GEOS F493 / F693
Geodetic Methods and Modeling

– Lecture 08: InSAR - Timeseries Analysis –

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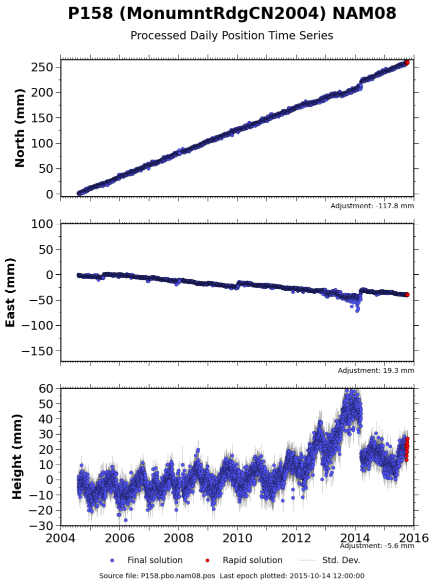
"Guess the Process"



UNAVCO, `https://plus.google.com/112042426109504523574/posts/62kUxwSWCiB`

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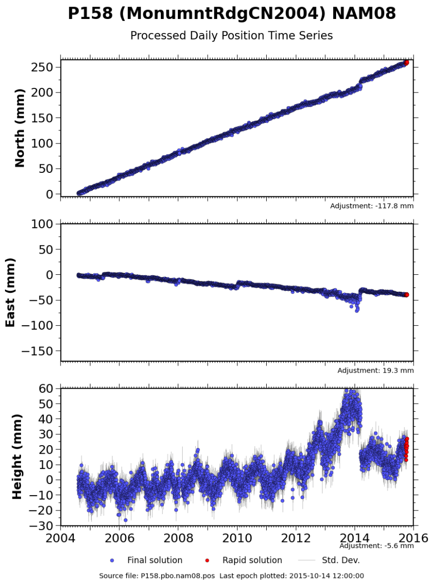

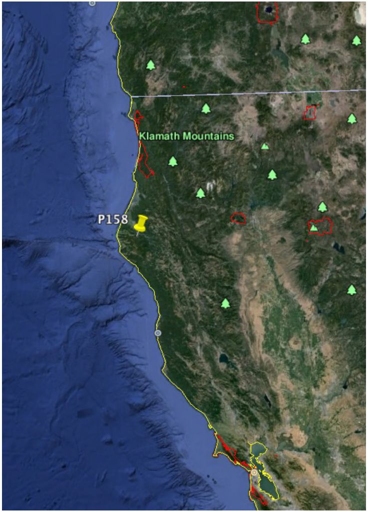

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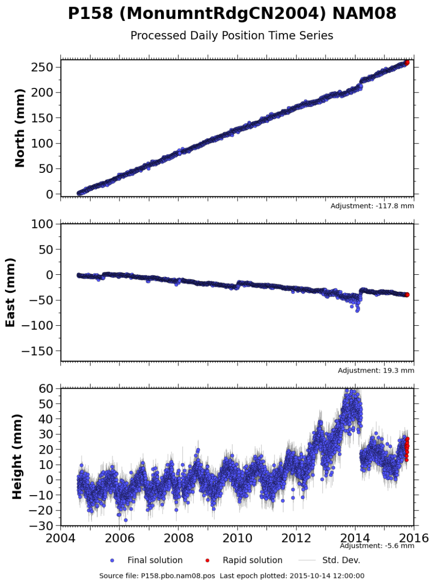

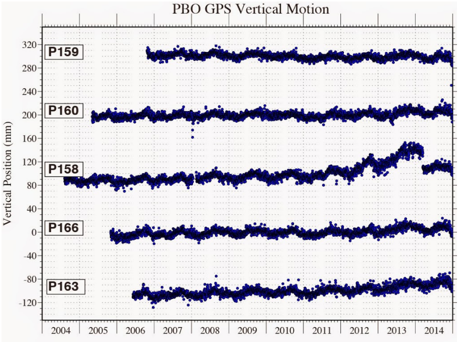

Figure 2. Comparison of vertical motion at P158 and nearby (<30 km) stations.

