University of Maryland Baltimore County - UMBC

Phys650 - Special Topics in Experimental Atmospheric Physics
(Spring 2009)

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http://userpages.umbc.edu/~martins/PHYS650/

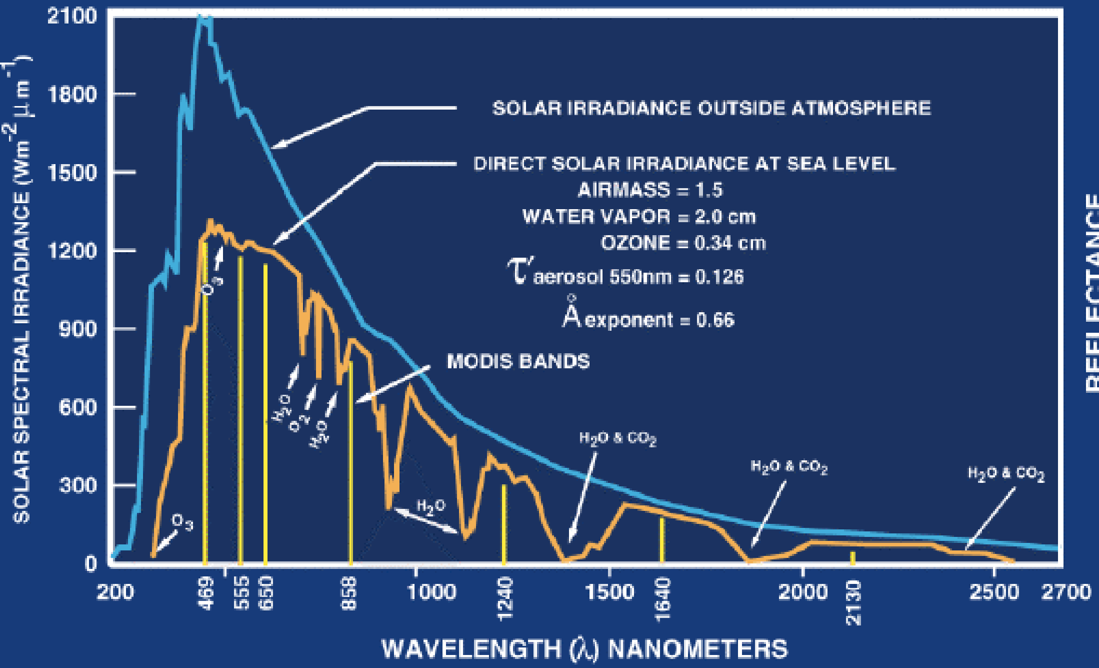
Class 11 – Introduction to Surface BRDF and Atmospheric Scattering

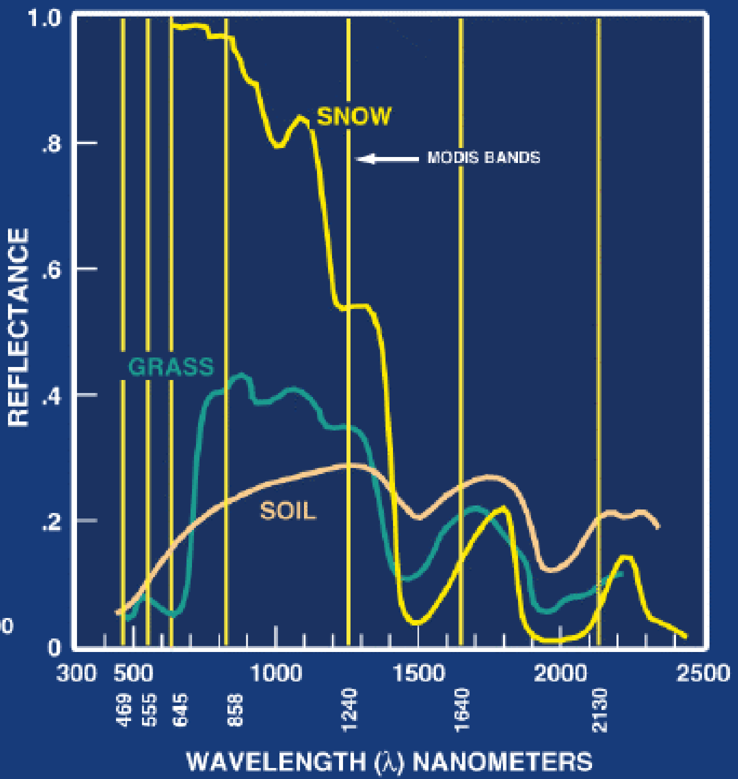
Class 12/13 - Measurements of Surface BRDF and Atmospheric Scattering

Directional Reflectance of Surfaces and Particles

- Surface color
- Reflectance by a smooth and flat surface
- Reflectance of a rough surface
- Reflectance by particles over a surface
- Reflectance by particles or molecules in suspension in the atmosphere

Solar (reflective) spectral domain

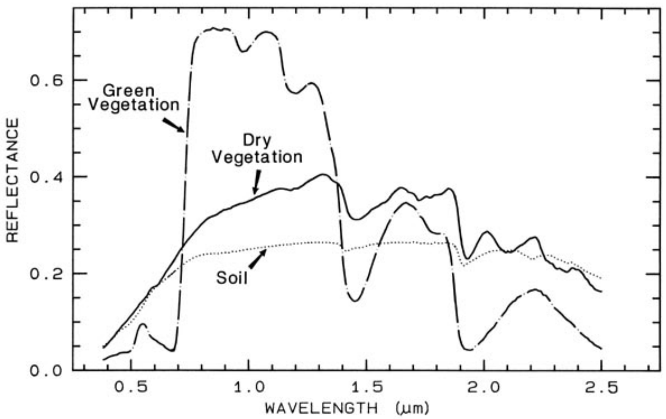




Vegetation reflection

Spectral dependence

(for angular dependence, see Lecture 2)



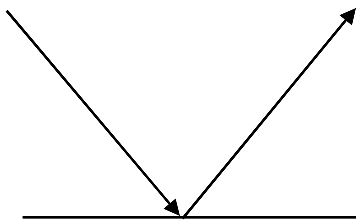
Frequent measure: Normalized Difference Vegetation Index

$$NDVI = \frac{R_{NIR} - R_{VIS}}{R_{NIR} + R_{VIS}}$$

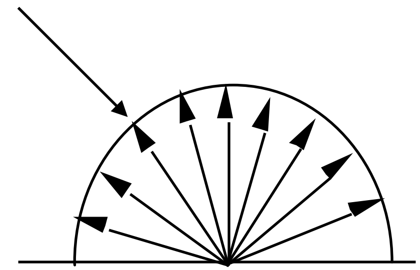
VIS **IR** **NDVI**

Figure thanks to Tamas Varnai/JCET - UMBC

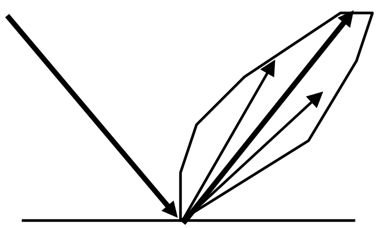
Different Types of Reflectors



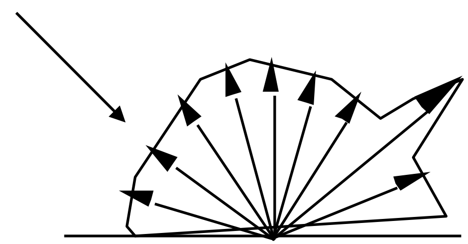
Specular reflector (mirror)



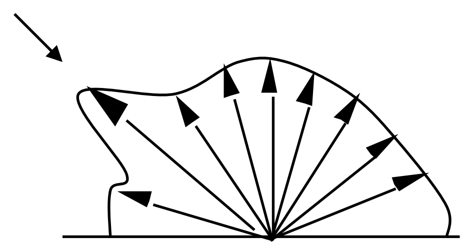
diffuse reflector (lambertian)



Nearly Specular reflector (water)



