PROGRAMME OF THE EUROPEAN UNION

co-funded with esa

Copernicus Marine High-Resolution Service: Correction of Detector Banding Effects

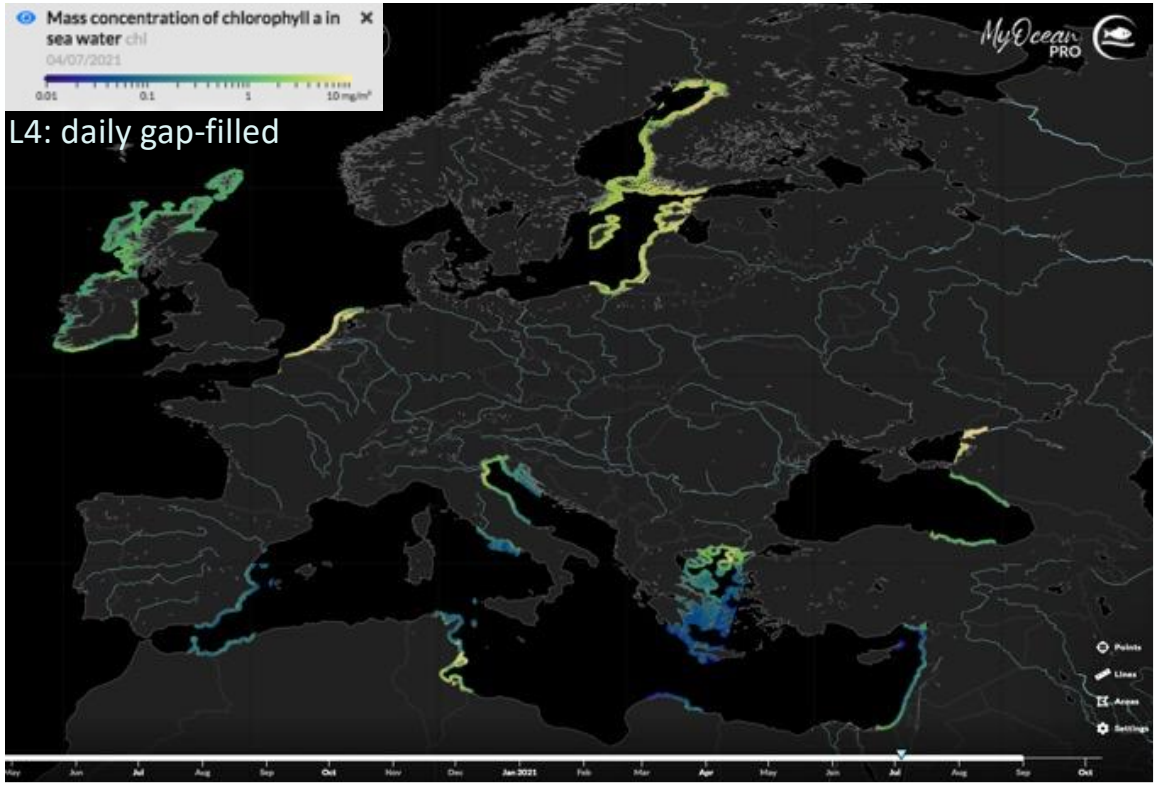
Dimitry Van der Zande, Quinten Vanhellemont, Kerstin Stelzer, Carole Lebreton, Antoine Dille, Martin Böttcher, Kevin Ruddick, Carsten Brockmann

Fact Sheet High Resolution Coastal Service

PROGRAMME OF THE EUROPEAN UNION · Copernicus Europe's eyes on Earth · co-funded with esa

- **Sensor:** Sentinel-2/MSI (A&B)
- Covering **coastal strips of 20km** for all European Seas
- **Spatial resolution**: 100m
- **Gridding:** Geographic lat/lon grid WGS84 / polar Lambertian Azimuthal Equal Area
- **Period:** 1/1/2020 to current day
- **Temporal:**
  - Daily NRT
  - Monthly NRT
  - Daily DINEOF gap-filled
- **Parameters**
  - Remote Sensing Reflectances - RRS(l)
  - Turbidity - TUR
  - Suspended particulate matter – SPM
  - Particulate Backscatter - BBP(l)
  - Chlorophyll Concentration – CHL
- **Production:** Cloud-based processing system running on CreoDias

https://cmems.lobelia.earth/



Chlorophyll-a concentration on 4/7/2021

Operational Processor

S2 L1C granules
TOA Reflectance

L1C

Mosaicking

Pixel Identification

Atmospheric Corrections

merging

Tiles
Water Reflectance
(Rrs + QUAL)

L2R

Water parameter retrievals

merging

Tiles
Water parameters
(TUR, TSM, CHL, bb
+ QUAL)

L2W

L1 mosaic

ACOLITE | iCOR | C2RCC | POLYMER

Rrs_a | Rrs_i | Rrs_c | Rrs_p

Select & merge Rrs

Rrs = Rrs_best

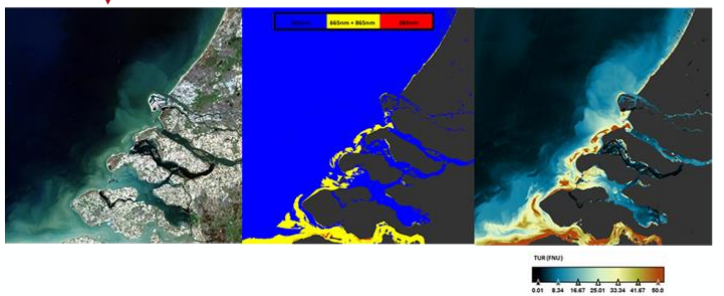
TUR/SPM: Nechad multiband retrieval

Chl: OC3 and Gons

BBP: QAA (Lee)

NOVOA merging

Lavigne merging



Wide range of different water types

Implemented Evolutions (Nov 2022)

Improvement of flagging

Gulf of Gdansk (Baltic Sea)

Bottom reflection flagging

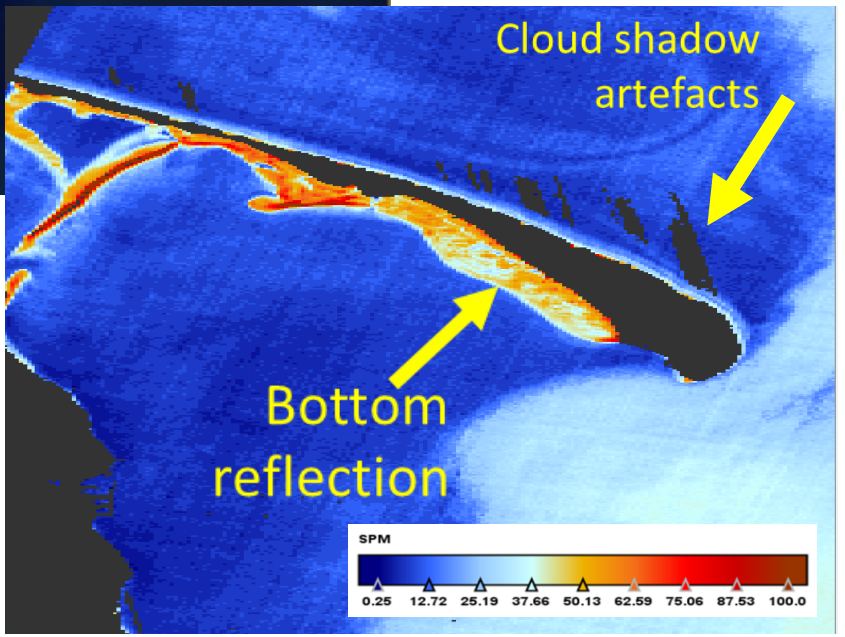
- HROC products cover intertidal flats impacted by bottom reflection
- They are insufficiently flagged with current approach

→**Improve flagging of pixels impacted by bottom reflection** (2022/05)

Cloud shadow artefact flagging

- Cloud shadow flagging performed by IDEPIX
- Some bright coastline features are detected as ‘cloud’ and activate the cloud shadow generation resulting in persistent artefacts

→**Improvement of cloud shadow detection** in IDEPIX by eliminating erroneous cloud detection from e.g. bright beaches (2022/07)

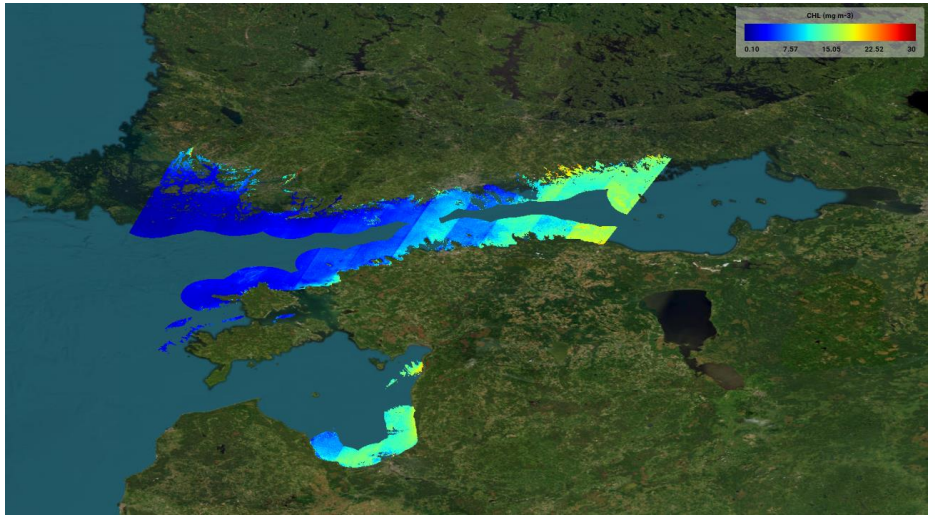


Running Evolutions (Nov 2023)

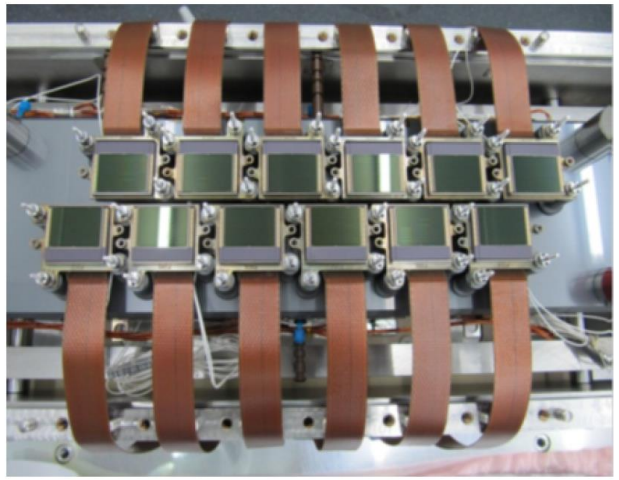
Reduce striping in products caused by detector orientation

- Sentinel-2 sensor construction leads to sharp changes in relative viewing azimuth angle between adjacent detectors causing **visible artefacts**
- influences not only the values of parameters but also the flagging

