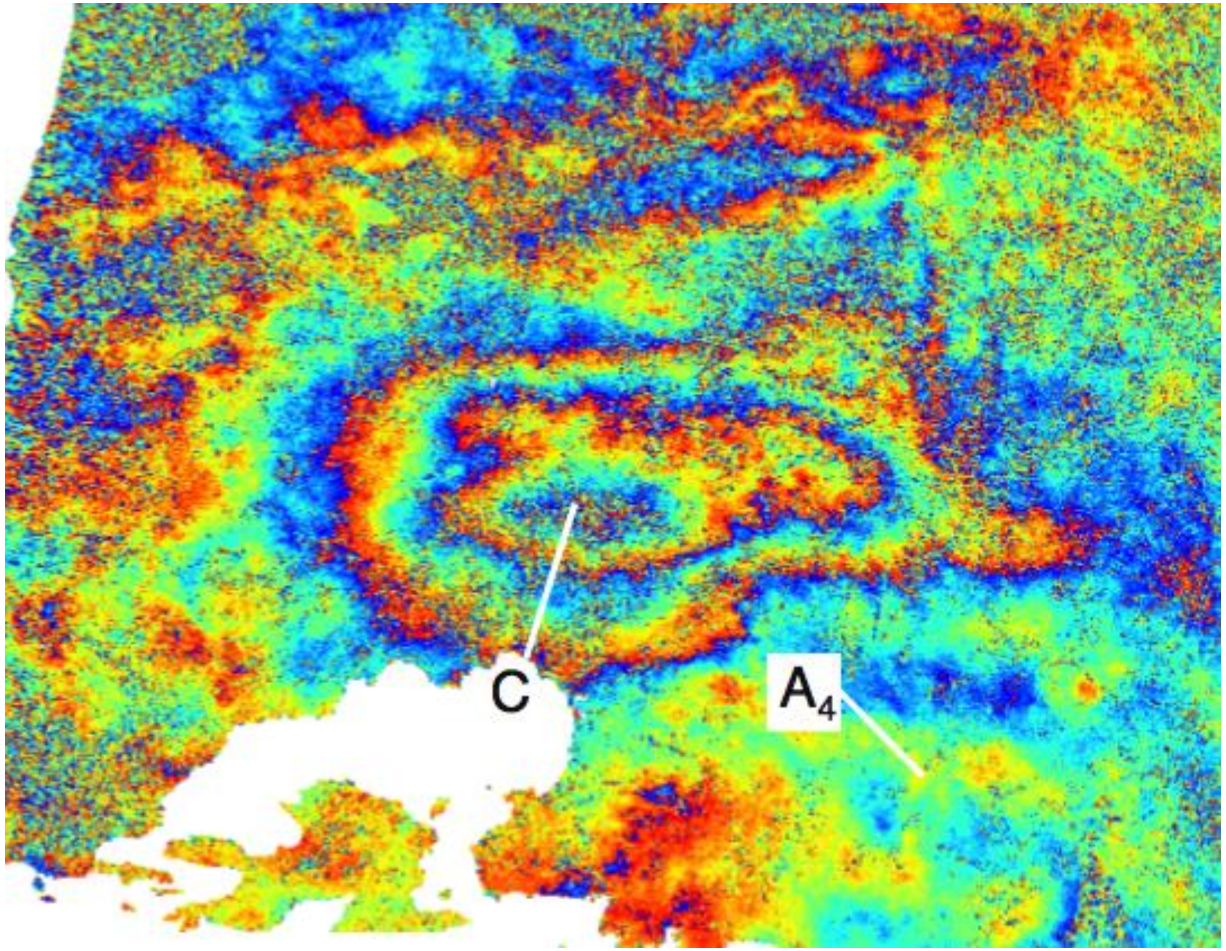
InSAR training 2024



Contributions to interferometric phase

Outline

The contributions to interferometric phase

- – orbit
- – topography
- – atmosphere
- – in-pixel scatterers
- – deformation

Components of interferometric phase

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

The phase of an individual interferogram can be divided into five parts:

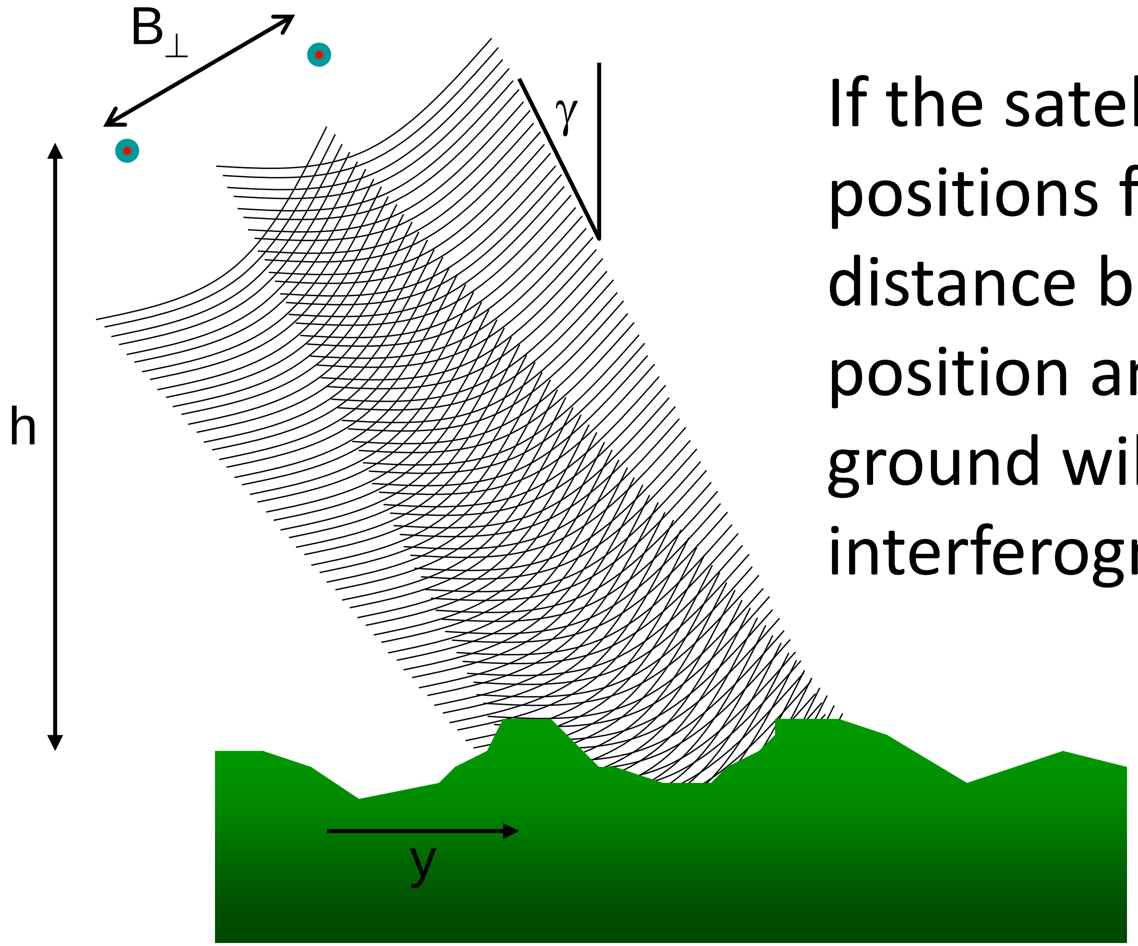
Three are related to the difference in distance between the satellite and the ground

One is related to the difference in the properties of the medium that the radar pulse moves through

One is related to the change in properties of the pixel on the ground

Orbital phase (1)

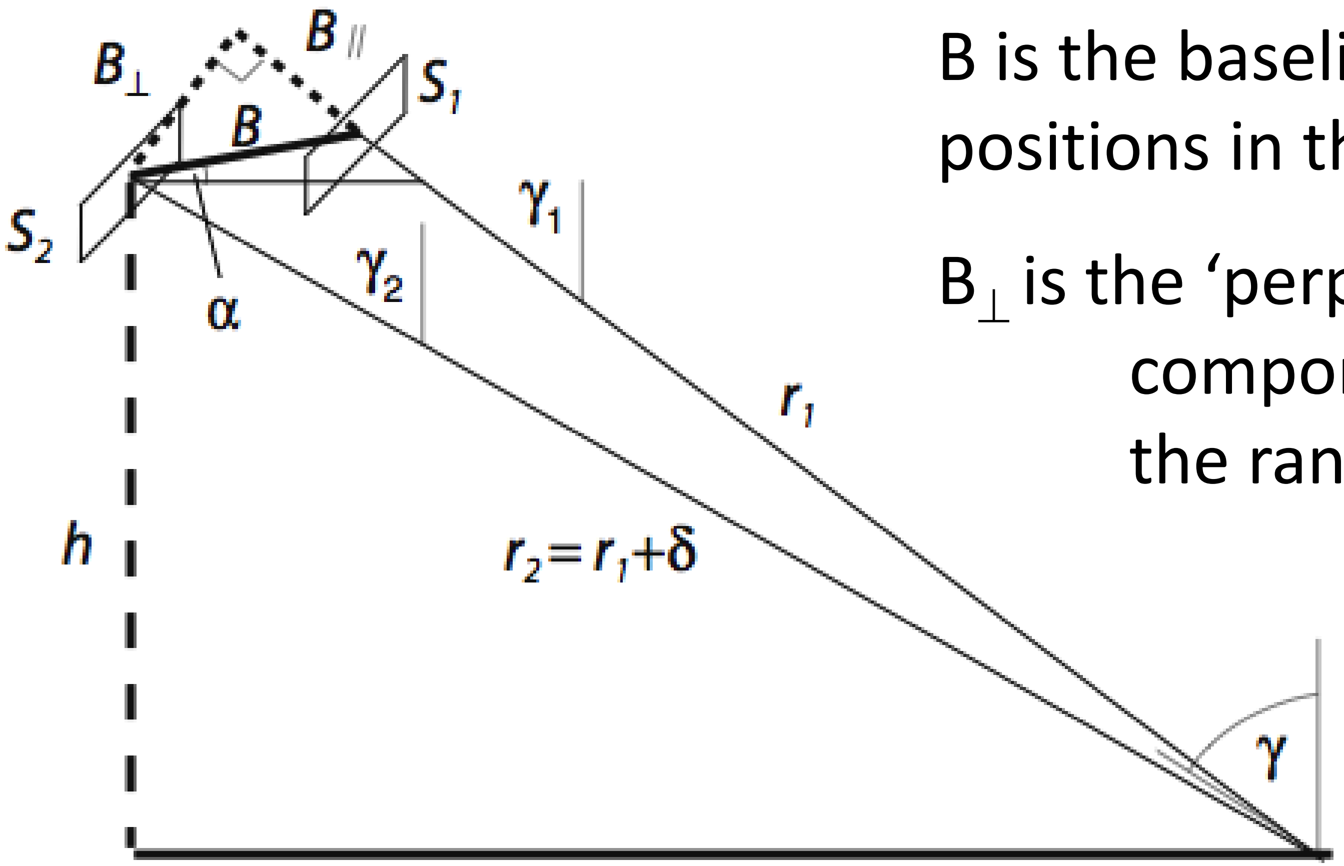
$$\Delta\phi_{int} = \Delta\phi_{orb} + \Delta\phi_{topo} + \Delta\phi_{atm} + \Delta\phi_{pixel} + \Delta\phi_{def}$$



If the satellite is in different orbital positions for the two images, the distance between each satellite position and successive points on the ground will vary across the whole interferogram

Orbital phase (2)

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



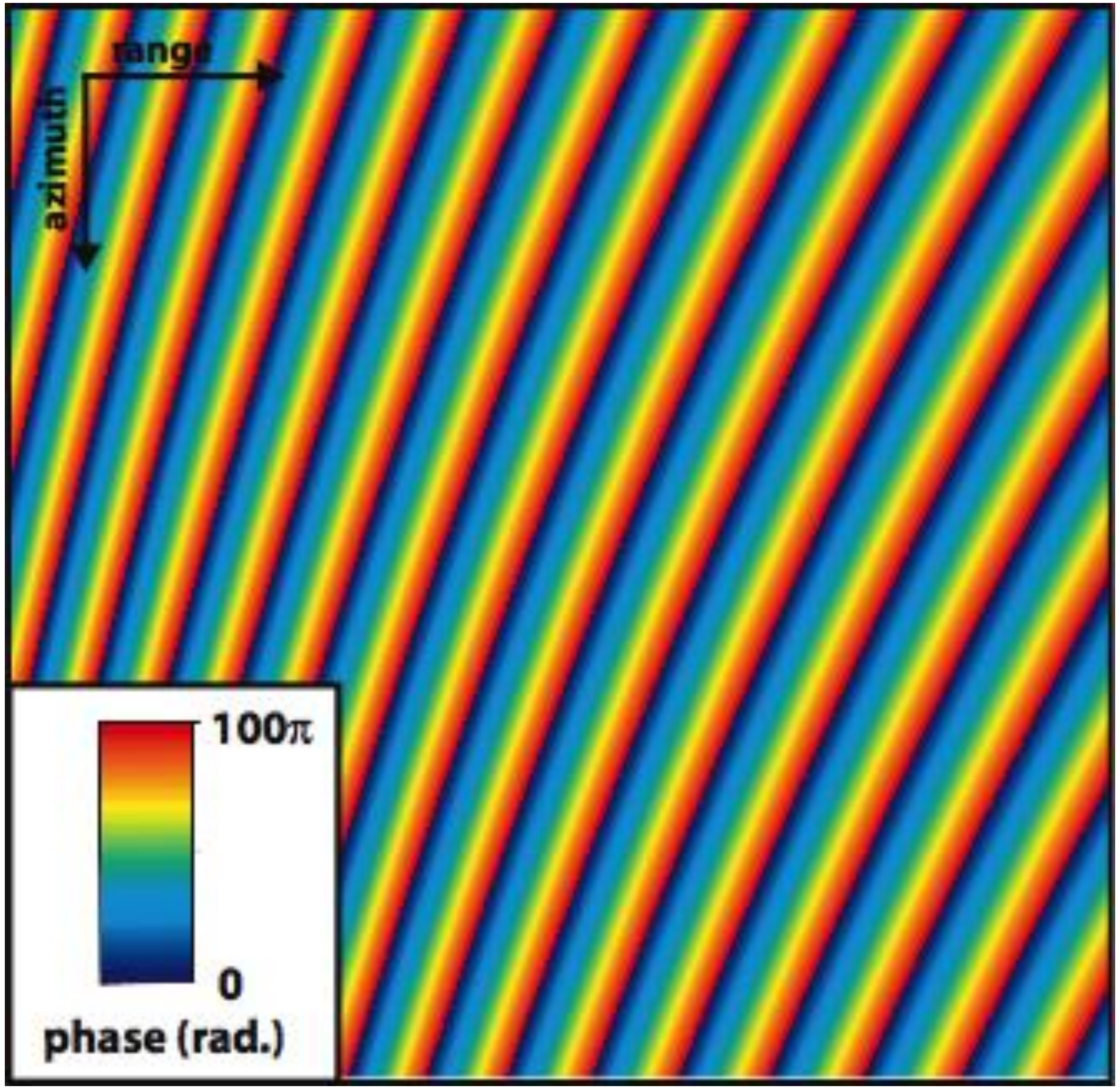
B is the baseline – the distance between satellite positions in the cross-track plane

