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Analyzing new test data from CIRES: CubeSat Imaging Radar for Earth Science*

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* The CIRES development and test effort, funded by ESTO ACT and IIP grants, was executed by SRI International. Patrick and Lauren led the CIRES effort to completion in January 2020 while at SRI. Aloft Research has analyzed the publicly available CIRES data to further investigate the potential of compact radar payloads for precision InSAR measurements, with a particular interest in stratospheric-based InSAR platforms and operations.

Earth Science Need for Persistent Interferometric SAR (InSAR)

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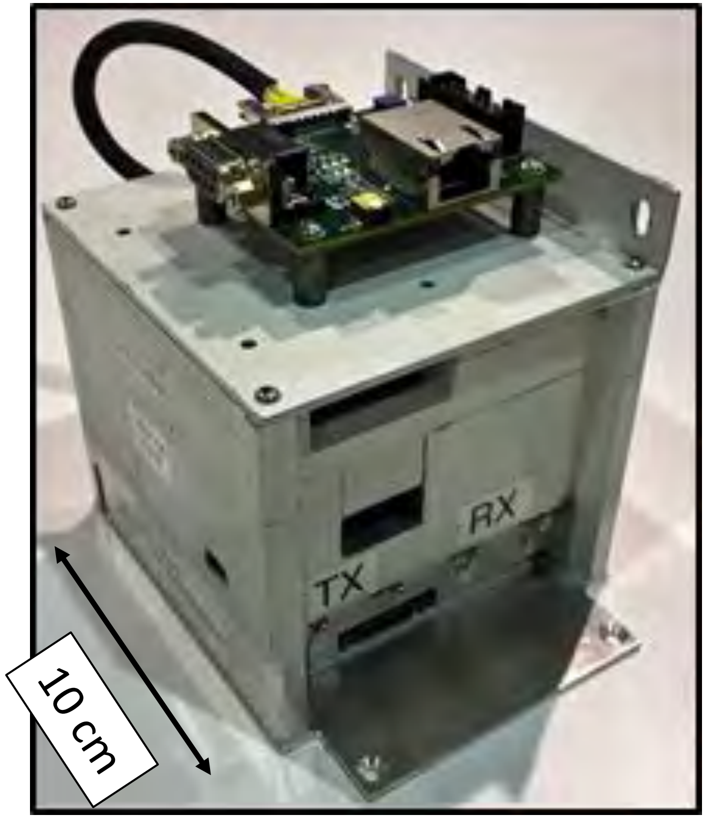
- **InSAR**: uses repeat passes to measure small surface changes using wide area radar interferometric imagery
- Precise (sub-cm) and frequent (daily/hourly) surface topography and deformation measurements improve modeling and forecasting of geophysical phenomena
- High-cost spaceborne platform revisit times are typically weeks

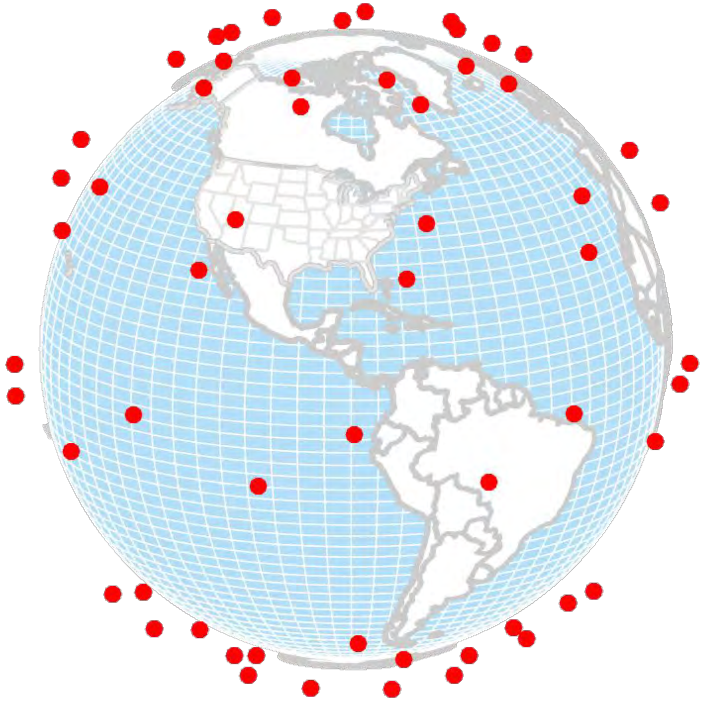
Compact InSAR Unit Enables Proliferated Sensing for Persistent Access

