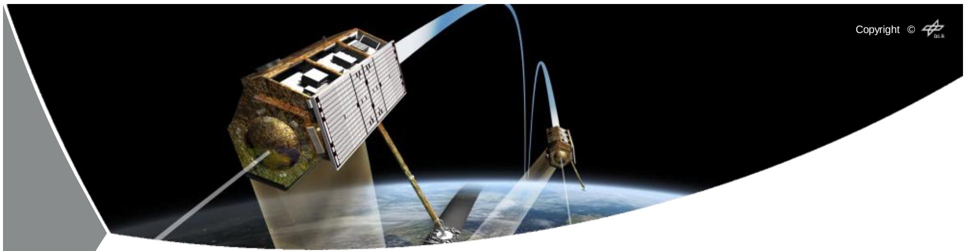
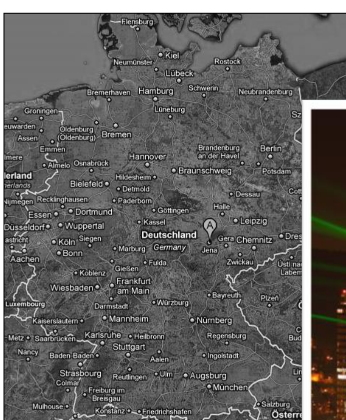


SAR Remote Sensing

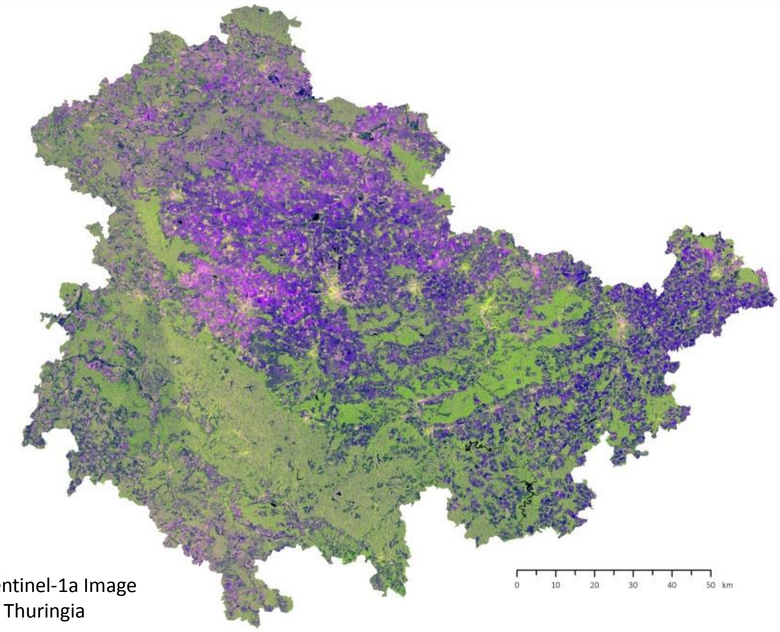
Introduction into SAR. Data characteristics, challenges, and applications.

PD Dr. habil. Christian Thiel, Friedrich-Schiller-University Jena

Jena & Friedrich-Schiller-University



©DLR-HR



Sentinel-1a Image
of Thuringia

©DLR-HR

Jena & Friedrich-Schiller-Ur

©DLR-HR

Jena & Friedrich-Schiller-Ur

©DLR-HR

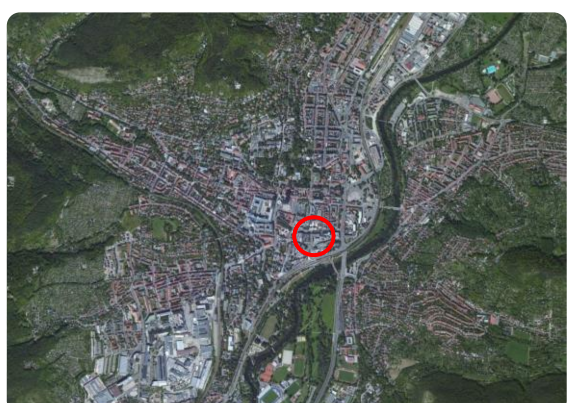
Dept. of Earth Observation

Basic Research
- E.g. SAR coherence & Forestry

Applied Earth Observation
- E.g. landcover mapping using multitemporal SAR data

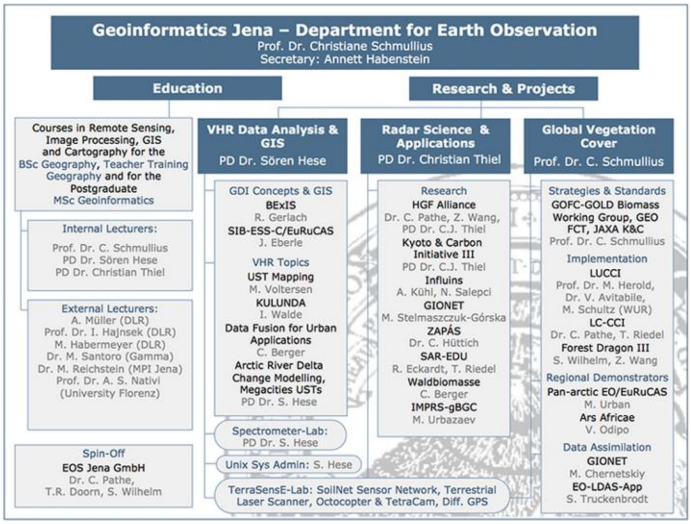
Project Coordination
- Coordination of many international projects

Education
- BSc Geography
- MSc Geoinformatics
- Various PhD Projects
- SAR-EDU



6

Dept. of Earth Observation



http://www.geographie.uni-jena.de/Fernerkundung.html

Contents

- What is Remote Sensing/Earth Observation?
- Active Radar Remote Sensing
- Summary

What is Remote Sensing/Earth Observation?

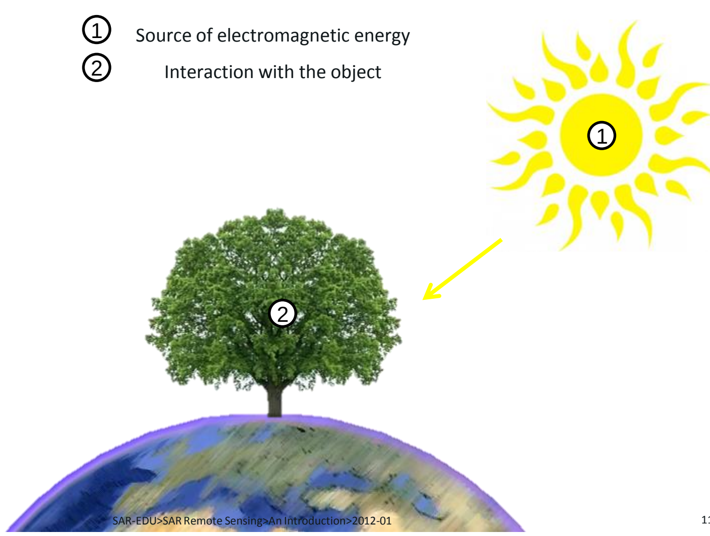
- ***Remote sensing (RS)***, also called earth observation, refers to ***obtaining information*** about objects or areas at the Earth's surface ***without being in direct contact*** with the object or area.

http://freeda.files.wordpress.com/2007/10/sv003.jpg

What is Remote Sensing/Earth Observation?

Components of the remote sensing process

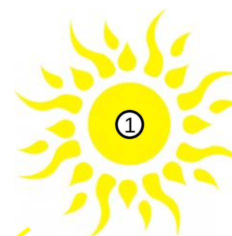
1. Source of electromagnetic energy
2. Interaction with the object



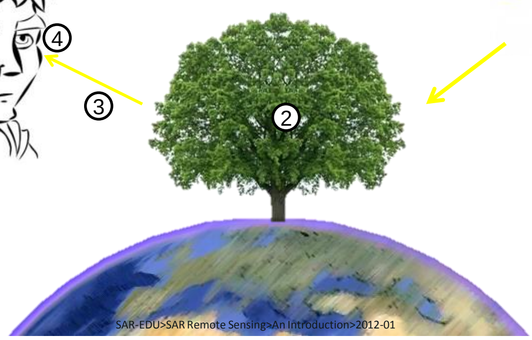
What is Remote Sensing/Earth Observation?

Components of the remote sensing process

1. Source of electromagnetic energy
2. Interaction with the object
3. Radiation back to sensor
4. Reception of radiation by sensor
5. Interpretation and analysis



3



Tab 1 Tab 2 Tab 3 Tab 4 Tab 5
Copyright ©

What is Remote Sensing/Earth Observation?

Components of the remote sensing process

5

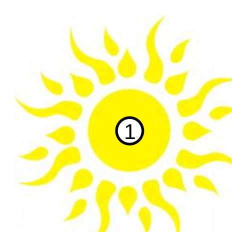
SPOT 5

Optical satellite
visible part of the spectrum

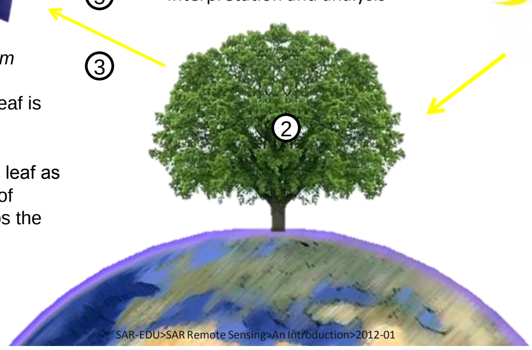
energy scattered off the leaf is dependent on:

The "**greenness**" of the leaf as a function of the amount of chlorophyll, which absorbs the energy that is needed for photosynthesis

1. Source of electromagnetic energy
2. Interaction with the object
3. Radiation back to sensor
4. Reception of radiation by sensor
5. Interpretation and analysis



3

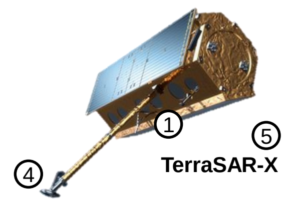


Tab 1 Tab 2 Tab 3 Tab 4 Tab 5

What is Remote Sensing/Earth Observation?

