HAROKOPIO UNIVERSITY

esa

→ 4th ADVANCED TRAINING COURSE IN LAND REMOTE SENSING

Synthetic Aperture Radar (SAR): Principles and Applications

Alberto Moreira

German Aerospace Center (DLR)

Microwaves and Radar Institute

82230 Oberpfaffenhofen, Germany

e-mail: alberto.moreira@dlr.de / Web: www.dlr.de/HR

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Remote Sensing: Motivation

- Provides unique information to solve societal changelles of global dimension

Climate Change

Environment

Resources

Sustainable Development

Megacities

Mobility

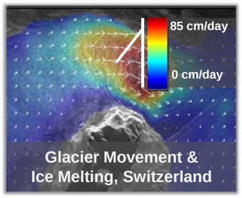
Hazards

Disaster

DLR

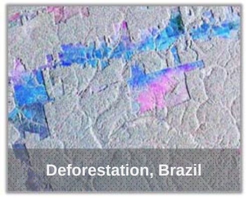
Remote Sensing: Motivation

- Provides unique information to solve societal changelles of global dimension

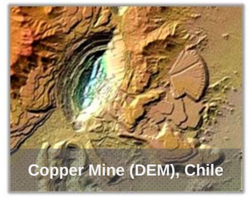


Glacier Movement & Ice Melting, Switzerland

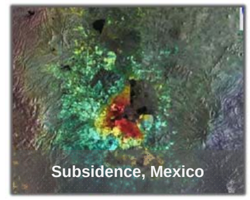
Climate Change


Deforestation, Brazil

Environment


Copper Mine (DEM), Chile

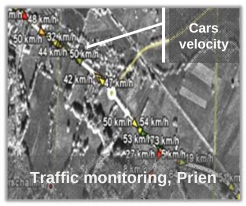
Resources


Subsidence, Mexico

Sustainable Development

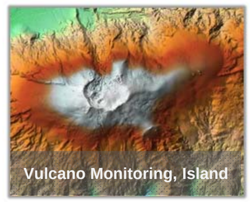

Urban Planing, Istanbul

Megacities



Traffic monitoring, Prien

Mobility


Vulcano Monitoring, Island

Hazards


Flooding, Deggendorf, Germany

Disaster

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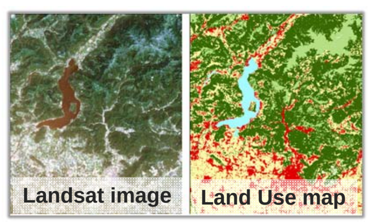
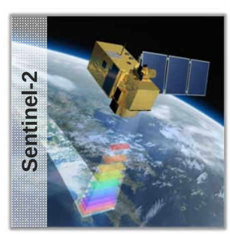
Remote Sensing

- Measuring objects properties from distance with dedicated instruments

- Acquired information
  - spatial (geometric resolution)
  - spectral (frequency resolution)
  - intensity (radiometric resolution)
  - temporal (revisit time)


Landsat image Land Use map

- Different types of remote sensing sensors:
  - Optical and infrared sensors
    - passive:
      - High-resolution
      - Multispectral, hyperspectral
    - active: Lidar


Sentinel-2

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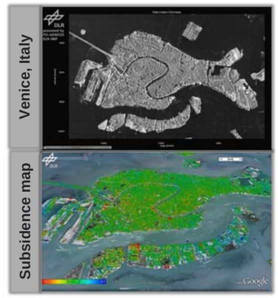
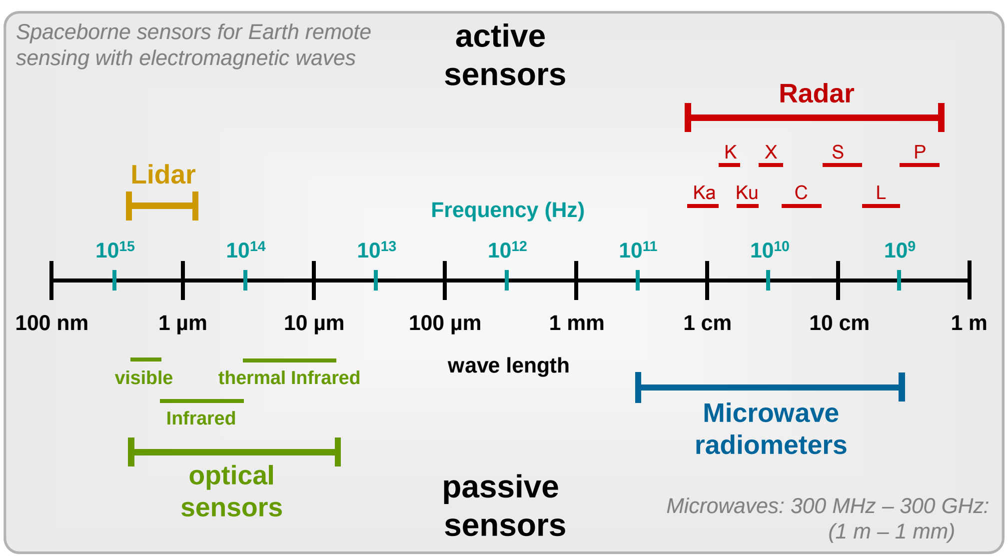
Remote Sensing

- Measuring objects properties from distance with dedicated instruments
- Acquired information
  - spatial (geometric resolution)
  - spectral (frequency resolution)
  - intensity (radiometric resolution)
  - temporal (revisit time)



- Different types of remote sensing sensors:
  - Microwave sensors
    - passive (radiometers)
    - active (radars)
      - Scatterometer, Altimeter
      - Synthetic Aperture Radar - SAR

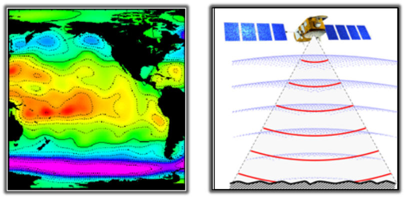
Types of Remote Sensing Sensors



Spaceborne Radar Remote Sensing

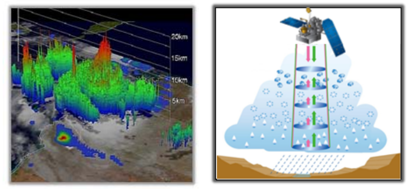
Radar Altimeter

Measures surface topography (surface height)



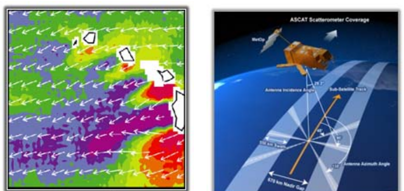
Weather Radar

Measures three-dimensional rainfall distribution



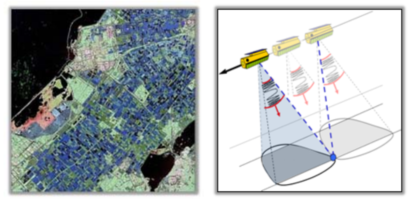
Radar Scatterometer

Measures surface backscattering (sea winds)



Synthetic Aperture Radar (SAR)

Measures 2D surface backscattering



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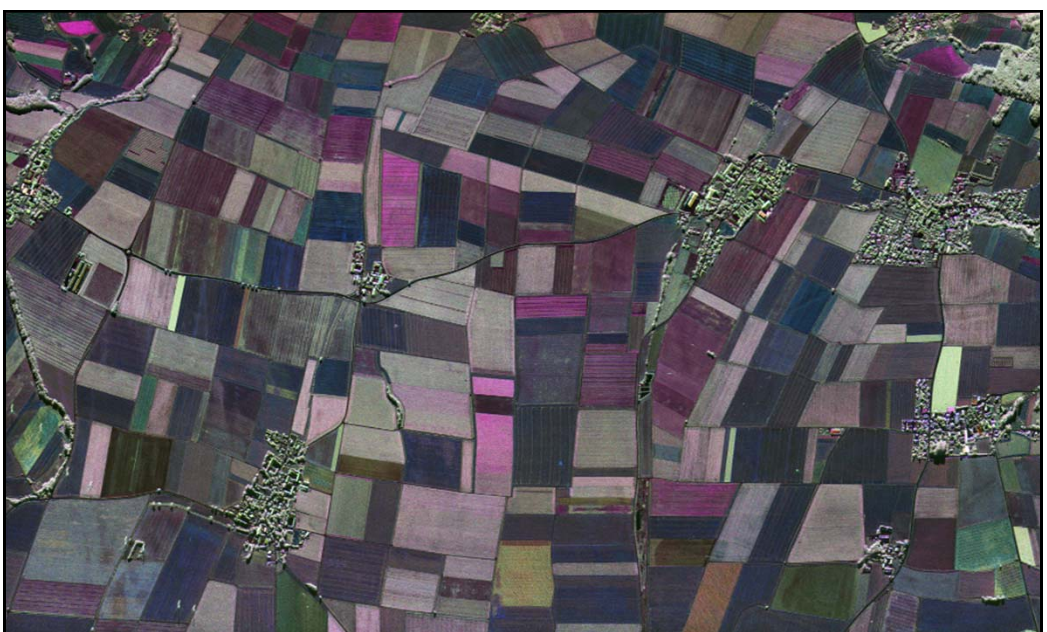
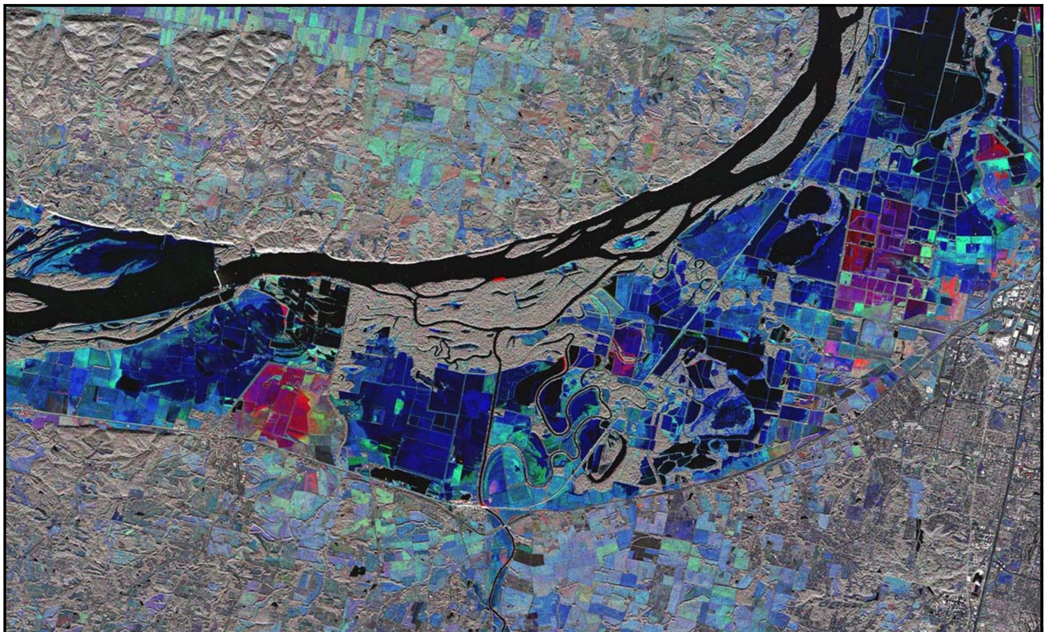
X-band, High Resolution Airborne SAR, F-SAR, Kaufbeuren, Germany

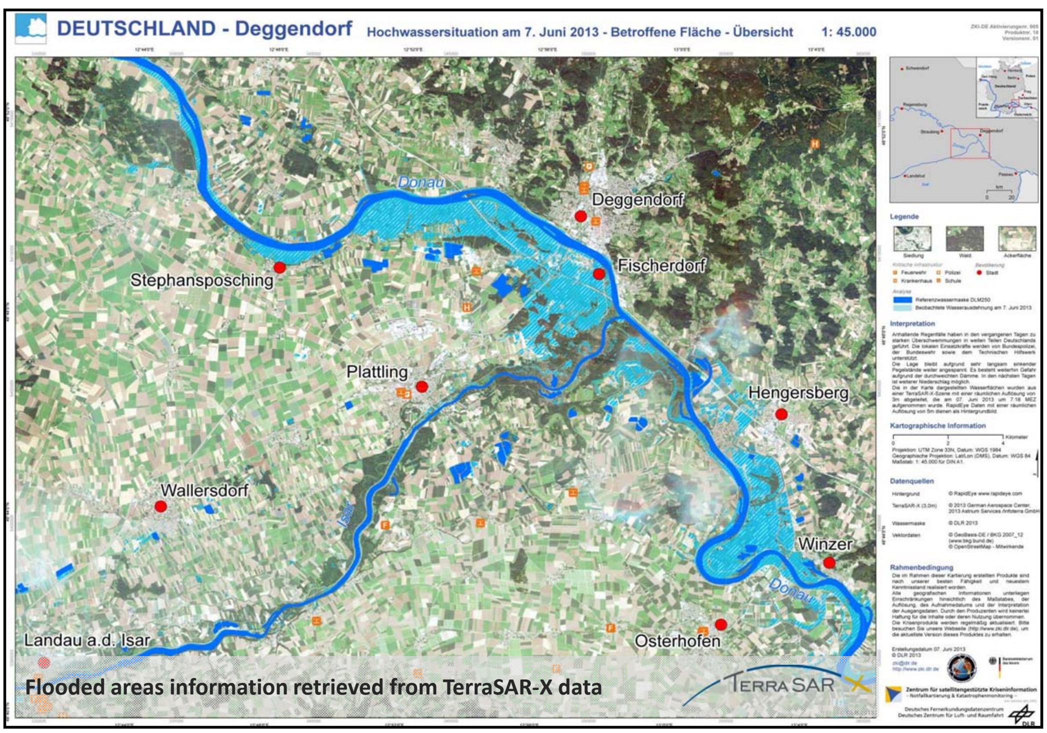
X-band, Airborne SAR, F-SAR, Full Polarimetric

