Apparent optical properties and radiative transfer theory*

- Apparent optical properties.
- The RTE and Gershun's equation
- The Secchi disk (and depth, an AOP).

*based in part on lectures by Roesler, Mobley, and Lewis

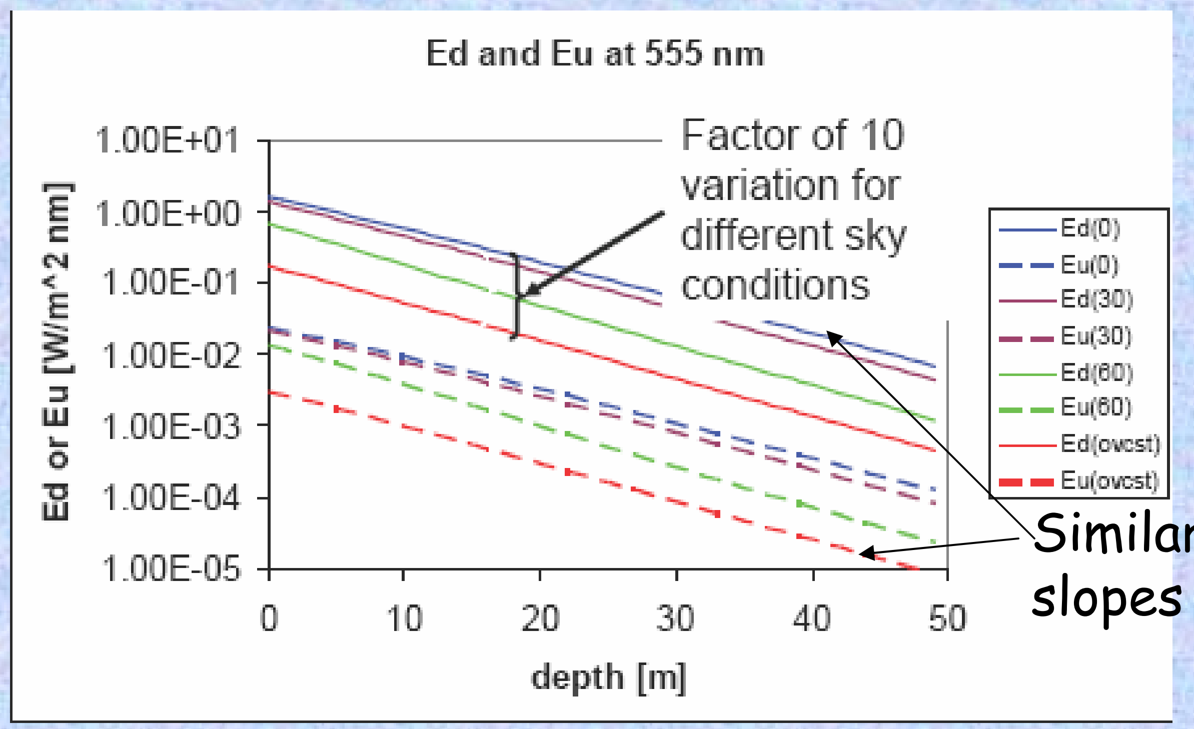
Apparent Optical Properties

usually: ratios of radiometric properties (L, E, etc') or normalized depth derivatives of radiometric properties.

Why AOPs?

- IOPs are not always easy to measure.
- Radiometric properties depends strongly on sky conditions.

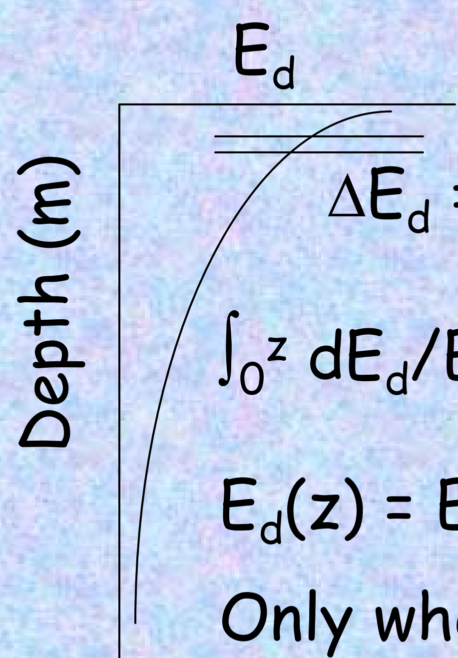
→ Relatively insensitive OPs



Mobley, 2004: Hydrolight runs with 1 mgchl./m^3, with sun at 0, 30, 60° in clear skies and overcast skies.

Apparent Optical Properties: diffuse attenuation coefficients.

Diffuse irradiance attenuation, K_d (m^{-1})



$\Delta E_d = -E_d \, \Delta z \, K_d$

$\int_0^z dE_d/E_d = \int_0^z K_d(z)\, dz$

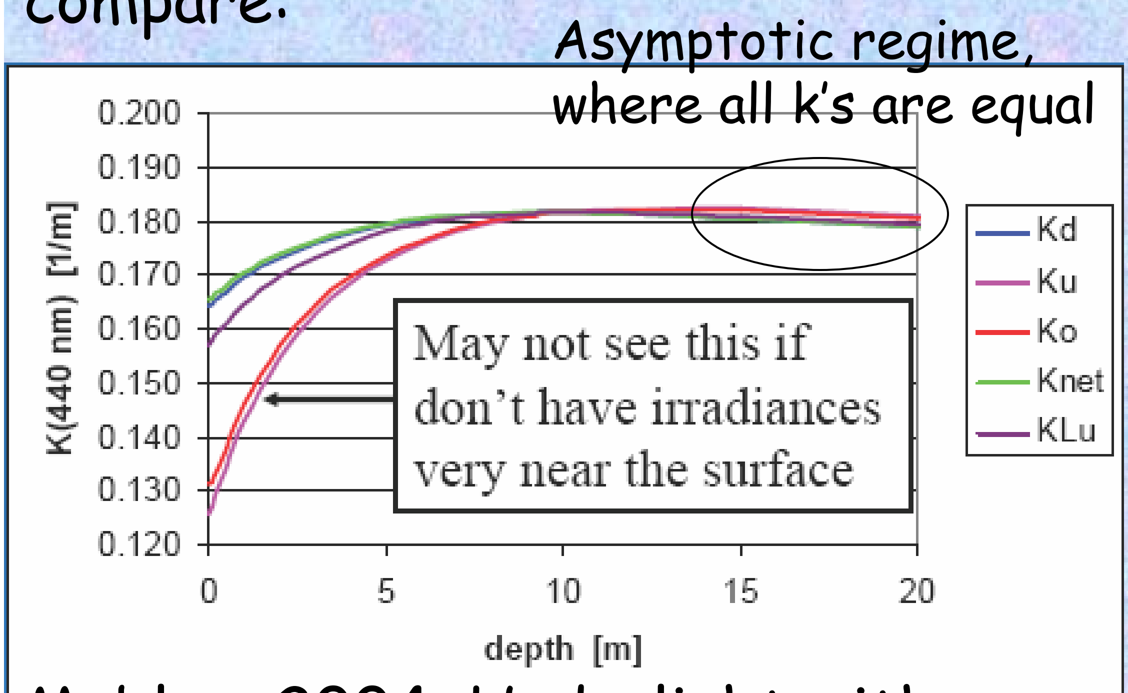
$E_d(z) = E_d(0)\, e^{-\int Kd(z)\, dz}$

