MONOCLE

Multiscale Observation Networks for Optical monitoring of Coastal waters, Lakes and Estuaries

Atmospheric correction validation innovations from MONOCLE

Stefan Simis, Thomas Jordan, Nick Selmes, Thomas Jackson (PML),
Liesbeth de Keukelaere (VITO), John Wood (Peak Design)

with:

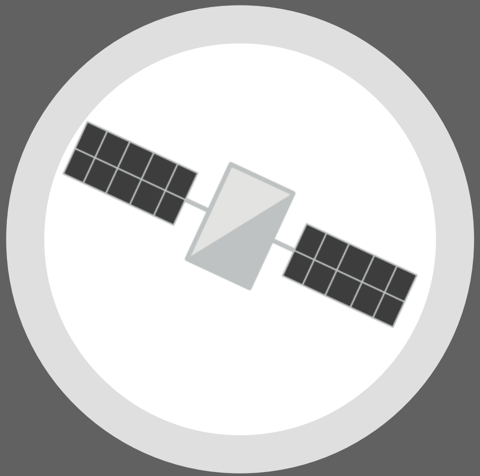
PML Plymouth Marine Laboratory | Universiteit Leiden | vito | University of Stirling | Earthwatch Institute
GeoEcoMar | CSIC Consejo Superior de Investigaciones Científicas | Water Insight | Sitemark | DDQ innovative mobile projects | Peak Design

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776480

Key objectives

More hyperspectral data urgently needed to characterize uncertainties of atmospheric correction

-> Lower the cost of in situ data collection

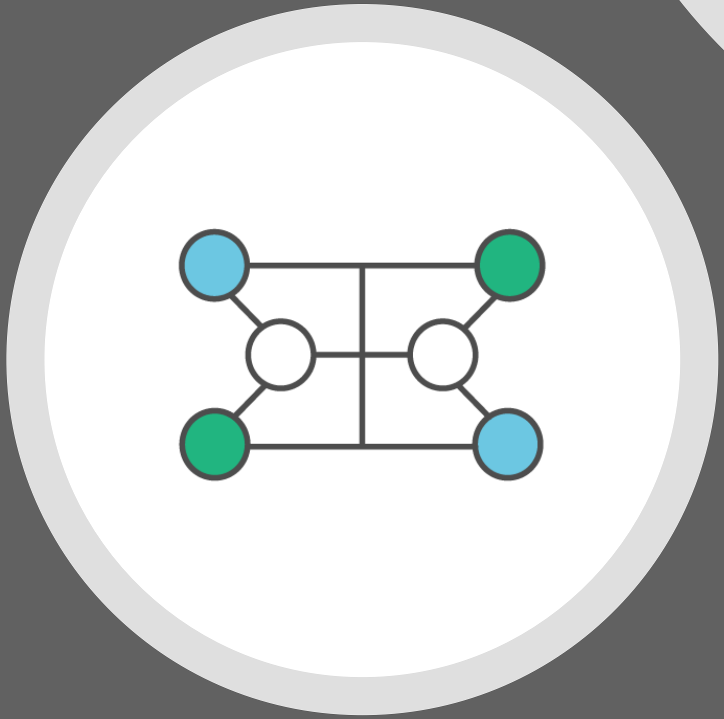


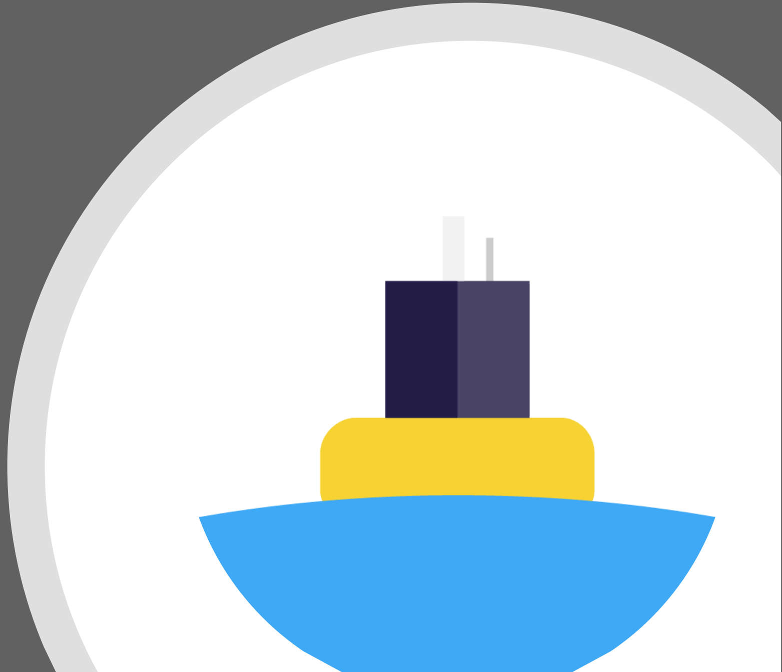
Focus:

- Optically complex lakes and coastal waterbodies
- Atmospheric and water radiometry

R&D:

- Autonomous reference systems
- High-resolution aerial systems
- Low-cost devices for citizen science

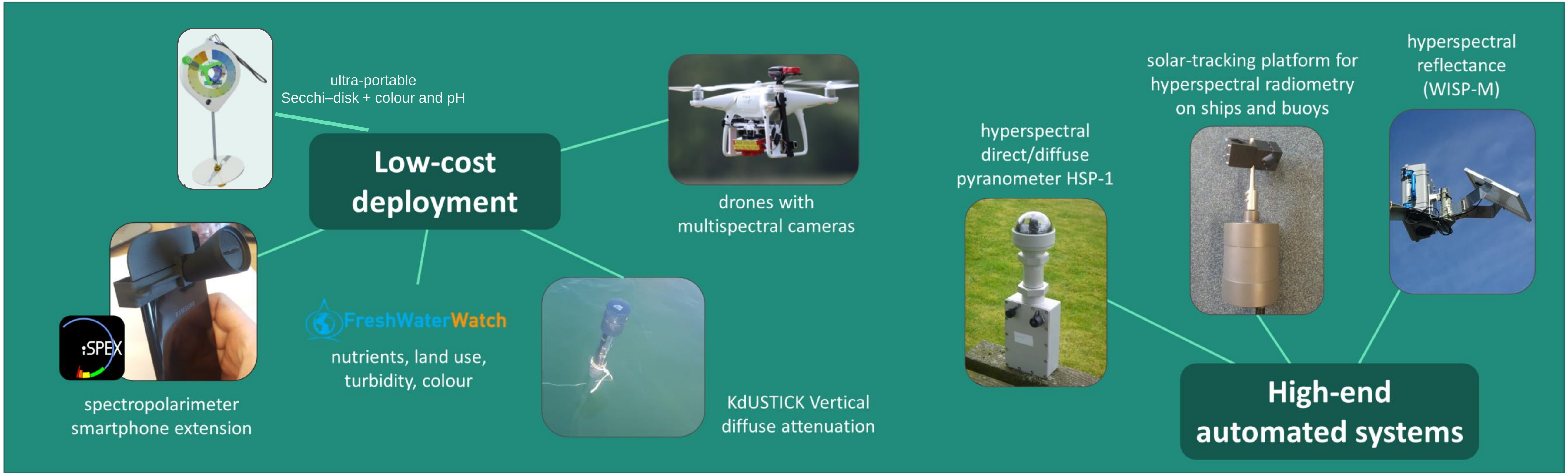




MONOCLE sensors and platforms

More participation:

More automation:



Technical specs, videos and training materials are available through
monocle-h2020.eu/Sensors_and_services

Data streams, not data sets

Example open-source software stack for (most) MONOCLE instruments:

Parse

mapEO

PostgreSQL

GeoServer

Data Processing
- Calibrations
- Quality Control
- Monitoring
- Alerting

Sensors and Apps
Generate data + all metadata in situ

Backend receives unstructured and semi-structured data

Data are calibrated and stored in **structured** formats, **GeoServer** exposes data publicly if data license allows. Traceable calibrations.

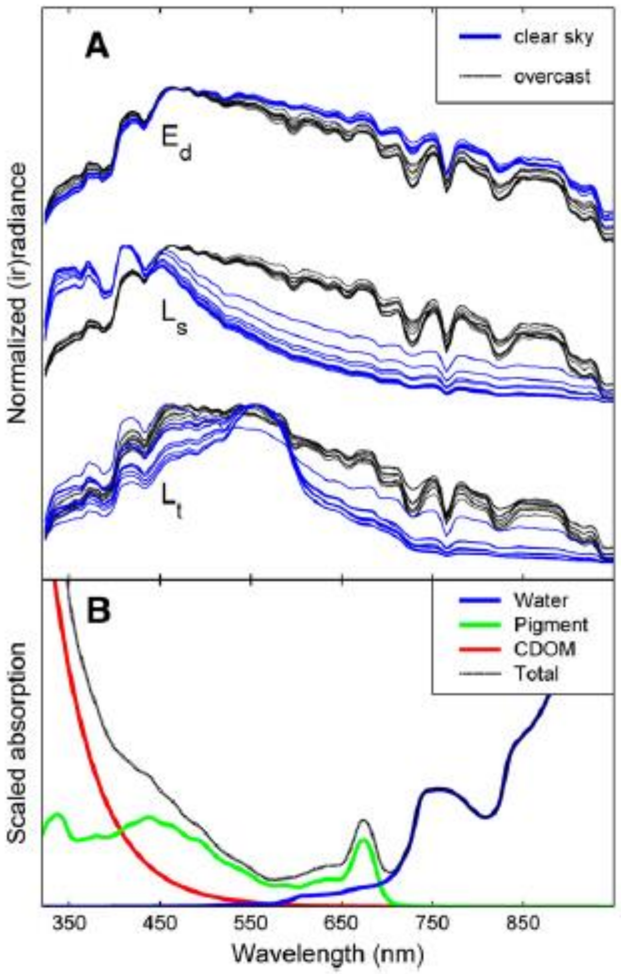
User then points script or GIS at layer of interest

