Ocean Optics Summer Class

Calibration and Validation for Ocean Color Remote Sensing

Overview of HydroLight and EcoLight 5.1

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SEQUOIA

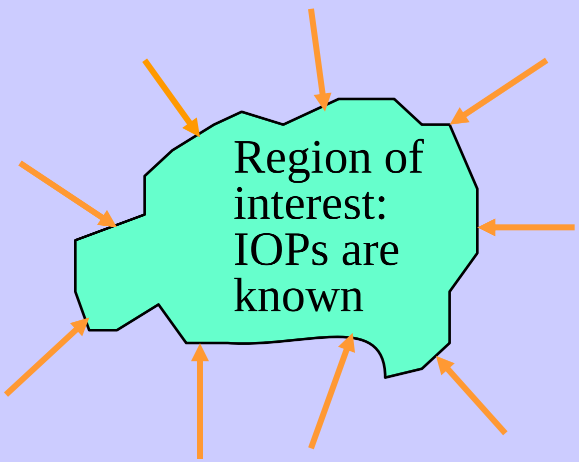
HYDROLIGHT

HydroLight Overview

- What is HydroLight?
  - Physical model
  - Computational model
  - Use as a tool
- Example HydroLight simulation
  - Input
  - Output
- Software Package
- Then do some runs….
- Install the code on your laptops

SOLVING THE RTE

A unique solution of the RTE requires:

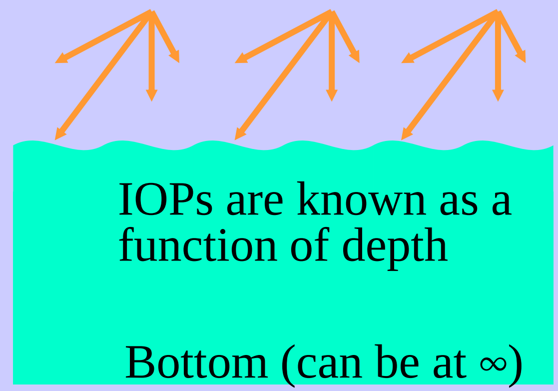


Radiance incident onto all boundaries from outside the region is known

A 3-D problem

Stretch out the region to make a horizontally homogeneous ocean

Radiance incident onto sea surface is known



A 1-D problem

THE RADIATIVE TRANSFER EQUATION (RTE)

$$\cos\theta \frac{dL(z,\theta,\phi,\lambda)}{dz} = -[a(z,\lambda) + b(z,\lambda)]\, L(z,\theta,\phi,\lambda)$$

$$+ b(z,\lambda) \int_0^{2\pi} \int_0^{\pi} L(z,\theta',\phi',\lambda)\, \tilde{\beta}(z,\theta',\phi' \rightarrow \theta,\phi,\lambda) \sin\theta'\, d\theta'\, d\phi'$$

$$+ S(z,\theta,\phi,\lambda)$$

Given the IOPs $a(z,\lambda)$, $b(z,\lambda)$, and $\tilde{\beta}(z,\theta',\phi' \rightarrow \theta,\phi,\lambda)$; the internal sources $S(z,\theta,\phi,\lambda)$; and boundary conditions at the air-water surface and the bottom, HydroLight solves for the radiance distribution $L(z,\theta,\phi,\lambda)$.

THE RADIATIVE TRANSFER EQUATION (RTE)

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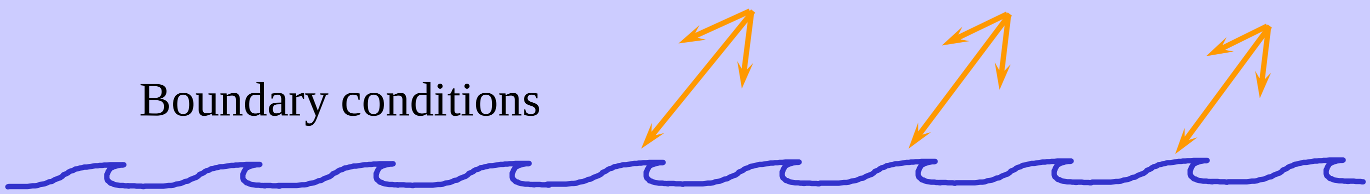
$$+\; b(z,\lambda) \int_0^{2\pi}\!\int_0^{\pi} L(z,\theta',\phi',\lambda)\, \tilde{\beta}(z,\theta',\phi' \to \theta,\phi,\lambda)\, \sin\theta' \, d\theta' \, d\phi'$$

