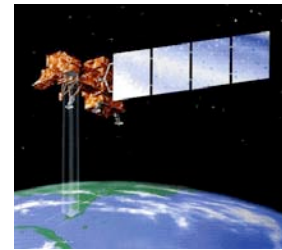


Satellite Remote Sensing

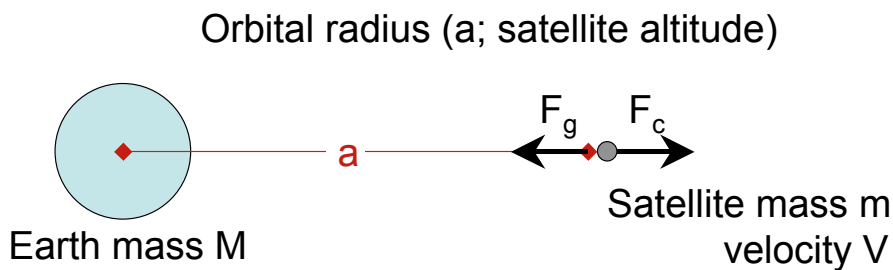
SIO 135/SIO 236

Lecture 2: Platforms and orbits

Helen Amanda Fricker



Force balance for satellites



$$F_g = m GM/a^2 \text{ and } F_c = m V^2/a = m\omega^2 a$$

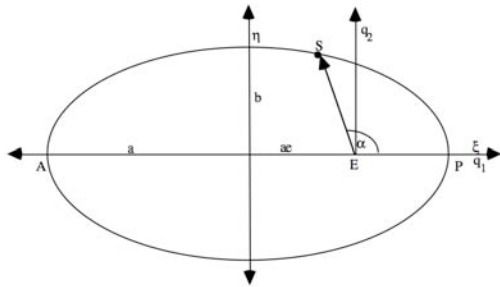
These forces are equal, therefore:

$$\omega^2 = GM/a^3$$

So the orbital frequency increases with decreasing orbit radius.

Orbital geometry and time

Orbital geometry: all orbits are elliptical with the Earth's center as one focus



S - satellite

E - Earth

A - apogee

P perigee

a/b semi-major/minor axis

E eccentricity

$$e^2 = \frac{a^2 - b^2}{a^2}$$

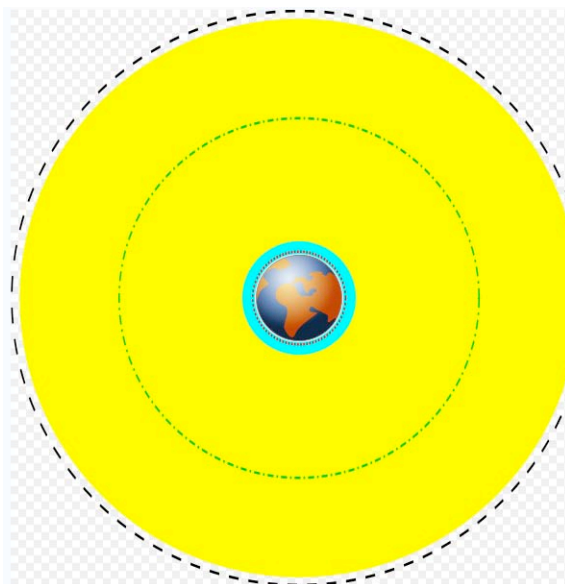
Orbital time (T_o): depends only on the orbital height (altitude).

R_p - Earth's radius (6380 km); H - orbit altitude;

g_s - gravitational acceleration at Earth surface $0.00981 \text{ km s}^{-2}$

$$T_o = 2\pi (R_p + H) \sqrt{\frac{(R_p + H)}{(g_s R_p^2)}}$$

Orbital altitudes



English	Marker	Distance above earth (km)
Earth	Blue/brown image	0
Low Earth Orbit (LEO)	Cyan area	160 to 2,000
Medium Earth Orbit (MEO)	Yellow area	2,000 to 34,780
International Space Station (ISS)	Red dotted line	500
Global Positioning System (GPS) satellites	Green dash-dot line	20,230
Geostationary Orbit (GEO)	Black dashed line	35,794