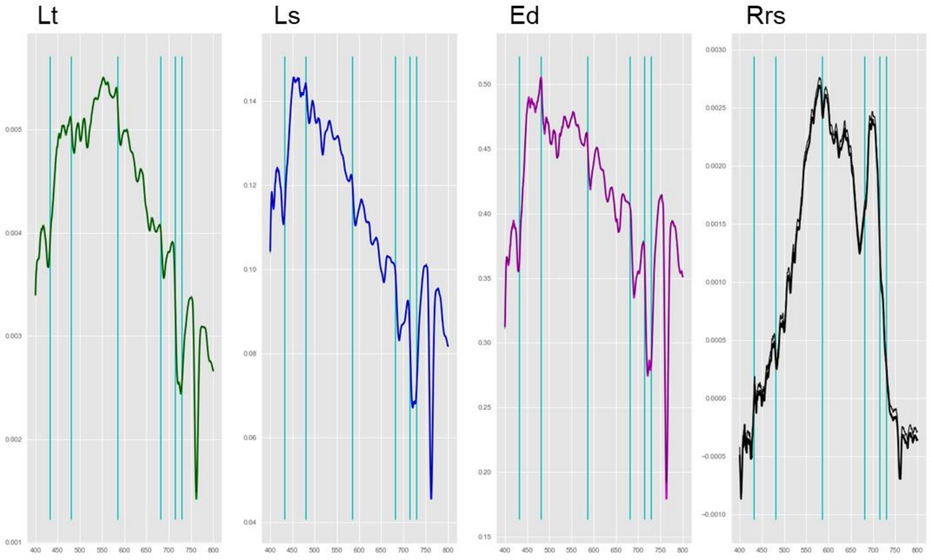
Instantaneous processing helps operators monitor data quality

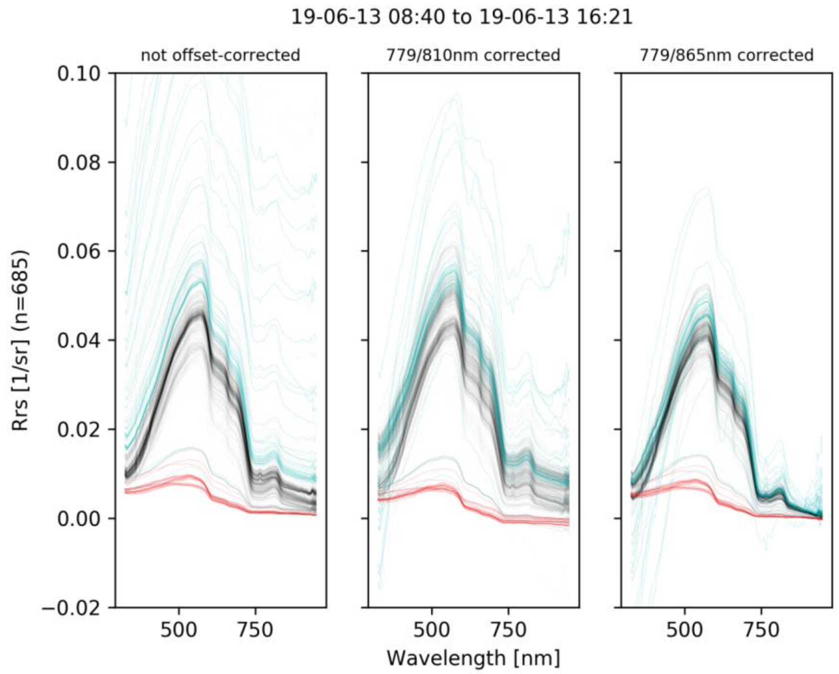
Automated Reflectance estimates (option 1)

Fingerprint method (fully naïve)

Simis and Olsson 2013, RSE







- No water-column optical model
- Optimizes for a spectrally neutral ρ_s (ρ^{eff}_F)
- Best results with UV-A and NIR included and when combined with NIR offset correction
- Used in several comparative AC evaluations (e.g. ACIX-II) and lines up well with AERONET-OC in regional analyses (e.g. Baltic Sea)
- Current version uses native sensor resolution to avoid convolution errors

Black – valid solution
Cyan – no solution (lower bound)
Red – no solution (upper bound)

Automating Reflectance estimates (option 2)

3C algorithm (Groetsch et al. 2017): R_{rs} derived from spectral optimization using water (Albert & Mobley, 2003) and atmospheric (Gregg & Carder, 1990) models, with user-defined fixed or bounded components in each.

Spectral-offset, Δ(λ): represents `additional spectral' basis functions (E_{dd}/E_d, E_{ds}/E_d) to perform glint correction.

Rationale: improved estimation of R_{rs} when L_s/E_d is not representative of surface-reflected radiance (i.e. wind-roughened surface, partial cloud cover).

Current limitation: spectral shape of E_{dd}/E_d and E_{ds}/E_d based on model inversion (using clear-sky model).

Conventional above-water R_{rs} equation:

$$R_{rs}(\lambda) \equiv \frac{L_w(\lambda)}{E_d(\lambda)} = \frac{L_t(\lambda)}{E_d(\lambda)} - \rho_s \frac{L_s(\lambda)}{E_d(\lambda)} - \delta,$$

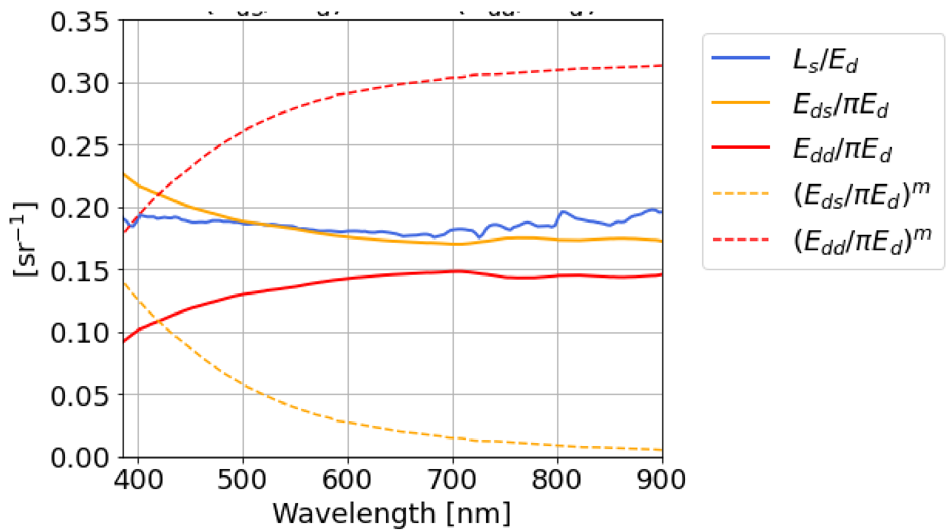
R_{rs} equation in 3C:

$$R_{rs}(\lambda) \equiv \frac{L_w(\lambda)}{E_d(\lambda)} = \frac{L_t(\lambda)}{E_d(\lambda)} - \rho_s \frac{L_s(\lambda)}{E_d(\lambda)} - \Delta(\lambda),$$

$$\Delta(\lambda) = \frac{\rho_{dd}}{\pi} . \left(\frac{E_{dd}(\lambda)}{E_d(\lambda)} \right)^m + \frac{\rho_{ds}}{\pi} . \left(\frac{E_{ds}(\lambda)}{E_d(\lambda)} \right)^m,$$

Example of `glint basis functions':

Dashed: model-optimized in 3C
Solid: measured by HSP



Data experiments (autonomous systems)

Synergy from along-track radiometry instruments

- So-Rad (Solar tracking Radiometry platform): L_s, L_t, E_d -> R_{rs}
- HSP1 (Hyperspectral Pyranometer): E_{ds} & E_{dd}

Experiment 1: Improved in situ R_{rs} combining So-Rad and HSP1?

- Modification of R_{rs} optimization algorithm (3C) to incorporate direct-diffuse irradiance from the HSP
- Illustration of improved precision in R_{rs}

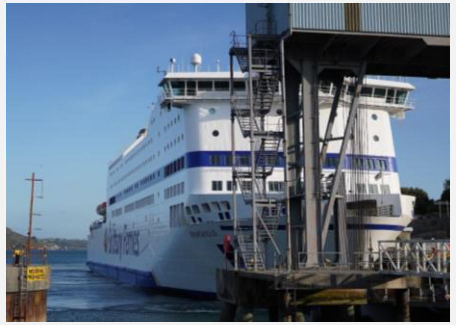
Experiment 2: Attribution of atmospheric correction uncertainty

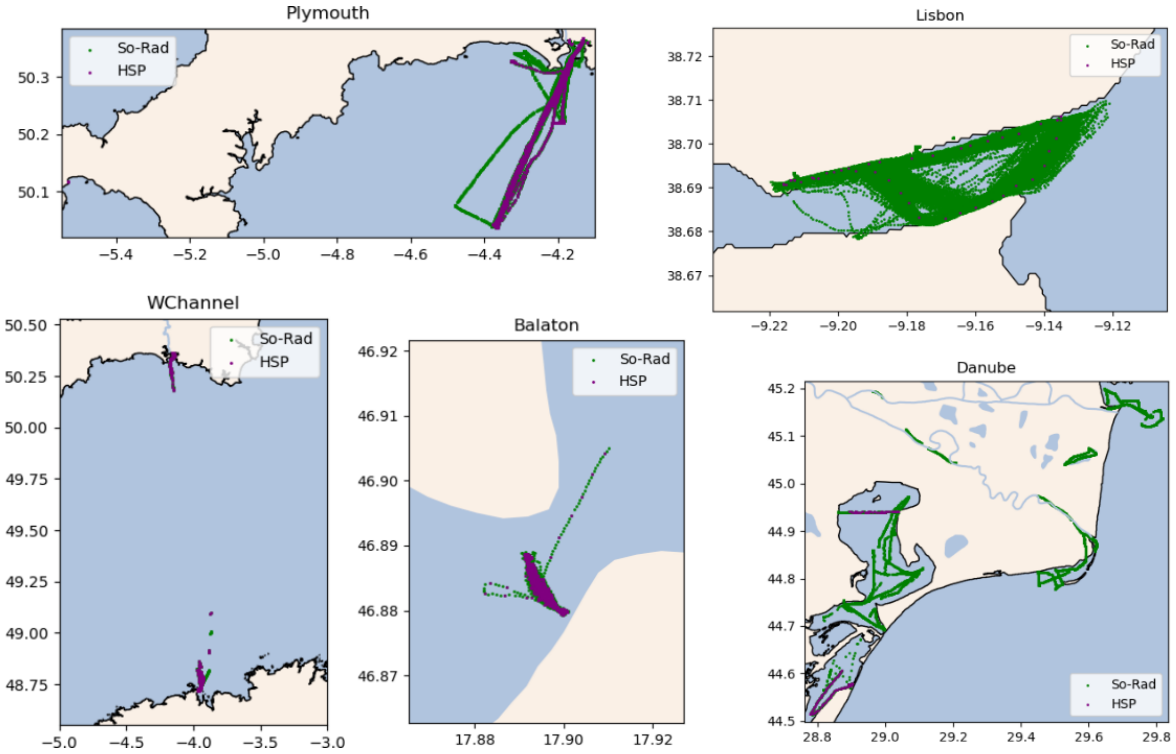
- Bias between in situ and satellite-derived R_{rs} as function of (hyperspectral) Atmospheric Optical Thickness

Data collection

HSP1 alongside So-Rad equipped with TriOS RAMSES sensors, recording spectral (ir)radiance, viewing geometry, location, heading and tilt whilst optimizing relative azimuth angle to sun (target 135°)

Operated on a car ferry (Lake Balaton), a tourist boat (Lisbon), a Ro-Ro ferry (Plymouth-Roscoff) and small and medium research vessels (Western Channel, Danube delta).



