A network approach for precise coregistration of the Sentinel-1 TOPS data

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Outline

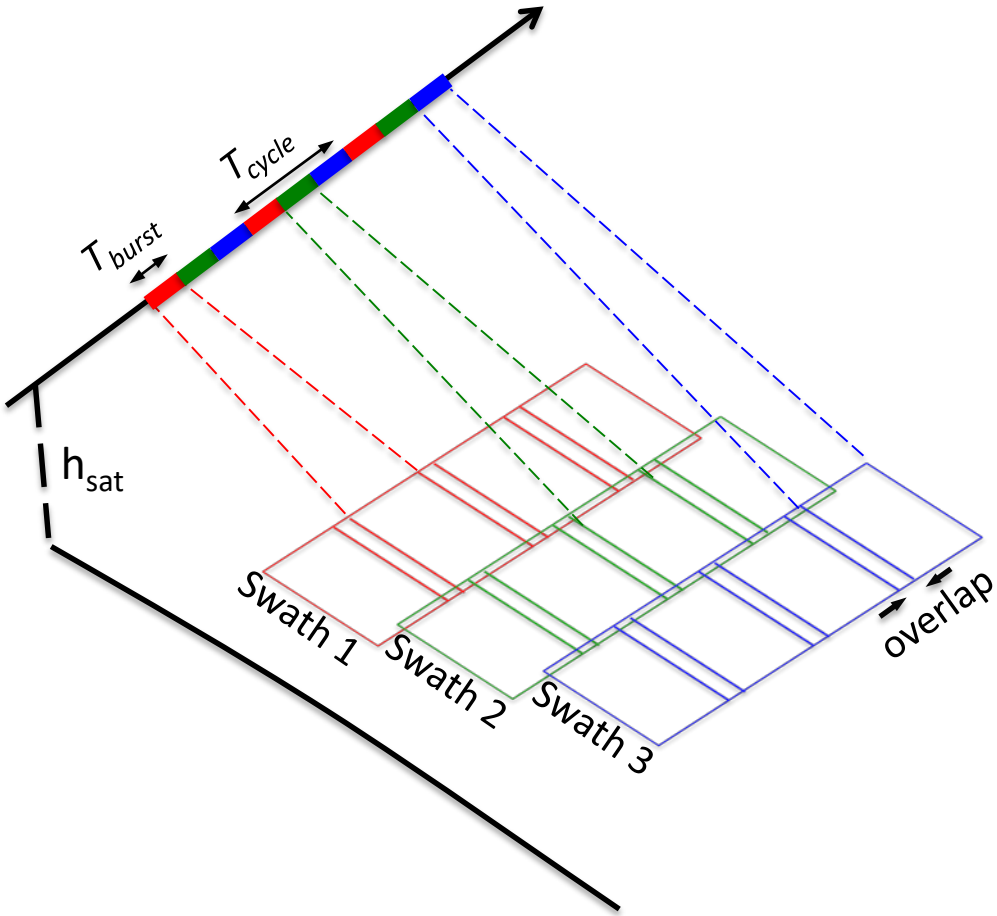
Sentinel-1 TOPS and precise coregistration

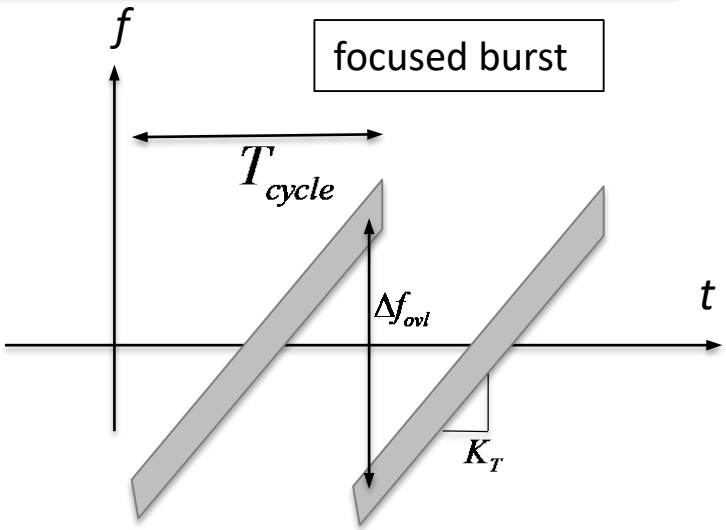
Network approach for Enhanced Spectral Diversity (NESD)

Experimental results for different stacks

Possible limitations for operationalizing NESD

TOPS (Terrain Observation by Progressive Scan**)**





$$\phi_{err} = 2\pi f_c \Delta t$$

ϕ_{err} : phase due to azimuth misregistration

f_c : center frequency

Δt : azimuth misregistration (in seconds)

Achievable coregistration accuracy with geometry	**Required** coregistration accuracy for Sentinel-1 TOPS
~ 1/100 pixel	1/1000 pixel

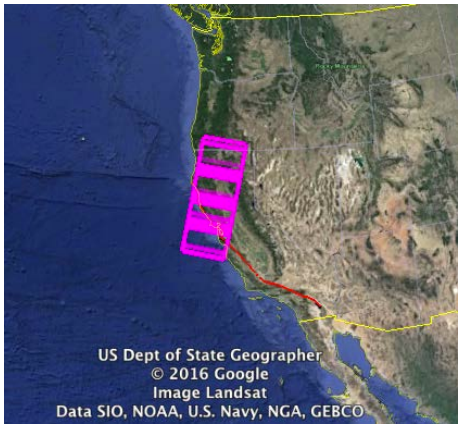
Impact of azimuth mis-registration on TOPS interferogram

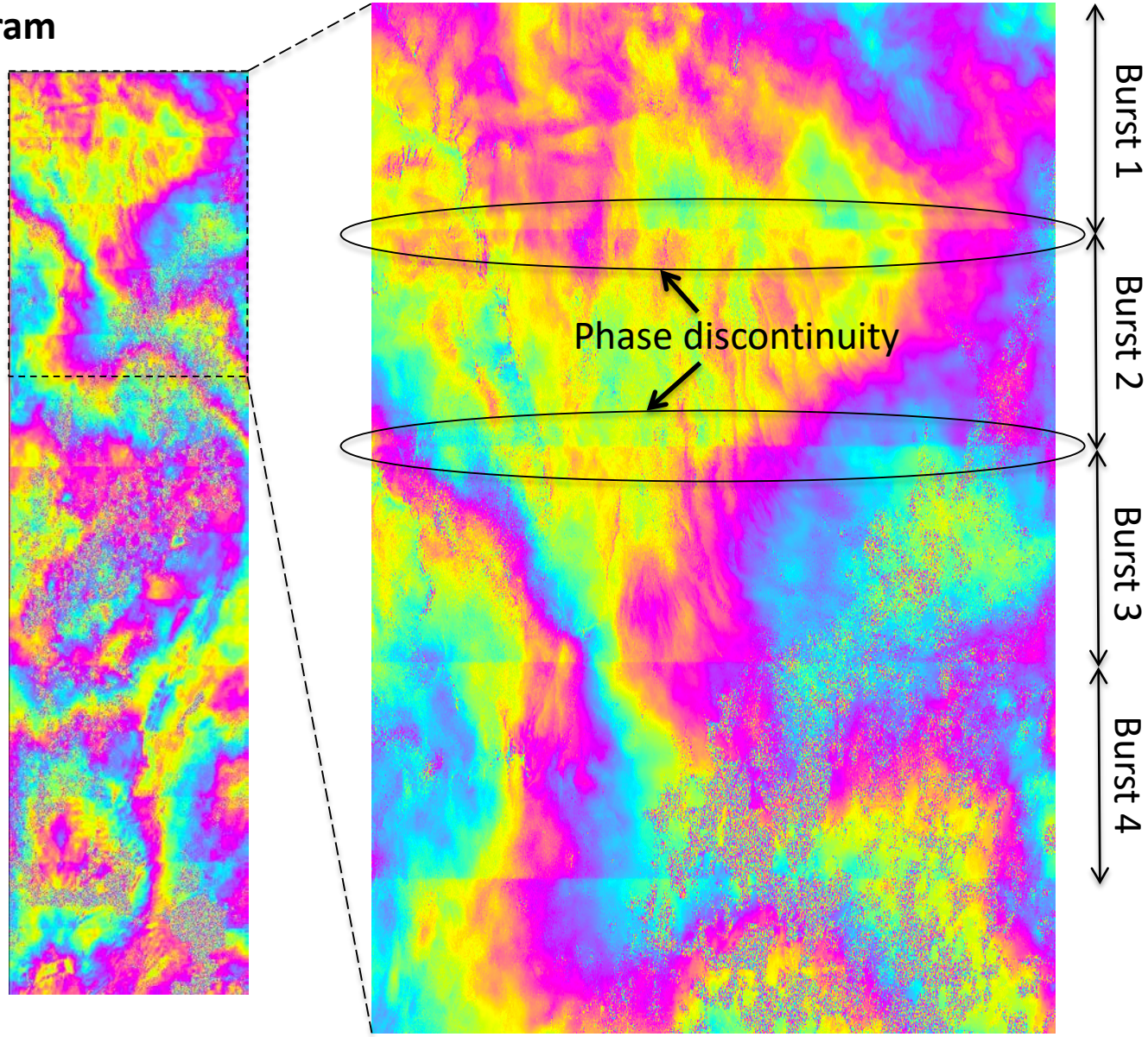
Sentinel-1A TOPS interferogram

Track 115 (Desc Orbit)
2015 Aug 21 – 2015 Sep 14
Swath: 1

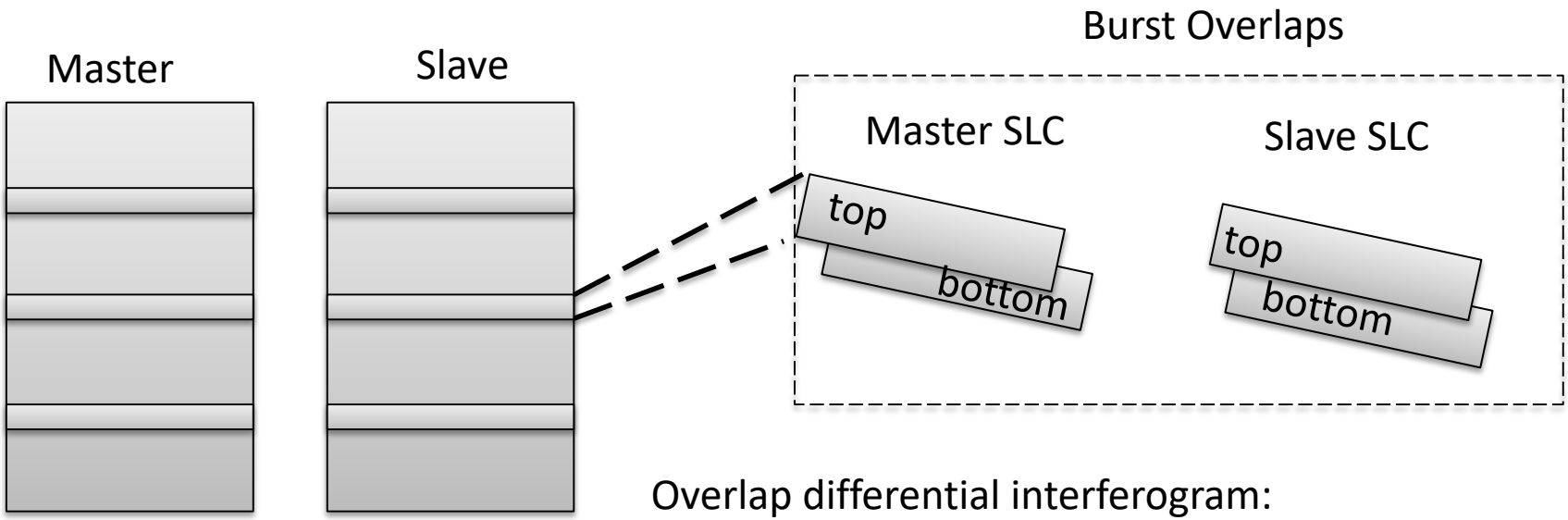
Geometrical coregistration with precise orbits and DEM

Azimuth mis-registration causes phase discontinuity at the burst boundaries.