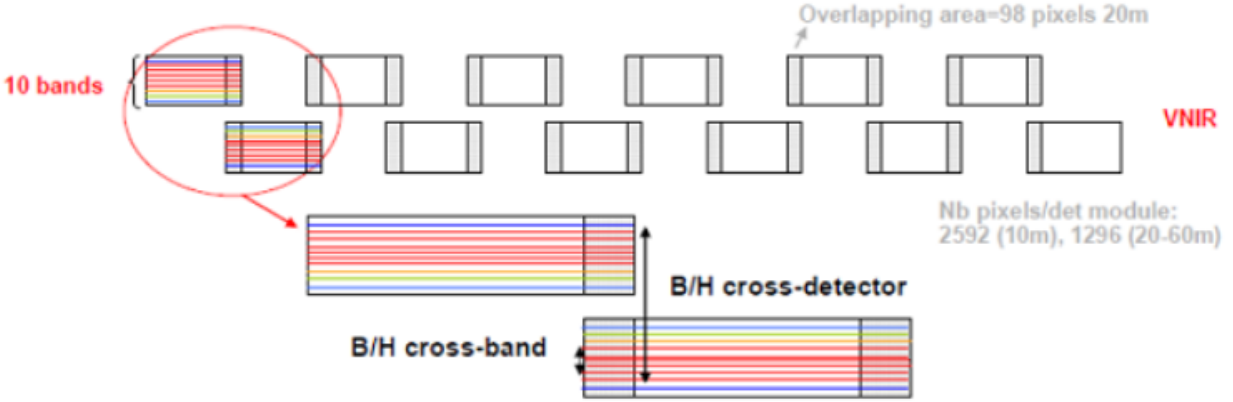
→Improvement of the products through adaptation RTOA, especially for glint areas



CHL products generated from band ratio algorithms show camera banding effects

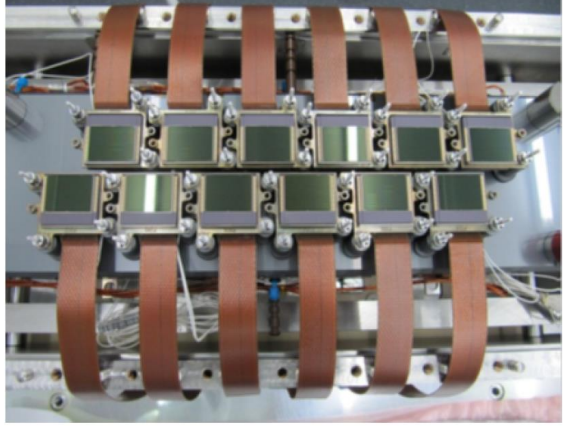


12 detectors of the MSI VNIR focal plane



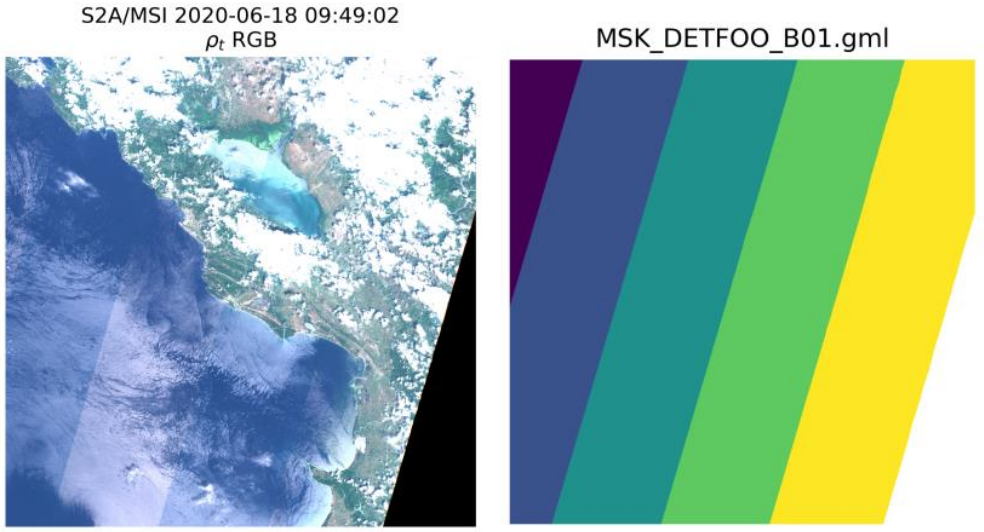
Bands are grouped according to resolution on the MSI detectors: B2, B8, B3, B4 (10 m bands), B5, B6, B7, B8A (20 m bands), B1, B9 (60 m bands).

Running Evolutions (Nov 2023)

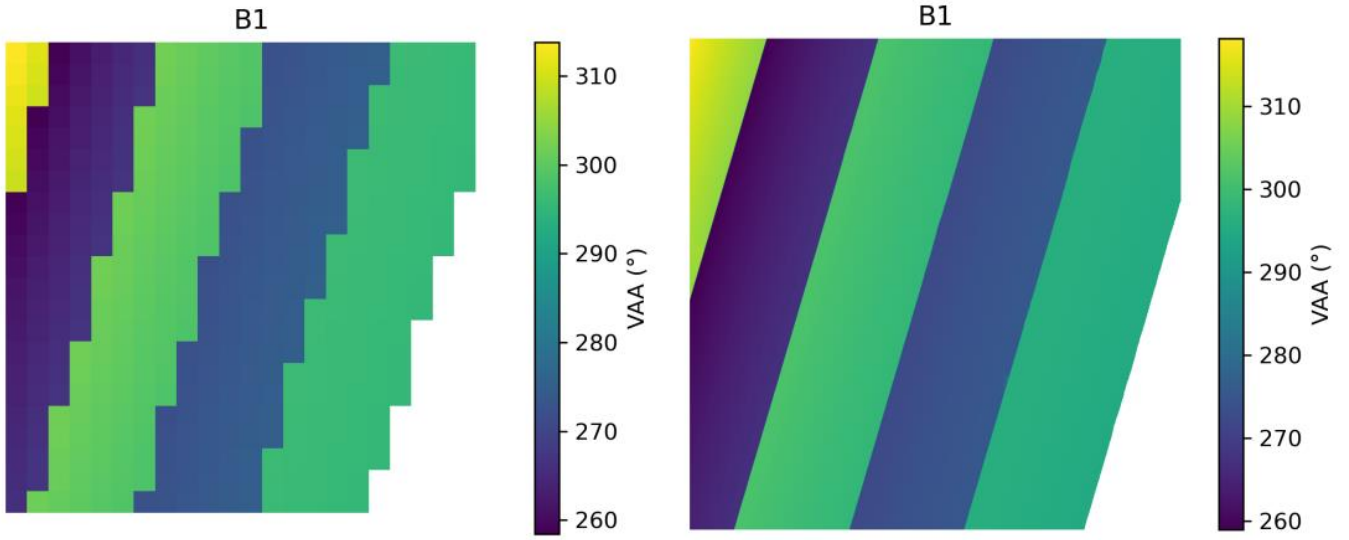


Reduce striping in products caused by detector orientation

- Sentinel-2 sensor construction leads to sharp changes in relative viewing azimuth angle between adjacent detectors causing **visible artefacts**
- influences not only the values of parameters but also the flagging

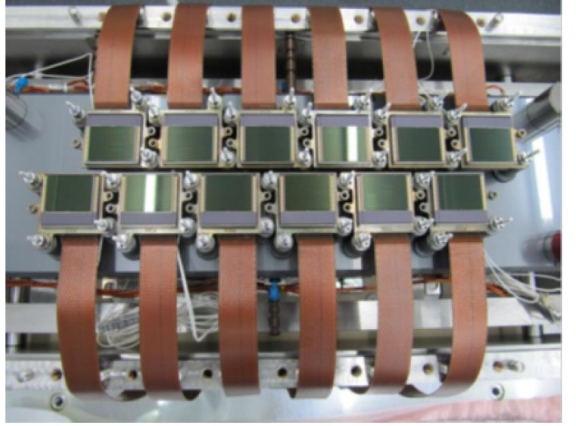


TOA RGB for S2A_MSIL1C_20200618T094041_N0209_R036_T34TCM (Albanian Coast) and B1 detector footprints (detectors 8-9-10-11-12)



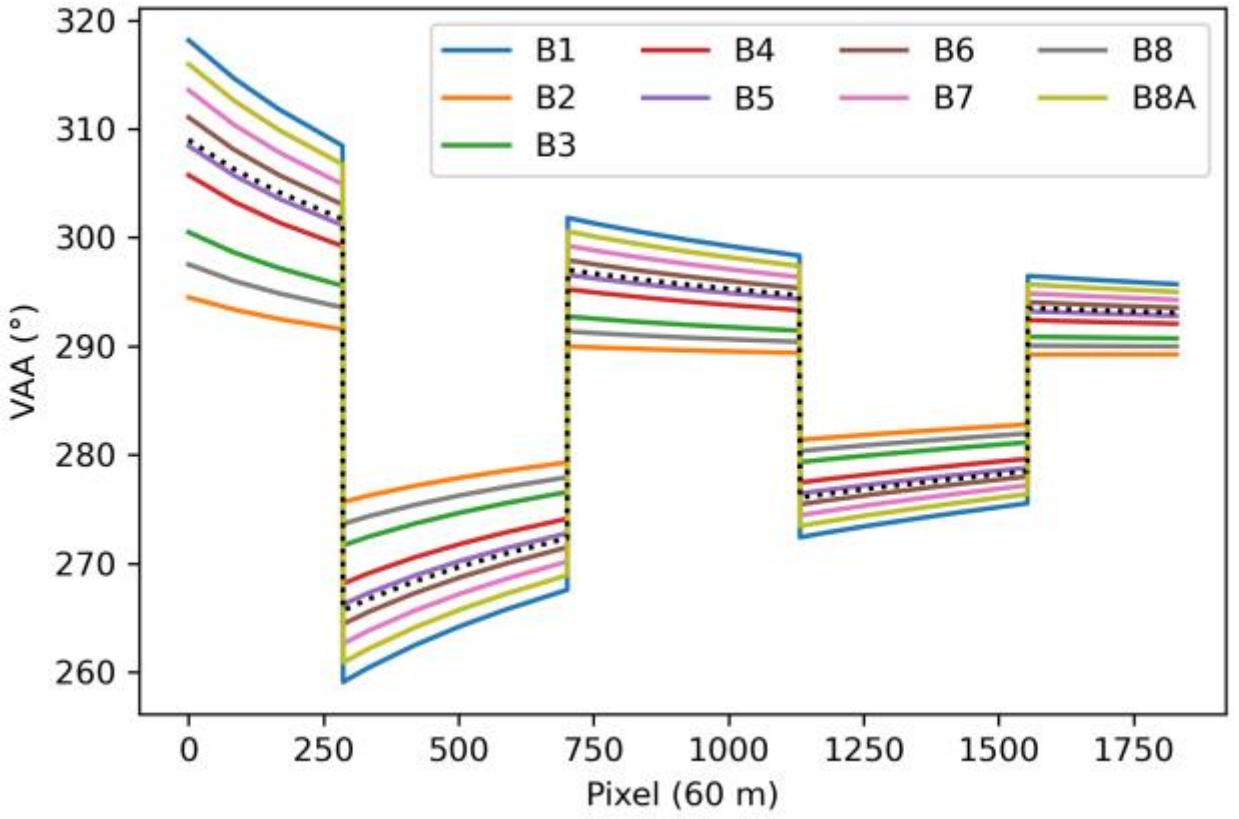
Viewing Azimuth Angle (VAA) for B1 (right) at 5 km grid cells (left) interpolated to detector footprints

Running Evolutions (Nov 2023)



