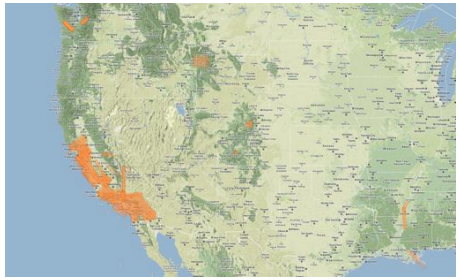
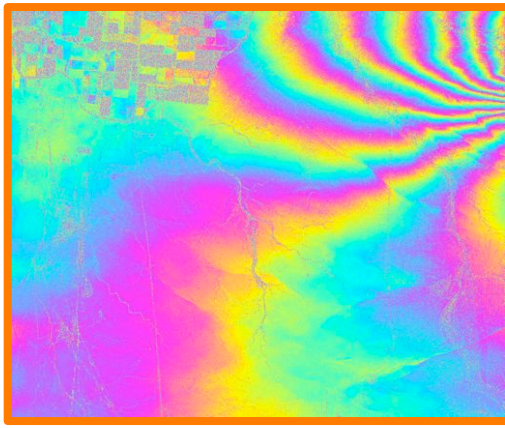
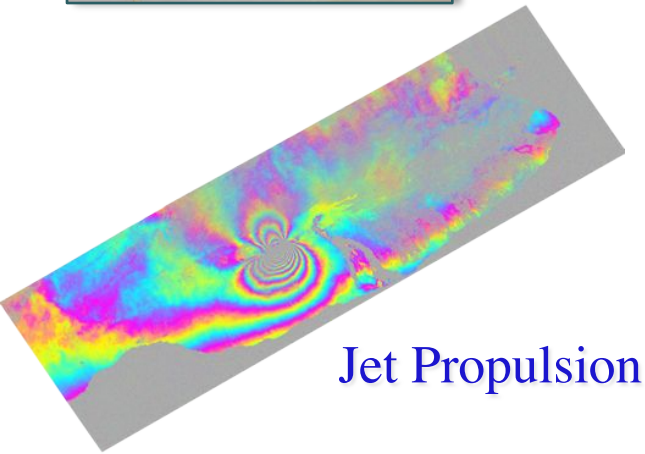


Overview of the NASA/JPL UAVSAR and Porting to the Global Hawk





by

Scott Hensley and Yunling Lou

Jet Propulsion Laboratory, California Institute of Technology

UAS Payloads Conference

Washington DC

June 19, 2012

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UAVSAR Overview

UAVSAR Overview

Electronics bay

Antenna bay with P-band antenna

- UAVSAR was developed under NASA ESTO funding beginning in 2004 as a PI driven development to support repeat-pass radar interferometry and was designed to also serve as a technology testbed.
- New instrument is compact, modular, and adaptable to support multiple airborne platforms and frequency upgrades.

Current Capabilities

- L-band repeat-pass polarimetric interferometry enabled by electronically scanned antenna and precision autopilot that can repeat tracks to within a 5 m tube.
- Applications include surface deformation for solid earth, cryospheric studies, vegetation mapping and land use classification, archeological research, soil moisture mapping, geology and cold land processes

Future Capabilities Under Development

- L-band single-pass polarimetric interferometry for topographic mapping and vegetation structure study
- P-band polarimetry for subsurface soil moisture and forest biomass measurements
- Ka-band single pass interferometry for arctic ice study

UAVSAR: Multi-Frequency Reconfigurable Imaging Radar

NASA Earth Science Division's airborne imaging radar testbed is used to develop, validate, and improve new radar technologies and algorithms for modeling geophysical phenomena for future Earth-observing satellite missions including SMAP, DESDynI, and SWOT.

	2004 - 2008	2009 - 2012	2011 - 2012	2009, 2011 - 2012
	ESTO IIP, R&A	ESTO ARRA	EV-1 AirMOSS	IPY, ESTO AITT GLISTEN-A
Technology	2 complete L-band radars; G-III precision auto-pilot	Repackage L-band radar in GH payload bay; build a third pod	Modify new pod and build P-band antenna and RF front-end electronics; modify JSC G-III for AirMOSS missions	Build Ka-band antennas and RF front-end electronics
Science	L-band repeat-pass InSAR for surface deformation, vegetation structure, soil moisture mapping, land use classification, cryospheric studies, and archaeological research	L-band polarimetry for land use and vegetation classification, and soil moisture mapping	P-band polarimetry for measuring subsurface and sub-canopy soil moisture	Ka-band single-pass InSAR for observing glacier and land ice topography

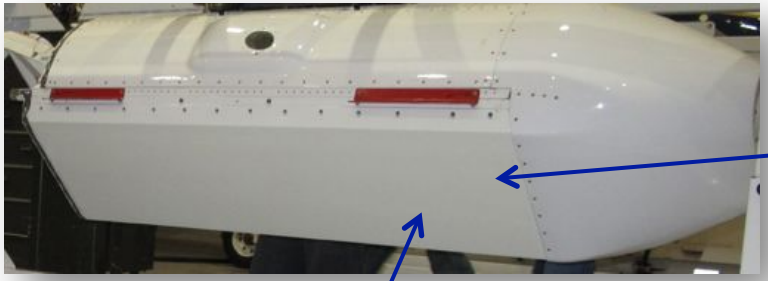
UAVSAR: Multi-Frequency Reconfigurable Imaging Radar

Backend electronics common to all radar frequencies

Antenna bay to house frequency specific antenna

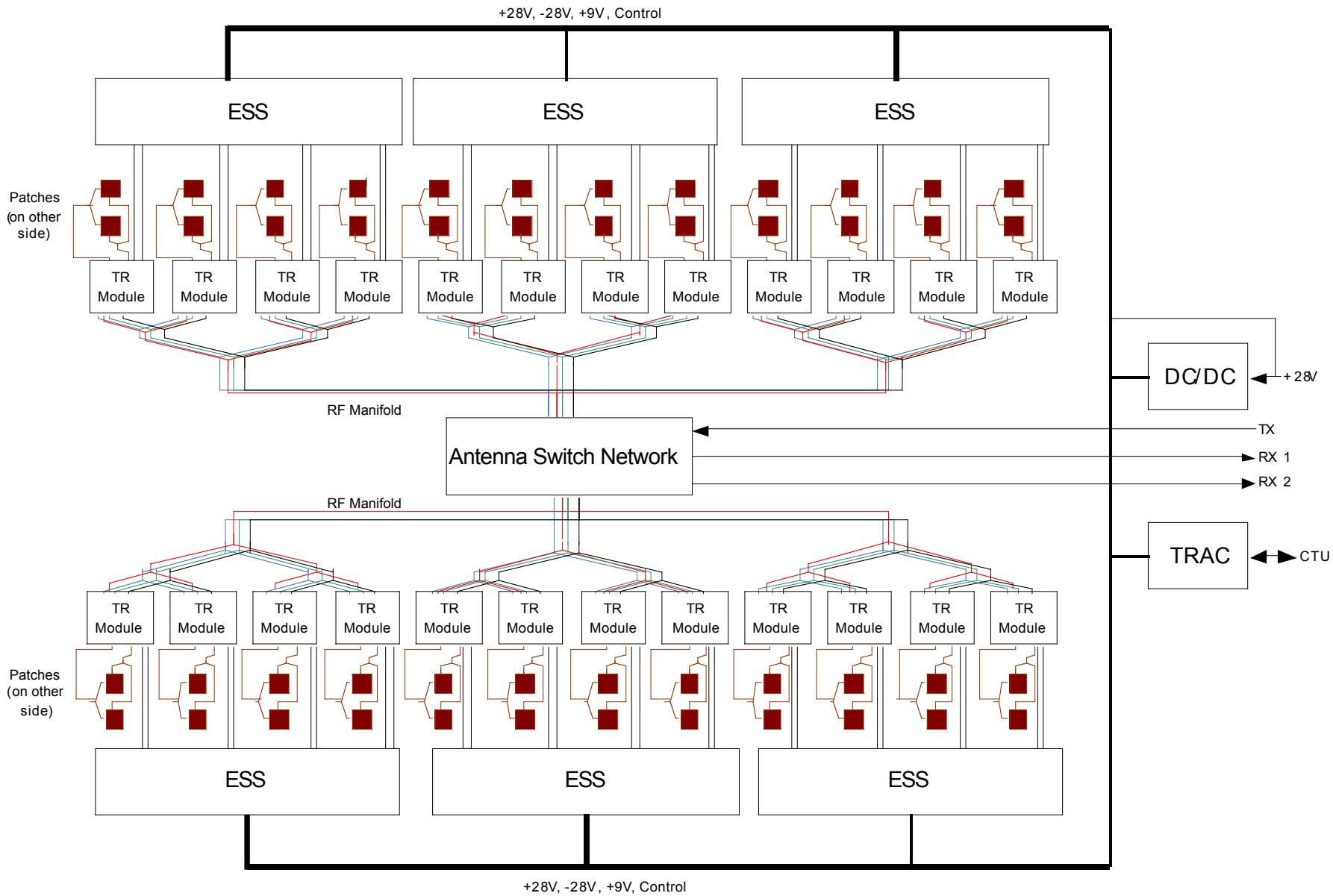
Original L-band Configuration:
Science demonstration since Oct, 2008

L-band Transmit/Receive Modules are mounted to the backside of the antenna baseplate



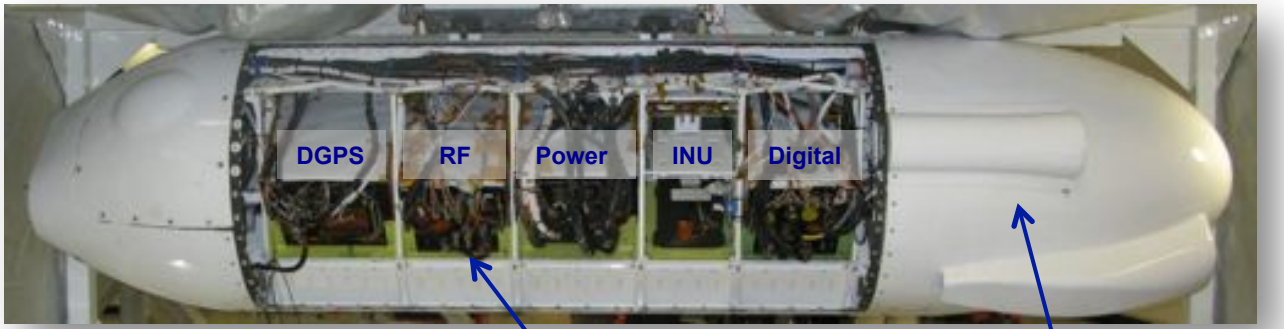
L-band antenna behind radome

Antenna Block Diagram



UAVSAR in P-band Configuration

Backend electronics common to all radar frequencies

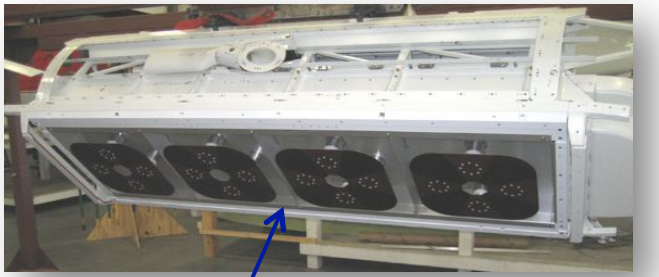


Antenna bay to house frequency specific antenna

Add electronics for frequency up/down conversion between L-band and P-band

P-band high power amplifier in the nosecone

EV-1 AirMOSS Configuration:
P-band flight testing in July 2012

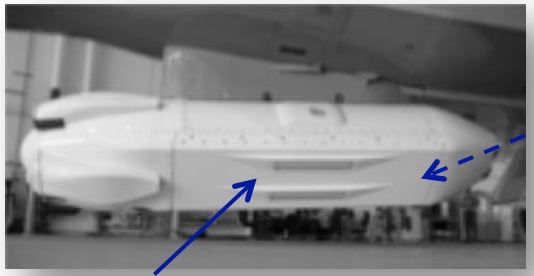


P-band antenna

UAVSAR in Ka-band Configuration

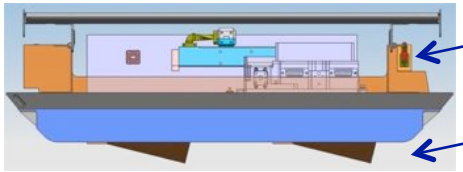
Backend electronics common to all radar frequencies