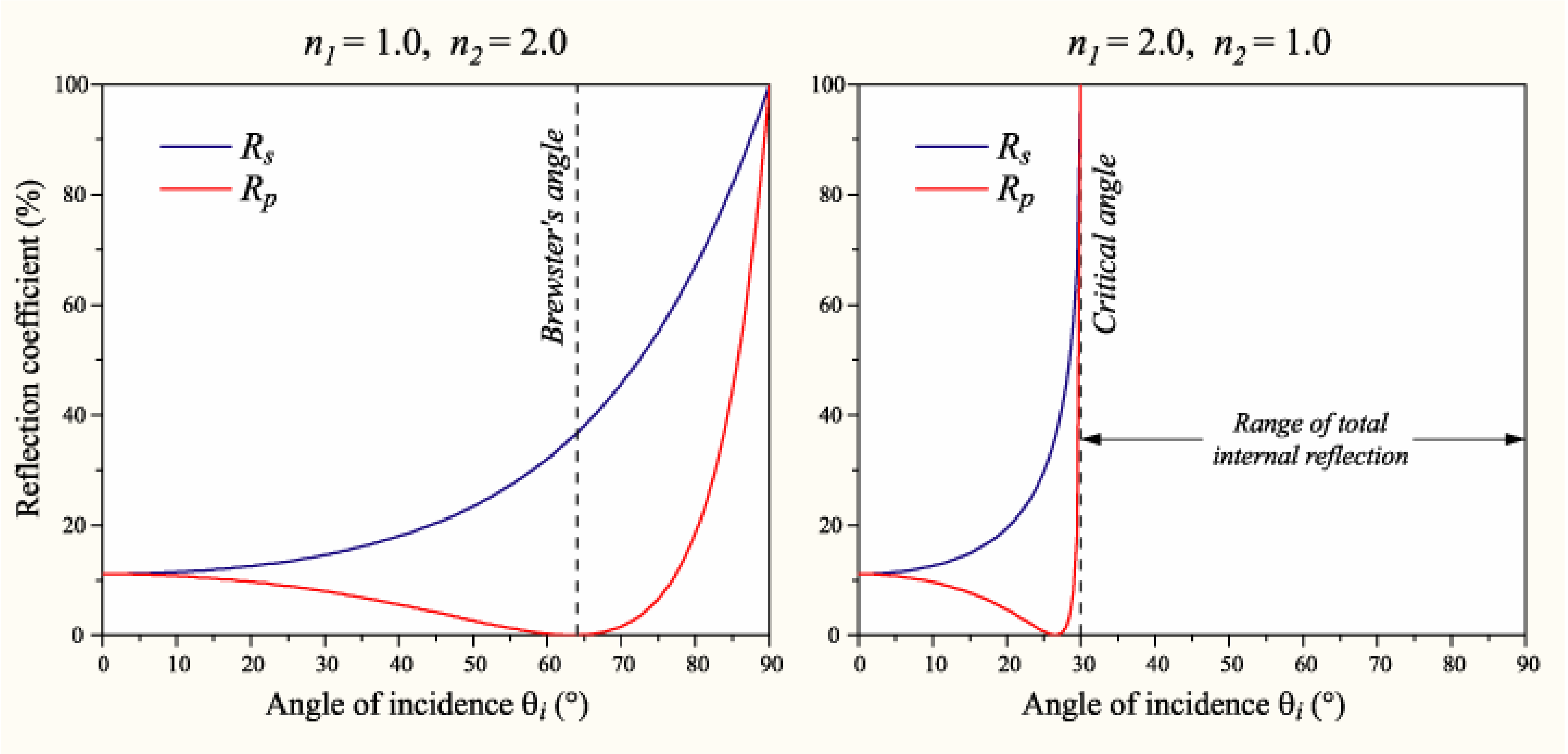
nearly diffuse reflector



Hot spot reflection

Figure thanks to Eric Vermote - UMD

Fresnel Curves for Flat and Smooth Surfaces



http://en.wikipedia.org/wiki/Fresnel_equations

Solar Energy Paths

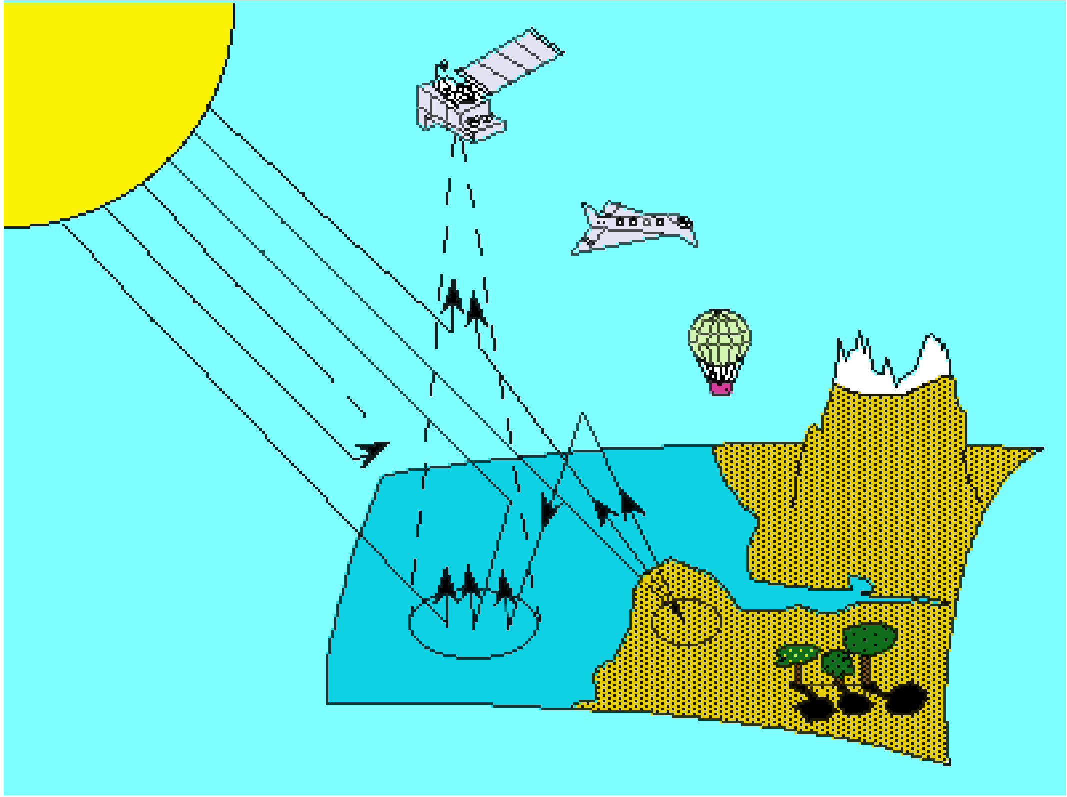


Figure thanks to Eric Vermote - UMD

Observation Geometry

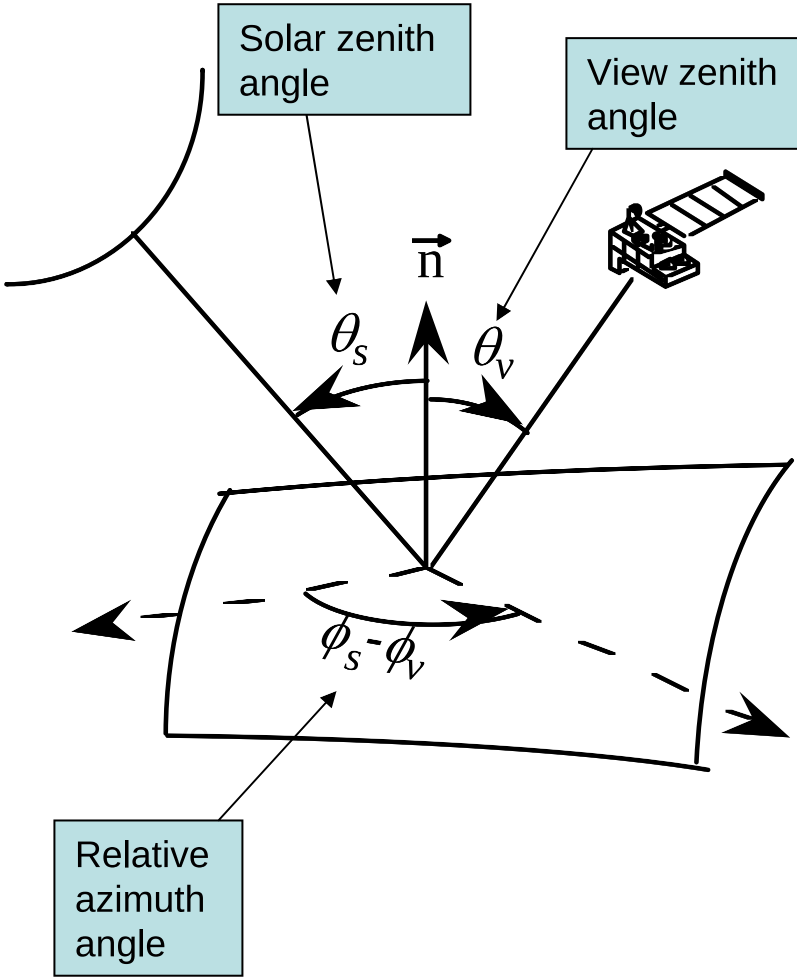
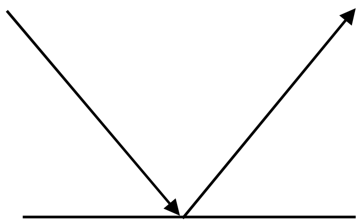
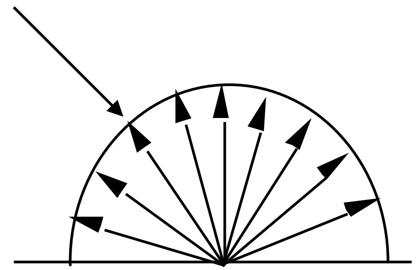


Figure thanks to Eric Vermote - UMD

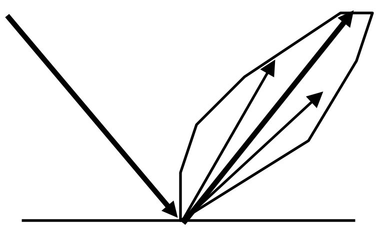
Different Types of Reflectors



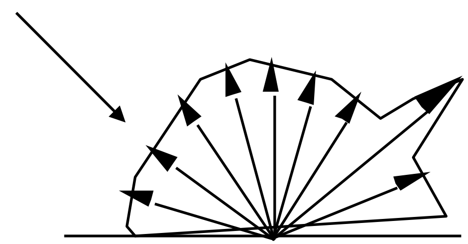
Specular reflector (mirror)



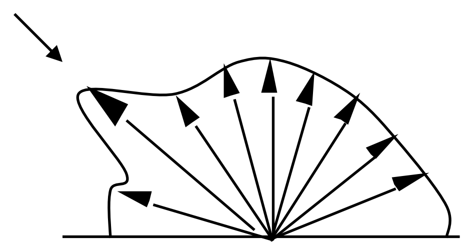
diffuse reflector (lambertian)



Nearly Specular reflector (water)



nearly diffuse reflector



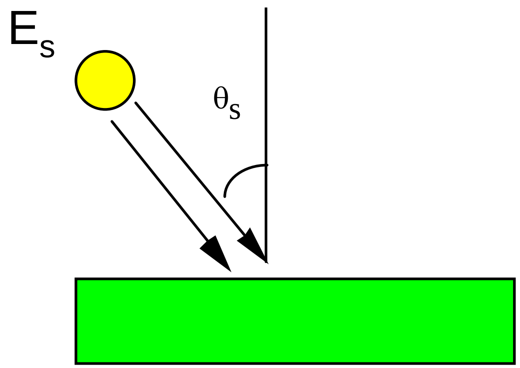
Hot spot reflection

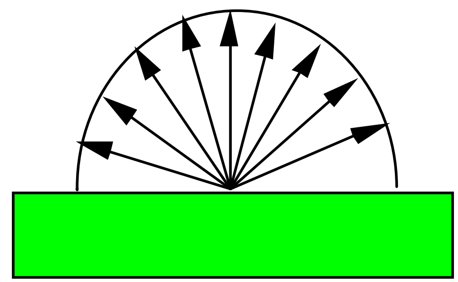
Figure thanks to Eric Vermote - UMD

Perfect Lambertian Reflector

Radiance of the Perfect Lambertian Reflector

$$\int_0^{\pi}\int_0^{2\pi} RPLF(\theta_S,\theta,\phi)\cos(\theta)\sin(\theta)\,d\theta\,d\phi = E_s\cos(\theta_s)$$





$$\rho_{Perfect\quad Lambertian\quad reflector}(\theta_S,\theta_V,\phi) = 1$$

$$\rho_{Lambertian\quad reflector}(\theta_S,\theta_V,\phi) = \rho$$

Figure thanks to Eric Vermote - UMD

Surface characterization

In atmospheric studies, surface often characterized using bulk properties:

Albedo: $\rho = \frac{F_\uparrow}{F_\downarrow}$

BRF (Bidirectional Reflection Function) or Simply **Reflectance** (*R*):

$$BRF = \frac{\pi \cdot I}{\mu_0 \cdot F_0} \qquad BRF = BRF(\Omega, \Omega_0, \lambda)$$

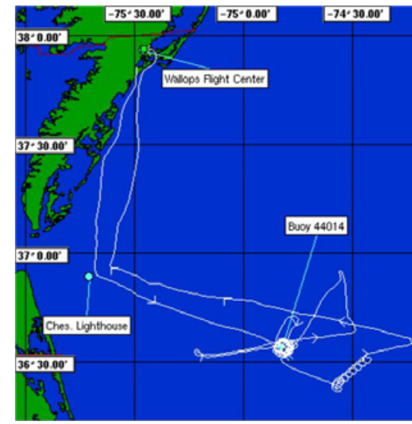
Advantages over *I*:

Interpretation and limits:

BRDF
(Bidirectional Reflection Distribution Function):

$$BRDF = \frac{BRF}{\rho}$$

Remote sensing
CAR (Cloud absorption radiometer)
measurement strategy



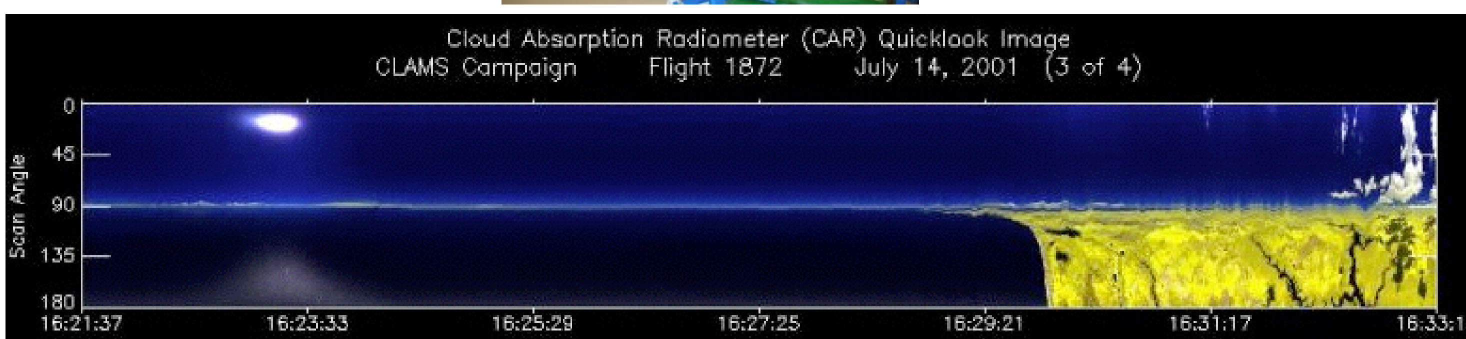
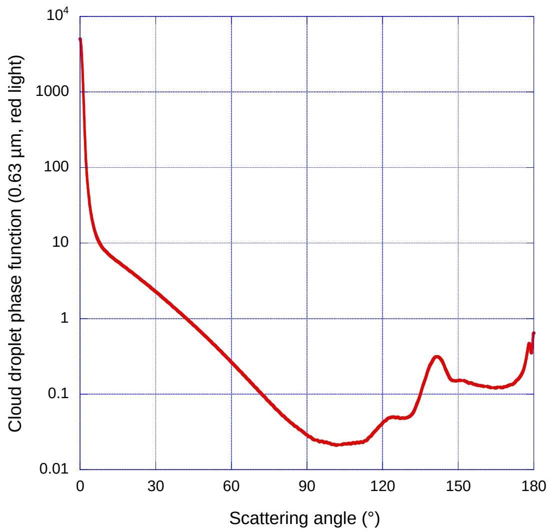
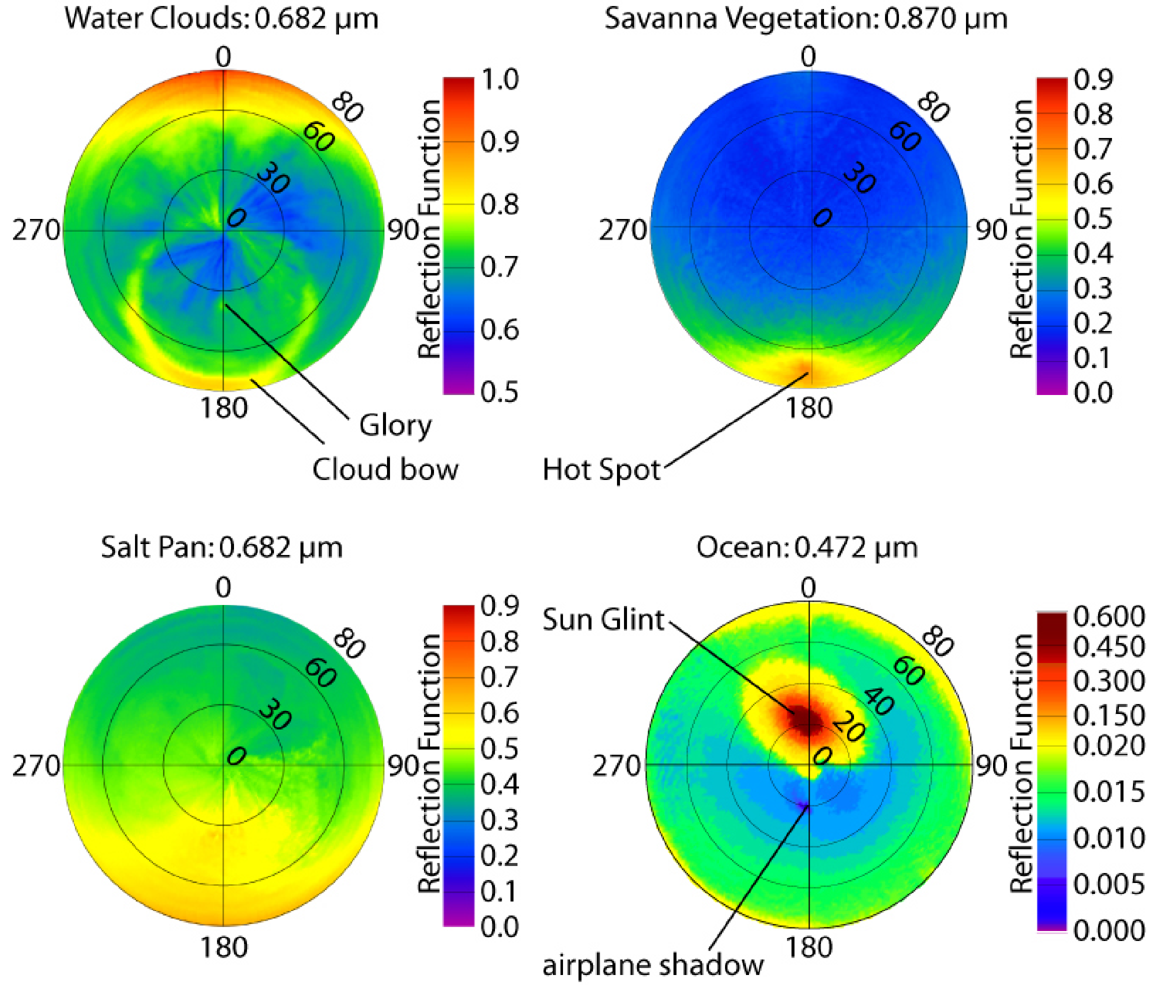


Figure thanks to Tamas Varnai/JCET - UMBC

Surface reflection patterns

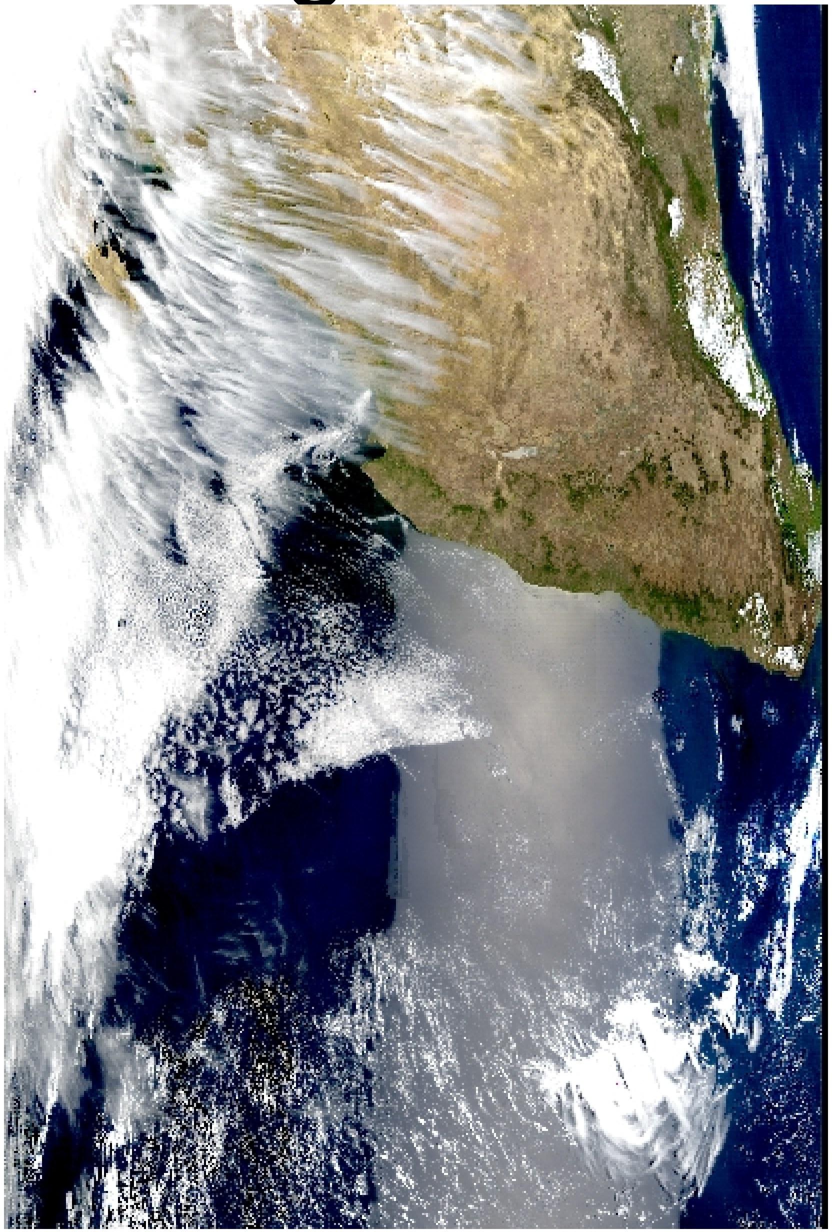




Explanation of features

Figure thanks to Tamas Varnai/JCET - UMBC

Sun glint as seen by MODIS



Gray level temperature image

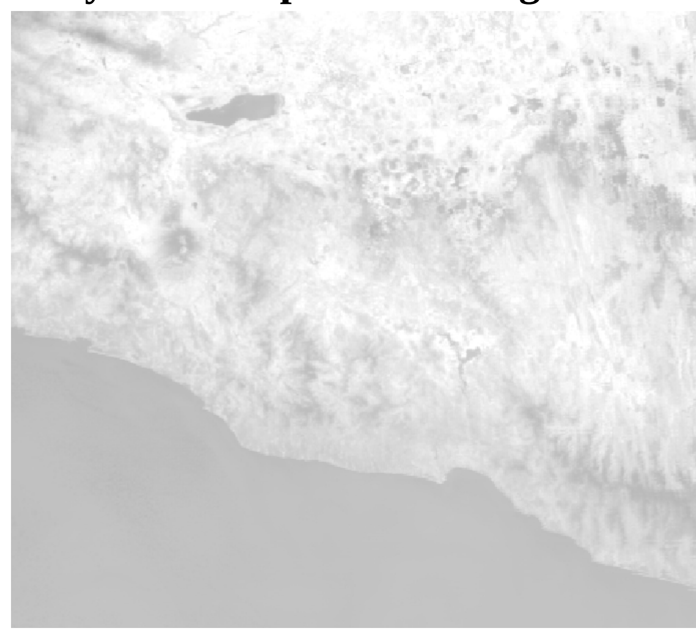
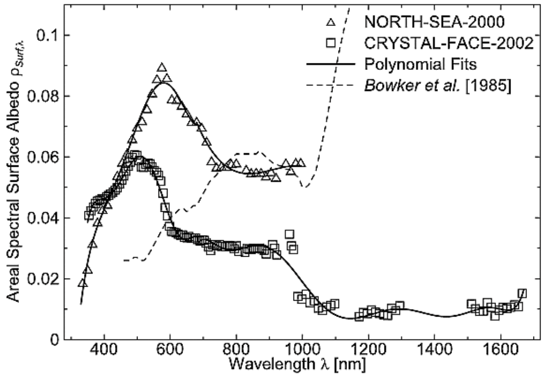


Figure thanks to Tamas Varnai/JCET - UMBC

Sea surface

Spectral dependence:
dark in infrared (?)



