InSAR training 2024

An introduction to InSAR and its applications

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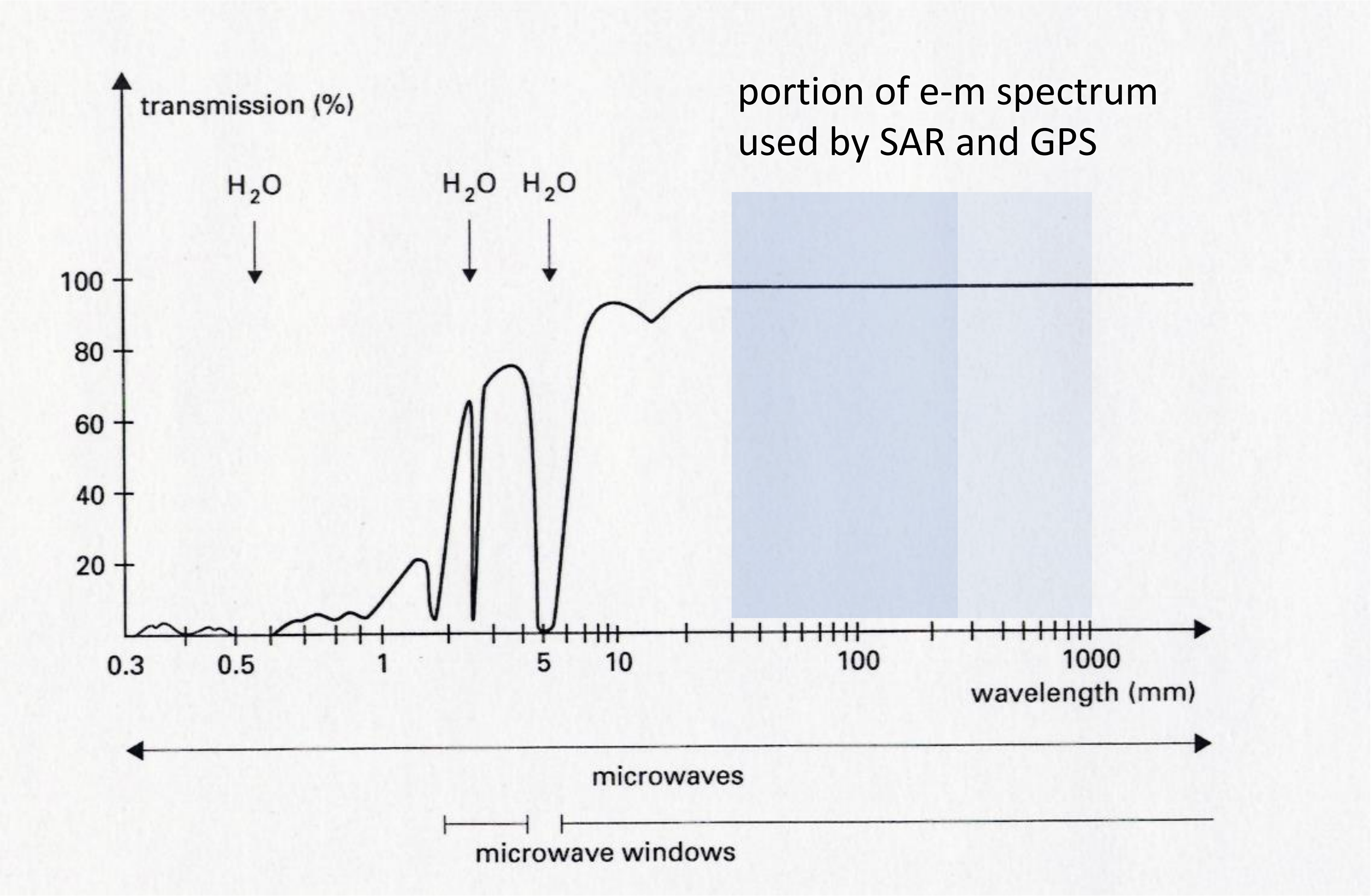
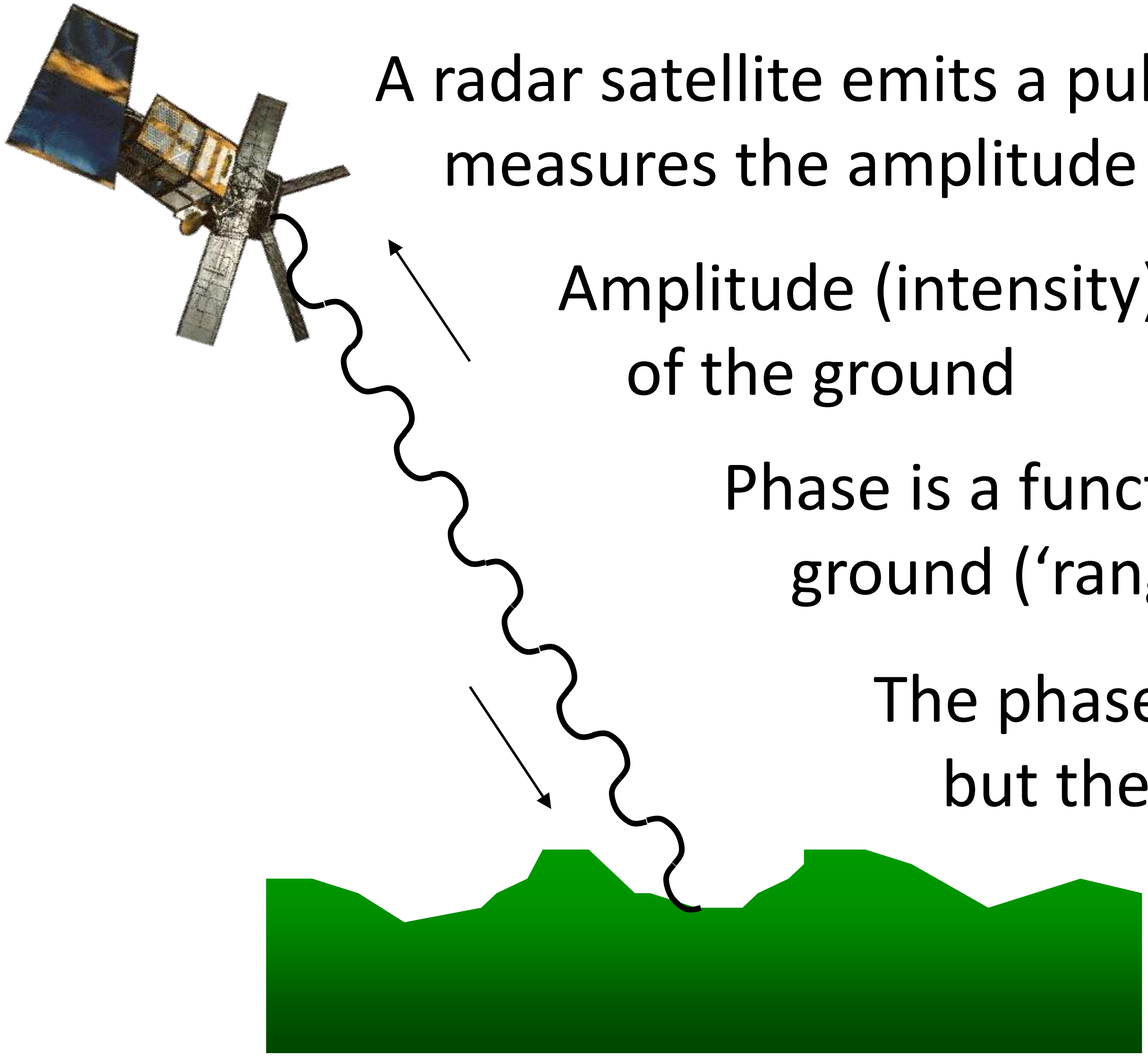
InSAR

Interferometric	–	use wave interference
Synthetic	}	pretend you have a big radar antenna
Aperture		
Radar	–	emit microwaves, measure echoes

Active remote sensing with microwaves



SAR images



A radar satellite emits a pulse of microwave radiation and measures the amplitude and phase of the echoes

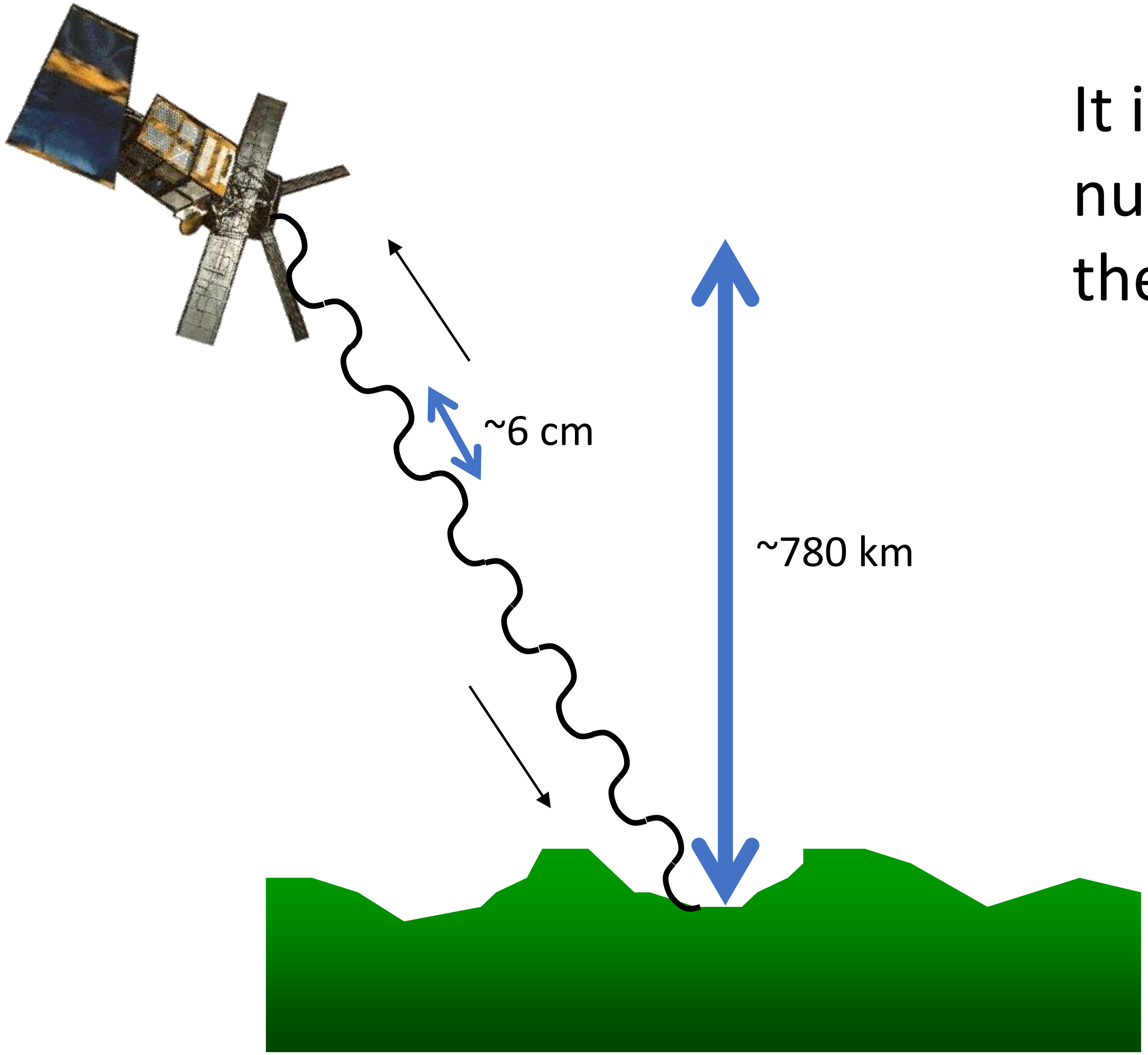
Amplitude (intensity) is a function of the roughness of the ground

Phase is a function of distance from satellite to ground (‘range’ in the jargon)

The phase of a single SAR image is not useful, but the difference between two images is…

Satellite: ERS-2 (1995–)

SAR image phase

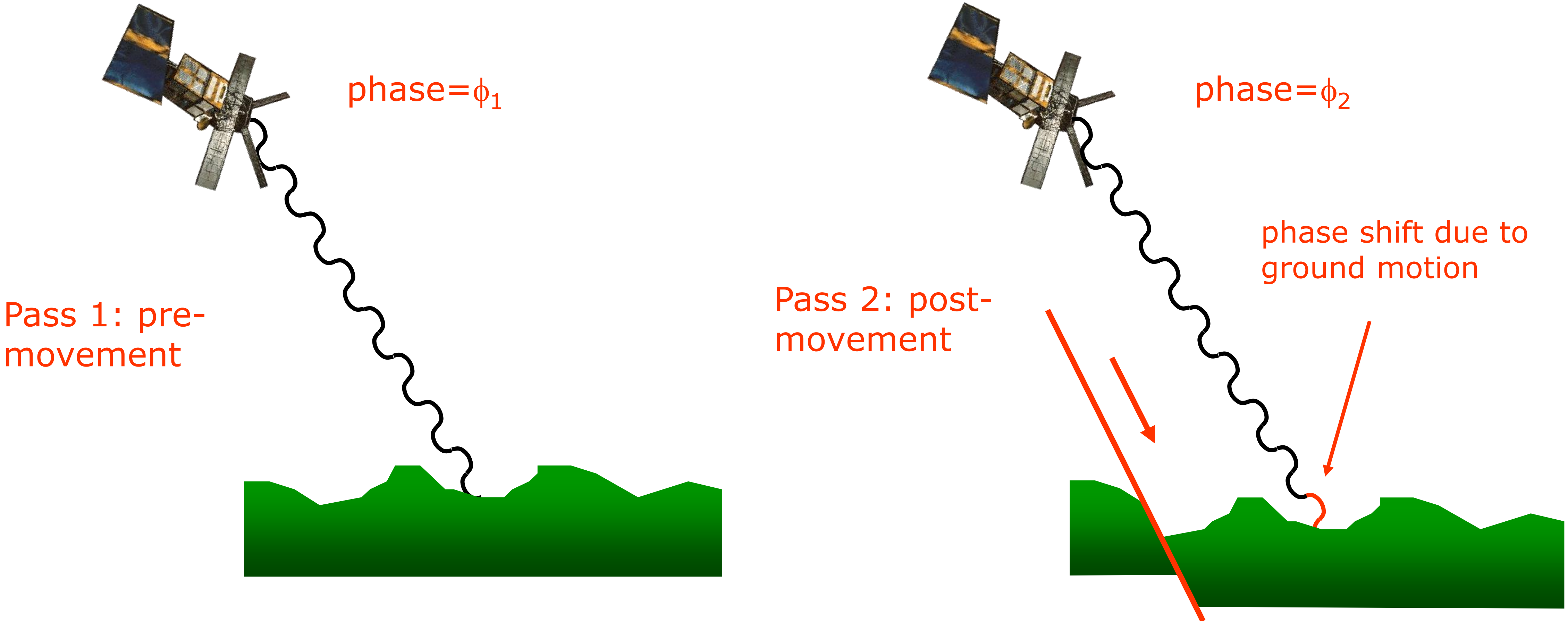


It is not feasible to count the number of wavelengths between the satellite and the ground target!