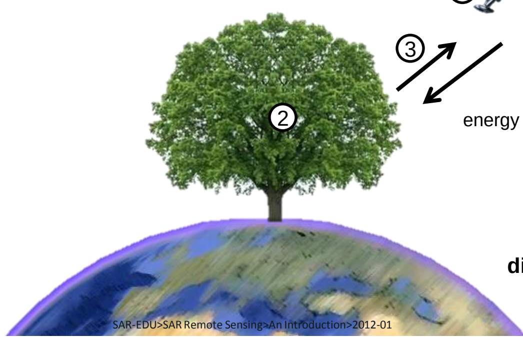
Components of the remote sensing process

1. Source of electromagnetic energy
2. Interaction with the object
3. Radiation back to sensor
4. Reception of radiation by sensor
5. Interpretation and analysis



TerraSAR-X

Radar satellite
microwave part of the spectrum



energy scattered off the leaf is dependent on:

size
shape
orientation
dielectric properties

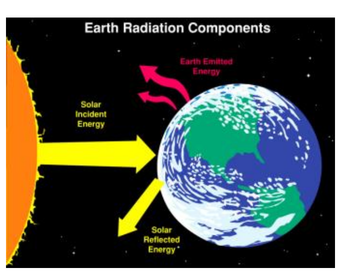
Tab 1 Tab 2 Tab 3 Tab 4 Tab 5

What is Remote Sensing/Earth Observation?

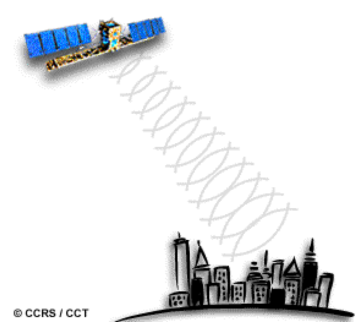
Source of electromagnetic energy

1. *Sun*
2. *Earth Emitted Energy*

3. Active Source of Energy (e.g. Satellite Sensor)



Source: http://modis.gsfc.nasa.gov/gallery/



© CCRS / CCT

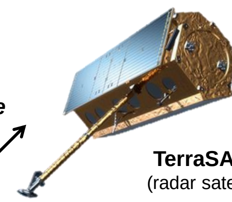
What is Remote Sensing/Earth Observation?

Source of electromagnetic energy

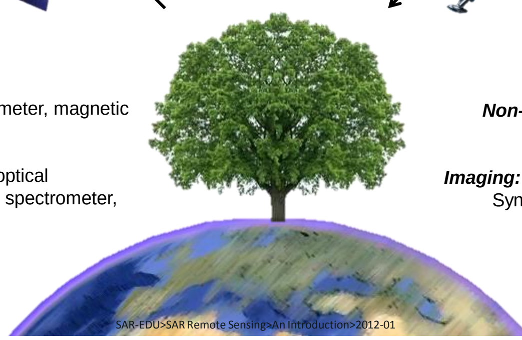
SPOT 5
(optical satellite)

passive

active



TerraSAR-X
(radar satellite)



Further Examples:

Non-imaging: radiometer, magnetic sensor

Imaging: cameras, optical mechanical scanner, spectrometer, radiometer

Further Examples:

Non-imaging: radiometer, altimeter, laser

Imaging: Real Aperture Radar, Synthetic Aperture Radar

What is Remote Sensing/Earth Observation?

Source of electromagnetic energy

Passive remote sensing systems:

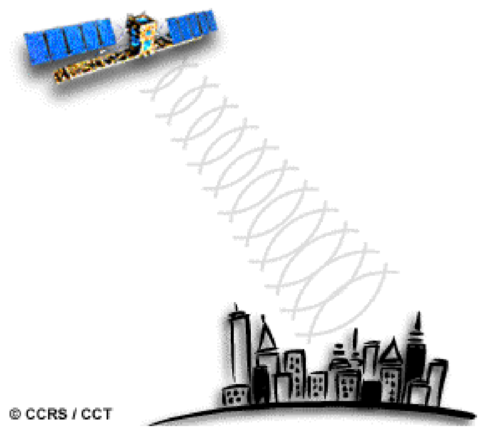
- Detect the reflected or emitted EM radiation from natural sources
- **Some of the images represent reflected solar radiation in the visible and the near infrared regions of the EM spectrum**
- **others are the measurements of the energy emitted by the earth surface itself i.e. in the thermal infrared wavelength region**

Active remote sensing systems:

- Detect **reflected responses** from objects irradiated by **artificially-generated energy** sources
- **energy is transmitted from the remote sensing platform**
- **measurement of relative return from the earth's surface**

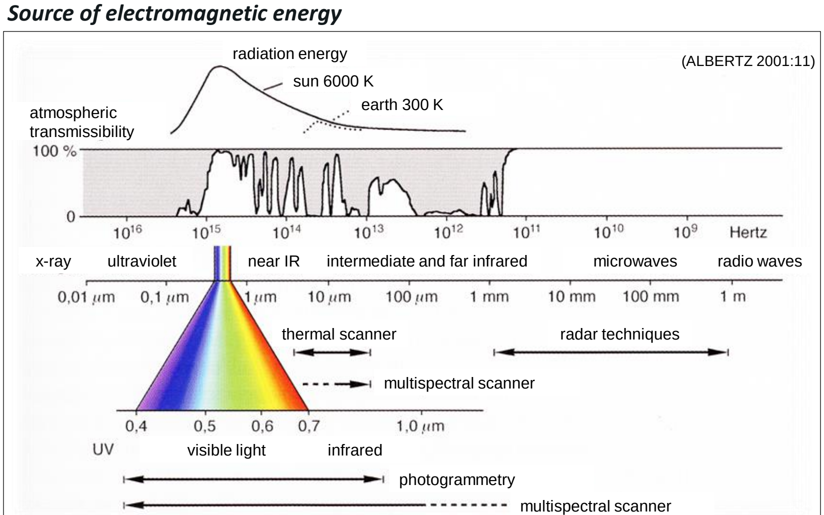
What is Remote Sensing/Earth Observation?

Source of electromagnetic energy - active



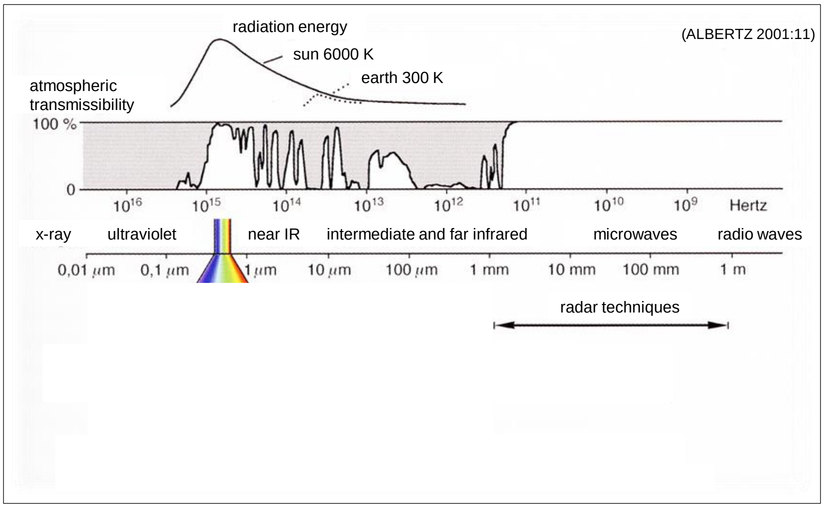
What is Remote Sensing/Earth Observation?

Source of electromagnetic energy



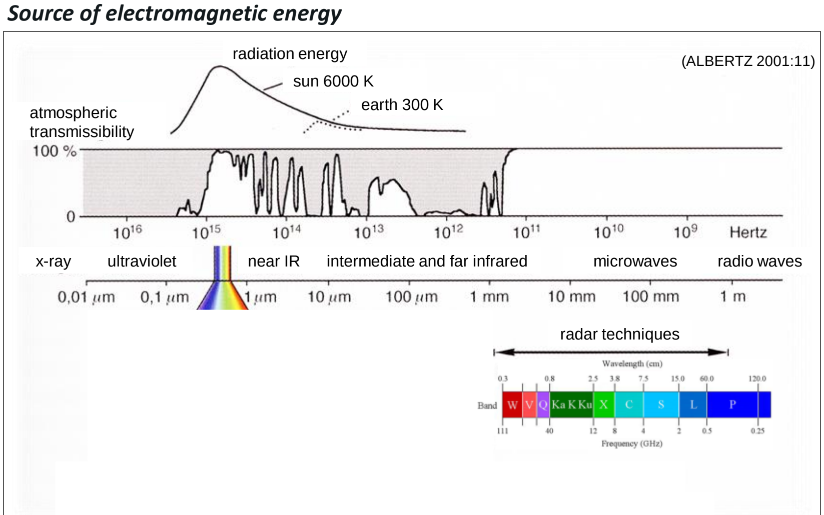
What is Remote Sensing/Earth Observation?

Source of electromagnetic energy

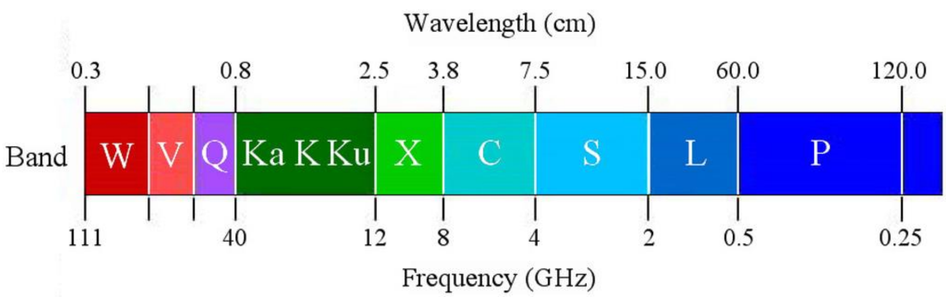


What is Remote Sensing/Earth Observation?