Only when K_d is not depth dependent
$E_d(z) = E_d(0)\, e^{-Kd\, z}$

Can be similarly defined for:
L_u, L_d, E_0, E_u, etc'.

Apparent Optical Properties: diffuse attenuation coefficients

How do different attenuation compare:



Mobley, 2004, Hydrolight with $2 mgChl./m^3$

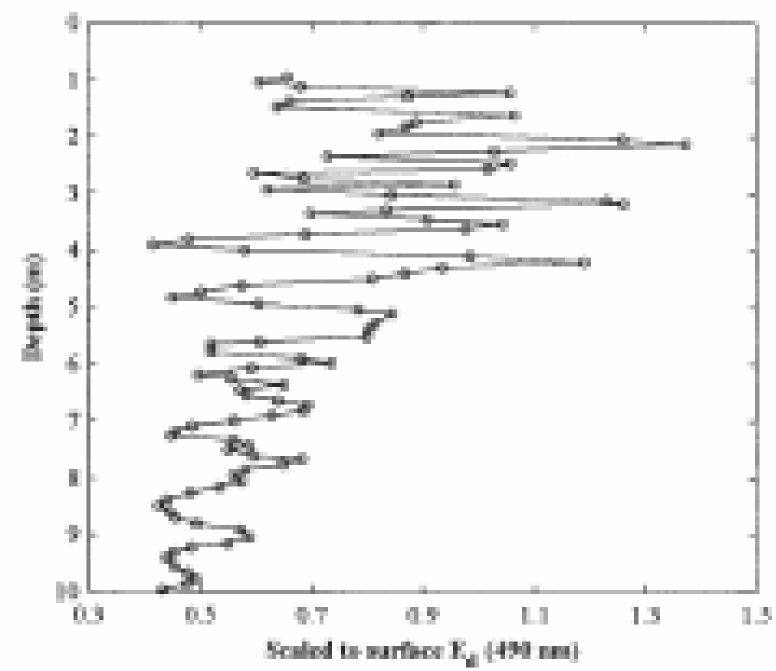


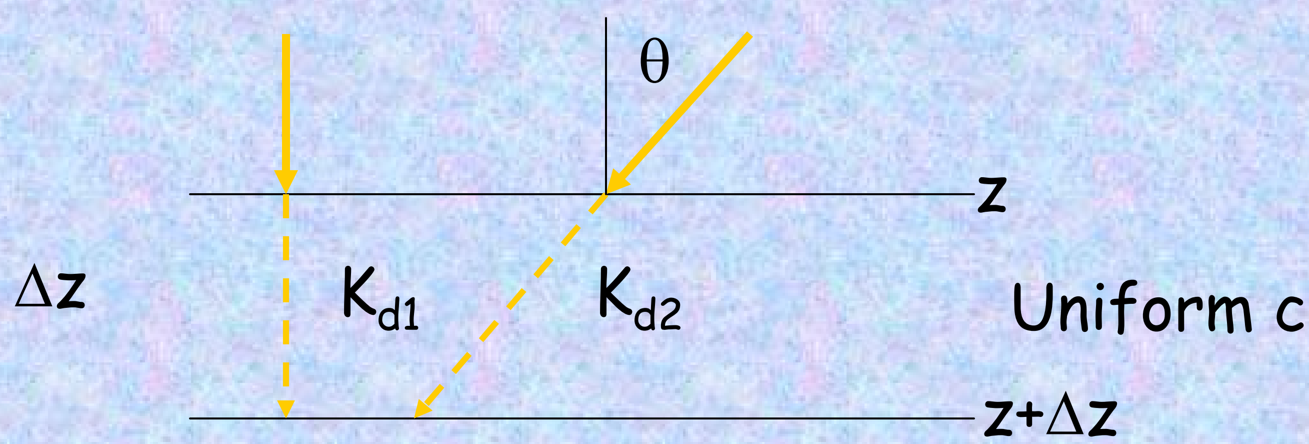
Fig. 1. Irradiance profile taken off the Oregon coast, September 1997, with a Satlantic irradiance profiler. The profiler drops at approximately 0.8 m/s and samples at 8 Hz. Conditions were calm.

Zaneveld et al., 2001.

Apparent Optical Properties

Diffuse attenuation, K (m^{-1}):

Note that c and K are very different because K depends upon the properties of the solar source near the surface