Reduce striping in products caused by detector orientation

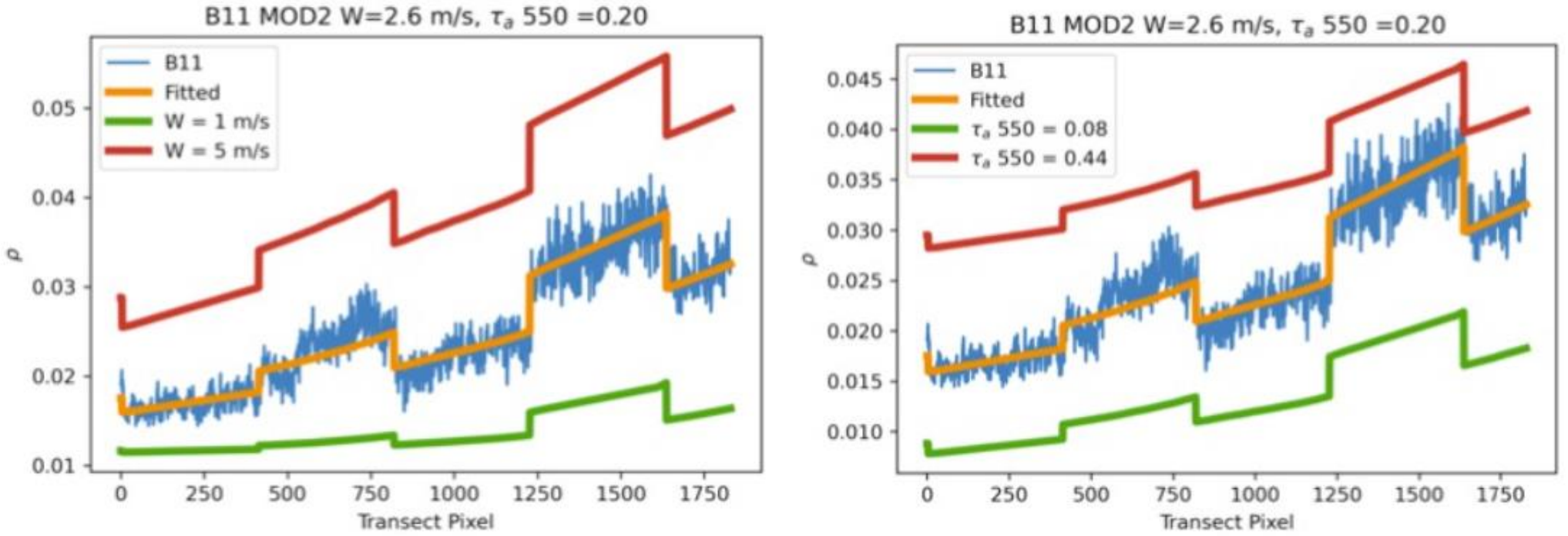
- Sentinel-2 sensor construction leads to sharp changes in relative viewing azimuth angle between adjacent detectors causing **visible artefacts**
- influences not only the values of parameters but also the flagging



- **Extract of Viewing Azimuth Angle for line 2 of the scene for B1 (443 nm) to B8A (865 nm).**
- **The black dotted line shows the result for the average viewing geometry.**
- **Bands, and hence VAA lines in this plot, are grouped according to resolution on the MSI detectors: B2, B8, B3, B4 (10 m bands), B5, B6, B7, B8A (20 m bands), B1, B9 (60 m bands).**
- **This band order is inverted in adjacent detectors due to the physical inversion of the detectors in the sensor assembly.**
- **This leads to relative band-specific VAA differences between detectors which is not considered when using the average viewing geometry**

Top of Atmosphere Glint Correction (TGC)

- **The signal in B11** can be used **to model the spectral shape and intensity of the glint per band and per detector at TOA** by considering **atmospheric transmittance** (aerosol model + concentration) and **windspeed** for the surface signal **taking into account the specific viewing geometry**
- This **glint signal is subtracted from the TOA signal which also removes the banding effect**



Fitting results varying the wind (left) and τ_a (right).

Top of Atmosphere Glint Correction (TGC)

PROGRAMME OF THE EUROPEAN UNION
opernicus Europe's eyes on Earth
co-funded with esa

