



# EITN90 Radar and Remote Sensing

## Lecture 13: Remote sensing

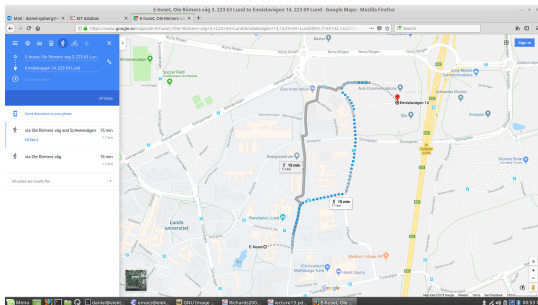
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Department of Electrical and Information Technology

# Lunch lectures at Axis Communications tomorrow

- ▶ Wednesday March 6.
- ▶ 12:15 Lunch sandwich is served
- ▶ 13:00 Radar lectures with speakers from Axis AB and Acconeer AB.

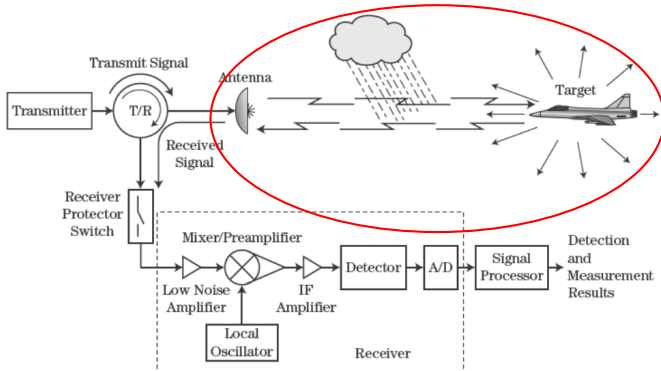
The lunch and the lectures are held at Axis Communications AB in Lund. It is at the main Axis building at Emdalavägen 14 (15 minute walk from LTH). First go to the reception and get a visitor badge.



# Learning outcomes of this lecture

In this lecture we will

- ▶ See how radar systems can provide earth observation data.
- ▶ Observe how different surface structure and materials affect reflection properties.
- ▶ Understand the difference between active and passive sensing.



**FIGURE 1-1 ■**  
Major elements  
of the radar  
transmission/  
reception process.

# Outline

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- 1 General features of remote sensing**
- 2 Scattering from earth surface features**
- 3 Passive microwave imaging**
- 4 Conclusions**



# Outline

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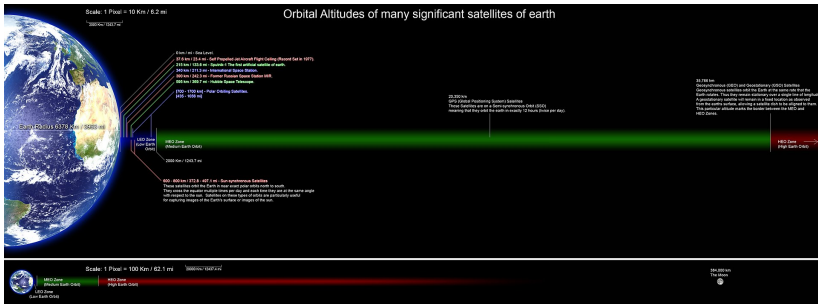
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# What is remote sensing?

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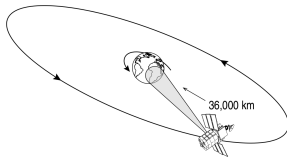
- ▶ Acquiring information about an object or feature without physical contact.
- ▶ Most often from a satellite or aircraft platform.
- ▶ Active or passive sensing possible.
- ▶ Optical regime gives high resolution but is sensitive to weather conditions.
- ▶ Microwaves have less resolution but good penetration.
- ▶ Earth observation over time provides global data, giving climate information.

# Satellite orbits to scale



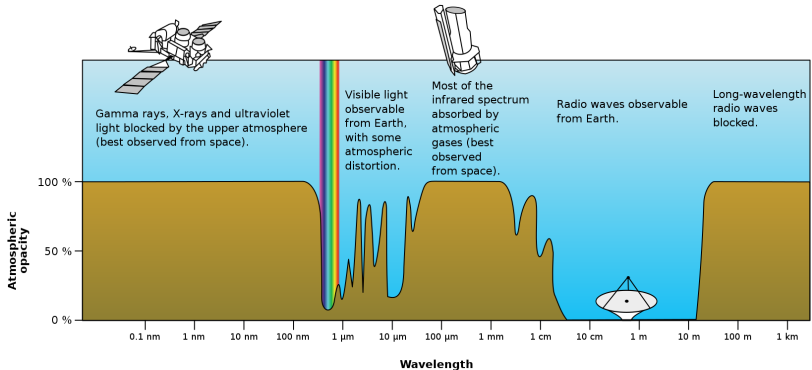
By Rrakanishu - Own work, GFDL, <https://commons.wikimedia.org/w/index.php?curid=4189737>

Earth observation satellites usually in Low Earth Orbit (LEO), around 800 km.



