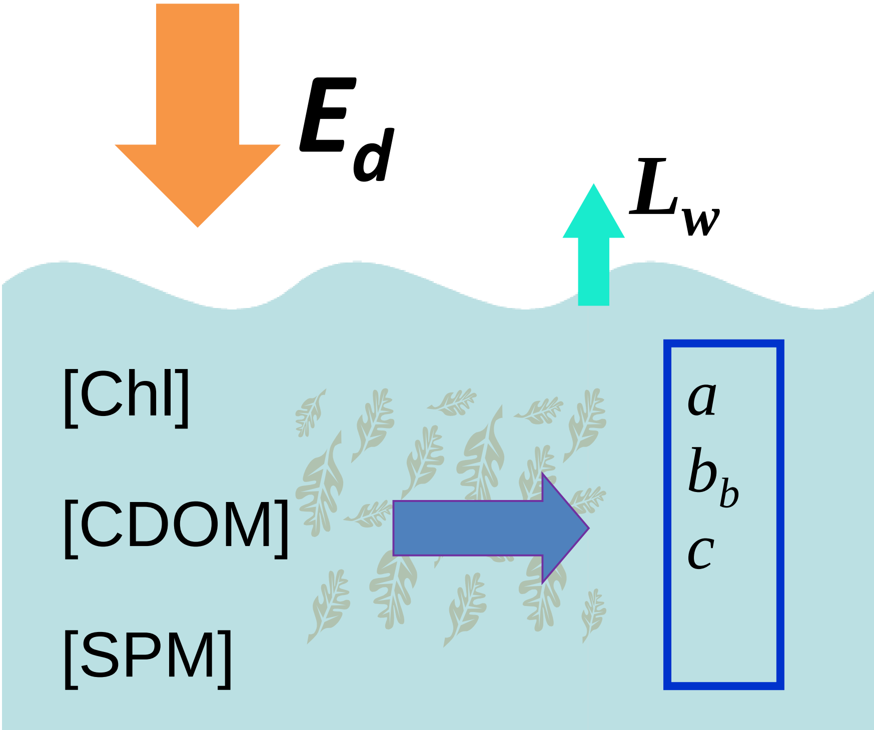
Lecture 5: Measure water-leaving radiance



Remote-sensing reflectance

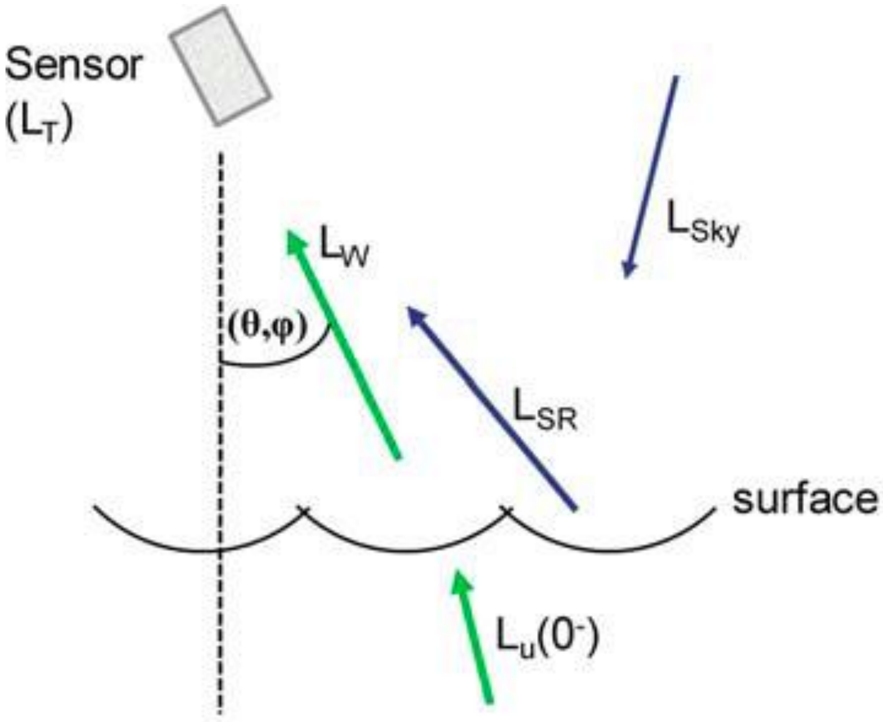
$$R_{rs} = \frac{L_w}{E_d}$$

It is Lw (or Rrs) containing information of in-water constituents!

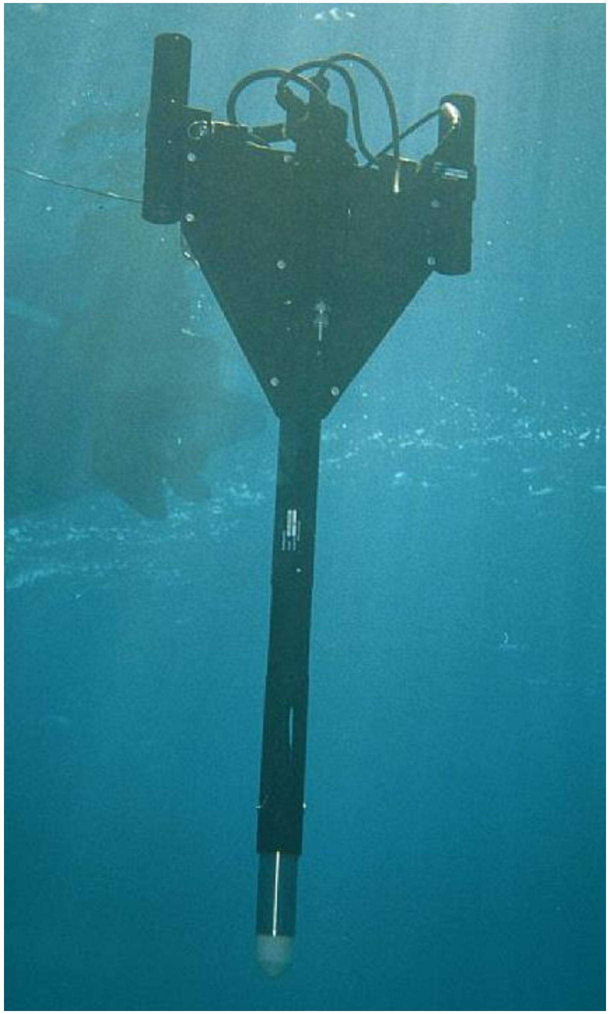
Lw (or Rrs) need to be measured as accurate as possible:

1. **To calibrate/validate satellite product**
2. **To develop inversion algorithms**

Above-water method:



In-water method:

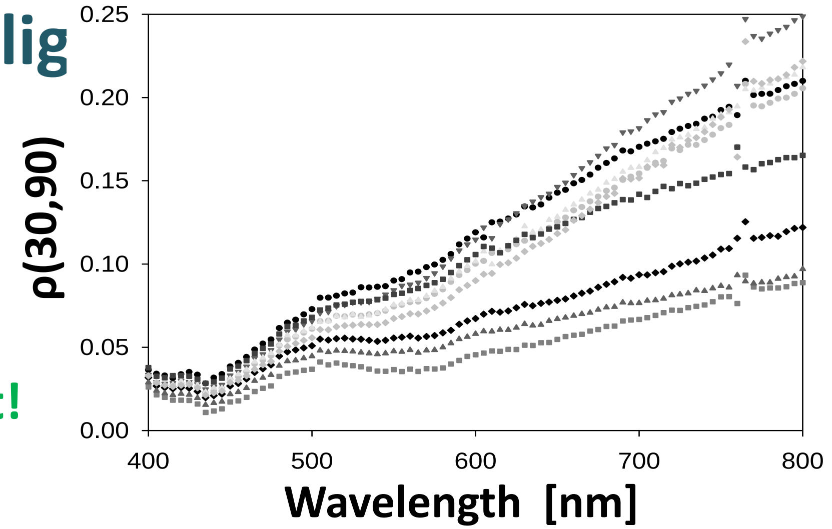


Main issue of above-water method:

Correcting surface-reflected lig

$$L_w(\lambda) = L_T(\lambda) - \rho L_{Sky}(\lambda)$$

ρ depends on wavelength and measurement!



