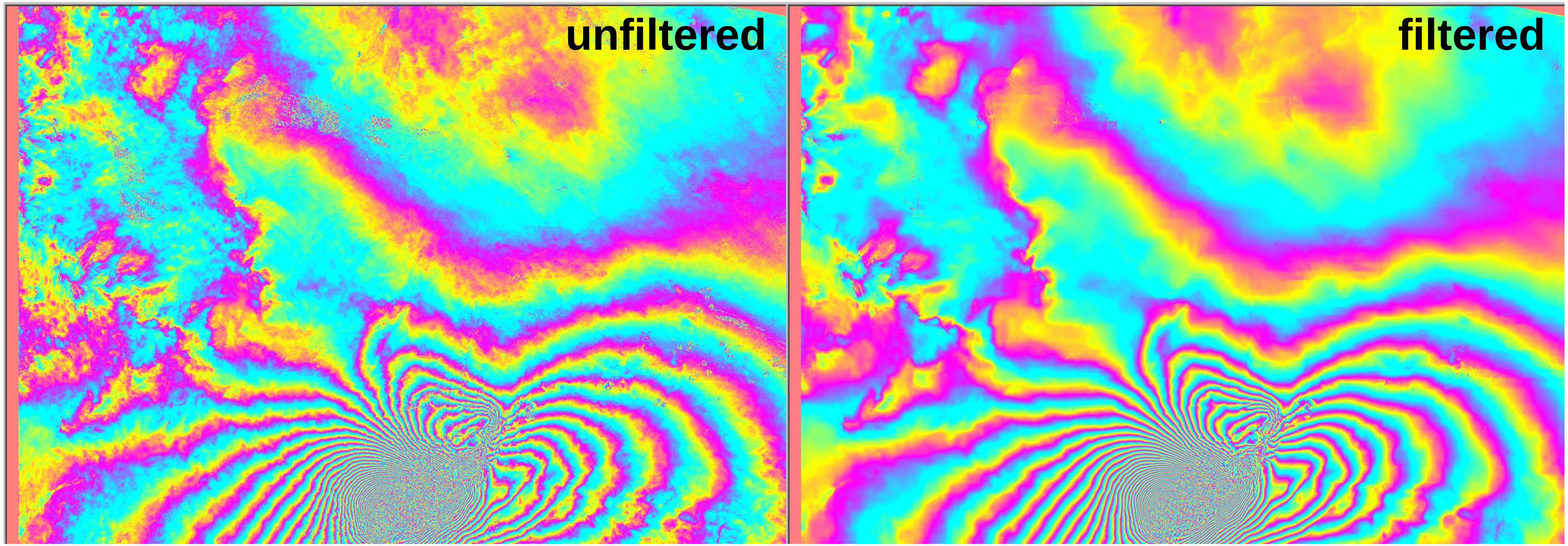
InSAR training 2024



InSAR data processing

Differential InSAR (DInSAR)

$$\boxed{\Delta\phi_{\text{int}} = \cancel{\Delta\phi_{\text{orb}}} + \cancel{\Delta\phi_{\text{topo}}} + \Delta\phi_{\text{atm}} + \Delta\phi_{\text{pixel}} + \Delta\phi_{\text{def}}}$$

A differential interferogram is one in which the effects of orbital baselines and topography have been removed

To most scientists (if not most engineers) this removal is implicit when we talk about InSAR, but technically it should be called DInSAR!

(D)InSAR processing in practice

A typical processing chain will have multiple steps, usually (but not always) in this order:

1) Matching (coregistering) the SLCs
2) Forming the interferogram by differencing phases
3) Removing the effects of orbit position, Earth curvature and topography
4) Multilooking, filtering and unwrapping
5) Geocoding

InSAR processing software

ISCE (InSAR Scientific Computing Environment): Next generation JPL/NASA software (free, up to date)

GMTSAR: Developed at Scripps, built on top of GMT (free, up to date)

SNAP (Sentinel Application Platform): ESA-supported software (free, up to date, easy to install but clunky to use)

ROI_PAC (Repeat Orbit Interferometry Package): 2000s-era JPL code (works with legacy data, free but defunct)

GAMMA: Commercial package from one of the original ROI_PAC developers (up to date, solid support, but expensive)

SARPROZ: Commercial, MATLAB-based code (I have no experience with it)

Coregistering SLC images

A critical stage of the processing is the matching of the two SLCs

- Unless the images are correctly coregistered, so that the same pixels in the reference and secondary are directly overlaid on each other, differencing of the phase will not work

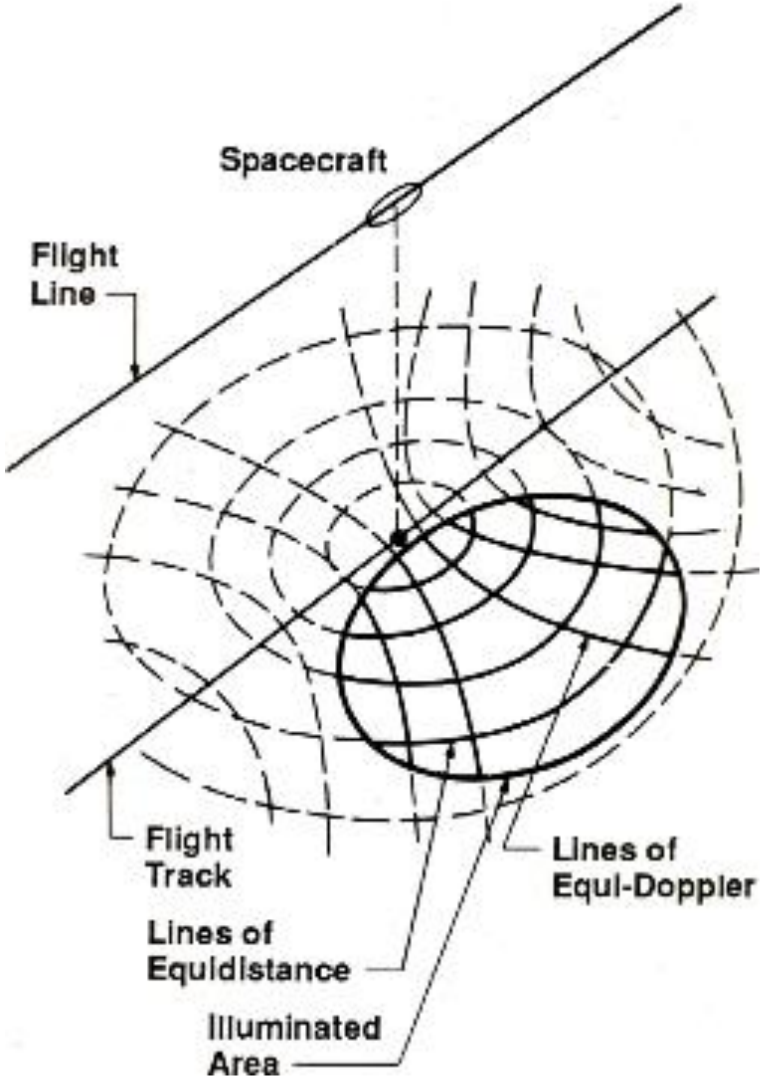
Modern generation software packages (e.g. ISCE) register the reference SLC to a digital elevation model (DEM) first, and then the secondary image to the reference – this helps to avoid distortions and decorrelation from steep topographic slopes

Registering the reference SLC to the DEM

With accurate orbit and timing information, we know where the satellite was when each pixel of the radar image was measured

We also know the range (distance) to each pixel, and the Doppler shift of the radar for each pixel

The combination of these things allows us to relate each specific pixel in the radar image to a specific pixel in the DEM