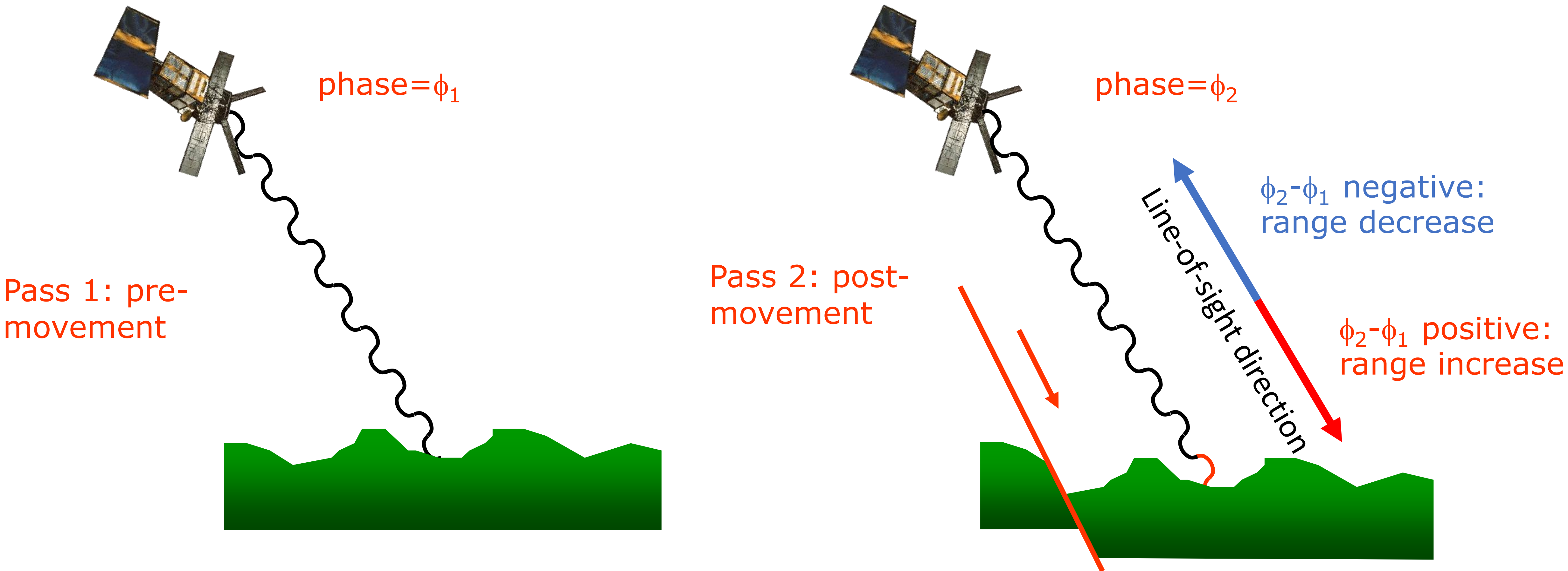
Satellite: ERS-2 (1995–)

SAR image phase

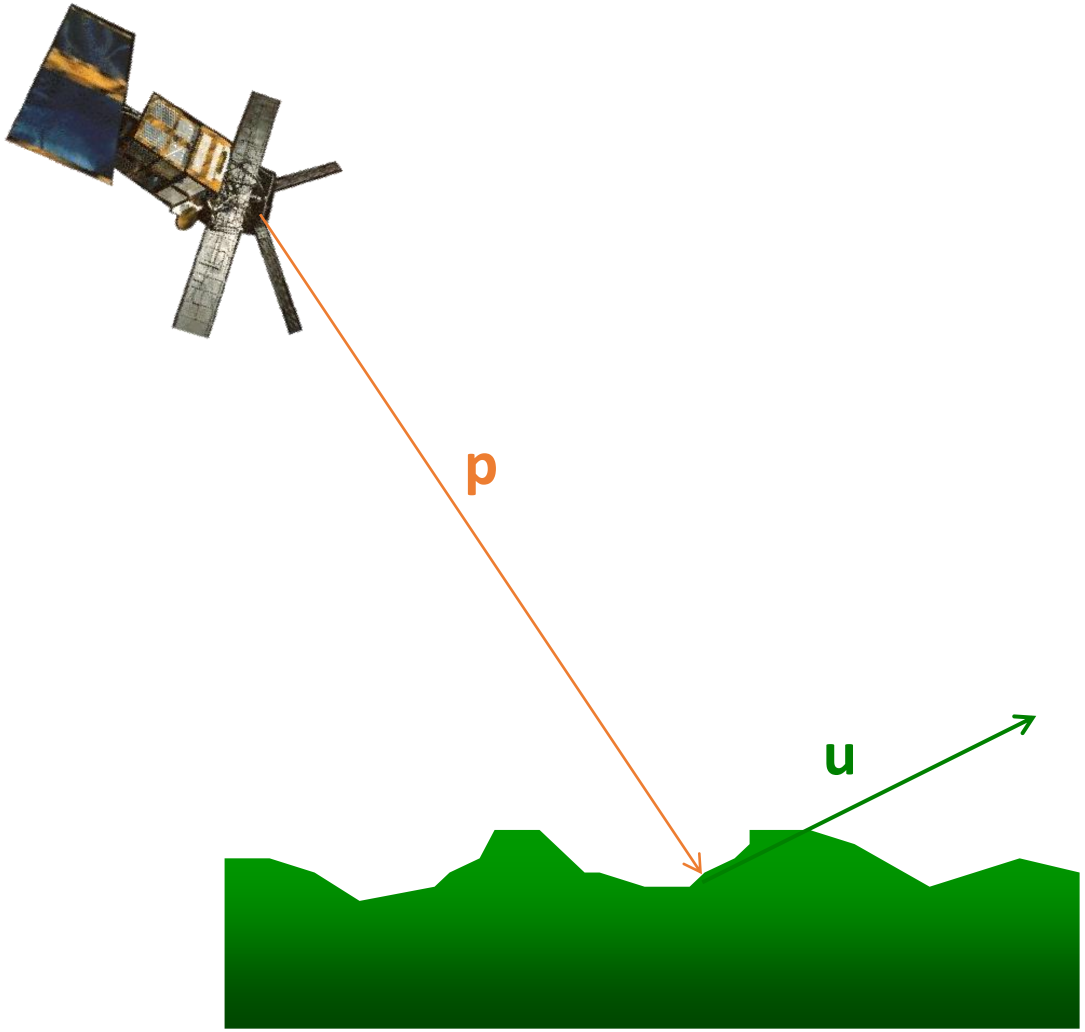
But differencing the phase between different passes of the satellite allows us to isolate a *change* in distance



An individual SAR interferogram measures deformation in one dimension, in the radar line-of-sight



Vector description of InSAR

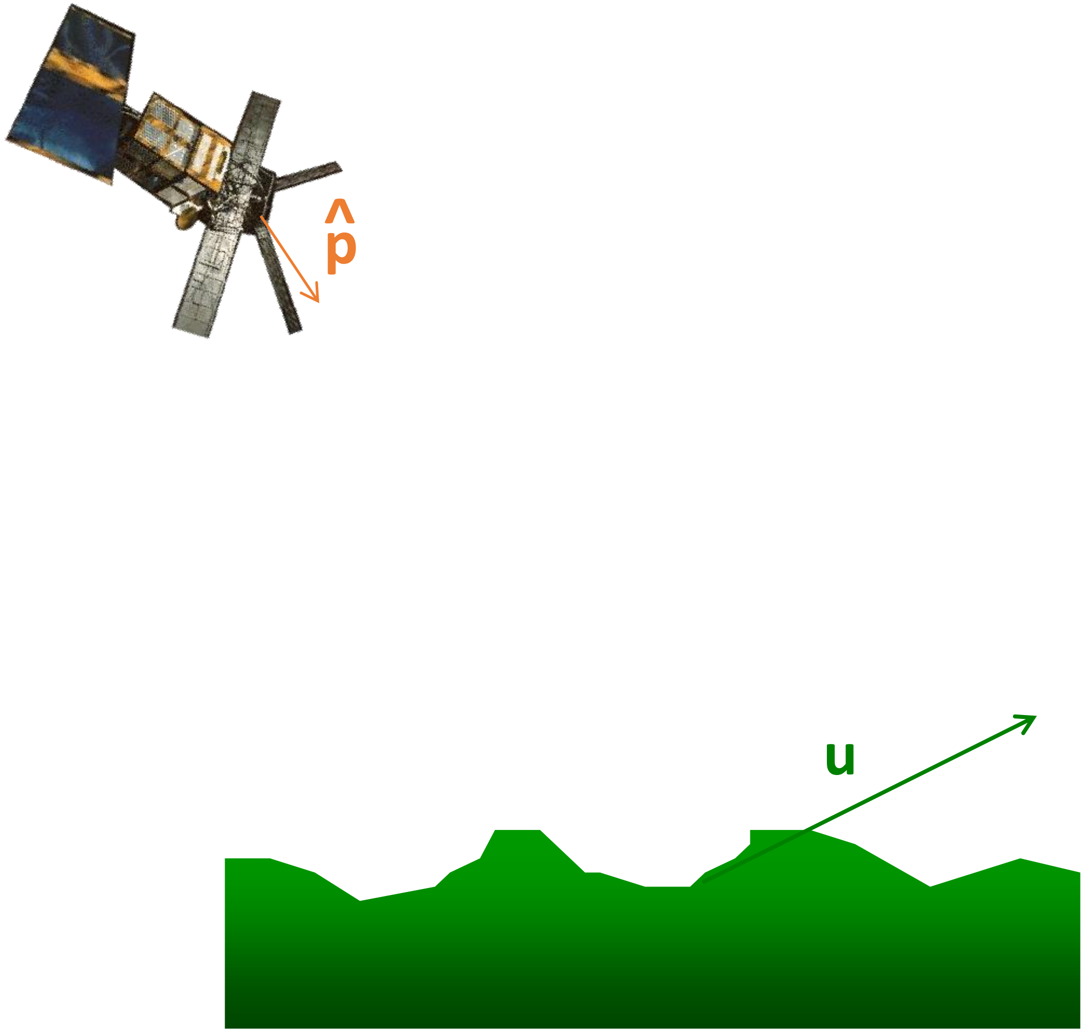


u = ground displacement vector

p = pointing vector (from satellite to ground target)

p is controlled by the satellite trajectory, beam mode (incidence angle) and position of the pixel within the swath

The unit pointing vector

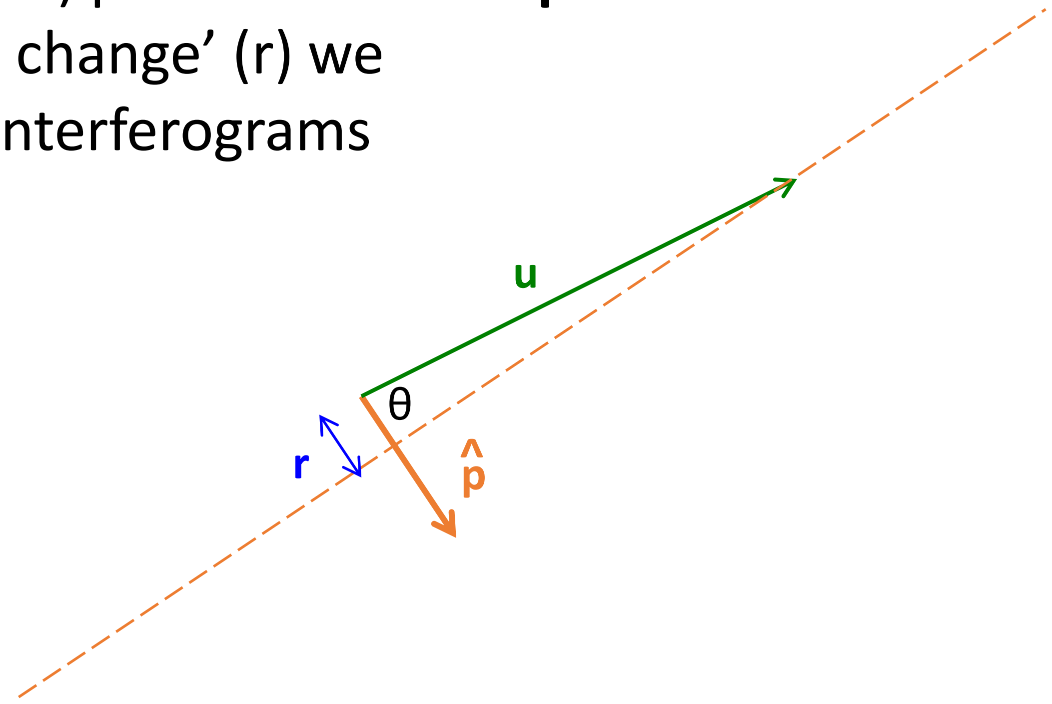


u = ground displacement vector

$\hat{\mathbf{p}}$ = <u>unit</u> pointing vector (from satellite to ground target)

Range change

the scalar (dot) product of **u** and $\hat{\mathbf{p}}$ is the 'range change' (r) we measure in interferograms

