# Facing the challenges imposed by variable cloud cover on optical field measurements

P. Gege[1], A. Göritz[2]

[1]DLR, Remote Sensing Technology Institute, Oberpfaffenhofen, D-82234 Wessling, Germany. Email: peter.gege@dlr.de

[2]Technical University of Munich (TUM), Dep. of Civil, Geo and Environmental Engineering, Chair of Remote Sensing Technology. Email: anna.goeritz@dlr.de

## Summary

- Broken cloud conditions
- Spectral irradiance model for induced artefacts
- Above-water reflectance allows estimate of CHL and TSM
- In-water irradiance allows determination of CHL and CDOM

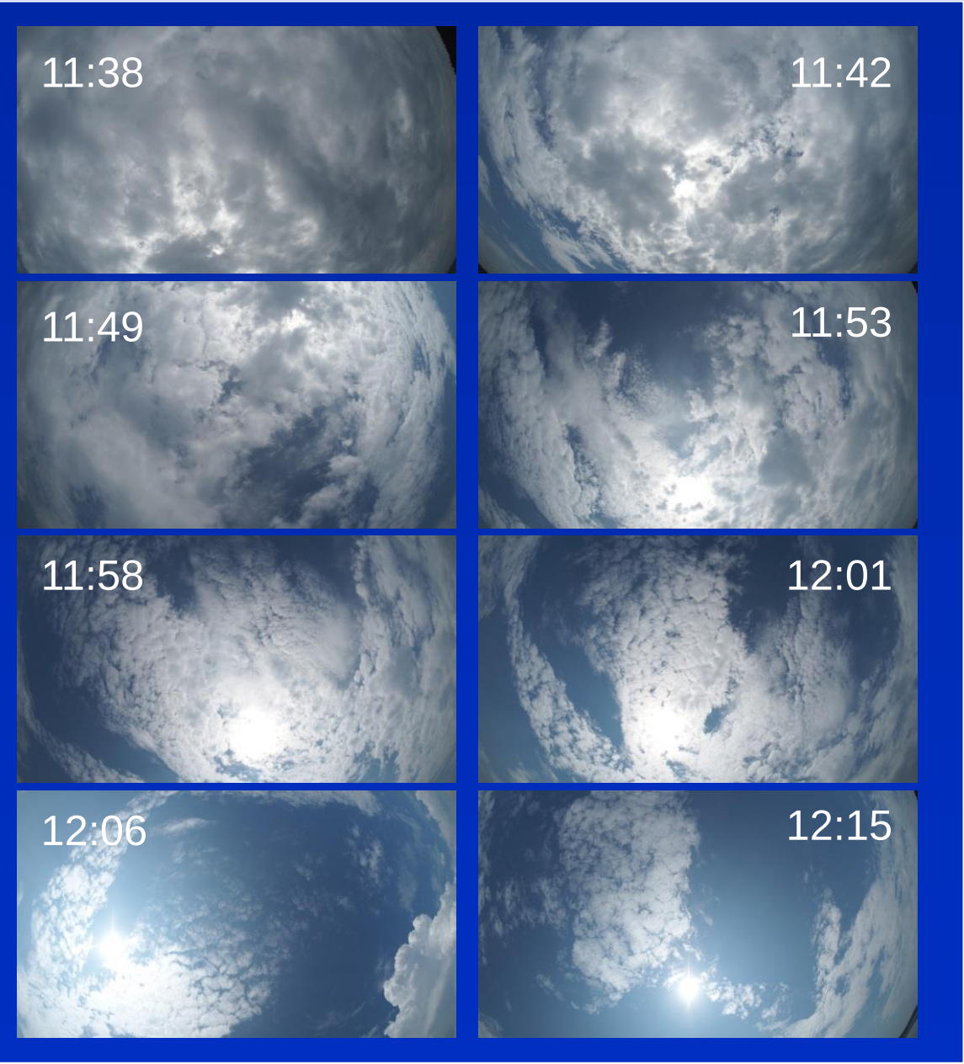
## Challenges

**Above water: Reflections at the water surface**

- reflections of sun, sky, clouds
- intensity can be much higher than water leaving radiance
- effect is frequently wavelength dependent