Antenna bay to house frequency specific antenna



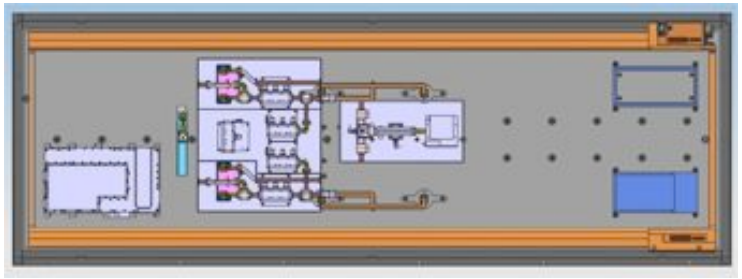
Ka-band antennas

AITT GLISTIN-A Configuration:
Ka-band flight testing in July 2012



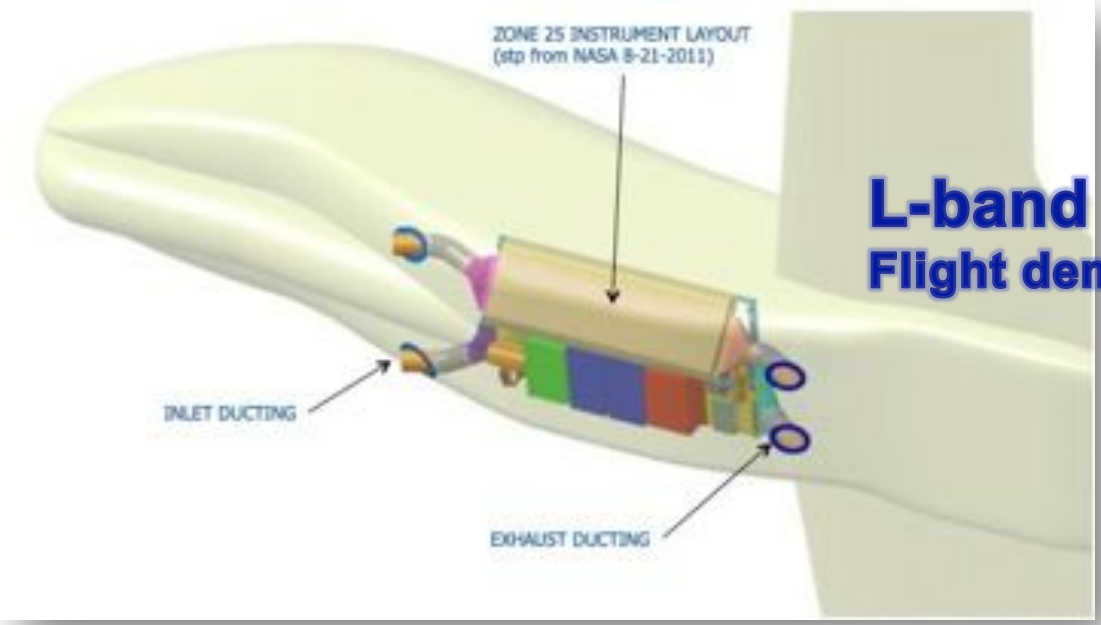
RF Electronics

Ka-band antennas protruding from L-band radome



Ka-band high power amplifier and RF electronics are mounted to the backside of the antenna baseplate

UAVSAR: Global Hawk Payload Bay 25 Configuration



L-band GH Configuration:
Flight demonstration in November 2012

L-band antenna frame

Radar backend electronics are mounted upside down to the custom pallet

UAVSAR End-to-End Flow

UAVSAR end-to-end operation involves multiple organizations

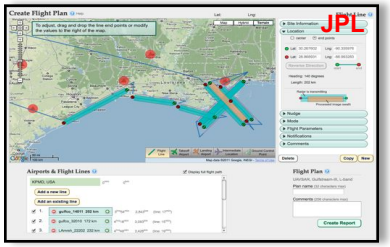
Submit flight request at Ames' online SOFRS

ARC
Airborne Science Program Science Operations Flight Request System (SOFRS)

ESD Program Manager

Approve flight request

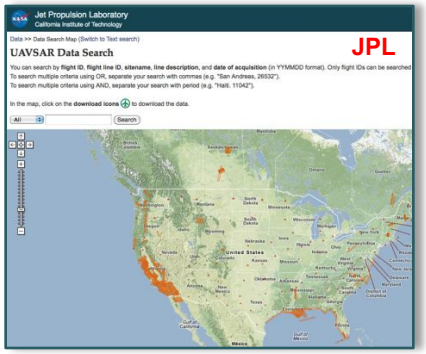
Plan flight lines using JPL's online Flight Planning System

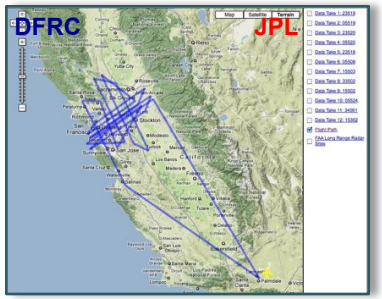


Principal Investigator

Archive processed data at ASF

Processed data are available through JPL's UAVSAR Data Search portal and ASF's SAR Data Center portal





Develop flight plan and schedule flight

Execute flight plan to acquire data

Download radar data to Ground Data System for processing

Perform SAR processing at Ames' Columbia supercomputing facility

Missions Summary

UAVSAR Data Acquisition Overview

UAVSAR began engineering flights in October 2007 and then transitioned from an ESTO managed development to R&A-funded science demonstration in October 2008 with operational flights commencing in February 2009 onboard the Dryden Gulfstream-III aircraft.

- **Science Demonstration Period**
  - Earthquakes, volcanoes, oil pumping, and other deformations
  - Vegetation classification and structure study
  - Ice and glacier monitoring
  - Soil moisture measurements
  - Oceanographic study
- **Technology Demonstration**
  - L-band 150 W T/R modules with pulse-by-pulse beam-steering capability
  - Real-time differential DGPS solution at better than 10 cm accuracy
  - Real-time DGPS-aided platform precision autopilot to ~ 5 m accuracy
  - FPGA-based onboard processor for real-time SAR image formation
  - SweepSAR demonstration with UAVSAR's radar controller and backend electronics
- **Applications**
  - Long term monitoring: levee break, earthquake fault movement, archaeology study
  - Event response: Haiti and Mexicali earthquakes, Mississippi River flooding, Gulf Coast oil spill
- **Mission support**
  - SMAP, DESDynI, SWOT (Ka-band demo), AirMOSS (P-band modification)

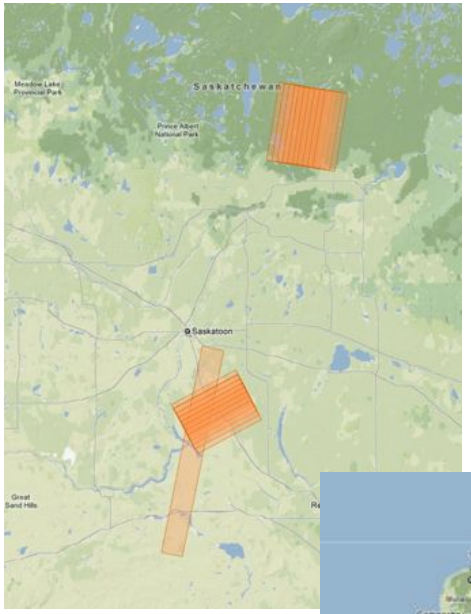
UAVSAR Data Acquisition Statistics

	FY 2009	FY 2010	FY 2011
Flights	65	84	86
Flight Hours	350	447	396
Flight Lines	649	925	735
Raw Data Volume (GB)	18,731	22,811	19,597
Flight Requests	23	30	27

- Major campaigns:
  - San Andreas Fault monitoring: semi-annual observations
  - Aleutians and Cascades, Hawaii, and Central America volcano monitoring deployments: annual observations
  - Greenland/Iceland deployment: study glaciers and ice sheets and demonstrate Ka-band radar for ice topography
  - Can-Ex-SM10: 3-week deployment to Saskatoon in preparation for SMAP mission
  - East Coast and Costa Rica terrestrial ecology campaigns: study DESDynI mission design
  - Hispaniola deployment: monitor post-seismic events (Feb. and Jun. 2010, Jun. 2011)
  - Gulf Coast Deployment: annual observations of deformation in New Orleans, coastal wetlands recovery from Deepwater Horizon oil spill
  - Sacramento levee monitoring: monthly observations
- Countries visited: Canada, Haiti, Dominican Republic, Costa Rica, Panama, Guatemala, Honduras, Nicaragua, El Salvador, Mexico, Iceland, Denmark (Greenland), USA

Foreign Campaigns

Canada
(17 days)

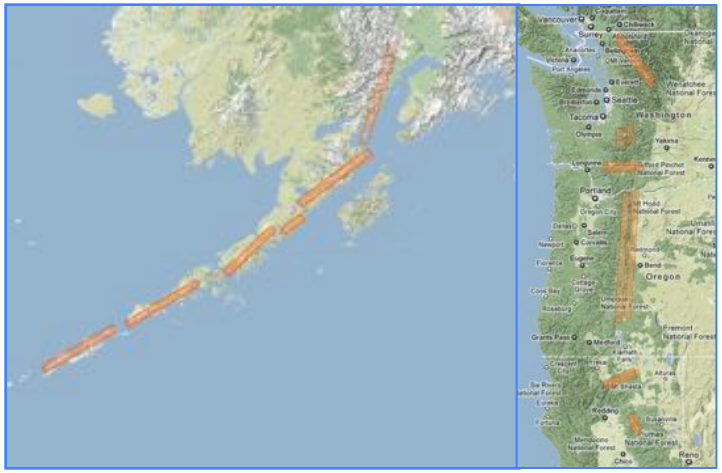


Greenland & Iceland
(32 days)

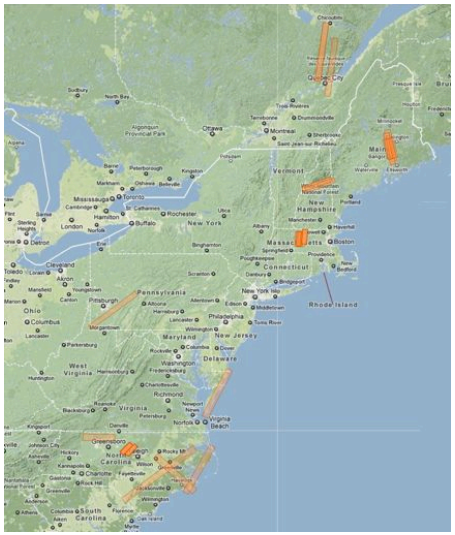
Central America & Hispaniola
(22 days)

US Campaigns

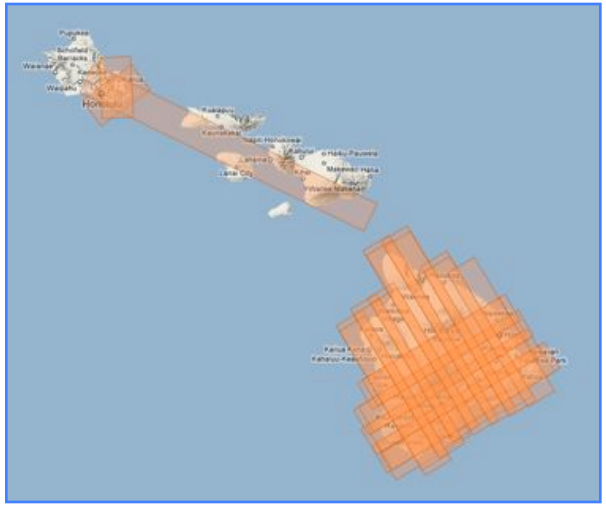
Aleutians and Cascades
(4 days)



