InSAR: deformation, noise and errors

Gareth Funning

University of California, Riverside

UC RIVERSIDE UNIVERSITY OF CALIFORNIA

Differential InSAR (DInSAR)

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

Remember that at the end of a typical (D)InSAR processing chain, the phase of the interferogram still has other components besides deformation

Next we shall cover what these are, and what these can do to the data

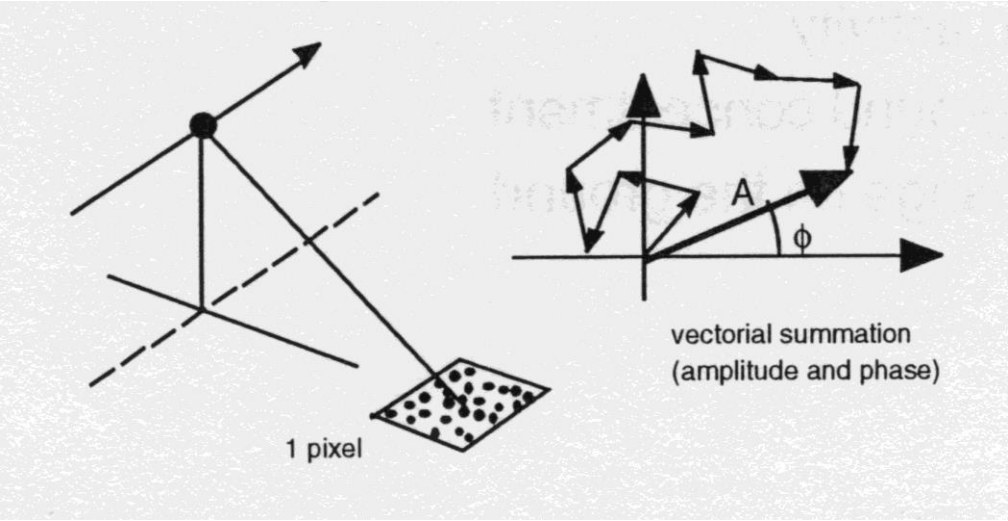
Outline

- Pixel phase, decorrelation and quantifying correlation
- Noise from the troposphere and ionosphere, and strategies for dealing with it
- Unwrapping errors
- Interpreting deformation phase

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 unchanged, this phase shift cancels out in the interferogram; if not, a random phase shift is generated for that pixel



Pixel phase (2)

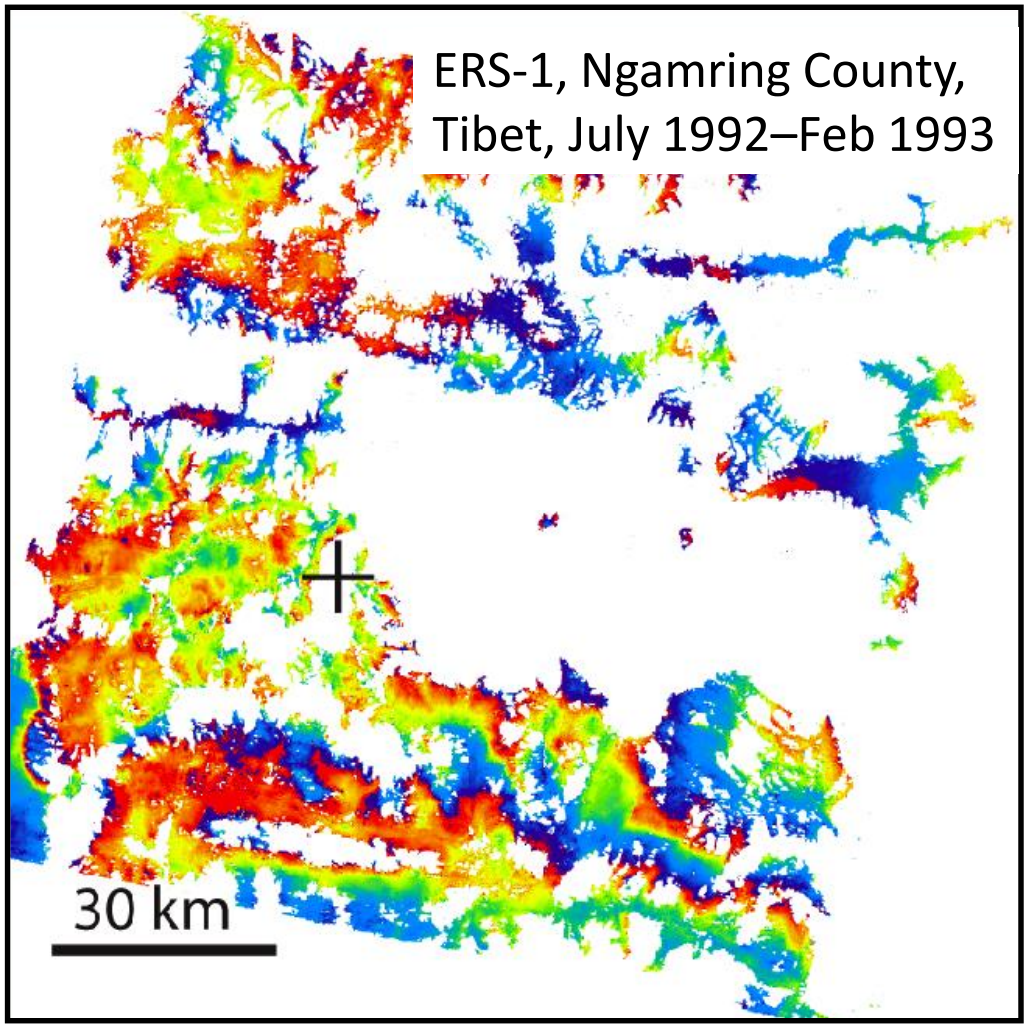
$$\Delta\phi_{\text{int}} = \Delta\phi_{\text{orb}} + \Delta\phi_{\text{topo}} + \Delta\phi_{\text{atm}} + \Delta\phi_{\text{pixel}} + \Delta\phi_{\text{def}}$$

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

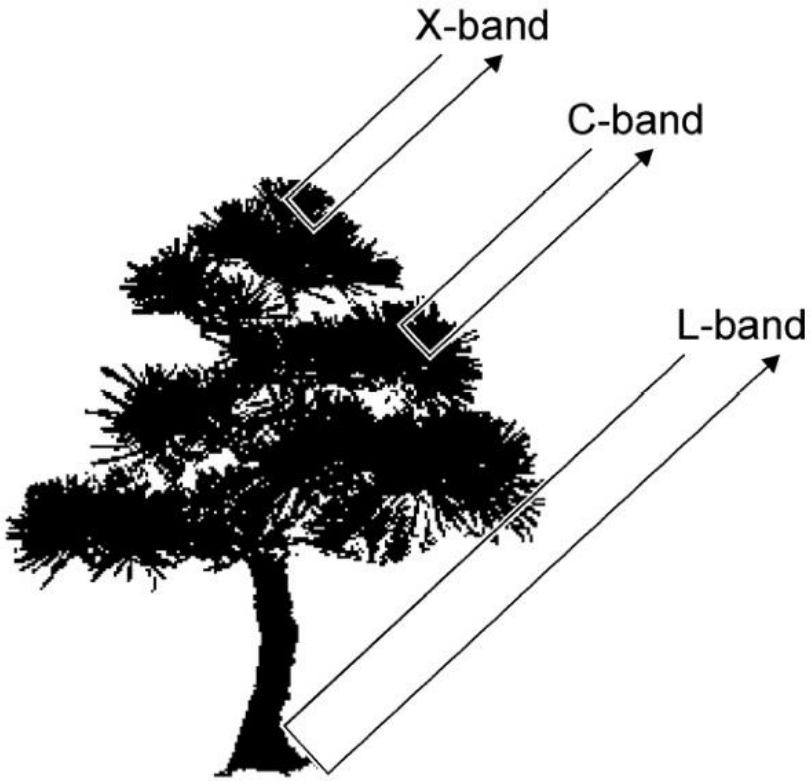
Temporal decorrelation

If the scattering properties of the pixel change (here due to snow), the signal is lost

The probability of this occurring increases with time (hence 'temporal decorrelation')



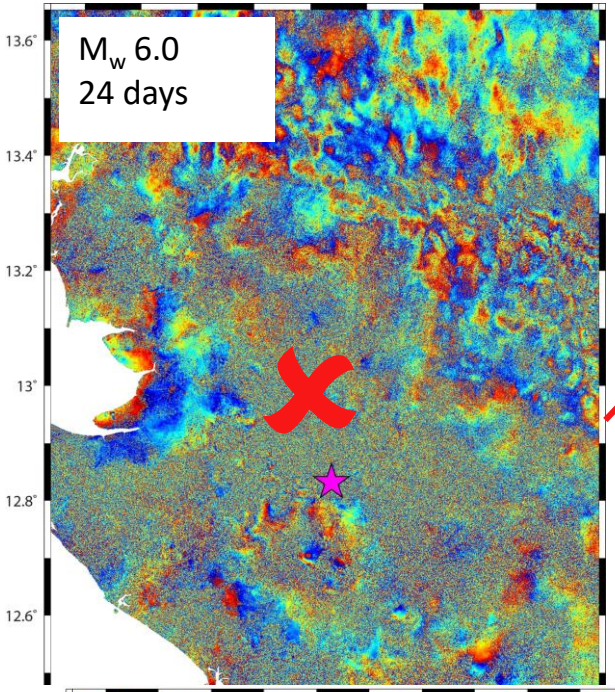
Volume scattering of radar

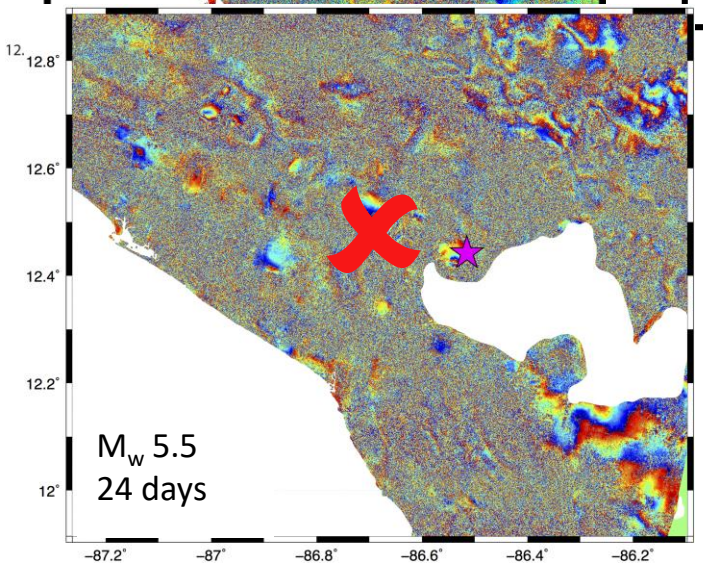


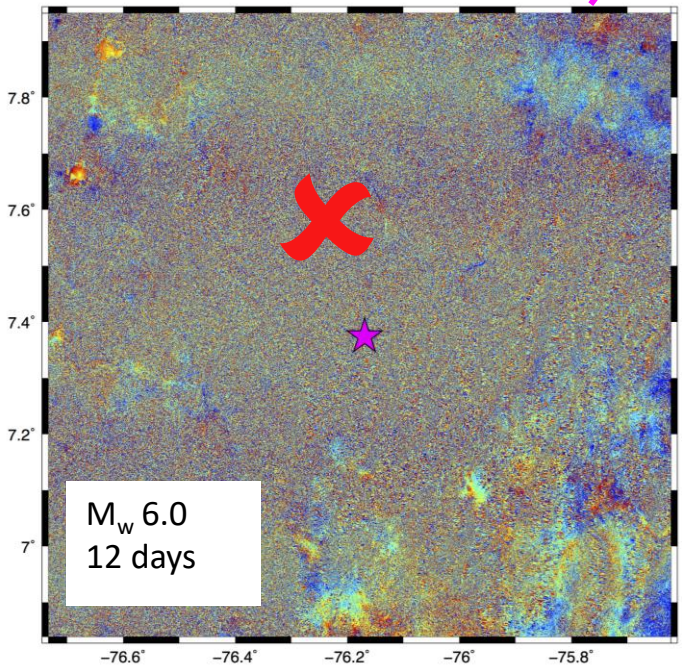
- Boreal vegetation is especially problematic for InSAR
- C-band radar (ERS, Envisat, RADARSAT) scatters off the canopies of trees
- If the tree grows/ branches blow in the wind/ leaves drop, the data will be decorrelated
- Longer wavelengths (e.g. L-band, as on ALOS) penetrate deeper into the tree,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

