IOCCG Summer Lecture Series 2026

Frontiers in Ocean Optics and Ocean Colour Science

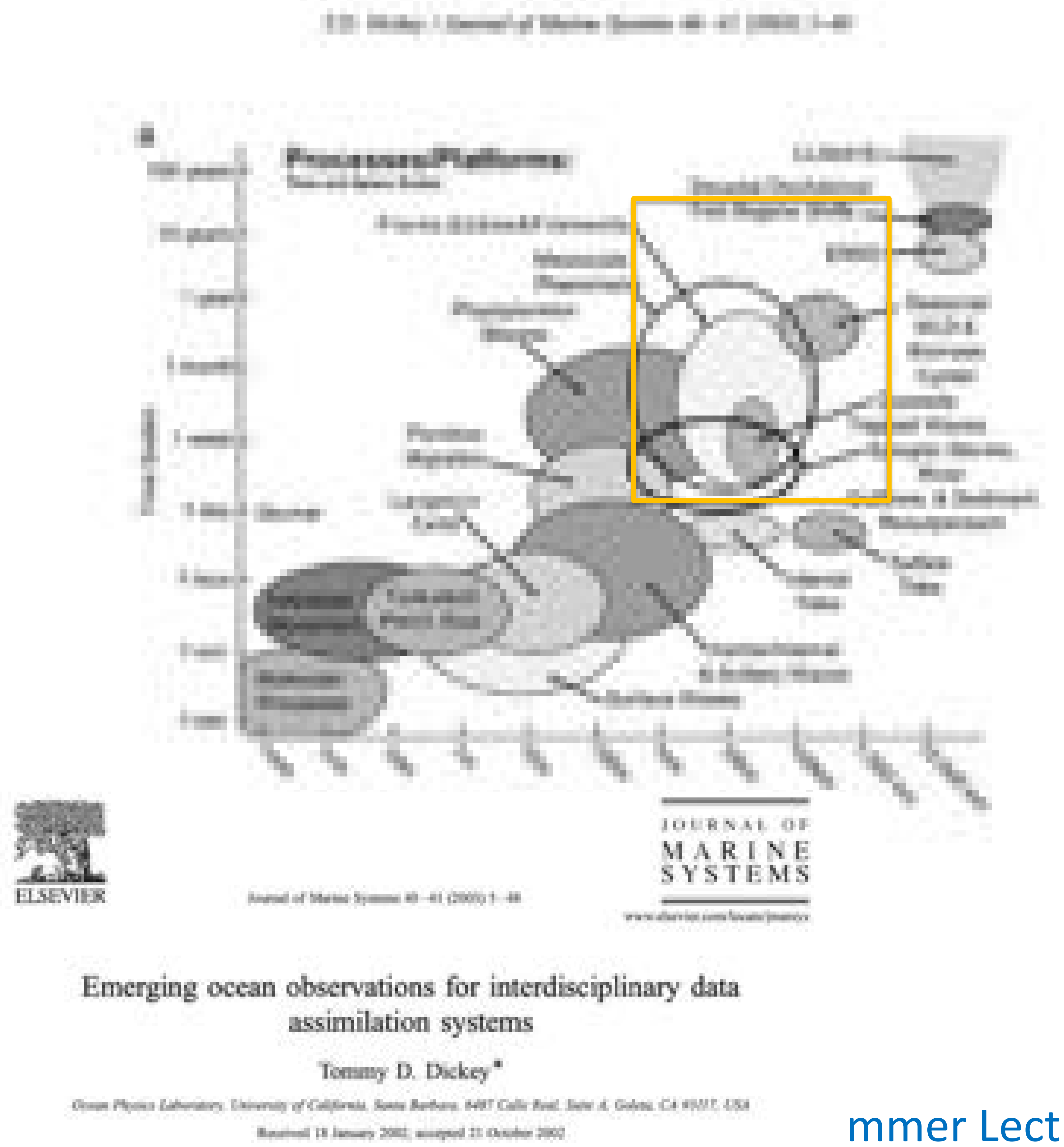
Multi sensor ocean colour radiometry

Vittorio E. Brando

CNR-ISMAR, Rome, Italy

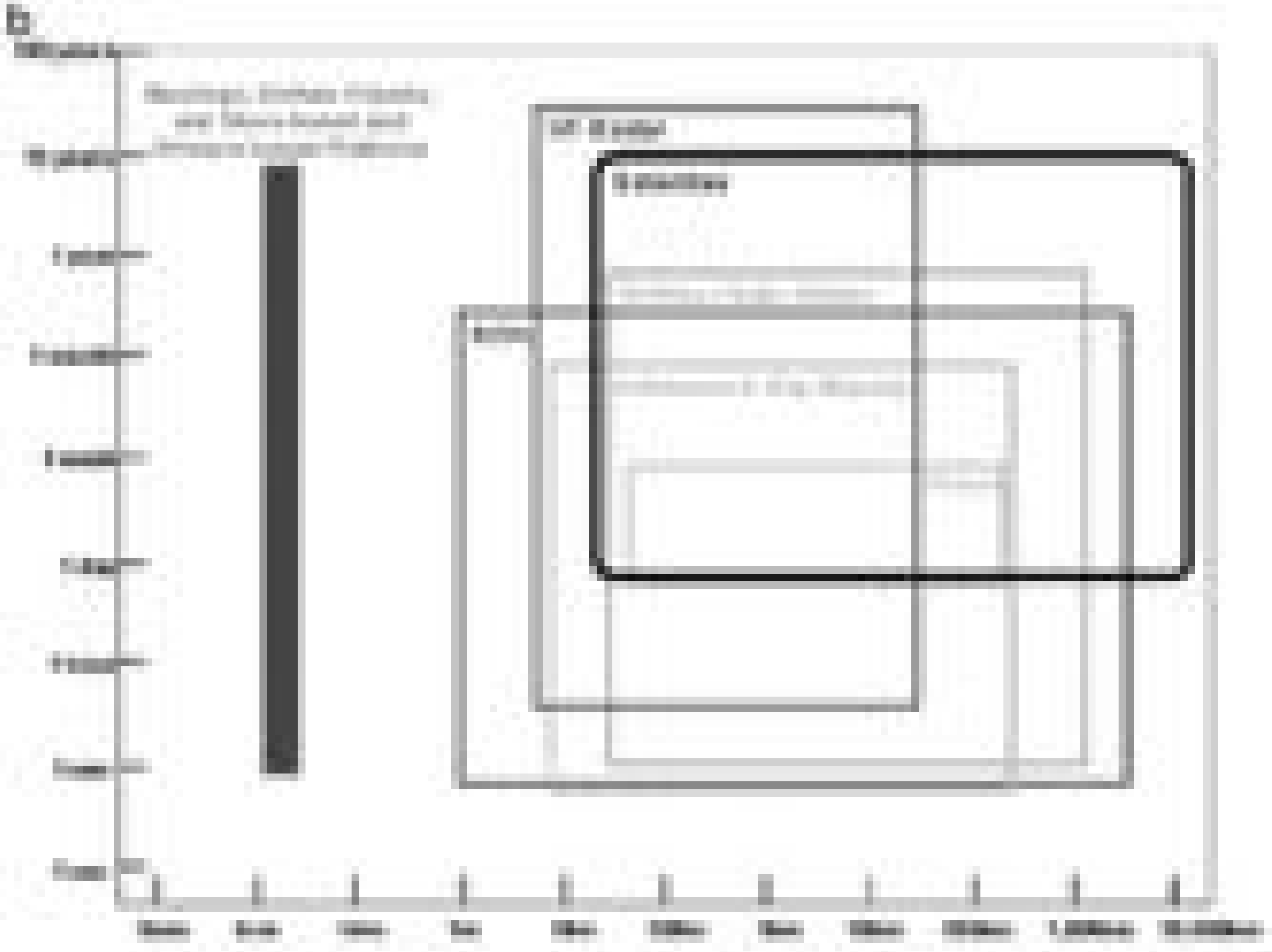
Venice, Italy - 16 July 2026

Processes scales and observation



Time-horizontal space scale diagram illustrating several physical and biological processes in ovals.

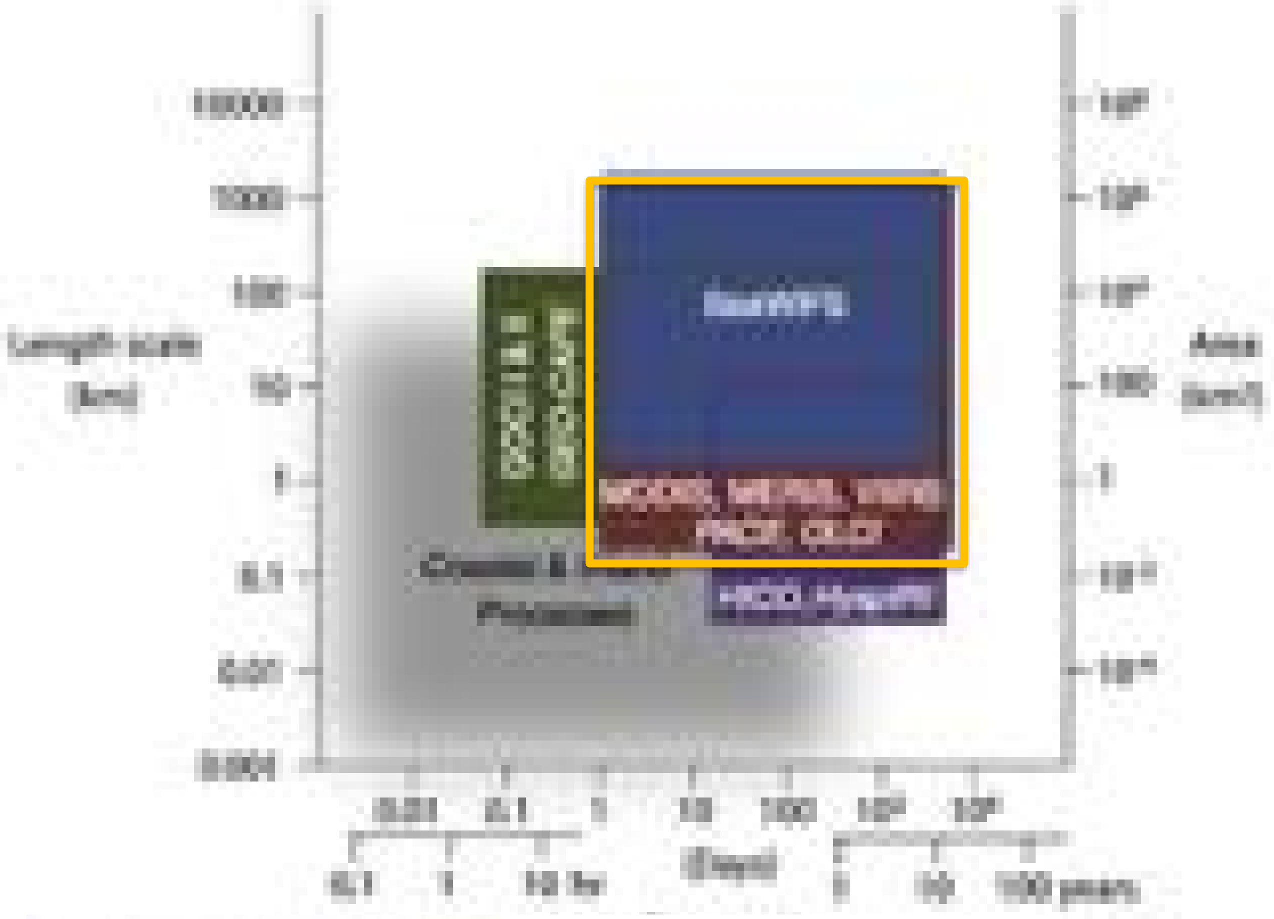
Rectangles indicate the approximate horizontal and temporal sampling domain capabilities of several platforms at in **2002**.



Processes scales and observation

Time-horizontal space scale diagram illustrating several physical and biological processes in ovals.

Rectangles indicate the approximate horizontal and temporal sampling domain capabilities of several platforms at in **2002** **and 2013**.

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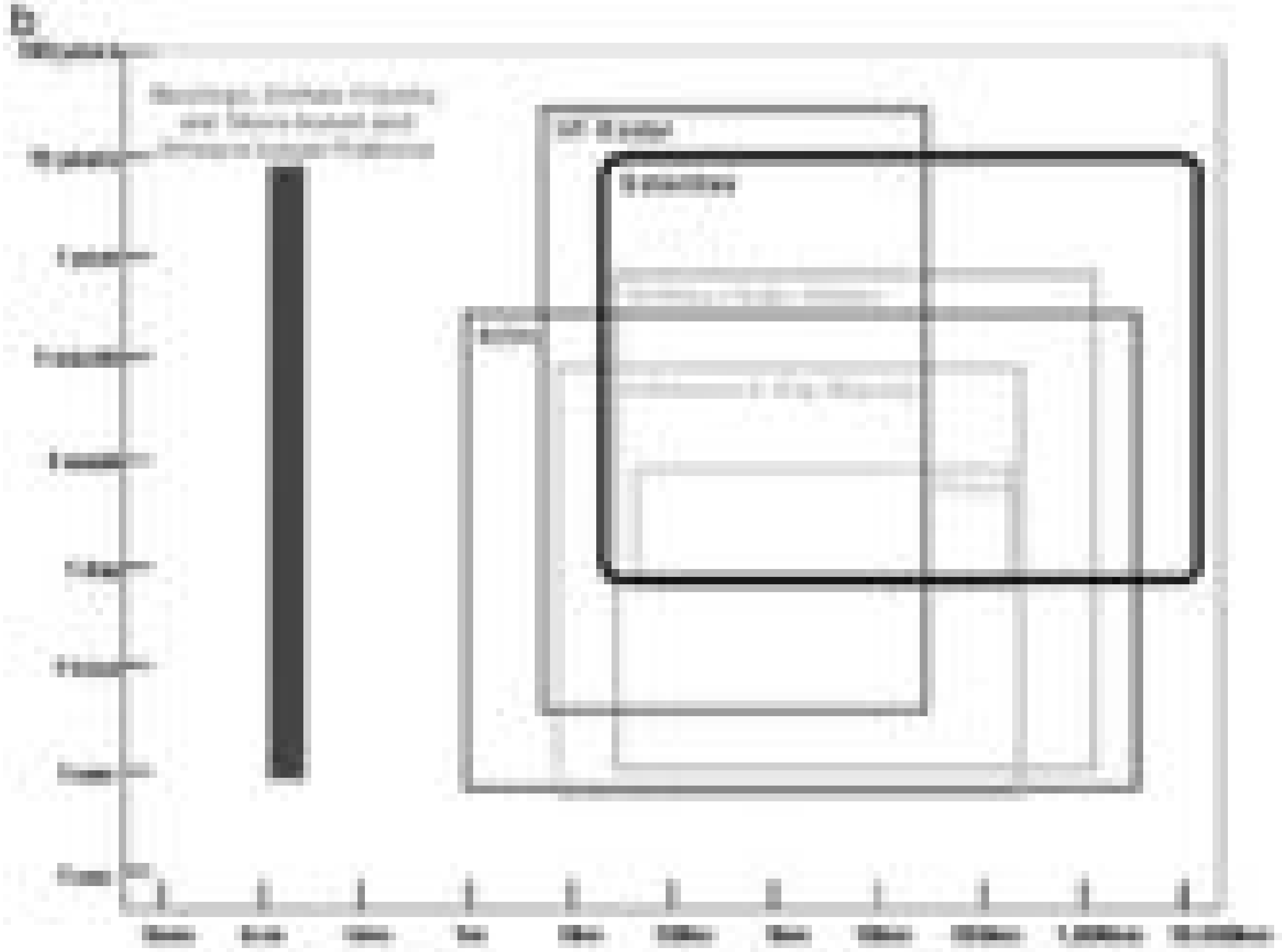

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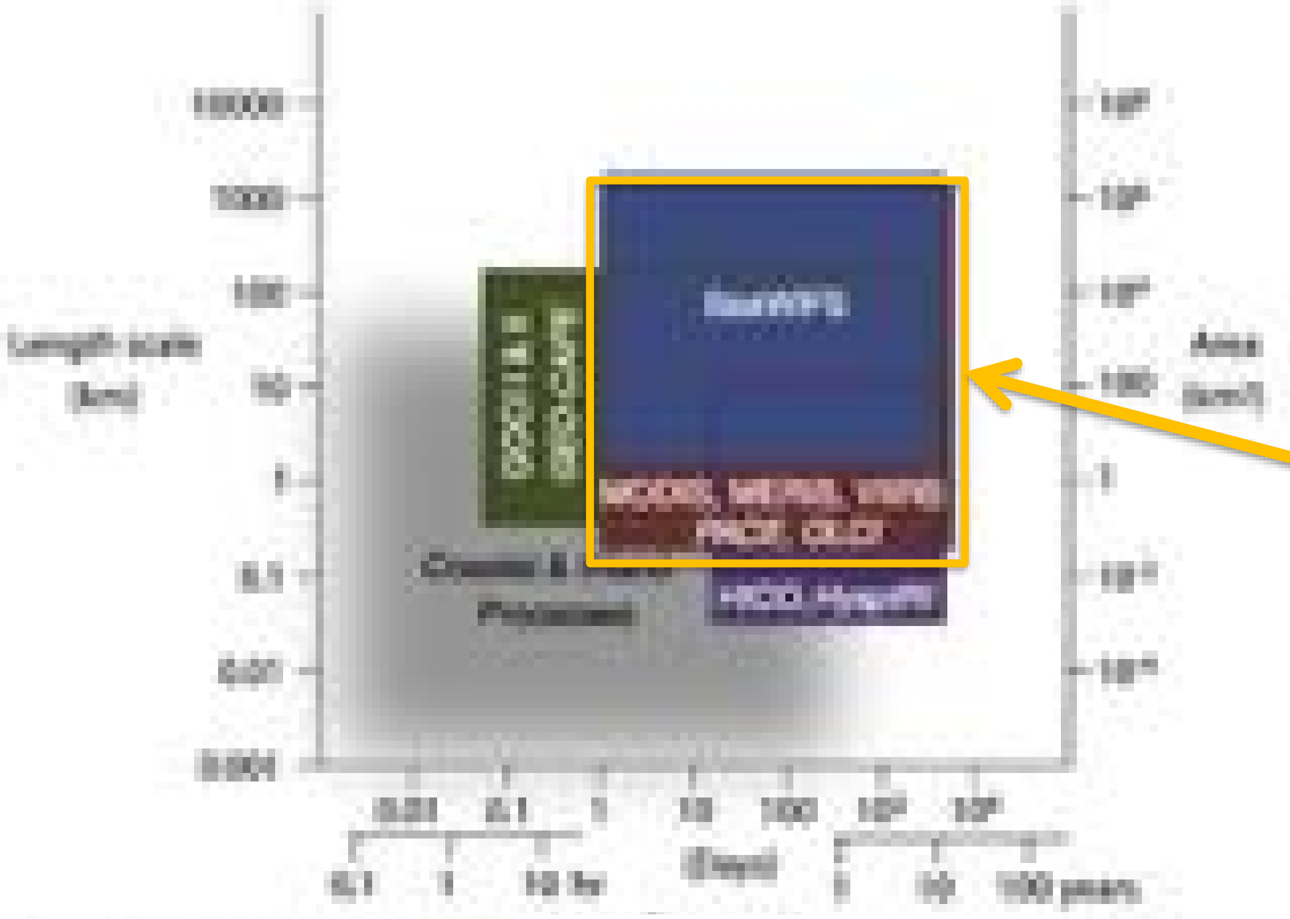

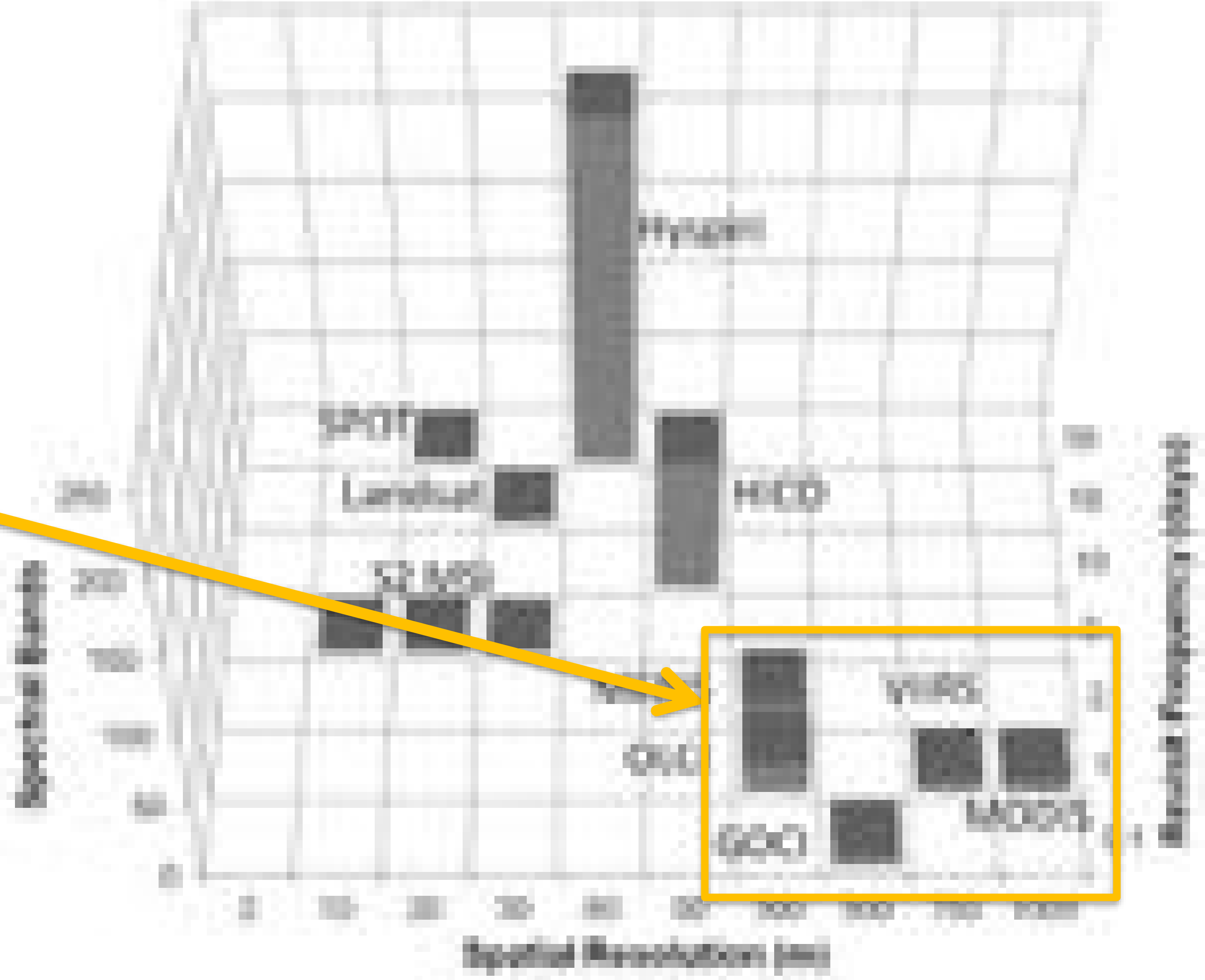

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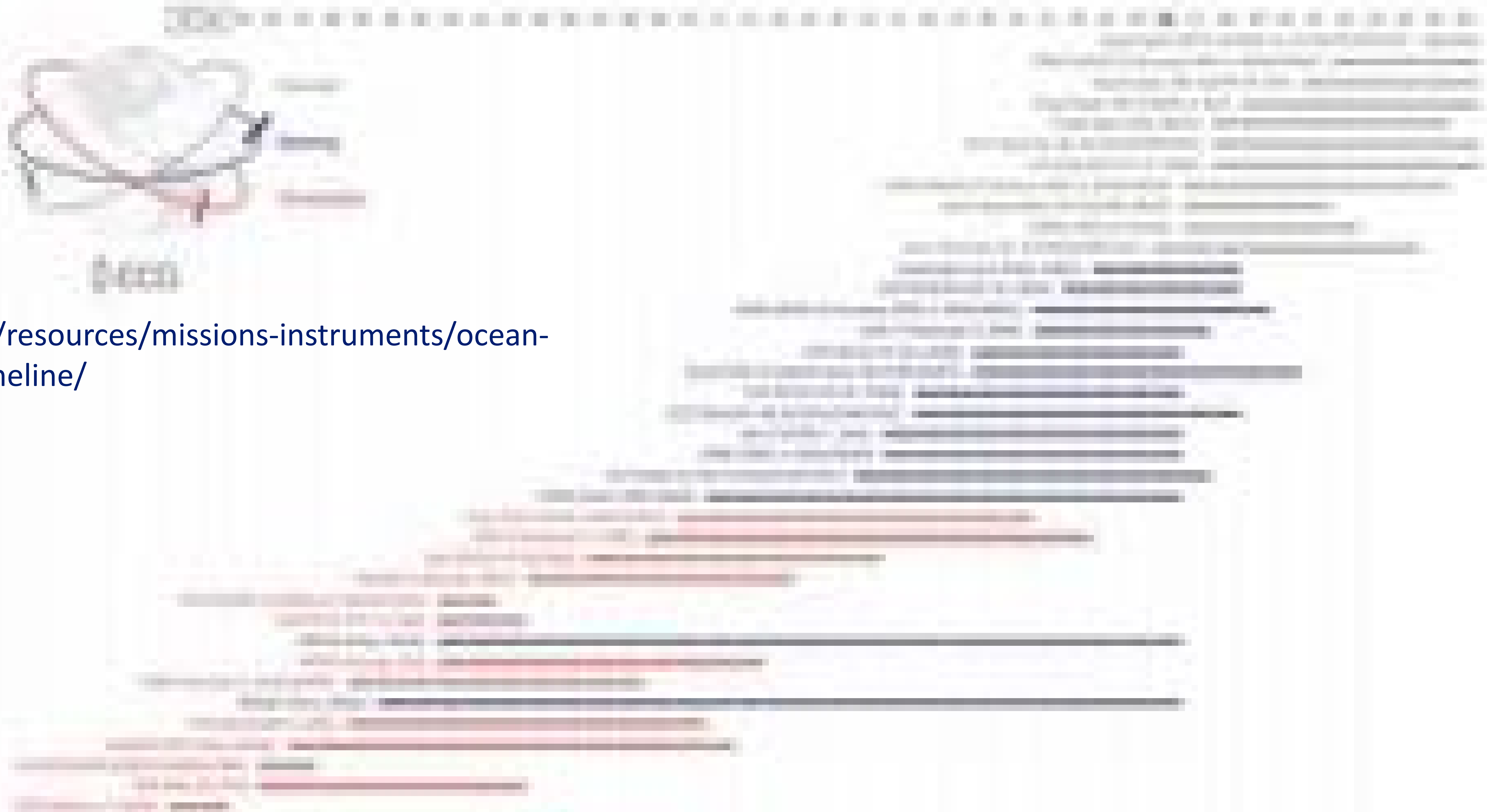
Measuring freshwater aquatic ecosystems: The need for a hyperspectral global mapping satellite mission

Erin Lee Hestir [a,b,*], Vittorio E. Brando [a,c], Mariano Bresciani [c], Claudia Giardino [c], Erica Matta [c], Paolo Villa [c], Arnold G. Dekker [a]

Ocean Colour missions: past, present and future

You are here!



https://ioccg.org/resources/missions-instruments/ocean-colour-sensor-timeline/

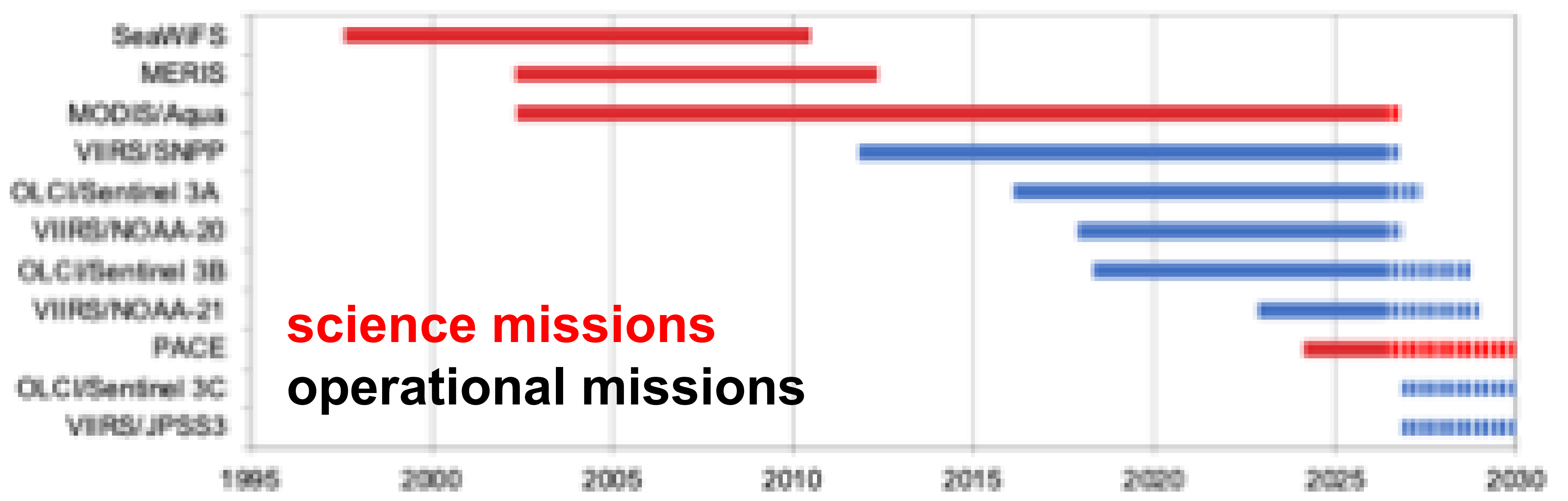
Operational multi sensor ocean colour

The operations era

Let’s do this…all the time…consistently…with redundancy!

In this era we:

- Linked up with agencies typically responsible for operating ‘weather’ satellites
- Developed long-term programmes to maintain the ocean colour record
- Developed approaches to merging records from multiple sensors towards ECVs, EOVs, CDRs.



Series of consistent mission/sensor

- USA: 4 VIIRS to cover 2015-2038
- EU: 4 OLCI to cover 2016-2036
- constellations of at least two sensors in orbit at the same time

The need for long records

It has long been recognised that there is a clear need for multi-sensor, long-term time series of ocean-colour products.

The requirement arises from the need to blend multiple sensors to create time series that are longer than the life-span of individual sensors for a variety of applications, with prominent applications, including climate studies and ecosystem management, such as for fisheries.

Blending multiple sensors also serves to minimise gaps in data at short time scales, such as in daily products, that is important for water quality, ecological disasters, and environmental impacts.

In response to this need, many space agencies and research groups have established, or are in the process of establishing, their own harmonised multi-sensor products.

Harmonisation is, in this case, where differing records are processed in such a way that they can be **used together freely with a level of parity** between available datasets. For example, averaging estimates from two different sensors into one record.

"Knowledge of ocean-colour remote-sensor characteristics is more important for successful data merging than high quality data. This is because all of the merging methods investigated have an error-reduction capability, and some even have a bias-correction capability."

IOCCG Report 6 (2007)

Ocean-Colour Data Merging. Edited by Watson W. Gregg. pp.

How long a record do we need?

It is important to note that in order to characterise biogeochemical cycles and identify trends, time-series duration > natural period of system variability.

The number of years required to detect a trend primarily depends on:

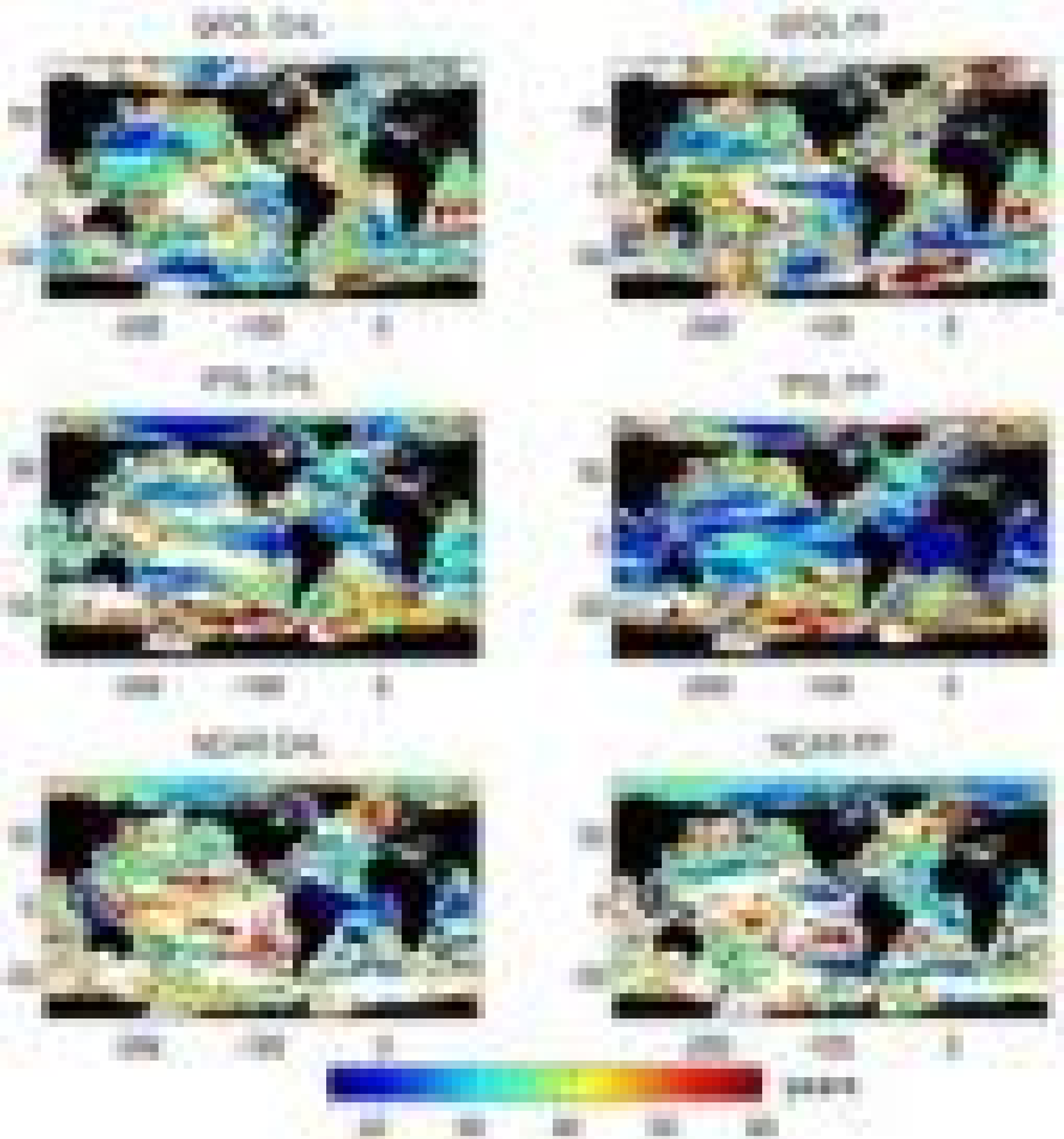
-The standard dev of the noise

-The magnitude of the trend

-autocorrelation of autoregressive noise

The length of the time series required is extended if there are gaps in the record.

No single ocean colour sensor has provided a climate quality data record of 20 years but we are getting to the point where the total record is sufficient to begin to try and detect long term shifts in oceanic ecosystems.



Henson et al. (2010) *Detection of anthropogenic climate change in satellite records of ocean chlorophyll and productivity.*

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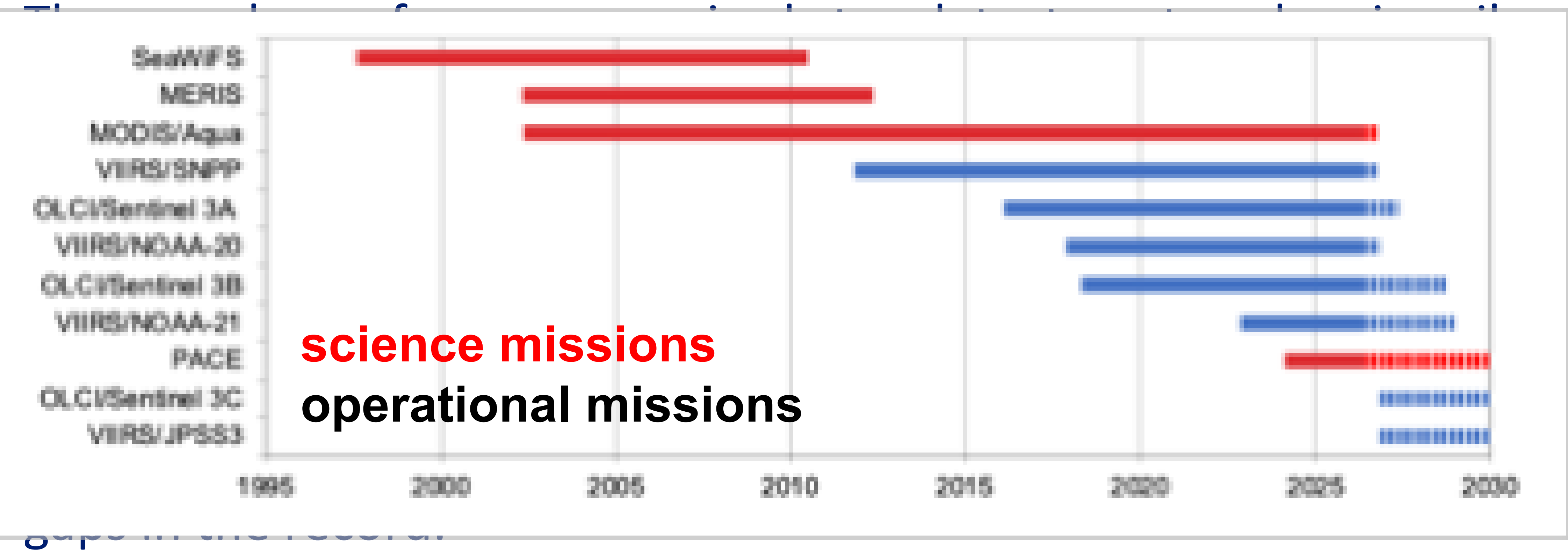

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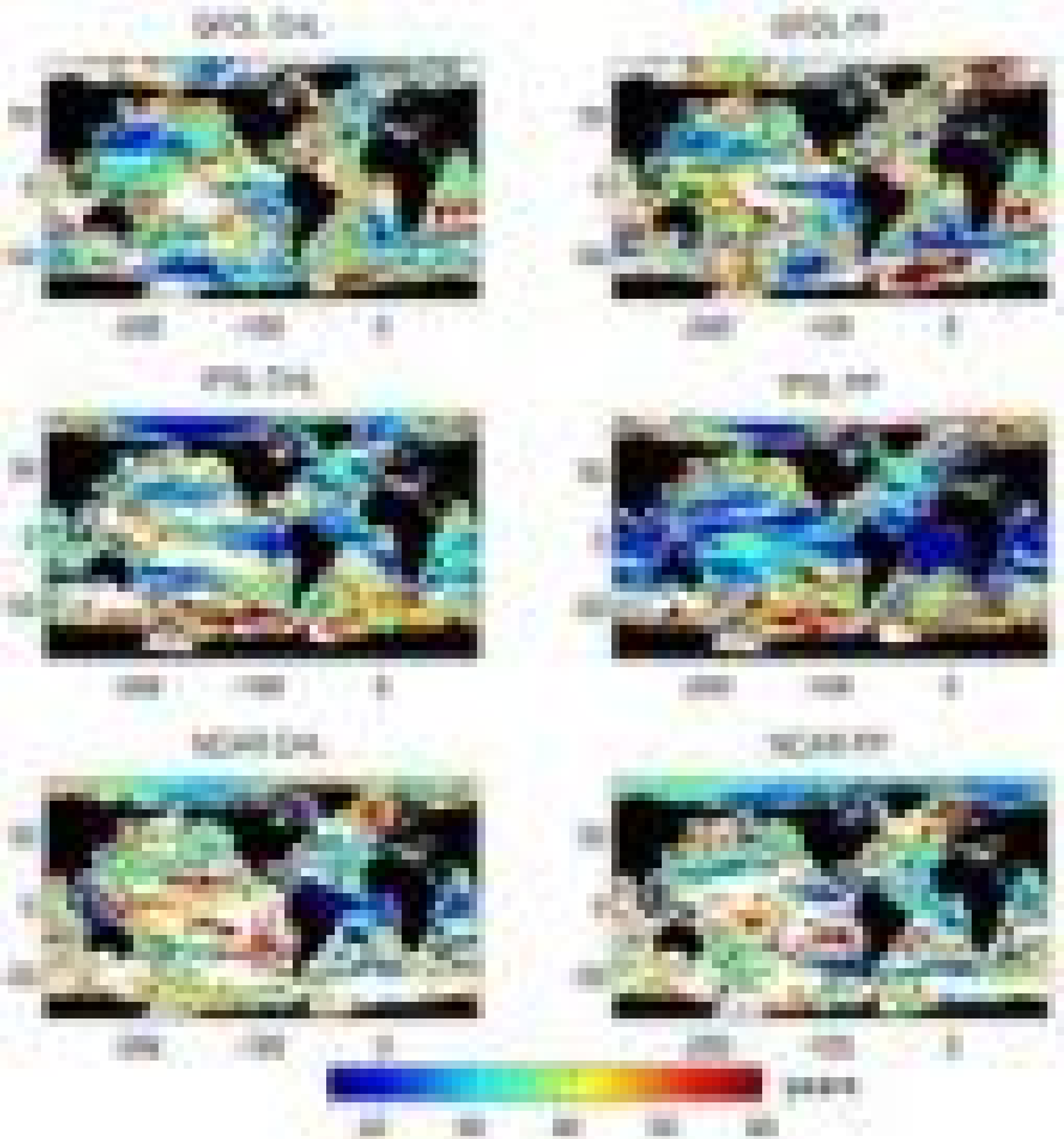

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The community requirements

Global Climate Observing System (GCOS) designated 50 Essential Climate Variables (ECVs) to support work of IPCC and UNFCCC.

