SAR Theory

Andy Hooper
COMET, University of Leeds

ESA Advanced Training Course
Remote Sensing of the Cryosphere

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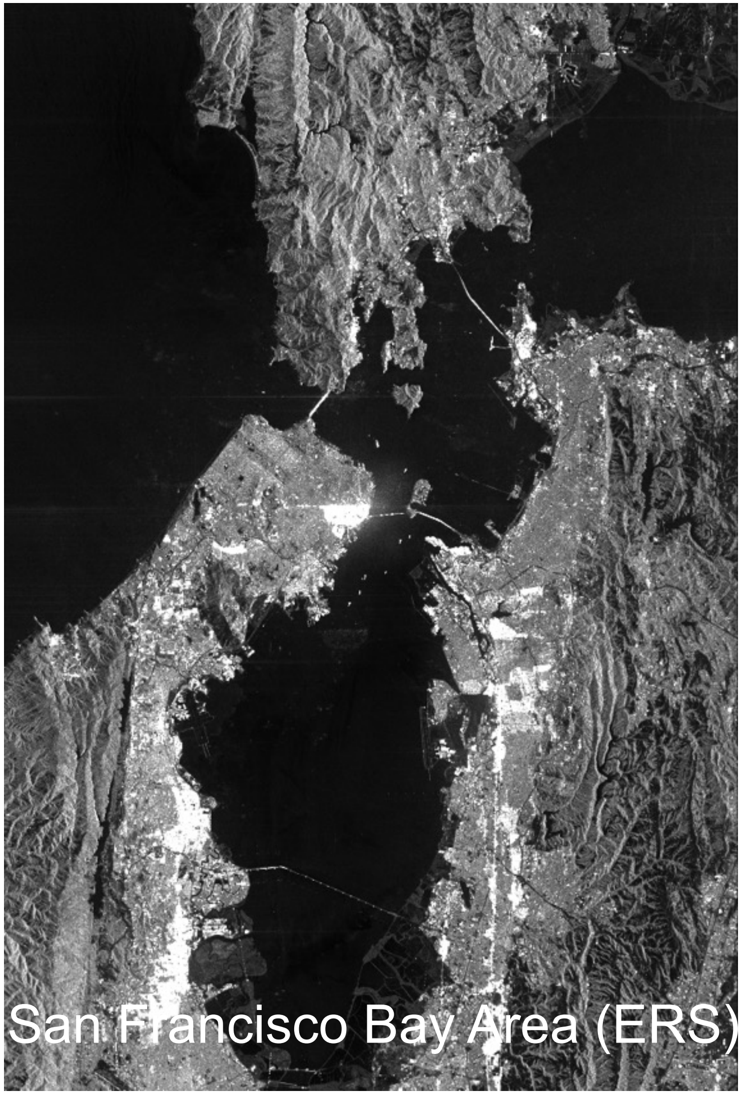
What is SAR?

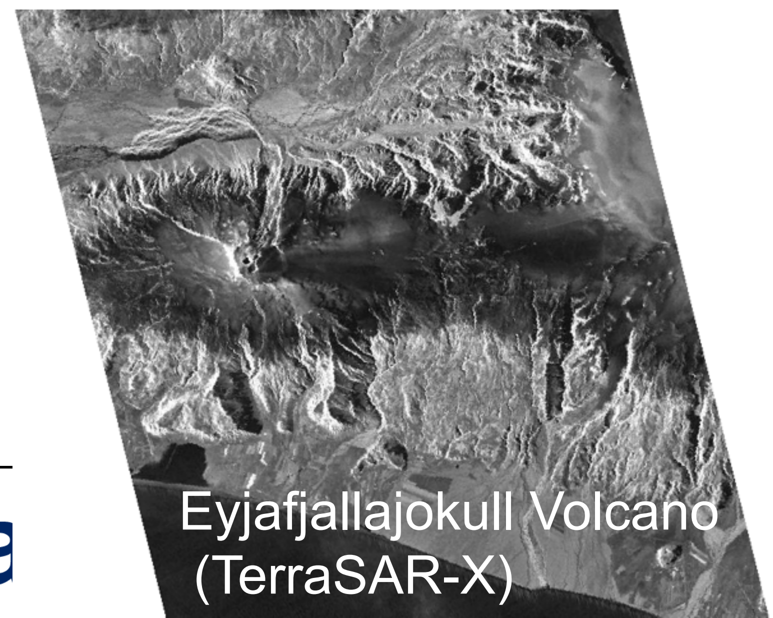
- Short for “Synthetic Aperture Radar”
- SAR is an active remote sensing technique (not dependent on Sun)

SAR amplitude examples



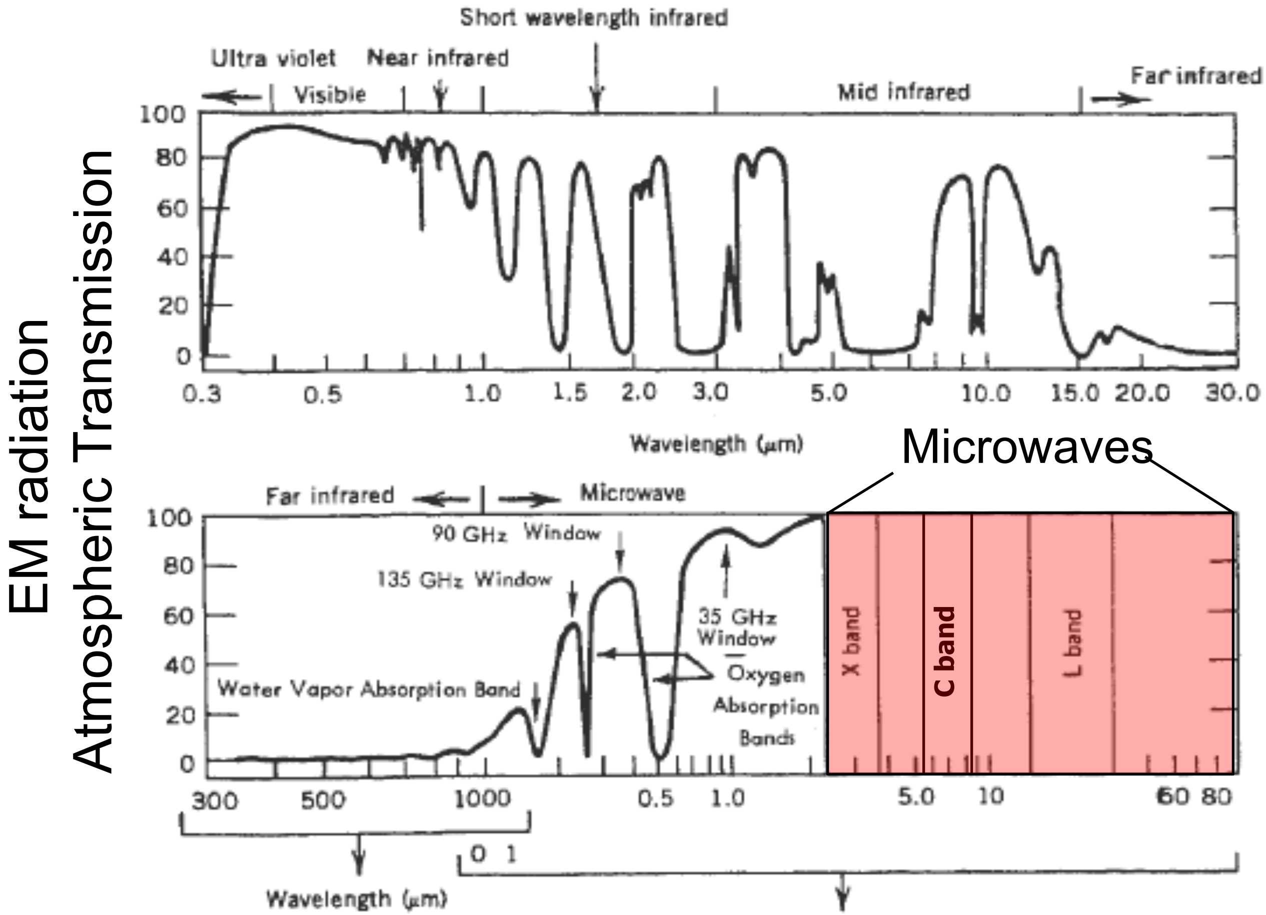
San Francisco Bay Area (ERS)

Beardmore Glacier (TerraSAR-X)



Eyjafjallajokull Volcano (TerraSAR-X)

Why use radars for imaging?



- Microwaves penetrate the atmosphere AND clouds
- Images can be acquired during day AND night
- Resolution does not depend on distance
- Information content complementary to optical

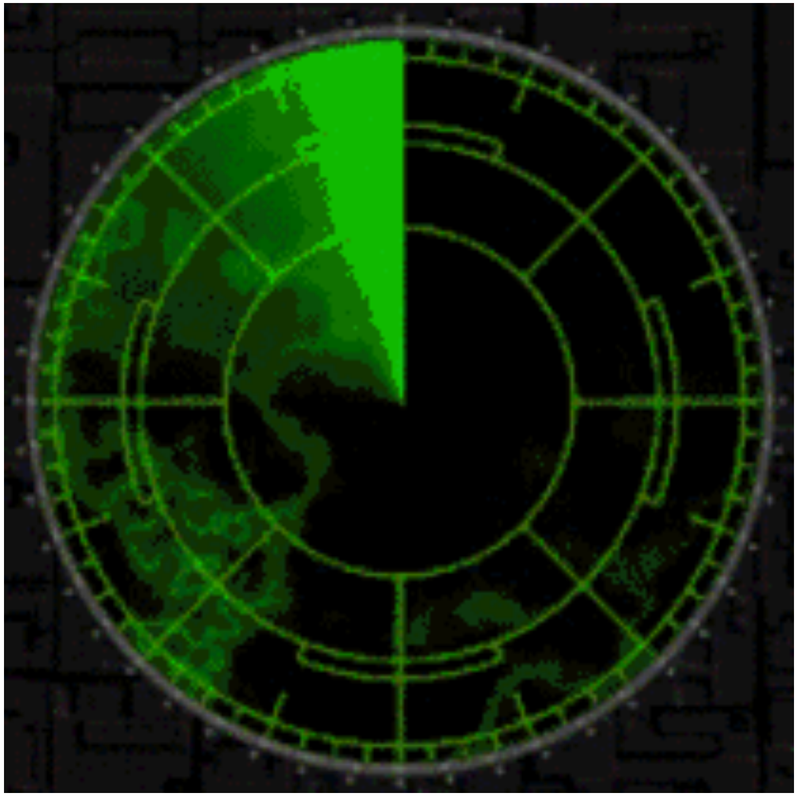
Uses of SAR amplitude

Include:

- Oceonography (wave spectra, wind speed, currents)
- Sea ice monitoring
- Glaciology (snow wetness, glacier monitoring)
- Agriculture (soil moisture, crop classification)
- Forestry (forest height, biomass)
- Environmental monitoring (urban growth, oil spills)
- Military surveillance

SAR images also have “phase”, allowing “interferometry” applications – covered in next lecture

