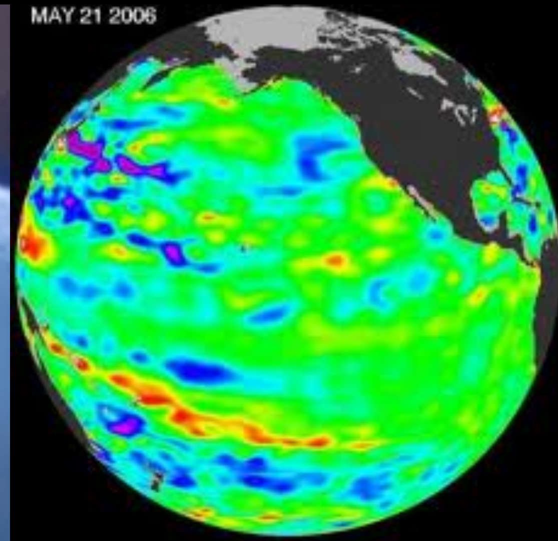

Microwave remote sensing

Xi Yang
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University of Virginia
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EVSC 4010/7010 Week 10

Bands of MW remote sensing

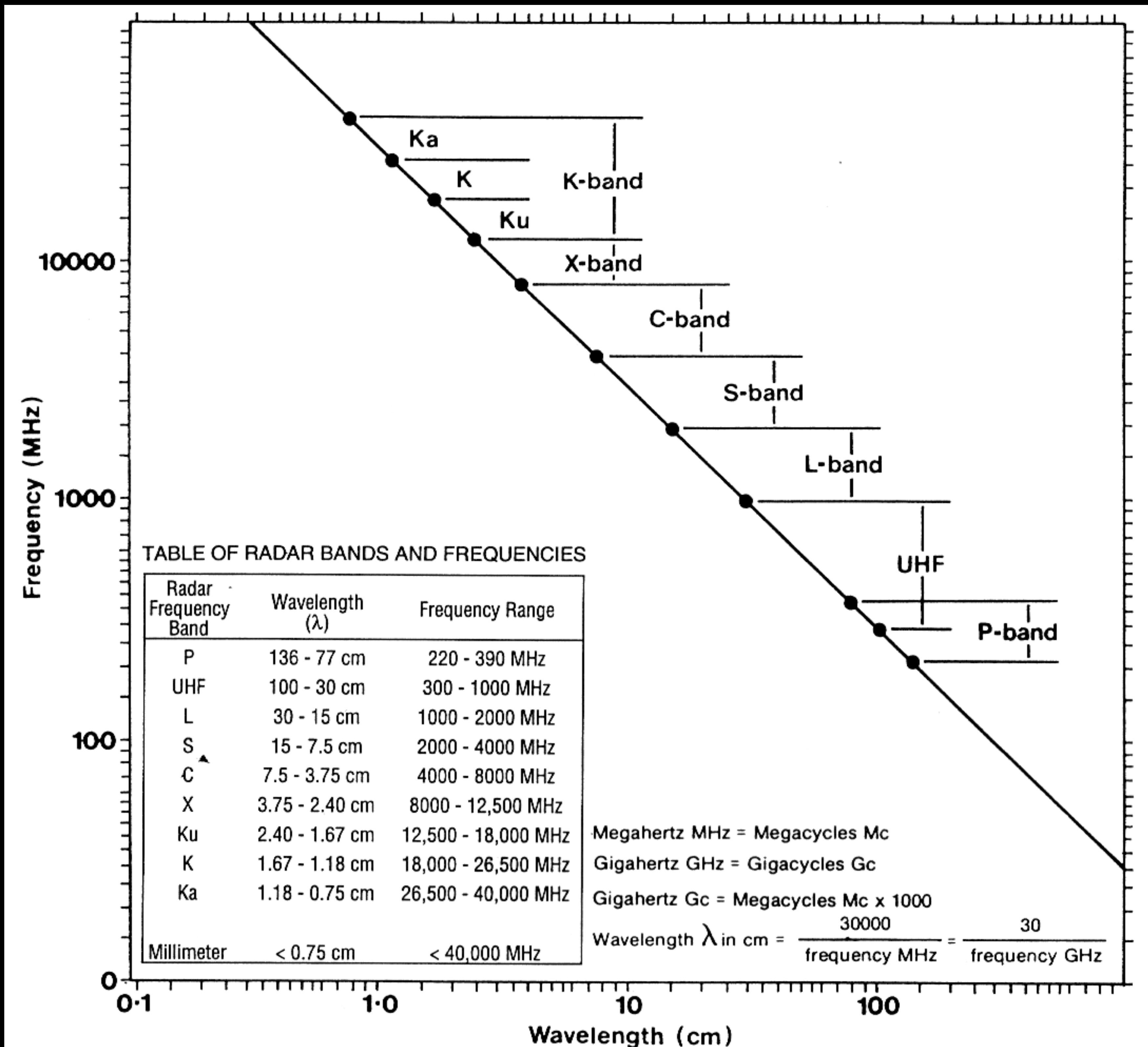


TABLE OF RADAR BANDS AND FREQUENCIES

Radar Frequency Band	Wavelength (λ)	Frequency Range
P	136 - 77 cm	220 - 390 MHz
UHF	100 - 30 cm	300 - 1000 MHz
L	30 - 15 cm	1000 - 2000 MHz
S	15 - 7.5 cm	2000 - 4000 MHz
C	7.5 - 3.75 cm	4000 - 8000 MHz
X	3.75 - 2.40 cm	8000 - 12,500 MHz
Ku	2.40 - 1.67 cm	12,500 - 18,000 MHz
K	1.67 - 1.18 cm	18,000 - 26,500 MHz
Ka	1.18 - 0.75 cm	26,500 - 40,000 MHz
Millimeter	< 0.75 cm	< 40,000 MHz

Ku band: 1.67-2.40 cm

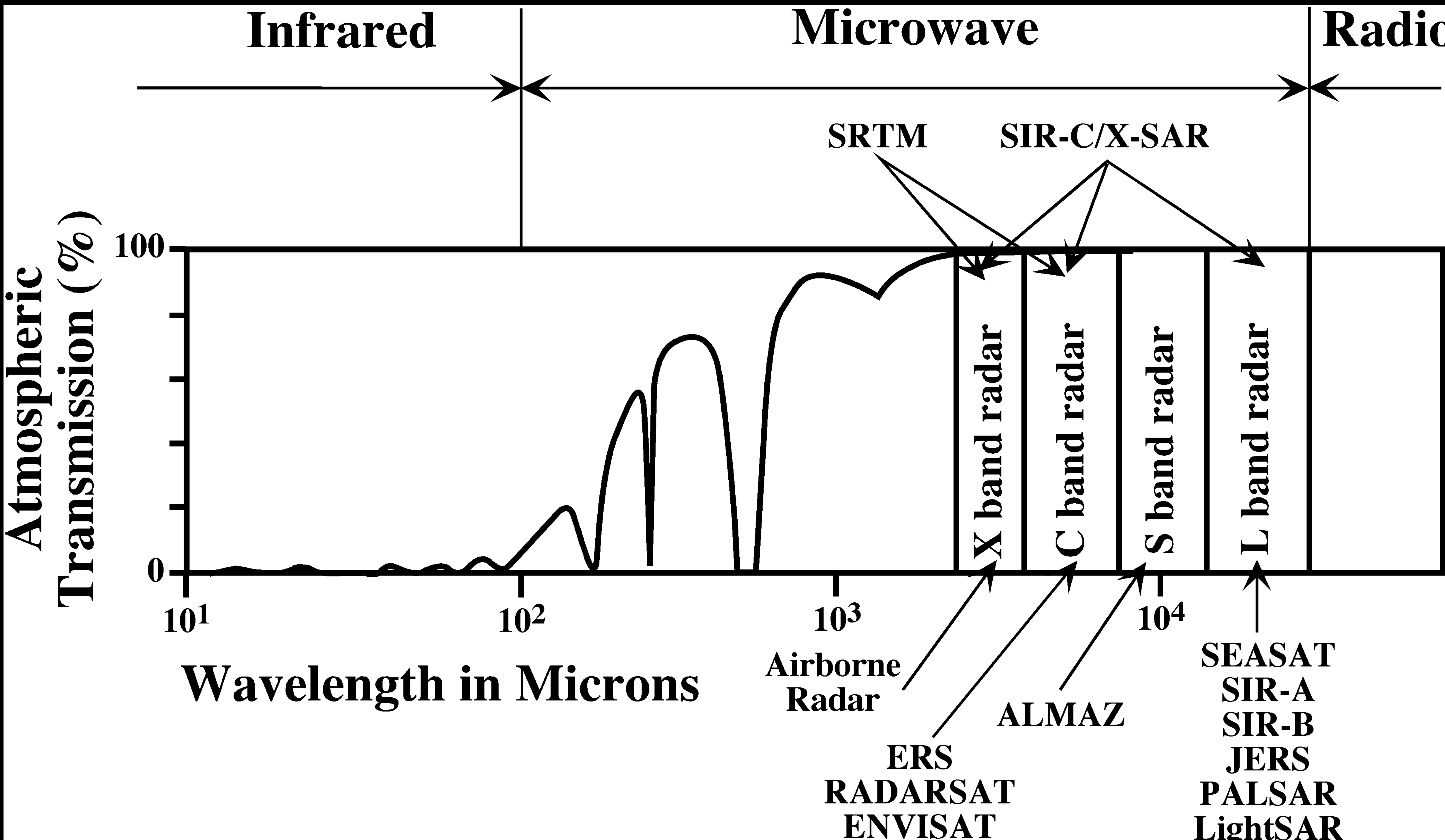
X band: 2.40-3.75 cm

C band: 3.75-7.50 cm

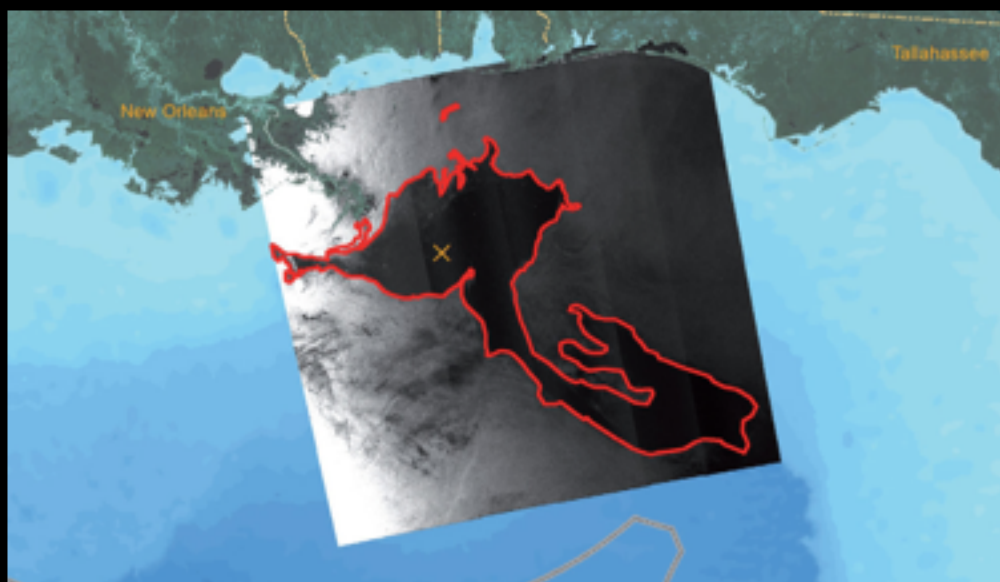
L band: 15.00-30.00 cm

P band: 30.00-100.00 cm

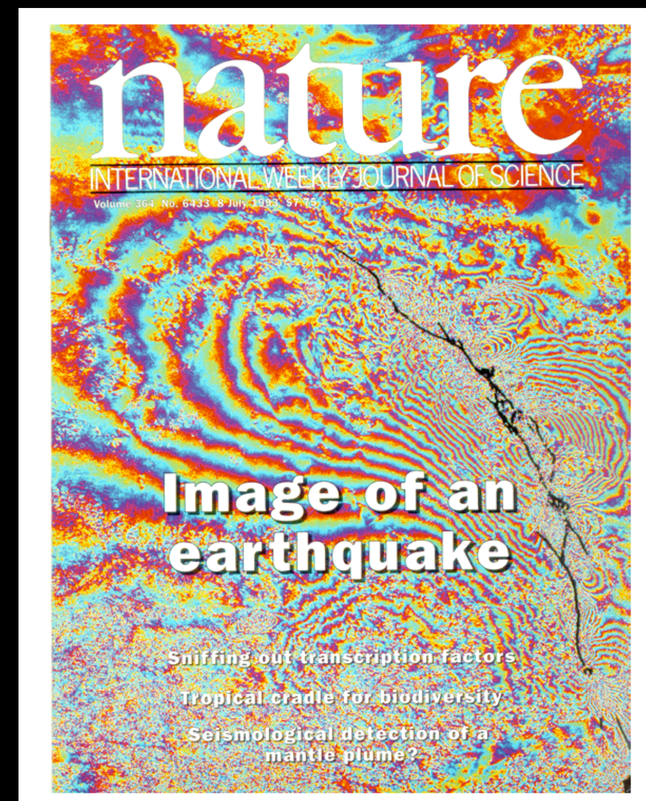
Every day is a good day for remote sensing