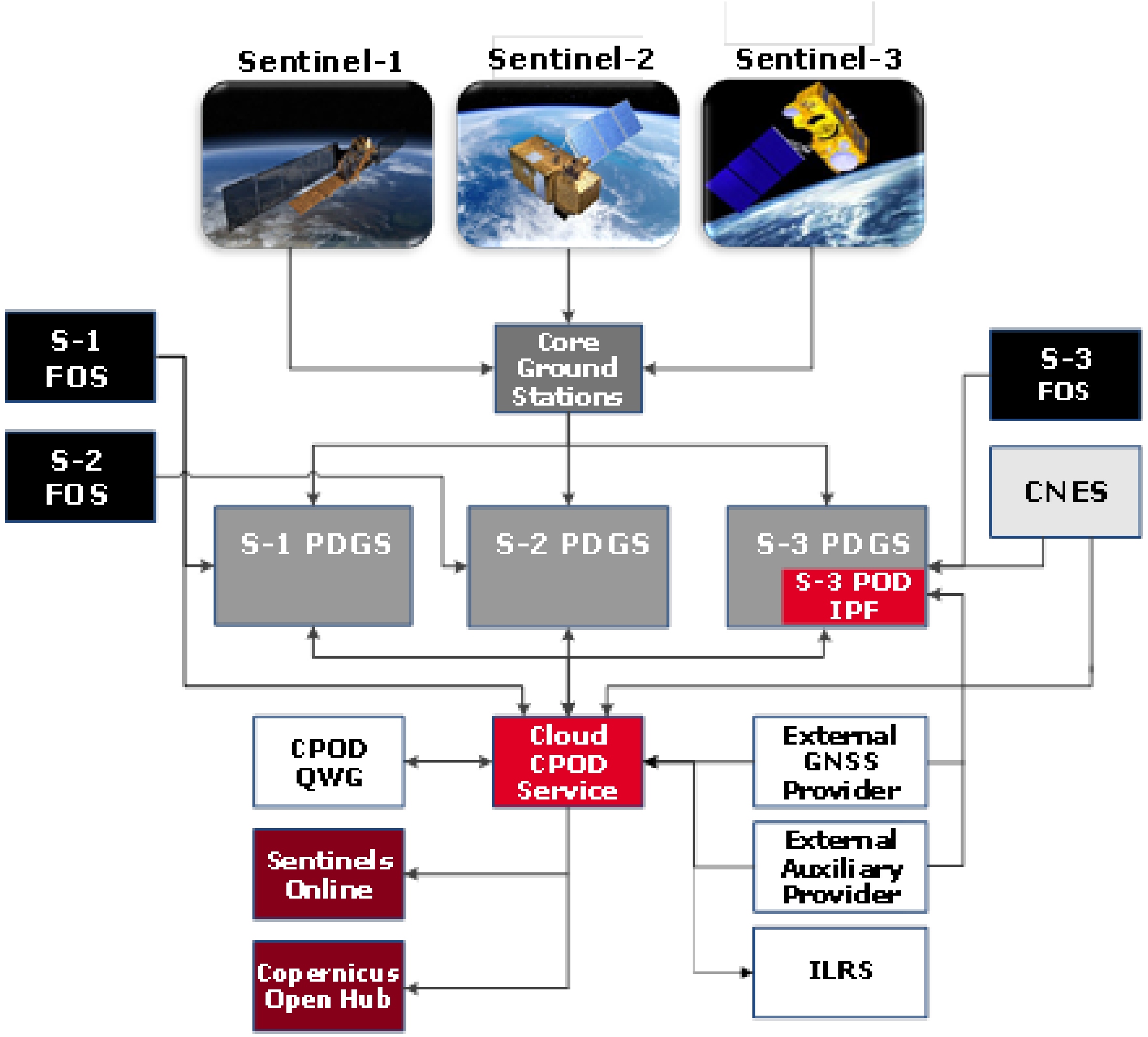


SAR image orbit information

InSAR, and satellite geodetic techniques in general (e.g. GPS/GNSS, altimetry, gravity) require precise orbit information

The main control on Sentinel-1 orbits is data from its onboard GNSS receiver

Precise orbits are made available after 20 days; preliminary ('restituted') orbits are available within hours

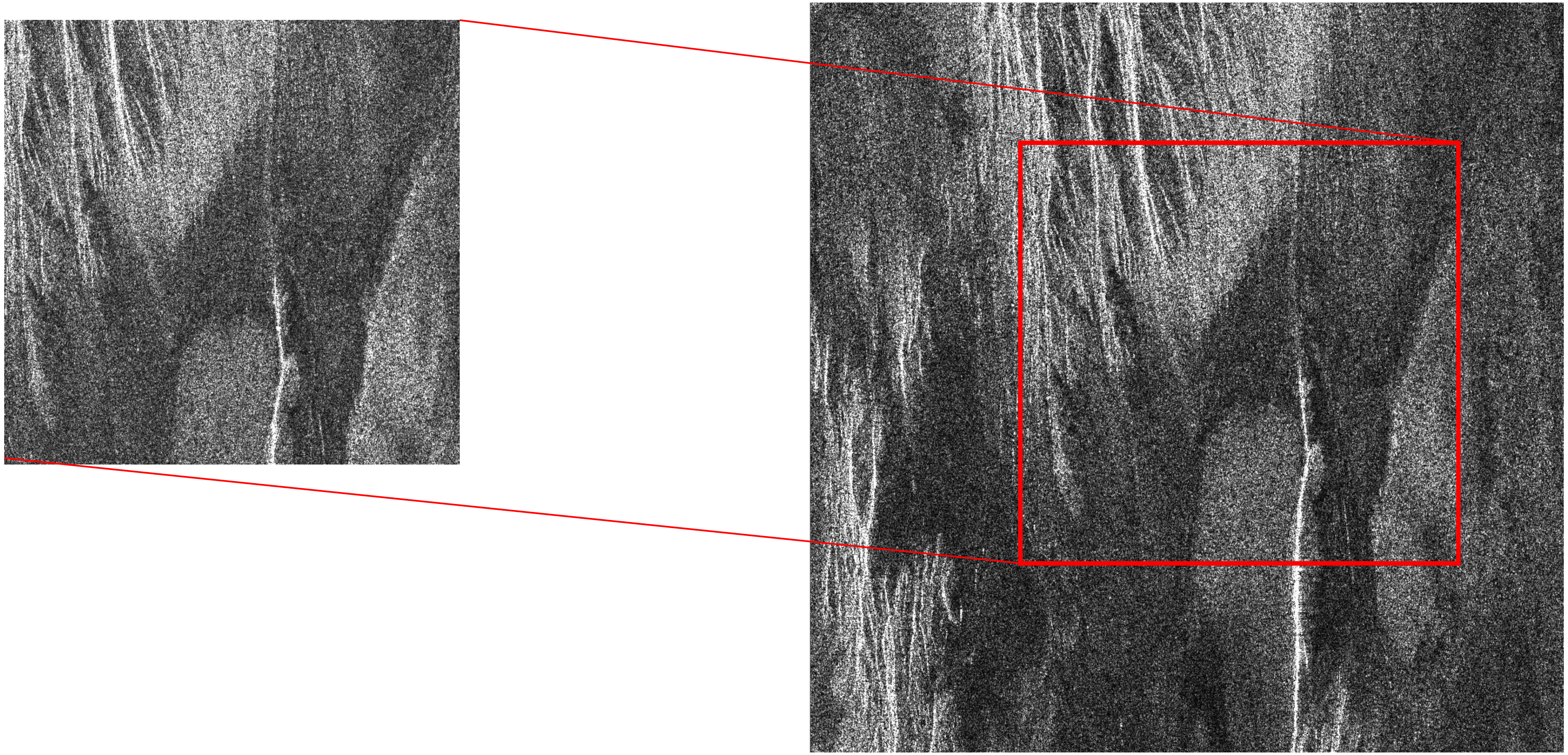


Measuring image offsets

A critical stage of the processing is the matching of the two SLCs –unless the images are correctly coregistered, the differencing of the phase will not work

This is achieved by cross-correlating subsets of the two images so that the shift between the two images can be estimated at multiple points between the images

