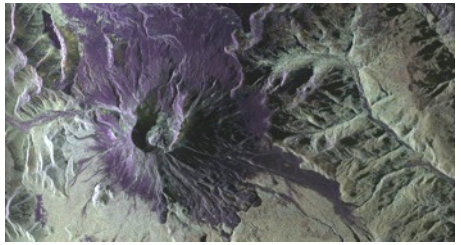
→ 3rd ADVANCED COURSE ON RADAR POLARIMETRY

NEW MISSIONS

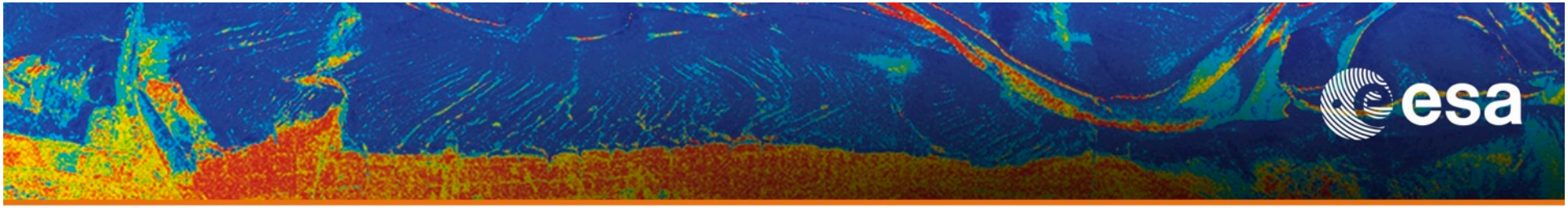
UAVSAR



Scott Hensley
Jet Propulsion Laboratory, California Institute of Technology

19–23 January 2015 | ESA-ESRIN | Frascati (Rome), Italy

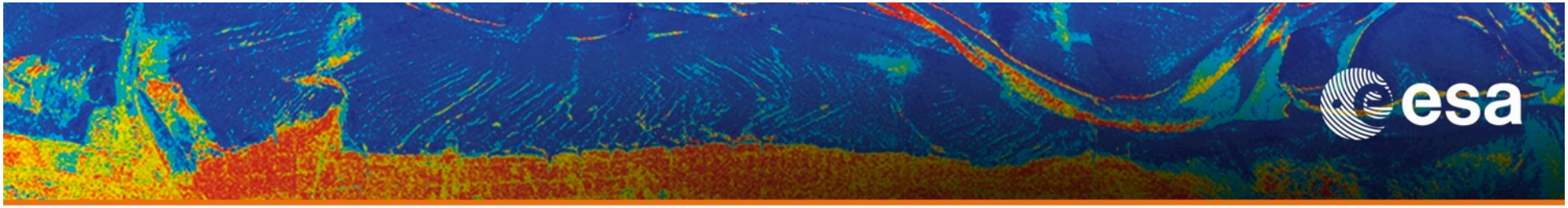
European Space Agency



Overview

Lecture Overview

- System Overview
- Data Examples
- UAVSAR Data Products
- How to Obtain UAVSAR Data



System Overview

Repeat Pass Radar Interferometry

- Repeat pass radar observations are used for a variety applications ranging from monitoring the earth deformation due to earthquakes, volcanoes, and anthropogenic sources (e.g. water or oil pumping), glacier motion measurements, vegetation structure, etc.
- Most repeat pass measurements have been made with satellite systems where the platform trajectory is smooth at a fraction of a wavelength.
- Airborne repeat pass radar interferometry is complicated by the irregular trajectory flown by airborne platforms due to atmospheric induced perturbations to the flight track.
  - Although these variations impose additional complications due to the uncorrelated nature of the high frequency motion between passes over a synthetic aperture, it is the lack of sufficient accuracy on the relative platform position between passes that seriously inhibits more routine use of this data.
  - Onboard motion metrology systems (INU and DGPS) recover the motion only to about 3 cm an order of magnitude from what is desired.

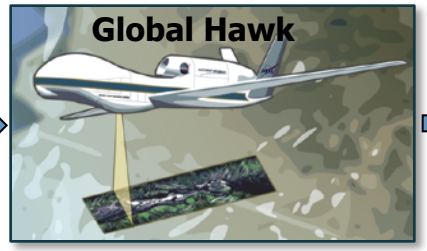
Evolution of UAVSAR Development

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, NI-SAR, and SWOT. UAVSAR also supports science investigations that are not otherwise possible with spaceborne observations.

2004 - 2008
ESTO IIP, R&A

L-band repeat-pass InSAR for surface deformation, vegetation structure, soil moisture mapping, land use classification, glaciology, And applied science

2009 - 2014
ESTO



L-band polarimetry for land use and vegetation classification, and soil moisture mapping

2011 - 2012
EV-1 AirMOSS

P-band polarimetry for measuring subsurface and sub-canopy soil moisture

2009, 2011 - 2013
IPY, ESTO AITT GLISTIN-A

Ka-band single-pass InSAR for observing glacier and land ice topography

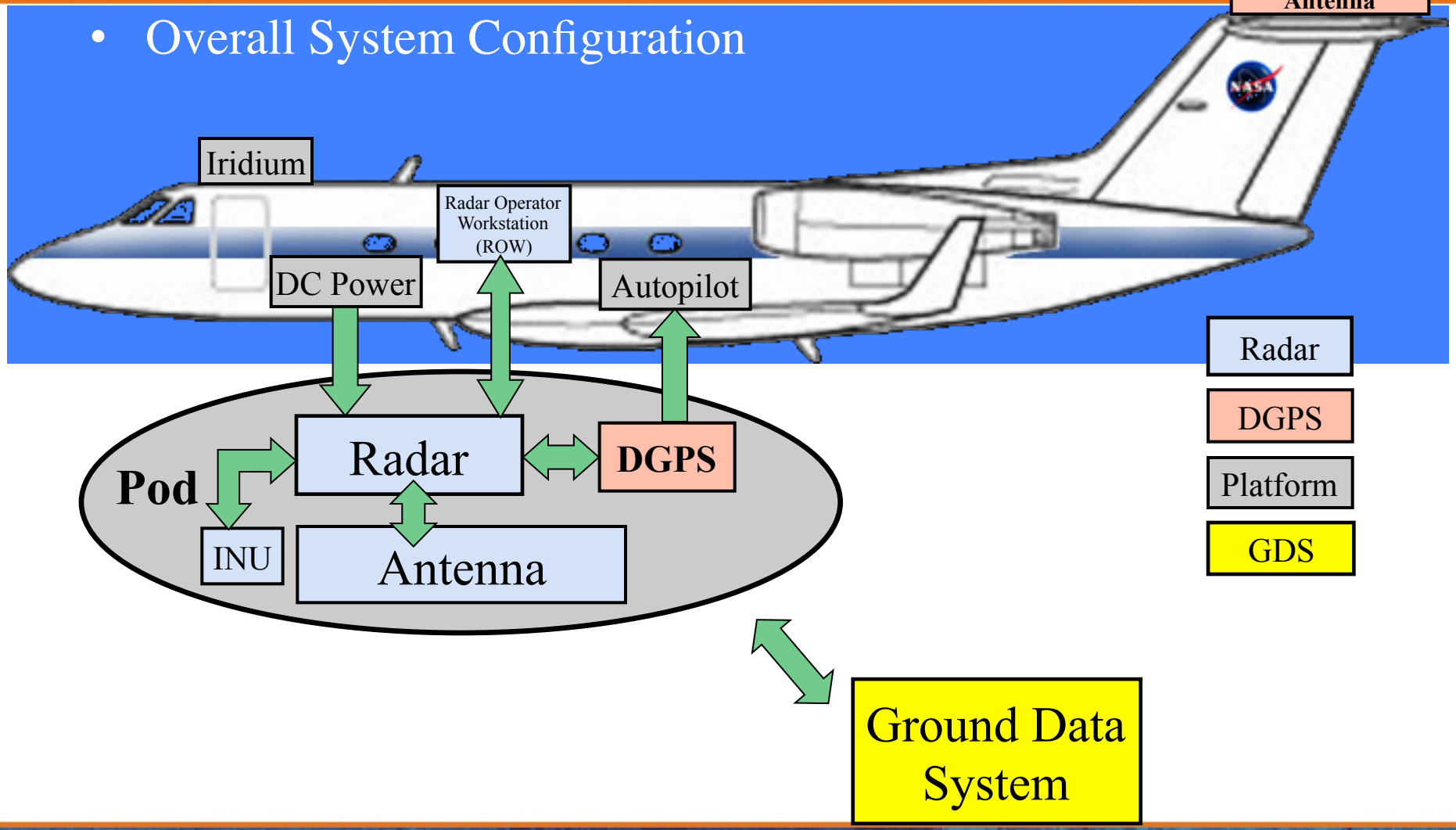
UAVSAR – L-Band

- UAVSAR is an L-band fully polarimetric SAR employing an electronically scanned antenna that has been designed to support a wide range of science investigations.
  - The UAVSAR design incorporates:
  - A precision autopilot developed by NASA Dryden that allows the platform to fly repeat trajectories that are mostly within a 5 m tube.
  - Compensates for attitude angle changes during and between repeat tracks by electronically pointing the antenna based on attitude angle changes measured by the INU.

Parameter	Value
Frequency	L-Band 1217.5 to 1297.5 MHz
Bandwidth	80 MHz
Resolution	1.67 m Range, 0.8 m Azimuth
Polarization	Full Quad-Polarization
ADC Bits	2,4,6,8,10 & 12 bit selectable BFPQ, 180Mhz
Waveform	Nominal Chirp/Arbitrary Waveform
Antenna Aperture	0.5 m range/1.5 azimuth (electrical)
Azimuth Steering	Greater than ±20° (±45° goal)
Transmit Power	> 3.1 kW
Polarization Isolation	<-25 dB (<-30 dB goal)
Swath Width	> 23 km

High Level Architecture

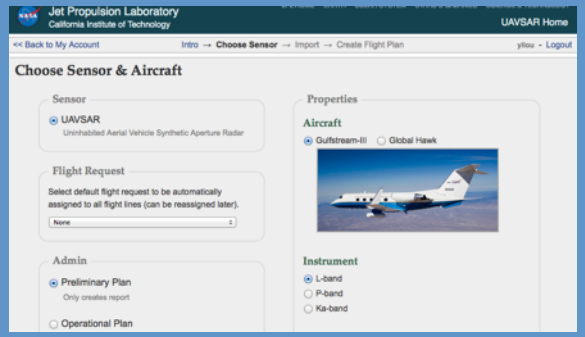
- Overall System Configuration



UAVSAR Program Elements

FLIGHT PLANNING

Choose frequency in Flight Planning Tool And SOFRS (NASA flight request interface)



INSTRUMENT

Back-end electronics (3 sets) and spares common to all frequencies

L-band **P-band** **Ka-band**

FLIGHT AND PROCESSOR OPERATIONS

Common Flight Operations **Ground Data System**

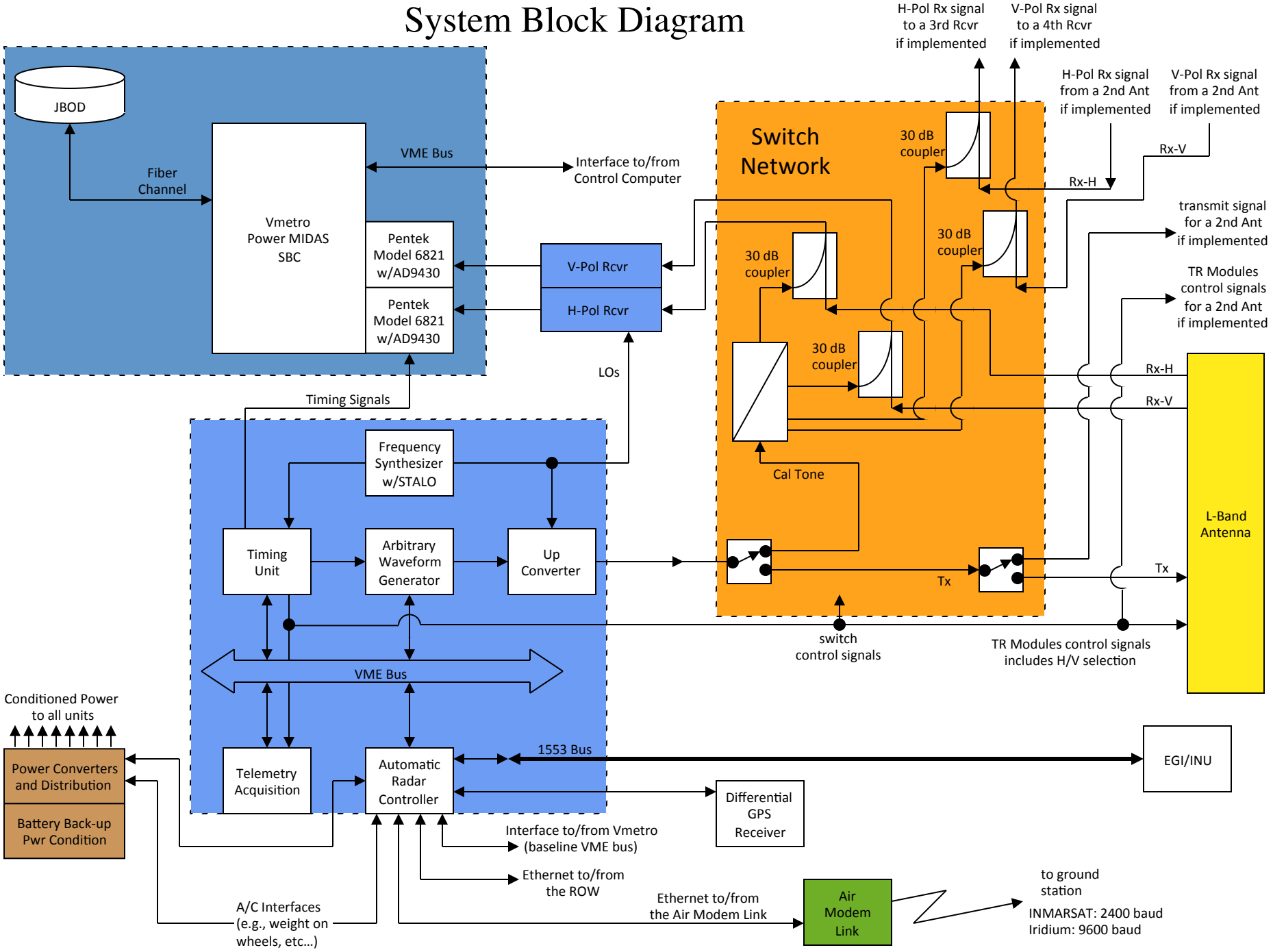
Perform SAR processing at Ames' Pleiades supercomputing facility

DATA DISTRIBUTION AND ARCHIVE

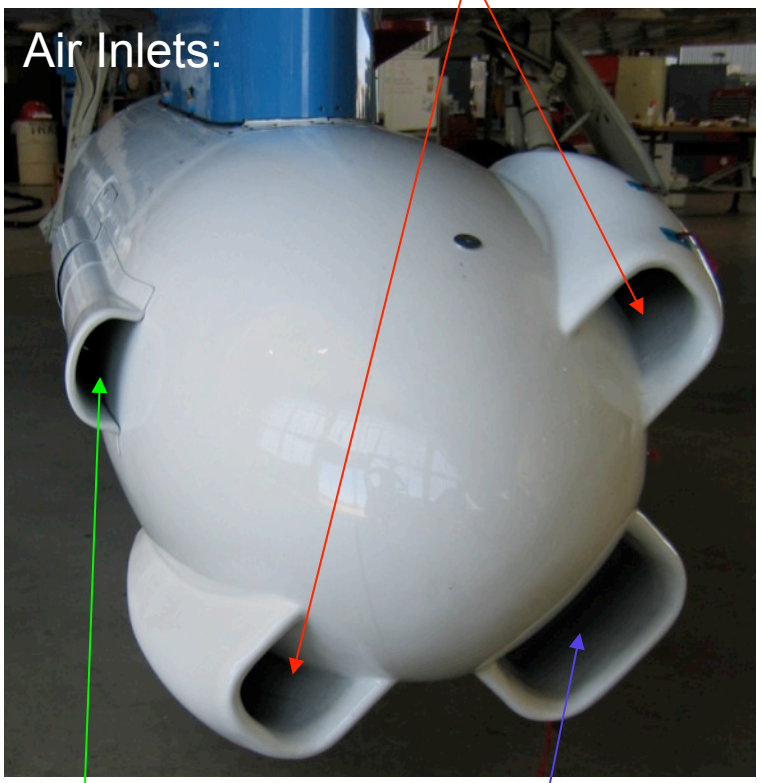
System Parameters All Bands

Parameter	P-band/UHF	L-band	Ka-band
Frequency (MHz)	280 – 440	1217.5-1297.5	35,620-35,700
Nominal Bandwidth (MHz)	20	80	80
Selectable Bandwidths (MHz)	6, 20, 40, 80	80	80
Polarization	Quad-pol	Quad-pol	Horizontal
Peak Transmit Power (kW)	2.0	3.1	0.8
Maximum Duty Cycle	10%	8%	10%
Look Angle Range	25 – 50 deg	25-65 deg	15-50
Nominal Range Swath (km)	9	22	10
Noise Equivalent Sigma0 (dB)	< -40	< -50	TBD
Radiometric Accuracy (dB)	< 1 absolute	< 1 absolute	TBD
Height Precision (30x30 m posting)	N/A	N/A	0.1 – 0.5 m

System Block Diagram

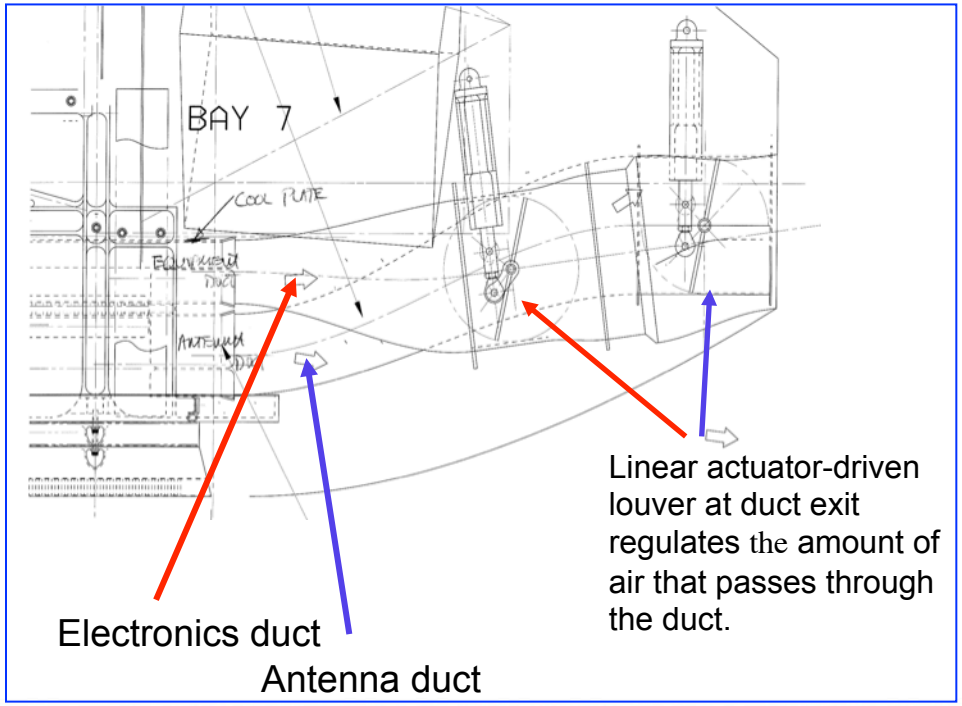


Ambient Air Cooling

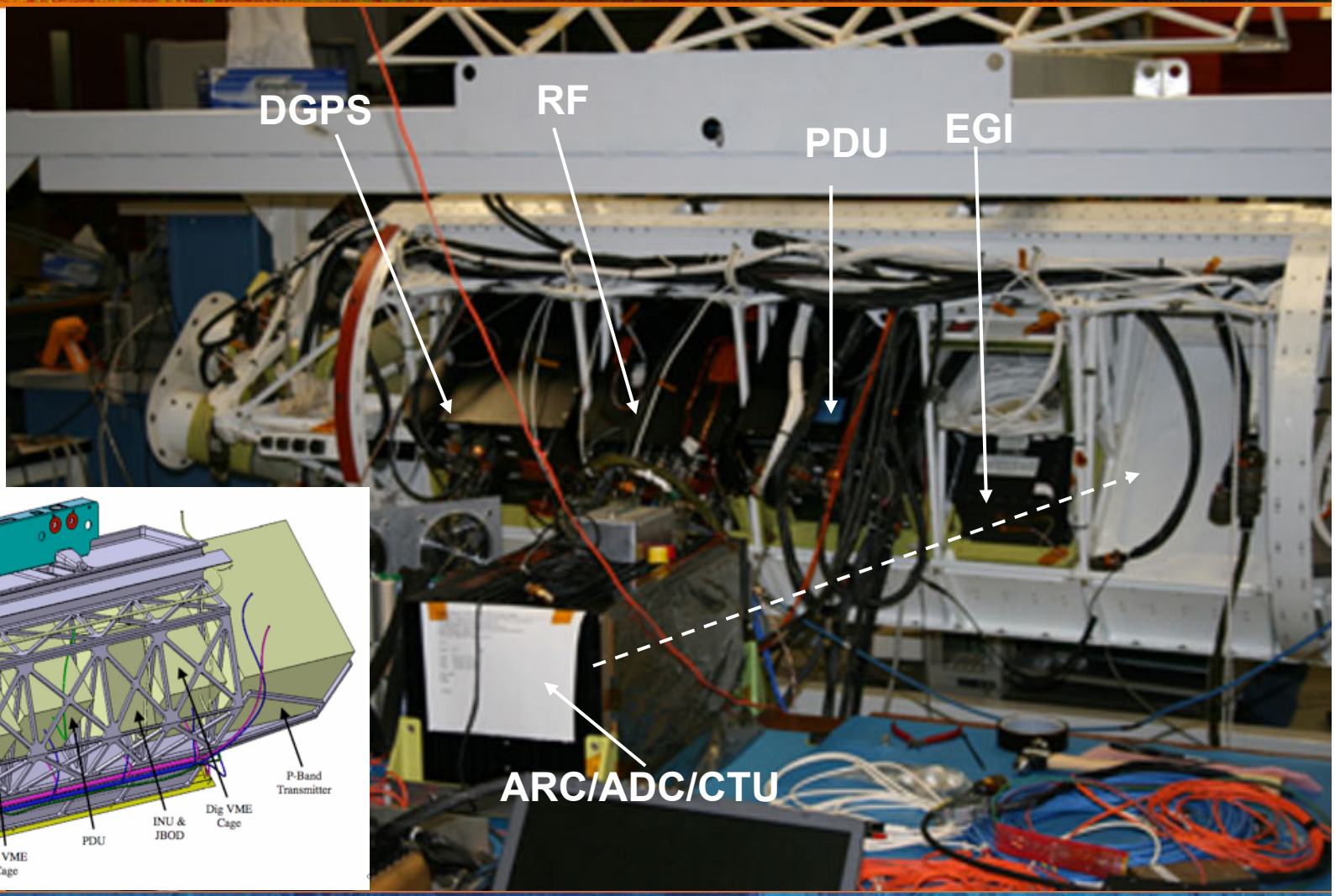


- Flying in an unpressurized pod allowed for maximal portability to other platforms, however this necessitated a fairly involved thermal control system to keep the various units within an acceptable temperature range and avoid condensation during descent.