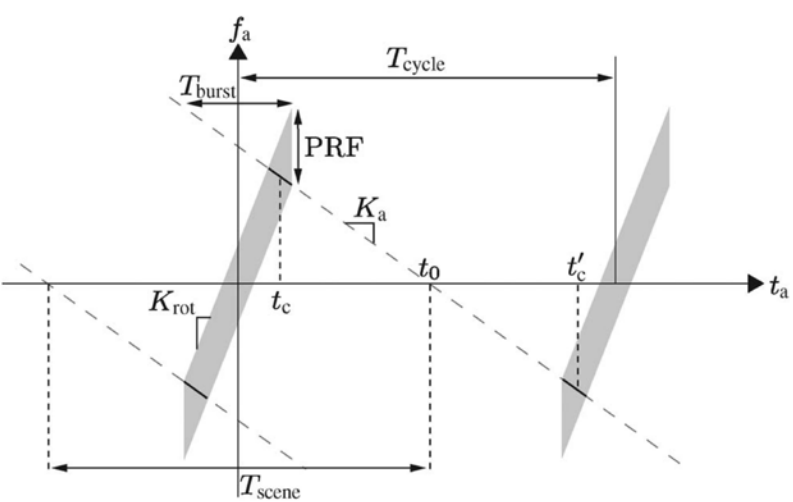
Enhanced Spectral Diversity (ESD)



Overlap differential interferogram:

$$sd = (M_{top} \ . \ S^*_{top}).(M_{bot} \ . \ S^*_{bot})^*$$

$$\phi_{sd} = 2\pi \Delta f \Delta t$$



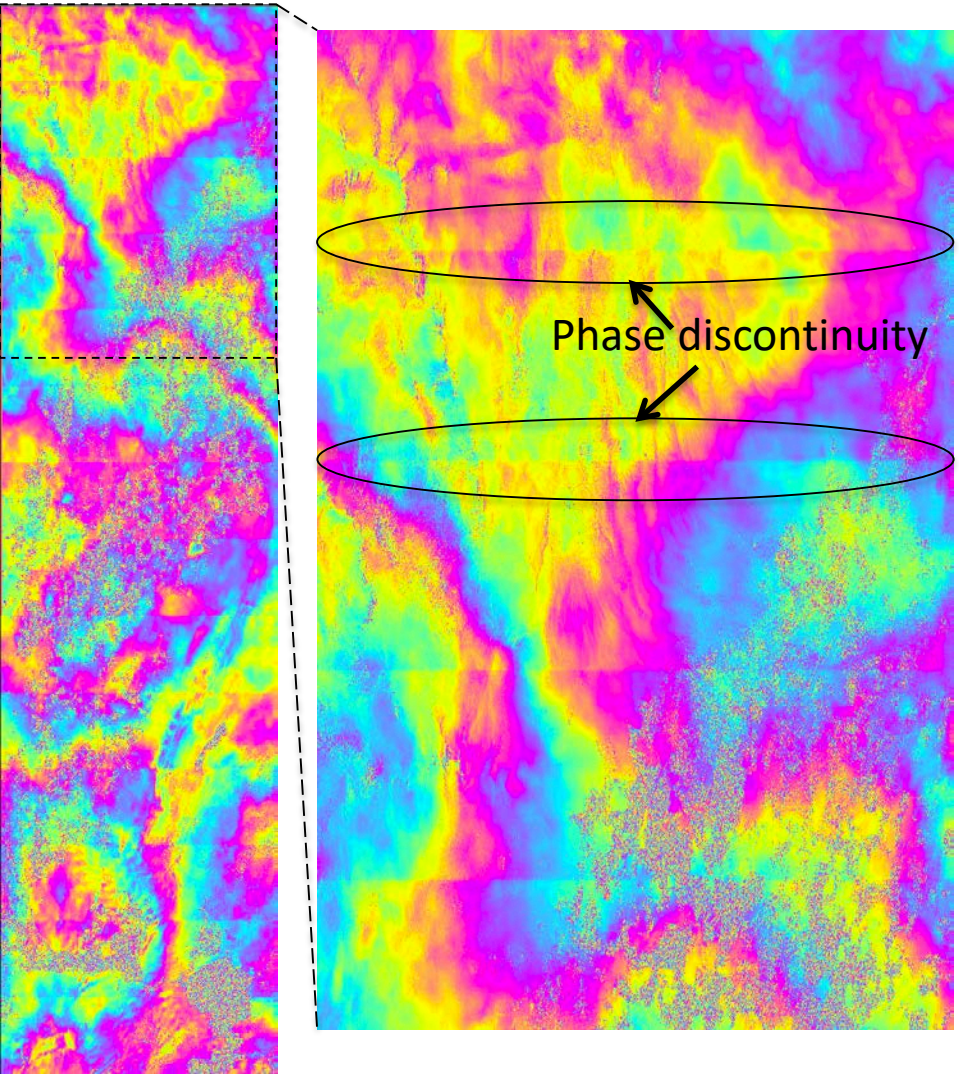
Δf : Spectral separation of the two sub-looks (can be computed from geometry)

Δt : Azimuth mis-registration (in seconds)

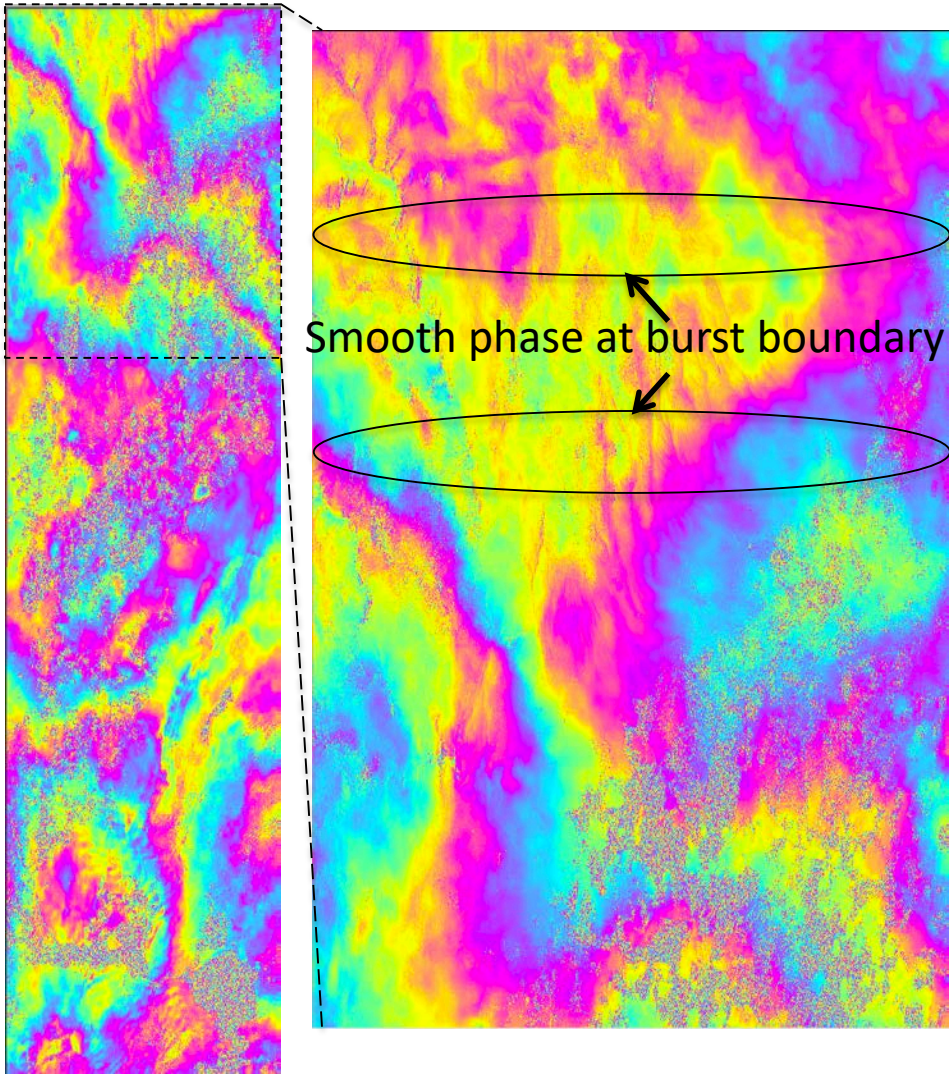
[Prats-Iraola et al, 2012]

Correcting the azimuth mis-registration using spectral diversity

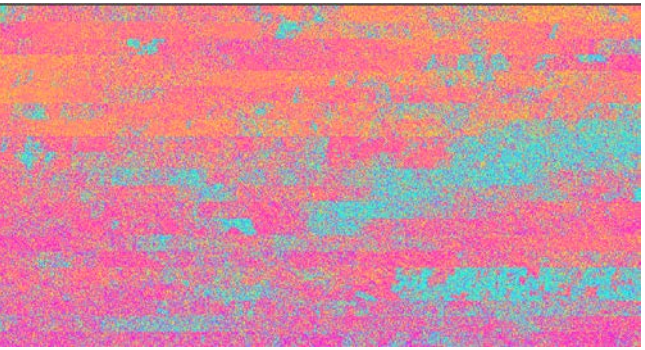
Geometry coregistration



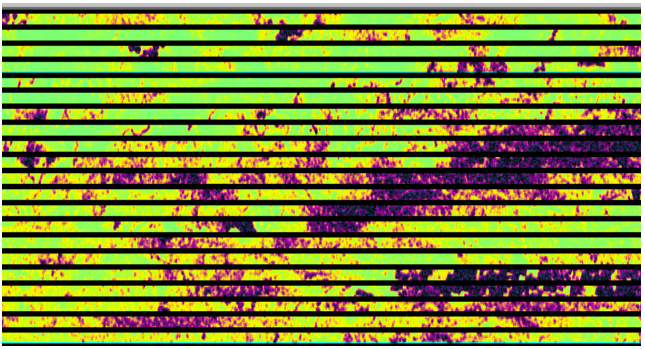
Geometry coregistration
+ constant azimuth misregistration



Accuracy of azimuth mis-registration using spectral diversity

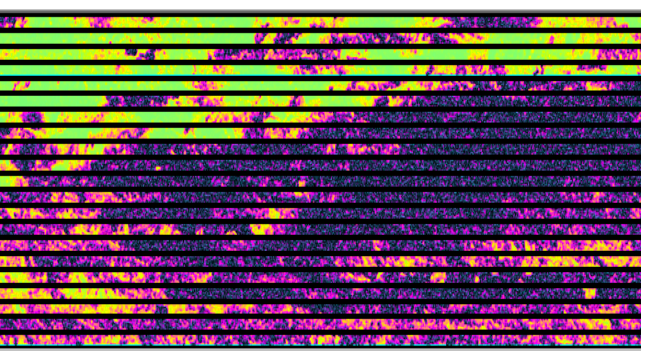


21 burst overlap interferograms



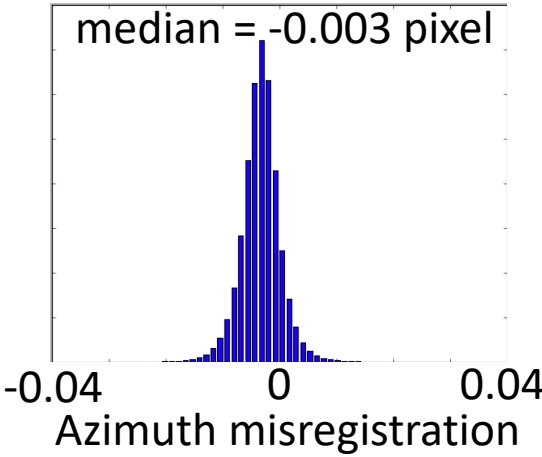
21 burst overlap coherence

20150706-20150730 (24 days)



21 burst overlap coherence

20141226 – 20150401 (96 days)



$$\sigma_{\phi_{\mathrm{azerr}}} = \frac{\sigma_{\mathrm{int}}}{\sqrt{2}}$$

Accuracy of estimated mis-registration is a function of the coherence

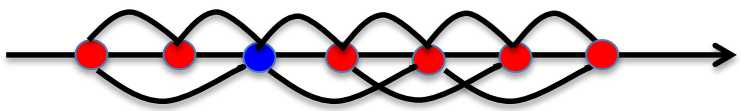
↓

This can be a problem for stack processing.
Low coherence between SLCs with long temporal separation

Network based Enhanced Spectral Diversity (NESD)

Estimatiing the azimuth misregistrations for small baseline pairs and inverting for the stack misregistrations

Small temporal baseline Network



Time

$$\delta t = A \delta T$$

Small baseline pair misregistrations

Misregistrations Of all dates relative to the stack Master date

a) Geometrical coregistration :

For the stack is the same as the single pair (Offsets of all dates relative to a master date).

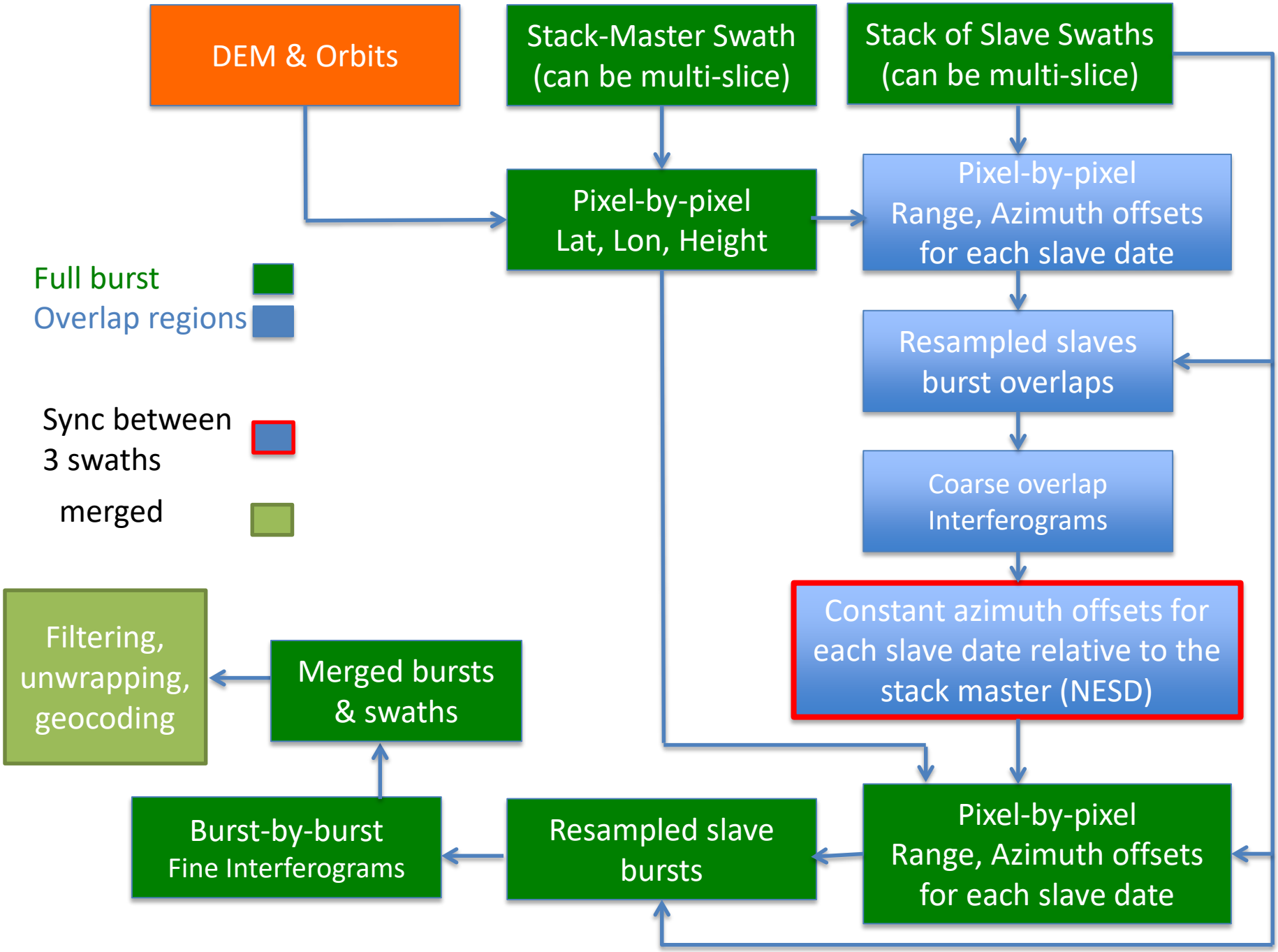
b) Enhanced Spectral Diversity :

For single pair (master-slave):

Doppler centroid rate of the slave SLC is enough to calculate the spectral separation.