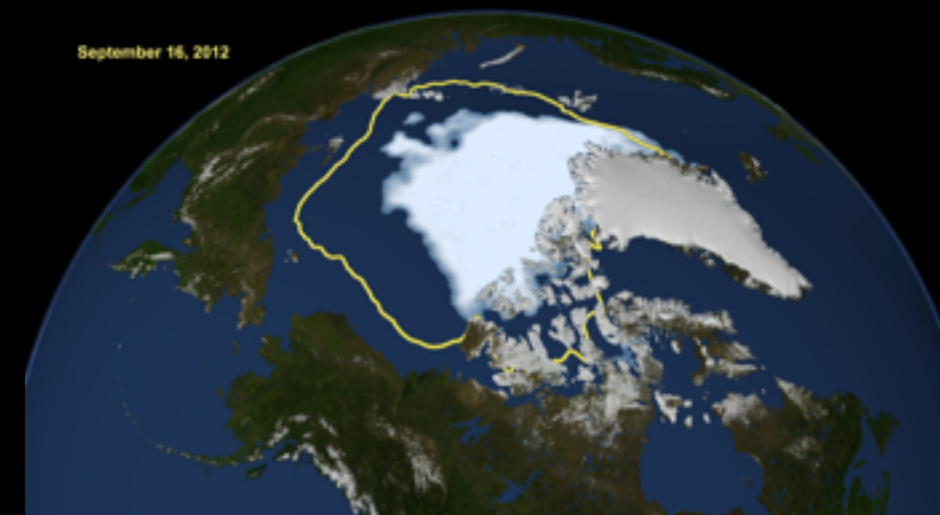
Microwave Remote Sensing Case Studies



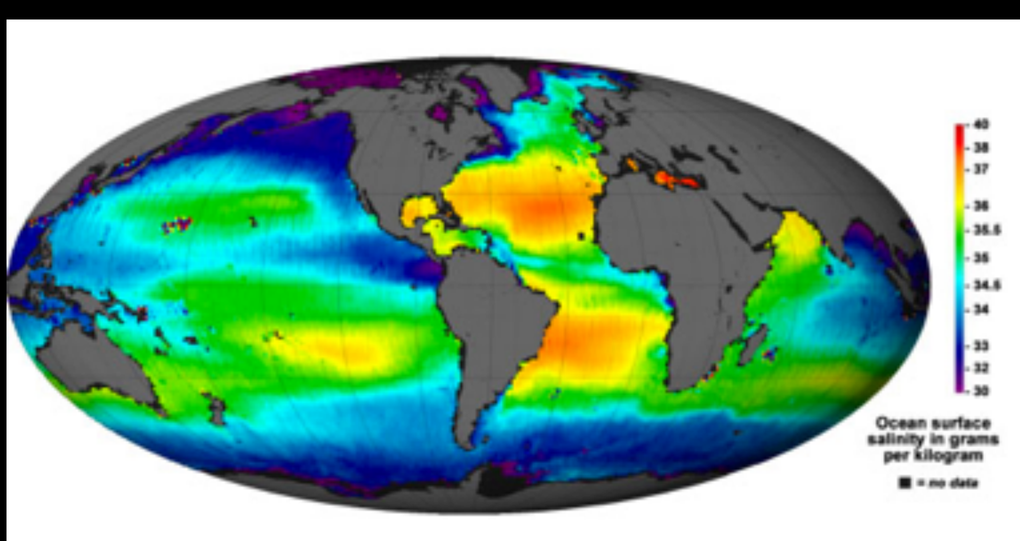
Oil spill



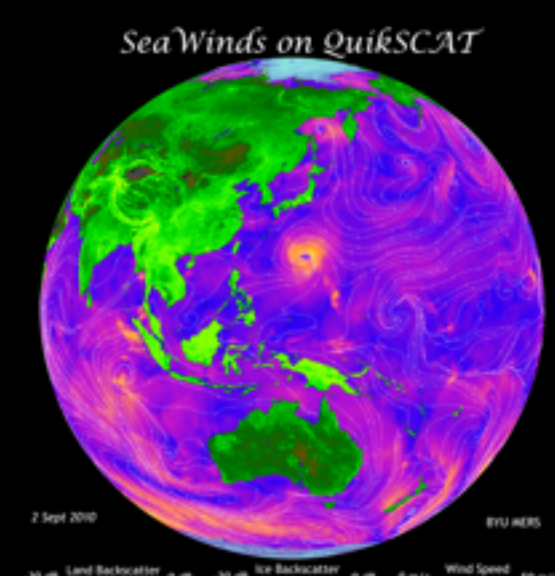
Seismology



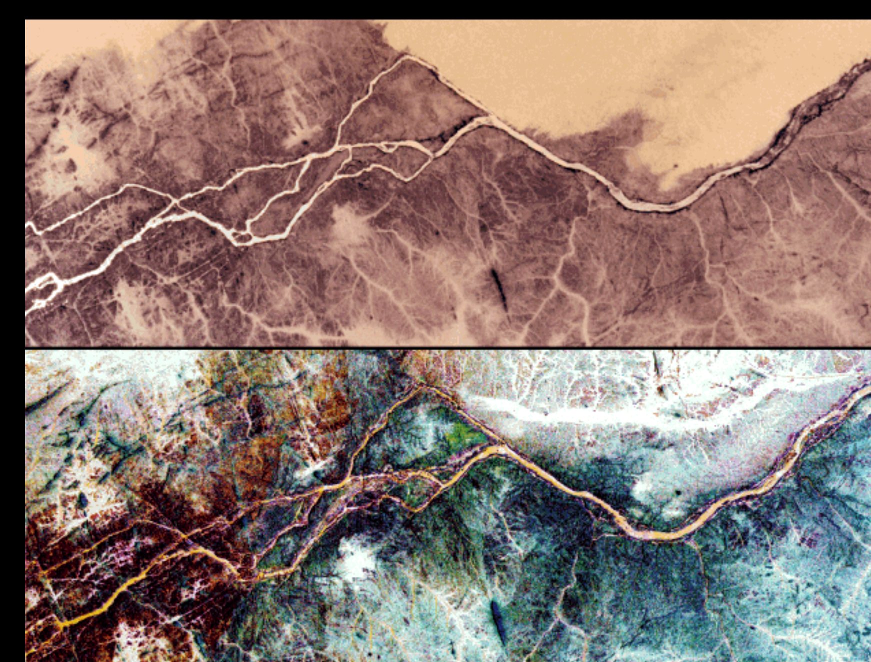
Hydrology



Ocean salinity

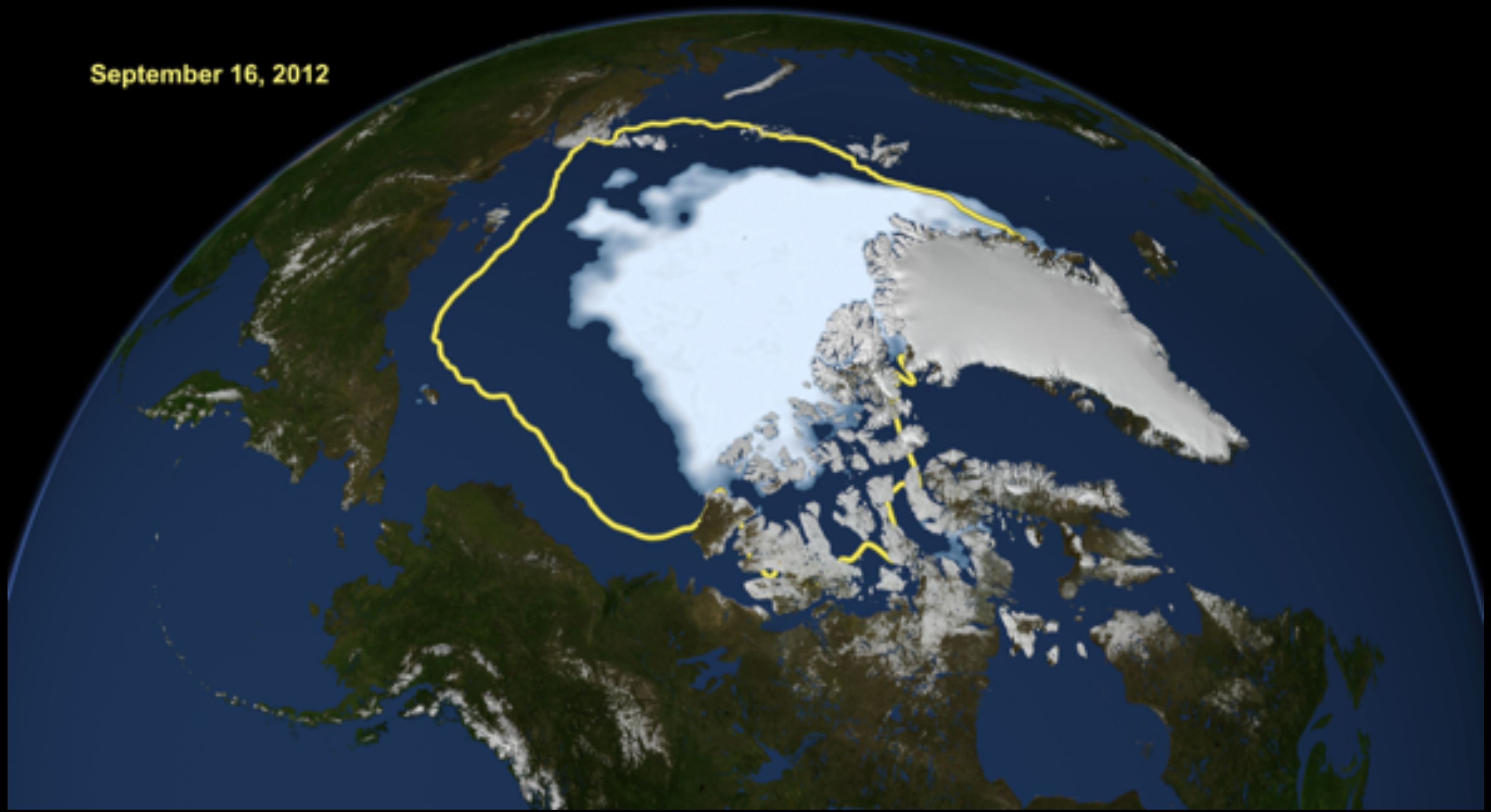


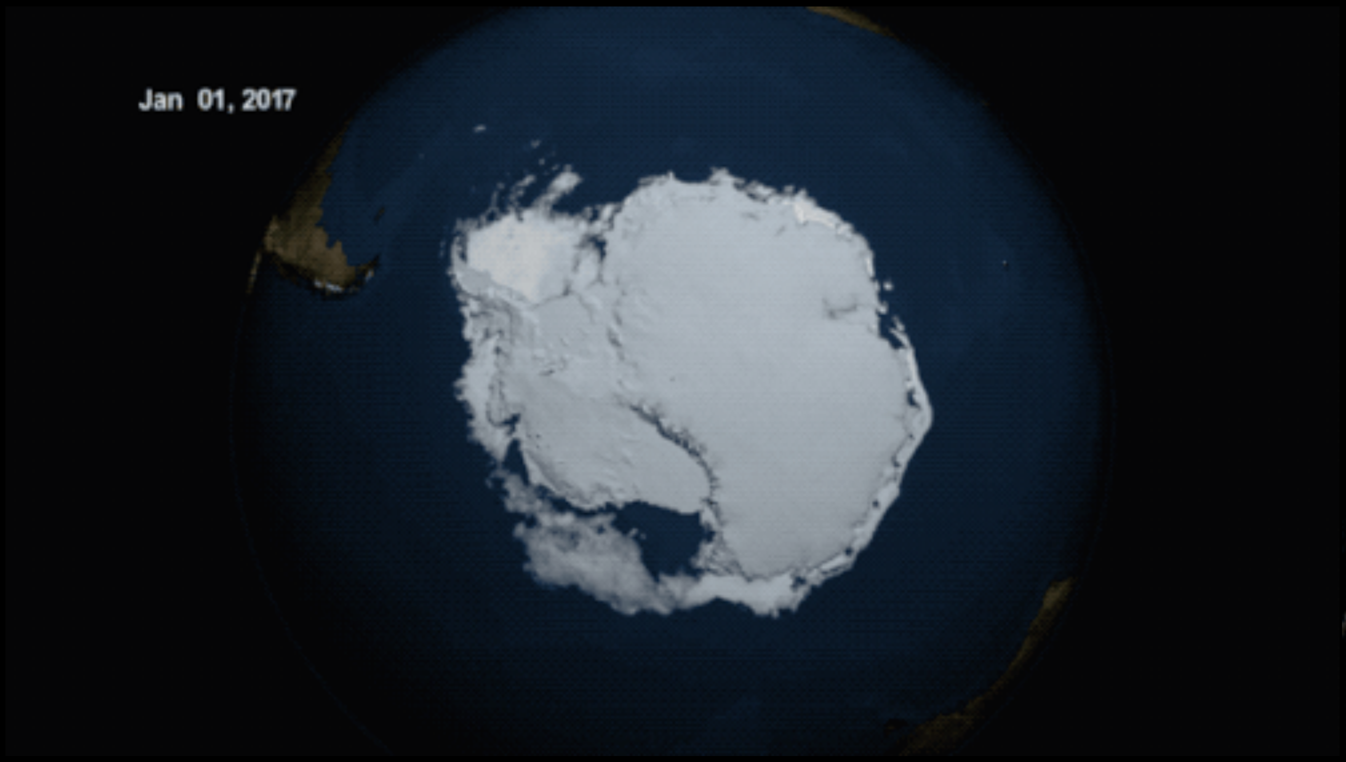
Sea winds

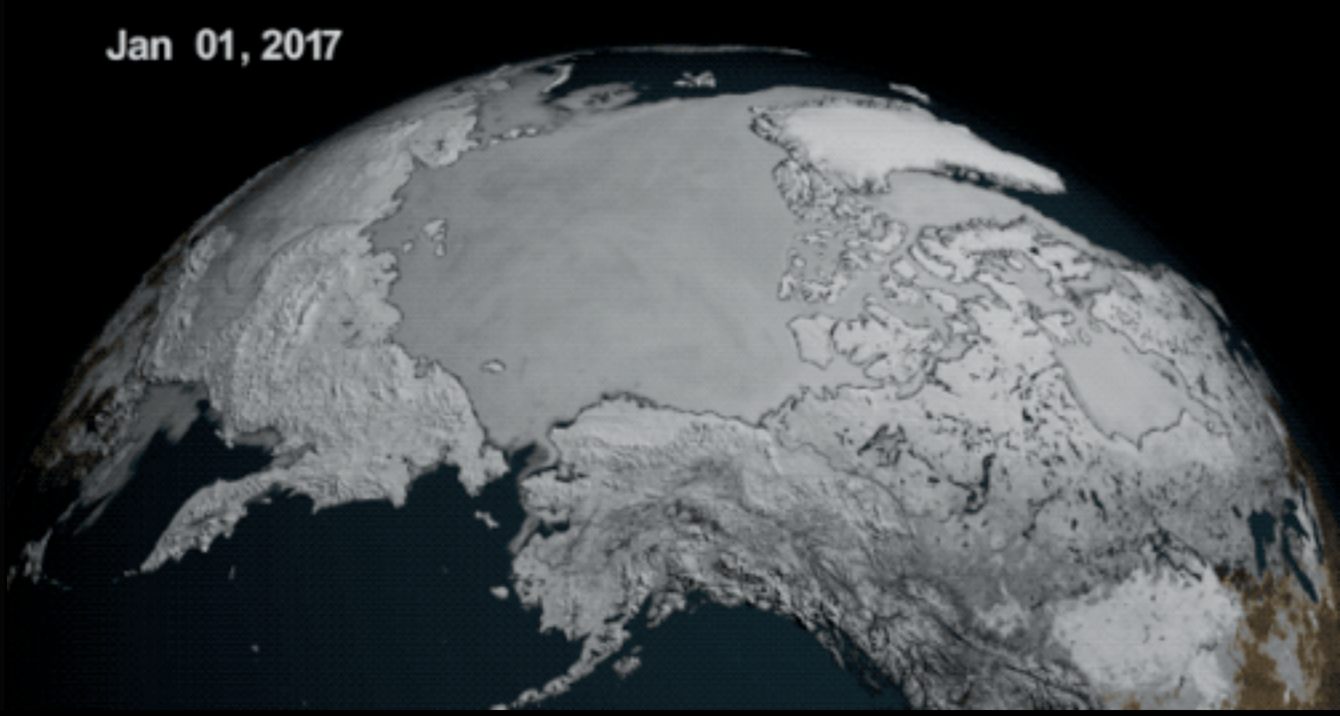


Archeology

Case I: Microwave Remote Sensing for Hydrology





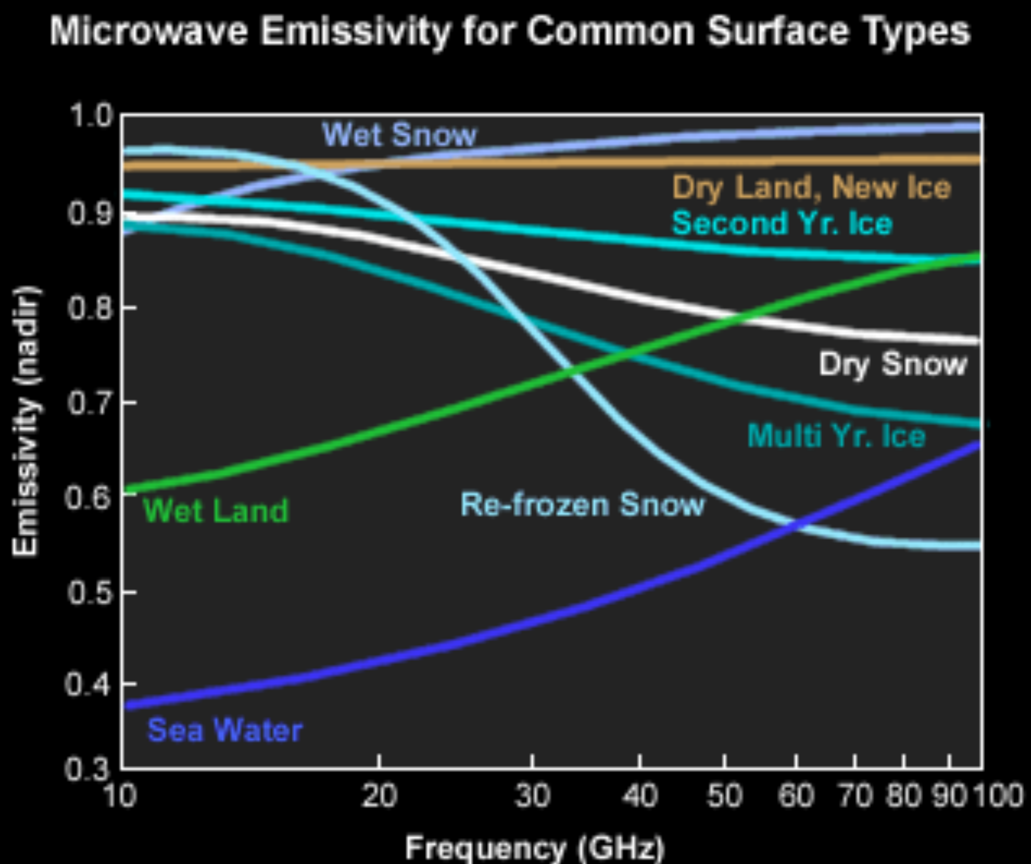


Planck's law in the microwave region

Rayleigh-Jeans Approximation

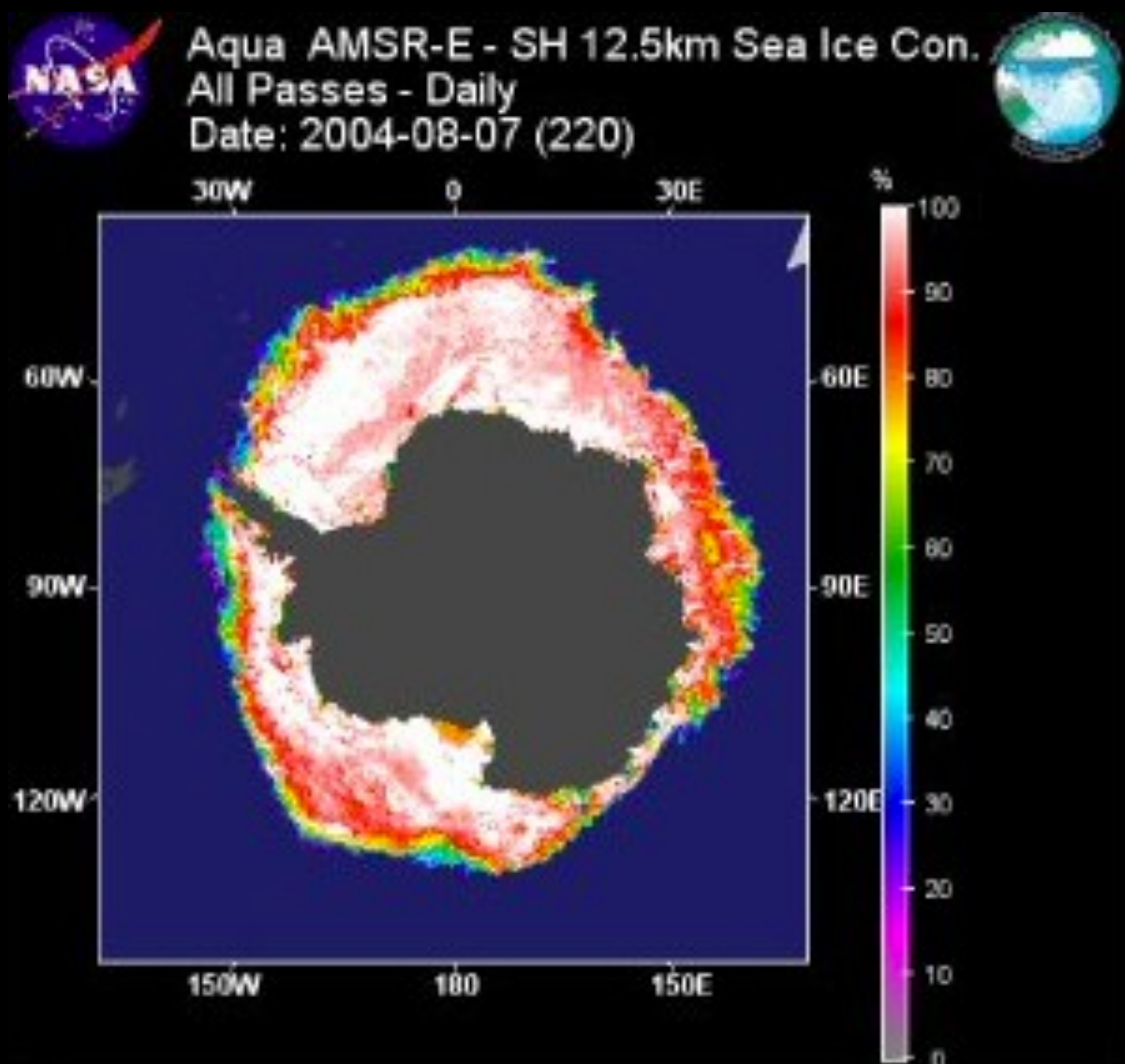
$$M_{\lambda} = \varepsilon \frac{2kcT}{\lambda^4}$$

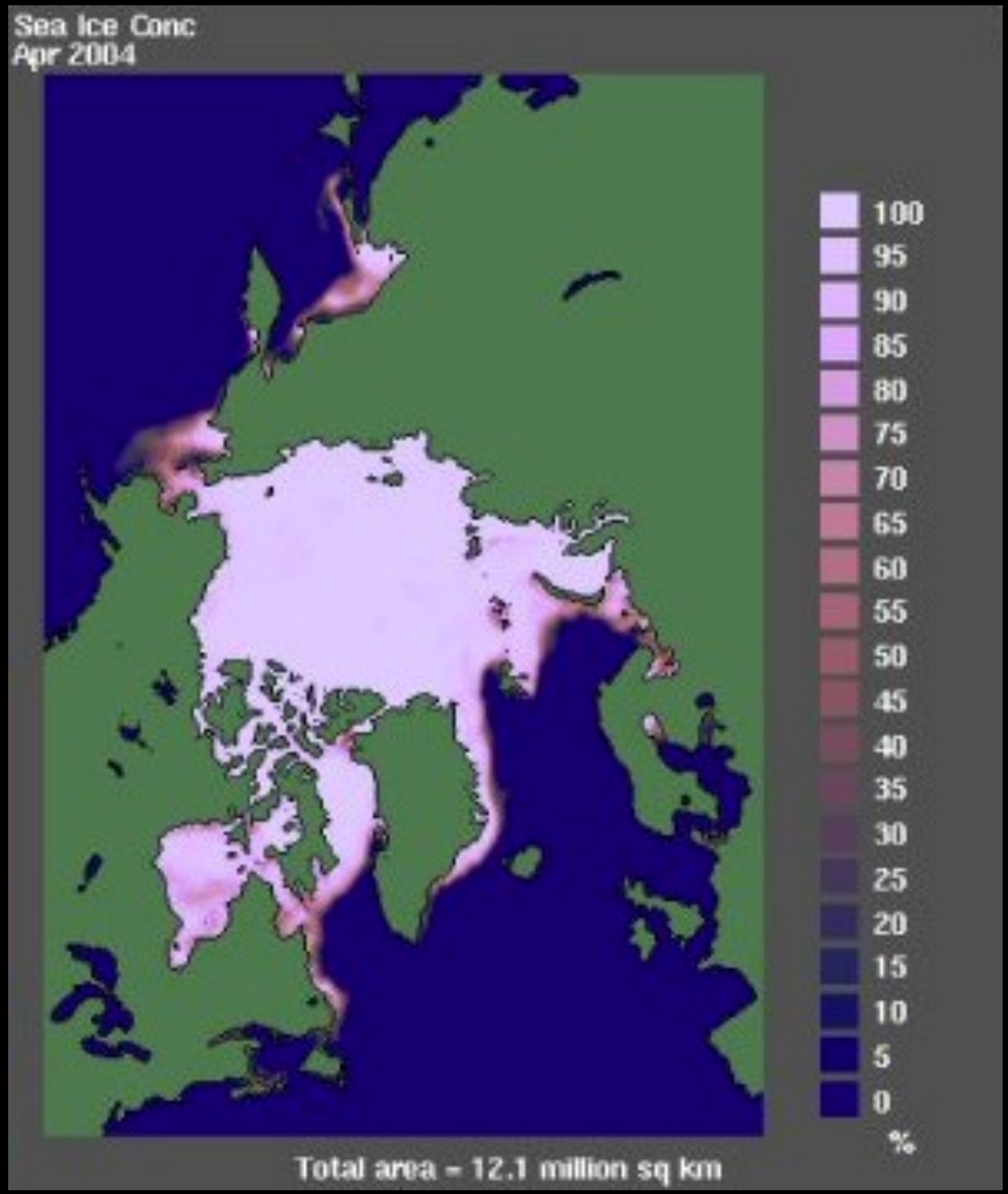
M_{λ}: spectral radiance
ε: emissivity
k: the Boltzmann constant
c: light speed
T: surface temperature
λ: wavelength