(Lee et al 2010)

Main issue of in-water method:

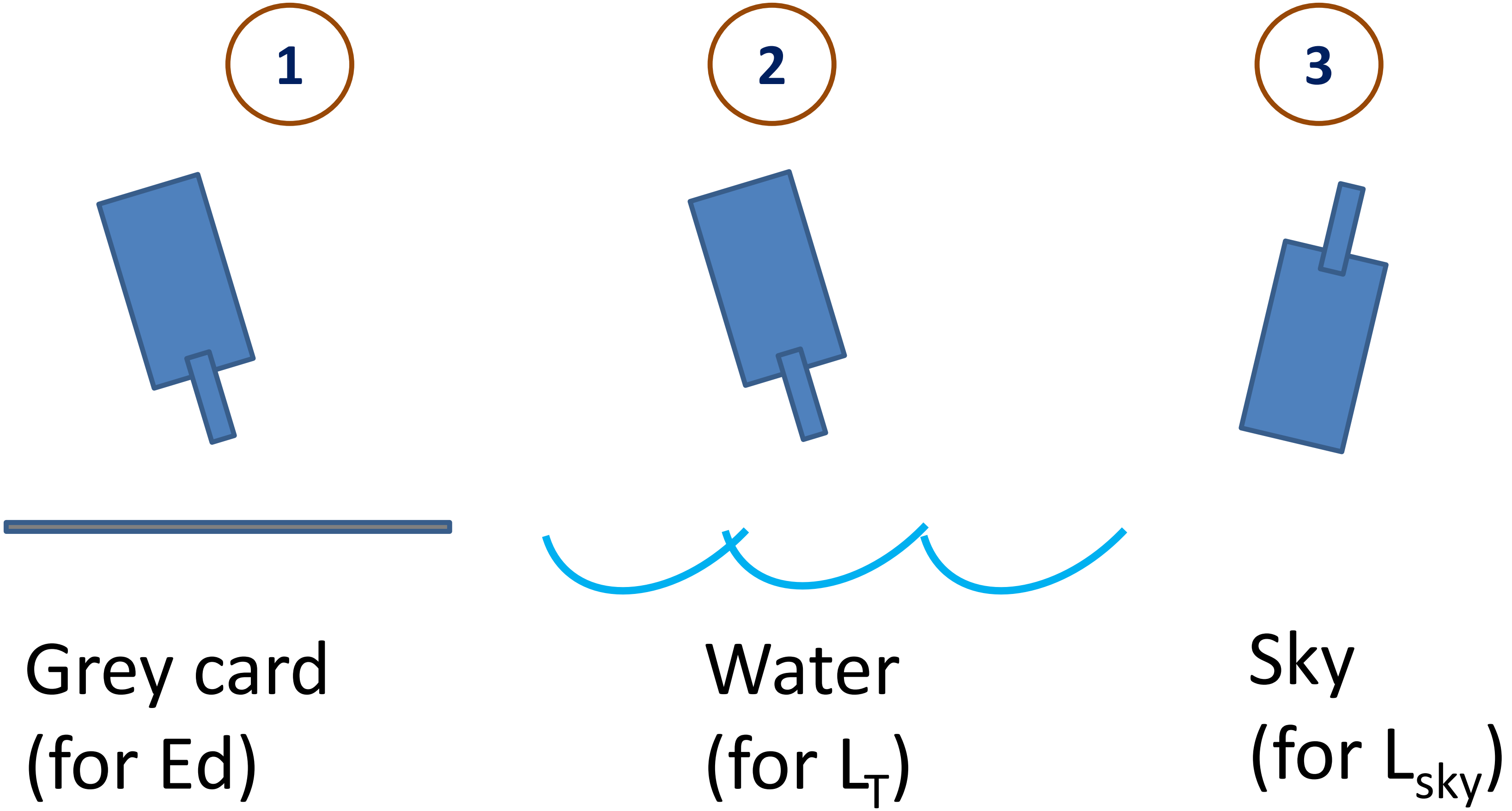
Propagating through the water-column and interface

$$L_w(\lambda) = \frac{t}{n^2} L_u(\lambda, z) e^{K_{Lu}(\lambda) z}$$

Both methods involve substantial data manipulations.

None of them *directly* measures water-leaving radiance!

Measurement sequence of above-water method:



Relationship of primary properties:

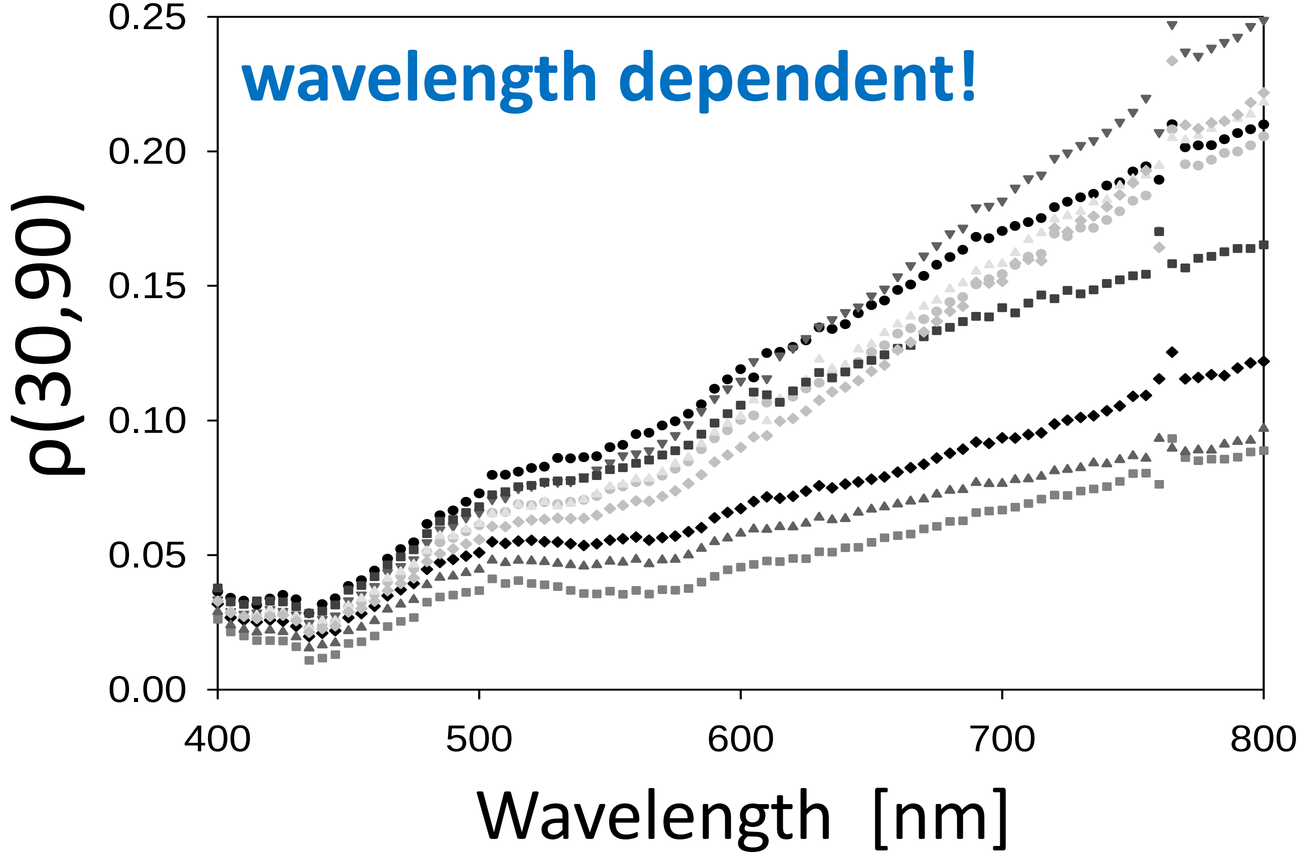
$$T_{rs} = \frac{L_T}{E_d} \qquad S_{rs} = \frac{L_{Sky}}{E_d}$$

$$R_{rs}(\lambda,\theta,\varphi) = T_{rs}(\lambda,\theta,\varphi) - \rho(\theta,\varphi)\,S_{rs}(\lambda,\theta',\varphi).$$

From Hydrolight simulation:

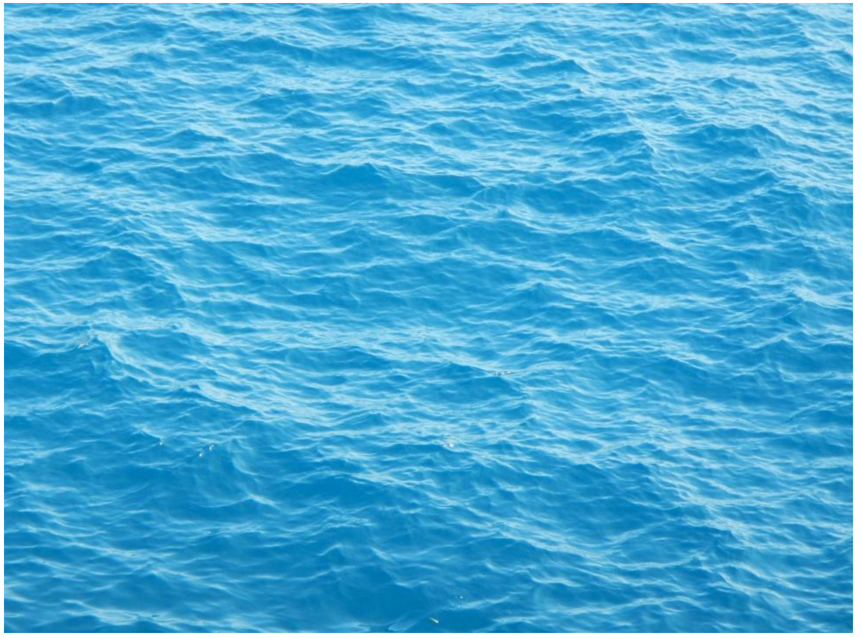
$$\rho(40{,}135) \approx 0.028$$

(Mobley 1999 Appl Opt)



(Lee et al 2010 Opt Express)

Why they differ so much?!