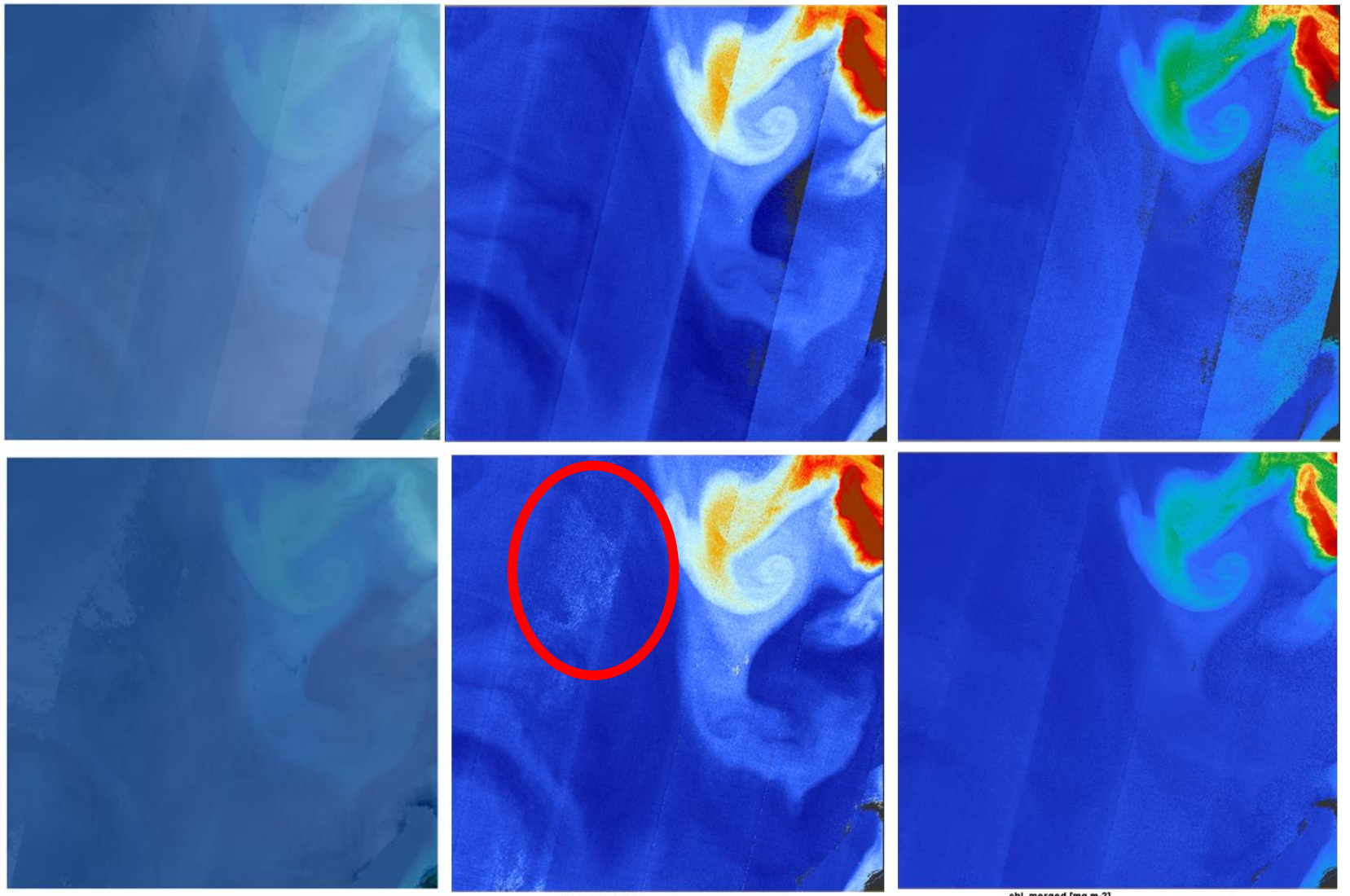
S2B/MSI 2021-05-12 08:18:20
ρ_t RGB

TUR

CHL

Original →

TGC →



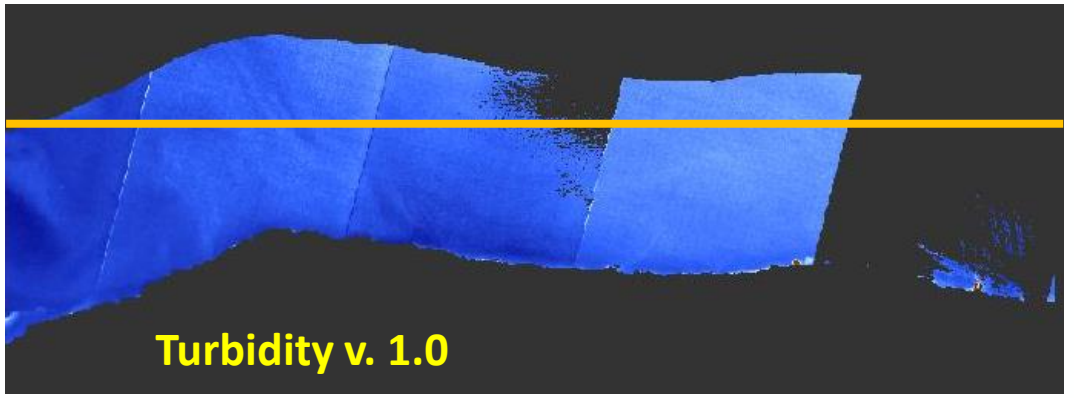
Sun glint

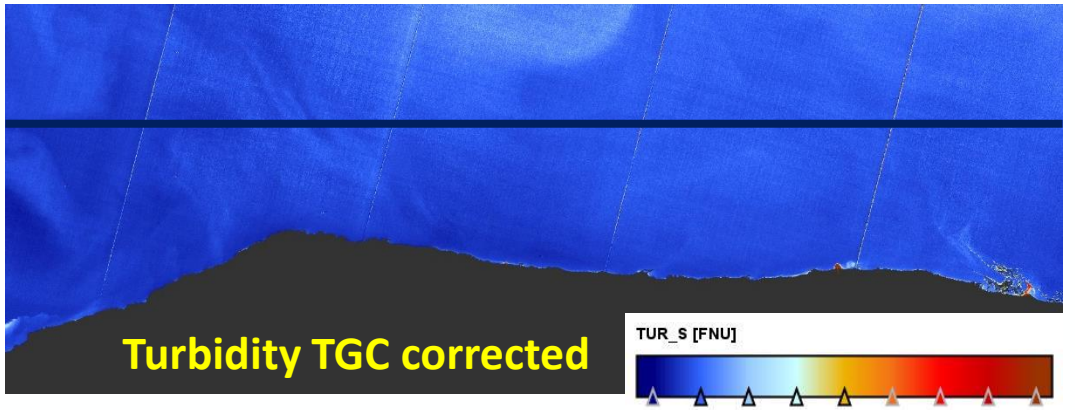
Destriping works well

but adding additional noise in non-glinted areas

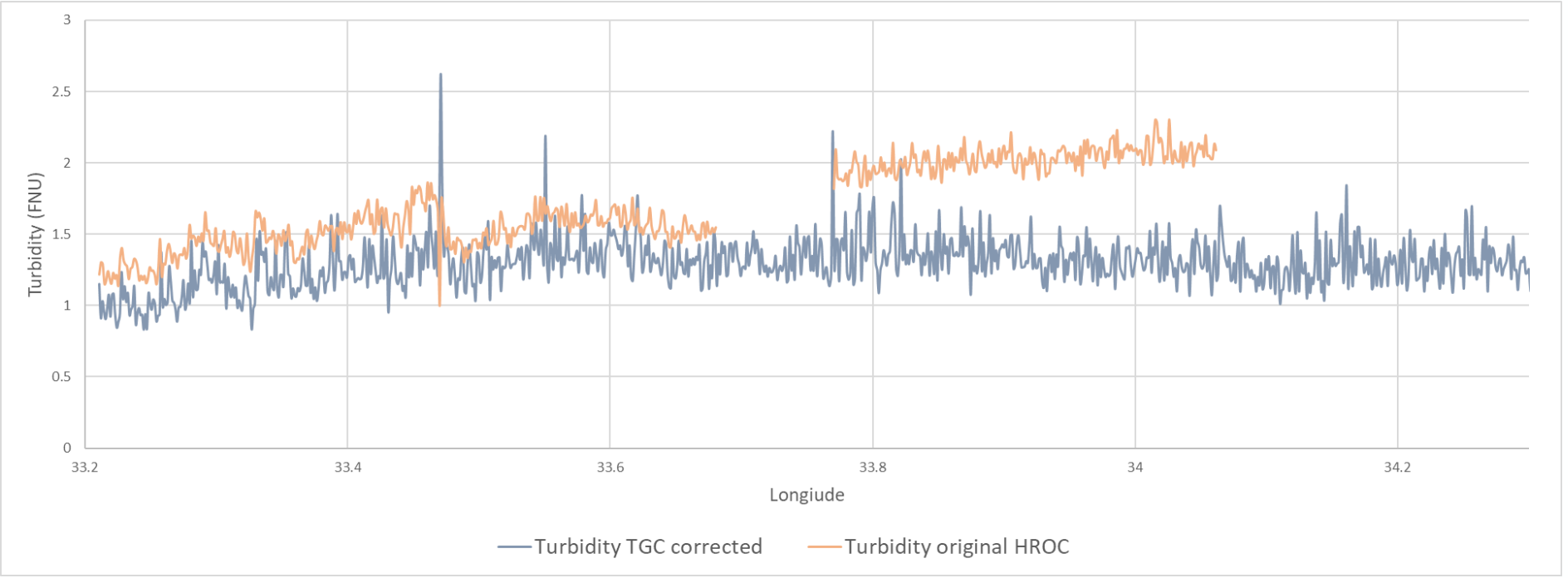
S2B_MSIL1C_20210512T080609_N0300_R078_T37TFG_20210512T102143

Top of Atmosphere Glint Correction (TGC)

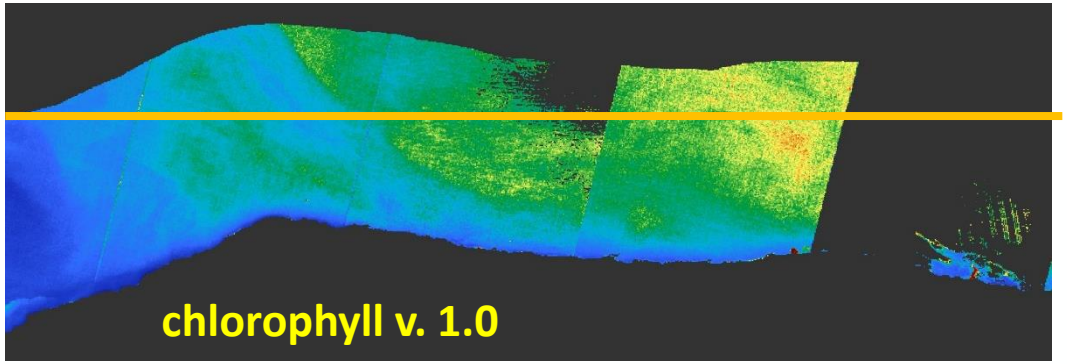


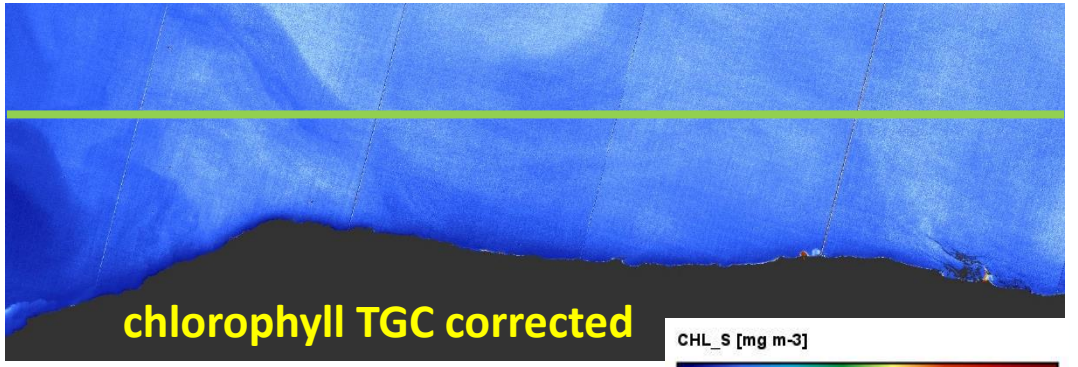


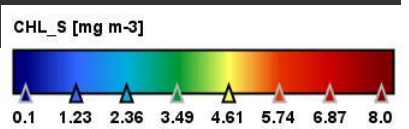
Turbidity products for the southern coast of BLK acquired on 20.07.2023.



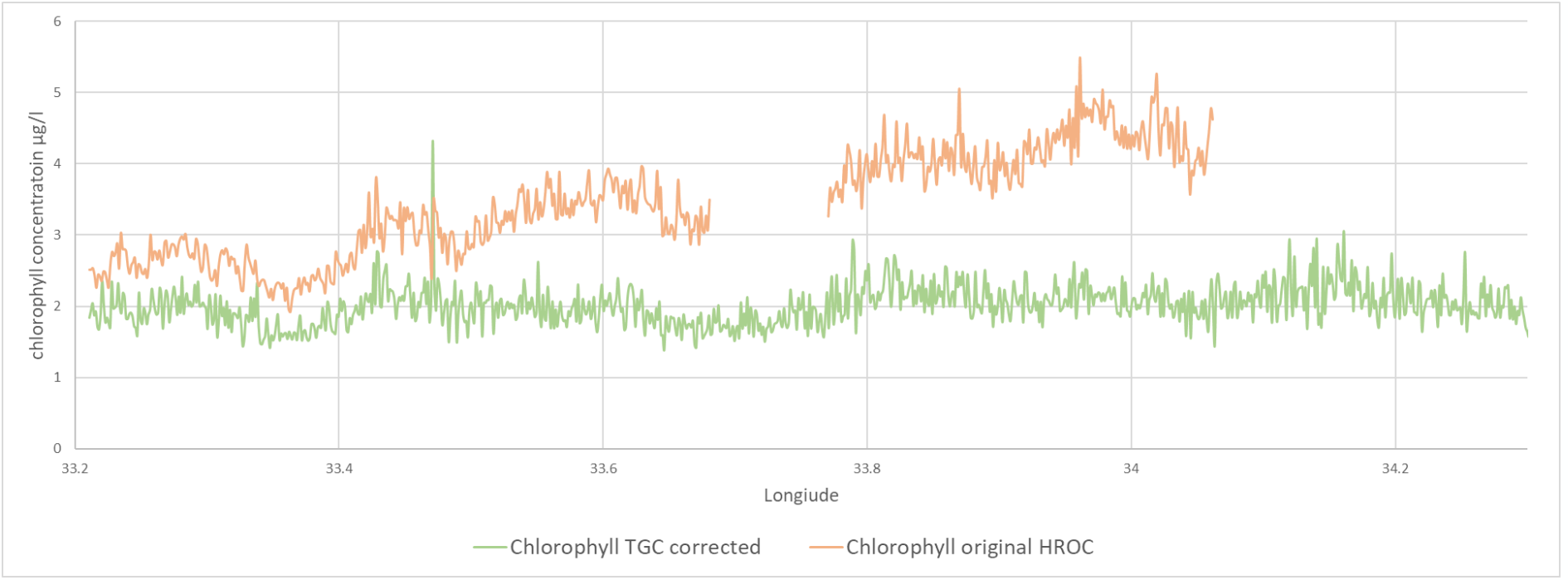
Top of Atmosphere Glint Correction (TGC)







Chlorophyll products for the southern coast of BLK acquired on 20.07.2023.



Top of Atmosphere Glint Correction (TGC)

PROGRAMME OF THE EUROPEAN UNION
opernicus Europe's eyes on Earth
co-funded with esa

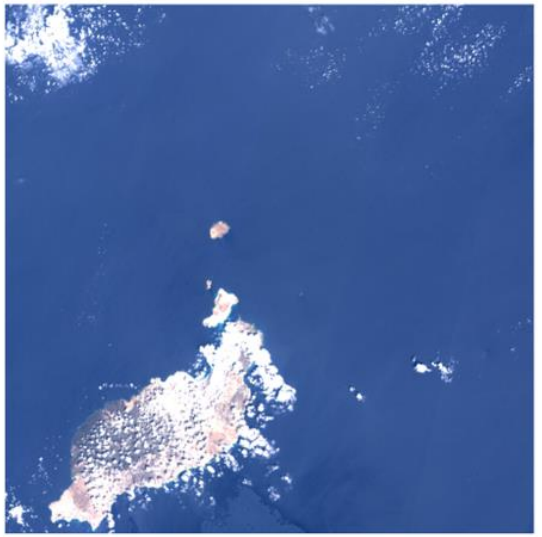
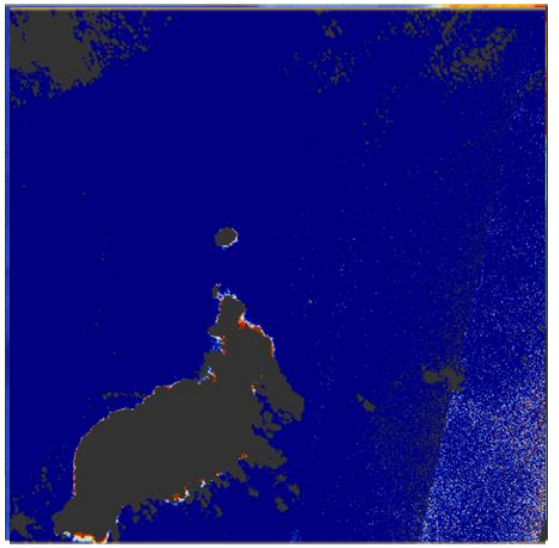
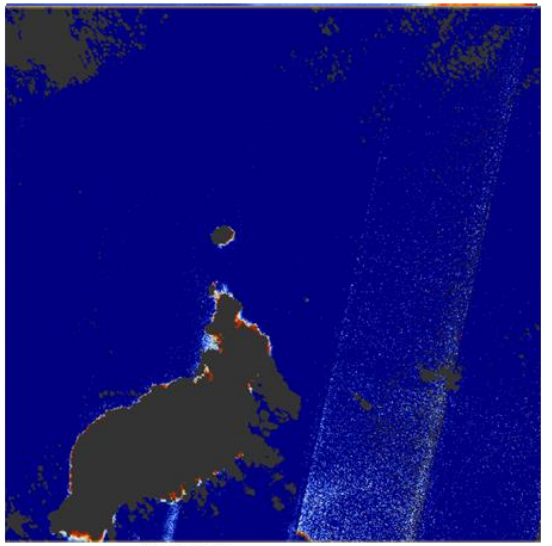
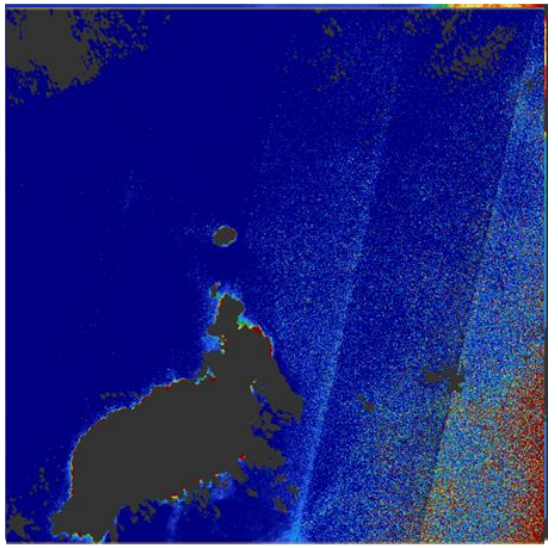
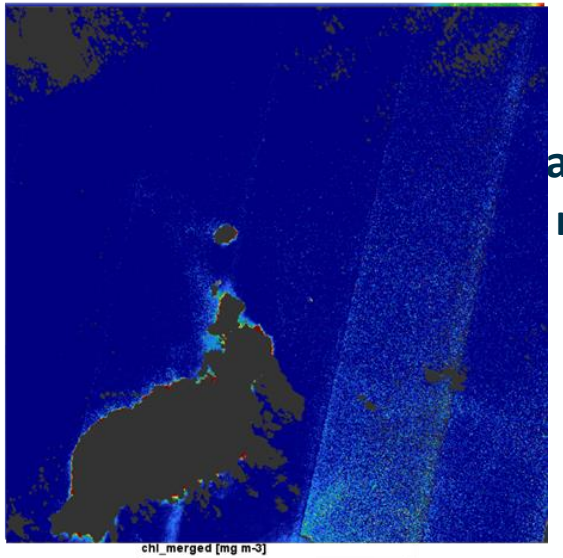
Original →

