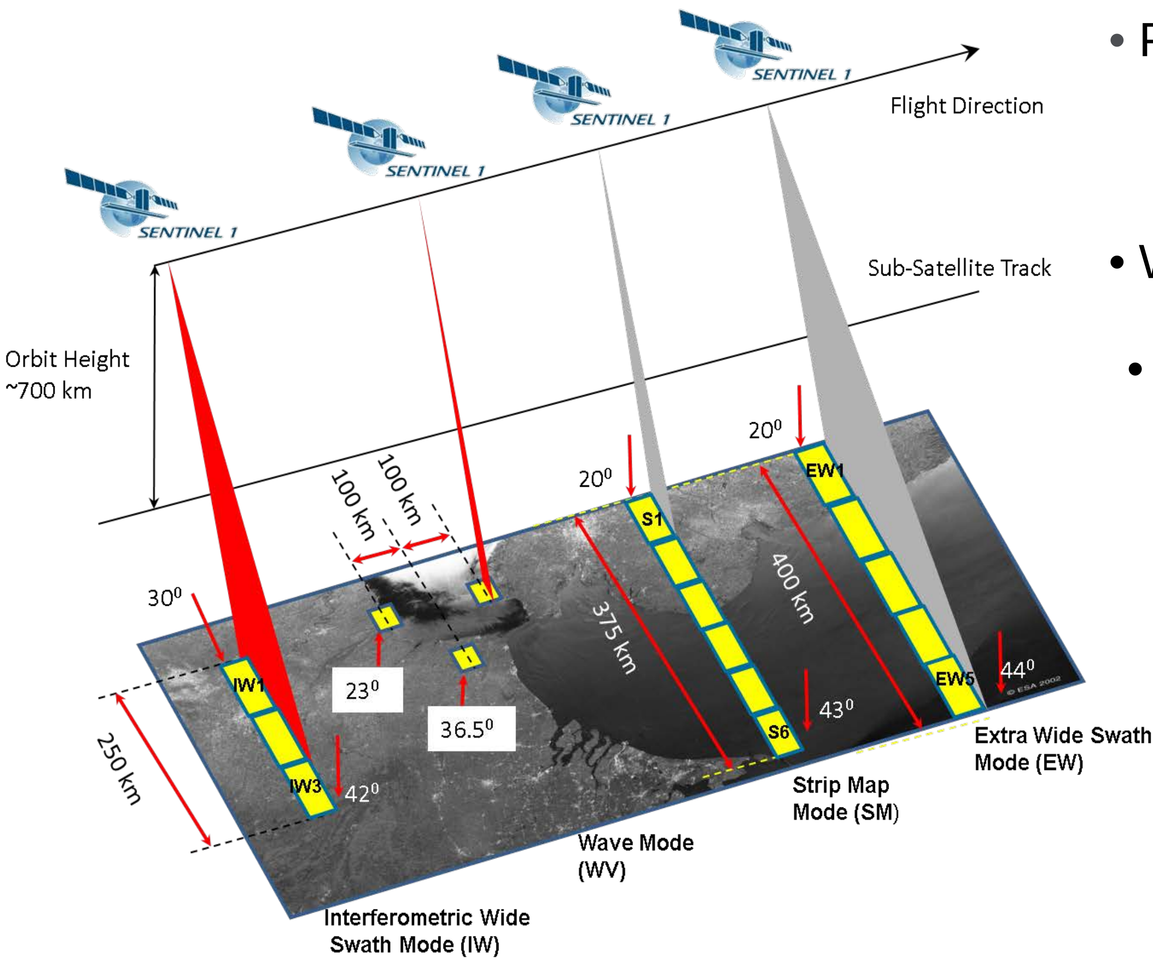
Sentinel-1 InSAR Capabilities: Results from the Sentinel-1A Commissioning Phase

Dirk Geudtner[1], Nestor Yaguee-Martinez[2], Pau Prats[3], Andrea Monti Guarnieri[4] and Itziar Barat[1]

[1]ESA ESTEC
[2] DLR, Remote Sensing Technology Institute
[3] DLR, Microwave and Radar Institute
[4] Politecnico Di Milano

Sentinel-1 SAR Imaging Modes

- SAR Instrument provides *4 exclusive SAR modes* with different resolution and coverage



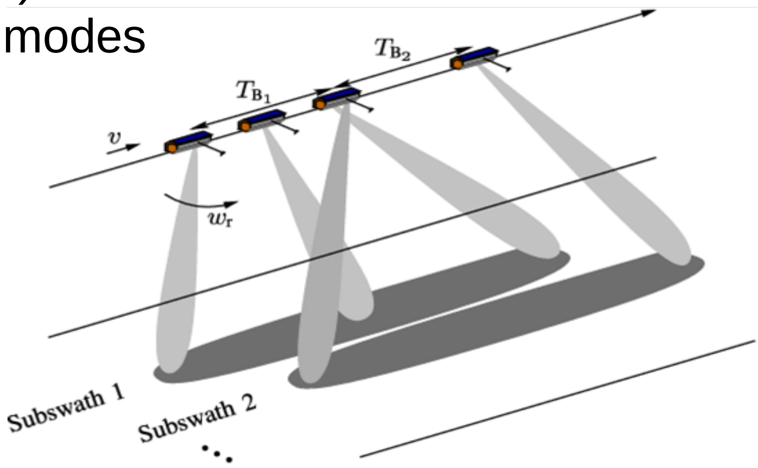
- Polarisation schemes for *IW, EW & SM*:
  - ✓ single pol: HH or VV
  - ✓ dual pol: HH+HV or VV+VH
- Wave mode (WV): HH or VV
- SAR duty cycle per orbit:
  - ✓up to *25 min* in any imaging mode
  - ✓up to *74 min* in Wave mode

Main mode of operations: *Interferometric Wide Swath (IW) mode* satisfies most *Copernicus* service and user requirements for land & coastal monitoring (i.e. resolution, swath width, polarisation)

Wave (WV) mode is continuously operated over open ocean

Sentinel-1 SAR TOPS Mode

TOPS (Terrain Observation with Progressive Scans in azimuth) for Sentinel-1 *Interferometric Wide Swath (IW)* and *Extra Wide Swath* (EW) modes