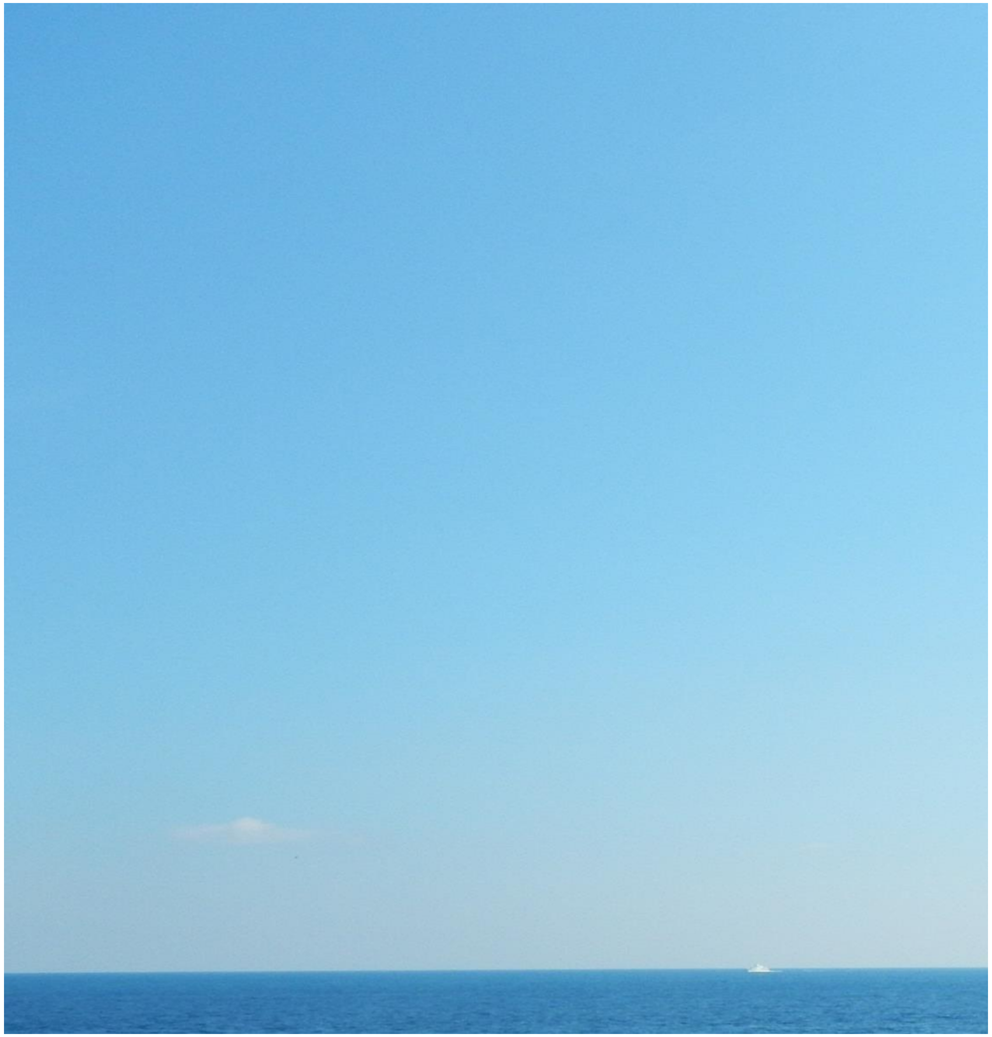


In the real world, if the sensor has a large FOV and integrates over a few seconds,

$$L_T(\lambda,\theta,\varphi) = L_W(\lambda,\theta,\varphi) + \sum_i w_i\ F(\theta_i',\varphi_i',\theta,\varphi)\ L_{Sky}(\lambda,\theta_i',\varphi_i').$$

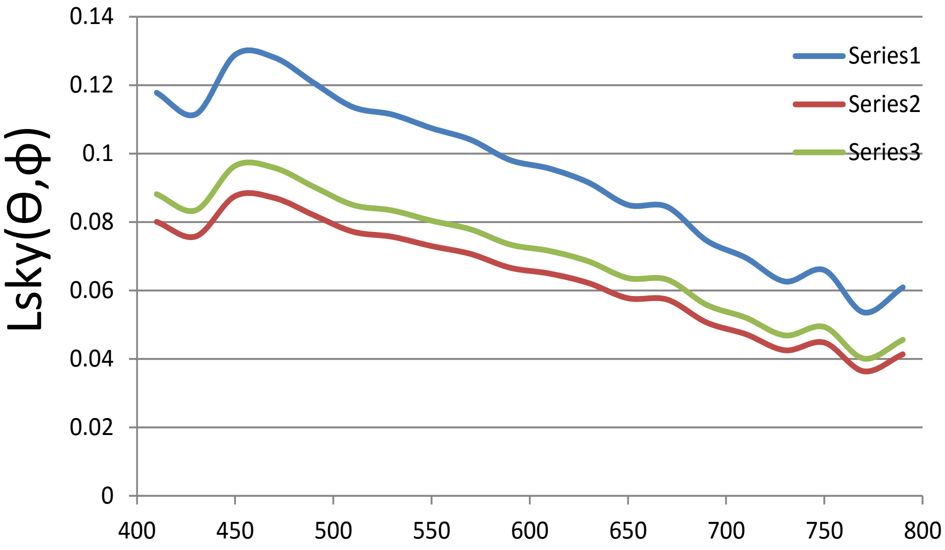
$$L_T(\lambda,\theta,\phi) = L_W(\lambda,\theta,\phi) + \rho(\theta,\phi)\,L_{Sky}(\lambda,\theta',\phi)$$

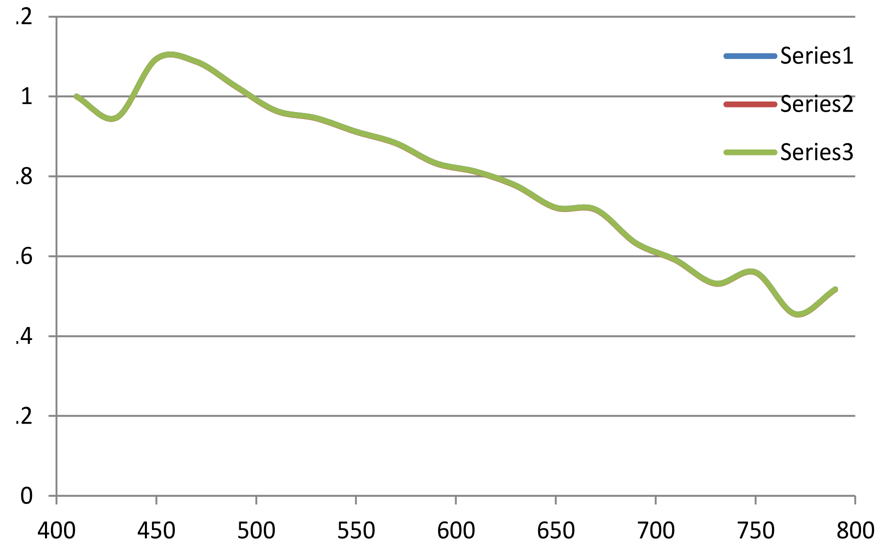
$$\rho(\theta,\phi) = \sum w_i\, F(\theta_i',\varphi_i',\theta,\varphi)\,\frac{L_{sky}(\lambda,\theta_i',\varphi_i')}{L_{Sky}(\lambda,\theta',\phi)}$$