TGC →

S2A/MSI 2019-09-05 11:43:20
ρ_t RGB

TUR

CHL

tur_merged [FNU]
0.25 1.47 2.69 3.91 5.13 6.34 7.56 8.78 10.0

chl_merged [mg m-3]
0.1 1.51 2.93 4.34 5.76 7.17 8.59 10.0

Sun glint in clear water

Destriping works well

but adding additional noise in non-glinted areas

S2A_MSIL1C_20190905T113321_N0208_R080_T28RFT_20190905T115747

Top of Atmosphere Glint Correction (TGC)

PROGRAMME OF THE EUROPEAN UNION
opernicus Europe's eyes on Earth
co-funded with esa

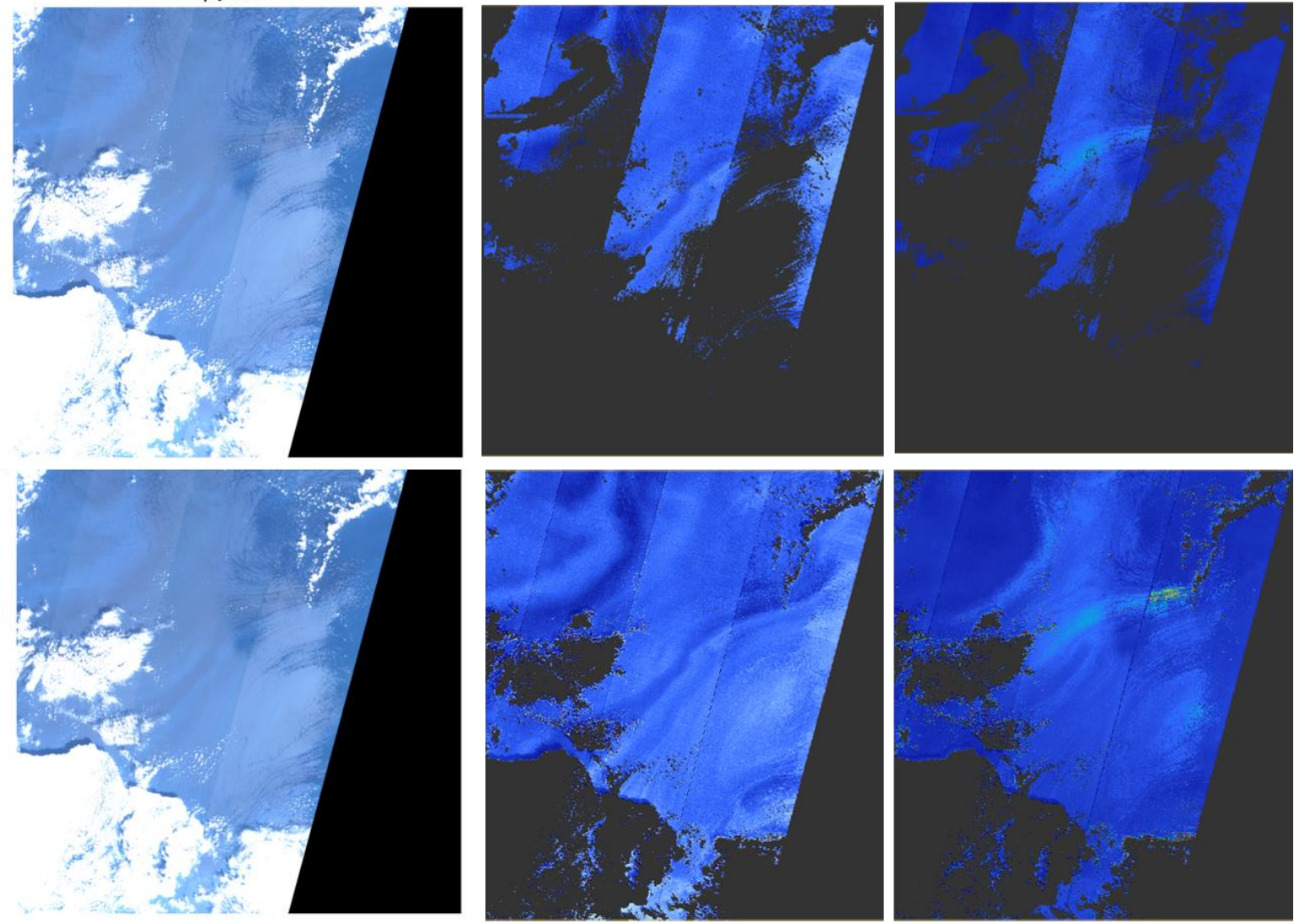
S2A/MSI 2022-08-03 08:28:32
ρ_t RGB

TUR

CHL

Original →

TGC →



tur_merged [FNU]
0.25 1.47 2.69 3.91 5.13 6.34 7.56 8.78 10.0

chl_merged [mg m-3]
0.1 1.51 2.93 4.34 5.76 7.17 8.59 10.0

S2A_MSIL1C_20220803T081611_N0400_R121_T37TEG_20220803T091427

Sun glint in clear water

Destriping works well

No correction over non-effected areas

Gain of valid pixels

Top of Atmosphere Glint Correction (TGC)

PROGRAMME OF THE EUROPEAN UNION
opernicus Europe's eyes on Earth
co-funded with esa

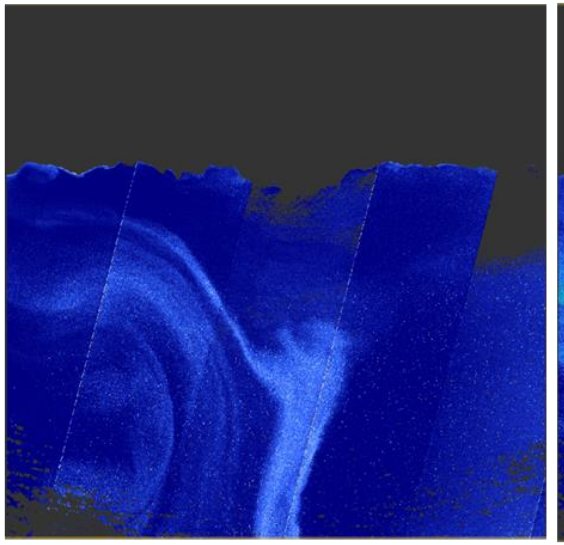
S2A/MSI 2023-04-18 11:11:03
ρ_t RGB

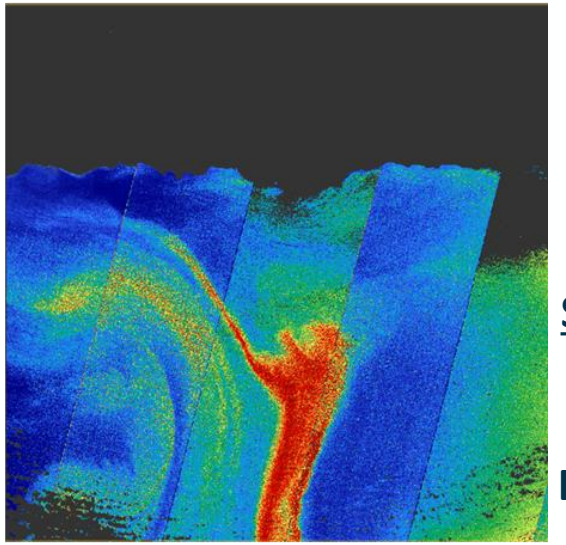
TUR

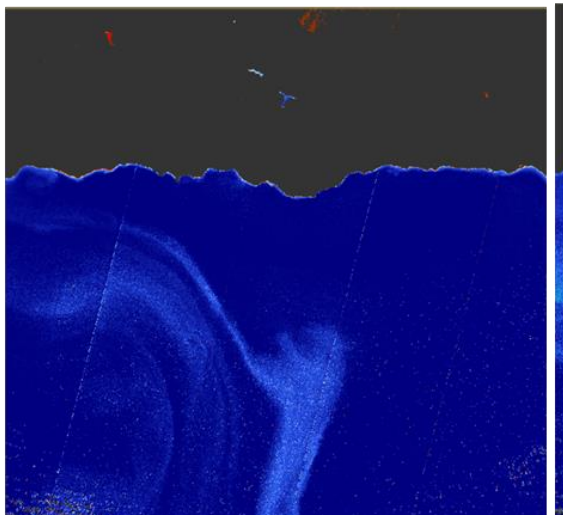
CHL

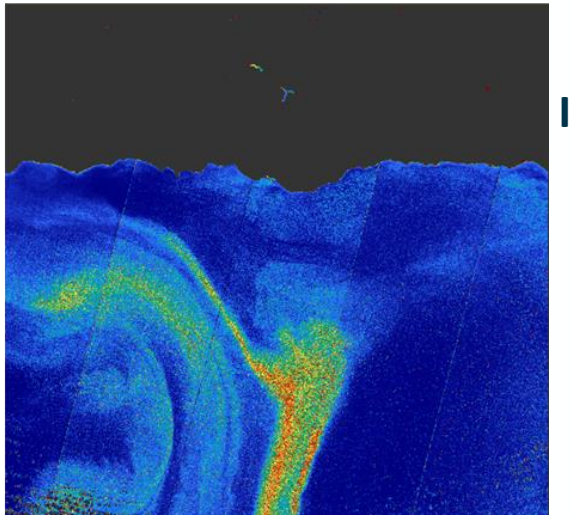
Original →

TGC →









tur_merged [FNU]
0.25 1.47 2.69 3.91 5.13 6.34 7.56 8.78 10.0

chl_merged [mg m-3]
0.1 1.51 2.93 4.34 5.76 7.17 8.59 10.0

Sun glint in clear water

Destriping works well

Introduced noise in bloom

Gain of valid pixels

S2A_MSIL1C_20230418T105621_N0509_R094_T30SVF_20230418T144035

Top of Atmosphere Glint Correction (TGC)