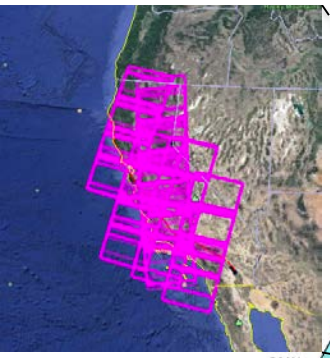
For stack processing :

For one pair (in stack) the Doppler centroid of both master and slave SLCs are required to calculate the spectral separation.


DEM & Orbits
Stack-Master Swath (can be multi-slice)
Stack of Slave Swaths (can be multi-slice)
Pixel-by-pixel Lat, Lon, Height
Pixel-by-pixel Range, Azimuth offsets for each slave date
Full burst
Overlap regions
Resampled slaves burst overlaps
Sync between 3 swaths
merged
Coarse overlap Interferograms
Constant azimuth offsets for each slave date relative to the stack master (NESD)
Filtering, unwrapping, geocoding
Merged bursts & swaths
Burst-by-burst Fine Interferograms
Resampled slave bursts
Pixel-by-pixel Range, Azimuth offsets for each slave date

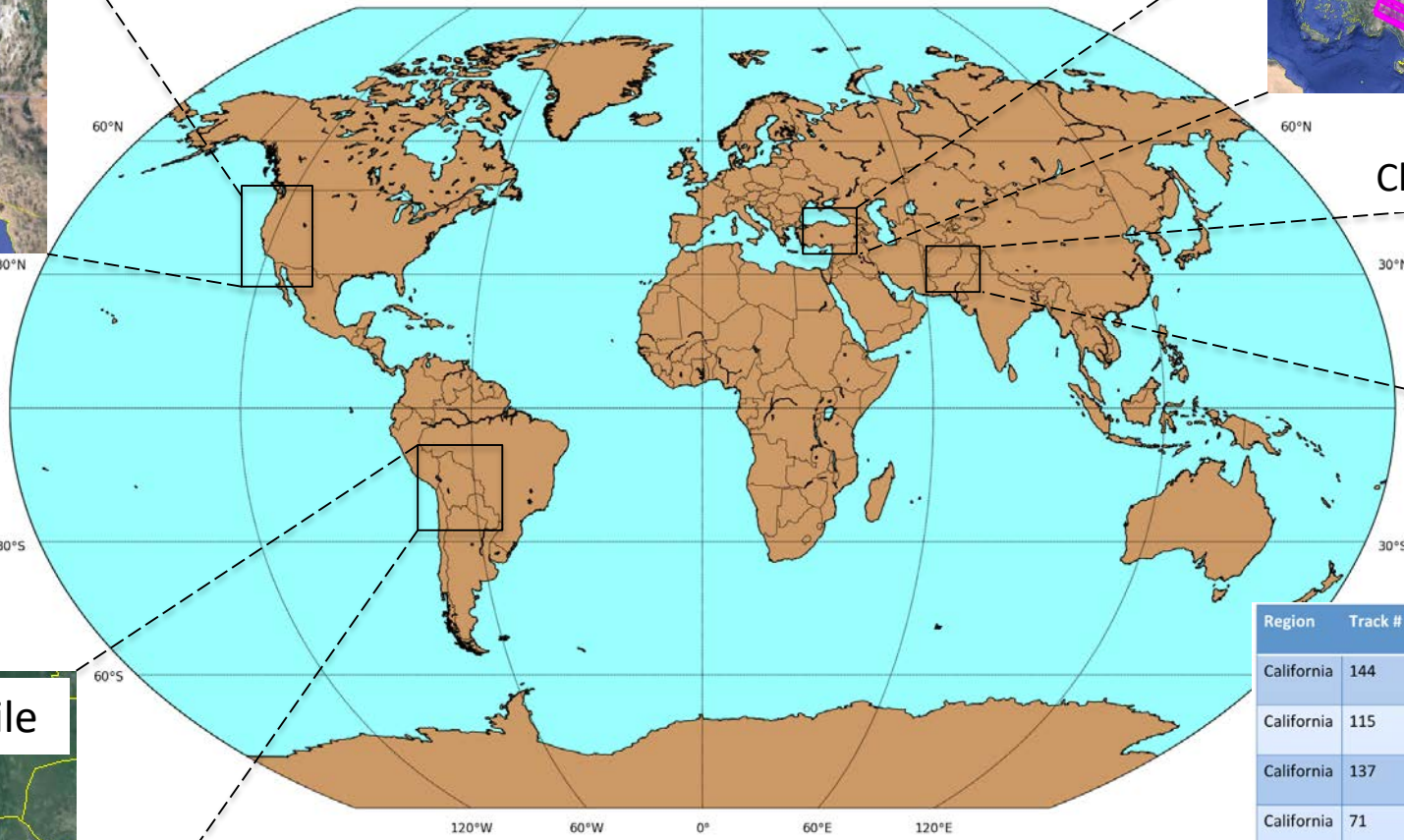
Evaluating the azimuth mis-registration in Sentinel-1 stacks

San Andreas Fault



North Anatolian Fault

Chaman Fault



Northern Chile

~160 acquisitions
~ 500 interferograms
Until Feb 2016

SLC Stack coregistration
(Geometry + Network ESD)

Region	Track #	Asc/Desc	# of acquisitions
California	144	Desc	17
California	115	Desc	16
California	137	Asc	19
California	71	Desc	27
Turkey	65	Desc	37
Chaman	42	Asc	12
Northern Chile	156	Desc	14
California	64	Asc	20

Example 1 : Track 144 California

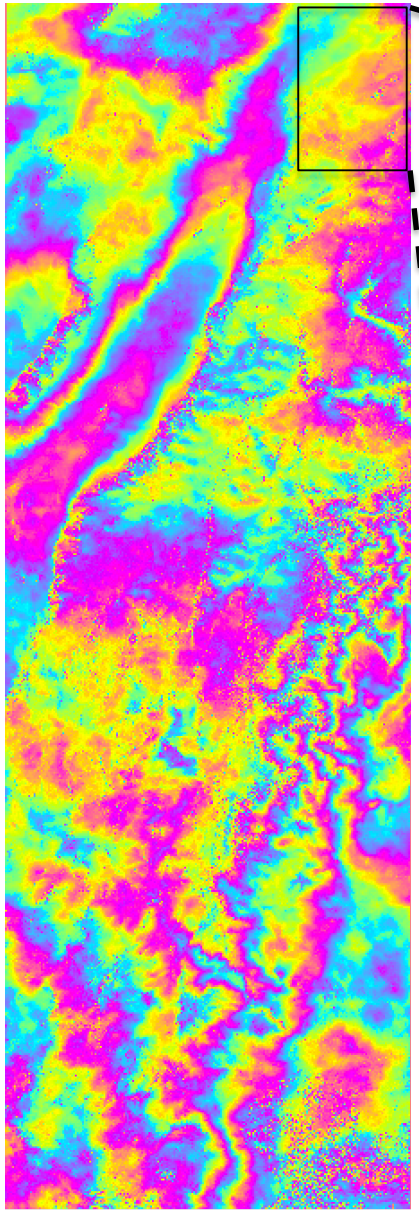
Geometrical coregistration:

- Precise orbits
- DEM

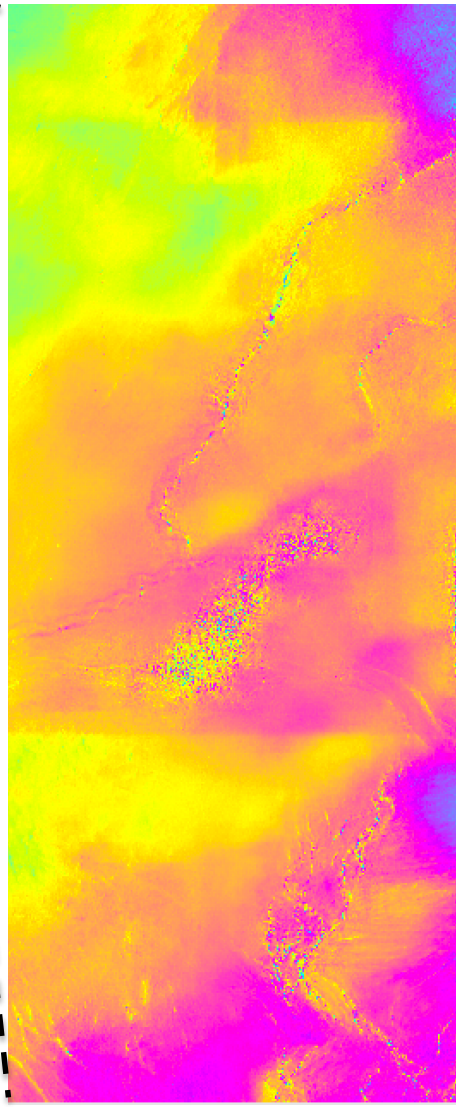
NESD:

- 17 acquisitions
- 2 neighboring interferogram

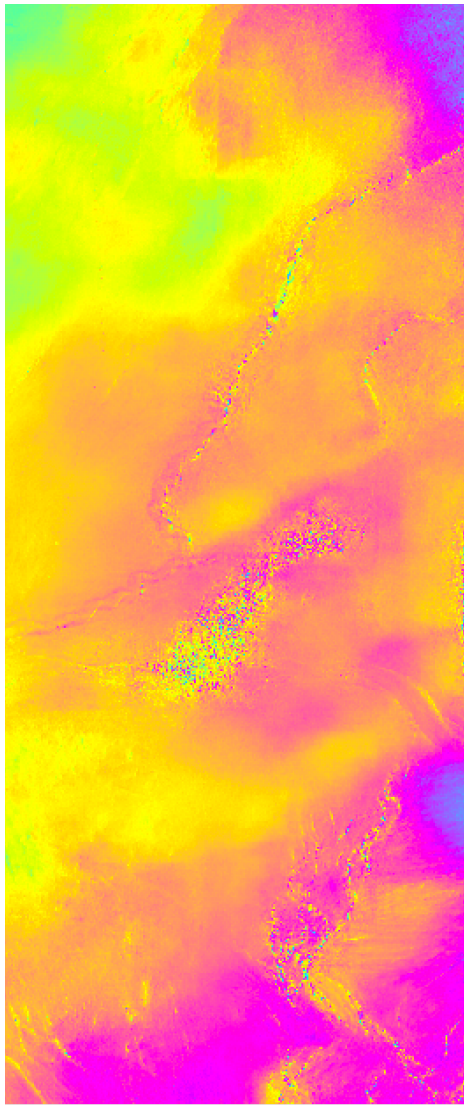
20150706 – 20150730



Geometrical coregistration



Geometrical coregistration + Spectral Diversity



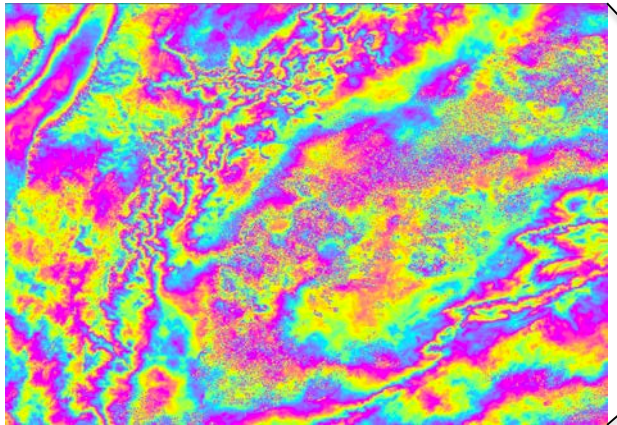
Spatial variation of azimuth mis-registration?

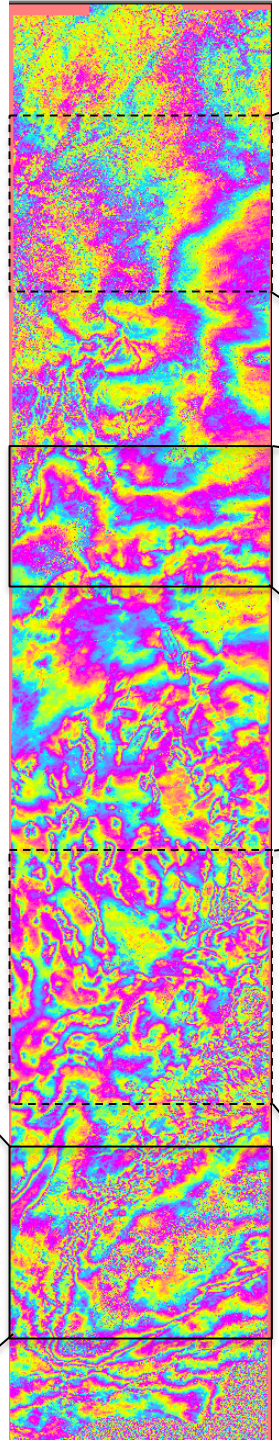
20150706 – 20150730

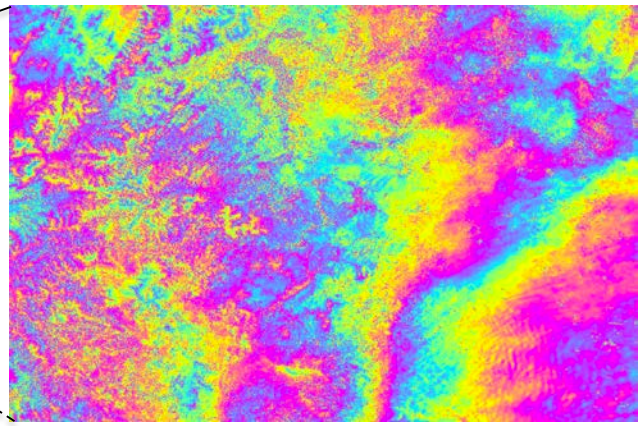
Track : 144
1750 km x 250 km
(across US)