Measuring image offsets



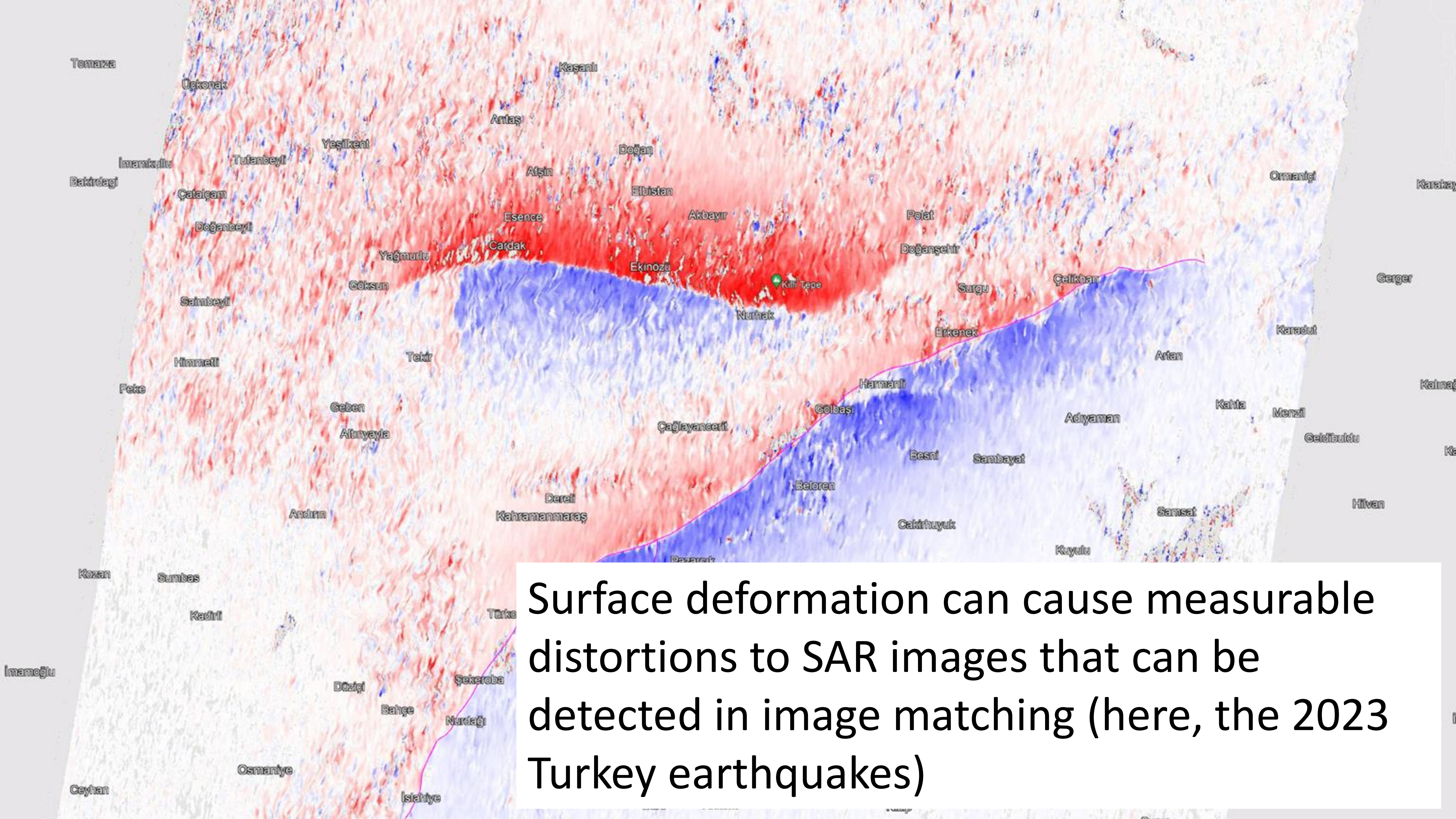
The subset of the secondary image is cross-correlated with the approximately corresponding area in the reference, within a certain tolerance

Measuring image offsets

This is typically achieved in the Fourier domain – it is quicker, and it also allows matching to be achieved to sub-pixel accuracy(!)

This is possible because, in effect, each image is a discrete sampling of a continuous function (the Earth's surface)…

…with a sufficient number of samples, we can match the shape of that continuous function, and we can do that with sub-pixel resolution



Surface deformation can cause measurable distortions to SAR images that can be detected in image matching (here, the 2023 Turkey earthquakes)

Forming the interferogram

Formally, an interferogram is formed by multiplying one SLC image by the complex conjugate of the other

Generally, an SLC image is represented by

$$S = A\ e^{i\phi}$$

If there are two SLCs, S_1 and S_2, the interferogram formed from them is given by

$$I = S_1 S_2^* = A_1 A_2 \exp(\phi_1 - \phi_2)i$$

(S_1 and S_2 are often referred to as the ‘reference’ and ‘secondary’ images)

Usually, we ignore the amplitude part, and concentrate on the phase difference,

$$\phi_1 - \phi_2 = \Delta\phi$$

Multilooking

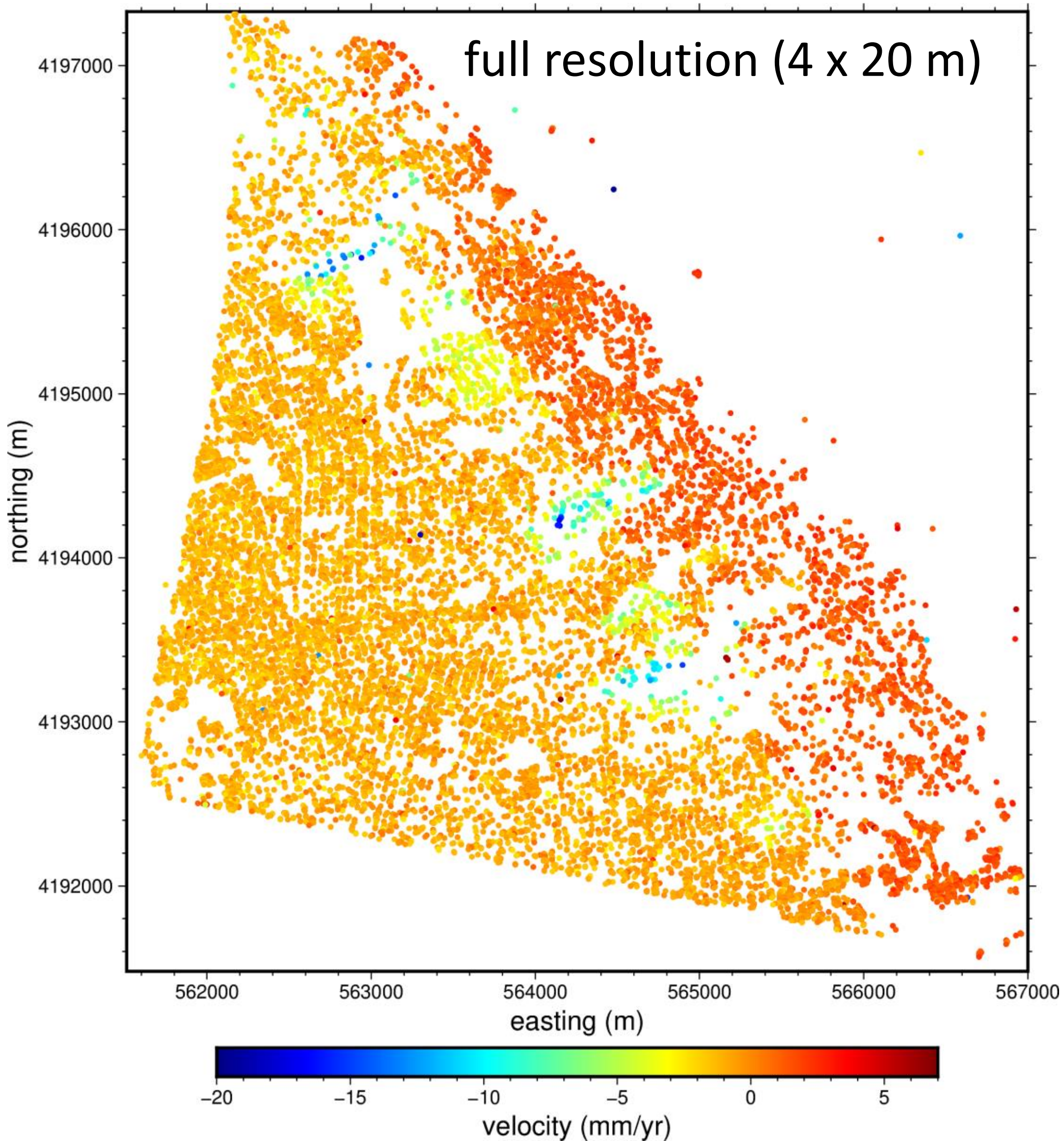
One way of amplifying signal is by averaging pixels together, known as multilooking or 'taking looks' of your data