**In water: Variability of downwelling irradiance**

- intensity usually changes strongly
- spectral shape can change

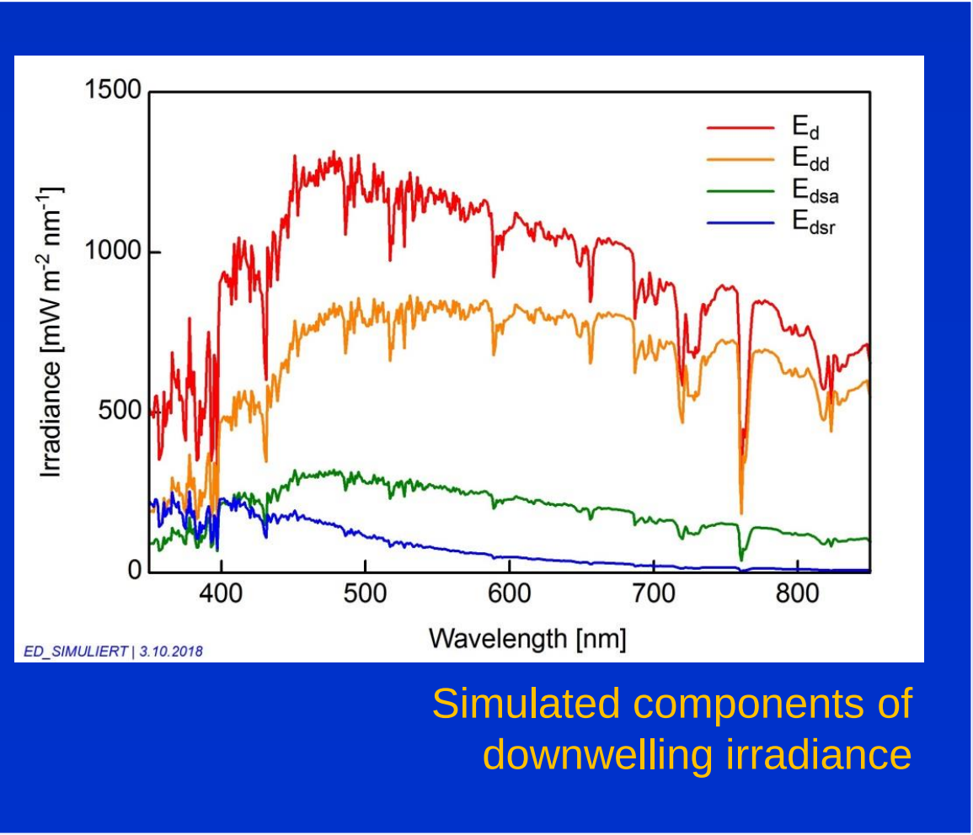


## Irradiance model

Based on analytic model of Gregg and Carder (1990):

$$\boldsymbol{E_d(\lambda) = E_{dd}(\lambda) + E_{dsr}(\lambda) + E_{dsa}(\lambda)}$$

| | |
|---|---|
| $E_{dd}(\lambda)$ | Direct component (from sun disc) |
| $E_{dsr}(\lambda)$ | Diffuse Rayleigh component (from sky) |
| $E_{dsa}(\lambda)$ | Diffuse aerosol component (from sky) |



Simulated components of downwelling irradiance

## Surface reflections

Sky radiance is calculated using irradiance model, clouds are approximated as "gray":

