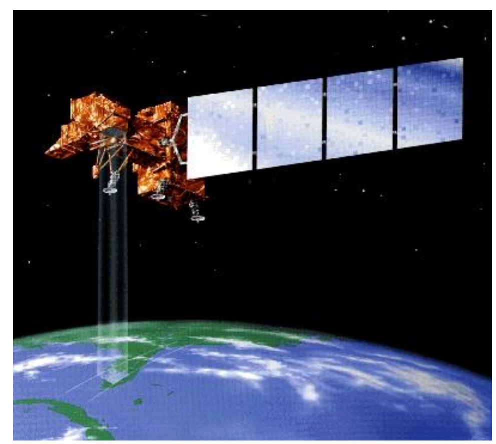



Satellite Remote Sensing
SIO 135/SIO 236

Propagation, Dispersion and Scattering
Rees 3.1, 3.3, 3.5



Electromagnetic Energy Interactions

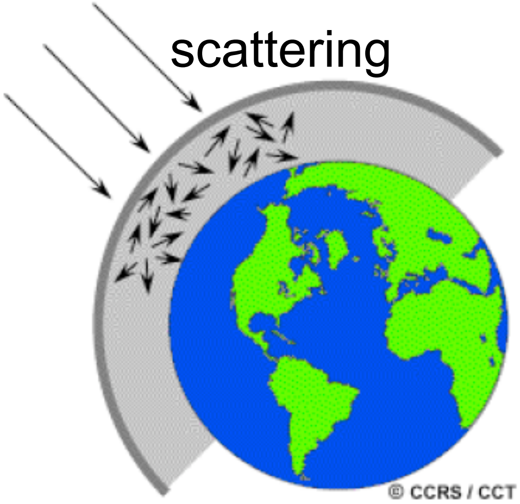
- EM energy is the means by which information is transmitted from an object to a sensor

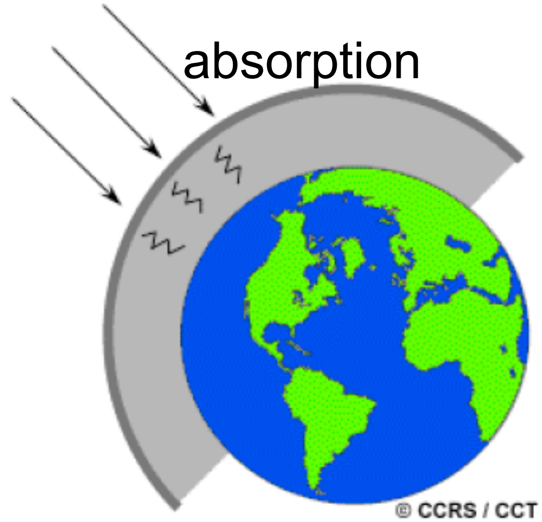
- Energy recorded by sensor undergoes interactions that must be understood to properly interpret the data.

    - Example: if the energy comes from the Sun the following interactions occur:
        - propagates through the vacuum of space at the speed of light
        - interacts with the Earth's atmosphere
        - interacts with the Earth's surface
        - interacts with the Earth's atmosphere again
        - finally reaches the sensor where it interacts with various optical systems, filters, emulsions, or detectors.

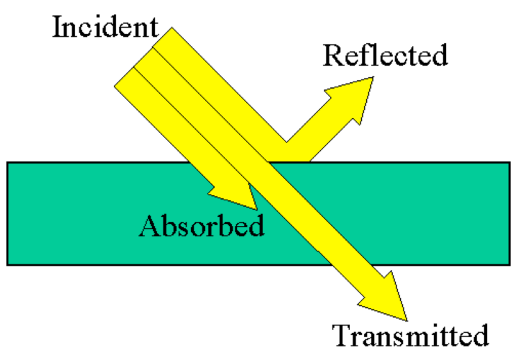
EMR interactions under consideration

- ★ Interaction of EMR with the atmosphere



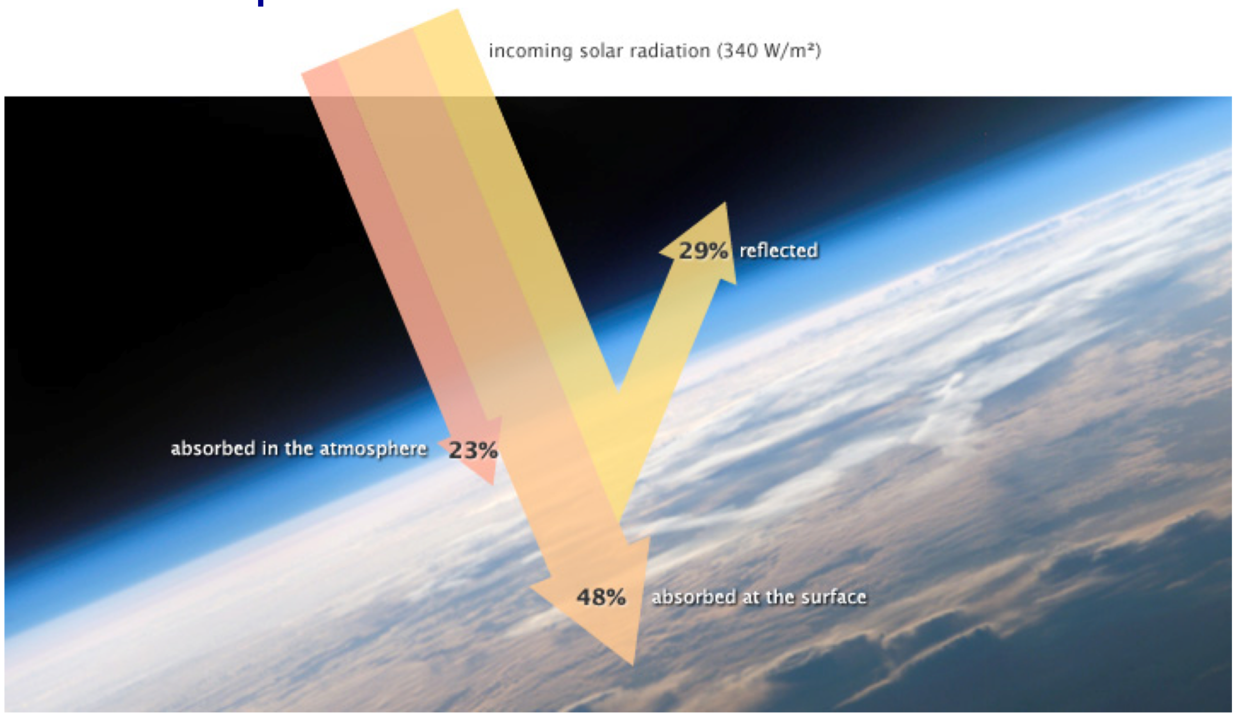


- ★ Interaction of EMR with surface



Interaction of EMR with the atmosphere

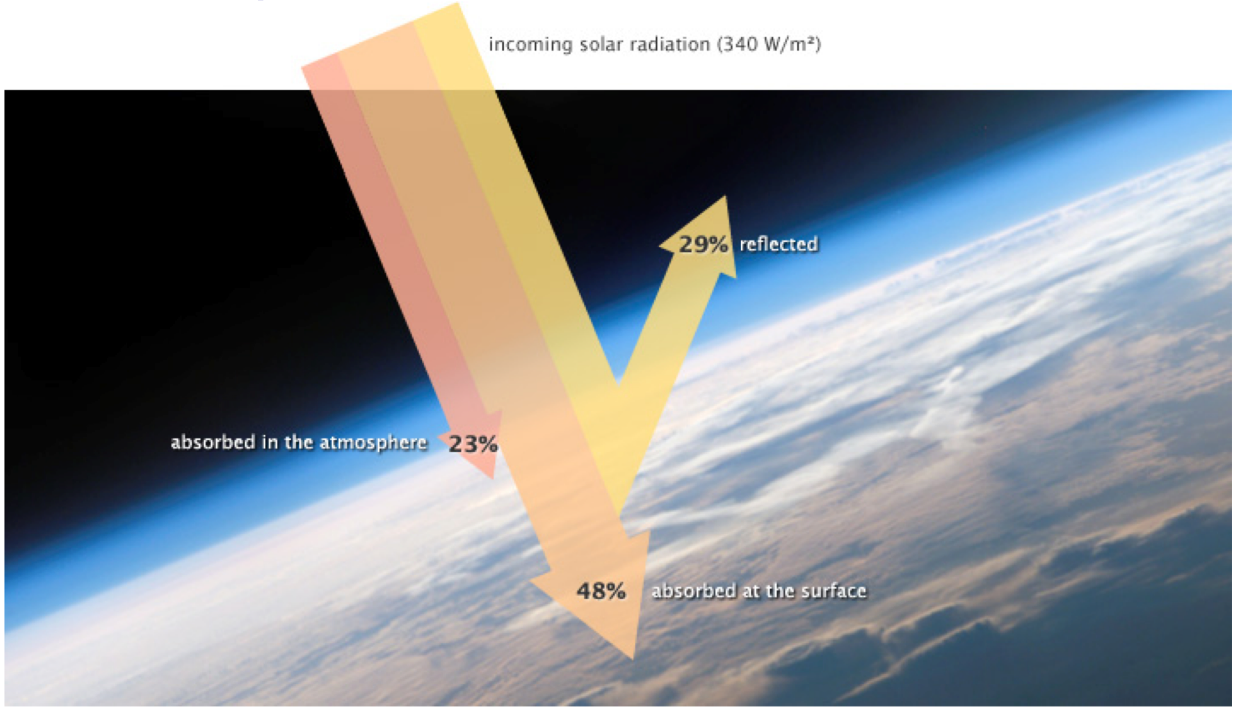
- ★ EMR is **attenuated** by its passage through the atmosphere via scattering and absorption



- ★ Scattering can severely reduce the information content of remote sensing data to the point that the imagery loses contrast and it is difficult to differentiate one object from another.

Interaction of EMR with the atmosphere

- EMR is **attenuated** by its passage through the atmosphere via scattering and absorption



- Scattering differs from reflection because the direction is unpredictable
- Wavelength dependent: scattering decreases with increase in wavelength
- Three types: Rayleigh, Mie & non-selective scattering

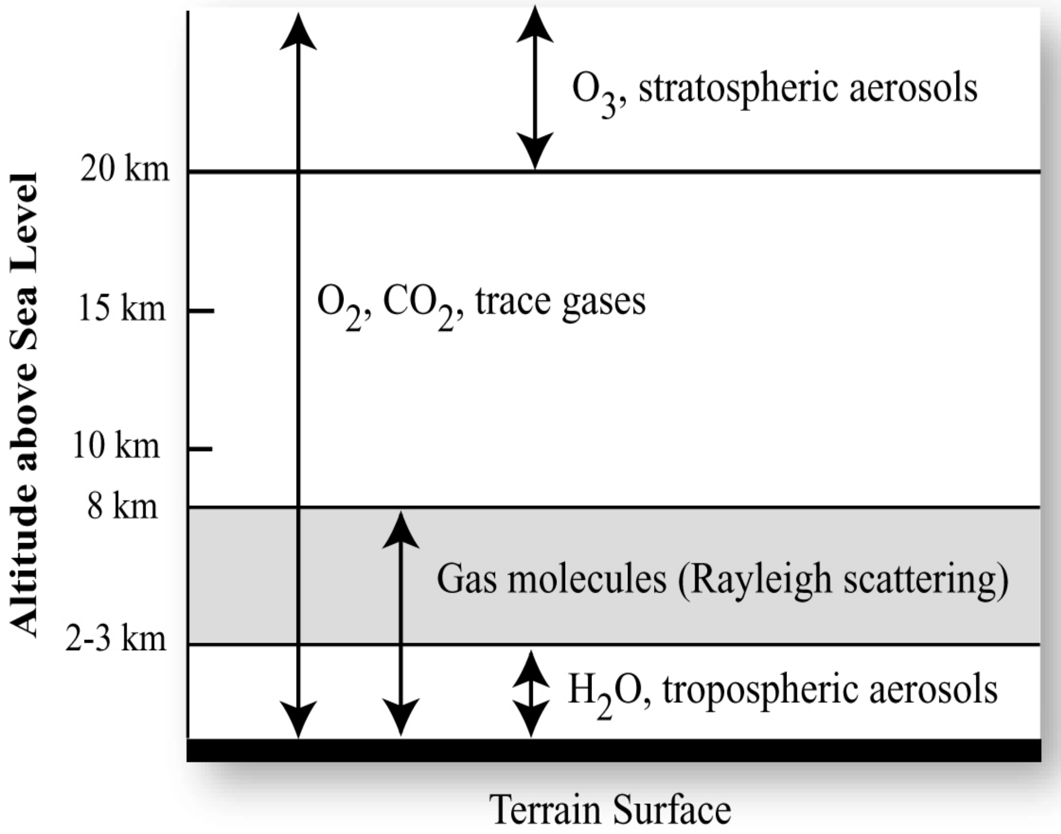
Absorption

- ★ Absorption is the process by which radiant energy is absorbed and converted into other forms of energy.

- ★ An absorption band is a range of wavelengths (or frequencies) in the EM spectrum within which radiant energy is absorbed by substances such as water (H_2O), carbon dioxide (CO_2), oxygen (O_2), ozone (O_3), and nitrous oxide (N_2O).

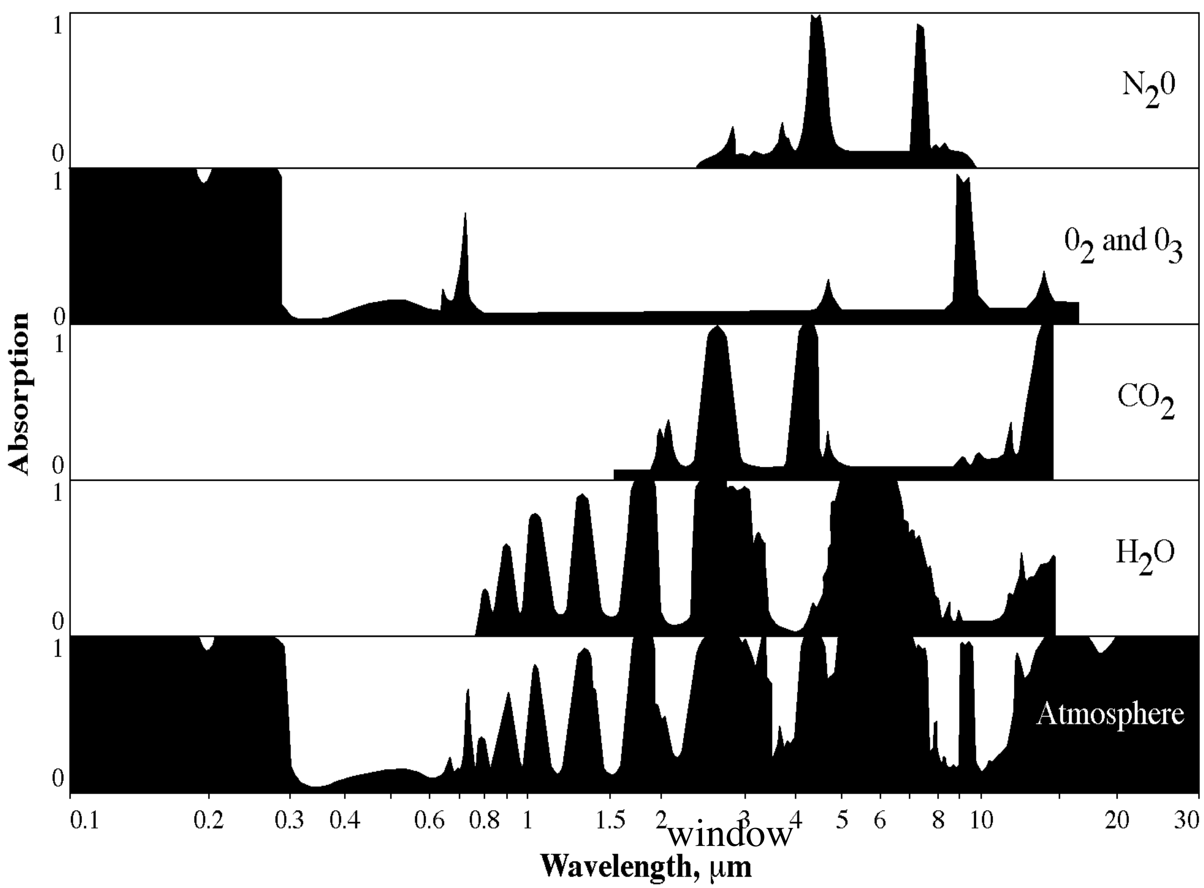
- ★ The cumulative effect of the absorption by the various constituents can cause the atmosphere to close down in certain regions of the spectrum. This is bad for remote sensing because no energy is available to be sensed.

Atmospheric Layers and Constituents



Major subdivisions of the atmosphere and the types of molecules and aerosols found in each layer.

Absorption of EM radiation by atmosphere

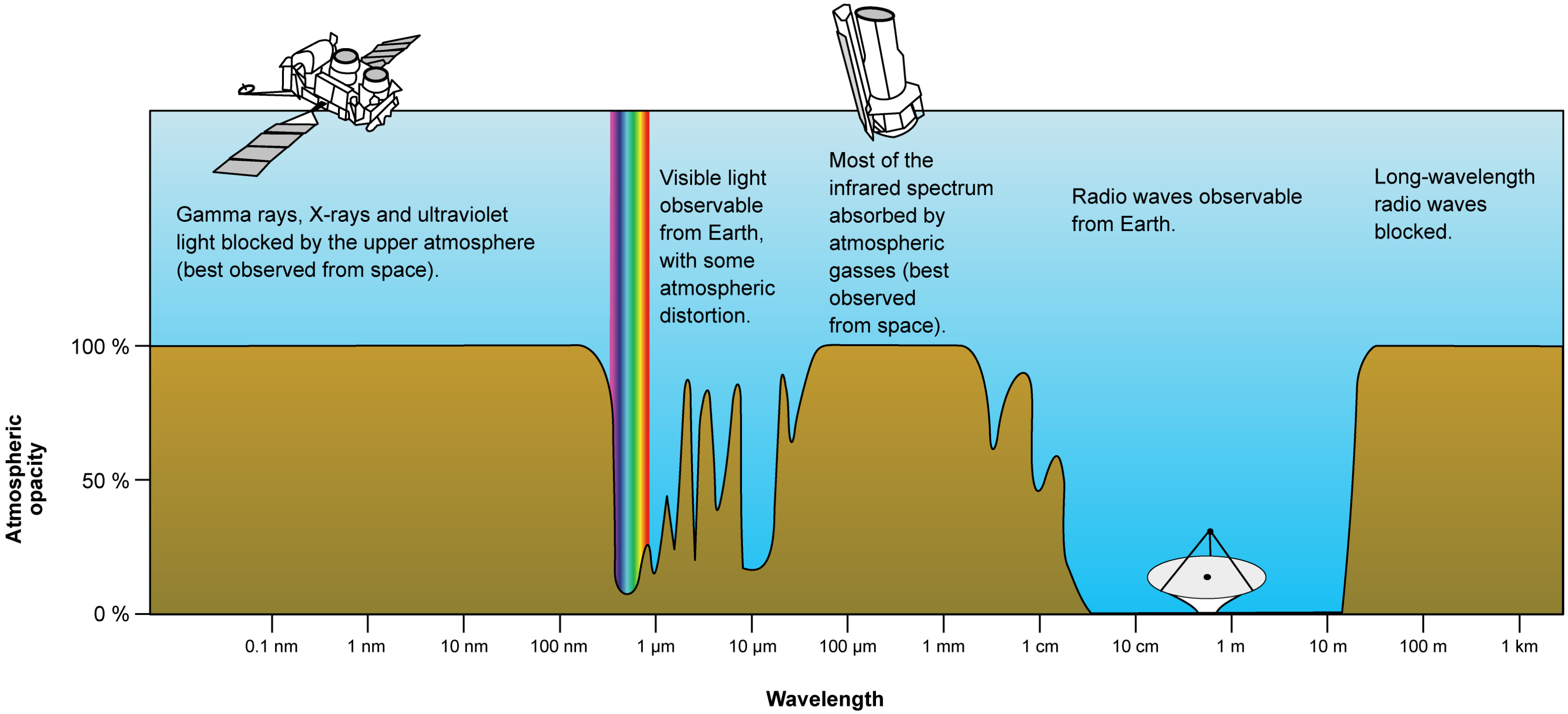


Different molecules absorb different wavelengths of radiation:

★ O_2 and O_3 absorb almost all wavelengths shorter than 300 nm.

