Current activities at DLR Oberpfaffenhofen for remote sensing of inland waters

Peter Gege

DLR, Earth Observation Center, Remote Sensing Technology Institute, Oberpfaffenhofen, 82234 Wessling, Germany

peter.gege@dlr.de

EAWAG Kastanienbaum, Switzerland, 15 April 2019

DLR

eoc Earth Observation Center

125 (IMF) + 220 (DFD) staff

60+ doctoral candidates

14 professors
(incl. adjoint teaching and guest professors)

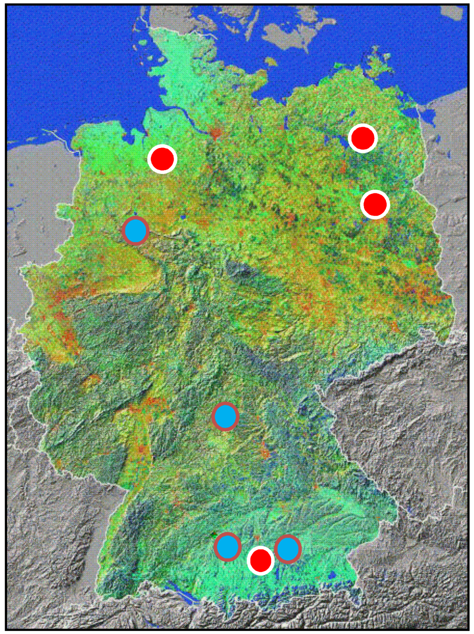
Third party funding: 46% (IMF) + 59% (DFD)

Remote Sensing Technology Institute (IMF)
Director: Prof. Dr. Richard Bamler

German Remote Sensing Data Center (DFD)
Director: Prof. Dr. Stefan Dech

Campusses of EOC

● Neustrelitz



● Berlin-Adlershof

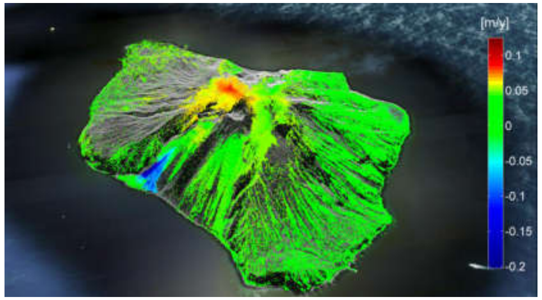
● Oberpfaffenhofen

● Bremen

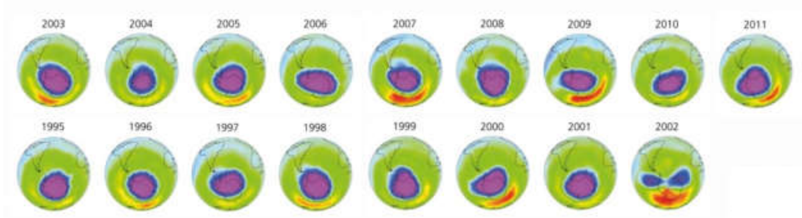
- University of Würzburg
- Technical University of Munich
- University of Augsburg
- University of Osnabrück

Remote Sensing Technologies at IMF

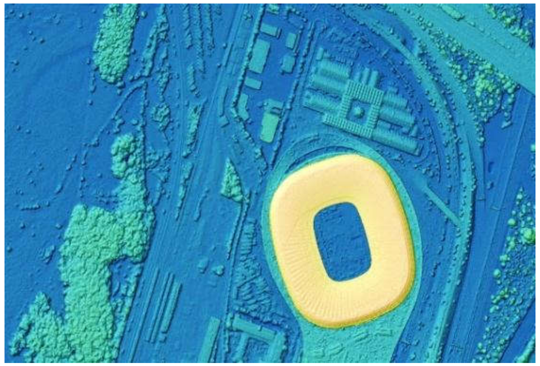
- **Synthetic Aperture Radar (SAR)**



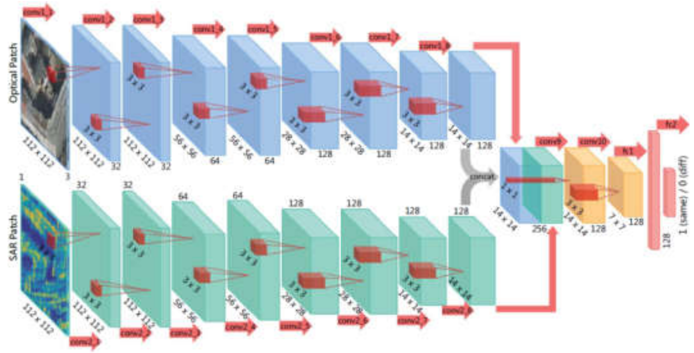
- **Atmospheric Spectrometry (Active and Passive)**



- **Optical Remote Sensing**



- **Data Science**
- Cross-technology



Current activities at DLR Oberpfaffenhofen for remote sensing of inland waters
Outline

- L0-L1: Sensors, Calibration
- L1-L2: Data, Validation
- L2-L3: Models, applications
  - Optically deep water
  - Inherent optical properties
  - Atmospheric correction
  - Reflections at the water surface
  - Optically shallow waters
- Software WASI

L0-L1: Sensors, Calibration

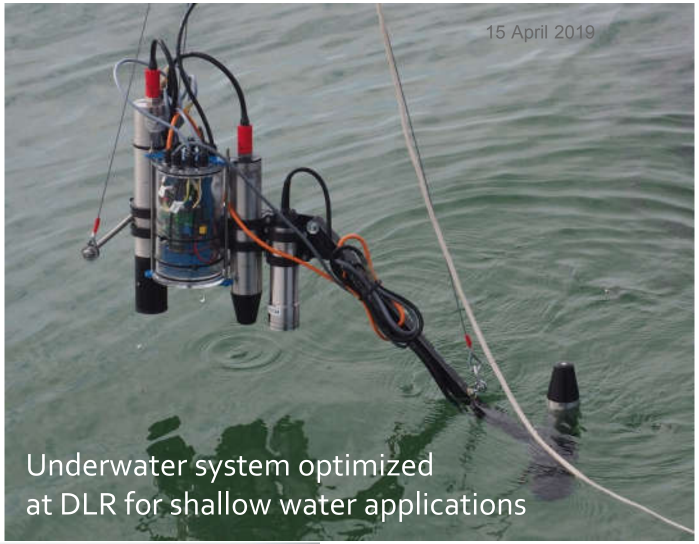
Hyperspectral sensors

- Laboratory spectrometers (various; 200 – 3000 nm). Usage:
  - sensor calibration
  - spectral data for material data bases

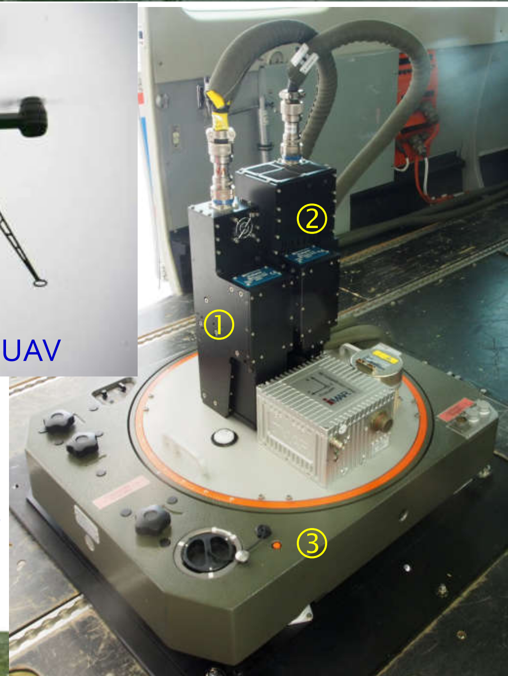
- Field spectrometers (various; 350 – 2500 nm). Usage:
  - development of physically based inversion algorithms
  - validation of remote sensing products (Level-2)
  - spectral data for material data bases

- Hyperspectral snapshot camera on UAV (Cubert; 450 – 950 nm).
  - hyperspectral mapping for local applications

- Imaging spectrometer on airplane (HySpex; 420 – 2500 nm). Usage:
  - simulation of multi- and hyperspectral satellite data
  - hyperspectral mapping for regional applications


Underwater system optimized at DLR for shallow water applications

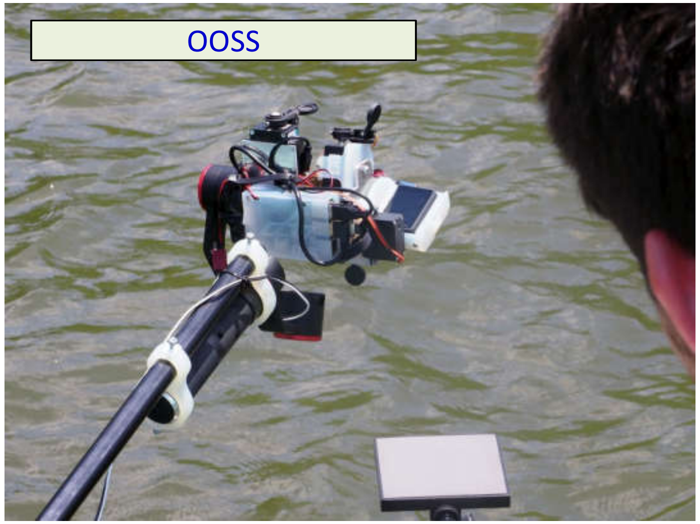

Cubert UHD-185 Firefly on UAV

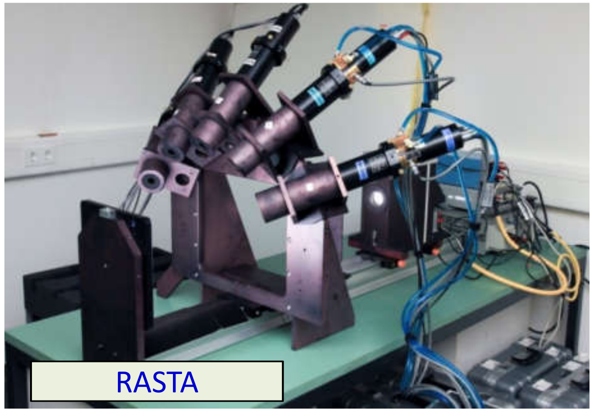


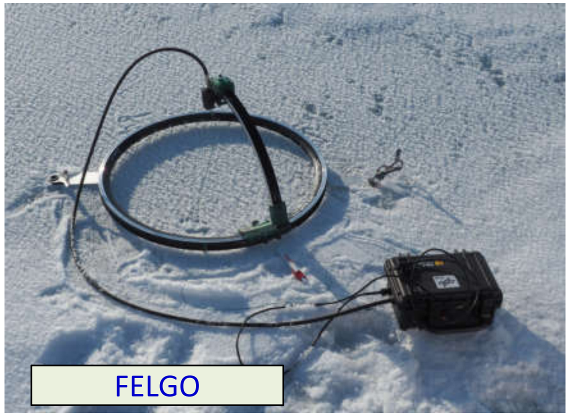
HySpex system in airplane
1: Camera VNIR-1600
2: Camera SWIR-320m-e
3: Stabilized platform

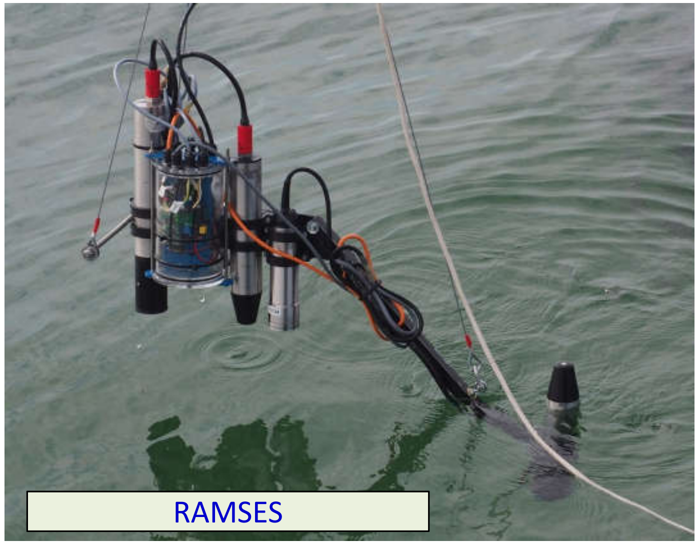
Hardware development and optimization

- **RASTA:** Radiance standard. Developed for sensor calibration.
- **Stray light source.** Developed for measuring stray light of EnMAP.
- **OOSS:** Ocean Optics sensor system. Developed for handheld measurements on swaying boats.
- **RAMSES.** System optimized for underwater measurements in shallow waters.
- **FELGO.** Goniometer for BRDF measurements.
- **AquaVIS.** Spectrometer on UAV. Under development.