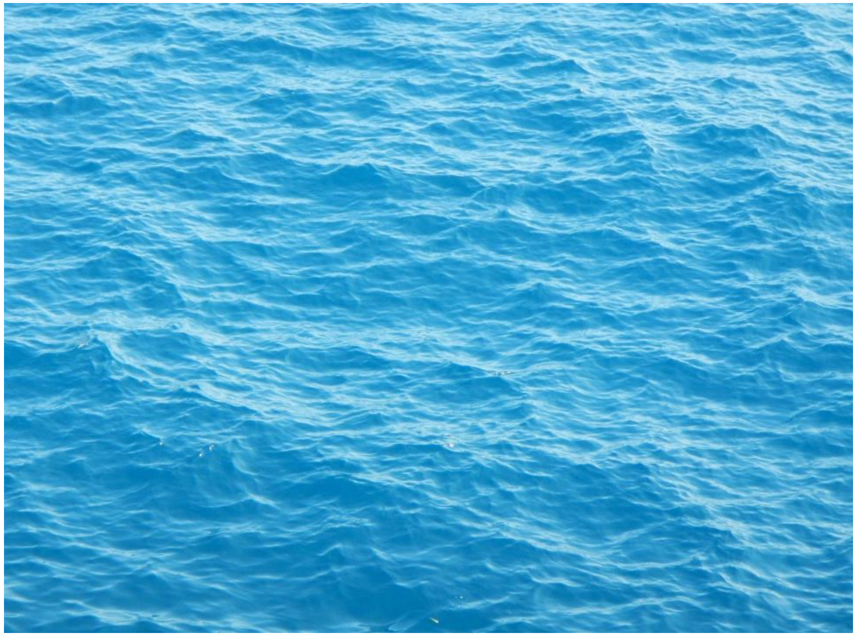
ρ will be wavelength dependent!

‘secrets’ of Hydrolight





$$L_{sky}(\lambda,\theta,\phi)=\varepsilon(\theta,\phi)\,E_{dsky}(\lambda,\theta,\phi)$$

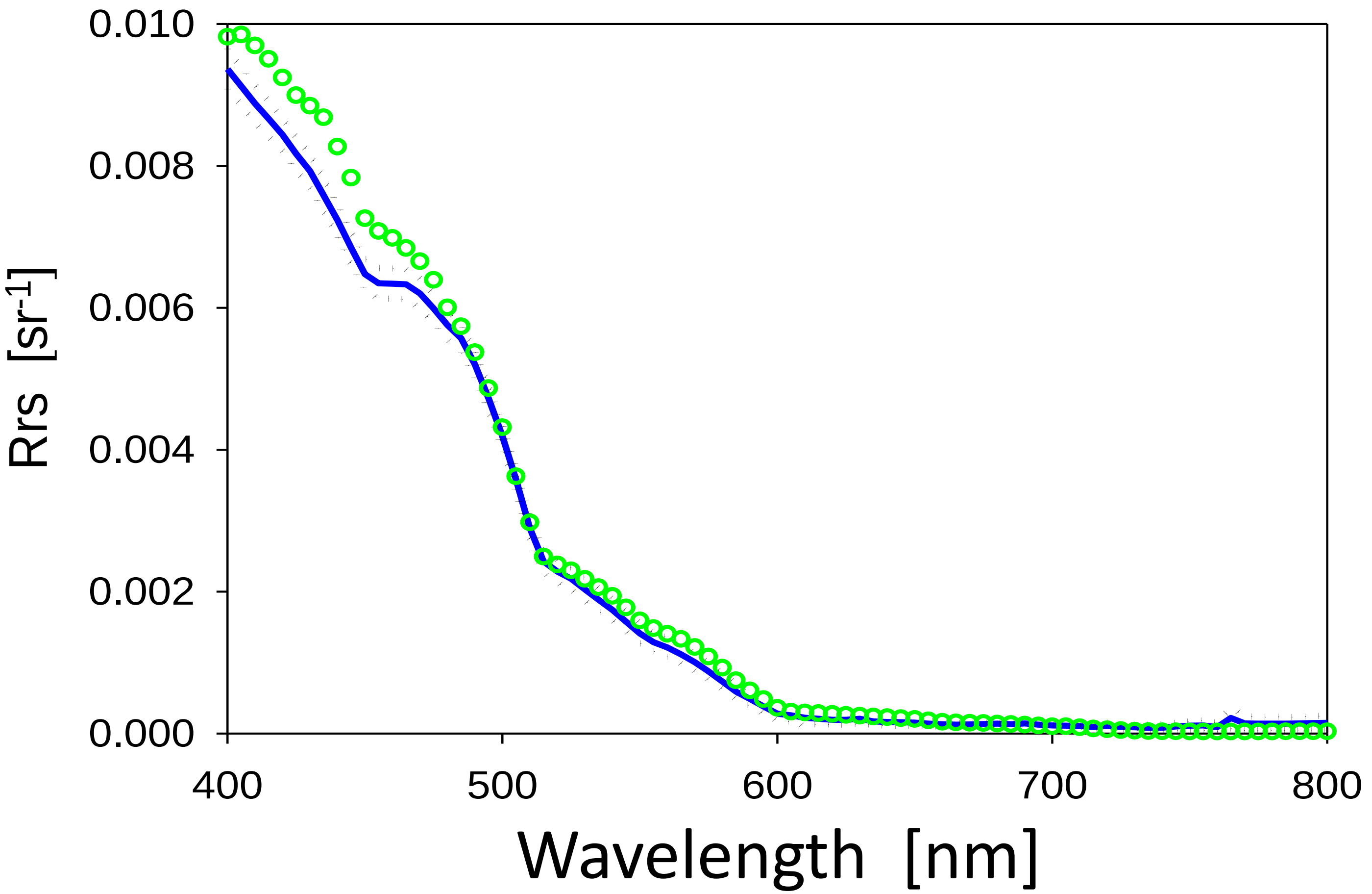


$$L_T(\lambda,\theta,\varphi) = L_W(\lambda,\theta,\varphi) + w_0\, F(\theta,\varphi)\, L_{Sky}(\lambda,\theta',\varphi) + \sum_{i-1} w_i\, F(\theta_i{}',\varphi_i{}',\theta,\varphi)\, L_{Sky}(\lambda,\theta_i{}',\varphi_i{}').$$

$$T_{rs}(\lambda,\theta,\varphi) \approx R_{rs}(\lambda,\theta,\varphi) + F(\theta,\varphi)\, S_{rs}(\lambda,\theta',\varphi) + \sum_{i-1} w_i\, F(\theta_i{}',\varphi_i{}',\theta,\varphi)\, S_{rs}(\lambda,\theta_i{}',\varphi_i{}').$$

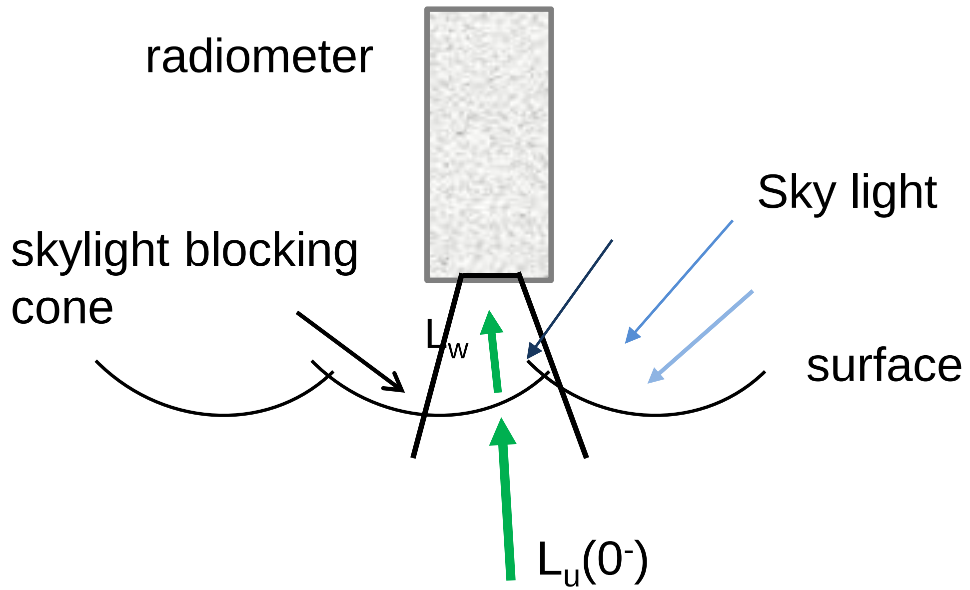
$$T_{rs}(\lambda,\theta,\varphi) \approx R_{rs}(\lambda,\theta,\varphi) + F(\theta,\varphi)\, S_{rs}(\lambda,\theta',\varphi) + \Delta(\theta,\varphi),$$

Using an Rrs model for helping the derivation of Δ. Example of results:



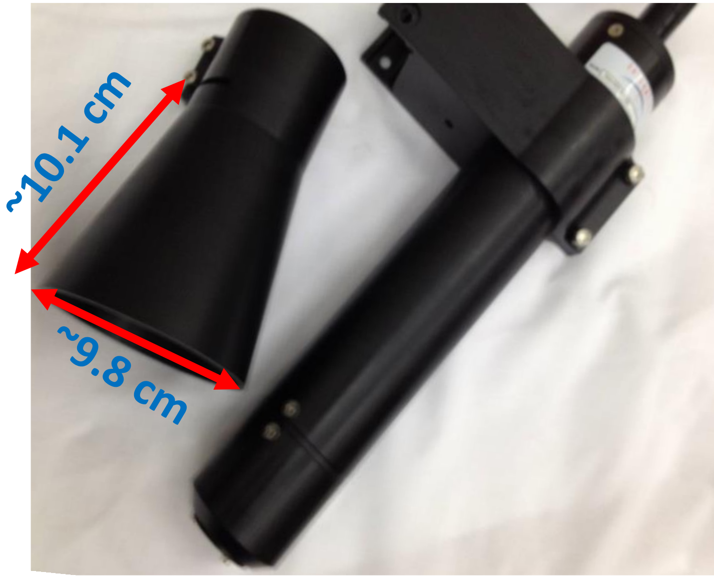
(Lee et al 2010 Opt Express)

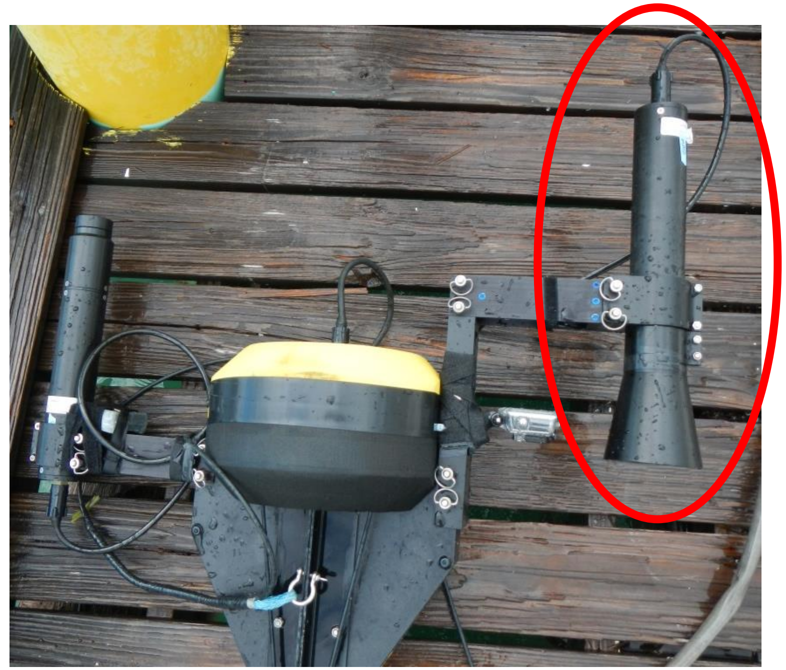
An approach to *directly* MERASURE Lw

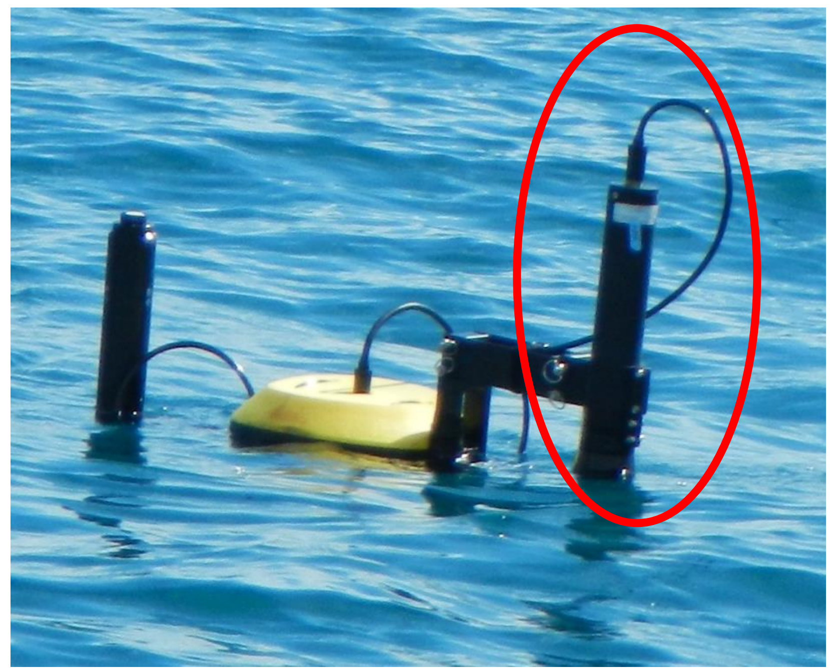


Skylight Blocked Approach (SBA)

(Ahn et al. 1999, Tanaka et al. 2006, Lee et al. 2013)

