SAR for Beginners

DEFENCE AND SPACE

V1.0
March 2020

AIRBUS

Scope of this Document

Radar imagery is not so easy to understand. Especially, if a new user has worked with optical imagery before some of the concepts or radar cannot be intuitively understood. This material will help understand radar and its potential use in a wide range of applications.

It is best to first look at very high resolution radar imagery of Delhi, India or San Francisco, USA and to compare these open source to optical data. Once the appearance of the sidelooking geometry and its effect on the final image are understood, medium and low resolution imagery will be easier to comprehend.

- What can be seen in a radar image, what cannot be seen and why?
- Is there any information included in radar imagery, which needs to be assessed with advanced methods?
- How can this be made visible?
- How can these weather independent time series of images be best exploited?

How to Use this Document?

The material starts off with the use of very high resolution data and **explains three possible workflows** to analyse the imagery:

1. Analysis Ready Data can be utilized in GIS software.
2. Short and long time series can be successfully analysed with Artificial Intelligence methods such as Machine Learning and Deep Learning.
3. Complex imagery and their time series can be analysed by Advanced Methods to retrieve information which cannot be captured visually: 3D-information, positional information, moving objects, surface movement rates and others.

Click on the icons to navigate through the material.

The journey begins with very high resolution data. These are taken to decipher radar terminology to get the full understanding radar with synthetic aperture.

Technical terms are explained without diving deep into mathematics and yet, advanced readers materials are referenced as well.
A glossary resolves terms and abbreviations.

SAR for Beginners

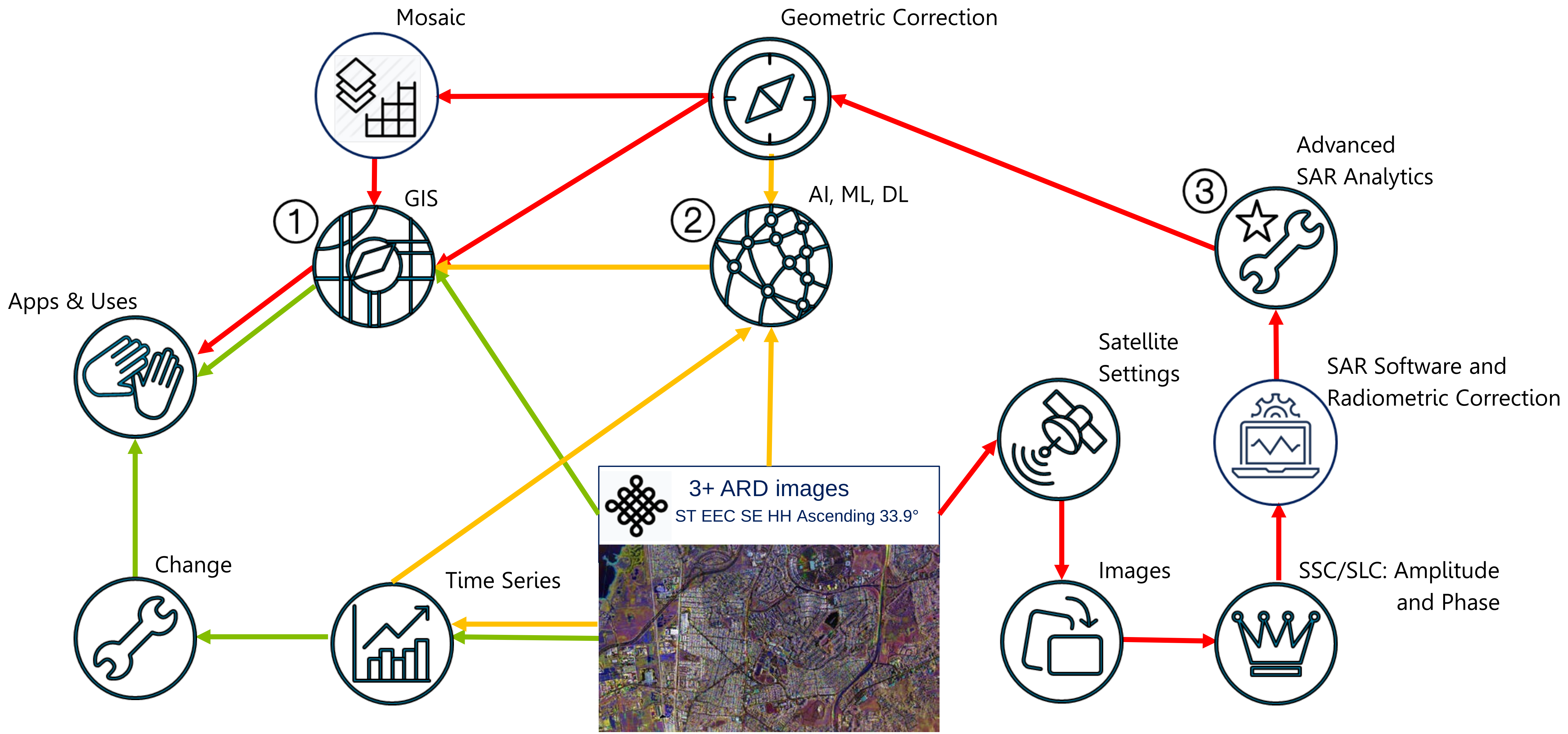
SAR images show the Earth's surface in a distinctive way which, on first glance, may be unusual. The grey values in the image are dependent on surface roughness, potential penetration into surface materials and the possible motion of objects present.

SAR images come in specialised formats and also in easy-to-handle Geotiff formats. The data volume is high and encoding is specific for TerraSAR-X, which requires dedicated software.

When displaying radar images on screen, the user needs to take care of contrast and brightness to get the most information out of the imagery as possible. Not all software packages can handle 16-bit data smoothly. Dynamic histogram manipulation settings enable a better interpretation of the very dark and very bright objects in the image. Image enhancement is often optimised for the bright objects in the image such as ships on the ocean or the very dark objects (types of land cover).

In addition to the brightness/darkness of the image, the measured phase distance between images with identical imaging geometries can also be exploited to generate maps. The position and motion of detected objects can be retrieved in a very precise manner.

Three Suggested Workflows



AIRBUS

Instructions to Topics and Documentation

- Icons guide the user through the material
- Five major topics are covered here
- Three types of resources are covered

Topics

SAR System Settings

Image Properties

Applications and Uses

Simple Analysis Method: e.g. Change Visualisation

Advanced Analytics

Resources

References

YouTube Video

Click it!

AIRBUS

Cryptology? *ST EEC SE HH Ascending 33.9°*

TerraSAR-X data are described by 6 main characteristics.
This sample is selected to demonstrate an easy way to analyse the image with GIS software.

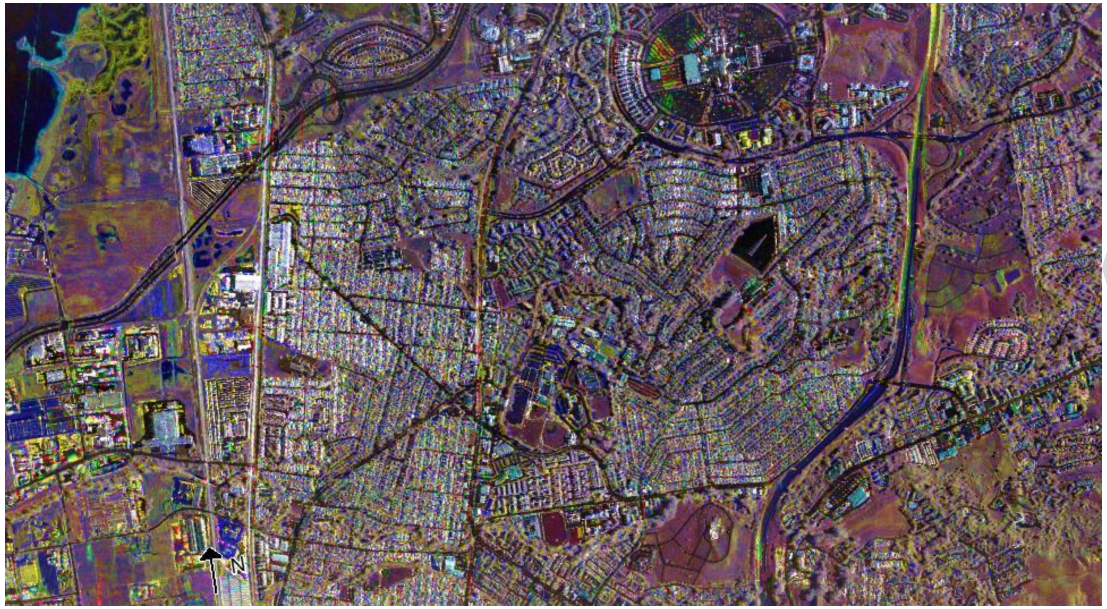
1. ST is one of the satellite settings or imaging modes: How large is the area covered and how much detail can be seen?
2. EEC is the processed image product, in this case analysis ready data (ARD) for use in a GIS software (data for GIS use)
3. SE is the product processing variant and identifies that the product has been optimised for its degree of spatial detail
4. HH is the polarisation setting which is optimal for the interpretation of man-made objects (one black/white image)
5. Ascending is the flight direction of the satellite (the image has been acquired at 6am UTC and the satellite path was South-East to North-West)
6. 33.9° is the viewing angle towards Earth. The image has been taken at an intermediate incidence angle and will be balanced.

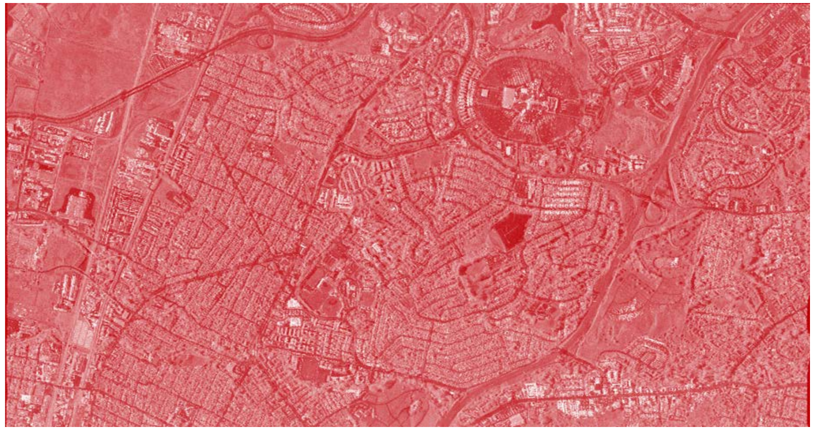
These 6 parameters together with the acquisition date and time tell you a lot about the features which can be recognised in the image at this type of viewing geometry.

San Pablo, CA, USA

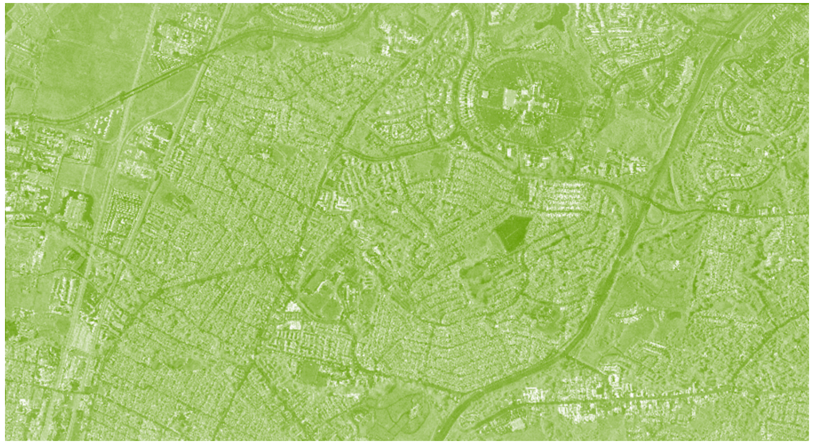
ST EEC SE HH Ascending 33.9°

Combine different acquisitions to a colour image on Red, Green and Blue.

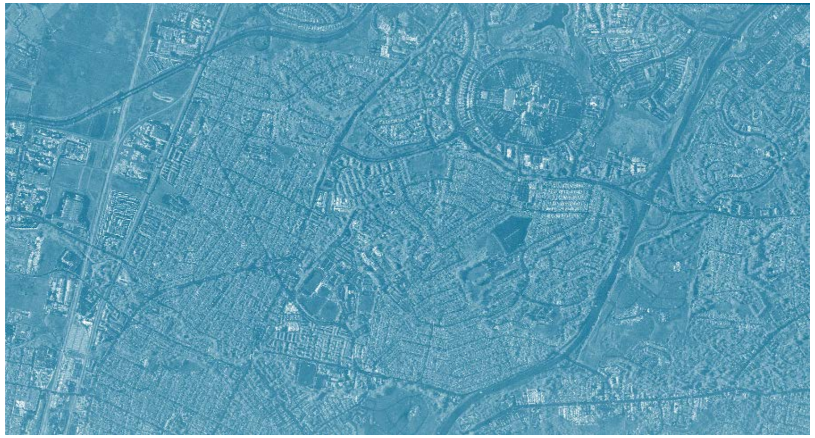




Red



Green



Blue

Three Suggested Workflows

B

AI, ML, DL: In-depth Image Processing*or**

- AI / Machine Learning / Deep Learning
- Statistical image processing
- Temporal stacks and spatial mosaics
- In-depth SAR processing

A

GIS, Rapid Mapping and Time Series*

- Focus on thematic map content
- Geocoded data ready to use
- Appealing design
- Use of short time series

Analysis Ready Data*

3+ or Staring SpotLight Images

Time Series

Minimum input data set

C

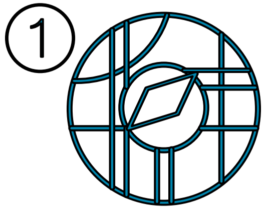
Advanced Analytics **

- Good understanding of maths and physics
- Exploitation of SAR physics needed
- Exact measurements necessary

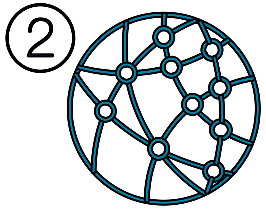
*: EEC product in same viewing geometry (orbit and incidence angle)

**: SSC product as in *

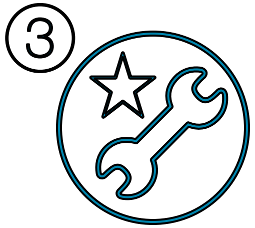
Three Suggested Workflows



1. **SAR Beginners Workflow: GIS, Rapid Mapping+ and Short Time Series**
   The images have been acquired with the same perspective settings or imaging geometry (InSAR-ready data stack transformed to analysis ready data [ARD]) with geometric and radiometric correction applied. The data can directly be used in a GIS software package and simple mapping tasks can be accomplished.



2. **AI, ML, DL: In-depth Image Processing and Long Time Series**
   Time series of data acquired by a fleet of satellites (TerraSAR-X, TanDEM-X and PAZ) are analysed together. Repeated passes every 4, 7, and 11 days can be achieved. Cloud computing is often involved. The data is prepared with radiometric and geometric corrections so that the pixel values are directly comparable.



3. **Advanced SAR Analytics**
   These methods require an in-depth understanding of SAR satellites, SAR data pre-processing and advanced analytics techniques. These methods are applied to the data in slant range geometry. Results are then geocoded and can be further exploited in a GIS software package.

GIS, Rapid Mapping and Short Time Series

Workflow 1

Geographic Information Systems (GIS)

- Geographic Information Systems work well with ARD data. These 16-bit amplitude images are the main component of the TerraSAR-X EEC product.
- The geocoded data (UTM, WGS84) can be superimposed and converted in to a colour image by combining three images of different acquisition dates. These images must have the same imaging geometry (orbit, incidence angle and polarisation).
- Images of different polarisations can be used to create colour composite images, provided they have the same imaging geometry.
- Amplitude images and coherence images can also be combined together.

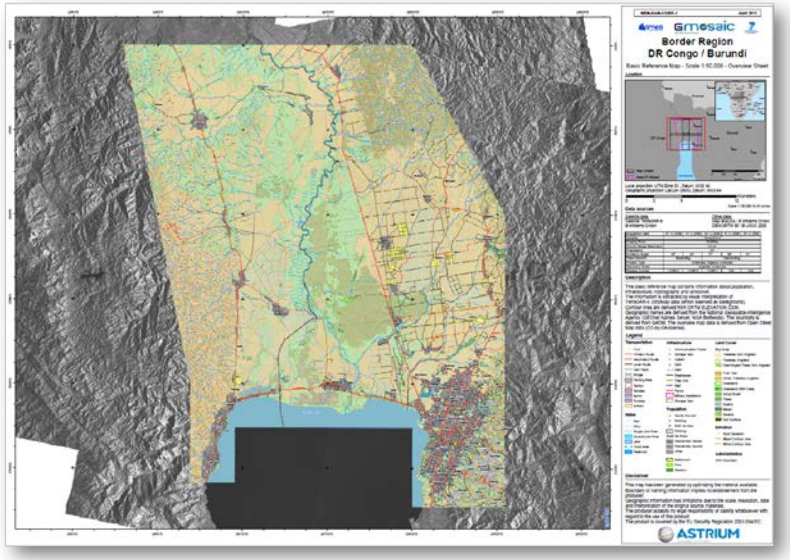
Typical GIS analysis of ARD radar data include:

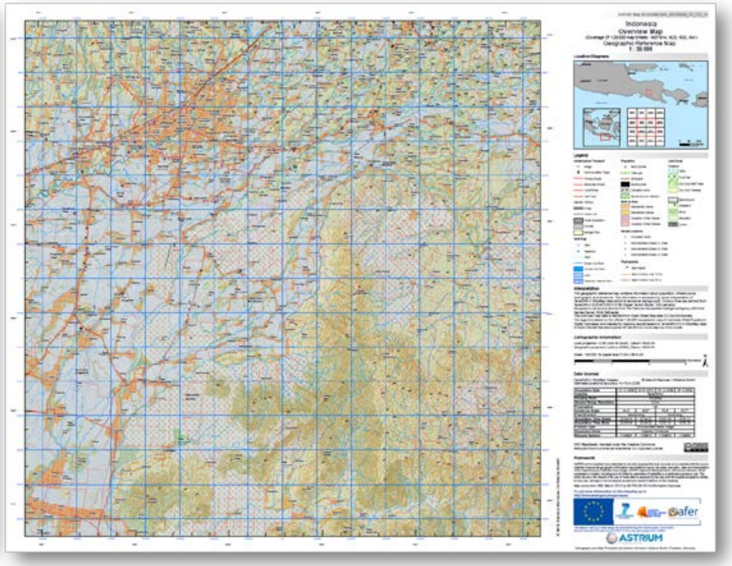
- Image statistics calculation without zero values
- Pyramid layer calculation for faster zooming (resampling strategy must be observed. Bilinear interpolation may be more suitable than nearest neighbour resampling)
- Histogram stretching to enhance the images
- Plotting temporal profile over time series of images (ARD data)
- Time series statistics min, max, difference and others to create new colour composites
- Thresholding to find water/non-water area
- Visualisation of ships detection results
- Draping an image over DEMs
- Combination with optical imagery
- Band maths to enhance certain features

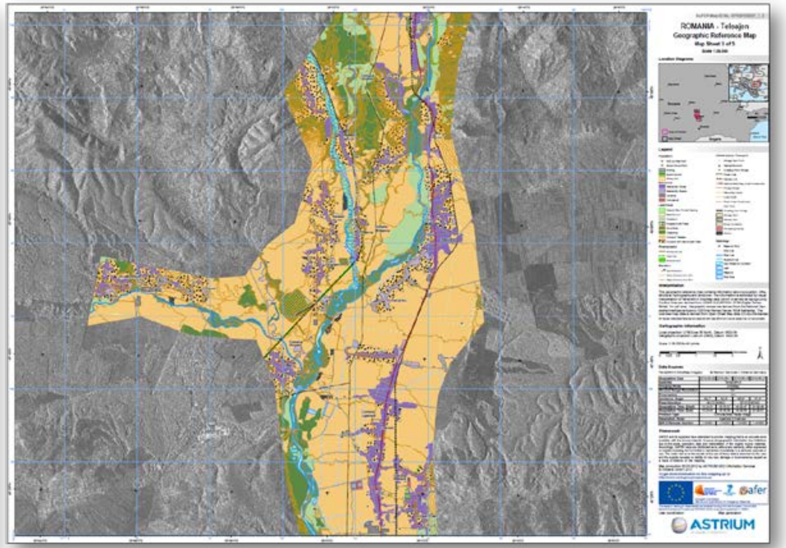
GIS and Rapid Mapping

On-demand and fast generation of thematic maps is often required in response to natural catastrophes.
Often, results are time critical and must be delivered within a few hours to a day.

- Processing often happens in a GIS environment.
- The initial delineation of features may be coarse but sufficient.
- Geocoded information, often terrain corrected maps, enable practical use in the field.
- Specialised and advanced SAR processing is therefore often not desired
- Instead, pre-processed ARD imagery with its generic image format is preferred which allows analysis to begin immediately.







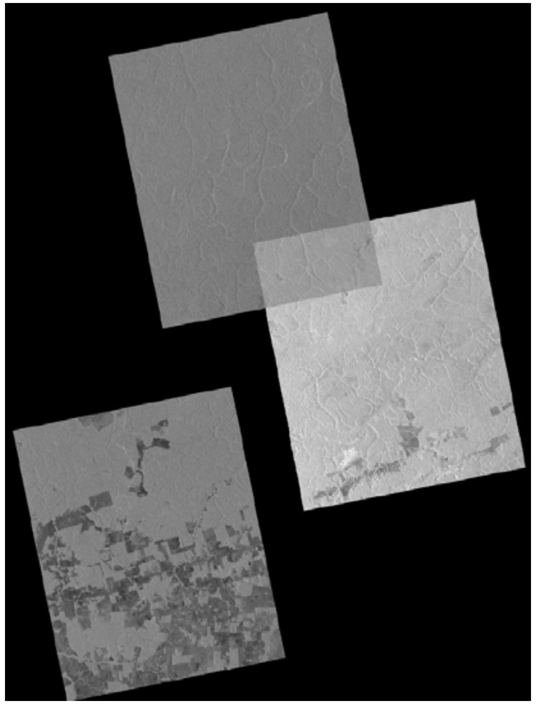
AIRBUS

Mosaic 1

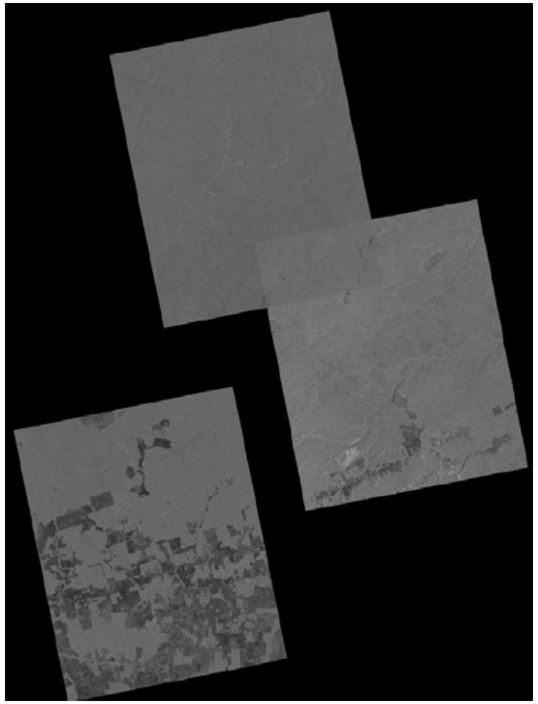
When a large area such as a county, island or country cannot be imaged in one image take, mosaicking of several image strips is required. Images are often acquired at different incidence angles. The difference in illumination must then be corrected to provide a smooth, seamless mosaic.

The prerequisites are:

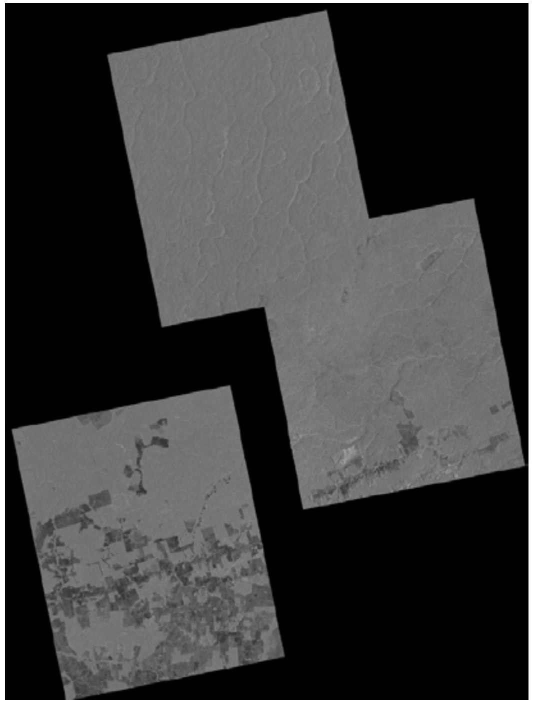
- Radiometric correction to compensate for illumination effects
- A digital terrain model to calculate sigma-0 or gamma-0.
- Further terrain compensation can be found in this reference.



Three images as Beta-0:
Brightness is not balanced



Sigma-0:
Better balanced

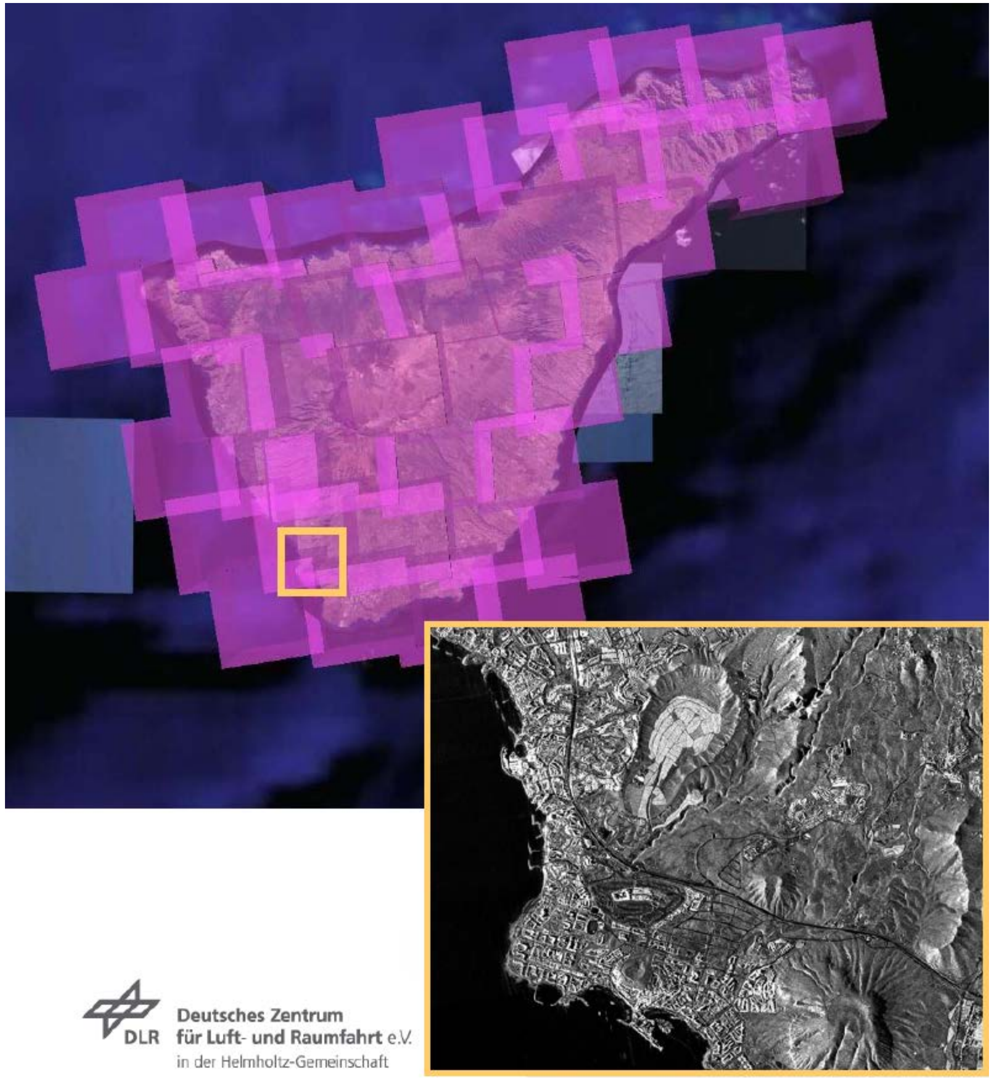


Gamma-0:
Fully balanced images

Mosaic 2

Mosaicking of larger areas seamlessly has been accomplished for the island of Tenerife in the Canary Islands, Spain.

Before mosaicking, images should be radiometrically corrected to gamma-0 in order to avoid brightness and contrast differences between images.



DLR Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft

AIRBUS

Geometric Correction

A radar satellite looks sideways at an angle towards the ground from its orbit. Distortions in flight direction (azimuth direction) and perpendicular to that (range direction) may occur. Layover, Shadow and Foreshortening are also SAR imaging effects that can occur due to this side-looking imaging geometry.

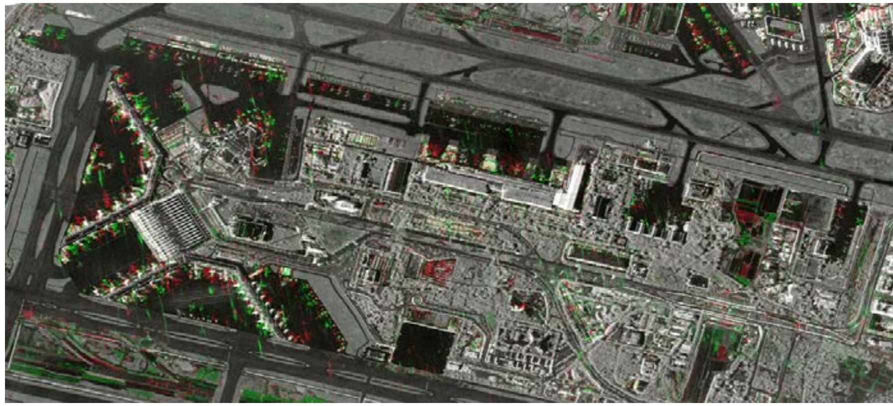
Geometric correction involves compensation of the side looking radar geometry (slant range to ground range projection) and the differing backscatter from the underlying terrain.

Change Detection of Short Time Series

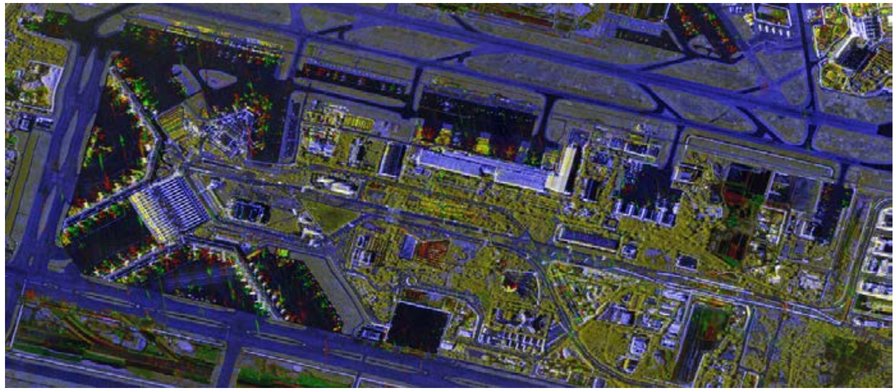
Surface changes due to human or natural causes can be detected by comparing 2 or more InSAR-ready radar images with the same imaging geometry.