Source of electromagnetic energy



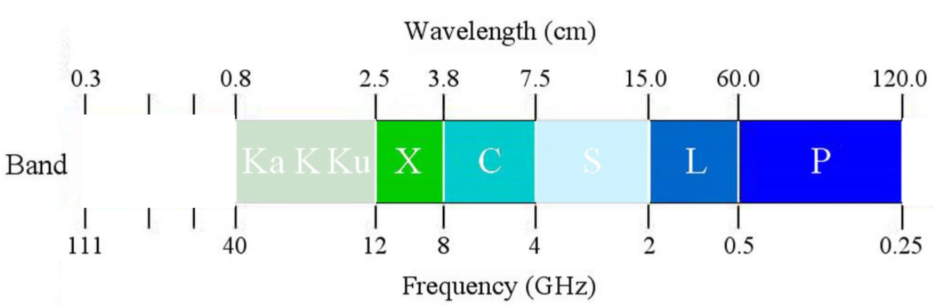
Synthetic Aperture Radar - SAR



Kazuo Ouchi (2013): Recent Trend and Advance of Synthetic Aperture Radar with Selected Topics, *Remote Sensing* **2013**, *5*(2), 716-807; doi:10.3390/rs5020716

SAR Remote Sensing Education Initiative

Synthetic Aperture Radar - SAR



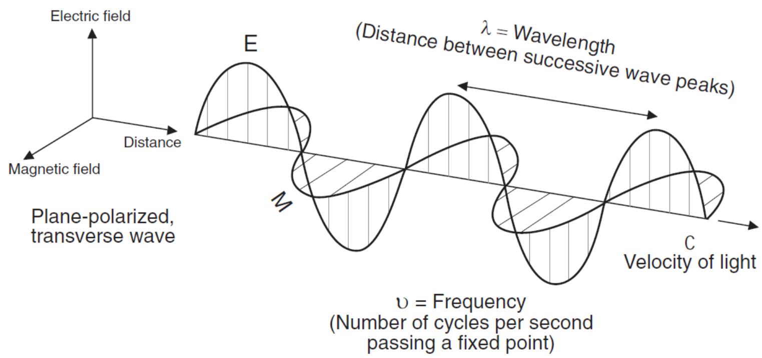
Kazuo Ouchi (2013): Recent Trend and Advance of Synthetic Aperture Radar with Selected Topics, *Remote Sensing* **2013**, *5*(2), 716-807; doi:10.3390/rs5020716

SAR Remote Sensing Education Initiative

Active Radar Remote Sensing

Interaction with the object

$$c = \lambda \, \nu \qquad\qquad c = 3 \text{ x } 10^{8} \text{ m s}^{-1}$$



Wave Theory and Polarization
(David P. Lusch, 1999).

Active Radar Remote Sensing

Interaction with the object

The Radar Concept (after ROSEN 2004:o.S.).

Active Radar Remote Sensing

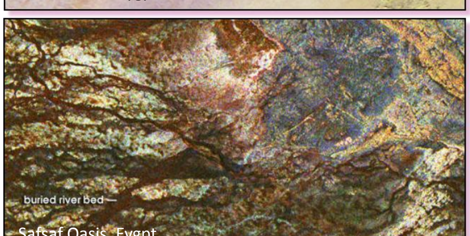
Characteristics of microwaves/SAR sensors

1. Active remote sensing sensors generate EM-waves → no sunlight required (night time acquisitions possible), no problems due to bad illumination
2. Microwaves are capable to penetrate into/through objects. This effect is depending on wavelength and dielectric characteristics of objects → (almost) no problems with clouds, dust, fog. Sensing of „hidden“ objects
3. Magnitude and characteristics of backscatter depend on geometric and dielectric properties of objects

Active Radar Remote Sensing

Advantages / Example subsurface penetration

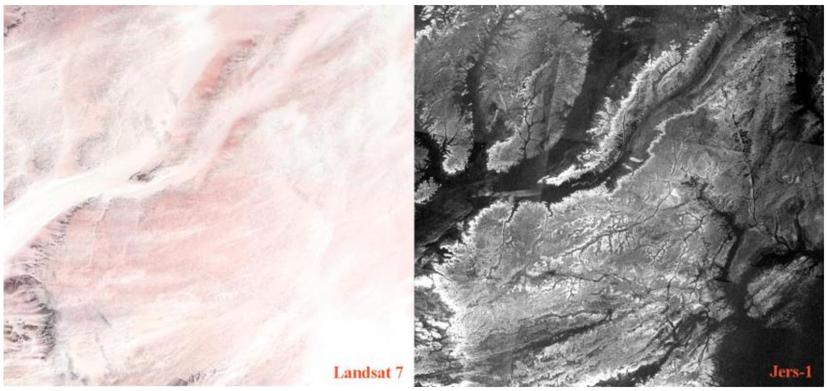
Landsat Thematic Mapper
shows the desert’s surface



SIR-C/X-SAR
shows what the landscape might look like if stripped bare of sand

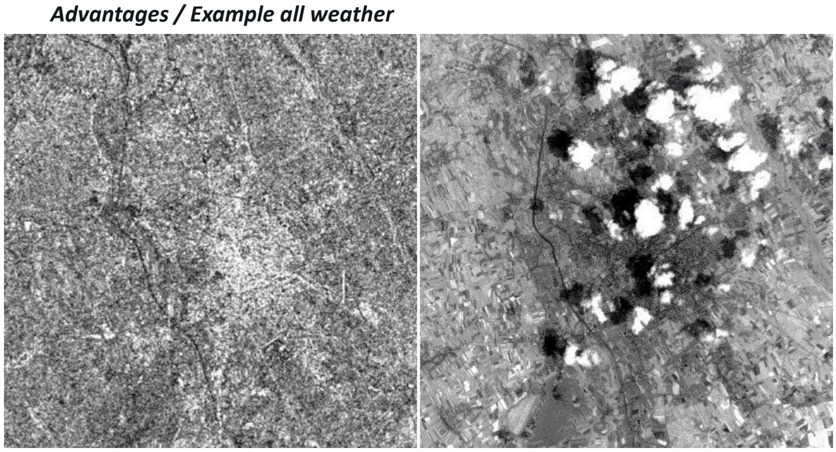
Active Radar Remote Sensing

Advantages / Example subsurface penetration



Active Radar Remote Sensing

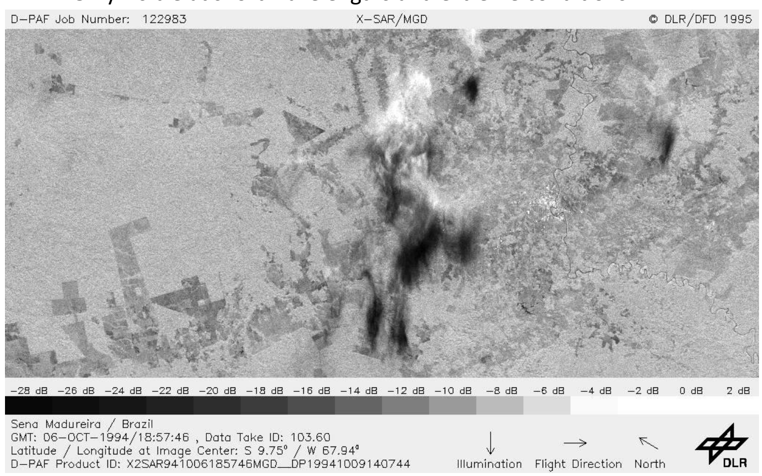
Advantages / Example all weather



These images were acquired over the city of Udine (I), by ERS-1 on the 4th of July 1993 at 9.59 a.m. (GMT) and Landsat-5 on the same date at 9.14 a.m. (GMT) respectively. The clouds that are clearly visible in the optical image, are not appearing in the SAR image.

Heavy Clouds and Rain Cells in X-Band SAR Images

→ Only visible at short wavelengths and extreme conditions



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Active Radar Remote Sensing

Characteristics of microwaves/SAR sensors

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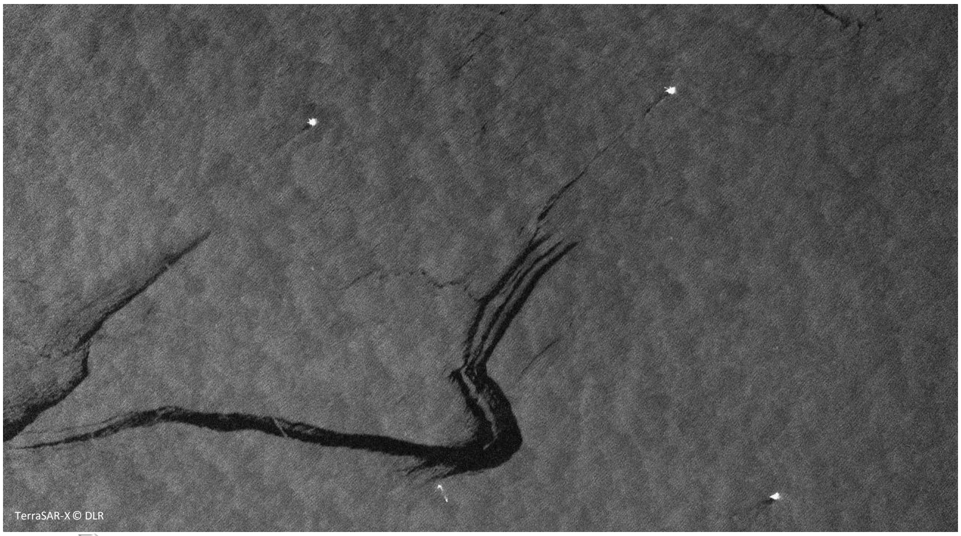
3. Magnitude and characteristics of backscatter depend on geometric and dielectric properties of objects

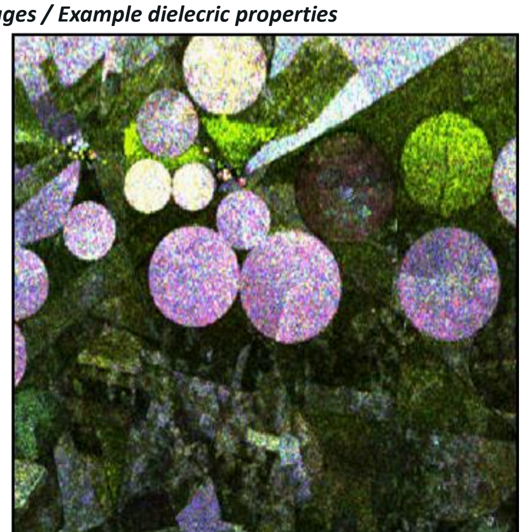
SAR Data Examples



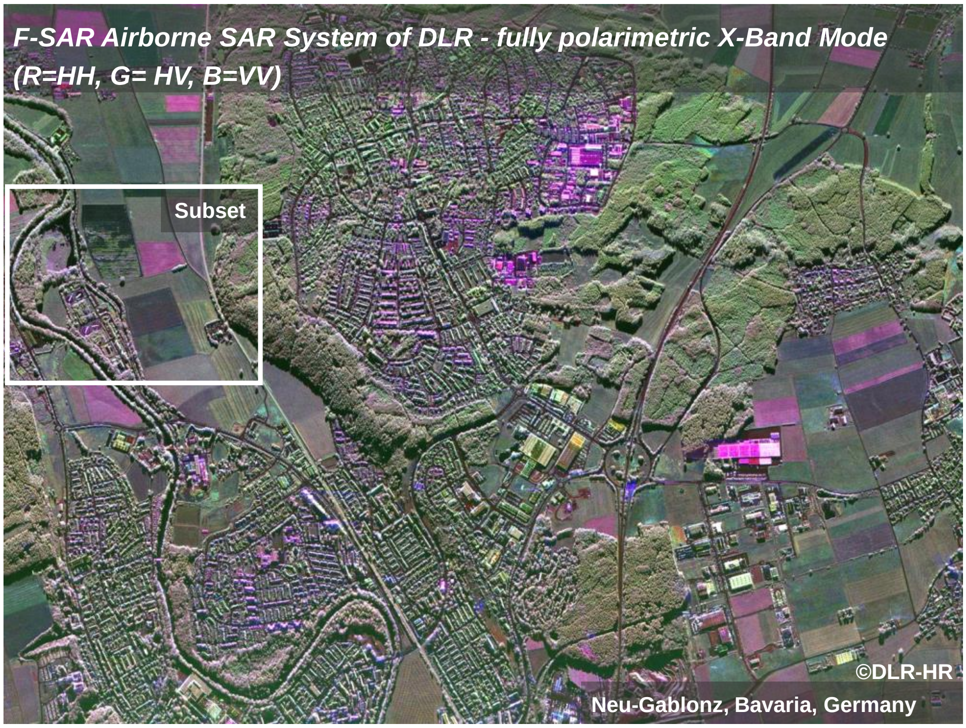
TerraSAR-X, 9. July 2010, Mediterranean Sea