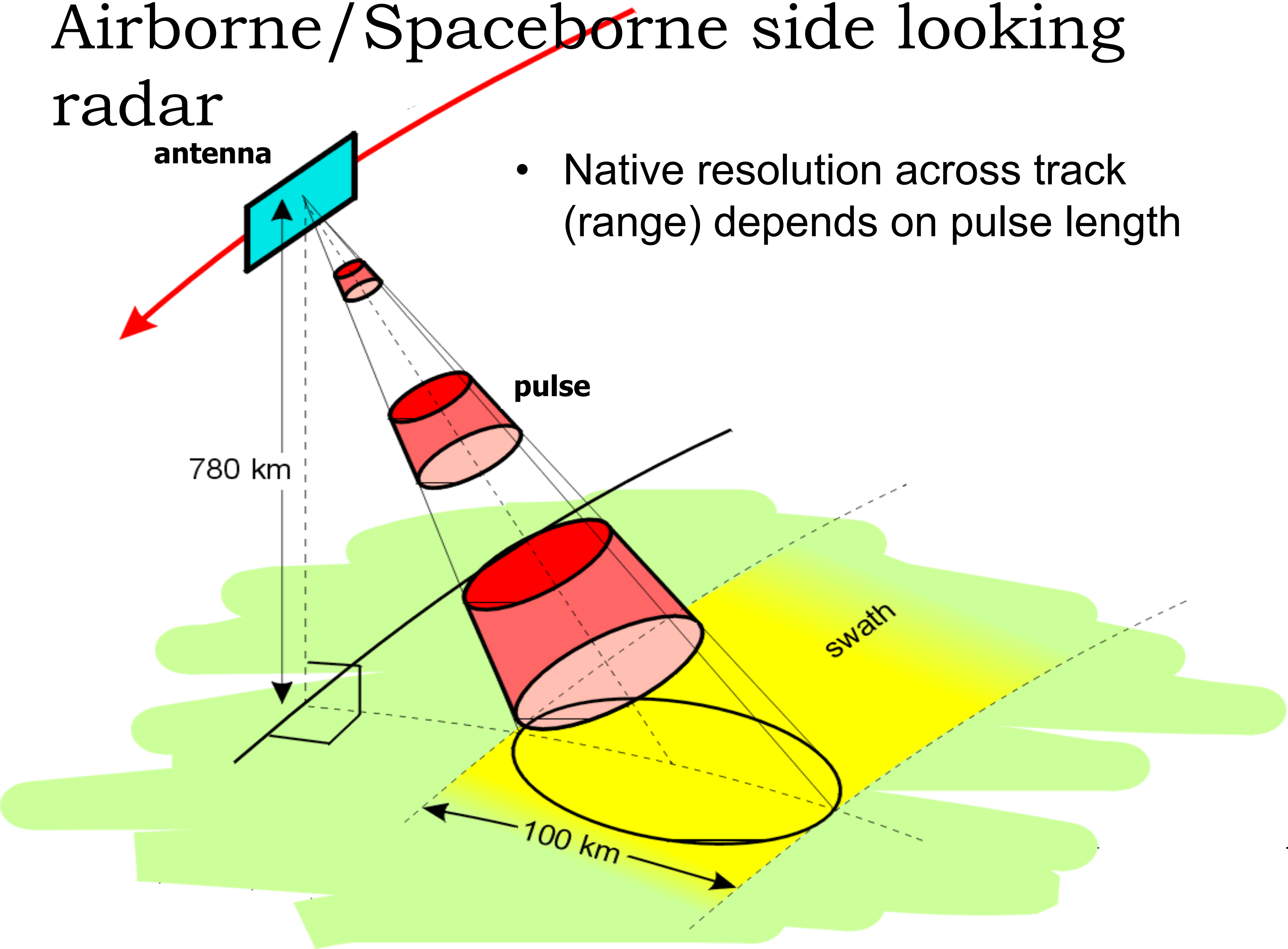
Radar = Radio detection and ranging



- Pulse transmitted, distance from time for echo come back

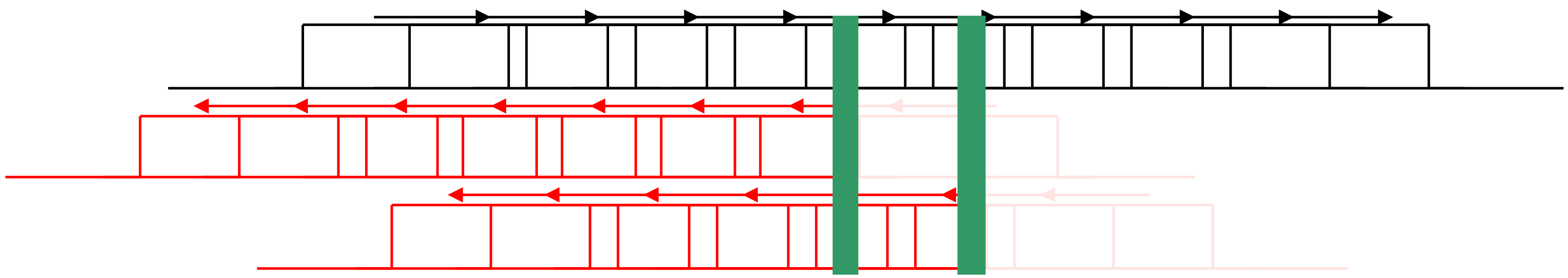
Airborne/Spaceborne side looking radar

- Native resolution across track (range) depends on pulse length



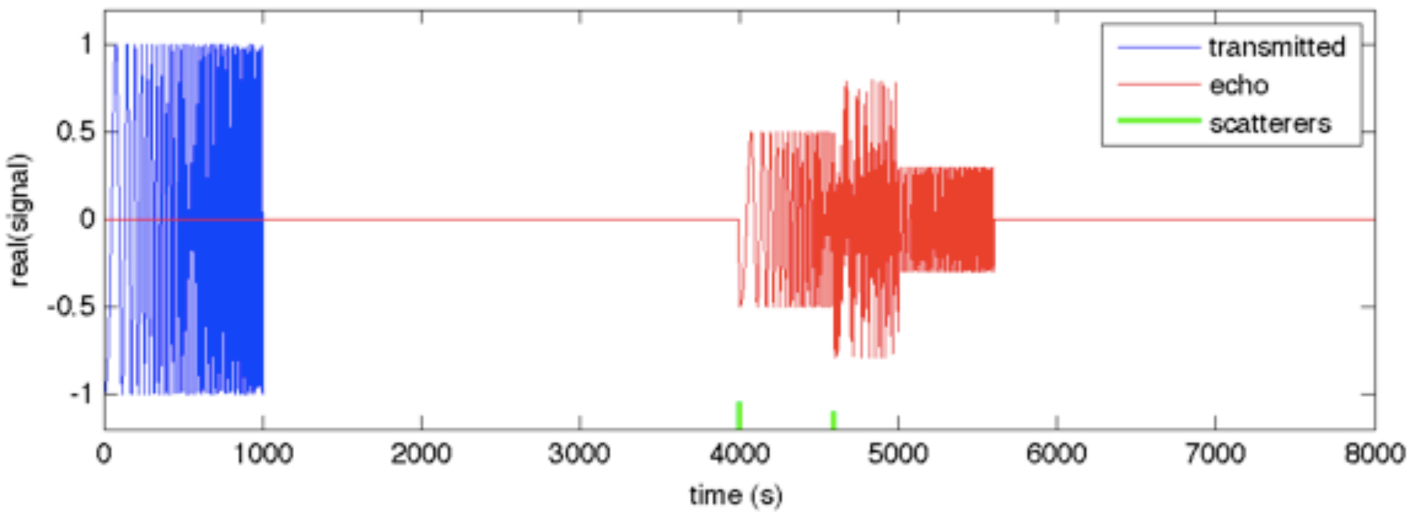
Range resolution

- Whether 2 scatterers can be distinguished depends on the pulse length:



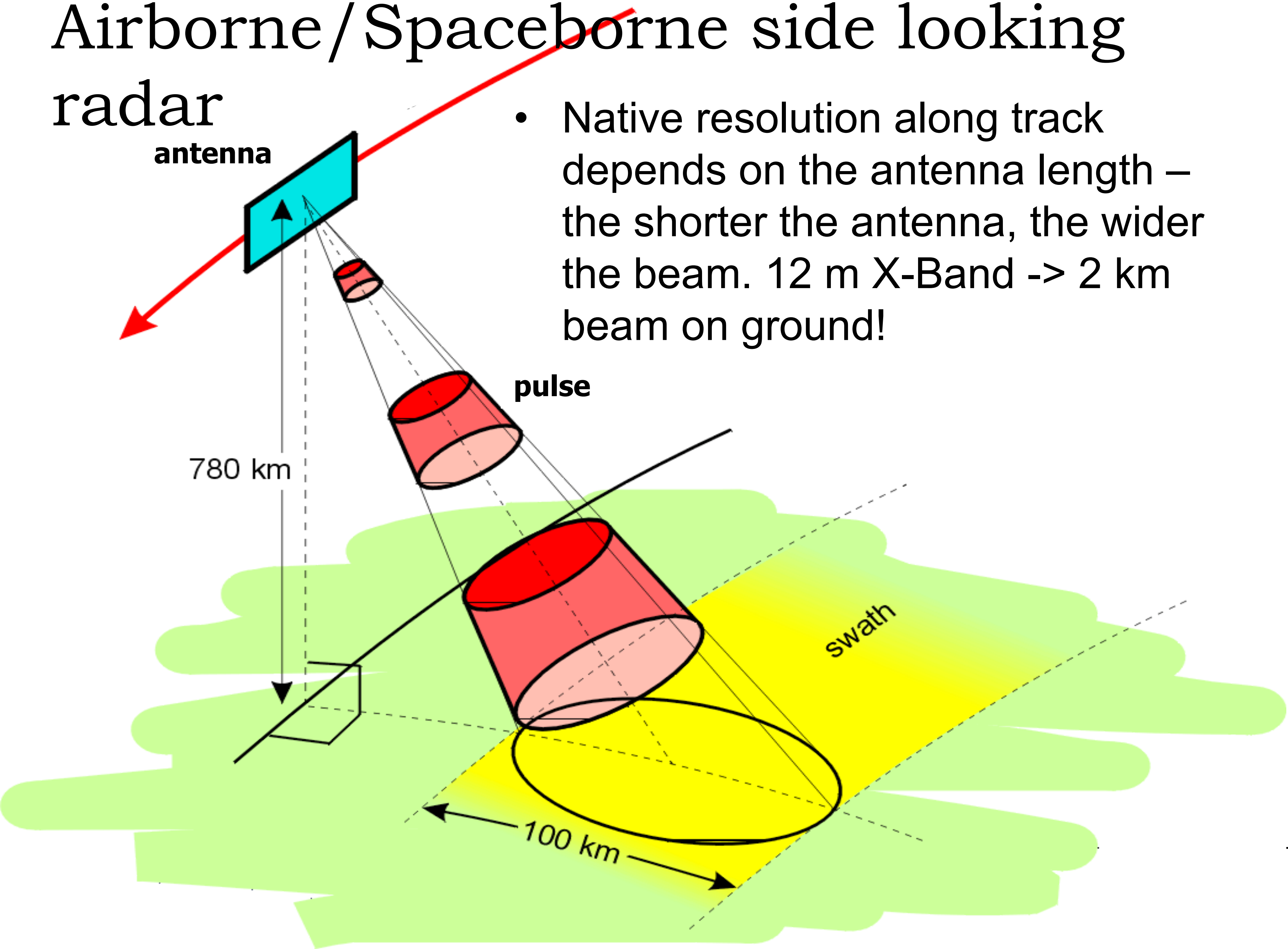
- So get good resolution by using short pulse
- In reality a longer pulse with variable frequency is used (a ”chirp”), which can be post-processed to simulate a short pulse, called “range compression”.
- Resolution typically several metres and does not depend on distance from target

“Range compression”



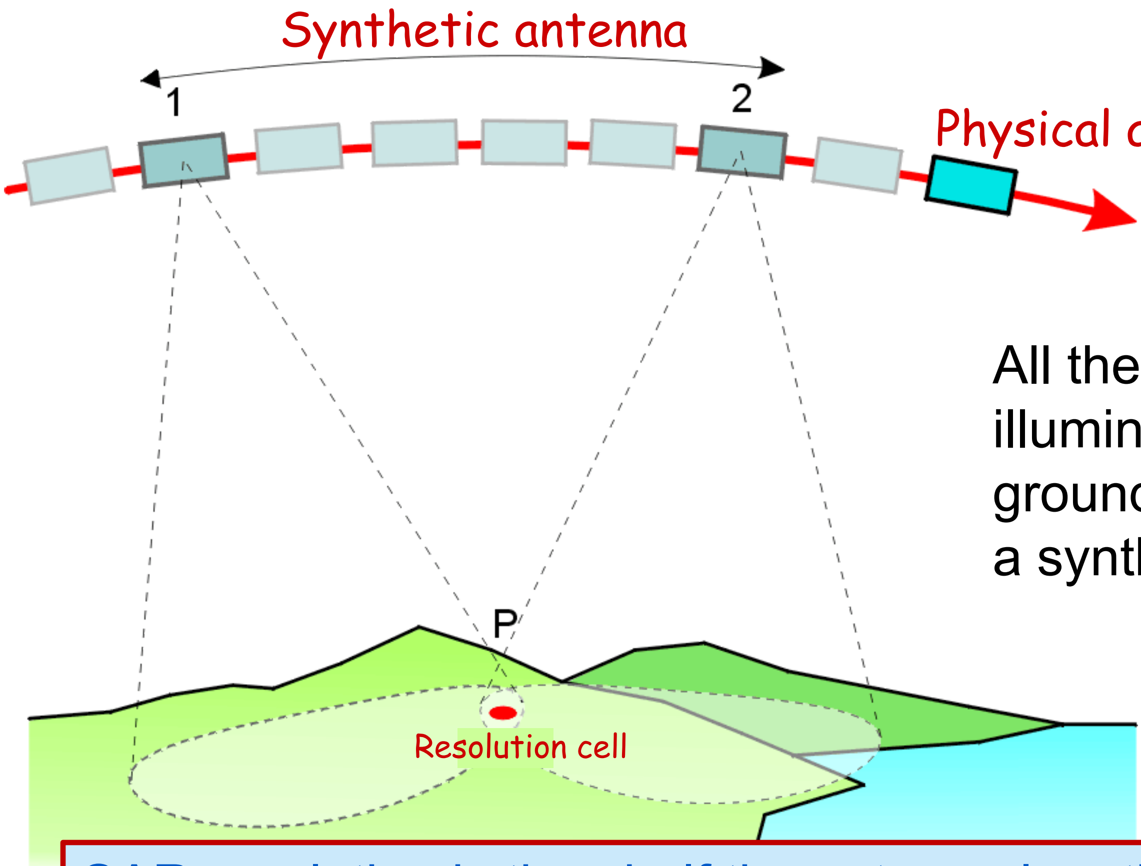
Airborne/Spaceborne side looking radar

- Native resolution along track depends on the antenna length – the shorter the antenna, the wider the beam. 12 m X-Band -> 2 km beam on ground!



