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School of Electrical
Engineering

E4230
Microwave EO Instrumetation

(5 cr)

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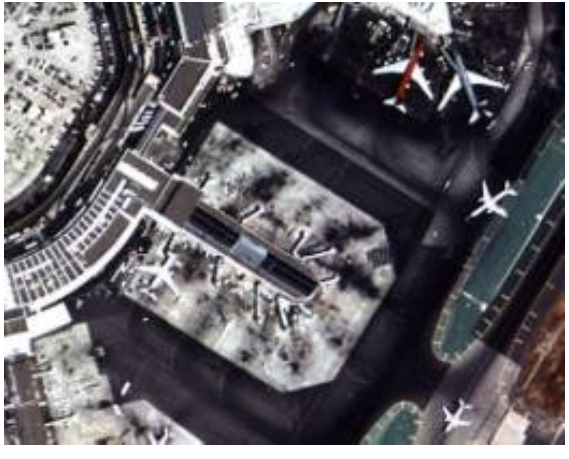
Aalto University

Few words about resolution

Resolution

- Resolution describes the distance between two bright targets which are separable on the image.

- Spatial resolution of remote sensing instruments varies from order of 1 m to 100 km.

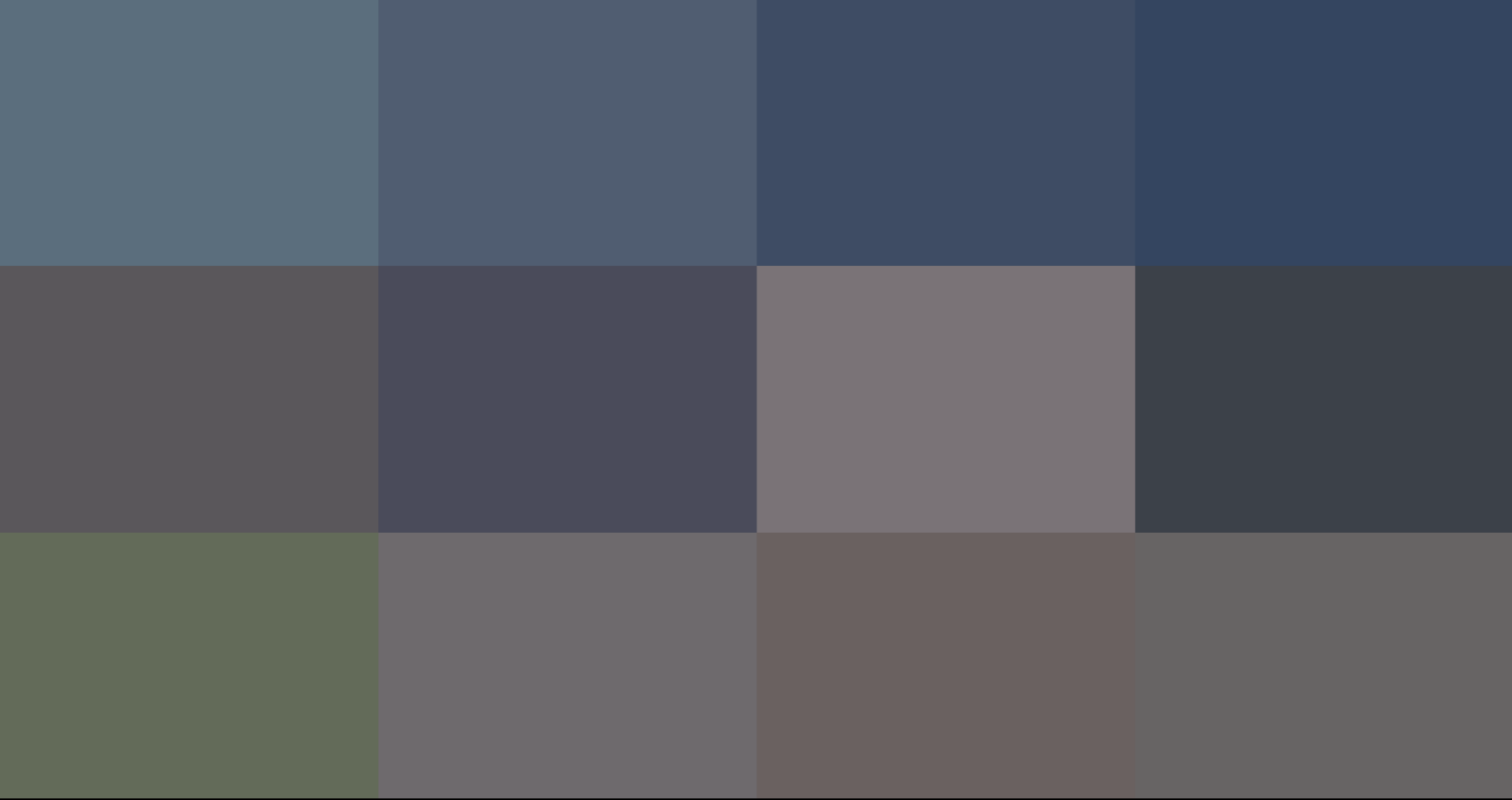


1077x687

200x128

80x51

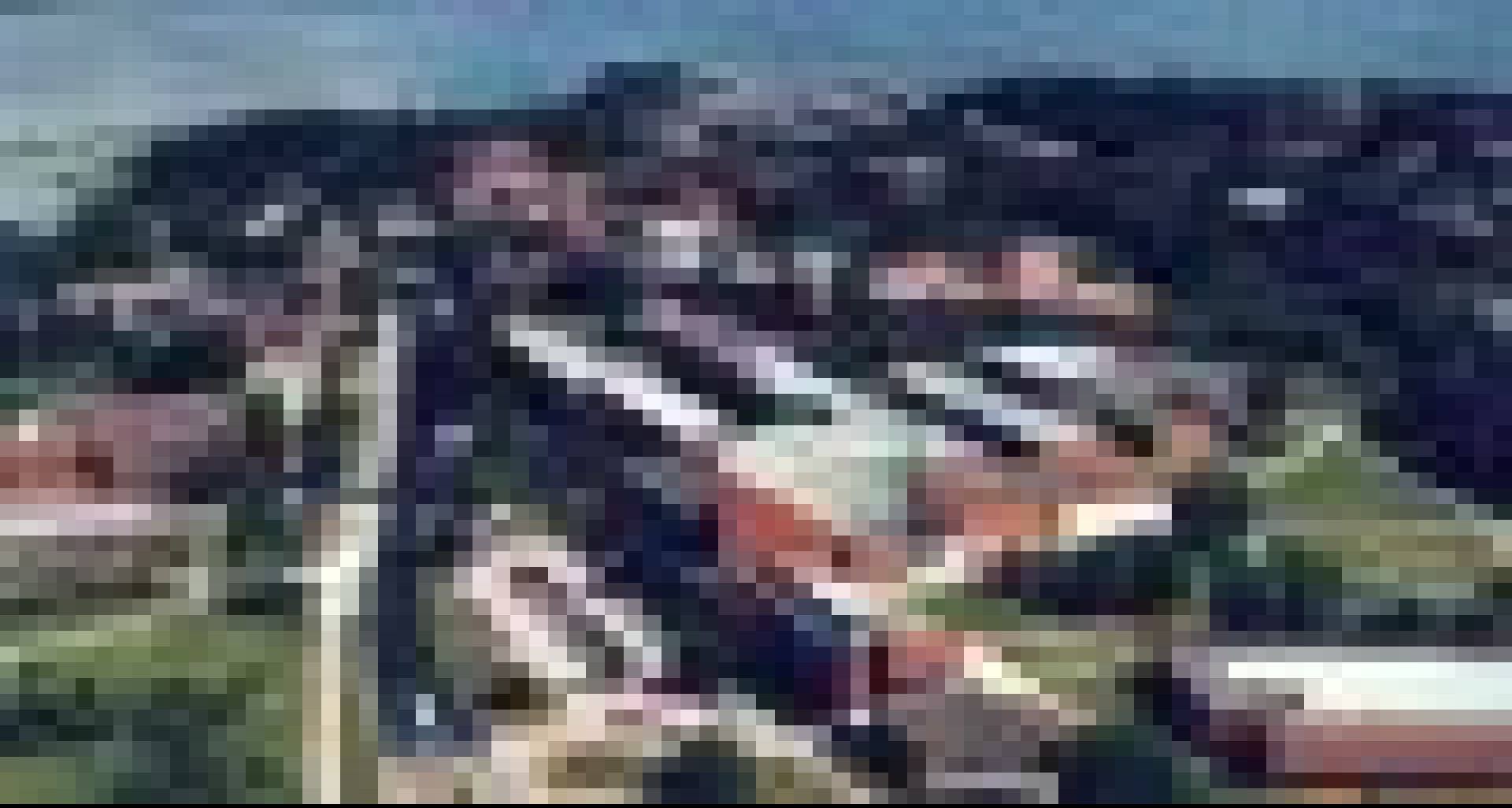
20x13



4x3

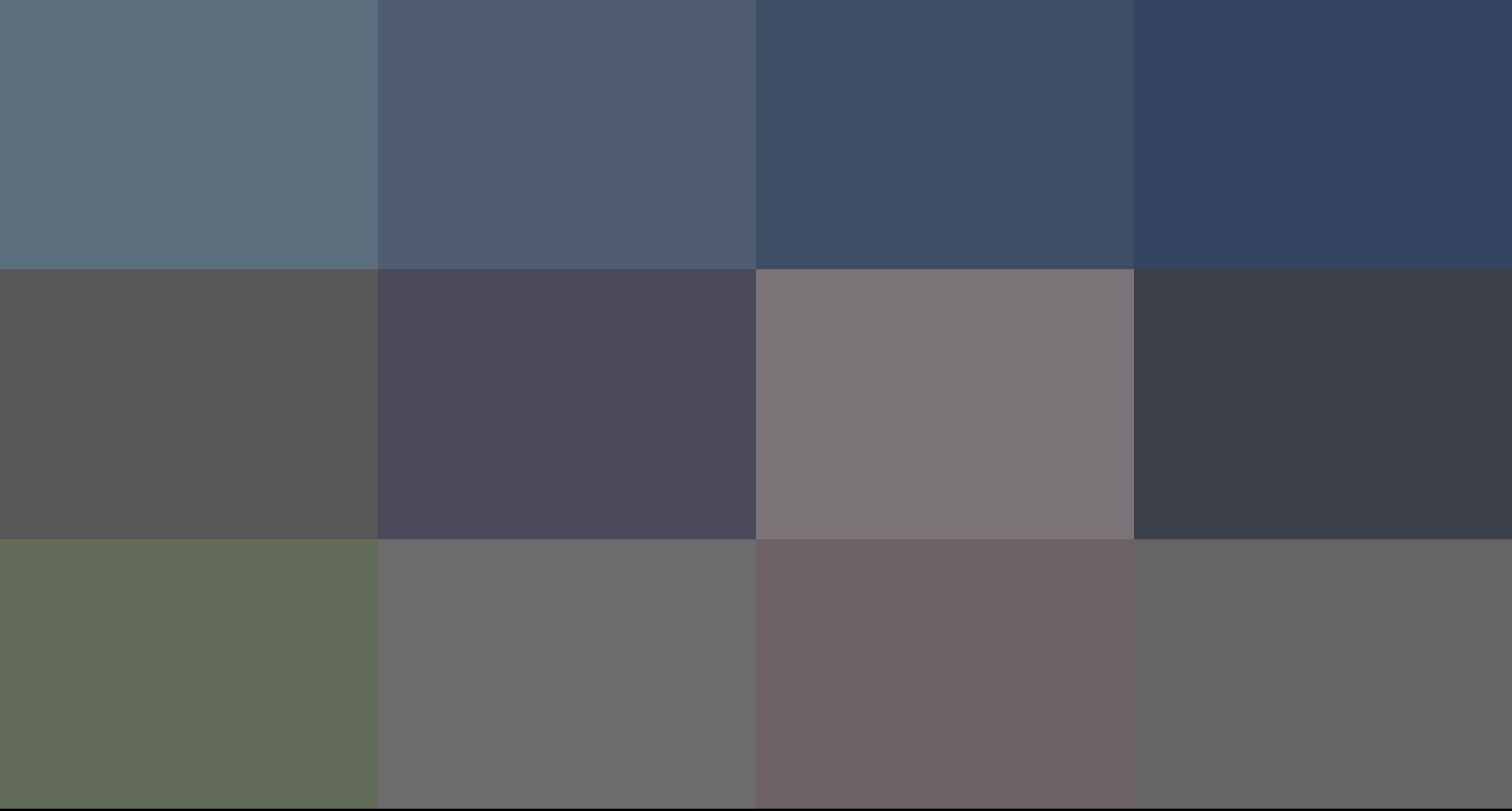
1077x687

200x128



80x51


20x13


4x3

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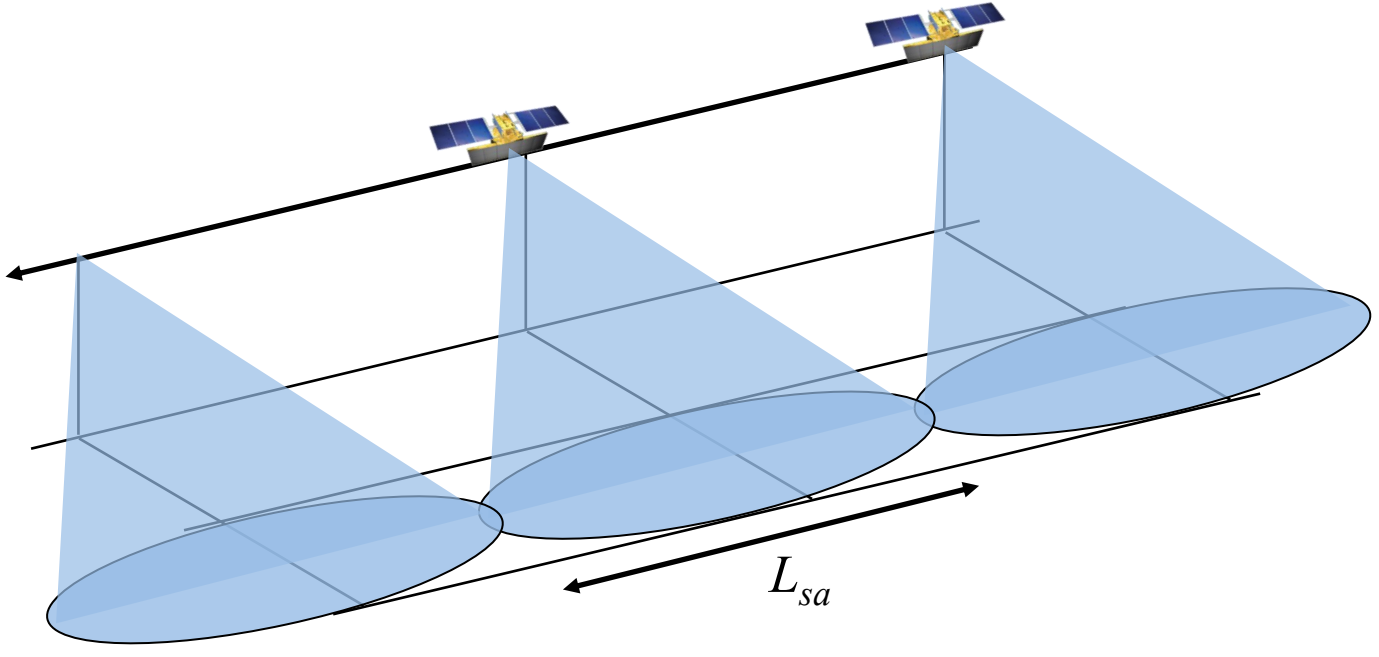
SAR image

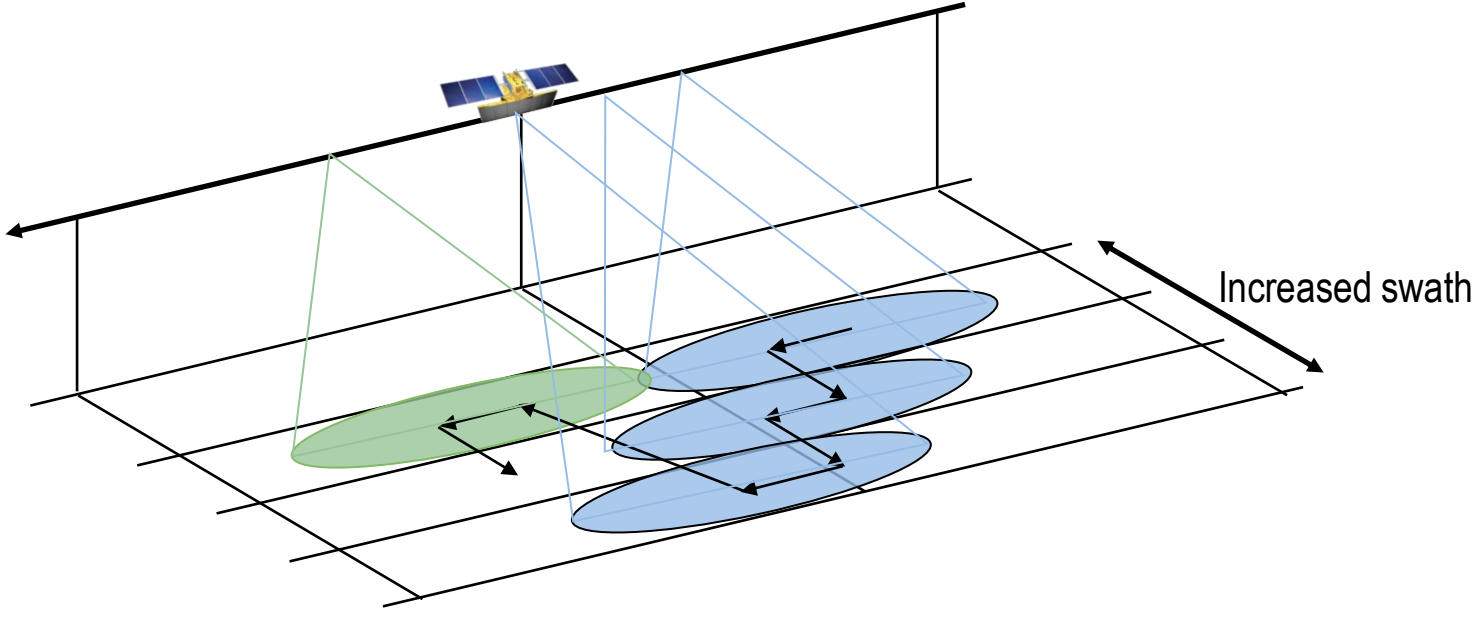
SAR acquisition modes

- Stripmap
  - Conventional mode: antenna pointing is fixed
  - Continuous mapping, good resolution and spatial coverage



