

Evaluating the quality of **Sentinel-2 aquatic reflectance data** over **diverse water types and sun and atmosphere conditions** using the **WATERHYPERNET** network

presented by Kevin Ruddick (RBINS)

with Q.Vanhellemont, A.Bialek, V.Brande, P. de Vis, A.Dogliotti, D.Doxaran, J.Kuusik, D.Vansteenkoven and M.Beck, I.Farace, K.Flight, A.Gammaru, C.Giardino, L.Gonzales Vilas, K.Laizans, F.Ortenzio, D.Pailler, P.Perna, E.Piegari, L.Rubinstein, K. Turpie, D.Van der Zande, P.Goryl

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HYPERNETS in a single slide

INSTRUMENTS

Automated hyperspectral measurements



PANTHYR system
[Vansteenwegen et al, 2019]
400-900nm, 10nm FWHM



HYPSTAR® system
[Kuusk et al, 2024]
380-1680nm, 3-10nm FWHM

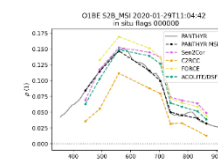
NETWORK

RBINS (BE, coordinator)
+ VLIZ (BE), CNR (IT), LOV (FR),
NPL (UK), GFZ (D), TARTU (ES),
CONICET (ARG), UMBC (USA),
UST21 (SKOR)

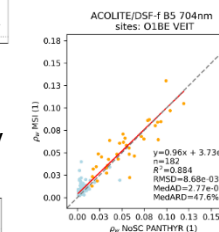


12 water and 7 land sites currently operating,
Slowly expanding internationally (but currently
limited by hardware manufacturing).
2025Q4: + Australia

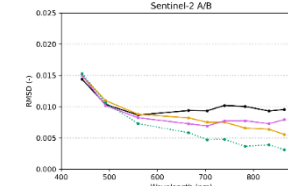
DATA PROCESSING and ANALYSIS



e.g. one matchup



one band (S2/704nm), many matchups



spectral stats, many matchups

Prototype network has provided validation data and information to:

Sentinel-2A&B&C, Sentinel-3A&B/OLCI, Landsat-8&9, Planet Doves and Superdoves, PRISMA, Pléiades, ENMAP, MODIS-A&T, VIIRS-1&2, (ACIX), PACE...

OBJECTIVE: To validate **all** VIS/NIR spectral bands (400-1700nm, @3nm FWHM) for **all** satellite missions measuring water or land surface reflectance

and preparing for:

ACIX, DESIS, MTG and SEVIRI, EMIT, CHIME, LSTM, GLIMR, SBG, GOCI, SABIAMAR, various Newspace, Planet Tanager, TRUTHS ... (national hyperspectral imagers from Canada, Norway, Australia, ...)

NEW: Since 2 years we are seeing many more Newspace and hyperspectrals ...

[Ruddick et al, 2024;
<https://doi.org/10.3389/frsen.2024.1372085>]

Water sites currently/recently running

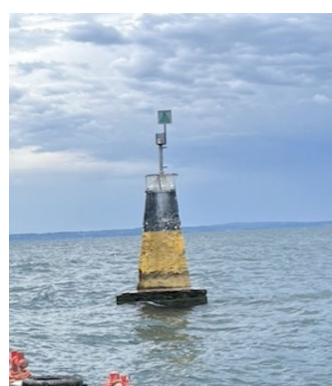
VLIZ: Oostende



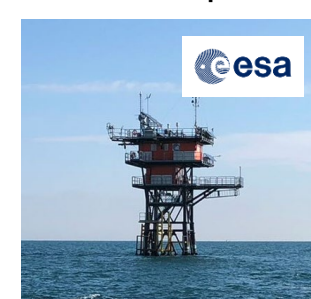
UST21 (GOCI): Socheongcho



CNR: Lake Garda



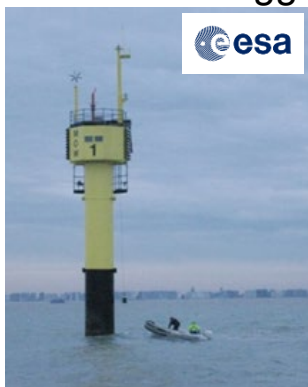
CNR: Acqua Alta



CSIRO: Lucinda Jetty



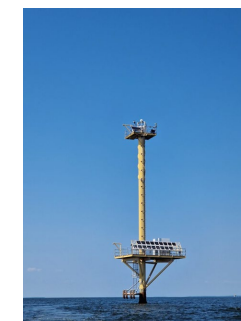
RBINS: Zeebrugge



CONICET: La Plata



UMBC: Chesapeake



RBINS: Thornton



LOV: Gironde



LOV: Etang Berre

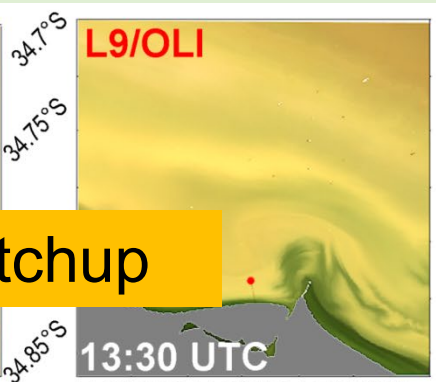
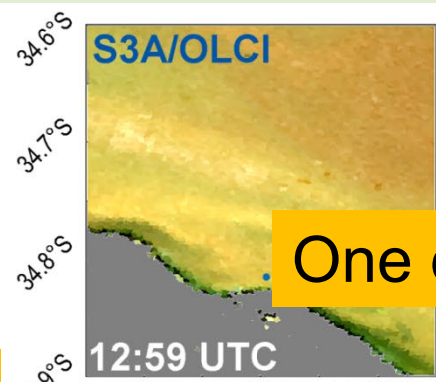