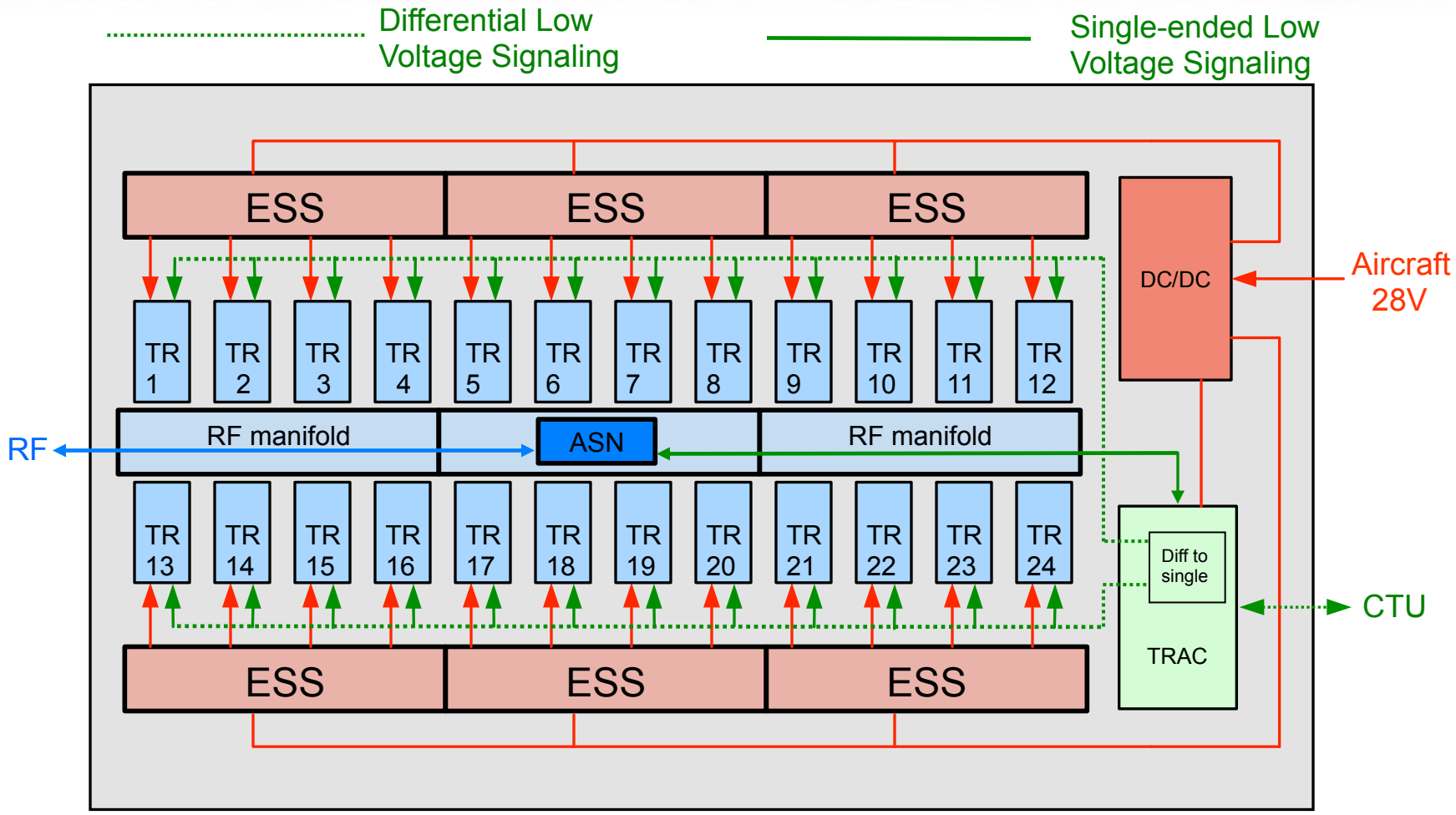
Louvers:



View Inside Pod

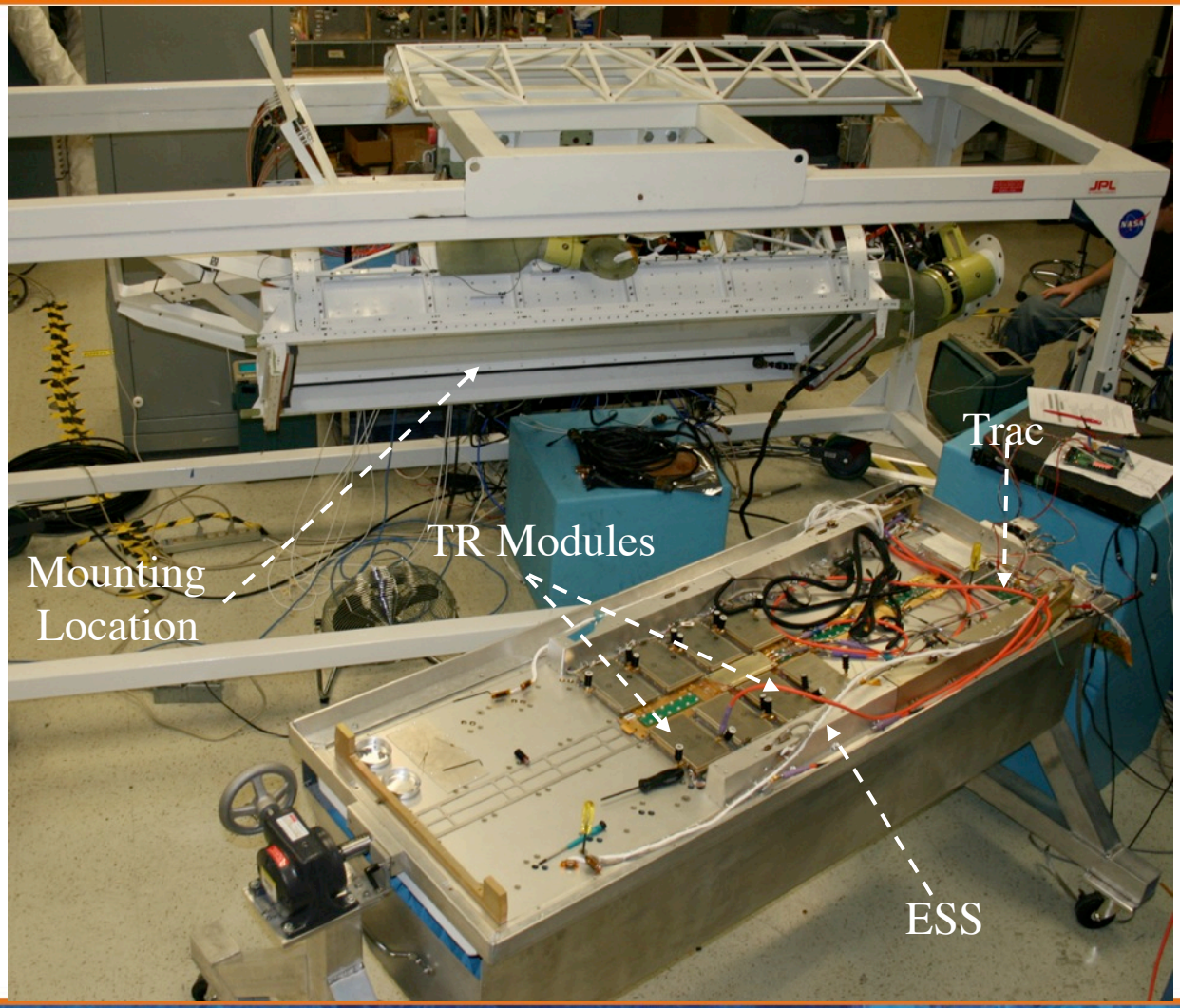


Antenna Overview

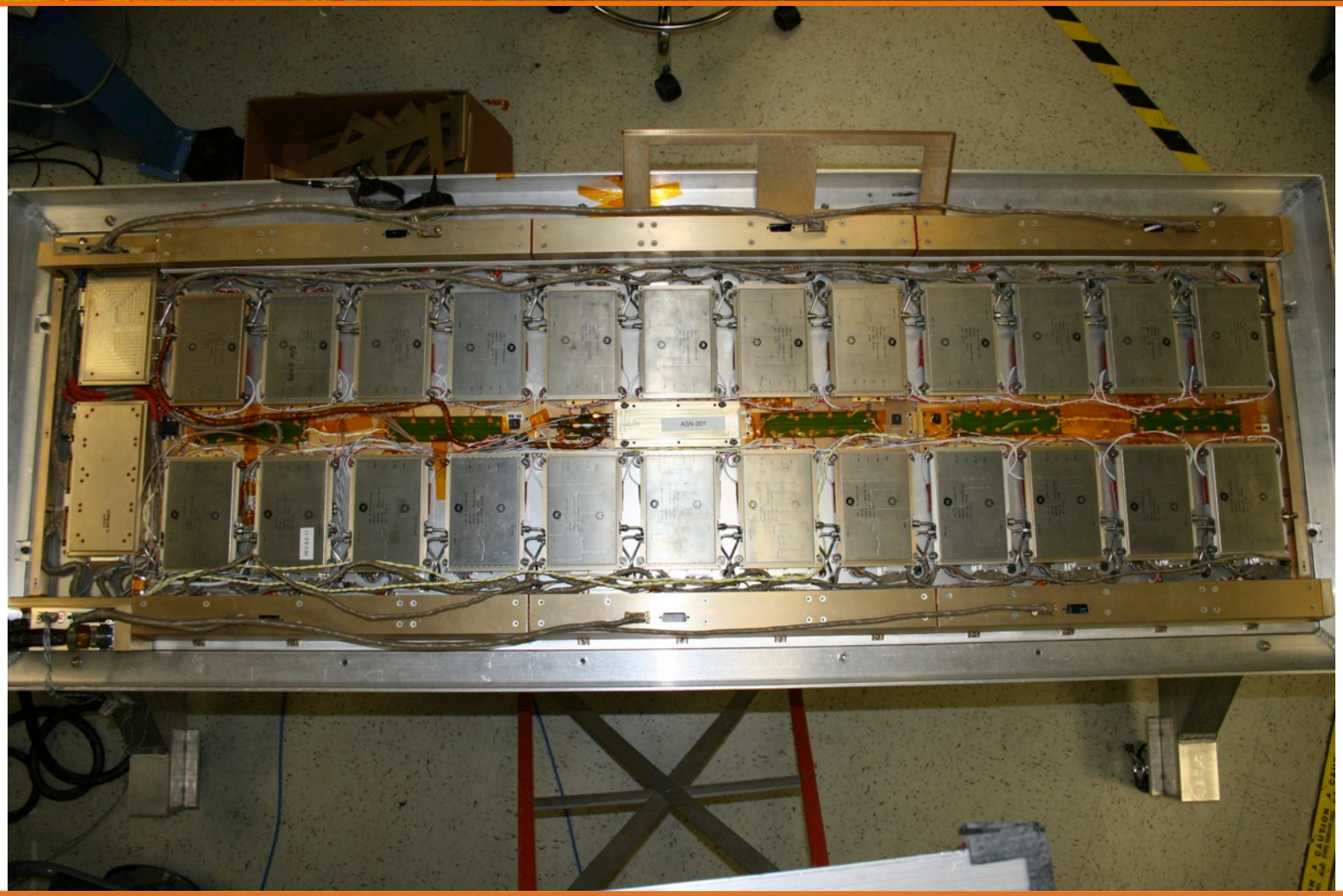


- **24 T/R Modules / 3 RF Manifold Boards ASN**

Antenna Side of Pod

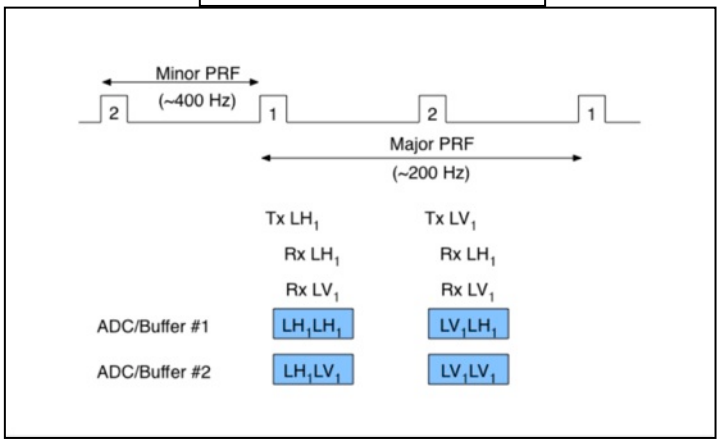


Full Array

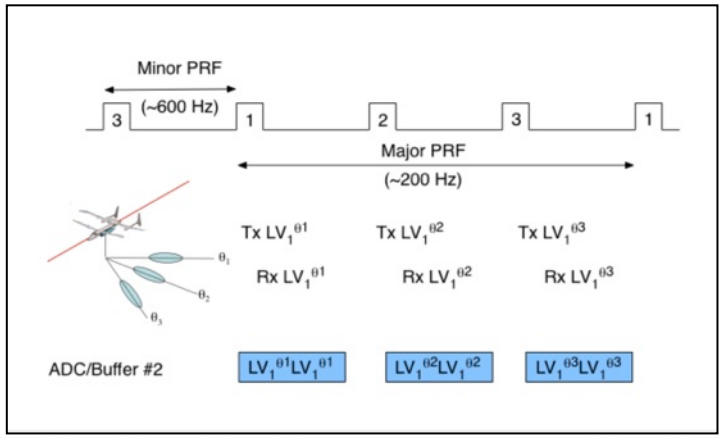


UAVSAR Modes

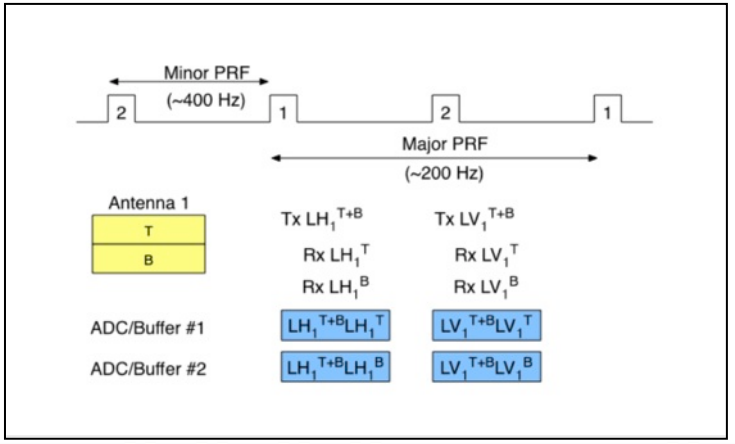
Polarimetric SAR



Multi-Squint Vector Deformation

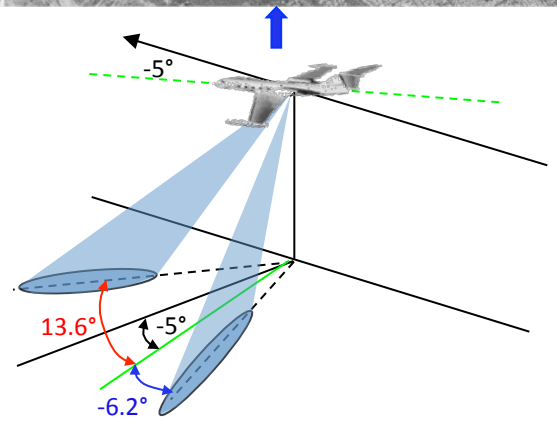


CoPol Monopulse



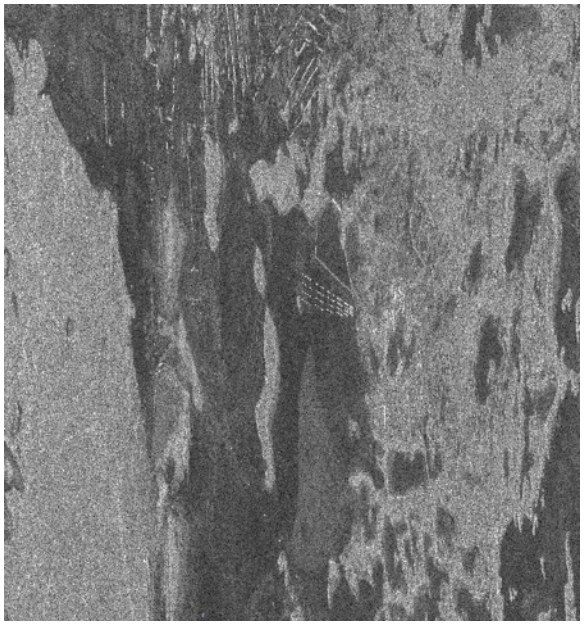
Multi-Squint Mode Example

- Data collected in the UAVSAR multi-squint mode. Yaw angle of -5.0° with azimuth steering angles of 13.6° and -6.2°.
- Anthropogenic features exhibit strong viewing angle scattering signatures.



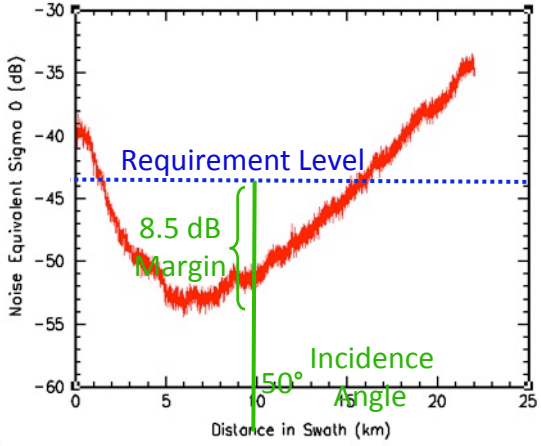
System Noise and Noise Equivalent σ_o

- Measurements of TR and Receiver noise figures at or better than required.
  - T/R NF = 2.3 with 23 dB gain (Required < 3dB)
  - Receiver NF = 4.9 with attenuator set to 24 dB
  - 350°K measured noise temperature from data (< 800°K Requirement)
  - Measured value of P_{sys} = 98 dB (Requirement is 95)
    - Combined System EIRP / loss
- Noise level in calibrated Rosamond Flight from April 24th shows better than -41 dB in darker part of the image. Scene not dark enough to estimate actual radar capability.
- Based on the measured values for noise and transmit power, Noise Equivalent σ_o for nominal data collection is expected to be < -50 dB across the swath.