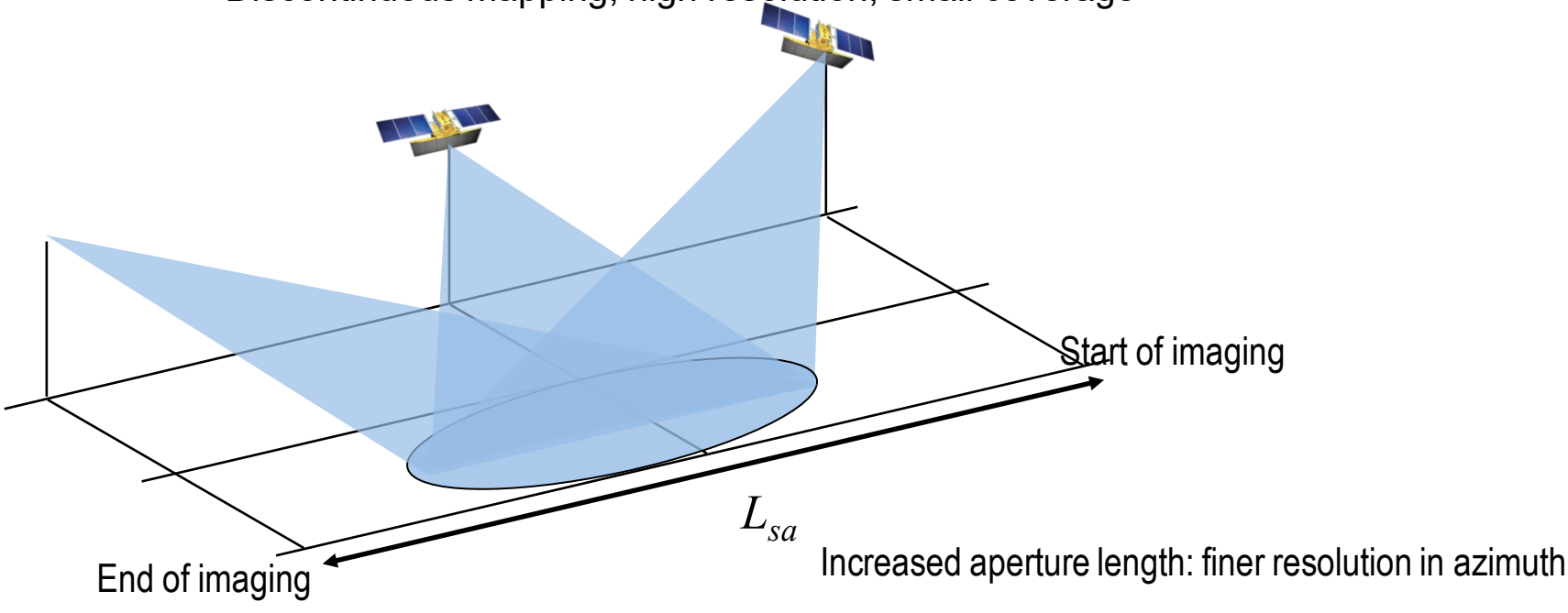
SAR acquisition modes

- ScanSAR
  - Antenna pointing changes: multiple beam scanning in elevation
  - Continuous mapping, lower resolution, larger coverage
  - Complicated processing

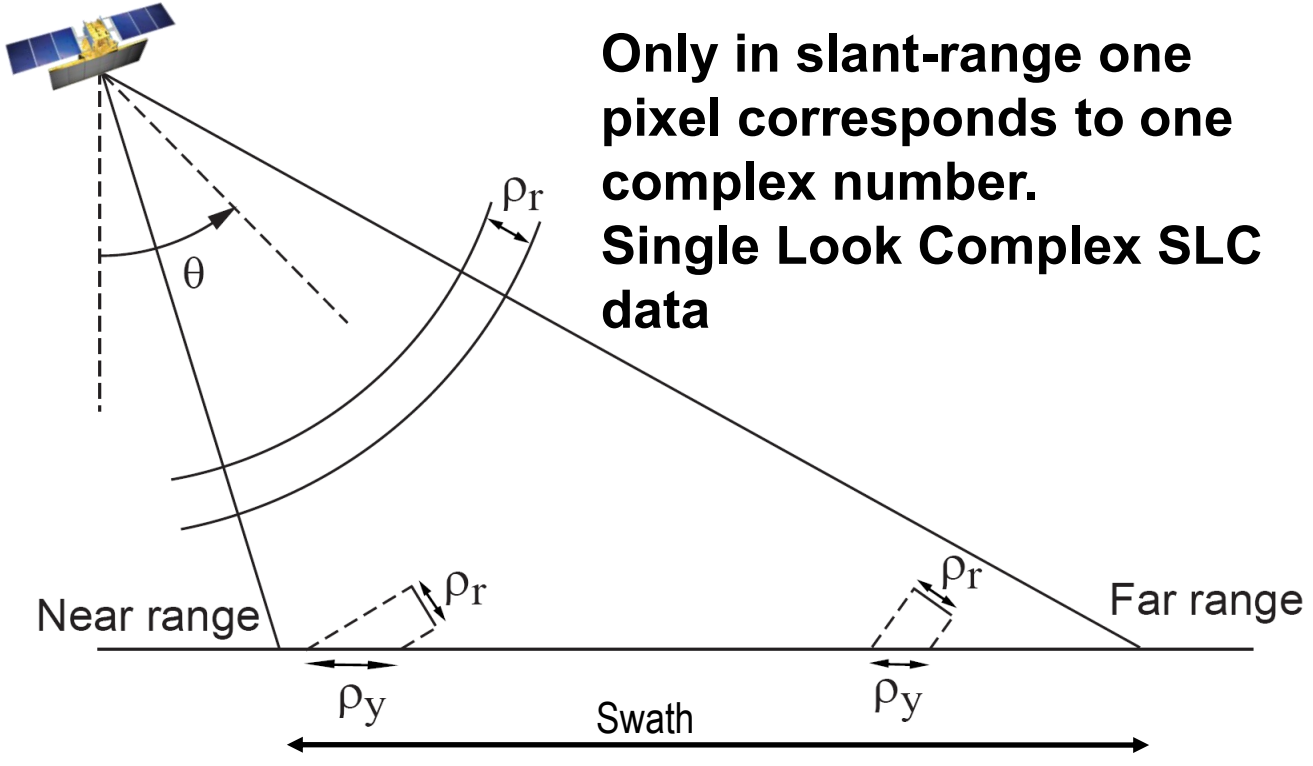


SAR acquisition modes

- Spotlight
  - Antenna points at a fixed place: antenna pointing changes
  - Discontinuous mapping, high resolution, small coverage

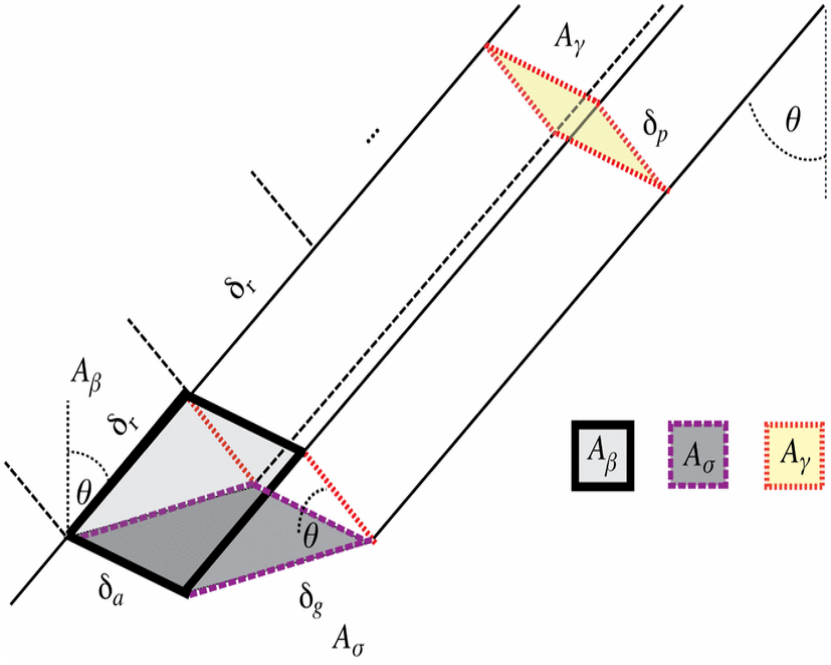


SAR slant range, natural coordinate

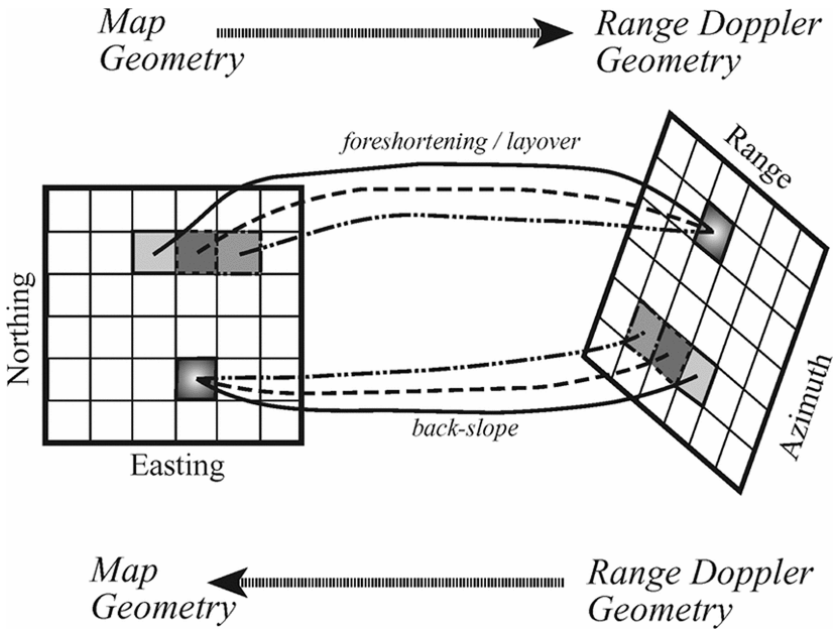


Only in slant-range one pixel corresponds to one complex number.
Single Look Complex SLC data

SAR conventions and projection



Typical backscatter conventions

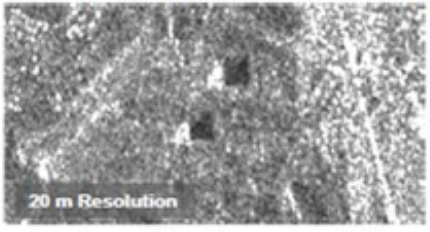


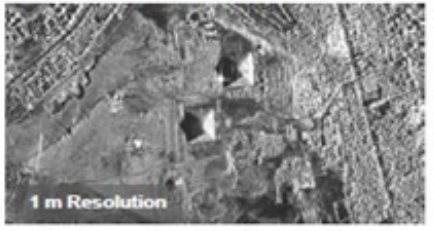
Topology of radar geometry

Resolutions summary

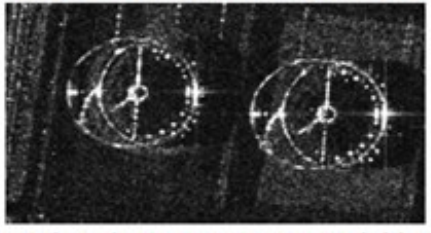
Spatial Resolution: refers to smallest possible size of object (scatterer) that can be detected;

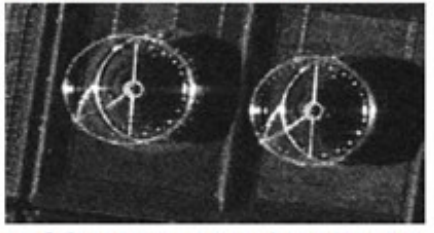
- Range Resolution;
- Azimuth Resolution:
  - Real Aperture Radar (RAR);
  - Synthetic Aperture Radar (SAR).





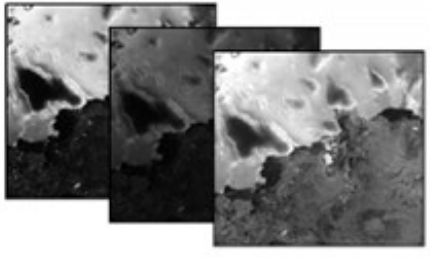
Radiometric Resolution: refers to the smallest possible intensity difference that can be distinguished;

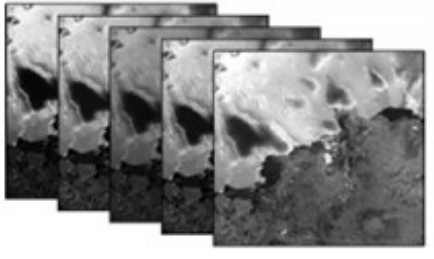




Temporal Resolution: refers to the smallest time between two acquisitions of the same area / scatterer;

- Instantaneous accessibility
- Cumulative accesibility

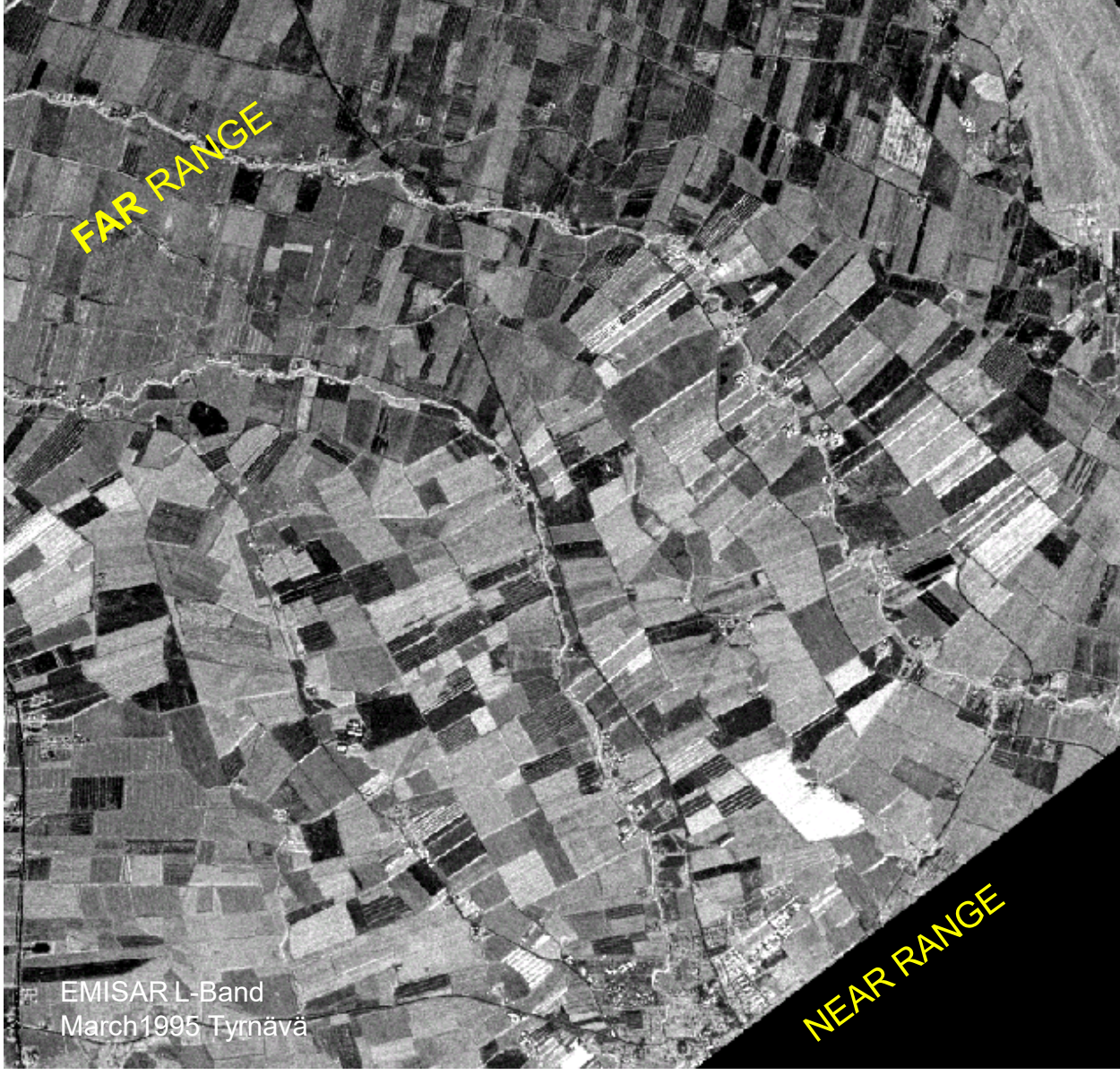




Far range
Near range

Smooth and moderaletly rough surfaces are brighter in near range due to steep incidence angle.

For volume scatterers (forest) incidence angle effect is not noticeable.