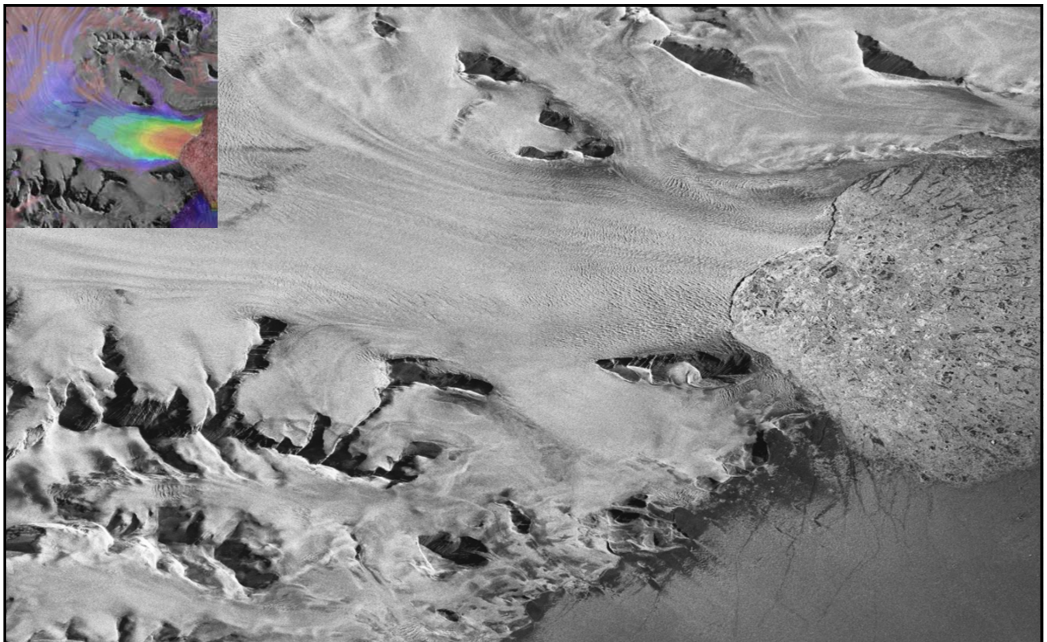


C-band, Airborne SAR, F-SAR, Full Polarimetric

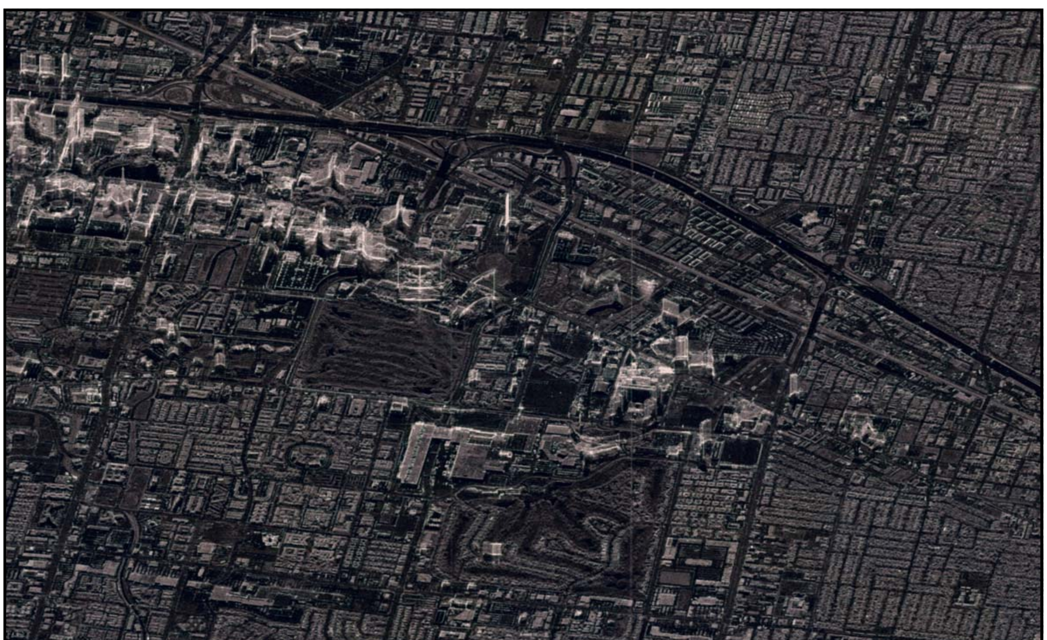


TerraSAR-X, Mississippi, USA - Flooding

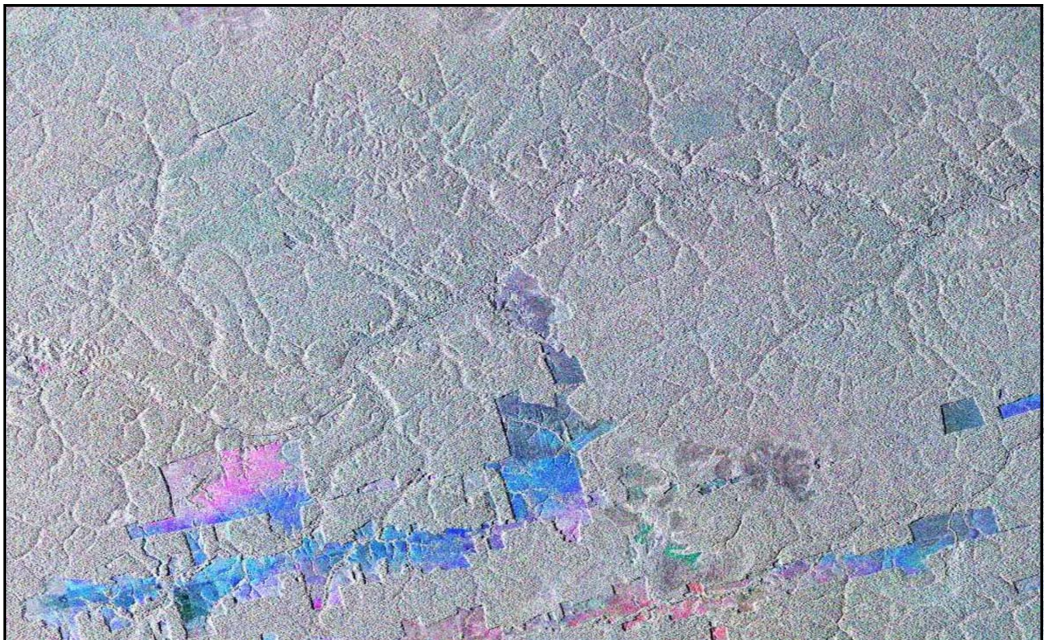




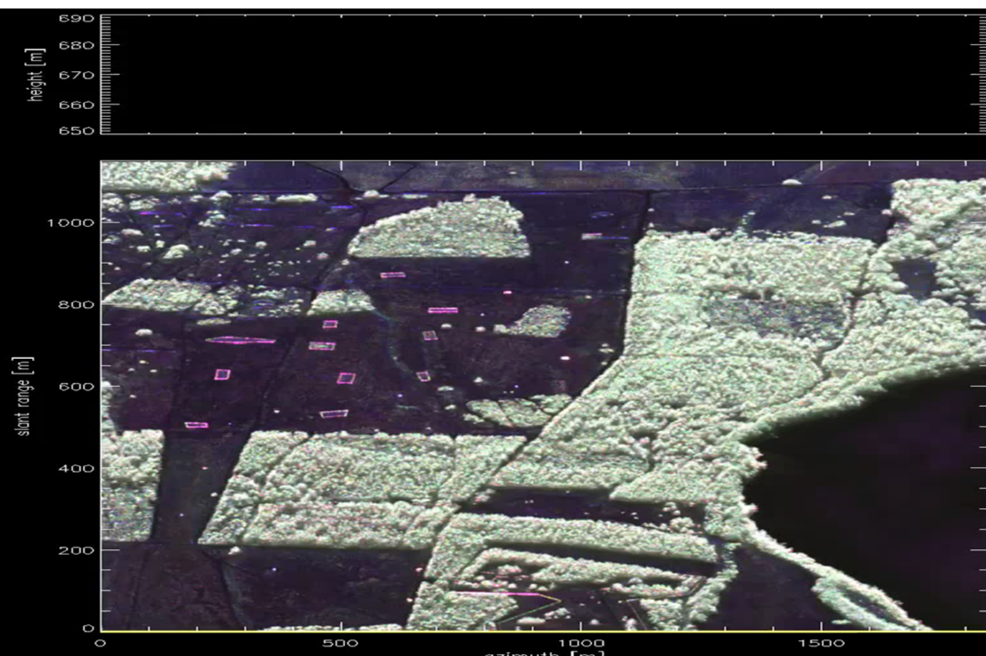
TerraSAR-X, Drygalski Glacier, Oct 2007 – July 2008



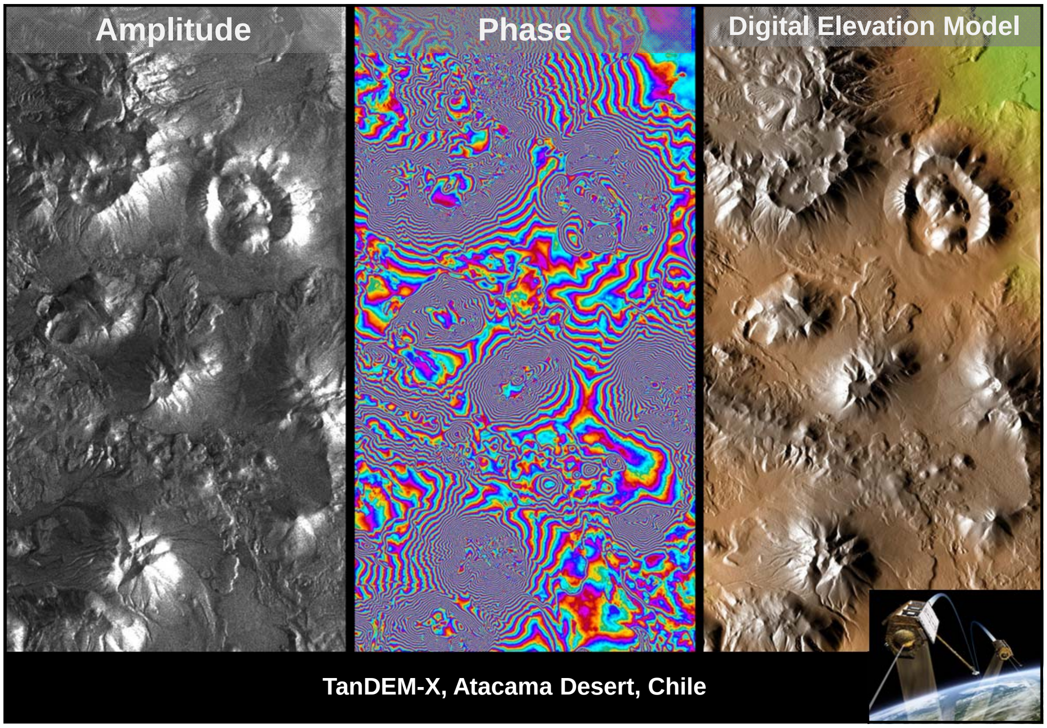
TerraSAR-X, Las Vegas, USA (time series of 20 images)



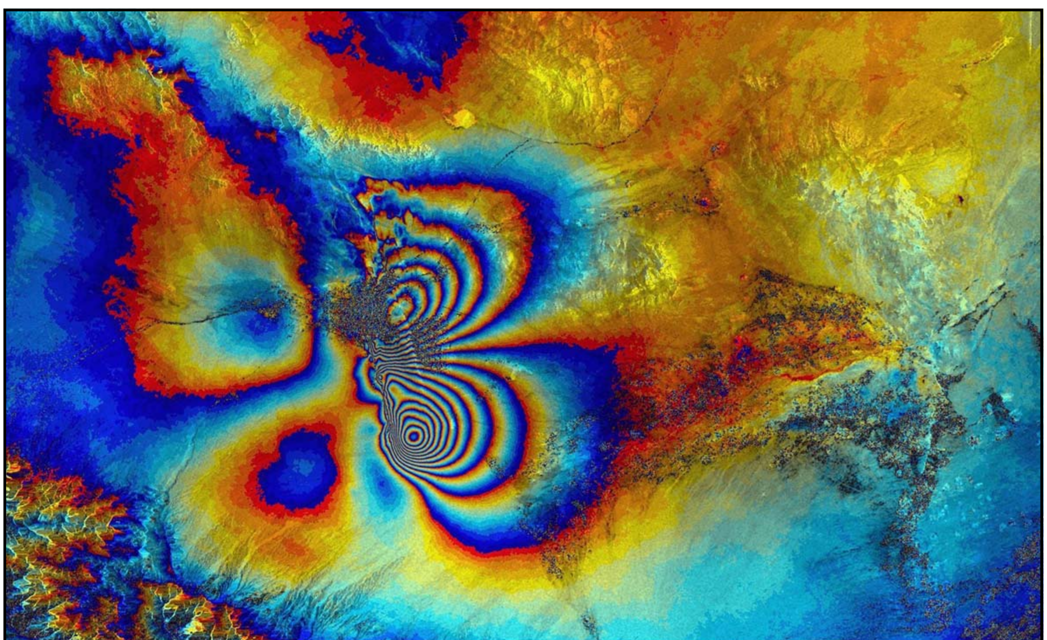
Mato Grosso, Brazil - Deforestation



SAR Tomography, L-Band, Airborne SAR, F-SAR, Germany



TanDEM-X, Atacama Desert, Chile



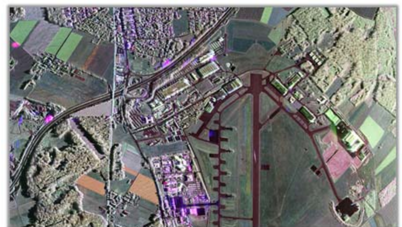
ENVISAT/ASAR, Bam Earthquake, 2003 (© ESA)

Motivation for Spaceborne SAR

- Complementary information to optical systems (e.g. polarimetry)

TerraSAR-X, Pyramids of Giza, Egypt

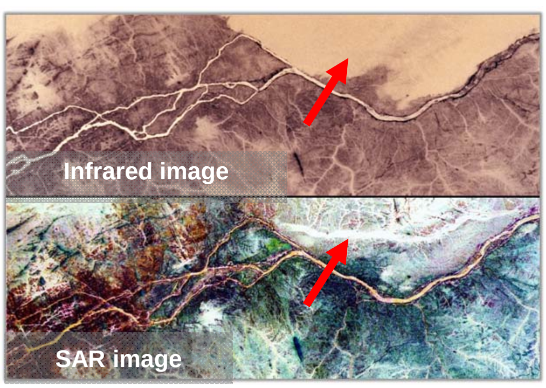
F-SAR, Kaufbeuren, Germany



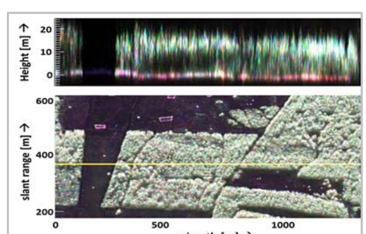
F-SAR, Oberpfaffenhofen, Germany

Motivation for Spaceborne SAR

- Complementary information to optical systems
- Penetration of radar waves



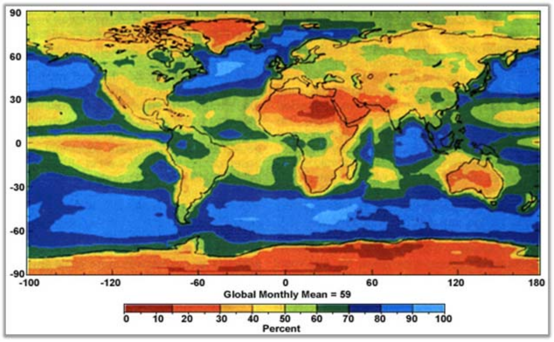
Forest height with
polarimetric SAR interferometry



Forest profile with SAR tomography

Motivation for Spaceborne SAR

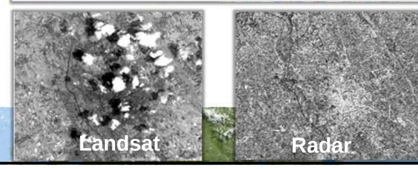
- Complementary information to optical systems
- Penetration of radar waves
- Weather independent



average global cloud coverage

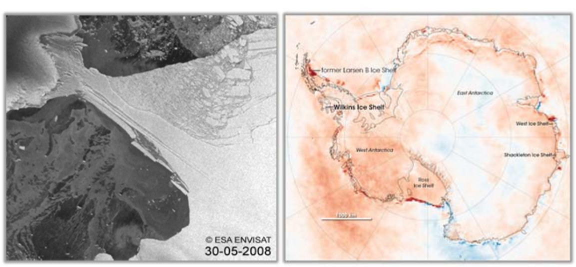
ENVISAT (ASAR and MERIS), Alps, Austria

SIR-C/X-SAR image, Kamchatka, Russia

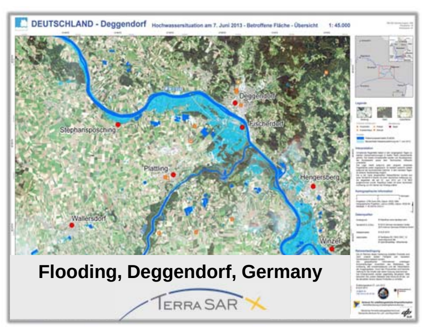


Motivation for Spaceborne SAR

- Complementary information to optical systems
- Penetration of radar waves
- Weather independent
- Day-and-night imaging capability



Wilkins ice shelf collapse during the antarctic winter

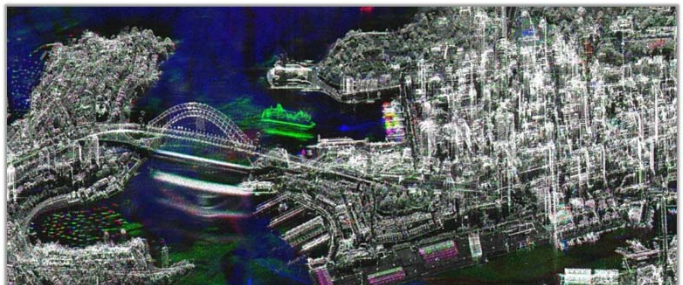


Flooding, Deggendorf, Germany

Motivation for Spaceborne SAR

- Complementary information to optical systems
- Penetration of radar waves
- Weather independent
- Day-and-night imaging capability
- Geometric resolution independent of the distance

TerraSAR-X, Berlin



TerraSAR-X, multi-temporal, Sydney, Australia

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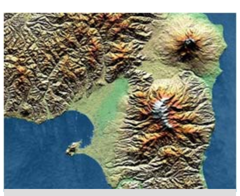
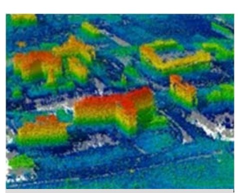
Motivation for Spaceborne SAR

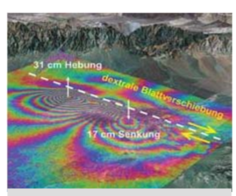
- Complementary information to optical systems
- Penetration of radar waves
- Weather independent
- Day-and-night imaging capability
- Geometric resolution independent of the distance
- New image products by coherent combination of radar images (i.e. using phase information in the radar images)



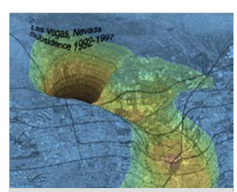
3D Mapping
(Digital Elevation Model)



Tomography
(Urban Mapping)



Differential Interferometry
(Earthquake deformation)



Differential Interferometry
(Subsidence)

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SAR Main Properties and Applications

- high resolution capability (independent of flight altitude)
- weather independence by selecting proper frequency range
- day/night imaging capability due to own illumination
- complementary to optical systems
- polarization signature can be exploited (physical structure, dielectric constant)
- innumerous applications areas:
  - Topography (DEM generation with interferometry)
  - Oceanography (wave spectra, wind speed, ocean currents)
  - Glaciology (snow wetness, snow water equivalent, glacier monitoring)
  - Agriculture (crop classification and monitoring, soil moisture)
  - Geology (terrain discrimination, subsurface imaging)
  - Forestry (forest height, biomass, deforestation)
  - Moving Target Indication (MTI)
  - Volcano and earthquake monitoring (differential interferometry)
  - Environment monitoring (oil spills, flooding, urban growth, global change)
  - Military surveillance and reconnaissance (strategic policy, tactical assessment)

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Outline of Lecture

- ***Part I : Motivation for Spaceborne SAR Remote Sensing*** ✓
- ***Part II : Basics of Synthetic Aperture Radar***

  Radar principle, SAR basic principles, backscattering coefficient, geometric resolution, spaceborne SAR systems, frequency bands, summary

- ***Part III: Theory: SAR Image Formation, Image Properties***

  SAR block diagram, synthetic aperture, SAR image formation, impulse response function, calibration, SAR signal for distributed targets, speckle, multi-look processing

- ***Part IV: Advanced SAR techniques and Future Developments***

  ScanSAR imaging, Spotlight SAR imaging, outlook, references

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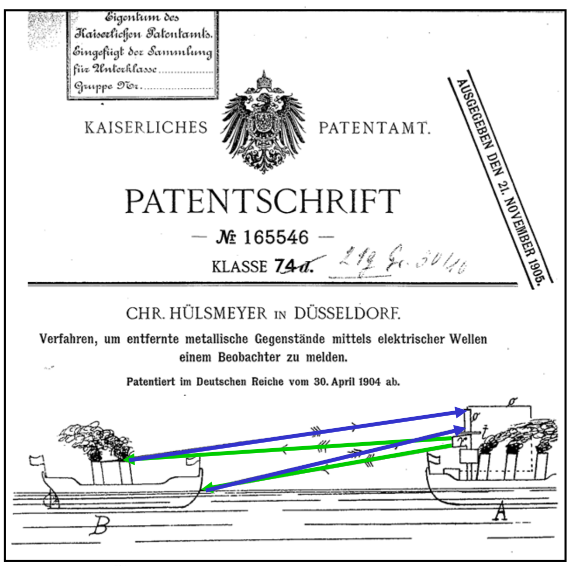
Radar: Radio Detection and Ranging

Christian Hülsmeyer and the Radar Invention (1904)


Eigentum des Kaiserlichen Patentamts.
Eingefügt der Sammlung für Unterklasse ....
Gruppe Nr. ....

KAISERLICHES PATENTAMT.

AUSGEGEBEN DEN 21. NOVEMBER 1905.