Adapted from Dr. Norman C. Grody

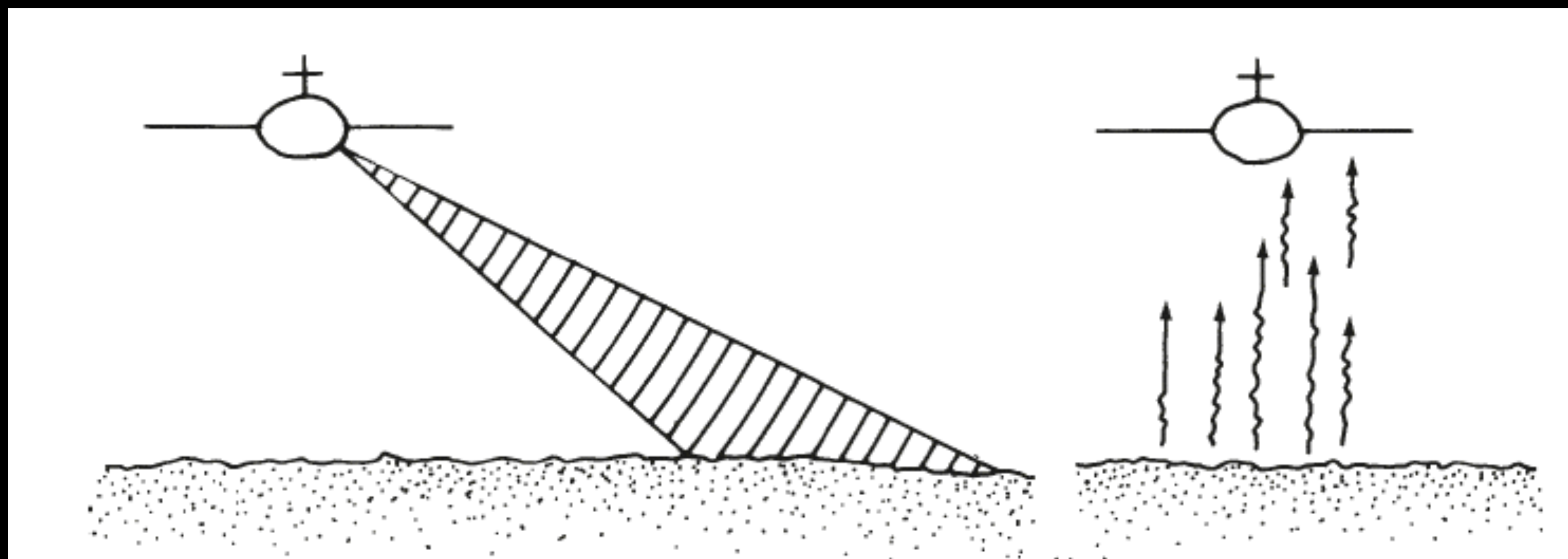
Examples of Passive Microwave RS





DMSP SSI/M

Passive vs. Active

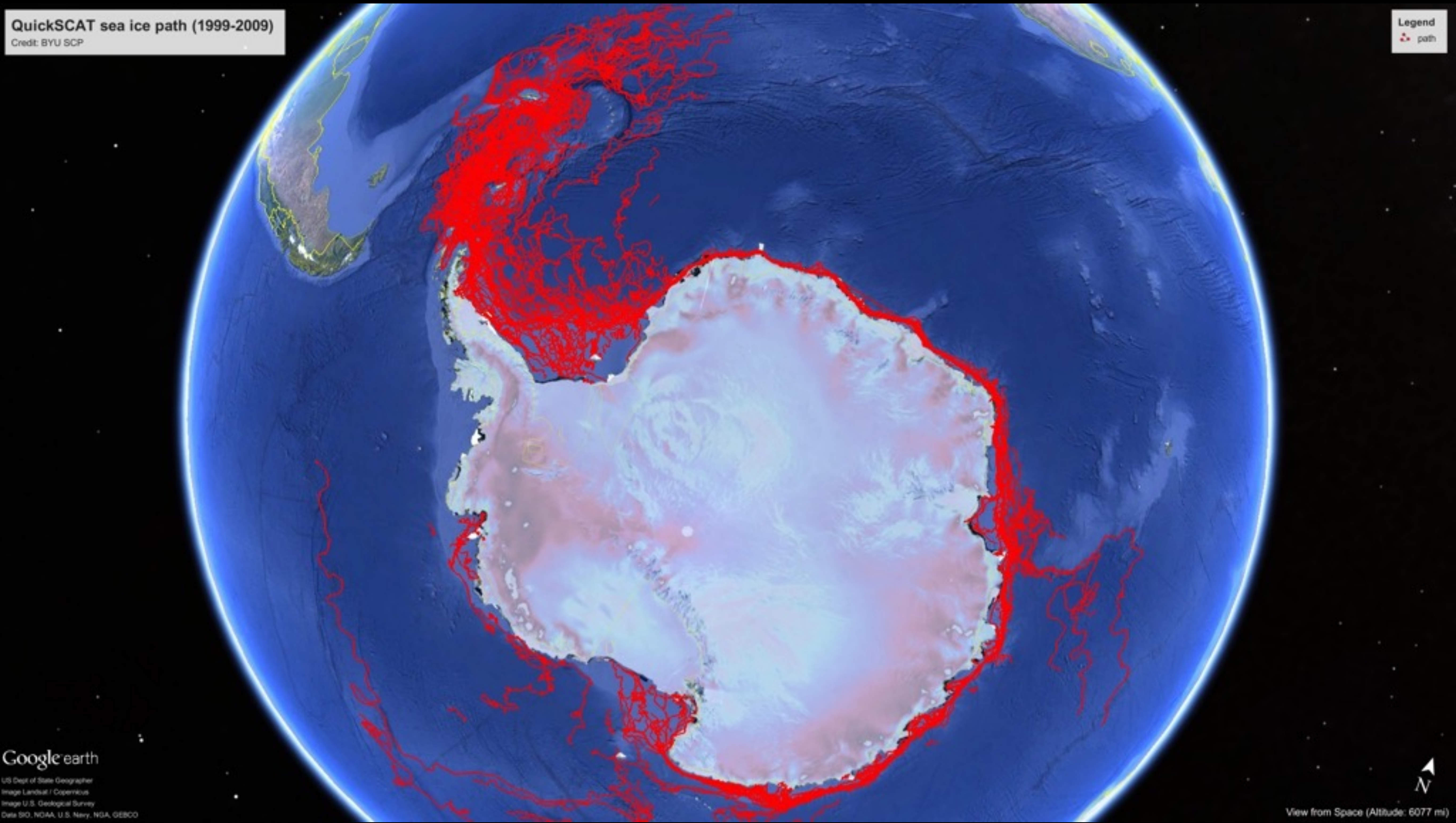


Active

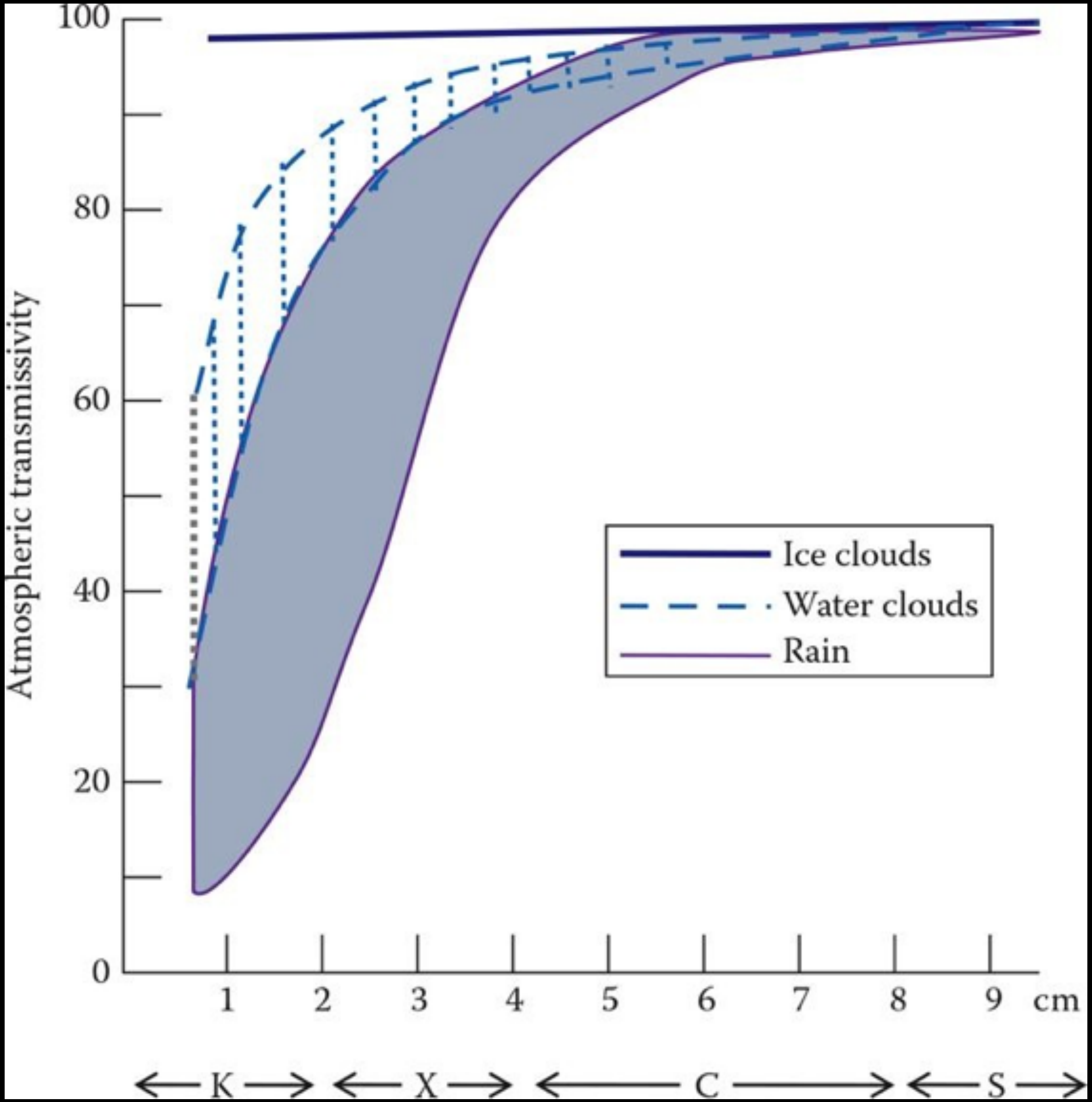
Passive

RADAR: **RA**dio **D**etection **A**nd **R**anging

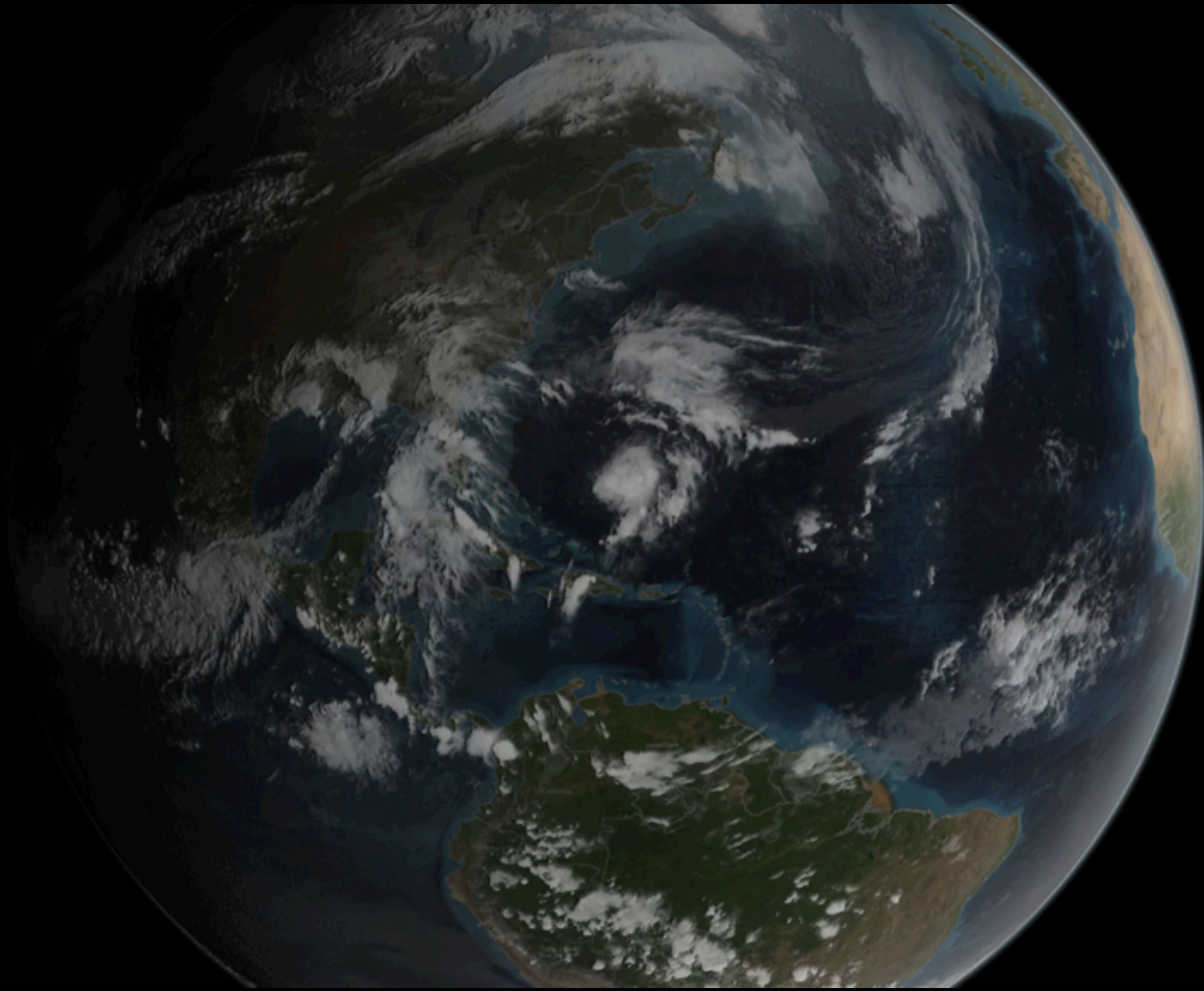
Active Microwave Remote Sensing



Transmission of MW in the atmosphere



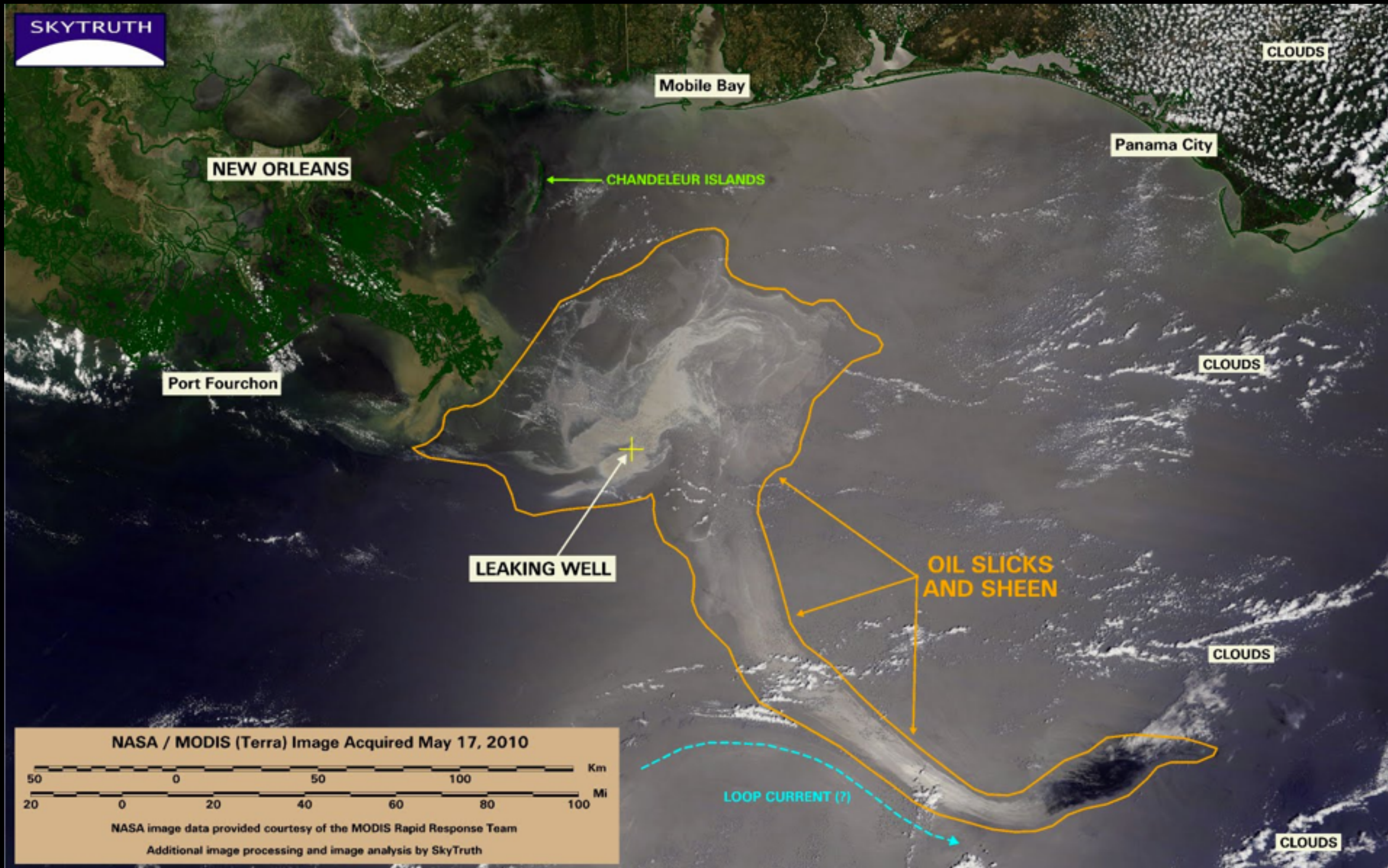
Global Precipitation Measurement (GPM)



Recap

- Passive vs. Active. Resolution
- Passive MW: emissivity. Sea ice >> water.
- Transmittance.

Case II: MWRS for Oil Spill Monitoring



Active Microwave Remote Sensing

What determines the return intensity?

$$P_r = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 D^4}$$

The only important parameter in this equation

P_r: received signal intensity

P_t: power emitted by the radar

σ: backscatter coefficient

D: distance from the sensor to the surface

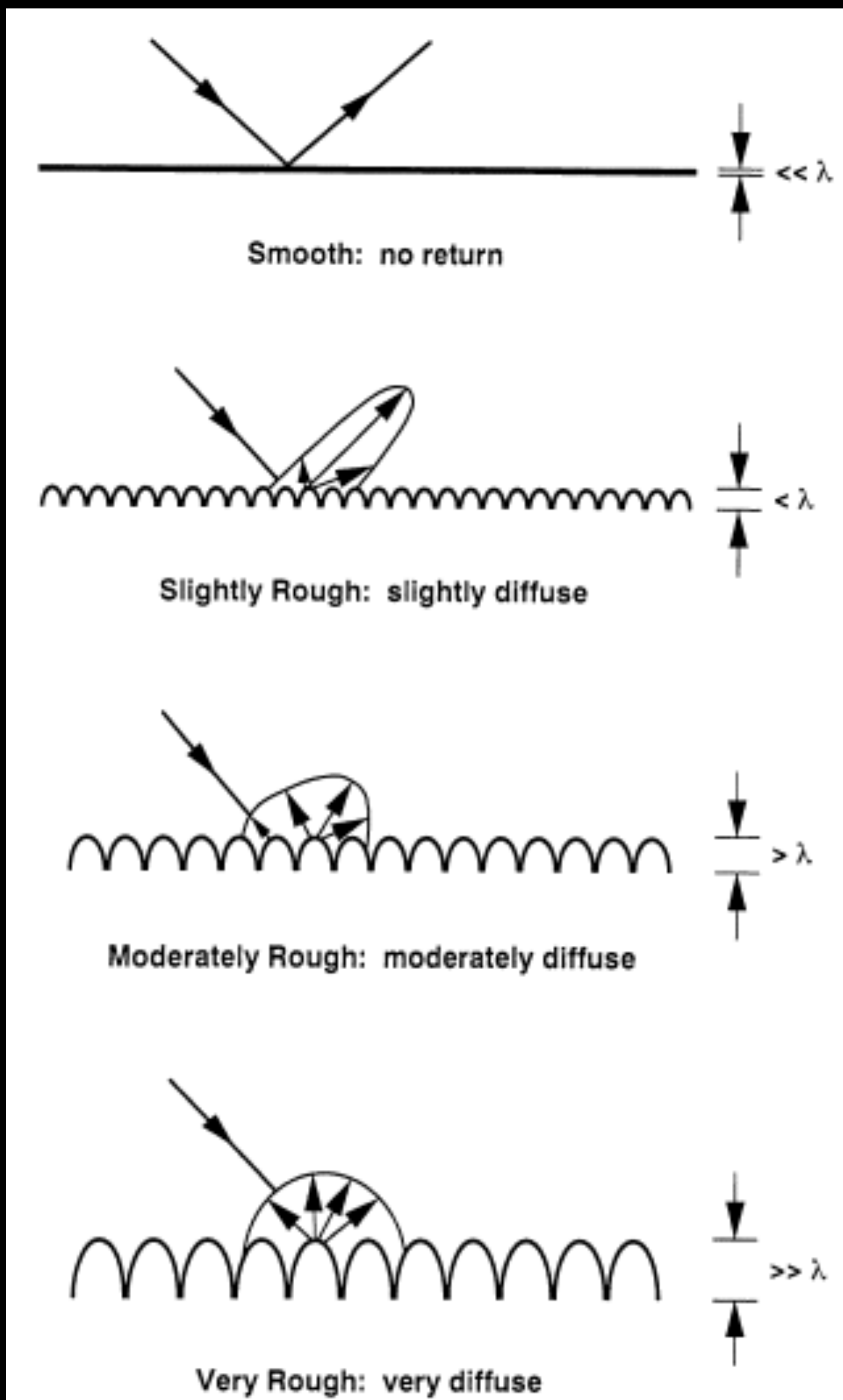
G: Gain factor, a constant

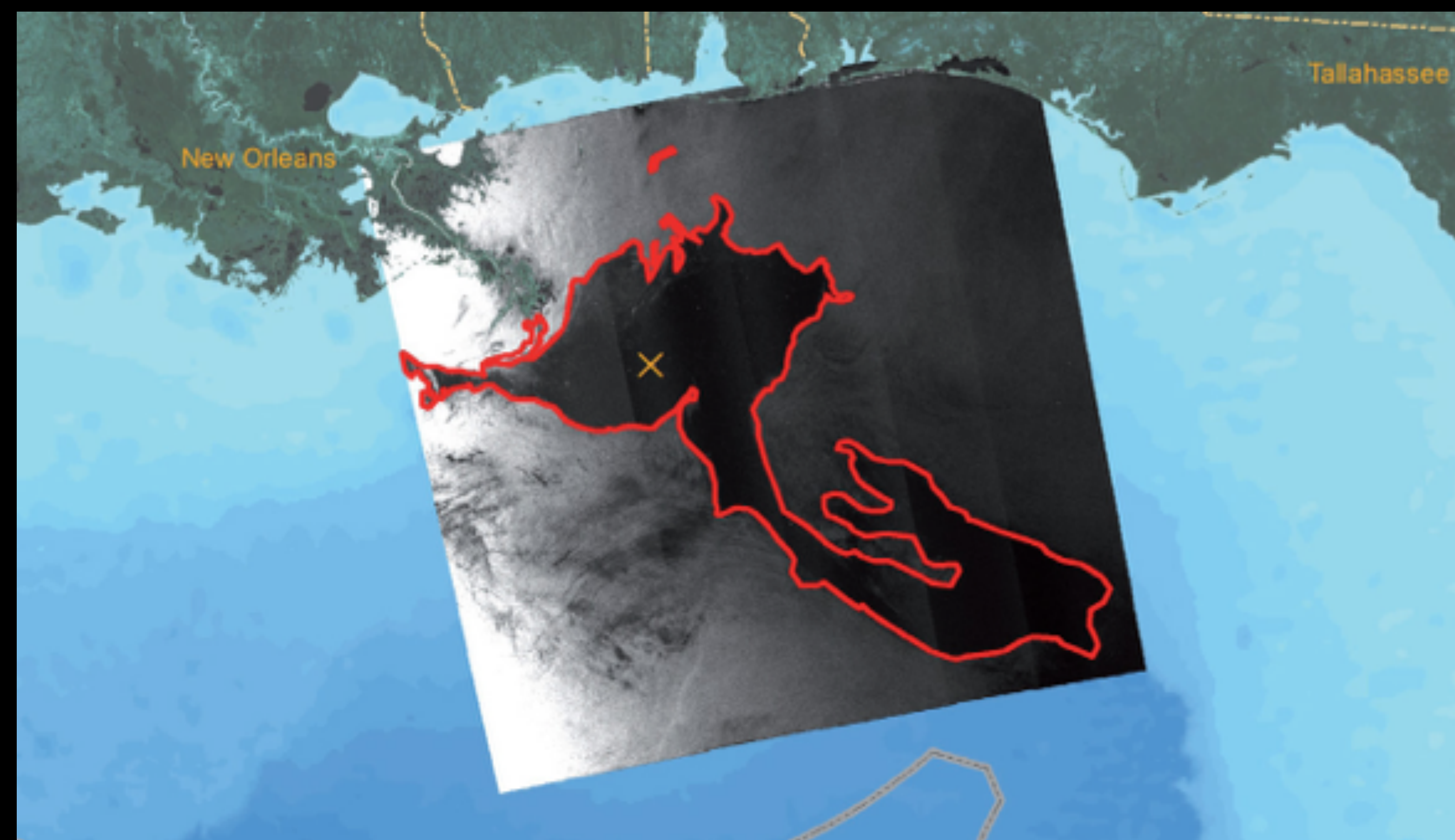
λ: wavelength

Backscatter coefficient

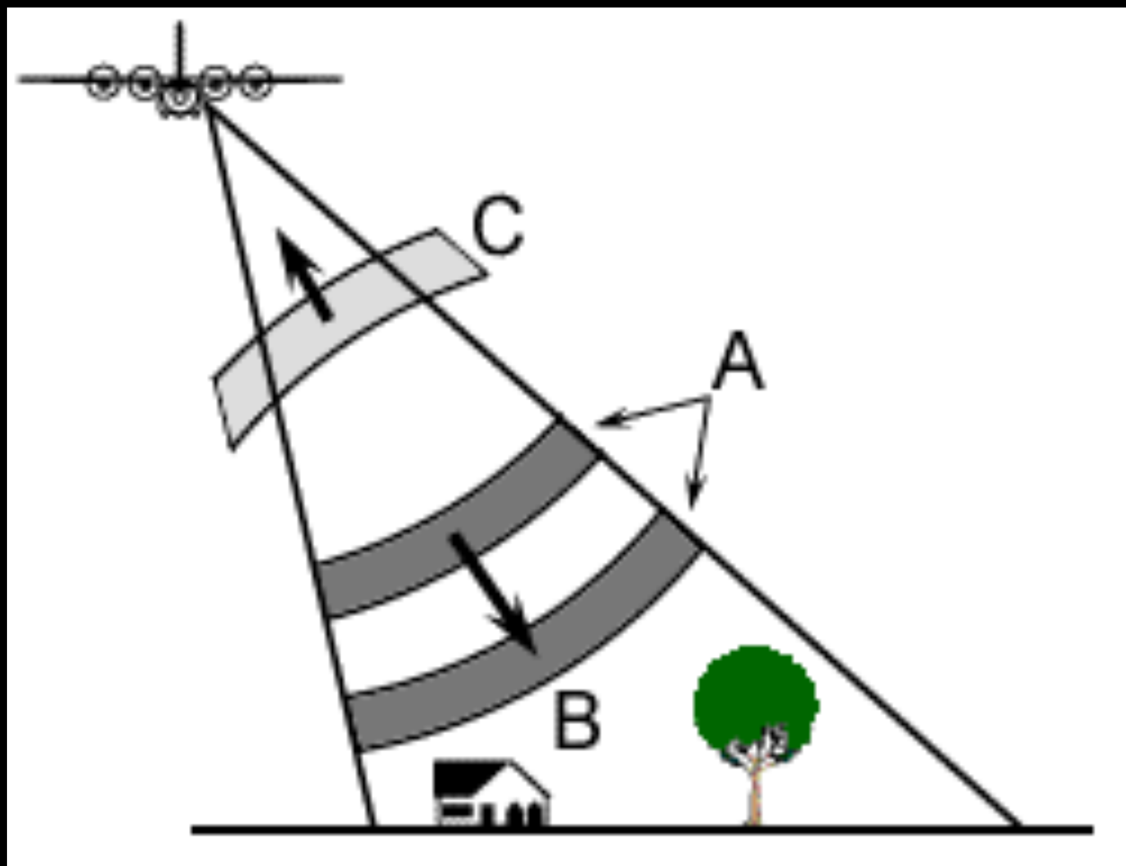
σ=*f*(surface roughness, dielectric factor, terrain, incidence angle, and polarization)

