Interferometric Evaluation of Sentinel-1A TOPS data

N. Yague-Martinez, F. Rodriguez Gonzalez, R. Brcic, R. Shau

Remote Sensing Technology Institute. DLR, Germany

ESTEC/Contract No. 4000111074/14/NL/MP/lf

ESRIN/Contract No. 4000109669/13/I-AM

FRINGE 2015 WORKSHOP

ESA–ESRIN | Frascati, Italy

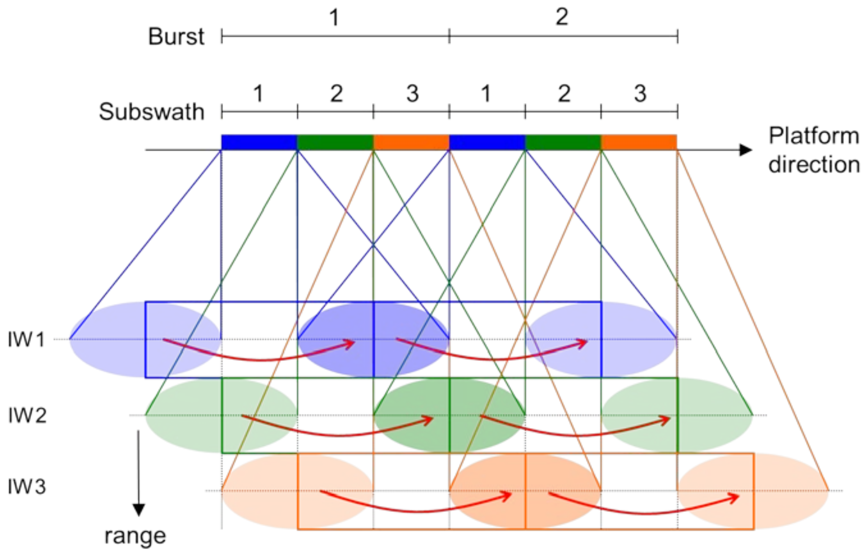
DLR

Overview

- Sentinel-1 TOPS IW mode
- Interferometric examples
- Integrated Wide Area Processor. InSAR Processing Chain
    - Spectral shift filtering
        - Burst synchronization evaluation
    - Coregistration
        - ESD estimator
        - Along-track shifts evaluation
    - Slices mosaicking
- Conclusions

Sentinel-1 TOPS IW mode

- Terrain Observation by Progressive Scan
- S1 Interferometric Wide Swath (IWS) mode
- Range Coverage: 250 km
- SLC data available in **slices** of approx. 200 km length
- Resolution: 5 m (rg) x 20 m (az)
- Three subswaths: IW1, IW2, IW3

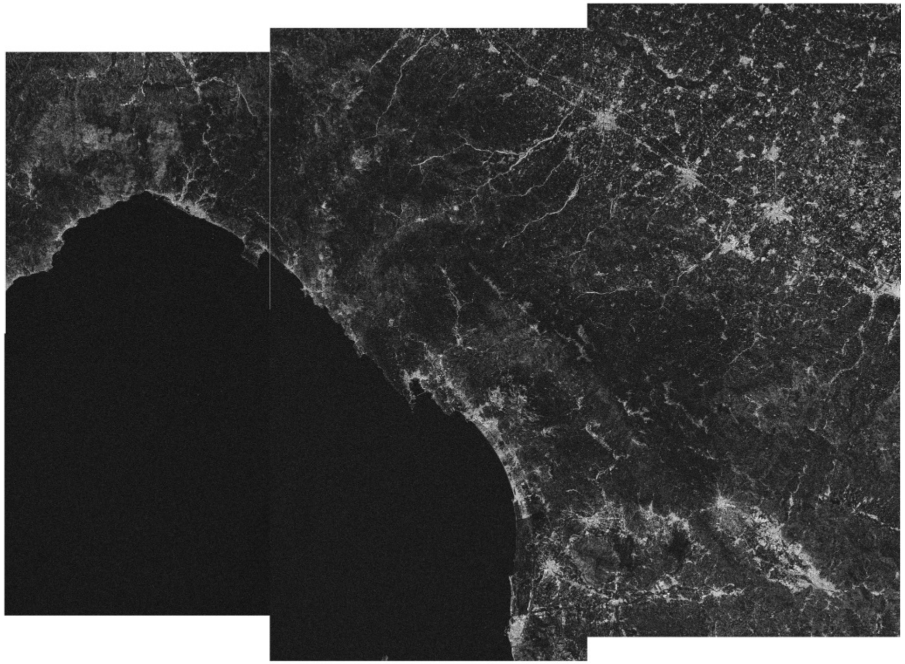


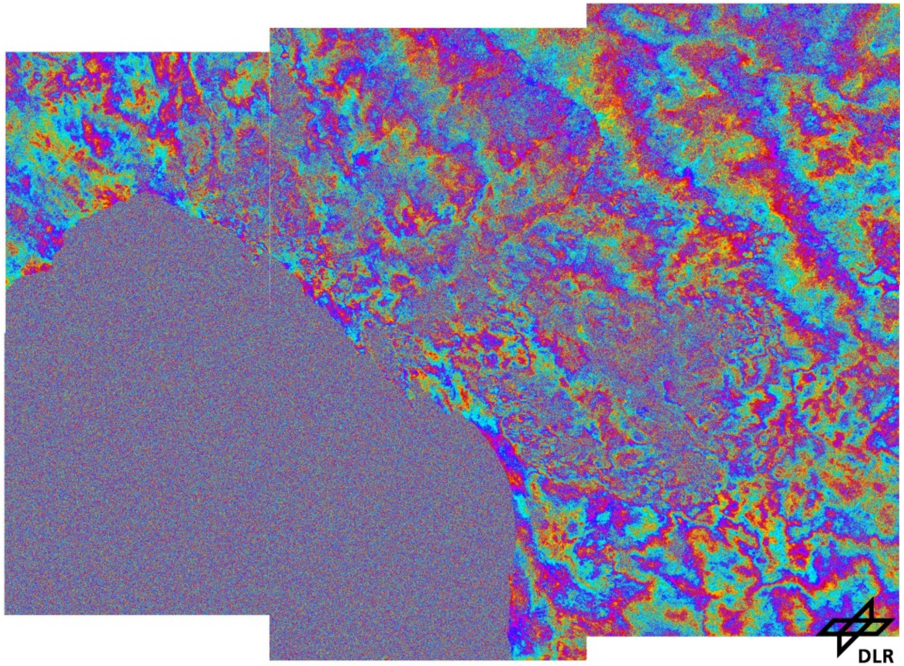
Sentinel-1 – IW TOPS, Genoa

Master Date	19-08-2014
Slave Date	07-08-2014 (12 days)
Mode	IW
Resolution	4.5 m x 20.9 m (Burst 1, Beam 1)
Extension	249 km x 179 km
Polarisation	VV
Orbit Direction	Ascending
Effective Baseline	121.4 m avg.
Height of Ambiguity	128.5 m avg.
Incidence Angle	30.5° – 45.9° (15.4°)
Average Coherence	0.17

- Acquisition lies over north-west Italy
- Elevation reaches 2000 m
- Urban areas, plains, forested mountains

