Antenna Chetumal: Use of Remote Sensing Data for Environmental and Civil Security Applications in Mexico

Training Session: Radar

Thomas Esch°, Achim Roth*, Alejandra Cervera^

° University of Wuerzburg, Department of Remote Sensing in co-operation with DLR, Wuerzburg
* German Remote Sensing Data Center (DFD) of DLR, Oberpfaffenhofen
^ Comisión nacional para el conocimiento y uso de la biodiversidad (CONABIO), Mexico City

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

Julius-Maximilians-Universität Würzburg

Content

- **Image understanding**
  - Fundamentals
    - Radar
    - Frequency & polarization
    - Imaging geometry
    - Geometric & radiometric resolution
  - Image properties
    - Distortions (E)
    - Target interaction (E)
- **Data Analysis**
  - Image enhancement
    - Data Stretch (E)
    - Speckle suppression (E)
  - Image classification
    - Textural features (E)
    - Generation of image objects (E)
    - Identification of built-up areas (E)

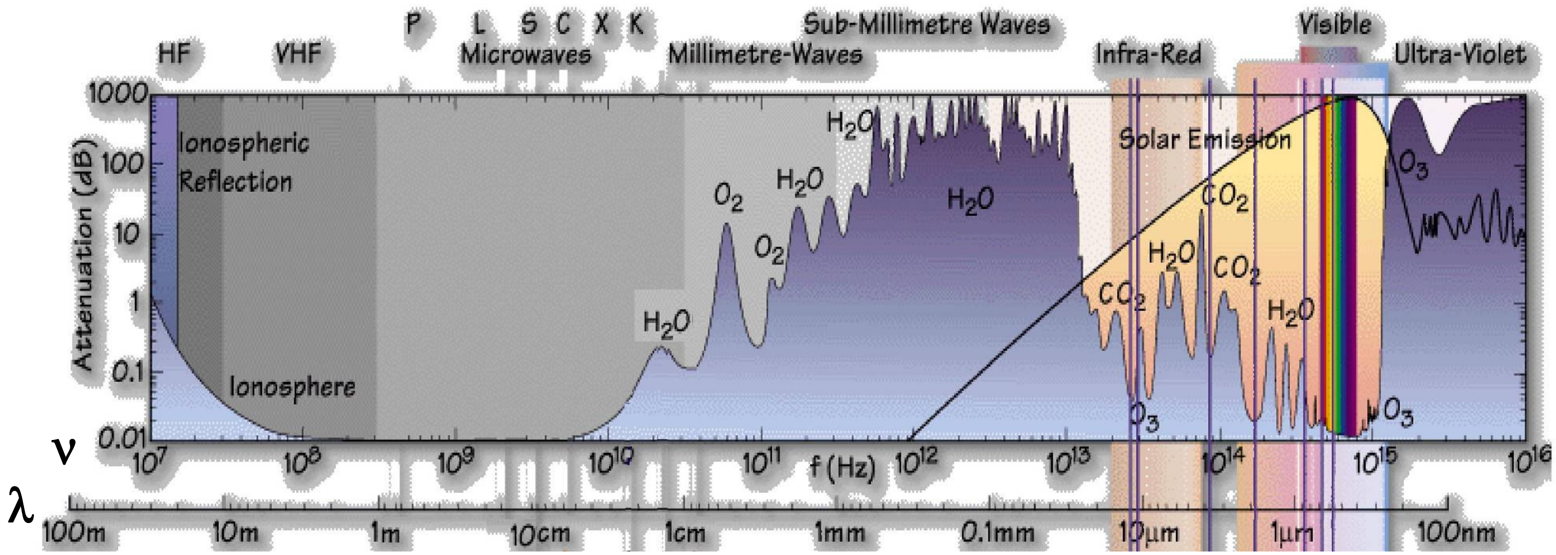
Radar image

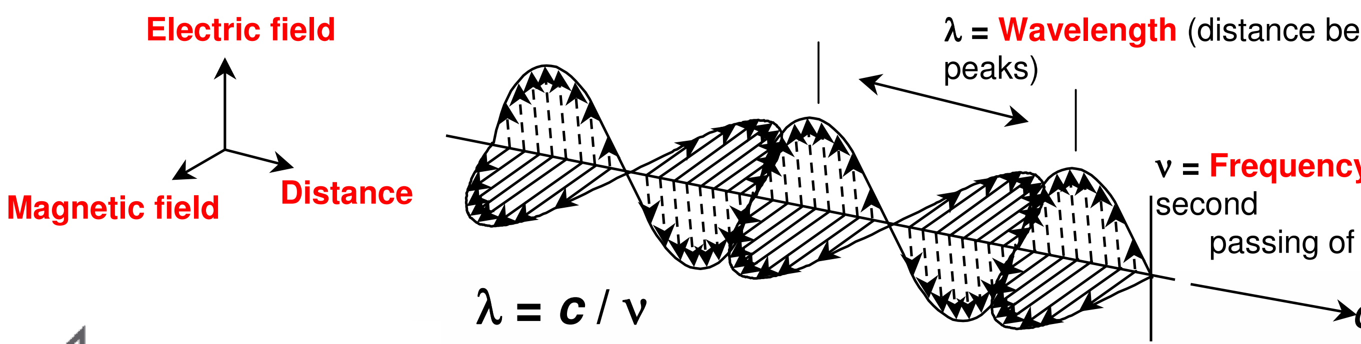
Optical image

Fundamentals: RADAR

- **Ra**dio **D**etection **a**nd **R**anging (active system)
- Transmits and receives coherent pulses of microwave radiation at regular intervals
- Imaging radar records the backscattered portion of the emitted signal
- Day, night and all weather observation capability

Fundamentals: **RADAR** Electromagnetic spectrum





λ = **Wavelength** (distance between successive wave peaks)

ν = **Frequency** (number of cycles per second passing of a fixed point)

$$\lambda = c / \nu$$

c = **Velocity of light**

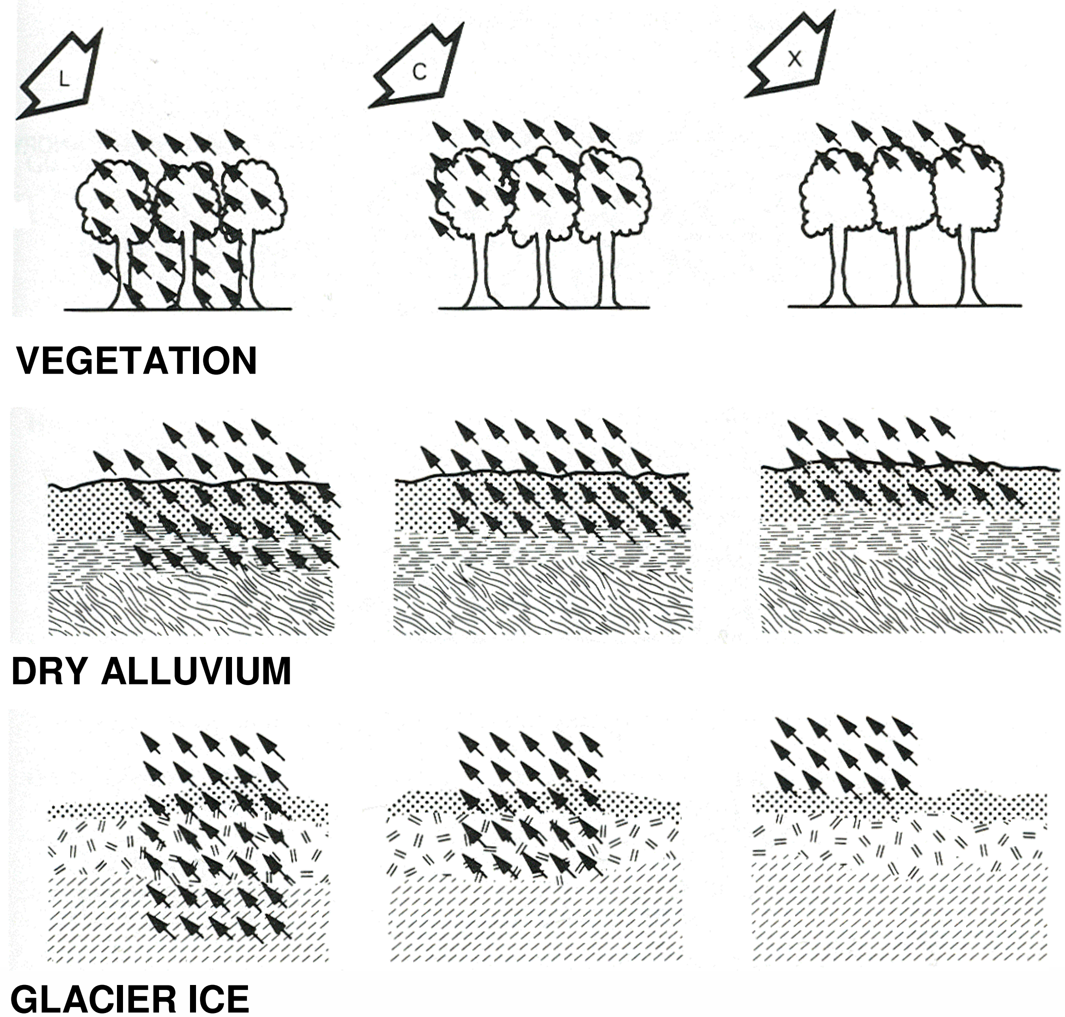
Fundamentals: Frequency

Frequency band	*Frequency range*	*Application Example*
• VHF	300 KHz - 300 MHz	Foliage/Ground penetration, biomass
• P-Band	300 MHz - 1 GHz	soil moisture, biomass, 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 bands used in the context of imaging radars

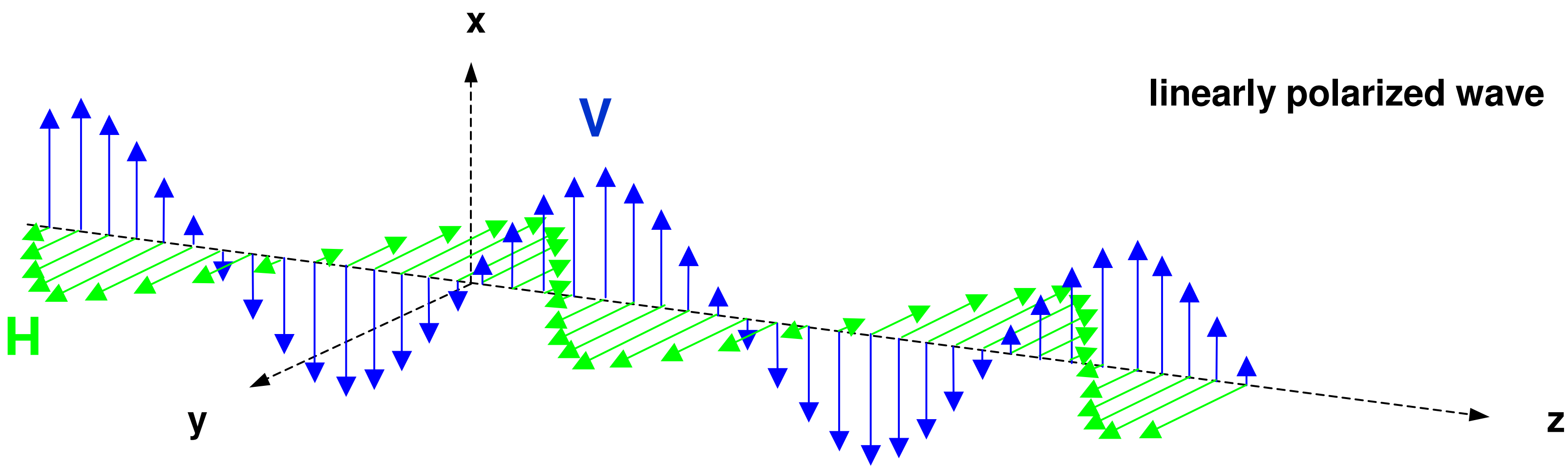
Fundamentals: Frequency

- L-band: 23 cm
- C-band: 6 cm
- X-band: 3 cm



Fundamentals: Polarization

- Orientation of the electric field of the radiation



- Polarimetric radar systems

HH: horizontal transmit and horizontal receive

HV: horizontal transmit and vertical receive

VV: vertical transmit and vertical receive

VH: vertical transmit and horizontal receive

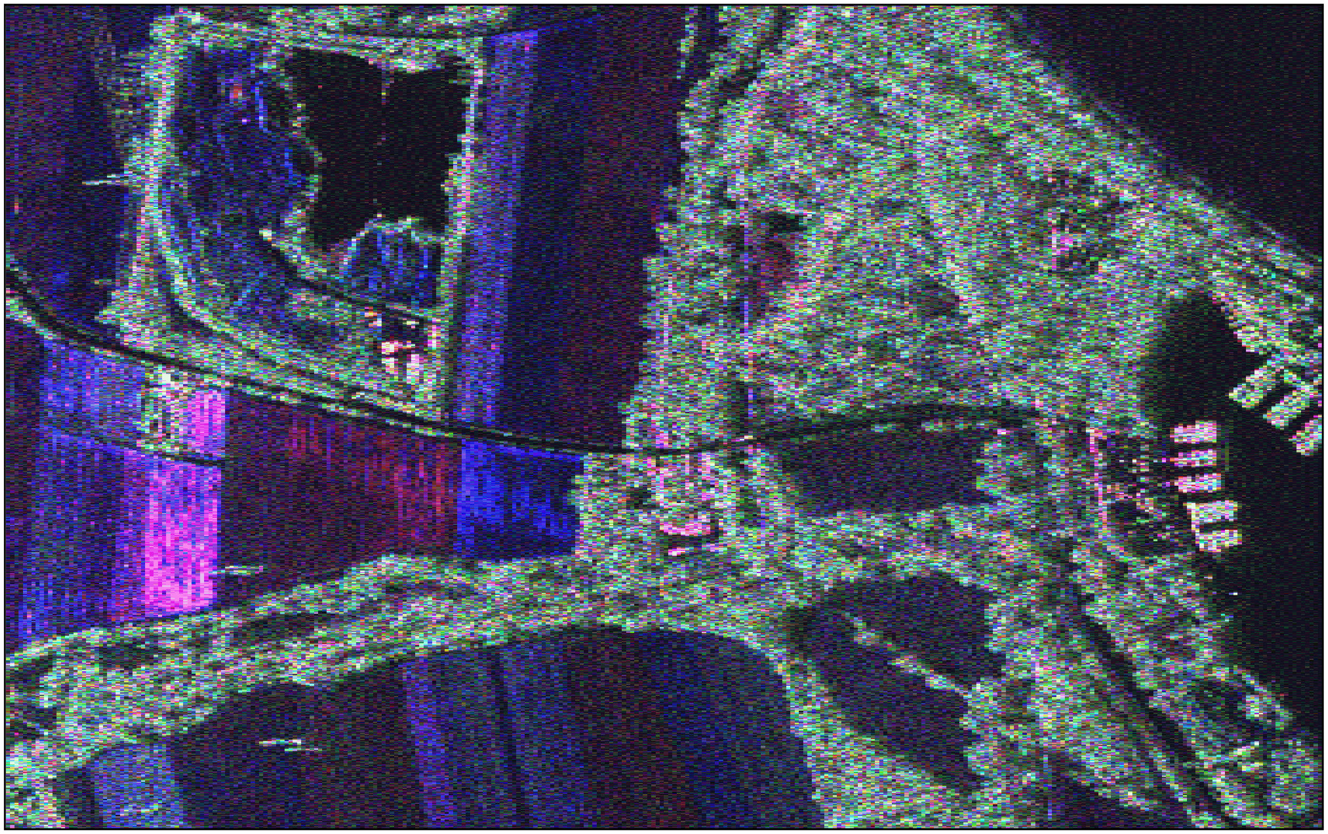
Fundamentals: Polarization

- Polarizations are provided as individual image layers
  - Co-polarized: HH, VV
  - Cross-polarized: VH, HV
  - Dual-polarized system: provides two layers
  - Quad- or fully polarized system provides four layers
- Fully polarized data allows generation of complex scattering matrix