# GEO

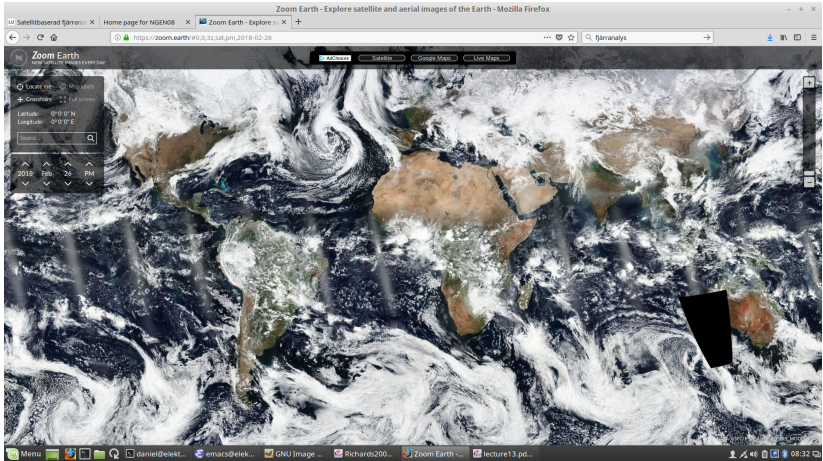
# Opacity of the atmosphere



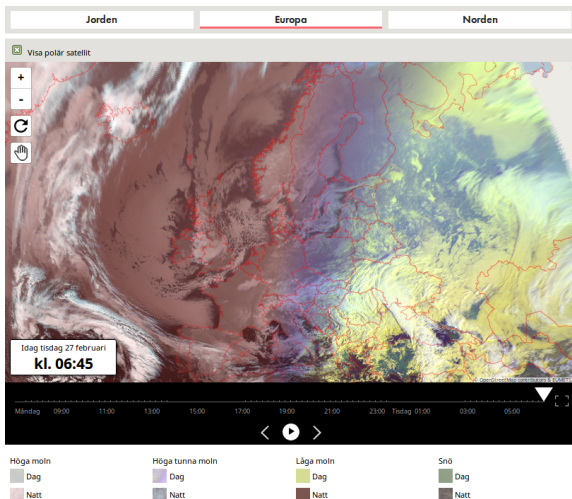
(Figure originally by NASA)

Windows of transparency are available in the electromagnetic spectrum.

# Zoomable satellite images



# Example of data: Weather



Data available from SMHI, composite image from several satellites and wavelengths.

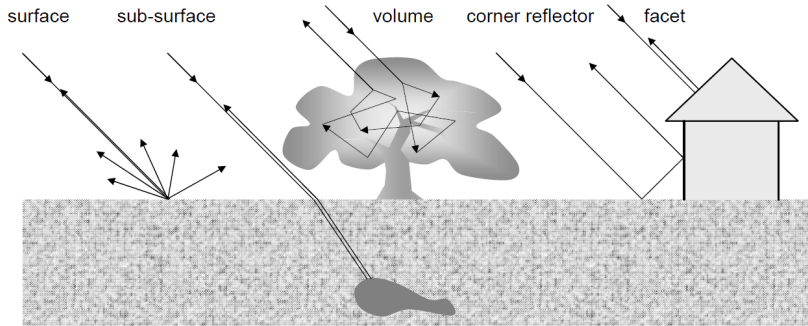
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# Scattering mechanisms

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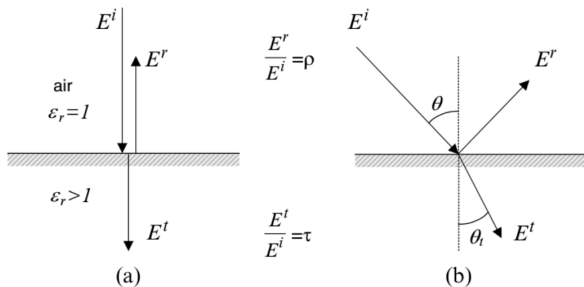


**Fig. 5.1.** Common scattering mechanisms

Scattering occurs due to many different features.