DEM Corrected Interferometric Coherence and Phase



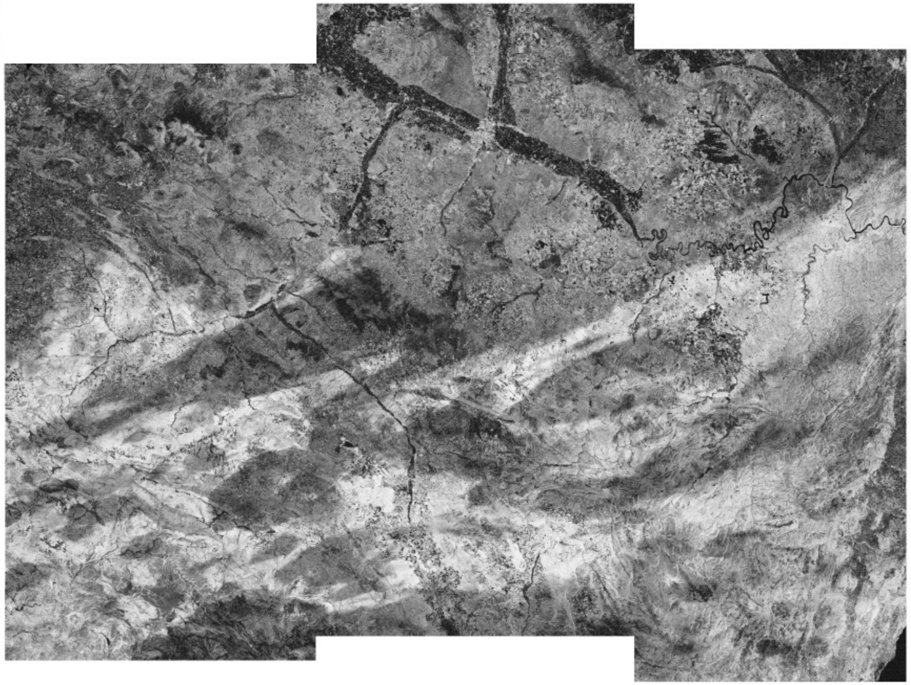


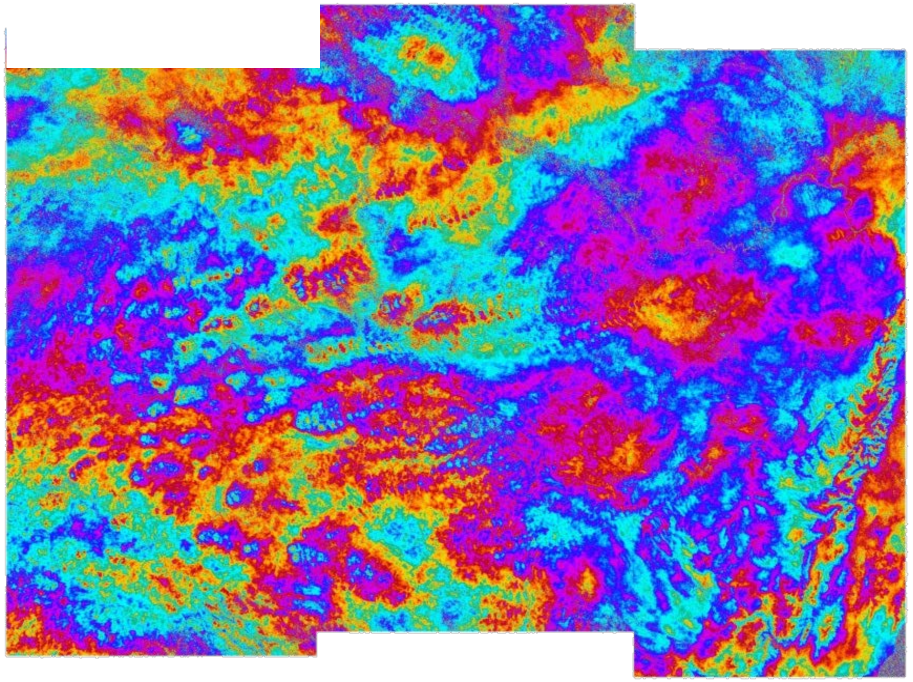
Sentinel-1 – IW TOPS, Spain

Master Date	19-08-2014
Slave Date	31-08-2014 (12 days)
Mode	IW
Resolution	4.5 m x 20.9 m (Burst 1, Beam 1)
Extension	249 km x 179 km
Polarisation	VV
Orbit Direction	Descending
Effective Baseline	49.0 m avg.
Height of Ambiguity	317.4 m avg.
Incidence Angle	30.5° – 45.9° (15.4°)

- Zaragoza, Aragón, Spain.
- Coherence-drop
- Heavy rains in August 2014, AEMET

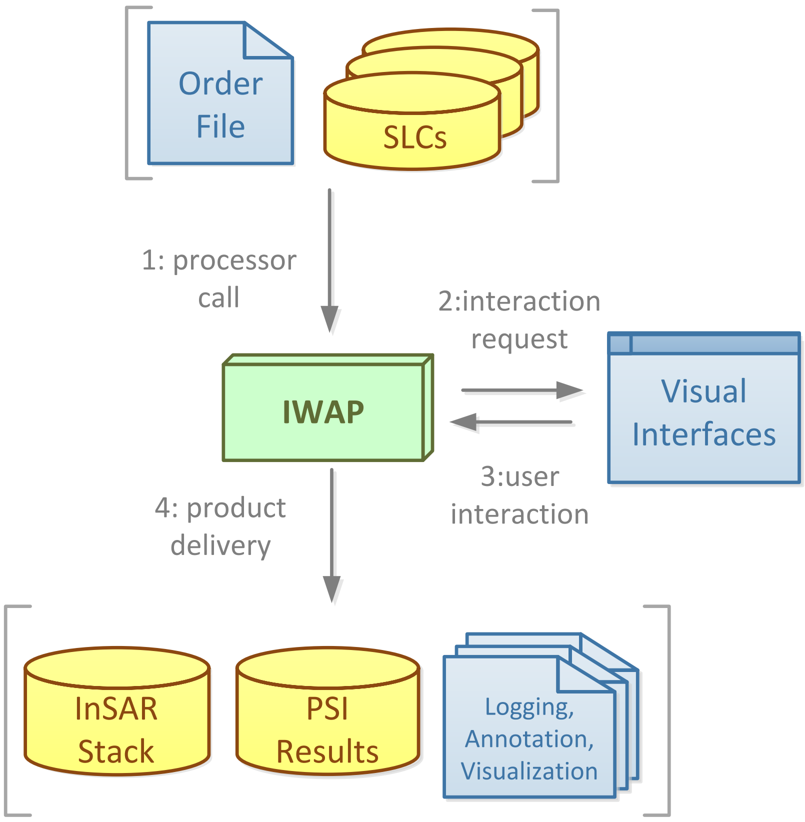
DEM Corrected Interferometric Coherence and Phase





Integrated Wide Area Processor (IWAP)

- *A multi-mode multi-sensor PS-InSAR processor*
- Based on TMSP, ITP, PSI-GENESIS
- Flexible modular approach
- Automated
- Multi-threading and parallel processing



TOPS Mode - three level hierarchical structure

Slice Level

Mosaics (interferogram, amplitude)