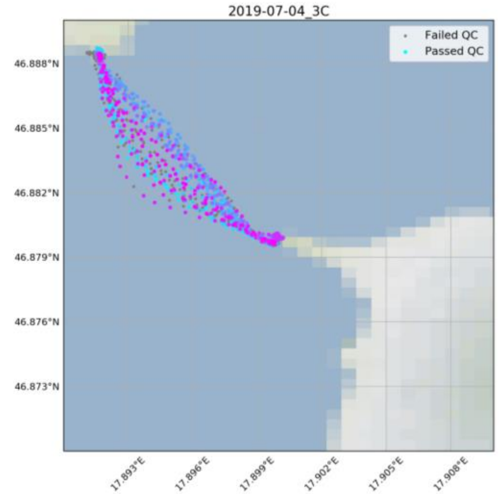


In collaboration with H2020-CERTO

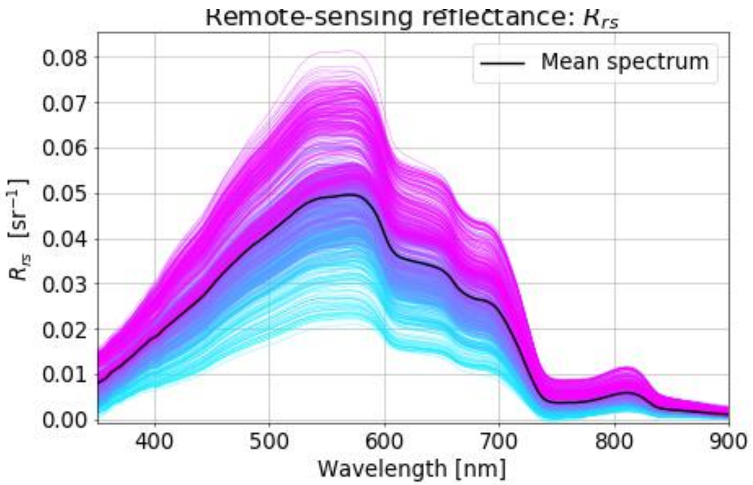
Jordan et al. 2022 RS
Selmes et al. *in prep*

