

Snow Depth Penetration Experiment for ESA Harmony Mission

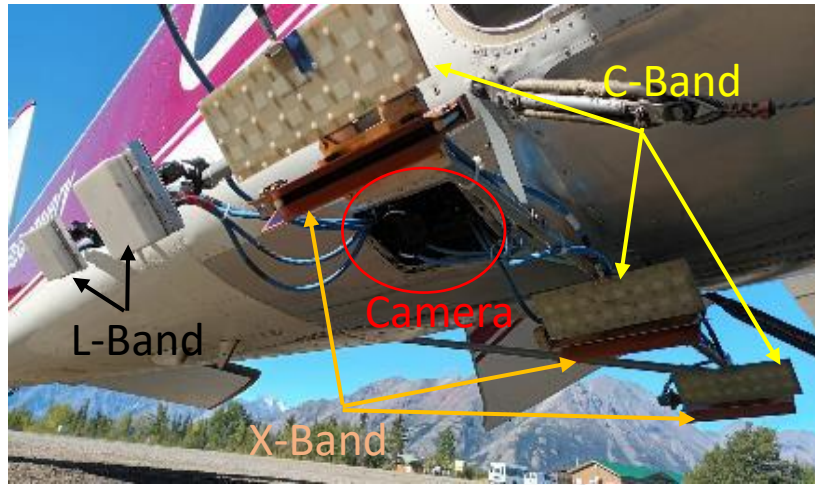
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(Simon Fraser University)

Objective of the Study

Measuring the elevation bias of C and X band single-pass InSAR data acquired over glacial accumulation area as a function incidence angle & snow/firn properties. The goal is to help improve models to correct for this penetration bias in topographic products of the future ESA Harmony Mission.



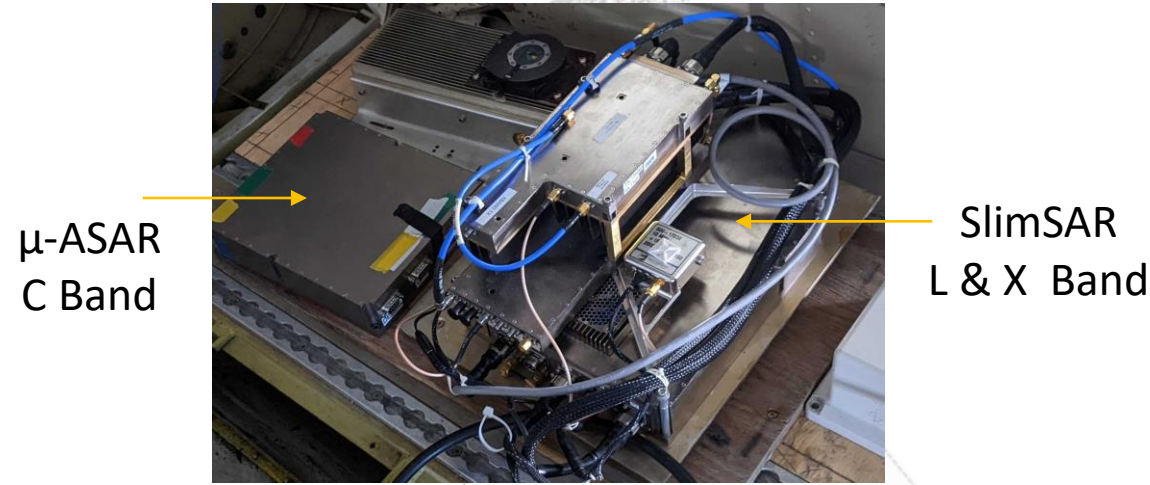
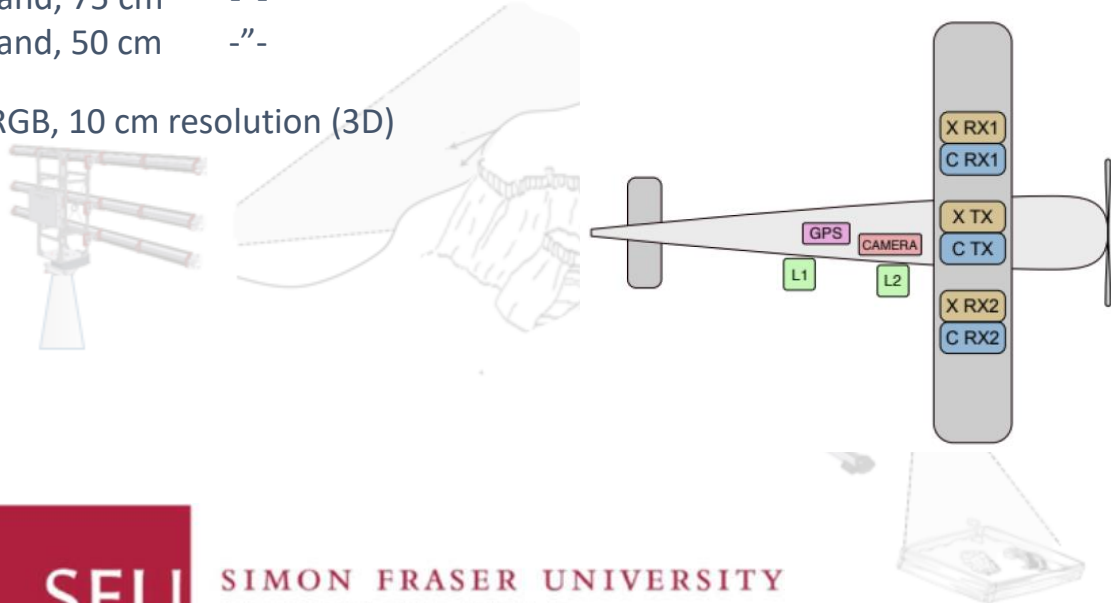
SFU Airborne SAR-Fodar System



X & C Band:
Across Track Configuration
L Band:
Along Track Configuration
Optical SfM:
Oblique co-incident with SAR

L-band, 85 cm resolution (range)
C-band, 75 cm "-
X-band, 50 cm "-

RGB, 10 cm resolution (3D)