PROGRAMME OF THE EUROPEAN UNION
opernicus Europe's eyes on Earth
co-funded with esa

S2A/MSI 2022-08-06 10:06:11
ρ_t RGB

TUR

CHL

Original →

TGC →

Revision of CHL algorithm planned in next evolutions (2024)

tur_merged [FNU]
0.25 1.47 2.69 3.91 5.13 6.34 7.56 8.78 10.0

chl [mg m-3]
0.1 2.94 5.79 8.63 11.47 14.31 17.16 20.0

Dark water (BAL)

No impact by TGC in low reflectance waters

S2A_MSIL1C_20220806T100611_N0400_R022_T34VCK_20220806T135051

Top of Atmosphere Glint Correction (TGC)

PROGRAMME OF THE EUROPEAN UNION
Copernicus Europe's eyes on Earth
co-funded with esa

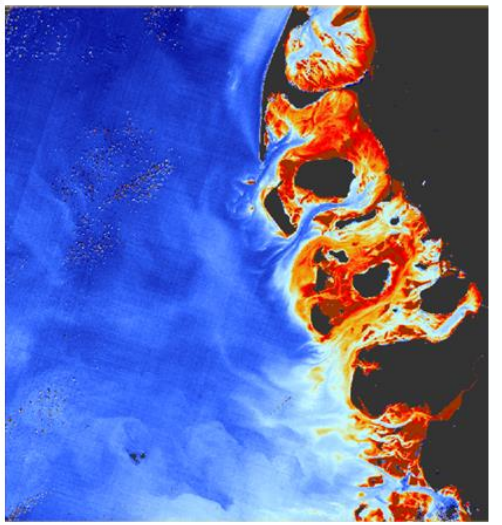
S2B/MSI 2022-08-10 10:45:52
ρ_t RGB

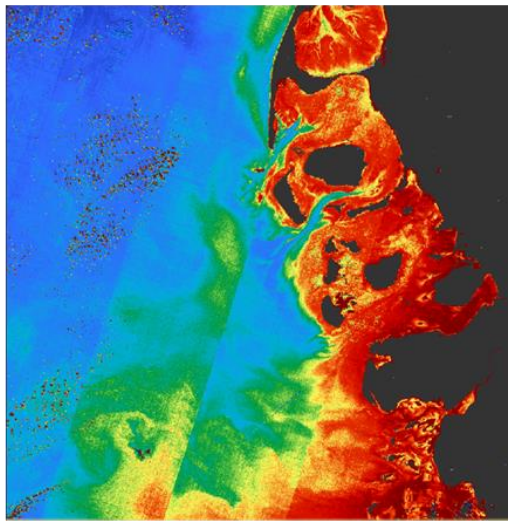
TUR

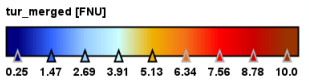
CHL

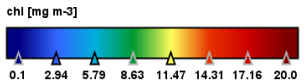
Original →

TGC →









Turbid waters

TGC is not activated (outside sun glint)

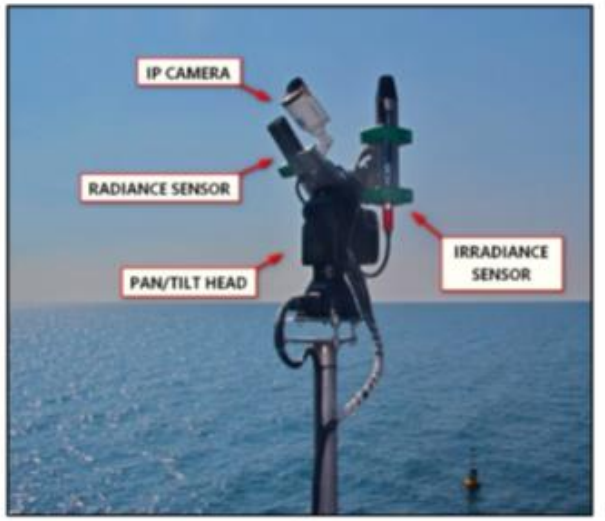
Stripes not corrected

S2B_MSIL1C_20220810T103629_N0400_R008_T32UMF_20220810T112405

Impact of TGC on HROC validation (RRS)

- Waterhypernet (2 PANTHYR stations)
  - Autonomous measurement of hyperspectral water reflectance
  - Pan-and-tilt system + Trios

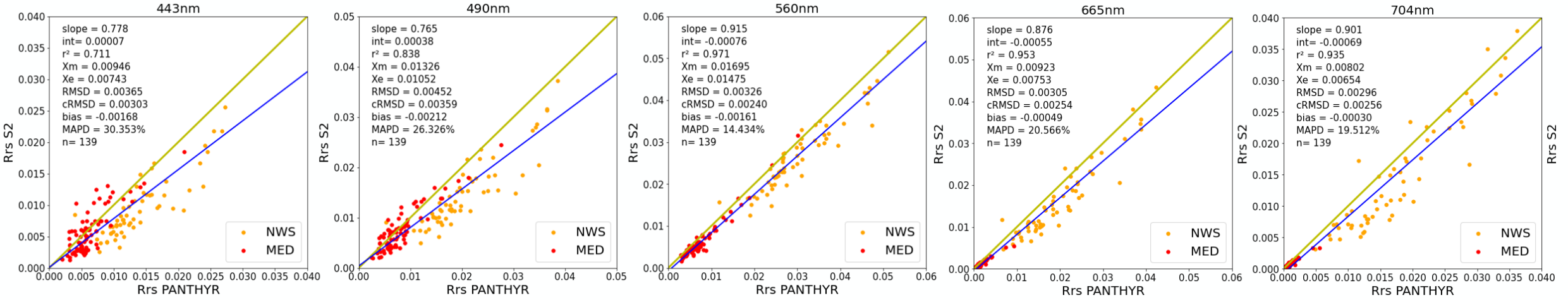
Oostende (BEL; PI: VLIZ)
Aqua-Alta (IT, PI: CNR)
2020-2023 operational product validation



(a)


(b)

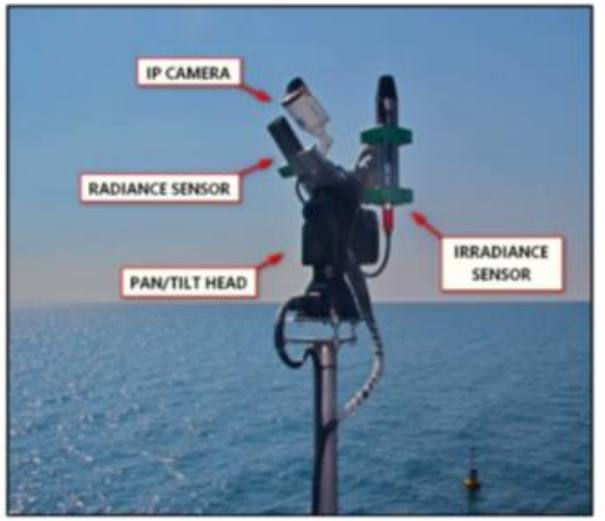
Original HROC



Impact of TGC on HROC validation (RRS)

- Waterhypernet (2 PANTHYR stations)
  - Autonomous measurement of hyperspectral water reflectance
  - Pan-and-tilt system + Trios

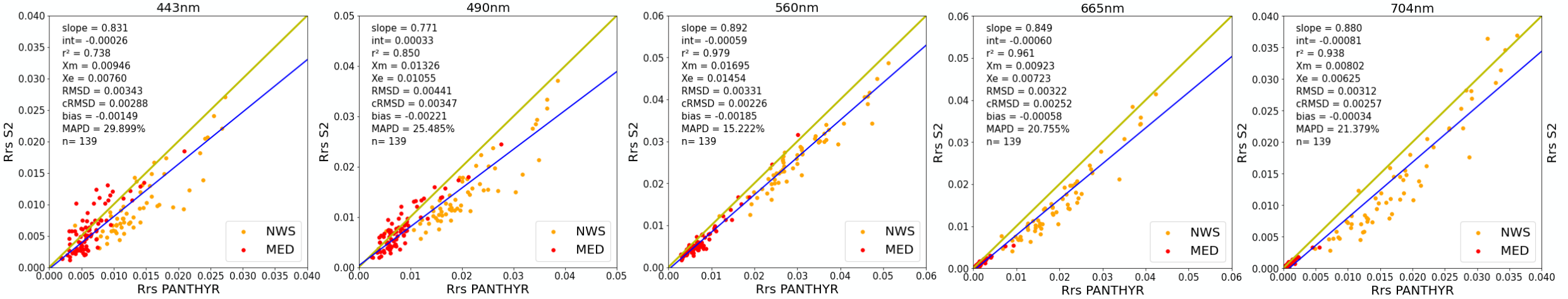
Oostende (BEL; PI: VLIZ)
Aqua-Alta (IT, PI: CNR)
2020-2023 operational product validation



(a)


(b)

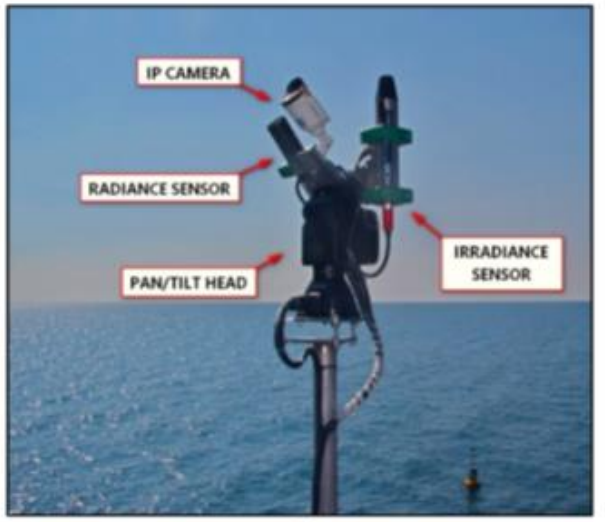
TGC



Impact of TGC on HROC validation (RRS)

- Waterhypernet (2 PANTHYR stations)
  - Autonomous measurement of hyperspectral water reflectance
  - Pan-and-tilt system + Trios