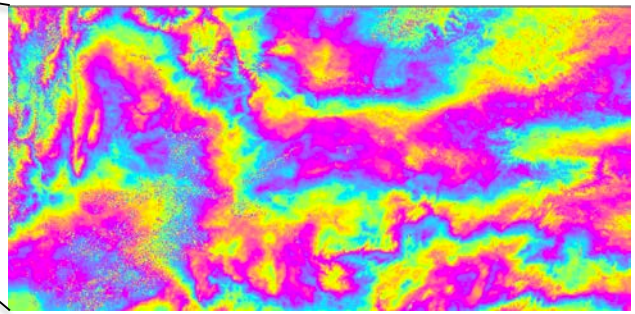
1750 km

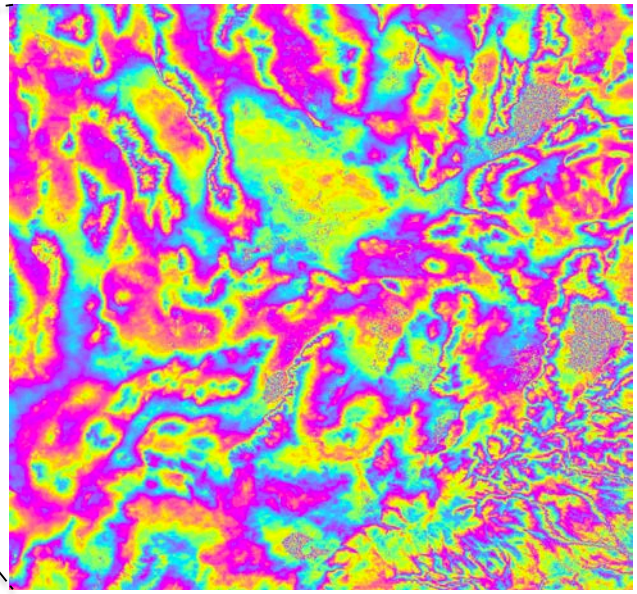
Constant azimuth misregistration
(ESD): 0.002 pixels along 1750 km



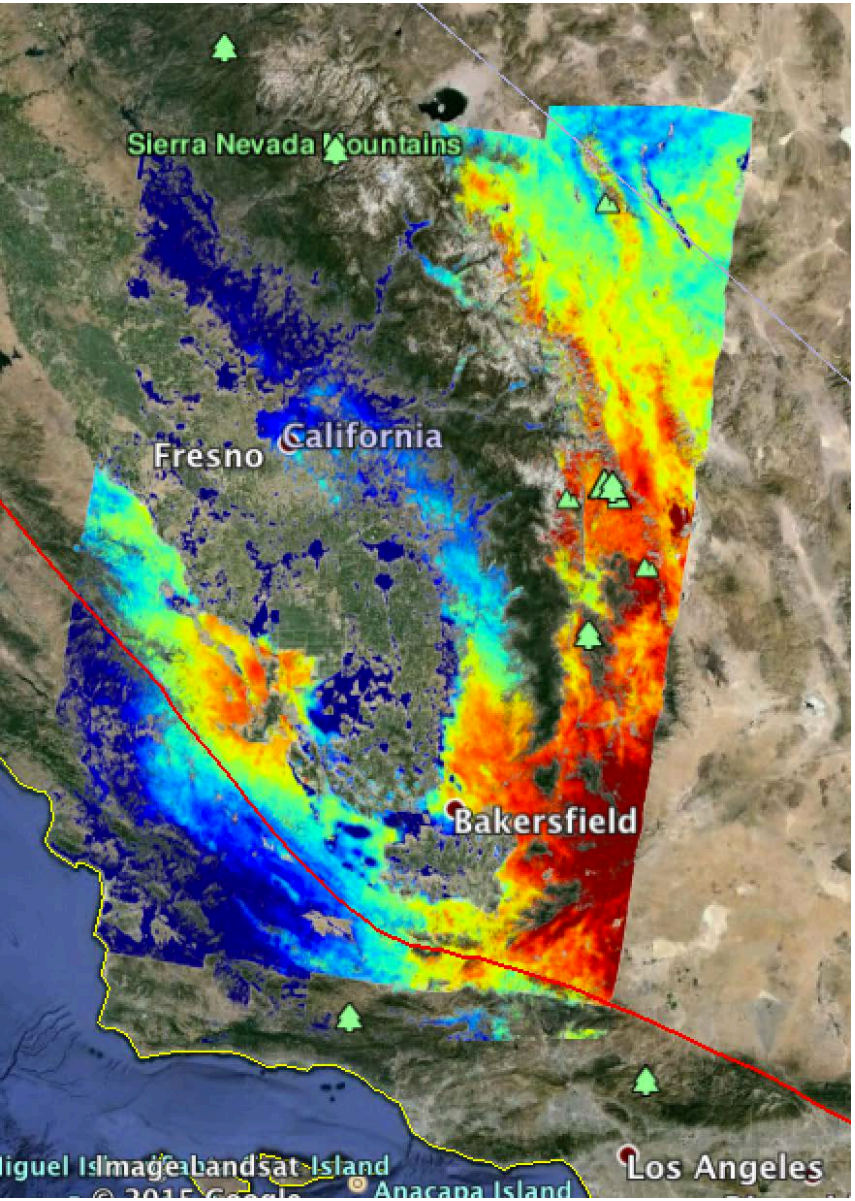


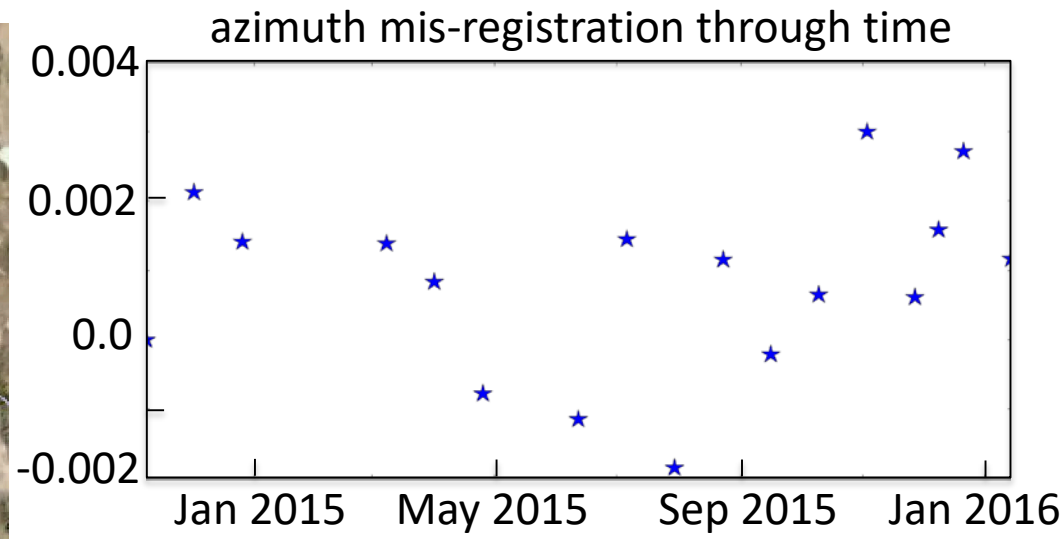


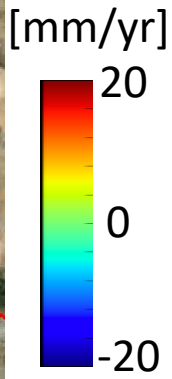




Example 1 : Track 144 California







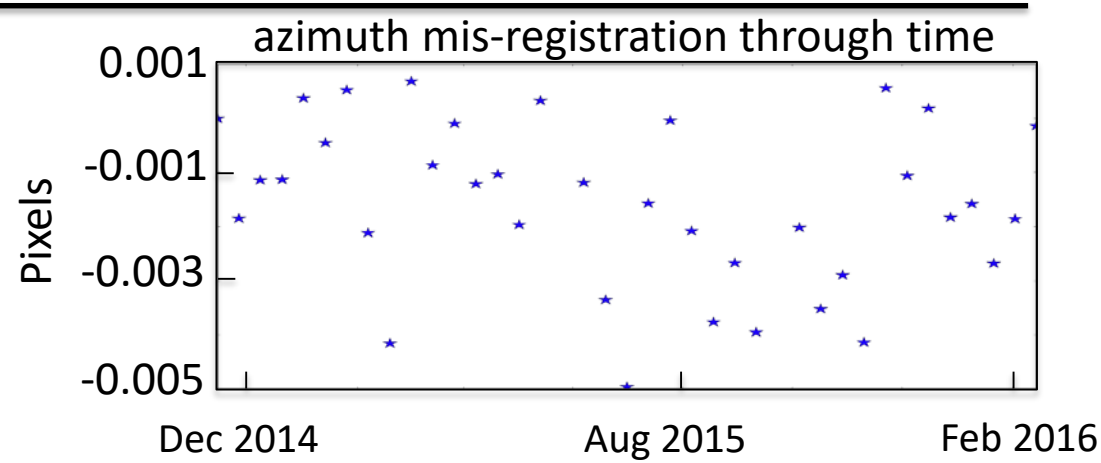
- No phase discontinuity after NESD
- Max azimuth misregistration : 0.005 pixels
- 1 year time-series captures ground subsidence in Central Valley and fault creep on Central SAF