TARTU: Vortsjävän



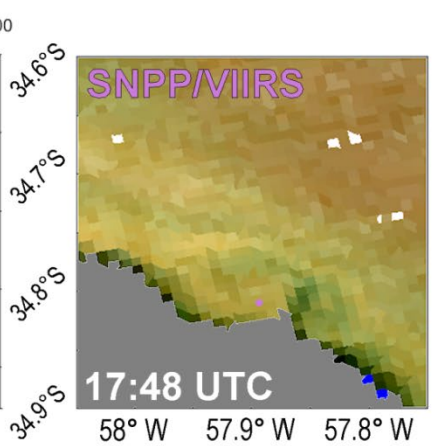
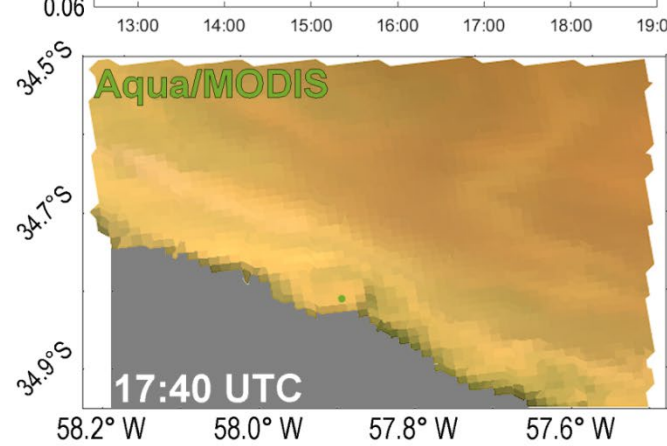
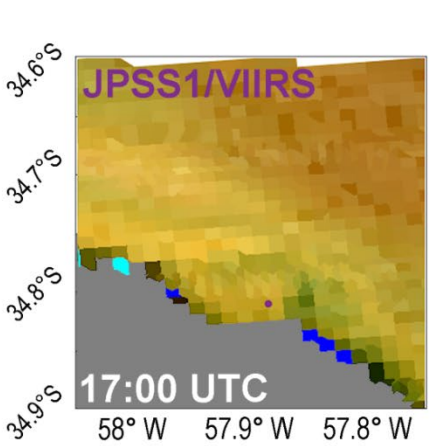
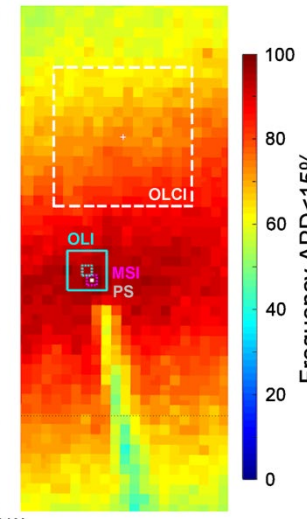
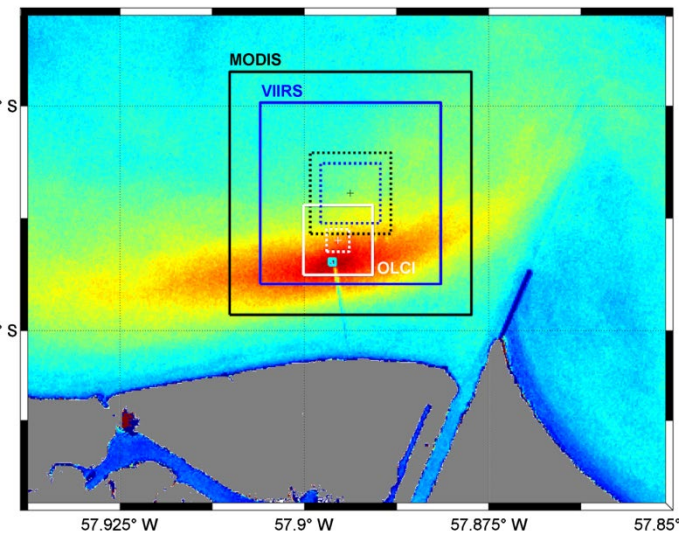
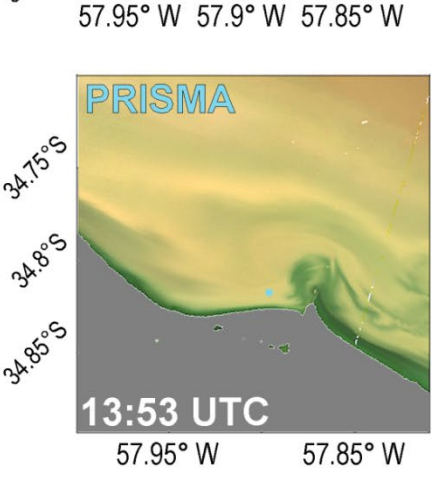
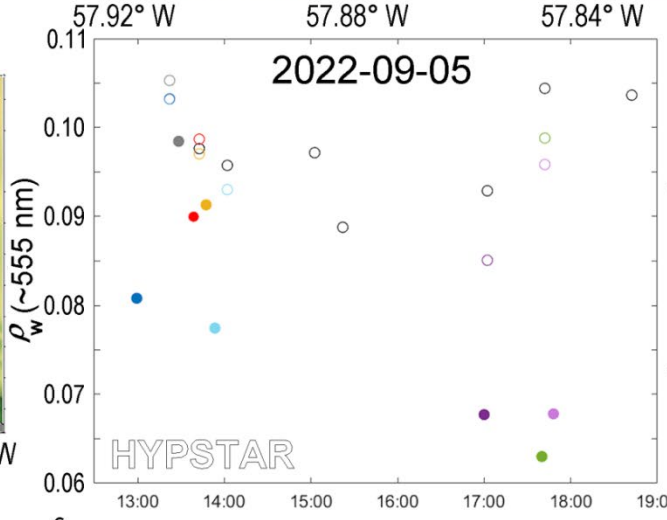
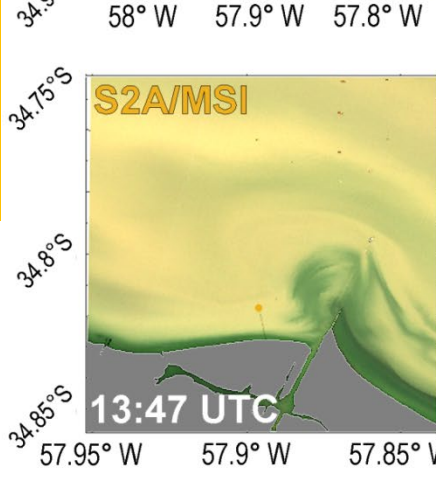
NPL: Wraysbury





One day, many missions matchup

S2 pixels binned up to simulate coarser res sat data => extra spatial difference uncertainty



Data Distribution - first large releases (beta)

