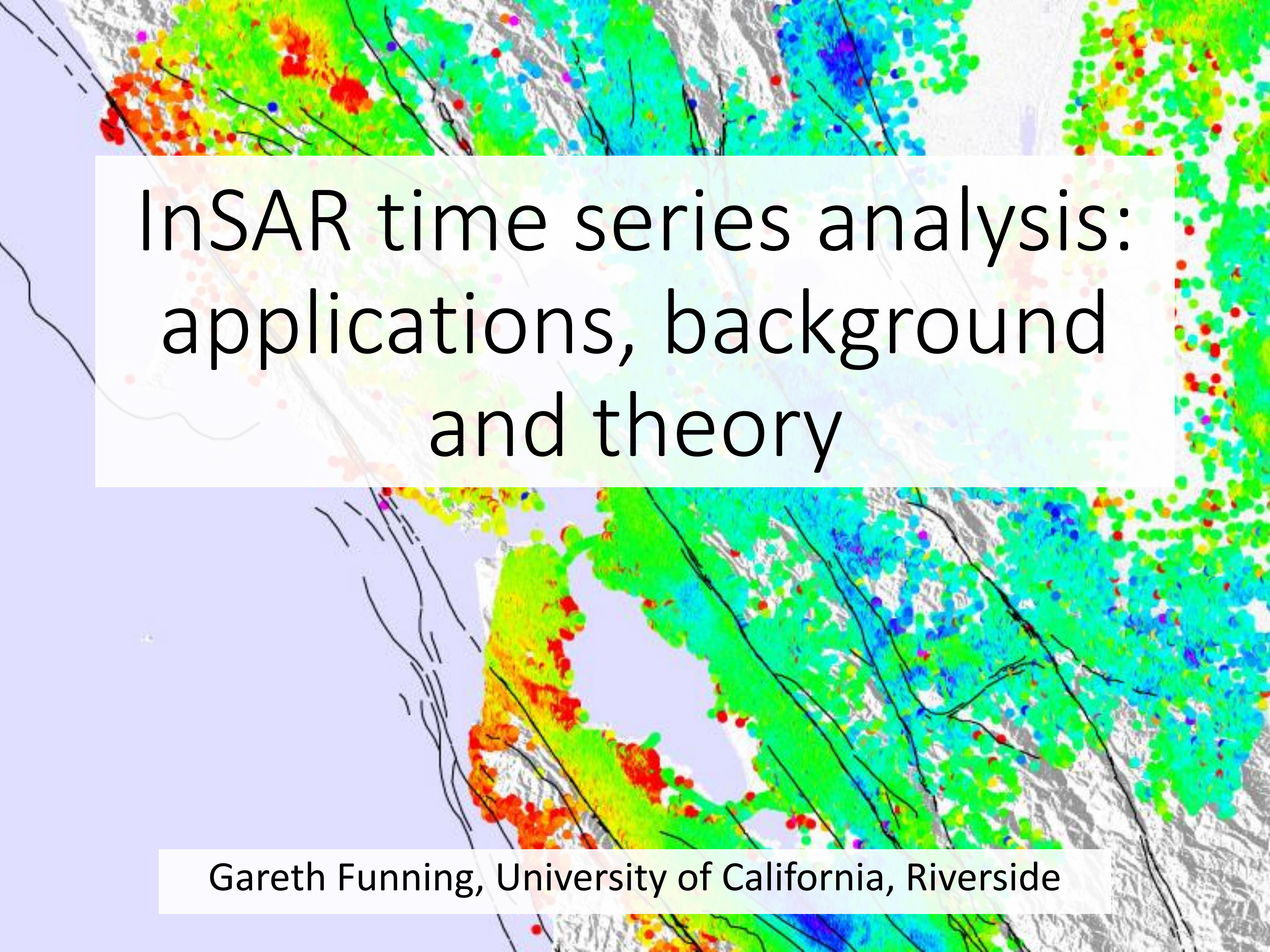


InSAR time series analysis: applications, background and theory

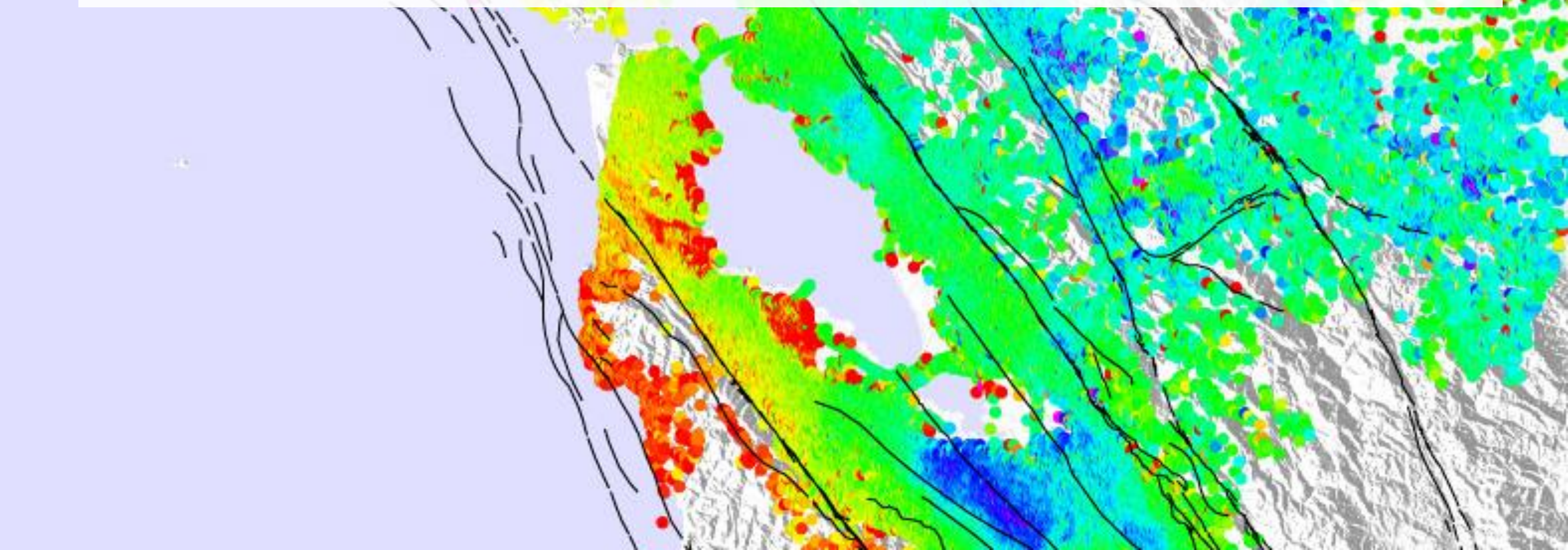
Gareth Funning, University of California, Riverside

Outline

Examples: time series InSAR of slow deformation in the San Francisco Bay Area and elsewhere

Persistent scatterer InSAR (PSI)

The small baseline subset (SBAS) method



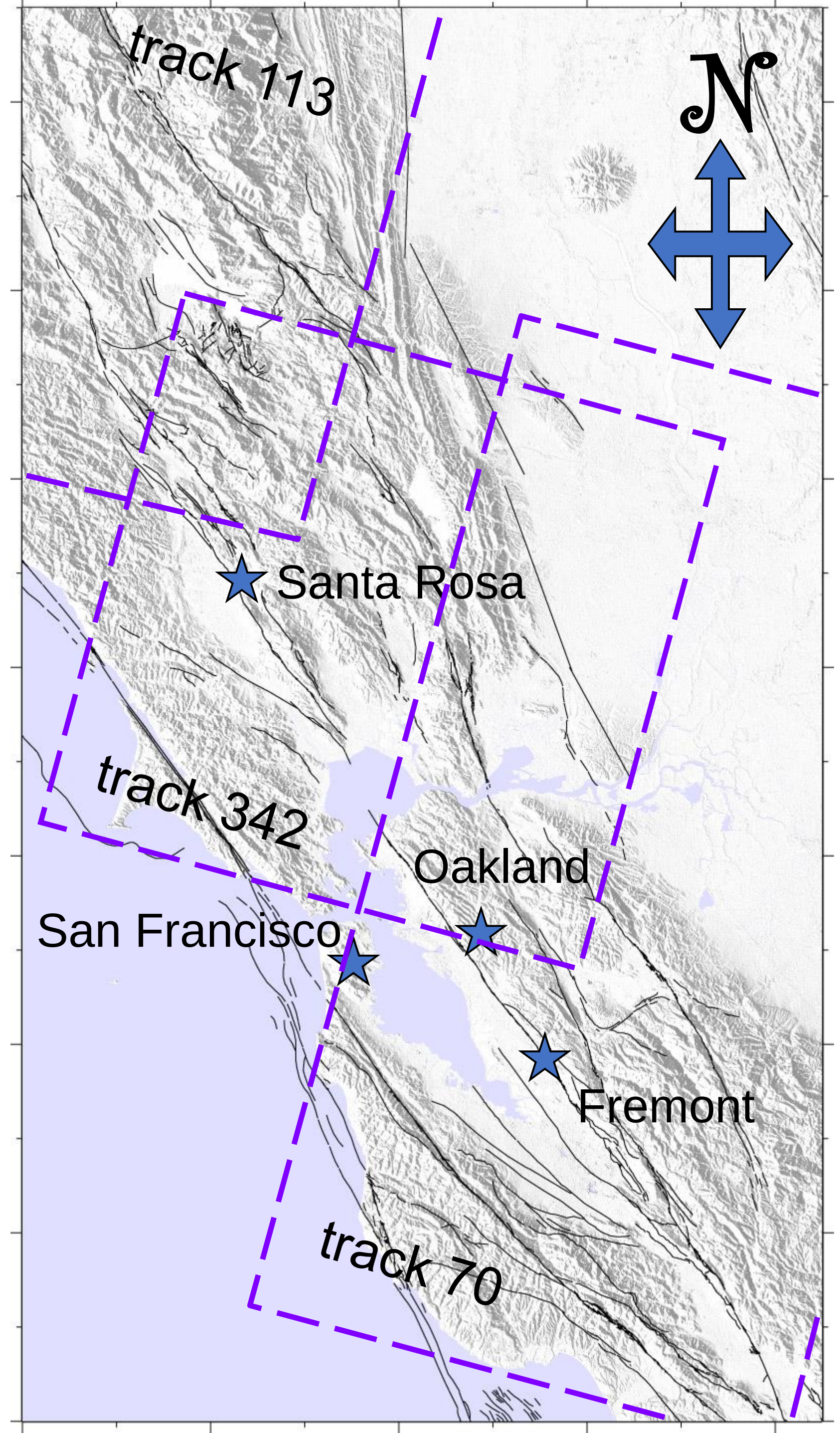
InSAR time series methods

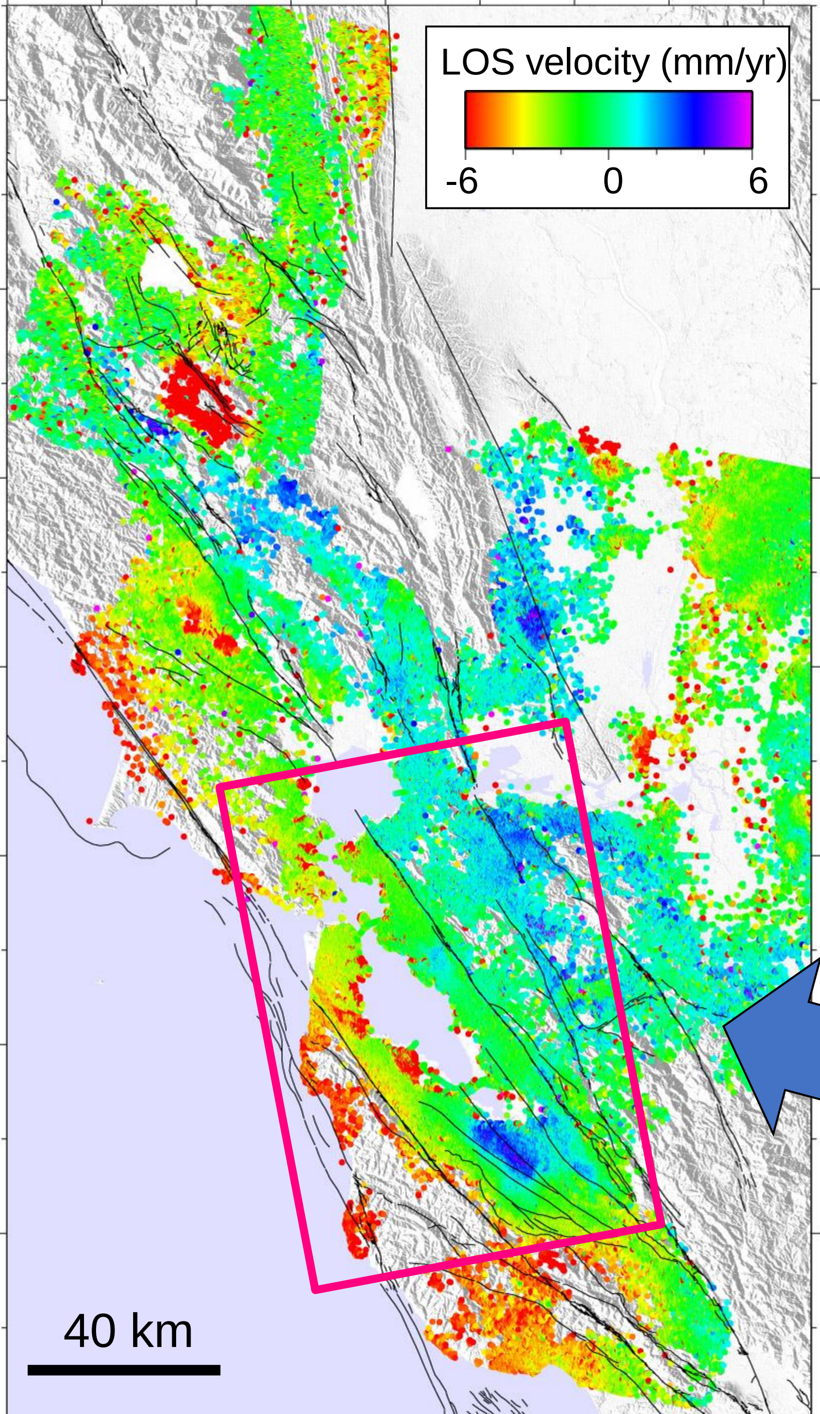
These methods make use of multiple interferograms in order to constrain:

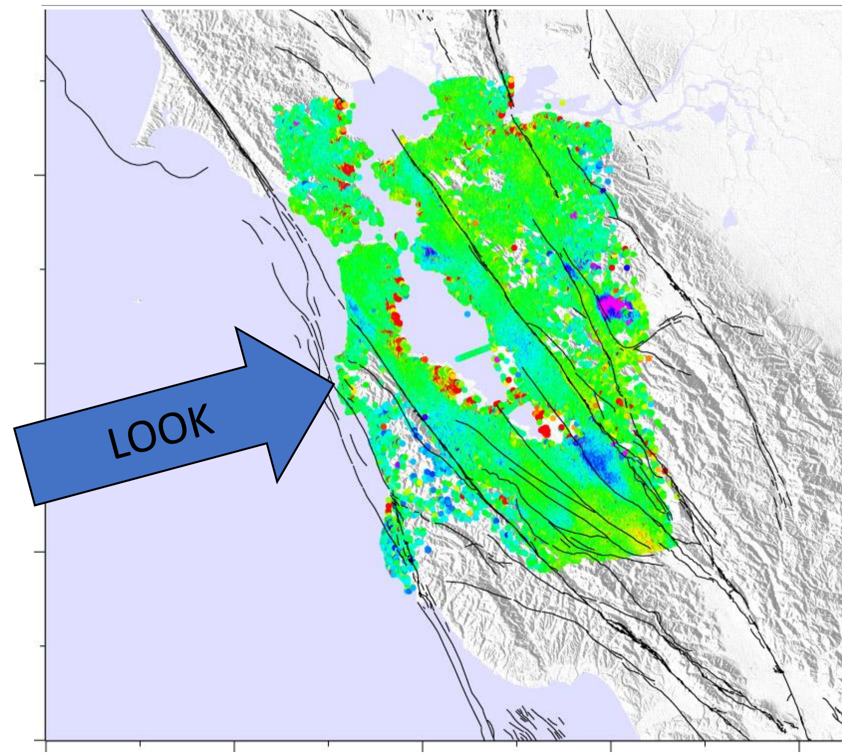
- Slow deformation processes (i.e. processes that are at or below the noise level in an individual interferogram)
- Time-variable processes

Time series methods typically make use of redundancy and/or temporal correlations in the data to maximize coherent pixels, extract deformation signals and mitigate noise

Example: the San Francisco Bay Area



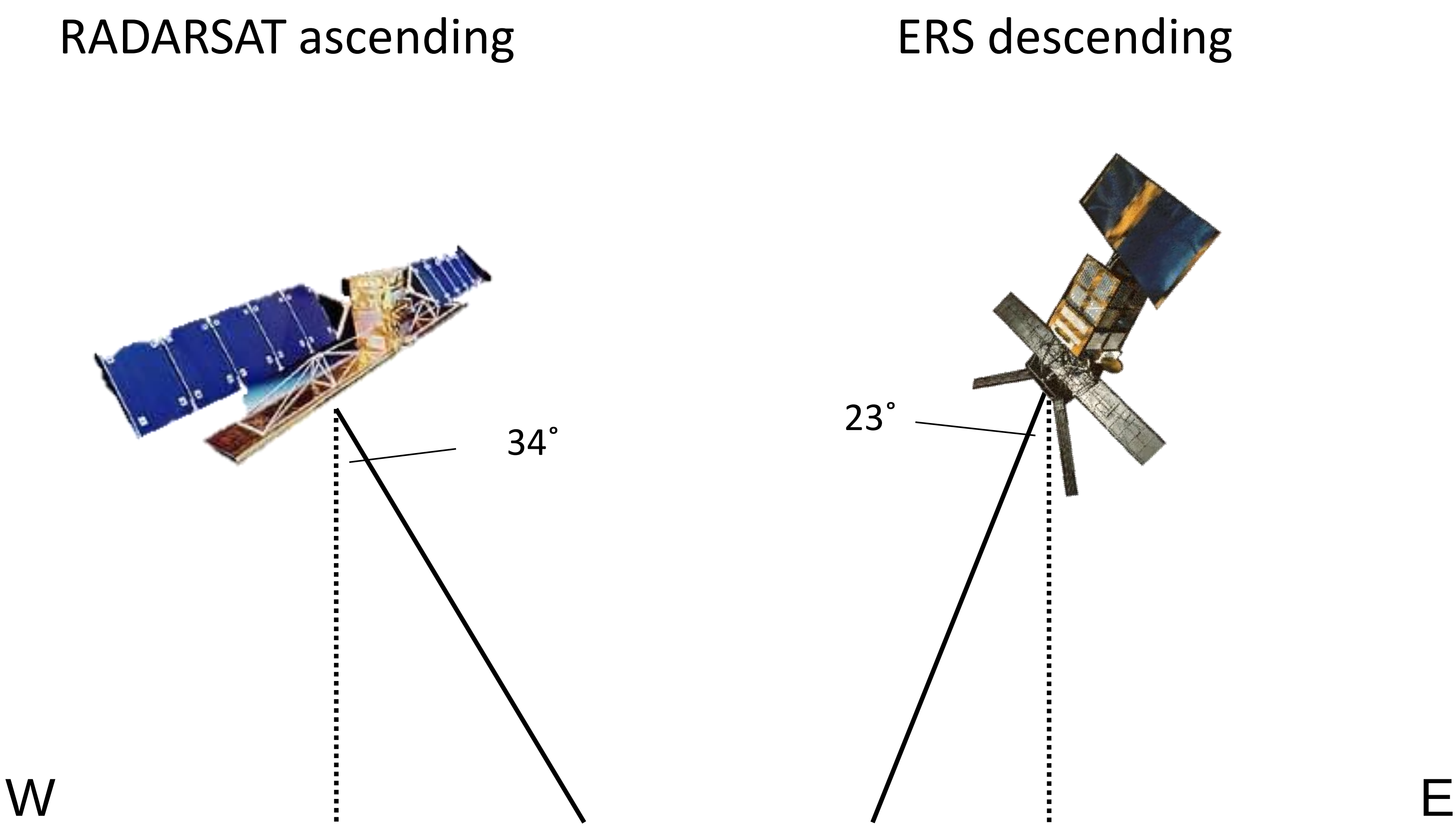




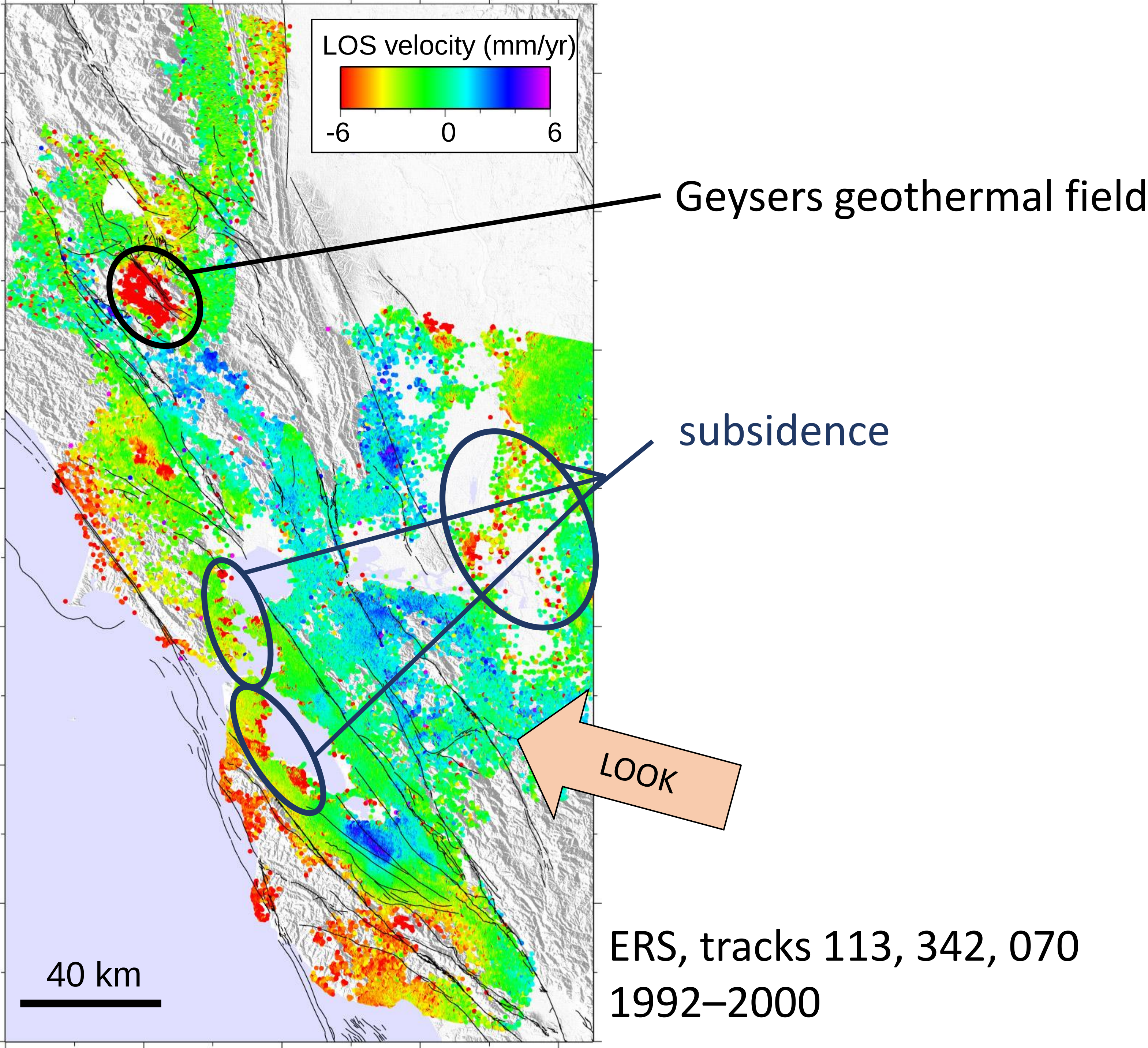
RADARSAT, track 38, beam S3
1998–2006

ERS, tracks 113, 342, 070
1992–2000

Processed by TRE



Deformation signals have same sign – vertical motion
Deformation signals have different signs – horizontal motion



ERS, tracks 113, 342, 070
1992–2000

Subsidence at Treasure Island

Treasure Island is a man-made island, built in 1936/7

http://walrus.wr.usgs.gov/geotech/treasureposter/treasure.html

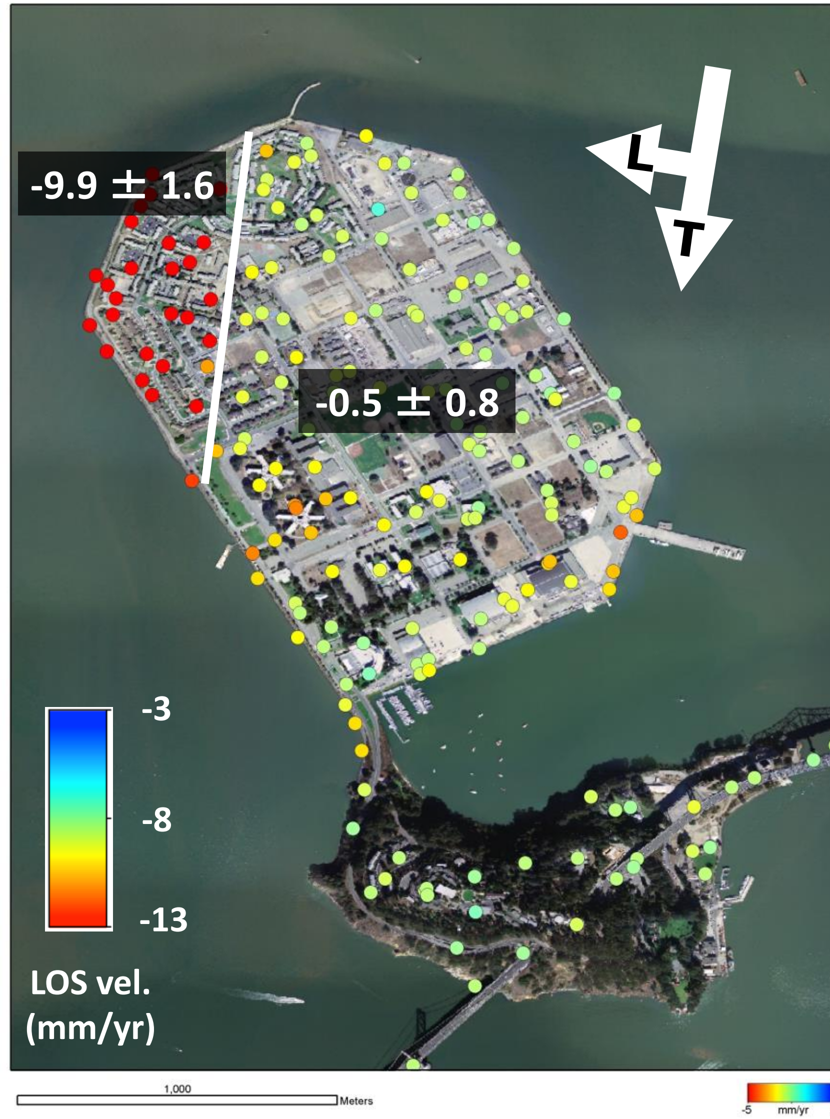
Subsidence at Treasure Island

Calculate velocities of NW and central Treasure Island with respect to Yerba Buena

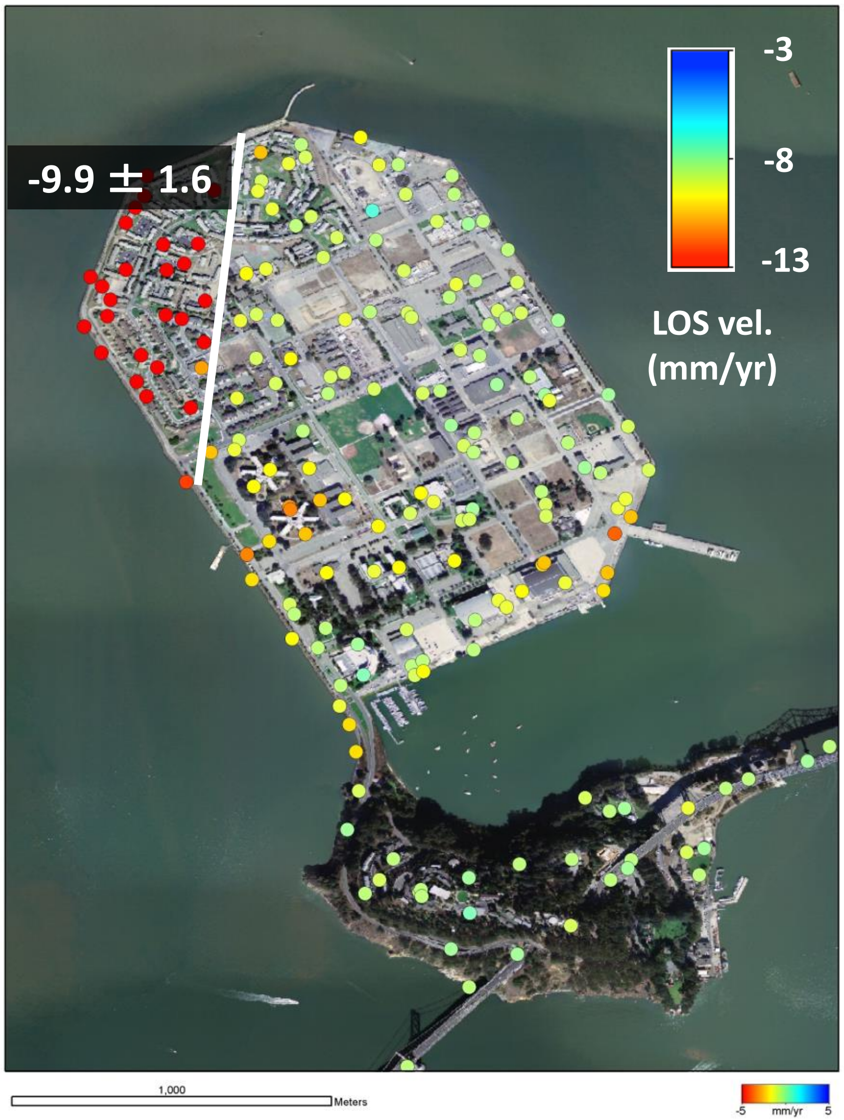
NW Treasure Island – significant high velocity