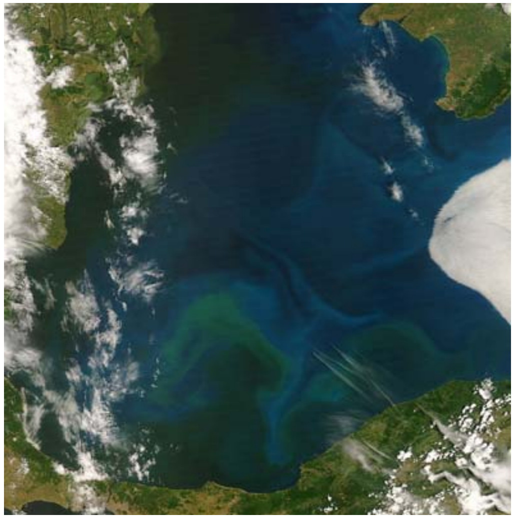


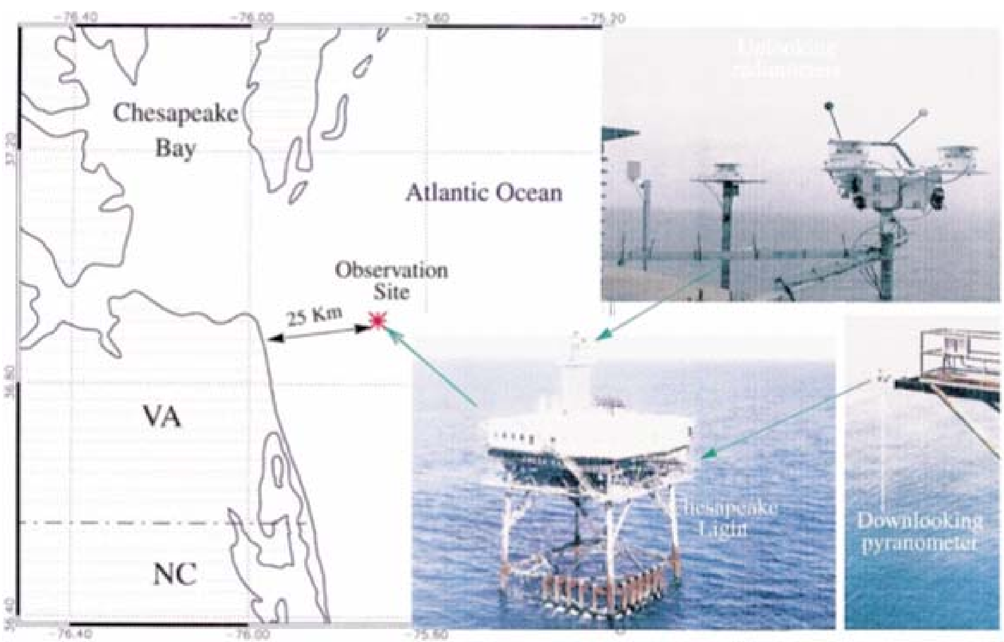
Figure thanks to Tamas Varnai/JCET - UMBC

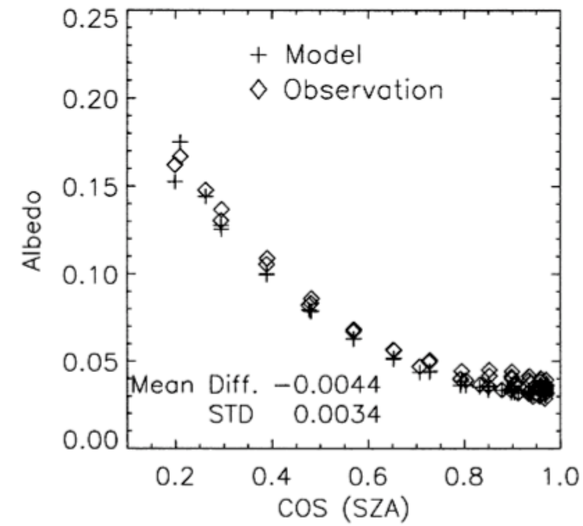
Sea surface: measurement and modeling

Cox and Munk model (1954):
•assumes sine waves
•parameterizes reflectance as a function of wind speed (2-10 m/s)

•Probability of surface orientation (*U* is wind speed):

$$p(\tan\theta_n) = \frac{1}{\pi\sigma^2}\exp\left(-\frac{\tan^2\theta_n}{\sigma^2}\right) \qquad \sigma^2 = 0.003 + 0.00512U$$



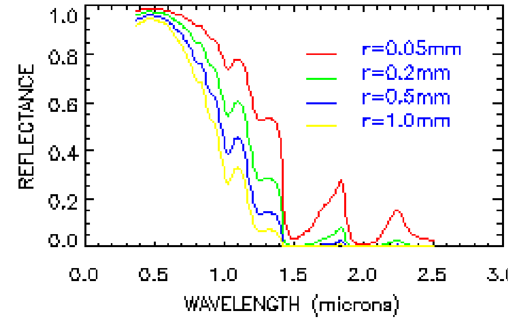


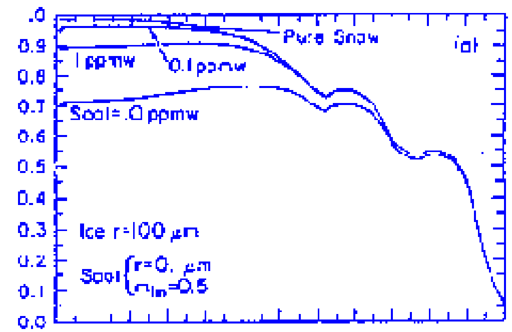
Current research:
•wider wind range (e.g., white caps, multiple reflection),
•underwater scattering (plankton)

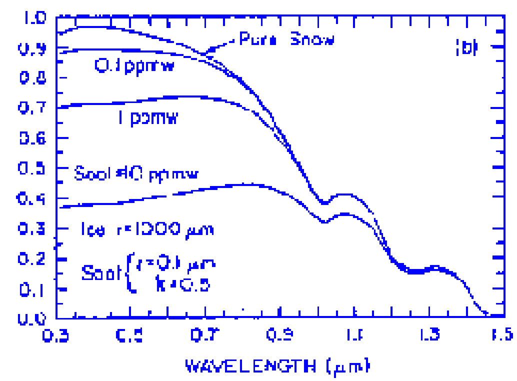
Figure thanks to Tamas Varnai/JCET - UMBC

Snow reflection

Nearly uniform spherical crystals







Size increases and extinction coefficient decreases with age

- Fresh snow: ~50 μm
- Old dry snow: ~200 μm
- Wet snow: ~1000 μm (=1 mm)

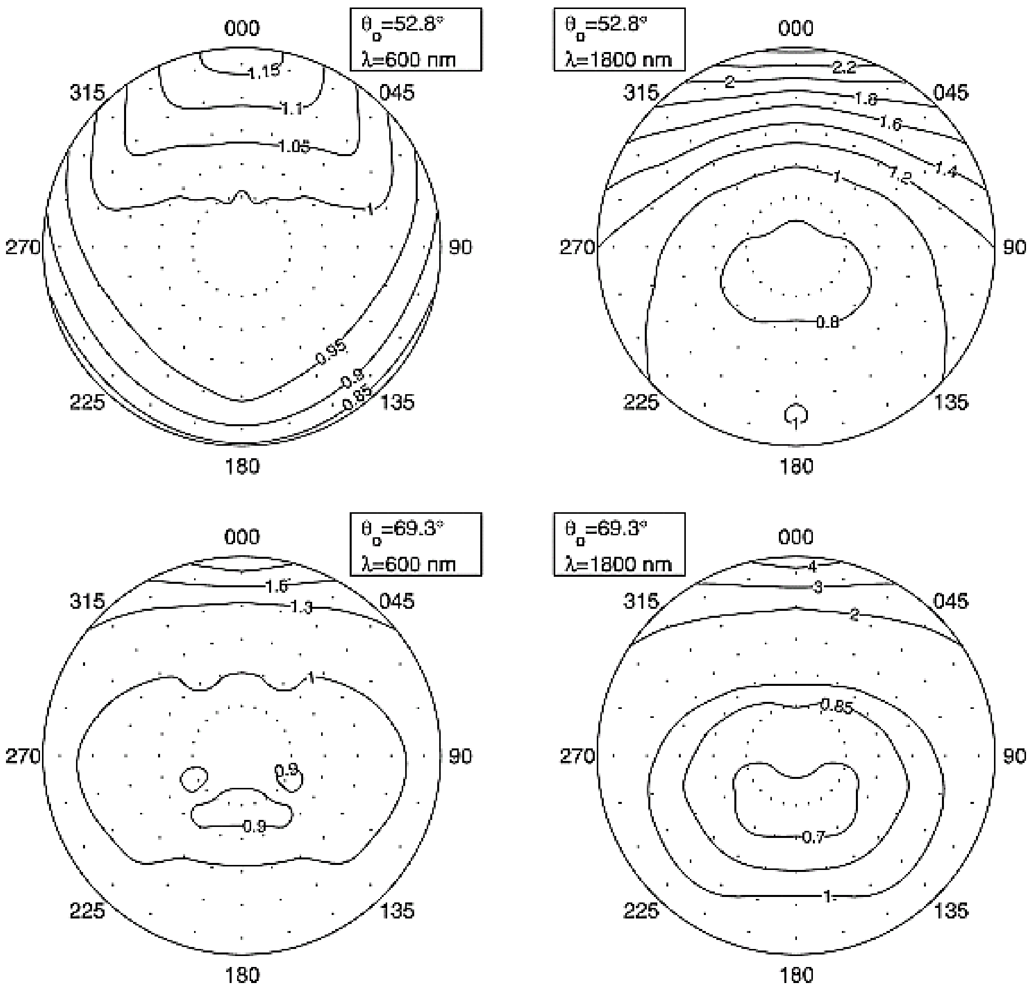
Radius (μm)	Density (g/cm^3)	N (1/m^3)	VEC (1/m)
50	0.1	2.07e11	3.25e3
200	0.2	6.49e9	1.63e3
1000	0.4	1.04e8	0.65e3

