Land Cover Mapping

Purpose

The purpose of this first day is

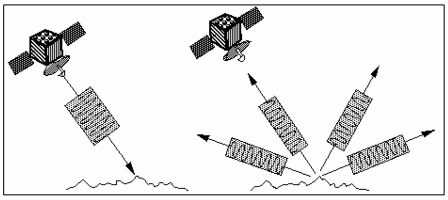
- To have an introduction on Synthetic Aperture Radar, in particular on
  - Acquisition principle
  - Intensity
  - Coherence

- To generate a land cover map including the main land cover classes based on ALOS PALSAR data.

The SAR System

Radar Imaging

Imaging radar is an active illumination system. An antenna, mounted on a platform, transmits a radar signal in a side-looking direction towards the Earth's surface. The reflected signal, known as the echo, is backscattered from the surface and received a fraction of a second later at the same antenna (monostatic radar).



For coherent radar systems such as Synthetic Aperture Radar (SAR), the amplitude and the phase of the received echo - which are used during the focusing process to construct the image - are recorded.

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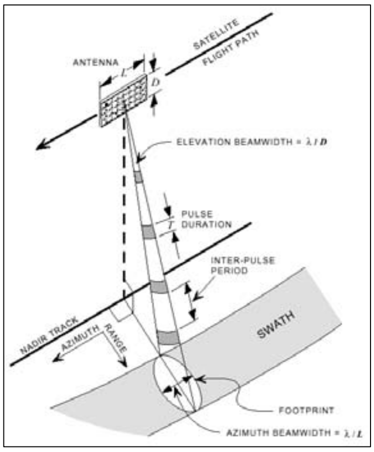
The SAR System

SAR versus other Earth Observation Instruments

	Lidar	Optical Multi-Spectral	SAR
Platform	airborne	airborne/spaceborne	airborne/spaceborne
Radiation	own radiation	reflected sunlight	own radiation
Spectrum	infrared	visible/infrared	microwave
Frequency	single frequency	multi-frequency	multi-frequency
Polarimetry	N.A.	N.A.	polarimetric phase
Interferometry	N.A.	N.A.	interferometric phase
Acquisition time	day/night	day time	day/night
Weather	blocked by clouds	blocked by clouds	see through clouds

The SAR System

Real Aperture Radar (RAR) - Principle



Aperture means the opening used to collect the reflected energy that is used to form an image. In the case of radar imaging this is the antenna.

For RAR systems, only the amplitude of each echo return is measured and processed.

The SAR System

Real Aperture Radar - Resolution

The spatial resolution of RAR is primarily determined by the size of the antenna used: the larger the antenna, the better the spatial resolution. Other determining factors include the pulse duration (τ) and the antenna beamwidth.

Range resolution is defined as

$$res_{range} = \frac{c\tau}{2\cos\theta}$$

where c is the speed of light, and θ the incidence angle.

Azimuth resolution is defined as

$$res_{azimuth} = \frac{\lambda R}{L}$$

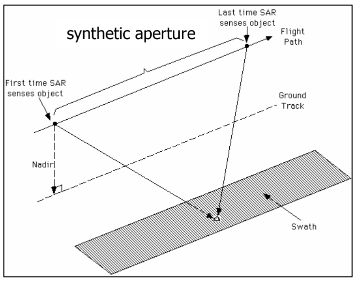
where L is the antenna length, R the distance antenna-object, and λ the wavelength. For systems where the antenna beamwidth is controlled by the physical length of the antenna, typical resolutions are in the order of several kilometres.

The SAR System

Synthetic Aperture Radar - Principle

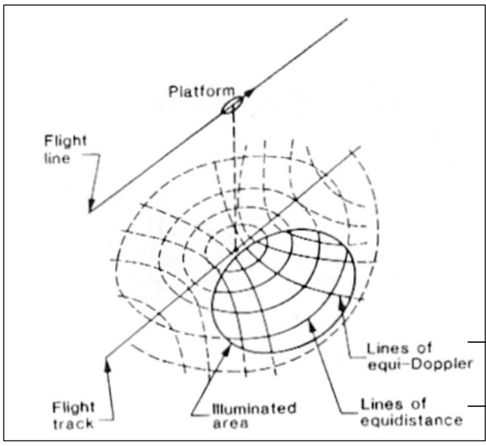
SAR takes advantage of the Doppler history of the radar echoes generated by the forward motion of the spacecraft to synthesise a large antenna (see Figure). This allows high azimuth resolution in the resulting image despite a physically small antenna. As the radar moves, a pulse is transmitted at each position. The return echoes pass through the receiver and are recorded in an echo store.