★ Water (H_2O) absorbs many wavelengths above 700 nm, depends on the amount of water vapor in the atmosphere (tropics vs poles)

Absorption of EM radiation by atmosphere



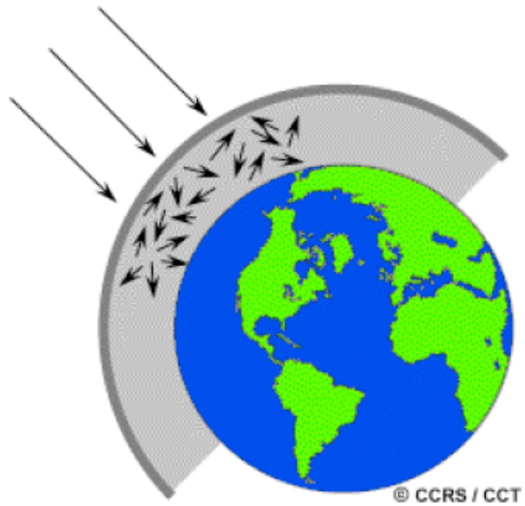
★ When you combine the absorption spectra of the gasses in the atmosphere, you are left with "windows" of low opacity, allowing the transmission of only certain EM radiation.

★ Optical window runs from around 300 nm (UV-C) up to 400–700 nm (visible spectrum) and continues to around 1100 nm (infrared).

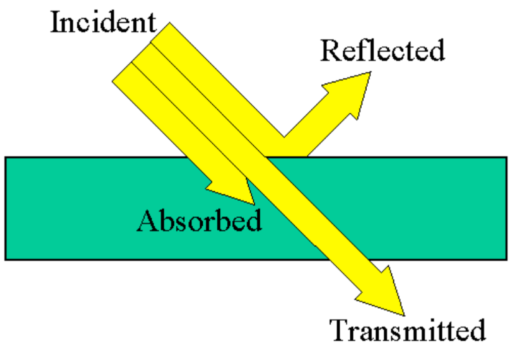
★ There are also infrared and radio/microwave windows.

Interactions under consideration

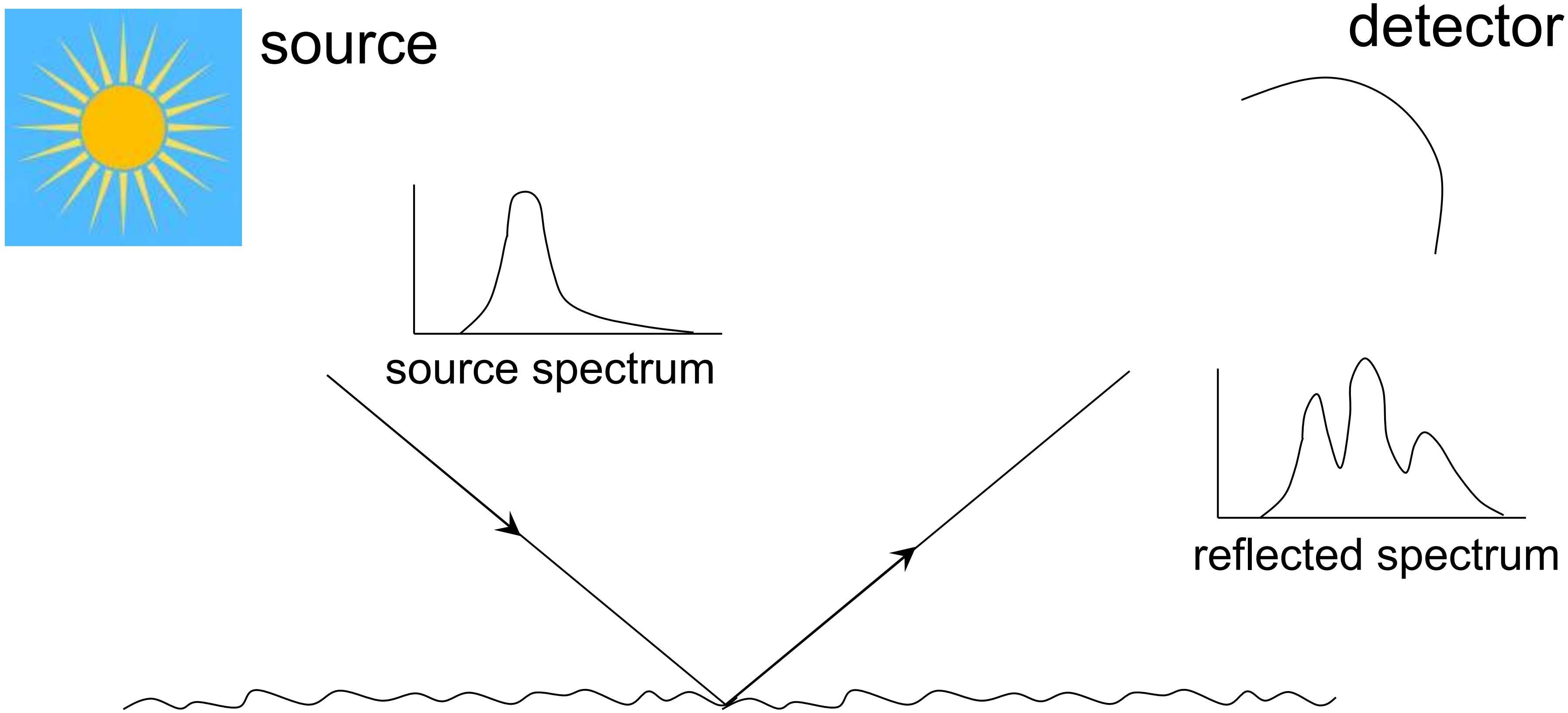
★ Interaction of EMR with the atmosphere



★ Interaction of EMR with surface



Interaction of EMR with matter



- ★ Some incident energy is reflected and some is absorbed
- ★ Surface spectral imprint is embedded in the spectrum of the reflected wave

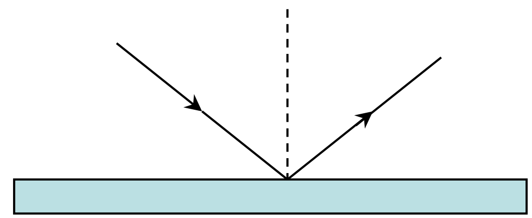
Reflection from rough surfaces

- All active remote sensing systems as well as passive systems which measure reflected sunlight involve reflection of radiation from a rough surface
- Surface roughness is important even for passive systems which measure thermal emissions since r = 1 - ε

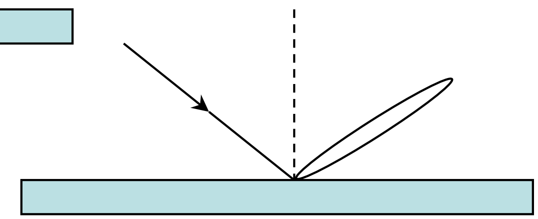
Term	Symbol	Definition	Units
Radiant flux	ϕ	$\frac{dQ}{dt}$	$[W]$
Radiant irradiance	E	$\frac{d\phi}{dA}$	$[W\ m^{-2}]$
Radiant exitance	M	$\frac{d\phi}{dA}$	$[W\ m^{-2}]$
Radiant intensity	I	$\frac{d\phi}{d\omega}$	$[W\ sr^{-1}]$
Radiance (radiant sterance)	L	$\frac{d^2\phi}{d\omega dA \cos\theta}$	$[W\ sr^{-1}\ m^{-2}]$

Surface scattering

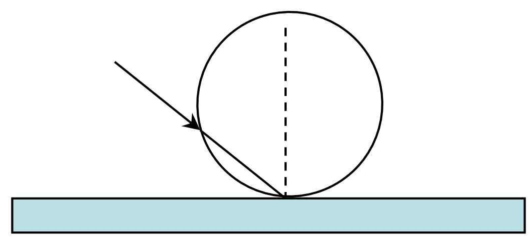
- Specular



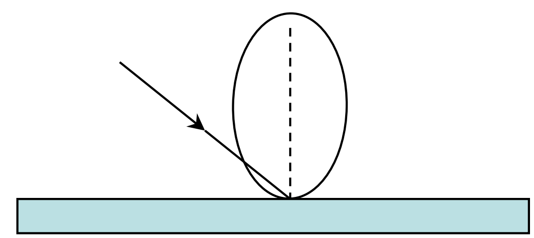
- Quasi-specular



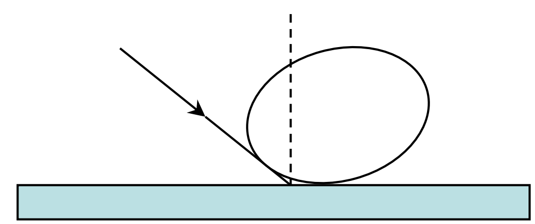
- Lambertian



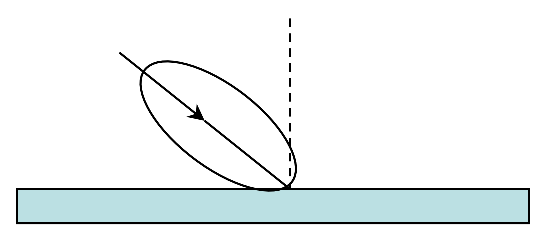
- Minnaert model



- Henyey-Greenstein model for forward scatter



- Henyey-Greenstein of backscatter



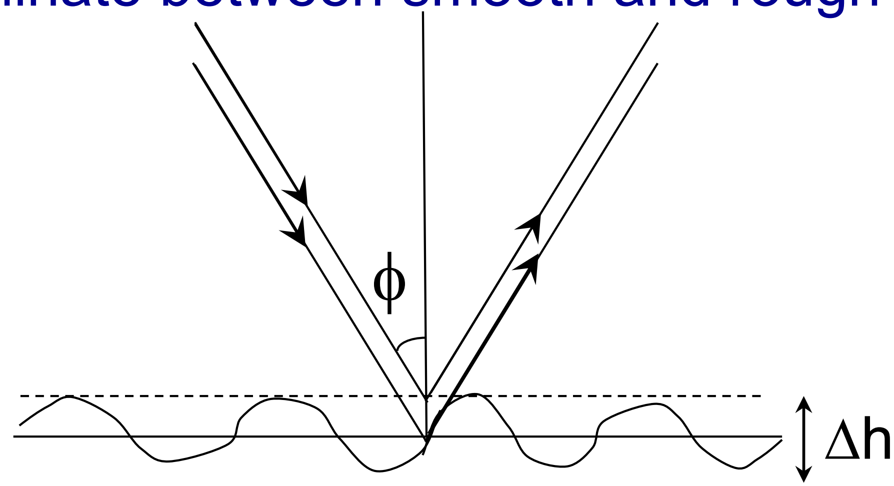
BRDF
Notes on BB

Some typical albedos

Material	Albedo (0 to 1)
Water (naturally occurring)	0.01 to 0.1
Water (pure)	0.02
Forest	0.05-0.1
Crops	0.05-0.15
Urban areas	0.05-0.2
Grass	0.05-0.3
Soil	0.05-0.3
Cloud (low)	0.05-0.65
Lava	0.15-0.2
Sand	0.2-0.4
Ice	0.25-0.4
Granite	0.3-0.35
Cloud (high)	0.3-0.85
Limestone	0.35-0.4
Snow (old)	0.45-0.7
Snow (fresh)	0.75-0.9
Global average	~0.35

Rayleigh criterion

The Rayleigh criterion is used to discriminate between smooth and rough surfaces.



Path difference $= 2\,\Delta h \cos\phi$

Phase difference $= \dfrac{2\pi}{\lambda}\,2\,\Delta h \cos\phi$

Surface is considered smooth if phase difference < π/2 (approx. 1 radian)

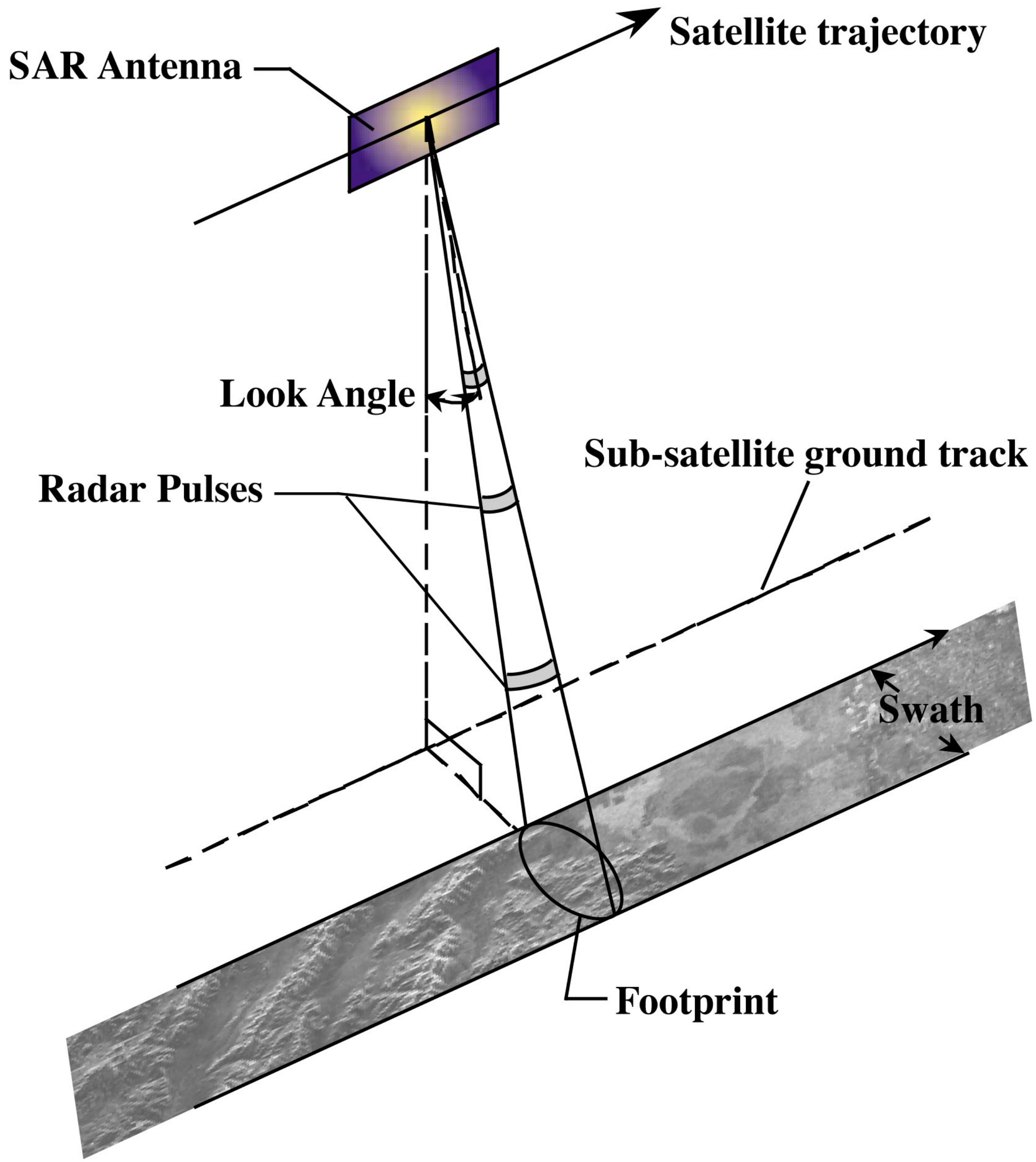
$$\frac{4\pi\,\Delta h \cos\phi}{\lambda} < \pi/2 \quad \Rightarrow \quad \Delta h < \frac{\lambda}{8\cos\phi}$$

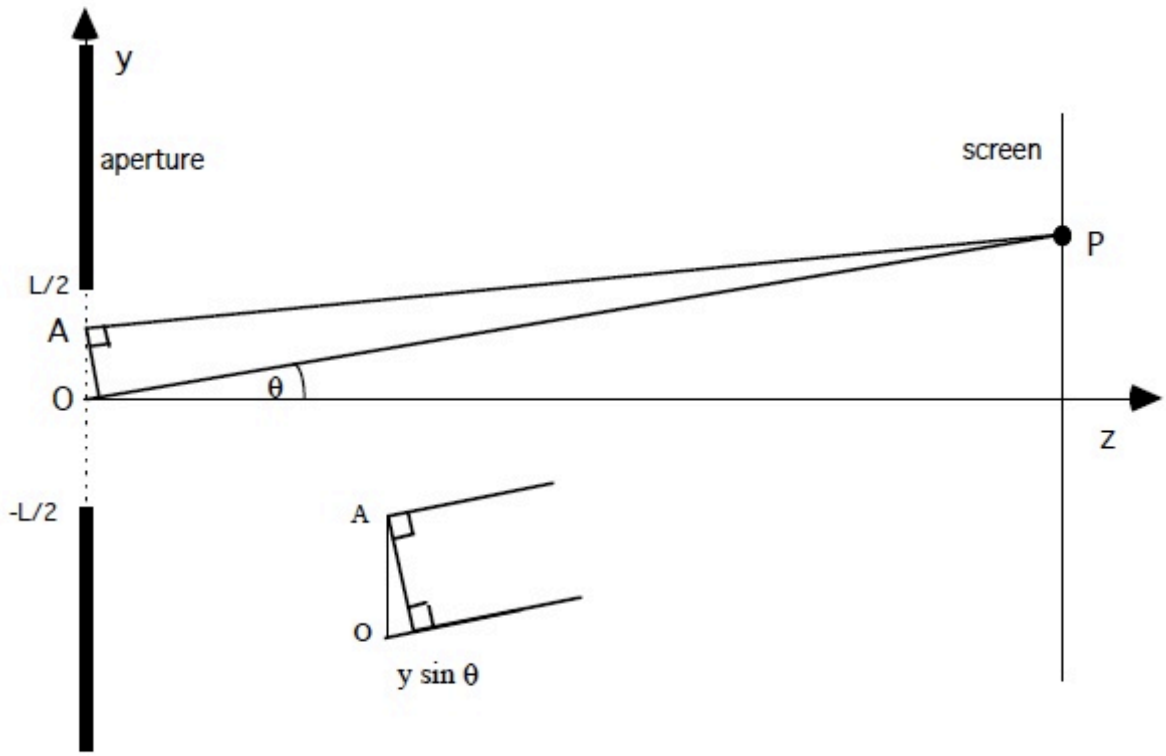
For ordinary incidence angles $\Delta h < \lambda/8$

For 0.5 μm (blue light) $\Delta h < 62$ nm

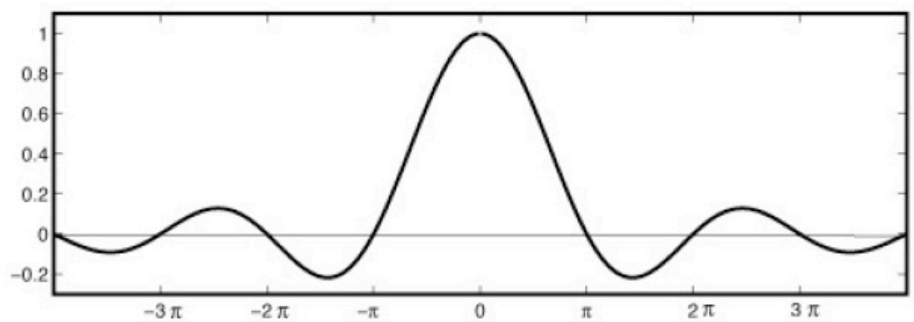
For 8 cm (microwave) $\Delta h < 1$ cm

Rayleigh roughness
Notes on BB


SAR Antenna
Satellite trajectory
Look Angle
Sub-satellite ground track
Radar Pulses
Swath
Footprint

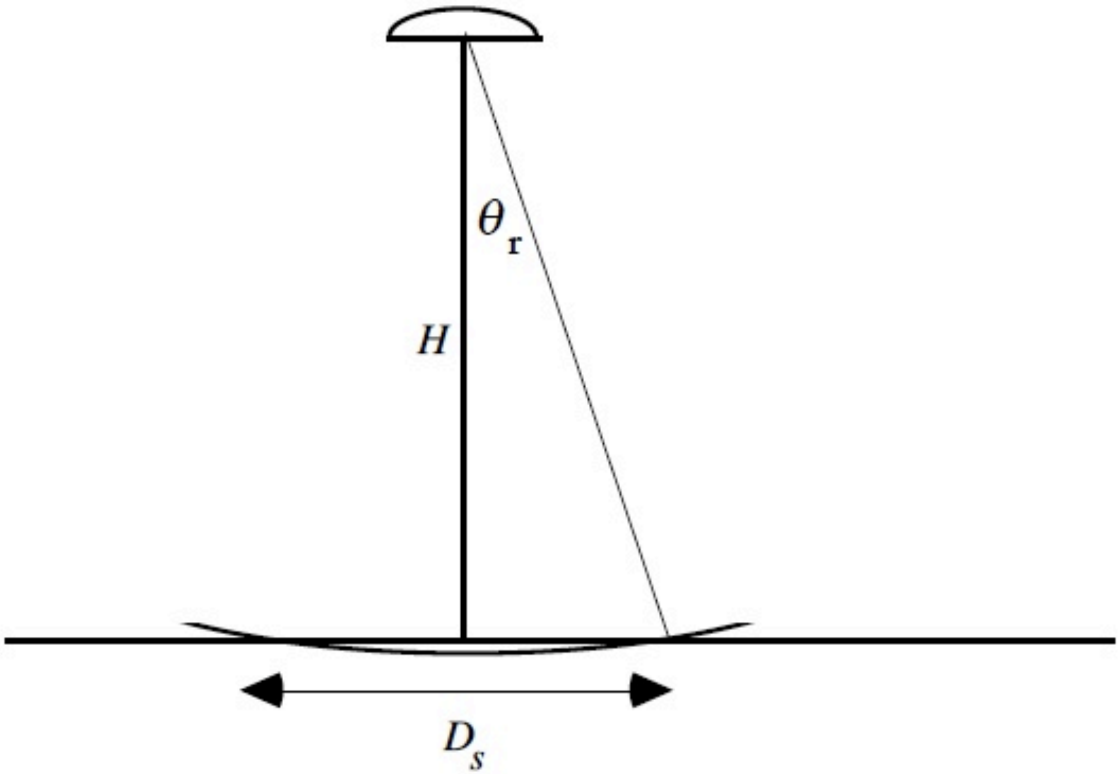


The illumination pattern on the screen is shown in the following diagram.