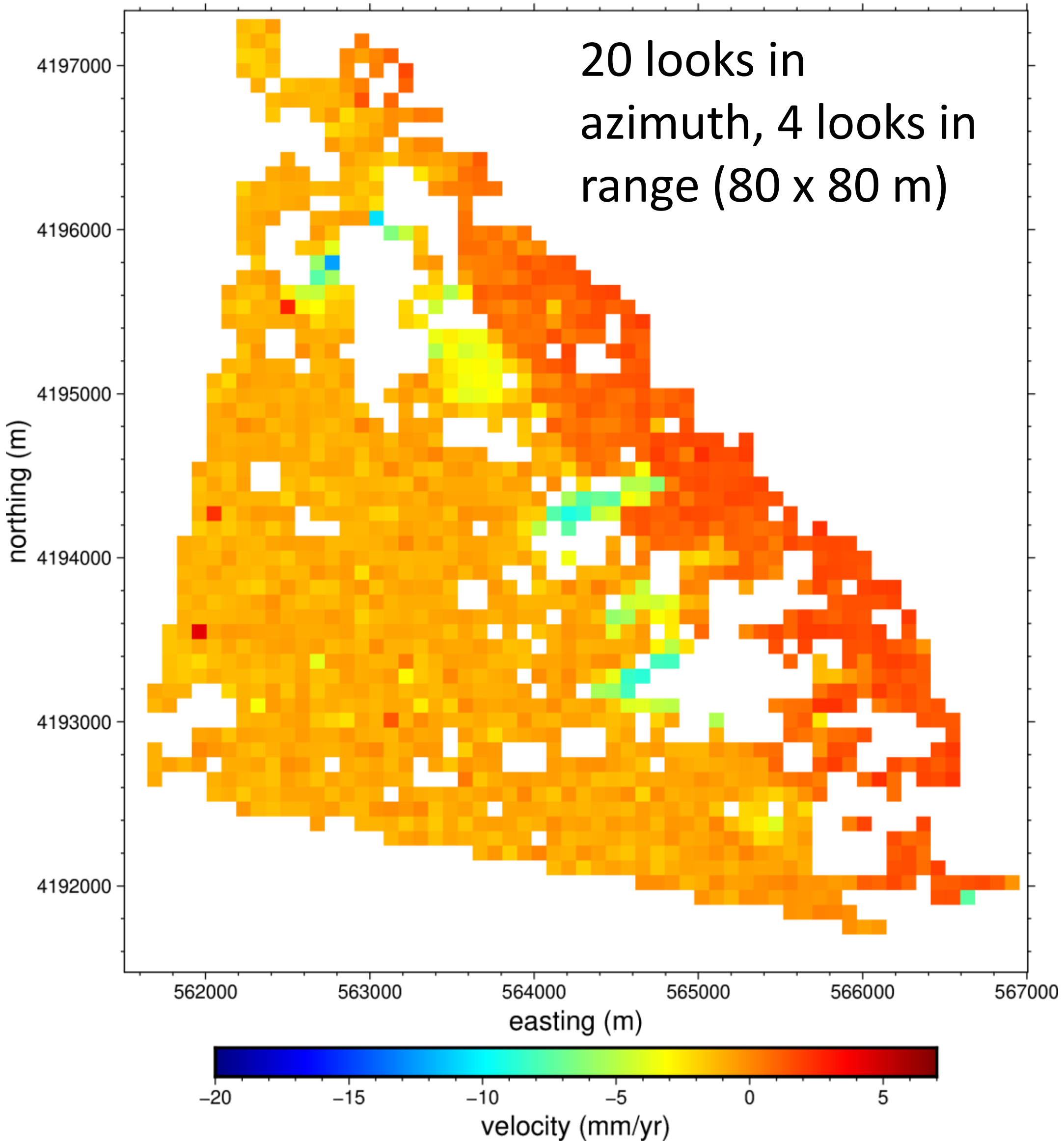
Taking 4 looks means averaging 4 pixels together in a particular direction (azimuth or range)

Coherent signals are often more prominent after taking looks

SAR image pixels are often not square, so taking a different number of looks in azimuth and range is one way of ensuring squarer pixels in your final dataset

Multilooking to form square pixels





Multilooking Sentinel-1 data

Sentinel-1 IW data has a pixel size of ~15 m in azimuth and ~3-5 m in range (far range vs near range)

A wide range of multilooking schemes are used in processing software, e.g.:

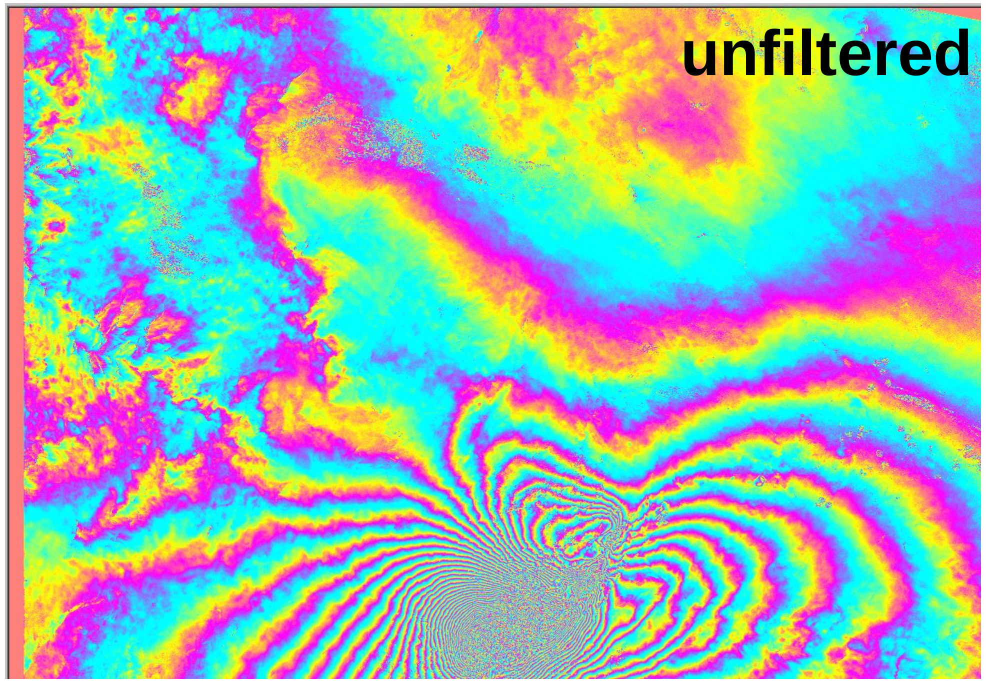
- 7 looks in azimuth, 19 looks in range (~100 m pixels)
- 4 looks in azimuth, 20 looks in range (~60 m pixels)
- 2 looks in azimuth, 10 looks in range (~ 30 m pixels)
- 1 look in azimuth, 5 looks in range (~15 m pixels)