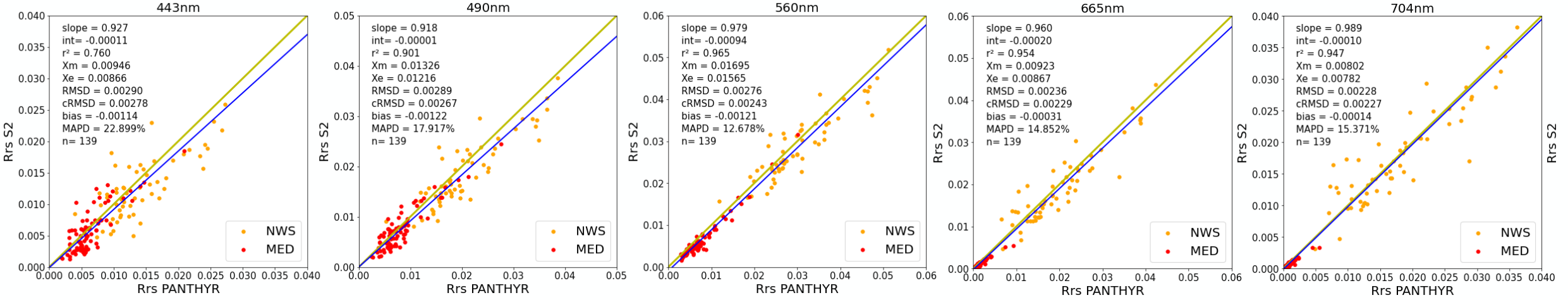
Oostende (BEL; PI: VLIZ)
Aqua-Alta (IT, PI: CNR)
2020-2023 operational product validation



(a)

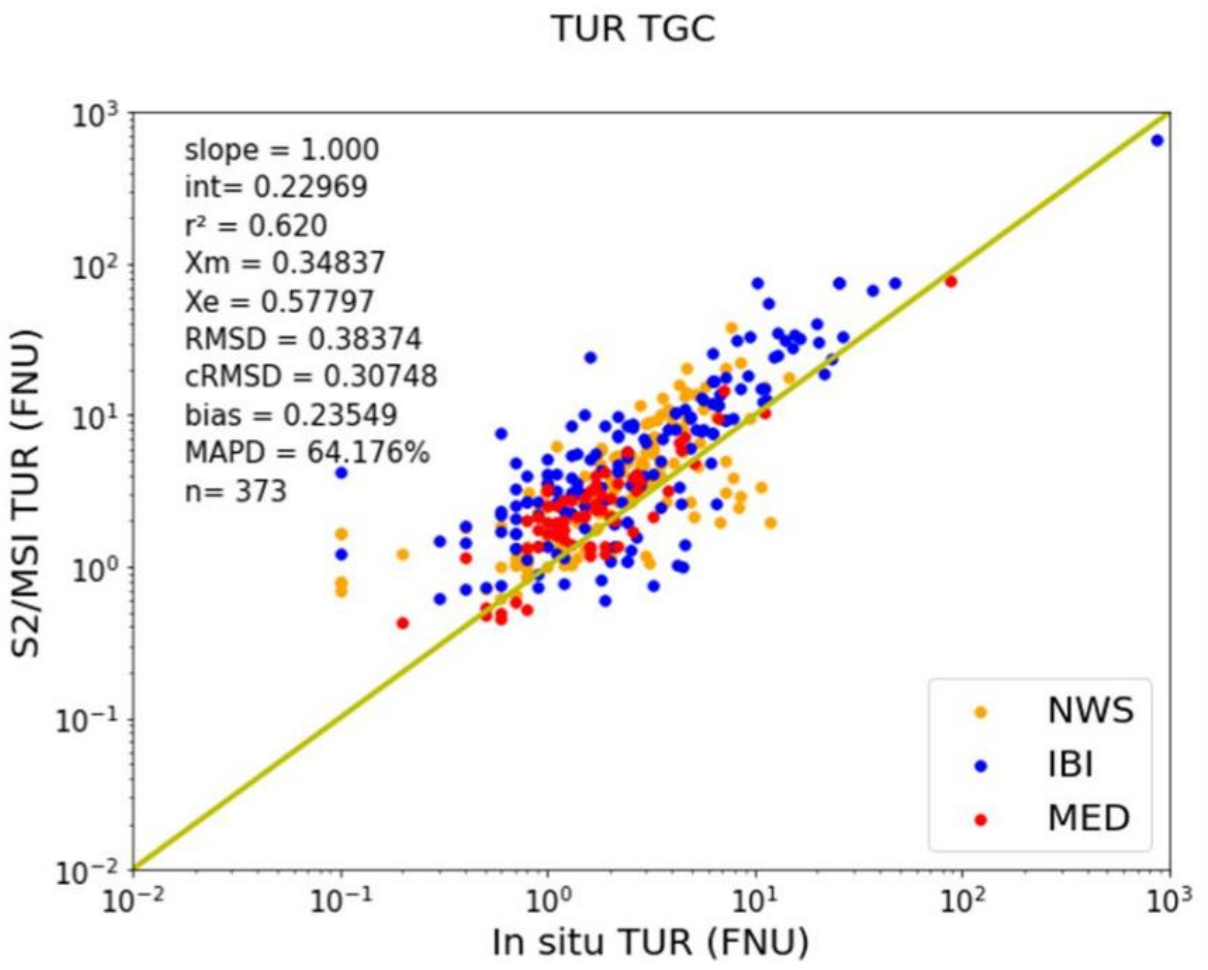

(b)

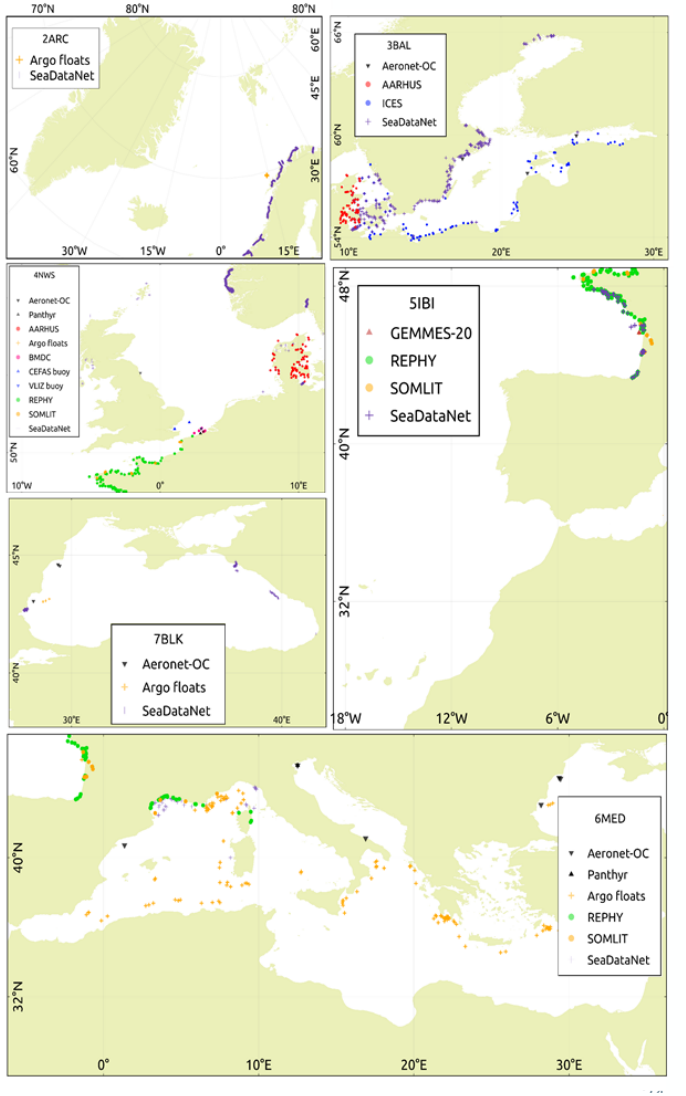
REPARAMETRIZATION of merging C2RCC and ACOLITE



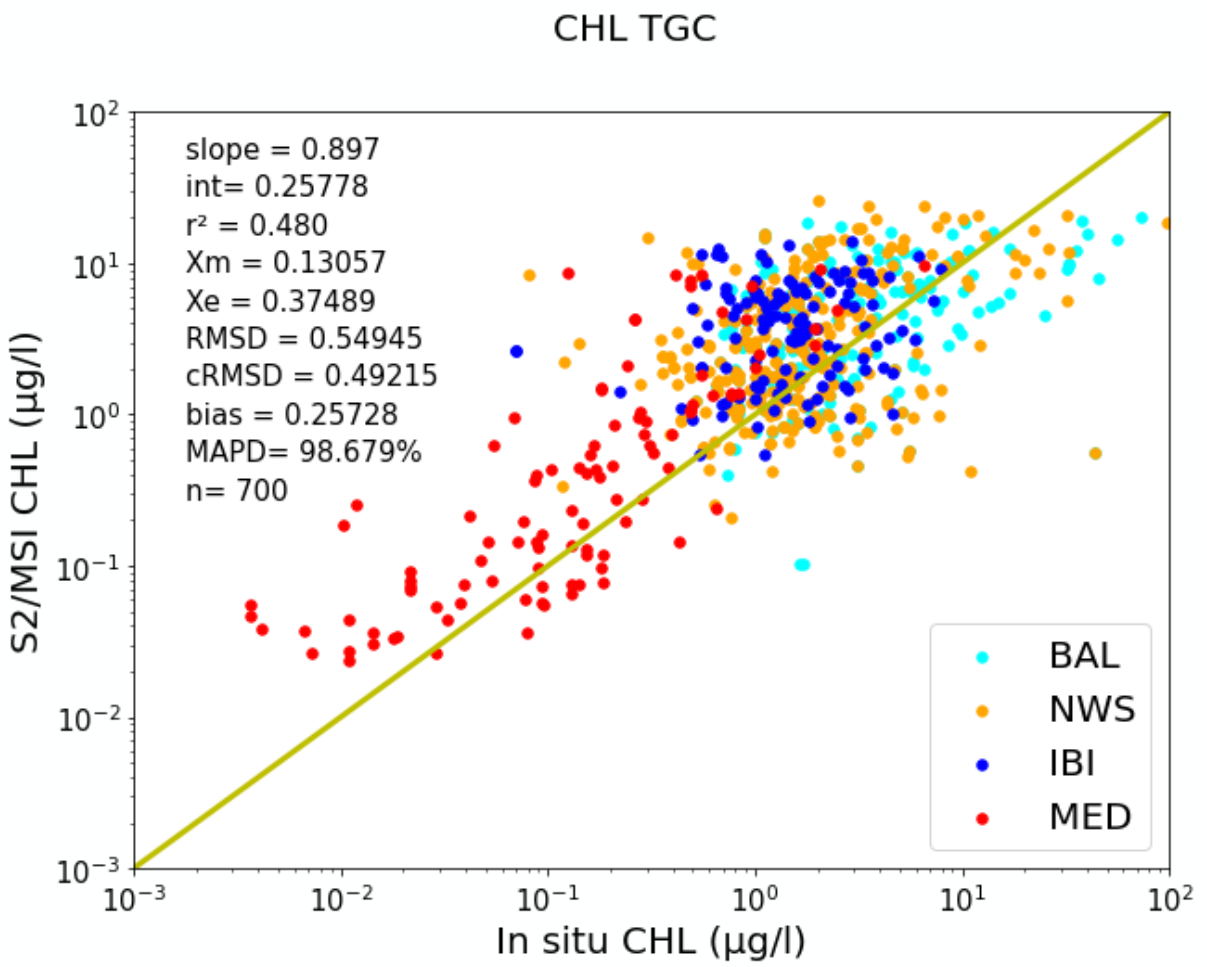
2024 evolution: Van der Zande et al. Improving operational ocean color coverage using a merged atmospheric correction approach. Proc. SPIE, 2023 (subm.)