Central America

Shortest Sentinel-1 pairs for shallow M>5.5 earthquakes

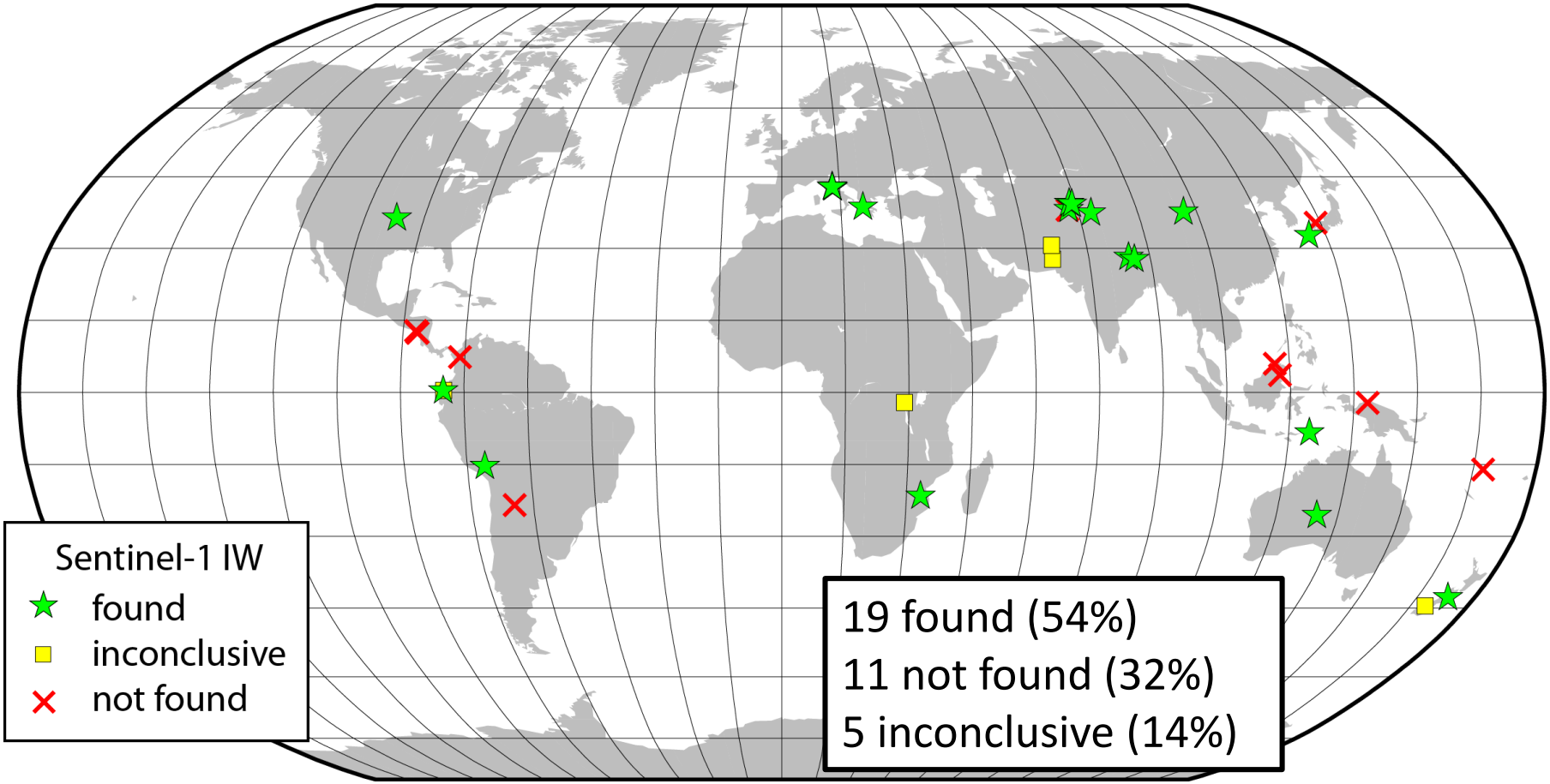






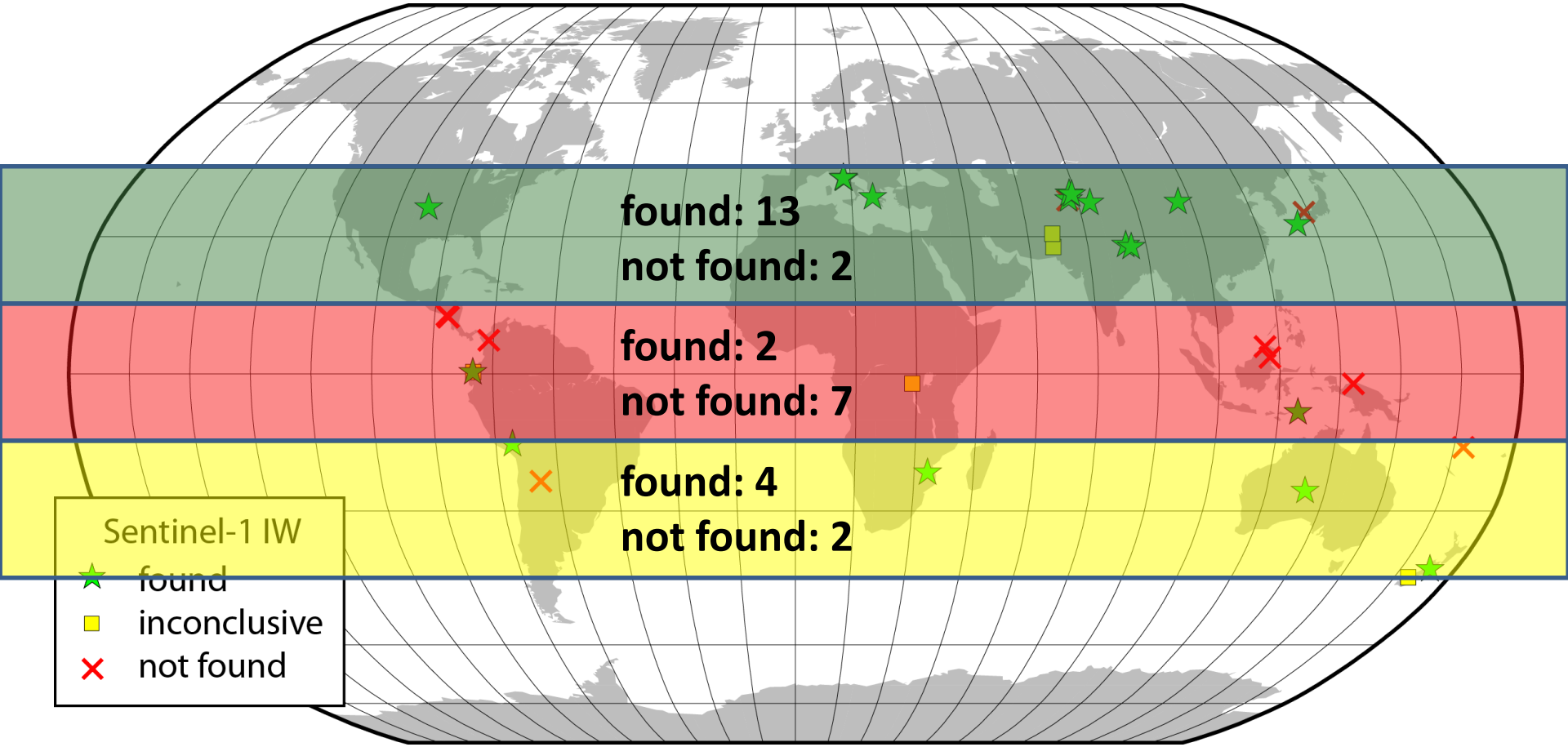
Funning and Garcia, 2018

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



Funning and Garcia, 2018

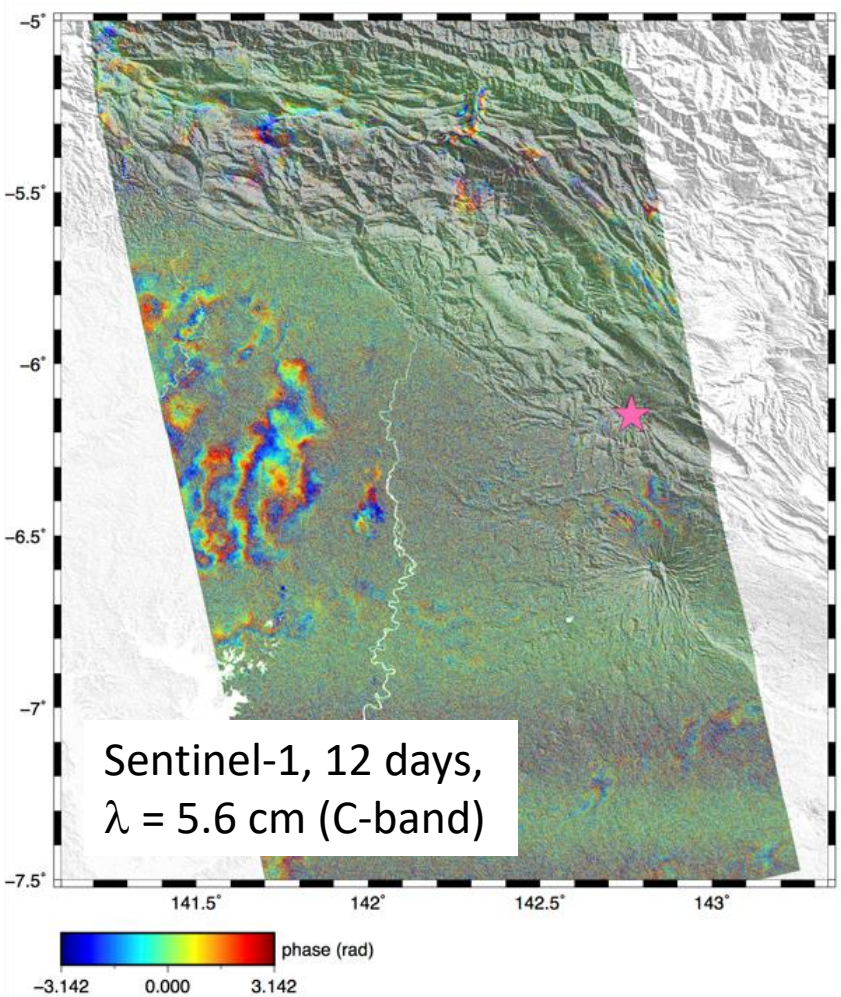
Most nondetections within 15° of equator – link to tropical climate and vegetation?