$B_\perp$ is the 'perpendicular baseline', the component of baseline perpendicular to the range direction

$$\frac{\partial\phi}{\partial y} = \frac{4\pi B_\perp \cos^2\gamma}{h\lambda}$$

Orbital phase (3)

The orbital phase component is usually the largest contributor to an interferogram



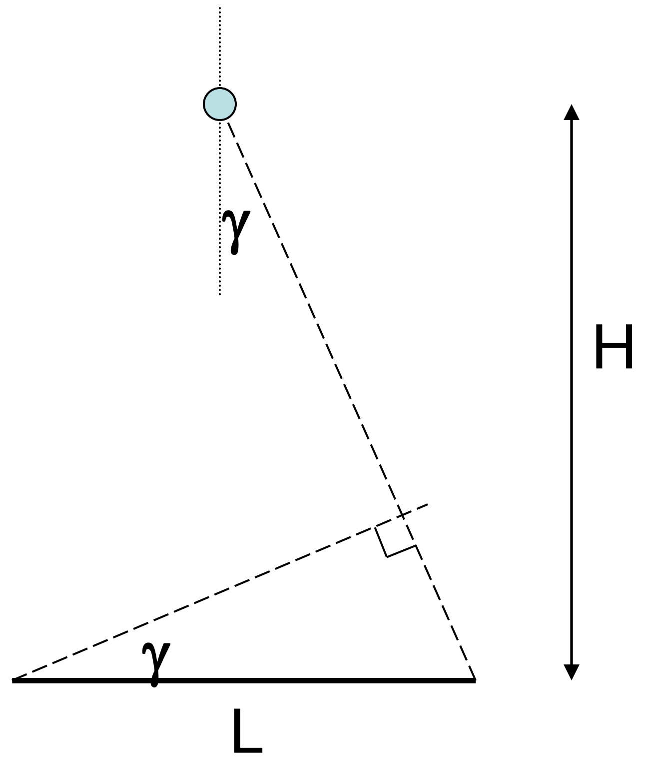
ERS-1, baseline varies between 121 m at the top and 136 m at the bottom

The critical baseline

In order to identify the phase ramp between pixels, it cannot exceed a shift of 2π (or a round-trip distance of λ) per pixel

Difference in round trip distance at ends of a pixel with length L:

$$2L \sin \gamma$$



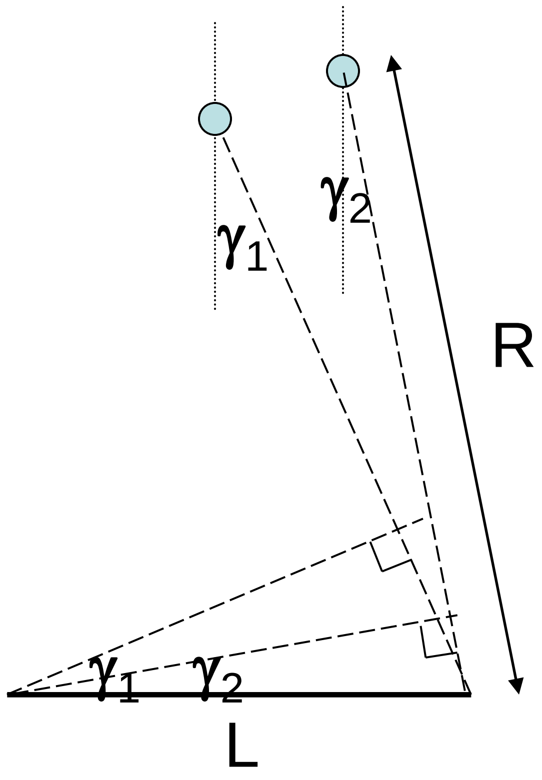
The critical baseline

In order to identify the phase ramp between pixels, it cannot exceed a shift of 2π (or a round-trip distance of λ) per pixel

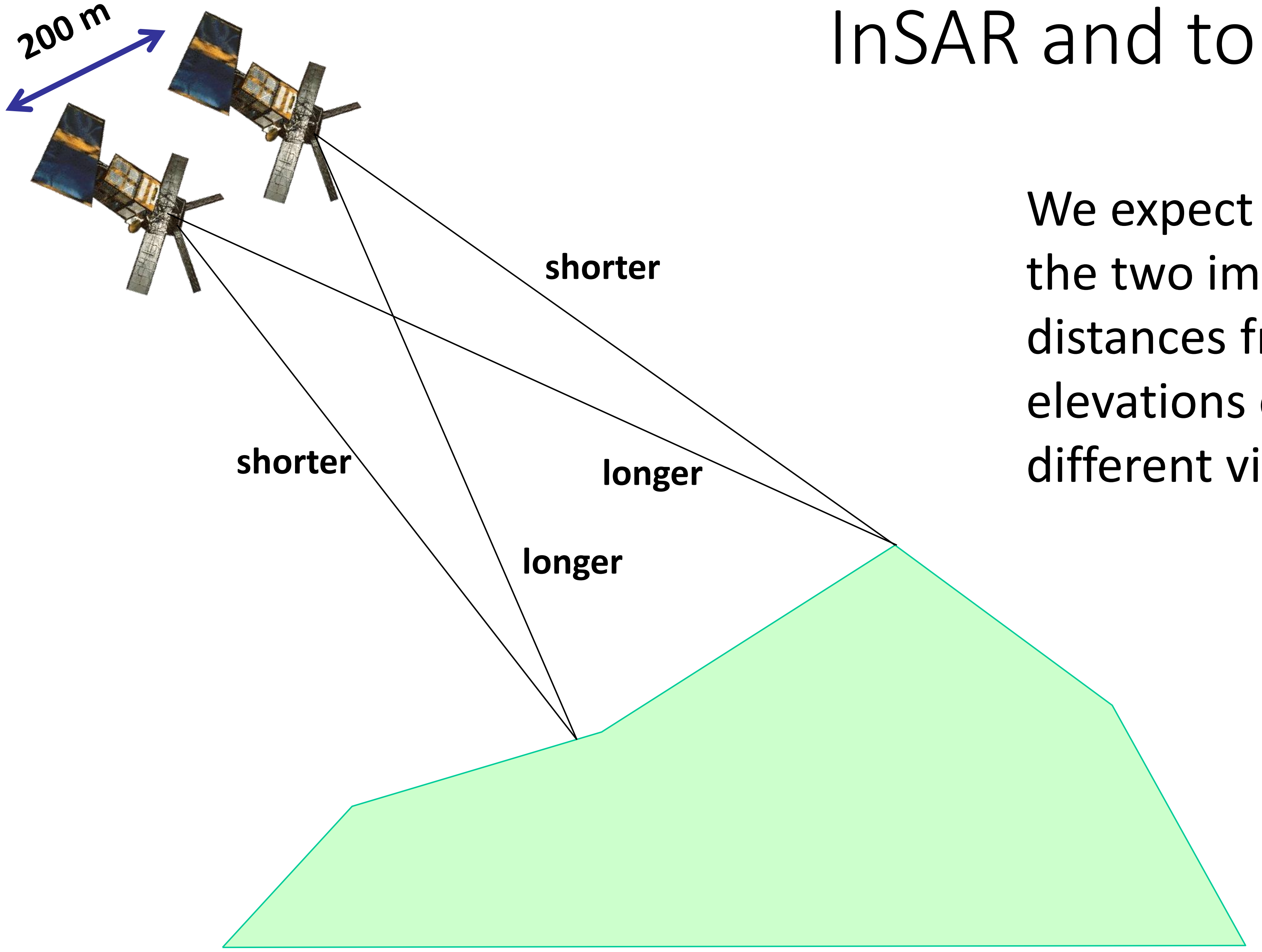
Difference in difference in round trip distance at ends of a pixel with length L must be less than λ:

$$2L\,(\sin \gamma_1 - \sin \gamma_2) < \lambda$$

If $L = 20$ m, $R = 850$ km, $\gamma_1 \approx \gamma_2 \approx 23°$ and $\lambda = 0.056$ m, what is the critical baseline?



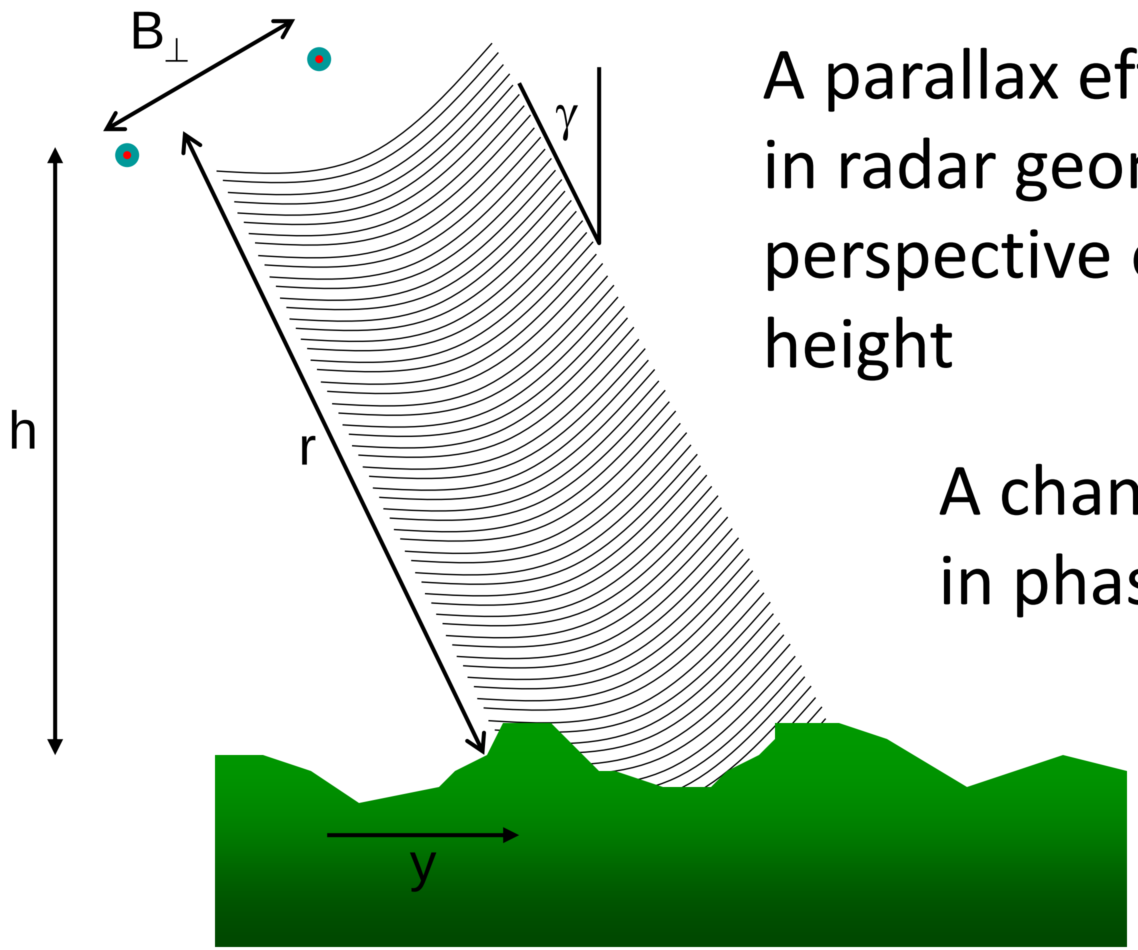
InSAR and topography



We expect phase shifts between the two images due to different distances from different elevations of the ground at different viewing positions

Topographic phase (1)

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



A parallax effect (like stereoscopy, but in radar geometry) gives different perspective on changes in topographic height

A change in height, h_a, equals 2π in phase change

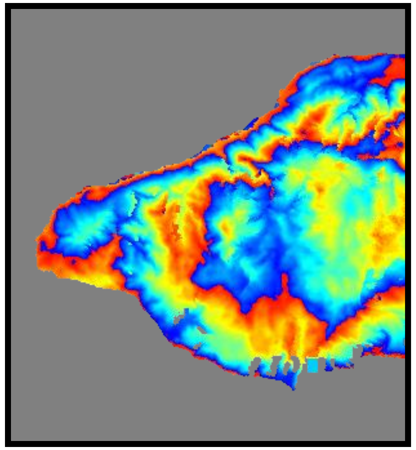
$$h_a = \frac{r\lambda \sin\gamma}{2B_\perp}$$

Topographic phase (2)