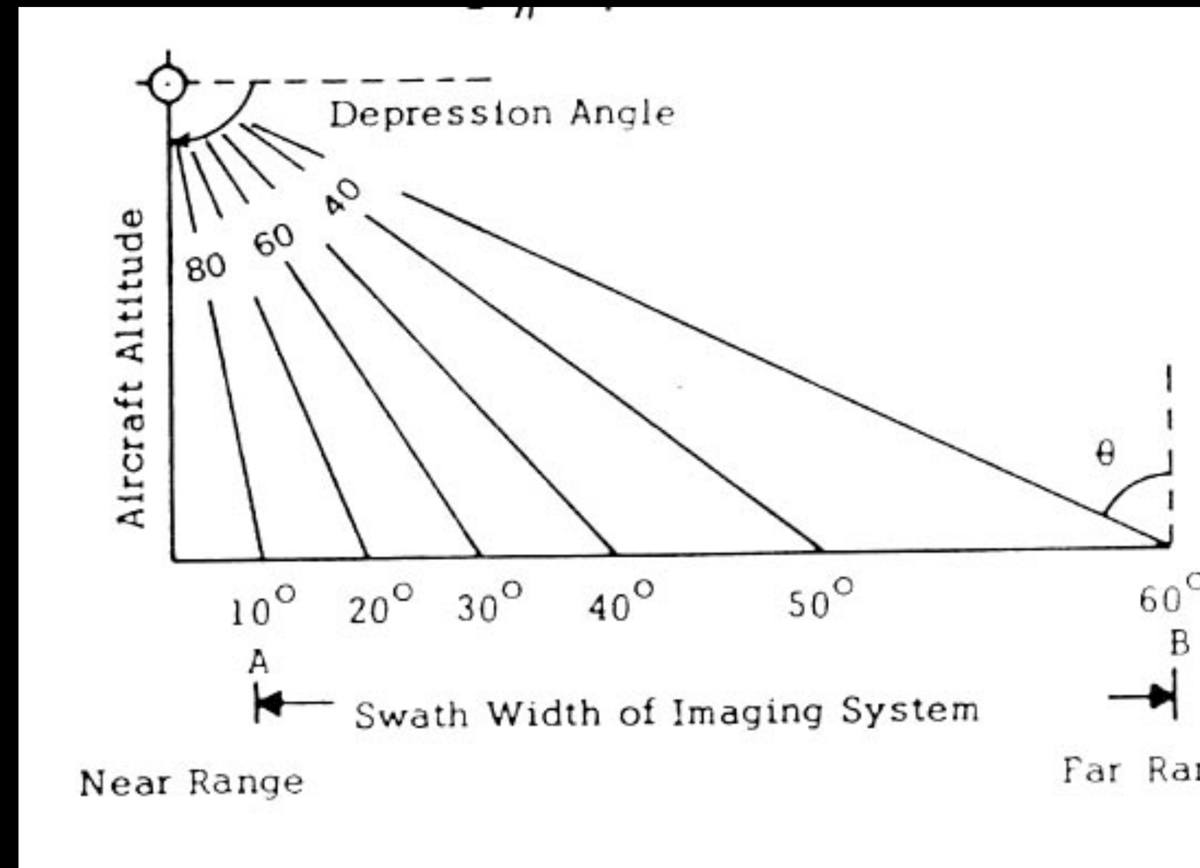
Oil spill makes water surface smooth

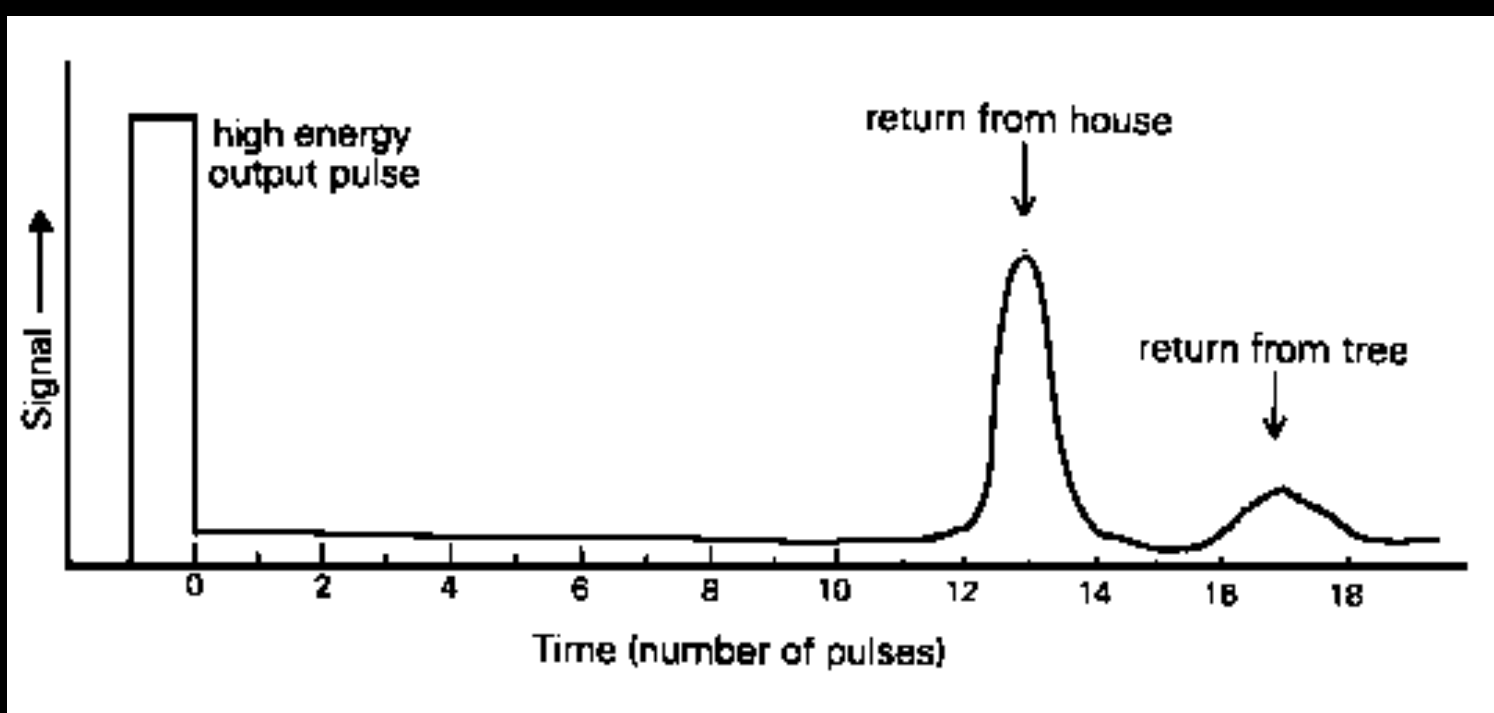




How Radar system works?







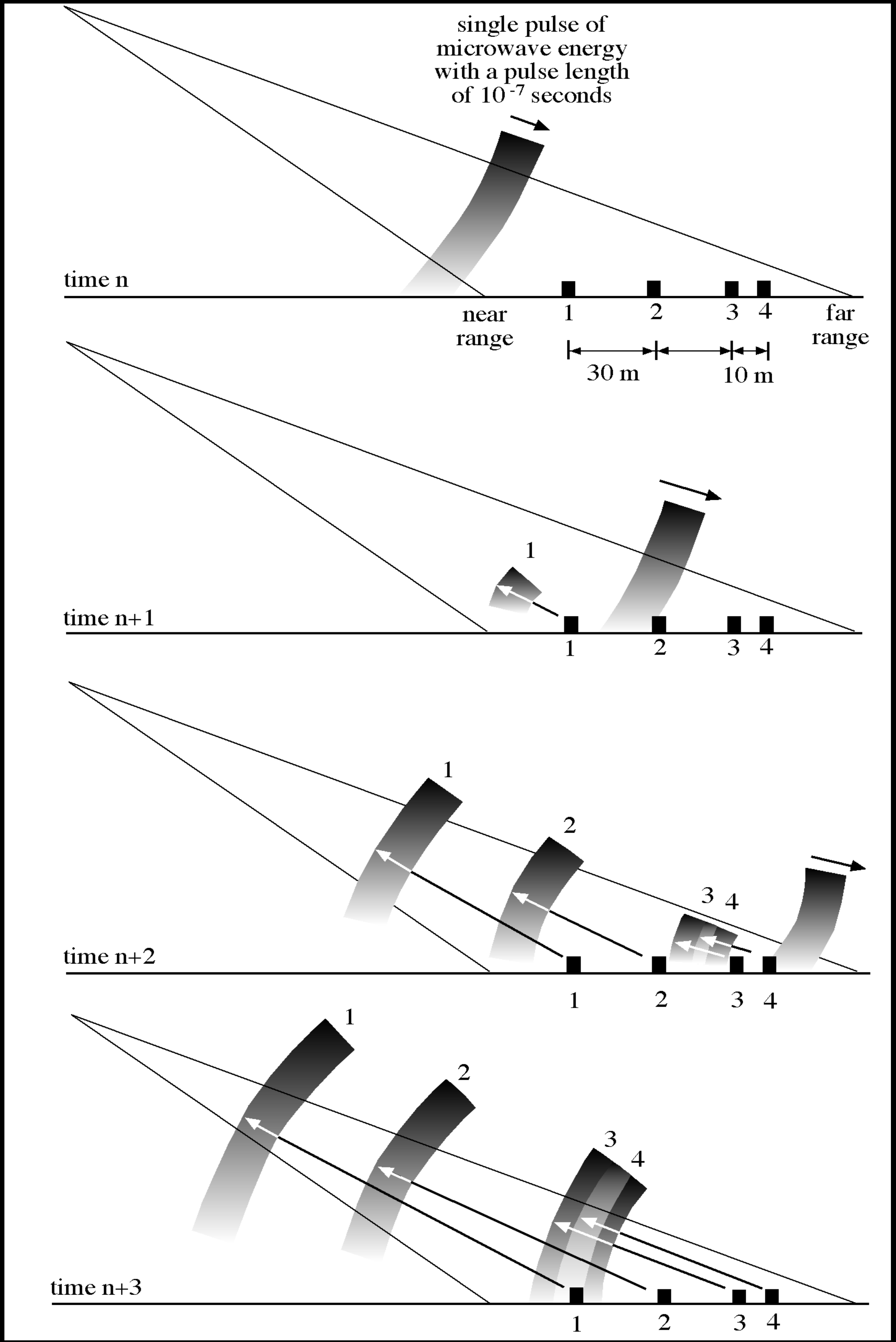
Resolution of radar

Radar measures returned energy as a function of TIME

The Geometry of the flight, angle, antenna etc. lead to the specific character of the image

Resolution to first order is controlled by PULSE width

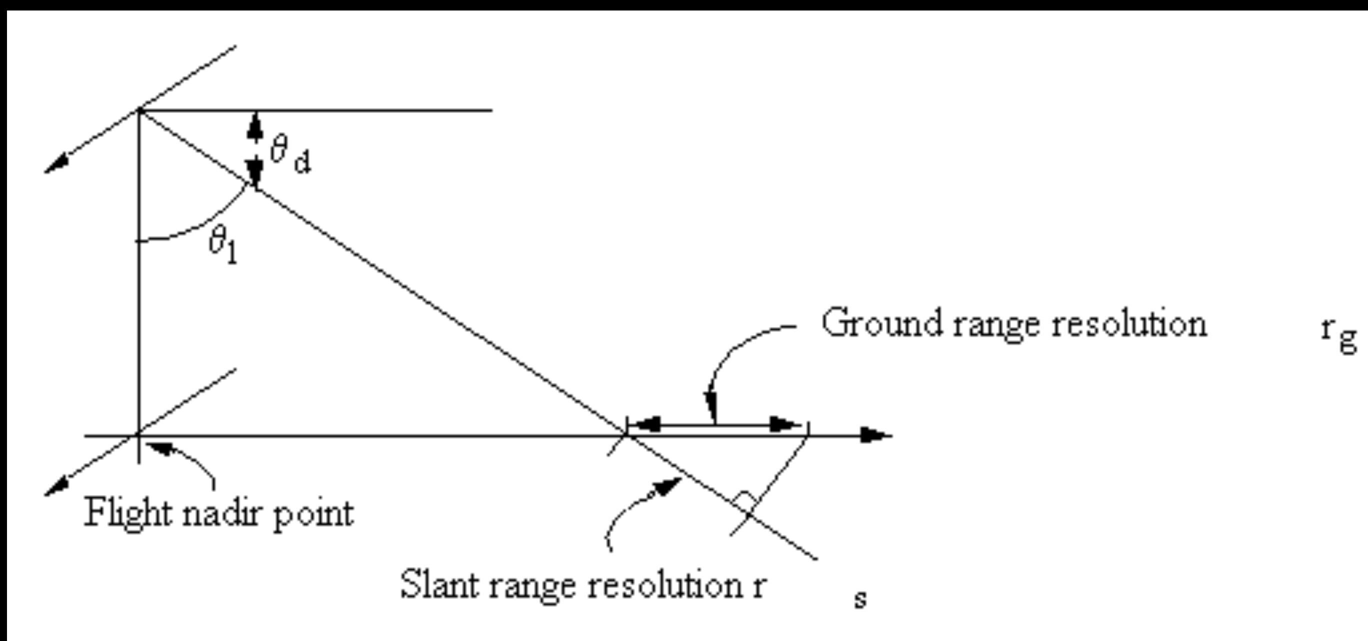
In the example to the right it is possible to resolve objects 1 and 2, but 3 and 4 are not resolved because they are illuminated simultaneously by the pulse
The 10^{-7} second pulse width equates to 30 m and resolution = ½ pulse length (15 m)
Objects 3,4 are not resolved as distinct objects but as a broad reflector



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

Spatial Resolution of Radar

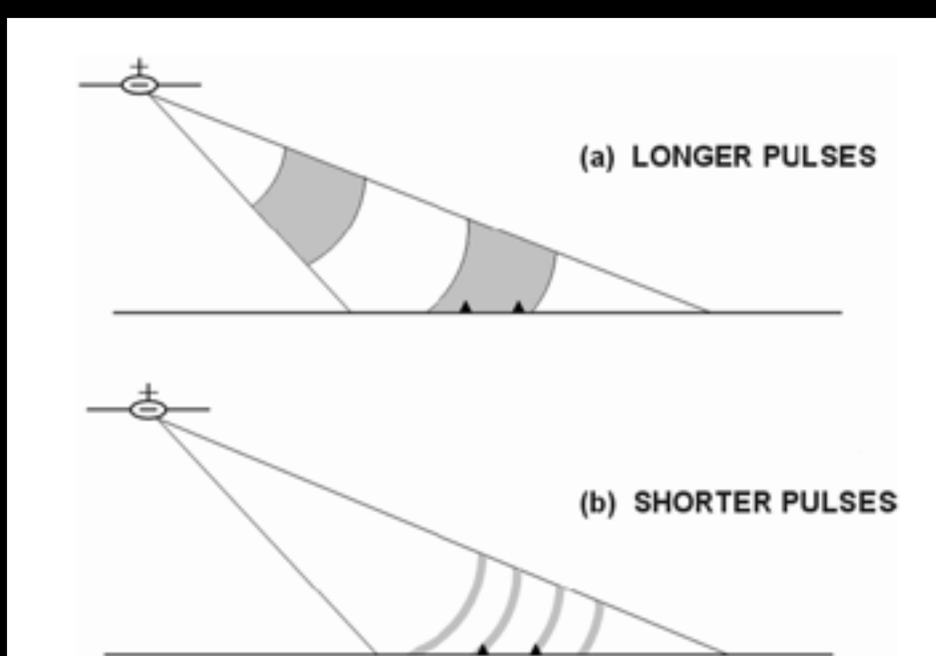
http://www.geos.ed.ac.uk/~ihw/hype/radar/intro2radar.html