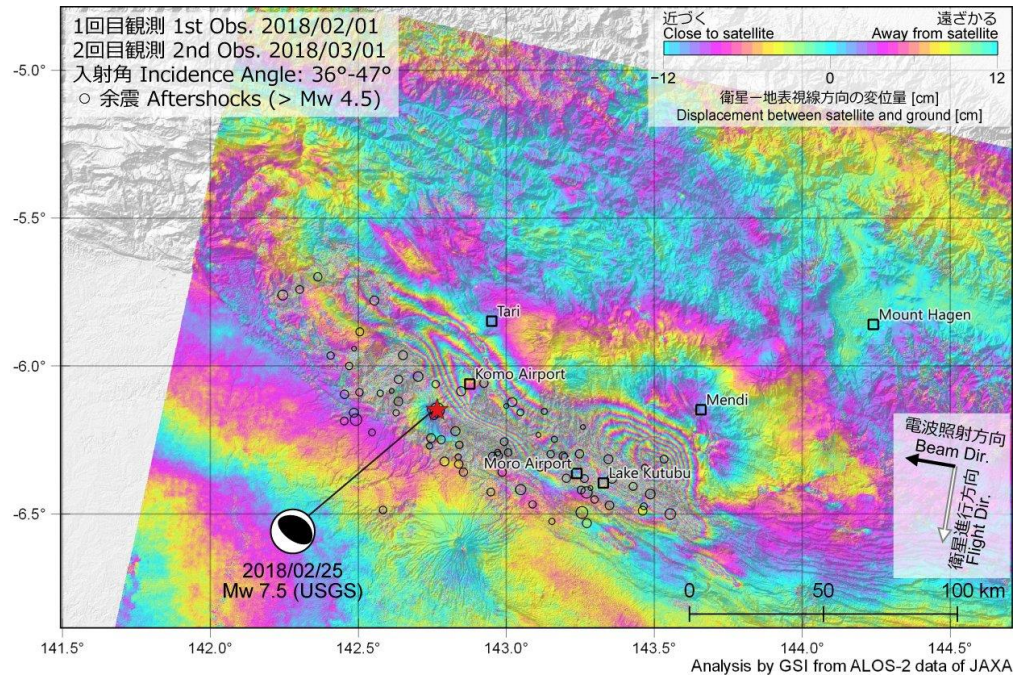
Funning and Garcia, 2018

Effect of wavelength on decorrelation

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



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



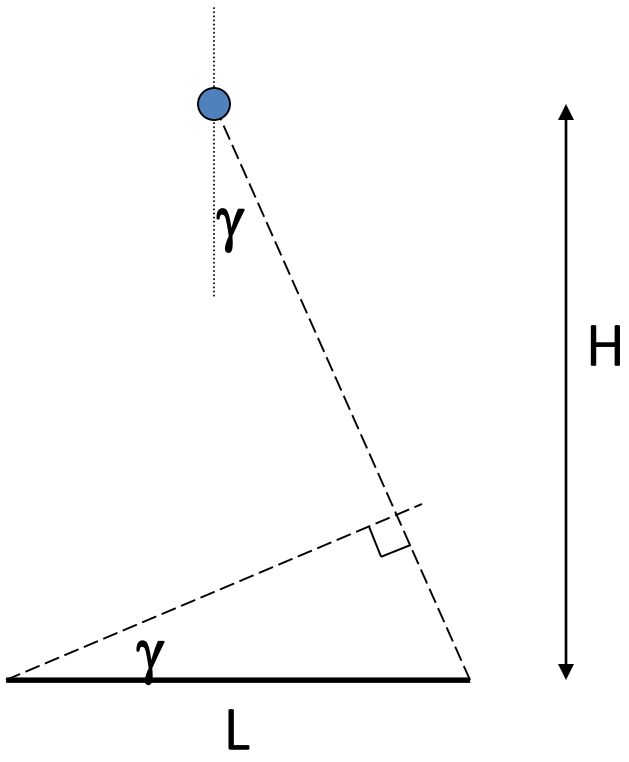
ALOS-2, 28 days,
λ = 23.8 cm (L-band)
[Processed by
Yu Morishita, GSI, Japan]

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; if it does, the interferogram is effectively decorrelated

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

$$2L \sin \gamma$$



The critical baseline

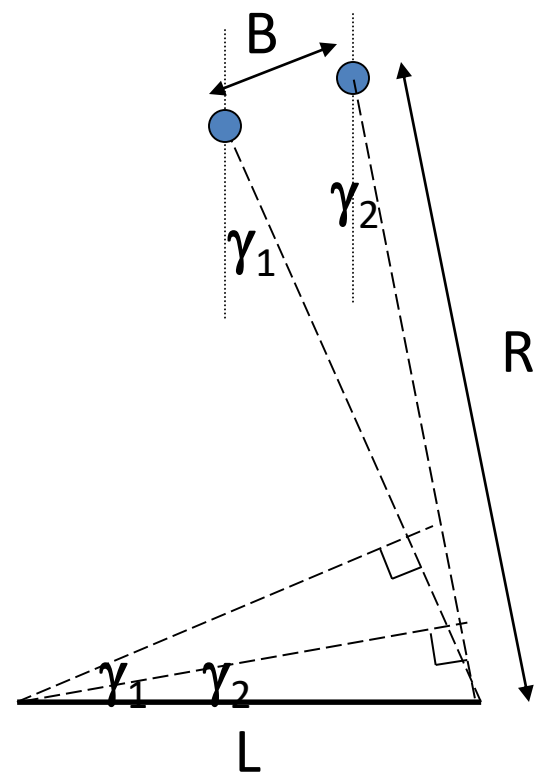
In order to identify the phase ramp between pixels, it cannot exceed a shift of 2π (or a round-trip distance of λ) per pixel; if it does, the interferogram is effectively decorrelated

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

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

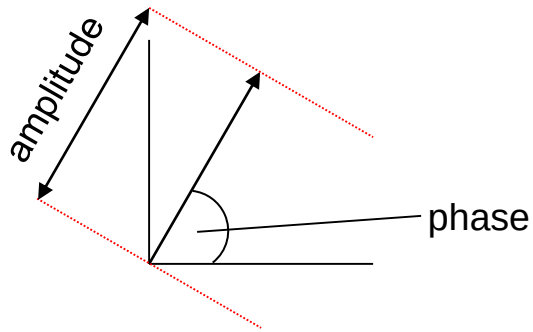
(approximately) $$2L\cos\gamma\,(B/R) < \lambda$$

If L = 20 m, R = 850 km, $\gamma_1 \approx \gamma_2 \approx 23^\circ$ and $\lambda = 0.056$ m, the critical baseline is ~1100 m



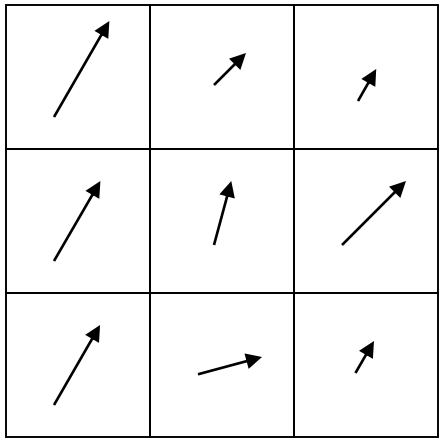
Interferometric correlation

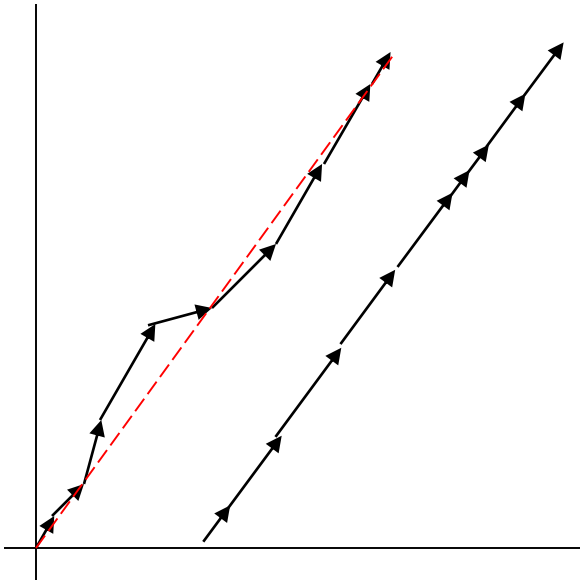
Interferometric correlation, C, compares the phase of a pixel to its neighbors over a specified window



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

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

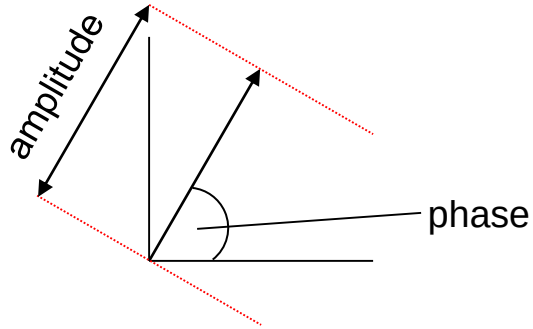




High correlation

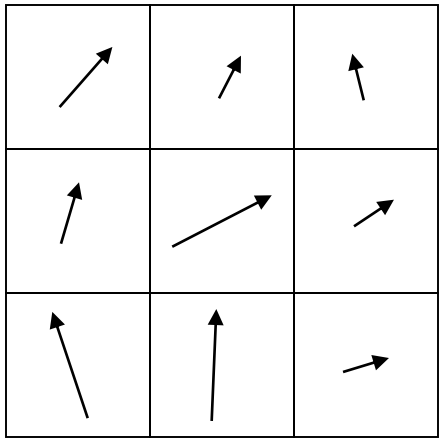
Interferometric correlation

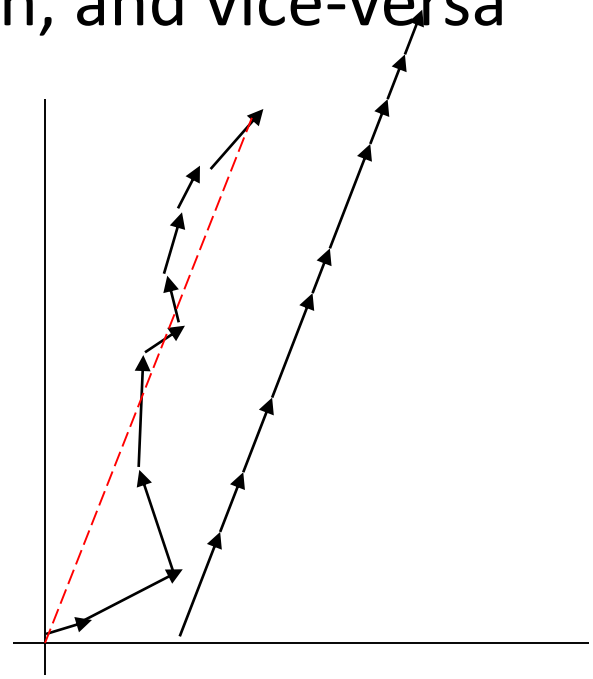
Interferometric correlation, C, compares the phase of a pixel to its neighbors over a specified window