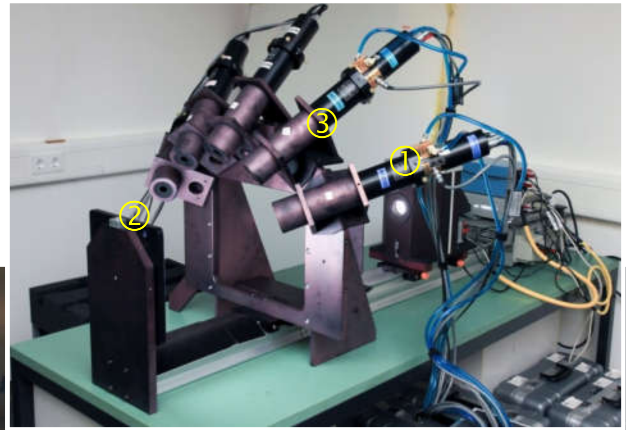


Calibration Home Base (CHB)

- Designed for hyperspectral instruments
  - Spectral range: 350 – 2500 nm
  - Suited for bulky and heavy instruments up to 500 kg
  - Same position as in aircraft
- Accurate characterization of sensor parameters
  - Spectral
  - Radiometric
  - Geometric
- Light sources traceable to SI units
- ISO certified

Radiance standard RASTA

1: Lamp
2: Diffuse reflector
3: Radiometers for monitoring



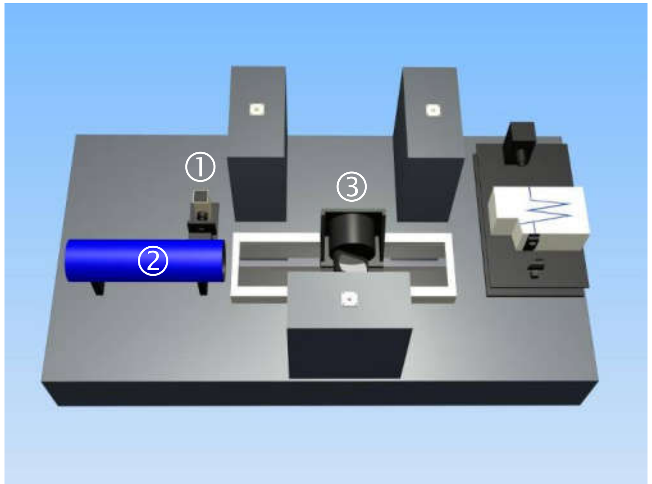
CHB laboratory for operational measurements

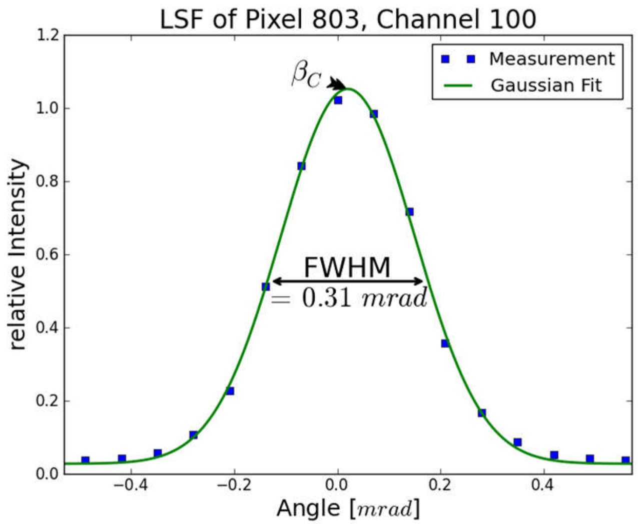
Geometric measurements

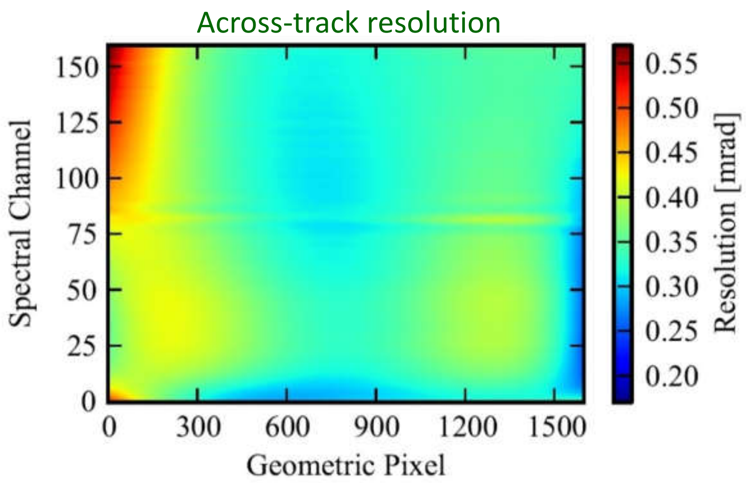
The sensor (not shown) is mounted on the pillars and looks downwards

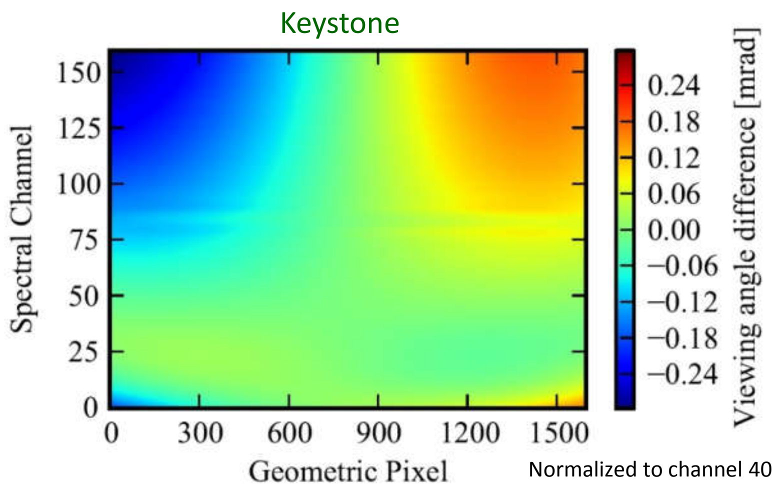
- Quartz halogen lamp ① illuminates narrow slit
- Collimator ② produces nearly parallel light beam
- Folding mirror ③ scans over pixels

Results for HySpex







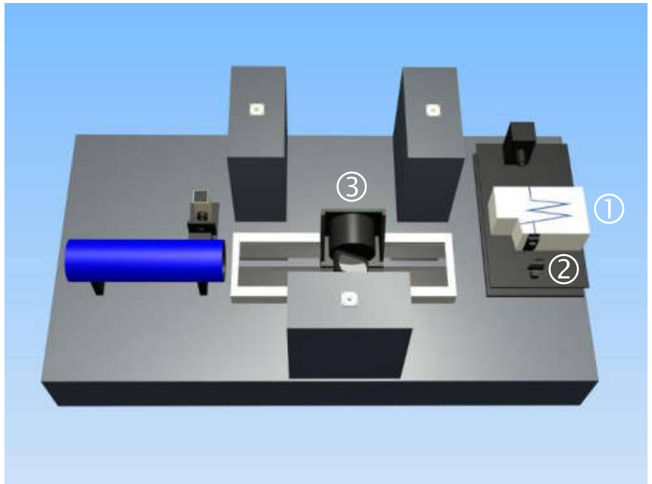


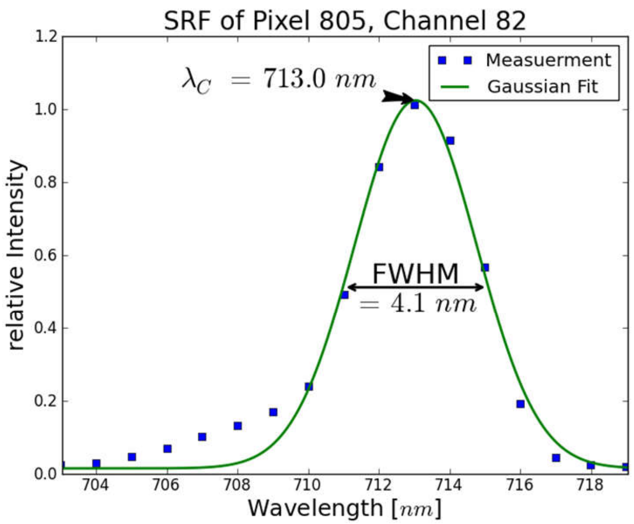
Normalized to channel 40

Spectral measurements

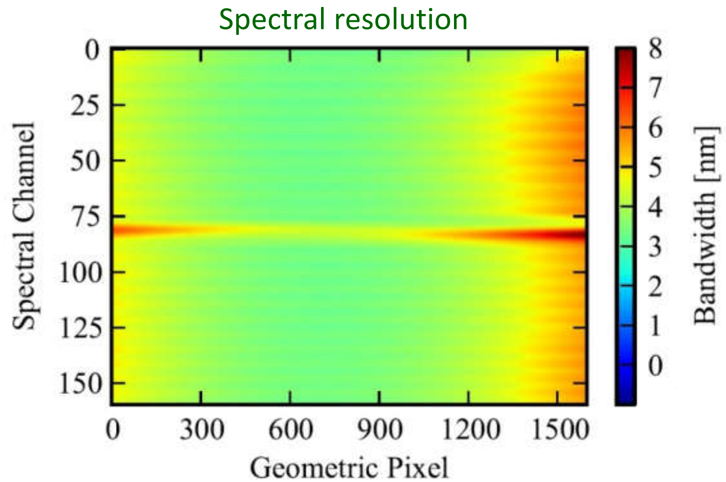
The sensor (not shown) is mounted on the pillars and looks downwards

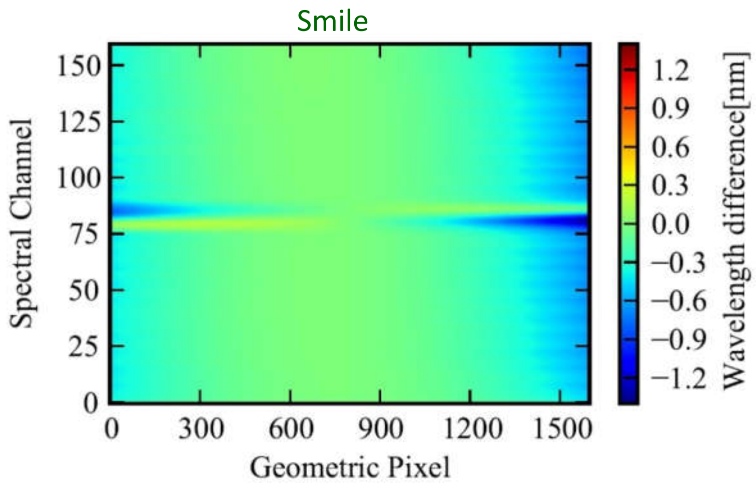
- Monochromator ① scans over wavelength
- Parabolic mirror ② focusses beam
- Folding mirror ③ selects some pixels





Results for HySpex





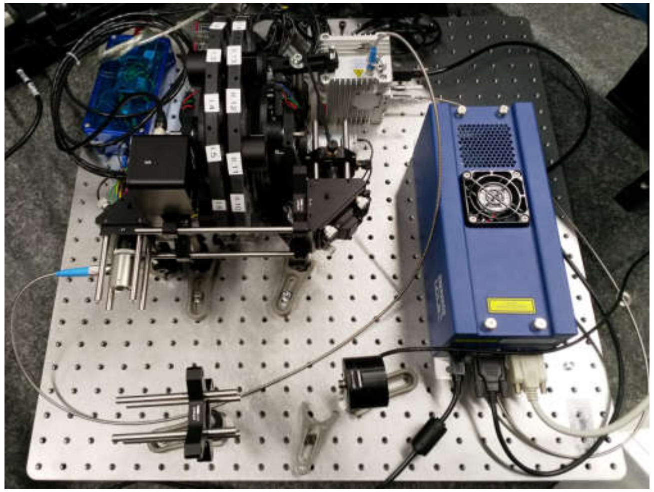
Sensor calibration

- **Airborne sensor: HySpex**
  - self-developed software LOAN for L0-L1a processing
  - input are the sensor parameters measured in the CHB
  - output is the spectral radiance of each pixel
  - non-linearities, stray light are corrected
  - data are resampled to a virtual sensor to equalize the differences between detector elements
  - LOAN is part of automatized processing chain CATENA
    - L0-L1a: spectral and radiometric calibration (LOAN)
    - L1a-L1b: georeferencing (ORTHO)
    - L1b-L2: atmospheric correction and conversion to reflectance (ATCOR)

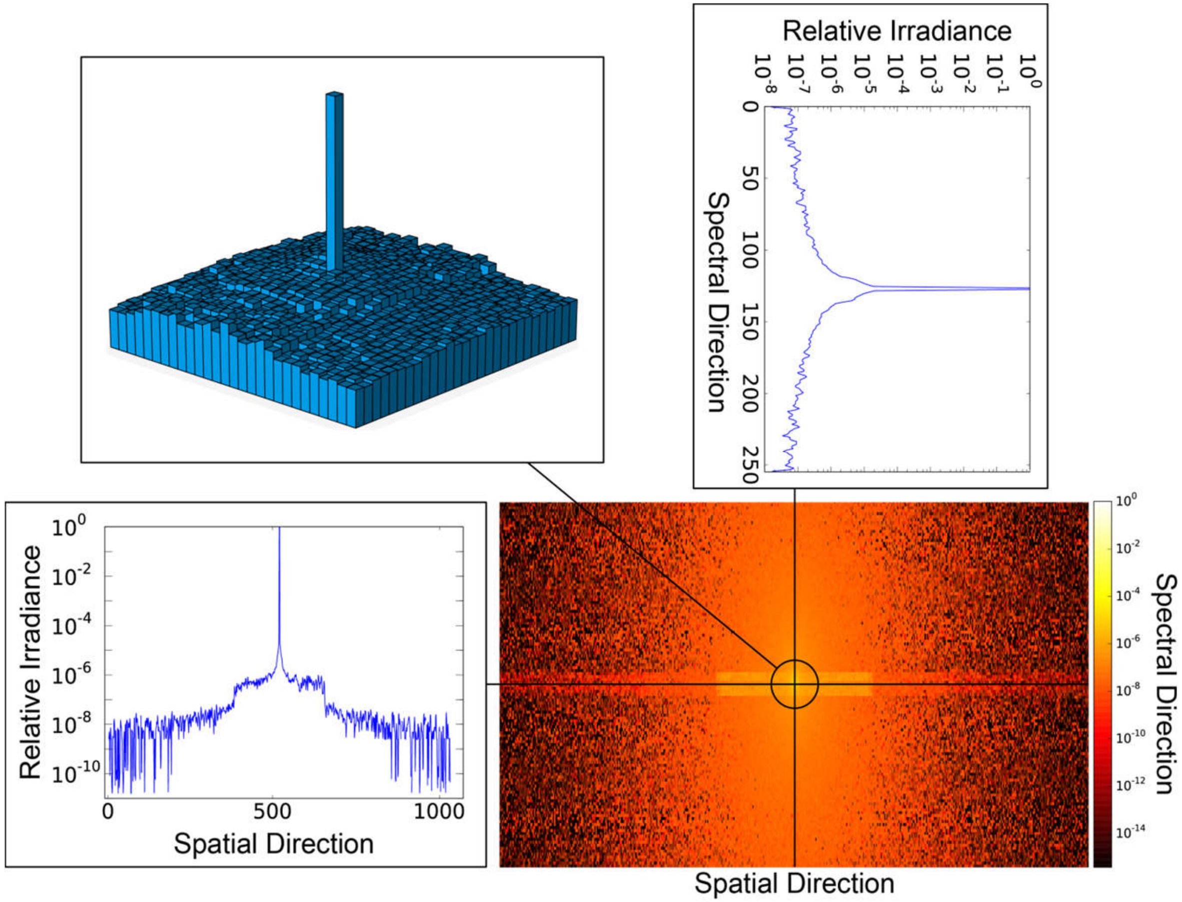
- **Field instruments: OOSS, Ibsen, RAMSES**
  - main usage of field instruments is based on L2 data (reflectance)
  - calibration to L1 (radiance, irradiance) so far not complete and consistent
  - self-developed, instrument-specific software SpecCon for L0-L2 processing