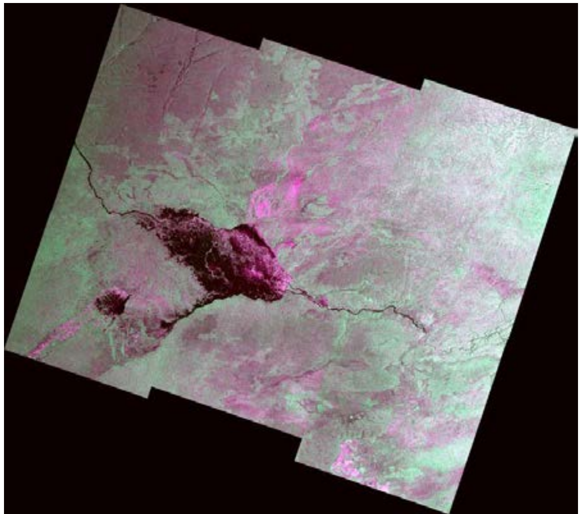
- *ScanSAR-type* beam steering in *elevation* to provide large swath width (IW: 250km and EW: 400km)
- Antenna beam is steered along *azimuth* from *aft* to the *fore* at a constant rate

  ✓All targets are observed by the entire azimuth antenna pattern *eliminating scalloping effect* in ScanSAR imagery

  ✓*Constant SNR* and *azimuth ambiguities*

  ✓Reduction of azimuth resolution due to decrease in dwell time

- S-1 IW TOPS mode parameters: ±0.6° azimuth scanning at Pulse Repetition Interval rate with step size of 1.6 mdeg.



Sentinel-1A IW dual-pol image, acquired over Namibia

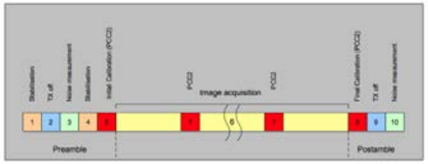
Sentinel-1 SAR System Calibration and Performance Verification

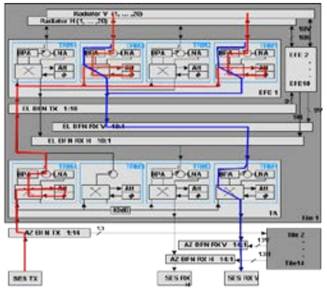
• Verification of in-orbit SAR system performance & monitoring of stability (temperature)

Internal Calibration

• Network of Cal pulses monitors potential drifts in the instrument's Tx & Rx signal paths + entire antenna system (T/R modules)

- Monitoring of instrument stability over time & vs. temperature
- Thermal system noise characterization
- Inter-channel gain and phase characterization
- Internal instrument delay characterization
- TRM and EFE drift characterization based upon RFC mode

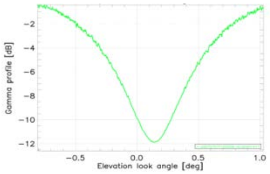


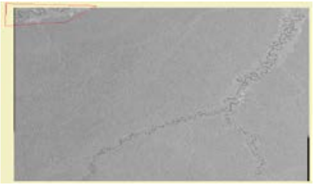


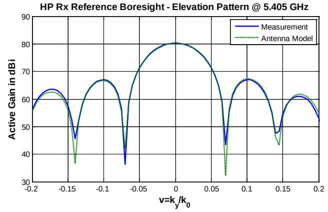
External Calibration

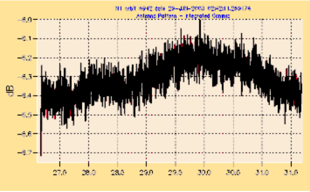
• Measurement of SAR system w.r.t. reference targets with known *radar cross section* (RCS)

- Absolute radiometric calibration (< 1 dB (3σ)) and stability (<0.5 dB (3σ)
- Antenna pointing calibration (< 0.01°)
- Antenna Model verification (0.2 dB (3σ) for 2-way gain)
- Geometric calibration (pixel localization: 2.5m (3σ))
- Interferometric verification
- Polarimetric calibration