R_{rs} from ships of opportunity in lakes & coastal waters

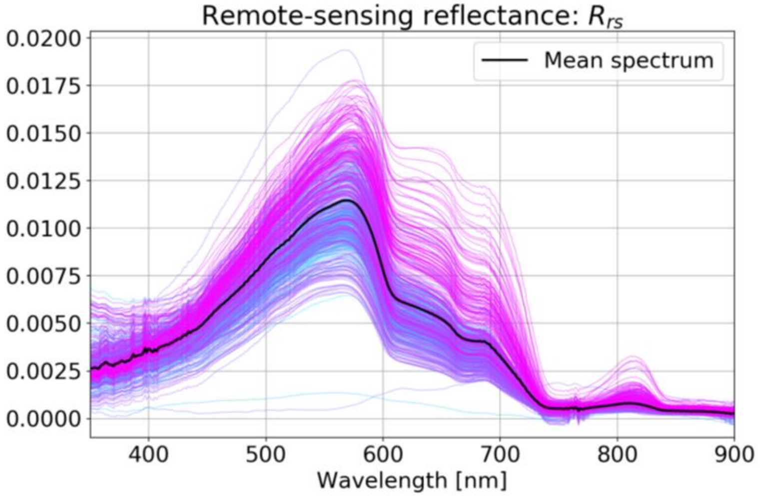
3C derived R_{rs}

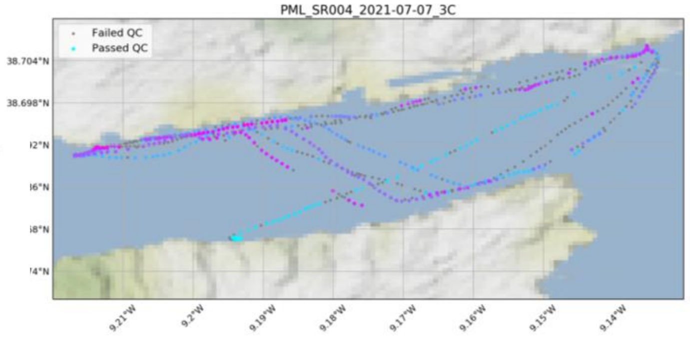


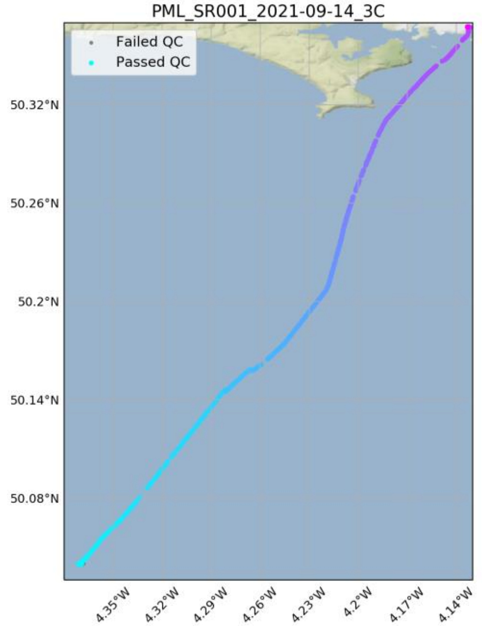
Lake Balaton, Hungary

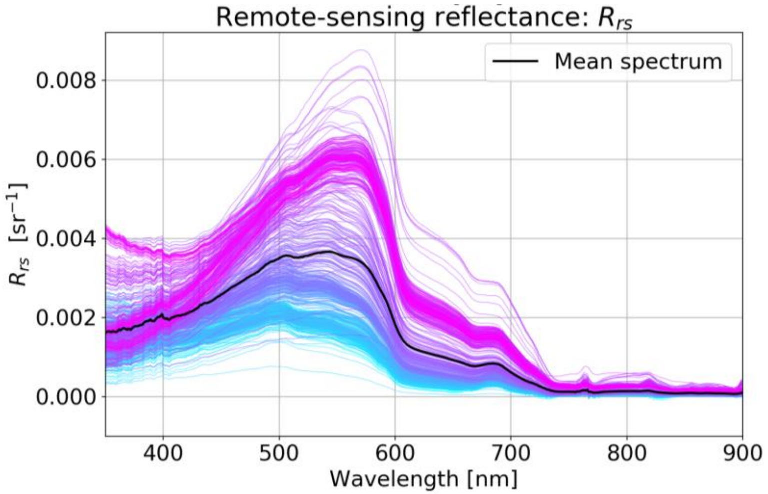


Tagus estuary, Portugal

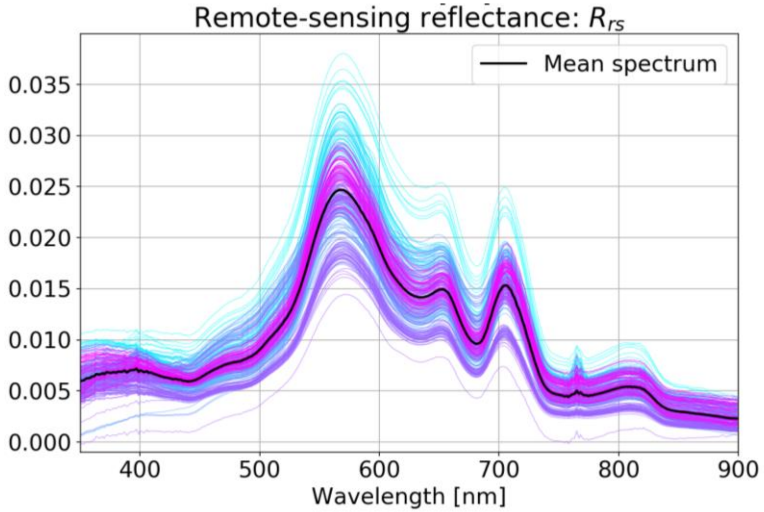




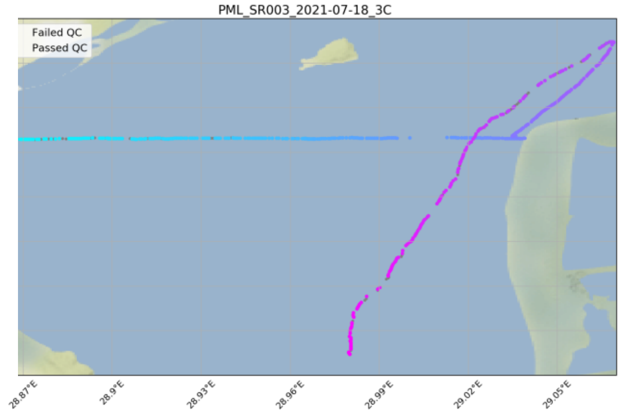




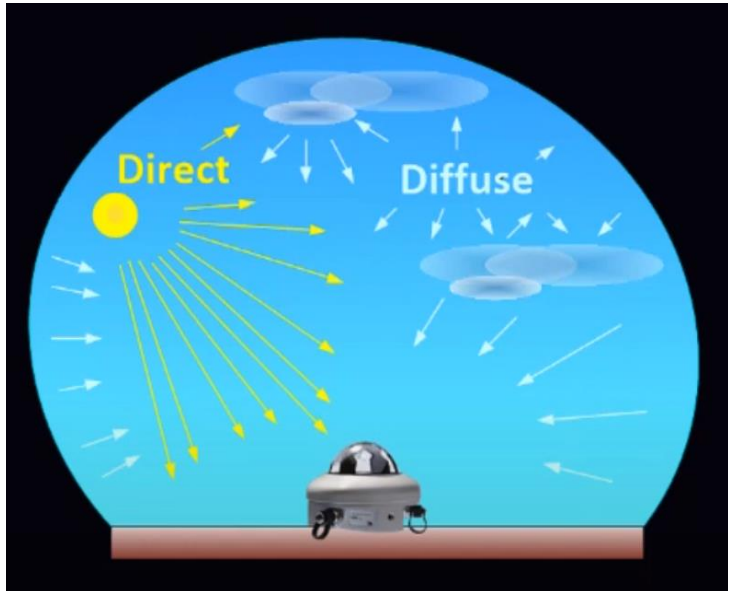
Western Channel, UK

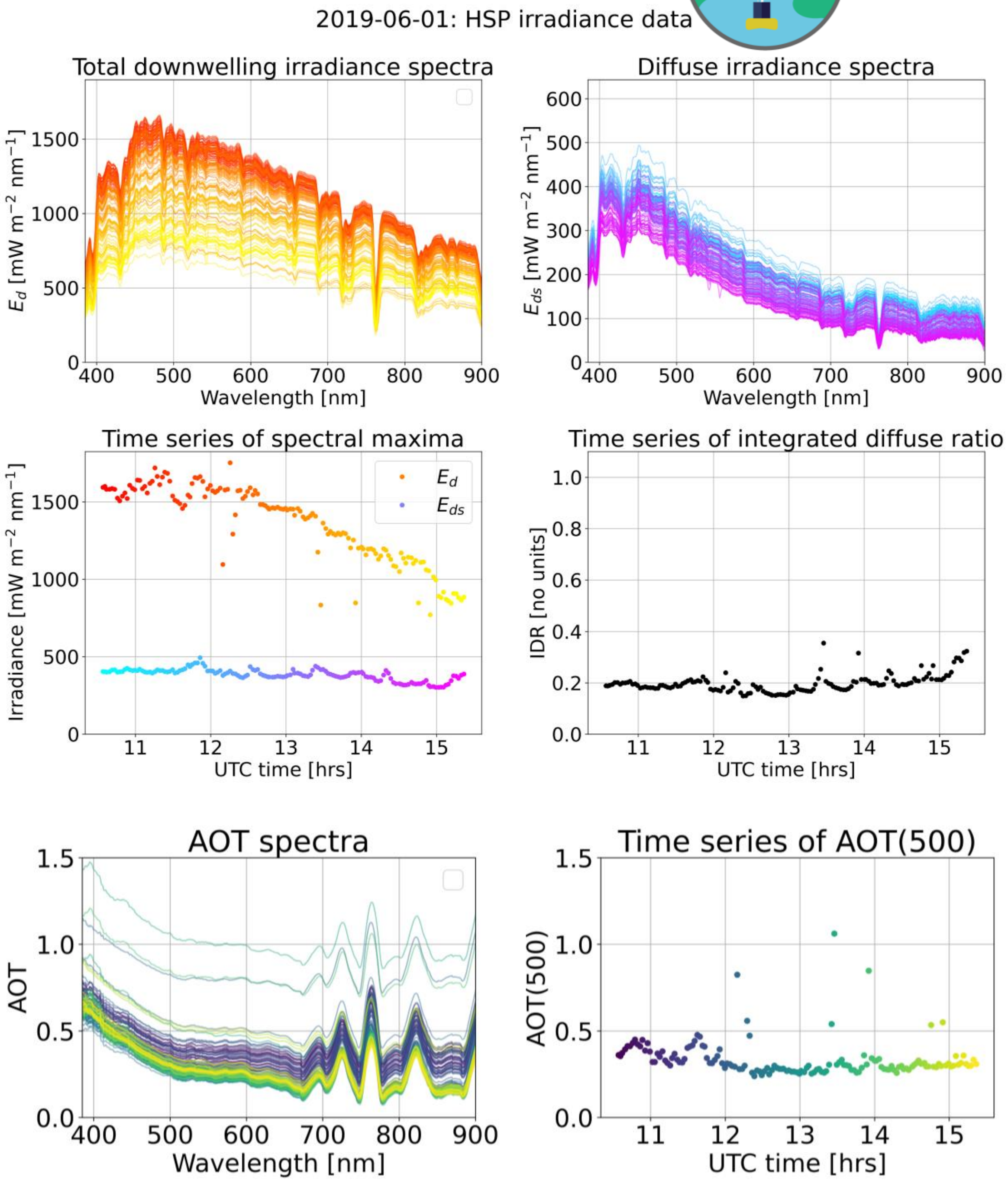


Danube Delta, Romania



Hyperspectral Pyranometer data (Peak Design)





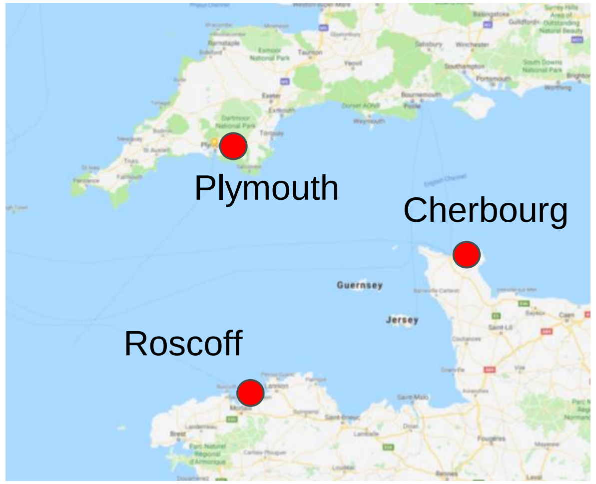
HSP1 partitions downwelling/global irradiance into direct (E_{dd}) and diffuse (E_{ds}) components using a shading pattern over multiple diffuser optics (no moving parts) – see Wood et al. 2017.

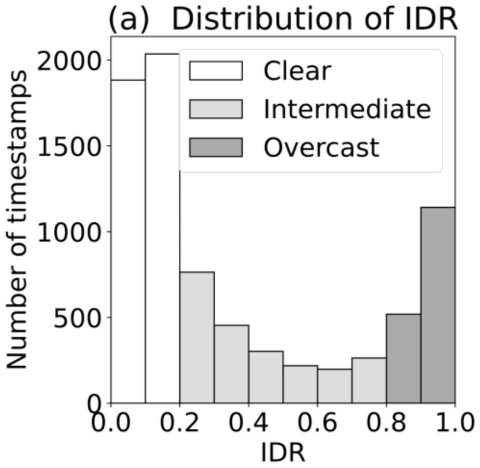
Provides hyperspectral characterization of atmospheric optical state (fraction of diffuse light) and derived aerosol optical thickness (AOT).

Improved in situ R_{rs} by combining So-Rad and HSP1

Improved in situ R_{rs} combining So-Rad and HSP – without knowing ‘true’ Reflectance

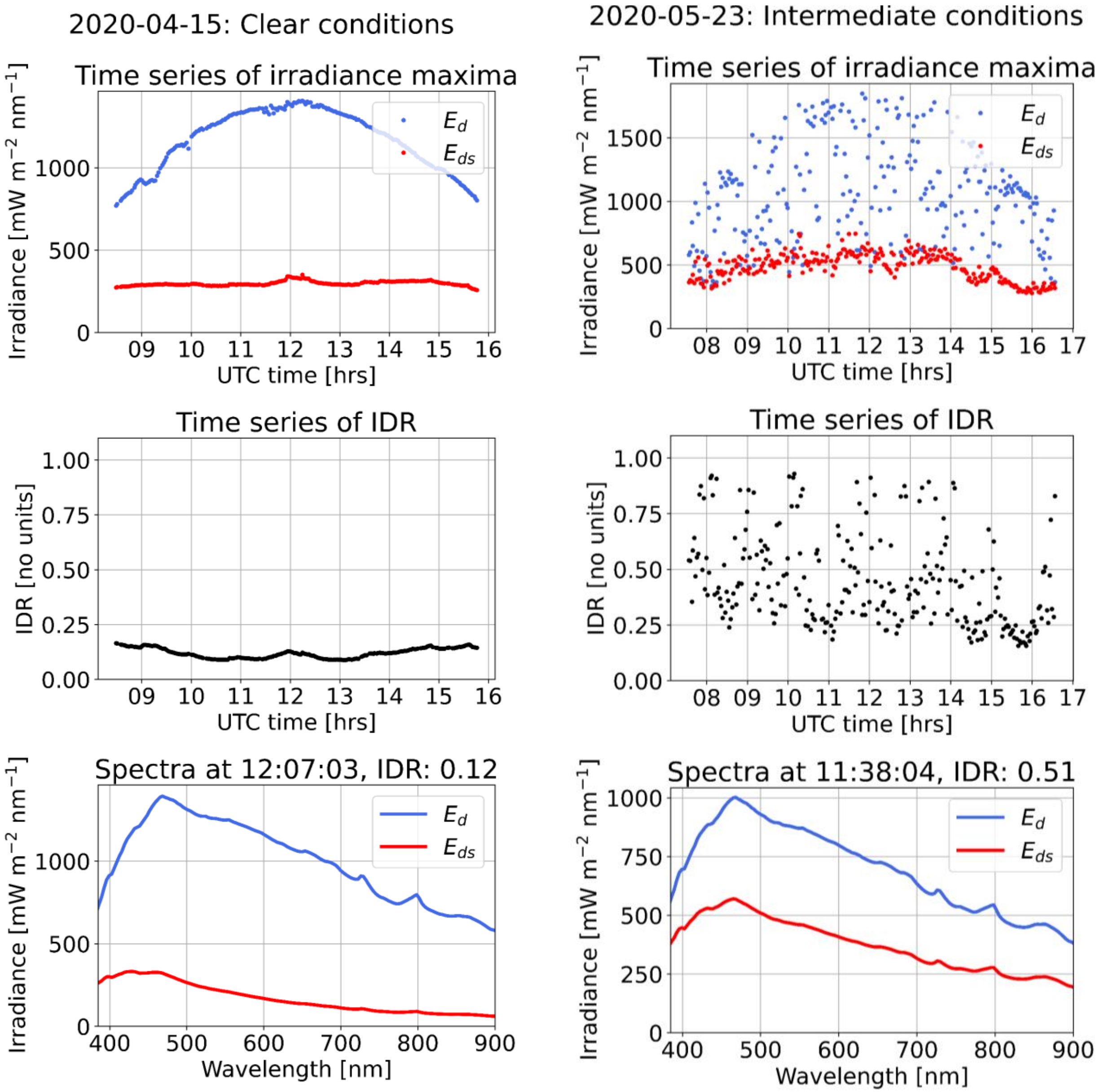
Using 4.5 months in-port data, Western Channel (summer 2020).





