
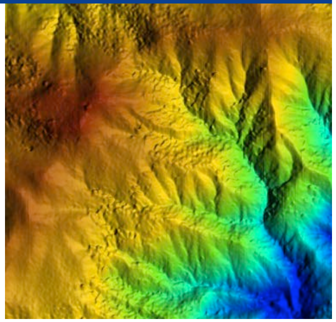


SRI CubeSat Imaging Radar for Earth Science (SRI-CIRES): Initial UAS Integration and Flight Demonstrations

Earth Science Technology Forum

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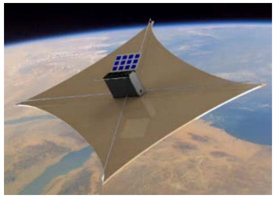
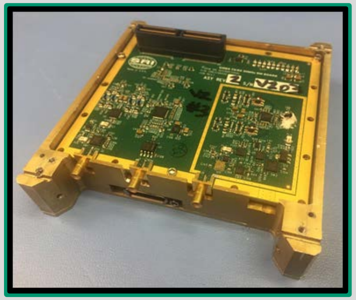
CIRES: CubeSat Imaging Radar for Earth Science



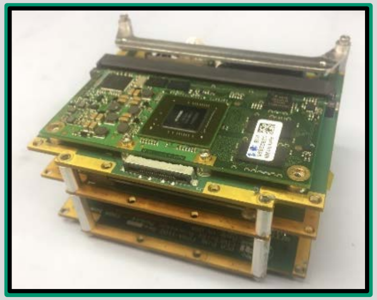
Miniaturized Synthetic Aperture Radar (SAR) payload* for resource-constrained platforms
Designed to support interferometric (InSAR) operation up to 500 km altitudes

* Funded by NASA Earth Science Technology Office

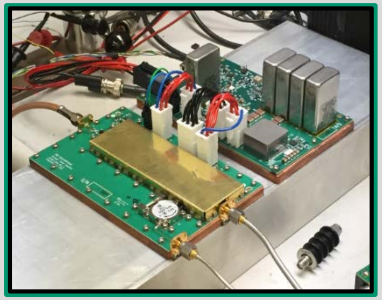
CubeSat SAR Payload advanced to 5 m resolution and extended up to 3.5 GHz



Tx/Rx Module: Transmit and Receive RF analog chains, calibration loopback circuits, integrated ADC and DAC capability.



High Speed Processor Module: Power Regulation, FPGA, Data Storage, Multi-core Processor; >250 MB/s write-speed to > 1 TB non-volatile storage; >500 GFLOPs on-board processing



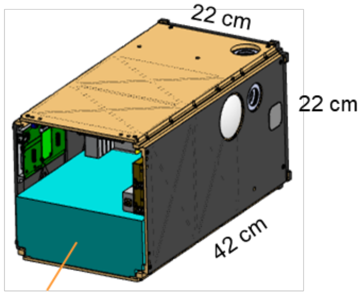
PA Module: 600 W peak (60 W avg), includes internal power regulation, power driver stages and RF power amplification (supports 2.9-3.1 GHz or 3-3.5 GHz)

CubeSat SWaP: Radar payload electronics packaged into 1.3U CubeSat form factor

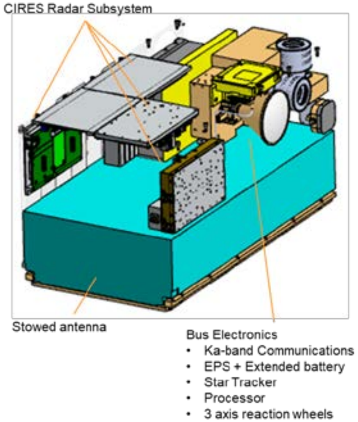
Designed to rapidly integrate with 16U bus and deployable antenna

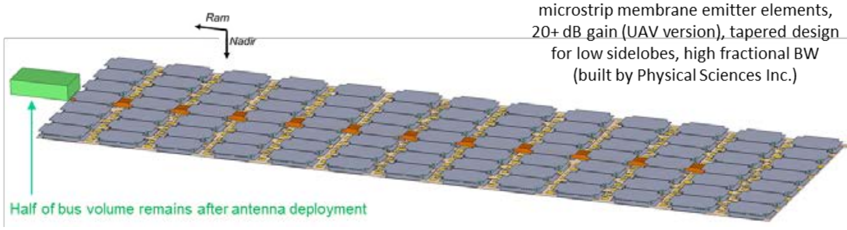
Sub-scale UAV Radar Antenna: High-power waveguide distribution, printed microstrip membrane emitter elements, 20+ dB gain (UAV version), tapered design for low sidelobes, high fractional BW (built by Physical Sciences Inc.)