ESA’s Climate Change Initiative (CCI) initially addressed 13 ECVs:

- Atmospheric Group: Cloud, Ozone, Aerosol, Green House Gases
- Ocean Group: Sea Level, Sea Ice, SST, Ocean Colour
- Land Group: Glaciers, Land cover, Fire, Ice sheets, Soil Moisture

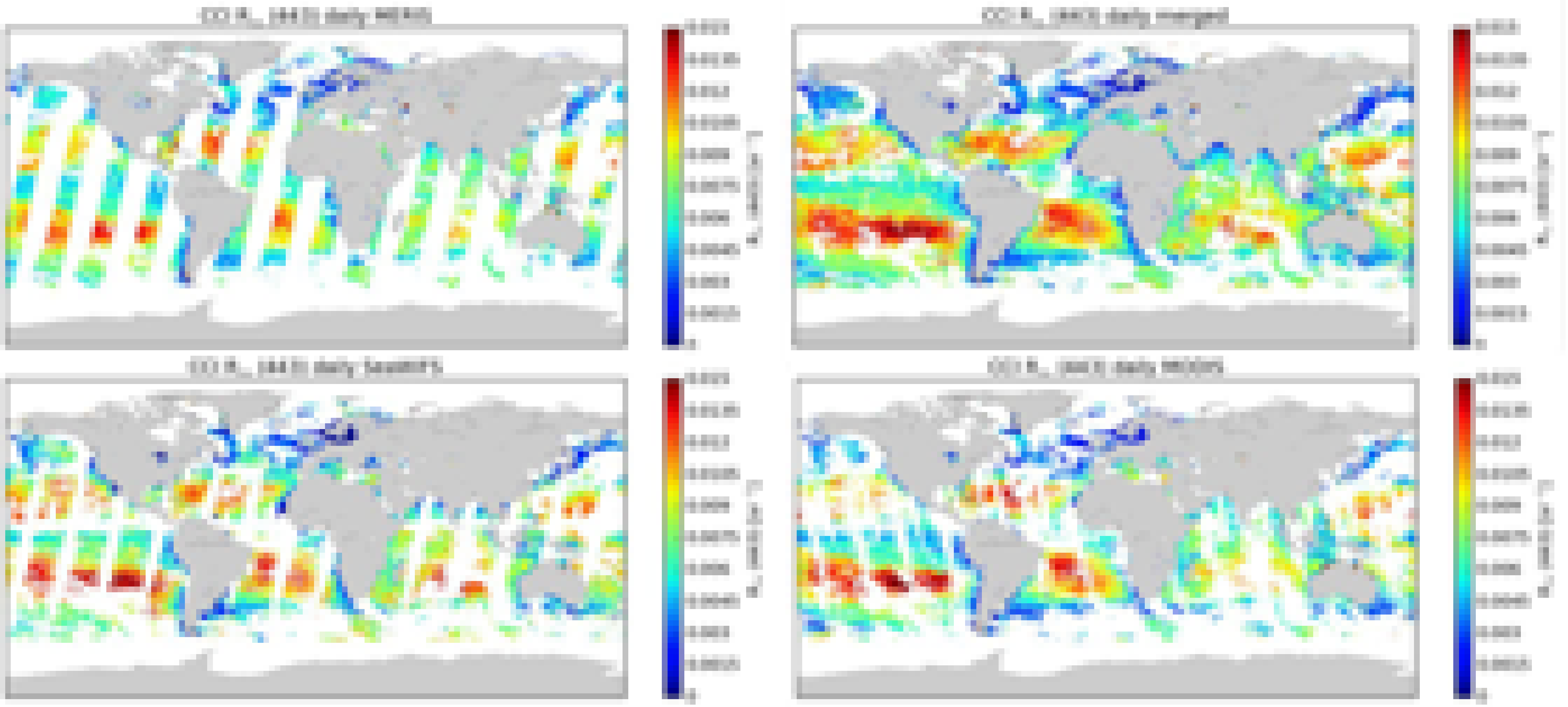
The Ocean Colour CCI (OC-CCI) encompasses water-leaving radiance in the visible domain and derived chlorophyll. Additional optical properties (inherent and apparent) are also provided.
OC-CCI currently utilises data from SeaWiFS, MERIS, MODIS, VIIRS and OLCI sensor archives.

The "simple" case

Here we see three sensors all measuring the same wavelength of radiance (though calculated reflectances are shown) on the same day.

The merging of data from all three sensors provides greatly increased coverage and patterns are consistent at this scale given the spatial variance of the global oceans.

But are the sensors really measuring the same thing?



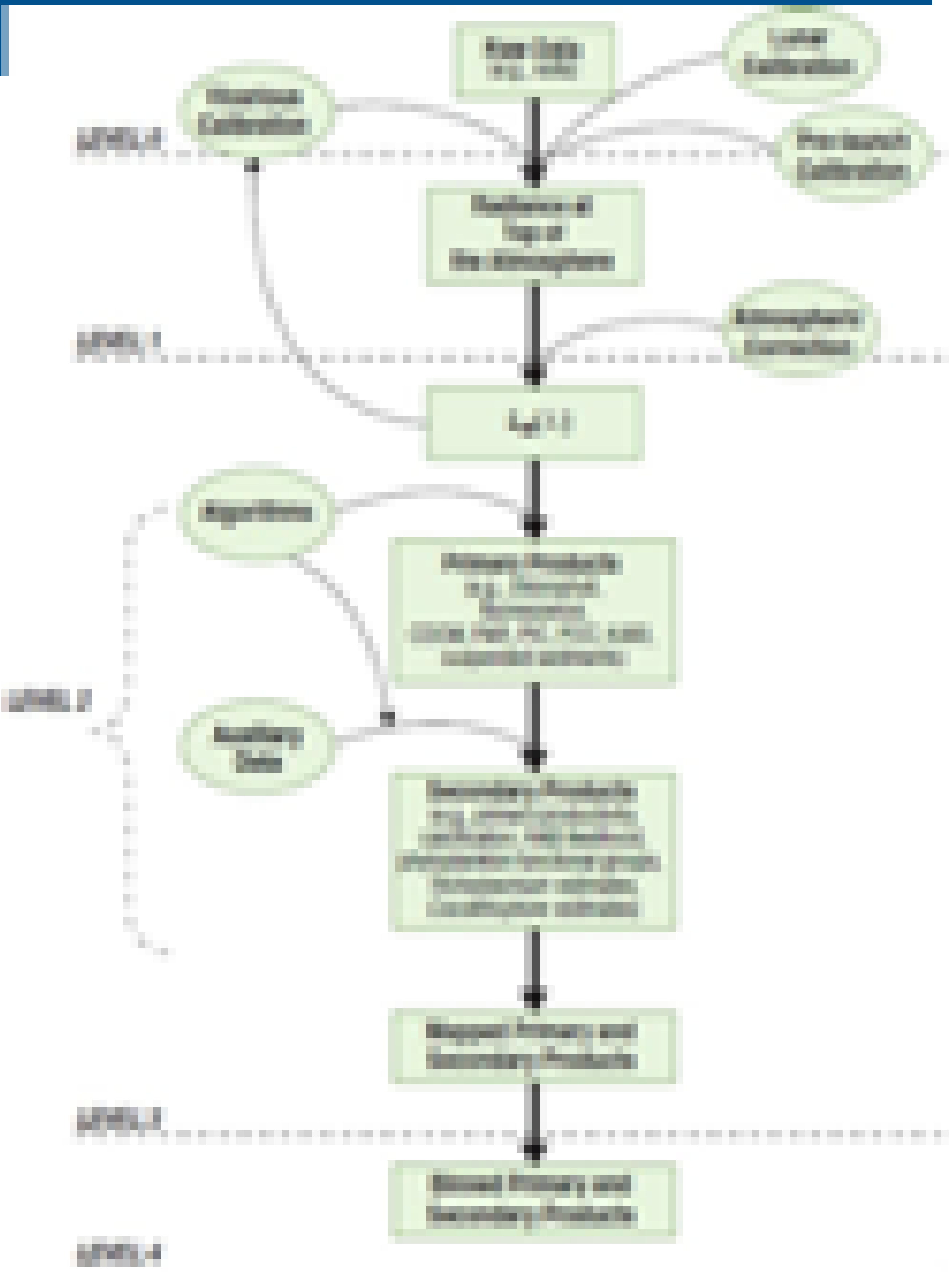
Harmonisation and the ocean colour product chain

A chain of operations from TOA radiance to in-water properties is complex process. Decisions/optimisations are often sensor/processing/region specific rather than keeping consistency in mind. We all know how complicated each of the steps in this chain can be.

The processing chain for different sensors can lead to difference in the output reflectance estimates due to many factors:

- Different radiometric calibrations
- Different spectral bands
- Different atmospheric correction approaches
- Spatial/temporal differences in sampling
- Sensor drifts, mission-to-mission gaps, variable quality control

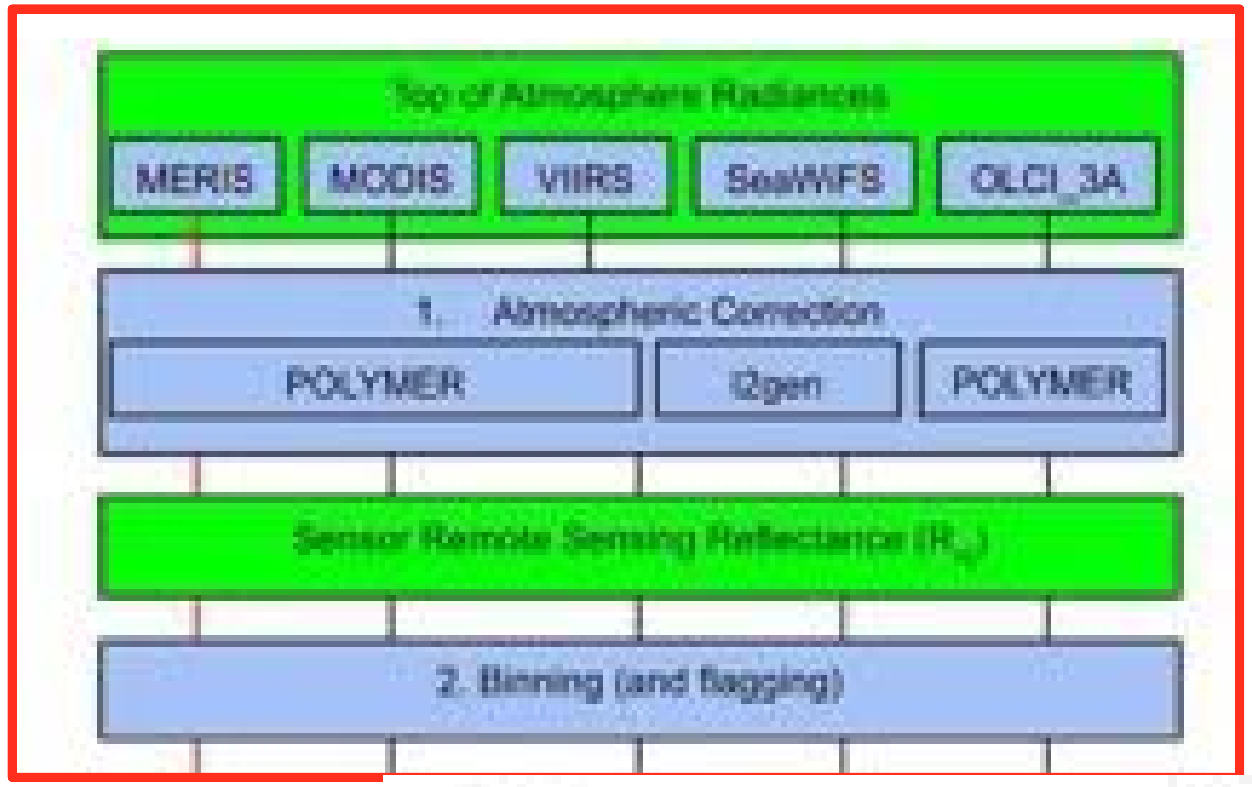
Even small calibration differences can propagate into large differences in derived Chl or IOP trends. Sensor-specific biases could dominate long-term variability.

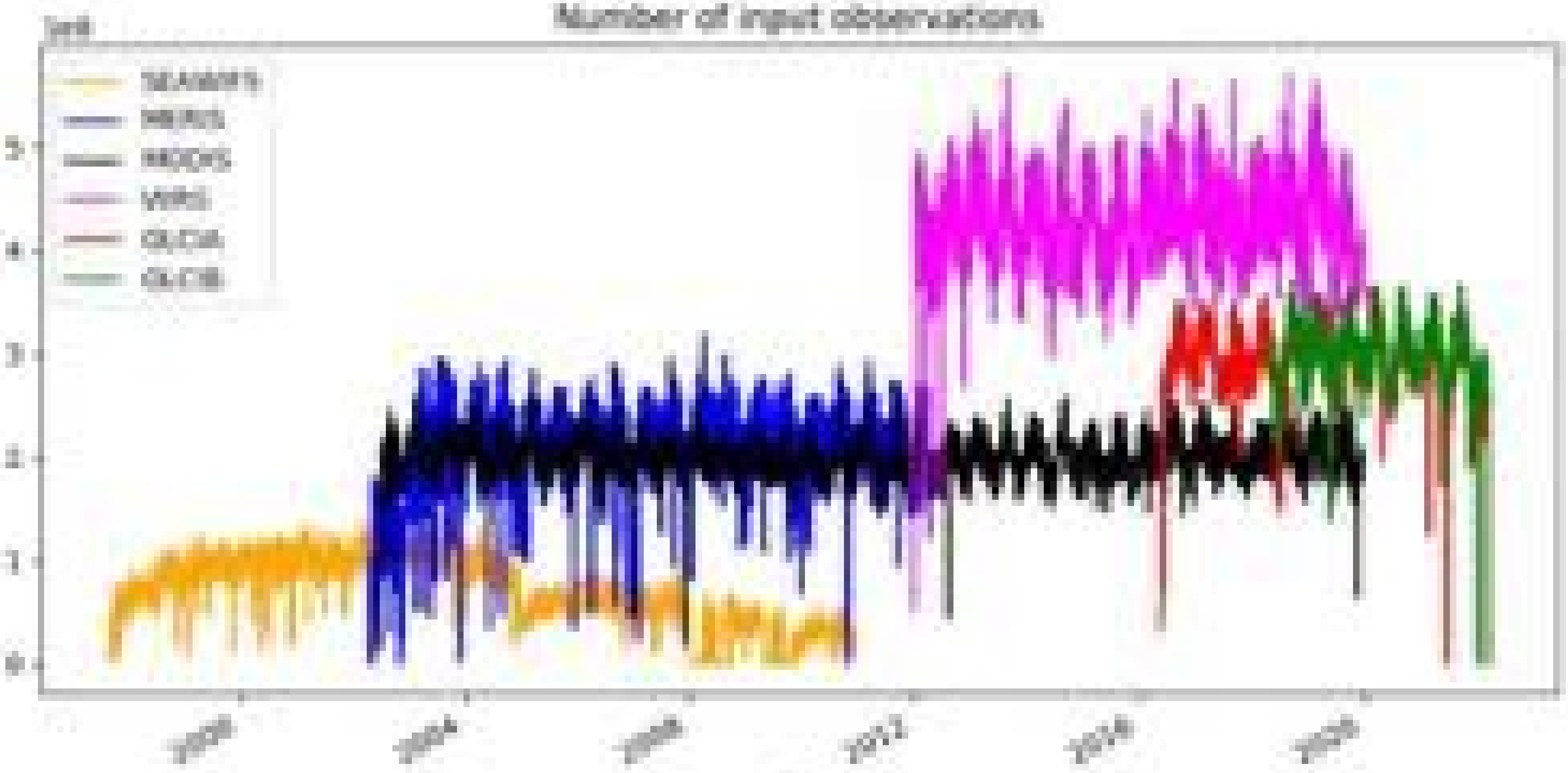


Flow diagram of Ocean Colour data processing levels. National Research Council, 2011 https://doi.org/10.17226/13127

Figure from product quality assessment report for OC-CCI (C3S). Documentation (V6) available at [Ocean colour daily data from 1997 to present derived from satellite observations]

Example merged climate record processing chain (OC-CCI)





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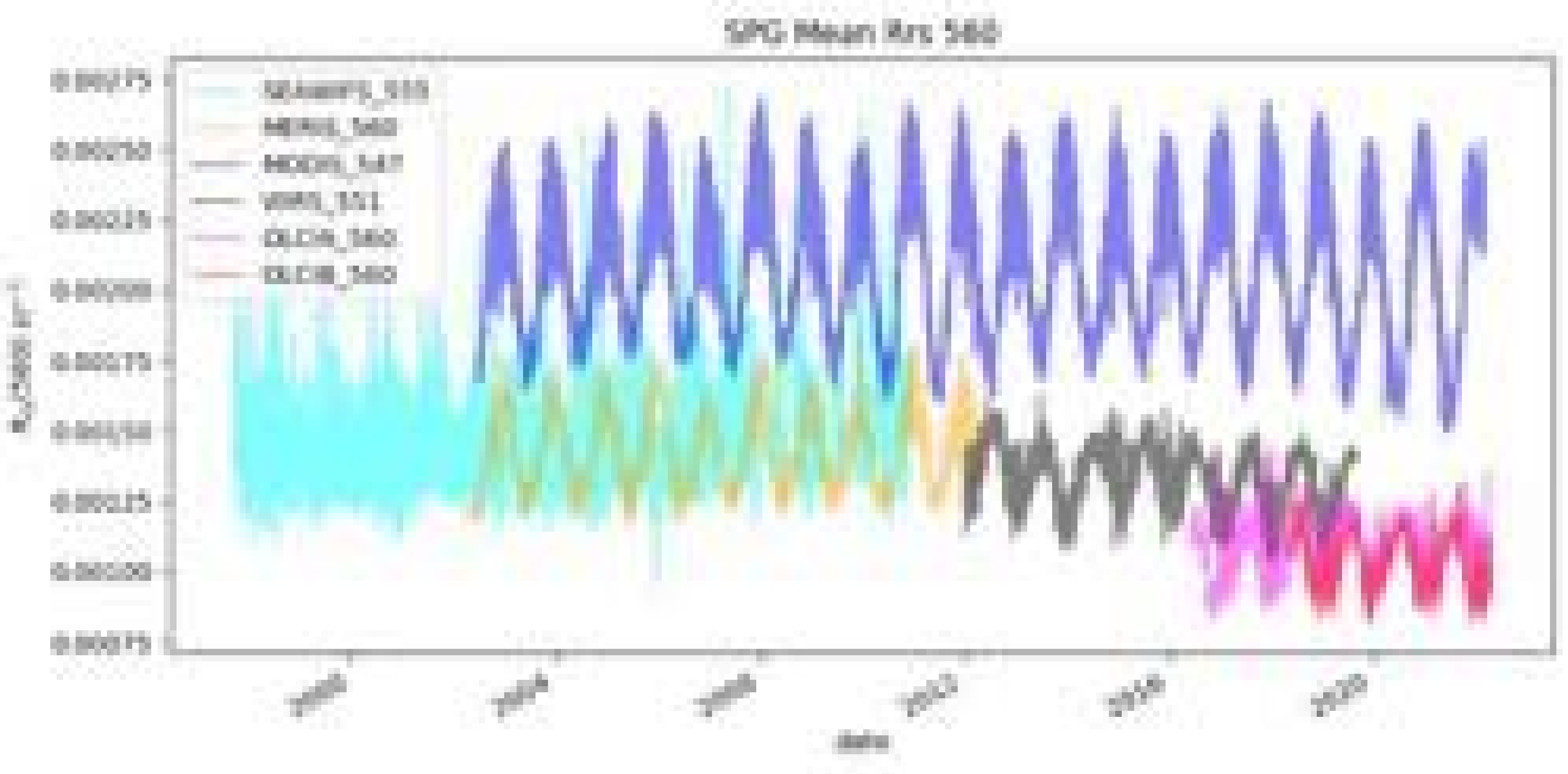


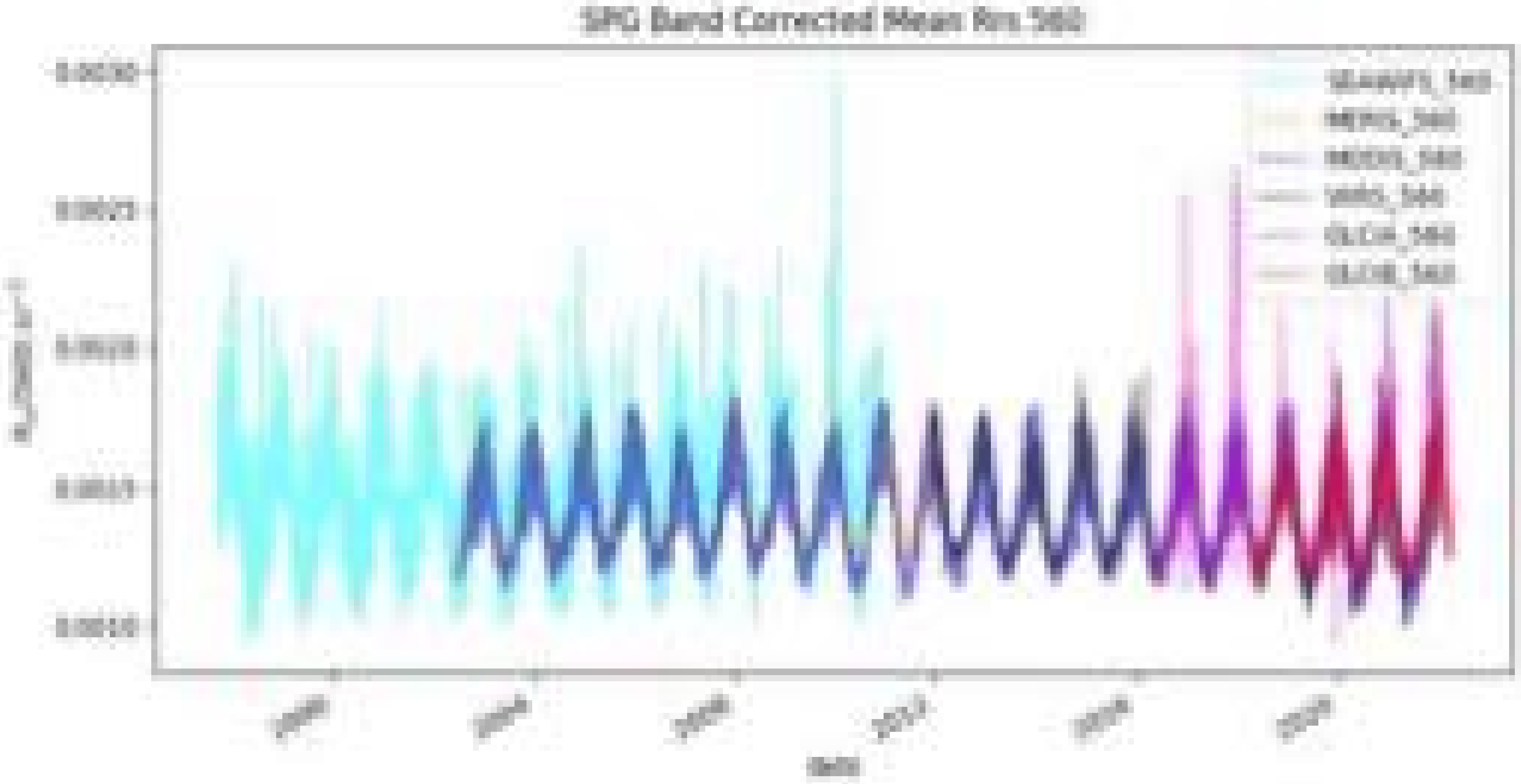
Example merged climate record processing chain (OC-CCI)

8.3 Band shifting

The non-reference sensors of SeaWiFS, MODIS, VIIRS and OLCI (though OLCI already contains the MERIS bands so this was not required) were band shifted to the six main MERIS bands (412, 443, 490, 510, 560, 665nm) by computing QAA IOPs and back computing the R_{rs} bands using a high-resolution spectral model. The output R_{rs} for 412-560nm were cleaned of any negative values, with the data removed. Negative R_{rs} values in the 665nm band frequently occurred due to low signal levels, and these were clamped to zero.

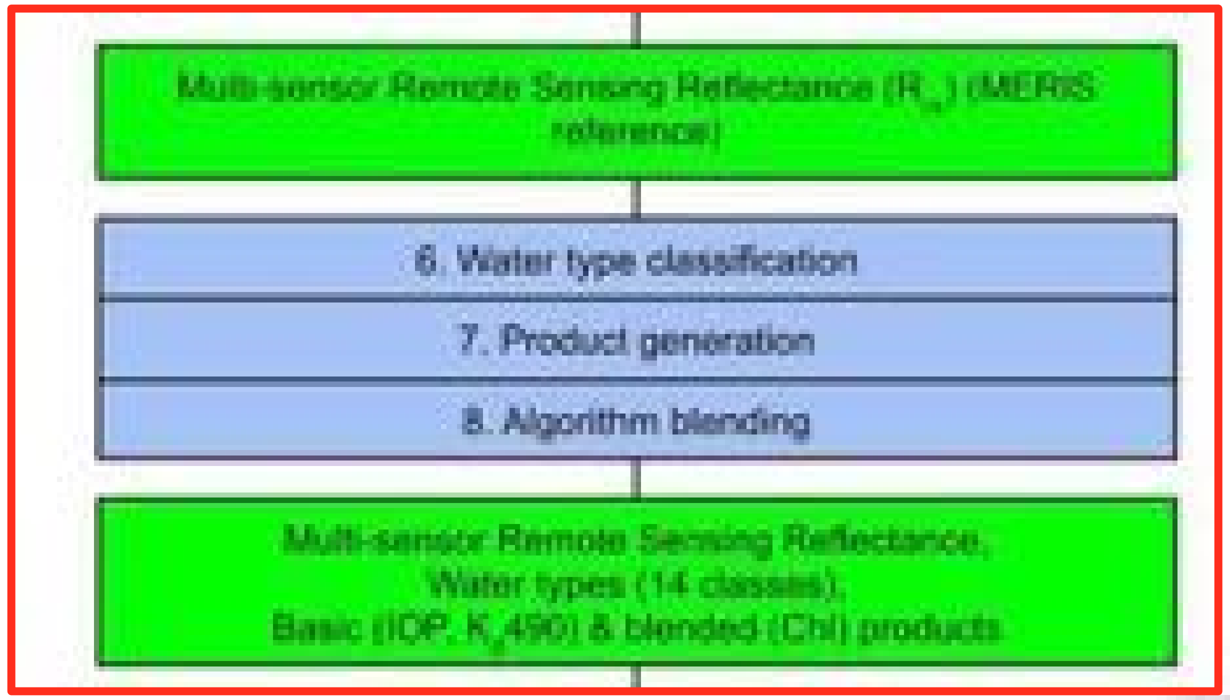
Nothing was done to the MERIS data.

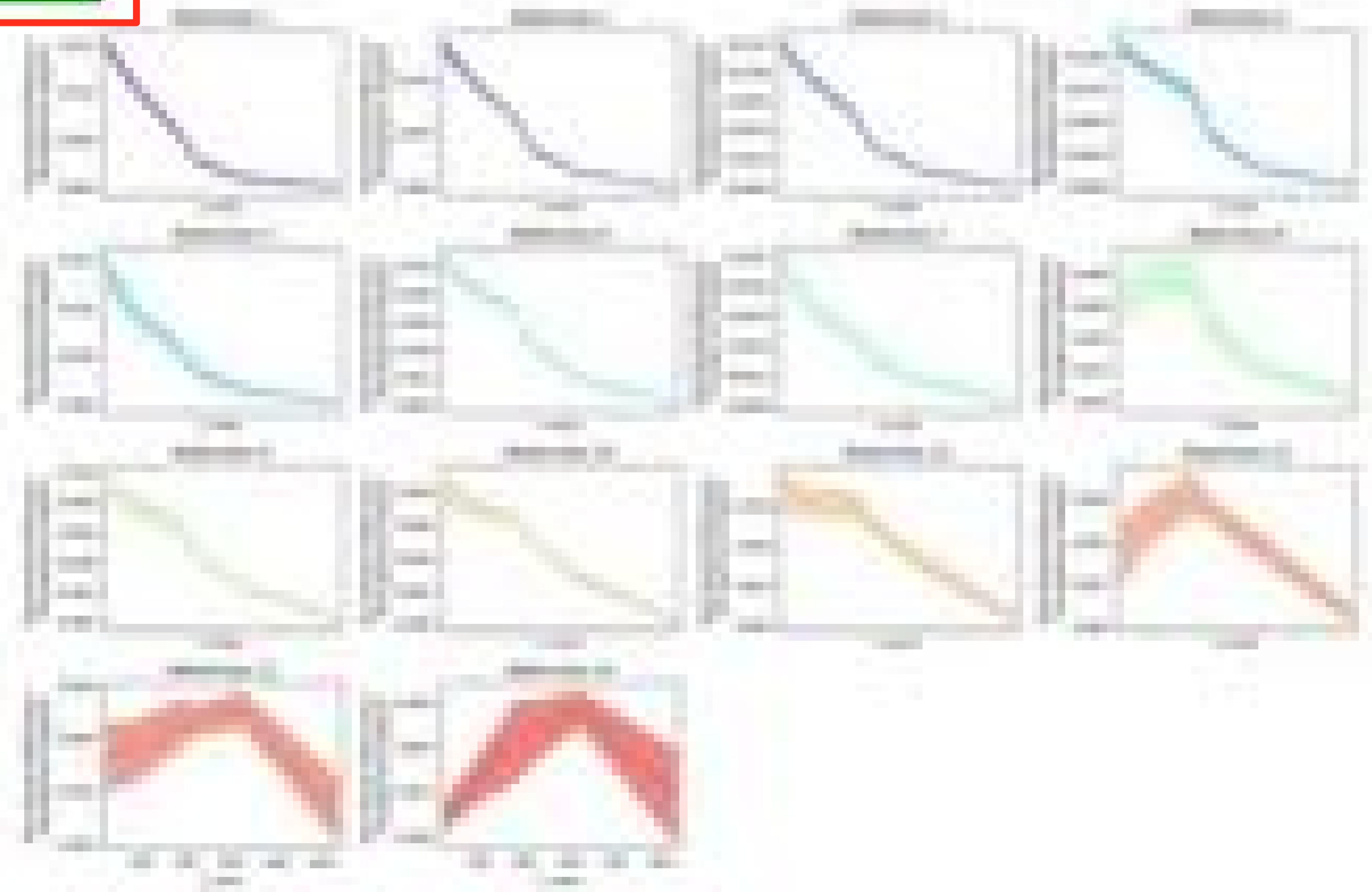
Example merged climate record processing chain (OC-CCI)



Example merged climate record processing chain (OC-CCI)

Ocean Colour





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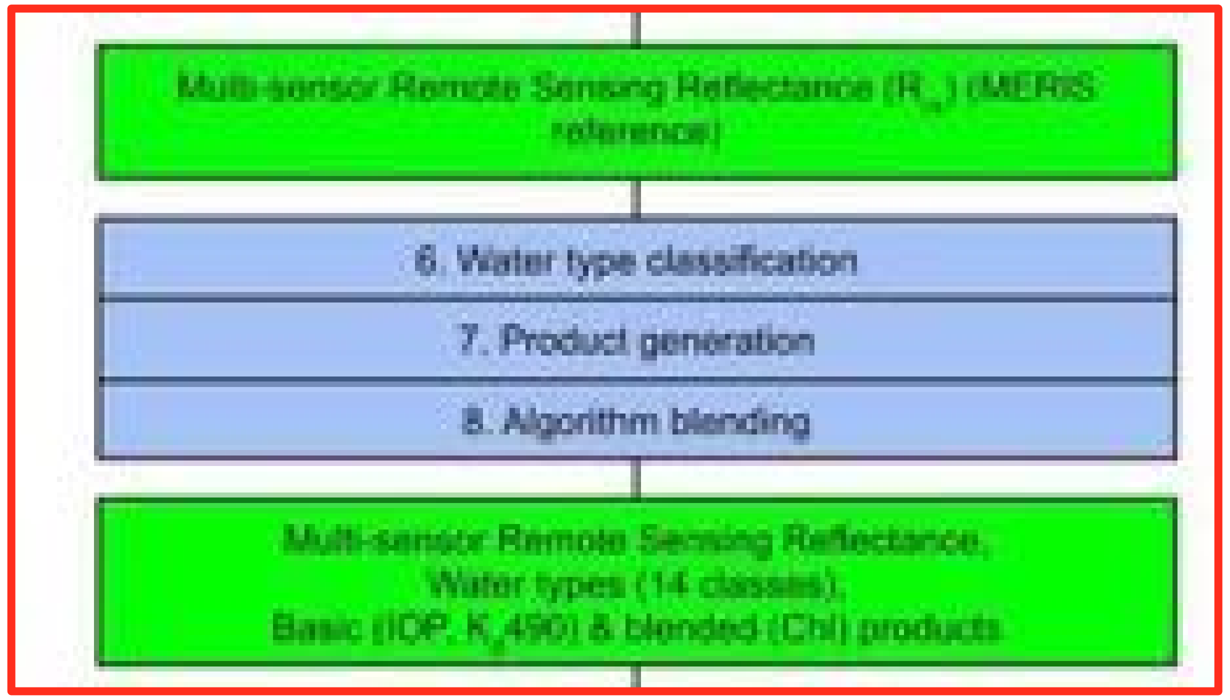
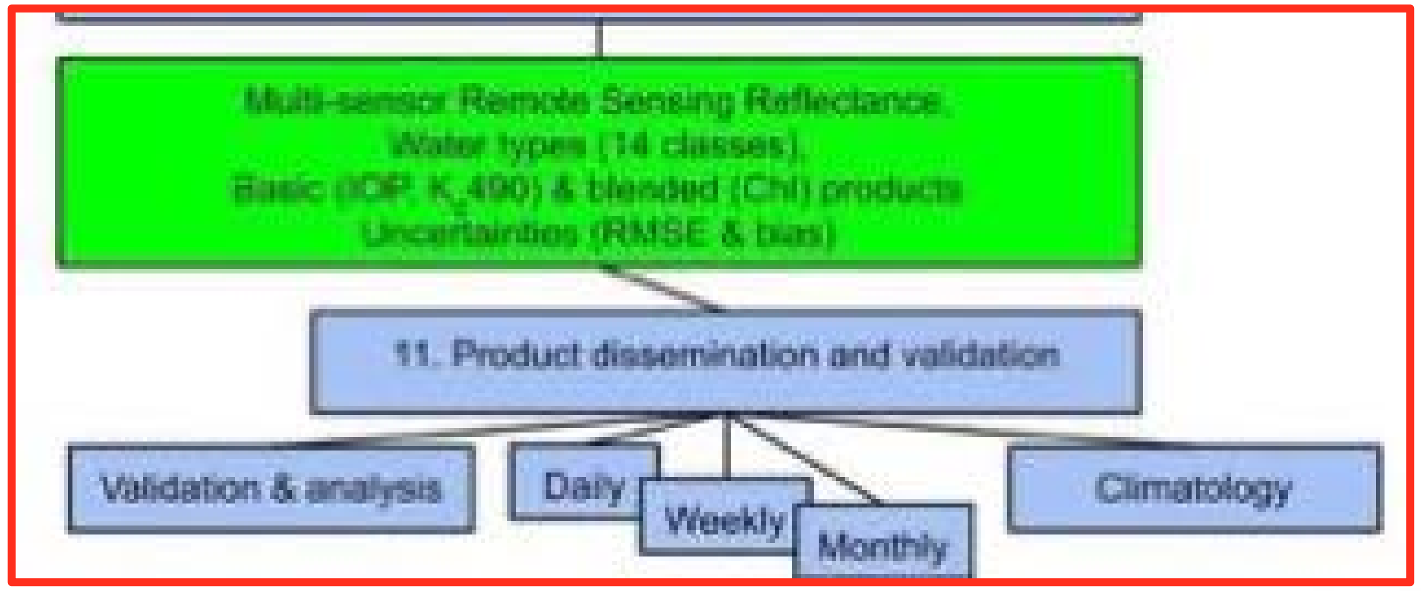


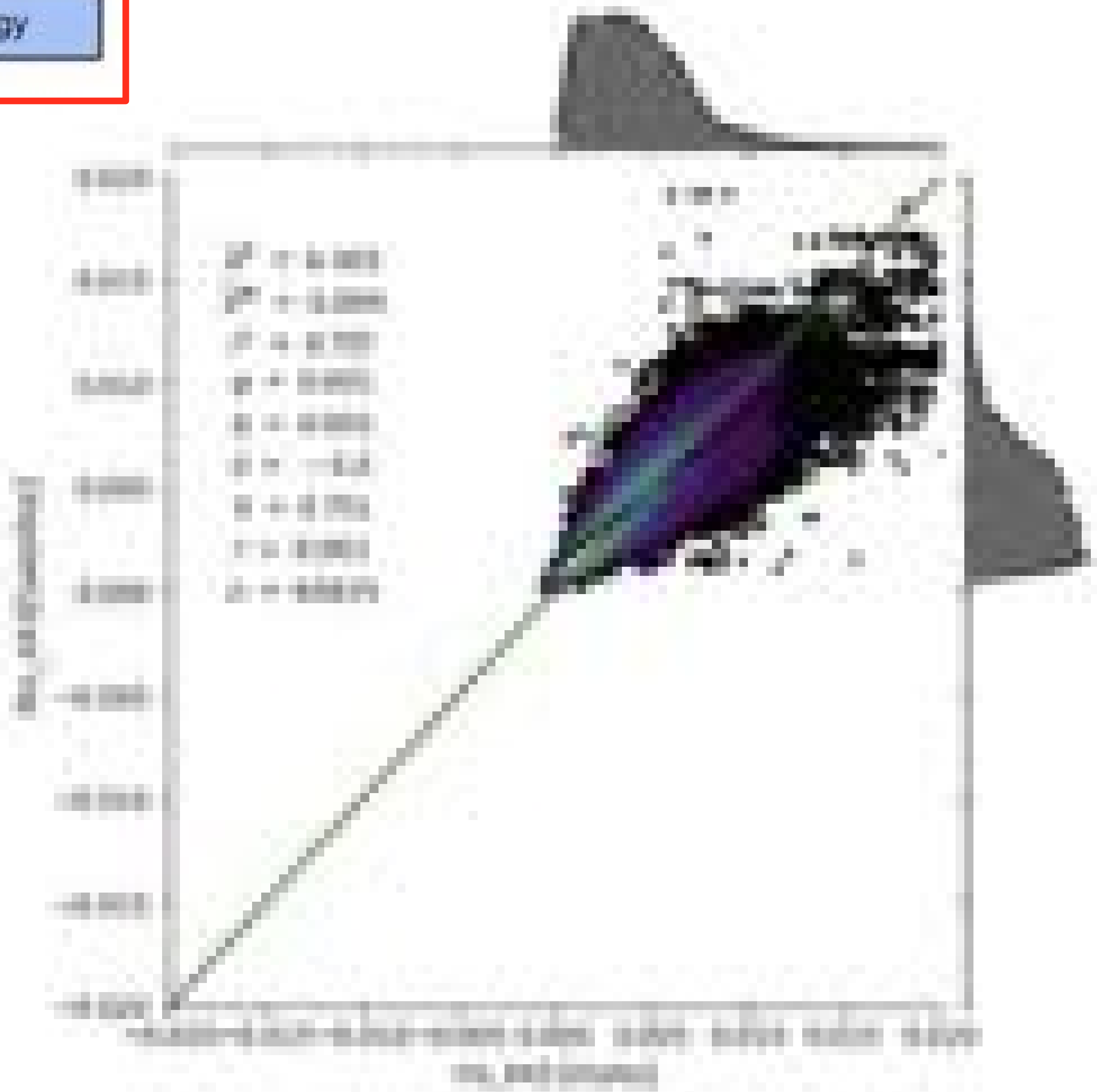
8.7 Product generation

A range of products were computed from the merged R_{rs}, directly using the validated algorithms in SeaDAS (with the exception of Kd490, which was independent due to implementation issues in the SeaDAS variant). Algorithms were selected from the best performers in the round-robin evaluation:

- Chlorophyll: blended merge of OCI, OCI2, OC2 and OCx, weighted by the relative levels of membership in specific water classes.
- IOP: QAA (with Zhang bb coefficients)
- KD: Lee variant (with Zhang bb coefficients)

Example merged climate record processing chain (OC-CCI)





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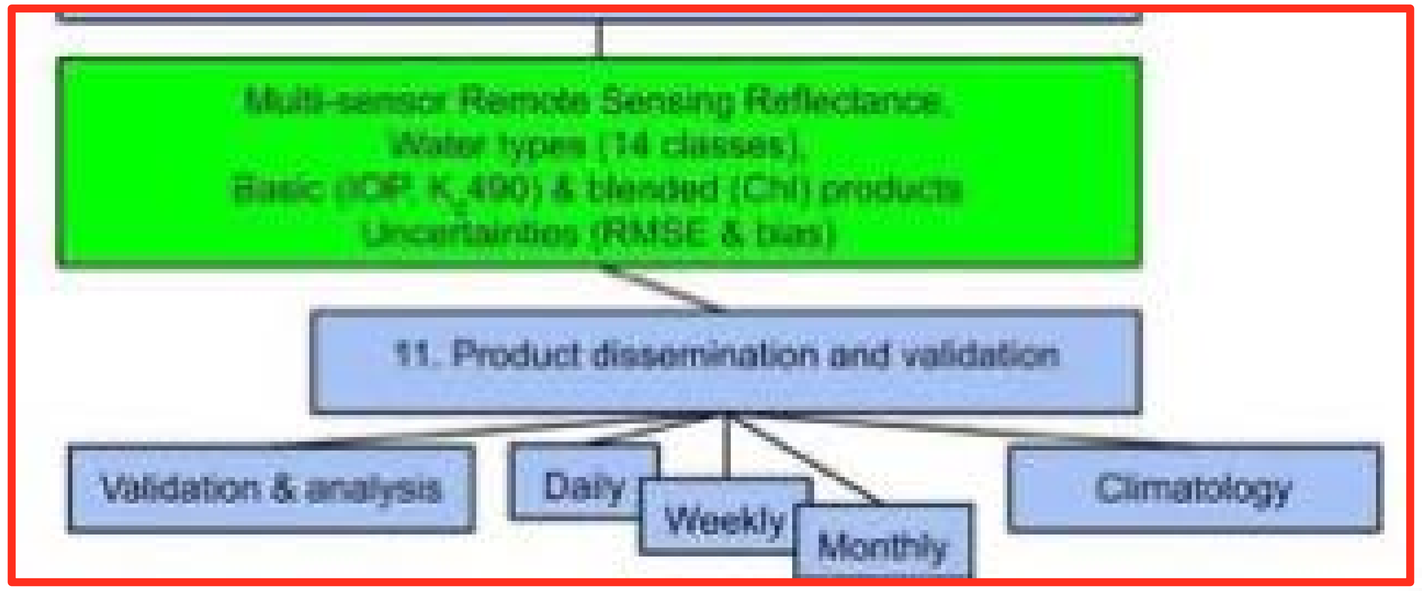
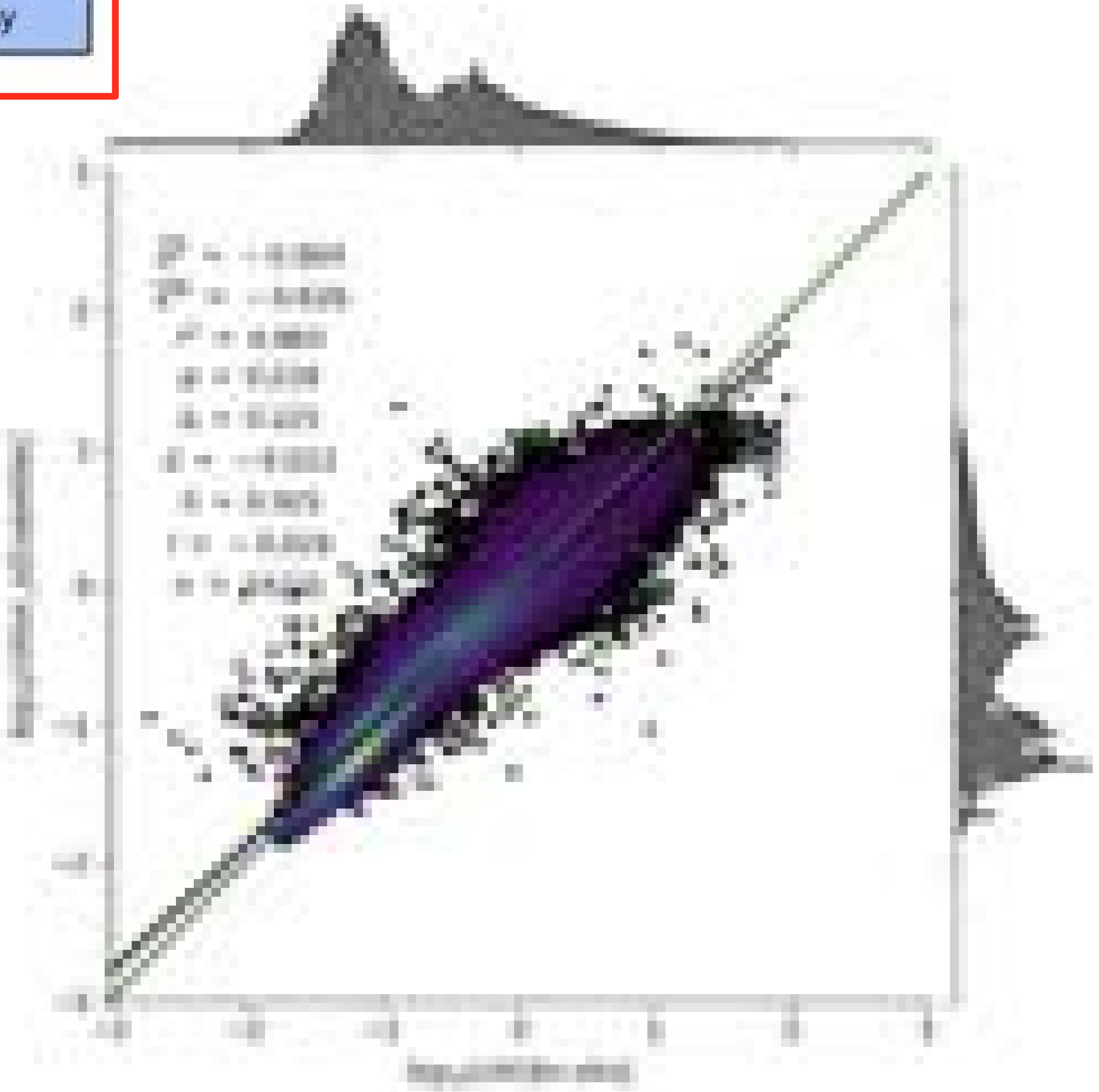


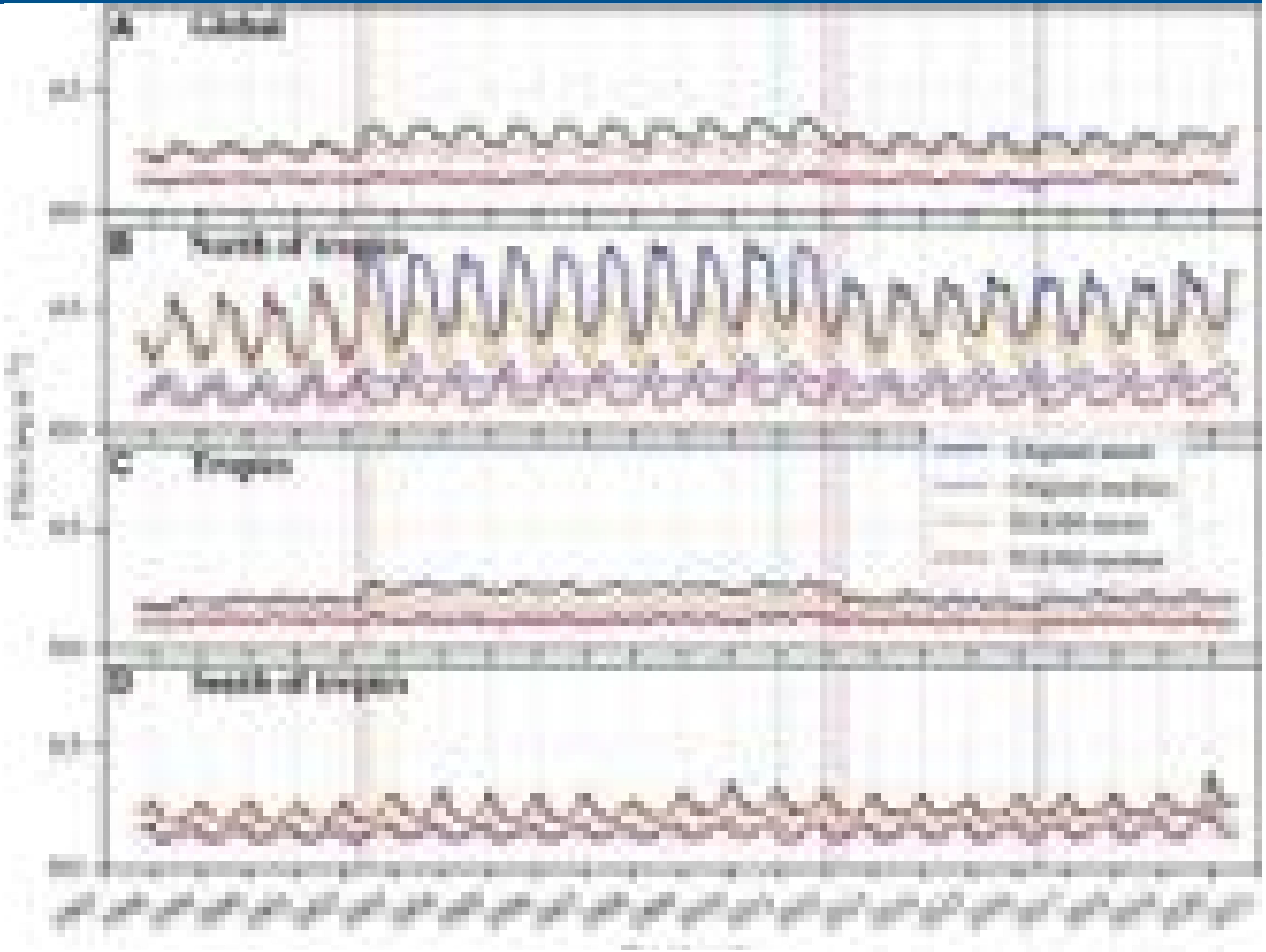


Other biases, eg Coverage bias

Even after correcting for differences in Rrs post atmospheric correction we can find ‘features’ in our time series that look like sensor biases.