# Fresnel coefficients

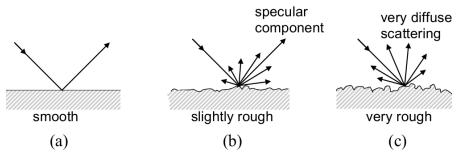


**Fig. 5.2.** Definition of reflection and transmission coefficients (a) vertical incidence and (b) oblique incidence

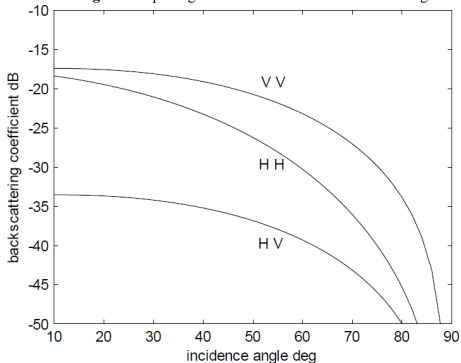
$$\rho_H = \frac{\cos \theta - \sqrt{\epsilon_r - \sin^2 \theta}}{\cos \theta + \sqrt{\epsilon_r - \sin^2 \theta}}$$
$$\rho_V = \frac{-\epsilon_r \cos \theta + \sqrt{\epsilon_r - \sin^2 \theta}}{\epsilon_r \cos \theta + \sqrt{\epsilon_r - \sin^2 \theta}}$$

Reflectance is  $\Gamma = |\rho|^2$ . Material  $\epsilon_r$ , angle of incidence  $\theta$ .

# Reflection from a rough surface

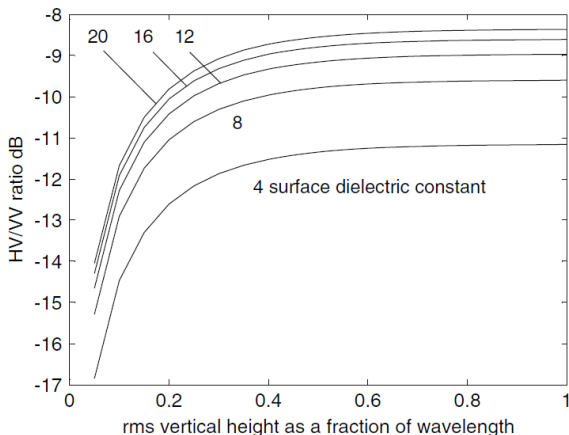


**Fig. 5.4.** Depicting the trend to diffuse surface scattering as roughness increases



**Fig. 5.6.** Demonstration of the differences in horizontal and vertical polarisation responses for a rough surface, and an illustration of typical cross-polarised scattering; generated using the semi-empirical model

## Cross-polarized ratio



**Fig. 5.7.** The cross polar ratio as a function of surface roughness and dielectric constant; the dependence on surface moisture content can be determined by referring to relationships such as that in Fig. 5.3 for sand

## Co-polarised ratio: almost equal

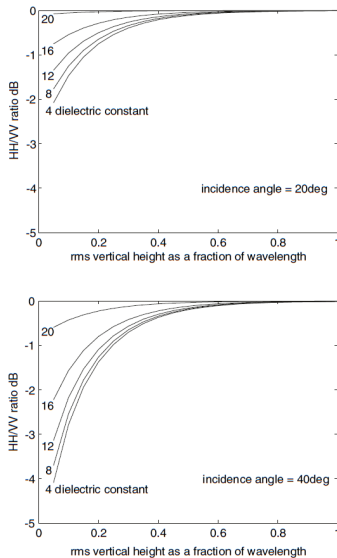


Fig.5.8. The co-polarised ratio as a function of surface roughness and dielectric constant for two values of incidence angle

# Co-polarized backscattering, absolute values

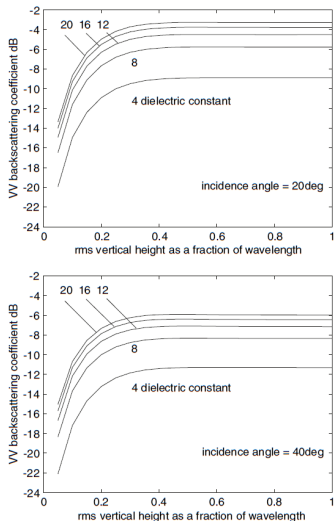
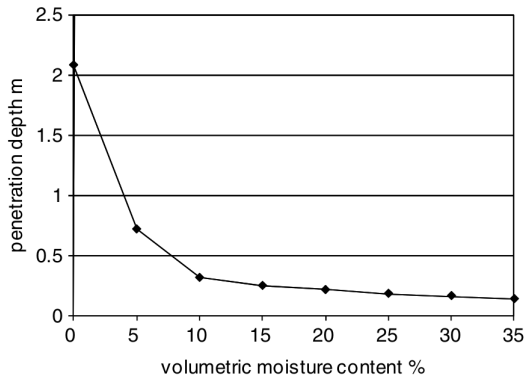


