



RAMSES Workshop, Limnolog. Station Iffeldorf, 4.5.2011

Ursachen der Variabilität der einfallenden Strahlung unter Wasser

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Motivation

Campaigns

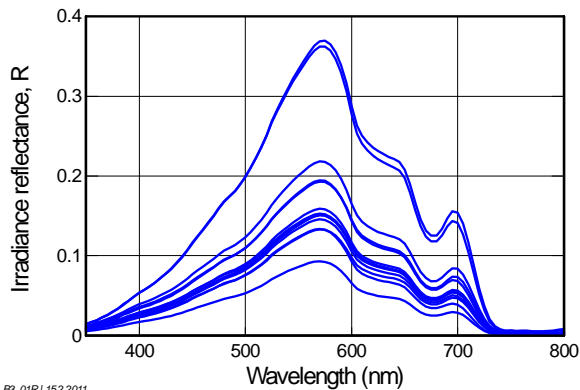
Small boat in shallow areas of 3 German lakes
421 data sets, 4375 spectra at 0–5 m depth

Observation

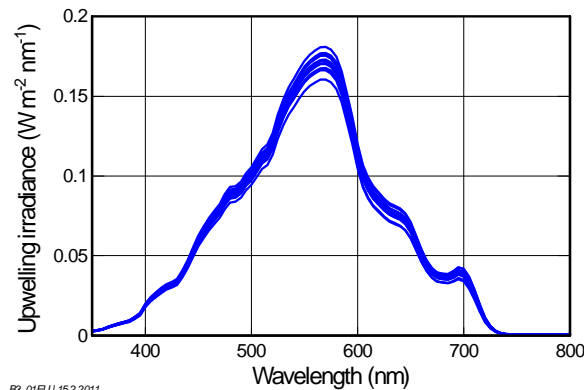
Reflectance spectra (in shallow water) can vary strongly in magnitude and spectral shape – **why?**



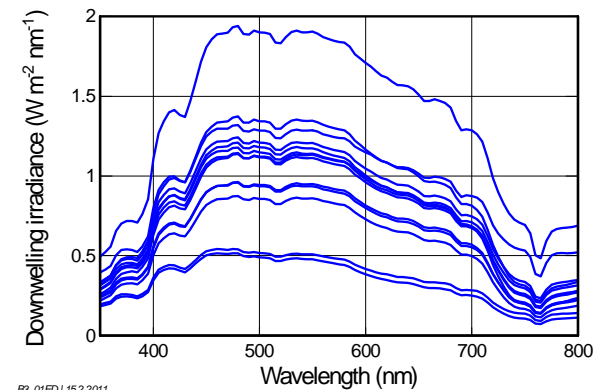
Bodensee 26.6.2004, 12:20
Bottom type: sediment
Water depth: 1.40 m
Sensor depth: 0.28 m
13 measurements within 65 s