Integrated Diffuse Ratio
(fraction of diffuse light)

$$IDR = \frac{\int_{\lambda_i}^{\lambda_f} E_{ds}(\lambda)d\lambda}{\int_{\lambda_i}^{\lambda_f} E_d(\lambda)d\lambda},$$



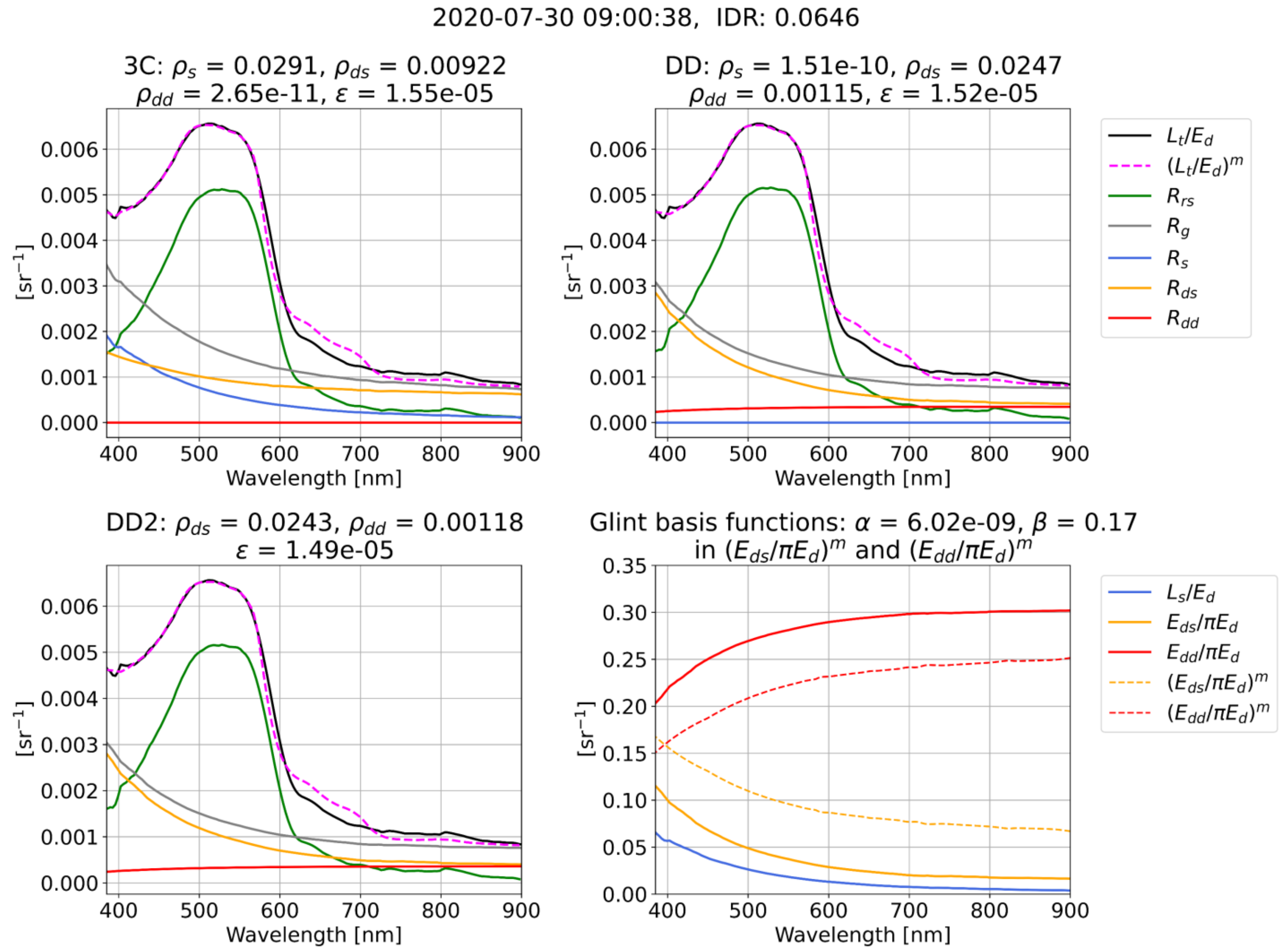
Improved in situ R_{rs} by combining So-Rad and HSP1

Concept: HSP1 measurements of E_{ds}/E_d and E_{dd}/E_d replace model-optimized terms in **3C** model.

Hypothesis: HSP1 addition will constrain the spectral-shape of glint correction. This removes atmospheric model dependence, reduces sensitivity of spectral optimization and gives more confidence in estimates of other free model parameters.

We benchmark 3 algorithm variants:

1. **3C** (3-component glint, default): model optimizes for E_{ds}/E_d and E_{dd}/E_d
2. **DD** (direct-diffuse): HSP1 measurements for E_{ds}/E_d and E_{dd}/E_d
3. **DD2**: 2-sensor variant of DD (no L_s sensor & lower cost solution)



Incorporating a hyperspectral direct-diffuse pyranometer in an above-water reflectance algorithm. Jordan et al. 2022, *Remote Sensing*

Improved in situ R_{rs} by combining So-Rad and HSP1

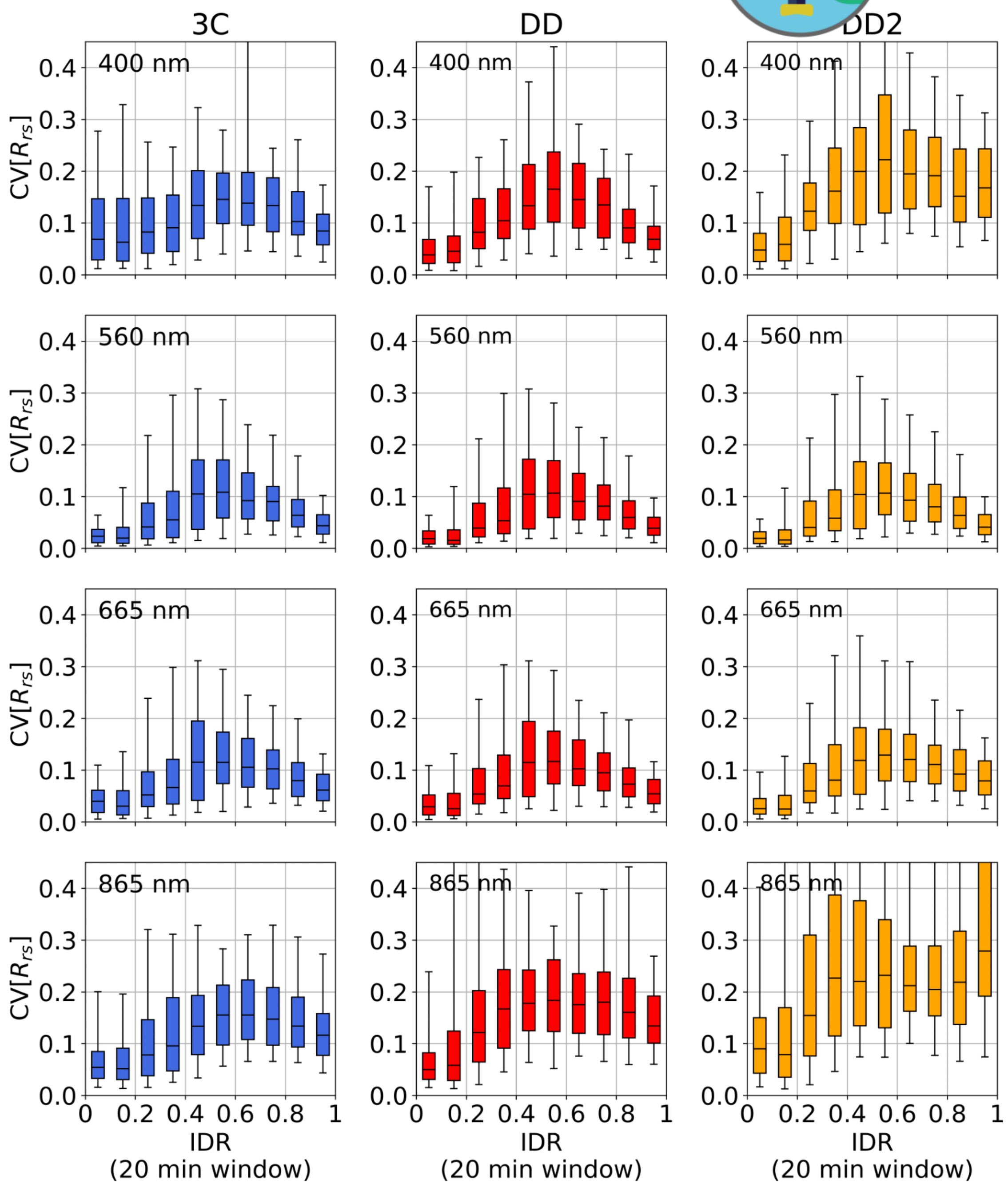
Algorithm precision assessed by looking at coefficient of variation in 20-minute windows.

Key result: DD (using HSP1 data) has significantly lower variability than 3C in clear conditions in blue (400 nm) band: **recommended for deployment**.

DD and the original 3C have comparable variability in green (560 nm), red (665 nm), and NIR bands (865 nm).

All algorithms have relatively high variability in intermediate conditions (scattered cloud).

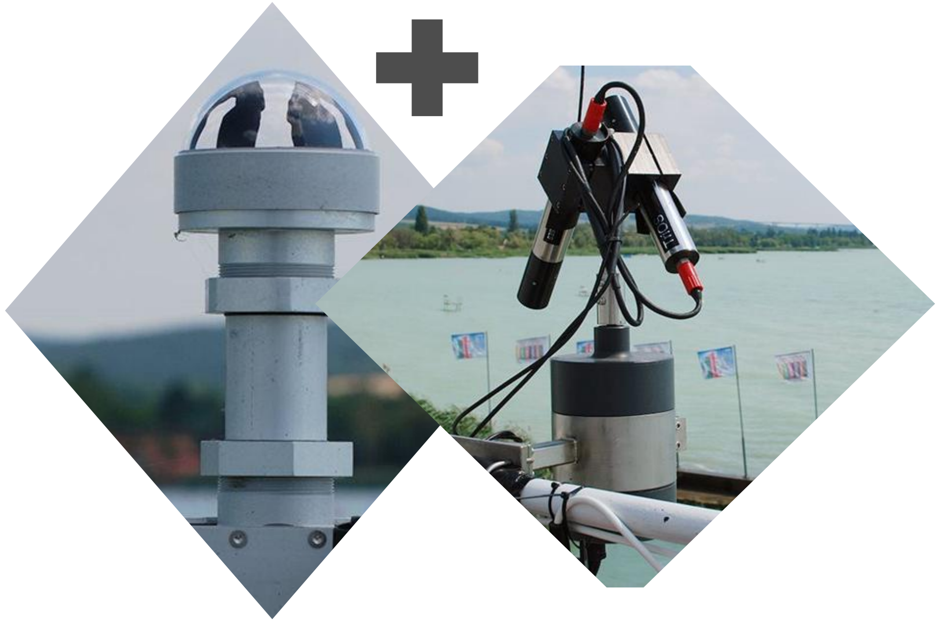
DD2 (no Lsky sensor) still better resolved in blue bands but with higher variability than 3C and DD in overcast conditions: **not recommended**.