Intervalometer Novatel IMU Nikon D850



SAR System Specs

Parameter	X-band	L-band	C-band
Waveform	Pulsed LFM	Pulsed LFM	LFM-CW
Frequency (GHz)	9.35 – 9.65	1.215 – 1.4	5.43
Max. Bandwidth (MHz)	245	185	160
Transmit Power (W)	25 (+ 50 w/ amplifier)	60	1.0
Antennas	1 Tx, 2 Rx	2 Rx/Tx	1 Tx, 2 Rx
Polarizations	VV	HH, HV, VH, VV	VV



Polarimetric SAR (R,G,B) \leftrightarrow (HH,VV,HV)

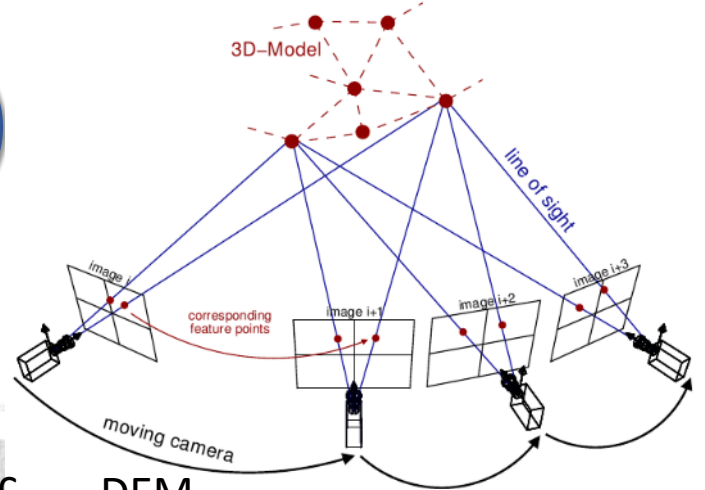


Multi-Frequency RGB (Red:X Green:C Blue:L)

Made by Artemis Inc. USA

Optical System (Fodar)

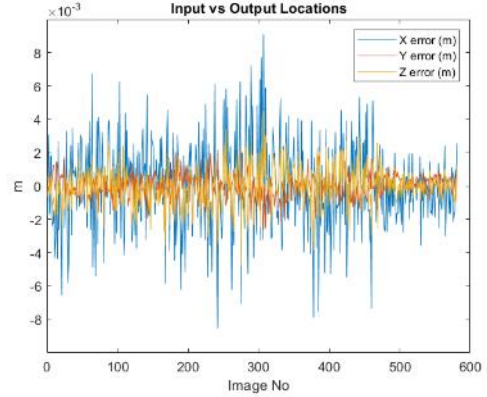
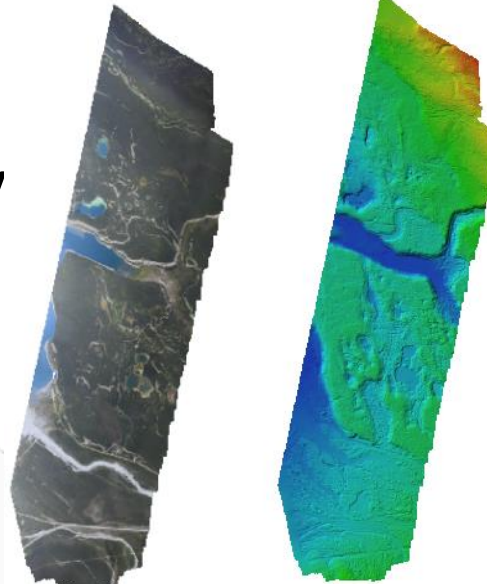
- Foto Detection and Ranging
- Photogrammetry Technique
 - Structure from Motion (SfM)
- Courtesy Fairbanks Fodar™
- Different from conventional photogrammetry
 - COTS small format camera
 - On-boards survey grade GPS/IMU vs GCP
- Outputs: DEMs, Ortho-Mosaics, Motion Refinement
 - ~ 10 cm x 10 cm