Van Oostende et al looked at OC-CCI v5 and found that due to the differing coverage of sensor-atmospheric correction pairings for the coastal zone there were residual features in the time series.

The Temporal Gap Detection Method (TGDM) was used to construct an annually equally represented daily time series for every geographical pixel.



van Oostende M et al (2022) Correction of inter-mission inconsistencies in merged ocean colour satellite data. Front. Remote Sens. 3:882418. doi: 10.3389/frsen.2022.882418

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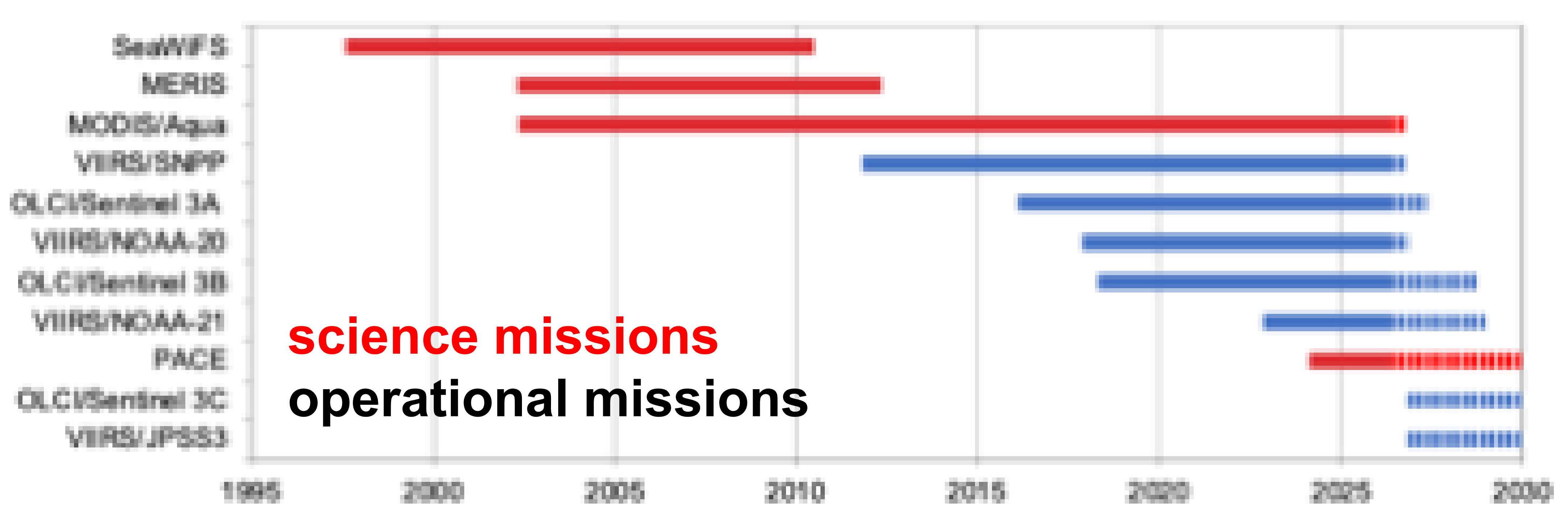

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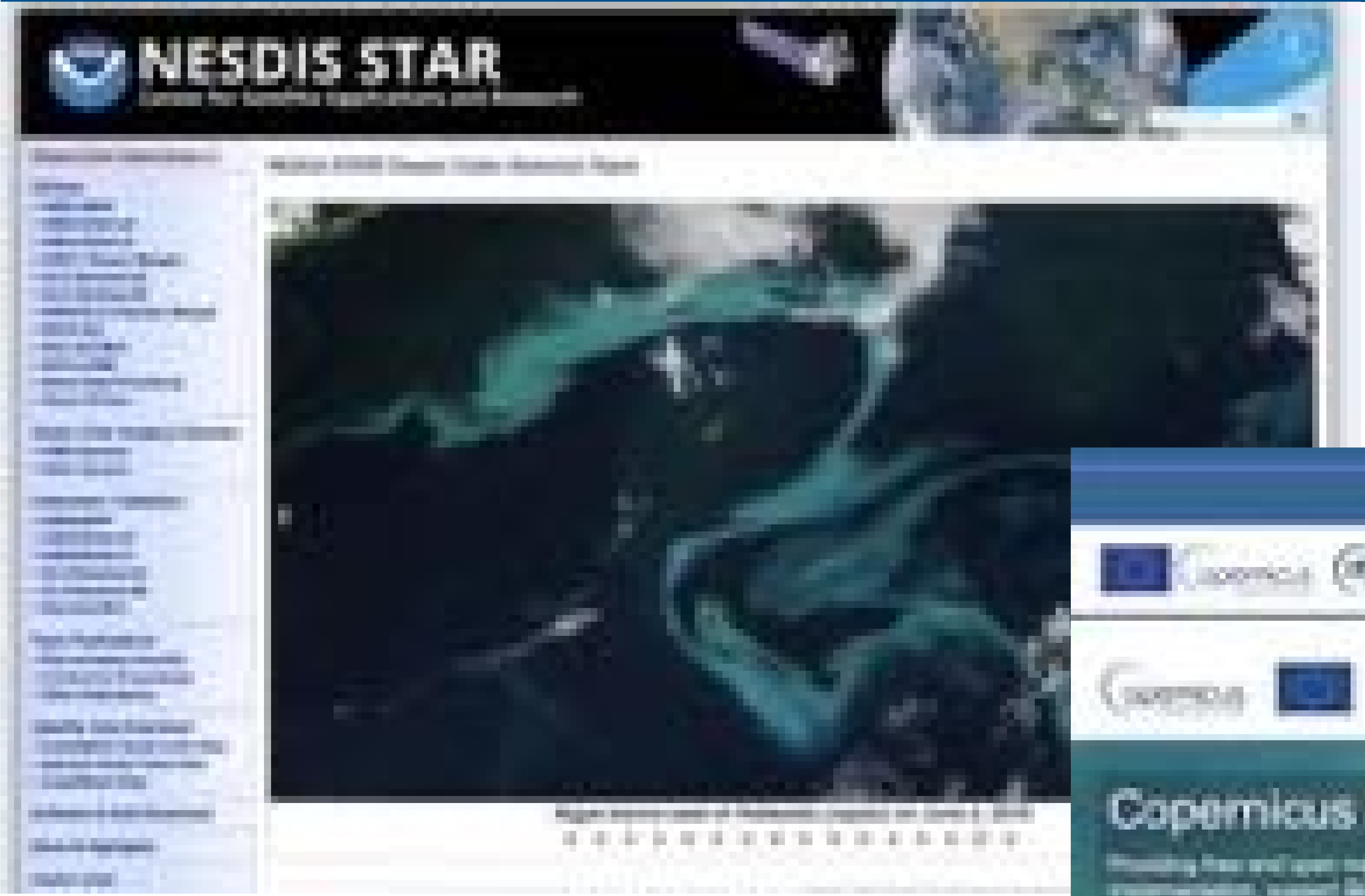
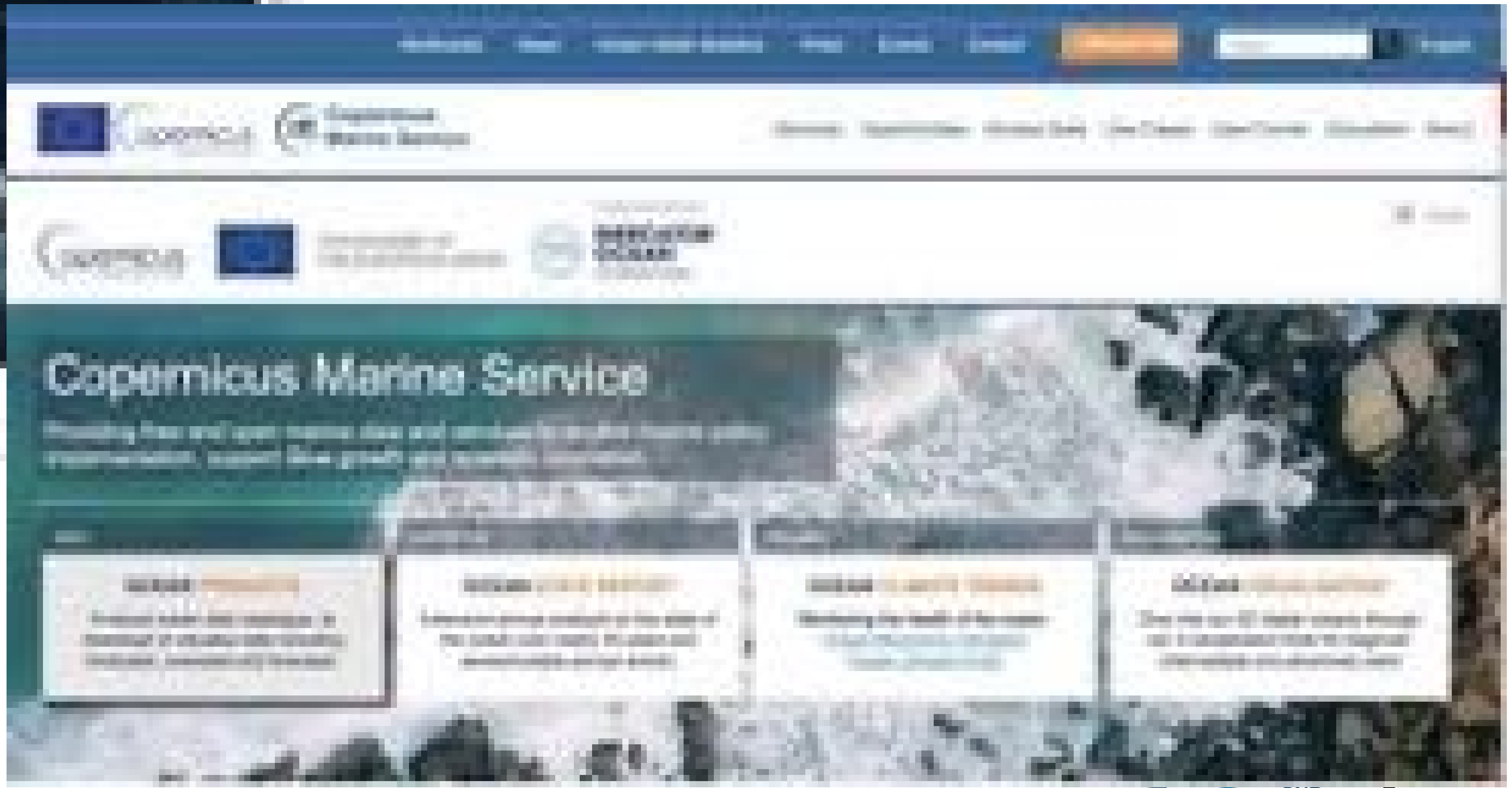
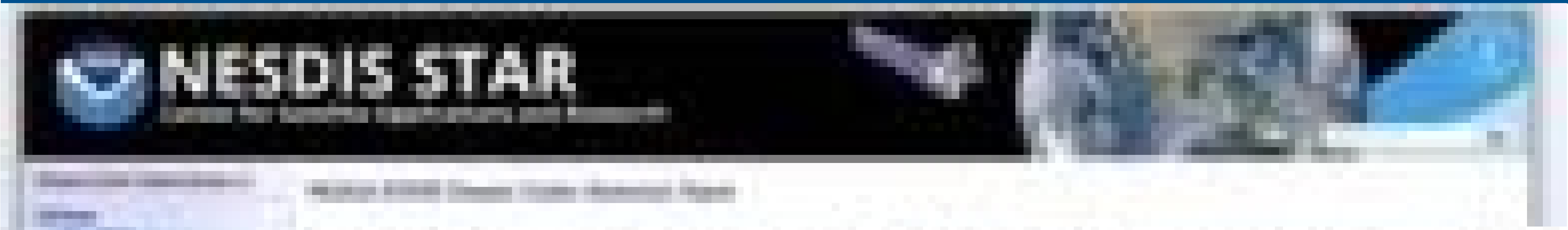




Operational multi sensor ocean colour

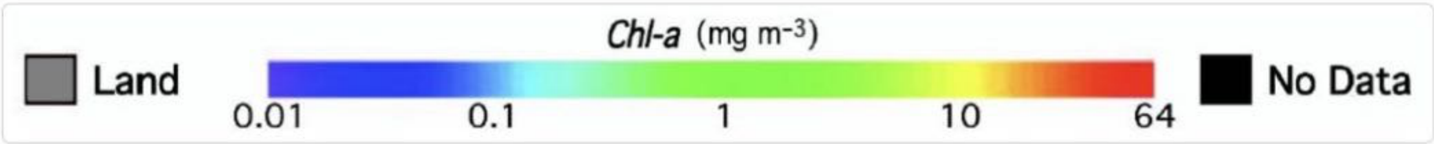


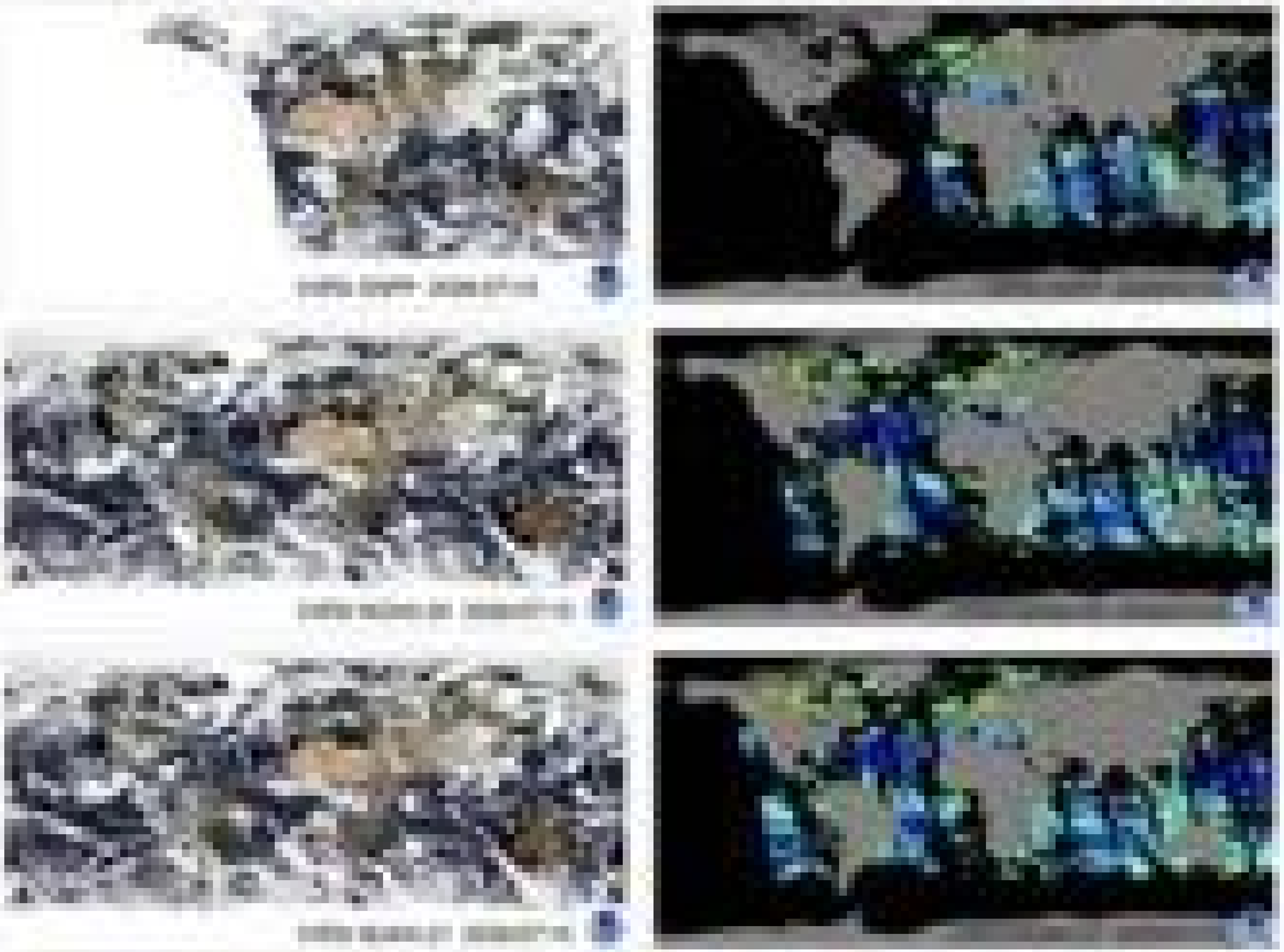
The ocean color science team in the Center for Satellite Applications and Research (STAR) of NOAA/NESDIS seeks to develop improved ocean color products from the current and future ocean color satellite sensors including the Sea-viewing Wide Field-of-view Sensor (SeaWiFS), the Moderate Resolution Imaging Spectroradiometer (MODIS), and the Visible Infrared Imaging Radiometer Suite (VIIRS) on the Suomi National Polar-orbiting Partnership (SNPP) and the Joint Polar Satellite System (JPSS), as well as various satellite sensors from other countries, e.g., the Medium Resolution Imaging Spectrometer (MERIS), Korean Geostationary Ocean Color Imager (GOCI), Sentinel-3 Ocean Land Colour Instrument (OLCI), GCOM-C Second-Generation Global Imager (SGLI), etc. The ocean color science team is currently focusing on:

- Characterization and calibration of satellite ocean color instrument (e.g., VIIRS, MODIS);
- Satellite on-orbit vicarious calibration using in situ measurements;
- Understanding, evaluating, and refining satellite ocean color data processing system (i.e., MSL12);
- Routine global ocean color data processing from Level-0 to Level-1B, Level-1B to Level-2, and Level-2 to Level-3;
- The end-to-end satellite ocean color data processing capability and system;
- Development and improvement of satellite retrieval algorithms in global open ocean and coastal and inland water regions;
- In situ data processing, evaluation, and improvement;
- Implementing and transitioning research algorithms to the NOAA operational data system;
- Various ocean color data research and applications in global open ocean and coastal and inland waters.

The STAR Ocean Color Science Team is also the NOAA VIIRS Ocean Color Environmental Data Records (EDR) Team, responsible for providing high quality VIIRS global ocean color products. Here we show results from VIIRS-SNPP.

Operational multi sensor ocean colour





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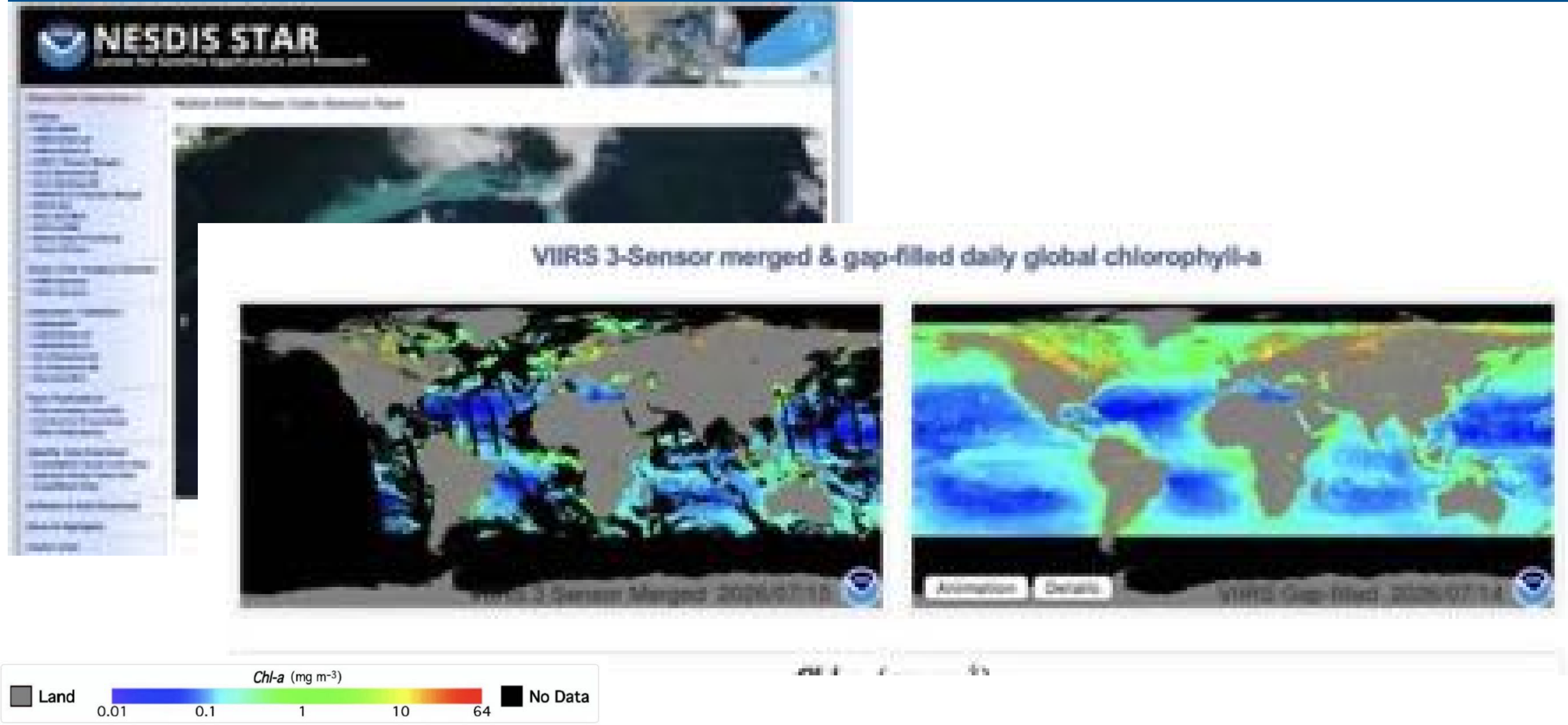

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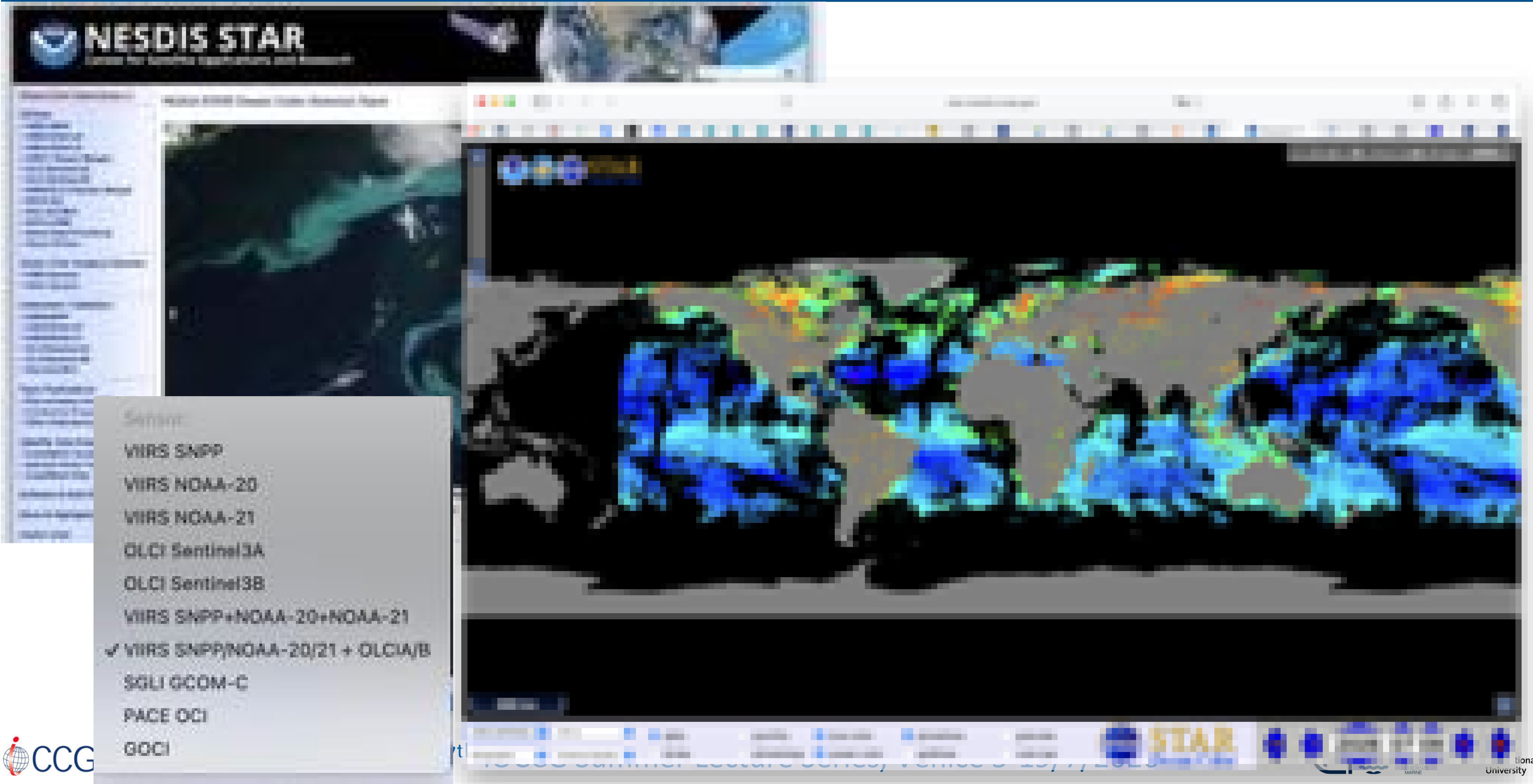
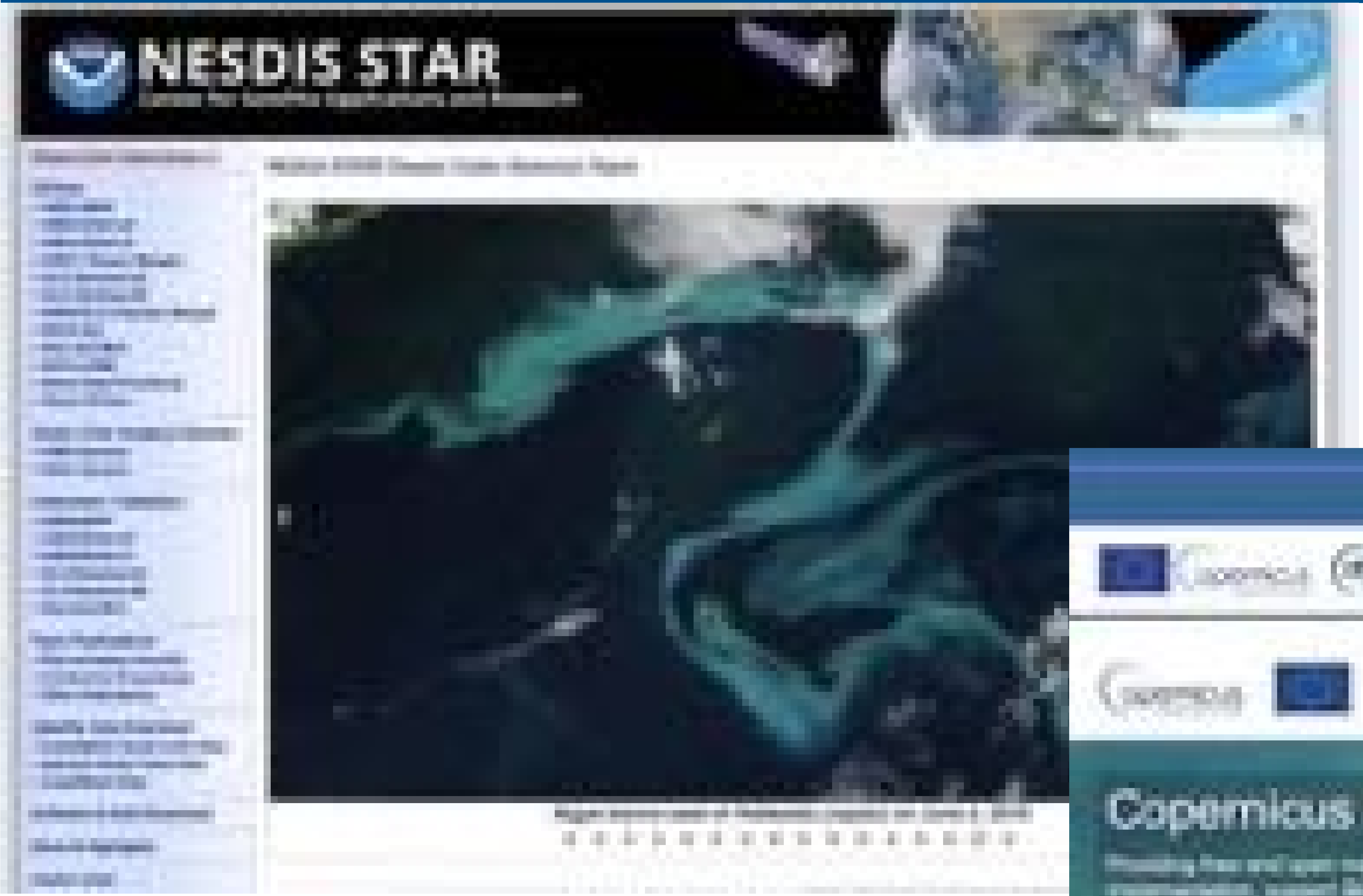
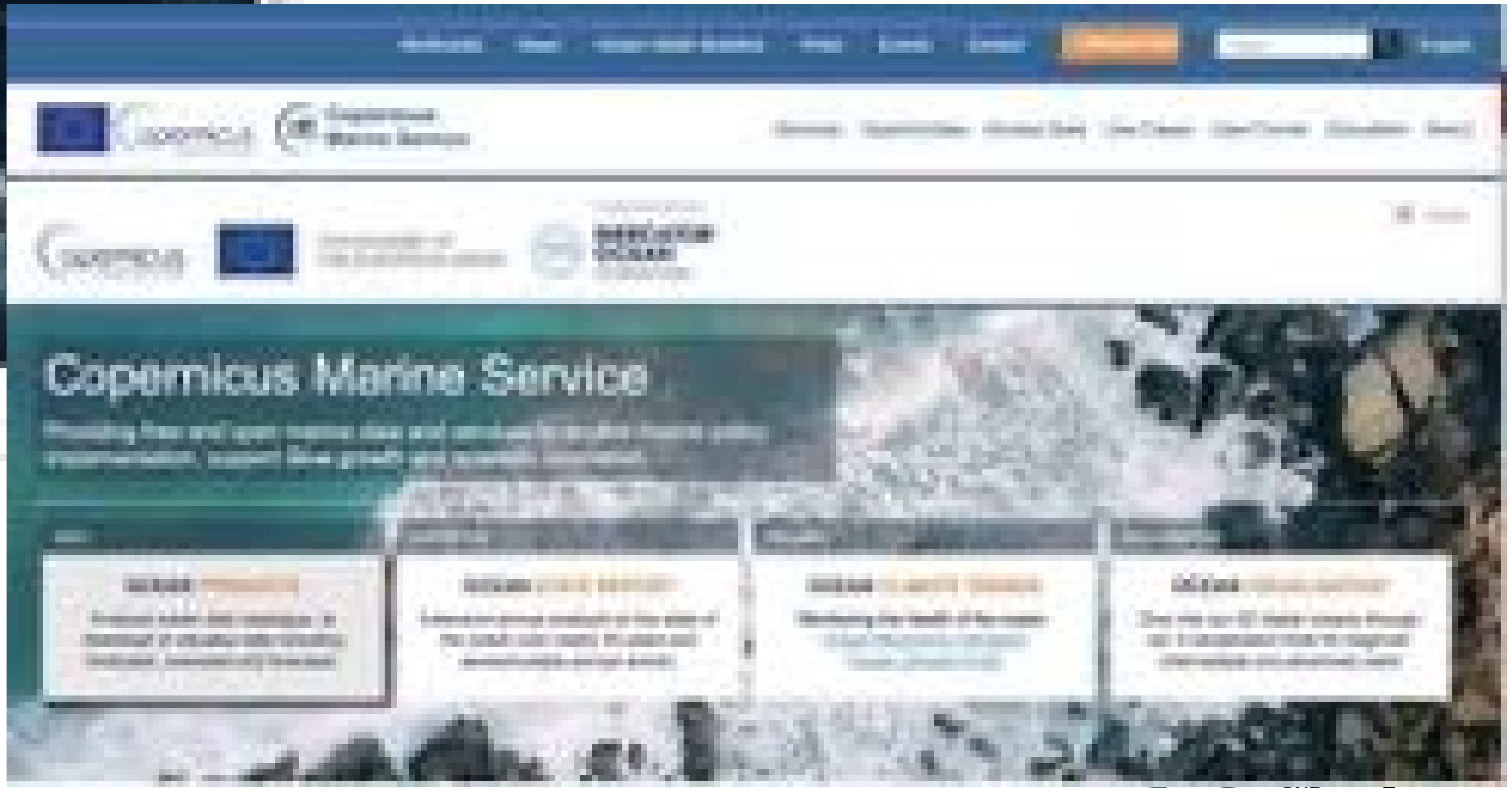


Opera Operational multi sensor ocean colour





The Ocean Colour Thematic Application Centre

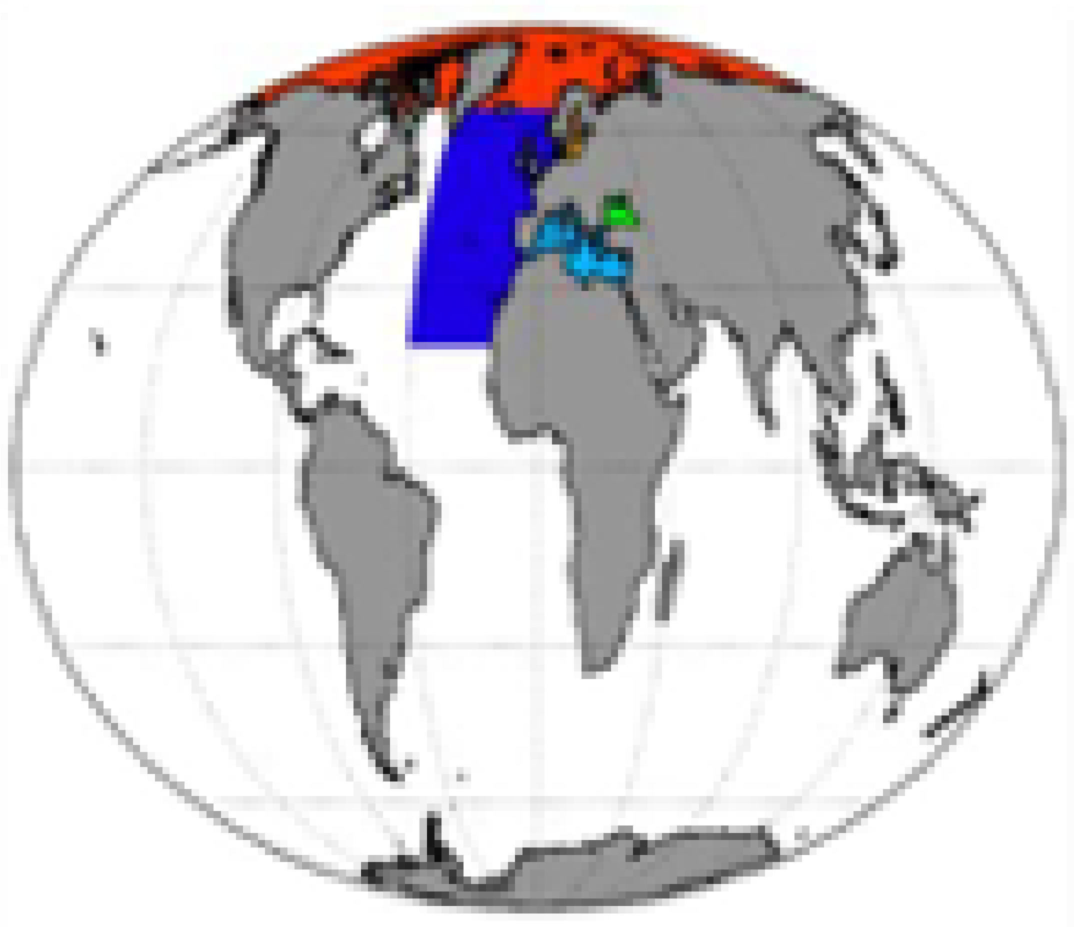
- Single mission data streams from Sentinel-2 MSI and Sentinel-3 OLCI are ingested into production of downstream single and multi-mission product by the **Copernicus Marine Service** (CMEMS)
- Within CMEMS, the **OCTAC** operates the European Ocean Colour component, bridging the gap between space agencies and end-user with high-quality core ocean colour products for the **Global Ocean** and the **European regional seas** based on multiple Ocean Colour missions.
- OCTAC provides a timely and sustained set of the Essential Ocean Variables (**EOVs**) that can be retrieved from **Ocean Colour** radiometry, i.e., **CHL, IOPs and PFTs/PSCs** (Phytoplankton Functional Groups and community structure).
- **Global and regional** products are **higher level observational combined** products providing an **added value to standard products** delivered by the space agencies.
- **Regional products** provide higher accuracy than standard global products as the **regionalisation of processing chains** takes into account the **bio-optical characteristics of each regional sea.**
- **Blended datasets** are generated by applying the **appropriate algorithms across the open ocean and coastal waters.**

PROGRAMME OF THE EUROPEAN UNION

implemented by

OCTAC: product overview

Product overview at the beginning of CMEMS-Copernicus Phase-2 in 2025:



CMEMS Region	Multi-Sensor 1 km (Regions) 4 km (ARC, GLO)				Sentinel-3 OLCI A+B 300 m (Regions and GLO) 4 km (GLO)				Sentinel-2 MSI A+B 100 m			
	NRT		MY		NRT		MY		NRT		MY	
	L3	L4	L3	L4	L3	L4	L3	L4	L3	L4	L3	L4
Arctic Ocean	-	-	✓	✓	✓	✓	✓	✓	✓	✓	-	-
NE Atlantic Ocean	✓	✓	✓	✓	✓	-	✓	-	✓ *	✓ *	-	-
Baltic Sea	-	-	✓	✓	✓	✓	✓	✓	✓	✓	-	-
Black Sea	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	-	-
Mediterranean Sea	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	-	-
Global	✓	✓	✓	✓	✓	✓	✓	✓	-	-	-	-
Global (C3S/OC-CCI)	-	-	✓	✓	-	-	-	-	-	-	-	-

Processing Levels:

L3: daily

L4: daily gap-filled and monthly averages

NRT: **N**ear **R**eal **T**ime

MY: reprocessed **M**ulti-**Y**ear time series

* the Sentinel-2 based products for the North Atlantic is produced over the IBI and NWS areas

OCTAC: product overview

Product overview at the beginning of CMEMS-Copernicus Phase-2 in 2025:

	Arctic	Black Sea	Mediterranean Sea	Baltic Sea	Atlantic Ocean	Global	Global

Each product contains up to six datasets:

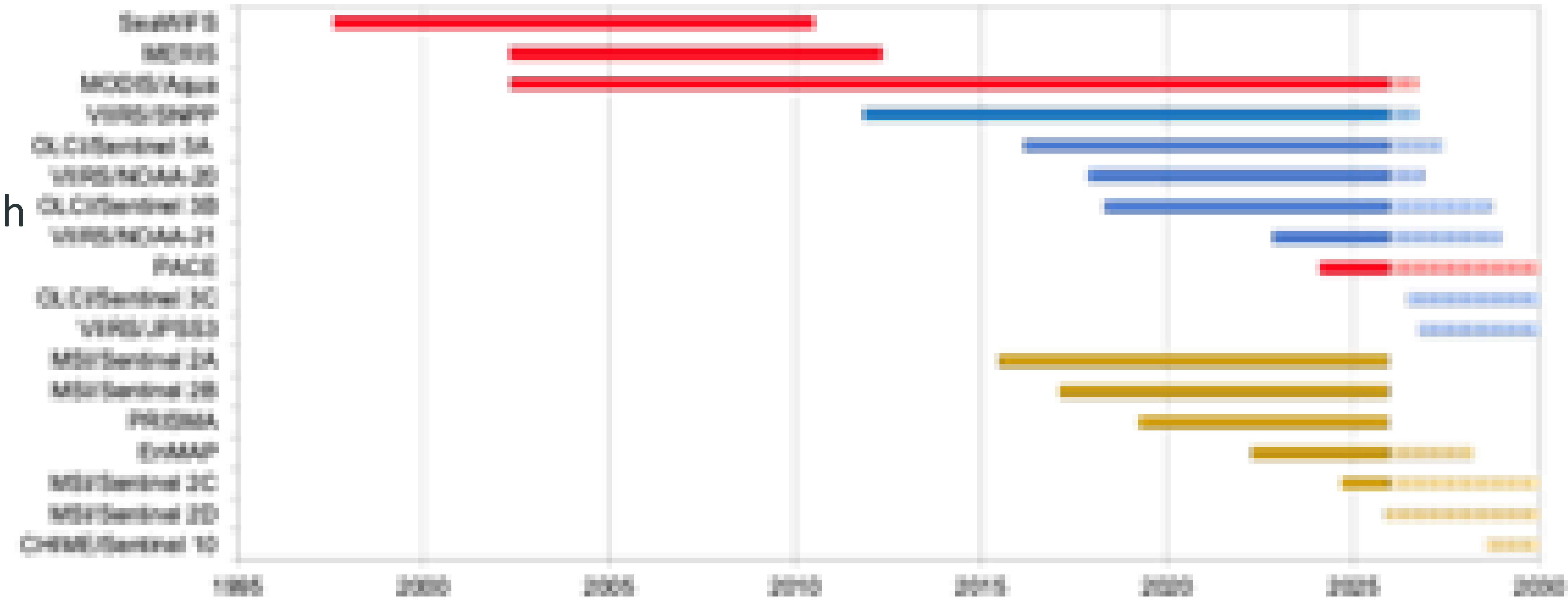
- **Plankton:** phytoplankton chlorophyll concentration (CHL), phytoplankton size classes (PSC) and phytoplankton functional types (PFT)
- **Carbon**: Particulate and Dissolved Organ Carbon Concentration (POC, DOC) ***NEW in 2026!***
- **Primary Production:** integrated productivity within the euphotic zone (PP)
- **Reflectance:** spectral remote sensing reflectance (Rrs)
- **Transparency:** diffuse attenuation coefficient at 490 nm (Kd490), Secchi Depth (ZSD), turbidity (TUR), and suspended particulate matter (SPM)
- **Optics:** inherent optical properties (IOPs), such as absorption and backscattering by particulate and dissolved matter

OCTAC: product overview

All L3 products in the CMEMS catalogue are merged multi sensor:

Multi-Sensor 1 km (Regions) , 4 km (ARC, GLO):

- SeaWiFS, Envisat/MERIS, MODIS-Aqua, VIIRS-SNPP/NOAA-20/NOAA-21, and OLCI-Sentinel-3A/B
- one to six sensors depending on the epoch



Sentinel-3 OLCI 300 m:

- S3A+ S3B

Sentinel-2 MS 100 m:

- S2 A+B, B+C

Within OCTAC, specific strategies to merge data from sensors with different sets of central wavelengths and spectral response functions are adopted in the processing chains.

