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# Spectral variability of downwelling irradiance in water induced by wave focusing

P. Gege, N. Pinnel

# Overview

- Motivation
- Observations
- Model results
- Summary and conclusions

# Motivation

<u>Campaigns</u>

Small boat in shallow areas of 3 German lakes

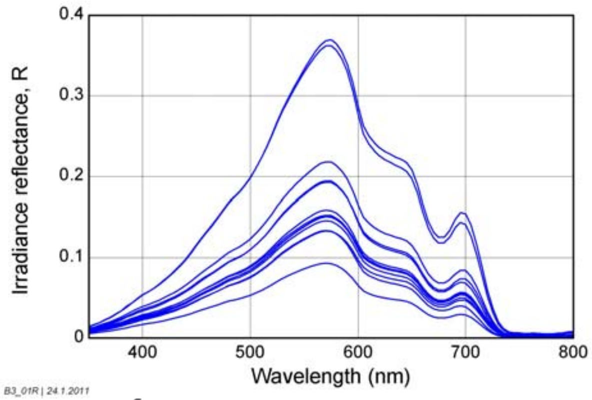
421 data sets, 4375 spectra at 0–5 m depth

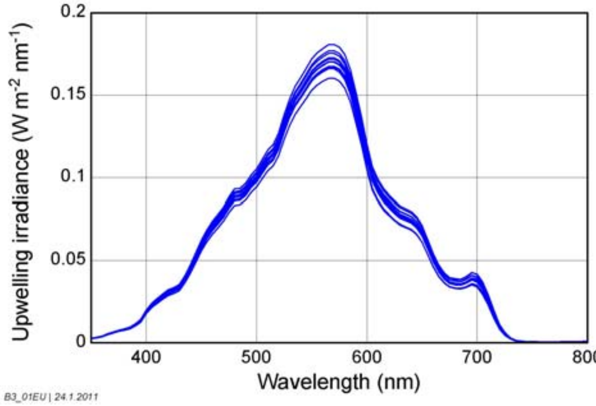
<u>Observation:</u>

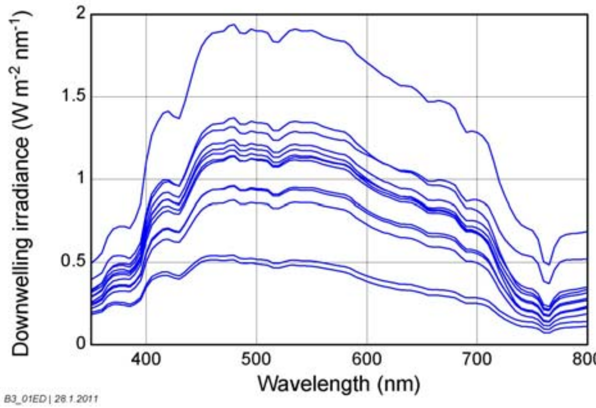
Reflectance spectra (in shallow water) can vary strongly in magnitude and spectral shape **– why?**