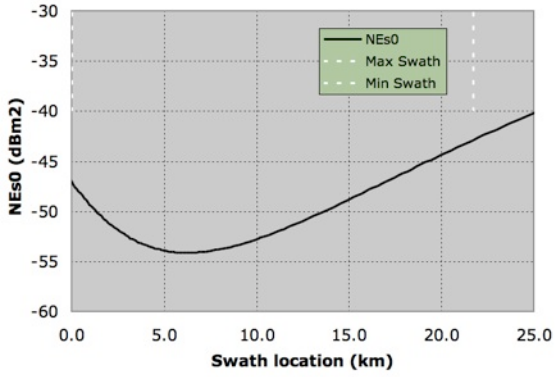


Rosamond HH SLC Image 4/24

Noise Equivalent σ_o Measured From Sniffer Pulses†



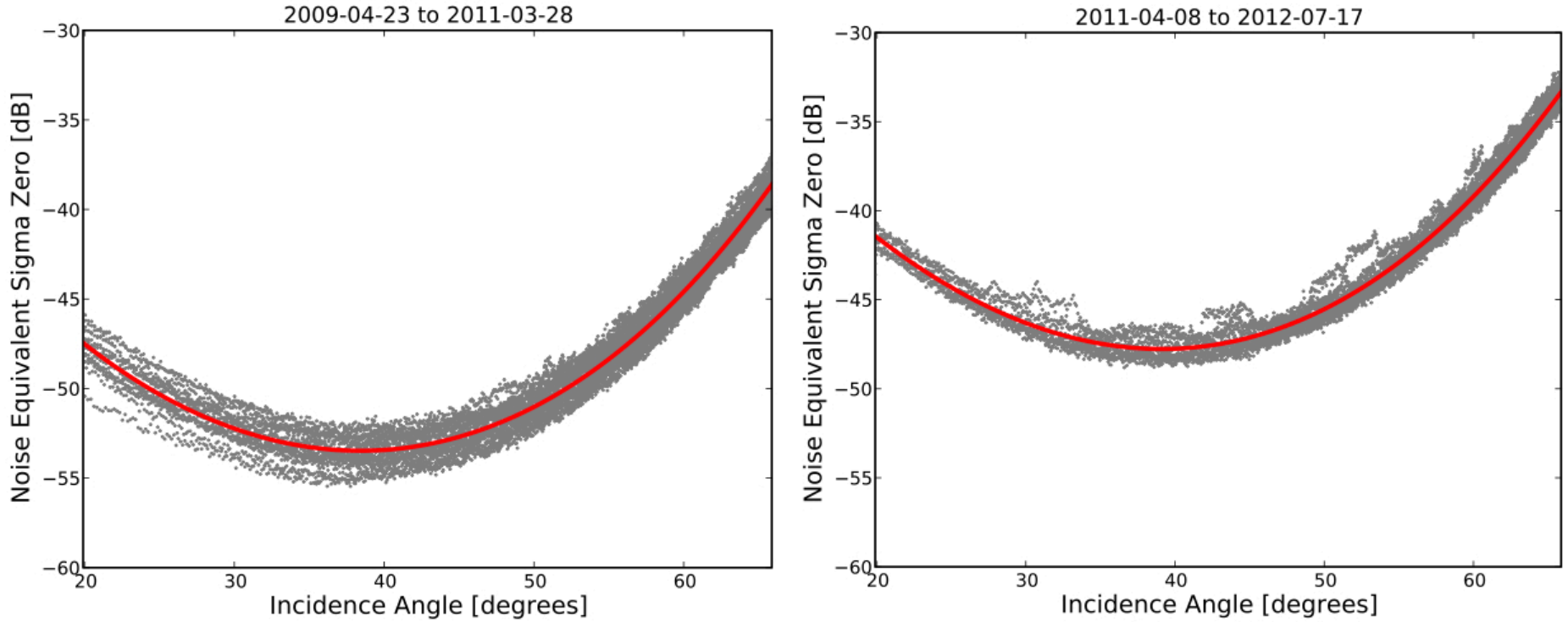
Predicted
Noise Equivalent σ_o



†Need to add 1.5 dB to normalize to 13.7 km

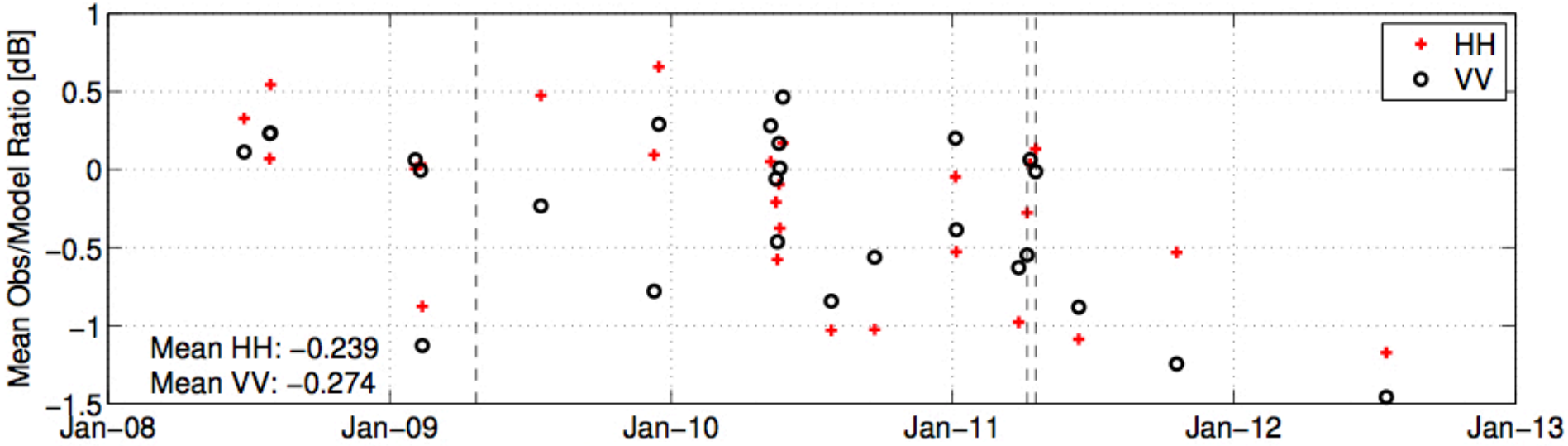
Noise Equivalent σ^o

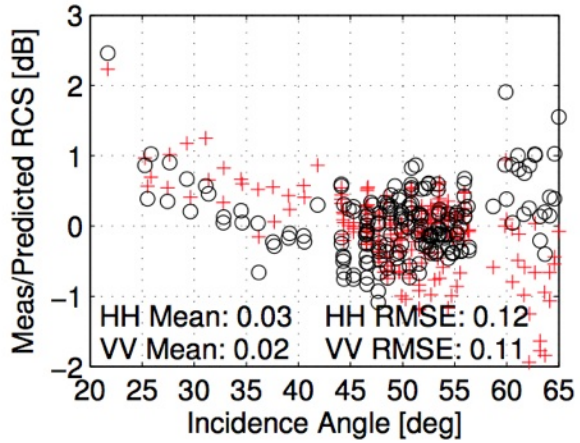
- UAVSAR has excellent noise equivalent σ^o making it suitable for a wide range studies involving radar backscatter.



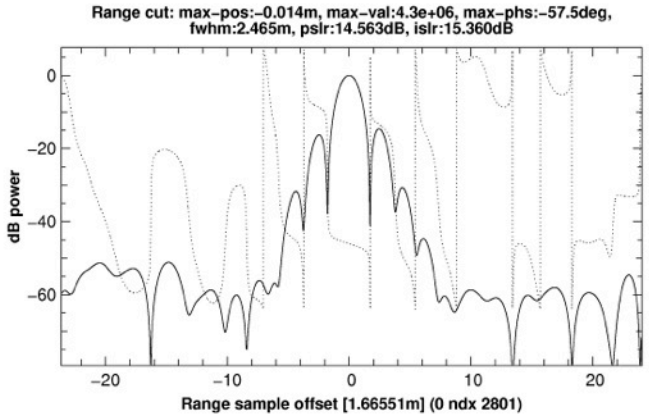
Radiometric Stability

- UAVSAR has had good radiometric stability over its five year science operations phase. Thus, UAVSAR is a good platform for testing applications that track temporal/spatial variations in radar backscatter.

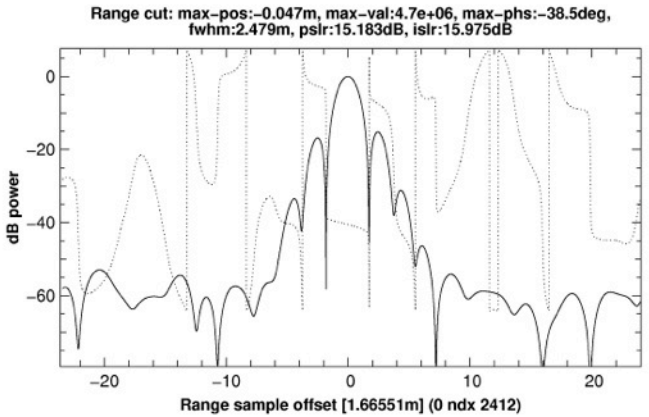




Measured Impulse Responses



f#18 170 000 cr 2



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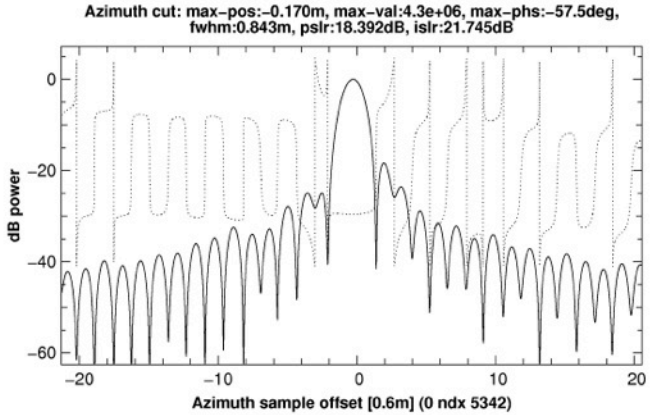
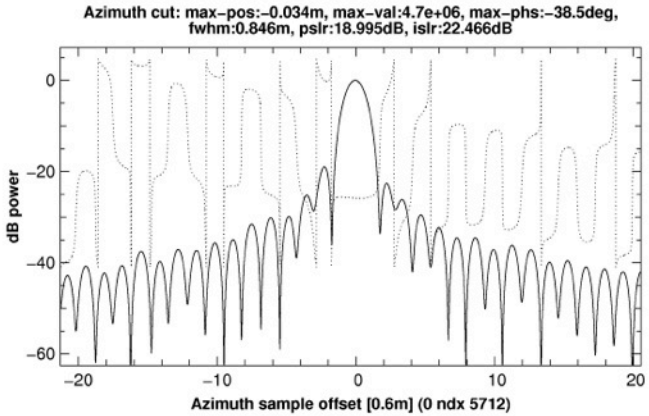
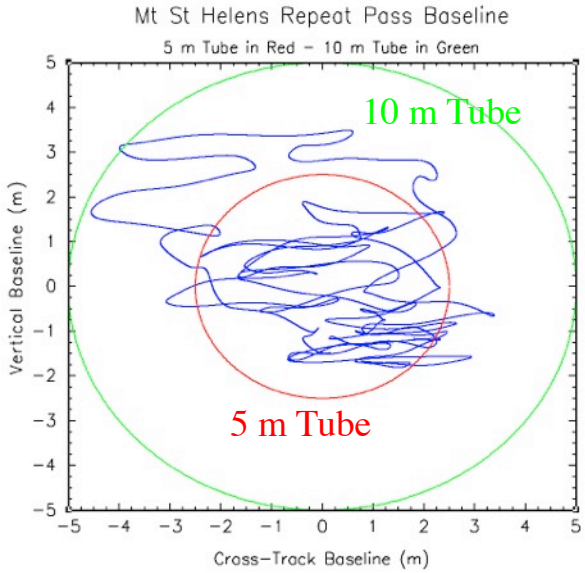
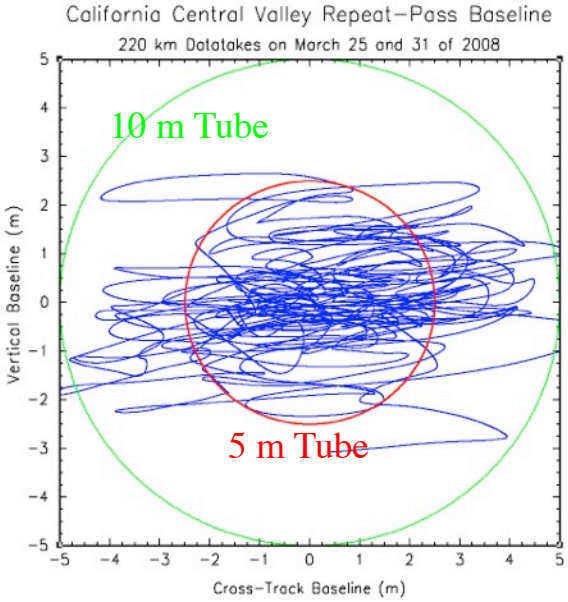
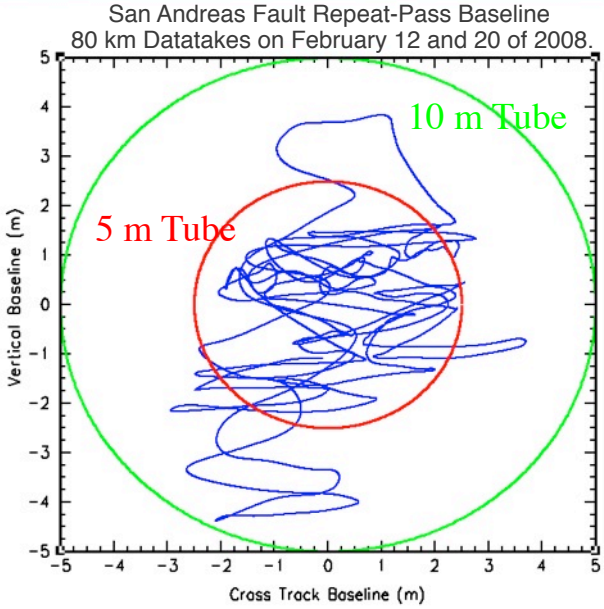




Staying in the Repeat Pass Tube

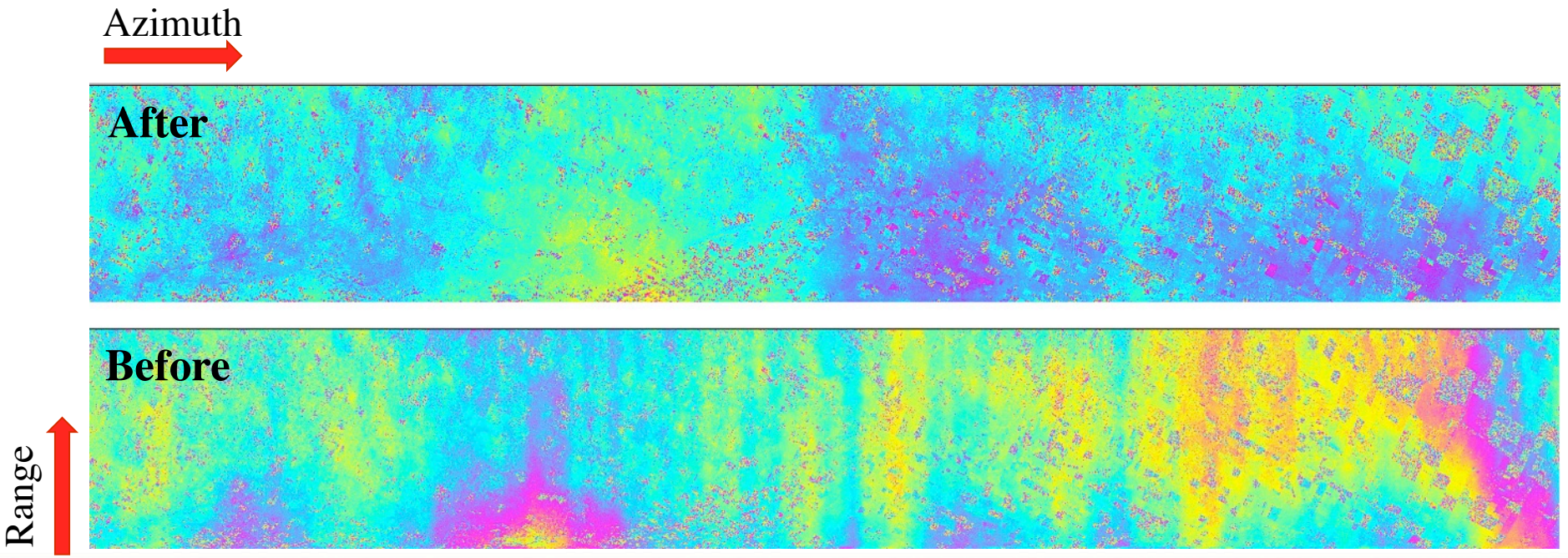




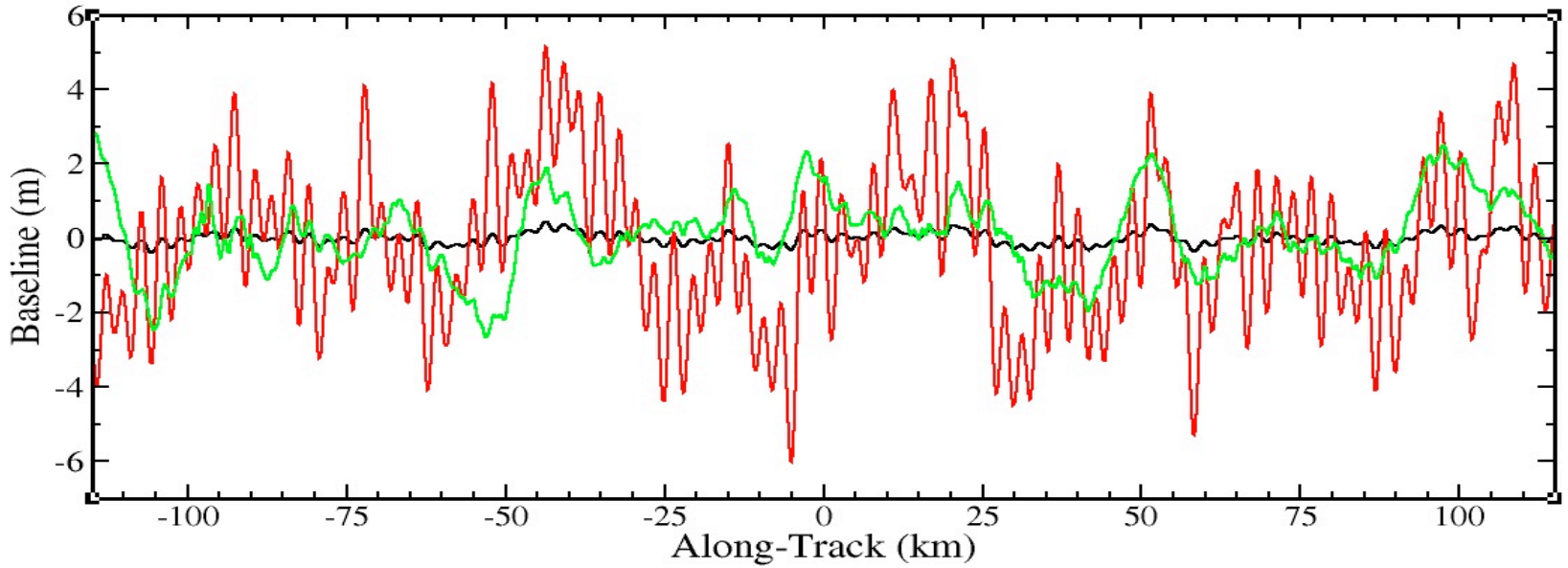


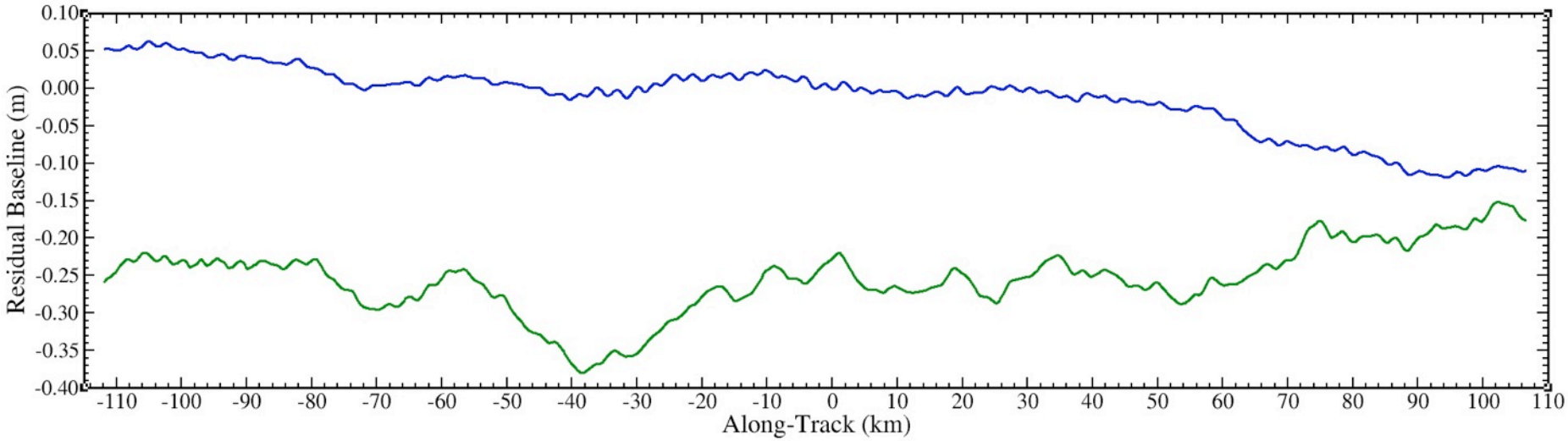
Residual Motion Removed

- Bottom interferogram shows the phase before residual motion correction and the top interferogram shows the phase after residual motion estimation.
  - Ability to remove residual motion depends on the a large extent on the quality of the data.
    - Too much temporal decorrelation, wavelength level changes within a resolution element, between observations degrades the ability to recover residual motion and hence obtain good phase measurements.