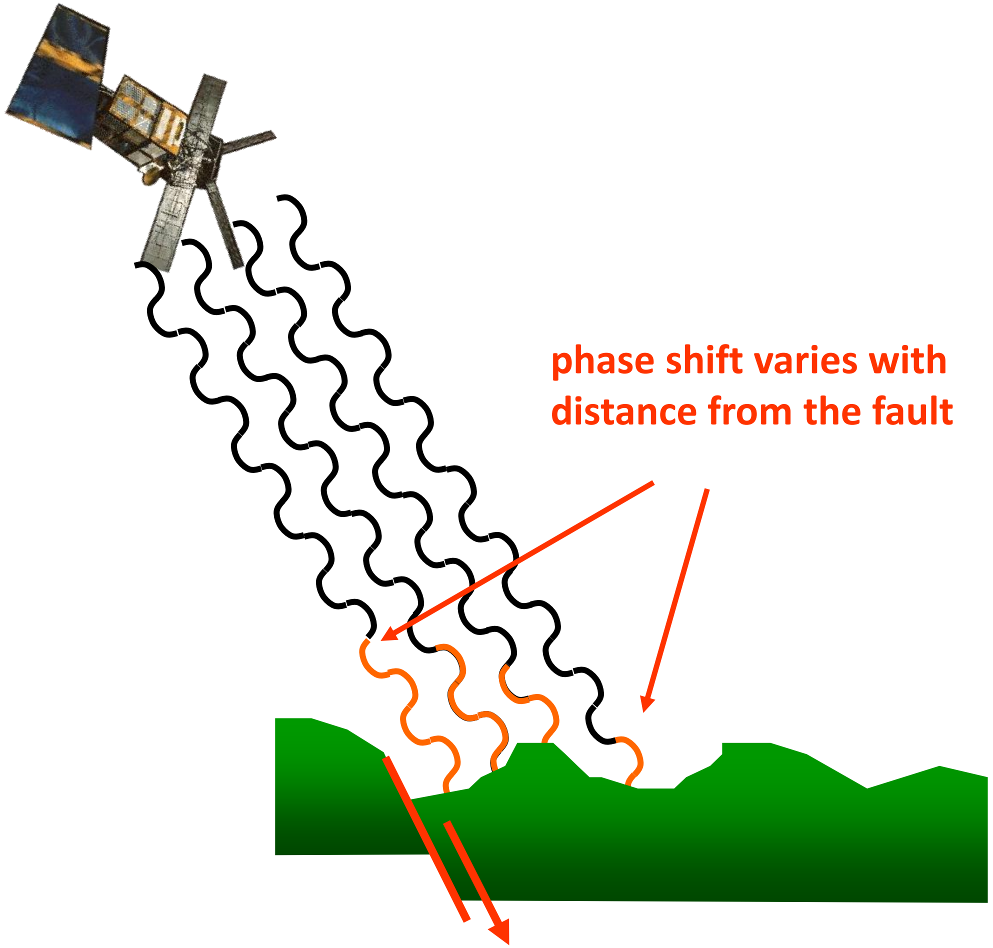


cross-section view

$$
\begin{aligned}
r &= \mathbf{u} \times \hat{\mathbf{p}} \\
&= |\mathbf{u}||\hat{\mathbf{p}}| \cos q \\
&= |\mathbf{u}| \cos q
\end{aligned}
$$

therefore, the key to modeling InSAR data is having a code that can simulate the displacements **u**

Typically the displacement varies spatially, and is diagnostic of the source



WARNING

Historically, people did not all use the same sign conventions in InSAR (including me…)

- Check whether your interferograms are ‘range change’ or ‘ground LOS displacement’
- Check if your pointing vectors are consistent with your interferograms (pointing from satellite to ground, or ground to satellite?)

Image A - 12 August 1999

Interferogram =
Phase A - Phase B

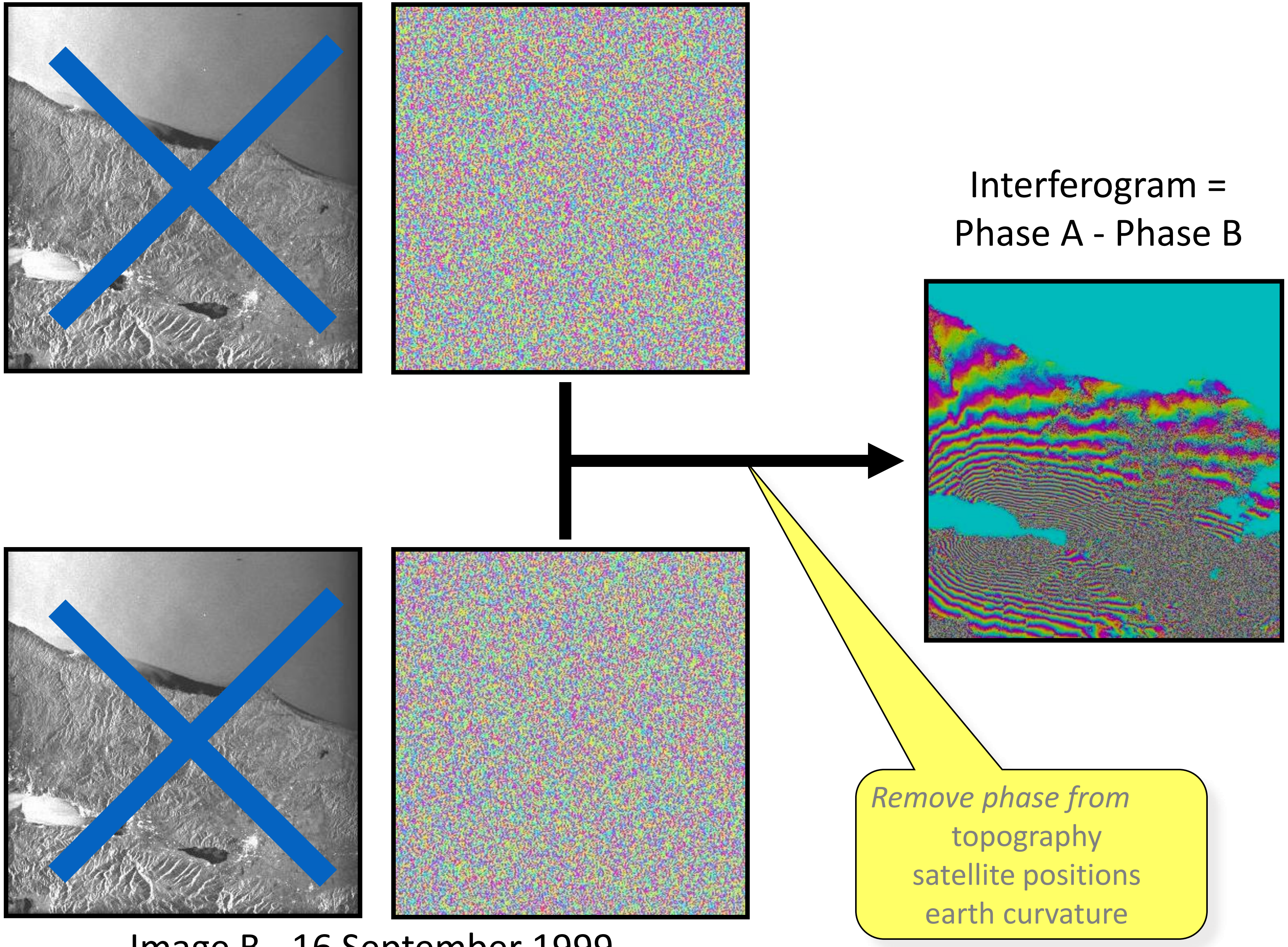
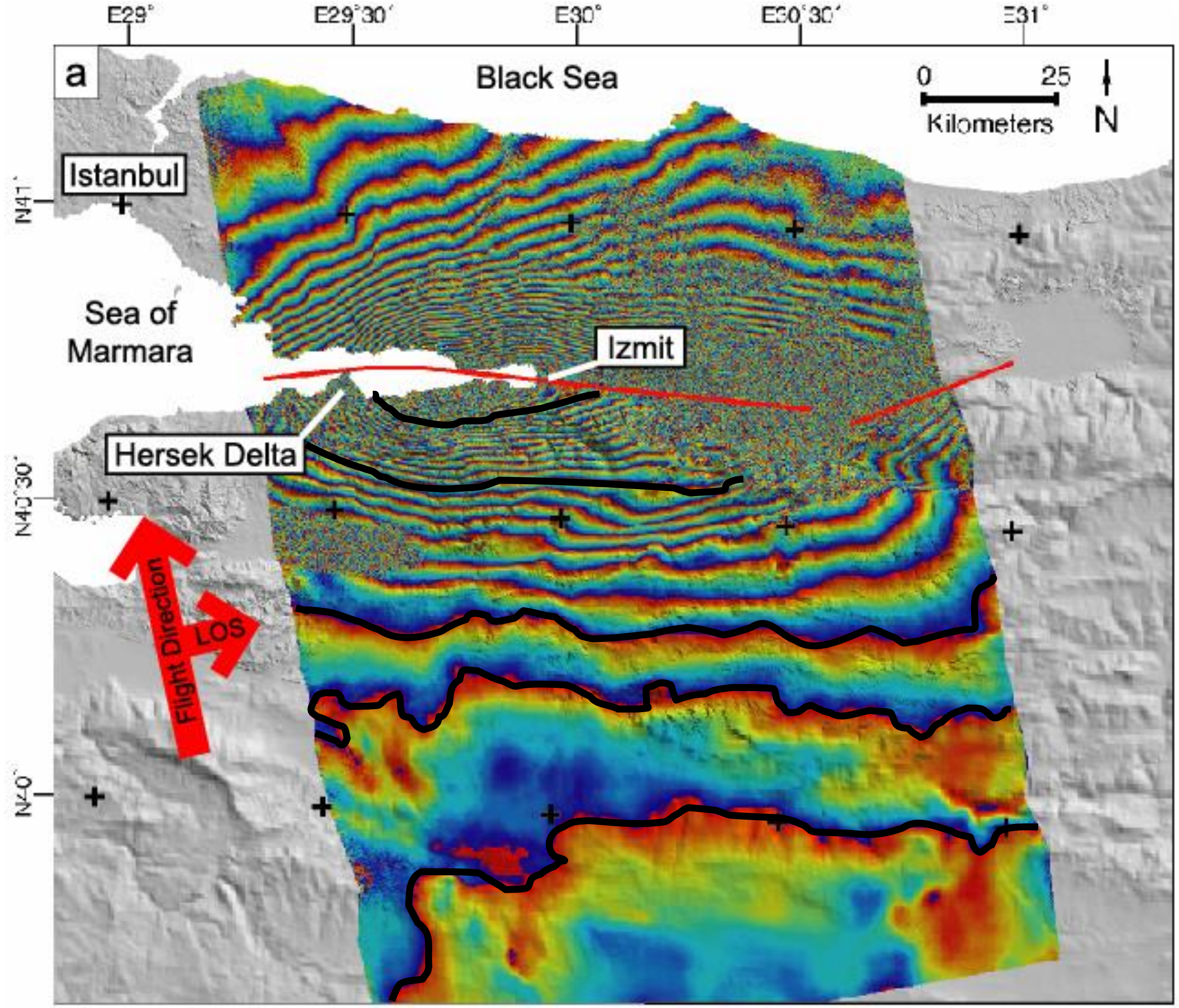


