Individual Interferograms to Stacks

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@UNAVCO

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Some Inconvenient questions

I can process individual interferograms.
Does that mean I can process Stacks?

My individual interferograms look good.
Does that mean my stack was properly processed?

Can a single processing workflow generate
products for all time-series approaches?

The inconvenient answers

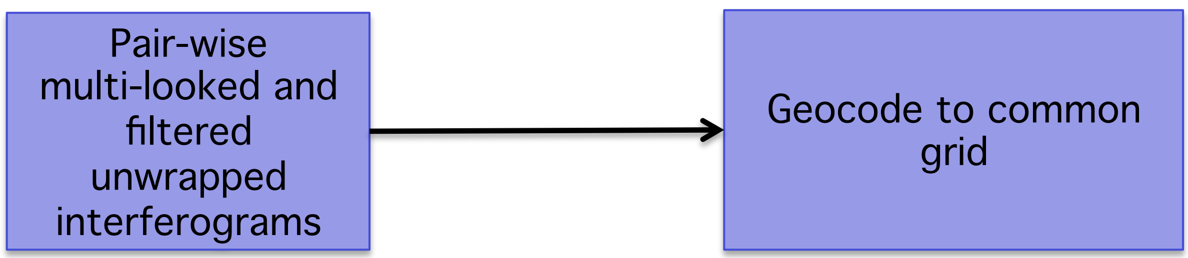
No. And. Maybe. And. No.

Process2pass / insarApp workflows are only designed to handle short baseline pairs

Short baseline – doppler and geometry

Simple approaches
popular among the science community

Method 1: Geocoded stacks



Can use tools designed to process a single pair

Coregistered stacks in geo-coordinates

Easily implemented with process2pass / insarApp

Disadvantages

- Cannot guarantee coregistration at sub-pixel level between interferograms
  - Alignment with DEM step crucial
  - Polynomial offset model may be insufficient

- Same SAR image is focused multiple times with different doppler centroids (pair averages)

- If baseline re-estimation is applied
  - Cannot guarantee consistent corrections across interferograms

- PS analysis not possible

Method 2: Radar geometry stacks

Pair-wise multi-looked and filtered unwrapped interferograms → Choose a master scene and align all interferograms using an affine / quadratic polynomial model

Can use tools designed to process a single pair

Coregistered stacks in radar coordinates

Easily implemented with minor modifications to process2pass / insarApp and reusing some of the modules

Disadvantages

- Cannot guarantee coregistration at sub-pixel level between interferograms
  - Alignment with DEM step crucial
  - Polynomial offset model may be insufficient
- Same SAR image is focused multiple times with different doppler centroids (pair averages)
- If baseline re-estimation is applied
  - Cannot guarantee consistent corrections across interferograms
- PS analysis not possible

Method 3: NSBAS-like approaches

Sub-optimal focusing but all products in same radar geometry

Align using polynomials or precise offsets

Filtering applied to interferograms

- NSBAS (Doin et al., 2011)
- All data processed to processed to constant doppler
  - Works well when enough data centered around constant doppler centroid (e.g, ENVISAT / ALOS)
- Focus data only once - coregistered SLCs
- More rigorous than previous 2 methods

Disadvantages

- Sub-optimal focusing of SLCs
  - Not optimal for PS processing
- Cannot handle doppler diversity
  - Unsuitable for long time-series (e.g, ERS post 2001)
- No connection between offsets and baseline
  - ROI-PAC baselines ignore doppler information (relatively minor issue)

If there are so many problems, why does this work?

Why do simpler approaches work?

- Not a mapping application
  - Typically used for geophysical modeling
  - Models at scale of few km
- Multi-looked and filtered interferograms
  - Resolution 3-4 less than pixel spacing
  - Sub-pixel shifts have less impact on results
- These approaches (except NSBAS) cannot be used for
  - full resolution analysis
  - Exploratory analysis / mapping applications
  - Wide swath analysis (long wavelength/ far-field deformation)