Combining Sentinel-3 A and B (Sentinel-3 OLCI datasets) and Sentinel-2 A, B and C (Sentinel-2 MSI datasets), does not require band-shifting or inter-sensor bias correction because the two companion sensors are assumed to be fully consistent following ESA/EUMETSAT sensor calibrations

OCTAC: data structure

Copernicus Marine Service

OCEAN COLOUR TAC

CMEMS Region	Sentinel-3 OLCI A+B 300m (Regions) 4km (GLO)			
	NRT		MY	
	L3	L4	L3	L4
GLO	**101**	**102**	**103**	**104**
ATL	**111**	**116**	**113**	**118**
ARC	**121**	**122**	**123**	**124**
BAL	**131**	**132**	**133**	**134**
MED	**141**	**142**	**143**	**144**
BLK	**151**	**152**	**153**	**154**

Data levels: _l3
_l4 (monthly averages)
_l4-gapfree (daily)

NRT only 8 days
MY+MYINT from 2016 up to D-8
(e.g. on 7/12 data up to 30/11)

Product names:

OCEANCOLOUR_<**Region**>_BGC_<**L3/L4**>_<**NRT/MY**>_009_**1XX**

Dataset names:

cmems_obs-oc_<**Region**>_bgc-<**dataset**>_<**nrt/my**>_<**l3/l4**>-olci-300m_P1<**D/M**>_<**EiS**>

Datasets	variables	
plankton	CHL, PSCs, PFTs	ARC: PFTs and PSCs in 202611
pp	Primary production	PP only in MULTI
reflectance	6 bands in MULTI, 11 RRS bands for OLCI	400 -708.75 nm
transp (for transparency)	KD, ZSD, SPM	
optics	BBP, ATOT, ADG, APH, CDM	
car (for carbon)	POC, DOC	*(from Nov 2026)*

https://data.marine.copernicus.eu/product/OCEANCOLOUR_GLO_BGC_L3_MY_009_103/files?subdataset=cmems_obs-oc_glo_bgc-plankton_my_l3-olci-300m_P1D_202211

https://data.marine.copernicus.eu/product/OCEANCOLOUR_ATL_BGC_L3_MY_009_113/files?subdataset=cmems_obs-oc_atl_bgc-plankton_my_l3-olci-300m_P1D_202303

https://data.marine.copernicus.eu/product/OCEANCOLOUR_ARC_BGC_L3_MY_009_123/files?subdataset=cmems_obs-oc_arc_bgc-plankton_my_l3-olci-300m_P1D_202303

https://data.marine.copernicus.eu/product/OCEANCOLOUR_BAL_BGC_L3_MY_009_133/files?subdataset=cmems_obs-oc_bal_bgc-plankton_my_l3-olci-300m_P1D_202211

https://data.marine.copernicus.eu/product/OCEANCOLOUR_MED_BGC_L3_MY_009_143/files?subdataset=cmems_obs-oc_med_bgc-plankton_my_l3-olci-300m_P1D_202211

https://data.marine.copernicus.eu/product/OCEANCOLOUR_BLK_BGC_L3_MY_009_153/files?subdataset=cmems_obs-oc_blk_bgc-plankton_my_l3-olci-300m_P1D_202211

OCTAC: more information

All (most of) the material on OCTAC is detailed in this paper published in 2024 and/or in the CMEMS Quality Information Documents (QuIDs)

remote sensing

MDPI

Review

Overview of Operational Global and Regional Ocean Colour Essential Ocean Variables Within the Copernicus Marine Service

Vittorio E. Brando [1,*], Rosalia Santoleri [1], Simone Colella [1], Gianluca Volpe [1], Annalisa Di Cicco [1], Michela Sammartino [1], Luis González Vilas [1], Chiara Lapucci [1], Emanuele Böhm [1], Maria Laura Zoffoli [1], Claudia Cesarini [1], Vega Forneris [1], Flavio La Padula [1], Antoine Mangin [2], Quentin Jutard [2], Marine Bretagnon [2], Philippe Bryère [2], Julien Demaria [2], Ben Calton [3], Jane Netting [3], Shubha Sathyendranath [3], Davide D'Alimonte [4], Tamito Kajiyama [4], Dimitry Van der Zande [5], Quinten Vanhellemont [5], Kerstin Stelzer [6], Martin Böttcher [6] and Carole Lebreton [6]

Remote Sens. **2024**, *16*, 4588. https://doi.org/10.3390/rs16234588 https://www.mdpi.com/journal/remotesensing

OCTAC: product overview

Regionalisation of processing chains takes into account the bio-optical characteristics of each regional sea.

		Arctic	Black Sea	Mediterranean Sea	Baltic Sea	Atlantic Ocean	Global	Global
RRS	MULTI at 1 km /4 km	OC-CCI V6.0 4 km	OC-CCI-Like 1km Volpe et al. (2019)	OC-CCI-Like 1km Volpe et al. (2019)	OC-CCI V6.0 1 km	GlobColur 1km (Garnesson et al., 2019)	GlobColur 4km (Garnesson et al., 2019)	OC-CCI V6.0 4 km
	MULTI reference sensor	MERIS	SeaWiFS	SeaWiFS	MERIS	N/A	N/A	MERIS
	OLCI (S3A+B) at 300m	EUM L2	EUM L2	EUM L2	Polymer (Gonzalez Vilas et al 2024)	EUM L2	EUM L2	N/A
CHL	MULTI at 1 km /4 km	ML algorithm (Zoffoli et al., 2025)	Zibordi et al., 2015 (Case1), Kajiyama et al., 2018 (Case2)	Volpe et al. (2019): Blend of MedOC (Case1) and Ad4 (Berthon &. Zibordi, 2004; Case 2)	MLP ensemble (Brando et al., 2021, Gonzalez Vilas et al 2024)	Garnesson et al., 2019: OC5 (Gohin et al. 2002) and CI (Hu et al. 2012)	Garnesson et al., 2019	Blended based on OWTs
	OLCI (S3A+B) at 300m						L3: EUMETSAT standard CHL	N/A

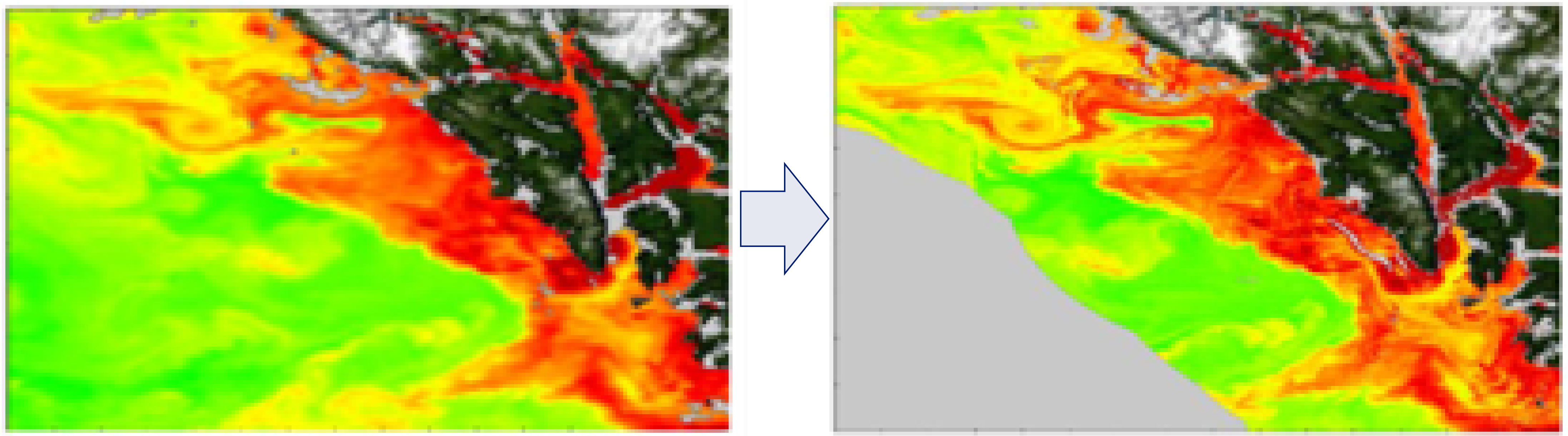
Summary of the OCTAC validation metrics for CHL datasets in Brando et al. 2024

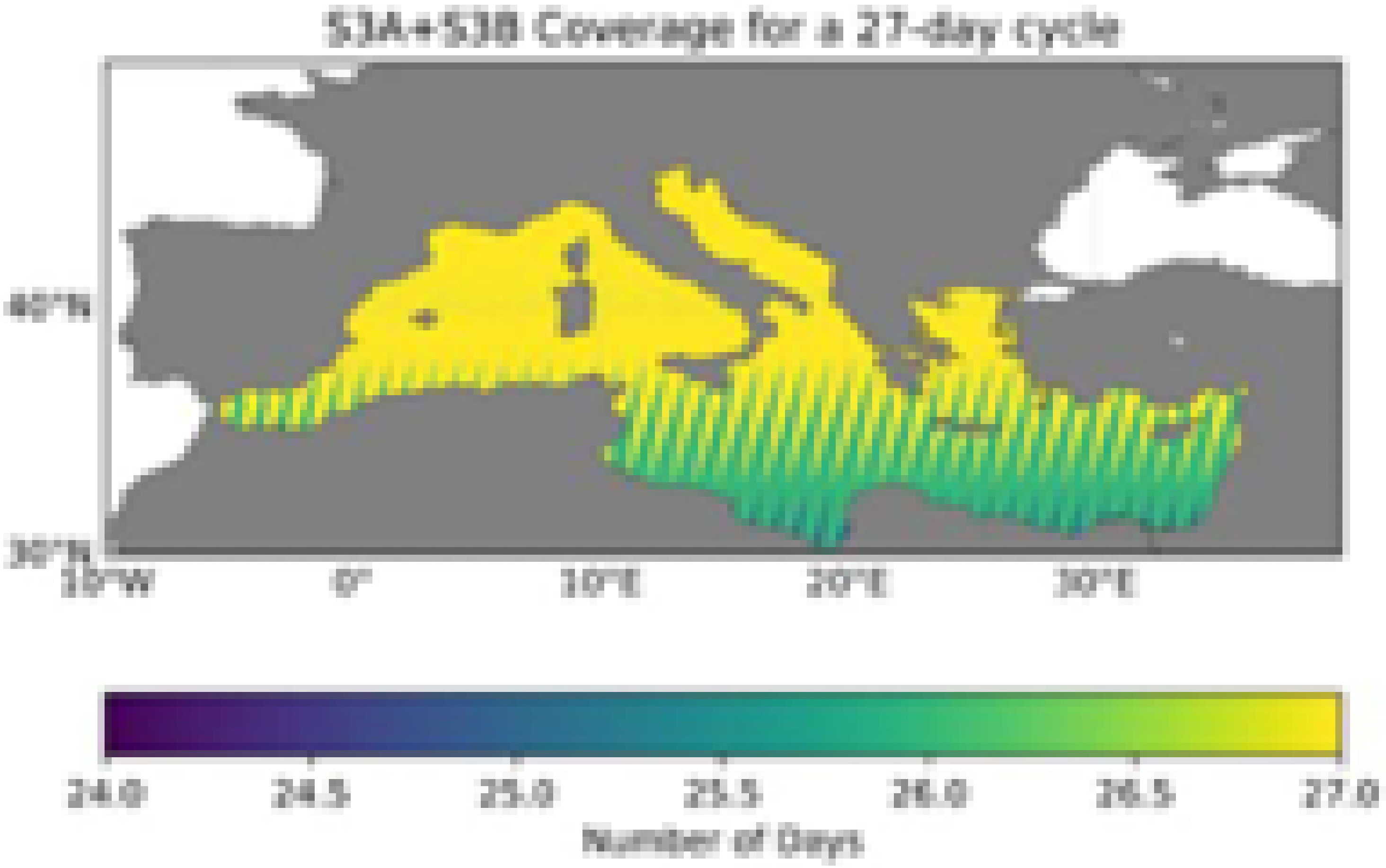
OLCI multi-sensor products

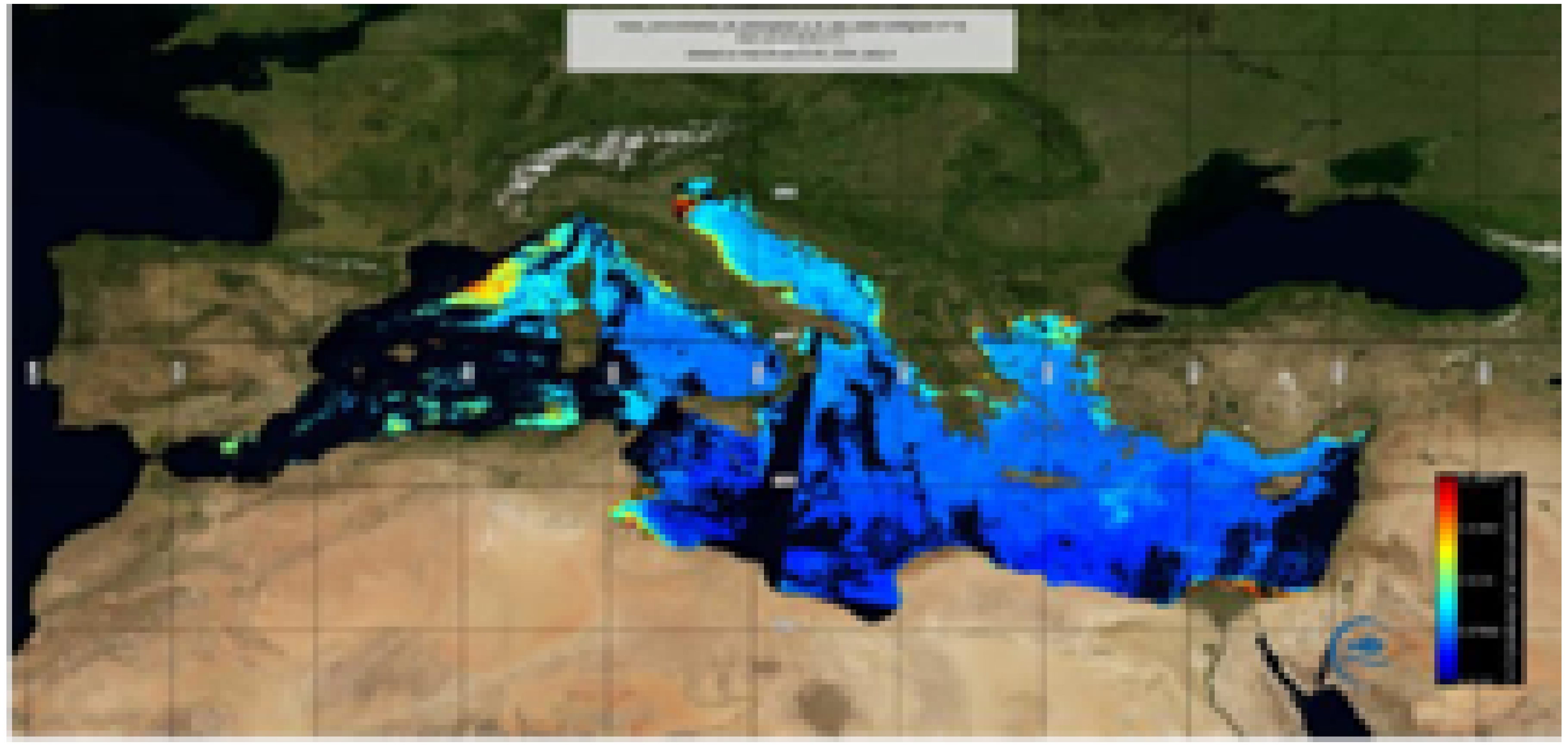
OLCI merged datasets (S3A+B): GLOBAL full coverage at 4km, Coastal (200km) at 300 meters

140º shift between S3A & S3B:

- full daily coverage above ~40N
- almost full for MED and ATL
- full for ARC, BLK and BAL







OLCI multi-sensor products

Copernicus Marine Service

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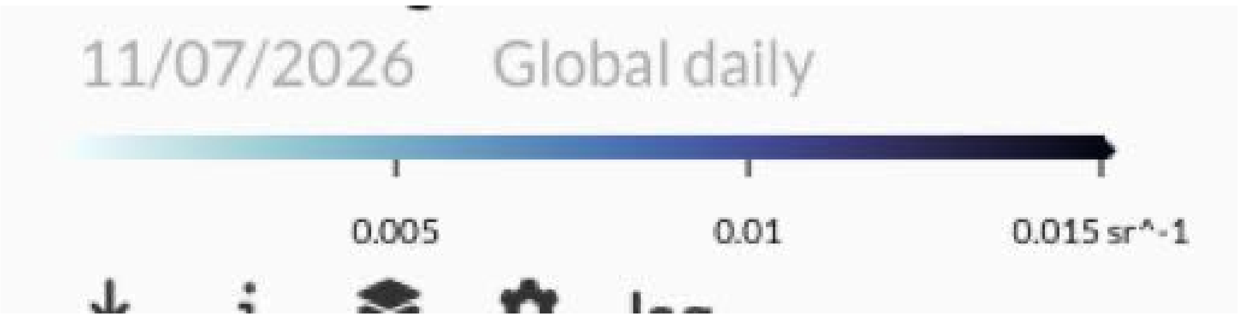
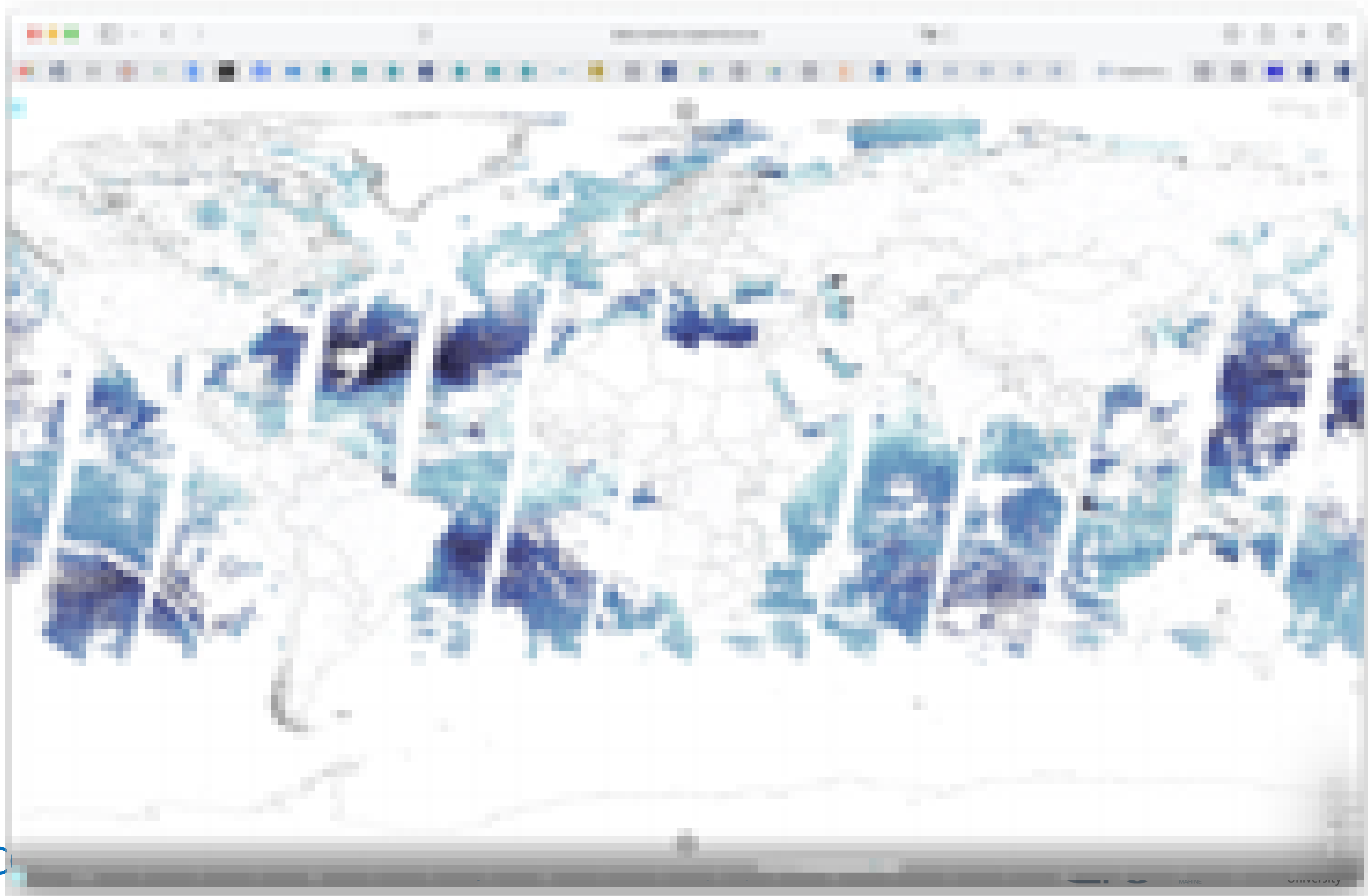
S3/OLCI A+B 4 km
Rrs(443)
11/7/2026





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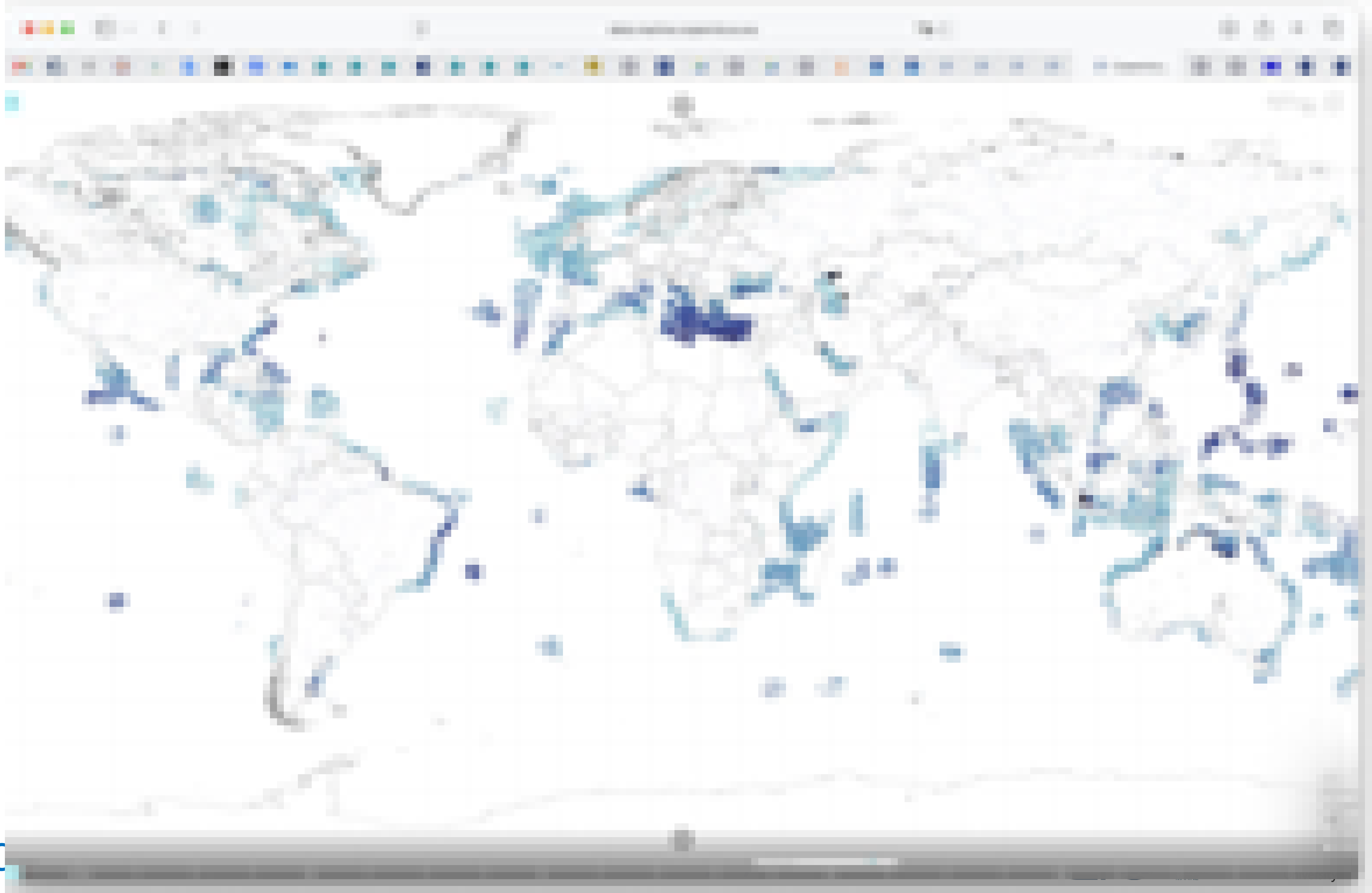
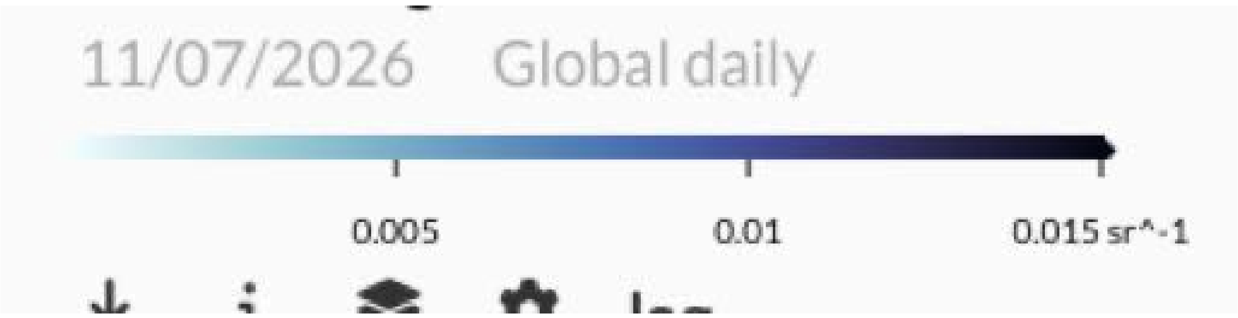


S3/OLCI A+B 300m
Rrs(443)
11/7/2026



The global products

CMEMS Region	Multi-Sensor 1 km (Regions) 4 km (ARC, GLO)				Sentinel-3 OLCI A+B 300 m (Regions and GLO) 4 km (GLO)				Sentinel-2 MSI A+B 100 m			
	NRT		MY		NRT		MY		NRT		MY	
	L3	L4	L3	L4	L3	L4	L3	L4	L3	L4	L3	L4
Global	✓	✓	✓	✓	✓	✓	✓	✓	-	-	-	-
Global (C3S/OC-CCI)	-	-	✓	✓	-	-	-	-	-	-	-	-

The **Copernicus-GlobColour** products for GLO (and ATL) are based on the **L2 data distributed by the agencies** with multisensor merging and flagging strategies detailed in Garnesson et al. 2019.
CHL concentration is estimated as a daily multisensor merged dataset, where CHL values are individually computed for each sensor using a blended algorithm and then combined

For the **OC-CCI** multisensor production, atmospheric correction is performed independently for each sensor, and the merging is performed for the calibrated reflectances, after band shifting to the reference sensor bands (Sathyendranath et al., 2017, 2019).
The CHL values are calculated by blending algorithms based on the water-types utilising the same OC-CCI Rrs.

- Polymer is mostly used for atmospheric correction in OC-CCI V6
- MERIS is the reference sensor in OC-CCI V6

Copernicus-GlobColour

Copernicus-GlobColour processor is mainly composed of 4 separate modules, namely:

1. a pre-processor module
2. a spatial binning module
3. a merging module
4. a temporal binning module

Sensor	RRS Wavelengths (nm)	Spatial Resolution At Nadir (km)	Swath width (km)	Equate crossing time	Period
SeaWiFS	412,443,490,510,555,670	1 & 4	1502	12:20	1997-2010
MERIS	413,443,490,510,560,620,667,681,709	1 & 0.3	1150	10:00	2002-2012
MODIS-Aqua	412,443,469,488,531,547,555,645,667,678	1	2330	13:30	2002-present
VIIRS-NPP	410,443,486,551,671	1	3040	10:30	2012-present
OLCI S3A	400,412,442,490,510,560,620,665,674,681,709	1.2 & 0.3	1270	10:00	2016-present
VIIRS-NOAA20	411,445,489,556,667	0.75	3040	9:50	Dec-2017-present
OLCI S3B	400,412,442,490,510,560,620,665,674,681,709	1.2 & 0.3	1270	10:00	2018-present
VIIRS-NOAA21	411,445,489,556,667	0.75	3040	9:50	Nov-2021-present

Standard agency L2

Ocean Sci., 15, 819–830, 2019
https://doi.org/10.5194/os-15-819-2019

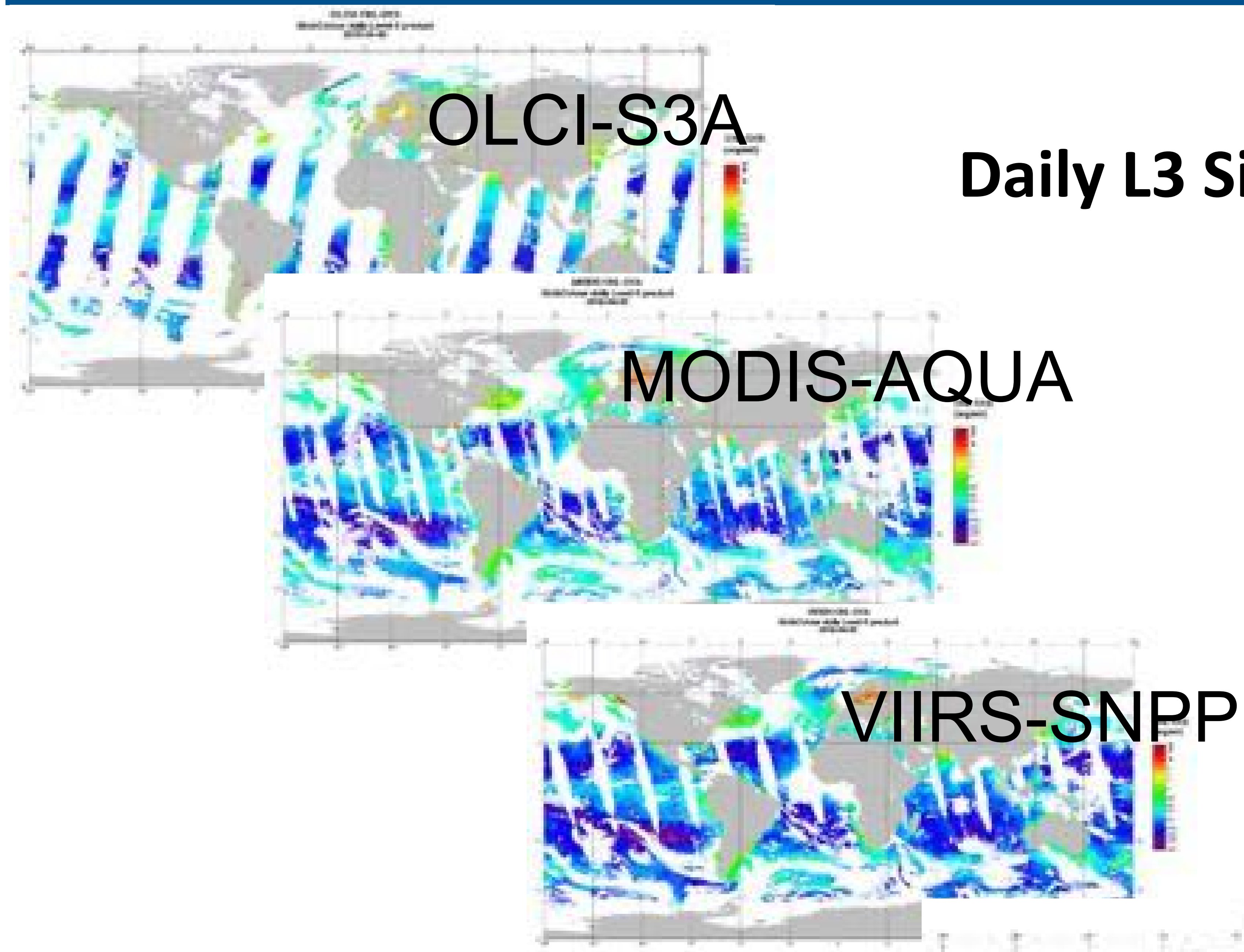
Ocean Science | EGU

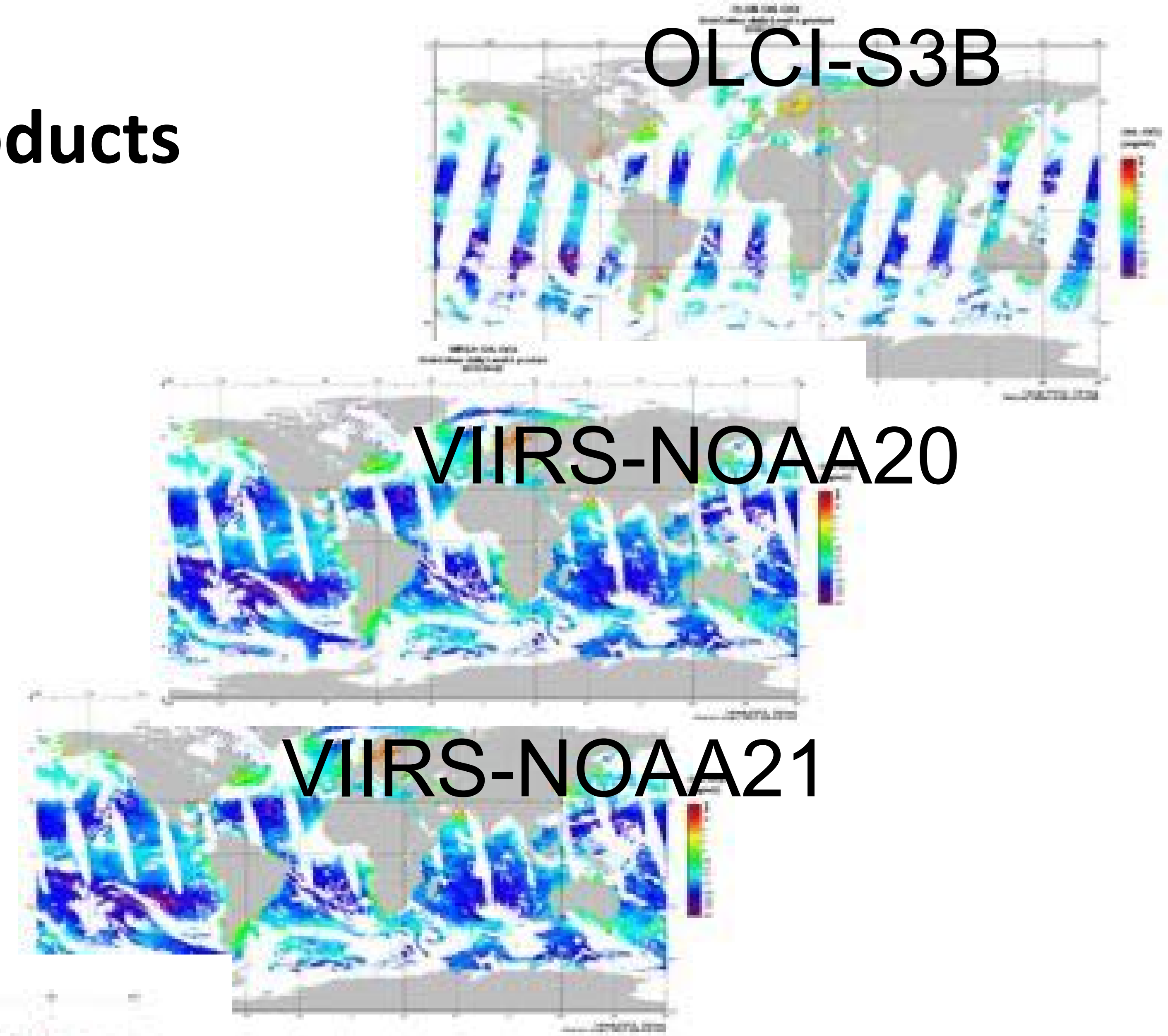
The CMEMS GlobColour chlorophyll *a* product based on satellite observation: multi-sensor merging and flagging strategies