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

**Due to variability of downwelling irradiance**



# Spectral variability of downwelling irradiance in water induced by wave focusing

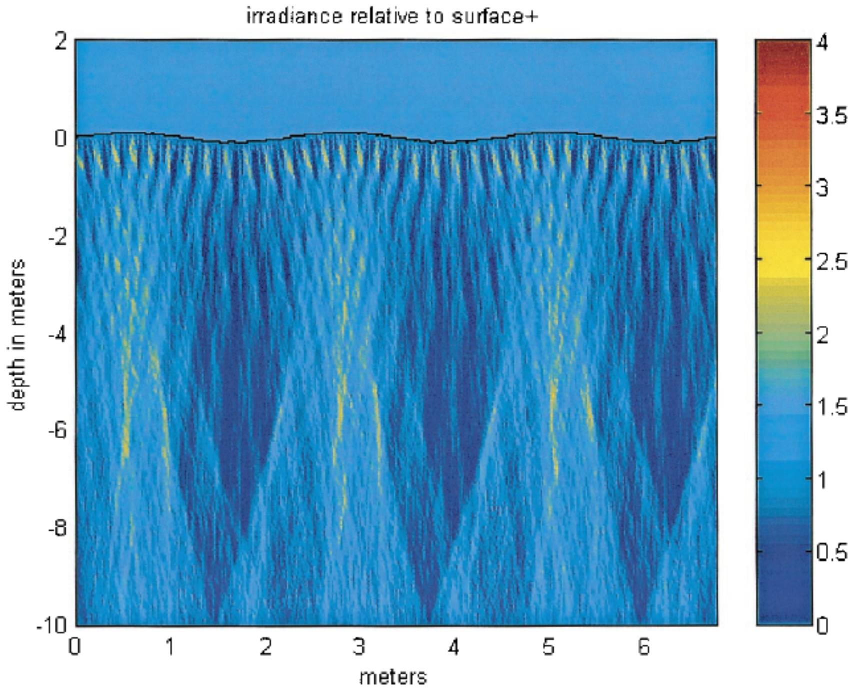


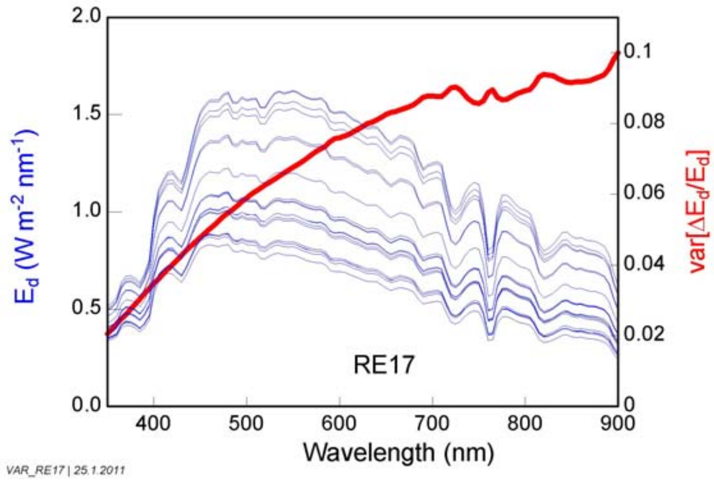

Fig. 6. Irradiance pattern beneath a superposition of sinusoidal waves with wavelengths of 2.25, 0.2, and 0.05 m and with amplitudes of 0.1, 0.01, and 0.002 m. Note that the addition of very small amplitude waves significantly alters the irradiance pattern.

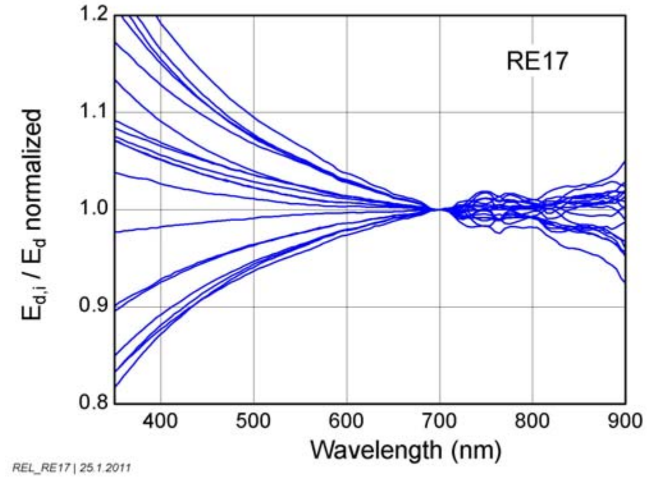
Zanefeld et al. (2001): Influence of surface waves on measured and modeled irradiance profiles. *Applied Optics* **40**, 1442-1449.

Very complete book on the topic:
R. E. Walker, Marine Light Field Statistics (Wiley, 1994)

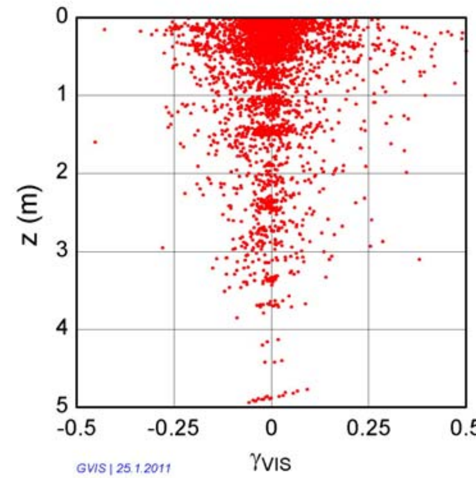
- Wave focusing induces large fluctuations
- Statistics is well known
- **Wavelength dependency?**
- **Other sources of variability?**