B3_01R| 15.2.2011



B3_01EU| 15.2.2011



B3_01ED| 15.2.2011

Due to variability of downwelling irradiance



Ursachen der Variabilität von E_d im Wasser

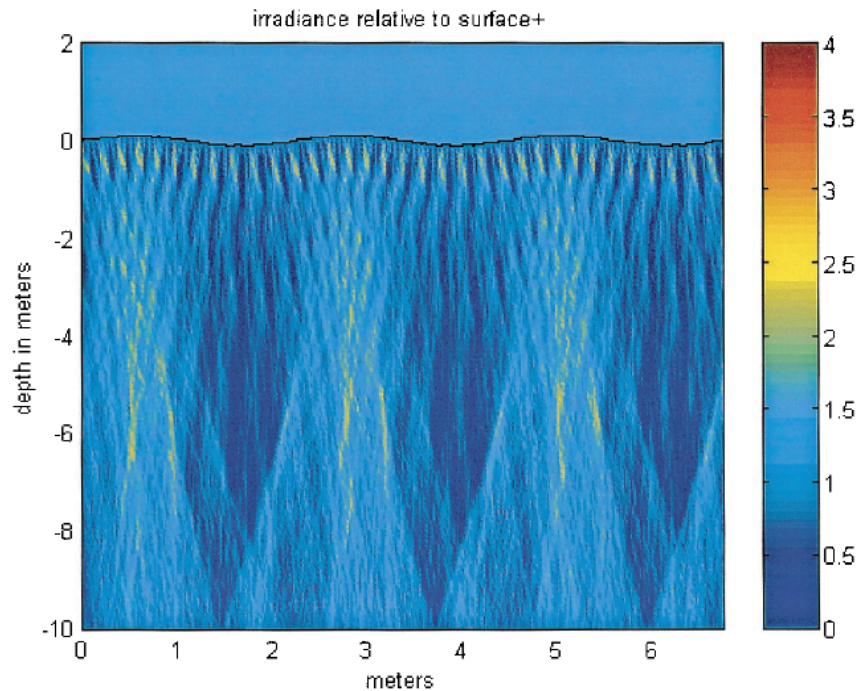


Fig. 6. Irradiance pattern beneath a superposition of sinusoidal waves with wavelengths of 2.25, 0.2, and 0.05 m and with amplitudes of 0.1, 0.01, and 0.002 m. Note that the addition of very small amplitude waves significantly alters the irradiance pattern.

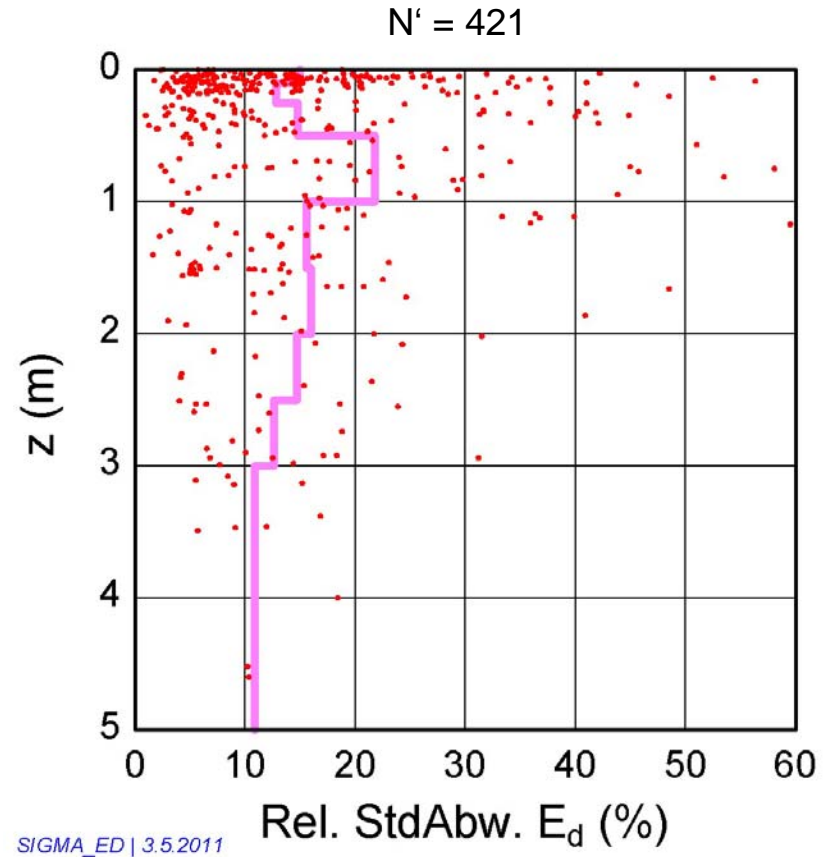
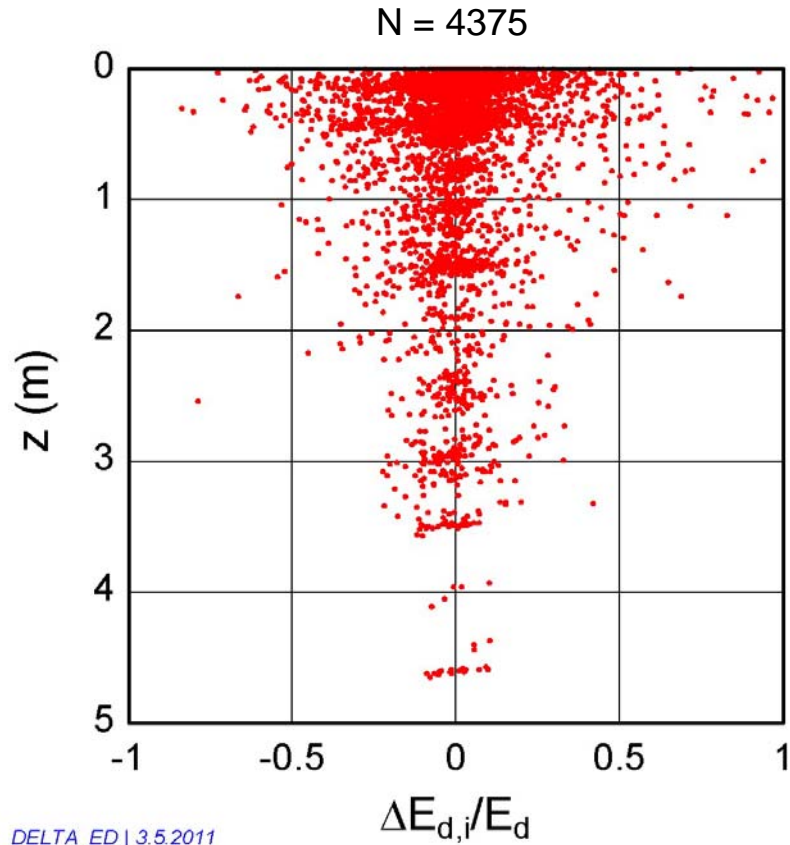
Zanefeld et al. (2001): Influence of surface waves on measured and modeled irradiance profiles. *Applied Optics* **40**, 1442-1449.