Central Treasure Island – stationary within error

ERS track 070 (1992-2000) velocities overlaid on 2004 airphoto



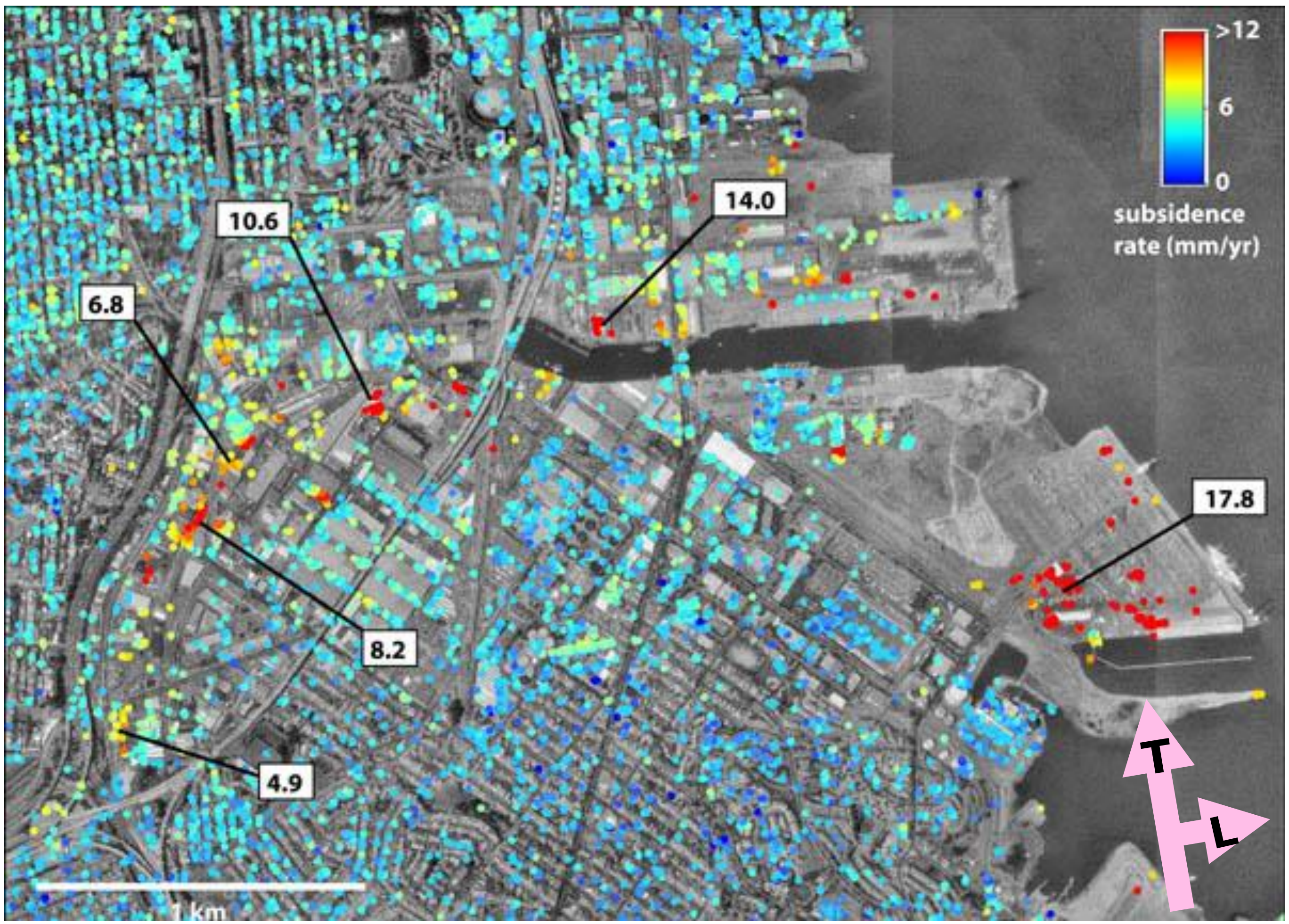
Subsidence at Treasure Island



Region of greatest velocities correlates with thickest Bay mud on island (> 20 m)

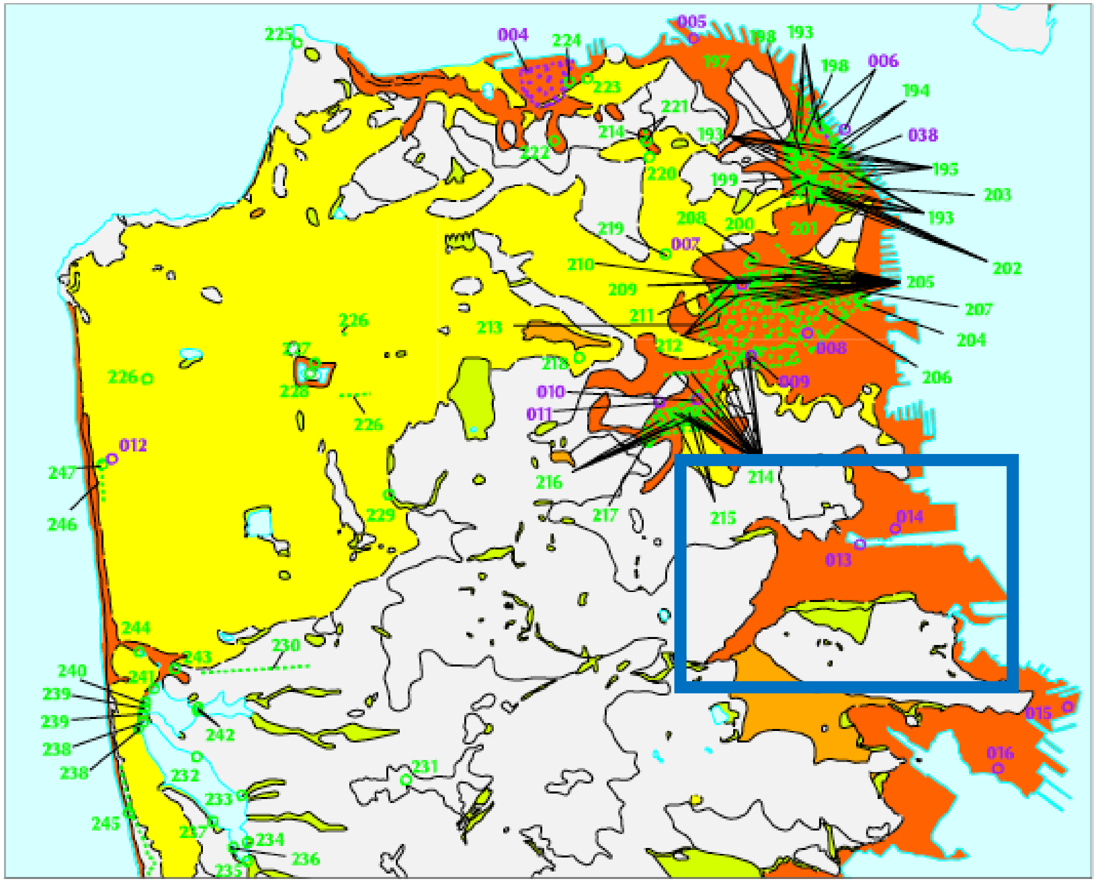
Subsidence in San Francisco

High subsidence rates at the location of an old stream channel



Subsidence in San Francisco

There is an excellent correlation between liquefaction risk and subsidence

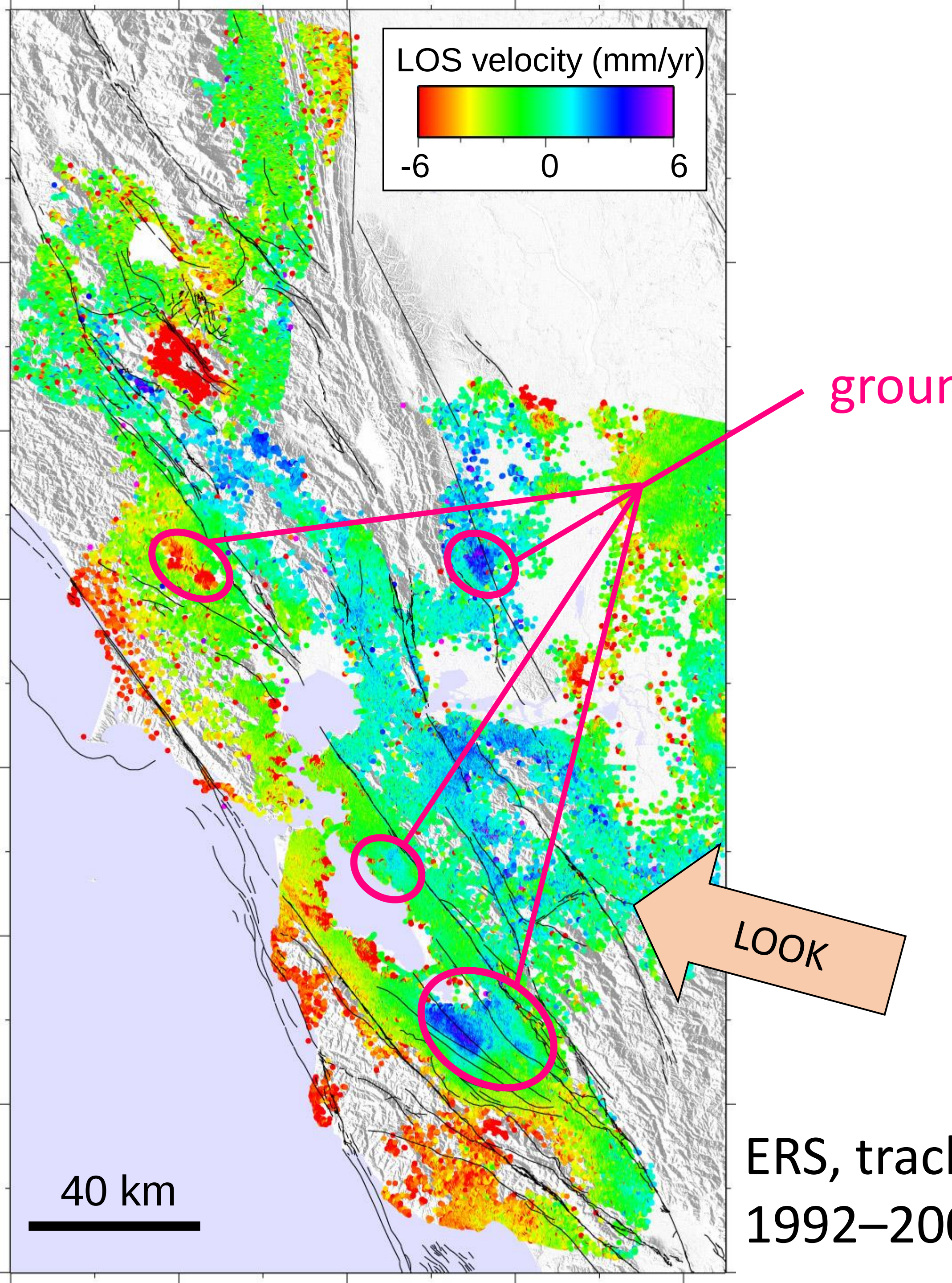


DETAIL OF SAN FRANCISCO AREA

MAP SCALE 1:100,000

0 5 KM

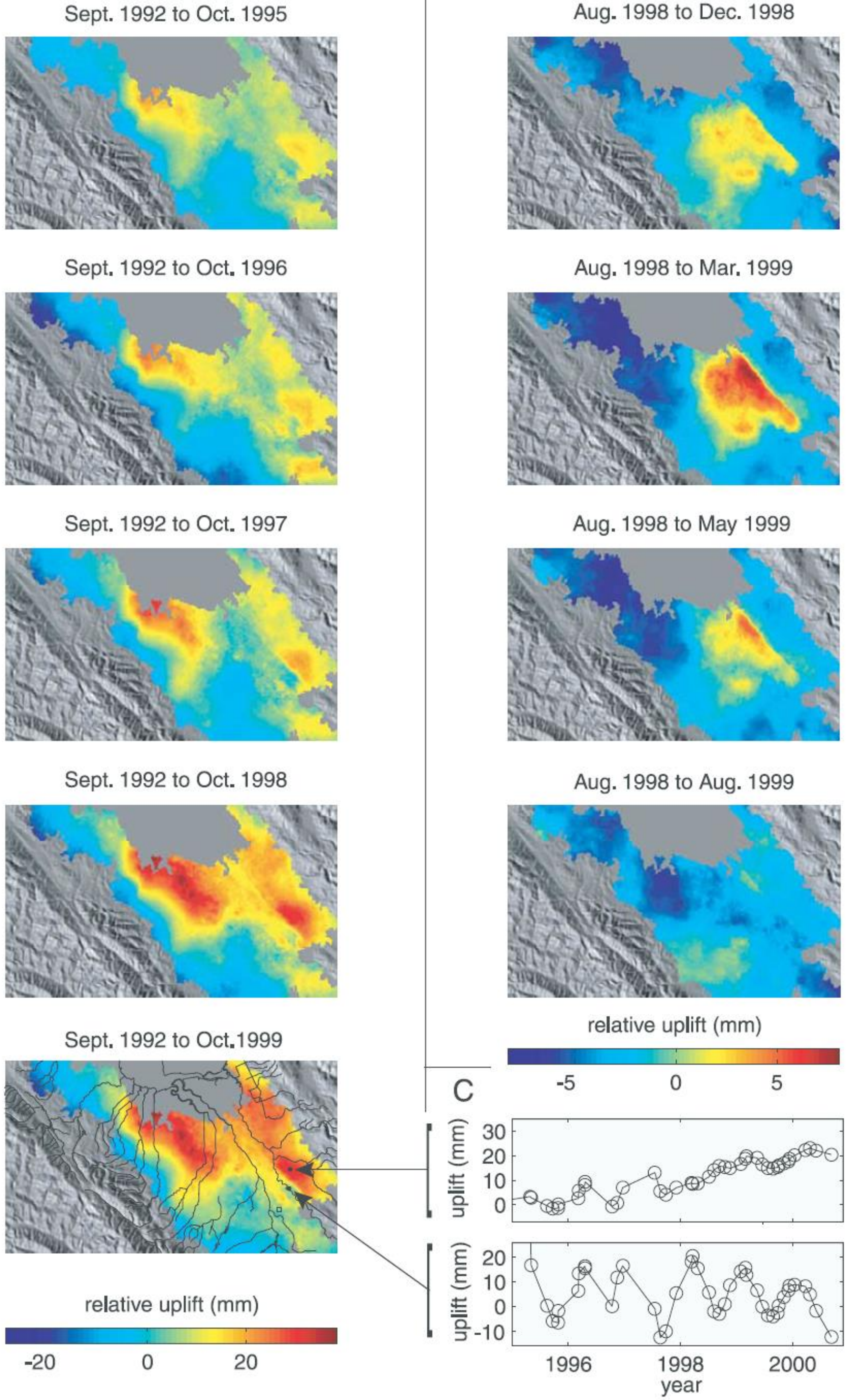
Knudsen *et al.*, 2000, USGS Open File Report 00-444