# Wavelength dependency of $E_d$ variability (Type 1)



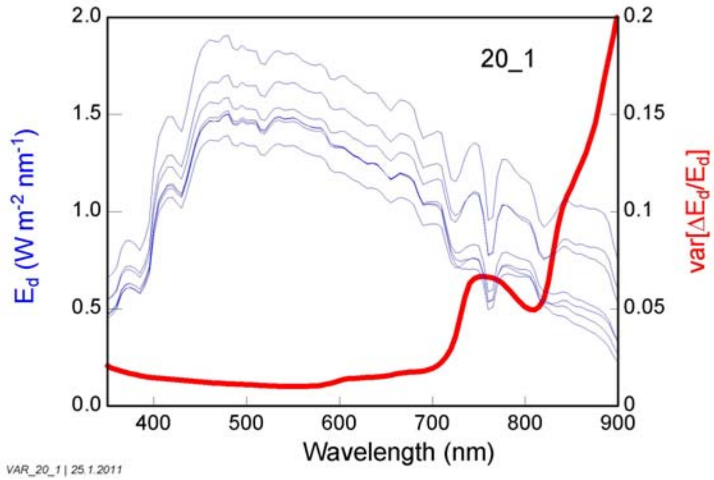



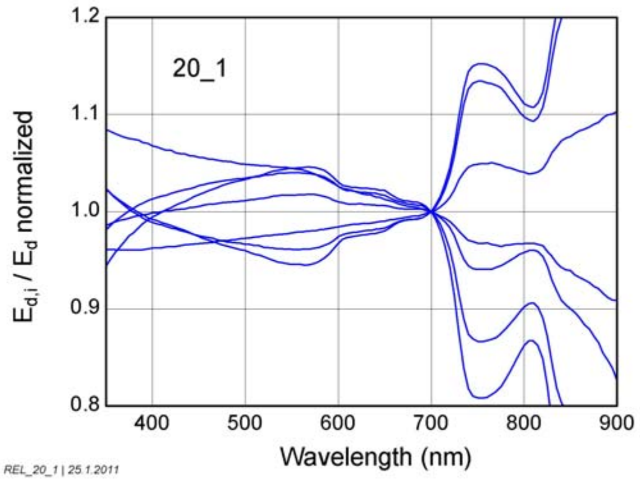

- Smooth spectral shape across VIS
  - no spectral fine structures from $E_d$
  - power law
- Relevance in our data set
  - on average: 5.4 %
  - little depth dependency



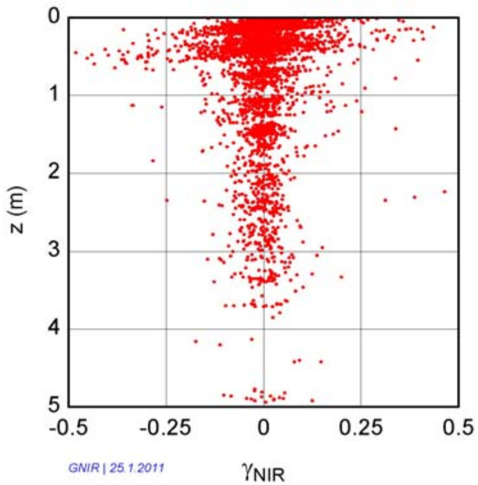

$$\gamma_{VIS,i} = \frac{E_{d,i}(400)}{E_d(400)} - \frac{E_{d,i}(700)}{E_d(700)}$$