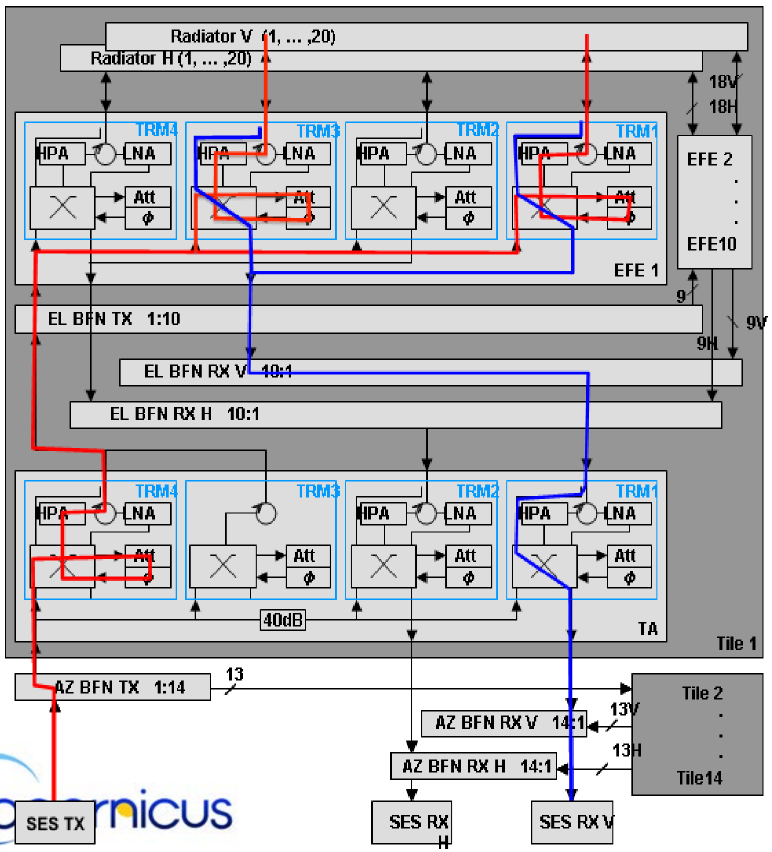




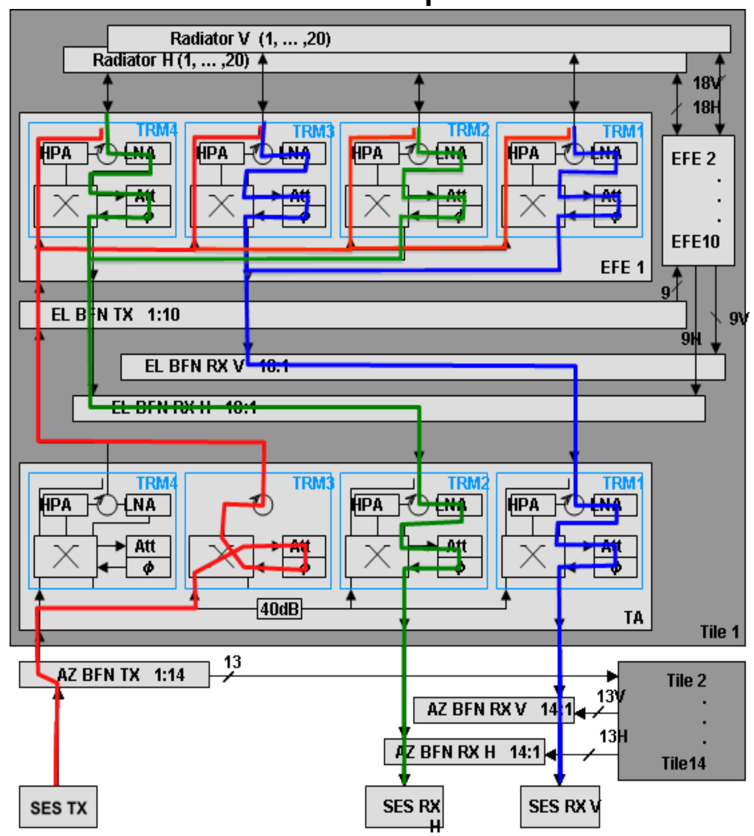
Sentinel-1 Internal Calibration

- Network of Cal pulses monitors potential drifts in instrument's Tx and Rx signal paths except for:
  - Antenna radiators (covered by Antenna Model)
  - Calibration couplers and calibration paths (strict stability requirements)

TxCal (V) single-pol

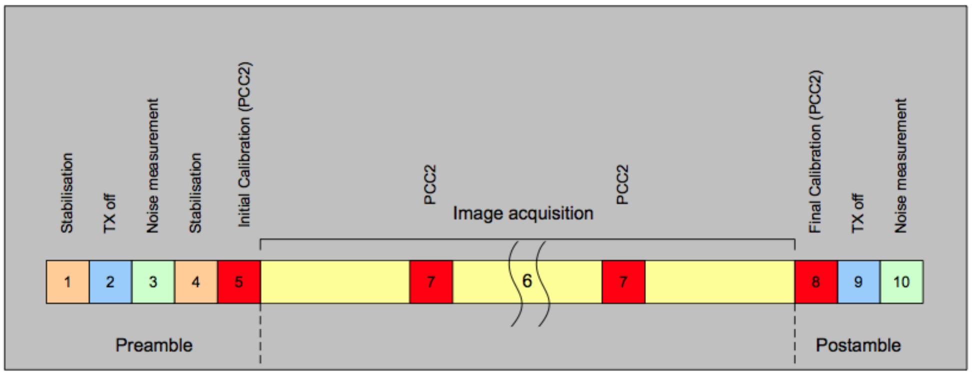


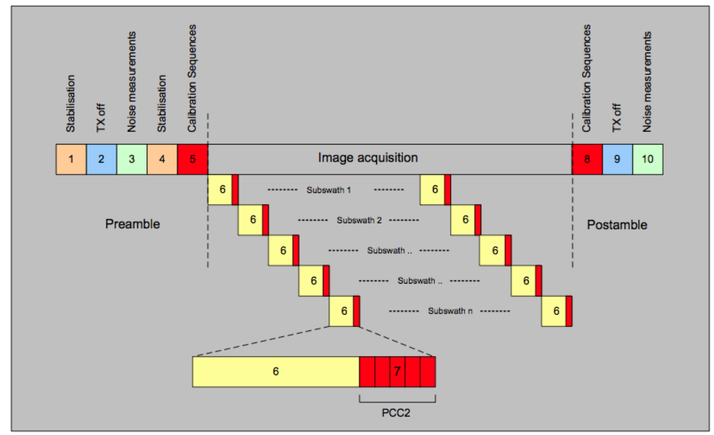
RxCal dual-pol



- Each DT starts and ends with sequences of 6 types of Cal pulses both at nominal signal BW and at 100MHz BW (400 PRIs required):

  − 4 PCC2 phase-coded pulses (RxCal, TxCal, EPDNCal, TACal)
  − 2 non phase-coded (TxCalHIso, APDNCal)





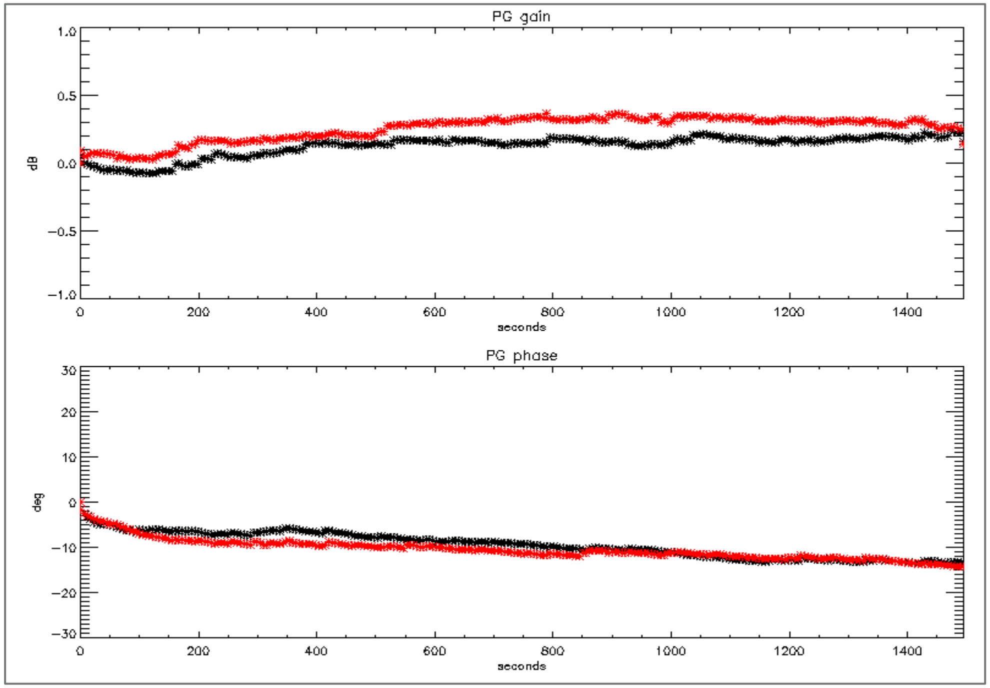
- Cal pulses are used in ground processing for gain and phase, i.e. PG product correction