SAR requires a complex integrated array of onboard navigational and control systems, with location accuracy provided by both Doppler and inertial navigation equipment. For sensors such as ERS-1/2 SAR and ENVISAT ASAR, orbiting about 900km from the Earth, the area on the ground covered by a single transmitted pulse (footprint) is about 5 km long in the along-track (azimuth) direction.



The SAR System

Synthetic Aperture Radar – Principle (cont.)



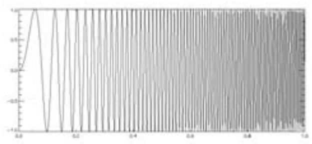
Iso-Doppler

Iso-range

The SAR System

Synthetic Aperture Radar - Range Resolution

The range resolution of a pulsed radar system is limited fundamentally by the bandwidth of the transmitted pulse. A wide bandwidth can be achieved by a short duration pulse. However, the shorter the pulse, the lower the transmitted energy and the poorer the radiometric resolution. To preserve the radiometric resolution, SAR systems generate a long pulse with a linear frequency modulation (or chirp).



Chirp

After the received signal has been compressed, the range resolution is optimised without loss of radiometric resolution.

The SAR System

Synthetic Aperture Radar - Azimuth Resolution

Compared to RAR, SAR synthetically increases the antenna's size to increase the azimuth resolution though the same pulse compression technique as adopted for range direction. Synthetic aperture processing is a complicated data processing of received signals and phases from moving targets with a small antenna, the effect of which is to should be theoretically convert to the effect of a large antenna, that is a synthetic aperture length, i.e. the beam width by range which a RAR of the same length, can project in the azimuth direction. The resulting azimuth resolution is given by half of real aperture radar as shown as follows:

- Real beam width $\beta = \lambda / D$
- Real resolution $\Delta L = \beta \cdot R = L_s$ (synthetic aperture length)
- Synthetic beam width $\beta_s = \lambda / 2 \cdot L_s = D / (2 \cdot R)$
- Synthetic resolution $\Delta L_s = \beta_s \cdot R = D / 2$

where λ is the wavelength, D the radar aperture, and R the distance antenna-object.

This is the reason why SAR has a high azimuth resolution with a small size of antenna regardless of the slant range, or very high altitude of a satellite.

The SAR System

Wavelength

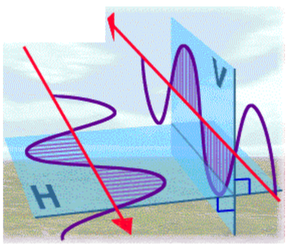
Radio waves are that part of the electromagnetic spectrum that have wavelengths considerably longer than visible light, i.e. in the centimetre domain. Penetration is the key factor for the selection of the wavelength: the longer the wavelength (shorter the frequency) the stronger the penetration into vegetation and soil. Following wavelengths are in general used:

P-band =	~ 65 cm	airborne	AIRSAR
L-band =	~ 23 cm	air- / spaceborne	JERS-1 SAR, ALOS PALSAR
C-band =	~ 5 cm	air- / spaceborne	ERS-1/2 SAR, RADARSAT-1/2, ENVISAT ASAR
X-band =	~ 3 cm	air- / spaceborne	TerraSAR-X , COSMO-SkyMed
K-band =	~ 1.2 cm	airborne	Military domain