Fig. 5.9. The vertically polarised surface backscattering coefficient as a function of surface roughness and surface dielectric constant for two angles of incidence

## Penetration depth vs moisture content

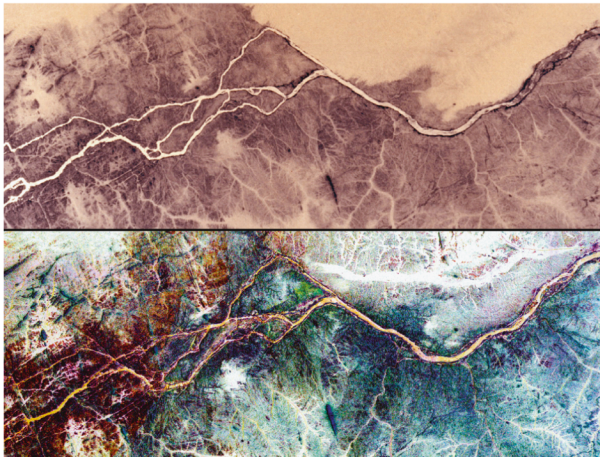


**Fig. 5.13.** Penetration depth for sand as a function of moisture content at L band, with a wavelength of 23.5cm

$$\delta \approx \frac{\lambda}{2\pi} \frac{\sqrt{\epsilon'_r}}{\epsilon''_r}, \quad \epsilon_{rc} = \epsilon'_r - j\epsilon''_r$$

# Moisture: infrared vs microwave

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**Fig. 5.14.** Colour infrared photograph (top) and SIR-C radar image (bottom) recorded in 1995 over the Sahara Desert in Sudan. In the top right hand quadrant of the radar image a previous, ancient channel of the Nile is evident, now buried under sand; the colour composite radar image was created by displaying the C band VH cross-polar channel as red, the L band VH cross-polar channel as green and the L band co-polar HH channel as blue; since the paleo channel appears white there is good penetration at each of those wavelength/polarisation combinations (image courtesy of NASA JPL)

# Effects from multiple reflections

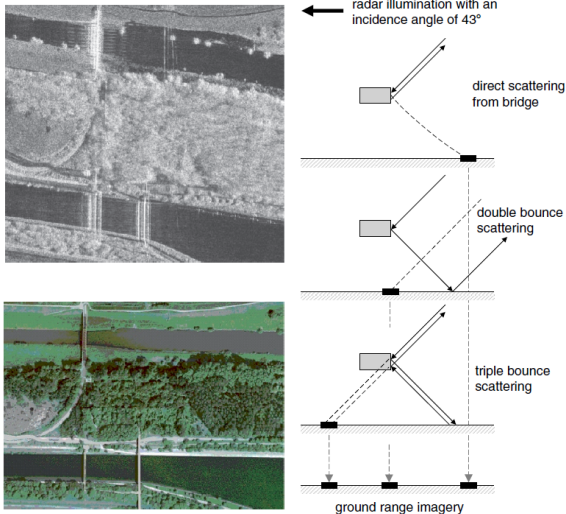
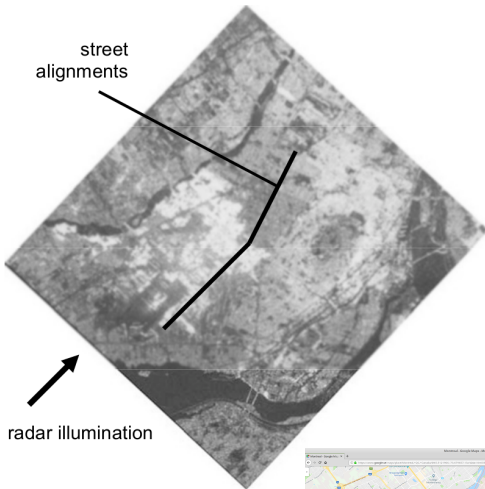


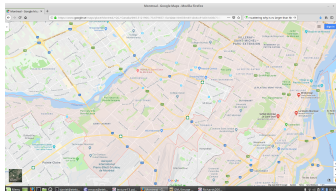
Fig. 5.24. Typical scattering from a bridge, showing how multiple reflections are formed; the imagery was taken by permission from U. Soergel, A. Thiele, H. Gross and U. Thoennessen, *Extraction of bridge features from high-resolution InSAR data and optical Image*", 2007 *Urban Remote Sensing Joint Event*, Paris ©2007 IEEE