Synthetic Aperture Radar

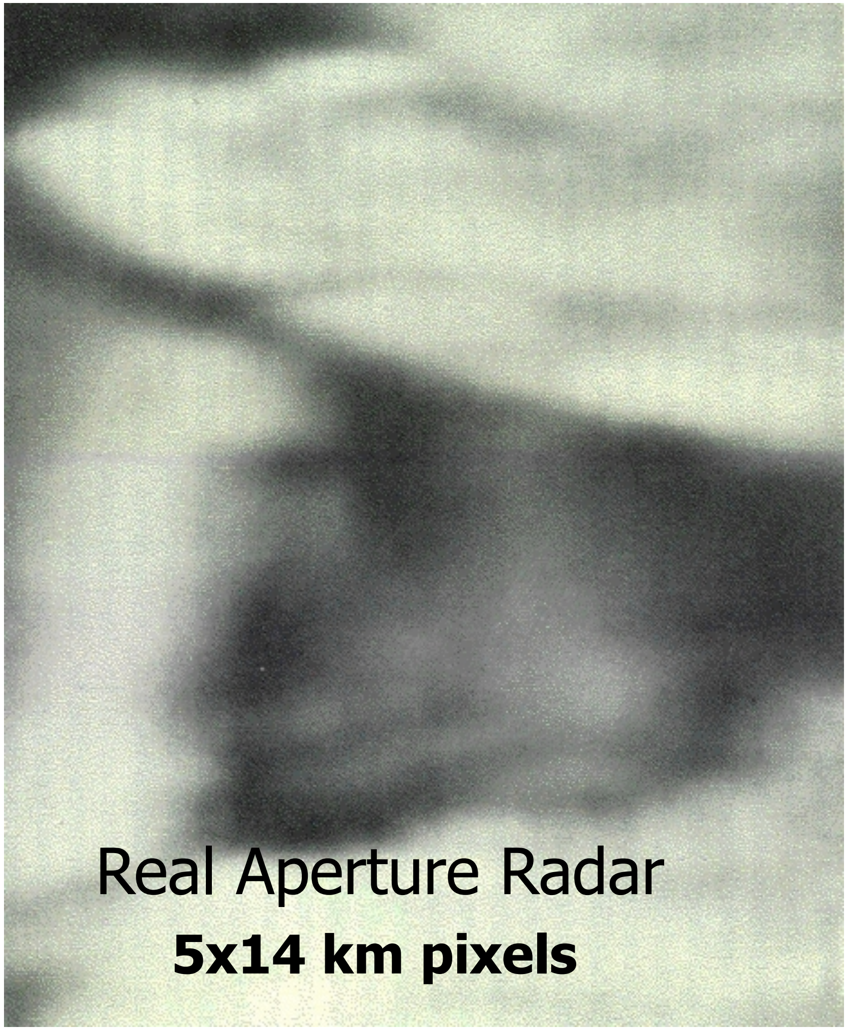
A trick to improve along-track resolution

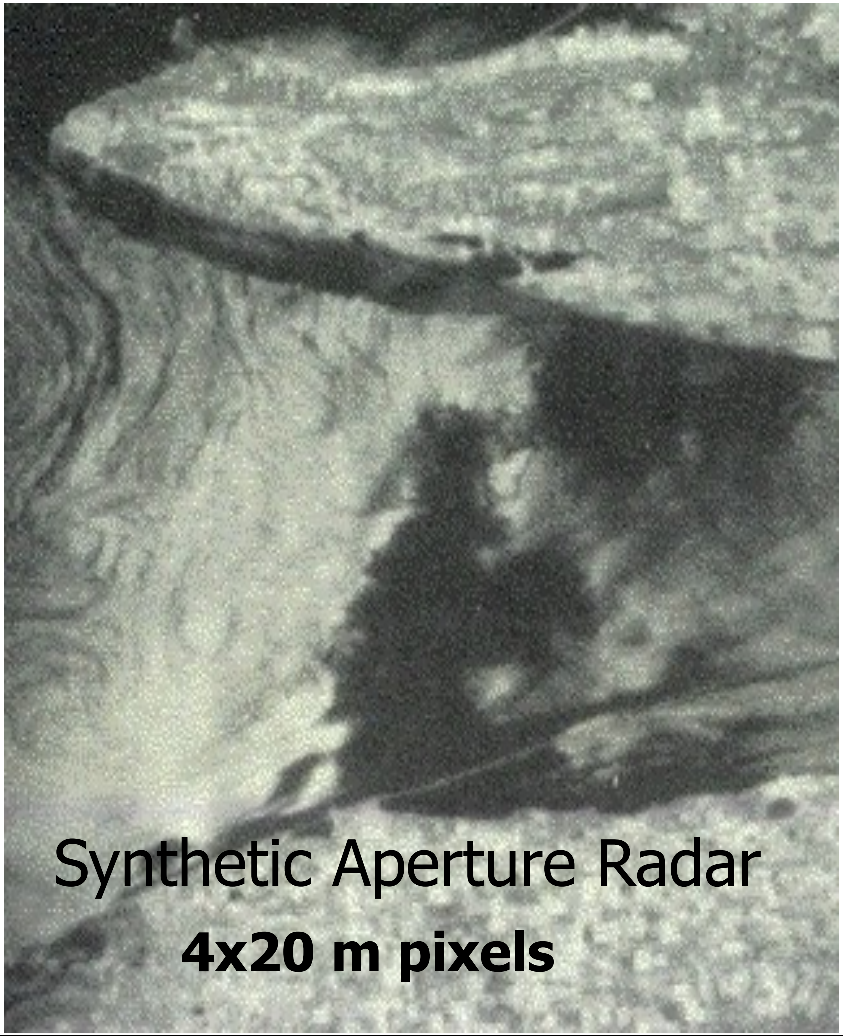


All the radar echoes that illuminate a given patch of ground are used to construct a synthetic larger antenna

SAR resolution is then half the antenna length (few m) and is independent of distance!

Improvement in Resolution
(Crimea, Ukraine, ERS satellite)





Massonnet and Feigl, 1998

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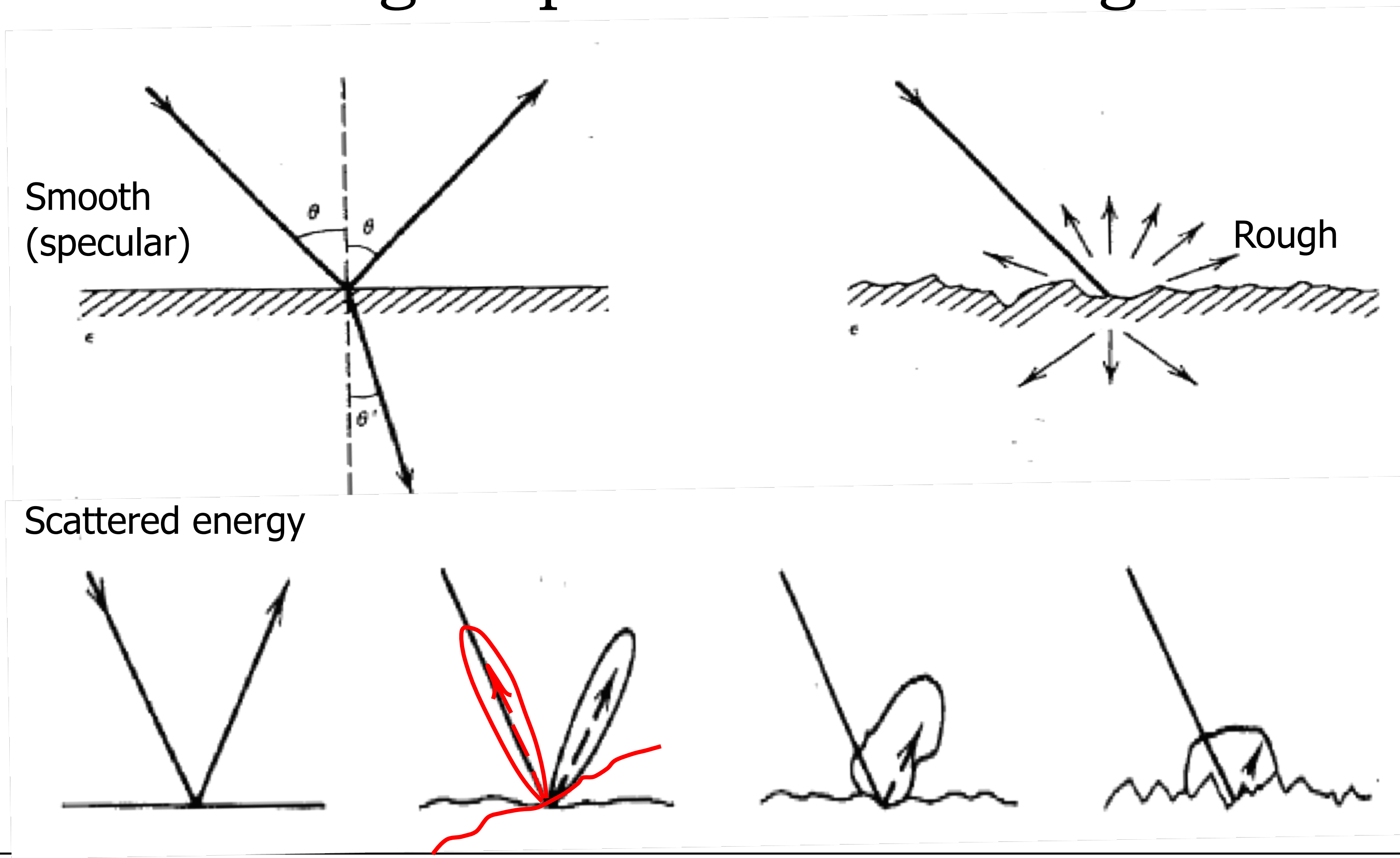
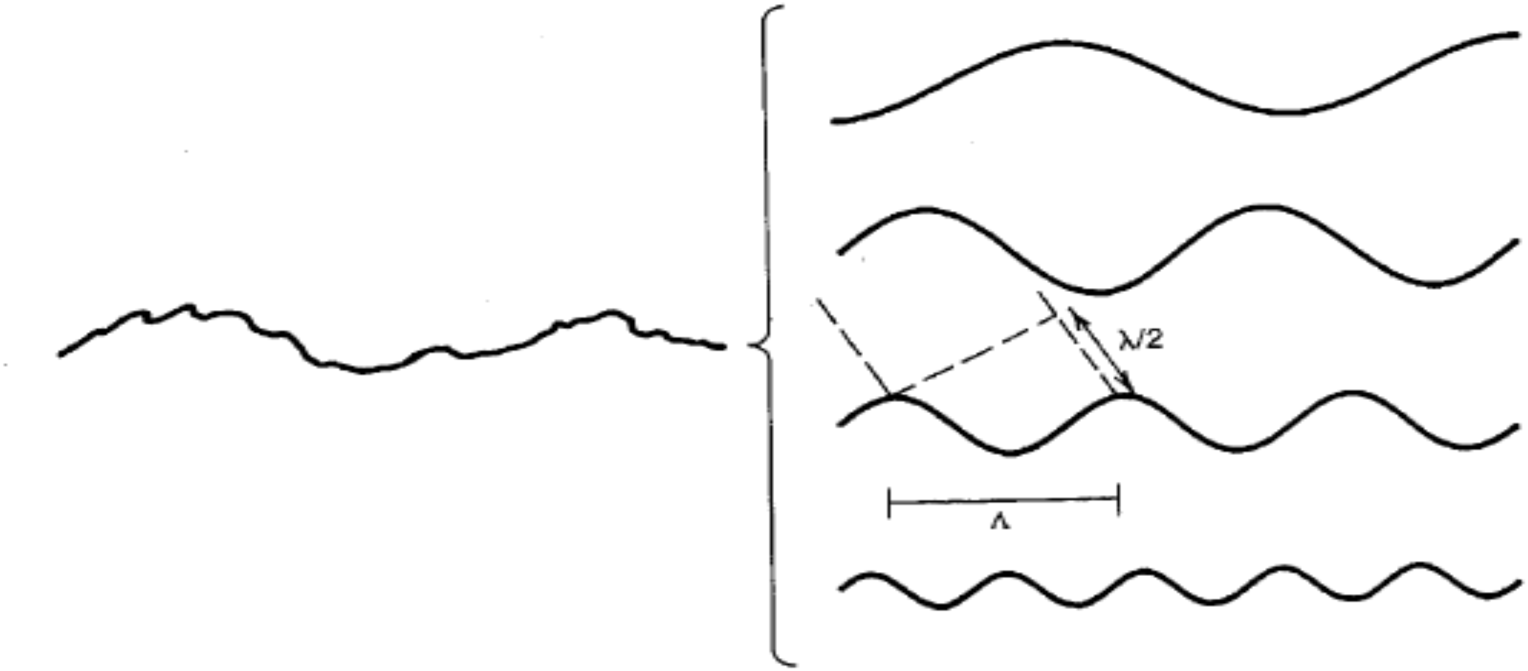
Scattering: dependence on roughness