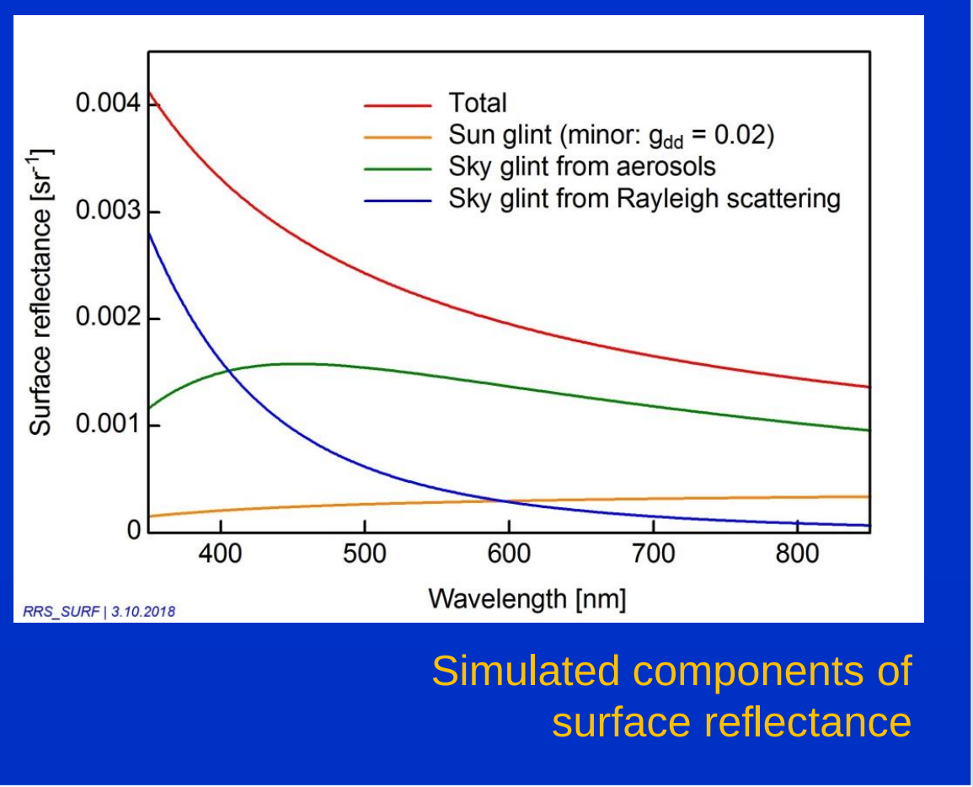
$$R_{rs}^{surf}(\lambda) = g_{dd}\frac{E_{dd}(\lambda)}{E_d(\lambda)} + g_{dsr}\frac{E_{dsr}(\lambda)}{E_d(\lambda)} + g_{dsa}\frac{E_{dsa}(\lambda)}{E_d(\lambda)} + d_r$$

Modelled

$E_x(\lambda)$ Irradiances from irradiance model

Possible fit parameters

$g_{dd}, g_{dsr}, g_{dsa}, d_r$



Simulated components of surface reflectance

## Above water measurements

Measured

$L_u(\lambda)$ Upwelling radiance

$E_d(\lambda)$ Downwelling irradiance

$$R_{rs}(\lambda) = \frac{L_u(\lambda)}{E_d(\lambda)} = \frac{\zeta \cdot r_{rs}^-(\lambda)}{1 - \Gamma \cdot r_{rs}^-(\lambda)} + R_{rs}^{surf}(\lambda)$$