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

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

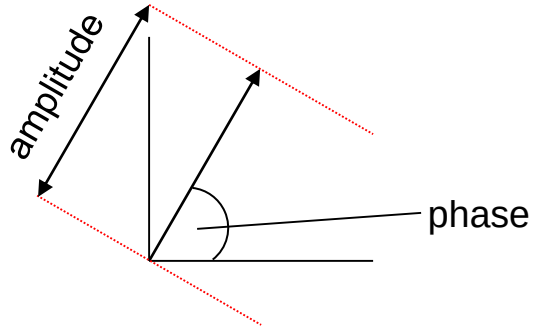




Lower correlation

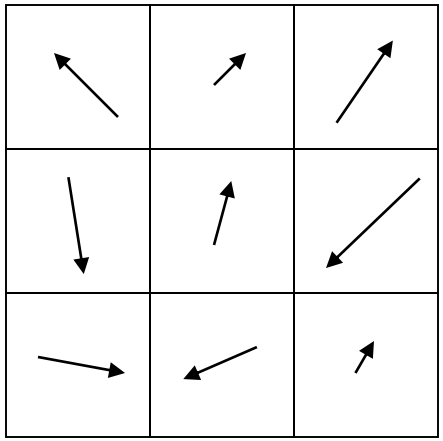
Interferometric correlation

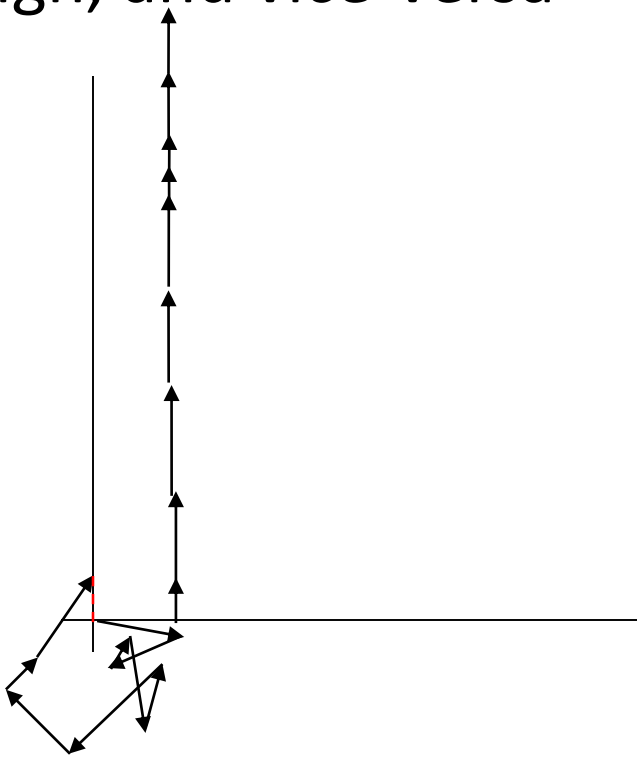
Interferometric correlation, C, compares the phase of a pixel to its neighbors over a specified window



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

Tips for avoiding decorrelation

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

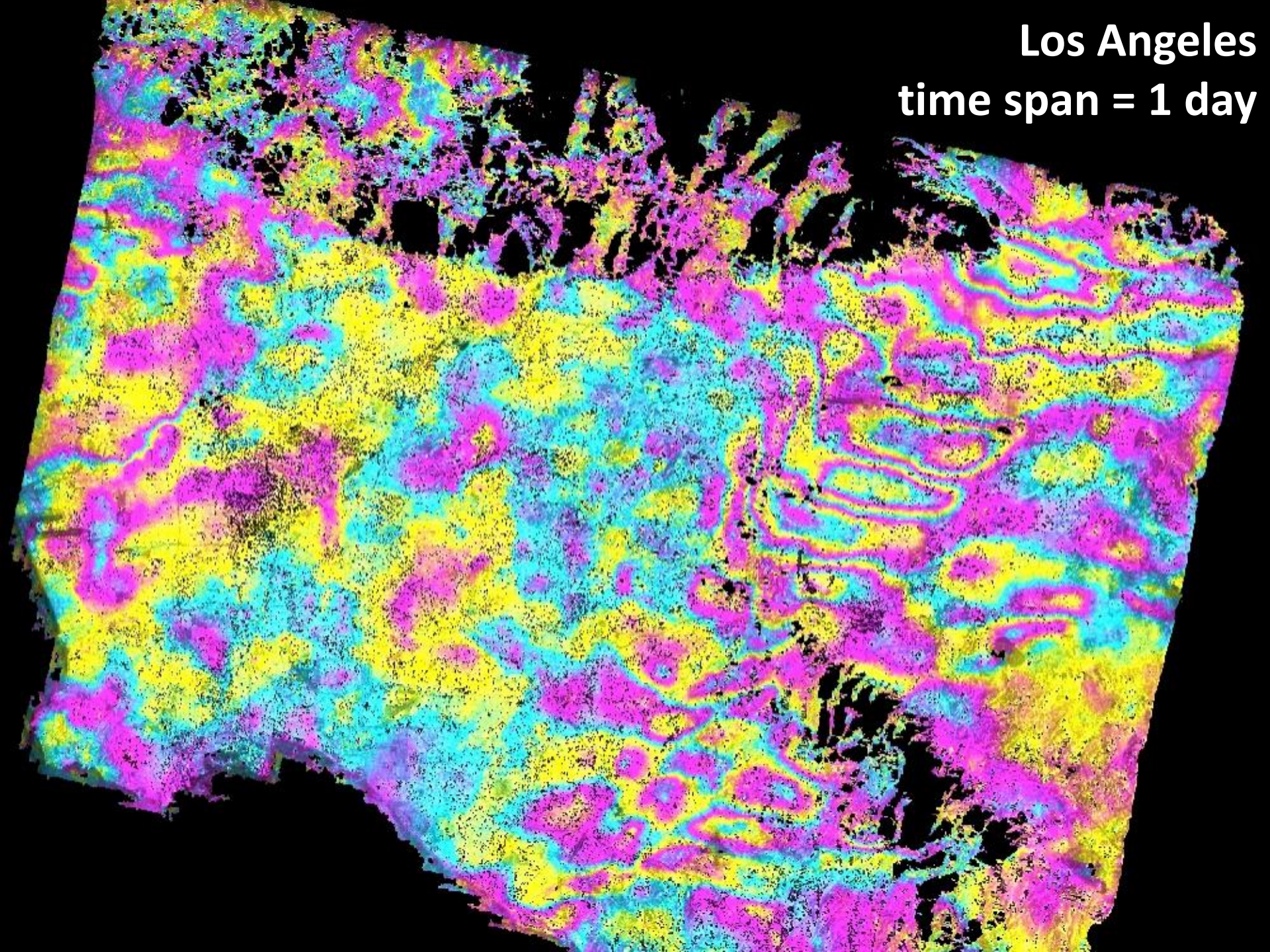
Less of a problem with modern missions

- Longer radar wavelengths are less susceptible to volume decorrelation

ALOS-2! NISAR! (one day)

- 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


Los Angeles
time span = 1 day

Tropospheric phase (1)

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

A foggy morning near ancient Mycenae, Greece

Tropospheric phase (2)

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

Troposphere contributes to measured phase, by refracting the radar, and adding a 'delay' to the path length

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

n = refractive index

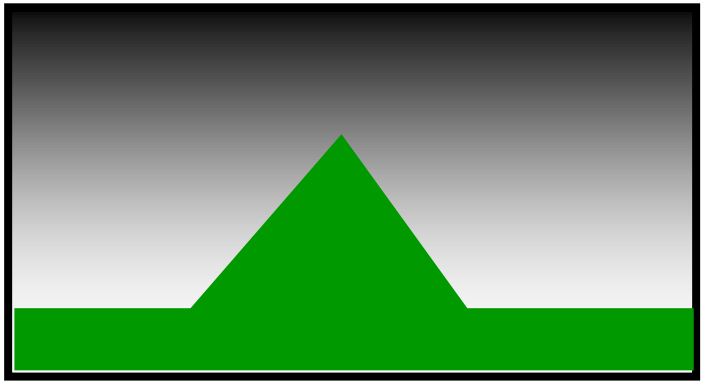
= f (humidity, temperature, pressure)

Integrated over whole troposphere, differential path delays of up to 10 cm are possible in extreme cases

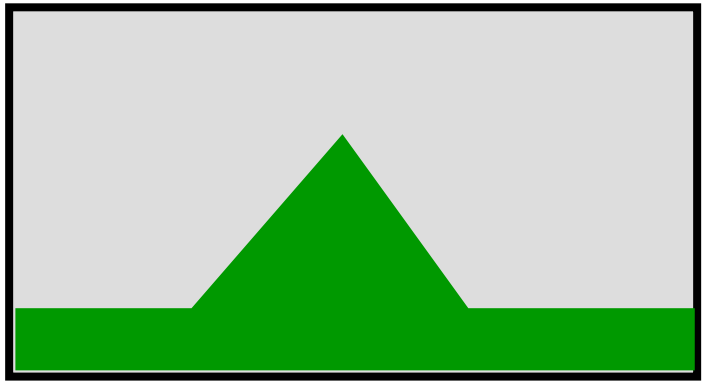
Tropospheric phase (3)

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

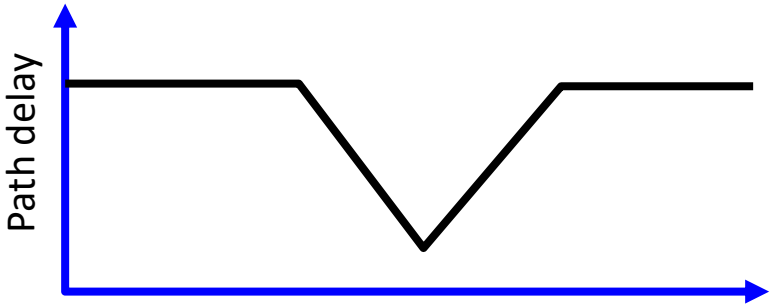
Layered troposphere



Pass 1



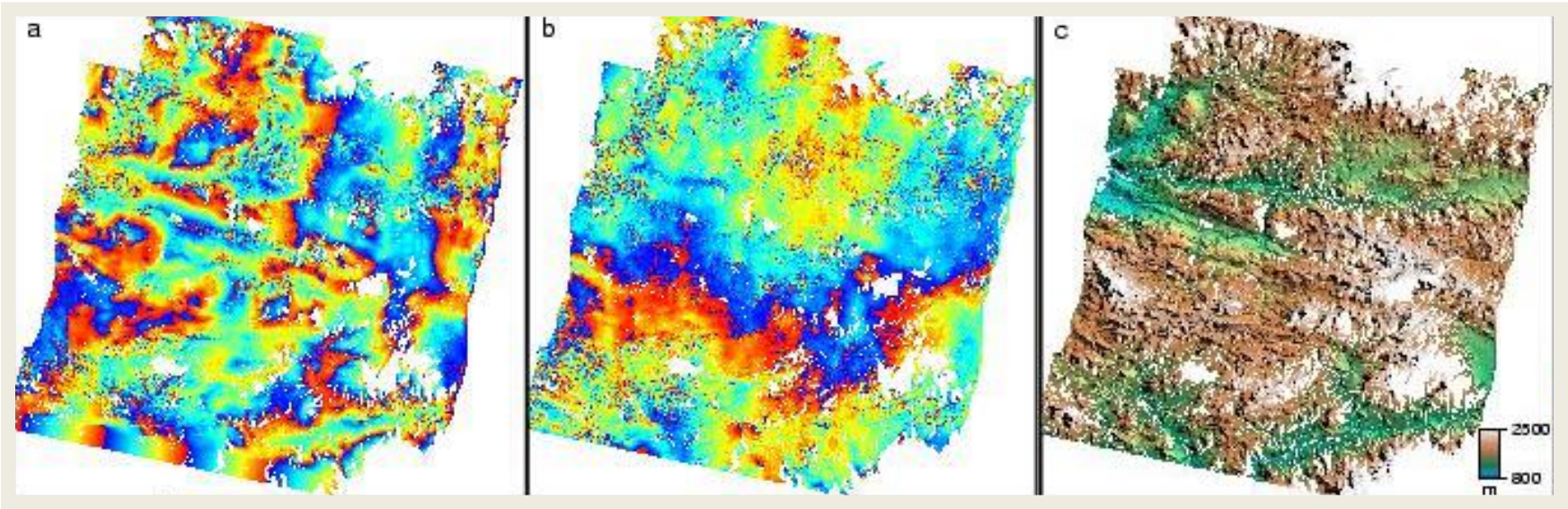
Pass 2



Tropospheric phase (4)