$$\sigma \approx \frac{3}{2}\frac{LWC}{\langle r \rangle \rho}$$

Figure thanks to Tamas Varnai/JCET - UMBC

Snow reflection

Angular dependence



Explain dependence on solar elevation and wavelength

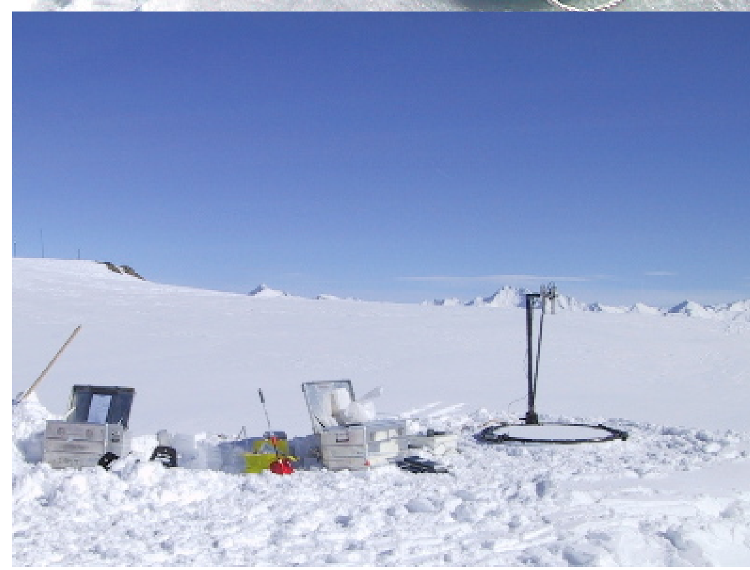
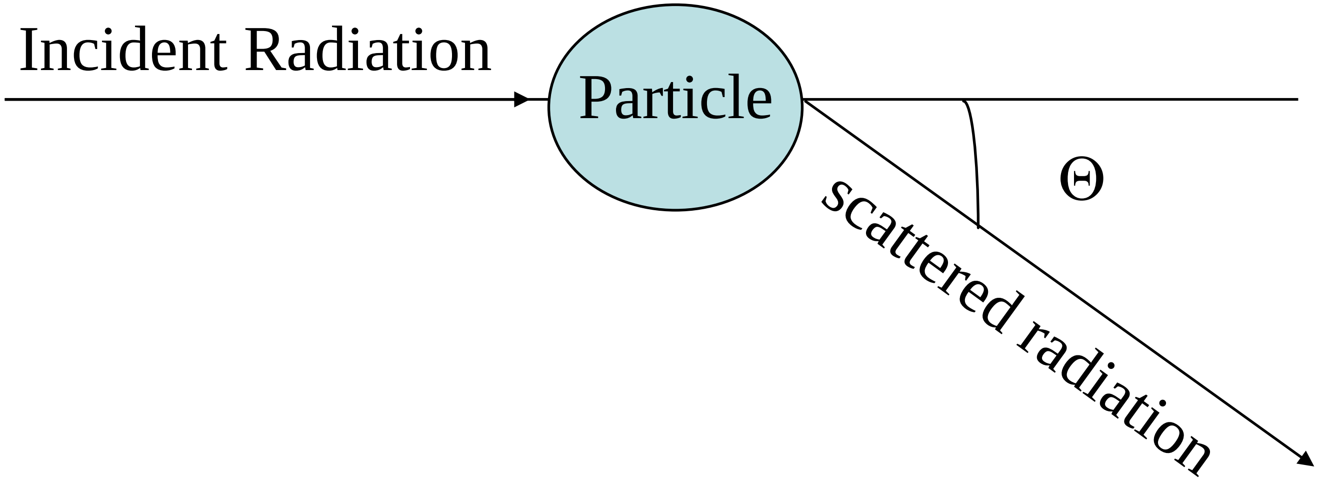


Figure thanks to Tamas Varnai/JCET - UMBC

Scattering by Particles:

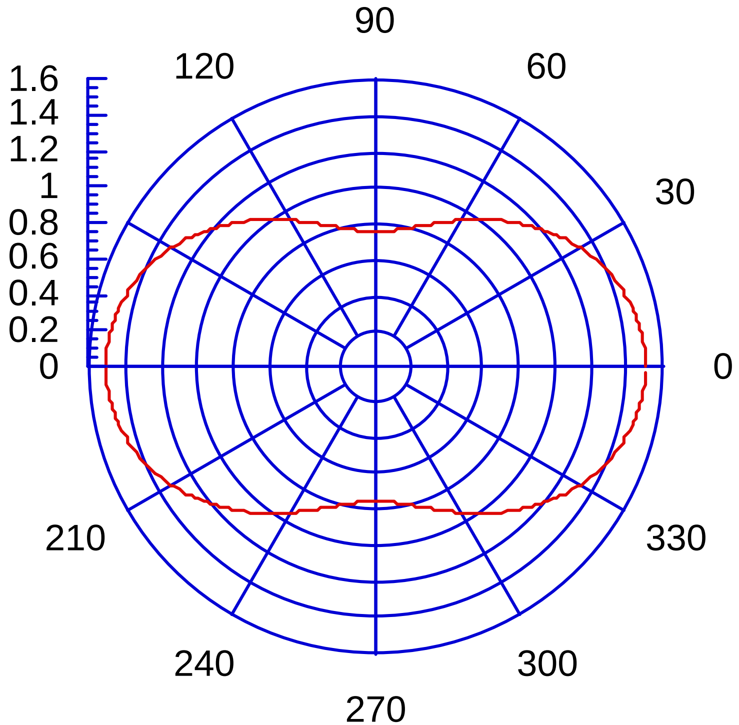
- The scattering angle, Θ, is the relative angle between the incident and the scattered radiation



Rayleigh/molecular scattering 1/4

- Rayleigh or molecular scattering refers to scattering by atmospheric gases, in that case:

$$P(\Theta) = \frac{3}{4}\left(1 + \cos^2(\Theta)\right)$$



Rayleigh phase function

Idea of polarization, sources of polarization

Two components of variations in electric field
Dipole scattering depends on angle between *E*-variations and plane of scattering (specified by incoming and outgoing directions):

Perpendicular component: $P(\Theta) = 1$
Parallel component: $P(\Theta) \propto \cos^2(\Theta)$

Overall: $$P(\Theta) = \frac{3}{4}\left(1 + \cos^2\Theta\right)$$

Clear-sky polarization

Multiple scattering reduces polarization (e.g., clouds)

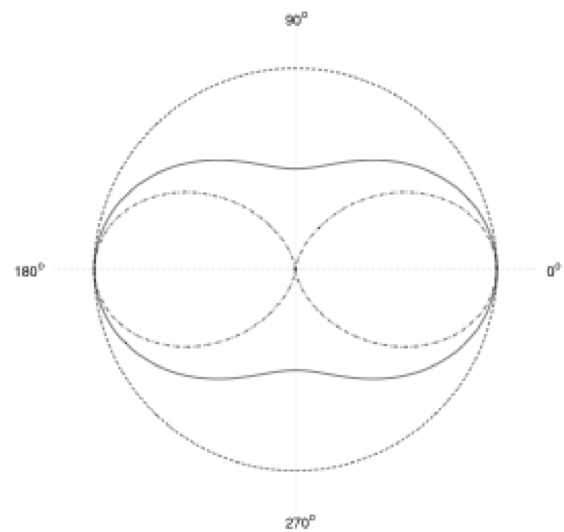
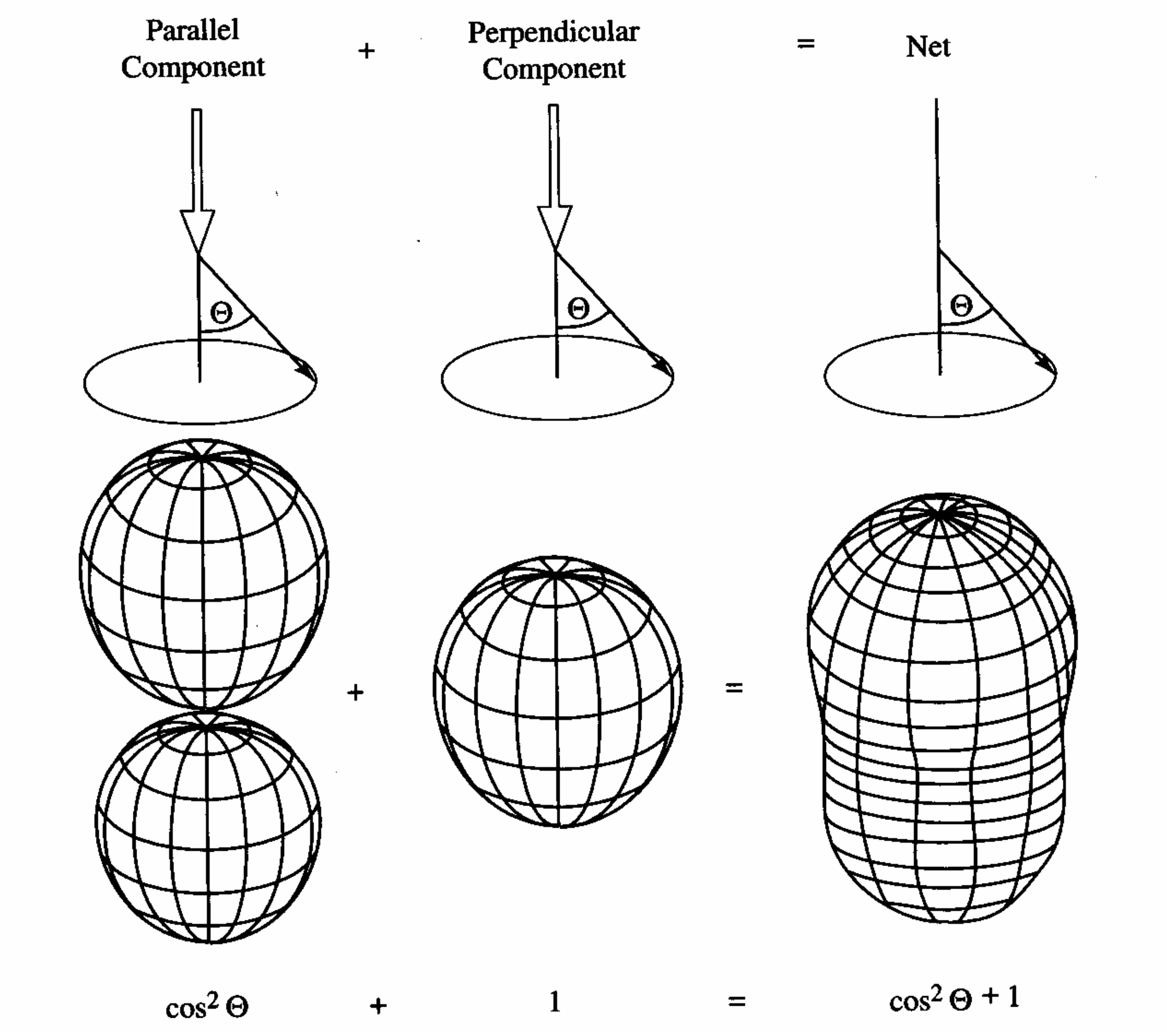
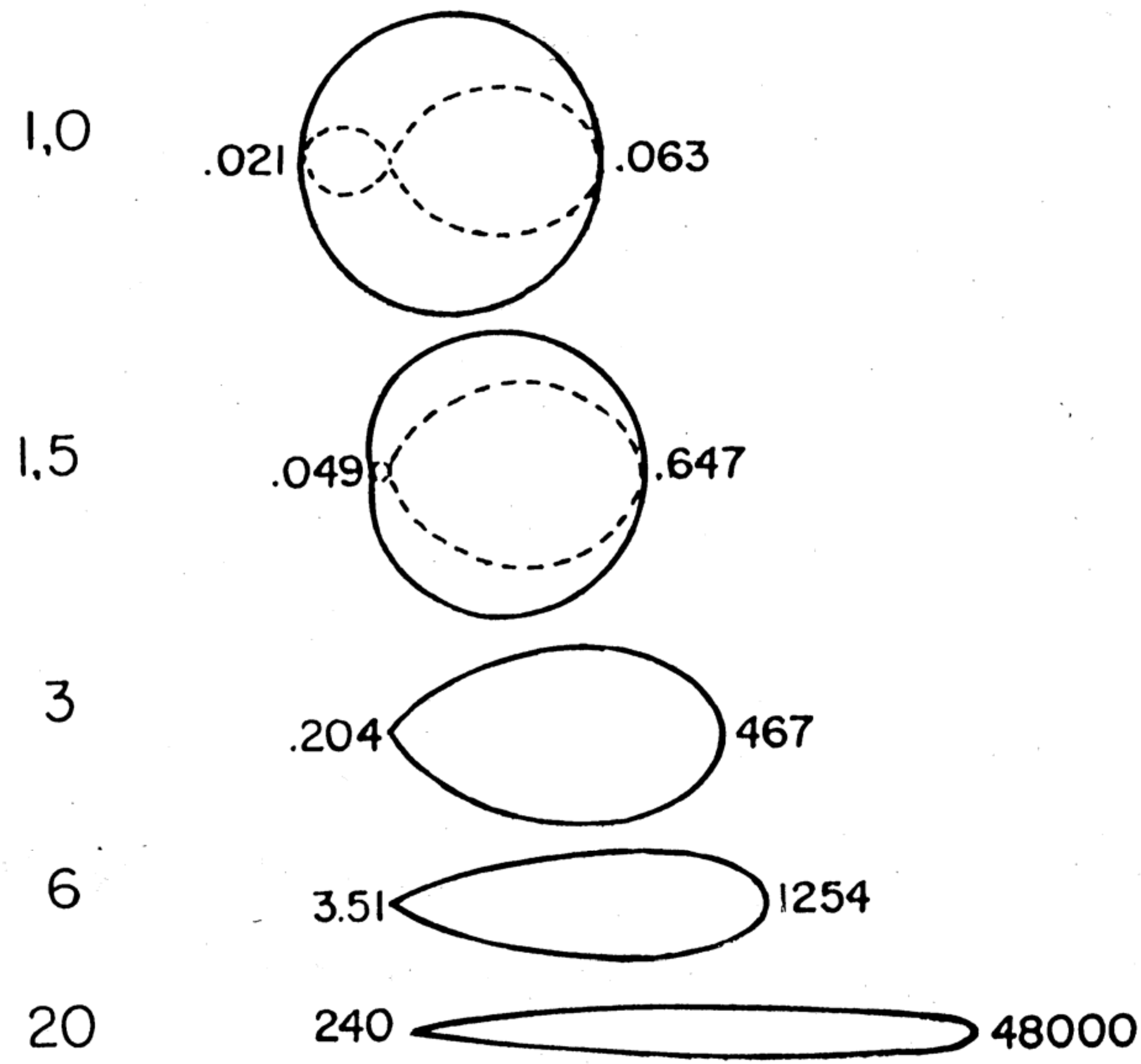