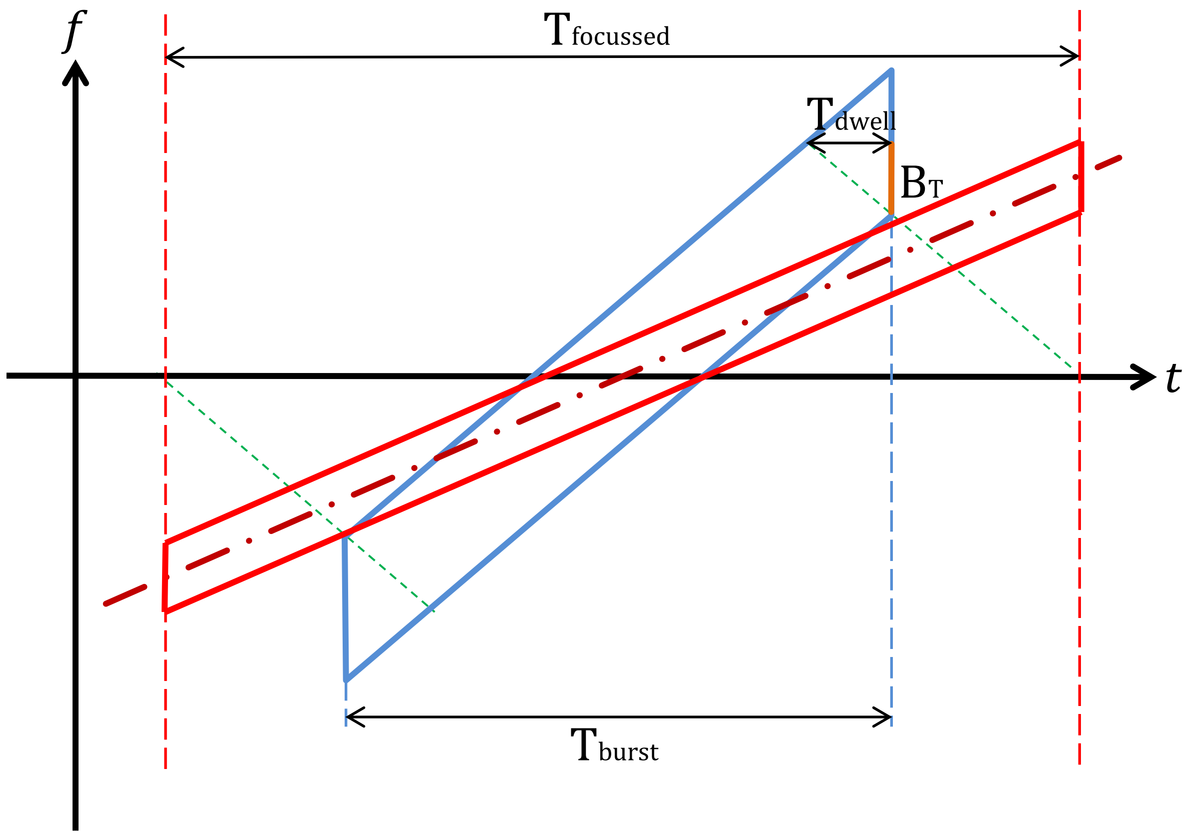
Subswath Level

Mosaics (interferogram, amplitude)

Burst Level

SLCs and Valid Pixel Masks (interferogram, amplitude)

TOPS bursts spectral properties



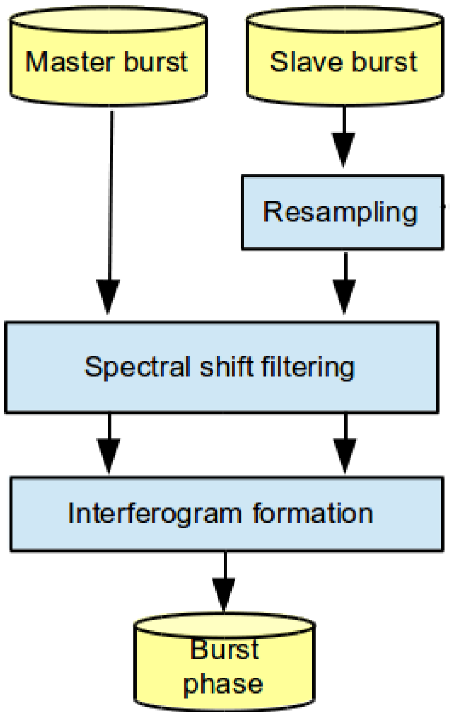
- $T_{dwell} << T_{burst}$

(T_{dwell}: integration time for a point target)

- Azimuth resolution worse due to steering of the antenna. Resolution controlled by T_{dwell}.

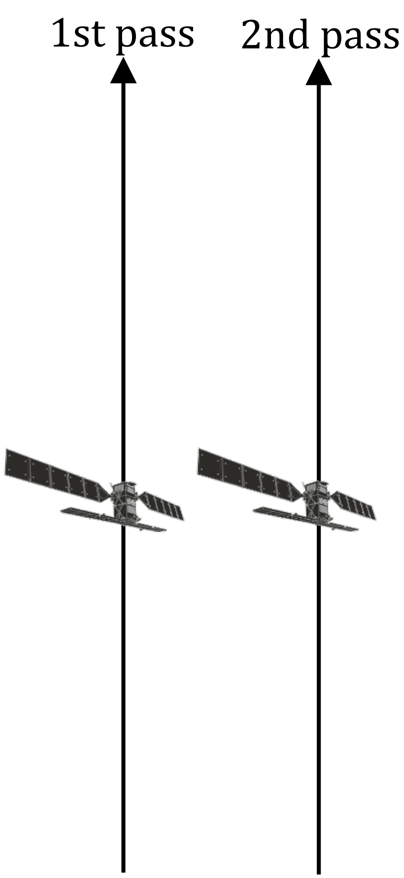
- **Time-varying spectrum**

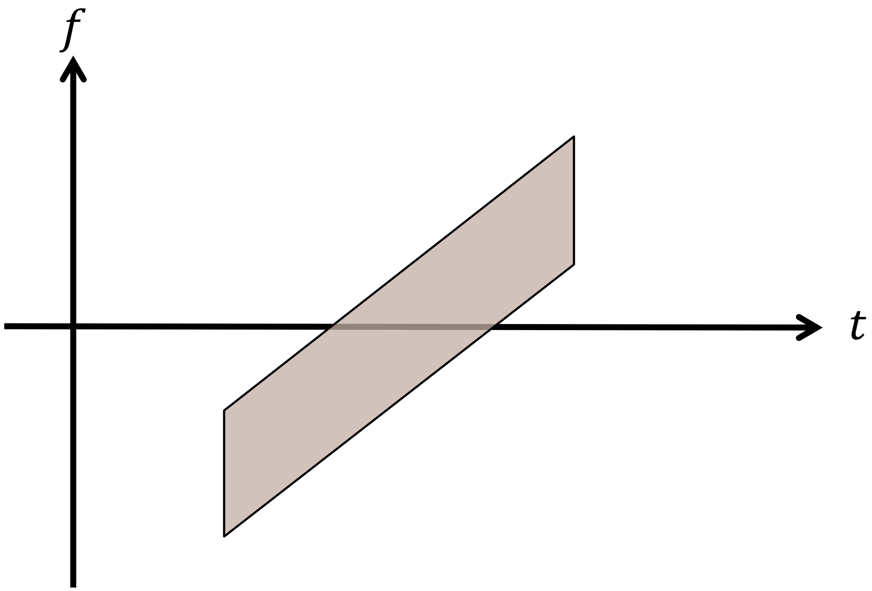
InSAR Processing Chain – Burst level



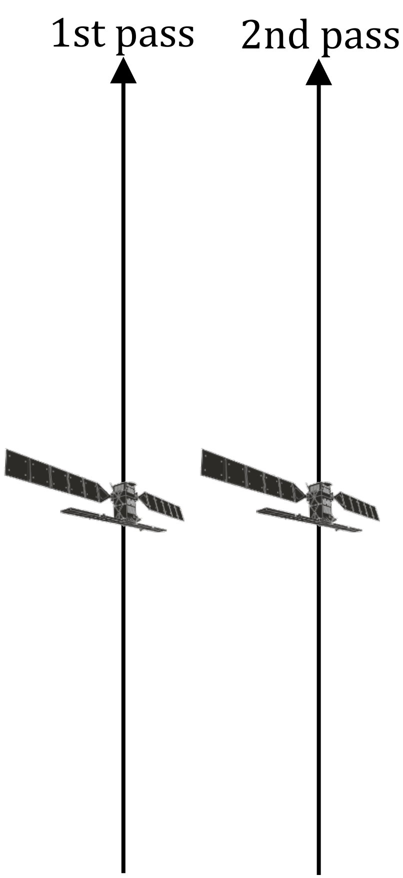
- Consideration of the time-varying Doppler centroid necessary.
- Spectral shift filtering
  - Range
    - Compensation of wavenumber shift (due to perpendicular baseline).
  - Azimuth
    - Similar principle to Spotlight mode: De-ramping / Re-ramping