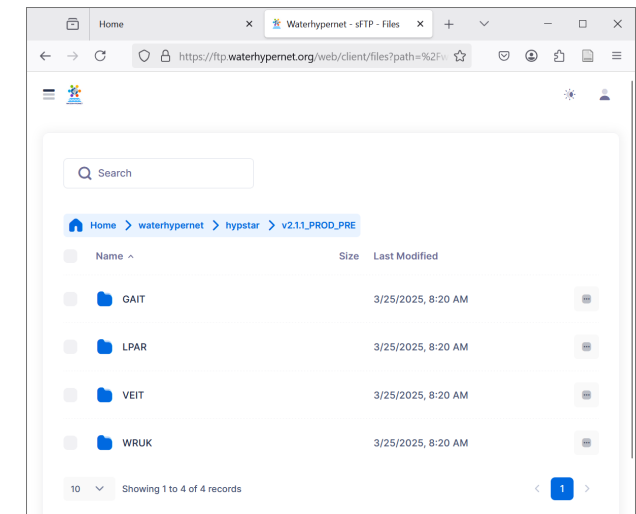
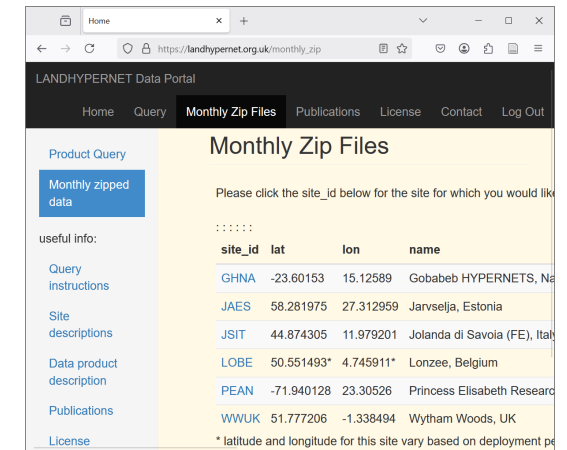
- **LANDHYPERNET** beta-testing by externals in progress

- More detailed in presentation **Wednesday 15 Oct, 09:30** and Science Results”
- Announcement: Pieter De Vis, “LANDHYPERNET Data Distribution **Meeting with land data users** after VHRODA, Frascati, 21 November PM

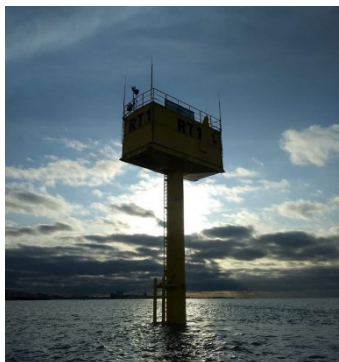
- **WATERHYPERNET** beta-testing by 21 externals in progress

- QC-approved 2023 and 2024 data from 7 sites
 - In Nov 2025 will be expanded to 4 more sites and up to Sep 2025 then NRT
- Access via <https://waterhypernet.org/data/>
- Announcement: **Meeting with water data users** after IOCS, Darmstadt, 4 December PM

(Please do not use data released on zenodo in 2023, data quality and QC has greatly improved since then)

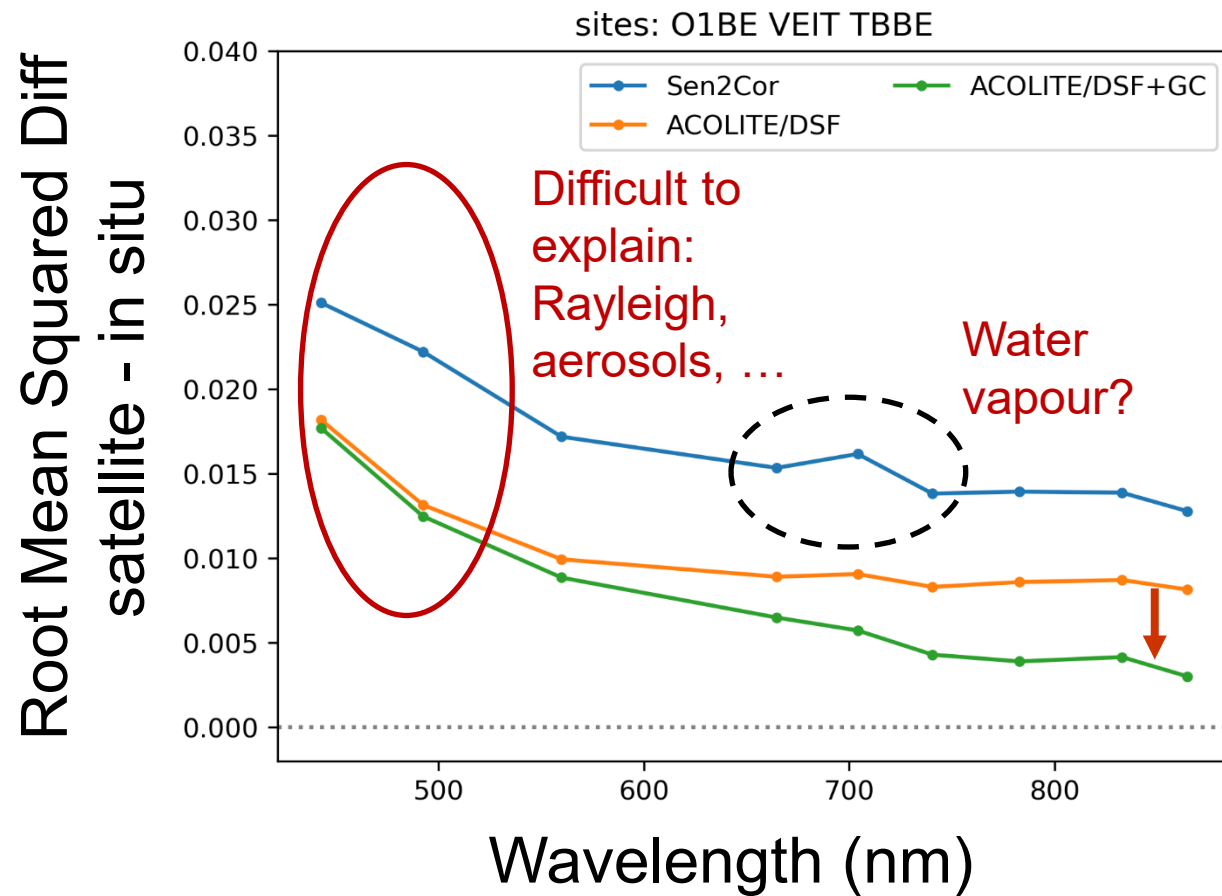
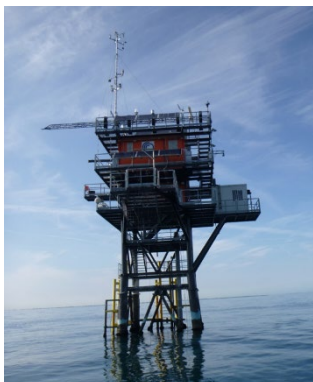


Sentinel-2 validation [Processing Q. Vanhellemont]