Two techniques are frequently applied:

- Amplitude Change Detection: 2 or more images are compared with regards to their brightness or darkness to indicate added or removed objects/materials. Often, the log-ratio is used to determine the threshold between added or removed items. This method can be used with EEC or SSC products, depending on available software. The identified areas of the image with an increased brightness and those with decreased brightness are often delineated by vectors or saved as a binary image mask for later use in a GIS context. Often Day 1 and Day 2 form a colour composite.



- Coherence Change Detection: 2 or more images are compared with regards to their similarity in amplitude and phase. The output is a coherence image which can be used as an additional layer e.g. in land cover classification. Increase and loss of coherence over time is an indicator for changed vegetation cover due to growth, burn or flood. Often Day 2, Day 2 and coherence are shown as colour composite.



AI, ML, DL: In-depth Image Processing and Long Time Series

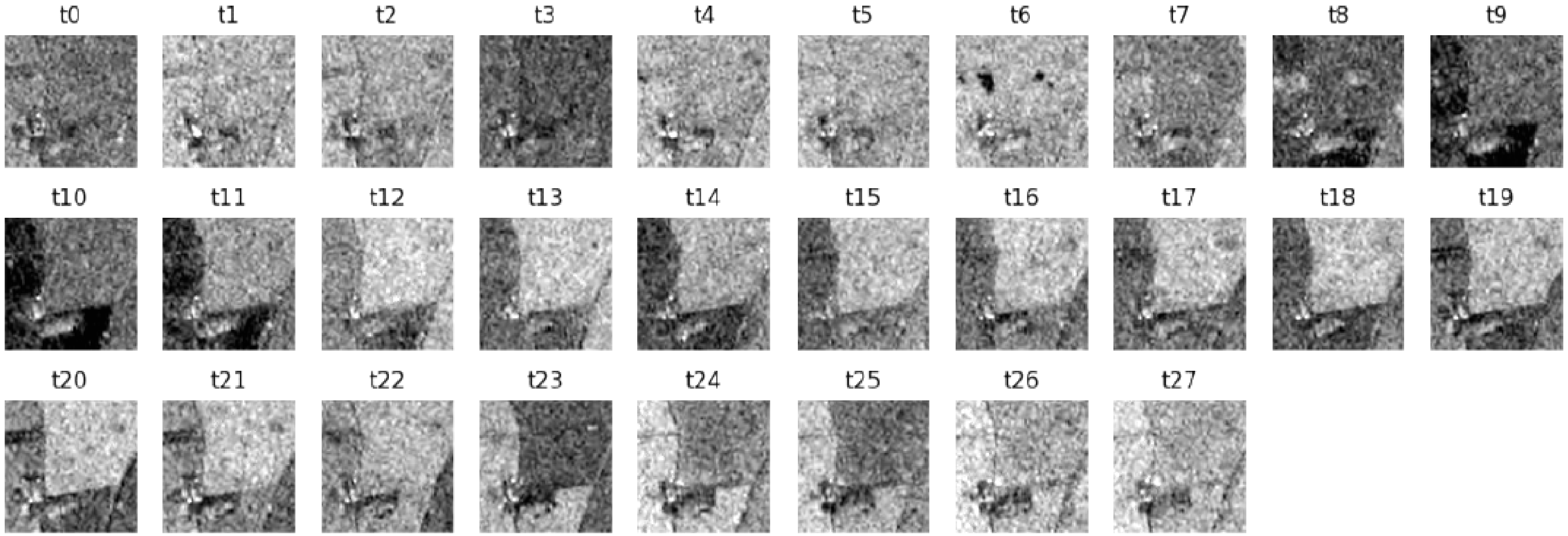
Workflow 2

AI, ML, DL

Artificial Intelligence can be used to group pixel values into meaningful and application related image segments to create maps. Machine Learning methods include ExtraTrees (ET) and Multilayer Perceptron (MLP), whilst potential Deep Learning methods include Convolutional Neural Networks (CNN), Recurrent Neural Networks (RNN) and Long Short-term Memory (LSTM)

These methods often require long time series, e.g. 1 year of data at 4-, 7- or 11-days repeat and a comprehensive training data set to start with. Radar can provide long times series which are rarely disturbed by any weather effects. Even a mixed series of radiometrically and geometrically calibrated images is possible.

Time series over an agricultural field covering almost 1 year.



AIRBUS

Advanced Analytics

Workflow 3

Advanced SAR Analytics 1

③

Advanced Methods for SAR data analysis involve exploiting the full information depth of a complex radar image.

Such methods are: interferometry, interferogram stacking, change detection methods, polarimetry, and 3D SAR.

The full information content of a radar data set is exploited by the following means:

- Imagery is analysed in the original SAR slant range geometry (range/time coordinates). For this, the SSC (also called SLC) product is utilised, which is very close to the raw data in terms of radiometry and geometry.
- Amplitude and phase information are exploited together: interferometric methods can be applied to obtain 3D information when the satellite orbit information is known with high precision.
- Analysis starts with image pairs acquired with the same imaging geometry (orbit direction and incidence angle).
- The more data available and the shorter the time interval been the images within the time series, the more precise the results can be (surface movement monitoring, DEM generation).

YouTube

Burgan Oilfield, Kuwait

YouTube

Mosul Dam, Iraq

Advanced SAR Analytics 2

	Method	Abbreviation	Required data	Potential application	Imaging mode	Required Product
Interferometry	Classical differential interferometry	DInSAR	At least one InSAR pair	DEM generation in non-vegetated areas	ST, HS, SL, SM	SSC
	Interferogram stacking	IS	A few InSAR pairs	More precise DEM generation in non-vegetated areas	ST, HS, SL, SM	SSC
	Small Baseline Interferometry	SBAS	At least 15 InSAR images	Surface movement monitoring of contiguous areas	ST, HS, SL, SM	SSC
	Persistant Scatterer Interferometry	PSI	At least 15 InSAR images	Surface movement monitoring of point-like objects (buildings)	ST, HS, SL, SM	SSC
Change detection methods	Amplitude Change detection	ACD	At least one InSAR pair	Land cover monitoring, forest change etc.	Any	SSC
	Coherence Change detection	CCD	At least one InSAR pair	Change of man-made objects, land –cover change	ST, HS, SL, SM	SSC
Polarimetry	Joint analysis of polarisations	PolSAR	Starting with one image	Change of man-made objects, land –cover change	HS, SL, SM	SSC or EEC
	Polarimetric decomposition	PolSAR	TerraSAR-X has two polarisations which allows Raney Decomposition	Differentiation of volume and surface scattering	HS, SL, SM	SSC
	Polarimetric Interferometry	PolInSAR	At least one InSAR pair	Differentiation of height and volume scattering	HS, SL, SM	SSC
3D SAR	Tomography	TomoSAR	Multiple images acquired at different incidence angles and orbits	3-d reconstruction of objects	HS, SL, SM	SSC
	Radargrammetry	RDG	One ascending and one descending image pair at a disparitiy angle of approx. 23°	DEM generation in vegetated areas	ST, HS, SL, SM	SSC or MGD depending on software

InSAR Methods

Radar not only measures the intensity of the backscattered signal but also the phase of the transmitted and received signal. This phase angle shift between repeat pass images is exploited in interferometry techniques.
Interferometric analysis can be grouped into four major methods: Classical Differential Interferometry, Interferogram Stacking, Small Baseline Interferometry and Persistant Scatterer Interferometry.

Classical DInSAR

Analysis of individual differential interferograms

- Spatial with some spatial gaps
- Discrete steps in time
- Spatial phase unwrapping
- Elimination of topographic and atmospheric disturbances is difficult
- Requires a suitable and precise DEM

Interferogram Stacking

Temporal summation of differential interferograms

- Spatial with some temporal gaps
- Short term time series
- Spatial phase unwrapping
- Elimination of topographic and atmospheric disturbances is difficult
- Requires a suitable and precise DEM

Small Baseline Interferometry SBAS

Network of interferograms at small temporal and spatial baselines

- Distributed scatterers are analysed
- Spatial with a lot of temporal gaps
- Short-term or long-term time series
- Spatial phase unwrapping with temporal adjustment
- Taking into account other phase components
- Requires multi-looked interferograms

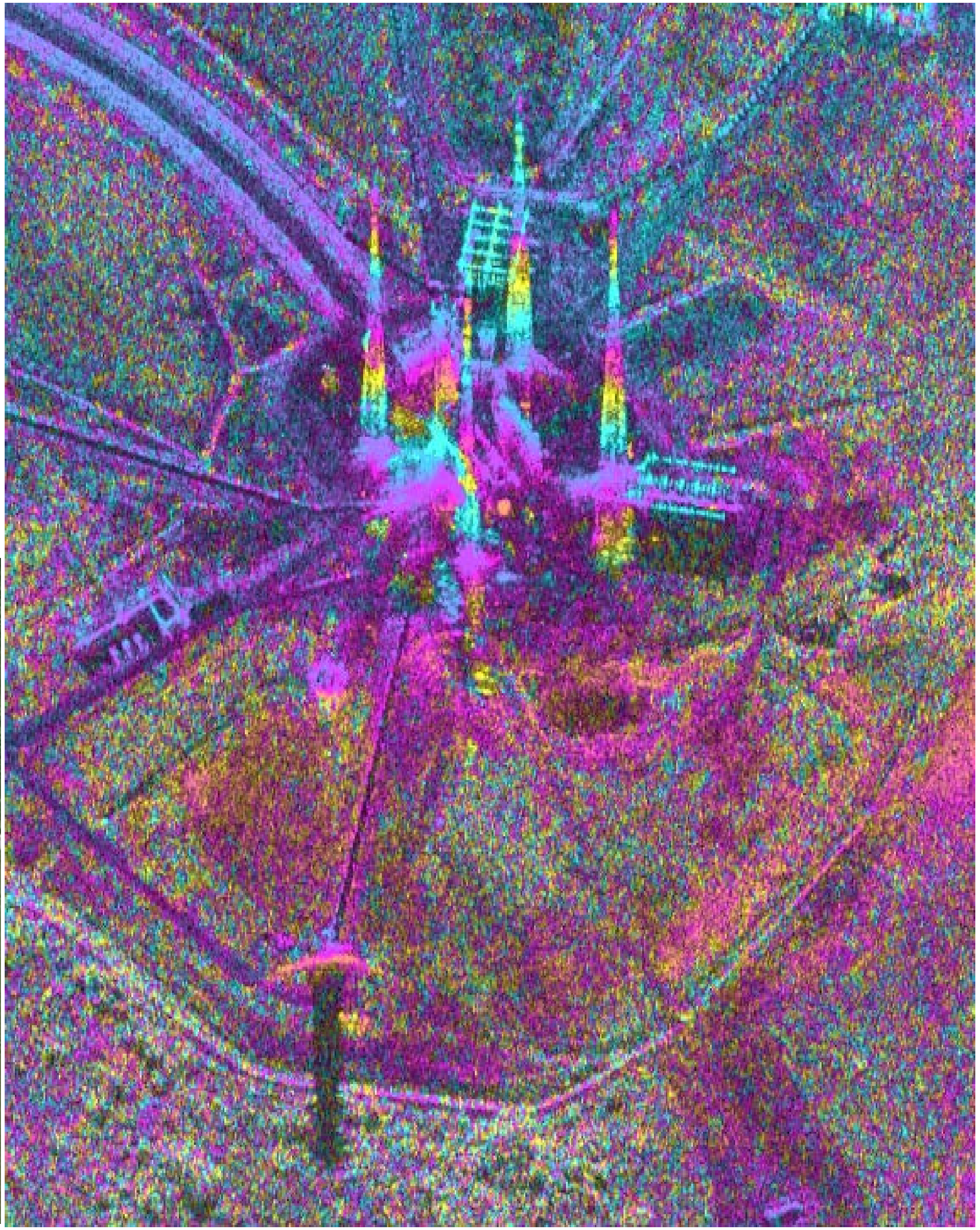
Persistant Scatterer Interferometry PSI

Analysis of longterm-stable point scatterers

- Analysis of point scatterers at high point density in built-up areas
- Long-term time series
- Spatial and temporal phase unwrapping including their adjustment
- Estimation of topographic errors and atmospheric phase components
- Requires at least 15-20 images

Differential Interferometry

The interferogram of an image pair acquired with identical imaging geometry (incidence angle, orbit direction and polarisation) shows colour fringes. These can be used to determine the height of the lattice masts here in Kourou, French Guiana.



AIRBUS

Surface Movement Monitoring: SMM

Three methods are widely used for SMM:

1. Differential interferometry which requires at least one InSAR image pair and is implemented in various COTS software packages
2. Small Baseline Interferometry (SBAS) is used for the monitoring of wider areas
3. Persistant Scatterer Interferometry (PSI) is used to study the movement of point-like objects

The first method can be applied relatively quickly but the results may only give a broad overview and at a low spatial resolution. Methods 2 and 3 require at least 15 InSAR image pairs but can give much more detailed results. These advanced processing techniques requires precise co-registration of the imagery in the Doppler frequency and time domain, a thorough understanding of the measured phase information and a meaningful interpretation of the motion vector at each pixel or a larger integration area.

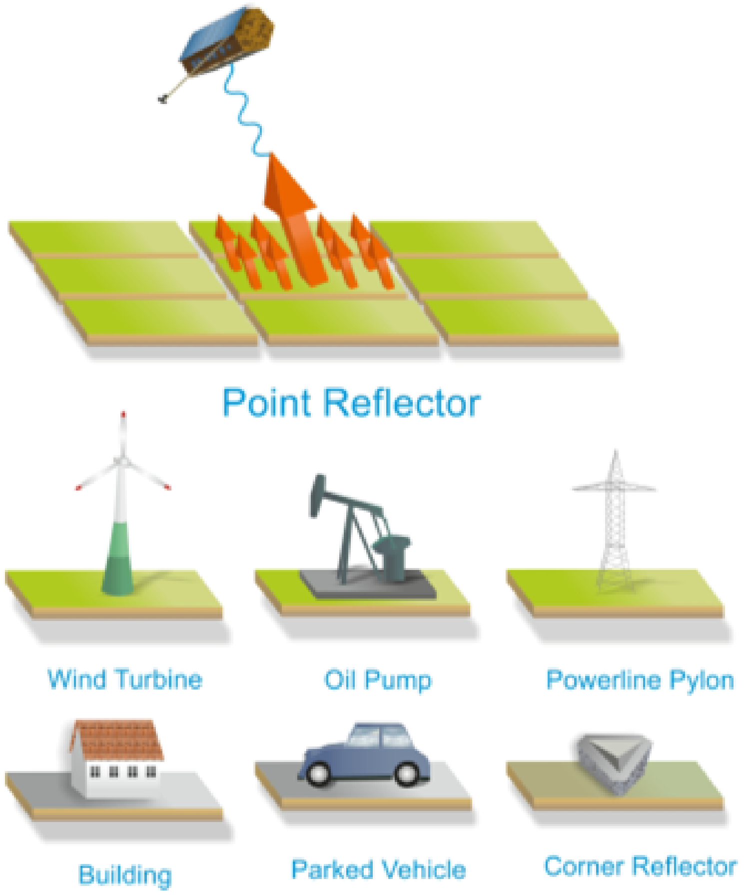
Point Scatterer

Small metal objects or the corners formed by different parts of objects can lead to very strong returns back to the radar.

These point scatterers including lattice masts, flag poles, buoys in the water and even fence posts can be seen in very high resolution radar. They create a bright dot pattern in the image.

For the most part, these objects do not change their position. Throughout a time series of image acquisitions, the position of these point scatterers can be evaluated to determine whether the objects moved along the line of sight of the satellite, i.e. towards or away from the satellite. This movement can be converted to assess an upward or downward movement.

Surface movement phenomena of point-like targets can best be measured with Persistant Scatterer Interferometry (PSI).

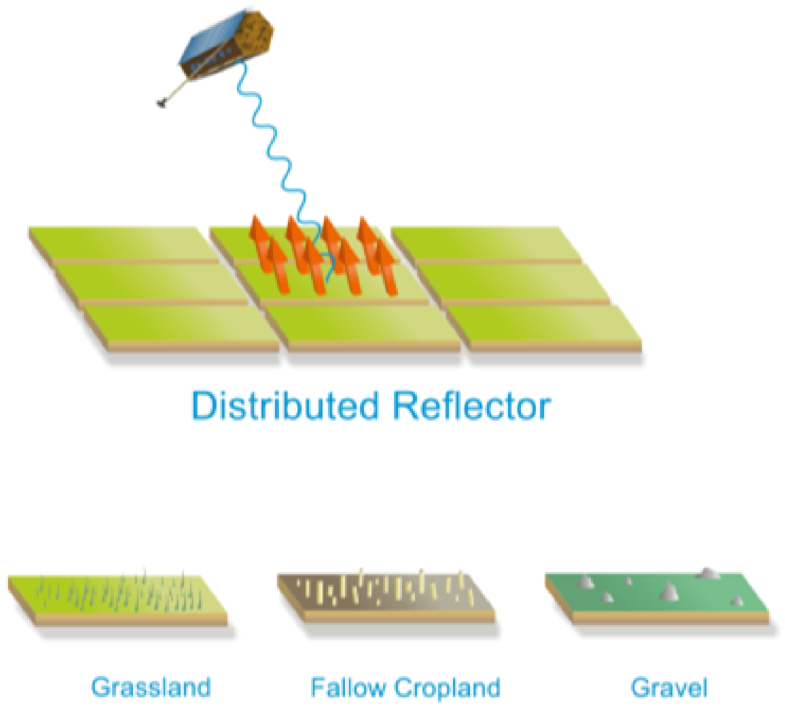


Distributed Scatterer

Larger areas such as opencast mining areas have an moderate signal return towards the radar. The strength of the return is measured and related to the initially transmitted signal.

If there is a strong return, the respective portion of the image will be white.
If it’s a weak return, the respective pixel will be dark. For cases in between, the pixel can have 65,536 different shades of grey.

Surface movement phenomena of objects or surfaces covering a wider area can best be measured with Small Baseline Interferometry (SBAS).



SAR System Settings

What does the satellite offer?

AIRBUS

SAR Synthetic Aperture Radar

The radar antenna sends out waves at the speed of light. In the case of TerraSAR-X, these waves have a wavelength of approximately 3cm. This is much longer than visible light. The radar wave hits an object on the ground and interacts with it. Scattering occurs (surface or volume scattering) and depolarisation may occur. Parts of the wave are scattered back to the radar, other parts are not.

To form the image, the time travelled by the signal from the antenna and back is measured across the image swath. Along side of the travelling path of the antenna, the Doppler frequency shift is measured in relation to the flight direction of the sensor. Together, time and frequency are extracted to form an image matrix composed of the received power at each position.

The antenna can be operated in three different imaging modes. These modes are typically called staring spotlight, sliding spotlight and stripmap modes in the radar world. These operation modes can be found with other radar sensors as well.

Due to their special settings, for TerraSAR-X six different imaging modes are achieved: Staring SpotlLight: ST, Sliding Spotlight or High Resolution SpotLight: HS, as well as SpotLight SL, StripMap modes: SM, SC, WS.

Satellite Settings

The satellites TerraSAR-X, TanDEM-X and PAZ possess a number of SAR system design features to satisfy a diverse variety of applications and users. The satellites can be set to acquire images in 6 imaging modes which differ in spatial coverage and spatial resolution.

Permanent settings:

- The transmit and receive **frequency** of the three satellites is 9.65 GHz which results in 3 cm wavelengths and thus is a much larger than the wavelengths used with optical satellite antennas.
- System **noise** may cause disturbances. This is compensated for in SAR processing.
- The **assessed area** can be set to cover 3 x 7 km at very high spatial resolution to an image size of 270 x 100 km at low spatial resolution.
- Ascending and descending orbit directions acquire Southeast-Northwest or Northeast-Southwest oriented images. This corresponds to morning and evening acquisitions.

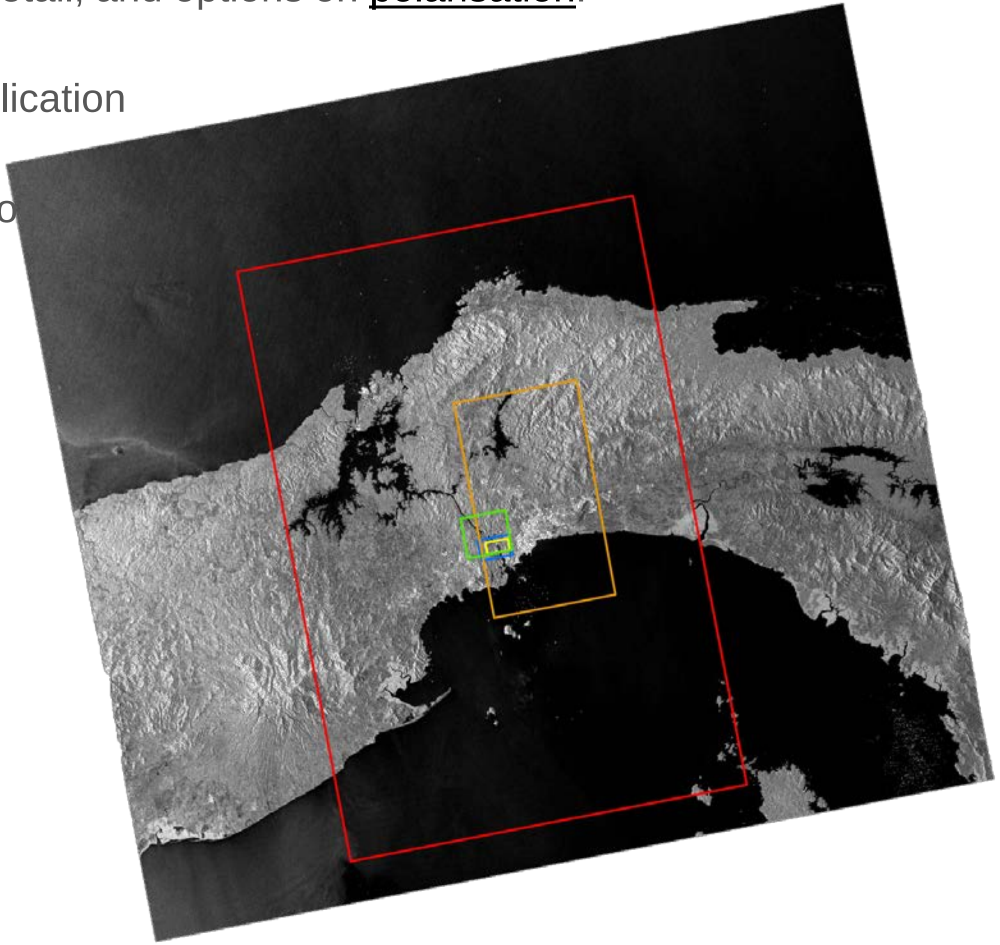
Variable settings:

- **Polarisation** enables different interactions with objects on the ground.
- The number of **looks** which are taken over one area determines the amount of speckle and the spatial resolution of the image.
- The **incidence angle** of the side-looking radar beam determines the degree of spatial resolution across the image swath.

Imaging Modes 1

The radar antenna of the satellite can be set to different imaging modes which differ in spatial coverage, degree of detail, and options on polarisation.

Depending on the intended application purpose,
e.g. mapping or target recognitio
the appropriate imaging mode
can be chosen.



Detailed description of imaging modes.

WS Wide ScanSAR mode

- Up to 270 km swath
- 40 m resolution

SC ScanSAR mode

- 100 km swath
- 18 m resolution

SM StripMap mode

- 30 km swath
- 3 m resolution

SL SpotLight mode

- 10 km x 10 km
- 2 m resolution

HS High Res. SpotLight mode

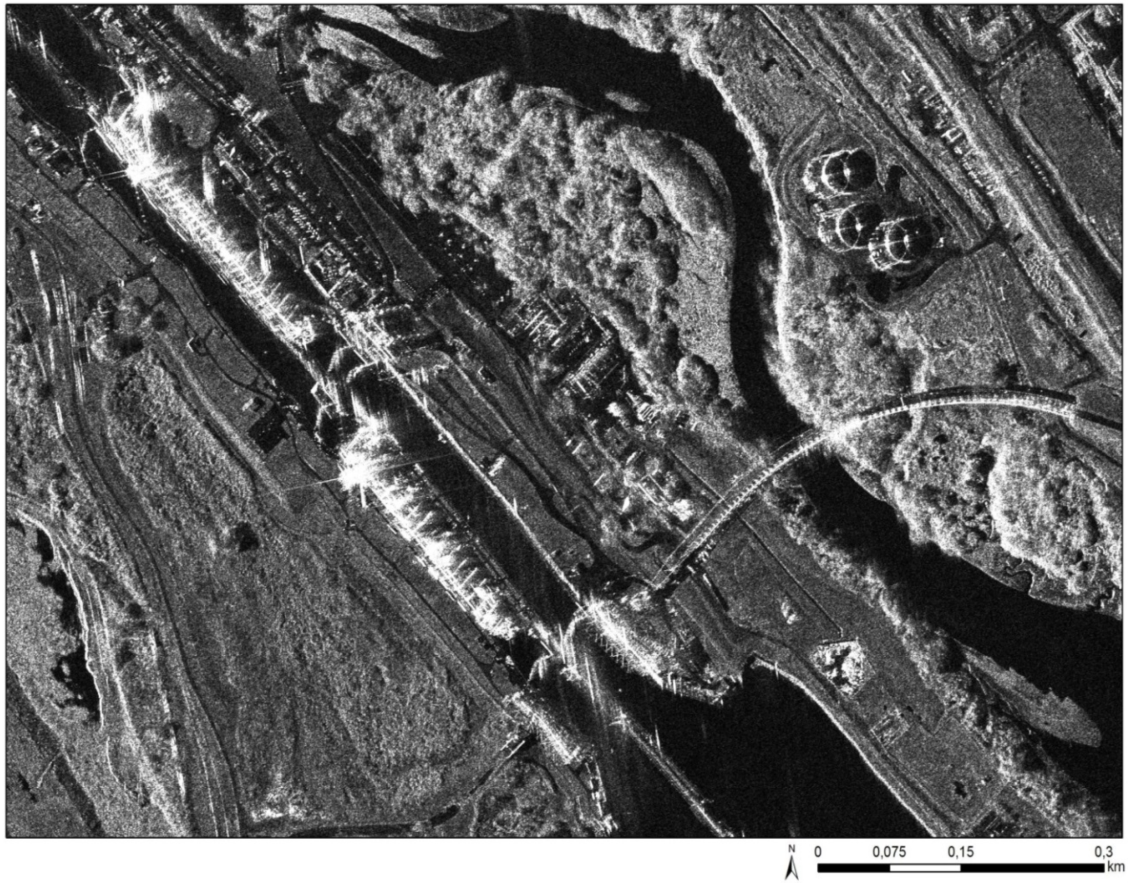
- 5 km x 10 km
- 1 m resolution

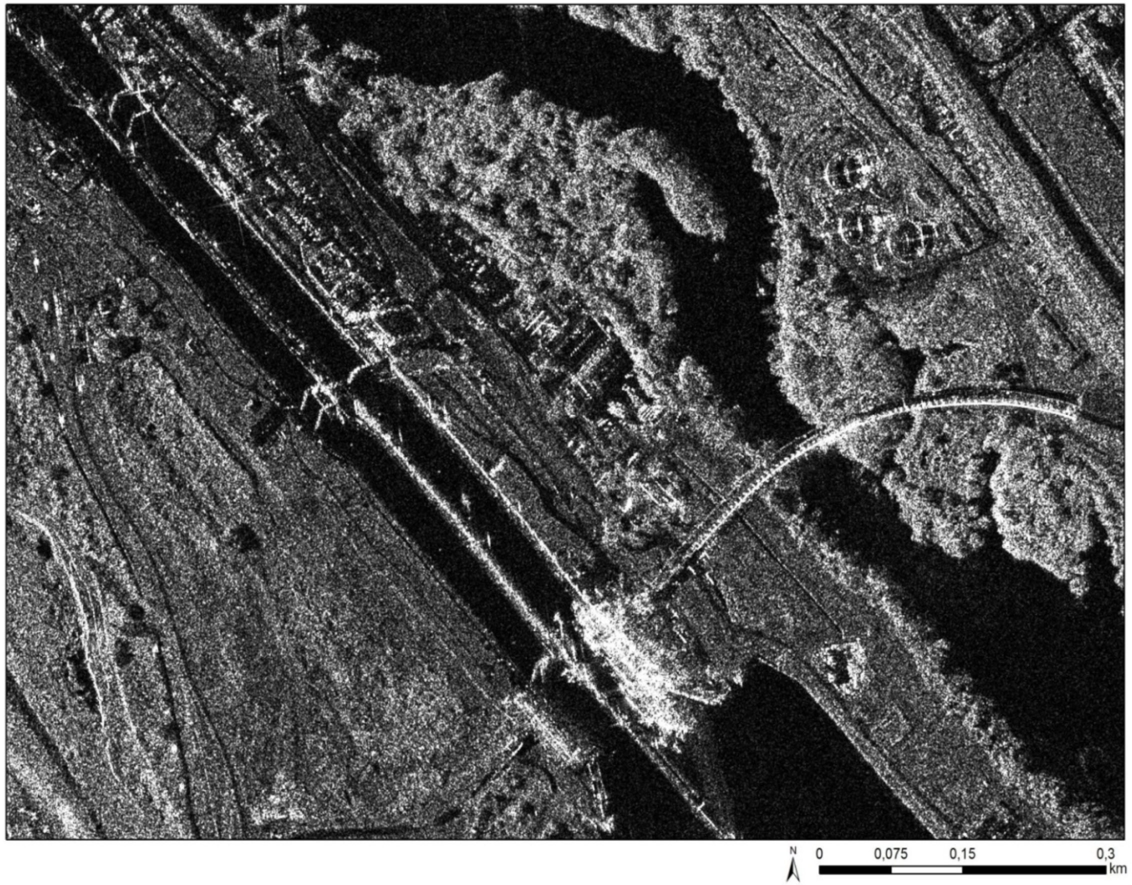
ST Staring SpotLight

- 5 km swath
- Up to 0.25 m resolution

Imaging Modes 2

The antenna can be set to six different imaging modes which differ in coverage, degree of detail and available polarisations.
Left Staring SpotLight ST 0.25m in azimuth and right High Resolution SpotLight HS 1m data of different days over Panama.