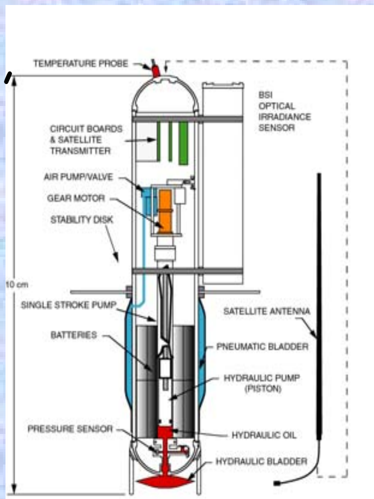


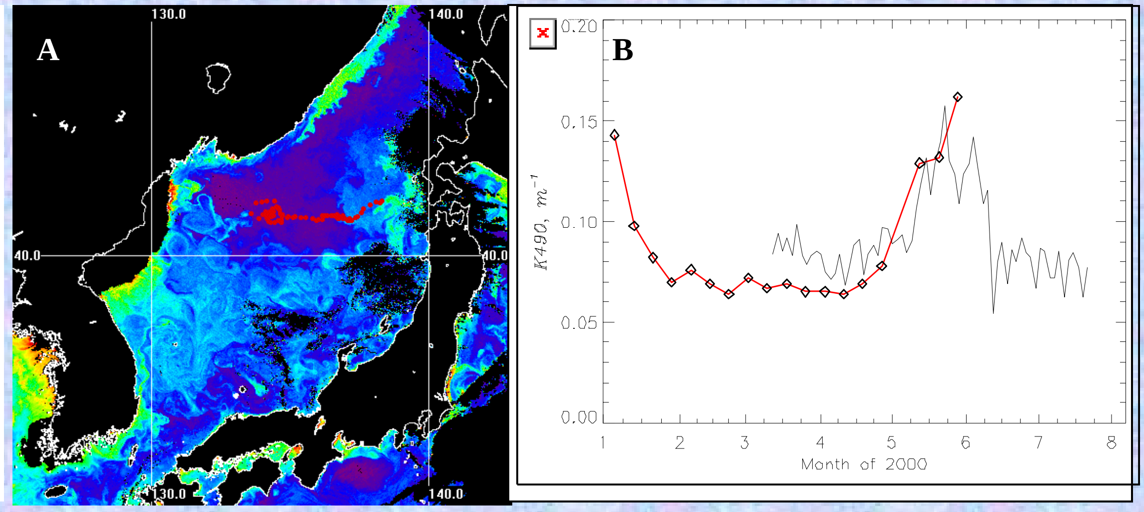
K_d describes the loss of E_d from z to z+Δz, $K_{d2} > K_{d1}$

but the pathlength traveled is $r = \Delta z/\cos\theta$ $K_d < c$

diffuse attenuation coefficients

Mitchell et al., 2000, OOXV





$K_d(490)$ in-situ compared with Ocean Color

Advantages of k's:

• K's are defined as ratios, so don't need absolutely calibrated instruments.
• Kd is very strongly influenced by absorption, so correlates with chlorophyll concentration.
• about 90% of water-leaving radiance comes from a depth of 1/Kd.

Limitations of k's:

•Vary near surface.

•Hard to obtain near surface from moving profilers

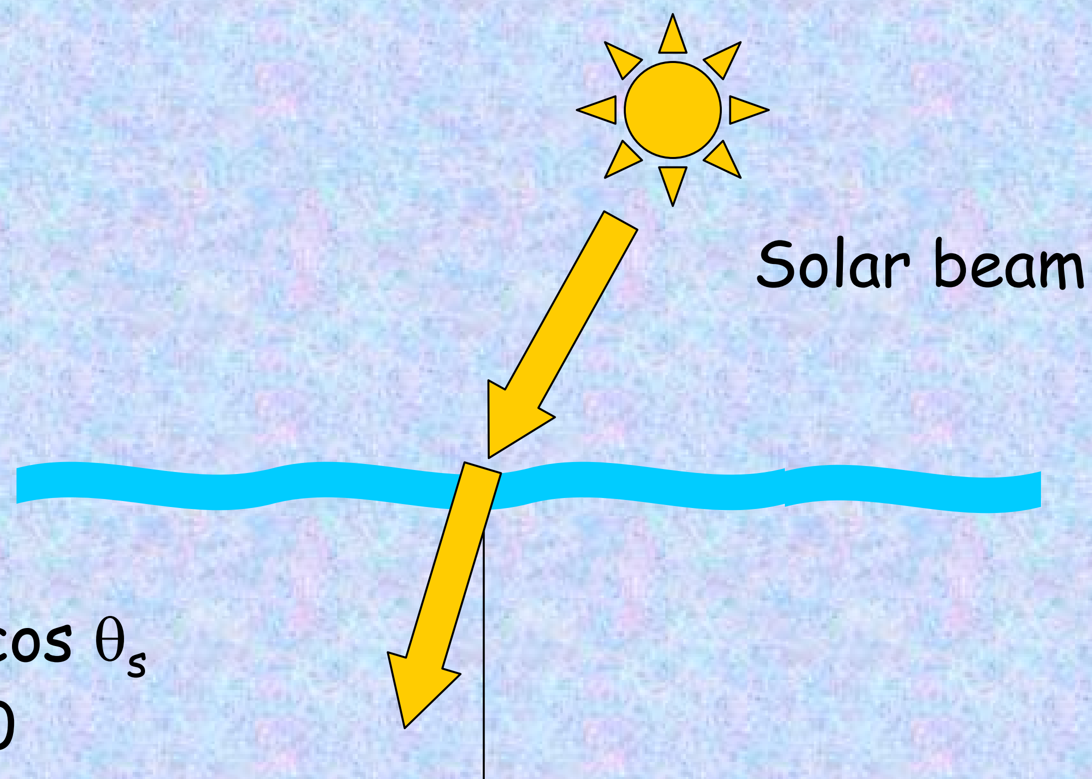
Another Apparent Optical Property: the average cosine.

Average cosines describe the angular distribution of the light field:

$\mu_d = E_d / E_{od}$

$\mu_u = E_u / E_{ou}$

$\bar{\mu} = \vec{E} / E_o$



$\mu_d = \cos \theta_s$

$\mu_u = 0$

$\bar{\mu} = \cos \theta_s$

Apparent Optical Properties

Average cosines describe the angular distribution of the light field

$\mu_d = E_d/E_{od}$

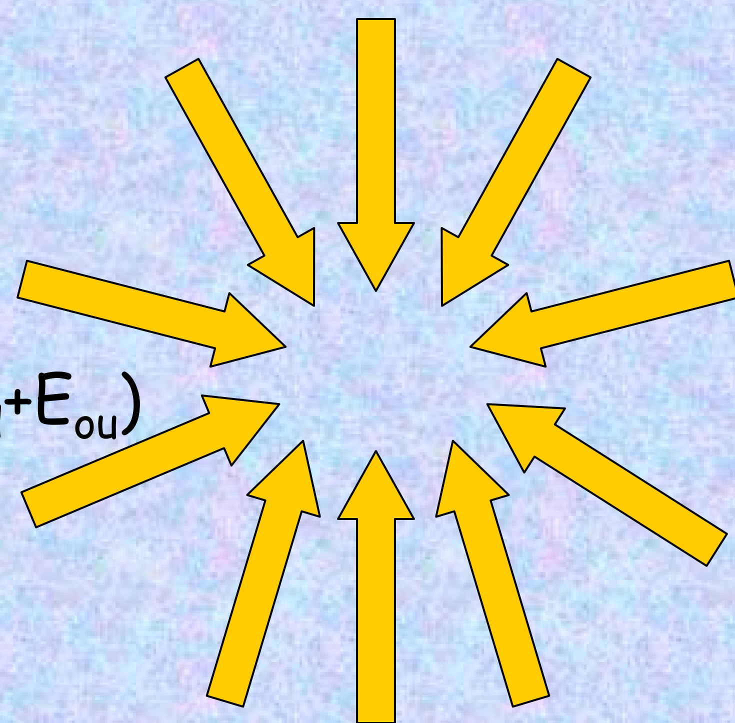
$\mu_u = E_u/E_{ou}$

$\bar{\mu} = \vec{E}/E_o = (E_d - E_u)/(E_{od} + E_{ou})$

$\mu_d = \frac{1}{2} \quad (\theta = 60^o)$

$\mu_u = -\frac{1}{2} \quad (\theta = 120^o)$

$\bar{\mu} = 0$



Isotropic light field

Average cosines

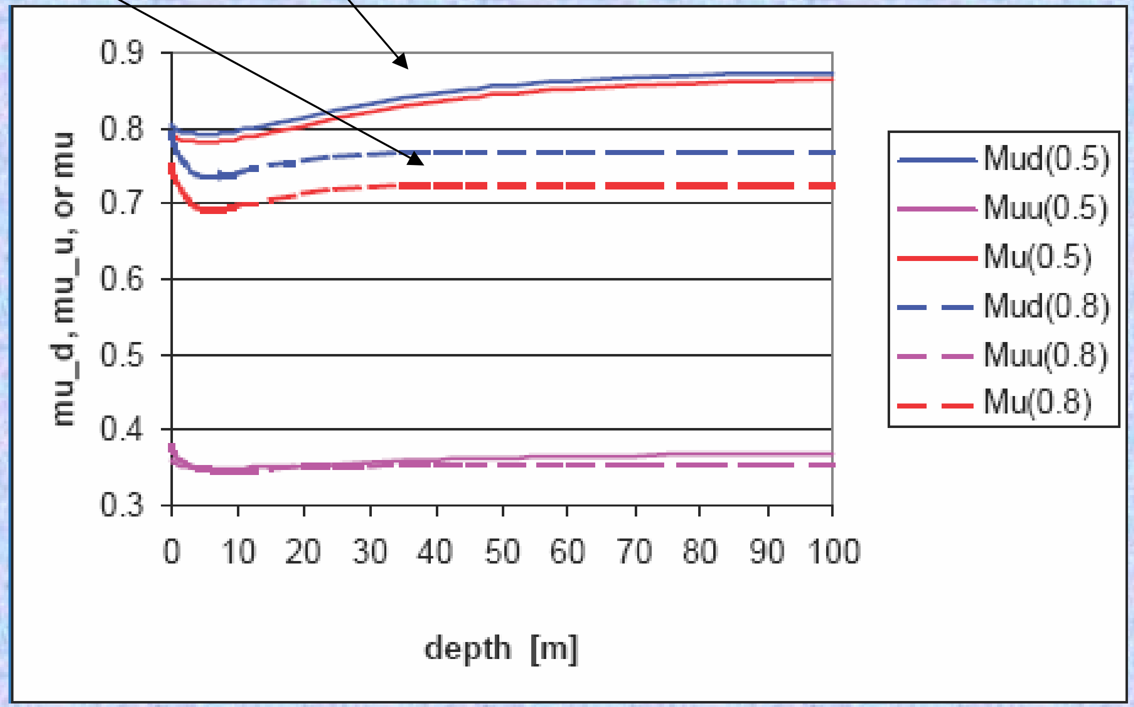
The more scattering → the fast is asymptotic attained