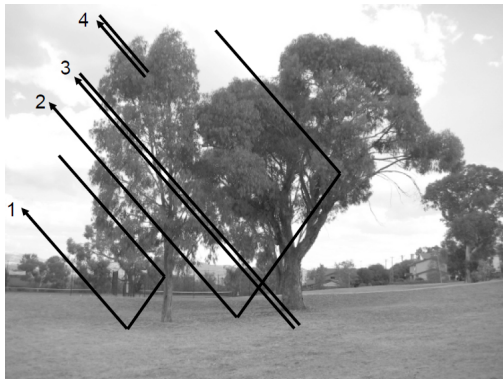
# Strong return from orthogonal structures



**Fig. 5.30.** Portion of a SIR-B image acquired over Montreal, Canada demonstrating the cardinal effect; the bright central portion of the image is where cross streets are aligned orthogonally to the incoming radar energy, whereas the portions to the north, of about the same urban density, have street patterns not orthogonal to the radar beam (from J.P. Ford, J.B. Cimino, B. Holt and M.R. Ruzek, *Shuttle Imaging Radar Views the Earth From Challenger: the SIR-B Experiment*, JPL Publication 86-10, NASA, 15 March 1986)



## Composite scatterers



**Fig. 5.31.** Typical scattering pathways for trees and forest stands: 1 is trunk-ground corner reflector scattering; 2 is canopy-ground scattering, 3 is scattering from the ground after transmission through the canopy and 4 is canopy volume scattering

Different scattering pathways may add coherently or incoherently. With a large number of randomly placed scatterers, incoherent addition (adding RCS) is a reasonable assumption.

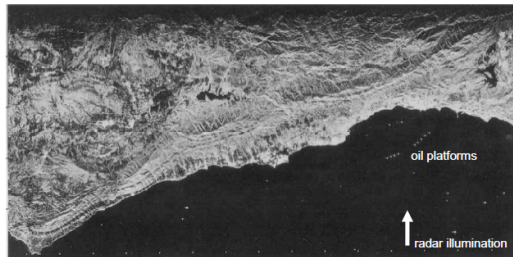
# Sea surface scattering: angle of incidence

20°



(a)

40°



(b)

Fig. 5.34. Seasat mosaic (a) and SIR-A (b) image of the coastal region around Santa Barbara, California (from J.P. Ford, J.B. Cimino and C. Elachi, *Space Shuttle Columbia Views the World With Imaging Radar: the SIR-A Experiment*, JPL Publication 82-95, NASA, 1 January 1983)

# Different ages of ice show up in different frequencies

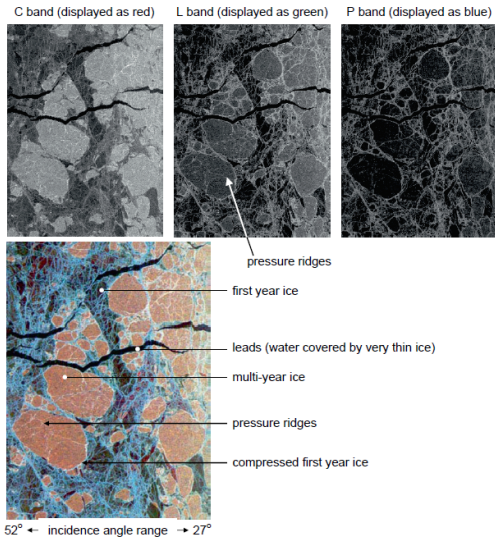


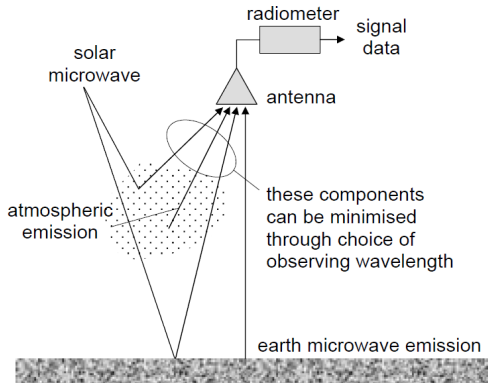
Fig. 5.39. Multi-wavelength aircraft SAR imagery of sea ice (from B. Scheuchl, I. Hajnsek and I. Cumming, Classification strategies for polarimetric SAR sea ice data, *Workshop on Applications of SAR Polarimetry and Polarimetric Interferometry*, Frascati, Italy, 14-16 January 2003, ©2003 ESA/ESRIN)