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

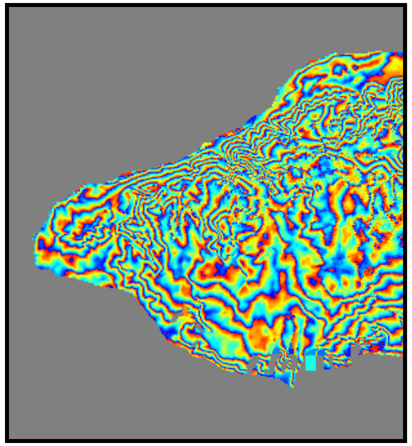
h_a = 500 m

$B_\perp$ = 20 m



h_a = 100 m

$B_\perp$ = 100 m



- Stereoscopic effect $\Rightarrow$ topographic fringes
- 1 fringe for each change in elevation h_a

$$h_a = \frac{r\lambda \sin\gamma}{2B_\perp} \approx \frac{10{,}000}{B_\perp} \quad \text{(for ERS)}$$

- Remove Df_{topo} using a pre-existing DEM
- Quality of DEM required f(h_a)

  Height error = ε_h

  $\Rightarrow$ phase error = 2p(e_h / h_a)

Atmospheric phase (1)

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

A foggy morning, near ancient Mycenae, Greece

Atmospheric phase (2)

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

Atmosphere contributes to measured phase:

$$path\_delay = \int_0^{atm\_thickness} (n_1(h) - n_2(h))dh$$

n = refractive index,

= f (**humidity**, temperature, pressure)

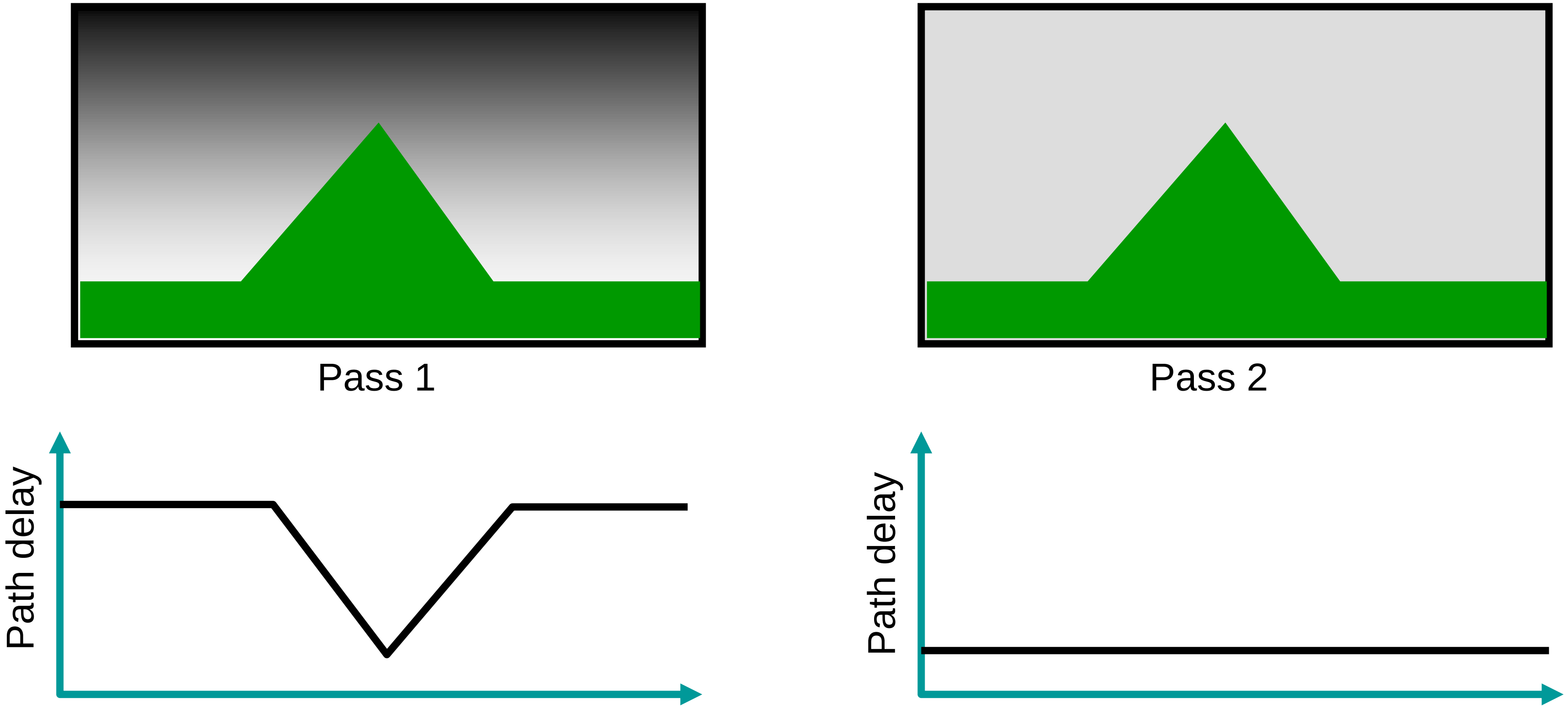
- varies by very small amount
- BUT, integrated over whole atmosphere

$\Rightarrow$ differential path delays of up to 10 cm in extreme cases.

Atmospheric phase (3)

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

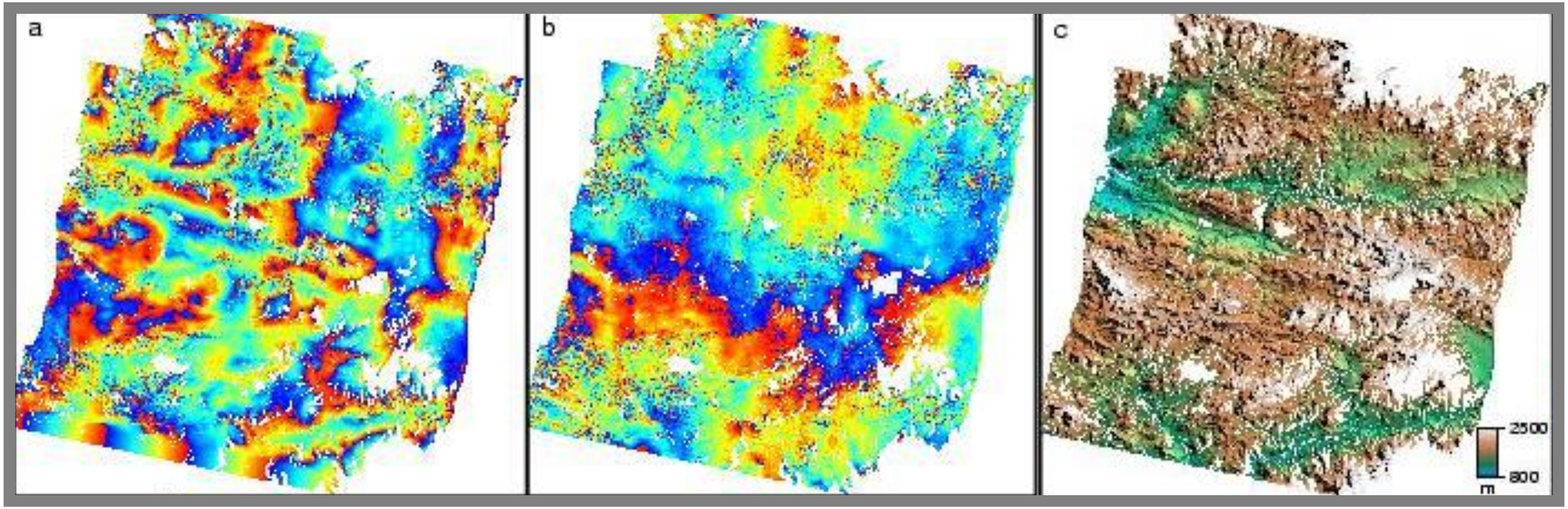
Layered atmosphere



Atmospheric phase (4)

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

Layered atmosphere



29/8/1995 to 29/7/1997

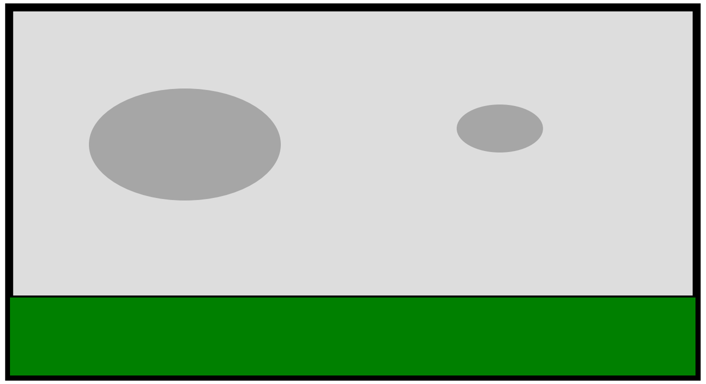
30/8/1995 to 29/7/1997

Topography

Atmospheric phase (5)

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

Turbulent atmosphere



Pass 1

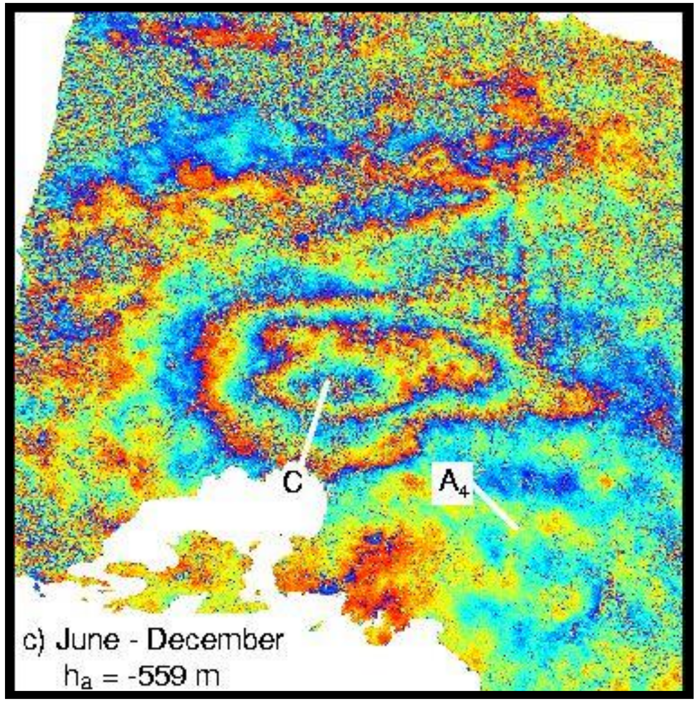
Pass 2

Atmospheric phase (6)

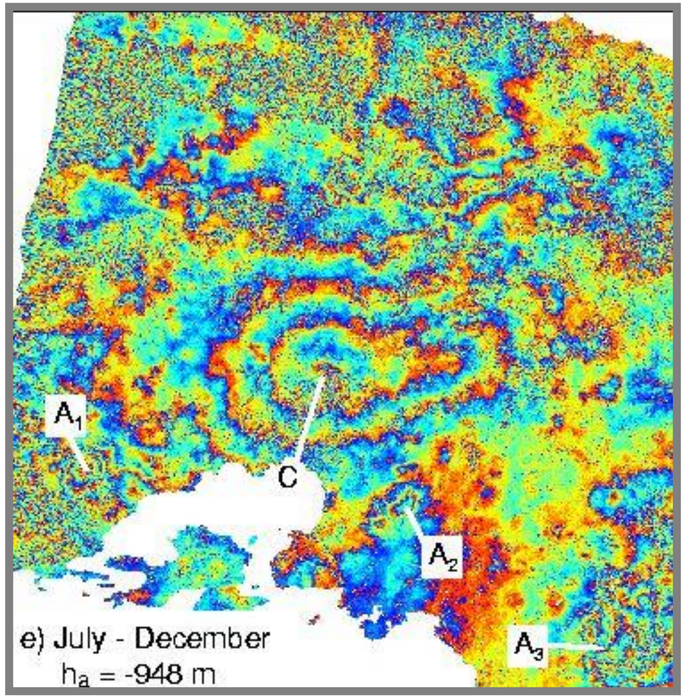
$$\Delta\phi_{int} = \Delta\phi_{orb} + \Delta\phi_{topo} + \Delta\phi_{atm} + \Delta\phi_{pixel} + \Delta\phi_{def}$$