Cost/value consideration

3 sensor So-Rad system: Lt, Ls + Ed

Approx €37k



2 sensor So-Rad + HSP1: L_t, L_s, E_{ds}&E_{dd}

Approx €45k

Attribution of atmospheric correction uncertainty

Many compounding sources of uncertainty

- Algorithmic, sensor, water type, observation angle, adjacency effects, atmospheric composition.
- Need high data volume, transects to untangle effects

Each AC method reports atmospheric conditions/results in its own way:

C2RCC: path radiance, up/downward transmittance, gas corrections

WFR: PAR, AOT(865), Ångström exponent (865), Water vapour column

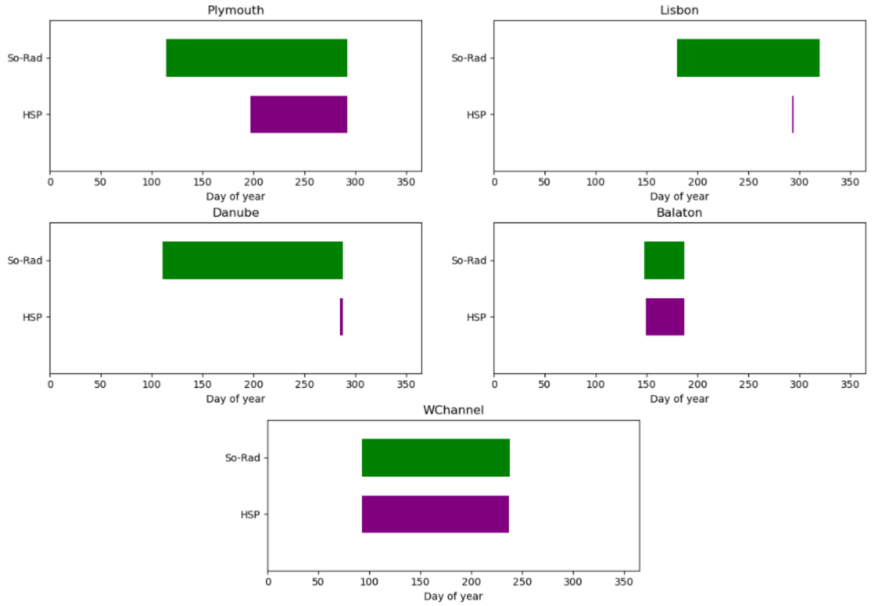
POLYMER: glint, Rayleigh, ozone corrections, molecular transmittance

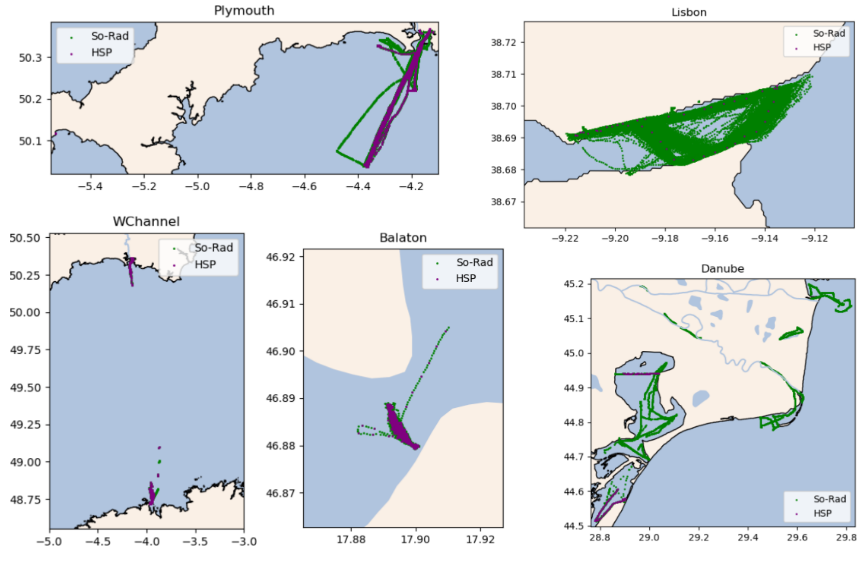
L2gen: Aerosol type, smoke index, aerosol model indices, aerosol single/multi scattering epsilon, AOT & Ångström wavebands, glint and Rayleigh components, polarization, gaseous transmittance, water vapour transmittance, oxygen transmittance, aerosol index, and more..

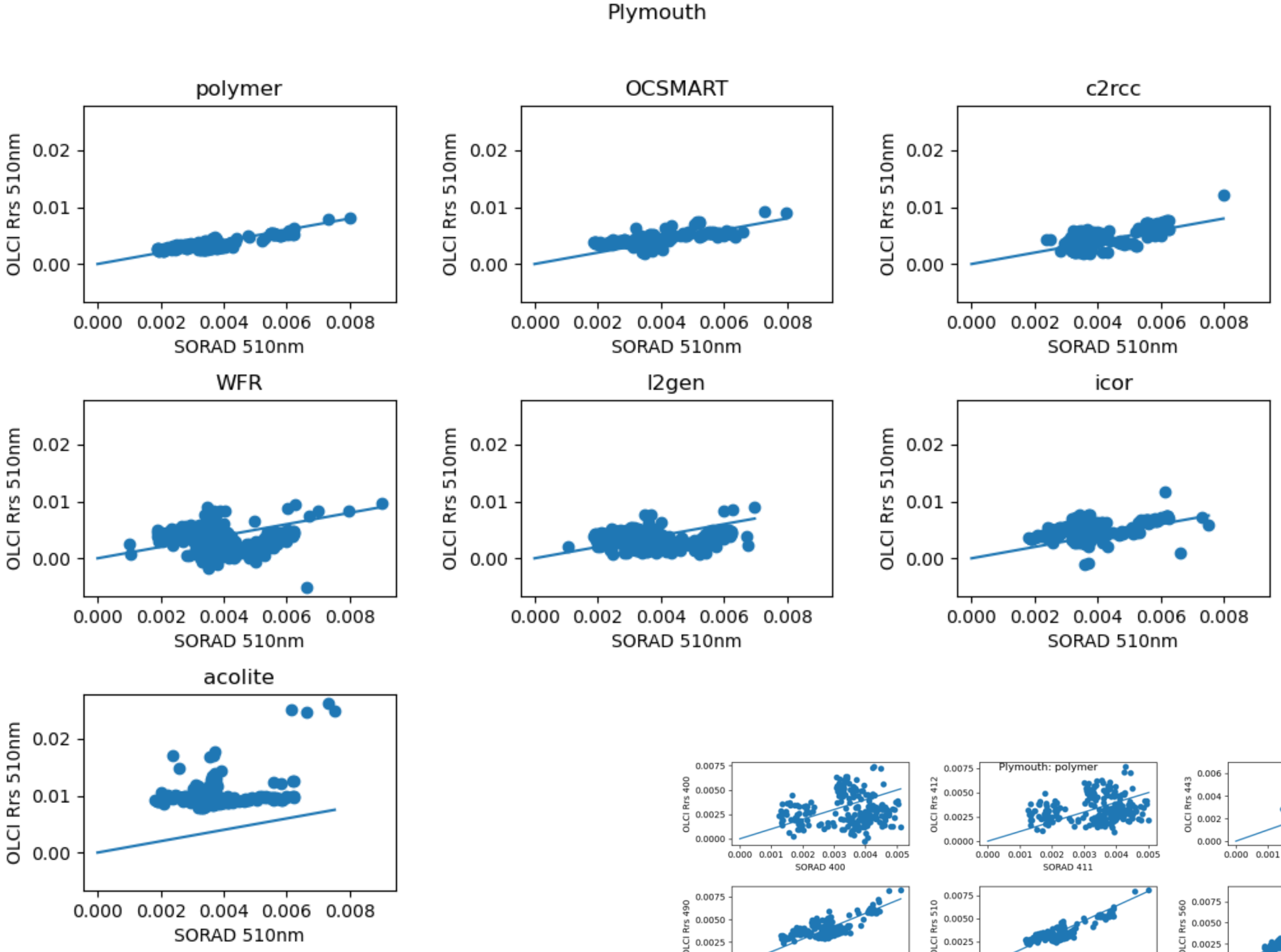
Algorithm	Reference	OLCI	MSI
POLYMER	Steinmetz et al. 2011	X	X
l2gen	Pahlevan et al., 2017	X	X
WFR	EUMETSAT default algorithm, see https://www.eumetsat.int/media/45743	X	
C2RCC	Brockmann and Doerffer, 2016	X	X
OCSMART	Fan et al., 2021	X	X
ACOLITE	Vanhellemont and Ruddick, 2014	X	X
iCOR	De Keukelaere et al., 2018	X	X
sen2cor	Main-Knorn et al., 2017		X

