Lecture 12

Reflectance from surfaces and remote sensing of ocean color

1. Reflectance from surfaces.

2. Applications of passive remote sensing using extinction and scattering: Remote sensing of ocean color.

Required Reading:

S: 6.5.1, 6.6, Petty: 4, 5

Additional reading:

NASA remote sensing of ocean color: http://oceancolor.gsfc.nasa.gov/

Ocean color training material:

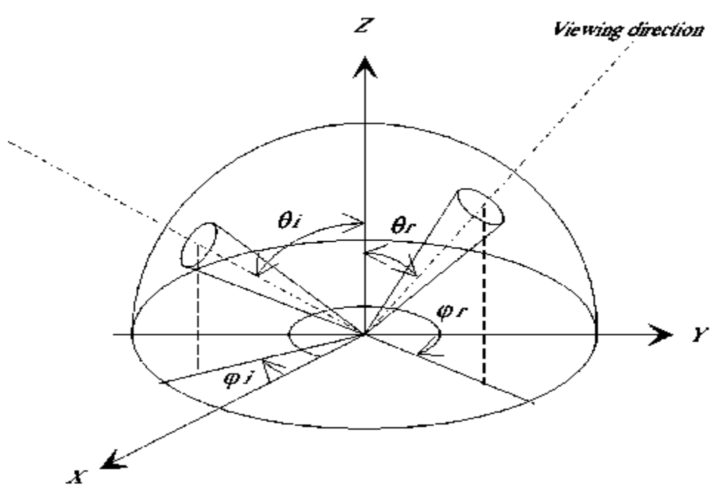
http://oceancolor.gsfc.nasa.gov/DOCS/SeaDAS/seadas_training.html

1. Reflection from surfaces.

Bi-directional reflectance distribution function (BRDF) is introduced to characterize the angular dependence in the surface reflection and defined as the ratio of the reflected intensity (radiance) to the radiation flux (irradiance) in the incident beam:

$$R(\mu_r, \varphi_r, \mu_i, \varphi_i) = \frac{\pi dI^{\uparrow}(\mu_r, \varphi_r)}{I^{\downarrow}(\mu_i, \varphi_i)\mu_i d\Omega_i} \qquad [12.1]$$

where $\mu_i = \cos(\theta_i)$ and θ_i is the incident zenith angle, φ_i is the incident azimuthal angle, and $\mu_r = \cos(\theta_r)$ and θ_r is the viewing zenith angle, φ_r is the viewing azimuthal angle.



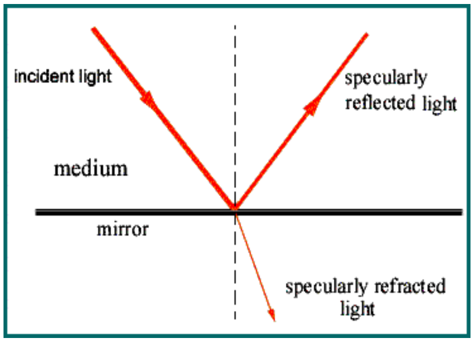
Two extreme types of the surface reflection:

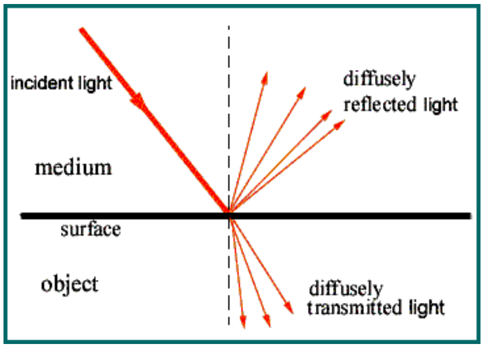
1) **Specular reflectance**
2) **Diffuse reflectance**

Specular reflectance is the reflectance from a perfectly smooth surface (e.g., a perfect mirror):

Angle of incidence = Angle of reflectance

- Reflection is generally **specular** when the "roughness" of the surface is smaller than the wavelength of radiation. In the solar spectrum (about 0.4 to 2 μm), reflection is therefore specular on smooth surfaces such as still water.
- Practically all real surfaces are not smooth and the surface reflection depends on the incident angle and the angle of reflection. Reflectance from such surfaces is referred to as **diffuse reflectance**.