Across track res: r_g

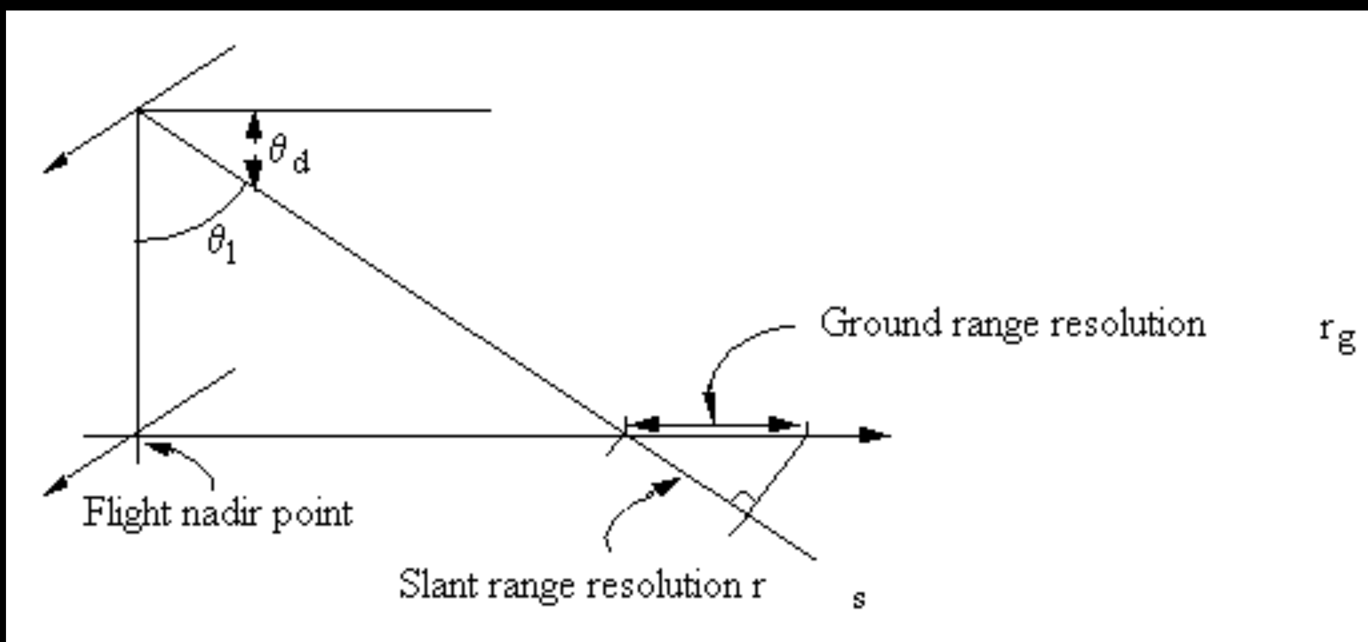
$$r_g = \frac{c\tau}{2\cos\theta_d}$$

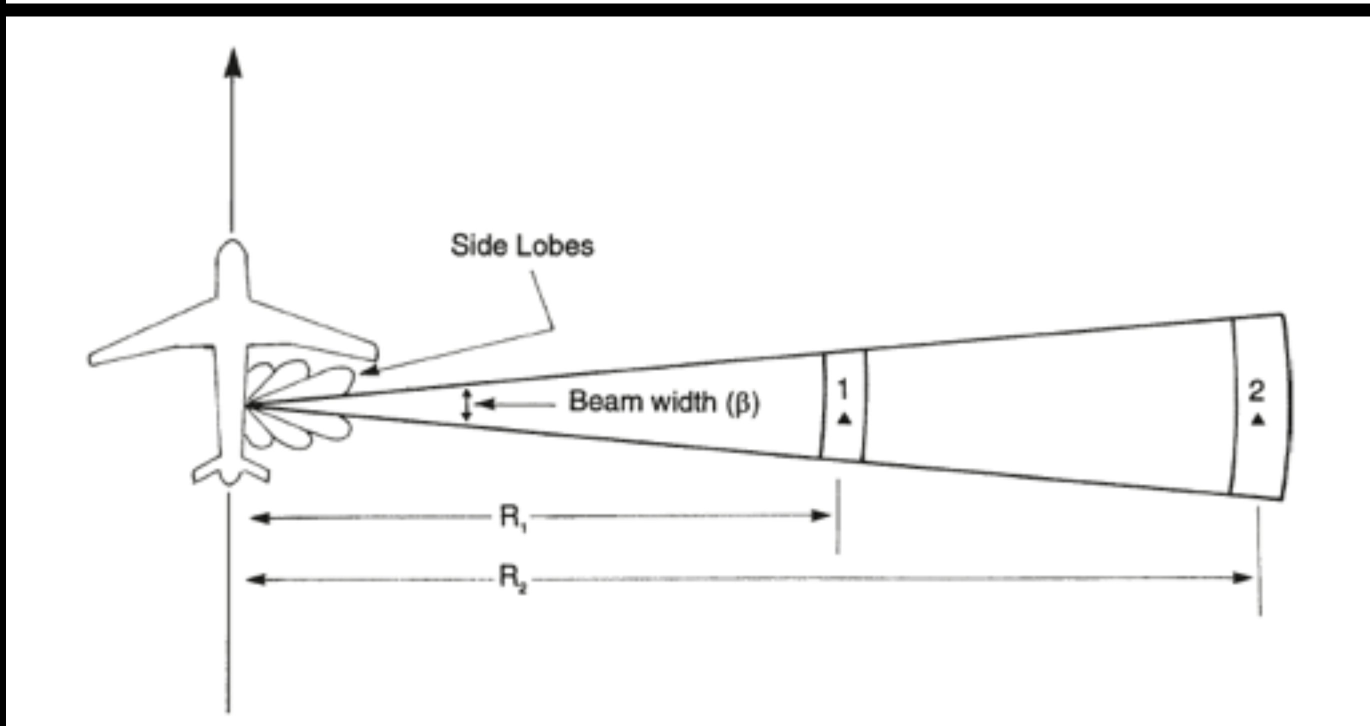
c: speed of light; τ: pulse duration



Spatial Resolution of Real Aperture Radar

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





Across-track res: r_g

$$r_g = \frac{c\tau}{2\cos\theta_d}$$

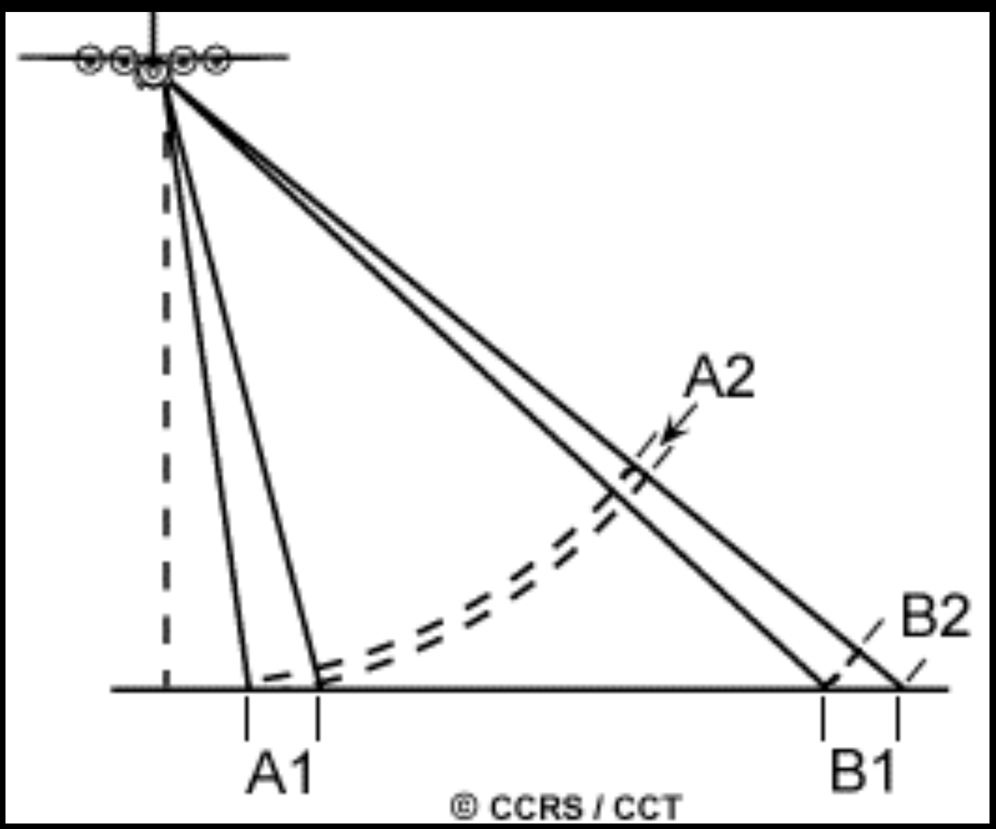
c: speed of light; τ: pulse duration

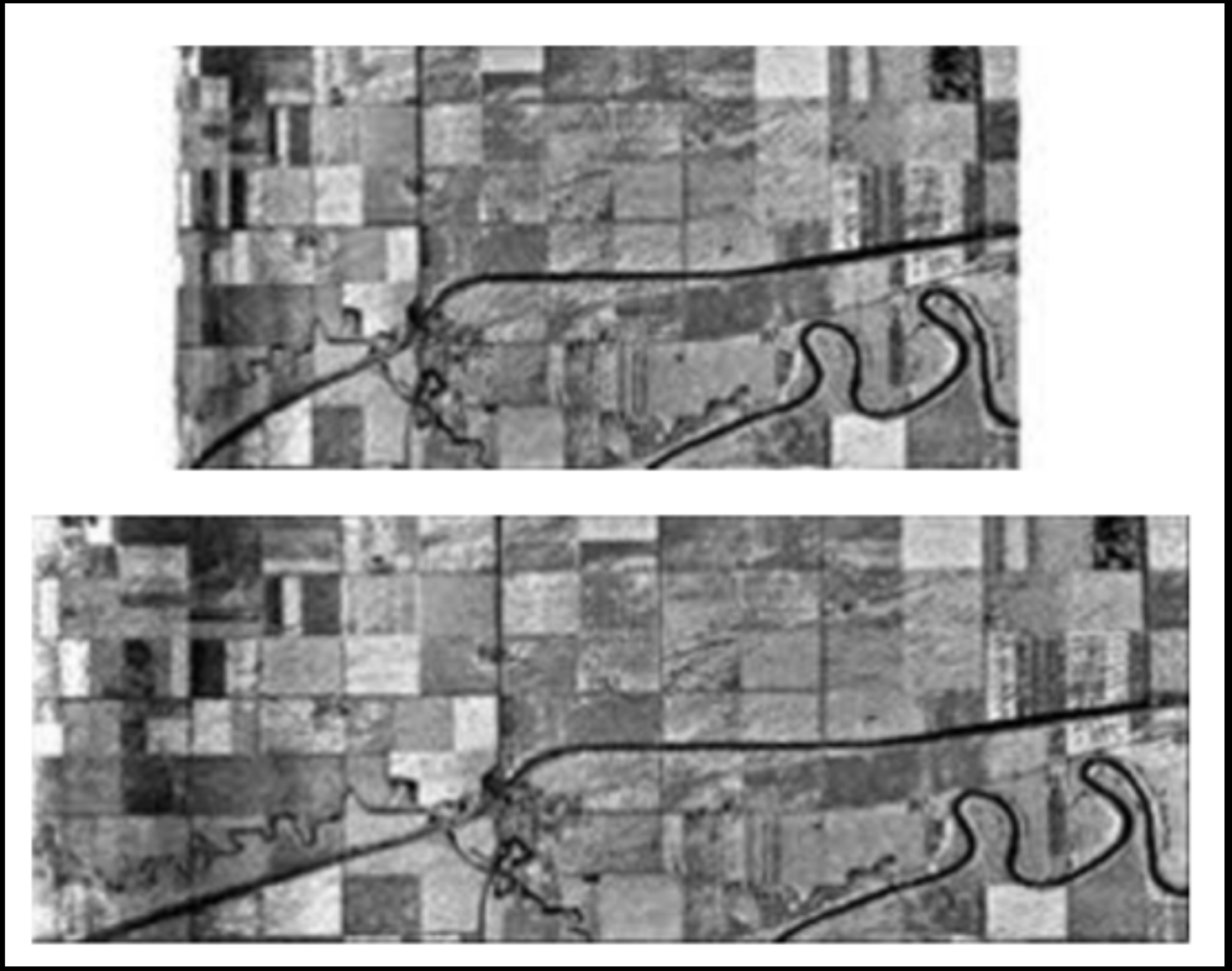
Along-track res: β

$$\beta = \frac{\lambda}{\alpha}$$

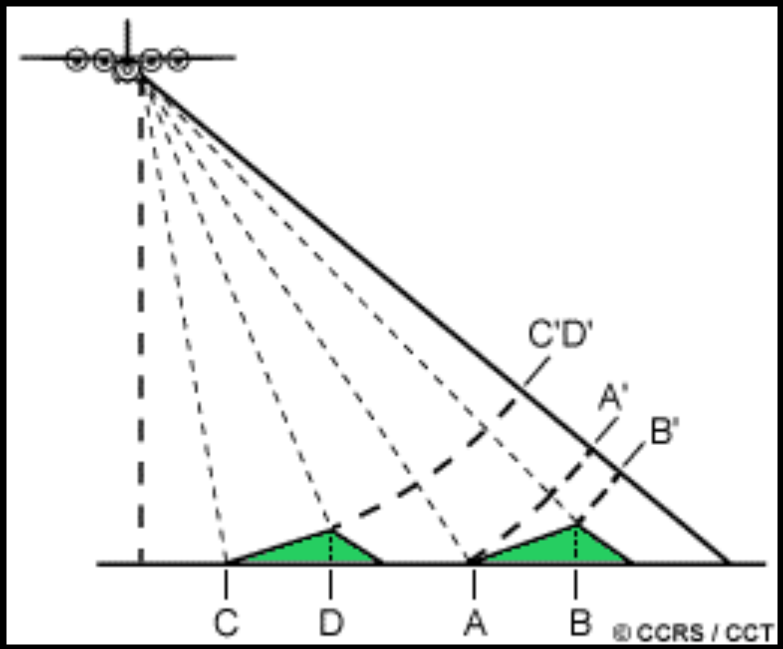
λ: wavelength; α: size of the aperture

Slant-range vs. Ground-range

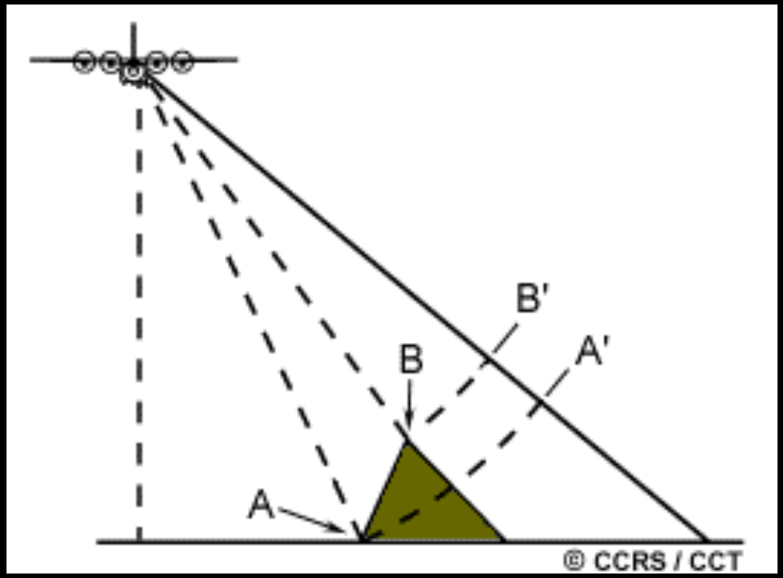




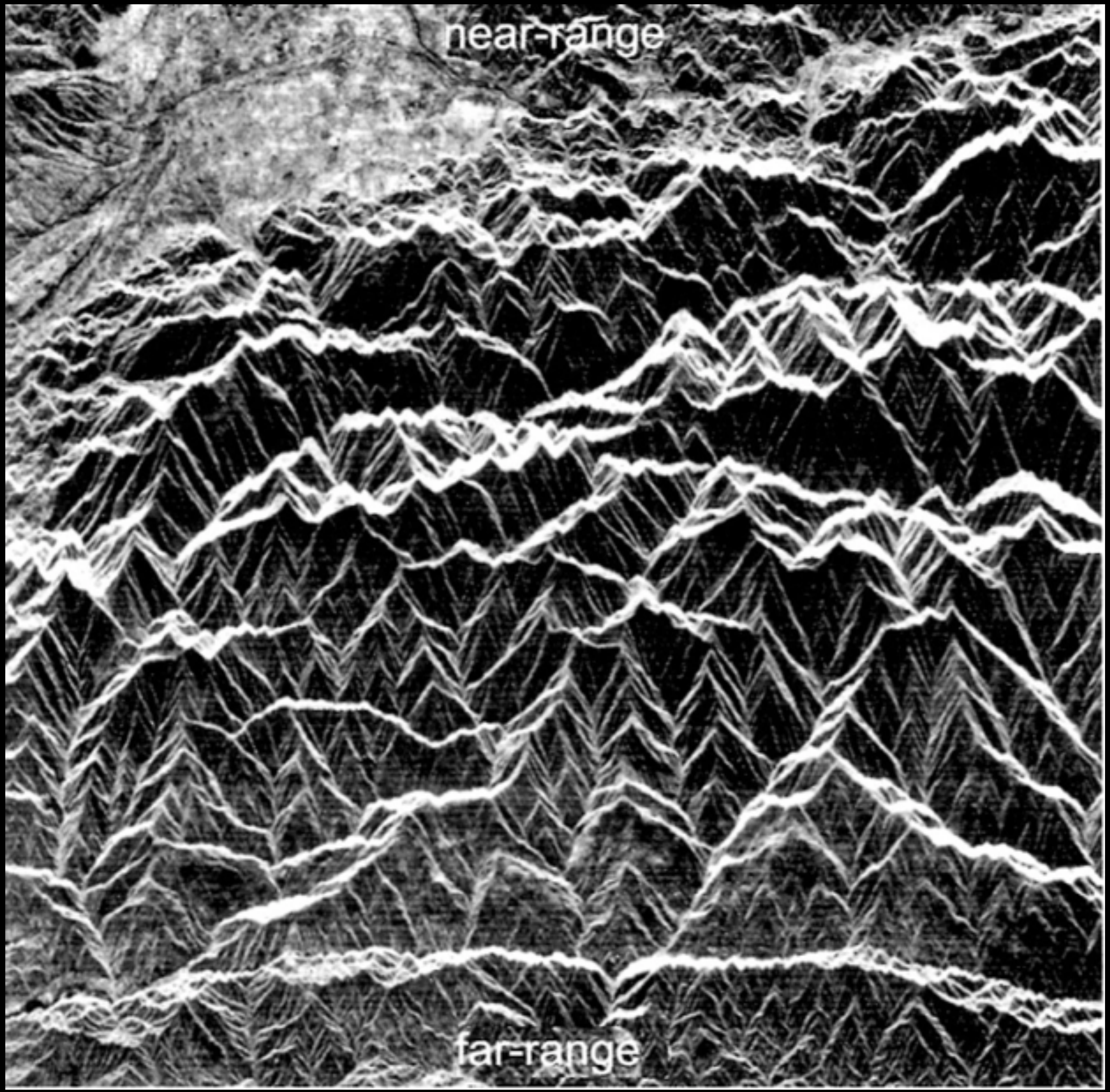
Foreshortening vs. Layover



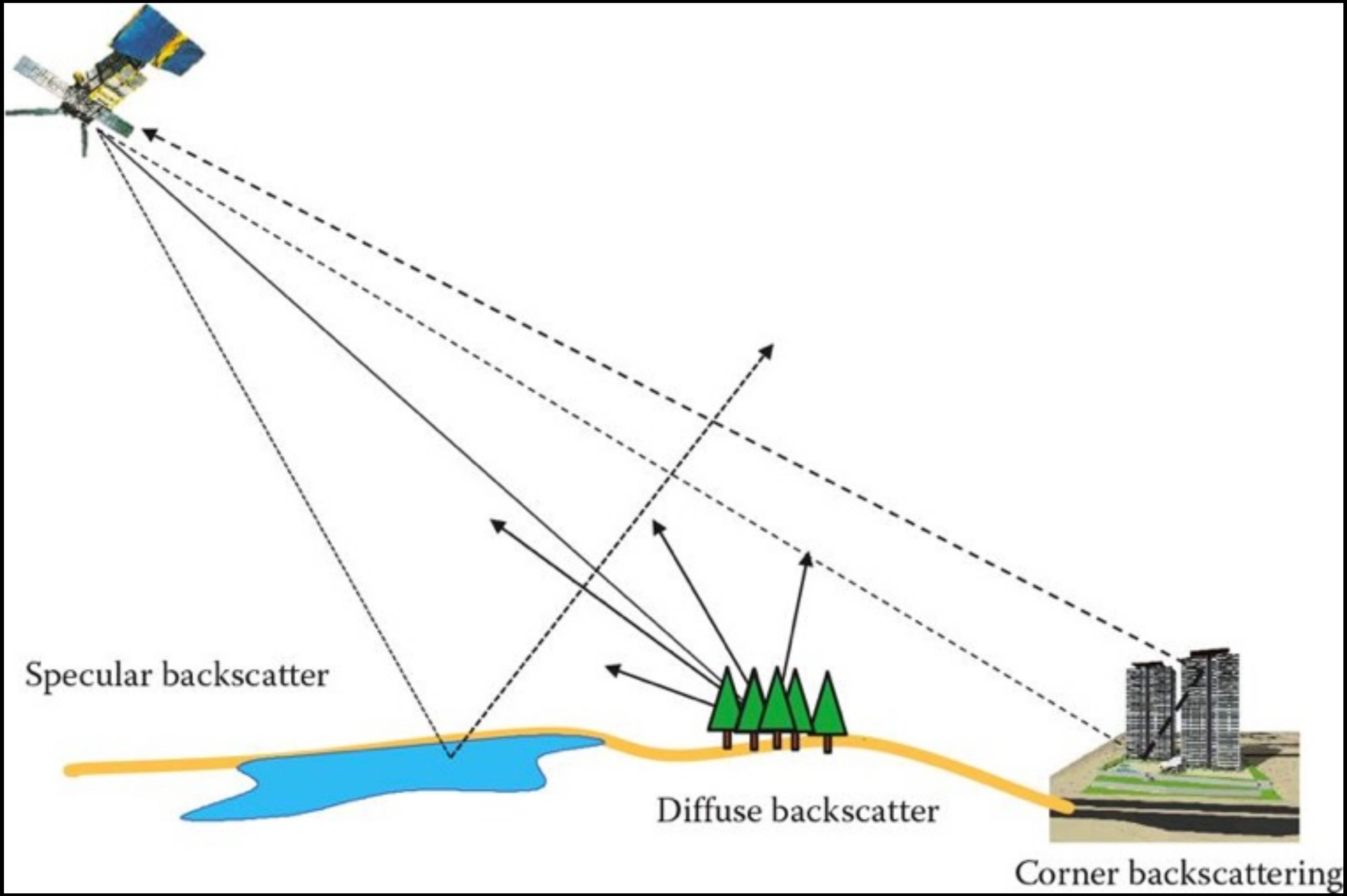
Foreshortening



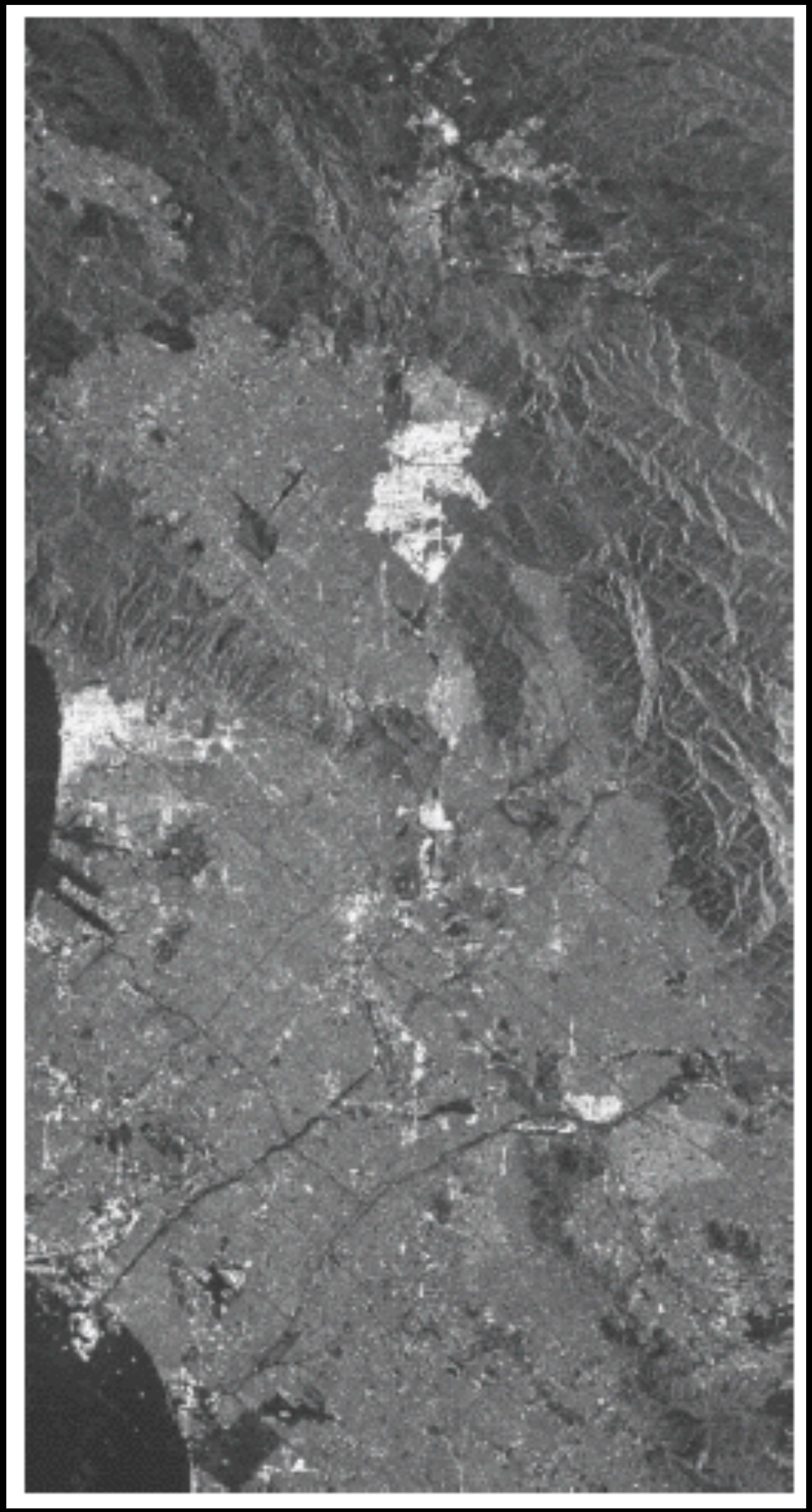
Layover



Three types of scattering



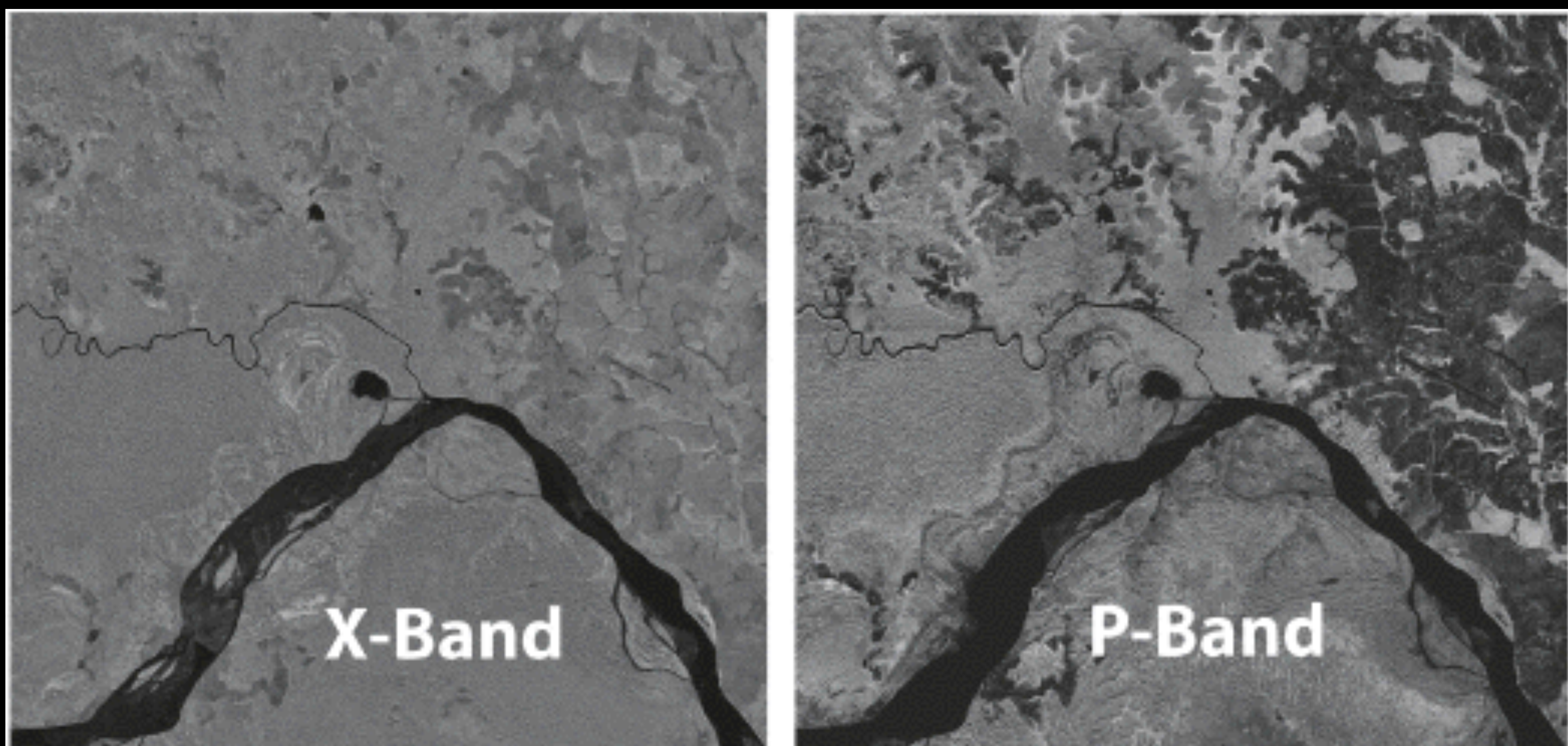
Urban area is highly reflective



SAR image of Los Angeles, California, acquired at L-band. This image illustrates the classes of features represented on radar imagery, including diffuse, specular, and corner reflectors. This image depicts the internal structure of the built-up urban region, including transportation, roads, and highways. Radar foreshortening is visible in its representation of the mountainous topography.
From NASA-JPL; SIR-C/XSAR, October 1994. PIA1738.