The SAR System

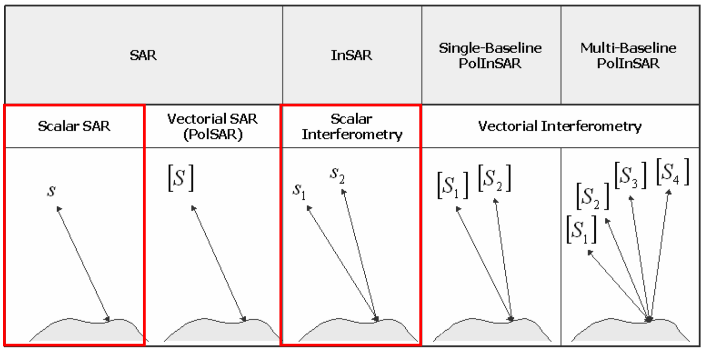
Polarization

Irrespective of wavelength, radar signals can transmit horizontal (H) or vertical (V) electric-field vectors, and receive either horizontal (H) or vertical (V) return signals, or both. The basic physical processes responsible for the like-polarised (HH or VV) return are quasi-specular surface reflection. For instance, calm water (i.e. without waves) appears black. The cross-polarised (HV or VH) return is usually weaker, and often associated with different reflections due to, for instance, surface roughness.



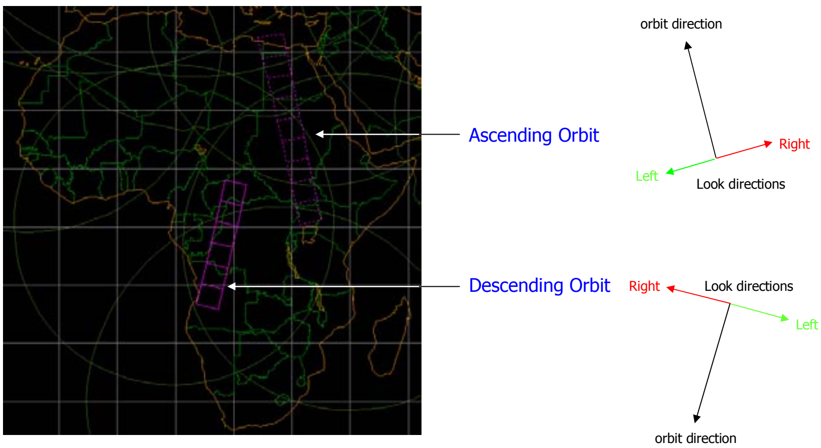
HV polarization

SAR Acquisition Modes and Techniques



Day 1 **Day 2**

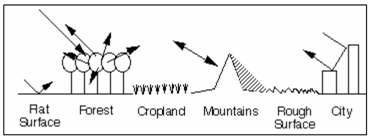
Basic Terminology



Intensity

General

SAR images represent an estimate of the radar backscatter for that area on the ground. Darker areas in the image represent low backscatter, while brighter areas represent high backscatter. Bright features mean that a large fraction of the radar energy was reflected back to the radar, while dark features imply that very little energy was reflected.

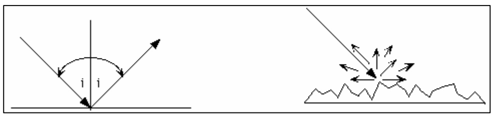


Backscatter for a target area at a particular wavelength will vary for a variety of conditions, such as the physical size of the scatterers in the target area, the target's electrical properties and the moisture content, with wetter objects appearing bright, and drier targets appearing dark. (The exception to this is a smooth body of water, which will act as a flat surface and reflect incoming pulses away from the sensor. These bodies will appear dark). The wavelength and polarisation of the SAR pulses, and the observation angles will also affect backscatter.

Intensity

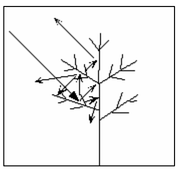
Surface and Volume Scattering

A useful rule-of-thumb in analysing radar images is that the higher or brighter the backscatter on the image, the rougher the surface being imaged. Flat surfaces that reflect little or no radio or microwave energy back towards the radar will always appear dark in radar images.



Surface Scattering

Vegetation is usually moderately rough on the scale of most radar wavelengths and appears as grey or light grey in a radar image.