$$+\; S(z,\theta,\phi,\lambda)$$

NOTE: The RTE has the TOTAL absorption and VSF. Only oceanographers (not photons) care how much of the total absorption and scattering is due to water, phytoplankton, CDOM, minerals, etc.

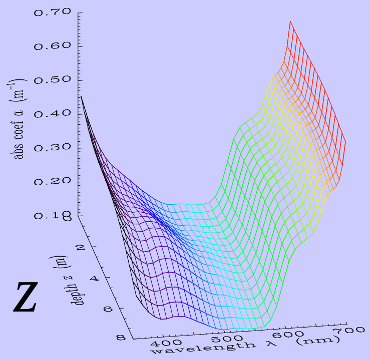
OVERVIEW

Boundary conditions



a

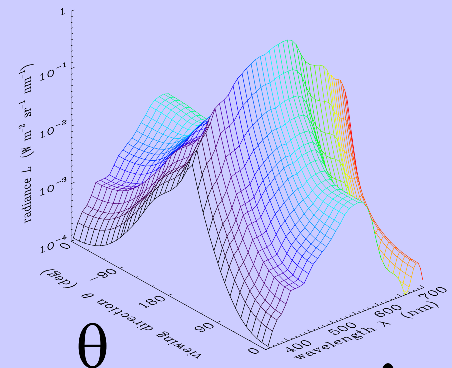
z



λ

$$\cos\theta \, \frac{dL(z,\theta,\phi,\lambda)}{dz} = \cdots$$

L



θ

λ

Inherent Optical Properties → Radiative Transfer Equation → Radiance Distribution

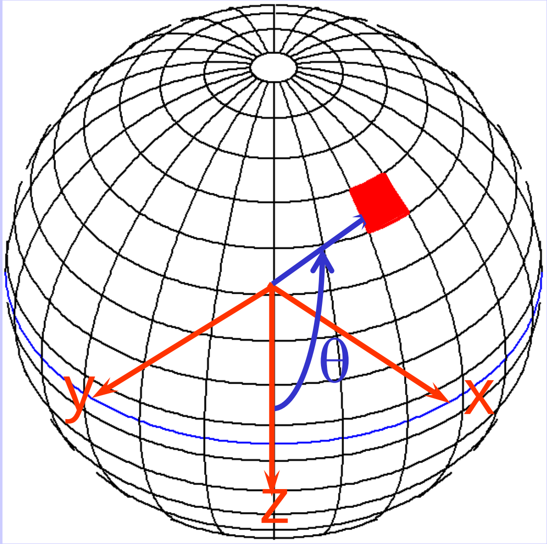
Physical Model

- time independent
- one spatial dimension (depth)
  - no restrictions on depth dependence of IOPs (not a “layered” model)
- no restriction on wavelength dependence from 300 to 1000 nm
- arbitrary sky radiance onto sea surface
- Cox-Munk air-water surface (parameterizes gravity & capillary waves via the wind speed)
- various bottom boundary options
- includes all orders of multiple scattering
- includes Raman scatter by water
- includes fluorescence by chlorophyll and CDOM
- includes internal sources (bioluminescing layers)
- polarization not included (the biggest inaccuracy in HydroLight)
- whitecaps not included

COMPUTATIONAL MODEL

Discretization: Average the RTE over directional "windows" (solid angle "quads") Ω_{uv} and over wavelength bands $\Delta\lambda_j$, and save output at a finite number of depths z_k

$$L(z,\theta,\phi,\lambda) \rightarrow L(k,u,v,j) = \frac{1}{\Delta\lambda_j \, \Delta\Omega_{uv}} \int_{\Delta\lambda_j} \int_{\Omega_{uv}} L(z_k,\theta,\phi,\lambda) \sin\theta \, d\theta \, d\phi \, d\lambda$$



HydroLight computes the directionally averaged radiance within each quad, averaged over the wavelengths within each band. Note: the outputs are still spectral quantities, not quad- or band-integrated values.