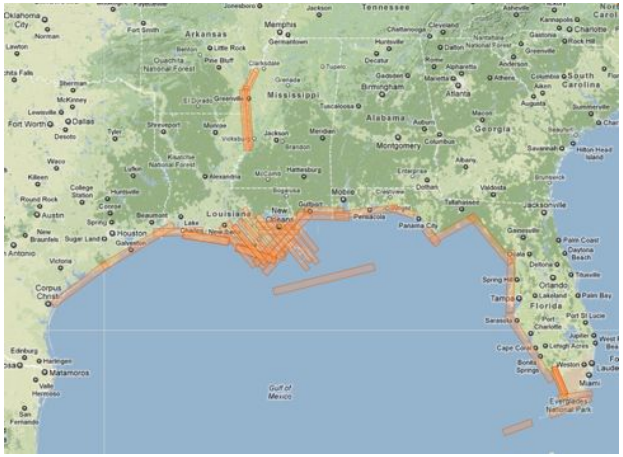
East Coast
(14 days)



Hawaii
(14 days)



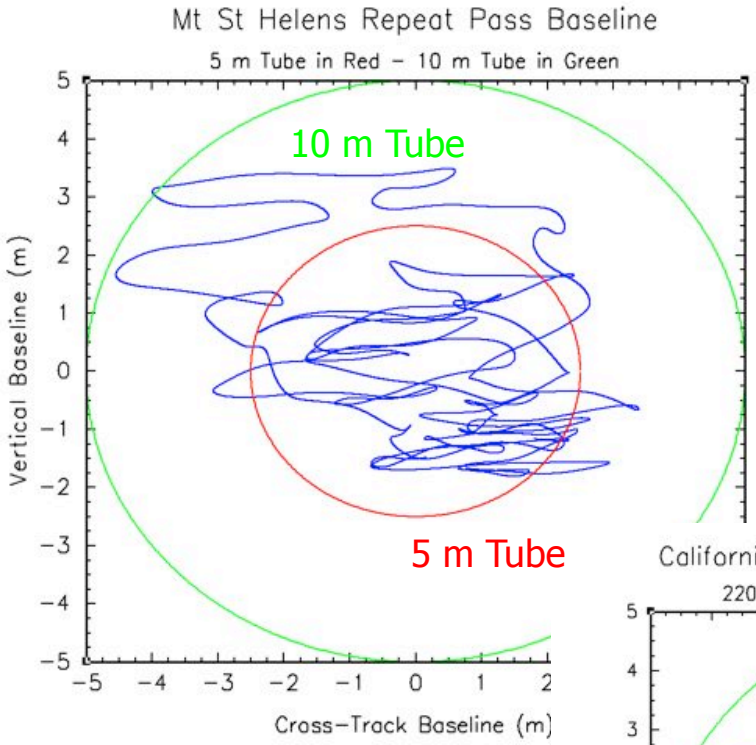
Gulf Coast
(3 days)