Baseline and Residual Baseline





L-band Global Hawk Configuration: Flight Demonstration on December 13, 2013

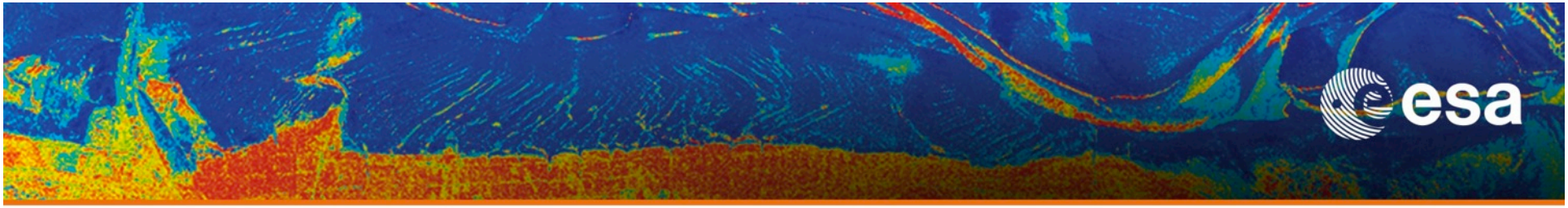
Provide ~8000 nmi range to enable data collection of distant areas of interest without complicated deployments.

- Conducted a 5-hour range flight near Death Valley and Eastern Sierra Nevada.
- Successfully acquired 4 data takes
- Tested communication with the radar and Onboard Processor via Iridium and Ku-band satcom respectively.

L-band Polarimetric color-overlay image of Owens Lake from the first flight on Friday, December 13. This data take was acquired at 41 kft, comparable to G-III altitudes.

Flight direction

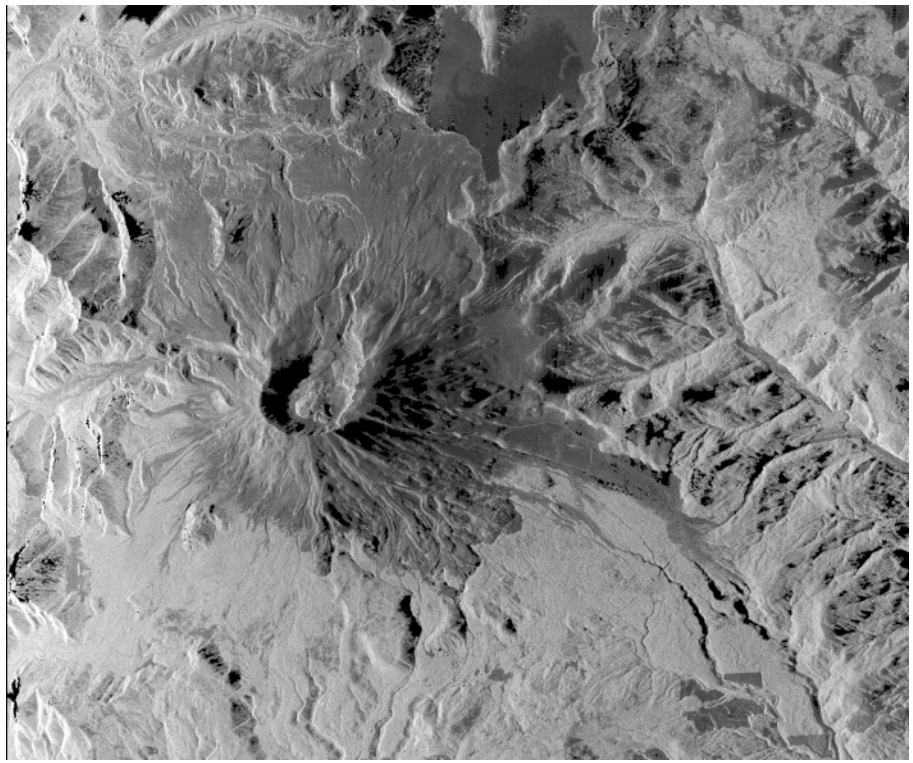
20 km cross track by 60 km along track

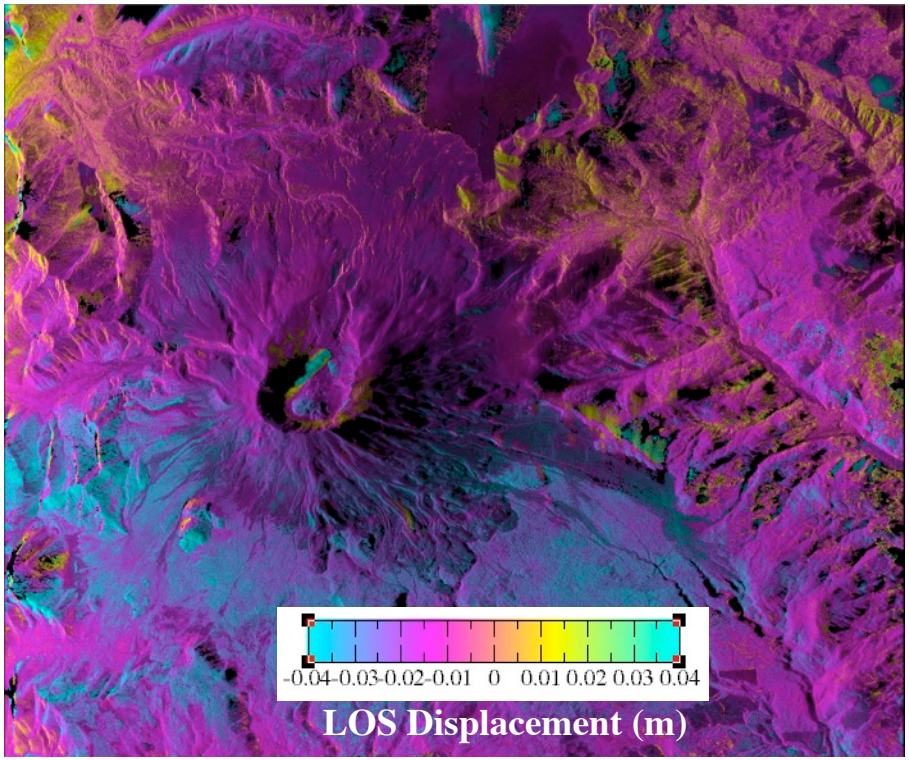


Data Examples

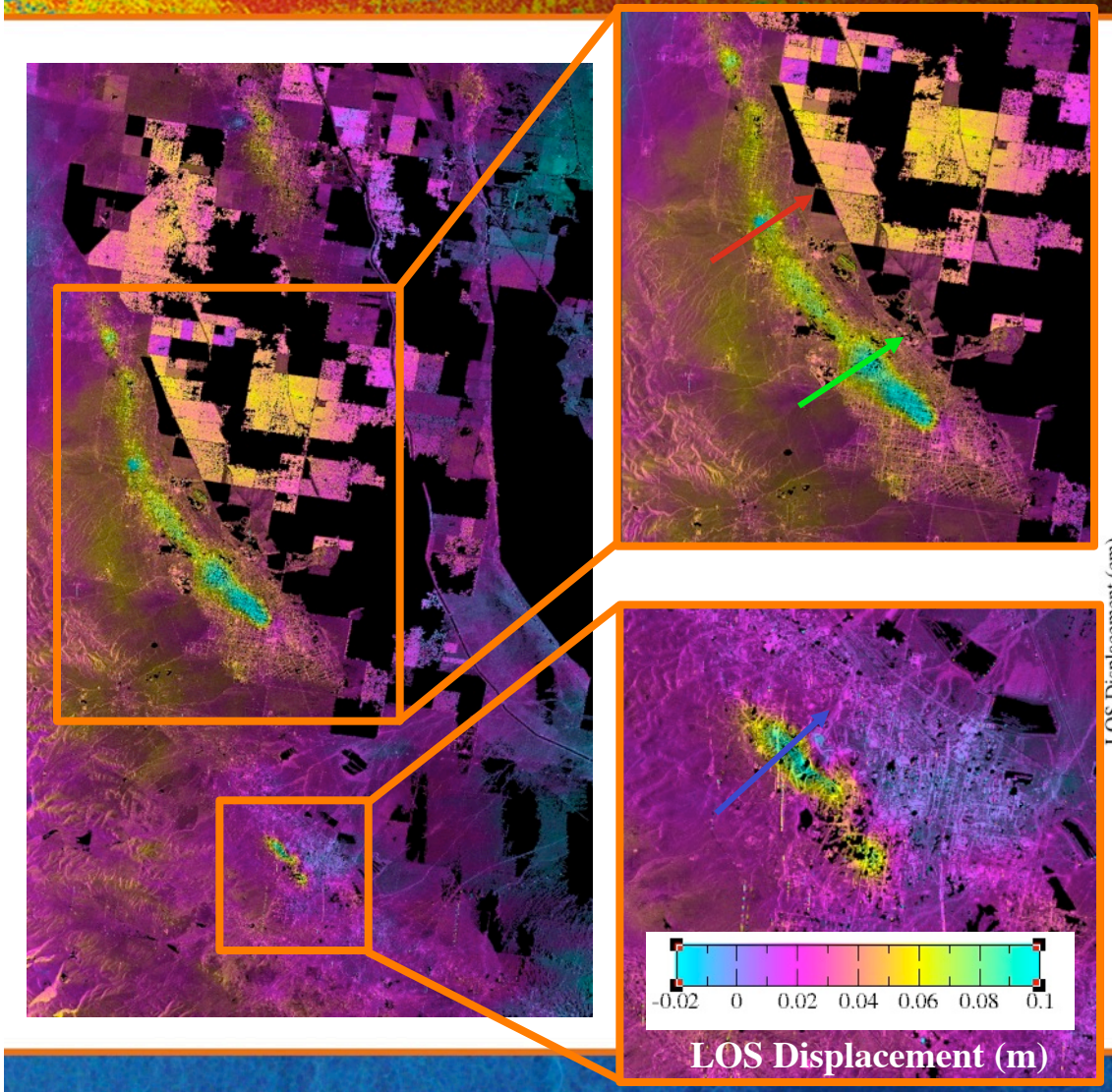
Alpine Glacier Motion on Mt St Helens

- Line-of-sight displacement map from unwrapped UAVSAR repeat pass interferogram of Mt St Helens.
  - Frozen lake in top middle shows floating logs visible beneath the snow and ice.

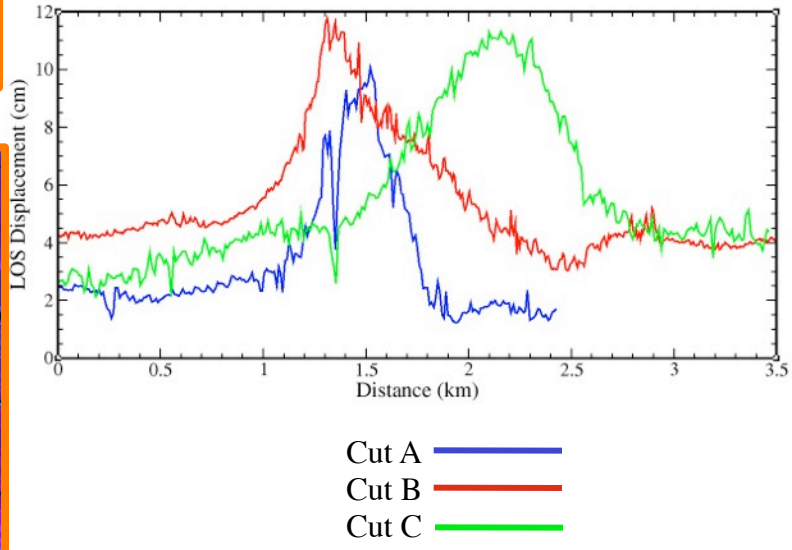




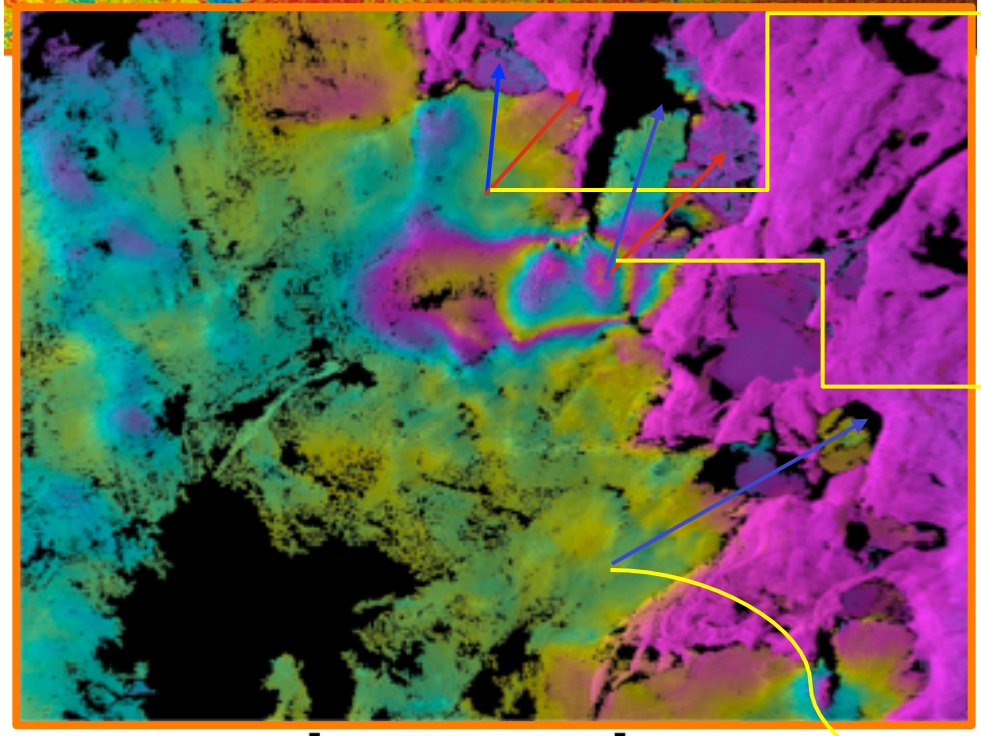
Anthropogenic Induced Surface Deformation

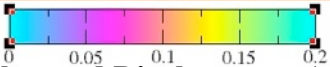


- Approximately 7 cm of surface displacement was observed due to oil pumping in Missouri Triangle, CA over an 80 day period corresponding to a maximal deformation rate of 0.88 mm/day.

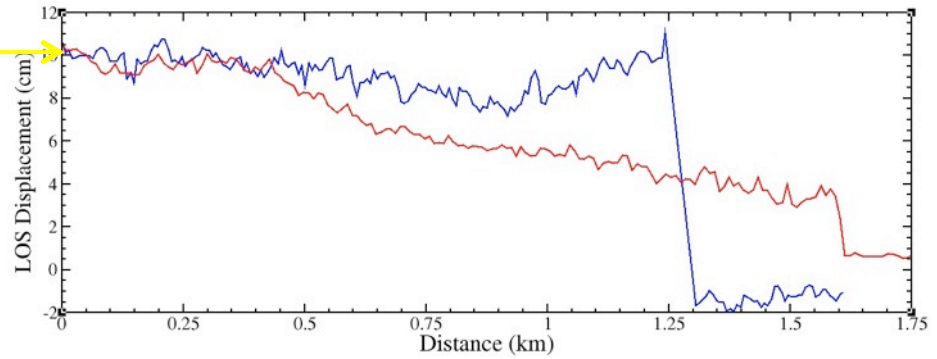


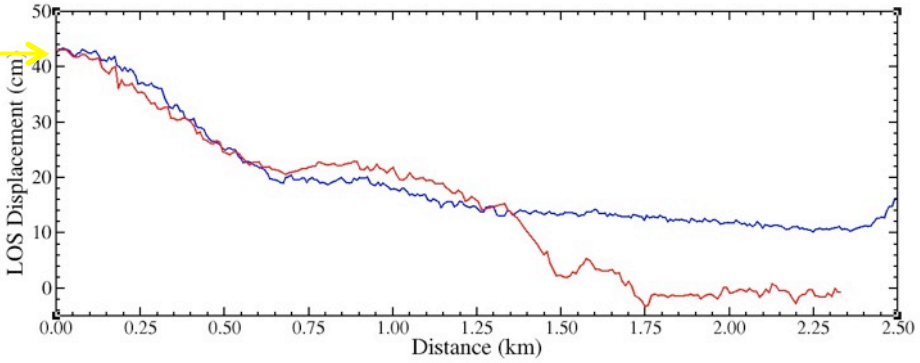
Ice Sheet Motion in Greenland

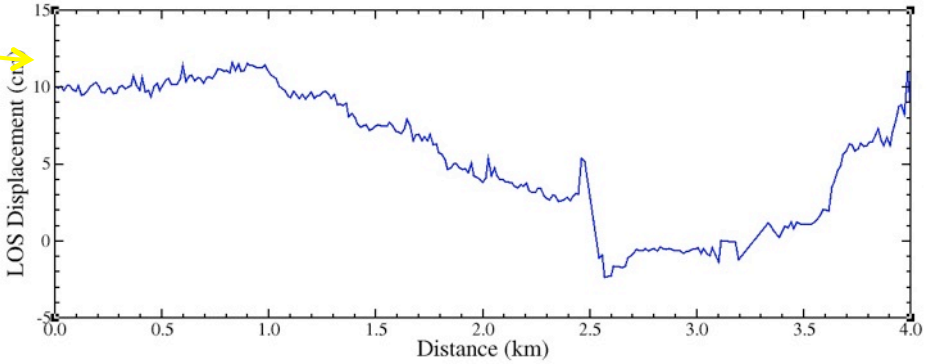




Wrapped Displacement (m)

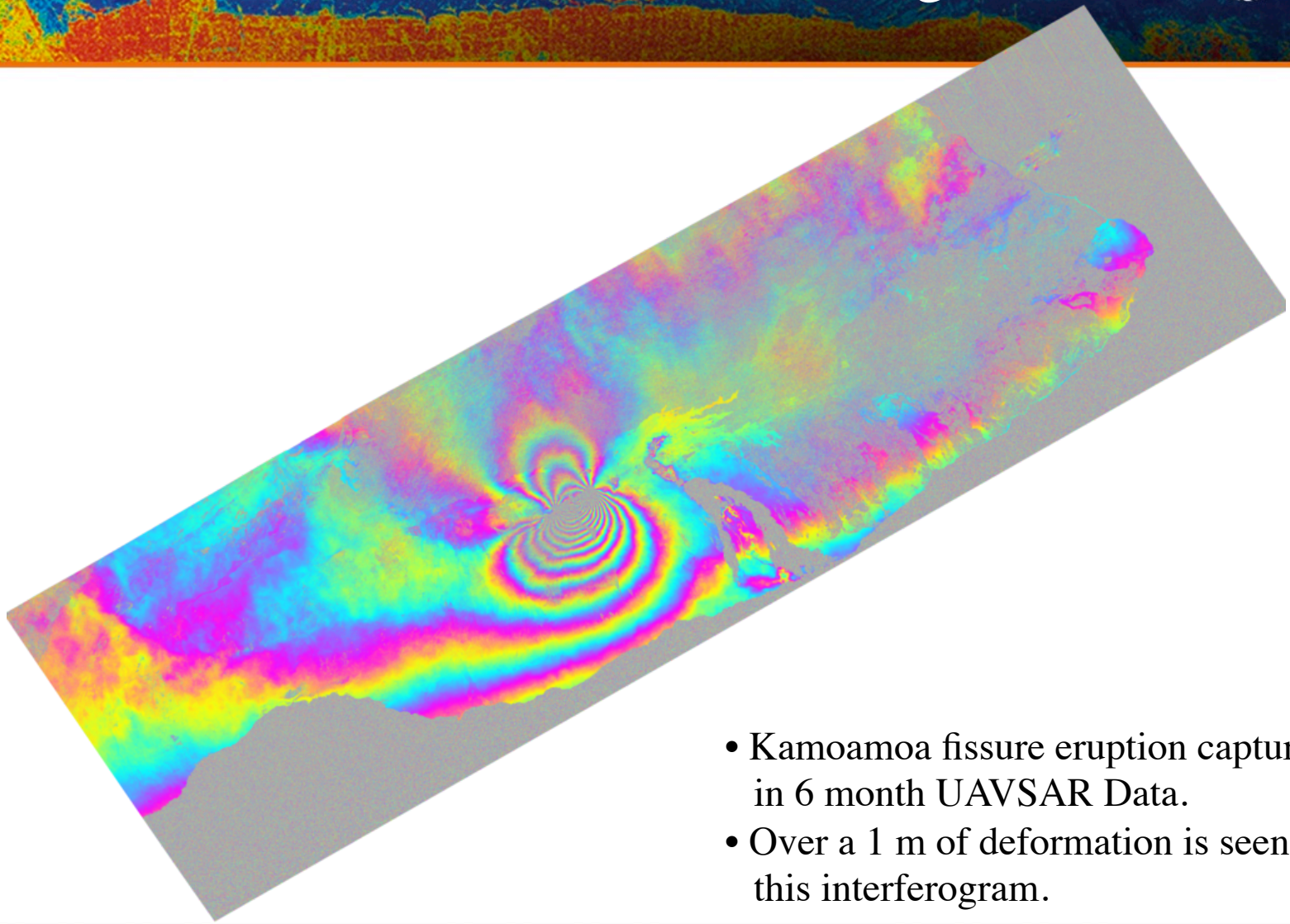






- UAVSAR's high resolution deformation maps (compared to spaceborne sensors) will provide additional information on ice dynamics not previously possible.