$$PG = \frac{TxCal \cdot RxCal}{EPDNCal} \frac{TACal}{APDNCal}$$

Product (complex) of Transmit power and Receive gain

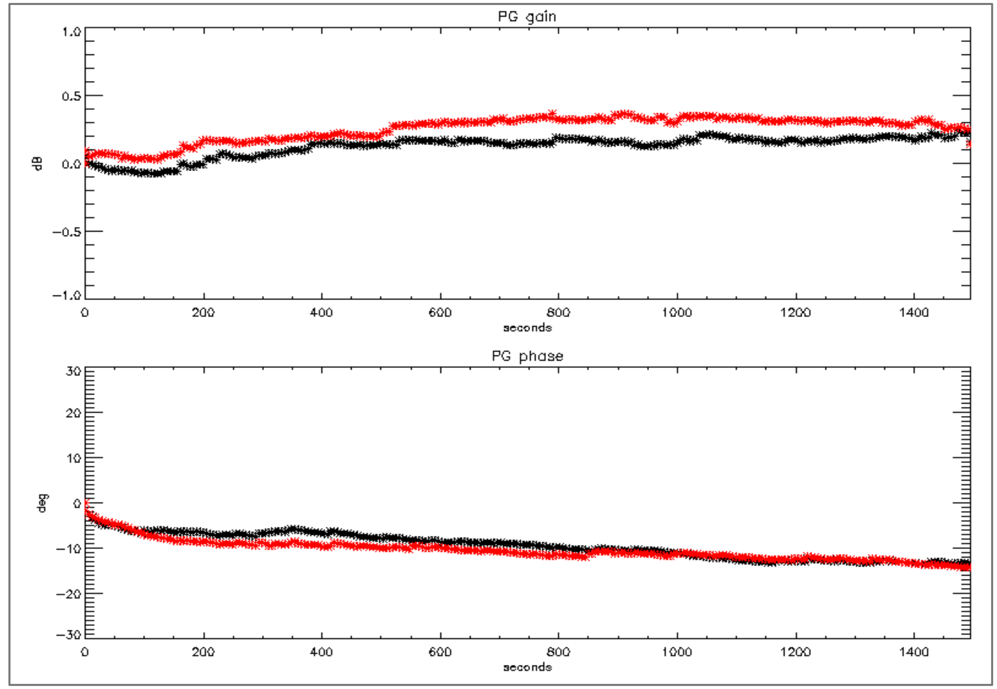
Sentinel-1A Instrument stability during long datatakes

Interferometric Wide Swath Mode



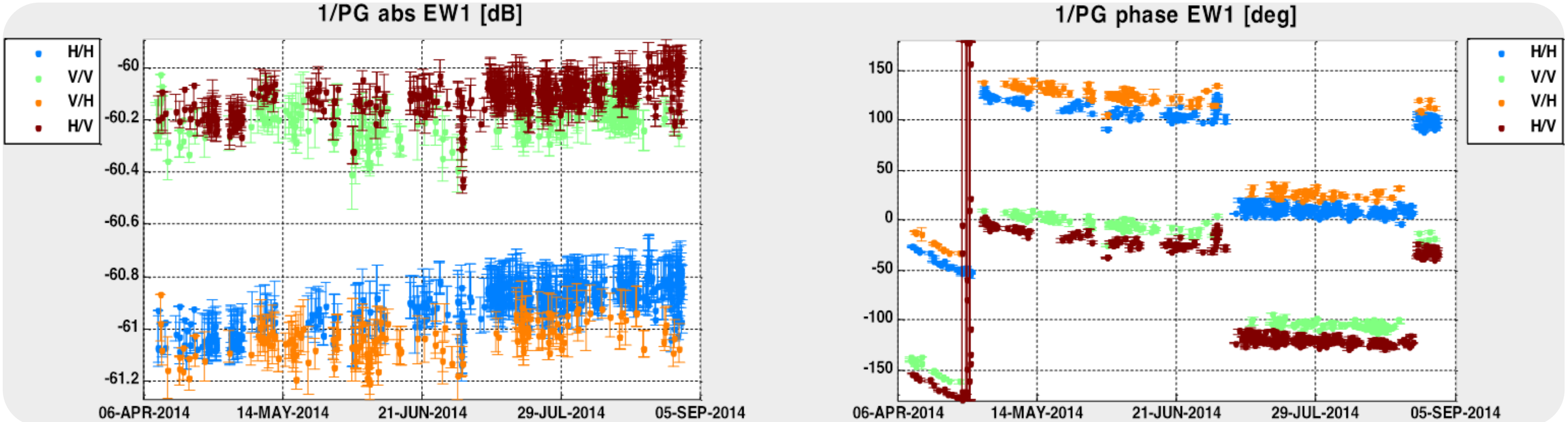
Variation over 25 min:	
Gain	0.31 dB (VV) 0.37 dB (VH)
Phase	-13.6° (VV) -14.3° (VH)

Stripmap 6



Variation over 21 min	
Gain	0.32 dB (VV) 0.43 dB (VH)
Phase	-14.0° (VV) -14.7° (VH)

Sentinel-1A Instrument stability over 5 months



- Variations in amplitude <0.6 dB in 150 days
- Discrete jumps in phase and internal delay occur when the SES is restarted
- Amplitude and phase variations are tracked by internal calibration and compensated for by the operational SAR processor (IPF)

Sentinel-1A Geometric Calibration

Measurement of *Range-Doppler geolocation* of known reference Point target in SAR image for estimation of *systematic SAR timing offsets* in:

- *slant range* (residual internal electronic path delay and Sample Window Start Time)
- *azimuth* (radar time and spacecraft GPS time)

⇒ Absolute Location Error (ALE) = predicted – measured (PTs)

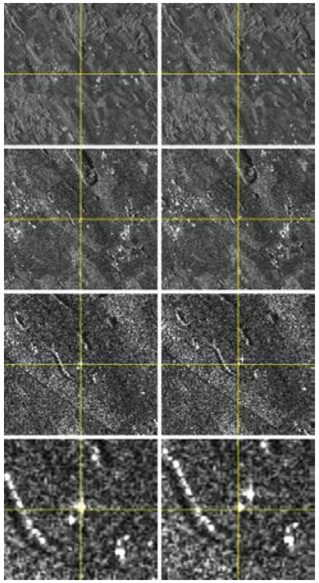
Geolocation accuracy may be affected by:

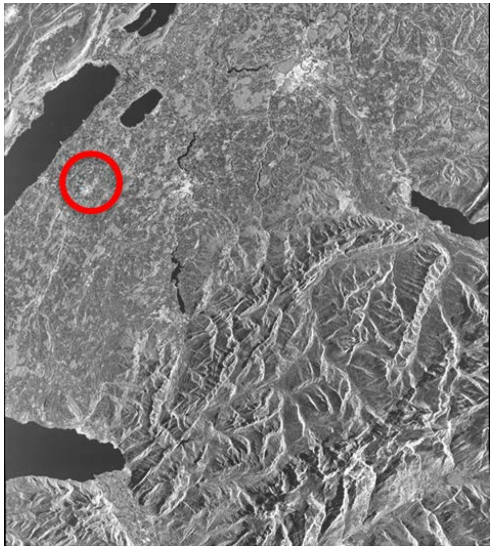
- Spacecraft position (orbital state vectors) accuracy
- Survey accuracy of reference target
- Atmospheric path delay of radar signal

Cross-hair prediction depends on orbit data type

Reference Point Targets (PTs)

- 4 corner reflectors (CRs) deployed at Torny-le-Grand, Switzerland
- 3 ESA transponders deployed in the Netherlands

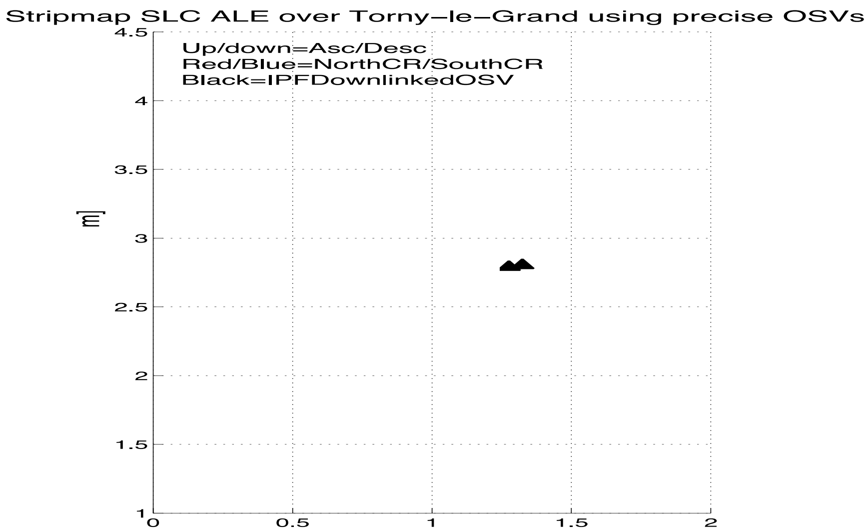


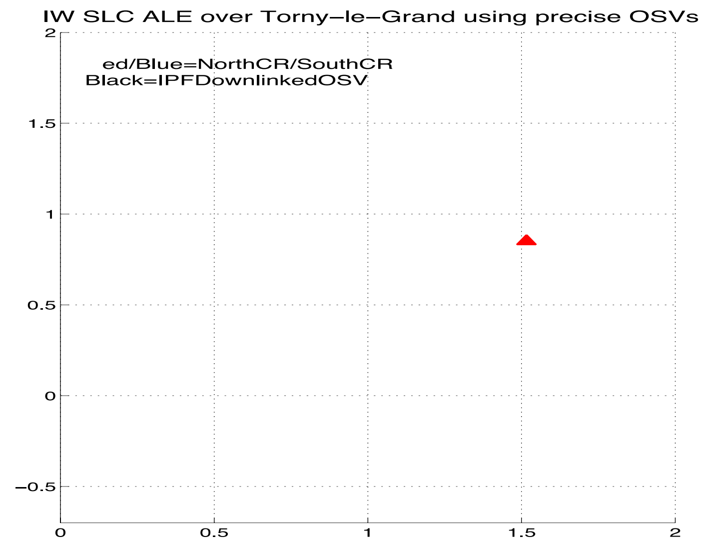


Sentinel-1A Geometric Calibration

Data analyzed over ***Torny-le-Grand* corner reflector** site by University of Zurich, RSL

- 19 SM and 3 IW and use of *Precise Orbit Data (POD)*





Applied corrections:

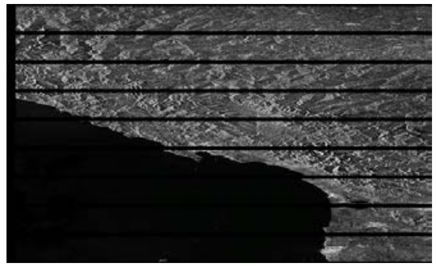
- Internal path delay
- Tectonic motion
- Solid Earth tides motion
- Atmospheric path delay

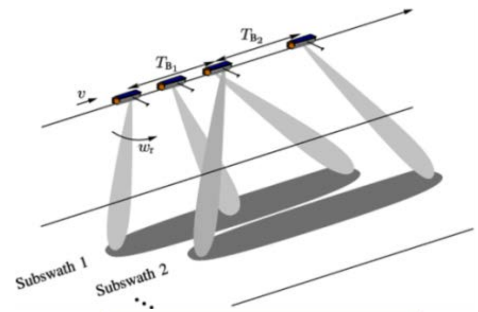
	ALE Slant range offset		ALE Azimuth offset	
SM	1.28 ± 0.07 m	8×10^{-9} sec	2.09 ± 0.49 m	$3.08 \times 10^{-4} \pm 6.79 \times 10^{-5}$ sec
IW	1.31±0.37 m	8×10^{-9} sec	0.53±0.74 m	$7.7 \times 10^{-5} \pm 1.1 \times 10^{-4}$ sec

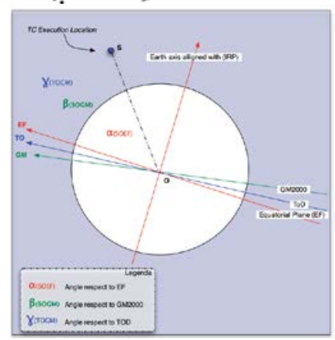
Recommendation: Annotate *slant range time delay* in SAR image data products

SAR Interferometry (InSAR) Verification

Repeat-pass TOPS InSAR using ***Interferometric Wide Swath (IW)*** data pairs worked on the ‘spot’