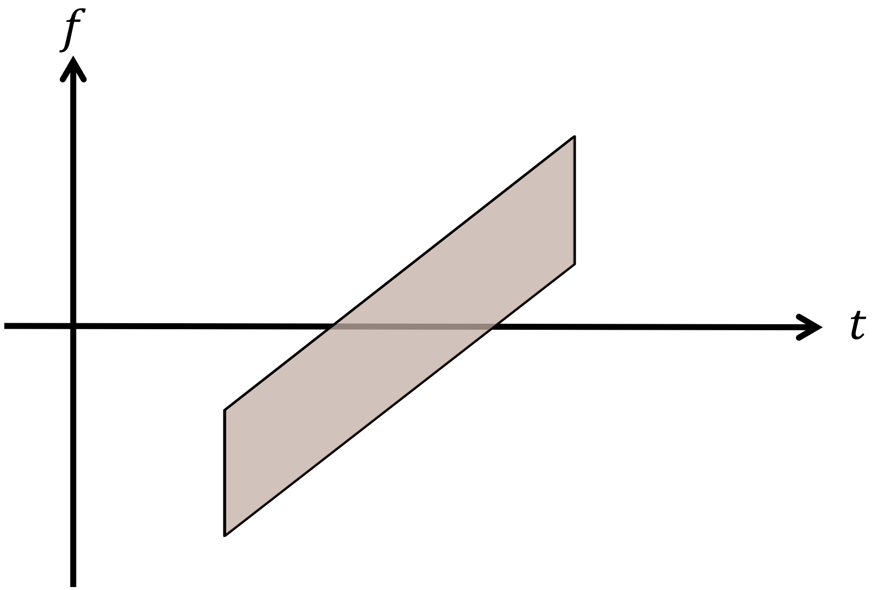
Burst synchronization: Mutual Along-track position





Burst synchronization: Pointing accuracy / TZDS





Common Doppler Bandwidth Evaluation

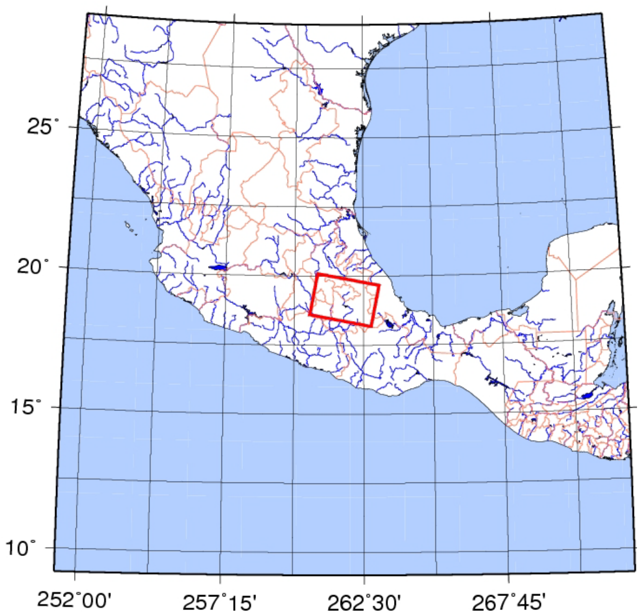
Ascending

Stack 9 IWS images

(06/10/2014 – 22/01/2015)

Master: 05/12/2014

Descending



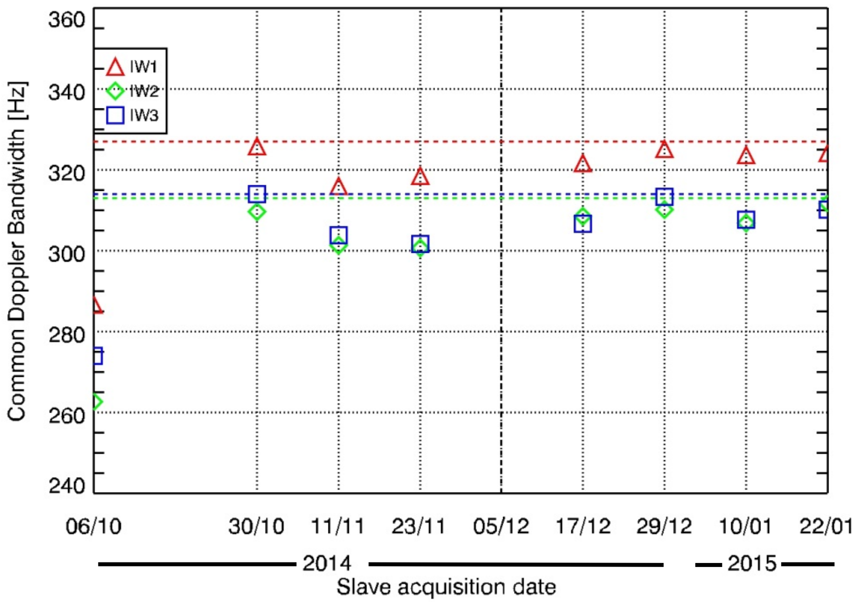
Stack 10 IWS images

(03/10/2014 – 31/01/2015)