Oostende
PI: D. Vansteenwegen

Acqua Alta
PI: V. Brando

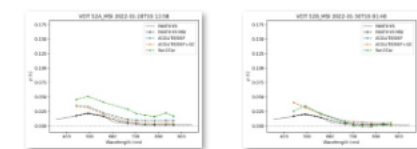
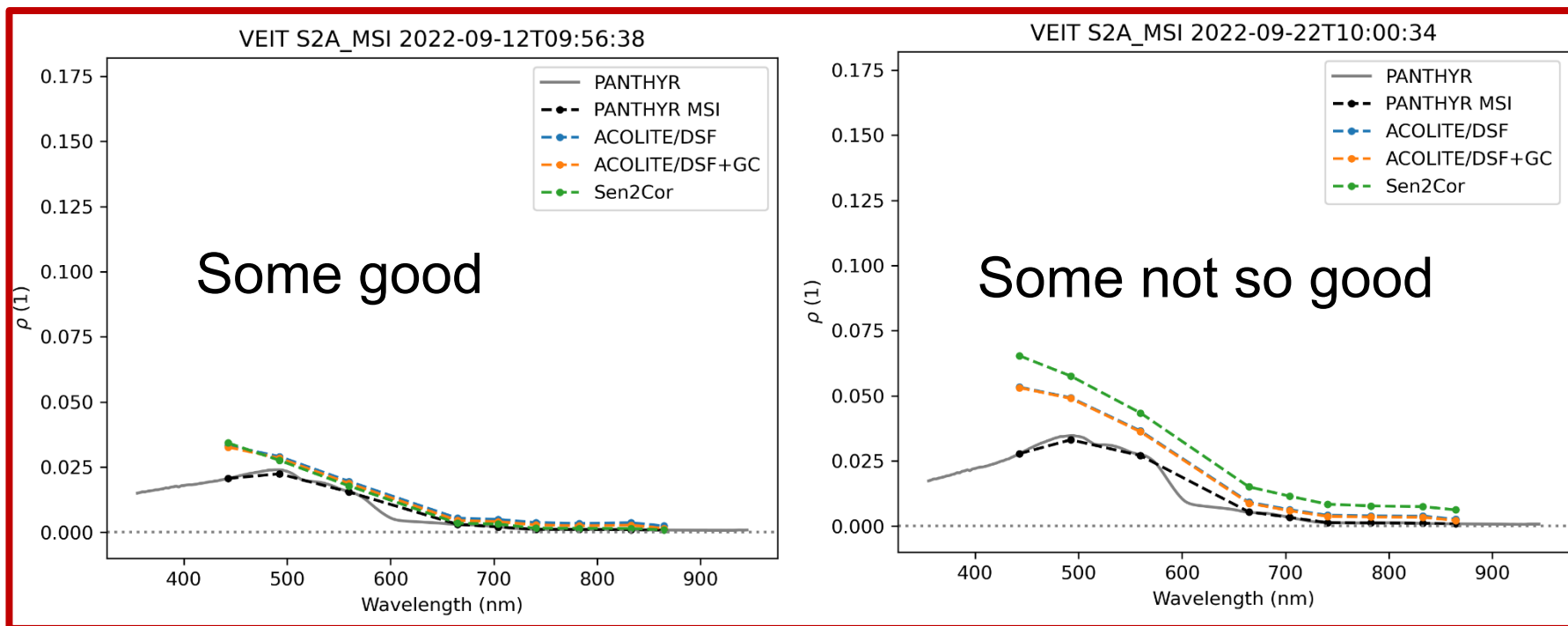


155
matchups

ACOLITE
glint
correction
reduces
difference
in NIR

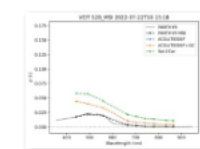
[Ruddick et al, 2024;
<https://doi.org/10.3389/frsen.2024.1347520>]

155 matchups - plenty to learn from individual matchups ...