16U Bus



Stowed antenna





5 m^2 Deployable Membrane Antenna

Earth Science Need for Rapid Repeat InSAR Data

- Time-variable geophysical processes require more frequent monitoring than a single space-borne InSAR sensor can provide
  - The revisit time of a single platform is restricted by orbital mechanics and spatial coverage requirements (e.g., every 16 days while achieving global coverage)
- Many science applications require sub-cm level deformation measurements, but each individual SAR measurement is corrupted by up to several cm of atmospheric noise.
  - Multiple acquisitions need to be averaged together to reduce atmospheric artifacts

InSAR Constellation Advances Solid-Earth Science by Understanding Geophysical Hazards

CIRES Address NASA Science Goal: Understanding Extreme Events including Earthquakes and Volcanic Eruptions

Sub-centimeter surface deformation measurements with high temporal resolution will advance our knowledge of critical Earth science questions related to natural hazards and resource mining activities.

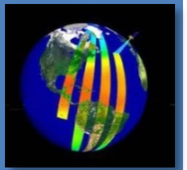
The Need for a Low-Cost Constellation of InSAR Satellites

Interferometric synthetic aperture radar (InSAR) is the only tool for measuring spatially dense deformation on a global scale.

Global spatial coverage is needed to capture the infrequent occurrence of natural and human-induced hazards.

Individual SAR satellites cannot provide the rapid revisit times required to characterize geophysical events.

On-orbit Demonstration Enables New Science Missions



A large constellation of InSAR CubeSats with spatial-temporal flexibility is needed to properly characterize time-variable processes and improve predictive geophysical models.

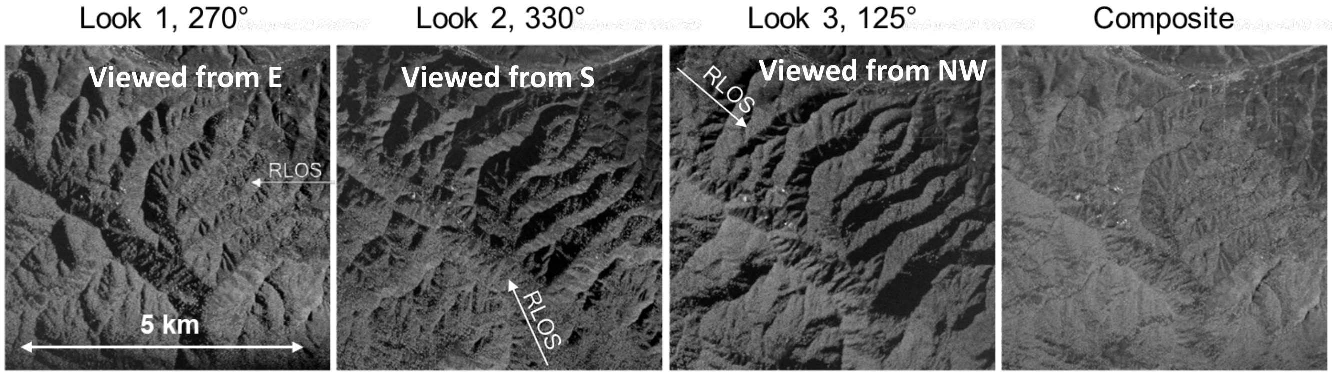
Prior to on-orbit deployment, CIRES is actively being tested on manned an unmanned aircraft, creating a useful and unique scientific research platform in its own right.