Figure thanks to Tamas Varnai/JCET - UMBC

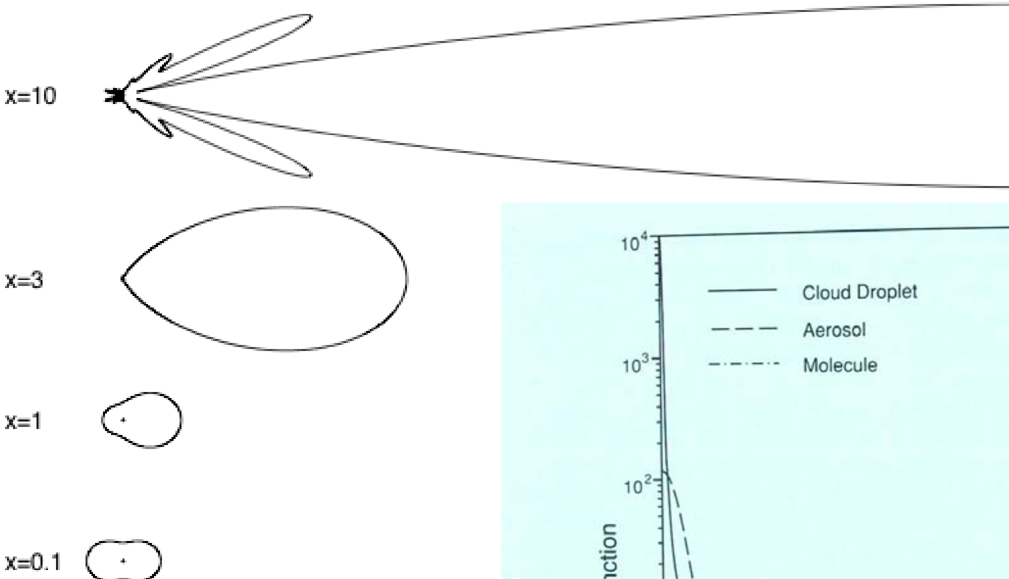
Phase diagram for Rayleigh scattering



Phase diagrams for aerosols



Phase function plots



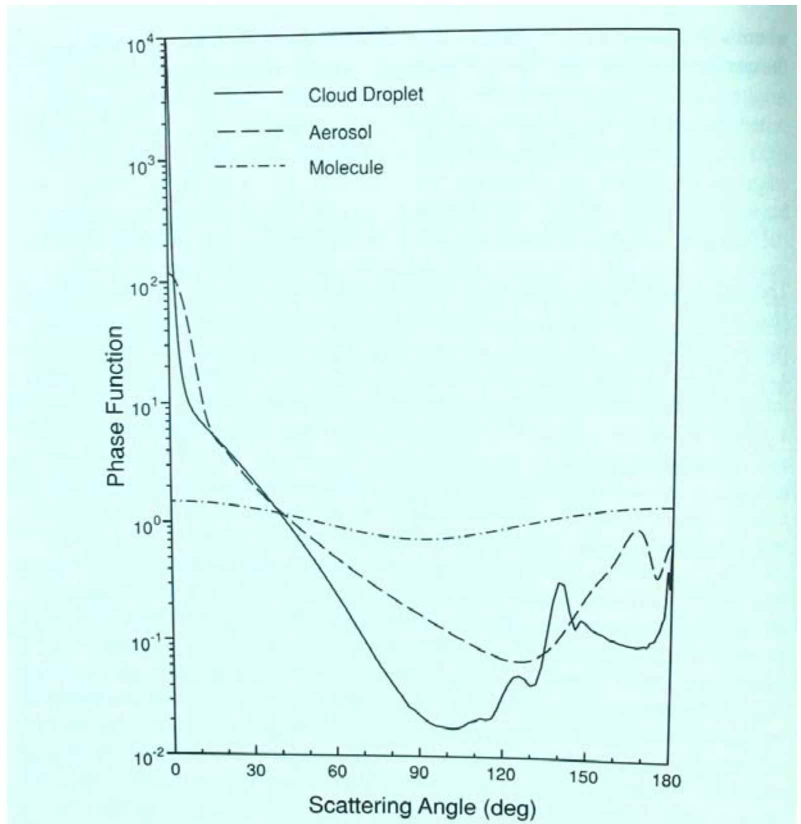


Figure 3.13 Normalized phase functions for cloud droplets (~10 μm), aerosols (~1 μm), and molecules (~10^{-4} μm) illuminated by a visible wavelength of 0.5 μm, computed from the Lorenz–Mie theory.

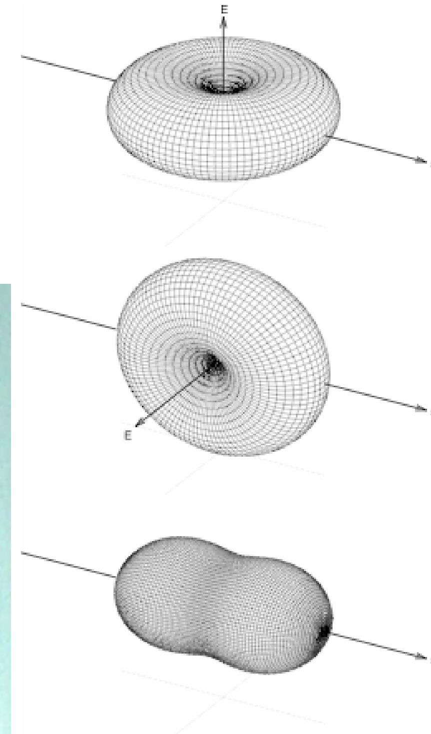
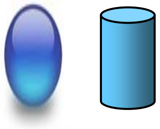


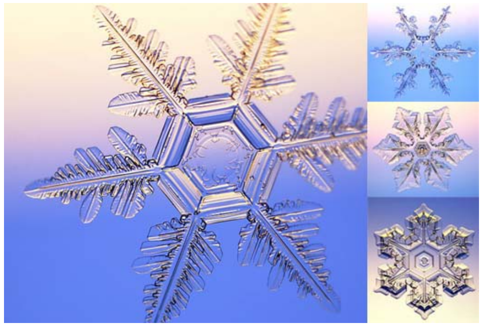
Figure thanks to Tamas Varnai/JCET - UMBC

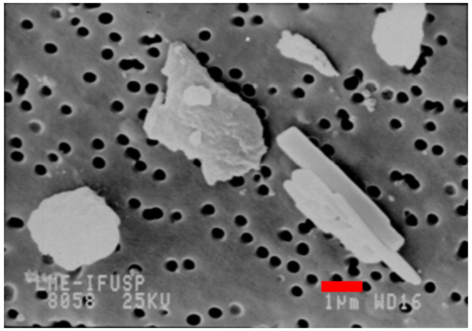
Non-spherical particles

T-matrix method: Rotational symmetrical particles: 

Series expansion uses spherical Henkel and Bessel functions, etc.
Free public codes (FORTRAN) available, fast

FDTD method: irregular particles
(e.g., ice crystals, aerosol)





Finite difference time domain
Computationally expensive
Codes available (commercial too)