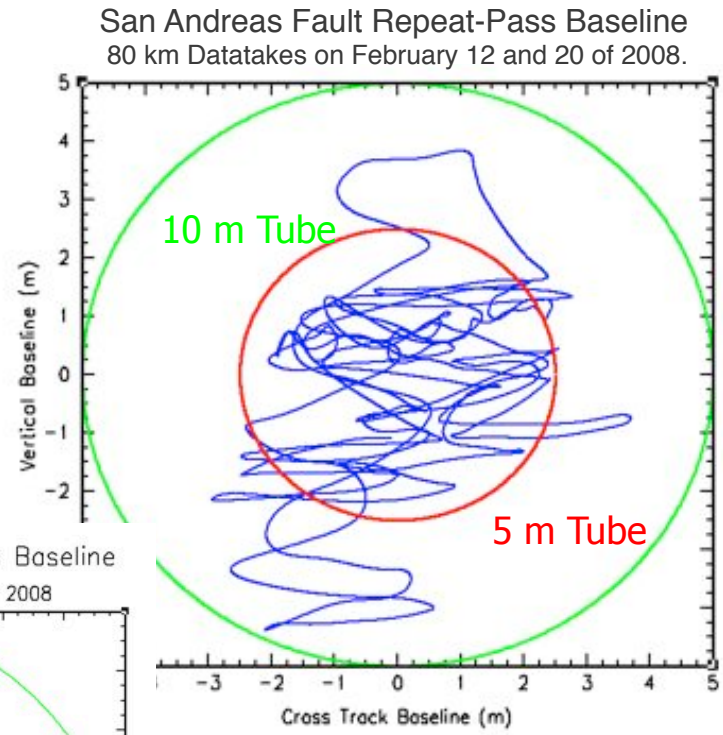


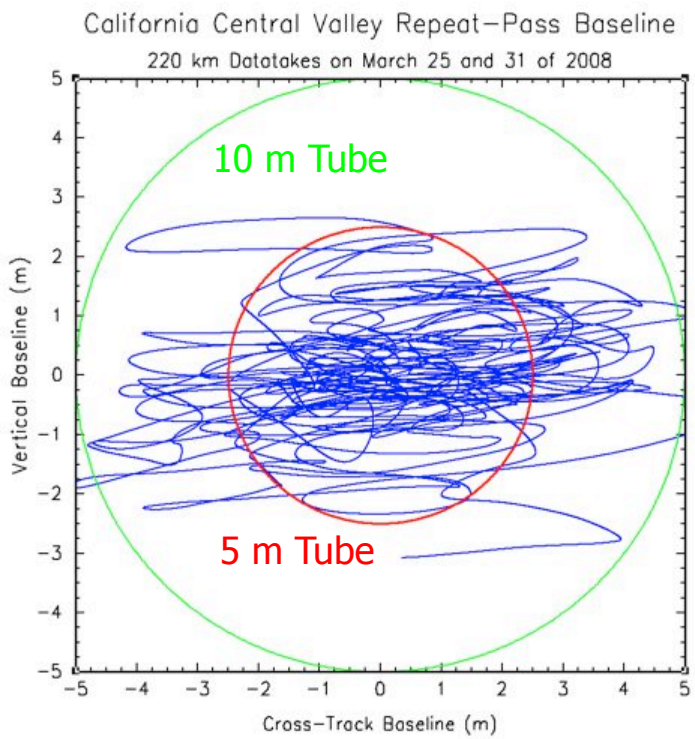
Local Flights out of Palmdale, CA

Residual Motion Estimation

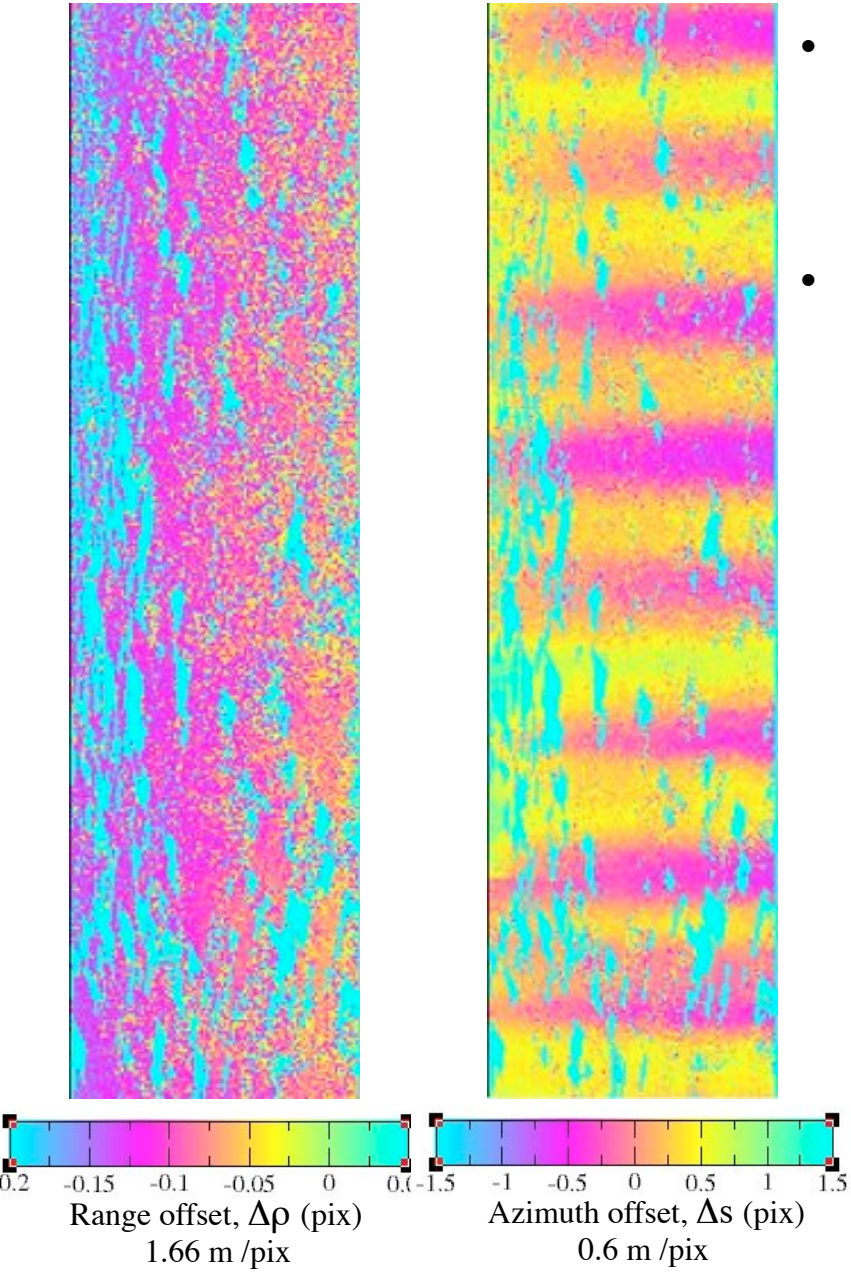
Example Repeat Pass Baselines





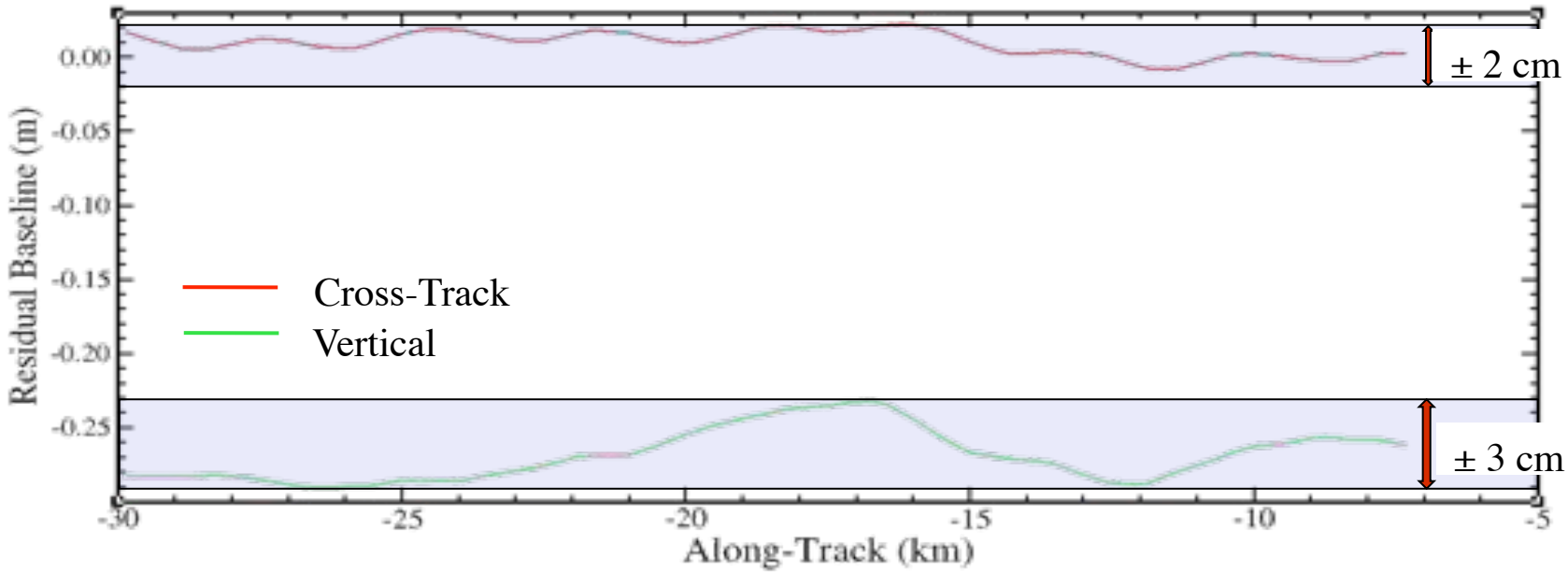


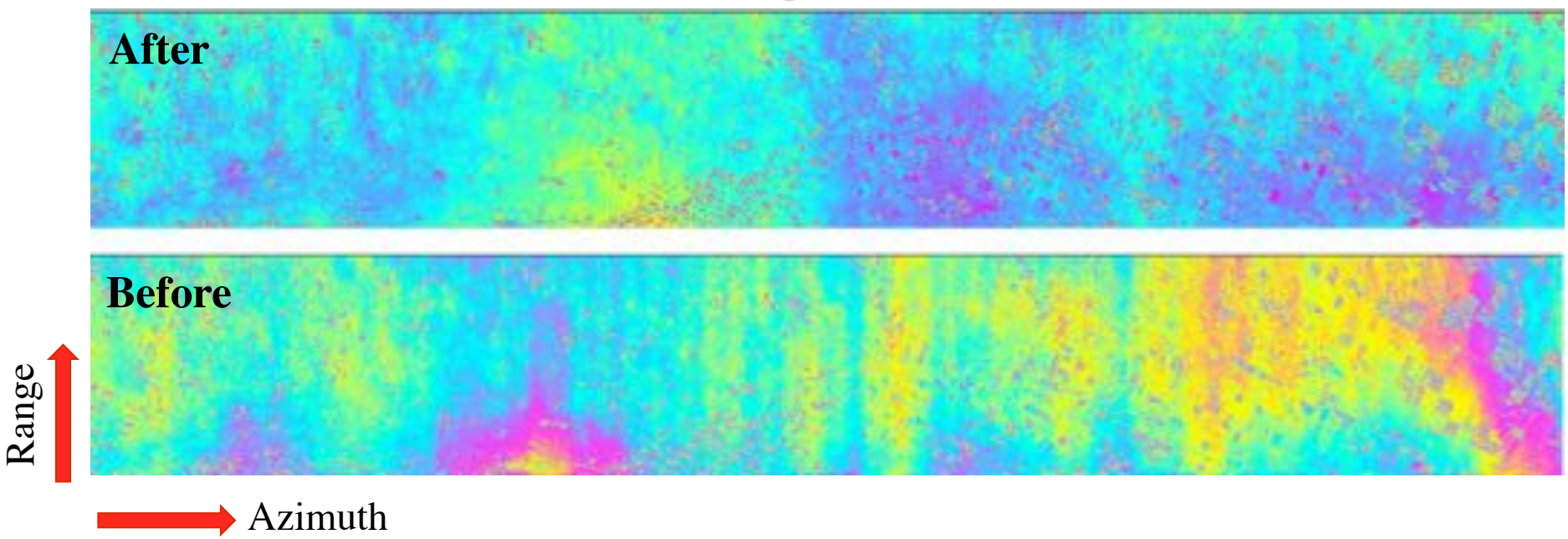
Measured Offsets for Central Valley



- Residual motion estimation currently uses offset or image displacement measurements between the two images comprising the interferometric pair to estimate the residual motion.
- The electronically scanned antenna complicates the formulas for residual motion estimation compared with flush mounted antennas used by most airborne systems.

Residual Motion Removed

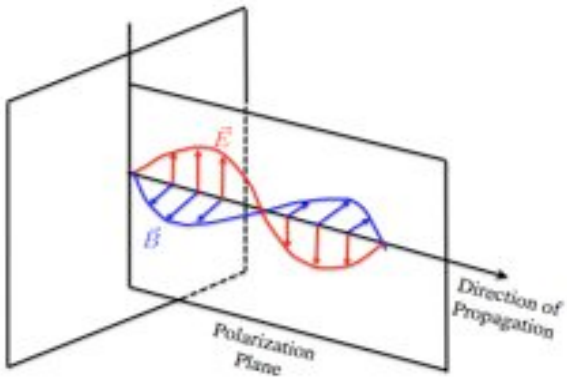


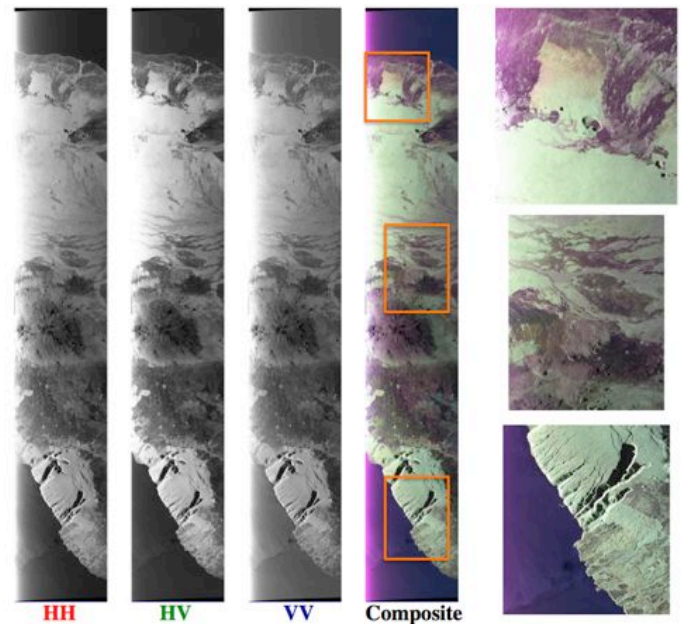


Science Results

Polarimetric Measurements

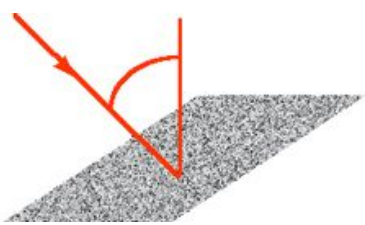
- Polarimetry exploits the vector nature of electromagnetic waves to obtain information about a surface.





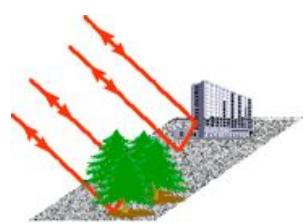
$$\vec{E}^s = \begin{bmatrix} E_h^s \\ E_v^s \end{bmatrix} = \frac{e^{i\frac{2\pi}{\lambda}\rho}}{\rho} \begin{bmatrix} S_{hh} & S_{vh} \\ S_{hv} & S_{vv} \end{bmatrix} \begin{bmatrix} E_h^i \\ E_v^i \end{bmatrix}$$

SINGLE BOUNCE SCATTERING
(ROUGH SURFACE)