Ortho-mosaic

DEM

Motion Refinement



Area of Study

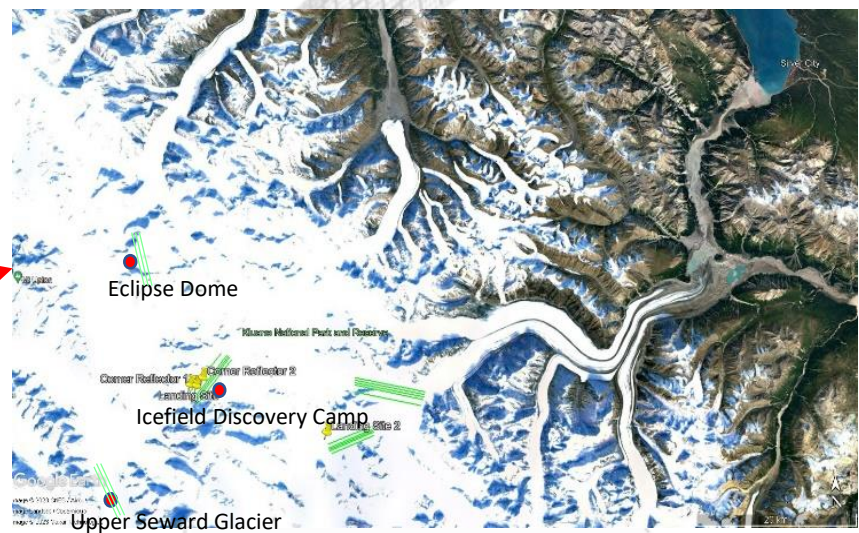
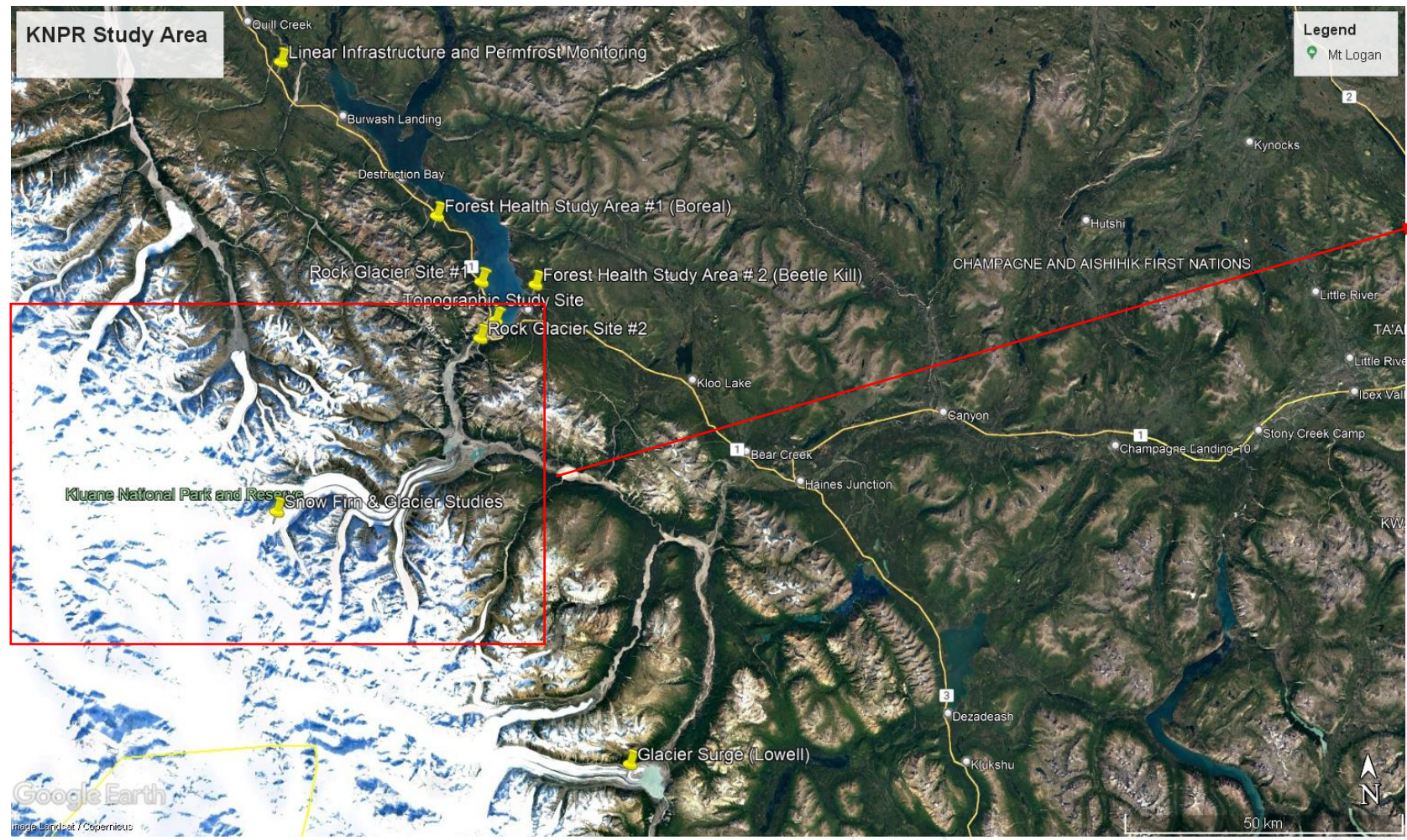
Kluane Lake National Park Reserve,
St Elias Mountains,
Yukon Territory, Canada



Area of Study

Kluane National Park Reserve, Yukon

Area of Interest

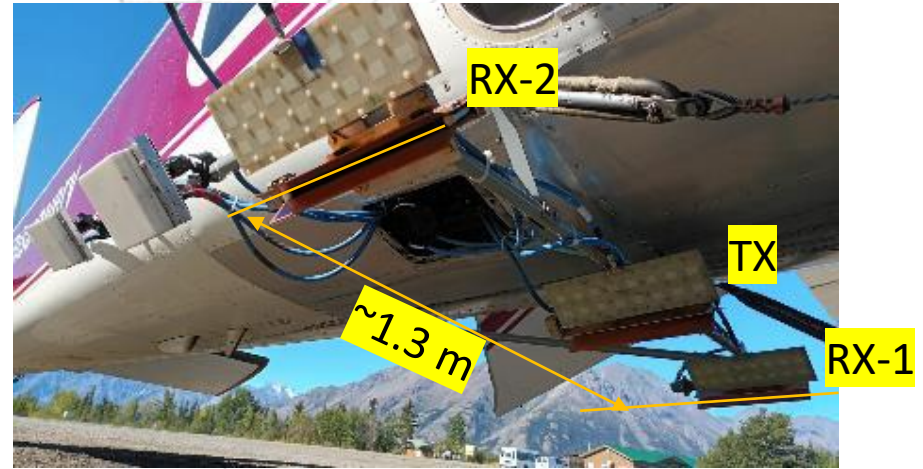


Tourist Plane by Icefield Discovery
 Helio-courier
 Silvercity, YT, CA Airstrip as home base



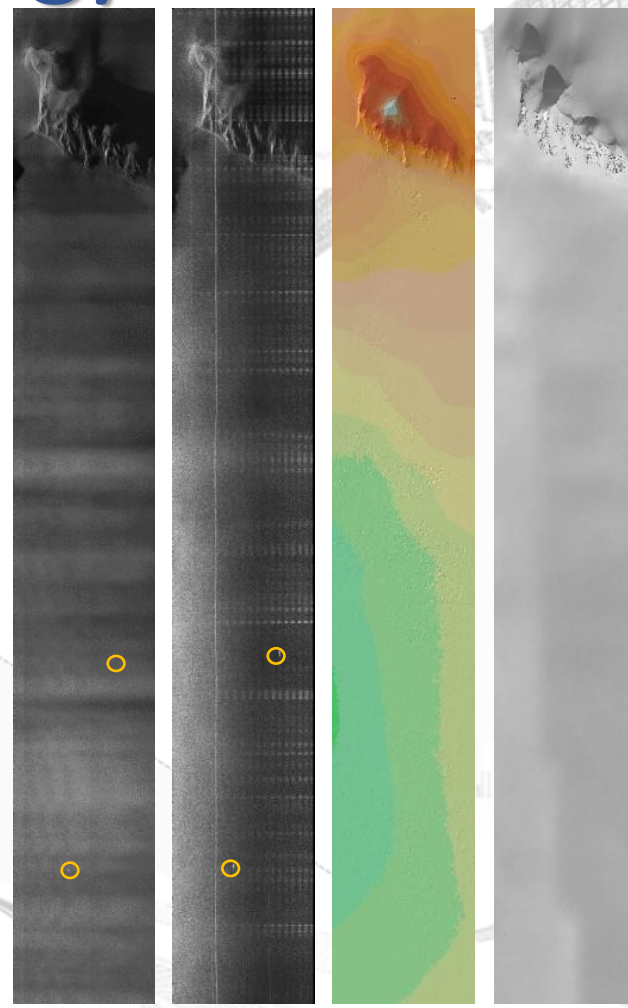
Experiment

- X & C Band Data Collection in XTI configuration with simultaneous Fodar Data collection
 - Physical baseline of ~ 1.3 m
 - Bistatic XTI configuration
 - Coincident Fodar Swath (Oblique Looking)
- Fodar DEM provides reference surface
- X and C Band Single Pass DEM provides penetration relative to true DSM by Fodar
- Correlation with Snow properties at three incidence angles and three different elevations