Volcano Monitoring



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

UAVSAR Captures Major Sinkhole Precursor

Bayou Corne Sinkhole Precursor:

- A ~2-acre sinkhole formed near Bayou Corne, Louisiana, on 3 Aug. 2012 following sidewall collapse of a storage cavity within the Napoleonville Salt Dome (photo, 8/12/2013).
- L-band UAVSAR captured precursory surface movement of up to 0.25 m that occurred ***at least one month before*** the sinkhole formed and covered a much more extensive area than that of the initially formed sinkhole.
- Detection of this was made possible by an ongoing campaign to image the Louisiana gulf coast for subsidence monitoring.
- Continued Gulf Coast acquisitions will enable observation of sinkhole progression (now ~25 acres in size).

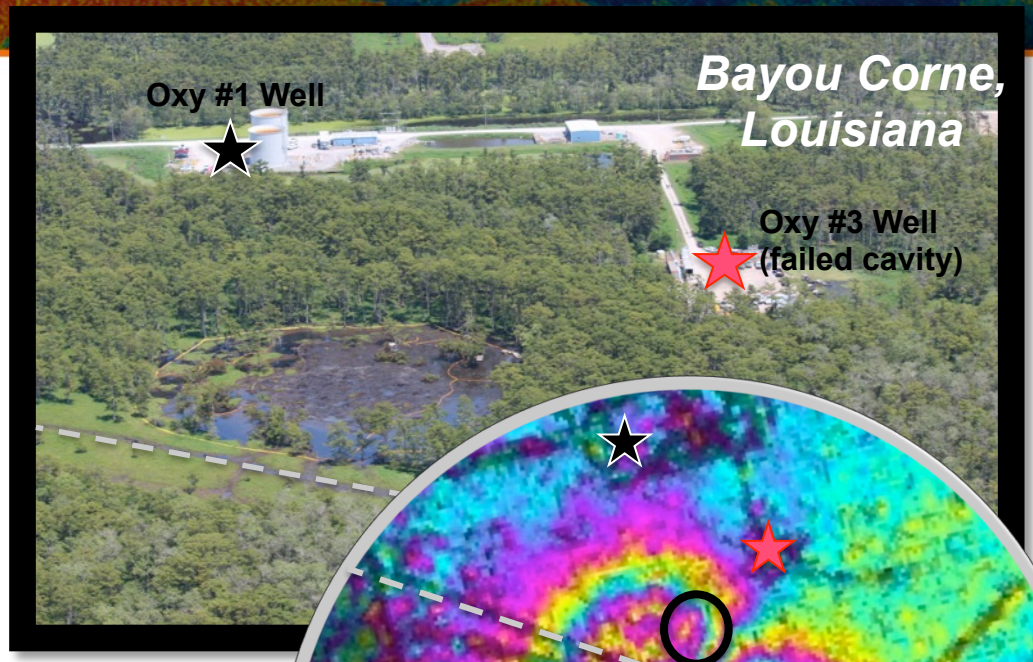
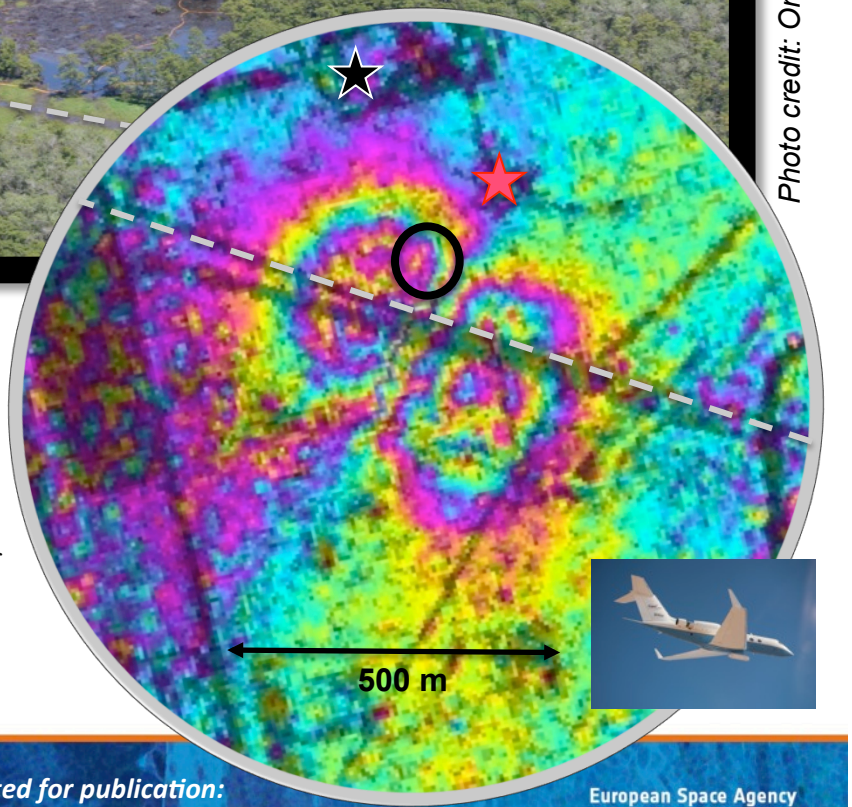


Photo credit: On Wings of Care, 2012



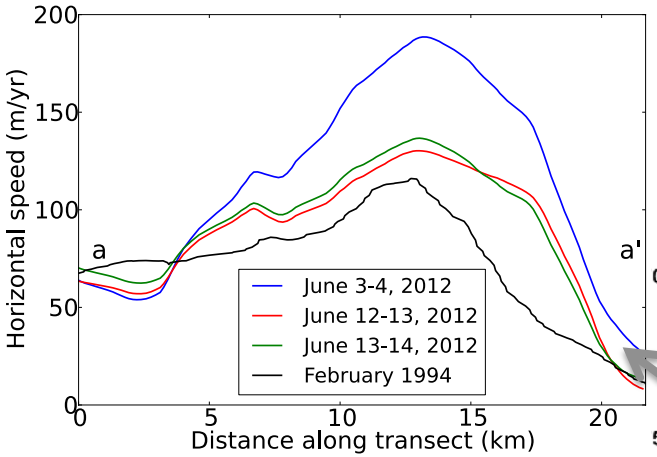
Initial sinkhole location shown in black. Colors represent movement of the surface, with one full color wrap corresponding to 120 mm of displacement. Well locations are indicated.

Peer reviewed article accepted for publication:
Cathleen Jones and Ronald Blom (2013), *Bayou Corne, Louisiana, sinkhole: Precursory deformation, in* Geology.

Glacier Seasonal Dynamics: Iceland

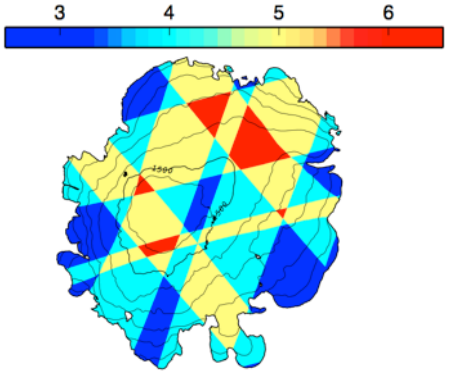
Caltech, JPL, UC Irvine, Univ. Iceland

Do warmer climates equal faster flowing glaciers? This question requires dynamic models that can couple large-scale hydrological behavior to ice flow.



Velocity profile along transect indicates a slowdown in mid June due to reduced sliding. How will this change in the winter? UAVSAR data acquired in January 2014 will help address this question.

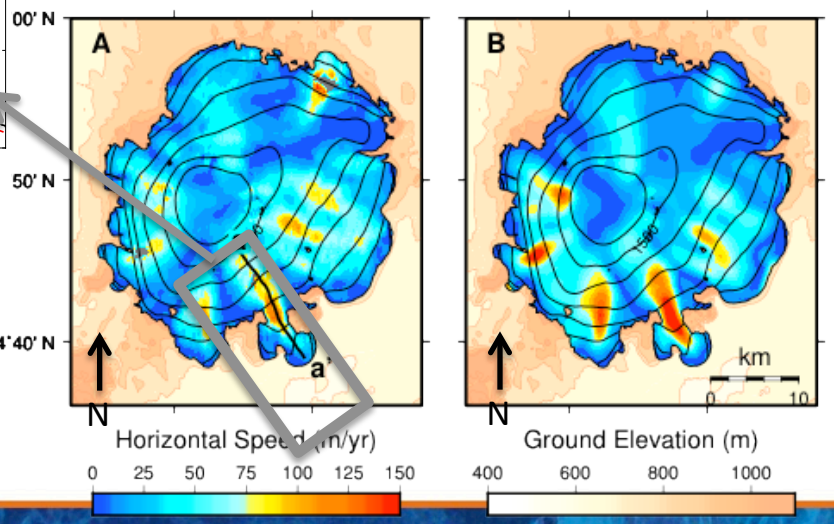
 # UAVSAR scenes acquired in Jun-12



UAVSAR imagery are being used to generate 3D surface velocity fields for the Hofsjökull glacier. Results provide **new empirical evidence to test dynamic models of glacial hydrology**. These will provide improved estimates of the influence of meltwater on glacier velocity.

Velocity fields inferred from InSAR

ERS1/2, Feb 1994 *UAVSAR, Jun 2012*

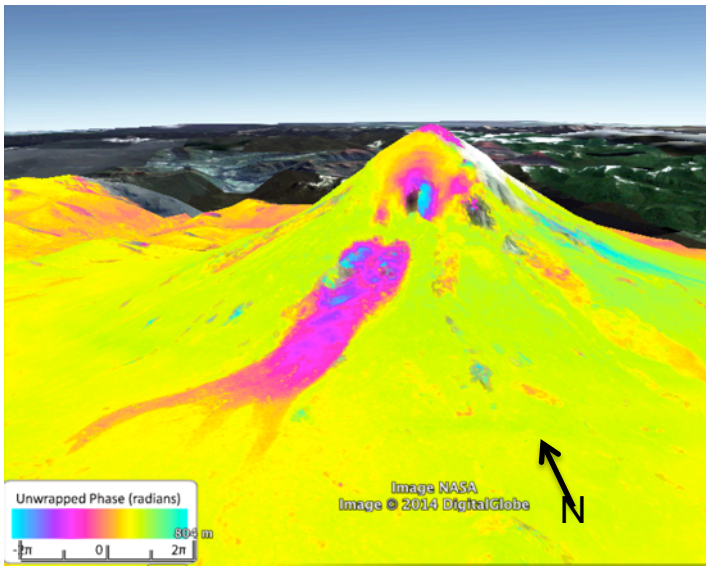


Minchew B., Simons M., Hensley S., Larour E., Morlighem M., Bjornsson H., Passion F. (2013). Temporal variation of basal stress in temperate Icelandic glaciers during the early melt season.

Short Time Glacier Deformation: Chile

A multi-agency collaboration between USGS, NASA, and the Chilean Air Force has been established to assess the health of Chile's glacier resources.

Climate-induced glacier retreat has important consequences for water resource management in Andean countries.



Two-day unwrapped interferogram over the Lanin Glacier.

In March 2013, UAVSAR imaged 4 glaciers at the Chilean-Argentinian border to provide a unique view of their short-timescale (< 4 day) temporal dynamics. In comparison to ground sensor data, the results indicate:

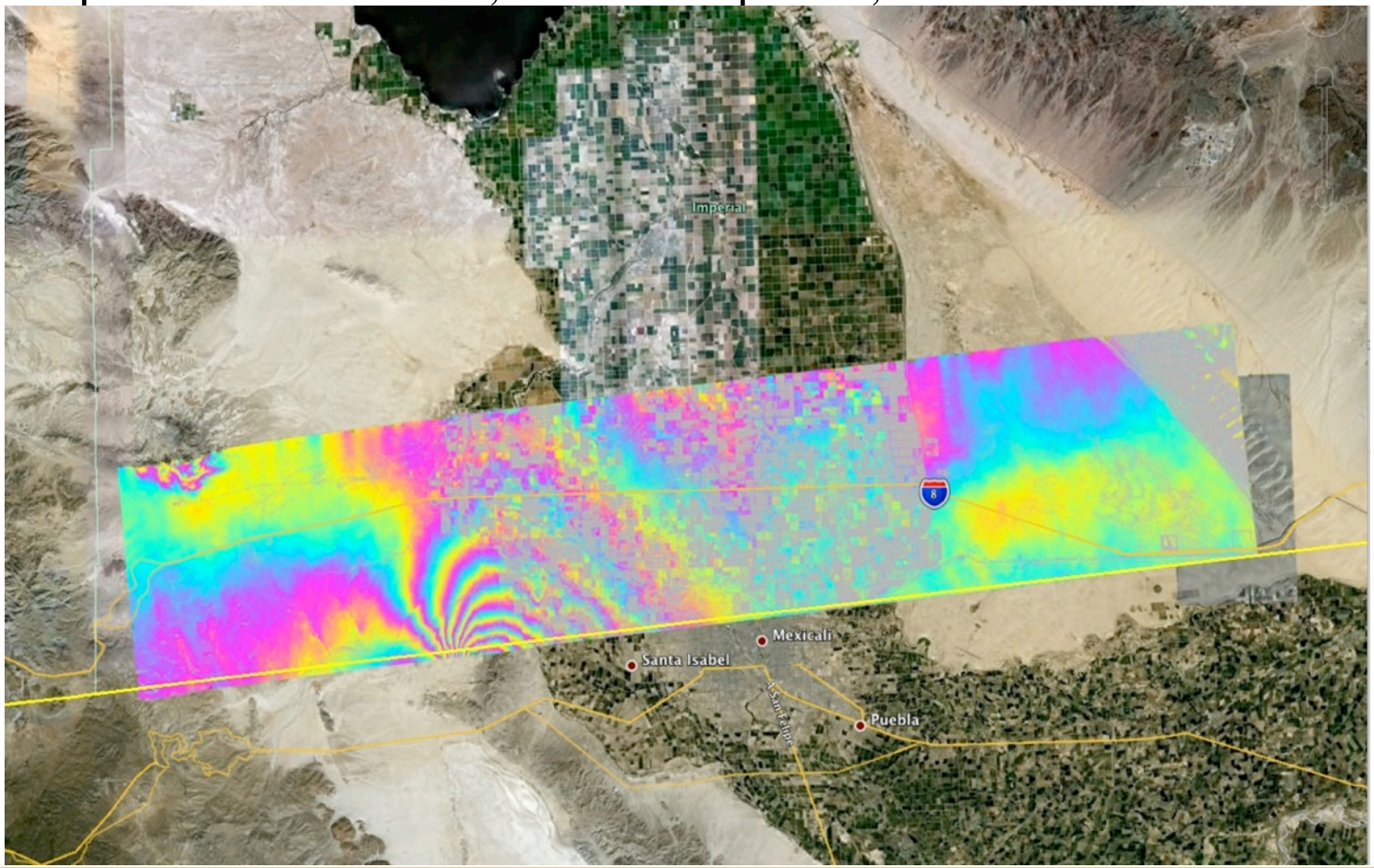
- Significantly faster velocities;
- More widespread activity.