CIRES Sensor*



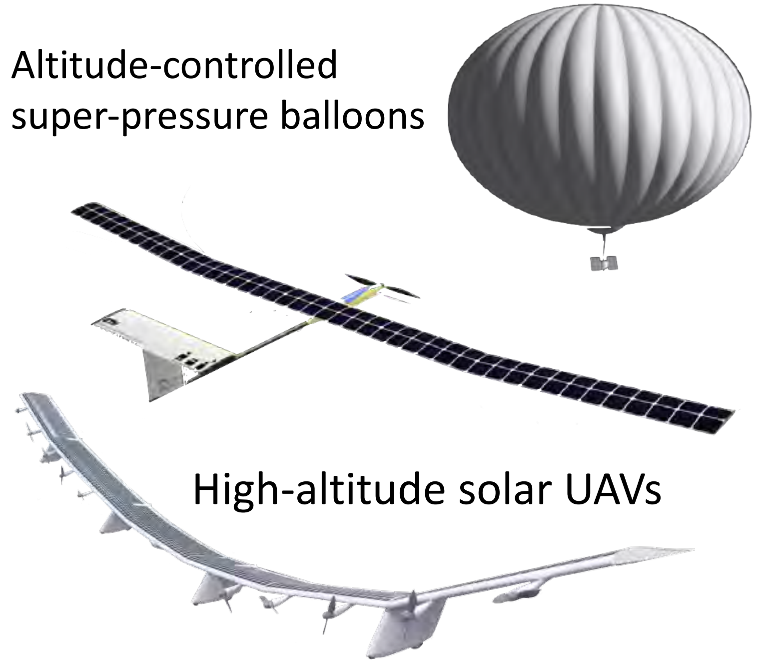
- Compact and low-power

CubeSat Constellation



- Global access, daily revisit
- Relatively high system cost

High Altitude, Long Endurance Platforms

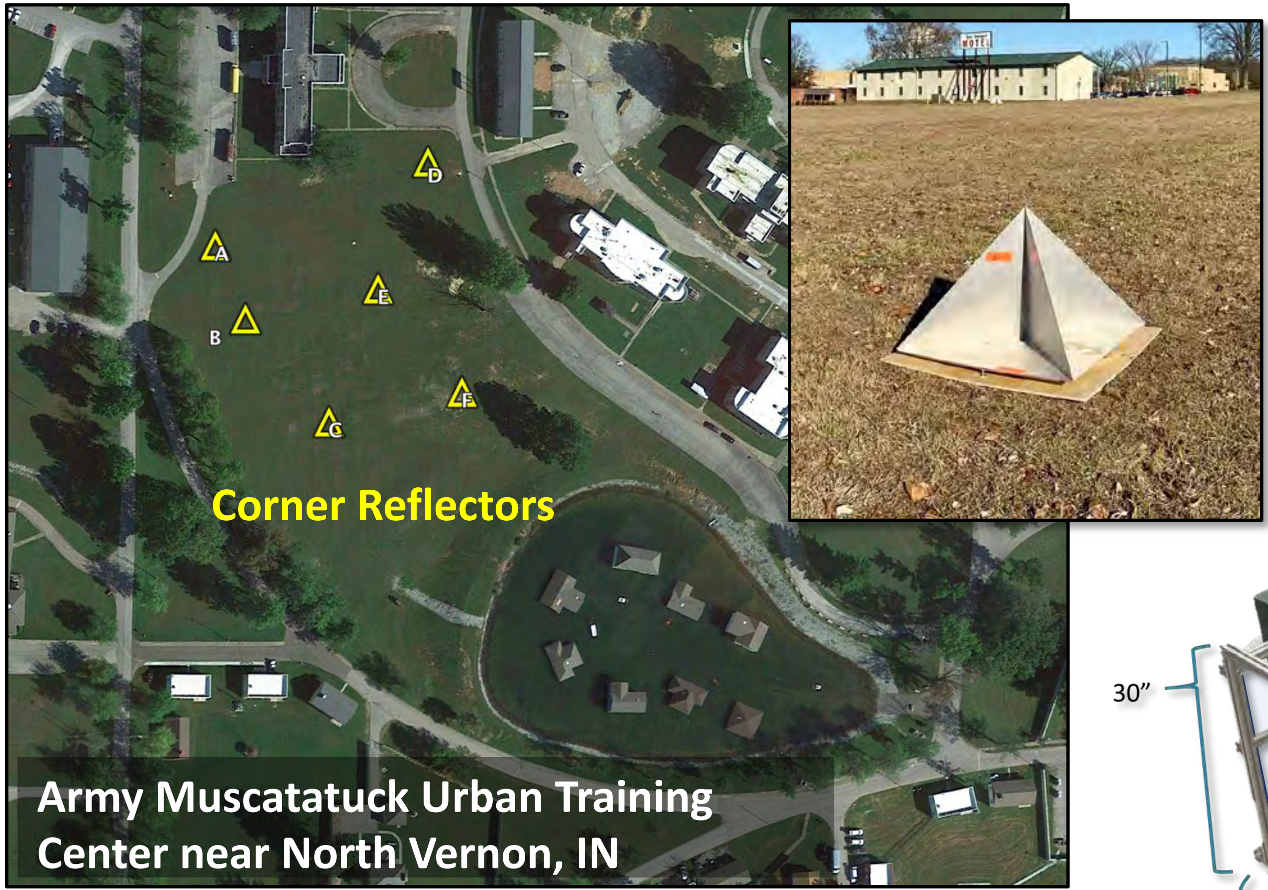


- Continuous monitoring
- Low system cost potential