The first zero crossing, or angular resolution θ_r of the sinc function occurs when the argument is π so $\sin\theta_r = \dfrac{\lambda}{L}$ and for small angles $\theta_r \cong \lambda/L$ and $\tan\theta_r \cong \sin\theta_r$. Note that

resolution: optical vs. microwave



$$D_s = 2H\sin\theta_r = 2H\frac{\lambda}{L}$$

$$H = 800km.$$

$Optical:$

$L = 1m$

$\lambda = 0.5\mu m$

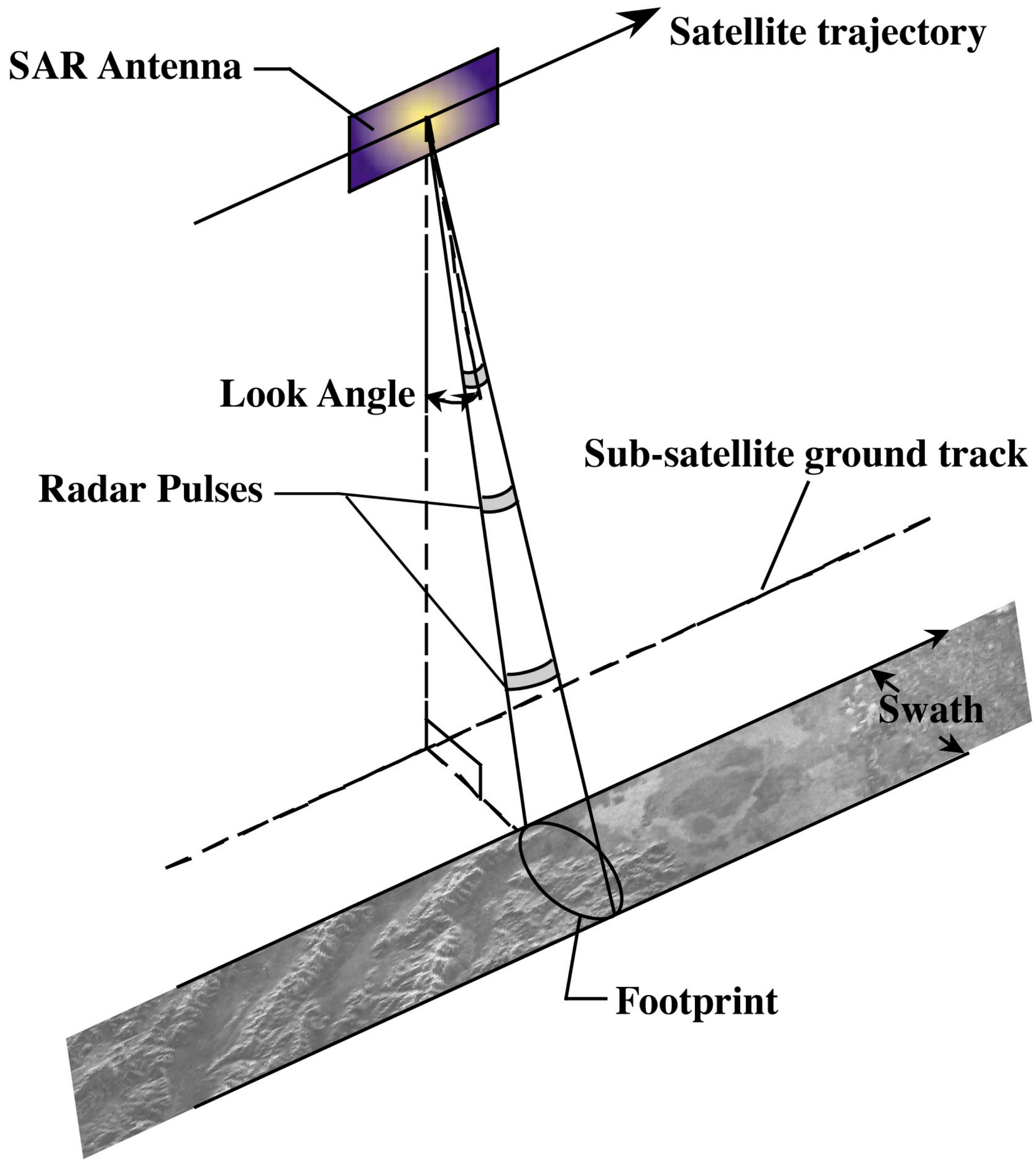
$D_s = 0.8m$

$Microwave:$

$L = 10m$

$\lambda = 0.23m$

$D_s = 46{,}000m$!!!!!!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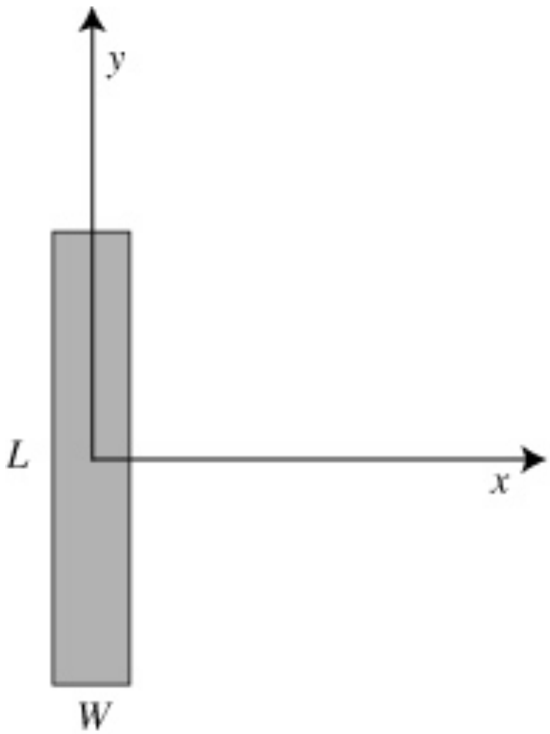
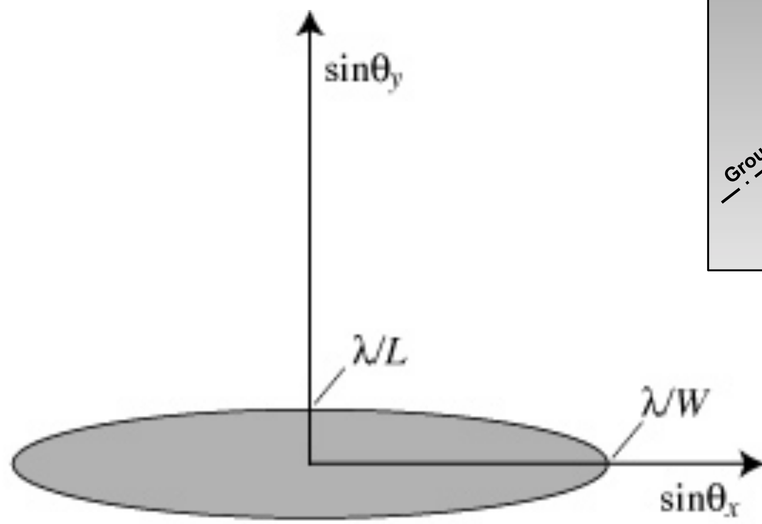
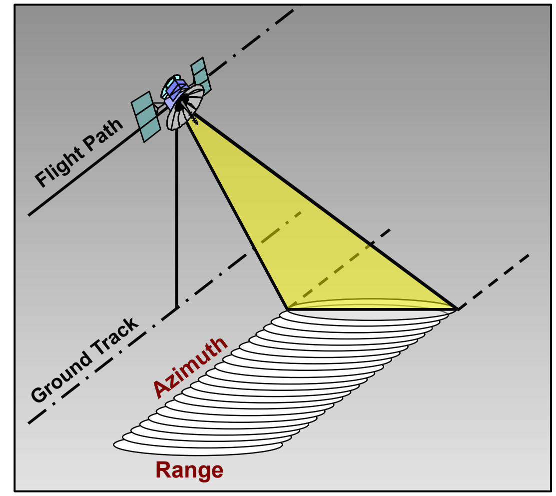
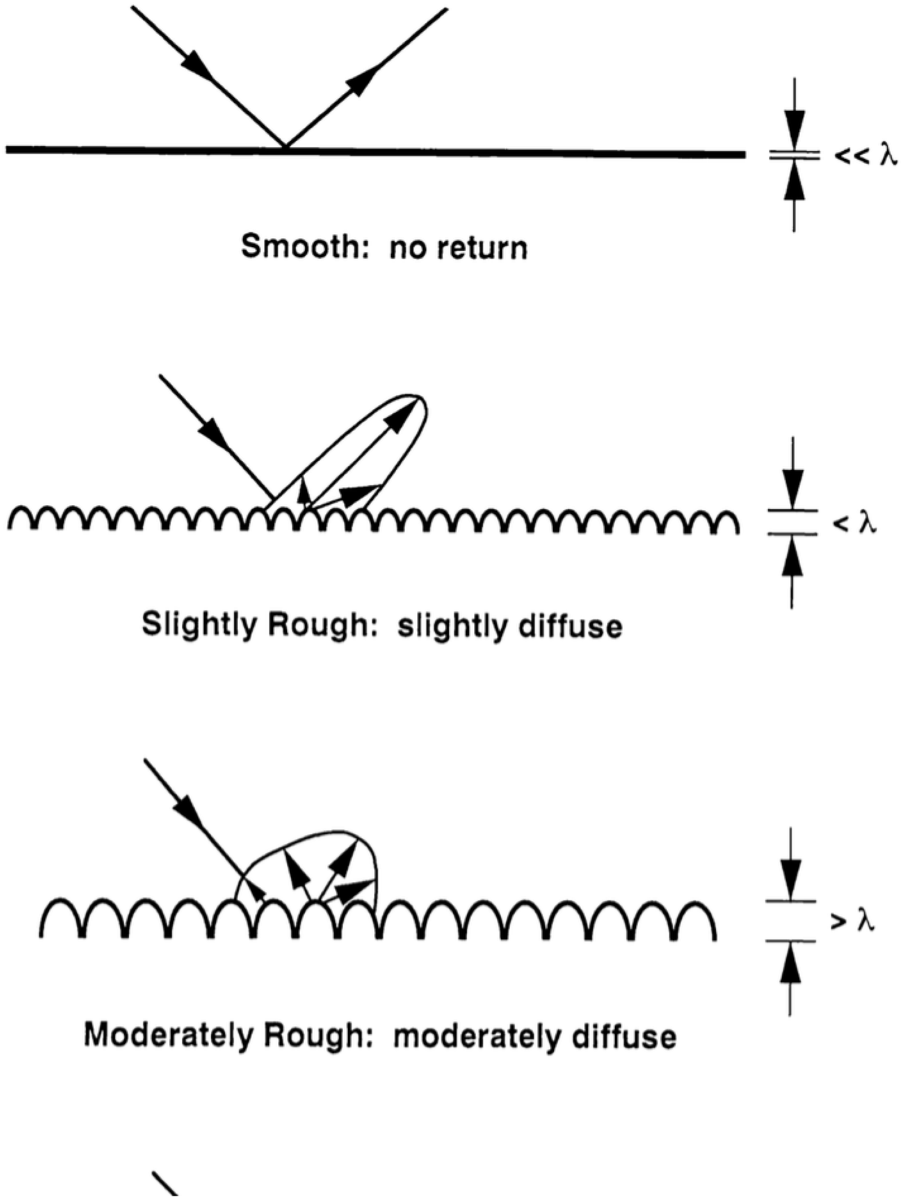
2-D Aperture







$$P(\theta_x,\theta_y) = \int_{-L/2}^{L/2}\int_{-W/2}^{W/2} A(x,y)\exp\left[i\frac{2\pi}{\lambda}\left(x\sin\theta_x + y\sin\theta_y\right)\right]dxdy \quad \longrightarrow \quad P(\theta_x,\theta_y) = LW\ \mathrm{sinc}\left(\frac{\pi W\sin\theta_x}{\lambda}\right)\ \mathrm{sinc}\left(\frac{\pi L\sin\theta_y}{\lambda}\right)$$



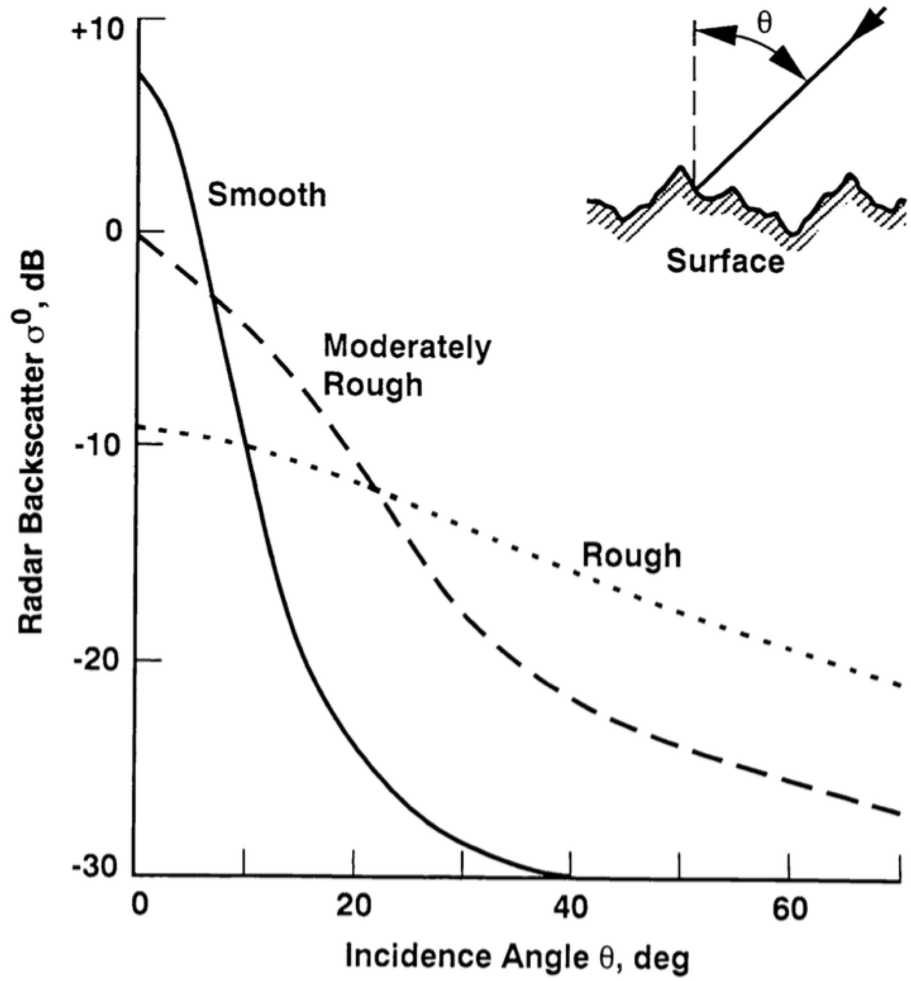
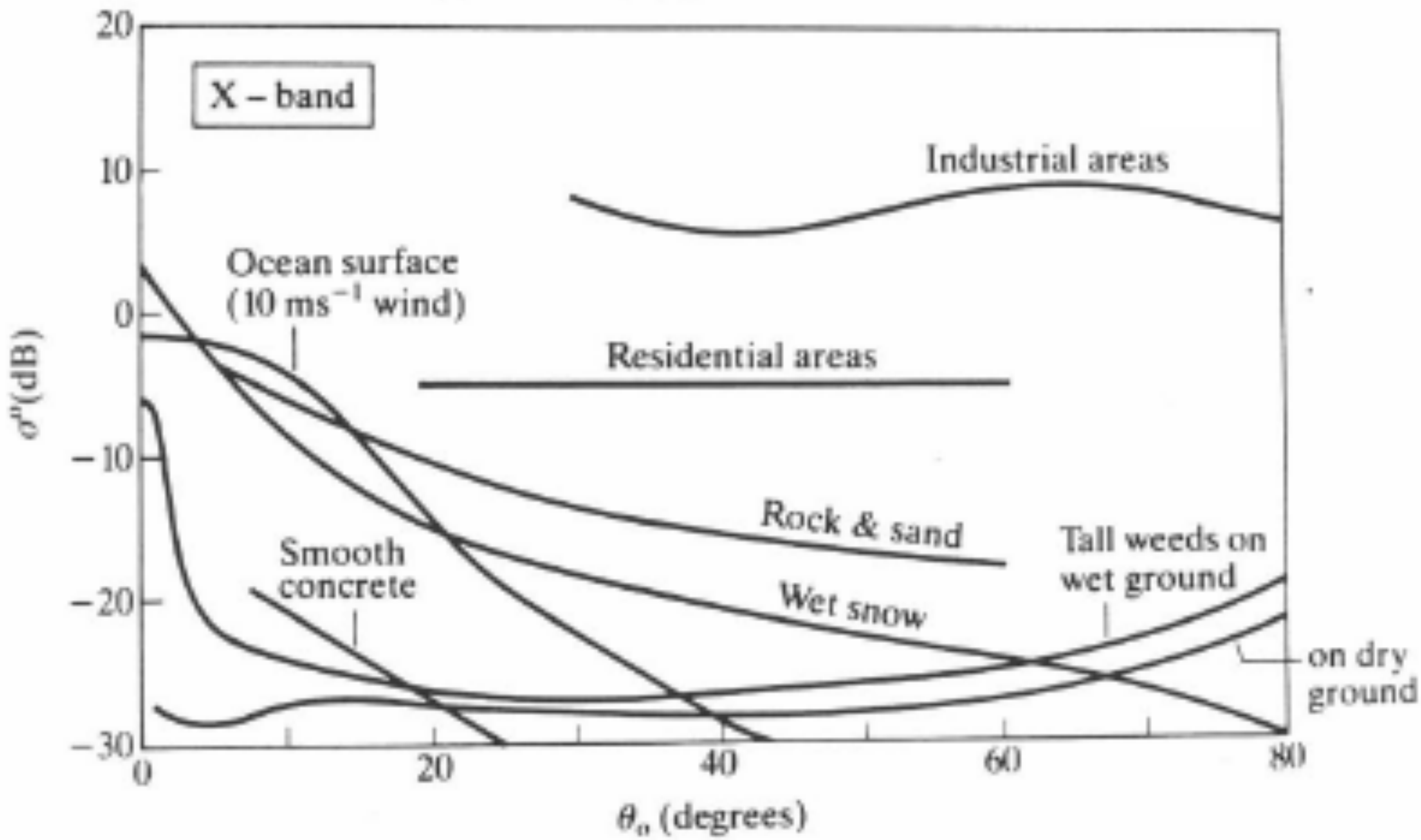


Figure 5-9. Radar backscatter as a function of incidence angle for representative surfaces. For angles less than about 25 deg, smoother surfaces have greater backscatter than rougher surfaces.