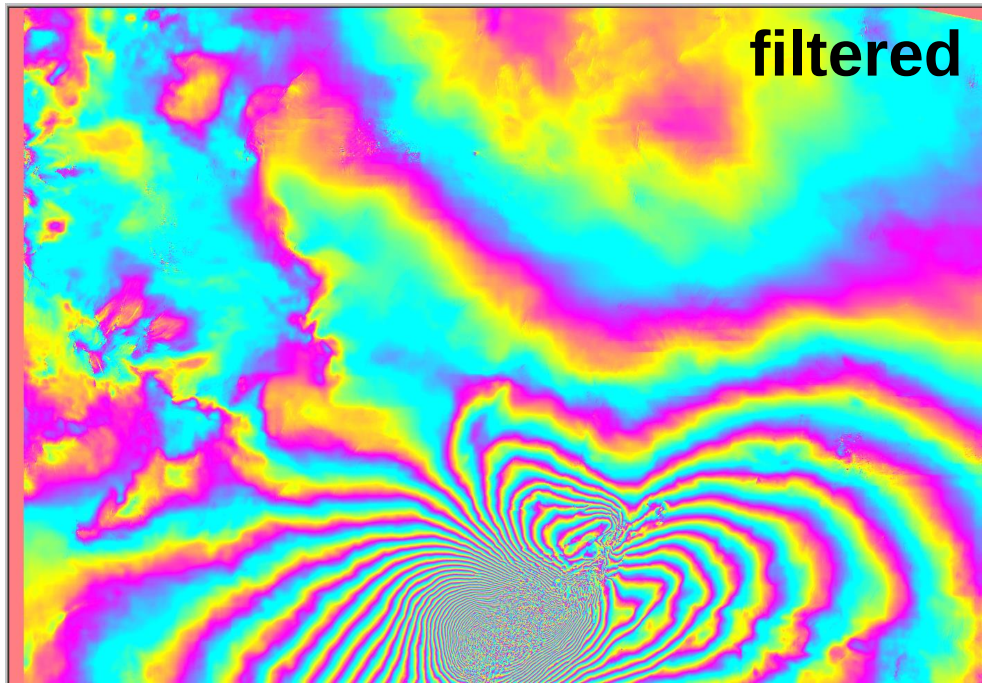
Smaller pixels can allow finer detail in deformation, but the data are noisier, take up more disk space and take longer to process

Filtering

To boost the signal over the noise, a power spectrum filter is applied

This increases the power of the most coherent information in the interferogram

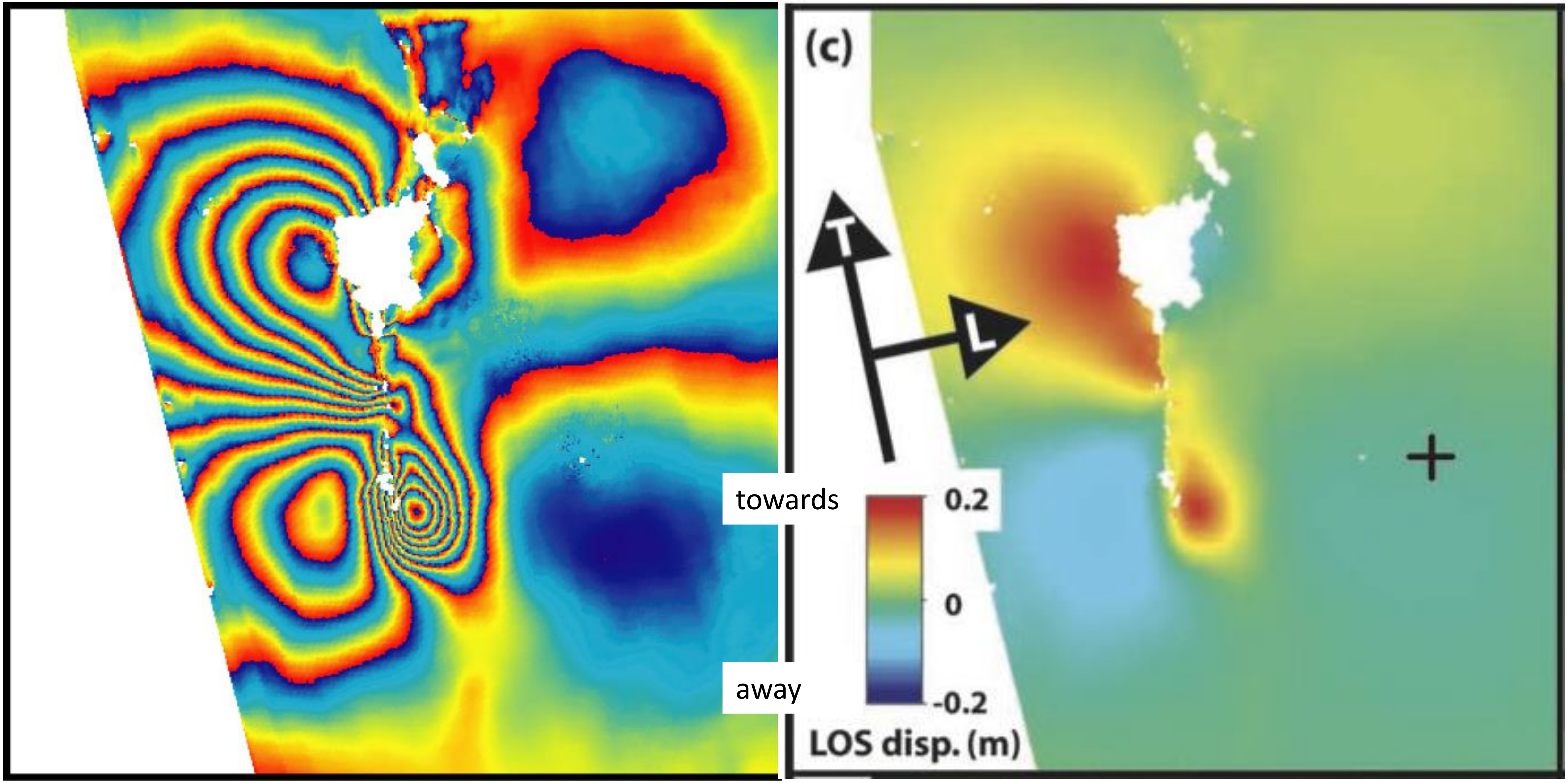




Unwrapping

'Unwrapping' is the process of converting the cyclical (modulo 2π) phase signal of an interferogram into a continuous phase signal

It is usually preferable to use unwrapped phase for deformation or topography estimation – the SBAS approach, for example, requires unwrapped interferograms “wrapped” “unwrapped”



Unwrapping

Several different algorithms exist for unwrapping. Although they differ in detail, they typically do similar things:

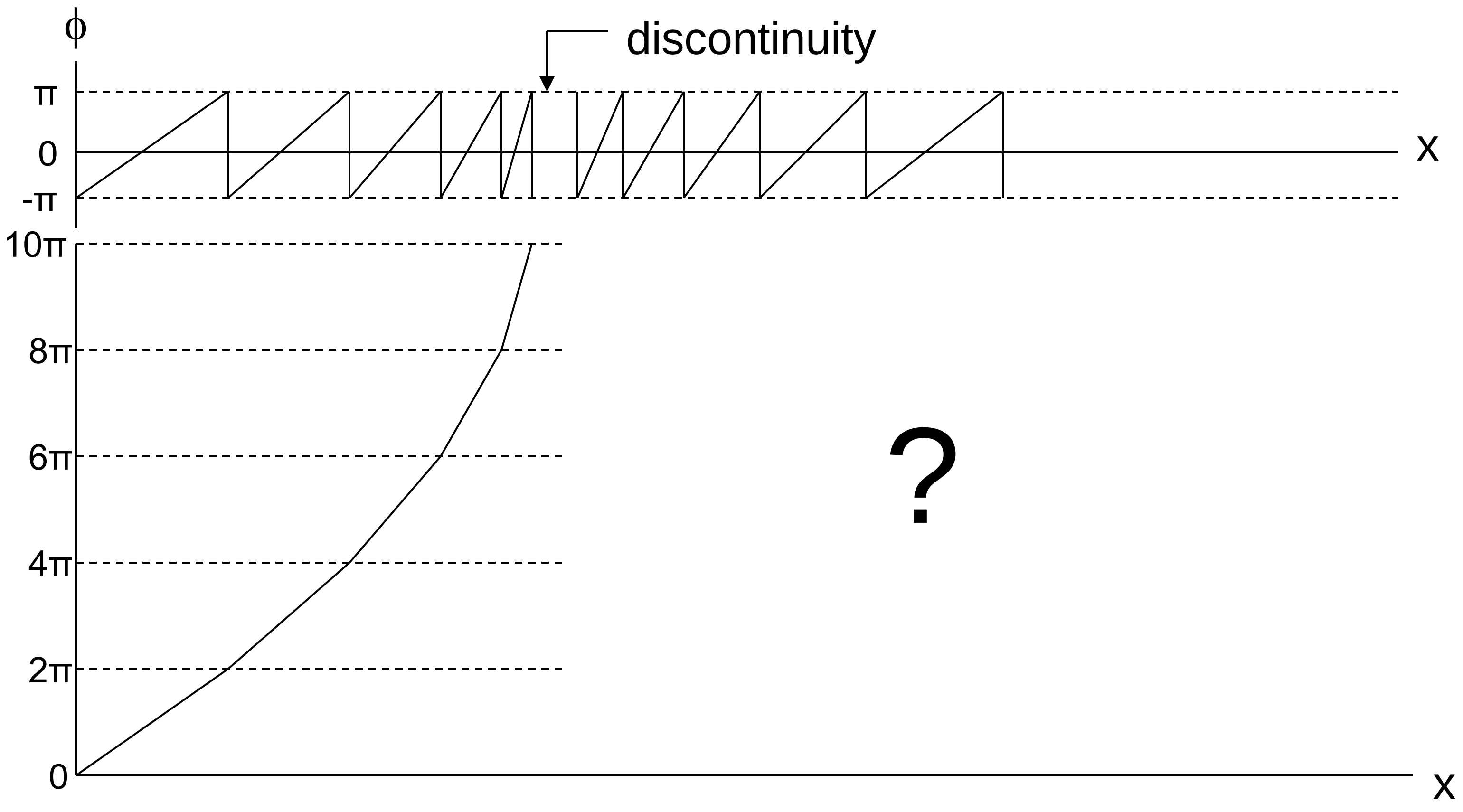
1) Find the connected components of an interferogram (e.g. by integrating around closed loops)

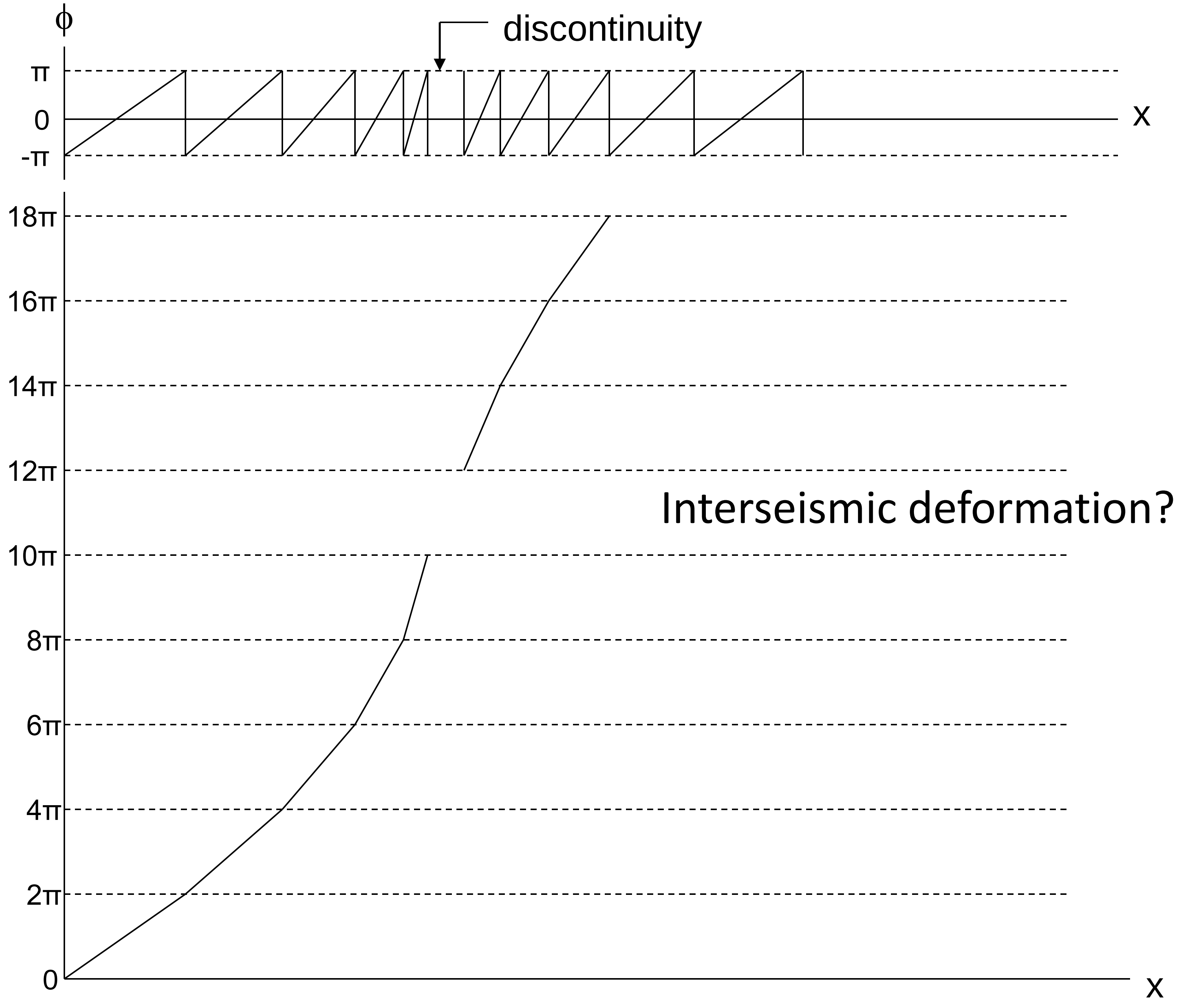
2) Estimate (manually or statistically) the adjustment between neighboring connected areas

These algorithms can produce false results (incorrect estimates of phase differences between neighbors), so always check the results!

