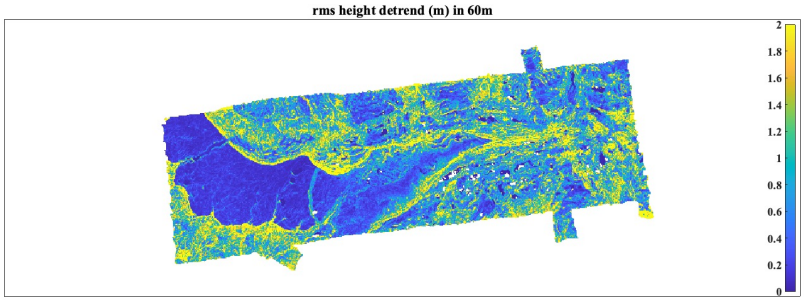
Weaker reflection over the forest

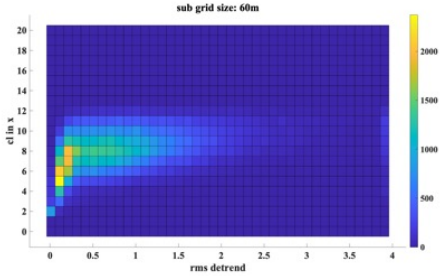
Summary

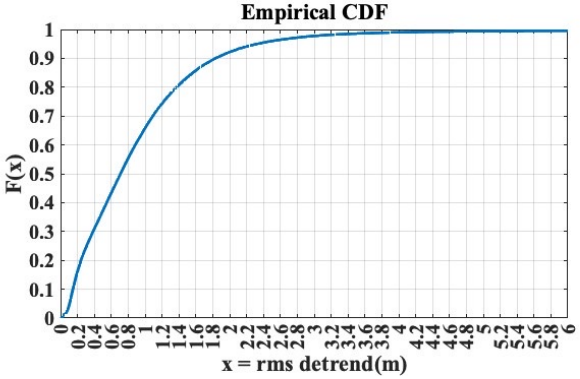
- Spaceborne SoOpSAR with 3 satellites and 2 antenna elements on each can provide significant global coverage every 6 days
- Airborne campaign demonstrated the feasibility of multi-static SoOp SAR processing.

SoOpSAR performance dependence on Surface Roughness

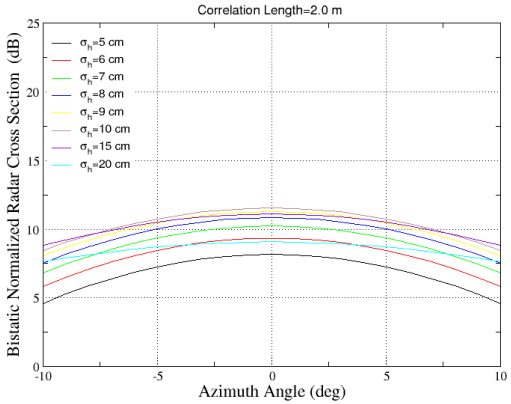
Rms height in 60m sub grid based on Lidar Survey over Grand Mesa, CO







- SoOpSAR performance depends on SNR
- SNR varies with bistatic radar cross-section (BRCS) of land surfaces
- BRCS depends on surface roughness
- BRCS for mountainous terrain is quite significant near the forward looking direction



Signal to Noise Ratio, H=613 km

- 3 Satellites, 2 Receivers, D=100 m, d=1.7 m, Soil Moisture=0.1, Correlation Length=2.0, IPL=1.5 dB