PATENTSCHRIFT

— № 165546 —

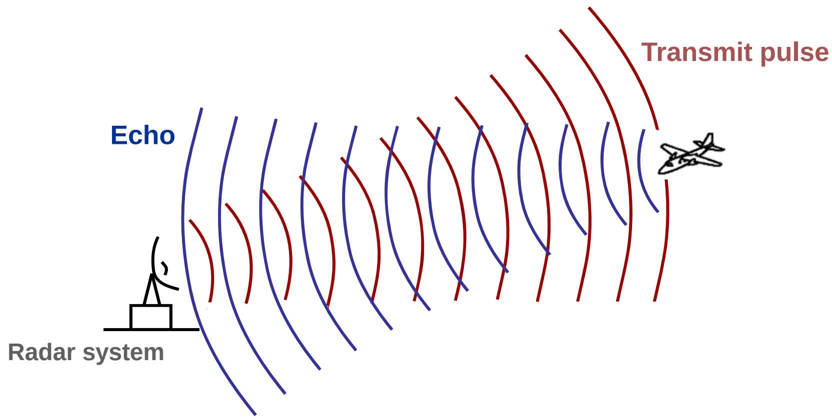
KLASSE 74d.

CHR. HÜLSMEYER IN DÜSSELDORF.

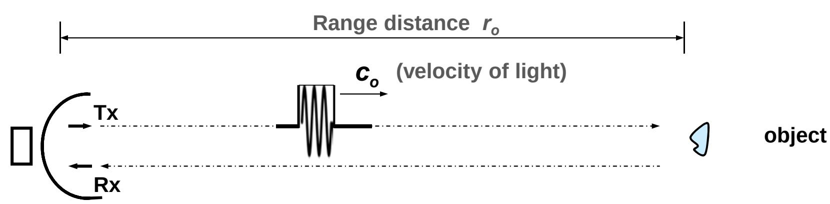
Verfahren, um entfernte metallische Gegenstände mittels elektrischer Wellen einem Beobachter zu melden.

Patentiert im Deutschen Reiche vom 30. April 1904 ab.

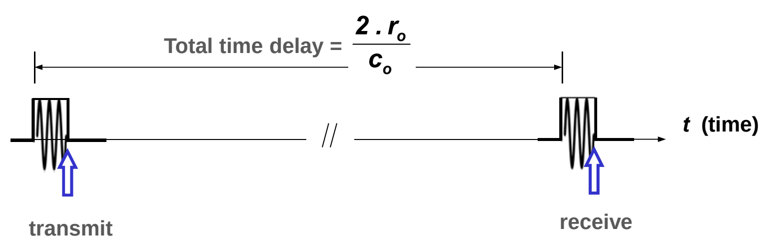
Radar Principle



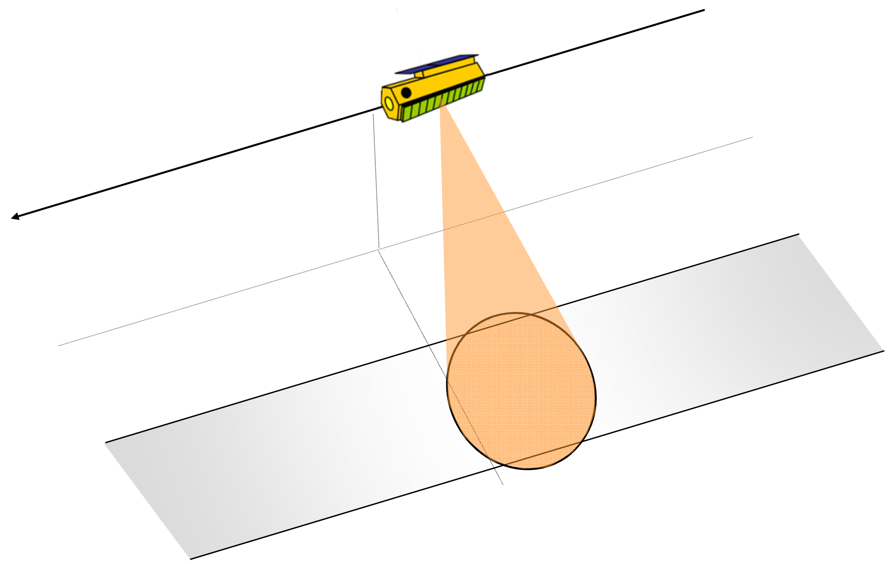
Radar Measurement Principle



- Received echo signal (back-scattered signal of imaged object):



Side-Looking Radar Imaging Geometry



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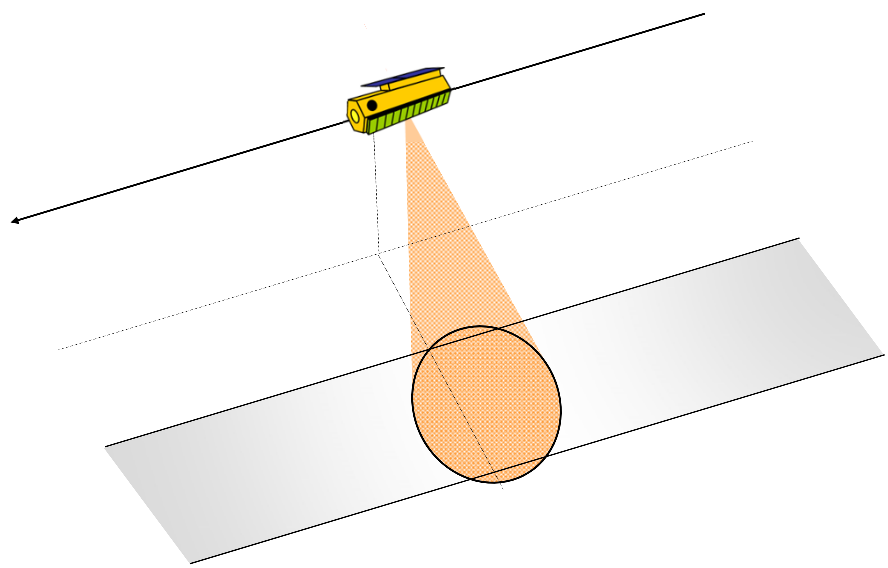
Side-Looking Radar Imaging Geometry



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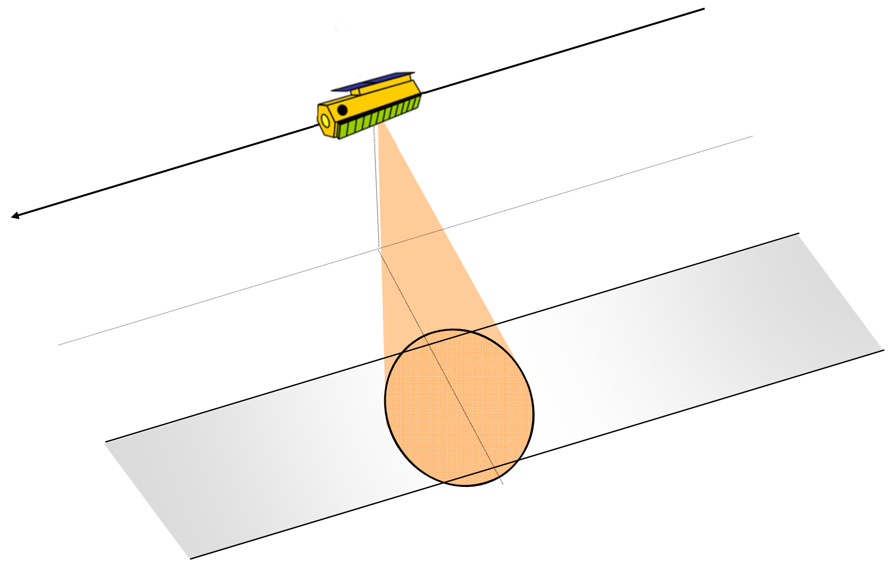
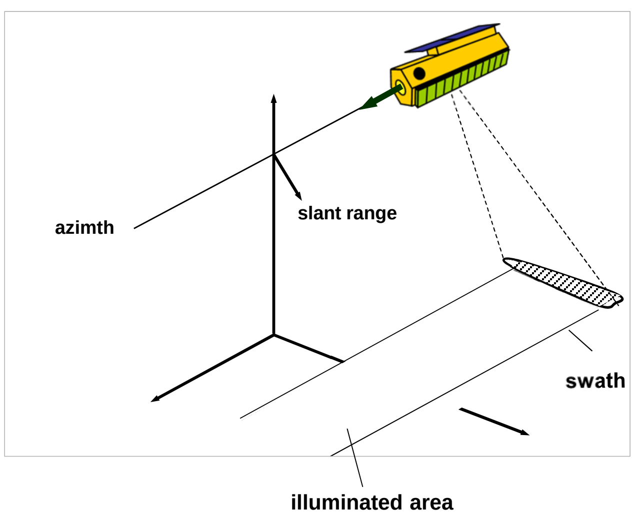
Side-Looking Radar Imaging Geometry

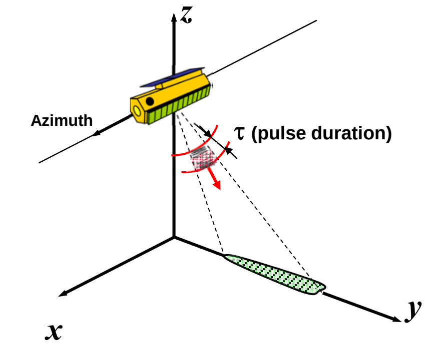


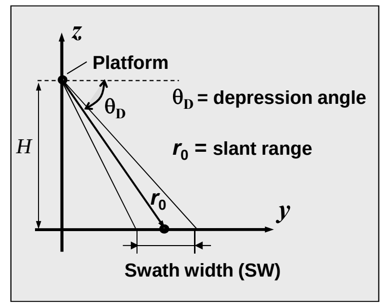
Side-Looking Radar Imaging Geometry



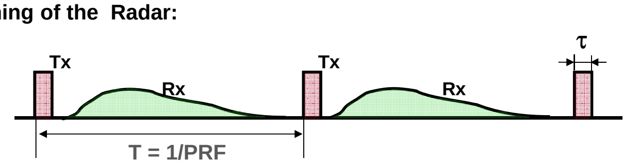
- Pulsed radar system
- Two-dimensional imaging (azimuth x slant range)

Side Looking Geometry and Timing



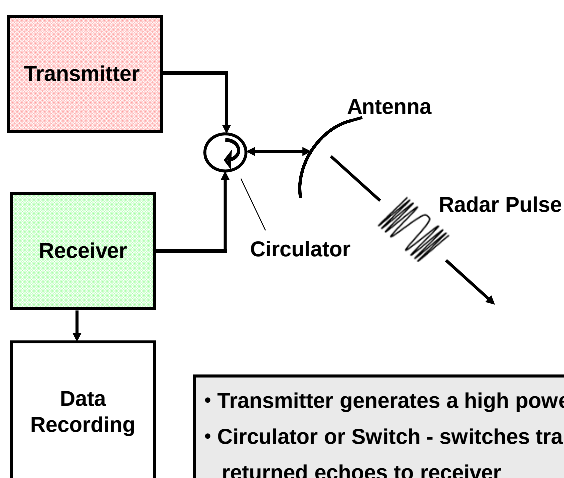


- Timing of the Radar:



PRF = pulse repetition frequency

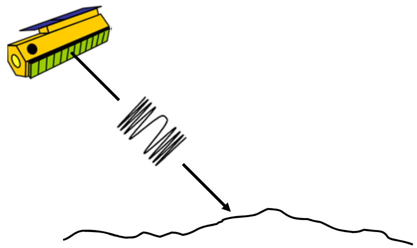
Basic Radar Block Diagram



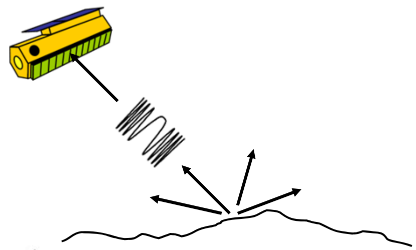
- Transmitter generates a high power pulse
- Circulator or Switch - switches transmitted pulse to antenna, returned echoes to receiver
- Antenna directs transmitted pulses towards the target area
- Receiver amplifies the received signal and converts to base band

What does the Radar measure ?

• *Radar reflectivity (backscattered signal) of targets as a function of their position*



• radar transmits a pulse (travelling velocity is equal to velocity of light)



• some of the energy in the radar pulse is reflected back towards the radar. This is what the radar measures.

It is known as radar backscatter σ_o

(sigma nought or sigma zero).

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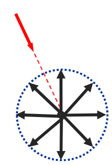
What does the Radar measure ?

• Normalized radar cross-section (backscattering coefficient) is given by:

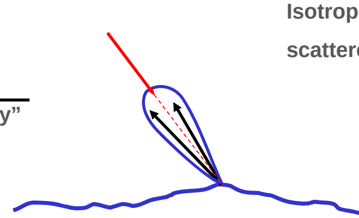
$$\boxed{\sigma_o\ (dB) = 10.\ Log_{10}\ (energy\ ratio)}$$



Isotropic scatterer

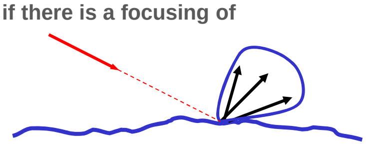
whereby

$$\text{energy ratio} = \frac{\text{received energy by the sensor}}{\text{“energy reflected in an isotropic way”}}$$



The backscattered coefficient can be a positive number if there is a focusing of backscattered energy towards the radar

or



The backscattered coefficient can be a negative number if there is a focusing of backscattered energy way from the radar (e.g. smooth surface)

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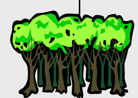
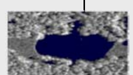
Backscattering Coefficient σ_o

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 terrain (sand)

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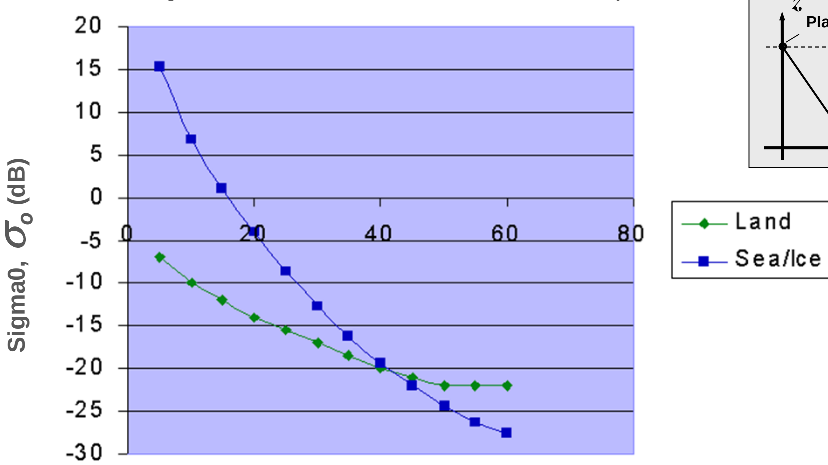
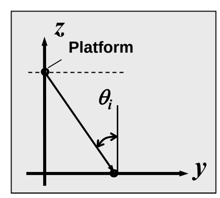
Backscattering Coefficient σ_o

• *Variation of* σ_o *as a function of incidence angle* θ_i



incidence angle, θ_i (degree)



• Dynamic range of received SAR signal is usually greater than 50 dB

DLR

Range and Azimuth Resolution for a Radar System

• ***Range Resolution*** **depends on the bandwidth or pulse duration of transmitted signal**

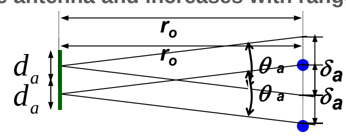
$$\delta_e = \frac{c_o . T_e}{2} = \frac{c_o}{2.B_e}$$

$$T_e = \frac{1}{B_e}$$

B_e ... ***Bandwidth of the radar***

• ***Azimuth Resolution*** **depends on the azimuth size of the antenna and increases with range**

$$\delta_a = \theta_a \, . \, r_o = \frac{\lambda}{d_a} . \, r_o$$



• ***Example 1:*** **Airborne system in X-Band, 25 MHz bandwidth, 3 m antenna, 3000 m range**

δ_e = 6 m $\qquad$ δ_a = 30 m

•***Example 2:*** **satellite system in X-Band, 25 MHz bandwidth, 12 m antenna, 800 km range**

δ_e = 6 m $\qquad$ δ_a = 2000 m !

DLR

Synthetic Aperture Radar (SAR)

DLR

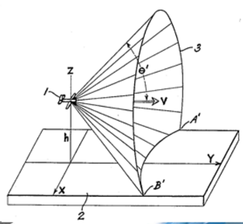
Carl Wiley and the Invention of the Synthetic Aperture Radar

(Carl Wiley, Patent in 1954)

United States Patent Office 3,196,436
Patented July 20, 1965

3,196,436
PULSED DOPPLER RADAR METHODS AND APPARATUS
Carl A. Wiley, Phoenix, Ariz., assignor to Goodyear Aerospace Corporation, a corporation of Delaware
Filed Aug. 13, 1954, Ser. No. 449,559
14 Claims. (Cl. 343—17)

This invention relates to pulsed radar methods and apparatus, and, more particularly, to terrain mapping radars borne by moving objects, for example, an airplane, and making use of the Doppler frequency shift phenomenon to obtain angular resolutions, and/or scanning in azimuth.



GOODYEAR
Goodyear Aircraft Corporation
AKRON 15, OHIO

June 4, 1952

Mr. Carl Wiley
Department 29-A
Basic Physical Research
Goodyear Aircraft Corporation
Litchfield Park, Arizona

Dear Carl:

I was very happy to read your report GER-15-A and to find that you were able to prove that the system tested in the sonic simulator proved your prediction to be correct.

We all here appreciate the significance of this accomplishment and are very proud of your and your associates work.

Kindly accept our congratulations and our best wishes for continued success.

