Differential Interferometry

The landslide of St. Etienne de Tinee
Estimated motion

Space-varying time-constant velocities have been hypothesized.

Color coded subsidence velocity in millimeters per year is shown.
Differential Interferometry

Interferogram  Synthetic Interferogram  Differential Interferogram
Differential phases along the Valle del Bove

1 August 95

2 August 95

Master: April 96
If the propagation medium changes the time interval between two SAR acquisitions (e.g. humidity, temperature, pressure …), an additive phase term, independent of the baseline, appears.

\[ \Delta \varphi_{\text{atmosphere}} \]
Summary of the SAR interferometric phase contributions

\[ \Delta \varphi = \Delta \varphi_{flat} + \Delta \varphi_{elevation} + \Delta \varphi_{displacement} + \Delta \varphi_{atmosphere} + \Delta \varphi_{noise} \]

\[ - \frac{4\pi}{\lambda} \frac{B_n s}{R \tan \theta} \]

\[ - \frac{\Delta q}{\sin \theta} \cdot \frac{B_n}{R_0} \cdot \frac{4\pi}{\lambda} \]

\[ + \frac{4\pi}{\lambda} d \]
THE SAR INTERFEROGRAM GENERATION
Interferogram generation

Orbits -> Registering parameters estimate -> Local frequency estimate

SLC

Master

Range 2x oversampling -> Co-registering & resampling

Slave

Spectral Shift & common band filtering

Coherence estimate -> Coherence maps

Complex multi-looking & subsampling

Flattening & mosaicking

Interferogram
Image-coregistering

Master
Slave
**Complex multilook**

A “cleaned” interferogram is achieved by averaging in areas of uniform phase. SNR improves $\propto$ the number of looks. Usually the averaging window is adaptive.
NOISE SOURCES
&
COHERENCE
*Noise sources in interferometry*

For evaluating noise performances, the interferometric phase difference (that is usually topographic-dependent) is assumed to be zero.
Noise in interferometry

The complex interferogram (pixel-to-pixel):

$$i(\vec{P}) = s_1(\vec{P}) \times s_2^*(\vec{P}) \propto (\nu + n_1)(\nu + n_2)^* = |\nu|^2 + n_1^* \nu + \nu^* n_2 + n_1 n_2^*$$

contains signal and noise contributes.

For SNR >> 1 the interferogram SNR is $\propto$ the image SNR. For SNR << 1 the interferogram SNR worsens, $\propto$ the image $(\text{SNR})^2$.

We are interested in phase noise, as phase is the signal. Phase statistics is known for homogenous target (speckle-only). Phase std can be expressed in terms of image SNR.

![Graph showing the relationship between SNR (dB) and phase standard deviation (\(\sigma_{\phi}\))](image)

This curve holds for 1 look. For pure noise $\sigma_{\phi} = \pi/3$. SNR $\rightarrow \phi$ is hardly invertible for SNR < 0, that would be useful to estimate multi-look-averaged performances.
Noise figures

\[ \sigma_\phi \]

\[ \text{SNR (dB)} \]

\[ \text{coherence} \]
Estimate of coherence

Coherence can be estimated, in each pixel, by averaging over area of stationary phase.

\[ \hat{\gamma} = \frac{\sum_{r_n} \sum_{x_m} v_1 v_2^* e^{-j\phi(r_n, x_m)}}{\sqrt{\sum_{r_n} \sum_{x_m} |v_1|^2 \sum_{r_n} \sum_{x_m} |v_2|^2}} \]

Topographic phase, \( \phi \), is assumed locally flat (a 2D complex sinusoid). Hence it can be retrieved by means of instantaneous frequency estimators.

Coherence is biased \( \rightarrow 1 \) when \# freedom degrees is one, or when one scatterer prevails.
Coherence maps

Amplitude

Phase

Coherence
Coherence estimate (ML)

\[ \text{mean} \]

\[ \text{variance} \]
Coherence histogram are used to evaluate image quality, like in comparing the output of two different interferometric processors.
Uses of coherence

Coherence maps are much useful for two purposes:

1. they provide a local measure of “quality” (e.g. DEM accuracy)
2. they provide useful and quantitative information on scene “features”.

These information are complementary with the intensity image ($\sigma_0$)
Etna precise coherence maps

April 96
May 96
August 95
September 95
November 95
December 95
Mt. Vesuvius

Detected

Coherence
Mt. Vesuvius segmentation
A vegetation model is used. A 1 x 1 degree NOAA AVHRR NDVI (Normalized Differential Vegetation Index) mosaic for the month of March (1994) was used to feed this model. The model was empirically derived by polynomial fitting to a scatterplot of average coherence values versus average corresponding NDVI values for 4005 frames of ERS tandem data collected over North America.

Predicted coherence (0.4…0.8) for the month of March.

Predicted coherence (0.4…0.8) for the month of September.

Image courtesy of Atlantis
Mt. Etna

Lansat TM

ERS Coherence
Atmospheric artifacts

Atmospheric inhomogeneities, due to variations in Pressure, Temperature, Humidity affects light speed velocity. The delay variation in the repeat interval results in a “phase screen”, hence a noise. “Atmospheric” noise is fractal ($f^a$) power spectrum ($a \sim 2/3$), hence it is correlated in space ($\sim$ hundred of meters). Coherence maps cannot measure this noise.

Atmospheric artifacts can be up to two fringes. This is converted in elevation error, depending on the baseline. The error cannot be estimated or recovered.
Atmospheric artifacts can be detected in a multi-baseline environment, since atmosphere is incorrelated in time.

**Error Map: May – December**

- **Etna**
- **Paris (+ reflectivity)**