EnMAP characterization

- EnMAP: German hyperspectral satellite sensor
- Launch planned end of 2020
- EnMAP instrument is developed by OHB
- We support OHB in sensor characterization



Light source developed to measure stray light of EnMAP (Courtesy A. Baumgartner)

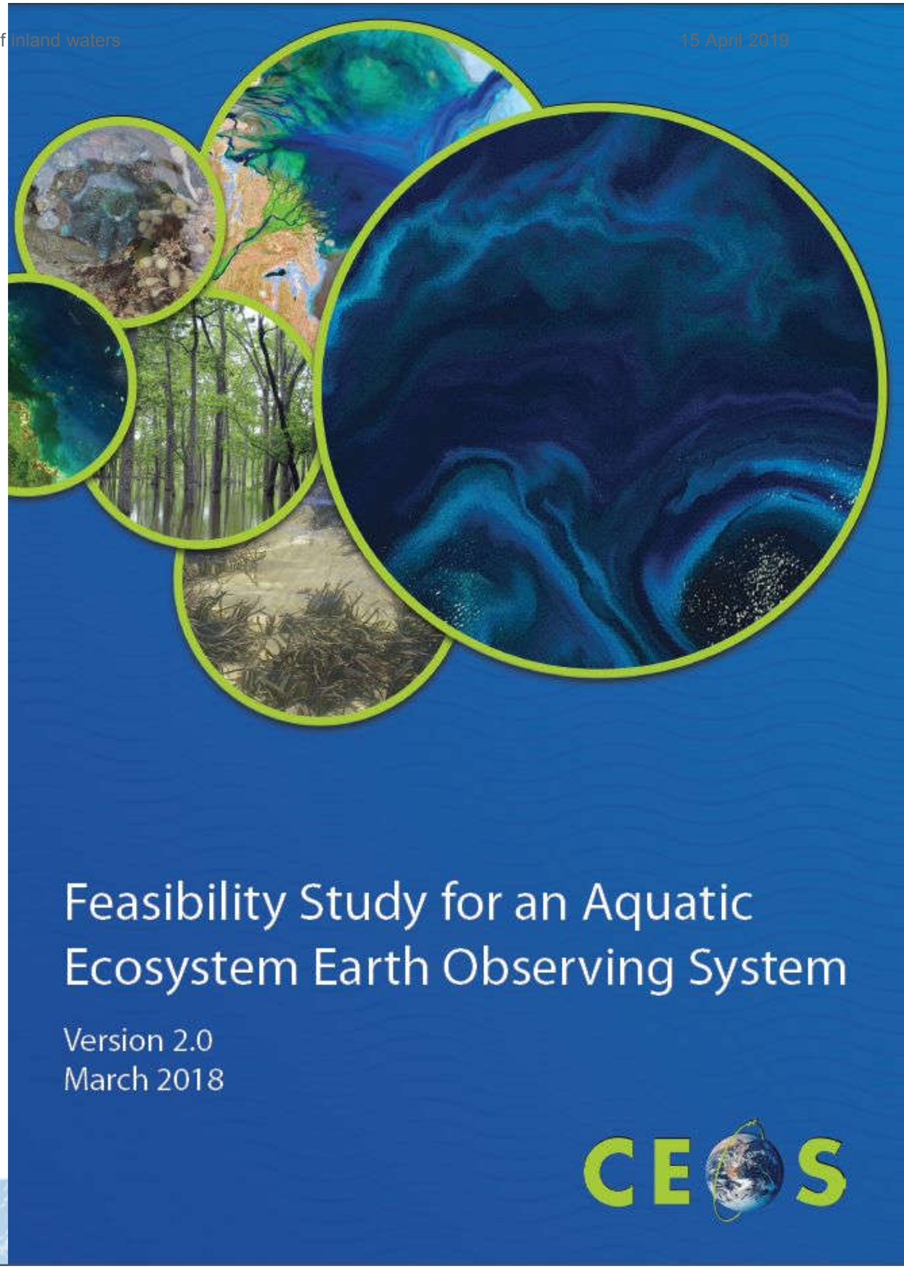


Expected stray light of EnMAP when illuminating a single detector element (Courtesy J. Brachmann)

Sensitivity analysis:
Sensor specification for aquatic satellite

- Key parameters
    - Concentrations: phytoplankton pigments, suspended matter, dissolved organic matter (CDOM)
    - Optical properties: phytoplankton fluorescence, absorption, backscattering, transparency
    - Others: water depth, bottom substrate type and coverage

- Sensor requirements
    - Spectral
    - Radiometric
    - Geometric
    - Temporal coverage

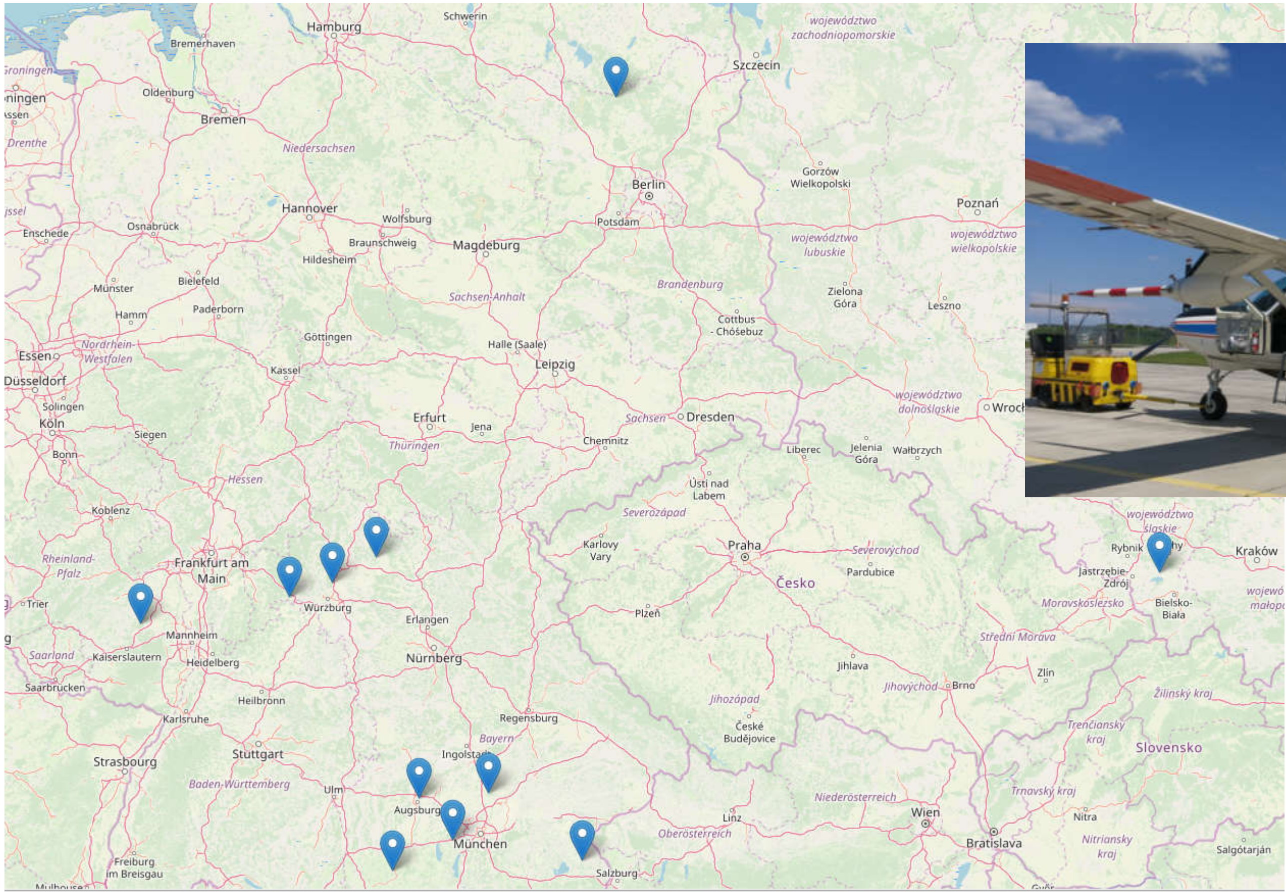


http://ceos.org/about-ceos/publications-2/

L1-L2: Data, Validation

Airborne campaigns for regional applications

OpAiRS: ISO certified service for airborne campaigns



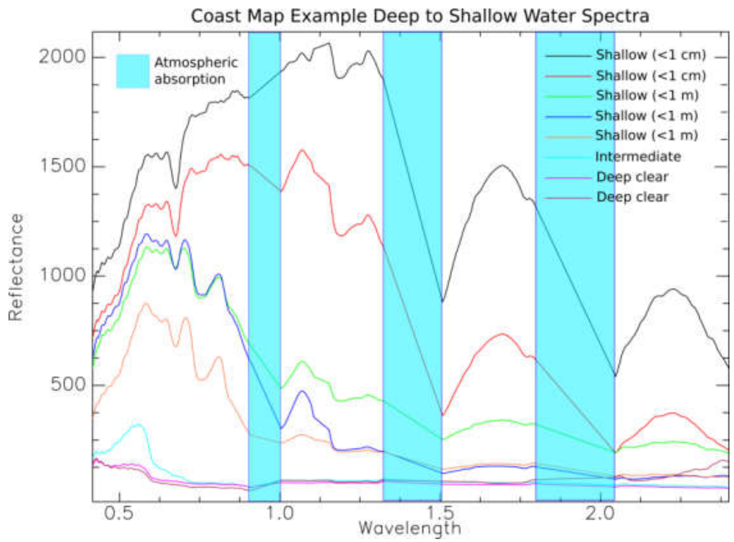
Airborne campaigns in 2018
(Courtesy C. Köhler)

Airborne campaigns for satellite data simulation
Simulation of EnMAP data

Courtesy M. Bachmann


Mosaic of 15 HySpex flight strips


Simulated EnMAP scene
Calculated by K. Segl (GFZ) using EeteS



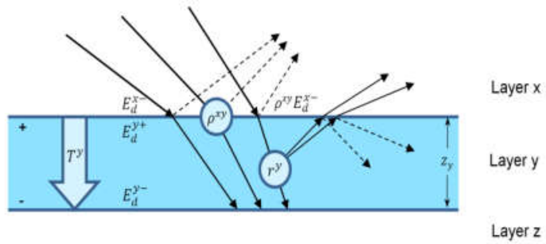
Reflectance spectra of water pixels
Water depths are estimated

Field campaigns for model development
Reflectance model of Arctic meltponds

Advantages of field spectrometer measurements compared to satellite data

- No errors from atmospheric correction
- Much better comparison with water samples
  - Temporal match-up: sampling can be nearly simultaneous
  - Spatial match-up: sampling can be at the same location
- Better spectral resolution
  - model errors can be better identified
- Variable measurement conditions
  - Above the surface / in water
  - Different viewing angles
  - Sunny, cloudy

Meltpond model



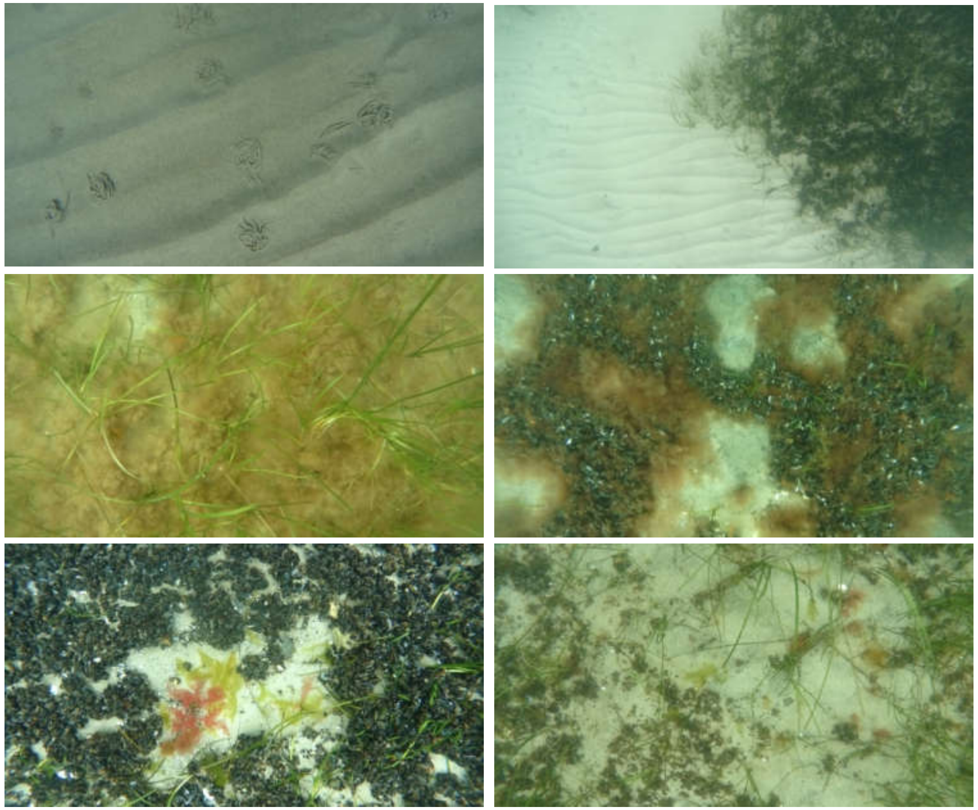
$$R^p = \rho^{ap} + \tau^{ap}\Big((1 - t_u^p T_d^p) r^{p,\infty} + t_u^p T_d^p \Big(\rho^{pi} + \tau^{pi}\Big((1 - t_u^i T_d^i) r^{i,\infty} + t_u^i T_d^i(\rho^{io} + \tau^{io} r^{o,\infty})\Big)\Big)\Big).$$