With kindest personal regards,

Sincerely yours,

Karl Arnstein

Karl Arnstein
Vice President

KA
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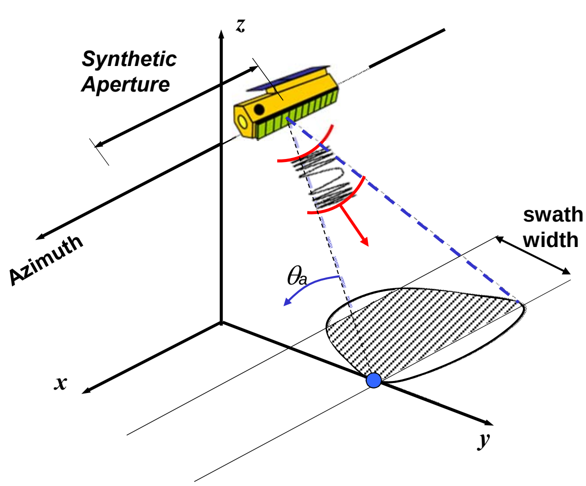
NO CONTRACT VALID UNLESS IN WRITING AND SIGNED BY DULY AUTHORIZED OFFICERS

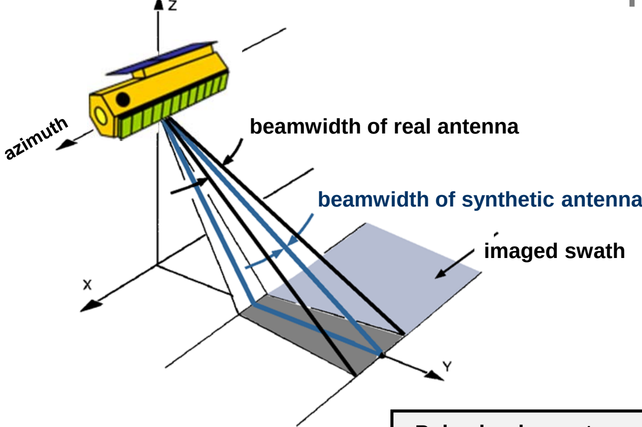
DLR

SAR Basic Principle



DLR

SAR Basic Principle



- Pulsed radar system
- Radar system must be coherent (stable local oscillator). Phase information is preserved
- Two-dimensional imaging (azimuth x slant range)
- Azimuth resolution is independent on range distance !

DLR

Azimuth Resolution of a SAR system

- Length of the synthetic aperture: L_{sa}

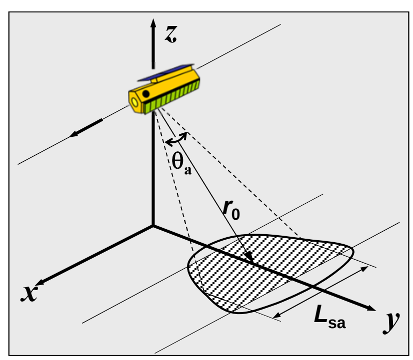
$$L_{\mathrm{sa}} = \Theta_{\mathrm{a}} \cdot r_0 = \frac{\lambda}{d_{\mathrm{a}}} \cdot r_0 \ .$$

- Beamwidth of the synthetic antenna: θ_{sa}

$$\Theta_{\mathrm{sa}} = \frac{d_{\mathrm{a}}}{2 \cdot r_0} \ .$$

- Azimuth resolution: δ_a

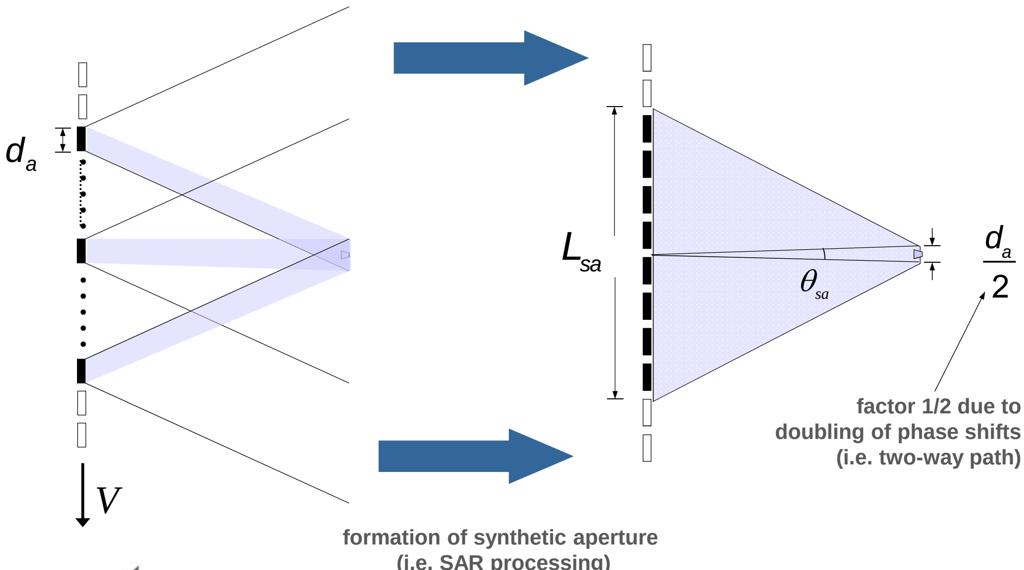
$$\delta_{\mathrm{a}} = \frac{d_{\mathrm{a}}}{2} \ .$$



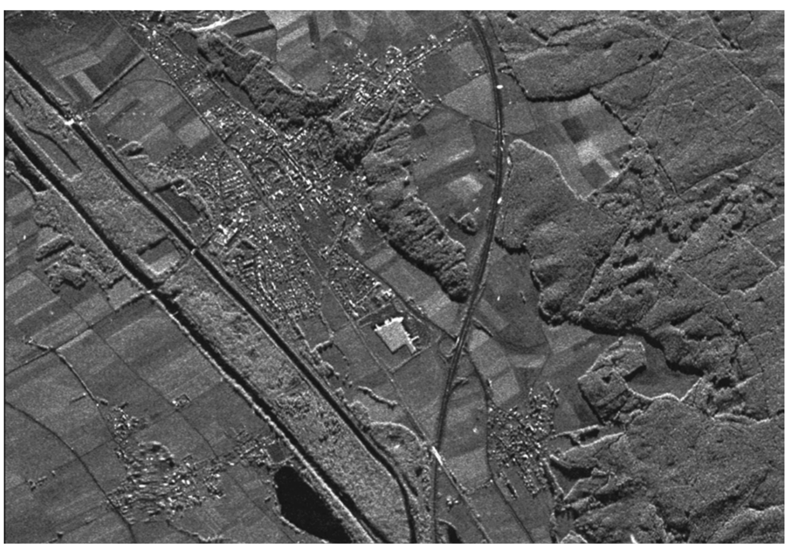
azimuth resolution = half antenna length in azimuth

DLR

Formation of a Synthetic Aperture

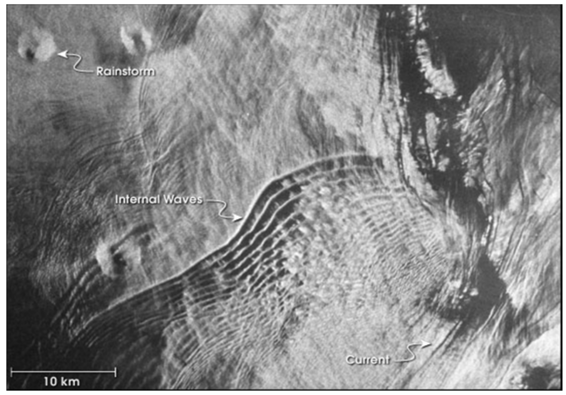


Single Channel Radar Image



E-SAR image (X-band) processed in real-time, 3 x 3 m resolution, 6 looks

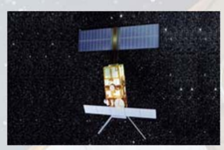
First Civilian SAR Satellite: SEASAT (1978)



Launch	June 26, 1978	Frequency	1,275 GHz
Altitude	~780 km	Bandwidth	19 MHz
Weight	2300 kg	Antenna Size	10,74 m x 2,16 m
Inc. Angle	~ 23°		
Swath Width	100 km	Resolution	25 m x 25 m

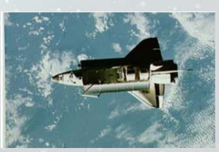
Spaceborne SAR Systems

SEASAT
NASA/JPL (USA)
L-Band, 1978



ERS-1/2
European Space Agency (ESA)
C-Band, 1991-2000/1995-2011

J-ERS-1
Japanese Space Agency (JAXA)
L-Band, 1992-1998

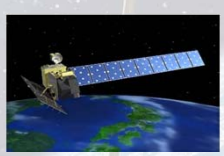


SIR-C/X-SAR
NASA/JPL, L- and C-Band (quad)
DLR / ASI, X-band 1994

RadarSAT-1
Canadian Space Agency (CSA)
C-Band, 1995-2013

Shuttle Radar Topography Mission (SRTM)
NASA/JPL (C-Band), DLR (X-Band)
February 2000

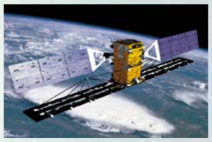
ENVISAT / ASAR
European Space Agency (ESA)
C-Band (dual), 2002-2012



ALOS / PALSAR
Japanese Space Agency (JAXA)
L-Band (quad), Jan. 2006-2011

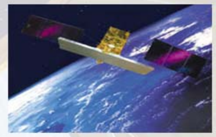
SAR-Lupe
BWB, Germany
5 satellites, X-Band, 2006/2008

Spaceborne SAR Systems



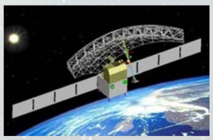
RadarSAT-II
Canadian Space Agency (CSA)
C-Band (quad), 2007

TerraSAR-X/TanDEM-X
DLR /Astrium, Germany
X-Band (quad), 2007/2010

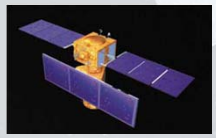


COSMO-SkyMed
ASI, Italy
4 Satellites, X-Band (dual), 2007/2010

Kompsat-5
KARI, Korea
X-band (dual), 2013



HJ-1C -SAR
CRESDA/CAST/NRSCC, China
S-Band (HH or VV), 2013

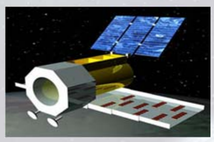


RISAT-1
Indian Space Agency (ISRO), India
C-Band (quad), 2012

SENTINEL-1a/b
ESA, Europe
C-Band (dual), 2014/2015

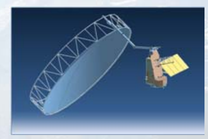
PAZ
Ministry of Defence, Spain
X-Band (quad), 2014

ALOS-2
Japanese Space Agency (JAXA)
L-Band (quad), 2014



SAOCOM-1/2
CONAE/ASI, Argentina
L-Band (quad), 2016/2018

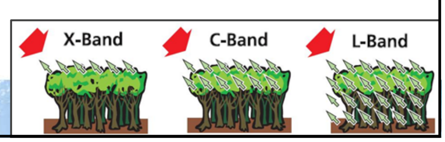
Radarsat Constellation 1-3
CSA/MDA, Canada
C-band (dual), 2016/2017

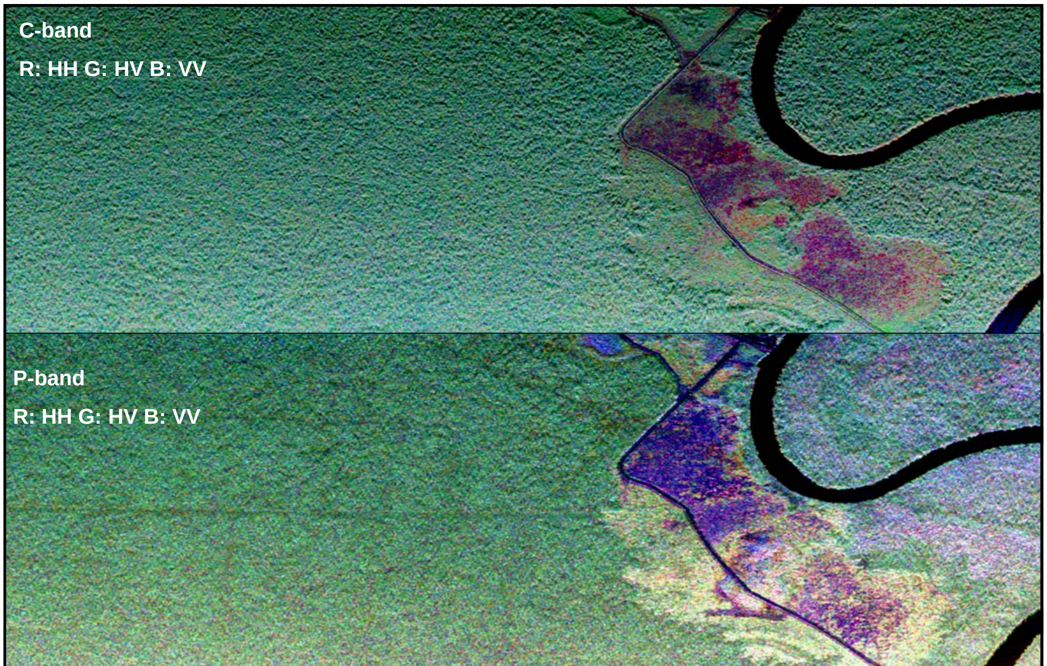


BIOMASS
ESA, Europe
P-Band (quad), 2019

Commonly Used Frequency Bands

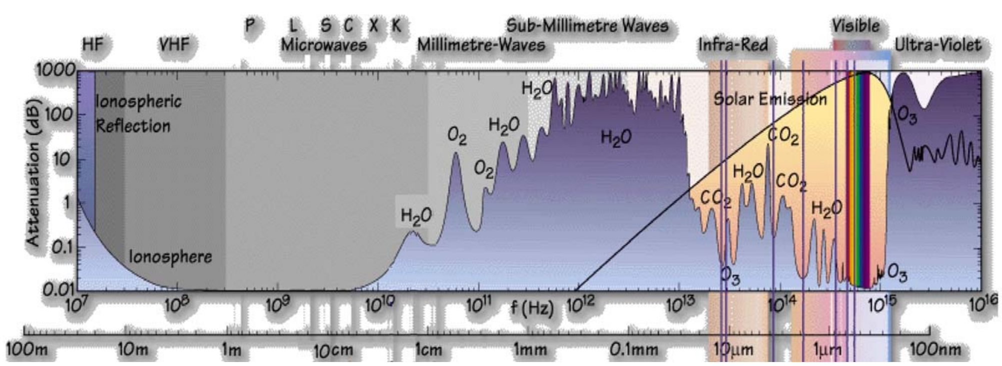
Frequency band	*Frequency range*	*Application Example*
• VHF	300 KHz - 300 MHz	Foliage/Ground penetration, biomass
• P-Band	300 MHz - 1 GHz	biomass, soil moisture, penetration
• L-Band	1 GHz - 2 GHz	agriculture, forestry, soil moisture
• C-Band	4 GHz - 8 GHz	ocean, agriculture
• X-Band	8 GHz - 12 GHz	agriculture, ocean, high resolution radar
• Ku-Band	14 GHz - 18 GHz	glaciology (snow cover mapping)
• Ka-Band	27 GHz - 47 GHz	high resolution radars





Frequency and Polarisation Diversity

Electromagnetic Spectrum



Electromagnetic Spectrum including the attenuation in the atmosphere

PART III

Theory: SAR Image Formation and Image Properties

Outline of Lecture

- *Part I : Motivation for Spaceborne SAR Remote Sensing* ✓
- *Part II : Basics of Synthetic Aperture Radar* ✓

  Radar principle, SAR basic principles, backscattering coefficient, geometric resolution, spaceborne SAR systems, frequency bands, summary
- *Part III: Theory: SAR Image Formation, Image Properties*

  SAR block diagram, synthetic aperture, SAR image formation, impulse response function, calibration, SAR signal for distributed targets, speckle, multi-look processing
- *Part IV: Advanced SAR techniques and Future Developments*

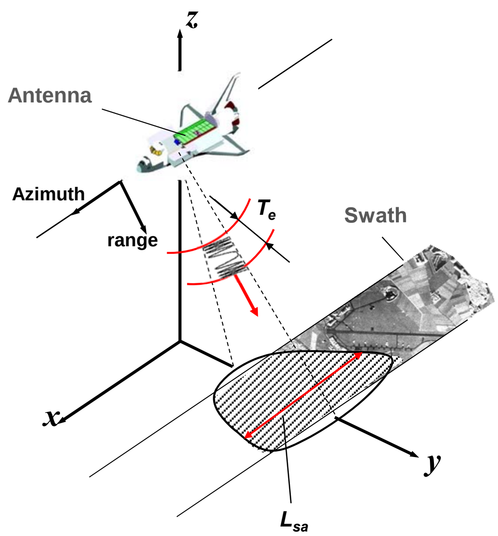
  ScanSAR imaging, Spotlight SAR imaging, outlook, references

DLR

SAR Image Formation

DLR

SAR Basic Principle



1) pulsed radar system
   (PRF = Pulse Repetition Frequency)

2) two dimensional imaging
   (range x azimuth)

3) range resolution

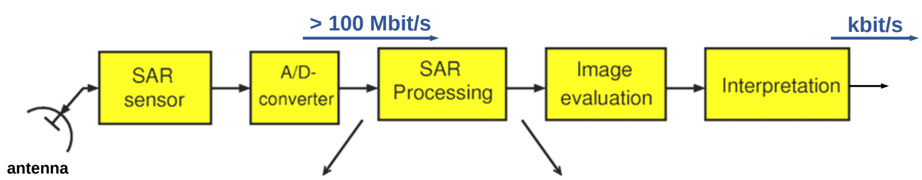
$$\delta_e = \frac{T_e \,.\, c_o}{2} = \frac{c_o}{2 \,.\, B_e}$$

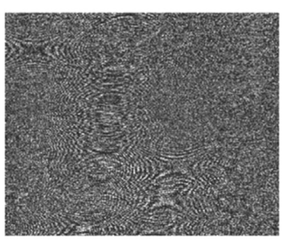
4) azimuth resolution

$$\delta_a = \frac{d_a}{2}$$

5) Radar system must be coherent!