[Very complete book on the topic:](#)

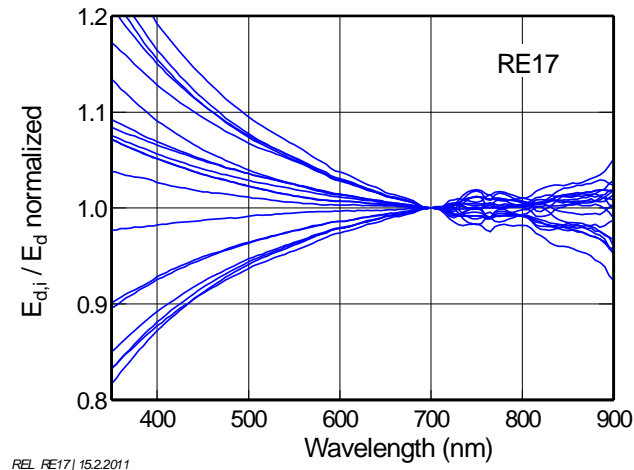
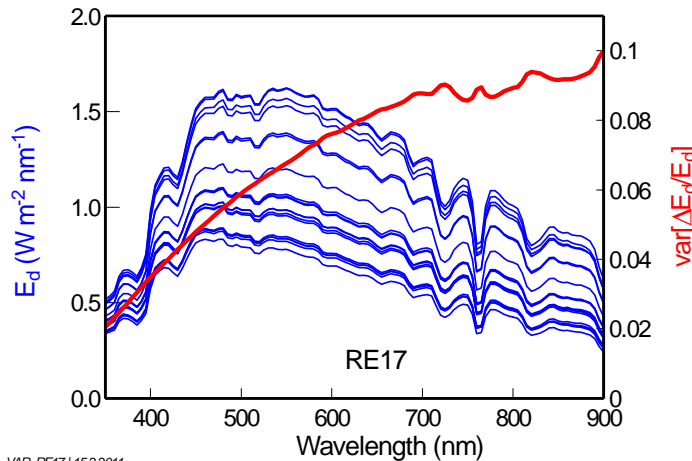
R. E. Walker, *Marine Light Field Statistics* (Wiley, 1994)

- Wave focusing induces large fluctuations
- Statistics is well known
- **Wavelength dependency?**
- **Other sources of variability?**