Attribution of atmospheric correction uncertainty

Seasonal distribution of input data

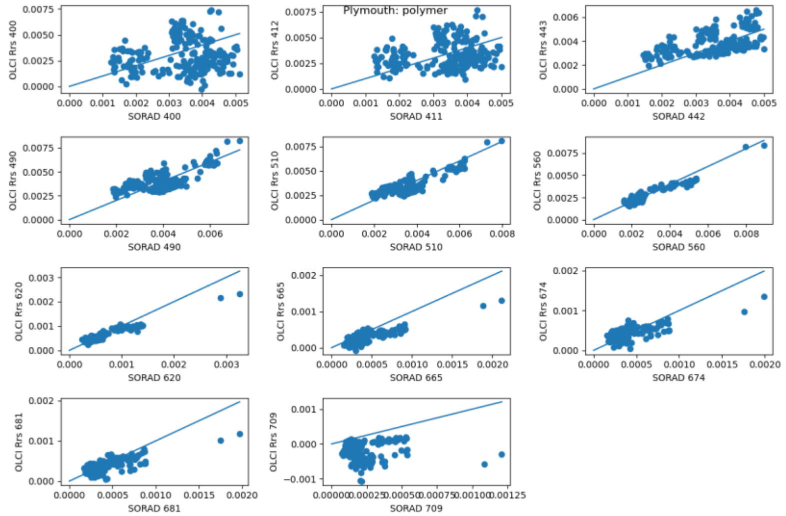




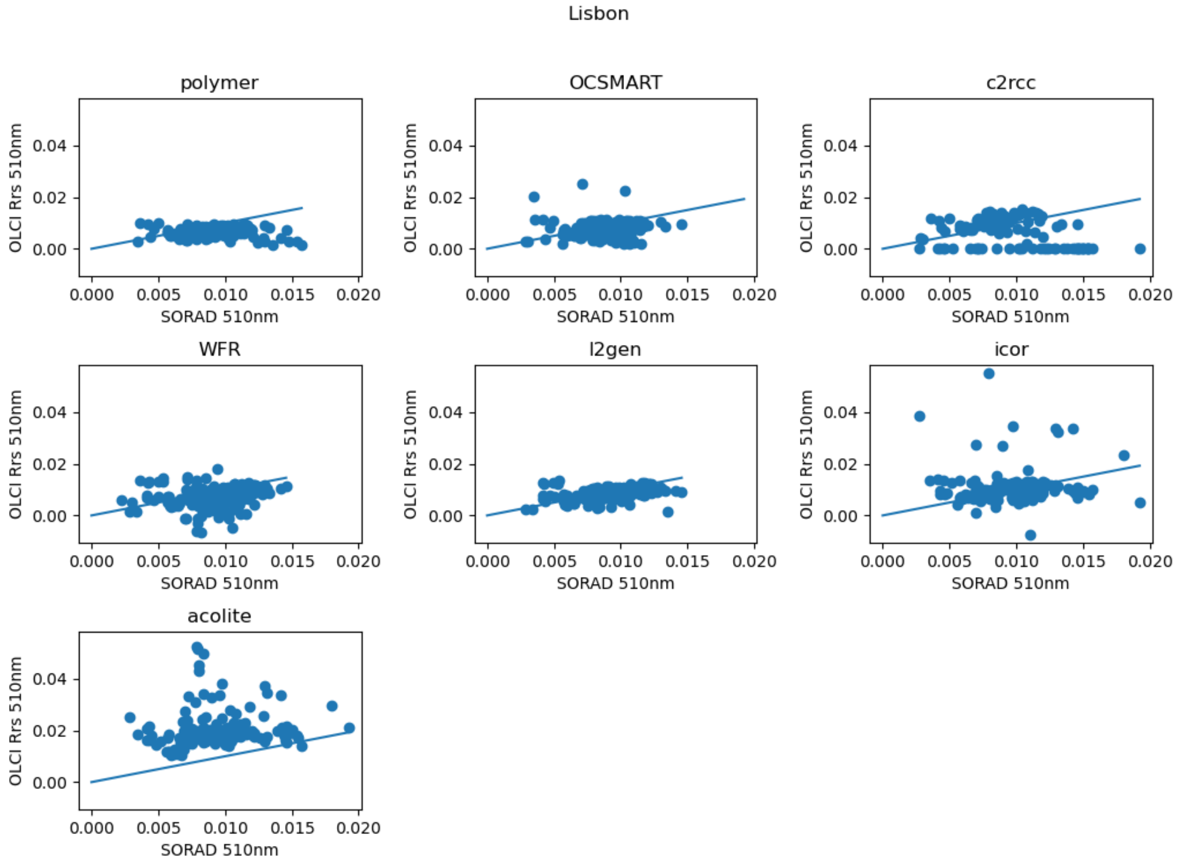


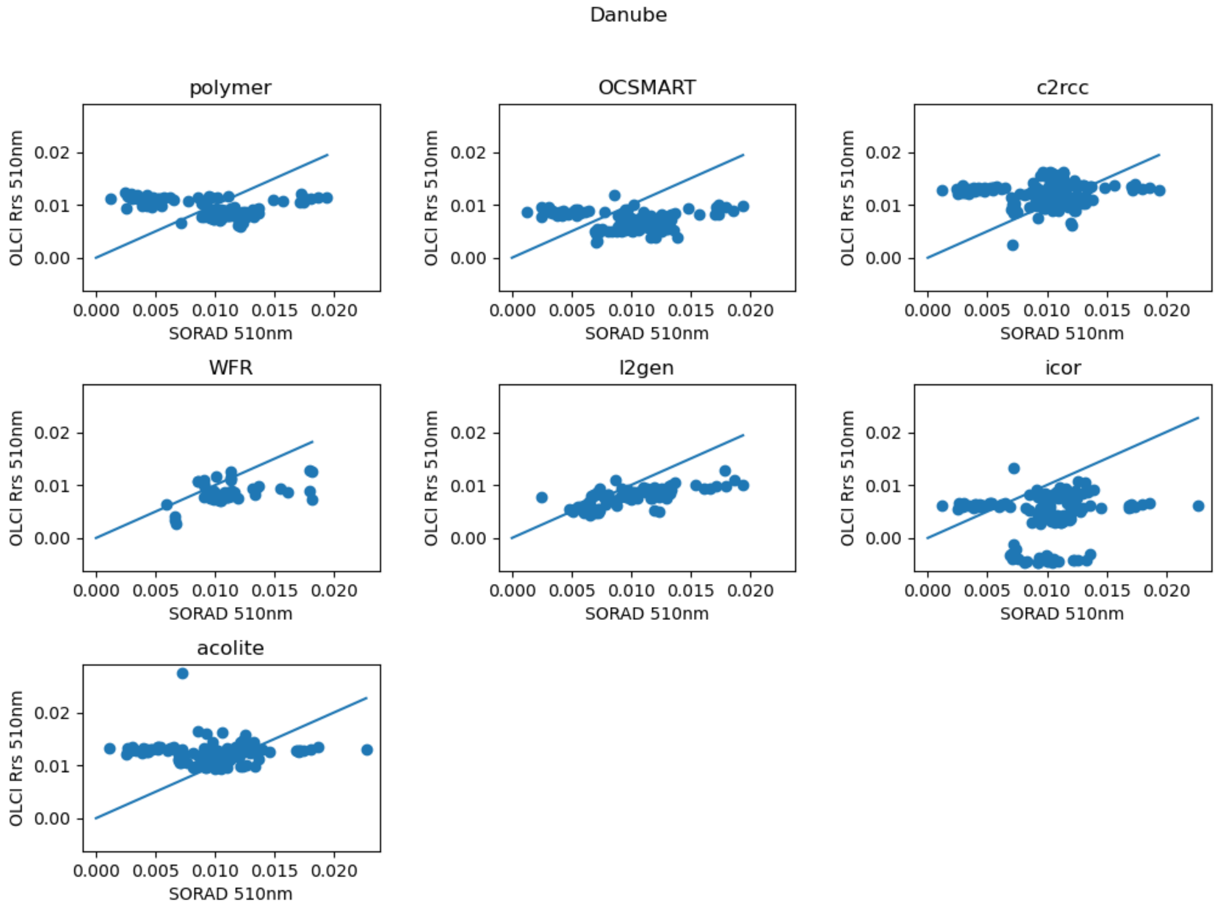
Large differences in $R_{rs}(510)$ bias between AC algorithms and in situ.

Right -> All bands using POLYMER

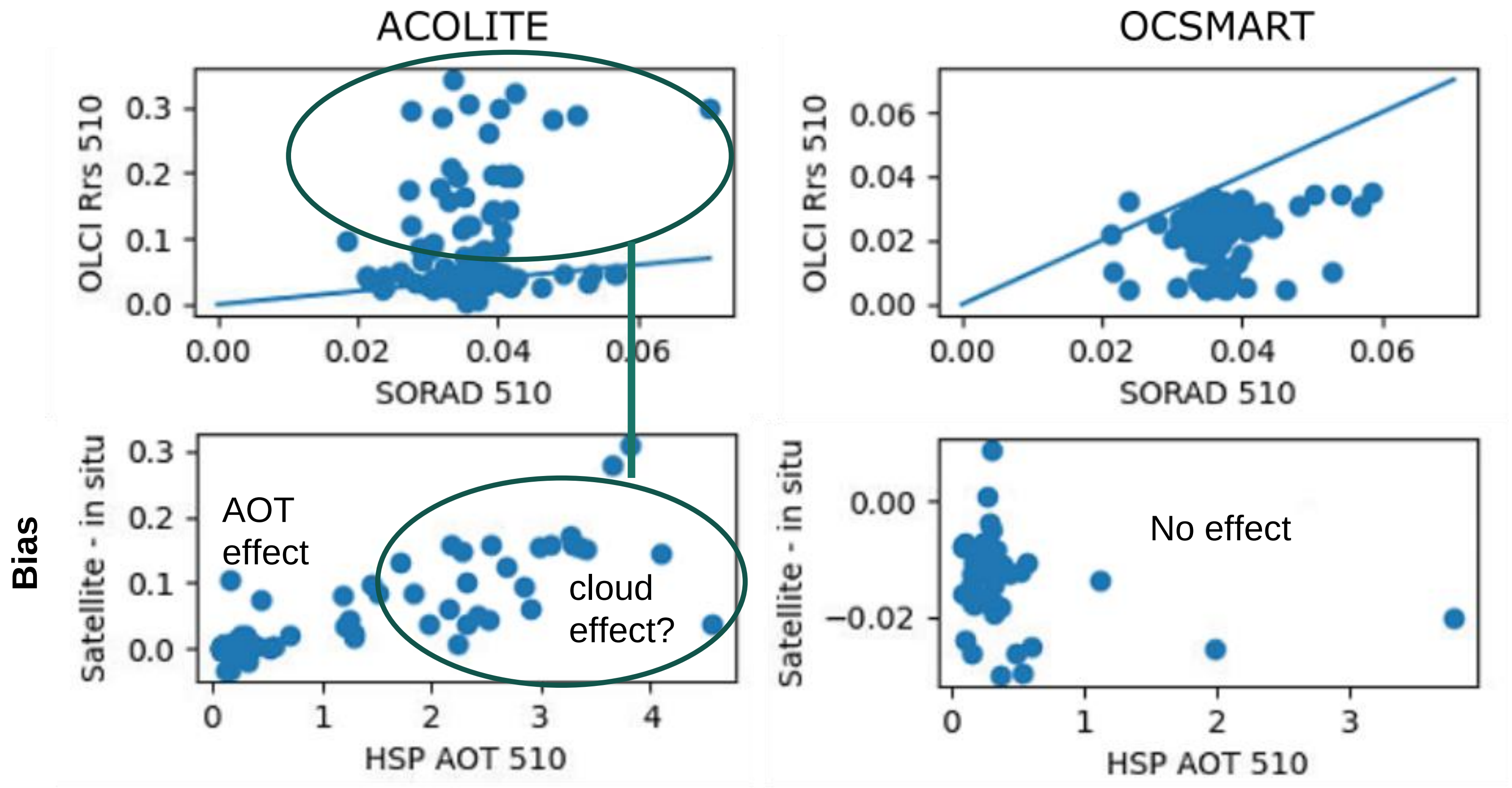


Attribution of atmospheric correction uncertainty





Attribution of atmospheric correction uncertainty



In some cases/algorithms, R_{rs} bias was correlated to AOT (for AOT<1)