SAR Data Flow

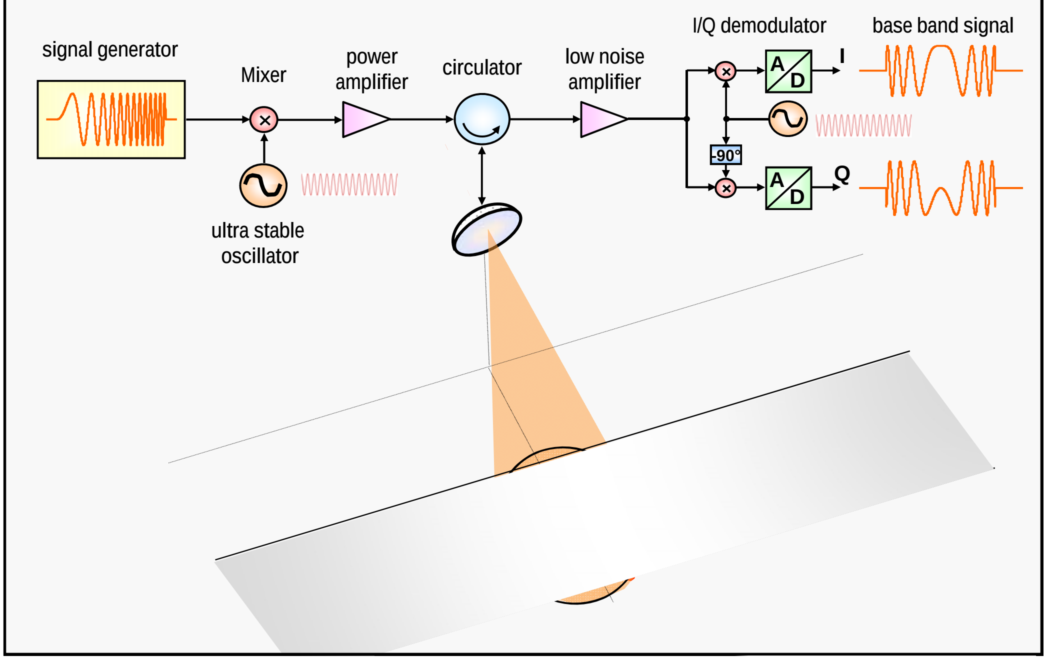




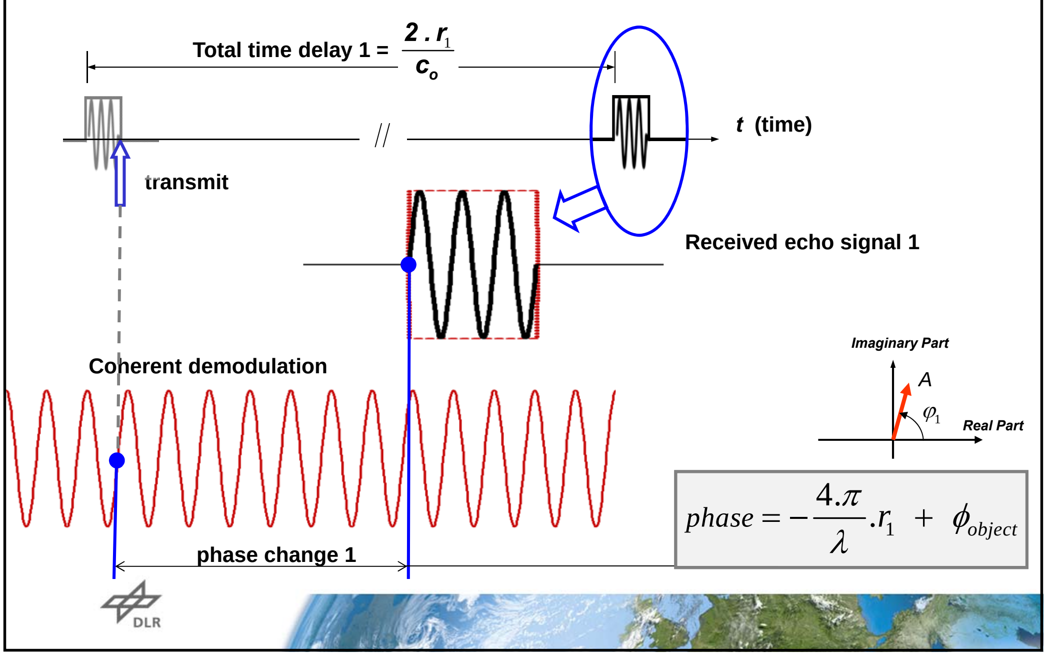
raw data

image data

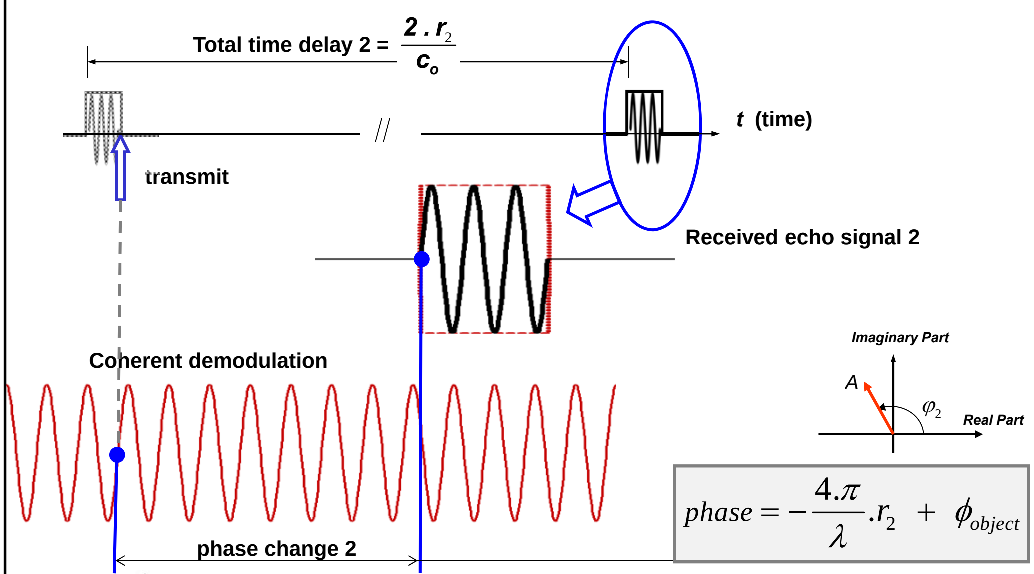
Synthetic Aperture Radar (SAR)



Coherent Measurement Principle



Coherent Measurement Principle



$$phase = -\frac{4.\pi}{\lambda}.r_2 + \phi_{object}$$

Phasor Representation of SAR Signal

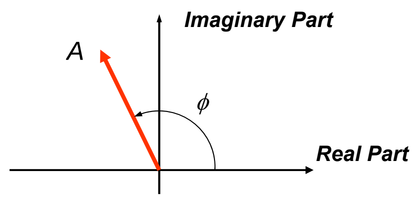
complex representation: $A \cdot \cos(2\pi f_0 t + \phi) \rightarrow A \cdot \exp[j(2\pi f_0 t + \phi)]$

after demodulation: $A \cdot \exp[j \cdot \phi]$

amplitude: A

intensity, power: A^2

phase: ϕ

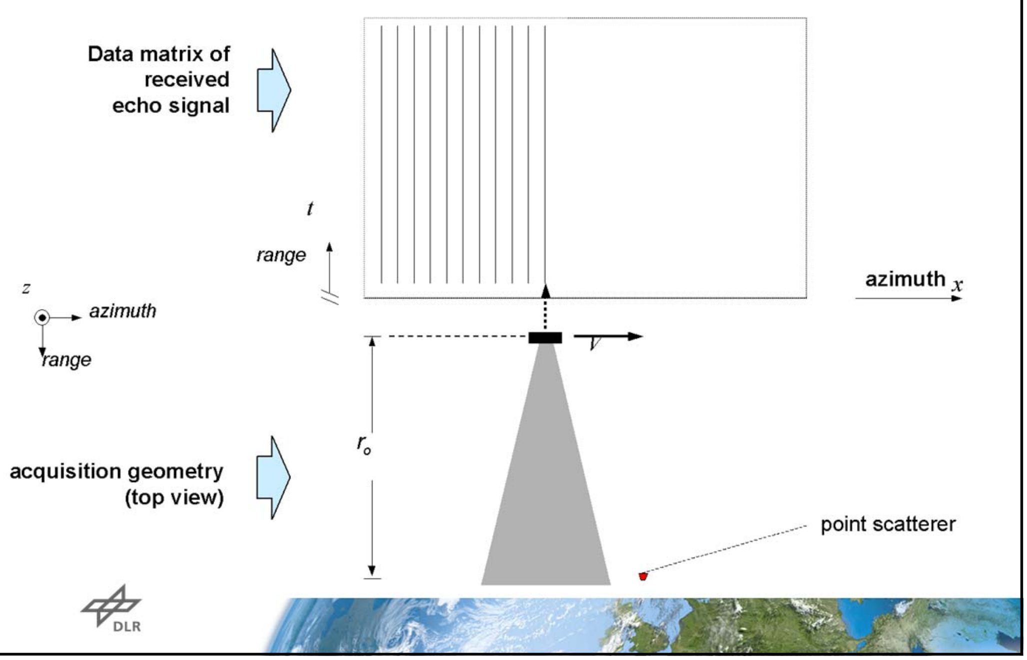


Every pixel of a complex SAR image consists of a real and an imaginary part, i.e. it is a phasor and contains amplitude and phase information.

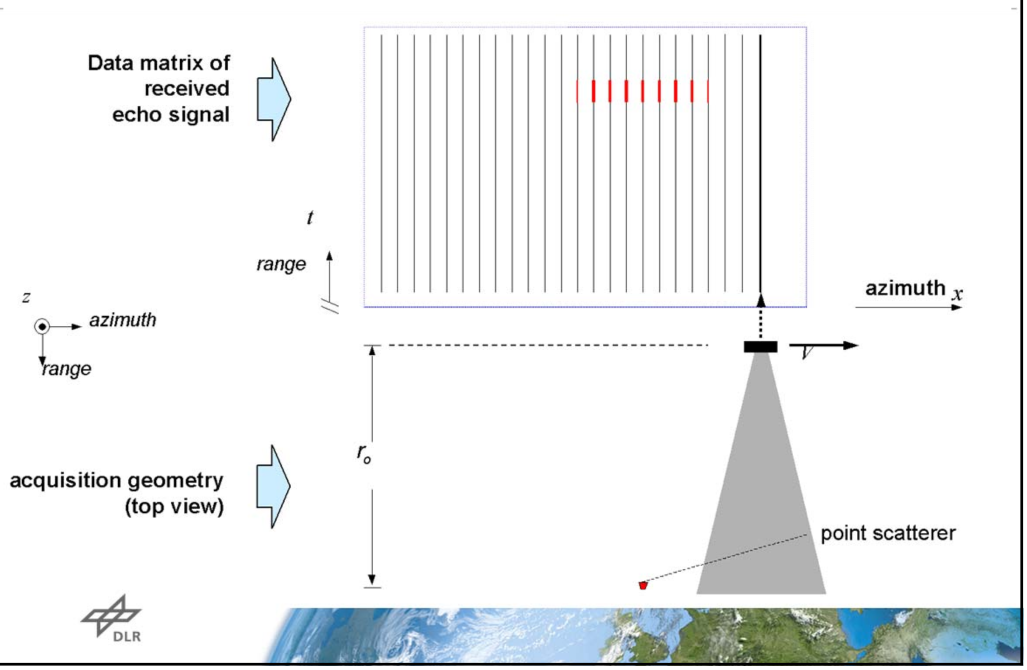
amplitude information $\rightarrow$ *backscattering coefficient* σ_o

$$phase\ information = -\frac{4.\pi}{\lambda}.r + \phi_{object}$$

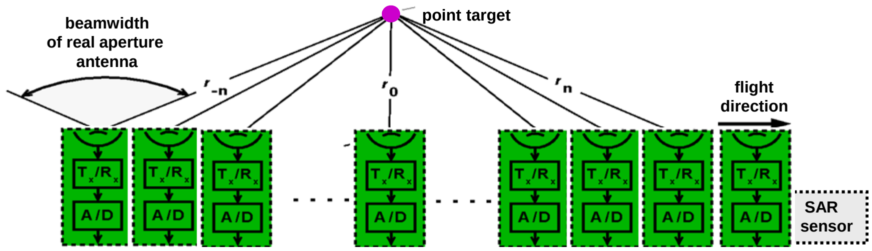
2D Raw Data Matrix



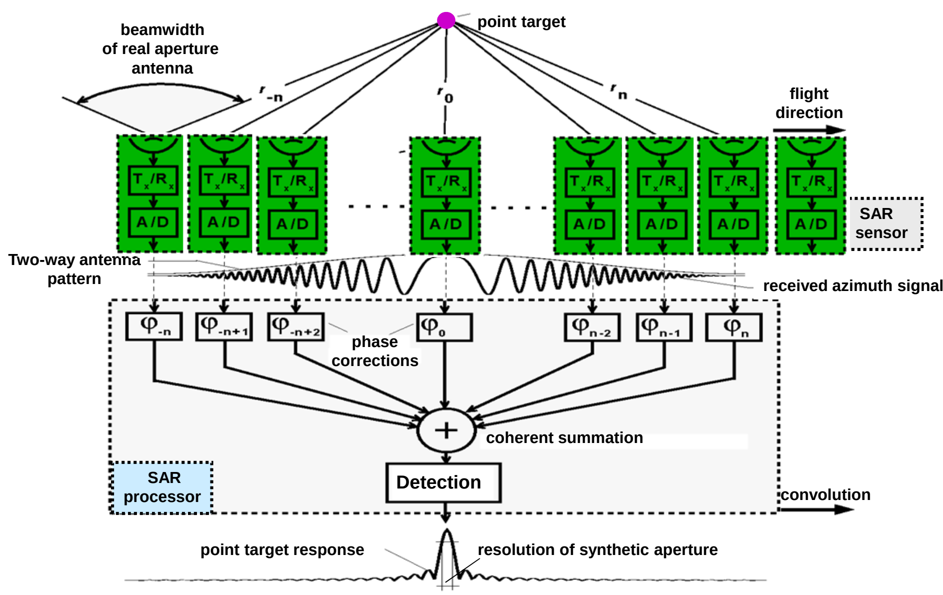
2D Raw Data Matrix



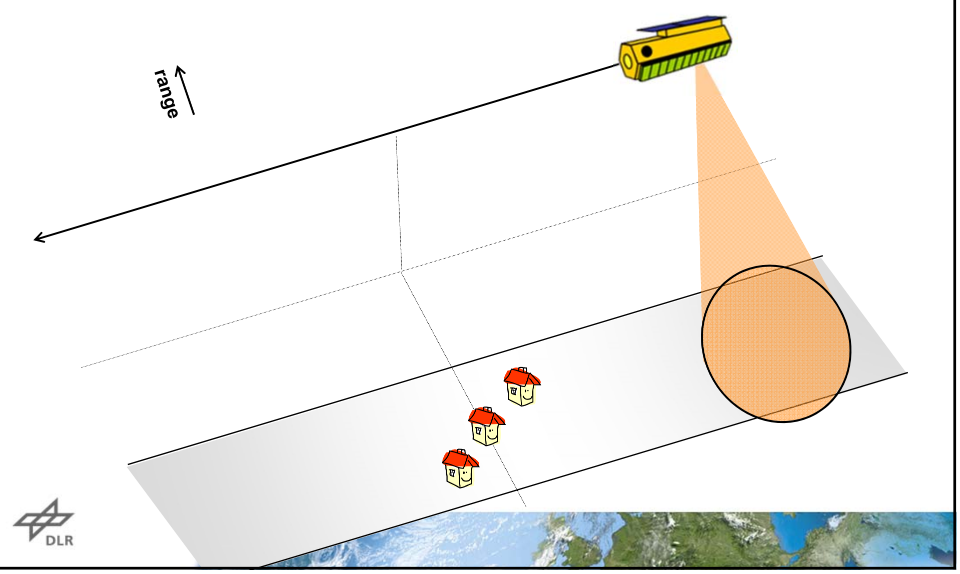
Synthetic Aperture Formation



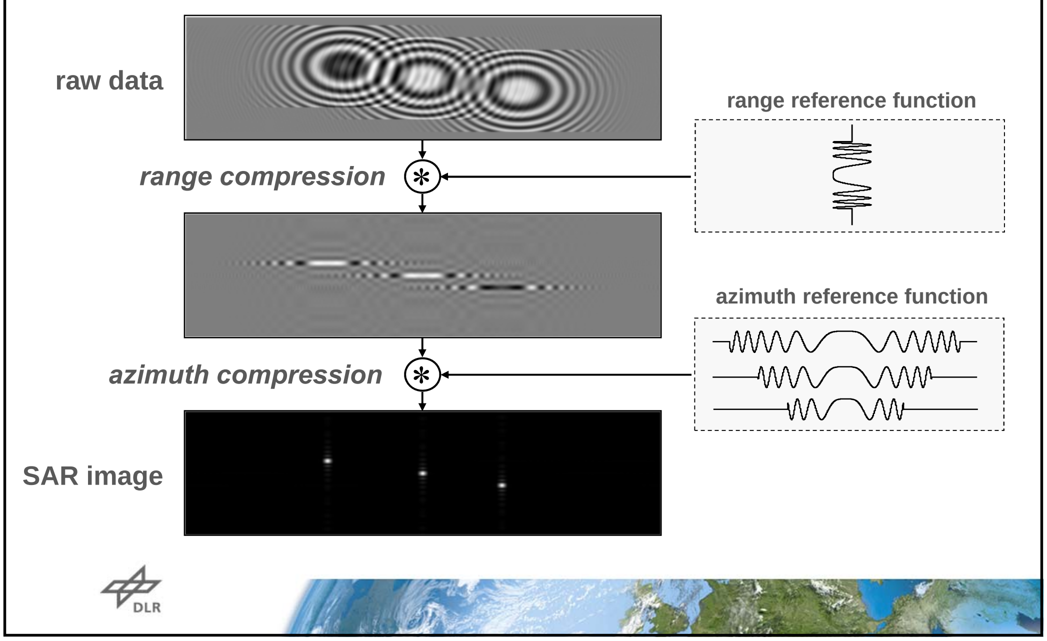
Synthetic Aperture Formation



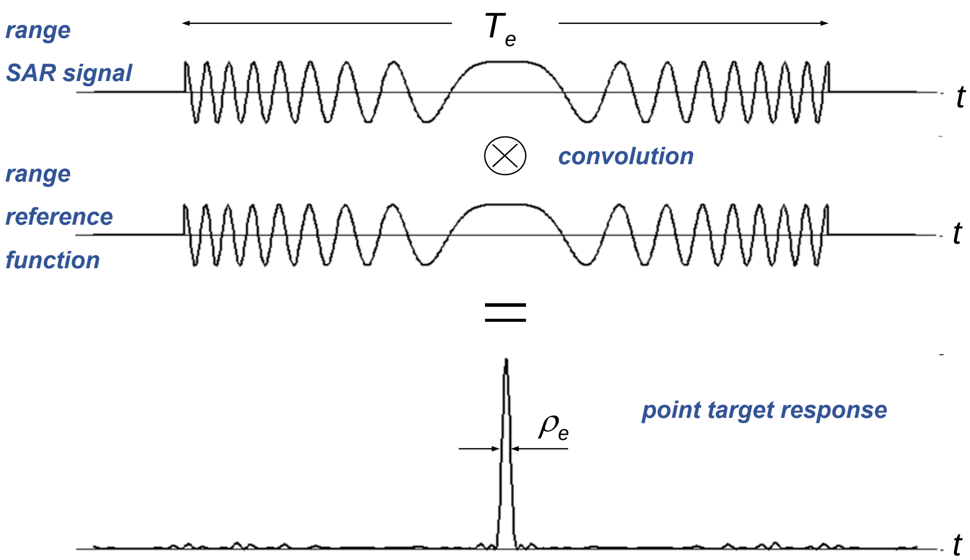
Synthetic Aperture Radar (SAR)