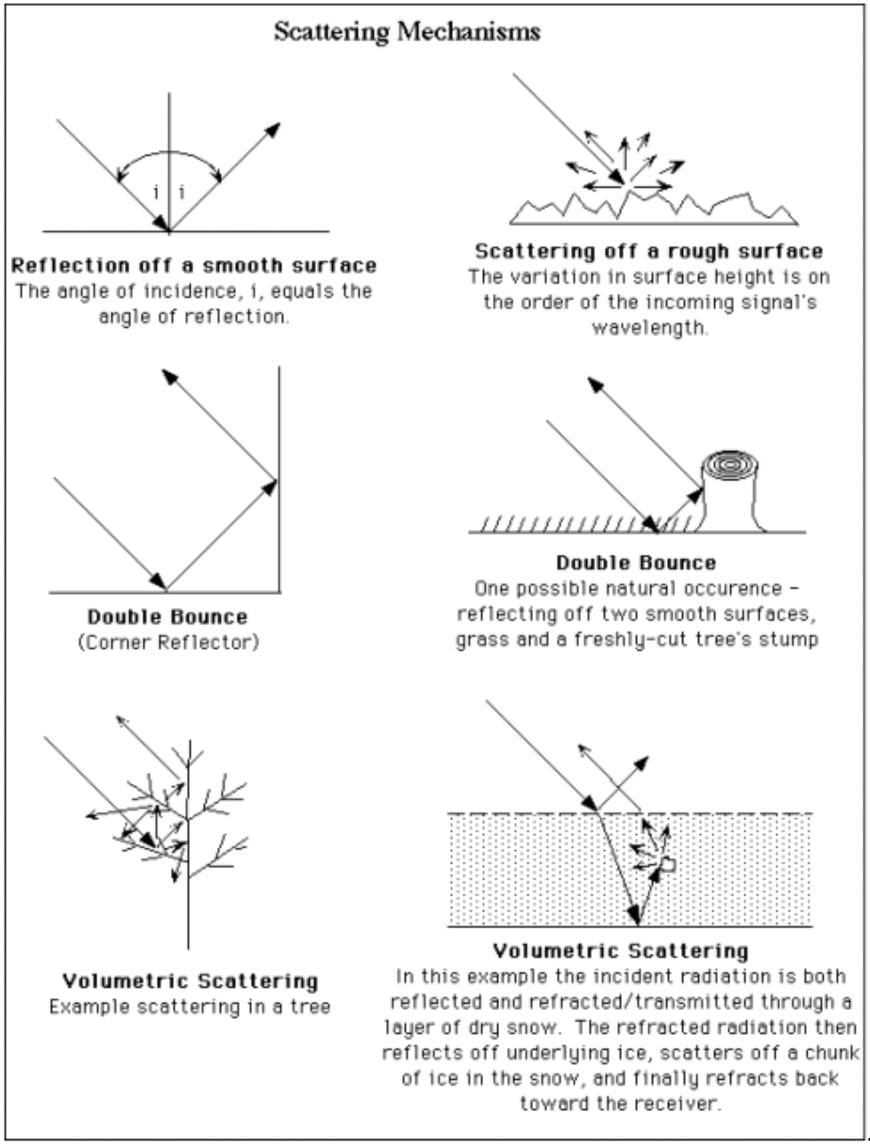
Bragg Scattering



Bragg scattering occurs mainly from spectral component with half radar wavelength

Scattering Mechanisms

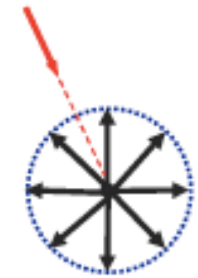
- Surface scattering
- Double bounce
- Volume scattering



What does the Radar measure ?

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

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



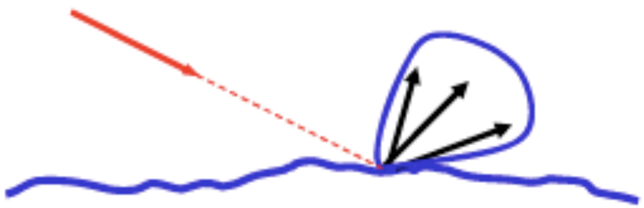
Isotropic scatterer

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



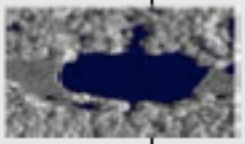
The backscattered coefficient can be a negative number if there is a focusing of backscattered energy way from the radar (e.g. smooth surface)

Dielectric Properties

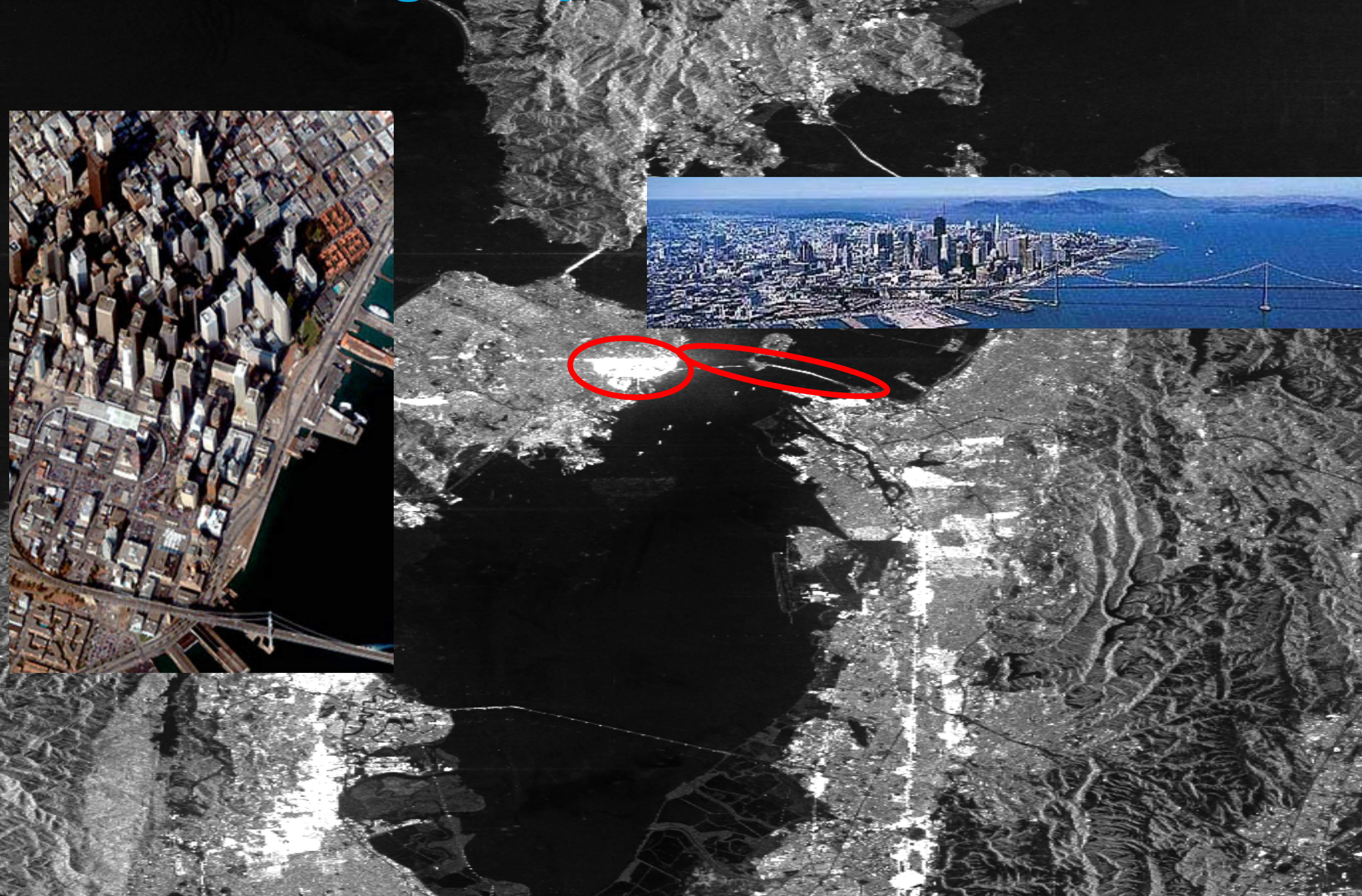
- Backscatter also depends on dielectric properties.
- Metal and water have high dielectric constant
- Amplitude can be used to determine soil moisture content

In summary, radar signal return depends on:
•Slope
•Roughness
•Dielectric constant