$$[S] = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix}$$

- Coherent target decomposition = extraction of physical information

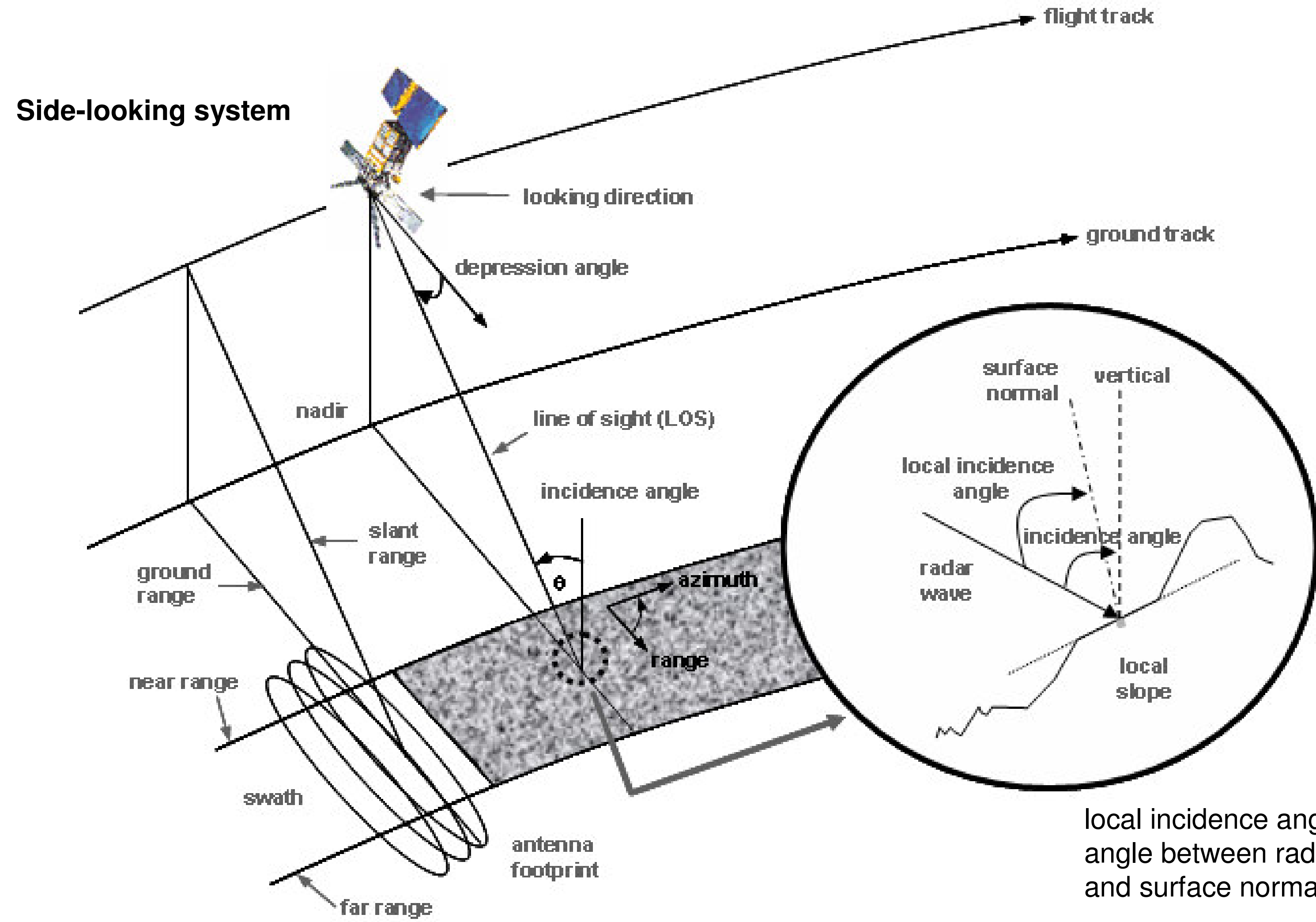
Fundamentals: Polarization



L-band: Pauli decomposition

Red:	$S_{HH} - S_{VV}$	= double bounce
Green:	$2\ S_{HV}$	= volume scattering
Blue :	$S_{HH} + S_{VV}$	= single scattering

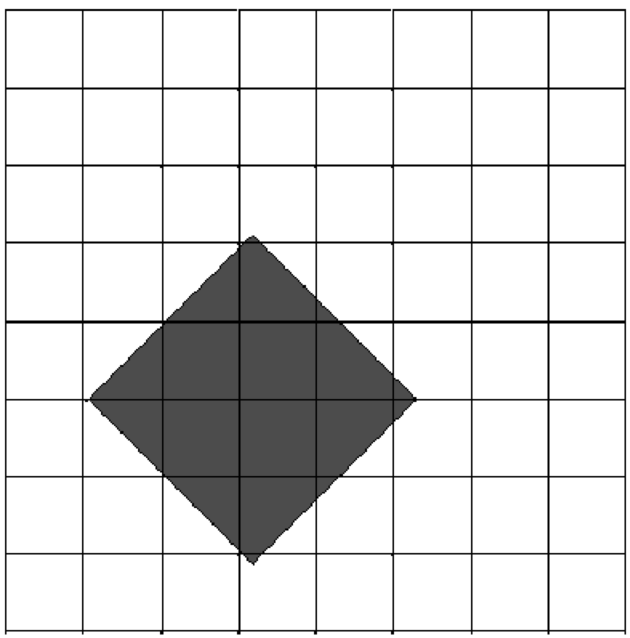
Fundamentals: Imaging geometry



local incidence angle =
angle between radar beam
and surface normal

Fundamentals: Geometric Resolution

- Dimension of the area on the ground in x- and y-direction which is covered by one resolution cell of the imaging system
- Determines smallest possible feature that can be detected



Real-world object

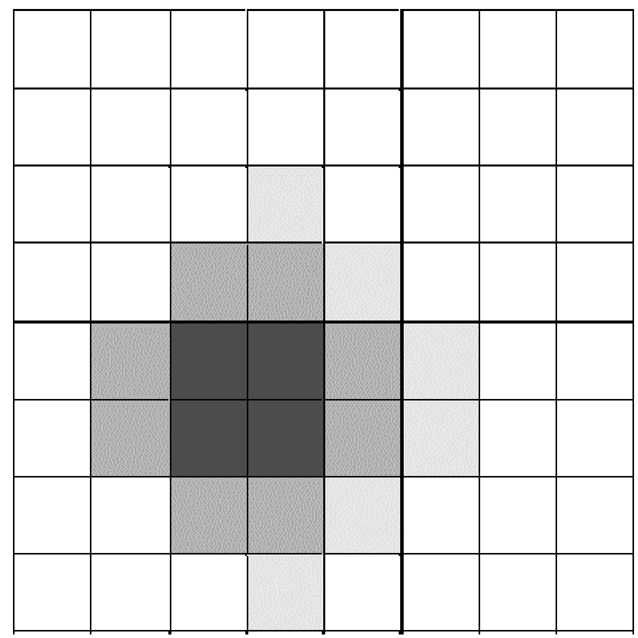
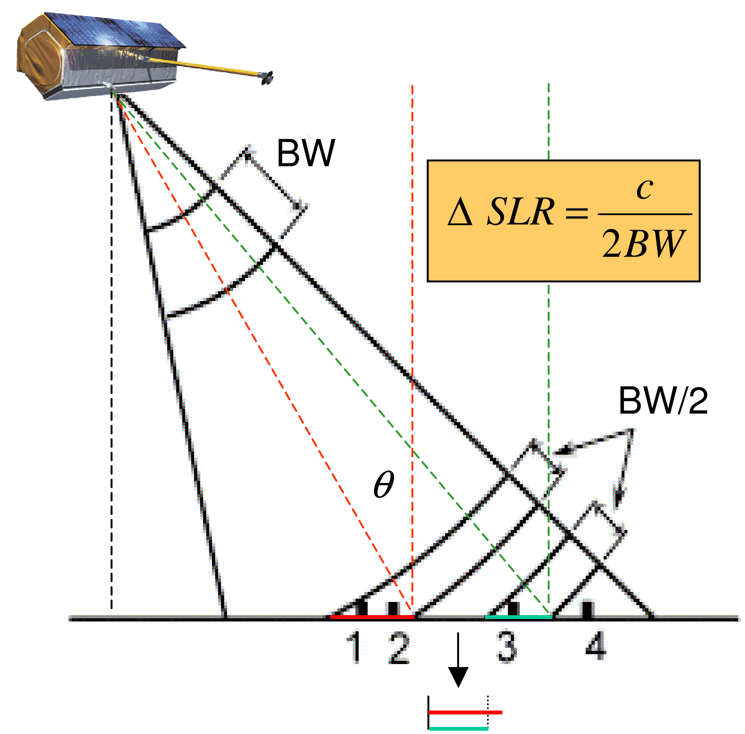


Image representation

Fundamentals: Geometric Resolution

- Range resolution

  - **Slant range**: Reflected signals must be received separately to avoid merging of objects
  - Depends on **bandwidth** (length of pulse), whereas distance between objects should be more than half of the pulse length
  - SLR remains constant, **independent of range**
  - Projection into **ground range** is **dependent of incidence angle θ**



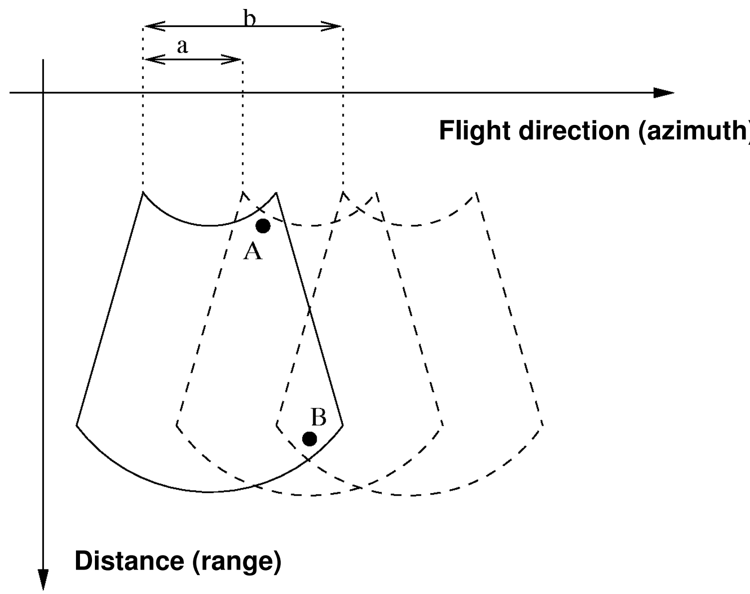
$$\Delta\ SLR = \frac{c}{2BW}$$

$$\Delta\, GRR = \frac{c}{2BW * \sin\theta}$$

Fundamentals: Geometric Resolution

- Azimuth resolution RAR: $\delta x = \dfrac{\lambda \cdot SLD}{A}$

  - **Length of antennas is limited** (airborne ~2m, spaceborne ~15m)
  - **Simulation of long antenna** (synthetic aperture) by utilizing forward motion of platform and special processing of signal
  - Length of synthetic aperture (a, b) corresponds to **distance along the orbit where target (A, B) is visible**
  - Theoretical resolution $\delta x'$ of the synthetic aperture is **half of the real antenna length**

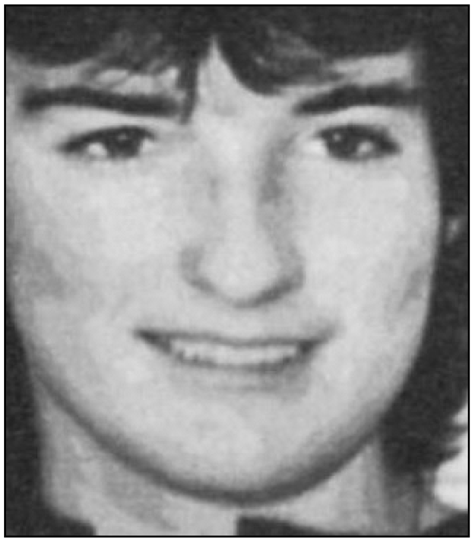


$$A = 2 \cdot \delta x \quad \rightarrow \quad \delta x = \frac{\lambda r}{2 \cdot \delta x} \quad \rightarrow \quad \boxed{\delta x = A/2}$$

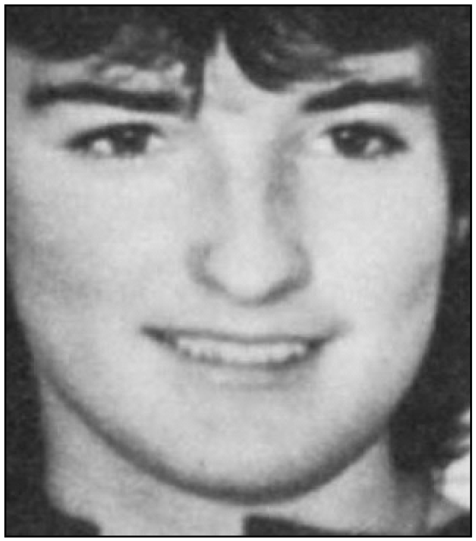
Fundamentals: Radiometric Resolution

- Sensitivity to the magnitude of the electromagnetic energy
- The finer the radiometric resolution, the better the ability to discriminate differences in the reflected or emitted energy

2-bit (2^2 = 4 grey values)



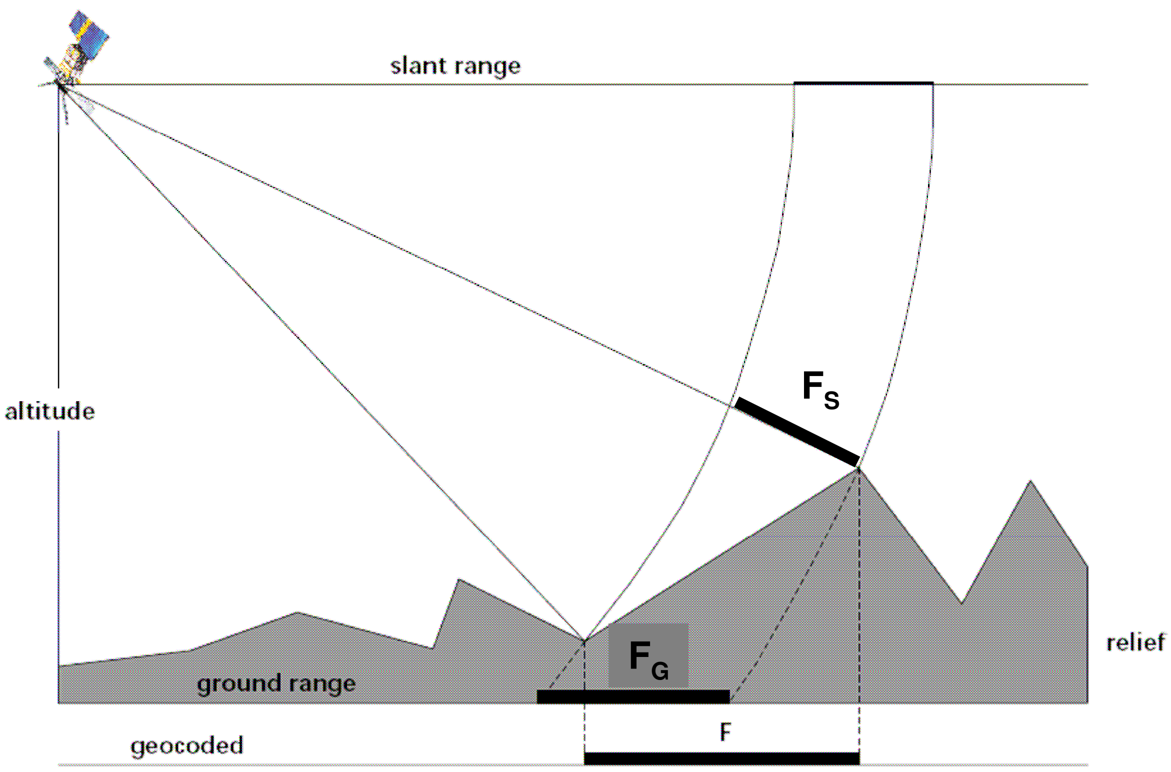
4-bit (2^4 = 16 grey values)