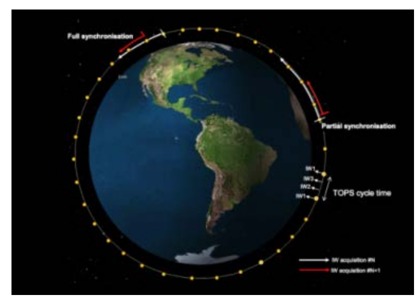


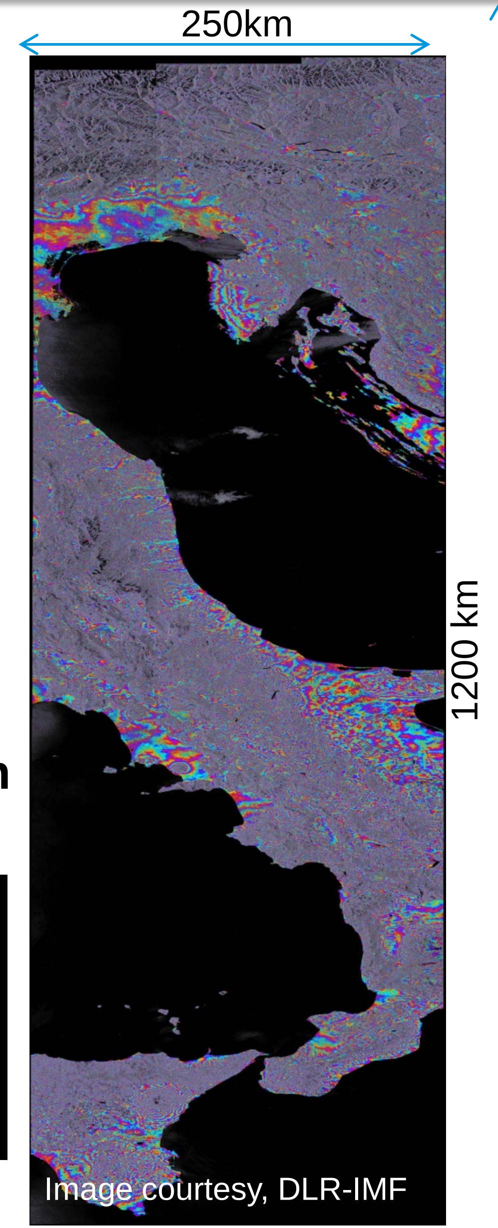


Provides ultimate verification of:

- SAR instrument phase stability (over repeat orbit cycles)
- Satellite on-board timing and GNSS solution to support *position-tagged commanding* (OPS angle)
- Accurate orbit control and maintenance (orbital tube)
- Mission Planning system using *TOPS cycle time grid points* for datatake start time estimation
- IPF produces phase-preserving Level-1 SLC product slices

Burst synchronization





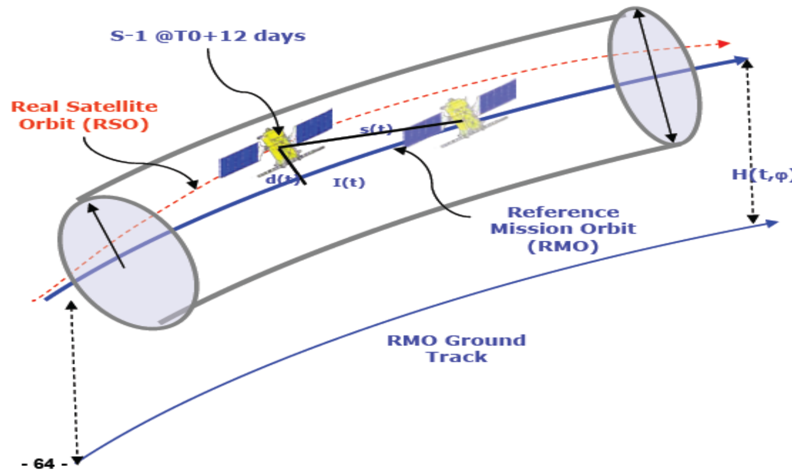
Sentinel-1 Orbital Tube and InSAR Baseline

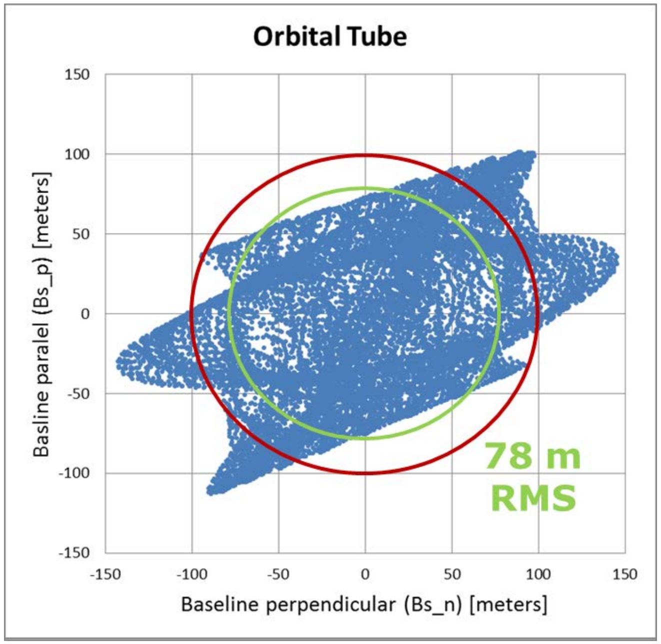
- Reference orbit was reached on August 7th, 2014
- Satellite will be kept within an *Orbital Tube* around a *Reference Mission Orbit* (RMO)
- Specified *Orbital Tube* radius of 50 (rms)

⇒ equivalent to ground-track dead band of 60m

- During S-1A Commissioning:
  Relaxation of ground-track dead band to 120m

⇒ *Orbital Tube* radius of roughly 100 (rms)