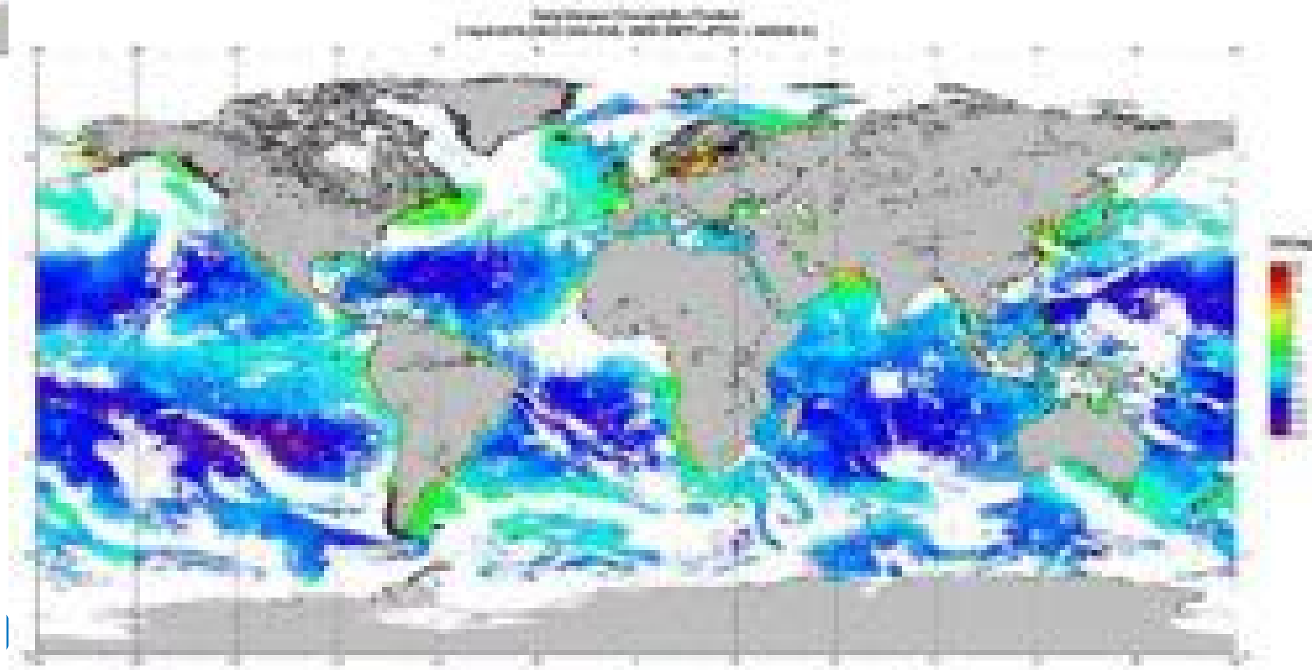
Philippe Garnesson, Antoine Mangin, Odile Fanton d'Andon, Julien Demaria, and Marine Bretagnon
ACRI-ST, Sophia Antipolis, 06904, France

Copernicus-GlobColour

Daily L3 Single Sensor products







Daily Merged CHL Product

Ocean Sci., 15, 819–830, 2019
https://doi.org/10.5194/os-15-819-2019

Ocean Science | EGU

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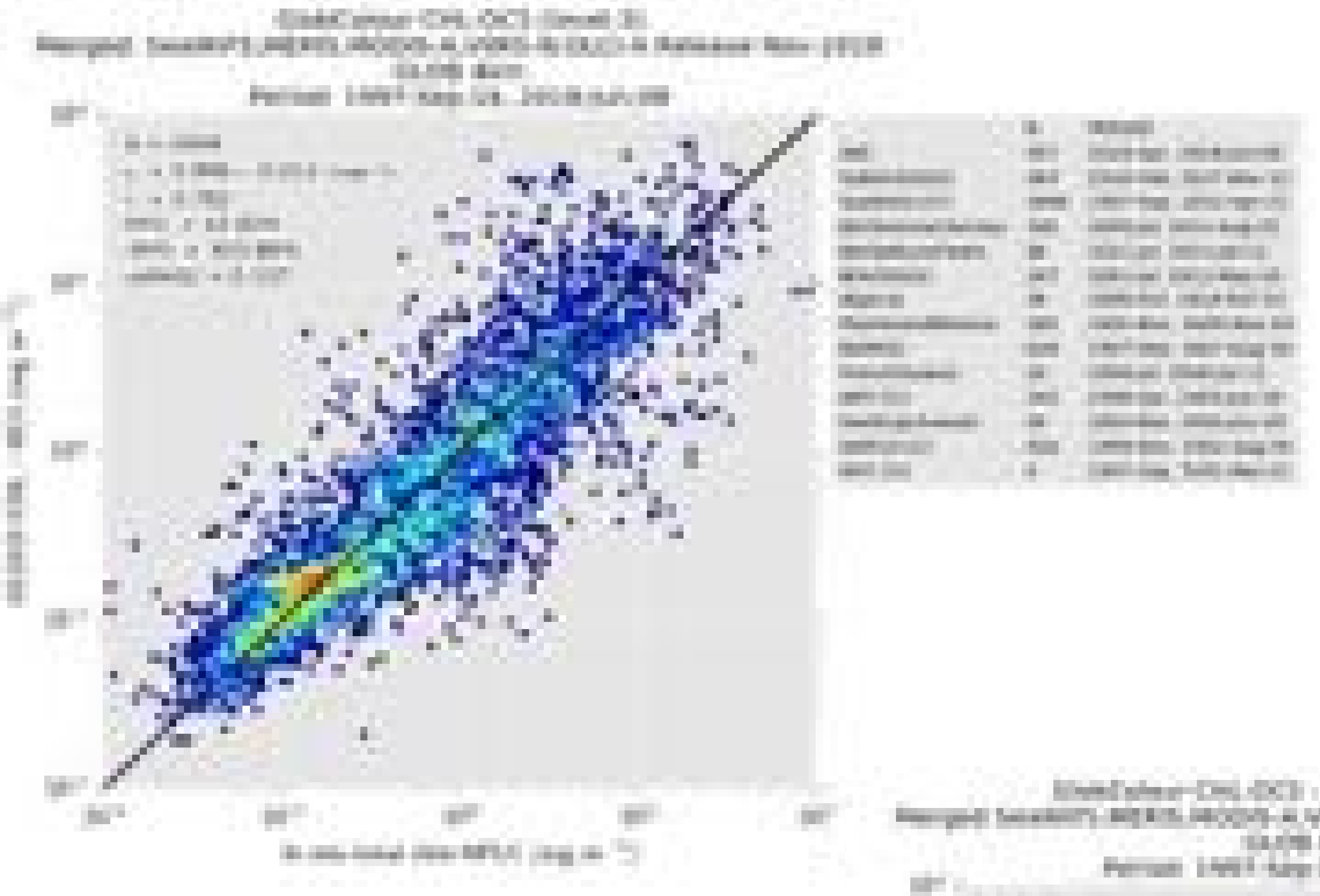
Copernicus-GlobColour

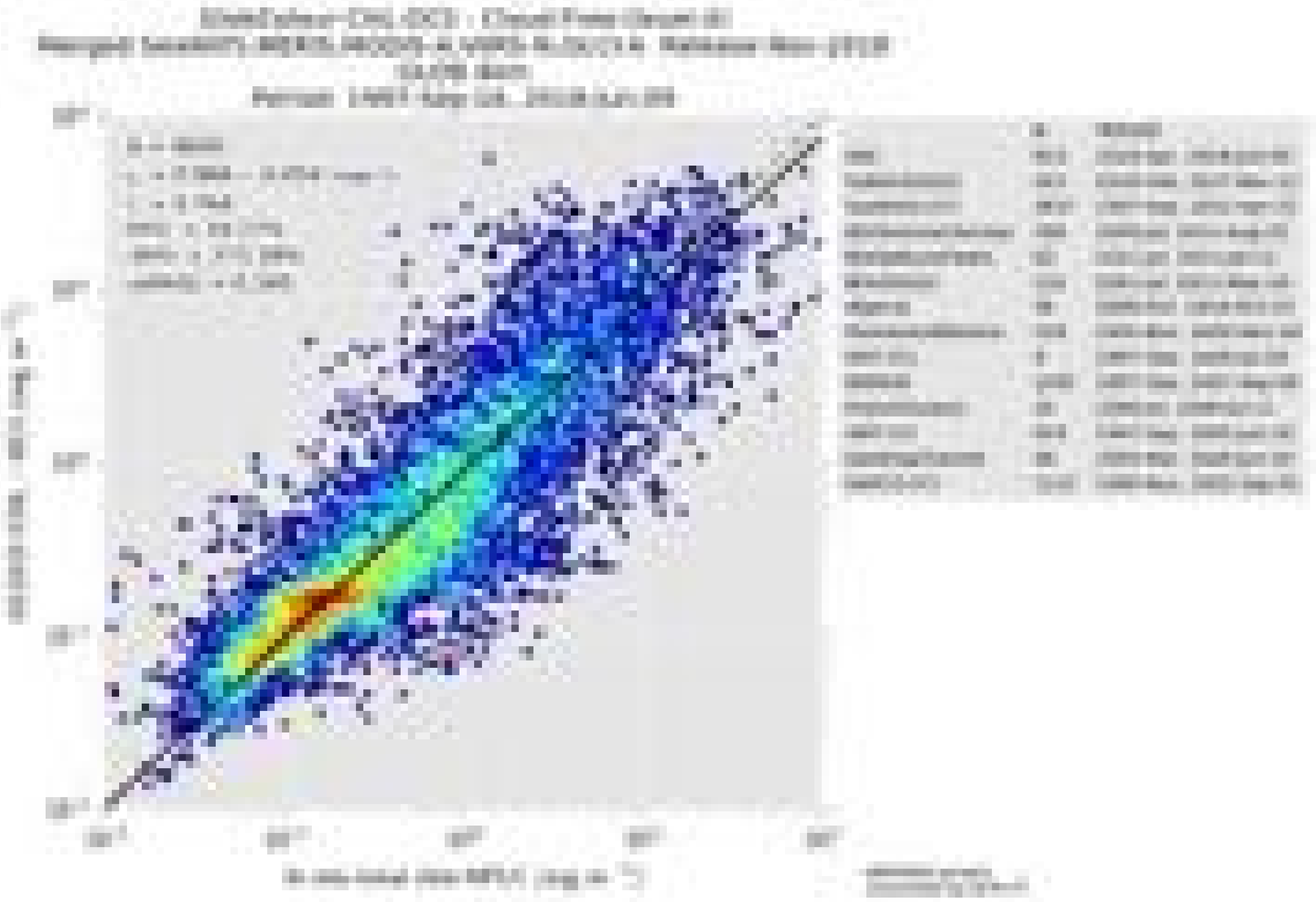
Copernicus Marine Service

Chlorophyll

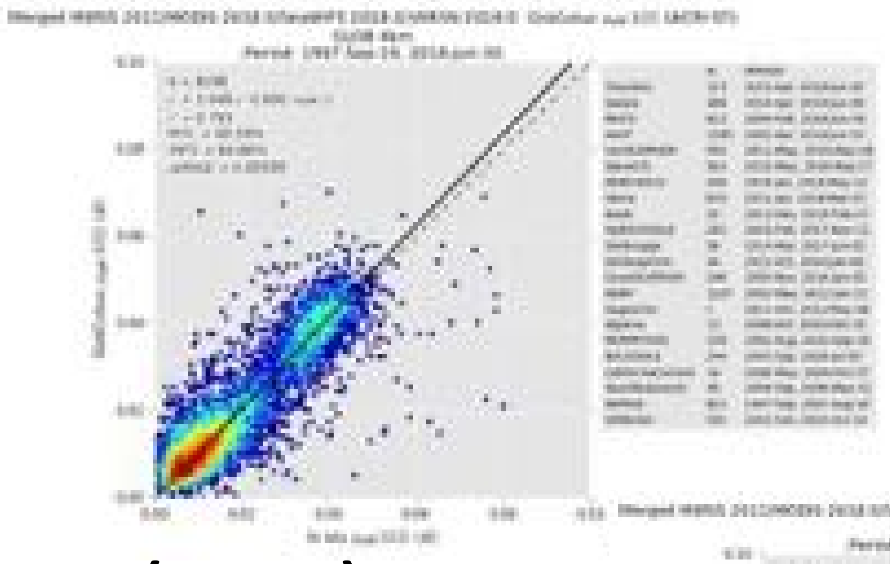
L3



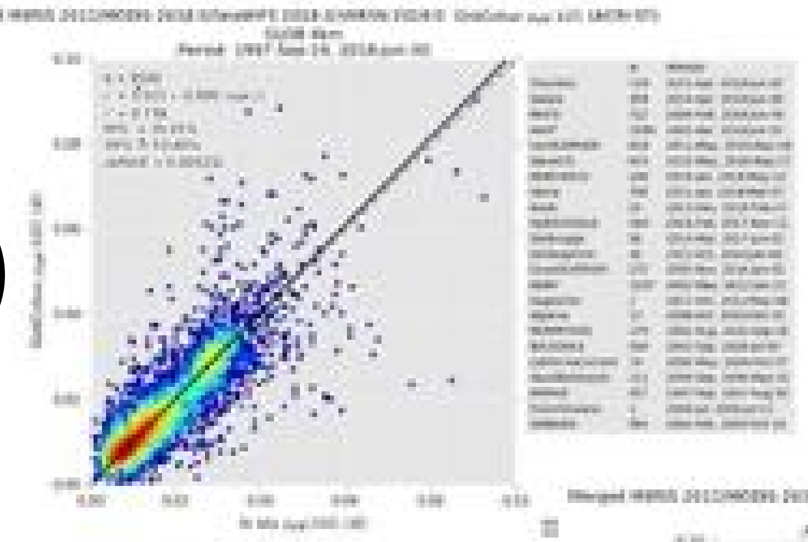
L4



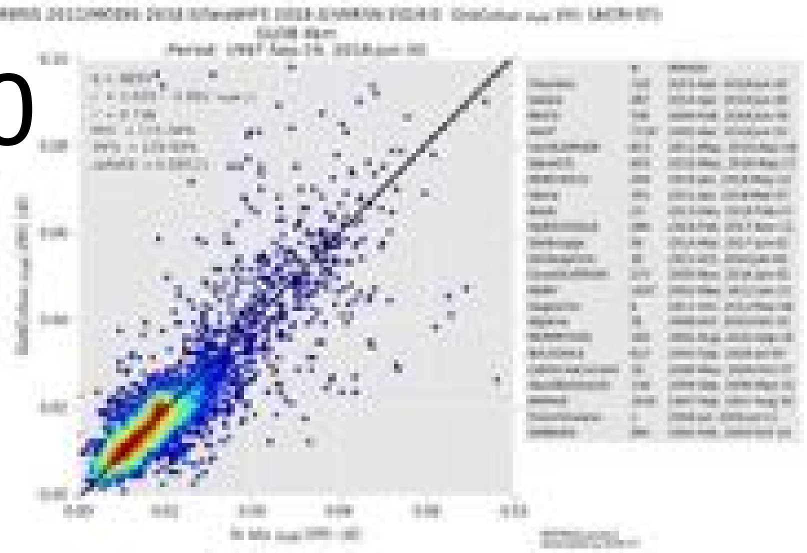
Rrs(412)



Rrs (443)



Rrs 490



Ocean Sci., 15, 819–830, 2019
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Ocean Science EGU

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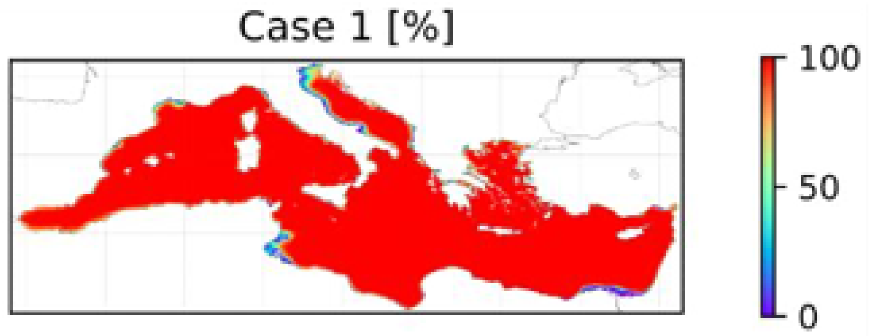
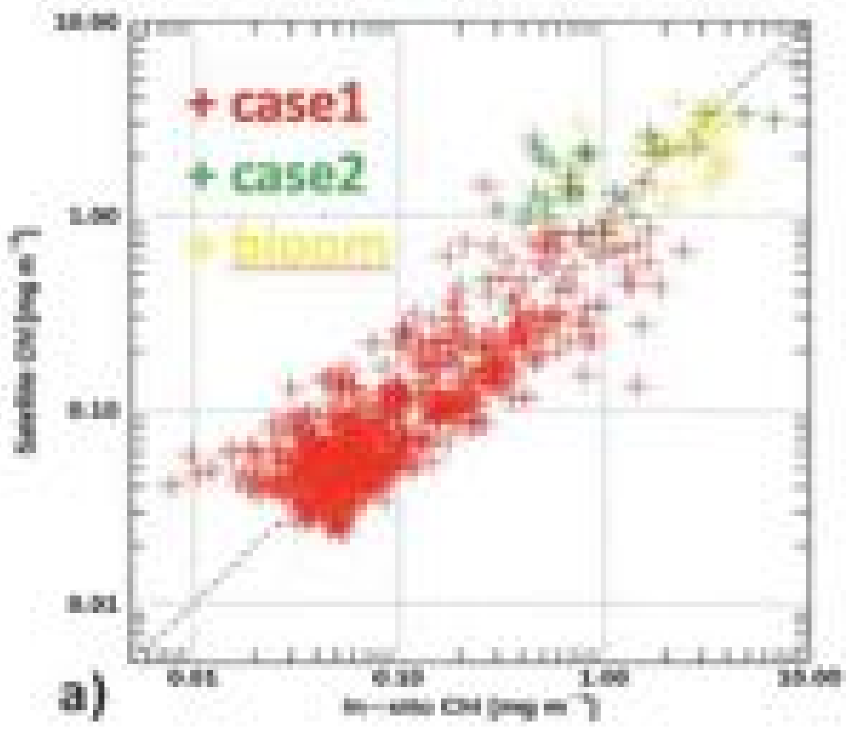
	MULTI reference sensor	MERIS	SeaWiFS	SeaWiFS	MERIS	N/A	N/A	MERIS
	OLCI (S3A+B) at 300m	EUM L2	EUM L2	EUM L2	Polymer (Gonzalez Vilas et al 2024)	EUM L2	EUM L2	N/A
CHL	MULTI at 1 km /4 km	ML algorithm (Zoffoli et al., 2025)	Zibordi et al., 2015 (Case1), Kajiyama et al., 2018 (Case2)	Volpe et al. (2019): Blend of MedOC (Case1) and Ad4 (Berthon &. Zibordi, 2004; Case 2)	MLP ensemble (Brando et al., 2021, Gonzalez Vilas et al 2024)	Garnesson et al., 2019: OC5 (Gohin et al. 2002) and CI (Hu et al. 2012)	Garnesson et al., 2019	Blended based on OWTs
	OLCI (S3A+B) at 300m						L3: EUMETSAT standard CHL	N/A

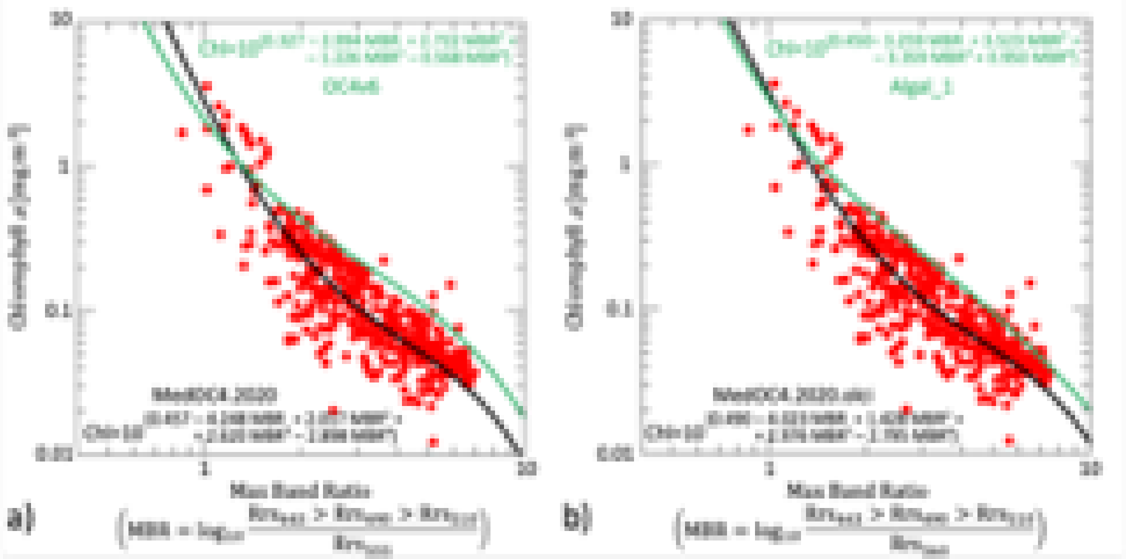
Summary of the OCTAC validation metrics for CHL datasets in Brando et al. 2024

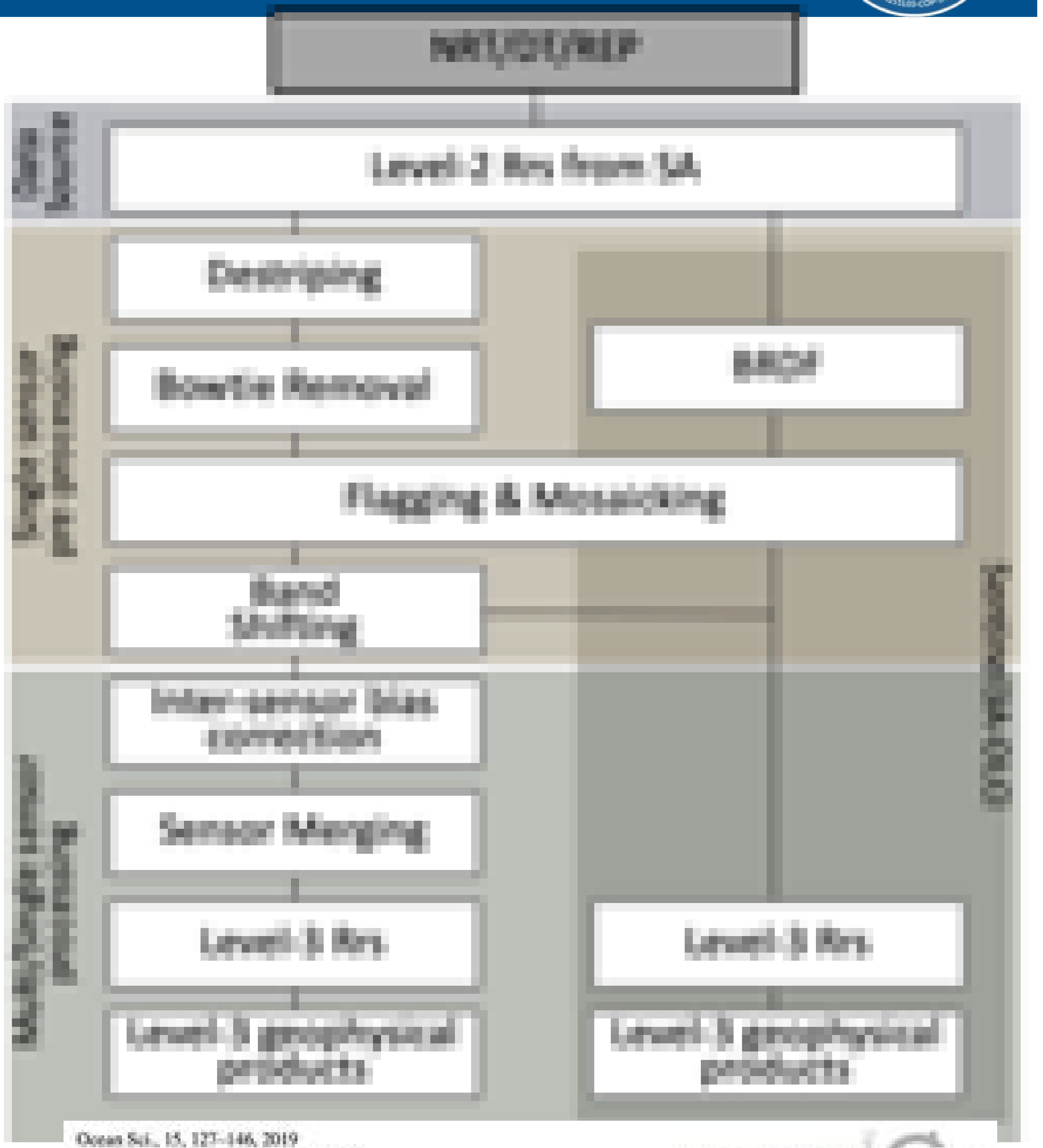
Mediterranean Sea

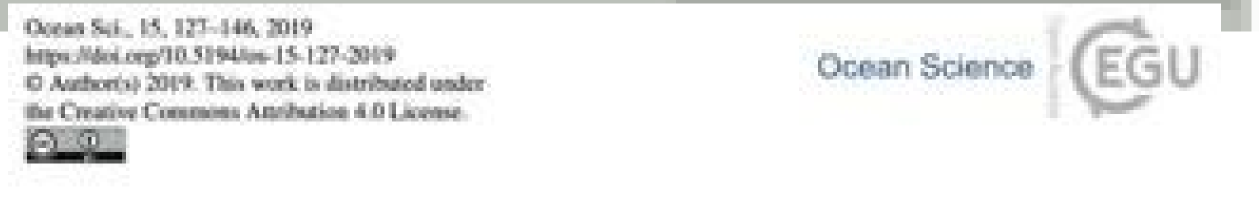
- **Mediterranean CHL**
  - Overall a Blue waters basin >>>>>>>>>>>>>>>
  - merging at common RRS wavelengths
  - CHL and Optics datasets are calculated with regional algorithms
  - Merged Case 1 & Case 2 CHL algorithm: MedOC4 + AdOC4









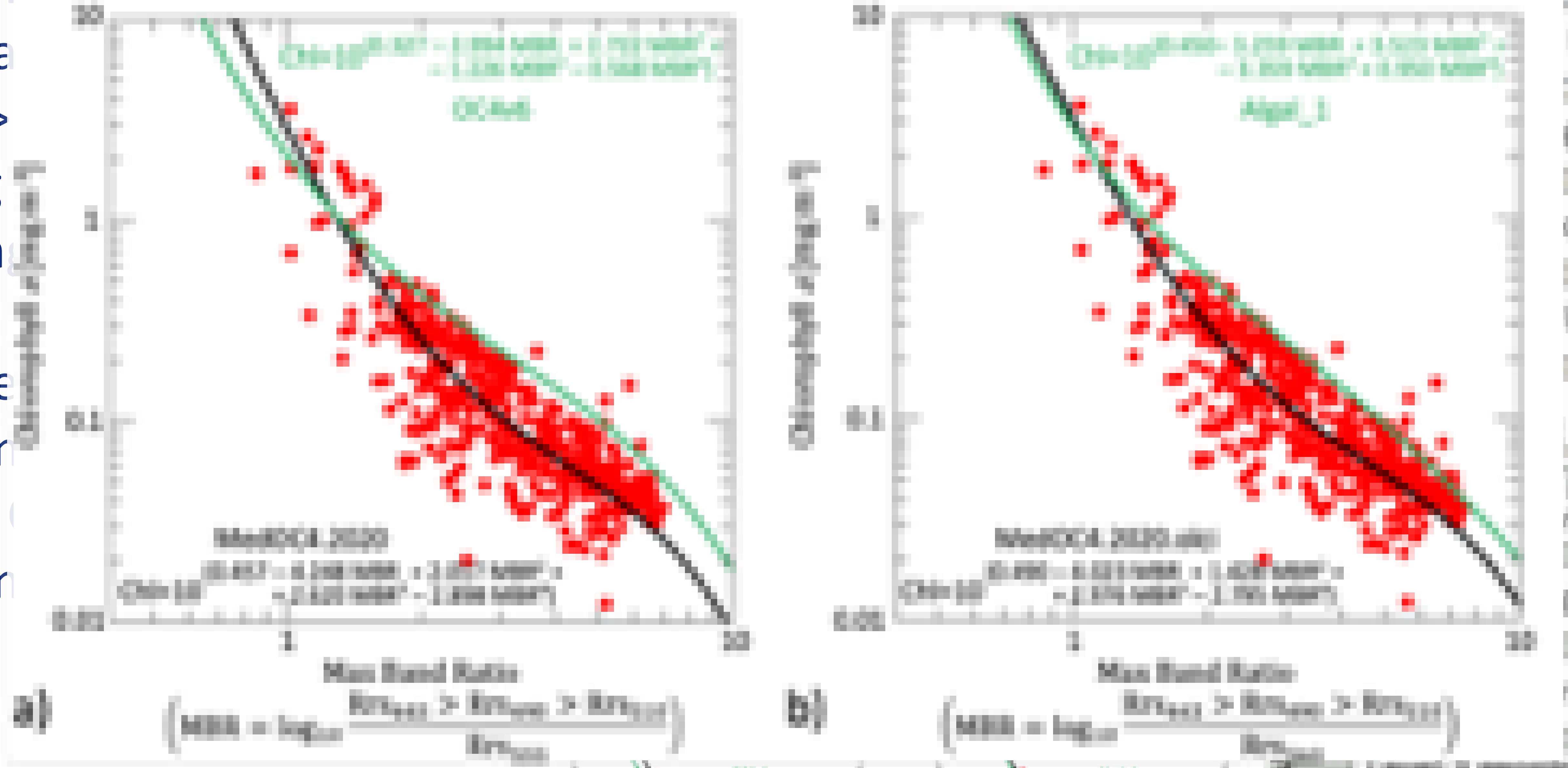

Ocean Sci., 15, 127–146, 2019
https://doi.org/10.5194/os-15-127-2019

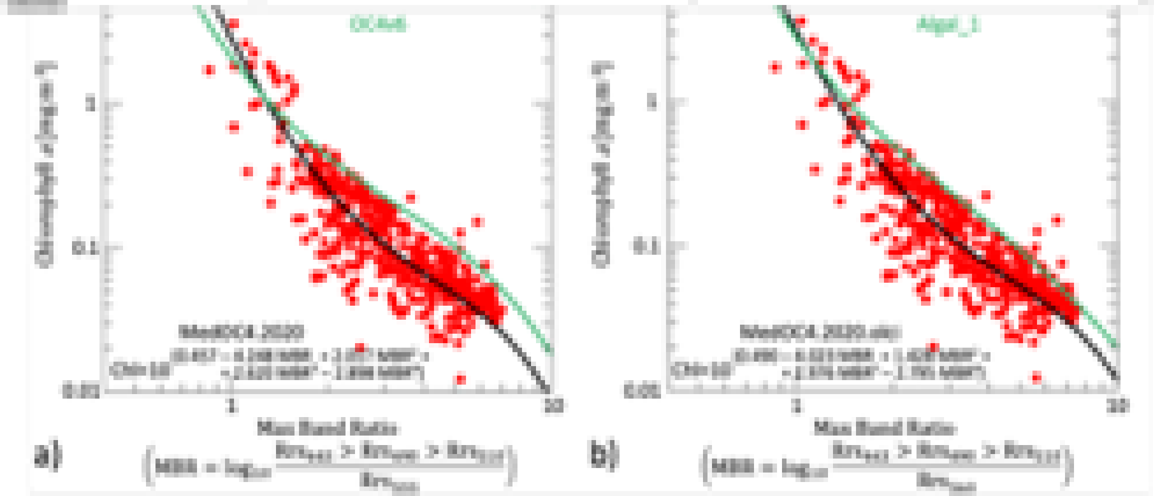
Mediterranean ocean colour Level 3 operational multi-sensor processing

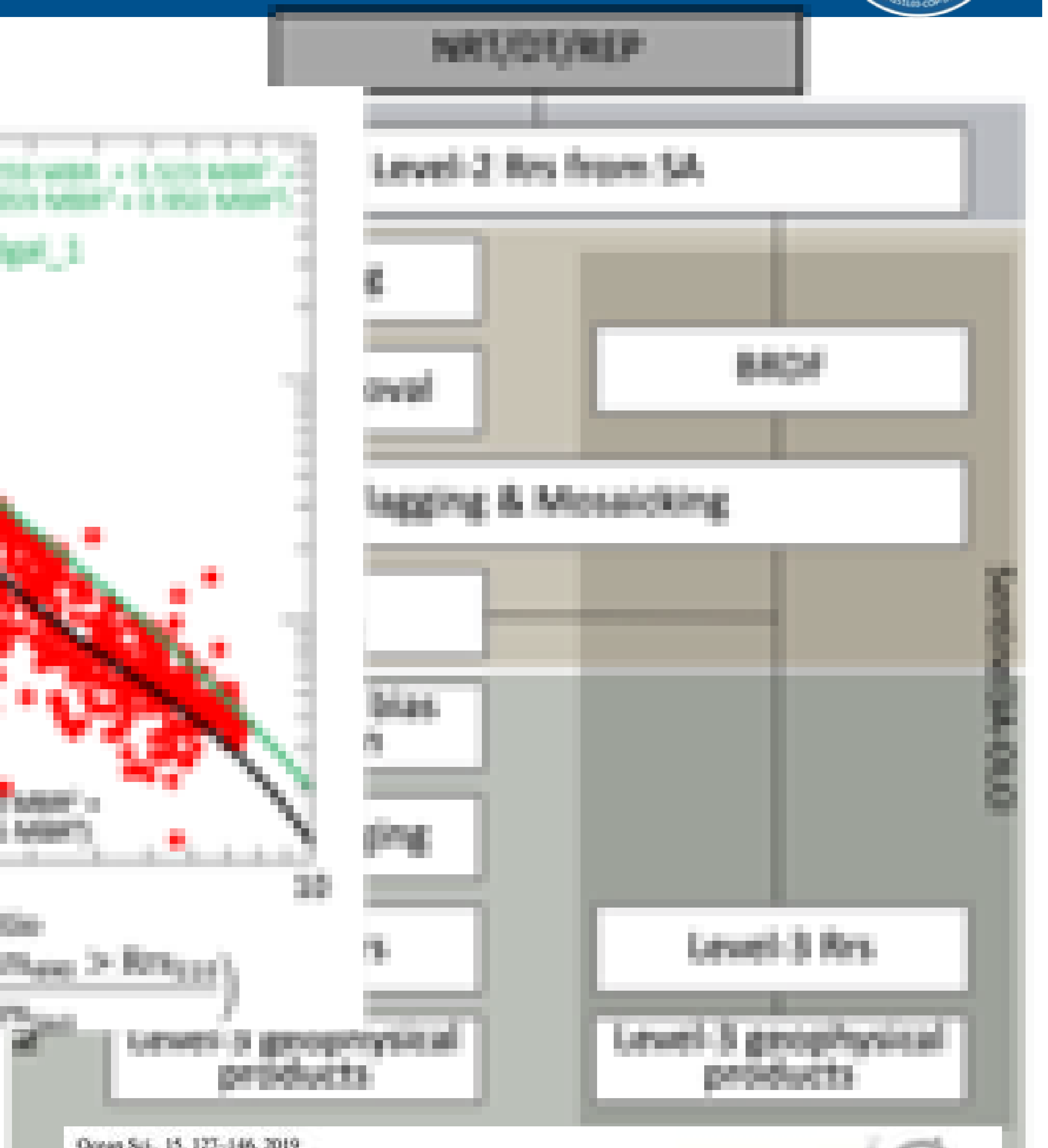
Gianluca Volpe[1], Simone Colella[1], Vittorio E. Brando[1], Vega Forneris[1], Flavio La Padula[1], Annalisa Di Cicco[1], Michela Sammartino[1], Marco Bracaglia[1,2], Florinda Artuso[3], and Rosalia Santoleri[1]

Mediterranean Sea

- **Mediterran**
  - Overall a
    >>>>>>>
  - merging
    wavelen
  - CHL and
    calculate
    algorithr
  - Merged
    algorithr







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Ocean Science EGU

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Mediterranean Sea

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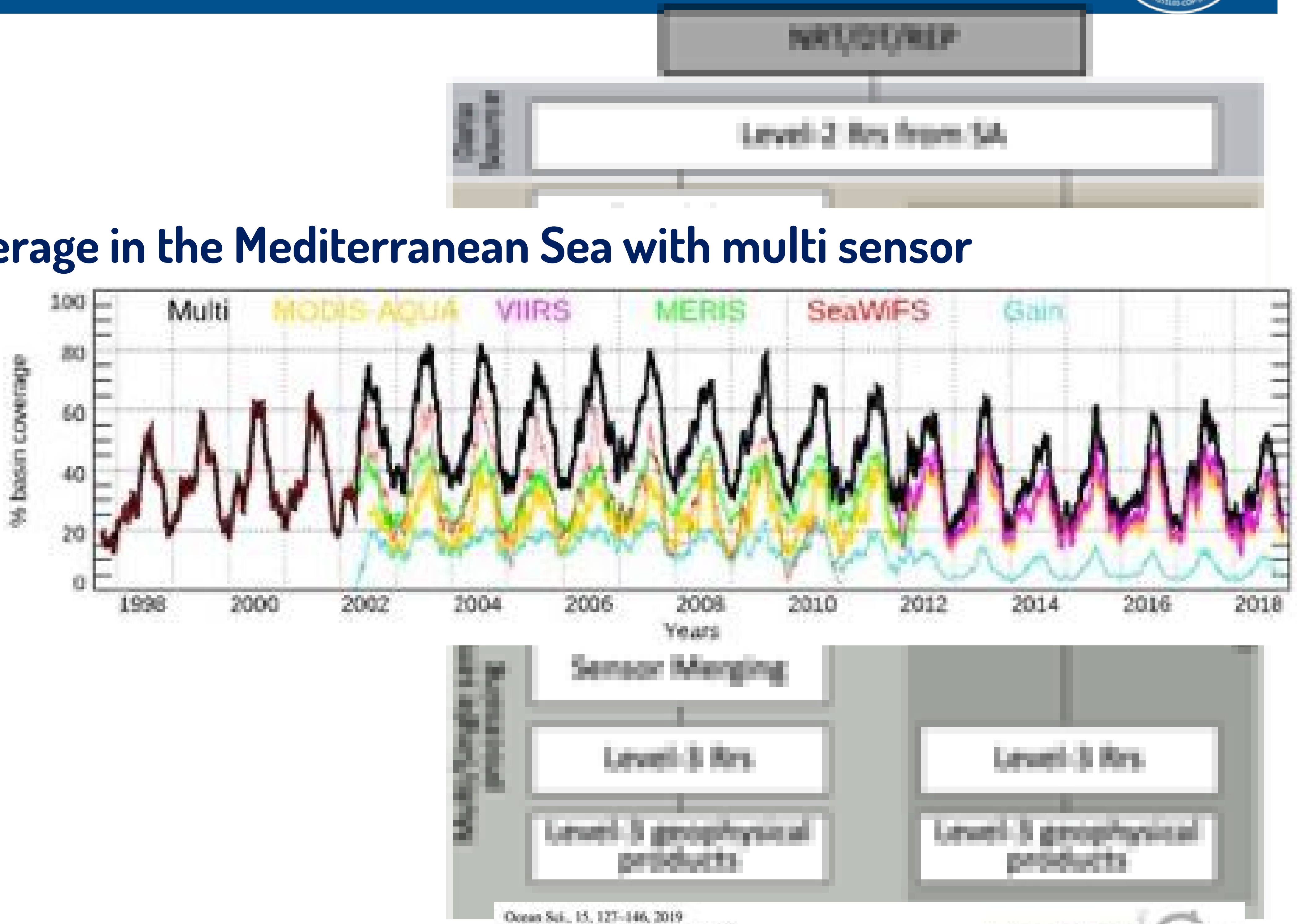
Basin coverage in the Mediterranean Sea with multi sensor

2018:



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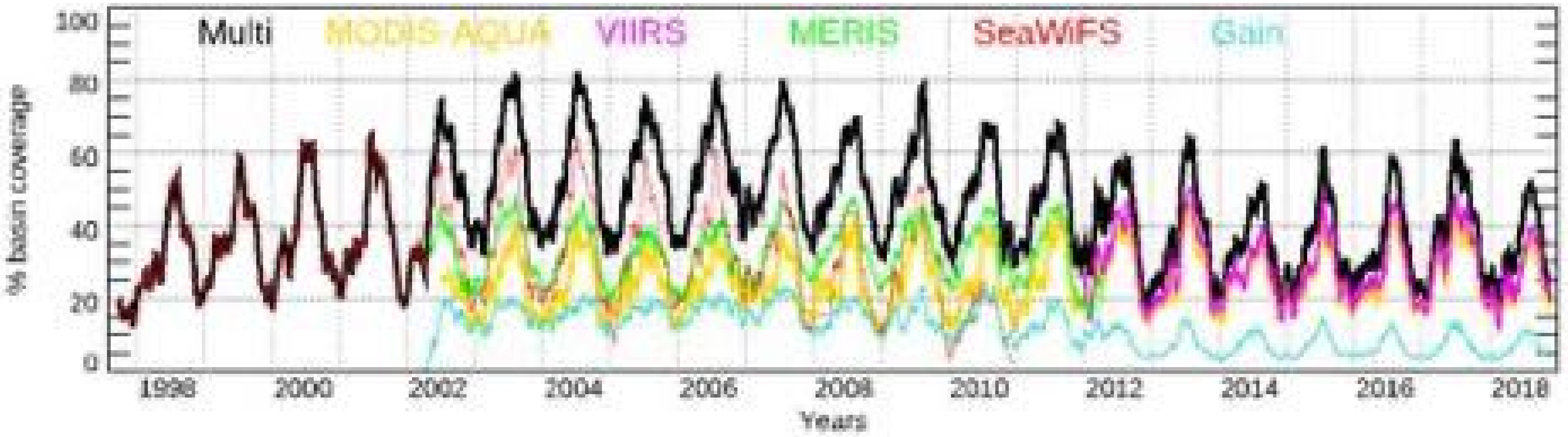
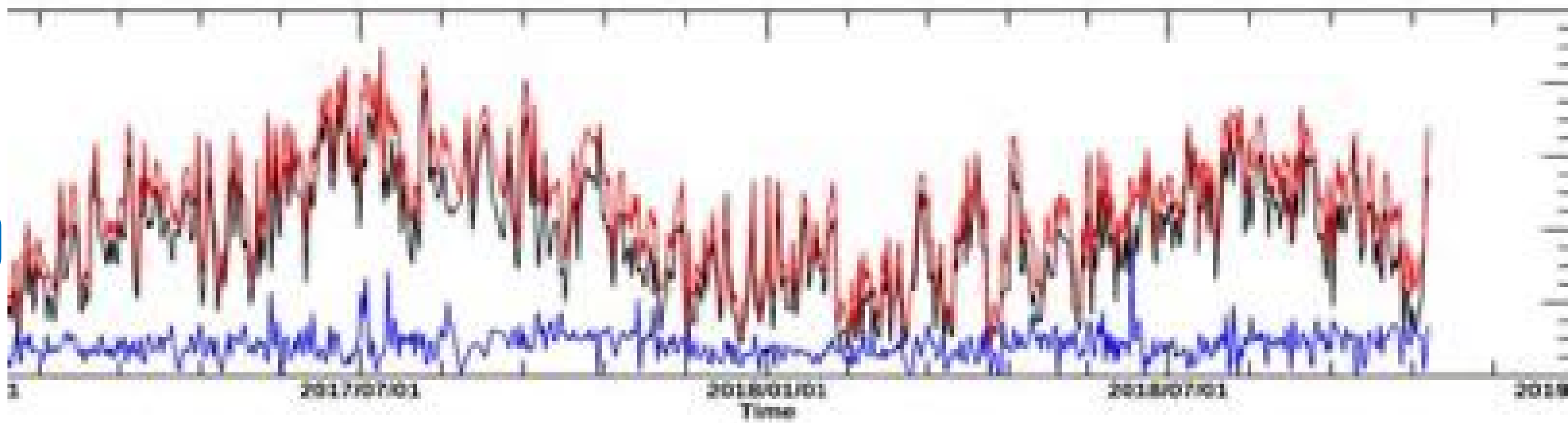
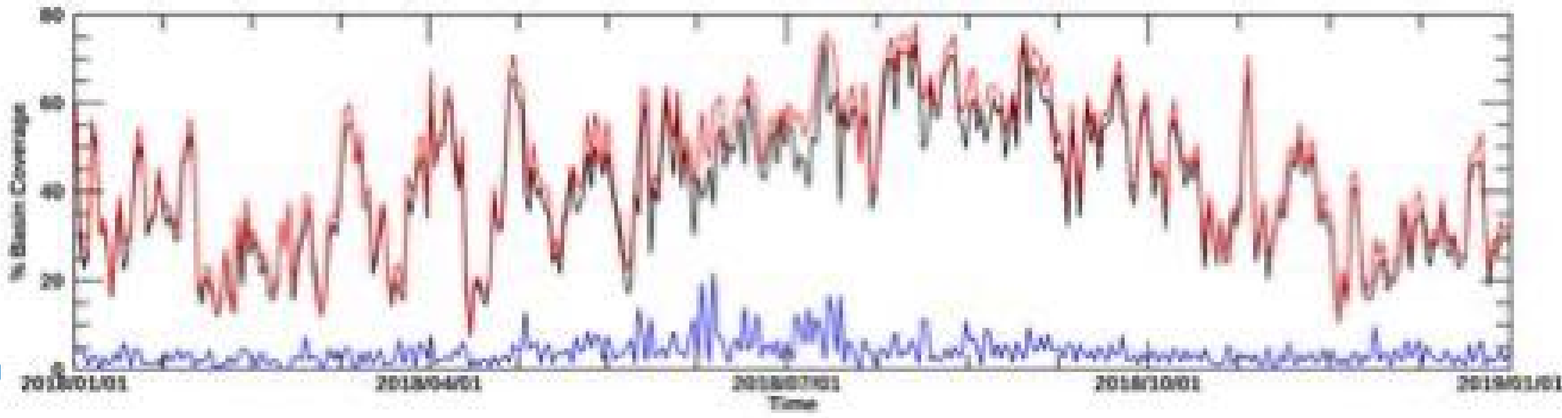