6-bit (2^6 = 64 grey values)

Image properties: Distortions

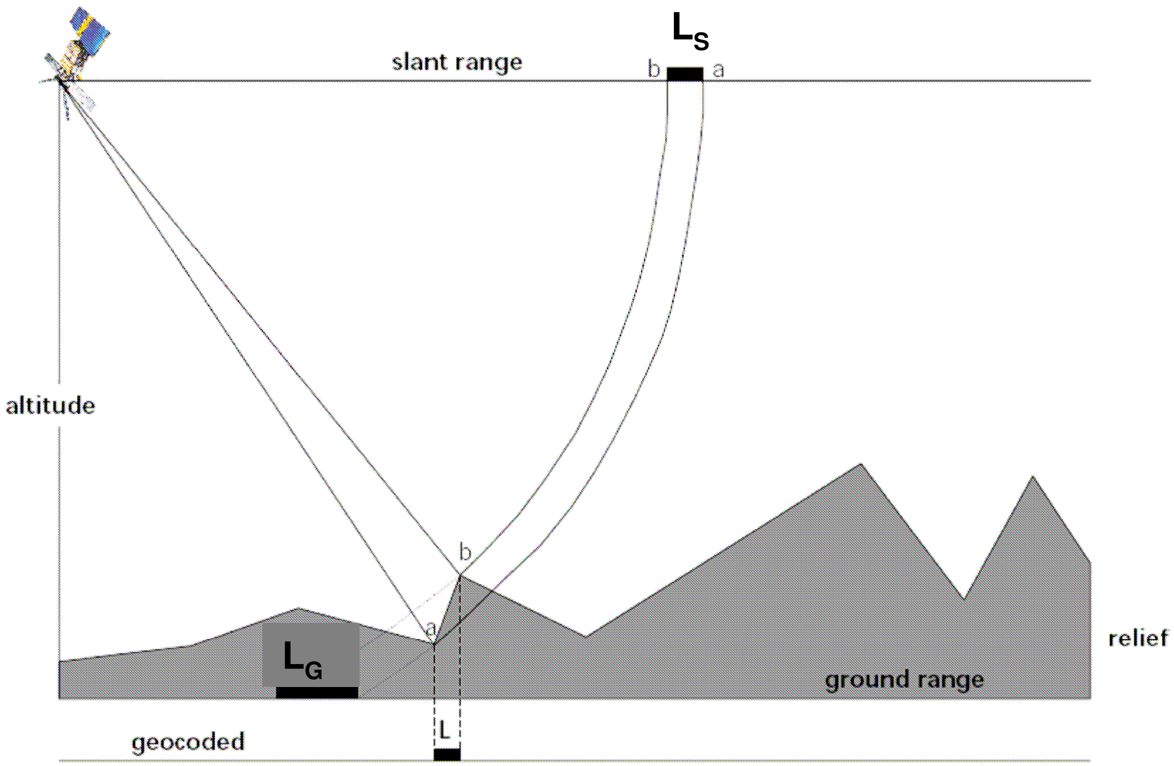
- Foreshortening



- Signal reaches base of tall feature tilted towards radar before it reaches top
- Slope appears compressed in slant (F_S) and ground range (F_G)
- Foreshortening occurs as bright area on the sensor's side of the feature

Image properties: Distortions

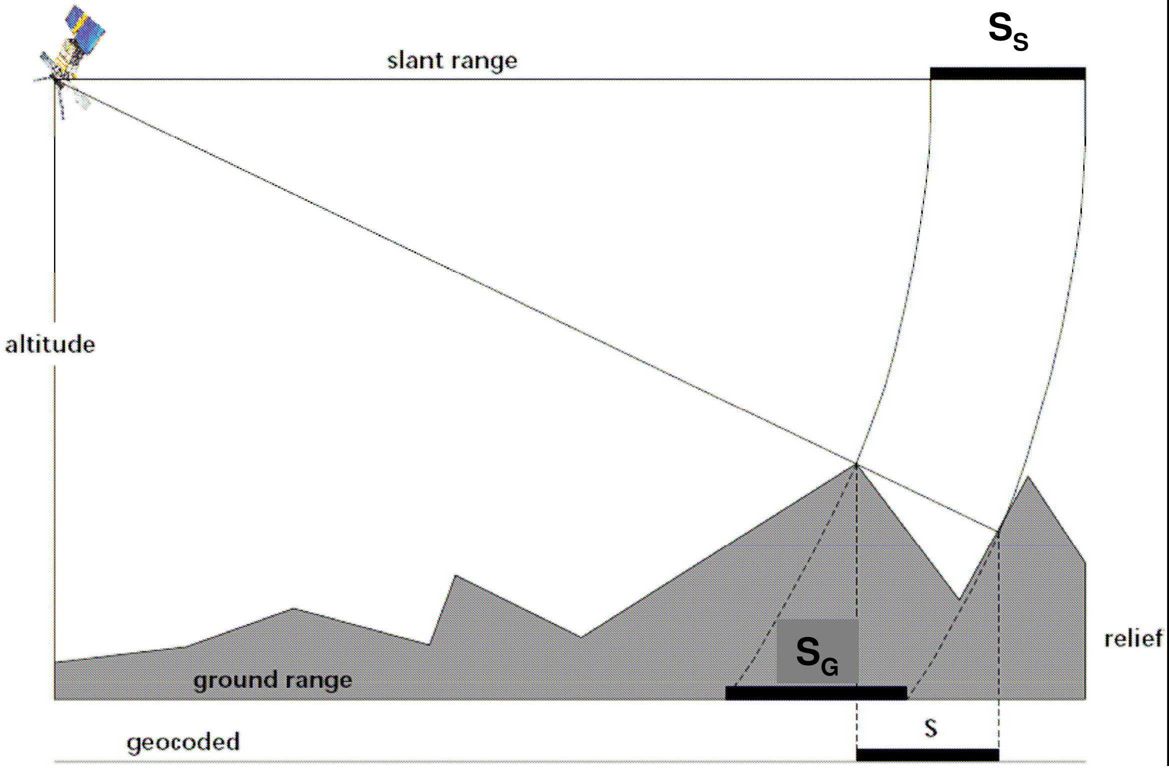
- Layover



- Extreme case of foreshortening
- Top of feature is closer to antenna than bottom
- Inversion of geometry
- Layover is visible as sharp fringe

Image properties: Distortions

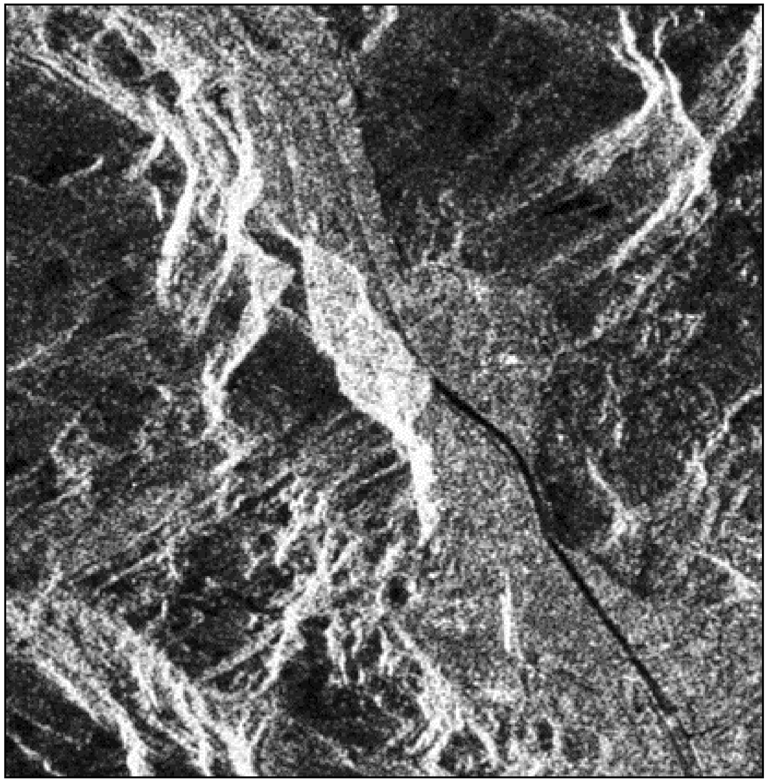
- Shadow



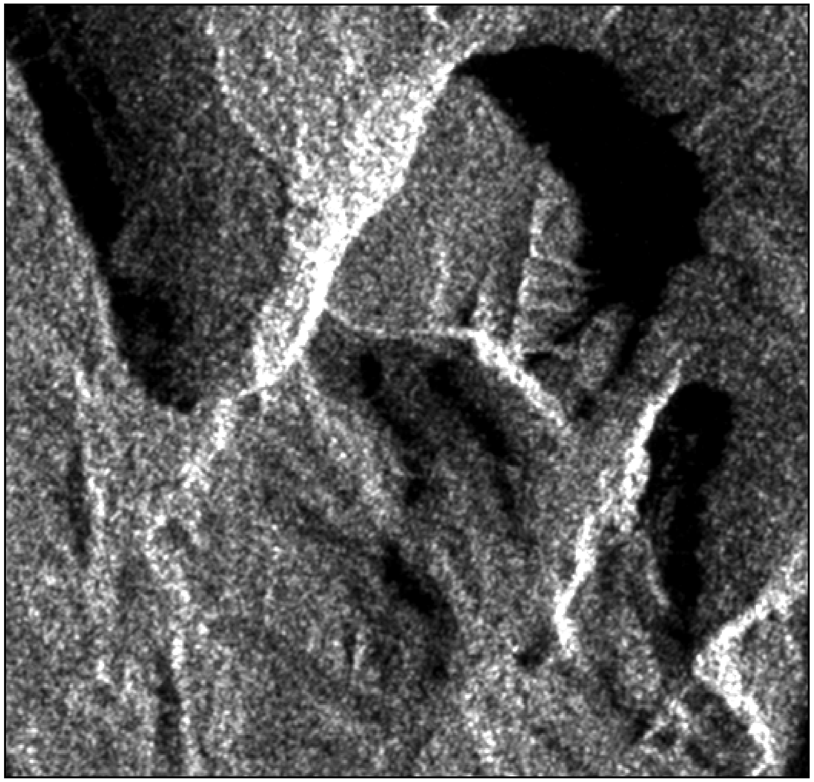
- Occurs behind vertical features when slope is steeper then incidence angle
- No image information
- Black image region

Image properties: Distortions

- Example



Layover



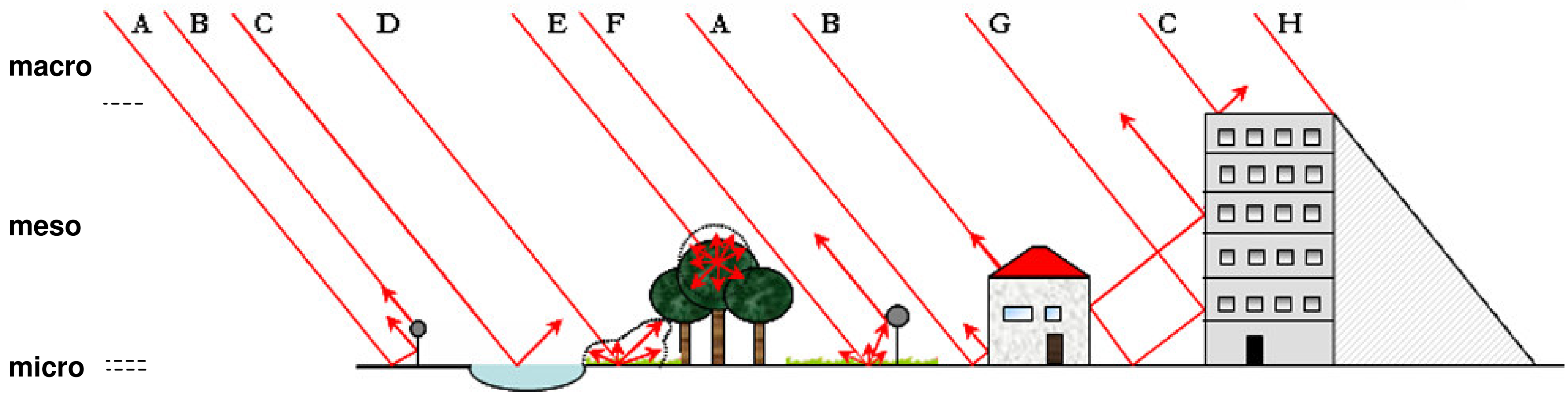
Foreshortening and shadow

Image properties: Target interaction

- Brightness of features in radar imagery depends on portion of energy that is backscattered to the SAR system
- Fundamental factors:
  - Surface roughness
  - Dielectric constant
  - Imaging and surface geometry

Image properties: Target interaction: Roughness

- Surface roughness
  - Smooth: height variation much smaller than signal wavelength: specular
  - Rough: height variations approach size of wavelength: diffuse
- Function of wavelength and incidence angle



A: double bounce (specular)
B: direct reflection (specular)
C: specular reflection
D: diffuse scattering with dominating direction
E: diffuse scattering (volume)
F: combination D & A
G: multiple double bounce
(H: shadow)

Image properties: Target interaction

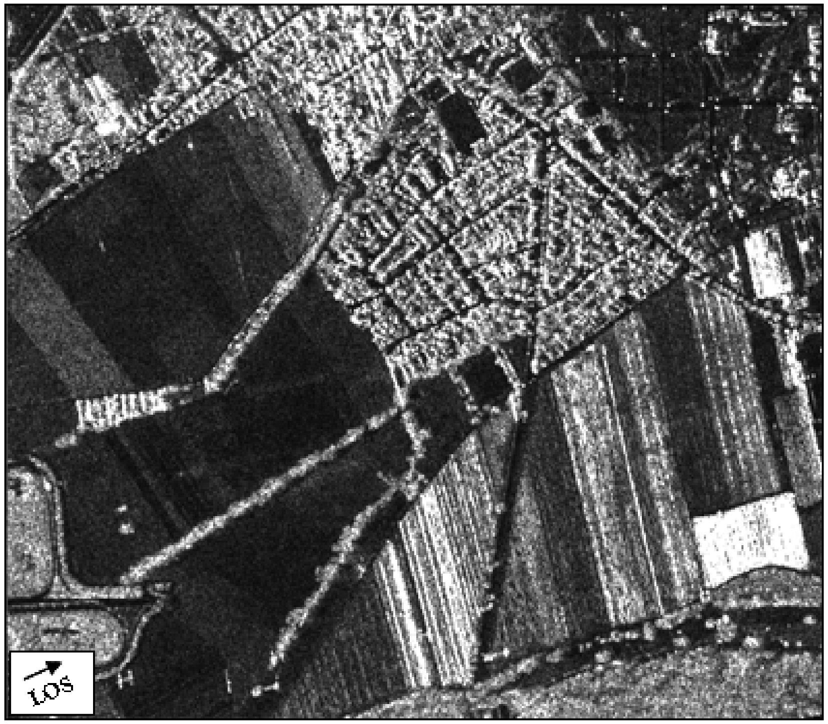
- Example: Wavelength

E-SAR X-band (3,1 cm, 9.6 GHz, 2m)