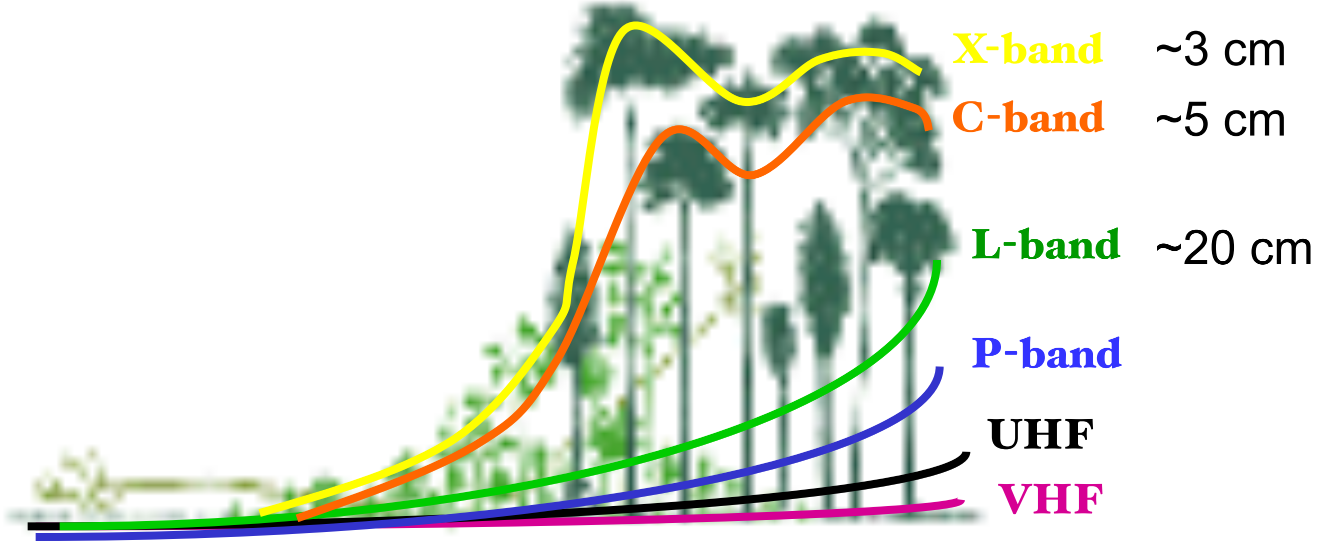
Backscattering Coefficient σ_o

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)

Scattering Amplitude



Scattering and wavelength

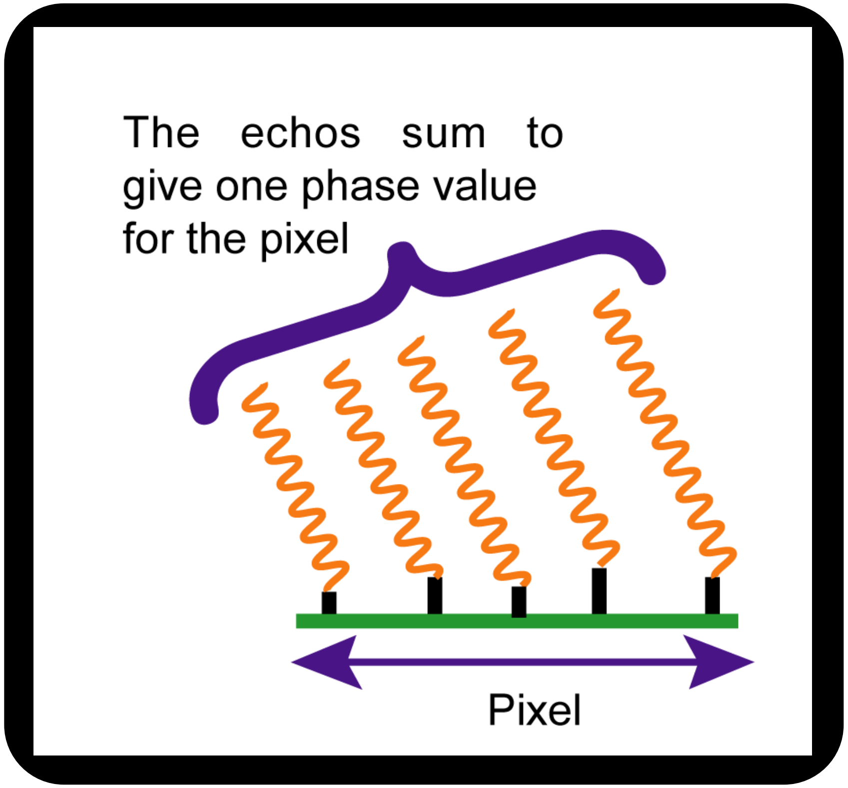


Radar Images at Different Frequencies

X-band

L-band

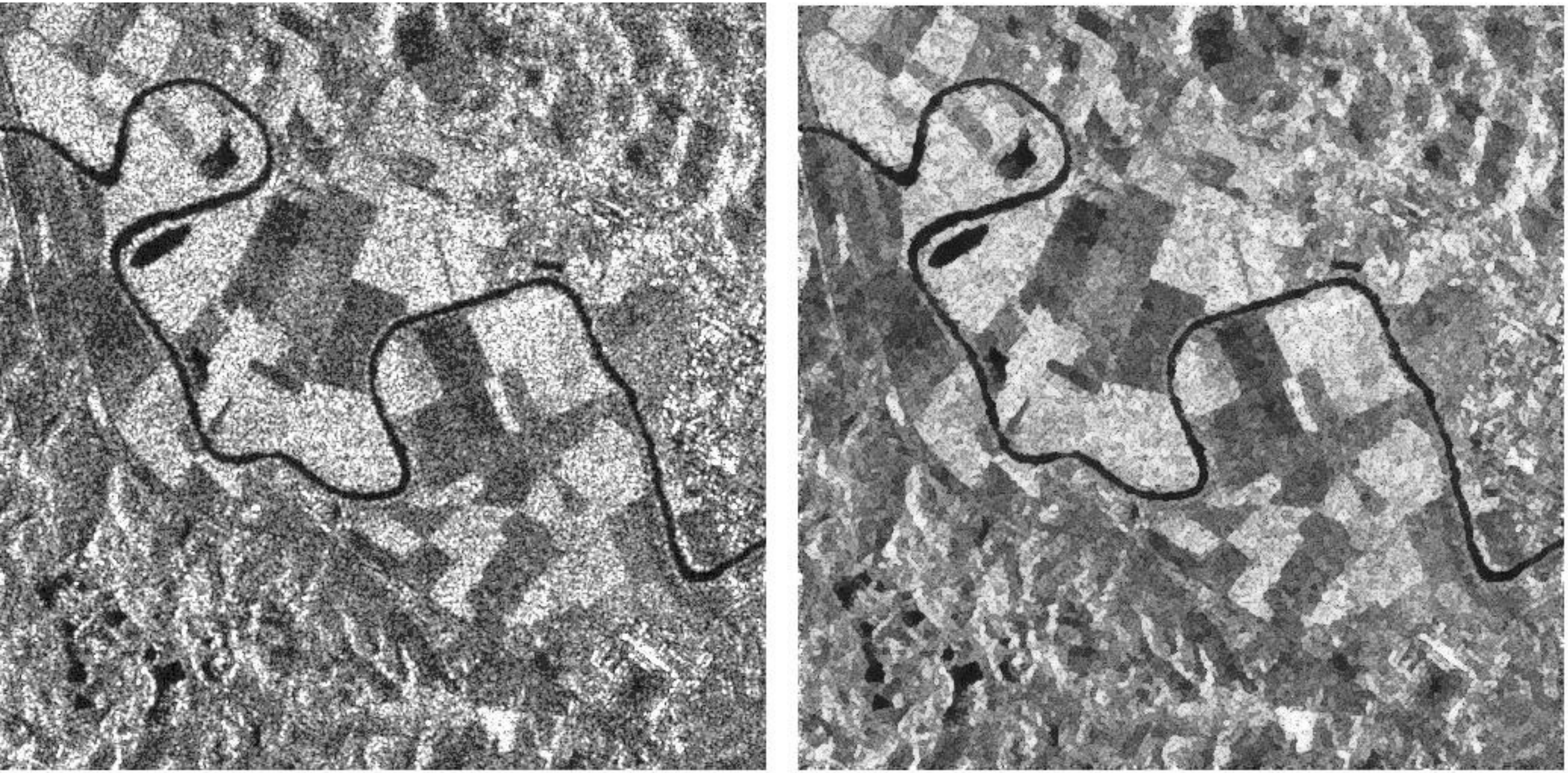
Speckle



Distributed scatterer pixel

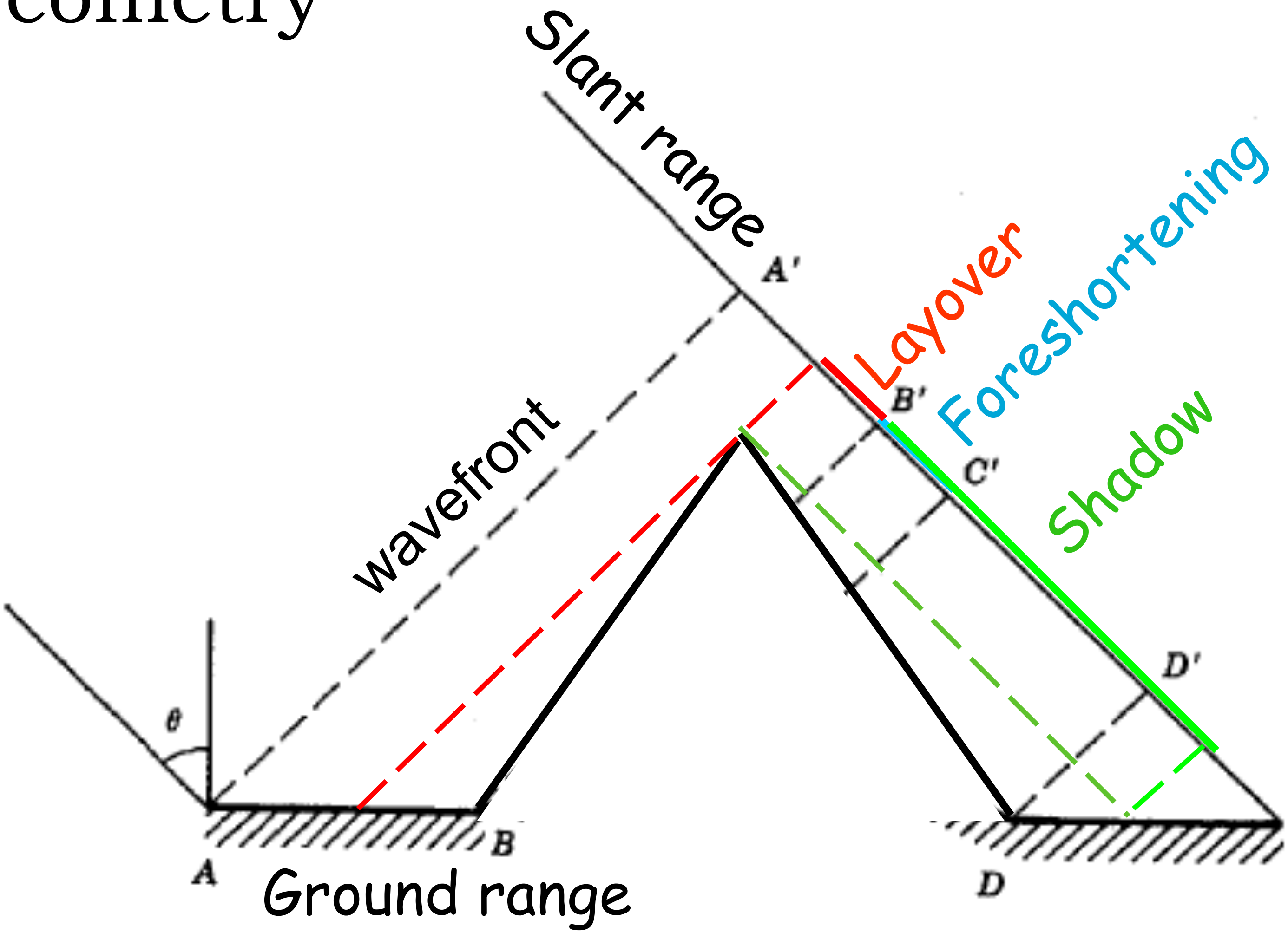
- Amplitude has a pseudorandom element
- Neighbouring resolution cells with same scattering properties can have different amplitude
- This effect known as "speckle"