Ice velocity fields derived from UAVSAR InSAR products are being integrated with remote sensing and ground data maintained by Chilean institutions:

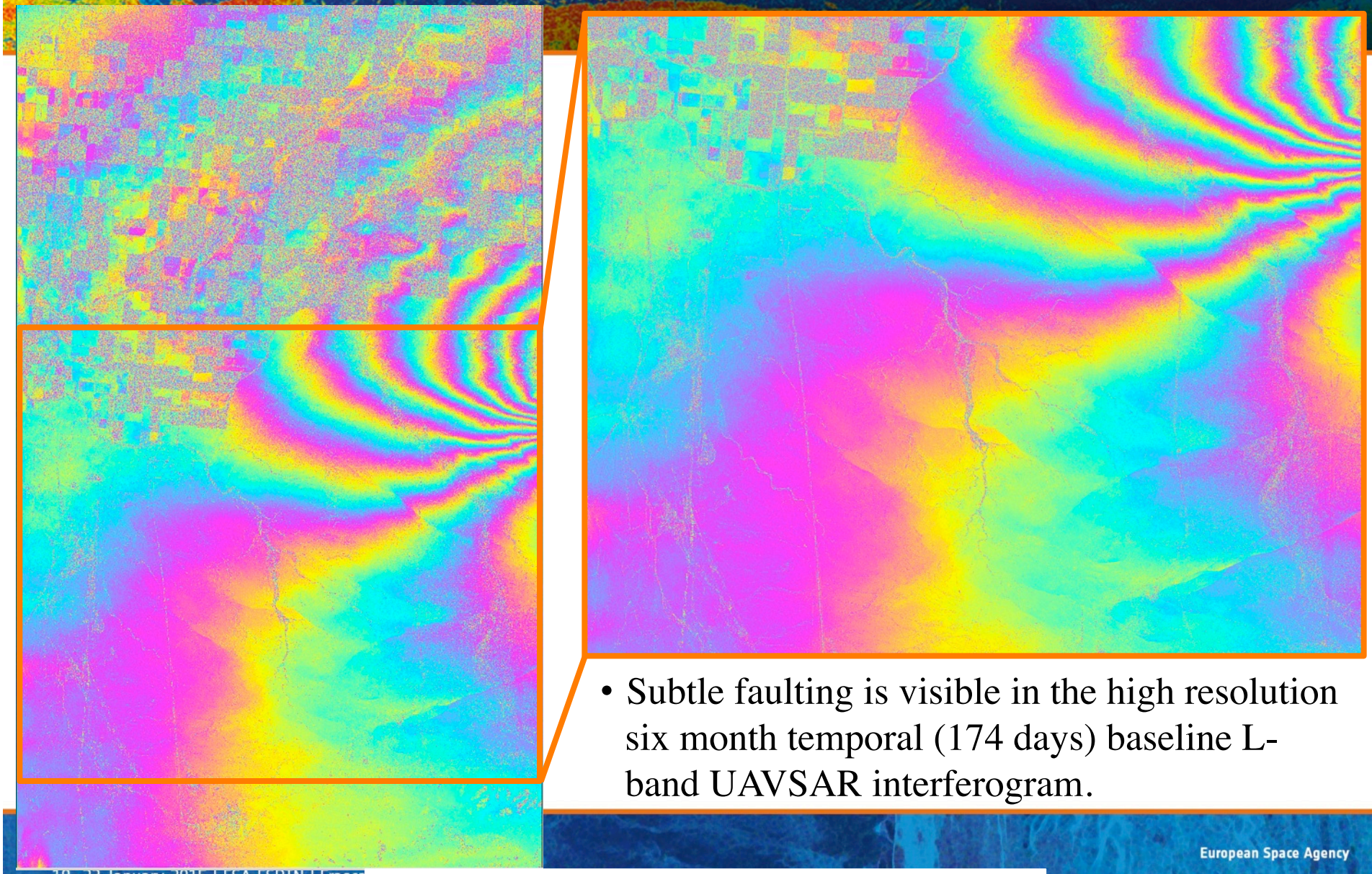
- Lidar
- GASS instruments: Glacier Ablation Sensor Systems

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

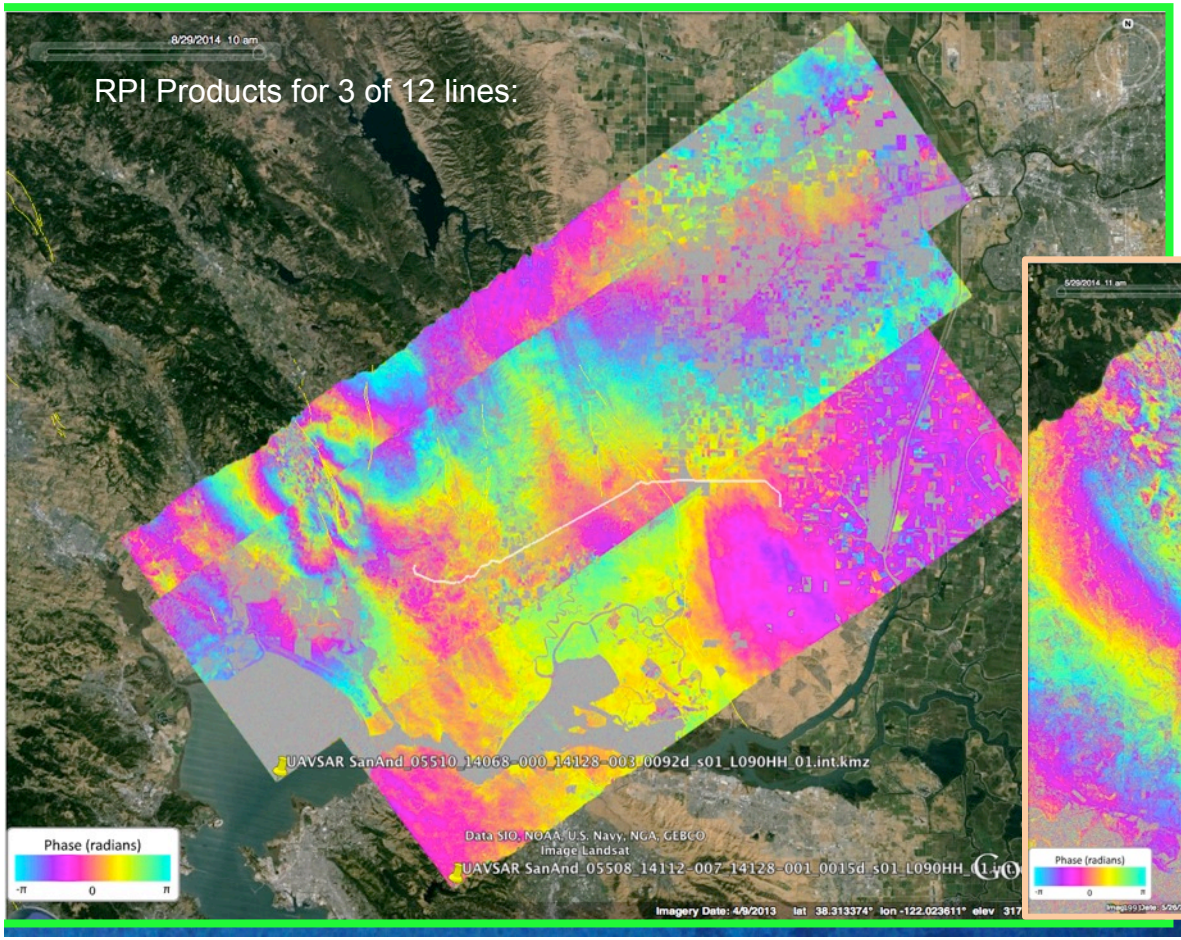


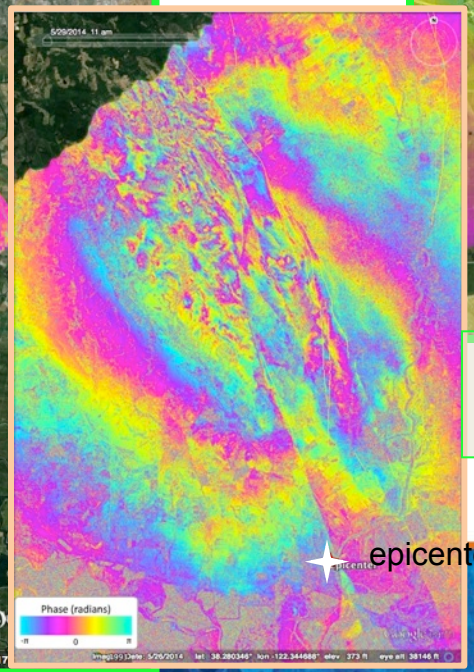
- Subtle faulting is visible in the high resolution six month temporal (174 days) baseline L-band UAVSAR interferogram.

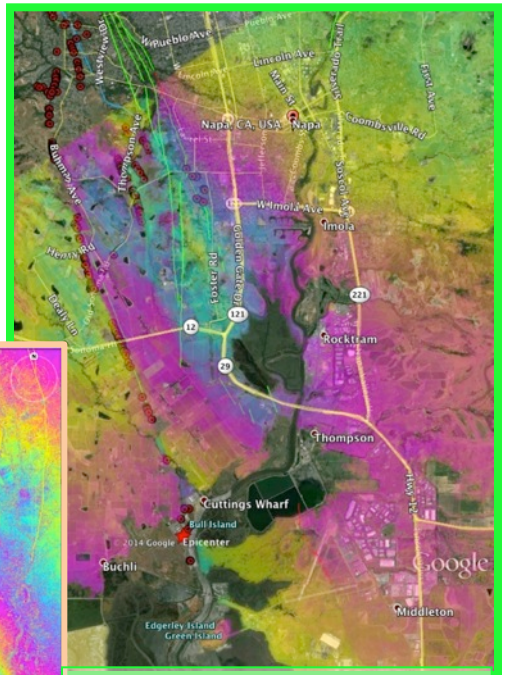
UAVSAR Napa Earthquake Rapid Response

NASA502 aircraft was redirected to support UAVSAR flight over Napa Valley on 8/29 to capture co- and post-seismic movement from the M. 6.0 South Napa earthquake that occurred on 8/24/14

- UAVSAR data were acquired to aid rapid response activities in determining faulting and levee, aqueduct damage assessment.
- Browse products were delivered to investigators within 2 days.



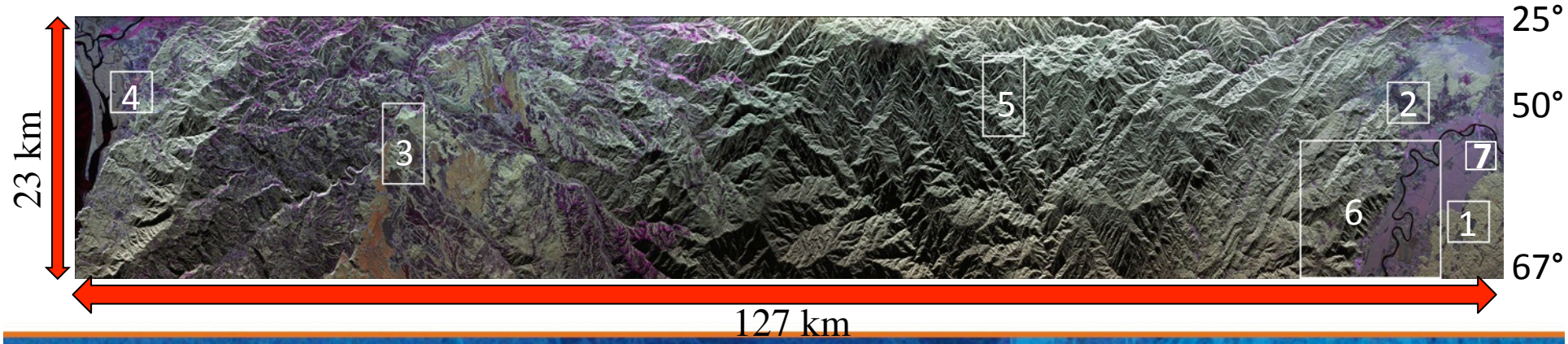




Red dots show locations of mapped offsets identified by USGS

Initial Study of La Amistad

- For our initial analysis we processed the short physical baseline pairs with lengths less than 100 m. This consisted of 5 tracks for a total of 10 interferometric pairs with physical baselines ranging from 1.6 to 100 m.
- Temporal baselines ranged from an half hour to three hours.
- From these pairs we picked 6 regions spanning a range of biomes, terrain types and incidence angle.
- Our initial study goals are:
  - Understand the variability of temporal correlation for short time repeat pass pairs in a tropical environment.
  - Check to consistency of PolinSAR inversions for a single baseline.



Physical/Temporal Baselines

Physical/Temporal Baselines (m/hr)

Track #	1	2	3	4	5
1		1.6	19.0	79.1	99.4
2	3.2		19.2	79.4	99.7
3	0.7	-2.6		60.2	80.5
4	1.3	-1.9	0.7		20.3
5	1.9	-1.3	1.3	0.6	

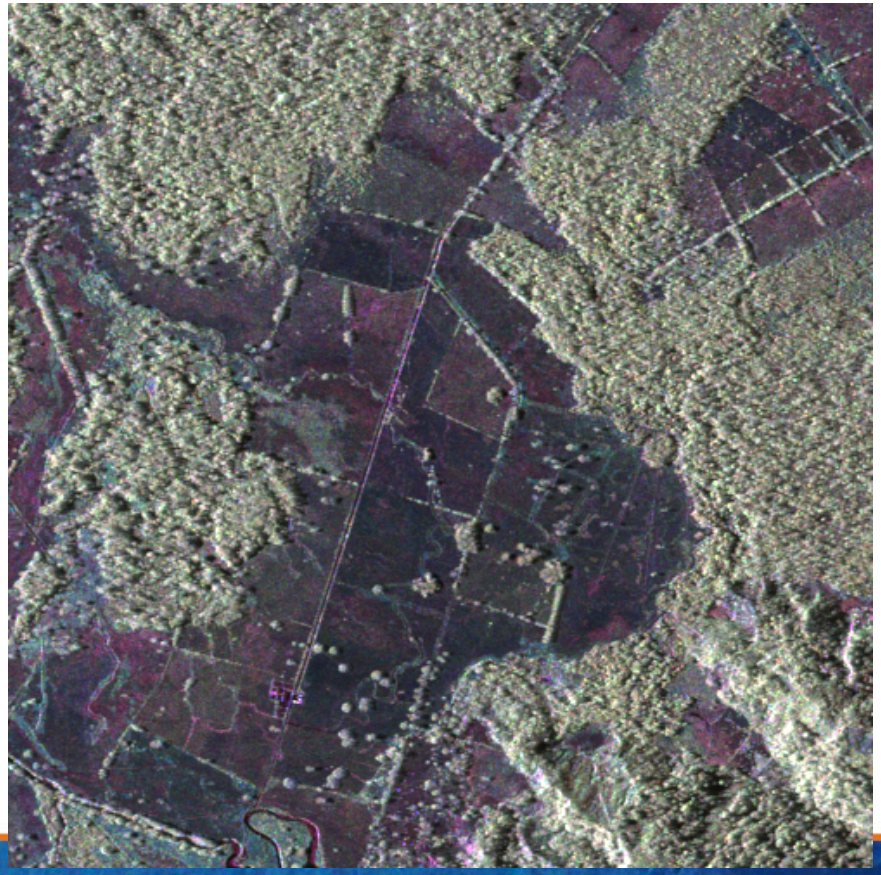
Baseline Number

Track #	1	2	3	4	5
1		0	1	3	6
2			2	4	7
3				5	8
4					9
5					

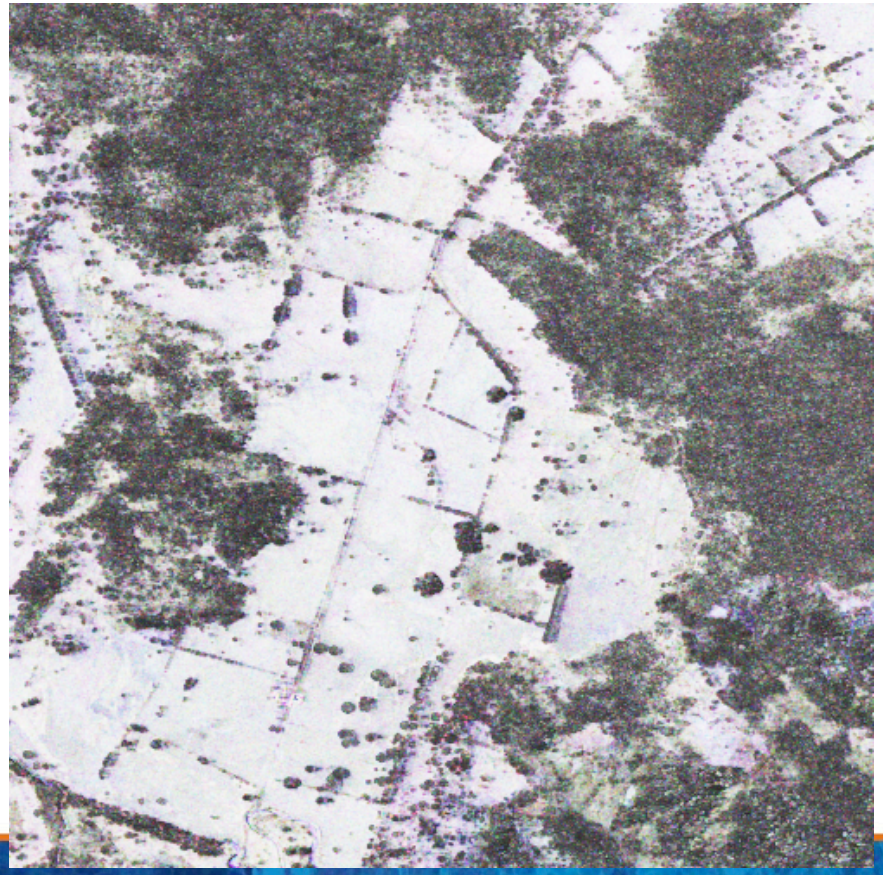
Average Backscatter and Correlation Images

- Average backscatter for all passes and average correlation over all interferometric pairs.

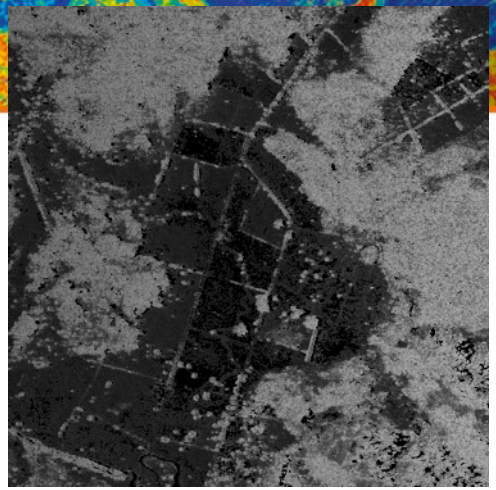
$\sigma_{hh} + \sigma_{vv}$ $\sigma_{hh} - \sigma_{vv}$ σ_{hv}