E-SAR L-band (15cm, 1.3 GHz, 3m)

Image properties: Target interaction

- Example: Polarization



E-SAR L-band (HH)

E-SAR L-band (HV)

Image properties: Target interaction

- Example: Incident angle

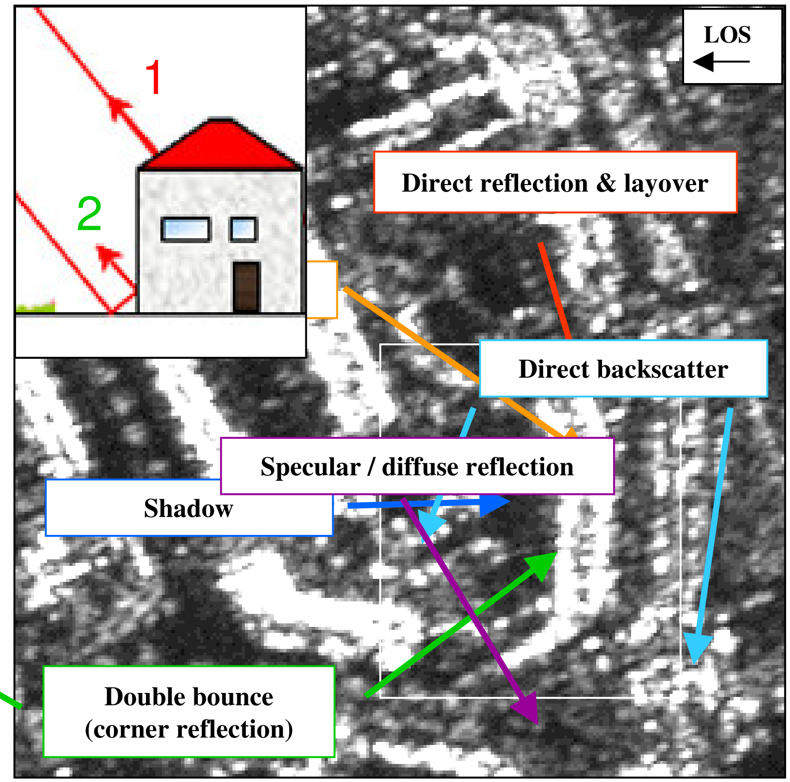
Plowed field in near range (~25°)

Identical field in far range (~40°)

Image properties: Target interaction

- Example: Complex scattering geometry in urban environment

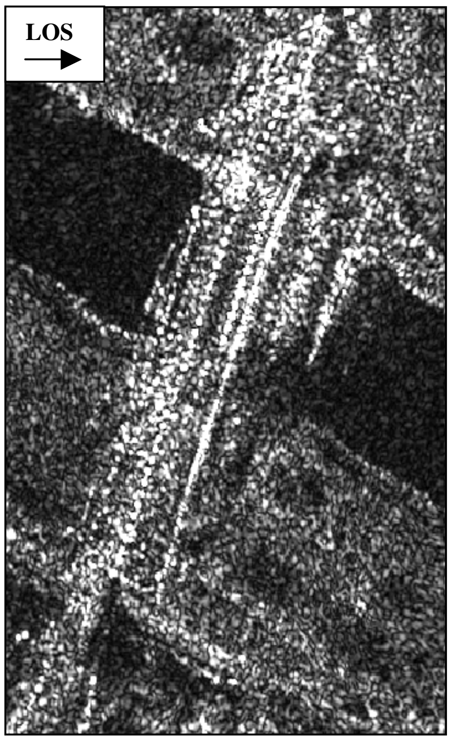
Aerial image (~30cm)



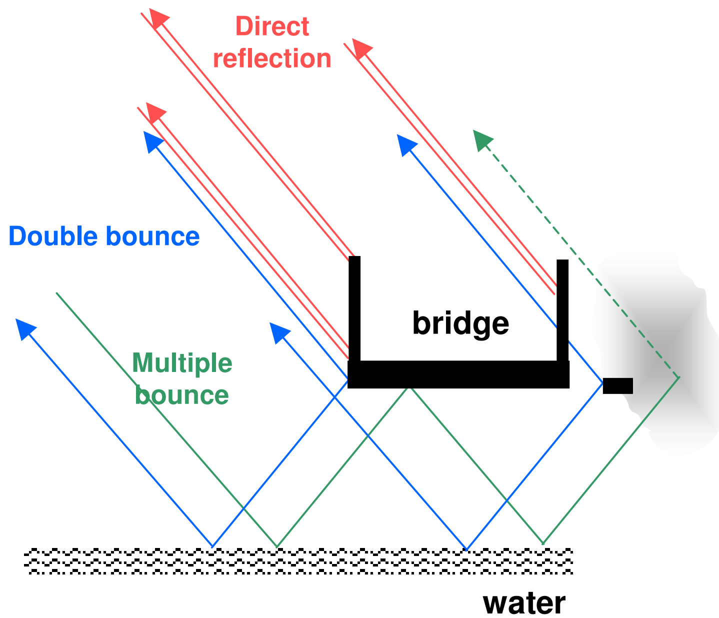
E-SAR X-band data (~1.5m)

Image properties: Target interaction

- Example: Multiple scattering



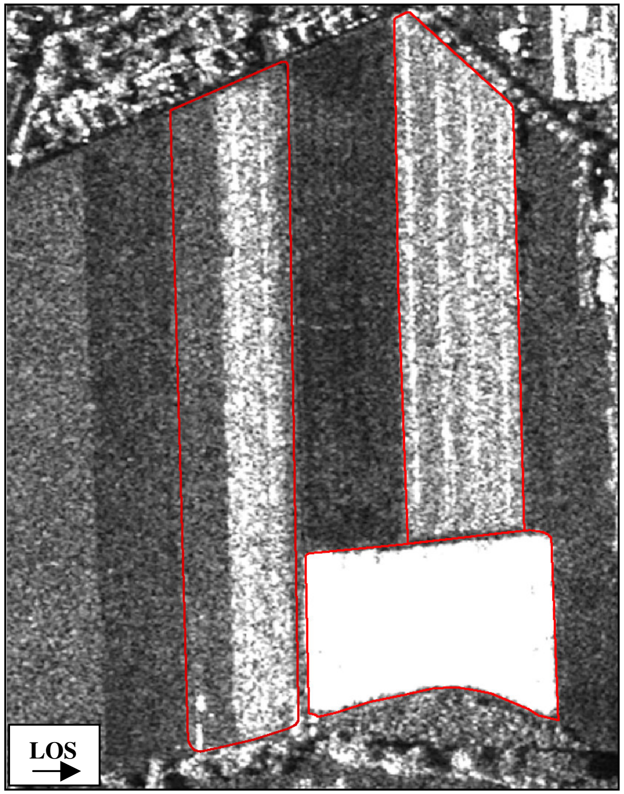
SAR image



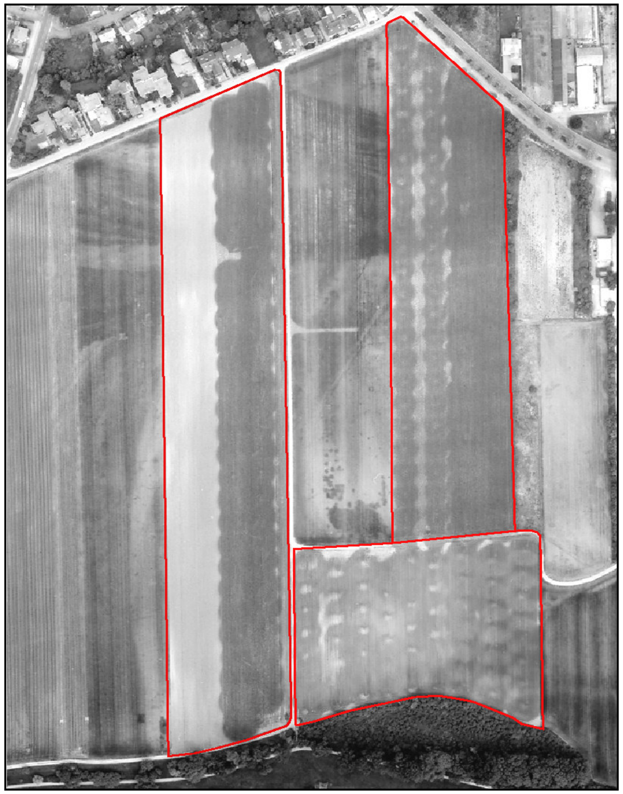
Optical image

Image properties: Target interaction

- Example: Moisture content and dielectric properties



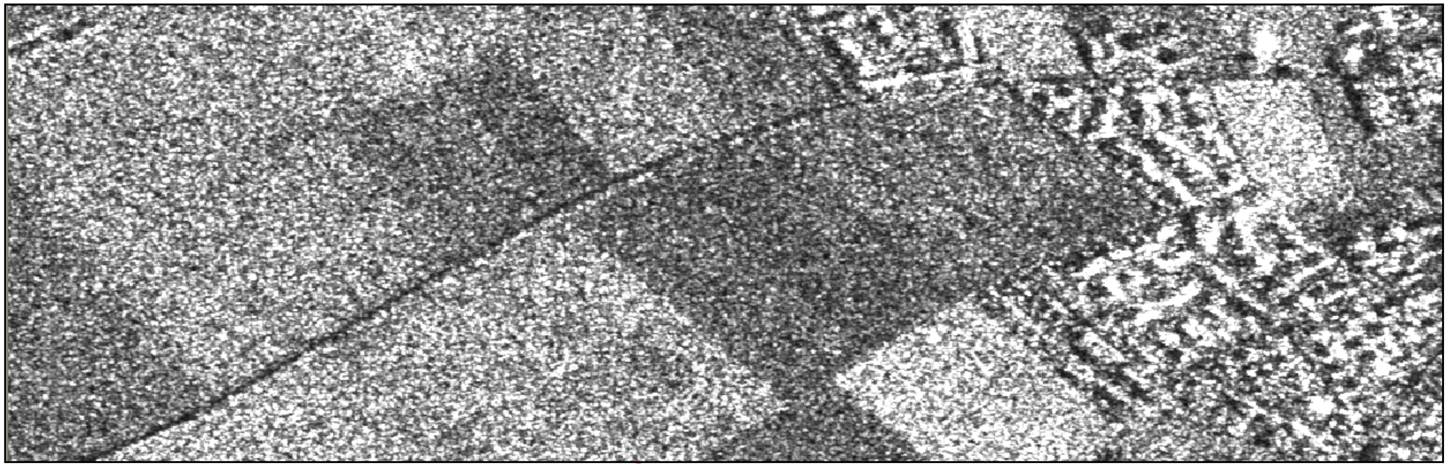
E-SAR X-band



Aerial image

Image properties: Target interaction

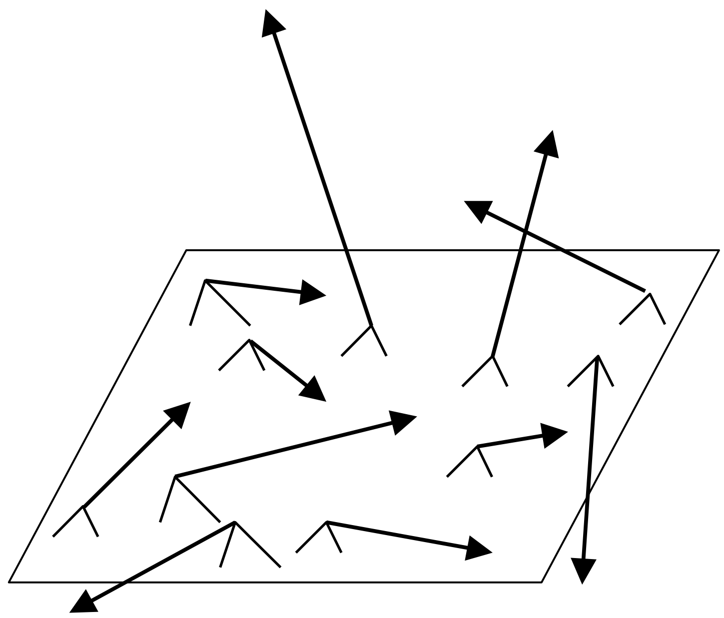
- Speckle noise
  - Grainy "salt and pepper" texture
  - Caused by random constructive and destructive interference from multiple scattering returns within each resolution cell
  - Speckle hampers visual and computer-aided analysis of SAR image data



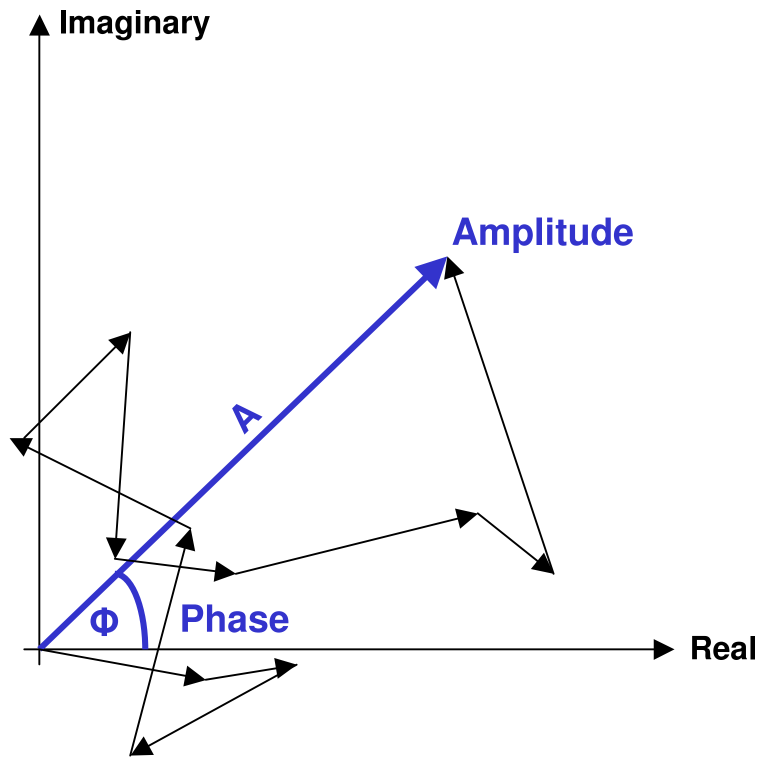
Appearance of speckle noise in TerraSAR-X data