Methodology

- Corner Reflector (CR) Deployment for Calibration
- Including Rocks and CRs in the Radar Swath
- Snow pits for ground truthing (Snow Properties)
- X & C Band Data Collection
- Fodar Data collection (simultaneous)
- Data Processing
 - Artemis Cicada vs SARlab TDBP processor vs SARlab RDA processor
- Preliminary Results & Analysis
 - Constant baseline used



X Band C Band DEM Optical

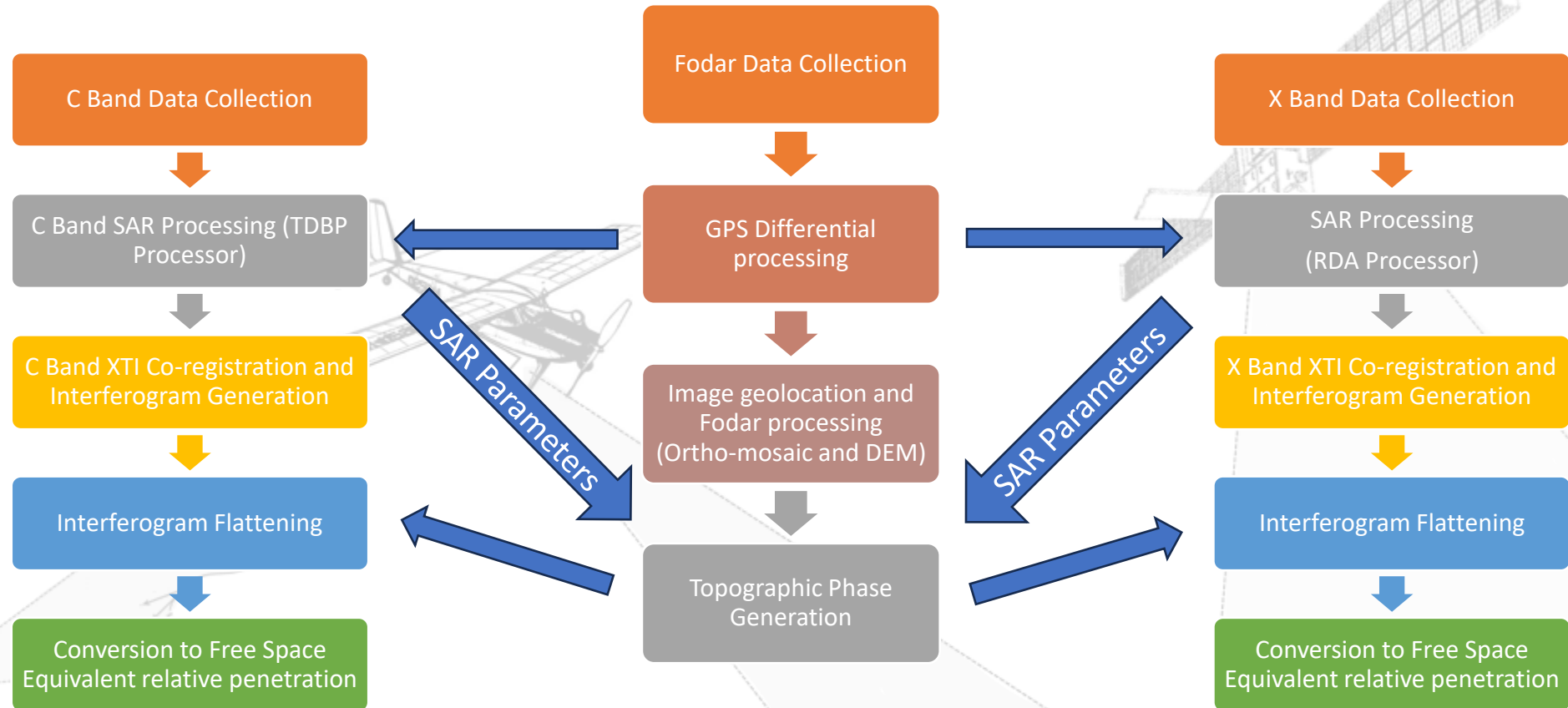


Corner Reflector
4x4x4 m Triangular



Snow Pits

Work Flow Diagram



$$P = \frac{\phi_{rel} \lambda \sin(\theta_{inc}) R_{slant}}{4\pi B}$$

Where ϕ_{rel} = Flattened phase with Fodar DEM, λ = Radar wavelength θ_{inc} = incidence angle