The more absorbing → the more collimated

$\mu_d = E_d/E_{od}$

$\mu_u = E_u/E_{ou}$

$\bar{\mu} = \vec{E}/E_o$

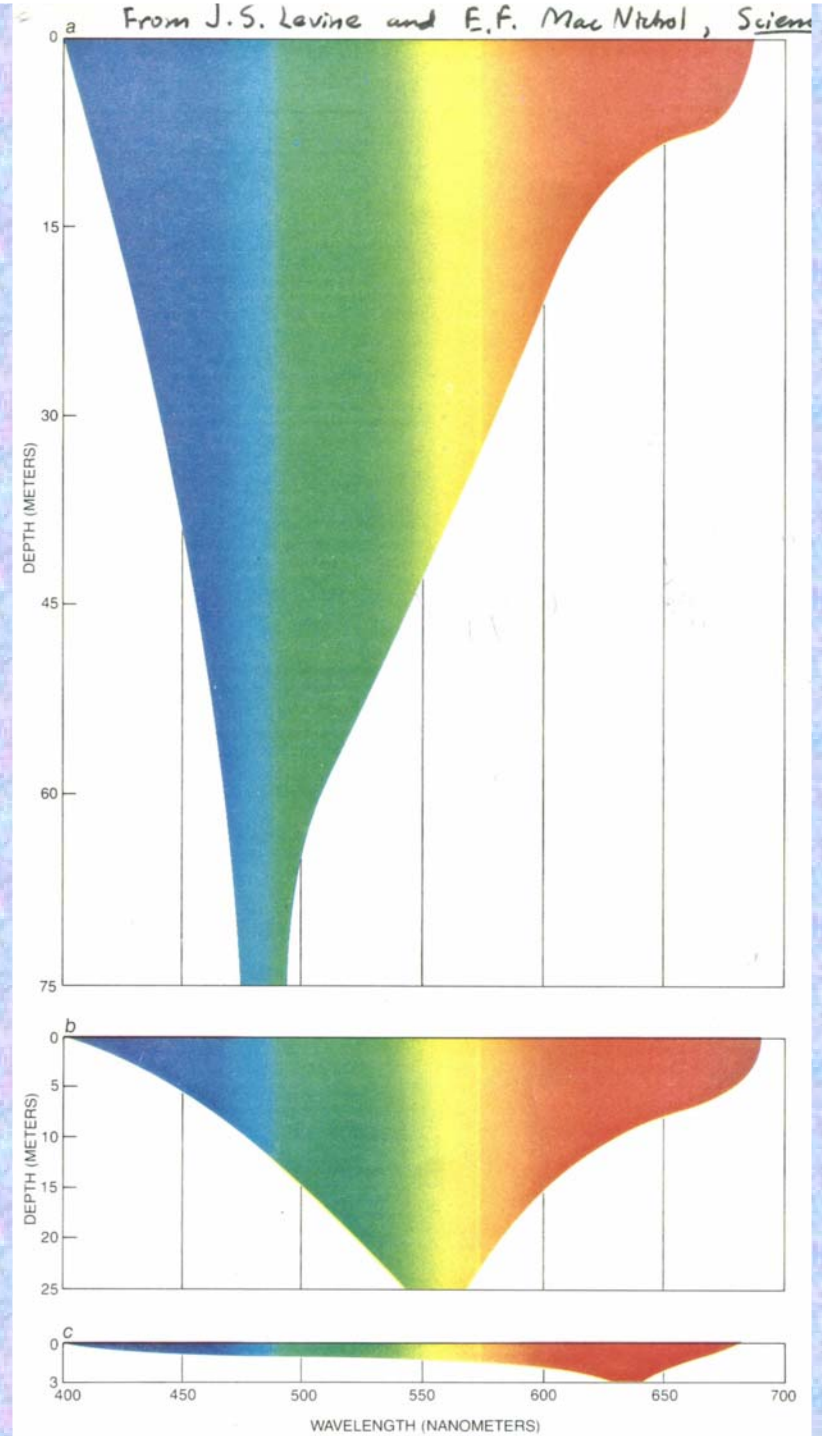


Mobley, 2004, Hydrolight with b=a (b/c=0.5) & b=4a (b/c=0.8).

Spectral light penetration with depth for different water bodies.

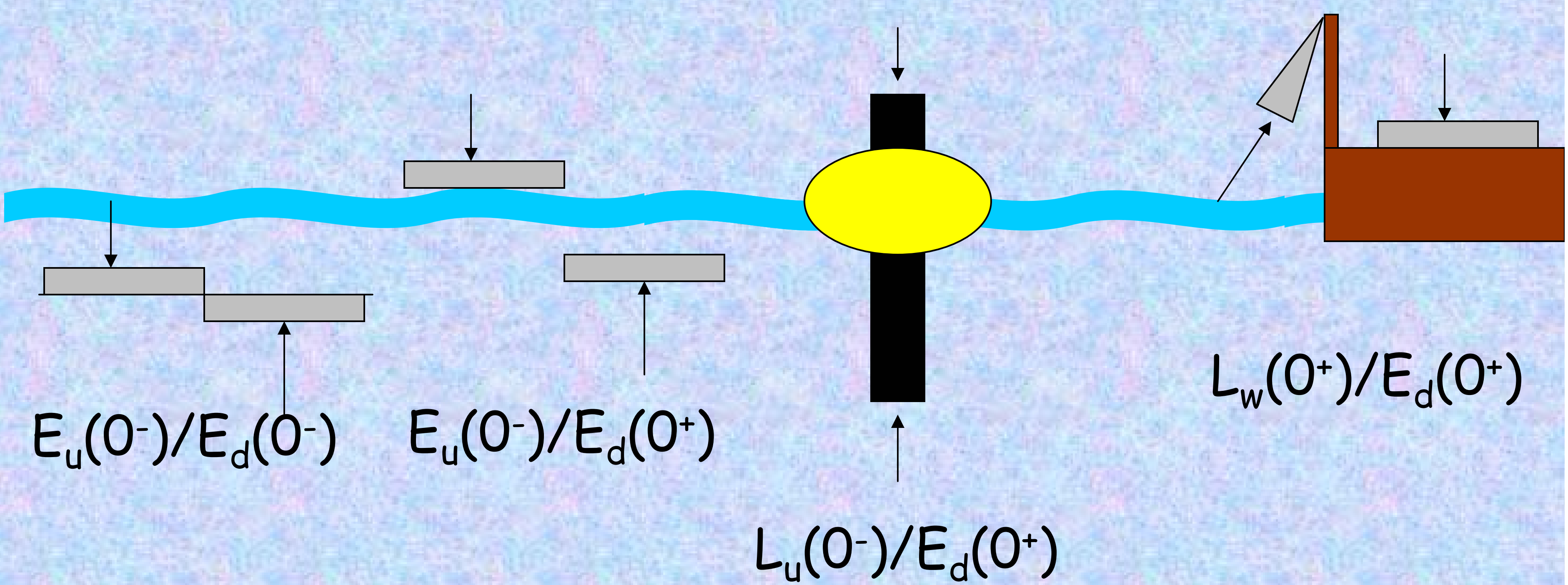
K_{PAR} has to vary near surface due to change in spectra (Morel, 1988).

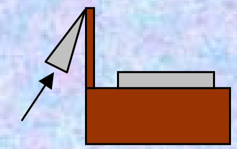
What causes the difference between different waters?



Apparent Optical Properties

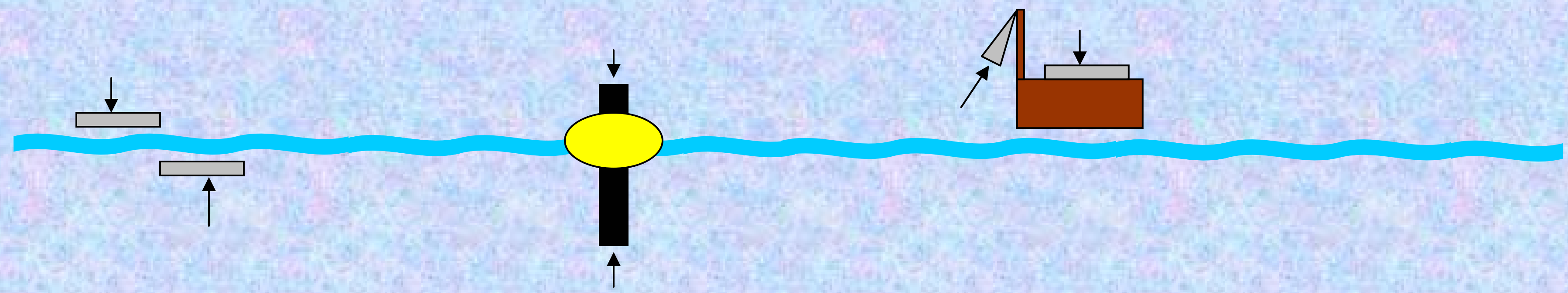
Reflectance ratios (upward to downward):