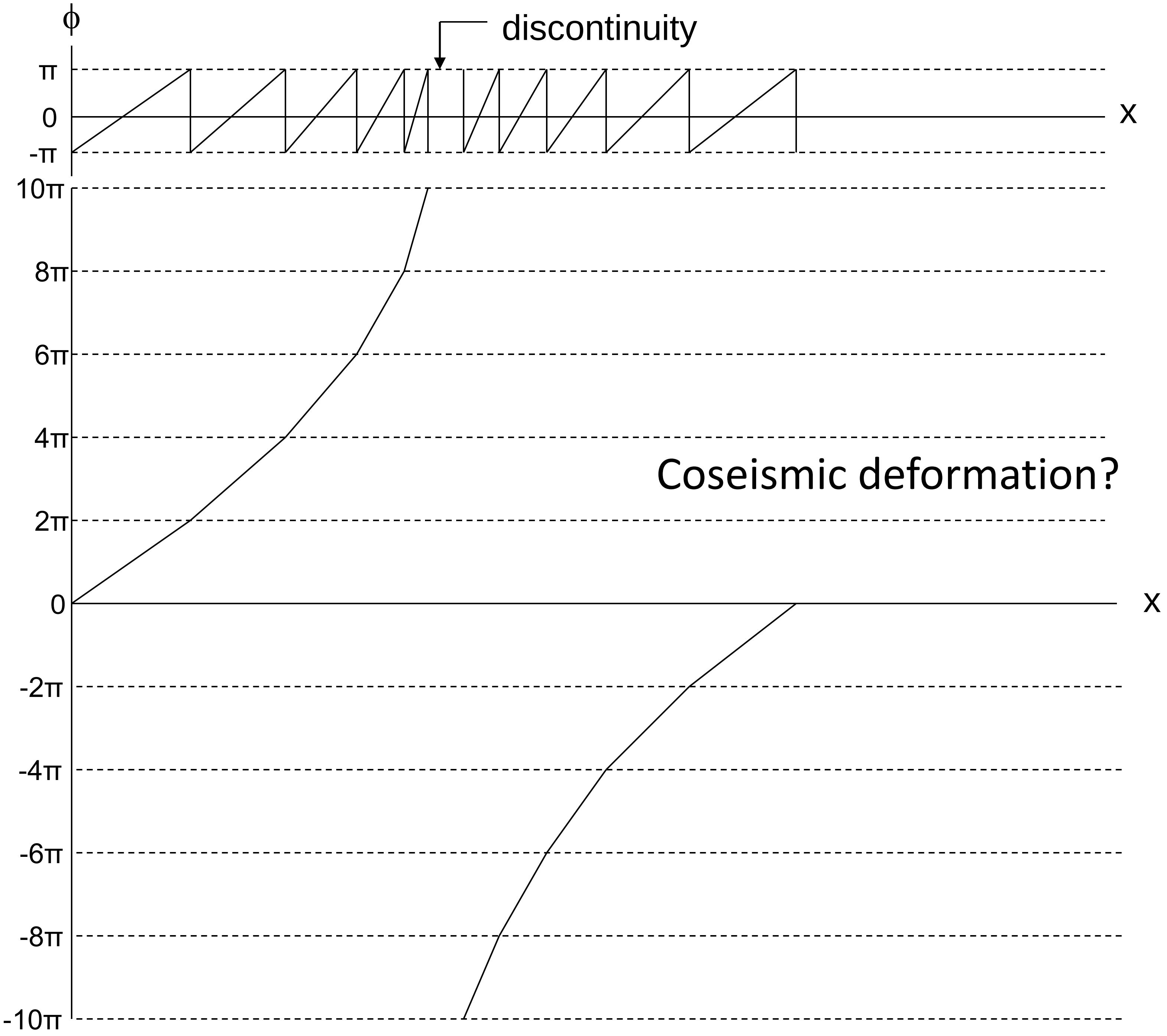
Unwrapping

At its simplest, phase unwrapping is just adding or subtracting 2π at a phase jump…

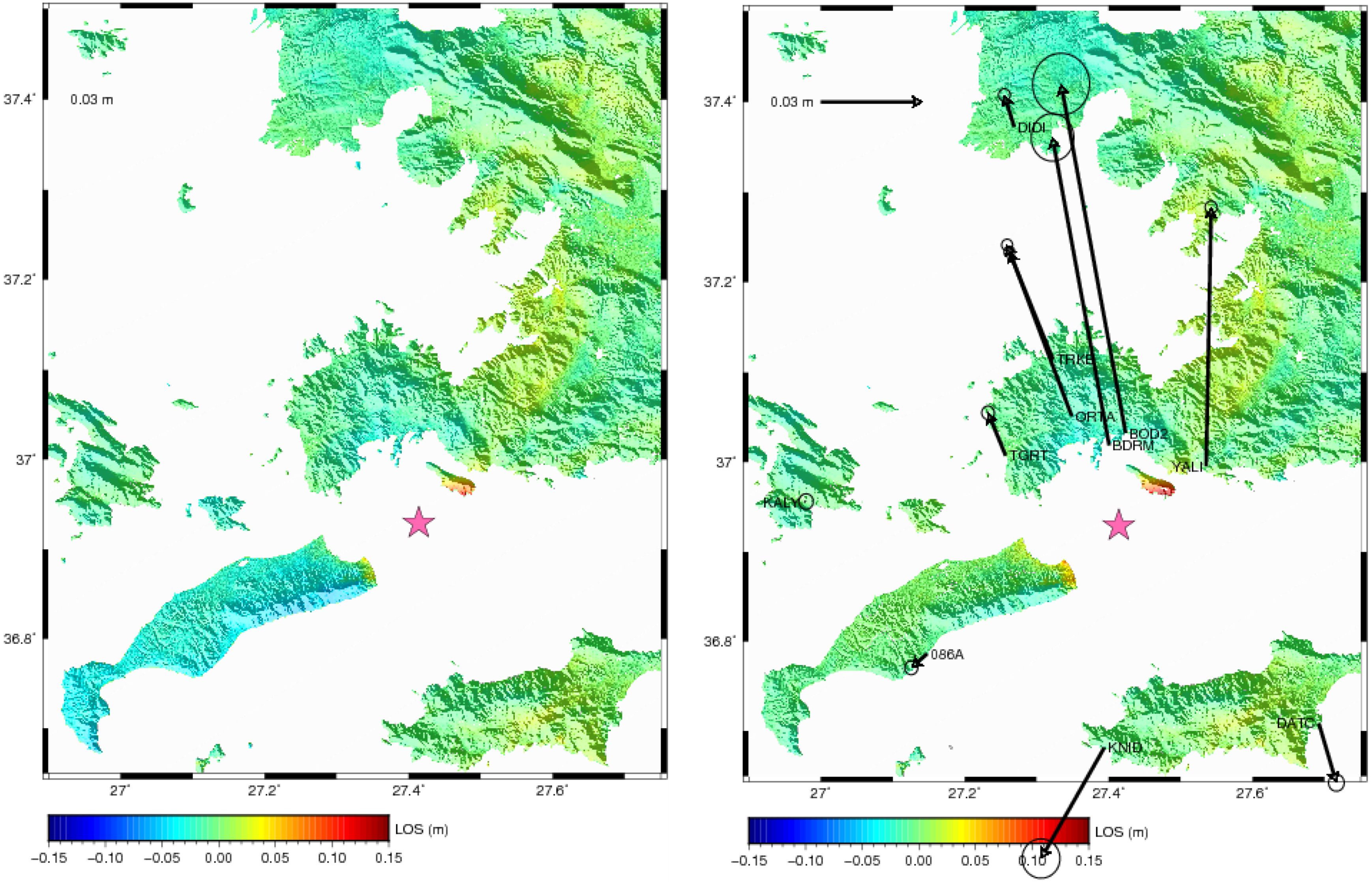




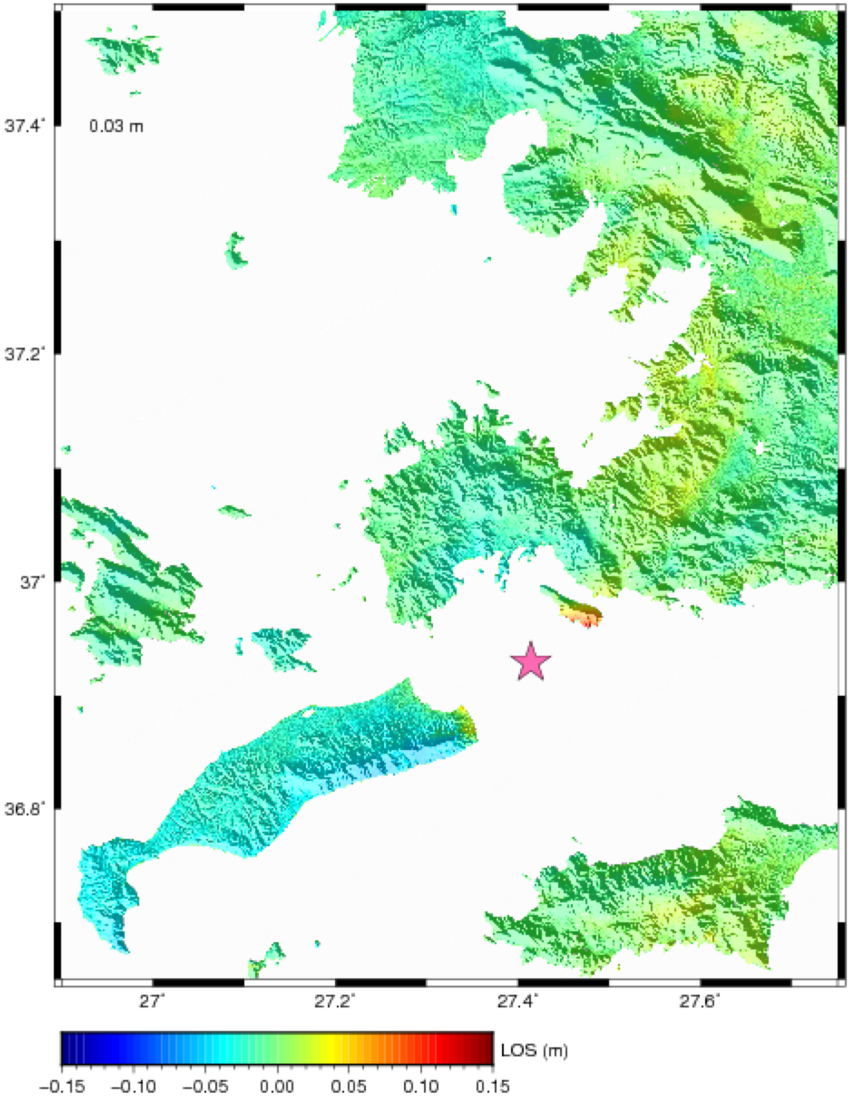
Interseismic deformation?