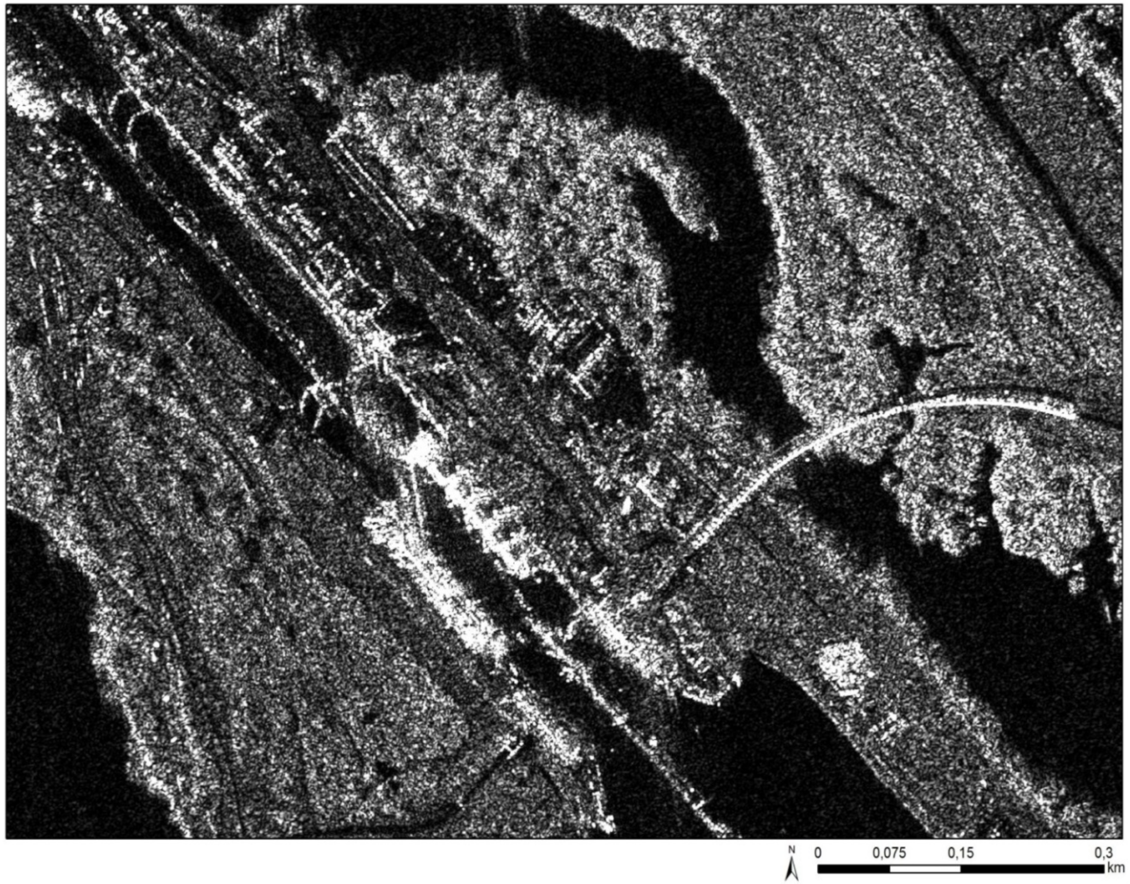




AIRBUS

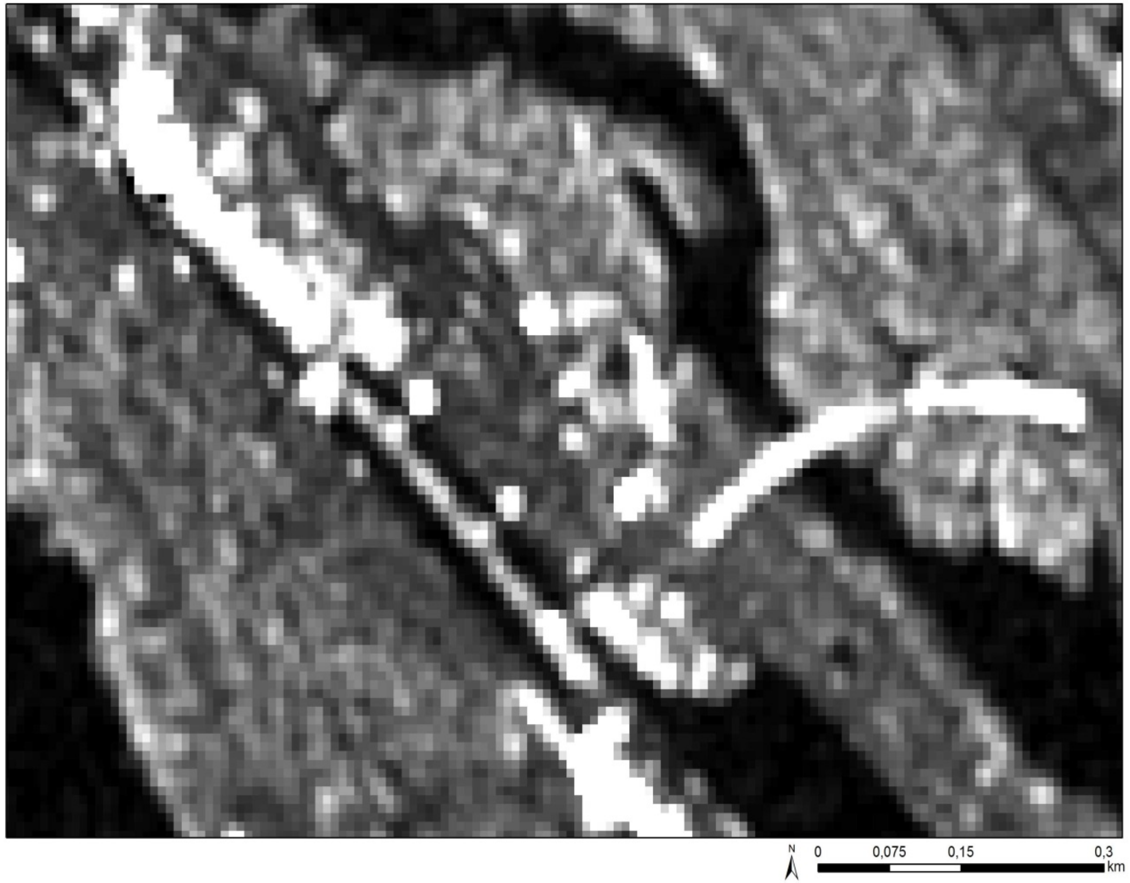
Imaging Modes 3

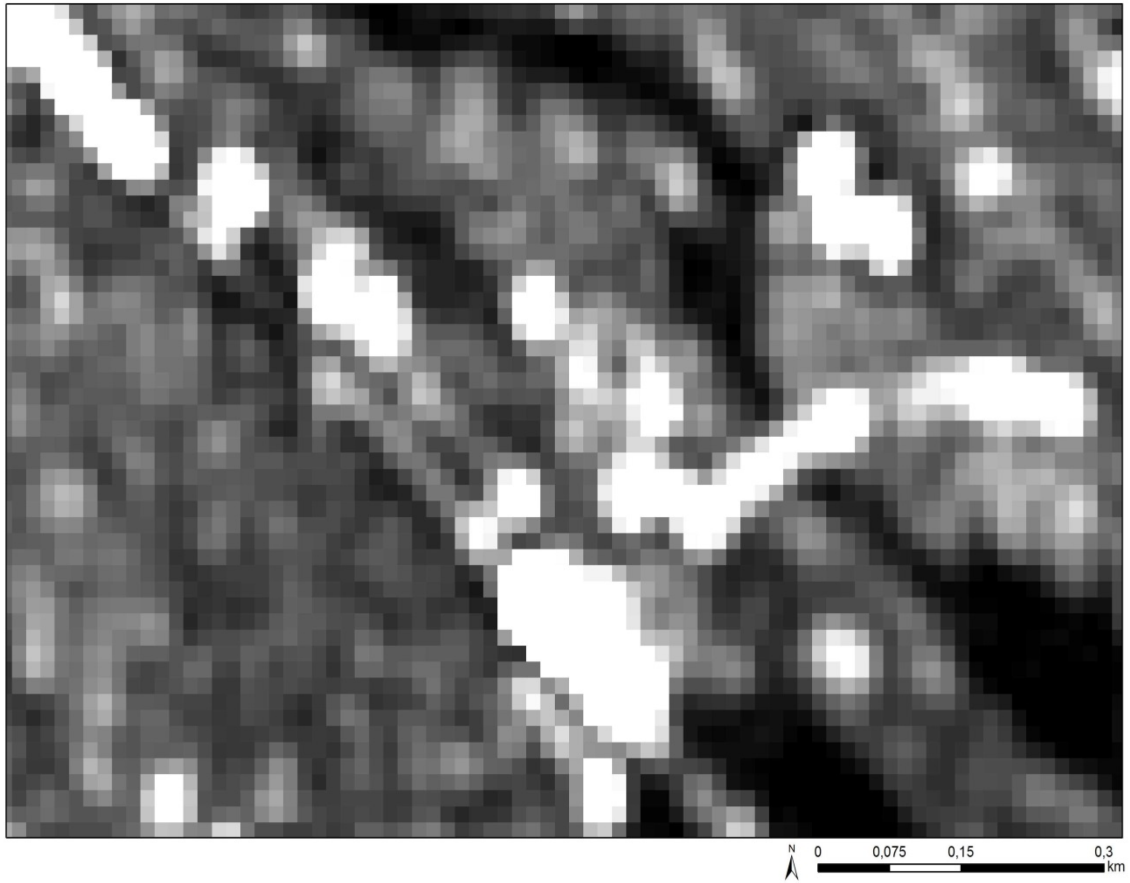
The antenna can be set to six different imaging modes which differ in coverage, degree of detail and available polarisations.
Left SpotLight SL 2m data and right StripMap SM 3m data of Panama



Imaging Modes 4

The antenna can be set to 6 different imaging modes which differ in coverage, degree of detail and available polarisations.
Left ScanSAR SC 18m data and right Wide ScanSAR WS 40m data over Panama





Polarisation in TerraSAR-X Images 1

Not all polarisations are available in every imaging mode (satellite setting).
For each polarisation, one image is produced. Images can be overlaid to create colour composites,
e.g. an HH image and a HV image and a repeat of one of these to create and RGB image.
Dual polarisation images will be reduced in spatial resolution (6m, 4m, and 2m for SM, SL, and HS and in area coverage (halved).

- HH polarisation images give the best contrast for the analysis of man-made objects
- VV and VH images are often preferred for mapping of vegetation
- VH or HV polarisation images will show less roughness over the water and ships will be easier to detect

See Application Guide

Polarisation	TerraSAR-X Imaging Mode
Single polarisation HH or VV	All modes: ST, HS, SL, SM, SC, WS
Dual polarisation with co-polarisations HH/VV	SM, SL, HS
Dual polarisation with cross polarisation HH/HV or VV/HV	SM

Polarisation in TerraSAR-X Images 2

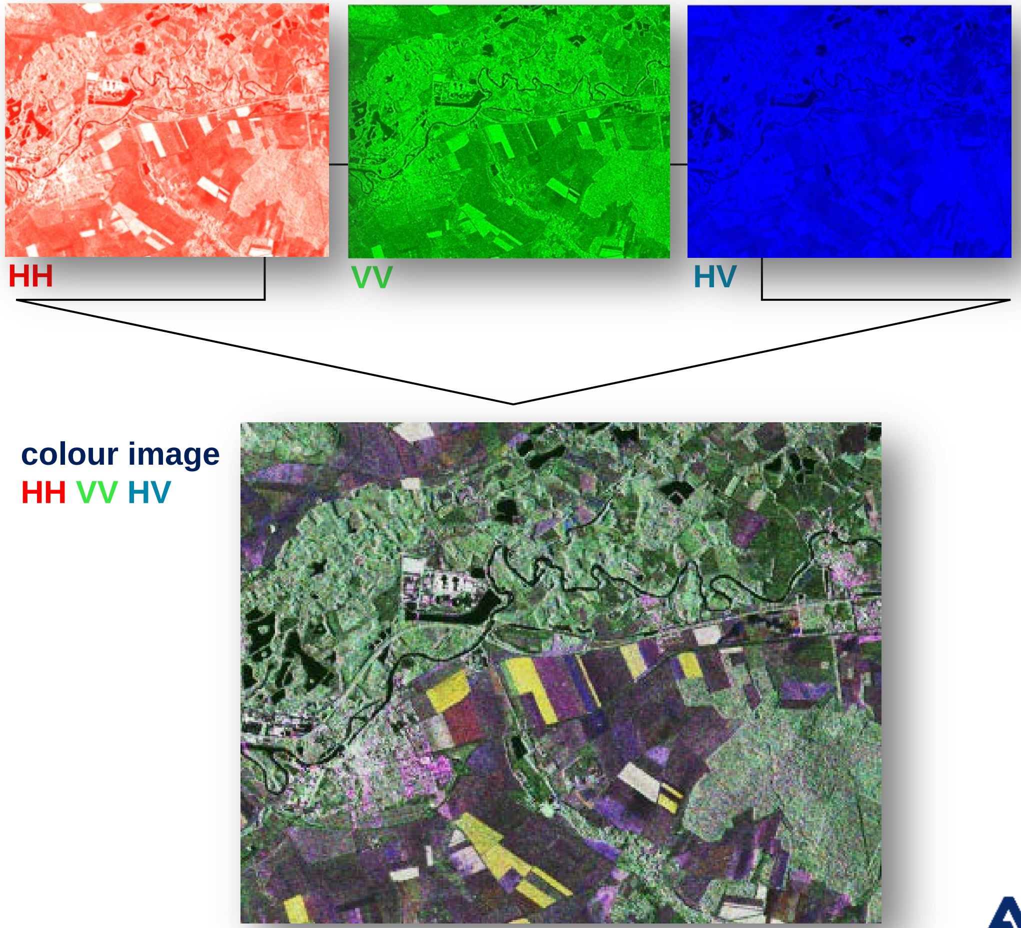
There are 4 possible polarisation combinations which are transmitted and received by a radar antenna. Each combination is delivered as an individual greyscale images, for example in Geotiff format and can be combined to form colour composite imagery for further interpretation of surface characterises.

- HH: Horizontal polarised waves on transmission and reception
- VV: Vertical on transmission and reception
- VH: Vertical on transmission and horizontal on reception
- HV: Horizontal on transmission and vertical on reception

At the moment, a selection of polarisations is available.
See imaging mode.

Backscattering depends on the surface roughness.
Scattering mechanisms cause different levels of brightness in the individual polarimetric images.

Rough surfaces:	VV > HH > HV
Double bounces:	HH > VV > HV
Volumes:	HV image is brightest

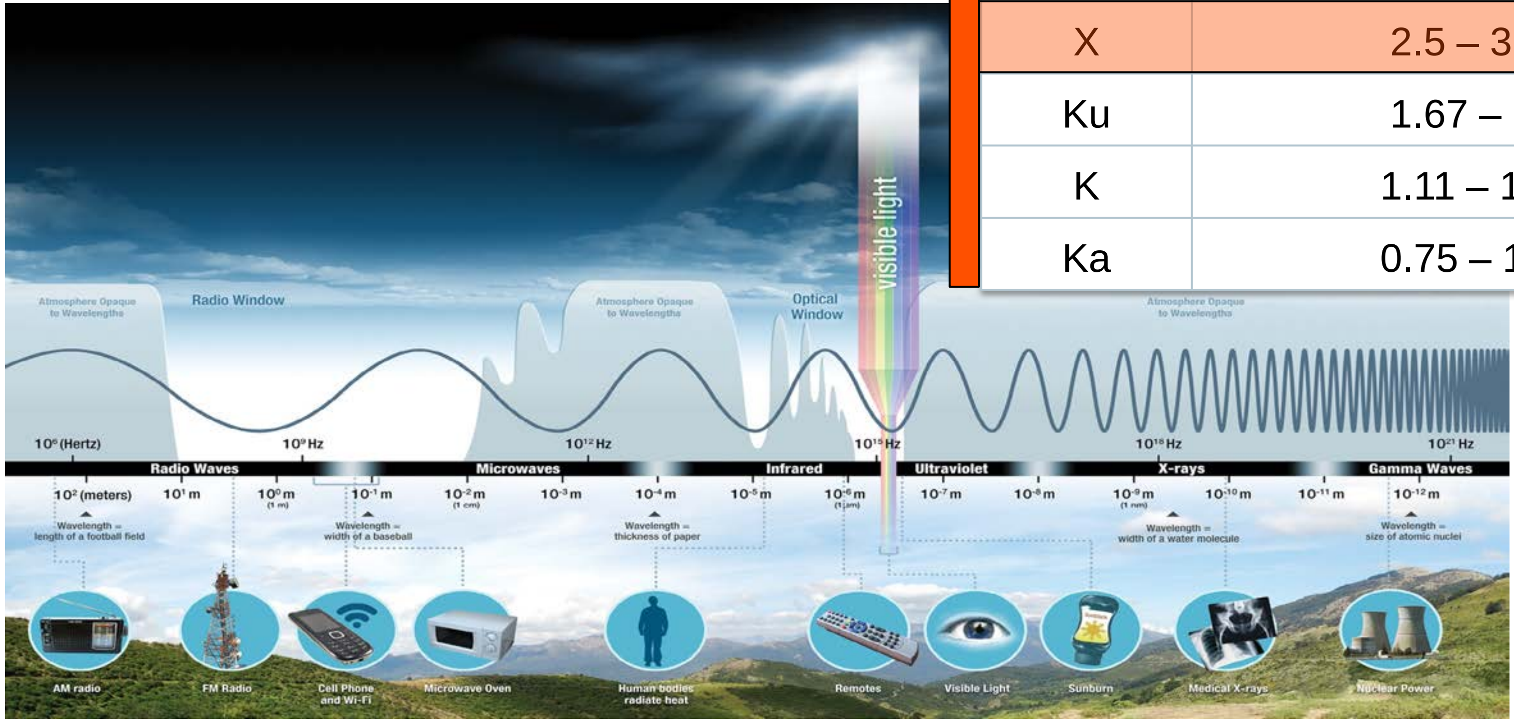


AIRBUS

Frequency

Radar antennas use a pre-set wavelength or frequency for their operation. In the case of TerraSAR-X, this is 9.65 GHz or 3 cm wavelength. Small details can be better recognized, if a short wavelength is used. Thus X-band is often used in IMINT.

Band	Wavelength [cm]	Frequency [GHz]
P	30 - 100	0.3 - 1
L	15 - 30	1 - 2
S	7.5 - 15	2 - 4
C	3.75 – 7.5	4 – 8
X	2.5 – 3.75	8 – 12
Ku	1.67 – 2.5	12 – 18
K	1.11 – 1.67	18 – 27
Ka	0.75 – 1.11	27 - 40

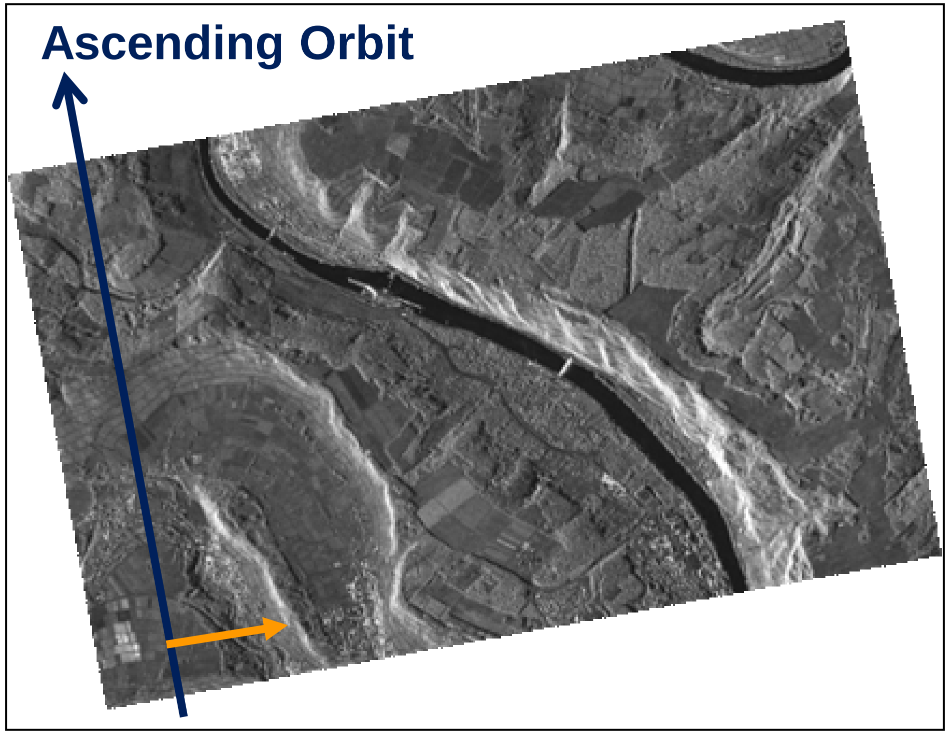


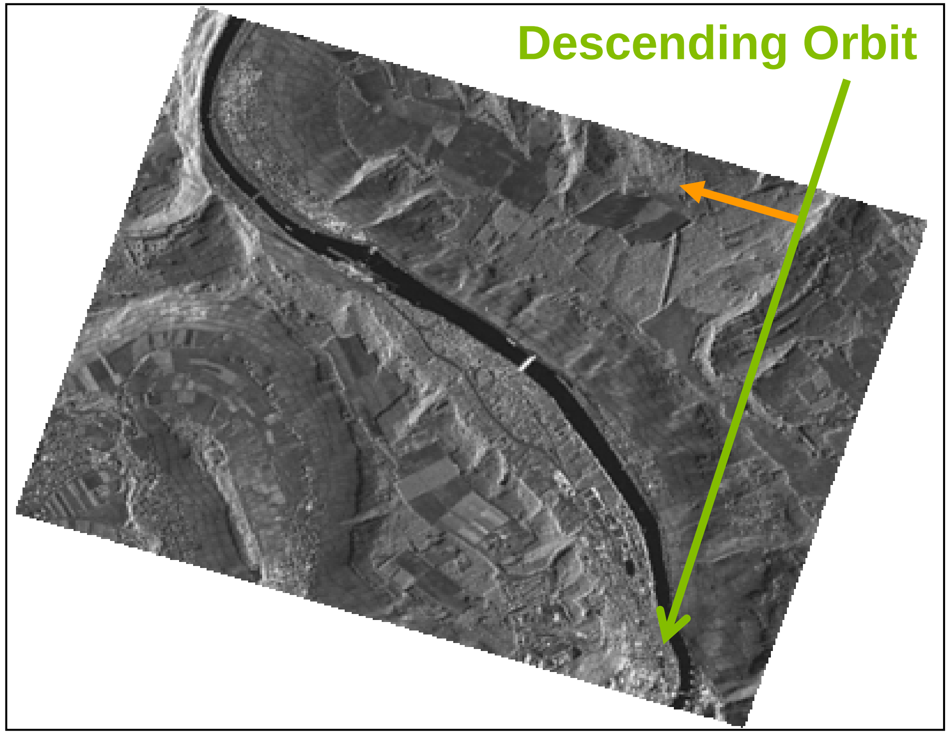
AIRBUS

Ascending or Descending Orbit

The ascending and the descending orbits are the different flight directions of the satellite.
In 99% of the image acquisition cases, the satellite is programmed to look right, which is indicated by the orange arrow.

- Ascending orbit: Southeast to Northwest
- Descending orbit: Southeast to Southwest





Incidence Angle 1

The radar looks sideways from its track towards the ground at a specific viewing angle. This viewing geometry governs the way particularly tall objects are shown in the image. On a global scale, the available angles depend on the geographic latitude at which the image is acquired. Towards the poles, more incidence angles are available than towards the equator, since the orbits are closer together and an area on the ground can be captured by more orbits. For future acquisitions, the available incidence angles in an area are identified and can be selected by the user.

For very high resolution radar images:

- Small incidence angles closer to 20 degrees may be suitable to look among objects and to see long layovers to learn about the sides of the object facing the radar.

- Large incidence angles closer to 45 or 55 degrees, depending on imaging mode, may be suitable to obtain long radar shadows to learn about objects, which do not cast a layover.

The applied incidence angles can be found in the product .xml header file or in the TerraSAR-X IMAGE name as the beam identifier. See Basic Product Specification Document.

Incidence Angle 2

SpotLight image of Svalbard, Norway.
A time series of images with different incidence angles (23-53 degrees) illustrates the effect on the image of the mountains.
Layover, foreshortening and shadow can be observed as they change with changing incidence angle.

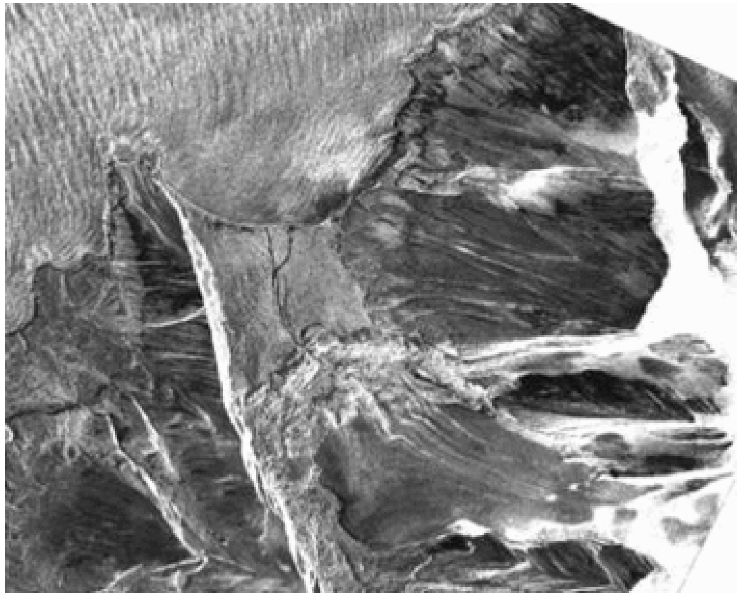


Image Properties

SAR System Settings, Object Properties and Resulting Image 1

To enable a multitude of applications by a wide variety of users, SAR satellites are designed with the following configurable settings:

- **Six** imaging modes can be used to generate maps at different degrees of detail. Different application domains and workflows require different image products.
- **Four** basic image products can be used to satisfy data needs from beginners to advanced users.
- Various object types, such as buildings, vehicles, vessels, forests, or land cover will be known by the end user. They are characterized by their geometry, their dielectric and their possible motion and need to be investigated for their special behaviour in a radar image.

SAR System Settings, Object Properties and Resulting Image 2

SAR System

- Frequency
- Polarisation
- Noise

Radiometry

- Looks
- Bandwidth
- Incidence angle

Range

- Antenna Size
- PRF
- Six Imaging Modes

Azimuth

- Ascending / Descending orbit

SAR Processing

- Slant or Ground Range; Looks
- Geocoding
- Radiometrically / spatially enhanced
- Four Basic Products

Resulting Image

- Complex or detected image format
- 32- or 16-bit Encoding
- Grey value histogram
- Separate image bands
- Texture
- Speckle
- Layover, foreshortening, shadow
- Mixed Information within Pixel
- Time series

Object Properties

Geometry

- Size & Shape
- Orientation
- Roughness
- Neighbouring

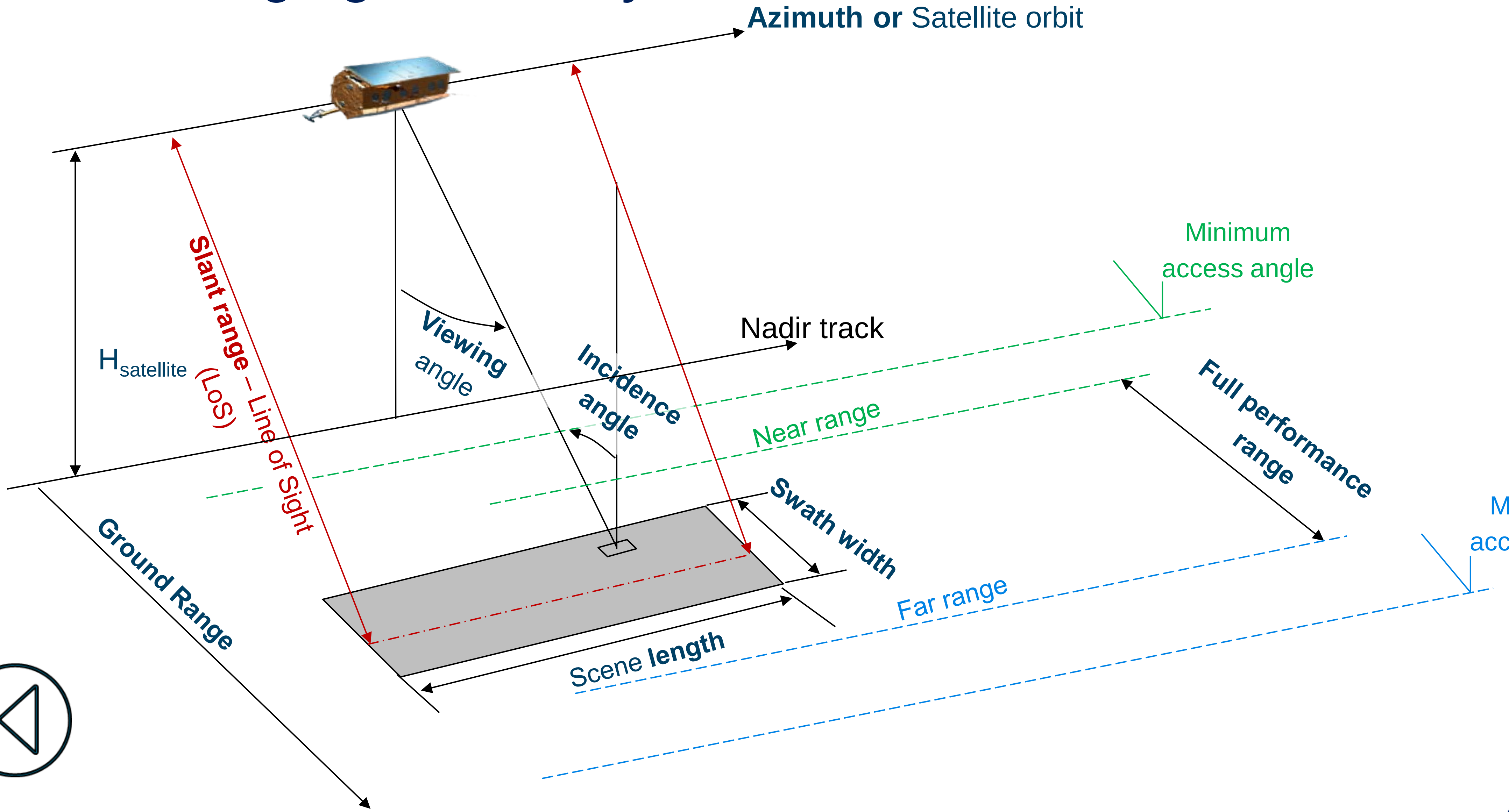
Dielectrics

- Water content
- Frozen/thawed
- Salt content
- Clay, iron oxides

Motion/Speed

- In range direction
- In azimuth direction

Radar Imaging Geometry



AIRBUS

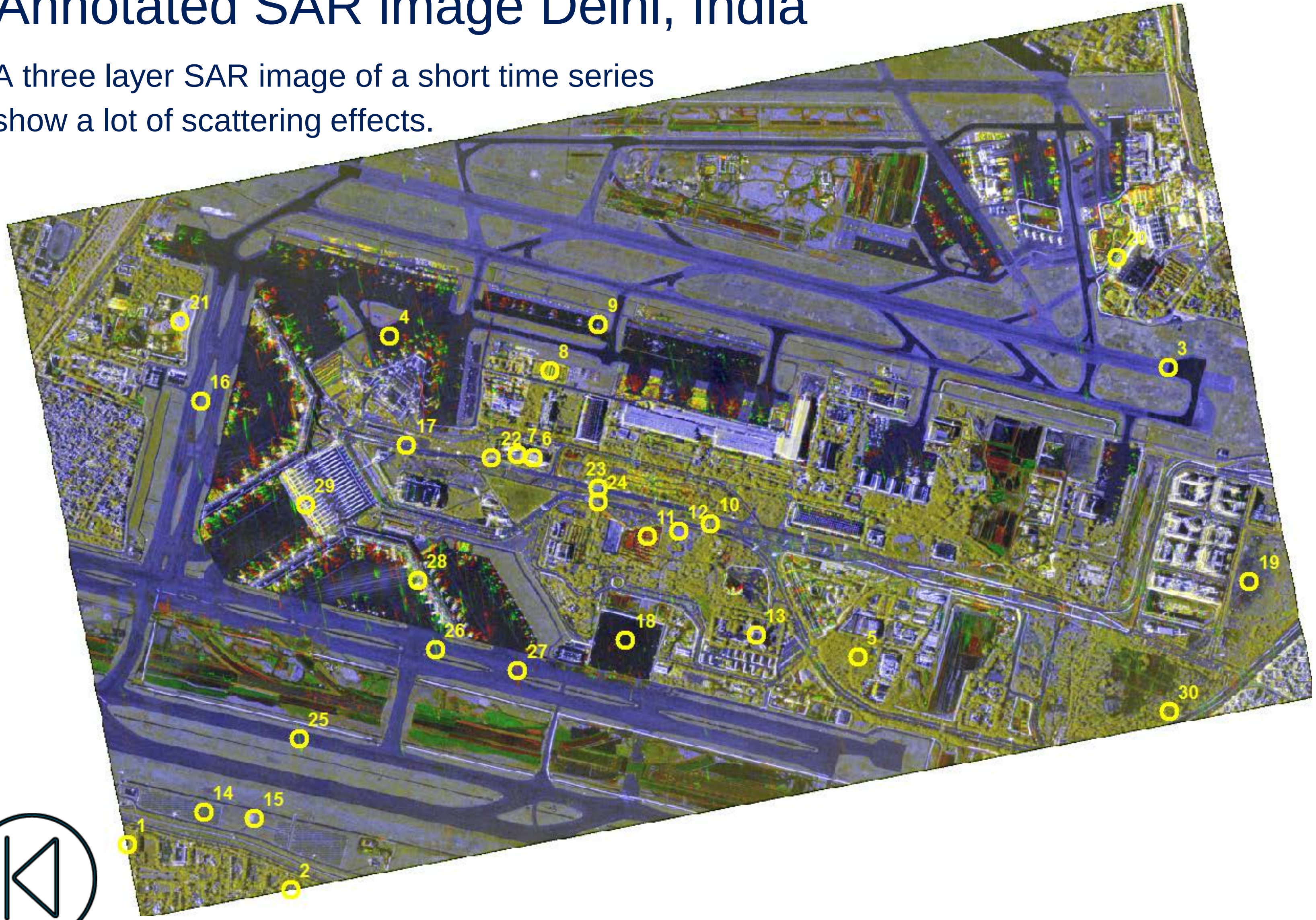
Image Content

Radar images show the Earths surface in an unusual way.