Example 2 : Track 65, North Anatolian Fault, Turkey

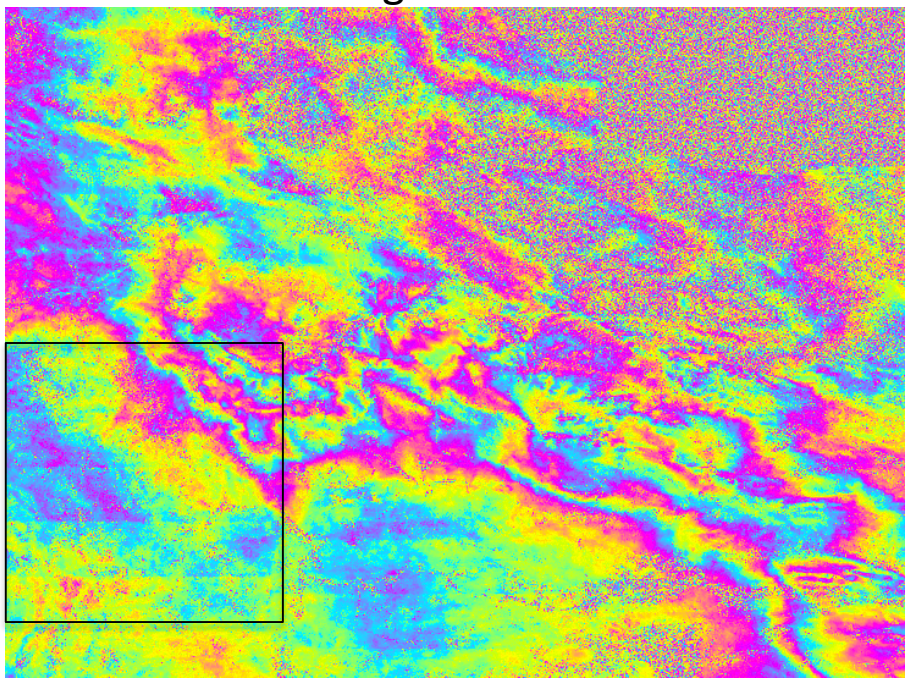
37 acquisitions

2014Nov15 – 2016Feb14

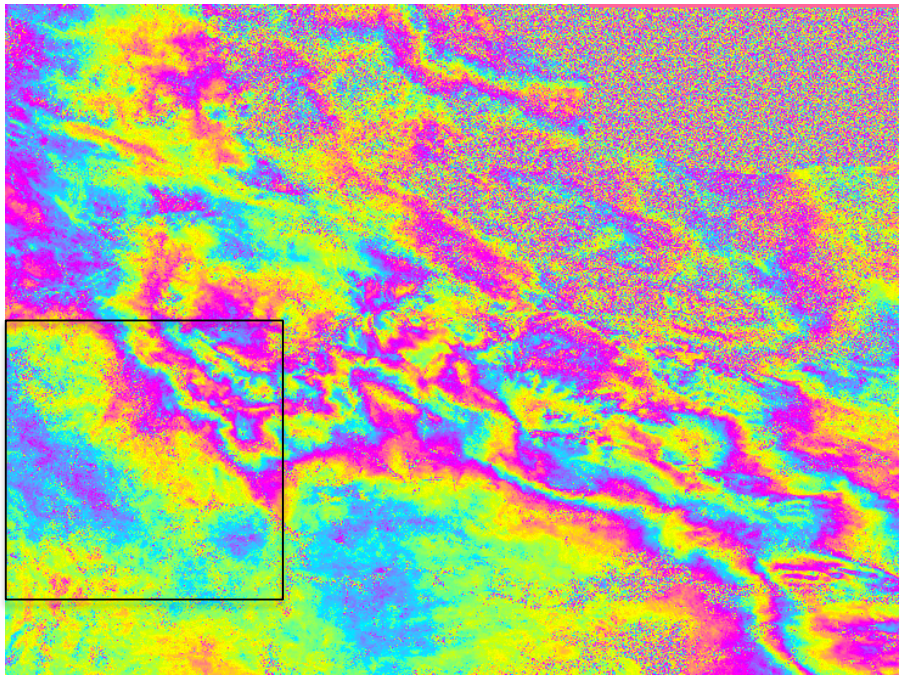
No Burst discontinuity after NESD



Geometrical coregistration

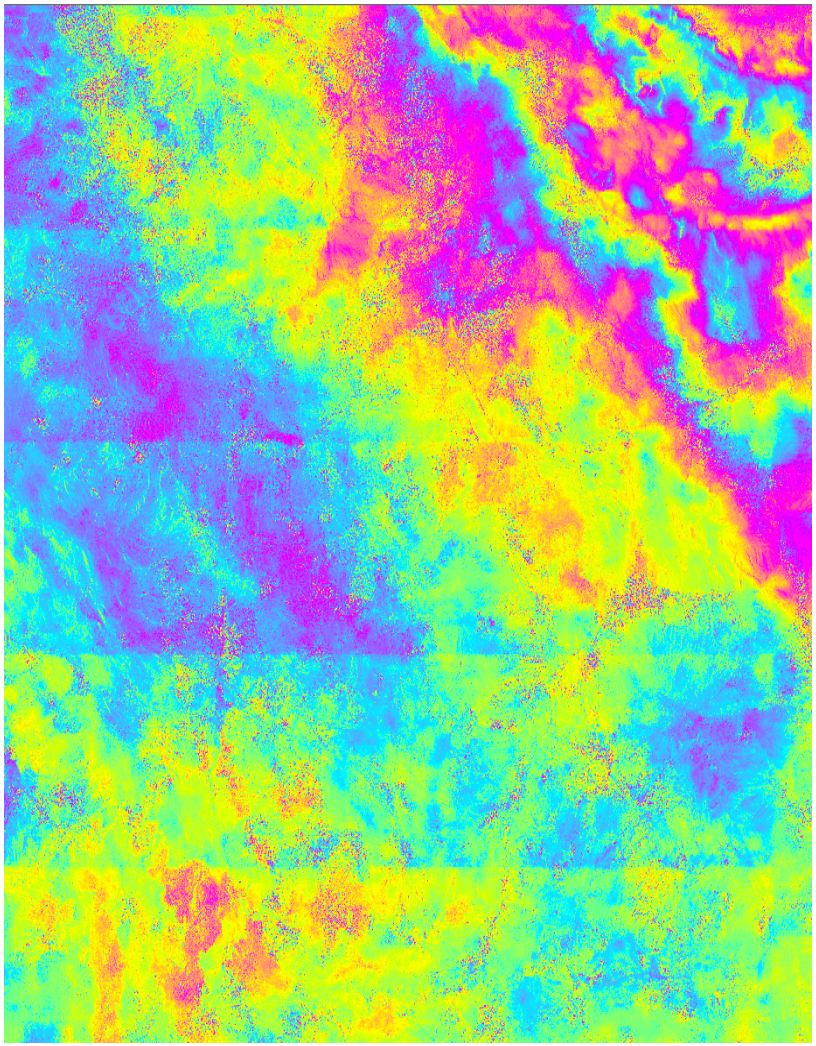


Geometrical coregistration + NESD

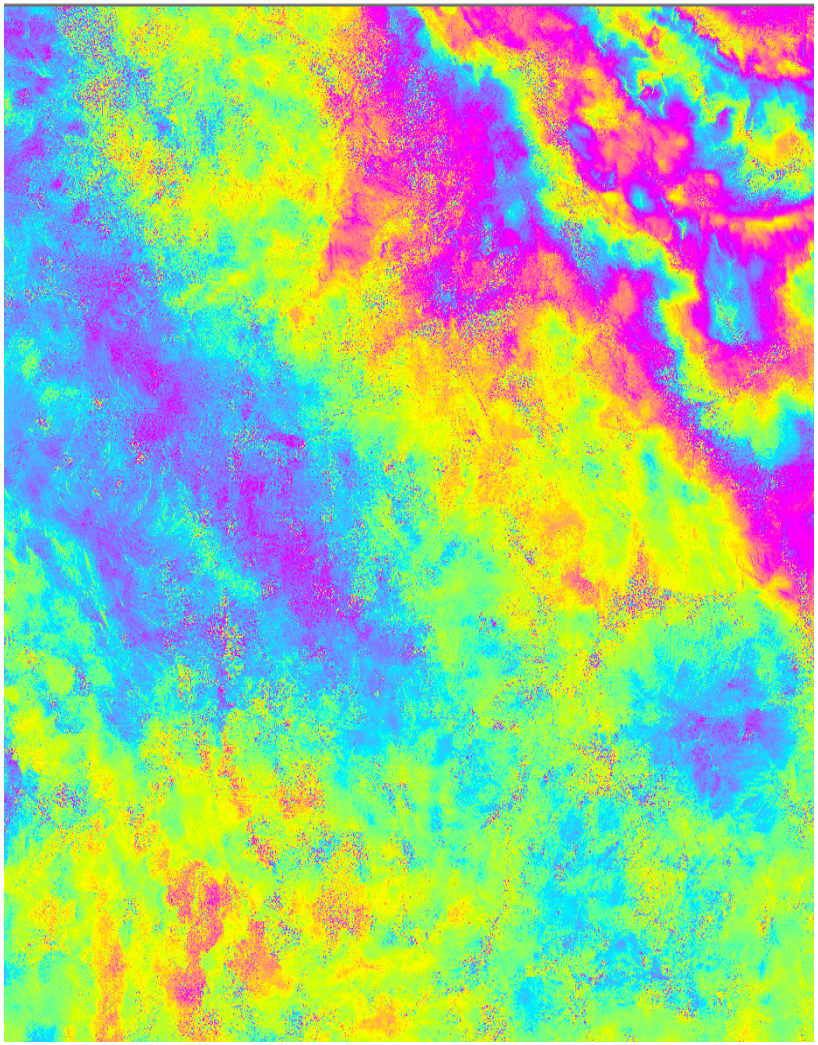


Example 2 : Track 65, North Anatolian Fault, Turkey

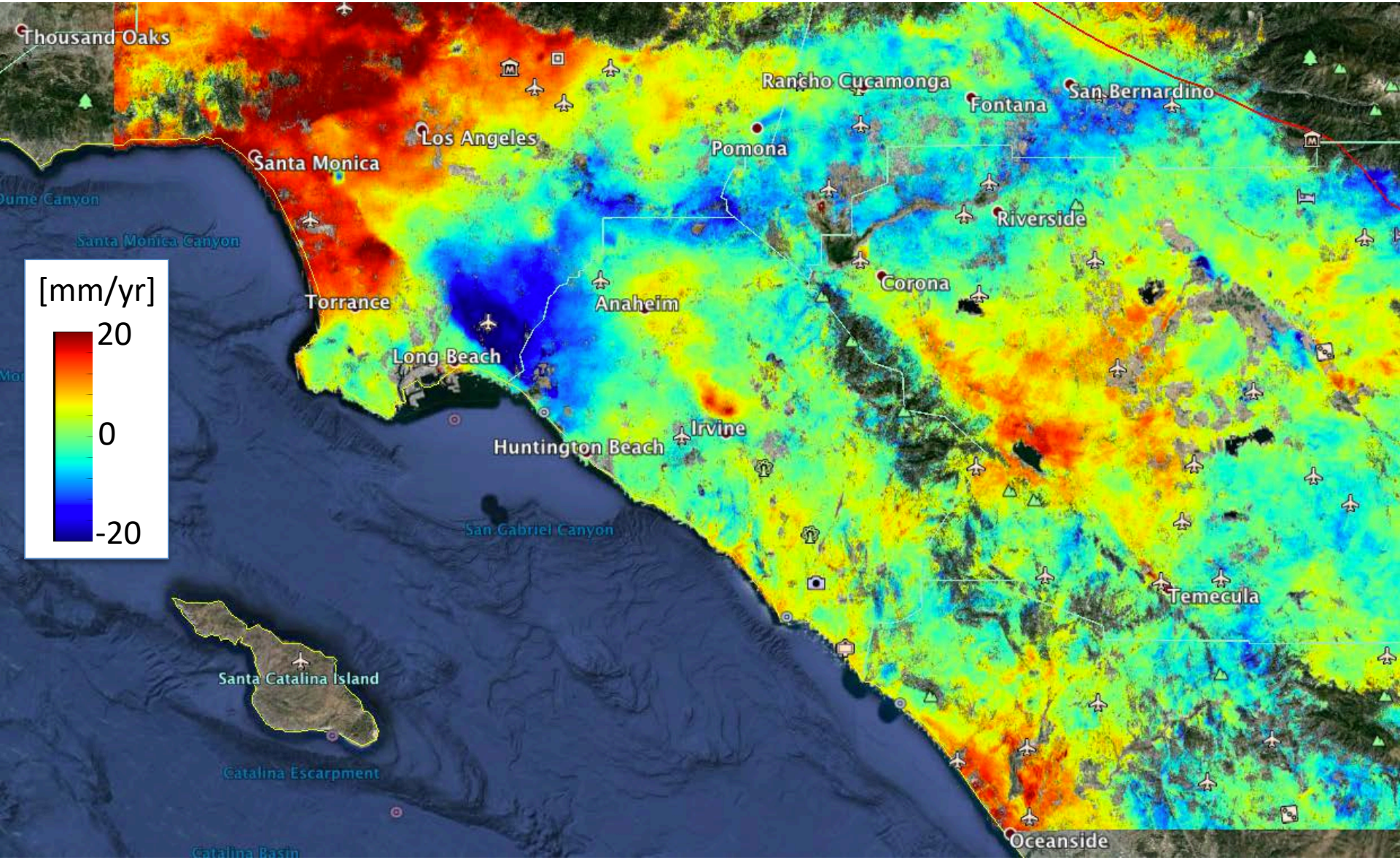
Geometrical coregistration



Geometrical coregistration + Spectral Diversity



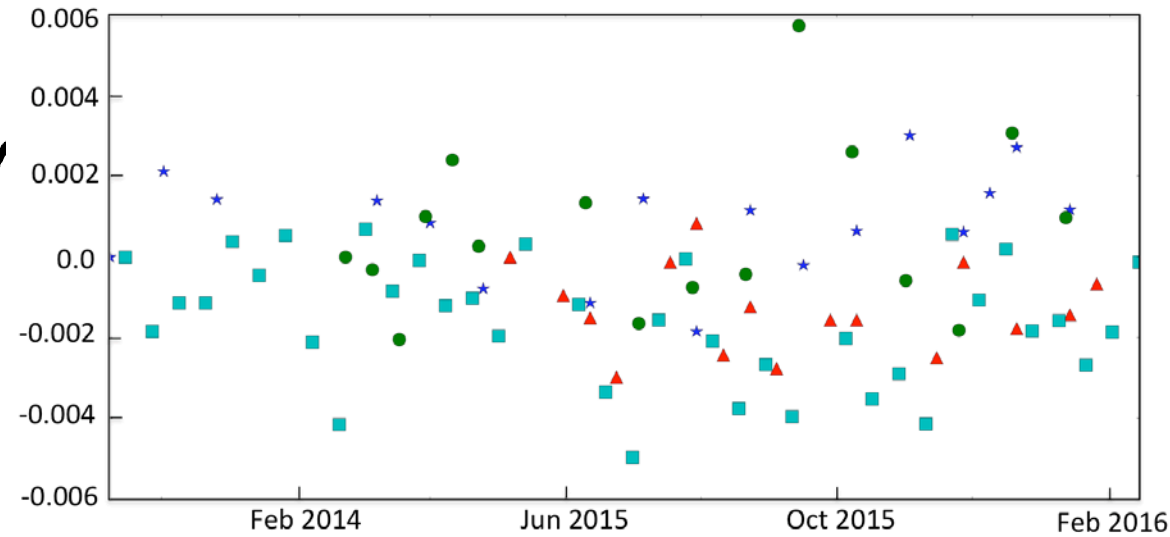
Example 3 : Track 64, Los Angeles



Azimuth mis-registration for different stacks

Region	Track #	Asc/Desc	# of acquisitions	Burst jums
California	144	Desc	17	✓
California	115	Desc	16	✓
California	137	Asc	19	✓
California	71	Desc	27	✓
Turkey	65	Desc	37	✓
Chaman	42	Asc	12	✗
Northern Chile	156	Desc	14	✗
California	64	Asc	20	✗

Time-series of azimuth mis-registrations



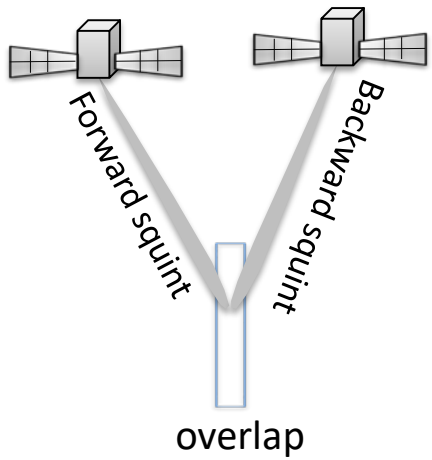
Variable azimuth mis-registartions in few pairs

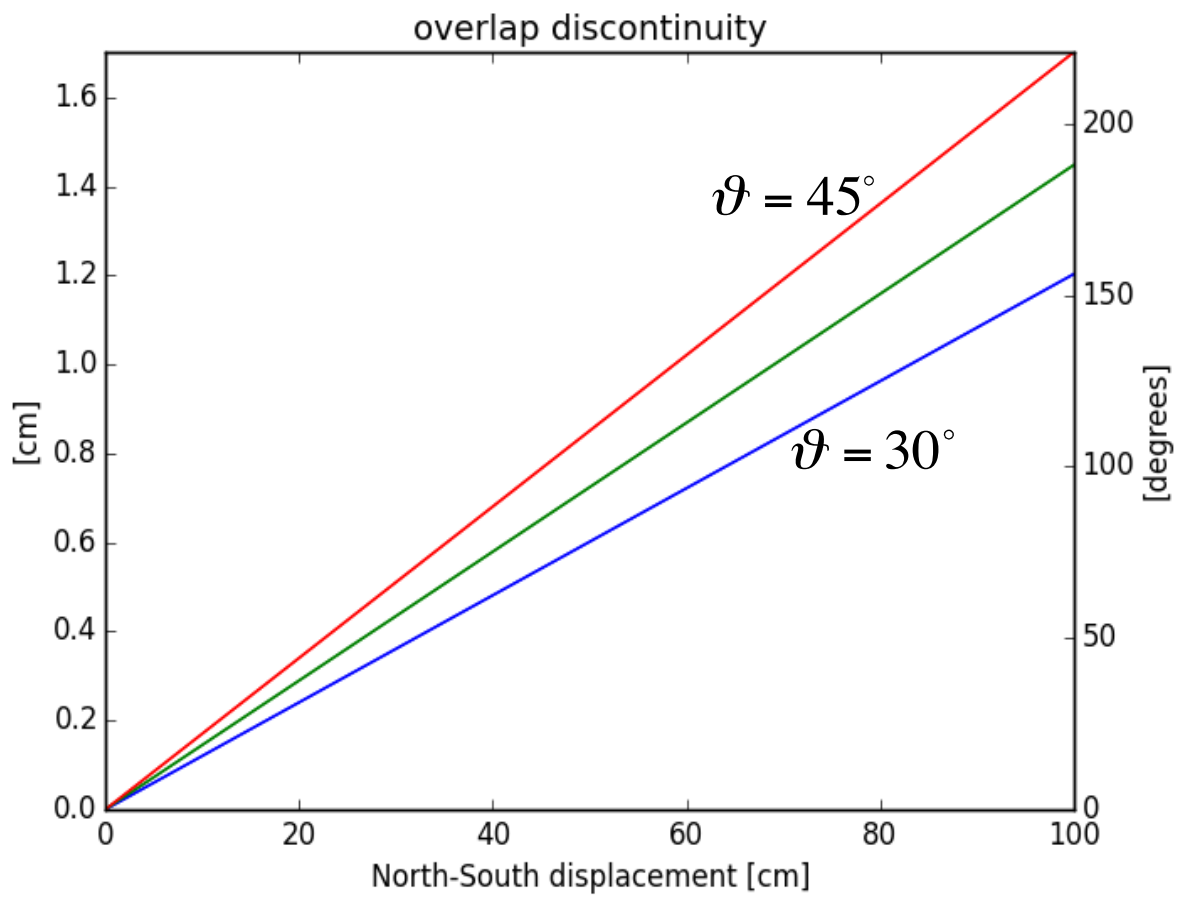
Possible sources of the variable mis-registration:

- Ionosphere
- Change in SLC processing strategy

Limitations for operationalizing the spectral diversity approaches

1) Large ground displacement in azimuth direction





Azimuth steering leads to variable LOS at the overlap regions.