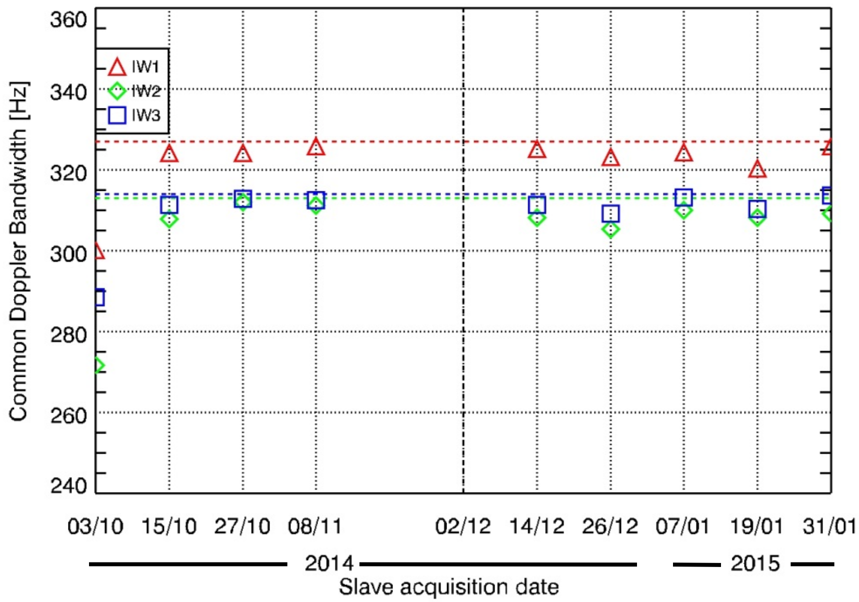
Master: 02/12/2014

Common Doppler Bandwidth Evaluation

Ascending



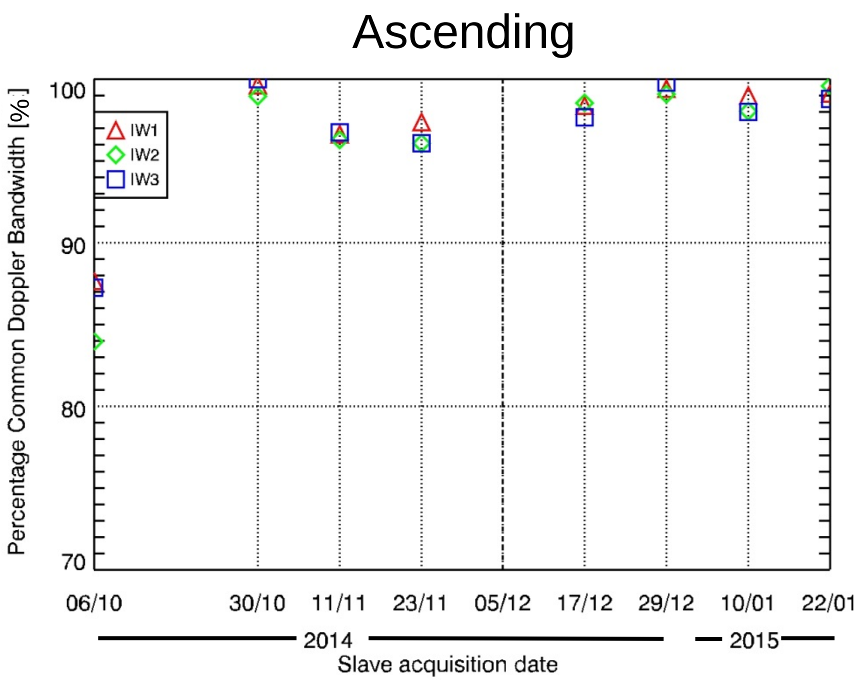
Descending

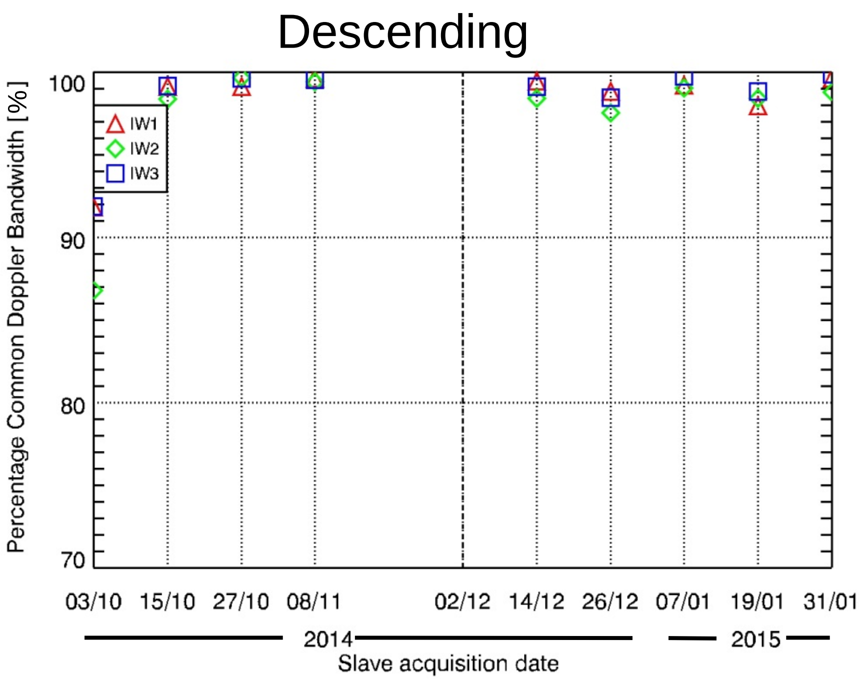


S1 IW. Doppler Bandwidth			
Subswath	**IW1**	**IW2**	**IW3**
Doppler BW	**327 Hz**	**313 Hz**	**314 Hz**

DLR

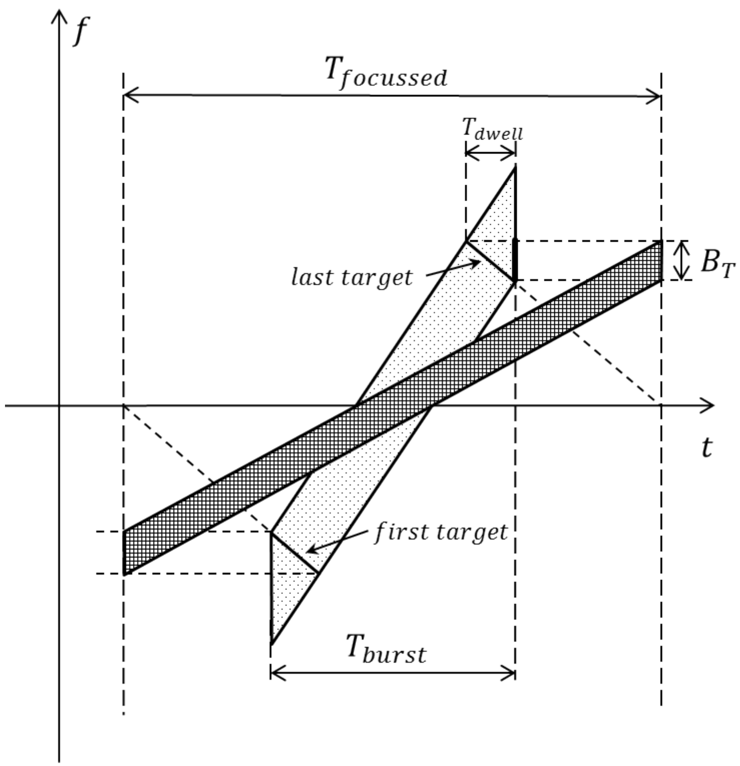
Common Doppler Bandwidth Evaluation (percentage)





No significant coherence loss if no-filtering in azimuth performed.
Analysis on more datasets on-going.

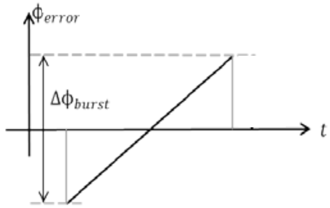
Coregistration requirements



Time-varying spectrum of TOPS bursts!

InSAR phase error due to an azimuth misregistration[1], Δt :

$$\Delta\phi_{\text{burst}} = 2\pi\Delta f_{dc}\Delta t$$



	S1 TOPS IW mode
Azimuth resolution	20 m
Azimuth pixel spacing	14.1 m
Needed Azimuth co-registration accuracy*	~0.001 pixel (1.4 cm)

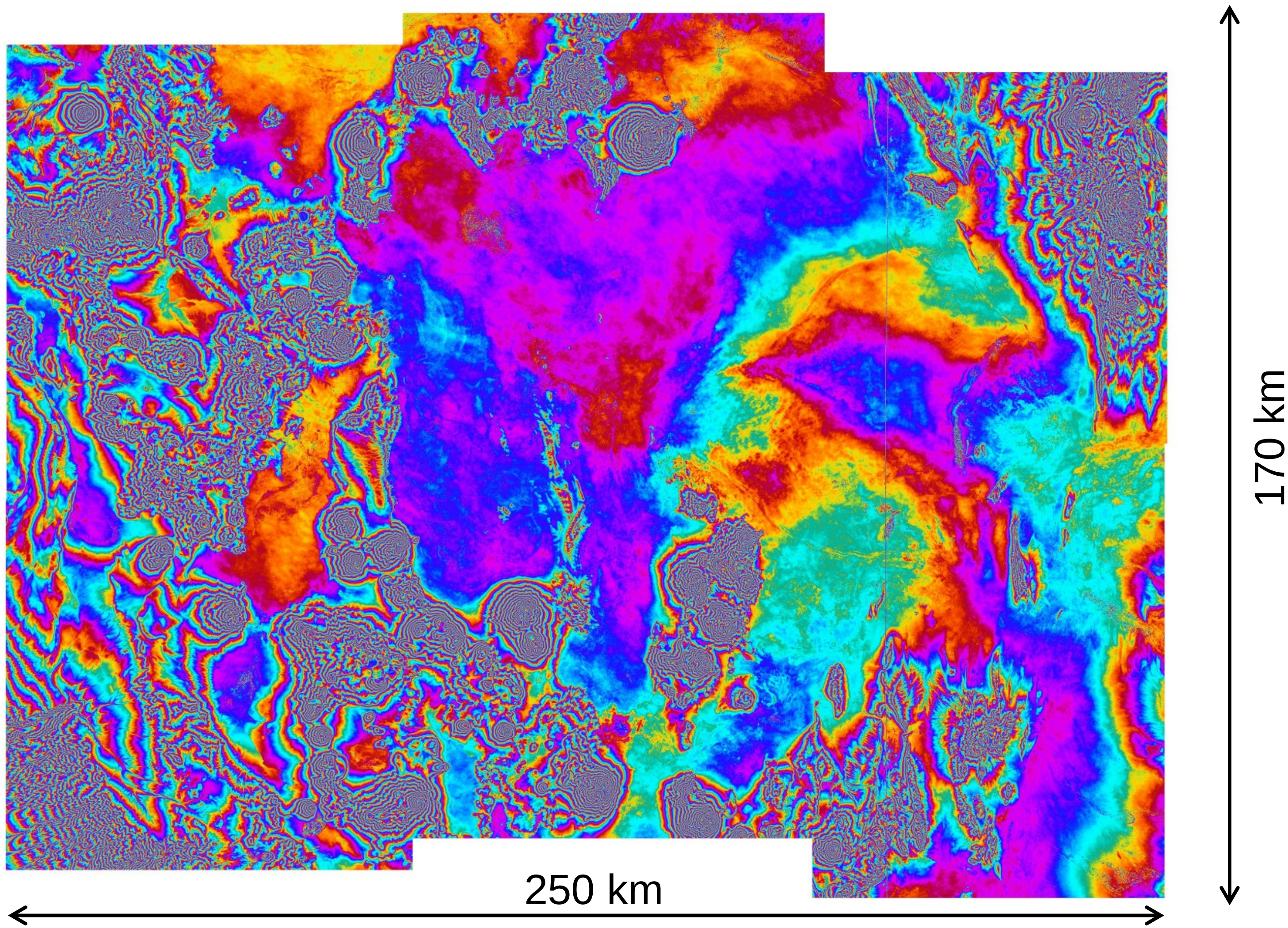
*Allowing $\Delta\phi_{\text{burst}}$ = 1/100 cycle = 3.6º