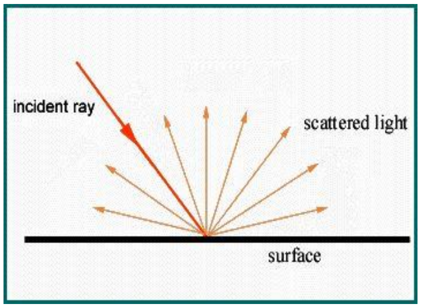


Diffuse reflectance is the reflectance from a rough surface, reflected radiation follows a particular distribution function

<u>Special case of diffuse reflection: Lambertian reflection.</u>

A surface is called a **Lambertian surface** if it obeys the **Lambert's Law** which states that the diffusely reflected light is isotropic and unpolarized (i.e., natural light) independent of the state of polarization and the angle of the incidence light.

✓ ***Reflection from the Lambertian surface is isotropic:***



$$R(\mu_r, \varphi_r, \mu_i, \varphi_i) = R_L \qquad [12.2]$$

where R_L is the **Lambert reflectance** (also called **surface albedo**).

✓ **In general, the surface reflectance (albedo) is a function of wavelength**.

Examples of representative surface albedo at ~ 550 nm wavelength:

fresh snow/ice = 0.8-0.9

deserts = 0.25-0.3

soil/vegetation = 0.1-0.25

ocean = 0.05

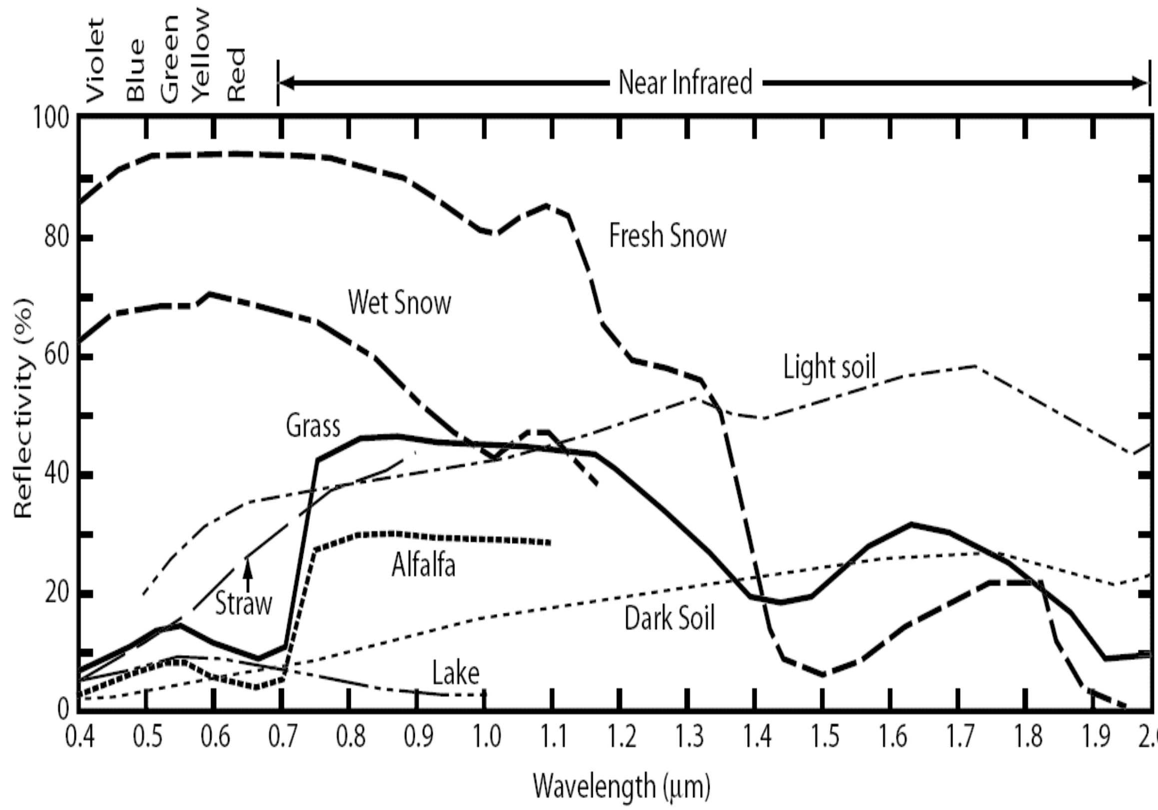


Figure 12.1 Examples of spectral reflectances (albedo) of various surfaces.

