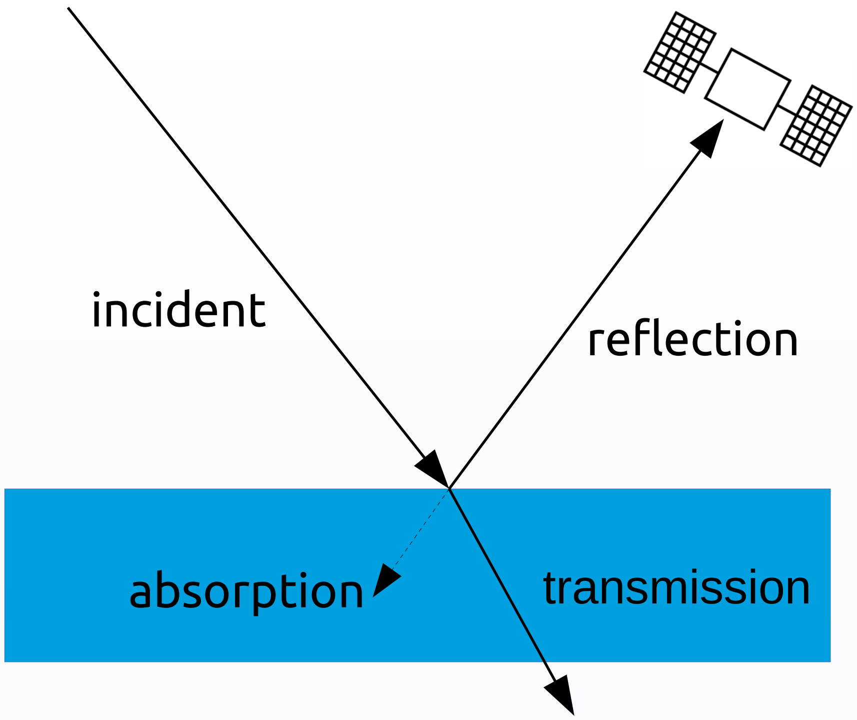
EGM703 – Advanced Active and Passive Remote Sensing

Week 3, Part 2: Surface and Atmospheric Interaction

EMR and Earth Surface

- EMR interacts with Earth surface similar to atmosphere:
  - Reflection
  - Absorption
  - Transmission
- How, and how much, depends on:
  - Properties of surface
  - Wavelength
  - Angle of illumination (incidence)



$$\Phi_i = \Phi_r + \Phi_a + \Phi_t$$

Kirchoff's radiation law

- For an arbitrary body emitting and absorbing in thermodynamic equilibrium:

$$\varepsilon(\lambda) = \alpha(\lambda)$$

- Most objects are opaque in thermal infrared (i.e., $\tau(\lambda) = 0$), so:

$$\boxed{\varepsilon(\lambda) + \rho(\lambda) = 1}$$

- In other words:
  - Low reflectance → high emissivity (like a blackbody!)
  - Low emissivity → high reflectance
- Microwave remote sensing:
  - We can derive emissivity (passive sensing) from reflectance (active sensing)

Propagation of waves

- Need to consider how EM waves propagate through different media
  - So far, mostly focused on atmosphere
- Depends on material's electromagnetic properties:
  - Electric permittivity, ε
  - Magnetic permeability, μ
  - Electric conductivity, g
- For non-conductive (dielectric) materials, ε is most relevant

Electric permittivity

- Electric permittivity describes how electric field interacts with a dielectric medium
  - i.e., how well does electric field polarize molecules in material?
- Normally described relative to a vacuum (ε_0):

$$\varepsilon = \varepsilon_r \varepsilon_0$$

  - ε_r is a dimensionless value
- Interaction with material causes a phase change → permittivity is often given as a complex number:

$$\varepsilon_r = \varepsilon'_r - i\,\varepsilon''_r$$

- "Dielectric constant" normally refers only to real part (ε'_r)

Electric permittivity

- As EM wave travels through dielectric medium, it loses energy (attenuation)