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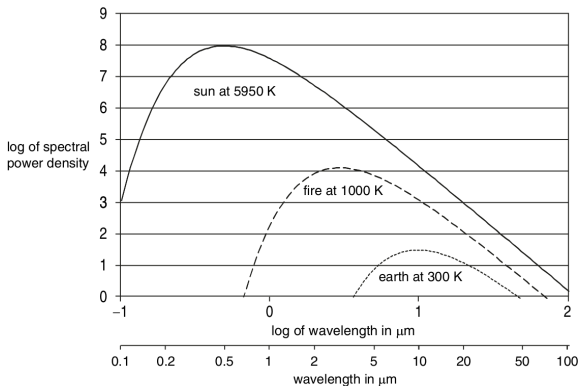
# Passive microwave energy available



**Fig. 9.1.** The components of passive microwave energy theoretically available for measurement

Passive technology means no SAR is possible. Pixel sizes on the order of 10 km.

# Radiometric brightness temperature



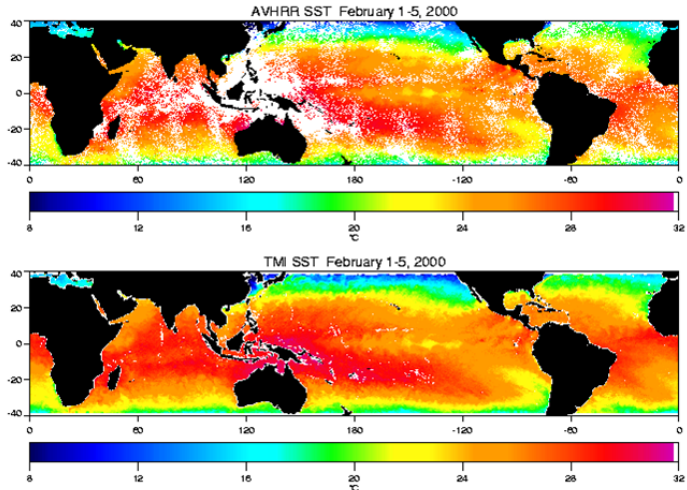
**Fig. 2.2.** Spectral power density available for ideal black bodies at three different temperatures, computed from (2.2)

Power received in bandwidth  $B$  from a surface at temperature  $T$  is

$$P_r = \varepsilon k T B = k T_B B, \quad \text{where} \quad T_B = \varepsilon T = \frac{P_r}{k B}$$

and  $\varepsilon \leq 1$  is the emissivity of the surface.

# Infrared vs microwave: sea surface temperature



(<http://www2.hawaii.edu/~jmaurer/sst/>)

Top: infrared, bottom: microwaves. Microwaves penetrate clouds more easily.

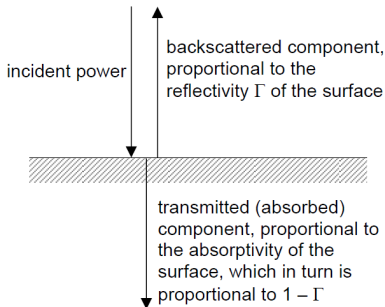


# Passive Microwave Remote Sensing Techniques for Studying Climate

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# Absorptivity and reflectivity



**Fig. 9.2.** Relationship between the absorptivity and reflectivity of a surface

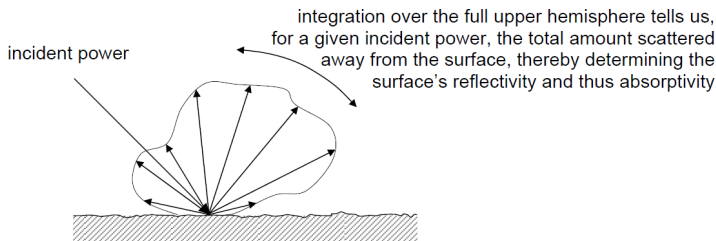
At thermal equilibrium, emitted power must be equal to absorbed power, or

$$\varepsilon = 1 - \Gamma$$

where  $\Gamma$  is the reflectivity (power measure). Note that a highly reflective surface ( $\Gamma \approx 1$ ) has low emissivity,  $\varepsilon \approx 0 \Rightarrow T_B \approx 0$ . Hence, metal surfaces appear as black in passive sensing.