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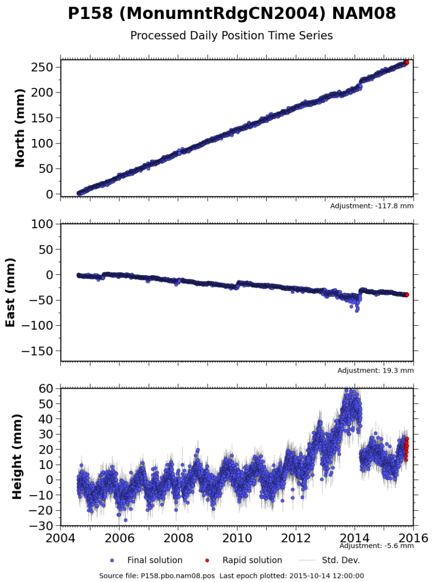

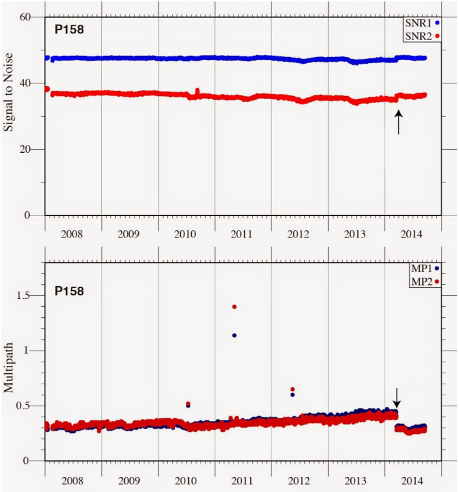

Figure 3. Signal to noise ration (top) and multipath (bottom) for P158.

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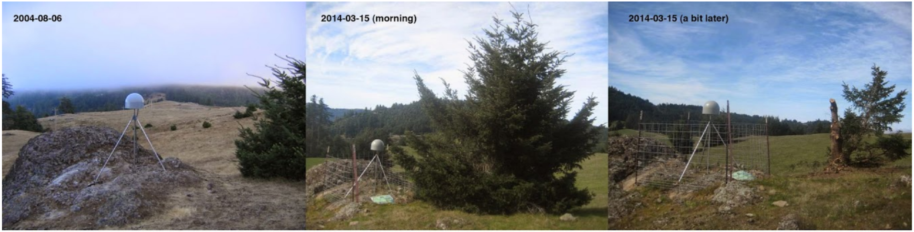

Figure 4. P158 at installation (left), ~10 years later (middle), ~10 years+2 hours later (right). The small tree north of the station grew into a larger tree and was removed on March 3, 2014.

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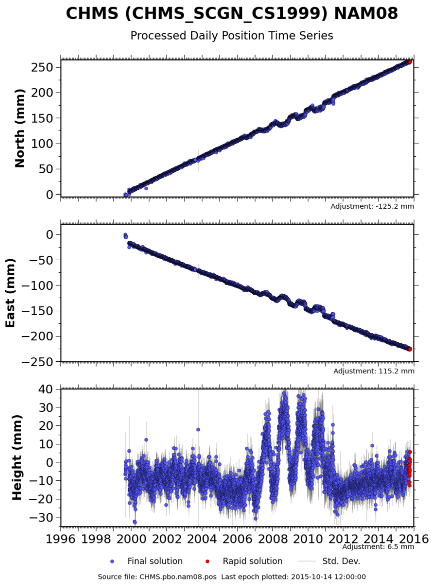

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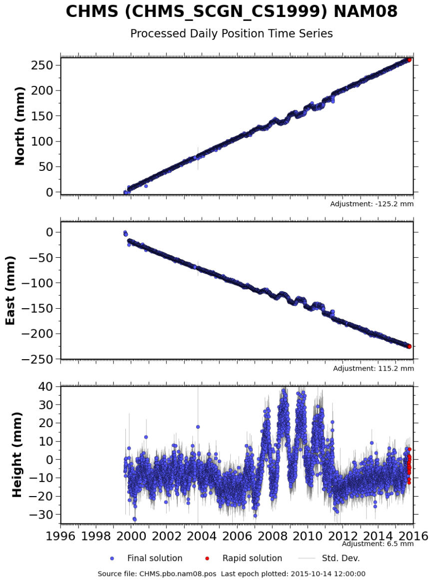