PS: Tectonics applications perspective

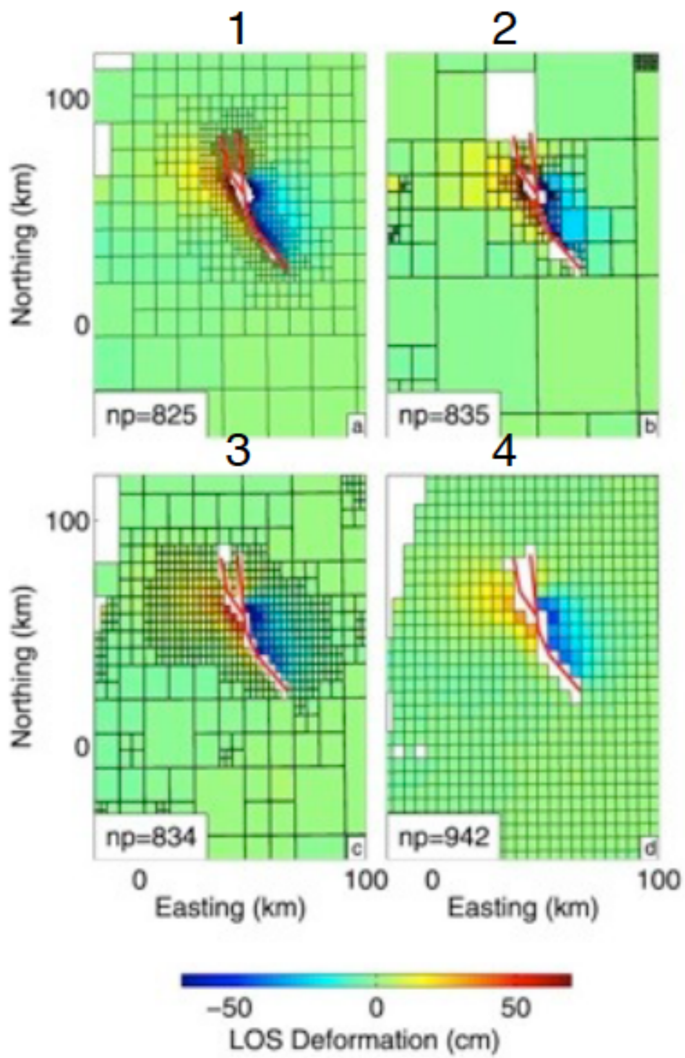


Image: Lohman (2013)

- Tectonic studies typically interested in areas of few 100 km x few 100 km.
- PS used for targeted studies – landslides, volcanoes etc.
- For modeling, scientists often reduce data from 10^6-10^7 observations to 10^2-10^3 points.
- Modeling tools use fault patches of few km. High resolution features not captured by these models.
- Resolution of few 100m more than sufficient for tectonic applications.
- PS-InSAR last resort after other methods fail to perform satisfactorily

What changes are needed for more rigorous stack generation?

(For exploratory analysis / mapping applications)

FormSLC

- Embrace doppler diversity
  - Process2pass / insarApp processing (after SLC formation) assumes data processed to constant doppler
  - Process every SAR image optimally to its own doppler centroid
  - Pick a consistent geometry system
    - Zero doppler / native doppler

- Process to full bandwidth
  - Process each scene to full bandwidth, ensure reusability of SLCs for multiple applications
  - Common bandwidth filtering operations implemented as post processing steps

Coregistration

- This is the biggest challenge when processing coregistered SLC stacks

- Process2pass / insarApp
  - Polynomial model for offsets only valid for
    - short baselines
    - Moderate resolution
    - Moderate topography
  - Polynomial model assumes that topography does not introduce significant pixel offsets