NOTE: Each surface type has a specific spectral fingerprint that is the surface reflectance has a specific dependence on the wavelength. This plays a central role in the remote sensing of land and ocean surfaces.

2. Applications of passive remote sensing using extinction and scattering: Remote sensing of ocean color

Remote sensing of ocean color provides information on the abundance of phytoplankton (chlorophyll) and the concentration of dissolved and particulate material in surface ocean waters.

Importance:

- biological productivity in the oceans (the oceans take up about 1/3 of CO_2, two major mechanism: solubility pump and biological pump, the latter is controlled by phytoplankton biomass)
- marine optical properties

- the interaction of winds and currents with ocean biology
- effects of human activities on the oceanic environment

Ocean color is the wavelength dependence of the water-leaving radiances at the ocean surface. Ocean color is the result of scattering and absorption by chlorophyll pigments, as well as dissolved and particulate matter in the surface ocean water.

<u>Principles of ocean color retrievals:</u>

Phytoplankton has a specific absorbing spectrum => its concentration can be retrieved if the spectral water-leaving radiances are measured.

<u>Need for accurate atmospheric correction:</u>

Water-leaving radiances can be as low as a few percent of the TOA (top-of-the-atmosphere) radiances measured by satellite sensors => it is critical to quantify and correctly remove the contribution from the atmosphere to the TOA radiances.

<u>Satellite sensors used for ocean color:</u>

(see more info at http://oceancolor.gsfc.nasa.gov/)

- **CZCS** (Coastal Zone Color Scanner, flown on the NIMBUS-7 satellite):
  - data available for 1978 – 1986
- **SeaWiFS** (Sea-viewing Wide Field-of-View Scanner, launched onboard Orbview-2 satellite):
  - data from 1997
- **MODIS** (Moderate Resolution Imaging Spectroradiometer), launched on Terra and Aqua satellites:
- data from 1999 for Terra and from June 2002 for Aqua

Table 12.1 MODIS, SeaWiFS, and CZCS channels and their central wavelengths used for ocean color retrievals.

λ (nm)	MODIS	SeaWiFS	CZCS
412	+	+	-
443	+	+	+
490	+	+	-
530	+	+	+
550	+	+	+
670	+	+	+
681	+	-	-
750	+	+	-
865	+	+	-

Concept of an ocean color retrieval algorithm (retrieval of the chlorophyll concentration):

CZCS, SeaWiFS and MODIS algorithms use the **normalized water-leaving radiance** $[I_w]_N$ defined as

$$I_w(\lambda) = [I_w(\lambda)]_N T(\lambda) \qquad [12.3]$$

where

$T(\lambda)$ is the diffuse transmittance

$I_w(\lambda)$ is the radiance reflected by water

The normalized water-leaving radiance is approximately the radiance that would exit the ocean in the absence of the atmosphere with the sun in the zenith.

Assuming the Lambertian surface, reflectance associated with the radiance $[I_w]_N$ can be defined as