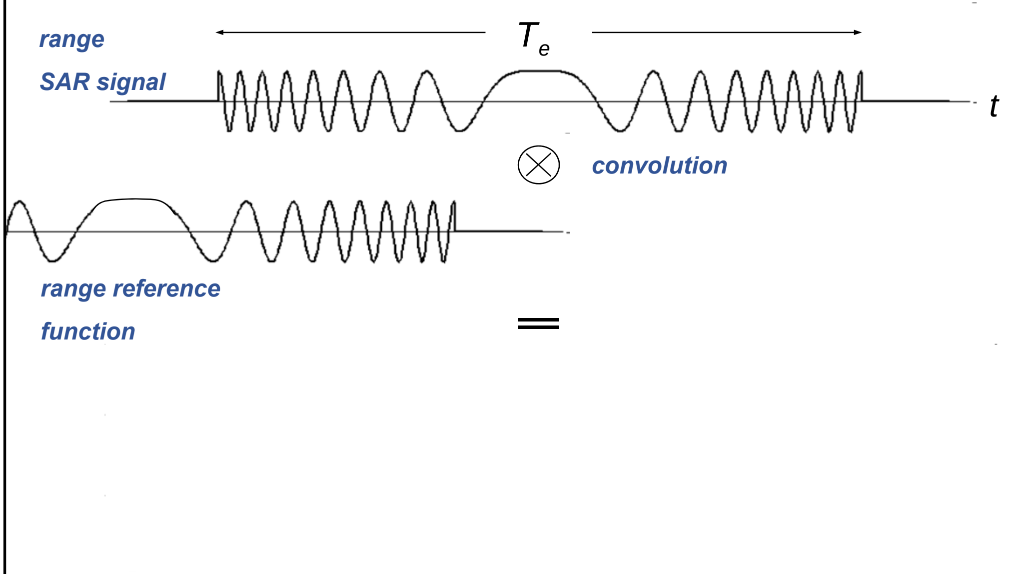
SAR Processing (Image Formation)



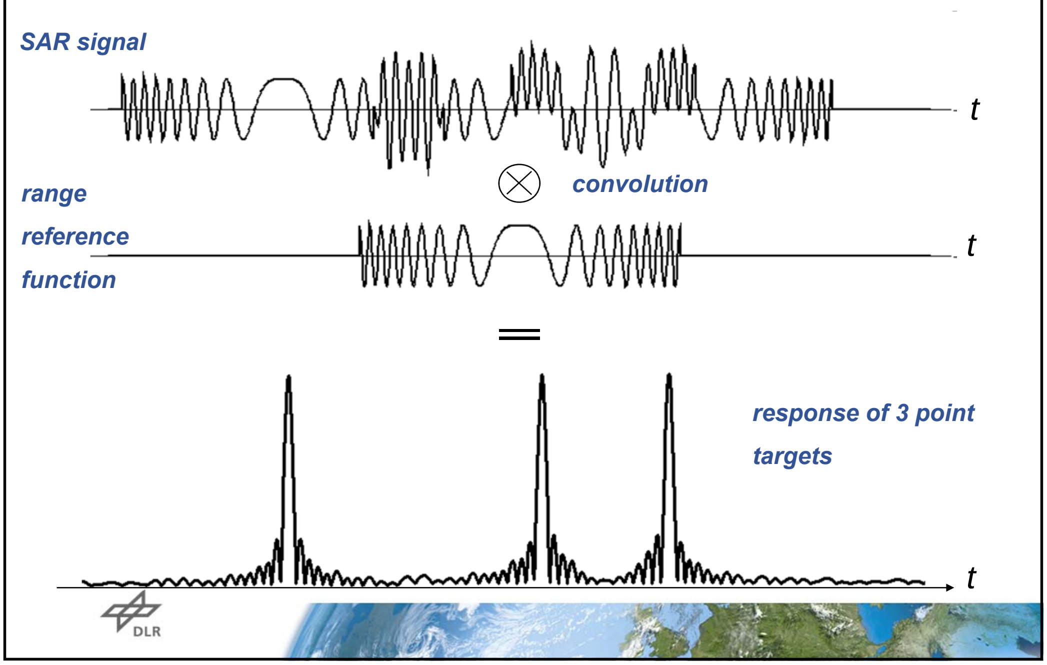
Pulse Compression by Convolution

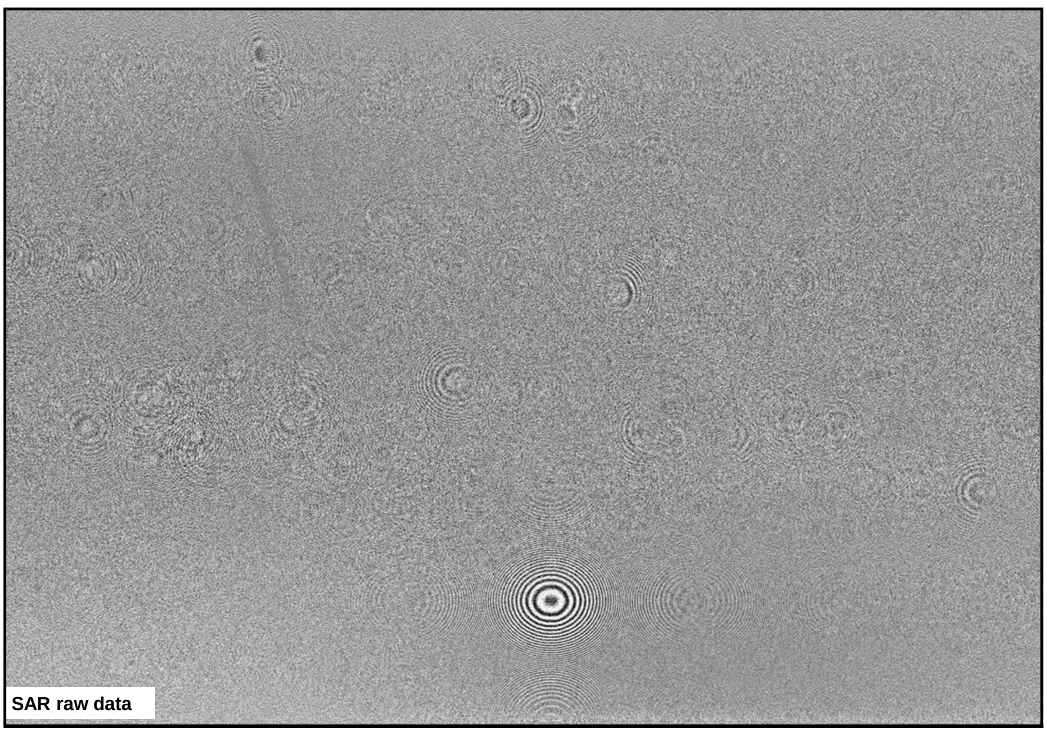


Pulse Compression by Convolution

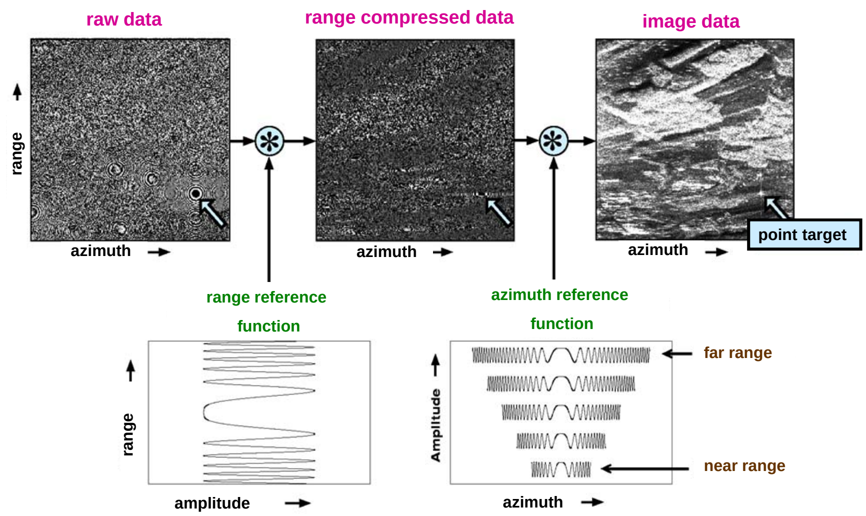


Linear Superposition of Chirps





SAR Processing (Image Formation)



DLR

Summary: SAR Processing

1. Step: Range compression

- Generation of range reference function
- Matched filtering using convolution of range signal with range reference function

2. Step: Azimuth compression

- Generation of azimuth reference function
- Matched filtering using convolution of azimuth signal with azimuth reference function

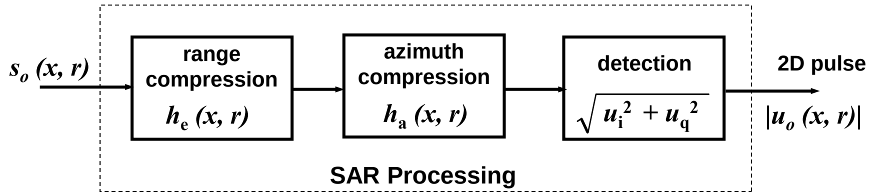
3. Step: Calculation of the modulus of the SAR image (detection)

- This step is not required in case that the phase information is used (e.g. polarimetry, interferometry etc.)

Normally the convolution is carried out in frequency domain

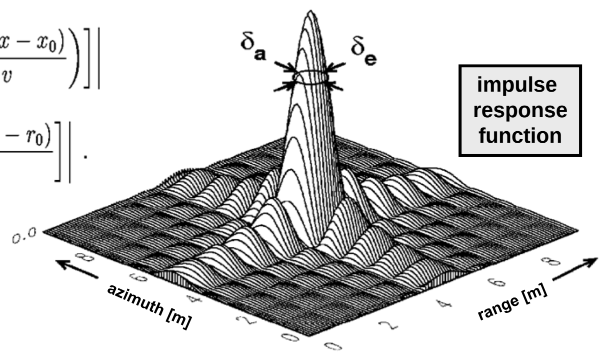
DLR

SAR Processing: 2D Matched Filter



$$|u_a(x)| = \left| \sqrt{B_a \cdot T_a} \cdot \operatorname{sinc}\left[\pi \cdot \left(\frac{B_a \cdot (x - x_0)}{v}\right)\right]\right|$$

$$|u_e(r)| = \left| \sqrt{B_e \cdot T_e} \cdot \operatorname{sinc}\left[\frac{2\pi \cdot B_e \cdot (r - r_0)}{c_0}\right]\right| .$$



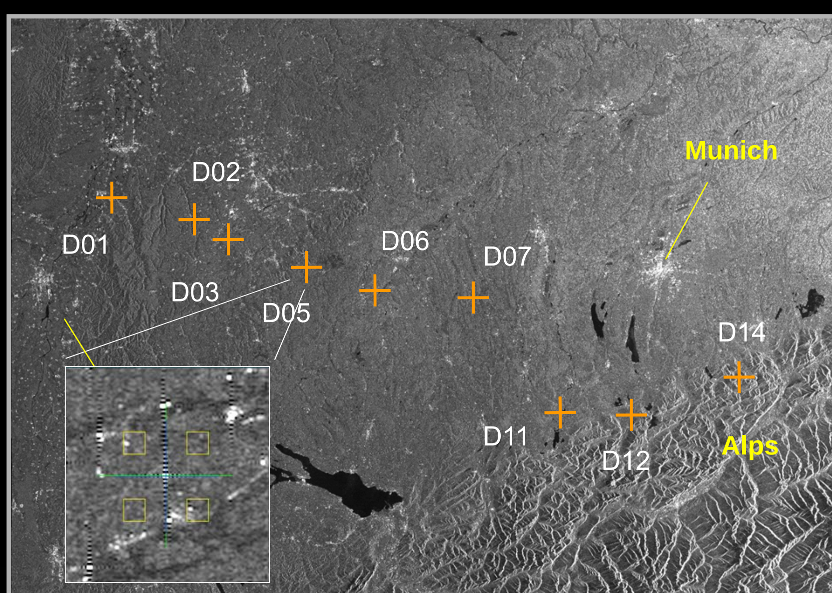
Calibration of SAR Images

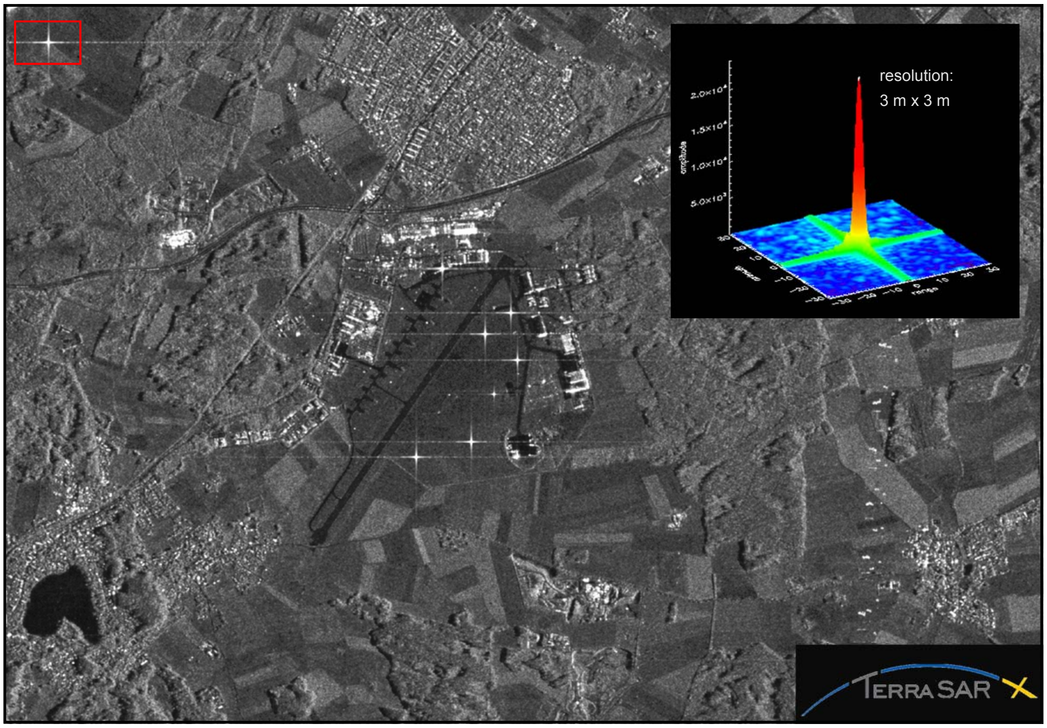
Calibration Devices

- Examples of calibration targets with well-known reflectivity (Radar Cross Section) for external calibration of the SAR system