Effect of misregistration

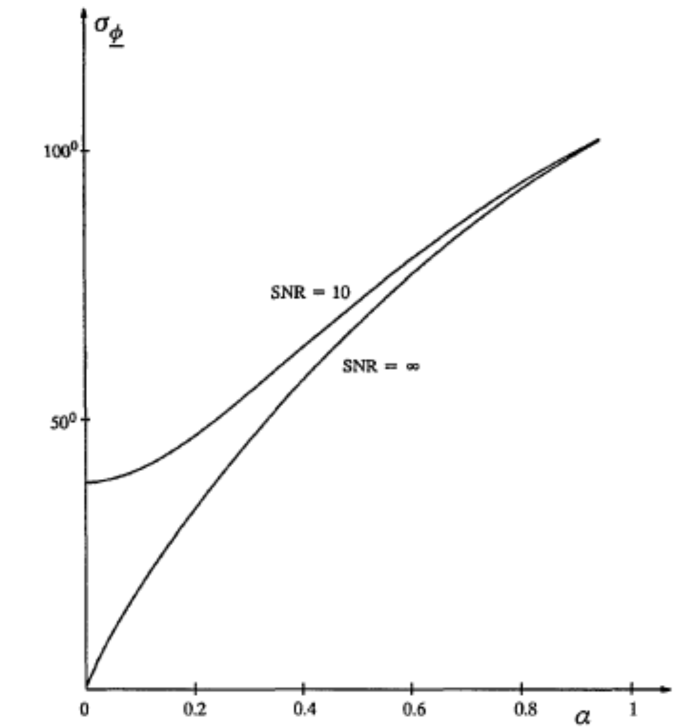
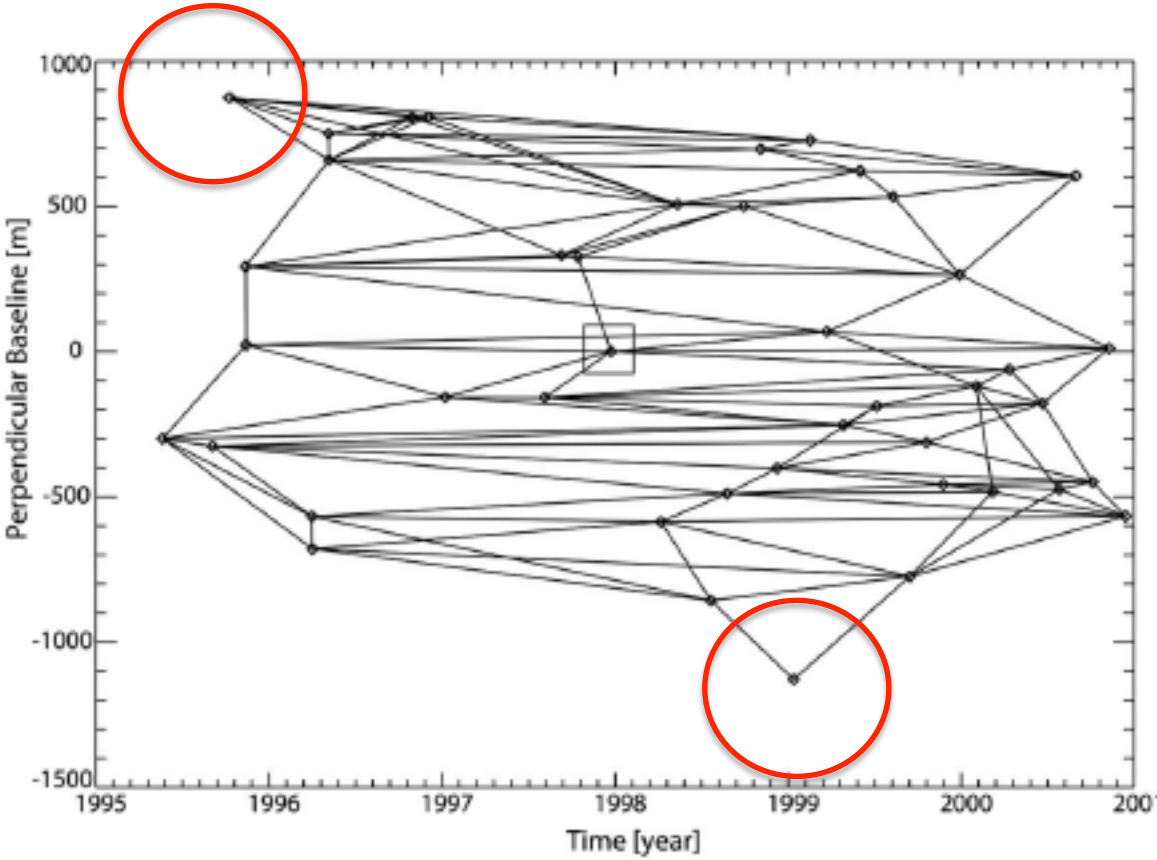


Fig. 5. Standard deviation σ_ϕ of the interferometric phase versus misregistration α for two different SNR's. The case of $\alpha = 1$ is tantamount to a misregistration of one resolution cell and results in complete decorrelation.