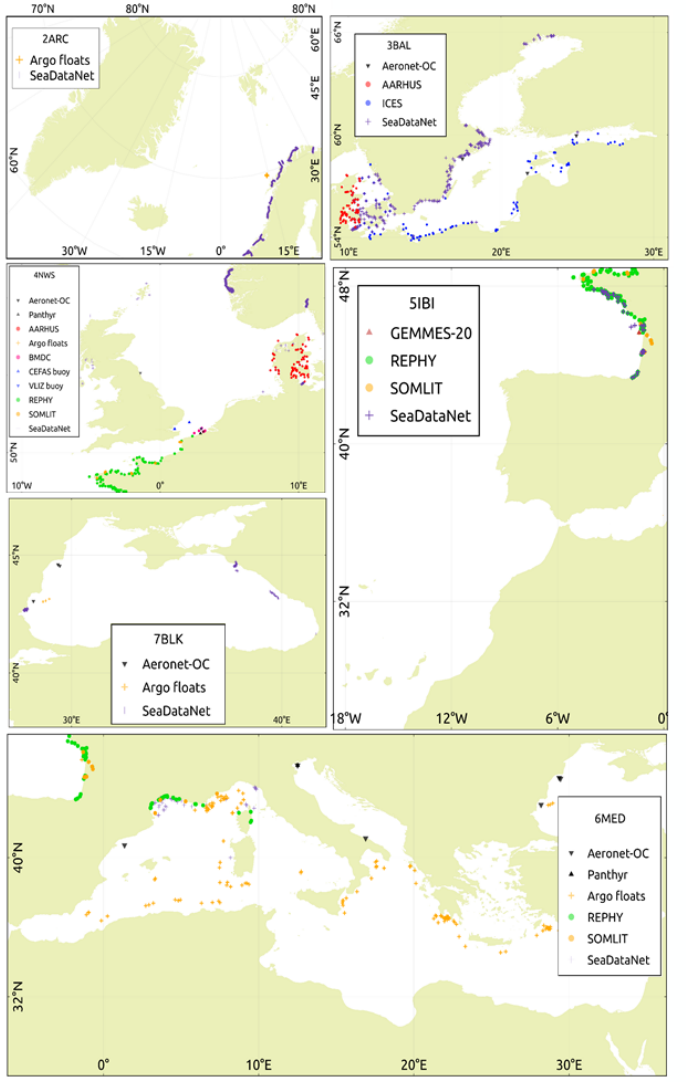
Impact of TGC on HROC validation (TUR)





Impact of TGC on HROC validation (CHL)





Operational Processor

Sen2Water

S2 L1C granules
TOA Reflectance

L1C

TGC

Mosaicking

Pixel Identification

Atmospheric Corrections

merging

Tiles
Water Reflectance
(Rrs + QUAL)

L2R

Water parameter retrievals

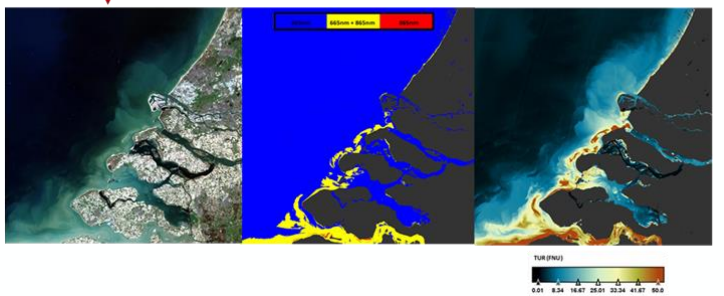
TUR/SPM: Nechad multiband retrieval

Chl: OC3 and Gons

BBP: QAA (Lee)

NOVOA merging

Lavigne merging



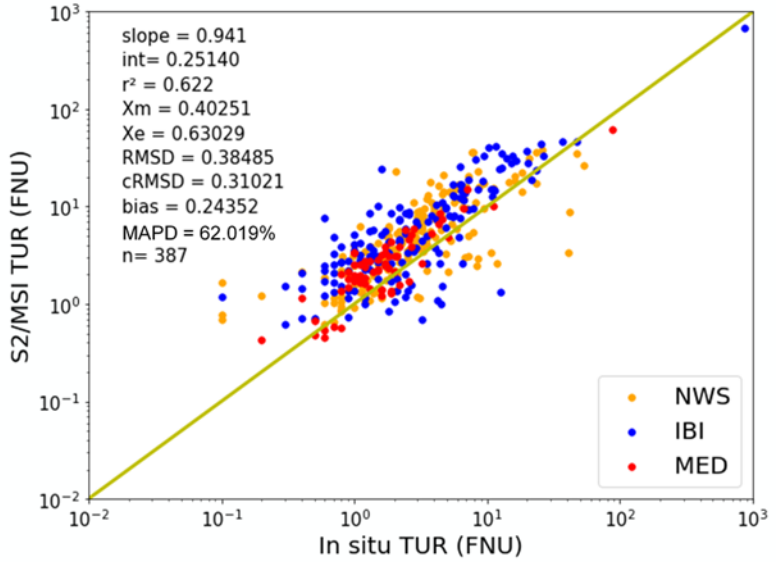
merging

Tiles
Water parameters
(TUR, TSM, CHL, bb
+ QUAL)

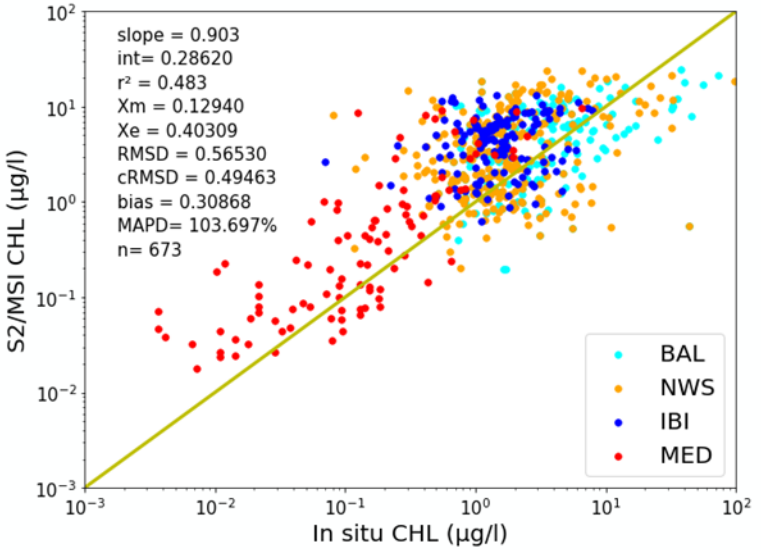
L2W

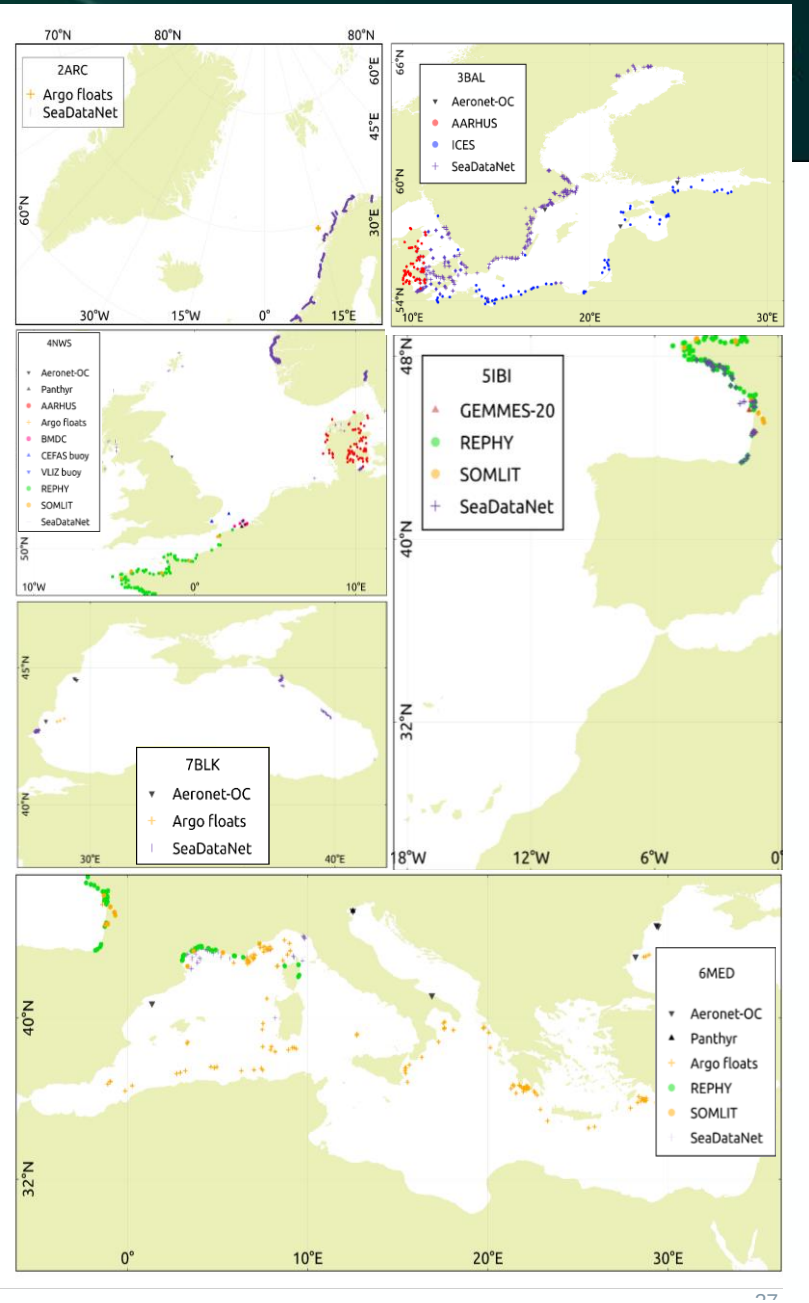
Planned evolutions (2024)

Turbidity



Chlorophyll-a





- Investigation of **basin specific ocean colour algorithms** for SPM, TUR and CHL and assess potential improvements in product quality
- **Improve coherency** between Sentinel-3 and Sentinel-2 products in COPERNICUS Marine
- Extension of **coastal zones validation dataset for all regions**

Take home messages

Copernicus Marine High-Resolution Service:

- **Operational for almost 3 years** providing ocean color products for 6 European Seas
- **Flexible application of the most appropriate algorithm** to deal with different water types of coastal waters

Yearly service evolutions:

- to keep the service **state of the art**
- Implemented evolutions focused on QC flagging (2022): **improved cloud shadow detection and bottom reflection detection**
- Upcoming evolutions focus on adapting the ocean color algorithms (2024)**: reparameterization of existing algorithms, increase coherency between medium and high-resolution ocean color products**

Top of Atmosphere Glint Correction (TGC) (2023)**:**

- Sentinel-2 sensor construction leads to sharp changes in relative viewing azimuth angle between adjacent detectors causing **visible artefacts**
- **Influences** not only the values of parameters but also the **flagging**
- **MSI banding artefacts** not properly addressed by any AC yet
- TGC provides a correction approach of the L1C product at locations impacted by glint which can be subsequently handles by existing ACs (ACOLITE, C2RCC)
- We need additional development to extend/adapt the approach to non-glinted conditions

- **Covered timeframe**: 01.01.2020 – ongoing
- **Service frequencies and timings**
  - NRT daily service: Daily products are available end of next day after acquisition (but allow 3 days)
  - NRT monthly products are available 3 days after each month, delivered 1/month
  - DINEOF Gap-filled daily products are available 1/quarter
- **Access via CMEMS catalogue**
  https://resources.marine.copernicus.eu/products