Lectures on

Radiative Transfer Theory, Optical Oceanography, and HydroLight

HydroLight Model-Data Closure

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Overview

- Show two examples of output from an advanced simulation that show what is necessary to achieve model-data closure, i.e., getting all of your inputs to H and outputs from H to agree with your measurements

- H lab 2 will demonstrate how to build up IOPs from several different components (water + phytoplankton + CDOM + ….), input your own data (ac9, bottom reflectance, etc) using HydroLight Standard Formats, etc.

Measurements Necessary for Model-Data Closure

HydroLight inputs

• absorption coef $a(z,\lambda)$ (e.g., from ac-9 or spectrophotometer)
• scattering coef $b(z,\lambda)$ (e.g., from ac-9)
• scattering phase function $\beta(z,\lambda,\psi)$ (almost never measured, but may have backscatter fraction $B = b_b/b$ from b_b (e.g,, HydroScat or EcoVSF) and b (ac-9)
• boundary conditions: sea state (wind speed); sun location and sky conditions (usually model), bottom reflectance (in shallow water)

HydroLight outputs

• radiometric variables (radiances and irradiances; usually measure $L_u(z,\lambda)$ and $E_d(z,\lambda)$ at a minimum)
• apparent optical properties (K_d, R, R_{rs} etc obtained from radiometric measurements). The most common for remote sensing is remote sensing reflectance R_{rs} (often measure E_d(air) and $L_u(z)$ and extrapolate upward from underwater L_u , or estimate R_{rs} using above-surface techniques)

Comprehensive Data Sets Are Extremely Scarce

Data set from ONR HyCODE (Hyperspectral Coastal Ocean Dynamics Experiment) 2000 off the coast of New Jersey (LEO-15 site)

measurements taken near local noon on 24 July 2000 at
39^{o} 24.91' N, 74^{o}, 11.78' W (station 19); cloudy sky, wind = 6 m/s

See Mobley et al, 2002, *Applied Optics* 41(6), 1035-1050 for details

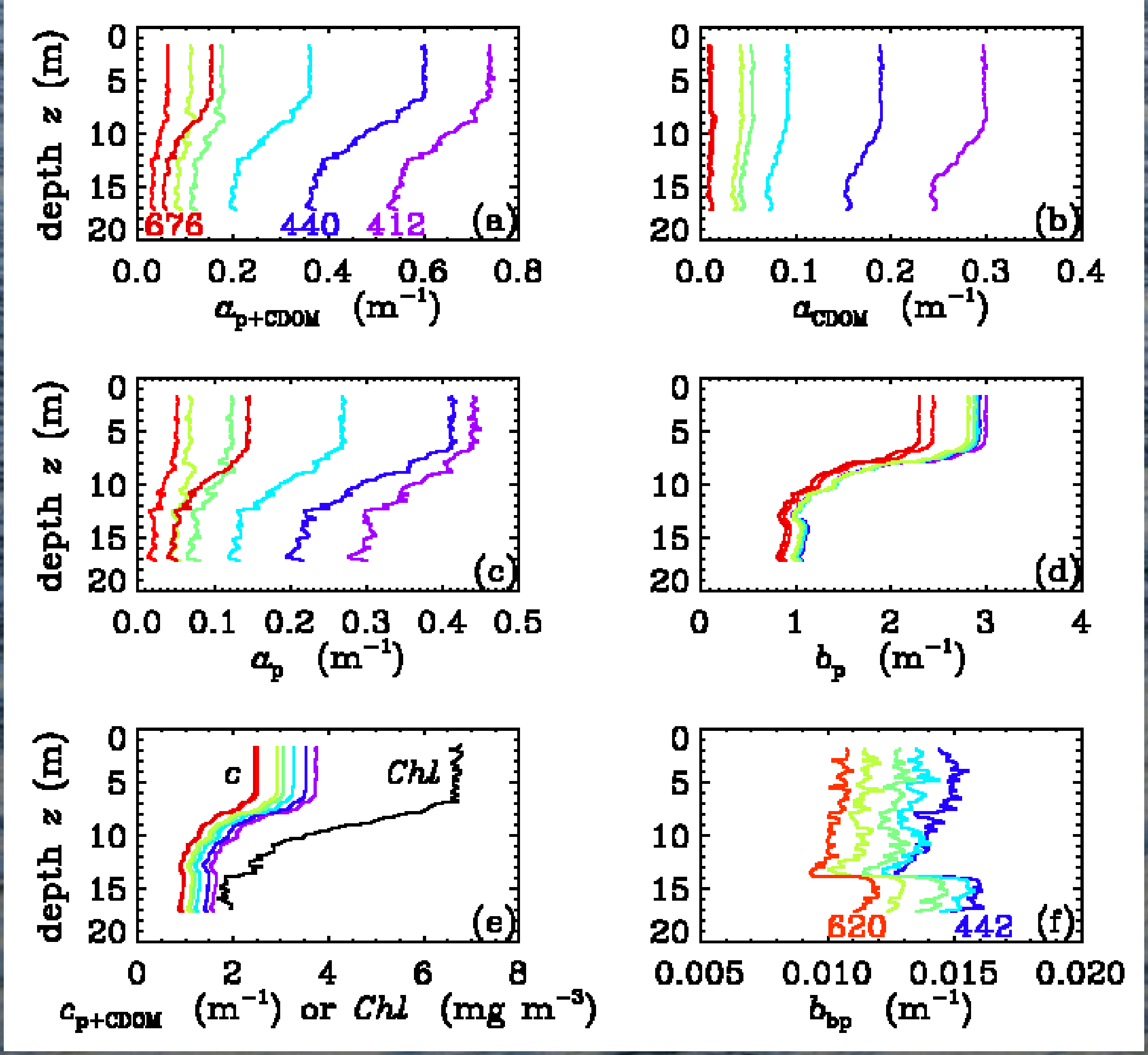
Table 4. Data Taken at the LEO-15 Site as Used to Model the In-Water Light Field[a]