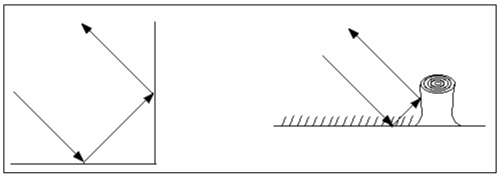


Volume Scattering

Intensity

Double Bounce

Surfaces inclined towards the radar will have a stronger backscatter than surfaces which slope away from the radar and will tend to appear brighter in a radar image. Some areas not illuminated by the radar, like the back slope of mountains, are in shadow, and will appear dark.

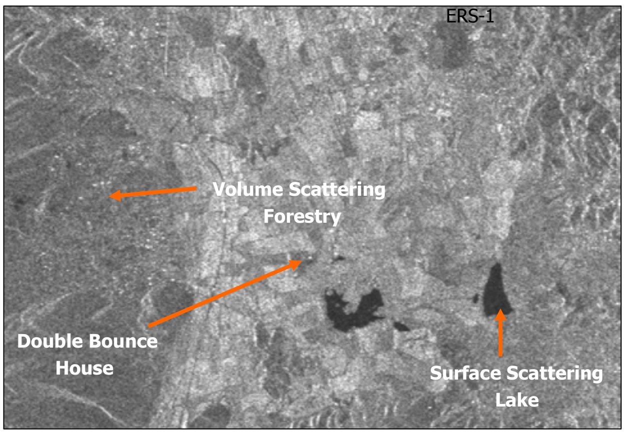


Double Bounce

When city streets or buildings are lined up in such a way that the incoming radar pulses are able to bounce off the streets and then bounce again off the buildings (called a double-bounce) and directly back towards the radar they appear very bright (white) in radar images. Roads and freeways are flat surfaces and so appear dark. Buildings which do not line up so that the radar pulses are reflected straight back will appear light grey, like very rough surfaces.

Intensity

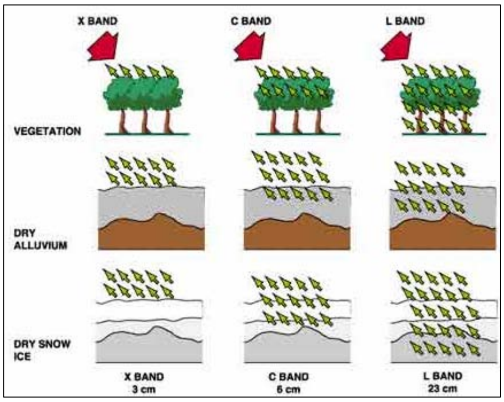
An Example



ERS-1 SAR (C-band) sample (ca. 17 km x 10 km)

Intensity

Penetration



Depending on the frequency and polarization, waves can penetrate into the vegetation and, on dry conditions, to some extent, into the soil (for instance dry snow or sand). Generally, the longer the wave-length, the stronger the pene-tration into the target is.

Coherence (Interferometric Correlation)

Principle

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

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

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)

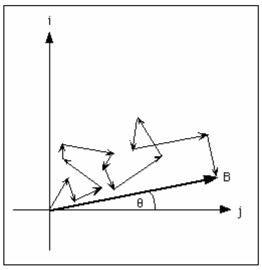
An Example

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.

Speckle

General

Speckle refers to a noise-like characteristic produced by coherent systems such as SAR and Laser systems (note: Sun's radiation is not coherent). It is evident as a random structure of picture elements (pixels) caused by the interference of electromagnetic waves scattered from surfaces or objects. When illuminated by the SAR, each target contributes backscatter energy which, along with phase and power changes, is then coherently summed for all scatterers, so called random-walk (see Figure). This summation can be either high or low, depending on constructive or destructive interference. This statistical fluctuation (variance), or uncertainty, is associated with the brightness of each pixel in SAR imagery.



SAR Geometry

General

Due to the completely different geometric properties of SAR data in range and azimuth direction, it is worth considering them separately to understand the SAR imaging geometry. According to its definition, distortions in range direction are large. They are mainly caused by topographic variations. The distortions in azimuth are much smaller but more complex.