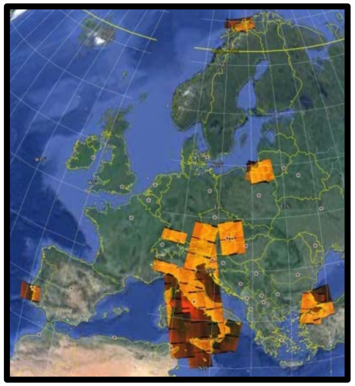




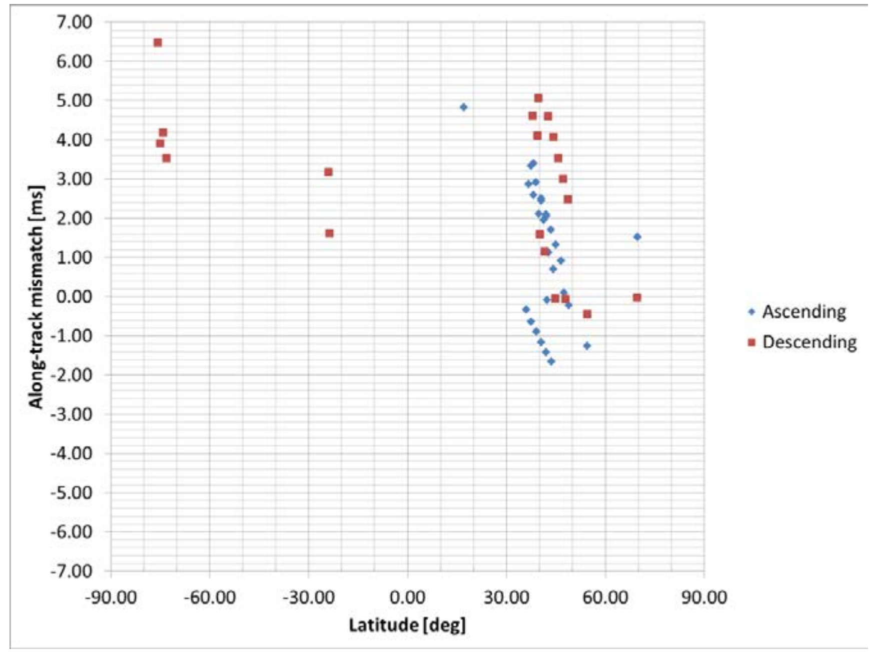
SAR Interferometry (InSAR) Verification

48 InSAR product pairs

- 28 ascending geometry
- 20 descending geometry
- 46 in IW mode
- 2 in EW mode

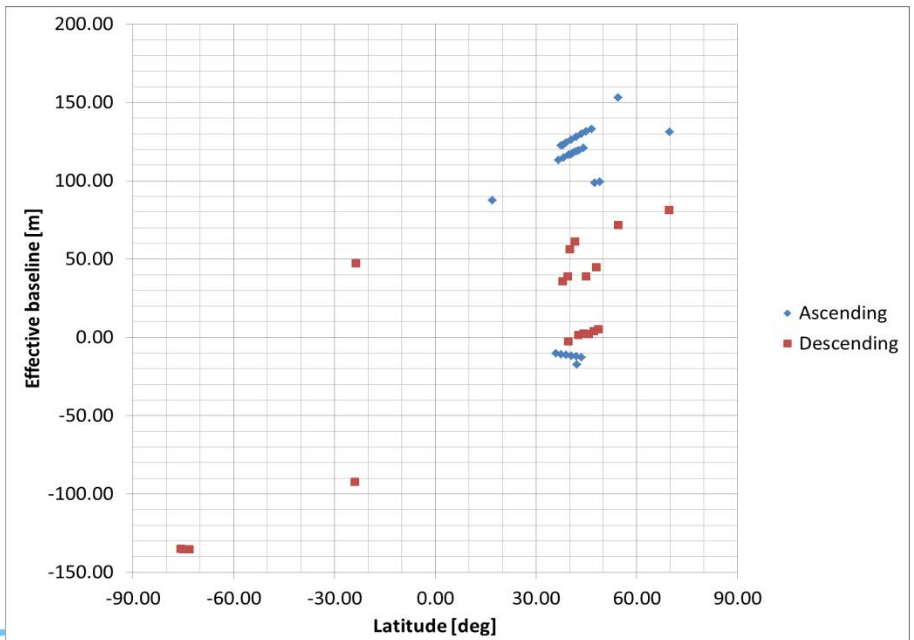


Along-track(burst) mis-synchronization< *2.83ms*



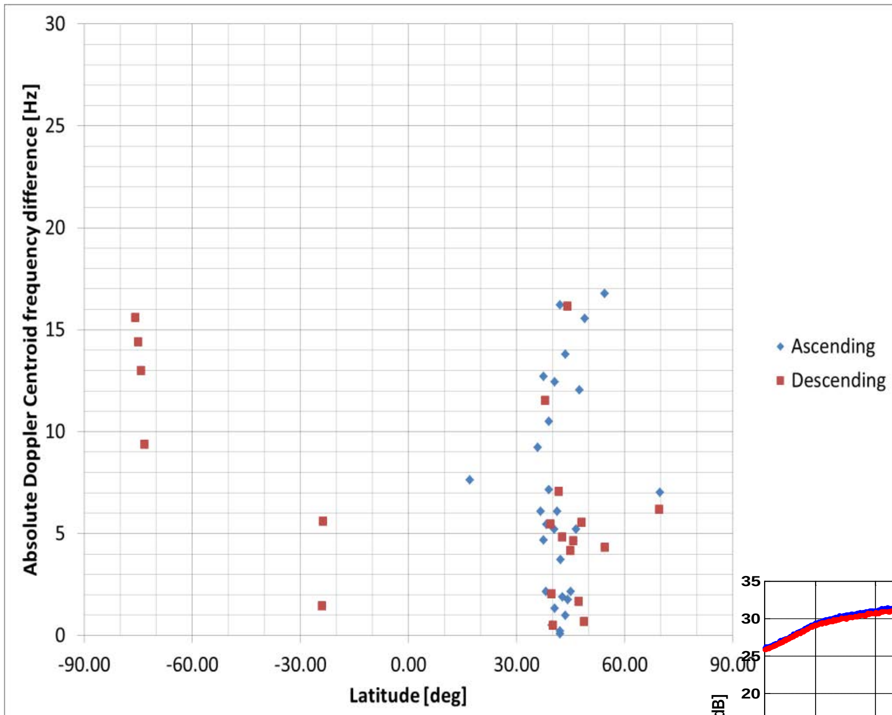
	Ascending	Descending
Mean AT mismatch [ms]	1.17	2.83
Stdev AT mismatch [ms]	1.71	1.97