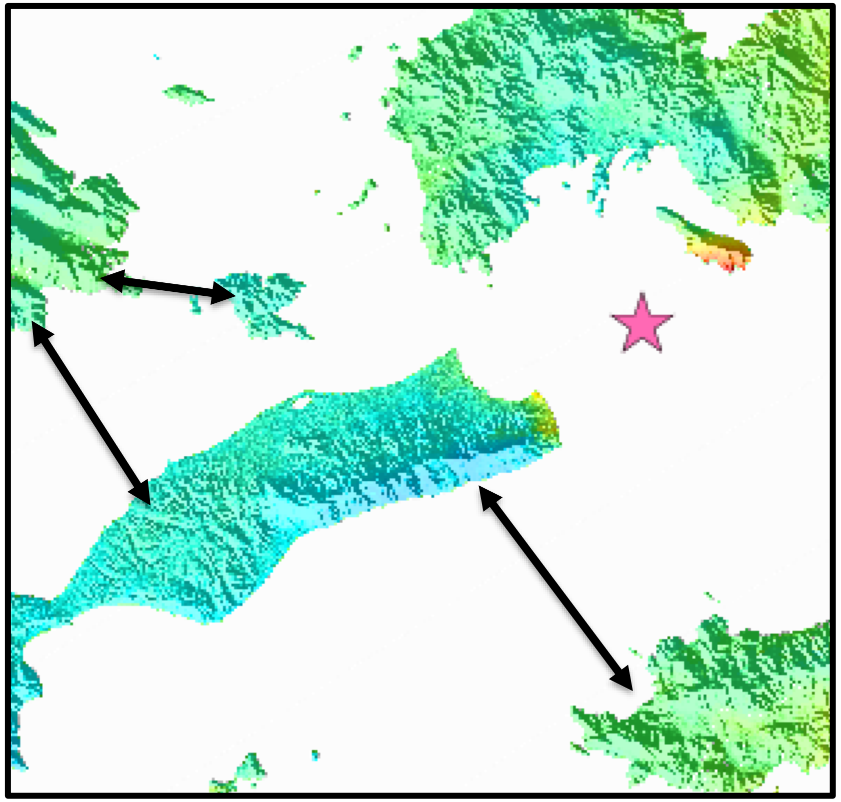

ϕ
discontinuity
π
0
-π
x
10π
8π
6π
4π
2π
0
-2π
-4π
-6π
-8π
-10π
x
Coseismic deformation?

2017 Bodrum, Turkey earthquake



2017 Bodrum, Turkey earthquake

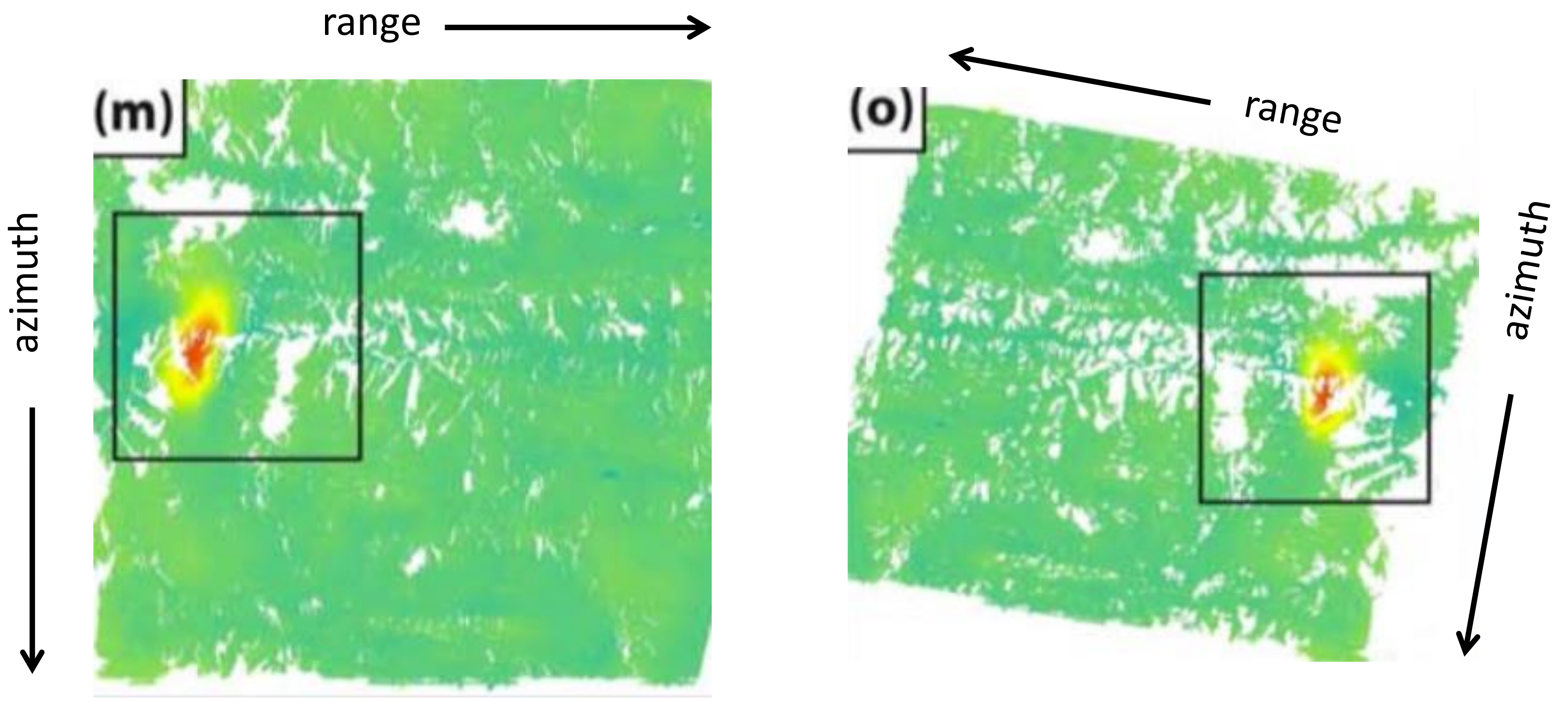




Phase jumps of 2π and 4π in far field indicative of unwrapping errors

Geocoding

Final stage of processing, converts the data from 'radar geometry' (left) to geographical coordinates (right), using the linkages determined during registration



Funning, 2005

Typical outputs of InSAR processing

When processing is complete, you will typically have:

- Wrapped phase, filtered and unfiltered, geocoded and radar geometry
- Filtered unwrapped phase, geocoded and radar geometry
- Amplitude, geocoded and radar geometry
- Interferometric correlation, geocoded and radar geometry
- Incidence and pointing azimuth data, geocoded and radar geometry