R_{slant} = Slant Range B = Baseline & P = Relative Penetration

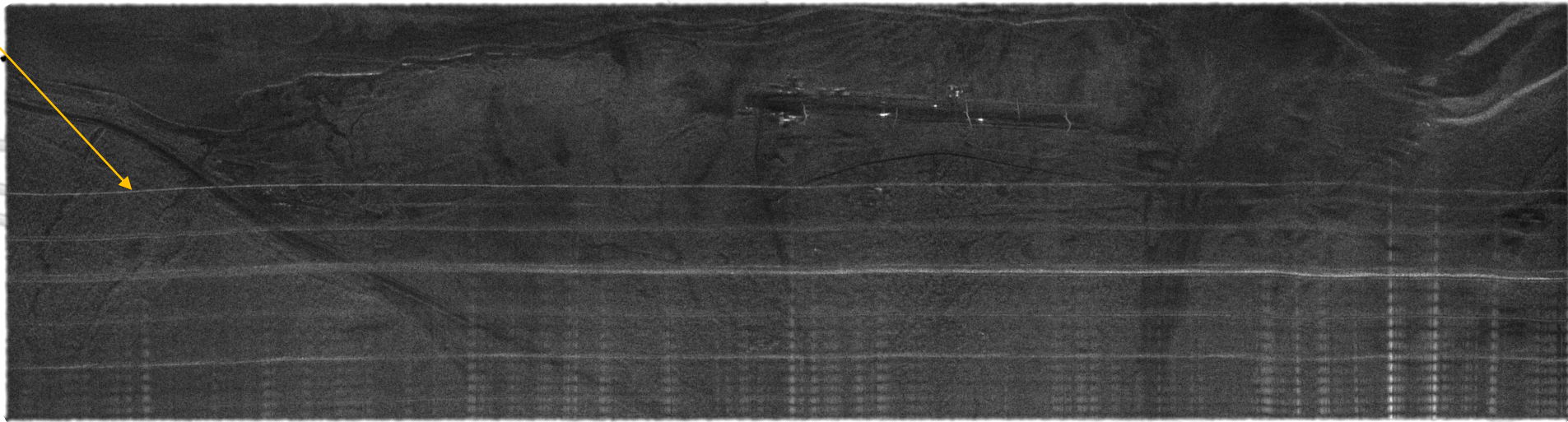
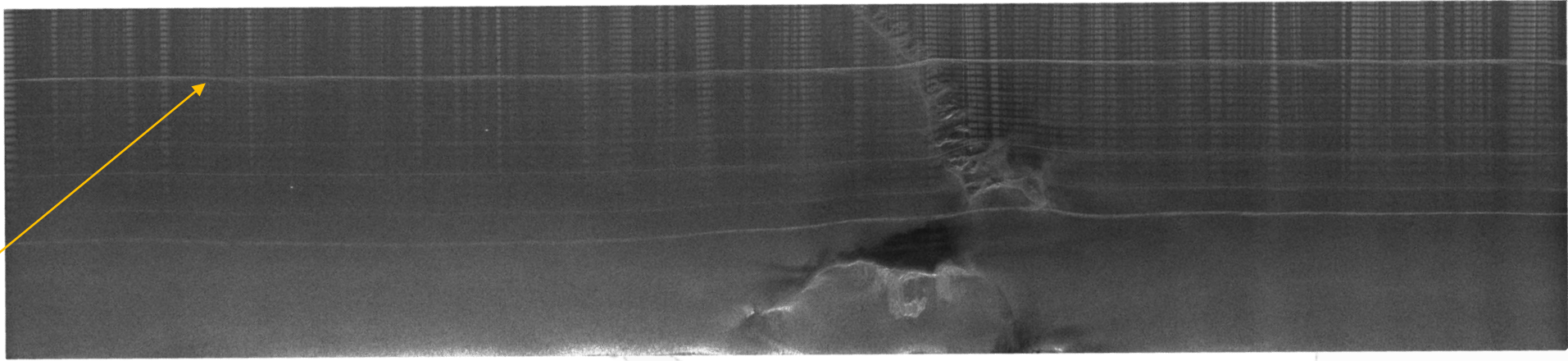
Field Campaigns to date (Summary)

Campaigns	Remarks	Sites (3 incidence angles at each site)	Ground Truth	Total Acquisitions
April 2022 (Fall)	Pilot Study : Ground truth by Dr. Gwenn Flowers (Glaciology Prof at SFU) C-band radar failure	Landing Site – 2600 m alt Lower Landing Site – 2000 m alt Confluence Collect – 1850 m alt	Snow pits within each acquisition profile plus two corner reflector deployed in the field	21 Acquisitions (X Band Only)
August 2022 (Spring)	No ground truth (not planned) Good C-band data Lower SNR than expected	Landing Site – 2600 m alt North Field – 2700 m alt	No Ground Truth	10 Acquisitions
April 2023 (Spring)	New C-band antennas 5x power, enhanced range artifacts Aircraft turbo broken (no sites > 9000 feet) Weather prevented landings - no ground truth	Landing Site – 2600 m alt Lower Landing Site – 2000 m alt Seward Glacier – 1650 m alt	Firn cores at Seward glacier by Dr Martin Truffer (U Alaska) + 2 Corner Reflectors deployed in the Icefield	22 Acquisition
May 2023 (Late Spring)	Range artifacts mitigated Good C-band data for Eclipse Dome + Camp	Landing Site – 2600 m alt Lower Landing Site – 2000 m alt	Detailed Ground Truthing at Eclipse Dome by U Maine (firn cores, gpr, 20 m core drilling)	23 Acquisitions
August 2023 (Fall)	Snow pit done at Eclipse Dome Weather delayed radar flights, then Aircraft broke down before the profiles could be acquired	No radar flights	Snow pit at Eclipse Dome, weather prevented landing elsewhere	Nil

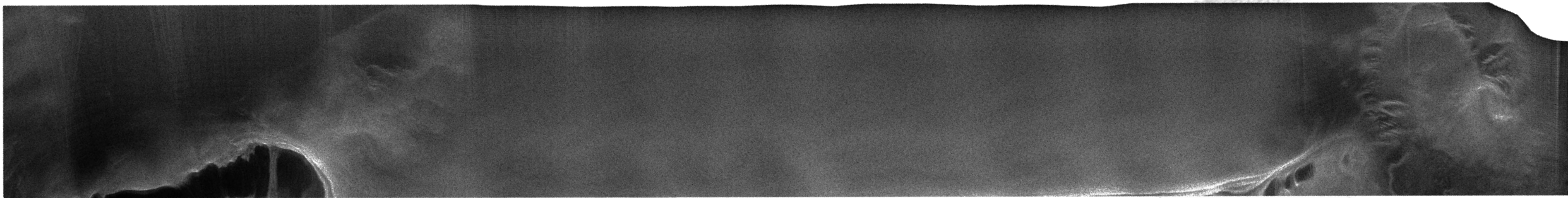
Total Acquisitions = 65 C & X Band Acquisitions