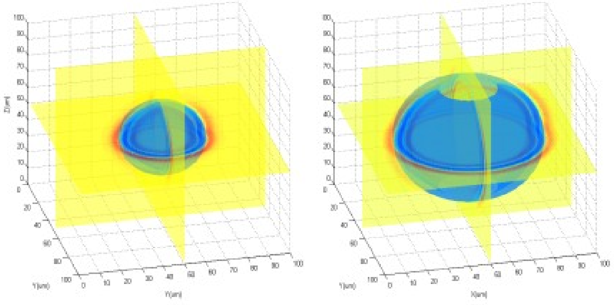
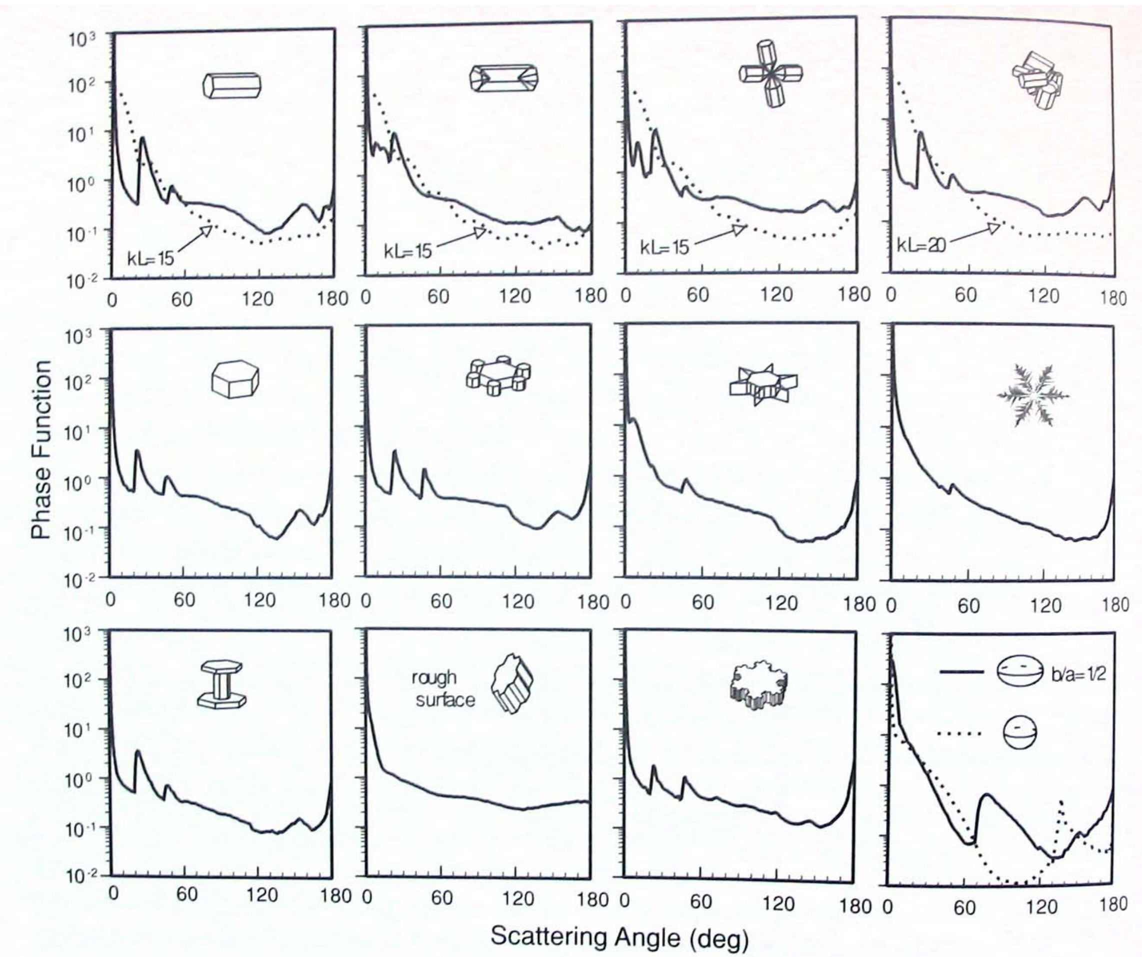


Figure thanks to Tamas Varnai/JCET - UMBC

Sample ice crystal phase functions



22° and 46° halos

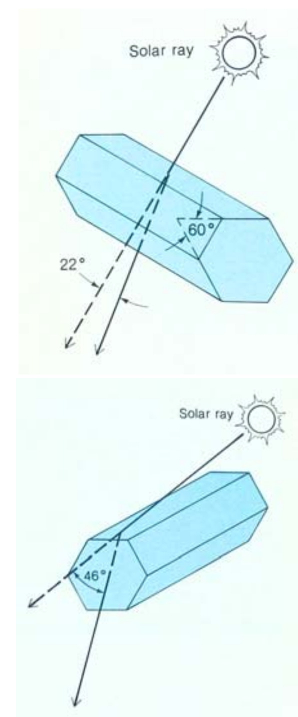


Figure thanks to Tamas Varnai/JCET - UMBC

Snow at longer wavelengths

Thermal infrared: Snow emissivity really high (~0.99)

Microwave:

One issue is closeness of particles
Rayleigh approximation so-so: 10-100 GHz or perhaps 0.5 to 5 cm wavelength
(snow grain size: 50μm when fresh, 1000μm when old and wet)

Remote sensing: compare effectiveness of scattering, emission at 2 frequencies
(e.g., 19, 37 GHz)

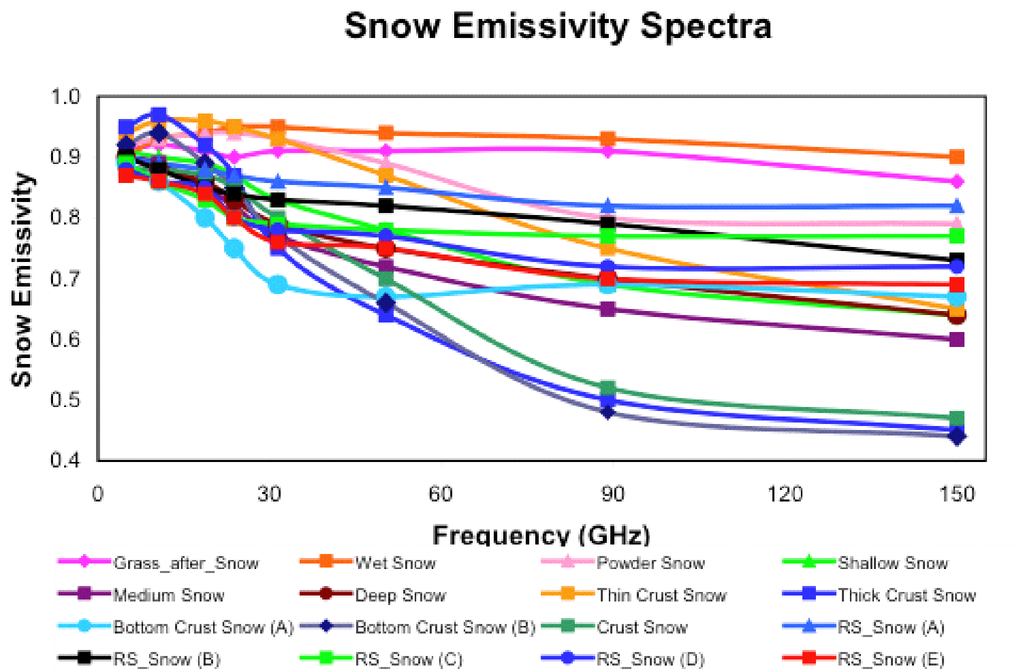
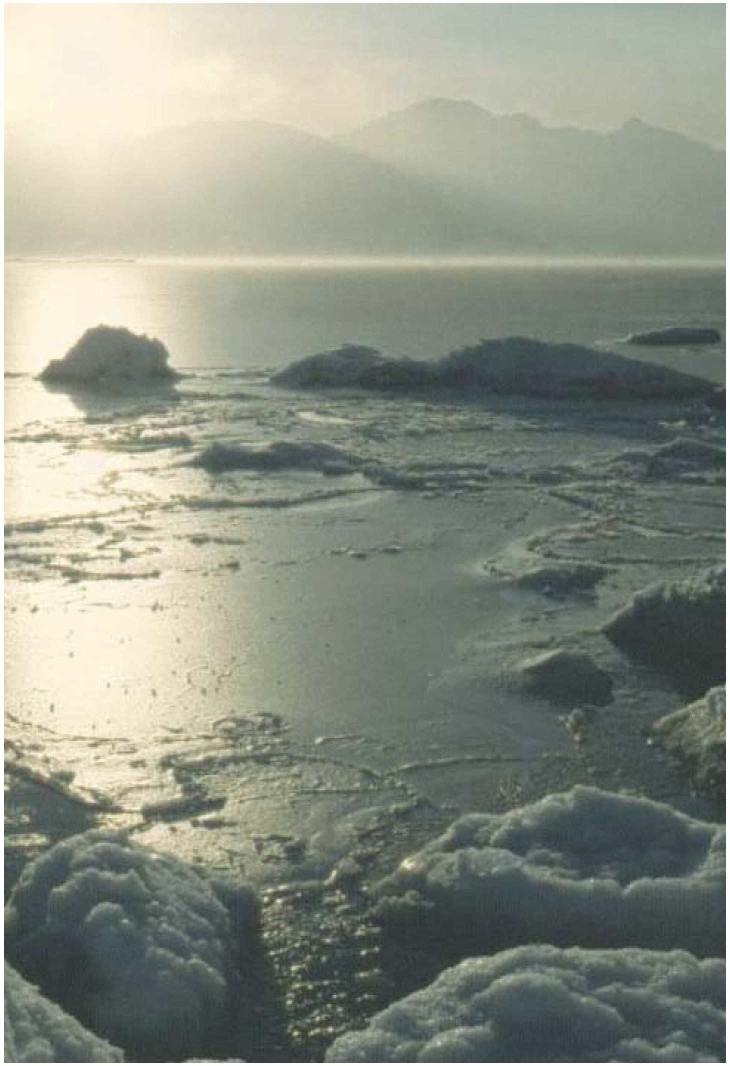


Figure thanks to Tamas Varnai/JCET - UMBC

Sea ice

Fresh ice, like a mirror



Often covered by snow

Melting ponds
(albedo decreases in summer)

Figure thanks to Tamas Varnai/JCET - UMBC

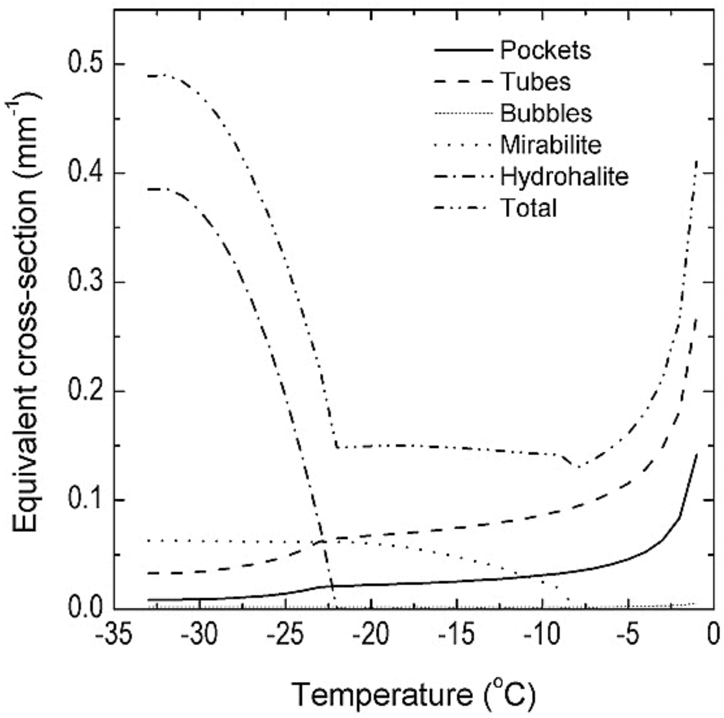
Sea ice: leads and pressure ridges

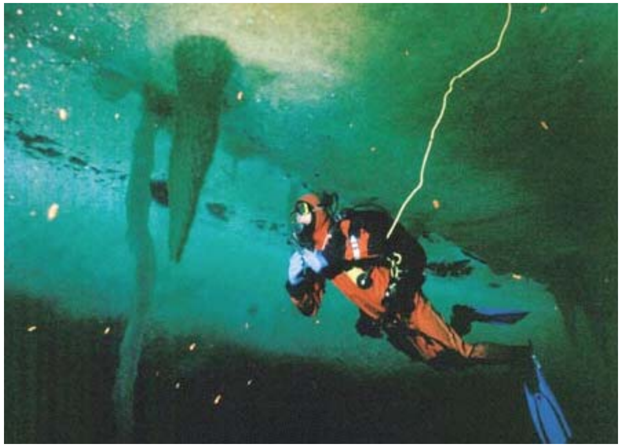
Figure thanks to Tamas Varnai/JCET - UMBC