ERS, tracks 113, 342, 070
1992–2000

The Santa Clara aquifer

Overall a pattern of increasing uplift, but there are large seasonal fluctuations (up in winter, down in summer)



Schmidt and Burgmann, 2003

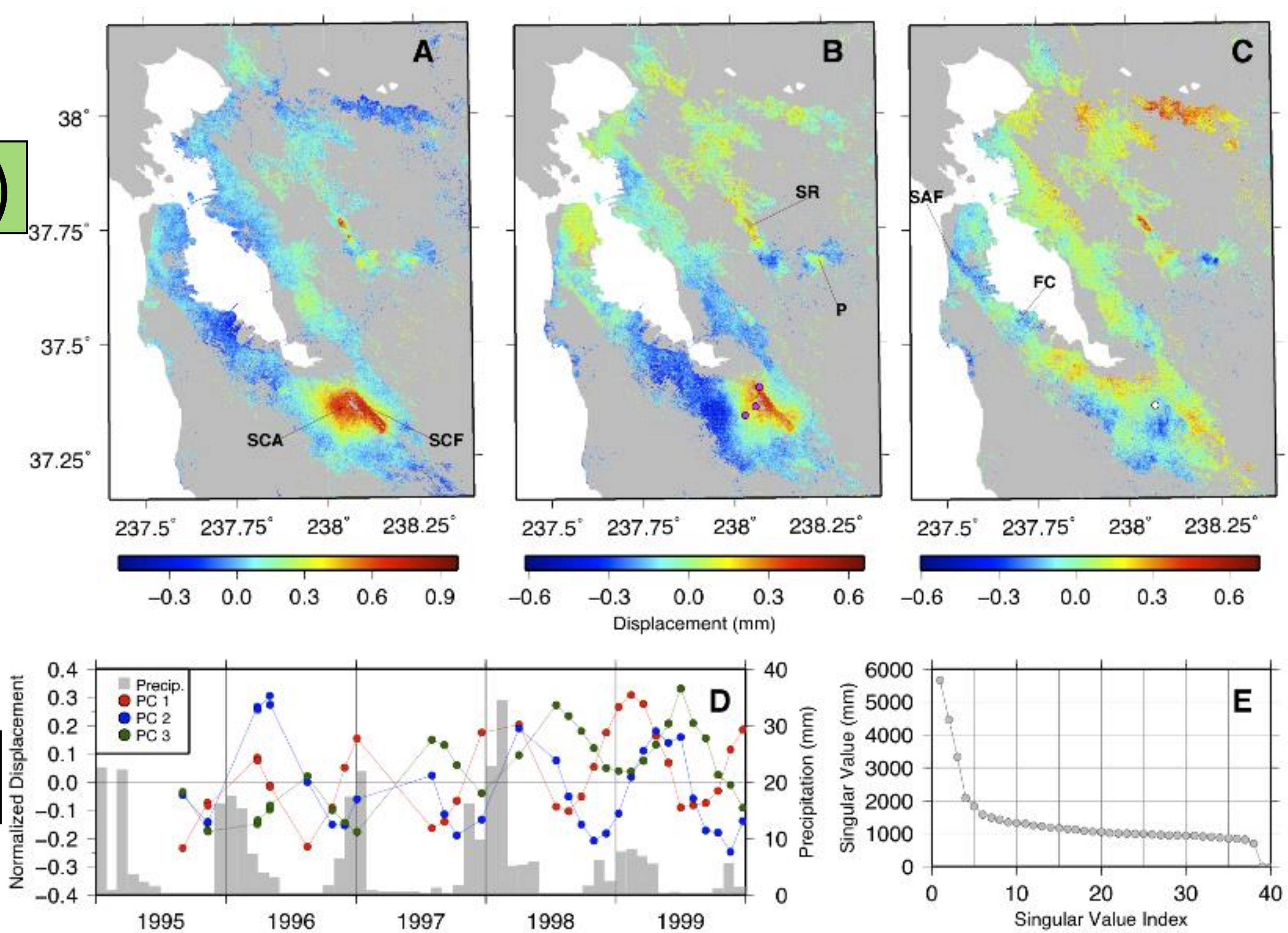
Principal component analysis of InSAR time series

$$\mathbf{D} = \mathbf{U}(t)\ \mathbf{S}\ \mathbf{V}(x)^T$$

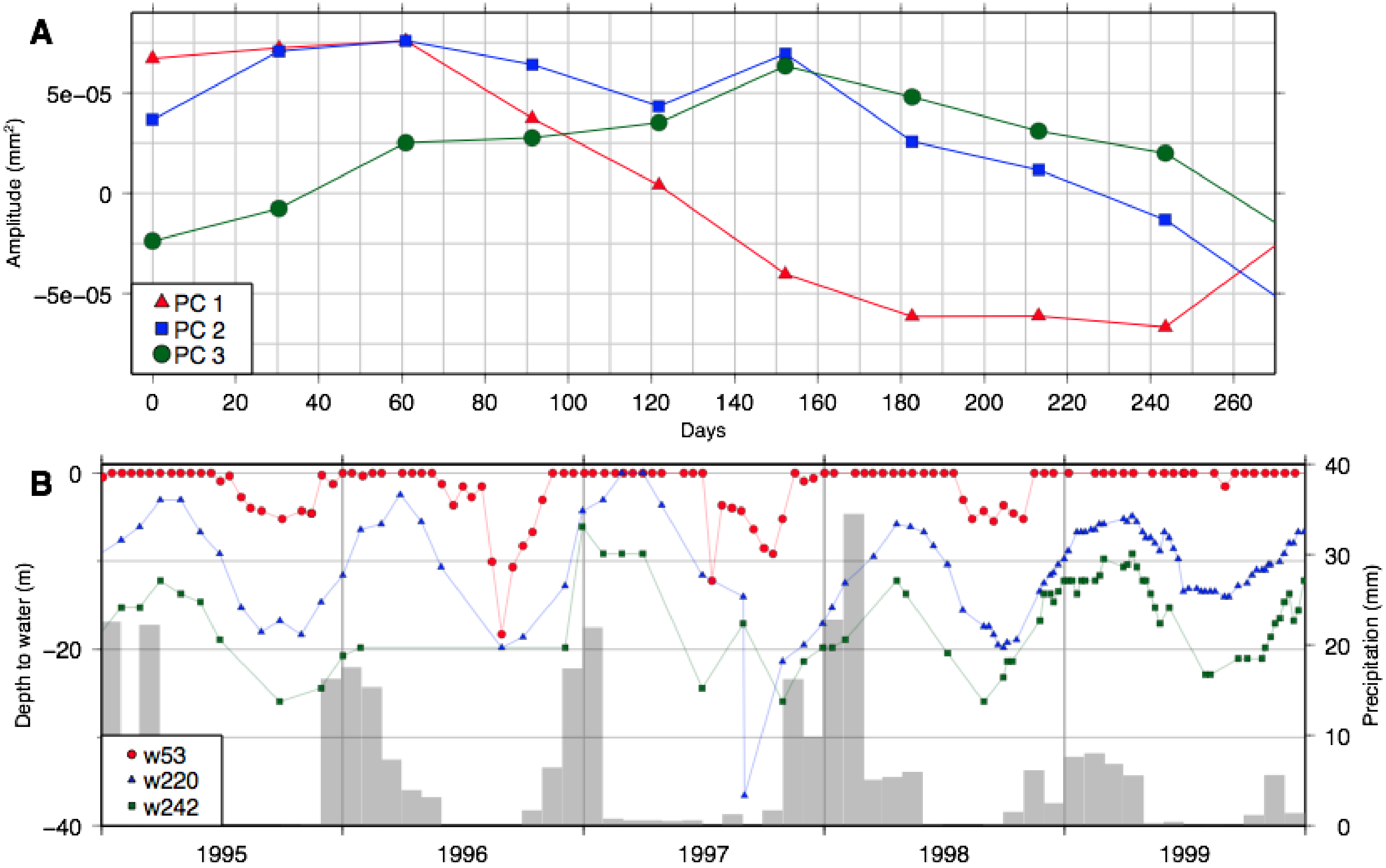
V(x)

U(t)