Note: All numerical models must discretize continuous functions of depth, direction and wavelength to get a finite number of quantities to be computed.

COMPUTATIONAL ADVANTAGES

- **Run time linearly proportional to optical depth**
  (Monte Carlo $\propto$ exp(optical depth))

- **Run time independent of IOP(z) profile; arbitrary depth resolution**
  (Discrete ordinates $\propto$ number of homogeneous layers)

- **Solution is "exact"**
  (all orders of multiple scattering, etc)

- **User can/must specify all input**
  (but defaults & examples are built in for everything)

- **Graphical user interface for input**
  (not necessary, but makes it easy to define your input)

- **Simple analysis of output with printout, Excel, or IDL plots**
  (So you can do even less thinking about your results)

USING HYDROLIGHT

- A **research** tool:
  Study the connections between the various inputs and outputs of marine light fields in a **controlled environment.**

- An **analysis** tool:
  Characterize the ambient light field for interpretation of empirical data.

- A **prediction** tool:
  Predict the optical environment associated with a predicted set of biological and geological parameters.

- A **teaching** tool:
  Bring radiative transfer theory to the classroom without needing to know advanced mathematics.

FROM THE USERS' GUIDE

…the HydroLight model per se is a radiative transfer model, not a model of oceanic optical properties. You, the user, must supply the inherent optical properties and boundary conditions to the HydroLight core code.

HydroLight does not know the inherent optical properties, or the chlorophyll profile, or the depth, or anything else about the water body you are interested in. *You* must provide this information to HydroLight. The various IOP models, phase functions, chlorophyll data sets, ac-9 data sets, etc. that come with HydroLight are *examples* of how to provide IOP and other information to HydroLight. *You* will need to replace these example routines and data sets with your own, in order to simulate the water body of interest to you.

It is not idiot proof. Garbage in, garbage out.

SUITABLE INPUT

clean up your data before giving it to H

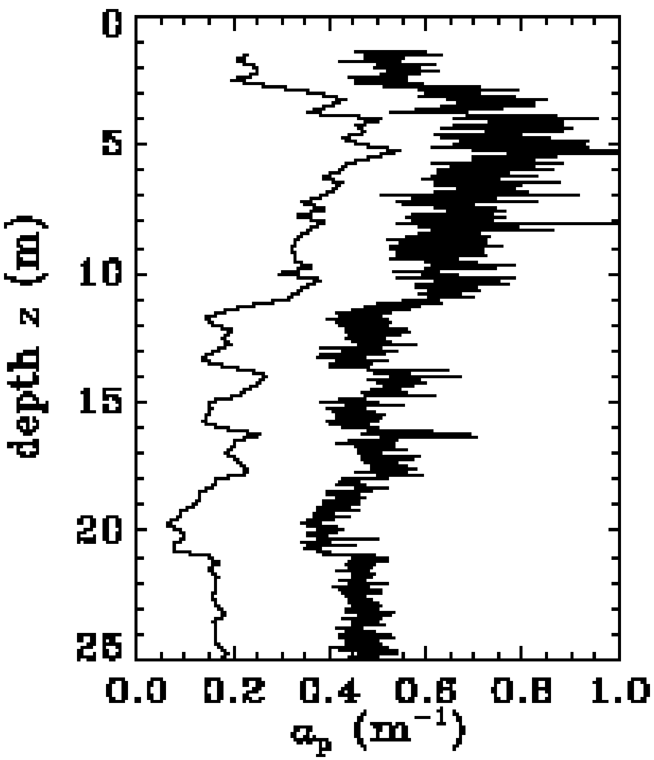


Figure 1. Smoothed and unsmoothed data. The right curve is 2,056 values of particulate absorption a_p obtained from an ac-9; this curve is too noisy to be used as input to HYDROLIGHT. The left curve (offset to the left by 0.3 for clarity) is the same data binned into 25 cm depth bins to give 95 a_p values; this curve is suitable for input to HYDROLIGHT and still contains adequate depth resolution of the absorption fine structure.