Quantity Measured	Instrument	Nominal Wavelength (nm)
Total $a(z, \lambda)$, total $c(z, \lambda)$	Unfiltered ac-9	412, 440, 488, 532, 555, 650, 676, 715
Dissolved $a(z, \lambda)$	Filtered ac-9	412, 440, 488, 532, 555, 650, 676, 715
Backscatter $b(z, \lambda)$ derived from VSF at $\psi = 140$ deg	HydroScat-6	442, 488, 532, 555, 620
Backscatter $b(z, \lambda)$ derived from VSF at $\psi = 100$, 125, and 150 deg	ECO-VSF	530
VSF ($\psi = 0.6$–179.6 deg)	VSM	530
$E_d(z, \lambda)$ and $L_u(z, \lambda)$	OCP	412, 443, 489, 533, 555, 591, 683
Sky $E_d(\lambda)$	Multichannel visible detector system	412, 443, 489, 533, 555, 591, 683
Sky $E_d(\lambda)$ and $L_u(z = 0.6\ \text{m}, \lambda)$	Hyper-TSRB	123 wavelengths between 396 and 798

[a]Most instruments have a nominal 10-nm bandwidth centered on the listed wavelengths.

See NRC_ComprehensiveDataSets on what should be measured in a field experiment, but never is (cost, lack of interest, ignorance, politics, …)

HyCODE Data



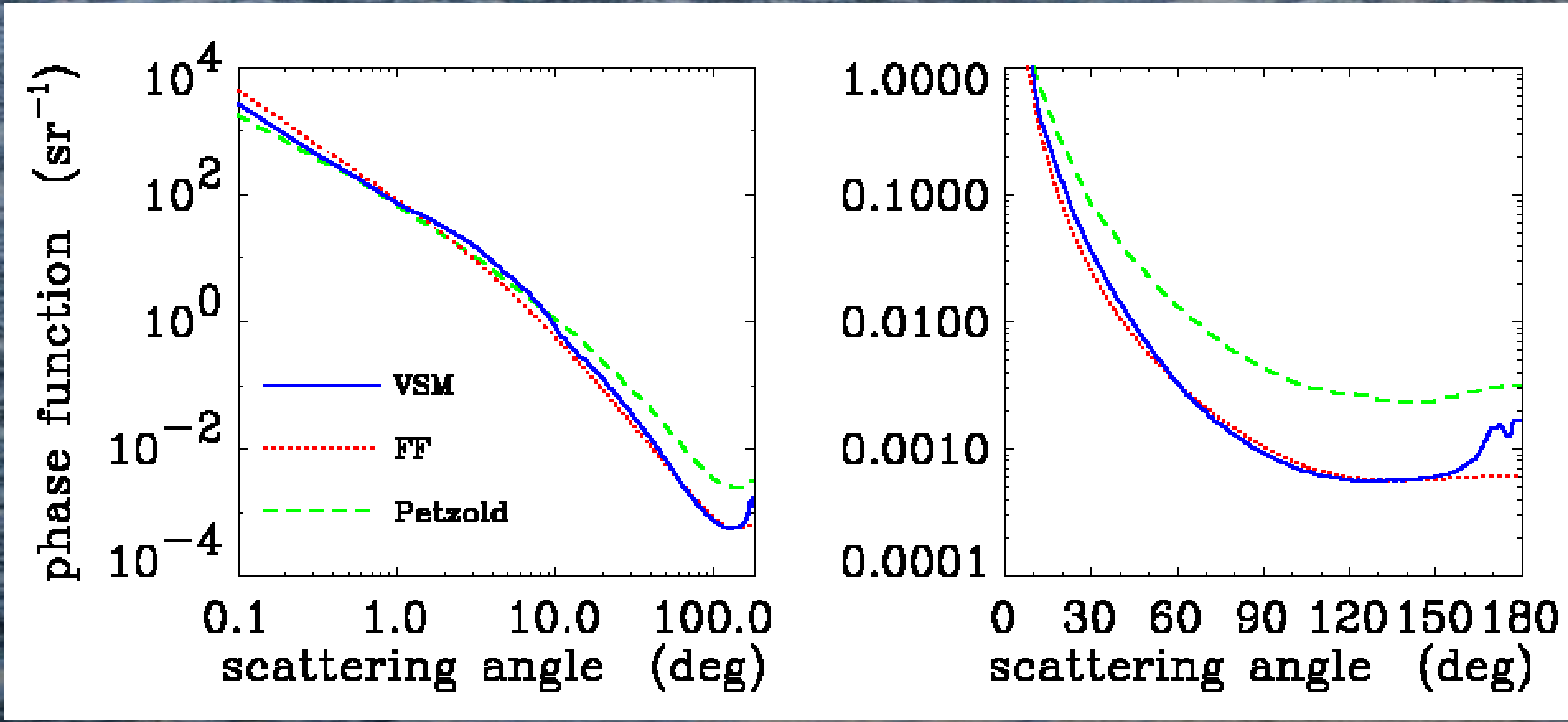
ac-9, both filtered (CDOM absorption) and unfiltered (total *a* and *b*)