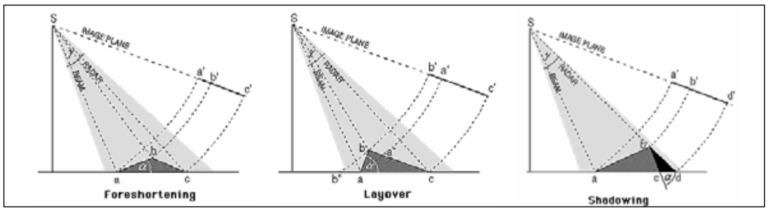
Geometry in Range

The position of a target is a function of the pulse transit time between the sensor and the target on the Earth's surface. Therefore it is proportional to the distance between sensor and target. The radar image plane (see figure included in the next slide) can be thought of as any plane that contains the sensor's flight track. The projection of individual object points onto this plane, the so-called slant range plane, is proportional to the sensor distance, and causes a non-linear compression of the imaged surface information.

SAR Geometry

Geometry in Range (cont.)

The points *a*,*b*, and *c* are imaged as *a′*,*b′*, and *c′* in the slant range plane (see figure). This shows how minor differences in elevation can cause considerable range distortions. These relief induced effects are called foreshortening, layover and shadow.



Layover is an extreme case of foreshortening, where the slope α is bigger than the incidence angle (θ). With an increasing (horizontal) distance, the slant range between sensor and target decreases.

Shadow is caused by objects, which cover part of the terrain behind them.

SAR Geometry

An Example

In mountainous areas, SAR images are i) generally strongly geometrically distorted, and, ii) from a radiometric point of view, SAR facing slopes appear very bright (see Figure). Steeper topography or smaller incidence angles - as in the case of ERS-1/2 SAR - can worsen foreshortening effects.

Note that foreshortening effects can be corrected during the geometric and radiometric calibration assuming the availability of high resolution Digital Elevation Model (DEM) data. Layover and Shadow areas can be exactly calculated, but not corrected. These areas have no thematic information.

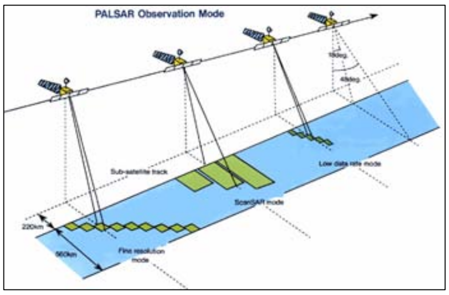
Data Set - ALOS PALSAR interferometric image pair

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 Zone 36 South.

Area - Malawi

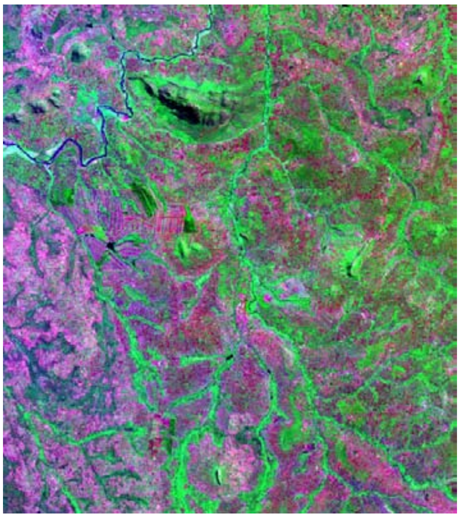
ALOS PALSAR coverage

Landsat Image

True color image: Bands 321

False color image: Bands 752

False color image: Bands 741



Processing Steps

Following processing steps must be performed:

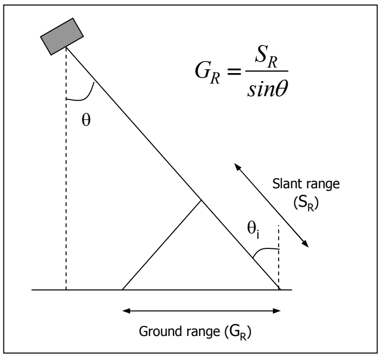
- Multilooking
- Coregistration
- Coherence generation (from interferometry chain)
- Geocoding, radiometric calibration and normalisation
- Intensity and Coherence filtering
- Colour compositing
- Classification

Cartographic and Geodetic System

Country	UTM
Zone	36
Hemisphere	South
Geodetic System	WGS-84

Multilooking

This step is used to obtain Intensity images with approximately squared pixels.