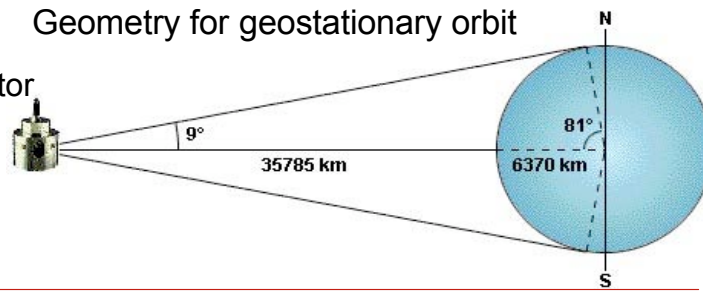
van Allen belts: 2000 to 5000 km
& 13000 to 19000 km

Source: Wikipedia, 2009

Satellite orbits

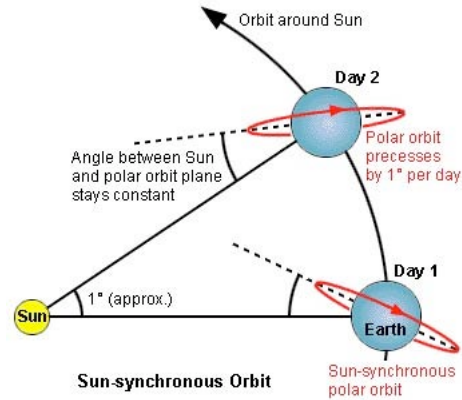
Geostationary

- 36,000 km above equator

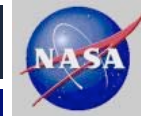


Polar

- varying heights
- often in Sun-synchronous orbits



Both diagrams from European Organisation for the Exploitation of Meteorological Satellites
www.eumetsat.de/en/mtp/space/polar.html



Satellite Remote Sensing SIO 135/SIO 236

Lecture 3: Electromagnetic Radiation and Polarisation

↑ Helen Amanda Fricker



Maxwell's Equations

Differential form in free space:

1 Gauss's law: $\nabla \cdot \mathbf{E} = 0$

2 Gauss's law for magnetism: $\nabla \cdot \mathbf{B} = 0$

3 Maxwell's Faraday rotation: $\nabla \times \mathbf{E} = -\partial \mathbf{B} / \partial t$

4 Ampere's circuital law: $\nabla \times \mathbf{B} = \mu_0 \epsilon_0 \partial \mathbf{E} / \partial t$

The harmonic plane wave $E_x = E_0 \cos(\omega t - kz)$; $E_y = 0$; $E_z = 0$
 $B_x = 0$; $B_y = E_0/c \cos(\omega t - kz)$; $B_z = 0$

satisfies Maxwell's equations, E_0 is amplitude of electric field
 E_0/c is amplitude of magnetic field

wave speed $c = \omega/k = 1/\sqrt{\epsilon_0 \mu_0}$

ω is the angular frequency, k is the wave number

$\omega = 2\pi f$ Flux density $F = \underline{E}_0^2$ where $Z_0 = (\mu_0/\epsilon_0)^{1/2}$
 $k = 2\pi/\lambda$ 27

Light is a traveling EM wave

So...Maxwell's equations tell us that the velocity of EM wave is equal to the speed of light \Rightarrow i.e. light travels as an EM wave.

$\lambda = c / f$

λ = wavelength (m)

c = speed of light (m/s)

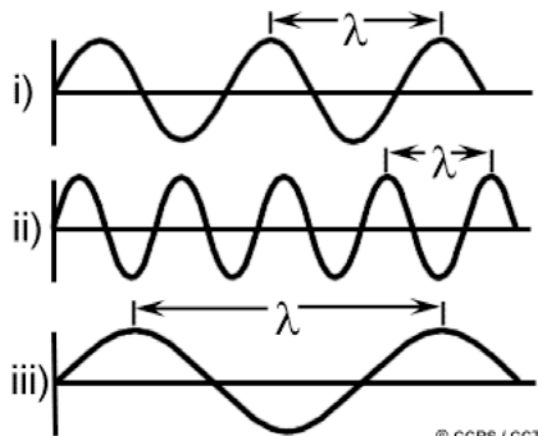
f = frequency (hz or s-1)