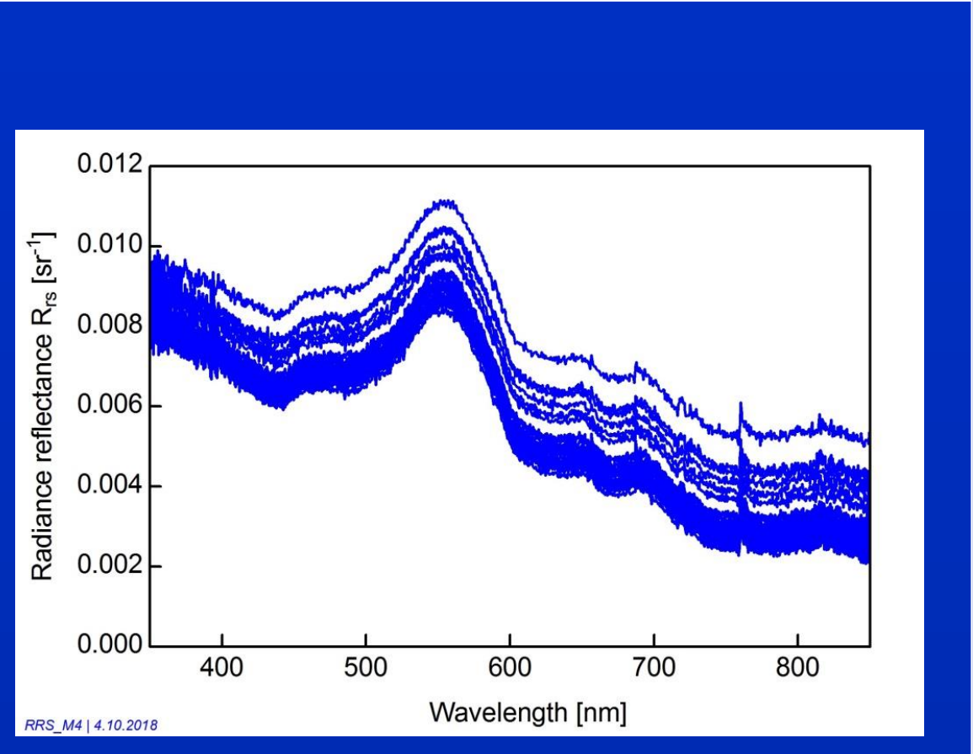
Modelled

| | |
|---|---|
| $r_{rs}^-(\lambda)$ | Subsurface radiance reflectance |
| $R_{rs}^{surf}(\lambda)$ | Surface reflectance |

$\zeta \approx 0.52, \Gamma \approx 1.6$

Possible fit parameters of $r_{rs}^-(\lambda)$

| | |
|---|---|
| C | CHL concentration |
| X | TSM concentration |
| Y | CDOM absorption at 440 nm |
| S | CDOM spectral slope |



30 subsequent reflectance measurements at 11:53 h. Integration time: 80 ms

## In water measurements

Measured

$E_d(\lambda, z)$ Downwelling irradiance at depth z

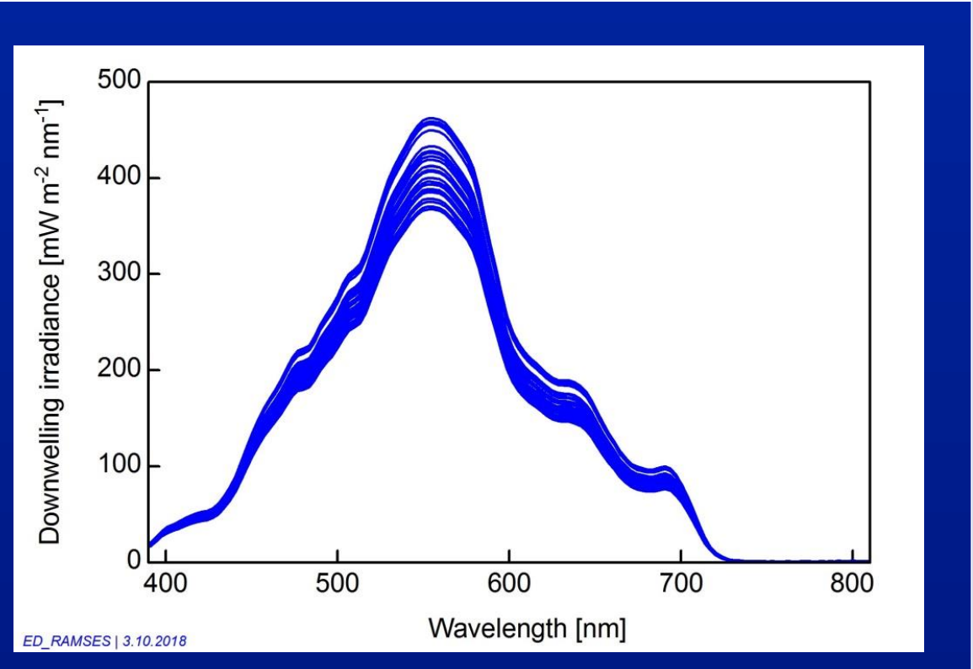
$$E_d(\lambda,z) = f_{dd}E_{dd}(\lambda)exp\{-\frac{[a(\lambda)+b_b(\lambda)]z}{cos\theta'_{sun}}\} + f_{ds}(E_{dsr}(\lambda) + E_{dsa}(\lambda))exp\{-[a(\lambda) + b_b(\lambda)]zl_{ds}(\theta'_{sun})\}$$