[1] R. Scheiber, A. Moreira. Coregistration of Interferometric SAR Images using Spectral Diversity", *IEEE Transactions on Geoscience and Remote Sensing, 2000*

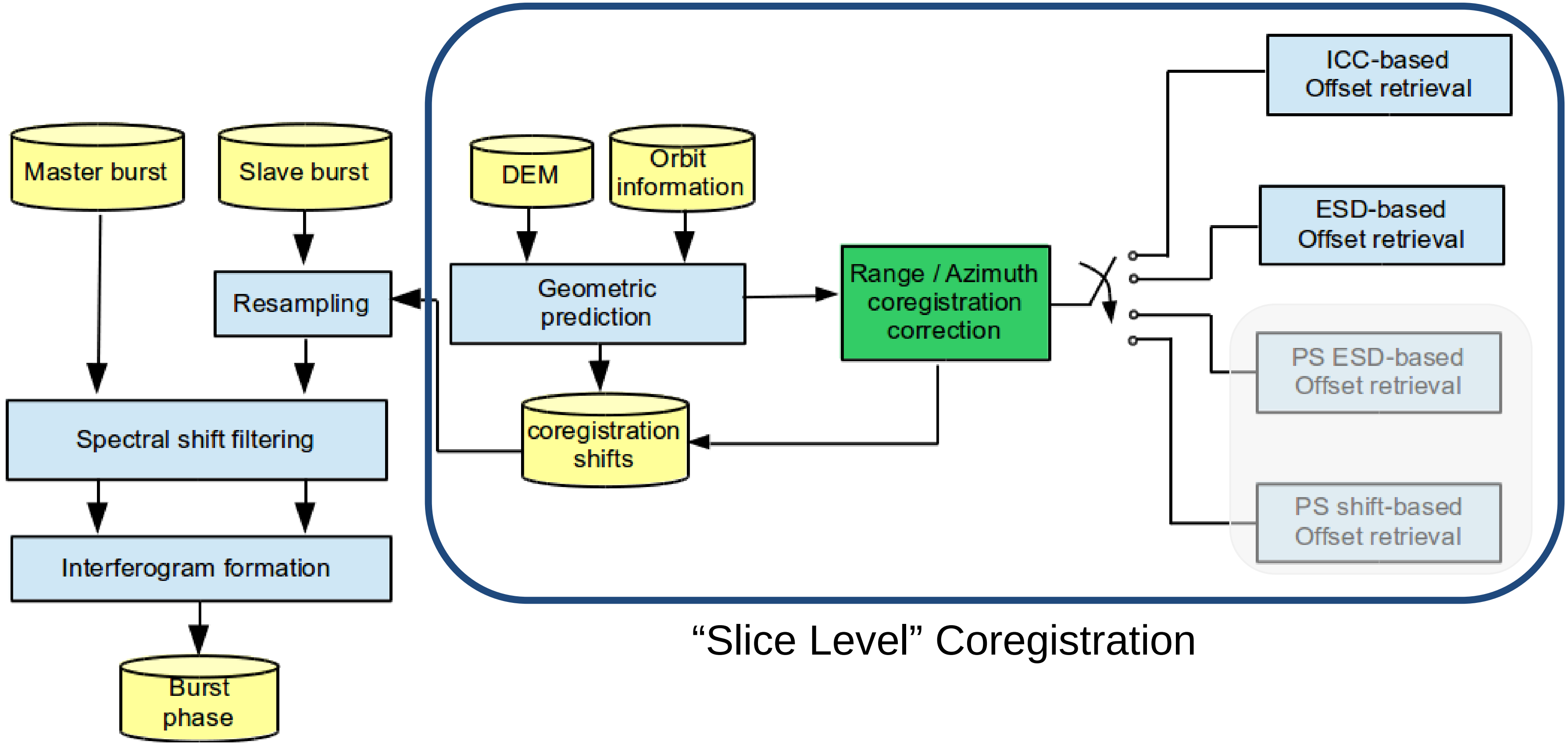
Coregistration error effect. Salar de Uyuni

Artificial azimuth shift of 0.05 pixels
(for demonstration)

Fine azimuth coregistration



Coregistration Workflow



"Slice Level" Coregistration

Mosaicking at sub-swath or slice level + Quality Control (ESD)

Coregistration

- Geometric prediction with external DEM and orbit information

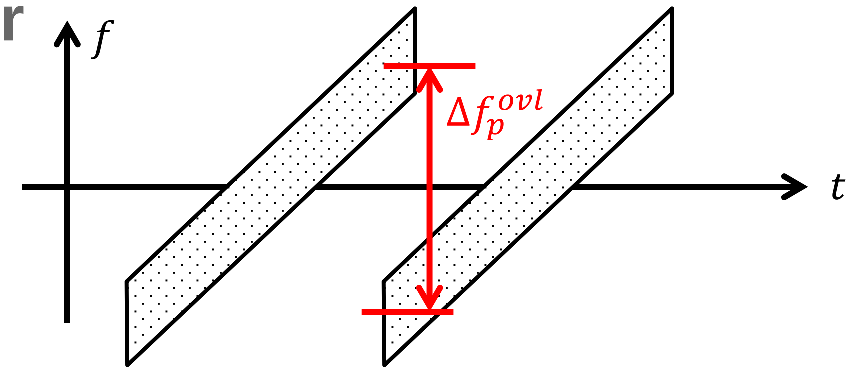
- **Range:** Linear correction to account for orbital errors / geodynamic effects
  - Incoherent Cross Correlation (ICC)
- **Azimuth:** Rigid shift correction to account for orbital timing error / geodynamic effects
  - Enhanced Spectral Diversity (ESD)[1] -> achieves fine azimuth coregistration requirement.

- Orbit sources:
  - Annotated in L1 Product / Restituted Orbit / Precise Orbit

	Restituted	Precise
Accuracy from Specs.	10 cm 2D (1-sigma)	5 cm 3D (1-sigma)
Expected AT **InSAR** accuracy	10 cm (1-sigma)	4.08 cm (1-sigma)

[1]P.Prats-Iraola, R. Scheiber, S. Wollstadt, A. Reigber “TOPS Interferometry with TerraSAR-X", *IEEE Trans. Geosci. Remote Sens.*, vol. 50, no. 8, pp. 3179 -3188. 2012

Coregistration: ESD estimator



- Basic ESD relation

$$\phi_{ESD,p} = 2\pi\Delta f_p^{ovl}\frac{\Delta y}{f_{az}}$$

Δy: az. shift (pix); f_{az}: SLC az. sampling freq.; Δf_p^{ovl}: freq. diff for each pixel in overlap area

- Apply **pixel-wise** to burst overlaps within subswath

$$\widehat{\Delta y} = \underset{\Delta y}{\operatorname{argmin}}\left\{\left|\operatorname{atan}\sum_p e^{j\left(\phi_{ESD,p}-2\pi\Delta f_p^{ovl}\frac{\Delta y}{f_{az}}\right)}\right|\right\}$$

- ESD phase ambiguity band

	IW1	IW2	IW3
$<\Delta f_p^{ovl}>$	4814.25 Hz	4044.80	4267.22
Amb. Band	± 0.71 m	± 0.85 m	± 0.80 m

- **ESD** can be applied directly after geometric coregistration if **Precise** / **Restituted** Orbits are used (Ambiguity band is solved).

