Introduction to SAR interferometry

Rüdiger Gens
Amplitude and phase

- **amplitude**
  - measure of the strength of the signal

- **phase**
  - angle of a complex number
Total phase

\[ \varphi = 2\pi \frac{2r}{\lambda} + \varphi_0 \]

- round-trip distance \( 2r \)
- scattering part \( \varphi_0 \) (interaction of the wave with the ground – unknown)
- radar wavelength \( \lambda \)
Baseline

- separation between the two antenna positions either mounted on an aircraft or realized by two repeating satellite orbits

Source: Gens and van Genderen, IJRS, 1996
Interferometric fringe

- represents the whole range of the phase in an interferogram from 0 to $2\pi$ in a full color cycle
Interferometric fringe

- fringes are not necessarily parallel
  - gradient can vary in near range versus far range
  - phenomenon is caused by the baseline vector varying as a function of time during acquisition when the two tracks are diverging or converging
Geometry of SAR interferometry
Why does InSAR work?

- coherent signal
  - single frequency and phase
- same geometry covering the same area from slightly different position in space
Interferometric techniques

- across-track interferometry
  - regular airborne geometry
- along-track interferometry
  - airborne geometry
  - monitoring ocean currents or other moving objects
- repeat-pass interferometry
  - usually spaceborne
- differential interferometry
  - change detection
complex multiplication of the two images; i.e. the corresponding amplitudes have to be averaged and the corresponding phases have to be differenced at each point in the image
Interferometric phase

\[ \Delta \varphi = 2\pi \frac{2\Delta r_{12}}{\lambda} = \Delta \varphi_{frac} + 2\pi \cdot N \]

- assumption the elementary scatterers within each pixel are undisturbed in the time between the two image acquisitions from exactly same location in space
  - scattering part \( \varphi_0 \) does not change
  - phase difference is independent of the scattering mechanism
  - phase difference is a measure of the line-of-sight component \( \Delta r \) of the target displacement vector over the time interval between acquisitions
  - \( \Delta \varphi_{frac} \) is interferometric phase
Coherence image

- measure for the correlation of corresponding signals
- ranges from 0 to 1
Digital elevation model
Digital elevation model
Differential interferogram

- change detection: measurement of small-scale movements in the vertical direction
- displacement measured is not vertical, but along the viewing direction
- relative accuracy of the order of a few centimetres or even less vs. absolute accuracy of digital elevation models of about 10-15 meters (for ERS data)
Differential InSAR phase

\[
\Delta r_{12} \approx \frac{\lambda}{4\pi} \left( \Delta \phi_{12} - \Delta \phi_{01} \frac{B_{12}}{B_{01}} \right)
\]

- fundamental equation for detecting and measuring changes with InSAR
- provides line-of-sight component of the three-dimensional surface displacement vector
  - combination of ascending and descending orbit data can recover two independent components
- assumption that surface within a pixel deforms homogeneously
Differential InSAR phase

- Backscatter behavior does not change significantly over time, i.e. unknown scatterer part can be neglected
  - Significant change leads to temporal decorrelation
- Phase unwrapping problem can be solved for large parts of the image
  - Phase is modulo $2\pi$
  - Integer number of phase cycles is known
- Large displacement cannot be detected
  - Phase gradient limited to half the wavelength
Differential InSAR phase

- Precision surface displacements requires accurate a priori estimate of topography

\[ \sigma_{\Delta \varphi} = \frac{4\pi}{\lambda} \left( \sigma_{\Delta r} + \frac{B_{\perp}}{R \sin \gamma} \sigma_h \right) \]
Interferometric applications

- Topographic mapping
- Digital elevation model
- Ocean currents
- Forestry
- Coastal zones
- Change detection
- Land subsidence
- Volcanic hazards
- Hydrology
- Polar research
- Seismic events
InSAR applications:
Deformation processes

- land subsidence
  - mining activities
  - withdrawal of water, gas and oil
- co-seismic and post-seismic displacement field related to earthquakes
- deflation and inflation of volcanoes
- dynamics of glaciers and ice sheets
InSAR applications: Deformation processes

- tectonic processes
- orogenesis and erosion
- coastal-zone changes
Trends and challenges

- Shuttle Radar Topography Mission (SRTM)
  - flown in February 2000
- swath processing
  - data volume
  - Doppler frequency issues
- DEM production for larger areas
  - SRTM
- long term monitoring
  - permanent scatterers