2019: OLCI-S3A (2016->)
in multisensor processor
- A+V - 3sensors - gain (~10%)



2020: NOAA20-VIIRS (2018->)
in multisensor processor
- A+V+O - 4sensors - gain (~4%)



Mediterranean Sea

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  - merging at common RRS wavelengths
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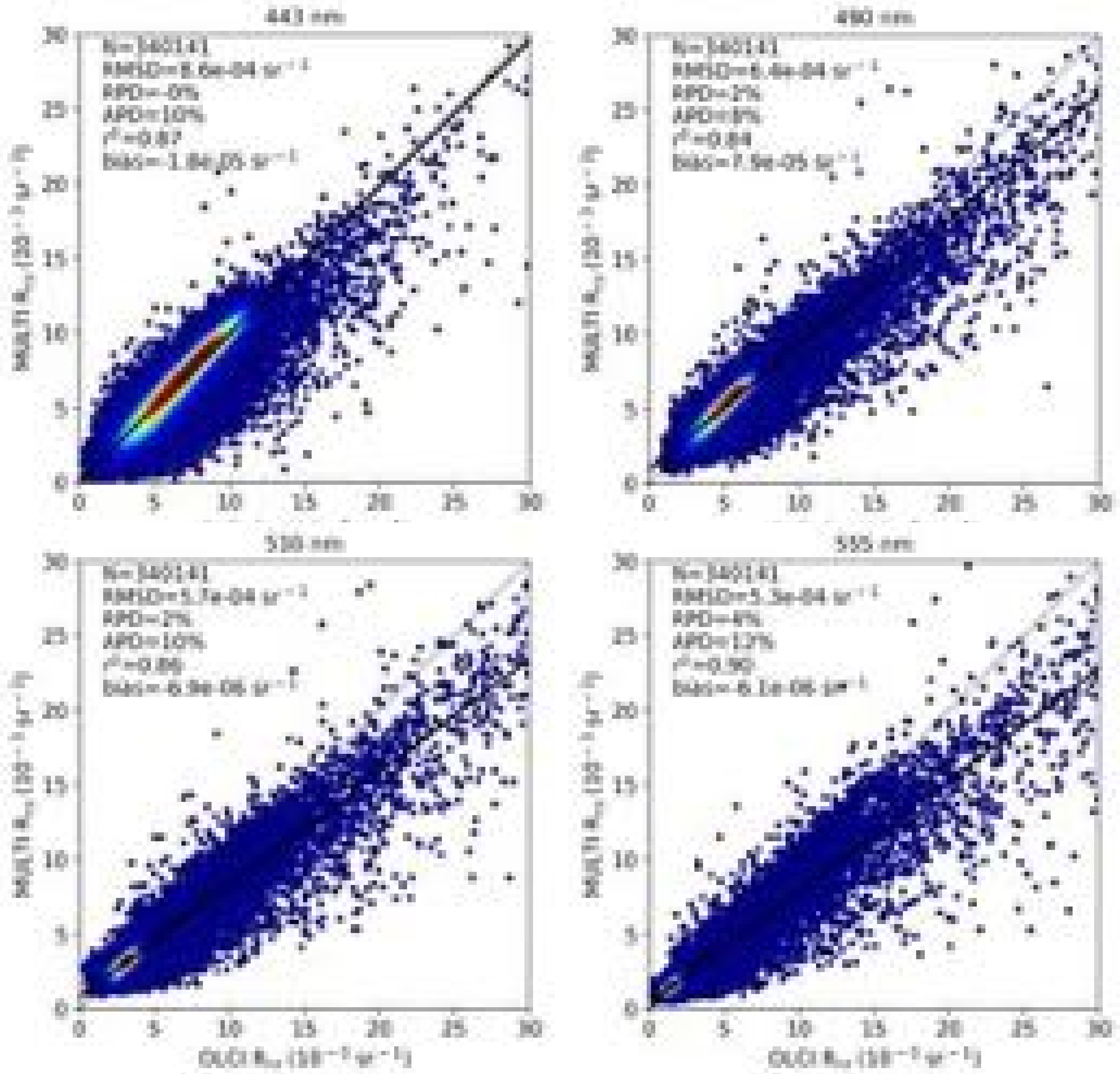
- Collocated OLCI and MULTI Rrs products well correlated (R^2: 0.84 - 0.90) for four Rrs bands used for CHL retrieval.
- CHL and Kd also well correlated (R^2: 0.92), with observed biases of -0.09 $mg.m^{-3}$) and -0.09 m^{-1}



Radiometric differences between the MULTI and OLCI datasets are mainly due to the absolute radiometric calibration of the reference sensor (SeaWifs for MULTI and S3A OLCI for the OLCI datasets), as well as other differences in processing chains, including atmospheric correction and flagging strategies.

Mediterranean Sea

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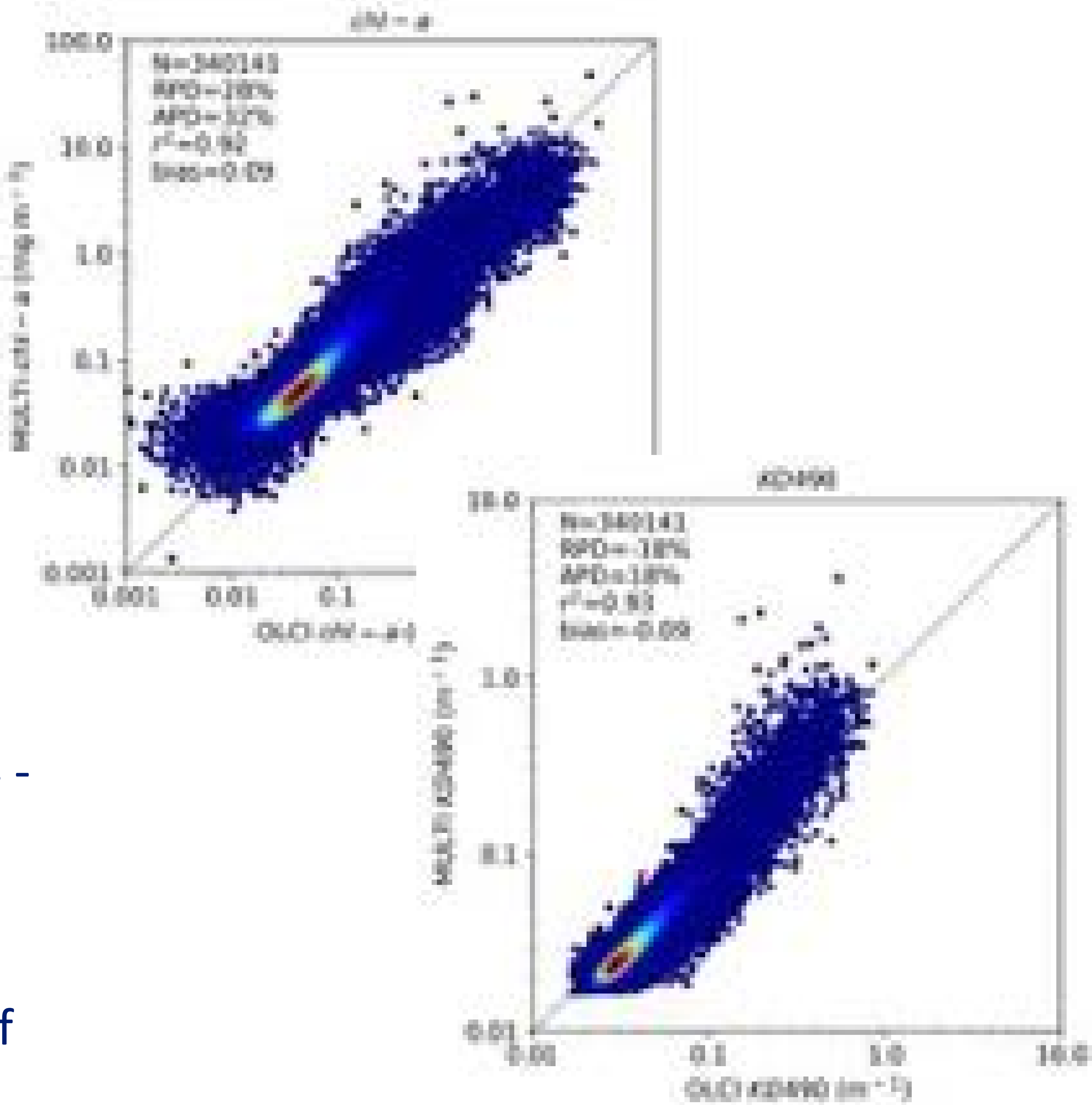

The observed bias for CHL between the OLCI and multi-sensor datasets is likely due to the propagation within the regional retrieval algorithms of the radiometric differences

The small radiometric differences between the datasets and hence in CHL and K_d and are likely to be minimised when it will be possible to adopt S3A OLCI as the reference sensor for the multi-sensor dataset at 1km spatial resolution.

Arctic chlorophyll

- **Arctic CHL** is retrieved by a new regional algorithm: **“CIAO (Chlorophyll In the Arctic Ocean)”. ML model** based on the combination of:
  - log(Rrs(443, 490, 510, 560))
  - day of the year: accounting for seasonal variability of the bulk phytoplankton community and/or to associated uncertainties in atmospheric correction (due to solar zenith angle and differences in aerosol content)


Contents lists available at ScienceDirect

Science of Remote Sensing

journal homepage: www.sciencedirect.com/journal/science-of-remote-sensing

CIAO: A machine-learning algorithm for mapping Arctic Ocean Chlorophyll-a from space

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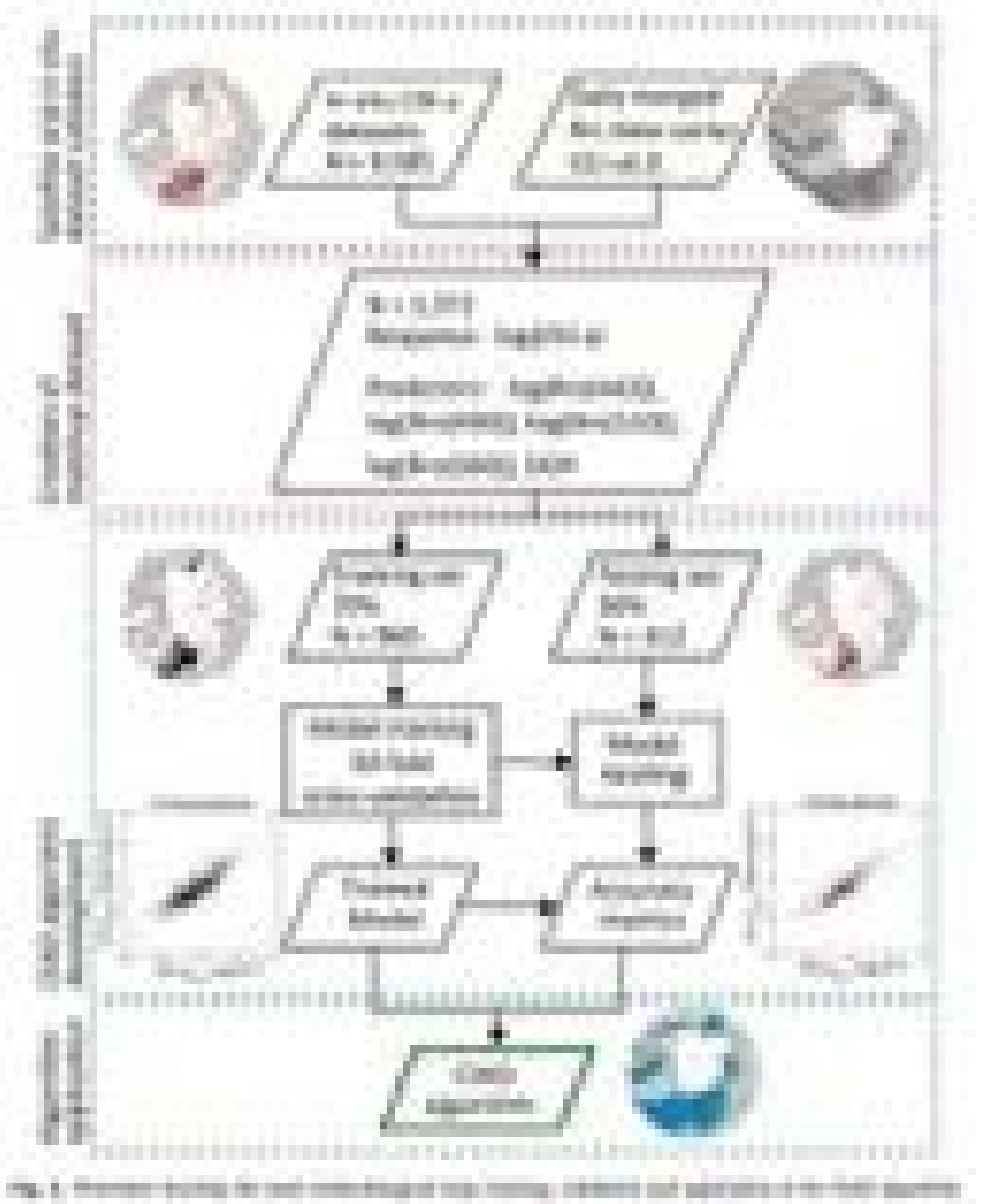
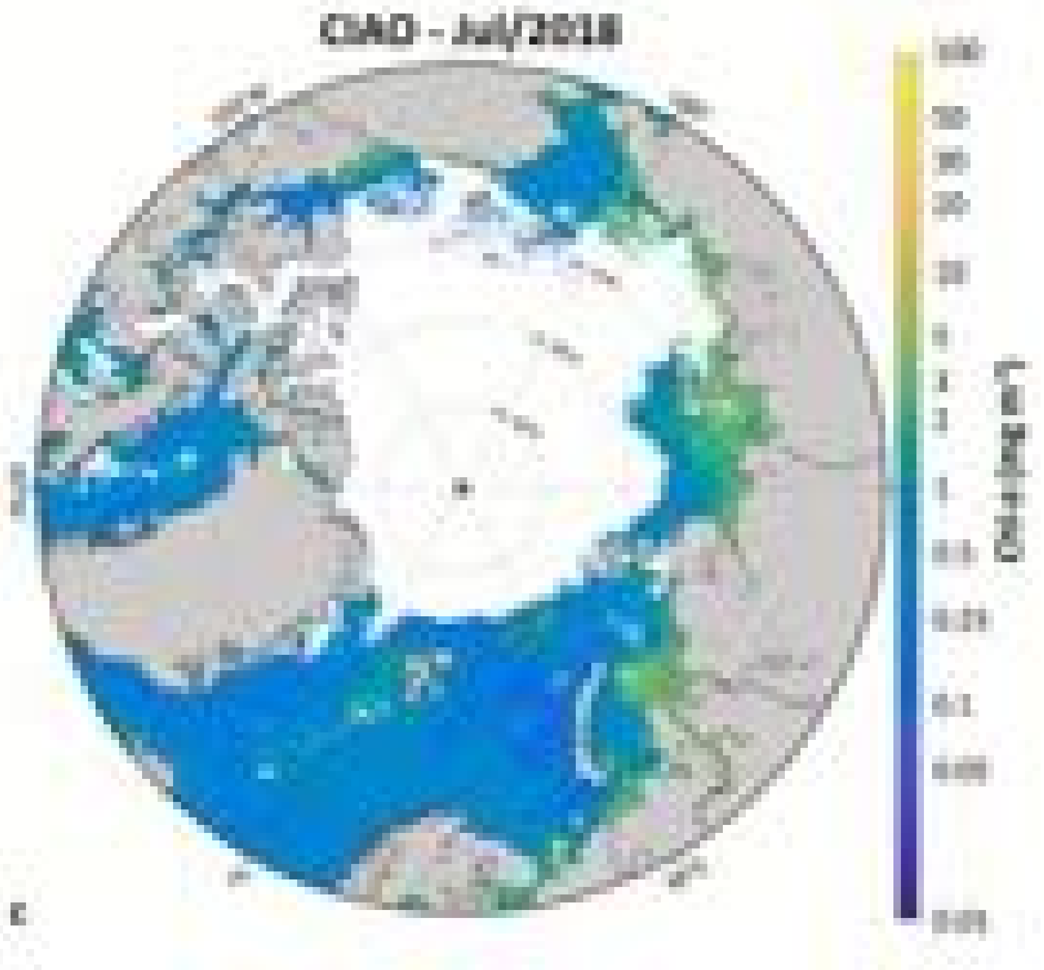


Arctic chlorophyll

Copernicus Marine Service

- **Arctic CHL** is retrieved by a new regional algorithm: **"CIAO (Chlorophyll In the Arctic Ocean)". ML model** based on the combination of:
    - log(Rrs(443, 490, 510, 560)
    - day of the year: accounting for seasonal variability of the bulk phytoplankton community and/or to associated uncertainties in atmospheric correction (due to solar zenith angle and differences in aerosol content)
- The CHL retrievals for OLCI at 300 m spatial resolution and OC-CCI v6 MULTI at 4km resolution are well correlated (r^2: 0.91) and very consistent (bias of 0.02 $ug.L^{-1}$, RPD: 10%).



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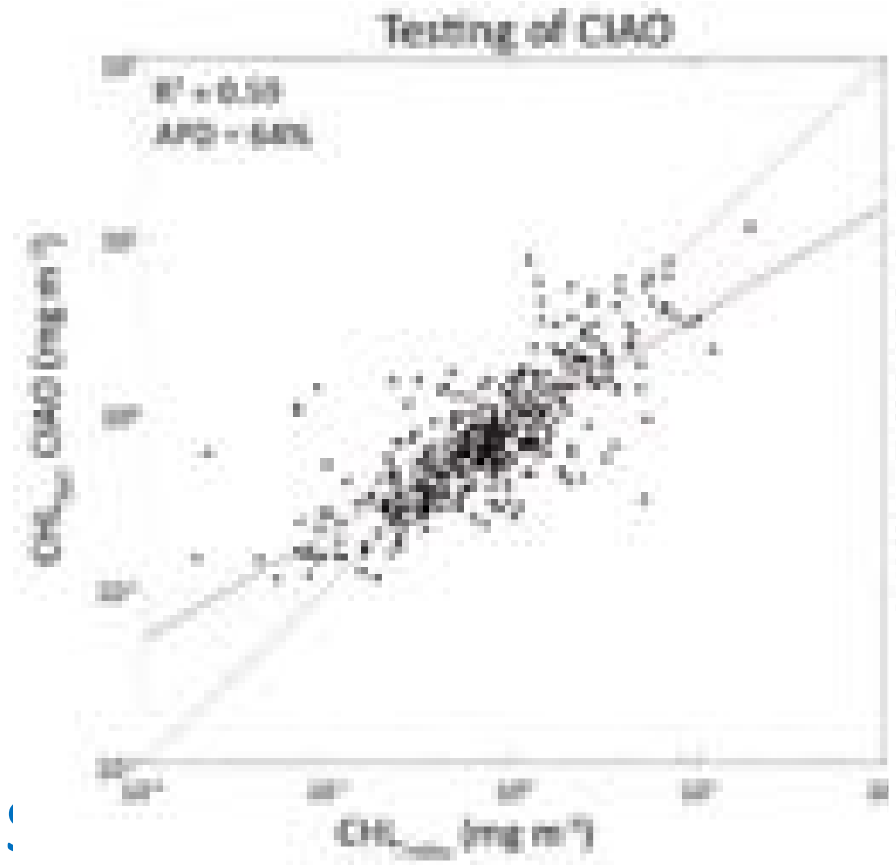
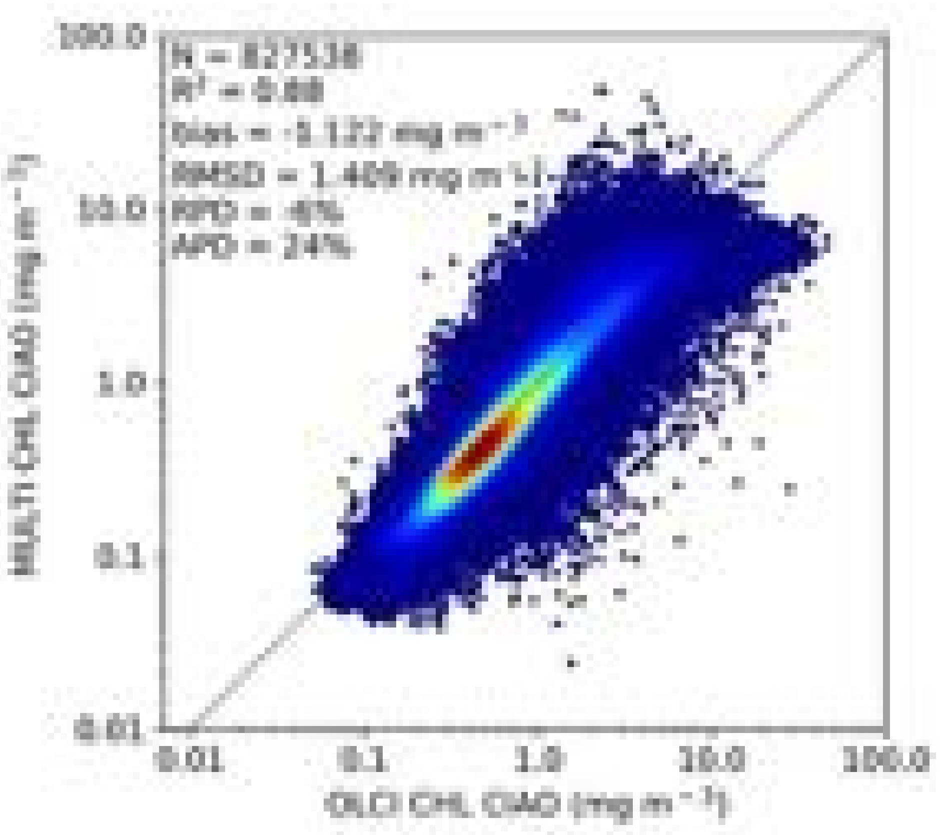




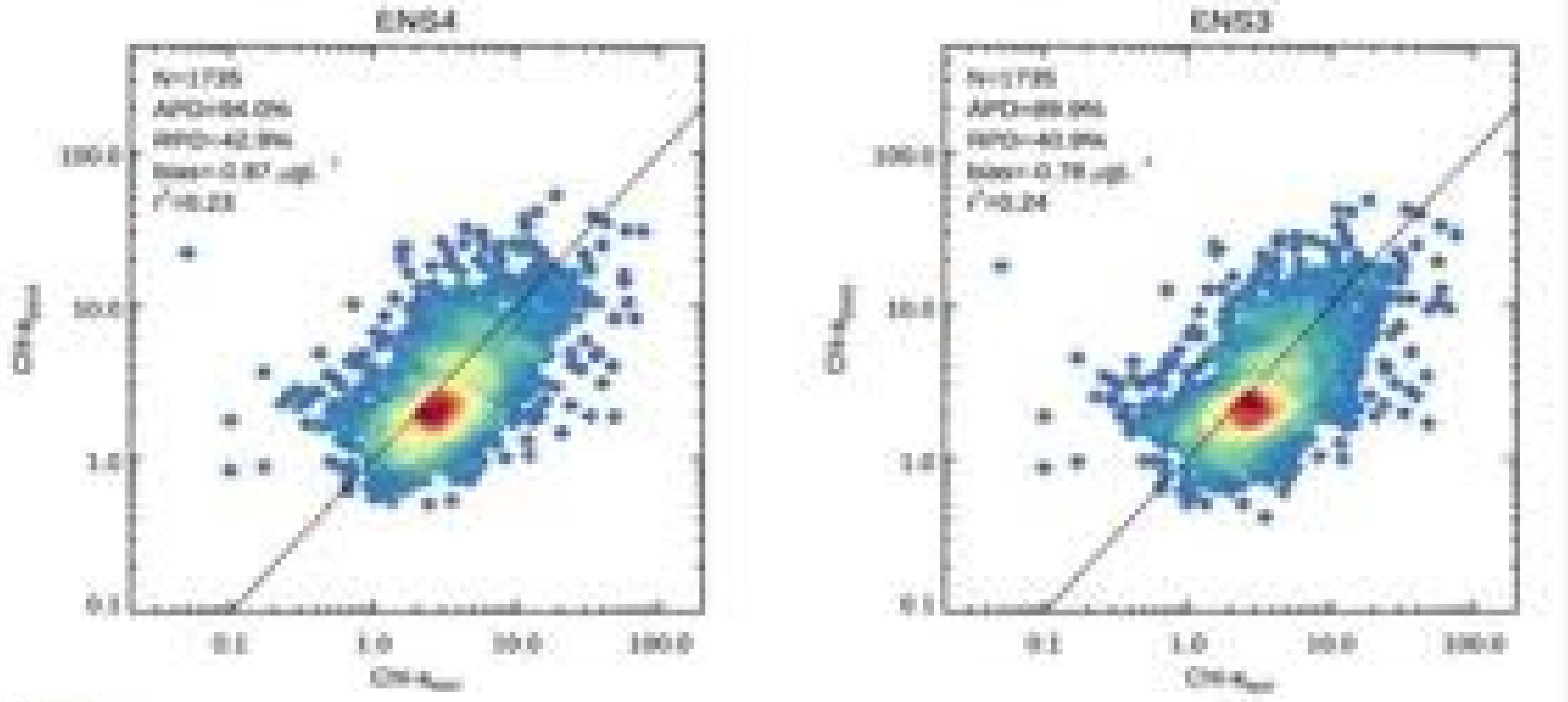
Copernicus Marine Service

(2021-2022)

MY: Multi-sensor

Ensemble of Multilayer Perceptron (MLP) neural nets, accounting for optical complexity.

(input OC-CCI v4.2 R_{rs} values at 412, 443, 490, 510, 555 and 670 nm)



remote sensing MDPI

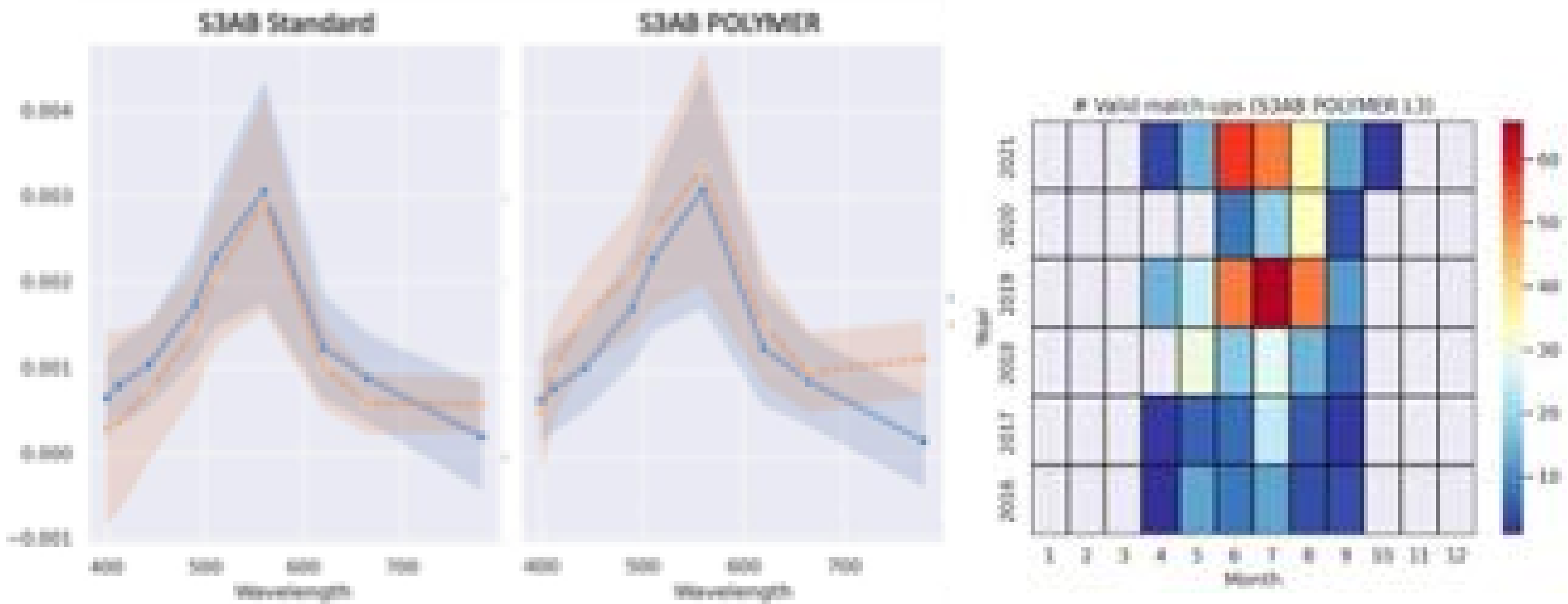
Article

Phytoplankton Bloom Dynamics in the Baltic Sea Using a Consistently Reprocessed Time Series of Multi-Sensor Reflectance and Novel Chlorophyll-a Retrievals

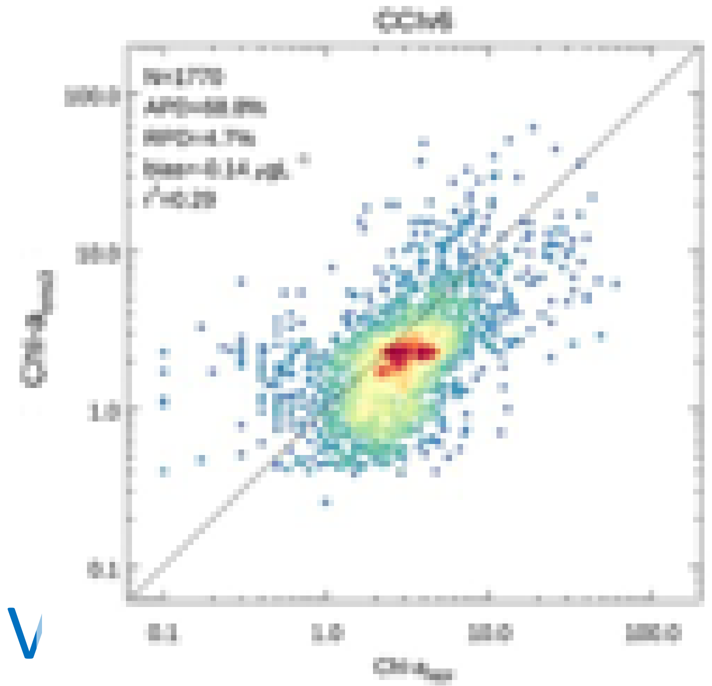
Vittorio E. Brando, Michela Sammartino, Simone Colella, Marco Bracaglia, Annalisa Di Cicco, Davide D'Alimonte, Tamito Kajiyama, Seppo Kaitala and Jenni Attila

NRT+MY: Sentinel 3A&B OLCI

1. Ad hoc L1 to L2 processing using POLYMER



1. MLP ensemble adapted to OLCI bands



CNR ISMAR

Venice International University

Baltic Sea

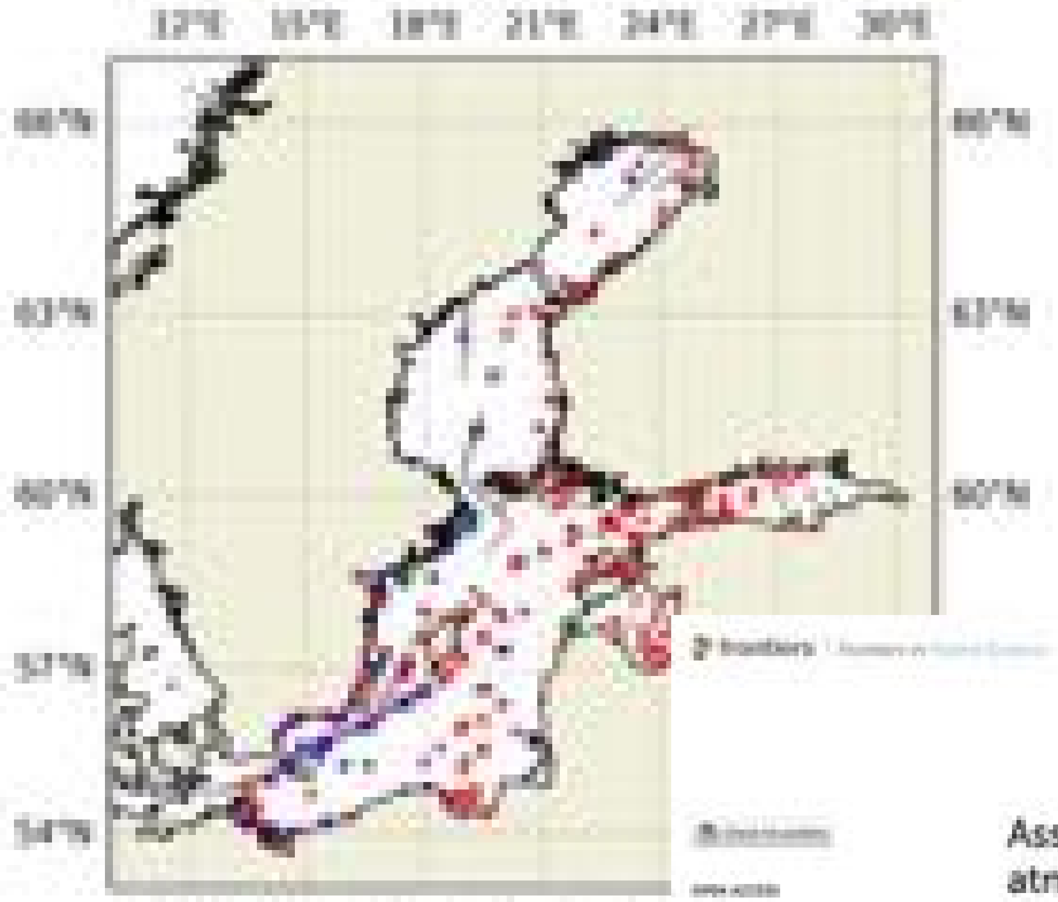
(2024)

MY: Multi-sensor 1 KM

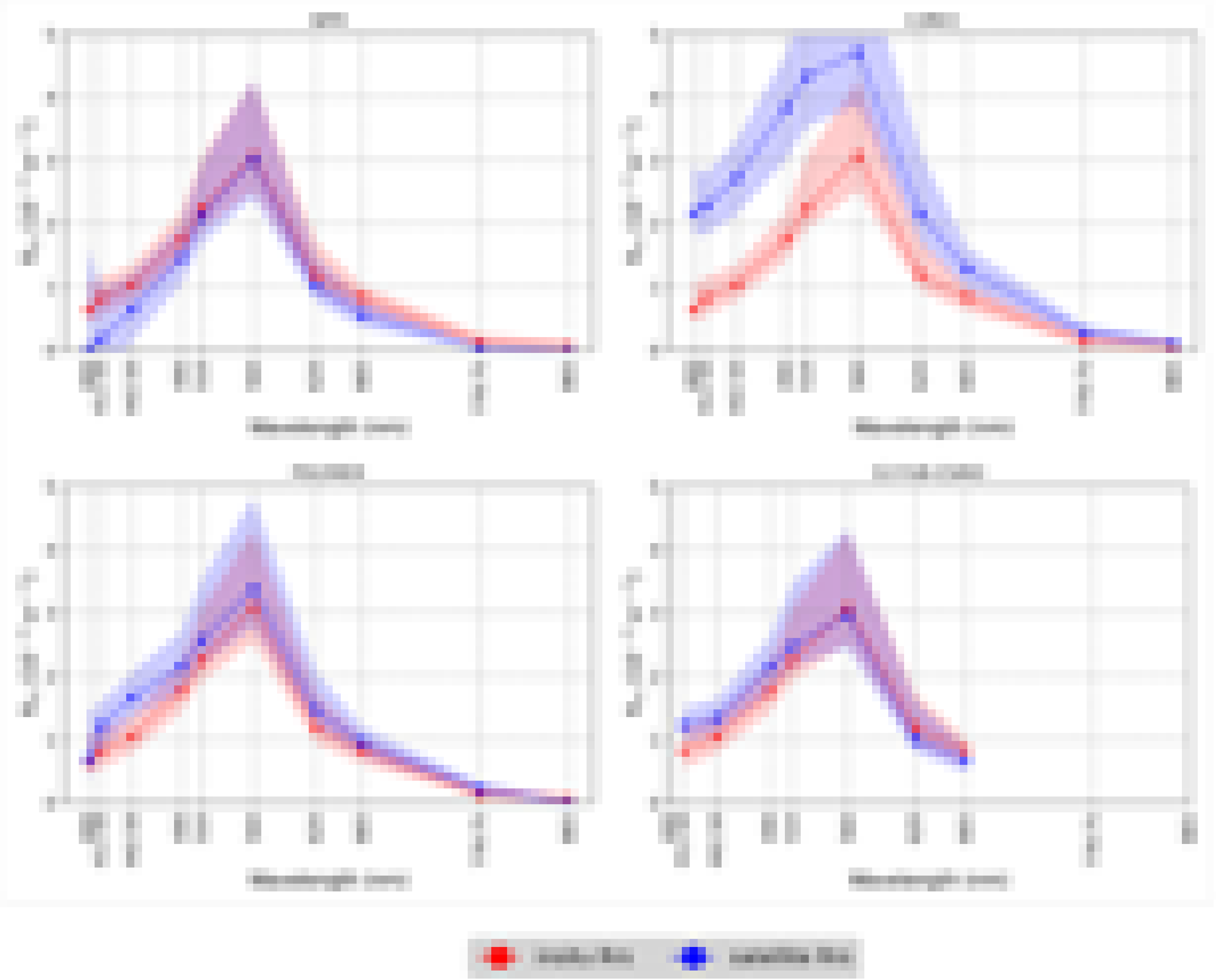
input OC-CCI v6 R_{rs} (412-670 nm)

NRT+MY: Sentinel 3A&B OLCI

1. Ad hoc L1 to L2 processing using POLYMER
2. MLP ensemble adapted to OLCI bands




Assessment of ocean color atmospheric correction methods and development of a regional ocean color operational dataset for the Baltic Sea based on Sentinel-3 OLCI



Comparison between in situ Rrs from AERONET-OC sites and OLCI level-2 Rrs obtained using four AC processors

Copernicus Marine Service

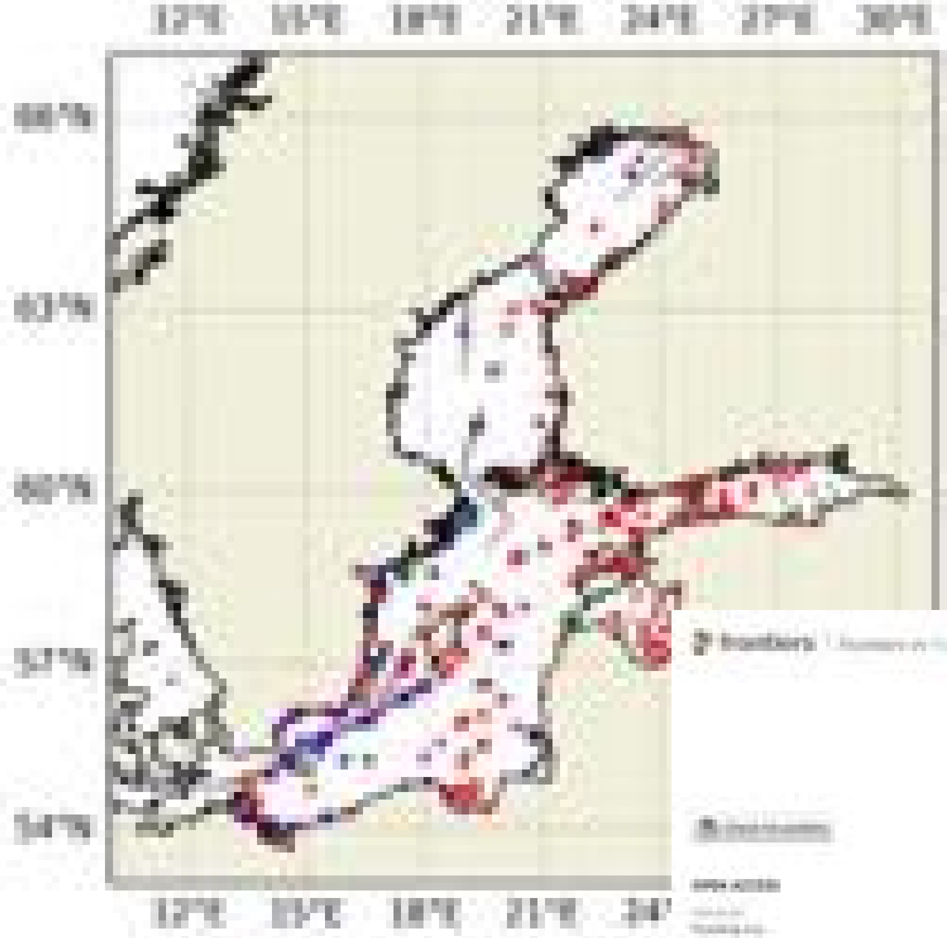
(2024)

MY: Multi-sensor 1 KM

input OC-CCI v6 R_{rs} (412-670 nm)