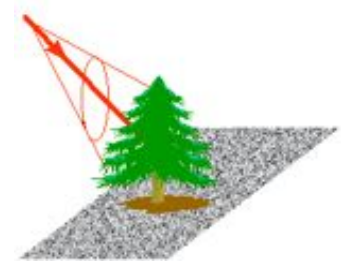
$$T_{11} = |S_{hh} + S_{vv}|^2$$

DOUBLE BOUNCE SCATTERING



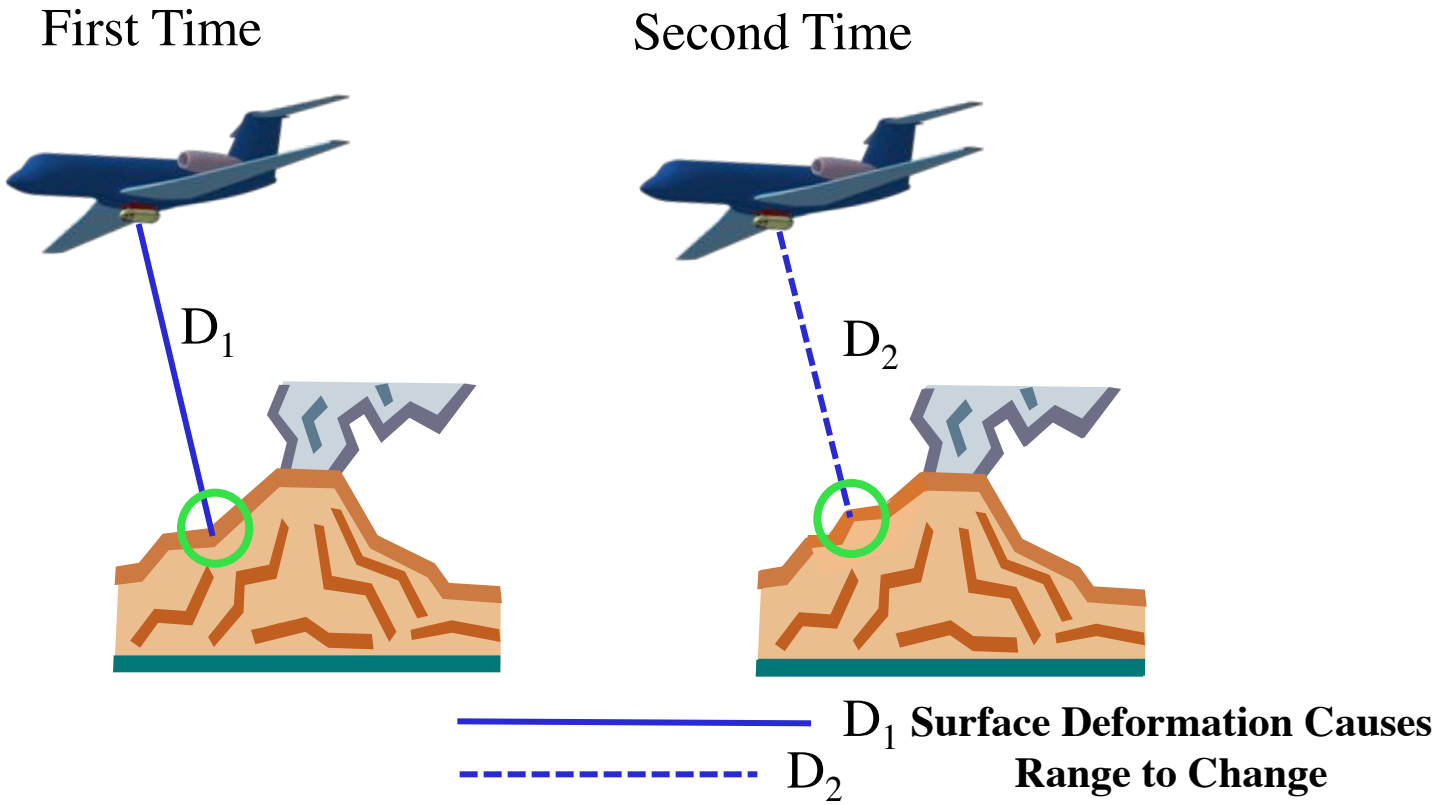
$$T_{22} = |S_{hh} - S_{vv}|^2$$

VOLUME SCATTERING



$$T_{33} = 2|S_{hv}|^2$$

Radar Interferometry and Surface Deformation

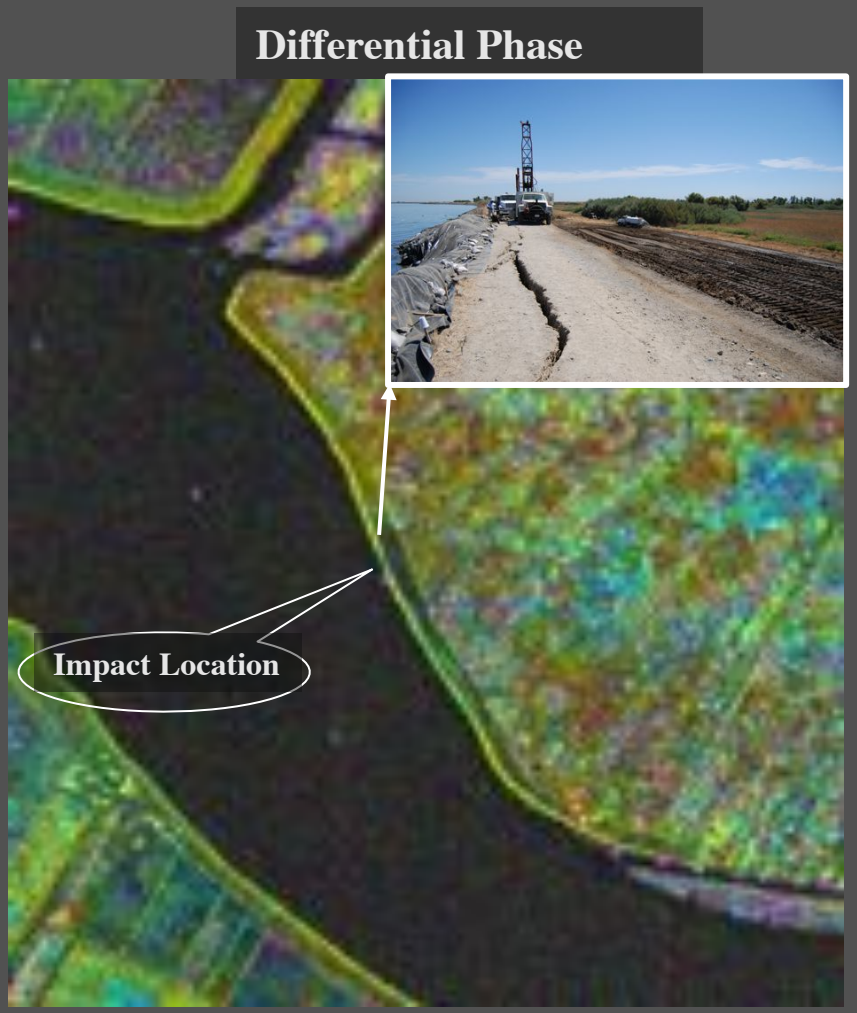


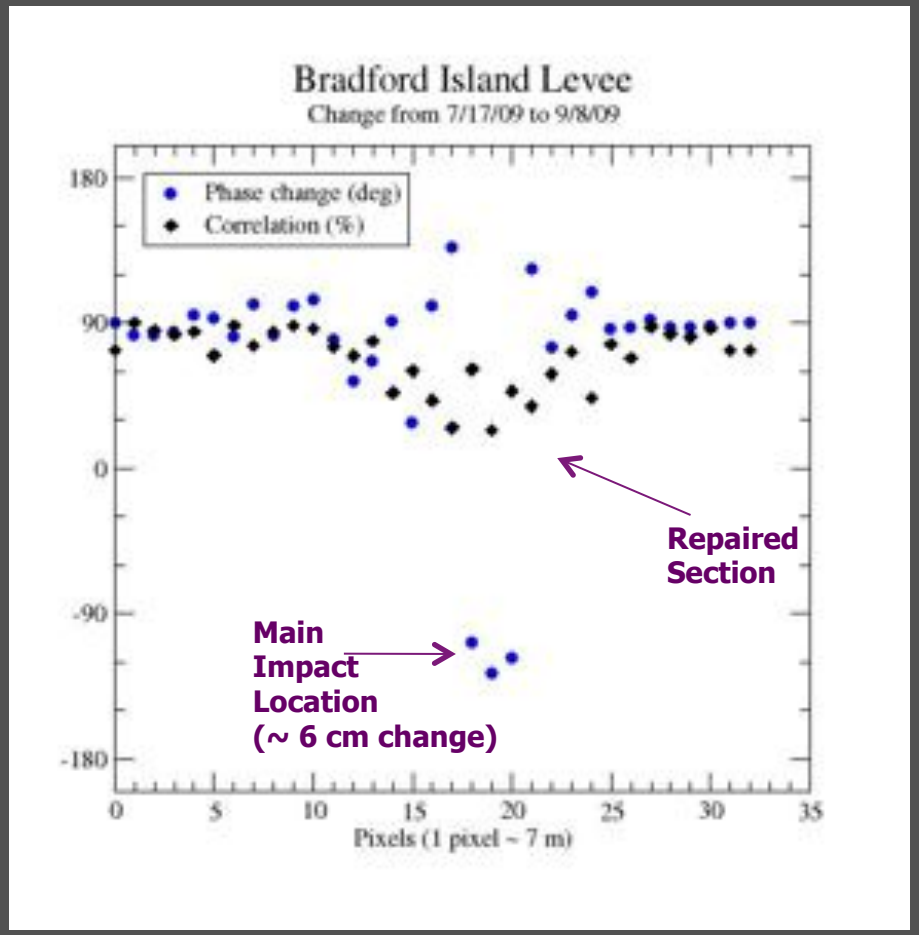
Surface deformation is reflected in the change in distance to a point.

$$\text{Surface Deformation} = D_2 - D_1$$

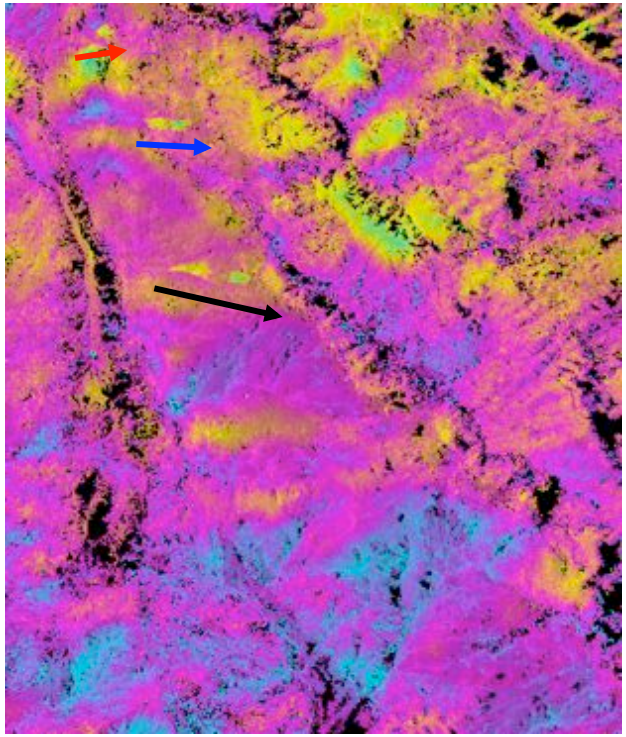
$$\text{Phase} = \underbrace{\text{Surface Deformation}}_{\text{Desired Signal}} + \underbrace{\text{“Topography”}}_{\text{Small baseline facilitates compensation of this term}}$$

Bradford Island Levee Interferogram

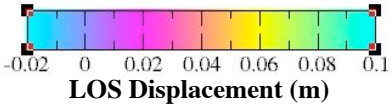


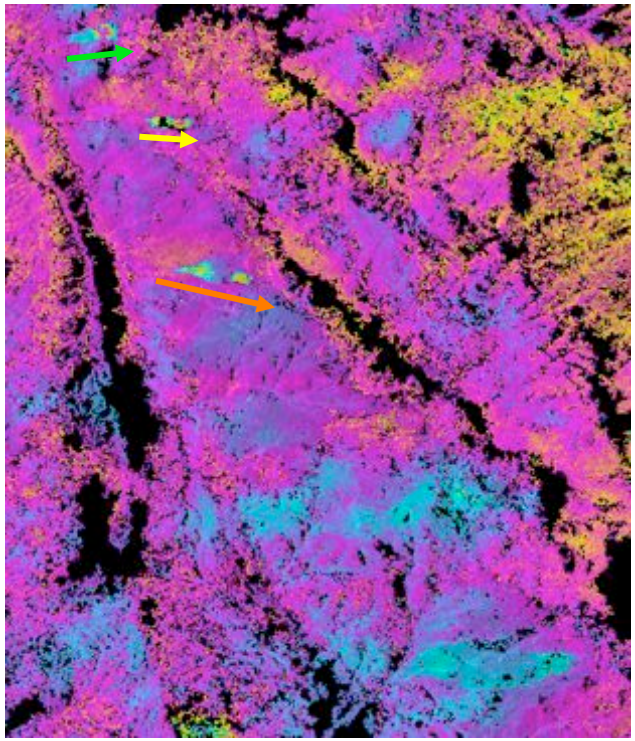


Landslide Motion Detection Near Parkfield, CA



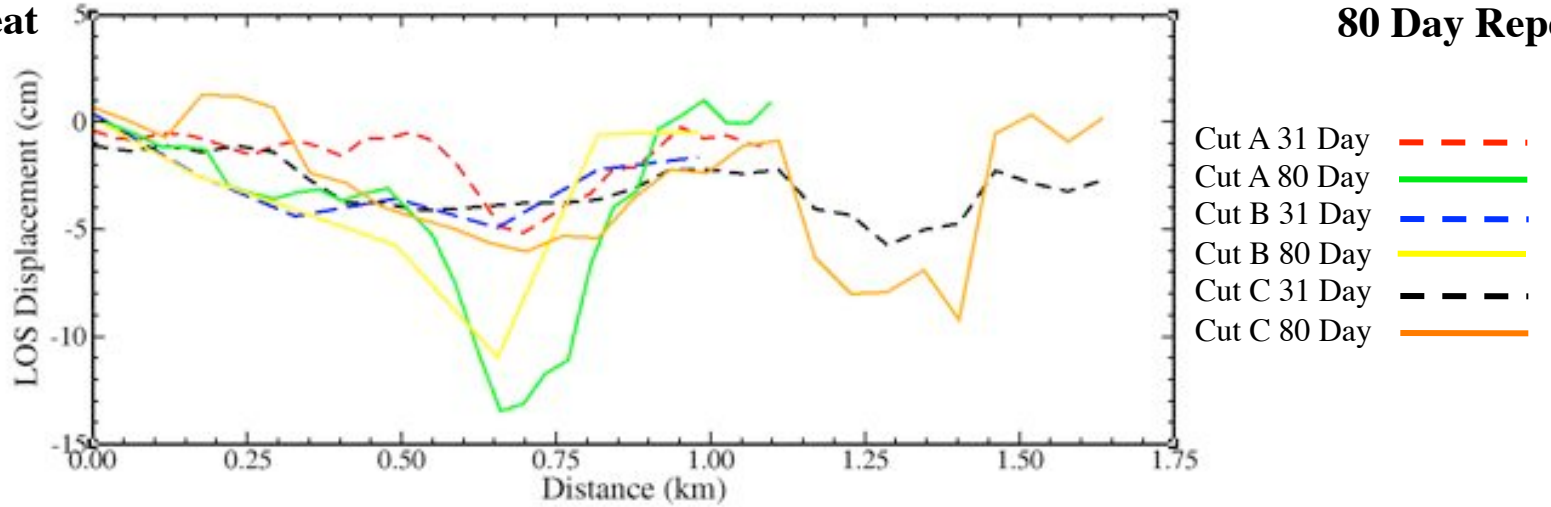
- Creeping landslides detected in 31 and 80 day repeat pass interferograms.
- The amount of deformation increased for the larger pair with the larger temporal baseline indicating continued creep from May to July 2008.