Penetration of the radar signal

Penetration is assessed by specifying the skin depth , the depth to which the strength of a signal is reduced to 1/e of its surface magnitude, or about 37%.



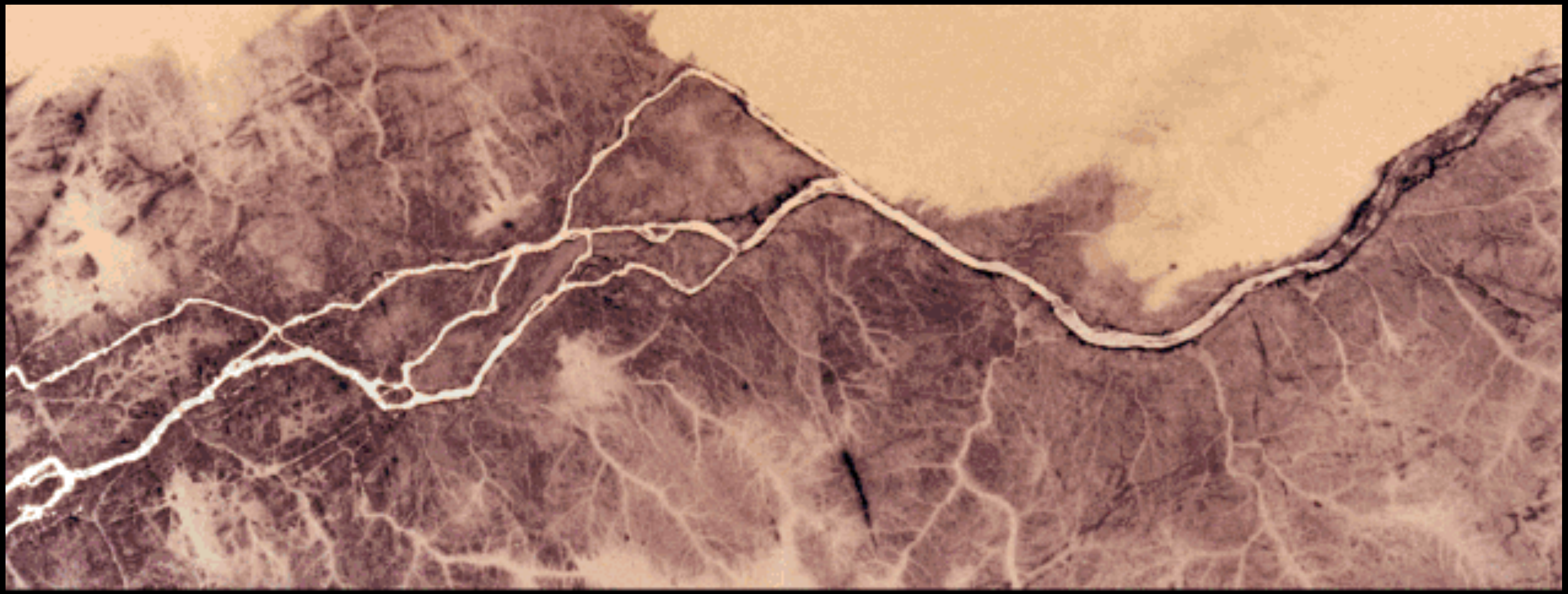
X band: 2.40-3.75 cm

P band: 30.00-100.00 cm

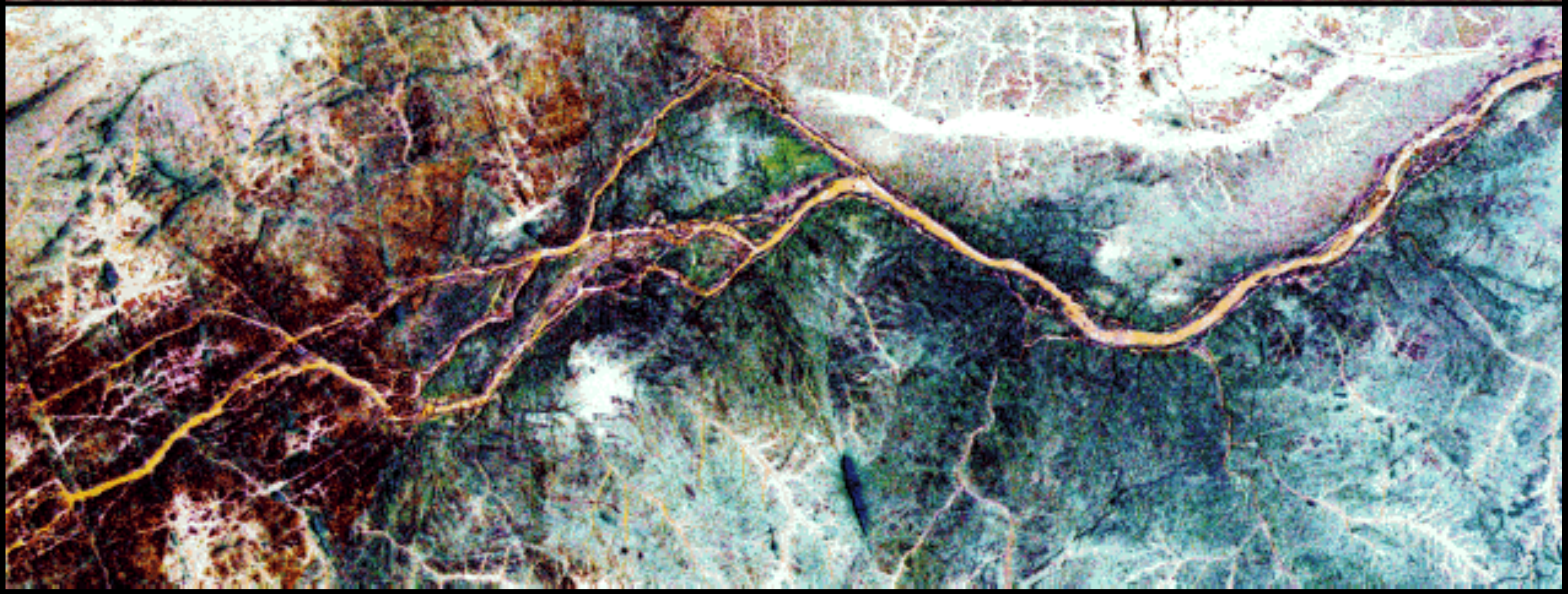
Remote Sensing helps Archeology

SIR-C image of Nile Paleochannel, Sudan

Color infrared film



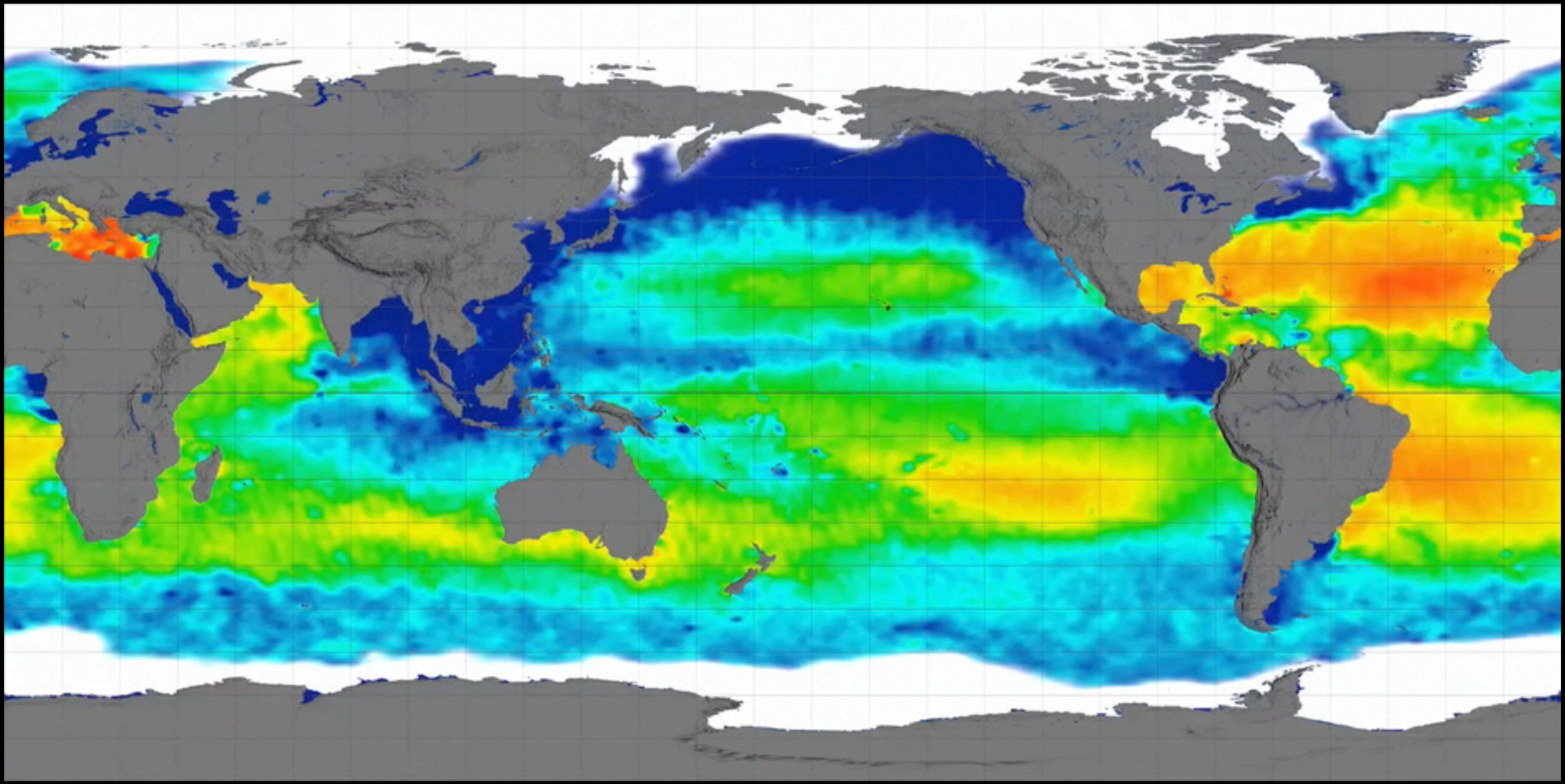
SIR-C/X-SAR image



Recap

- Surface roughness matters a lot!
- Active RS: energy received in different times
- Active RS: corner reflectors.
- Penetration.

Ocean Salinity (Aquarius)



Implications: Hydrology; Oceanography; Biology

Dielectric coefficient (Passive MWRS)

Rayleigh-Jeans Approximation $$M_\lambda = \varepsilon \frac{2kcT}{\lambda^4}$$

Brightness Temperature $$T_b = \frac{\lambda^4}{2kc} M_\lambda \longrightarrow T_b = \varepsilon T$$

ε=*f*(dielectric coefficient, incidence angle, and polarization)

dielectric coefficient = f(salinity, sea surface temperature, radio frequency)

Dielectric coefficient & emissivity

- Dielectric coefficient represents the energy reflected and scattered by the material.

$$\varepsilon = 1 / \varepsilon_r$$

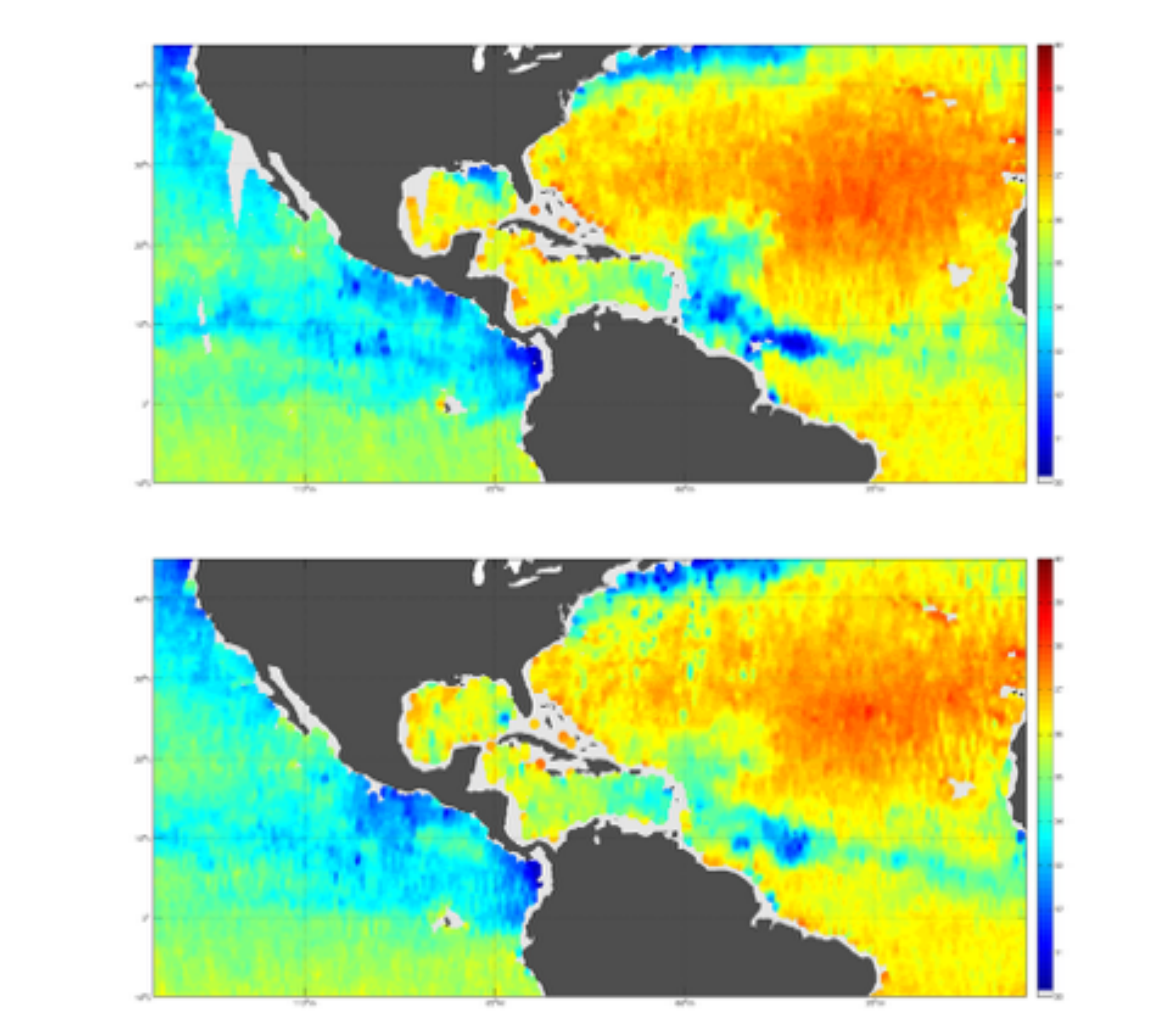
Emissivity

Dielectric constant

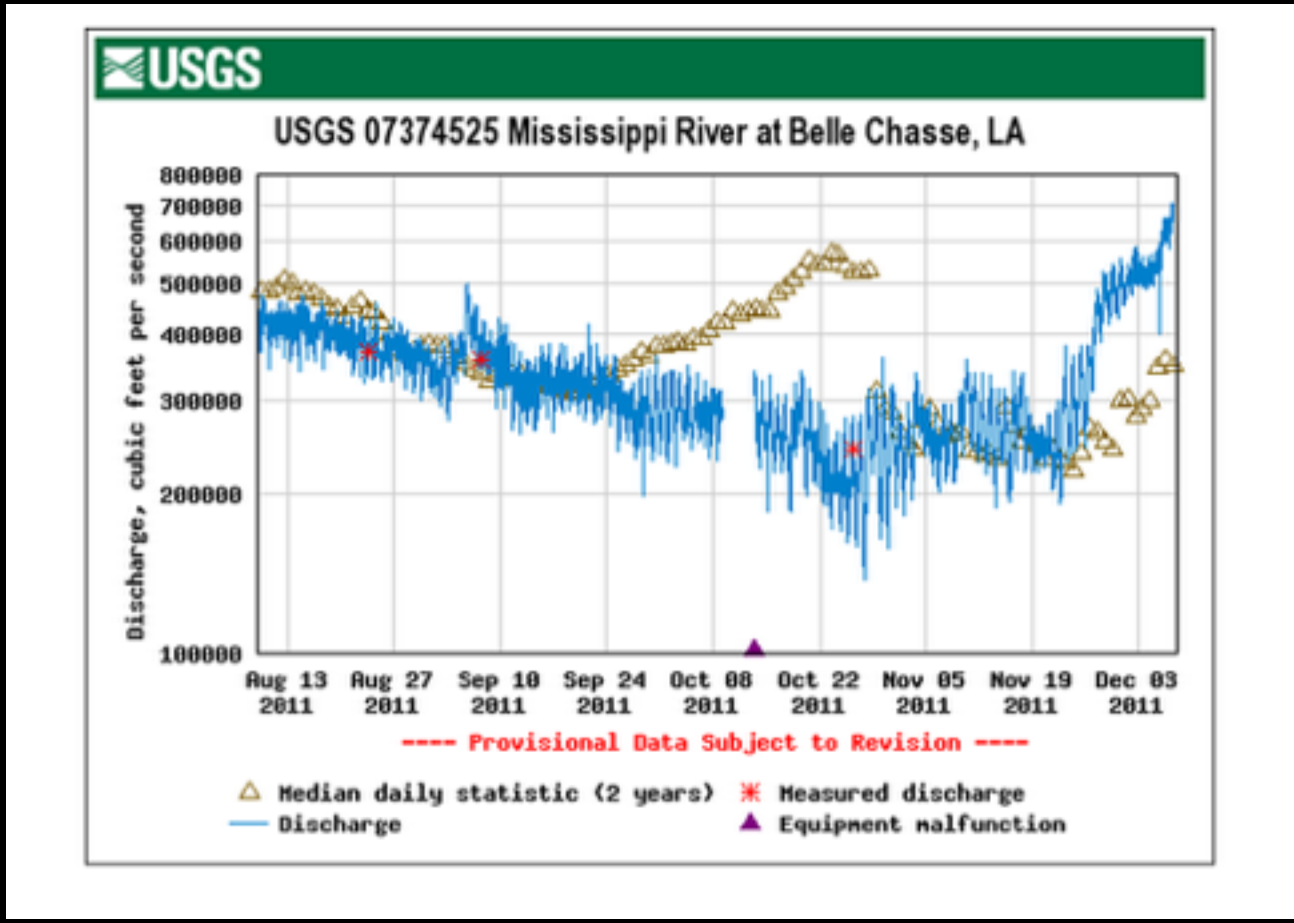
- Dielectric coefficient is sensitive to water, salinity, and temperature