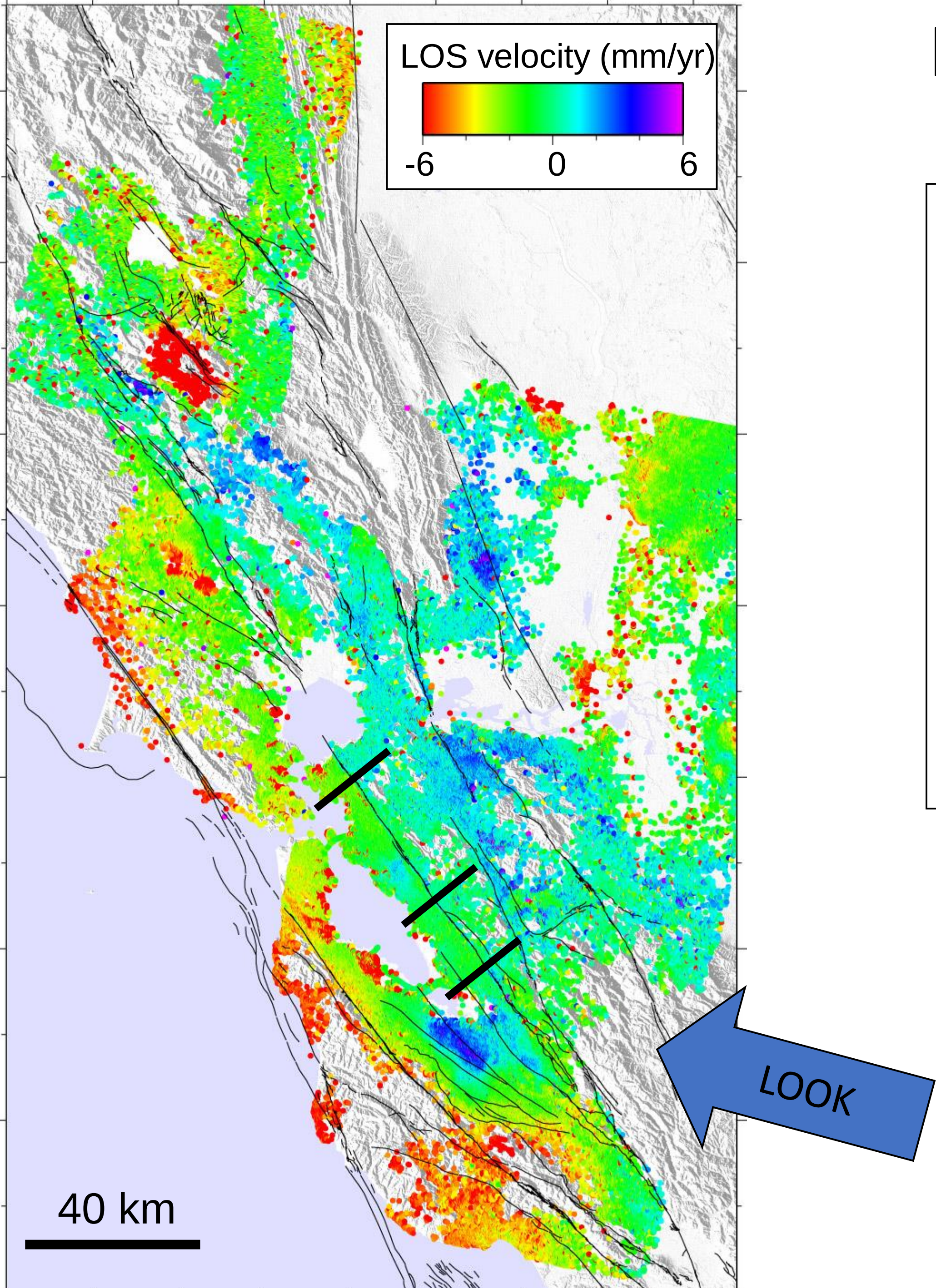
S

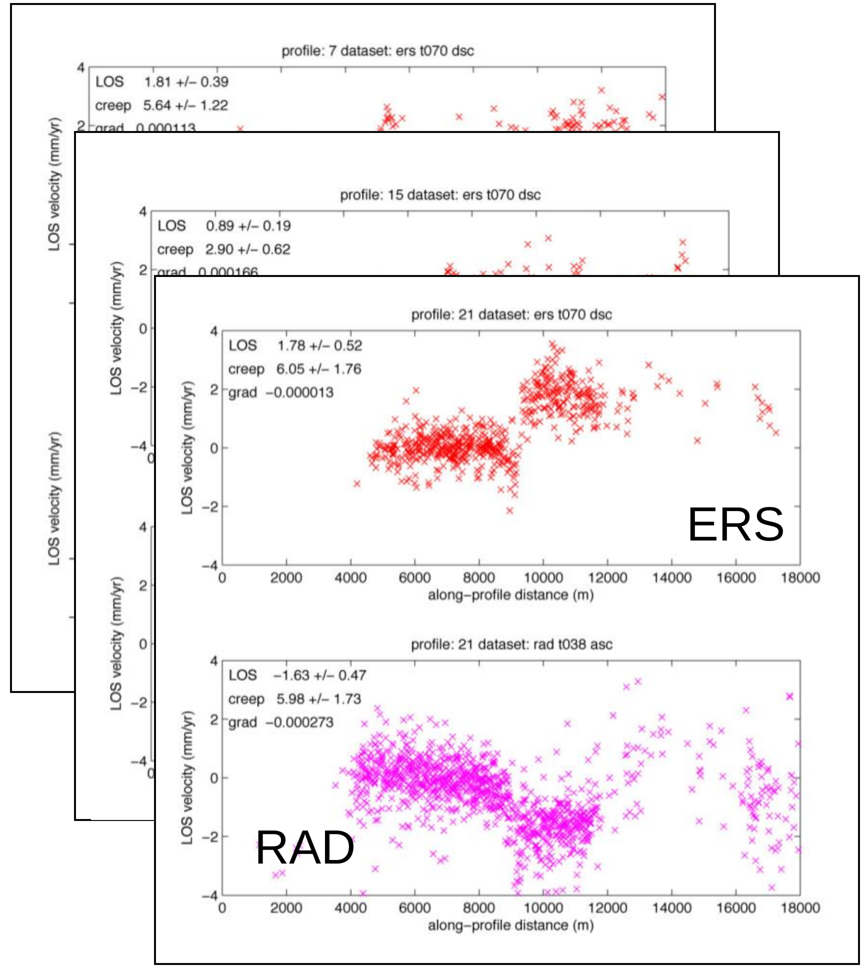


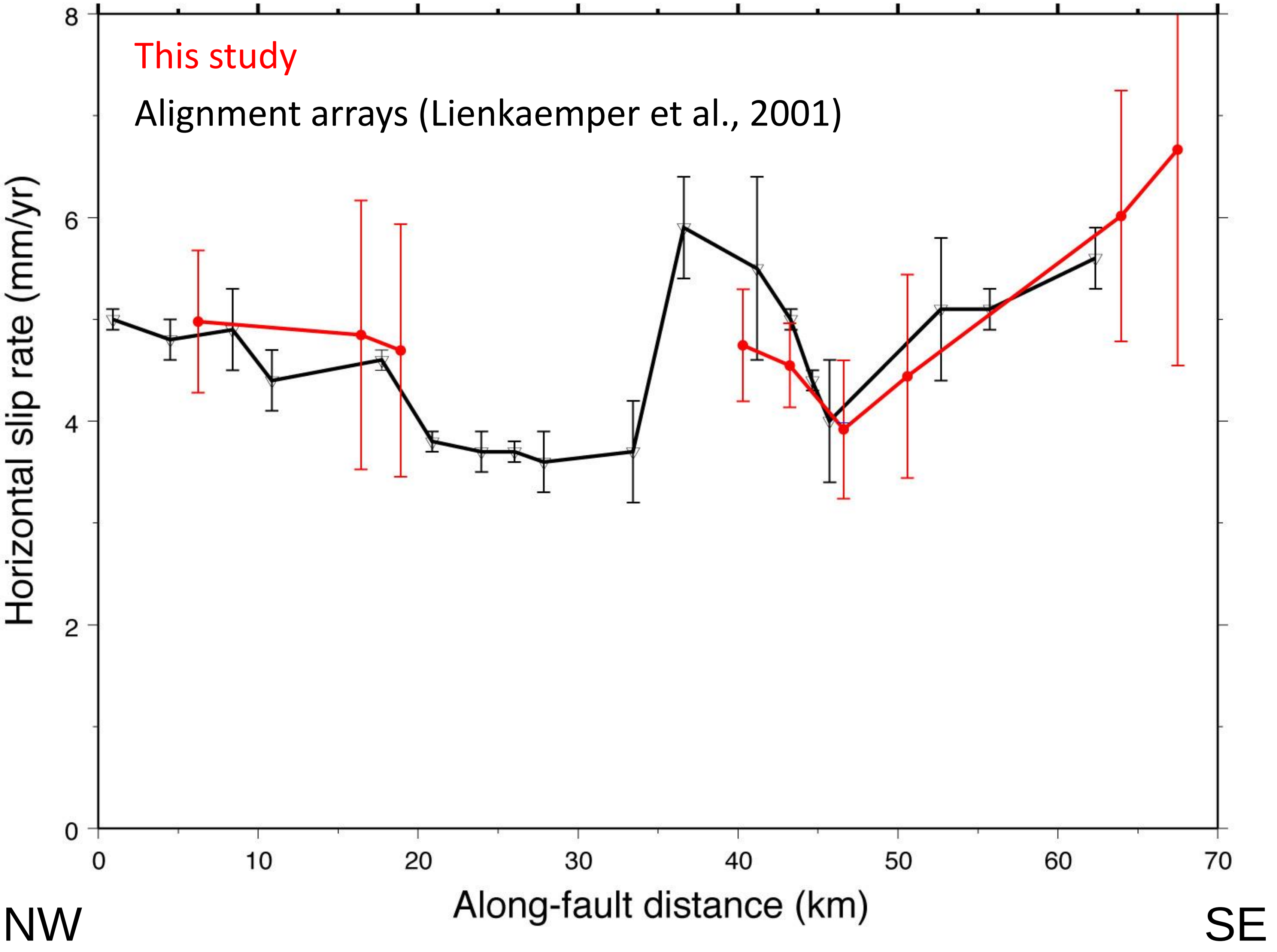
Principal components can be tied to well and precipitation data



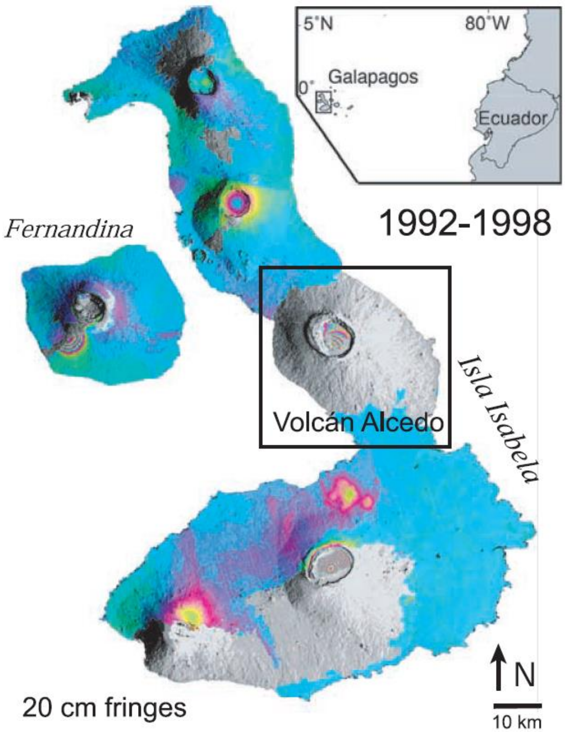
Hayward fault creep



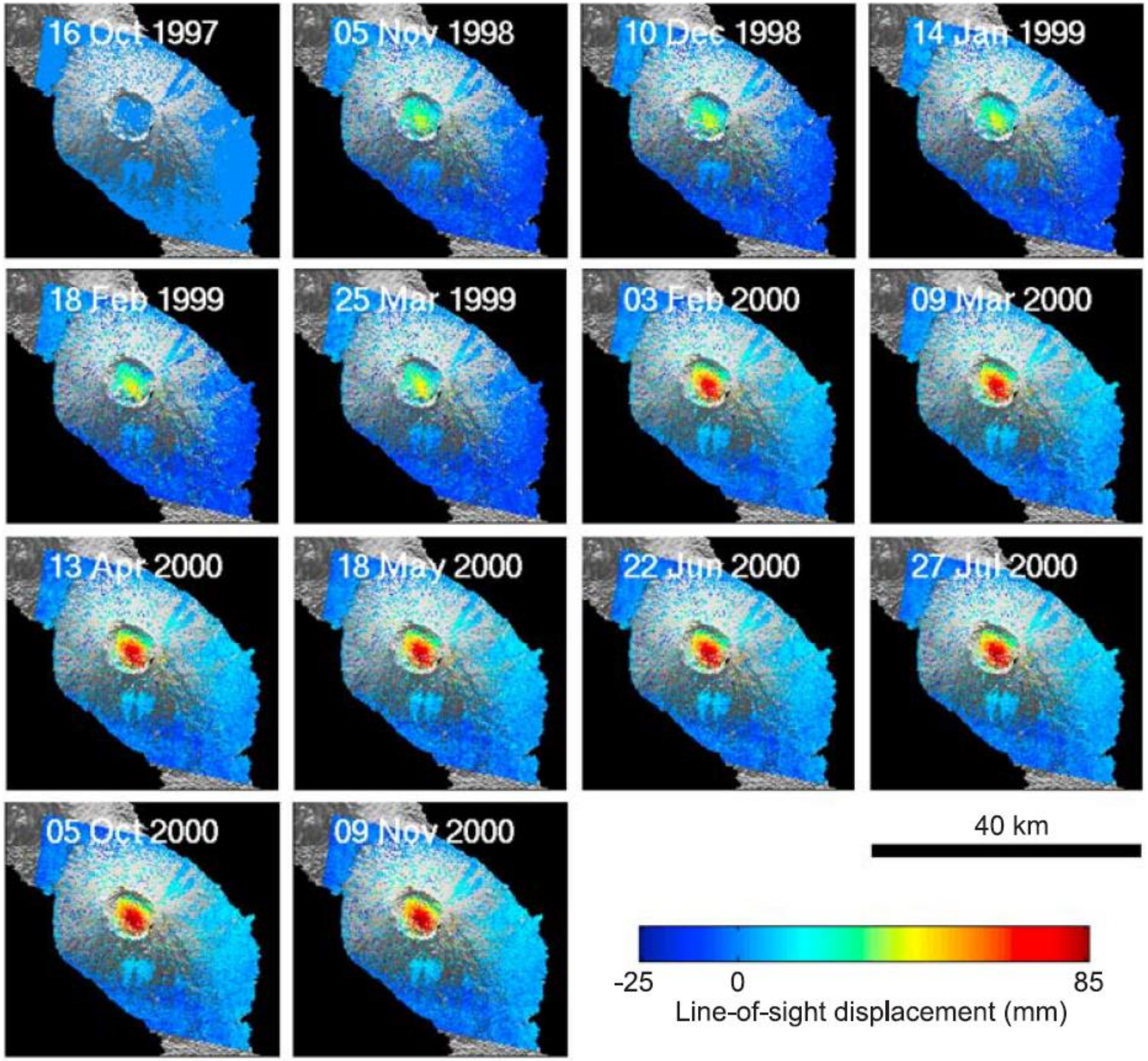



This study
Alignment arrays (Lienkaemper et al., 2001)
Horizontal slip rate (mm/yr)
0
2
4
6
8
0
10
20
30
40
50
60
70
Along-fault distance (km)
NW
SE

Volcan Alcedo, Galapagos



Deflation/contraction in the caldera over three year period



Hooper, 2007

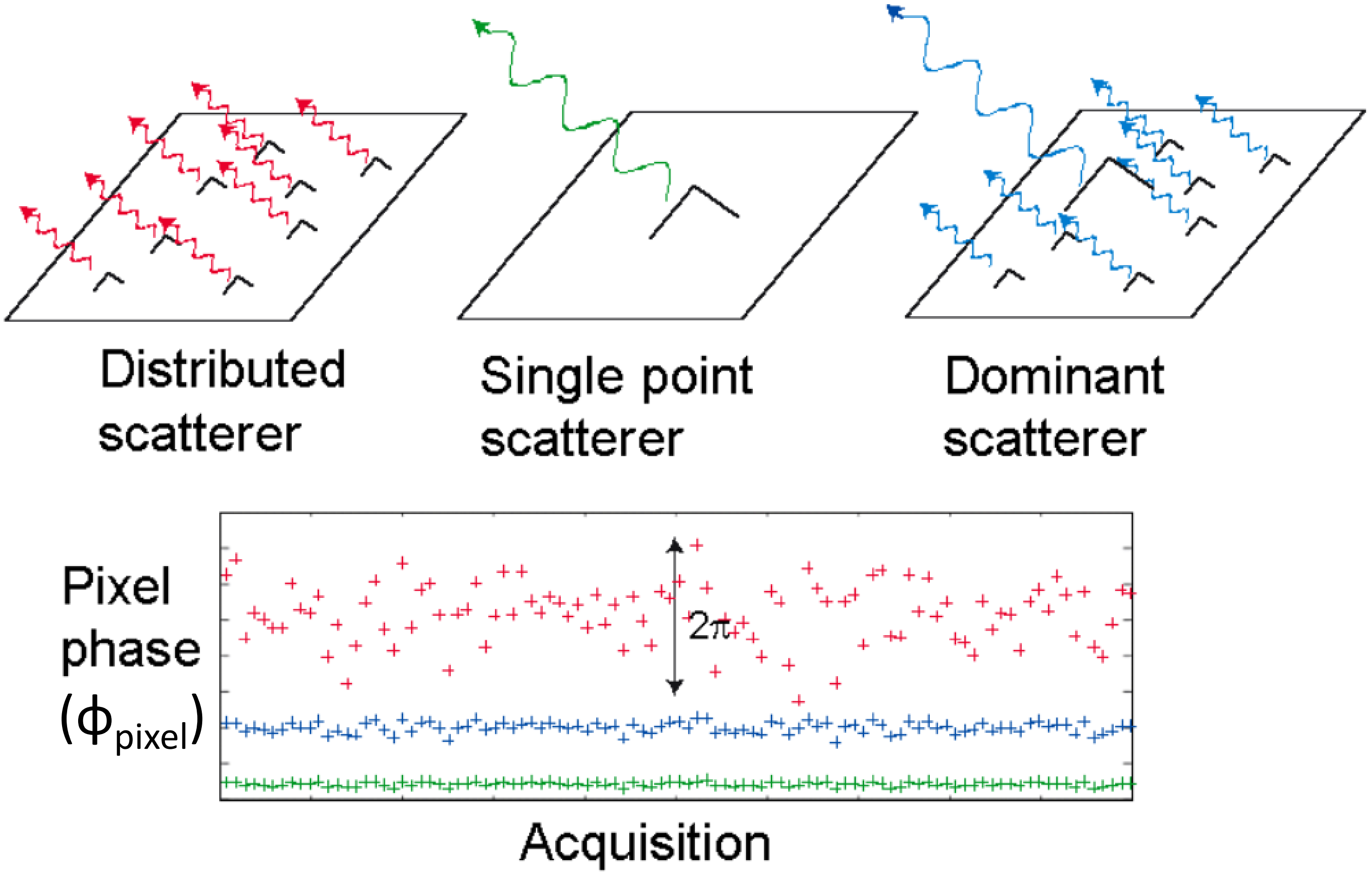
Persistent Scatterer InSAR

Persistent/Permanent Scatterer InSAR (PSI) offers a means to overcome these problems