CIRES Air-based Instrument Demonstrations

- CarSAR – CIRES SAR from an SRI stake-bed truck
- SkySAR – CIRES SAR imagery from a commercial aircraft platform
- SRI UAVSAR – CIRES SAR Imagery from an SRI-built hobbyist group-II UAV
- SIERRA-B* – CIRES SAR / InSAR from NASA ARC Airborne Science Program UAS

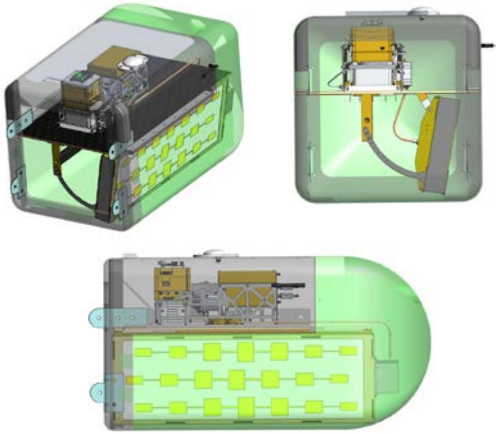
  * SIERRA-B CIRES first flight scheduled early-July 2019

<u>Air-based observations offer the versatility needed to best address some science needs</u>

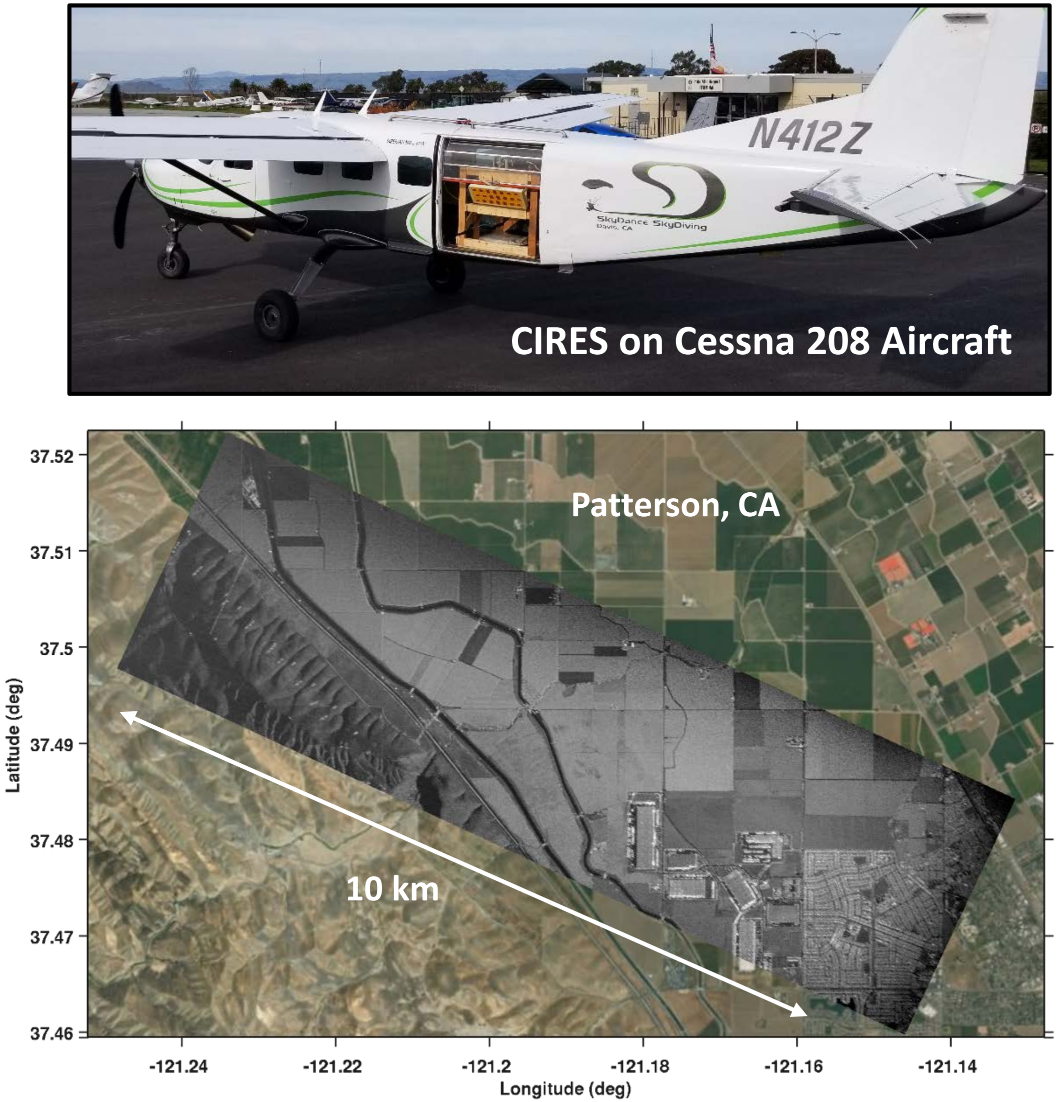


Three CIRES observations of the same scene from different angles show that a registered combination of these multiple views can provide near-uniform illumination coverage of mountainous areas.