Image properties: Target interaction

- Speckle noise



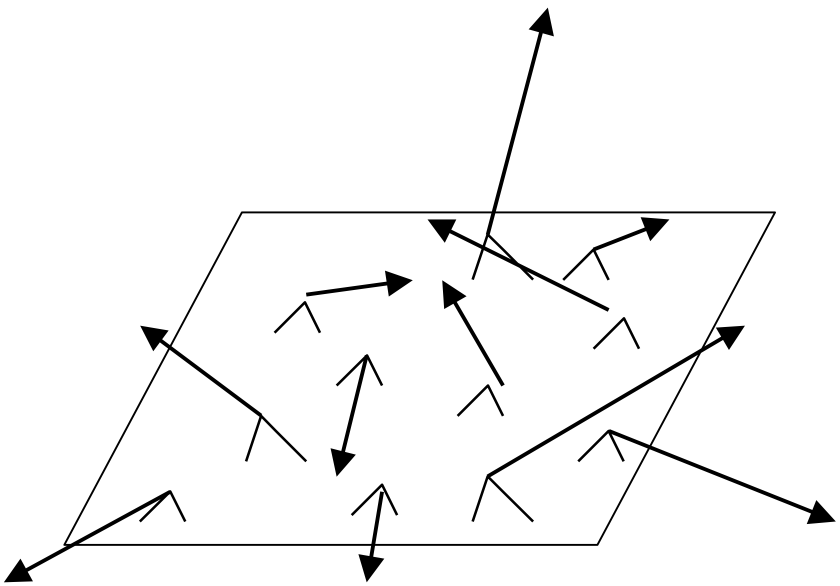
Resolution cell A



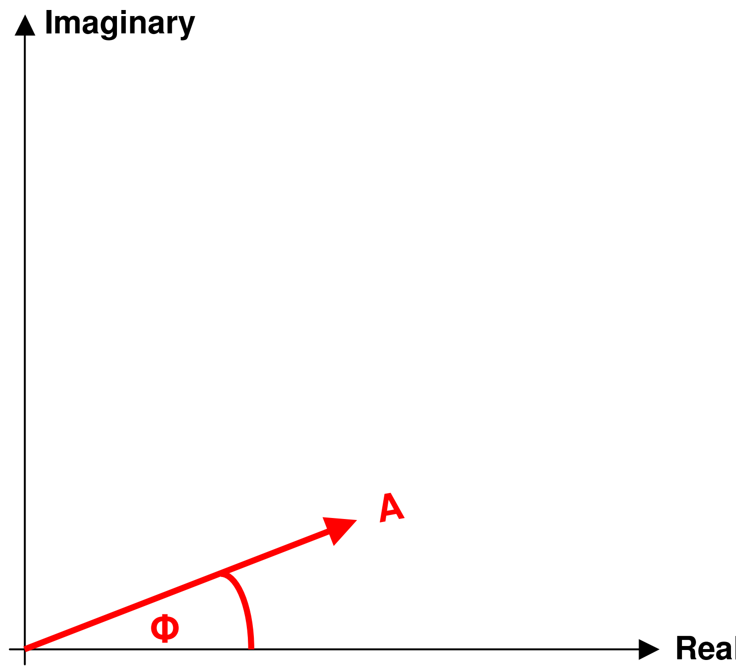
Resulting signal

Image properties: Target interaction

- Speckle noise



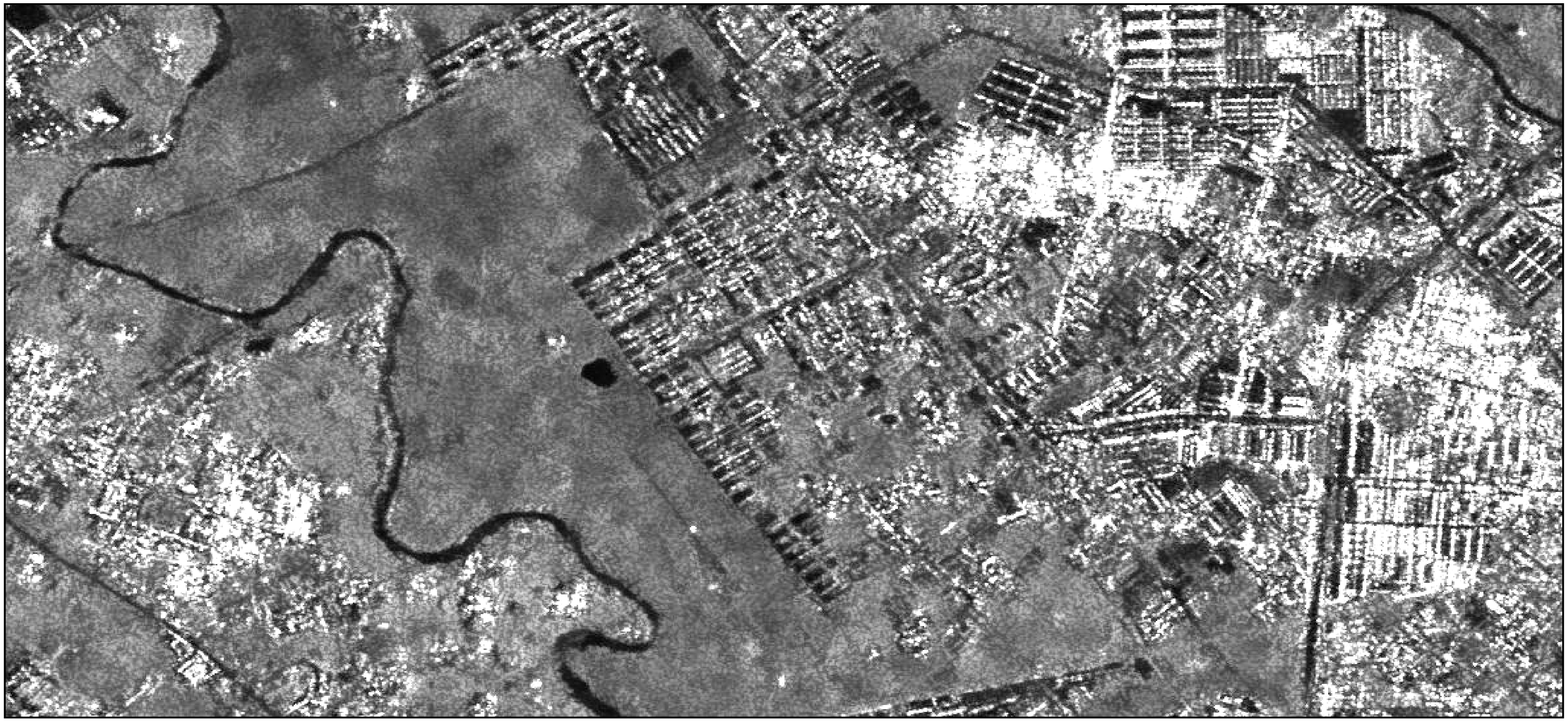
Resolution cell A+1



Resulting signal

Image properties: Target interaction

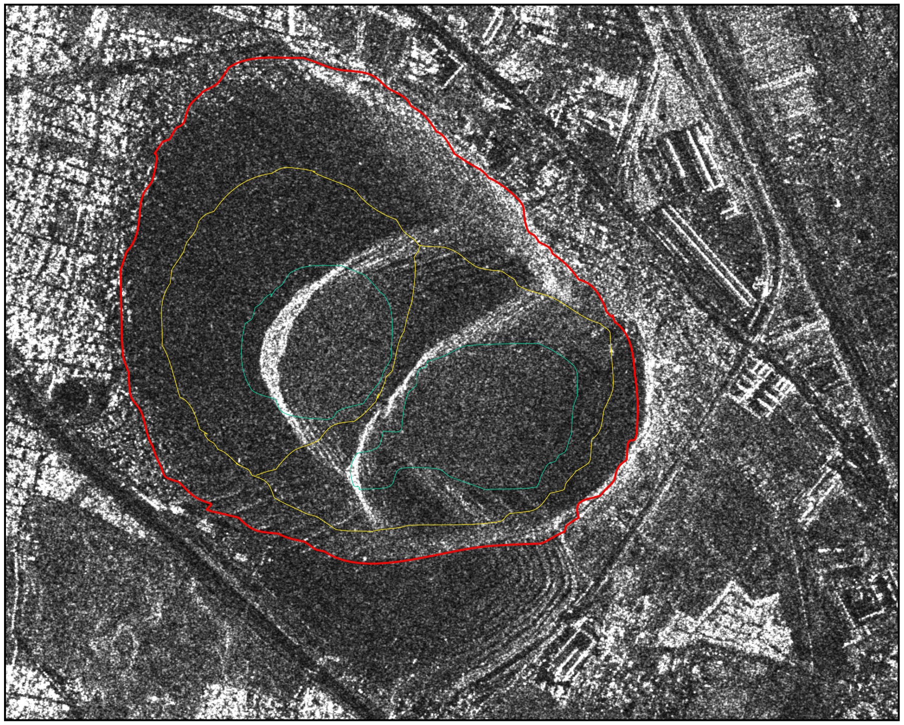
- Speckle noise: Filtering



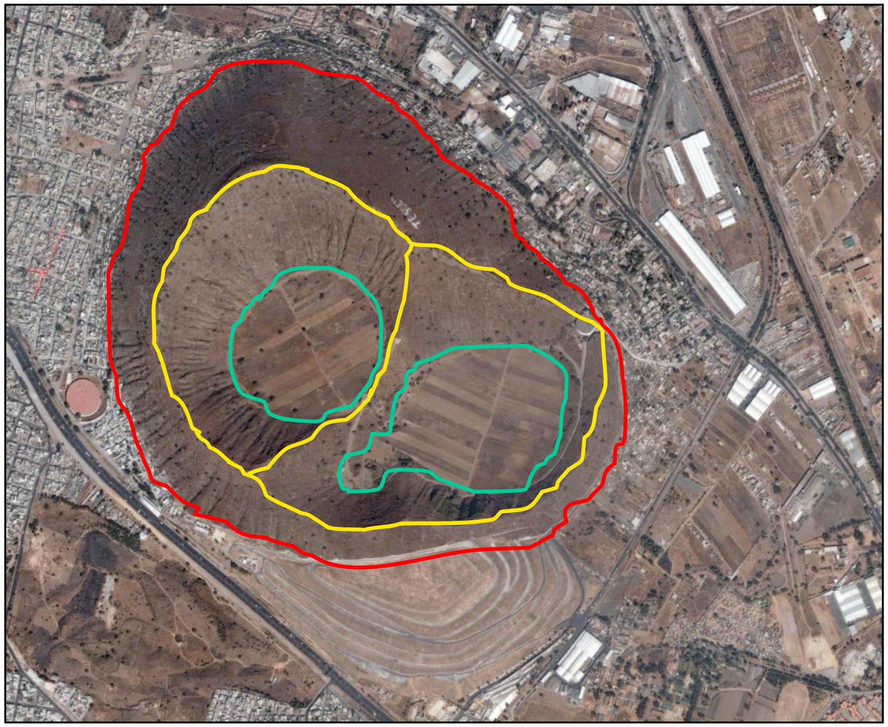
Filtered TerraSAR-X intensity image


…. let‘s go „hands-on“ ….

Image understanding: Example “Volcano”



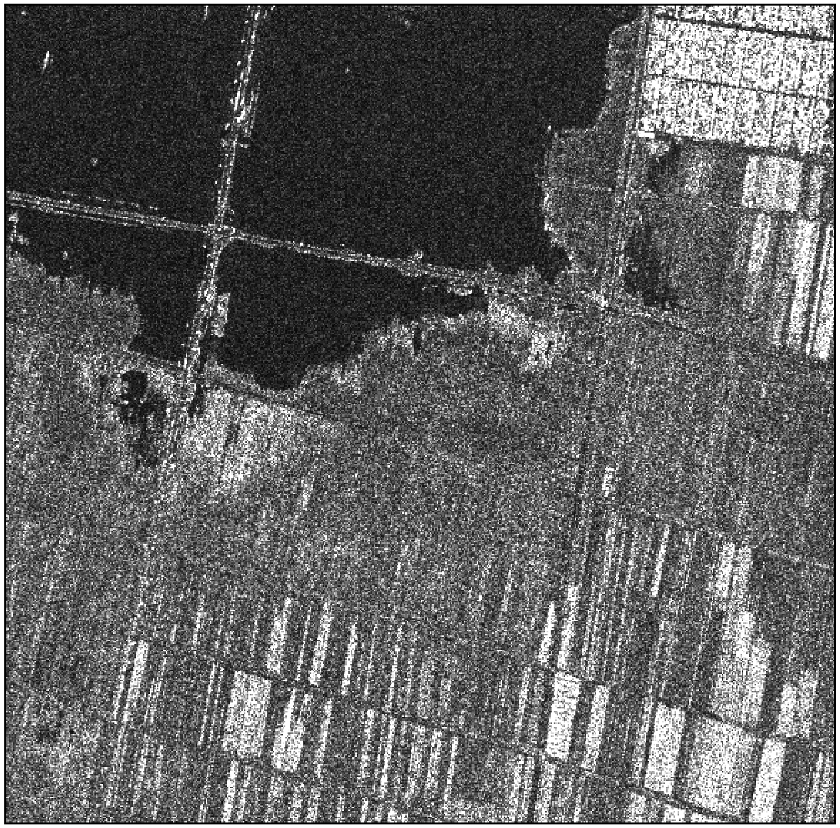
Volcano captured by TerraSAR-X (SM, 3m, 27°)



Aerial image

- Which effects do you expect at the footprint, ridge and bottom of the crater/volcano?
- From which direction did the sensor illuminate the area?
- Can you identify any effects due to distortions?

Image understanding: Example "Land use"

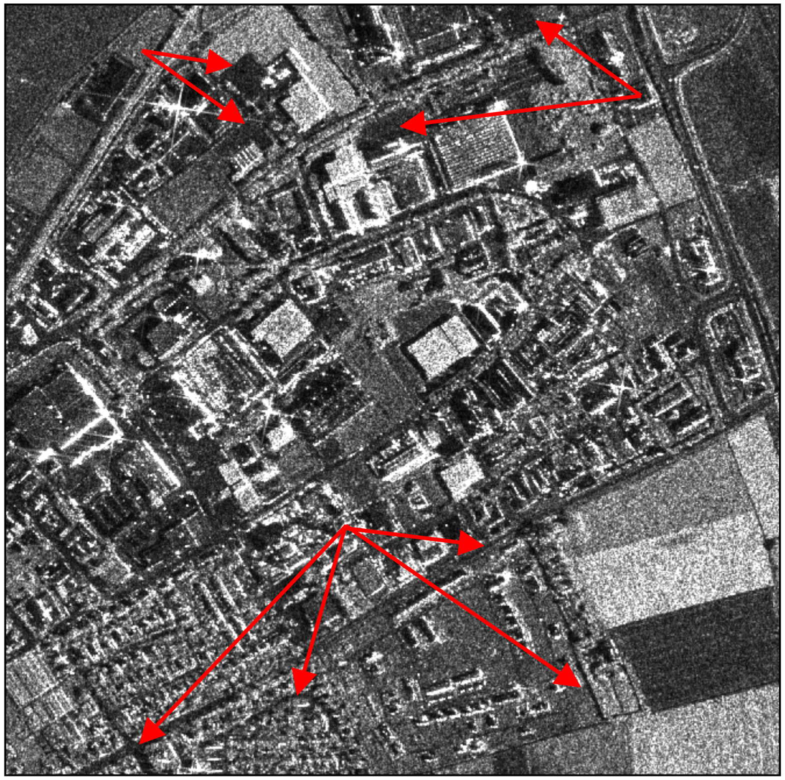


TSX data (SM, 3m, 27°)

Aerial image

- Which land use types and/or man-made structures do you find in the SAR image?