In this case the ALOS PALSAR data is multi-looked 2 (in azimuth) and 1 (in range), hence enabling to obtain a ground resolution of approximately 10 metres.

Co-registration

This step is performed in an automatic way, according to the following procedure:

- A gross shift estimation is computed based on the orbital data parameters.
- A set of sub-windows is selected automatically based on the reference image and on the image(s) to be co-registered.
- The cross-correlation function is computed between the pixels of corresponding sub-windows in the two images.
- The maximum of the cross-correlation function indicates the proper shift for the selected location.
- The shift to be applied in azimuth direction and range direction is calculated by a polynomial depending on the pixel position respectively in azimuth and range.

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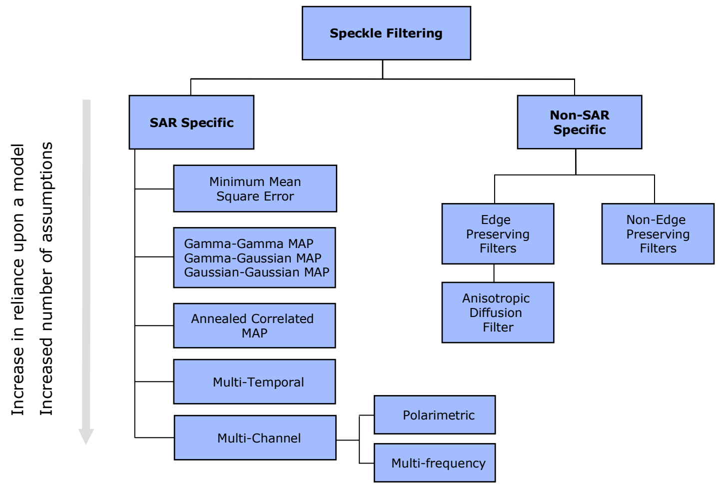
Speckle Filtering



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Speckle Filtering

Example I

ENVISAT ASAR AP (HH polarization) multi-looked unfiltered (left) and Gamma-Gamma MAP filtered image (right). Note the speckle reduction while preserving the structural features of the Gamma-Gamma MAP one.

Speckle Filtering

Example II

Mean (left) and Multi-Temporal (De Grandi) filtered (right) ENVISAT ASAR AP (HH polarization) image. Note the blurring effects of the mean filter, and the strong speckle reduction while preserving the structural features of the De Grandi one.

Geocoding (Ortho-rectification)

Range-Doppler Approach

The removal of geometric distortions requires a high precision geocoding of the image information. The geometric correction has to consider the sensor and processor characteristics and thus must be based on a rigorous range-Doppler approach. For each pixel the following two relations must be fulfilled:

$$R = S - P \qquad \text{Range equation}$$

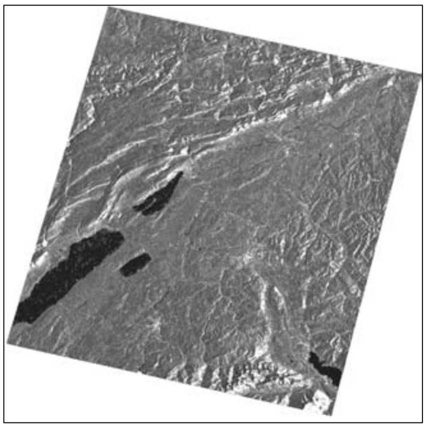
$$f_D = \frac{2 f_0 (v_p - v_s) R_s}{c \left| R_s \right|} \qquad \text{Doppler equation}$$

where

R_s = Slant range
S, P = Spacecraft and backscatter element position
v_s, v_p = Spacecraft and backscatter element velocity
f_0 = Carrier frequency
c = Speed of light
f_D = Processed Doppler frequency

Geocoding

Terrain Geocoding - ERS-2 SAR



The picture shows an ERS-2 SAR image of the Bern area (Switzerland). This image has been focused, multi-looked, speckle filtered using a Gamma-Gamma MAP filter, and finally terrain geocoded in the Oblique Mercator (Bessel 1814 ellipsoid) reference system. The terrain geocoding using a high resolution Digital Elevation Model (DEM) has been performed in a nominal way using precise orbits of the DORIS system.