Polarstern cruise PS 106 (2017)

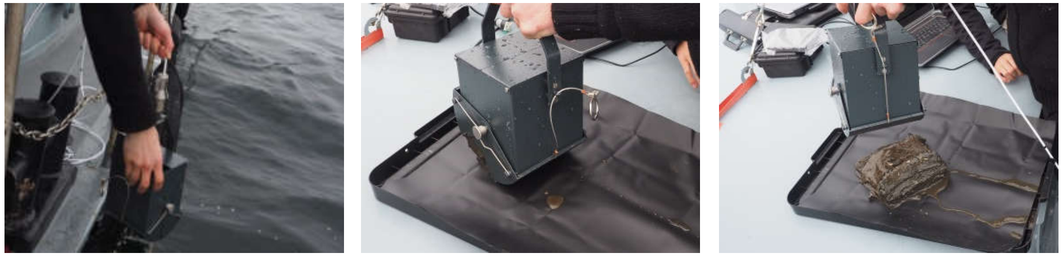
BRDF of ice

Reflectance of meltponds

Field campaigns for extending data bases
Reflectance of bottom substrates



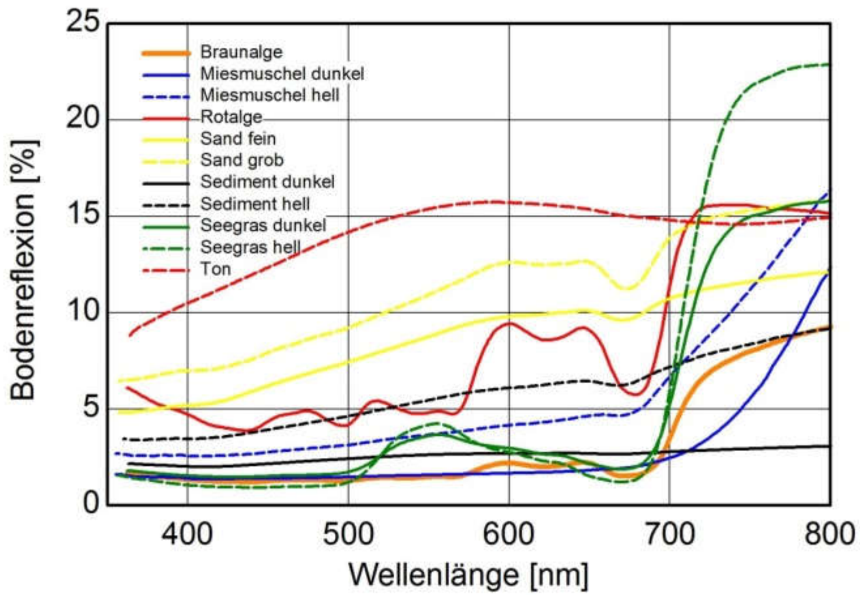
Diversity and heterogeneity of the seabed in the Baltic Sea



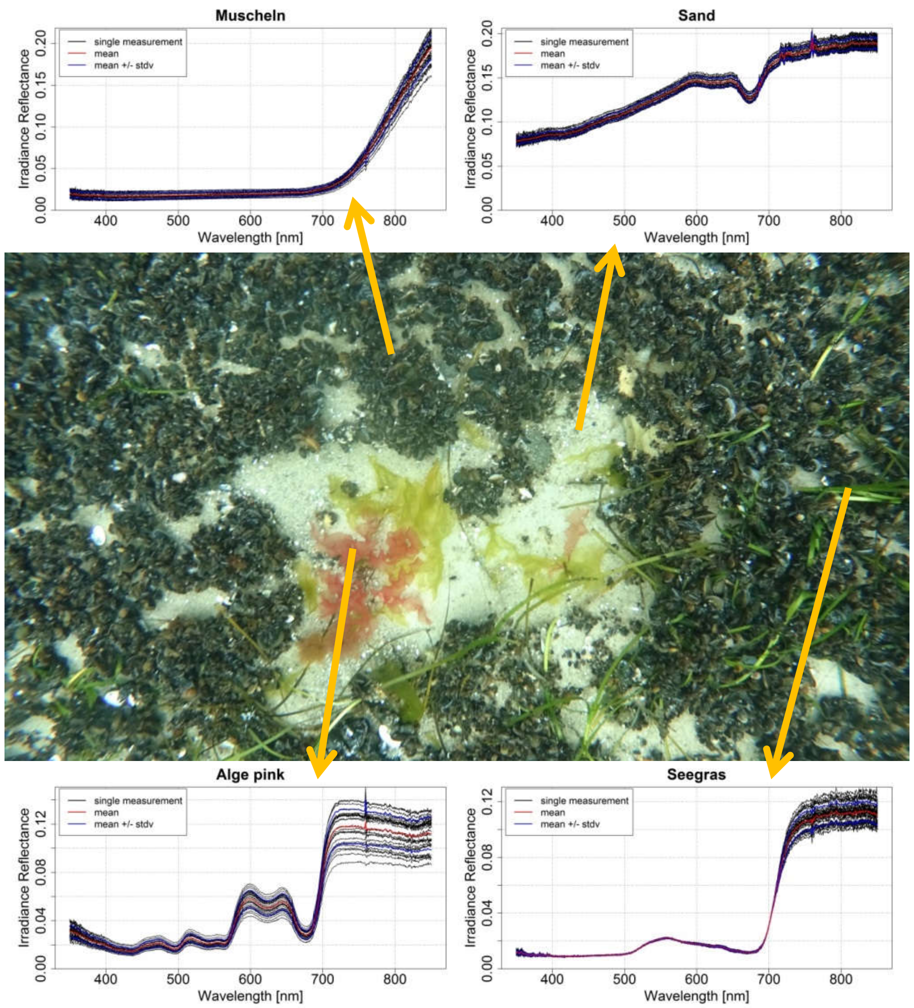
Substrate sampling with the Ekman-Birge sampler

Spectral measurement of a substrate sample

Field campaigns for extending data bases
Reflectance of bottom substrates



Spectral database of the Baltic Sea substrate types



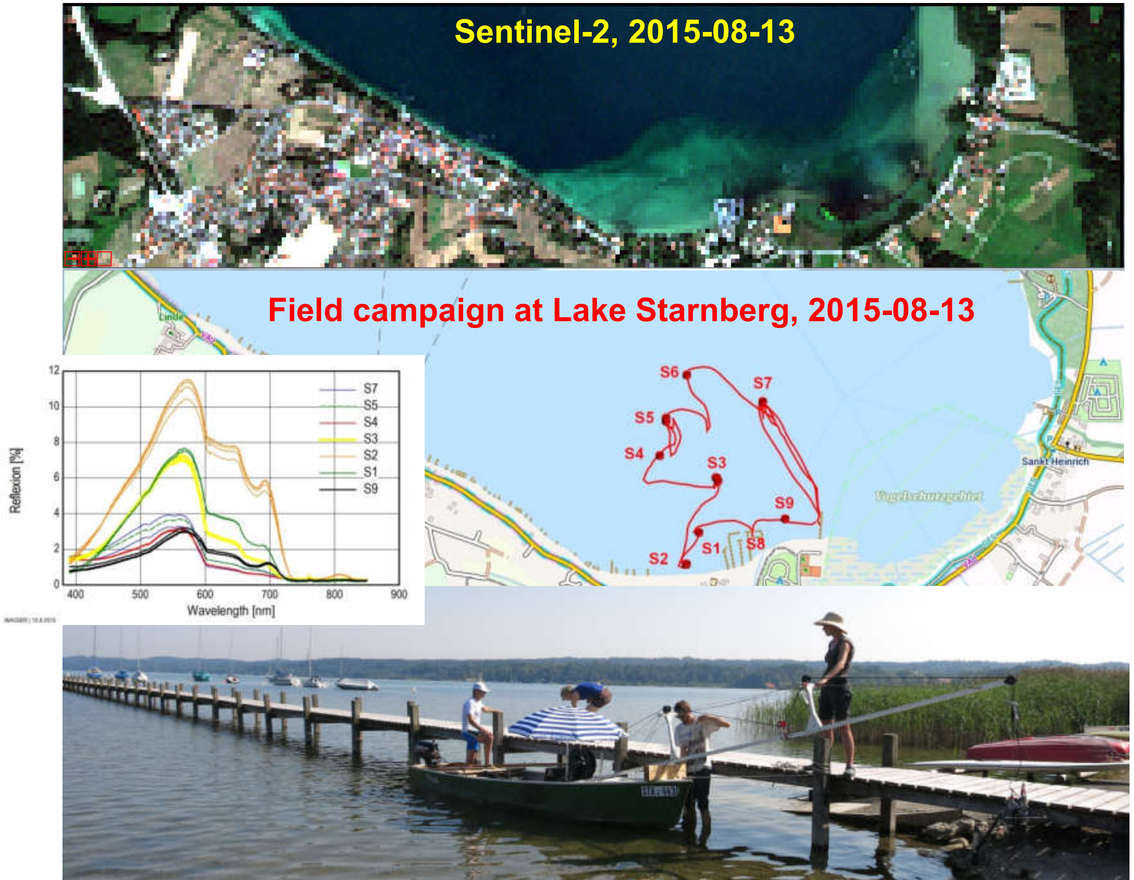
Diversity of the substrates and the associated reflectance spectra

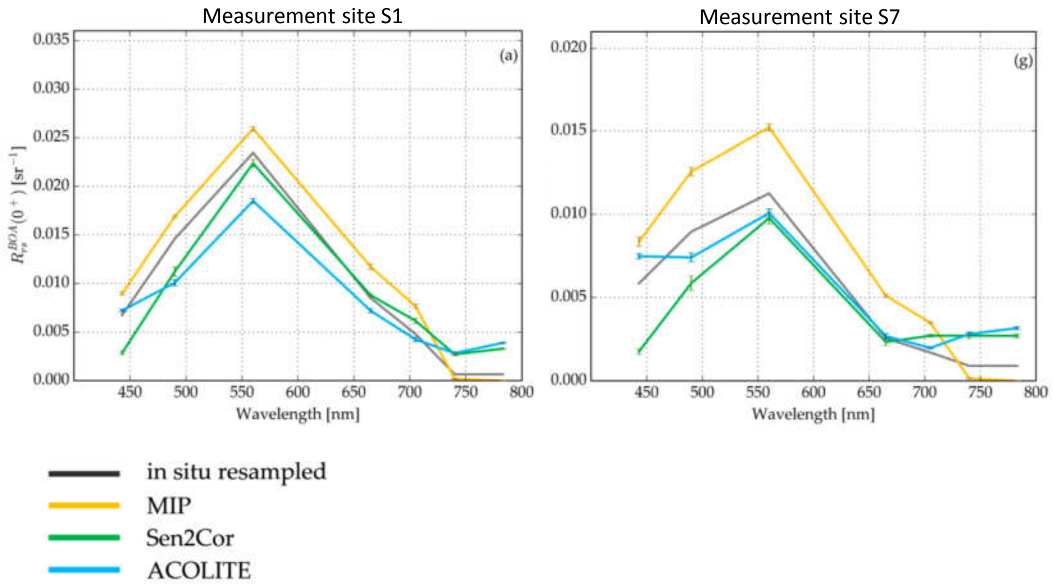
K. Schnalzger, 2017. Spektrale Datenbank für den Untergrund der Ostsee sowie Einfluss auf die Bestimmung der Wassertiefe. *Masterarbeit Universität Augsburg, 68 Seiten.*