Example Simulation

Upper boundary:

- sun at 60° in a hazy sky
- wind speed of 5 m/s

Lower boundary:

- water is 8 m deep
- bottom is covered by green algae

Water IOPs:

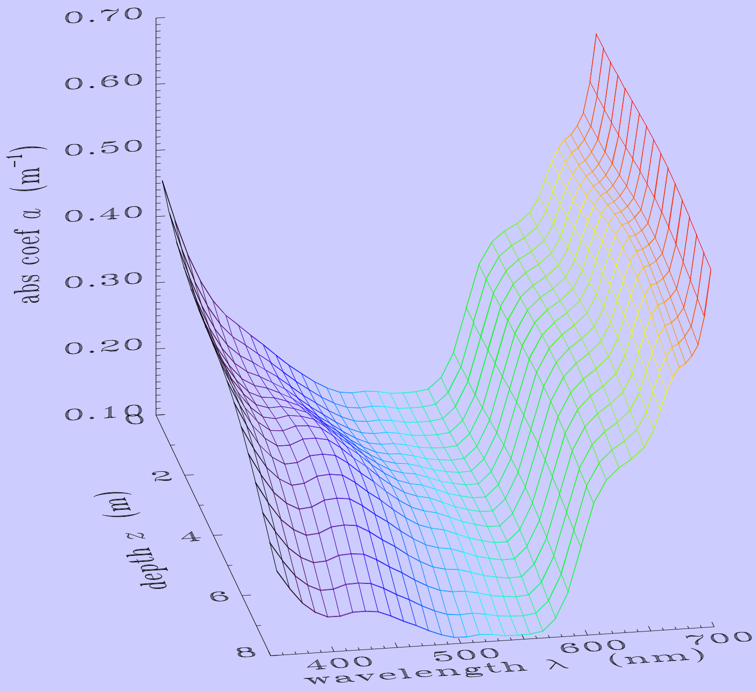
- Case 2 water: Chl and CDOM do not covary with depth
- use simple analytical models for IOPs
- include Chl and CDOM fluorescence; Raman scatter by water

Resolution of output:

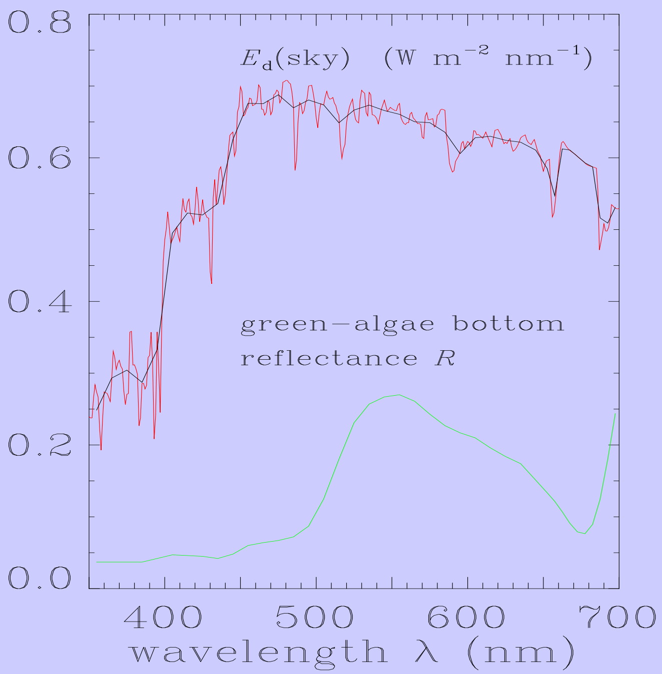
- 350-650 nm by 10 nm bands; 650-700 by 5 nm bands
- save output every 0.5 m in depth
- 10° θ bands, 15° ϕ bands