Speckle

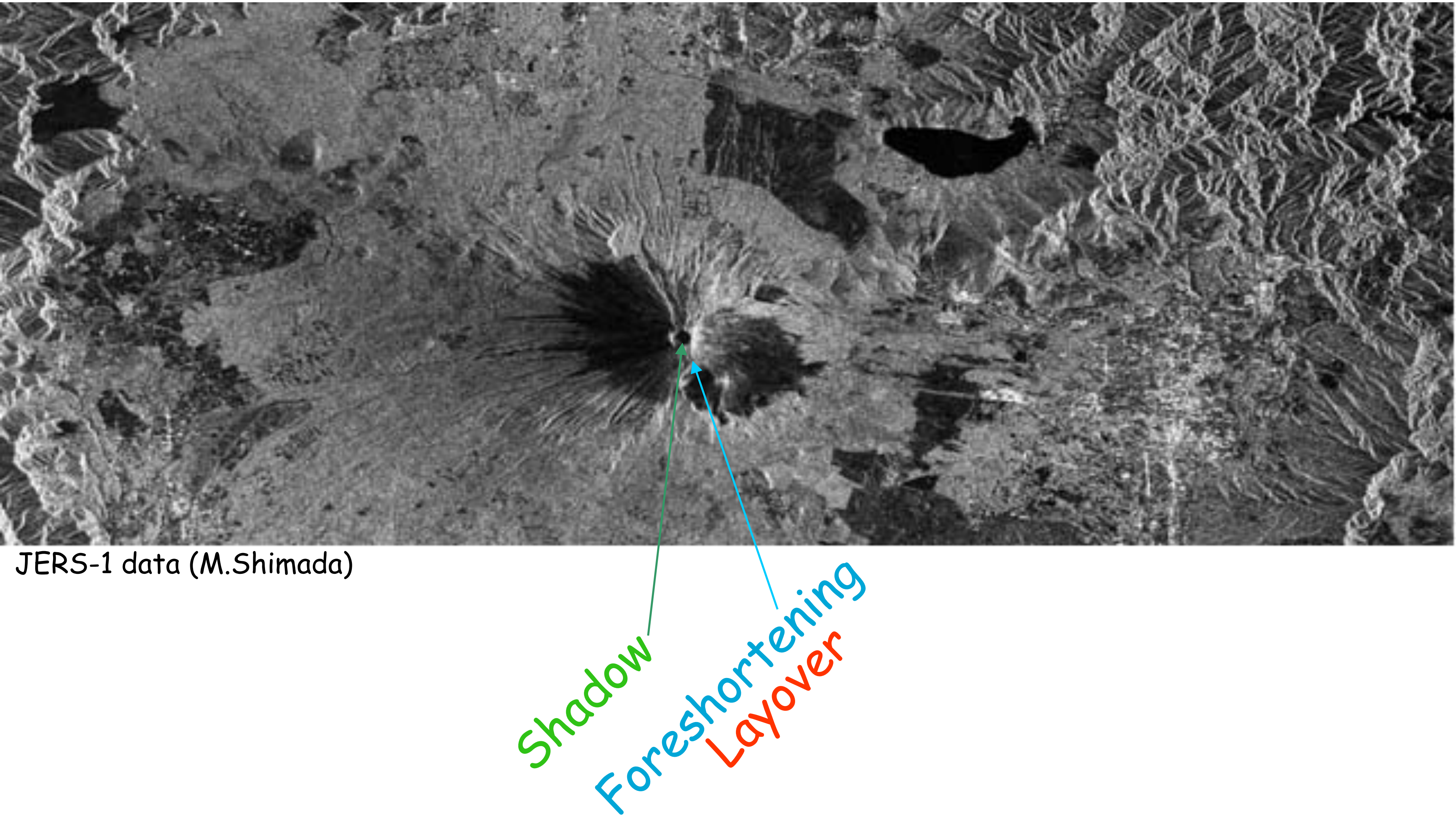


Filtered

Geometry

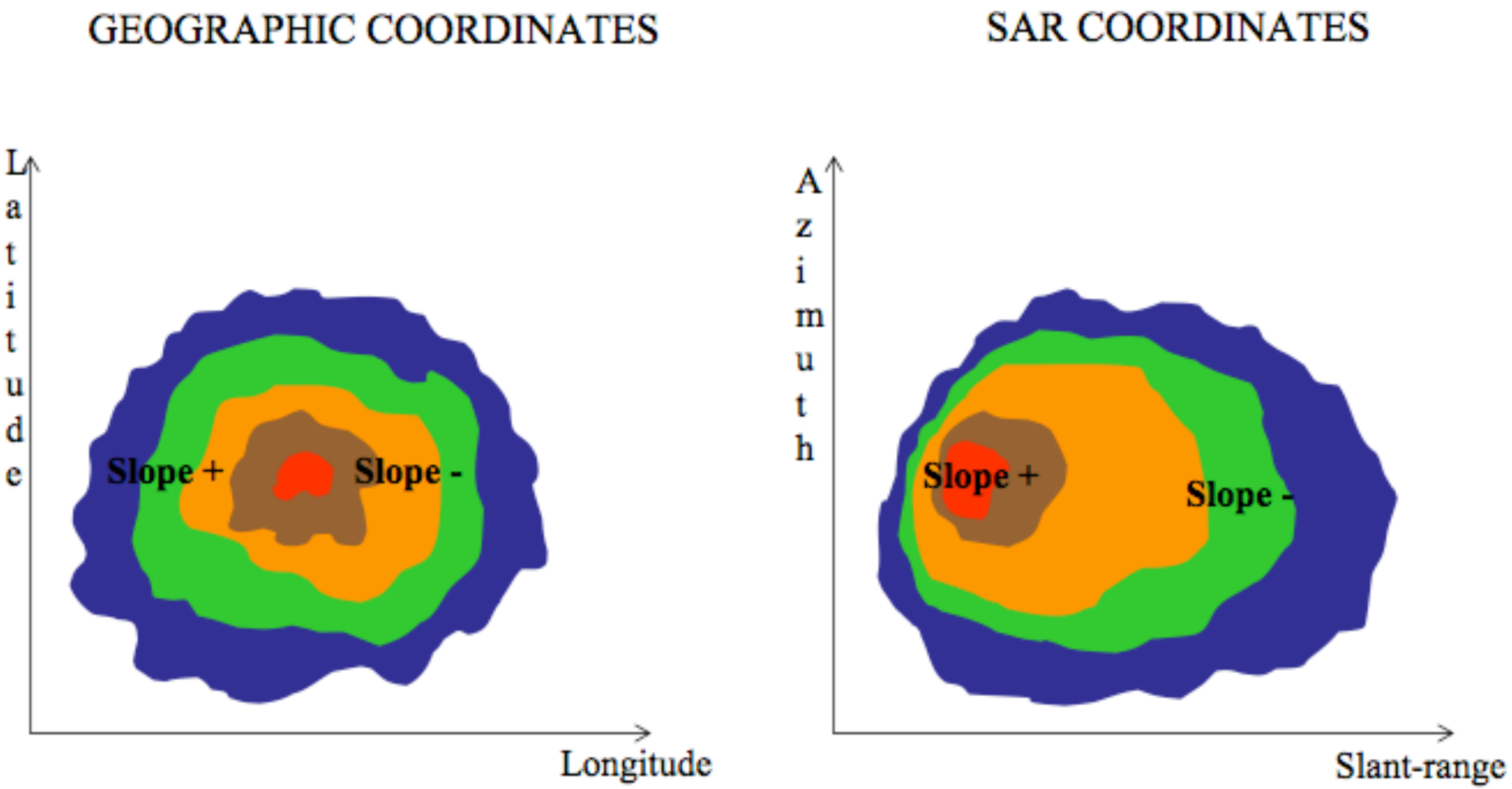


Slant range
Layover
Foreshortening
Shadow
A'
B'
C'
D'
wavefront
θ
A
B
D
Ground range

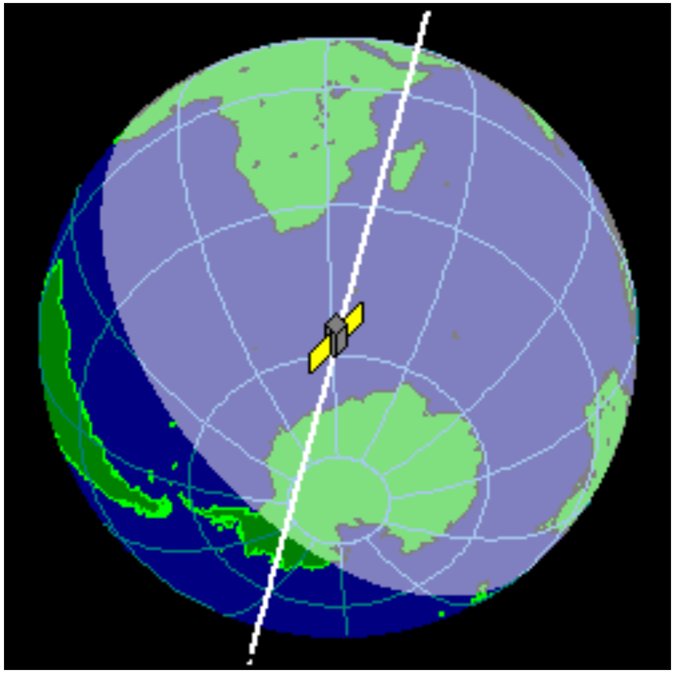


JERS-1 data (M.Shimada)