Turbulent atmosphere

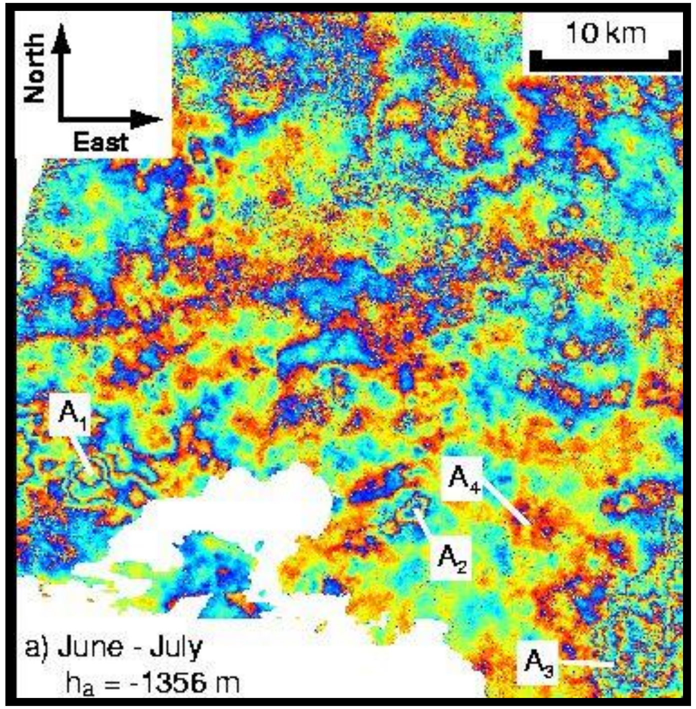
Athens Earthquake – September 1999



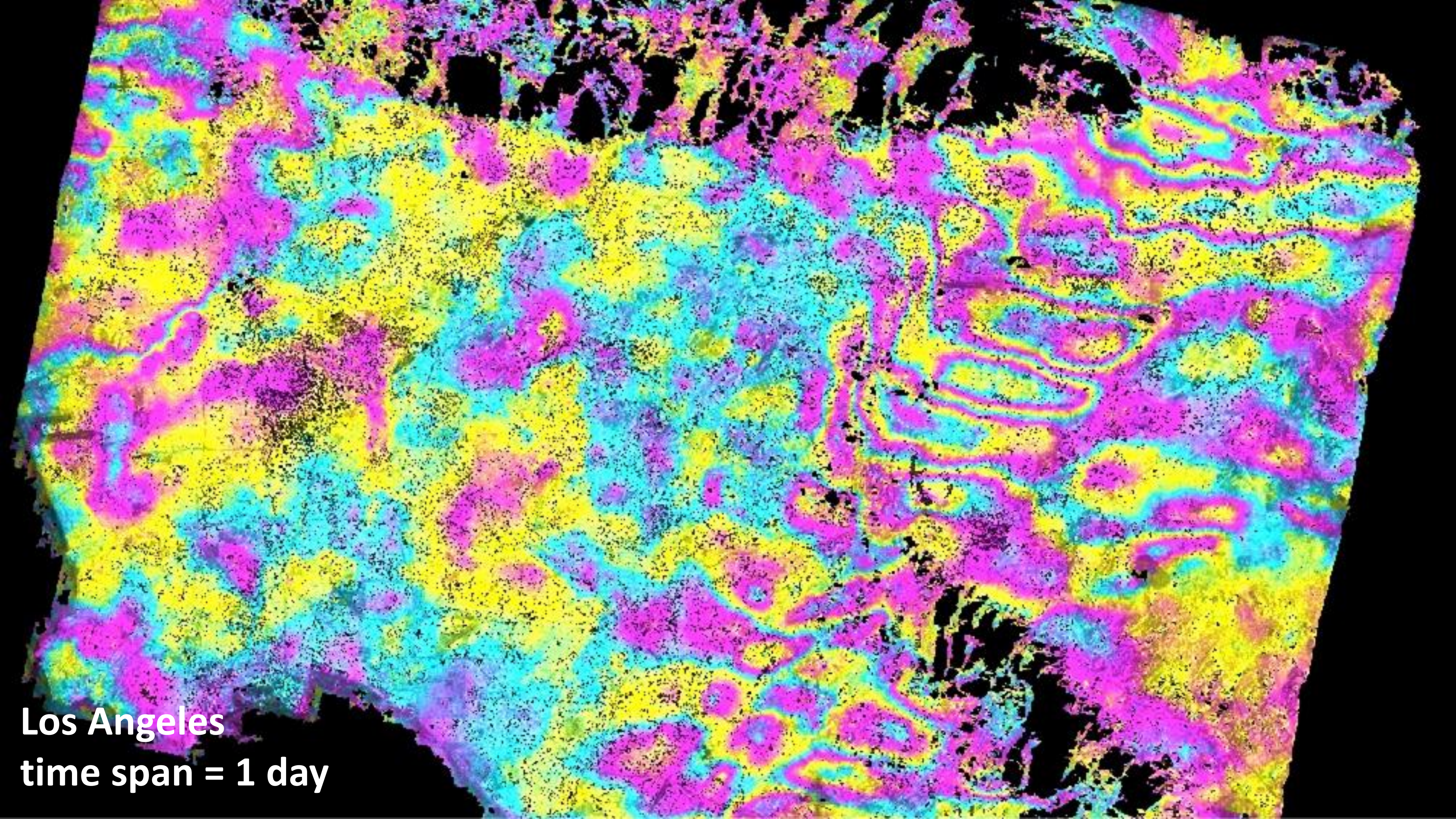
June to December



July to December

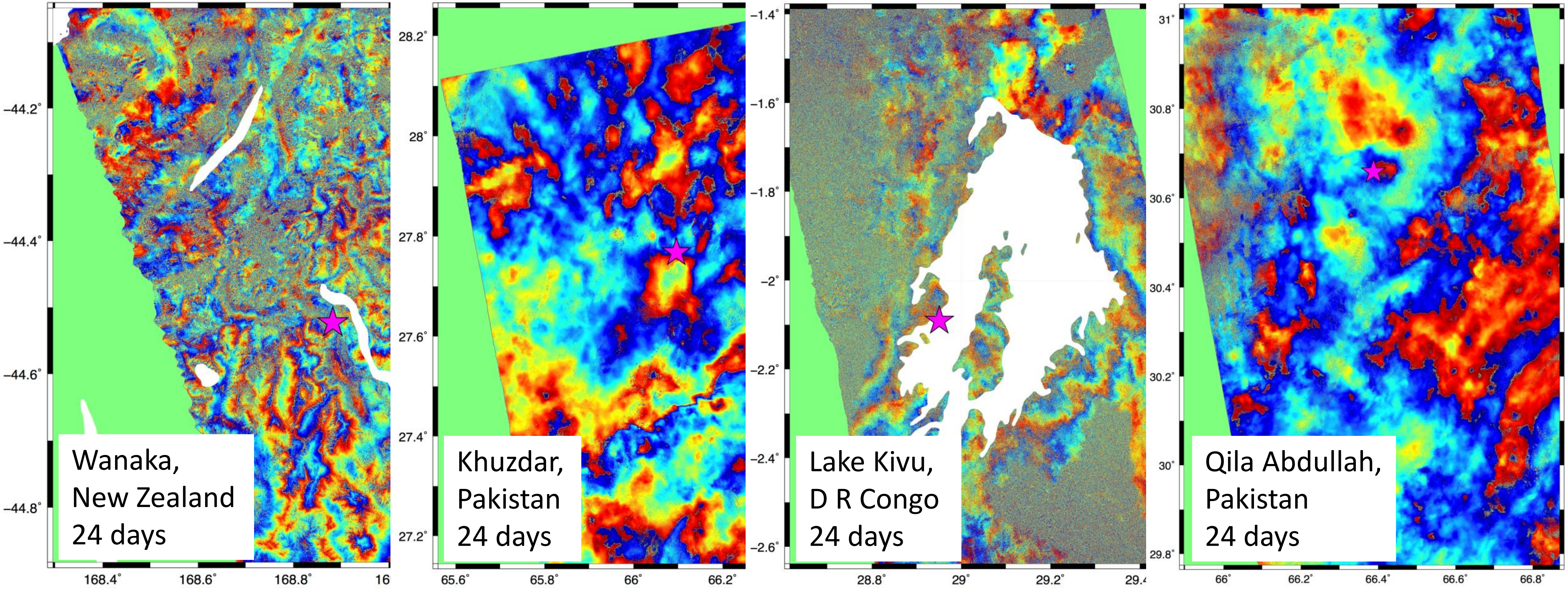


June to July


Los Angeles
time span = 1 day

Which blob?

Shortest Sentinel-1 pairs for shallow M>5.5 earthquakes



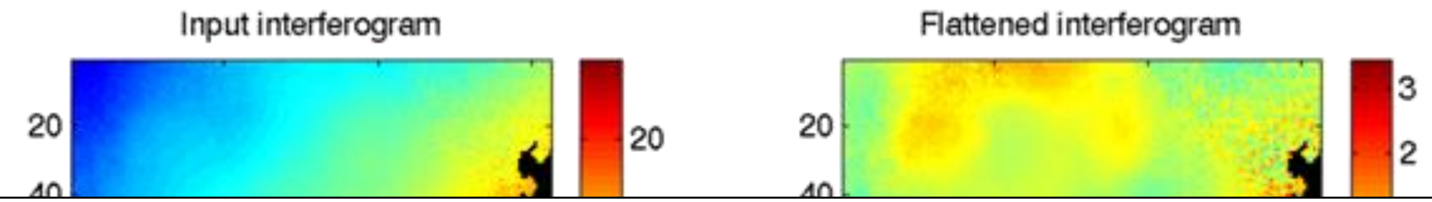
Atmospheric phase (7)

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

Size of Df_{atm} (at sea level) ~ 0 to 3 fringes (90 mm)

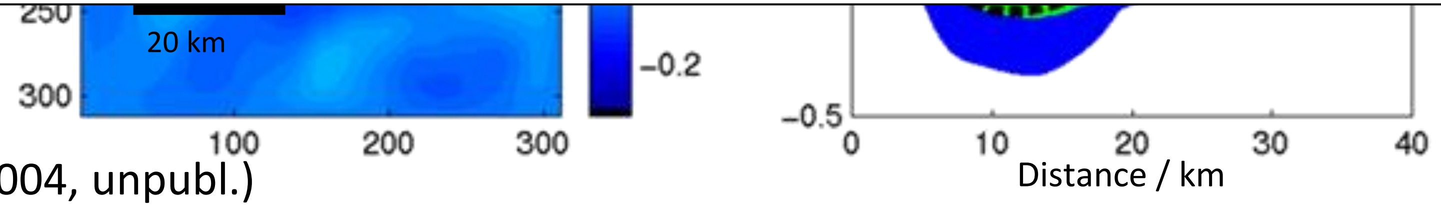
Methods for dealing with Df_{atm}

- Ignore (most common)
- Exclude
- Quantify
- Model based on other observations (e.g. GPS, meteorology…)
- Increase SNR by stacking

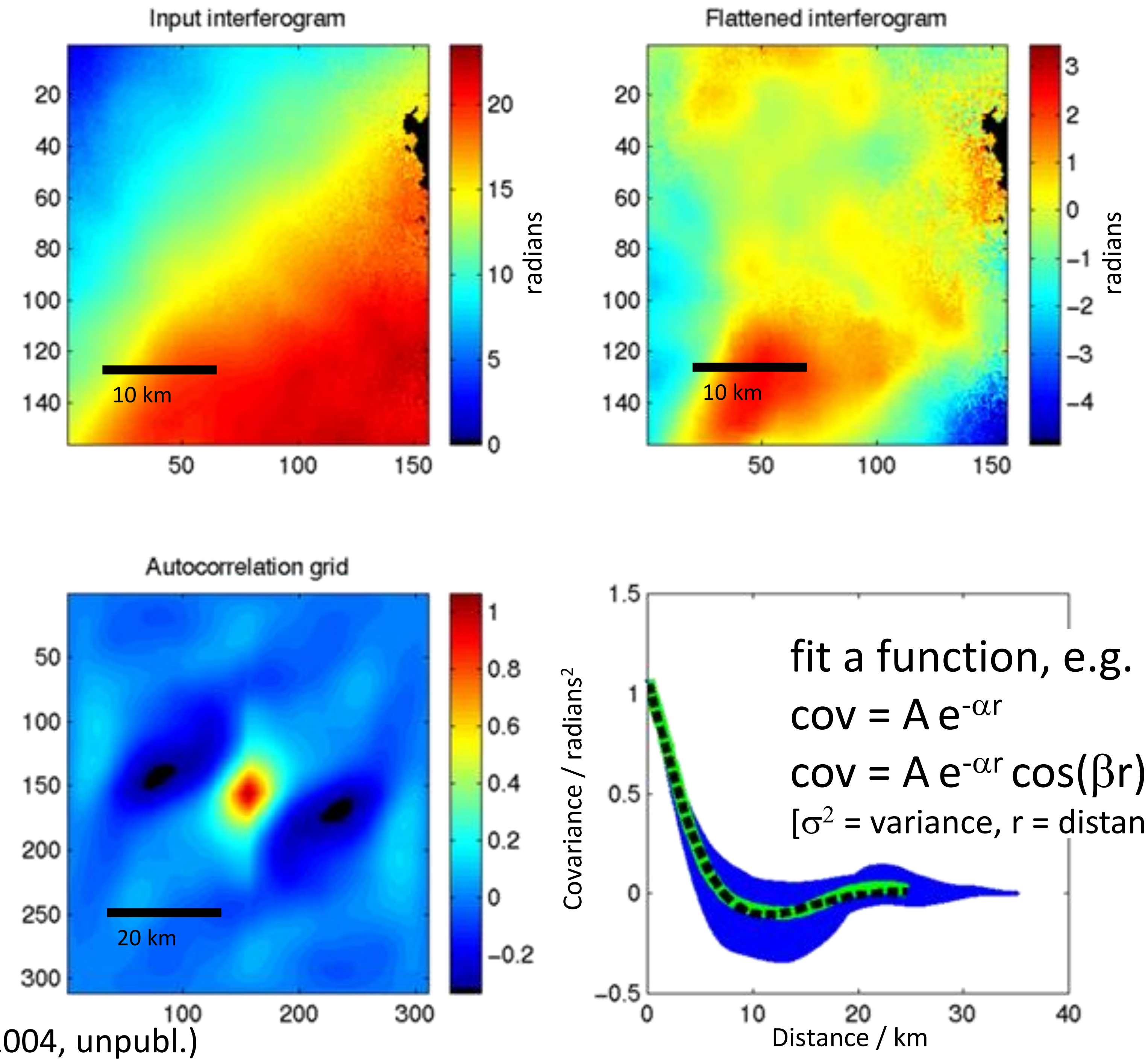


Several studies have **quantified** the tropospheric noise in interferograms (e.g. Hanssen, 2002; Wright et al., 2003; Funning et al., 2005; Lohman and Simons, 2005)

- Remove a best-fitting ramp from data
- Compute autocorrelation (can be achieved in Fourier domain) or semi-variogram
- Calculate the radial average and fit a function; its e-folding wavelength is an estimate of the correlation length scale of the noise; its amplitude an estimate of the variance of the noise



Wright, Clarke, Funning (2004, unpubl.)



fit a function, e.g.