HydroScat-6 (b_b)

can get B_p from measured b_{bp}/b_p

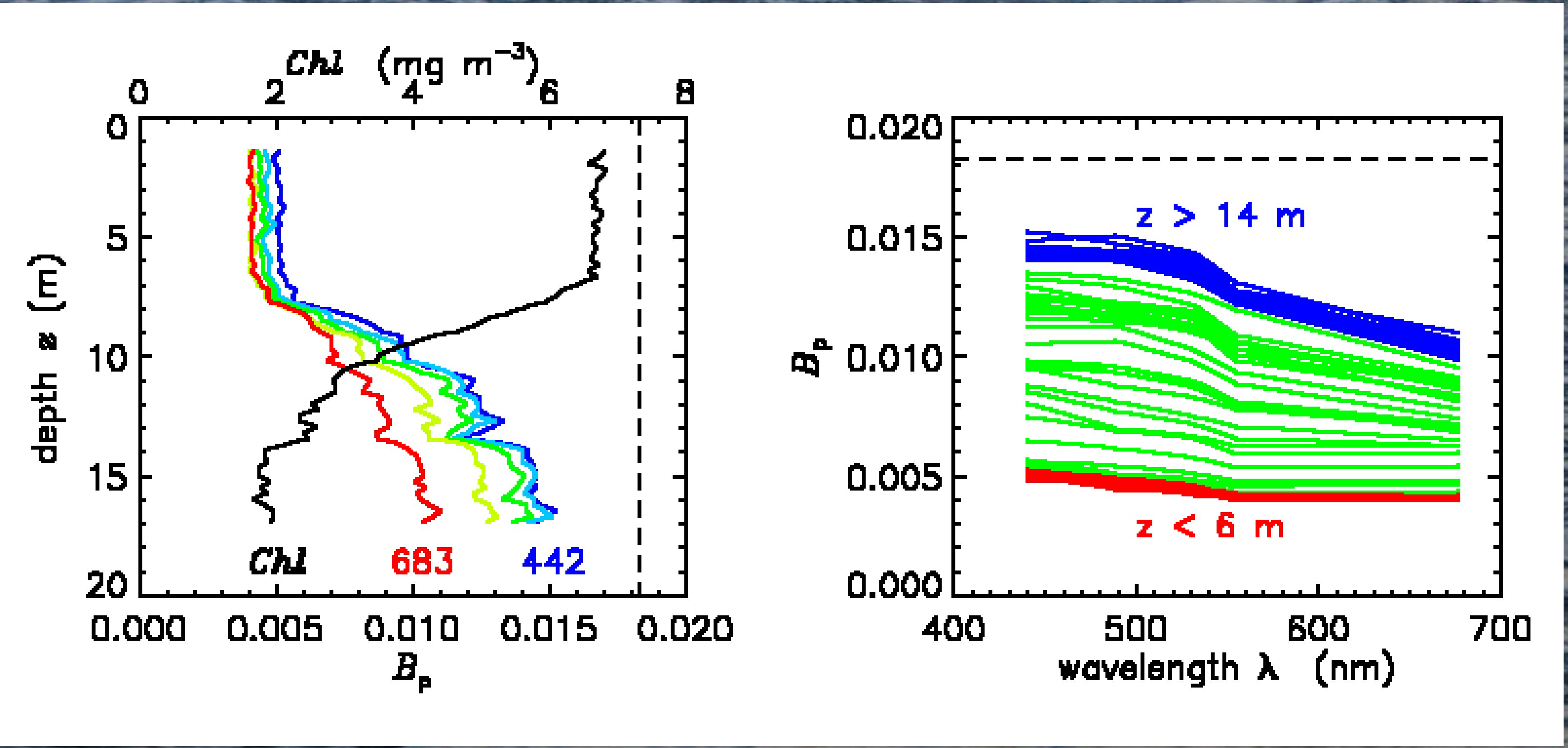
can then use B_p to define a Fournier-Forand phase function with the same backscatter fraction (Mobley, 2002. *AO* 41(6), 1035-1050)