# Rough surface

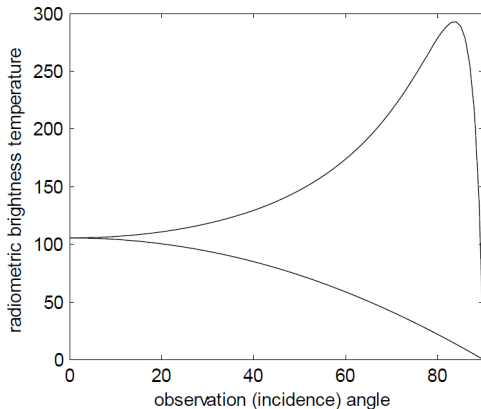
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**Fig. 9.3.** All the power scattered into the upper hemisphere has to be found when determining reflectivity for a rough surface

For rough surfaces, the reflectivity  $\Gamma$  must correspond to power reflected in all directions.

## Brewster angle

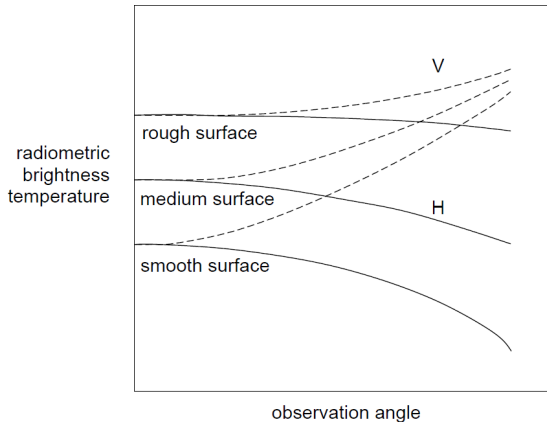


**Fig. 9.4.** Radiometric brightness temperature for still water as a function of observation angle and polarisation

At the Brewster angle for a smooth surface (like still water), there is zero reflection of vertical polarization, hence large emissivity corresponding to physical temperature.

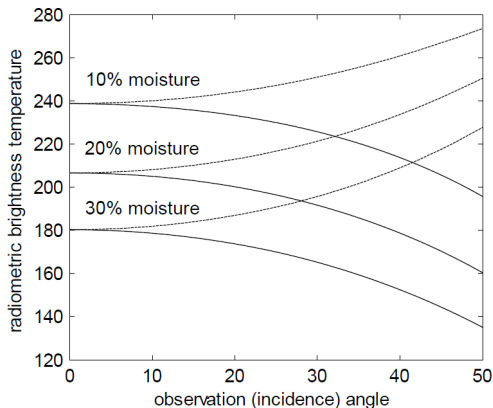
# Brightness of different surfaces

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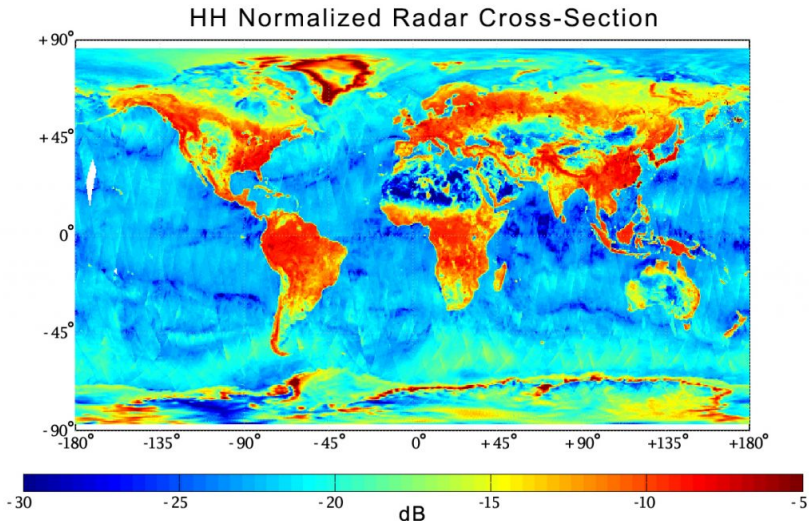
**Fig. 9.6.** Dependence of radiometric brightness temperature on surface roughness and polarisation