$c = 300,000 \text{ km/s}$

$f = 5.6 \text{ GHz}$; $\lambda = 5.6 \text{ cm}$

$f = 1.2 \text{ GHz}$; $\lambda = 24 \text{ cm.}$

$\lambda = 0.4 \text{ mm}$; $f = 750 \text{ GHz.}$



Light is a traveling EM wave

Maxwell's equations also tell us that EM waves don't carry any material with them. They only transport **energy**:

$$E = h f = h c / \lambda$$

c = speed of light (m/s)

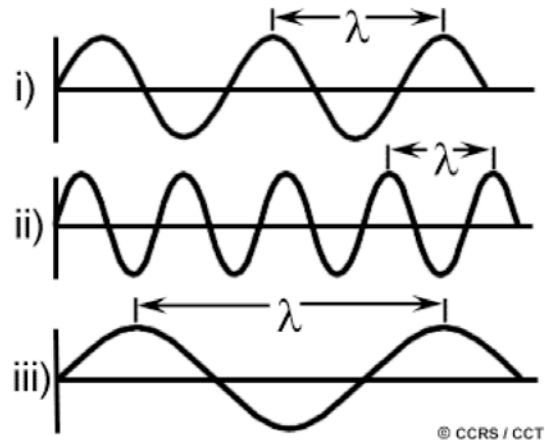
h = Planck's constant.

f = frequency (hz or s⁻¹)

λ = wavelength

High-frequency electromagnetic waves have a short wavelength and high energy;

Low-frequency waves have a long wavelength and low energy



© CCRS / CCT

Electromagnetic Spectrum

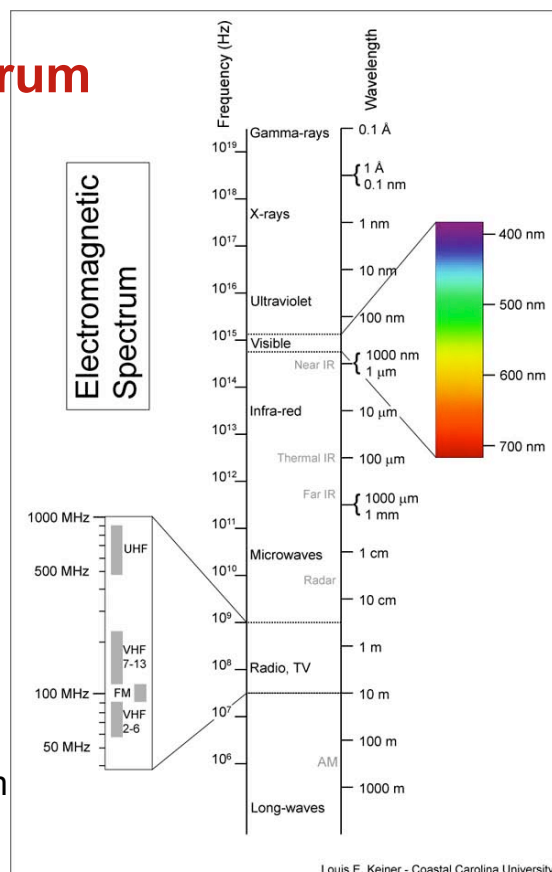
Visible: Small portion of the EMS that humans are sensitive to:
 blue (0.4-0.5 μm); green (0.5-0.6 μm);
 red (0.6-0.73 μm)

Infrared: Three logical zones:

1. Near IR: reflected, can be recorded on film emulsions (0.7 - 1.3μm).
2. Mid infrared: reflected, can be detected using electro-optical sensors (1.3 - 3.0μm).
3. Thermal infrared: emitted, can only be detected using electro-optical sensors (3.0 - 5.0 and 8 - 14 μm).