- The image looks grainy (speckle effect).This can be compensated for by mono- or multi-temporal filtering.
- Often, grainy texture patterns, pure black and white or strange colours are visible in the image, which look unreal (single polarisation image, roughness and volume scattering).
- Tall objects seem to fall (layover) to the side of the image.
- Tall objects cast a shadow (radar shadow of the area behind tall objects = no return).
- Tall objects are not shown in full length (foreshortening).
- These effects occur because the radar is looking sideways towards the ground.
- Bright lines or stars may cross the image (sidelobes of the main beam).
- Short bent streaks are sometimes visible and objects are not in the expected place (moving objects).

Annotated SAR image Delhi, India

A three layer SAR image of a short time series show a lot of scattering effects.



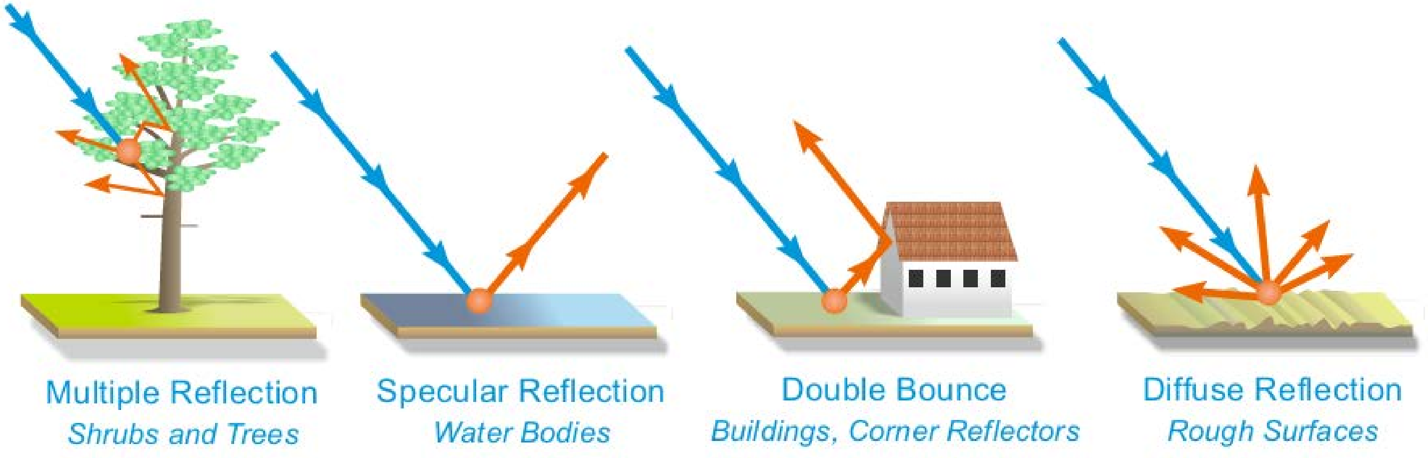
No.	Imaging effect or feature
1	image edge, azimuth direction
2	image edge, range direction
3	left tarmack, right concrete surface
4	smooth concrete surface with aircrafts
5	dense tree vegetation
6	large 5 story building with bright layover
7	foot of the air traffic control tower
8	container storage area
9	parked aircrafts
10	azimuth ambiguities on both days
11	vehicle parking
12	mixed grass and bush vegetation
13	x-shaped Centaur hotel
14	solar panel farm
15	air traffic control DVOR
16	taxi ways, really bent or DEM correction artefact
17	flagpoles and lamps
18	concrete surface with streaks from moving objects
19	short grassy vegetation, partly bare soil
20	truck parked at logistics firm
21	bulk material storage; gravel and sand
22	circle is top of air control tower, layover
23	toll payment station with guardrails and tents
24	toll payment station with guardrails and tents
25	moving object on day 1
26	moving object on day 1
27	moving object on day 2
28	bright terminal structures facing the radar
29	terminal building partially transparent
30	tree vegetation

Scattering of Radar Waves

We distinguish between four types of scattering effects.

- The radar beam interacts with shrubs or trees (volumes) to create multiple reflections. These areas will have a textured pattern in the greyscale image. This shows strongly in the VH or HV polarisation.
- If the radar beam is reflected forward and away from the radar (specular reflection) the image will be black in these areas.
- The radar beam can interact with man-made objects, such as buildings and create very bright patches in the image (best in HH).
- And the interaction with a so-called radiometrically rough surface will cause diffuse reflection and also some texture pattern in the image.

- Understanding these effects helps to interpret the image. Brightness or backscatter patterns in the image can change over time due to environmental effects or human interaction (building and demolishing; shifting and moving objects).



Grainy Image

Radar images often look grainy. This pattern is caused by scattering of neighbouring objects across pixels.
Graininess can be overcome by using adaptive filter techniques on single images or on multiple images, which are often not fully implemented in commercial software yet. Sometimes open source software or own implementations are more suitable. Time series data over an extended period of time such as a year, can be used to create smooth images.

Take note of the software implementation: which input product do they require

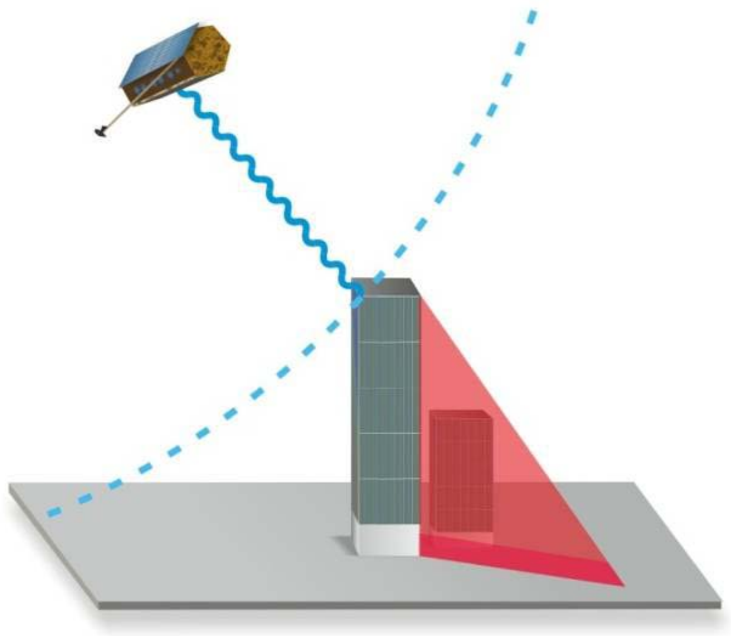
- Speckle filtering is a trade-off between speckle removal (radiometric resolution) and preservation of small details (spatial resolution)
- Low pass filtering (e.g. 3x3) can be sufficient for viewing the data or to prepare print outs. It works on any detected product.
- More speckle filters include Lee, Kuan, Frost, Gamma-MAP or De Grandi filter time series filter.

Some software implementations work either complex or detected images:

- Local adaptive filtering (dedicated speckle filtering): e.g. Gamma-MAP filter
- Multi-temporal filtering (if time series of images is available): e.g. De Grandi filter

Shadow 1

Radar looks sideways from its track to the ground. Any tall building, vegetation or mountain will cast a shadow, from which no energy can return back to the radar. Radar shadow is one of three striking effects in a radar image and will occur together with foreshortening and layover.
Buildings which are located behind the tall tower will not be seen in the image.



Vegetation can also cast radar shadows. Harwell, UK

Shadow 2

Special topic:

- The length of the shadow can be used to calculate the height of the object by using: h=tan(90-theta)*length of shadow
- The length of the shadow can be measured in a 45 degree image without error.
- Here, only the water tower in the south casts a shadow. The lattice masts of the lightning arresters do not.

Optical reference

ST: 3 days

HS: 3 days

Foreshortening 1

Due to the side looking radar geometry, any tall objects or mountains will be imaged differently than in an optical satellite image that tends to look straight down.

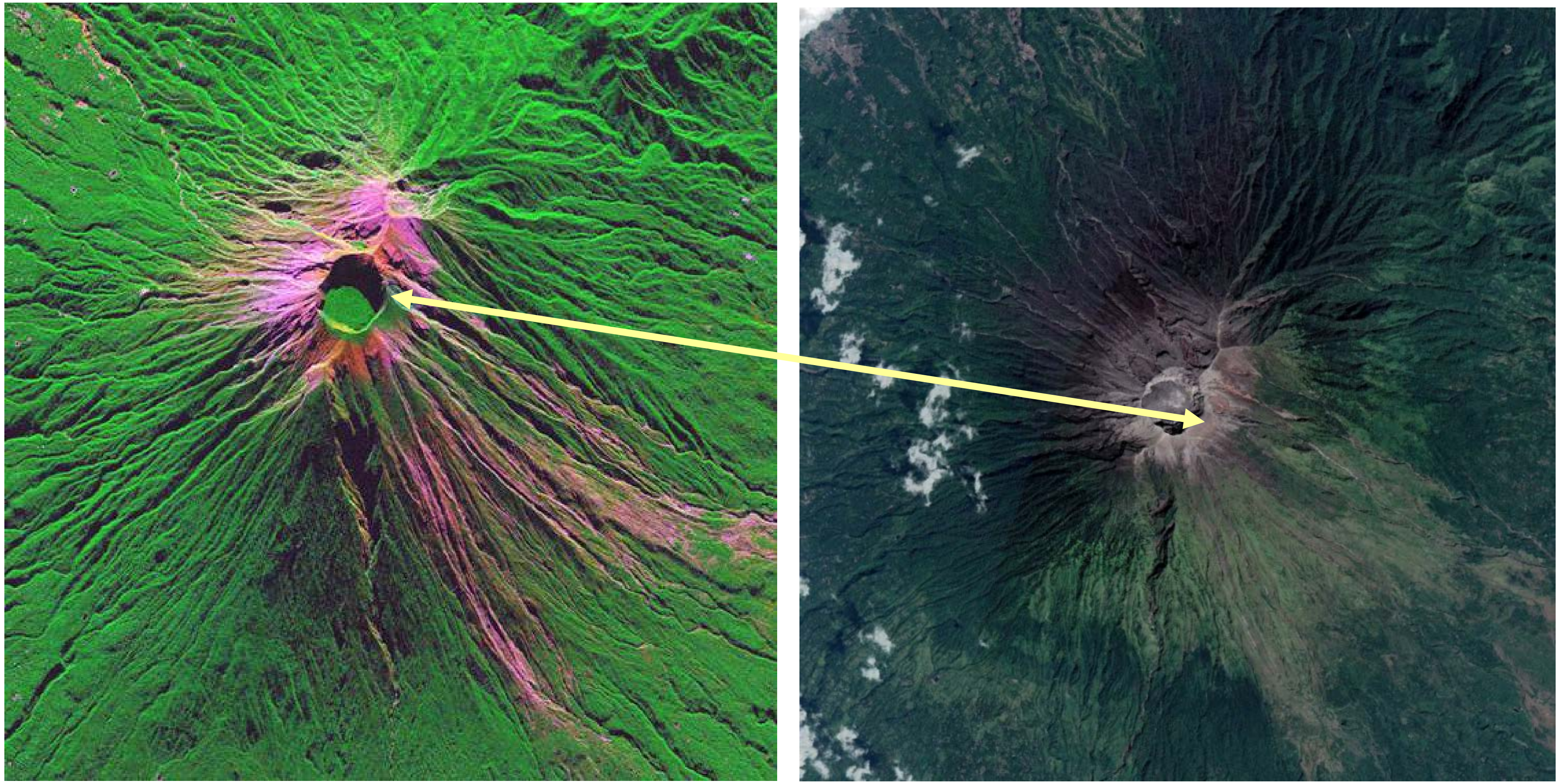
The length of the object's side that is facing the radar will be condensed in the image. It will be shorter than it's actual length.
This also occurs in conventional pencil drawings: an arm reaching forward to the viewer is foreshortened and not drawn in its full length.

In a geocoded image, the top of a mountain can be place at its precise location but the shortened side will need to be filled in with pixels with grey values resampled from its neighbours. Interpolation techniques for this resampling could be nearest neighbour, bilinear, bicubic or Lagrange. It is recommended to check the settings of COTS software to see which resampling technique is applied.

For this reason, it may be favourable to perform analysis on slant range data and then geocode the results (Advanced Analysis path).

Foreshortening 2

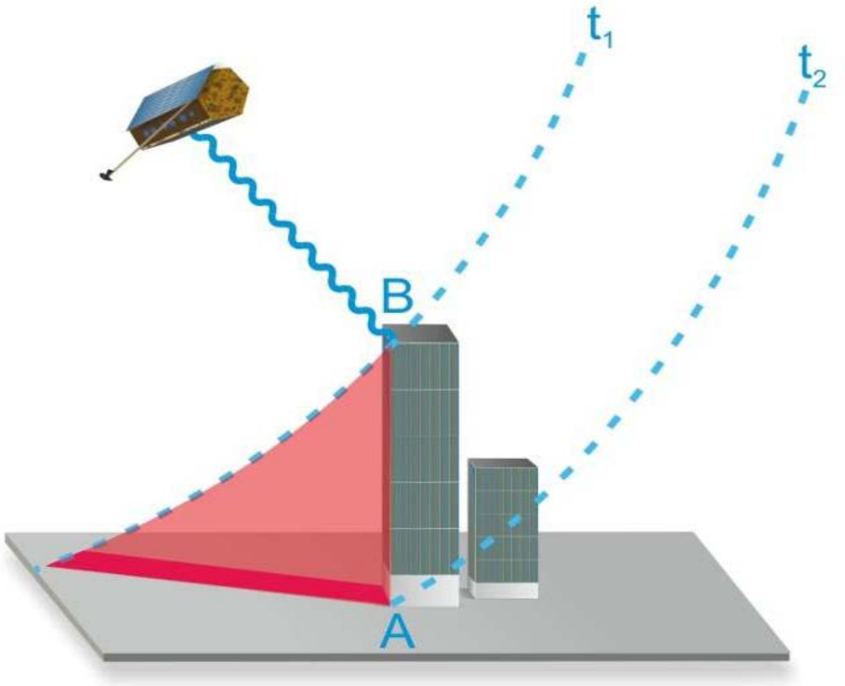
The radar image has been rotated so that layover and foreshortening are upright.
Left color composite of Mt. Agung, IDN, right, open source color image.

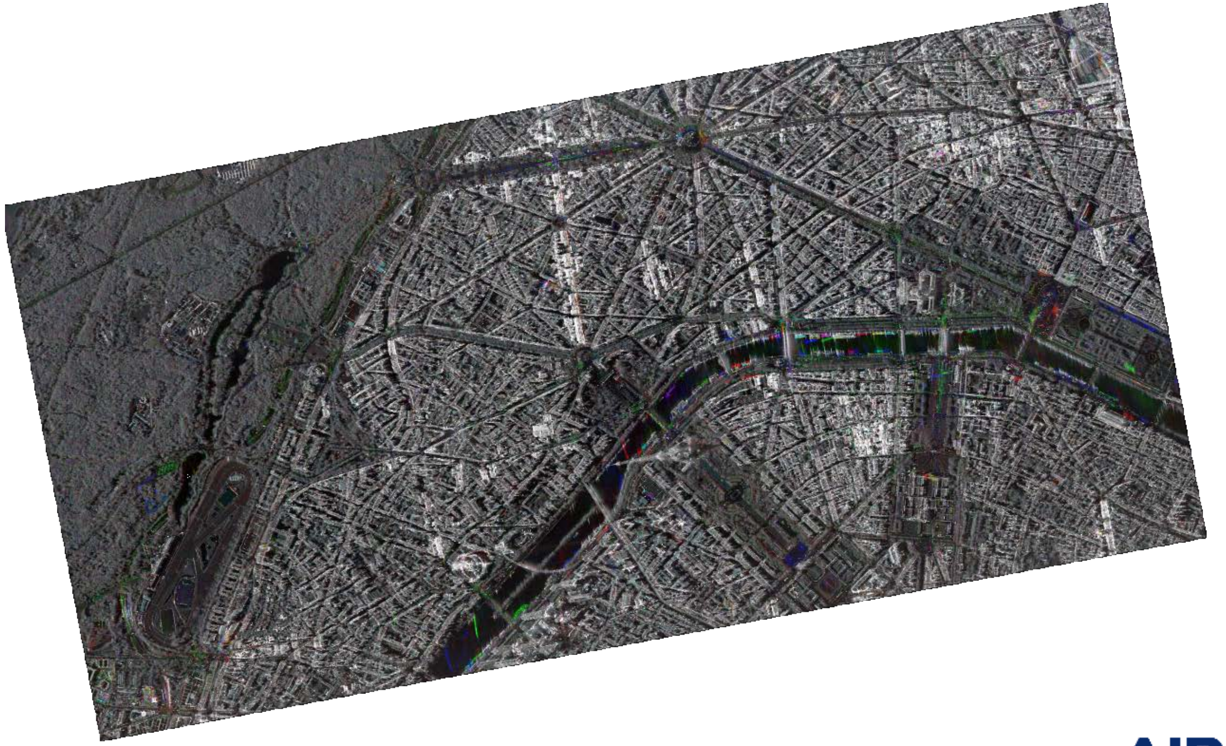


AIRBUS

Layover 1

Side looking radar geometry results in tall building, vegetation or mountains appearing “folded over” towards the satellite. If the image is rotated so that the layovers point upwards, a pseudo 3D effect can be observed. It is similar to a pop-up postcard.
In the image (north is up), the top of the building (B) will be located on the far left (where the t1 dotted line meets the ground). The actual bottom of the façade (t2) will be imaged at point A. All of the skyscraper will be folded sideways onto the ground in the image.
Find the Eiffel Tower in the Paris image.





Layover 2

Special topic:

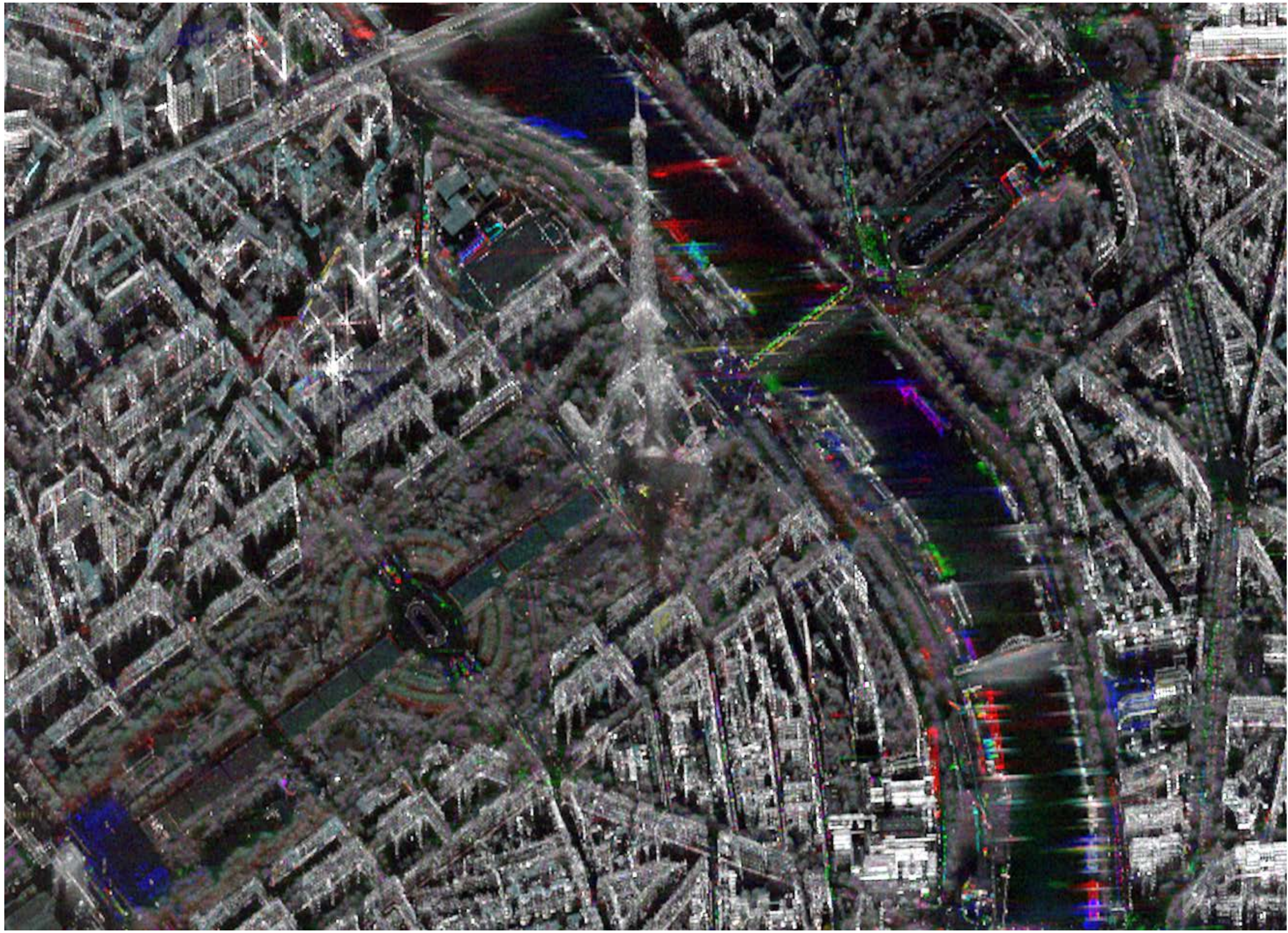
- The length of the layover can be used to calculate the height of the object by using: h=tan(theta)*length of layover
- The length of the shadow can be measured in a 45 degree geocoded image without error.
- One could use the incidence angle at image centre or interpolate the incidence angle from the 5 angles given in the *.xml header file.

AIRBUS

Layover 3

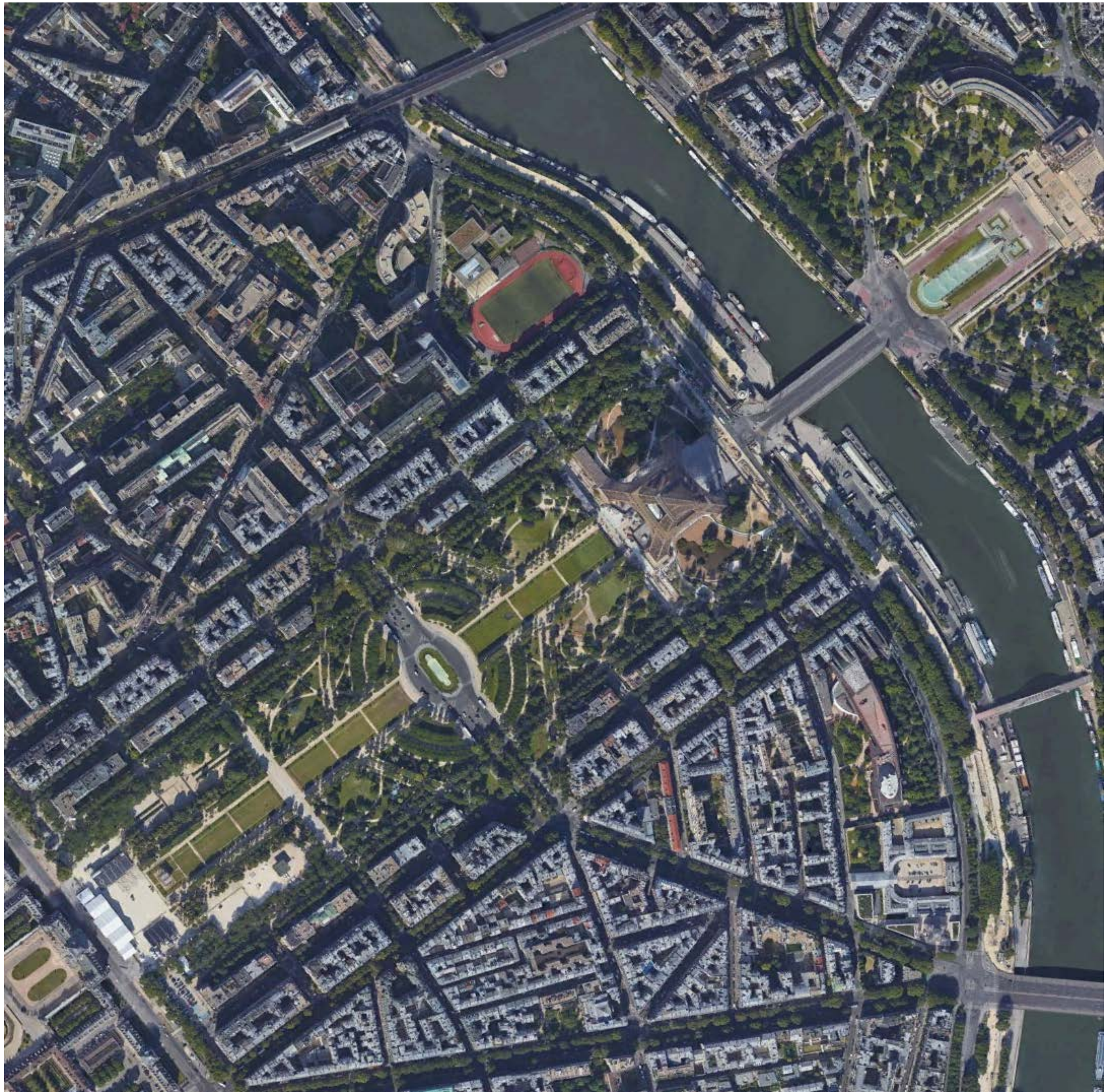
The Eiffel Tower in Paris, France stands at 324m tall (to the top). The structures and platforms of the tower can be seen in the layover of the tower. The length of the tower's layover on the ground can be different in other radar images. It depends on how steeply the tower was looked at. The steeper the view (closer to 20° incidence angle), the longer the layover on the ground.

The colour radar image is a combination of 3 images taken between April and June 2017 mapped on Red, Green and Blue.



Layover 4

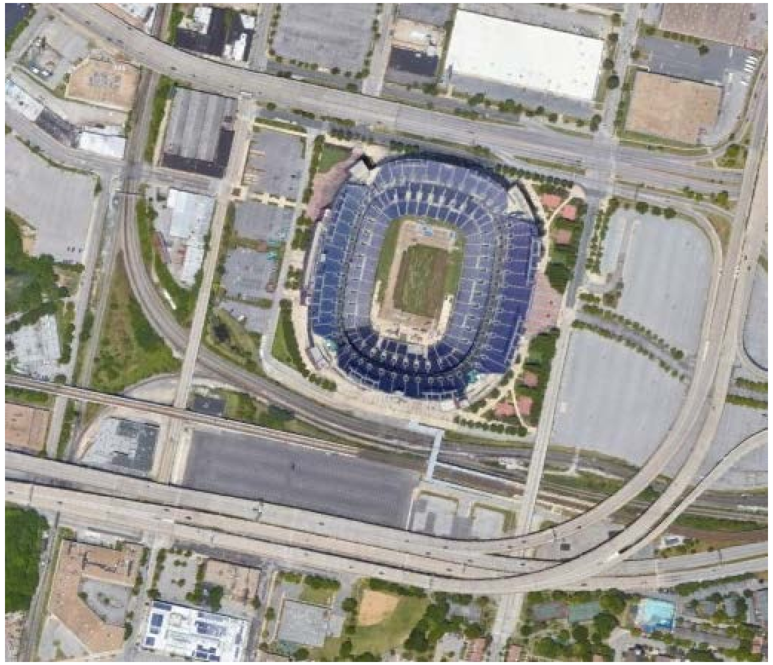
The Eiffel Tower in Paris, France
Optical reference.



Layover 5

This very high resolution (75cm) radar image below shows the M&T Bank Stadium in Baltimore, USA. The colour radar image of the stadium has been rotated so that the bright layover (highlighted in yellow in centre image) is upright.

Coloured radar image from 3 acquisition dates placed on Red, Green and Blue.



Optical reference image.

Colour Composite

SAR images can be combined to create colour images
Additive colour mixing: 3 greyscale images are displayed in the red, green and blue channels in the image processing software.

In the overlapping area, mixed colours are created:

- Bright pixels in red and blue are purple in the image
- Bright pixels in red and green create yellow pixels
- Bright pixels in blue and green create light blue or cyan pixels
- If pixels are equally bright in all three bands, the result is white
- If pixels are equally dark, the result is a black pixel

- Colour composites serve as an interpretation aid or can be used in thematic image classification

- See example: San Francisco

AIRBUS

SSC/SLC Amplitude and Phase

Single Look Slant Range Complex (TerraSAR-X) or Single Look Complex (Sentinel-1) are generated from raw data which required advanced SAR processing to obtain imagery. Raw data are not available to the client, SSC data are. SSC data are used for advanced applications (advanced analytics) which require the full complex data in its original geometry following the slanted line of sight during image acquisition.

Both amplitude and phase information are stored in complex numbers. Both are required for image to image coregistration.

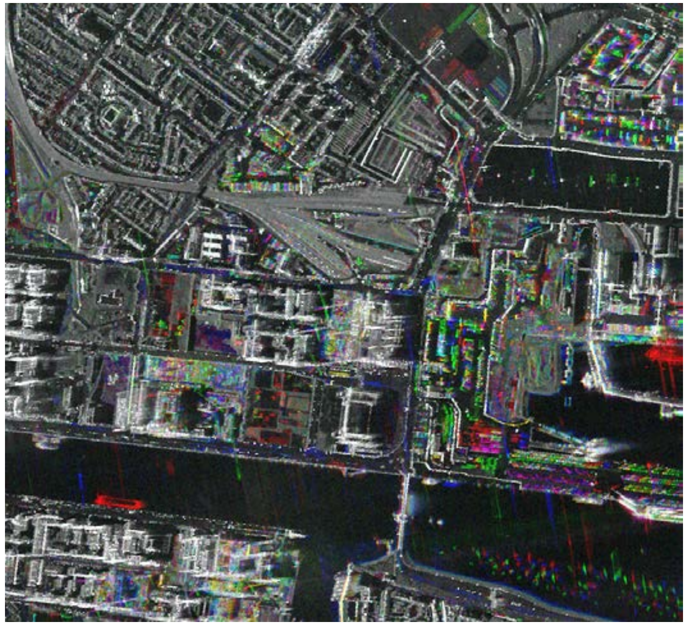
A selection of off-the-shelf software packages can read and display SSC data on screen. This works well for ST, HS, SL and SM imaging modes but is often not supported for ScanSAR and Wide ScanSAR images. In this case, visualisation must be programmed by the user in their own software or alternatively, TerraSAR-X EEC products can be used instead.