HyCODE Data



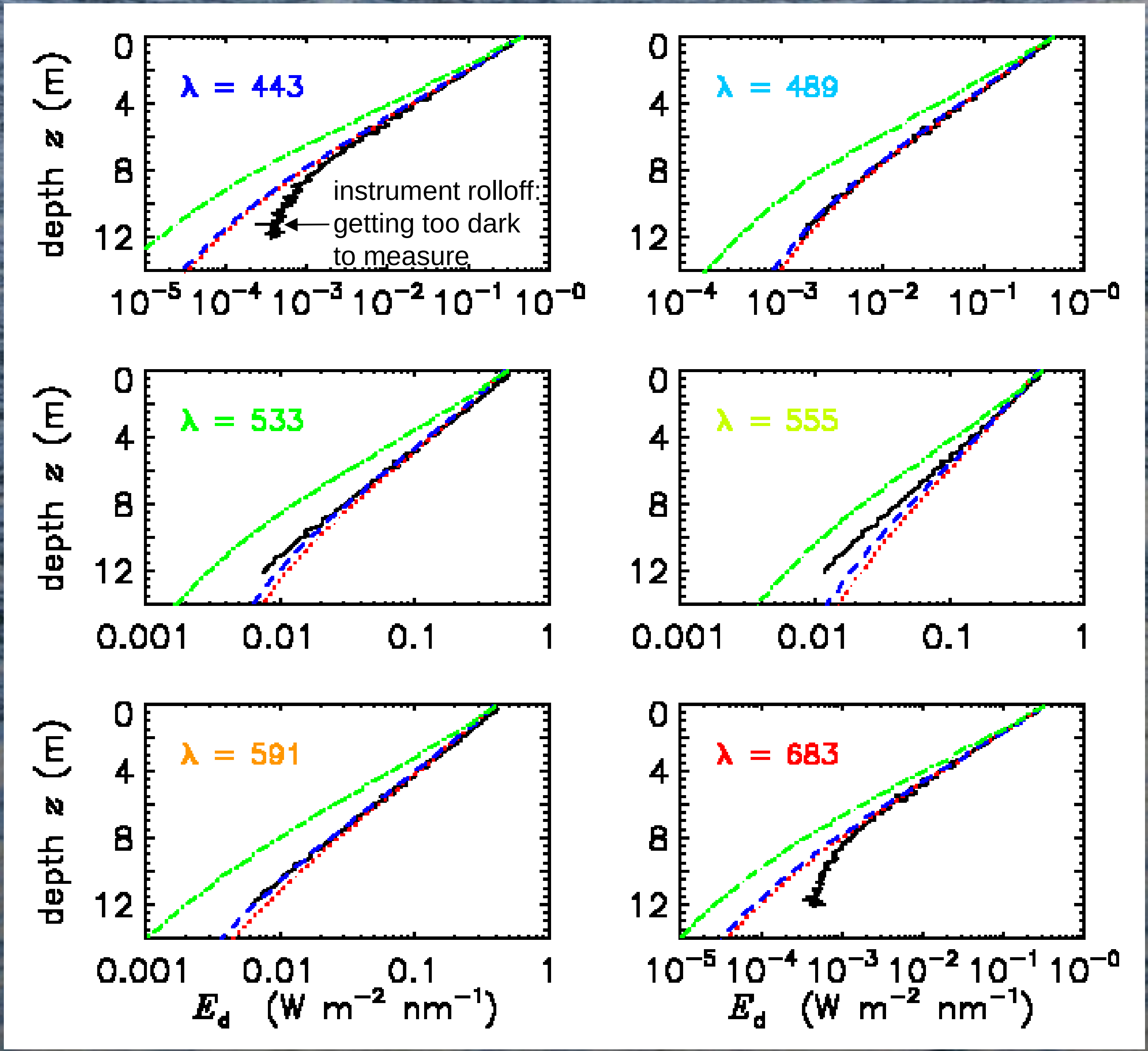
Also have VSF measurements (extremely rare) at 2 m depth at 530 nm from a novel Ukrainian instrument (Lee and Lewis, 2003. *J Atmos Ocean Tech* 20(4), 563-571)

HyCODE Data



Note that the measured B_p is much less than for the commonly used Petzold "average particle" phase function (0.0183), and B_p varies with depth and wavelength; value depends on type of particles: predominately phytoplankton near surface vs resuspended sediments near the bottom (18 m depth)