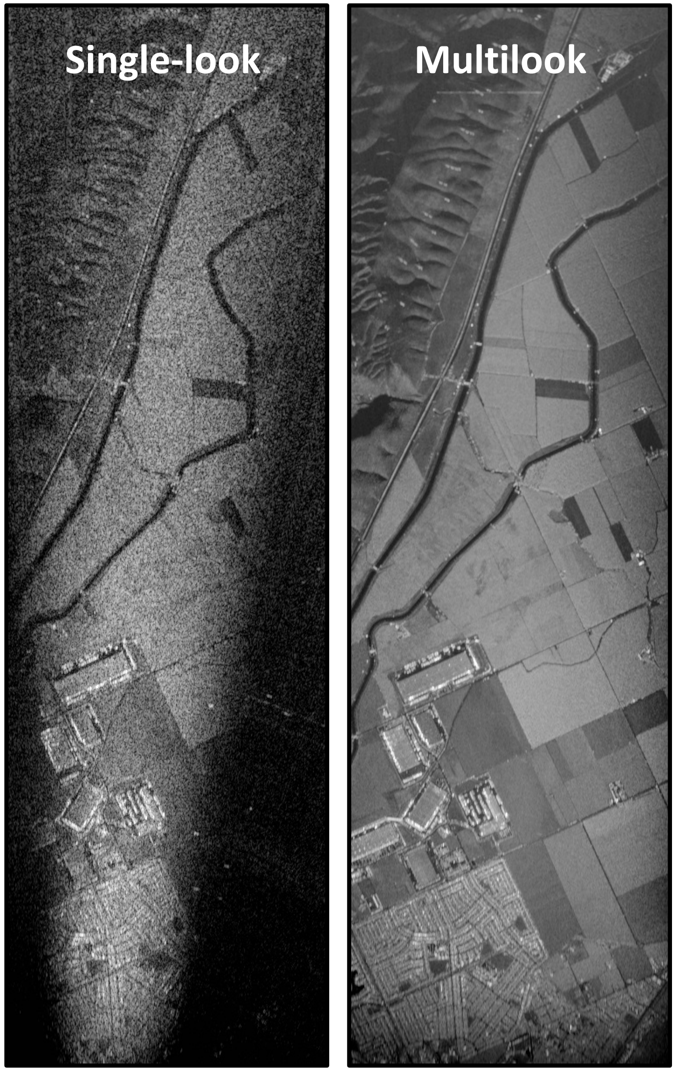
CIRES in SIERRA-B Custom Nose



CIRES SkySAR Airborne Demonstration



- 10x30 km image, 9000 ft altitude, 20 m resolution



A single-look CIRES image with 3x15 resolution cells exhibits significant noise compared with an image of the same resolution averaged over 77 looks. The SAR backprojection processing inherently registers the multiple looks to a common grid.

CIRES Science Relevancy Demonstration

July 2018: SRI IR&D-funded collection campaign to obtain scientific-relevant data for IIP processing validation

CIRES Kilauea Collection

Date: 3-5 July 2018, **Location**: Island of Hawai'i, Kilauea Volcano, **Frequency**: S-band, **Bandwidth**: 12.5 MHz

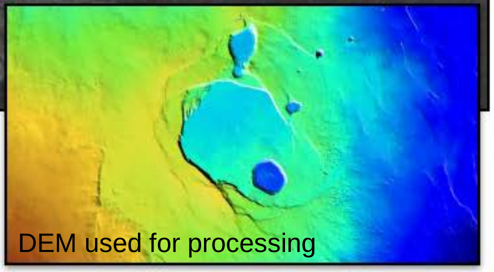
- Dates: 30 June - 5 July 2018
- Location: Kilauea summit and rift zone
- Science utility:
  InSAR measurements of active summit deformation can inform subsidence and conduit collapse, processes that drive hazardous explosive eruptions and thus have a direct impact on the surrounding community.