April 2023 Data Examples

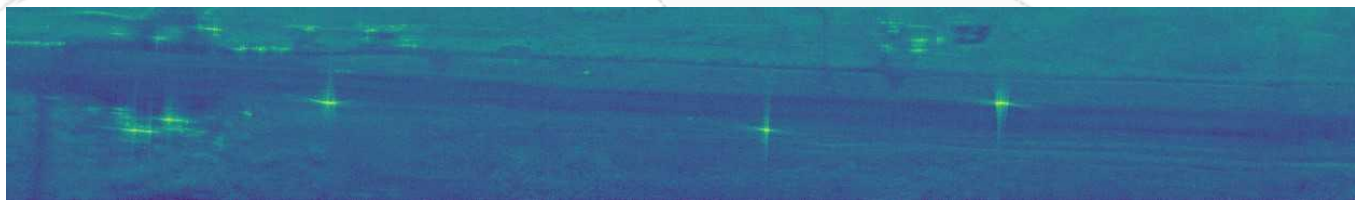
Artefacts



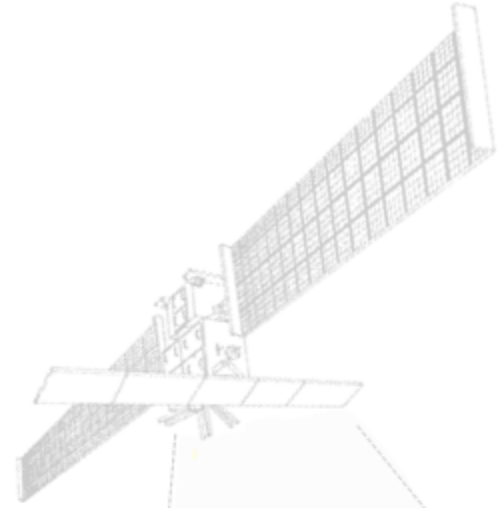
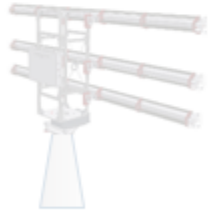
May 2023 Data Examples



No Artefacts!!