$\text{cov} = A\, e^{-\alpha r}$

$\text{cov} = A\, e^{-\alpha r} \cos(\beta r)$

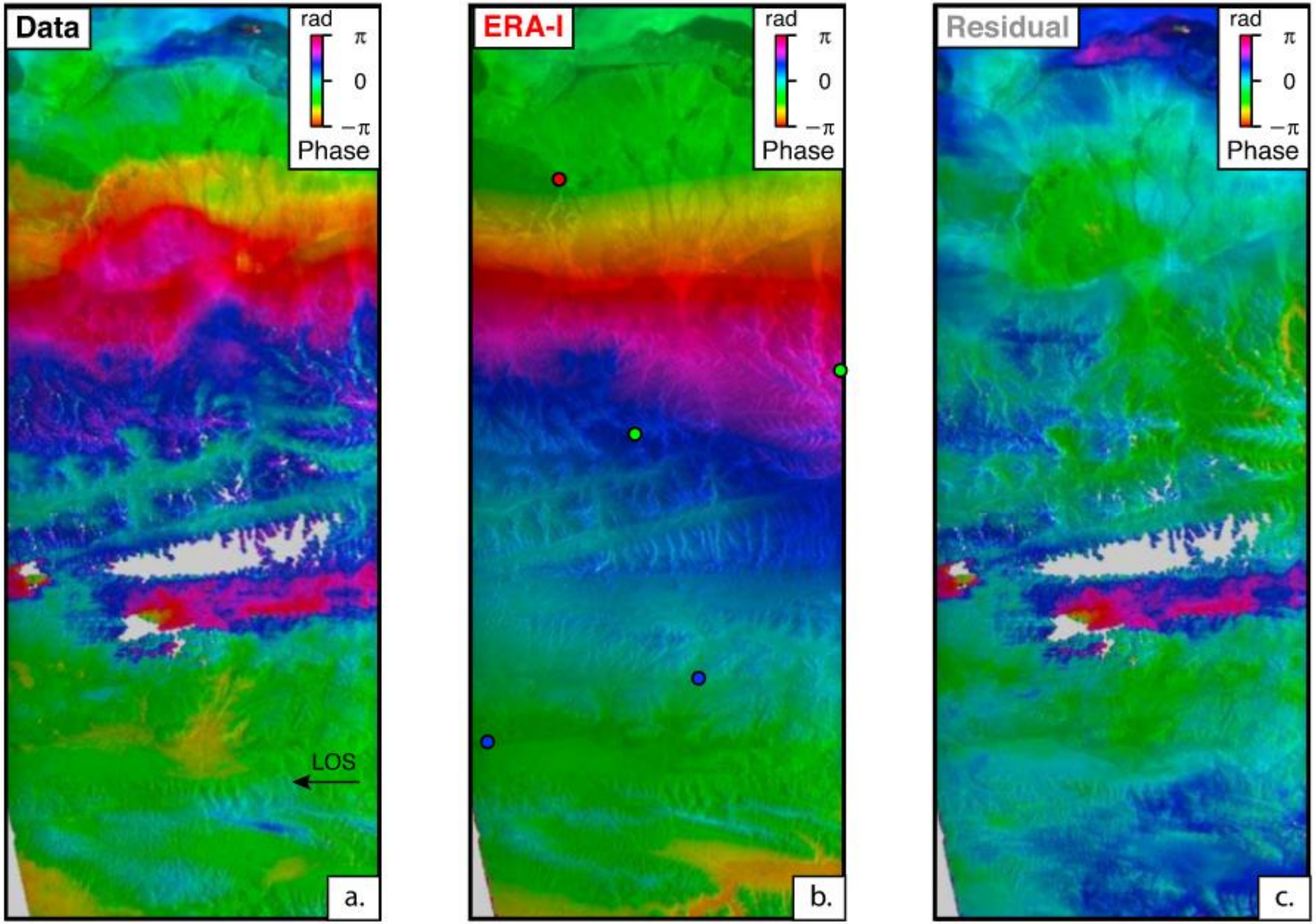
[σ^2 = variance, r = distance]

Wright, Clarke, Funning (2004, unpubl.)

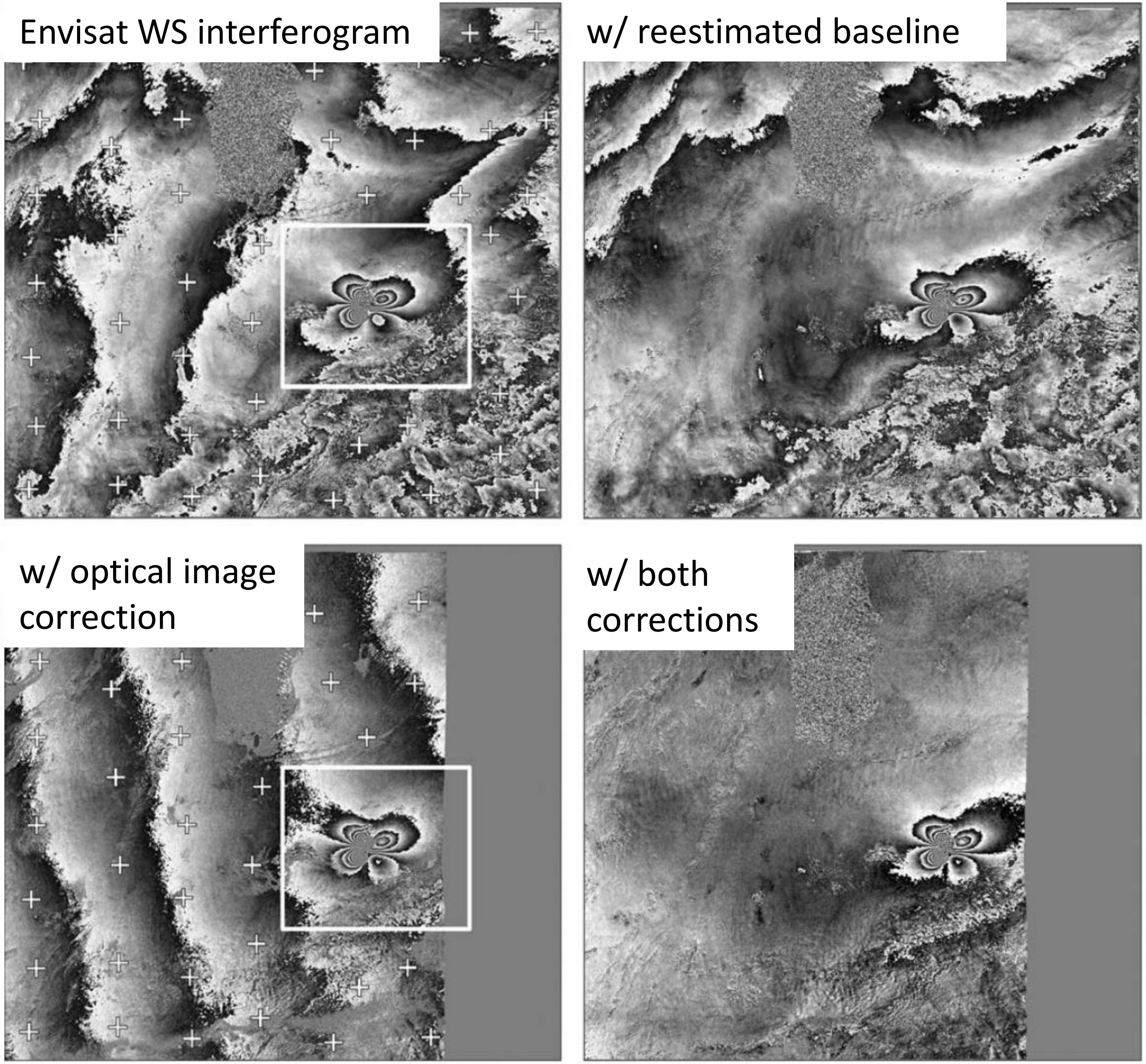
Modeling the troposphere

The static, layered portion of the troposphere depends on temperature, pressure, humidity and elevation, and can be estimated using weather/ atmospheric reanalysis models such as ERA-I/ERA5

The turbulent portion is a bit more difficult, requiring contemporaneous measurements of the troposphere by other means (e.g. GPS, optical imagery). These corrections are not (yet) routine…

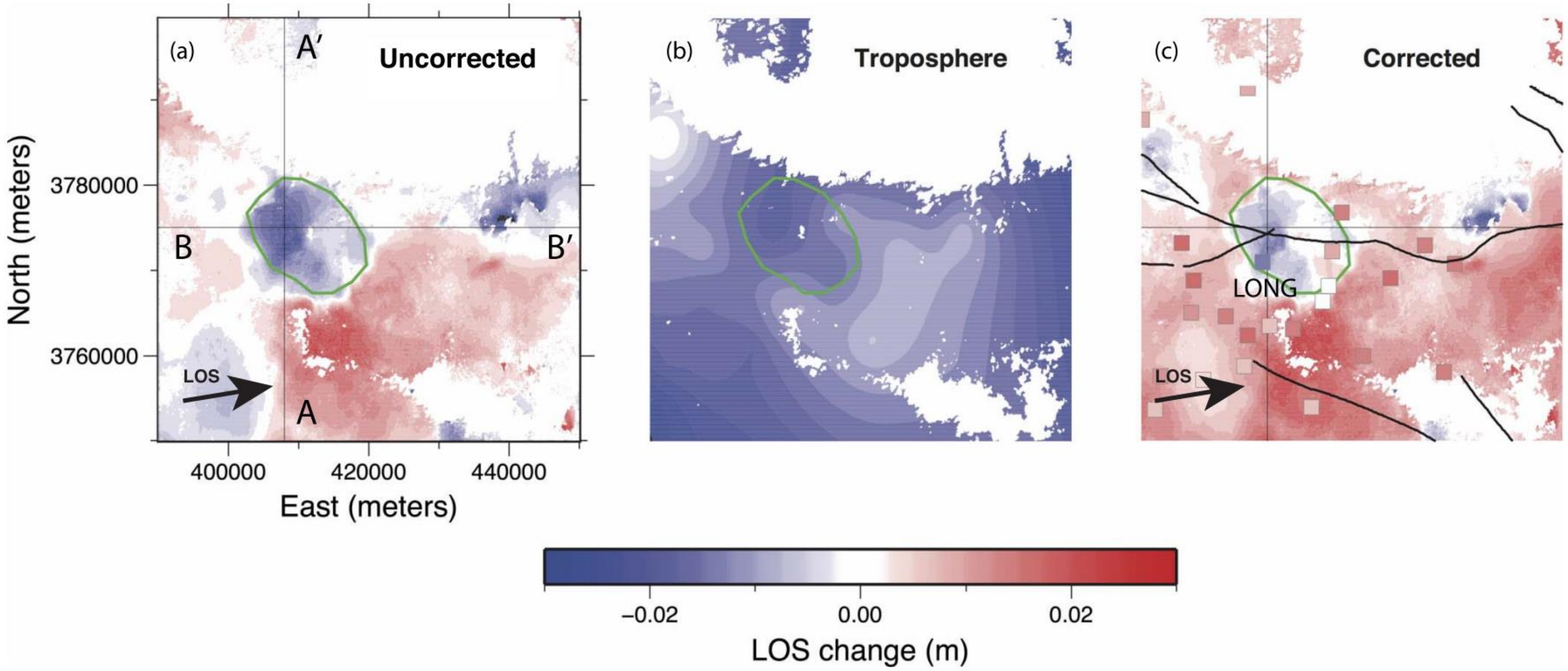


Jolivet et al., 2011

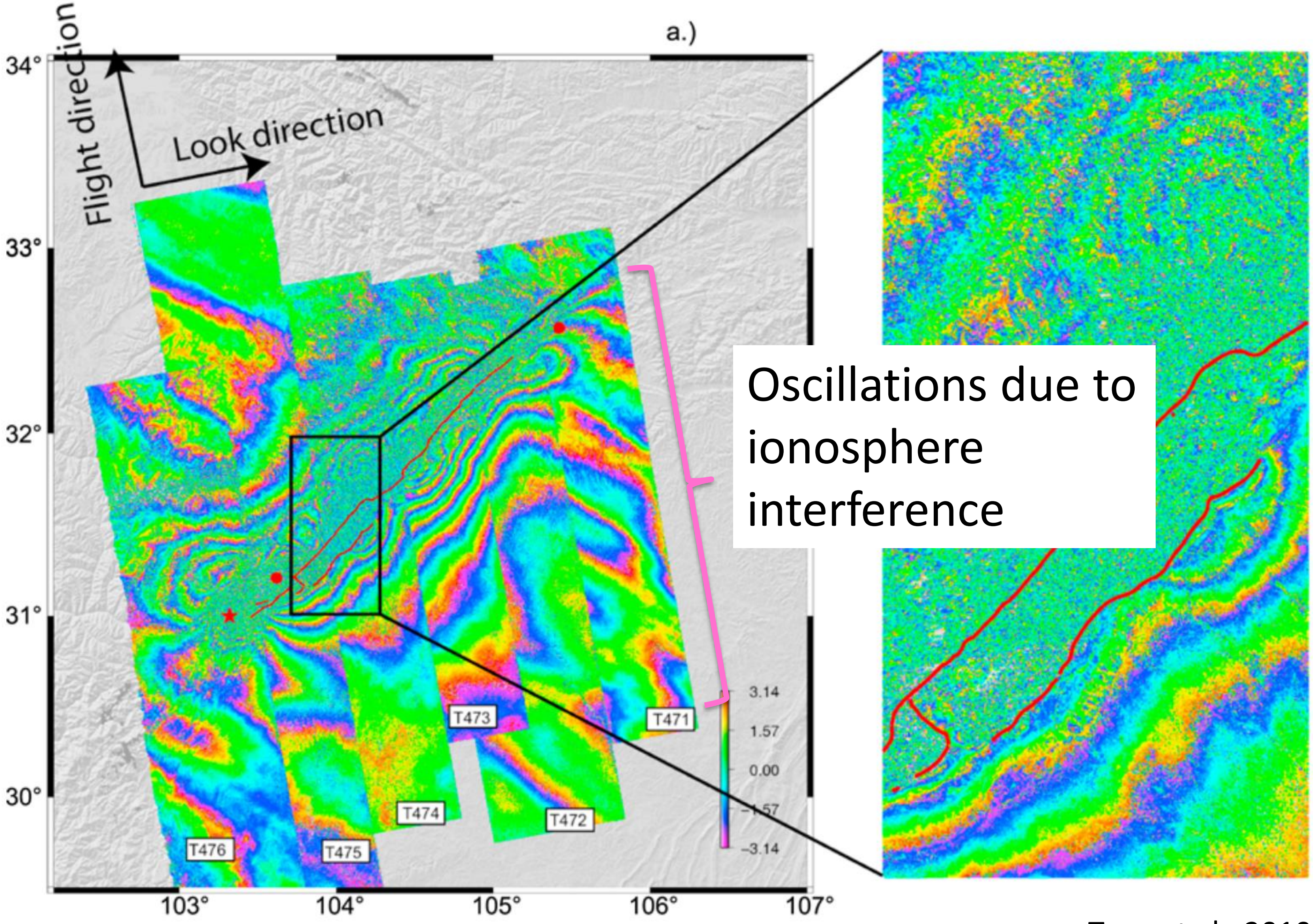

Envisat WS interferogram
w/ reestimated baseline
w/ optical image correction
w/ both corrections