SAR Coordinates



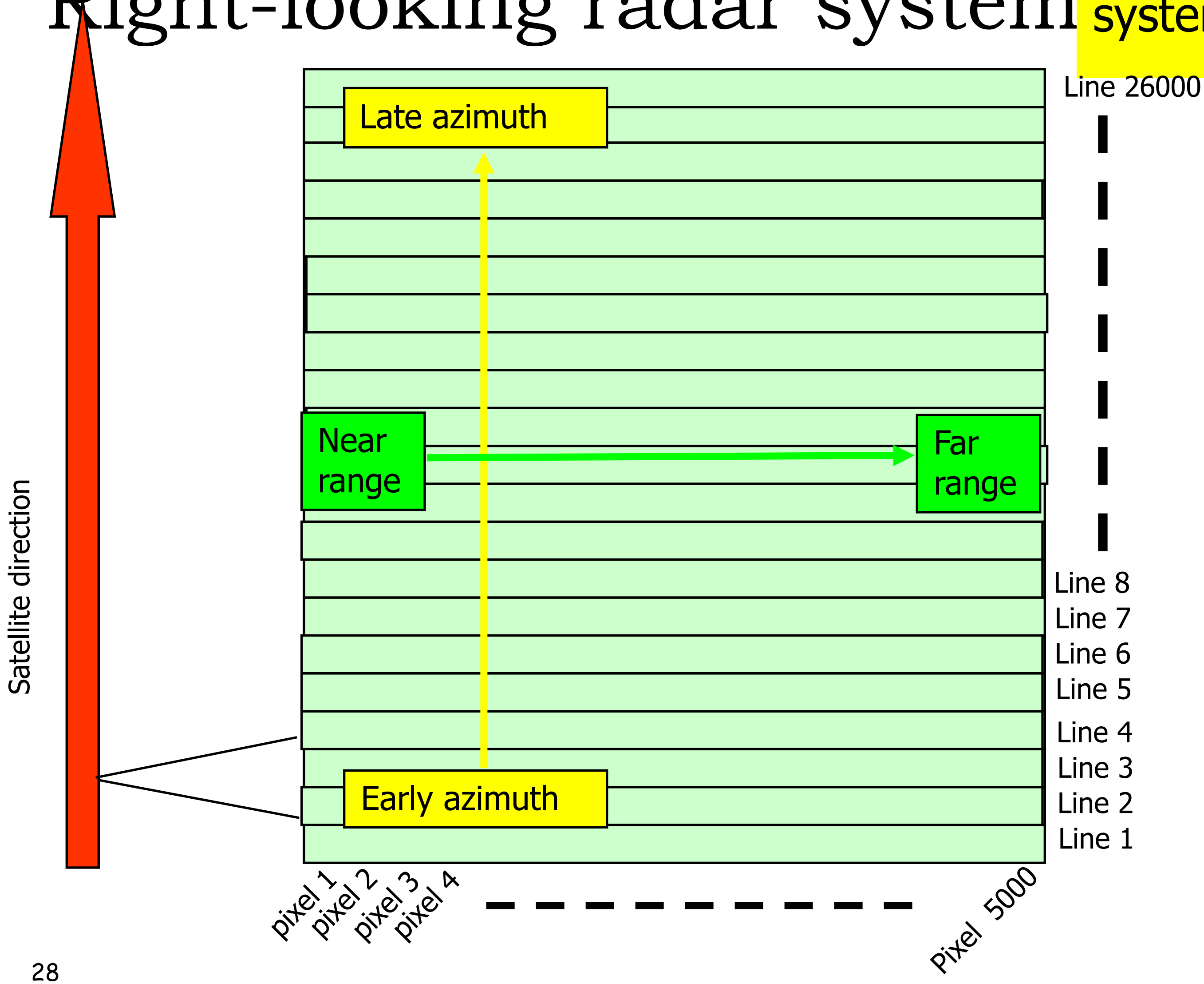
Orbit



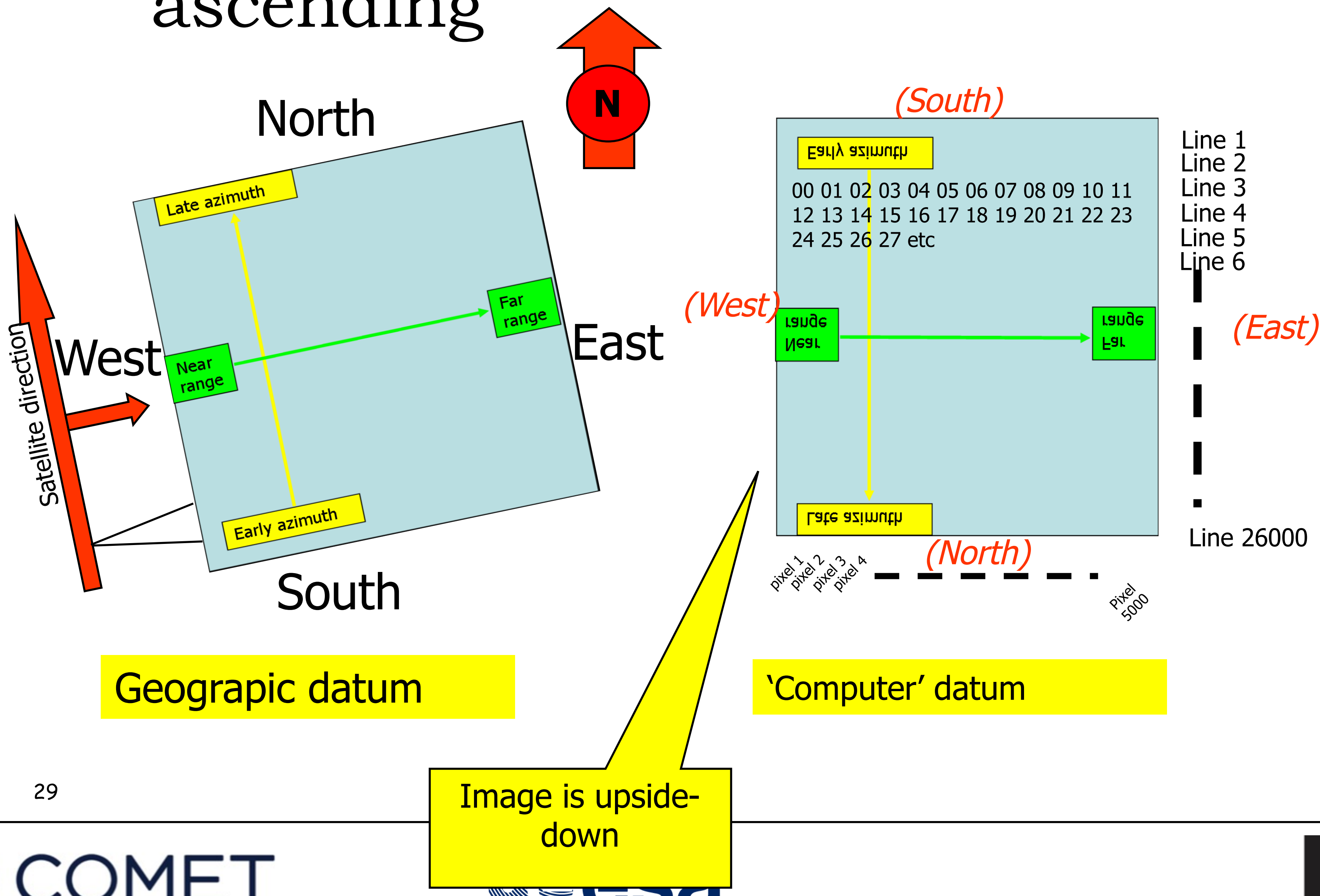
- All SAR satellites fly in a near-polar orbit
- Acquisitions when flying south to north called "Ascending"
- Acquisitions when flying north to south called "Descending"

Right-looking radar system

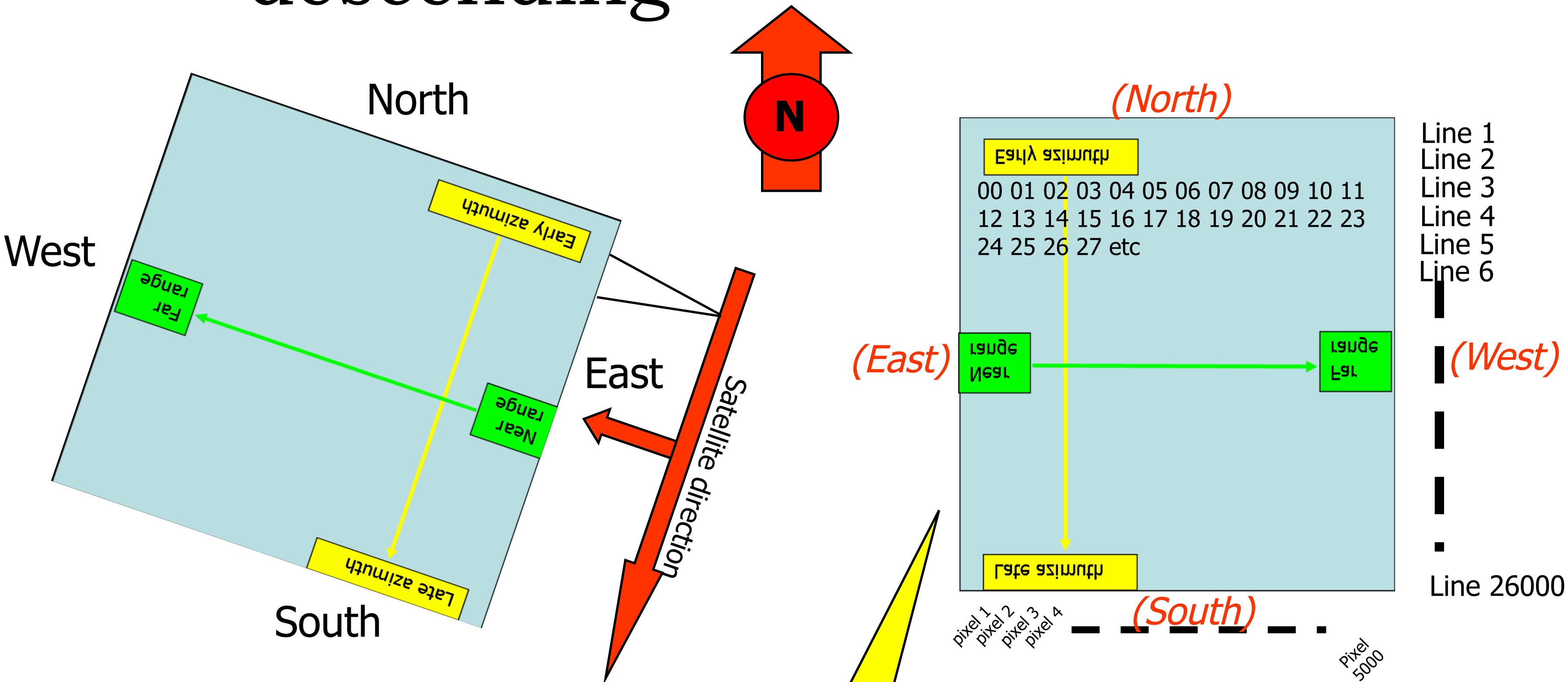
Internal datum: Radar coordinate system



Geographic datum: ascending



Geographic datum: descending



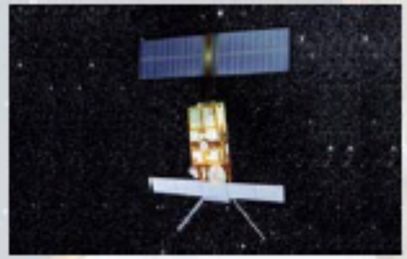
Geograpic datum

'Computer' datum

Image is flipped left-right

Spaceborne SAR Systems (1)

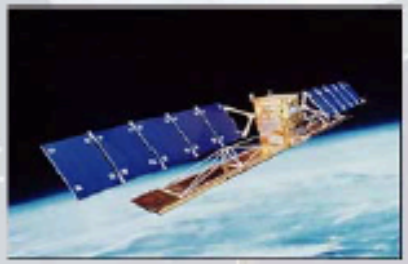
SEASAT
NASA/JPL (USA)
L-Band, 1978



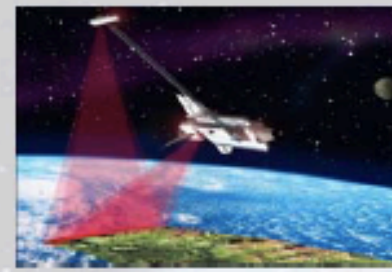
ERS-1/2
European Space Agency (ESA)
C-Band, 1991-2000/1995-2011

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

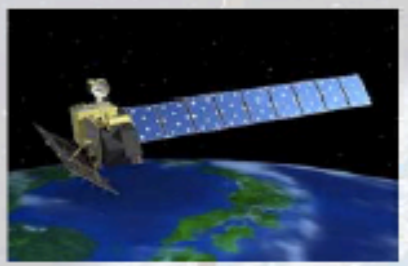


RadarSAT-1
Canadian Space Agency (CSA)
C-Band, 1995-2013



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

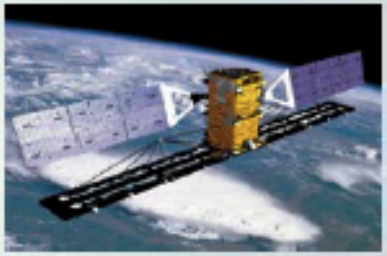
ENVISAT / ASAR
European Space Agency (ESA)
C-Band (dual), 2002-2012



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

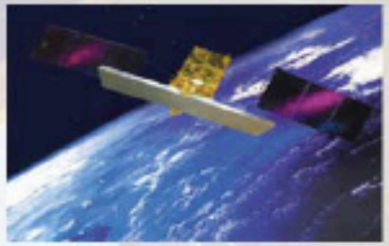
SAR-Lupe
BWB, Germany
5 satellites, X-Band, 2006/2008

Spaceborne SAR Systems (2)



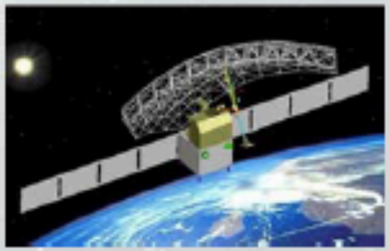
RadarSAT-II
Canadian Space Agency (CSA)
C-Band (quad), 2007

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

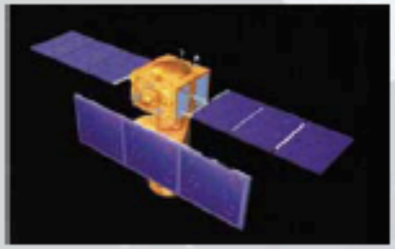


COSMO-SkyMed
ASI, Italy
4 Satellites, X-Band (dual), 2007/2010

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

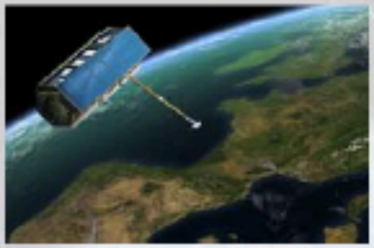


HJ-1C -SAR
CRESDA/CAST/NRSCC, China
S-Band (HH or VV), 2013



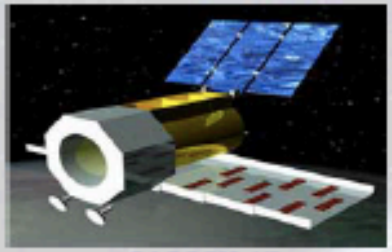
RISAT-1
Indian Space Agency (ISRO), India
C-Band (quad), 2012