HyCODE Data: HydroLight vs E_d Measurements



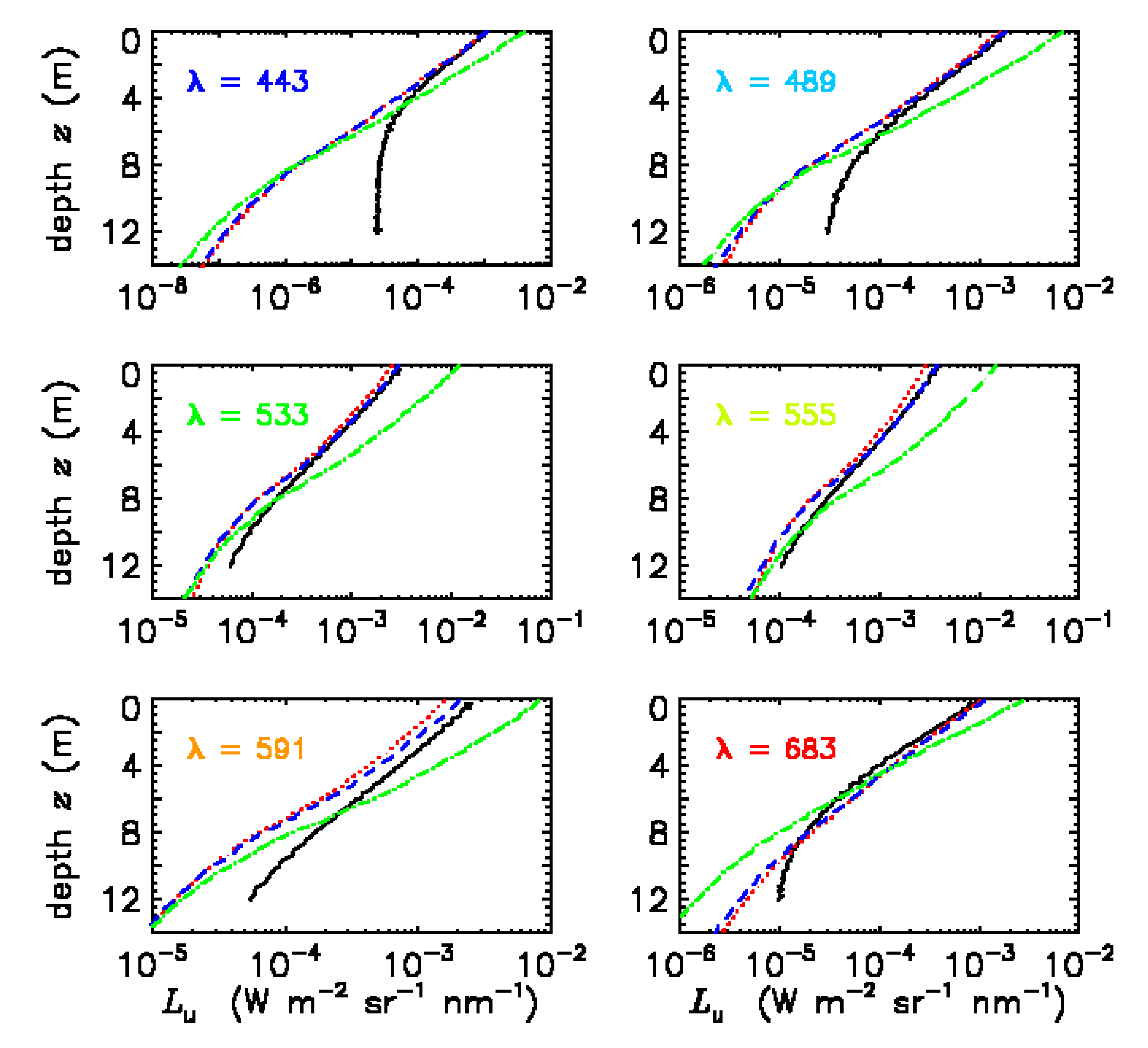
black: measurements

green: H with Petzold phase function

red: H with FF phase function determined from measured b_b/b

blue: H with measured pf

HyCODE Data: HydroLight vs L_u Measurements



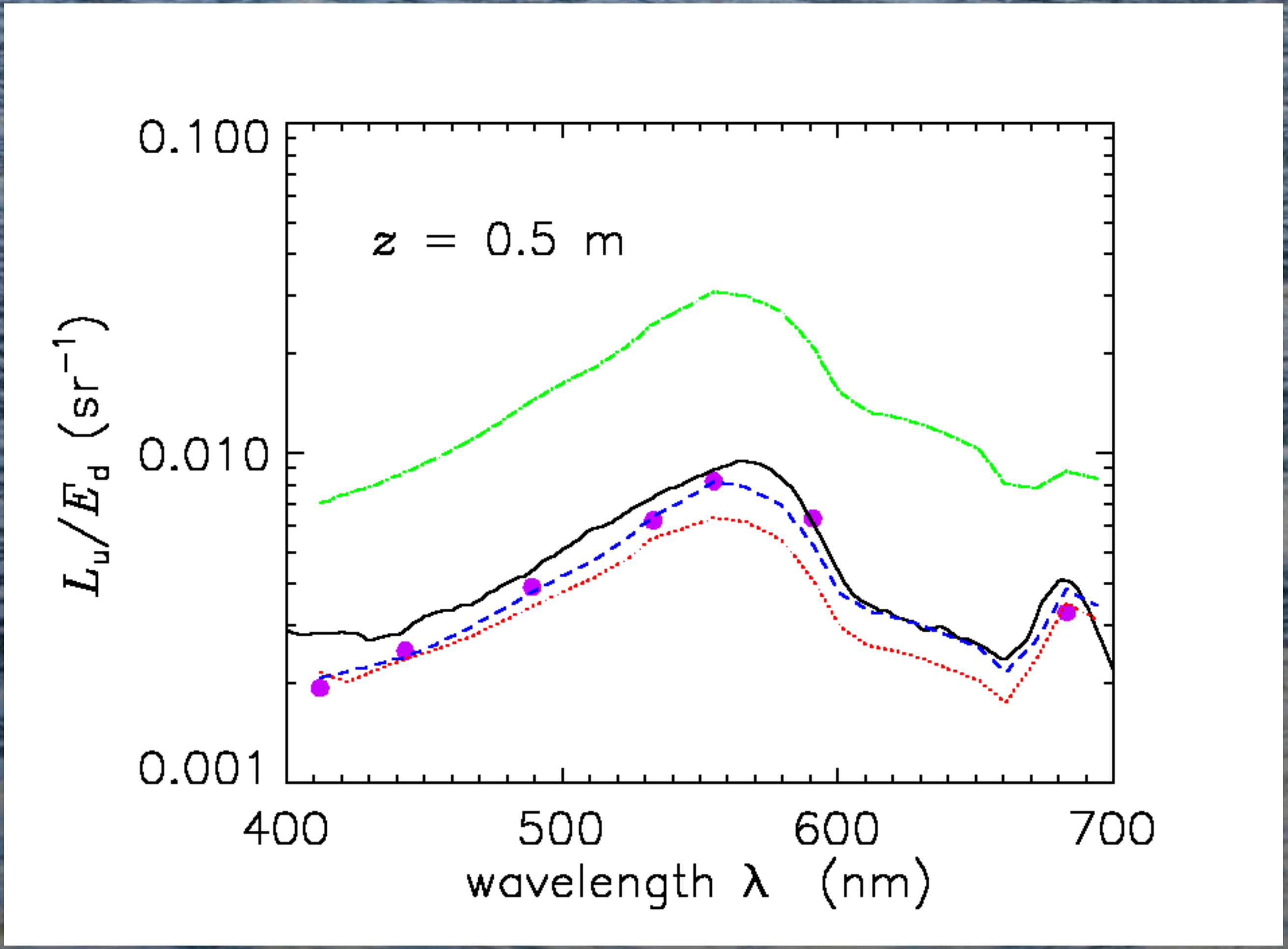
black: measurements

green: H with Petzold phase function

red: H with FF phase function determined from measured b_b/b

blue: H with measured pf

