Generation of Digital Elevation Model

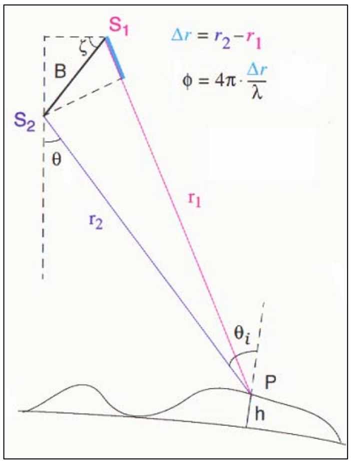
Purpose

The purpose of this second day is

- To have an introduction on SAR Interferometry, in particular on
    - Acquisition principle
    - Phase
    - Coherence
- To generate a Digital Elevation Model based on ALOS PALSAR data.

SAR Interferometry

Purpose



The difference r_1 and r_2 (Δr) can be measured by the phase difference (ϕ) between two complex SAR images. This is performed by multiplying one image by (the complex conjugate of) the other one, where an interferogram is formed. The phase of the interferogram contains fringes that trace the topography like contour lines.

Two possible acquisition modes:

- Single-Pass Interferometry
- Repeat-Pass Interferometry

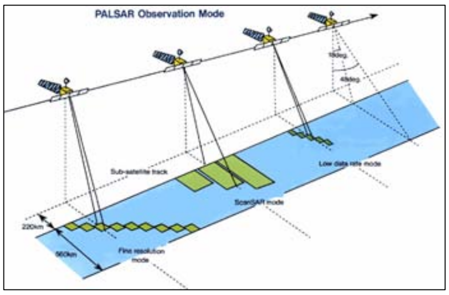
Data Set - ALOS PALSAR interferometric image pair

It consists of **2 slant range ALOS PALSAR images** (sample of around 30 x 30 km, 10 meter resolution) acquired over Malawi on:

- June 08th 2006
- July 24th 2006

The SAR data are available in **Single Look Complex format**

ALOS PALSAR sensor



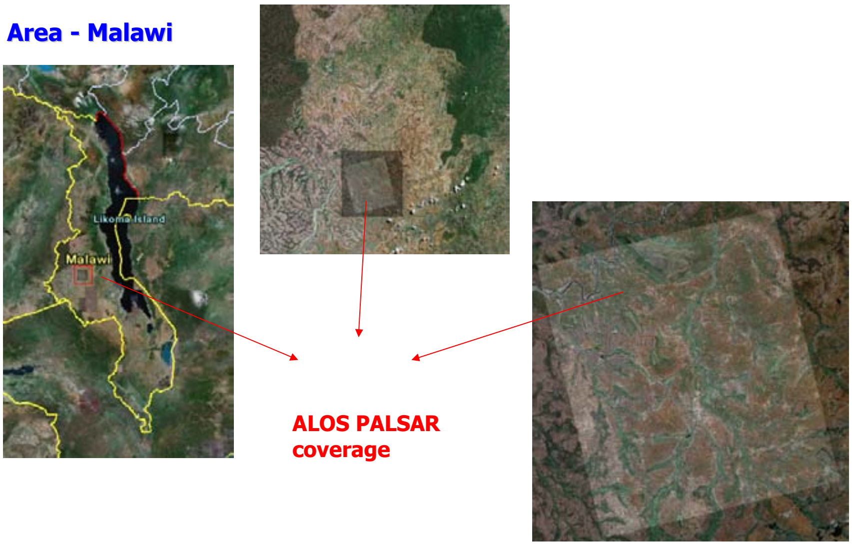
Agency	Japan Aerospace Exploration Agency
Frequency	L-band
Polarization	Single Pol, Dual Pol, Full Pol
Acquisition Modes	Stripmap (Fine) and ScanSAR
Ground Resolution	7 to 100 m
Swath	20 to 350 km
Repeat Cycle	46 days
Launch	2006
Further Information	http://www.eorc.jaxa.jp

Additional Data - SRTM Digital Elevation Model

SRTM DEM

USGS Shuttle Radar Topographic Mapping Digital Elevation Model sample (original pixel size 90 x 90 meters), interpolated to 10m grid size, WGS-84, Utm 36, South.