EXAMPLE INPUT

absorption as a function
of depth and wavelength

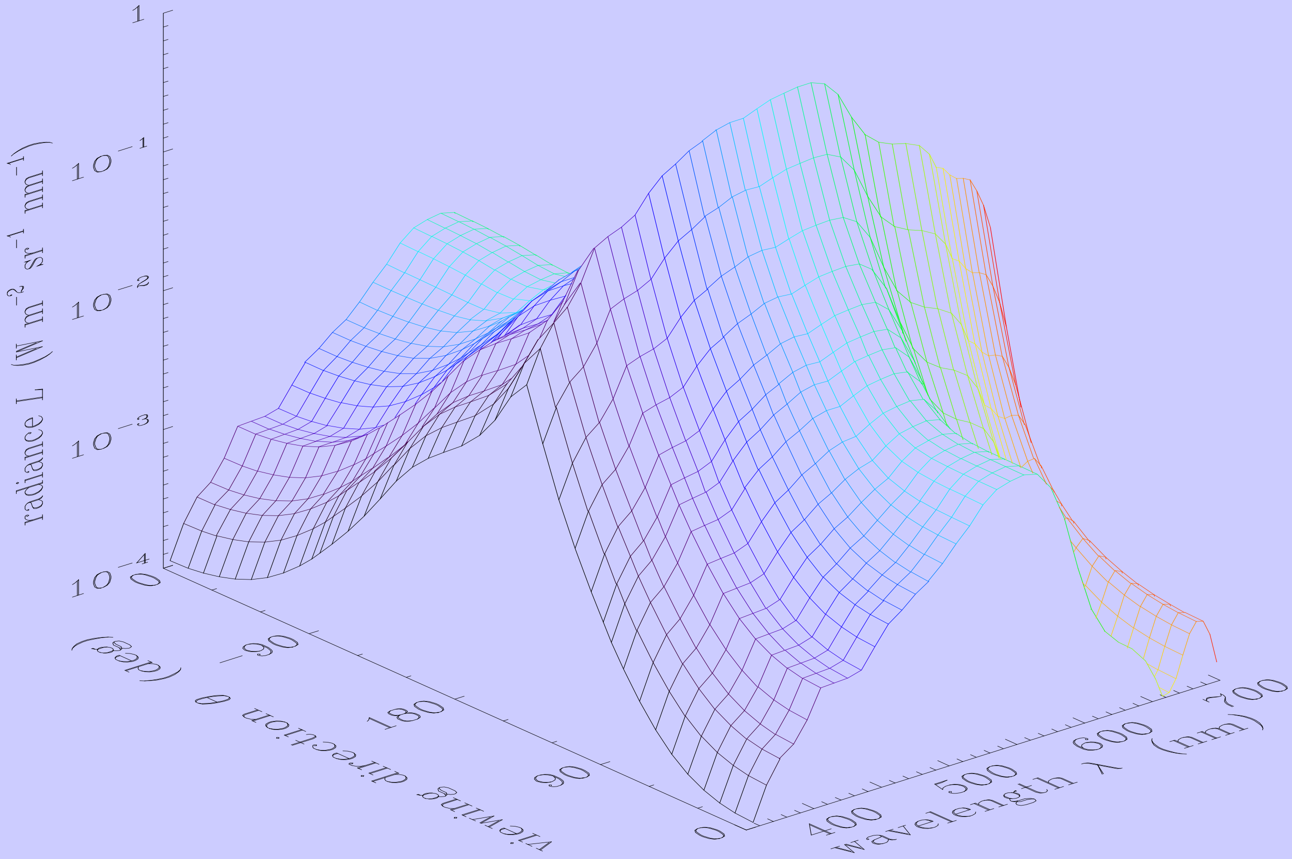


incident sky irradiance
and bottom reflectance



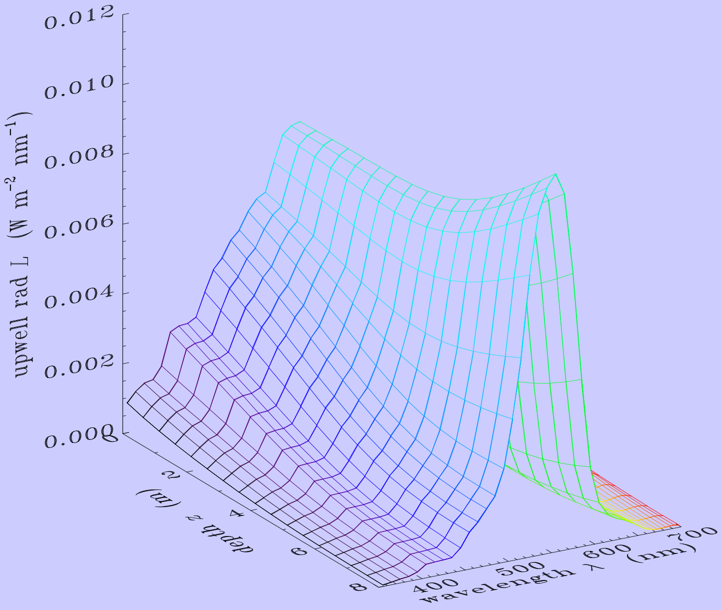
EXAMPLE OUTPUT

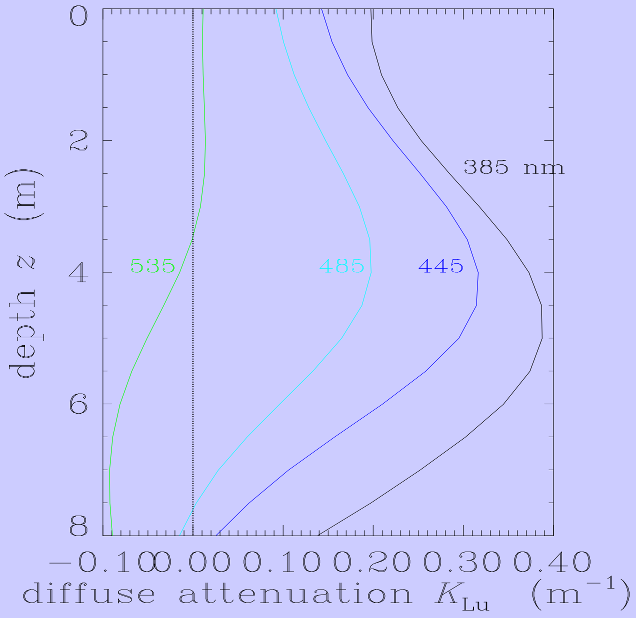
Radiance distribution as a function of polar angle and