HyCODE Data: HydroLight vs L_u/E_d Measurements



black: measured by Hyper-TSRB (Satlantic)

purple dots: measured by OCP (Ocean Color Profiler; Satlantic)

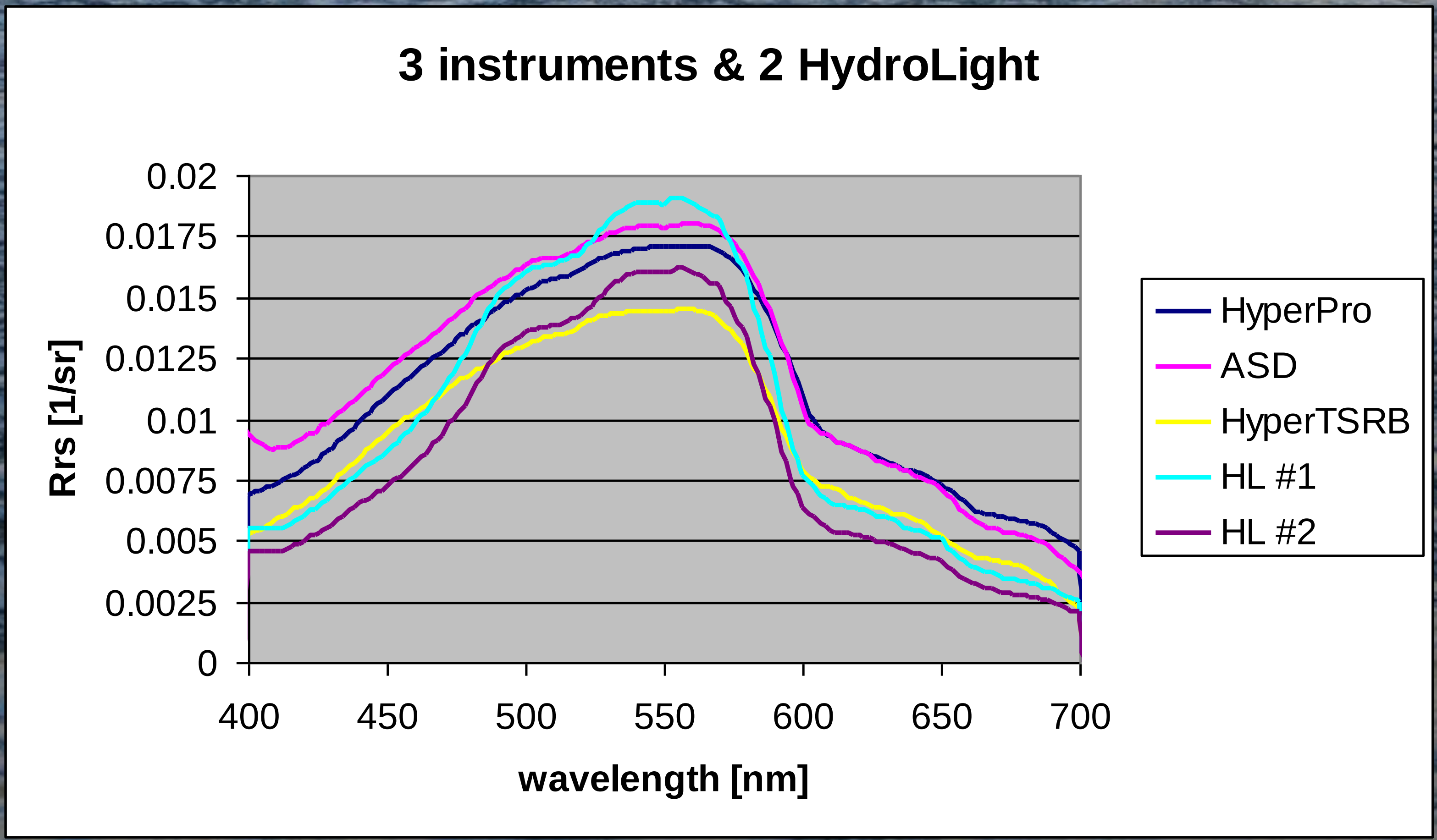
green: H with Petzold phase func.

red: H with FF pf determined from measured b_b/b

blue: H with measured pf

Measured vs HydroLight for CICORE Station ER01

CICORE data and analysis by Heidi Dierssen, Univ. Conn.; used measured ac-9 *a* and *b*; best-guess Fournier-Forand phase function, etc.]