Area - Malawi



ALOS PALSAR coverage

Cartographic and Geodetic System

Country	UTM
Zone	36
Hemisphere	South
Geodetic System	WGS-84

Processing Steps

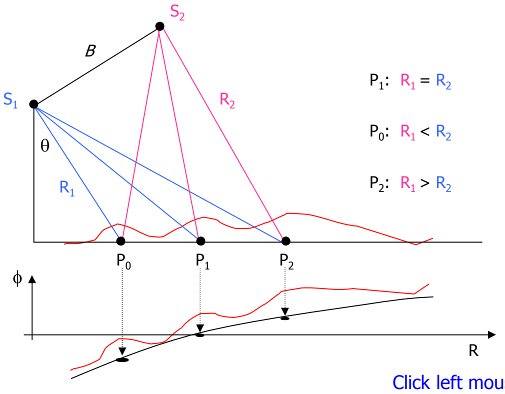
Following processing steps must be performed:

- Baseline Estimation
- Download reference SRTM DEM
- Interferogram Generation
- DEM Interferogram Flattening
- Adaptive Filter and Coherence generation
- Phase Unwrapping
- Baseline Fit
- DEM Interferogram Flattening
- Convertion from Phase to Height
- Difference between the SRTM DEM

Interferogram Generation

General

After image co-registration an interferometric phase (ϕ) is generated by multiplying one image by the complex conjugate of the second one. A complex interferogram (*Int*) is formed as schematically shown in the illustration below.



P_1: $R_1 = R_2$

P_0: $R_1 < R_2$

P_2: $R_1 > R_2$

$Int = S_1 \cdot S_2{}^*$

$\phi = 4\pi (R_1 - R_2) / \lambda$

Click left mouse-button to visualise the illustration

Interferogram Generation

Critical Baseline

The generation of an interferogram is only possible when the ground reflectivity acquired with at least two antennae overlap. When the perpendicular component of the baseline (B_n) increases beyond a limit known as the critical baseline, no phase information is preserved, coherence is lost, and interferometry is not possible.

The critical baseline $B_{n,cr}$, can be calculated as

$$B_{n,cr} = \frac{\lambda\, R \tan(\theta)}{2\, R_r}$$

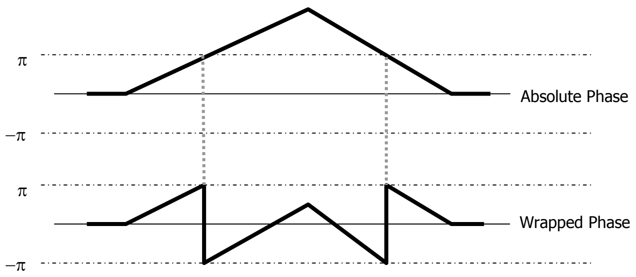
where R_r is the range resolution, and θ is the incidence angle. In case of ERS satellites the critical baseline is approximately 1.1 km.

The critical baseline can be significantly reduced by surface slopes that influence the local incidence angle.

Interferogram Generation

Interferometric Phase

The interferometric phase (ϕ) is expressed as ϕ = tan(Imaginary(*Int*) / Real(*Int*)), modulo 2π.



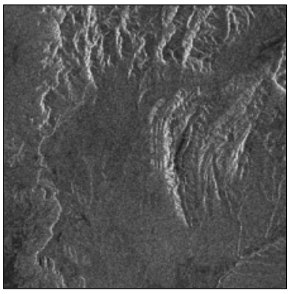
In order to resolve this inherent ambiguity, phase unwrapping must be performed.

Click left mouse-button to visualise the illustration

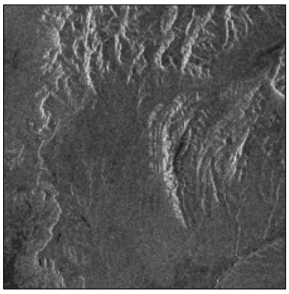
Interferogram Generation

An Example

The Figure illustrates two ENVISAT ASAR images of the Las Vegas area (USA). Note that the two images have been acquired with a time interval of 70 days. The two scenes, which in InSAR jargon are defined as Master and Slave image, are in the slant range geometry and are used to generate the interferometric phase, corresponding interferogram, and interferometric coherence.



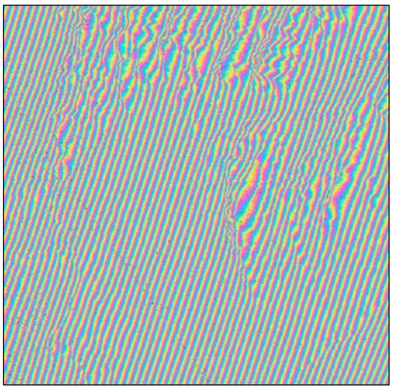
Master image



Slave image

Interferogram Generation

An Example



The Figure illustrates the interferogram generated from the two ENVISAT ASAR images (previous page). In essence, the complex interferogram is a pattern of fringes containing all of the information on the relative geometry. The colours (cyan to yellow to magenta) represent the cycles (modulo 2π) of the interferometric phase. Due to the slightly different antennae positions, a systematic phase difference over the whole scene can be observed. In order to facilitate the phase unwrapping, such low frequency phase differences are subsequently removed.