NRT+MY: Sentinel 3A&B OLCI

1. Ad hoc L1 to L2 processing using POLYMER
2. MLP ensemble adapted to OLCI bands

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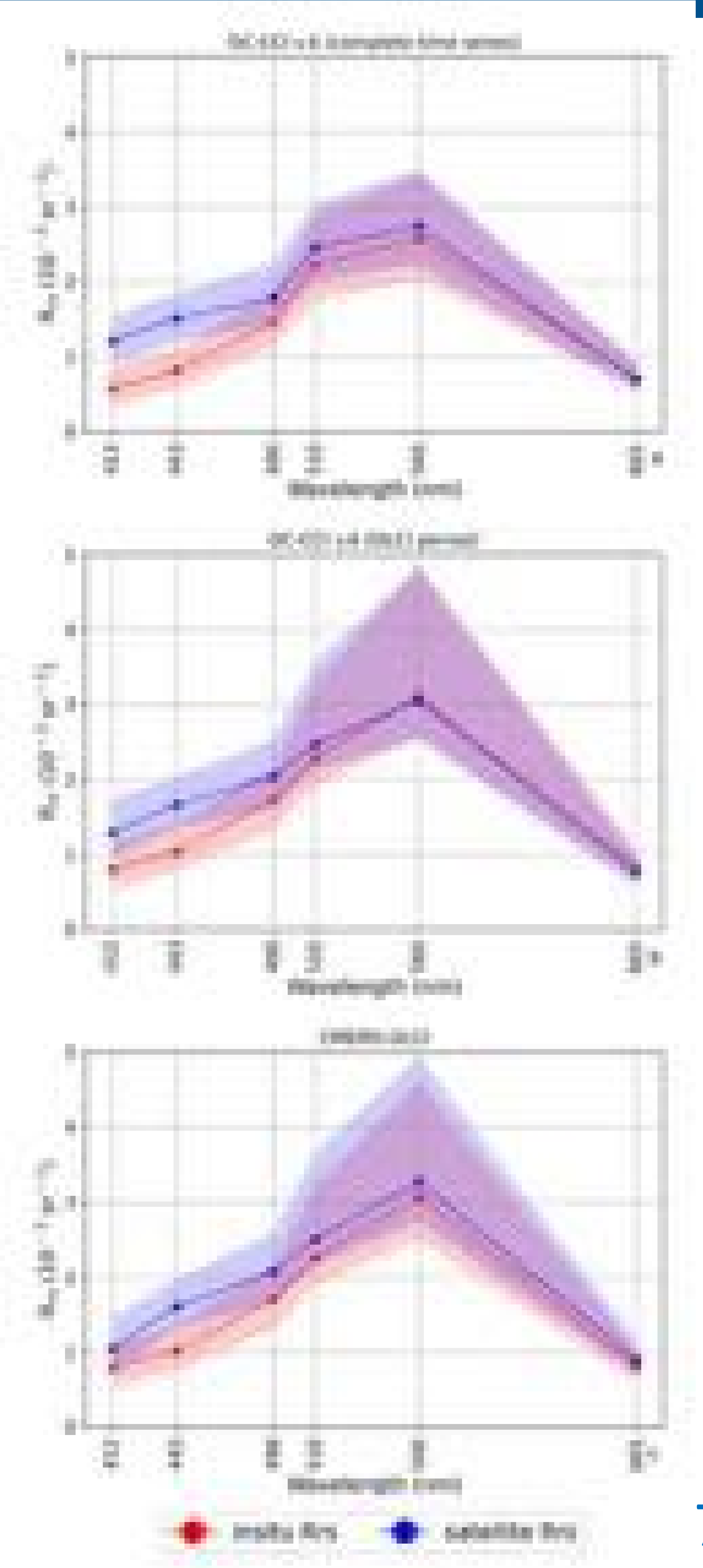
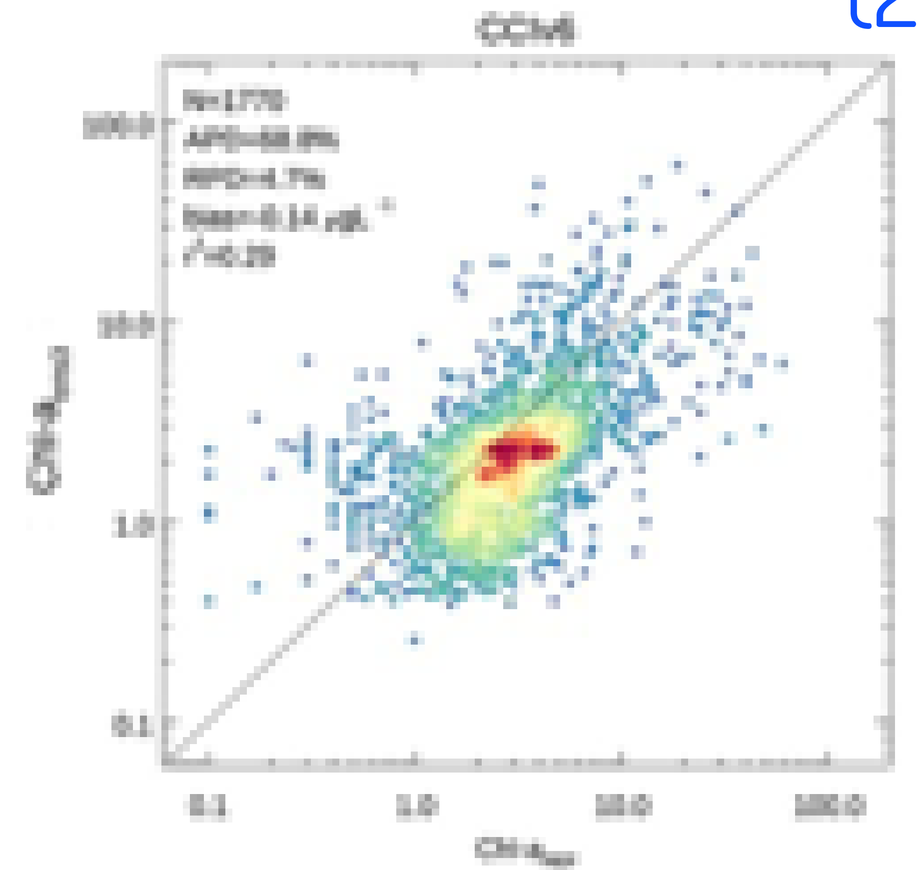
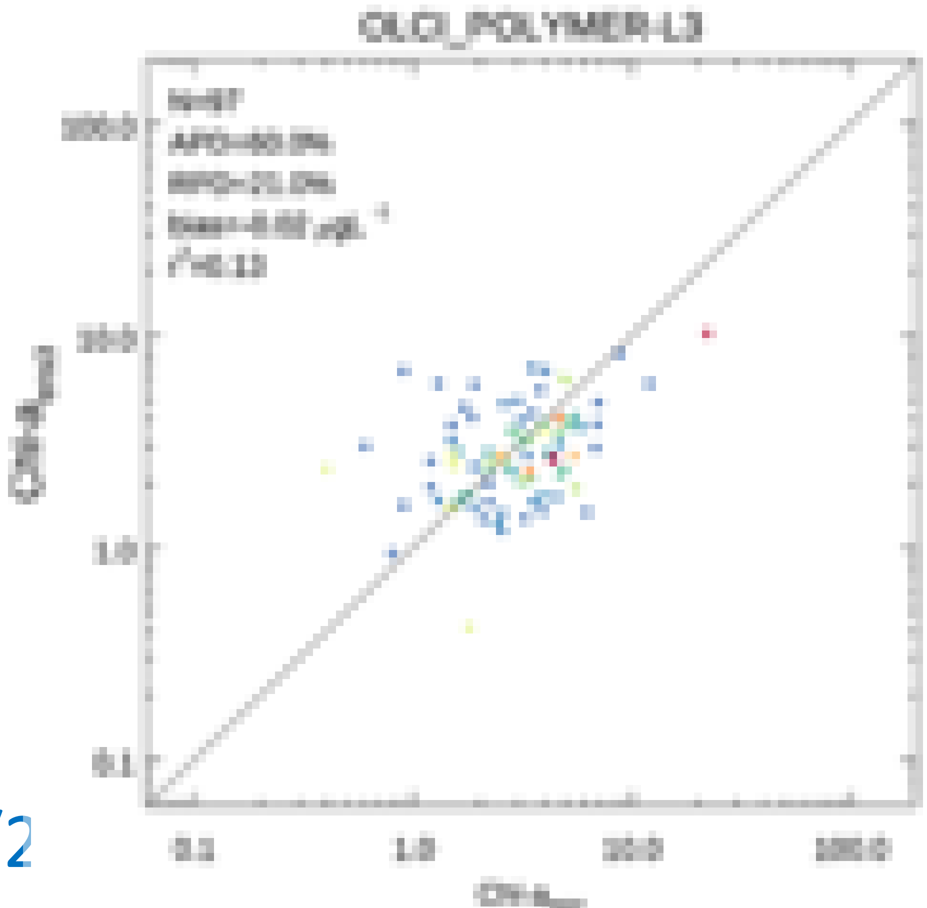






Baltic Sea

Copernicus Marine Service

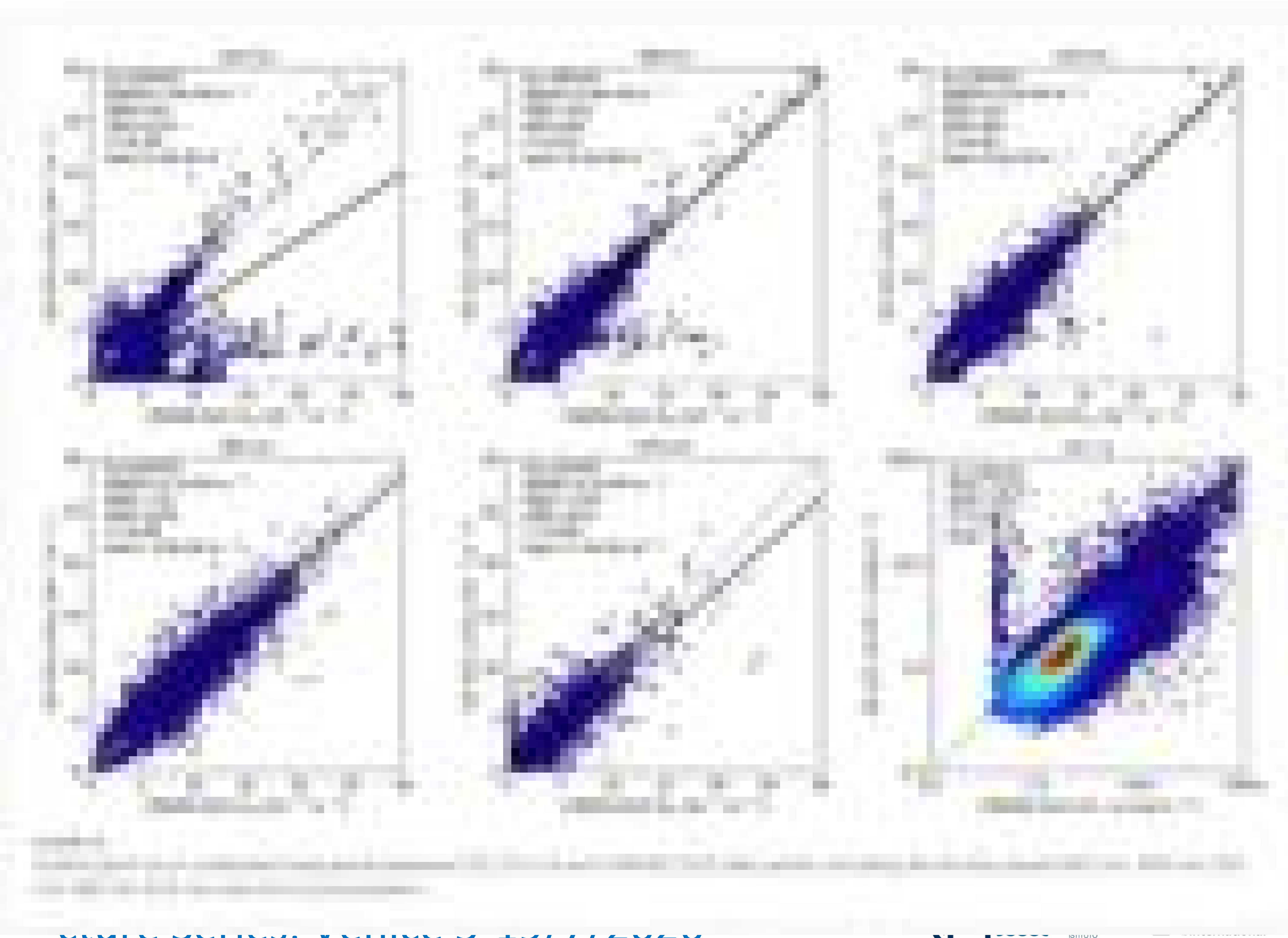
Comparison from co-located datasets

OLCI S3A+B 300m (X-axis) and **MULTI 1KM (Y-axis)**

Co-collocated OC-CCI v.6 and CMEMS-OLCI Rrs ar
well correlated data (0.90-0.94, except for 443 nn

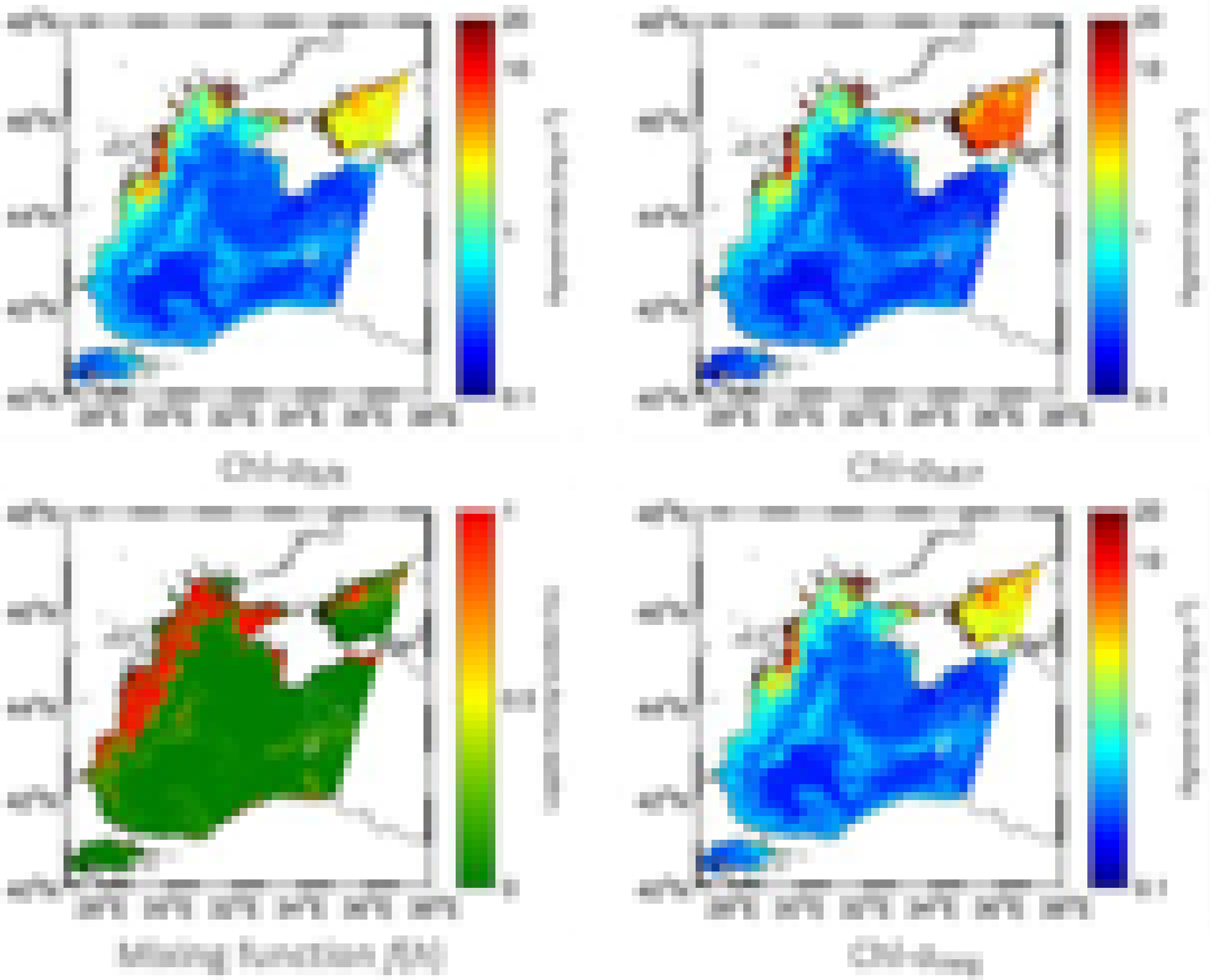
- outliers are possibly related to the resolution and coverage of both datasets.
- Rrs differences can be attributed to the specificities of data processing, including the atmospheric correction, and absolute radiometric accuracy of the reference sensor (MERIS for OC-CCI v.6 and OLCI for CMEMS-OLCI).

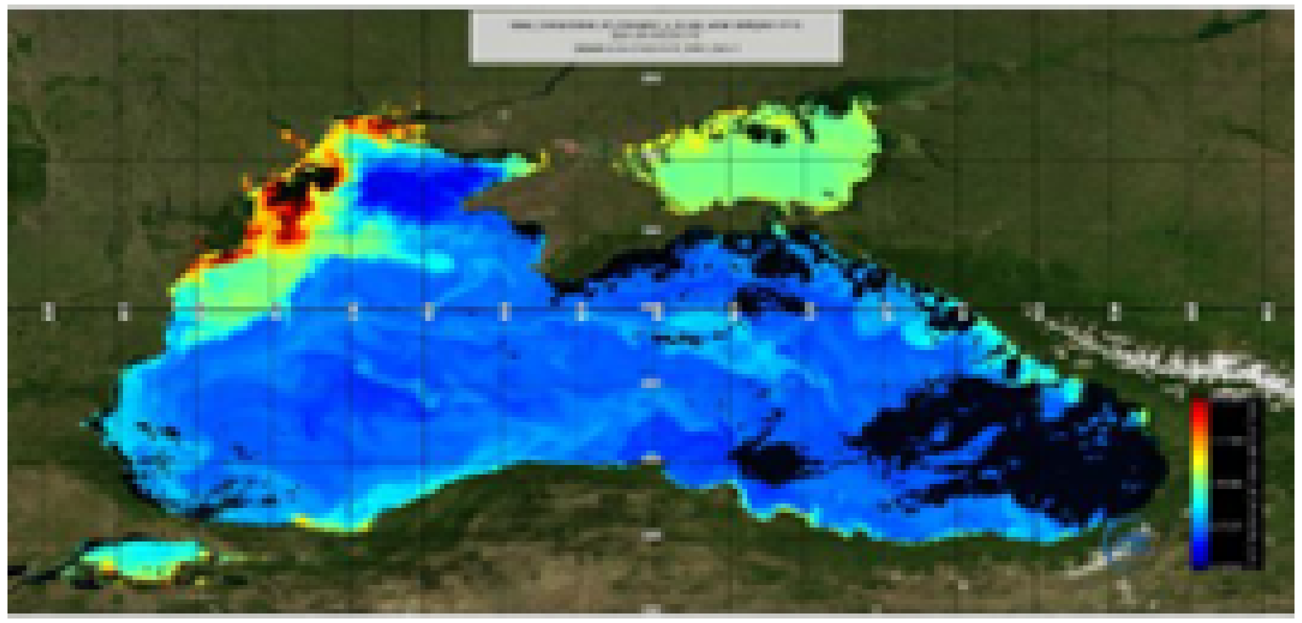
An overall good agreement was found in the comparison between chl-a retrievals from CMEMS OLCI and OC-CCI v.6, with a tendency of CMEMS-OLCI toward higher chl-a values.



Black Sea

- **Black Sea CHL** retrieved merging of two different regional algorithms
  - a band-ratio (B/R)
  - Multilayer Perceptron (MLP) neural net, accounting for optical complexity.
  - reduces the Chl-a overestimation of the B/R algorithm
  - broadens the range of applicability of the MLP neural net.
- Collocated OLCI and MULTI products well correlated (R^2: 0.95) for three Rrs bands (490-555nm) used for CHL retrieval.
- Radiometric differences between OLCI and MULTI due to absolute radiometric calibration of reference sensor (OLCI vs SeaWIFS), AC and flagging.
- CHL and Kd also well correlated (R^2: 0.91), with observed bias in CHL (0.08 $mg.m^{-3}$) attributed to propagation of radiometric calibration differences.
- Adoption of Sentinel-3A as reference sensor in MULTI should minimise these issues (waiting for collection 4!)





Algorithms Merging for the Determination of Chlorophyll- a Concentration in the Black Sea

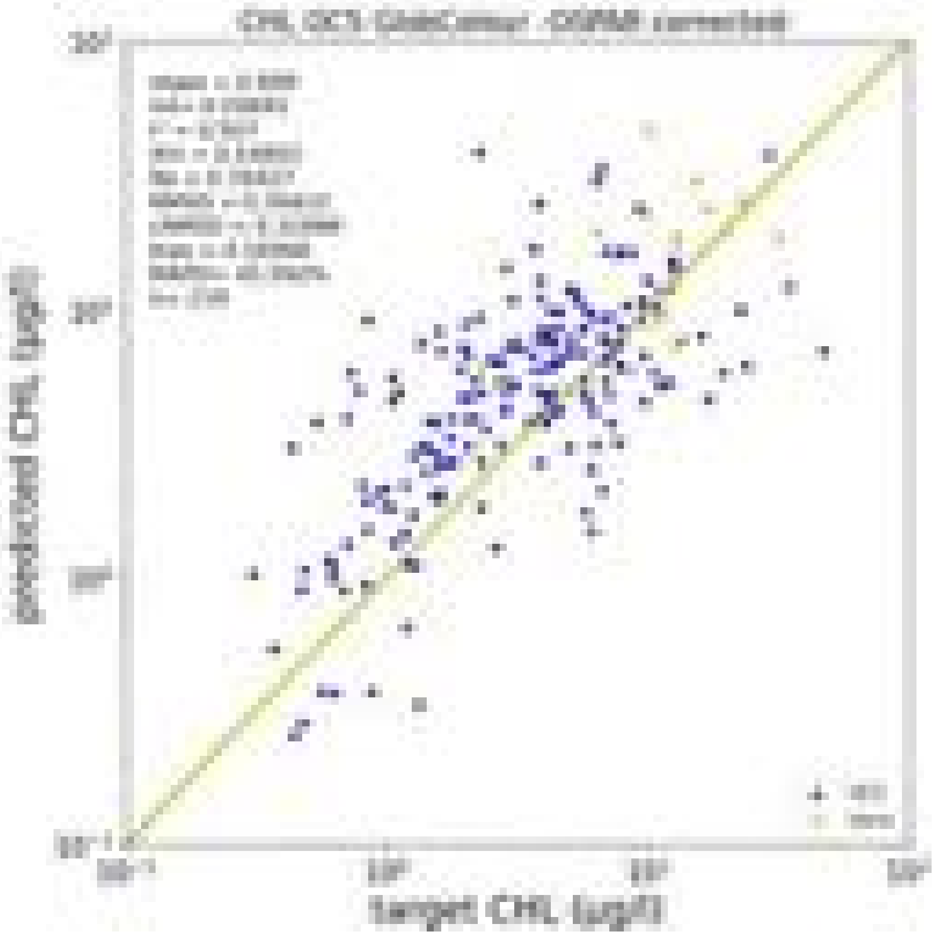
Publisher: IEEE Cite This PDF

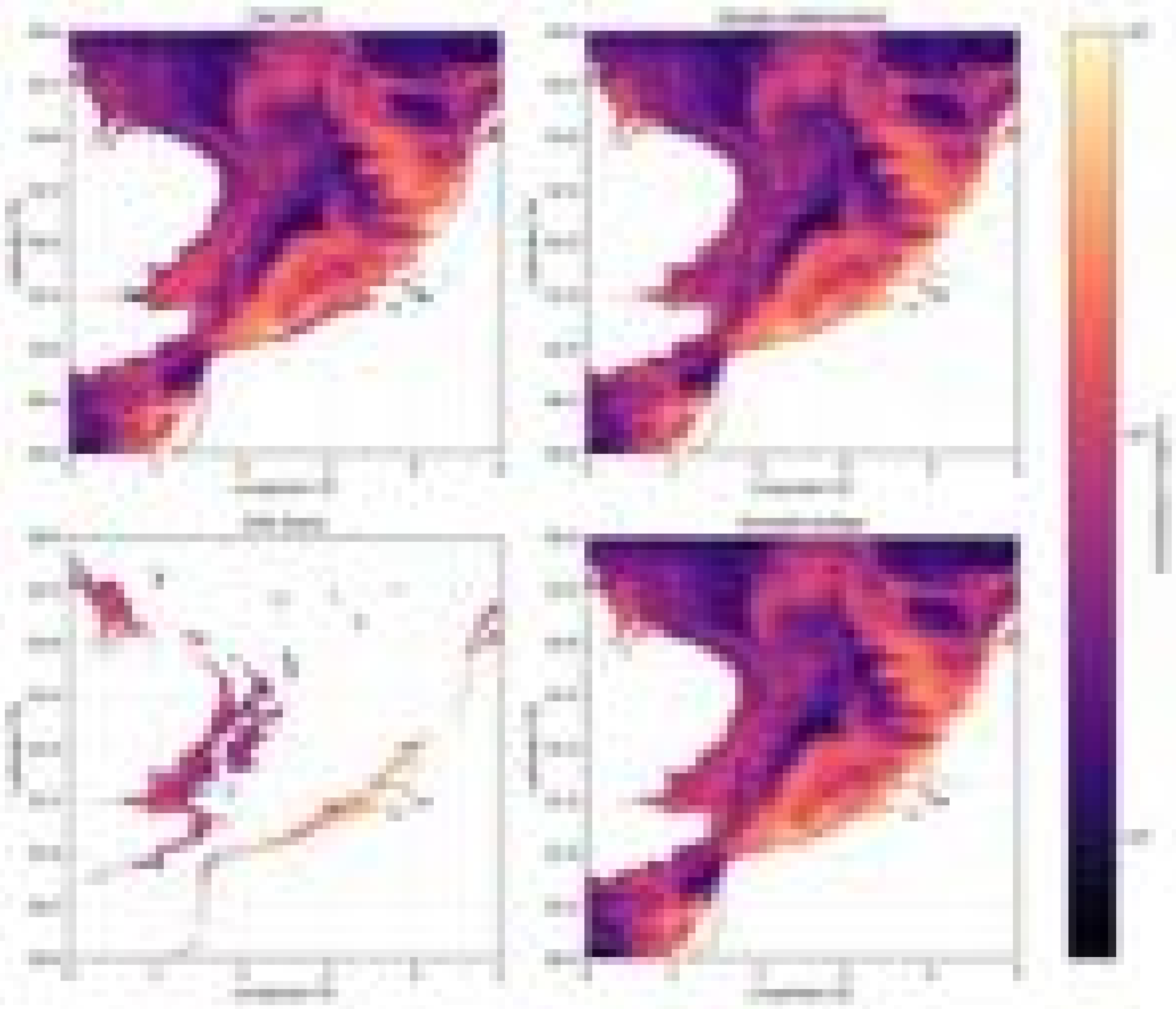
Tamito Kajiyama ; Davide D'Alimonte ; Giuseppe Zibordi **All Authors**

Atlantic CHL for OSPAR

The ATL products based on the Copernicus-GlobColour processor now include the approach of Lavigne et al., 2021 for CHL retrieval the coastal waters in the North Sea to be in line with the OSPAR requirements for eutrophication assessment (QSR).

Validation with CHL reference data used by relevant OSPAR groups.





L4 approaches

Regionalisation of processing chains takes into account the bio-optical characteristics of each regional sea.

	Arctic	Black Sea	Mediterranean Sea	Baltic Sea	Atlantic Ocean	Global	Global
L4M	CHL	CHL	CHL	CHL	CHL	CHL	CHL
L4D (gap-filled)	*N/A*	DINEOF-like Volpe et al., 2018	DINEOF-like Volpe et al., 2018	*N/A*	CHL Garnesson et al., 2019	CHL Garnesson et al 2019	*N/A*
L4 D all	*N/A*	Marchese et al., 2024	Marchese et al., 2024	*N/A*	*N/A*	*N/A*	*N/A*

L4 approaches

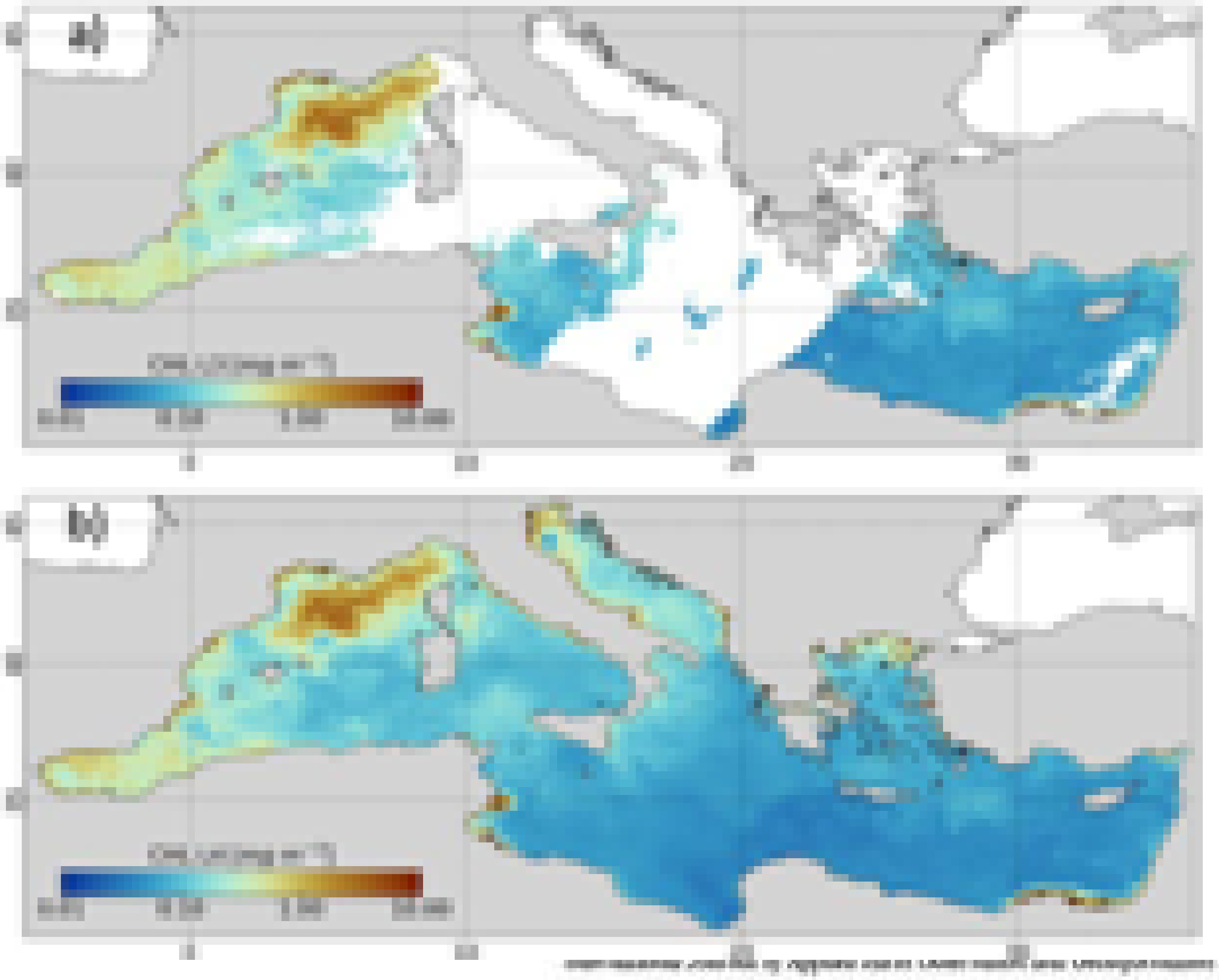
New gap-filled RRS and IOPs datasets in L4 for MED and BLK MULTI

currently across the catalogue we have only CHL as gap-filled L4 dataset in MULTI

DINEOF is used to interpolate multispectral Rrs to produce a consistent and gap-free L4 Rrs dataset.

This “upstream interpolation” method enables the introduction of all L3 datasets also in L4:

- Reflectance (6 bands)
- Plankton— CHL, PSC and PFTs
- Transparency
- Optics: IOPs



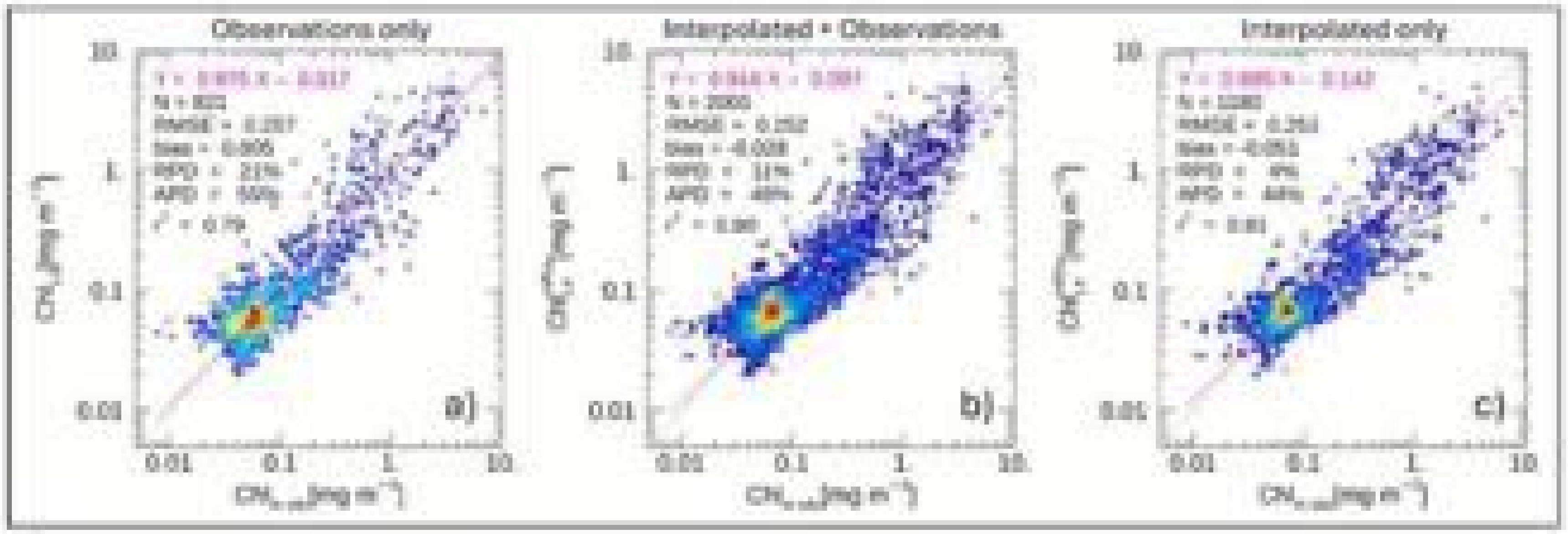
Contents lists available at ScienceDirect

International Journal of Applied Earth Observation and Geoinformation

journal homepage:

Towards accurate L4 ocean colour products: Interpolating remote sensing reflectance via DINEOF

Christian Marchese, Simone Colella, Vittorio Ernesto Brando, Maria Laura Zoffoli, Gianluca Volpe



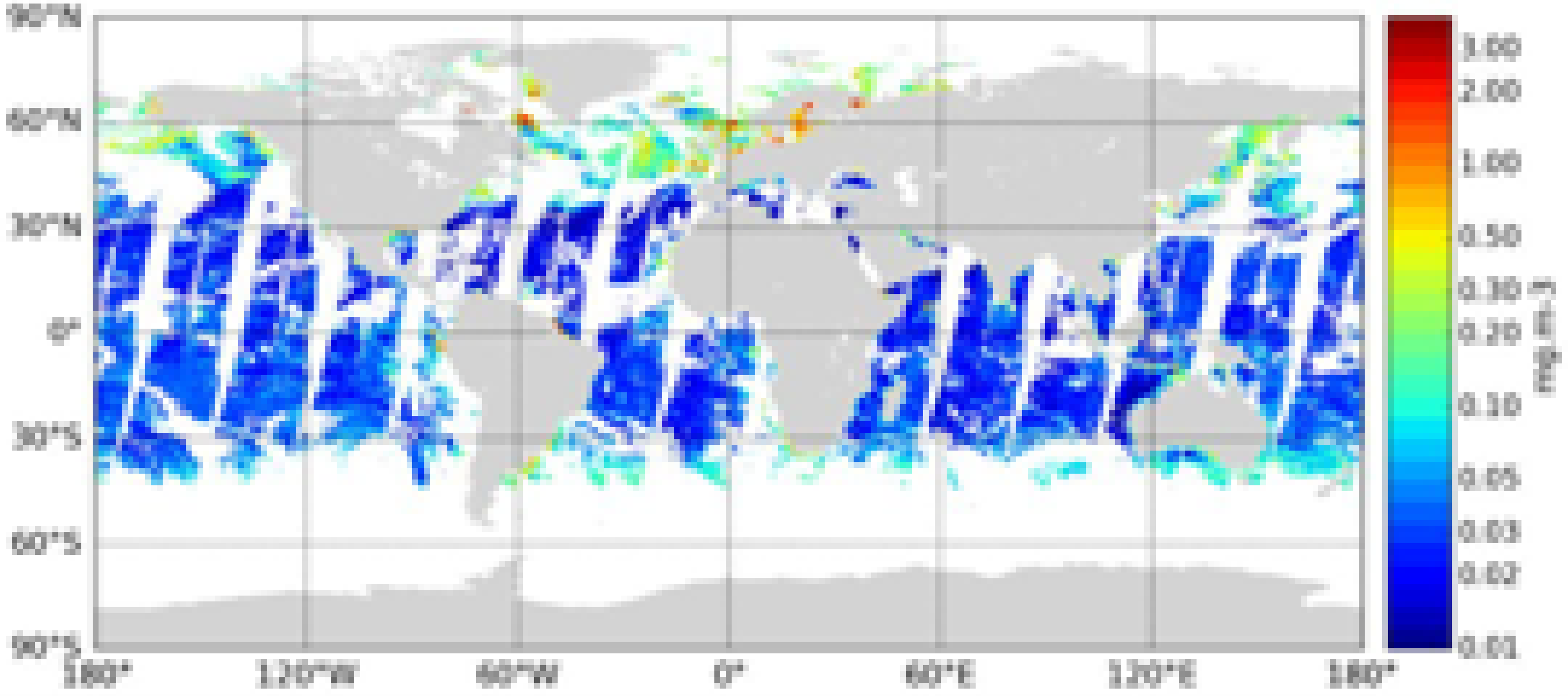
Beyond chlorophyll…

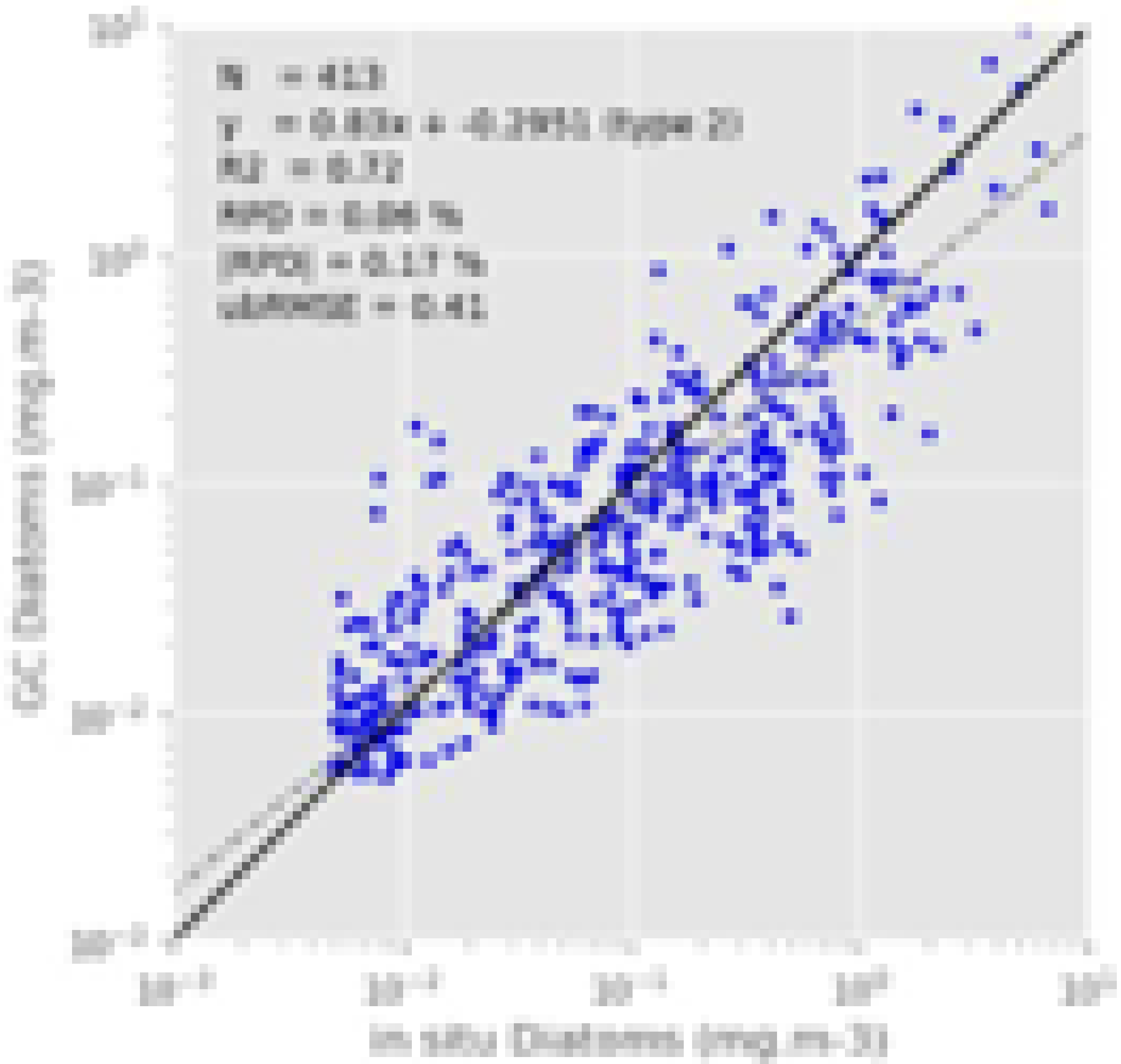
Regionalisation of processing chains takes into account the bio-optical characteristics of each regional sea.