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

Layered troposphere



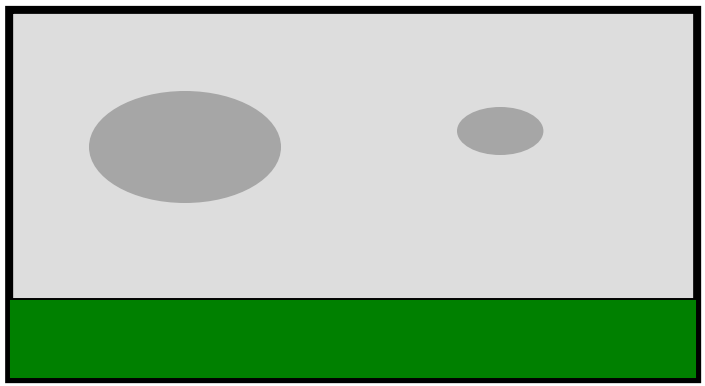
29/8/1995 to 29/7/1997 30/8/1995 to 29/7/1997 Topography

Wright (2001)

Tropospheric phase (5)

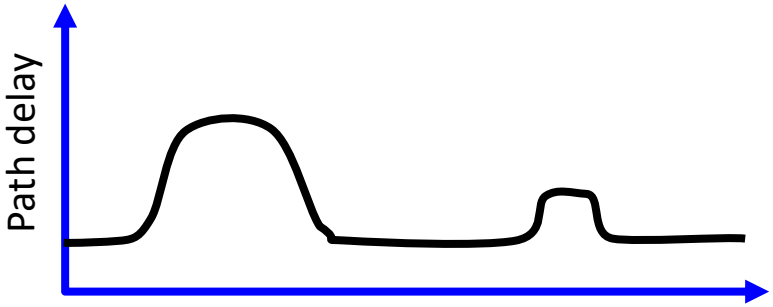
$$\Delta\phi_{\text{int}} = \Delta\phi_{\text{orb}} + \Delta\phi_{\text{topo}} + \Delta\phi_{\text{atm}} + \Delta\phi_{\text{pixel}} + \Delta\phi_{\text{def}}$$

Turbulent troposphere



Pass 1

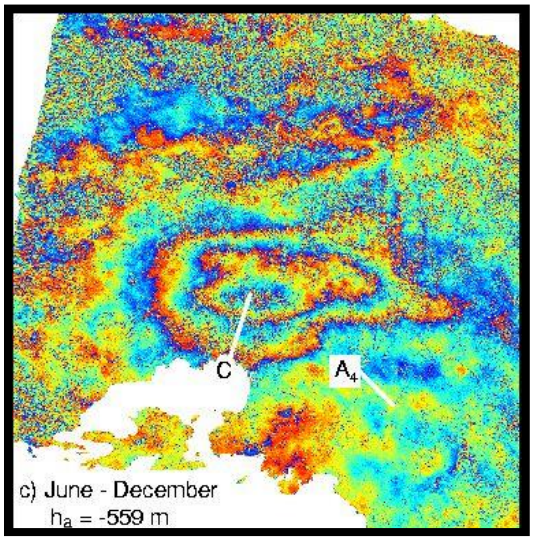
Pass 2



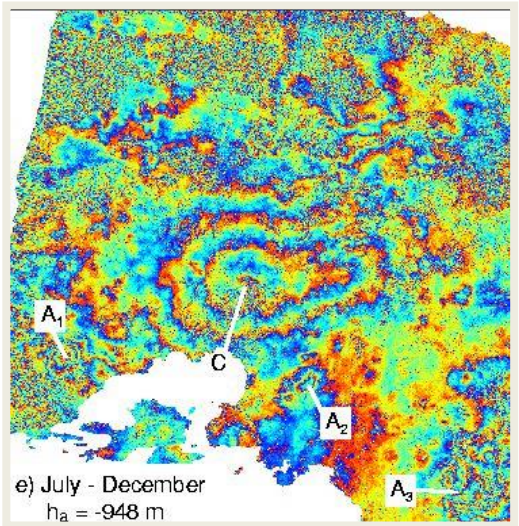
Tropospheric phase (6)

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

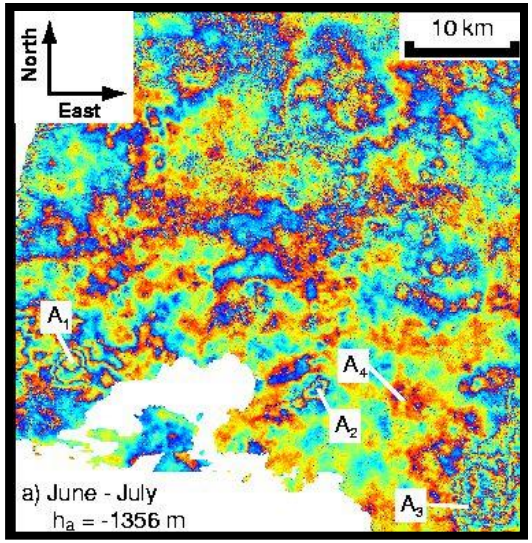
Turbulent troposphere



June to December



July to December



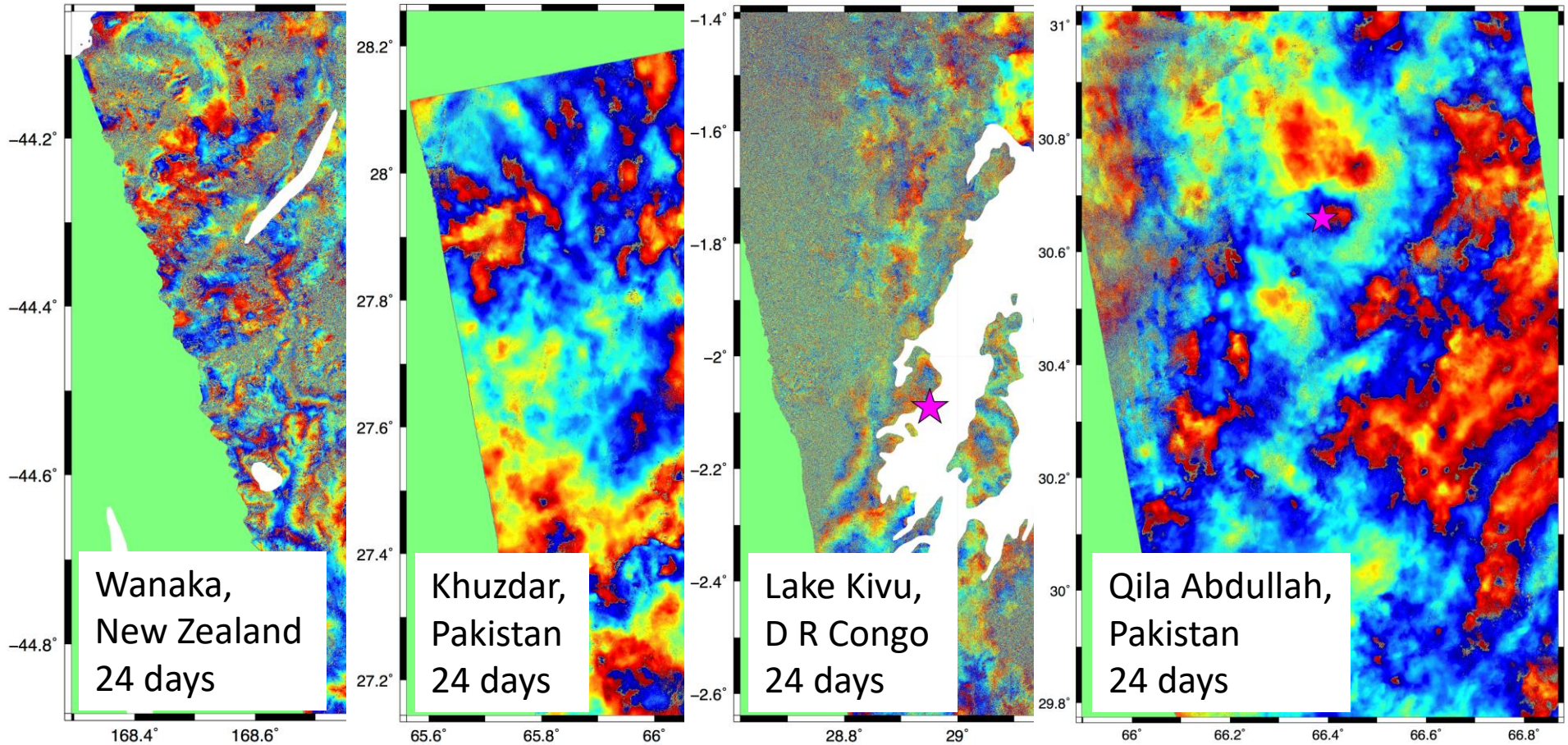
June to July

Athens Earthquake – September 1999

Wright (2001)

Which blob?

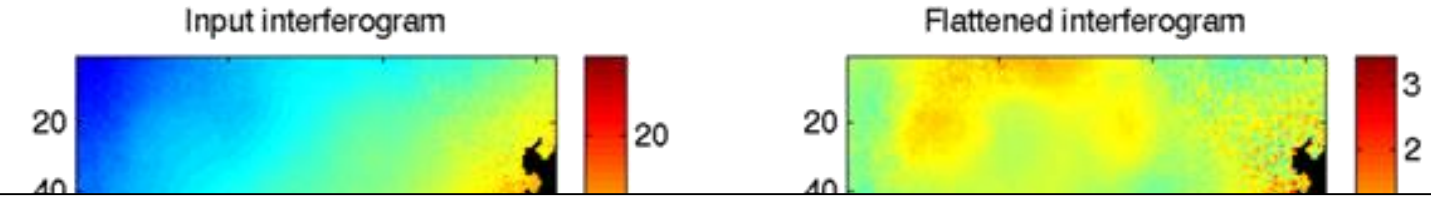
Shortest Sentinel-1 pairs for shallow M>5.5 earthquakes



Tropospheric phase (7)

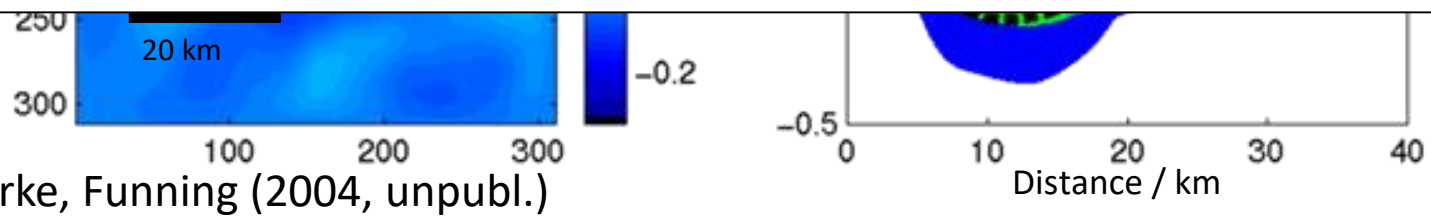
$$\Delta\phi_{\text{int}} = \Delta\phi_{\text{orb}} + \Delta\phi_{\text{topo}} + \Delta\phi_{\text{atm}} + \Delta\phi_{\text{pixel}} + \Delta\phi_{\text{def}}$$

- Size of $\Delta\phi_{\text{atm}}$ (at sea level) ~ 0 to 3 fringes (90 mm)
- Methods for dealing with $\Delta\phi_{\text{atm}}$
  - Ignore (only works for large deformation signals!)
  - Exclude
  - Quantify
  - Model based on other observations (e.g. GPS, meteorology…)
  - Increase SNR by stacking