Intensity changes of E_d during a measurement



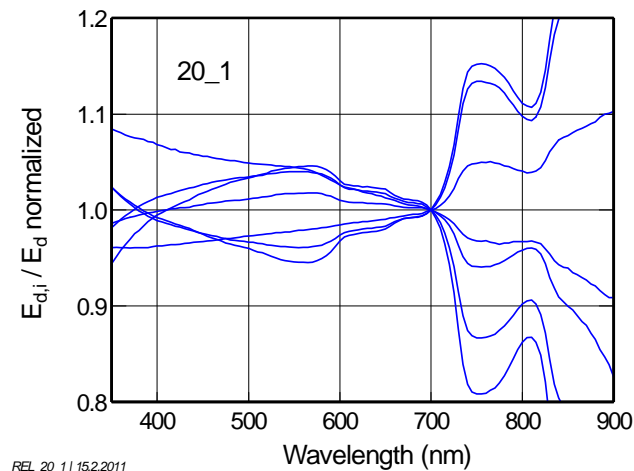
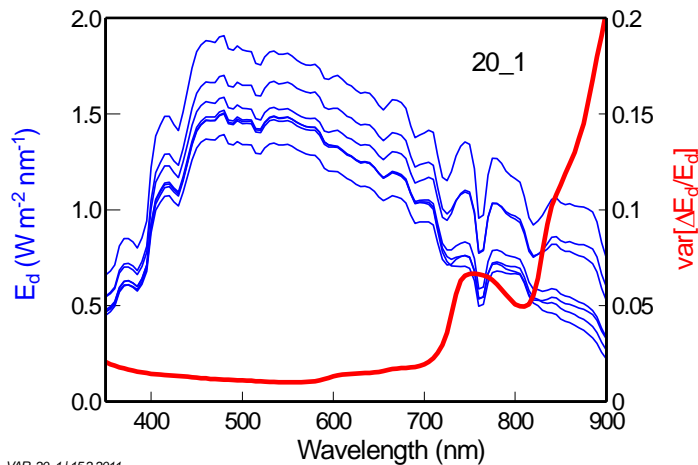
Wavelength dependency of E_d variability (Type 1)



- Smooth spectral shape across VIS
 - no spectral fine structures from E_d
 - power law
- Relevance in our data set
 - γ_{VIS} average = 5.4 %
 - little depth dependency

$$\gamma_{VIS,i} = \frac{E_{d,i}(400)}{E_d(400)} - \frac{E_{d,i}(700)}{E_d(700)}$$

Wavelength dependency of E_d variability (Type 2)



- Characteristic feature in NIR
 - dominated by water absorption
- Relevance in our data set
 - 0–1 m: γ_{NIR} average = 5.7 %
 - > 1 m: γ_{NIR} average = 3.7 %

$$\gamma_{\text{NIR},i} = \frac{E_{d,i}(755)}{E_d(755)} - \frac{E_{d,i}(700)}{E_d(700)}$$

Irradiance model

Irradiance is sum of a direct and a diffuse component

$$E_d(\lambda, z) = f_{dd} E_{dd}(\lambda, z) + f_{ds} E_{ds}(\lambda, z)$$

E_d : downwelling irradiance

E_{dd} , E_{ds} : direct / diffuse component of E_d

f_{dd} , f_{ds} : actual fraction of E_{dd} , E_{ds}

Wave focusing changes f_{dd} and f_{ds}

Depth dependency of each component according to Lambert-Beer law

$$E_{dd}(\lambda, z) = E_{dd}(\lambda, 0-) \exp\{-[a(\lambda) + b_b(\lambda)]z / \cos\theta_{\text{sun},w}\}$$

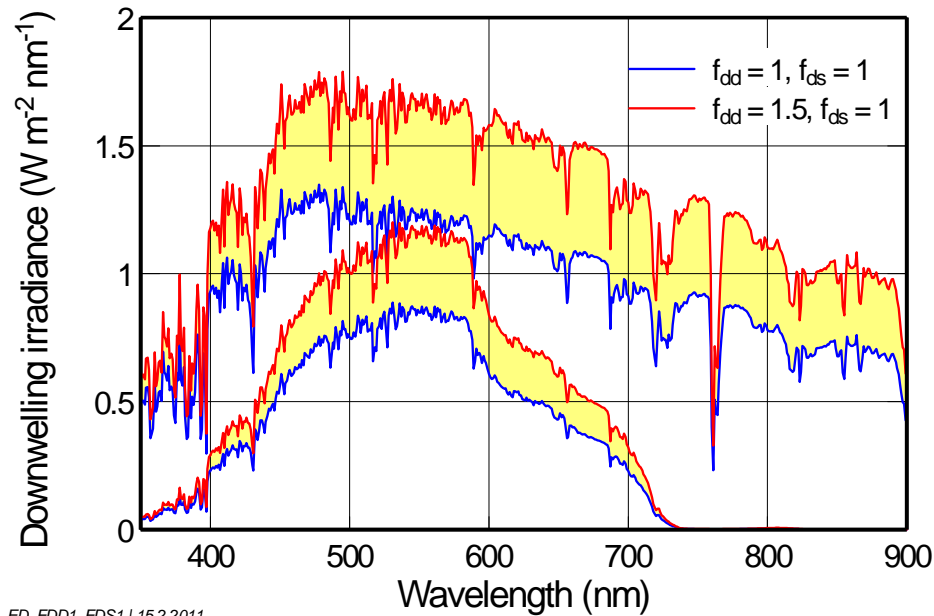
$$E_{ds}(\lambda, z) = E_{ds}(\lambda, 0-) \exp\{-[a(\lambda) + b_b(\lambda)]z l_{ds}\}$$