2009 vs 2015

UNAVCO, `https://plus.google.com/112042426109504523574/posts/62kUxwSWCiB`

InSAR - Processing Flow

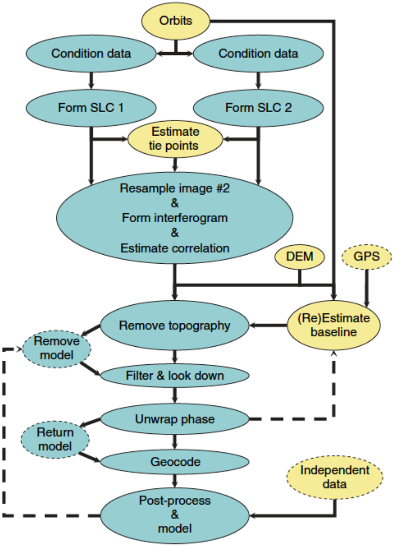


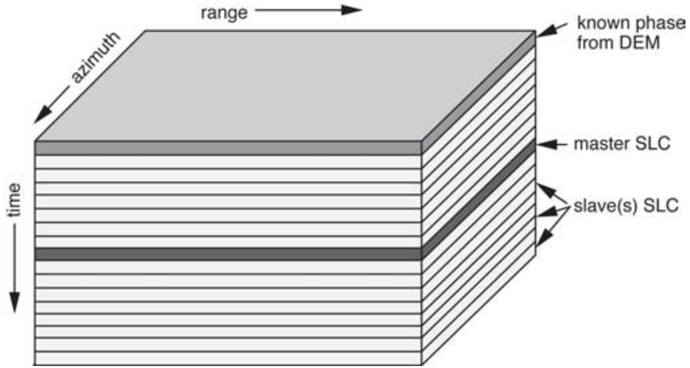
Figure 6 Representative differential InSAR processing flow diagram. Blue bubbles represent image output, yellow ellipses represent nonimage data. Flow is generally down the solid paths, with optional dashed paths indicating potential iteration steps. DEM, digital elevation model; SLC, single look complex image.

Simons and Rosen, 2007

InSAR - Timeseries

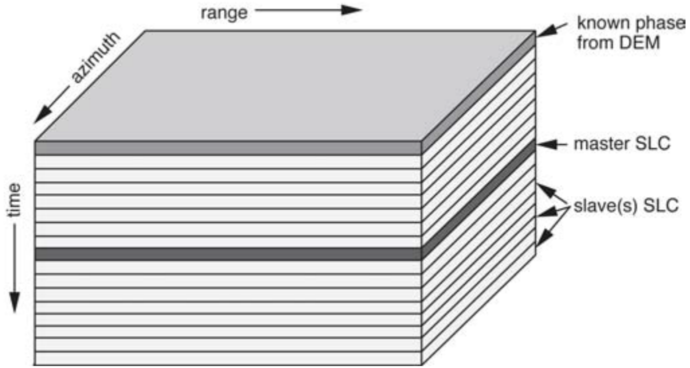
Improve signal to noise ratio by creating multiple interferograms.

InSAR - Timeseries: Stacking



Sandwell et al., 2011

InSAR - Timeseries: Stacking



Sandwell et al., 2011

What could be difficult about this?

InSAR - Timeseries: Stacking

- often most challenging: geometrical alignment of large stack of images, align with topographic phase
- alignment problematic: temporal and geometric decorrelation
- subpixel alignment can fail due to lack of correlated areas

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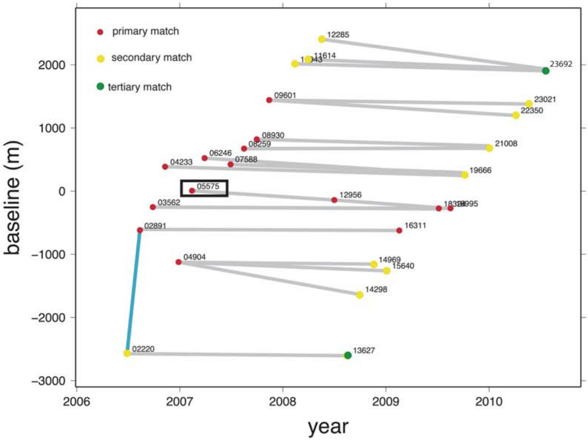