*CIRES developed at SRI International

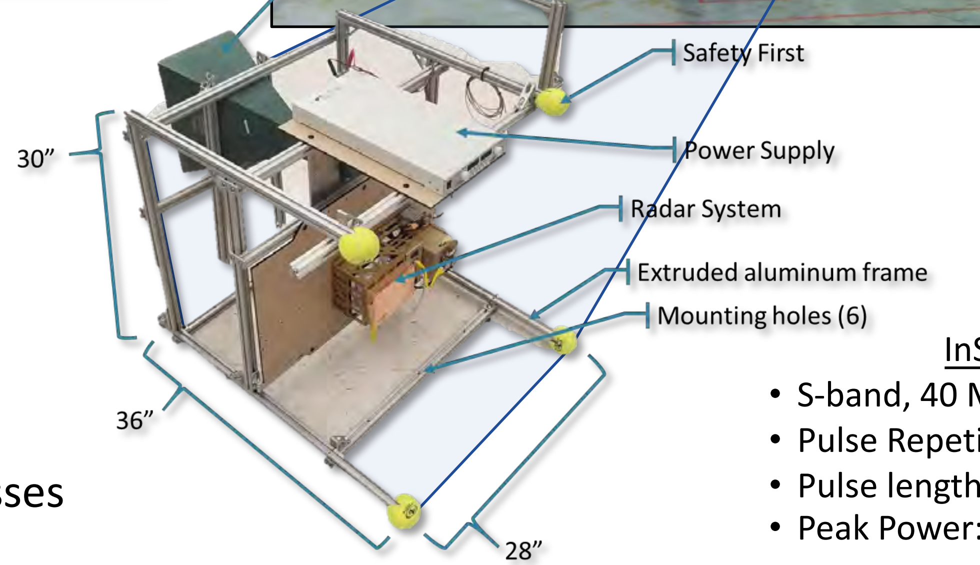
CIRES Final Test and Validation Flight Campaign*

- Test Site: Muscatatuck Urban Training Center



- Corner reflector array provides precise ground truth
- Reflectors adjusted by 5, 10, and 30 mm between passes