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



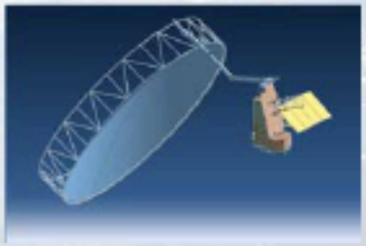
PAZ
Ministry of Defence, Spain
X-Band (quad), 2014

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



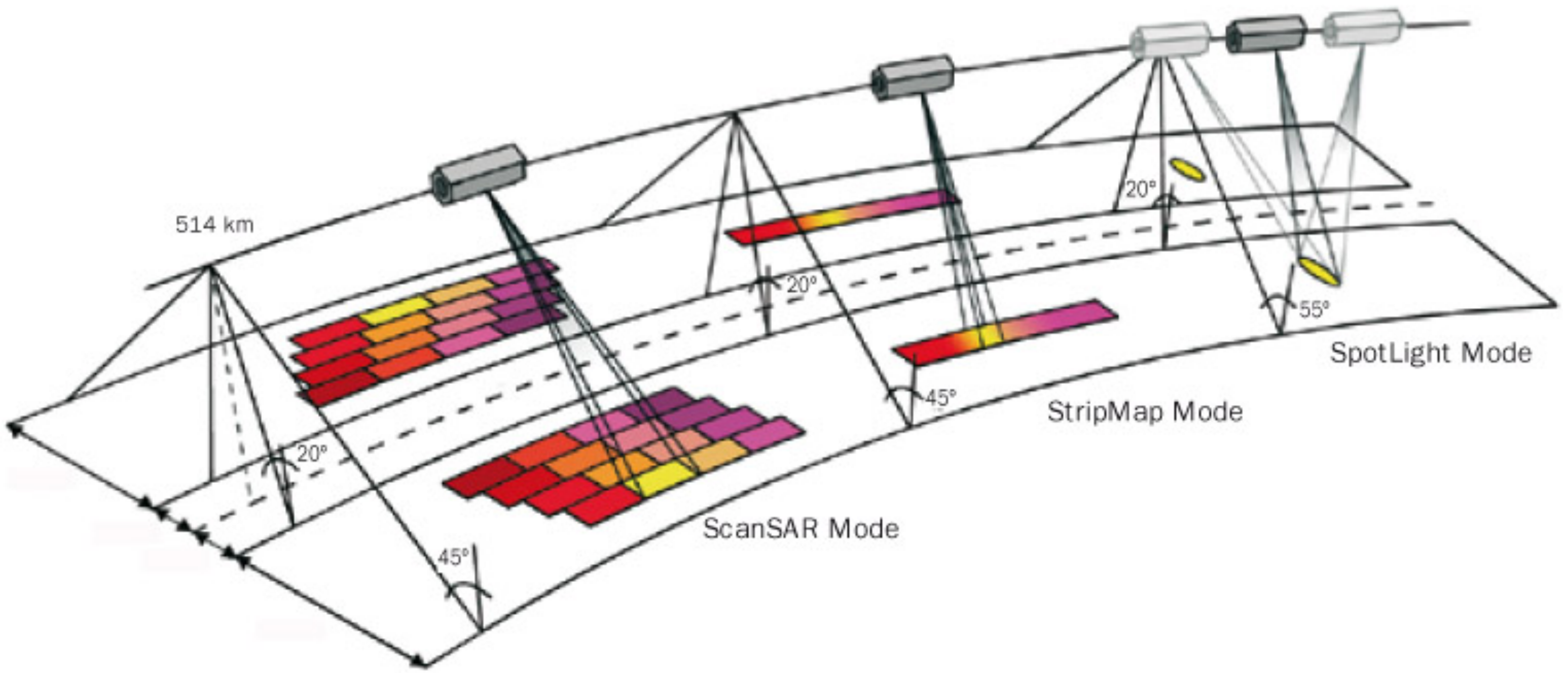
SAOCOM-1/2
CONAE/ASI, Argentina
L-Band (quad), 2016/2018

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



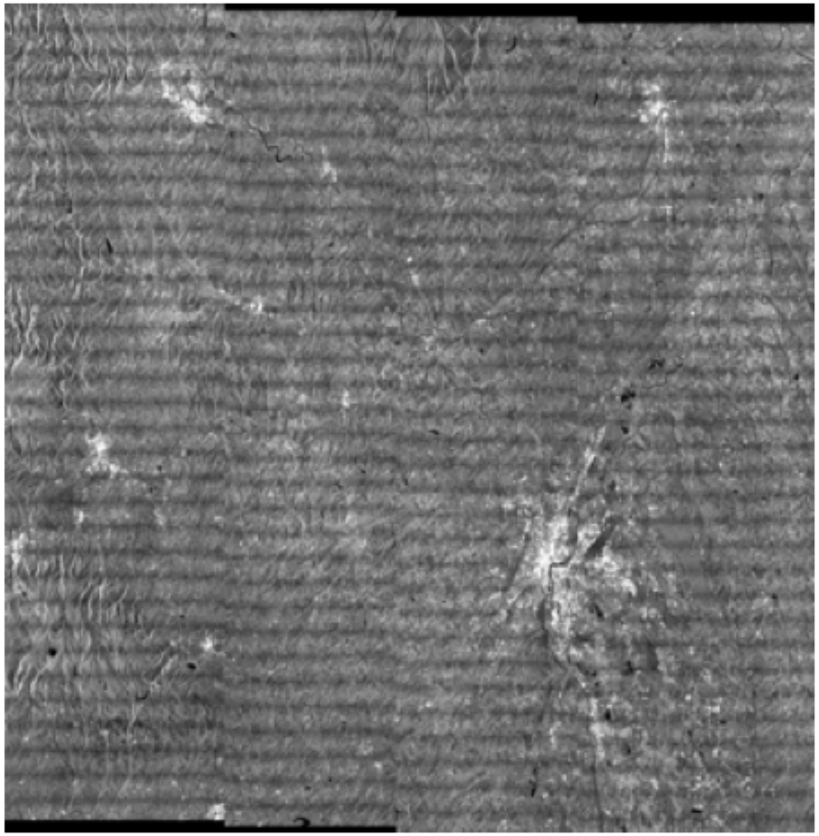
BIOMASS
ESA, Europe
P-Band (quad), 2019

Main acquisition modes



Traditional ScanSAR

TSX-ScanSAR image



- Synthetic aperture is smaller, reducing resolution
- Number of illuminations for points on groud varies causing "scalloping"

Sentinel-1 Wideswath mode: TOPS

(Terrain Observation with Progressive Scans)

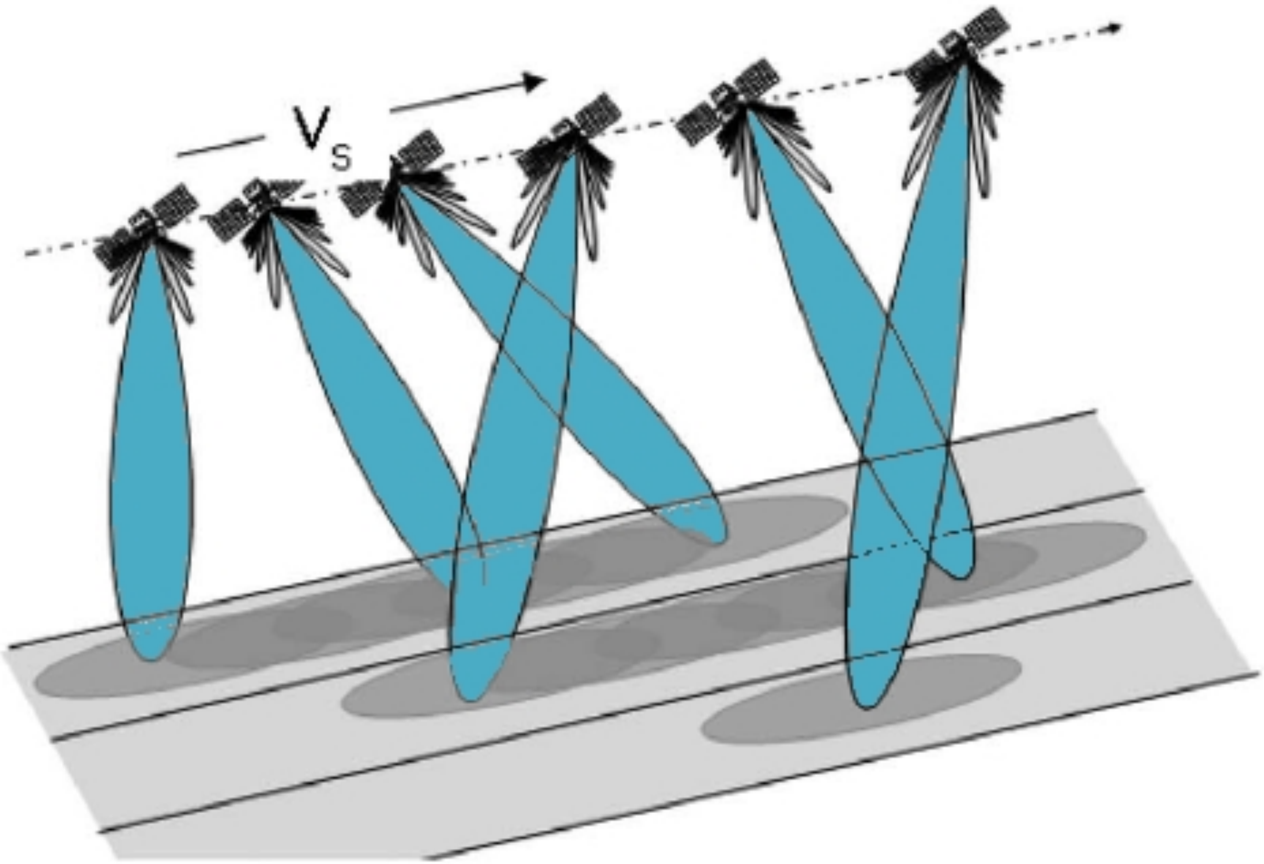
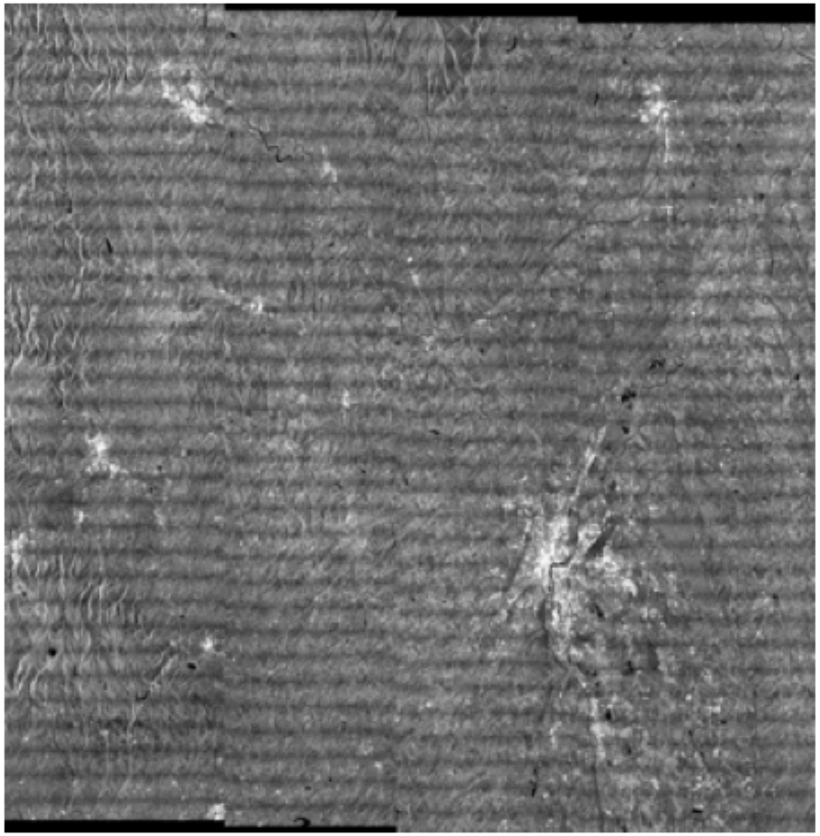


Image: ESA

Why TOPS?

TSX-ScanSAR image



TSX-TOPS image