Areas with large North-South ground displacement should be excluded for ESD estimation

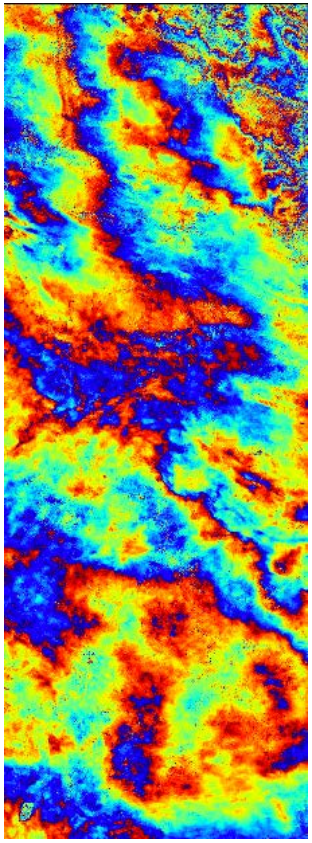
Limitations for operationalizing the spectral diversity approaches

2) Abrupt changes in scene scattering properties

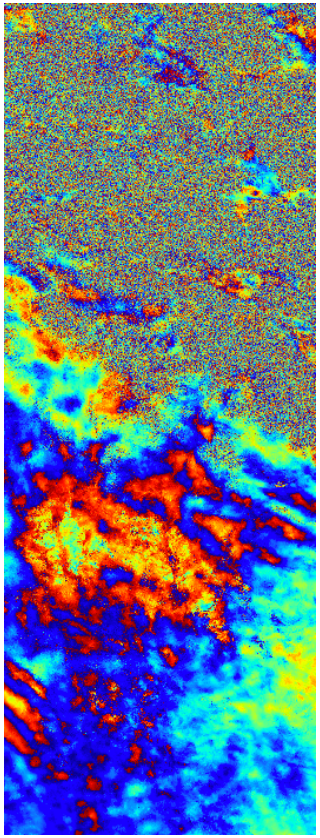
Phase decorrelation in small temporal baseline interferograms (eg: snow)

Two 12 days Sentinel-1A TOPS interferograms over Turkey show significant phase decorrelation in the winter (due to snowing)

12 days Summer pair



12 days Winter pair



Assuming stationary mis-registrations, only regions with high coherence should be used for NESD

3) ESD ambiguity band

~70 cm to 85 cm for Sentinel-1

- Not a problem for Sentinel-1A
- How about S1-A S1-B cross interferogram?

Limitations for operationalizing the spectral diversity approaches

4) Non-stationary mis-registrations (Spatially variable mis-registration)

Sources of azimuth mis-registration	Stationary status
Orbital timing error	Stationary
SAR instrument timing error	Stationary
SAR processing effect	Stationary/Non-stationary
Geodynamic effect (tide)	Stationary?
Ionospheric effect	Stationary/Non-stationary

Azimuth mis-registration due to ionosphere TEC gradient:

$$\Delta x = \frac{40.23}{f^2} \frac{\partial TEC}{\partial x} R_0$$

Sentinel-1 TOPS:

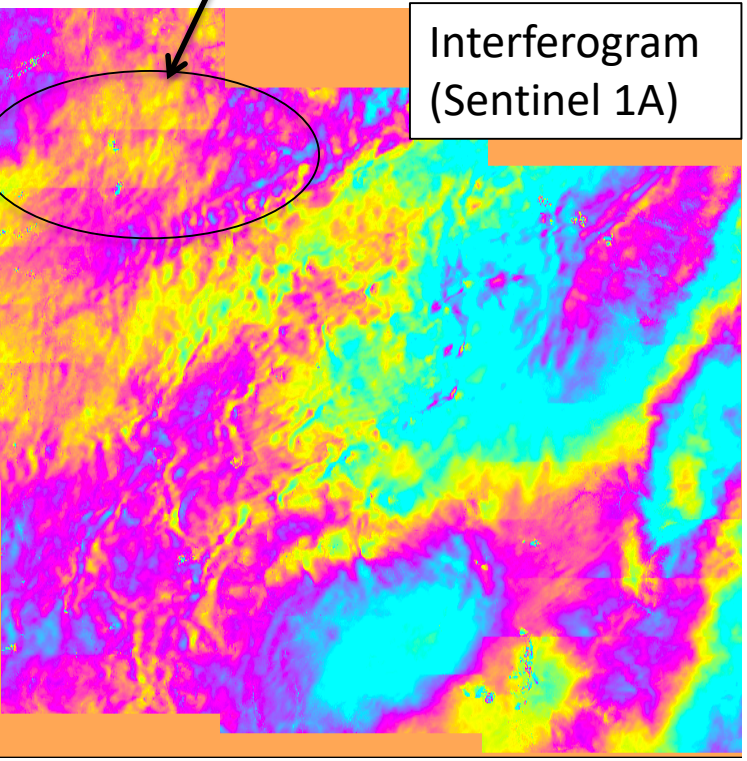
TEC gradient of 0.3 TECU → 0.66 to 0.78 m azimuth offsets for near and far ranges (equivalent to ~0.042 to 0.05 pixels)

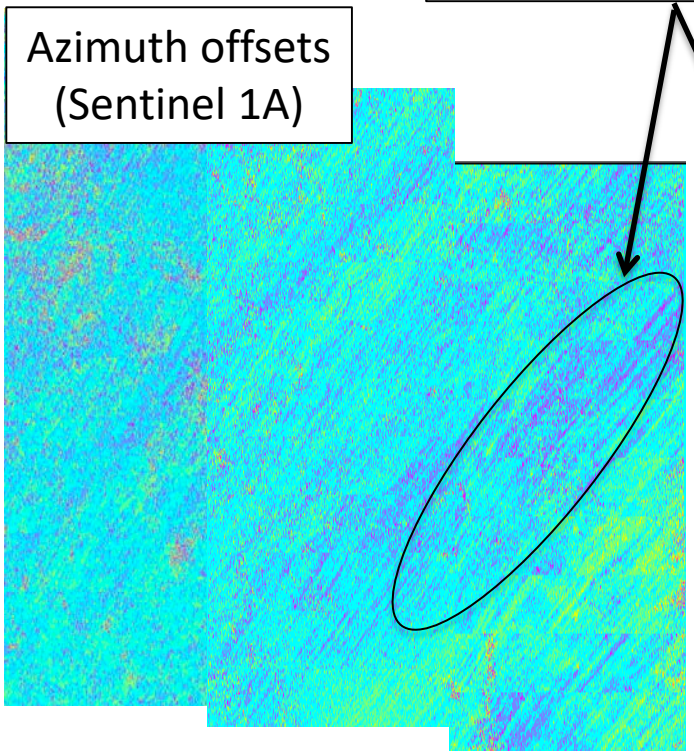
Ionospheric effect on TOPS coregistration

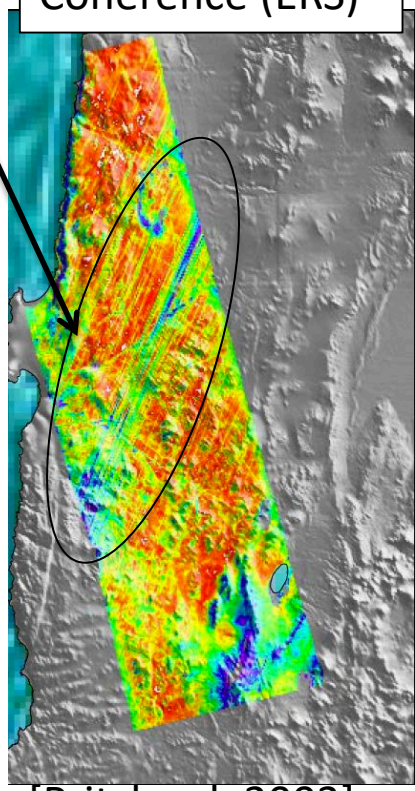
To investigate any pattern in the azimuth mis-registration, after geometrical coregistration we evaluate the mis-registration computed with the amplitude cross-correlation

Phase discontinuity caused by the coregistrations errors (most likely due to ionosphere)

Ionosphere streaks ?!







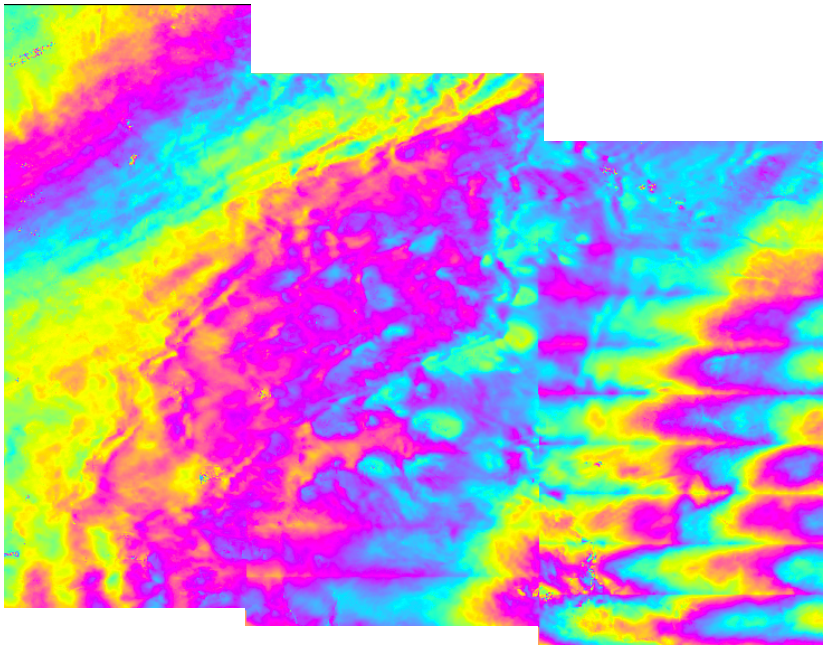
[Pritchard, 2003]

Differences in SLC processing strategy (currently solved by ESA)

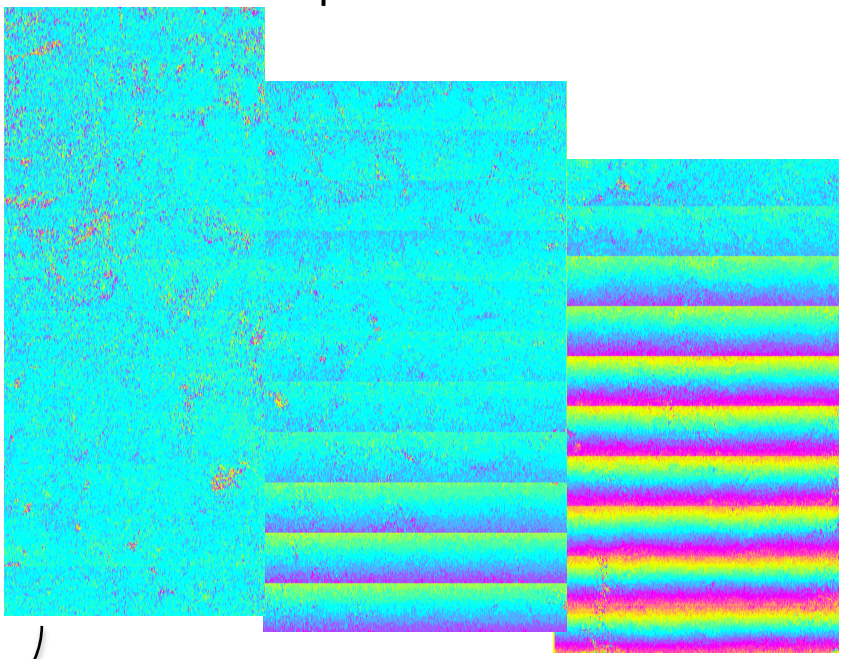
2015 Nov 04 – 2015 Nov 28

IPF=2.53

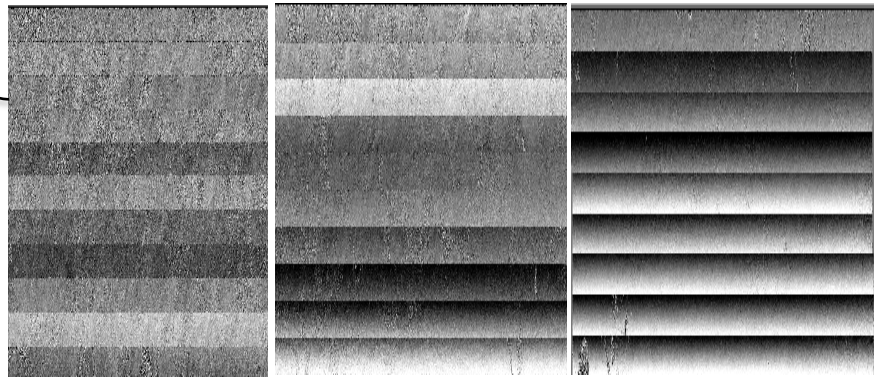
IPF=2.6



Full burst Azimuth misregistration from amplitude cross-correlation



Burst overlap azimuth misregistration from spectral diversity



Independent azimuth mis-registrations (from spectral diversity and amplitude cross-correlation) indicate systematic ramp in the azimuth mis-registrations, which causes quadratic phase signature for each burst.