Active Radar Remote Sensing

Advantages / Example dielecric properties

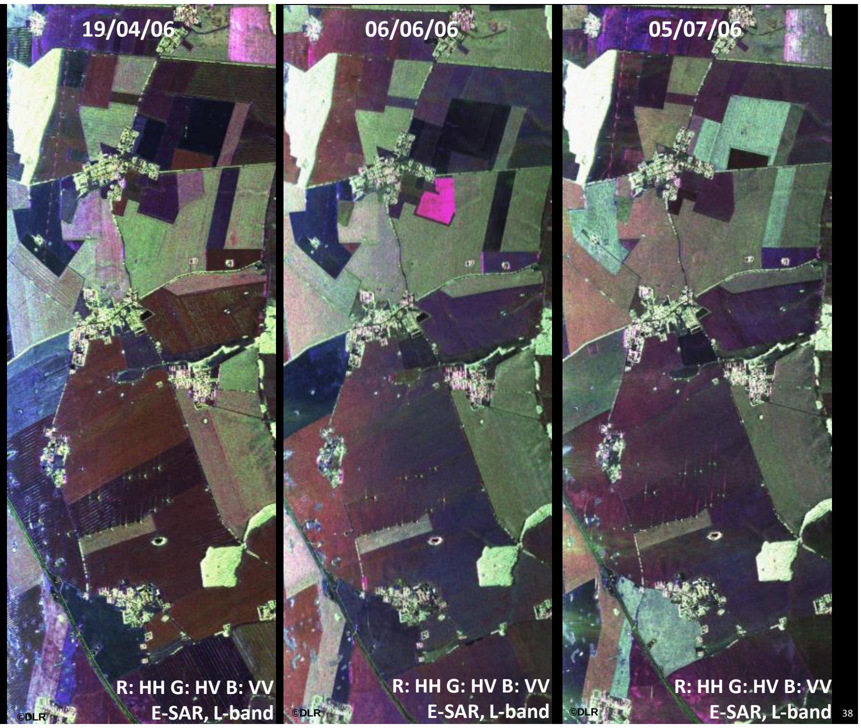


Irrigated fields:
Higher backscatter


F-SAR Airborne SAR System of DLR - fully polarimetric X-Band Mode
(R=HH, G= HV, B=VV)
Subset
©DLR-HR
Neu-Gablonz, Bavaria, Germany


Subset of Neu-Gablonz Area - River, Fields and …
(R=HH, G= HV, B=VV)
… a purification plant
©DLR-HR

Crop monitoring with several observations



What is Remote Sensing/Earth Observation?

Interaction with the object

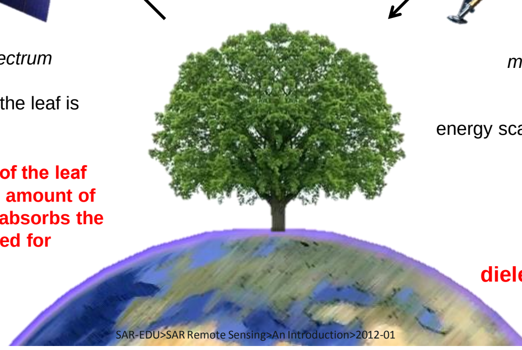
SPOT 5

Optical satellite
visible part of the spectrum

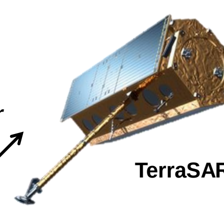
energy scattered off the leaf is dependent on:

The "greenness" of the leaf as a function of the amount of chlorophyll, which absorbs the energy that is needed for photosynthesis

optical



radar



TerraSAR-X

Radar satellite
microwave part of the spectrum

energy scattered off the leaf is dependent on:

size
shape
orientation
dielectric properties

What is Remote Sensing/Earth Observation?

Interaction with the object

SPOT 5

Optical satellite
visible part of the spectrum

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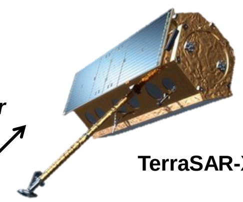
optical

radar



TerraSAR-X

Radar satellite
microwave part of the spectrum

energy scattered off the leaf is dependent on:

size
shape
orientation
dielectric properties

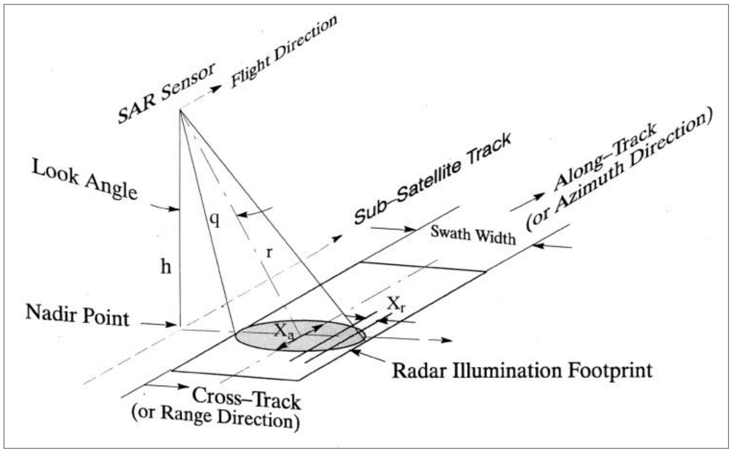
Copyright ©

What is Remote Sensing/Earth Observation?

Source of electromagnetic energy - active

Active Radar Remote Sensing

Interaction with the object

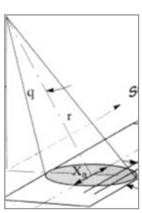


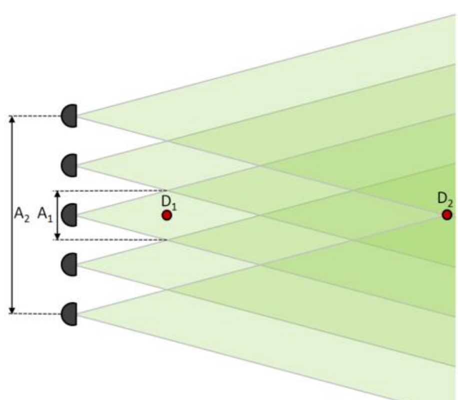
Side-looking SAR geometry.

SAR

What is Remote Sensing/Earth Observation?

Synthetic Aperture Radar





Length of synthetic aperture depending on distance between antenna and target

→ Azimuth resolution independent on range distance

SAR

What is Remote Sensing/Earth Observation?

Synthetic Aperture Radar

Is side looking really necessary?

http://www.geos.ed.ac.uk/~ihw/hype/radar/intro2radar.html

SAR Imaging Geometry

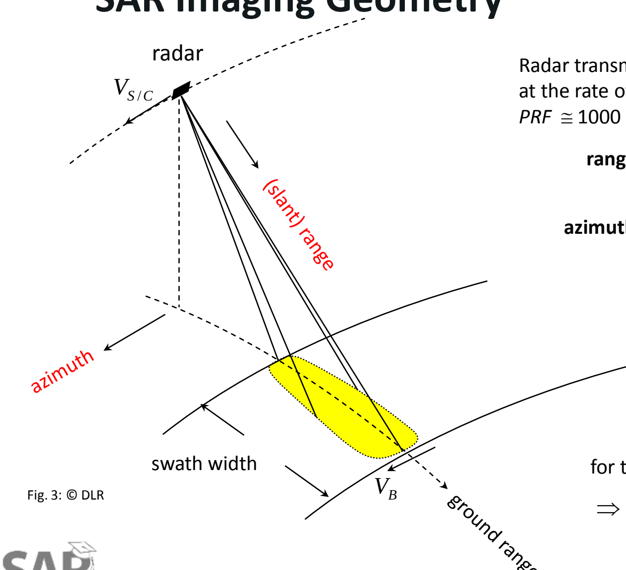


Fig. 3: © DLR

Radar transmits pulses and receives echoes at the rate of the pulse repetition frequency: *PRF* $\cong$ 1000 - 4000 Hz