Interferogram Flattening

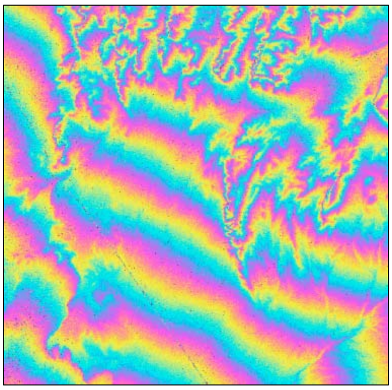
Purpose

In preparation for the phase unwrapping step to come, the expected phase, which is calculated using a system model, is removed, producing a flattened interferogram, that is easier to unwrap.

Neglecting terrain influences and Earth curvature, the frequency to be removed can be estimated by the interferogram itself. However, the most accurate models for removal of the fringes are those that estimate the expected Earth phase by assuming the shape of the Earth is an ellipsoid or, more accurately, by using a Digital Elevation Model.

Interferogram Flattening

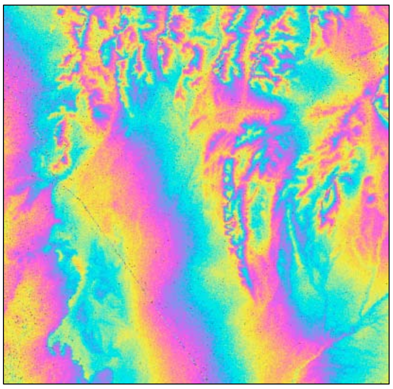
An Example



The Figure illustrates the interferogram flattened **assuming the Earth's surface an ellipsoid**. If compared to the initial interferogram, it is evident that the number of fringes has been strongly reduced, hence making it possible to facilitate the phase unwrapping process and the generation of the Digital Elevation Model or, in case of differential interferometry, the measurements of ground motions.

Interferogram Flattening

An Example



The Figure illustrates the interferogram flattened by considering **a low resolution Digital Elevation Model**, i.e. the topography. If this is compared to the initial interferogram, or to the ellipsoidal flattened one, it is evident that the number of fringes has been strongly reduced, hence facilitating the phase unwrapping process and the generation of the Digital Elevation Model or, in case of differential interferometry, the measurements of ground motions.

Coherence (Interferometric Correlation)

Purpose

Given two co-registered complex SAR images (S_1 and S_2), one calculates the interferometric coherence (γ) as a ratio between coherent and incoherent summations:

$$\gamma = \frac{\left|\sum s_1(x)\cdot s_2(x)^*\right|}{\sqrt{\sum \left|s_1(x)\right|^2 \cdot \sum \left|s_2(x)\right|^2}}$$

Note that the observed coherence - which ranges between 0 and 1 - is, in primis, a function of systemic spatial decorrelation, the additive noise, and the scene decorrelation that takes place between the two acquisitions.

In essence coherence has, in primis, a twofold purpose:

- To determine the quality of the measurement (i.e. interferometric phase). Usually, phases having coherence values lower than 0.2 should not be considered for the further processing.
- To extract thematic information about the object on the ground in combination with the backscattering coefficient (σ^o).

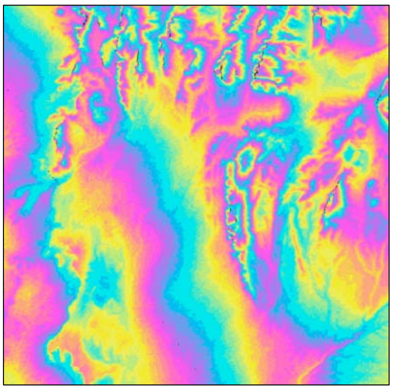
Coherence (Interferometric Correlation)

An Example

The Figure illustrates the estimated coherence. Bright values correspond to values approaching to 1, while dark values (black = 0) are those areas where changes (or no radar return, radar facing slope, etc.) occurred during the time interval, 70 days in this case. Note that coherence is sensitive to microscopic object properties and to short-term scatter changes. In most cases, the thematic information content decreases with increasing acquisition interval, mainly due to phenological or man-made changes of the object or weather conditions. Since the selected sites are located in dry areas, high coherence information is observed even over long timescales.

Interferogram Flattening

An Example



The Figure illustrates the filtered interferogram after an adaptive filtering. Compare this picture with the unfiltered one (Interferogram Flattening with Digital Elevation Model). The basic idea of this adaptive filtering is to use the coherence values in order to obtain irregular windows and thus specifically filter the different features.