Li et al., 2012

In regions of dense GPS, the zenith delay correction (a troposphere delay estimate) can be used to correct the troposphere



Houlie et al., 2016



Tong et al., 2010

Ionosphere distortions

The ionosphere also adds a distortion to radar waves. It is dispersive (frequency-dependent) and affects long wavelengths (e.g. L-band missions such as ALOS and ALOS-2) more than shorter wavelengths

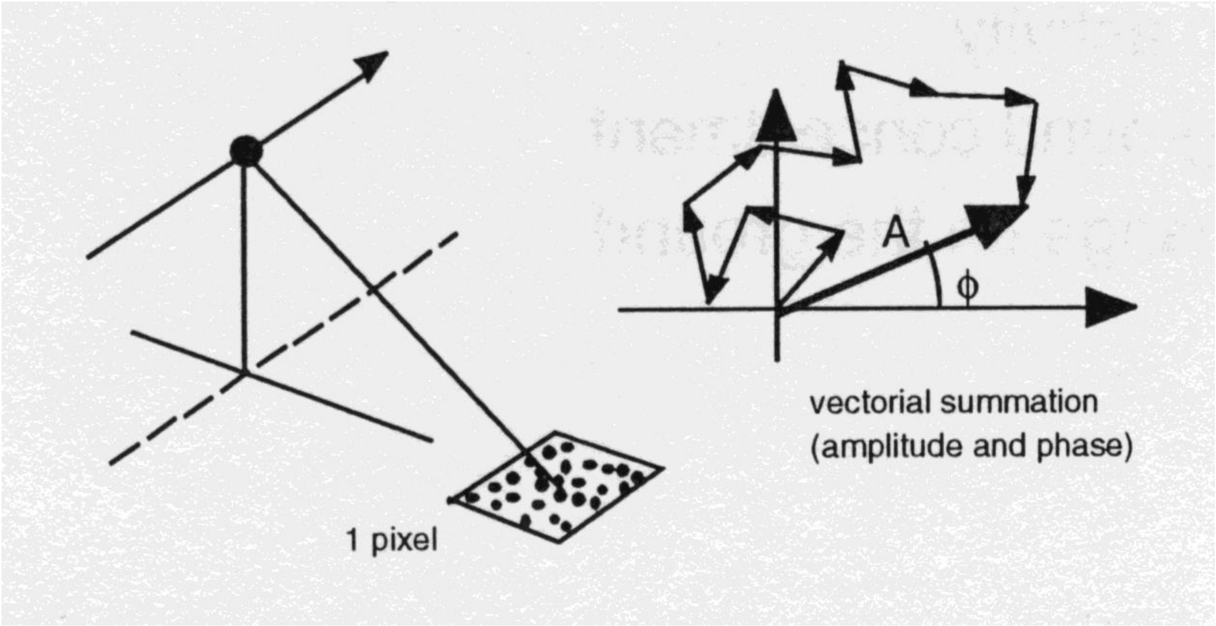
Since it is frequency dependent, this property can potentially be used to correct for it, as it is in GPS – split the bandwidth in processing, and form a higher frequency and lower frequency interferograms

This technique is known as 'enhanced spectral diversity'

Pixel phase (1)

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

- Each pixel on the ground scatters radar in a unique way; there is a phase shift associated with the configuration of objects within it
- If the pixel is undisturbed, this phase shift cancels out in the interferogram; if not, the phase is effectively random



Pixel phase (2)

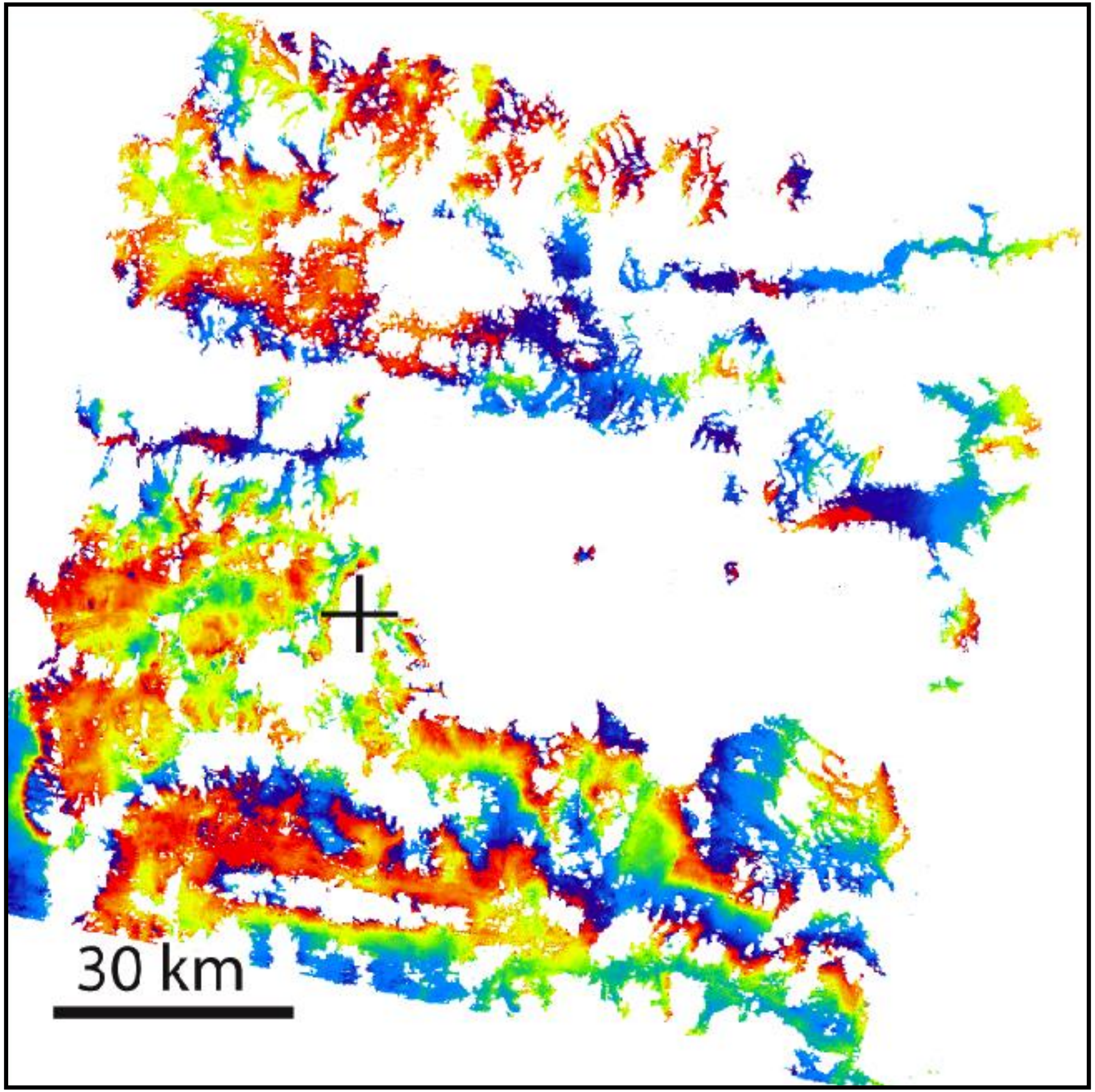
$$\boxed{\Delta\phi_{\text{int}} = \Delta\phi_{\text{orb}} + \Delta\phi_{\text{topo}} + \Delta\phi_{\text{atm}} + \Delta\phi_{\text{pixel}} + \Delta\phi_{\text{def}}}$$

- The effect of this effectively random signal is termed *decorrelation* (or *incoherence*), and the deformation signal cannot be recovered.
- Can use *multilooking* (spatial averaging) to pull out coherent signal from larger effective pixel sizes (at cost of reduced spatial resolution).

Decorrelation

If the scattering properties of the pixel change between acquisitions, the signal is lost

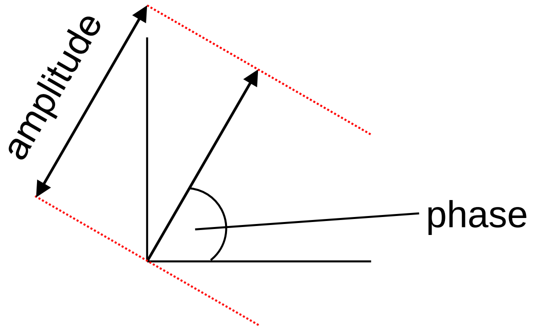
The probability of this occurring increases with time



ERS-1, Ngamring County, Tibet, July 1992–Feb 1993

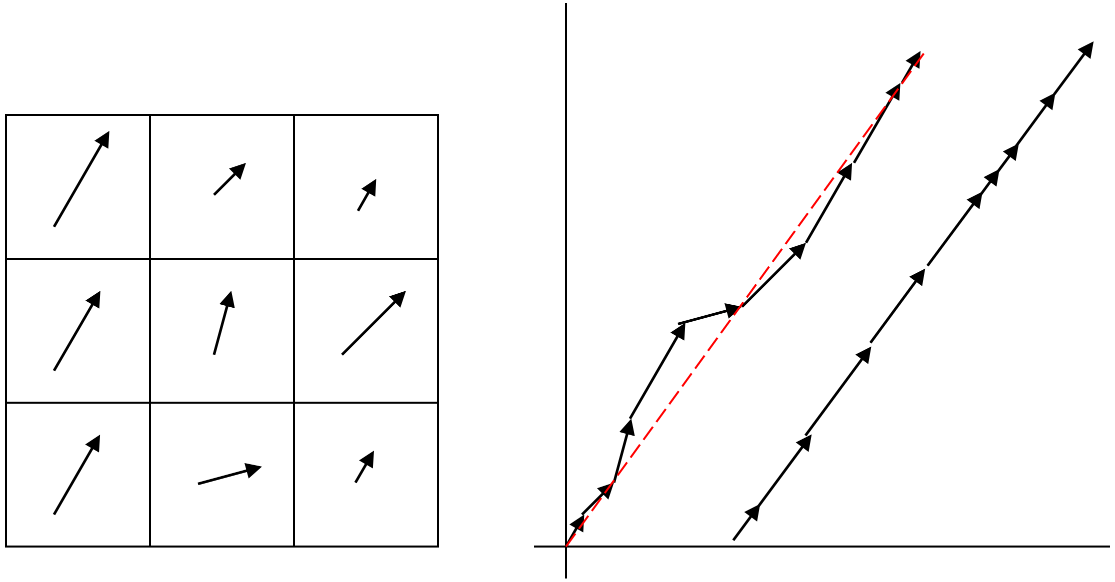
Interferometric correlation

Interferometric correlation, C, compares the phase of a pixel to its neighbors over a specified window



If the phases are similar, the correlation is high, and vice-versa

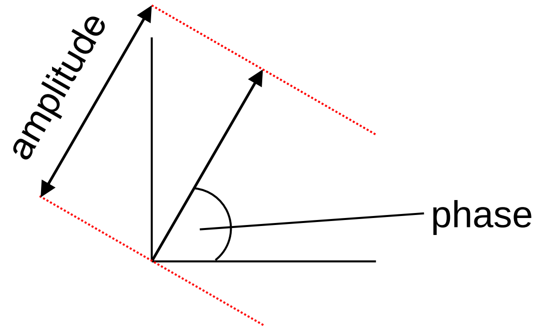
$$C = \frac{\left|\sum_{i=1}^{n} I_i\right|}{\sum_{i=1}^{n} \left|I_i\right|}$$



High correlation

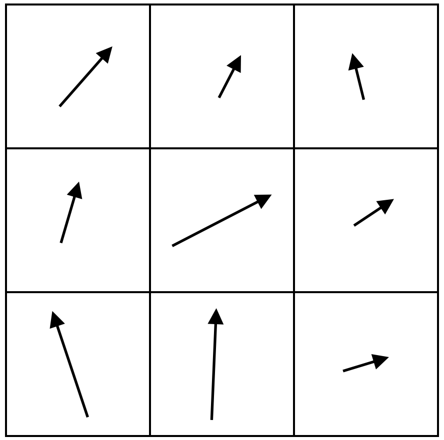
Interferometric correlation

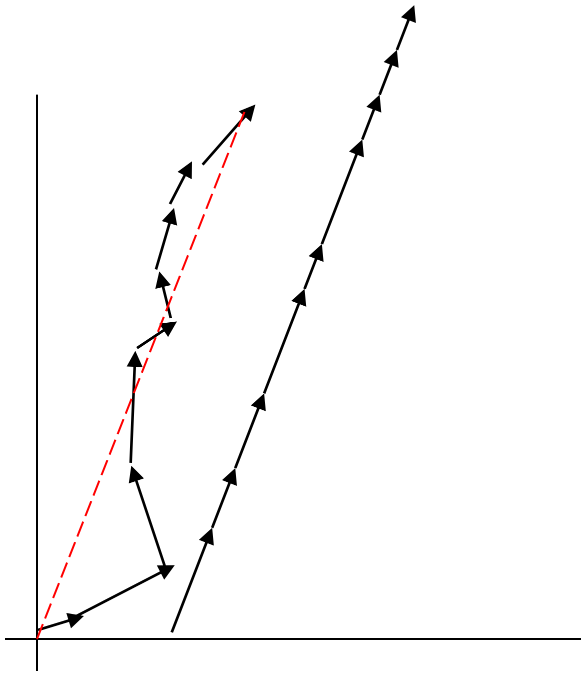
Interferometric correlation, C, compares the phase of a pixel to its neighbors over a specified window