l_{ds} : average path length of diffuse radiation.

z : water column thickness above sensor.

Waves alter z .

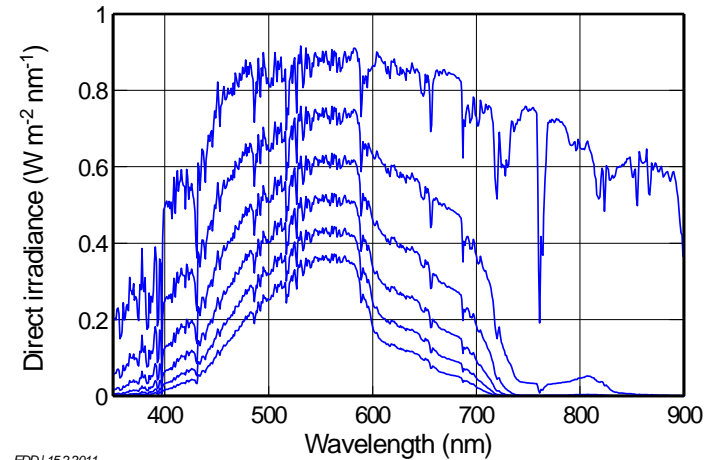
Illustration of irradiance model



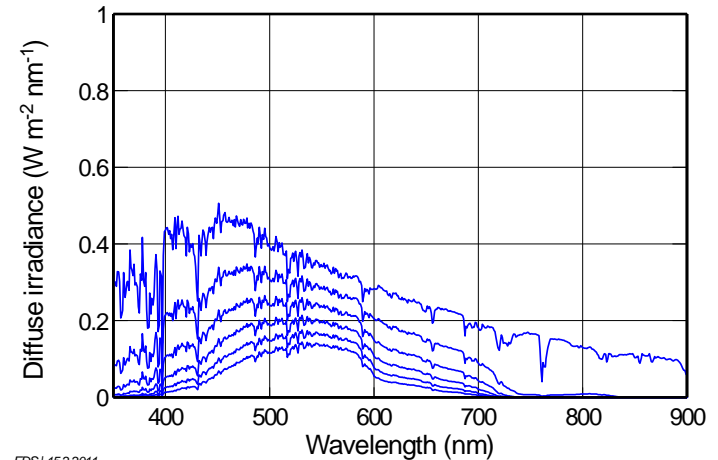
ED_FDD1_FDS1 | 15.2.2011

$$E_d(\lambda, z) = f_{dd} E_{dd}(\lambda, z) + f_{ds} E_{ds}(\lambda, z)$$