Accomplishments

- Collaborative mission planning:
  - Worked closely with USGS volcano hazard scientists to arrange and execute collections of scientific interest
- Collection campaign experience:
  - Initial integration of CIRES 12.5 MHz radar onto a Cessna 206 in approximately 6 hours
  - Final integration in approximately 1 hour
  - De-integration in 15 minutes
  - Five flights for test and mission collections
  - 15 collection passes on Kilauea summit
  - 1 collection at rift zone
- Instrument and processing validation
  - Backprojection imagery processed
  - Initial interferogram formed

Optical image from test plane

Cessna 206 platform

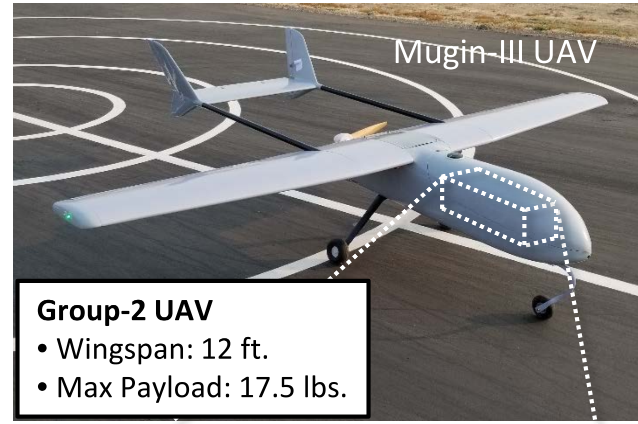


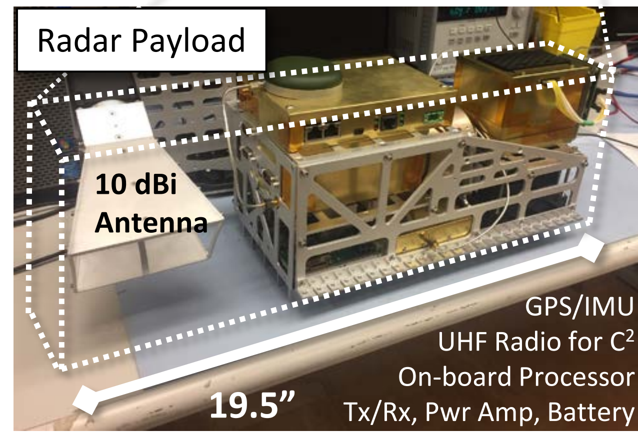
DEM used for processing

CIRES UAVSAR Demonstration

SRI IR&D to add second receive channel for GMTI

- COTS Mugin III UAV
  - Built/tested by SRI
- Upgrade Path
  - 200/500 MHz,
  - 2nd Rx Channel



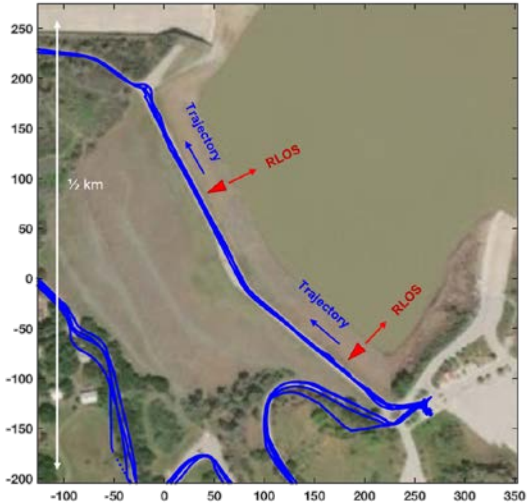


Frequency	S-band
Bandwidth	40 MHz (upgrade: 200 MHz)
Resolution	6×6 m (upgrade: 1×1 m)
Weight	16 lbs (includes 3 lbs. battery)
Power	60 W (ave) 600 W (peak)
Endurance	1.5 hrs (depends on battery)

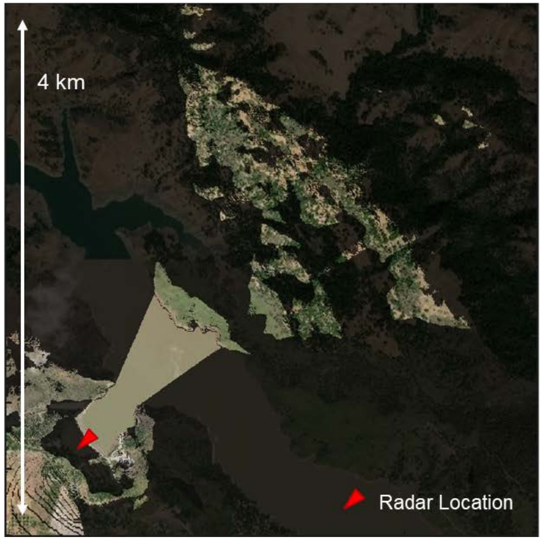
CIRES InSAR Capabilities evaluated from CarSAR