# Wavelength dependency of $E_d$ variability (Type 2)




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




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

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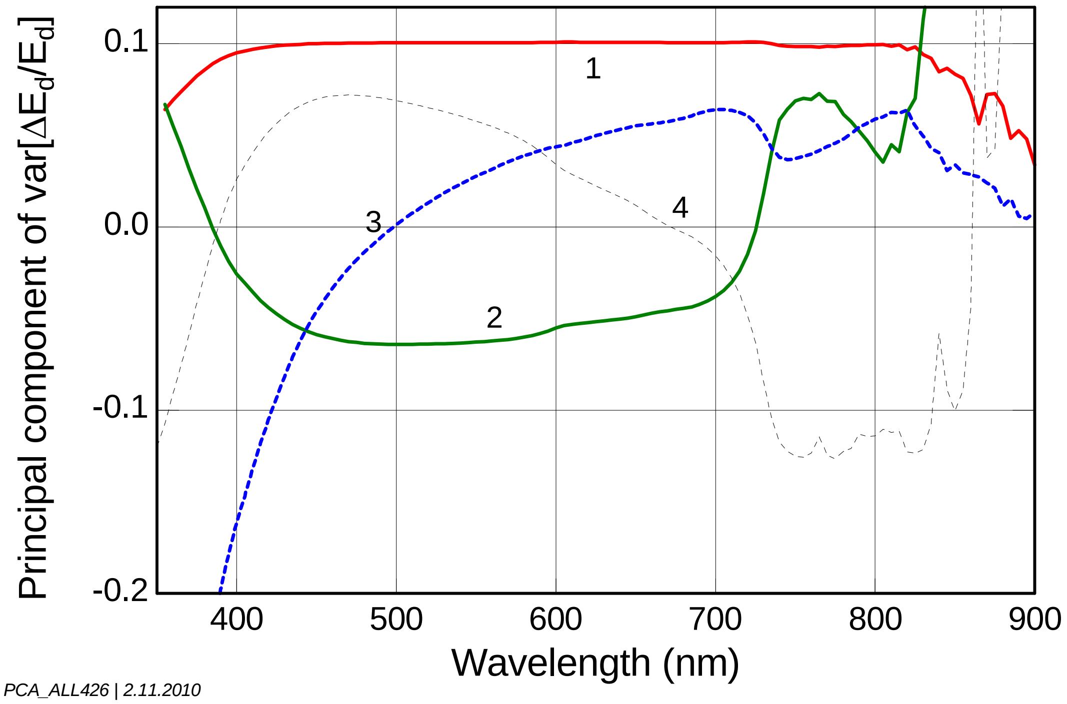
in der Helmholtz-Gemeinschaft

# Sources of irradiance variance (from PCA)




421 data sets from depths 0 to 5 m

Proportions of variance: 1 = 85.5 %, 2 = 6.2 %, 3 = 4.7 %, 4 =1.6 %.

# 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 $f_{ds}$**

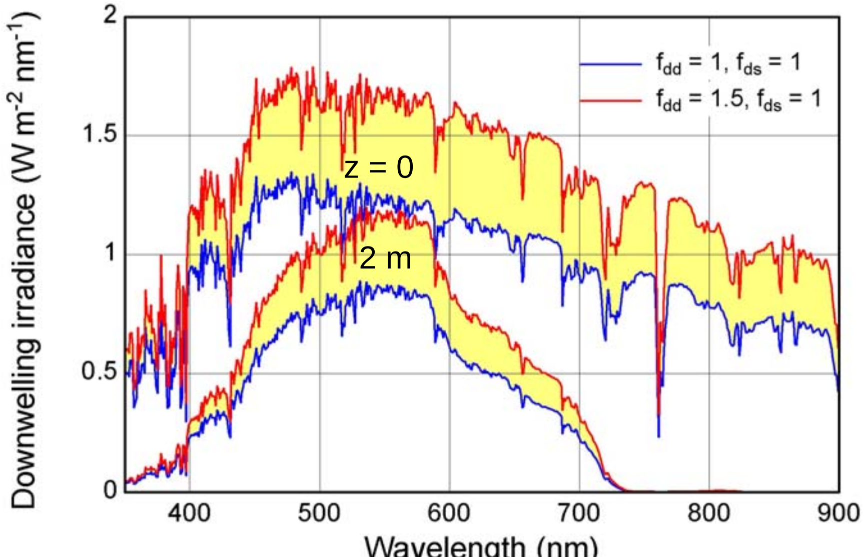
Depth dependency of each component according to Lambert-Beer law