DLR

SAR Image of ASAR/ENVISAT, 12-10-02

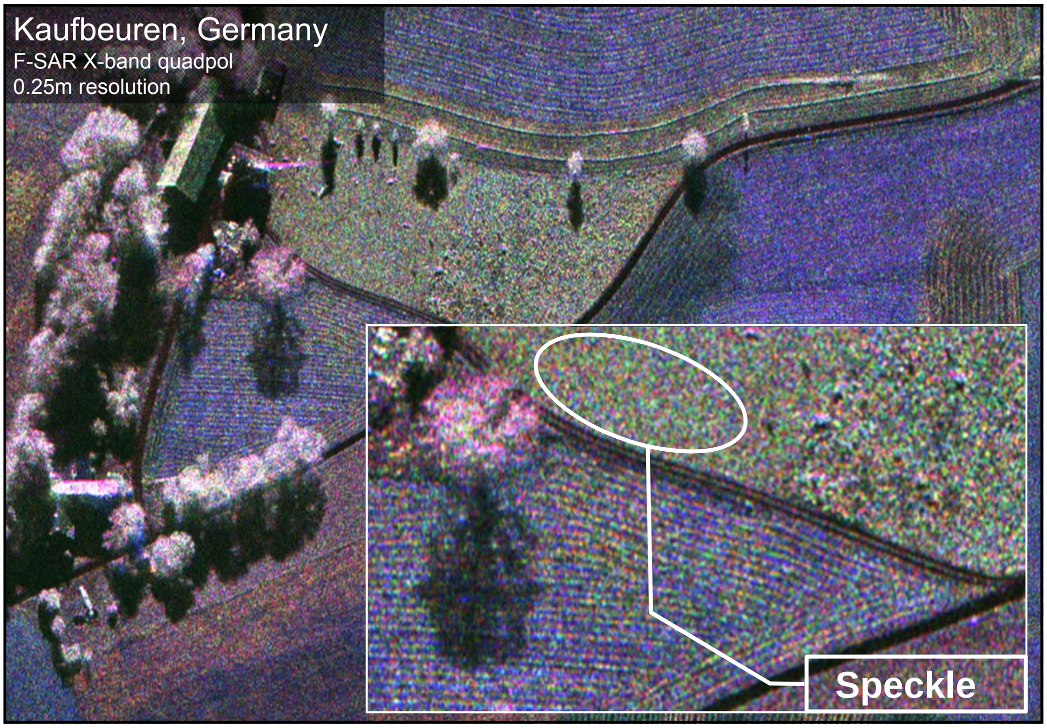




SAR Image Properties
- Speckle -


ERS-1 image / © ESA


Kaufbeuren, Germany
F-SAR, X-band quadpol
0.25m resolution



SAR signal modeling

- SAR image can be modeled as:

$$|u(x, r)| = |\gamma(x, r) \otimes u_o(x, r)|$$

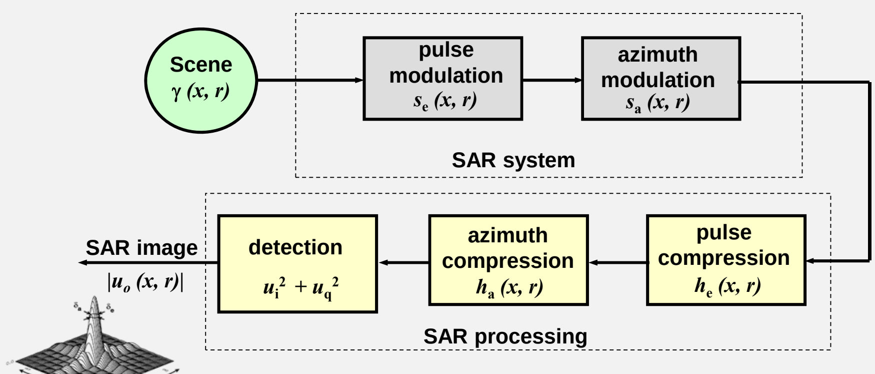
- For a point target: $\gamma = 1$

where

$|u(x, r)|$ *SAR image*

$\gamma(x, r)$ *scene complex reflectivity*

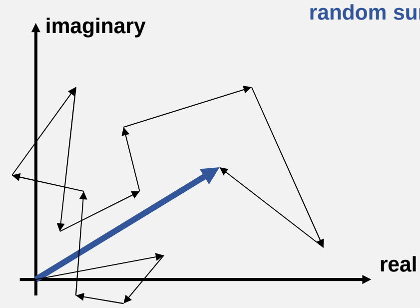
$u_o(x, r)$ *SAR impulse response*



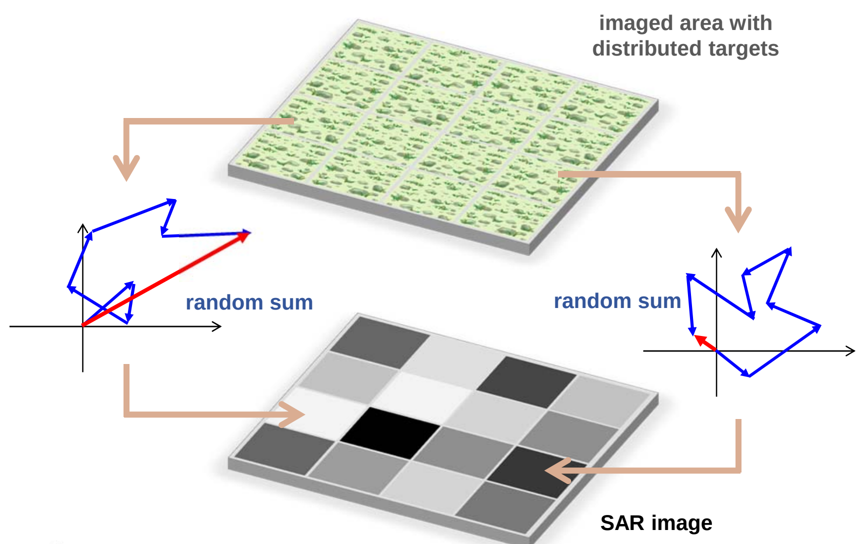
SAR signal modeling

- Distributed targets have surface roughness comparable or smaller than radar wavelength
- Resolution of the SAR sensor cannot resolve individual scatterers
- For each resolution cell, $\gamma\ (x, r)$ is equal to the sum of all scatterers contributions i. e.

$$|u(x_o, r_o)| = |\ \gamma\ (x_o, r_o) \otimes u_o\ (x, r)\ | = |\ \underbrace{\sum \gamma_i}_{\text{random sum}}\ (x_o, r_o) \otimes u_o\ (x, r)\ |$$



Speckle



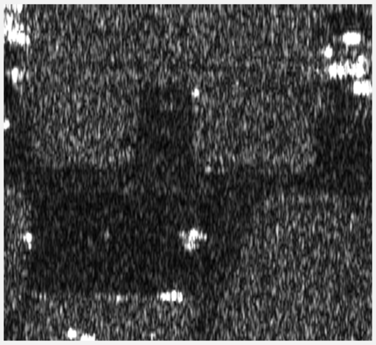
Speckle

• Inherent to coherent systems

• Probability distribution function has a exponential distribution, i.e.

average value = standard deviation

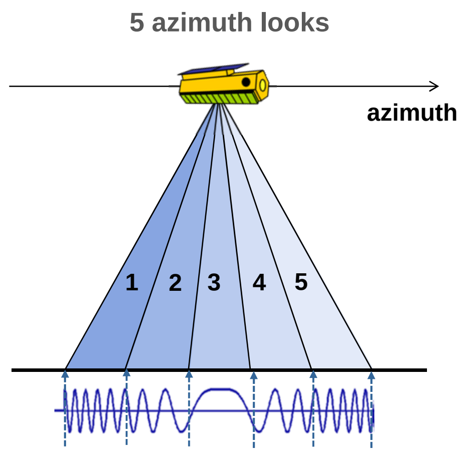
• Speckle makes SAR image interpretation more difficult

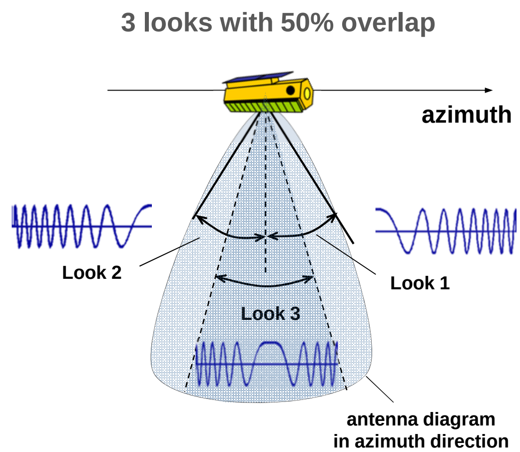


E-SAR high resolution image
(0.6 m x 2 m)

Multi-Look Processing

Multi-Look Processing





→ overlap of 50% between the looks is commonly used.

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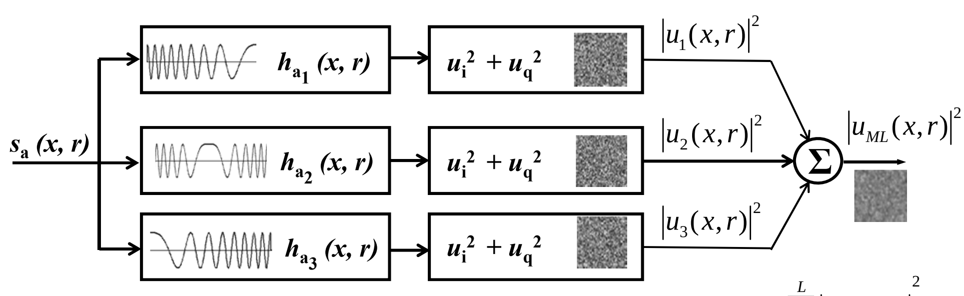
Multi-Look Processing (@ SAR Processor)



- SAR impulse response function with multi-looking (L looks): $|u_{ML}(x,r)|^2 = \dfrac{\sum_{i=1}^{L} |u_i(x,r)|^2}{L}$
- azimuth resolution deteriorates: $\delta_{a,ML} = \delta_a . L$
- Standard deviation of the speckle noise is reduced by the square root of the number of looks:

standard deviation = average value / sqrt(L)

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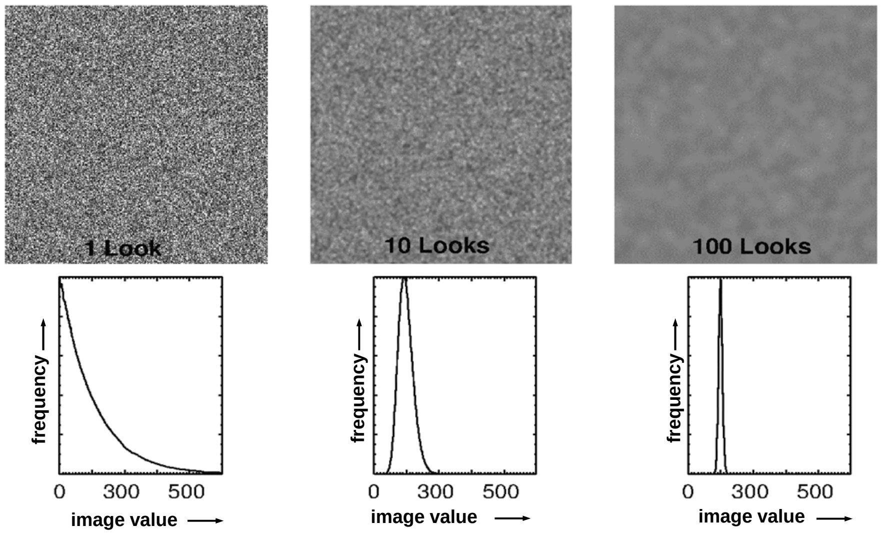
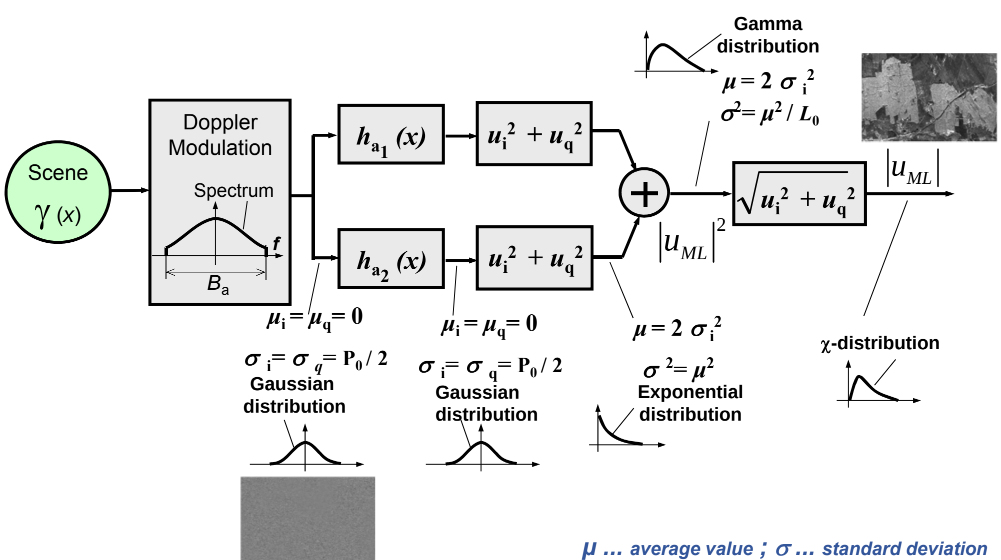
Multi-Look Processing

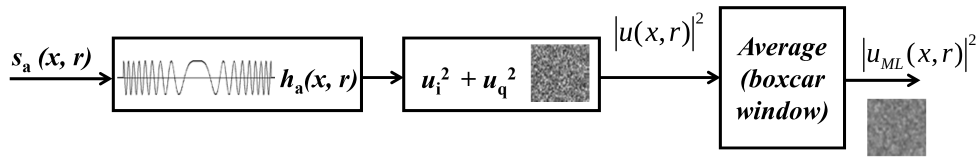


Statistics of SAR Signal for Distributed Targets



μ … average value ; σ … standard deviation

Multi-Look Processing (@ SAR Image)



• SAR impulse response function with average of L image pixels: $$|u_{ML}(x,r)|^2 = \frac{\left|\sum_{n,m=1}^{n+m=L} |u(x_n, r_m)|\right|^2}{L}$$

• azimuth resolution deteriorates: $\delta_{a,ML} = \delta_a . L$

L = number of looks

• Standard deviation of the speckle noise is reduced by the square root of the number of looks:

standard deviation = average value / sqrt(L)

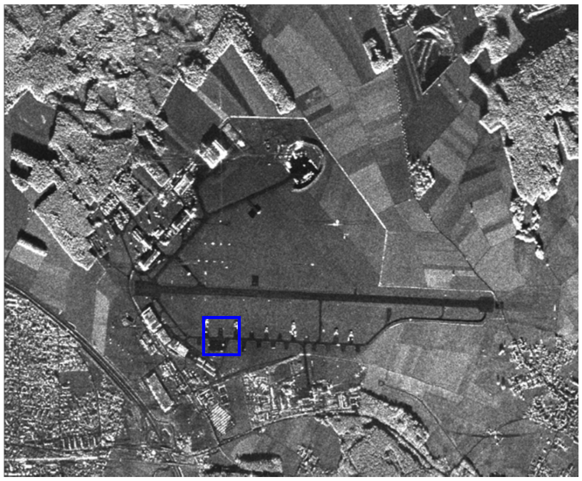
Single-Look and Multi-Look Processing

5 looks
20 m x 20 m resolution

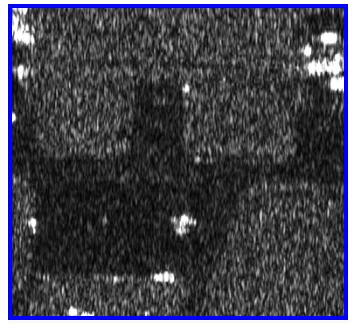
320 looks (average of 64 images)
20 m x 20 m ground resolution

ERS-1 satellite images (processing DLR-IMF)

Single-Look and Multi-Look Processing



E-SAR multi-look image, 8 looks, 50 % overlap
(2 m range resolution, 3 m azimuth resolution)



E-SAR single-look image
(0.6 m azimuth resolution)

E-SAR: airborne SAR of DLR

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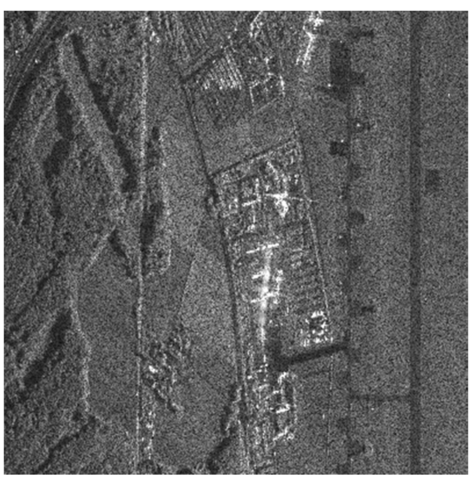
Speckle Reduction with Image Filtering



original SAR image (1 look)
Airborne SAR AeS-1

speckle filtered
Adaptive Filtering
(Model based approach)

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Summary: Speckle

• SAR image of distributed targets contains speckle noise.

• Speckle noise is inherent in coherent radar systems.

• The average value of the speckle amplitude is equal to its standard deviation (exponential distribution).

• Multi-look processing or spatial averaging is used to reduce the speckle noise. Standard deviation decreases with $\sqrt{L_{eff}}$.

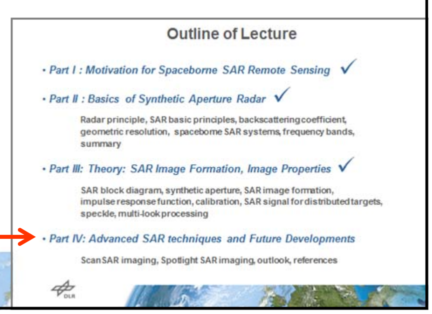
• An overlap of 50% between the looks is commonly used.