Fresh water input to the ocean

September, 2011



October, 2011

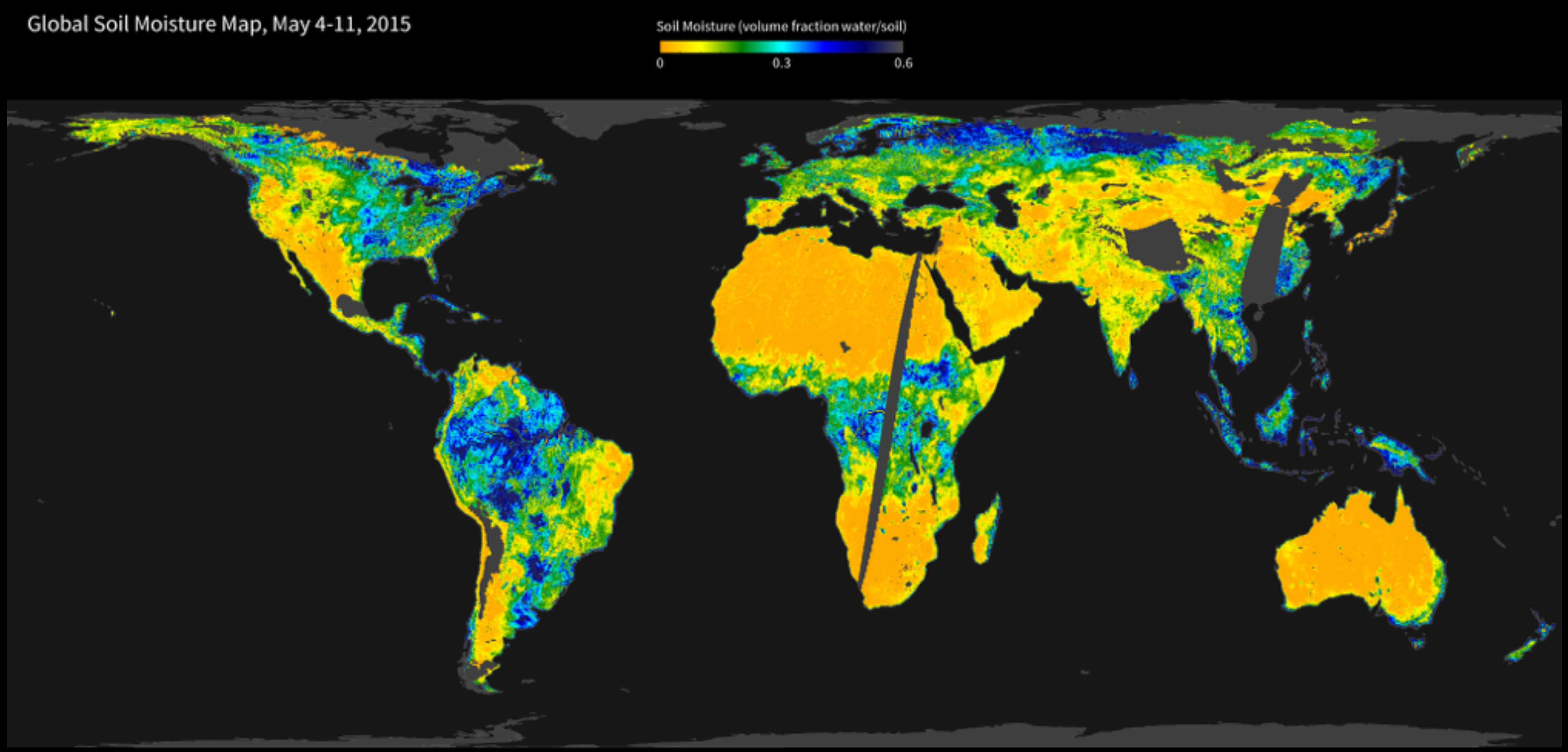


Dielectric coefficient of various materials

Dielectric Constants for Various Materials

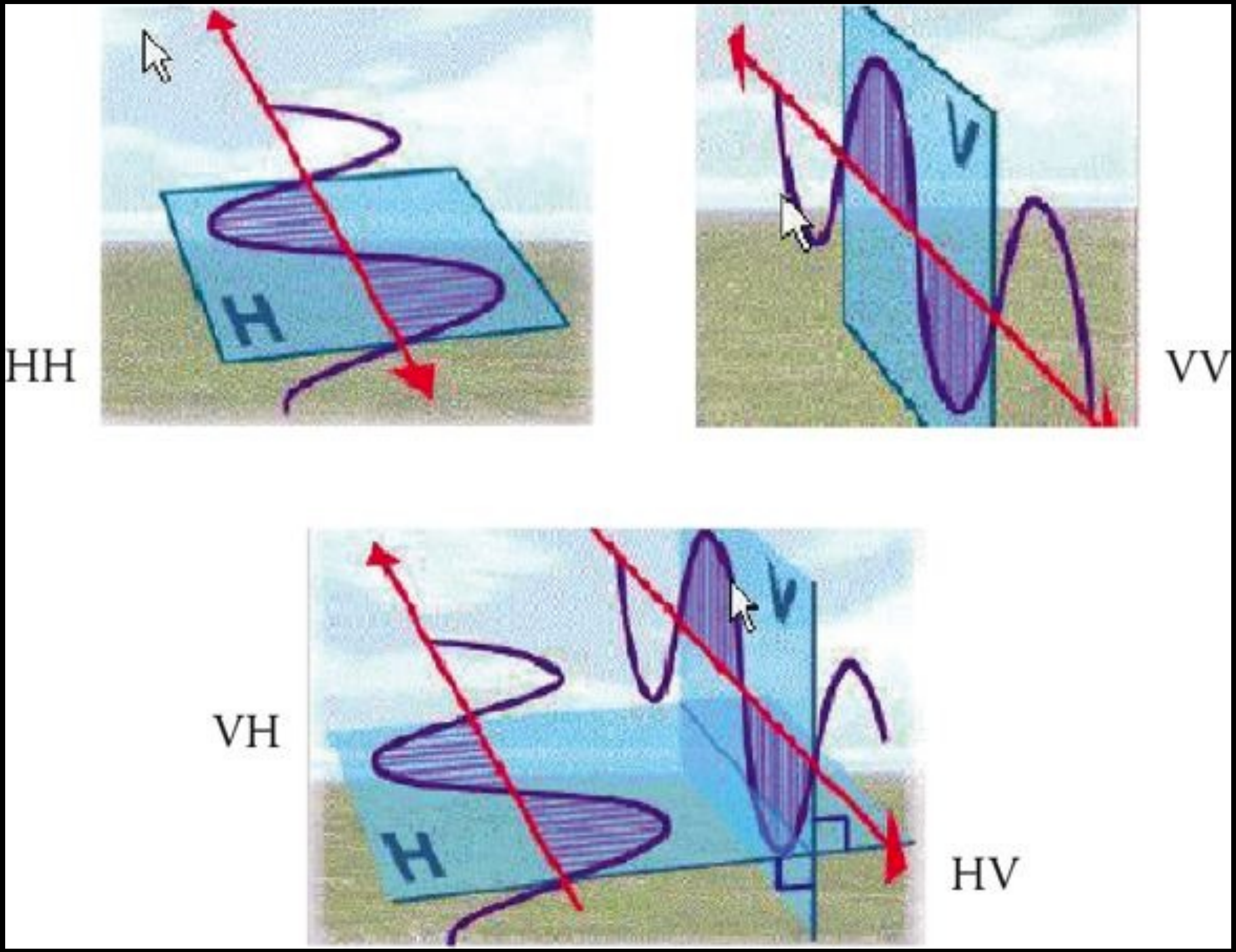
Common naturally occuring materials	Typical Dielectric Constants between ~1 to 100 GHz ε'
Air, vacuum	1.00059, 1.0 (by definition)
Ice (fresh, sea)	3.2, 4-8
Snow (dry, wet)	1.3-1.6, 1.4-1.9
Permafrost	4-8
Water (fresh)	80 (20°C, <3 GHz), ↓15-25 (~3 GHz) and decreasing with frequency
Sea water	78 (20°C, <3 GHz), decreasing with frequency
Sandy soil (dry, wet)	2.5-5, 15-30
Loamy soil (dry, wet)	4-6, 10-20
Clayey soil (dry, wet)	4-6, 10-15
Silts	5-30
Granite	4-6
Limestone	4-8
Salt	4-7

Soil moisture from SMAP



How does SMAP work?

Polarization

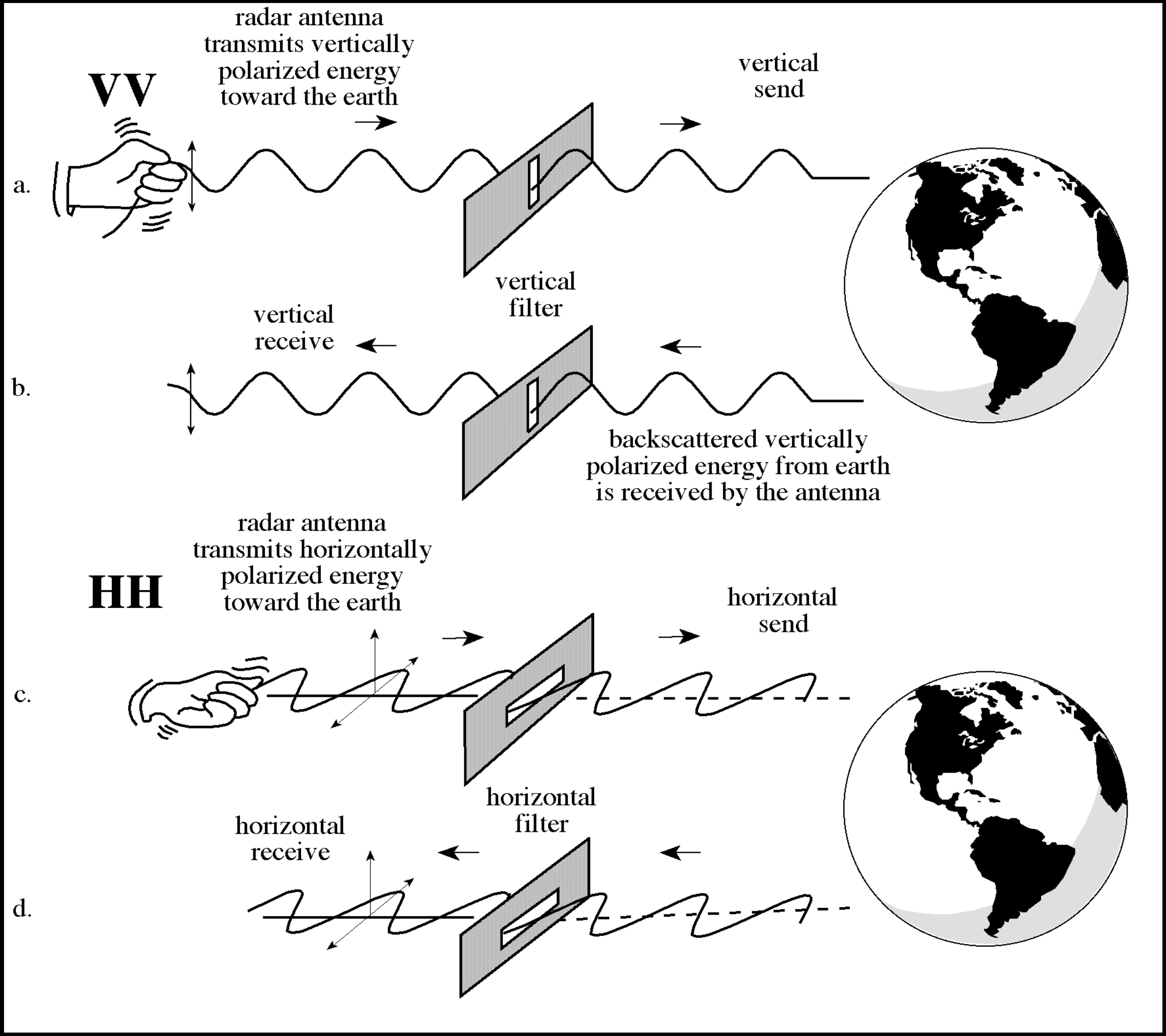


Plane of incidence = the plane defined by the vertical and the direction of propagation

Vertical polarization: the wave is parallel to the plane of incidence

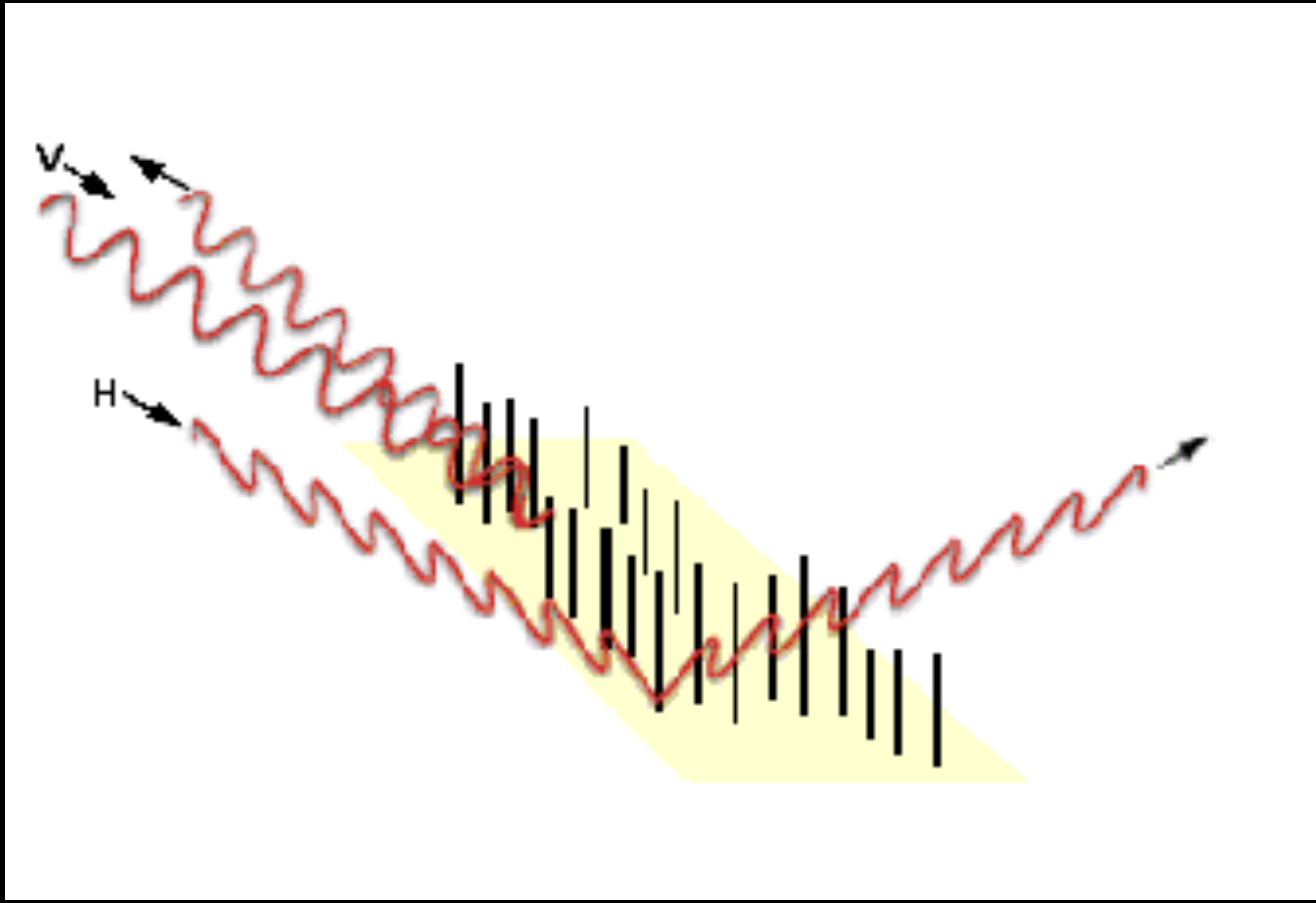
Horizontal polarization: the wave is perpendicular to the plane of incidence

Sensors can receive EMR in a certain polarization



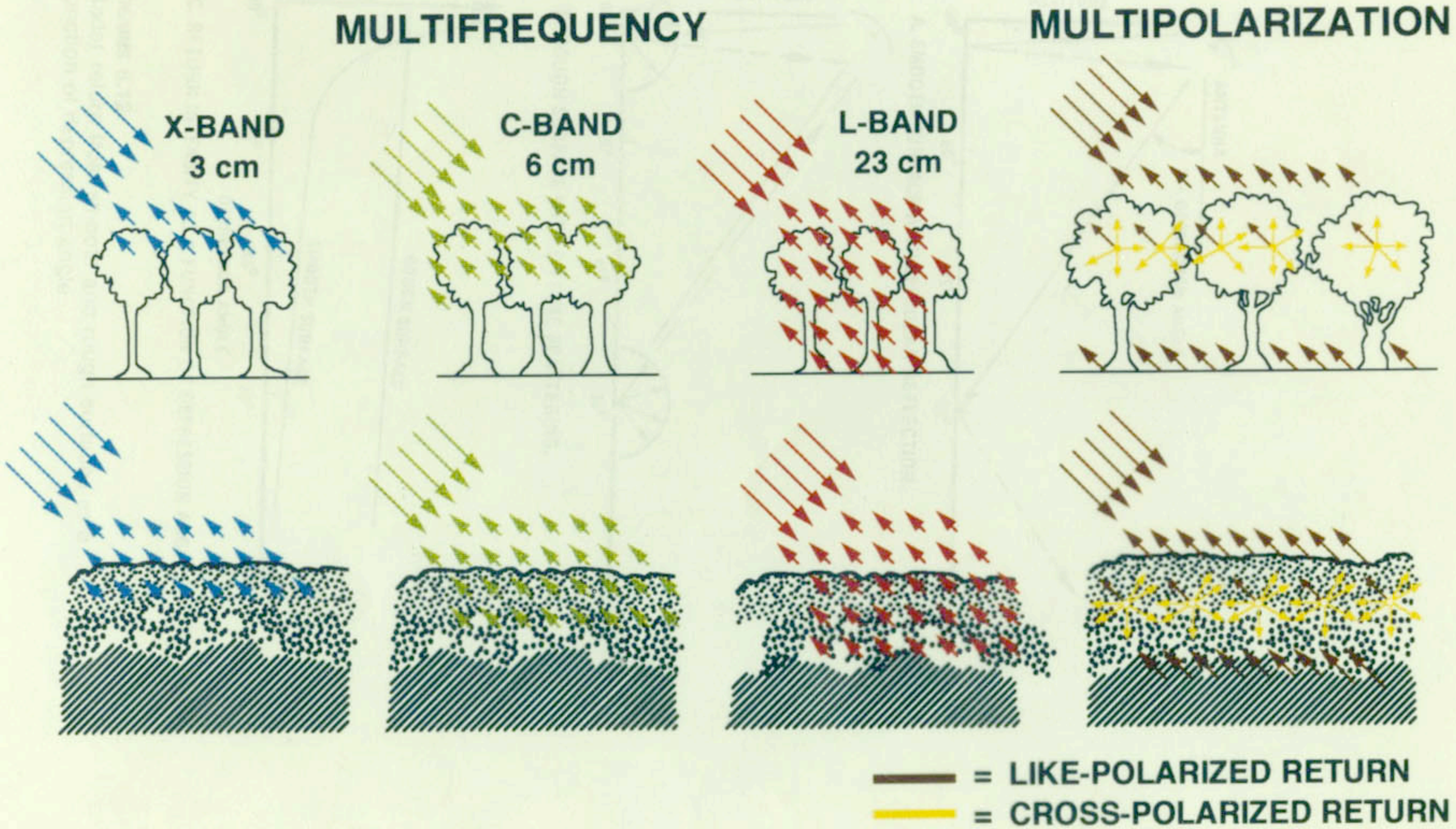
like-polarized

Vertical objects reflect more V-polarization EMR

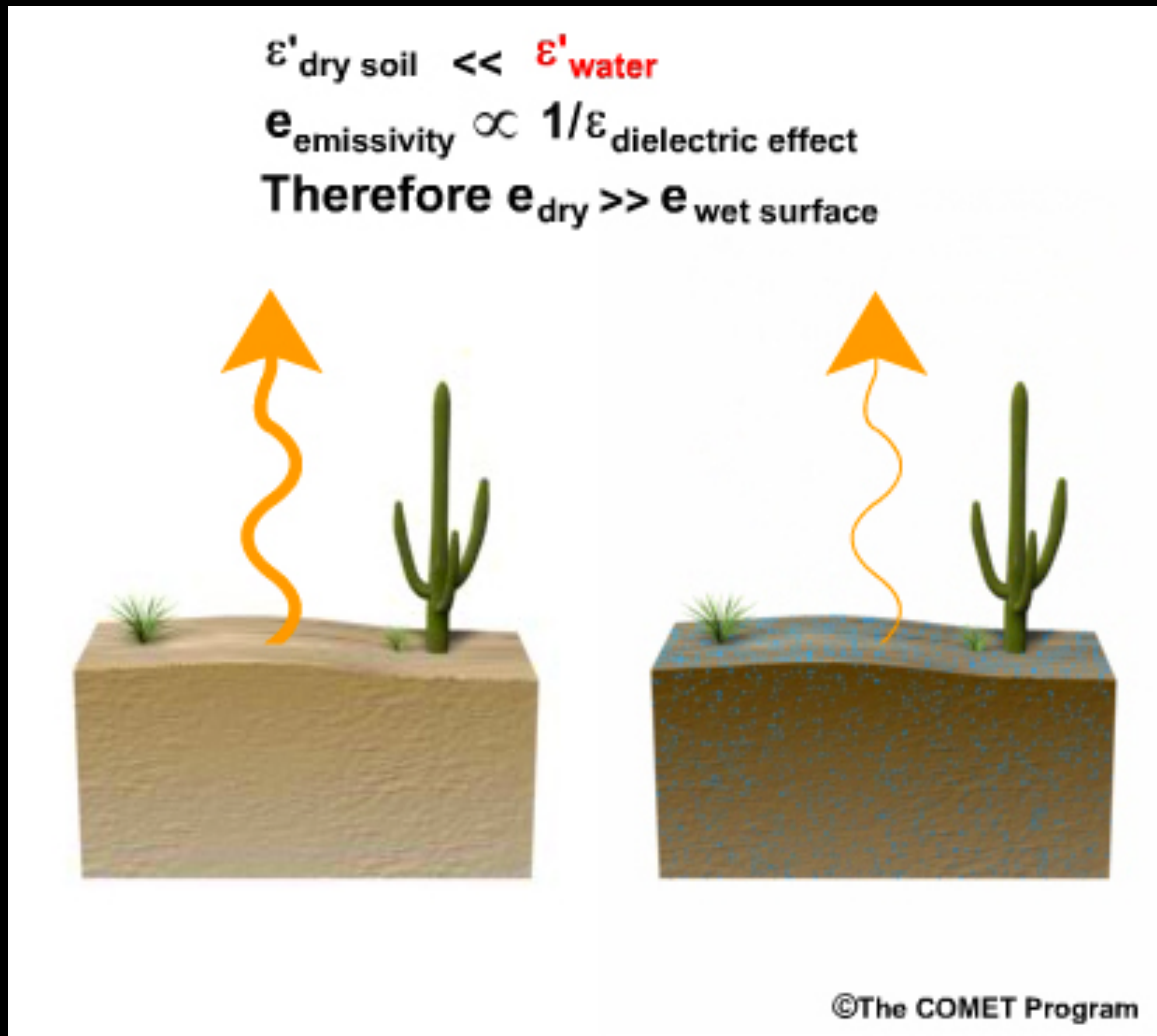


Vertical objects (trees) more likely to reflect vertical polarized radiation
Horizontal polarization less likely to be reflected

RADAR RESPONSE TO VEGETATION AND SUBSURFACE HORIZONS



Dry vs Wet soil



Passive MW sensors for Soil Moisture

Passive MW Instrument Capabilities and Product Characteristics for Soil Moisture

Instrument (Satellite)	Coverage	Sensor Resolution	Product	Range & Accuracy
SSM/I & SSMIS (DMSP)	• 12 hourly • Satellites clustered for early morning and evening coverage	~ 55 (low freq.) ~ 15 km (high freq.)	• Surface Soil Moisture (%)	Range: 0 - 70% (>70% = water) Accuracy: Not available
MIRAS (SMOS)	• 12 hourly for early morning and early afternoon coverage • 3-day repeat cycle	30 to 50 km @ 1.413 GHz	• Surface Soil Moisture • Vegetation Water Content	Range: 0 - 100 %vol/vol Valid: ≤ 5 cm Accuracy: ~0.01 m^3/m^3
AMSR-2 (GCOM-W1 and future W2 & W3)	• 12 hourly for early afternoon and nighttime	70 km @ 7 GHz 14 km @ 37 GHz 5 km @ 89 GHz	Surface Soil Moisture	Range: ~0 - 0.3 g/cm Valid: ≤ 5 cm depth Accuracy: ~0.043 g/cm
SMAP Observatory (2015) Passive & Active	• 12 hourly for early morning and early evening coverage	40 km @ 1.41 GHz (passive radiometer) 30 km @ 1.26 GHz (active, SAR))	• Surface Soil Moisture • Freeze/Thaw State	Valid: ≤ 5 cm depth Accuracy: ~± 0.04 cm^3/cm^3 for veg. water content ≤ 5 kg/m^2
GMI (GPM Core and GPM Brazil, 2016)	• Twice daily, drifting orbit with coverage between 65° S and 65° N latitude	~25 km @ 10.65 GHz ~11 km @ 36.5 GHz ~ 6 km @ 89 GHz	• Surface Soil Moisture	Not available

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Active MW sensors for Soil Moisture

Active MW Instrument Capabilities and Product Characteristics for Soil Moisture

Instrument (Satellite)	Coverage	Sensor Resolution	Product	Range & Accuracy
OSCAT Scatterometer (ScatSat-1, 2015 OceanSat-3, 2017)	• 12 hourly near local noon and midnight • OSCAT on board OceanSat-2 failed Feb. 2014	45 km	• Surface Soil Moisture	Details not available
• **Metop ASCAT Scatterometer** • **SCA (EPS Second Gen. Scatterometer, 2022-2043)**	• 12 hourly for mid-morning and mid-evening local time	• 12.5 (ASCAT sampling res.) • 6.25 to 12.5 km (SCA sampling res.)	• Surface Soil Wetness (< 2 cm) • Soil Wetness Index (SWI) • SWI Anomaly	Range: 0 to 1 Accuracy: ~25% **Range: 0 - 100% Range: - 45 to +45 Accuracy: Model dependent
• **RADARSAT-2 SAR** • **RCM (2018-2025)** • **ESA Sentinal SAR-C (ERS and Envisat follow-on mission, 2015-2024)**	• 7-day repeat cycle for local noon and midnight • 4-day repeat cycle for 3-sat. constellation • 5-day repeat cycle	• 3 m to 100 m (RADARSAT and RCM) • 4 m to 80 m (Sentinal SAR-C)	• Experimental Surface Soil Moisture	Range: 5 to 95% defined by percentile between dry and wet reference Accuracy: Unknown

** Values are relative to the amount of water typically found within the root zone (0 to 1 m) between the wilting point (0%) and total soil capacity (100%).