Depth dependency: $z = 0.5 m$



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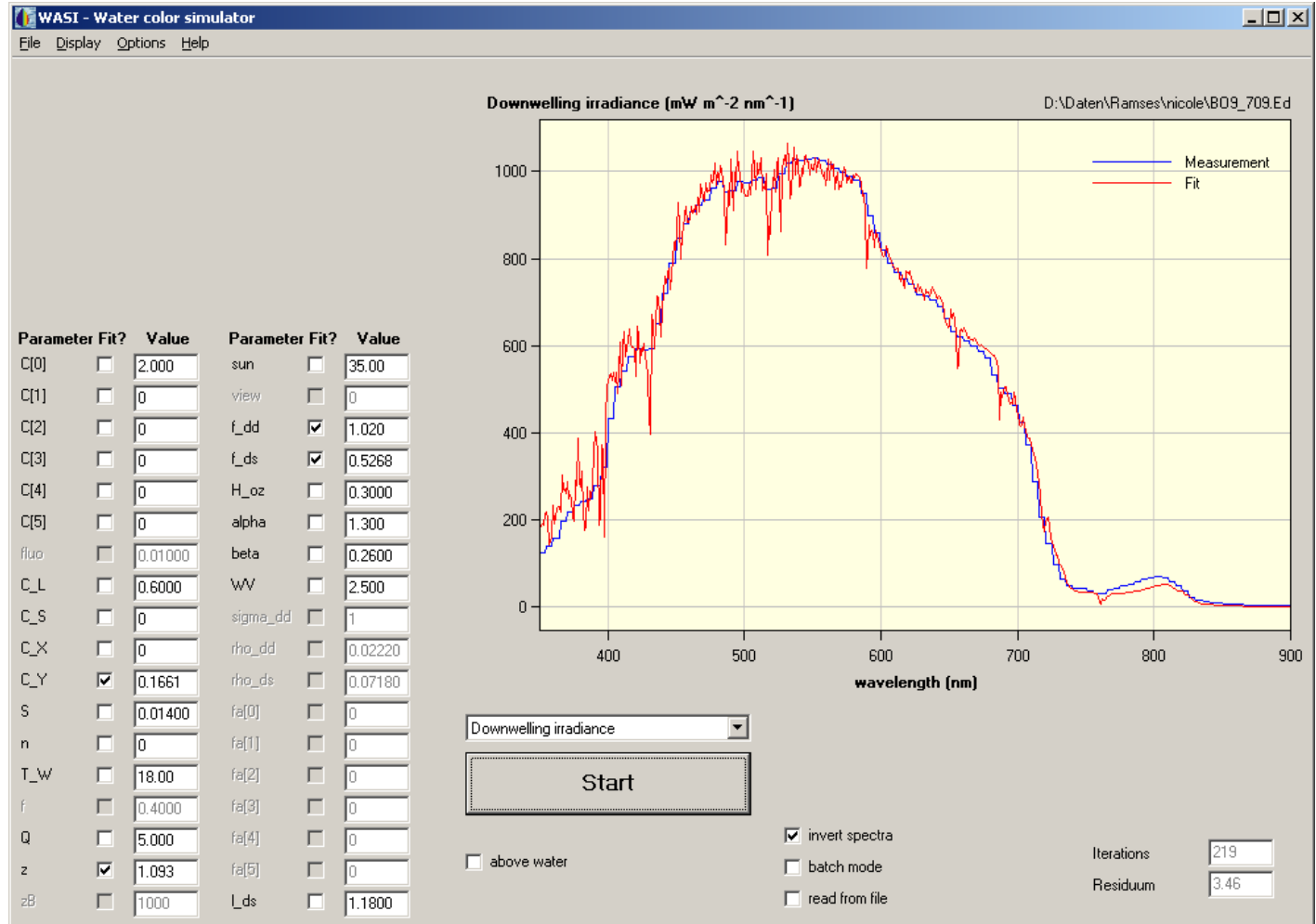


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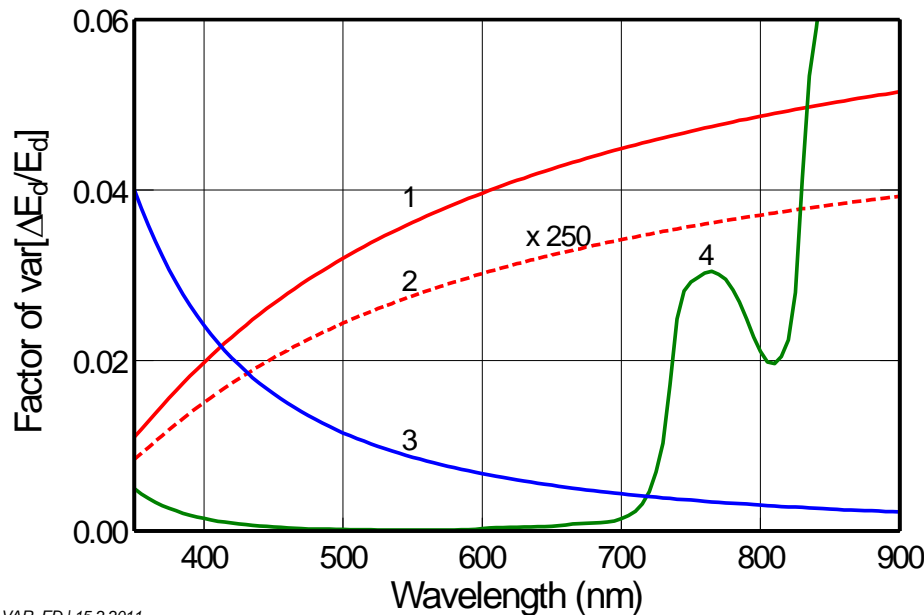
Inversion of irradiance measurements