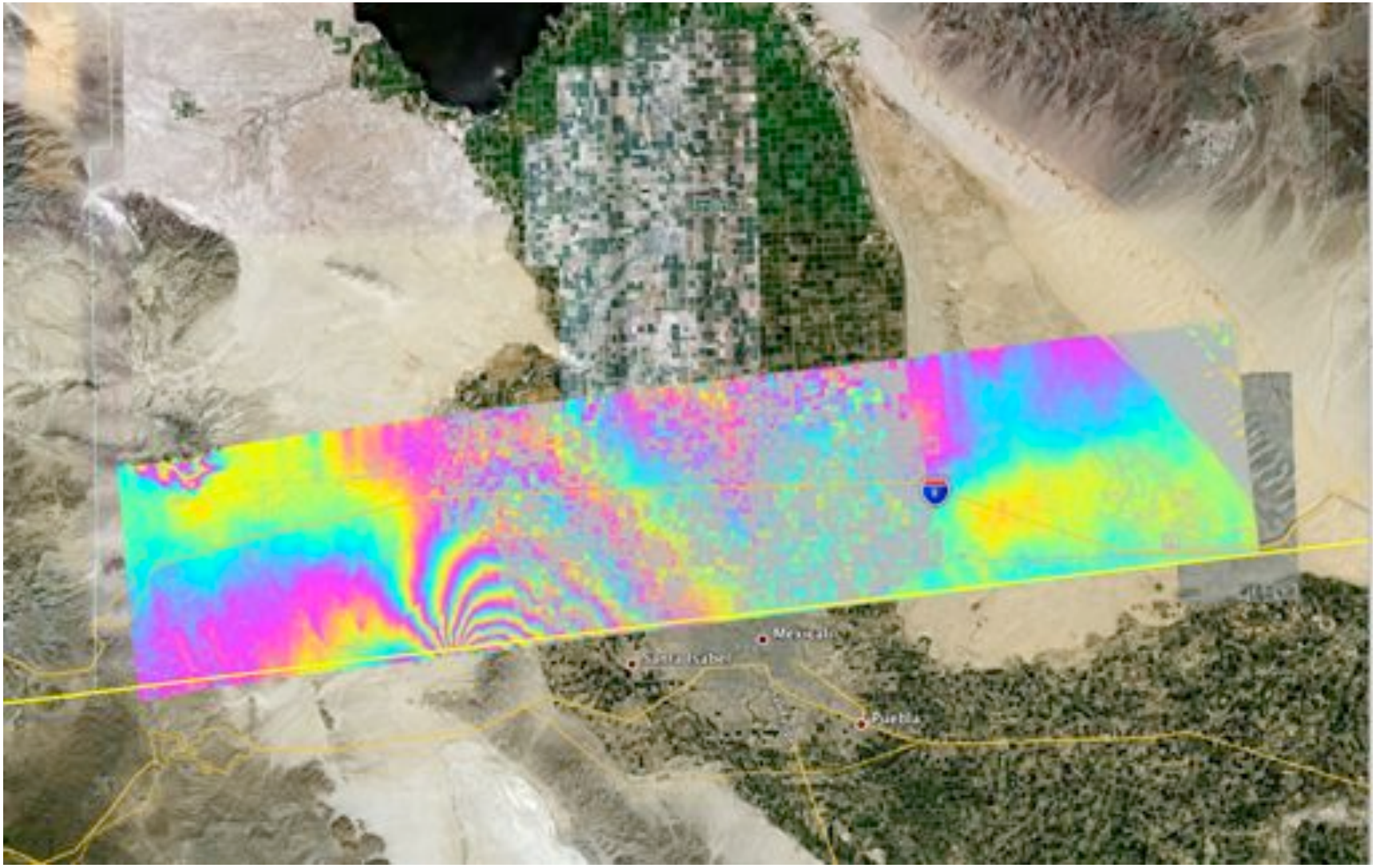
31 Day Repeat

80 Day Repeat

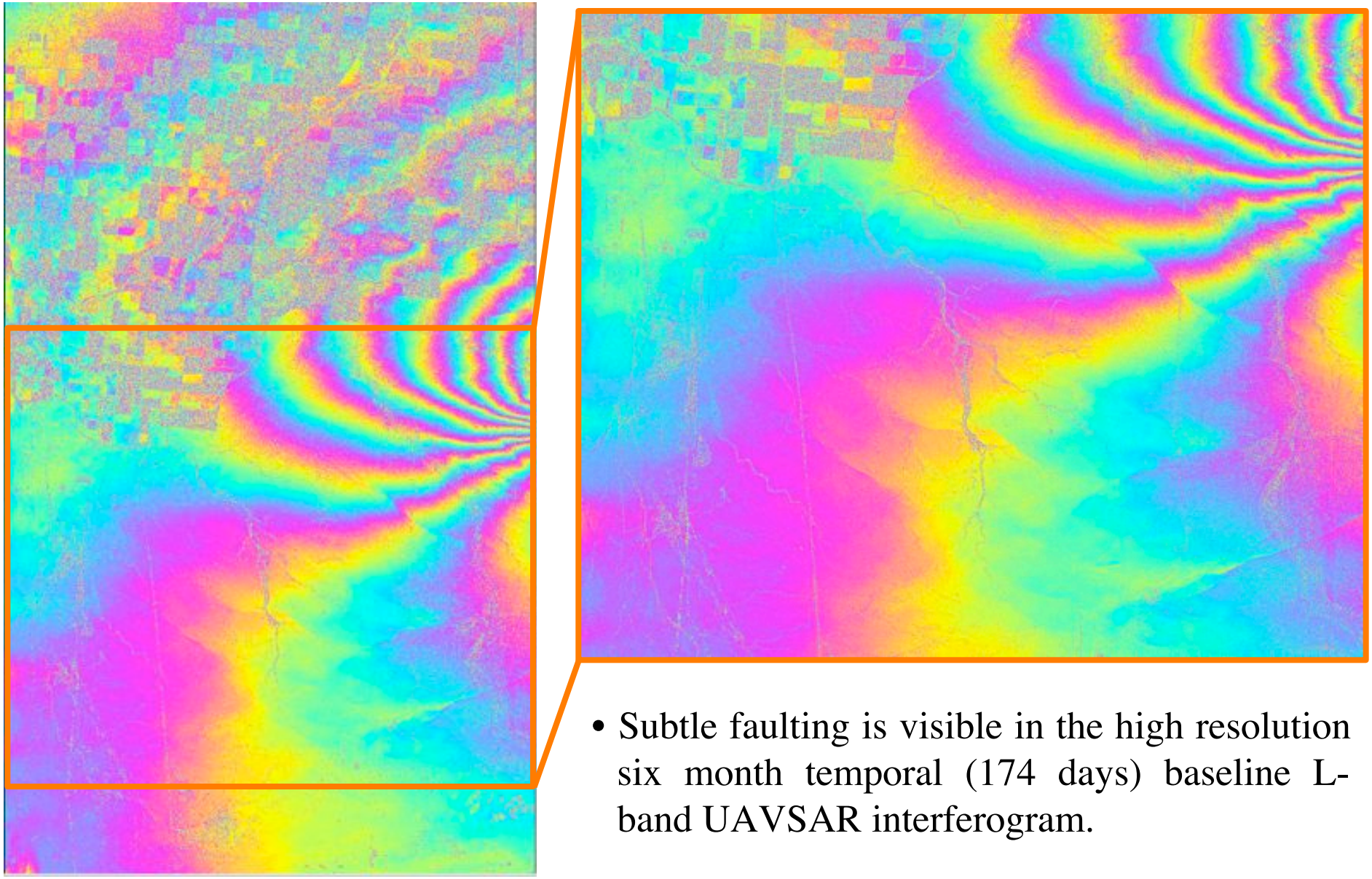


April 4, 2010 M 7.2 Baja California Earthquake

- First earthquake deformation captured by the UAVSAR system using data acquired on October 21, 2009 and April 13, 2010.



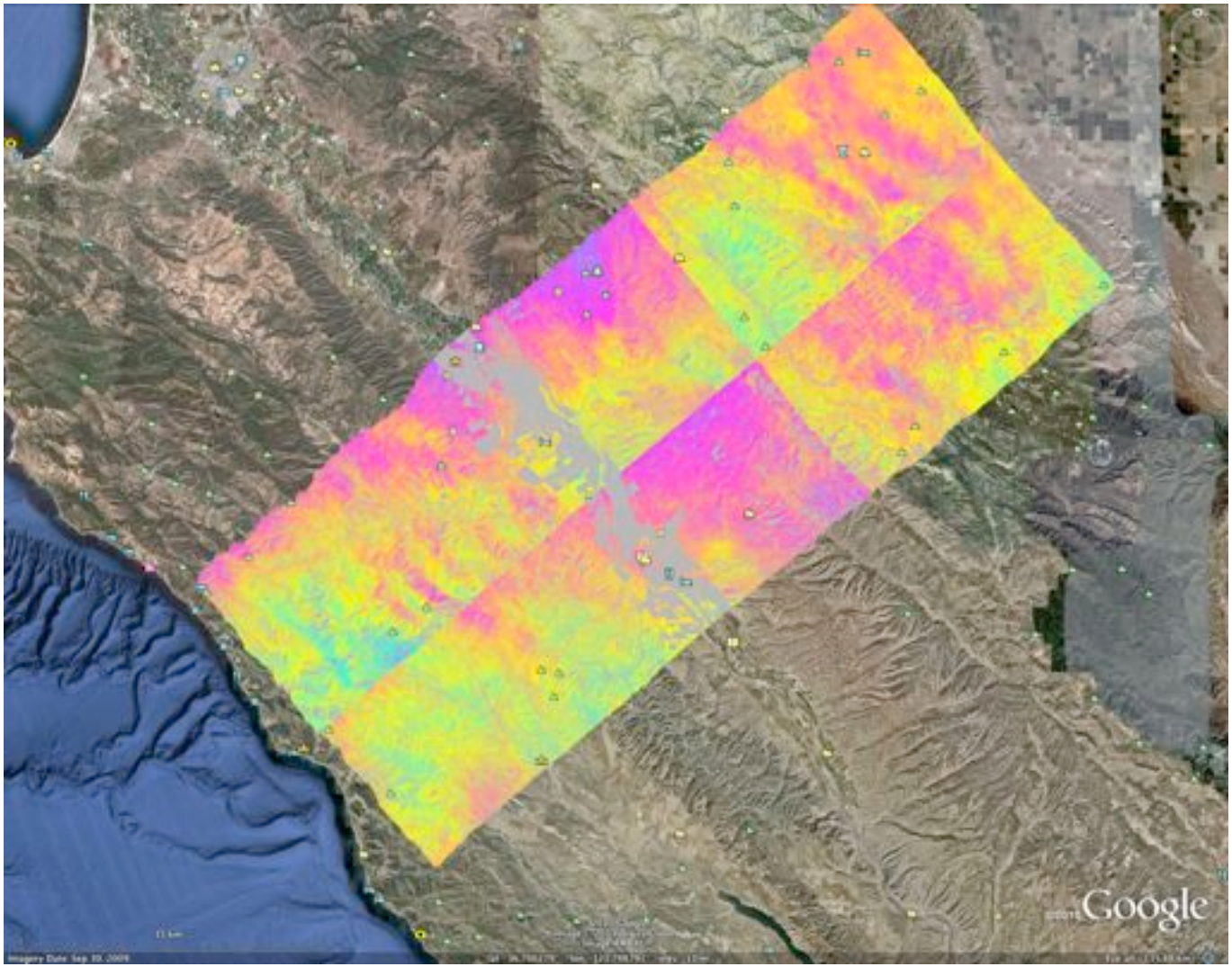
Expanded View of Earthquake



- Subtle faulting is visible in the high resolution six month temporal (174 days) baseline L-band UAVSAR interferogram.