$$[R_w(\lambda)]_N = \frac{\pi}{F_0}[I_w(\lambda)]_N$$

and Eq. [12.3] becomes

$$R_w(\lambda) = [R_w(\lambda)]_N T(\lambda)$$

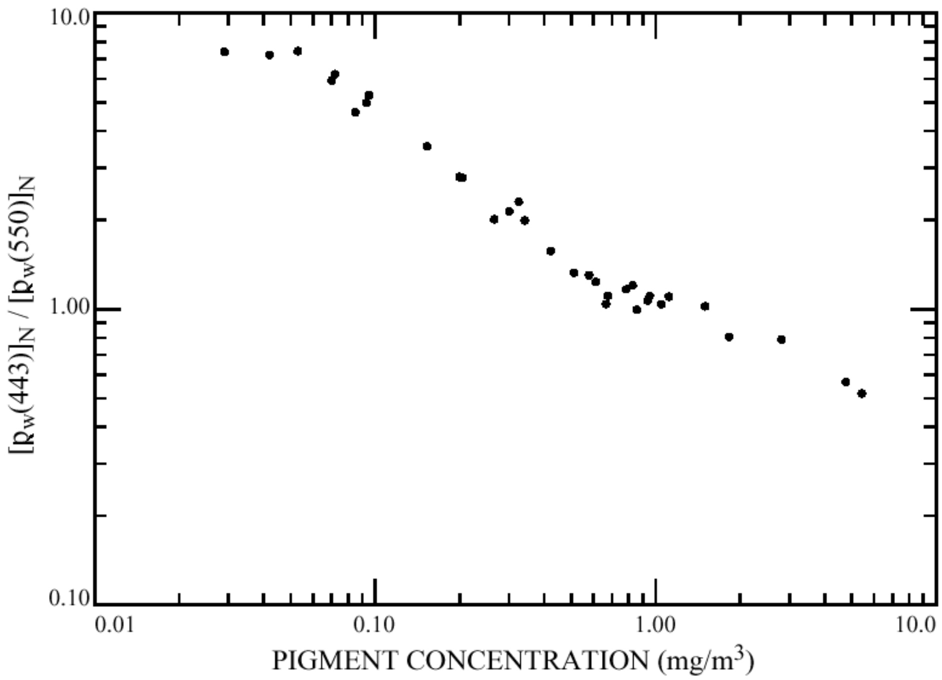


Figure 12.2 Normalized water-leaving reflectance ratio as a function of pigment (chrolophyll *a*) concentration (Gordon et al. 1988).

If the ratio $[R_w(443)]_N \,/ [R_w(550)]_N$ is known, the pigment concentration C can be approximated as

$$\log_{10}(3.33C) = -1.2\log_{10} r + 0.5(\log_{10} r)^2 - 2.8(\log_{10} r)^3$$

where $r = 0.5[R_w(443)]_N \,/ [R_w(550)]_N$

NOTE: Retrievals of ocean color are strongly affected by atmospheric conditions.
No retrievals in the presence of clouds and heavy aerosol plumes (i.e., large optical depth, τ large).
NOTE: **"**Ocean color"**-**like algorithms are also widely used for characterizing lakes, rivers, and other water bodies.

Importance of accurate sensor calibration and atmospheric correction:

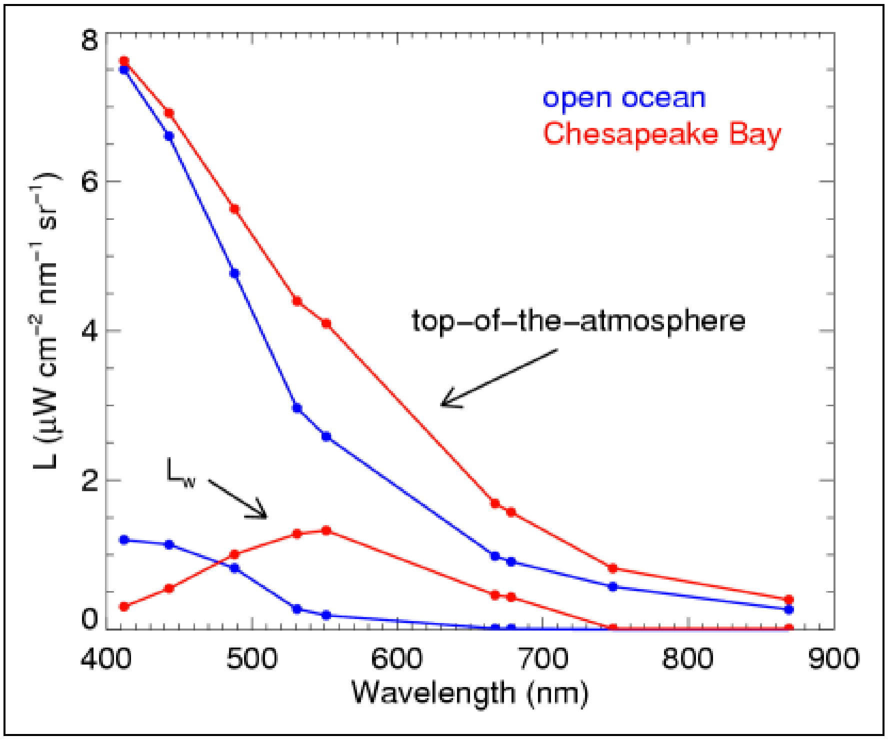


Figure 12.3 Example of water leaving radiances and TOA radiances as a function of wavelength

The atmosphere is 80-90% of the total top-of-atmosphere signal in blue-green wavelengths (400-600 nm)

~1% error in instrument calibration or atmospheric model leads to ~10% error in water leaving radiances $I_w(\lambda)$

NOTE: Water leaving radiances are low at ~800-900 nm (called dark ocean) so that radiances measured by channels located in this spectral region are affected by atmosphere only -> used for atmospheric correction.