WASI
software

[ftp.dfd.dlr.de/
pub/wasi](ftp.dfd.dlr.de/pub/wasi)



Sources of irradiance variance (from model)

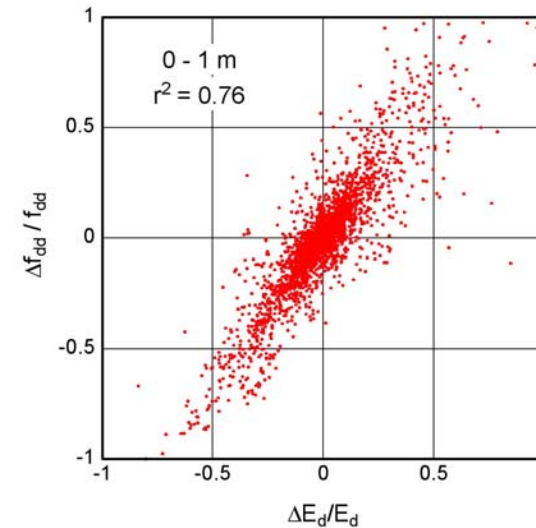
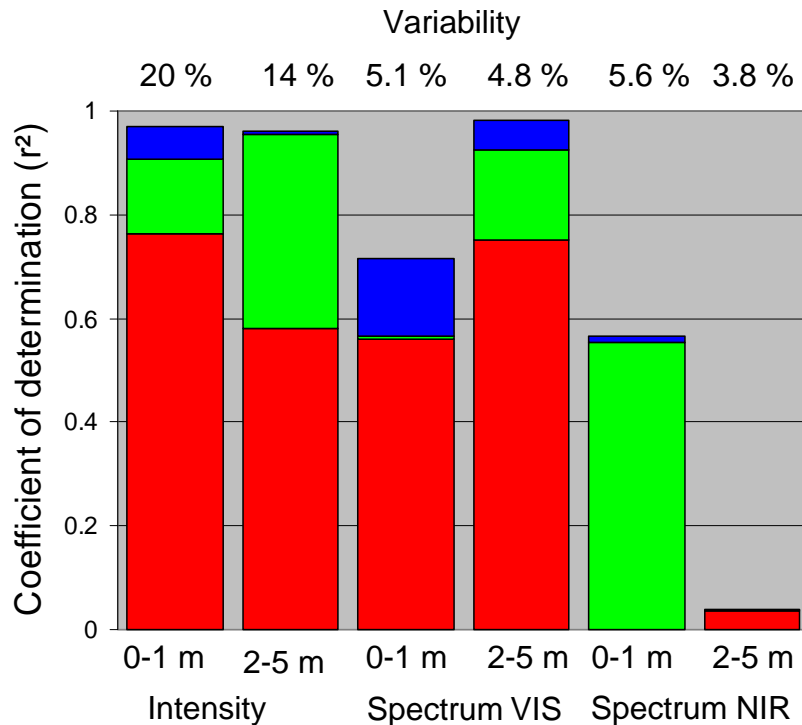


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1. Changes of direct radiation due to waves
- ~~2. Changes of direct radiation due to sensor tilt~~
3. Changes of diffuse radiation due to waves
4. Changes of sensor depth due to waves and swaying boat

$$\text{var} \left[\frac{\Delta E_d(\lambda, z)}{E_d(\lambda, z)} \right] = \boxed{1} \left[\frac{r_d(\lambda, z)}{r_d(\lambda, z) + 1} \right]^2 \text{var} \left[\frac{\Delta f_{dd}}{f_{dd}} \right] + \boxed{2} \left[\frac{r_d(\lambda, z)}{r_d(\lambda, z) + 1} \right]^2 \tan^2(\theta'_{sun} + \theta_s) \text{var}[\theta_s] + \boxed{3} \left[\frac{1}{r_d(\lambda, z) + 1} \right]^2 \text{var} \left[\frac{\Delta f_{ds}}{f_{ds}} \right] + \boxed{4} \left[\frac{1}{r_d(\lambda, z) + 1} \right]^2 [a(\lambda) + b_b(\lambda)]^2 \left[\frac{r_d(\lambda, z)}{\cos \theta'_{sun}} + l_{ds} \right]^2 \text{var}[z]$$