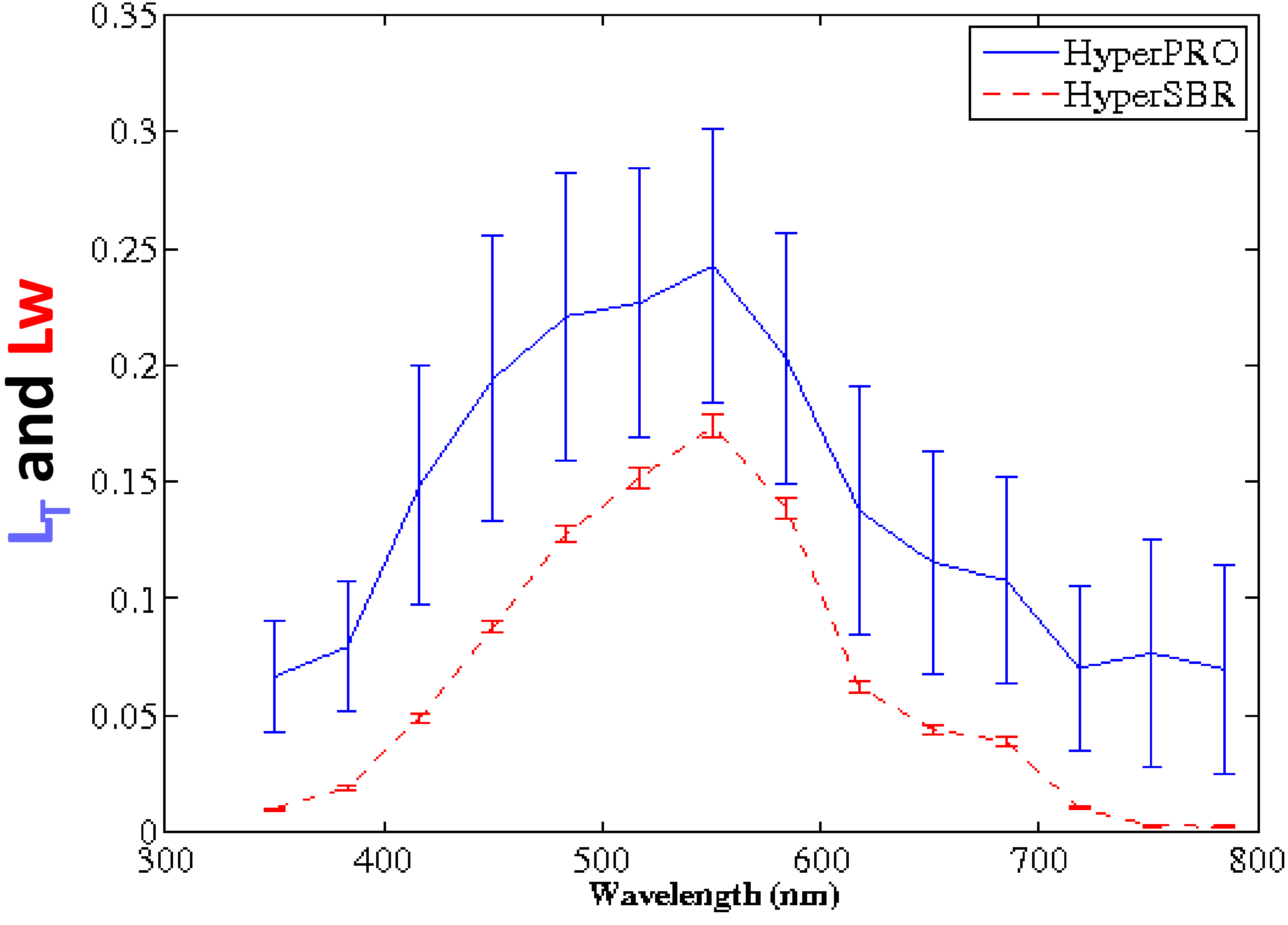

~10.1 cm
~9.8 cm



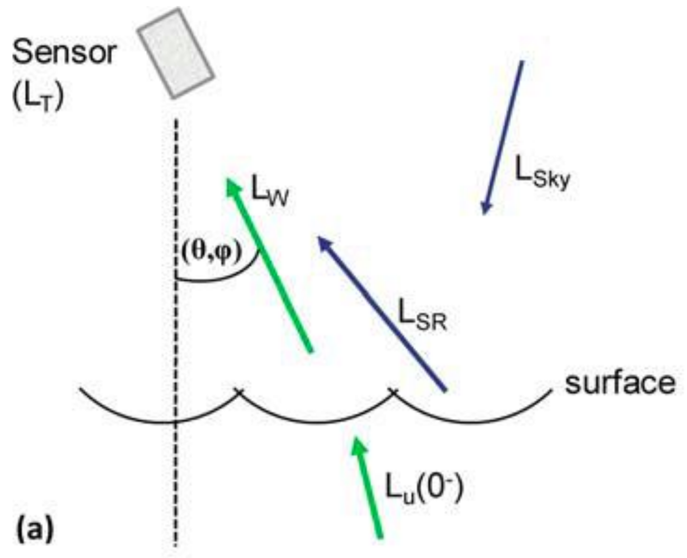


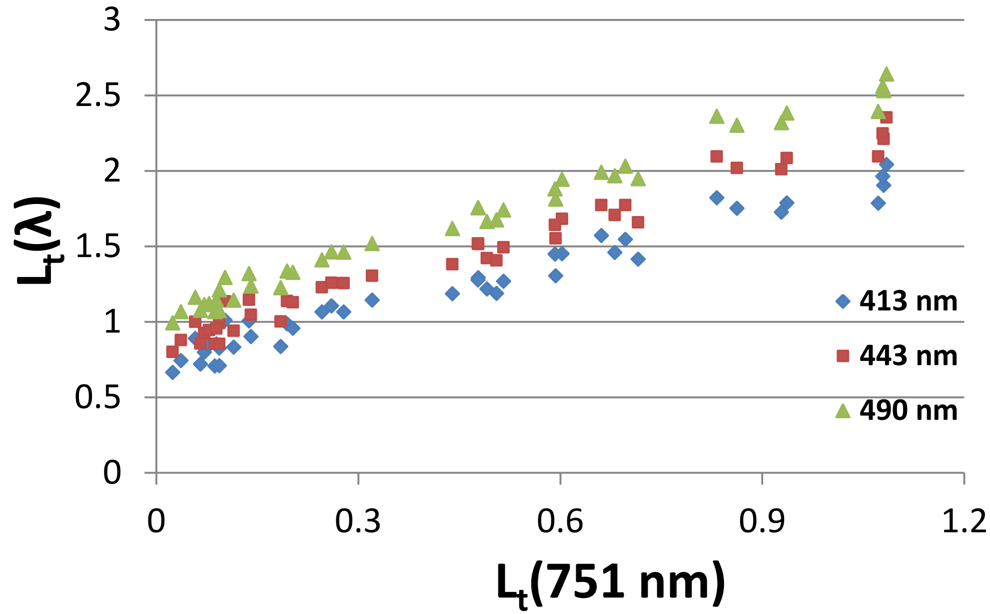
Sample result

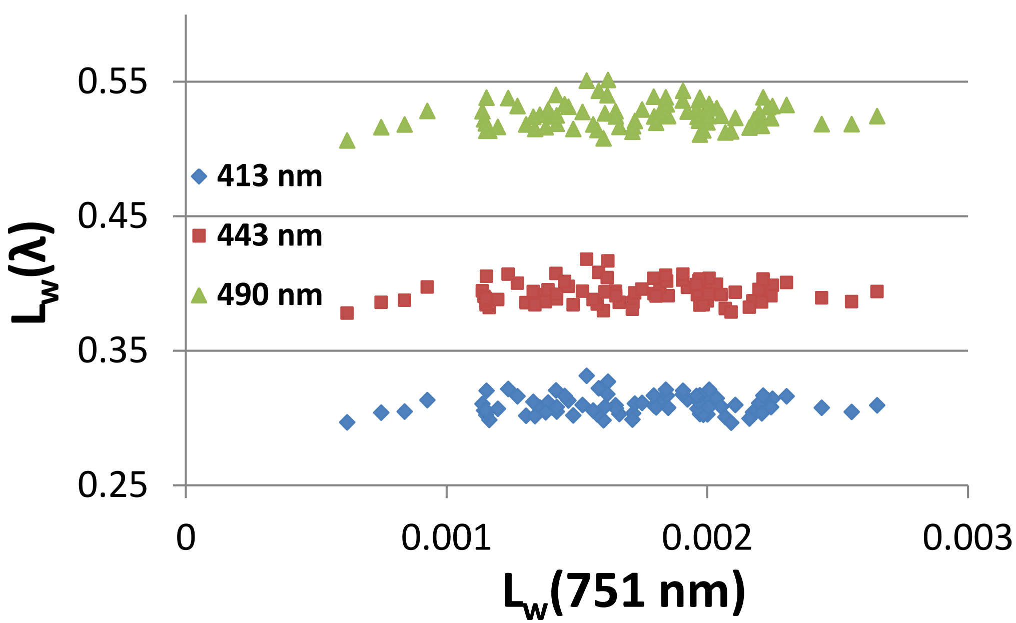
(~10 Knots wind!)



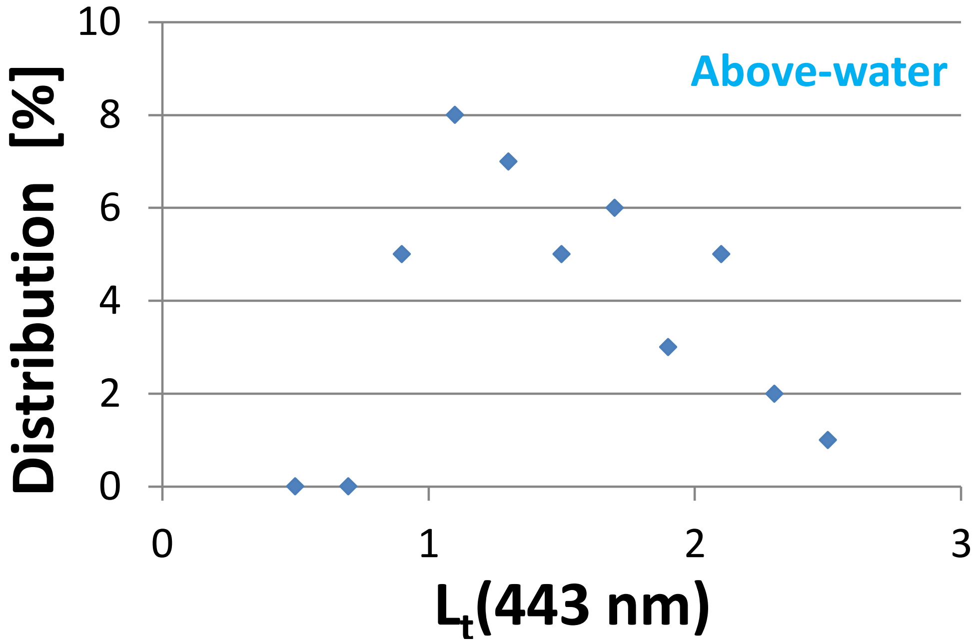
Comparison between above-water method and SBA method