Image B - 16 September 1999



(-20) 567 mm range decrease

(-10) 283 mm range decrease

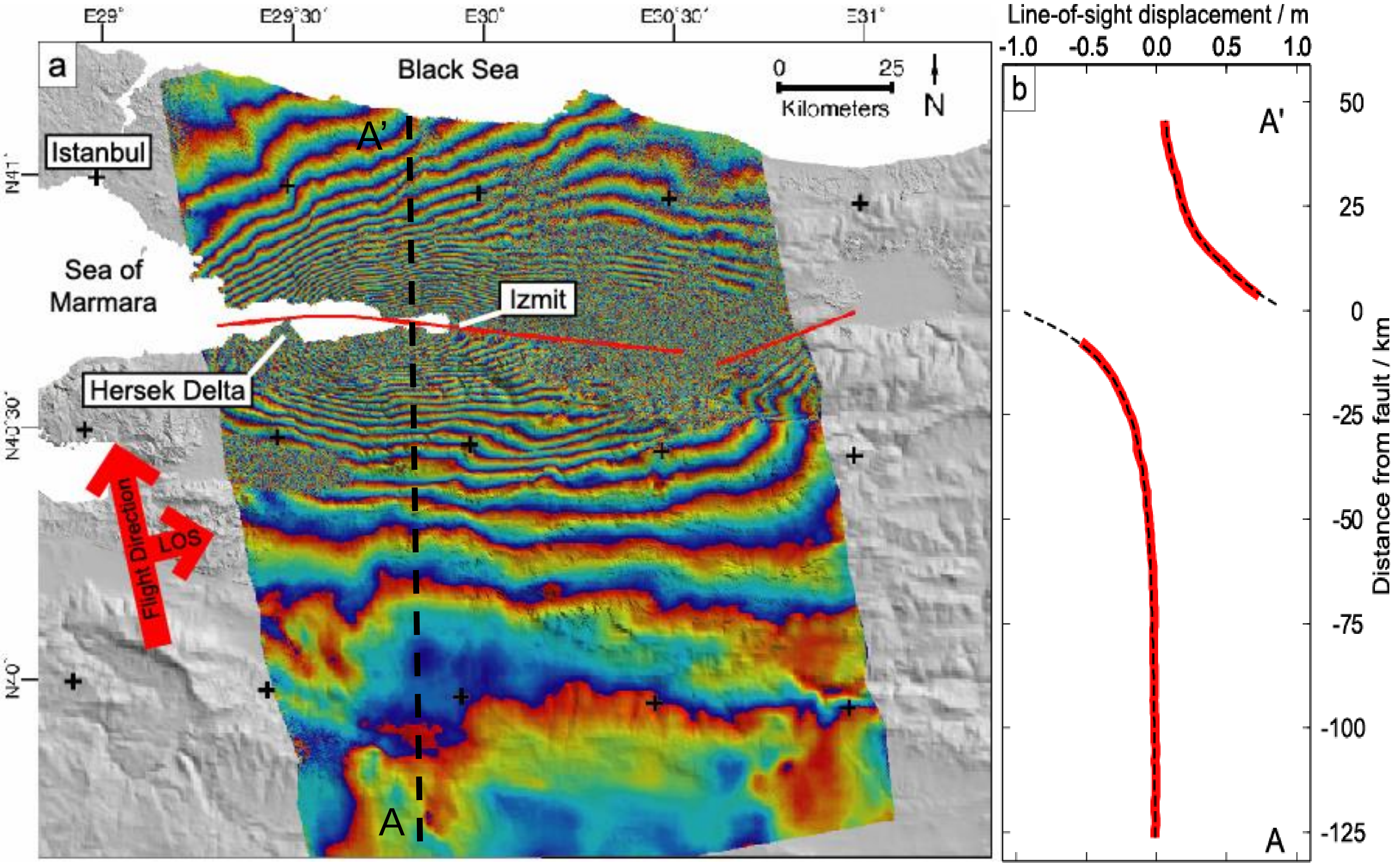
(-2) 57 mm range decrease

(-1) 28 mm range decrease

(0) 0 mm range change

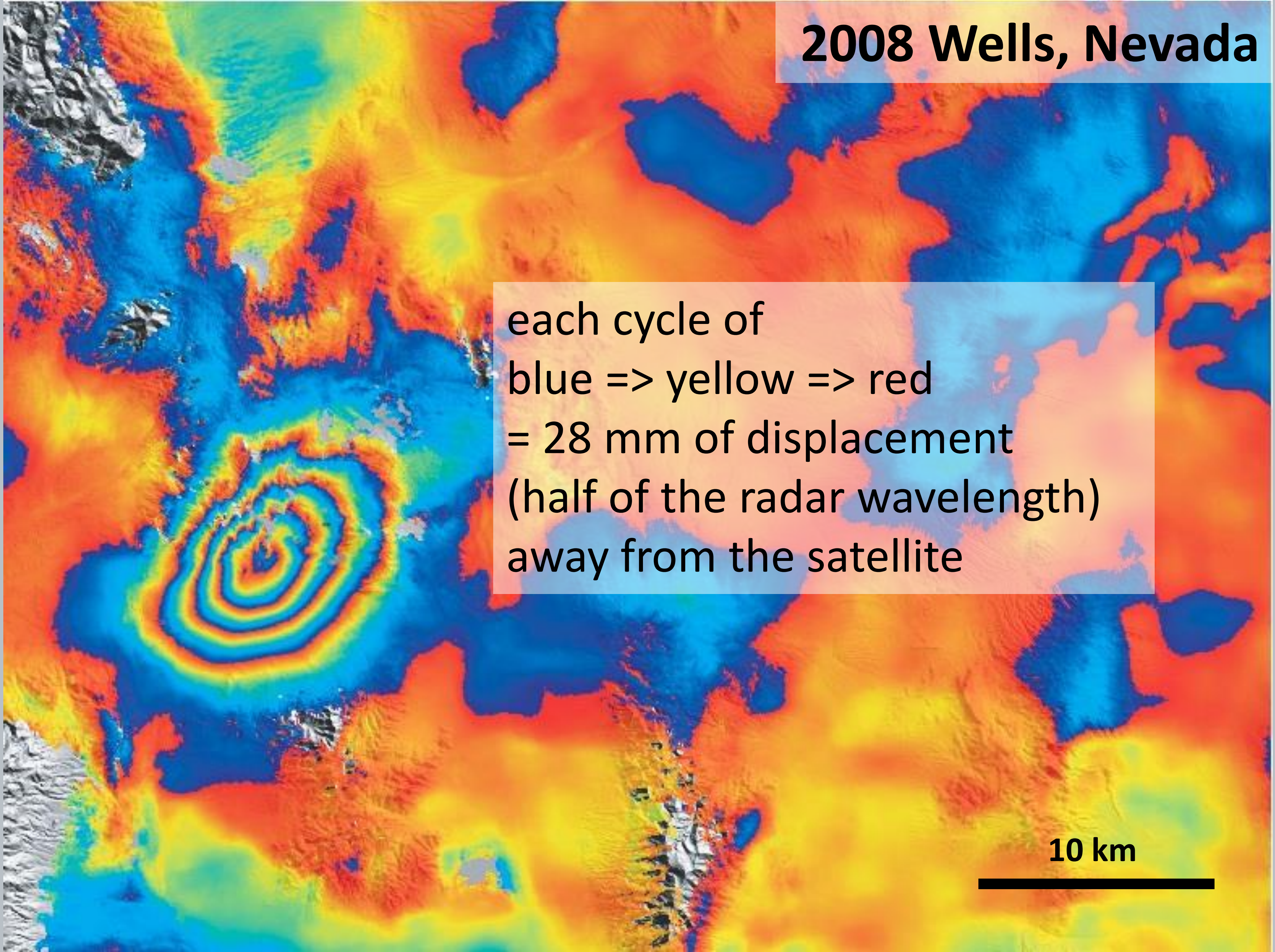
17 August 1999, Izmit earthquake (Turkey)

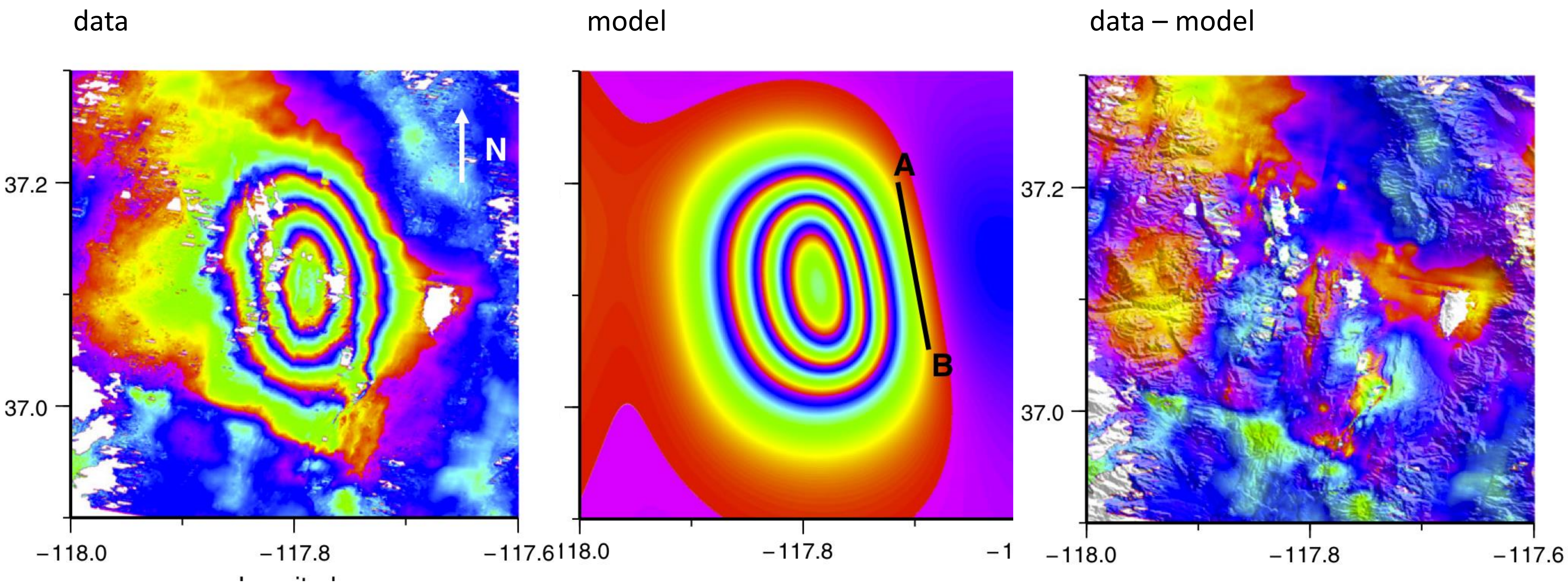
Tim Wright



17 August 1999, Izmit earthquake (Turkey)

Tim Wright


2008 Wells, Nevada
each cycle of
blue => yellow => red
= 28 mm of displacement
(half of the radar wavelength)
away from the satellite
10 km

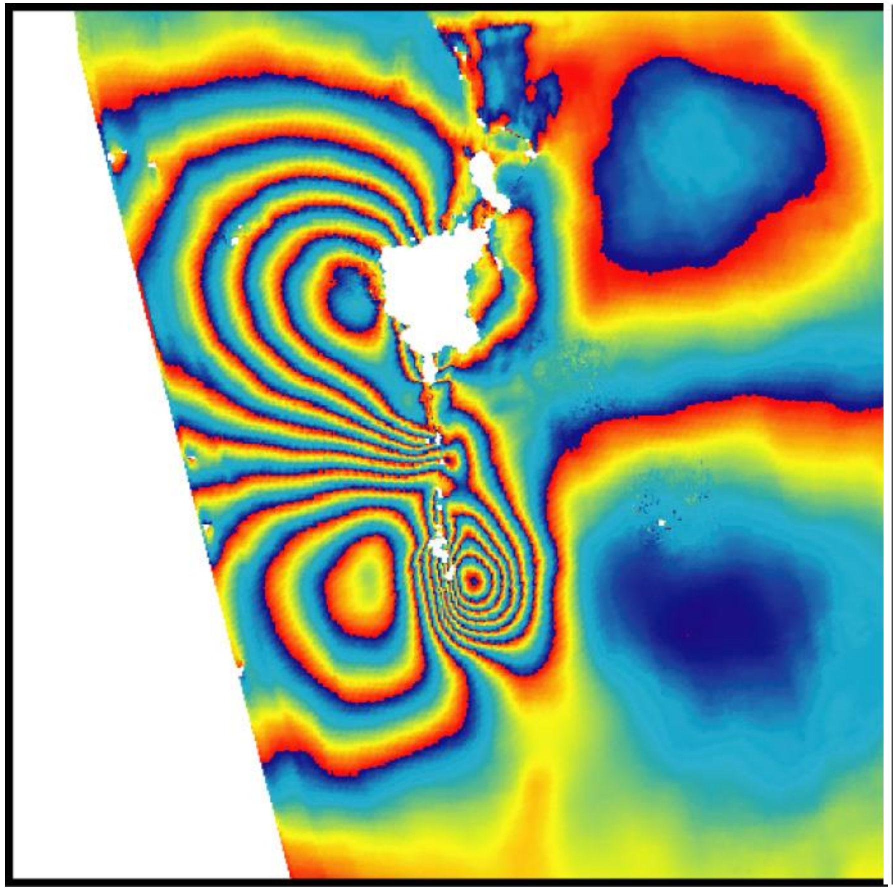


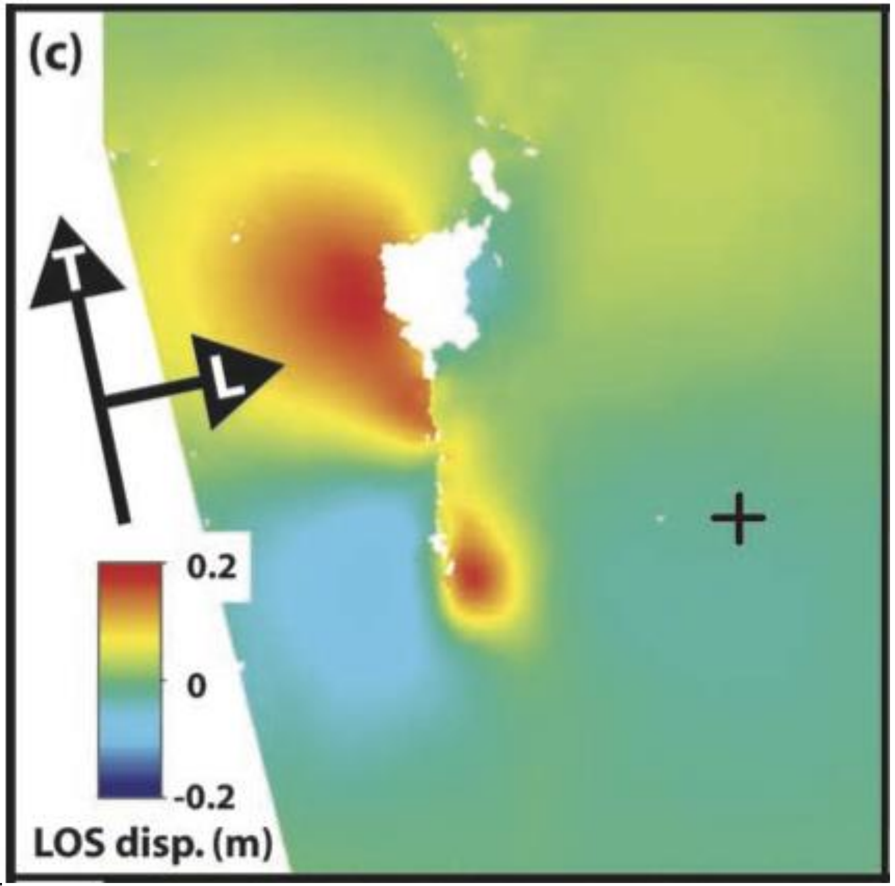
Strike: 172°
Dip: 38°
Rake: –95°
M_w: 6.06