wavelength, at a depth of 5 m, in the plane of the sun (plotted using IDL and an output file formatted for input to IDL)



Example Output

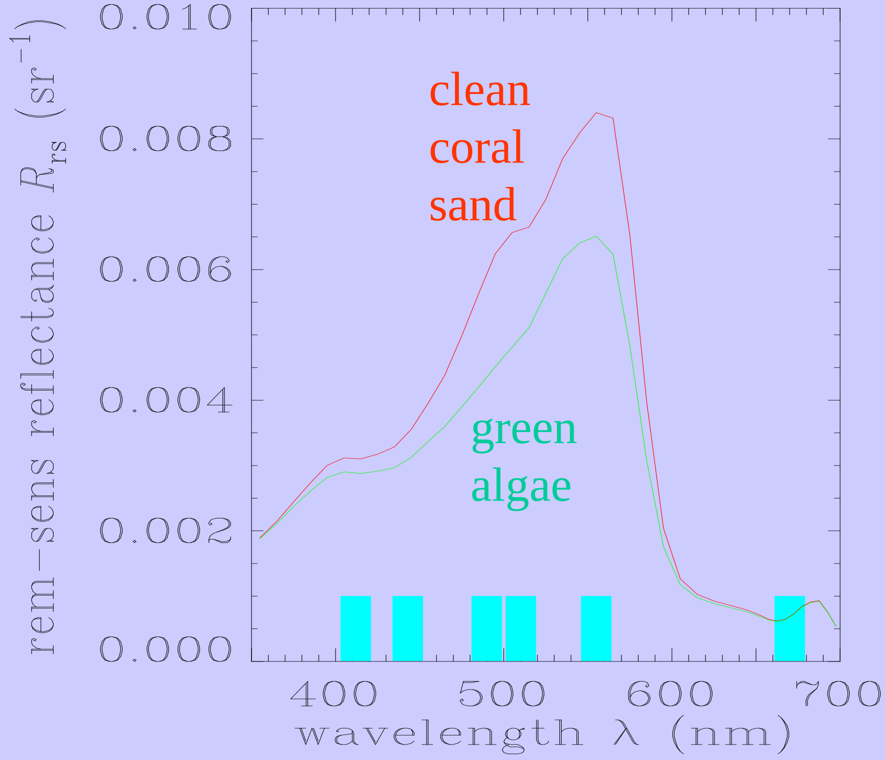
Upwelling (nadir-viewing) radiance L_u and diffuse attenuation K_{Lu} as functions of depth and wavelength (plotted using IDL)