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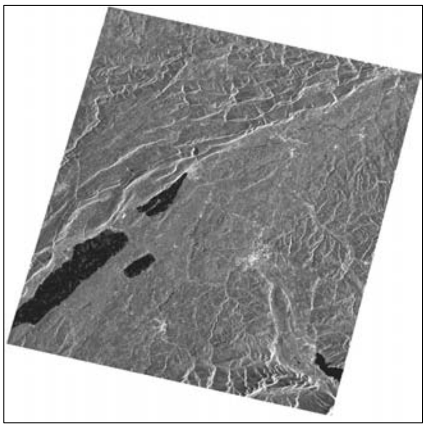
Geocoding

Ellipsoidal Geocoding - ERS-2 SAR



The picture shows an ERS-2 SAR image of the Bern area (Switzerland). The image has been focused, multi-looked, speckle filtered using a Gamma-Gamma MAP filter, and ellipsoidal geocoded in the Oblique Mercator (Bessel 1814 ellipsoid) reference system. The ellipsoidal geocoding using a (constant) reference height has been performed in a nominal way using precise orbits of the DORIS system. Note the location inaccuracies - due to the lack of the DEM information - with respect to the terrain geocoded image. Compare this image with the corresponding terrain geocoded one.

www.sarmap.ch 21st June 2007

Radiometric Calibration

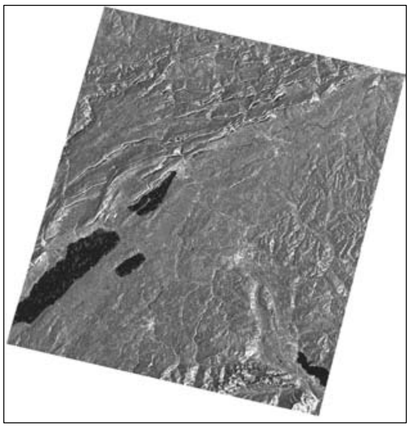
The Radar Equation

The radiometric calibration of the SAR images involves, by considering the radar equation law, corrections for:

- The scattering area (*A*): each output pixel is normalised for the actual illuminated area of each resolution cell, which may be different due to varying topography and incidence angle.
- The antenna gain pattern (G^2): the effects of the variation of the antenna gain (the ratio of the signal, expressed in dB, received or transmitted by a given antenna as compared to an isotropic antenna) in range are corrected, taking into account topography (DEM) or a reference height.
- The range spread loss (R^3): the received power must be corrected for the range distance changes from near to far range.

Radiometric Calibration

Backscattering Coefficient - ERS-2 SAR

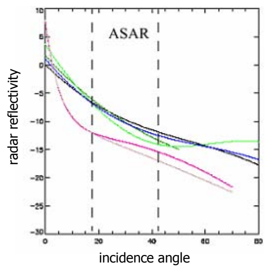


The picture shows the backscattering coefficient (σ^o) estimated from an ERS-2 SAR image of the Bern area (Switzerland). The image has been focused, multi-looked, speckle filtered using a Gamma-Gamma MAP filter, and finally terrain geocoded in the Oblique Mercator (Bessel 1814 ellipsoid) reference system. The radiometric calibration has been performed during the terrain geo-coding procedure. Note that a rigorous radiometric calibration can be exclusively carried out using DEM data, which allows the correct calculation of the scattering area. Compare this image with the corresponding terrain geocoded (but not radiometrically calibrated) one in the previous slide.

Radiometric Normalization

Purpose

Even after a rigorous radiometric calibration, backscattering coefficient variations are clearly identifiable in the range direction. This is because the backscattered energy of the illuminated objects is dependent on the incidence angle. In essence, the smaller the incidence angle and the wider the swath used to acquire an image, the stronger the variation of the backscattering coefficient in the range direction. Note that this variation represents the intrinsic property of each object, and thus may not be corrected.