Modelled

| | |
|---|---|
| $E_x(\lambda)$ | Irradiances from irradiance model |
| $a(\lambda)$ | Absorption coefficient |
| $b_b(\lambda)$ | Backscattering coefficient |
| $l_{ds}(\theta'_{sun})$ | Path length of diffuse radiation |

Possible fit parameters

| | |
|---|---|
| $f_{dd}, f_{ds}$ | Relative intensities |
| C, Y, S | Parameters of $a(\lambda)$ |
| X | Parameter of $b_b(\lambda)$ |



30 subsequent irradiance measurements at 3 m depth. Integration time: 32 ms

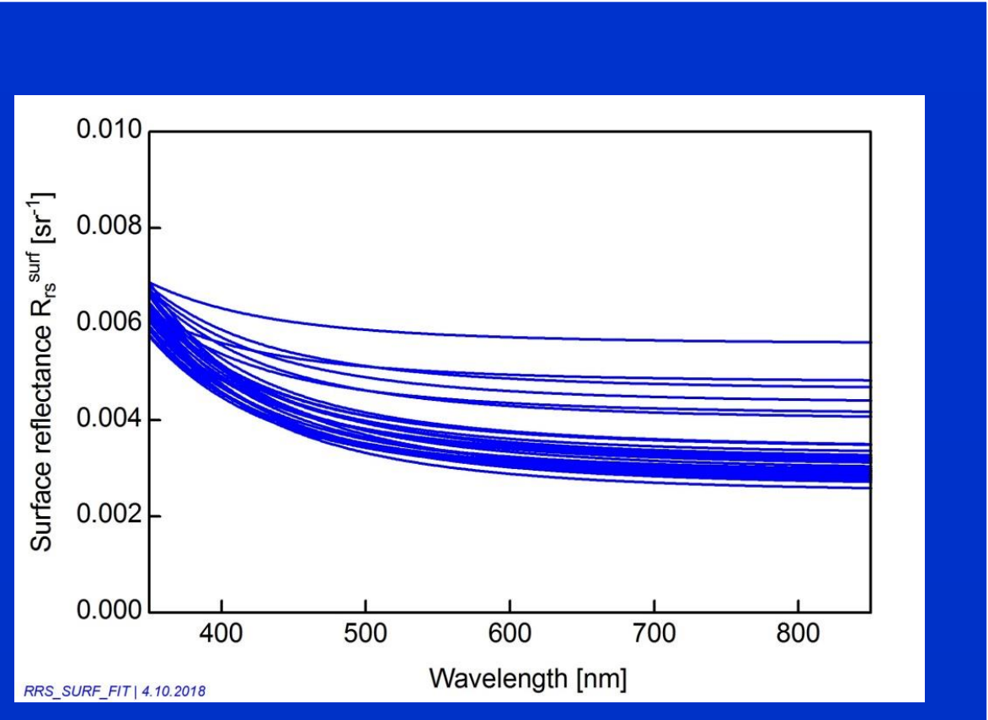
## Data

- Field campaign in May 2016 at Lake Stechlin, Germany
- Above water spectra: Ibsen FREEDOM VIS FSV-305. 350–850 nm, 0.5 nm sampling interval. 10% reflectance standard for downwelling irradiance.
- In water spectra: TriOS RAMSES ACC-VIS. 320–950 nm, 3.3 nm sampling interval.
- In situ: CHL using HPLC and bbe-fluoroprobe;TSM by filtering 0.5, 1, 1.5 and 2 l lake water; CDOM absorption using PSICAM and LWCC.