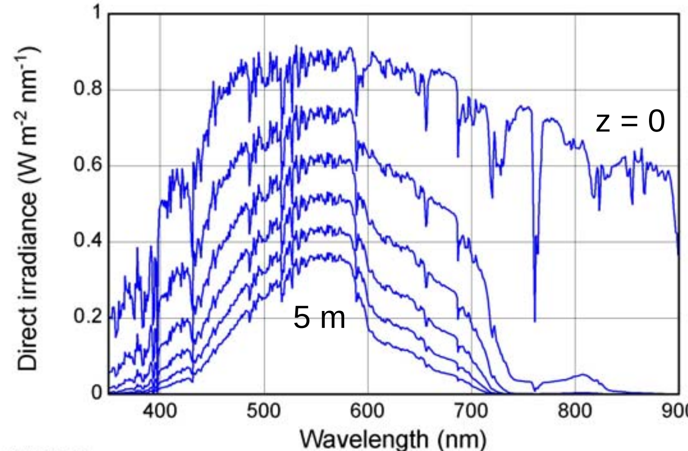
$$E_{dd}(\lambda,z) = E_{dd}(\lambda,0-) \exp\{-[a(\lambda)+b_b(\lambda)]z/\cos\theta_{sun,w}\}$$

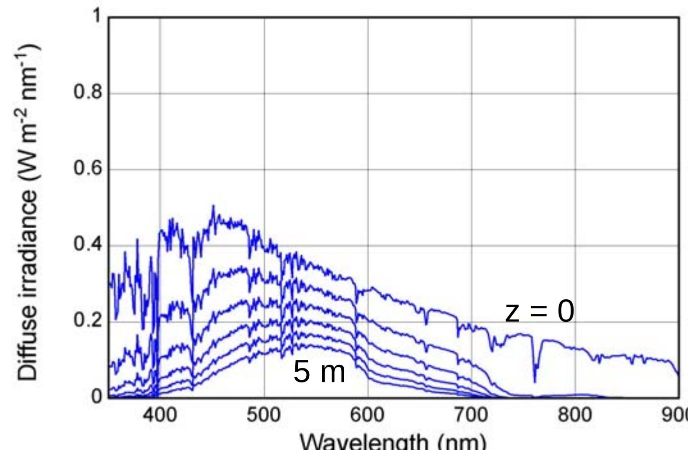
$$E_{ds}(\lambda,z) = E_{ds}(\lambda,0-) \exp\{-[a(\lambda)+b_b(\lambda)]zl_{ds}\}$$