- Test Aircraft and CIRES Radar System



Flight Campaign

- 3 Days
- 5 Flights
- 3 Crew + Pilot
- 100+ passes

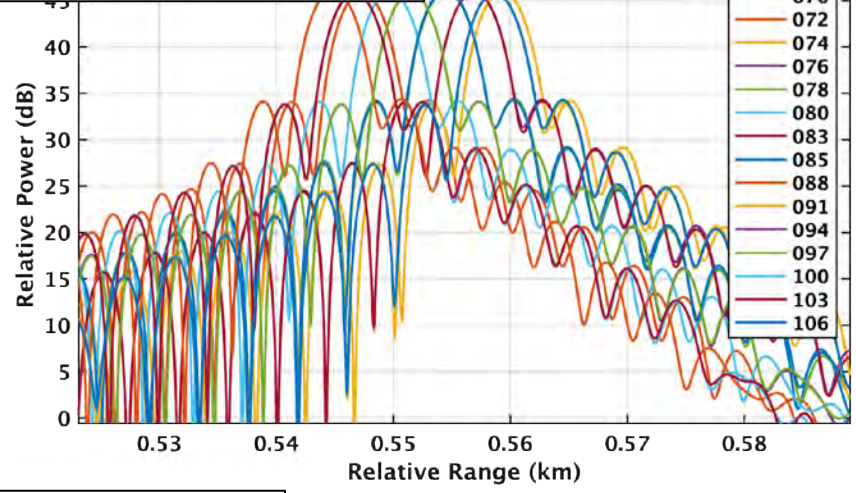
InSAR Parameters

- S-band, 40 MHz bandwidth
- Pulse Repetition Freq: 4 kHz
- Pulse length: 12 µsec
- Peak Power: 600 W

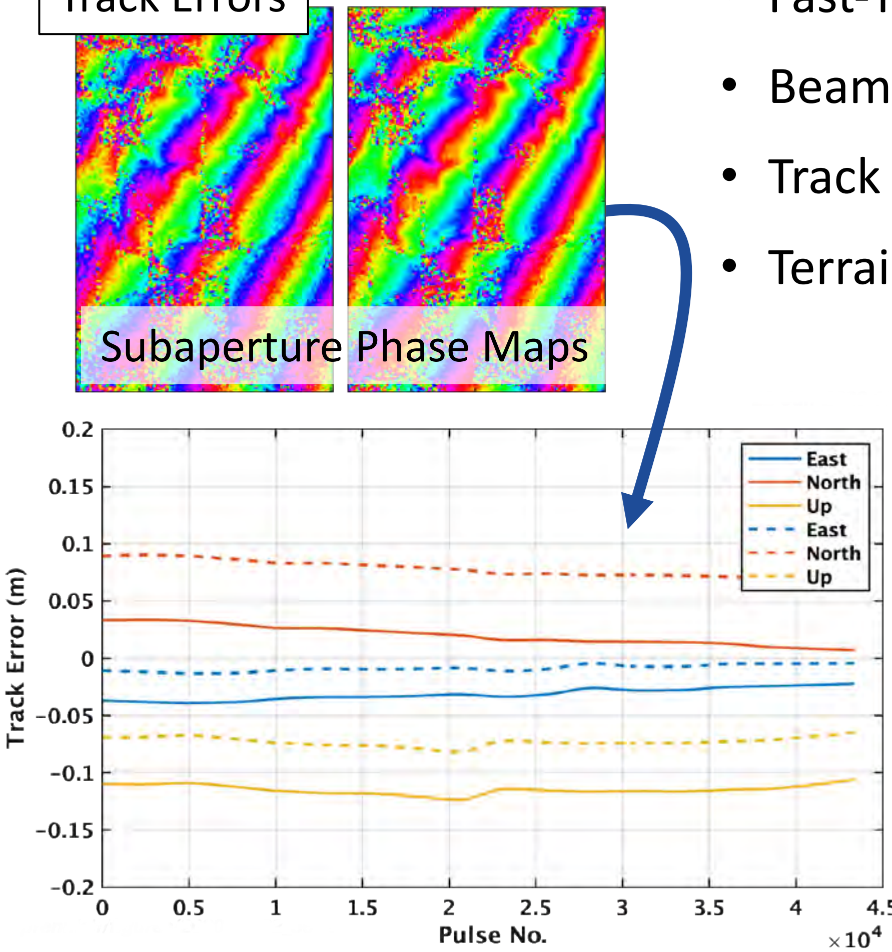
*Test campaign conducted by SRI International