Microwave

Radar sensors, wavelengths range from 1mm - 1m (K_a, K_u, X, C, S, L & P)



Louis E. Keiner - Coastal Carolina University

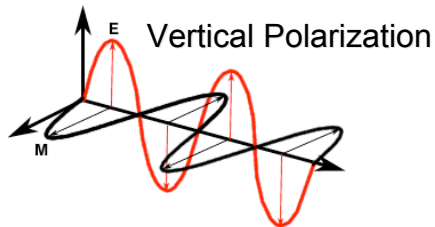
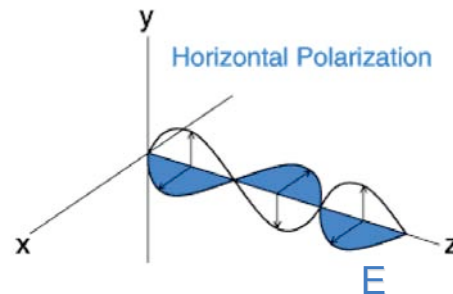
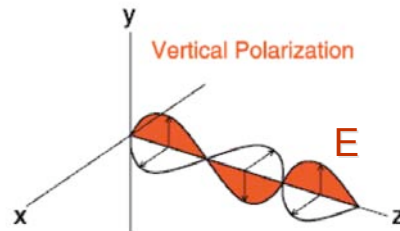
Polarization

Refers to orientation of the electric field \mathbf{E}

If both \mathbf{E} and \mathbf{B} remain in their respective planes, the radiation is called “**plane or linearly polarized**” :

- vertically polarized (E is parallel to the plane of incidence)
- horizontally polarized (E is perpendicular to the plane of incidence)

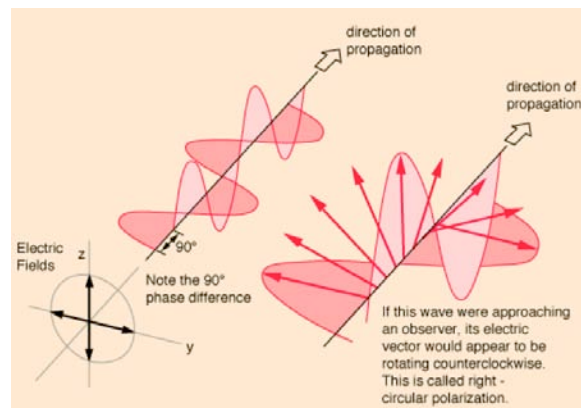
Plane of incidence = the plane defined by the vertical and the direction of propagation



Polarization

If instead of being confined to fixed direction, \mathbf{E} rotates in the x-y plane with constant amplitude, it is said to be circularly polarized (either right- or left-hand circular (clockwise/anti-clockwise respectively))

Circularly polarized light consists of two perpendicular EM plane waves of equal amplitude and 90° difference in phase. The light illustrated is right-hand circularly polarized

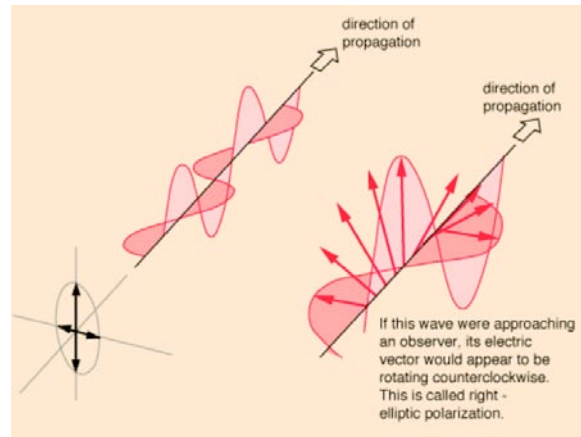


Radiation from the sun is unpolarized (at random angles)

Polarization

Elliptically polarised light consists of two perpendicular waves of unequal amplitude which differ in phase by 90° . The illustration shows right-hand elliptically polarised light.

If the thumb of your right hand were pointing in the direction of propagation of the light, the electric vector would be rotating in the direction of your fingers.