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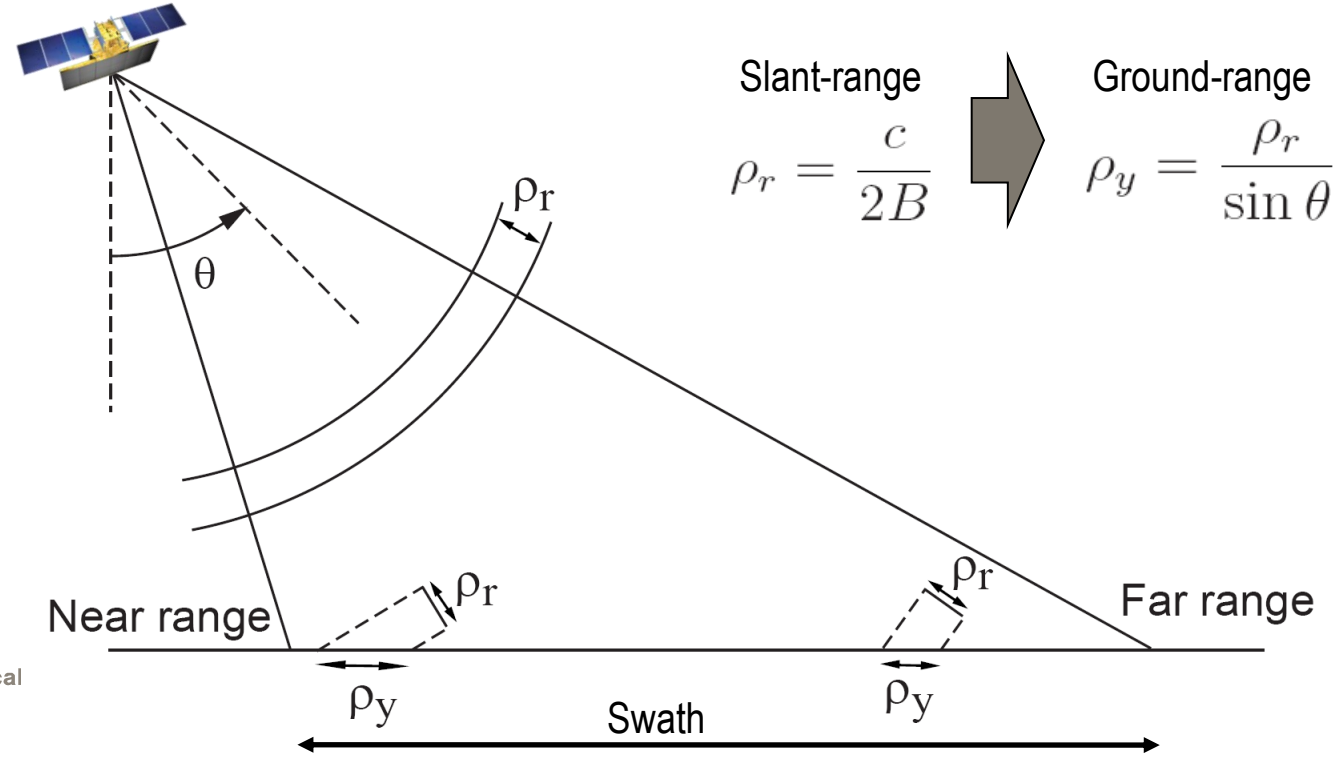
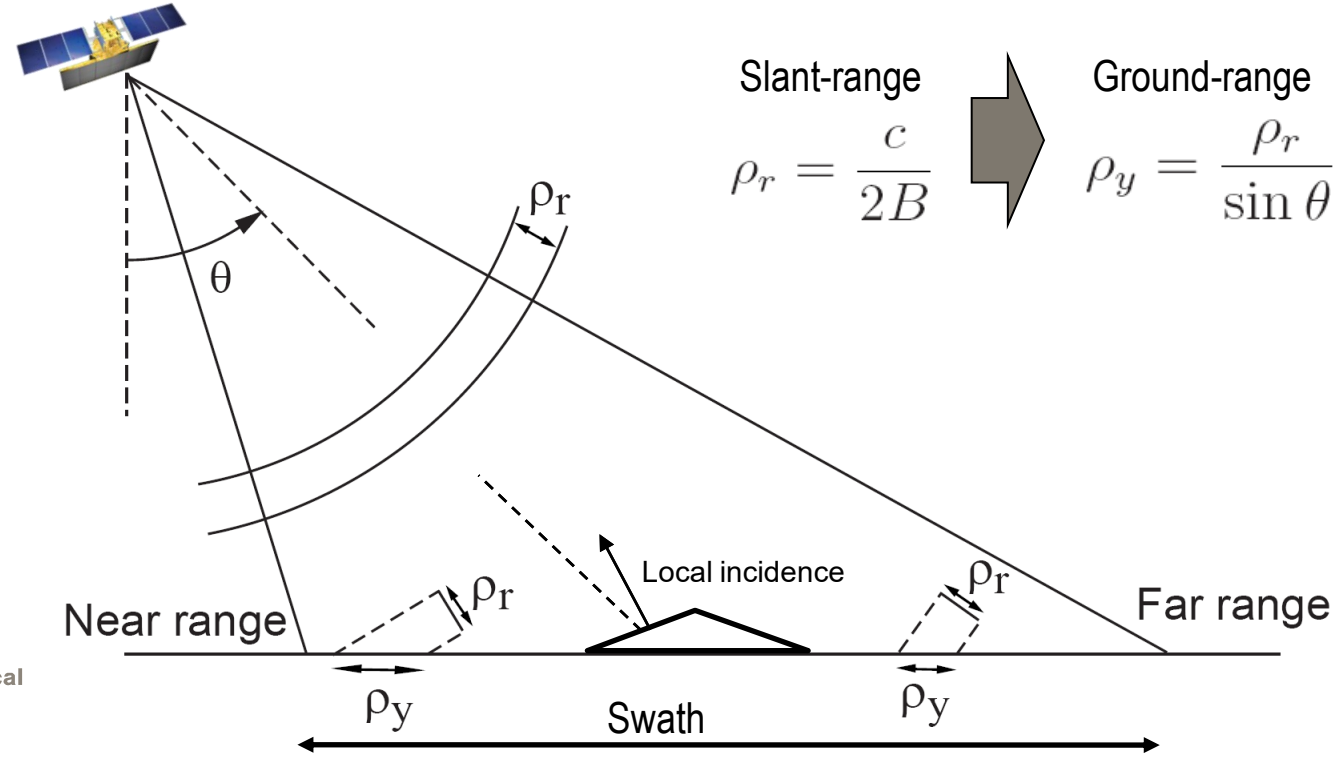
SAR geometrical correction

- First example: A constant resolution in (slant-) range does not correspond to the same resolution in ground-range along the whole scene
  - More relevant for airborne than for satellite

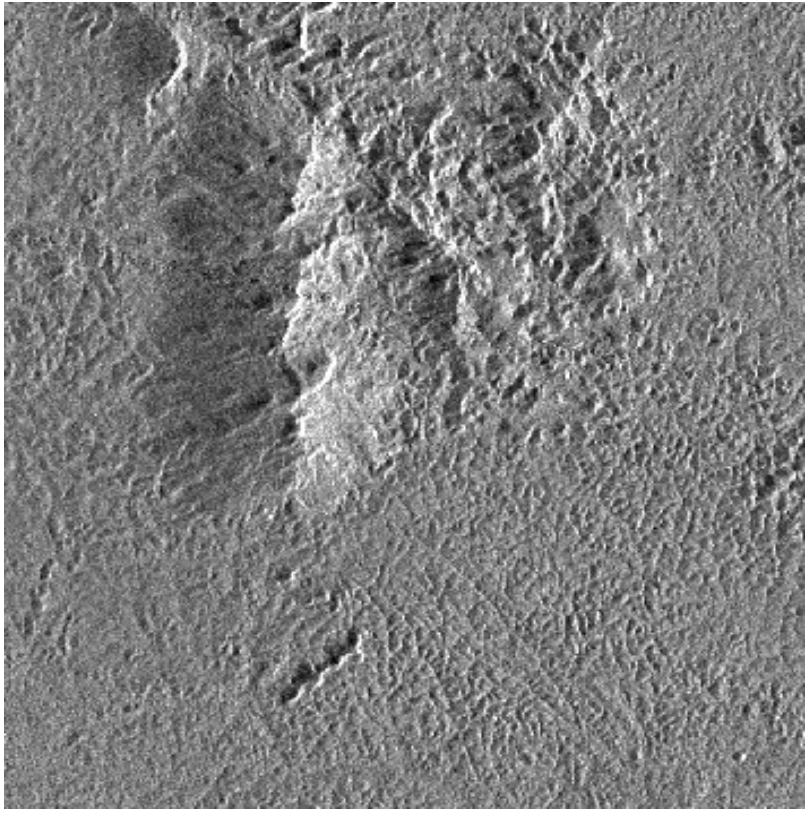


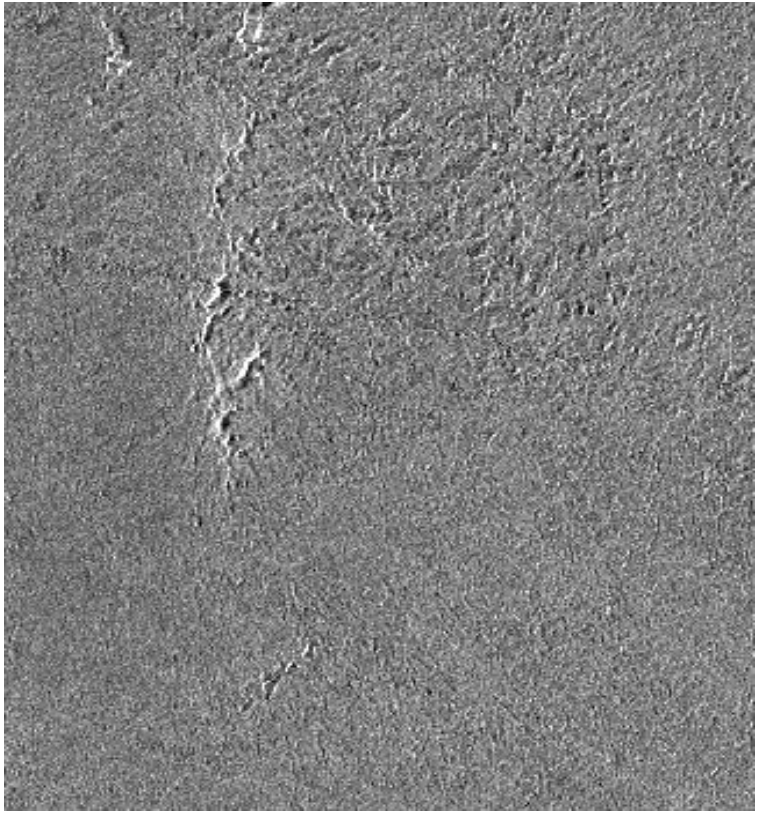
SAR geometrical topography correction

- First example: A constant resolution in (slant-) range does not correspond to the same resolution in ground-range along the whole scene
  - More relevant for airborne than for satellite



SAR image topography correction





Example of uncorrected and DEM-corrected SAR imagery.

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Statistical nature of SAR image

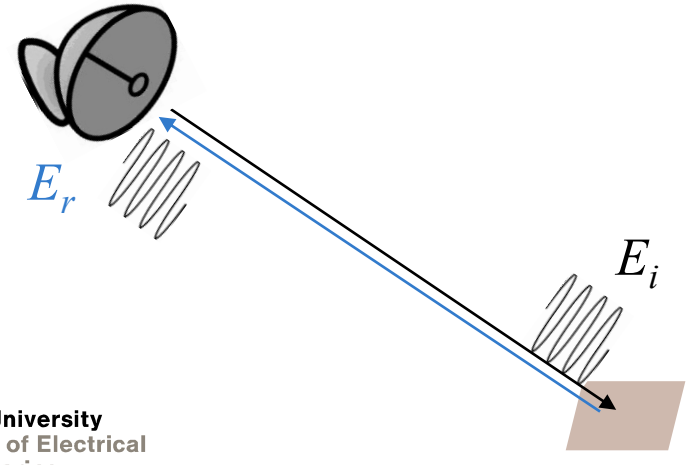
Distributed targets Slant-range

We are interested in areas.

Areas have statistical properties.

SAR pixel is a complex number

- Each pixel of the SAR image is a complex value
  - It has real and imaginary parts
  - Or, equivalently, amplitude (modulus) and phase
- What is the meaning of such complex numbers?
  - They correspond to the ratio of the received electrical field (received signal) over the field incident to that location on Earth

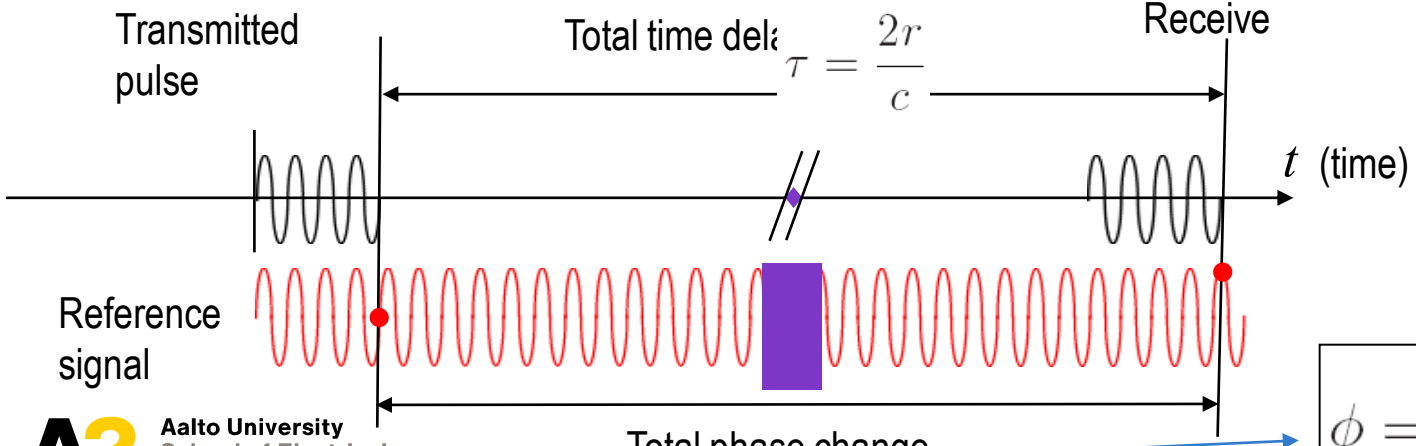


$$\rho = \frac{E_r}{E_i} = a + jb = Ae^{j\phi}$$

SAR image pixel values

- Amplitude: amount of signal returned to the radar

- Phase information



$$\phi = -\frac{4\pi r}{\lambda} + \phi_{scatt}$$

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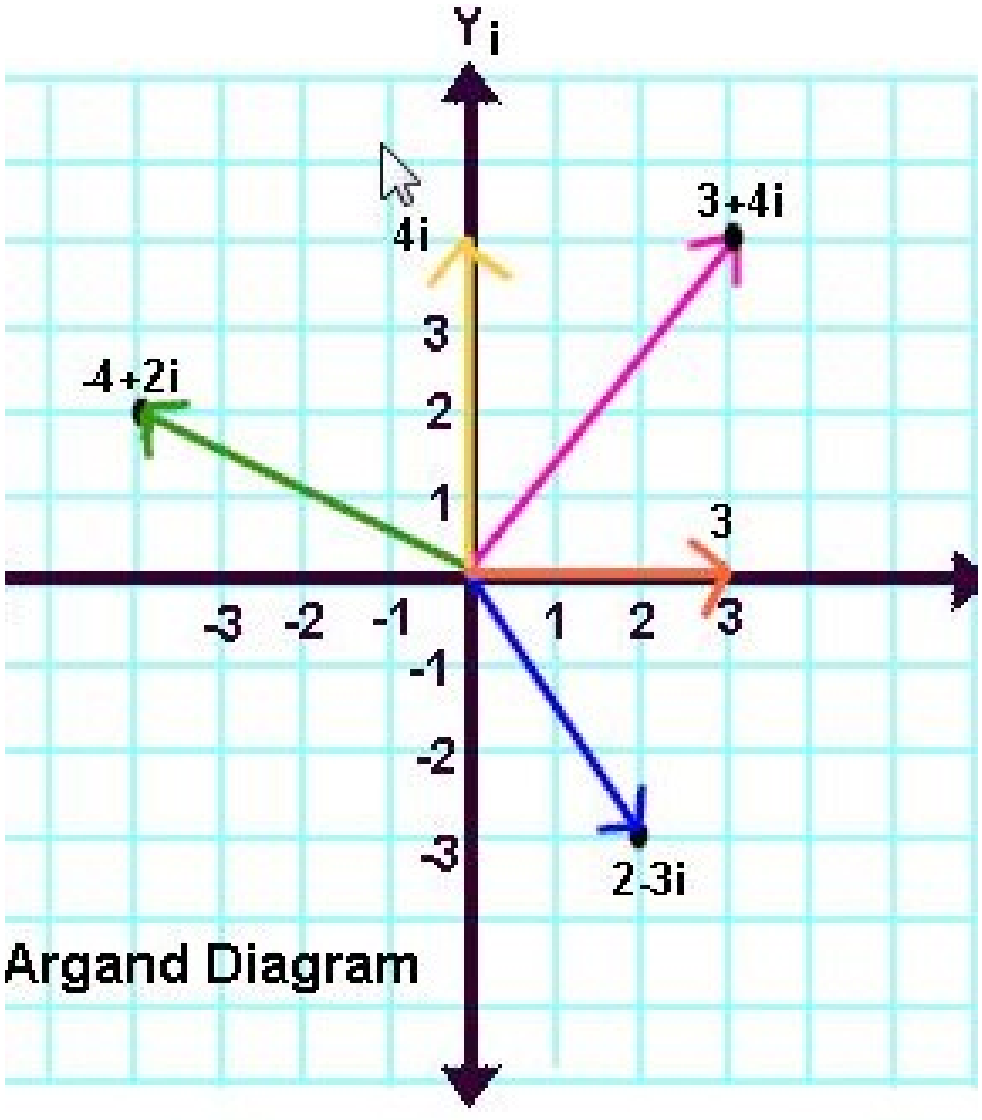
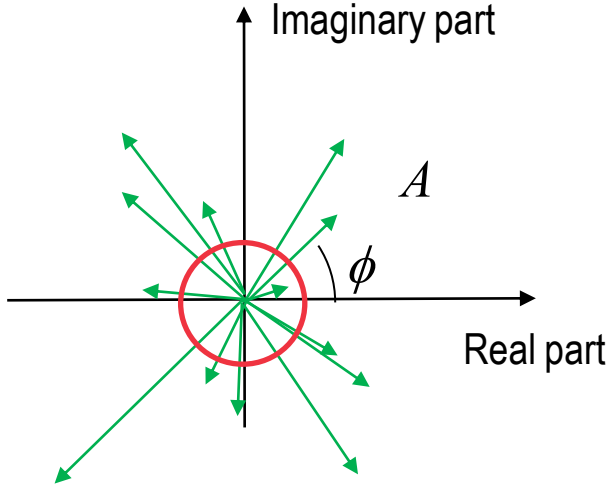
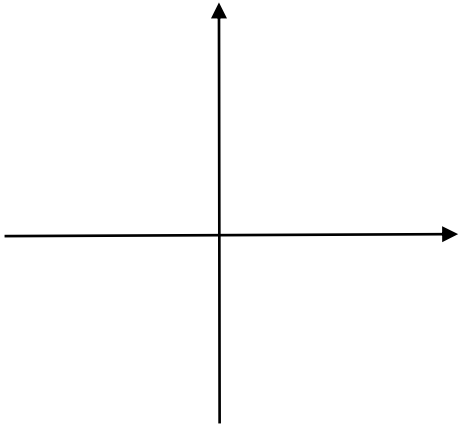
Reminder about complex numbers