Sea ice: inside

Ice itself: absorption (hence blue color), but not much scattering except algae at boundaries

Scatterers





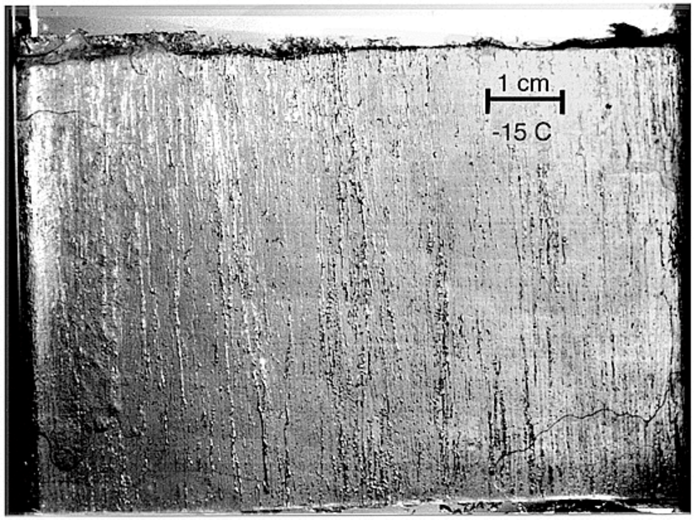


Figure 1. Vertical thick section of first-year sea ice taken from interior first-year ice at a depth of approximately 80 cm. Sample thickness is approximately 5 mm.

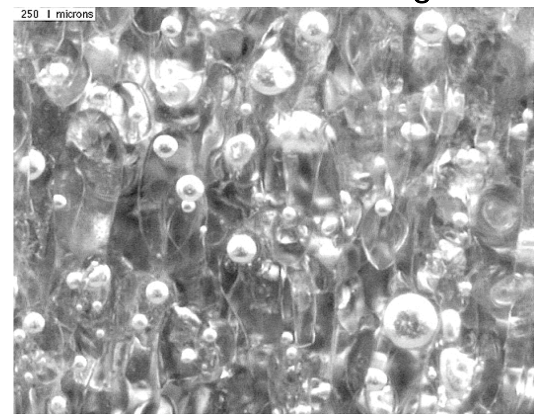
Figure thanks to Tamas Varnai/JCET - UMBC

Sea ice: inside

Close-up photo of sea ice

Figure 4. Photomosaic of vertical thin section of first-year ice in transmitted light at -15°C. Ten boxed subregions were used for counting inclusions. Overall dimensions of scene are 12.1 × 4.7 mm, with 2 mm thickness. Arrows indicate examples of (1) brine tubes, (2) brine pockets, (3) bubbles, (4) drained inclusions, (5) transparent areas, and (6) poorly defined inclusions. (right) An enlargement of box outlined with dashed line. Arrows indicate (A) solitary brine pocket, (B) cluster of small pockets, and (C) string of pockets.

Bubbles in near-melting ice



Vertical structure of sea ice

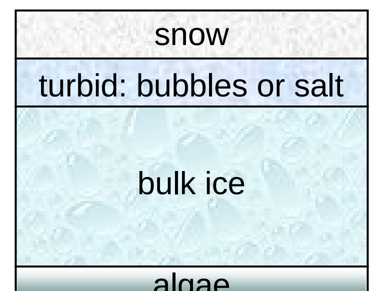
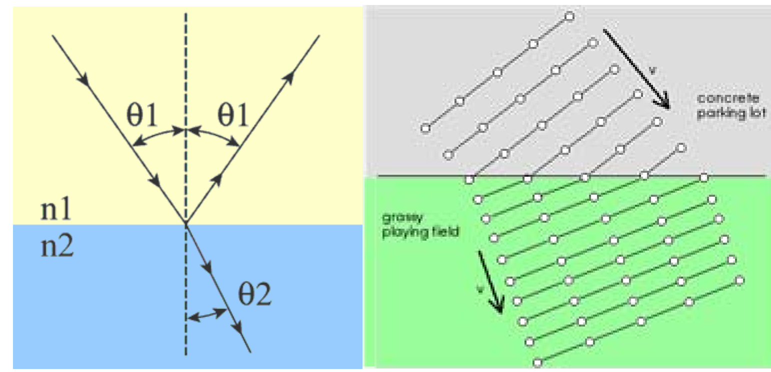


Figure thanks to Tamas Varnai/JCET - UMBC

Extra Slides:

Scattering by large particles—geometric optics

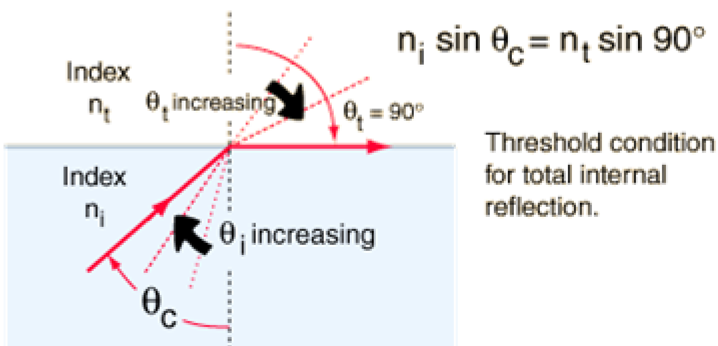
If x > 1000, diffraction is not too important (what examples?)

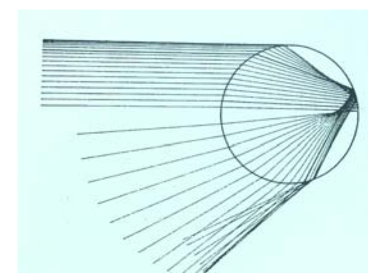


(Figure uses a different notation, *n* instead of m_r)

Snell's laws (1625): $\theta_{1,out} = \theta_{1,in}$ $\qquad \dfrac{\sin\theta_1}{\sin\theta_2} = \dfrac{c_i}{c_2} = \dfrac{m_{r,2}}{m_{r,1}}$

Critical angle: θ_t=90° (sin(θ_t)=1) ,
If θ is greater than critical angle: internal bouncing





For light coming out of water, critical angle is about 50°.

Nice online demonstration (http://www.physics.northwestern.edu/ugrad/vpl/optics/snell.html)

Figure thanks to Tamas Varnai/JCET - UMBC

Sample Mie phase functions

Cloud droplet, r = 10 µm, λ = 0.55 µm (green)

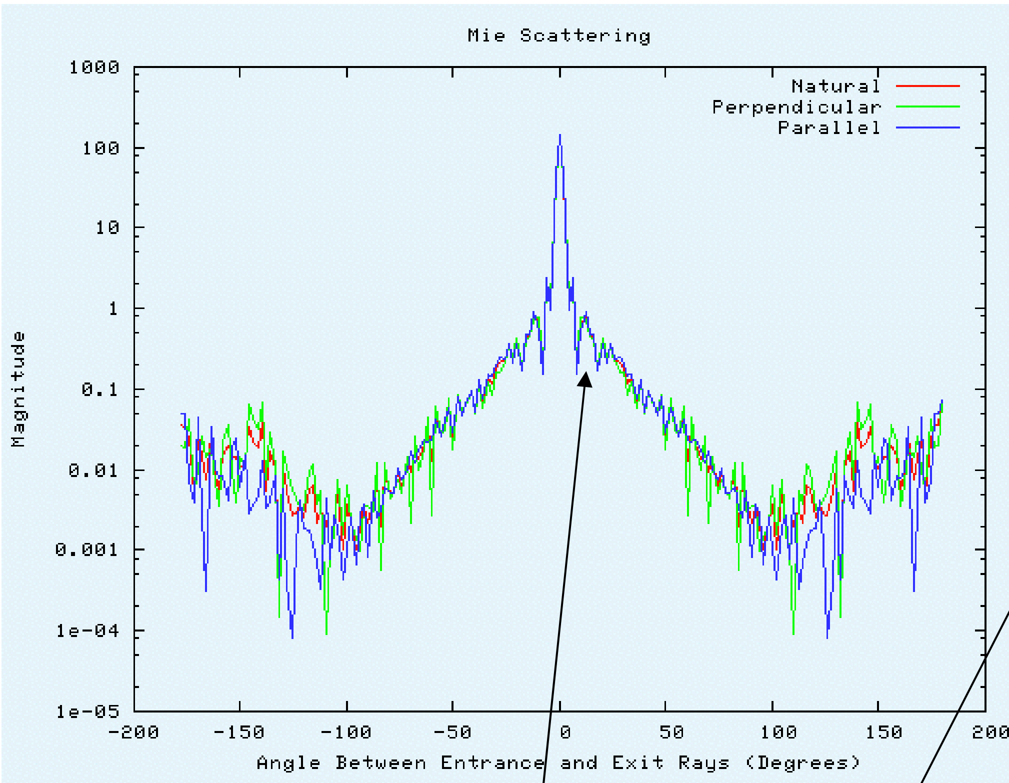


Figure from a book

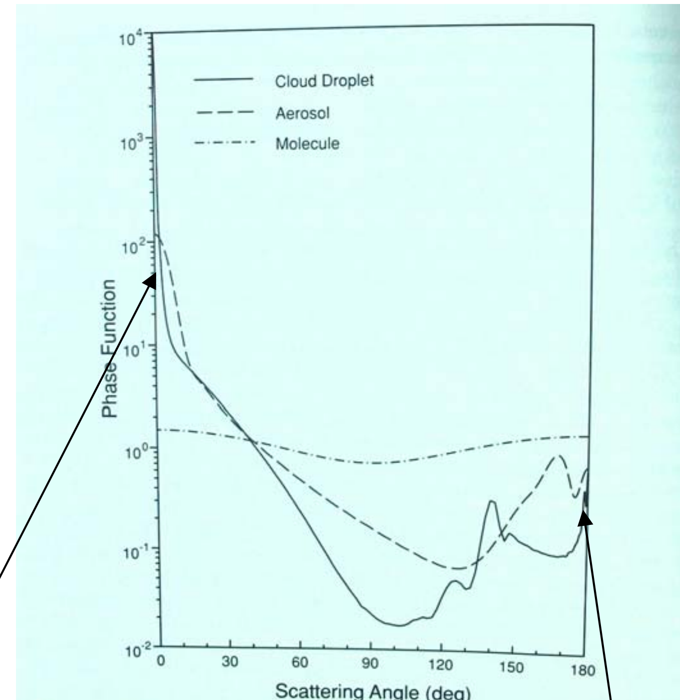


Figure 3.13 Normalized phase functions for cloud droplets (~10 µm), aerosols (~1 µm), and molecules (~10^{-4} µm) illuminated by a visible wavelength of 0.5 µm, computed from the Lorenz–Mie theory.

corona

aureole

glory

Why no ripples?

Why no polarization?

Figure thanks to Tamas Varnai/JCET - UMBC

Corona, aureole

Figure thanks to Tamas Varnai/JCET - UMBC

Aerosol size effect on Scattering:

Fine particles from smoke

Coarse dust particles

Fine particles from smoke