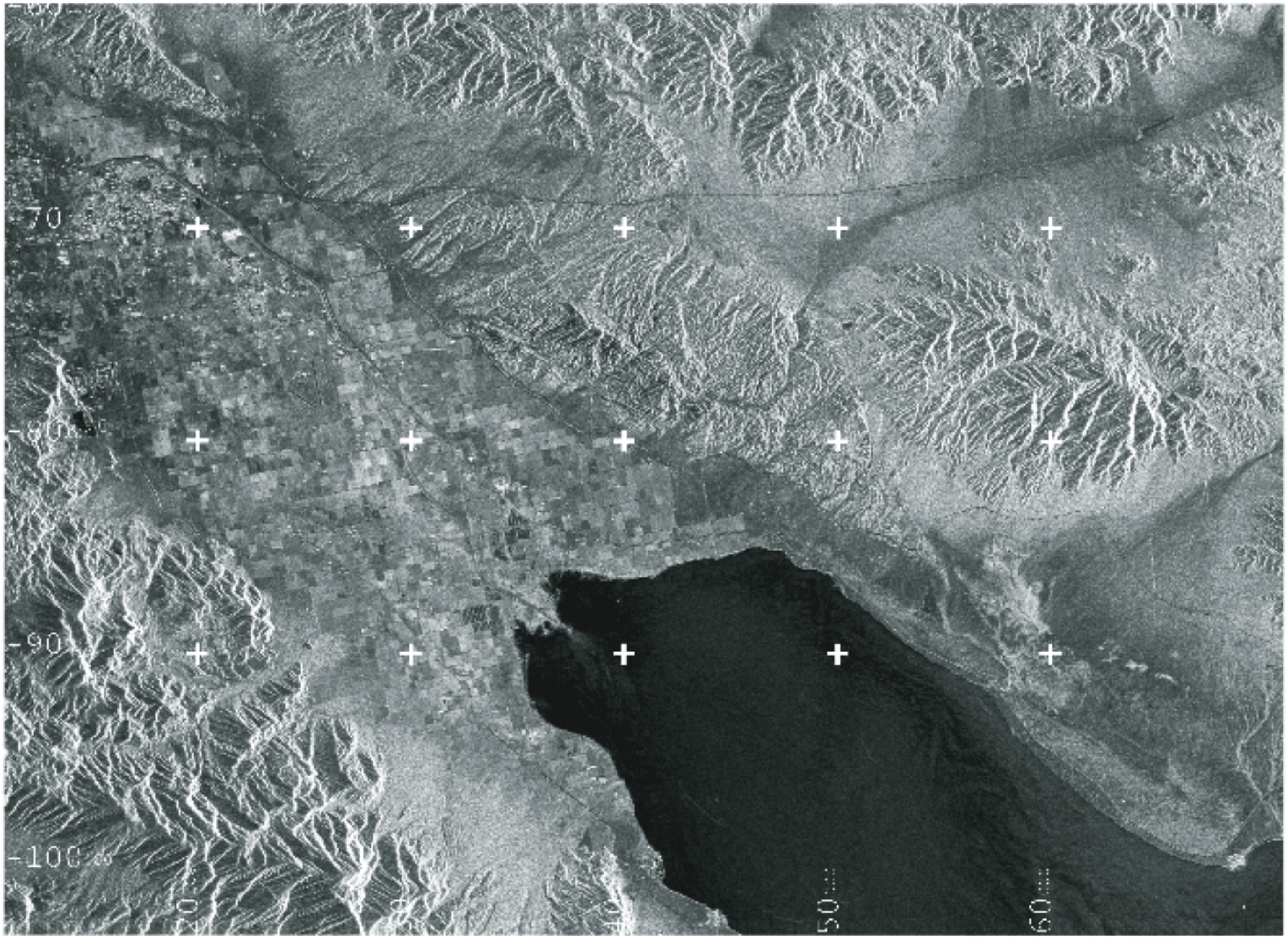
[Farr, 1993,Radar Interactions With Geological Surfaces]

Backscattering coefficients

Typical values of the dimensionless backscattering coefficient σ°, as a function of incident angle



amplitude image



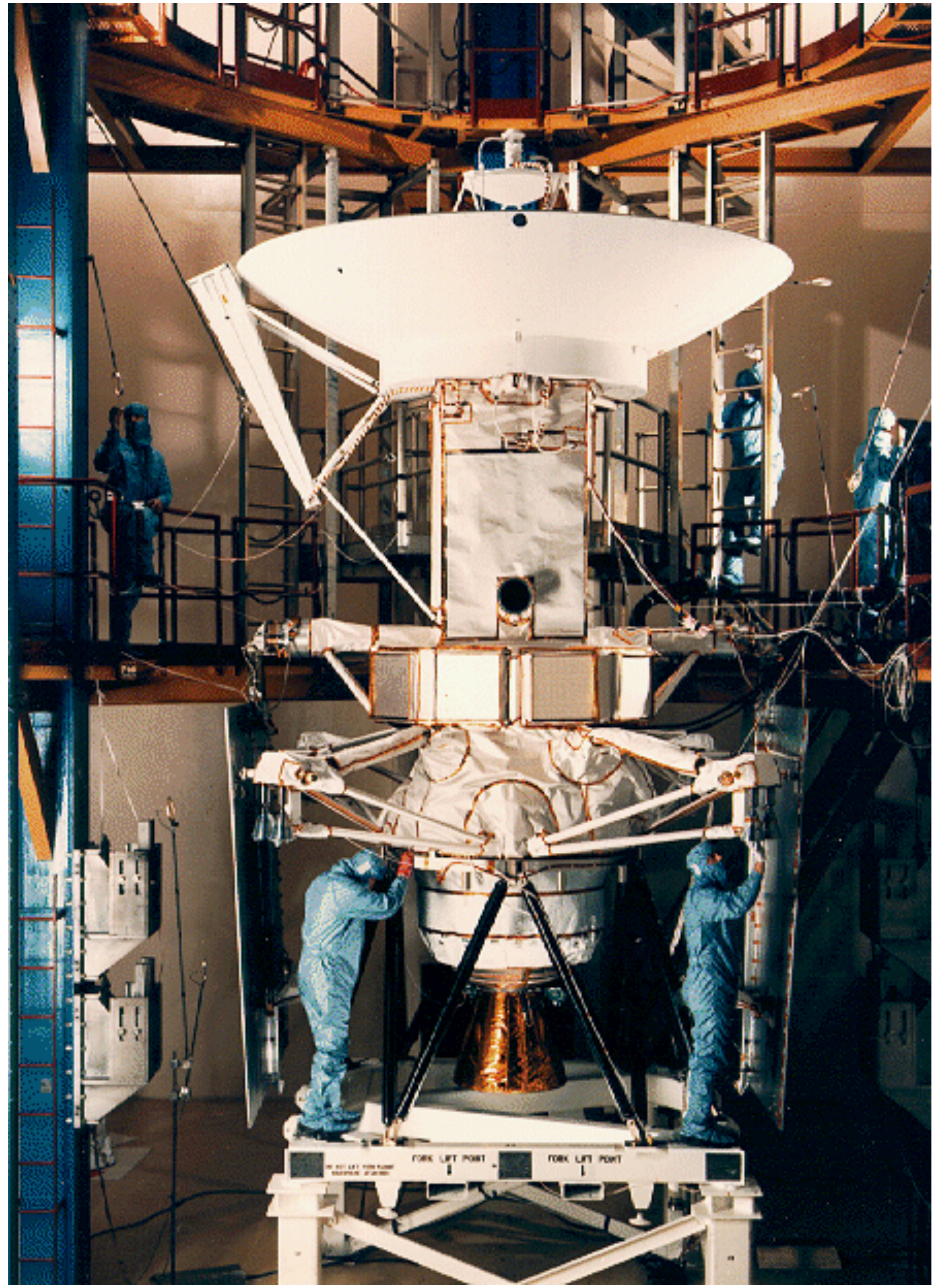
1) This is an image of radar backscatter from a stack of ERS SAR data. The flight path is top to bottom and the radar looks from the right. The area is the Salton Sea and Cochella Valley, and the tic marks are spaced at 10 km. The satellite is 7159717m from the center of the Earth, the local Earth radius is 6371593 m, and the range to the center of the image is 850148 m. Calculate the look angle to the center of the image. Identify areas of layover. What is the minimum mountain slope in the areas of layover? Why is the Salton Sea dark?

zoom of amplitude image

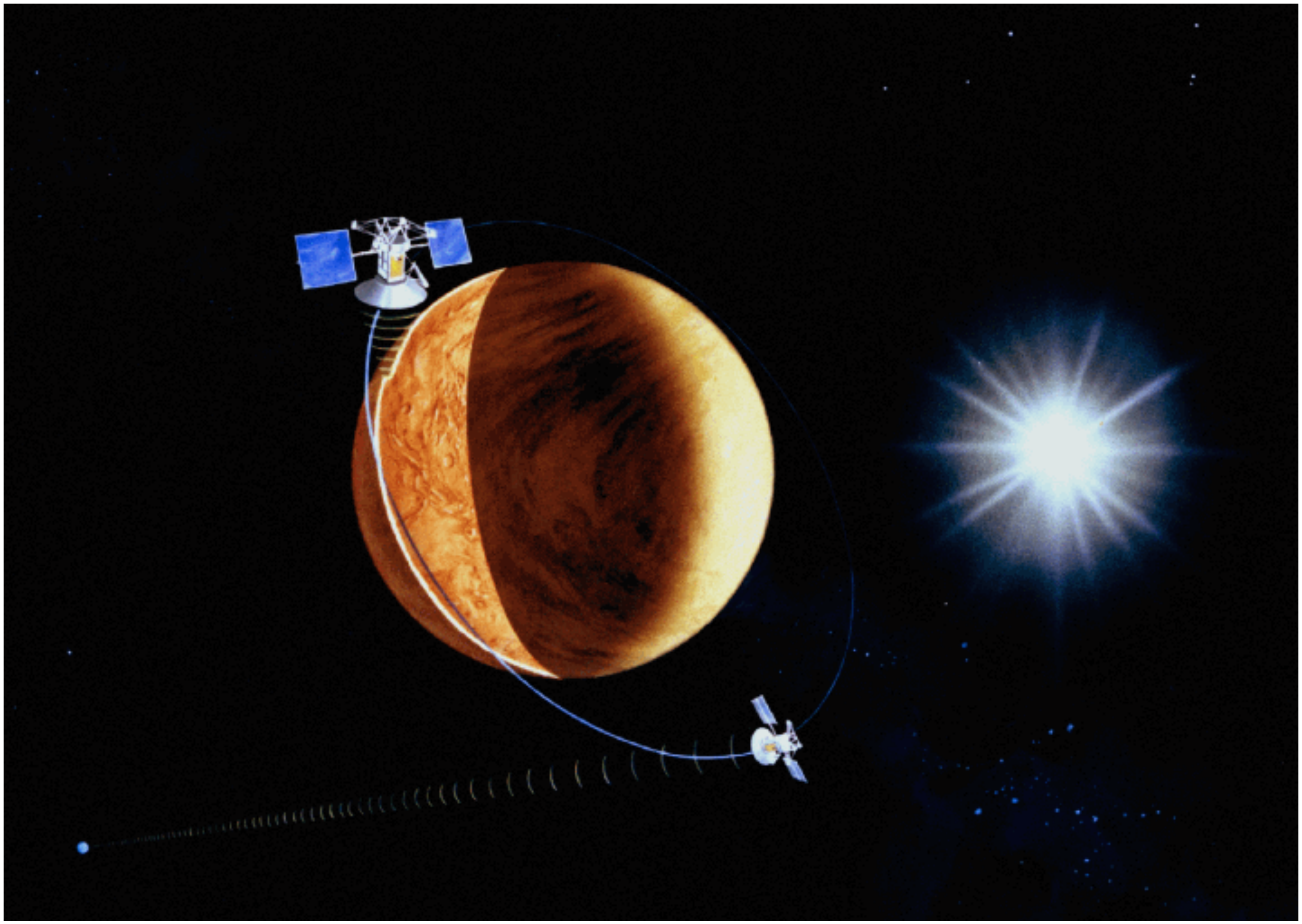
2) This is a zoom of the previous image with 5 km tic marks. Use a map to identify each of the three curved lines running through the images. Why do the fields have different backscatter? Why aren't the fields exactly square? Why do the bright spots have cross patterns?

Magellen SAR

1990-1994



Magellen SAR 1990-1994

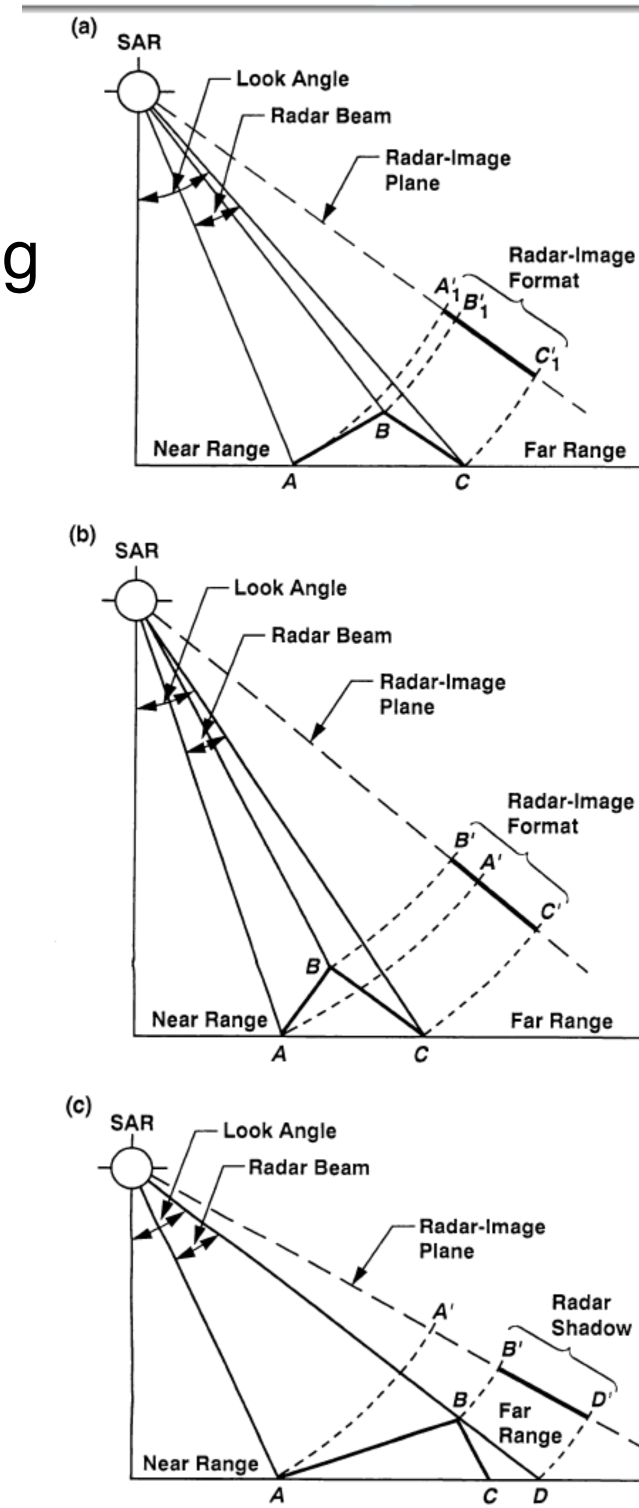


geometry

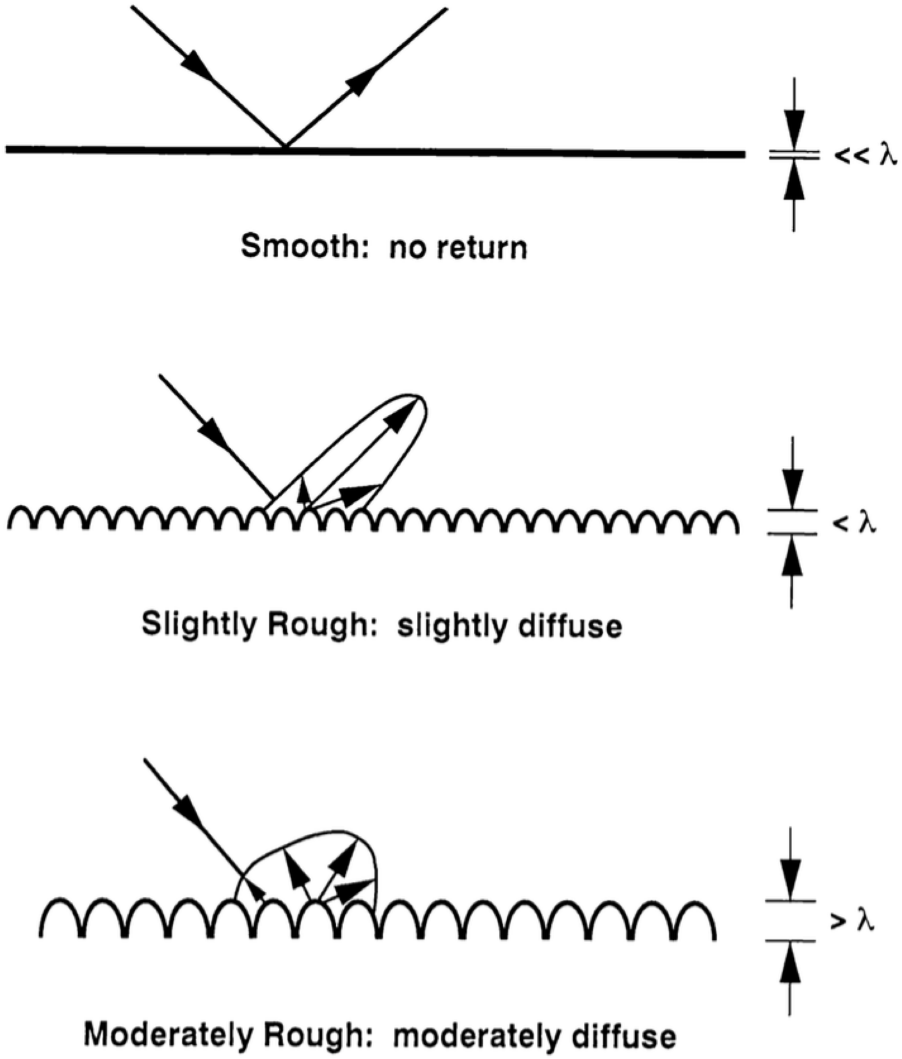
foreshortening

layover

shadowing



[Farr, 1993,Radar Interactions With Geological Surfaces]



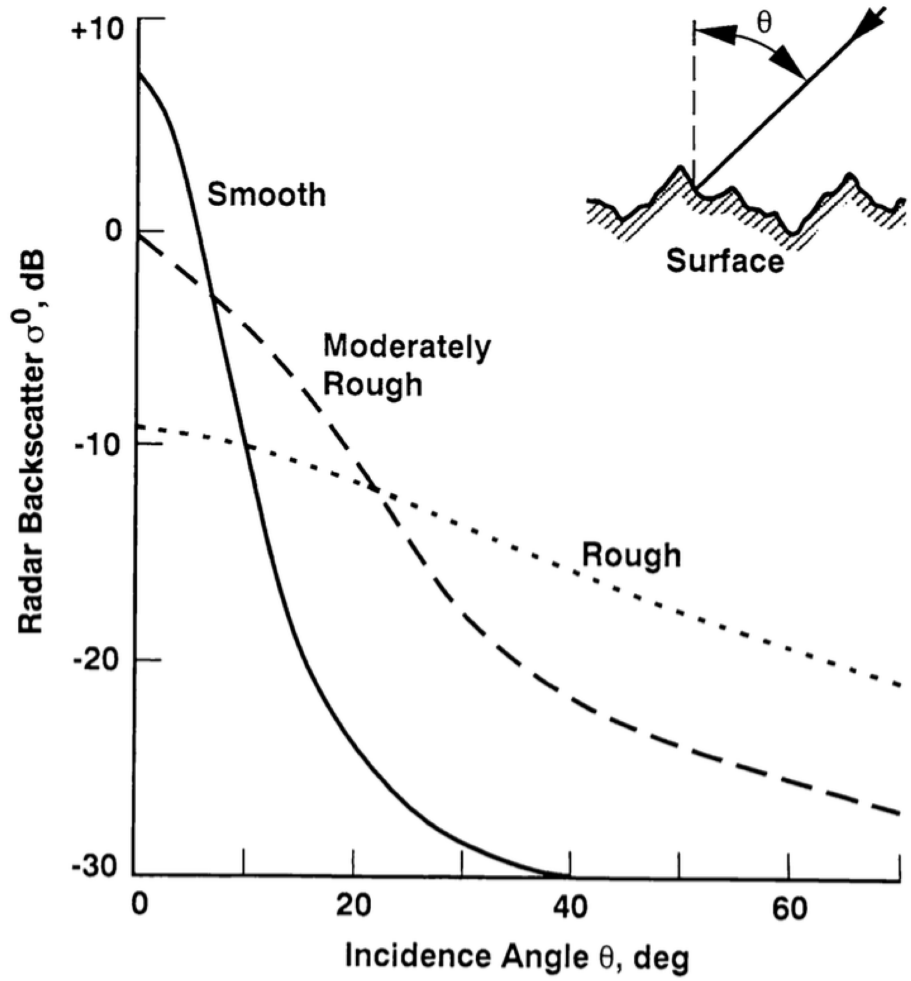


Figure 5-9. Radar backscatter as a function of incidence angle for representative surfaces. For angles less than about 25 deg, smoother surfaces have greater backscatter than rougher surfaces.