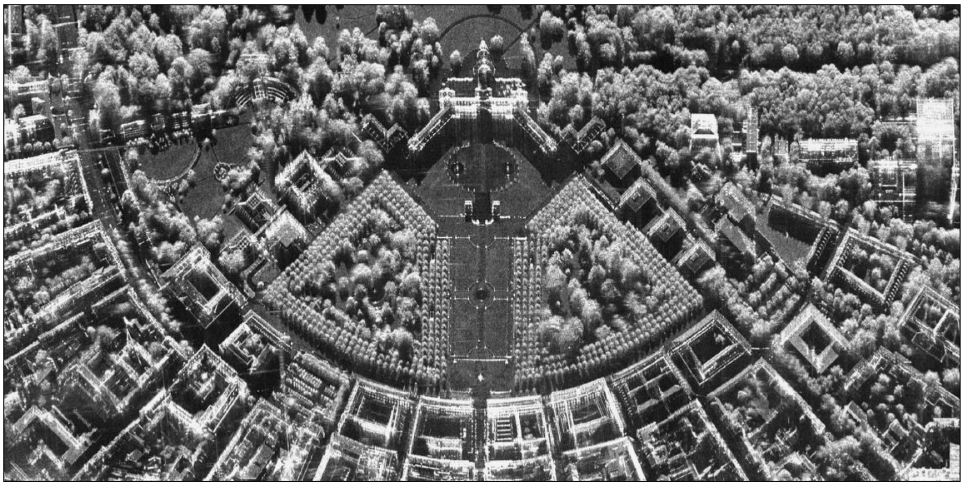
range: radar principle = scanning at speed of light

azimuth: scanning in flight direction

for this lecture: straight flight path

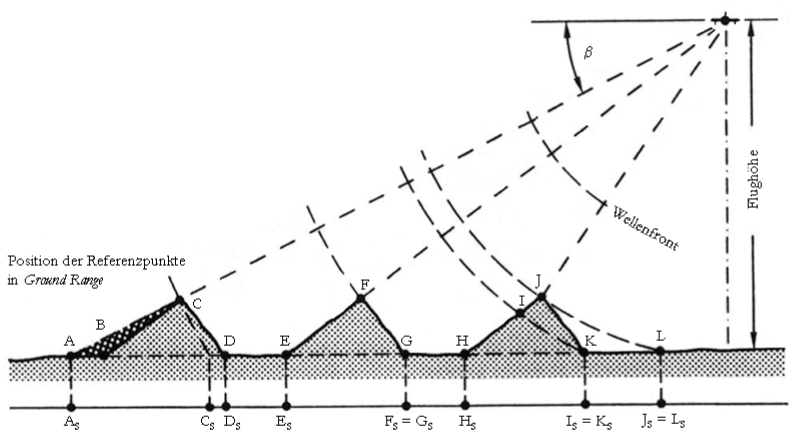
$$\Rightarrow \quad V_{S/C} = V_B = V$$

SAR Data Examples



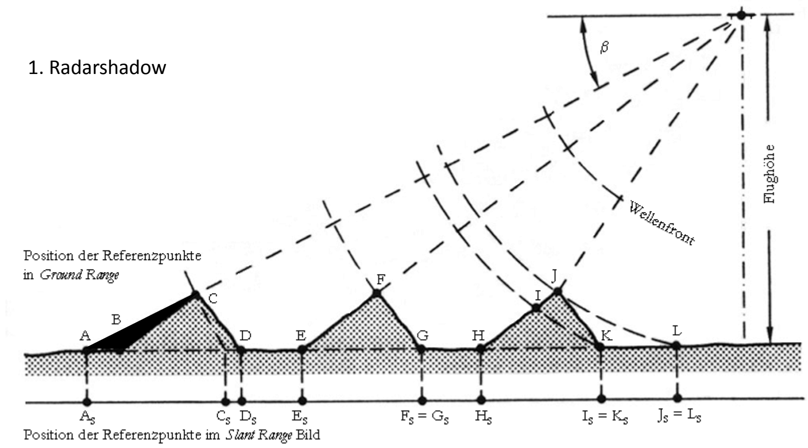
Andreas R. Brenner and Ludwig Roessing, Radar Imaging of Urban Areas by Means of Very High-Resolution SAR and Interferometric SAR, IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 46, NO. 10, OCTOBER 2008 (X-band)

Effects of side-looking geometry



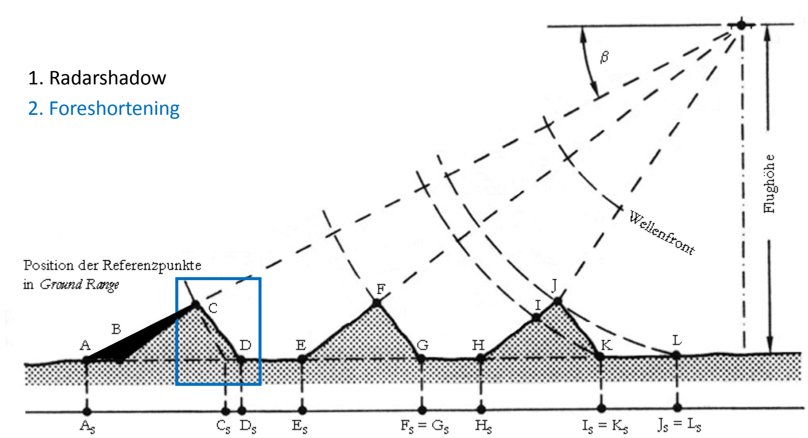
Effects of side-looking geometry

1. Radarshadow



Effects of side-looking geometry

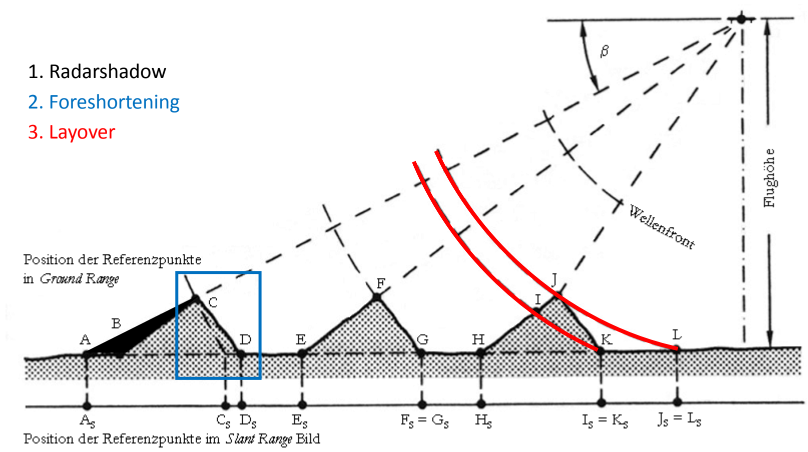
1. Radarshadow
2. Foreshortening



©DLR-HR

Effects of side-looking geometry

1. Radarshadow
2. Foreshortening
3. Layover



SAR Image Examples

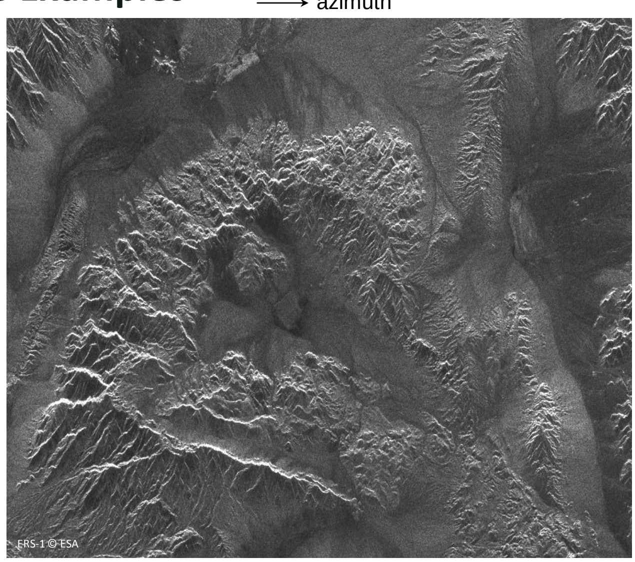
→ azimuth

→ range

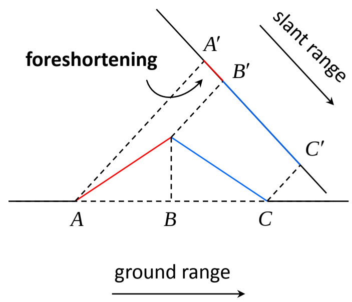
Sensor: ERS-1

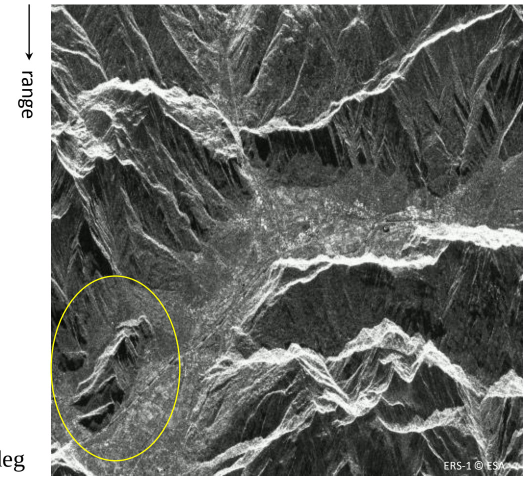
Mojave Desert
CA, USA

Size ≈ 40 km x 40 km



Geometry of SAR Images - Foreshortening



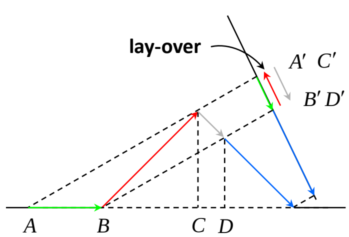


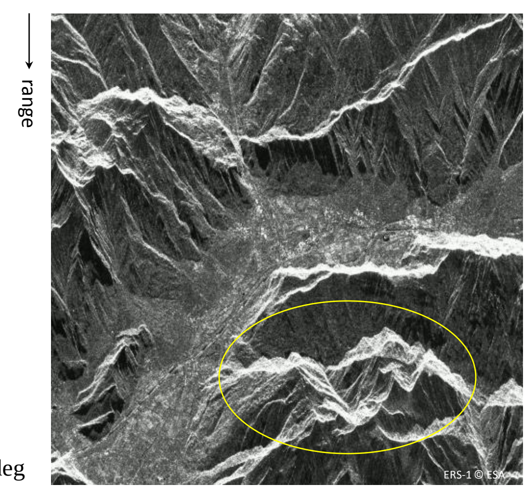
→Slopes oriented to the SAR appear compressed

$\theta = 23\,\text{deg}$

Fig. 33: © DLR

Geometry of SAR Images - Layover





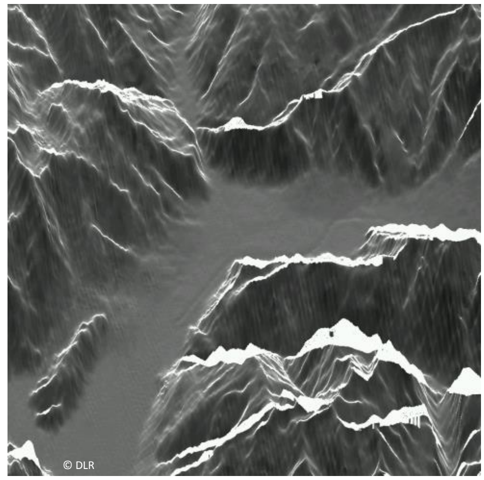
→Steep slopes oriented to the SAR lead to ghost images