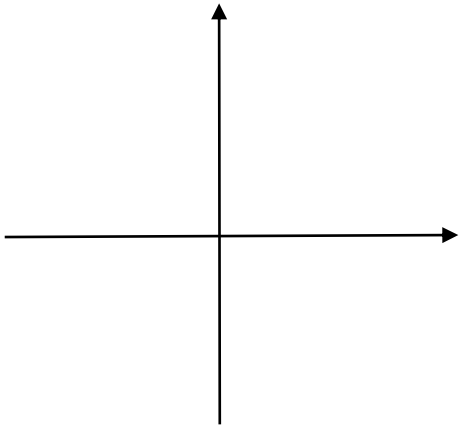


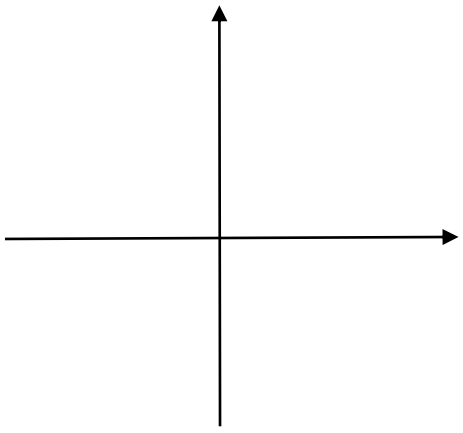
Average of random complex vectors is zero!

Be always careful while averaging complex variables!









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What is on the image

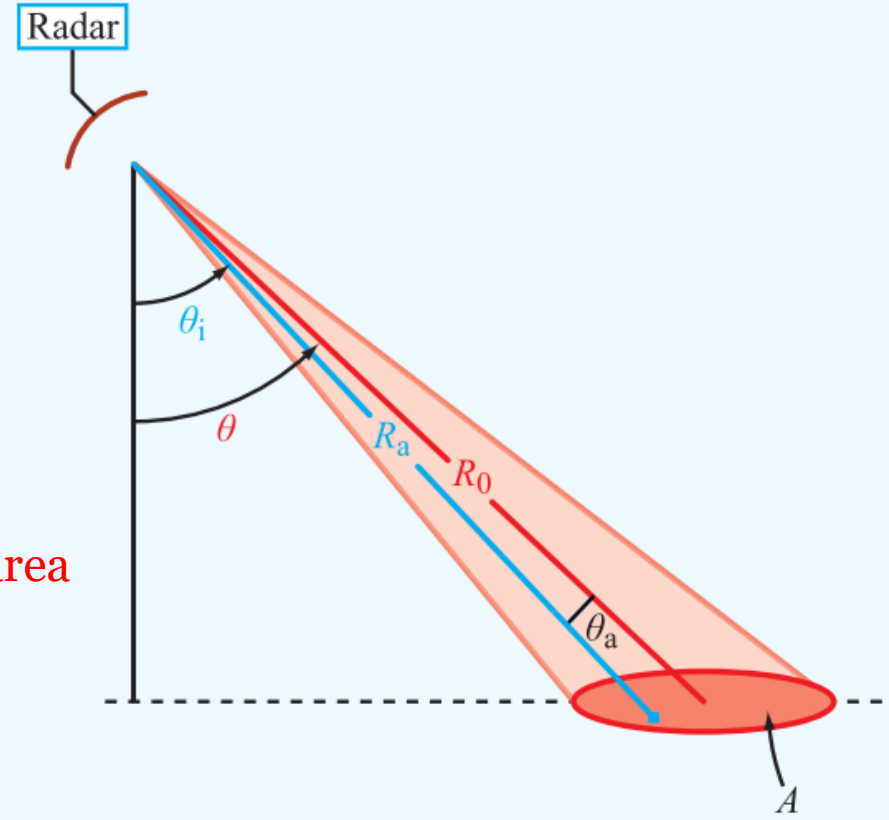
Distributed target over an area

$$P_p^{\mathrm{r}}(\theta) = \iint_A \frac{P_q^{\mathrm{t}}\, G^2(\theta_{\mathrm{a}}, \phi_{\mathrm{a}})\, \lambda^2}{(4\pi)^3 R_{\mathrm{a}}^4} \cdot \sigma_{pq}^0 \, dA$$

$$\sigma_{pq}^0 = \sigma_{pq}/A$$

- backscattering cross section per unit area
- backscattering coefficient
- radar reflectivity

are the same parameter



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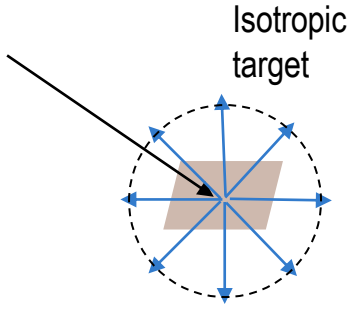
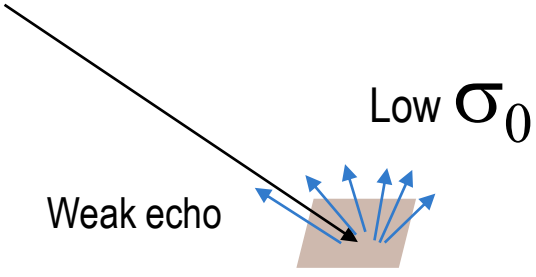
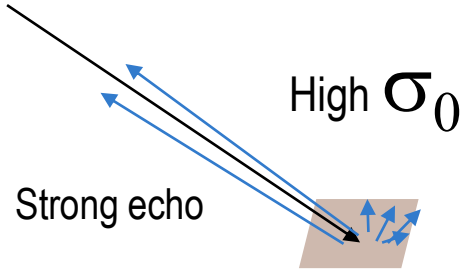
Backscattering coefficient

- Square of the amplitude: ratio of energies (or powers)
- Normalised magnitude: backscattering coefficient σ_0
  - Definition: surface density of radar cross section (RCS)
  - Dimensionless: m^2/m^2
  - Physical meaning:

$$\sigma_0 = \frac{\text{Energy received by the radar from the pixel}}{\text{Energy that would be received by the radar if the pixel were isotropic}}$$



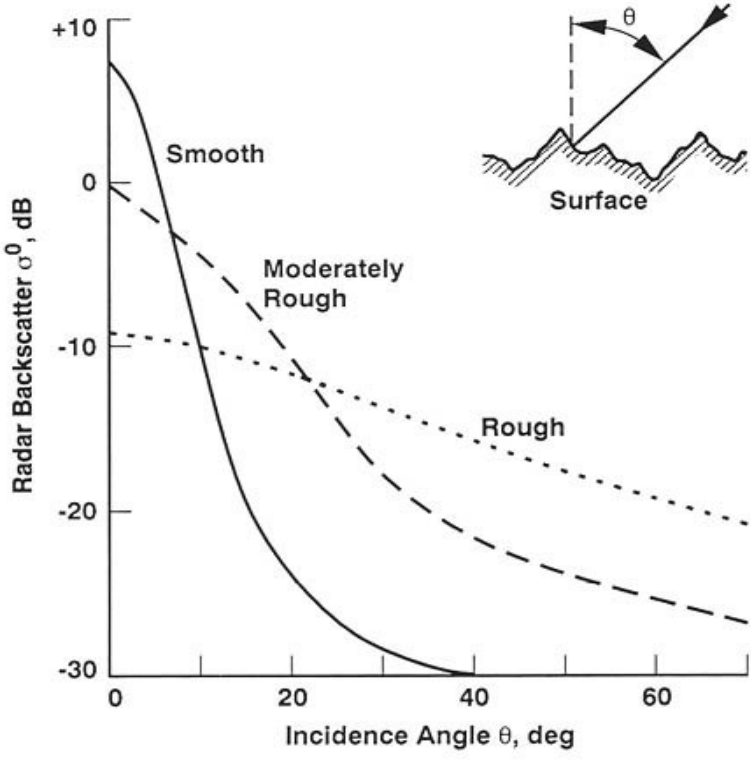


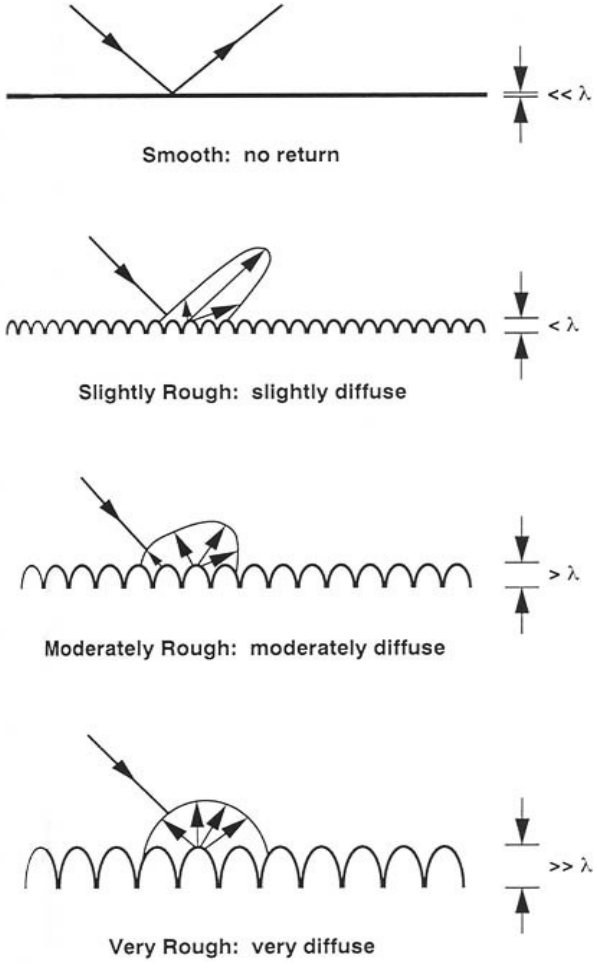


  - Common representation in dB:

$$\sigma_0(\text{dB}) = 10 \log_{10} \sigma_0$$

Incidence angle and surface roughness





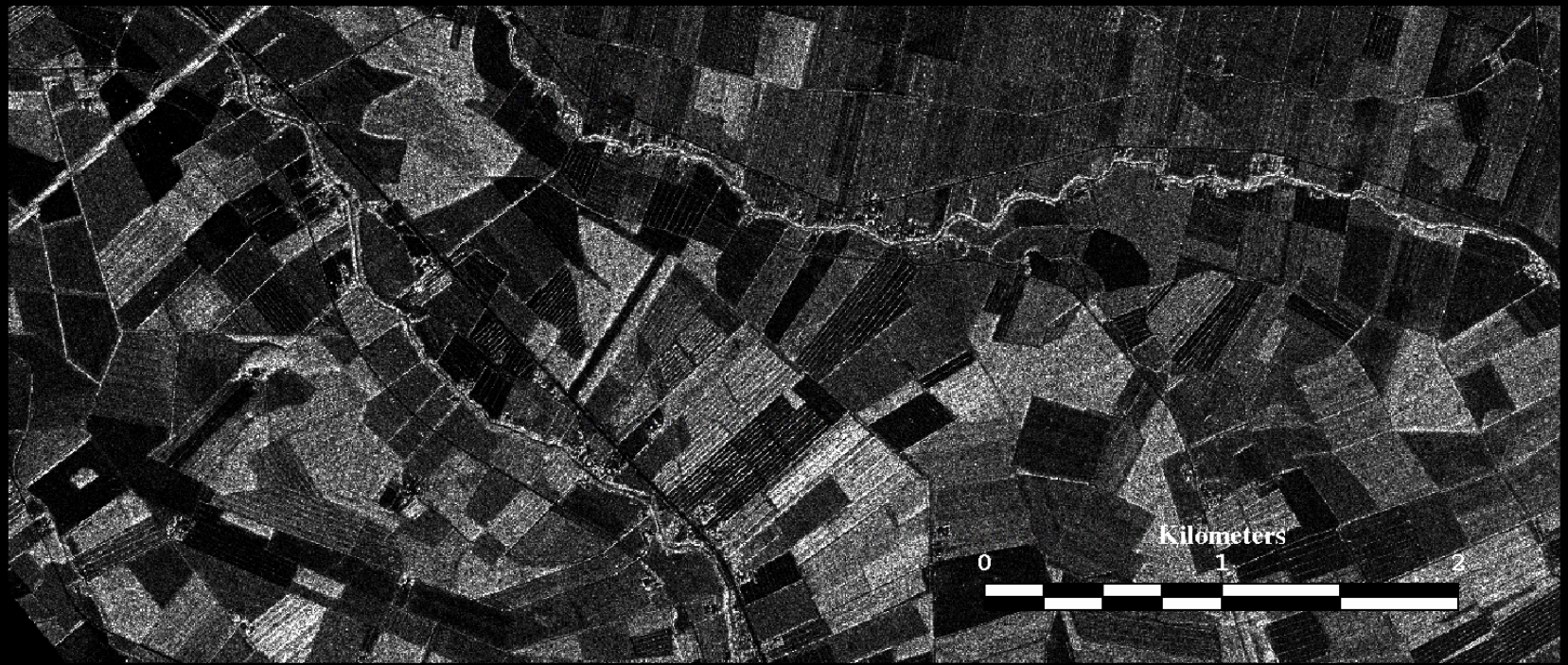
http://history.nasa.gov/JPL-93-24/ch5.htm
NASA: Guide to Magellan Image Interpretation
Chapter 5. Radar Interactions With Geologic Surfaces
Tom G. Farr

EMISAR 1995

SAR image from Tyrnävä

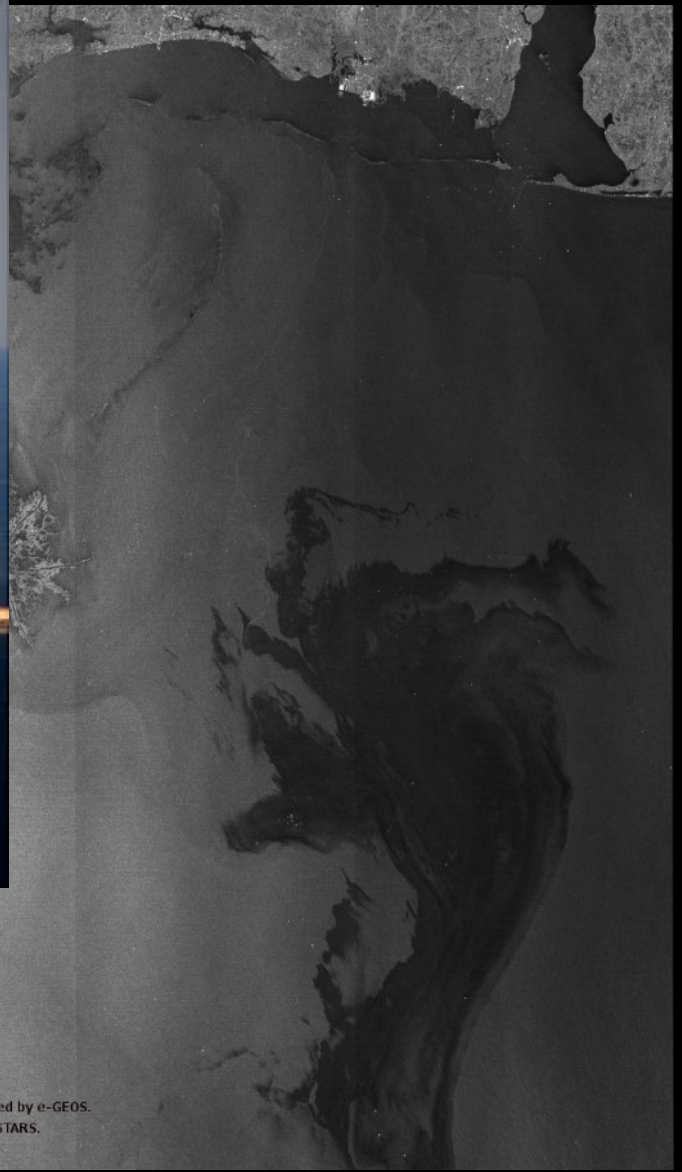
C-band HH polarization
March 1995

EMISAR 1995



SAR image from Tyrnävä

L-band HH polarization
May 1995



CSTARS

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ICEYE


Bahamas
Road network data © OpenStreetMap contributors
ICEYE

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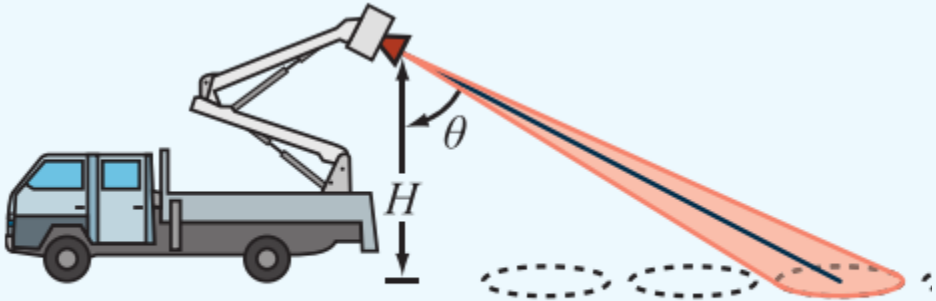
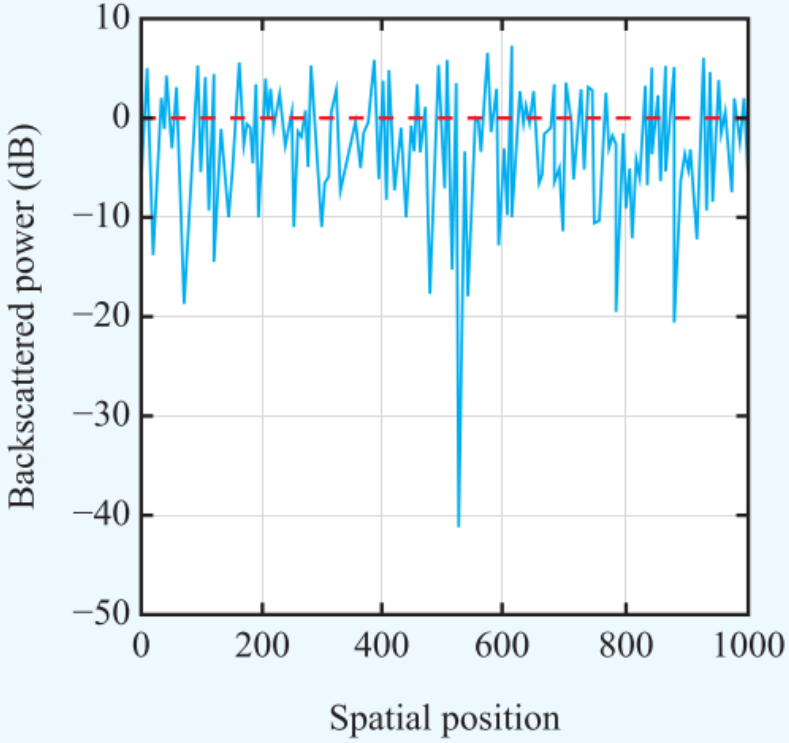
Speckle

What is the “salt and pepper” noise?