- It relies on pixels that maintain coherence (hence the term 'persistent scatterer') and thus maximizes the number of observations
- It uses the idea that deformation signals are correlated over time…
- …and that atmospheric signals are correlated in space, but uncorrelated in time, as a means of separating the two

Characteristics of PS

PS are pixels with a single or dominant radar scatterer



PSI: the basics

- Typically need a minimum of 25 SAR images
- All images are coregistered; a multi-image amplitude map is made
- Interferograms are made with respect to a common master (in the center of baseline/time space)
- PS candidates are selected on the basis of high, stable amplitude
- Phase of the PS candidates is used to estimate a best pixel height/velocity, considering pairs of points
- Atmospheric 'phase screen' estimated from residuals

PSI: the basics

First, coregister every SAR image (SLC) to a common master image

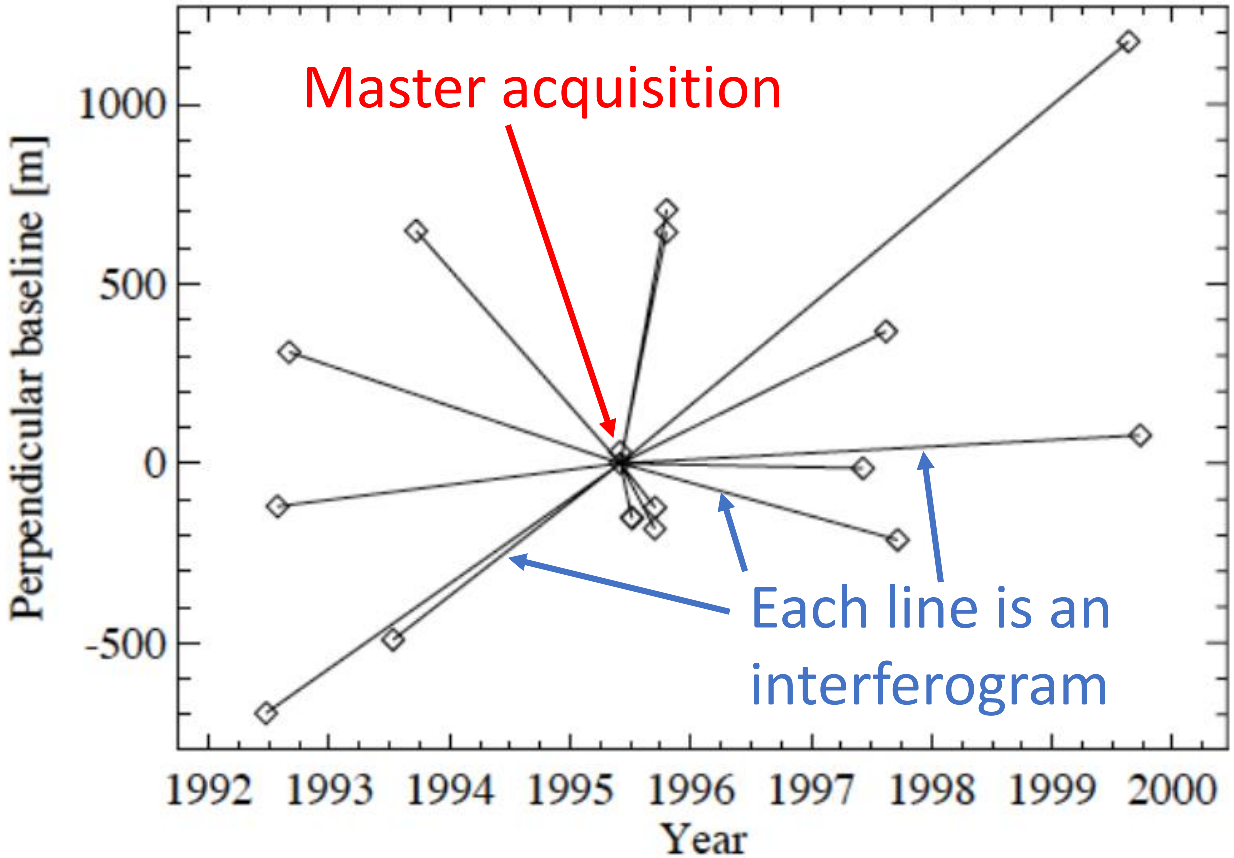


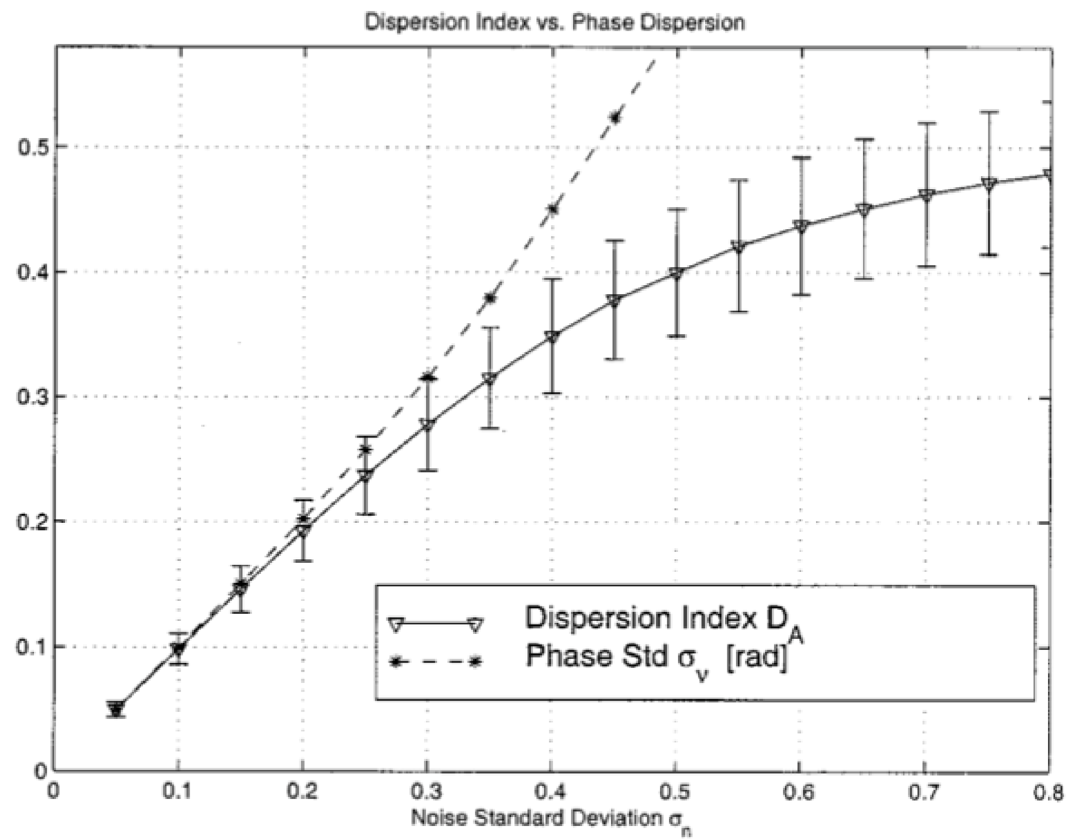
Image: Lauknes et al. (2008)

PSI: the basics

Ferretti et al. (2001) showed that bright radar scatterers had consistent pixel phase over time

Amplitude dispersion, D, is a measure of amplitude variation

Phase std. dev. is a measure of phase variation

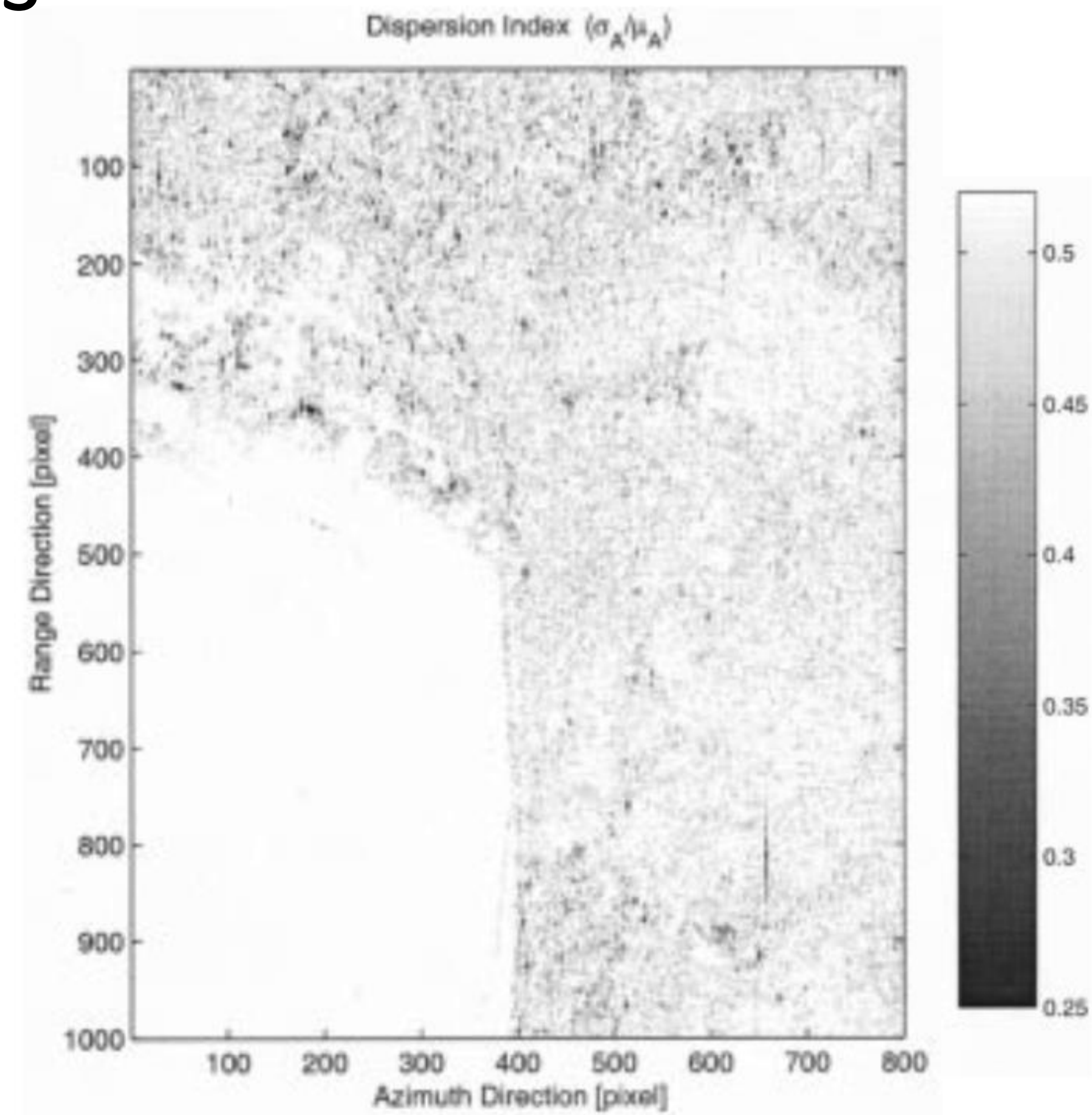


Ferretti et al., 2001

PS candidates

Thus, the search for 'good' pixels is reduced to a (easier) search for consistently radar-bright pixels

These are referred to as 'PS candidates'



Ferretti et al., 2001

Phase-stable targets

Examples of the most common phase stable targets:

Roof

Dihedral (wall+ground)

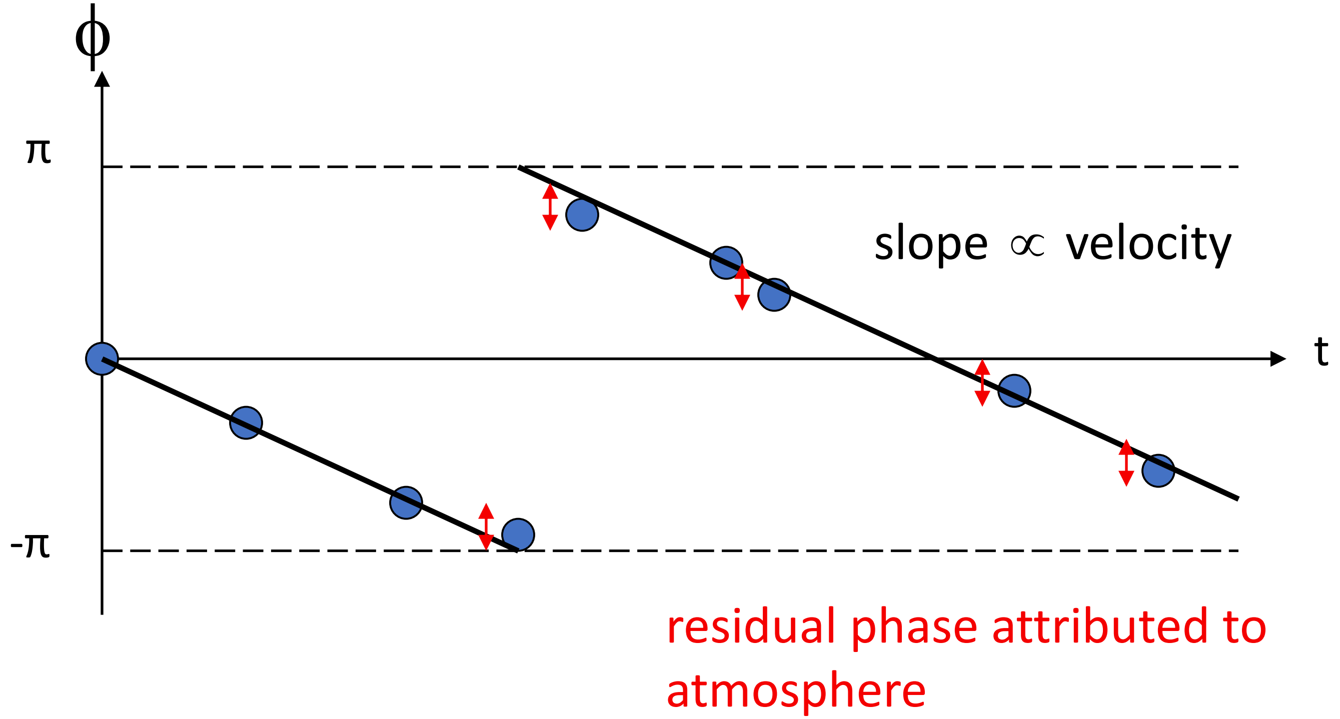
Pole

Trihedral (2 walls+ground)