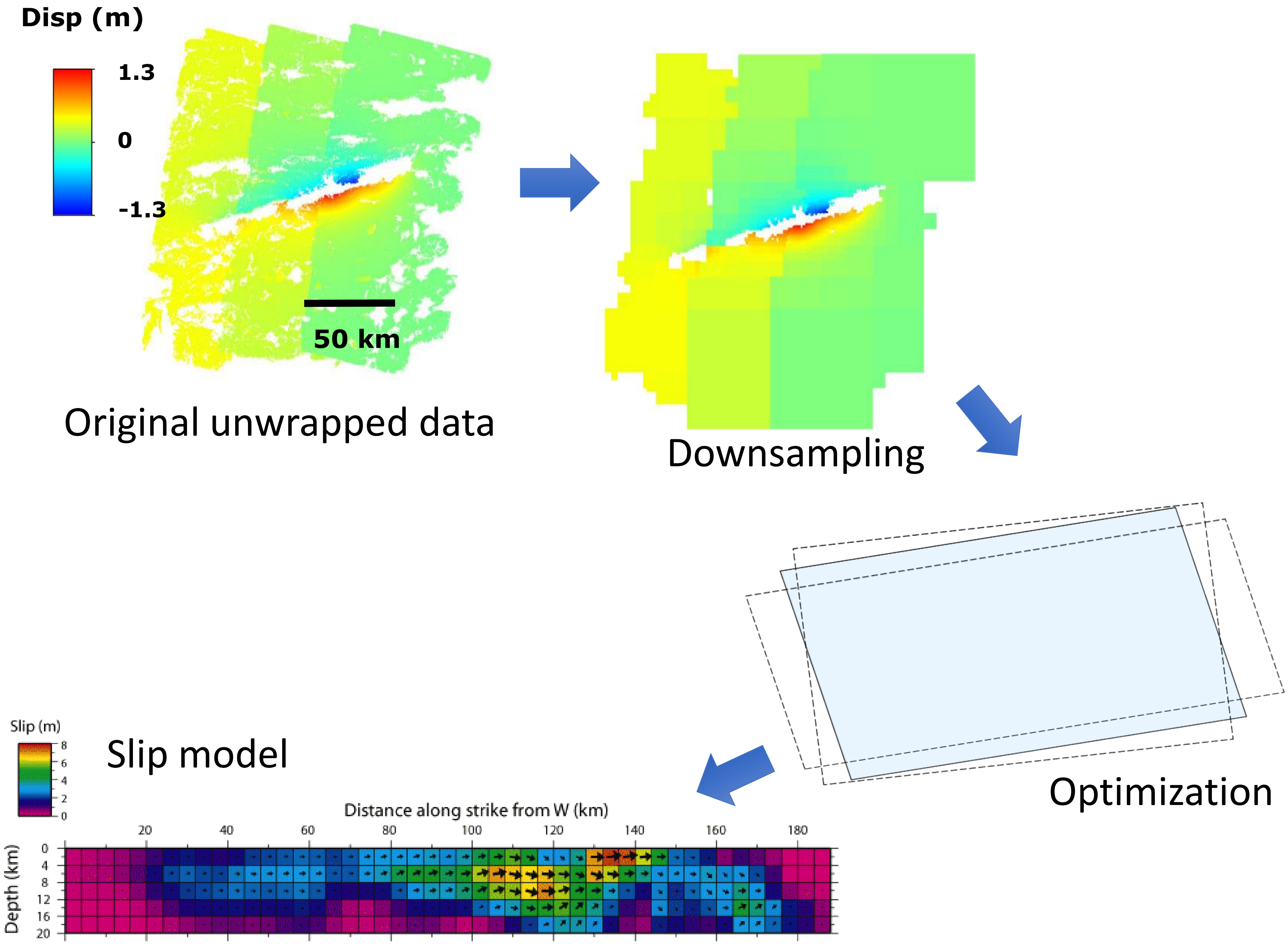
Weston et al., 2012

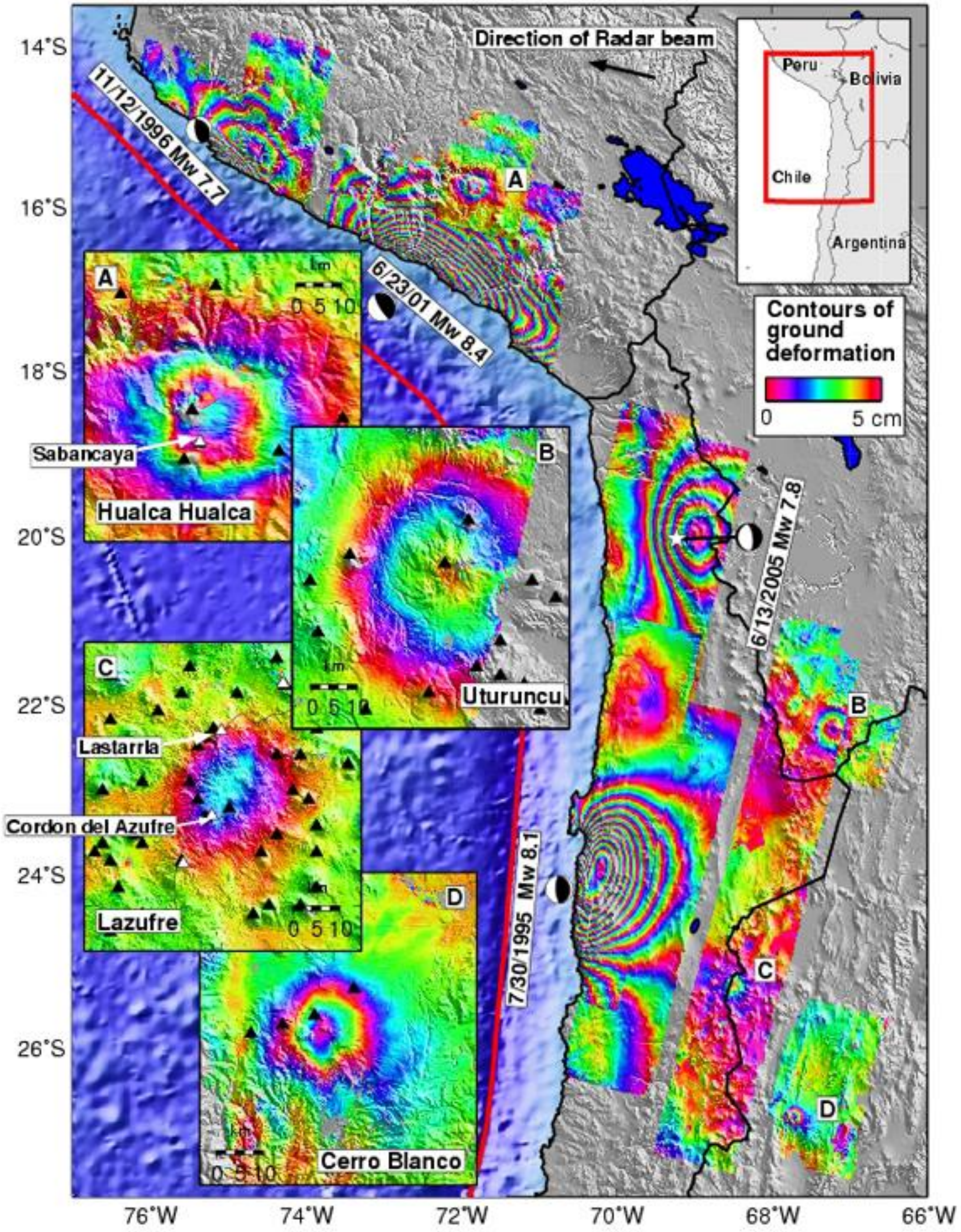
‘wrapped’

‘unwrapped’

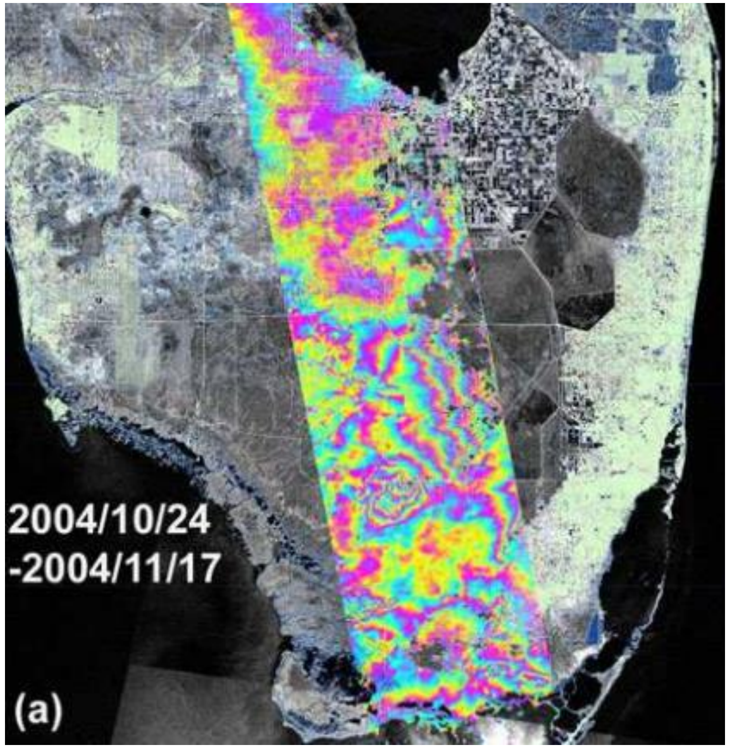





Disp (m)
1.3
0
-1.3
50 km
Original unwrapped data
Downsampling
Optimization
Slip model
Slip (m)
8
6
4
2
0
Distance along strike from W (km)
20
40
60
80
100
120
140
160
180
Depth (km)
0
4
8
12
16
20

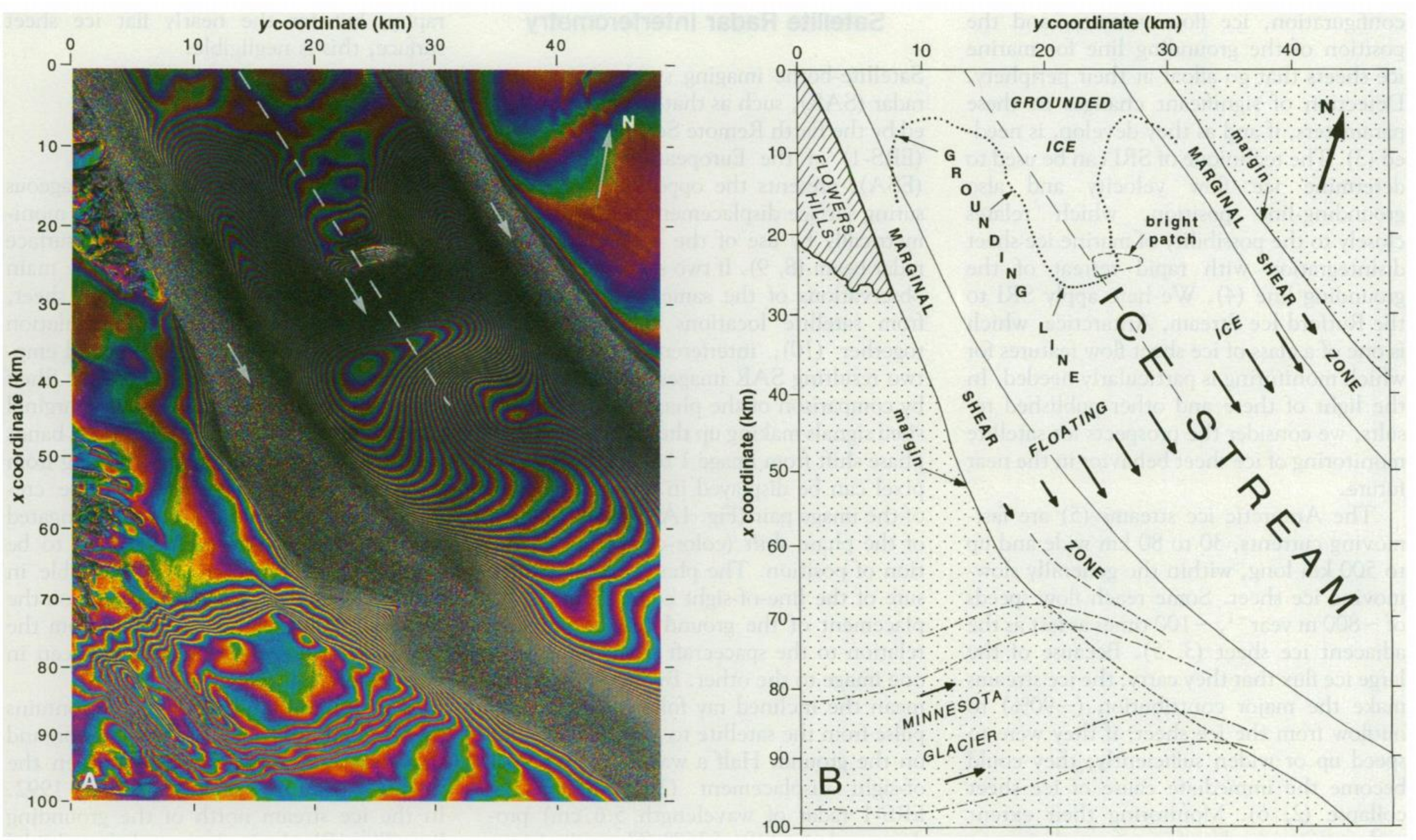


Matt Pritchard



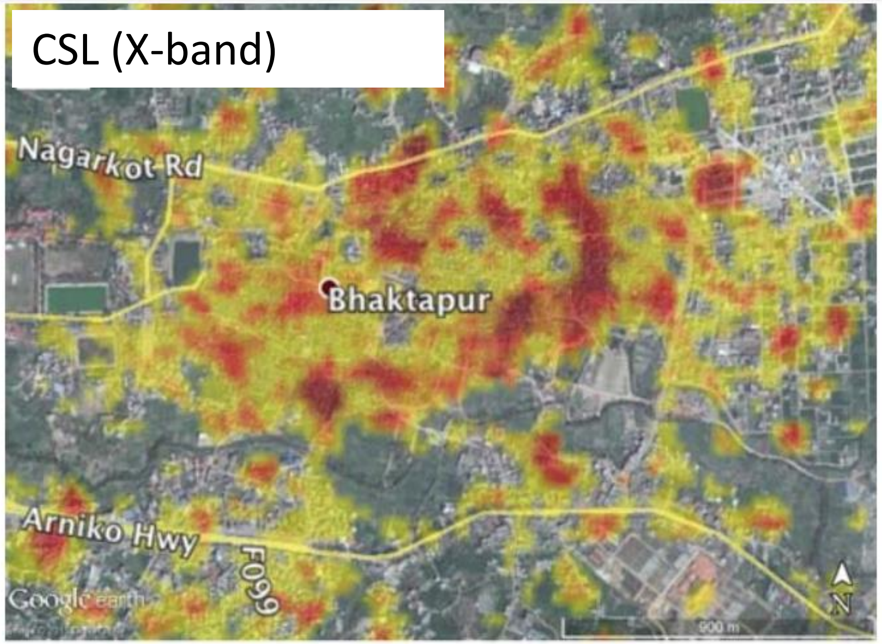
Shimon Wdowinski

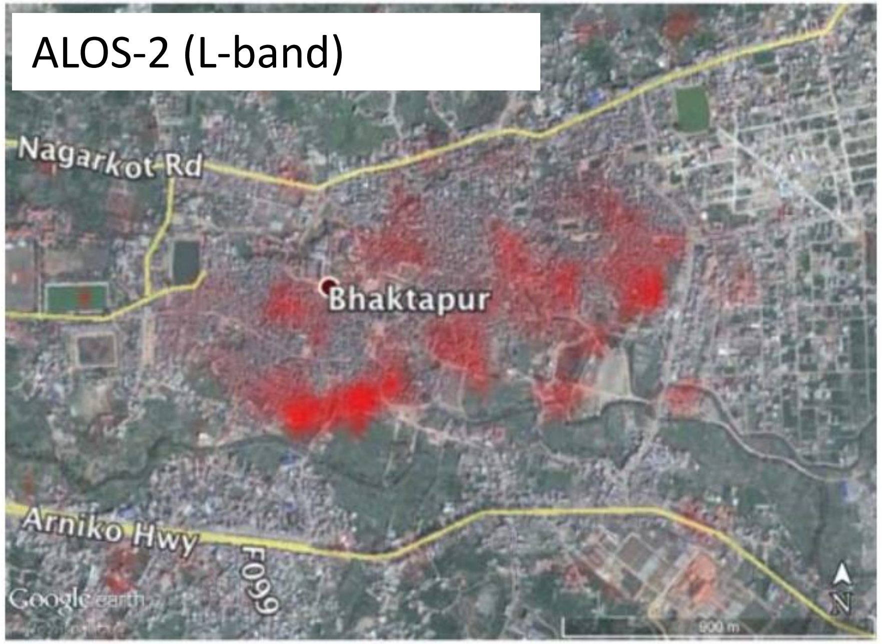
Glaciers also produce deformation detectable in a single interferogram