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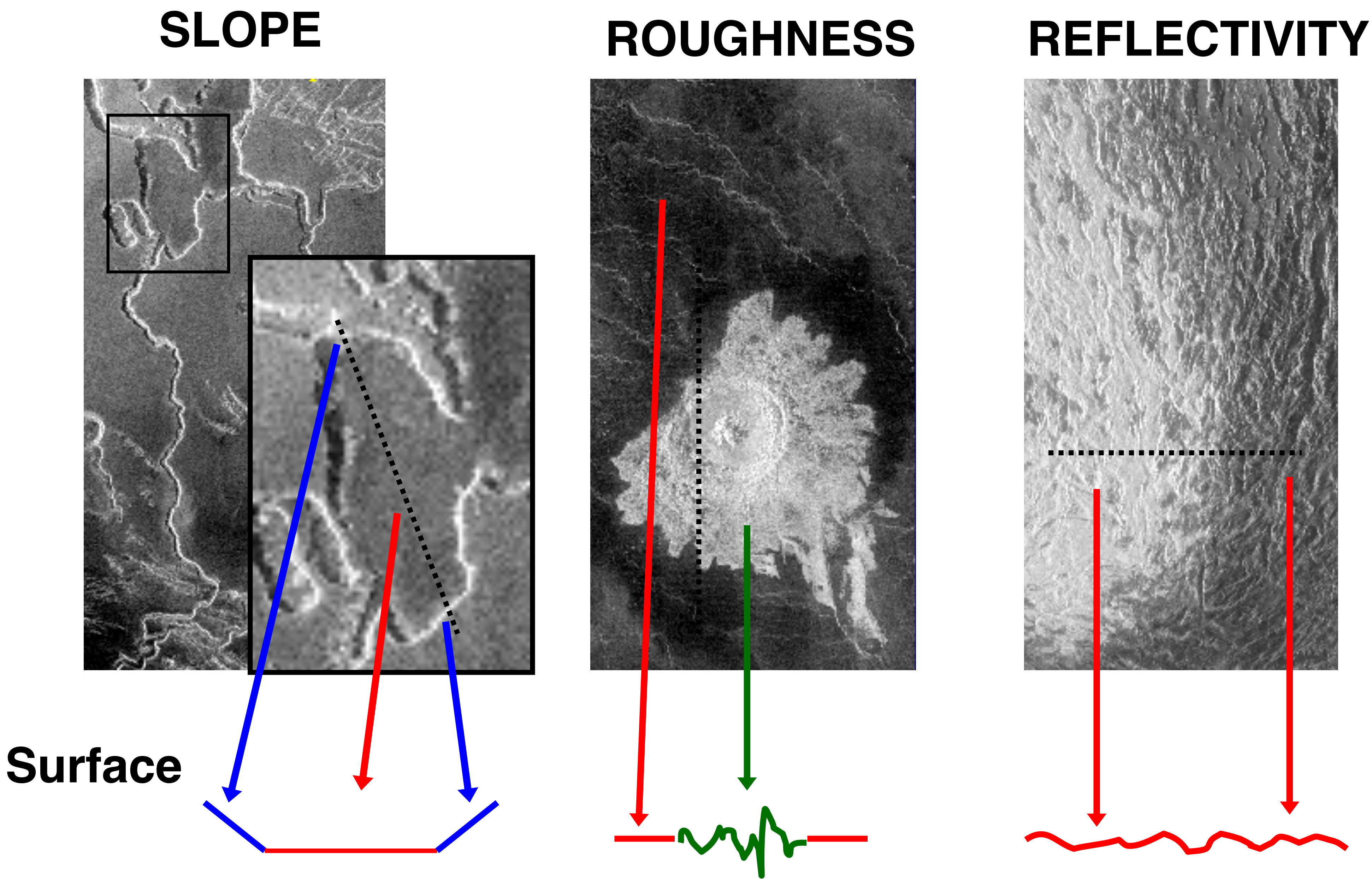
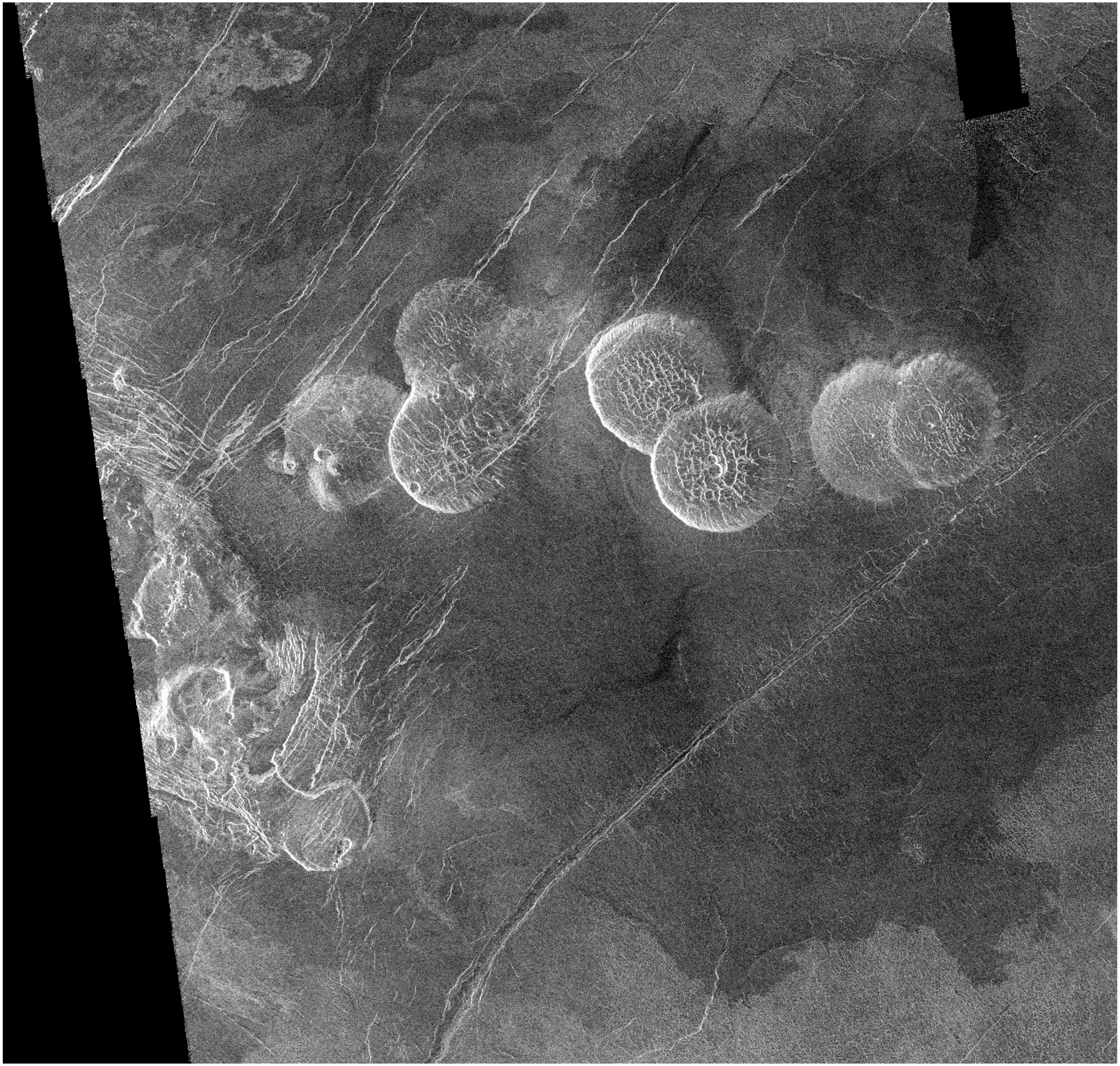
Radar Image Properties



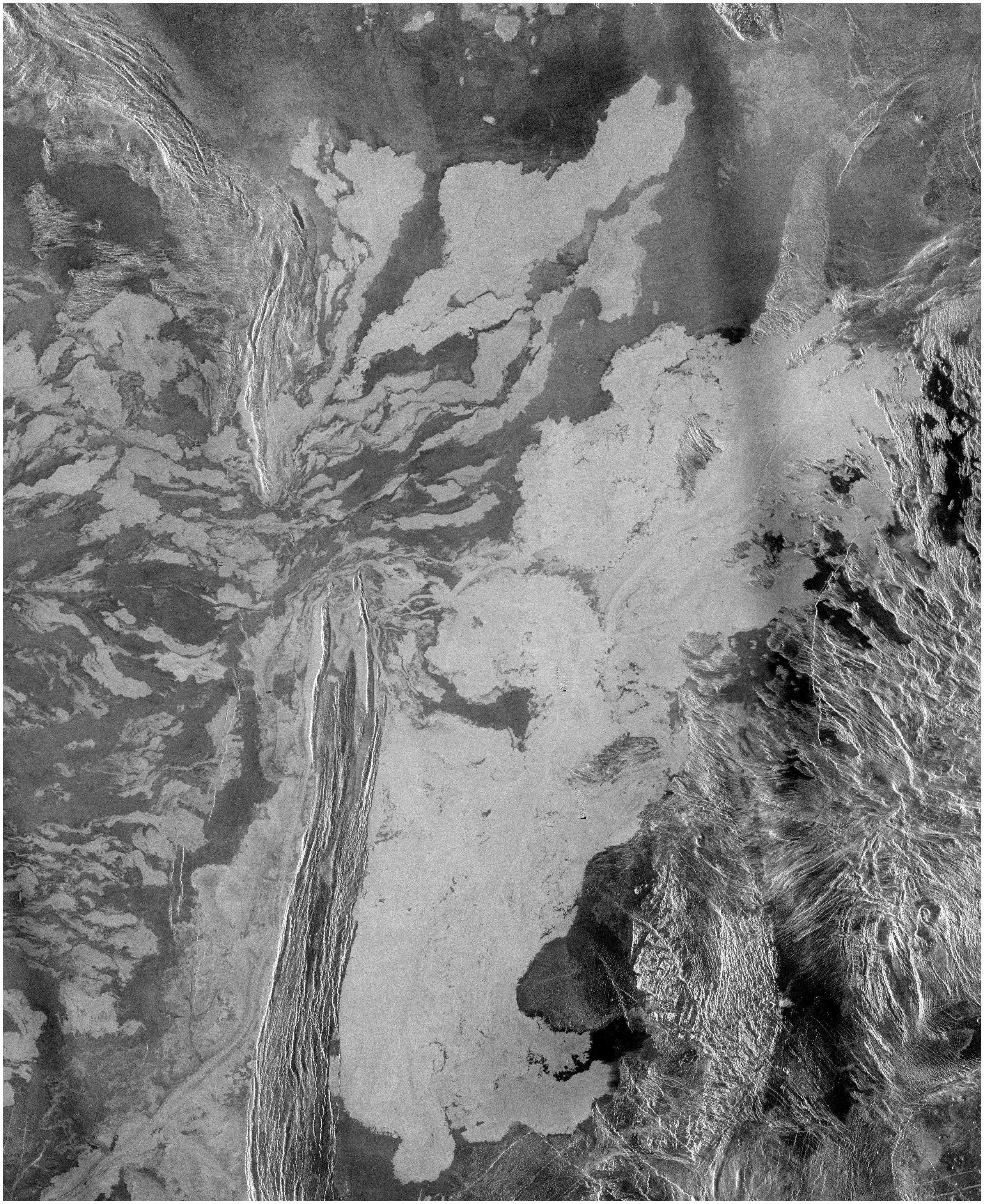
slope

pancake
domes
Venus



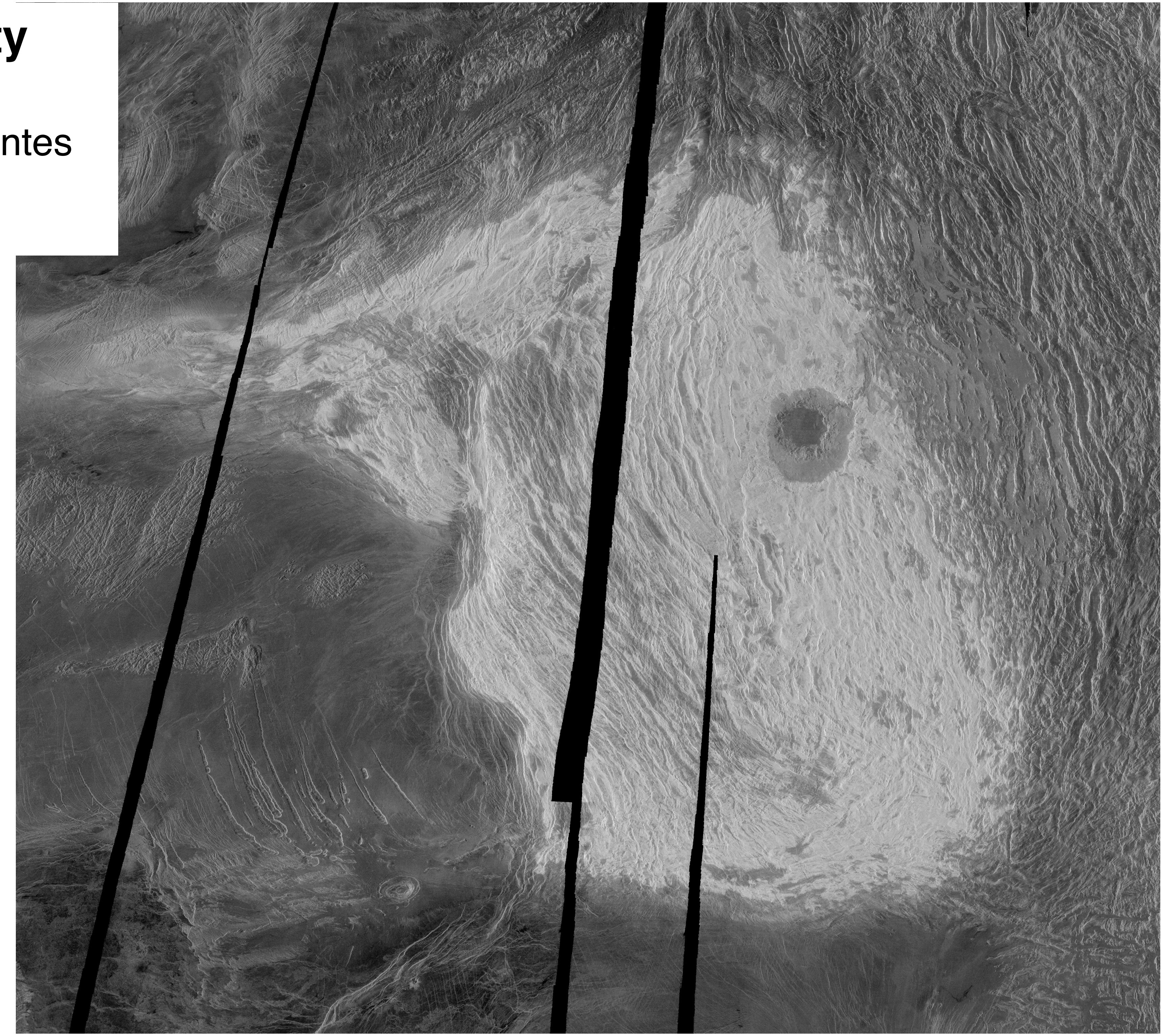
roughness

lava flows
Venus



reflectivity

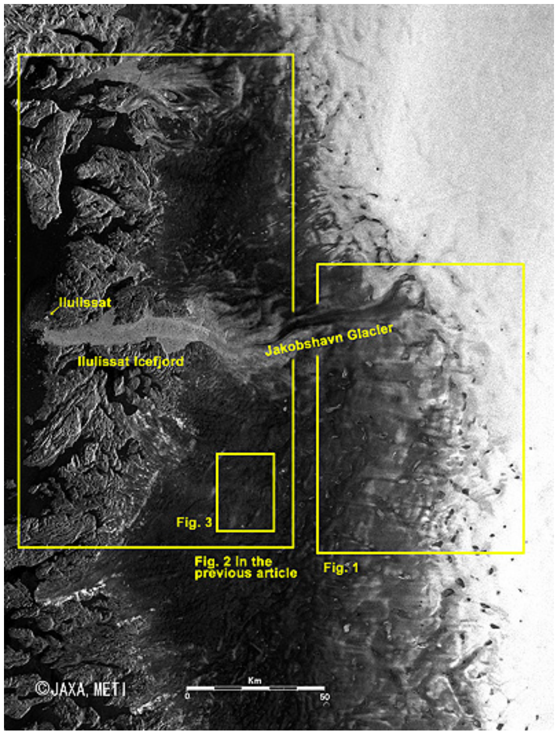
Maxwell Montes
Venus



reflectivity - Venus

Surface melting in Greenland

Image from optical sensor AVNIR-2 on July 3, 2008 (day)



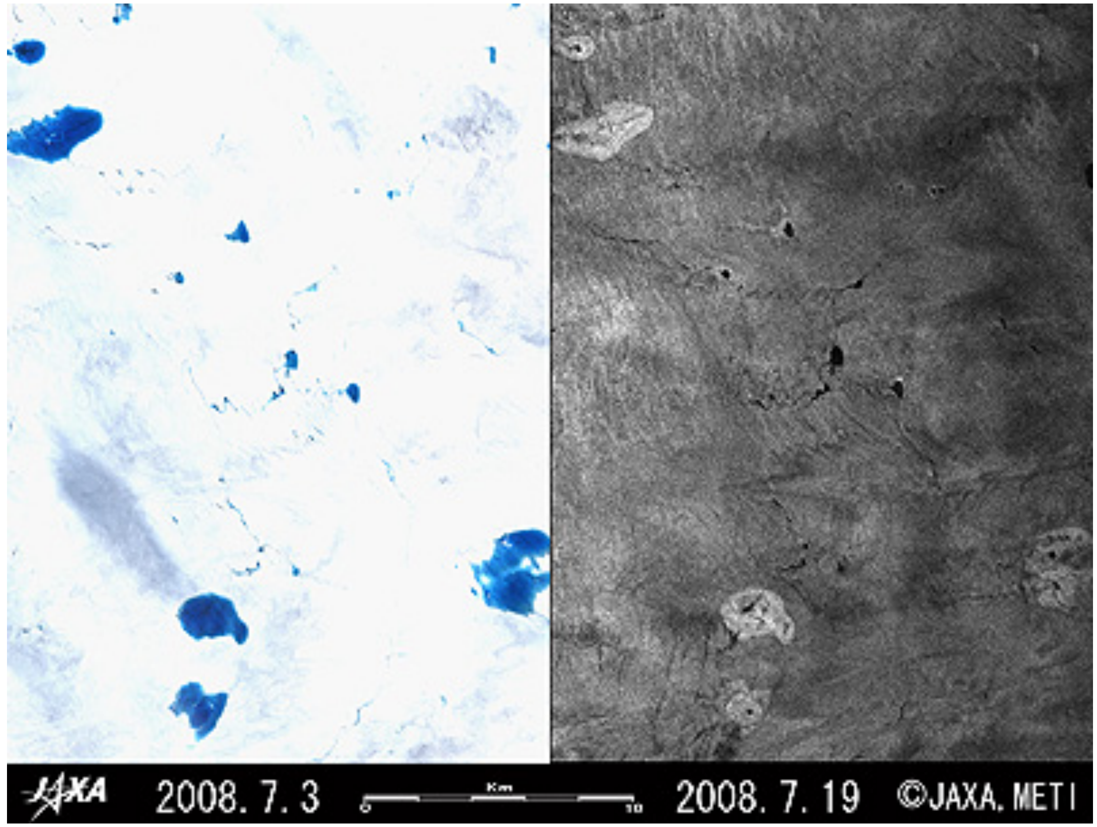


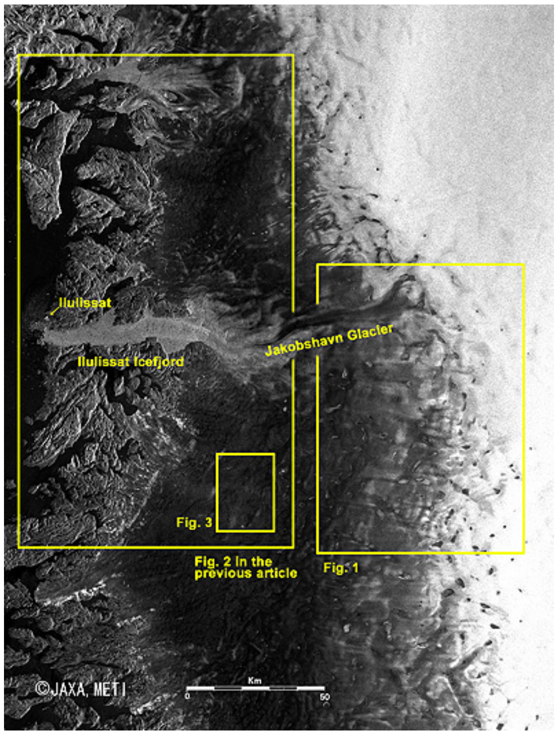
Image from PALSAR two weeks later (night).