DLR

Field campaigns for validation of L2 remote sensing data

Comparison of atmospheric correction models

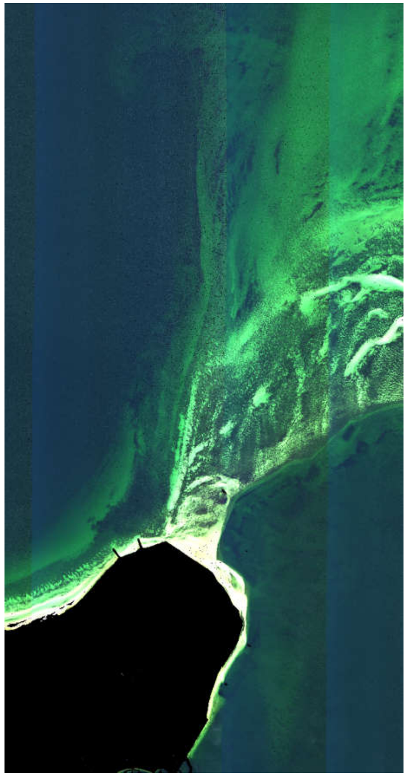




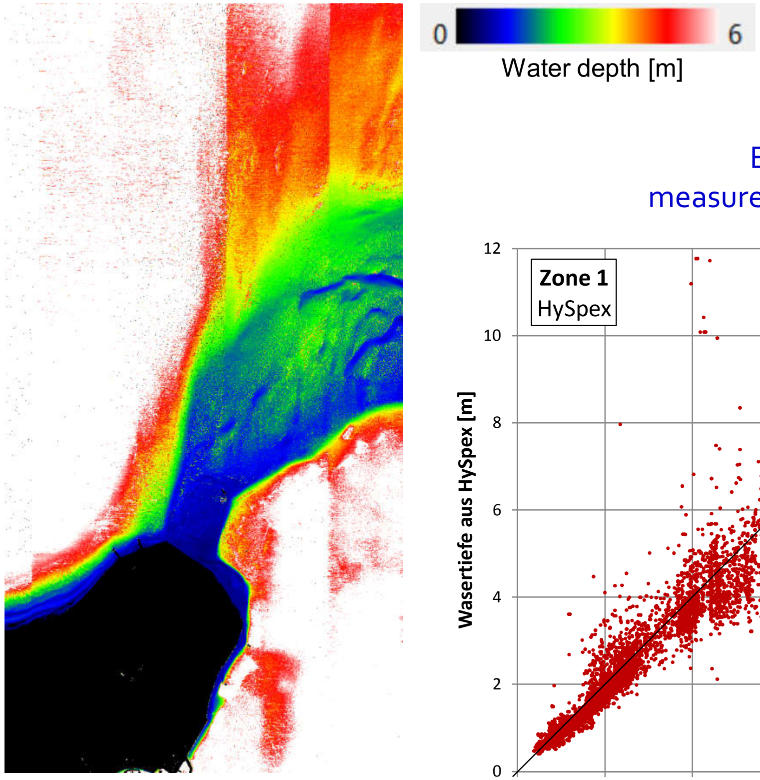
K. Dörnhöfer, A. Göritz, P. Gege, B. Pflug, N. Oppelt (2016): Water constituents and water depth retrieval from Sentinel-2A – a first evaluation in an oligotrophic lake. *Remote Sensing*, 8, 941. doi:10.3390/rs8110941

Field campaigns for validation of L3 remote sensing data

Bathymetry in the Baltic Sea derived from airborne data (HySpex)

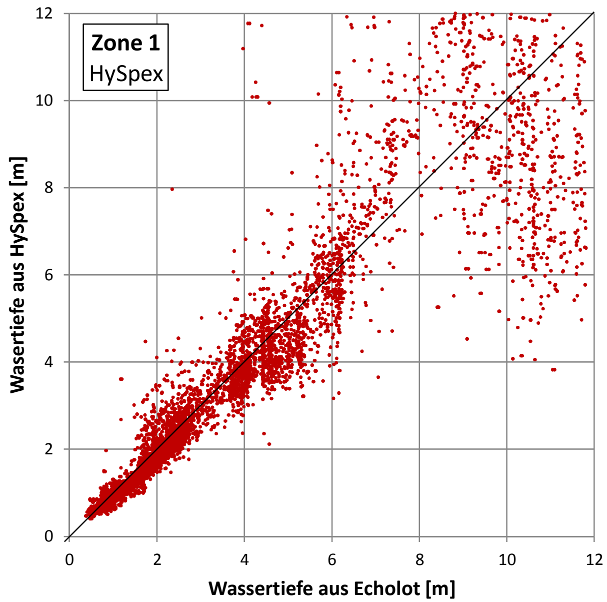


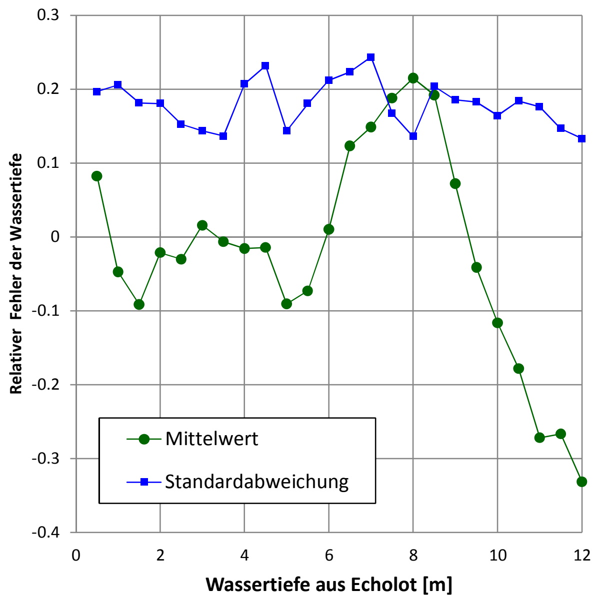
Baltic Sea coast near Wismar. HySpex 441, 549, 650 nm.



Water depth derived from HySpex data using WASI.

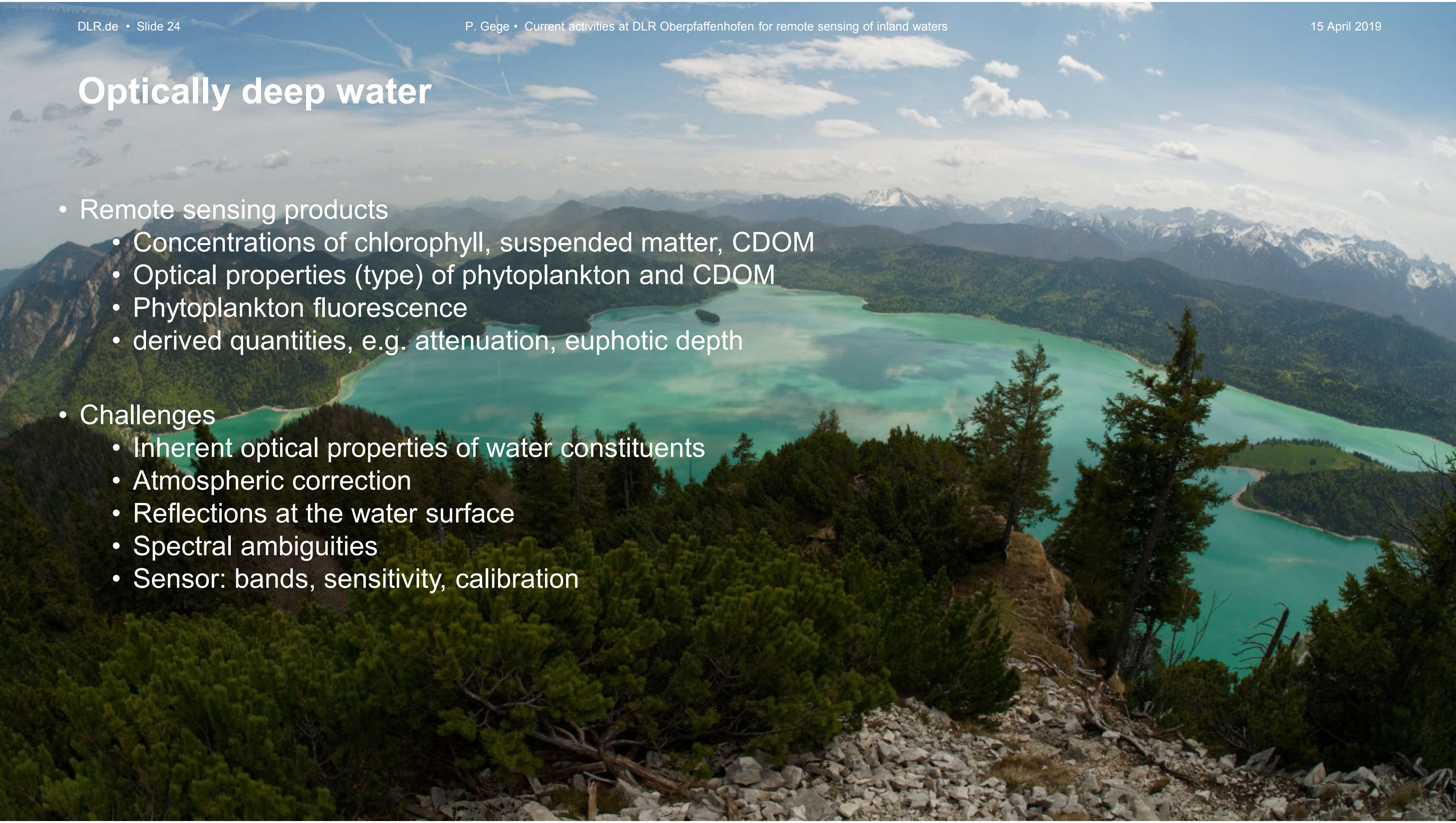
Echo sounding measurement by TUM





L2-L3: Models, applications

Optically deep water



- Remote sensing products
  - Concentrations of chlorophyll, suspended matter, CDOM
  - Optical properties (type) of phytoplankton and CDOM
  - Phytoplankton fluorescence
  - derived quantities, e.g. attenuation, euphotic depth
- Challenges
  - Inherent optical properties of water constituents
  - Atmospheric correction
  - Reflections at the water surface
  - Spectral ambiguities
  - Sensor: bands, sensitivity, calibration

Bio-optical models

Relationships between AOPs, IOPs and concentrations

- Irradiance reflectance (Gordon 1979: i = 1..3; Albert and Mobley 2003: i = 1..4

$$R(\lambda) = \frac{E_u(\lambda)}{E_d(\lambda)} = \sum_i f_i \left(\frac{b_b(\lambda)}{a(\lambda) + b_b(\lambda)}\right)^i$$

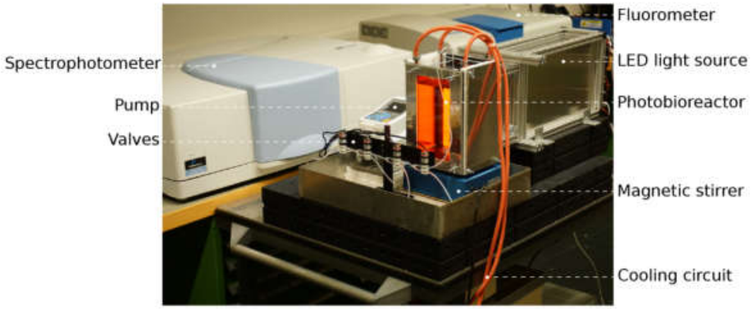
- Remote sensing reflectance (Lee et al. 1998, 1999: i = 1..2; Albert and Mobley 2003: i = 1..4)

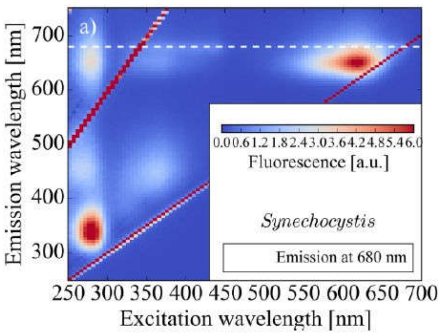
$$R_{rs}(\lambda) = \frac{L_u(\lambda)}{E_d(\lambda)} = \sum_i g_i \left(\frac{b_b(\lambda)}{a(\lambda) + b_b(\lambda)}\right)^i$$

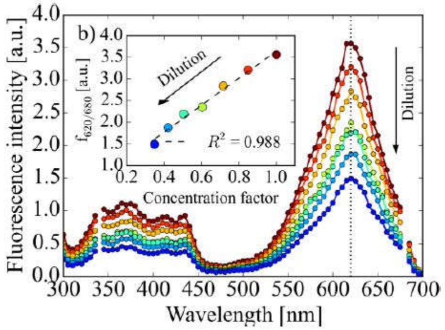
- $a(\lambda)$: absorption coefficient of water.
  Depends on type and concentration of water constituents.
- $b_b(\lambda)$: backscattering coefficient of water.
  Depends on type and concentration of water constituents.
- f_i, g_i: Geometry factors.
  Depend on sun zenith angle, viewing direction, wind speed, $a(\lambda)$ and $b_b(\lambda)$.
  WASI uses the parameterization of Albert and Mobley (2003).