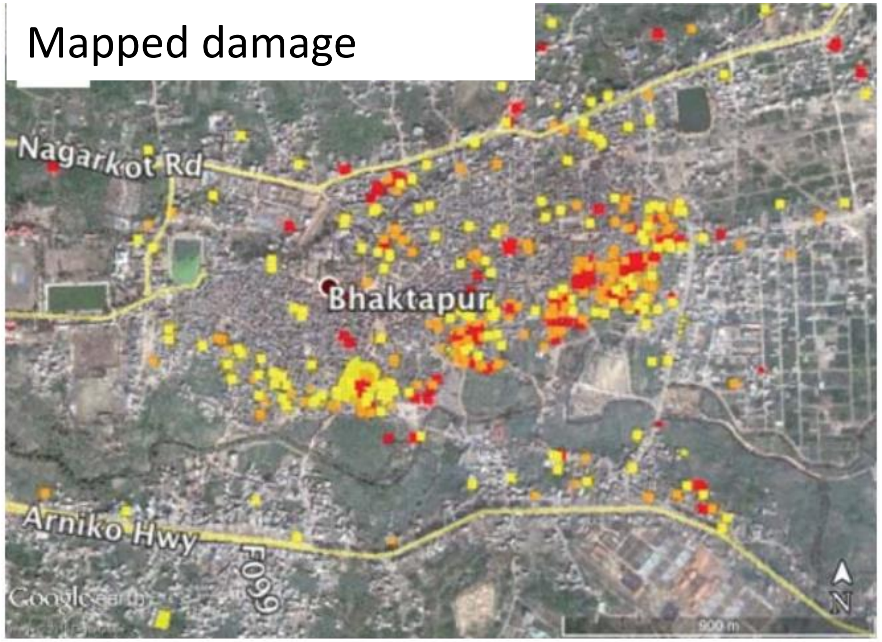


Goldstein et al. (1993)

Decorrelation can be used to map building damage in earthquakes or other disasters

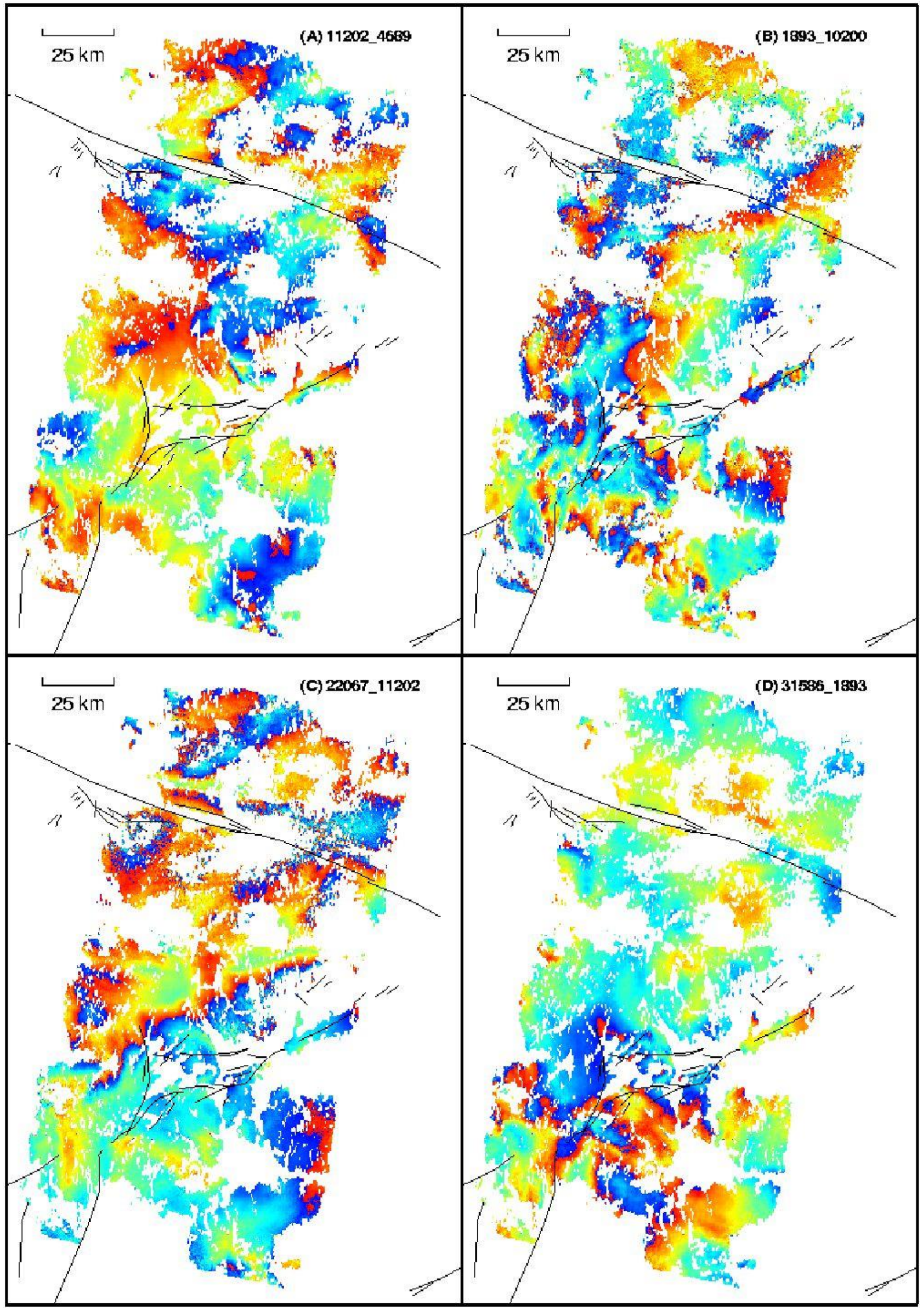






Yun et al. (2015)