	Arctic	Black Sea	Mediterranean Sea	Baltic Sea	Atlantic Ocean	Global	Global
PSCs	MICRO, NANO, PICO	MICRO, NANO, PICO	MICRO, NANO, PICO	MICRO, NANO, PICO	MICRO, NANO, PICO	MICRO, NANO, PICO	MICRO, NANO, PICO
PFTs	DIATO, DINO, GREEN, HAPTO, PROCHLO, PROKAR	*N/A*	CRYPTO, DIATO, DINO, GREEN, HAPTO, PROKAR	CRYPTO, DIATO, DINO, GREEN, PROKAR	DIATO, DINO, GREEN, HAPTO, PROCHLO, PROKAR	DIATO, DINO, GREEN, HAPTO, PROCHLO, PROKAR	*N/A*
PSC/PFT algorithm	Palamara et al., in prep.	Di Cicco et al., in prep.	Di Cicco et al., 2017, 2025	Gonzalez Vilas et al., in prep.	Xi et al. (2020, 2021) + GLOPHYTS (Xi et al., 2025)	Xi et al. (2020, 2021) + GLOPHYTS (Xi et al., 2025)	Brewin et al. 2015
PP algorithm	N/A	Colella et al., 2026 (OSR10)	Colella et al., 2026 (OSR10)	Colella et al., 2026 (OSR10)	Antoine and Morel (1996)	Antoine and Morel (1996)	*N/A*

Chlorophyll a concentration of Phytoplankton Functional Types (GLO, ATL)

July-2020: OLCI S3A NRT
Dec-2020: MODIS, VIIRS and MERIS for multi sensor NRT and REP
May 2021: uncertainty field





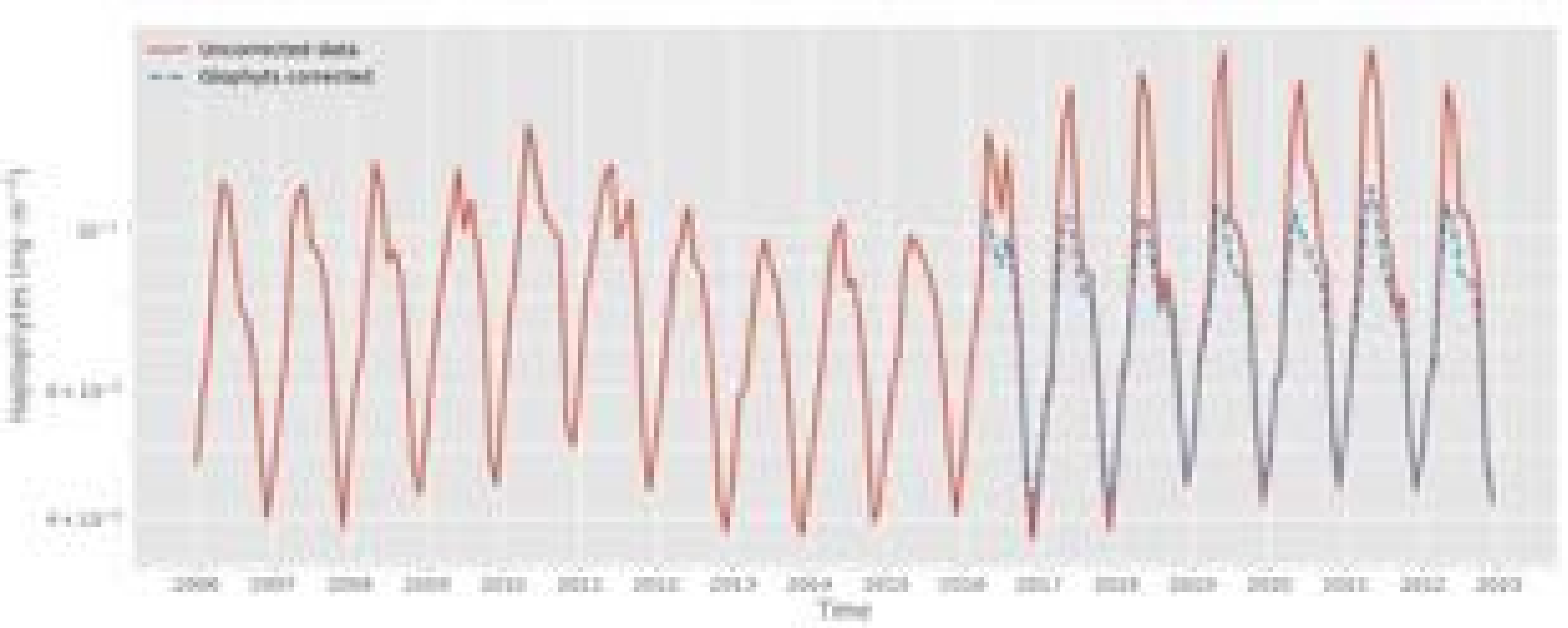
Daily diatoms concentration estimated by the merged product OLCI-S3A and OLCI-S3B for May 15th of 2019 ((Xi et al., 2020, 2021)

Chlorophyll a concentration of Phytoplankton Functional Types (GLO, ATL)

July-2020: OLCI S3A NRT
Dec-2020: MODIS, VIIRS and MERIS for multi sensor NRT and REP
May 2021: uncertainty field
Nov-2026: PFT time series for the OLCI era by integration of the GLOPHYTS algorithm into ACRI-ST's processing chain in GLO-L3 and L4 products (MY and NRT).

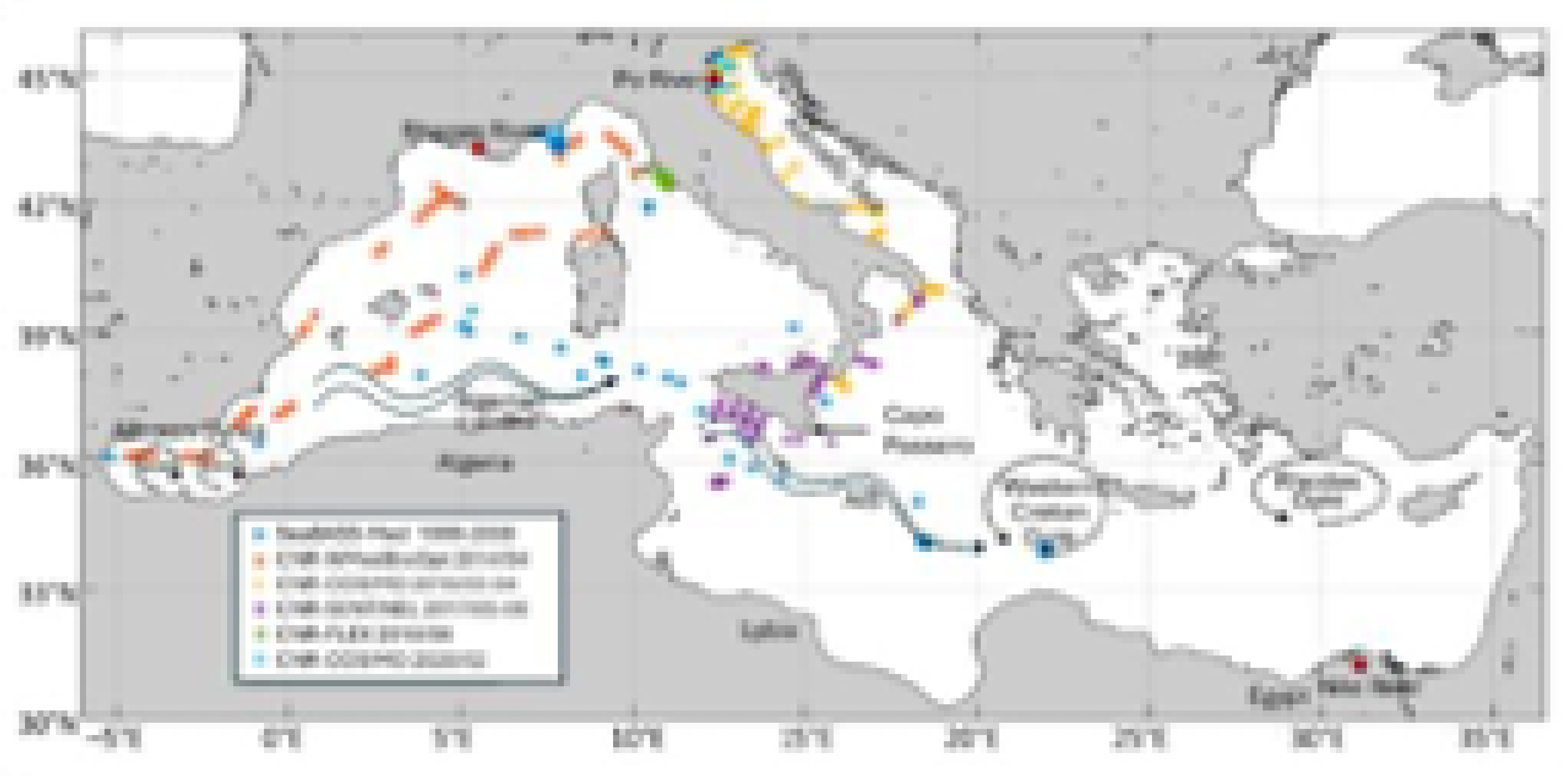
The improvement of the PFT product is based on a recalibration of the OLCI product allowing to get a consistent time-series over the ocean colour archive.

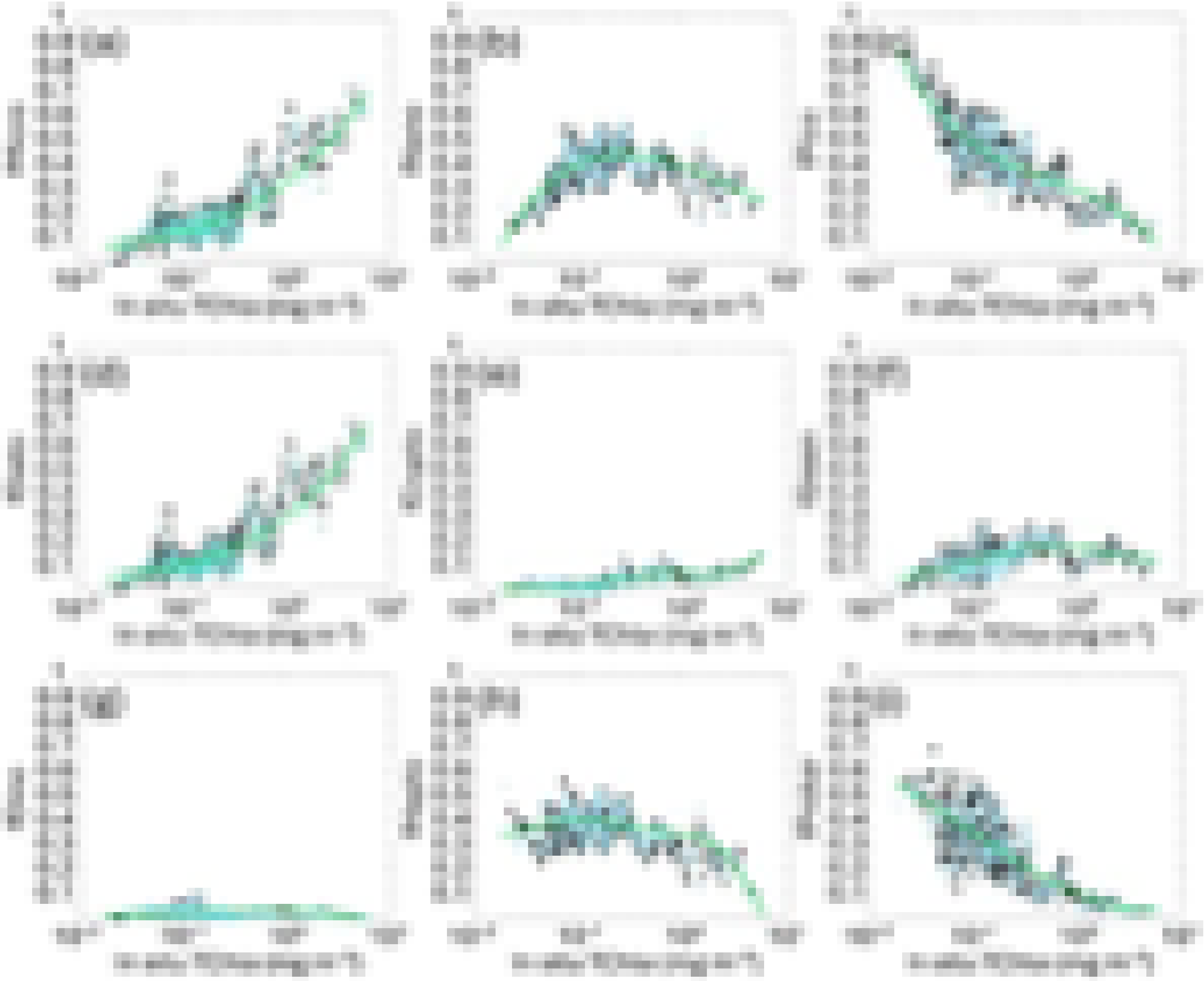
time series of Haptophytes, averaged over the entire ATL monthly product



Chlorophyll a concentration of Phytoplankton Functional Types (MED)

Diagnostic pigment data for the determination of the in-situ PFTs and PSCs come from a Mediterranean subset of the SeaBASS HPLC pigment in-situ dataset and from CNR cruises.



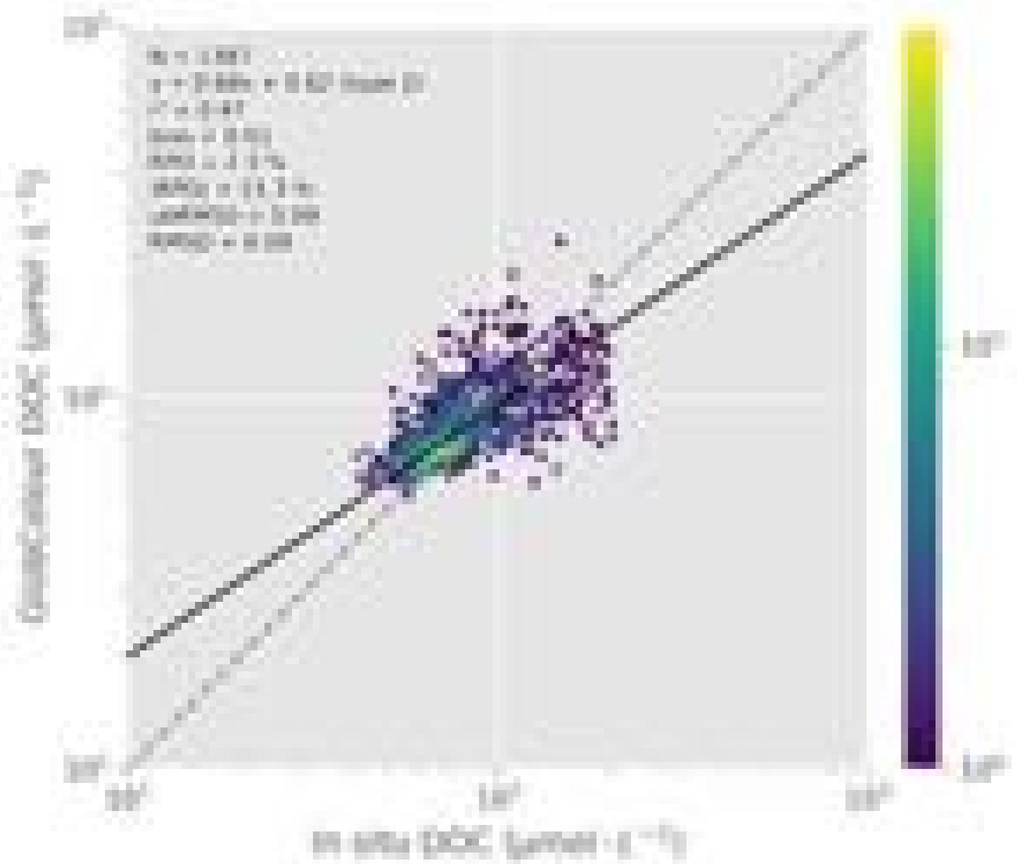


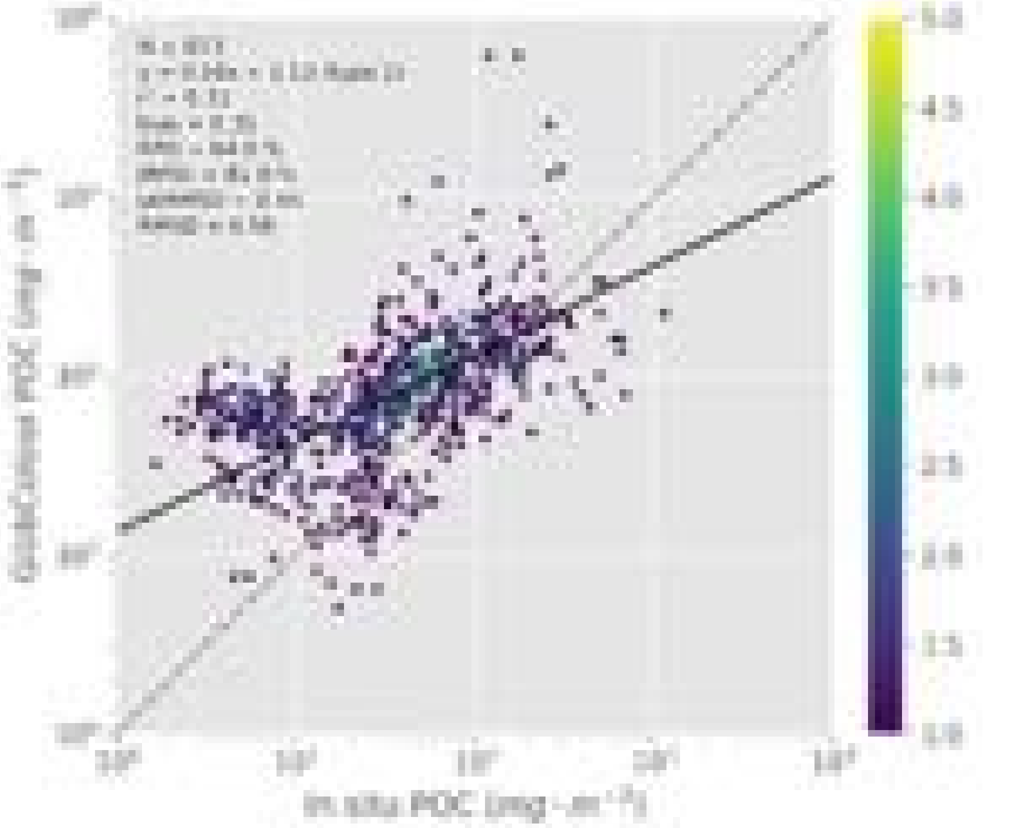
Di Cicco et al., 2017, 2025

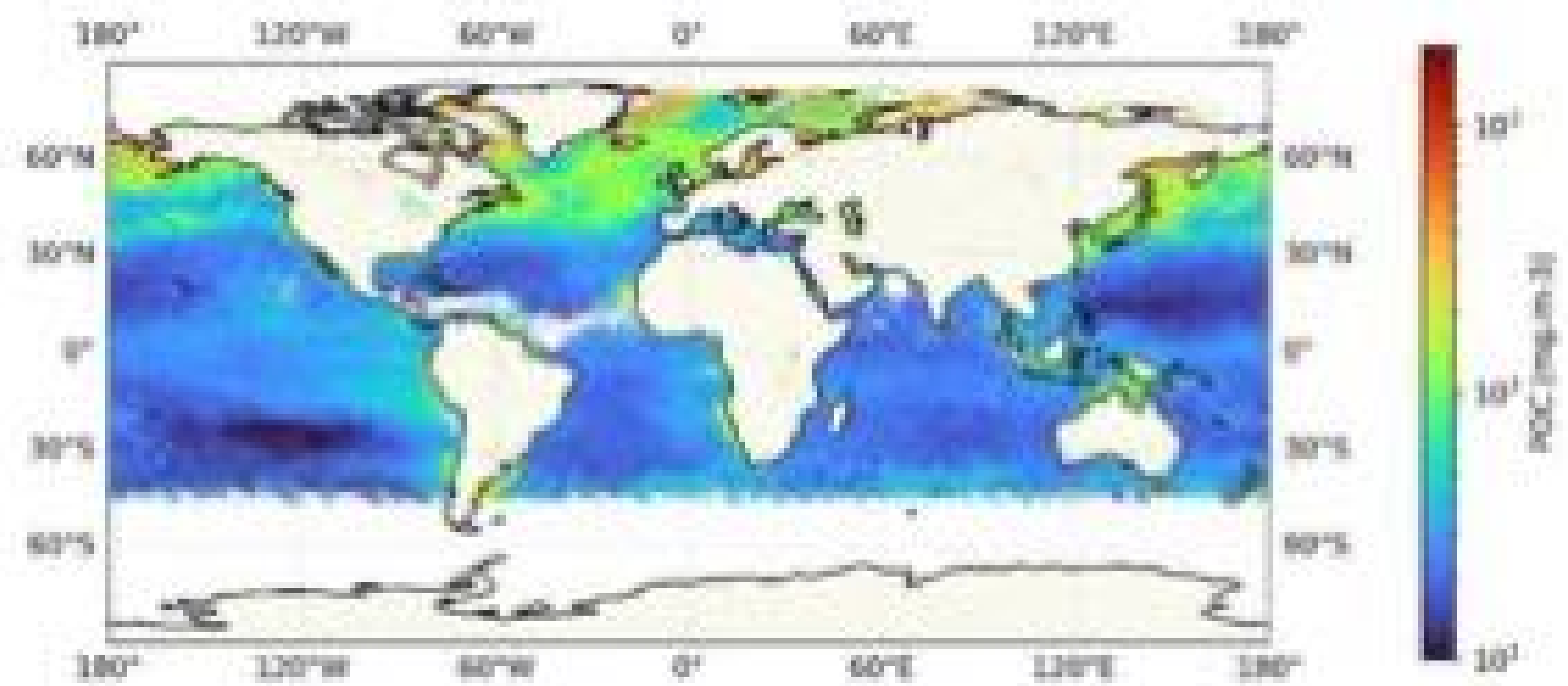
The global models underestimate most of the functional classes
Best performances of the regional algorithms for all the functional classes considered

DOC and POC

New DOC and POC variables in the new *Carbon* datasets
Integration of the **OCROC SE** algorithms in L3 and L4 products (MY and NRT) for GLO, MED, BLK, BAL, ARC
The DOC algorithm approach consider a temporal window to account for the fate of the organic matter with neural network.
POC algorithm results in a combination of different algorithms in function of the optical water classes.







MSI multi-sensor products

Copernicus Marine Service

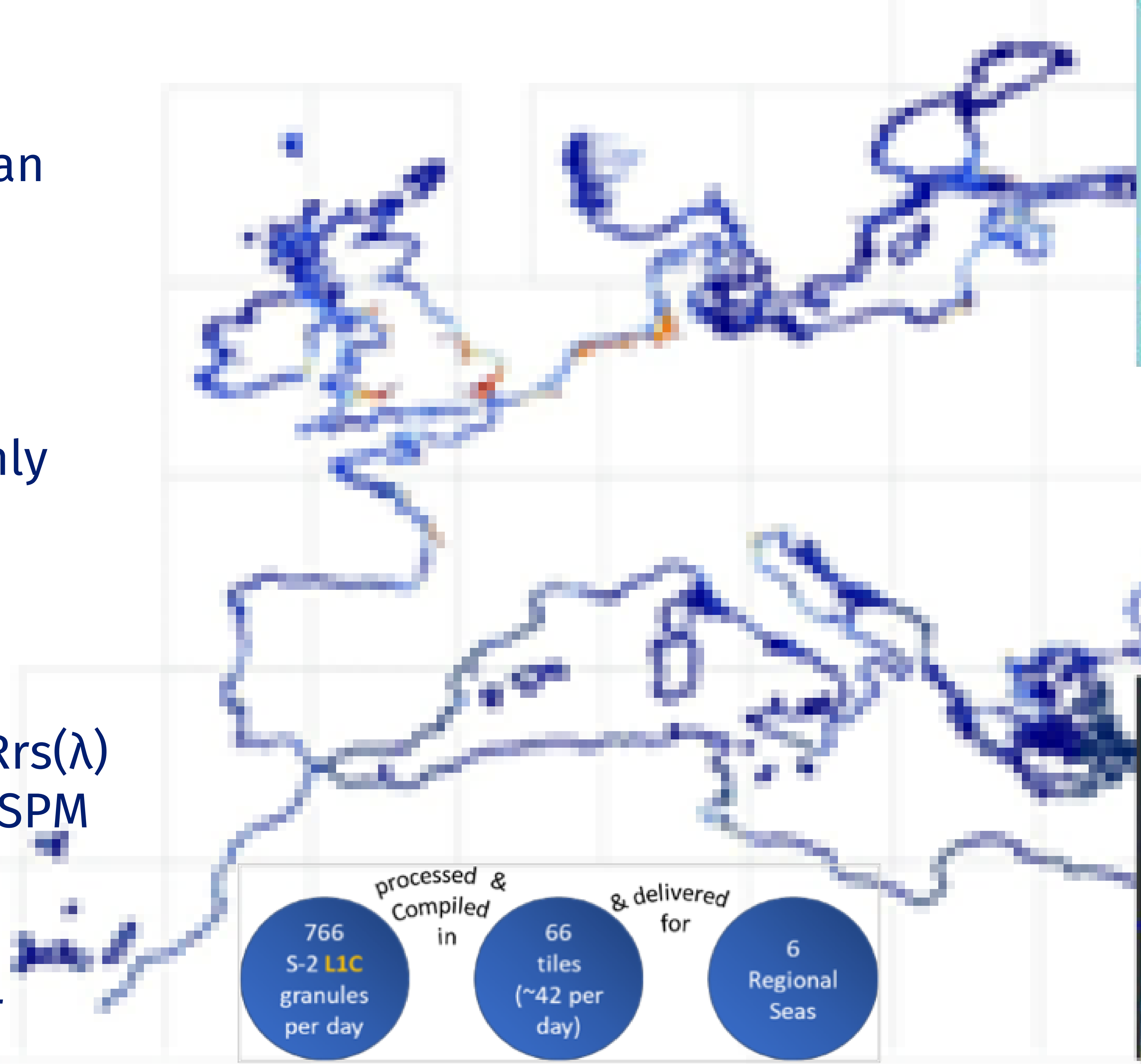
S2 MSI

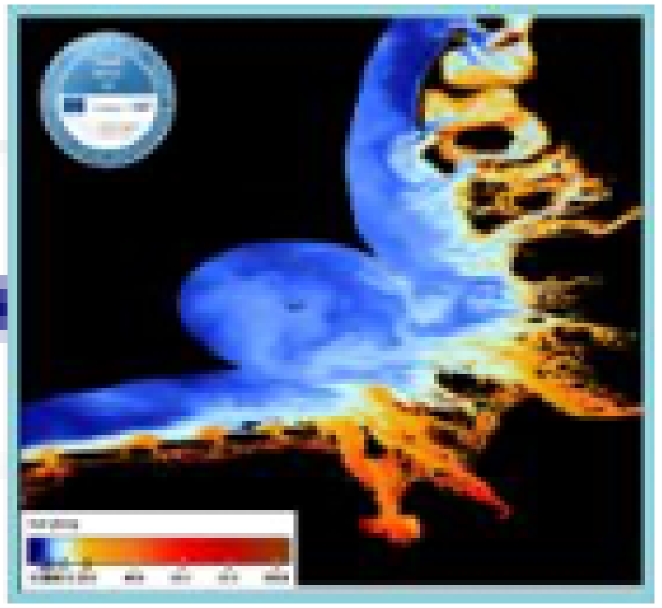
Coastal stripes of 20km for European Seas

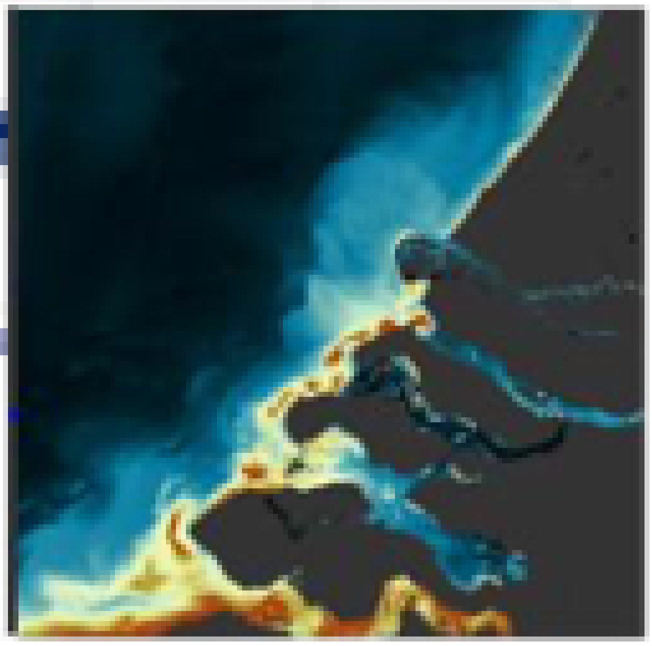
- S2 B&C at 100m resolution
- NRT 1/1/2020 ->
  - L3: daily;
  - L4: daily gap-filled and monthly averages

Parameters

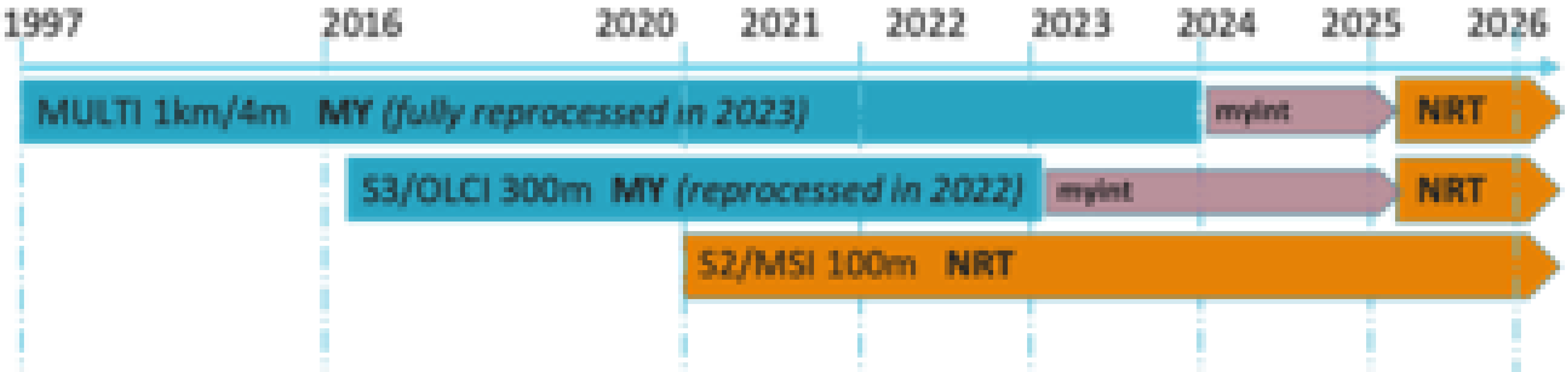
- Remote Sensing Reflectances - Rrs(λ)
- Suspended Particulate Matter – SPM
- Turbidity - TUR
- Particulate Backscatter - BBP(l)
- Chlorophyll Concentration – CHL (one algorithm for all European waters)







OCTAC: product timespan



NRT/MYINT/MY continuity for each MULTI product line (no MULTI NRT for ARC, BAL)
NRT/MYINT/MY continuity for each S3/OLCI product line
Same chains for MULTI and S3/OLCI for each product line (apart for GLO)
No specific regional algorithms for S2/MSI

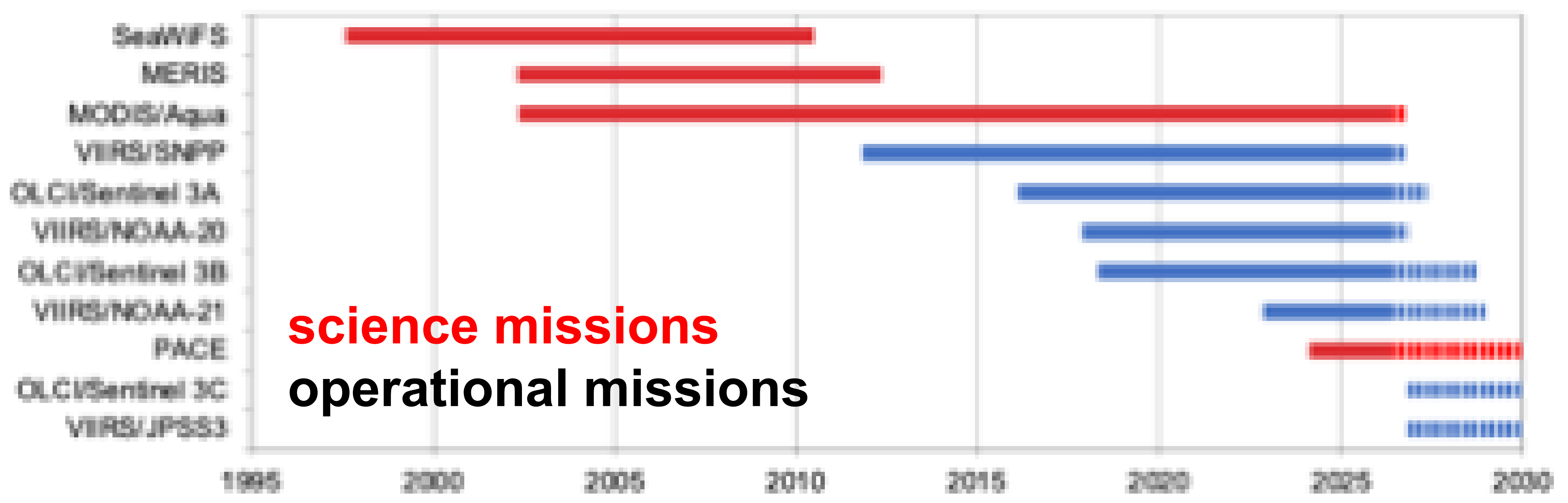
Operational multi sensor ocean colour

The operations era

Let's do this…all the time…consistently…with redundancy!

In this era we:

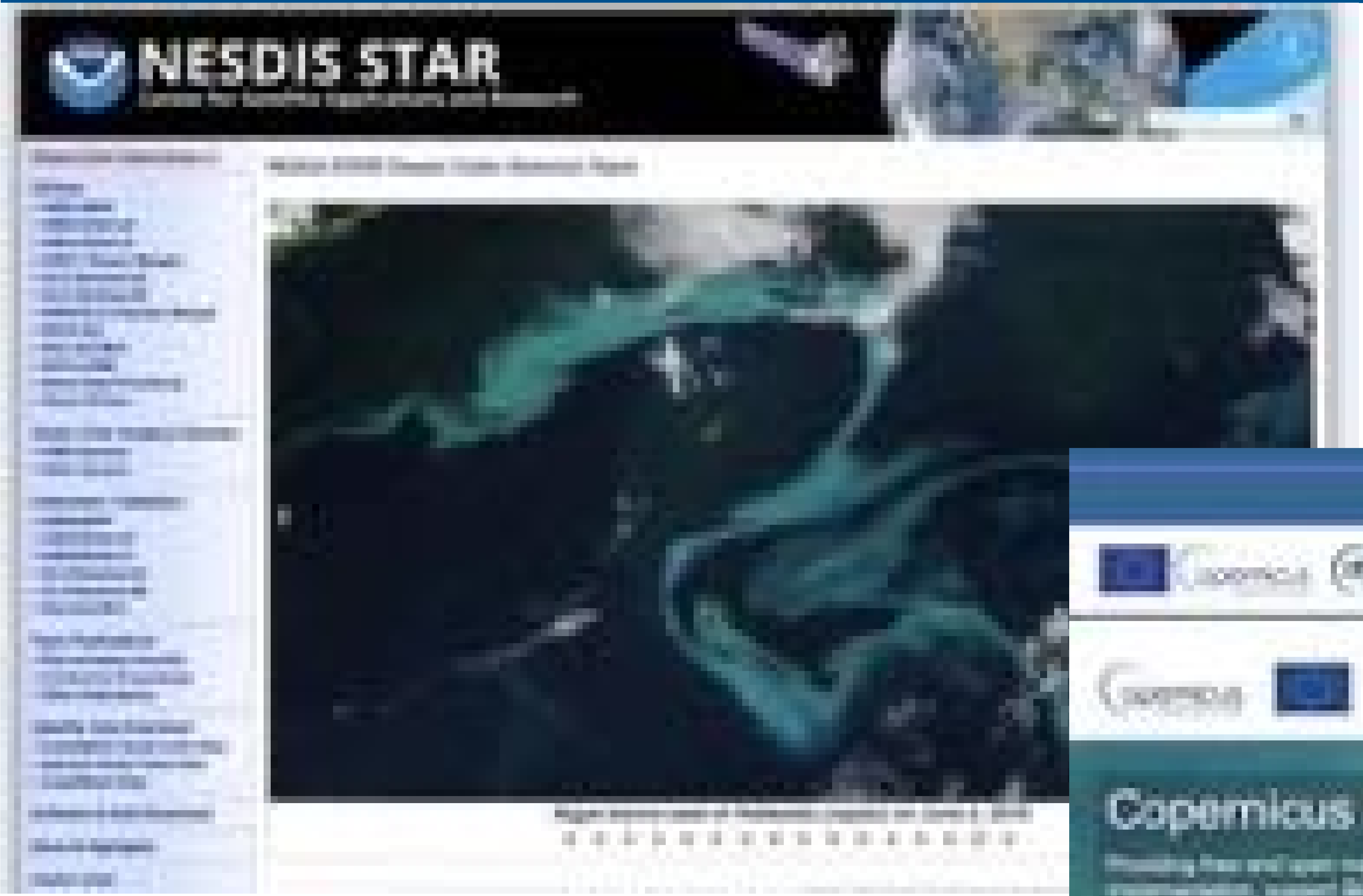
- Linked up with agencies typically responsible for operating 'weather' satellites
- Developed long-term programmes to maintain the ocean colour record
- Developed approaches to merging records from multiple sensors towards ECVs, EOVs, CDRs.

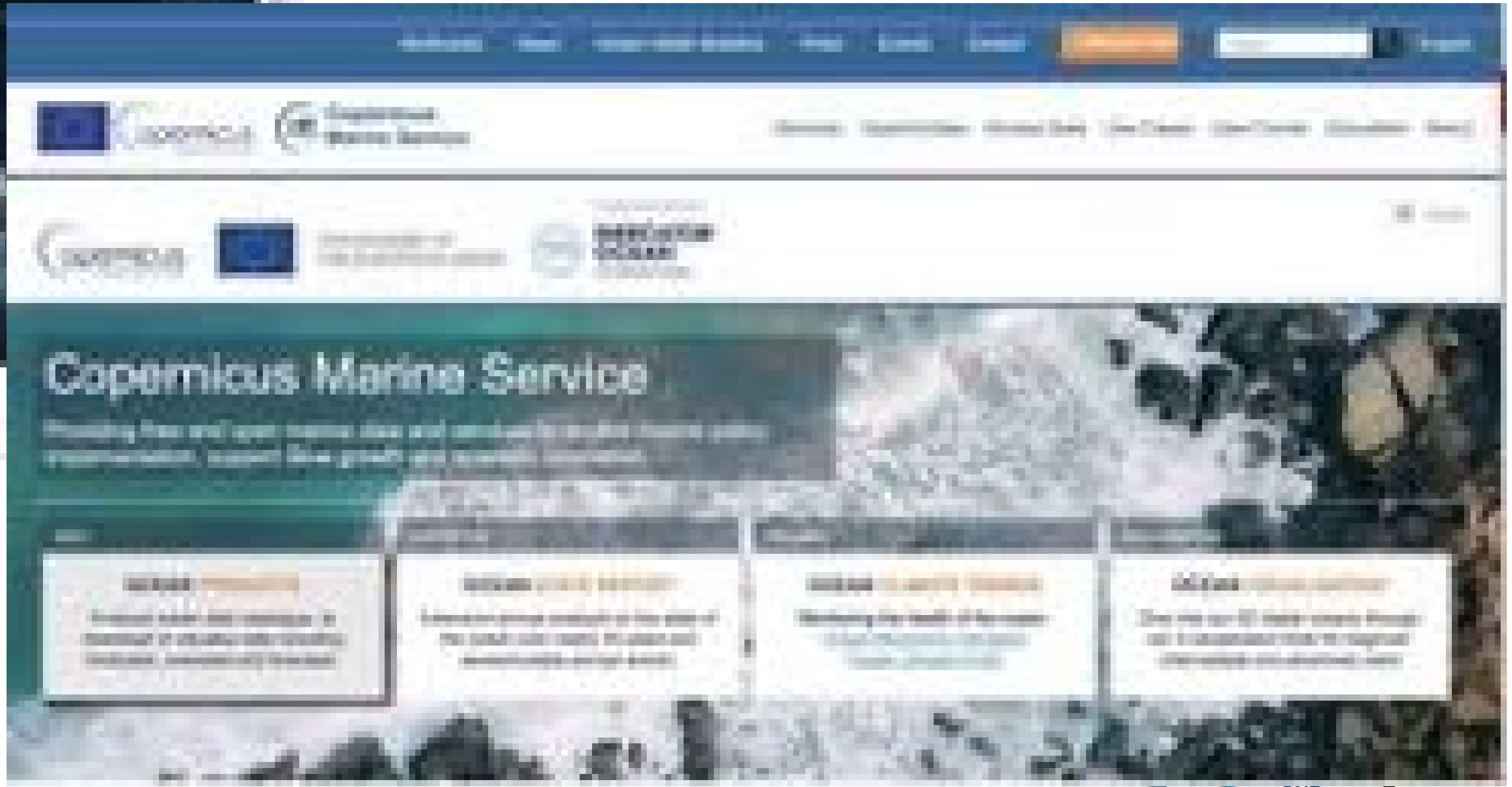


Series of consistent mission/sensor

- USA: 4 VIIRS to cover 2015-2038
- EU: 4 OLCI to cover 2016-2036
- constellations of at least two sensors in orbit at the same time

Operational multi sensor ocean colour





Operational multi sensor ocean colour

Copernicus Marine Service

All (most of) the material on OCTAC is detailed in this paper published in 2024 and/or in the CMEMS Quality Information Documents (QuIDs)

remote sensing MDPI

Review

Overview of Operational Global and Regional Ocean Colour Essential Ocean Variables Within the Copernicus Marine Service

Vittorio E. Brando [1,*], Rosalia Santoleri [1], Simone Colella [1], Gianluca Volpe [1], Annalisa Di Cicco [1], Michela Sammartino [1], Luis González Vilas [1], Chiara Lapucci [1], Emanuele Böhm [1], Maria Laura Zoffoli [1], Claudia Cesarini [1], Vega Forneris [1], Flavio La Padula [1], Antoine Mangin [2], Quentin Jutard [2], Marine Bretagnon [2], Philippe Bryère [2], Julien Demaria [2], Ben Calton [3], Jane Netting [3], Shubha Sathyendranath [3], Davide D'Alimonte [4], Tamito Kajiyama [4], Dimitry Van der Zande [5], Quinten Vanhellemont [5], Kerstin Stelzer [6], Martin Böttcher [6] and Carole Lebreton [6]

Remote Sens. **2024**, *16*, 4588. https://doi.org/10.3390/rs16234588 https://www.mdpi.com/journal/remotesensing

IOCCG Summer Lecture Series 2026

Frontiers in Ocean Optics and Ocean Colour Science

Multi sensor ocean colour radiometry

Vittorio E. Brando

CNR-ISMAR, Rome, Italy

Venice, Italy - 16 July 2026