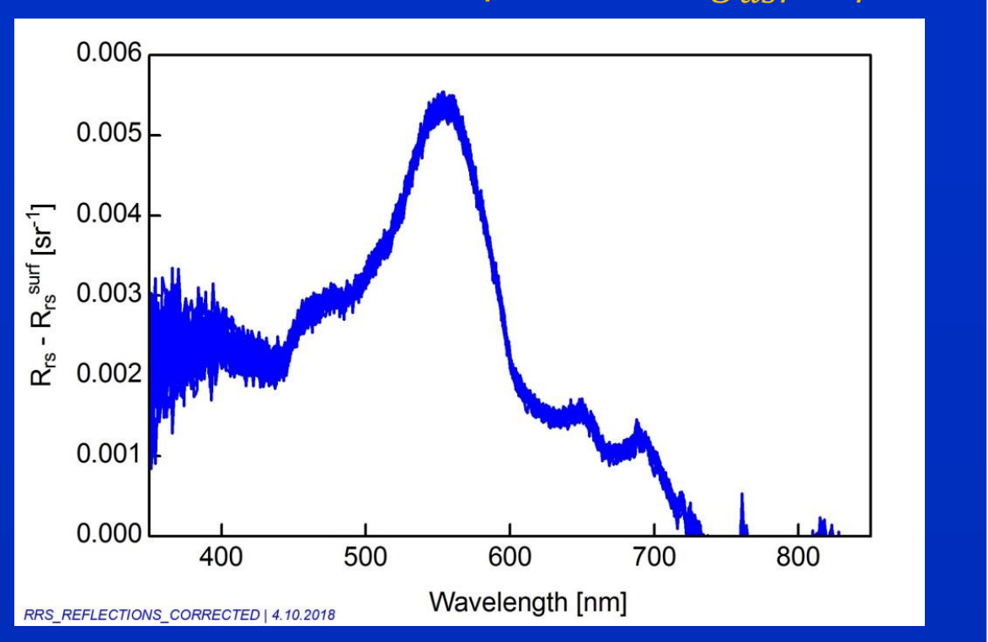
## Results

Above water  reflectance measurements

- Model fits measurements accurately
- Model parameters are ambigous
  - minimize number of fit parameters
- Recommended set of fit parameters
  - water constituents: C, X, Y
  - surface reflections: $g_{dsr}$, $d_r$
- Derived underwater spectra $r_{rs}^-(\lambda)$ are consistent
  - correction of surface reflections seems to work well
- The fit parameters are slightly correlated
  - some error propagation remains
- Assessment of potential for
  - CHL: estimate possible (error ~35%)
  - TSM: estimate possible (error ~35%)
  - CDOM: very difficult (error > 60%)