Just and Bamler (1994)

- Misregistration leads to decorrelation
- Any pixel-by-pixel statistical measure in a stack is affected by misregistration

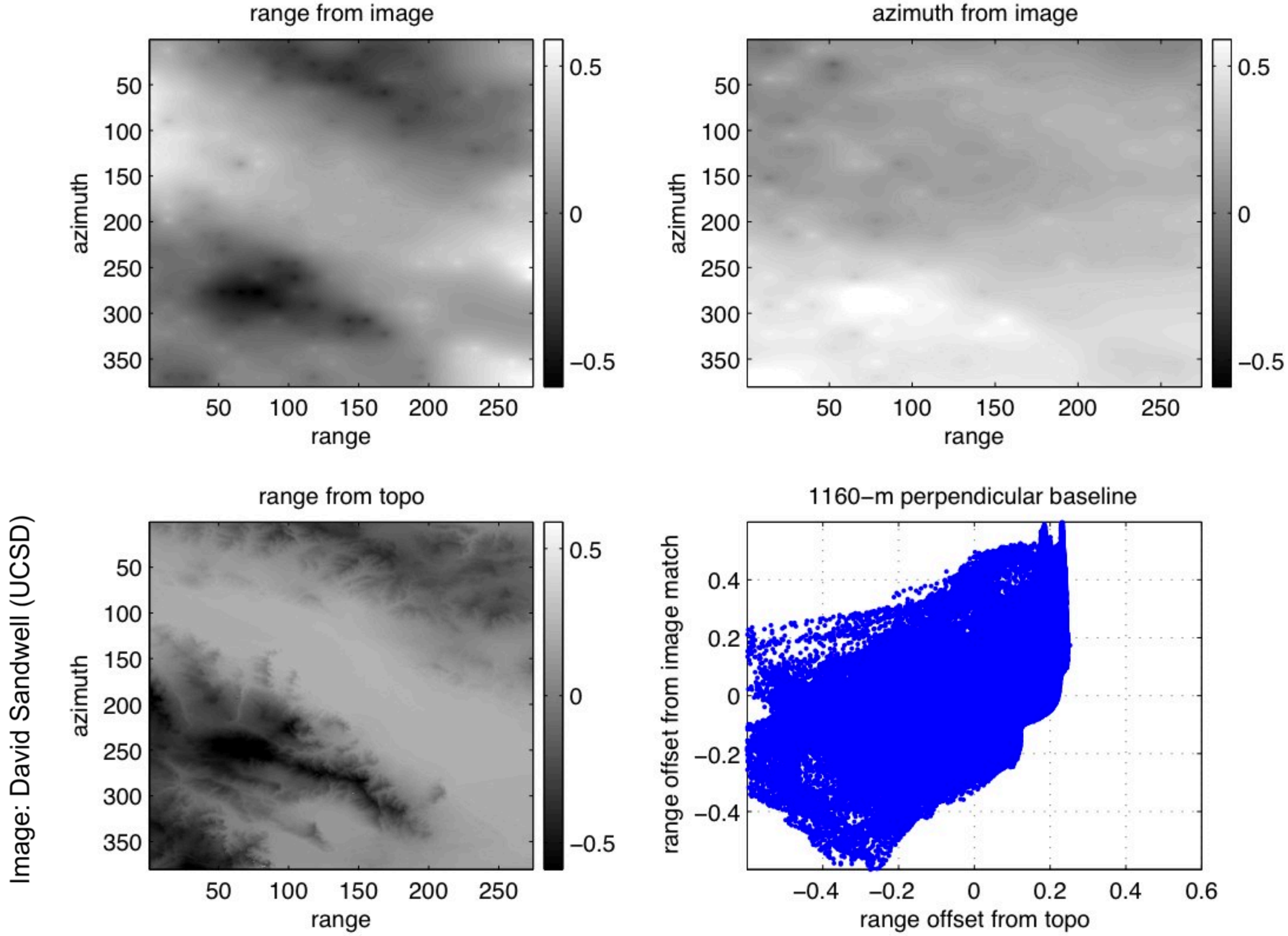
Coregistration of long baseline pairs



Time-baseline plot for San Francisco ERS dataset (Agram et al., 2011)