Orbital InSAR baseline of < *150m*

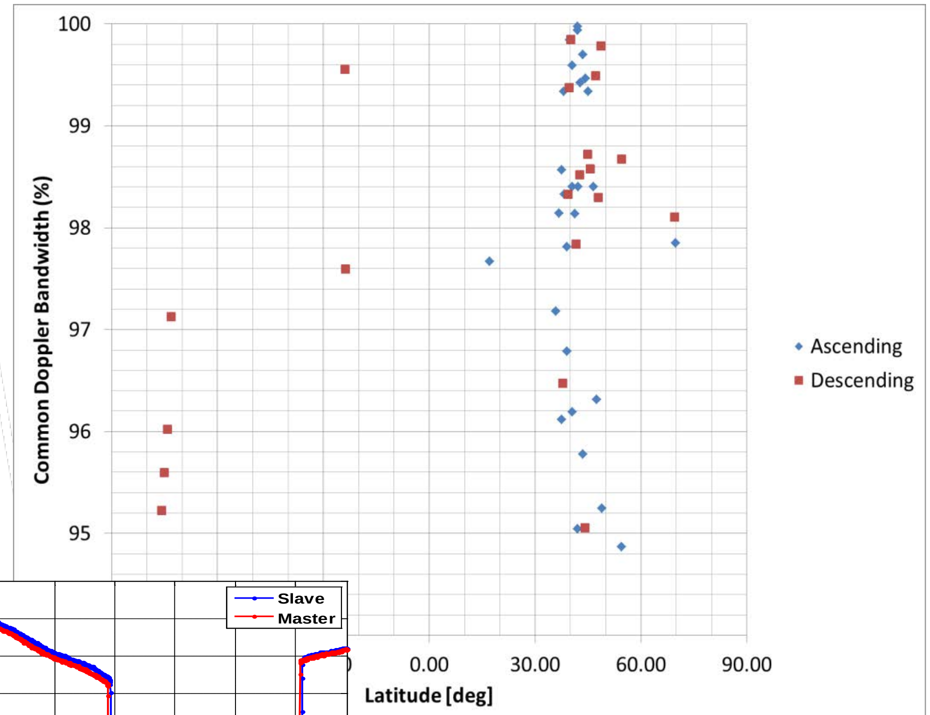


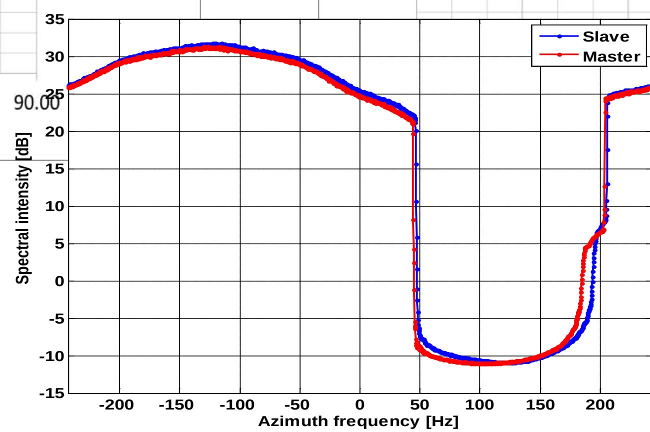
SAR Interferometry (InSAR) Verification

Doppler centroid difference < *20 Hz*
stable attitude and antenna pointing



Common InSAR Doppler bandwidth > *95%*
of available azimuth bandwidth





SAR Interferometry (InSAR) Verification

Demonstration of *Differential* and *Multi-Aperture (Squint)* SAR Interferometry

M6.0 South Napa Valley earthquake on August 24th, 2014

Use of Stripmap (SM-1) data pairs acquired on August 7th and 31st, 2014

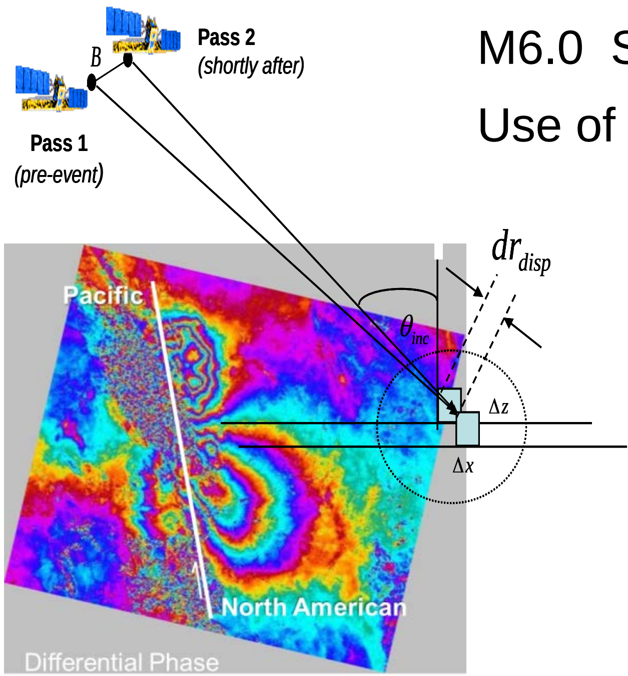
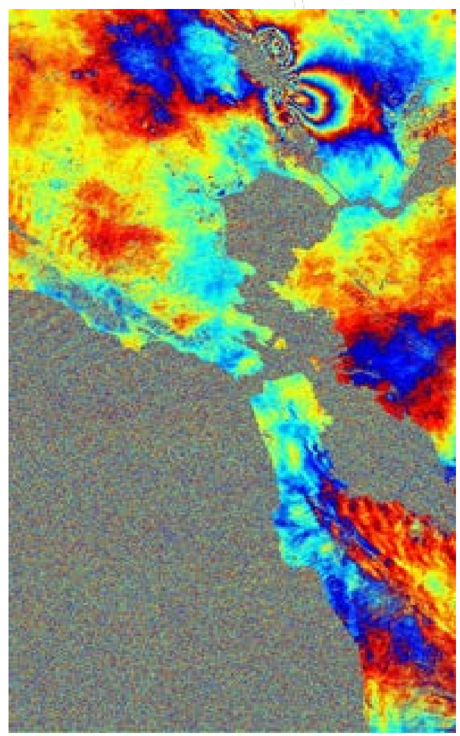


Image courtesy, DLR-IMF

D-InSAR



MAI (MS-InSAR)

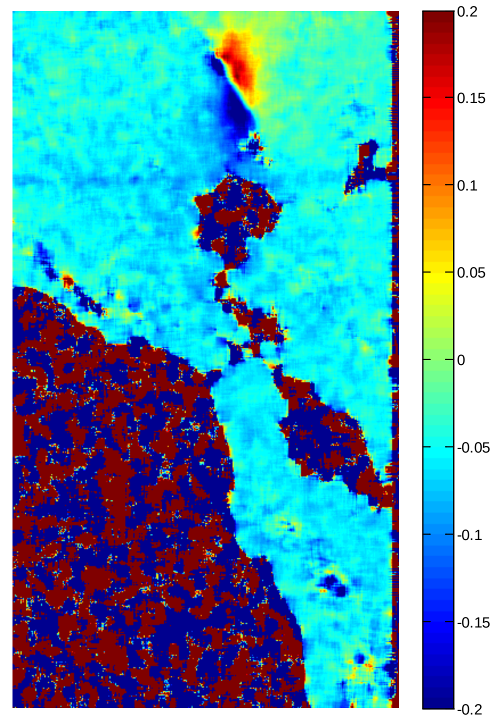


Image courtesy, Andrea Monti Guarnieri, POLIMI