Image understanding: Example "Urban"

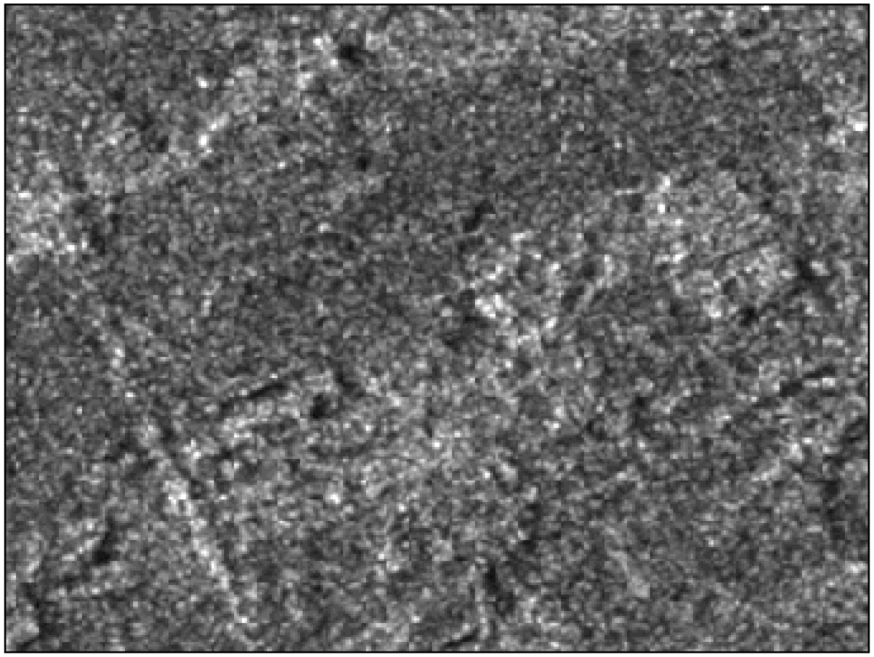


Urban TerraSAR-X scene (HS, 2m, 34°)

Aerial image

- Can you distinguish between different urban structural types?
- Which effects occur with respect to the roofing of buildings?
- Can you spot impervious surfaces – except of buildings?

Image understanding: Example "Forest"



Woodland captured by TerraSAR-X (SM, 6m, 35°)

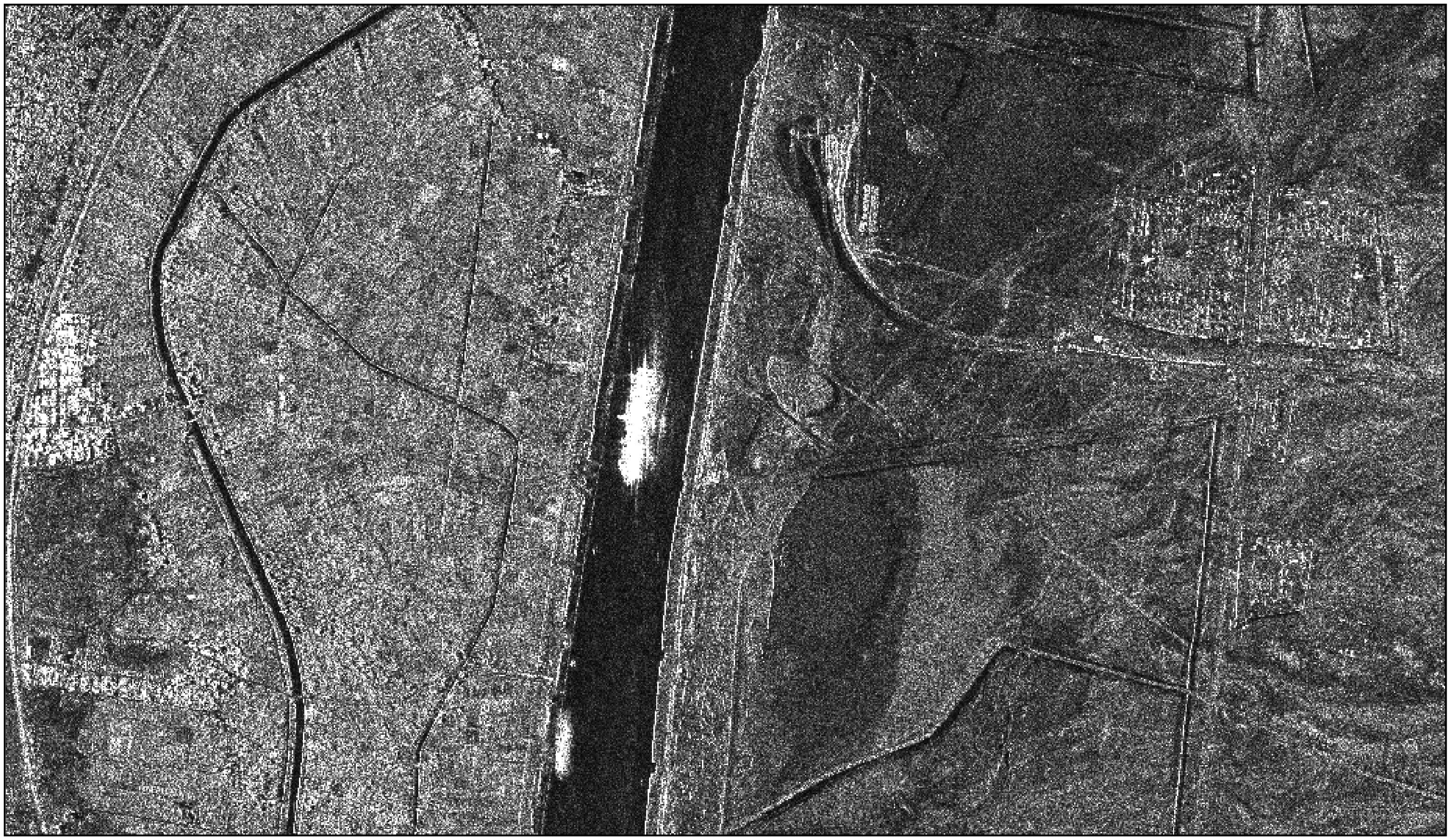
Aerial image (30cm)

- What causes the differences in backscatter within the woodland?

Content

- **Image understanding**
  - Fundamentals
    - Radar
    - Frequency & polarization
    - Imaging geometry
    - Geometric & radiometric resolution
  - Image properties
    - Distortions (E)
    - Target interaction (E)
- **Data Analysis**
  - Image enhancement
    - Data Stretch (E)
    - Speckle suppression (E)
  - Image classification
    - Textural features (E)
    - Generation of image objects (E)
    - Identification of built-up areas (E)

Image enhancement: Data stretch (Example “Ship”)



TerraSAR-X image of Suez channel (linear stretch 0 - 250)

Image enhancement: Data stretch (Example “Ship”)

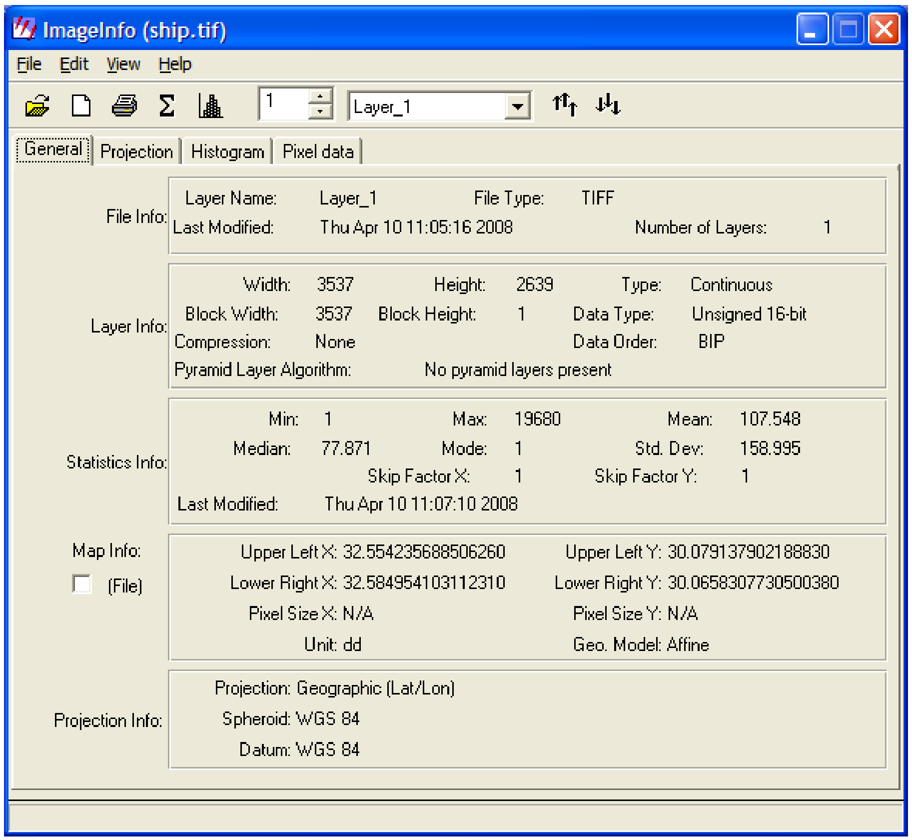
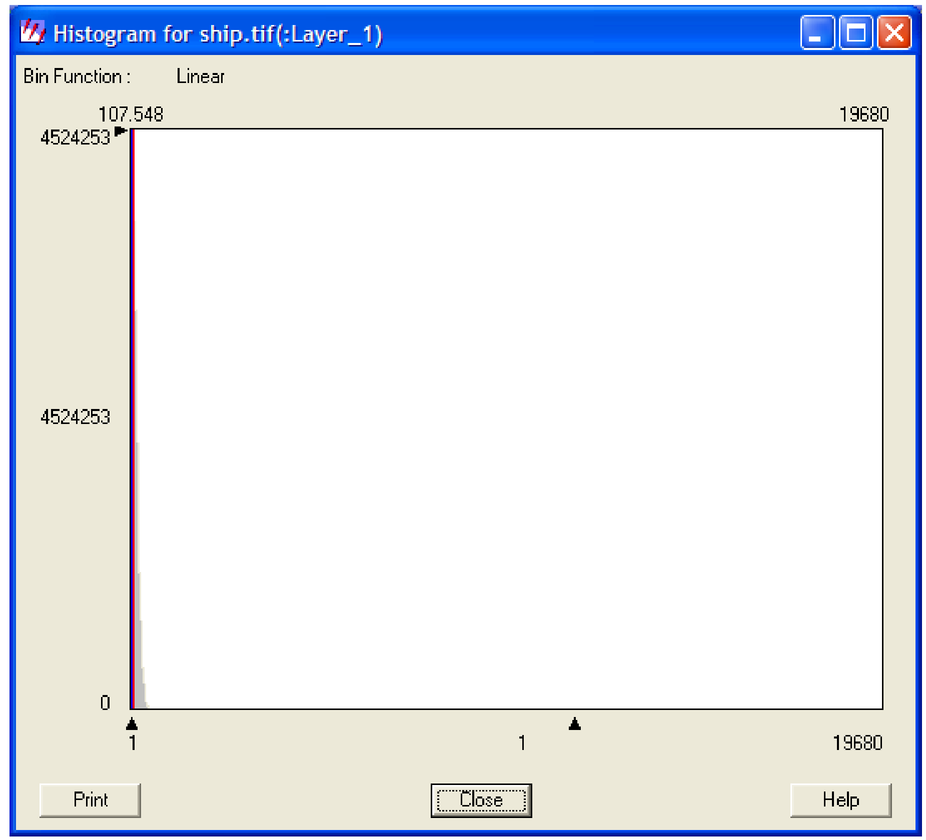
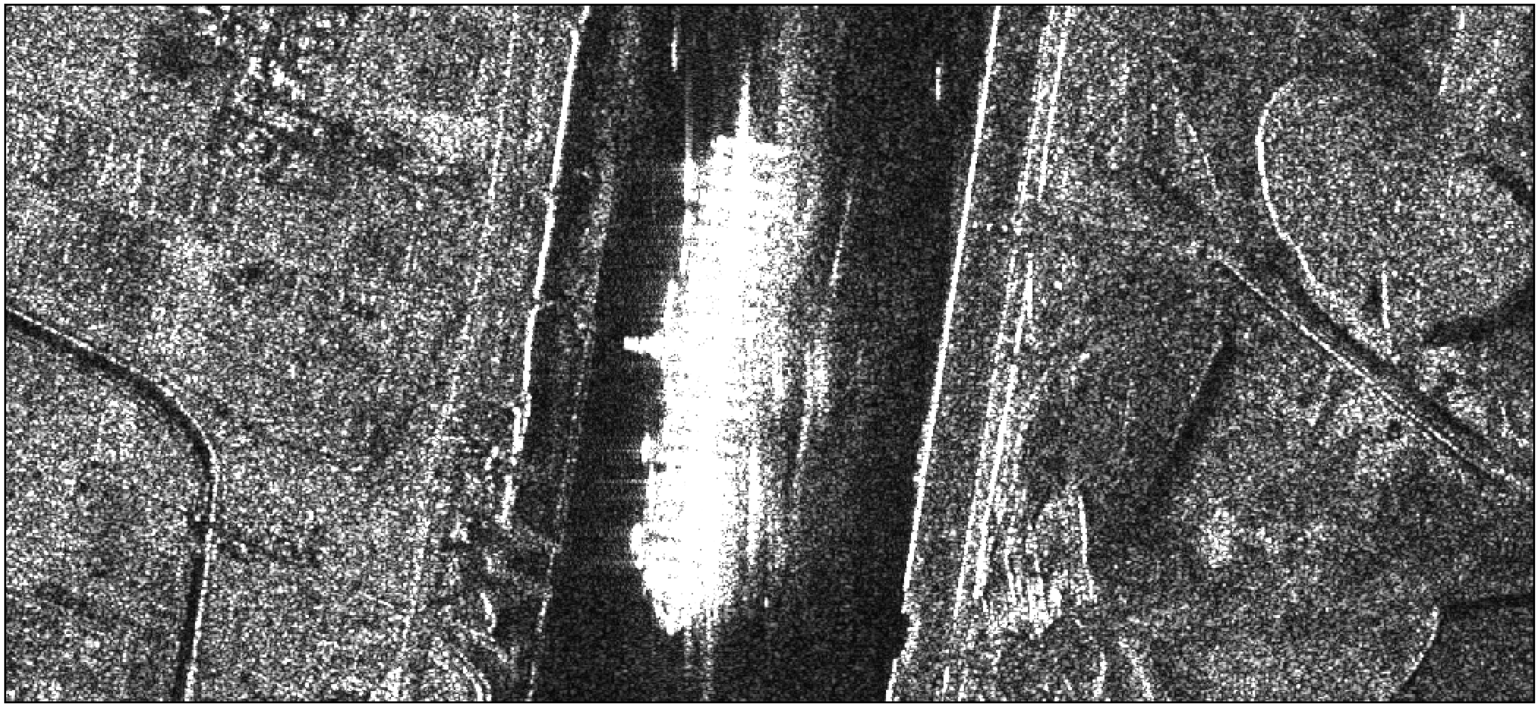