Conclusions

- A network approach presented to estimate the azimuth mis-registration for coregistering the stack of Sentinel-1 TOPS SLC data.

- Spatiao-temporal variation of azimuth mis-registration in Sentinel-1A TOPS data:

Temporal variation:

- maximum 0.01 pixel misregistration
- no temporal pattern observed so far
- standard deviation of mis-registartions (2-3 cm) is in the order of the orbital accuracy of (6 cm).

Spatial variation:

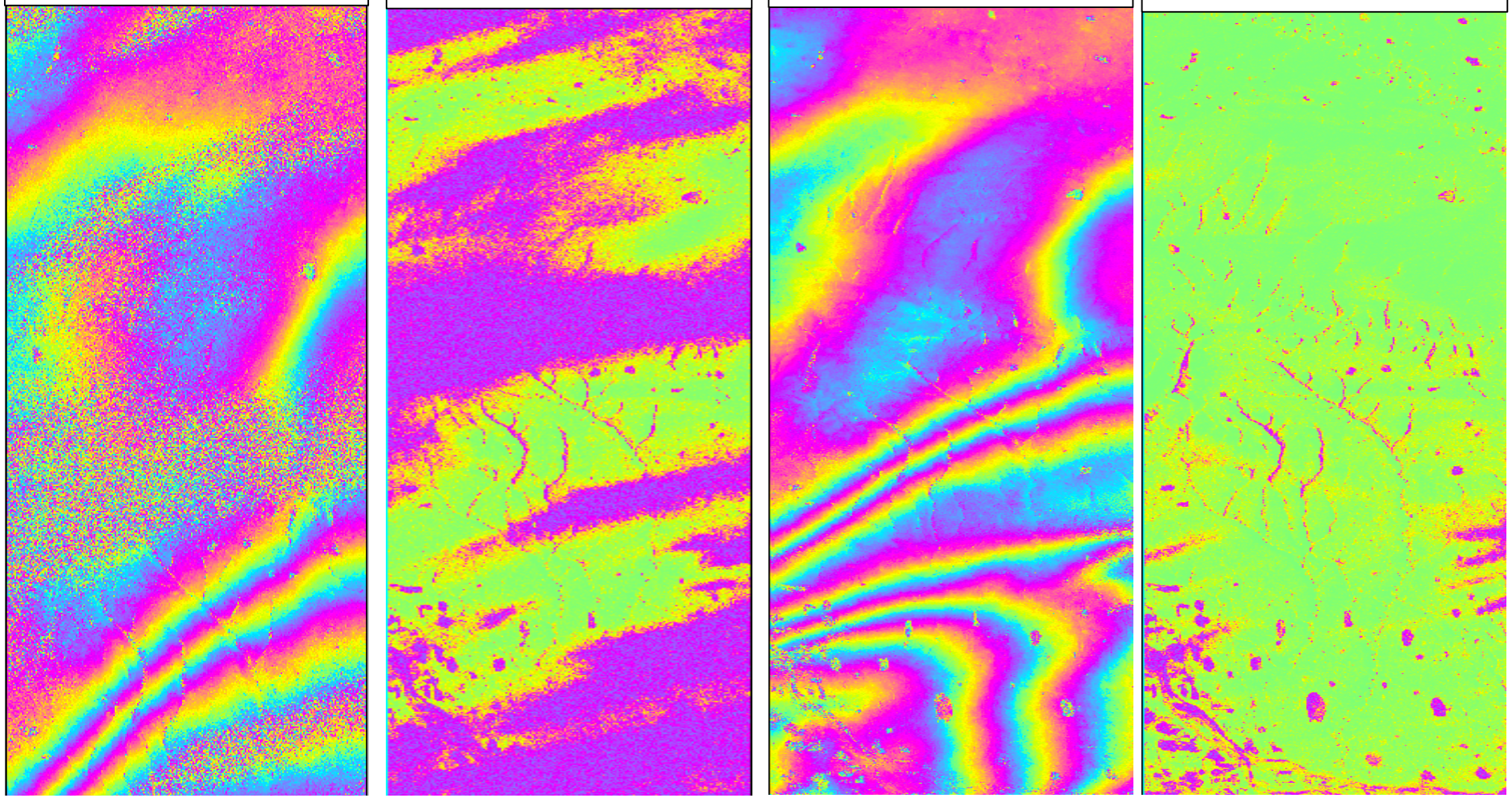
- **Constant azimuth mis- registration** in 5 different TOPS stacks (10-20 bursts slices)
- A **constant azimuth misregistration** of 0.002 pixels does not vary along **1750 km** (for 1 pair from track 144)
- Possible sources of **spatially variable azimuth mis-registration** was identified

Metadata issue : **Already solved by ESA**
Ionosphere **: Needs further investigation and probably special care**

Backup slides

Ionospheric impact on Coregistration (ALOS-1 stripmap example)

Original interferogram (07/04/01-07/05/17)	Coherence (affected by ionosphere)	Interferogram after accounting for the ionosphere offsets	Coherence (accounted for ionosphere offsets)



[ALOS , L-band imagery, Alaska]

Impact of azimuth misregistration on TOPS interferogram

Phase due to azimuth misregistration:

$$\phi_{err} = 2\pi f \Delta t$$

ϕ_{err} : phase due to azimuth misregistration

f_c : center frequency

Δt : azimuth misregistration (in seconds)

0.003 pixels azimuth misregistration

~ 0.4 radians ramp in azimuth direction for each burst

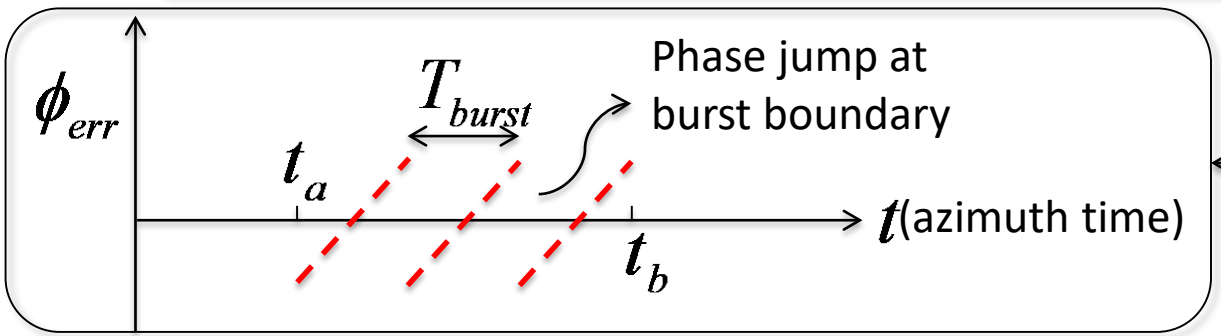
Constant Δt **:**

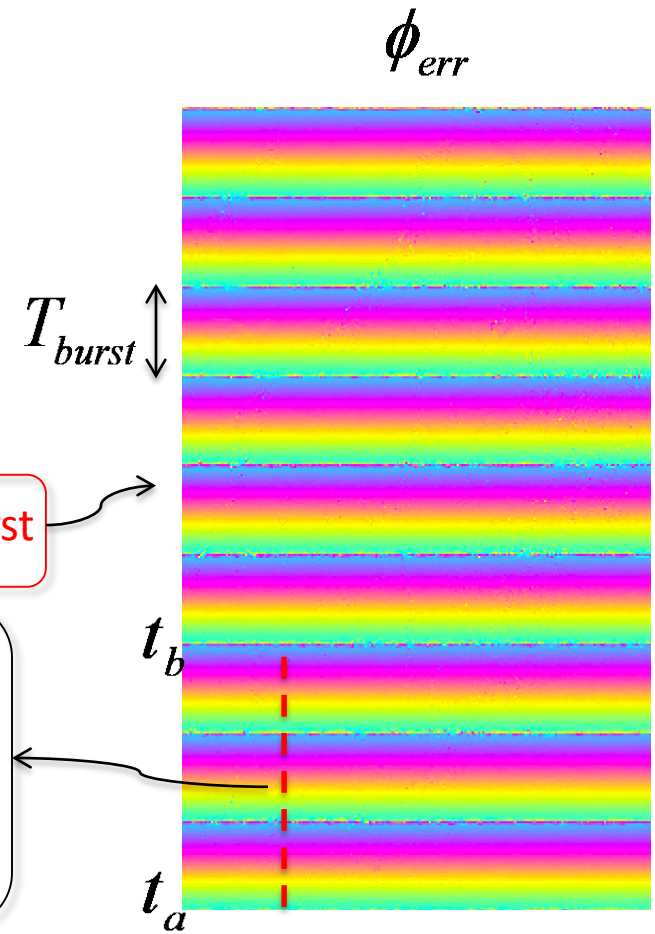
TOPS:

linear Doppler centroid variation in azimuth

linear frequency in azimuth for each burst

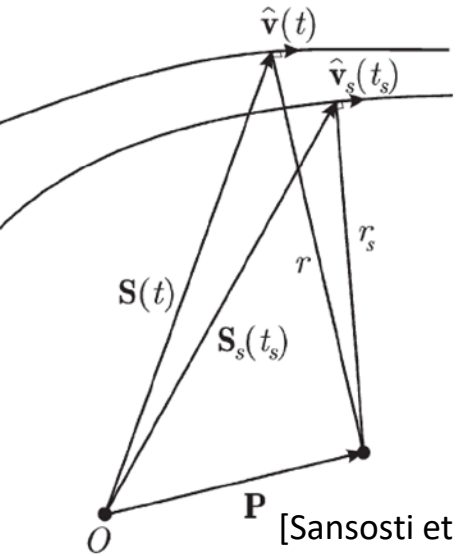
linear phase ramp (in azimuth direction) for each burst



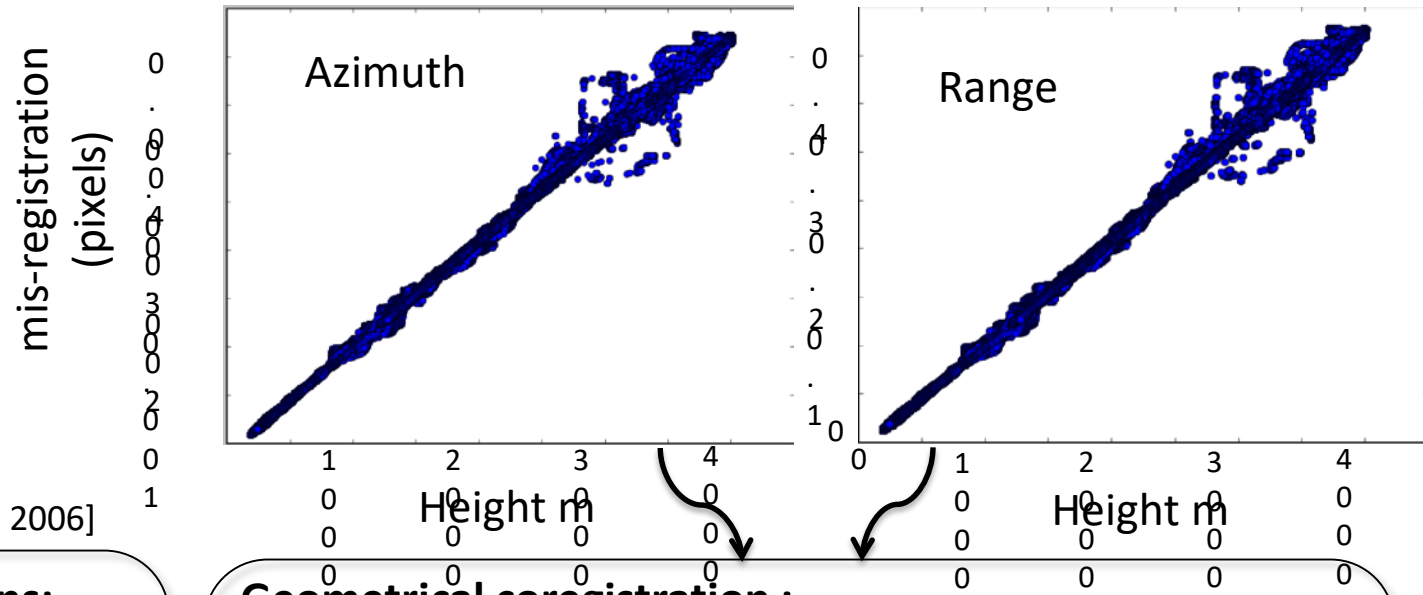


Geometrical coregistration

Radar coordinate (Time-Range) ⟷ Using Orbit & DEM ⟷ Geo-coordinate



[Sansosti et al, 2006]



Range-Doppler equations:

$$\begin{cases} \tau = \frac{2}{c}\,|\mathbf{P} - \mathbf{S}(t)| \\ \hat{\mathbf{v}}(t)\cdot(\mathbf{P} - \mathbf{S}(t)) = 0 \\ \tau_s = \frac{2}{c}\,|\mathbf{P} - \mathbf{S}_s(t_s)| \\ \hat{\mathbf{v}}_s(t_s)\cdot(\mathbf{P} - \mathbf{S}_s(t_s)) = 0. \end{cases}$$