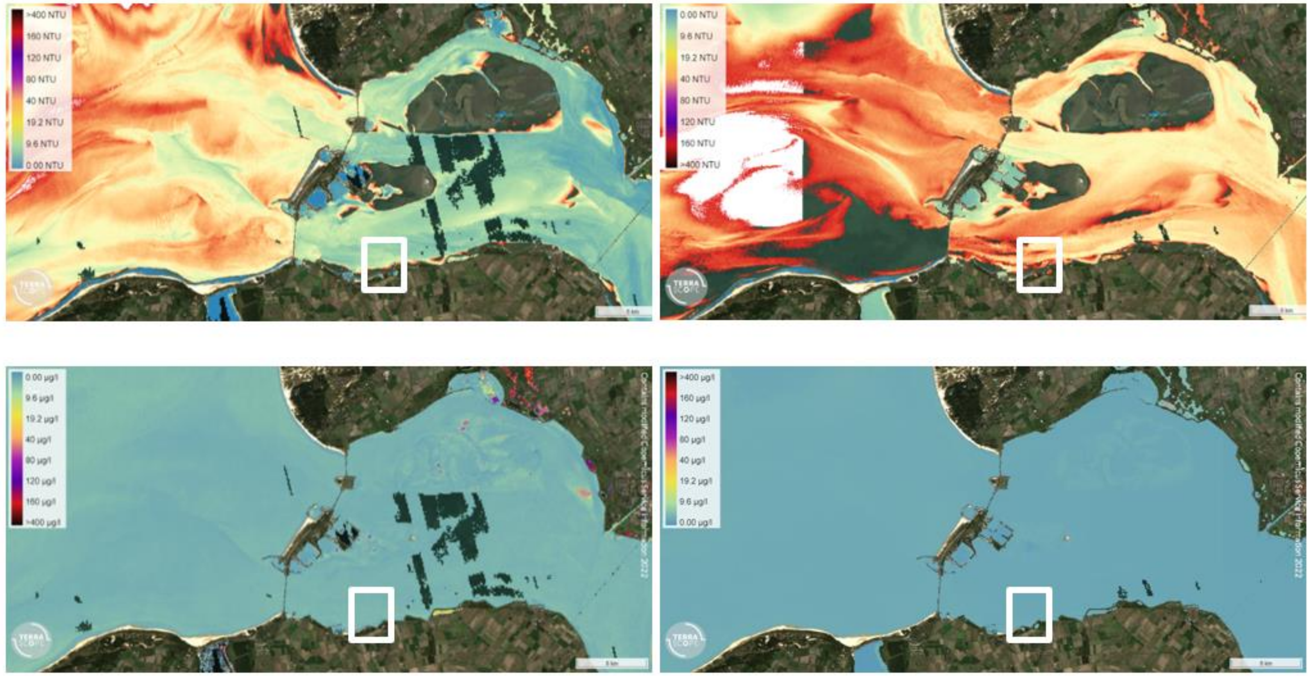
Work in progress:

- Adjacent land (contrast + distance)
- OLCI vs MSI: effect of spatial resolution
- Nature of aerosols (exploiting hyperspectral observation)

Top row: Satellite versus in-situ Rrs(510). Line marks unity

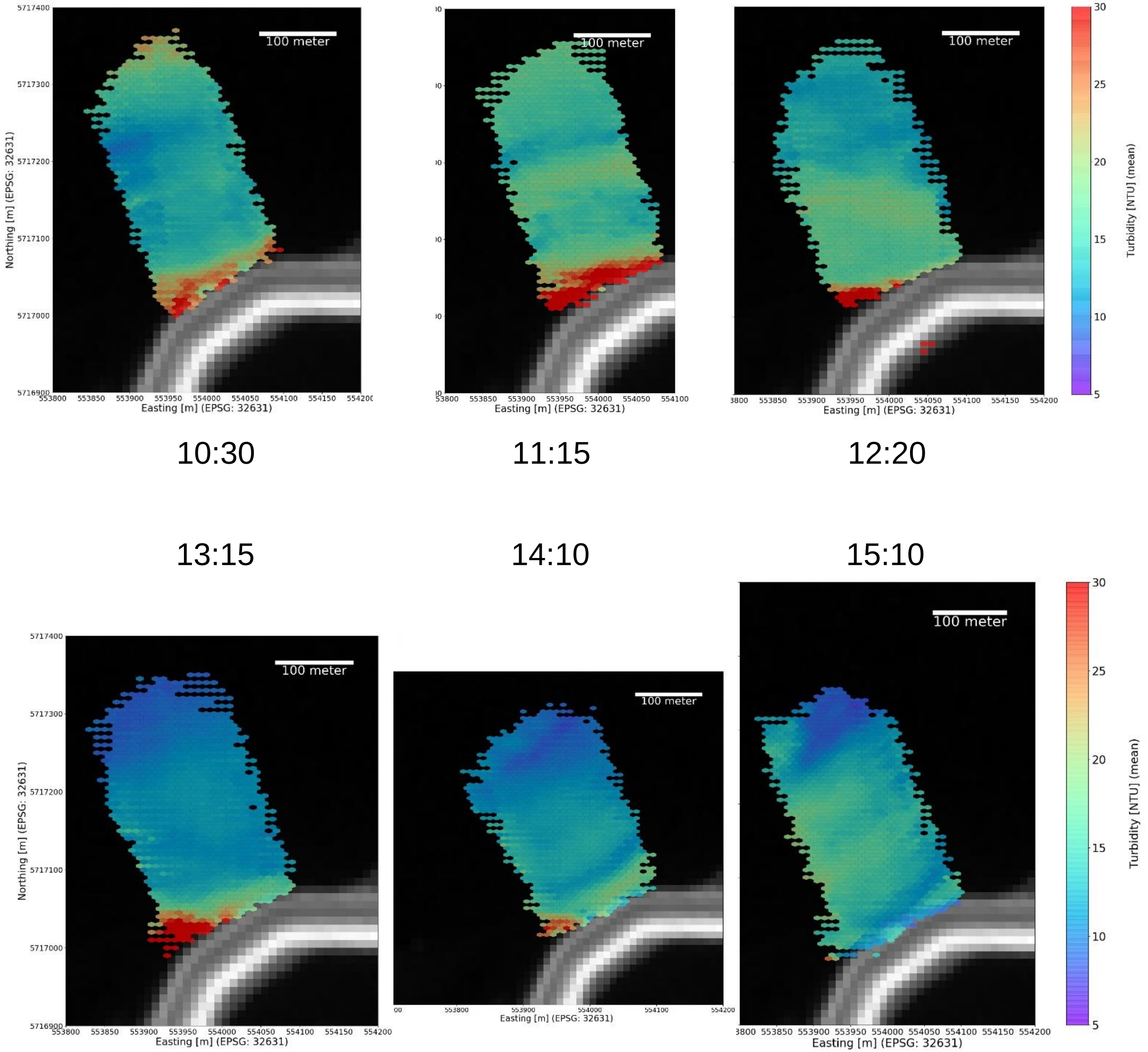
Bottom row: Bias (satellite - in situ R_{rs}) against AOT from coincident HSP1 observation.

Microscale observations…



Sentinel-2 MSI overpass one day prior (left) and two days after (right) drone flights.

Top: turbidity (top). Bottom: Chl-a



Key messages from MONOCLE

Autonomous platforms:

- Operate across optical gradients - more optical diversity captured for AC studies
- End-to-end automation and processing = less drain on resources. Improvements welcome.
- Need more systems at strategic sites, particularly inland + coastal areas, ships-of-opportunity
- Maybe rethink how we combine high-frequency and manual data collections, to avoid bias

Hyperspectral R_{rs} + $E_{dd,}$ E_{ds}

- Directly observing the sky radiance distribution (HSP1) is better than using sky colour proxy (L_s/E_d) in coupled atmosphere-water estimates of in situ R_{rs} (3C). Could these models also estimate BRDF?
- Strong need to describe in situ R_{rs} methodology in shared datasets (observed vs model reconstruction)
- Attribution of atmospheric correction uncertainty through hyperspectral R_{rs} + AOT systems
  - Predictability? Atmospheric composition, land distance & contrast, optical water type?
  - Algorithm developers could provide comparable diagnostic info and terminology (e.g. AOT)

Low-cost approaches:

- Not yet deployed at scale, implementation into citizen science projects to be developed
- Microscale variability is exciting to measure in close proximity to shore
- Additional methodologies (smartphone spectropolarimetry) – watch this space.

Goodbye from MONOCLE

monocle-h2020.eu

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Multiscale Observation Networks for Optical monitoring of Coastal waters, Lakes and Estuaries (MONOCLE)

Low cost and high-autonomy sensors and platforms for optical water quality monitoring.

The MONOCLE project has developed an affordable ecosystem of networked sensors and platforms to provide better integration of monitoring methods for optical water quality and atmospheric properties with satellite observation. Methods range from low-cost devices for citizen-science projects to the use of consumer drones, to fully automated reference systems for ships-of-opportunity and stable offshore platforms. Please watch the animated introduction on the right for a two-minute introduction to the project outputs.

About the project | Sensors and platforms | Access data

The MONOCLE ecosystem consists of observation platforms and data. Open, shared data following the FAIR principles are already available from past and ongoing deployments. Join the sensor network to become part of a global water quality monitoring community!

The MONOCLE sensors, platforms and services have gradually started entering the market for use by monitoring agencies and research organisations. Follow the links below to learn more about each solution, contact the manufacturers or register your interest for further product