March 4, 2019: InSAR Verification at Anderson Reservoir, CA

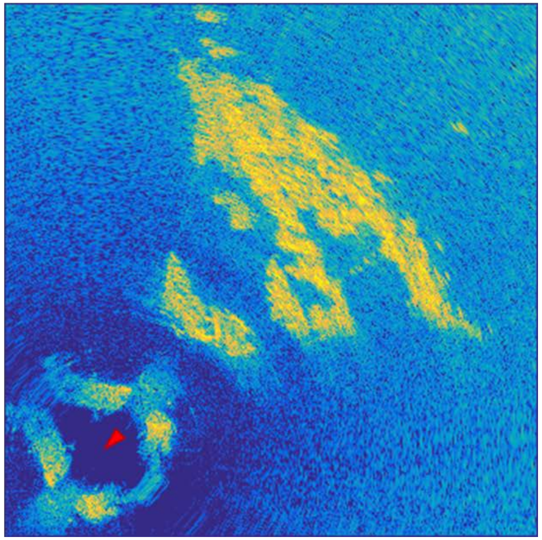
- CarSAR testing enables early diagnosis of interferometric instrument calibration and operation
- Anderson dam provides straight and level trajectory for CarSAR
- Natural terrain on far side of reservoir provides good test scene for InSAR



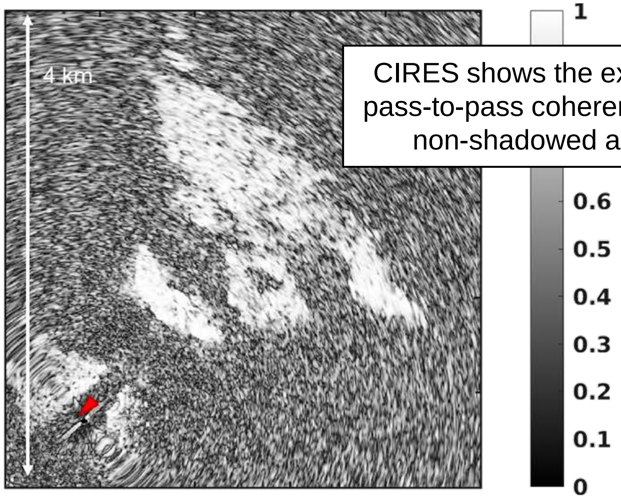
Test Site (with shadowing)