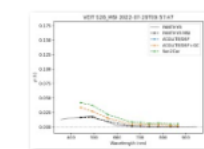


matchup_spect rum_VEIT_2022_01_28T10_12_58_S2A_MSI

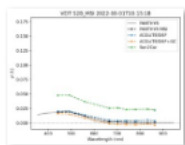
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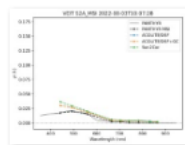
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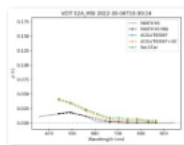
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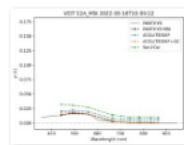
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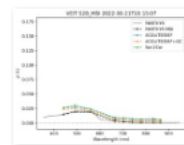
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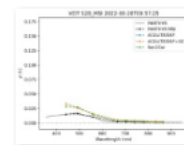
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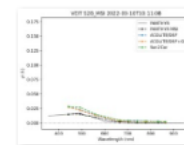
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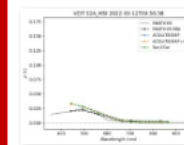
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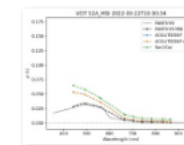
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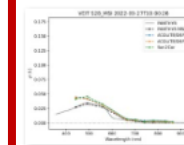
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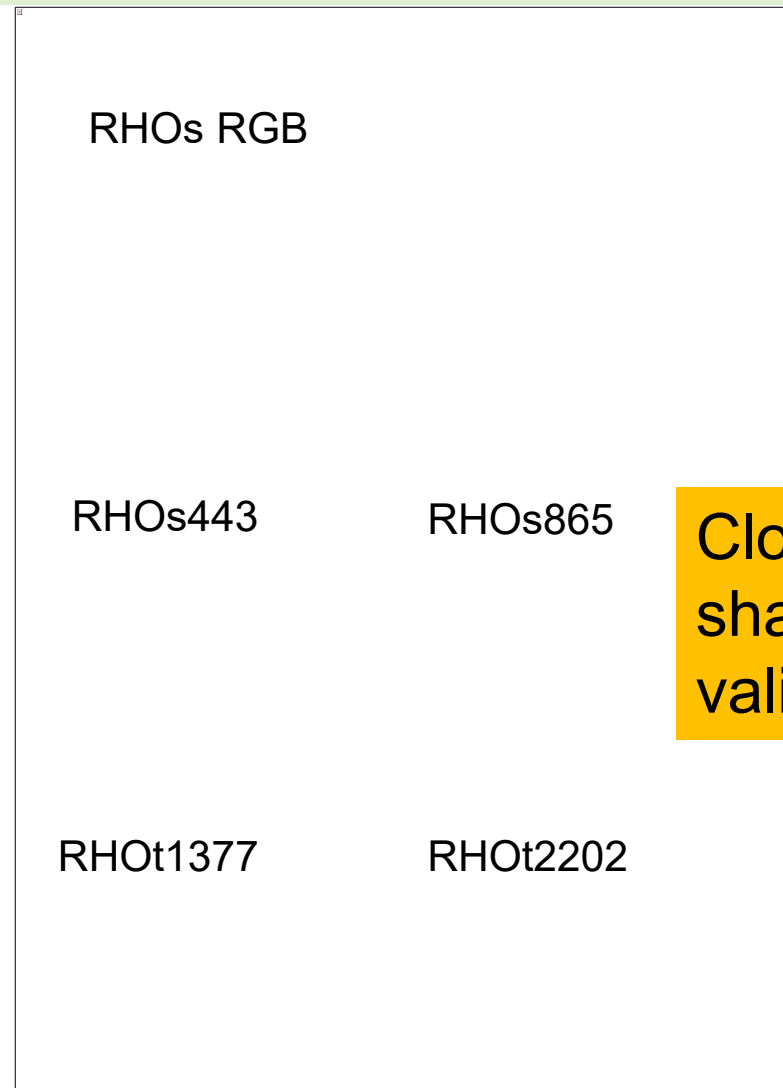
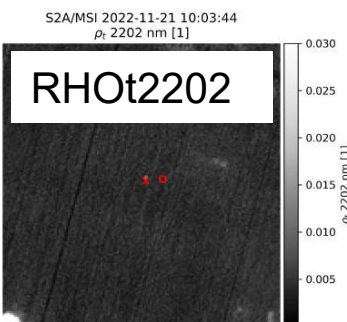
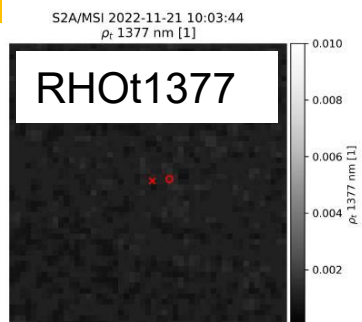
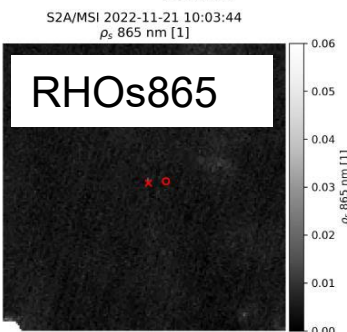
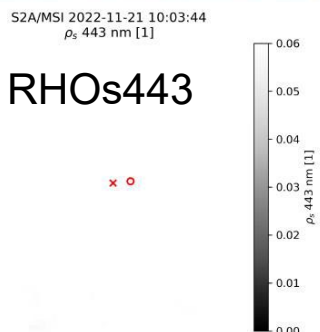
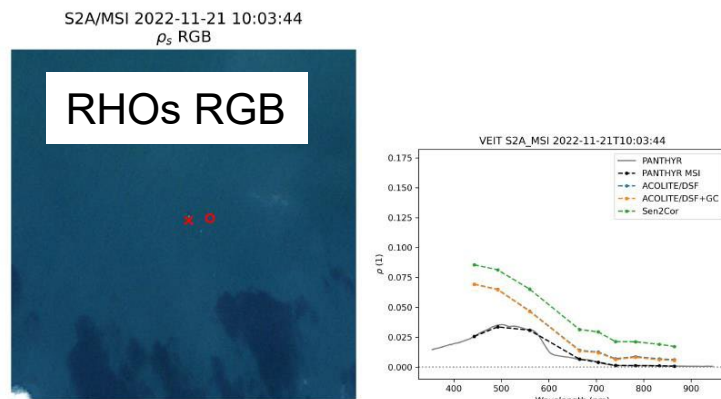


matchup_spect rum_VEIT_2022_09_22T10_00_34_S2A_MSI



matchup_spect rum_VEIT_2022_09_27T10_00_26_S2B_MSI

Validation diagnostic sheets for each of 155 matchups (3km*3km)



Retrieved AOT too low (S2 noise => ACOLITE bias, SZA 66°)

Cloud shadow over validation site

[Ruddick et al, 2024; <https://doi.org/10.3389/frsen.2024.1347520> Supplementary]

e.g. S2A 2022-11-21 Acqua Alta

e.g. S2A 2022-06-12 Oostende

S2VT2023 CONCLUSIONS

Sentinel-2 is amazing! We see so much more! Well done ESA&co!!!

Over water Sentinel-2 data quality problems from:

- Aerosol correction
- Sun glint correction
- Short wavelength (443 nm) everything: Rayleigh, aerosol, sun glint, TOAcal, .
- Adjacency effects in inland waters
- Cloud shadows over all waters (and mountain shadows)

Improve A/C OR tighten satellite data QC?

Over land Sentinel-2 data quality problems from:

- Don't really know yet, this is very early experience with in situ measurements of land reflectance
- ... need to understand angular and spatial variability during matchup procedure

HYPERNETS automated h/spectral water and land surface reflectance measurements are **super-useful**

- Work still needed to understand all measurement uncertainties
- Water: skyglint correction in high wind
- Land: angular and spatial variability
- Both: platform perturbations

BUT the **early HYPERNETS data is clearly useful** (better than almost nothing), sometimes show A/C weaknesses

Can we improve, e.g. with a **sensor noise bias correction (SNBC)** or with a different **percentile (P5?)** for Dark Spectrum?