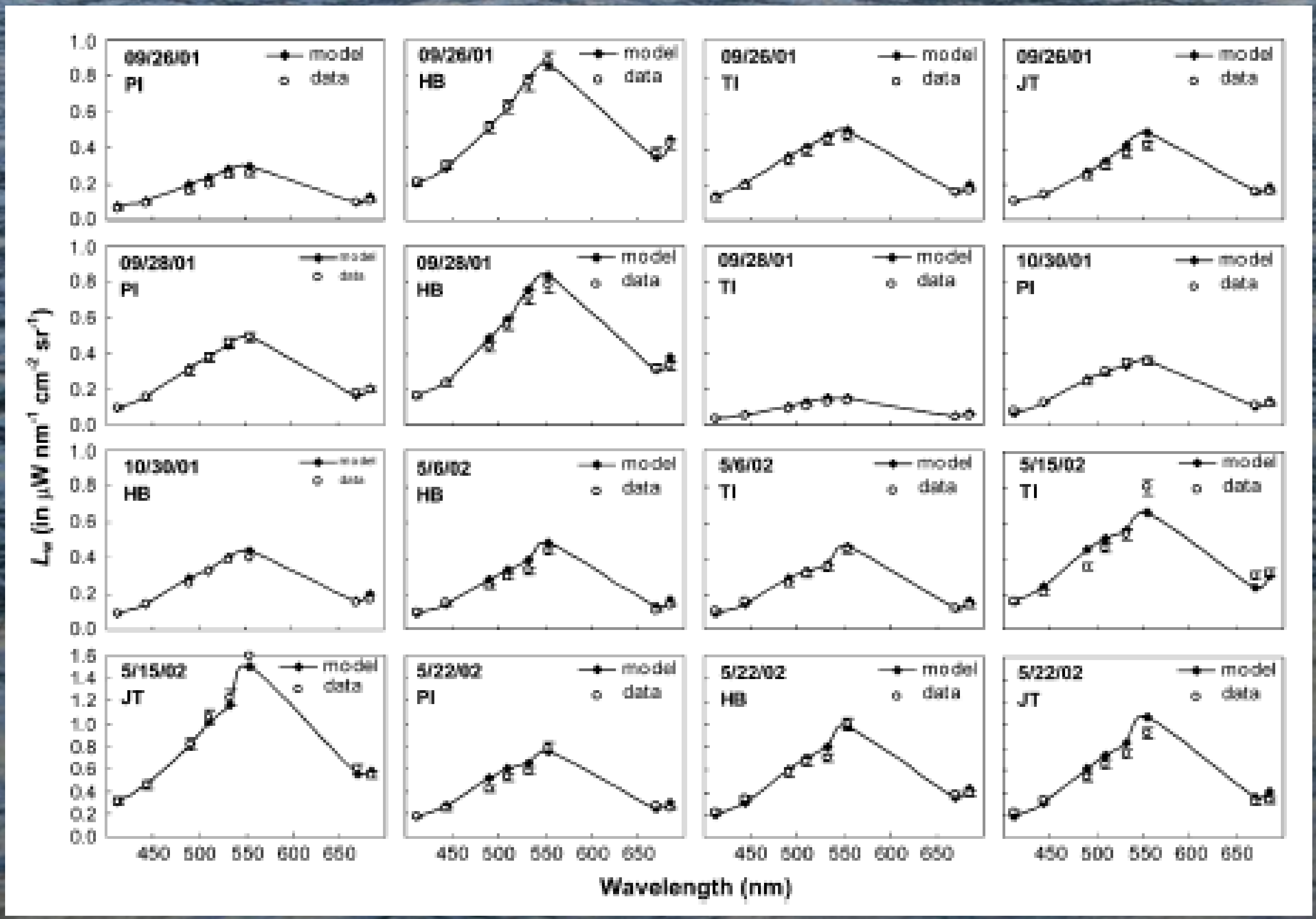


Note that the 3 instruments disagree by about the same amount as the two H simulations (using different guesses for the phase function)