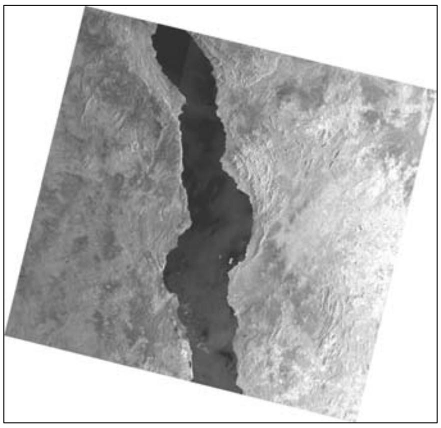


This plot shows the backscattering variation for different land cover classes (colours), while the dashed lines highlight the swath range for ENVISAT ASAR data.

In order to equalize these variations usually a modified cosine correction is applied.

Radiometric Normalization

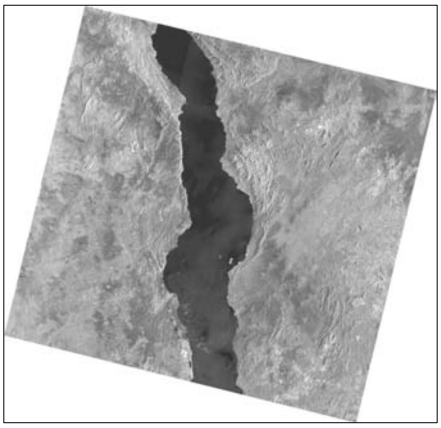
Backscattering Coefficient - ENVISAT ASAR Wide Swath



The picture shows the backscattering coefficient (σ^o) estimated from an ENVISAT ASAR Wide Swath mode image (405 km swath) from the area of Malawi (Africa). The image, which has a pixel spacing of 150 m, has been focused, multi-looked, speckle filtered using a Gamma-Gamma MAP filter, terrain geocoded in the WGS-84 (UTM zone 36 reference system), and radiometrically calibrated. Note the strong brightness variations from near (left) to far range (right).

Radiometric Normalization

Normalized Backscattering Coefficient - ENVISAT ASAR Wide Swath



The picture shows the normalized backscattering coefficient (σ^o) estimated from an ENVISAT ASAR Wide Swath mode image (405 km swath) from the area of Malawi (Africa). The image, which has a pixel spacing of 150m, has been focused, multi-looked, speckle filtered using a Gamma-Gamma MAP filter, terrain geocoded in the WGS-84 (UTM zone 36 reference system), and radiometrically calibrated. Note the brightness homogeneity after the radiometric normalization procedure.

Coherence generation

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

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

Now it is possible to obtain an rgb image combining the coherence in the RED channel, the mean value of the pair in GREEN, and the difference of the pair in BLUE. This the so called “interferometric land use” image.

Classification

Supervised or unsupervised?

Looking at the existing classification algorithms, a first distinction may be made based on the involvement of an operator within the classification process, i.e.

- **Supervised Algorithms** require a human user that defines the classes expected as result of the classification and reference areas – training sets – that can be considered as representative of each class. In a similar way, an operator may define a set of rules that, if fulfilled, will result in a pixel assigned to one of the possible classes.
- **Unsupervised Algorithms** autonomously analyse the input data and automatically identify groups of pixels with similar statistical properties.

It is widely recognized that the accuracy obtainable with supervised algorithms usually exceeds that of unsupervised algorithms. Although they are more demanding because they involve a trained operator, the greater accuracy of supervised algorithms generally makes them a better choice.

Useful Links

- **Polarimetry and Polarimetric SAR Interferometry in tutorial ESA course (http://earth.esa.int/polinsar/).**
- **Imaging Radar at NASA/JPL** http://southport.jpl.nasa.gov/
- **Radar Imaging Systems** http://ccrs.nrcan.gc.ca/radar/index_e.php
- **ALOS PALSAR** http://www.eorc.jaxa.jp/ALOS/
- **Earth Observation at ESA** http://earth.esa.int/