(a) Beam movement



(b) Backscattering variation

The sketch in (a) shows how the measurements [shown in (b)] of the backscatter from an asphalt surface were acquired. The incidence angle was 40◦, the frequency 35 GHz, the platform height 10.4 m, and the polarization vv [from Ulaby et al., 1988a].

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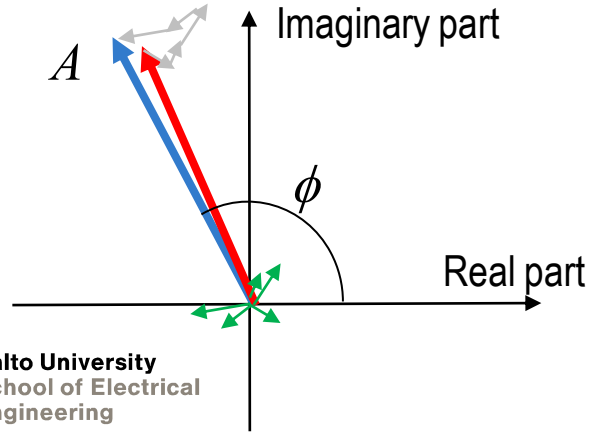
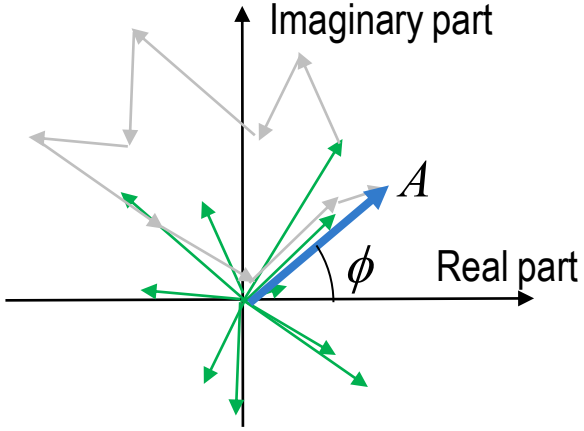
Scattering

- Each pixel of the image (or resolution cell) is usually much larger than the wavelength and contains many scattering elements (scatterers)
- The received signal (pixel value) is the result of the coherent combination (sum) of all individual echoes
- Typical types of pixels:

Dominated by a single scatterer



Distributed targets



Speckle

Two ground patches with the same statistical properties may produce backscattered signals with different magnitudes because the individual scatterers in the two patches have different locational arrangements. This variability in the magnitude of the backscattered signal is referred to as **signal fading** or **signal scintillation**.

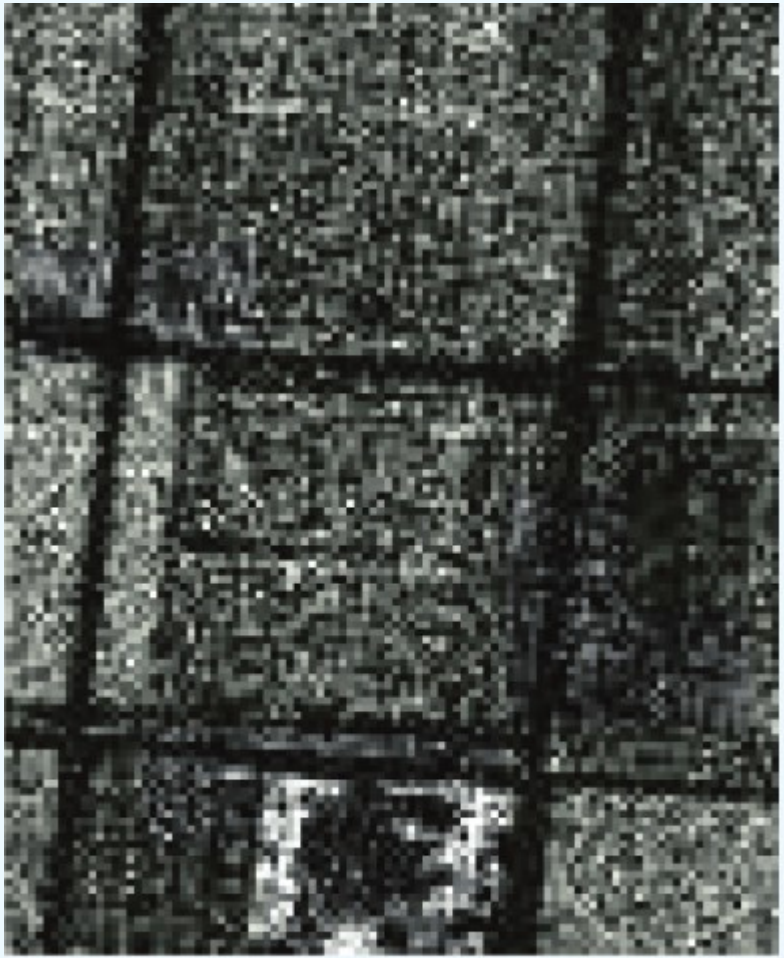


Figure 5-13: Image speckle refers to the pixel-to-pixel variation of image tone. This is a 1 m × 1 m resolution Ku-band SAR image of an agricultural area [Sandia National Lab].

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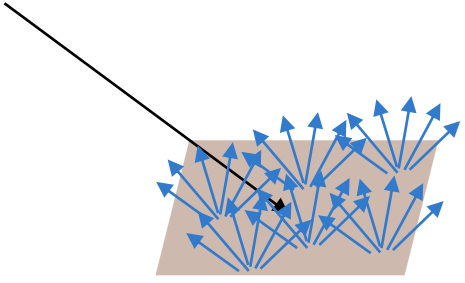
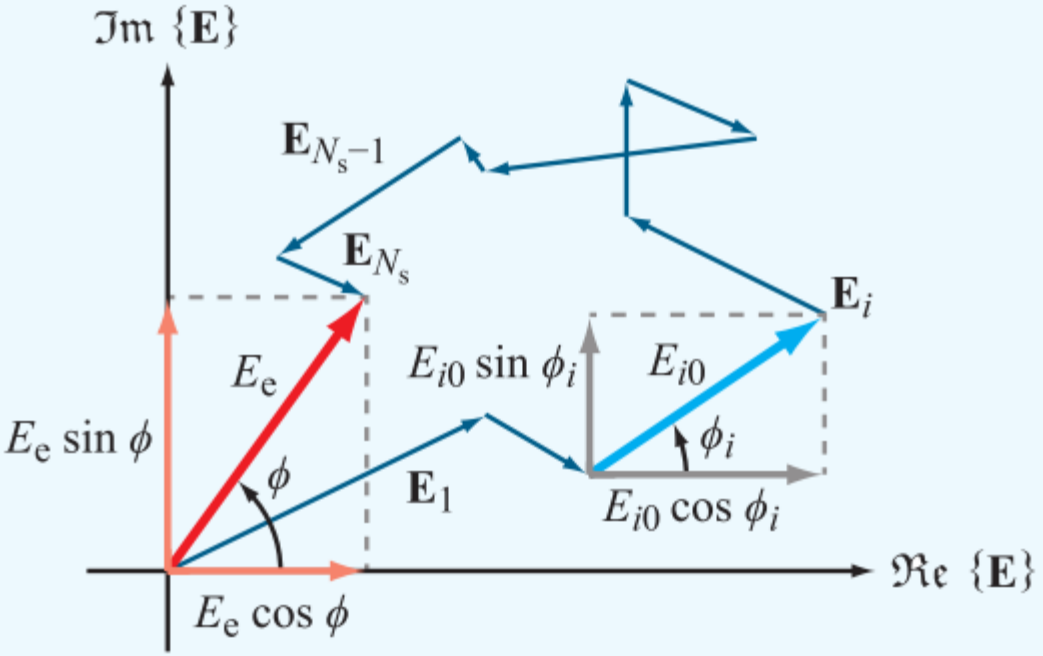
Speckle

- Most natural scenes correspond to distributed targets: composed of many scatterers



- The sum of all individual responses from elements inside the resolution cell changes from pixel to pixel, (even for a homogeneous portion of the scene): a statistical characterisation is required
- Fluctuations produced by these changes from pixel to pixel produce the granular appearance of the images: speckle

Distributed targets on SAR image



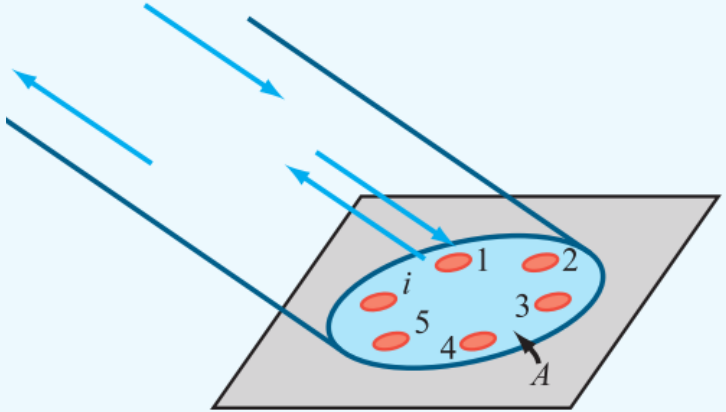


Figure 5-15: The vector $\mathbf{E} = E_e e^{j\phi}$ is the phasor sum of N_s fields.

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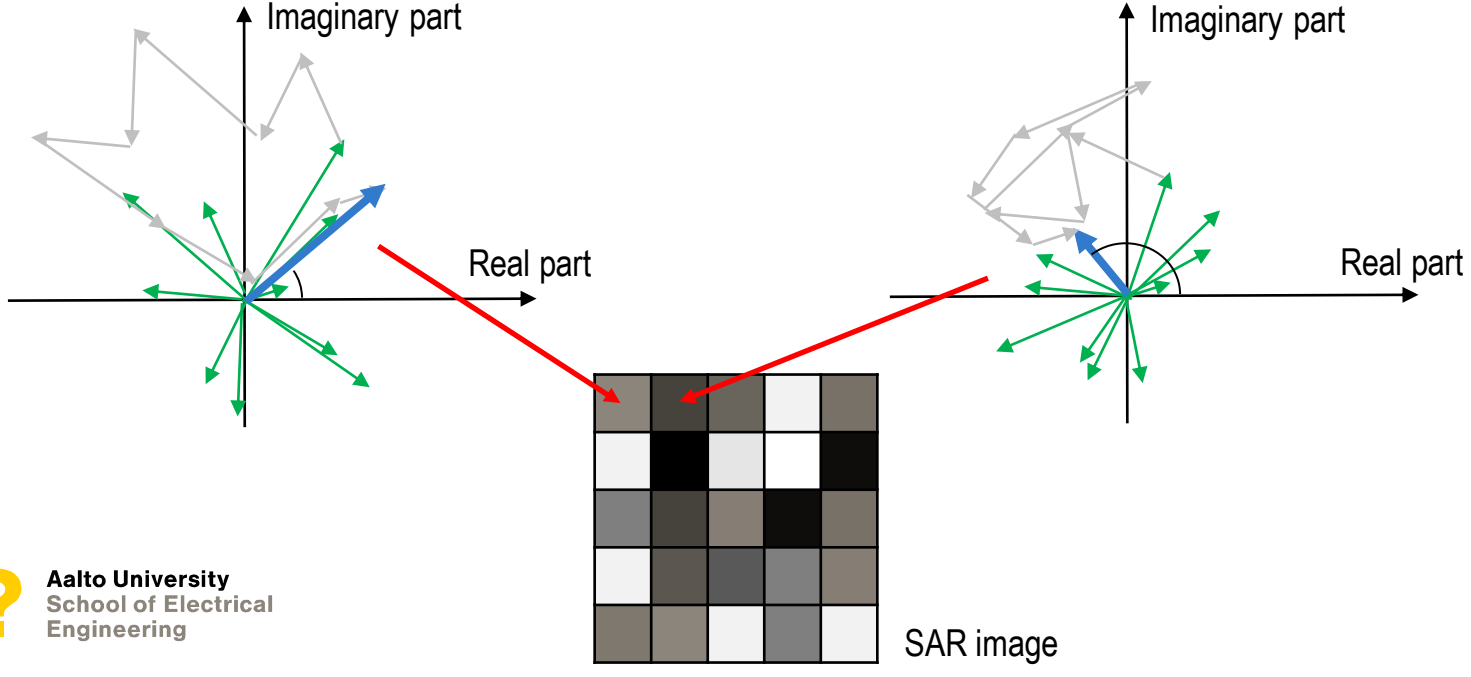
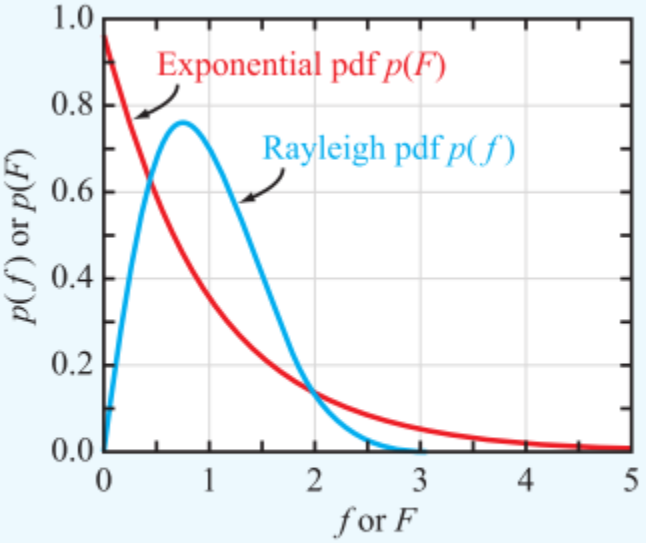
Speckle

- Noisy appearance of an homogeneous area of the scene
- Difficult interpretation
- Erroneous quantitative estimation if based on one pixel
- Cause: SAR is a coherent system



Radar pixel of distributed target is a random variable



(a) Rayleigh and exponential pdfs

$$f = \frac{E_e}{\overline{E_e}} \qquad F = \frac{E_e^2}{\overline{E_e^2}} = \frac{I}{\overline{I}}$$

Random Variables

For any random variable x, defined over the range x_1 to x_2 and characterized by a probability density function (pdf) $p(x)$:

$$\overline{x} = \langle x \rangle = \int_{x_1}^{x_2} x\, p(x)\, dx = \text{mean value of } x$$

$$\overline{x^2} = \langle x^2 \rangle = \int_{x_1}^{x_2} x^2\, p(x)\, dx = \text{second moment of } x$$

$$s_x^2 = \langle x^2 \rangle - \langle x \rangle^2 = \text{variance of } x$$

$$s_x = \text{standard deviation of } x$$

$$\beta_x = \left(\frac{s_x}{\overline{x}}\right)^2 = \text{normalized variance of } x$$

$$P(x \le x') = \int_{x_1}^{x'} p(x)\, dx$$

$$= \text{cumulative distribution of } x \le x'$$

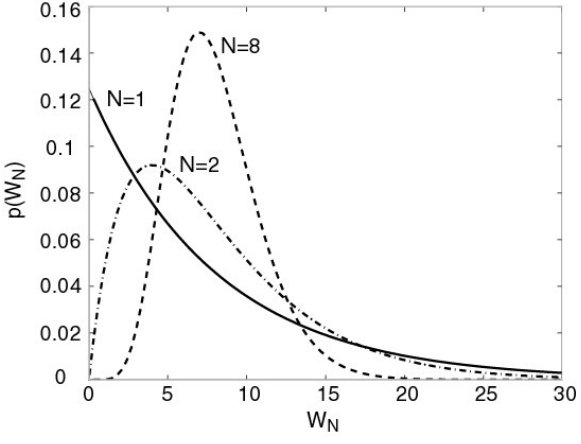
From: Microwave Radar and Radiometric Remote Sensing, by Ulaby and Long, 2014, with permission.