Melt ponds appear blue in the left image and are either black or brighter than the surroundings in the right image.

Black: very little of PALSAR's radar signal is returned to the satellite, indicating that the surface is smooth, unfrozen water.

Bright grey: some of PALSAR's radar signal returns to the satellite, suggesting that the frozen surface contains many air bubbles or that the water surface is ruffled but unfrozen.

Surface melting in Greenland



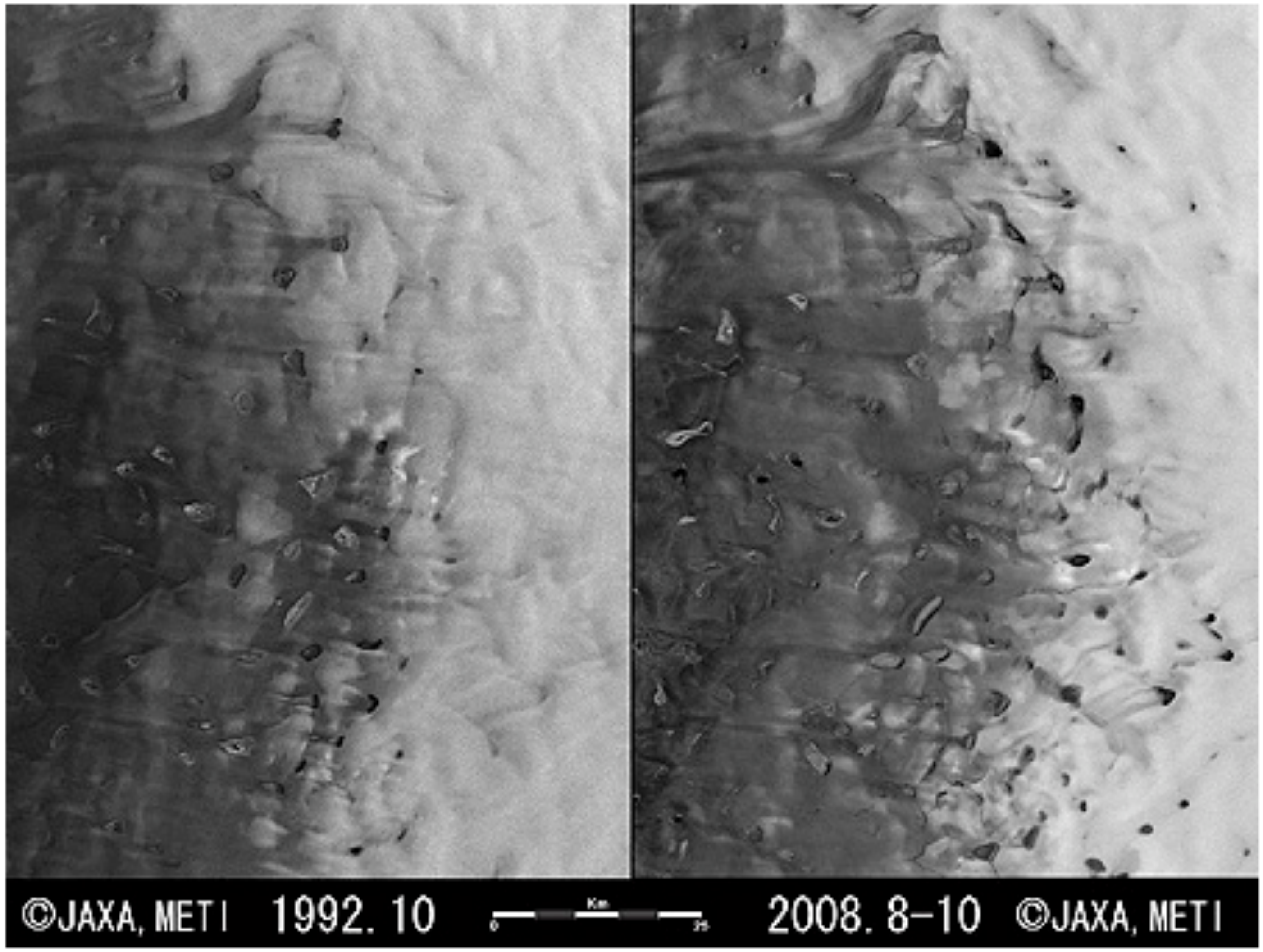


Fig. 1 Changes of melt ponds on ice sheet in western Greenland in last 16 years

SAR images of 100 to 175km area in western Greenland. The left image acquired by JERS-1 in October 1992; right image acquired by ALOS August and in October of 2008.

Surface melting in Antarctica

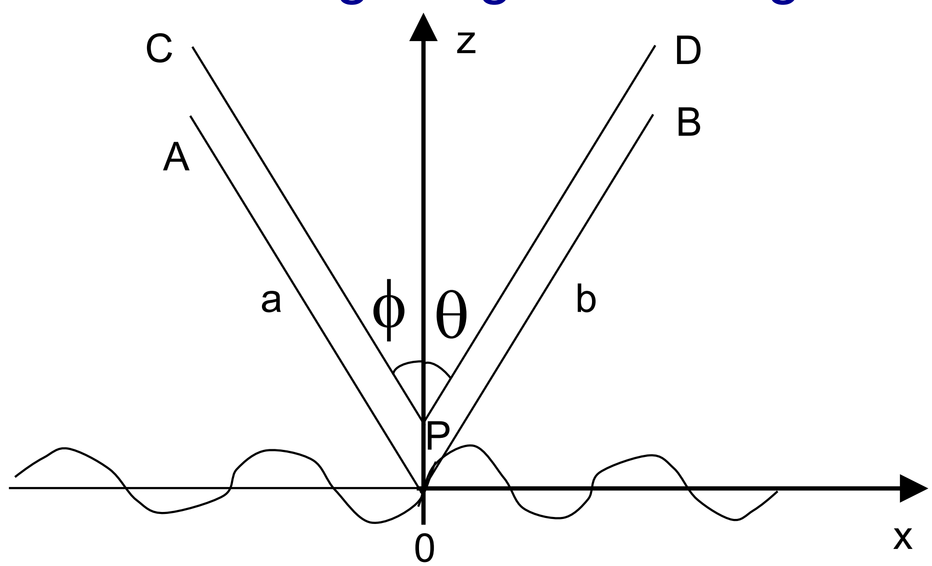
SAR image acquired over Amery Ice Shelf survey region on 15 August 1993.

Dark wish-bone shaped feature is a surface meltstream, only active during austral summer

Bragg scattering

Page 64-66 Rees

- Consider a surface where dh << λ. The surface is smooth so most of the incident energy undergoes specular reflection.
- For an active system such as SAR, most of the energy will not return to the radar.
- However, if the rough surface has a characteristic λ that matched the radar wavelength, then one can get resonant scattering
- This commonly occurs over the ocean and is called **Bragg scattering** (just like the scattering of light from regular crystal lattices).



What is the phase difference between paths AB and CD?

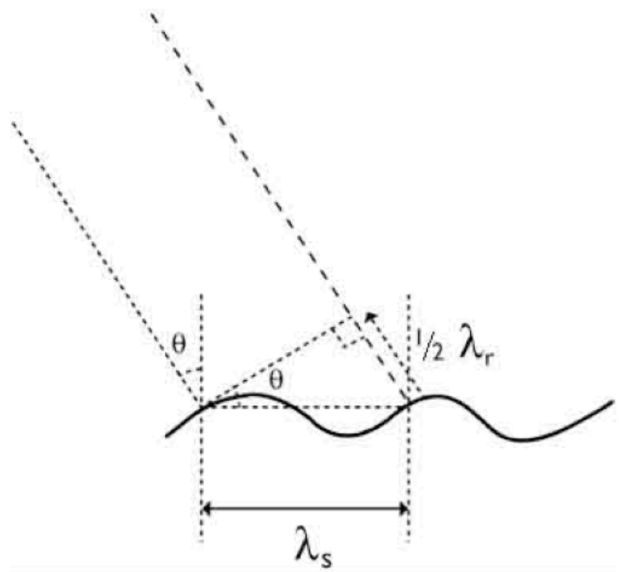
Bragg scattering

Page 64-66 Rees

- ★ As the incidence angle of the ERS SAR is oblique (23º) to the local mean angle of the ocean surface, there is almost no direct specular reflection except at very high sea states.
- ★ So it is assumed that at first approximation Bragg resonance is the primary mechanism for backscattering radar pulses.
- ★ The Bragg equation defines the ocean wavelengths for Bragg scattering as a function of radar wavelength and incidence angle

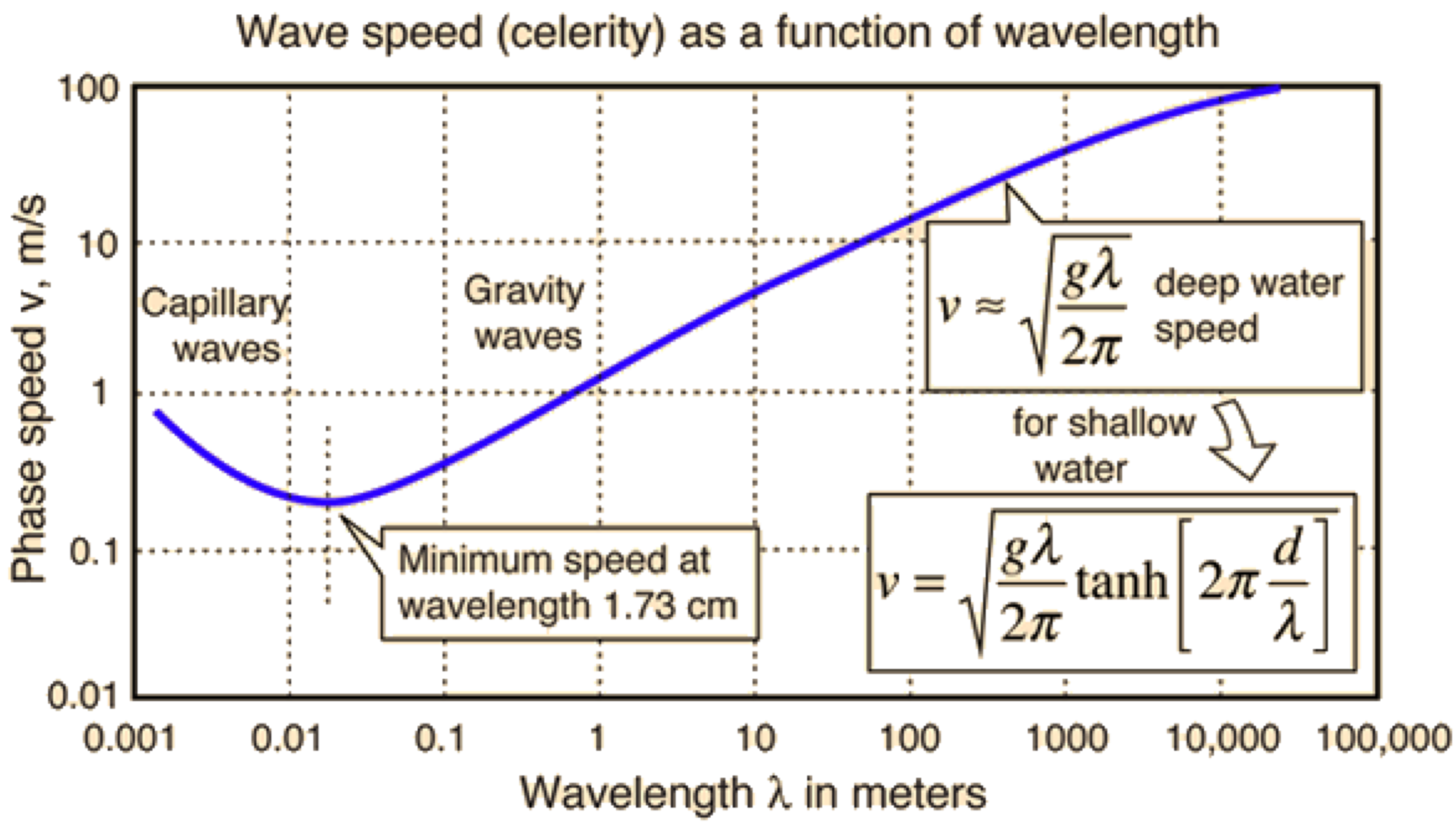
$$\lambda_s = \frac{\lambda r}{2 \sin \theta}$$

where λ_r radar wavelength
λ_s sea surface wavelength
θ incidence angle



- ★ The short Bragg-scale waves are formed in response to wind stress. If the sea surface is rippled by a light breeze with no long waves present, the radar backscatter is due to the component of the wave spectrum which resonates with the radar wavelength.

Wind Waves

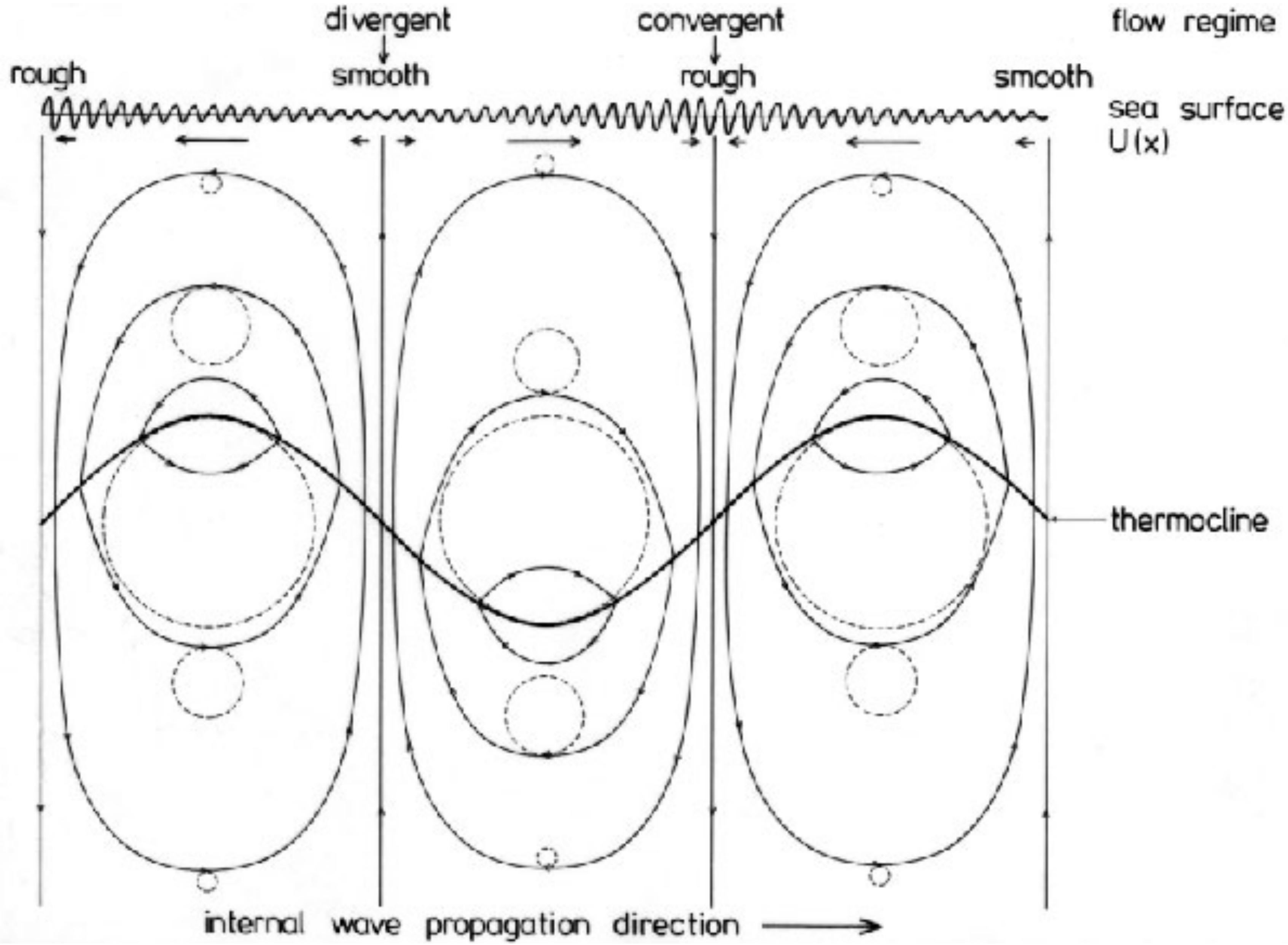


Wave speed (celerity) as a function of wavelength
100
10
1
0.1
0.01
Phase speed v, m/s
0.001
0.01
0.1
1
10
100
1000
10,000
100,000
Wavelength λ in meters
Capillary waves
Gravity waves
Minimum speed at wavelength 1.73 cm
$v \approx \sqrt{\frac{g\lambda}{2\pi}}$ deep water speed
for shallow water
$v = \sqrt{\frac{g\lambda}{2\pi}\tanh\left[2\pi\frac{d}{\lambda}\right]}$