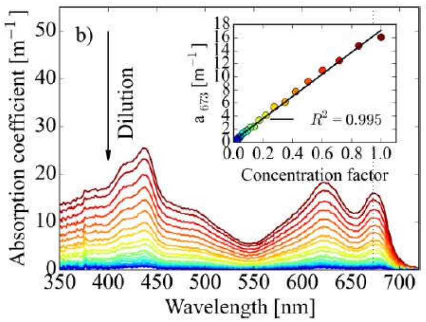
Inherent optical properties (IOPs)
Phytoplankton: Parameterization of absorption and fluorescence

Development of a bioreactor for the cultivation of phytoplankton under near-natural conditions







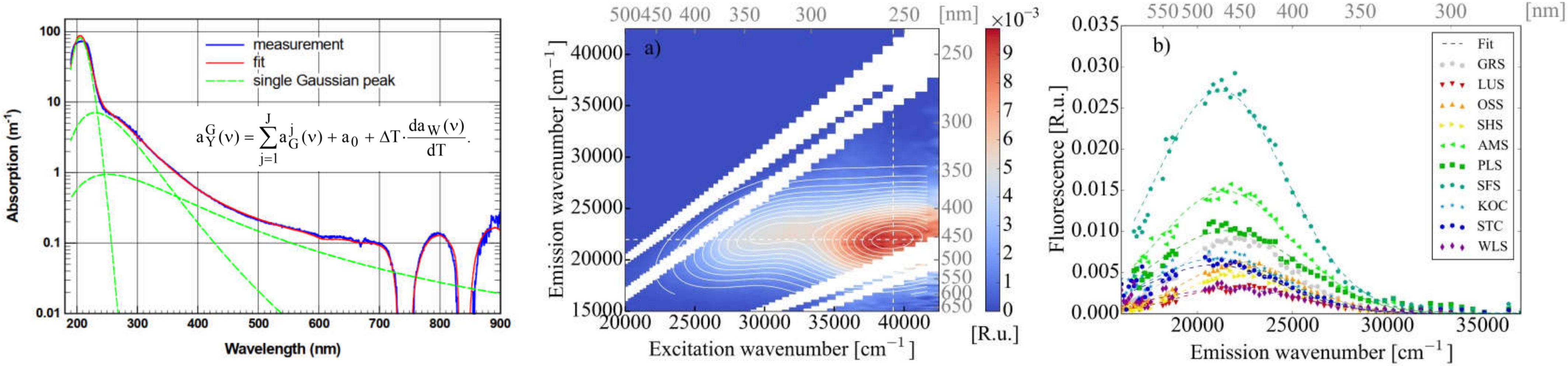


A. Göritz, S. von Hoesslin, F. Hundhausen, P. Gege (2017): ENVILAB: Measuring phytoplankton in-vivo absorption and scattering properties under tunable environmental conditions. *Optics Express 25(21), 25267-25277*. doi: 10.1364/OE.25.025267

Inherent optical properties (IOPs)

CDOM: Parameterization of absorption and fluorescence

Measuring and modelling absorption and fluorescence excitation-emission matrices



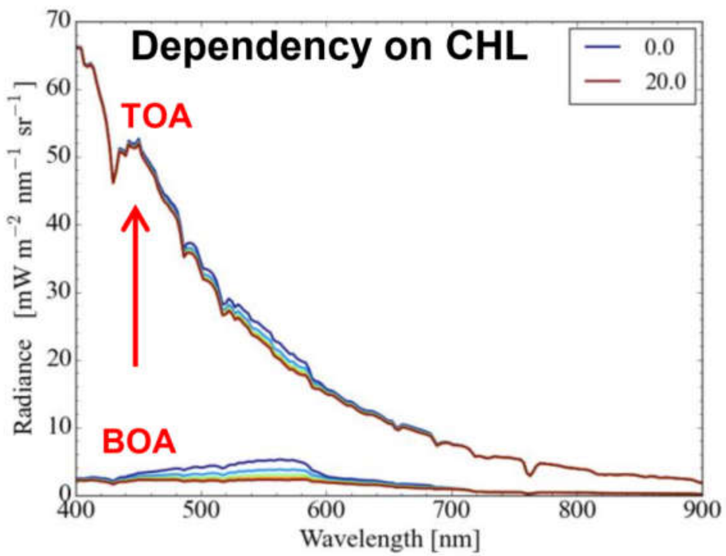
P. Gege (2000): Gaussian model for yellow substance absorption spectra. *Ocean Optics XV Conference, October 16-20, 2000, Monaco.*

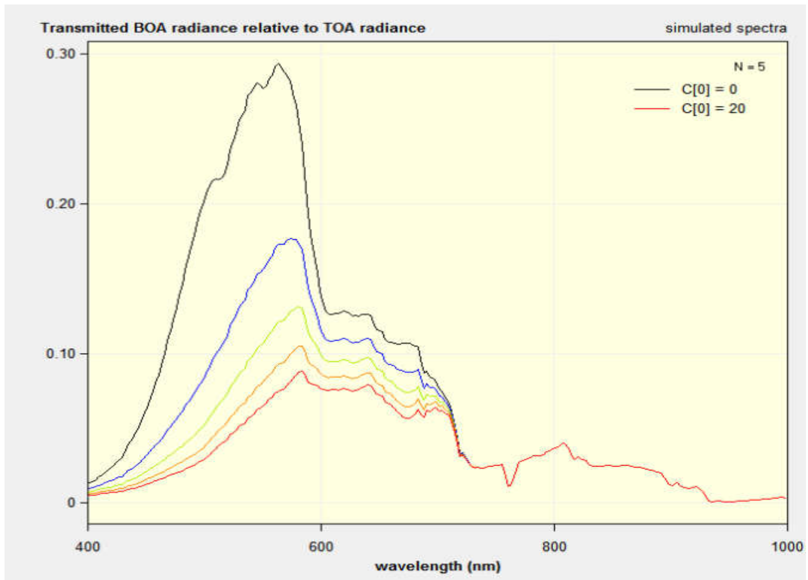
A. Göritz, P. Gege (2019): GLEAM: A spectral absorption and fluorescence model for dissolved organic matter in the UV-VIS. *In preparation*.

Atmospheric correction

- Water leaving radiance is usually an order of magnitude less than radiance of the atmosphere
- Accurate and reliable software for atmospheric correction of inland waters does not exist
- ATCOR is currently being adapted to water conditions

Simulations using MODTRAN and WASI.
Conditions: TSM 1 mg/l, CDOM 0.5 m^{-1},
Chl-a 0–20 µg/l, SZA 30°, VIS 100 km.

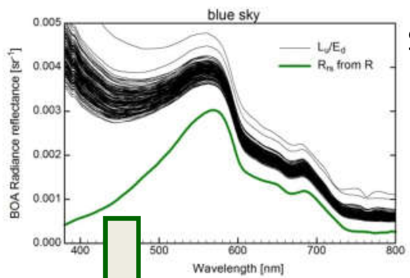




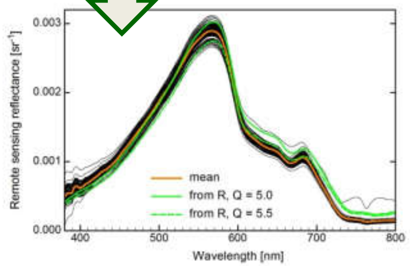
Correction of reflections at the water surface

- Sun glint and sky glint
  - Usually more light is reflected at the surface than in water
  - No reliable correction algorithm exists so far
  - Errors can be huge, making data analysis unreliable

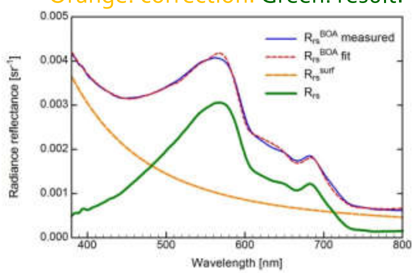
- Model for correction has been developed
  - Spectral model (not geometric as usual)
  - Accounts for atmospheric parameters
  - Models reflections from sun, blue sky, haze, clouds
  - Good results for field measurements and remote sensing data



Correction algorithm



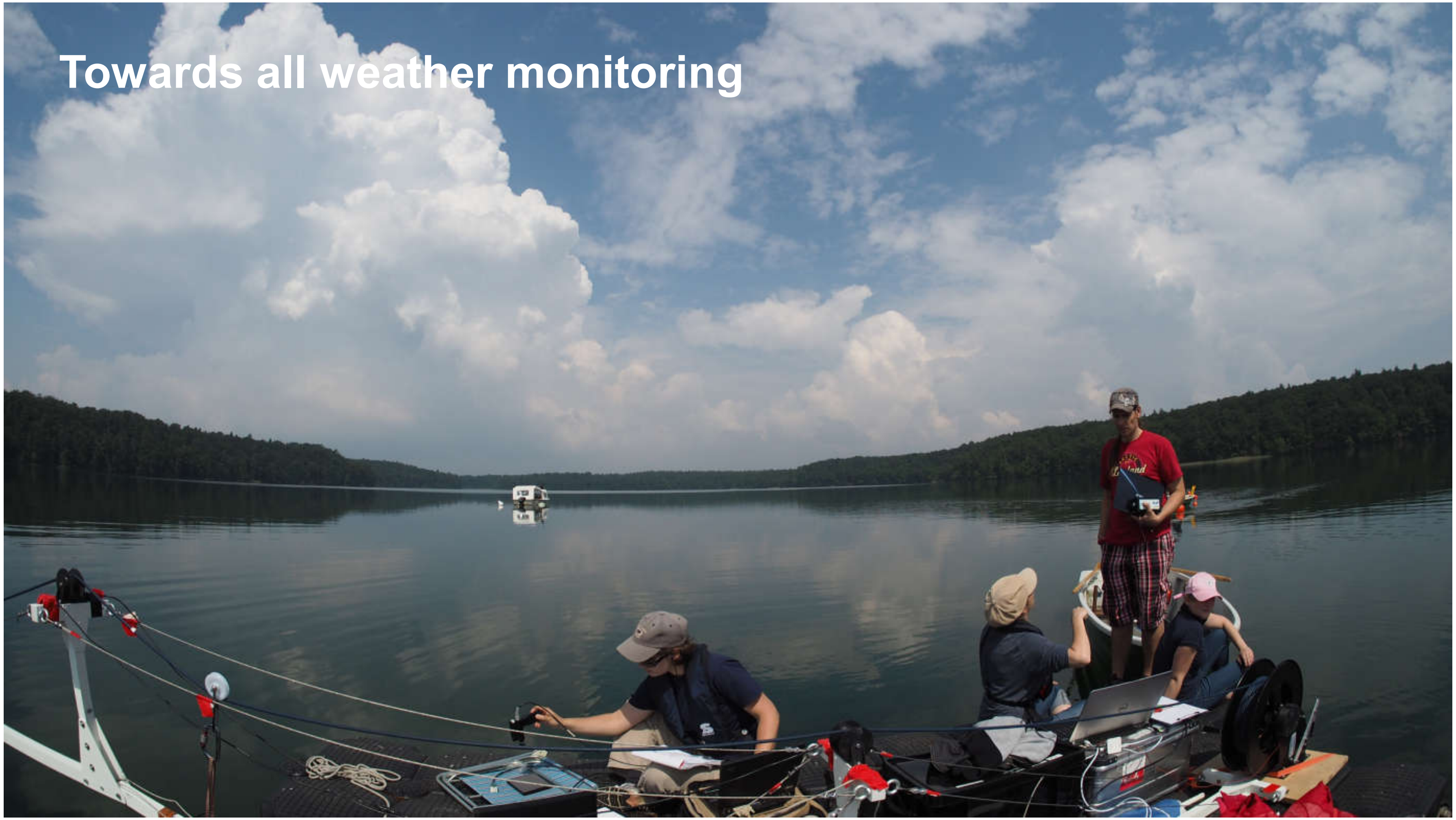
Blue: measurement. Red: fit.
Orange: correction. Green: result.



P.M.M. Grötsch, P. Gege, S.G.H. Simis, M.A.Eleveld, S.W.M. Peters (2017): Validation of a spectral correction procedure for sun and sky reflections in above-water reflectance measurements. *Optics Express 25, A742-A761*.

DLR

Towards all weather monitoring



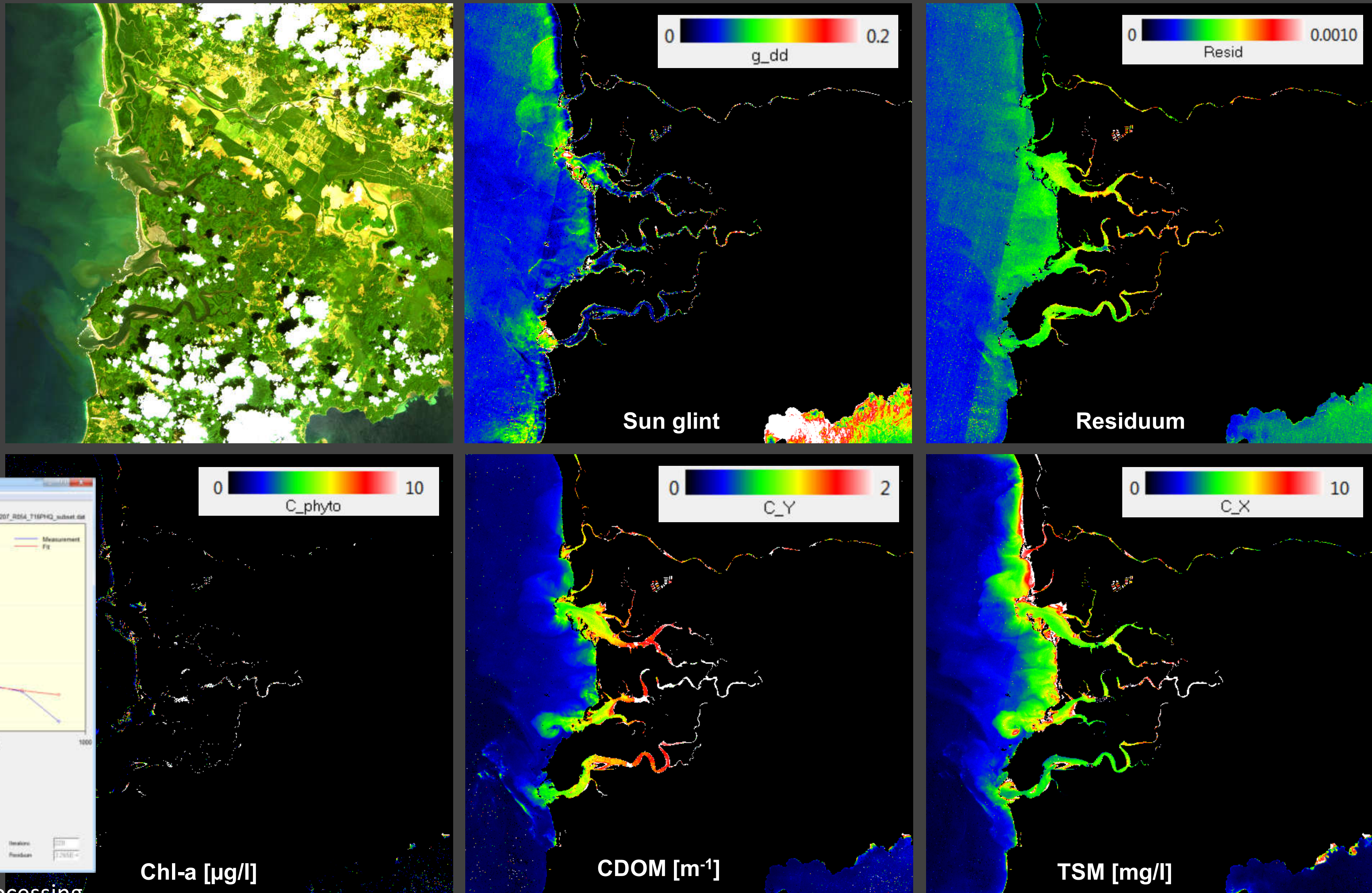
Field campaign at Lake Stechlin, 2016-05-31