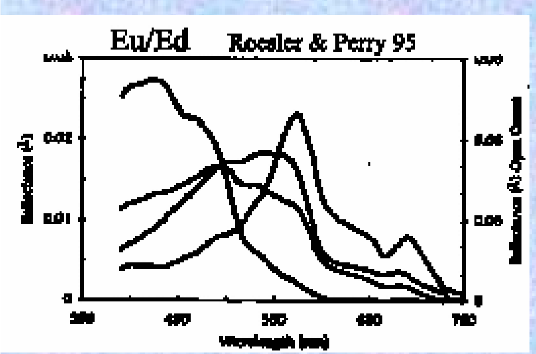


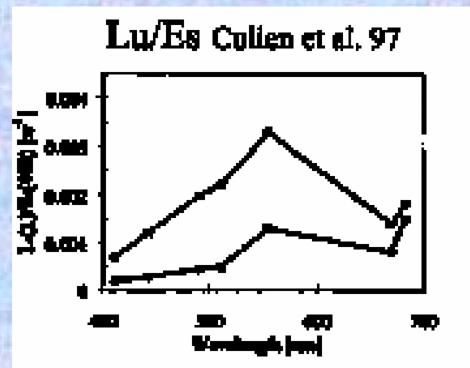


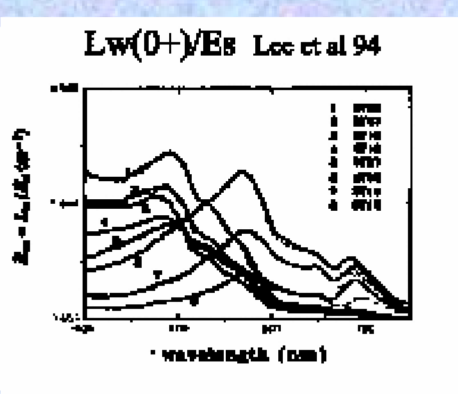
Apparent Optical Properties

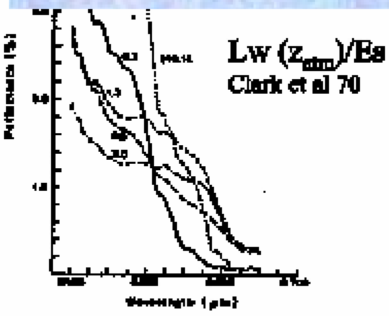
Reflectance ratios (upward to downward)





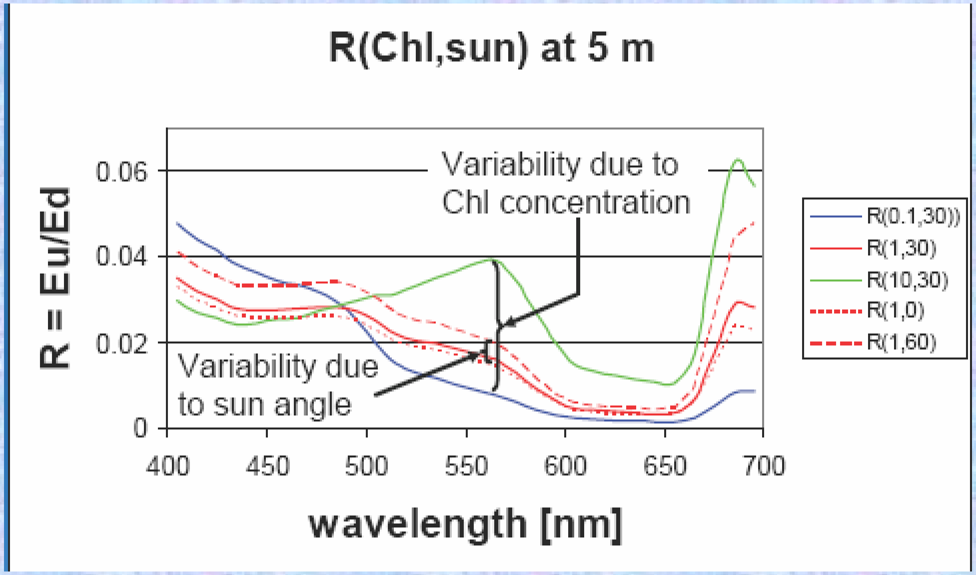






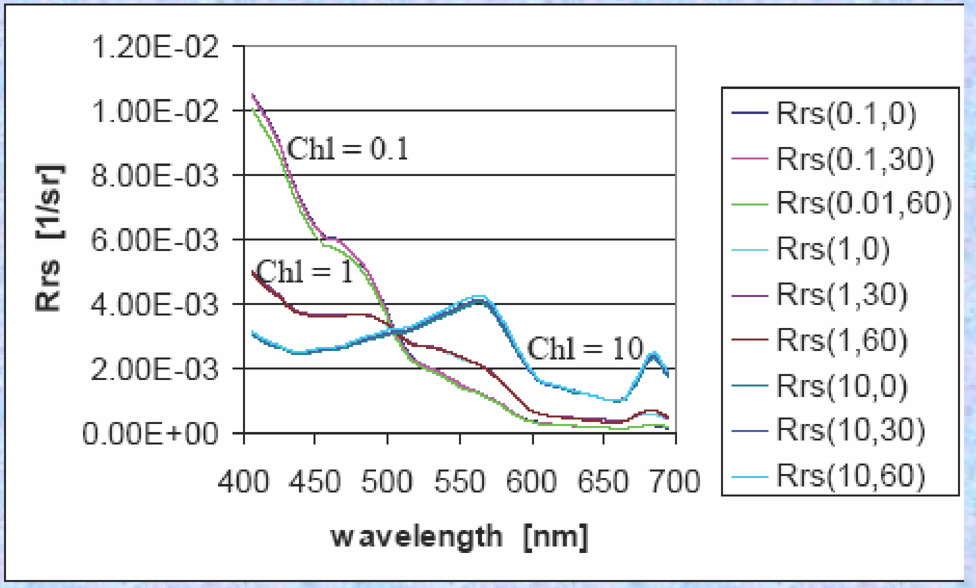
Sample spectra

Not all reflectances are equally good:



Mobley, 2004, Hydrolight
with chl.=0.1,1,10
and sun angle, 0, 30 & 60°

Rrs is less dependent on sun angle compared to R, a better AOP.