Interaction of EMR with matter

Propagation of EMR in a uniform homogenous material depends on two properties of medium:

- 1) **relative electric permittivity ϵ_r , or dielectric constant $\epsilon_r = \epsilon/\epsilon_0$**
- 2) **relative magnetic permeability $\mu_r = \mu/\mu_0$**

with no absorption, ϵ_r and μ_r are real, dimensionless numbers

$$E_x = E_0 \cos(\omega t - kz) \quad \text{and} \quad B_y = E_0/c \cos(\omega t - kz)$$

wave speed (phase velocity) $\omega/k = c/\sqrt{\epsilon_r \mu_r}$

The **refractive index $n = (\epsilon_r \mu_r)^{1/2}$** is a measure of how much the speed of EMR is reduced inside the medium [for free space, $n=1$]

Complex dielectric constant

For most media we shall need to consider, $\mu_r = 1$ (non magnetic materials)

If the medium absorbs energy from the wave, the dielectric constant becomes complex (real + imaginary)

$$\epsilon_r = \epsilon' - i\epsilon'' \quad \text{or} \quad \epsilon_r = \epsilon'(1 - i \tan \delta)$$

↑
loss tangent

See page 36 of Rees, arrive at the following wave equation:

$$\rightarrow E_x = E_0 \exp(-\omega k z / c) \exp(i[\omega t - \omega m z / c])$$

Simple harmonic wave whose amplitude decreases exponentially with z
Flux density $F = F_0 \exp(-2 \omega k z / c)$

$$\rightarrow \text{Absorption length } l_a = c / 2\omega k$$



Satellite Remote Sensing SIO 135/SIO 236

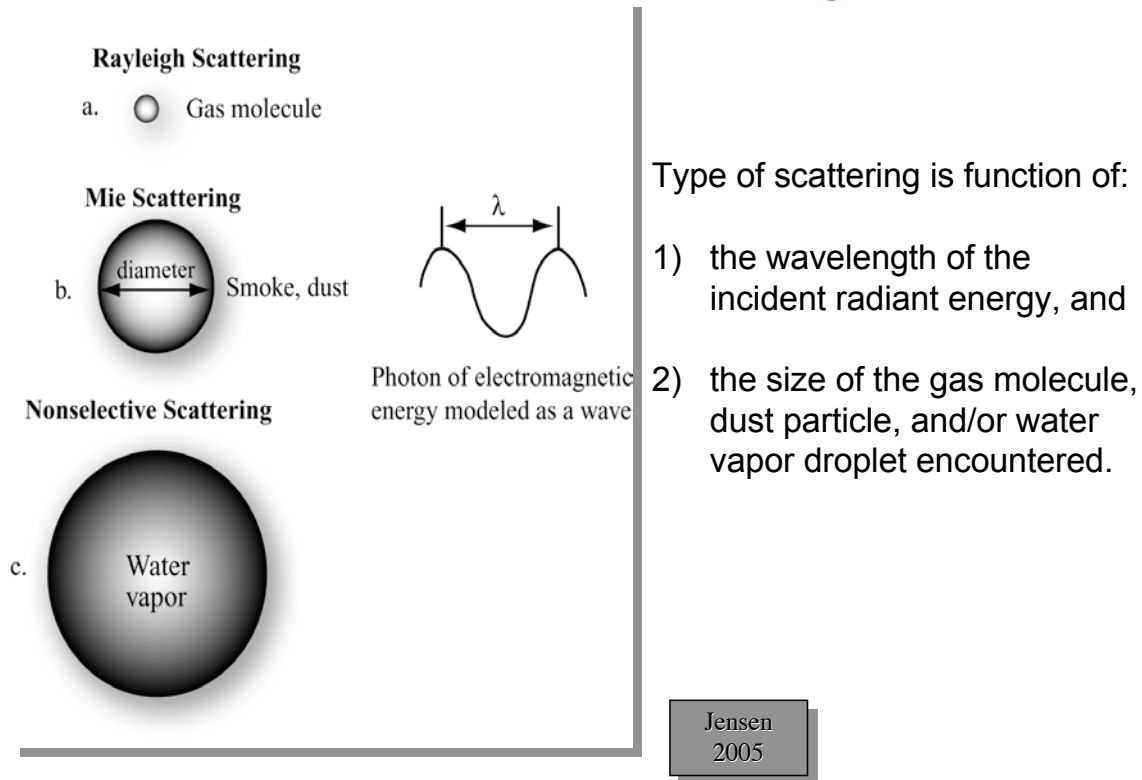
Lecture 7: Propagation, Dispersion and Scattering