Perissin *et al.*, 2005, *Proc. 4th Ann. FRINGE Meeting*

Unwrapping in time

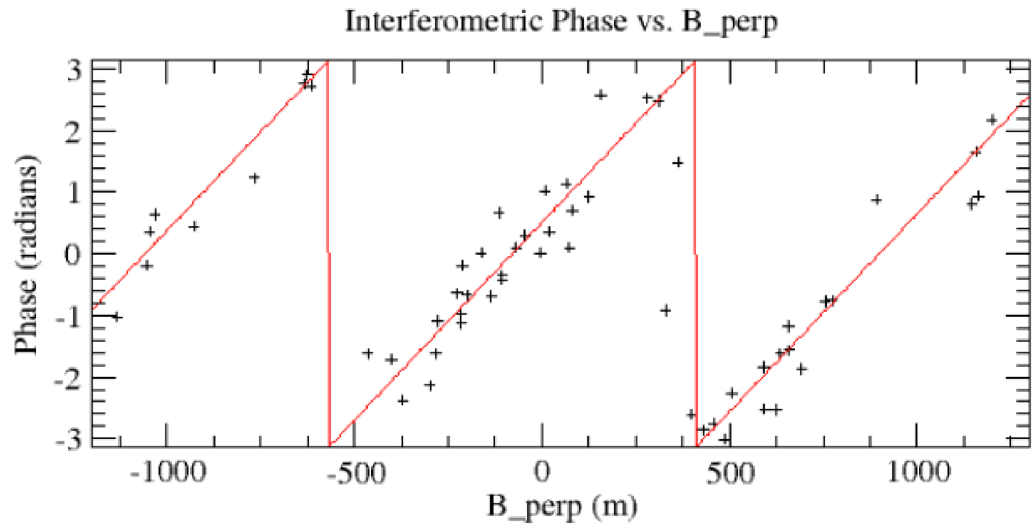
If we expect a particular behavior with time, we can unwrap the phase (and estimate the noise as whatever is left)

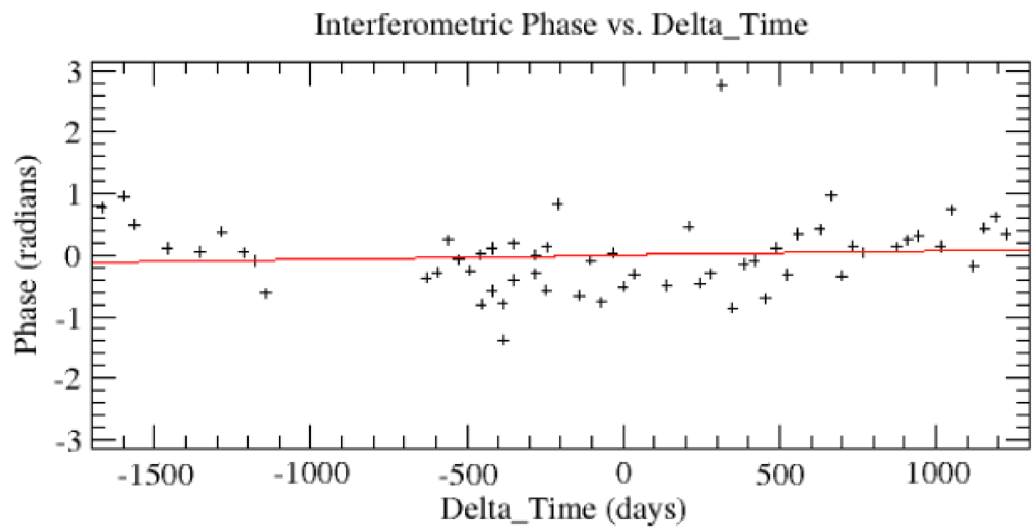


Unwrapping the phase

In the Ferretti PS analysis, phase is unwrapped in time

The relative phase for a pair of points is unwrapped by finding the combination of scatterer height and velocity that best fits the wrapped time/baseline series



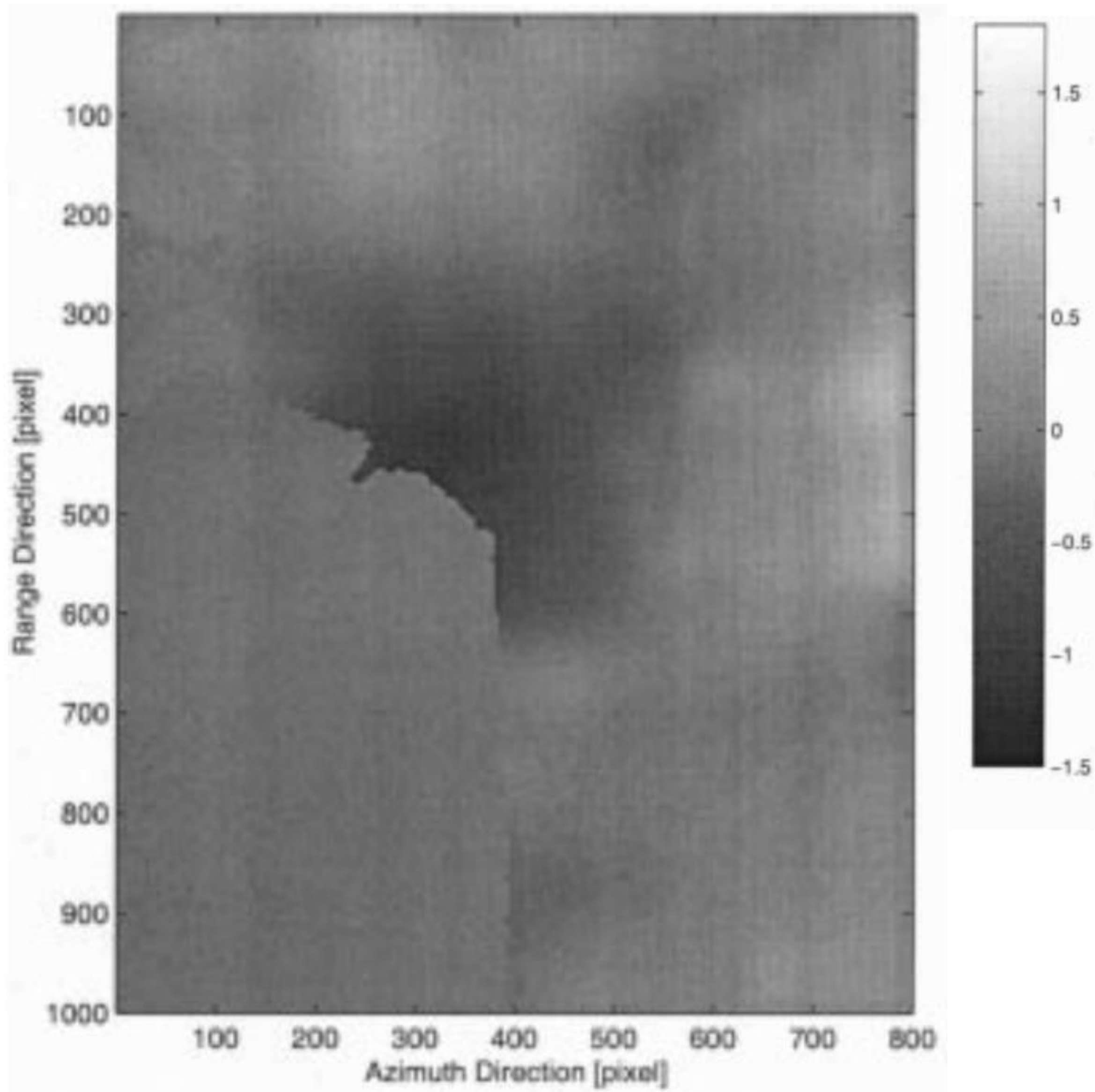


The atmospheric phase screen

The APS is made by kriging (interpolating) the residuals to the velocity/height fit

It is a prediction of the atmospheric phase in a given interferogram

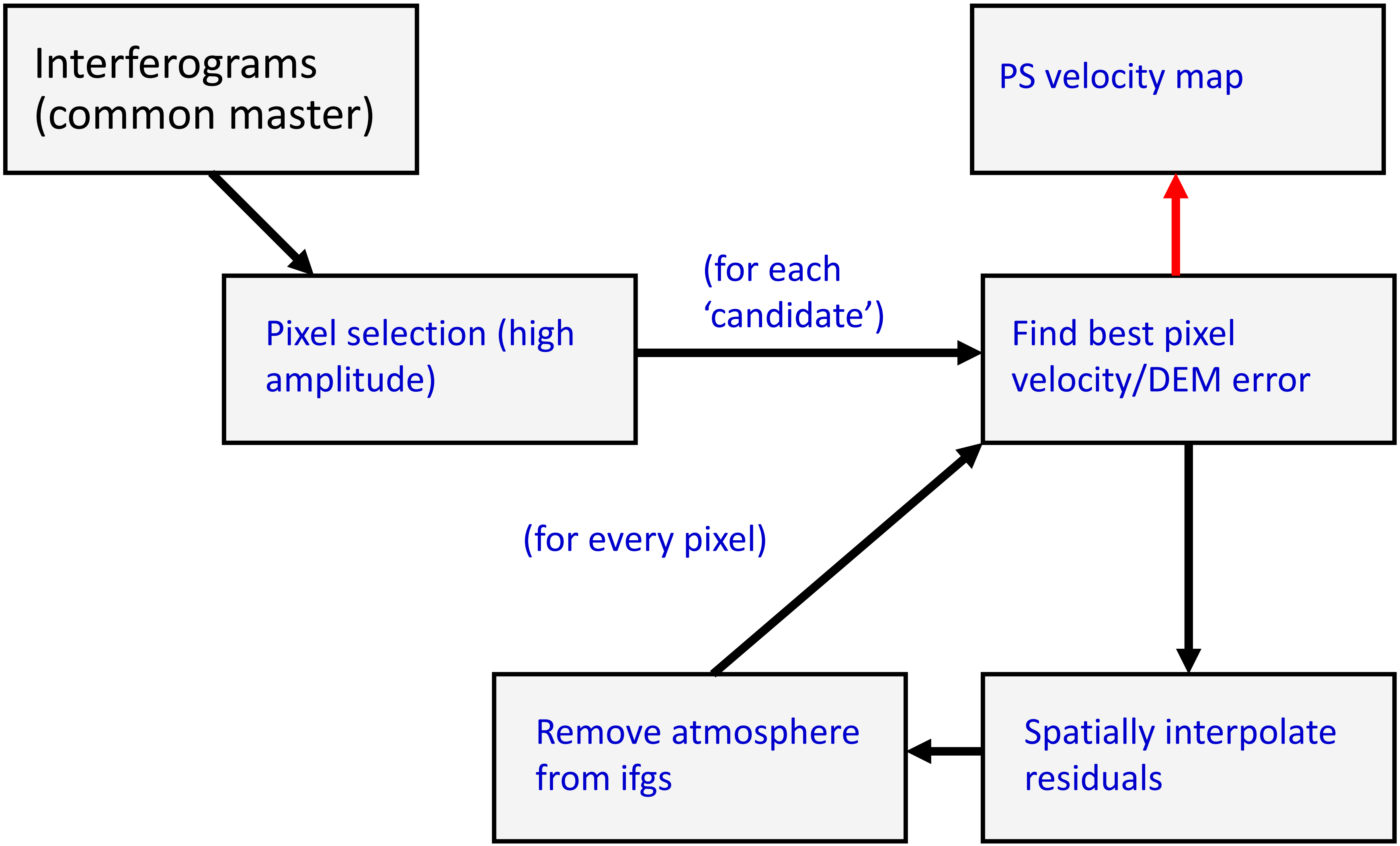
Such estimates can be subtracted from all interferograms



PSI: step two

- Atmospheric phase screens subtracted from all interferograms
- Velocity/scatterer height estimation repeated for every single pixel (not just the high amplitude ones)
- Pixels with phase stability within a specified threshold are considered permanent scatterers (PS)
- Typically get 100-1000x more PS than PS candidates

PSI methodology



Advantages of PSI

- Mitigates effect of atmospheric noise on data

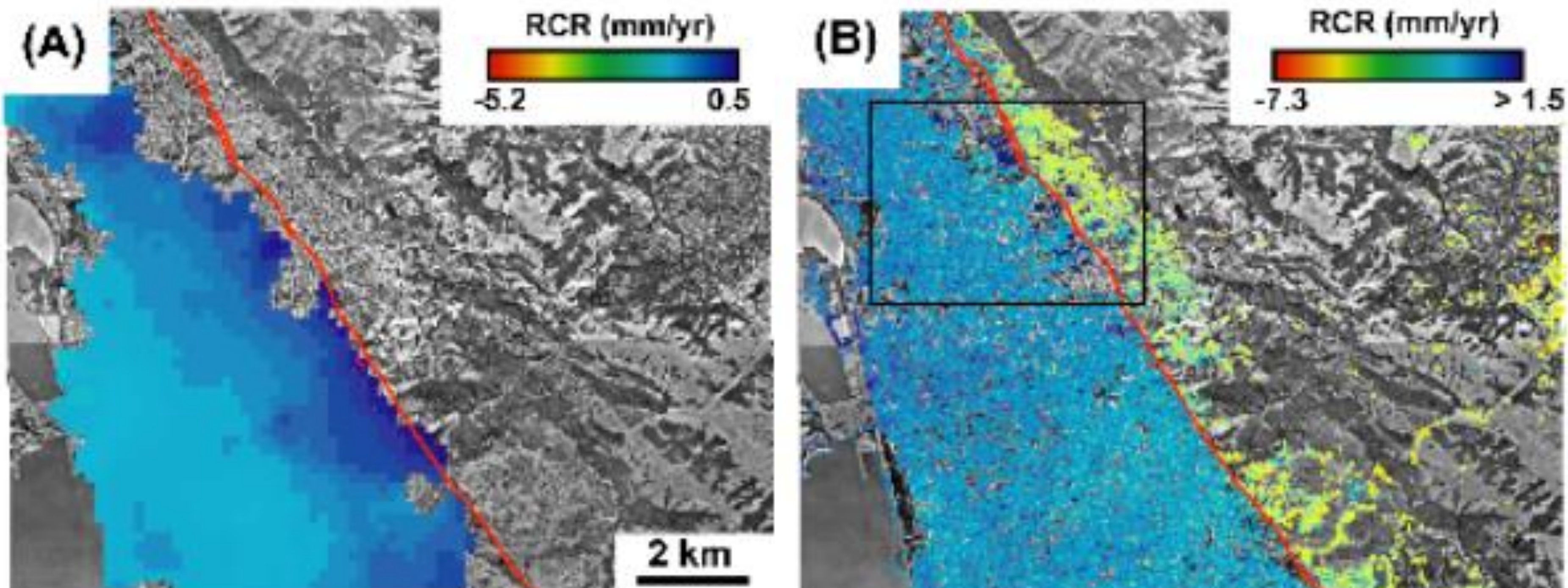
  => High precision in velocity estimates

- Maximizes number of observations with time
- As a scatterer is often smaller than a full SAR pixel, can increase the range of useable baselines (important for legacy satellites, not so important now)
- Does not require stable pixels to be adjacent to each other – each pixel can be identified independently

More coverage in vegetated areas

Interferogram stack (Schmidt et al., 2005)

PSI



PSI gives better coverage in the heavily vegetated East Bay Hills

But is it overkill?