Bright lines or stars in the image

The radar transmits a wavelength of 3 cm. Any object with a greater or equal length to this can cause enhanced returns towards the radar antenna which show as bright cross-like patterns or 4 pointed stars in the radar image. They occur, for example, when 2 - 3 surfaces form a perfect backscatterer directly facing the radar.

The 4 bright streaks can be used to reconstruct the viewing direction of the satellite. If the image is oriented north-up, the vertical streak coincides with the flight direction (azimuth) and the horizontal streak is aligned with the range direction across the image in approximately West-East direction. The star is slightly rotated, since it is a geocoded image taken from the ascending orbit.

Lille, FRA



Dublin, IRE

AIRBUS

Bent streaks in the image 1

Radar antennas measure the travelling time from signal transmission to reception. Any moving object which is fast enough in relation to the propagation of the radar signal will cause streaks in the image. These do not occur at the object's location but are slightly offset.

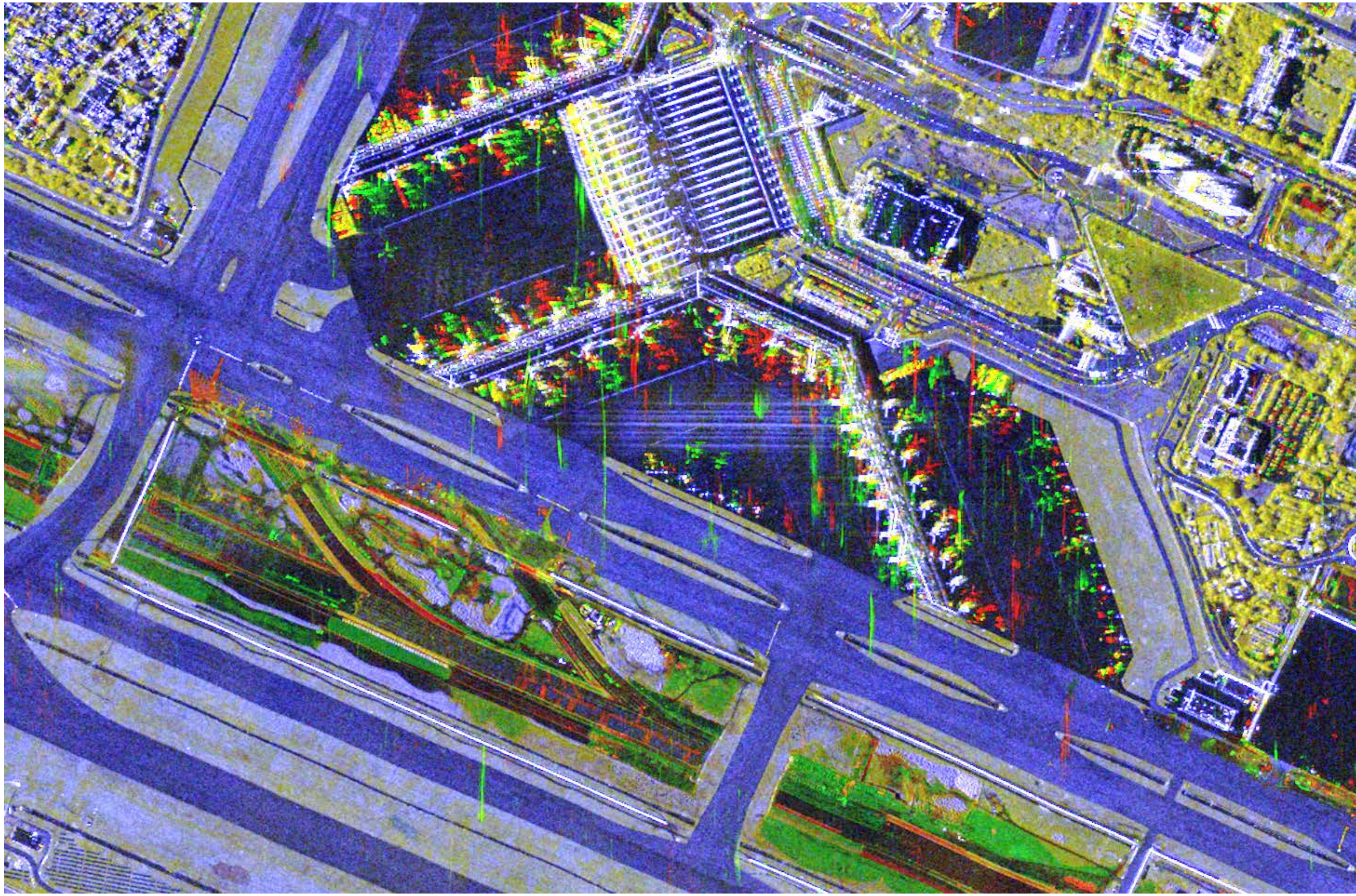
In this colour composite of three days, red and blue streaks alongside the looping rail track indicate rolling stock or moving train

The streaks and their offset are an indication of the speed of objects. Also, if the offset is seen in the image, the direction of travel can be determined.

Port Hedland, AUS

Bent streaks in the image 2

This image of Indira Gandhi International Airport in Delhi, India is a colour composite image where the red, green and blue channels are composed of intensity on day 2, intensity on day 1 and coherence, respectively. Several green and red streaks can be seen. Smearing is observed in satellite flight direction (azimuth). These smears are cars from a nearby road.



Contrast and brightness: Histogram 1

The grey value distribution (histogram) of a SAR image is different from what we might be used to with optical data.
Usually there are peaks at the lower (Earth surface types) and highest grey values (mostly metal man made objects).

- Detected image data is often scaled to 16 bit, which means that they need to be rescaled for the 8-bit computer screen. Portions of the histogram can be used or dynamic grey value scaling can be applied when working interactively with the data.
- Slant range image data is stored in complex format in 32-bits per pixel.

Intensity or power data ($I=A^2$)
Follows a negative exponential distribution

Amplitude data (A)
Follow a Rayleigh distribution. TerraSAR-X data is delivered as amplitude data.

Data scaling of TerraSAR-X imagery in dB: radiometrically calibrated data in beta-0, sigma-0 and gamma-0 notation are often shown in decibel scaling. $Log10(A^2+K) = [dB]$

Radiometric calibration

Contrast and brightness: Histogram 2

A histogram is a graph showing the frequency (y) of grey values (x) in a image. Since 16-bit values (2^16 values) can only be shown on the 8-bit computer display, an appropriate subset of these values is selected.
A transfer function from 16 to 8-bit can be linear, non-linear, exponential, Gaussian etc.

In COTS software packages, the histogram is often clipped by ~2% on both ends. The default preference settings can be checked.

The grey value distribution curve can be have different shapes:

- Skewed to the left indicates the image is very dark
- A normal distribution suggests the image contrast is well balanced.
- Skewed to the right shows the image shows very bright objects

The distribution curve can be very narrow (low contrast) or wide (good contrast).

Dynamic range adjustment or dynamic histogram usage is often implemented in COTS software. Especially when looking at very bright metal objects, histogram adjustment is crucial to avoid extremely bright objects on a very dark background.

Pyramid Layers

For quick zooming the image, reduced resolution data sets (RRDs) or pyramid layers are created by most image processing software.

For visualisation, different grey or colour interpolation methods can be applied by the software such as nearest neighbour, bilinear, cubic convolution interpolation.

Pyramid layers are stored in the same data container or stored in separate files depending on the image processing software.

ARD Analysis Ready Data 1

According to CEOS (Committee of Earth Observation Satellites) these are satellite data that have been processed to a minimum set of requirements and organised into a form that allows immediate analysis with a minimum of additional user effort and interoperability both through time and with other datasets. ARD is used in Earth observation data cube (EODC) technology.

Having ARD significantly reduces the amount of work and prior knowledge which is required to prepare remote sensing data. Image time series are now consistent in terms of radiometry and geometry.

TerraSAR-X, TanDEM-X and PAZ ARD data can be generated by starting with SSC products.

ARD Analysis Ready Data 2

In the case of TerraSAR-X, several EEC products (enhanced ellipsoid corrected image) form a time series of pre-processed images which are ready for a user to analyse. The data is geocoded to a common map projection and Earth ellipsoid (UTM, WGS84), and radiometrically calibrated to radar brightness values. The data can directly be used in GIS software packages to create thematic maps, image maps, or backgrounds to other vector data.

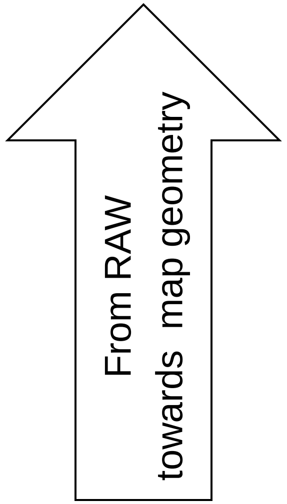
Since radar antennas look sideways to the satellite track, the measured backscattering at the antenna is modified by the terrain slopes. Those slopes facing the radar will be very bright, and on their backside, dark radar shadow areas will occur in the image. Also, the image will have been draped over a digital terrain model, so that layover and foreshortening effects will cause “stretch marks” in the image.

If terrain is flat in the area, these effects will not occur and the data is ready for analysis.

Further correction to sigma-0 or gamma-0 can be applied by the advanced user by starting off with the TerraSAR-X SSC product.

Image Products 1

TerraSAR-X, TanDEM-X and PAZ satellite data are processed to 4 Basic Products (expert reference)

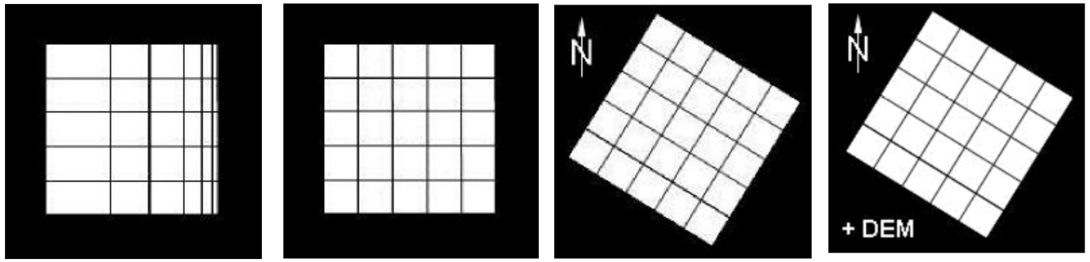


EEC **Enhanced Ellipsoid Corrected image = GIS-ready data in UTM WGS84**

GEC Geocoded Ellipsoid Corrected image = usable, if images do not need to be aligned-by-pixel but need a coarse geographic orientation (high co-registration accuracy is on the other hand required for change detection)

MGD Multi-looked Ground Range Detected image = usable, if storage space is small and geocoding does not matter. Co-registration will require back-transformation to slant range.

SSC **Single look slant range corrected image = advanced users data for all types of data analysis, but SAR expertise is required to handle both radiometric and geometric correction.**

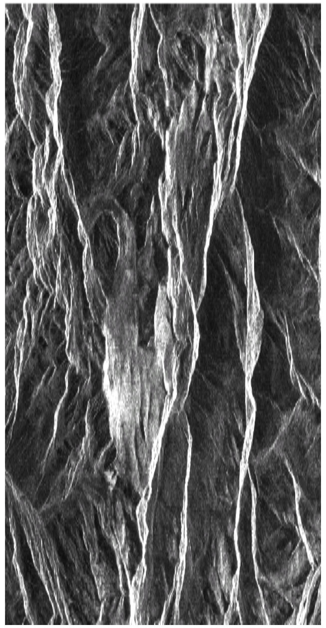


SSC MGD GEC SSC

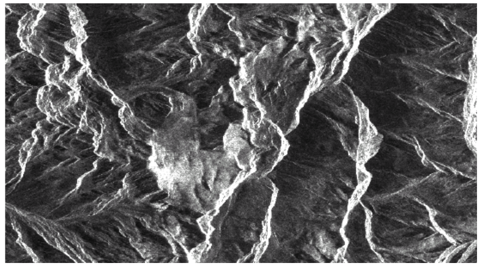
SSC

Image Products 2

An image acquisition can be processed into all of the four basic products.
Their visual appearance is visualized here. The area is Sion, CHE.

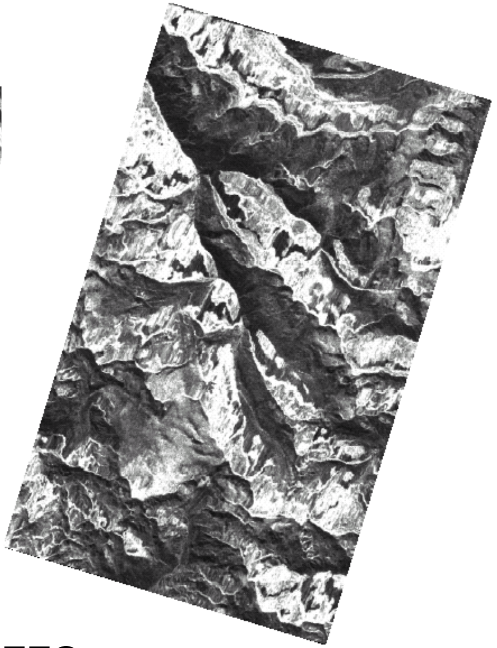


SSC
Single Look
Slant Range Complex



MGD
Multilook Ground
Range Detected

GEC
Geocoded Ellipsoid
Corrected



EEC
Enhanced Ellipsoid
Corrected
using DEM

Geocoding

TerraSAR-X detected or ground range images are geocoded to Universal Transverse Mercator projection (UTM) using a WGS84 Earth Ellipsoid. Geocoding, particularly orthorectification, requires the use of a digital terrain model. Depending on the quality of the DEM, positional errors and/or resampling errors at faulty DEM values can occur and lead to unwanted errors.

The positional accuracy of the TerraSAR-X EEC products is documented here.
The example below shows how an erroneous DEM can distort a bridge across water.

Basic Product Specification

Image format

TerraSAR-X data is distributed in two formats:

- Single look slant range complex (SSC): mathematical complex number containing magnitude and phase stored in 32 bit DLR COSAR format. This product is used for all interferometric methods.
- Geotiff format, 16-bit calibrated beta-0 amplitude data (brightness). This format is used for the detected products (in ground range) and thus the MGD, GEC, and EEC products.
- See Level-1b format specification.

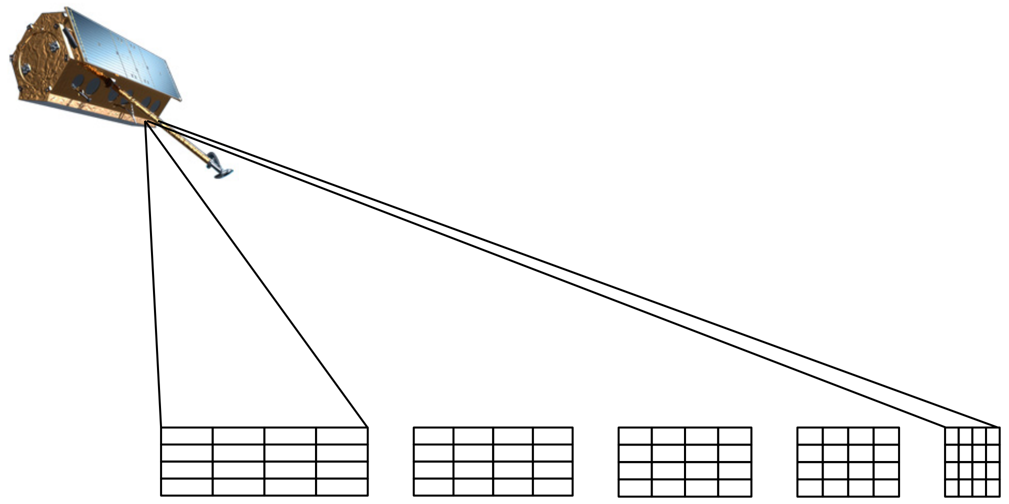
Format Specification

Slant Range to Ground Range

- Slant range describes the slanted side view of the radar antenna (SSC images). Pixels are rectangular and are largest if they are located very close to the radar track (near range) and smallest if they are located far away from the radar antenna (far range). Thus, if the finest spatial resolution is required for the analysis, far range images should be used which have been acquired at large incidence angles (closer to 45 - 55° depending on imaging mode). The image will appear sharper. Yet the length of the radar shadows will be larger than the length of the layover at this position inside the accessible swath.

If a map of the slant range data is required, the image matrix can be transformed into ground range and then orthorectified.

- Ground range images (MGD, GEC and EEC) come from the slanted geometry and have been projected to the ground. Pixels are square. The same rules regarding spatial resolution, as mentioned above, also apply.



AIRBUS

Amplitude and Phase

In software packages, image data is often referred to by different terms. Magnitude, Amplitude, Intensity are often used for the essential grey value pixel. Phase values only make sense, if the phases of at least two images are compared in interferometry.

The complex data (SSC product) includes:

$$magnitude = amplitude = \sqrt{real\ part^2 - imaginary\ part^2}$$

$$phase = \varphi = tan^{-1}\left(\frac{imaginary}{real}\right) = arctan\left(\frac{imaginary}{real}\right)$$

The detected products (MGD, GEC, EEC) include amplitude information only.

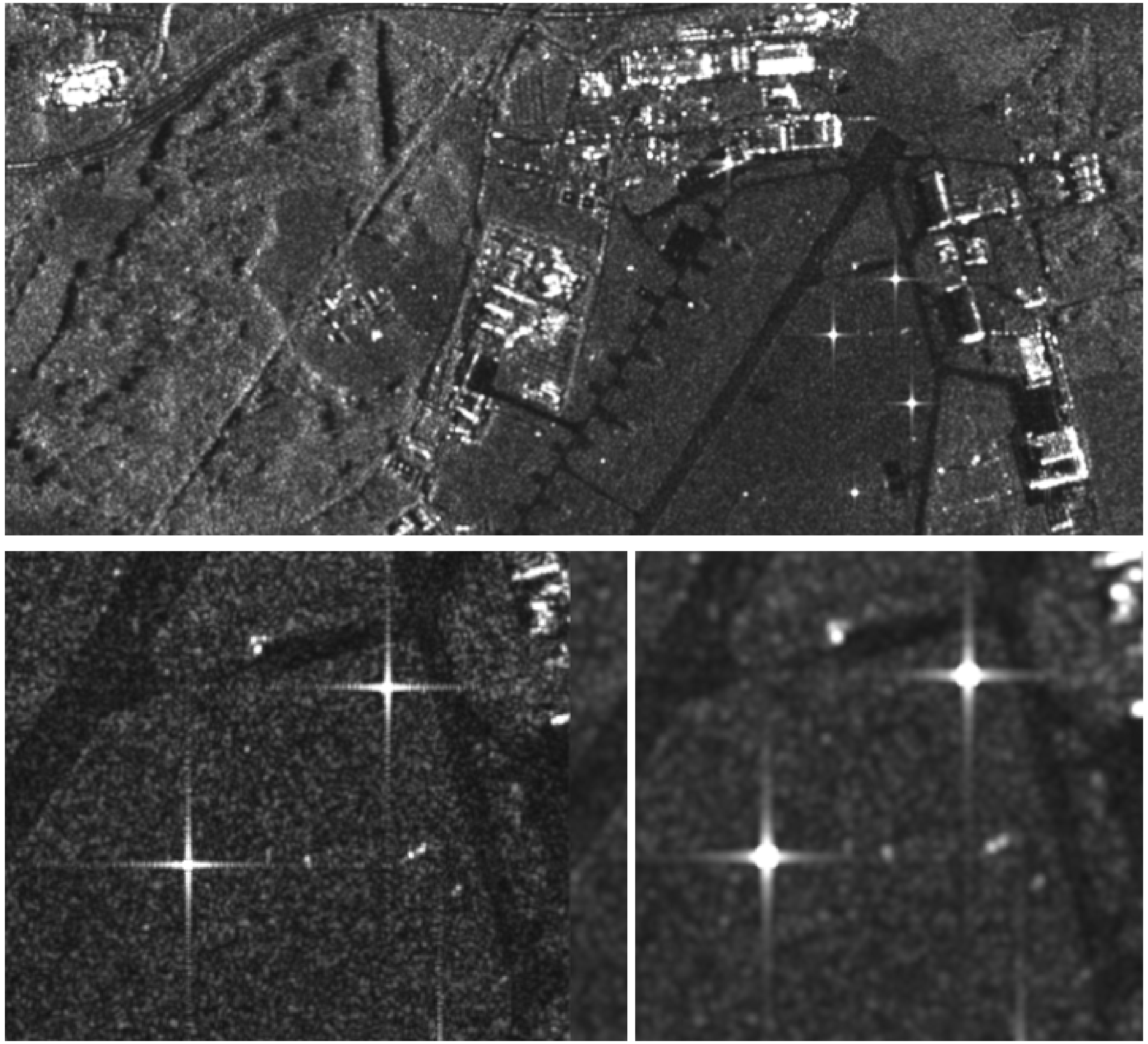
Processing Variant

The detected products MGD, GEC and EEC can be ordered in 2 processing variants:

- SE: Spatially enhanced product. High spatial detail at the cost of radiometry. This variant is best for visual object interpretation.

- RE: Radiometrically enhanced product at the cost of spatial resolution. This is ideal for time series analysis. This variant is used for absolute comparison of images e.g. for retrieval of biophysical properties.

- Oberpfaffenhofen, Germany



AIRBUS

Amplitude Image

ARD data from TerraSAR-X (EEC products) include the backscattered amplitude for each pixel. These are encoded in 16-bit unsigned format stored as Geotiff.

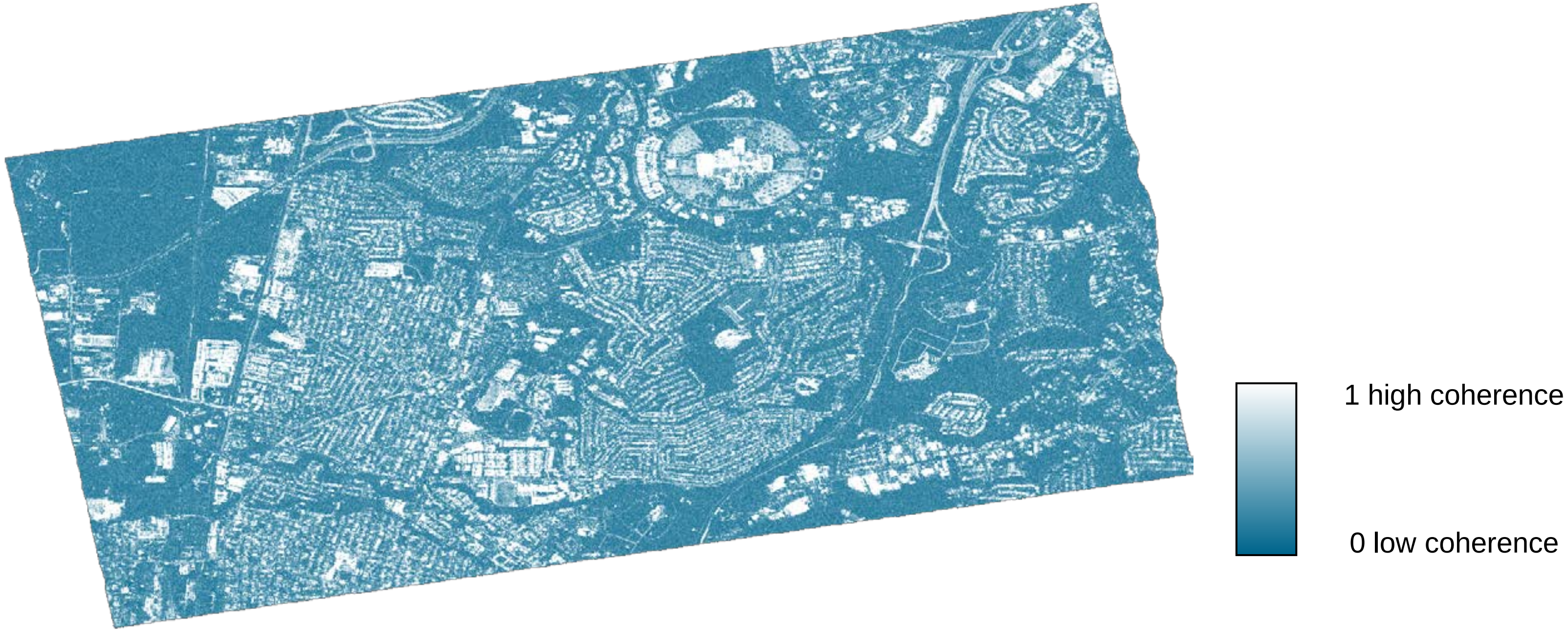
These include 2^{16} or 65,536 grey values. The histogram typically has a large number of very dark and very bright pixels. Depending on the analysis, the lower or the upper end of the histogram may need enhancement or may be considered when the data is reduced to 8-bit quantisation.

- Dark pixels represent low backscattering from smooth surfaces.
- Bright pixels represent strong backscattering from metal objects, multiple bounces at rough surfaces or direct backscattering towards the radar antenna.

Coherence Image

Interferometric coherence is a measure of the similarity between 2 radar images. These images need to be acquired at the same geometric condition (incidence angle, orbit, and polarisation).

Coherence is calculated between image pairs, e.g. day 1 and day 2 of a time series. The resulting image contains values which range between 0 and 1. Low coherence (0.0) indicates that the images are dissimilar and the surface has changed between image acquisitions. High coherence (1.0) indicates that the images are almost the same and the surface has not changed between day 1 and day 2. All potential changes are due to different terrain heights or movements along the line of sight.



Applications and Uses

Applications and Uses of TerraSAR-X

Radar image applications can be tried out with data provided in the Airbus image download area or with data which can be found in the TerraSAR-X archive:

Application	Sample Location
Agricultural Crop Type Mapping	Dessau, Germany
Change Detection	Qom, Iran
Deforestation	Pangkalan Bun, Indonesia
DEM generation	Grand Canyon, USA
Earthquake impact	Hawaii, USA. April – May 2018 InSAR stack
Flood mapping	River Sava, Serbia; Rockhampton, Australia
Glacier velocity mapping	Glacier Greenland, 4 InSAR images Feb and Mar 2018
GEOINT/IMINT	Monino, Russia
Grassland fire scar mapping	Garamba National Park, Democratic Rep. Congo; 2015 and 2016
Precise Ground Control Point extraction	Denver, USA
Land slide monitoring	Lyngenfjord, Norway
Land/water masking	South Mississippi, USA
Moving target detection	Rotterdam harbour; Singapore harbour
Object detection	Lillestroem, Norway
Oil spill detection	Gulf of Mexico, USA
Rice mapping	Ho Chi Min City, Vietnam, 2018-02 to 2018-12
Sea ice mapping and ship routing	Baffin Bay, Greenland 1 WS; Belle Isle, Newfoundland, Canada, 1 SC
Ship detection	Singapore
Surface movement monitoring	Burghan, Kuwait
Topographic Mapping	Marseille, France
Typhoon observation	Japan, 2019-09 and 2019-10, 10 images
Urban classification	Netherlands/Germany, 2018-04 to 2018-07
Water body mapping	Rockhampton, Australia; Vishakhapatnam, India

SAR Software and Radiometric Correction

Dedicated SAR software often offers the following processing steps:

- Handling of different image acquisition **modes** (generic names: stripmap, spotlight, scansar, TopSAR).
- Handling of **slant range and ground range** geometries and conversion between the two.
- **Multi-looking** the data to obtain square pixels (ground range) from rectangular pixels (slant range).
- **Radiometric correction** to beta-0, sigma-0, gamma-0 (RTC correction) using terrain information (DEM data).
- Speckle filtering and/or speckle divergence calculation
- **Conversions** between different radiometric representations of the data in magnitude, phase, amplitude and intensity displayed in power or decibel in both floating point and integer formats.
- **Exploitation of phase** information for interferometric data analysis such as CCD, DEM generation, PSI and SBAS
- **Polarimetric processing** (partially polarised data)
- Change detection (ACD, CCD)
- Data **geocoding and mosaicking** with or without using DEM information, depending on orthorectification needs.

Time Series 1

Radar images need to be acquired using the same orbit and viewing angle (incidence angle).
An image series acquired like this is called an InSAR-ready image stack.

If the images are provided as slant range images (SSC or SLC) radiometric and geometric correction should be applied aided by a dedicated SAR software so that pixel values are comparable throughout the time series.

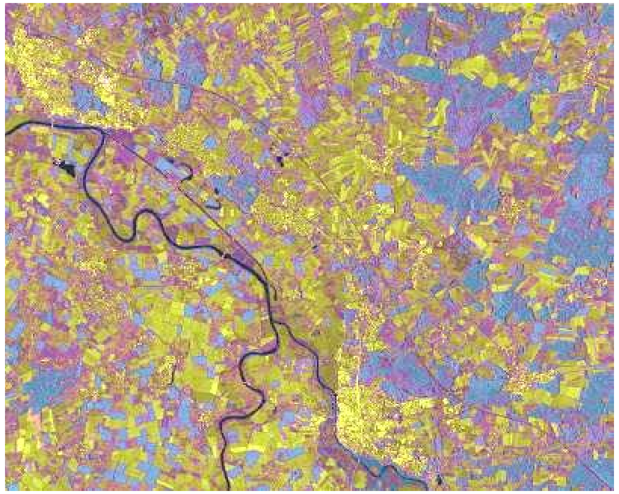
Geocoded and terrain corrected images (EEC) products can also be used for time series analysis after they are radiometrically calibrated and normalized. The preprocessed and easy to use nature of EEC images makes them a type of analysis ready data (ARD).

Applying a DEM to the data may introduce errors into the change analysis anywhere where DEM information is missing or erroneous.

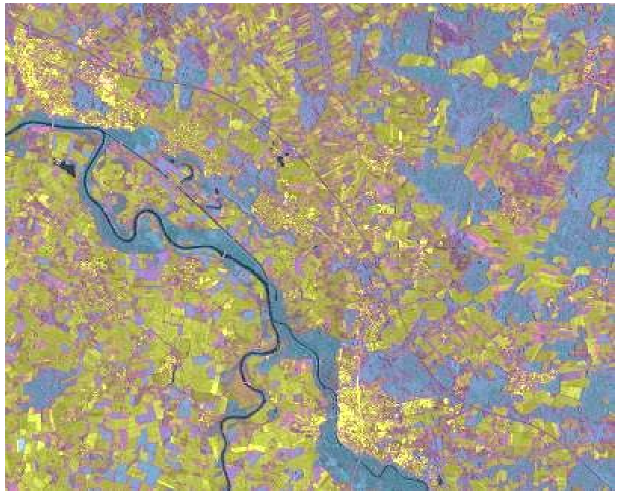
Time Series 2
Interferometric Coherence Images

In the image, interferometric coherence values range between 0 and 1. The colour scaled coherence time series below shows shades of blue, through red, to yellow where blue indicates low coherence, i.e. the images are dissimilar and unsuitable for DEM calculation or InSAR analysis. Areas of red indicate moderate similarity and yellow shows areas within the image pairs that are very similar.

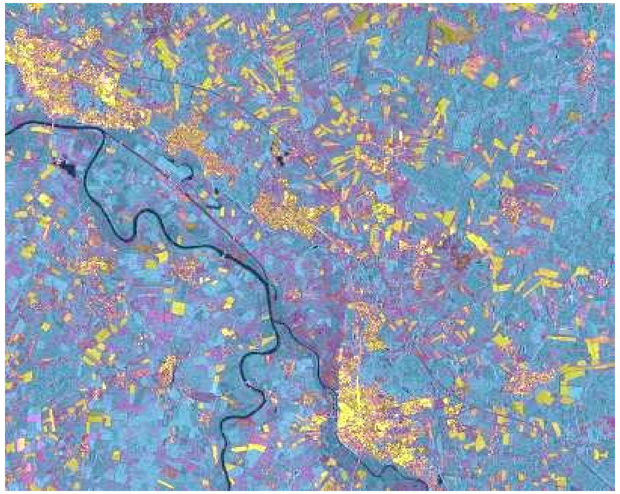
Throughout the time series, vegetation growth, snow fall and wind effects may alter the similarity of images.
Image to image coherence is a quality indicator for possible further analysis towards DEM calculation or surface movement monitoring (SMM).