Radar Imagery

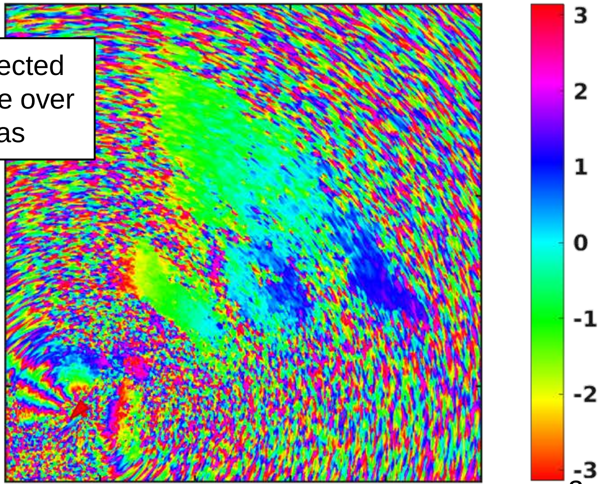


Coherence Magnitude



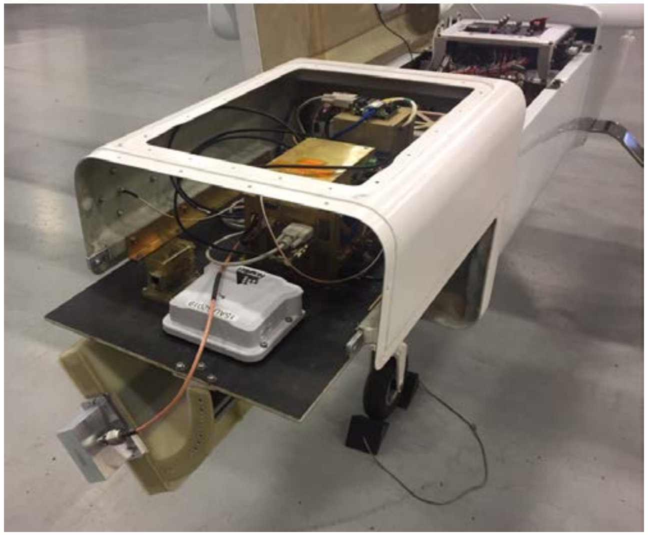
CIRES shows the expected pass-to-pass coherence over non-shadowed areas

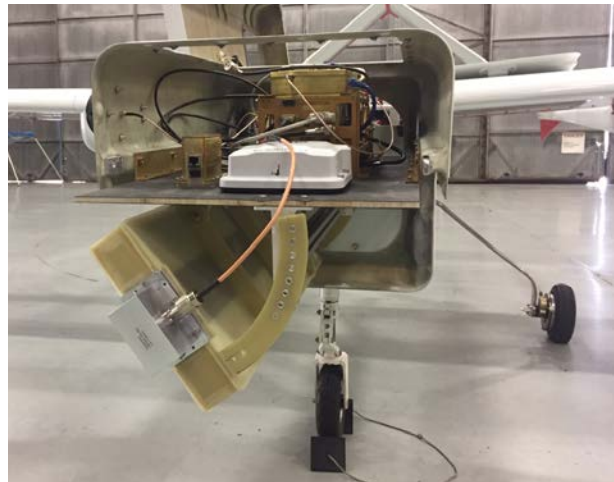
Coherence Phase



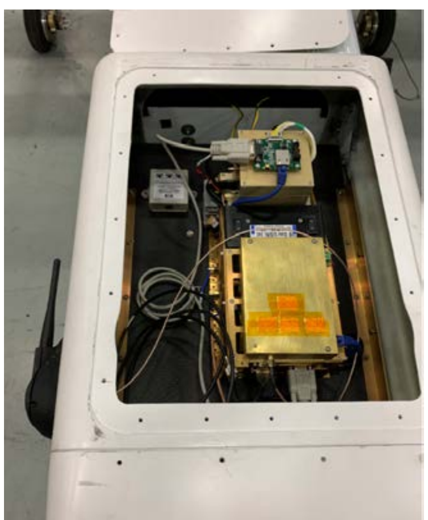
Next up: CIRES InSAR validation from SIERRA-B

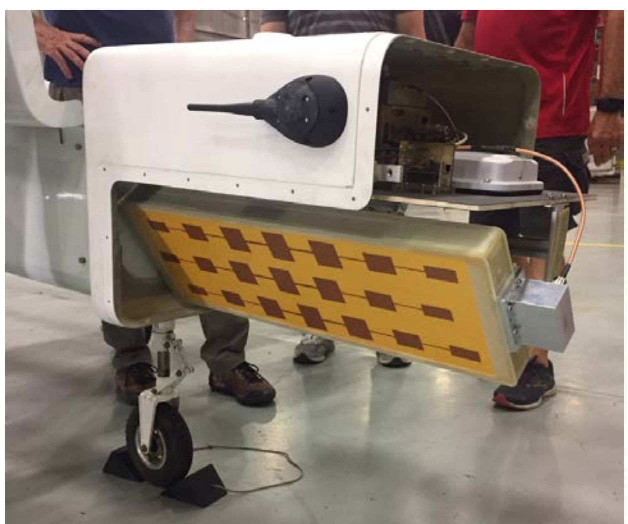
CIRES Integration with SIERRA-B occured June 11, 2019





Calibration Target





Summary

- SRI-CIRES designed and developed for limited-resource environments (e.g., CubeSats, UAVs)
- CIRES instrument tested and verified on moving ground vehicle and airborne platforms demonstrating InSAR coherence
- CIRES instrument integrated with SIERRA-B UAV June 11, 2019
- UAV-based science relevancy demonstrations to be conducted in 2019 on NASA ESTO IIP funds
- CIRES on-orbit antenna in development

QUESTIONS?