Critical Radar System Calibrations*

Fast-time Calibration

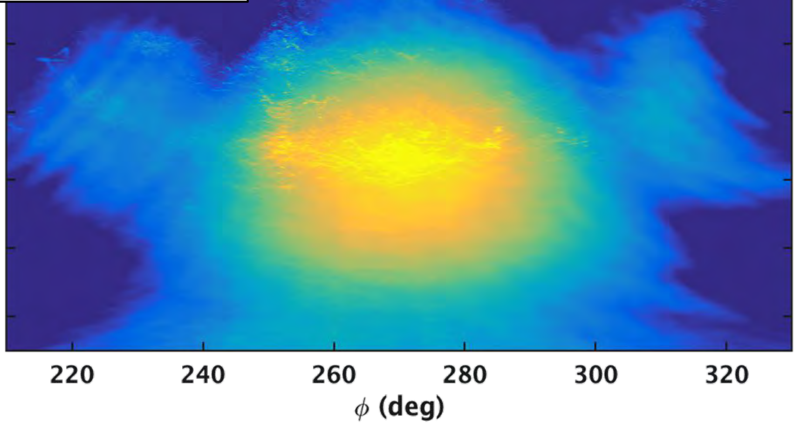


Track Errors

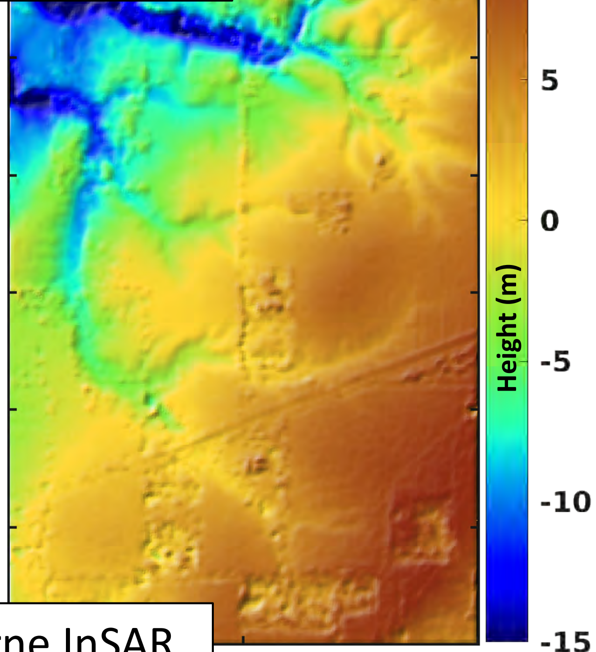


- Fast-Time: 10 pico-second alignment
- Beam Pattern: 1-dB amplitude
- Track Errors: mm-level estimation
- Terrain Errors: decimeter estimation

Beam Pattern



Terrain Errors



- Aloft's algorithms estimate and precisely account for system errors, enabling precision airborne InSAR

*Analysis conducted by Aloft Research

Selected Surface Deformation Measurement Results

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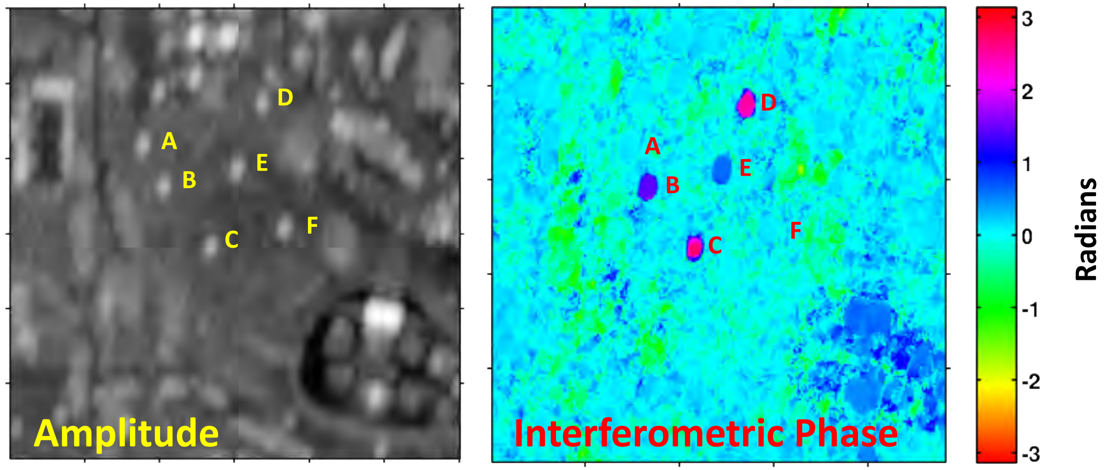
- CIRES instrument achieves mm-level height change accuracies