If the phases are similar, the correlation is high, and vice-versa

$$C = \frac{\left|\sum_{i=1}^{n} I_i\right|}{\sum_{i=1}^{n} |I_i|}$$

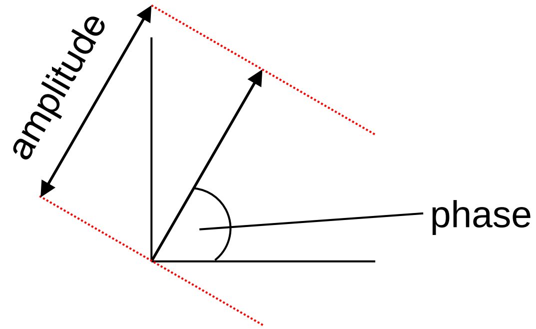




Lower correlation

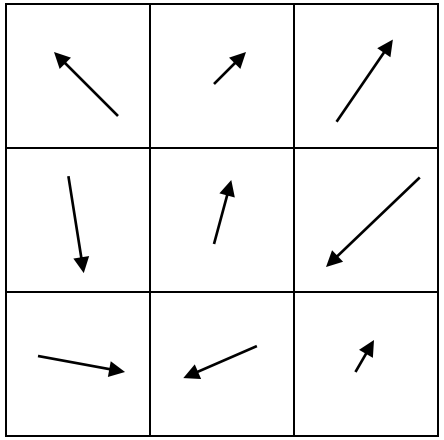
Interferometric correlation

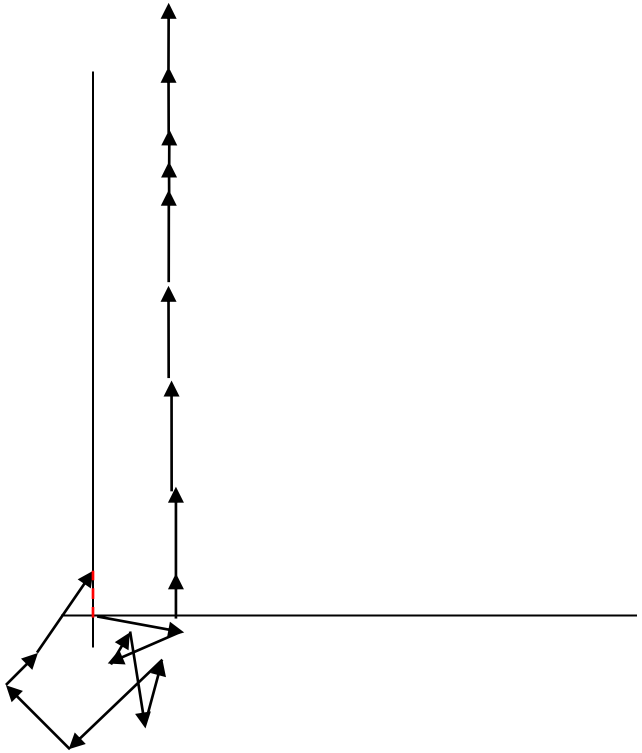
Interferometric correlation, C, compares the phase of a pixel to its neighbors over a specified window



If the phases are similar, the correlation is high, and vice-versa

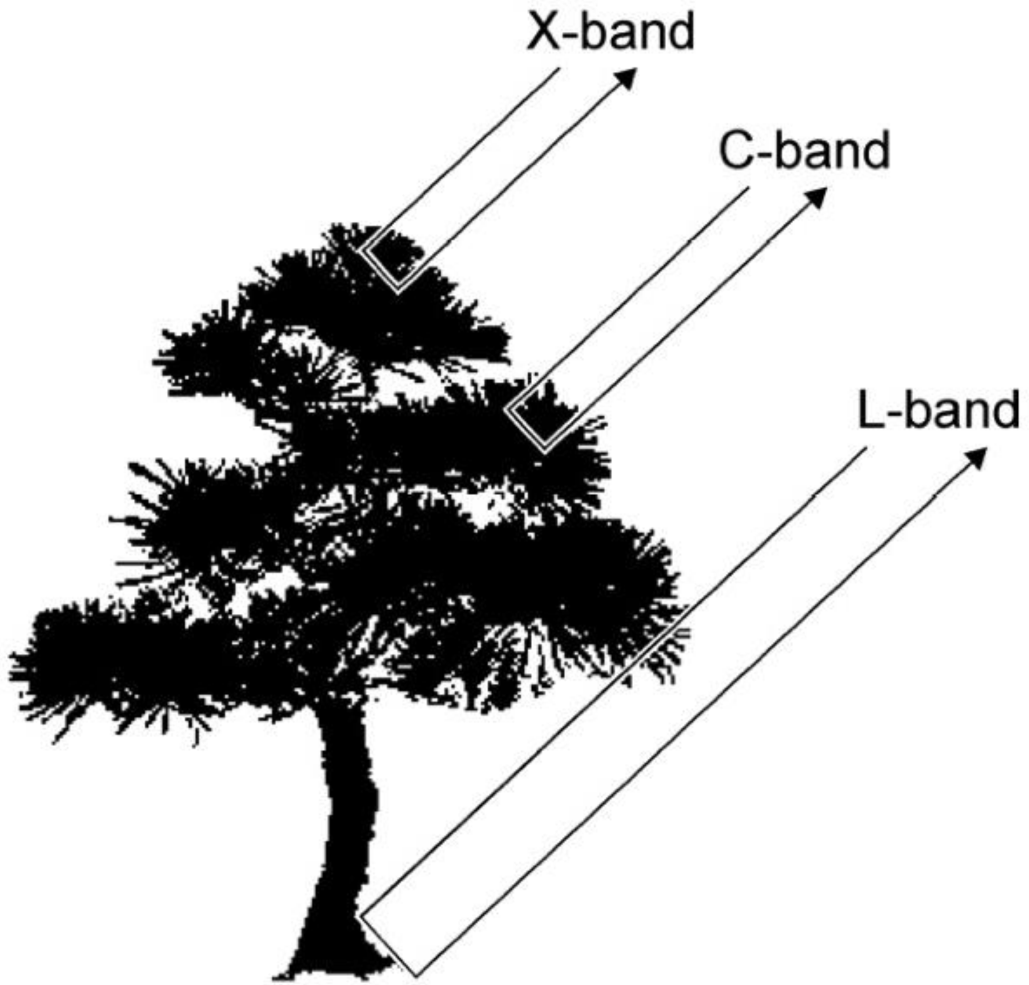
$$C = \frac{\left|\sum_{i=1}^{n} I_i\right|}{\sum_{i=1}^{n} \left|I_i\right|}$$





Low correlation

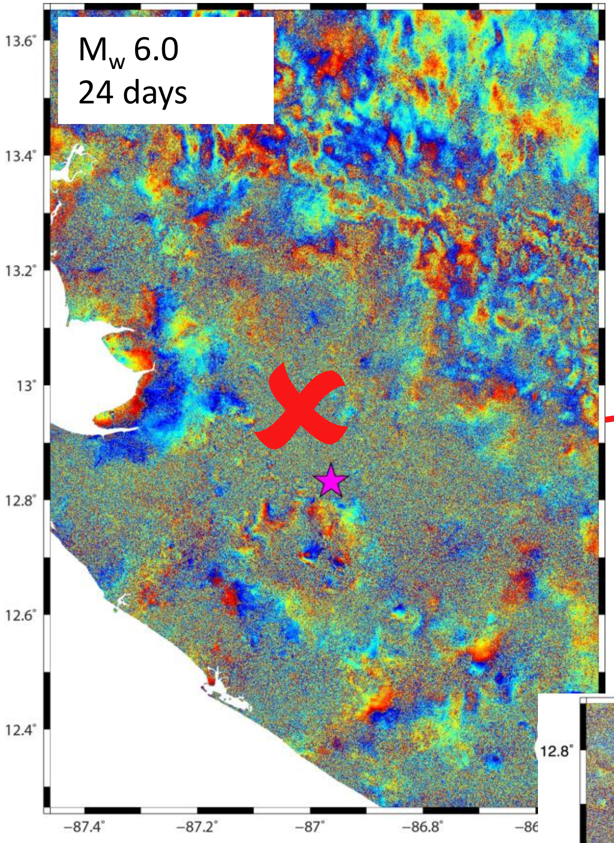
Volume scattering of radar

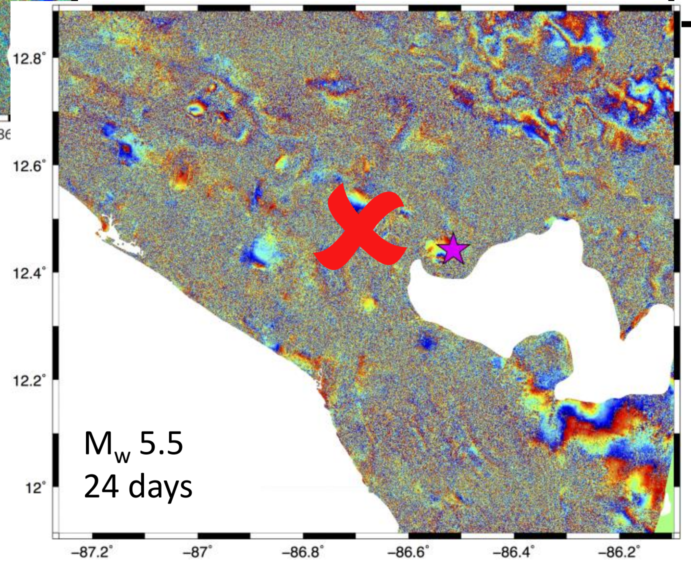


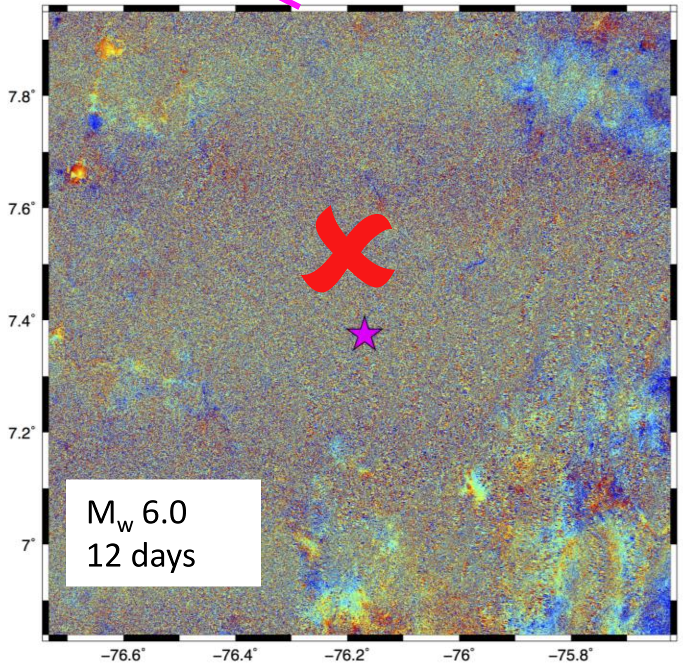
- Vegetation is especially problematic for InSAR
- C-band radar (ERS, Envisat, RADARSAT) scatters off the canopies of trees
- If the tree grows/ branches blow in the wind/ leaves drop, the data will be decorrelated
- Longer wavelengths (e.g. L-band, as on ALOS) penetrate deeper into the tree, and perform better for InSAR