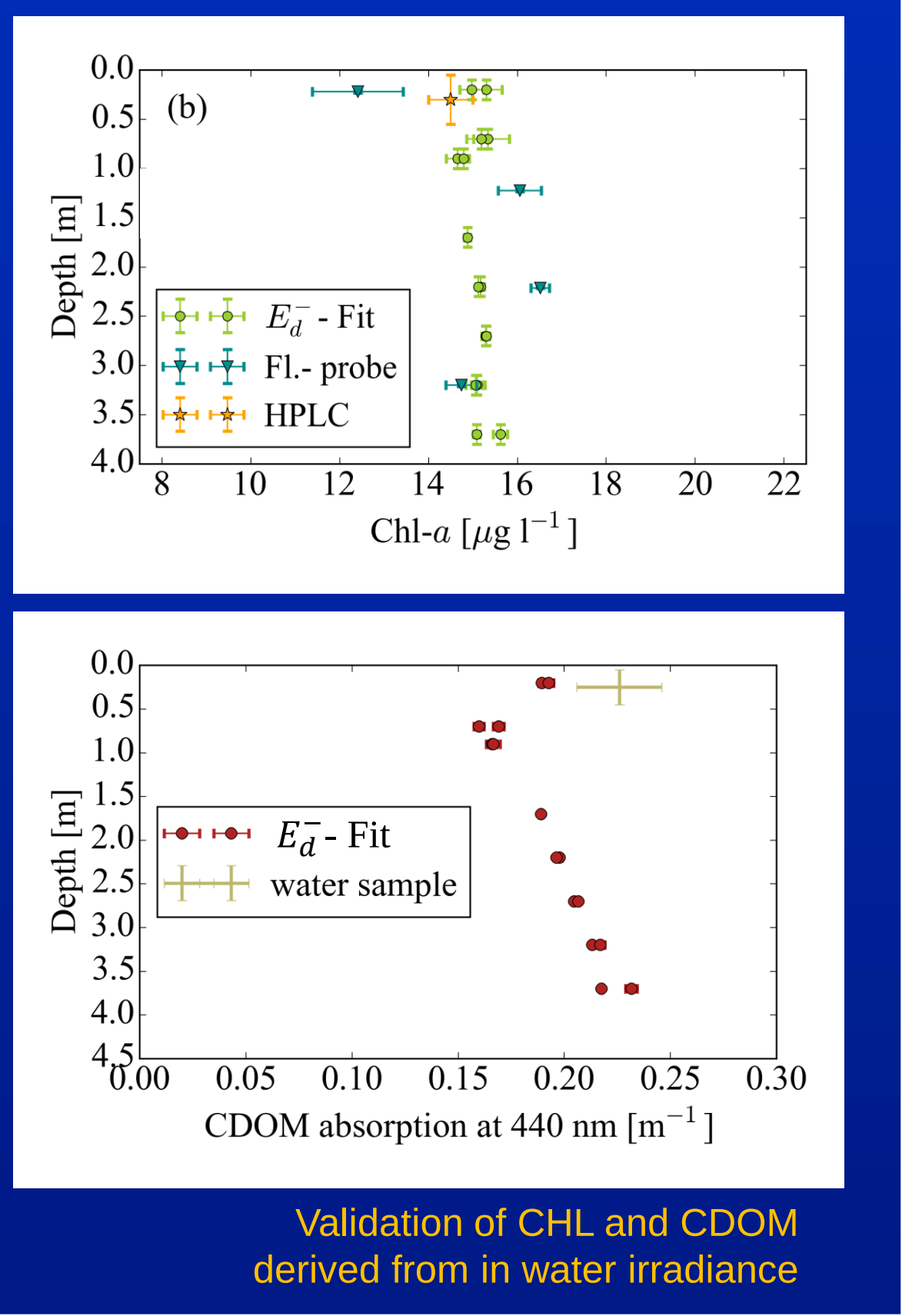
Surface reflectance calculated from fit parameters $g_{dsr}$, $d_r$



30 reflectance measurements at 11:53 h corrected for surface reflectance

In water irradiance measurements

- Model fits measurements accurately
- Useable spectral range decreases with depth
- Recommended set of fit parameters:
  - water constituents: C, Y
  - light field: z, $f_{dd}$, $f_{ds}$
- Assessment of potential for
  - CHL: determination possible (error < 20%)
  - CDOM: determination possible (error < 20%)
  - TSM: not possible



Validation of CHL and CDOM derived from in water irradiance

**Related paper.** A. Göritz, S.A. Berger, P. Gege, H.-P. Grossart, J.C. Nejstgaard, S. Riedel, R. Röttgers, C. Utschig (2018): Retrieval of water constituents from hyperspectral in-situ measurements under variable cloud cover – A case study at Lake Stechlin (Germany). *Remote Sensing 10(2), 181.*

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DLR Deutsches Zentrum
für Luft- und Raumfahrt e.V.