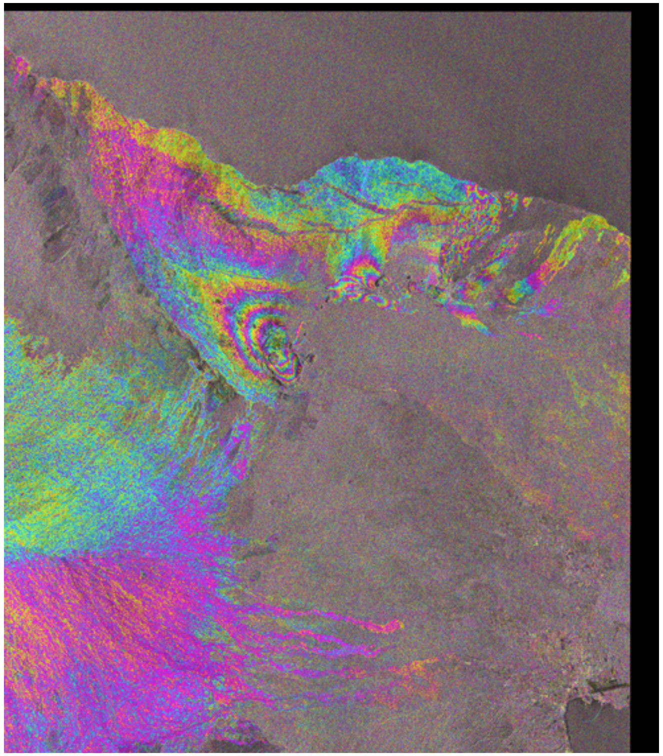
- Scenes with the largest baseline separation must also be well coregistered.
  - Particularly for PS approaches
  - Any pixel-by-pixel analysis method demands precise coregistration

Coregistration: Example

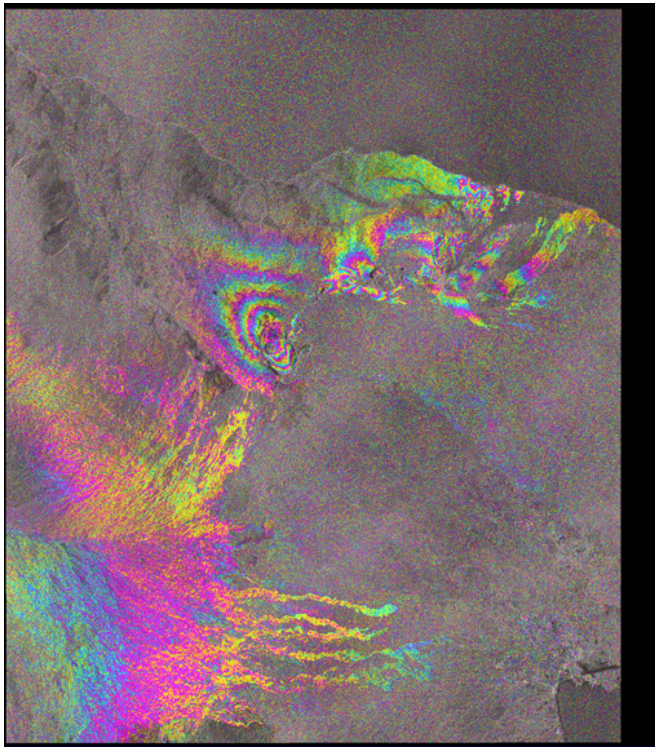


ALOS PALSAR example: Moderate topography + moderate baseline + high range bandwidth can lead to pixel offsets that cannot be accounted for by simple polynomial models.

DEM-assisted coregistration



Dem assisted coregistration



Traditional polynomial based coregistration

Tomorrow: Hands-on example, 4 year, 4km baseline ALOS-1 pair

Connection between offsets and baseline

- Process2pass / insarapp
  - No feedback from offsets
  - Offset estimation / resampling is done independently from topo correction
  - No timing corrections are applied

- If images focused correctly
  - Offsets estimated using geometry should be correct to within a constant in range and azimuth
  - Preliminary/poor orbits may need an affine model instead of constant corrections
  - SLCs delivered by various missions appear to meet this criterion
  - Tomorrow: Hands-on example

Relative timing corrections

- Constant range shift
  - Relative error in starting range between master and slave
  - Possibly also due to atmosphere for high res data
- Constant azimuth shift
  - Relative error in azimuth time of first line between master and slave
- With timing corrections
  - reliable generation of stack of coregistered SLCs
  - Baseline estimates also improved
- Estimation of a single constant for the entire image is more robust than estimating higher degree offset polynomials

Master timing corrections

- The timing information for the master scene also needs to be corrected
  - More challenging than correcting relative timing errors

