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

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PI: Dr. Lauren Wye (SRI)
PM: Simon Lee (SRI)

SRI Collaborators: Mark Schutzer, Leon Tao, Dave Watt, Jacob Cooper, Dean Jordan, Tyson Shimomi, Sam Phan, Mike Huff

ESTO IIP Team members

Physical Sciences Incorporated, NASA Airborne Sciences Program, Stanford University, JPL
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
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**

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

Air-based observations offer the versatility needed to best address some science needs

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.
CIRENS SkySAR Airborne Demonstration

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.

- 10x30 km image, 9000 ft altitude, 20 m resolution
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 8 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  
Altitude: 12.5 kft  
Cessna 206 platform  
DEM used for processing
**CIRES UAVSAR**

SRI IR&D to add second receive channel for GMTI

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**Demonstration**

**Group-2 UAV**
- Wingspan: 12 ft.
- Max Payload: 17.5 lbs.

**Radar Payload**
- GPS/IMU
- UHF Radio for C2
- On-board Processor
  - Tx/Rx, Pwr Amp, Battery

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**UAV Airfield in Livermore, CA**

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

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<thead>
<tr>
<th>Frequency</th>
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<tbody>
<tr>
<td>Bandwidth</td>
<td>40 MHz (upgrade: 200 MHz)</td>
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<tr>
<td>Resolution</td>
<td>6\times 6 m (upgrade: 1\times 1 m)</td>
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<tr>
<td>Weight</td>
<td>16 lbs (includes 3 lbs. battery)</td>
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<tr>
<td>Power</td>
<td>60 W (ave) 600 W (peak)</td>
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<tr>
<td>Endurance</td>
<td>1.5 hrs (depends on battery)</td>
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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.

CIRES InSAR Capabilities evaluated from CarSAR
March 4, 2019: InSAR Verification at Anderson Reservoir, CA

Test Site (with shadowing)

Radar Imagery

Coherence Magnitude

Coherence Phase

CIRES shows the expected pass-to-pass coherence over non-shadowed areas.
Next up: CIRES InSAR validation from SIERRA-B

CIRES Integration with SIERRA-B occurred June 11, 2019
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