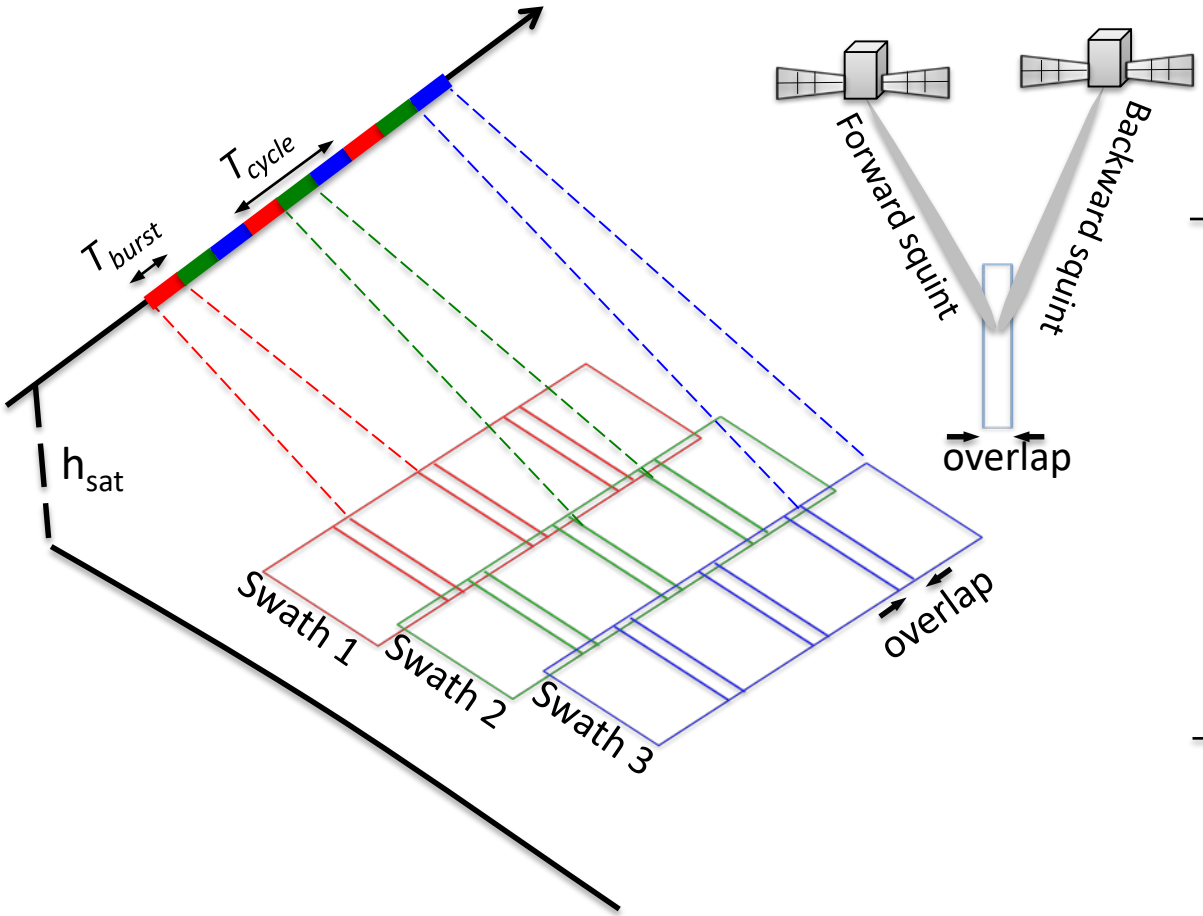
Geometrical coregistration :

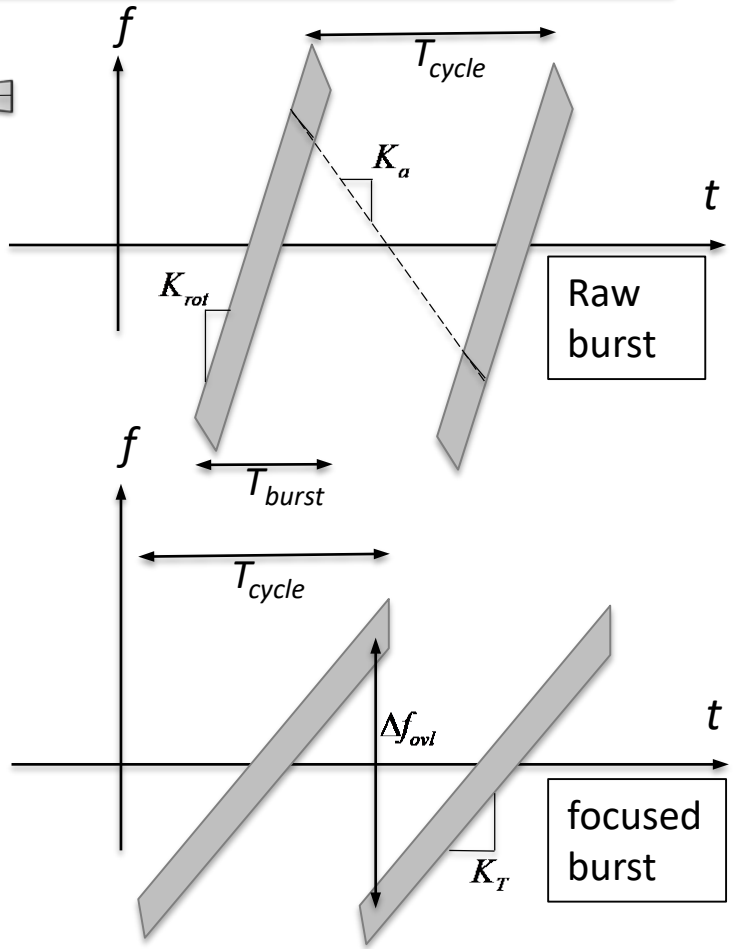
Doesn't Need Accurate DEM
(few 10s of m vertical accuracy is enough)

Precise Orbits are required (few cm accuracy)

Achievable coregistration accuracy with geometry	**Required** coregistration accuracy for Sentinel-1 TOPS
~ 1/100 pixel	1/1000 pixel

TOPS (Terrain Observation by Progressive Scan**)**





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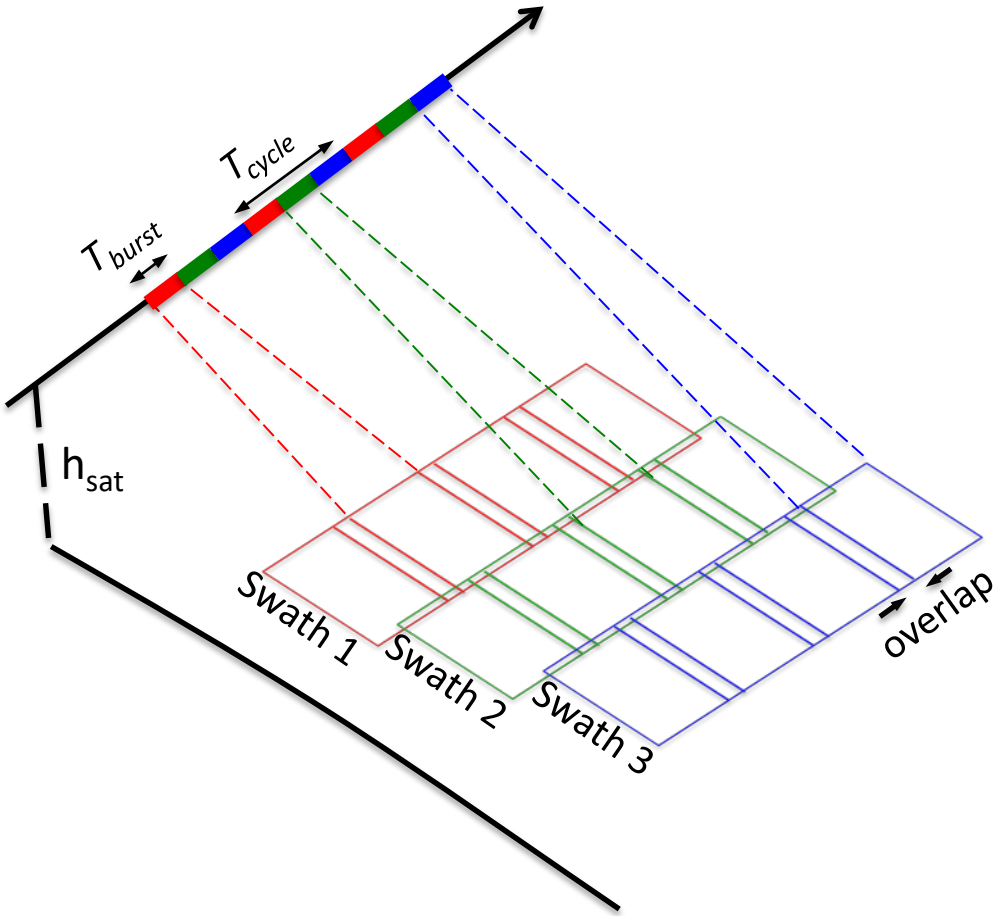
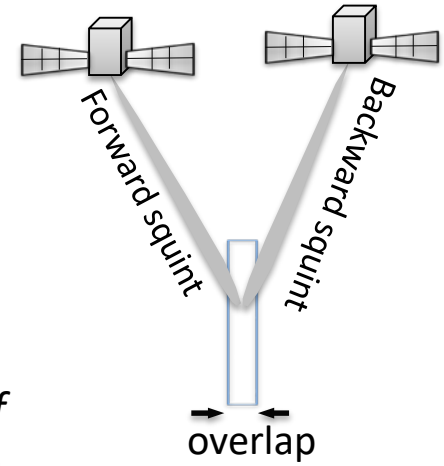
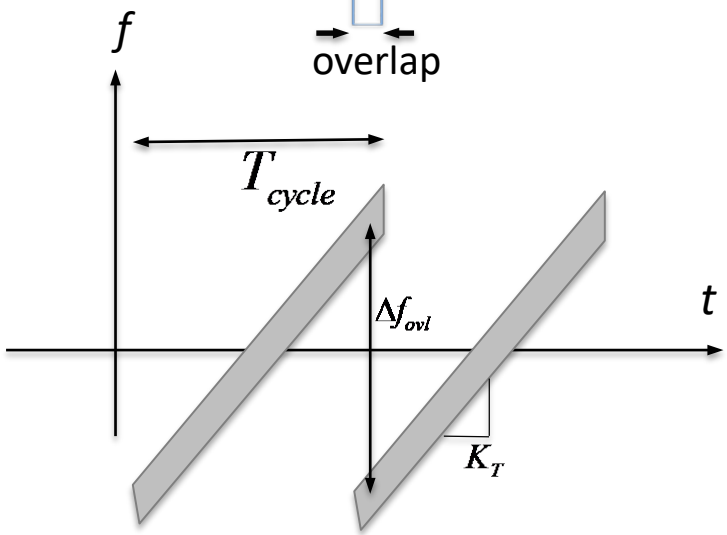
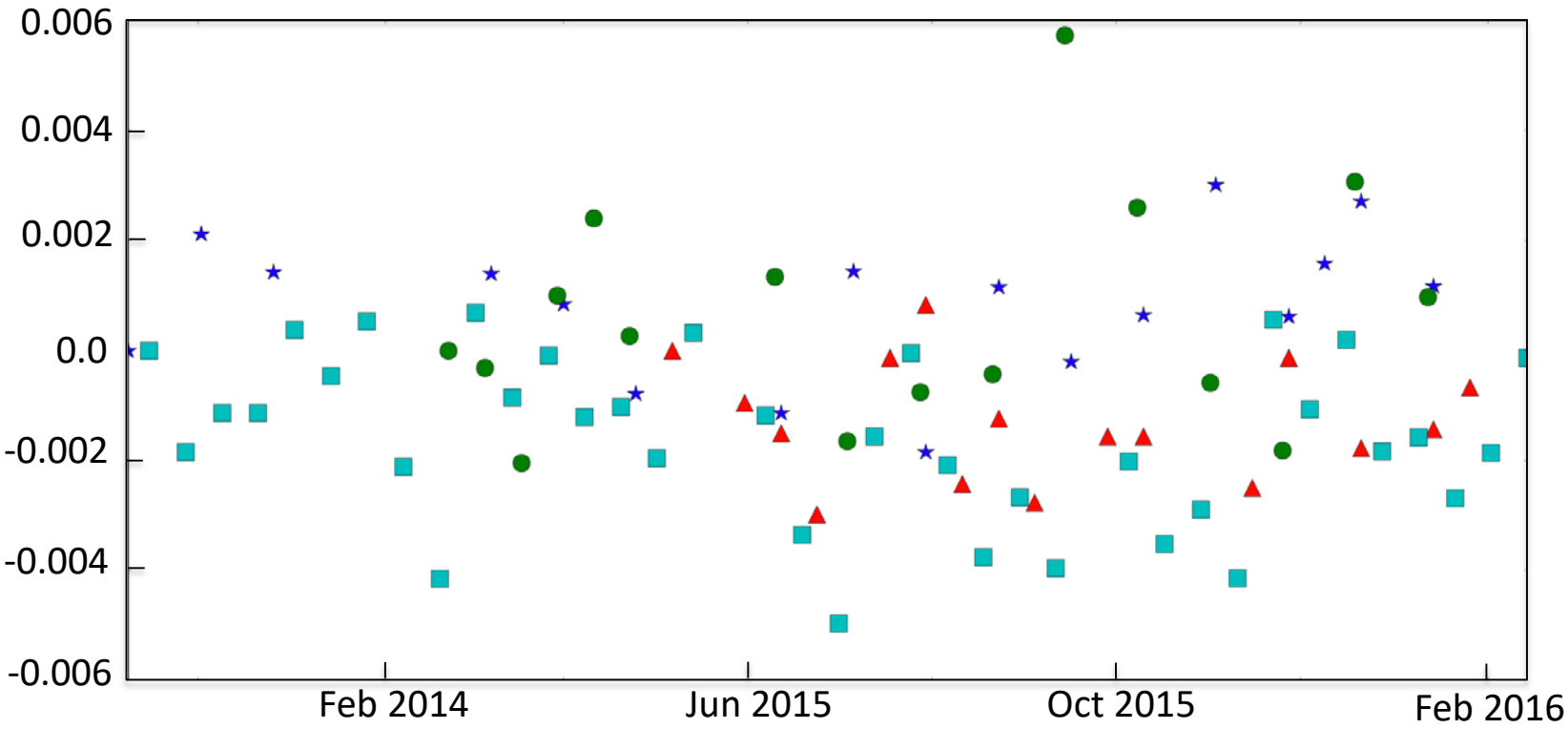
TOPS (Terrain Observation by Progressive Scan**)**







Achievable coregistration accuracy with geometry	**Required** coregistration accuracy for Sentinel-1 TOPS
~ 1/100 pixel	1/1000 pixel


0.006
0.004
0.002
0.0
-0.002
-0.004
-0.006
Feb 2014
Jun 2015
Oct 2015
Feb 2016