Image Info



Histogram

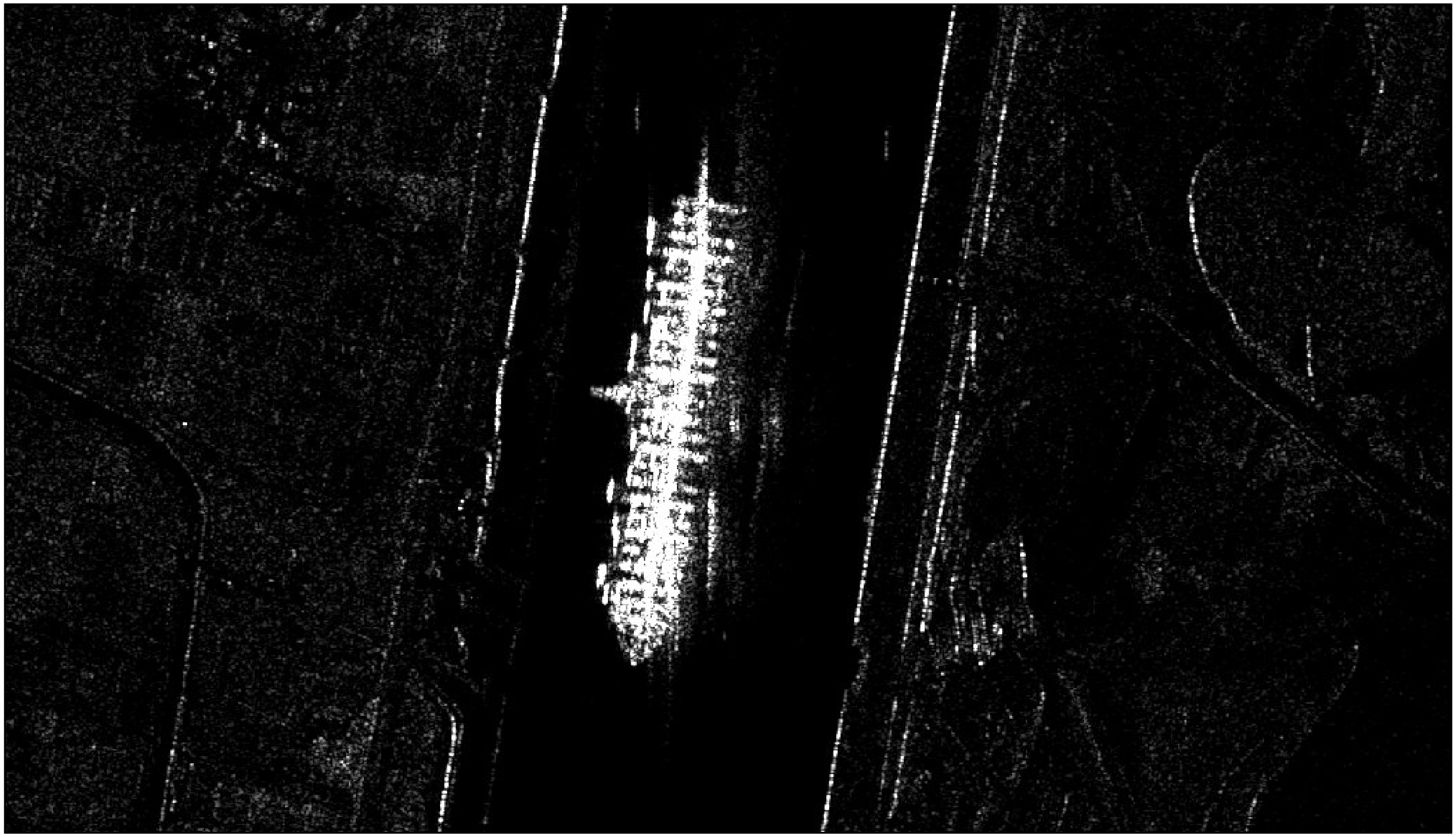
Image enhancement: Data stretch (Example "Ship")



TerraSAR-X image of Suez channel (linear stretch 0 - 300)

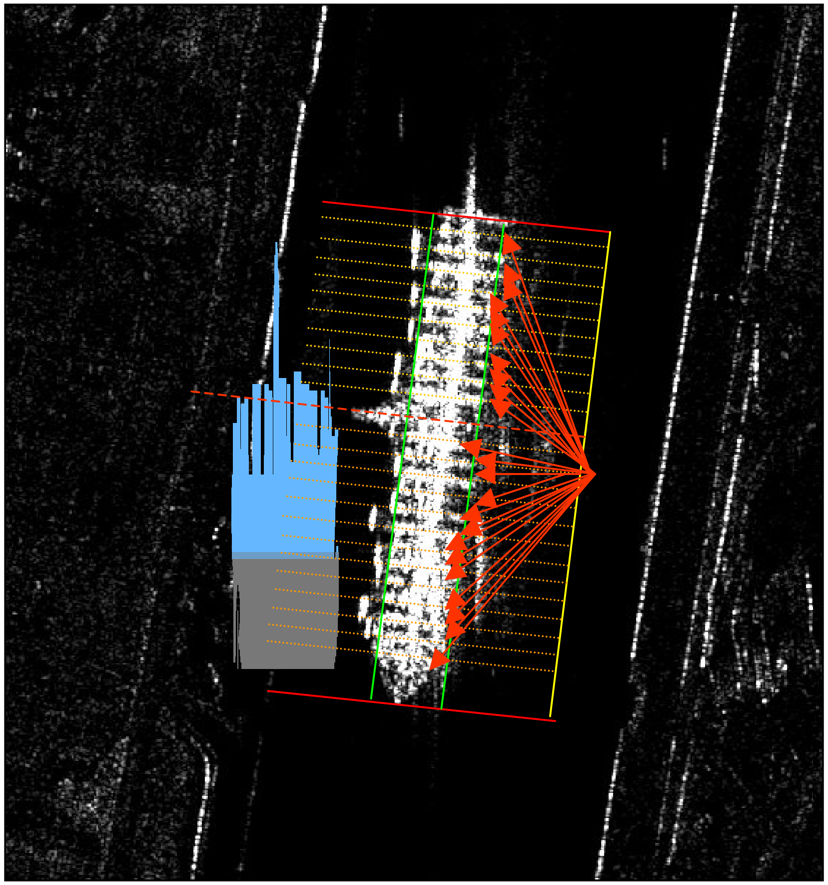
- **Improve the visualization of the ship in order to increase the level of detail.**
- **Try to characterize of the ship!**

Image enhancement: Data stretch (Example “Ship”)



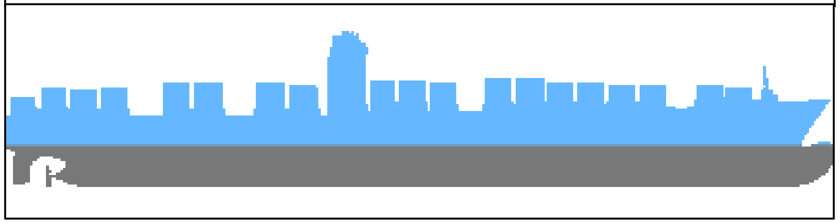
TerraSAR-X image of Suez channel (linear stretch 100 - 1000)

Image enhancement: Data stretch (Example “Ship”)



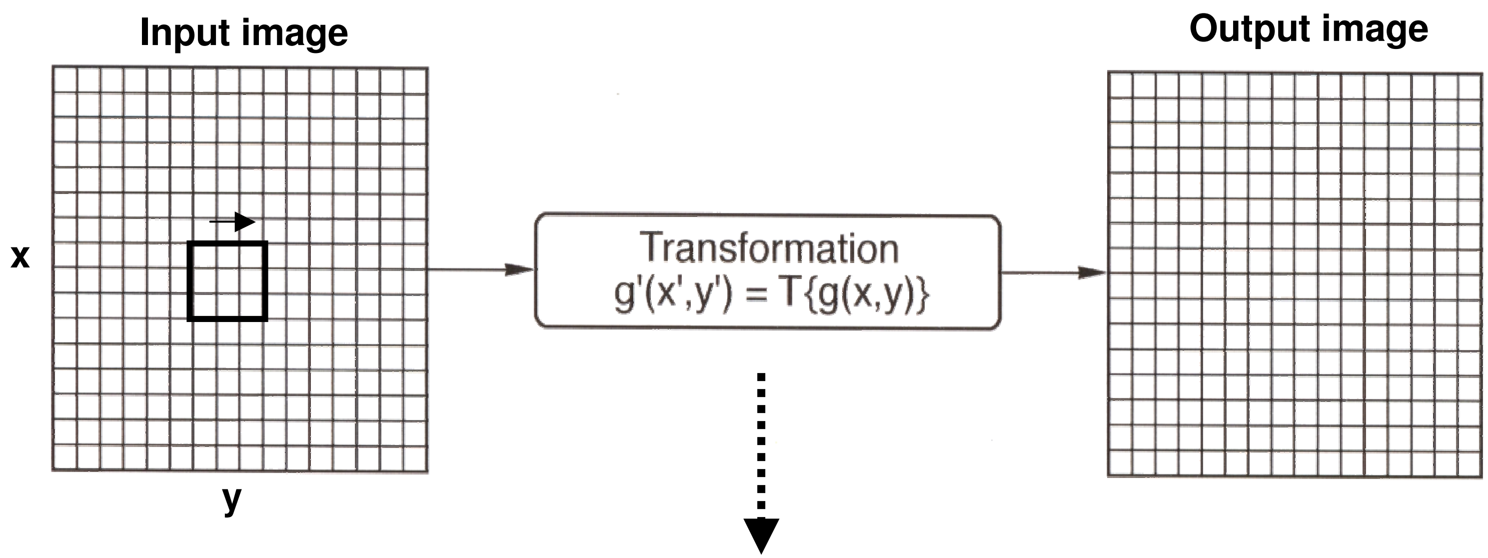
Ship captured by TerraSAR-X

- Container ship
- Bridge almost in central position (OK)
- Length : ~ 400m (397m)
- Width: ~ 55m (56m)
- ~ 24 rows of containers (13 front, 11 back) (23, 13/10)



Container ship “Emma Mærsk”

Image enhancement: Speckle suppression



10	10	10
36	36	36
17	17	17

Input image

1	1	1
1	1	1
1	1	1

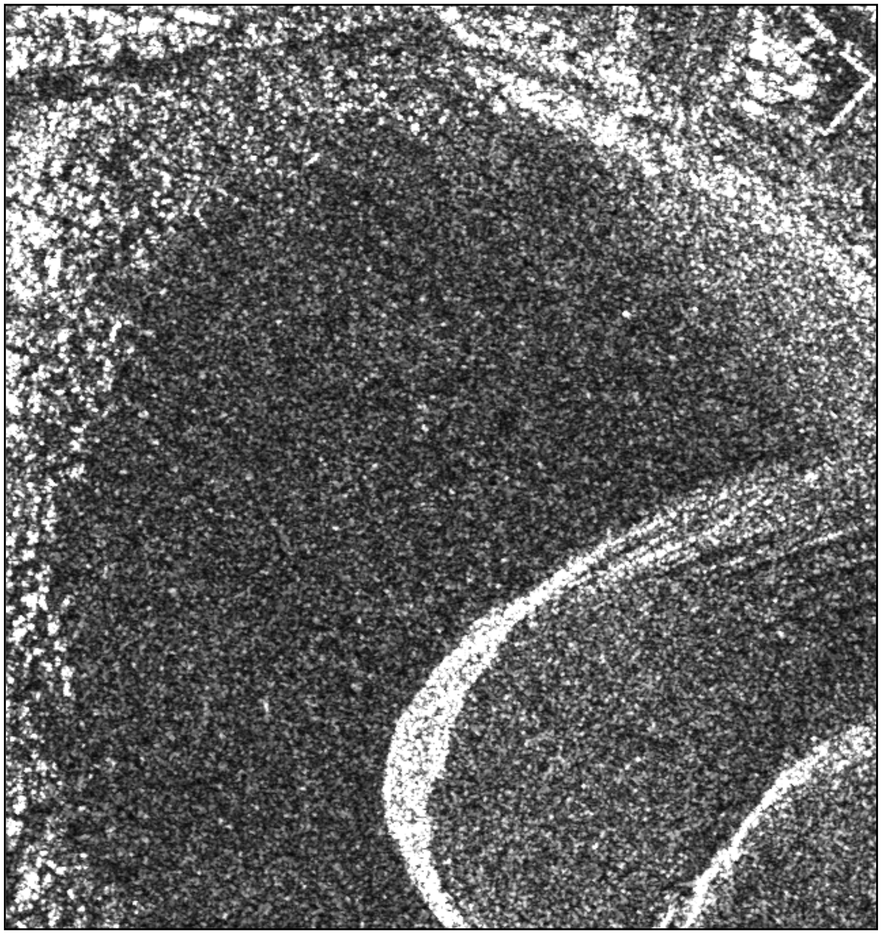
Transfer function

x	x	x
x	21	x
x	x	x

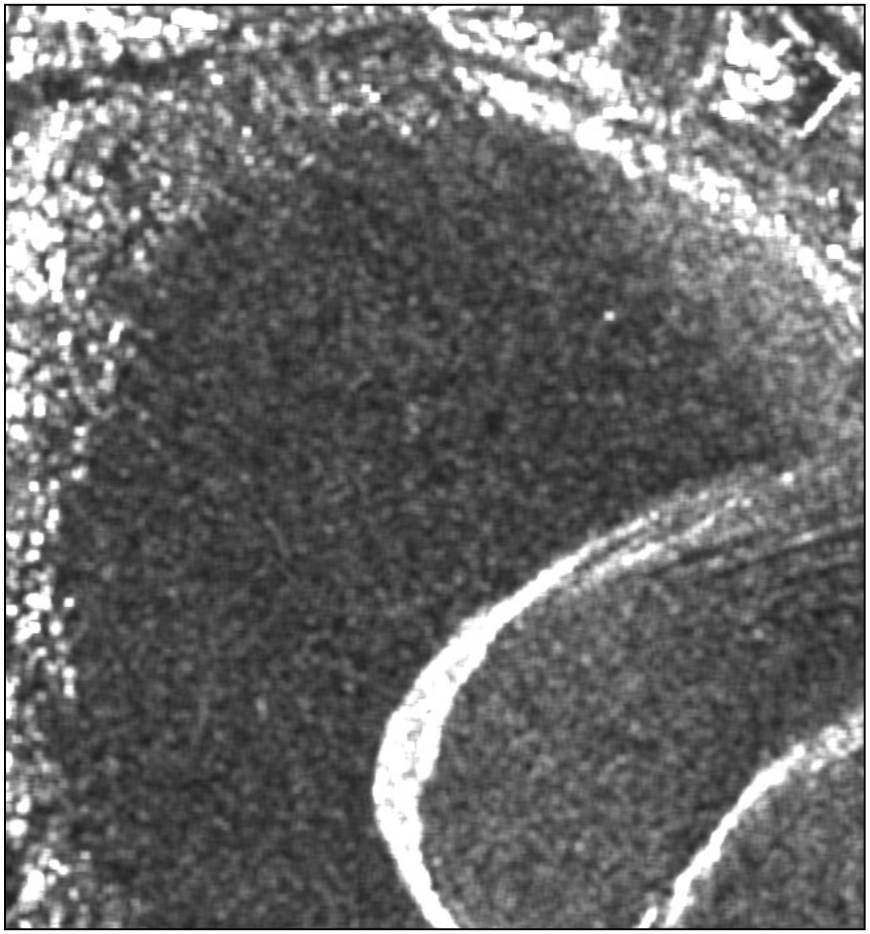
Output image

$$\frac{\sum(10+10+10+36+36+36+17+17+17)}{9}$$

Image enhancement: Speckle suppression ("Volcano")