- Estimate constant offset between master SLC and simamp image
  - Again adjust starting range and azimuth time

- Adjust the master and ensure consistency between master SLC and topo simulation before DEM assisted coregistration

However, Every sensor is unique

- Example 1: Envisat and possibly ALOS-1

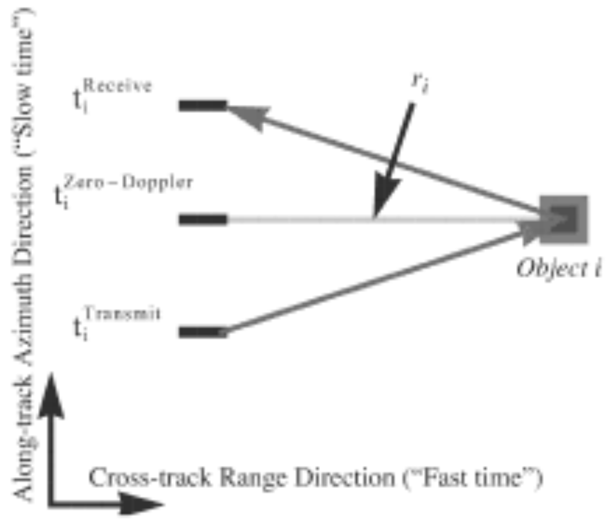


Fig. 4: Azimuth "bistatic" effect in idealised Zero-Doppler case

Small et al. (2005) and Small (2008)
Similar shift in both master and slave
Impacts geolocation

Every sensor is unique ....

- Example 2: Sentinel-1A

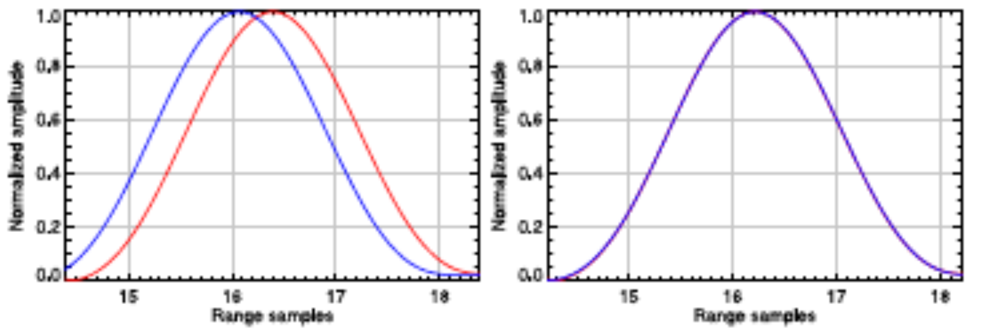


Fig. 8. Interpolated range impulse response of a CR. The CR is located at the overlap region between two bursts. The lines correspond to the (red) first burst and the (blue) following burst. Stop-and-go not corrected (left) and corrected (right).

Rodriguez-Cassola et al. (2015)
Azimuth dependent range shift.
Similar shift in both master and slave.
Impacts geolocation

Remember

- Every sensor is unique

- It is unavoidable to include some pre/post processing modules to process data from each sensor very precisely

- An optimized workflow for data from one sensor may / may not be exactly relevant from data from other sensors.

Interferogram formation

- Process2pass / insarApp
  - Azimuth filtering accomplished by common doppler processing and reducing azimuth resolution
  - Direct cross multiplication
  - First order Prati filtering with offset polynomials

- Isce.crossmul
  - Oversampling in range by a factor of 2
  - Prati filtering with DEM (being tested)

- What is the best way to generate stacked interferograms?
  - Depends on application

Interferogram formation in stacks

- Any form of filtering introduces inconsistencies in Insar phase

$$(A \cdot B^*) \cdot (B \cdot C^*) \neq (A \cdot C^*)$$

- Filtering includes
  - Multi-looking
  - Prati / Low pass/ Goldstein-Werner/ adaptive filtering

- Filtering also changes the number of equivalent looks in each interferogram
  - Should be accounted for in unwrapping and time-series inversion?