Central America

Shortest Sentinel-1 pairs for shallow M>5.5 earthquakes

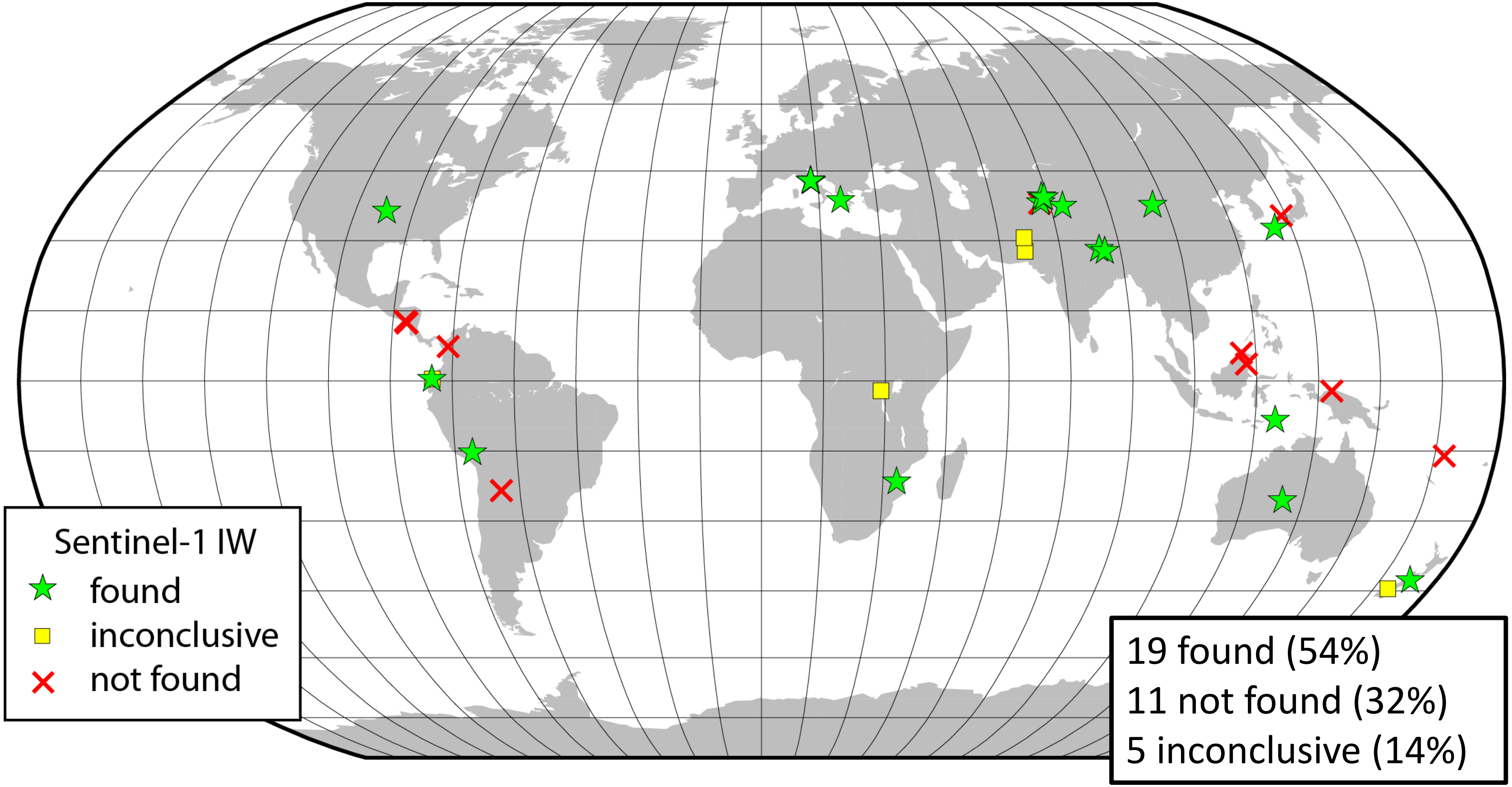






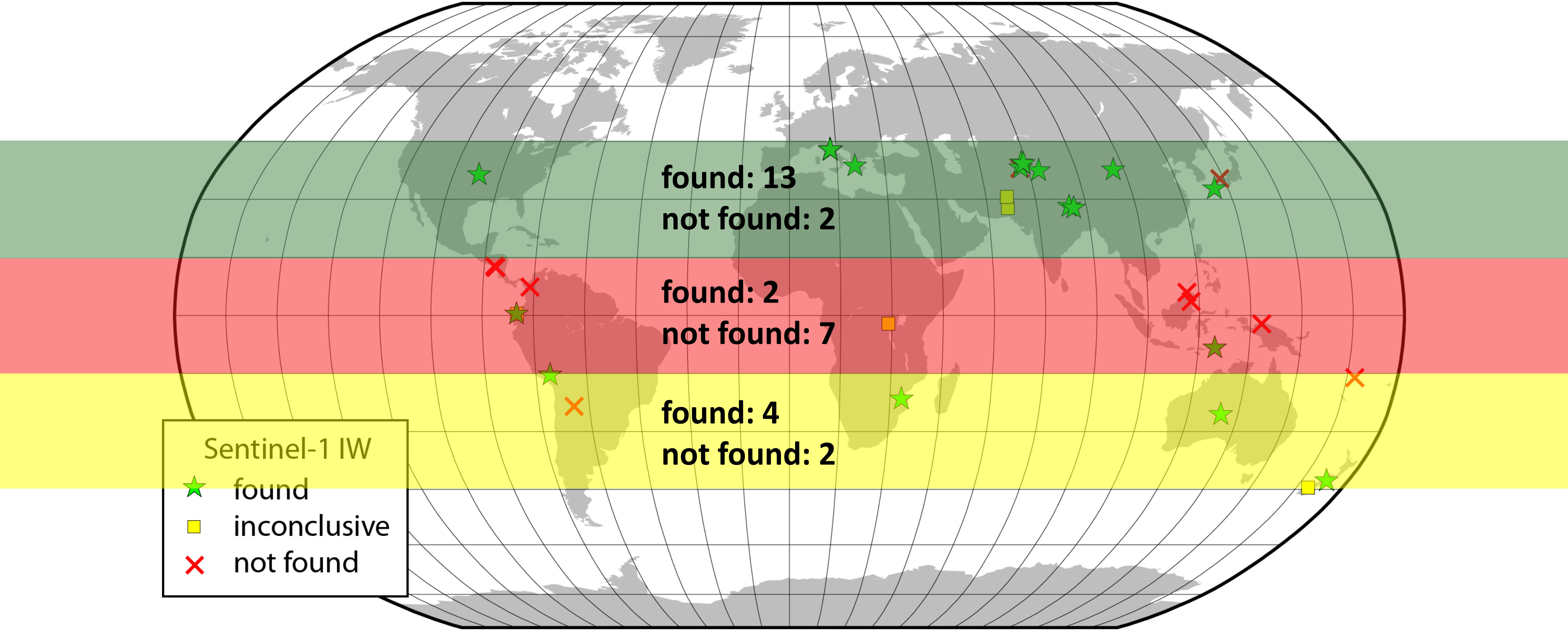
Funning and Garcia, 2018

35 M>5.5 earthquakes in 18 months with Sentinel-1



Funning and Garcia, 2019

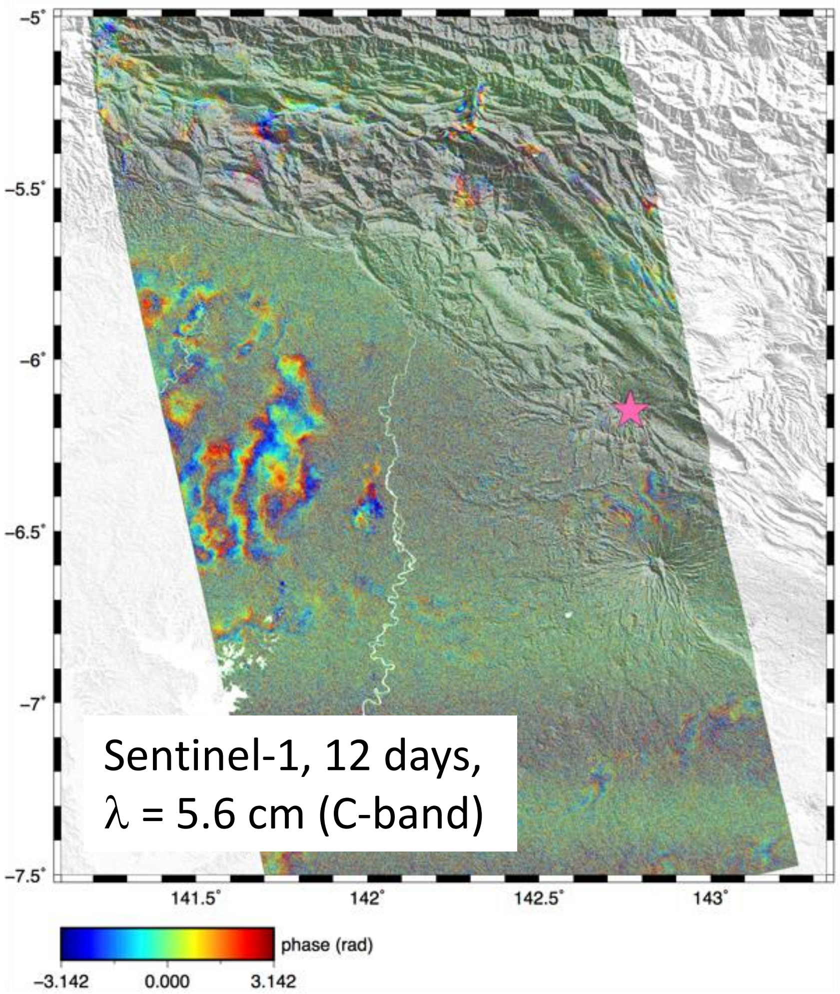
Most nondetections within 15° of equator – link to tropical climate and vegetation?



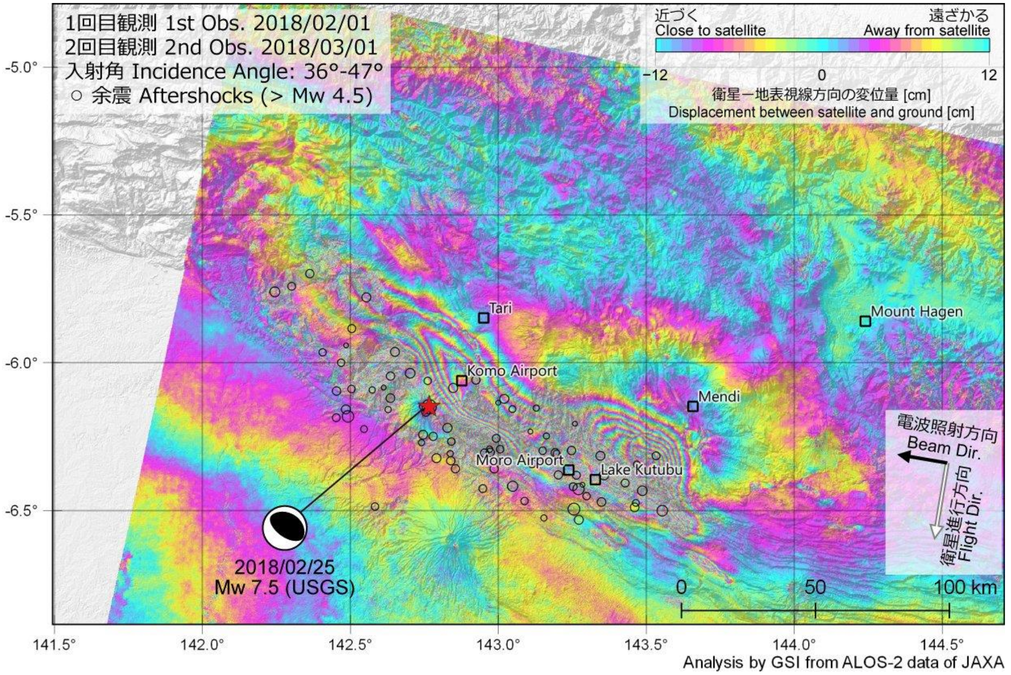
Funning and Garcia, 2019

Effect of wavelength on decorrelation

M7.6, Papua New Guinea, February 25th, 2018



Sentinel-1, 12 days,
λ = 5.6 cm (C-band)



ALOS-2, 28 days,
λ = 23.8 cm (L-band)
[Processed by
Yu Morishita, GSI, Japan]

Tips for avoiding decorrelation

- Short interferogram time spans reduce the probability of temporal decorrelation
- Short perpendicular baselines reduce geometric decorrelation

Less of a problem with modern missions

- Longer radar wavelengths are less susceptible to volume decorrelation

ALOS-2! NISAR! (2023?)

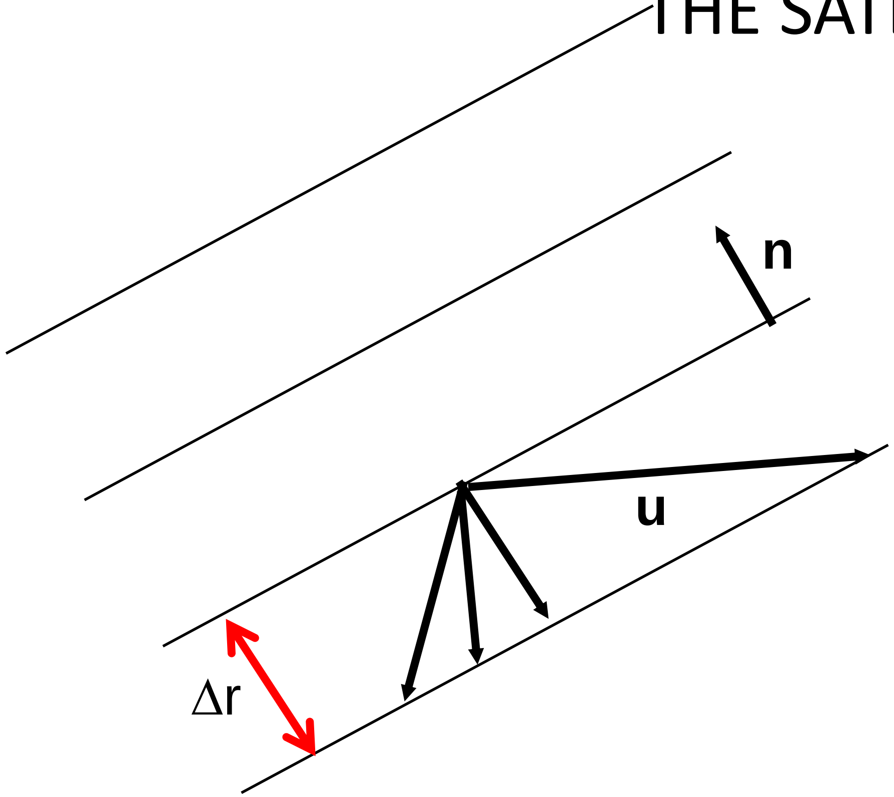
- Don't work on forested areas or the tropics?
- Only work in urban areas or the mid-latitudes?

No, but you might need to choose data carefully

Deformation phase

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

INSAR ONLY MEASURES THE COMPONENT OF SURFACE DEFORMATION IN THE SATELLITE'S LINE OF SIGHT (LOS)



$$\boxed{\Delta r = -\,\mathbf{n.u}}$$

where n is a unit vector pointing from the ground to the satellite

$$\boxed{\Delta\phi_{def} = (4\pi / \lambda)\, \Delta r}$$

i.e. 1 fringe = 28.3 mm LOS deformation for ERS