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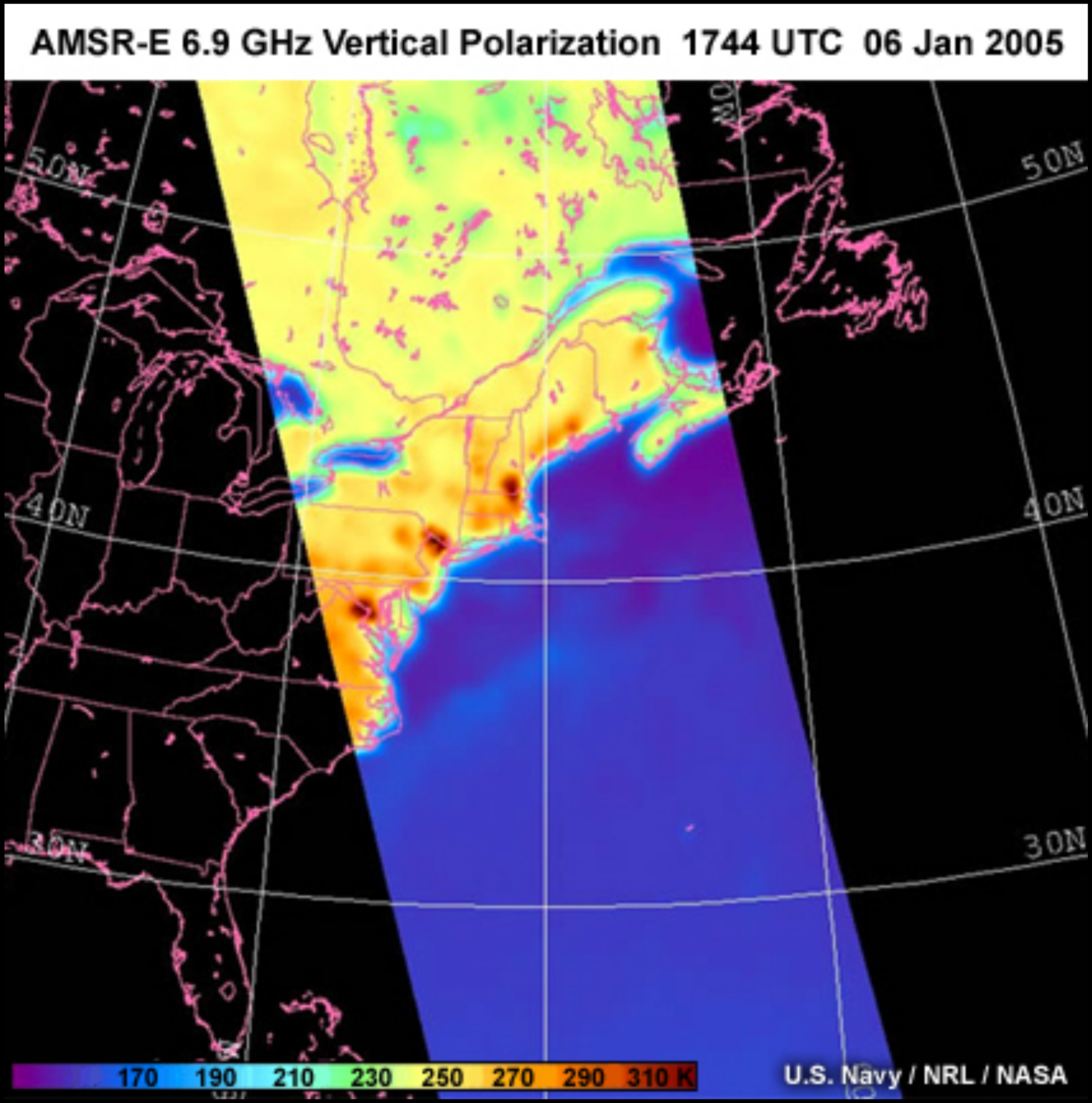
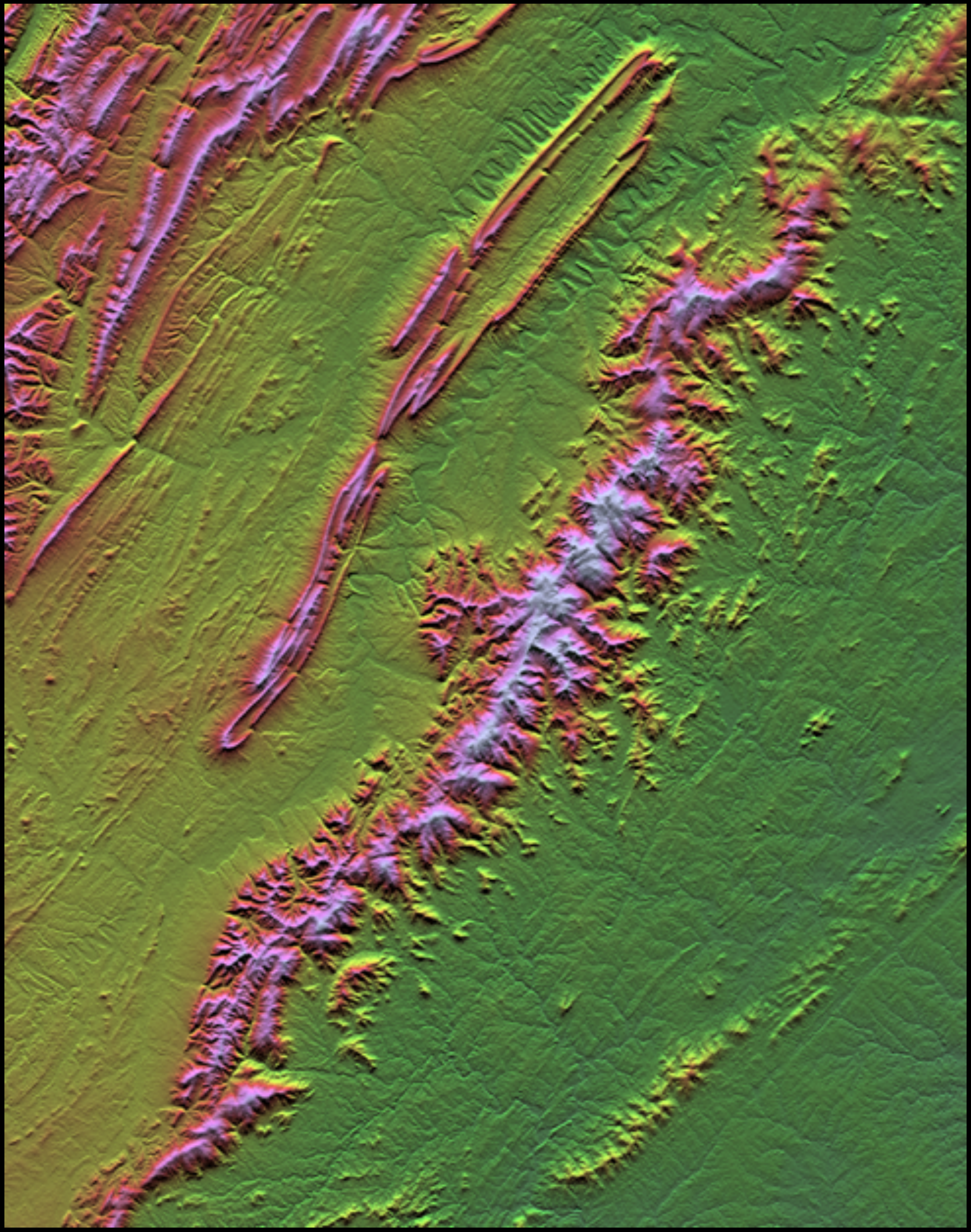
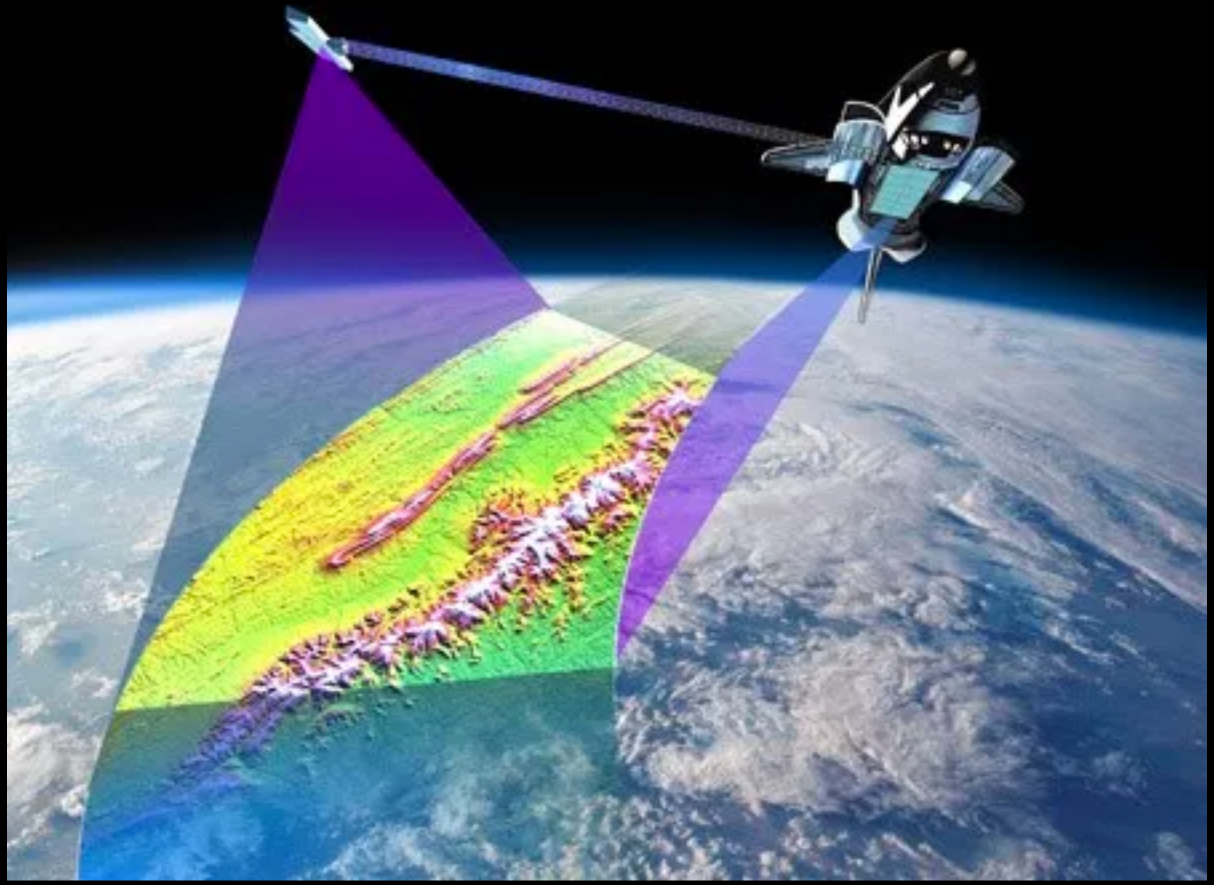
Radio frequency interference



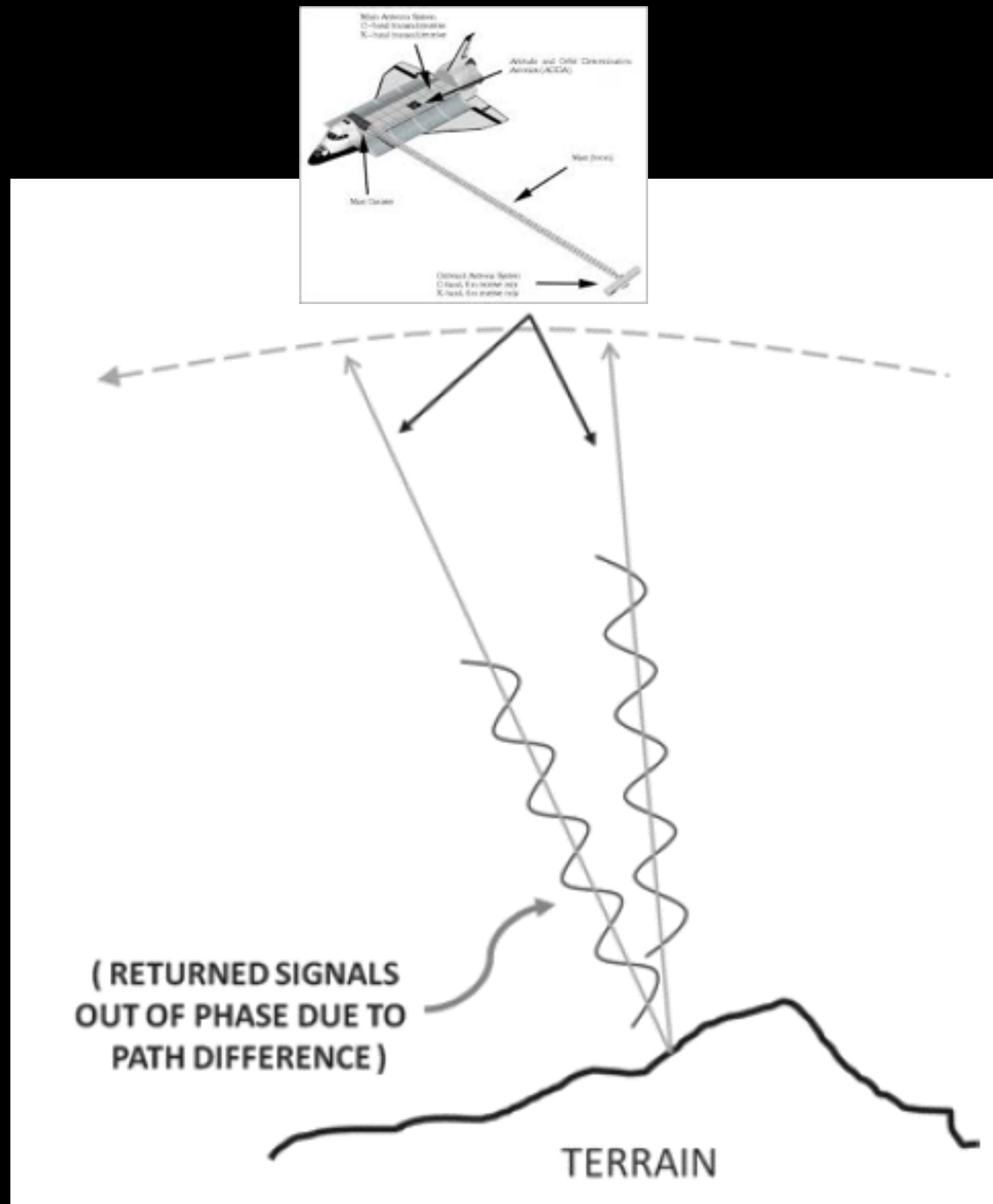
Digital Elevation Model from SRTM



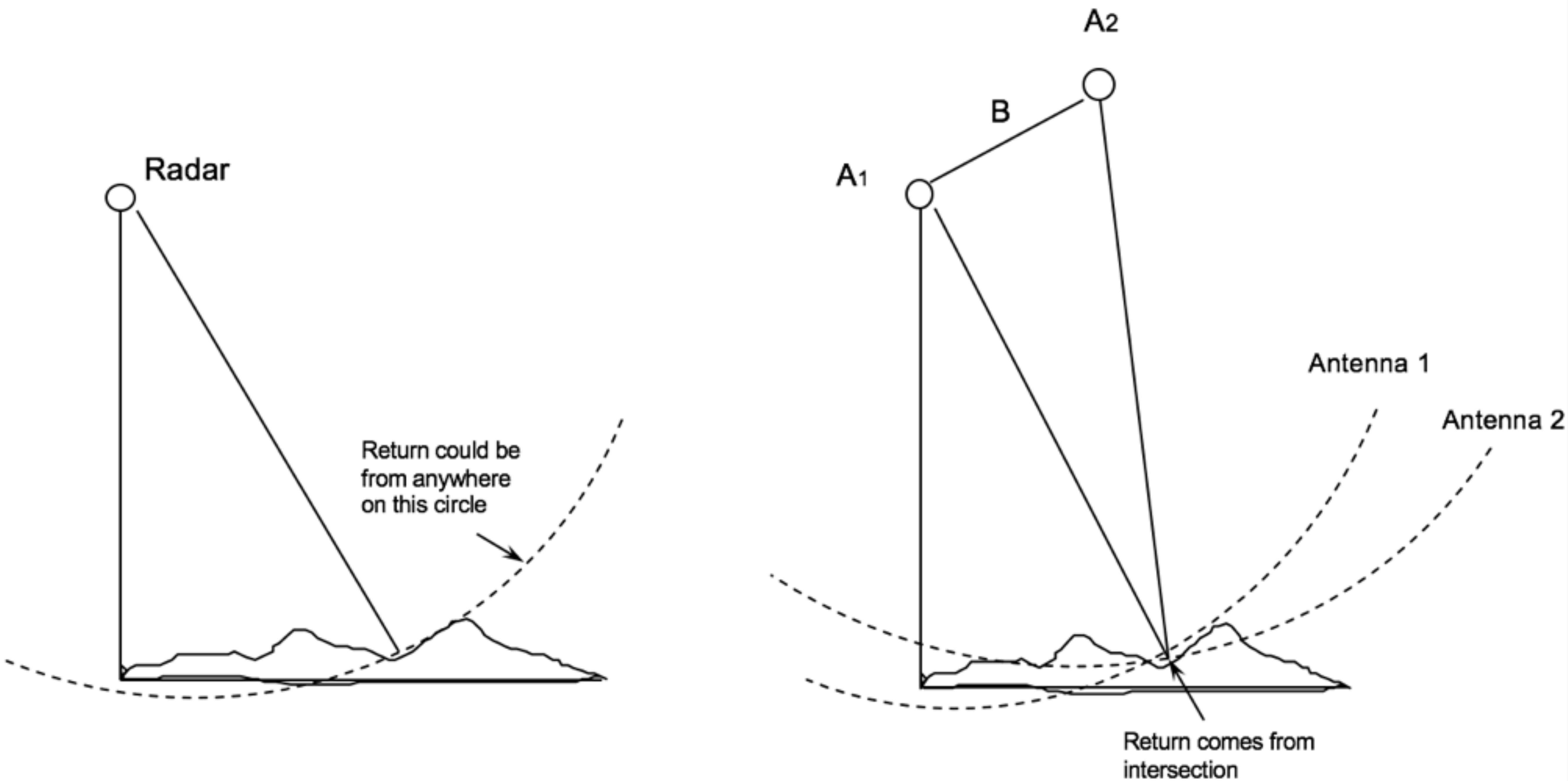


Shuttle Radar Topography Mission (SRTM)

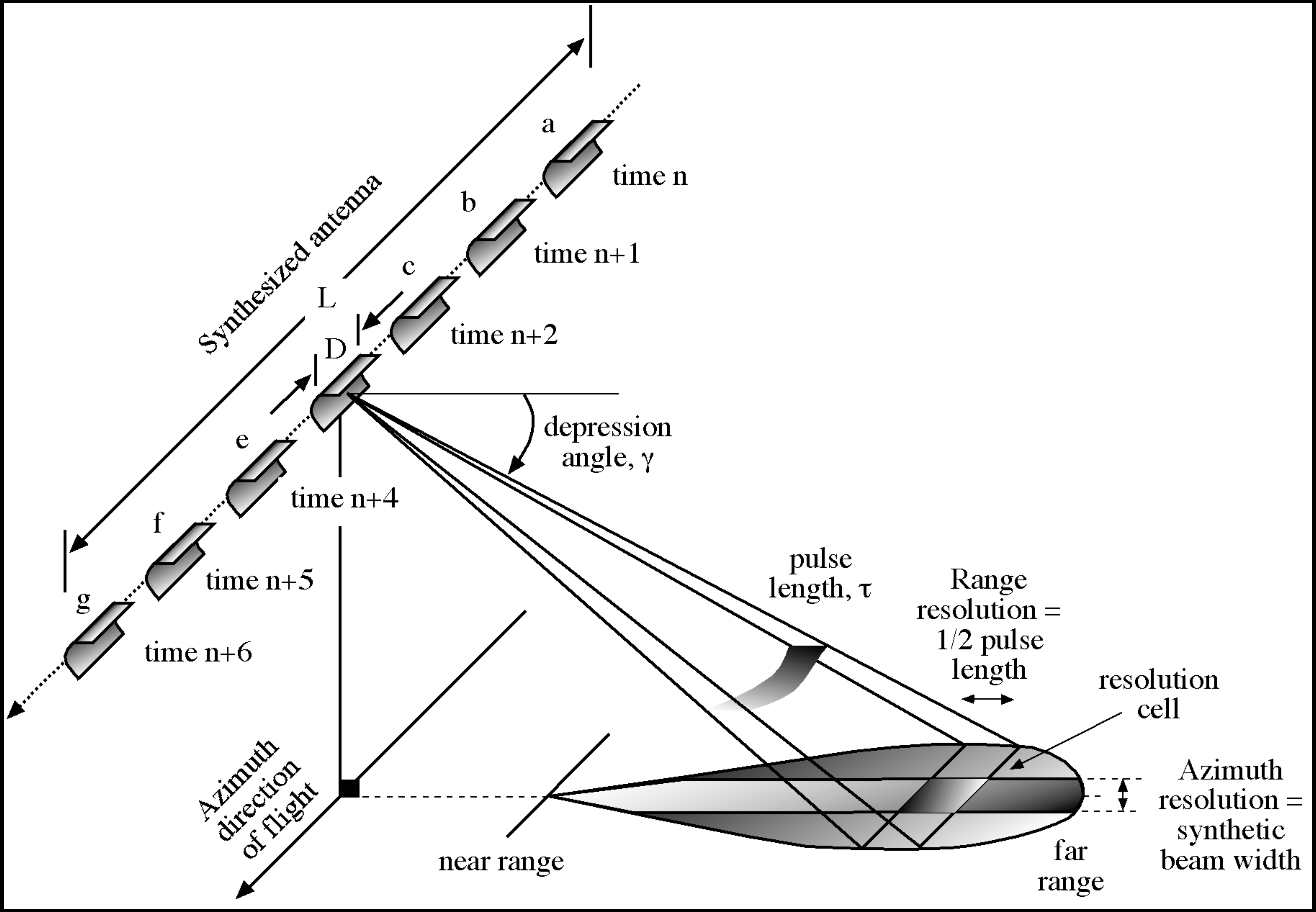
Interferometry SAR (inSAR)



Interferometry SAR (inSAR)



Synthethized Aperture Radar (SAR)



Doppler effect: https://en.wikipedia.org/wiki/File:Speeding-car-horn_doppler_effect_sample.ogg