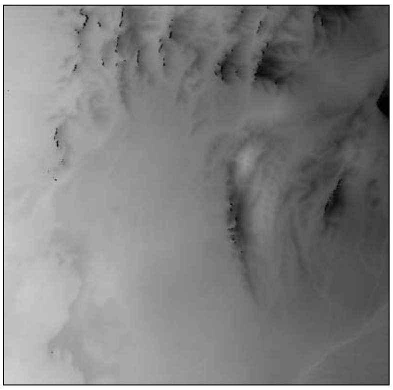
Phase Unwrapping

Purpose

The phase of the interferogram can only be modulo 2π. Phase Unwrapping is the process that resolves this 2π ambiguity. Several algorithms (such as the branch-cuts, region growing, minimum cost flow, minimum least squares, multi-baseline, etc.) have been developed. In essence, none of these are perfect, and depending on the applied technique some phase editing should be carried out in order to correct the wrong unwrapped phases. The most reliable techniques are those in which different algorithms are combined.

Phase Unwrapping

An Example



The Figure illustrates the unwrapped phase. At this stage the grey levels representing the phase information are relative and must be absolutely calibrated in order to convert it to terrain height. Note that no grey level discontinuities can be observed. This indicates that the phase unwrapping process has been correctly performed.

Orbital Correction

Purpose

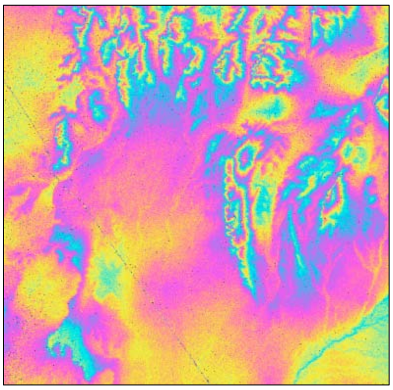
The orbital correction is crucial for a correct transformation of the phase information into height values. In essence, this procedure, which requires the use of some accurate Ground Control Points, makes it possible to

i) calculate the phase offset (hence allowing to calculate the absolute phase), and ii) refine the orbits and thus obtain a more accurate estimate of the orbits and the corresponding baseline. Generally, this step is performed by taking into account

- Shift in azimuth direction
- Shift in range direction
- Convergence of the orbits in azimuth direction
- Convergence of the orbits in range direction
- Absolute phase

Orbital Correction

An Example



The Figure illustrates the filtered DEM flattened interferogram after the orbital correction. Compare it with the non corrected one. From a visual comparison it is clear how fringes that have been induced by inaccurate orbits may be removed in order to obtain a proper interferogram.

Phase to Map (Height) Conversion

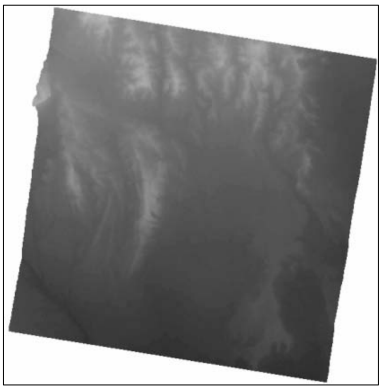
Purpose

The absolute calibrated and unwrapped phase values are converted to height and directly geocoded into a map projection. This step is performed in a similar way as in the geocoding procedure, by considering the Range-Doppler approach and the related geodetic and cartographic transforms. The fundamental difference with the geocoding step is that the Range-Doppler equations are applied simultaneously to the two antennae, making it possible to obtain not only the height of each pixel, but also its location (*x*,*y*,*h*) in a given cartographic and geodetic reference system. Formally, the system is:

$$\begin{cases} \left|\vec{P}-\vec{S}_1\right| - \left|\vec{R}_1\right| = 0 \\ \dfrac{2}{\lambda}\cdot\dfrac{\left(\vec{P}-\vec{S}_1\right)\cdot\left(\vec{V}_P-\vec{V}_{S_1}\right)}{\left|\vec{P}-\vec{S}_1\right|} + f_D = 0 \\ \left|\vec{P}-\vec{S}_2\right| - \left|\vec{R}_2\right| = 0 \\ \dfrac{2}{\lambda}\cdot\dfrac{\left(\vec{P}-\vec{S}_2\right)\cdot\left(\vec{V}_P-\vec{V}_{S_2}\right)}{\left|\vec{P}-\vec{S}_2\right|} + f_D = 0 \\ \left|\vec{R}_1\right| - \left|\vec{R}_2\right| = \dfrac{\lambda}{4\pi}\cdot\phi \end{cases}$$

Phase to Map (Height) Conversion

An Example



The Figure illustrates the derived Digital Elevation Model (DEM) in the UTM coordinate system. Dark values correspond to the low height values, while bright areas correspond to higher elevations.

The height accuracy of the obtained DEM, which has a spatial resolution of 20m, is of +/- 5 meter.