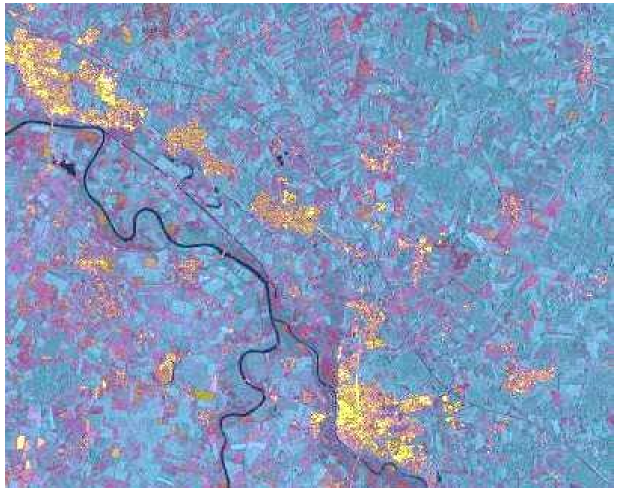
Jan 23, 2008 and Feb 3, 2008



March 3, 2008 and March 18, 2008



May 12, 2008 and May 23, 2008



June 25, 2008 and July 6, 2008

Detectable Content

Detectable Objects Properties

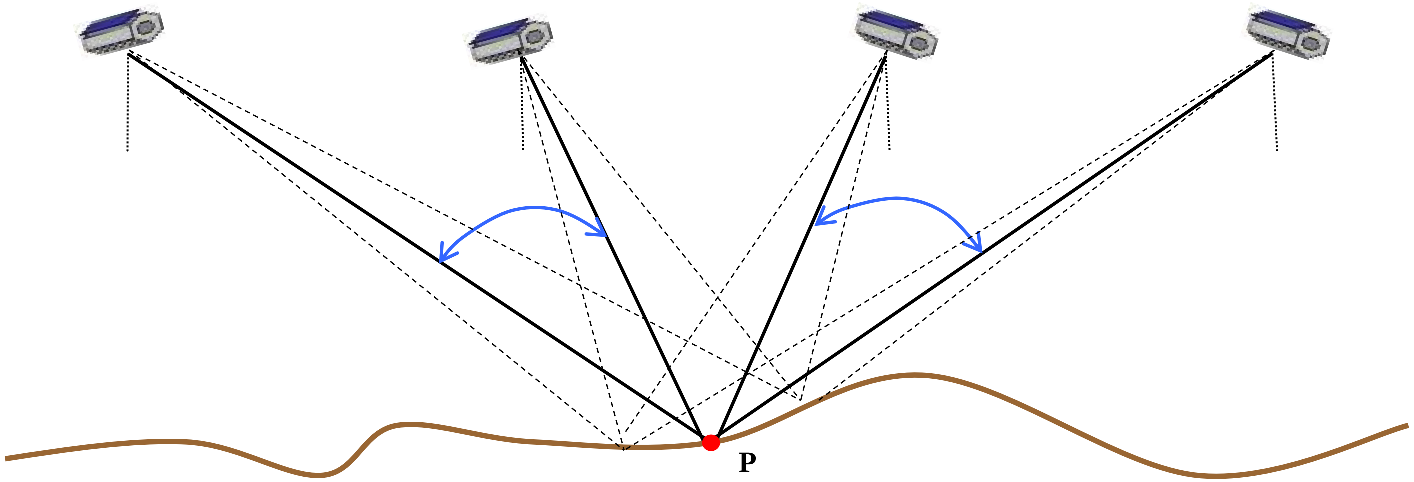
From this list of detectable object properties, a number of applications can be envisaged.

- Position of objects
- Small metal objects
- Rough/smooth surface
- Tall objects, tall vegetation
- Lattice objects
- Rounded objects
- Moving objects
- Penetration of material
- Leaf on/leaf off
- Snow/ice cover

Position of Objects

The precise position of objects can be accurately determined with radargrammetry, a technique similar to photogrammetry. Ground control points (GCPs) identify the x, y and z location of such objects. Ideally, 2-3 images are used: either 2 images from one orbit or 3 when including an image from the other orbit direction. The disparity angle between images from the same orbit direction should be approximately 20°. The accuracy of the retrieved positions is better than 1 m and dependent on the input imagery and product type chosen can be as high as 20 cm.

These highly accurate GCPs serve as an input to the orthorectification of optical imagery, which can sometimes be misplaced by 4 to 6 m from its actual position. Optical imagery is rectified by identifying the matching points in the optical imagery for each radar derived GCP.

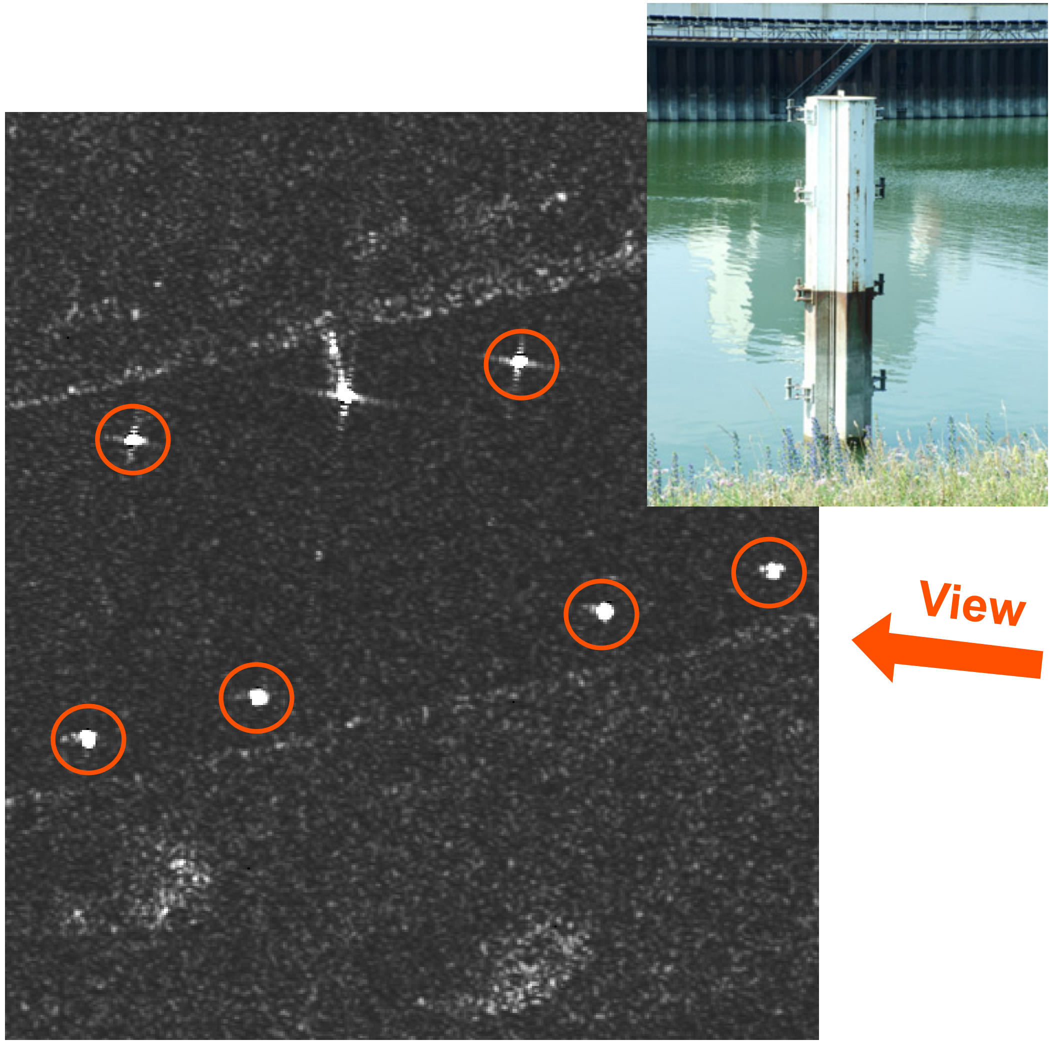


GCP imaging geometry options: at least 2 images from one orbit direction are required with 20° disparity angle (blue). Each additional image will improve point density and accuracy.

Small Metal Objects 1

Small metal objects act as perfect scatterers and can spread their strong backscattering across a number of neighbouring pixels both in range and azimuth direction. Sometimes star-like signatures are found in images, whereas sometimes only bright spots can be seen, especially in very high resolution radar images.

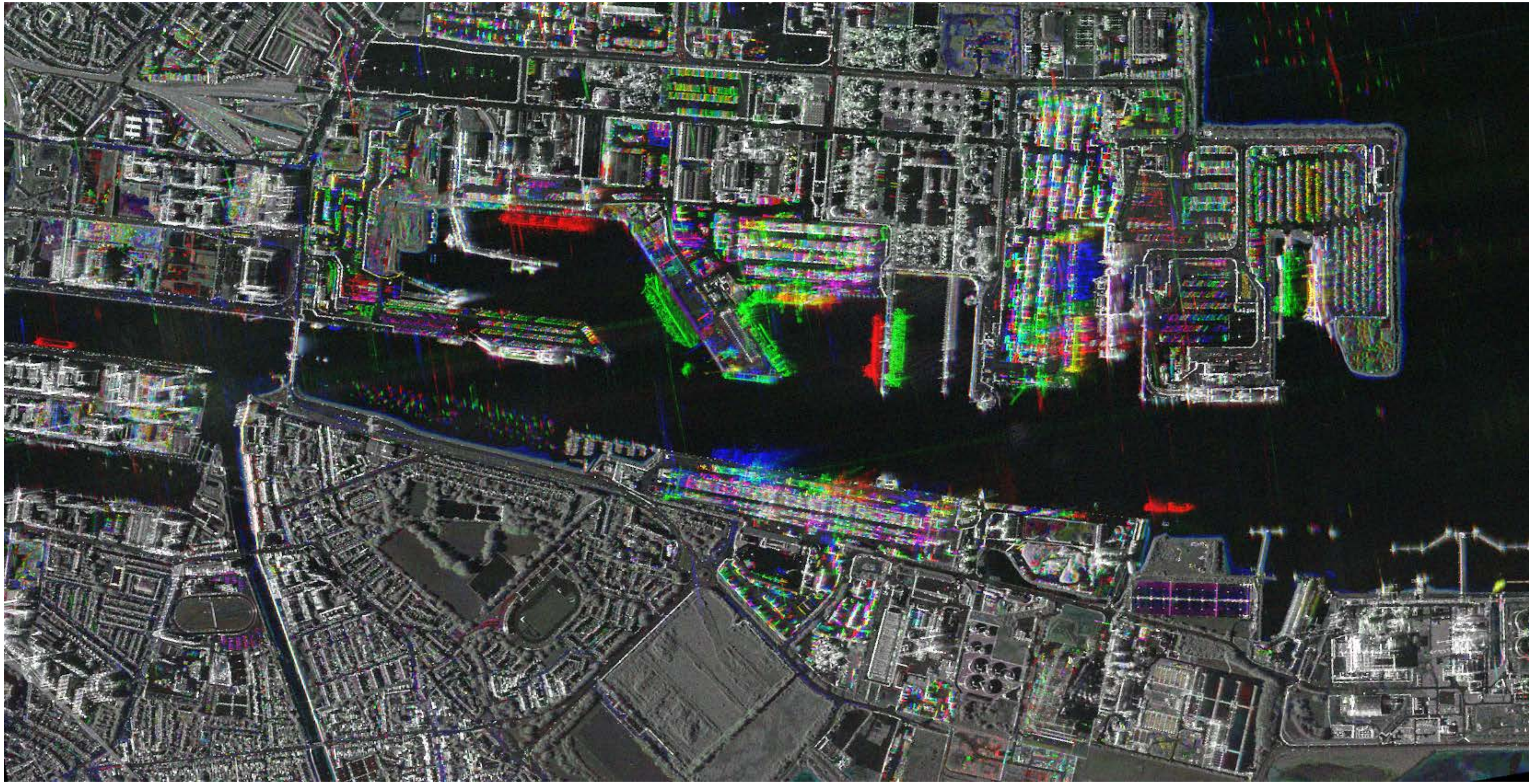
These objects can be fence posts, flag poles, streetlamps, mooring dolphin structures, ventilation systems on roof tops, small boats, and buoys.



DPL 3507 Duisport

Small Metal Objects 2

Container harbour, storage tanks and small boats in the harbour of Dublin, Ireland



Surface Roughness

TerraSAR-X radar images depict surface roughness more strongly than the penetration of materials.
The impact of differing surface roughness can best be appreciated by looking at smooth and wavy water surfaces (Svalbard images).
Roughness also applies to bare soil, rock, vegetation and manmade surfaces. If neighbouring surfaces have different surface roughness, they can be distinguished from each other.

Tall Objects

Tall objects cast a radar shadow and a layover depending on the incidence angle at which the image has been acquired.
Sometimes only parts of the object show in the layover, since the side of the tall object was rounded and thus invisible to the radar. Sometimes the shadow is incomplete due to the complicated shape of the object or the merging of the shadow with the layover of neighbouring objects.
Schwedt, Germany.

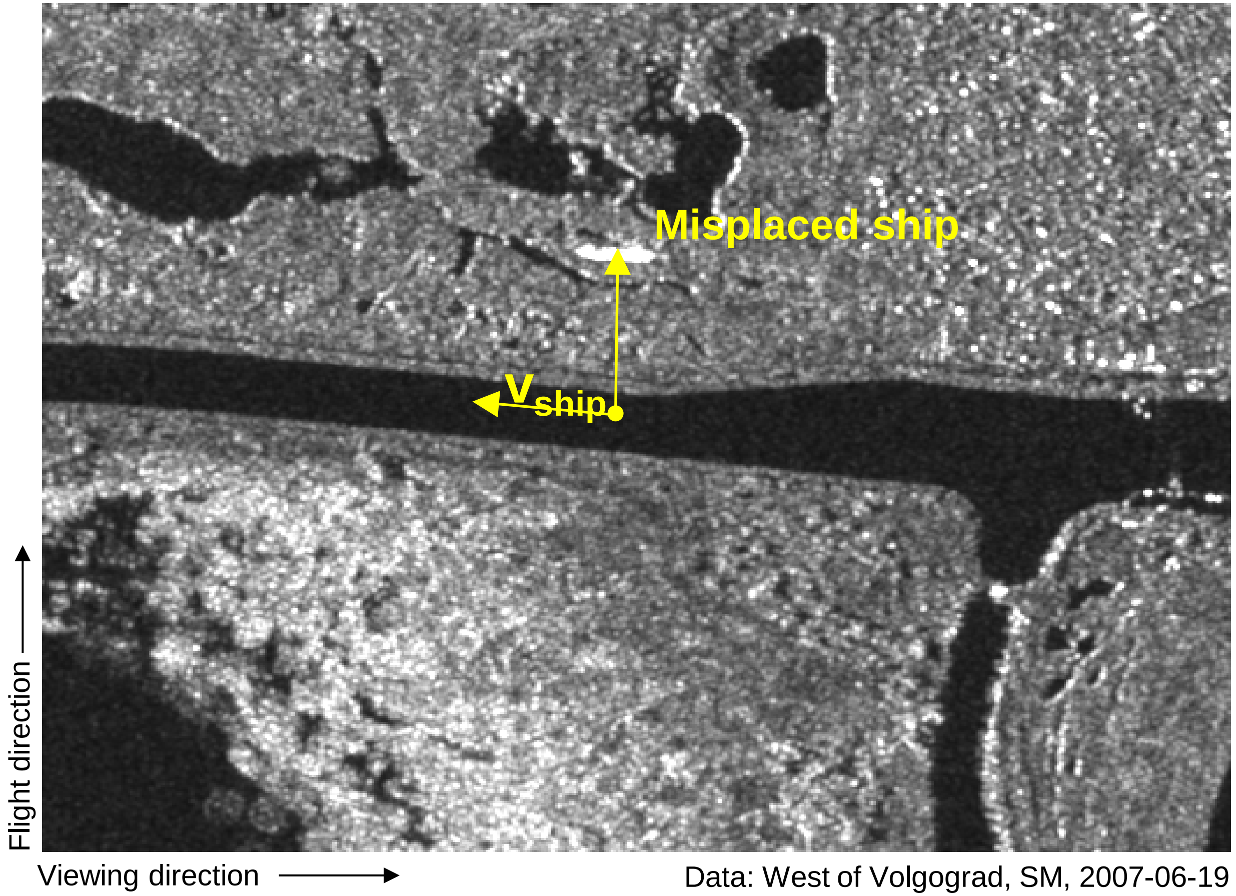
Moving Object Detection 1

There are different methods available to find moving objects in radar imagery:

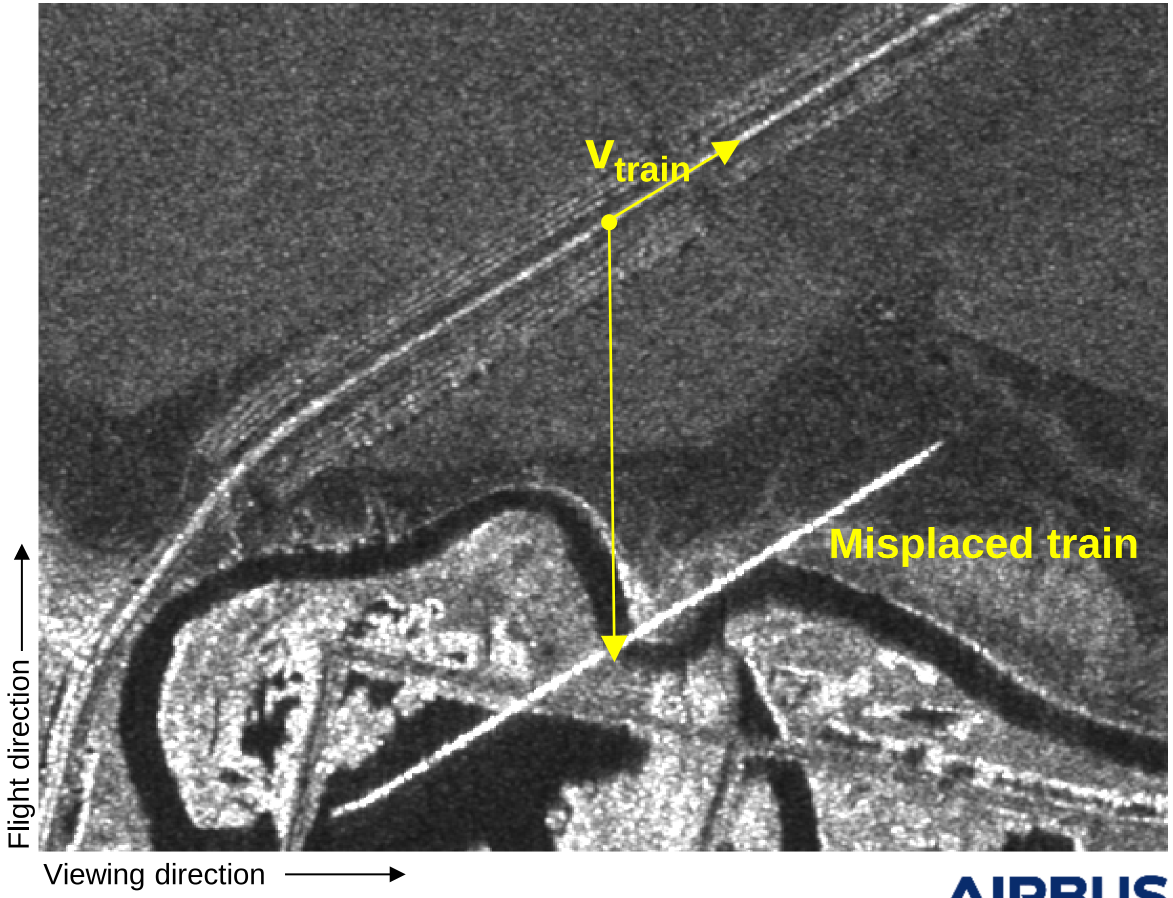
- Moving objects can be identified visually even in single images by their characteristic spatial offset and blurred appearance.
- In very high and high resolution images (Staring SpotLight and High Resolution SpotLight modes), measurements of the offset can be made to calculate the velocity of objects such as a ship or trains.
- In single Staring SpotLight or High Resolution SpotLight images, the data set can be subdivided in up to seven otherwise overlapping images of the same area. These sub-aperture images can be combined to form colour images showing, for example with “rainbow colours”, moving objects.
- Moving surfaces or objects can be monitored over time with interferometric techniques (see SMM). Movement can be measured along the line of sight using SBAS or PSI methods. For this type of time series analysis of the changing phase angle, complex data (SSC products) at medium spatial resolution data are often used, e.g. TerraSAR-X StripMap data at 3m pixel resolution.

Moving Object Detection 2

Objects moving towards the radar are misplaced in line with the satellite flight direction.
Objects travelling away from the radar are misplaced counter to the satellite flight direction.
The faster the object, the larger the misplacement.

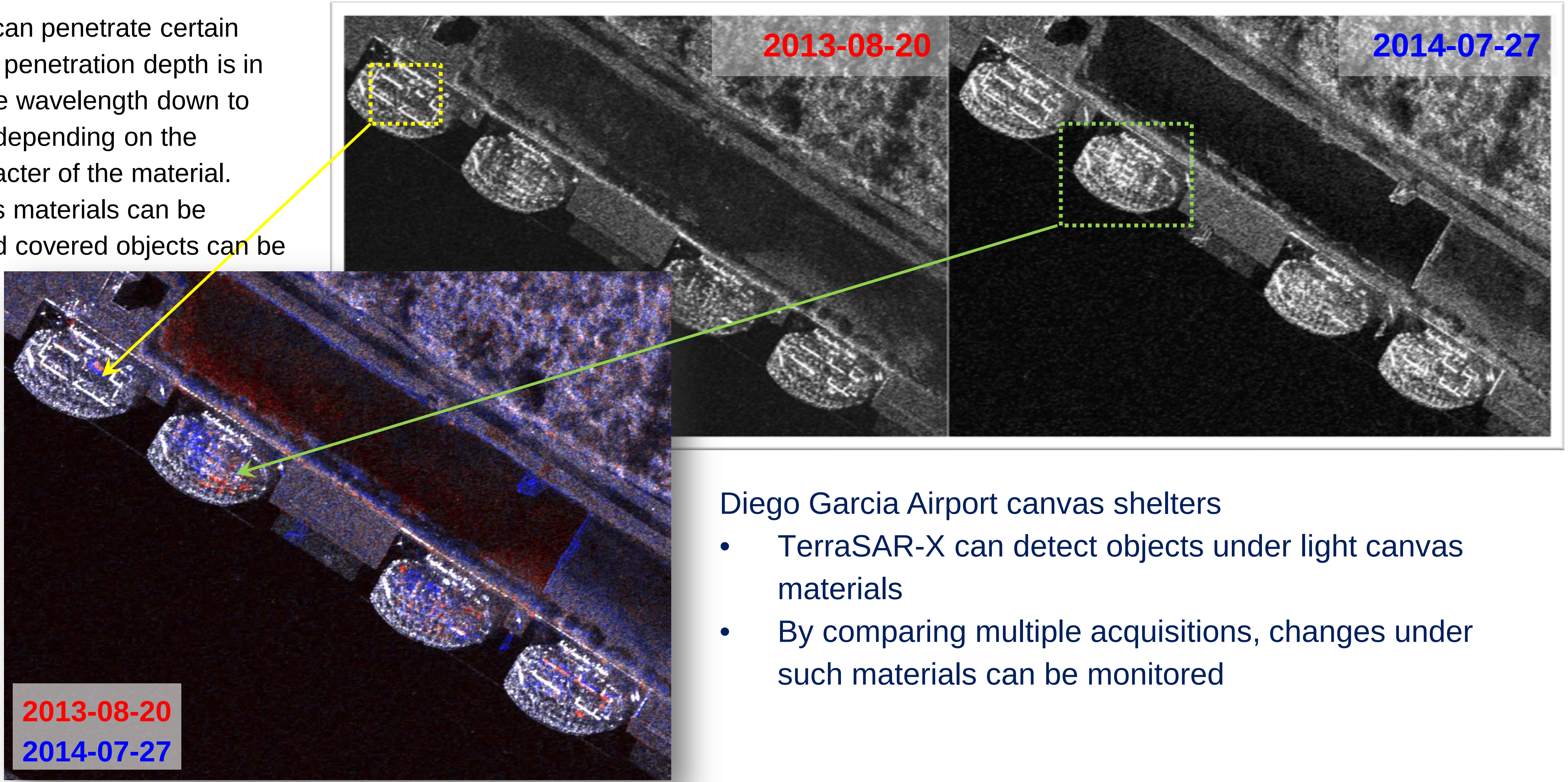


Data: West of Volgograd, SM, 2007-06-19



Penetration

Radar waves can penetrate certain materials. The penetration depth is in the order of the wavelength down to 1/wavelength depending on the dielectric character of the material. Certain canvas materials can be penetrated and covered objects can be seen.



Diego Garcia Airport canvas shelters

- TerraSAR-X can detect objects under light canvas materials
- By comparing multiple acquisitions, changes under such materials can be monitored

Leaf-on or Leaf-off Season

In temperate climates of the mid latitudes, leaf-on and leaf-off periods can be observed in radar images. Early in the year, trees look fuzzy and vegetation can hardly be captured. Later in the year, trees look more rounded and can be distinguished from surrounding objects. In the amination, the changing foliage seems like a shift among the 8 images.
Especially during image co-registration, this effect is sometimes neglected, which can lead to co-registration errors.

Animated image

AIRBUS

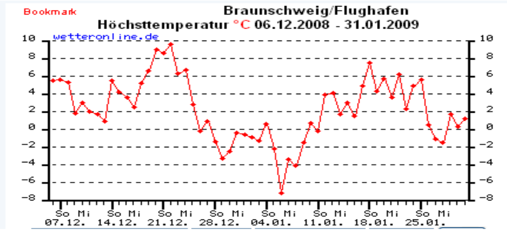
Snow in radar images

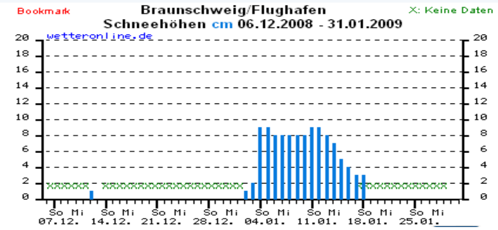
Snow is visible in two TerraSAR-X StripMap images acquired at 3 m spatial resolution.

- Grey: 2008-12-24
- Red: 2009-01-15

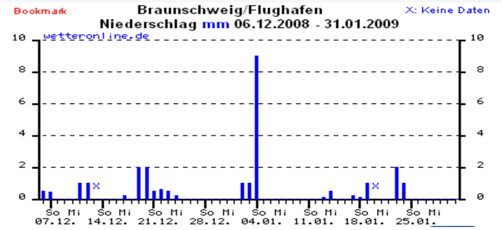
The red areas show wet snow in the lee of forest patches that dissipates across all land cover types. This shows the area is only partly covered by snow.

Temperature in degrees Highs





Snow height in cm

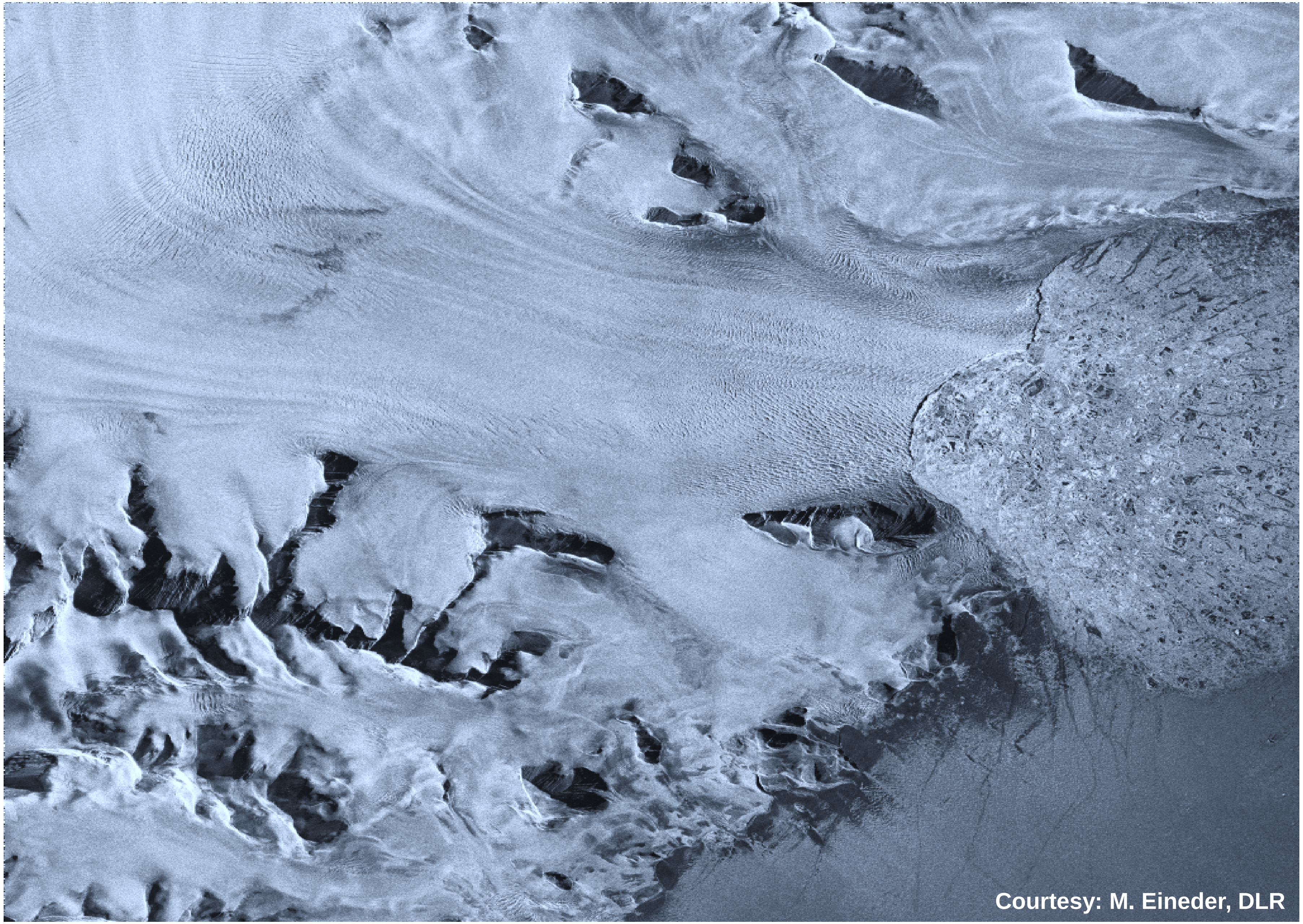


Precipitation in cm

Sea Ice

Drygalski Glacier Terminus, Antarctic
23 images from Oct 2007 to July 2008
Motion: 5.5 m per day

Brightness switches from white to black and back.
This is due to the temporary coverage with dry or wet snow.