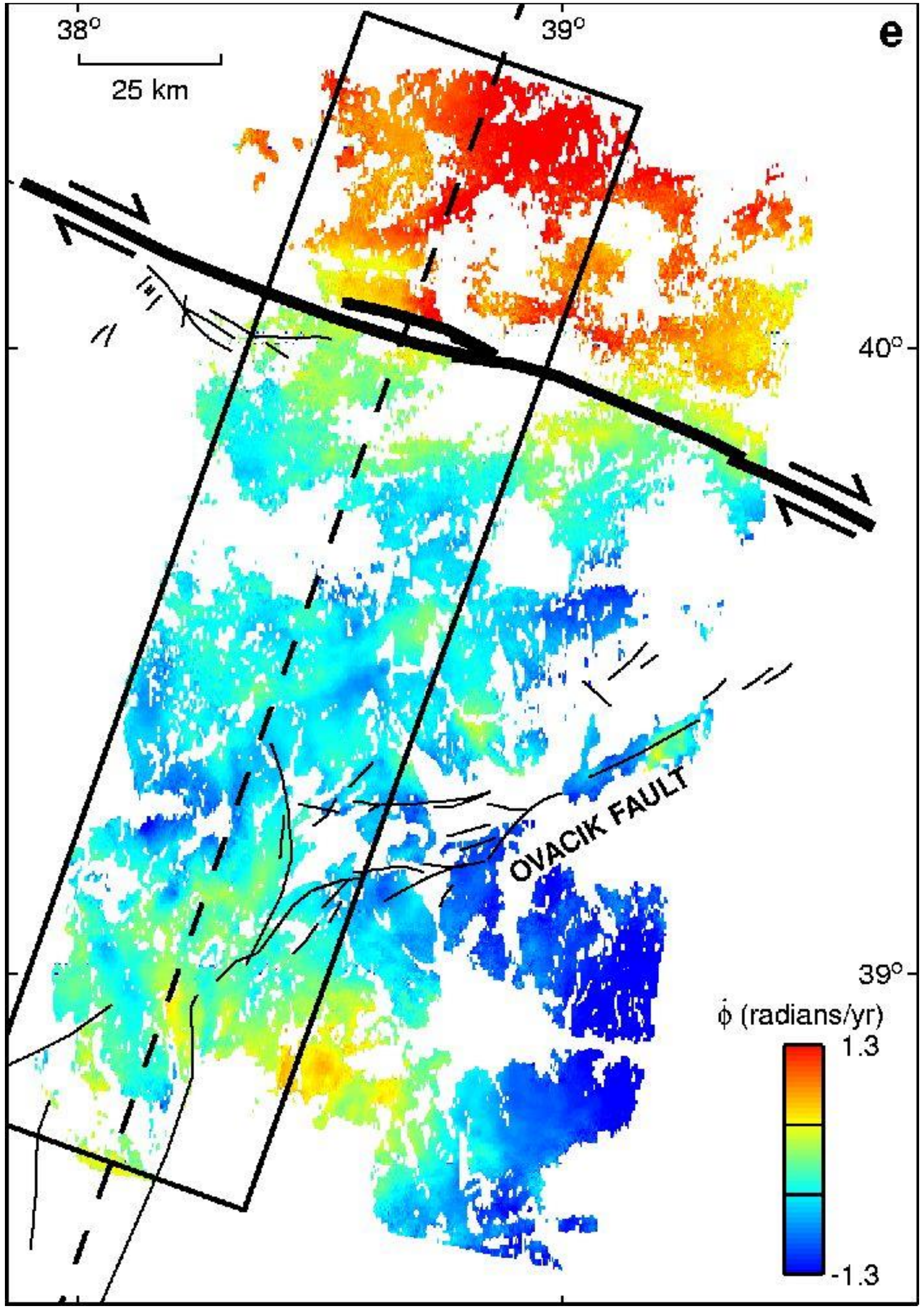
Four good interferograms



Wright et al., 2001

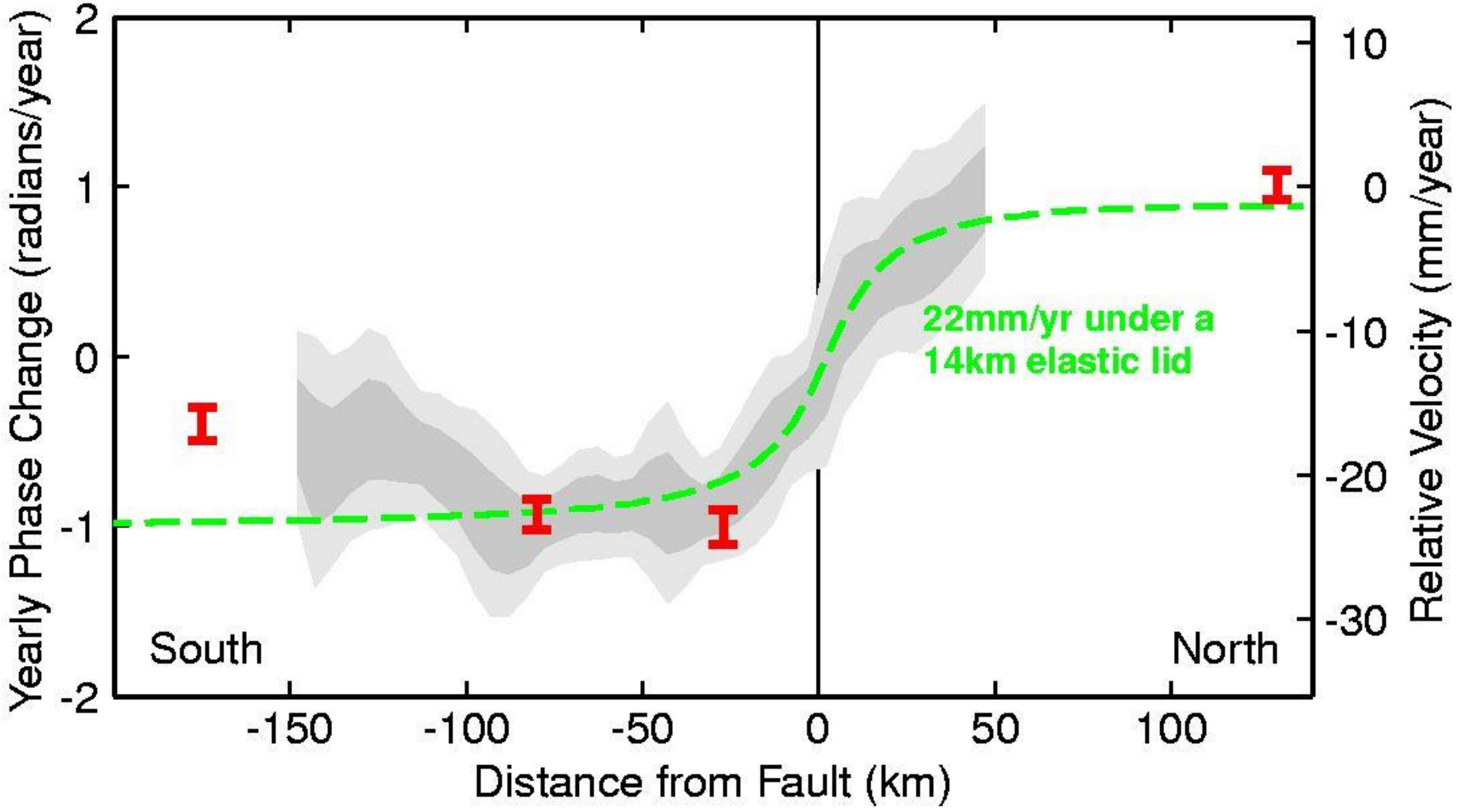
The stack

$$\text{Stack} = \frac{I1 + I2 + I3 + I4}{\Sigma\ (\text{time intervals})}$$

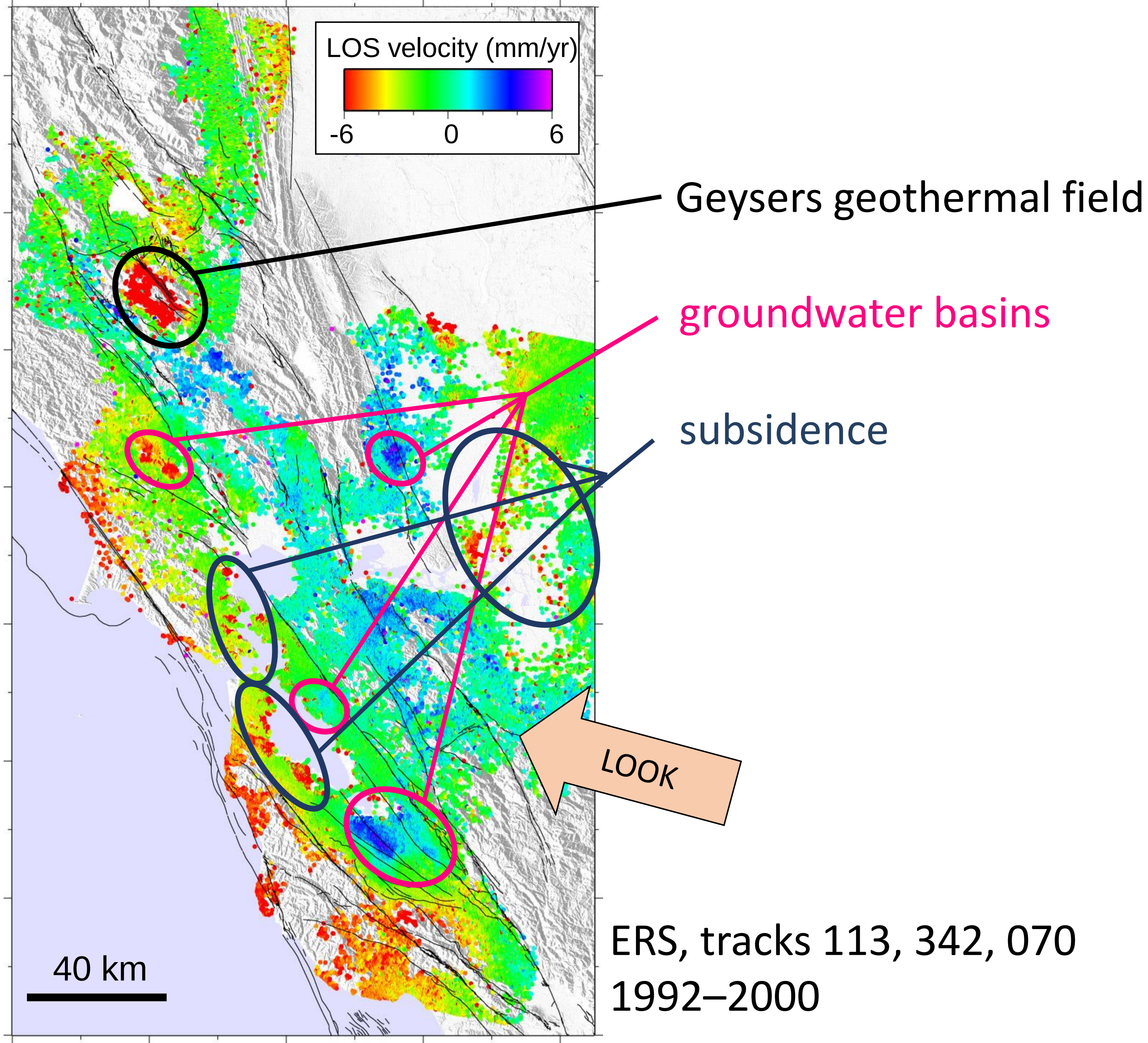


Wright et al., 2001

Interseismic deformation model fits a profile through the stack

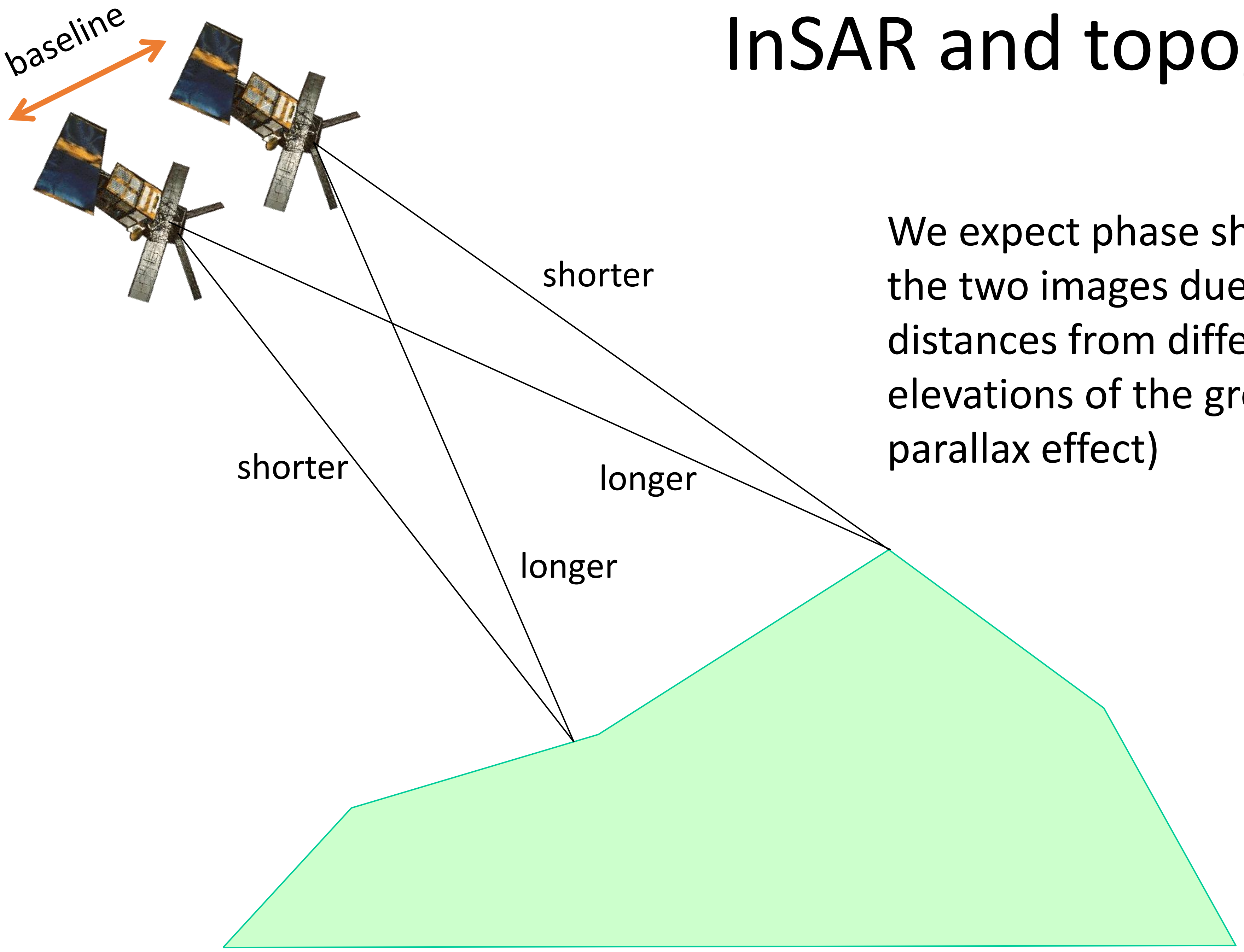


Wright et al., 2001



ERS, tracks 113, 342, 070
1992–2000

InSAR and topography

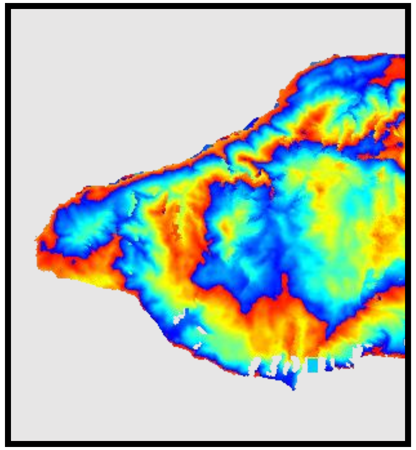


We expect phase shifts between the two images due to different distances from different elevations of the ground (a parallax effect)

Relationship between phase and topography

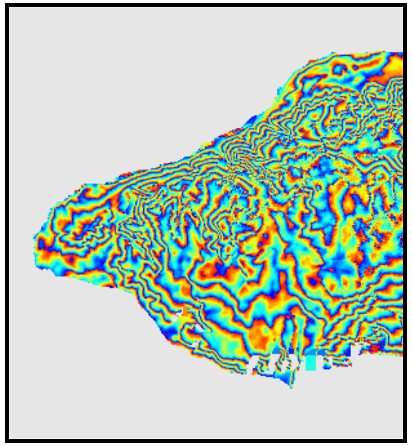
$h_a = 500$ m

$B_\perp = 30$ m



$h_a = 100$ m

$B_\perp = 150$ m



- The phase shift due to topography is more pronounced the further apart (in space) the two images were acquired (i.e. the larger the perpendicular baseline)
- We define h_a, the 'altitude of ambiguity', as the change in elevation that would cause 1 fringe

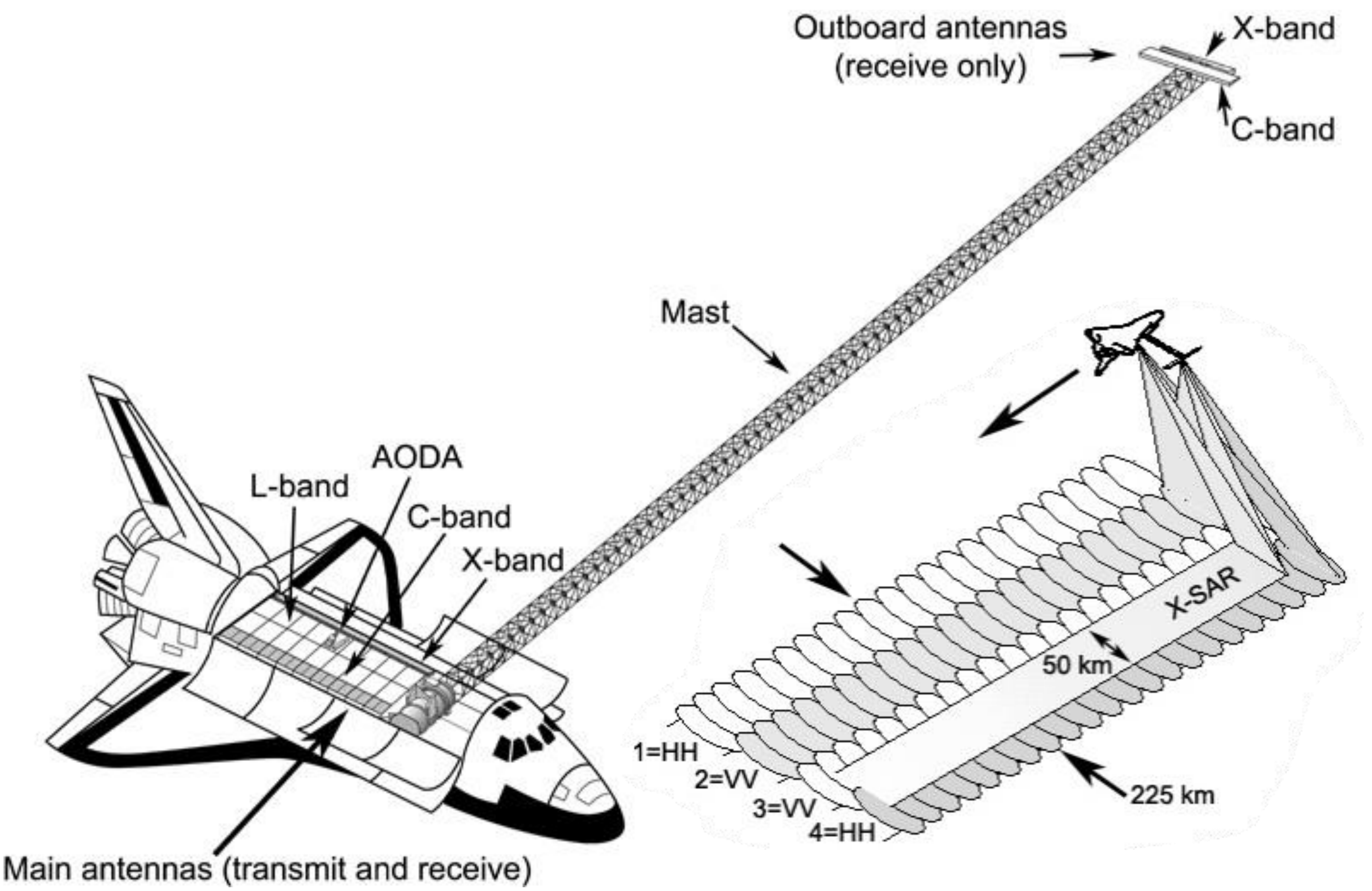
For Sentinel-1: $$h_a \approx \frac{15000}{B_\perp}$$