Importance of sources



- 1 $r^2(\text{var}[\Delta E_d/E_d], \Delta f_{dd}/f_{dd})$
- 2 $r^2(\text{var}[\Delta E_d/E_d], \Delta Z)$
- 3 $r^2(\text{var}[\Delta E_d/E_d], \Delta f_{ds}/f_{ds})$

1: Changes of direct radiation due to waves

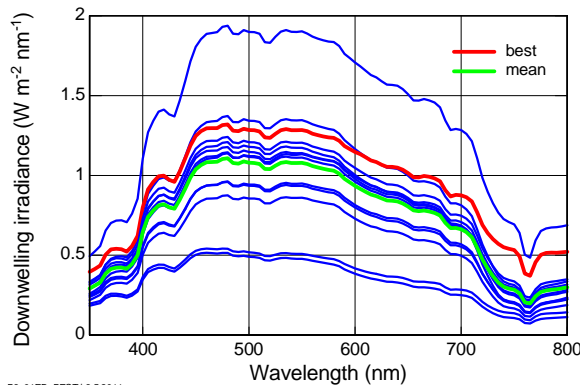
2: Changes of sensor depth due to waves and swaying boat

3: Changes of diffuse radiation due to waves

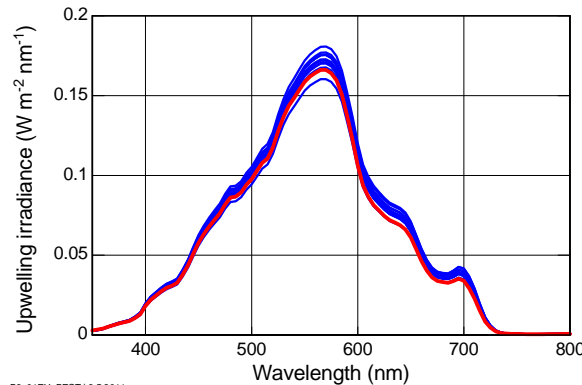
Summary and conclusion

3 relevant sources of irradiance variability (intensity and spectral shape)

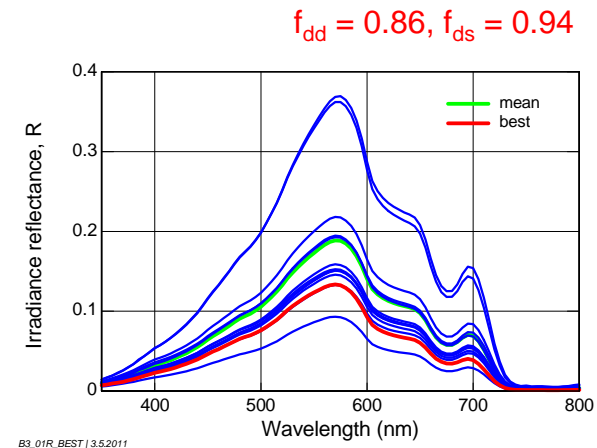
- Rank 1: Changes of direct radiation due to waves. $\text{var } E_d \sim [r_d/(r_d+1)]^2$. Typical: $\pm 5\%$ across VIS.
- Rank 2: Changes of sensor depth due to waves and swaying boat. $\text{var } E_d = f(r_d, a, b_b, \theta_{\text{sun}}, l_{\text{ds}})$. Typical: $\pm 6\%$ across NIR.
- Rank 3: Changes of diffuse radiation due to waves. $\text{var } E_d \sim [1/(r_d+1)]^2$



B3_01ED_BEST | 3.5.2011



B3_01EU_BEST | 3.5.2011



B3_01R_BEST | 3.5.2011

Assignment of „best“ in-water measurement requires above-water measurement
in order to determine the actual values f_{dd} , f_{ds} .

P. Gege, N. Pinnel (2011): Sources of variance of downwelling irradiance in water. *Applied Optics* (in press).