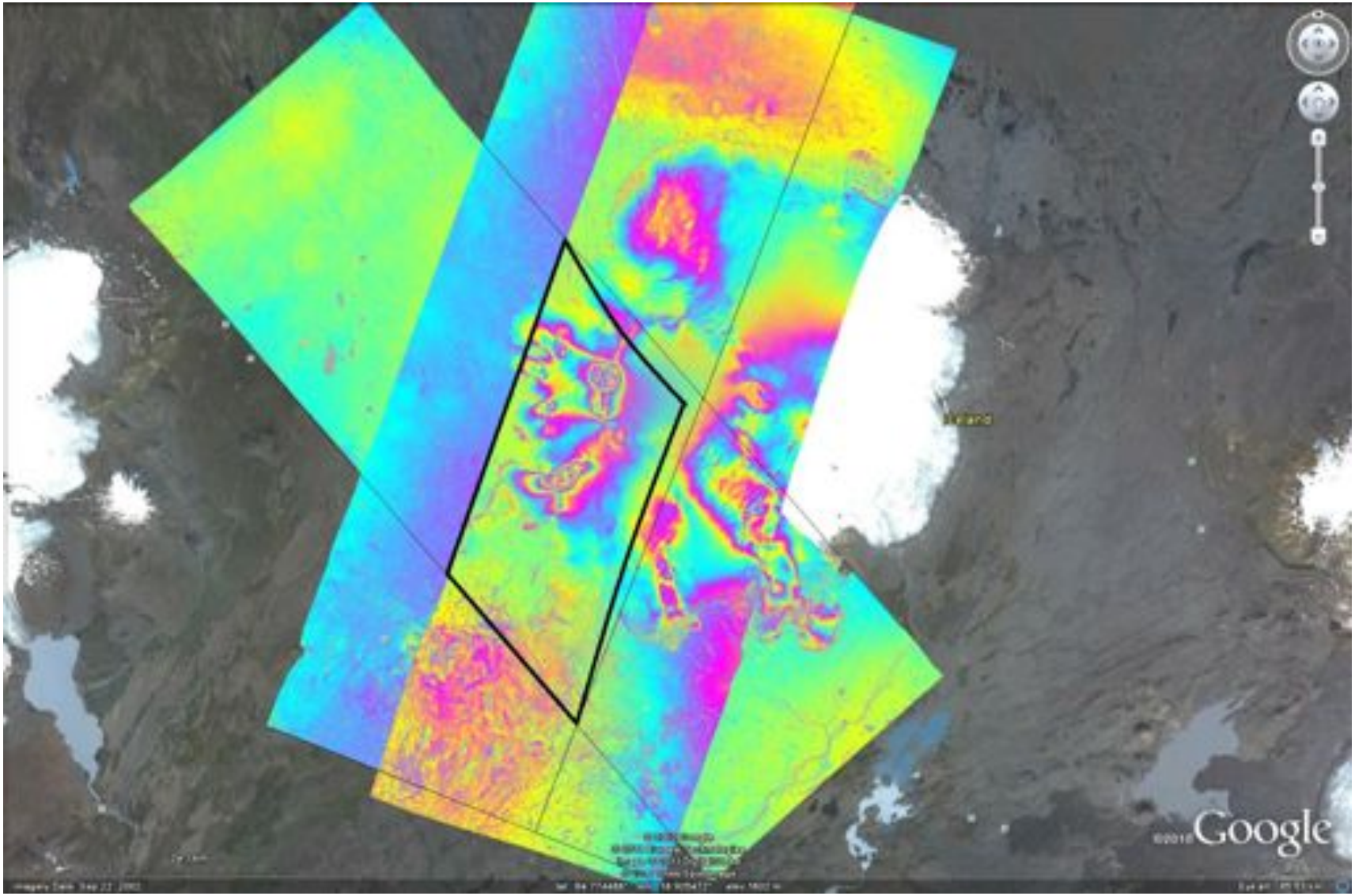
Motion on San Andreas Fault

- Fault slip along the San Andreas detected in 370 day interferogram with data from November 2009 and 2010.



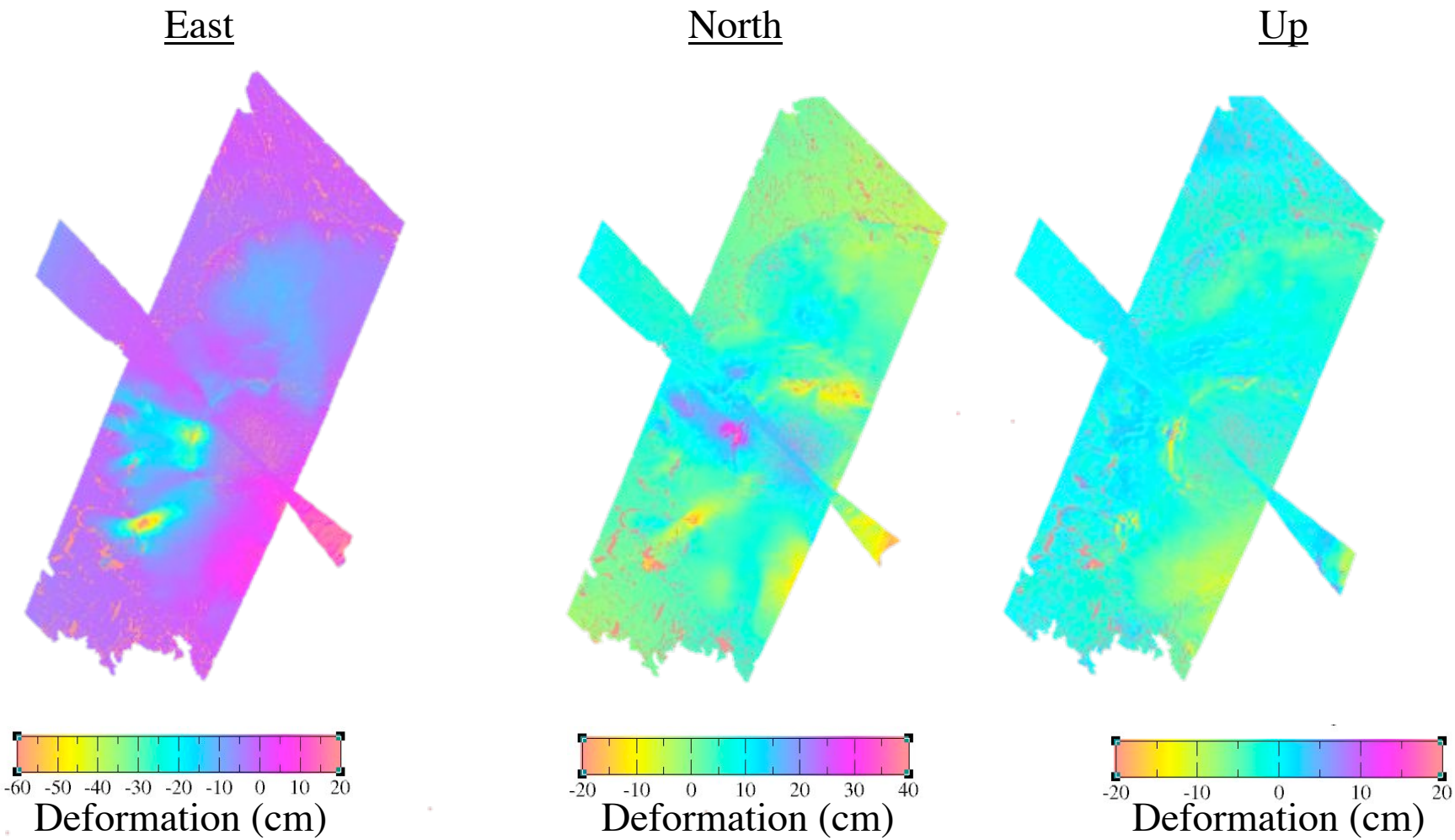
Vector Deformation on Glaciers

- Three passes of headings 20°, -160° and -40° used to generate vector deformation measurements (data from May 2009).

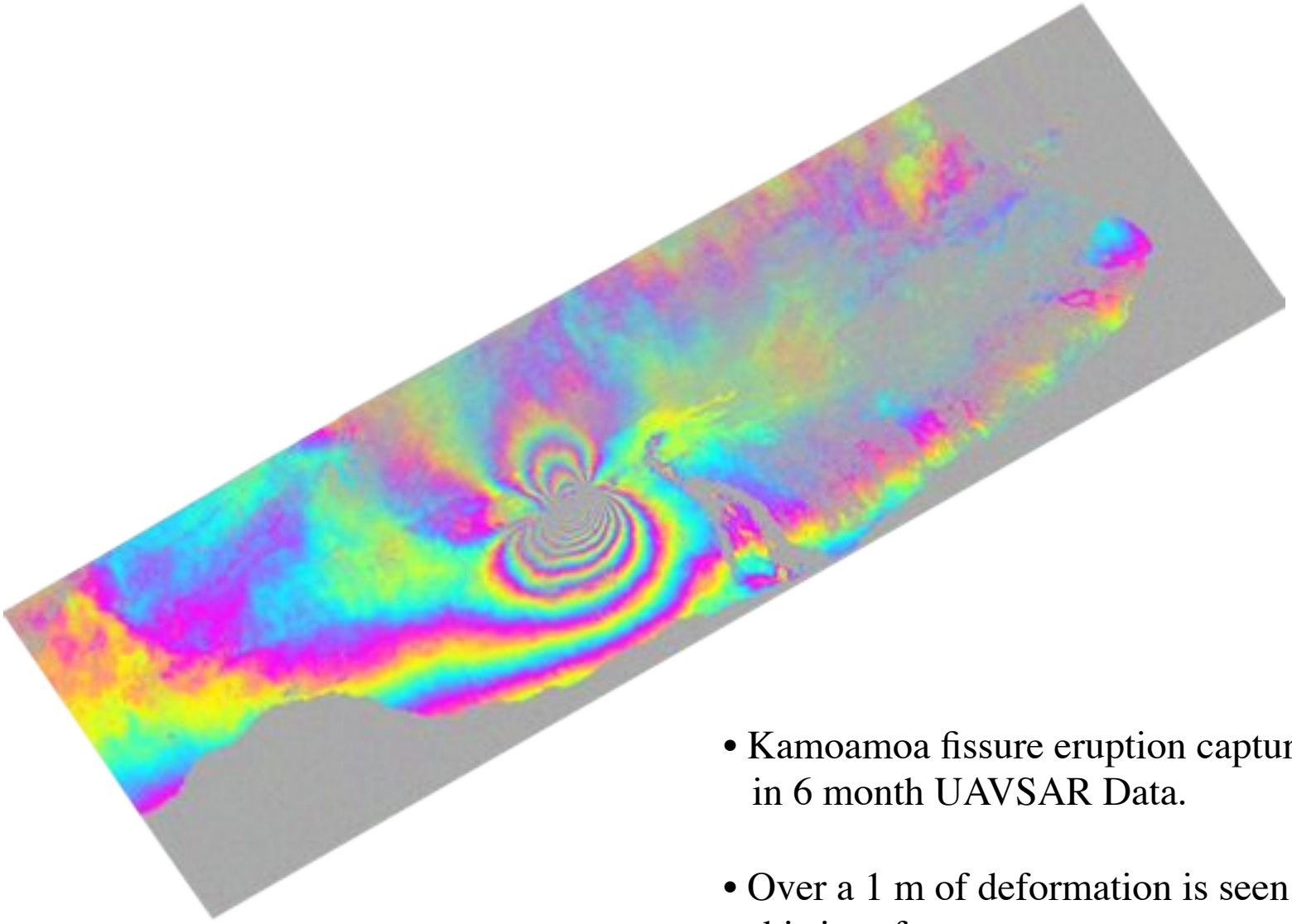


Four Pass Deformation Map

- Sample vector deformation products generated from UAVSAR data collected in May, 2009 over the Hofsjkull glacier (repeat intervals of 24-27 hrs).
- Data from headings of 20°, -160, -40° and 140° and were combined to generate vector deformation products.