Measured vs HydroLight for Chesapeake Bay

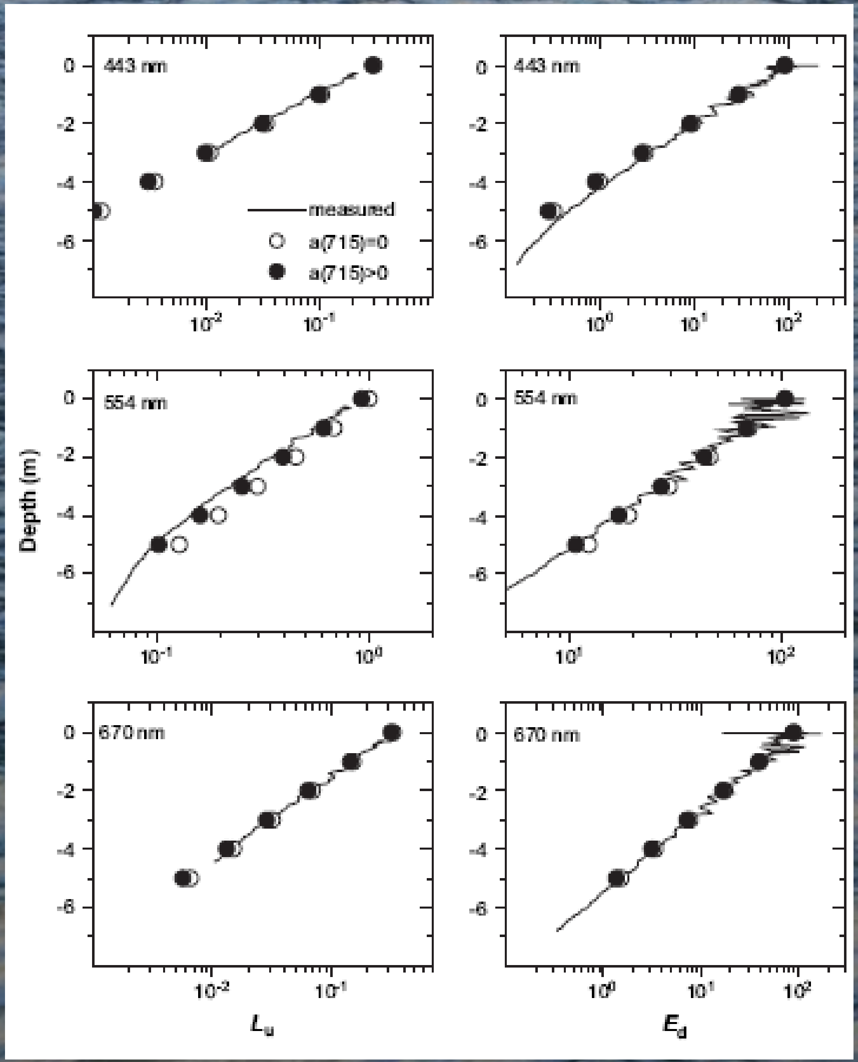
Case 2 water. From Tzortziou et al, Estuarine & Coastal Syst. Sci. (2006). She shows how to "do it right" in taking and processing data, and modeling it with HydroLight. **Read this paper!**

L_w (μW cm^{-2} sr^{-1} nm^{-1})



wavelength (nm)

Measured vs HydroLight for Chesapeake Bay



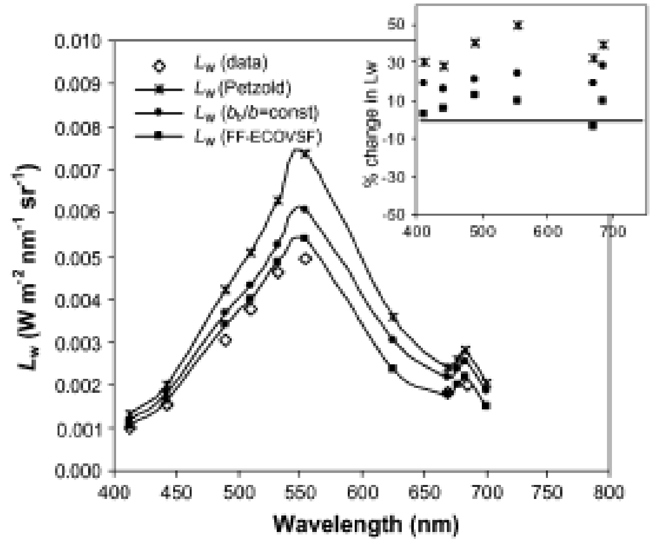


Fig. 3. L_w spectra estimated using: (1) a Petzold "average particle" scattering phase function (stars), (2) an FF scattering phase function with a constant backscattering ratio, $b_b/b = 0.015$ (filled circles); and (2) an FF scattering phase function as determined by measured wavelength- and depth-dependent b_b/b (filled squares). Measured L_w are shown as open diamonds. Percent differences in L_w between measurements and model estimations are shown in the inset figure (percent differences estimated as $(L_{w(model)} - L_{w(data)})/L_{w(data)}$).

other examples from Tzortziou et al. 2001

You Get the Idea

You do the best you can with the data you have. Sometimes very good, sometimes not so good, sometimes completely useless. That's science.

If you didn't measure the VSF, can you get the backscatter fraction from b_b/b? If not, treat b_b/b as a "fitting parameter" and tweak to get the best fit for R_{rs}, for example.

Even if you can't get agreement between measured and modeled E_d and L_u, for example, can you get agreement with L_u/E_d or with K_d?

Compare as many things as possible, e.g., the measured E_d from the HyperPro and from the ship deck cell and with H's default sky irrad model.

The disagreements are often where you learn the most.

Play around with HydroLight. Have fun!

Kayak Camp, Lofoten Islands, Norway, June 2010