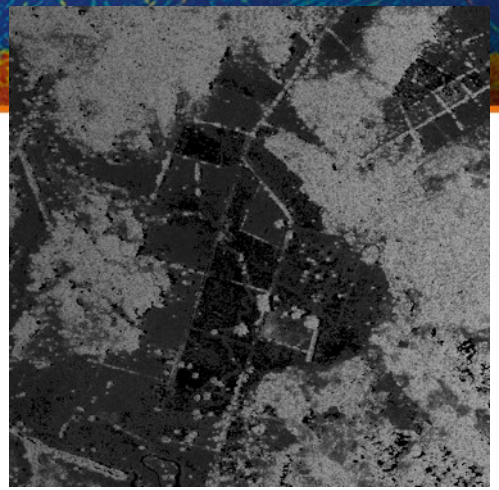
γ_{hh+vv} γ_{hh-vv} γ_{hv}



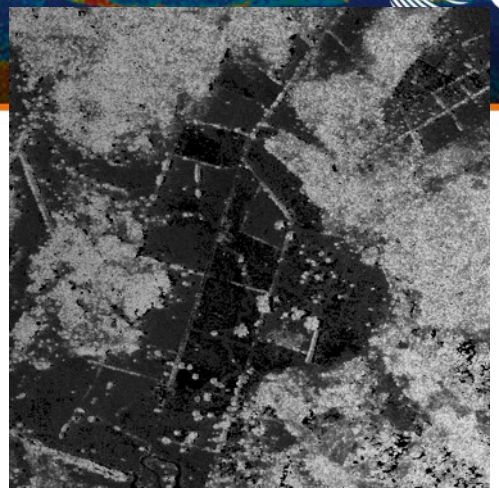
PolinSAR Vegetation Height Estimates



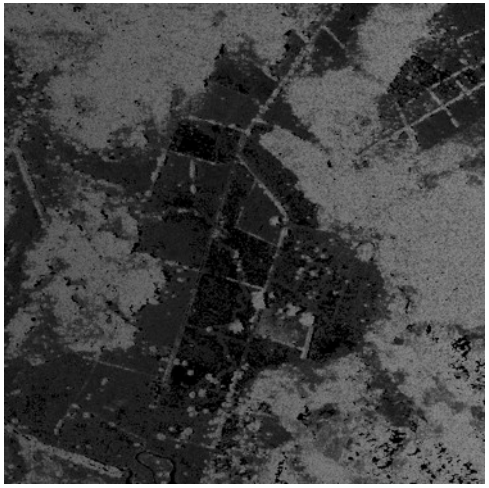
Baseline #: 3
B: 79 m
Dt: 1.3 h



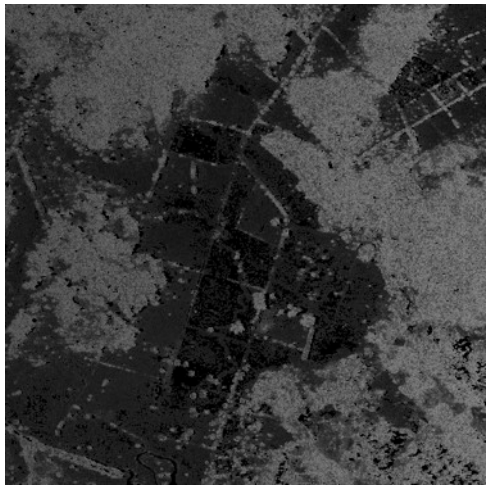
Baseline #: 4
B: 79 m
Dt: 1.9 h



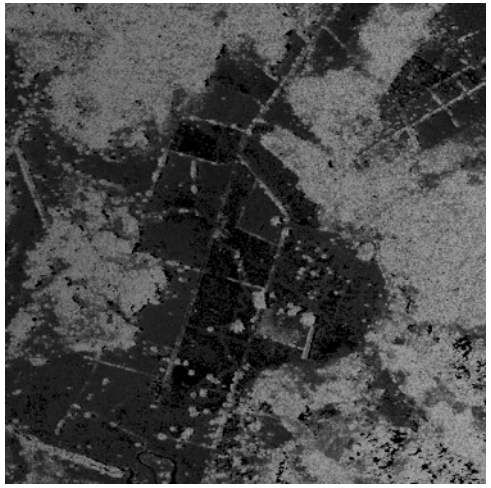
Baseline #: 5
B: 60 m
Dt: 0.7 h



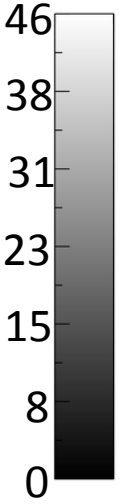
Baseline #: 6
B: 99 m
Dt: 1.9 h



Baseline #: 7
B: 99 m
Dt: 1.3 h

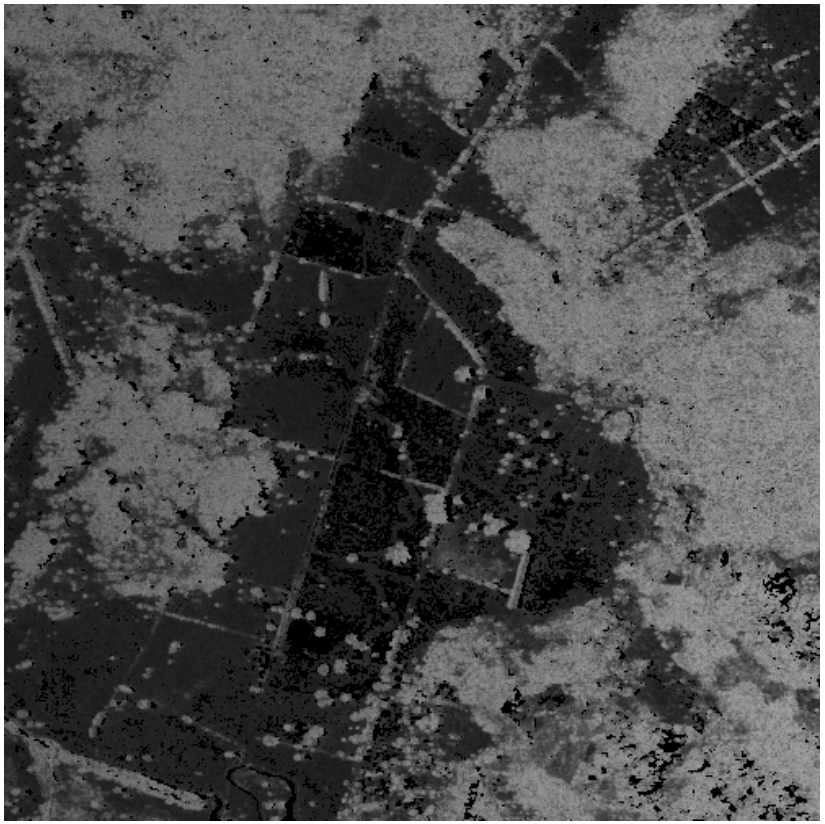


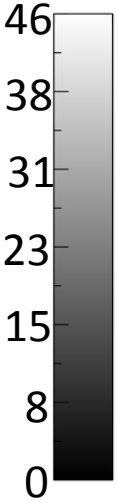
Baseline #: 8
B: 81 m
Dt: 1.3 h

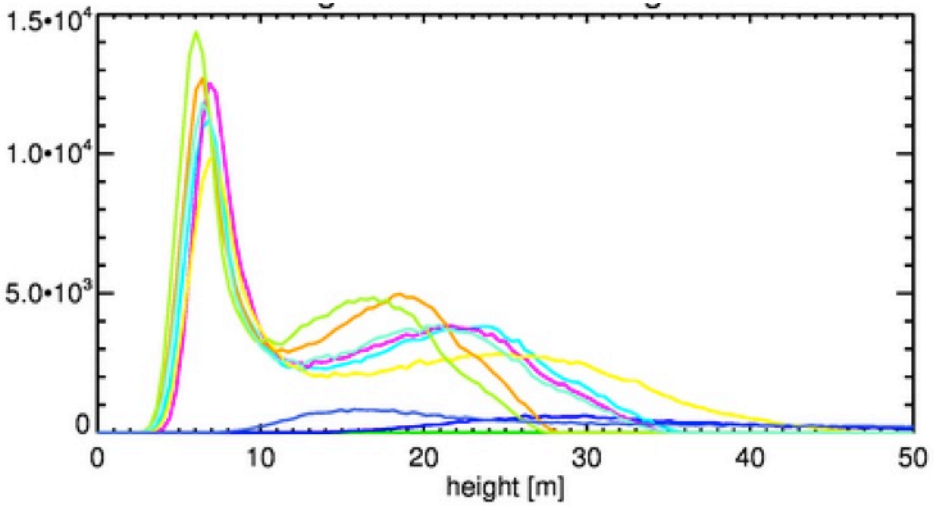


Average Height and Histograms

- Height estimate averaged over all interferometric pairs and height histograms for the various baselines.





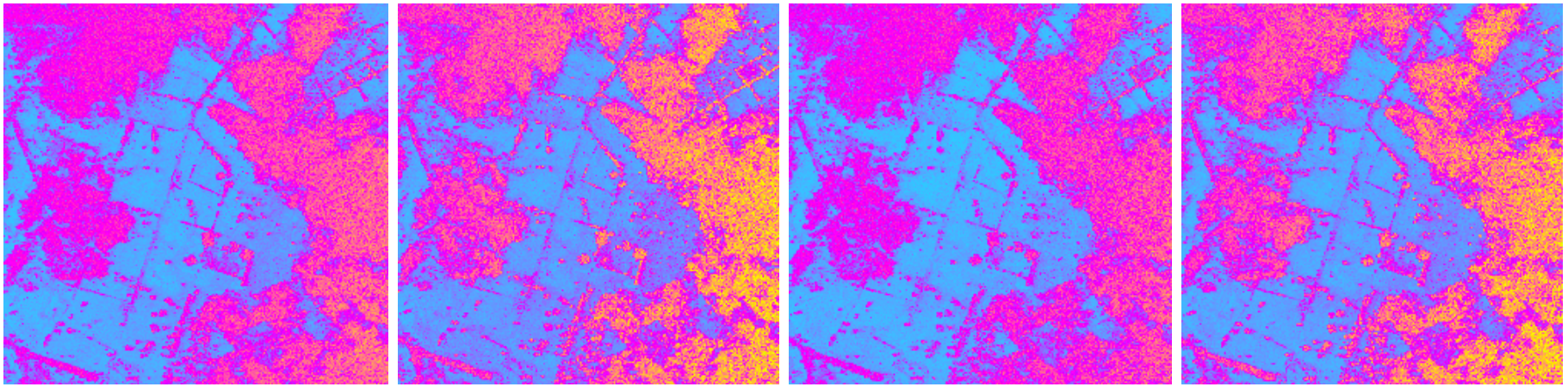


bl0
bl1
bl2
bl3
bl4
bl5
bl6
bl7
bl8
bl9

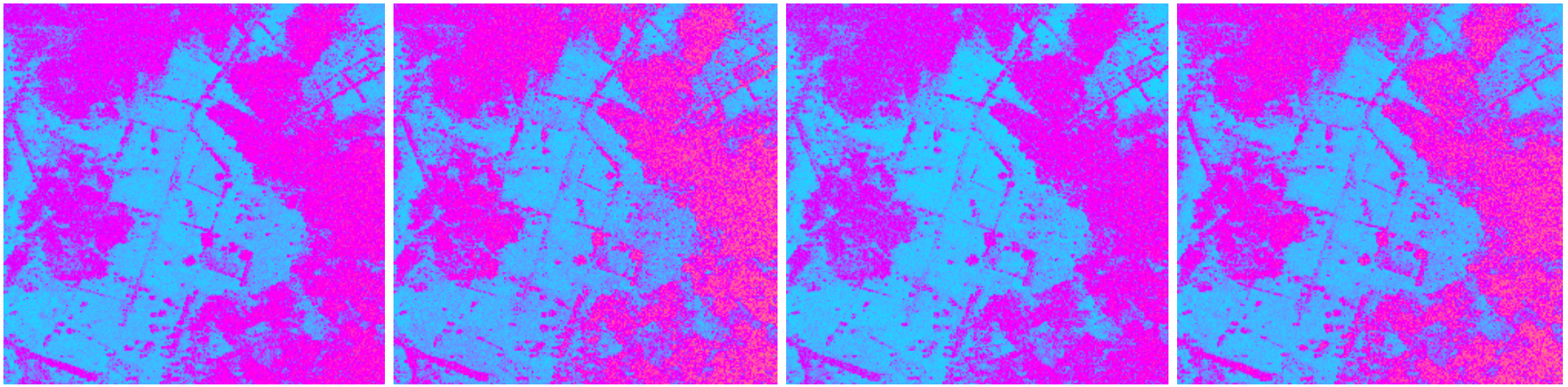
Estimated Tree Height RVoG vs RMoG – Region II

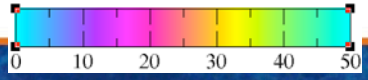
RVoG

Baseline #: 6 | Baseline #: 4 | Baseline #: 7 | Baseline #: 8



RMoG

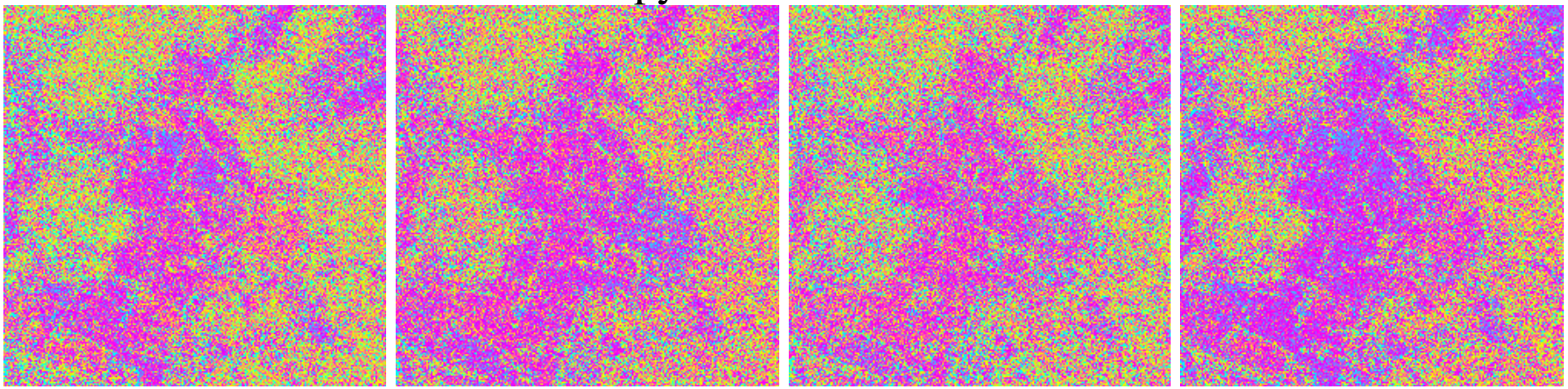




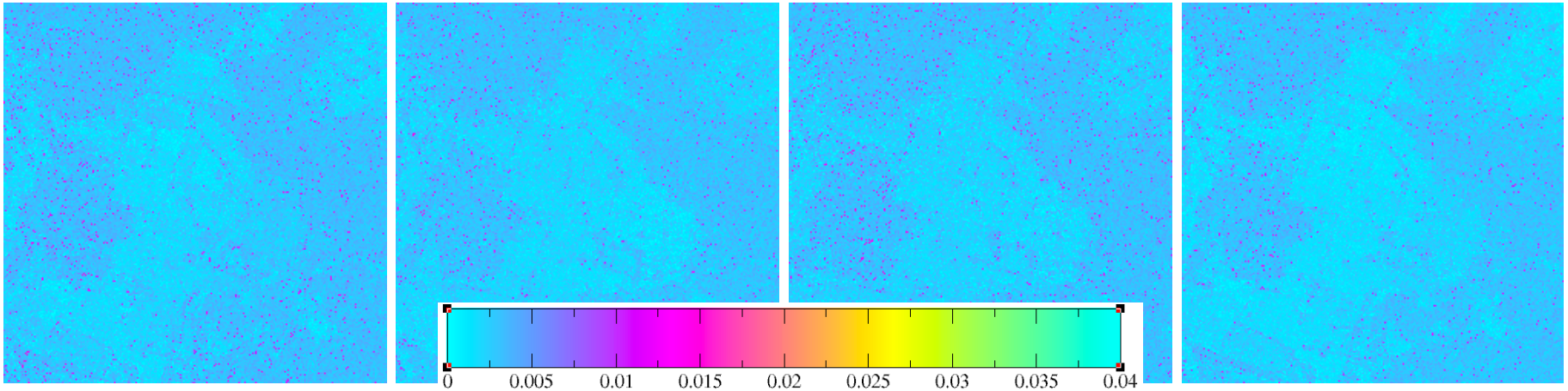
Tree Height (m)

RMoG Estimated Scatterer Motion

Canopy scatterers motion

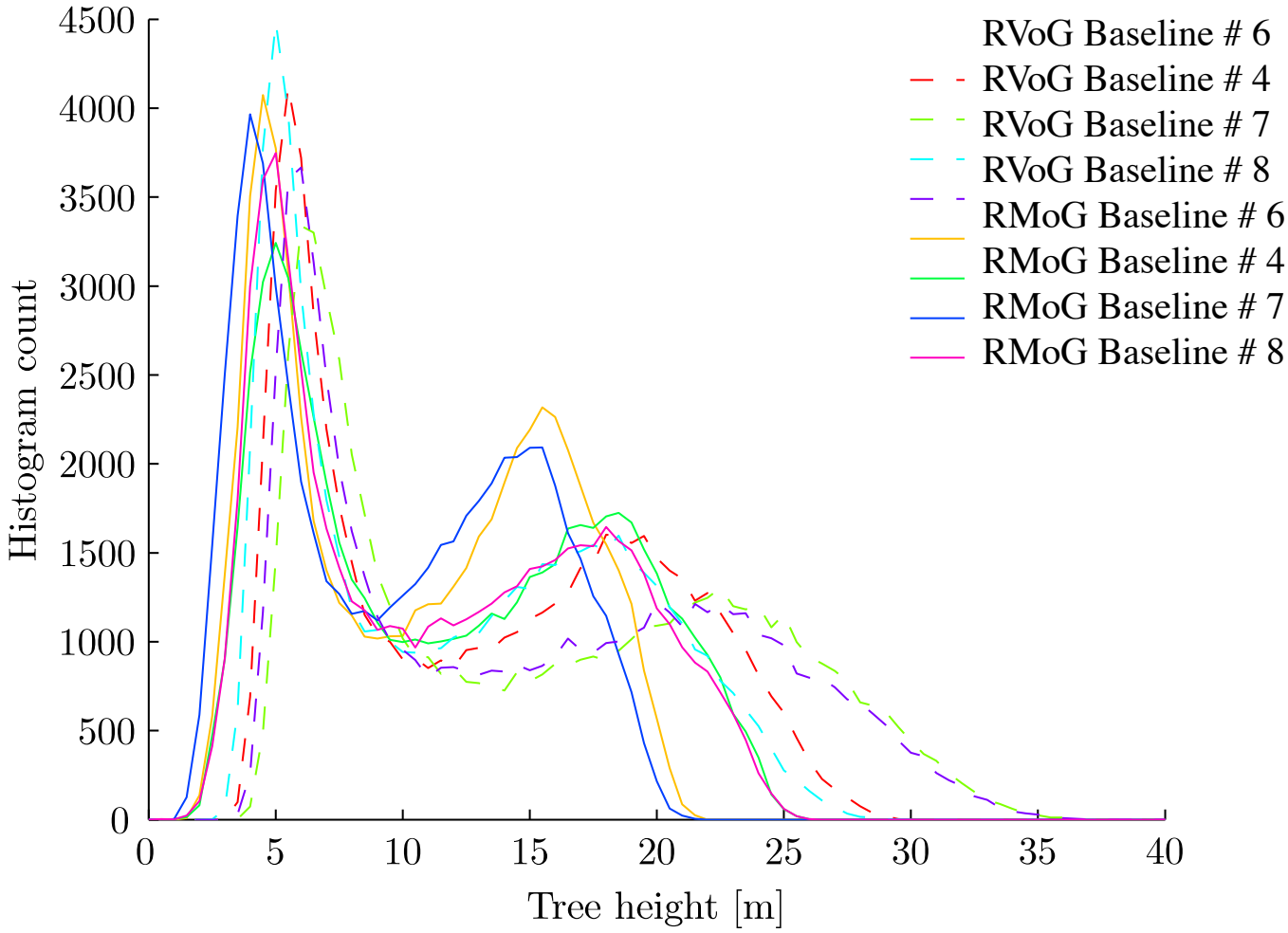


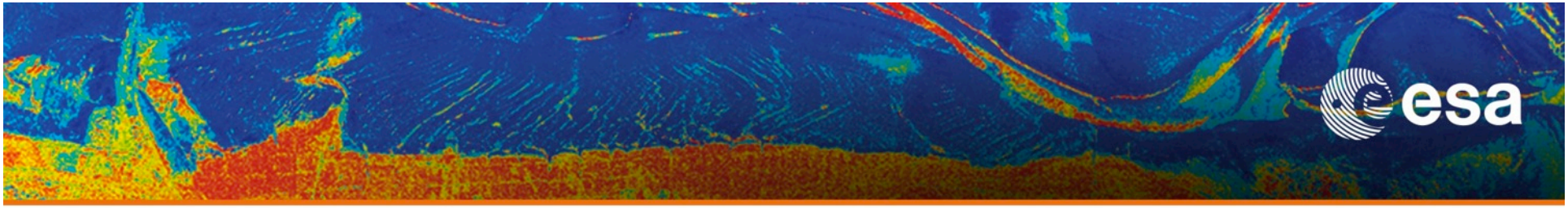
Ground-level scatterers motion



RMS Motion (m)

RVoG and RMoG Tree Height Histograms





UAVSAR DATA Products

UAVSAR Data Products

- **Polarimetric Data**
  - UAVSAR collects almost all data in the fully polarimetric 80 MHz bandwidth mode using 12-8 BAQ compression
  - All data is processed and is freely available
  - Two types of product are available
    - Slant range products
    - Orthorectified products (in geographic coordinates on a fixed lat/lon grid)
    - All products are multilooked to 7 m resolution (36 looks) unless a special order for SLC data is requested.
  - All data are in flat files consisting of IEEE floating points numbers. ASF provides an ability to get data in Geotiff format and we are in the process of implementing ENVI headers to go along with the data. KMZ format products are also available.
  - DEM data used in orthorectification also is available for download with the data as well an incidence angle maps for newer data sets.