Helen Amanda Fricker



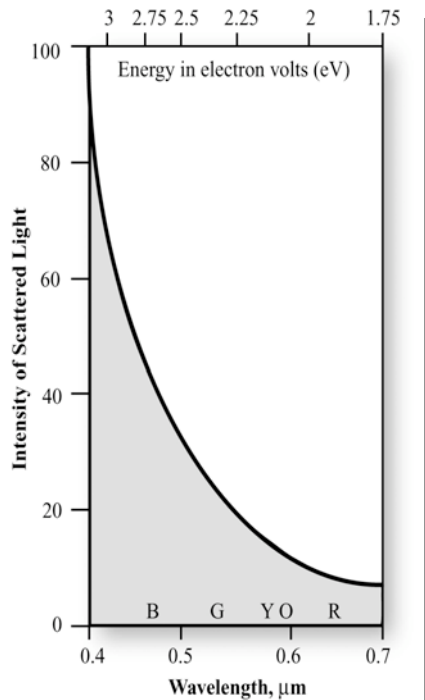
Atmospheric Scattering



Rayleigh scattering

- Rayleigh scattering is molecular scattering and occurs when the diameter of the molecules and particles are many times smaller than the wavelength of the incident EMR
- Primarily caused by air particles i.e. O_2 and N_2 molecules
- All scattering is accomplished through absorption and re-emission of radiation by atoms or molecules in the manner described in the discussion on radiation from atomic structures. It is impossible to predict the direction in which a specific atom or molecule will emit a photon, hence scattering.
- The energy required to excite an atom is associated with short-wavelength, high frequency radiation. The amount of scattering is inversely related to the fourth power of the radiation's wavelength (λ^{-4}).

Rayleigh scattering

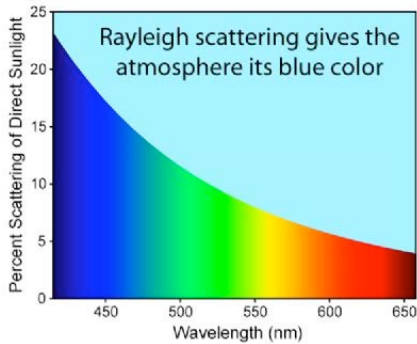


The intensity of Rayleigh scattering varies inversely with the fourth power of the wavelength (λ^{-4}).

So blue light (0.4 μm) is scattered 16 times more than near-infrared light (0.8 μm).

Jensen
2005

Rayleigh scattering



- Responsible for the **blue sky**. The short wavelengths (violet/blue) are more efficiently scattered than the longer wavelengths (orange/red). Blue sky is a result of the preferential scattering of the short wavelength light.

- Responsible for **red sunsets**. Since the atmosphere is a thin shell of gravitationally bound gas surrounding the solid Earth, sunlight must pass through a longer slant path of air at sunset/sunrise than at noon. Short wavelengths (violet/blue) are scattered even more during their longer path through the air, what we see when we look toward the Sun is the residue - the long wavelengths of sunlight that are hardly scattered (orange/red).



Rayleigh scattering

The approximate amount of Rayleigh scattering in the atmosphere in optical wavelengths (0.4 – 0.7 μm) may be computed using the Rayleigh scattering cross-section (τ_m) algorithm:

$$\tau_m = \frac{8\pi^3(n^2 - 1)^2}{3N^2\lambda^4}$$

where n = refractive index, N = number of air molecules per unit volume, and λ = wavelength.