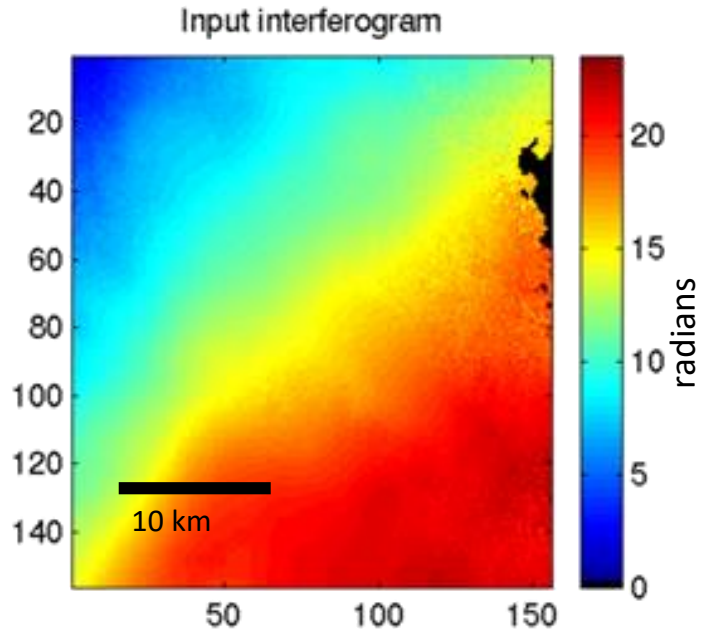


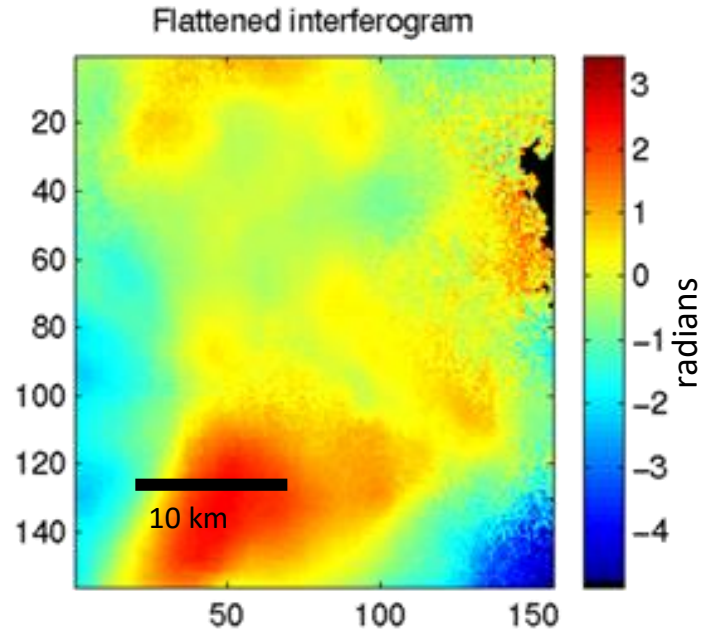
Several studies have **quantified** the tropospheric noise in interferograms (e.g. Hanssen, 2002; Wright et al., 2003; Funning et al., 2005; Lohman and Simons, 2005)

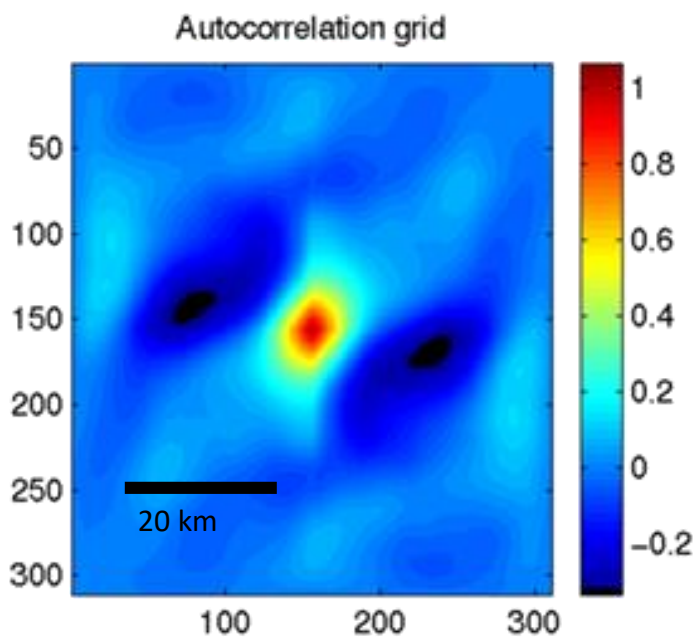
- Remove a best-fitting ramp from data
- Compute autocorrelation (can be achieved in Fourier domain) or semi-variogram
- Calculate the radial average and fit a function; its e-folding wavelength is an estimate of the correlation length scale of the noise; its amplitude an estimate of the variance of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

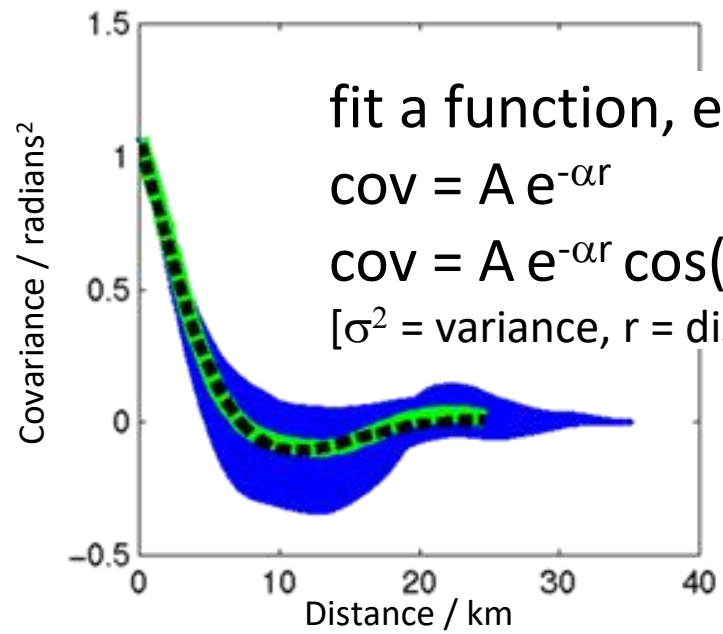


Wright, Clarke, Funning (2004, unpubl.)









fit a function, e.g.

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

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

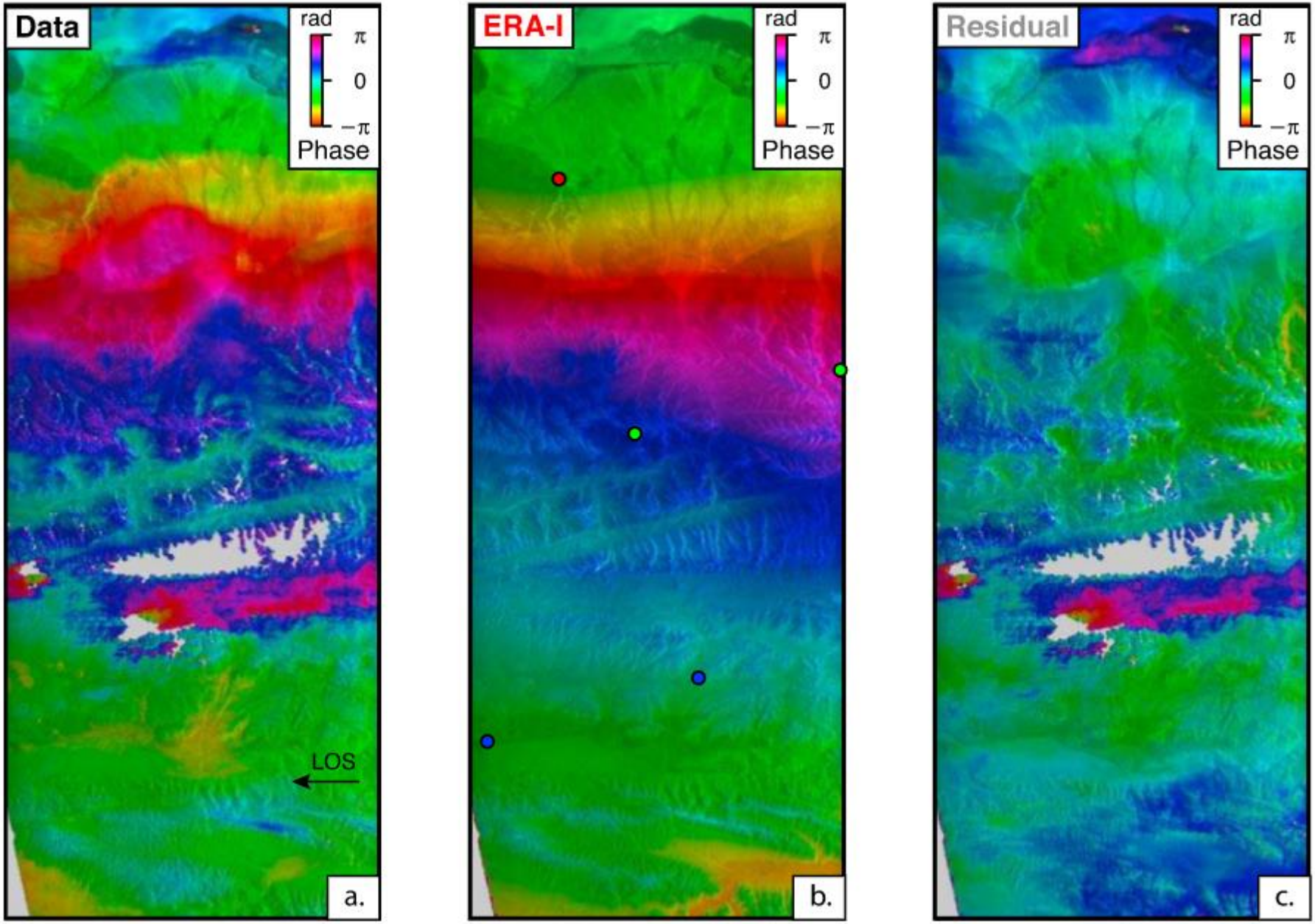
[σ^2 = variance, r = distance]

Wright, Clarke, Funning (2004, unpubl.)