Radar data distribution

- Both amplitude and intensity (σ_0) present a variance
- Solution: averaging a number of uncorrelated samples
  - W_n are the uncorrelated elements in the image, called “looks”
  - Their average is W_N:

$$W_N = \frac{1}{N}\sum_{n=1}^{N} W_n$$

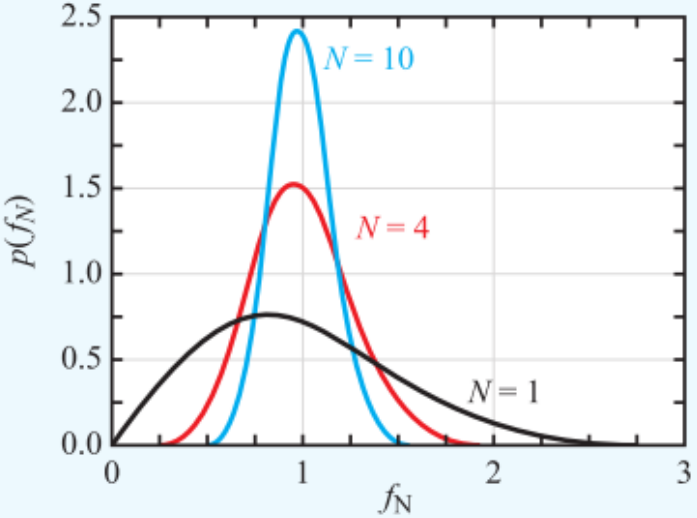
  - If all samples (looks) have the same mean and variance (i.e. they belong to the scene or area), the resulting variance is reduced by N
  - After multi-looking, the backscattering coefficient follows the Gamma distribution



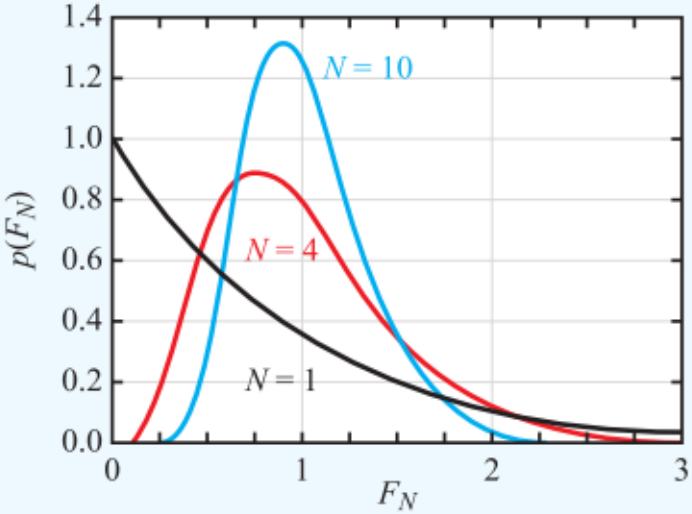
Multilooking

Multilooking improves the image by averaging the pixels (looks) over time or area.

Multilooking changes the distribution function of your image!



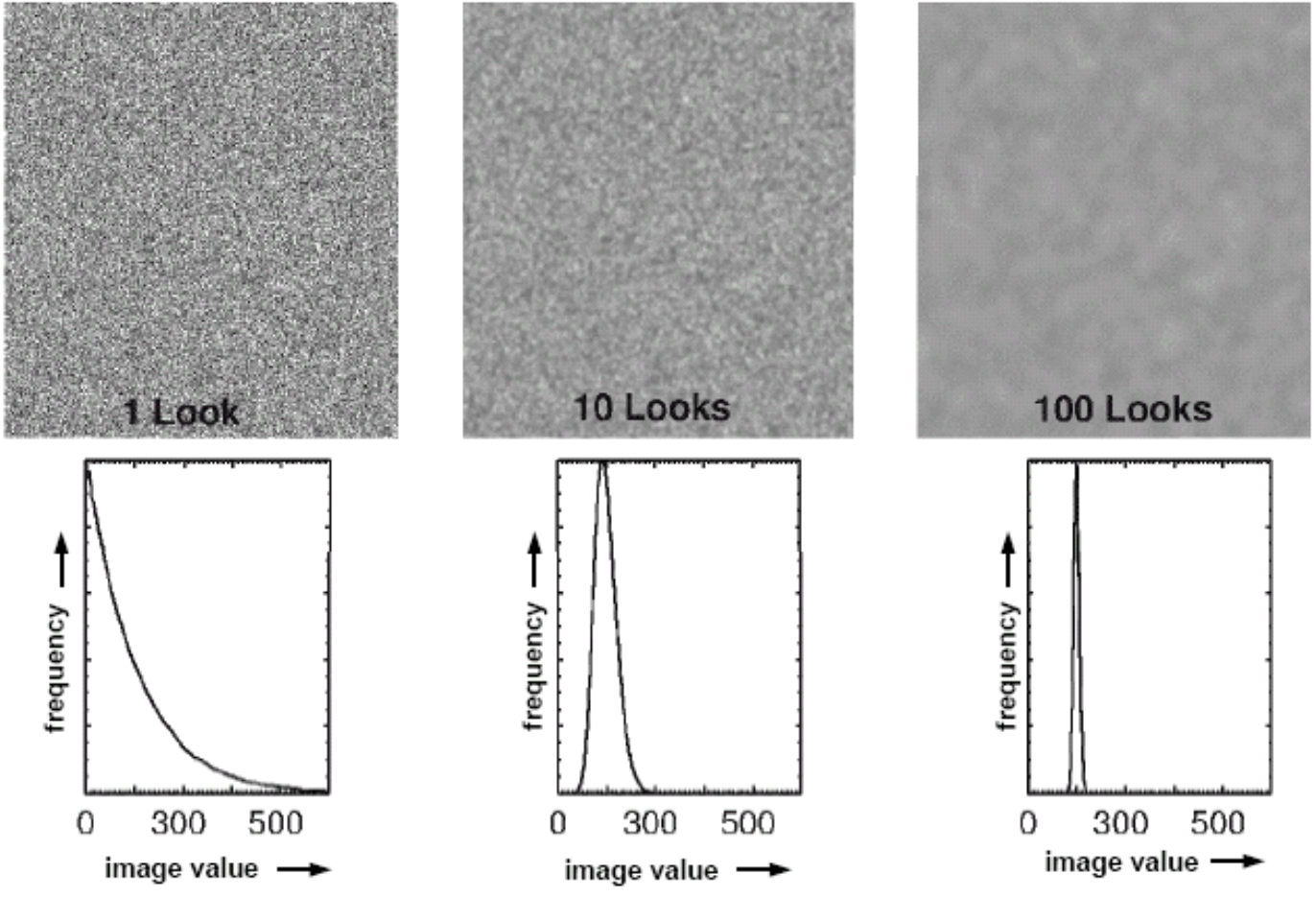
(a) pdf of f_N



(b) pdf of F_N

From: Microwave Radar and Radiometric Remote Sensing, by Ulaby and Long, 201⁴

Speckle multilooking



After the multi-look we can trust in the value of the pixels

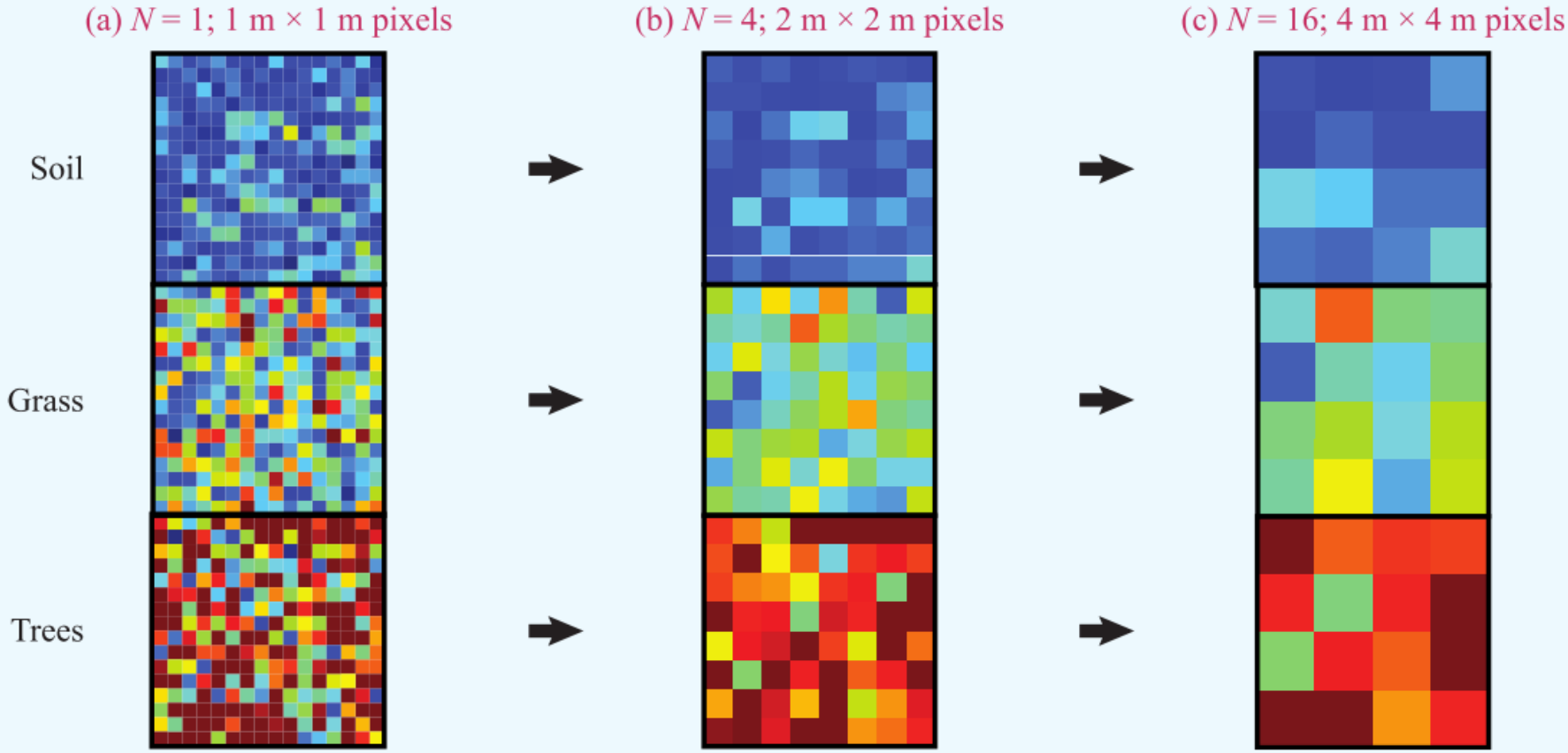


Figure 5-21: Simulated amplitude images of three distributed targets: trees with $\sigma_t^0 = 36\ m^2/m^2$, grass with $\sigma_g^0 = 16\ m^2/m^2$, and soil with $\sigma_s^0 = 4\ m^2/m^2$. Averaging multiple pixels trades off spatial resolution for improved radiometric resolution (less pixel-to-pixel variation).

From: Microwave Radar and Radiometric Remote Sensing, by Ulaby and Long, 2014, with permission.

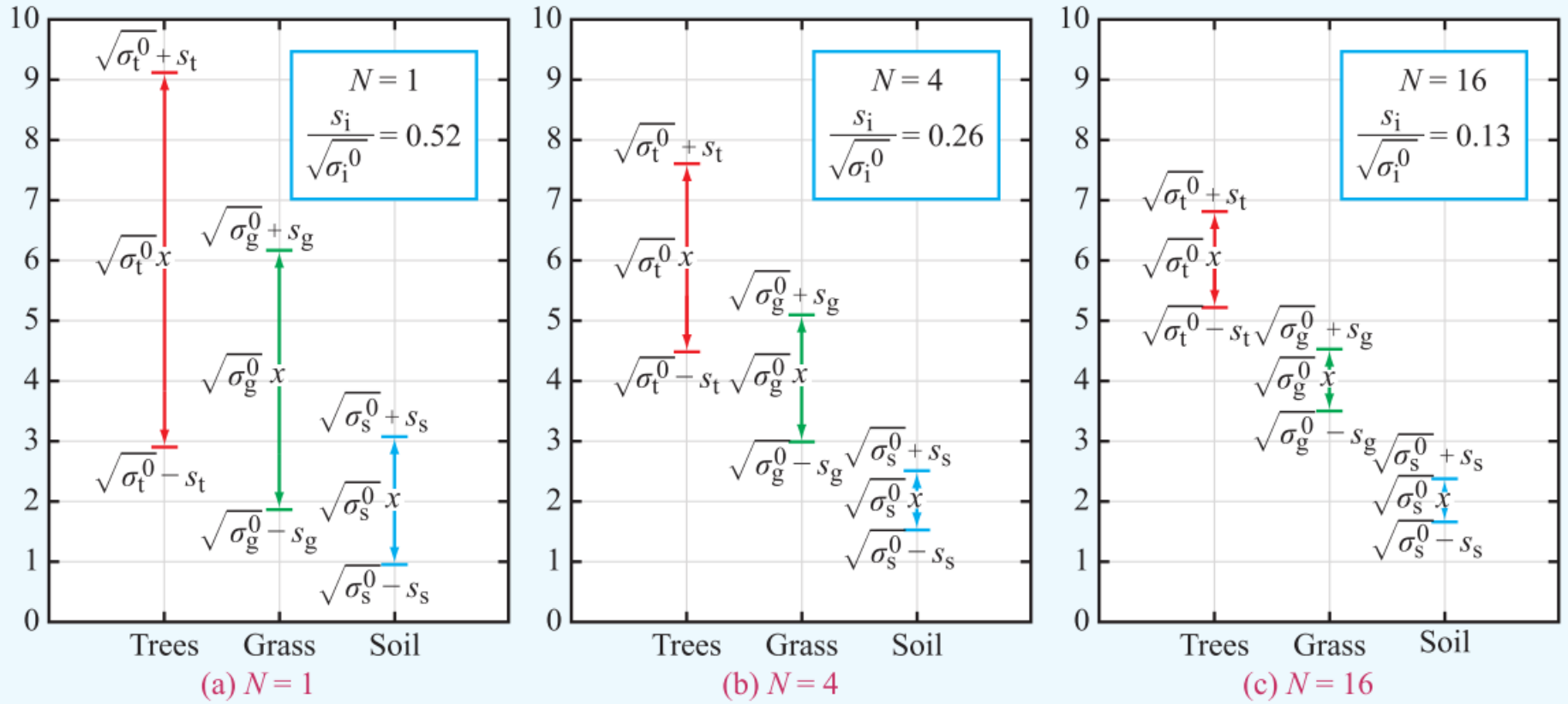


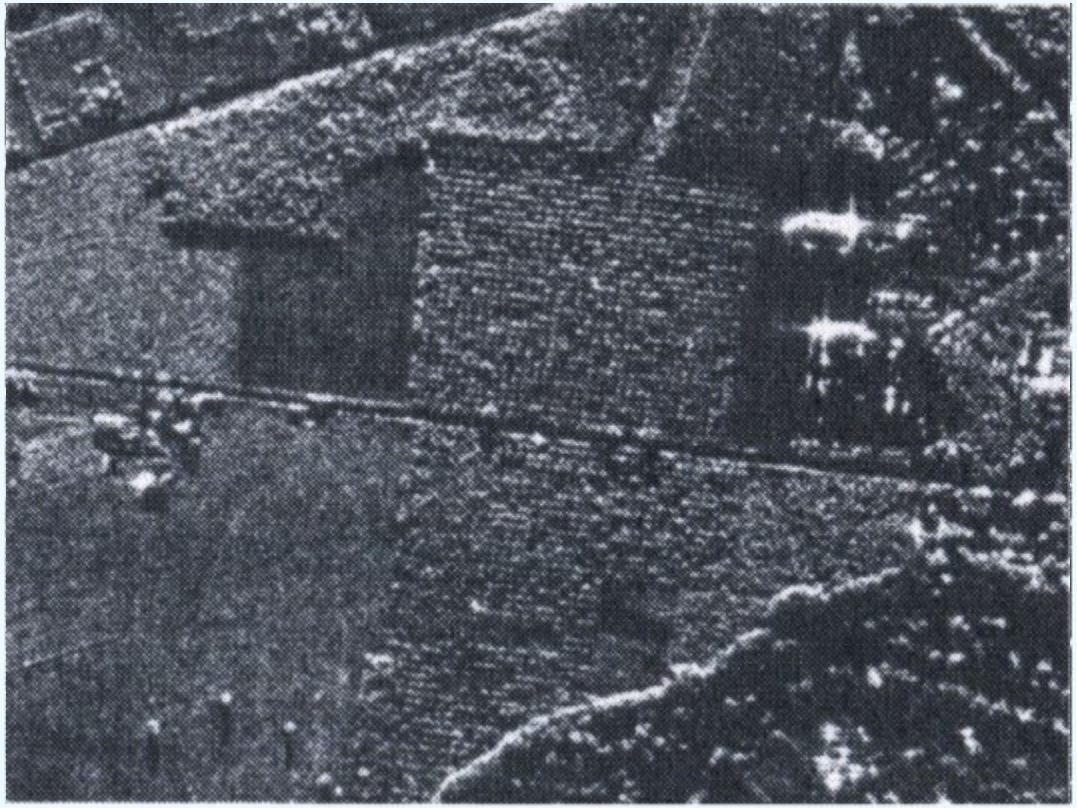
Figure 5-22: As the number of independent samples N is increased from 1 to 16, the confidence intervals around the means decrease by $1/\sqrt{N}$.

From: Microwave Radar and Radiometric Remote Sensing, by Ulaby and Long, 2014, with permission.

Q?

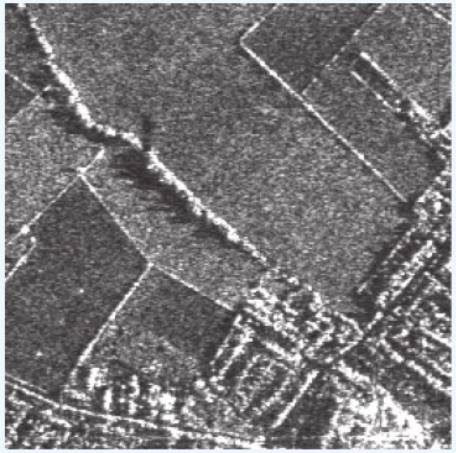
What does multiplicative noise mean?
Why speckle ocurs?
Where else you can see speckle?
How to reduce speckle?