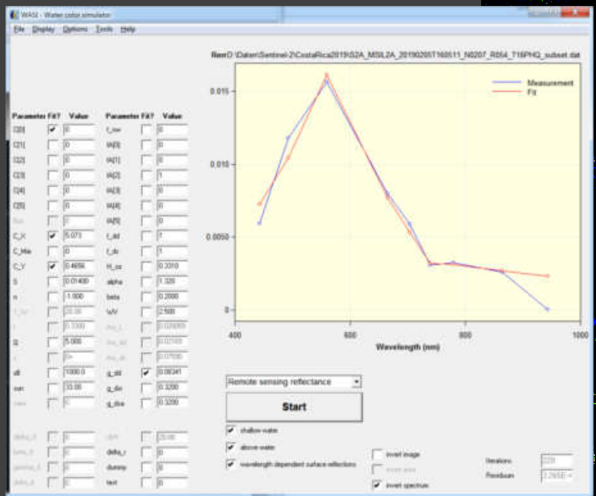
A. Göritz, S.A. Berger, P. Gege, H.-P. Grossart, J.C. Nejstgaard, S. Riedel, R. Röttgers, C. Utschig (2018): Retrieval of water constituents from hyperspectral in-situ measurements under variable cloud cover – A case study at Lake Stechlin (Germany). *Remote Sensing 10, 181.*

DLR

Analysis of satellite data

Sentinel-2
2019-02-05
Terraba Sierpe
Costa Rica



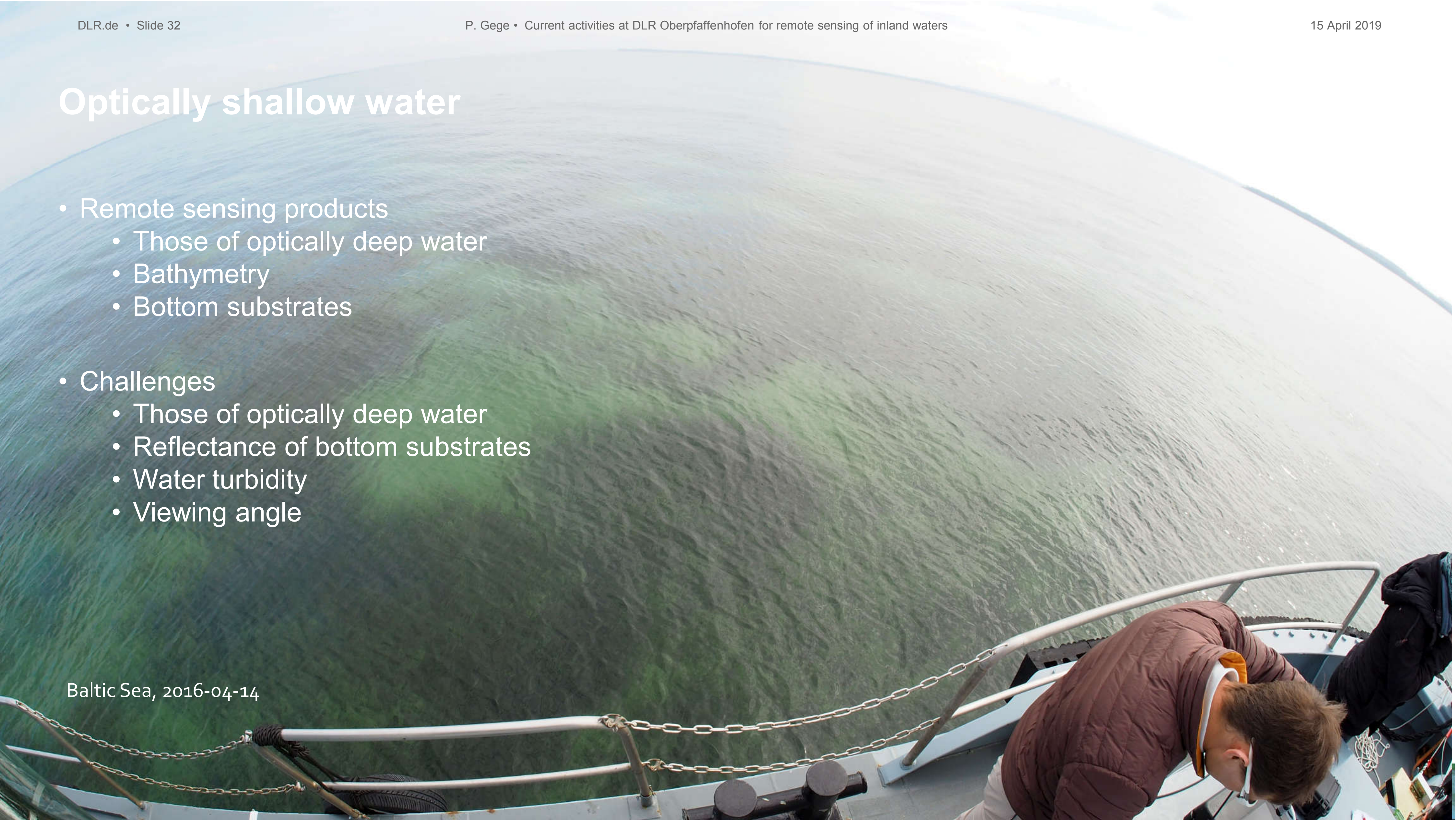


Screenshot of WASI during data processing

Optically shallow water

- Remote sensing products
  - Those of optically deep water
  - Bathymetry
  - Bottom substrates

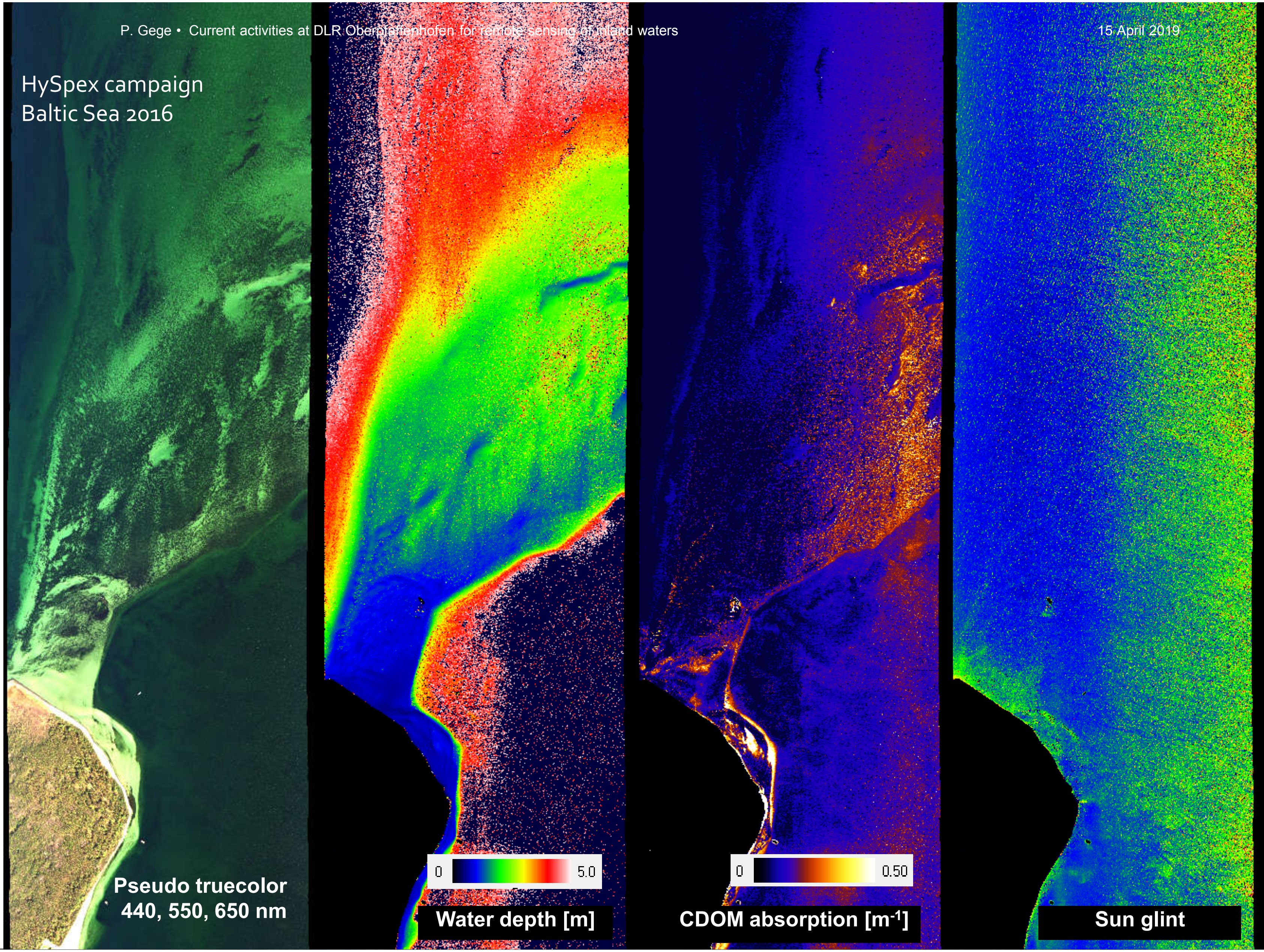
- Challenges
  - Those of optically deep water
  - Reflectance of bottom substrates
  - Water turbidity
  - Viewing angle



Baltic Sea, 2016-04-14

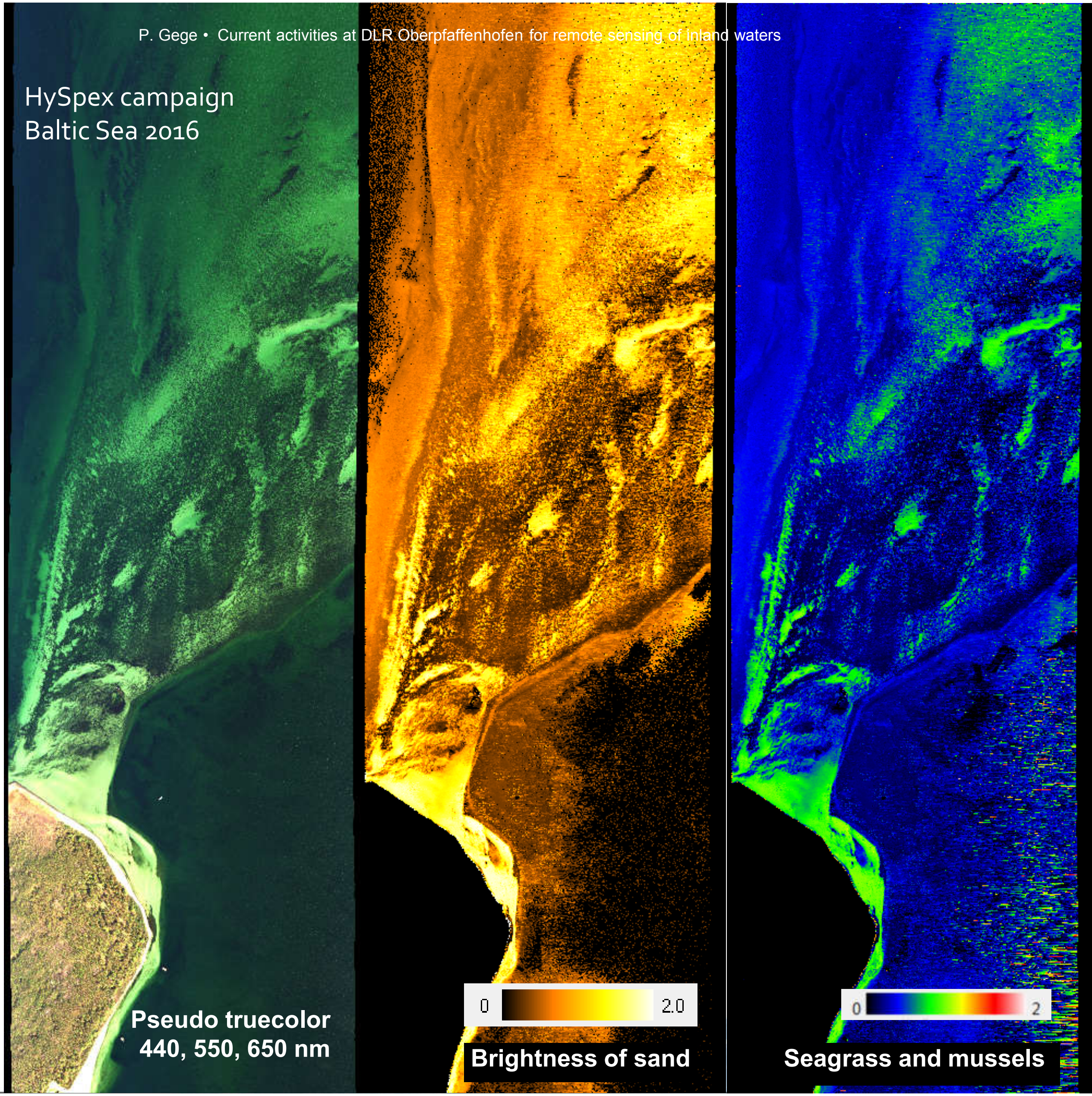
Shallow water

- Model development
- Spectral data base
- Inversion algorithm
- Validation



Shallow water

- Model development
- Spectral data base
- Inversion algorithm
- Validation



Software WASI

WASI
Water color simulator

✓Simulation and analysis of spectral measurements in water $(a, R_{rs}, E_d, L_u, \ldots)$