Radiative Transfer Theory in the Ocean

The radiative transfer equation relates the apparent optical properties to the inherent optical properties

Radiative Transfer Theory in the Ocean

Path radiance(given λ):

How does $L(\theta,\phi)$ vary along path r

$dL(\theta,\phi)/dr$

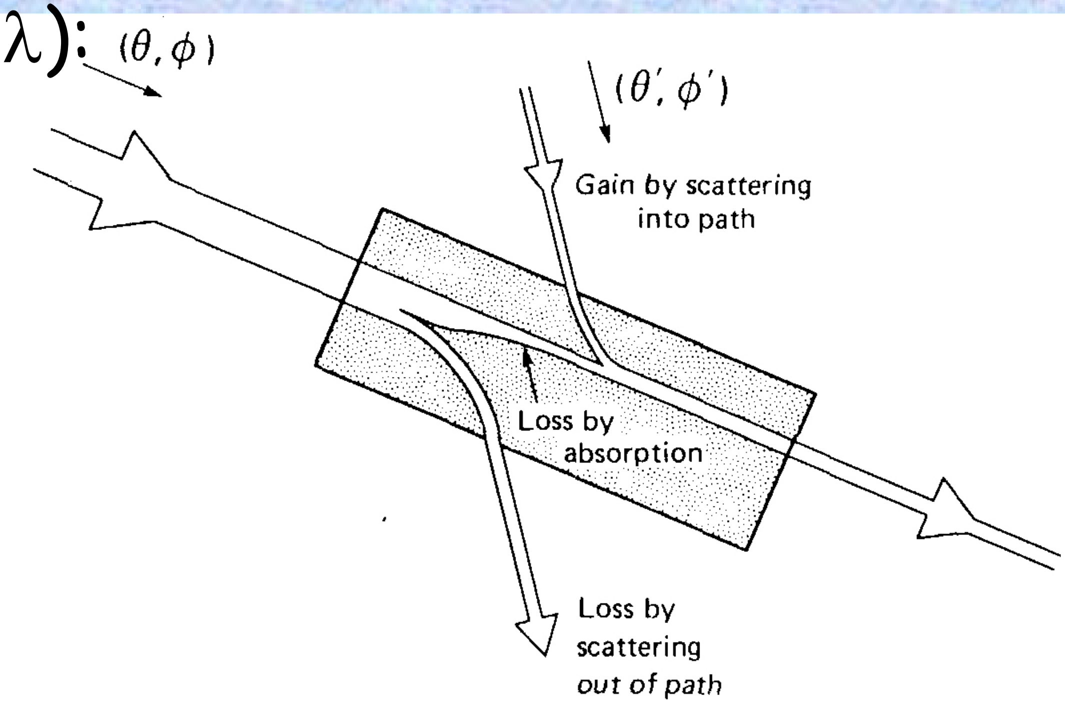


Fig. 1.6. The processes underlying the equation of transfer of radiance. A light beam passing through a distance, dr, of medium, in the direction θ, ϕ, loses some photons by scattering out of the path and some by absorption by the medium along the path, but also acquires new photons by scattering of light initially travelling in other directions (θ', ϕ') into the direction θ, ϕ.