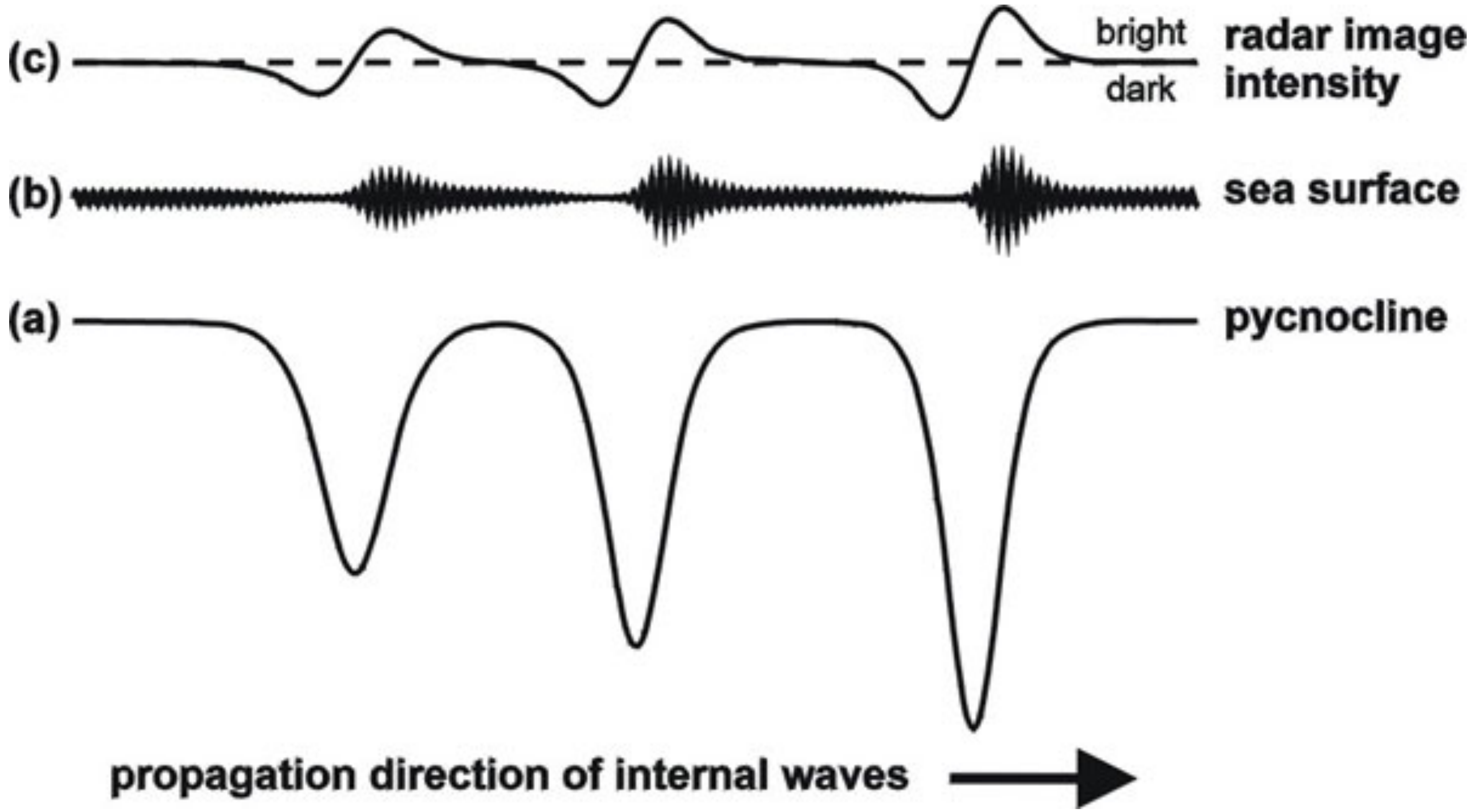
Slides on SAR over the Ocean

https://earth.esa.int/web/guest/-/ers-sar-tropical-oceanic-phenomena-5887

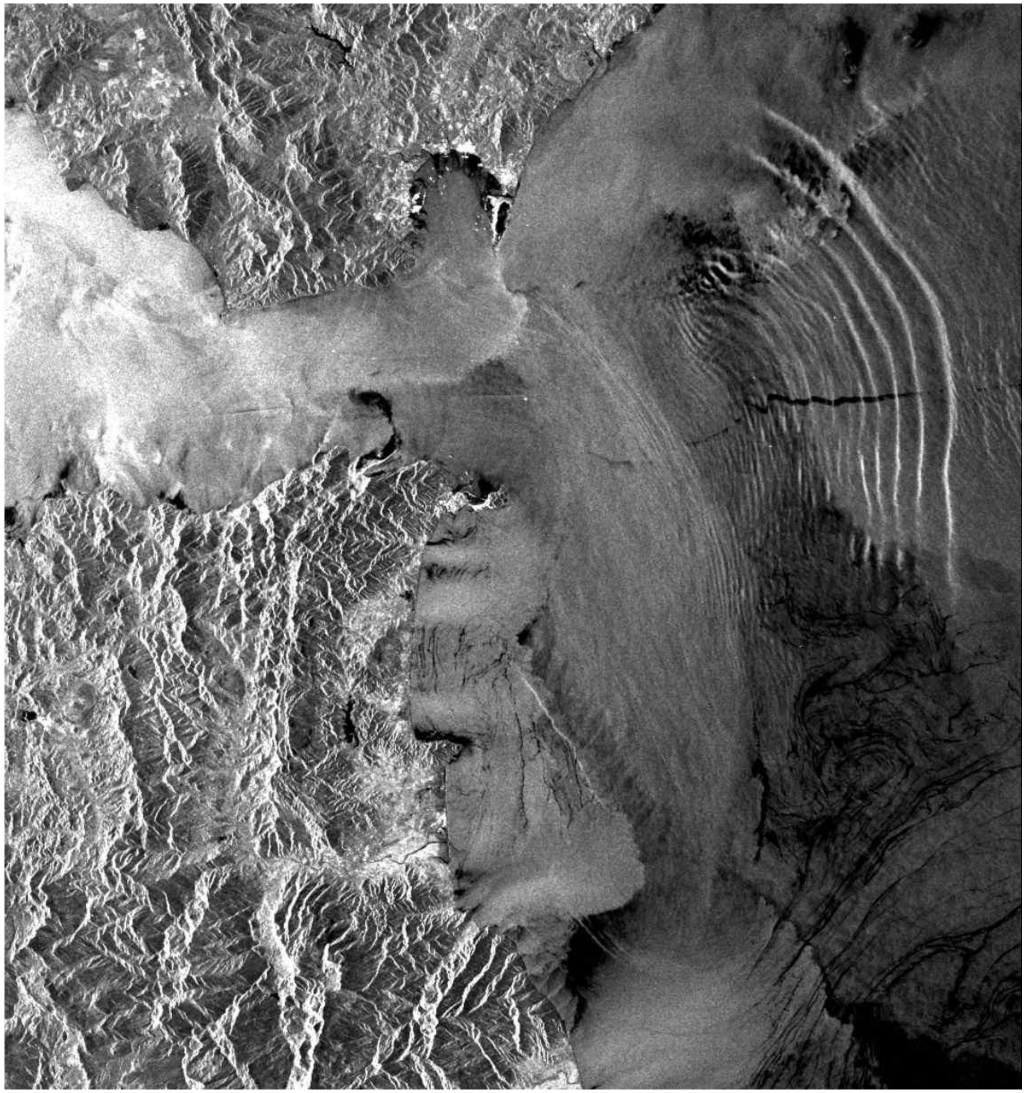
Internal Waves



Internal waves seen by SAR



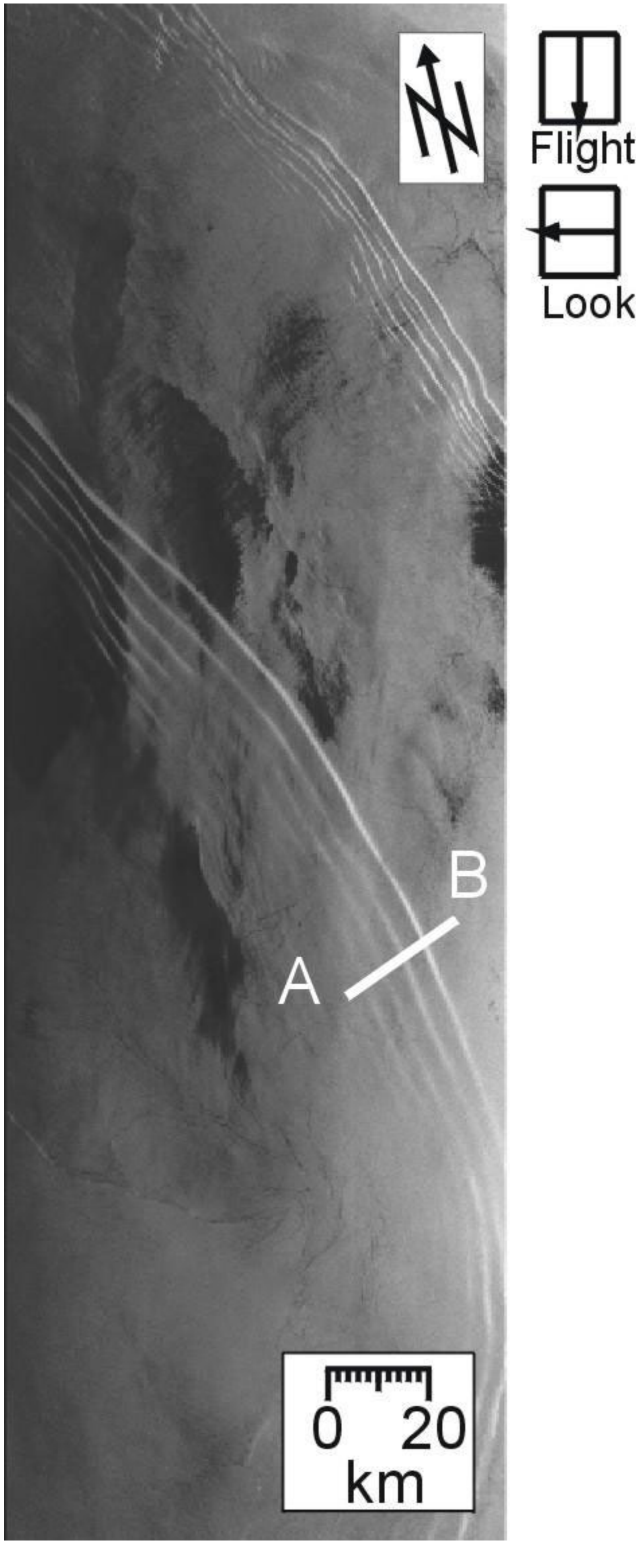
Internal waves in the Gibraltar Strait



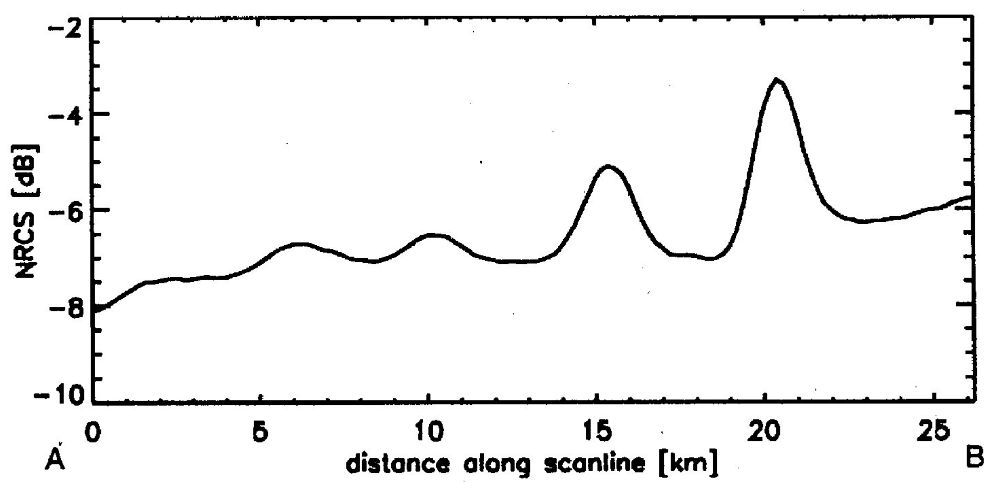
ERS-1 SAR image of the strait of Gibraltar in which roughness patterns associated with nonlinear internal waves propagating eastwards can be delineated.

If slicks are floating on the sea surface (see right part of image), they are forced to follow the underlying water movement, and mesoscale oceanic phenomena become also visible by the spatial distribution of the slick material on the sea surface.

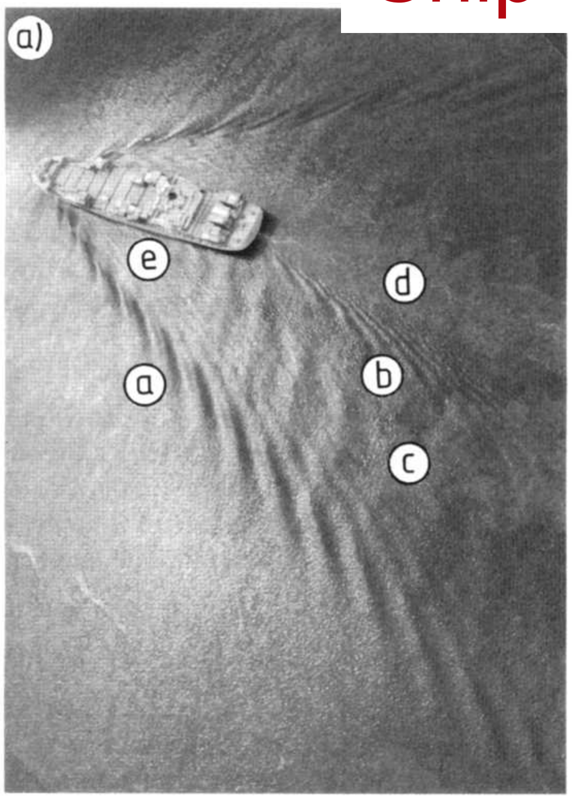
Internal waves in Andaman Sea



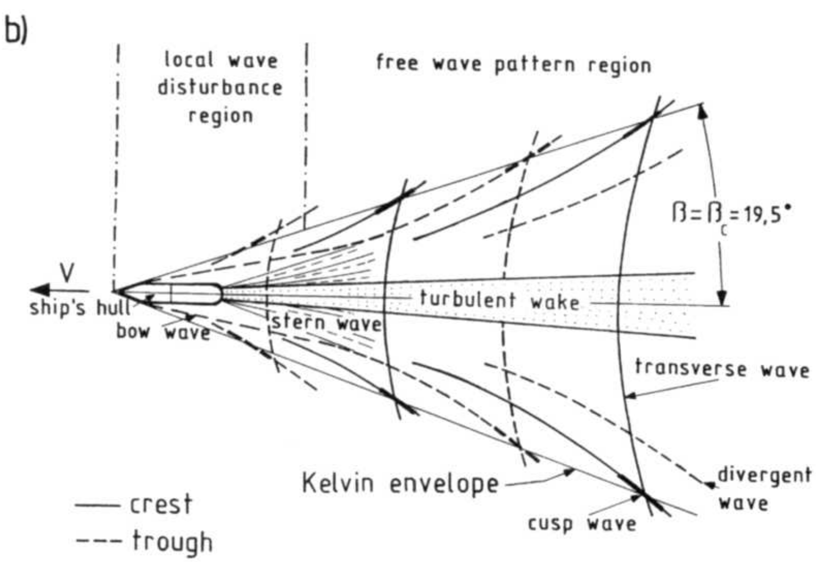
Sea surface manifestations of two internal wave packets generated at successive semi-diurnal tidal cycles. The variation of the NRCS along the profile AB is shown in the figure below.

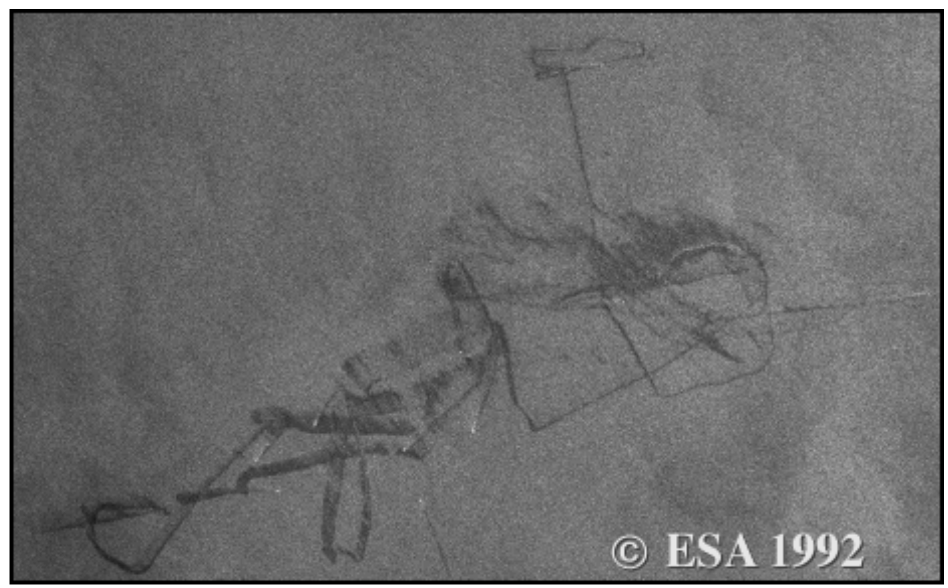


Ship wake detection by SAR

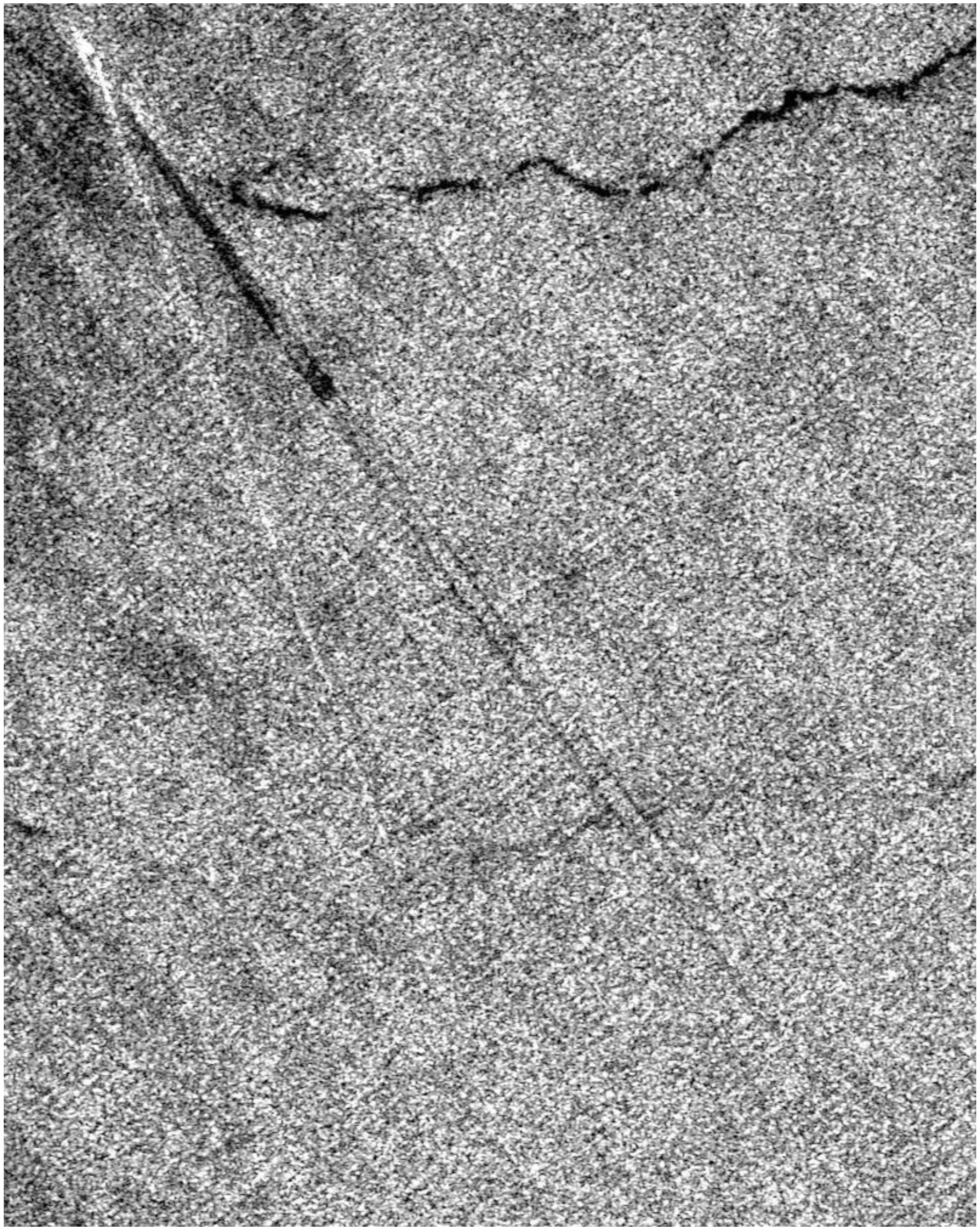


- With larger incidence angles, the ocean background clutter effects are reduced, increasing signal to noise.
- A ship is a bright point target against the ocean background clutter and can be detected using image thresholding techniques.
- As the ocean clutter increases with increasing wind speeds, ship detection becomes more difficult. At wind speeds > 10 m/s it is difficult to detect small fishing vessels.
- As wind speeds increase, radar cross-section of the ocean increases, reducing contrast between feature of interest and surrounding ocean.





Ship wake detection by SAR

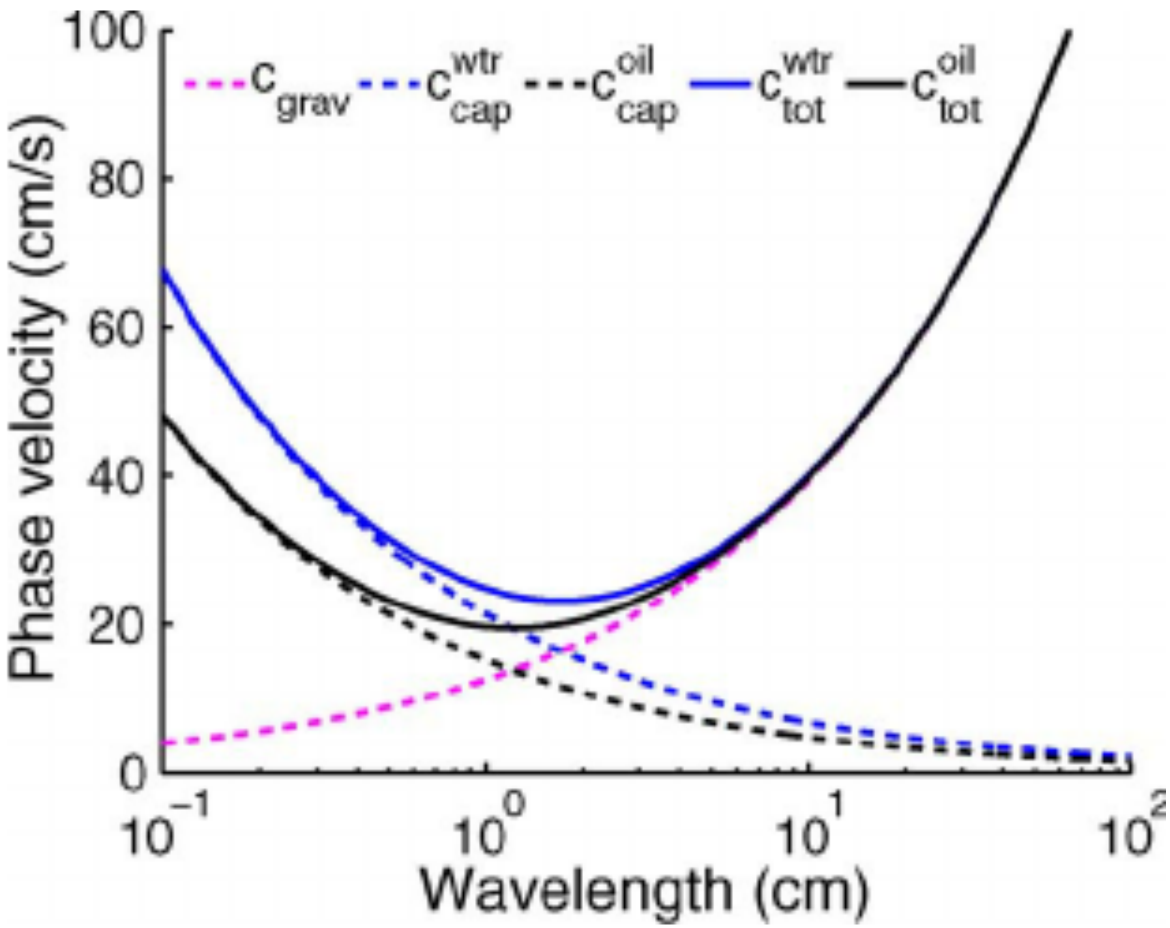


This image shows a 10 km x 12.6 km subsection of an ERS-1 SAR scene in the Strait of Malacca. A ship, its turbulent wake (partially dark band) and one arm of its Kelvin wake (bright line) can be seen. Interestingly, the far-end of the turbulent wake is imaged as two quasi- parallel dark lines. We interpret this as being caused by the accumulation of surface slicks at the convergent lines at both rims of the turbulent wake. These convergent lines are produced by the orbital motions associated with the two counter-rotating vortices in the wake of a ship (see introduction).