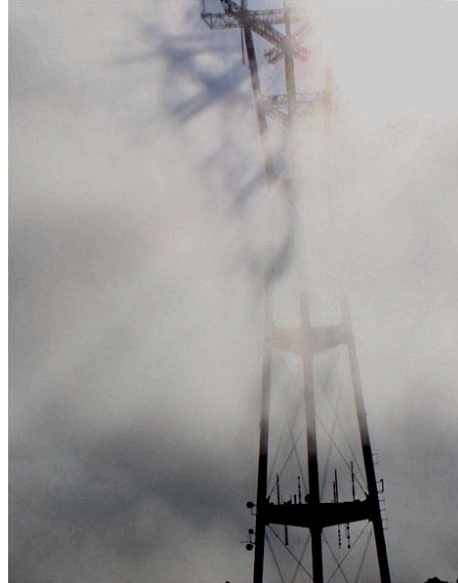
Mie scattering

- Mie scattering takes place when there are essentially spherical particles present in the atmosphere with diameters approximately equal to the wavelength of radiation.
- For visible light, water vapor, dust, and other particles ranging from a few tenths of a micrometer to several micrometers in diameter are the main scattering agents. The amount of scatter is greater than Rayleigh scatter and the wavelengths scattered are longer.
- Pollution also contributes to beautiful **sunsets** and **sunrises**. The greater the amount of smoke and dust particles in the atmospheric column, the more violet and blue light will be scattered away and only the longer **orange** and **red** wavelength light will reach our eyes.

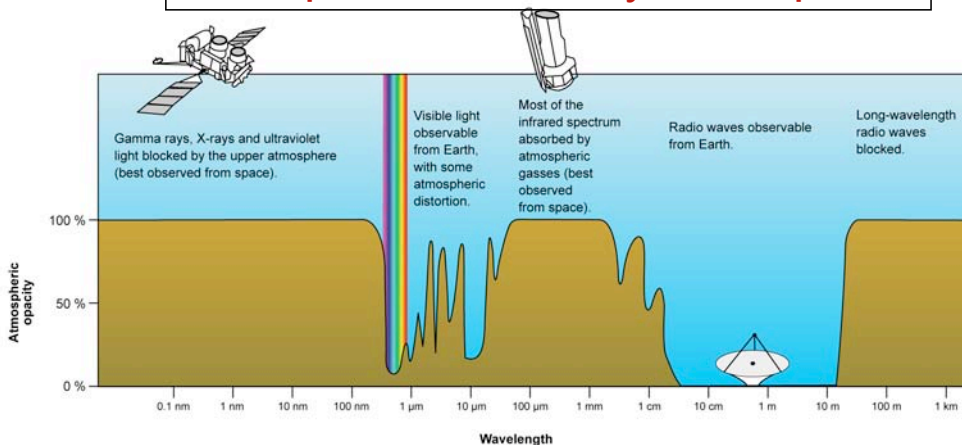
Non-selective scattering

- Non-selective scattering is produced when there are particles in the low atmosphere several times the diameter of the radiation being transmitted. This type of scattering is non-selective, i.e. all wavelengths of light are scattered, not just blue, green, or red. Thus, water droplets, which make up clouds and fog banks, scatter all wavelengths of visible light equally well, causing the cloud to appear white

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



Absorption of EMR by atmosphere

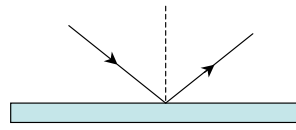


Different molecules absorb different wavelengths of radiation:

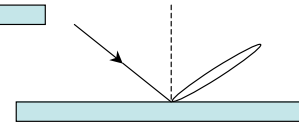
- O_2 and O_3 absorb almost all wavelengths shorter than 300 nm.
- Water (H_2O) absorbs many wavelengths above 700 nm, but this depends on the amount of water vapor in the atmosphere (tropics vs poles)
- When you combine the absorption spectra of the gasses in the atmosphere, you are left with "windows" of low opacity, allowing the transmission of only certain EMR.