✓Bio-optical models for deep water [1] and shallow water [2]

✓Analytical model of downwelling irradiance

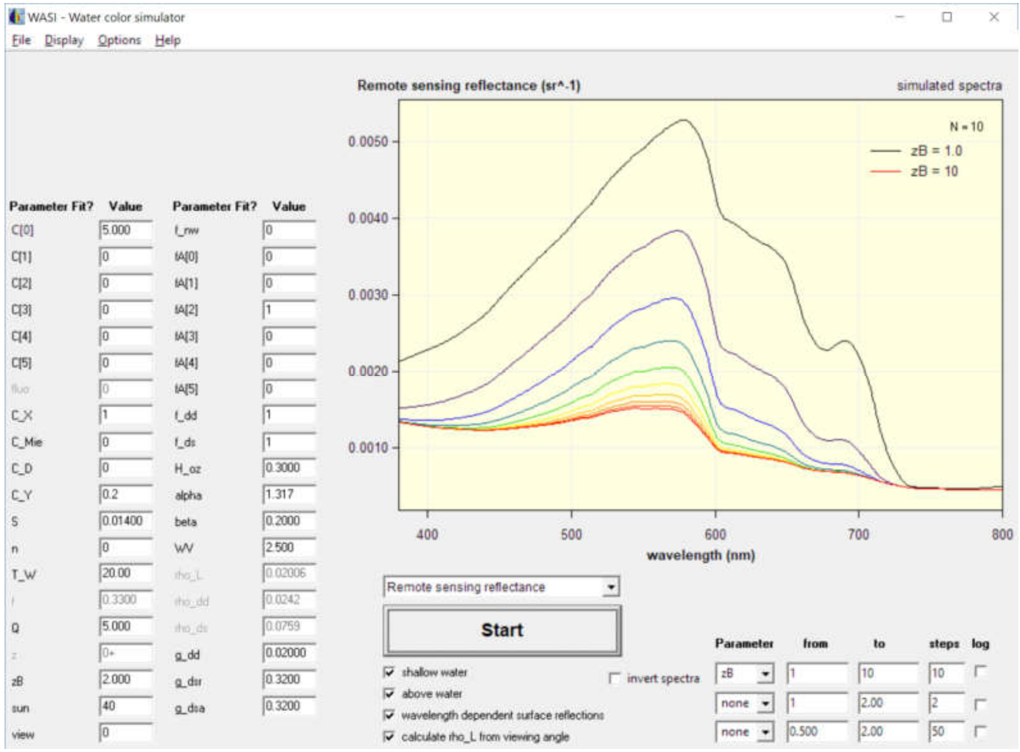
✓Elementary data base of SIOPs, bottom substrates, atmospheric absorbers

✓Physically traceable and transparent calculation steps

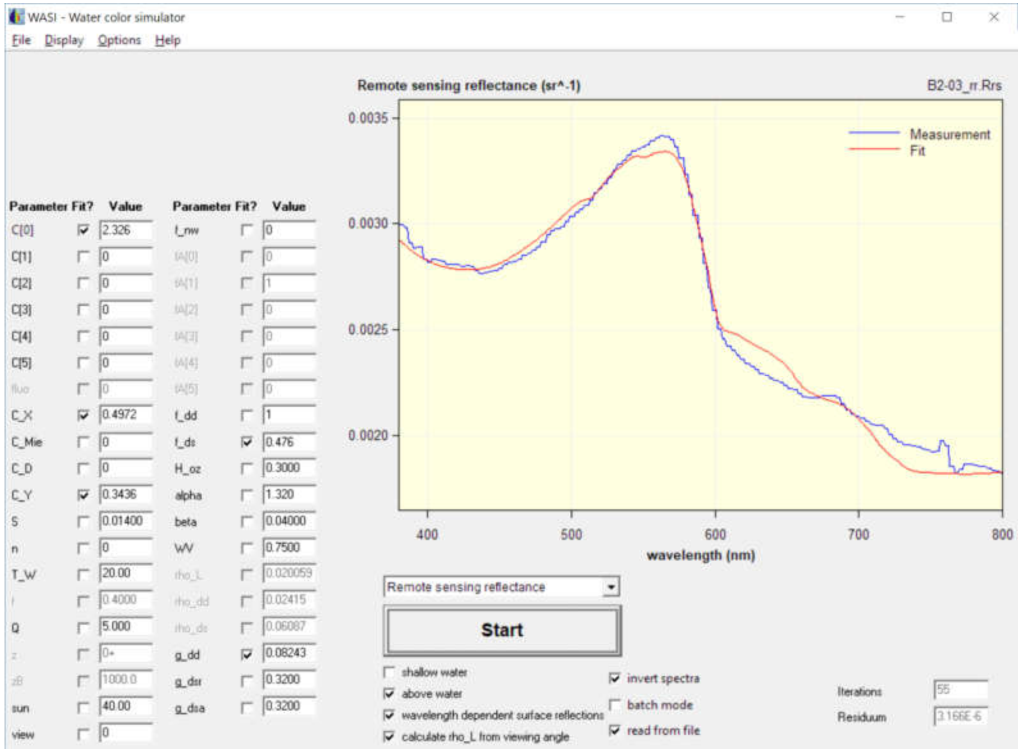
[1] P. Gege (2004): The water colour simulator WASI: An integrating software tool for analysis and simulation of optical in-situ spectra. *Computers & Geosciences 30, 523–532.*

[2] P. Gege, A. Albert (2006): A tool for inverse modeling of spectral measurements in deep and shallow waters. *In: L.L. Richardson and E.F. LeDrew (Eds): "Remote Sensing of Aquatic Coastal Ecosystem Processes: Science and Management Applications", Kluwer book series: Remote Sensing and Digital Image Processing, Springer, ISBN 1-4020-3967-0, pp. 81-109.*

WASI
Water color simulator



Forward mode: simulation of measurements



Inverse mode: analysis of measurements

WASI-2D
Module of WASI for local image data processing

✓widely customizable to local conditions

✓easily adaptable to any suitable sensor
- multispectral, hyperspectral (400–1000 nm)
- on satellite, aircraft, UAV ...

✓user can fine-tune all relevant steps

✓physically traceable

✓standard ENVI file format (BIL, BSQ)

– no uniform processing of global data sets

– input data must be atmospherically corrected
- requires sensor calibration
- minor errors from ac can be corrected

– not optimized for high speed

– requires a data base

– no support of sensor specific data formats

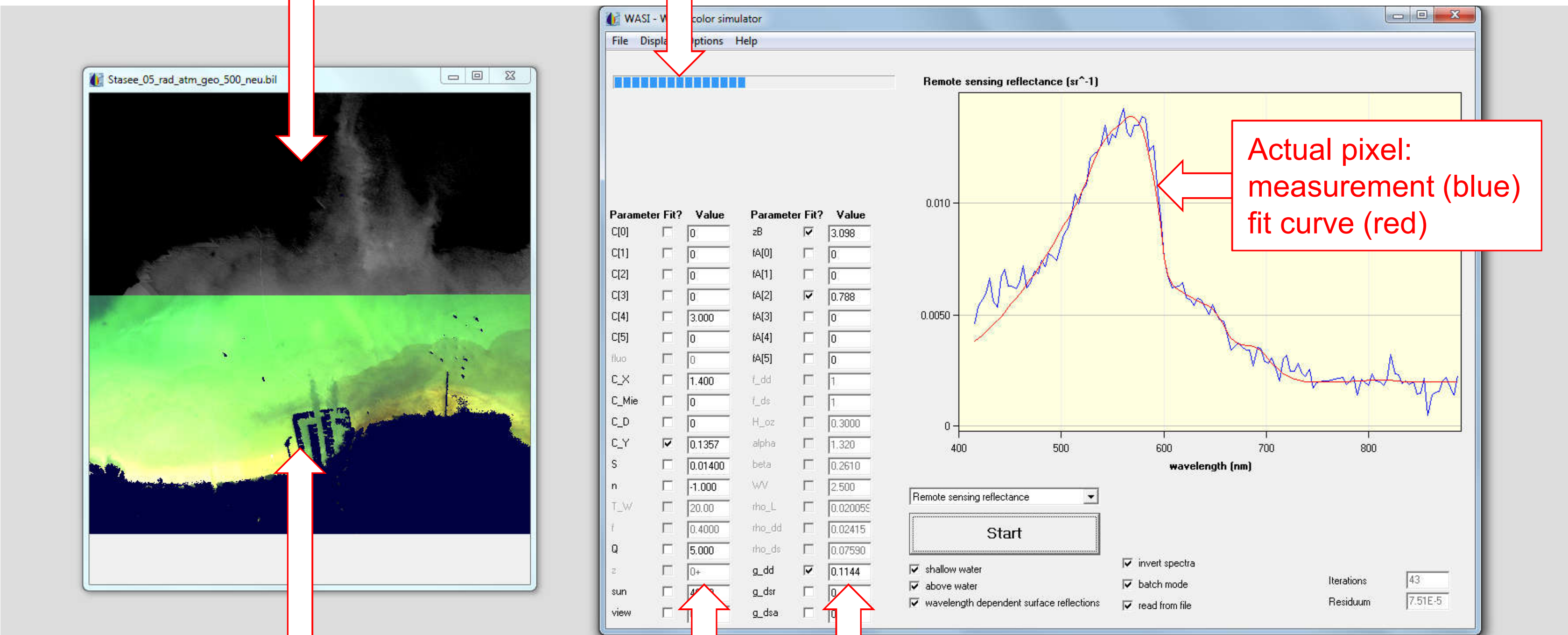
P. Gege (2014): WASI-2D: A software tool for regionally optimized analysis of imaging spectrometer data from deep and shallow waters. *Computers & Geosciences 62, 208-215*. http://dx.doi.org/10.1016/j.cageo.2013.07.022

WASI-2D

Module of WASI for local image data processing

Preview of selected fit parameter

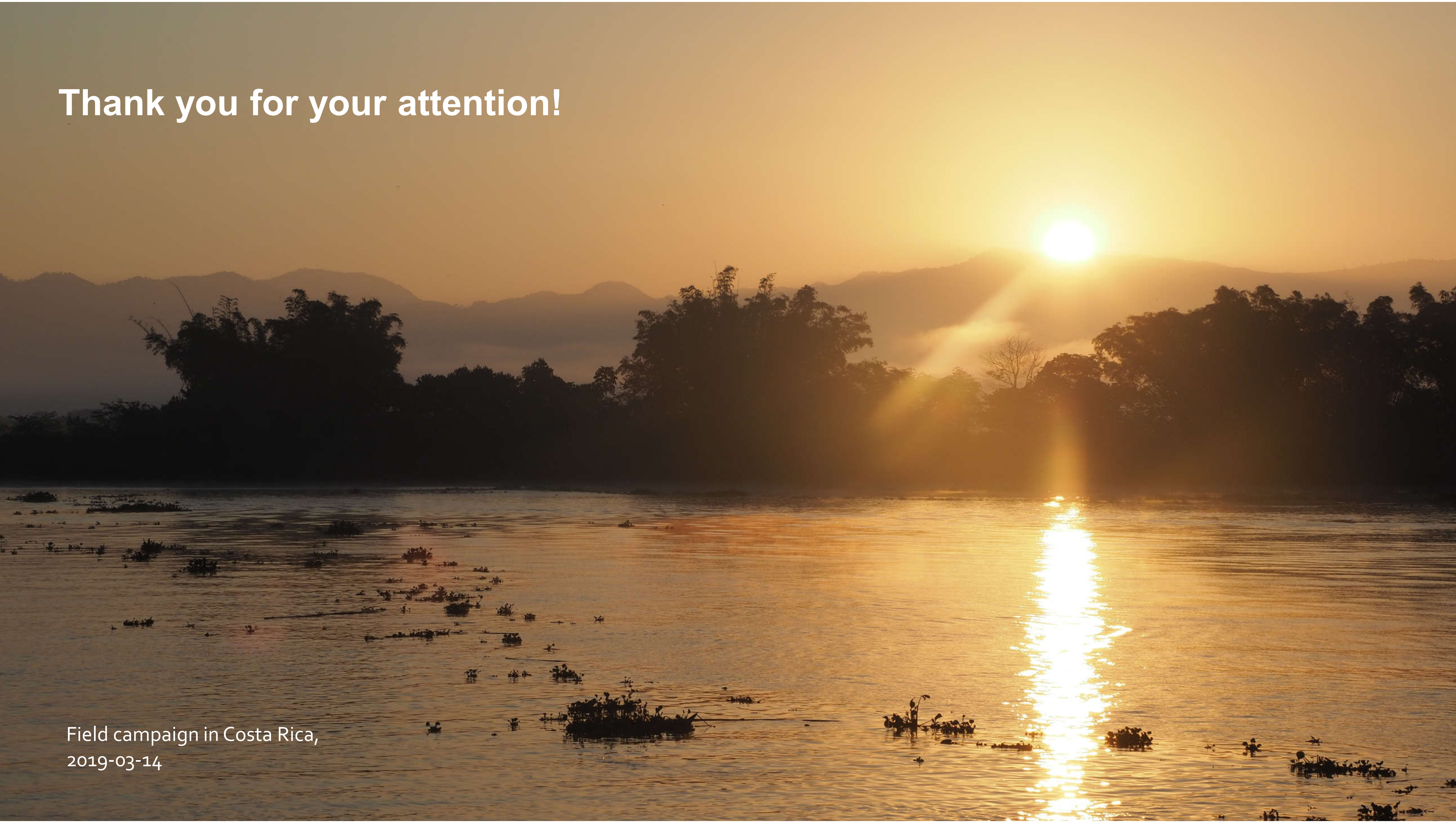
Progress bar



Actual pixel: measurement (blue) fit curve (red)

Image preview of 3 selected bands

Actual pixel: (fit) parameters


Thank you for your attention!
Field campaign in Costa Rica,
2019-03-14