Persistent Scatterers

- Data to be processed at highest resolution to detect point targets
  - Oversample in range and azimuth to avoid aliasing

- No filtering is desired as this leads to reduction of effective bandwidth

- All connected network of interferograms generated at full resolution without any filtering are equivalent (Agram and Simons, 2015)

Short Baseline Methods

- SBAS methods target distributed scatterers
- Multilooking is optional (Lanari et al., 2004; Hooper, 2008)
- Can process all scenes to common azimuth bandwidth (0.5 -0.6 PRF) depending on the doppler spread
  - Ensures that all interferograms have similar spectral overlap and noise properties

Filtering and DEM Errors

- insarApp / process2pass
  - Default workflow includes interferogram filtering
  - Not possible to estimate DEM errors in stacks

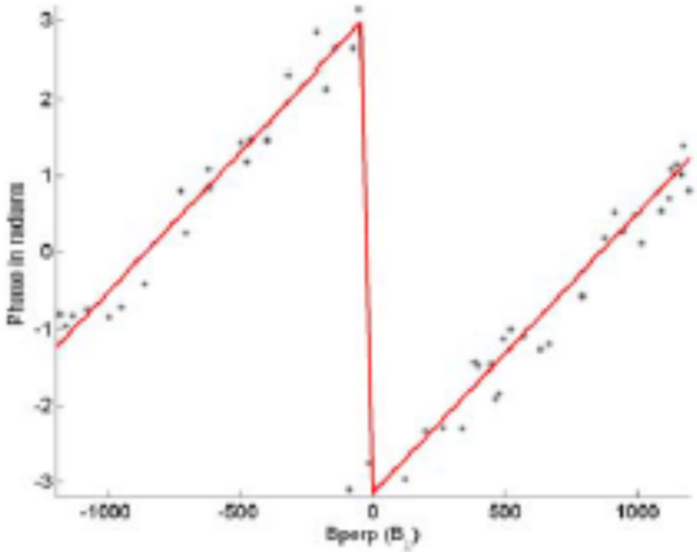
- DEM Errors cannot be estimated because
  - Each pair in a stack processed to different dopplers, thus using slightly different satellite positions used for estimating baseline for same point on ground
  - Use different offset polynomials to match DEM and interferogram, thus no guarantees that the geocoded products will match exactly

DEM error estimation

- Sub-pixel location of scattering center
  - All geometry computations assume that the scattering center corresponds to center of pixel
  - Sub-pixel position of dominant scatterer produces same effect as DEM error
  - Sub-pixel position assumed independent for each pixel

- DEM error estimation possible only when
  - We work with coregistered SLCs
  - Do not apply filtering
  - Use same satellite positions consistently for estimating baseline in every interferogram pair in the network

DEM errors



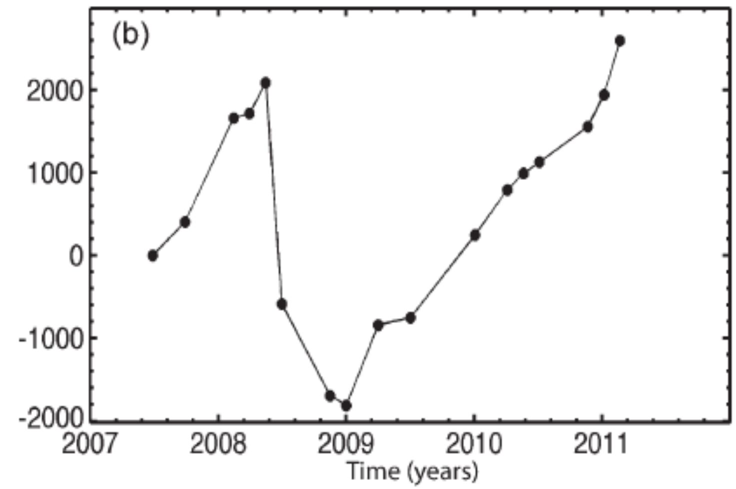


Image: Fattahi (2014)

$$\phi_{dem} = \frac{4\pi}{\lambda} \cdot \frac{B_{\perp}}{r \cdot \sin\theta} \cdot \delta z$$

(Pixel phase – local average) vs Bperp

Bperp vs Time for ALOS PALSAR

- (Pixel phase – local average) shows a trend w.r.t perpendicular baseline
- DEM error cannot be distinguished from deformation in the case of systematic orbit drift – ALOS PALSAR.

Once we have good quality interferogram stacks, we are ready to apply favorite pixel selection / unwrapping algorithm

Time-series applications inherently assume that the interferometric products are of high quality.