Multilooking



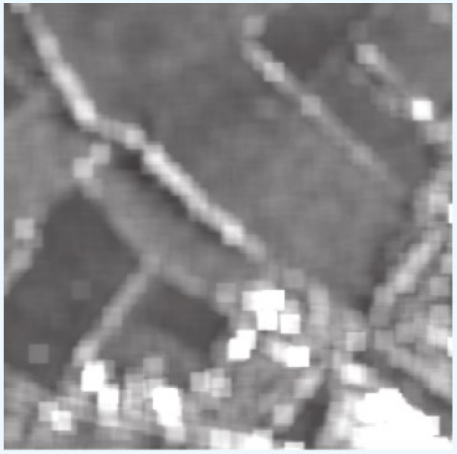
(d) 1.5 m × 2.1 m, $N = 1$

From: Microwave Radar and Radiometric Remote Sensing, by Ulaby and Long, 2014, with permission.

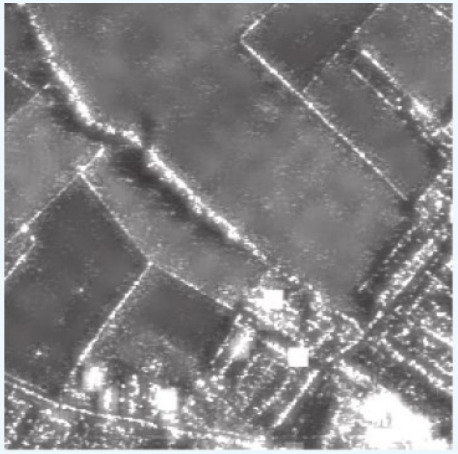


Unfiltered image

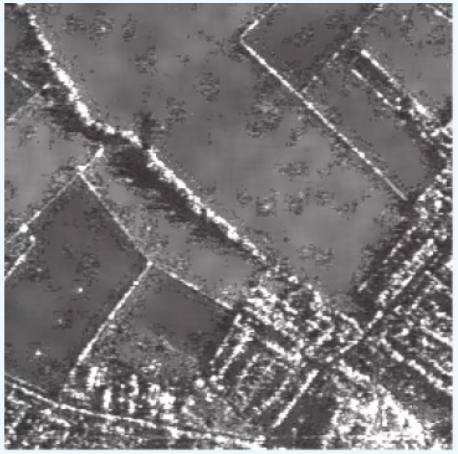
(a) DRA X-band airborne SAR image of a rural scene: 3 m resolution, 2-look



(b) Despeckled: multilook



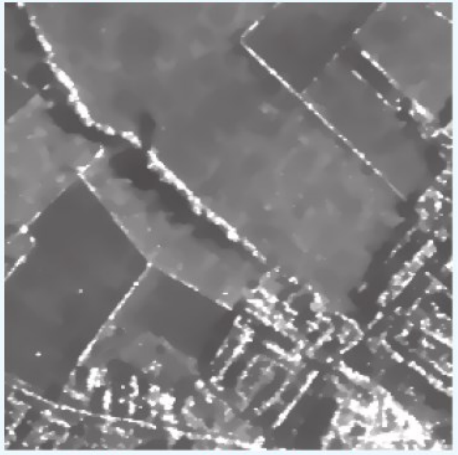
(c) Despeckled: MMSE



(d) Despeckled: structural gamma MAP

(e) Despeckled: CML

(f) Despeckled: CMAP



(g) Despeckled: Crimmins

Spackle filters

Figure 5-26: The 3 m × 3 m resolution 2-look image in (a) was subjected to six different despeckling filters [courtesy of Oliver and Quegan].

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SLC image: 1 look

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Engineering

Temporal average: 31 looks

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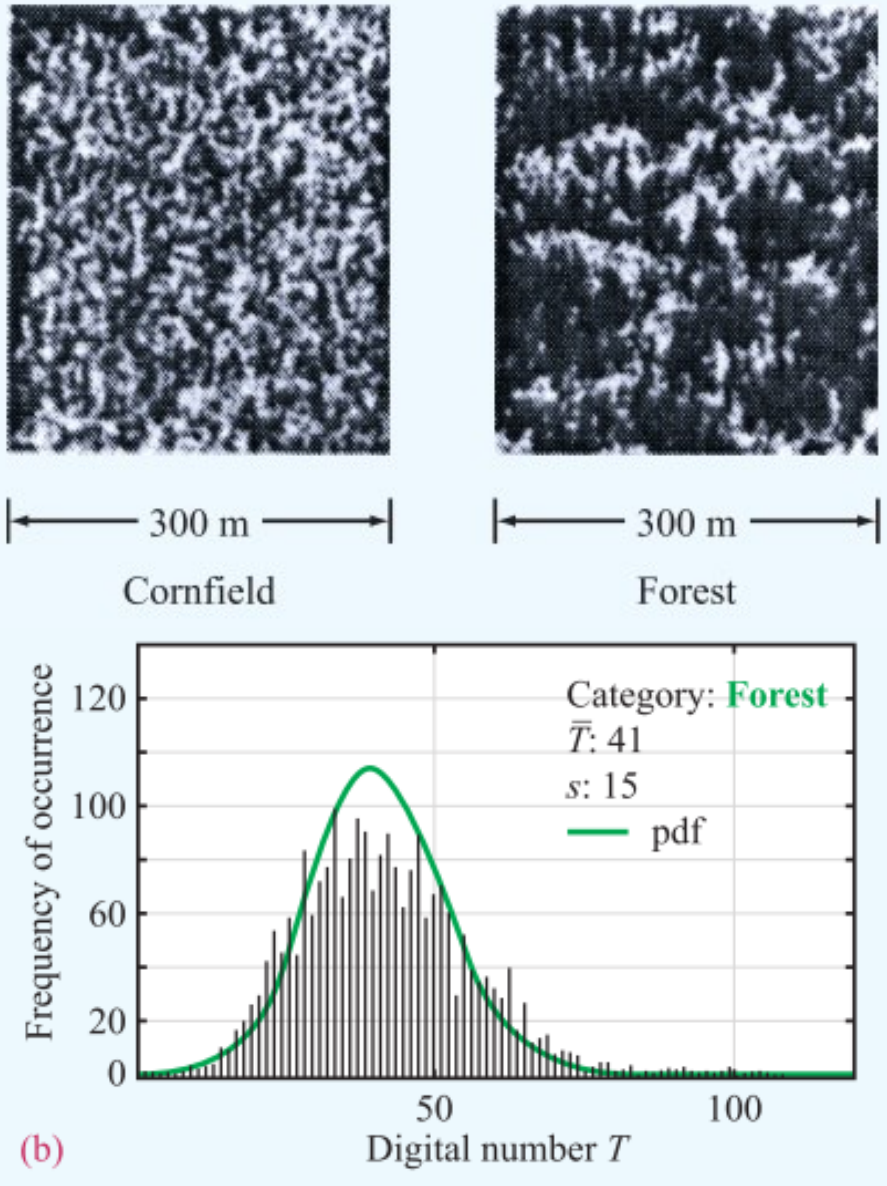
Engineering

Texture

Image texture refers to the intrinsic spatial variability of image tone, beyond that caused by speckle, due to corresponding spatial variabilities in the physical and/or electromagnetic properties of the distributed target.

Texture is described by higher order statistics.



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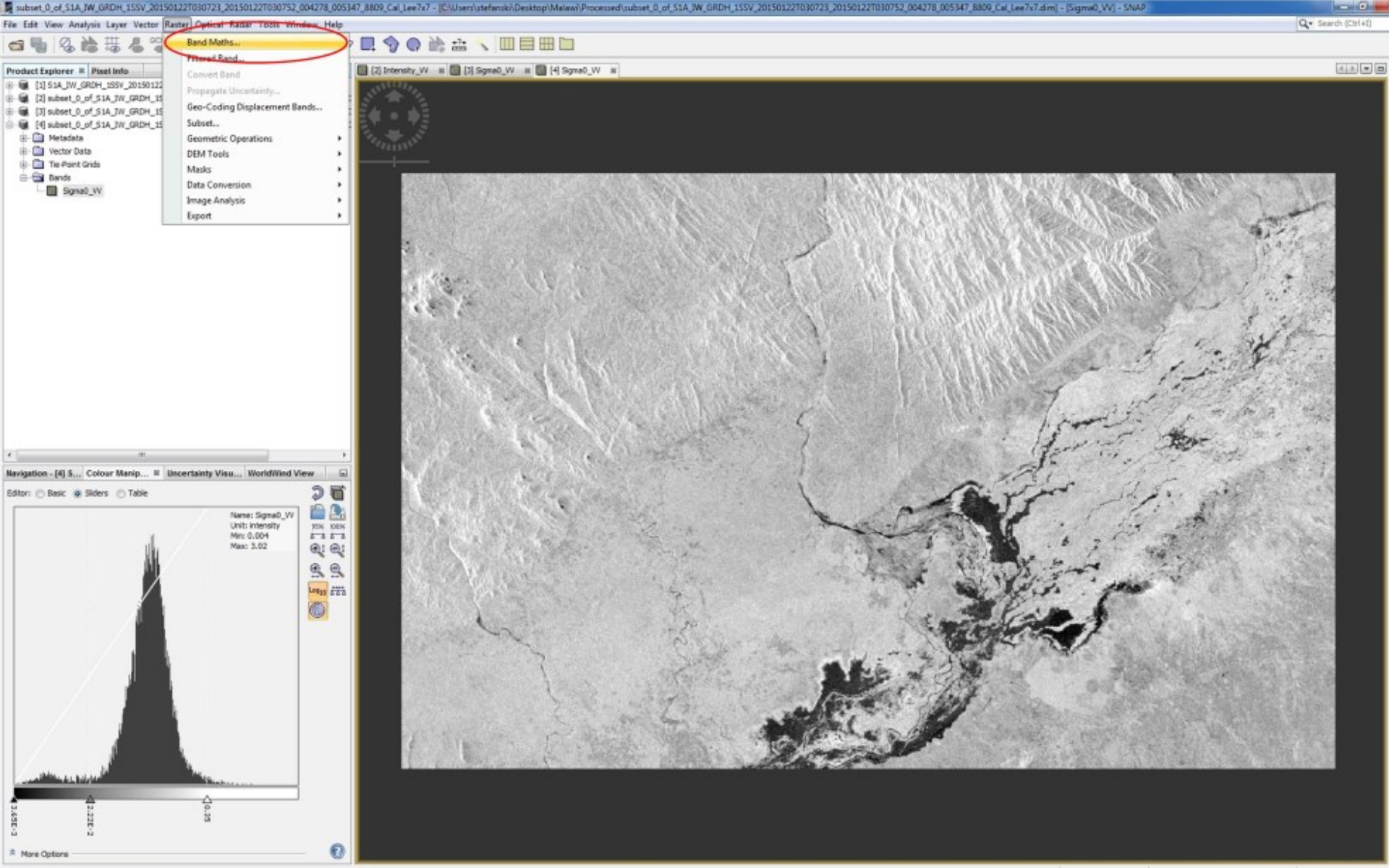
File Edit View Analysis Layer Vector Raster Optical Radar Tools Window Help
Band Maths...
Filtered Band...
Convert Band
Propagate Uncertainty...
Geo-Coding Displacement Bands...
Subset...
Geometric Operations
DEM Tools
Masks
Data Conversion
Image Analysis
Export
Product Explorer
Pixel Info
Metadata
Vector Data
Tie-Point Grids
Bands
Sigma0_VV
[2] Intensity_VV
[3] Sigma0_VV
[4] Sigma0_VV
Navigation - [4] S...
Colour Manip...
Uncertainty Visu...
WorldWind View
Editor: Basic Sliders Table
Name: Sigma0_VV
Unit: intensity
Min: 0.004
Max: 3.02
More Options

Q?

What does the histogram tool in SNAP tell you about statistical variables?