EXAMPLE OUTPUT

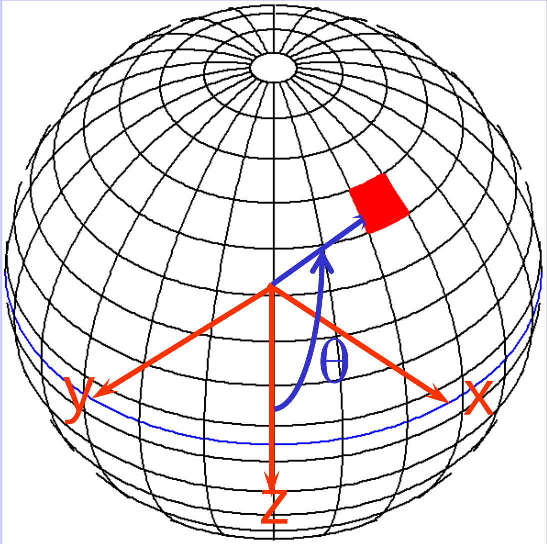
Remote-sensing reflectance R_{rs} for two different bottom types



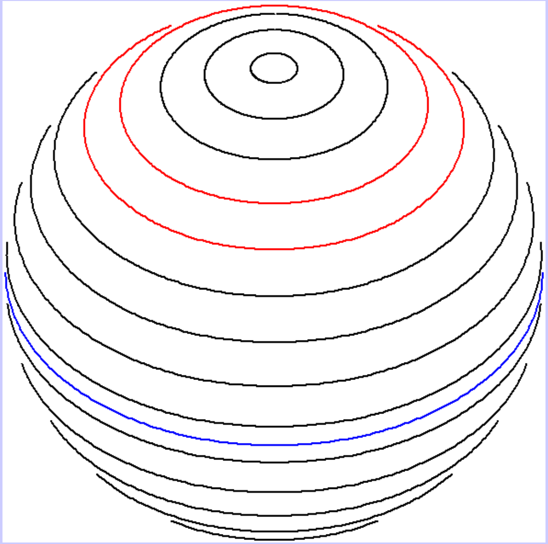
ECOLIGHT COMPUTATIONAL MODEL

Discretization: Average the RTE over azimuthal angle ϕ and over polar angle "bands" (solid angles) Ω_u and over wavelength bands $\Delta\lambda_j$, and save output at a finite number of depths z_k

$$L(z,\theta,\varphi,\lambda) \rightarrow L(k,u,j) = \frac{1}{\Delta\lambda_j\ 2\pi\ \Delta\Omega_u} \int_{\Delta\lambda_j} \int_0^{2\pi} \int_{\Delta\Omega_u} L(z_k,\theta,\varphi,\lambda)\ \sin\theta\ d\theta\ d\varphi\ d\lambda$$



HydroLight quads



EcoLight bands

EcoLight computes the azimuthally averaged radiance within each solid angle band.

The irradiances and polar cap radiances are the same for H & E.