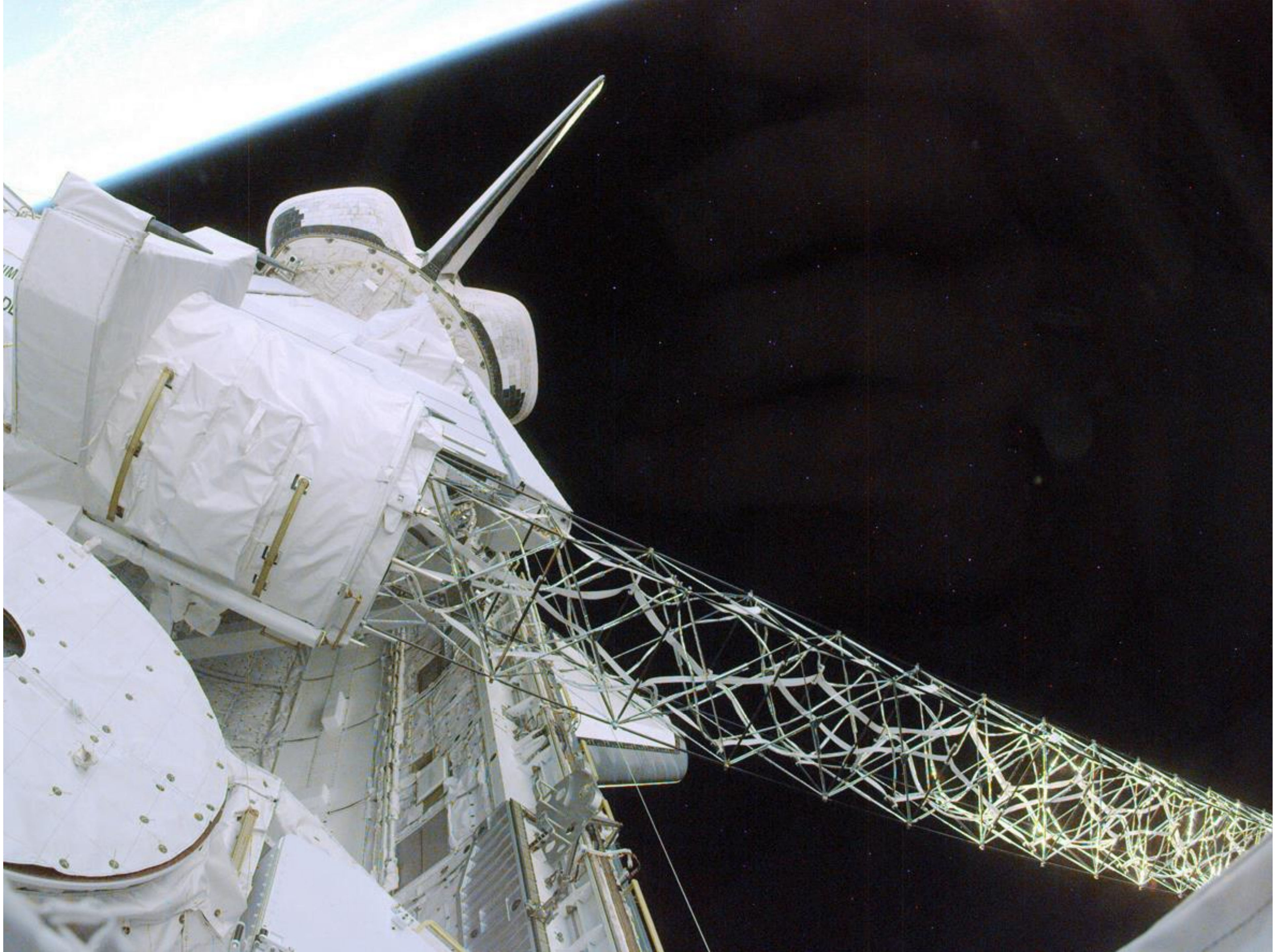
- $B_\perp$ is the component of the baseline between the satellite positions that is perpendicular to the line-of-sight to the ground.

The Shuttle Radar Topography Mission

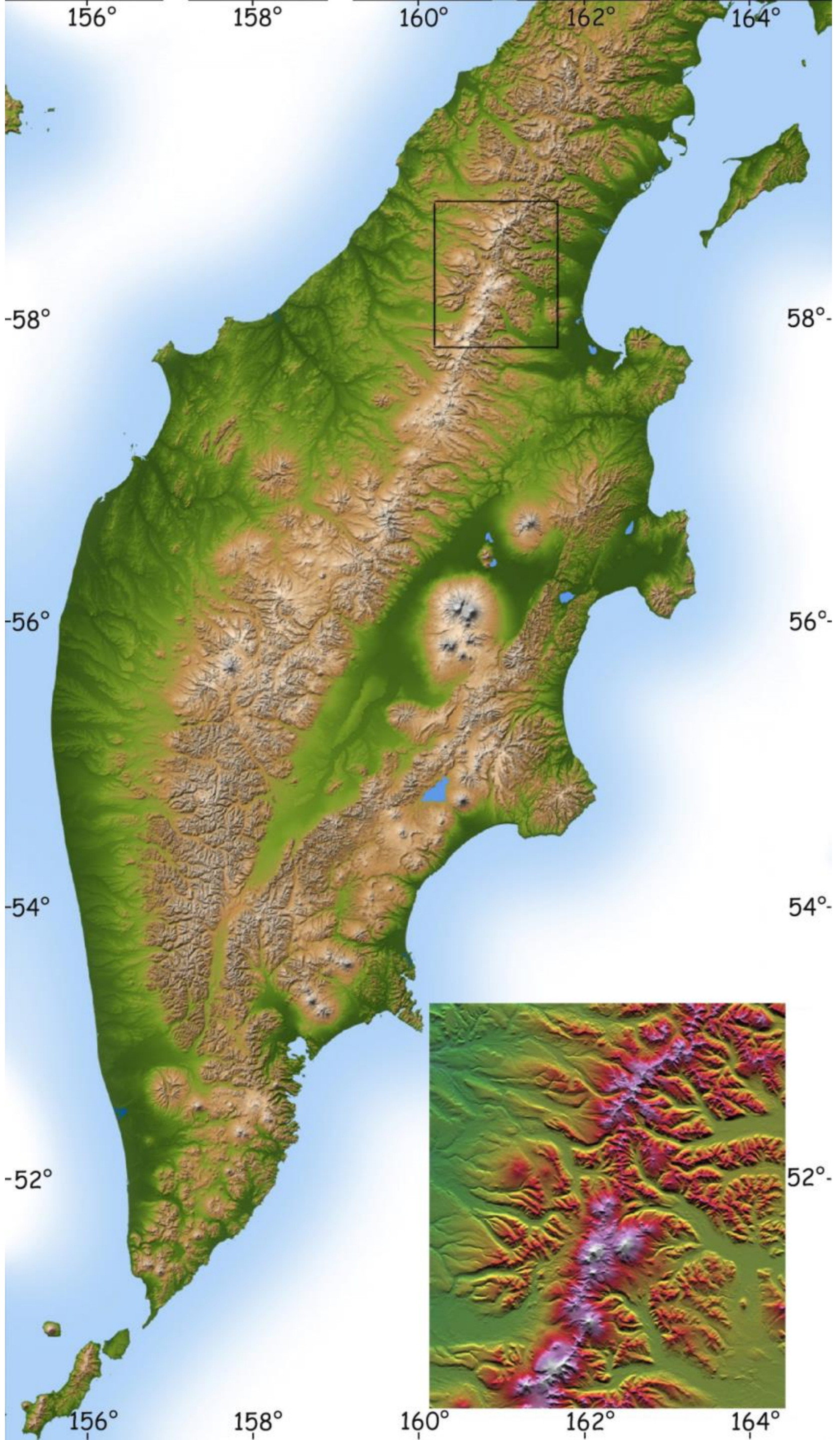
- Space Shuttle Endeavour flew for 11 days in February 2000 carrying 2 pairs of SAR antennae (C- and X-band)
- Simultaneous data acquisiton – no problems from decorrelation or atmosphere
- Swath width of 225 km meant that the whole world between 60ºN and 56°S could be mapped in 1 orbit cycle
- 12.3 terrabytes of data recorded
- 1 arcsecond resolution (~30 m); 3 arcsecond also available
- Ocean height was used as ground control

The Shuttle Radar Topography Mission

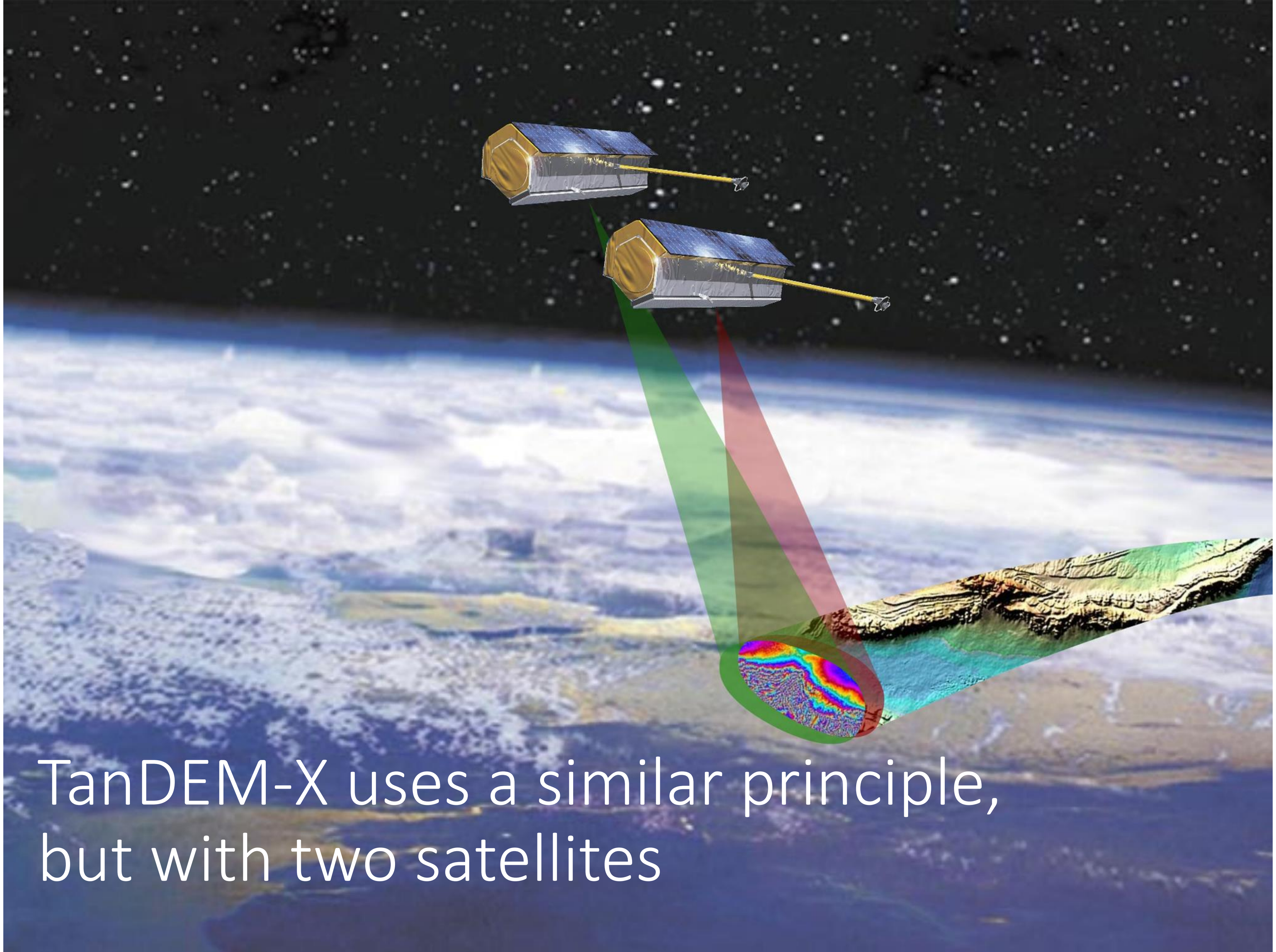




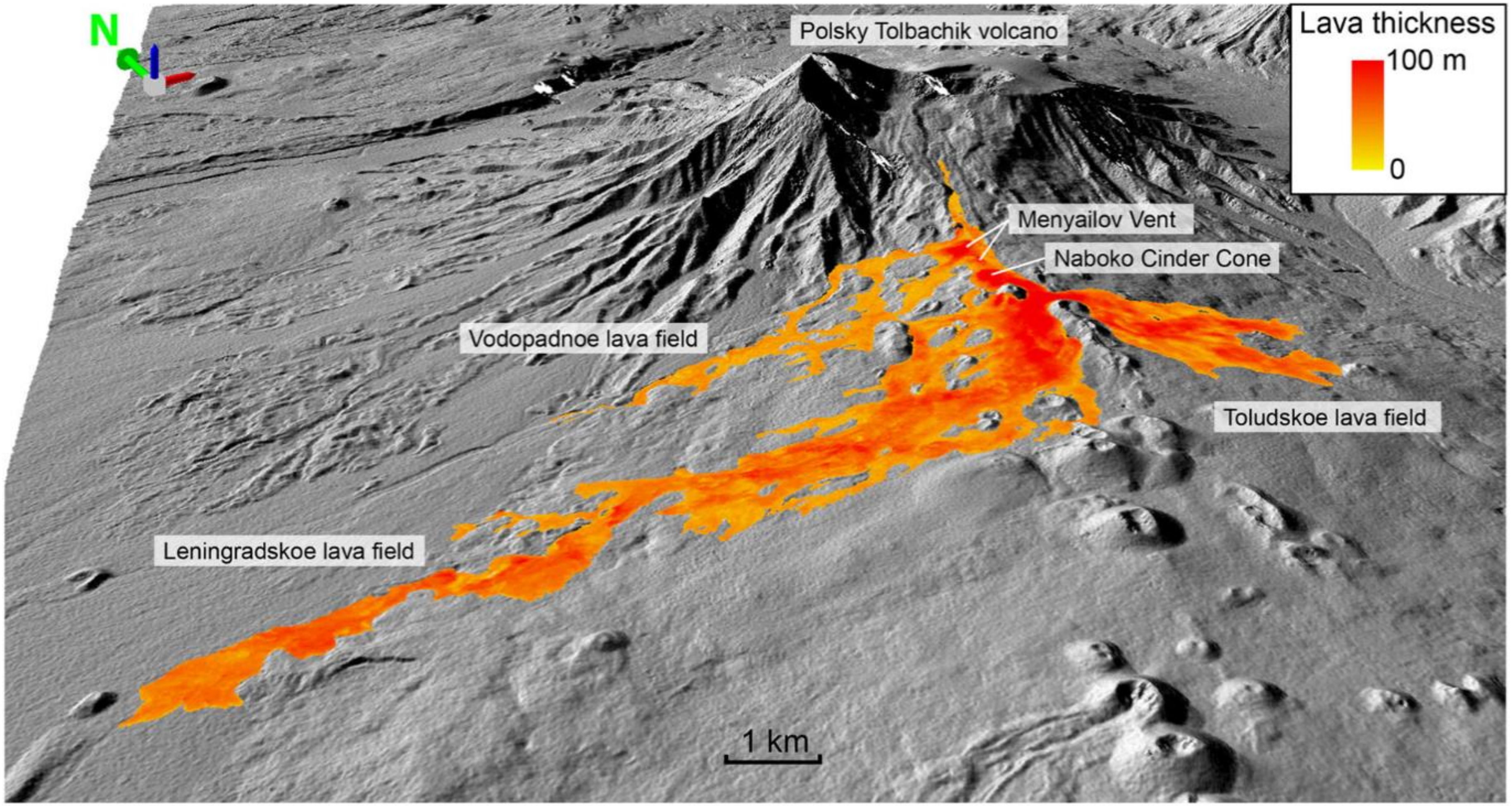
SRTM data: the Kamchatka peninsula



All released data available at http://earthexplorer.usgs.gov


TanDEM-X uses a similar principle,
but with two satellites

DEM differencing can reveal erupted lava volume, volcano shape changes



Kubanek et al., 2015