$$\varepsilon_r = \boxed{\varepsilon'_r} - \boxed{i\,\varepsilon''_r}$$

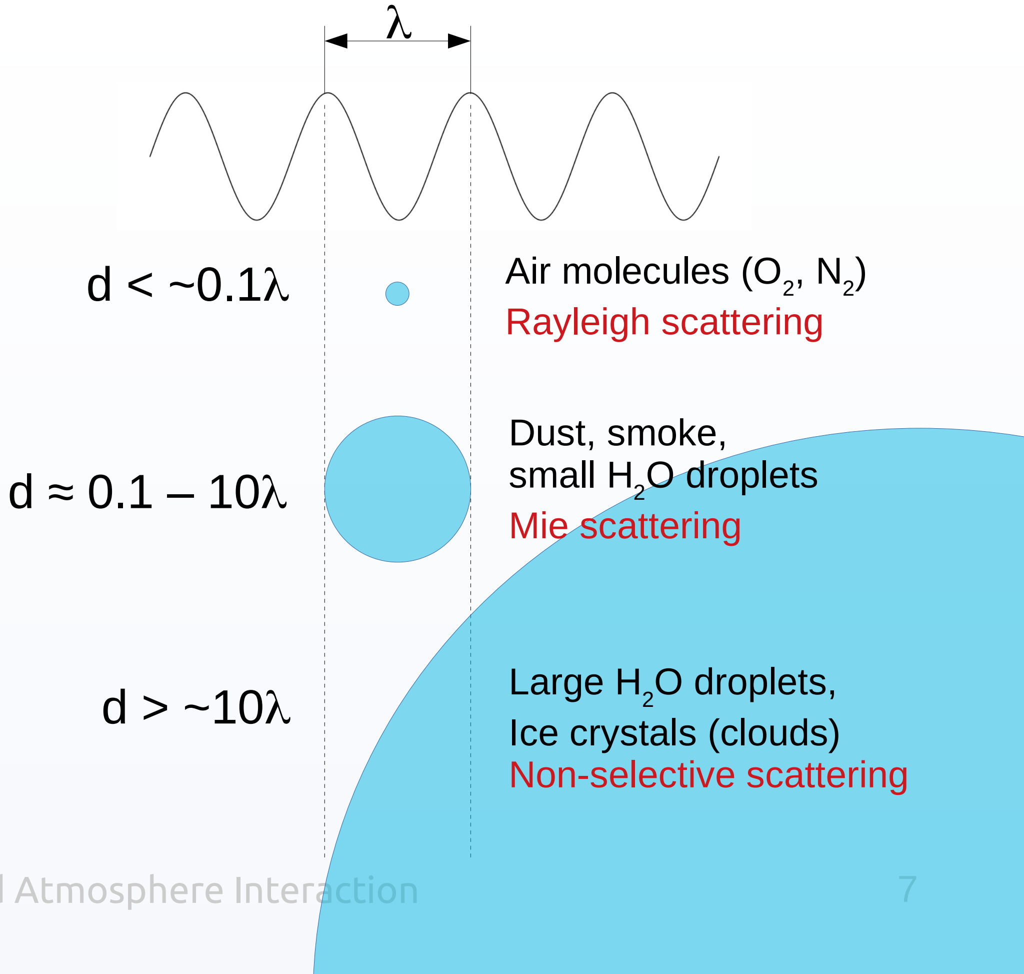
  - Real part: dielectric constant (lossless)
  - Imaginary part: absorption (energy loss)
- Attenuation is exponential (amplitude decays exponentially with depth)
- Propagation depth δ_p can be approximated:

$$\delta_p \approx \frac{\lambda \sqrt{\varepsilon'_r}}{2\pi \varepsilon''_r}$$

- Most materials have some penetration depth (except for liquid water, wet snow)
  - Spoiler alert: liquid water is <u>really</u> important in microwave remote sensing

Scattering

- At boundaries between media with different dielectric properties, EMR is redirected (scattered)
  - Reflection: ordered redirection from a “smooth” surface
- Most of the time, we mean random redirection:
  - Absorption + re-emission (small-diameter particles)
  - Physical scattering (large-diameter)
- Two main cases:
  - Scattering from surfaces (area >> λ)
  - Scattering from objects (area ≈ λ)
- Three main mechanisms, depending on particle size



Scattering cross-section

- We measure how effective a scatterer is using the scattering cross-section, σ:

$$\sigma(\theta) = \frac{\text{scattered power per unit solid angle into direction } \theta}{\text{intensity of original plane wave} / 4\pi}$$

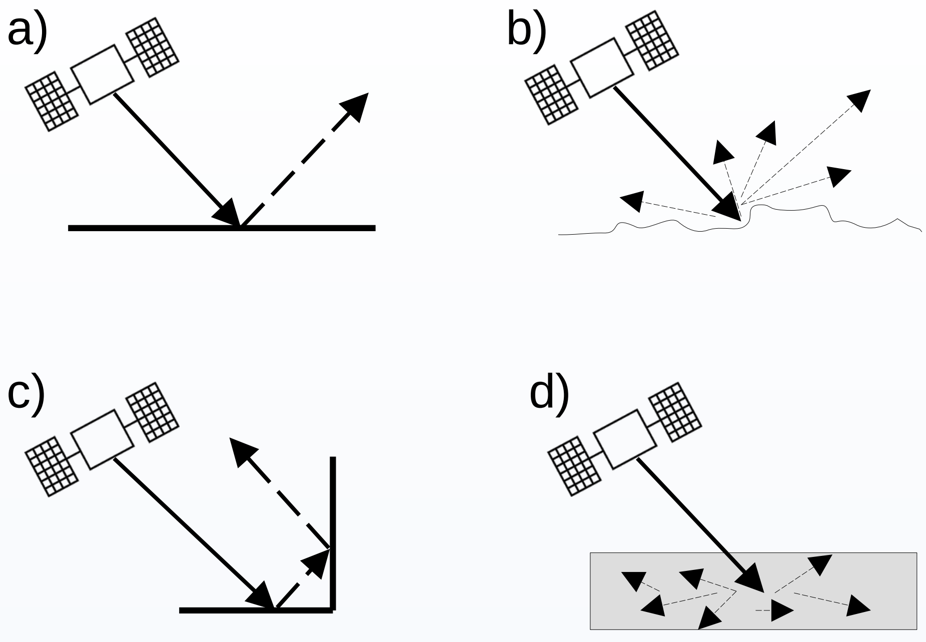
- With radar systems, we have the backscattering or radar cross-section:

$$\sigma = \frac{I_{\text{received}}}{I_{\text{incident}}} 4\pi R^2$$

- Because σ depends on sensor resolution, normally divide by area of object to get normalized radar cross-section, σ^0

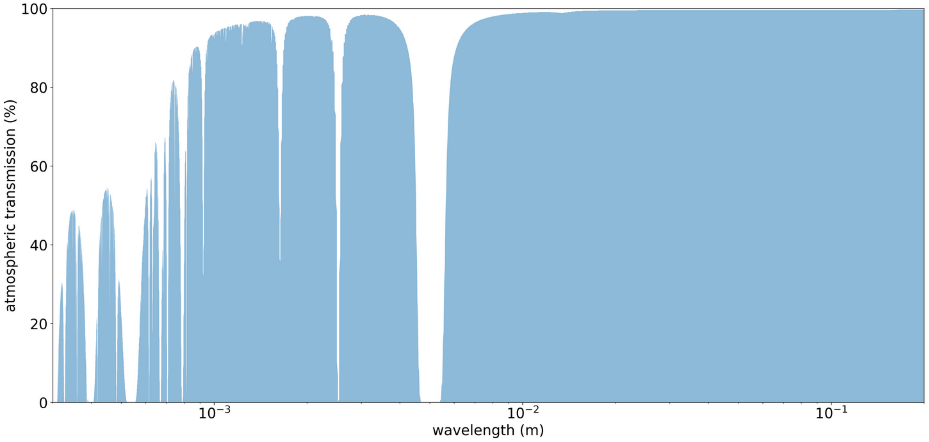
Types of scattering

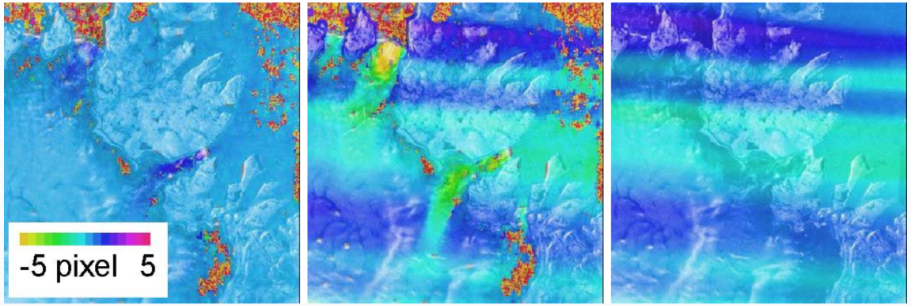
- We can categorize scattering into four main categories:
  a) Smooth (specular) surface
  b) Rough surface
    - Periodically rough: Bragg scattering
  c) Edge and corner reflectors
  d) Diffuse (volume) scattering
- Smooth: irregularities << λ
- Rough: irregularities > λ
- Also depends on incidence angle



The atmosphere

- Atmosphere is almost completely transparent to microwaves
  - Including clouds
- Ionosphere: the ionized portion of Earth's atmosphere
  - Faraday rotation: rotation of polarization vector due to external magnetic field, charged medium
  - Can pose serious problems depending on microwave sensor





Wegmüller et al., 2006

Summary

- Microwave interaction depends heavily on electromagnetic properties of material
- Scattering (redirection) takes place at the boundary between media
  - For microwaves, primarily non-selective scattering
  - Mechanism depends on “smoothness” relative to wavelength
- The atmosphere is (mostly) transparent to microwaves, though the ionosphere can be a problem.

Additional resources

- Lillesand, Kiefer & Chipman – Chapter 1.3
- Campbell & Wynne – Chapter 2.5-2.6, 7.4-7.6
- Wegmüller et al., 2006 [IGARSS 2006]
- Why the sky is blue [How&Why]
- Specular and Diffuse Reflection [Khan Academy]