$\theta = 23\,\text{deg}$

Fig. 34: © DLR

Layover Mask Computed from DEM

100m DEM

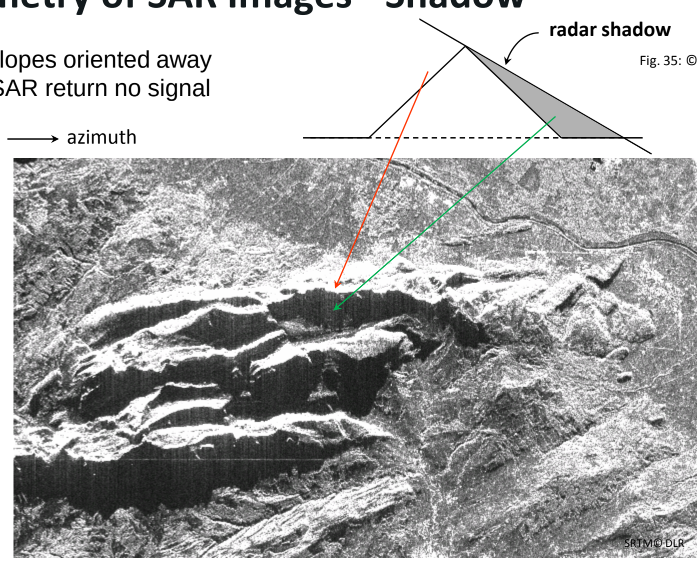


simulated ERS-Image
white: lay-over

Geometry of SAR Images - Shadow

→Steep slopes oriented away from the SAR return no signal

Fig. 35: © DLR



range

SRTM/X-SAR
$\theta = 54$ deg

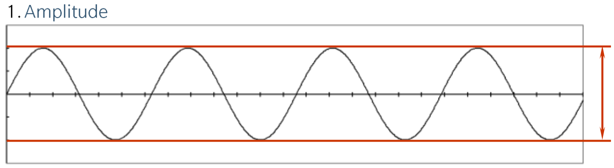
Active Radar Remote Sensing

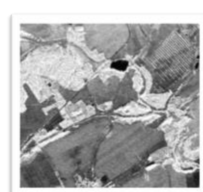
Parameters measured by SAR

Active Radar Remote Sensing

Parameters measured by SAR

1. Amplitude





Parameters Influencing Radar Brightness

- Sensor Parameters
  - wavelength (e.g. penetration through canopy)
  - polarization
  - look angle
  - resolution (texture)
- Scene Parameters
  - surface roughness (e.g. Bragg scattering at ocean surfaces)
  - local slope and orientation ⇐ geomorphology
  - scatterer density, e.g. biomass, leaf density
  - 3-D distribution of scatterers and scattering mechanism, e.g. surface, volume, or double bounce (canopy, trunks, buildings)
  - dielectric constant ε ⇐ scattering material
soil moisture
vegetation status

Backscattering Coefficient σ_o

Levels of Radar backscatter	Typical scenario
Very high backscatter (above -5 dB)	*Man-Made objects (urban)* *Terrain Slopes towards radar* *very rough surface* *radar looking very steep*
High backscatter (-10 dB to 0 dB)	*rough surface* *dense vegetation (forest)*
Moderate backscatter (-20 to -10 dB)	*medium level of vegetation* *agricultural crops* *moderately rough surfaces*
Low backscatter (below -20 dB)	*smooth surface* *calm water* *road* *very dry soil (sand)*

Calibration of SAR Systems

- Instrument parameters to be calibrated:
  - transmit power
  - receiver gain
  - elevation antenna pattern (satellite roll angle)

- Calibration objects:
  - corner reflectors
  - active radar calibrators (ARCs)
  - rain forest

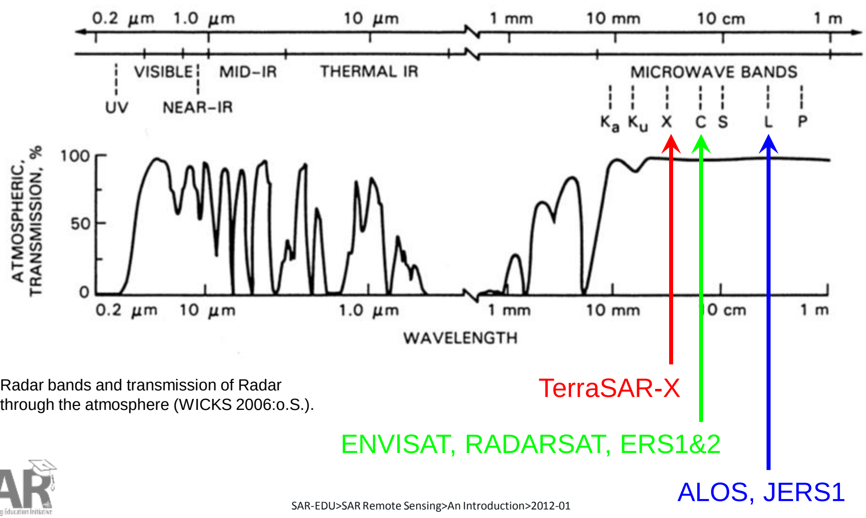
Corner Reflectors for SAR End-to-End Calibration

radar cross section of
a trihedral corner reflector:

$$\sigma = \frac{4\pi\, L^4}{3\,\lambda^2} \quad \left[m^2\right]$$

Active Radar Remote Sensing

Interaction with the object



Radar bands and transmission of Radar through the atmosphere (WICKS 2006:o.S.).

Synthetic Aperture Radar - SAR

- active ⇒ independent of sun illumination
- microwave ⇒ penetrates clouds and (partially) canopy, soil, snow

  wavelengths:
  - X-band: 3 cm
  - C-band: 6 cm
  - L-band: 23 cm
- coherent ⇒ interferometry, speckle
- polarization can be exploited
- spatial resolution:
  - space-borne: 0.5 m - 100 m (TerraSAR-X: ≈1 m)
  - air-borne: > 0.2 m

Penetration of Microwaves

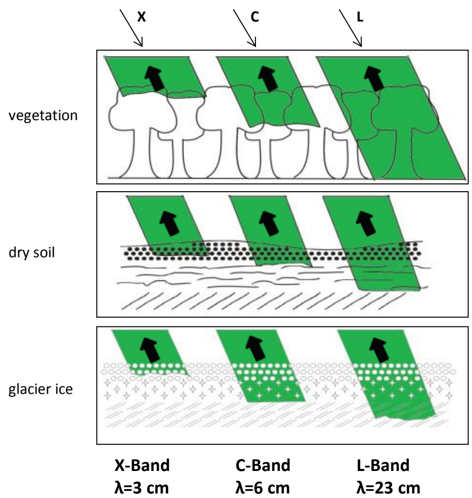
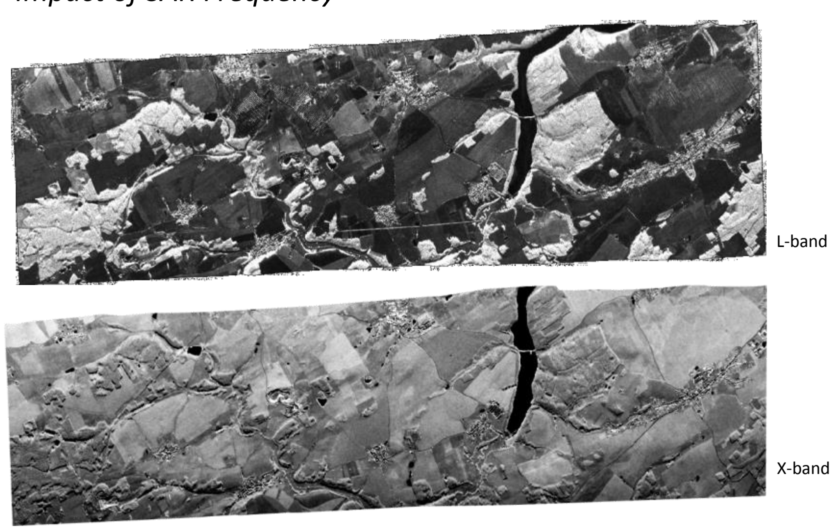


Fig. 30: © DLR

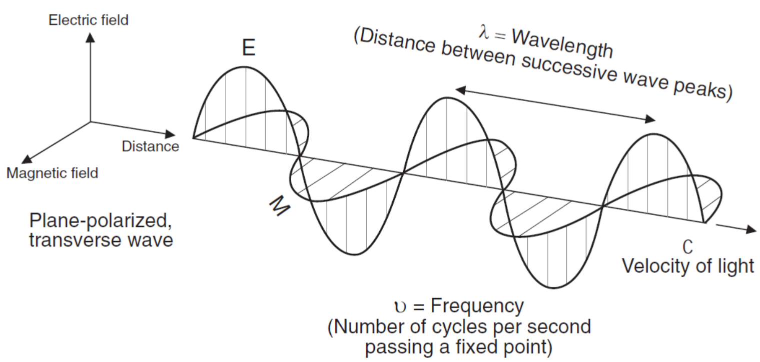
Impact of SAR Frequency



Active Radar Remote Sensing

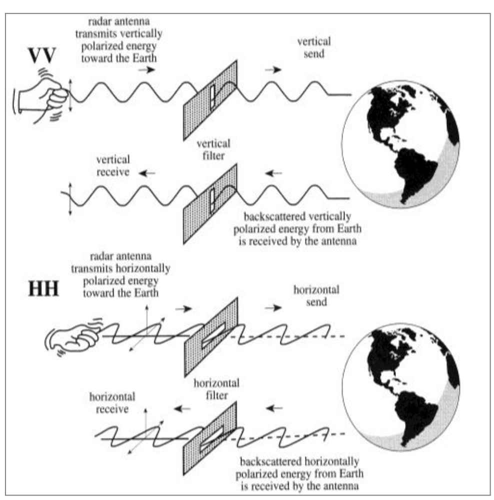
Interaction with the object

$$c = \lambda\, \nu \qquad\qquad c = 3 \text{ x } 10^8 \text{ m s}^{-1}$$



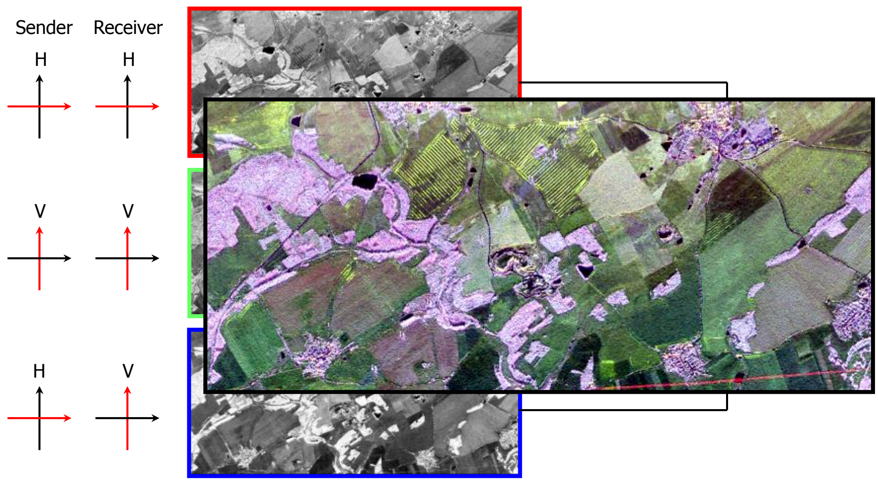
Wave Theory and Polarization
(David P. Lusch, 1999).