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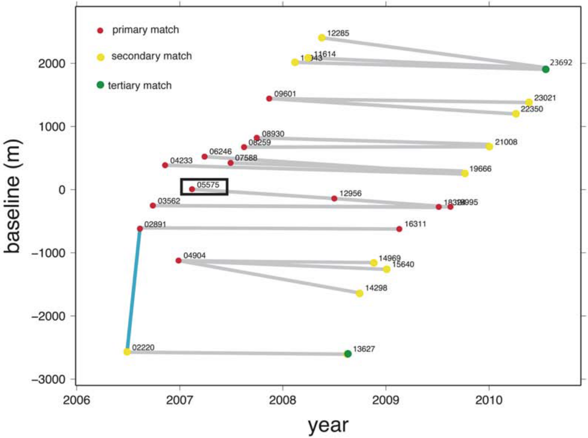

Sandwell et al., 2011

- ALOS stack, track 213, frame 0660, Coachella Valley, California
- temporal decorrelation not as problematic: desert
- geometry: 5 km perpendicular baseline change over 2 years

InSAR - Timeseries: Stacking

gmtSAR processing:

1. preprocess all images independently
2. use `pre_proc_batch.csh` – creates the baseline plot above
3. select master image in middle of baseline vs. time plot
   - alignment to overall $<$ 2-pixel precision
   - multi-step approach
   - *primary match* – images near master in baseline vs time plot aligned directly to master
   - *secondary match* – each primary match slave is surrogate master to its neighbors
   - *tertiary match* – possible to define for images very far from master
4. use `align_batch.csh` – to run alignment (time consuming!)
5. generate/retrieve a DEM
6. use `intf_batch.csh` – to make set of interferograms

InSAR - Baseline Errors

InSAR - Baseline Errors

- orbit errors can induce long-wavelength phase ramps (incorrect topo removal)
- long perpendicular baseline can induce short-wavelength error in rough topography
- can deal with this by ramp removal or use GPS constraints on geometry

InSAR - Propagation Delays

InSAR - Propagation Delays

- due to atmosphere and ionosphere, inhomogeneous over space and time
- more severe in repeat-track than along track observations
- GPS can be used to estimate correction, however: point-based
- might miss or focus on regional variations
- statistical approaches deal with interpolations of wet-delay
- high-resolution weather models promise help
- merging weather models with GPS / radiosonde observations may bring improvement

InSAR - Image Stacking

- target is event that occurred quickly (in between 2 measurements) or process w/ constant rate
- could increase signal to noise ration by stacking/averaging multiple **interferograms**
- reduces effect due to tropospheric delay (uncorrelated on these time scales)
- discover small signals
- reduce number of observations
- work in radar or geocoded coordinates

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Methods:

- brute force: average all interferograms together
  - regions of decorrelation are union of decorrelation in individual pictures
  - e.g, co-seismic displacements for smaller earthquakes
- use weighted average, weight is inverse of covariance matrix
- more formal: pose as least-squares problem (may include model parameters)

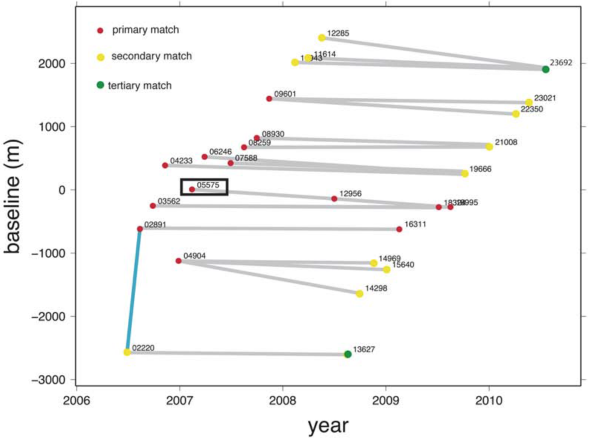
InSAR - Time Series

InSAR - Time Series

Improve by removing models for:

- seasonal deformation (snow, atmosphere, ...)
- co-seismic steps
- post-seismic exponential decays
- similar to (and maybe informed by) GPS timeseries ‘cleaning’ based on physical models

InSAR - Timeseries: Stacking



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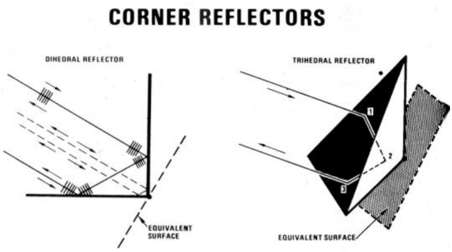
InSAR - Timeseries: Permanent Scatterers

- in addition to temporal/geometric decorrelation: errors due to temporal & spatial variations of atmosphere, ionosphere (random)
- corner reflectors: continuously reliable coherent scatterers
- identify consistent reflectors in series of images,

http://uavsar.jpl.nasa.gov/technology/calibration/cr2.html



http://www.geog.ucsb.edu/~jeff/115a/remote_sensing/radar/radar2.html

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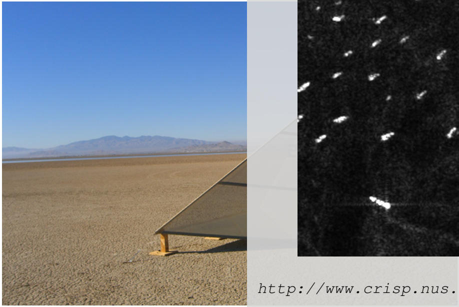
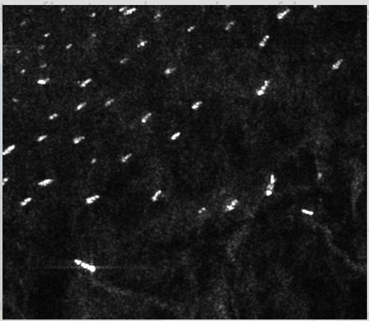
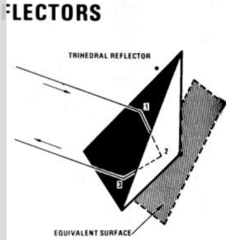




http://www.crisp.nus.edu.sg/~research/tutorial/sar_int.htm



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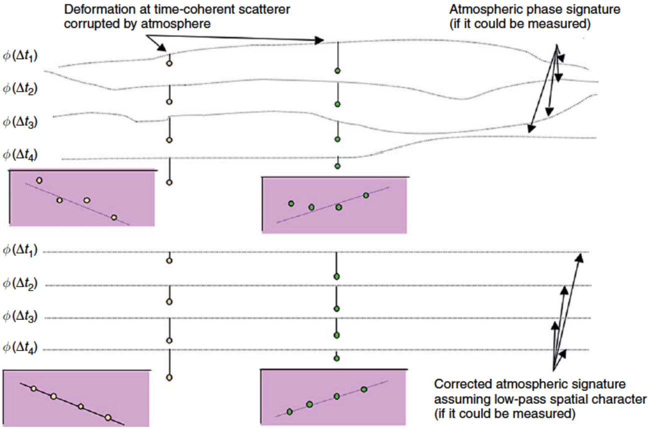


Figure 14 The 'permanent scatterer' technique identifies time-coherent scatterers by estimating the contributions of topography, deformation, and atmospheric delay to the phase under model constraints through correlation maximization. Topography is assumed to be static (with the interferometric phase proportional to baseline), deformation is assumed to follow some functional form (e.g., linear or sinusoidal with time), and atmospheric delay is assumed to vary randomly in time and with long spatial wavelength.