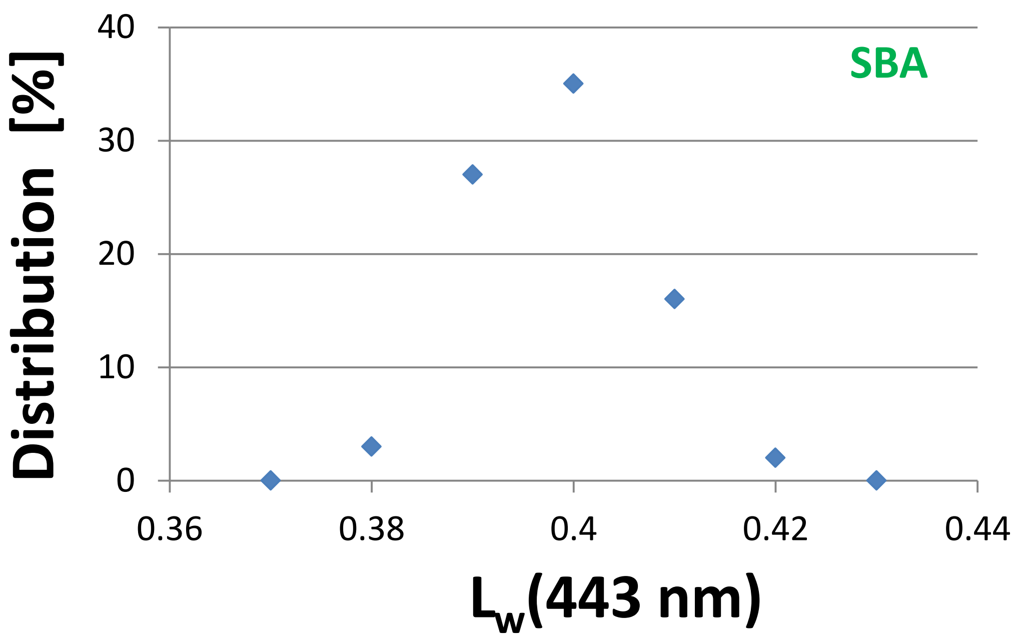


Comparison between above-water method and SBA method



CV = STD/MEAN = 32%

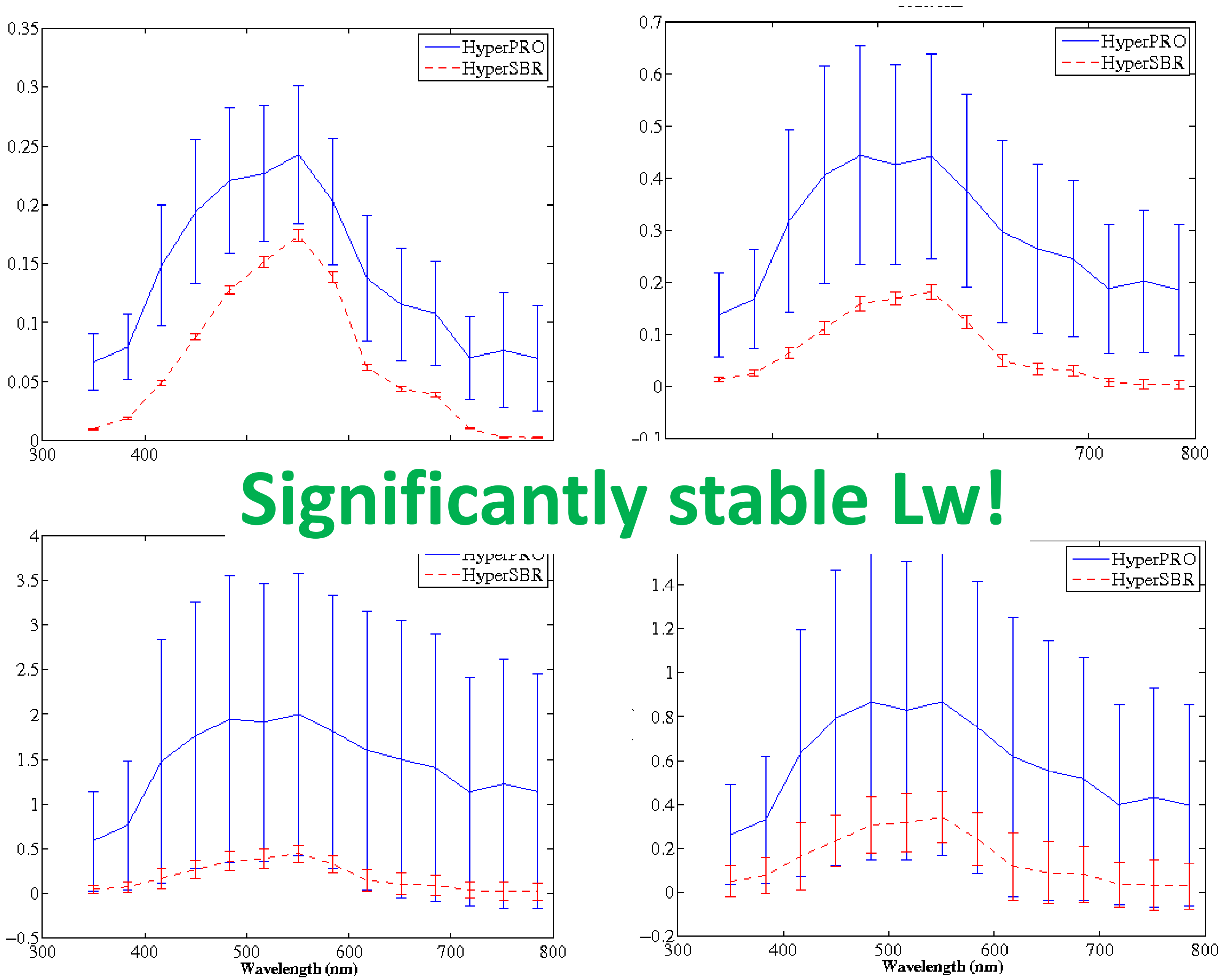
All these deviations will be propagated to Rrs!



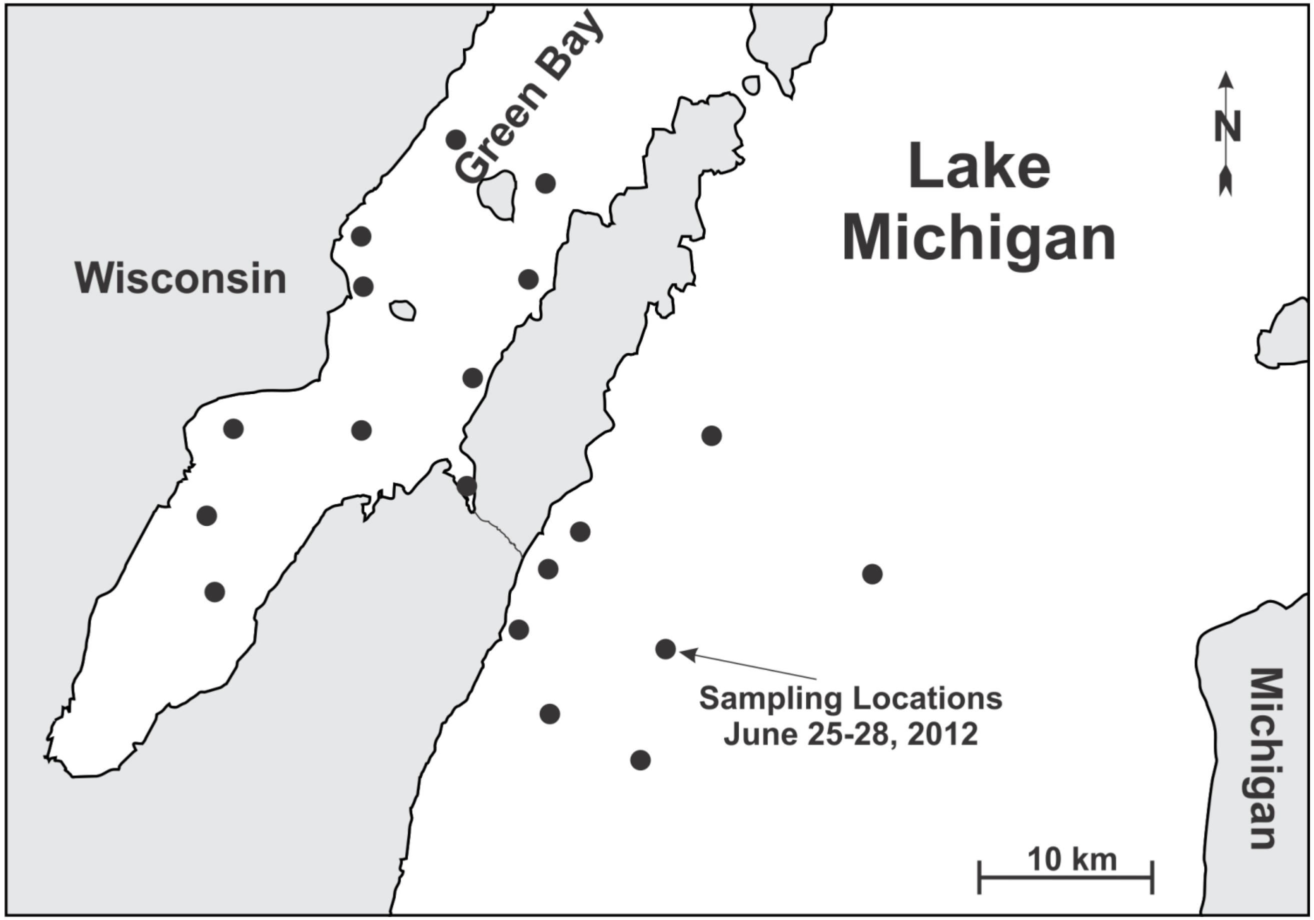
CV = STD/MEAN = 2.1%

More examples to demonstrate the stability of Lw under various windy conditions!