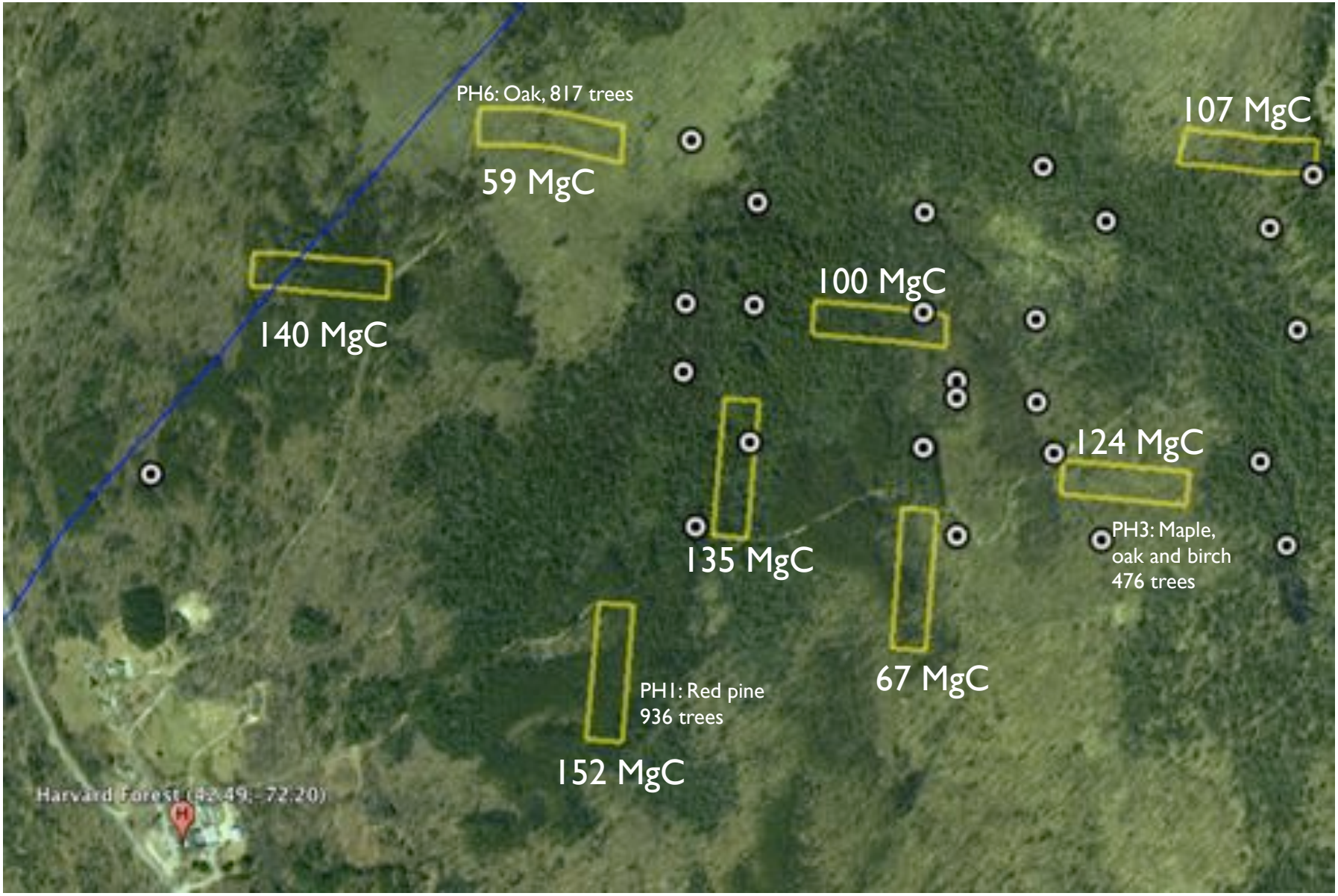


Volcano Monitoring



- Kamoamoa fissure eruption captured in 6 month UAVSAR Data.
- Over a 1 m of deformation is seen in this interferogram.

Biomass Level at Ground Truth Sites



UAVSAR Radar Collections

- UAVSAR data was collected on dates from August 6-17, 2009.
- Lines were collected in both zero baseline and non-zero baselines to study temporal decorrelation and PolinSAR techniques.

UAVSAR Image of Harvard Forest Region

Track Number	Date	Time of Day
1	August 6, 2009	13:59:57
2	August 6, 2009	14:31:27
3	August 6, 2009	15:01:56
4	August 6, 2009	15:32:54
5	August 8, 2009	15:13:26
6	August 8, 2009	15:43:51
7	August 8, 2009	16:14:49
8	August 13, 2009	19:15:09
9	August 13, 2009	19:48:39
10	August 16, 2009	13:51:11
11	August 17, 2009	14:57:43
12	August 17, 2009	13:58:03
13	August 17, 2009	13:28:53

Spatial and Temporal Baselines

- A total of 13 non-zero baseline passes were collected with baselines ranging from 16 to 123 m.
- Selected 9 of 78 possible interferometric pairs for initial analysis.

Spatial Baseline (m)

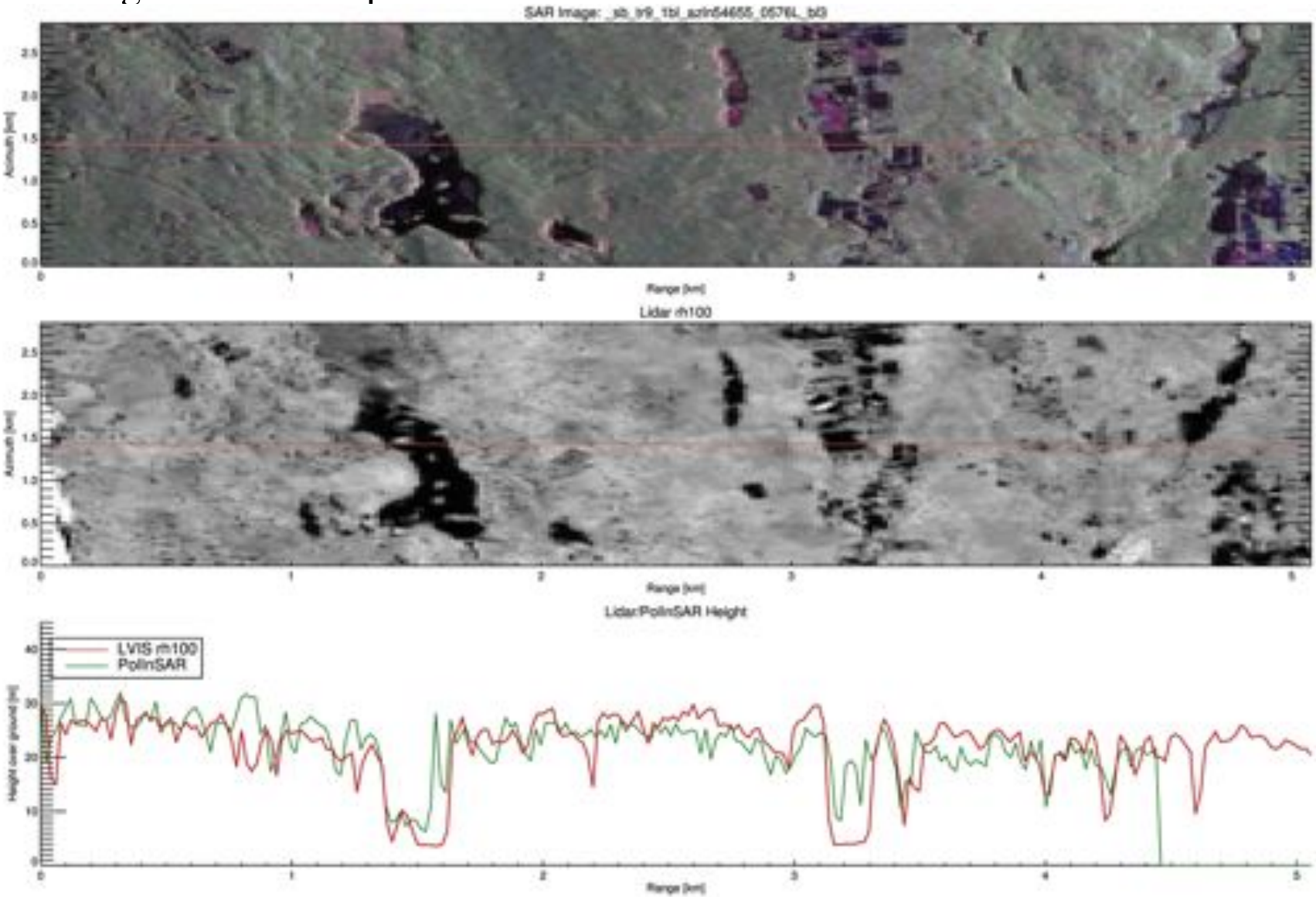
PASS	1	2	3	4	5	6	7	8	9	10	11	12	13
1	0	10.2	25.4	55.5	19.2	35.5	65.7	80.4	108.8	50.2	40.2	-5	-14.8
2		0	15.2	45.3	9	25.3	55.5	70.2	98.6	40	30	-15.2	-25
3			0	30.1	-6.2	10.1	40.3	55	83.4	24.8	14.8	-30.4	-40.2
4				0	-36.3	-20	10.2	24.9	53.3	-5.3	-15.3	-60.5	-70.3
5					0	16.3	46.5	61.2	89.6	31	21	-24.2	-34
6						0	30.2	44.9	73.3	14.7	4.7	-40.5	-50.3
7							0	14.7	43.1	-15.5	-25.5	-70.7	-80.5
8								0	28.4	-30.2	-40.2	-85.4	-95.2
9									0	-58.6	-68.6	-113.8	-123.6
10										0	-10	-55.2	-65
11											0	-45.2	-55
12												0	-9.8
13													0

Temporal Baseline (hr)

PASS	1	2	3	4	5	6	7	8	9	10	11	12	13
1	0.0	-0.5	-1.0	-1.5	-49.2	-49.7	-50.2	-173.3	-173.8	-239.9	-265.0	-264.0	-263.5
2		0.0	-0.5	-1.0	-48.7	-49.2	-49.7	-172.7	-173.3	-239.3	-264.4	-263.4	-263.0
3			0.0	-0.5	-48.2	-48.7	-49.2	-172.2	-172.8	-238.8	-263.9	-262.9	-262.4
4				0.0	-47.7	-48.2	-48.7	-171.7	-172.3	-238.3	-263.4	-262.4	-261.9
5					0.0	-0.5	-1.0	-124.0	-124.6	-190.6	-215.7	-214.7	-214.3
6						0.0	-0.5	-123.5	-124.1	-190.1	-215.2	-214.2	-213.8
7							0.0	-123.0	-123.6	-189.6	-214.7	-213.7	-213.2
8								0.0	-0.6	-66.6	-91.7	-90.7	-90.2
9									0.0	-66.0	-91.2	-90.2	-89.7
10										0.0	-25.1	-24.1	-23.6
11											0.0	1.0	1.5
12												0.0	0.5
13													0.0

PolinSAR Tree Heights – 576 Looks

- Estimated tree heights from PolinSAR compared with lidar tree heights for 28 m^2 pixels or 576 looks.



Global Hawk Porting Status

Global Hawk Flight Demo Plan

- Mechanical fit check with new payload pallets were completed in March 2012.
- Electrical interface and communication check with the Global Hawk simulator is scheduled for mid-October.
- Integration with the Global Hawk aircraft is scheduled for early November.
- Plan to have 3 short engineering flights around Edwards AFB in Southern California in November.
- Science flight may begin in March/April 2013.

Conclusions

Conclusions

- UAVSAR has demonstrated the combined Precisions Autopilot coupled with the L-band electronically steered allow for robust repeat pass radar interferometric collections.
- Science results in the areas of soil moisture, volcanology, solid earth science, glaciology, archeology, and ecosystem system science have been achieved using the UAVSAR platform.
- Extensibility of the system from L-band to other frequencies has been demonstrated with the:
  - Ka-band Glisten single radar interferometer for ice topography measurement
  - P-band fully polarimetric radar for root zone soil moisture measurement
- Porting the UAVSAR instrument to the Global Hawk will allow new science applications including:
  - Science campaigns in Antarctica now possible with the G-III platform
  - Long term persistent observations of major events like earthquakes and volcanoes.