Simons and Rosen, 2007

InSAR - Timeseries: Permanent Scatterers

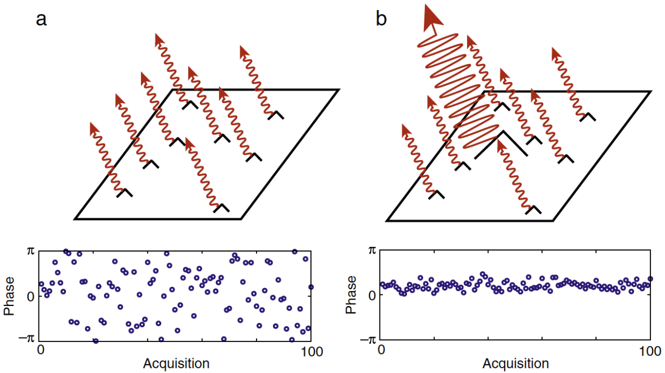


Fig. 2. Phase simulations for (a) a distributed scatterer pixel and (b) a persistent scatterer pixel. The cartoons above represent the scatterers contributing to the phase of one pixel in an image and the plots below show simulations of the phase for 100 acquisitions, with the smaller scatterers moving randomly between each iteration. The brighter scatterer in b is three times brighter than the sum of the smaller scatterers.

Hooper et al., 2012

- One scatterer in pixel returns significantly more energy
- PS algorithms work on time series of interferograms wrt to single master

InSAR - Timeseries: Permanent Scatterers

Estimate decorrelation noise to select PS Pixels(1)

- model deformation in time
- suppress orbit, atmosphere error by by phase differencing neighboring candidate pixels
- residuals between "differences phase" and deformation DEM model give estimate of noise level

InSAR - Timeseries: Permanent Scatterers

Estimate decorrelation noise to select PS Pixels(1)

- model deformation in time
- suppress orbit, atmosphere error by by phase differencing neighboring candidate pixels
- residuals between "differences phase" and deformation DEM model give estimate of noise level

Estimate decorrelation noise (2, better coverage in rural areas)

- estimate spatial correlation of most phase terms
- apply spatial filtering to estimate spatially-correlated terms (deformation, atmosphere, orbit error) for each candidate scatterer
- subtract spatially correlated phase, residual contribution from DEM error in remaining phase modeled for time series
- residual between phase and model provides noise estimate

InSAR - Timeseries: SBAS

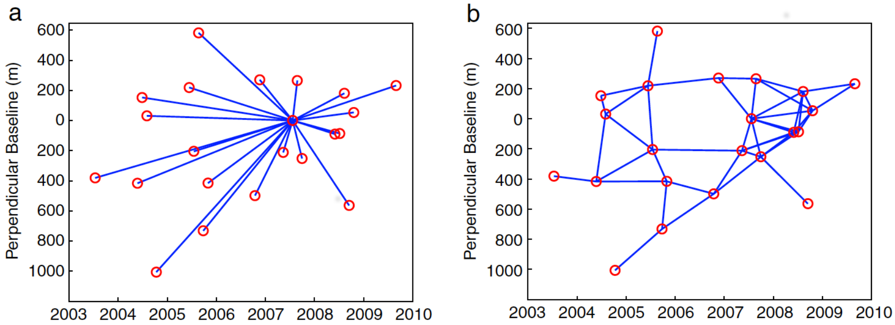


Fig. 3. An example baseline plot for (a) the persistent scatterer method and (b) the small baseline approach. Red circles represent SAR images and blue lines indicate the interferograms that are formed. Perpendicular baseline refers to the component of the satellite separation distance that is perpendicular to the look direction, and is proportional to the difference in look angle.

Hooper et al., 2012

- no dominant scatterers: decorrelation can be large enough to mask deformation signal
- interfere spatially and temporally close SAR images