PRELIMINARY RESULTS



SFU

SIMON FRASER UNIVERSITY
ENGAGING THE WORLD



Aug 2022 Campaign

Google Earth Image

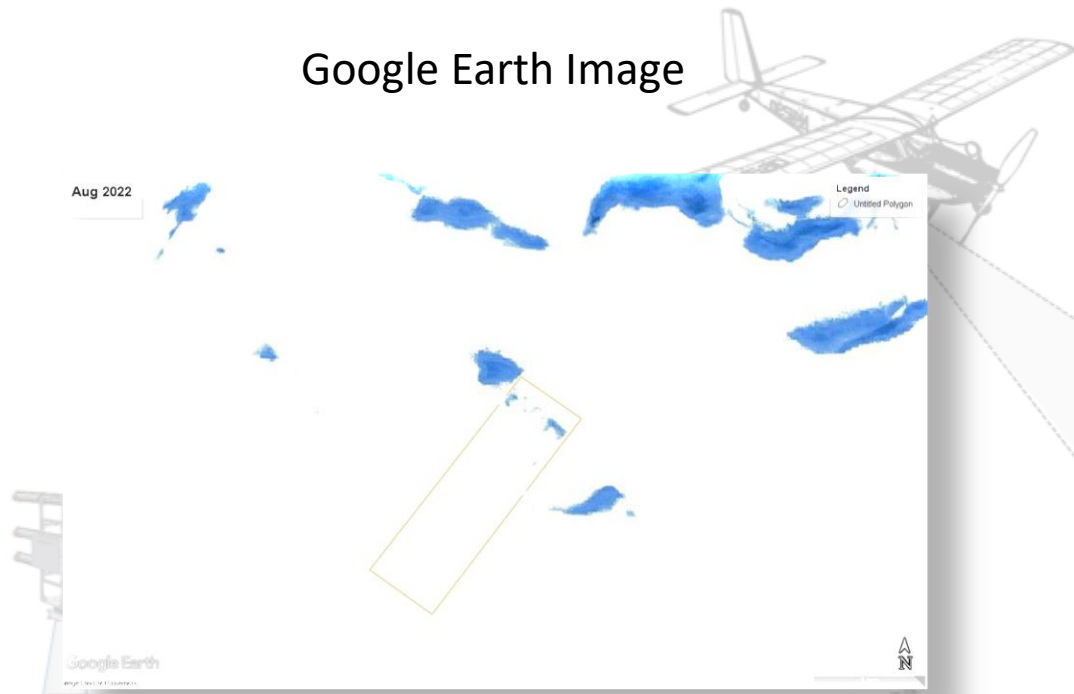


Image Size 2.0 km x 0.3 km

Ortho-mosaic Image



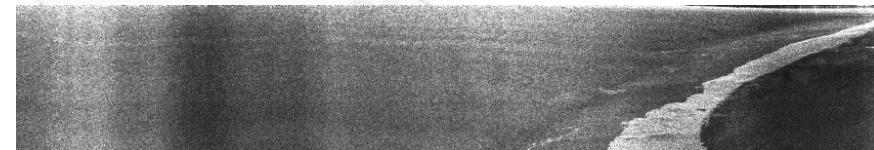
Fodar DEM



C-Band MLI

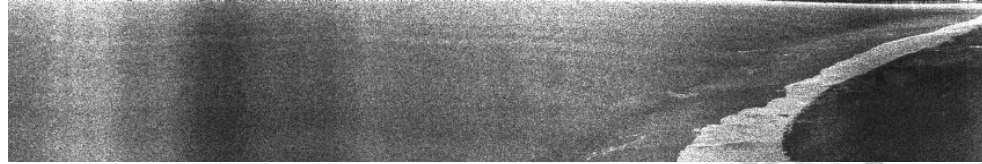


X-Band MLI

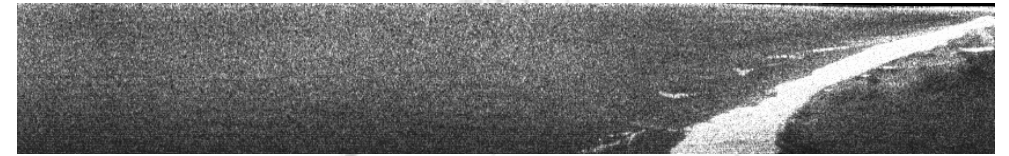


Aug 2022 Campaign Results

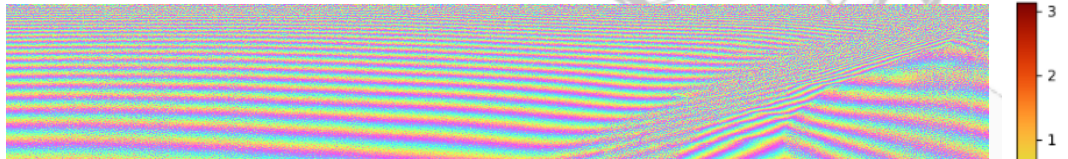
X Band MLI



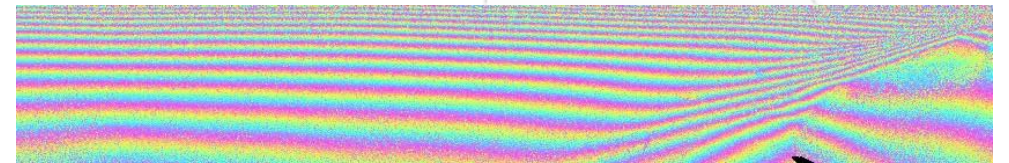
C Band MLI



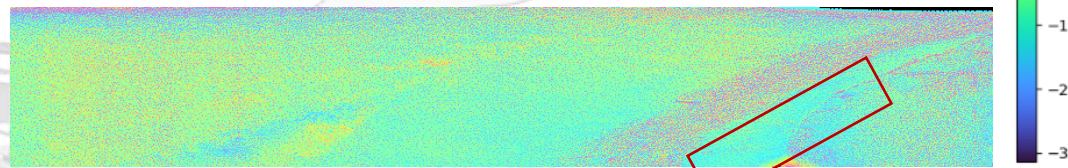
X Band Raw Interferogram (ML 3x3)



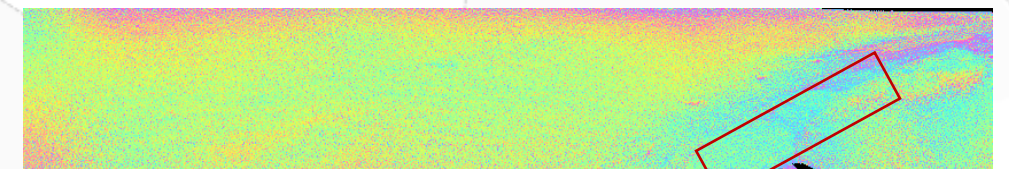
C Band Raw Interferogram (ML 3x3)



X Band Flattened Interferogram (ML 3x3)



C Band Flattened Interferogram (ML 3x3)



Mean Phase over Rock = 0.01 radians

Mean Phase over Rock = 0.015 radians

April 2023 Campaign Results

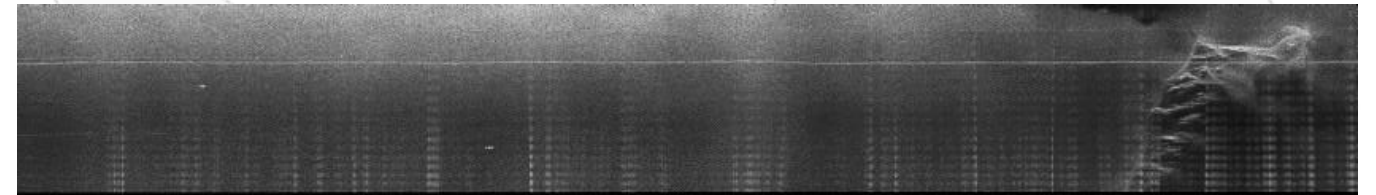
Ortho-mosaic Image



Fodar DEM



C-Band MLI



X-Band MLI



Google Earth Image

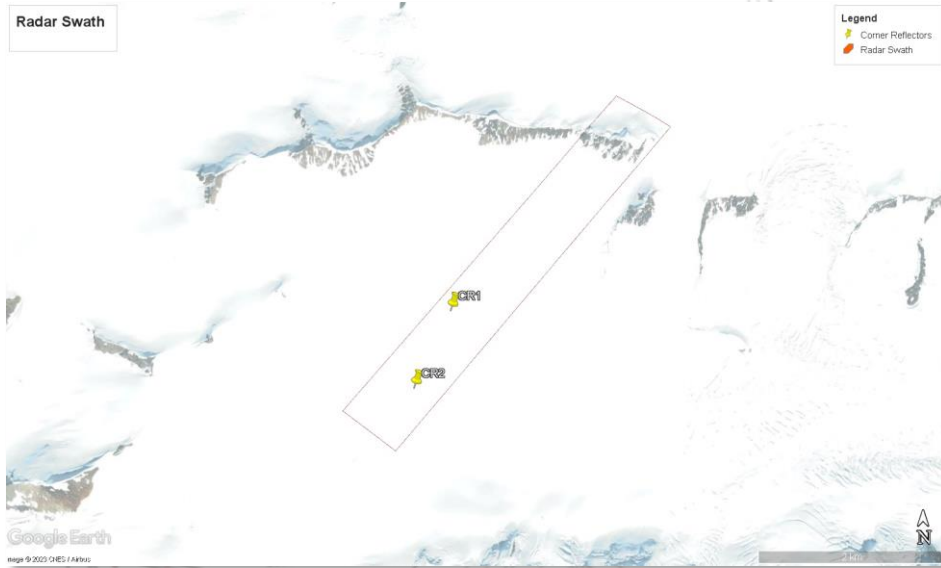


Image Size 4.5 km x 0.7 km

April 2023 Campaign Results

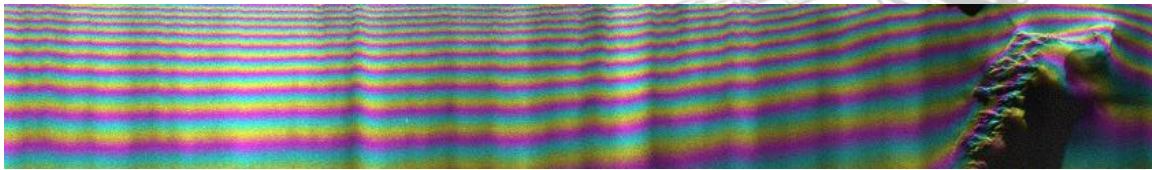
X Band MLI



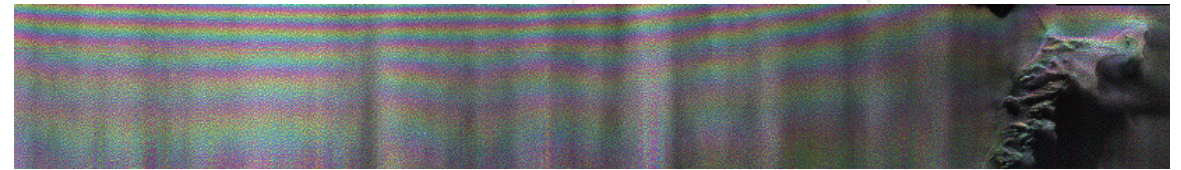
C Band MLI



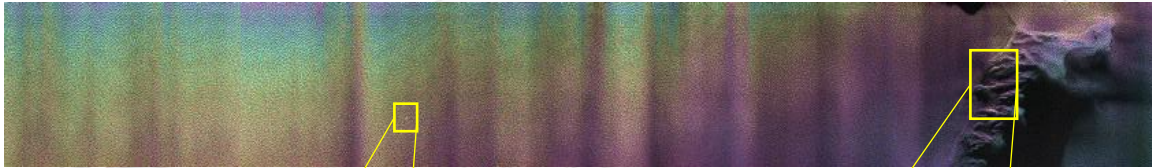
X Band Raw Interferogram (ML 3x3)