Surface scattering

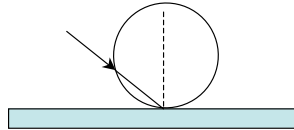
1) Specular



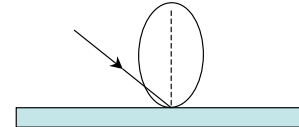
2) Quasi-specular



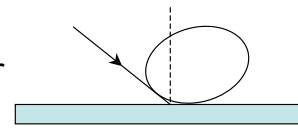
3) Lambertian



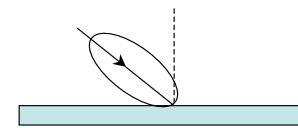
4) Minnaert model



5) Henyey-Greenstein model for forward scatter



6) Henyey-Greenstein of backscatter

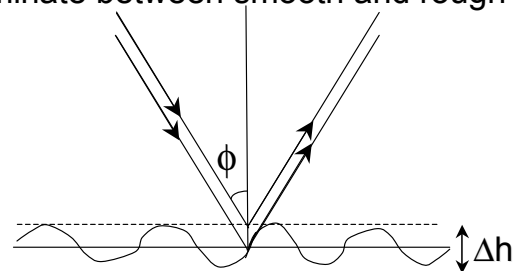


Rayleigh criterion

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

$$\Delta \text{path length} = 2 \Delta h \cos \phi$$

$$\text{Phase difference} = \frac{2\pi}{\lambda} 2 \Delta h \cos \phi$$



Surface is considered smooth if phase difference $< \pi/2$

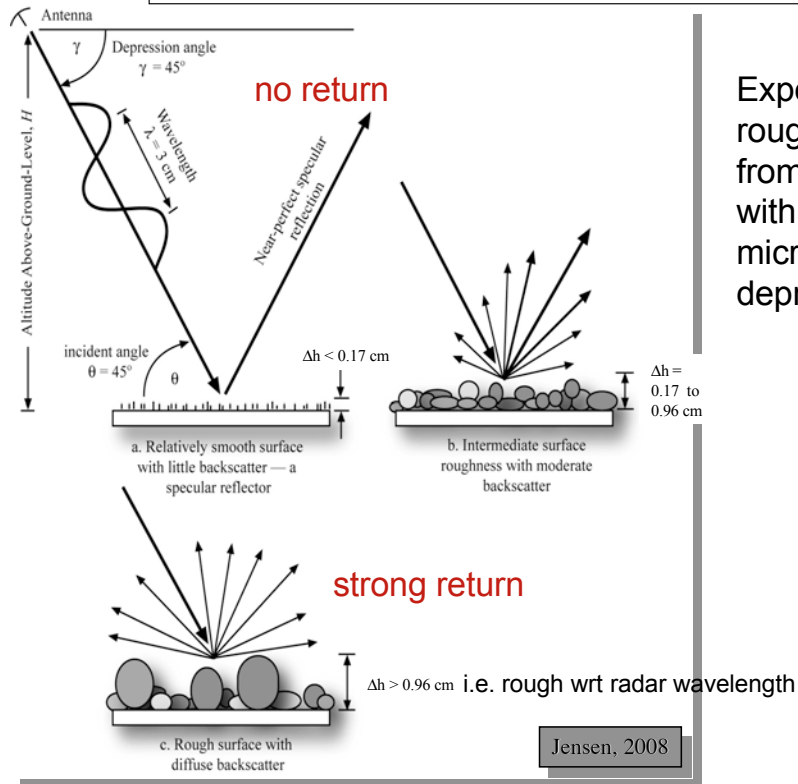
$$\frac{4\pi \Delta h \cos \phi}{\lambda} < \frac{\pi}{2} \quad \text{or} \quad \Delta h < \frac{\lambda}{8 \cos \phi}$$

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

For $0.5 \mu\text{m}$ (blue light) $\Delta h < 62 \text{ nm}$

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

Surface roughness in radar imagery



Expected surface roughness back-scatter from terrain illuminated with 3 cm wavelength microwave energy with a depression angle of 45° .

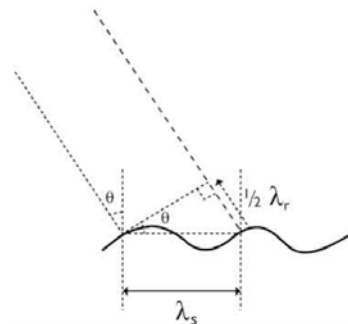
Bragg scattering

Page 53-55 Rees

- As the incidence angle of the ERS SAR is oblique (23°) to the local mean angle of the ocean surface, there is almost no direct specular reflection except at very high sea states.
- It is therefore 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.