Along-tracks shifts evaluation

- Analysed orbits:
    - **Restituted**
    - **Precise**

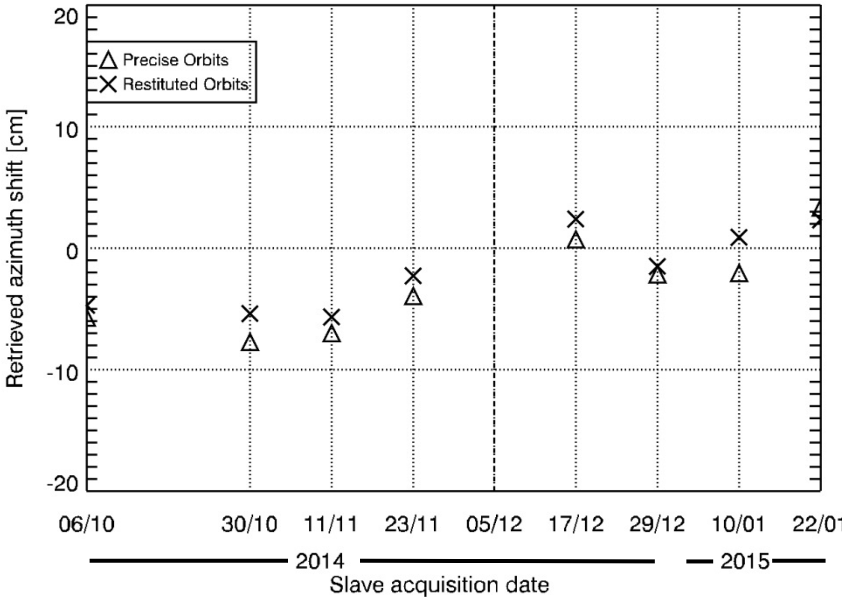
- **Temporal analysis**
    - Use two stacks of acquisitions over Mexico City.
    - Analysis of the residual azimuth shift over time.

- **Spatial Analysis**
    - Use of a datatake over Germany with six slices.
    - Analysis of the residual azimuth shift along azimuth.

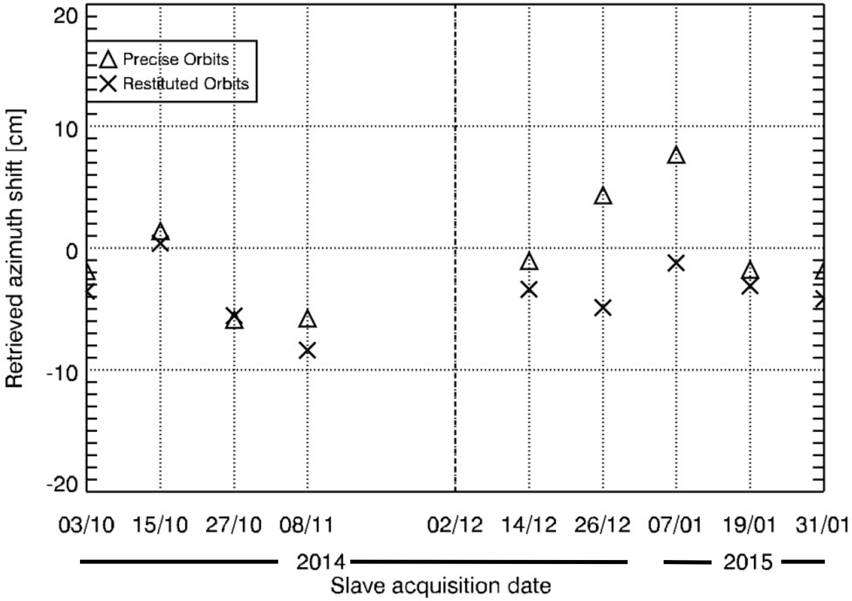
Along-tracks shifts evaluation: Temporal analysis

Solid Earth Tides considered

Ascending



Descending



Std dev Along-track shift (InSAR)		
	REST.	PREC.
Measured	3.35 cm	3.81 cm
From Specs	10 cm	4.08 cm

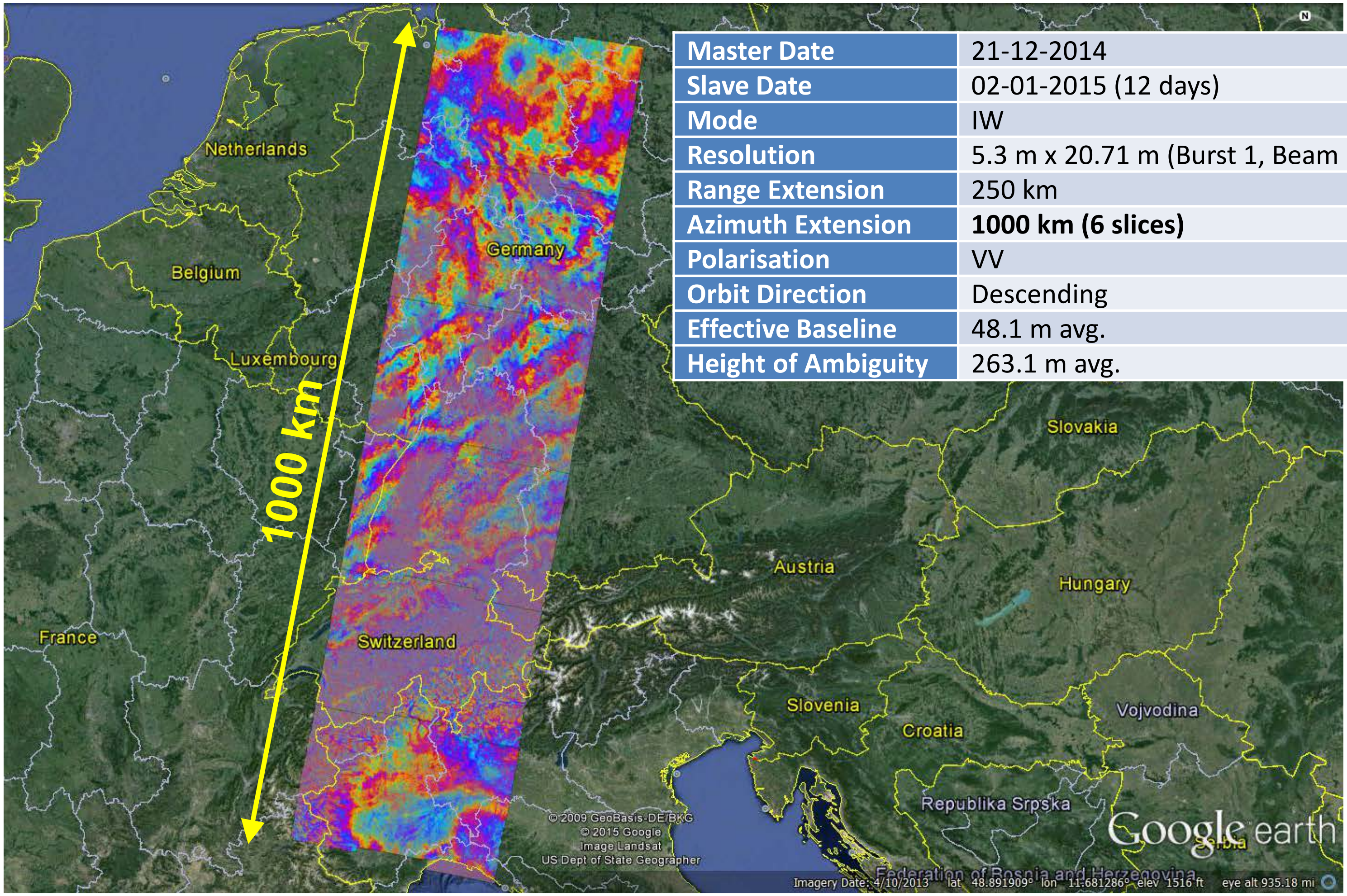
Necessary to perform a fine refinement of the geometric shifts.