AIRBUS

San Francisco, USA Imagery

StripMap and Staring SpotLight

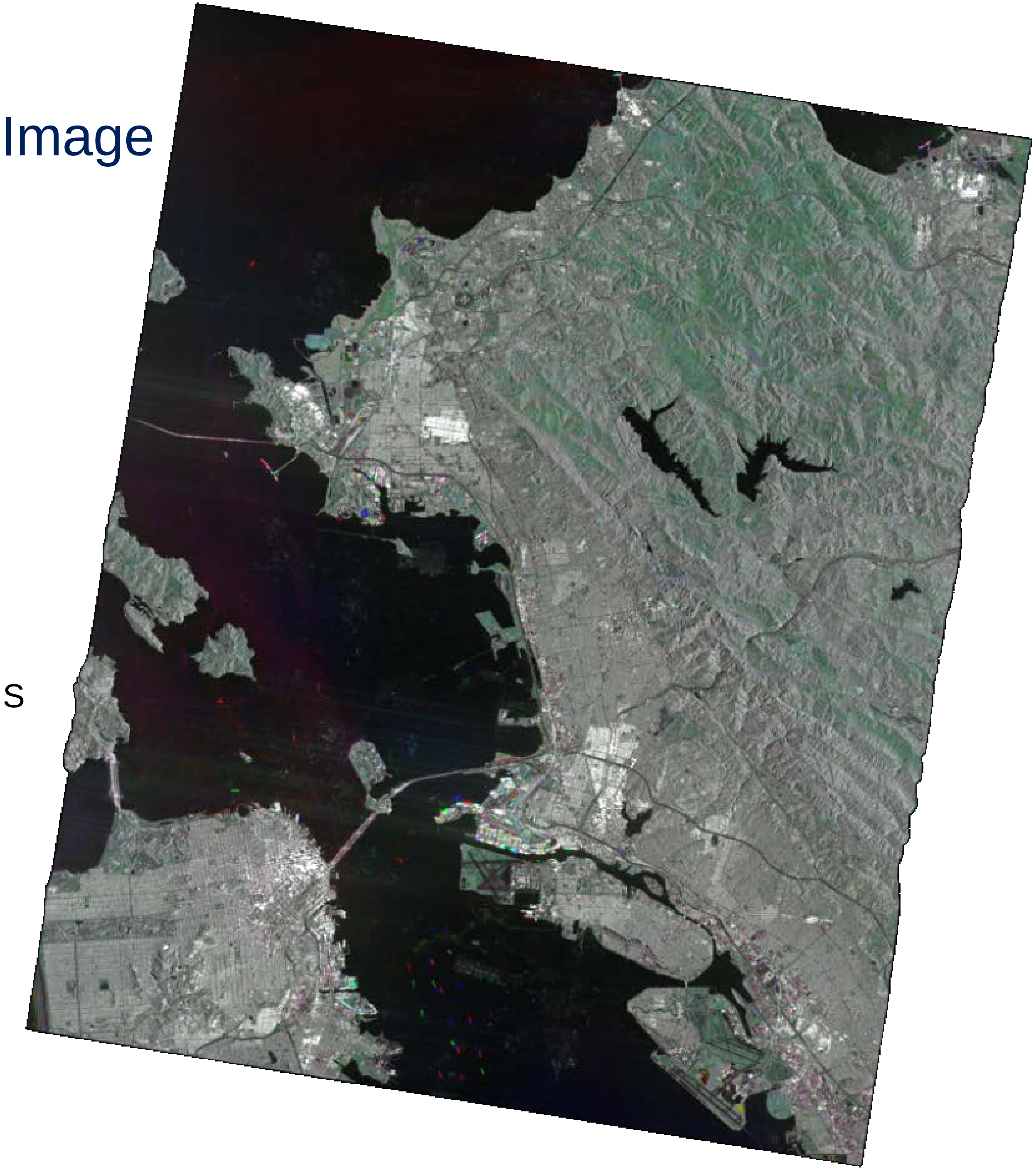
San Francisco, USA StripMap Image

TerraSAR-X StripMap repeat pass images at 3m spatial resolution of three acquisition dates can be combined to create a coloured image.

Images acquired:

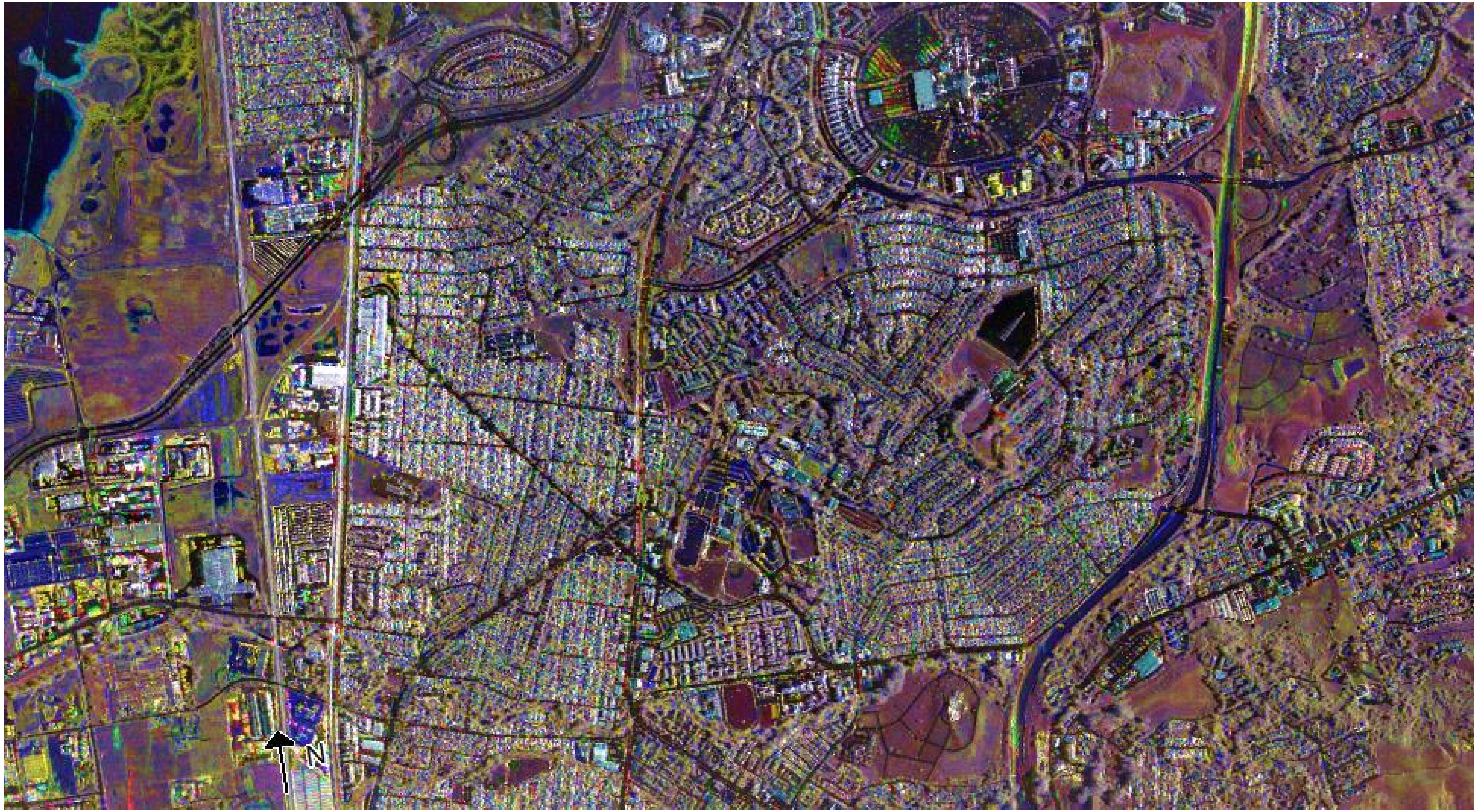
2017-12-15
2018-01-06
2018-01-28

For example, this composite can be created in a GIS by using the EEC product of the TerraSAR-X satellite family as the input data.



San Francisco, USA Staring SpotLight

Colour composite of three images over the San Pablo area near San Francisco



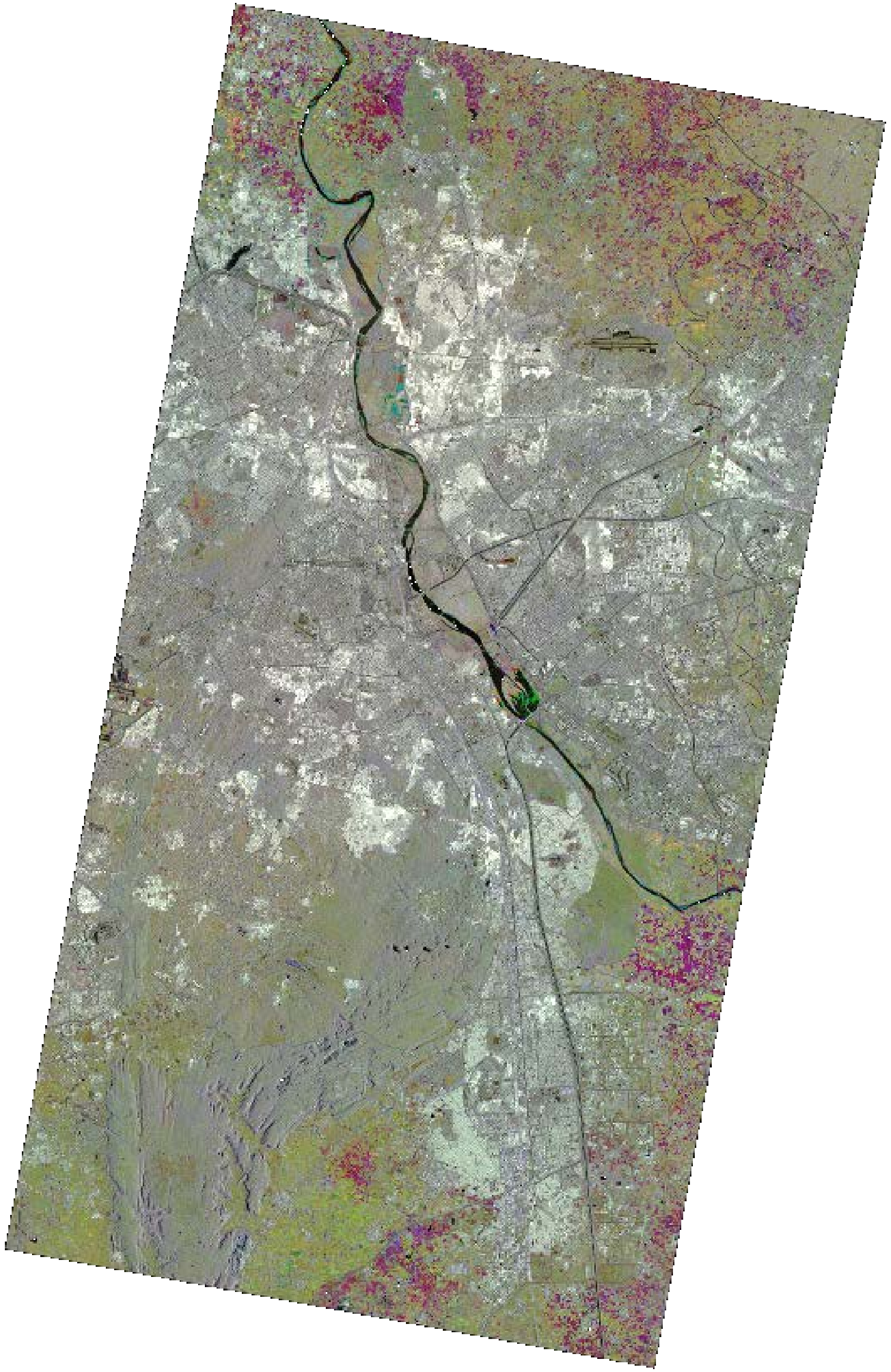
AIRBUS

Delhi, India Imagery

StripMap and Staring SpotLight

Delhi, India: StripMap Image

The image covers most of the city of Delhi, India.
Time series analysis has shown that the land is subsiding due to intense groundwater extraction for large construction projects. Railways, bridges, highways, metro bridges and tunnels are potentially affected.



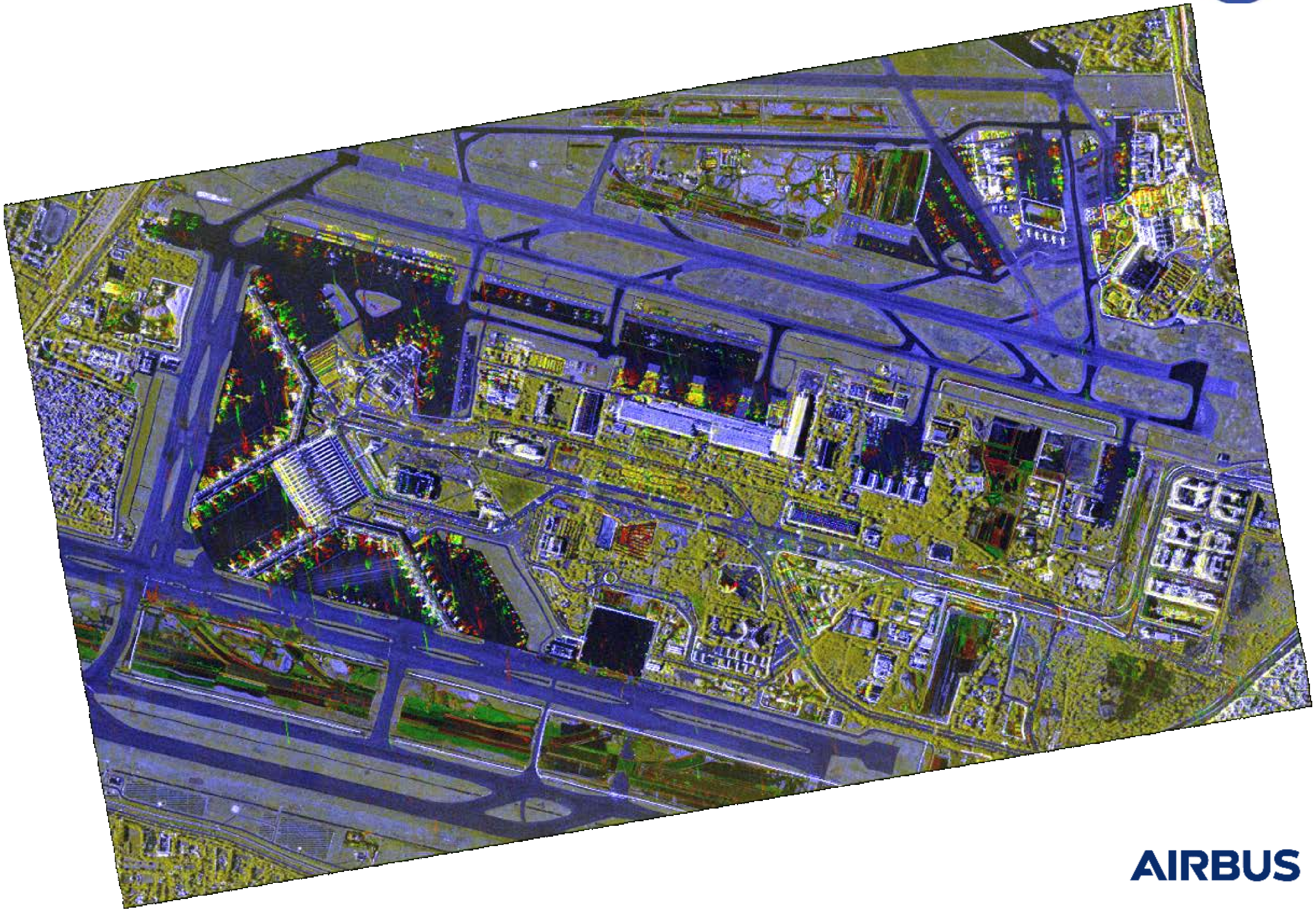
AIRBUS

Delhi, India: Staring SpotLight Image Sample Data

Indira Gandhi International Airport

Co-registered and geocoded image

Red:	Day 2 intensity
Green:	Day 1 intensity
Blue:	Coherence between day 1 and day 2



AIRBUS

Delhi, India StripMap Sample Data

Okhala Bird Sanctuary

Water body changes during 4 months in 2019

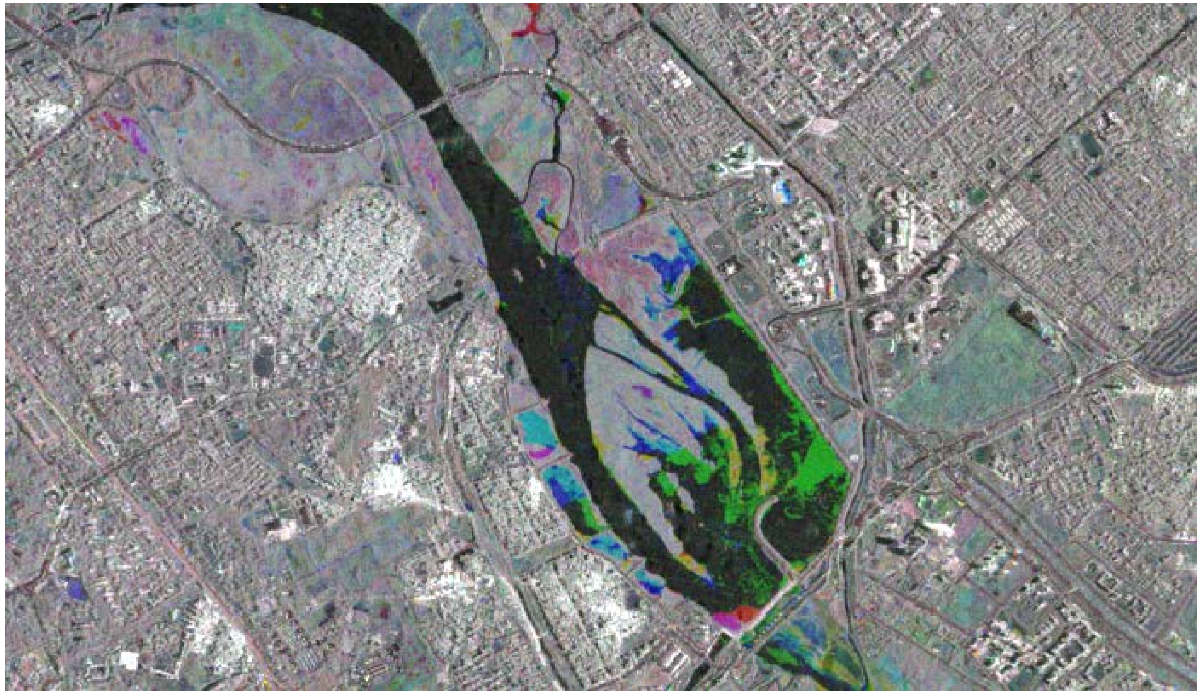
Colour composite and individual days

Red 2019-05-02

Green 2019-08-18

Blue 2019-09-22

Lat: 28.564415° N, Lon: 77.341308° E



2019-05-02

2019-08-18

2019-09-22

AIRBUS

References

Links

- **TerraSAR-X documents: almost all of the answers to any technical question:**
  https://www.intelligence-airbusds.com/en/228-terrasar-x-technical-documents

- **Level 1B Product Format Specification:**
  https://www.intelligence-airbusds.com/files/pmedia/public/r460_9_030201_level-1b-product-format-specification_1.3.pdf

- **Radiometric calibration document:**
  https://www.intelligence-airbusds.com/files/pmedia/public/r465_9_tsxx-airbusds-tn-0049-radiometric_calculations_d1.pdf

- **TerraSAR-X Archive Viewer:**
  https://terrasar-x-archive.terrasar.com/

- **WorldDEM Archive Viewer:**
  https://worlddem-database.terrasar.com/

- **Tips and Tricks, T. Fritz, DLR:**
  https://docplayer.net/12699838-Terrasar-x-products-tips-and-tricks.html

- **Slideshow:**
  http://slideshow.terrasar.com

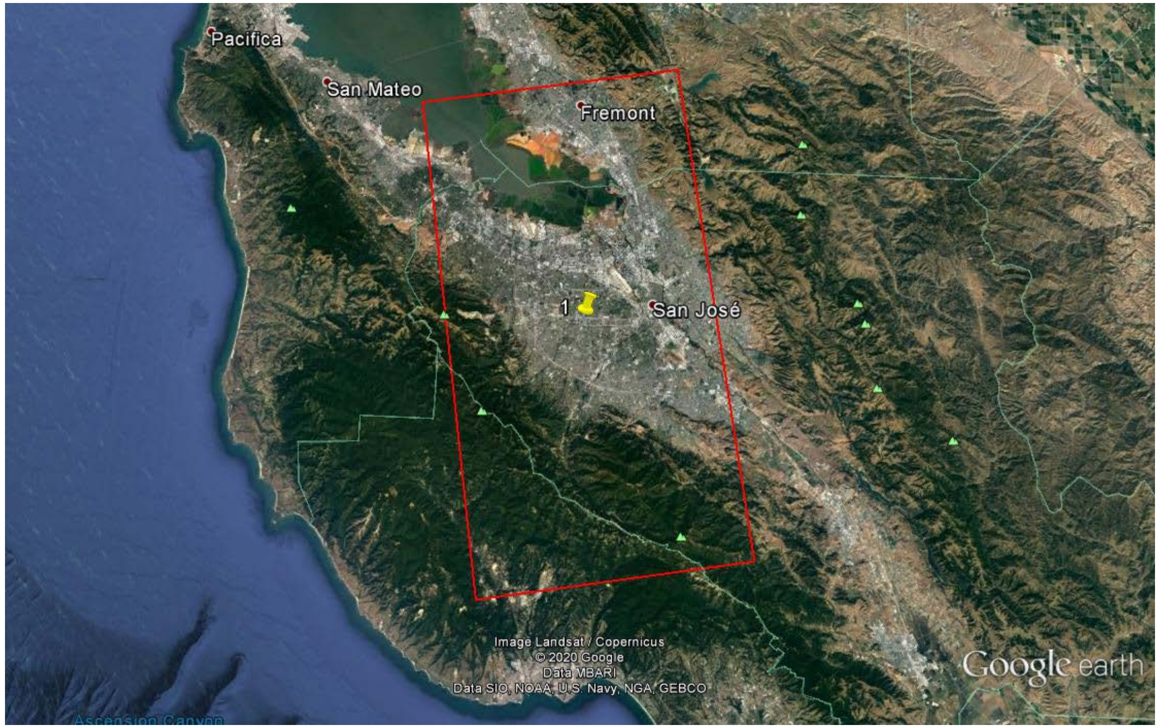
- **SMM GeoView:**
  https://smm-geoview.intelligence-airbusds.com/login/

TerraSAR-X Sample Data Stacks in Up42

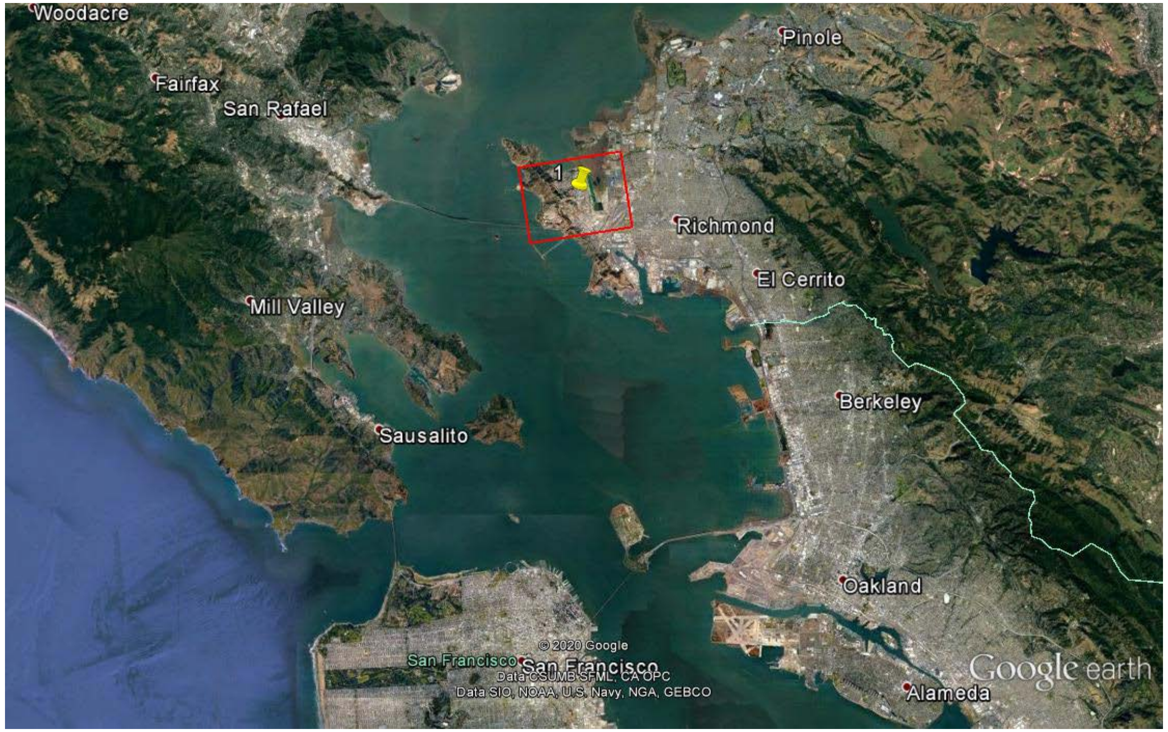
AOI	Mode	Pol	Inc. angle	Orbit directtion	Nr. of scenes per stack at campaign start [Apr 1, 2020]	Stack starting date [yyyy-mm-dd]
Silicon Valley, CA, USA	SM	HH	35°	ascending	18	2019-09-11
Richmond, CA, USA	ST	HH	47°	Ascending	2	2020-03-10
Delhi, IND	SM	HH	31°	decending	18	2019-09-22
Indira Gandhi International Airport Delhi, IND	ST	HH	43°	ascending	5	2020-02-07

AOI Silicon Valley / SF Bay Area, CA, USA

The area of interest covers Silicon Valley, San Francisco Bay Area. The time series covers both archived and new and ongoing acquisitions. Both image stacks are InSAR-ready and are provided as SSC (Advanced Analysis) and EEC products (Basic Analysis).



Silicon Valley 3m StripMap



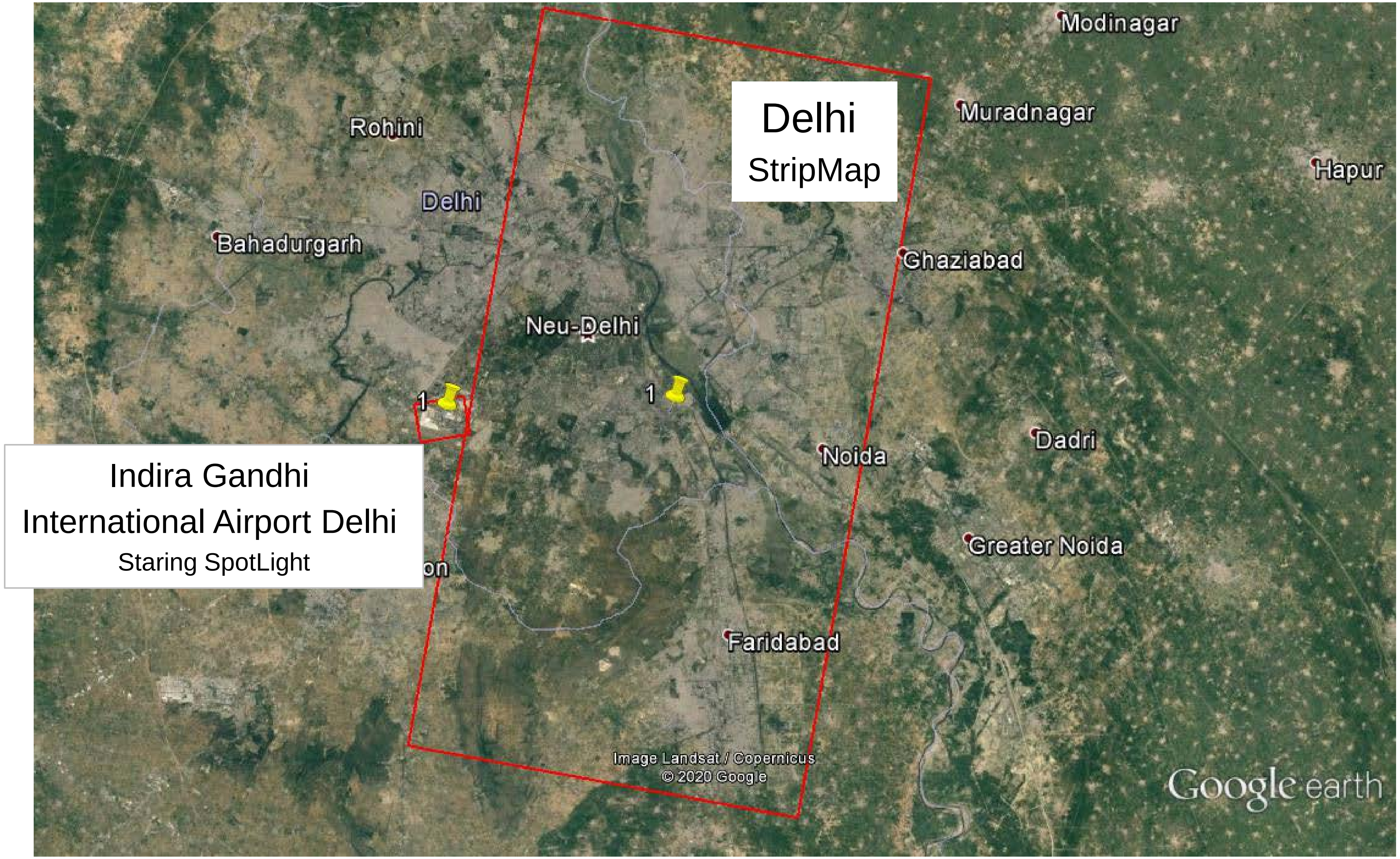
Richmond 0.25m azimuth resolution Staring SpotLight

AIRBUS

AOI Delhi, India

The area of interest over Delhi, India consists of a time series of StripMap Imagery at 3 m spatial resolution. The images are InSAR-ready and provided as SSC images, for advanced applications and as EEC product in UTM WGS84 for GIS applications.

The same image products are available as Staring SpotLIght (0.25 m azimuth resolution) for a time series starting 2020 over Indira Gandhi International Airport.



Locations of Illustrations

In this material a number of TerraSAR-X images are used to illustrate imaging effects

Location	Latitude	Longitude
Panama	8°59'41.95"N	79°35'24.64"W
Baltimore, MA, USA	39°16'40.53"N	76°37'21.59"W
San Pablo, CA, USA	37°58'15.64"N	122°20'10.39"W
Tenerife, Spain	28°18'23.15"N	16°32'20.13"W
Demmin Germany	53°53'45.07"N	13°11'51.52"E
Okhala, India	28°33'29.75"N	77°18'23.21"E
Svalbard, Norway	76°55'48.51"N	15°45'13.12"E
Oberpfaffenhofen, Germany	48°4'50.96"N	11°17'9.77"E
Salzgitter, Germany	52° 7'1.36"N	10°24'17.59"E
Diego Garcia, UK	7°18'51.90"S	72°25'10.42"E
Duisport, Germany	51°27'10.57"N	6°45'25.74"E
Tokyo, Japan	35°40’19.14’’N	139°47’3.39’’E
Port Hedland, Australia	20°18'30.18"S	118°33'39.52"E
Eiffel Tower, Paris, France	48°51'28.49"N	2°17'41.69"E
Mount Agung, Indonesia	8°20'17.10"S	115°31'9.91"E

Thank you

SAR for Beginners:
Technical Terms and Abbreviations

A

ACD	Amplitude Change Detection; a method to highlight changes in the area caused by changed roughness or dielectric characteristics of the objects. Often displayed as **red has fled, blue is new**.
Acquisition	Recording of a data set at the satellite to later create an image by use of SAR raw data processing
Additive colour mixing	red + blue: magenta, red + green: yellow, green + blue: yellow, red+green+blue: white; no colour in either band: black
ADMSAR	Value added product from TerraSAR-X; Ascending/Descending orbit merged image to get rid of layover and shadowing, i.e. missing pixels.
Amplitude	Strength of backscattering; DN in the image data set; amplitude squared equals the intensity.
Ascending	Orbit direction coming from south east, travelling towards northwest
az	Azimuth resolution
Azimuth compression	SAR raw data processing step; deconvolve a known illumination chirp function. Performed on each column of previously range-compressed, range-migrated data.
Azimuth resolution	Pixel dimension in flight direction of the satellite. For TerraSAR-X it is typically less than the range resolution. Note the special case of staring spotlight mode, where overlapping looks of the forward and backward staring radar antenna are used to obtain a finer spatial resolution
Azimuth	Flight direction; along track direction of the satellite.