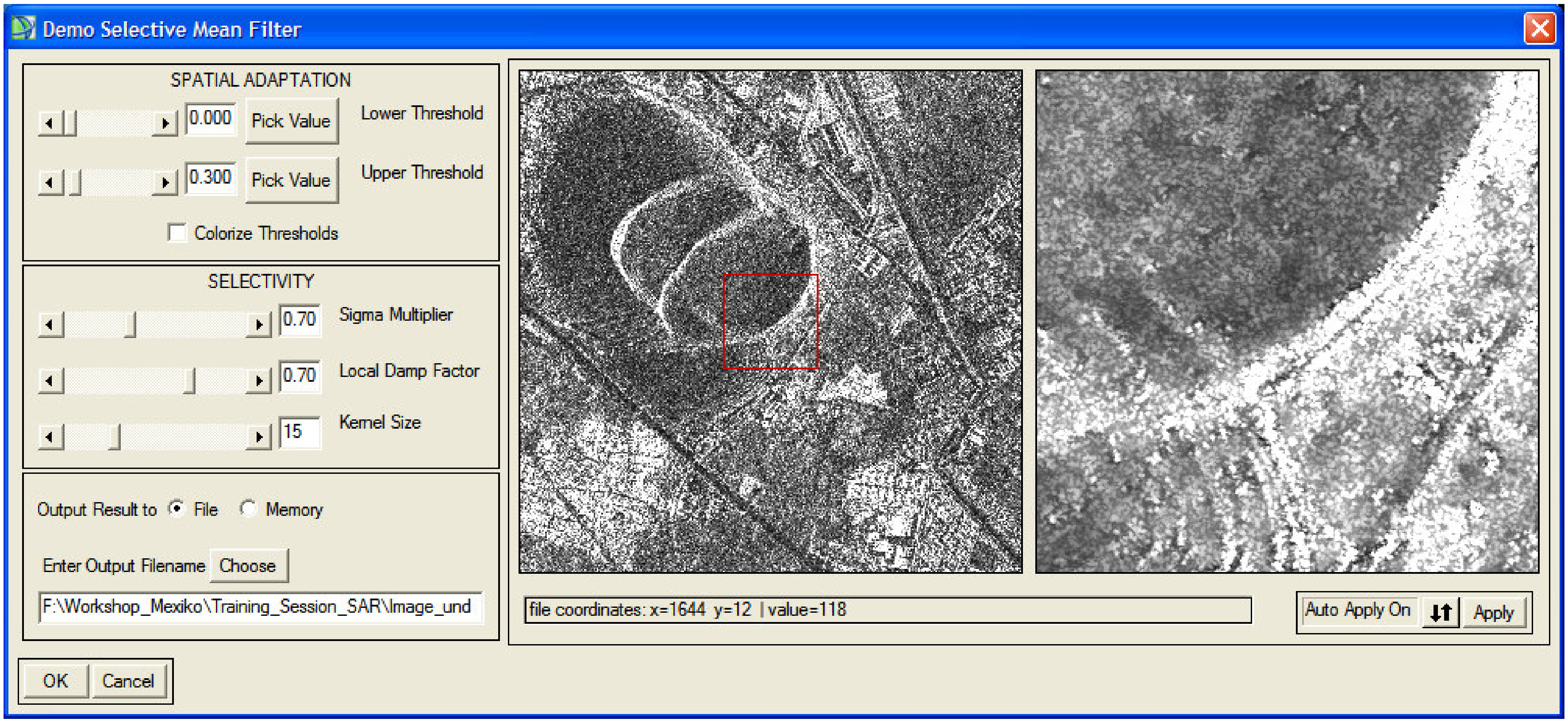


Original image



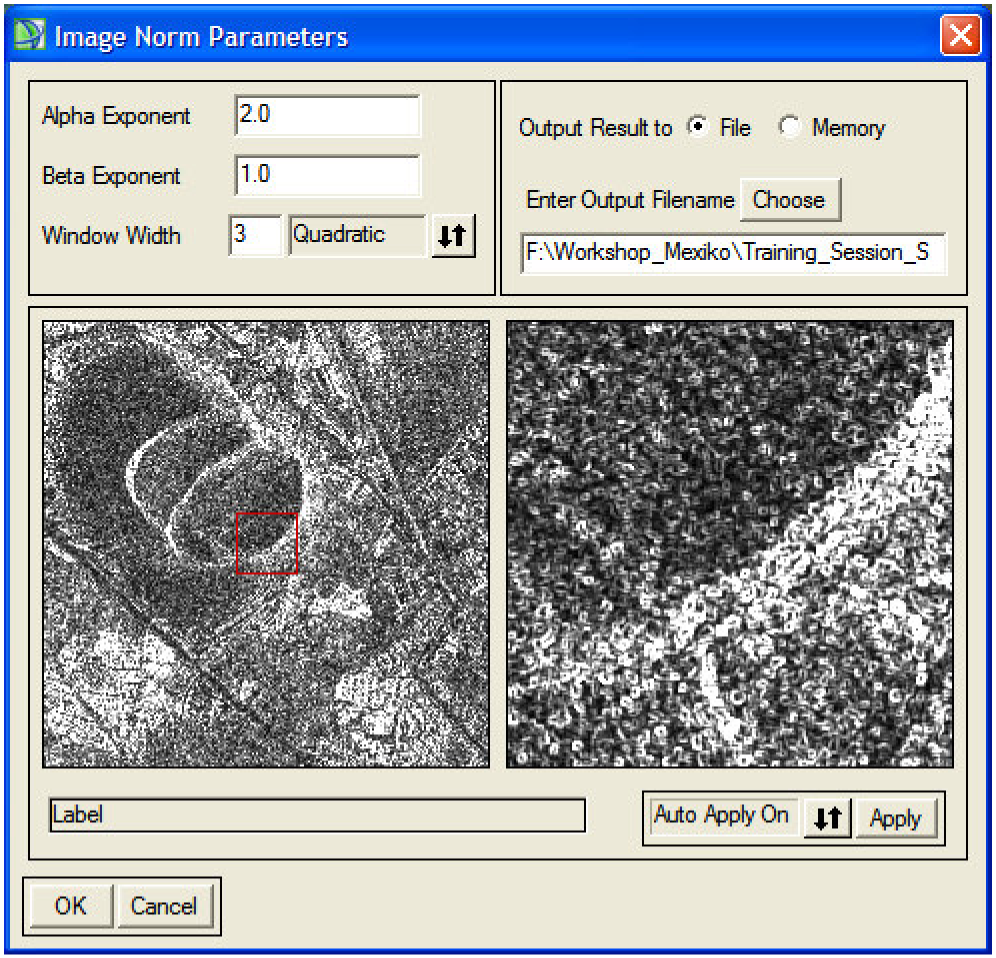
Filtered image (7x7 mean)

Image enhancement: Speckle suppression ("Volcano")



Graphical User Interface (GUI) of SelectiveMean filter

Image classification: Textural features ("Volcano")



GUI of texture analysis tool

$$norm_{Envi\_Gui} = \frac{\frac{1}{N-1}\sum \left|x_i - \bar{x}\right|^{\alpha}}{\bar{x}^{\beta}}$$

Image classification: Textural features ("Volcano")

Original image

Image norm (alpha = 2 , beta = 1)

Image classification: Detection of built-up areas

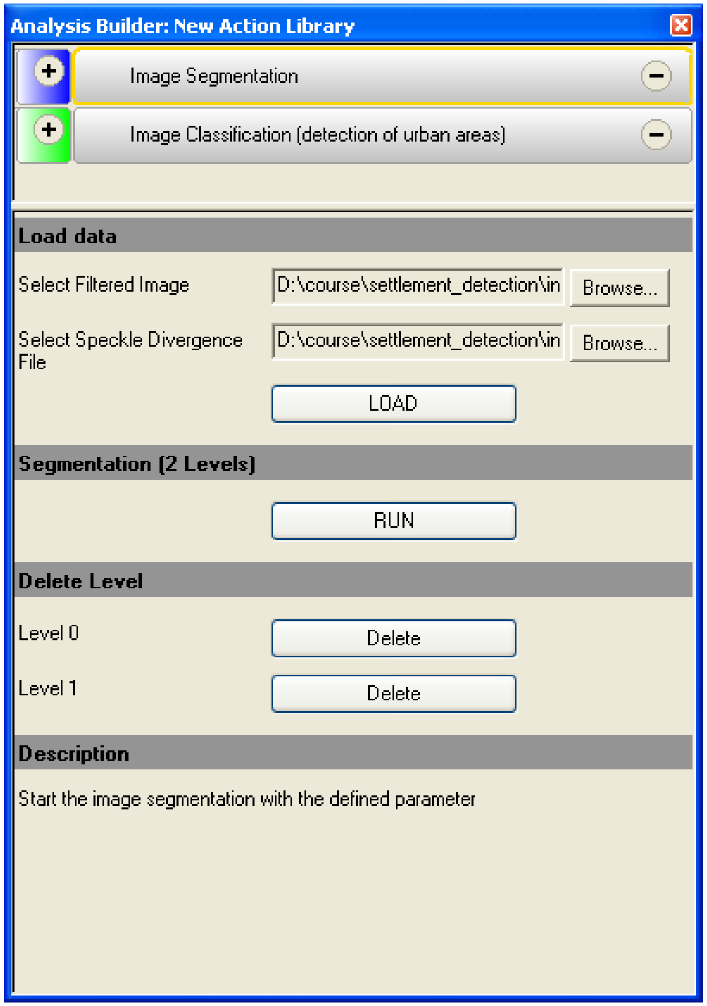
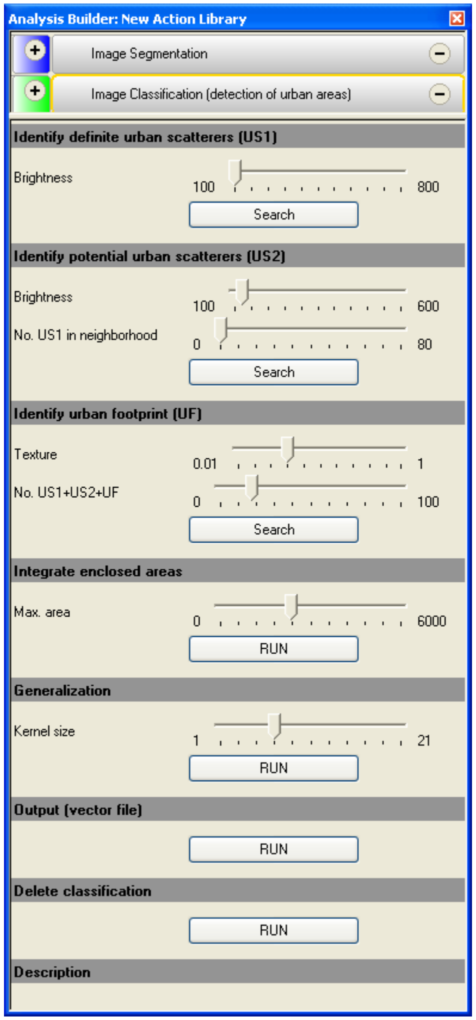


Image classification: Detection of built-up areas



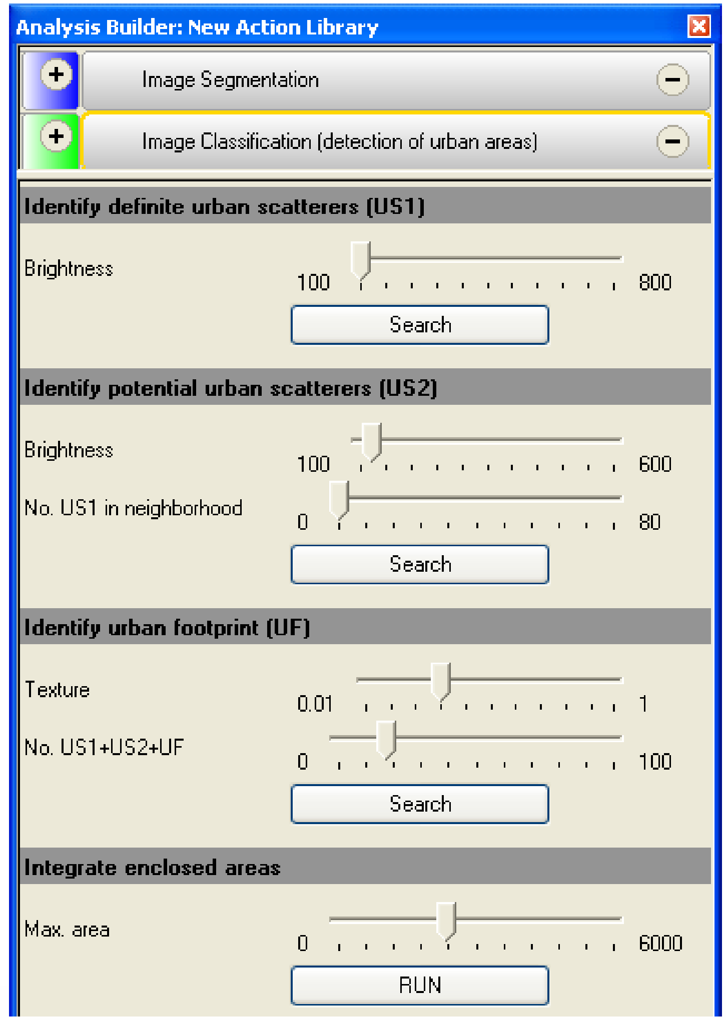
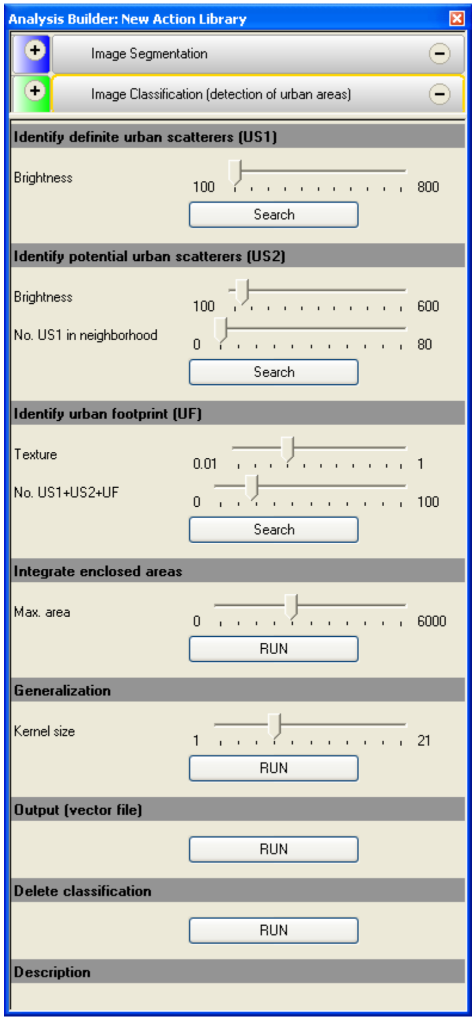
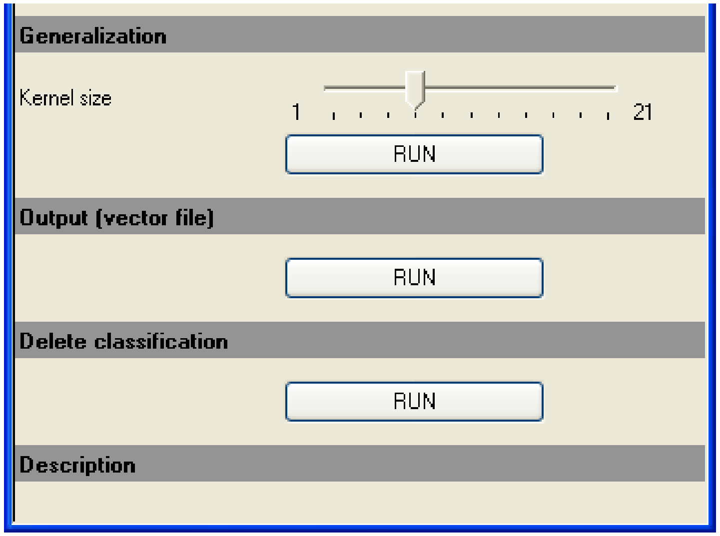


Image classification: Detection of built-up areas






Thank you very much for your attention!!
Contact: Thomas.Esch@uni-wuerzburg.de
Achim.Roth@dlr.de