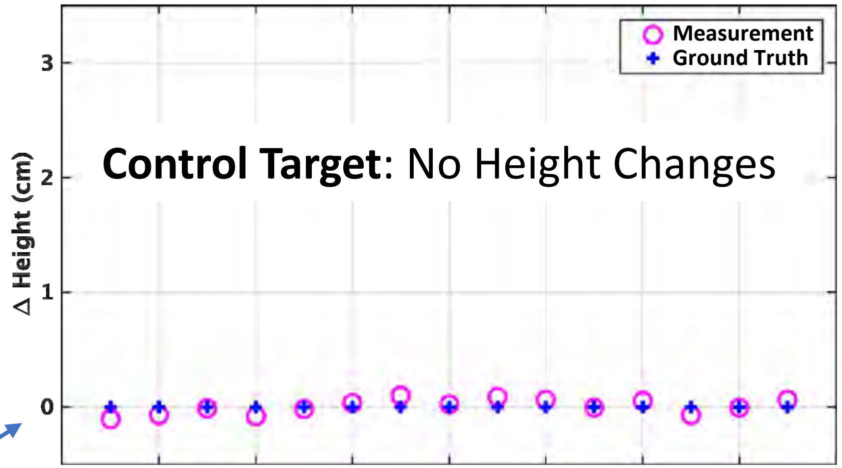
Example Image and Interferogram

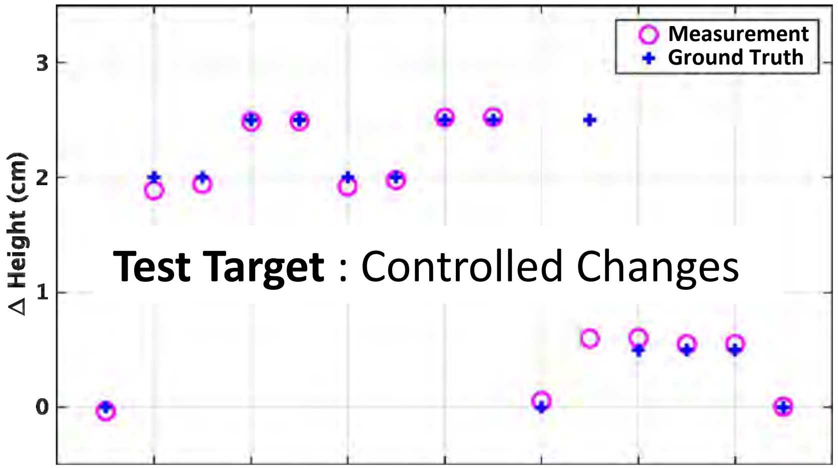


Results Summary

Reflector	Mean Error (μ)	Std Error (1-σ)
A	0.0 mm	0.6 mm
B	2.6 mm	2.2 mm
C	-2.3 mm	1.6 mm
D	-1.5 mm	2.0 mm
E	0.0 mm	0.6 mm
F	-0.7 mm	1.1 mm

Measurements: 15 InSAR Pairs





- First demonstration of mm-level InSAR from an extremely compact instrument

Benefits of Low-Cost Proliferated InSAR Sensing to Earth Science

- Continuous monitoring captures temporal evolution
  - Earthquake swarms, eruption events, landslide precursors, shifting glaciers, etc.
- Multiple observation geometries provide full 3-D deformation
  - Important for landslide and earthquake modeling, magmatic shifting
- Complimentary to the large satellite systems (e.g., NISAR)
  - Validates observations, provides dense temporal sampling
- Future Development at Aloft†: HALE-InSAR
  - **Potential**: continuous and low-cost earth sensing
  - **Challenges**: relatively low velocity and flight path control
  - **Solutions**: novel algorithms for on-board calibration and novel lighter-than-air station keeping vehicles