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

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SRI International
Earth Science Need for a Constellation of InSAR Sensors

- Time-variable geophysical processes require more frequent monitoring than a single 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.
CIRES: CubeSat Imaging Radar for Earth Science

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

CIRES S-band Radar Payload (17 m range res now, 5 m res in mid-2018)

**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

**PA Module:** Includes internal power regulation, power driver stages and RF power amplification. (2.9-3.1 GHz)

**Custom Phased Array 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.)

**Designed to rapidly integrate with 16U bus and deployable antenna**

- SRI SAR Electronics (1.25U form factor)
- ~6.5 m² Deployable Membrane Antenna
- Ka-band downlink (320+ Mbps)
- Long 16U bus
CIRES Key Technologies and Demonstrations

- **Key Technologies**
  - Compact S-band SAR instrument
  - On-Orbit Deployable Antenna (~6.5 m², Gain: >36 dB including losses)

- **Instrument Demonstrations**
  - CIRES CarSAR – SAR from a ground vehicle platform*
  - CIRES SkySAR – SAR from a commercial aircraft platform**

Example CIRES Image
(12.5 MHz bandwidth)

Patterson, CA

10x30 km image, 9000 ft altitude, 20 m resolution, multiple looks, non-coherently averaged

* CarSAR test platform developed on NASA ESTO IIP funds
** Aircraft collections funded by SRI International
CIRES Technology Progression

**ESTO Advanced Component Technology (ACT) Funds**

- **Radar Hardware Subsystem**
  - TRL-2 → TRL-5

**2015**

- **Esto Instrument Incubator Program (IIP) Funds**
  - Deployable Membrane Antenna (TRL-4 → TRL-6)
  - Radar Hardware + Software Integrated Instrument (TRL-4 → TRL-6)
  - UAV Instrument Development and Science Demo

* ESTO PM Parminder Ghuman

**2020**

- **ESTO In-Space Validation of Earth Science Technologies (InVEST) Funds (Proposed)**
  - On-Orbit Instrument Validation

- **SMD Earth System Science Pathfinder (ESSP) Earth Venture Suborbital (EVS) Funds (Proposed)**

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**CIRES SAR Electronics Subsystem (TRL-5)**

- ESTO ACT-funded

**CIRES SAR Imaging Software (TRL-4)**

- SRI-funded

**High-Gain Deployable Membrane Antenna Subsystem (TRL-4)**

- SBIR-funded; to be revised, developed, and tested

Physical Sciences Inc.
CIRES to be tested on a UAV platform with ESTO IIP funds

SIERRA-B UAV platform provided by NASA Airborne Sciences Program
CIRES CarSAR Demonstration Overview

- Allows for flight configuration to be tested on ground
- Easily deployed to locations local to SRI in Menlo Park, CA
- Locations:
  - Marshlands Road (20 min.)
  - Mt. Hamilton (1 hr)
  - Anderson Reservoir (1 hr)
CIRES CarSAR Reveals Instrument Time Delays

- Scene
  - Fremont, CA Marshlands
  - Convenient location to SRI
  - Enables quick assessment of sensor calibration

Moving tower responses indicate time delay

After time delay correction

View in presentation mode for animation
CIRES SkySAR Airborne Demonstration*

CIRES on Cessna 208 Aircraft

Patterson, CA

Single-look

Multilook

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

* Aircraft collections funded by SRI International
Additional CIRES Airborne Imagery*

* Aircraft collections funded by SRI International
• Two passes with CarSAR
• Site: Anderson Reservoir overlooking Morgan Hill valley (CA)
• Date: 1 June 2018, 12:36 pm

• CarSAR testing enables early diagnosis of interferometric instrument calibration and subsystem operation
  • Time-delay calibration improvements in progress
  • GPS sub-system refinements for InSAR operation in progress

Noisy result due to imperfect calibration and GPS operation
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 in early 2018; interferometric calibration in progress.

• CIRES instrument to be integrated with SIERRA-B UAV late-2018

• UAV-based science relevancy demonstrations to be conducted in 2019 on NASA ESTO IIP funds

• CIRES on-orbit antenna in development; sub-scale version ready for 2019 on-orbit testing and demonstrations
QUESTIONS?