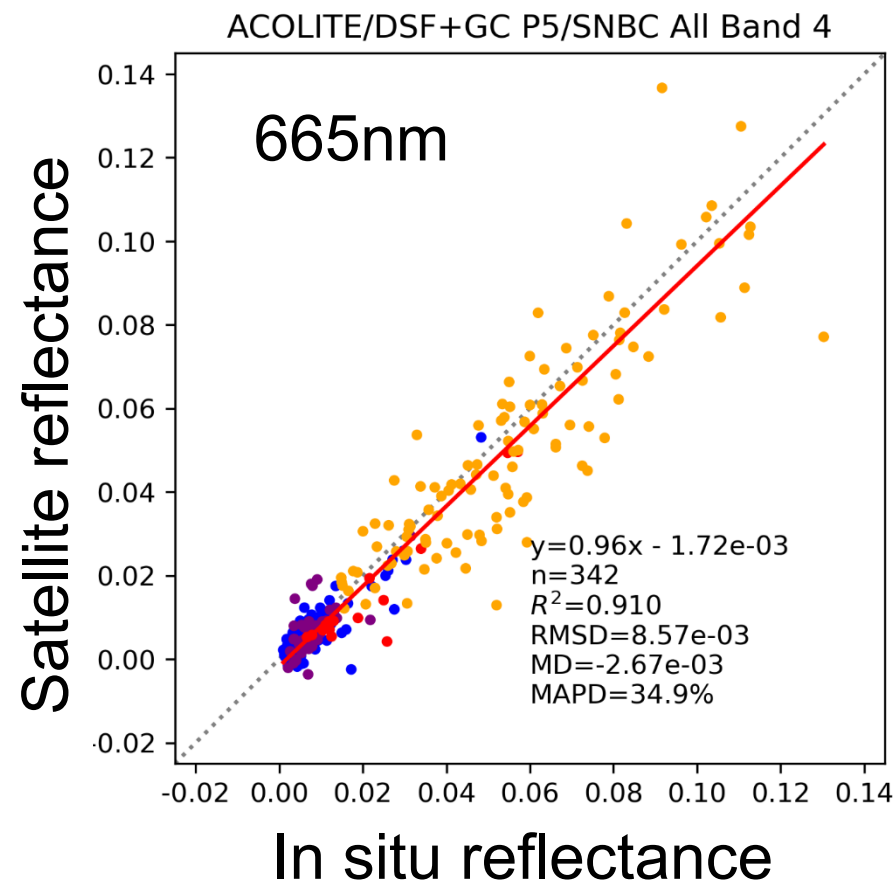
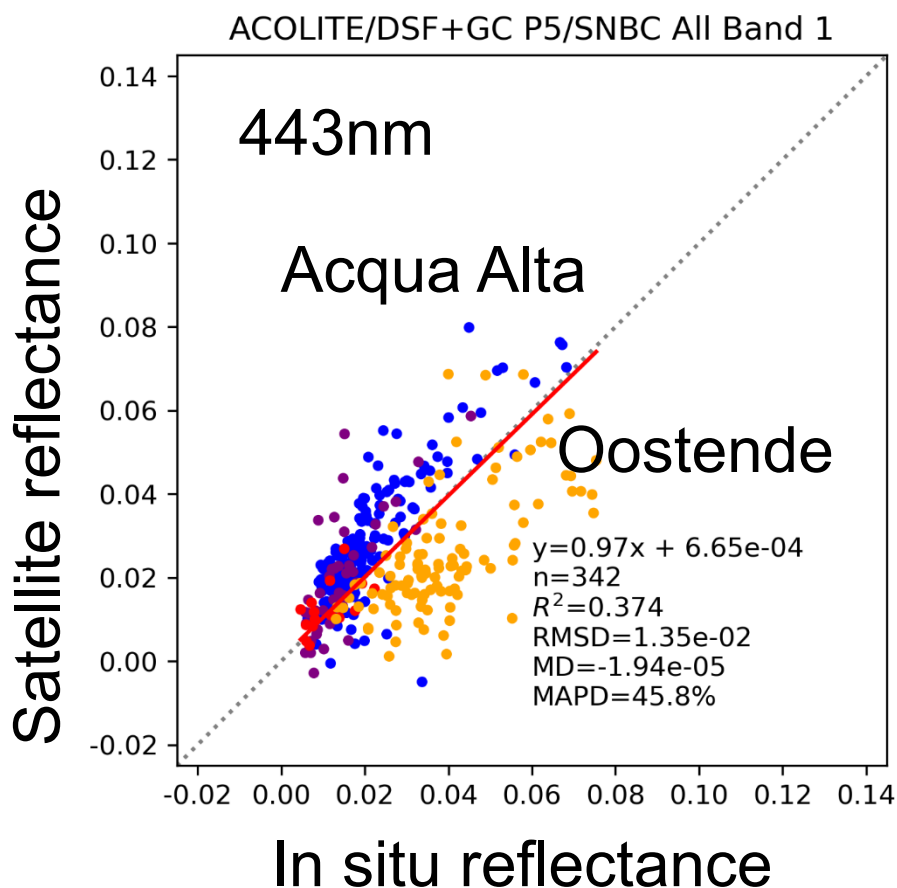
What about Sentinel-2C?

New results with more matchups (inc S2C)

Sat data: S2A+S2B+S2C, e.g. for ACOLITE DSF with Glint Corr, 5% DSF and SNBC

In situ HYPERNETS data 2019-25 (**342** matchups):

Acqua Alta [V.Brando], Oostende [D.Vansteenwegen], Chesapeake [K.Turpie], Thornton [F.Ortenzio]