InSAR - Timeseries: PS & SBAS

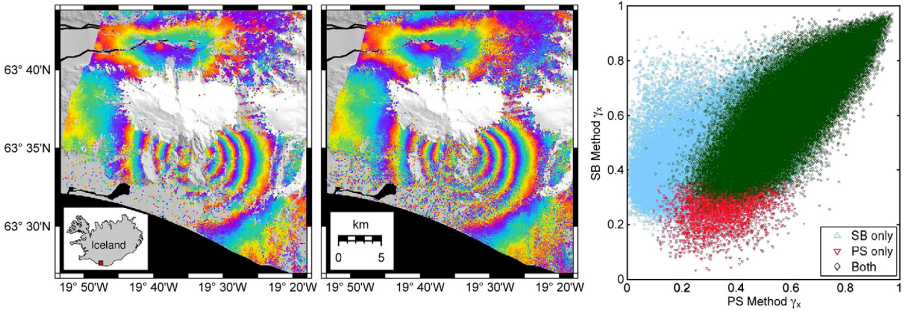
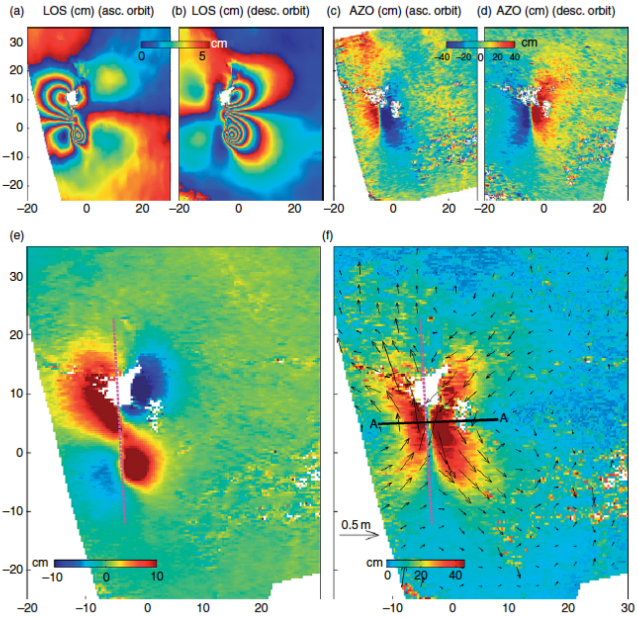


Fig. 6. Comparison of pixels selected by PS and small baseline methods from data acquired by the C-band ERS satellites, on and around Eyjafjallajökull volcano, Iceland. Left, pixels selected by aPS method and middle, pixels selected by a full-resolution small baseline method. The pixels are plotted on topography in shaded relief, with white representing the approximate area of permanent ice cover. The location of the area analysed is shown left inset. 27 images were used in the analysis although only one interferogram is shown here, which spans 27 June 1997 to 10 October 1999, and shows deformation due to the intrusion of a sill at 5.7 ± 0.5 km. Each colour fringe represents 2.8 cm of displacement in the line-of-sight. Right is a comparison of estimated coherence magnitude (γ_x) for all pixels selected by either, or both, methods. These values are estimated from the residual phase after subtraction of the spatially-correlated phase and correction for look angle (DEM) error (Hooper et al., 2007). A higher coherence magnitude indicates less phase noise. From Hooper, 2008.

Hooper et al., 2012

InSAR - 3D Deformation

- better constrain physical models (volcano, earthquake)
- earthquake in LOS only: tradeoff amplitude / rake of slip
- worse if we don't know location of small events well
- don't assuming purely vertical/horizontal deformation



Fialko et al., Nature, 2005

InSAR - 3D Deformation

For example (*Fialko et al., GRL, 2001*):

- ascending and descending LOS displacement
- ascending and descending azimuthal displacements (cross-correlate radar amplitude pixels along satellite track)

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- ascending and descending azimuthal displacements (cross-correlate radar amplitude pixels along satellite track)

LOS-displacements, d_{los} are projection of vector displacement field U_i onto look vector:

$$d_{los} = [U_n \, sin(\phi) - U_e \, cos(\phi)] \, sin(\lambda) + U_u \, cos(\lambda) + \epsilon_{los}$$

with ϕ: azimuth of satellite heading (clockwise from North)
λ: radar incidence angle
ϵ: measurement error

InSAR - 3D Deformation

For example (*Fialko et al., GRL, 2001*):

- ascending and descending LOS displacement
- ascending and descending azimuthal displacements (cross-correlate radar amplitude pixels along satellite track)

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with ϕ: azimuth of satellite heading (clockwise from North)
λ: radar incidence angle
ϵ: measurement error
Azimuthal offset, d_{azo} is projection of horizontal displacement onto satellite heading:

$$d_{azo} = U_n\, cos(\phi) - U_e\, sin(\phi) + \epsilon_{azo}$$