B

B	bandwidth of the chirp pulse which is used by the radar antenna (150 MHz or 300 MHz of TerraSAR-X satellites)

Backscatter component	Portion of the total scattered energy, that goes back to the radar antenna. Portion will be scattered away from the radar as well.
Backscattering	The process of scattering the incoming radar energy back towards the radar antenna. It's strength is modified by the roughness of the object and it's dielectric characteristics.
Band	A range of frequencies which are labelled X, C, L, P, Ku, Ka etc. by the IEEE (Institute of Electrical and Electronics Engineers)
Bandwidth	A measure of the span of frequencies available in the signal or passed by the band limiting stages of the system. Bandwidth is a fundamental parameter of any imaging system and determines the ultimate resolution available.
Baseline	a) temporal baseline: how far are the interferometric images apart in terms of days, b) spatial baseline: how far are the interferometric images apart in terms of spatial distance of the antennas.
Beta-nought	ß°, radar brightness coefficient. The reflectivity per unit area in slant range which is dimensionless
Blooming	Strong scatterers may appear over bright in the image, due to their strong directional backscattering towards the antenna. Use Dynamic Range Adjustment, brightness and contrast or gamma controls to see different enhancements of the image on screen.
Blurring	Due to the motion of an object, it is detected by the radar as blurred.
Bragg scattering	Enhanced backscattering due to the interaction of the cm wave with surface structure in the same order of magnitude (e.g. corrugated sheet metal roof versus 3 cm X band waves). Reference: ESA document

C

C band	roughly 5 cm wavelength SAR, available from the European Sentinel-1 A and B, 5 m azimuth resolution, 20 m range resolution.
c	speed of light 299,792,458 meters per second or approximately 300,000 km/s (186,000 mi/s) at which a radar wave is travelling to or from a target on the ground.
Cardinal effect	Enhanced backscattering if the object is direct perpendicular to the radar viewing direction.
CEOS	Committee on Earth Observation Satellites. A consortium of roughly 60 agencies.

CCD	Coherence Change Detection using InSAR-ready data or SSC products.
Chirp	Radar pulse
Coherence image	An interferometric image pair can be used to calculate the similarity between the images. Coherence runs from -pi … +pi. Low coherence/similarity is reached at 0.0, high coherence is reached at 1.0. The lower the coherence, the less reliable the interferogram and thus any retrieved DEM or surface movement values.
Coherence	Coherence is the fixed relationship between waves in a beam of electromagnetic (EM) radiation. Two wave trains of EM radiation are coherent when they are in phase. That is, they vibrate in unison. In terms of the application to things like radar, the term coherence is also used to describe systems that preserve the phase of the received signal.
Complex number	For radar systems, a complex number implies that the representation of a signal, or data file, needs both magnitude and phase measures. In the digital SAR context, a complex number is often represented by an equivalent pair of numbers, the real in-phase component (I) and the imaginary quadrature component (Q). For coherent systems such as SAR, the role of complex numbers is an essential part of the signal, since signal phase is used in the processor to obtain high-resolution. Reference: ESA document
Corner reflector	Ideal shape and material to result in the maximum backscattering of the transmitted wave. Used for geometric and radiometric calibration of a radar antenna. See dihedral and trihedral corner reflectors.

D

Decomposition	Subdividing the radar signal into its backscattering components using the theory of polarimetry. Polarimetric decomposition methods: ESA document
DEM	Digital elevation model, which can be a DTM (bare ground) or a DSM (top of everything)
Depolarisation	The transmitted polarisation cannot be measured, since the polarisation plane was modified upon the interaction with the object. The polarisation state of an electromagnetic wave can change when the wave scatters from a target. Depolarisation is a measure of the change in the degree of polarisation of a partially

	polarised wave upon scattering. For example, a target may scatter a wave with a greater degree of polarisation than the incident wave, in which case the depolarisation is negative. Depolarisation is also used to indicate spatial or temporal variation of the degree of polarisation for a completely polarised wave. (source: ESA)
Depression angle	Depression angle usually refers to the line of sight from the radar to an illuminated object as measured from the horizontal plane at the radar.
Descending	Orbit direction; travelling from north east towards southwest
Dielectric properties	The complex dielectric constant is a measure of the electric properties of surface materials. It consists of two parts (permittivity and conductivity) that are both highly dependent on the moisture content of the material considered. In the microwave region of the electromagnetic spectrum, most natural materials have a dielectric constant between 3 and 8, in dry conditions. Water has a high dielectric constant (80), at least 10 times higher than for dry soil. As a result, a change in moisture content generally provokes a significant change in the dielectric properties of natural materials; increasing moisture is associated with an increased radar reflectivity. The electromagnetic wave penetration in an object is an inverse function of water content. In the specific case of vegetation, penetration depth depends on moisture, density and geometric structure of the plants (leaves, branches). (Source: ESA) Note that surface roughness effects may prevent the wave from penetrating into the soil/material.
Diffuse scattering	Radar wave scattering in multiple direction. Compared to the transmitted energy, the portion of the energy which reaches the antenna upon backscattering is reduced. Rough surfaces act as diffuse scatterers.
Dihedral corner reflector	Two planes are joint at 90° angle. A perfect scatterer used for geometric or radiometric calibration.
Disparity angle	angle between the ascending and the descending image which is used for radargrammetry (3-d exploitation of radar images to generate a digital surface model or a digital terrain model)
DLR	Deutsche Forschungsanstalt für Luft- und Raumfahrt.
DN	Digital number in an image. 8 bit = 2^8: 0…255, 16 bit = 2^{16} : 0…65,535
Doppler frequency	The Doppler frequency depends on the component of satellite velocity in the line-of-sight direction to the target. This direction

	changes with each satellite position along the flight path, so the Doppler frequency varies with azimuth time. For this reason, azimuth frequency is often referred to as Doppler frequency. (Source: ESA)
Double bounce	Backscattering effect caused by the corner reflector between the front wall of the building and its surrounding ground area. This leads to an enhanced backscattering.

E

Elevation angle	The angle measured between nadir and the radar beam.
Enhanced Ellipsoid Corrected or	**EEC** image product for whose generation a digital terrain model has been applied. Delivered as UTM, WGS84 map projection and ellipsoid.
Extended range return	see multipath propagation

F

far range	Far end of the image in range.
fD	Doppler frequency
Footprint	illuminated area on the ground, resulting in the image size after radar raw data processing into the four basic products
Foreshortening	Abbreviated length of a slope facing the radar due to the applied incidence angle.
Frequency	Number of oscillations per unit time or number of wavelengths that pass a point per unit time. This is the rate of oscillation of a wave. In remote sensing, this term is most often used with radar. The frequency bands used by radar (radar frequency bands) were first designated by letters for military secrecy. In the microwave region, frequencies are on the order of 1 GHz (Gigahertz) to 100 GHz. ("Giga" implies multiplication by a factor of a billion). For electromagnetic waves, the product of wavelength and frequency is equal to the speed of propagation, which, in free space, is the speed of light. * In the microwave region, frequencies are on the order of 0.3 GHz-300 GHz, having wavelengths of 1 mm - 1 m respectively. (Source: ESA)

G

Gain	Antenna gain describes how well the antenna converts input power into radio waves headed in a specified direction.

Gamma-nought	Radiometric calibration of backscattered energy by using the brightness (beta-nought) and by multiplying it by the tangent of the local incidence angle which can be obtained from the incidence angle mask. This representation is best for mosaicking images taken at different incidence angles but the same orbit direction.
GCP	Ground control points retrieved from radar images which are used to orthorectify other satellite imagery.
Geocoded Ellipsoid Corrected	**GEC** is the Geocoded and Ellipsoid corrected image, which has square pixels and has been multi-looked, but which is not orthorectified.
Geometric resolution	It determines the size of objects which can be shown in an image. Distinguish between slant range along the line of sight and ground range resolution of detected images (projected to the ground). Range resolution is determined by the transmitted pulse width. Azimuth resolution depends on the length of the antenna.
GHz	Gigahertz, frequency, in which radar antennas are operated.
Global Incidence angle	Rough incidence angle in degrees given for the image centre or the near range and far range edges of the image (1st range line, last range line of the image).
gr	ground range
Grazing angle	Calculated 90 degrees minus the incidence angle.
Ground range	Line of sight projected on the ground in the so-called detected image (MGD, GEC and EEC products).

H

Height above ground	Height of the satellite in space given in kilometres and refers to the ground track of the satellite.
HH	Horizontal polarisation upon transmission and reception of the electromagnetic wave. It can be delivered as one 16 bit raster image. It can be combined with other polarisation images to create a colour composite.
HH+VV	Two polarisation images added up by band maths to create and image plane for the joint display with other layers.
HRWS	High Resolution Wide Swath satellite mission to follow TerraSAR-X family satellites

HS	High Resolution SpotLight imaging mode of TerraSAR-X family satellites, roughly 1m resolution and 10 km x 10 km coverage.
HS300	Former name of HS mode
HV	Horizontal polarisation upon transmission and vertical polarisation upon reception of the electromagnetic wave. It can be delivered as one 16 bit raster image. It can be combined with other polarisation images to create a colour composite.

I

ILU image	Colour image in Red, Green, Blue created from interferometric coherence, average intensity of the two acquisitions, intensity change between the two acquisitions. ESA document
Image tone	Grey value of the image at each pixel or DN. Sometimes called brightness.
Imaging mode	SAR antenna setting to retrieve a certain spatial resolution, spatial coverage and polarisation. Imaging modes of TerraSAR-X are: ST, HS, SL, SM, SC and WS.
Incidence angle	a) global incidence angle, b) local incidence angle modified by the underlying terrain (angle between surface normal and incident beam). The local incidence angle can be retrieved for each pixel by illuminating a terrain model by use of the radar geometry.
Inphase	The real component of the signal that has the same phase as the complex reference frequency. In-phase is represented by the constant I. See Complex Number (Source: ESA)
InSAR pair	An image pair which is consistent in orbit direction, incidence angle and polarisation.
InSAR	Abbreviation for SAR-interferometry, a method to compare image pairs or time series of images.
Intensity	Measured backscattered amplitude squared which is used to display the image by some software packages. Some full resolution radar imagery are delivered as intensity data rather than amplitude data.
Interferometry	A method to retrieve 3-D surface information of interferometric image pairs (consistent in orbit direction (e.g. all ascending), polarisation (e.g. all HH) and incidence angle (e.g. all 35 degrees). This method works in arid areas without any vegetation. A technique that uses the measured differences in the phase of the return signal between two satellite passes to detect slight changes

	on the Earth's surface. The combination of two radar measurements of the same point on the ground, taken at the same time, but from slightly different angles, to produce stereo images. Using the cosine rule from trigonometry to calculate the distance between the radar and the Earth's surface, these measurements can produce very accurate height maps, or maps of height changes. Mapping height changes provides information on earthquake damage, volcanic activity, landslides, and glacier movement. (Source: ESA)
IR sensor	Remote sensing sensor operated in the infrared region of the electromagnetic spectrum. 780 nm - 1400 nm.

L

L	Length of the Antenna
Layover	Tall objects illuminated by the radar seem to fall towards the radar. The length of the layover can be measured in a geocoded image and can be used to calculate the height of an object by multiplying it by the tangent of the incidence angle at that point (the incidence angle at image centre may serve as a simplification).
Local Incidence angle	The angle measured between the surface normal and the radar beam. It can be determined for every pixel by the help of a DEM and the radar viewing geometry. It is provided as an additional layer with the EEC product in shape of the GIM file.
Looks	Radar terminology refers to individual looks as groups of signal samples in a SAR processor that splits the full synthetic aperture into several sub-apertures, each representing an independent look of the identical scene. The resulting image formed by incoherent summing of these looks is characterised by reduced speckle and degraded spatial resolution. The SAR signal processor can use the full synthetic aperture and the complete signal data history in order to produce the highest possible resolution, albeit very speckled, single-look complex (SLC) SAR image product. Multiple looks may be generated by averaging over range and/or azimuth resolution cells. For an improvement in radiometric resolution using multiple looks there is an associated degradation in spatial resolution. Note that there is a difference between the number of looks physically implemented in a processor, and the effective number of looks as determined by the statistics of the image data. (Source: ESA)
LOS	Line of sight; along the radar beam.

M

MCSAR	Mosaicked SAR images which are radiometrically balanced and have seamlessly been composed.
MHz	Megahertz; unit in which bandwidth is measured
MMU	Minimum Mapping Units; smallest detectable area
Mode	Setting of the satellite for a specific spatial resolution and spatial coverage.
MTC image	Colour composite of the amplitude of day 2 on red, the amplitude of day 1 on green and the coherence image on blue. Depending on the applied software package, the order of bands may differ.
MTD	Moving target detection e.g. based on subaperture decomposition.
Multilook Ground Range Detected or **MGD**	image which is a detected image (projected to the Earth's surface) and which has a general placement coordinate on Earth but which is not fully geocoded yet. It saves disk space as opposed to the GEC and EEC which contain black wedges around the edges due to the rotation of the image.
Multilooking	A method to reduce speckle in the image during the conversion of rectangular slant range pixels to squared ground range pixels. In the conversion to ground range, images can either be optimized for spatial resolution (less looks, more speckle, clearer contours) or for radiometric resolution (more looks, less speckle, blurrier impression).
Multipath propagation	see multiple bounce
Multiple bounce	Also called multipath propagation. Multiple interactions of the incoming radar wave with objects and surfaces, e.g. inside a lattice mast or the open hull of a vessel. The echoes from the multiple bounces have a prolonged path to travel and are thus placed in the far range of the actual object.

N

Nadir	Vertical below satellite resulting in the satellite track on the ground
Near range	Image edge in range direction which is closer to the satellite track.
NIR	Near Infrared part of the electromagnetic spectrum
Noise	Additive noise overlying the radar image caused by thermal conditions of the satellite in space.

Normal brightness	The normalised measure of the radar return from a distributed target is called the backscatter coefficient, or sigma nought, and is defined as per unit area on the ground.
NRT	Near real time delivery. Up to 6 hours after acquisition to the sftp pickup point. Geometric correction relies on the RAPID orbit calculation.

O

Odd bounce scattering	Also called single bounce scattering from plates or spheres.
OISAR	TerraSAR-X value added subset of an image or Oriented Image.
ORISAR	Orthorectified TerraSAR-X image based on the geocoding using the scalable W42 DEM data base of DLR.

P

Pauli image	Displaying image layers created with band maths on Red, Green and Blue. HH-VV on Red to show even bounce returns, HV+VH on Green to show 45 degree tilted bounce effects, HH+VV on Blue to show odd bounce effects.
Penetration	Radar waves can penetrate into a material, since their wavelength is in the order or centimetres or tens of centimetres. The penetration depth depends on the dielectric properties of the volume. If the material is dry, the wave can penetrate deeper into the material and may show obscured objects (canvas material penetration; dry sand penetration).
Perfect scatterer	An ideal backscatterer, e.g. a trihedral corner reflector which return 99% percent of the transmitted energy back to the antenna. Small metal objects (dolphins to moor ships, fence posts, corner reflectors can be perfect scatterers. Their energy is spread out over the adjacent pixels in both azimuth and range direction, sometimes with strong side lobes. Small metal objects, smaller than the pixel size, are well recognized.
Permeability	Measure of the resistance of a material against the formation of a magnetic field. It also determines the dielectric constant of a material.
Permittivity	Measure of the electric polarizability of a dielectric material. It also determined the dielectric constant of a material.

Perpendicular specular return	Another expression for the cardinal effect. Direct return back to the radar from ideally oriented objects which are directly facing the radar.
Phase	The position of a point in time (an instant) on a waveform cycle: expressed in degrees or -pi to +pi. Part of a complex SAR product (SSC or SLC). One phase image by itself is not useful. Only the phase difference between two interferometric images can be used to calculate the phase coherence or interferogram which is then used to a) calculate the DEM or b) to calculate the surface displacement (By differential interferometry, SBAS, PSI or other methods).
POL	Petrol, Oil or Lubricant tanks.
Polarisation	The process of confining the vibrations of the magnetic, or electric field, vector of light or other radiation to one plane (Source: ESA). HH, VV, VH or VH images represent a certain combination of transmit and receive polarisations and form one image each.
PRED	Predicted orbit calculation for positional correction of the radar image
PRF	Pulse Repetition Frequency; 2.2 KHz – 6.5 KHz depending on imaging mode
PSI	Persistant scatterer interferometry. A method to calculate surface displacement.

Q

Quadrature	The signal component that is 90° out of phase with respect to the reference frequency. It is represented by the letter Q. It is the imaginary part, which indicates the magnitude of the signal, of the complex number. See Complex Number.

R

R	Range distance
Radar	Radio Detecting and Ranging
Radar equation	Basic formula, which describes the received power at the antenna. $P_r = (P_t*G*\sigma)/((4\pi)^2*R^4)$. P_t transmit power [W], G gain, σ radar cross section [m²], R range distance [m].
Radargrammetry	A method to create a 3-D model of the Earth's surface even if vegetation is present.

Radiometric resolution	The different amplitudes A (A^2= Intensity) which occur in the image. The histogram of the 16 bit amplitude image shows the gray value distribution. Distinguish between the theoretical radiometric resolution and the measured radiometric resolution in the image. The radiometric resolution depends on the SNR and the number of looks.
Radiometrically enhanced	RE Image has been optimized for the maximum radiometric resolution on the cost of spatial resolution to gain square pixels from the initial rectangular radar pixel. This type of enhancement is important for any retrieval of quantitative information or relation of time series images, e.g. in thematic image classification.
Range compression	SAR raw data processing step; deconvolve a known chirp function. Performed on each radar echo.
Range direction	Across flight track direction; 90 degrees across from azimuth direction.
Range resolution	Spatial resolution in range direction, which depends on the incidence angle. It is getting finer, the further away from the radar.
Range	Side looking distance of the radar
Range/Doppler coordinates	In a slant range image, the positions of each pixel are defined by the Doppler frequency shift in azimuth and by the signal runtime in range direction.
RAPD	Rapid orbit calculation to obtain quick delivery of NRT data.
Rayleigh criterion	It defines a smooth or rough surface in relation to the applied radar wavelength. Smooth: $h < \lambda/(8 * \cos \Theta)$, rough: $h > \lambda/(8 * \cos \Theta)$ where h is the surface height variation, λ is the wavelength, Θ is the incidence angle.
RDG	Radargrammetry. A method to derive terrain height from ascending and descending orbits. The images need to have a disparity angle of ~20-25 degrees.
Red has fled, blue is new	A way to display 2 overlapping SAR images of day 1 and day 2 on red (reduced backscattering or removed object) and blue (increase backscattering or added object).
Reflected component	Part of the transmitted radar wave which is backscattered/reflected back to the radar antenna.
Reflection	Return of optical wavelengths (optical satellite data). Sometimes used synonymously for backscattering.

RFI	Radio frequency interference. Disturbance in the image due to ground based radars.
rg	range resolution
RGB	red-green-blue colour mixing on screen
Rough surface, roughness	This could be a desert surface with rocks, a ploughed agricultural field, a vegetation cover, a wind affected water surface. Vertical roughness measurements are then related to the applied radar wavelength. Rayleigh roughness criteria apply.

S

SAR raw data processing	Digital SAR processing using the raw signal data file and a parameters file to carry out range compression, patch processing range migration, azimuth compression; result is an SLC or SSC product
SAR	Synthetic Aperture Radar. A long antenna is synthesized by moving the satellite along the orbit in azimuth direction. This is done in order to obtain a finer spatial resolution.
SBAS	Small Baseline Interferometry. A differential interferometric method to calculate interferogram between image pairs coming from a time series. Well suited for extended targets outside of cities and to determine surface displacement along the line of sight or landslides. SSC or SLC images are required for this type of analysis. More than 15 images are required.
ScanSAR	a) 4 beam ScanSAR at 18 m resolution covering 100 km x 150 km, b) 6 beam ScanSAR at 40 m resolution covering 270 km x 200 km.
Scattering	Absorption of energy and re-emission of electromagnetic waves in different directions with different intensity and polarisation. Backscattering to the radar (diffuse or volume scattering) or forward scattering away from the radar (specular reflection).
SCIE	Science orbit calculation
Shadow	No-return area behind a tall object or a mountain range which cannot be reached by the radar energy. It can be used to calculate the height of an object from a geocoded image by measuring the length of the shadow and multiplying it by the tangent of 90 degrees minus the local incidence angle. See also layover.
Side lobe star	Bright cross-like signatures in a radar image, which are caused at corners. Their ends always follow range and azimuth direction and

	can be used to reconstruct imaging geometry, jointly with shadow and layover.
Sigma-nought	Radiometrically calibrated radar image through the compensation by the sine of the incidence angle. Usually expressed in decibels [dB]. Thus images will be comparable with each other, e.g. in automated image classification. See document on radiometric calibration of TerraSAR-X
Single bounce	Direct return of the transmitted radar beam back to the satellite.
Single Look Slant Range Complex or **SSC**	Slant image imagery in mathematical complex format usable for interferometric applications or any other application in today's modern radar image processing software.
SL	SpotLight mode of TerraSAR-X producing 2 m resolution images.
Slant range	Along the line of sight of the radar. The image looks squished and pixels are rectangular being larger in range than in azimuth. Geometric resolution in radial dimension alongside of the radar beam.
SLC	Single look slant range complex data of Sentinel-1; equivalent to SSC
Smooth surface	Radiometrically smooth surface; see Rayleigh
SNR	Signal to noise ratio depends on the thermal noise power and the reflected signal power. It depends on the incidence angle and on the physical properties of the target.
Spatially enhanced	SE are spatially enhanced radar images, on the cost of radiometry. Best suited for visual image interpretation.
Speckle	Additive noise overlaying the image due to the coherent nature of the radar antenna and the interference with objects on the ground.
Specular reflection	Smooth surface lead to forward scattering away from the radar antenna, which results in black pixels in the image (smooth water surfaces or on smooth tarmac)
Specular scattering	see specular reflection
SpotLight	1 m resolution, 10 km x 5 km
sr	Slant range
Staring SpotLight	TerraSAR-X imaging mode at a spatial resolution of 0.25 m azimuth, < 1 m in range; 4 km x 7.5 km coverage
StripMap	3 meter imaging mode covering 30 km x 50 km

Surface Displacement	Due to subsurface work, earthquakes or volcanism, the Earth surface may sink. This displacement rate per year can be measured by the analysis of a time series of interferograms by SBAS or PSI methods.
Swath	width of the image strip

T

TanDEM-X	Second German X-Band satellite launched June 21, 2010
TerraSAR-X	German X-band satellite launched July 15, 2007
Trihedral corner reflector	A shape formed by 3 triangular shaped surfaces which acts as a perfect scatterer
Triplets	Triple or threefold signatures from a bridge spanning over a water surface (layover of superstructures, top of bridge and double bounce between water surface and lower side of the bridge.

U

UPS	Universal Polar Stereographic map project using by TerraSAR-X products at the poles.
UTC	Universal Time Coordinated
UTM	Universal Transverse Mercator map projection used by TerraSAR-X products.

V

V	velocity
Vertical cylinders	These can be POL tanks, which show a distinct backscatter pattern with a bottom ring return, a top ring layover, cardinal effects at the apex of the rings and point like returns from the top of the floating roof.
VH	Vertical polarisation upon transmission and horizontal polarisation upon reception of the electromagnetic wave. It can be delivered as one 16 bit raster image. It can be combined with other polarisation images to create a colour composite.
Viewing direction	Ascending or descending orbit
Volume scattering	Backscattering caused by the interaction of the electromagnetic wave with a plant canopy or any other volume material.

VV — Vertical polarisation upon transmission and reception of the electromagnetic wave. It can be delivered as one 16 bit raster image. It can be combined with other polarisation images to create a colour composite.

W

Wavelength — Applied wavelength λ for the actively transmitted electromagnetic wave given in cm. It can be converted to frequency by using λ=c/f, speed of light divided by frequency.

WorldDEM — Airbus digital terrain model with 12.5 m posting, which is available as DSM or DTM.

X

X band roughly 3em wavelength SAR, available from TerraSAR-X, TanDEM-X and PAZ as well as some competitors of Airbus

Y

Yyyy-mm-ddThh:mm:ss year-month-day and time in hours, minutes and seconds given in UTC (Universal Time Coordinated) or GMT (Greenwich Mean Time)

Z

Zero Doppler Time — The along track (azimuth) time at which a target on the ground would have a Doppler shift of zero with respect to the satellite (i.e. when the target was perpendicular to the flight path). Also called the closest approach azimuth time. The SAR processor locates targets in the image at the zero-Doppler azimuth time. (Source: ESA)

Greek letters

α — Heading angle of a ship or vessel

β — Radar brightness

γ — Backscattering coefficient modified by the tangent of the incidence angle

ϴ — Incidence angle

λ — Wavelength

σ — Backscattering coefficient modified by the sine of the incidence angle

Important TerraSAR-X *.xml tags

- <incidenceAngle> 4.77859388031433667E+01; i.e. 47.7 degrees incidence angle
- <polLayer> HH Polarisation
- <orbitDirection> ASCENDING Orbit direction
- <rangeTime> Slant range distance R0 between <firstPixel>, <lastPixel>
- <zeroDopplerVelocity> Beam velocity, <velocity>
- <filename> 20090611T172629 Time stamp
- <customerID> sales order number for further reference

Abbreviations used by TerraSAR-X Services in the Acquisition Plan and Financial Quotations

0DEM Raw digital elevation model (DEM) derived from TerraSAR-X.

1DEM Basic Digital elevation model (DEM) derived from TerraSAR-X.

2DEM DEM elevation data set derived from TerraSAR-X; hydro enforced: water areas and rivers have been smoothed out.

3DEM Digital terrain model (DTM) based on TerraSAR-X.

A Ascending Orbit; both descending and ascending orbits are available and will show different aspects of the investigation area.

Abs Orbit Absolute Orbit; orbit identifier for absolute reference of the scene since first orbit of satellite mission.

Acqu Prior Acquisition Priority; describes the urgency of the data acquisition; standard is 3 days no surcharges, priority acquisition is less equal 24 hours and requires surcharges to the price; exclusivity mean less equal 6 hours and requires additional surcharges to the price.

Acqu Start/End Time Acquisition Start/End Time; important for the client if ground truth experiments have to be carried out synchronously with the acquisition.

Beam ID TerraSAR-X beam ID in range direction which corresponds to certain incidence angles; e.g. Strip_021. Important for reordering the same location, e.g. for InSAR purposes or other time series. See Basic Product Specification Document.

Coord Coordinates; latitude and longitude at scene center

CoSAR DLR CoSAR format for the SSC product which is 32 bit encoded and includes amplitude and phase information. Can be read by software packages such as Envi IDL, Erdas Imagine, PCI Geomatics, SARScape.

Cross pol	Here cross polarisation denotes a set of two images in VV and VH or HH and HV, respectively. Otherwise often used to describe VH or HV in contrast to the like polarisations VV and HH.
D	Descending; both descending and ascending orbits are available and will show different aspects of the investigation area.
Delvry Mode	Delivery Mode; via secure file transfer protocol ftps, as DVD.
DSM	Digital Surface Model (top of vegetation or buildings) derived by means of radargrammetry.
Dual pol	Here dual polarisation image denotes a set of two images acquired at HH and VV polarisation. Otherwise often used to generally describe the existence of 2 images at different polarisation for the same area.
EEC	Enhanced Ellipsoid Corrected; One out of four TerraSAR-X Basic Image Products; Geocoded to UTM WGS84 and DEM corrected data.
ERP Ref. ID	Enterprise Resource Planning Software Reference number of identification of the ordered scene.
GEC	Geocoded Ellipsoid Corrected; One out of four TerraSAR-X Basic Image Products; geocoded to UTM WGS84 without DEM information but reduced to an average terrain height.
GIM	Geocoded Incidence Angle Mask; tif raster file with indications of the presence of layover and shadow areas.
HH	Horizontal-Horizontal Polarisation
HS	High Resolution SpotLight imaging mode, available at 150 MHz (2 m range pixel spacing) 300 MHz bandwidth (1 m range pixel spacing)
Img Mode	Imaging Modes HS300, HS, SL, SM and SC are available.
Incid Angle	Incidence Angle range covered by the image; especially important with SC and SM data.
LL	Lower left coordinate of the covered area or scene extent.
Look Dir	Antenna look direction of the TerraSAR-X antenna is "right" by default.
LR	Lower right coordinate of the covered area or scene extent.
MDG	Multilook Ground Range Detected; One out of four TerraSAR-X Basic Image Products; ground range projection without geocoding by a general latitude, longitude for better scene location on Earth.
n/a	not applicable

Orb Acc	Orbit Accuracy; responsible for the placement accuracy of the image scene.
ORI	Orthorectified Image; a TerraSAR-X Enhanced Image Product.
P	Predicted orbit determination; one out of three orbit precision possibilities; estimation accuracy 700 m along track; processing of Near Real Time products; calculation of a 24 h prediction of the orbit; available before acquisition.
Pass Dir	Pass Direction; orbit direction ascending or descending orbit.
Pol Chan	Polarisation Channel; four possible channels: HH, VV, HV, VH.
Pol Mode	Polarisation Mode; options single polarisation, dual polarisation (here HH and VV), cross polarisation (here VV and VH or HH and HV), quadruple polarisation and twin polarisation (experimental mode for scientific applications only).
Proc Opt	Processing Option RE or SE
Proc Prior	Processing Priority until delivery. Determined by Customer Service. The higher the number the longer the delivery will take.
Prod Type	Production Type; CEOS Level 1B SSC, MGD, GEC or EEC TerraSAR-X products.
Proj	Map Projection; UTM WGS84 or UPS are default map projections.
Q	Quicklook; low resolution overview image for own image catalogues.
R	Rapid orbit precision determination; one out of three orbit precision possibilities; estimation accuracy 2 m, 3-d, 1 sigma; standard processing of TerraSAR-X basic image products; available 5 to 15 hours after last satellite contact by ground station.
RADAR	Radio Detection and Ranging
RE	Radiometrically enhanced; maximum radiometric resolution on the cost of spatial resolution. Appropriate data type for quantitative analysis as well as segmentation and classification.
Rel Orbit	Relative Orbit in dependence on the 11 day repeat cycle of TerraSAR-X.
Res Var	Resolution Variant; RE or SE possible (see there)
S	Science orbit precision determination; estimation accuracy 20 cm, 3-D, 1 sigma, aiming at 10 cm Processing of products from archive if orbit
SAR	Synthetic Aperture RADAR
SC	ScanSAR imaging mode with 18 m pixel spacing.
SE	Spatially enhanced; maximum geometric resolution on the cost of radiometric resolution. Appropriate data type for quantitative analysis as well as segmentation and classification.

SL Spot Light imaging mode with 2 m pixel spacing.

SM Strip Map imaging mode with 3 m pixel spacing

SSC Single Look Slant Range Complex image; one of the four TerraSAR-X Basic Image Products; slant range geometry; includes amplitude and phase information and is e.g. required for quantitative analyses such as Persistant Scatter Interferometry (PSI), Interferometric SAR (InSAR), Differential Interferometry (DInSAR), Interferogram Stacking (IS), extraction of radiometric values, image segmentation and classification.

UL Upper left coordinate of the covered area or scene extent.

UR Upper right coordinate of the covered area or scene extent.

UTC Coordinated Universal Time

UTM Universal Transverse Mercator map projection grid.

VAT Value Added Tax

VV Vertical - Vertical polarisation.