## Example: smooth sand with different moisture



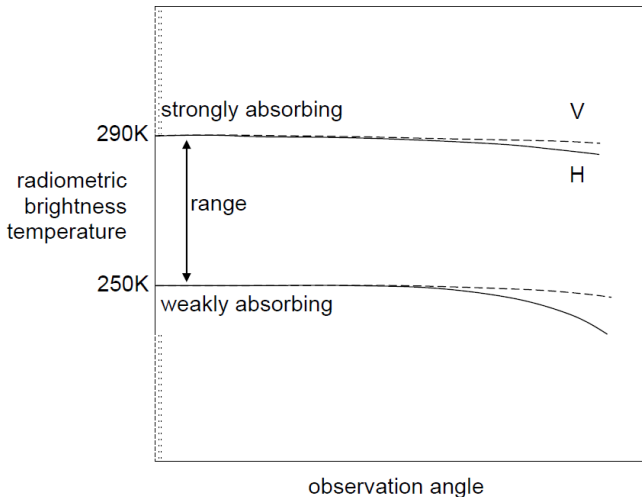
**Fig. 9.8.** Computed radiometric brightness temperature of smooth sand at 1.4GHz as a function of moisture content using the dielectric constants of Table 9.1, ignoring the effect of the (small) imaginary component of the dielectric constant and any surface roughness; the full lines represent horizontal polarisation and the dotted (upper) lines vertical polarisation

# Soil Moisture Active Passive (SMAP) Radar, L-band



SMAP produced this map of soil moisture between March 31 and April 3, 2015, as a test of the radar and radiometer instrumentation. Weaker radar signals (shown in blue) correspond to low soil moisture, while stronger (red) signals show high soil moisture. Image Credit: NASA.

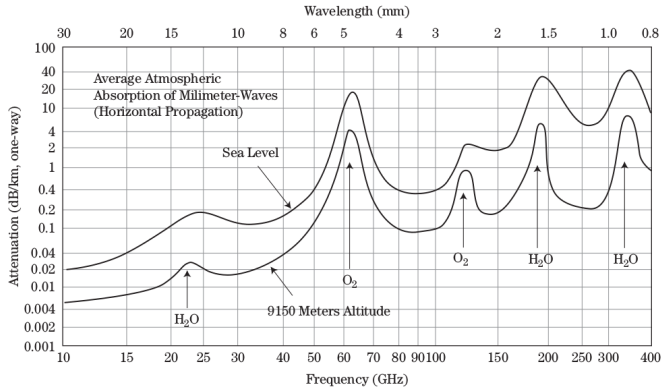
# Typical range of brightness temperature



**Fig. 9.9.** Likely range of radiometric brightness temperatures for a volume medium



# Passive microwave sensing of the atmosphere

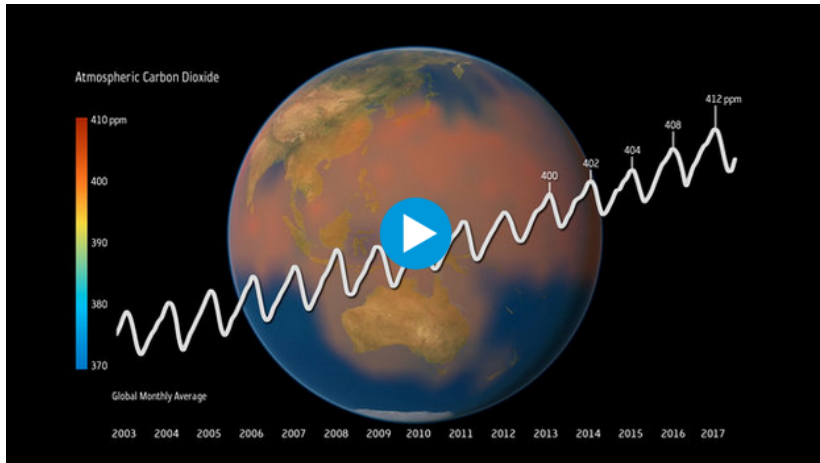


**FIGURE 1-13 ■** One-way atmospheric attenuation as a function of frequency at sea level and at 9150 meters altitude. (From U. S. Government work.)

(Figure from POMR)

Due to thermal equilibrium, the atmosphere will have strong emission in the absorption bands. In order to detect atmospheric content with a passive sensor, frequency can be chosen corresponding to absorption peaks.

# Putting it all together: the carbon cycle (ESA)



As part of the way Earth works as a system, carbon is continuously passed between the ocean, the land and the atmosphere. This involves a range of different processes, some of which can be observed by satellites. Human activity is disturbing these natural processes and causing a rise in atmospheric carbon dioxide. Satellites and ESA's Climate Change Initiative are helping to improve our understanding of the carbon cycle and its role in climate change. [<https://earth.esa.int/web/guest/content/-/article/carbon-cycle>]

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# Conclusions

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- ▶ Remote sensing provides possibilities for long time earth observation, facilitating data for climate observations.
- ▶ Active sensors use radar/lidar techniques, high resolution.
- ▶ Passive sensors detect the brightness temperature of the scene, low resolution.