Std dev Along-track shift (InSAR)		
	REST.	PREC.
Measured	2.52 cm	4.42 cm
From Specs	10 cm	4.08 cm

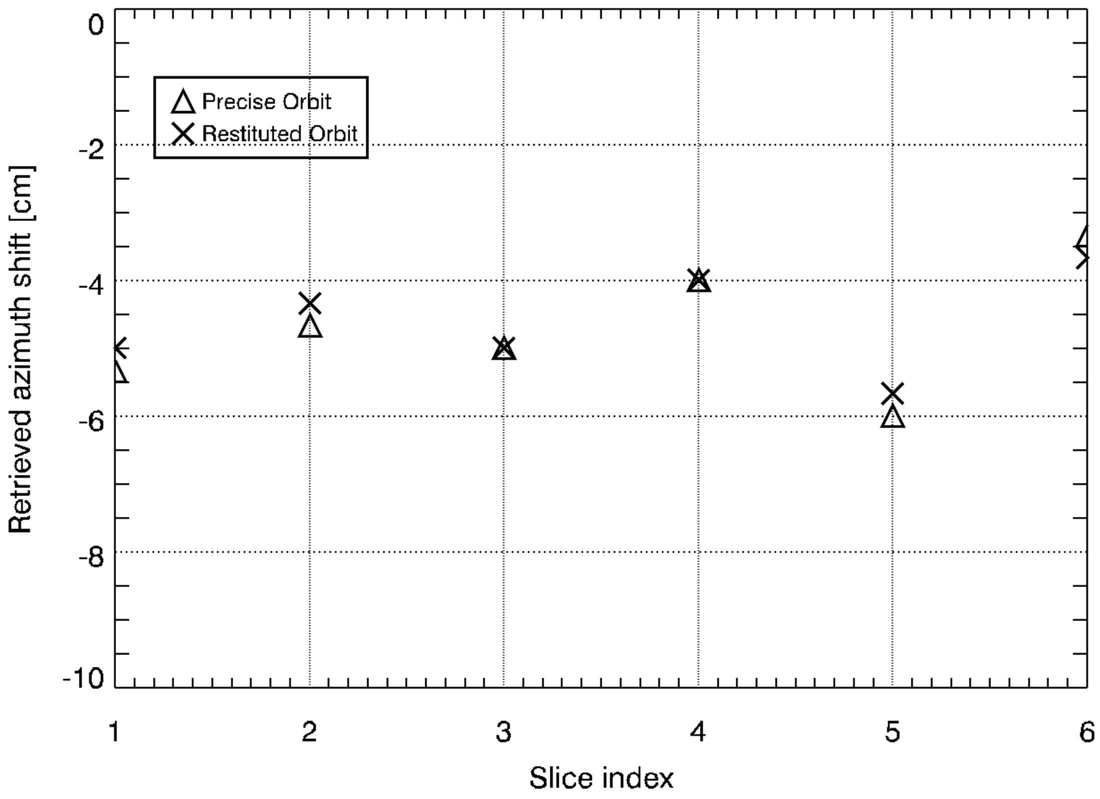
DLR

Along-tracks shifts evaluation: Spatial analysis

Master Date	21-12-2014
Slave Date	02-01-2015 (12 days)
Mode	IW
Resolution	5.3 m x 20.71 m (Burst 1, Beam 1)
Range Extension	250 km
Azimuth Extension	**1000 km (6 slices)**
Polarisation	VV
Orbit Direction	Descending
Effective Baseline	48.1 m avg.
Height of Ambiguity	263.1 m avg.



Along-tracks shifts evaluation: Spatial analysis

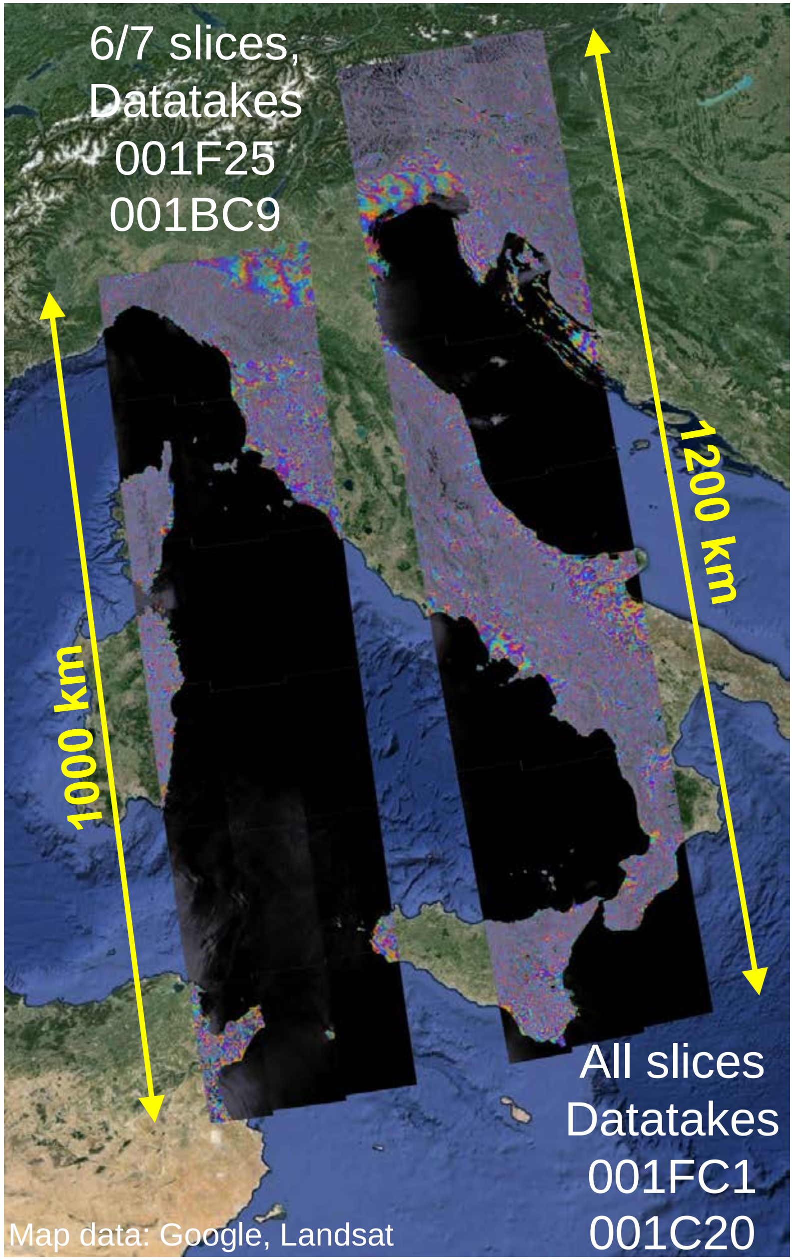


Std dev REST.	Std dev PREC.
7.4 mm	9.5 mm

Good spatial stability allows to retrieve timing offset from one slice, being applicable to the rest of slices.

Slice Mosaicking

- An L0 datatake packaged as L1 slice products (IW mode)
- All slices are processed with the same parameters on a common grid
- IW slice products were interferometrically processed using IWAP and then mosaicked
    - Varying mean height between slices for FEP calculation → phase jumps InSAR phase → set consistently mean height.
- Could also mosaic L1 slice products and then perform InSAR processing → datatake level coregistration



Conclusions

- IWAP InSAR processing chain presented.
    - Uses a combination of ICC and ESD for fine coregistration

- S1A analysed data presents very good burst synchronization. Azimuth spectral shift filtering necessary? More analysis on-going.

- Necessary to refine azimuth geometric shifts.

- Stability of along-track shifts within a DT (6 slices analysed) allows to retrieve orbital timing offset from one slice (if enough coherence) and apply it to the rest of slices.