HYDROLIGHT VS ECOLIGHT

Run time ∝ fixed overhead + number of quads or bands squared, so for $N = 20$ θ bands and $M = 24$ ϕ bands (10 deg x 15 deg angular resolution):

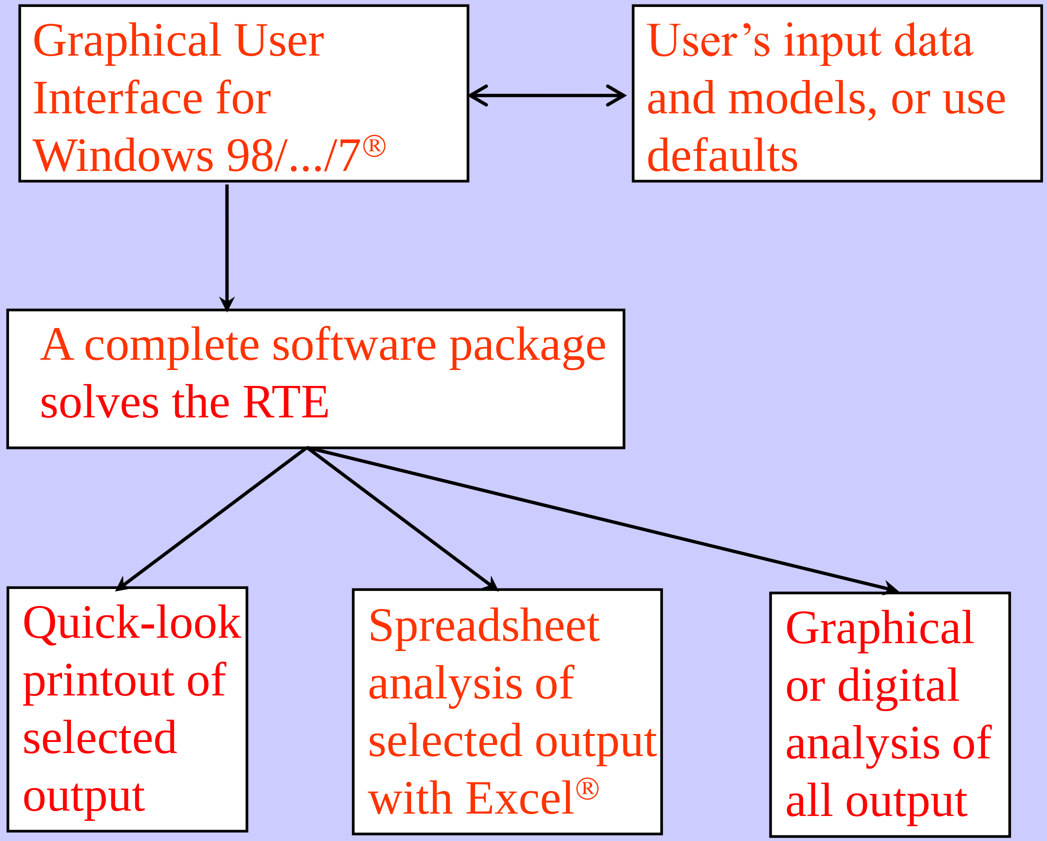
HL run time ∝ $FO + (NM)^2 = FO + (20*24)^2$

EL run time ∝ $FO + (N)^2 = (20)^2$

EL/HL = $[FO + (20)^2]/[FO + (20*24)^2] \sim 1/100$ so EL ~100 times faster (can be ~20 to 1000 times faster, depending on the problem and whether other speed optimizations are used)

The inputs to H & E are identical, and the computed irradiances, diffuse attenuation coefs, reflectances, etc. are almost identical (<1% difference due to numerical algorithms). Only H can output the directional structure of the radiance distribution.

SOFTWARE PACKAGE



THE RULES OF THE GAME

HydroLight is a commercial product of Sequoia Scientific, Inc. and is copyrighted code. It is not in the public domain.

The code provided to students for this course is an executable version of HydroLight-EcoLight version 5.1. This code does not have all of the features of the full HE5, and does not include the source code.

The code for this class will run for 500 executions or until the end of July 2011, whichever comes first.

(BTW, I have received no funding for the development and continued improvement of HydroLight or for user support. It must pay its own way as a commercial product.)

Star tracks, Grand Canyon