PSI is very successful at recovering detailed information, especially in areas where InSAR is marginal, but it is very computationally expensive

- It assumes that each pixel is independent, but we know that most geophysical signals of interest are correlated spatially

- It does not make use of spatial unwrapping

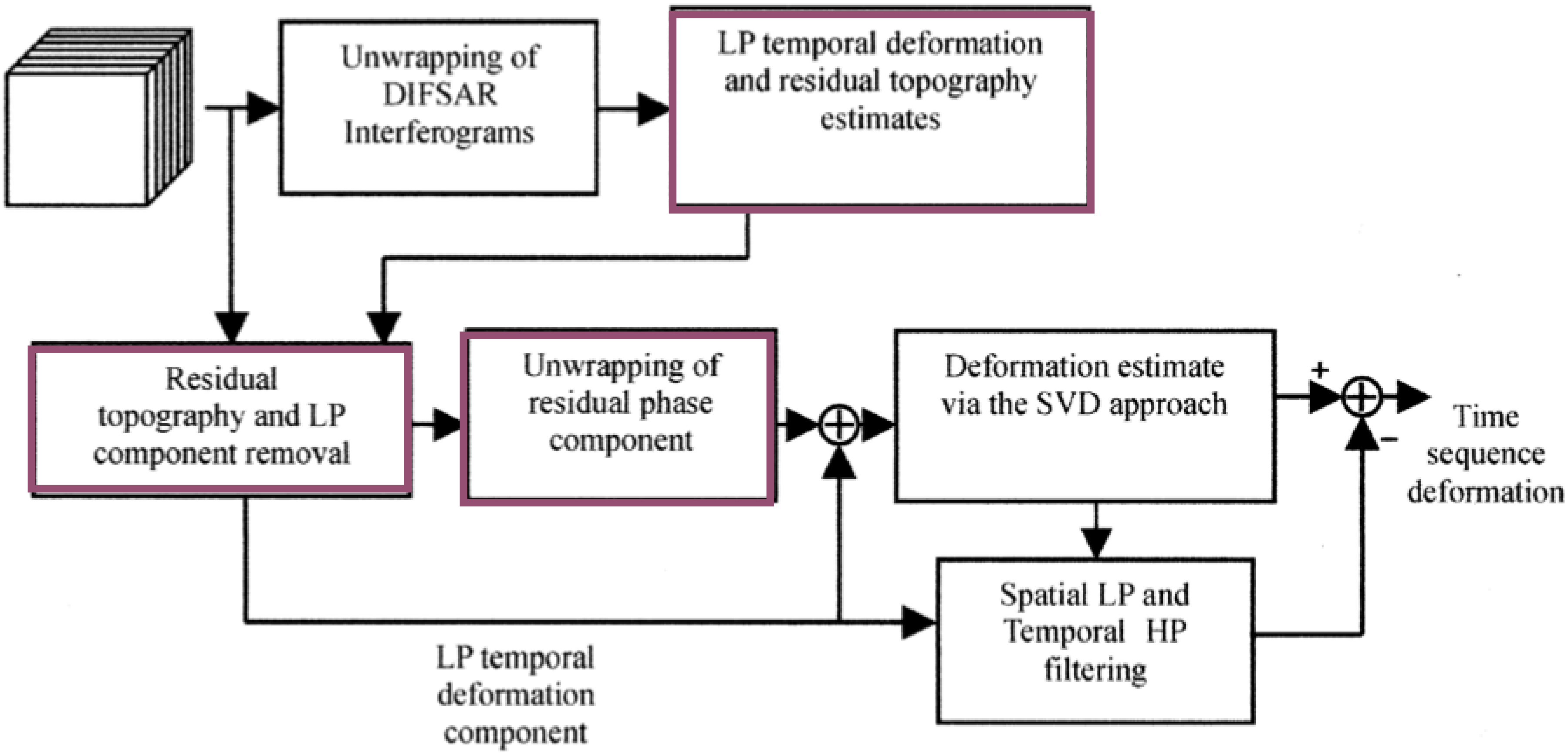
SBAS

The **S**mall **BA**seline **S**ubset algorithm (SBAS) was proposed by Berardino et al. (2002) as a means of making use of spatially correlated information and time series approaches

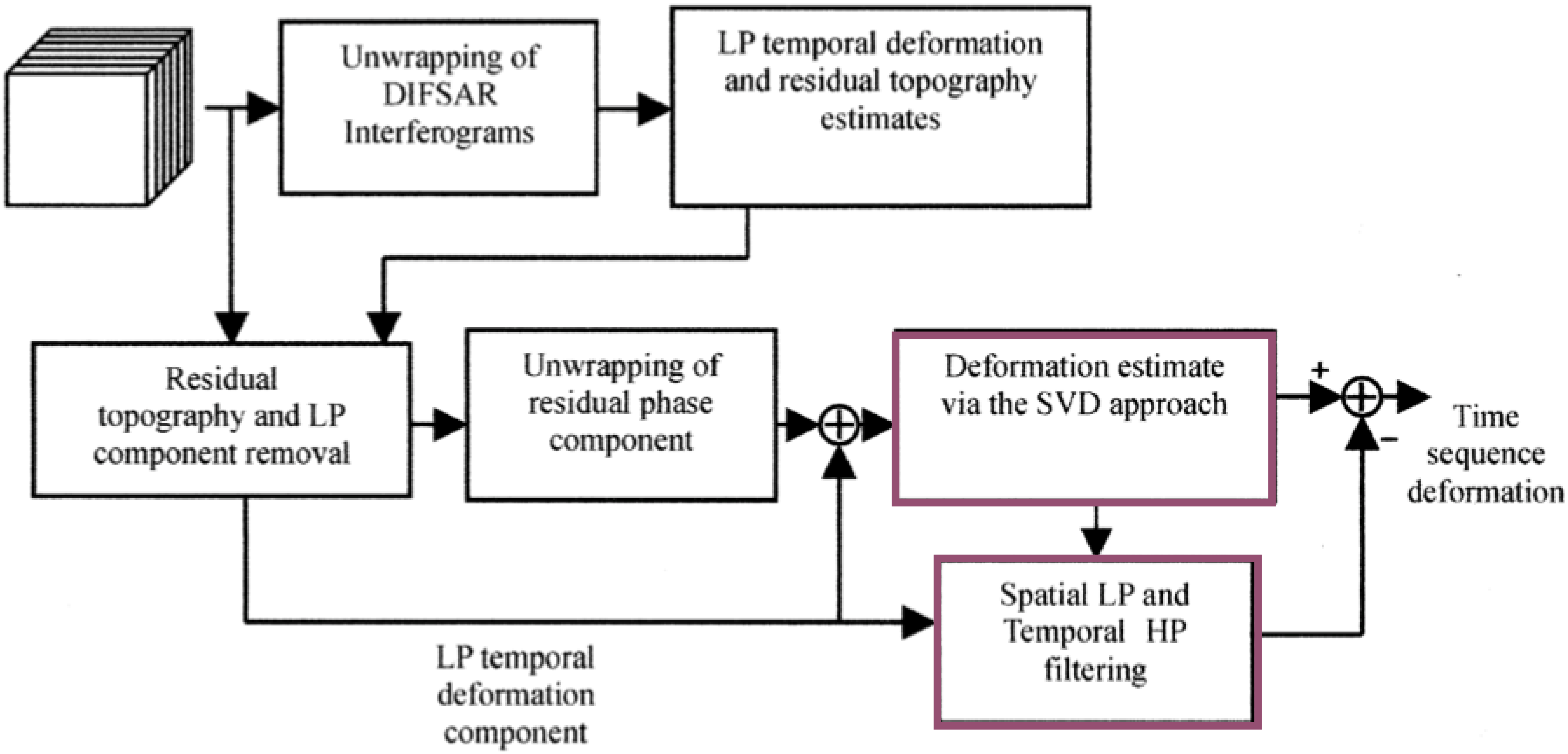
- Only pairs of images with short spatial baselines are used

- Interferograms are unwrapped in space first

- Pixel phase time series are estimated by a smoothed inversion (similar process to Schmidt & Burgmann, 2003)



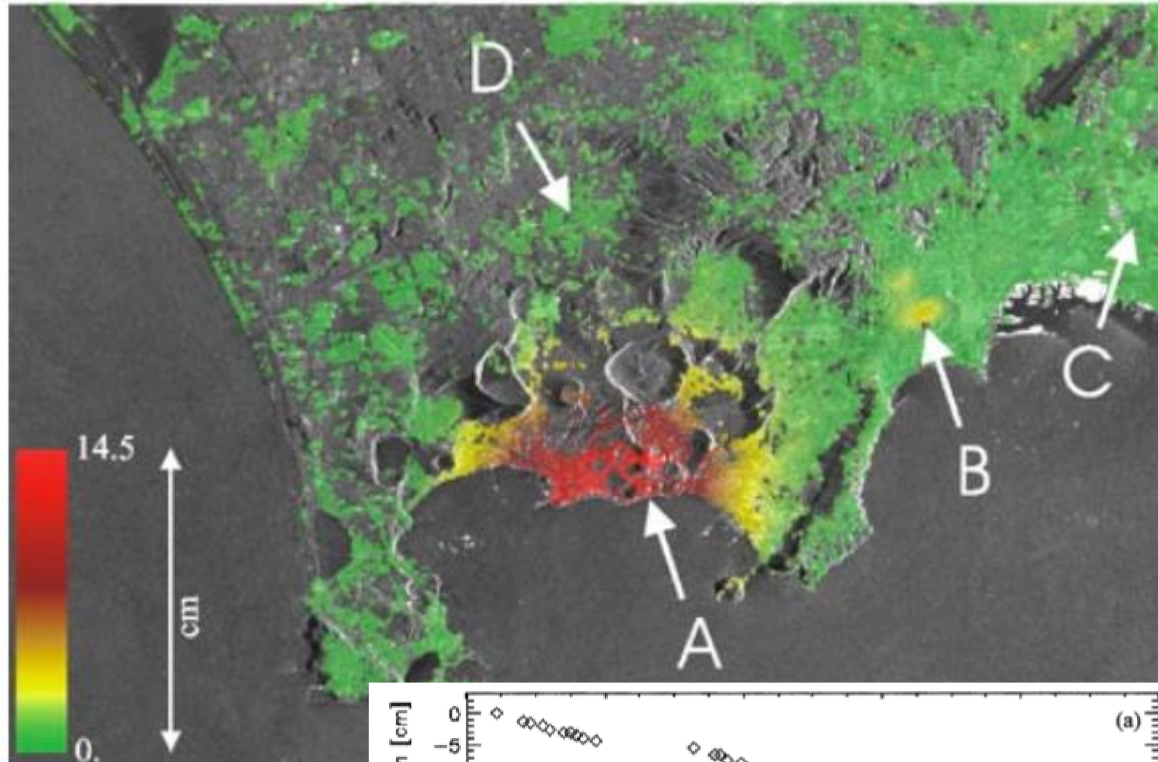
A low pass (LP) estimate of the deformation is subtracted from the deformation before unwrapping (it is added back later) – this reduces the likelihood of unwrapping errors

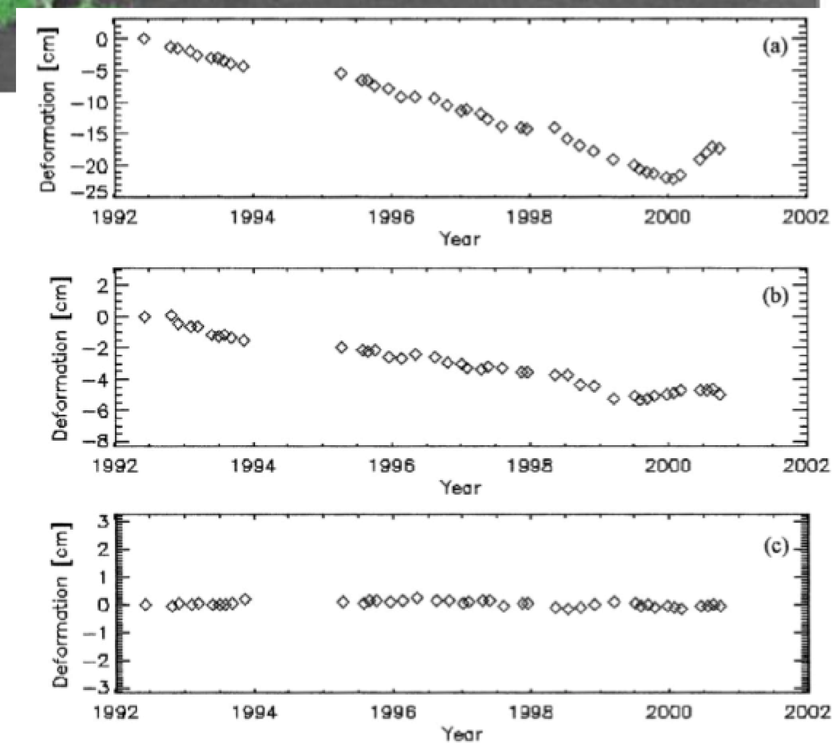


Deformation rates are estimated using a constrained (somewhat smoothed) SVD approach

Atmosphere contributions are estimated in a similar manner to the PSI approach

Deformation in Naples





The deformation need not be linear in velocity, or have a prescribed form

Berardino et al., 2002

So, which should I use?

PSI

- Good for monitoring of infrastructure and buildings (where high pixel resolution is necessary)
- Areas with isolated targets surrounded by vegetation
- Small spatial scales
- Usually requires processing interferograms yourself
- Computationally very expensive

SBAS

- Good for geophysical/tectonic applications (large spatial coverage needed, high resolution less important)
- Can use processed, unwrapped interferograms
- Computation is less expensive

Freely-available codes

A number of groups have implemented versions of the PSI and SBAS algorithms (or both)

GIAnT (Generic InSAR Analysis Tools; Agram et al., 2013) is a set of Python-based tools for time series analysis of unwrapped interferograms, includes SBAS

PySAR (Yunjun et al., 2018) is another Python-based SBAS code that uses unwrapped interferograms

StaMPS (Stanford Method for Persistent Scatterers; Hooper et al., 2004; Hooper, 2008) incorporates both PSI and SBAS approaches, but requires interferogram processing