Interferometry Data Products

- **Interferometry Data**

- *InSAR Browse Products*
  - Repeat pass InSAR browse products are low-resolution products intended to give users an idea of the quality of data collected for repeat pass interferometry and a rough indication of whether an interferogram contains useful signals. They contain kml, kmz and metadata files, as well as data quality metrics such as absolute and relative motion information. They are automatically generated for sequential pairs.
- There are webpages describing in detail:
  - InSAR Browse Data Format
  - InSAR Browse Data Quality Metrics
  - InSAR Pair Products

Interferometry Products (Continued)

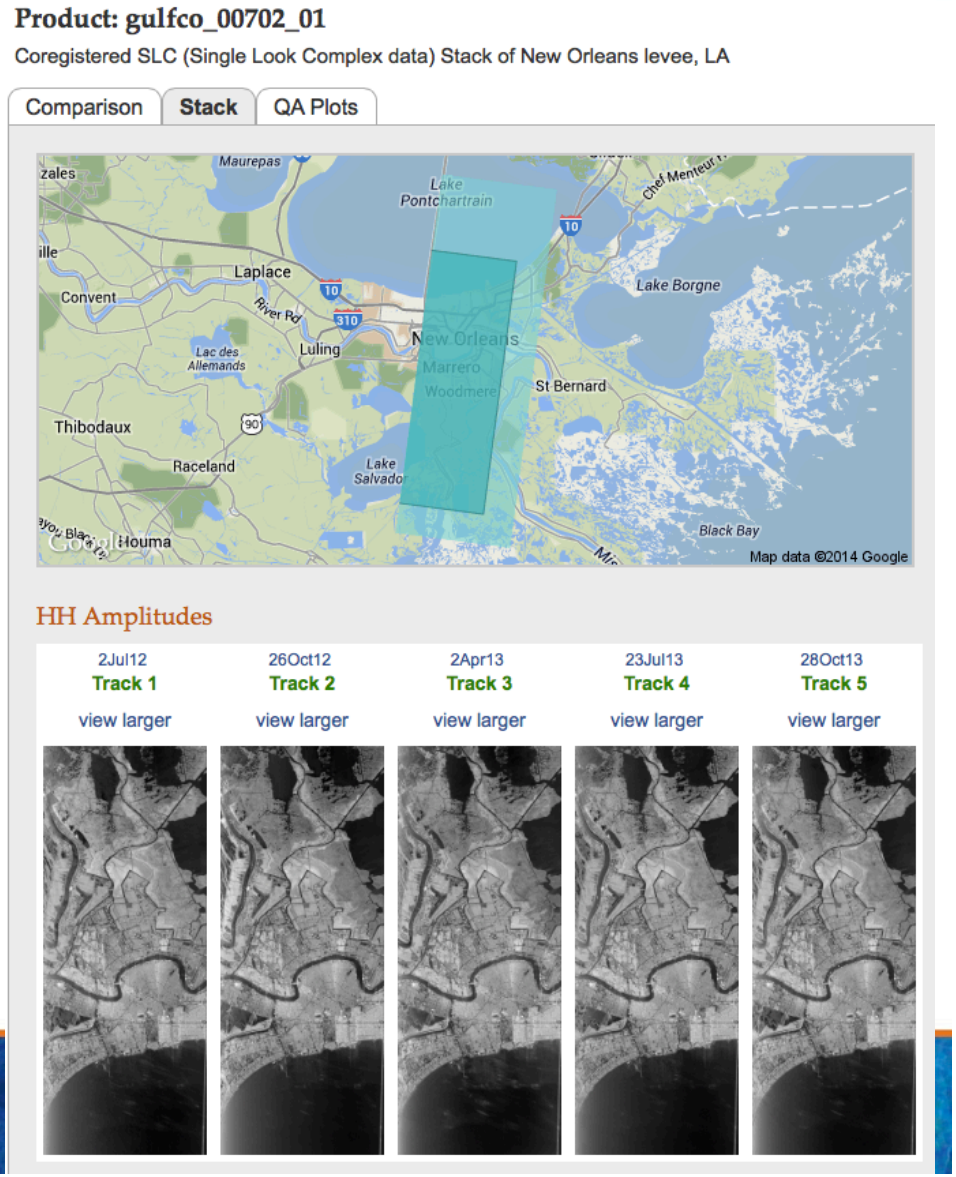
- *Pair Products*
  - Repeat pass InSAR pair products are high-resolution interferometric products for in-depth scientific analysis. They contain slant range and ground range interferogram, unwrapped phase, coherence, amplitude, as well as ground range digital elevation map (DEM) and metadata files. InSAR pair data are processed based on PI request using the UAVSAR web tool. They can have residual motion corrected or uncorrected based on PI choice.
    - InSAR Pair Data Format

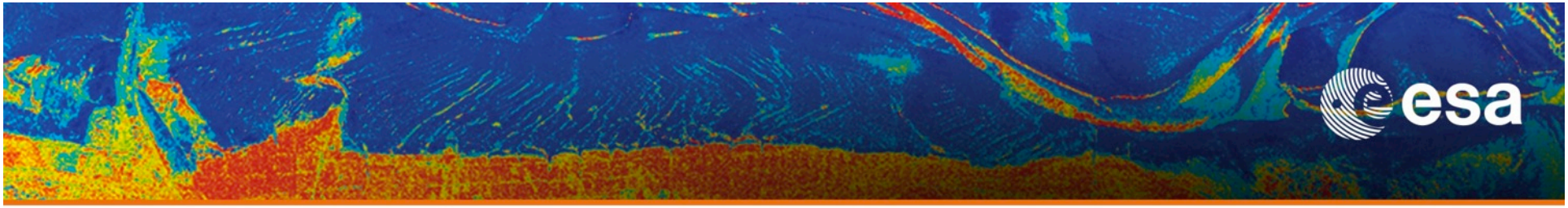
- *SLC Stack Products*
  - Repeat pass SLC stack products are co-registered time series data. They contain slant range single look complex (SLC), latitude/longitude/height, look vector, doppler, and metadata files. SLC stack data are processed based on PI request using the UAVSAR web tool. They can have residual motion corrected or uncorrected based on PI choice.

UAVSAR Coregistered Stack Product

New Coregistered Stack Product:

- Began delivery in June 2014.
- Enables use of advanced time-series InSAR methods with UAVSAR data.
- Is tailored for investigators who are investigating small changes over long time periods, e.g., fault slip or ground subsidence.



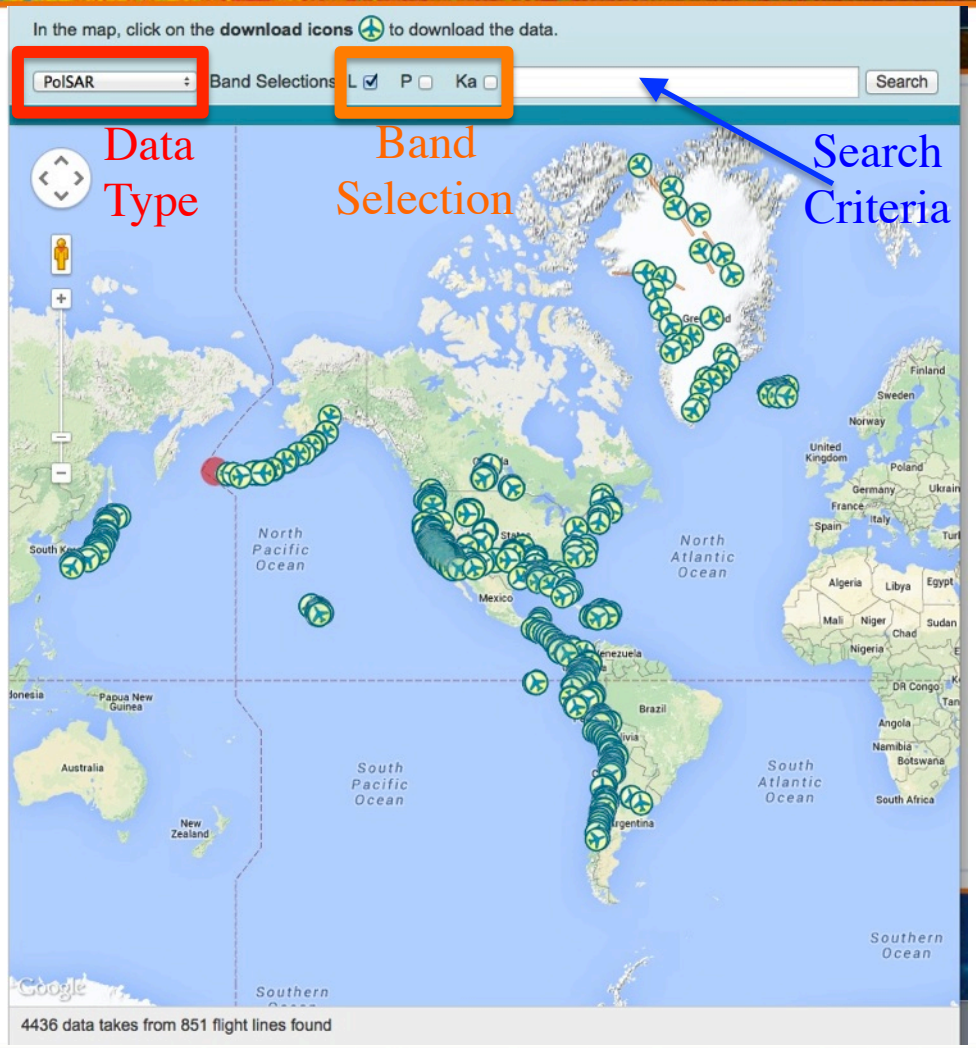


How to Obtain UAVSAR Data

How to Obtain UAVSAR Data

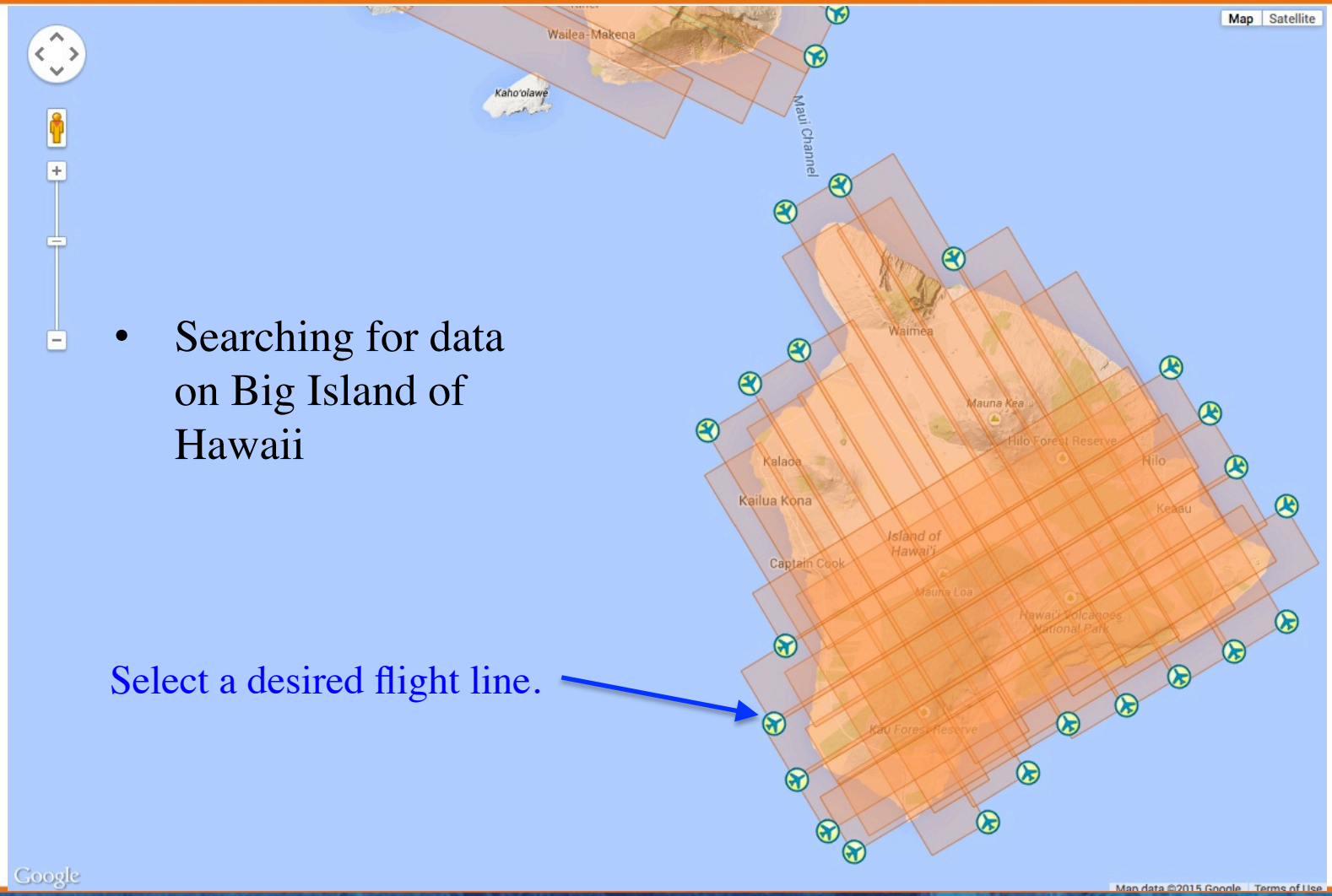
- Go to the UAVSAR website: http://uavsar.jpl.nasa.gov/
- You need to register at UAVSAR site for advanced features and at ASF to download data.
  - Procedure takes only a few minutes
- Select the Search for Data icon
- From here you can select band (L, P or Ka-band) and select whether you want polarimetric or interferometric products
  - For interferometric products you can select browse, pair or stack products
  - Also, possible to order SLC data for polarimetric products

Searching for Data



- UAVSAR Data Search
- You can search by flight ID, line ID, line sitename, line description, and date of acquisition (in YYMMDD format). Only flight IDs can be searched as a range (e.g. "09001-09035").
- To search multiple criteria using OR, separate your search with commas (e.g. "San Andreas, 26532").
- To search multiple criteria using AND, separate your search with period (e.g. "Haiti. 11042").
- To search multiple criteria using NOT, separate your search with exclamation mark (e.g. "Haiti! 11042").

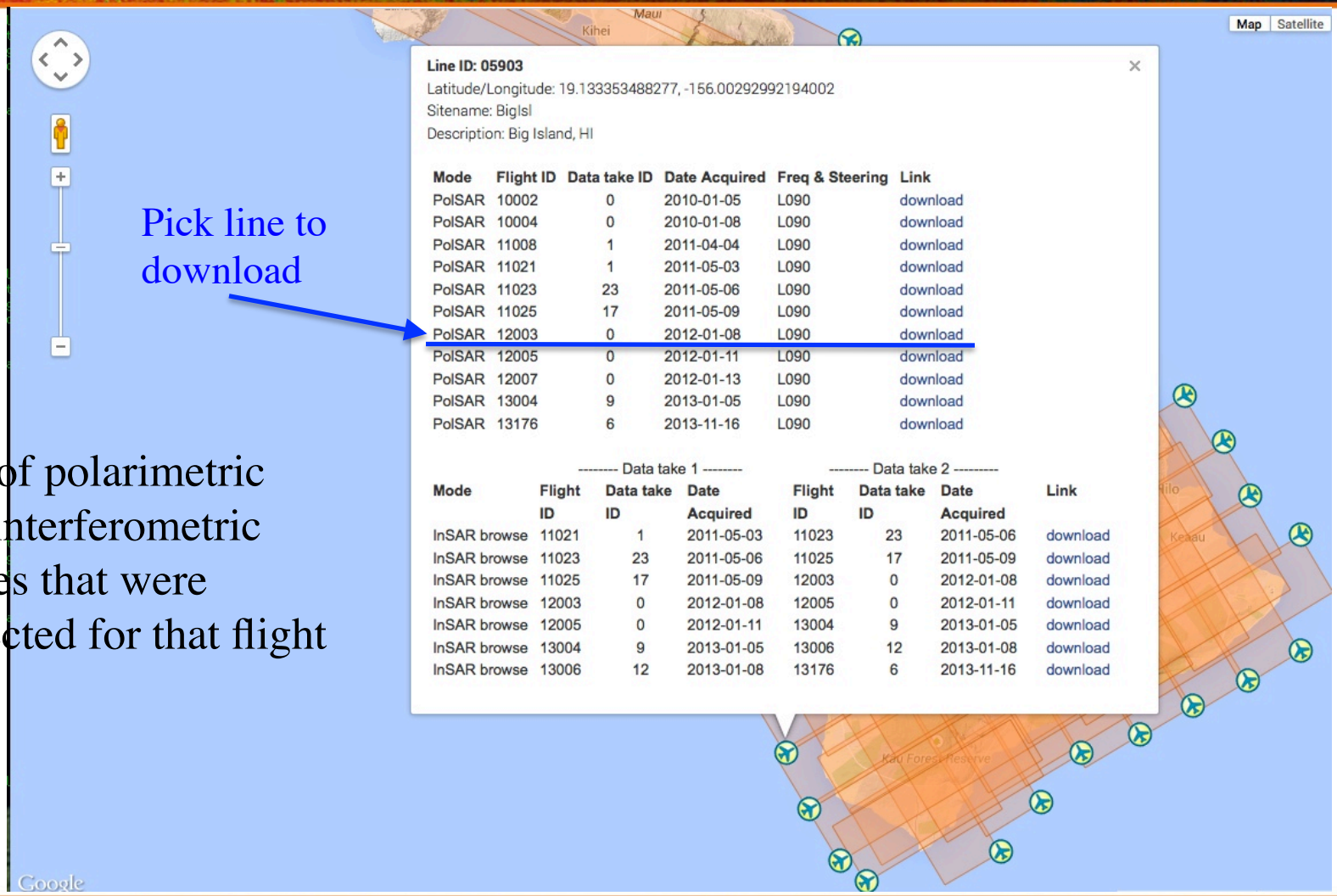
Selecting Data



- Searching for data on Big Island of Hawaii

Select a desired flight line.

See What Data is Available



Line ID: 05903

Latitude/Longitude: 19.133353488277, -156.00292992194002

Sitename: BigIsl

Description: Big Island, HI

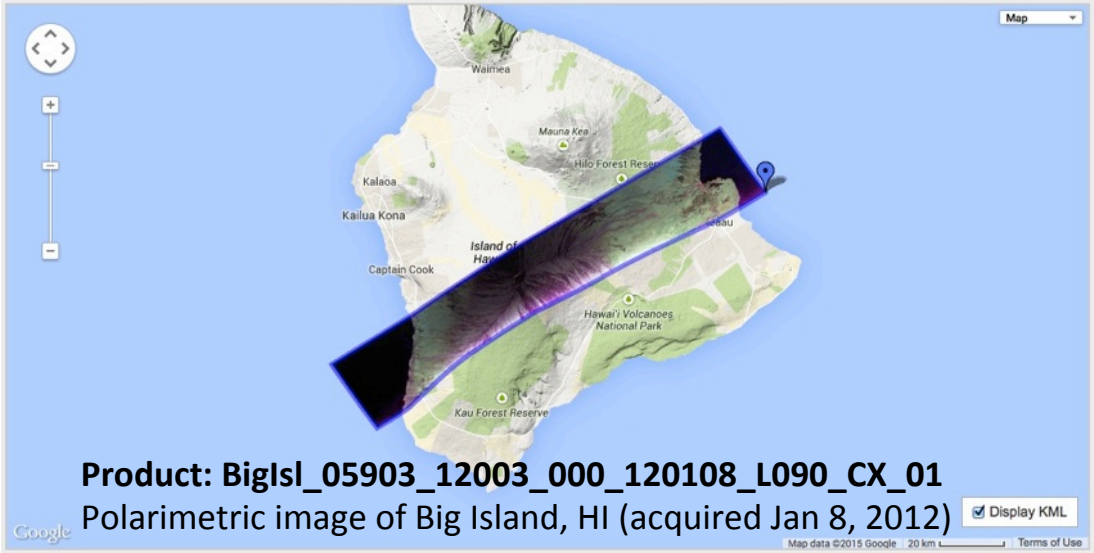
Mode	Flight ID	Data take ID	Date Acquired	Freq & Steering	Link
PolSAR	10002	0	2010-01-05	L090	download
PolSAR	10004	0	2010-01-08	L090	download
PolSAR	11008	1	2011-04-04	L090	download
PolSAR	11021	1	2011-05-03	L090	download
PolSAR	11023	23	2011-05-06	L090	download
PolSAR	11025	17	2011-05-09	L090	download
PolSAR	12003	0	2012-01-08	L090	download
PolSAR	12005	0	2012-01-11	L090	download
PolSAR	12007	0	2012-01-13	L090	download
PolSAR	13004	9	2013-01-05	L090	download
PolSAR	13176	6	2013-11-16	L090	download

Pick line to download

	-------- Data take 1 --------			-------- Data take 2 ---------			
Mode	Flight ID	Data take ID	Date Acquired	Flight ID	Data take ID	Date Acquired	Link
InSAR browse	11021	1	2011-05-03	11023	23	2011-05-06	download
InSAR browse	11023	23	2011-05-06	11025	17	2011-05-09	download
InSAR browse	11025	17	2011-05-09	12003	0	2012-01-08	download
InSAR browse	12003	0	2012-01-08	12005	0	2012-01-11	download
InSAR browse	12005	0	2012-01-11	13004	9	2013-01-05	download
InSAR browse	13004	9	2013-01-05	13006	12	2013-01-08	download
InSAR browse	13006	12	2013-01-08	13176	6	2013-11-16	download

- List of polarimetric and interferometric passes that were collected for that flight line.

Select Products to Download



Product: BigIsl_05903_12003_000_120108_L090_CX_01
Polarimetric image of Big Island, HI (acquired Jan 8, 2012)

Download Low Resolution KML File

Precision Data

The NASA data archive at ASF now requires login. If you do not have an account, any user can create one here (this is a separate login from the UAVSAR webpage login).

Metadata	Text Annotation File
Slant Range Products	ShhShh* (0.2463 Gbytes) ShvShv* (0.2463 Gbytes) SvvSvv* (0.2463 Gbytes) ShhShv* (0.4926 Gbytes) ShhSvv* (0.4926 Gbytes) ShvSvv* (0.4926 Gbytes) Compressed Stokes Matrix (AIRSAR format) (0.6159 Gbytes)
Orthorectified Products (geographic projection)	ShhShh* (1.2903 Gbytes) ShvShv* (1.2903 Gbytes) SvvSvv* (1.2903 Gbytes) ShhShv* (2.5806 Gbytes) ShhSvv* (2.5806 Gbytes) ShvSvv* (2.5806 Gbytes) High Resolution KMZ file (0.2918 Gbytes)
SRTM DEM	DEM used in projection (1.2903 Gbytes)

- After selecting line for download get a list of data layers.
- Data can be download in slant range or orthorectified format depending or both depending on your investigation
- Data is multilooked complex products needed to construct the polarimetric coherency of correlation matrix.
- You can also download the SRTM data used in the orthorectification process and kmz to use in overlaying other data layers in Google Earth.