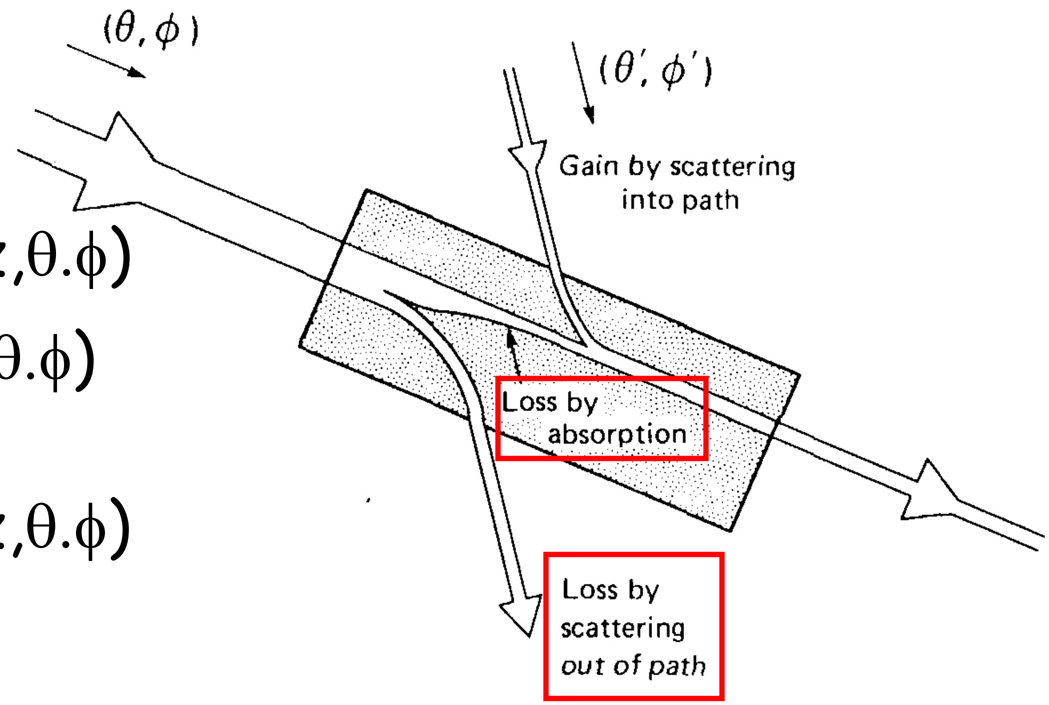
Radiative Transfer Theory in the Ocean

Path radiance

- losses

$$dL(\theta,\phi)/dr = -a(z)\, L(z,\theta.\phi)$$
$$-b(z)\, L(z,\theta.\phi)$$

$$\rightarrow dL(\theta,\phi)/dr = -c(z)\, L(z,\theta.\phi)$$



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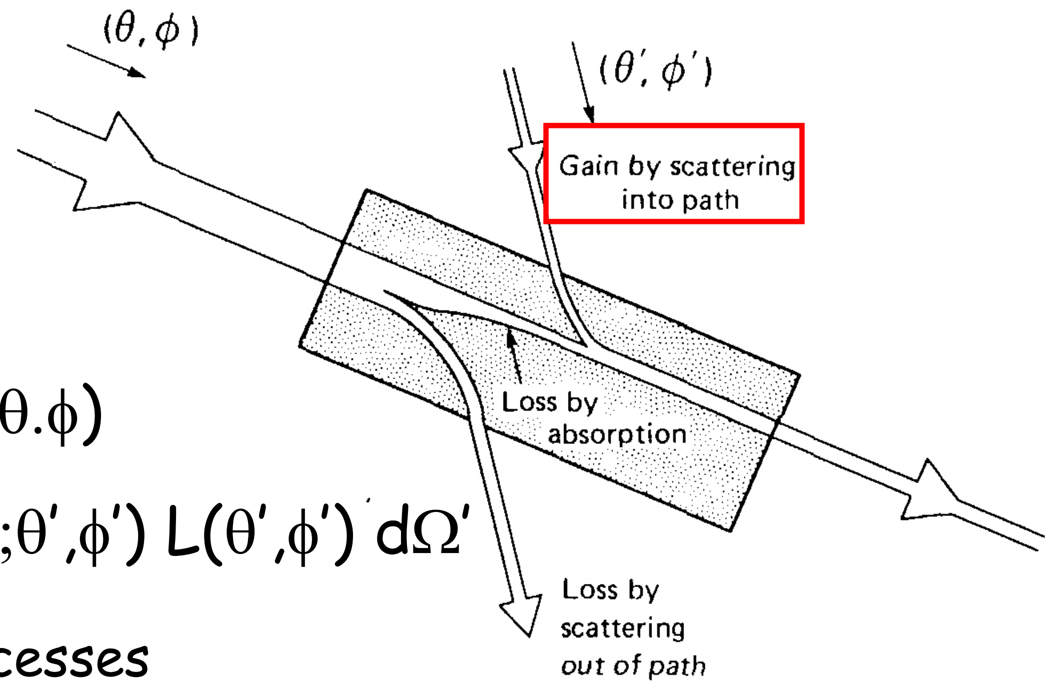
Radiative Transfer Theory in the Ocean

Path radiance

- gains



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$$dL(\theta,\phi)/dr = - c(z)\, L(z,\theta.\phi) + \int_{4\pi} \beta(z,\theta,\phi;\theta',\phi')\, L(\theta',\phi')\, d\Omega'$$

+ inelastic scattering processes (Raman, fluorescence)

a function of absorption at λ_e and re-emission at λ_f

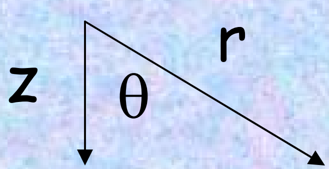
Radiative Transfer Theory in the Ocean

Path radiance

- RT Equation

$$dL(\theta,\phi)/dr = - c(z)\, L(z,\theta.\phi) + \int_{4\pi} \beta(z,\theta,\phi;\theta',\phi')\, L(\theta',\phi')\, d\Omega'$$

We measure as a function of depth rather than pathlength



$r = z / \cos\theta$

$$\cos\theta\, dL(\theta,\phi)/dz = - c(z)\, L(z,\theta.\phi) + \int_{4\pi} \beta(z,\theta,\phi;\theta',\phi')\, L(\theta',\phi')\, d\Omega'$$

We cannot usually solve this equation analytically.

Radiative Transfer Theory in the Ocean

Ex. of simplifications: Divergence Law, integrate $d\Omega$

$$\int_{4\pi} \{\cos\theta \, dL(\theta,\phi)/dz \} d\Omega$$

$$= - \int_{4\pi} c(z)\, L(z,\theta.\phi)\, d\Omega + \int_{4\pi} \int_{4\pi} \beta(z,\theta,\phi;\theta',\phi')\, L(\theta',\phi')\, d\Omega'\, d\Omega$$

$$d\vec{E}/dz = - c\, E_o + b\, E_o = -a\, E_o$$

$$1/\vec{E}\; d\vec{E}/dz = - c\, E_o/\vec{E} + b\, E_o/\vec{E}$$

$$K_E = a / \overline{\mu}$$

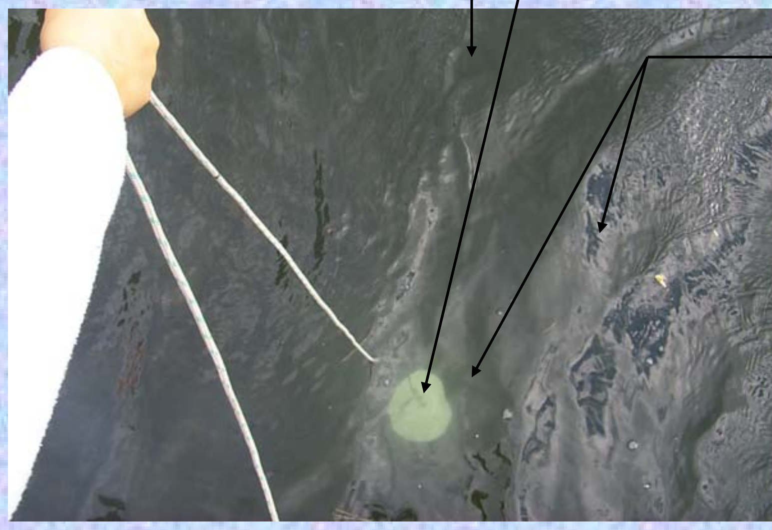
Gershun's Equation relating k_E, $\overline{\mu}$, and a

Secchi disk optics:

Background reflectance just below surface

Reflectance of disk

Sea surface effects



$$Z_{SD} = \frac{1}{\overline{c} + \overline{K}} \ln \left[\frac{\Gamma\{A - R(0)\}}{R(0)C_l} \right]$$

Optical Properties of the Sea

Eyeball Response

The primary source of variability in the Secchi disk depth is the optical properties of the sea, specifically the attenuation of light. (the other parameters are in the logarithmic term).

But, to what wavelengths of *c* and *K* is the secchi sensitive to?
See secchi lecture on CD