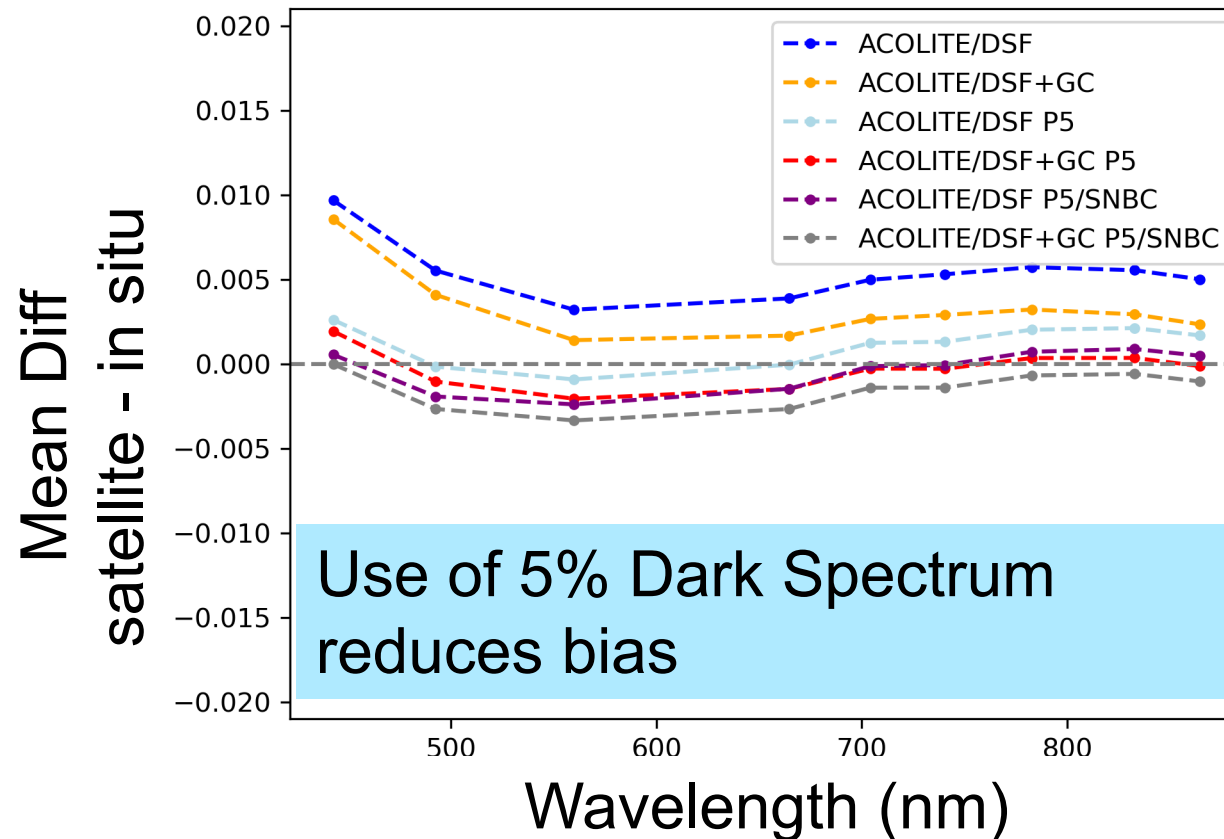
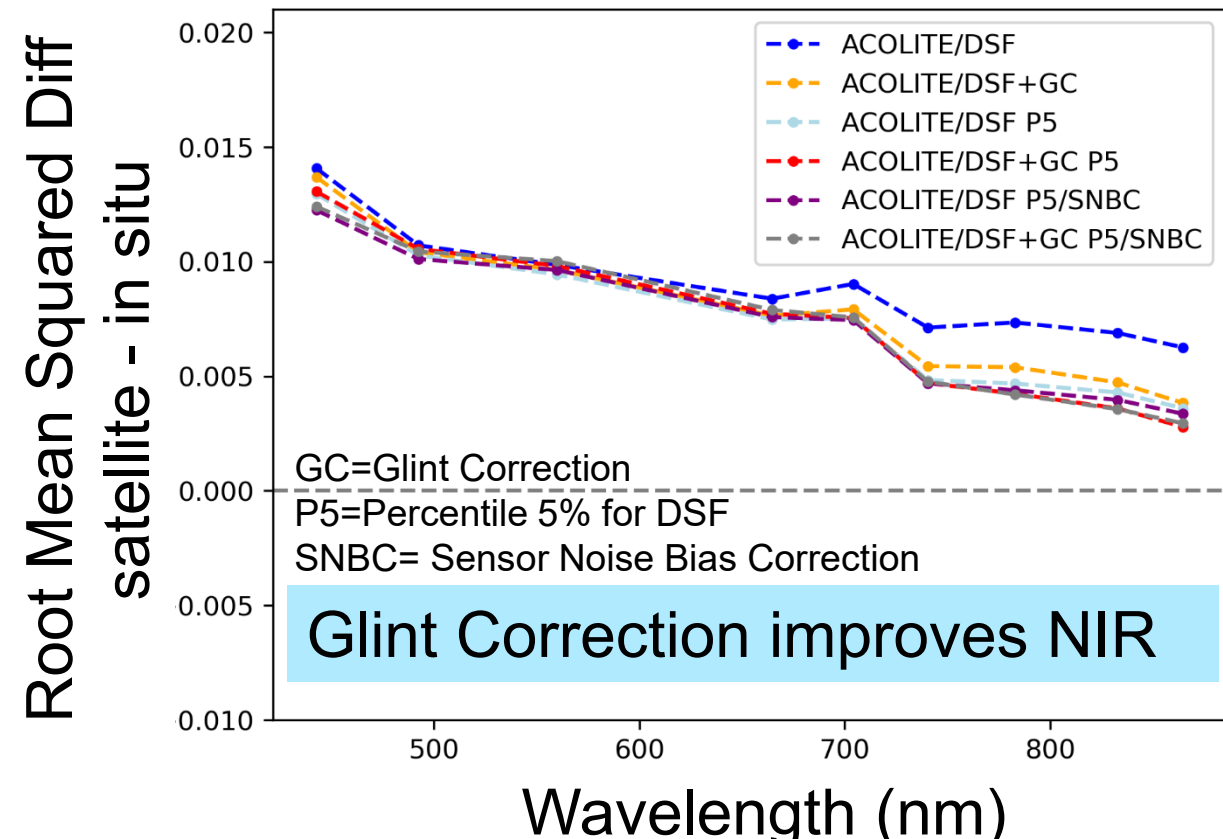


New results with different ACOLITE variants [Processing: Q.Vanhellemont]

Sat data: S2A+S2B+S2C

In situ HYPERNETS data 2019-25 (**342** matchups):

Acqua Alta [V.Brande], Oostende [D.Vansteenwegen], Chesapeake [K.Turpie], Thornton [F.Ortenzio]



BUT many problems can occur especially for short wavelengths

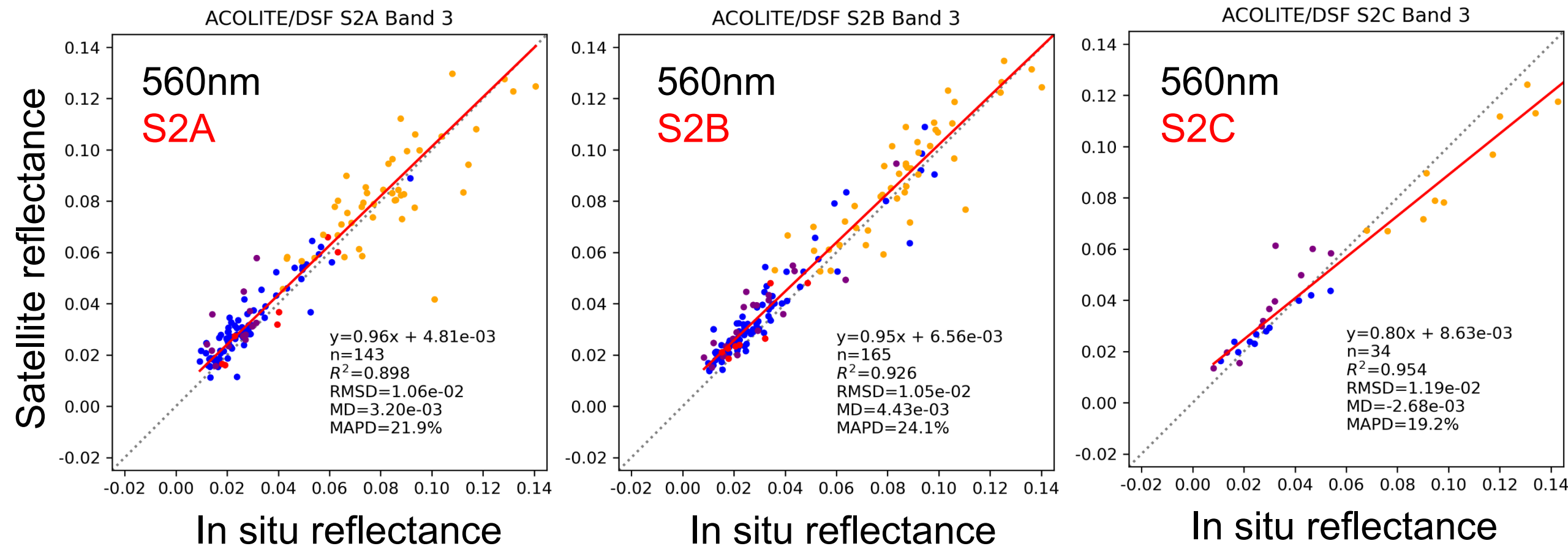
Sentinel-2C early performance

Similar performance for Sentinel-2C
(matchups/site different in 2025)