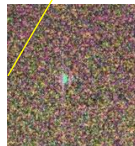
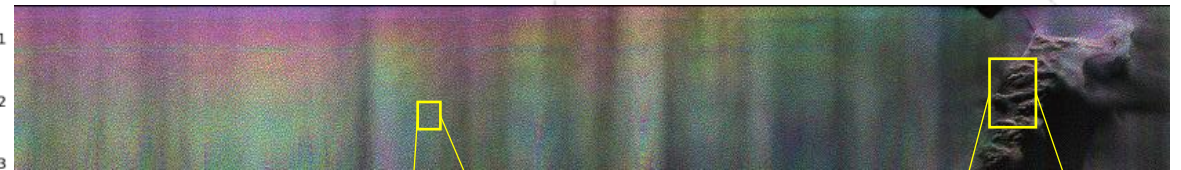
C Band Raw Interferogram (ML 3x3)



X Band Flattened Interferogram (ML 3x3)

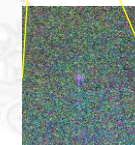
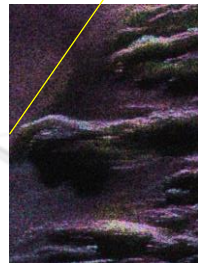


C Band Flattened Interferogram (ML 3x3)



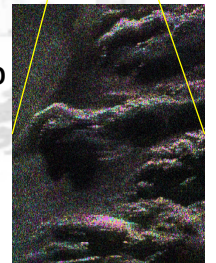
Phase Diff = $\sim 230^\circ$
 $\rightarrow \sim 7.0$ m
 free space equiv.

CR-1



Phase Diff = $\sim 290^\circ$
 $\rightarrow \sim 18.0$ m
 free space equiv.

CR-1



May 2023 Campaign Results

Google Earth Image



Image Size 3.0 km x 0.3 km

Ortho-mosaic Image



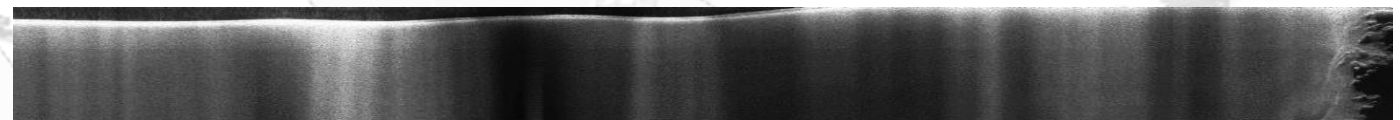
Fodar DEM



C-Band MLI

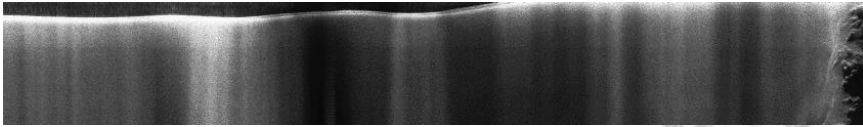


X-Band MLI

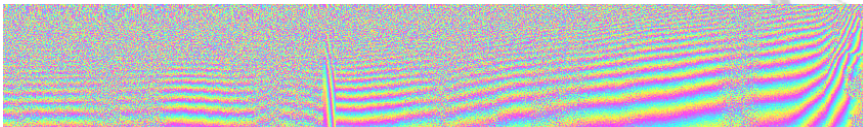


May 2023 Campaign Results

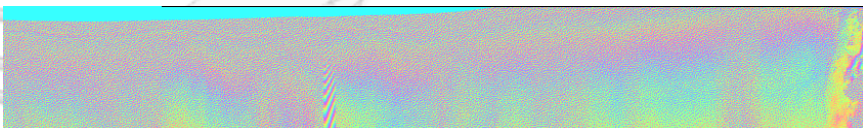
X Band MLI



X Band Raw Interferogram (ML 3x3)



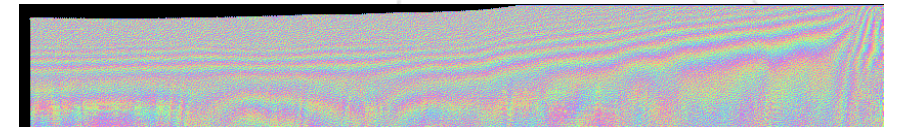
X Band Flattened Interferogram (ML 3x3)



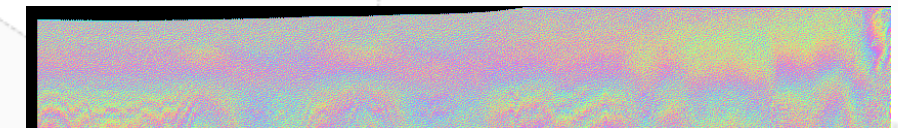
C Band MLI



C Band Raw Interferogram (ML 3x3)



C Band Flattened Interferogram (ML 3x3)



Phase Quality is good, Motion artefacts visible
Work in progress!!

CONCLUSION

- **Despite multiple adversities we still have good data repository for detailed analysis**
 - **More acquisitions needed to achieve the project goals (spring and fall acquisitions with concurrent ground truthing)**
- **Focusing quality of original Artemis provided Cicada processor very poor → Low phase quality**
– SLC quality improved significantly with SARlab's TDBP processor
- **Rock Method seems to work as expected**
 - **CR Calibration can be replaced with rock-based calibration**
- **Small baseline needed to resolve ambiguities better**
- **Waiting for U Maine field campaign ground truth data analysis**
- **Promising Research Outcomes**
 - **Contribution to ESA Harmony Mission Objectives**