Submarine detection

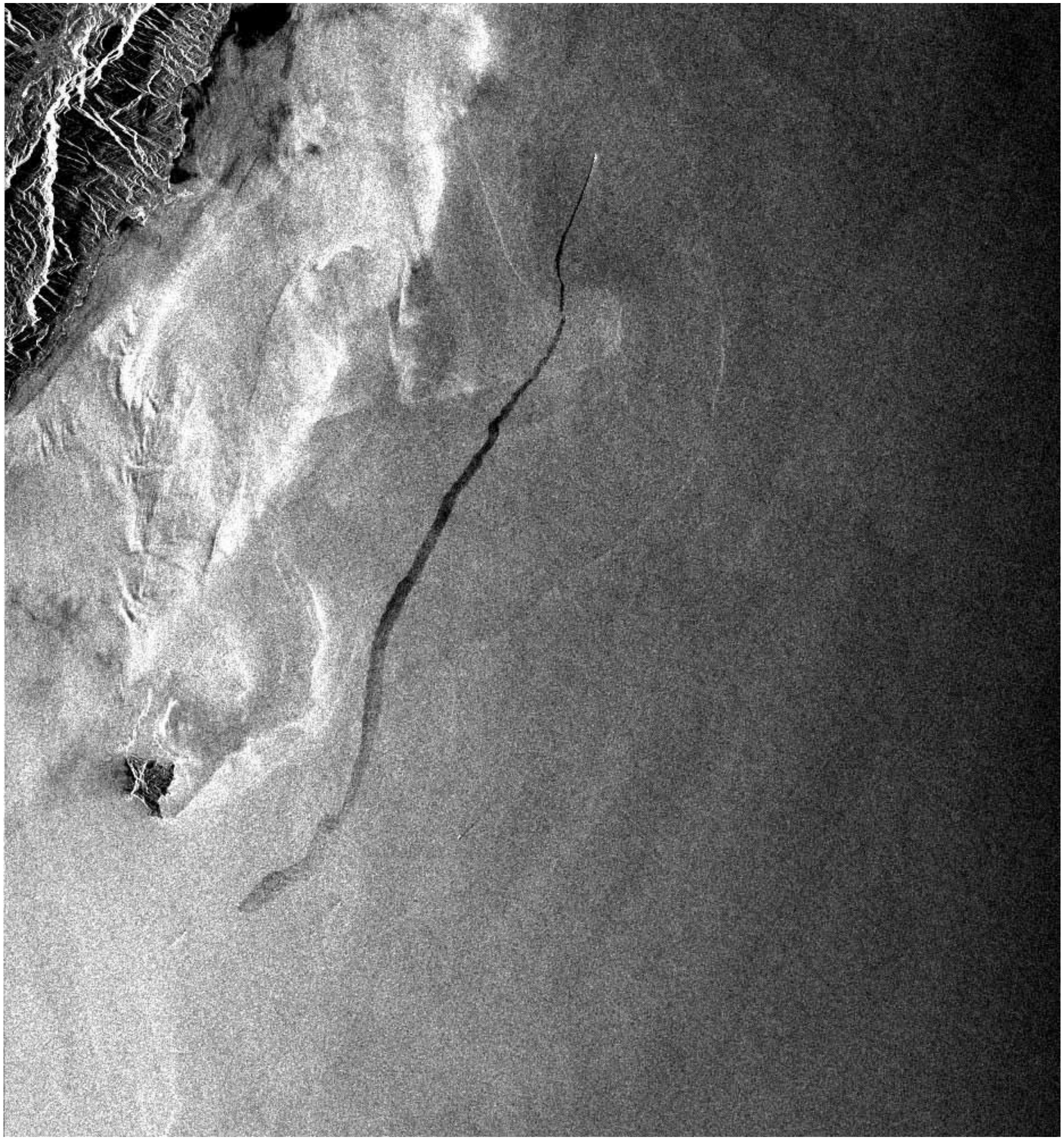
- Vortices and internal waves generated by submarines modulate the wavelength of the short surface waves
- Short wave amplitude spectrum proportional to λ^4
- Bragg scattering dominates the ocean surface reflection for SAR incidence angles of 20-70º
- Surface convergence = radar bright
- At what radar wavelength are submarine wakes most visible? (many clear examples in Seasat data; 30 m resolution is adequate)

Oil Slick



100
80
60
40
20
0
Phase velocity (cm/s)
c_{grav} c^{wtr}_{cap} c^{oil}_{cap} c^{wtr}_{tot} c^{oil}_{tot}
10^{-1}
10^{0}
10^{1}
10^{2}
Wavelength (cm)

Oil slicks detection by SAR



A ship travelling northward (bright spot at the front of the black line) discharging oil. The oil disperses with time causing the oil trail to widen. This oil trail is more than 80 km long. The bright area between the east coast of Taiwan and the oil trail is the Kuroshio current whose water temperature is higher than the temperature of the surrounding waters. Here the air-sea interface is unstable causing a higher wind stress and thus a larger NRCS

Oil slicks detection by SAR

Oil pollution in the South China Sea off the west coast of Sabah (Borneo). The dark streaks visible in the left-hand section of the image result from oil discharged from ships. In one case the ship (white spot) is visible at the front of the oil trail. It could be that the dark streaky features visible in the right-hand section of the image originate from oil seeps.

Scatterometry

- Scatterometry is a form of radar remote sensing that can measure various geophysical properties of surfaces and volumes based on the amplitude of microwave electromagnetic pulses that are transmitted from and scattered back to an antenna aboard the spacecraft.

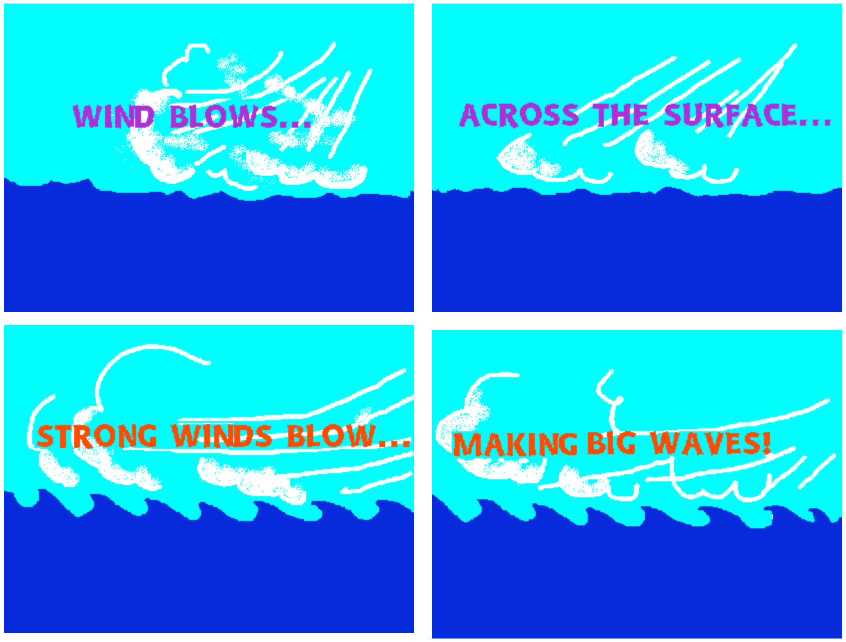
- Scatterometer is a radar system that provides a quantitative measure of the backscattering cross section as a function of the incident angle.

  - Backscatter cross-section is a measure of how detectable an object is with a radar. When radar-waves are beamed at a target, a number of different factors determine how much electromagnetic energy returns to the source, such as the angles created by the surface/plane intersections.

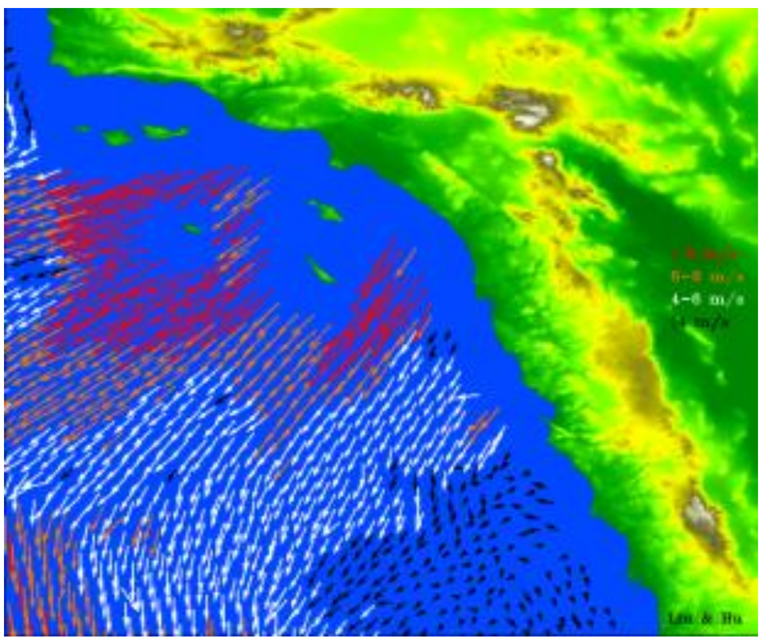
- A scatterometer transmits a continuous signal or a series of pulses and the strength of the returned signal is recorded.

http://cires.colorado.edu/~maurerj/scatterometry/what_is_scatterometry.htm

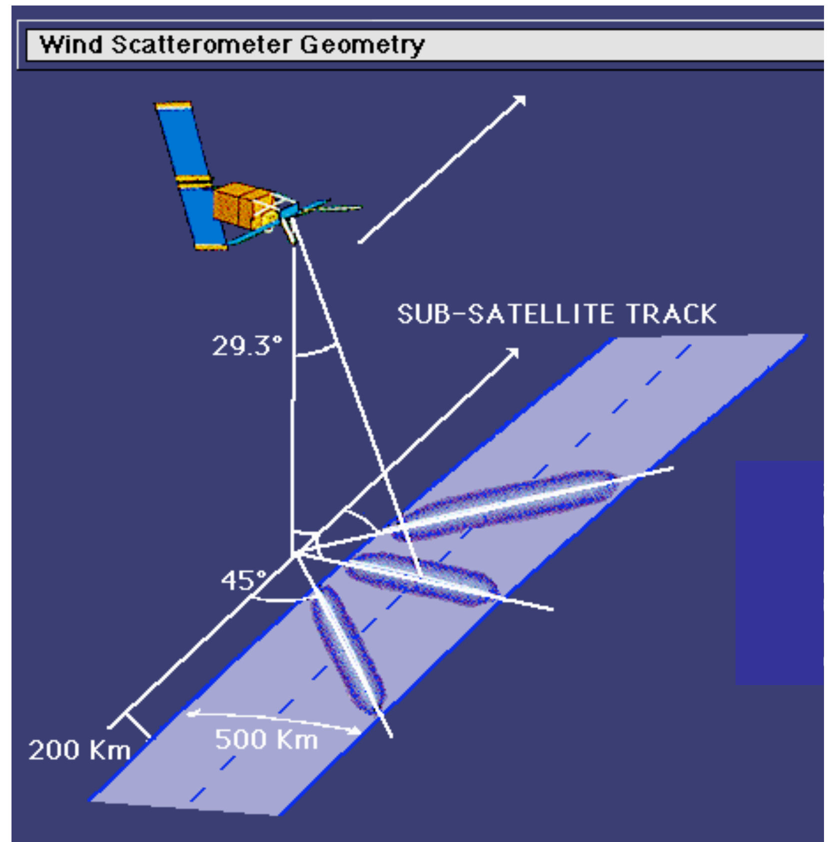
Wind speed retrieval by scatterometer



Example: SeaWinds scatterometer on QuikScat -- a microwave radar designed specifically to measure ocean near-surface wind speed and direction.

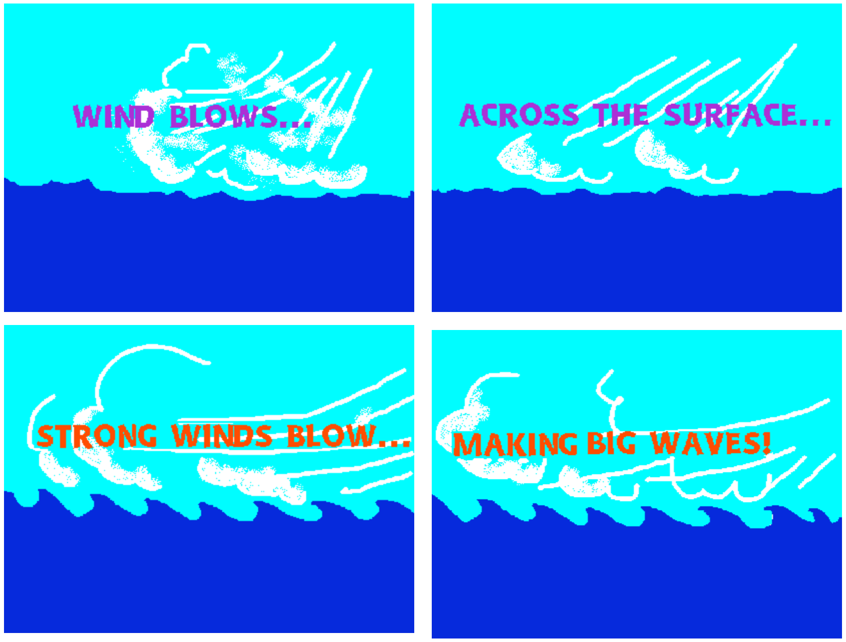


Santa Ana winds off CA coast



The three Wind Scatterometer antennae generate radar beams 45º forward, sideways and 45º backwards across a 500km wide swath, 200km to the right of the sub-satellite track.

Wind speed retrieval by scatterometer



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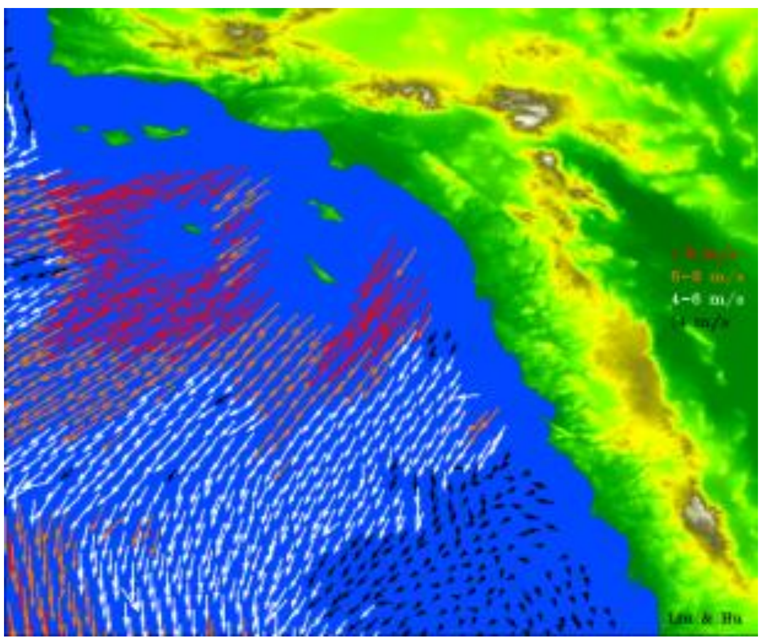
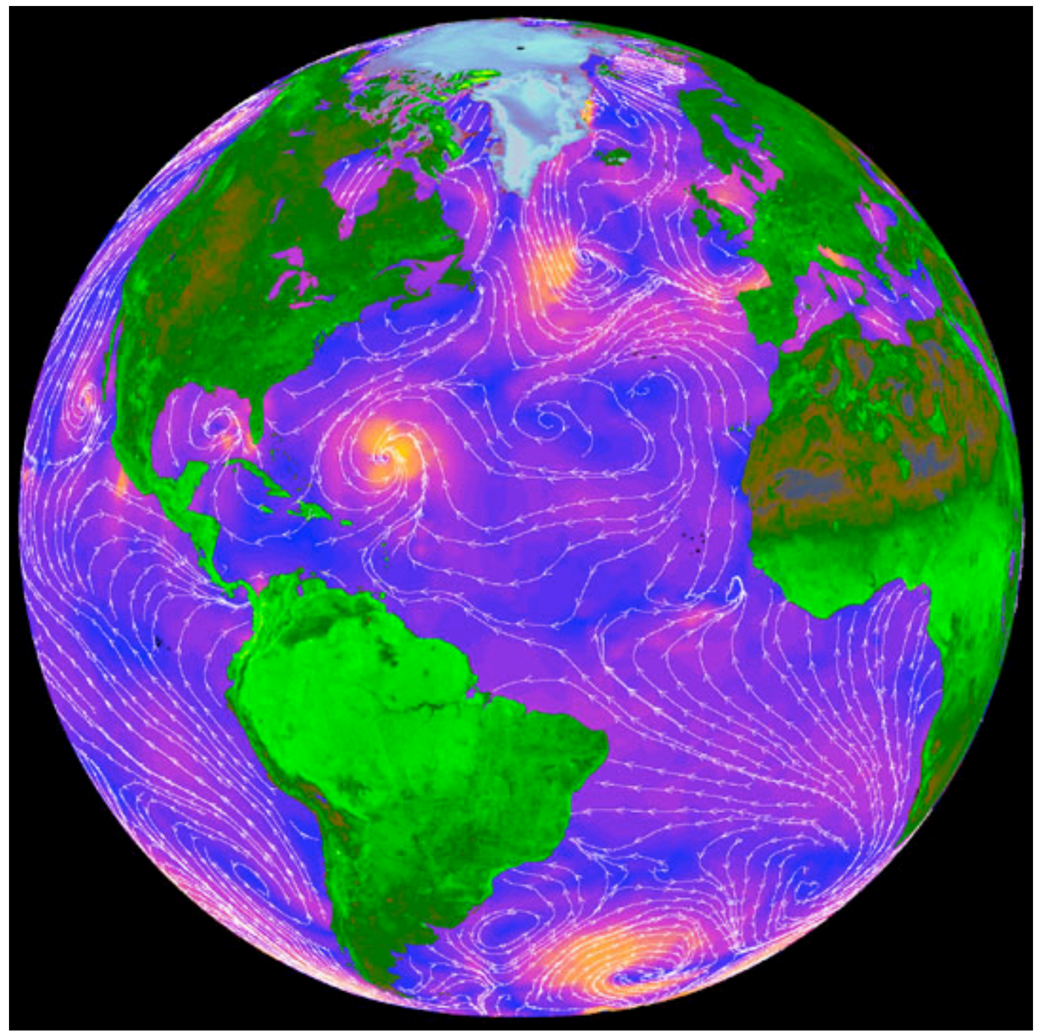


Santa Ana winds off CA coast



Conclusions

- EM radiation is absorbed and scattered by the atmosphere as well as the land and ocean surfaces. (Atmospheric effects are not covered in this course.

- The BRDF is a model for the optical spectral reflectivity of land surfaces. The hemispherical average of the BRDF is the albedo which is the ratio of total energy reflected to incident energy.

- The Rayleigh roughness criterion is used to classify a surface as smooth when the height variations are less than about 1/8 wavelength. A smooth surface has a specular reflection while a perfectly rough surface has a Lambertian reflection function.

- Calm ocean surfaces are generally smooth relative to the wavelength of a radar. Resonant (Bragg) scattering occurs when the wavelength of the short waves generated by local wind is about ½ the radar wavelength.