$z$: water column thickness above sensor. **Waves alter $z$.**

# Illustration of irradiance model



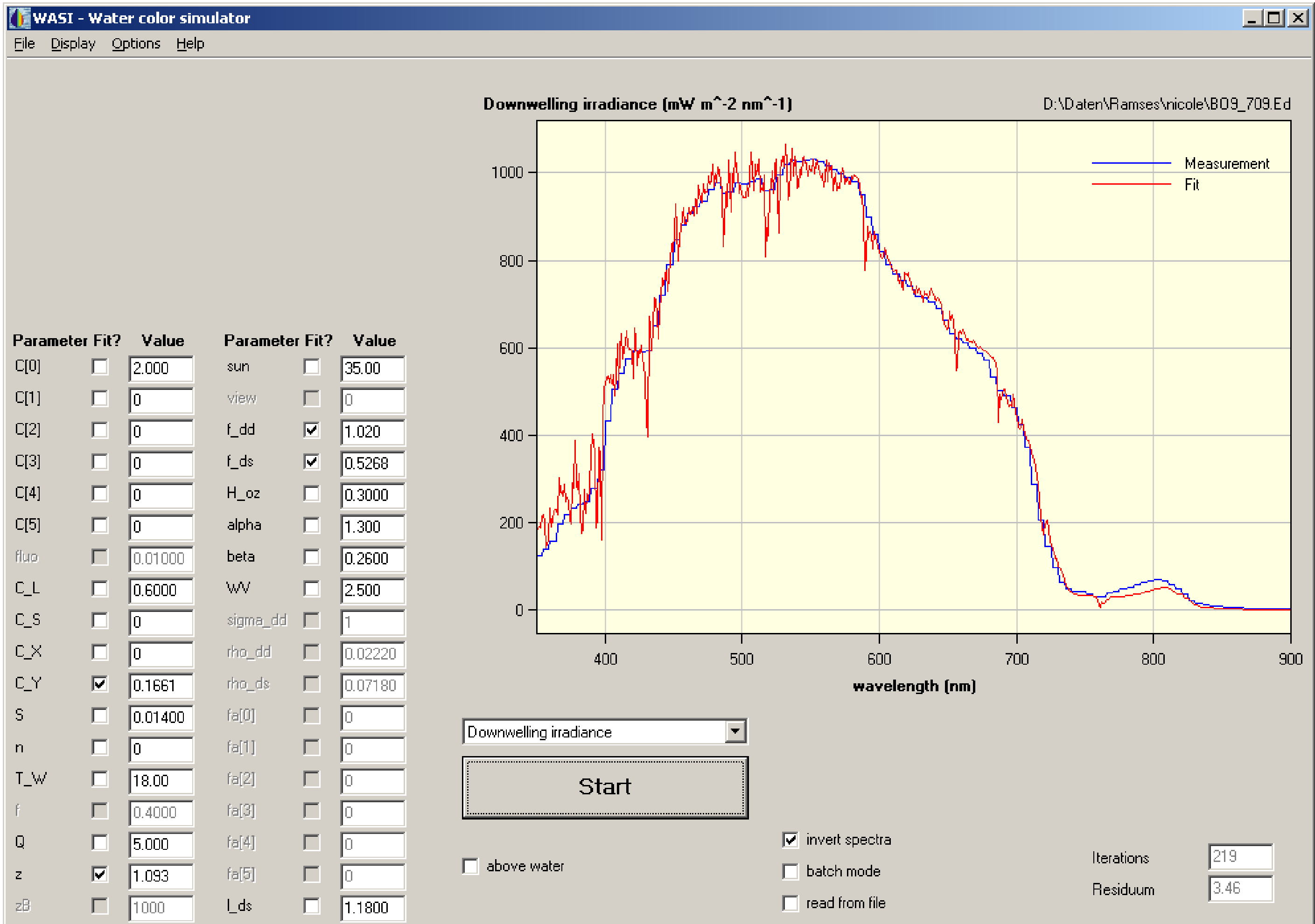




$$E_d(\lambda,z) = f_{dd}E_{dd}(\lambda,z)+ f_{ds}E_{ds}(\lambda,z)$$

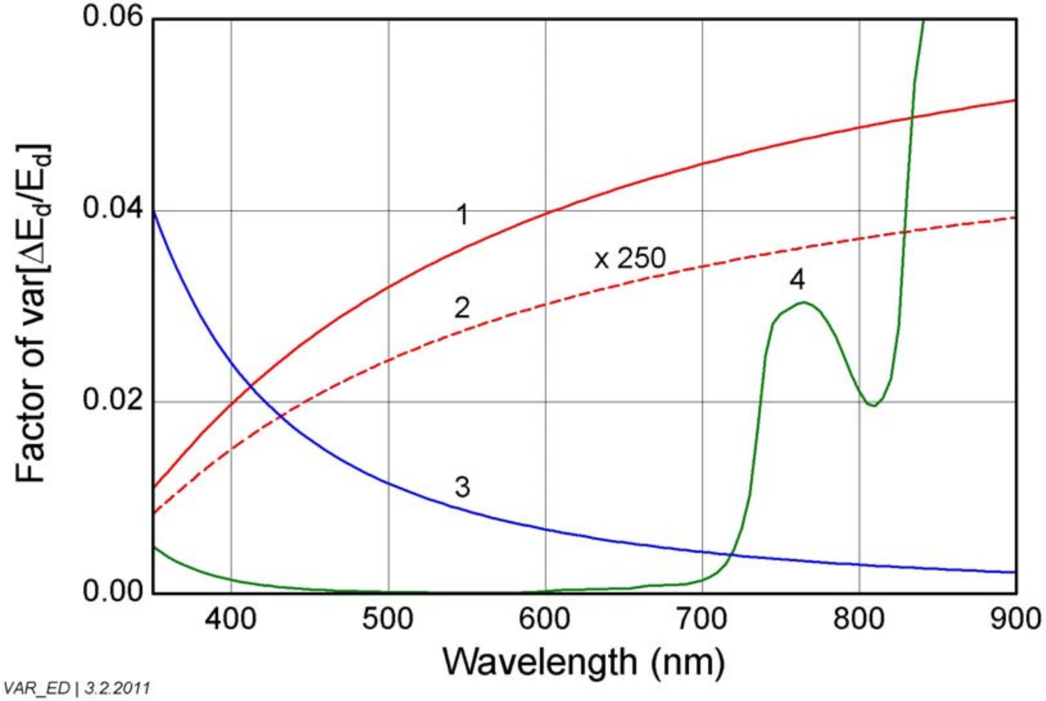
# Inversion of irradiance measurements

WASI
software

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



# Sources of irradiance variance (from model)




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

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

# Summary

## 3 sources of irradiance variability

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