• Speckle noise can also be reduced by averaging the final image

PART IV

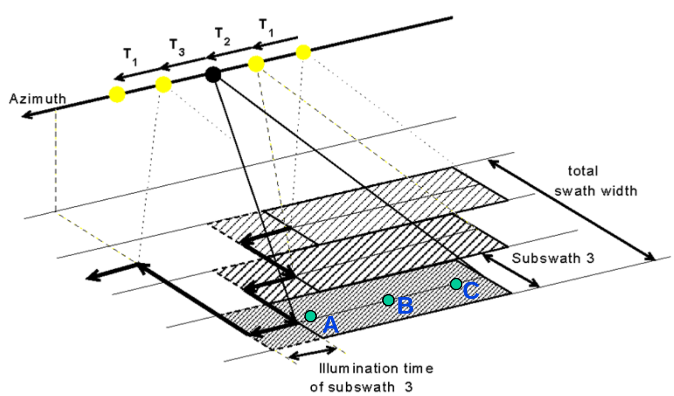
Advanced SAR Techniques

and Future Developments



Advanced SAR Imaging Modes
- ScanSAR Mode -

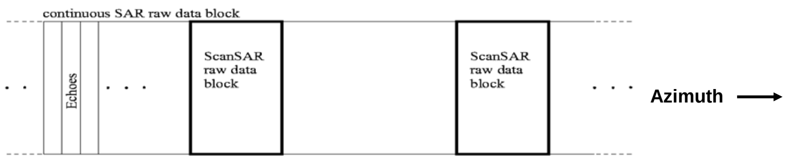
ScanSAR Imaging



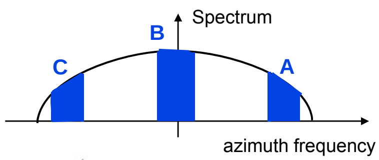
• Synthetic aperture is shared between the subswaths (not contiguous within one subswath)
• Mosaic Operation is required in azimuth and range directions to join the azimuth bursts and the range sub-swaths

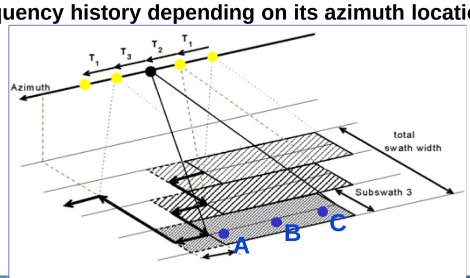
ScanSAR Main Properties

- ScanSAR leads to a large swath width
- The azimuth signal consists of several bursts



- Azimuth resolution is limited by the burst duration
- Each target has a different frequency history depending on its azimuth location





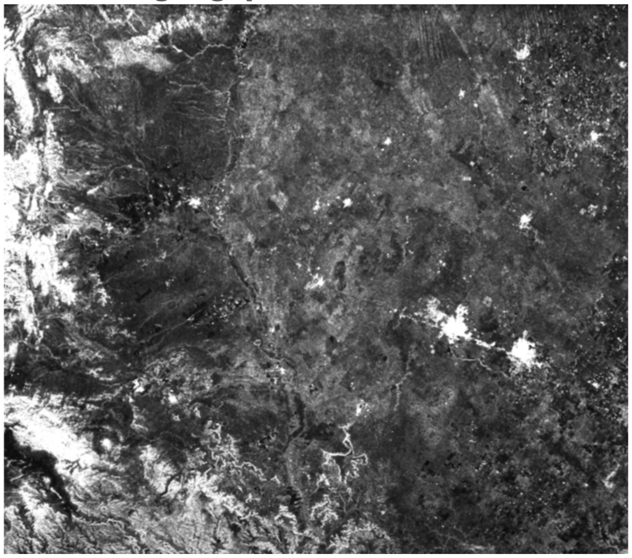
ScanSAR Imaging (Chickasha, Oklahoma, USA)

Subswath 1 (near range)

Subswath 2

Subswath 3

Subswath 4 (far range)



azimuth →

SIR-C image
L-band, VV

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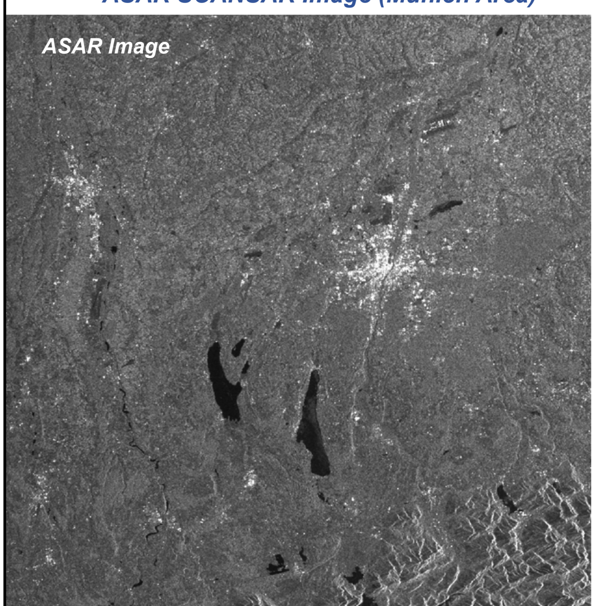
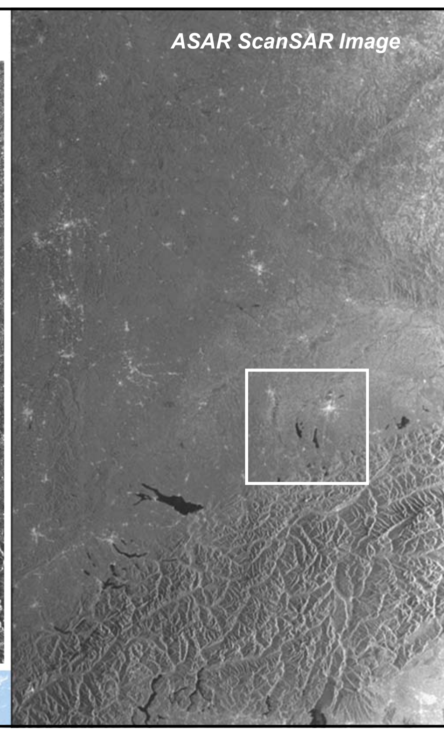
ASAR SCANSAR Image (Munich Area)





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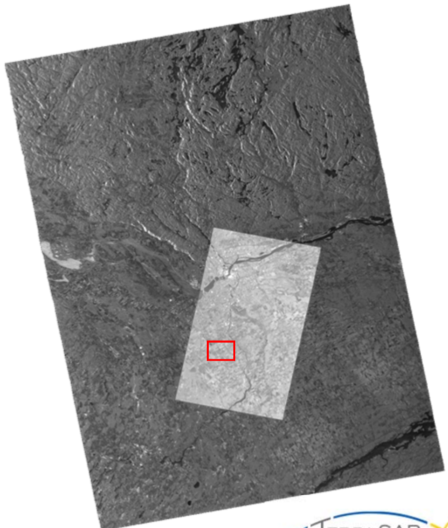
Comparison: ScanSAR vs. Stripmap (TerraSAR-X)

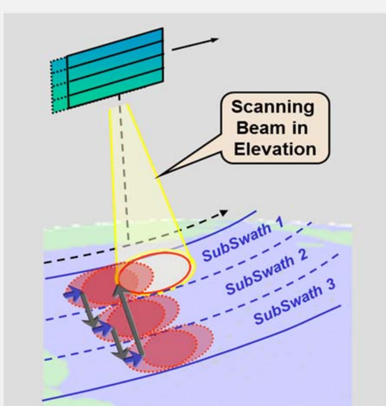


- ***ScanSAR (HH)***
  - 150 MHz
  - 17 m resolution
  - 1 (az) x 6.9 (rg) looks
  - ascending orbit
- ***Stripmap (HH)***
  - 150 MHz
  - 7 m resolution
  - 2.9 (az) x 3.4 (rg) looks
  - descending orbit
- ***3 days time separation***

TOPS-SAR (Terrain Observation by Progressive Scan)

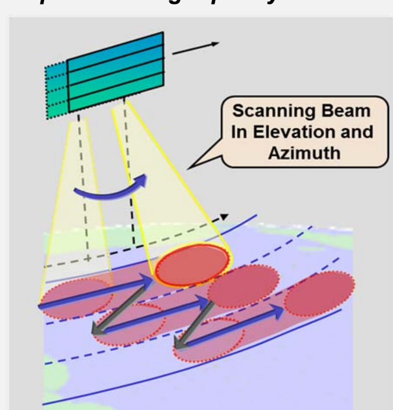
ScanSAR

- Shares illumination time between multiple swaths



TOPS-SAR

- Shares illumination time between multiple swaths
- Improved image quality



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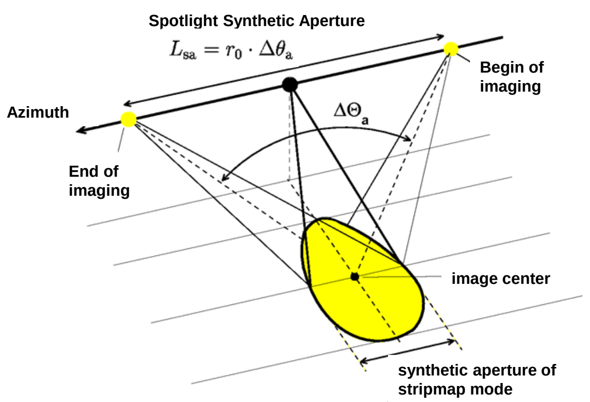
Advanced SAR Imaging Modes
- Spotlight Mode -

Spotlight SAR Imaging

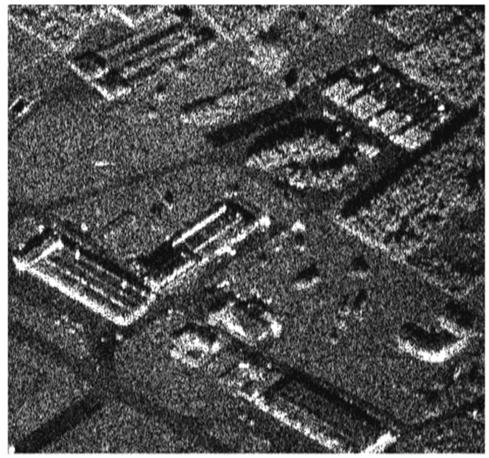


- Non continuous imaging mode, but very high azimuth resolution
- Spotlight azimuth resolution

$$\delta_a = \frac{\lambda}{2 \cdot \Delta\theta_a}$$

Spotlight SAR Imaging

Stripmap image
3 m azimuth resolution



Spotlight image
0.46 m azimuth resolution

E-SAR System, X-Band, Oberpfaffenhofen, Germany

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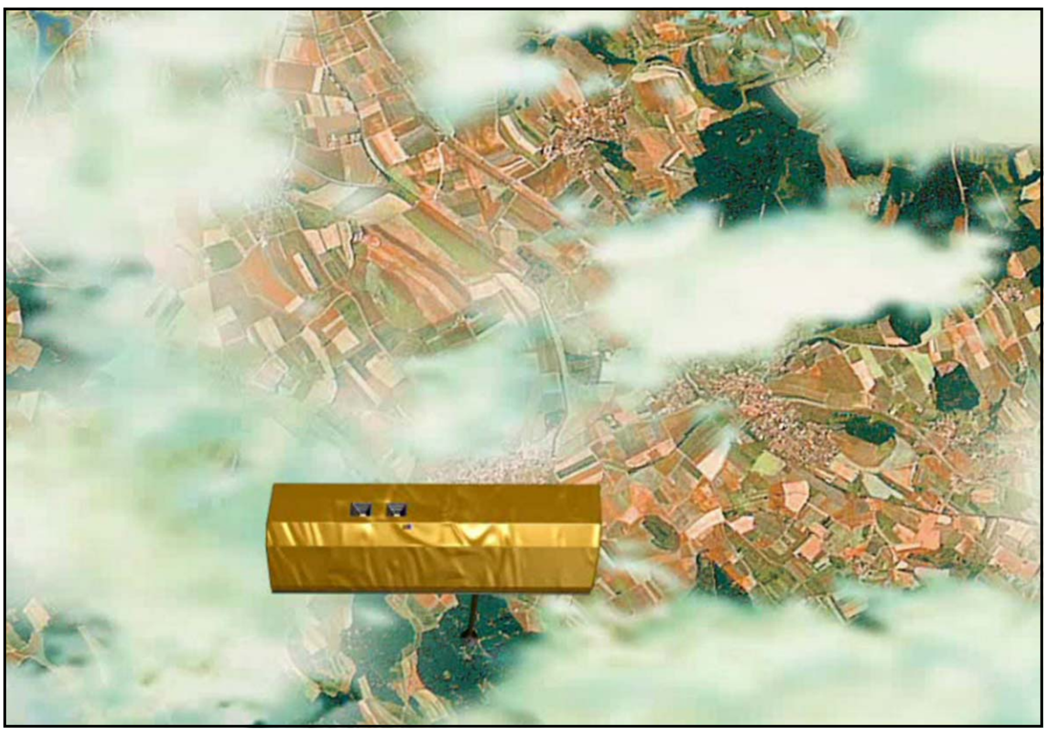


Chuquicamata, Chile

Spotlight Imaging Mode

Oberpfaffehofen

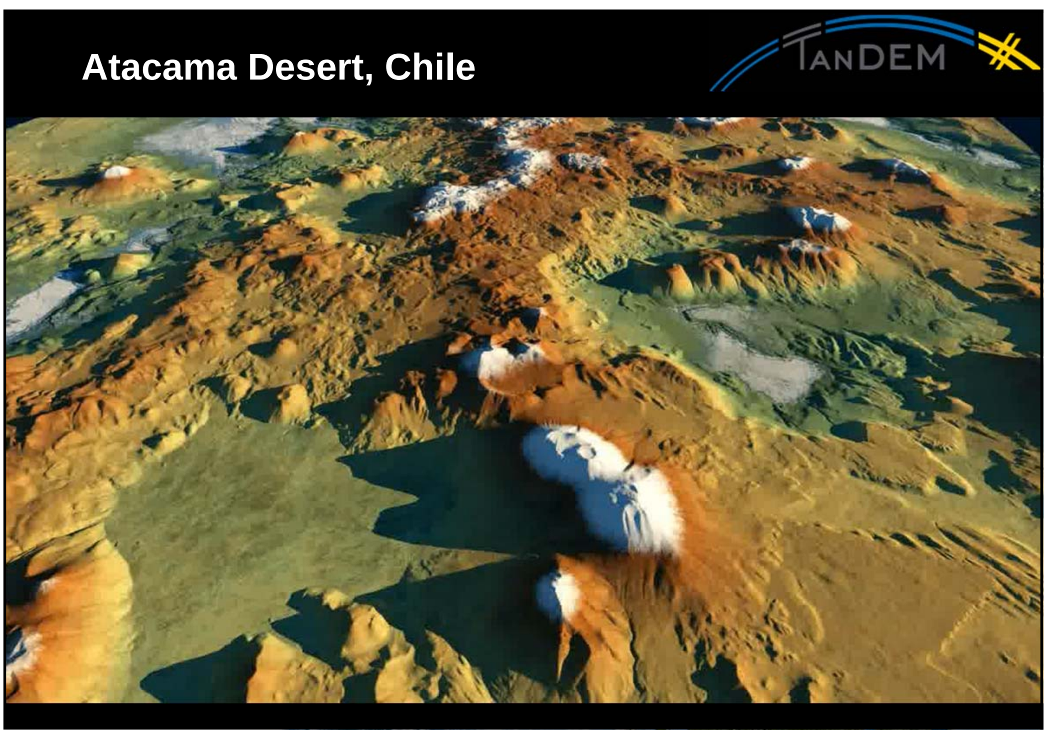
Outlook

SAR Application Trends

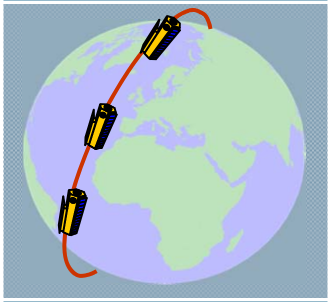
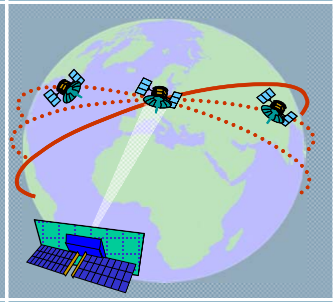
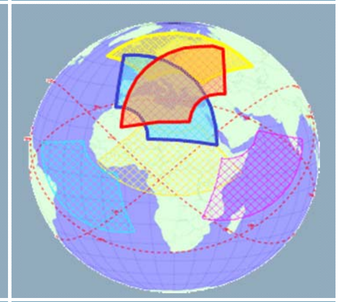
Trends in Earth Science & Applications:

- ✓ Day / night, all-weather coverage of the Earth's surface
- ✓ Frequent revisit times (time series):
  - ✓ hours to 1 day: coastal zones, ocean, traffic and disaster monitoring
  - ✓ days to weeks: differential interferometry, soil moisture, agricultural areas
  - ✓ months to year: tropical, temperate and boreal forests, differential interf.
- ✓ Variable resolution (1 to 100 m) and wide coverage (25 to 450 km swath width)
- ✓ High (2 m) and medium resolution (10-15 m) global topography
- ✓ Information products of key inputs to global change models:
  - ✓ above ground biomass, soil moisture, wetland areas, land cover types
  - ✓ ocean surface & currents, ice mass balance, glacier velocity
- ✓ Calibrated and geo-coded data products are required (e.g. compatibility to GIS)
- ✓ Model based inversion algorithms are needed for reliable information extraction


TerraSAR X
TanDEM X
Launch: June 15, 2007
Launch: June 21, 2010
DLR
ASTRIUM
infoterra


Atacama Desert, Chile
TanDEM X

Future SAR System Concepts

LEO Satellites	Geostationary Illuminator + LEO Receivers	MEO Satellites
		
• Short revisit times by multiple SAR satellites	• Constant illumination with geostationary transmitter	• Huge simultaneous access area
• Conventional technique with low risk	• Signal reception by passive micro-satellites	• Multiple revisits per day with one satellite

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Summary: SAR Principles and Applications

- High resolution capability (independent of flight altitude)
- Weather independence by selecting proper frequency range
- Day/night imaging capability due to own illumination
- Complementary to optical systems
- Polarization signature can be exploited (physical structure, dielectric constant)
- Terrain Topography can be measured by means of interferometry
- Innumerous applications areas
- Great interest in the scientific community as well as for commercial and security related applications

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SAR Image Properties

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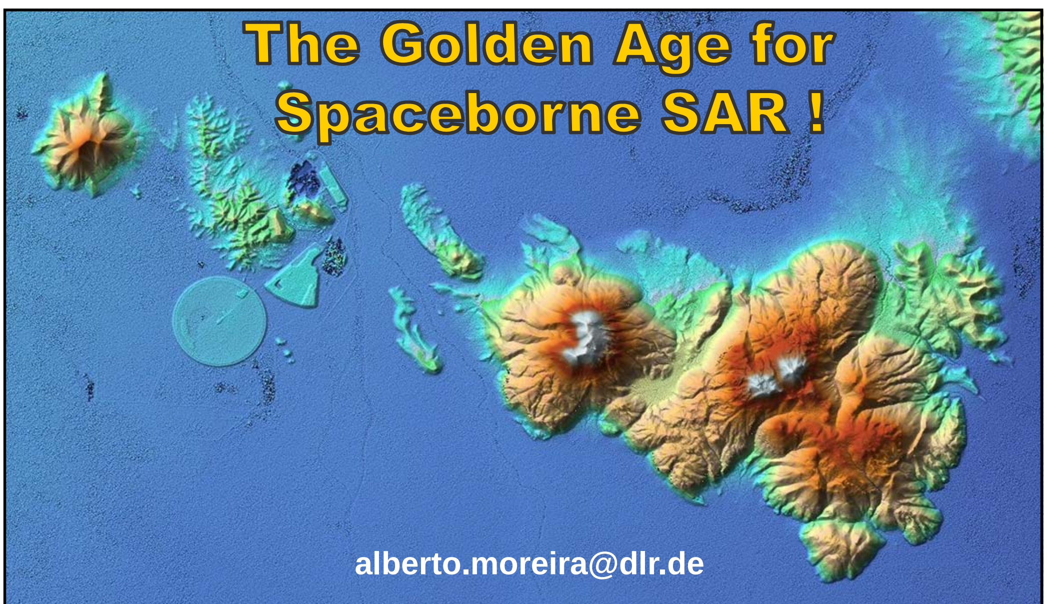

TanDEM-X, Kori Kollo, Bolivia