Sat data: S2A (143) +S2B (165) +S2C (34)

In situ HYPERNETS data 2019-25 (342 matchups):

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Conclusions (1/2) - general

- The HYPERNETS network measures **hyperspectral water (380-900 nm) and land surface (380-1680 nm) reflectance** for satellite validation
 - inc. multiple viewing angles for land HDRF
- **Diverse water (~12) and land (~7) surface types**
 - International expansion in 2025-26 inc more Southern hemisphere (Argentina, Australia) + USA, S. Korea
- **Demonstration validation studies** for Sentinel-2, Sentinel-3/OLCI, Landsat-89/OLI, VIIRS, PRISMA, ENMAP, Pléiades, **Planet/Doves+Superdoves, PACE**
 - =>useful for determining **fitness-for-purpose** of sat data and **identifying where improvements** can be made esp Atmospheric Correction, Cloud and Cloud shadow masking, sunglint over water, ...
- **Validation site coordinates** useful for cal/val acquisition planning:

https://www.hypernets.eu/network/validation_sites

For the purpose of planning satellite acquisitions, e.g. during the Commissioning Phase or for regular cal/val, a list of current HYPERNETS validation sites can be found here [HYPERNETS_VALIDATION_SITE_COORDINATES_2024-08-08_PUBLIC.csv](#)

- Example study uses S2 to quantify additional **uncertainty from spatial difference** (in situ/sat)

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BUT the **early HYPERNETS data is clearly useful** (better than almost nothing),

Some improvements from sensor noise bias correction (SNBC) and with a different percentile (P5?) for Dark Spectrum

S2C similar performance to S2A BUT need more matchups in 2025 ...

Pixel-level geometry would be useful (sunglint, Rayleigh)

WATERHYPERNET

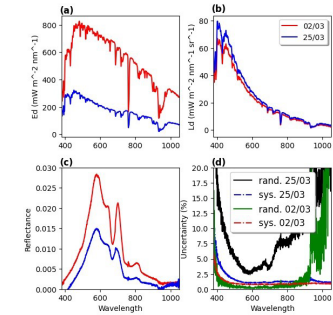
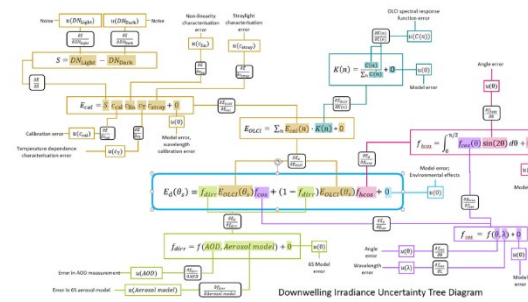
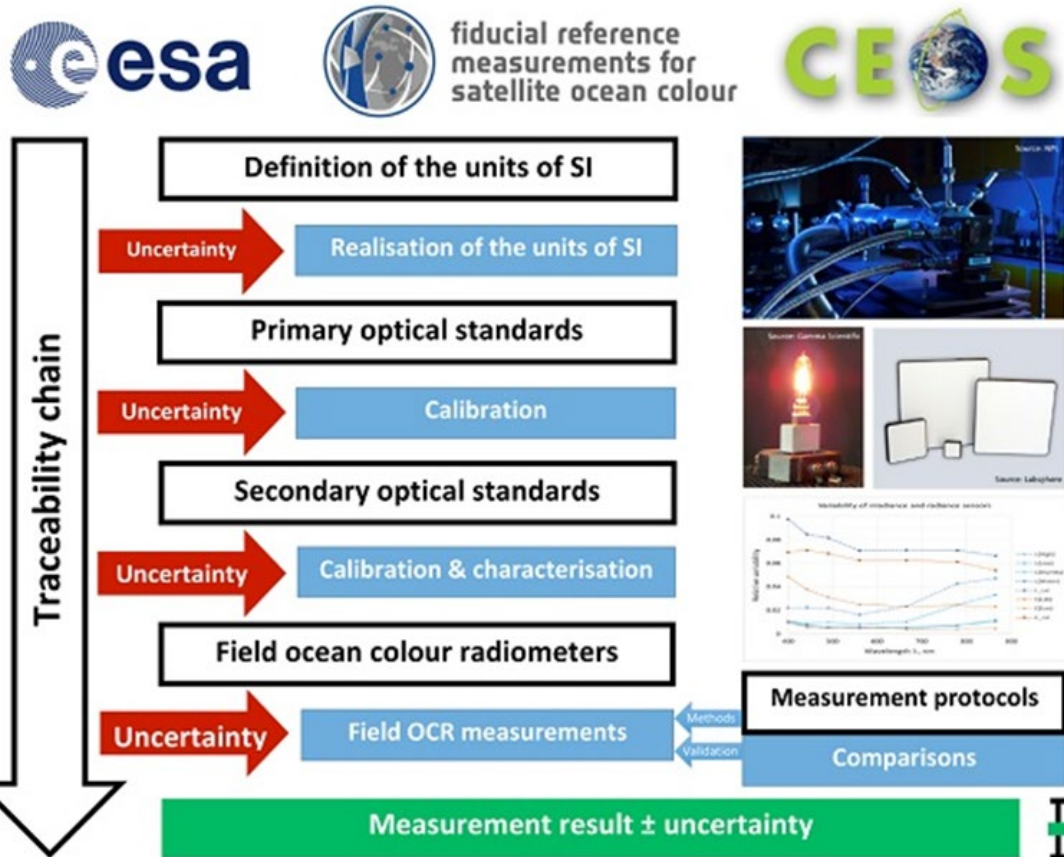
- Details of instrument, processing and demonstration studies at:
<https://www.hypernets.eu/network/publications>
- Data access:
<https://waterhypernet.org/data/>
- Join us at [IOCS/WATERHYPERNET side meeting \(4 Dec, Darmstadt\)](#) for data users:

And for LANDHYPERNET:

- Presentation Wednesday 15 Oct, 09:30 by Pieter De Vis
- Join us at post-VHRODA meeting (21 Nov, Frascati) for data users

(Fiducial Reference) Measurement Uncertainty

- GUM methodology and propagation software mature
- Uncertainty tree diagram for downwelling irradiance [Bialek, 2020]
- Data provided with uncertainties [De Vis et al, 2024]



Extra uncertainties
(variability)
Spatial
Temporal
Spectral
Angular

UPSCALING_land (spatial)
HCR_land (angular)
BRDF_water (angular)
studies in progress ...

← Matchup validation →



[Banks et al. "Fiducial Reference Measurements for Satellite Ocean Colour (FRM4SOC)". Remote Sens. 2020, 12, 1322. <https://doi.org/10.3390/rs12081322> and <https://frm4soc.org>]