Use of polarized waves



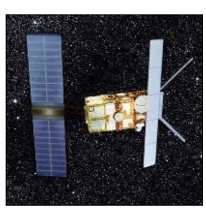
Polarisation (Jensen, 2000).

Use of polarized waves



Active Radar Remote Sensing

Examples of satellite based radar sensors


ERS-1, 2


JERS-1


Radarsat 1, 2


ALOS (PALSAR)


Envisat (ASAR)


TerraSAR-X

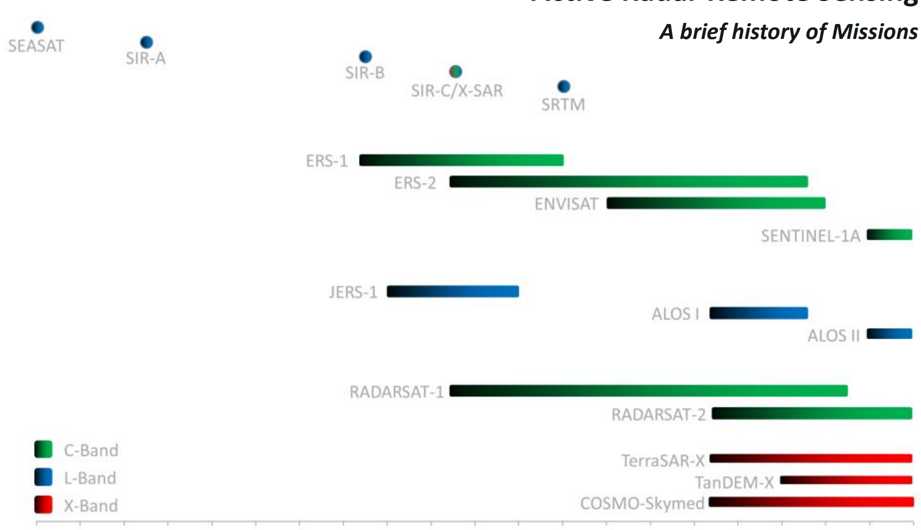
Active Radar Remote Sensing

Examples of satellite based radar sensors

Sentinel-1A (launch: April 2014)

Active Radar Remote Sensing

A brief history of Missions



Current and Future Civil Spaceborne SARs

satellite	owner	band	resolution	look angle	swath	lifetime
ERS-1	ESA	C	25 m	23°	100 km	1991-2000
ERS-2	ESA	C	25 m	23°	100 km	1995-2012
Radarsat-1	Canada	C	10 m - 100 m	20°- 59°	50 - 500 km	1995-2013
ENVISAT	ESA	C	25 m - 1 km	15°- 40°	100 - 400 km	2002-2012
ALOS	Japan	L	10 m -100 m	35°- 41°	70 - 360 km	2006-2011
Cosmo	Italy	X	ca. 1 m - 16 m	…	…	2007-
TerraSAR-X & TanDEM-X	Germany	X	1 m - 16 m	15°- 60°	10 - 100 km	2007/2010-
Radarsat-2	Canada	C	3 m - 100 m	15°- 59°	10 - 500 km	2007-
ALOS-2	Japan	L	3 m – 100 m	8°-70°	25 – 350 km	2014-
Sentinel-1A	ESA	C	5 m – 50 m	20°-46°	20 - 400 km	2014-

SAR Remote Sensing Education Initiative

Tab 1 Tab 2 Tab 3 Tab 4 Tab 5

Active Radar Remote Sensing

Advantages

- ***all weather*** capability (small sensitivity of clouds, light rain)
- ***day and night*** operation (independence of sun illumination, active instruments, they have their own source of energy)
- ***no effects of atmospheric constituents*** (multitemporal analysis)
- sensitivity to ***dielectric properties*** (water content , biomass, ice)
- sensitivity to ***surface roughness*** (ocean wind speed)
- accurate measurements of ***distance*** (interferometry)
- sensitivity to ***man made objects***
- sensitivity to ***target structure*** (use of polarimetry)
- ***subsurface penetration*** (the longer the wavelength, the higher the transmission through a medium)

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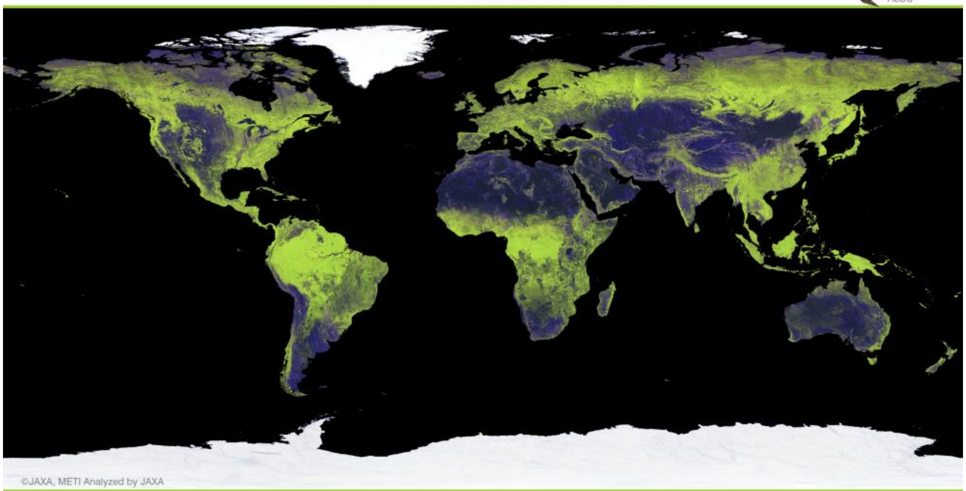
PALSAR 10m Global Mosaic 2009

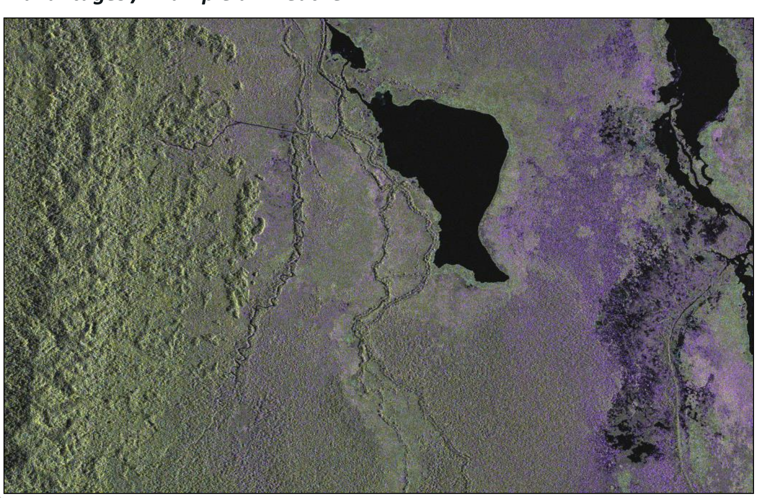


R:HH G:HV B:HH/HV

Tab 1 | Tab 2 | Tab 3 | Tab 4 | Tab 5

Active Radar Remote Sensing

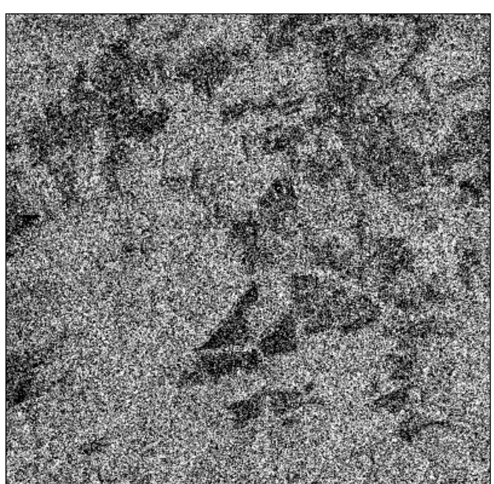
Advantages / Example all weather



TS-X, Brazil

Speckle "Noise" – Salt and Pepper

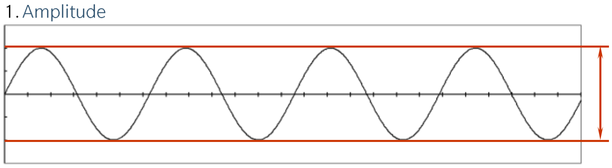
Speckle "Noise" – Salt and Pepper

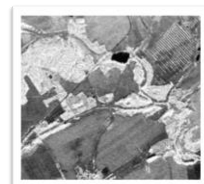


Active Radar Remote Sensing

Parameters measured by SAR

1. Amplitude



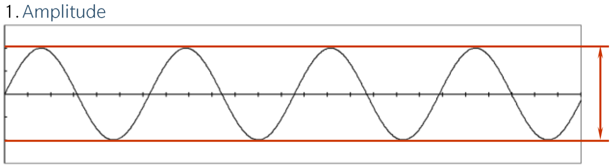


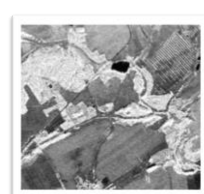
Copyright ©

Active Radar Remote Sensing

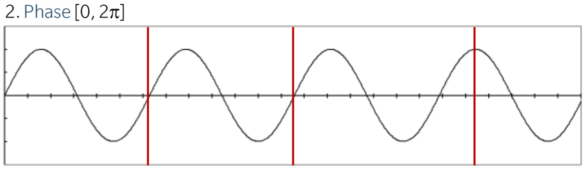
Parameters measured by SAR

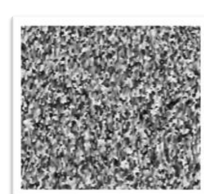
1. Amplitude





2. Phase [0, 2π]

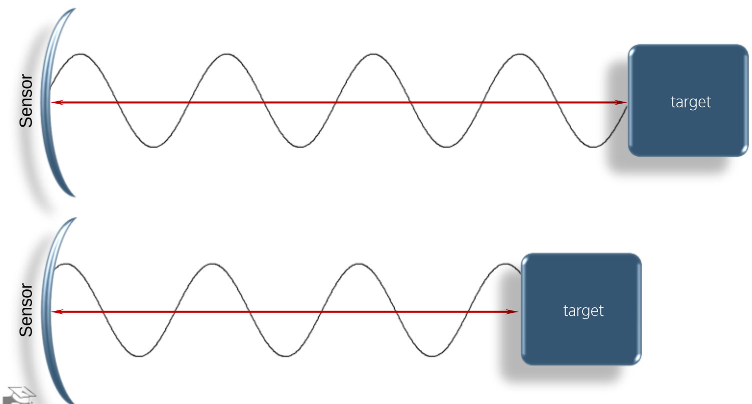




Active Radar Remote Sensing

Phase depends on:

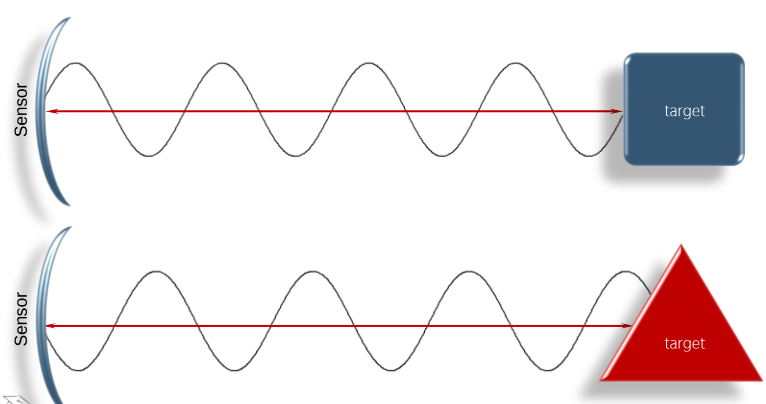
1. Distance between sensor und target



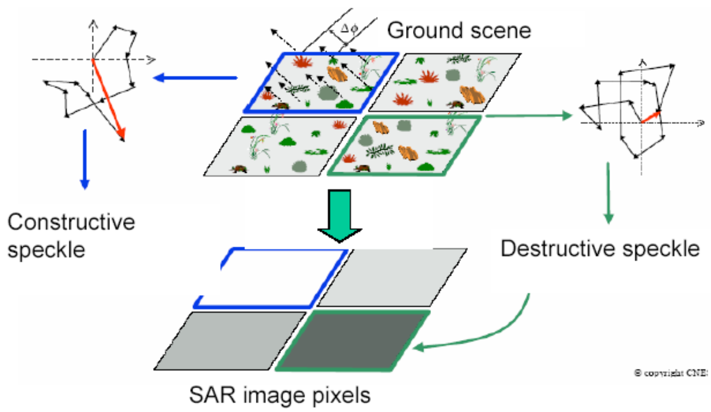
Active Radar Remote Sensing

Phase depends on:

2. Characteristics of target



Speckle “Noise”



Speckle “Noise”

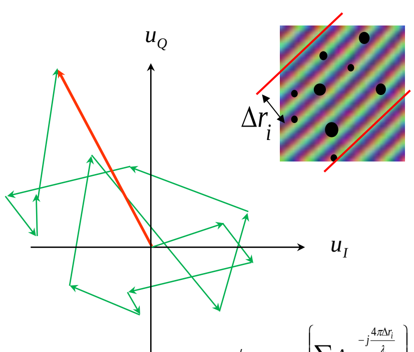
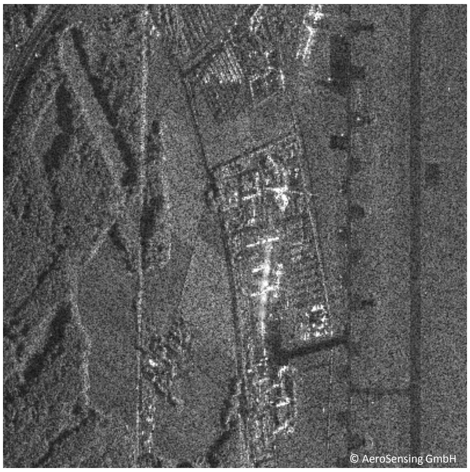


Fig. 28: © DLR

$$\phi_{scatt} = \arg\left\{\sum A_i e^{-j\frac{4\pi\Delta r_i}{\lambda}}\right\}$$

- Random positive and negative interference of wave contributions from the many individual scatterers within one resolution cell
  - varying brightness from pixel to pixel even for constant σ_0
  - granular appearance even of homogenous surfaces

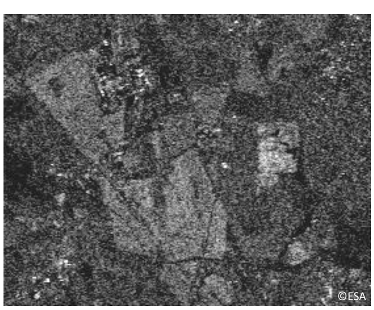
Example for Bayesian Speckle Reduction

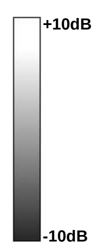


original SAR image
SAR data © AeroSensing GmbH

speckle filtered
Bayesian algorithm

Speckle Reduction by Temporal Multilooking (ERS)

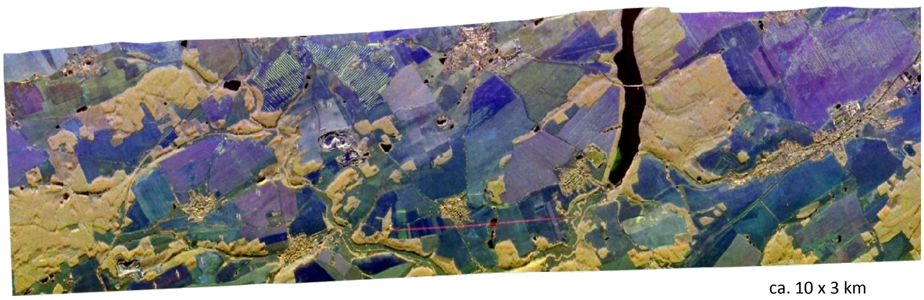




5 spatial looks
20 x 20 m ground resolution
2 dB radiometric resolution

320 spatio-temporal looks
20 x 20 m ground resolution
0.3 dB radiometric resolution

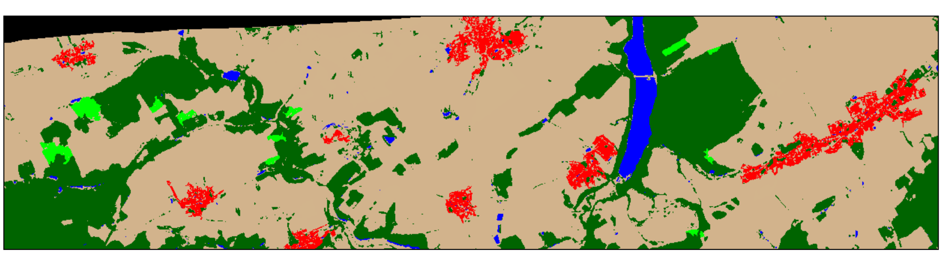
Applications - Examples



ca. 10 x 3 km

E-SAR (L-HH, L-HV, X-VV), Zeulenroda, Germany

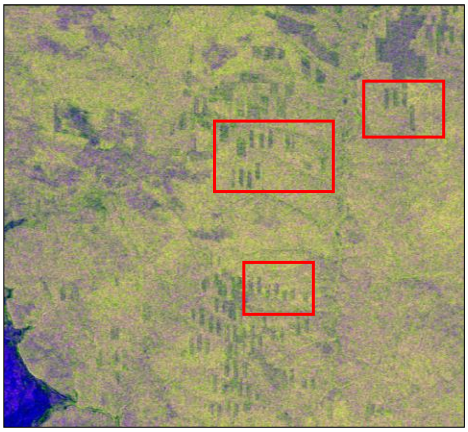
Applications - Examples



Classification of Land Cover

Applications - Examples

Detection of Change



ASAR APP (HH, HV, HV/HH), Siberia 2006

Landsat (4, 5, 3), Siberia 1990

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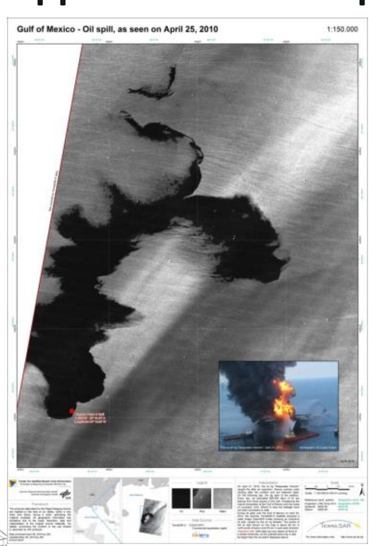
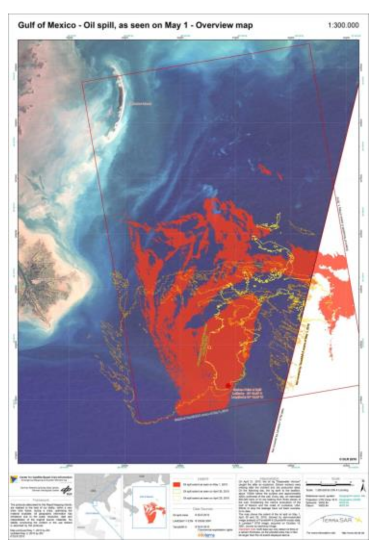
Applications - Examples





Rapid situation analysis

SAR Remote Sensing Education Initiative

Summary

Applications of radar remote sensing systems

SAR's ability to pass relatively unaffected through clouds, illuminate the Earth's surface with its own signals, and precisely measure distances makes it especially useful for the following applications:

- Sea ice monitoring
- Cartography
- Surface deformation detection
- Glacier monitoring
- Crop production forecasting
- Forest cover mapping
- Ocean wave spectra
- Urban planning
- Coastal surveillance (erosion)
- Monitoring disasters such as forest fires, floods, volcanic eruptions, and oil spills
- etc.