Differential InSAR (DInSAR)

\[ \Delta \phi_{\text{int}} = \Delta \phi_{\text{urb}} + \Delta \phi_{\text{topo}} + \Delta \phi_{\text{atm}} + \Delta \phi_{\text{pixel}} + \Delta \phi_{\text{def}} \]

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
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.
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)

\[
\Delta \phi_{\text{int}} = \Delta \phi_{\text{orb}} + \Delta \phi_{\text{topo}} + \Delta \phi_{\text{atm}} + \Delta \phi_{\text{pixel}} + \Delta \phi_{\text{def}}
\]
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')

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

- 19 found (54%)
- 11 not found (32%)
- 5 inconclusive (14%)

Funning and Garcia, 2018
Most nondetections within 15° of equator – link to tropical climate and vegetation?

- found: 13
- not found: 2

- found: 2
- not found: 7

- found: 4
- not found: 2

Funning and Garcia, 2018
Effect of wavelength on decorrelation

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

Sentinel-1, 12 days, \( \lambda = 5.6 \text{ cm (C-band)} \)

ALOS-2, 28 days, \( \lambda = 23.8 \text{ cm (L-band)} \)

[Processed by Yu Morishita, GSI, Japan]
The critical baseline

In order to identify the phase ramp between pixels, it cannot exceed a shift of $2\pi$ (or a round-trip distance of $\lambda$) 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 $2\pi$ (or a round-trip distance of $\lambda$) 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 $\lambda$:

$$2L \left( \sin \gamma_1 - \sin \gamma_2 \right) < \lambda \quad \text{(approximately)}$$

$$2L \cos \gamma \left( \frac{B}{R} \right) < \lambda$$

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

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

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

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

\[
C = \frac{1}{n} \sum_{i=1}^{n} \frac{I_i}{|I_i|}
\]
Interferometric correlation

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

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

If the phases are similar, the correlation is high, and vice-versa.
Tips for avoiding decorrelation

• Short interferogram time spans reduce the probability of temporal decorrelation
• Short perpendicular baselines reduce geometric decorrelation
• Longer radar wavelengths are less susceptible to volume decorrelation
• Don't work on forested areas or the tropics?
• Only work in urban areas or the mid-latitudes?

Less of a problem with modern missions

ALOS-2! NISAR! (one day)

No, but you might need to choose data carefully
Los Angeles

time span = 1 day
Tropospheric phase (1)

\[ \Delta \phi_{\text{int}} = \Delta \phi_{\text{orb}} + \Delta \phi_{\text{topo}} + \Delta \phi_{\text{atm}} + \Delta \phi_{\text{pixel}} + \Delta \phi_{\text{def}} \]
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.

\[ \text{path \_ delay} = \int_0^{\text{atm \_ thickness}} (n_1(h) - n_2(h))dh \]

\[ n = \text{refractive index} = f(\text{humidity, temperature, pressure}) \]

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
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

Path delay

Path delay
Tropospheric phase (6)

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

Turbulent troposphere

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) \( \sim \) 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.
\[ \text{cov} = A e^{-\alpha r} \]
\[ \text{cov} = A e^{-\alpha r} \cos(\beta r) \]
[\(\sigma^2 = \text{variance, } r = \text{distance}\)]

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.
Oscillations due to ionosphere interference
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 $2\pi$ and $4\pi$ in far field indicative of unwrapping errors.
Deformation phase

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

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

\[ \Delta r = - \mathbf{n} \cdot \mathbf{u} \]

where \( \mathbf{n} \) is a unit vector pointing from the ground to the satellite

\[ \Delta \phi_{\text{def}} = \left( \frac{4\pi}{\lambda} \right) \Delta r \]

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