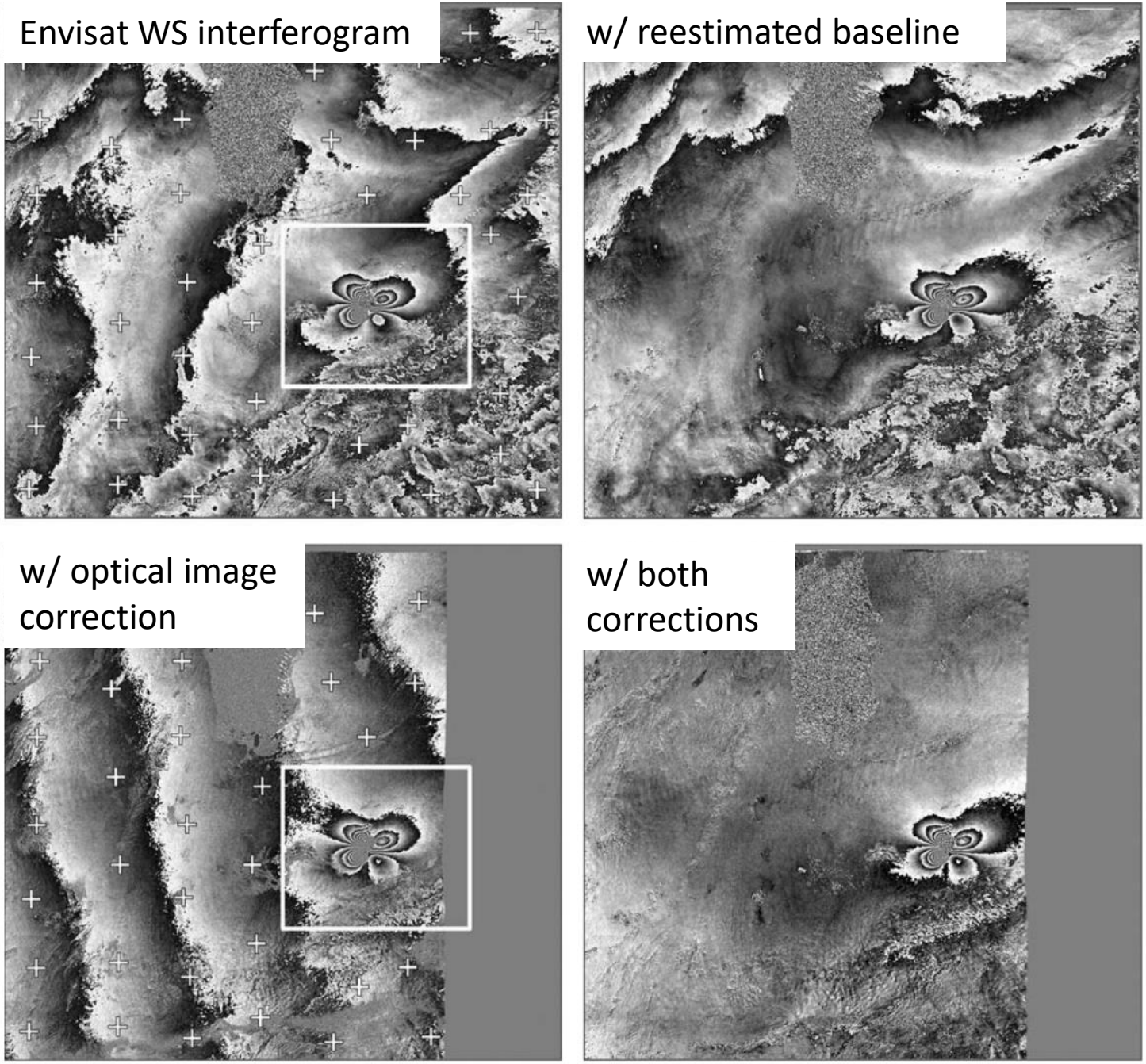
Modeling the troposphere

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

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…

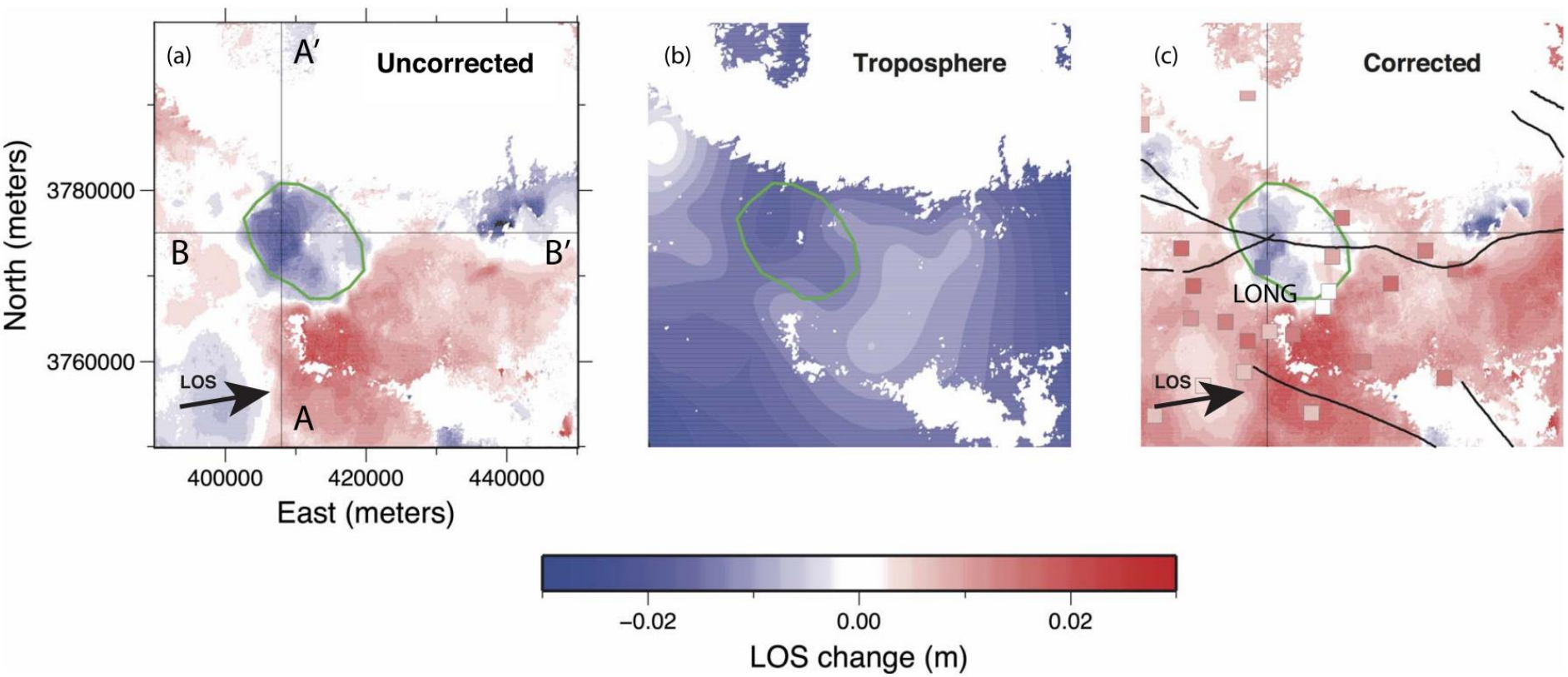


Jolivet et al., 2011

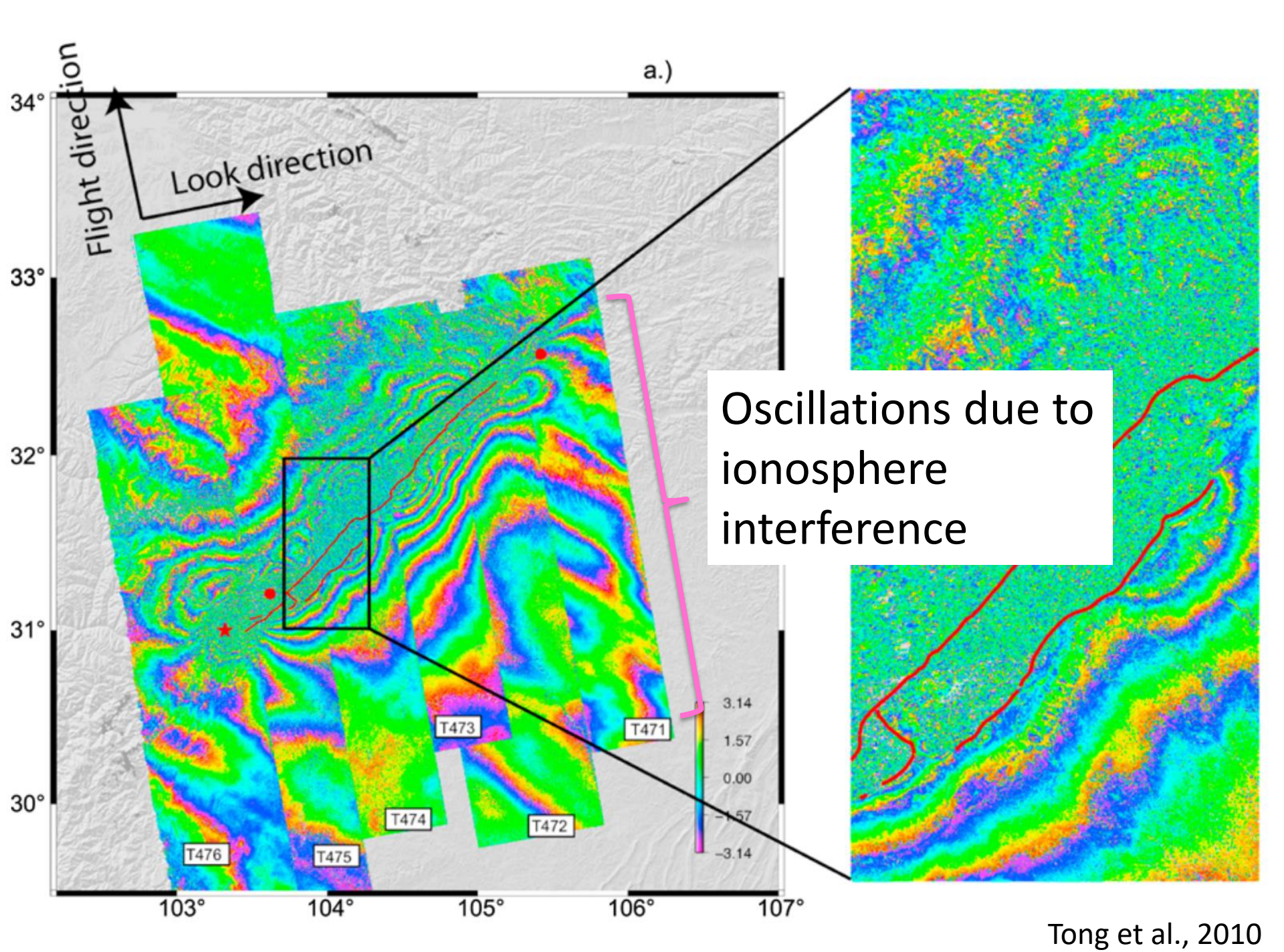

Envisat WS interferogram
w/ reestimated baseline
w/ optical image correction
w/ both corrections