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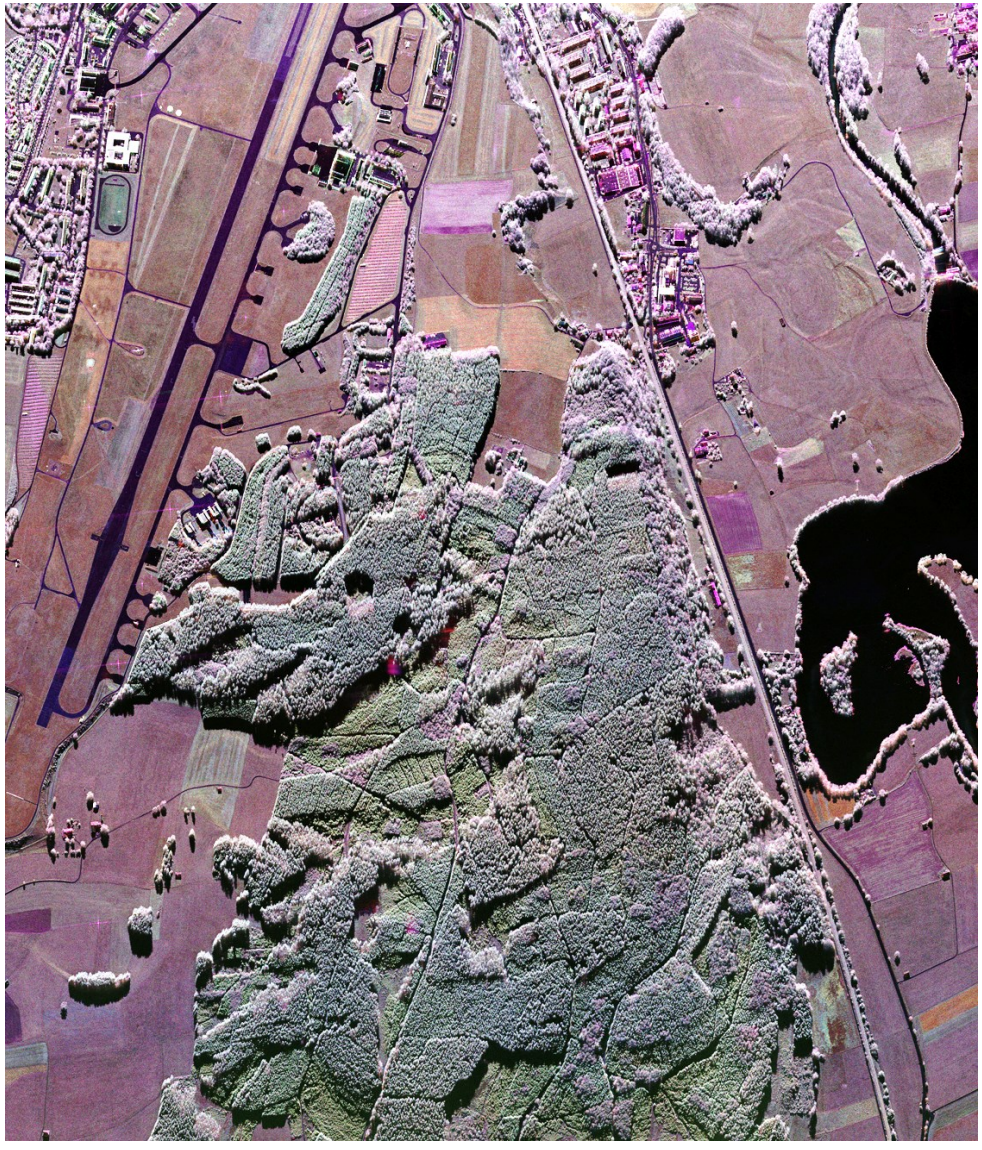
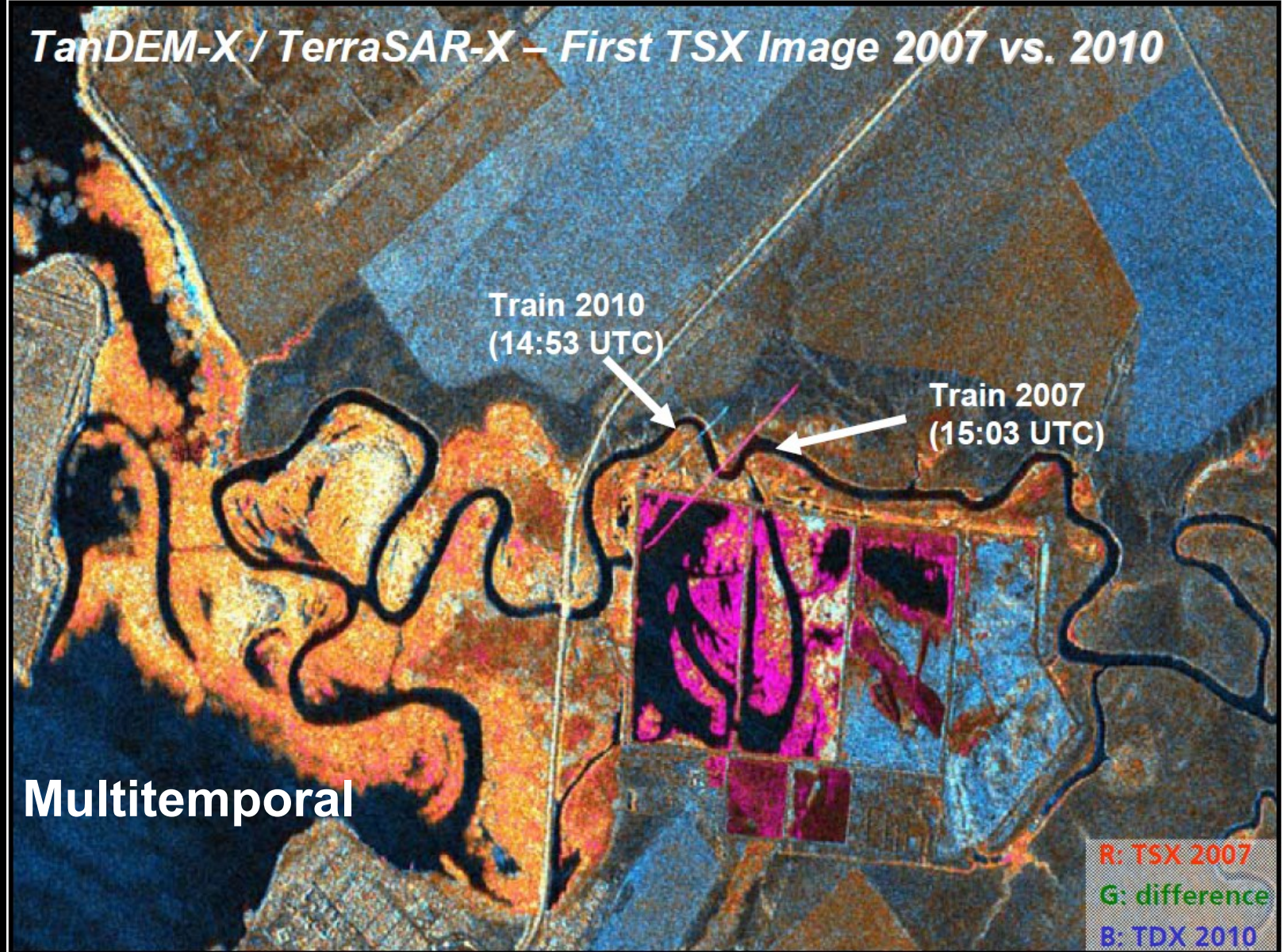
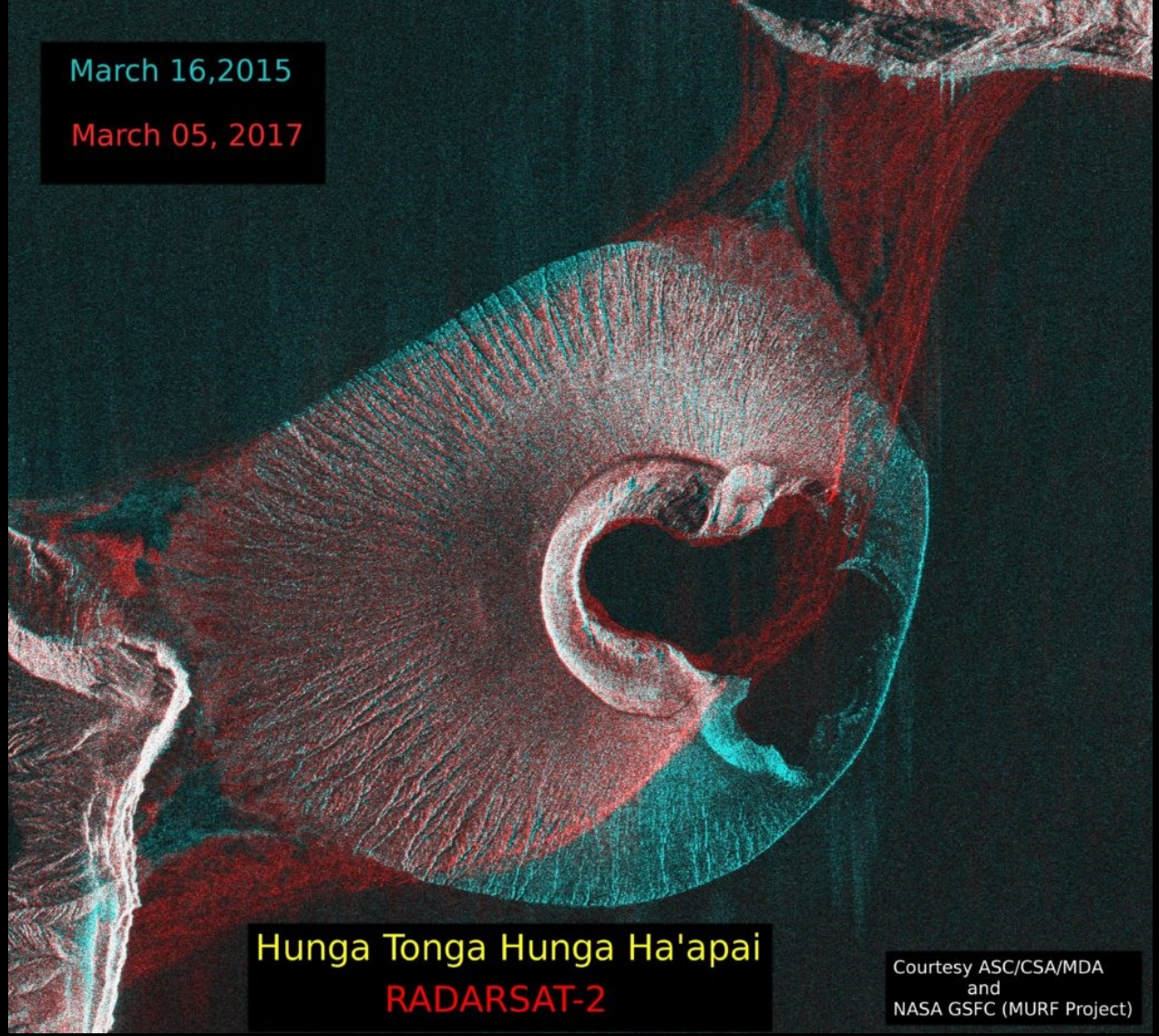
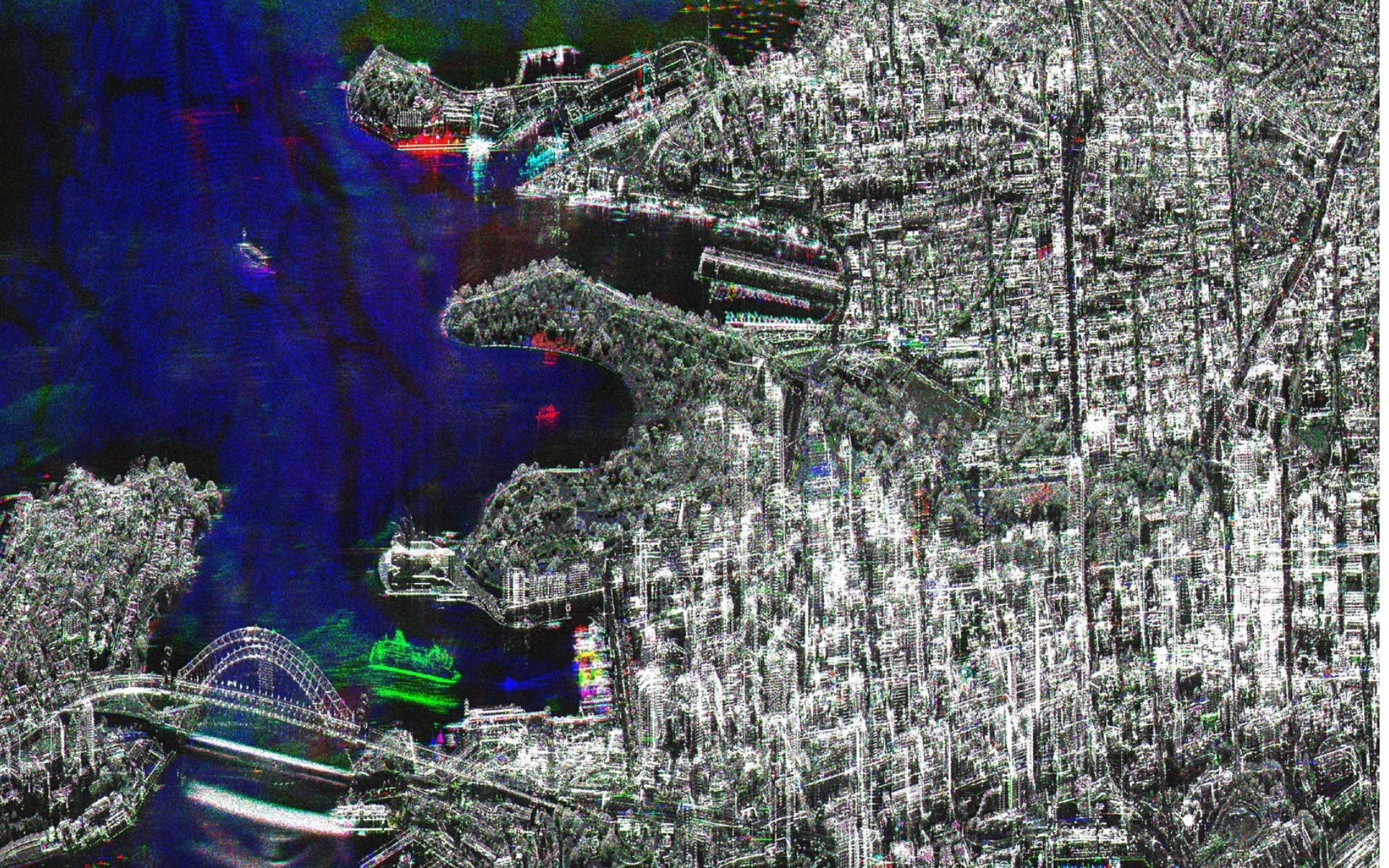
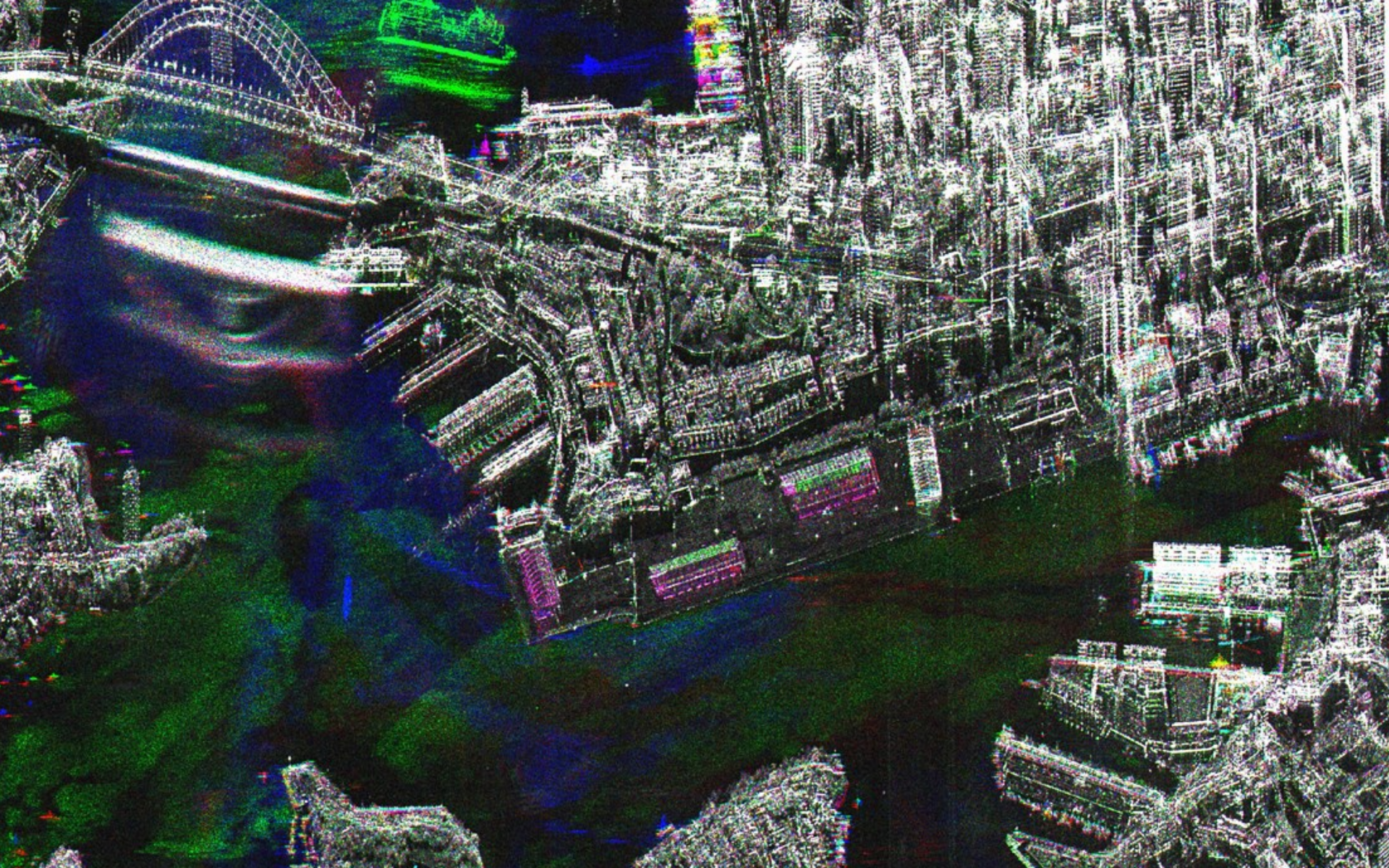
SAR temporal changes




TanDEM-X / TerraSAR-X – First TSX Image 2007 vs. 2010
Train 2010
(14:53 UTC)
Train 2007
(15:03 UTC)
Multitemporal
R: TSX 2007
G: difference
B: TDX 2010


March 16,2015
March 05, 2017
Hunga Tonga Hunga Ha'apai
RADARSAT-2
Courtesy ASC/CSA/MDA
and
NASA GSFC (MURF Project)



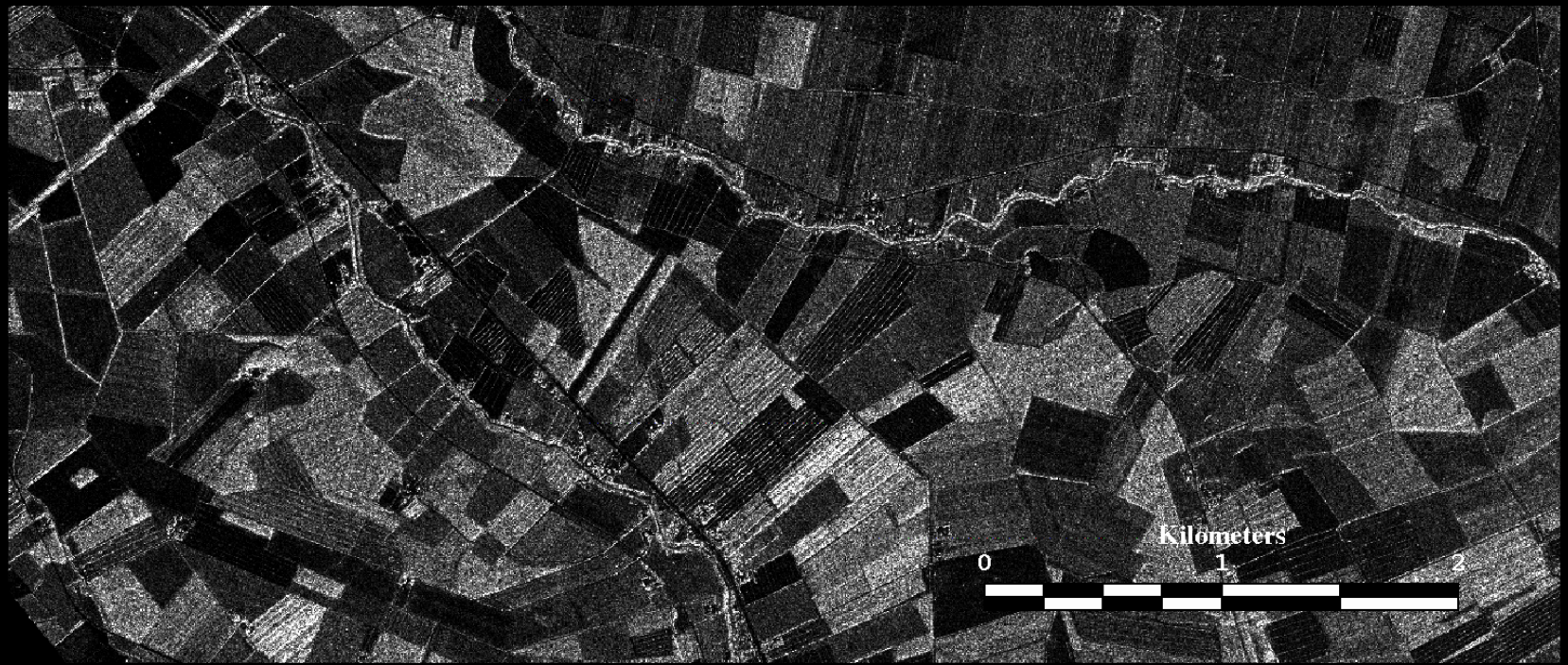


EMISAR 1995

SAR image from Tyrnävä

C-band HH polarization
March 1995

EMISAR 1995



SAR image from Tyrnävä

L-band HH polarization
May 1995

EMISAR 1995

HELSINKI UNIVERSITY OF TECHNOLOGY

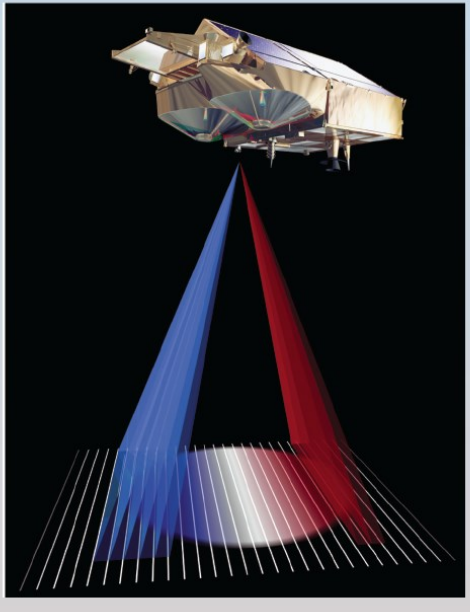
Multitemporal SAR image from Tyrnävä

RED: L-Band total power in May
GREEN: L-Band total power in March
BLUE: C-Band total power in March

Jaan Praks

- Ulaby
- Long
- Blackwell
- Elachi
- Fung
- Ruf
- Sarabandi
- Zebker
- Van Zyl

Microwave Radar and Radiometric Remote Sensing



END