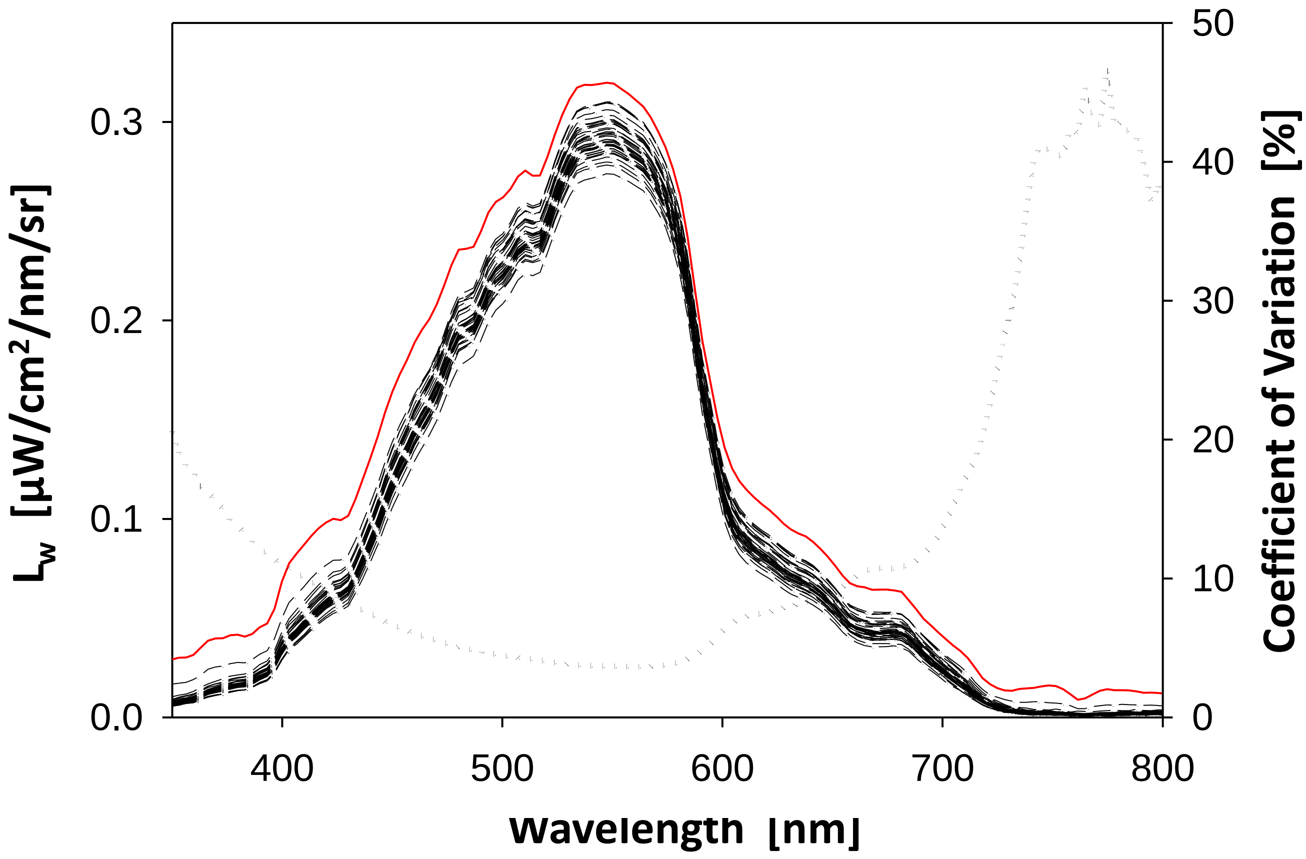
L_T vs Lw



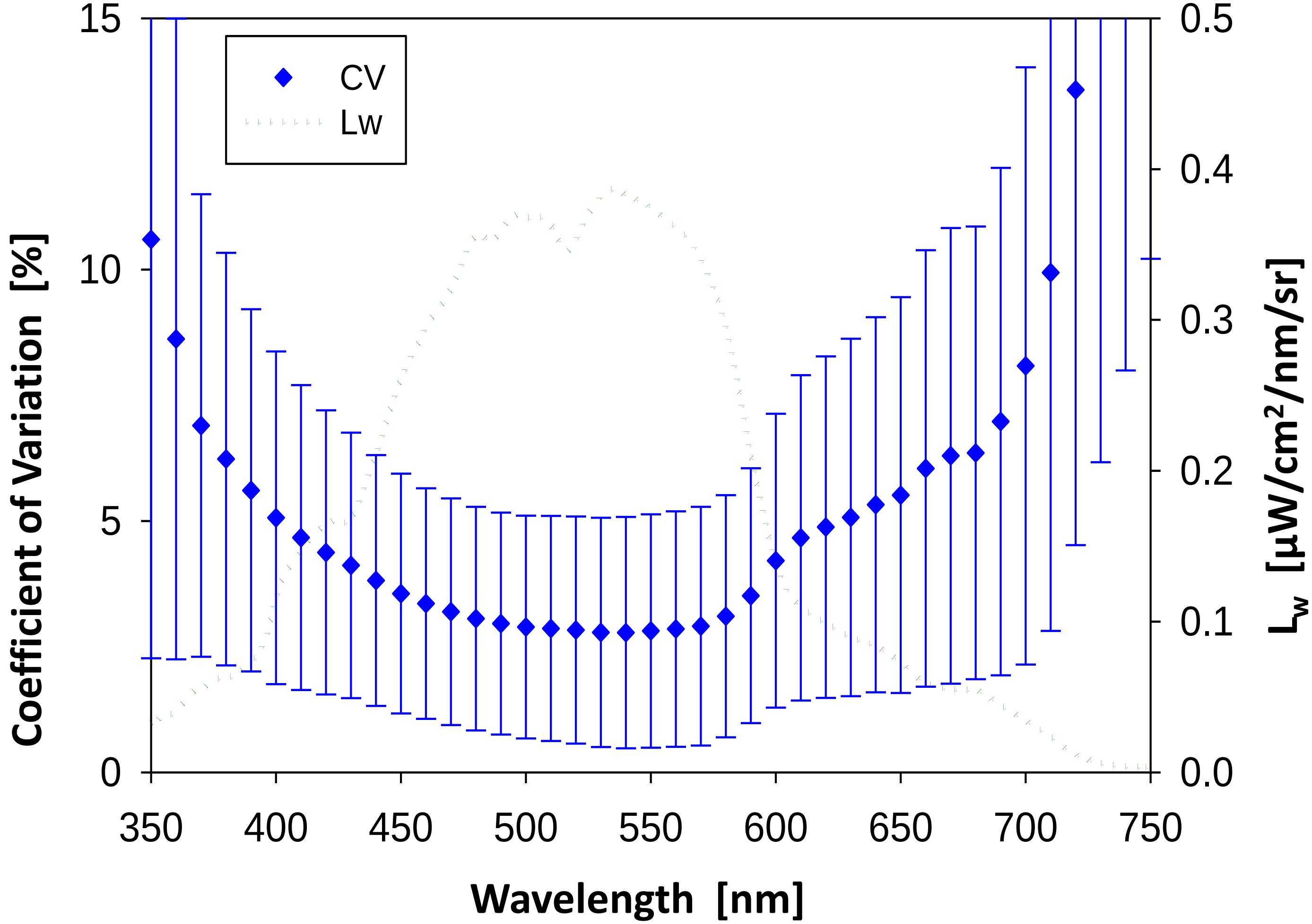
Significantly stable Lw!



Green Bay
Lake Michigan
N
Wisconsin
Sampling Locations June 25-28, 2012
Michigan
10 km



0.3
0.2
0.1
0.0
L_w [µW/cm²/nm/sr]
400
500
600
700
800
Wavelength [nm]
50
40
30
20
10
0
Coefficient of Variation [%]


CV
Lw
Coefficient of Variation [%]
L_w [μW/cm²/nm/sr]
Wavelength [nm]
0
5
10
15
0.0
0.1
0.2
0.3
0.4
0.5
350
400
450
500
550
600
650
700
750

Conclusions:

1. Mobley (1999) formula over-simplified the correction of surface reflected light.

2. SBA system provides a <u>direct</u> measurement of Lw!

3. Because of the significantly reduced requirement of post-measurement data processing, Lw from an SBA system is stable and highly precise.

4. SBA system is especially useful for complicated environment: e.g., stratified water, shallow bottoms, or seagrass/kelp beds, etc.