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

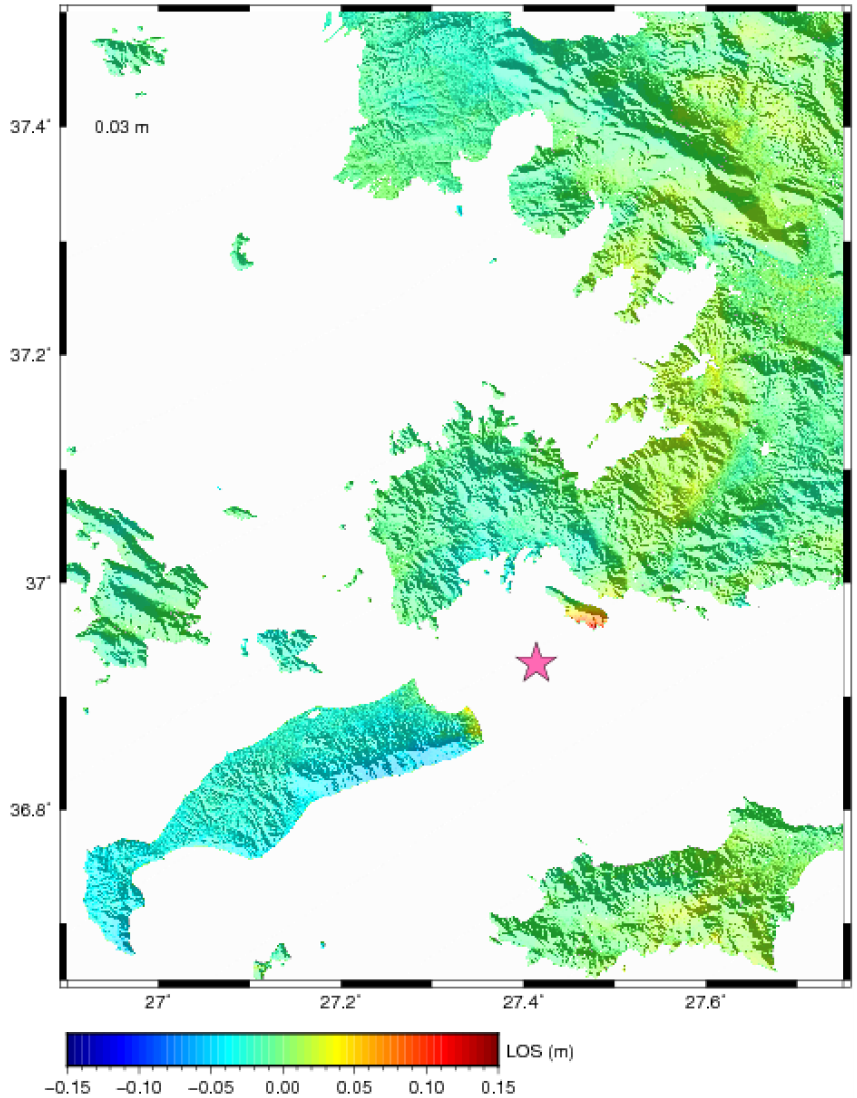
Ionosphere distortions

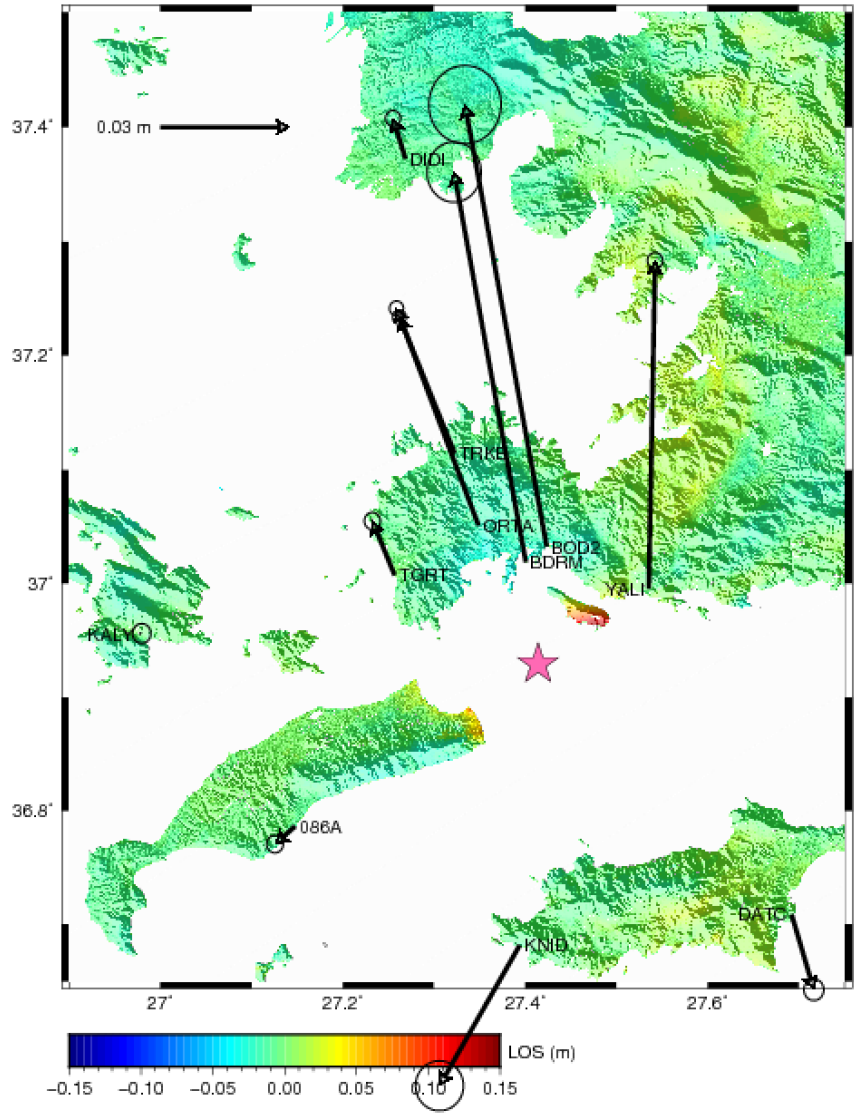
The ionosphere also adds a distortion to radar waves. It is dispersive (frequency-dependent) and affects long wavelengths (e.g. L-band missions such as ALOS and ALOS-2) more than shorter wavelengths

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

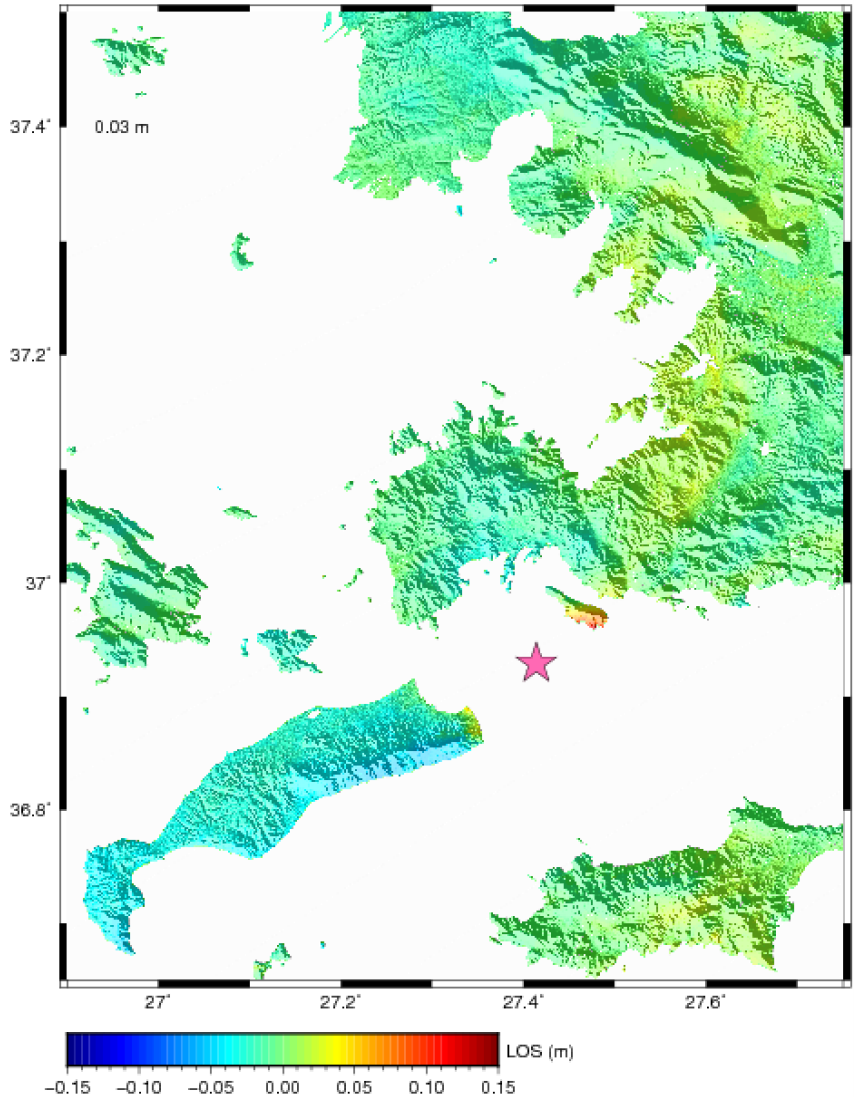
This technique is known as 'enhanced spectral diversity'

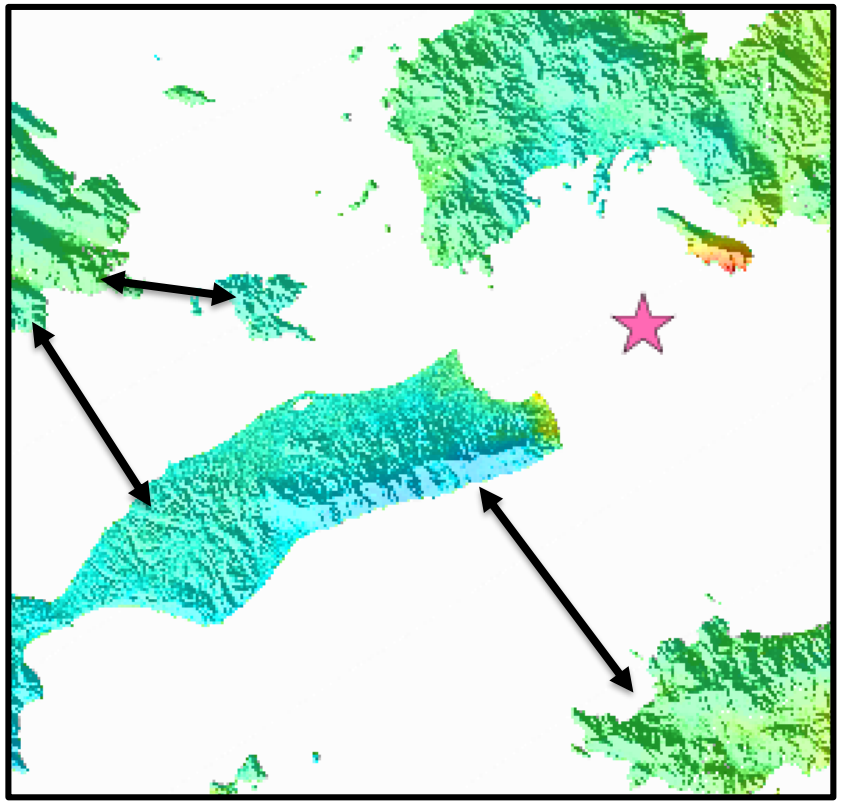
2017 Bodrum, Turkey earthquake





2017 Bodrum, Turkey earthquake



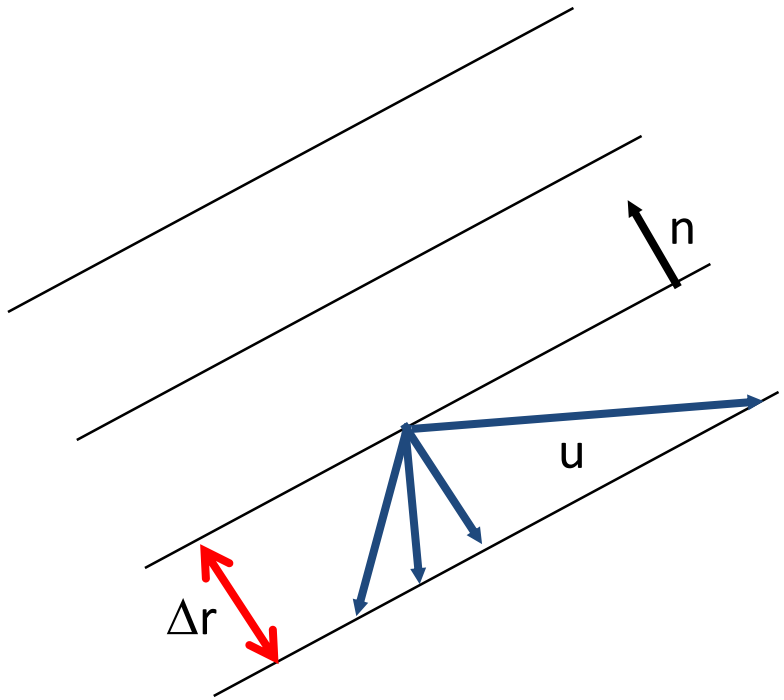


Phase jumps of 2π and 4π in far field indicative of unwrapping errors

Deformation phase

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

InSAR ONLY MEASURES THE COMPONENT OF SURFACE DEFORMATION IN THE SATELLITE'S LINE OF SIGHT



$$\Delta r = - n.u$$

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

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

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