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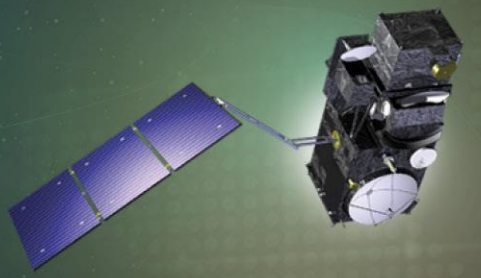


7th Sentinel-3 Validation Team Meeting 2022

18-20 October 2022 | ESA-ESRIN | Frascati (Rm), Italy

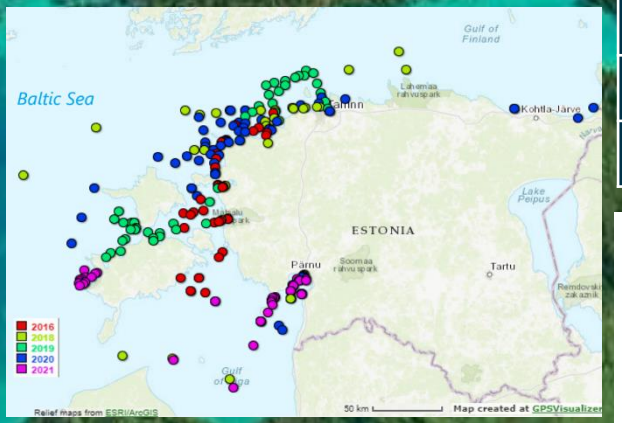
How good are the chlorophyll-a products for the Baltic Sea?

Tuuli Soomets, Kaire Toming, Birgot Paavel and Tiit Kutser

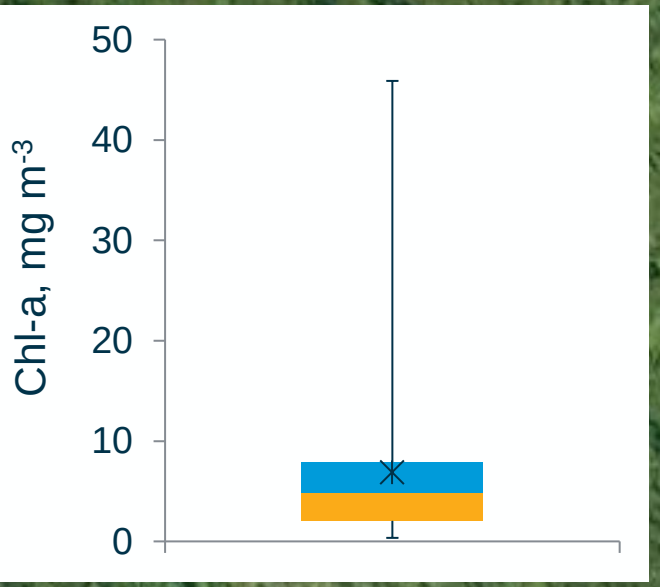
Estonian Marine Institute, University of Tartu

In situ data

Year	2016	2018	2019	2020	2021				Total
n	34	55	46	80	52				267
Month	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Total**
n	12	54	53	43	50	33	12	10	267

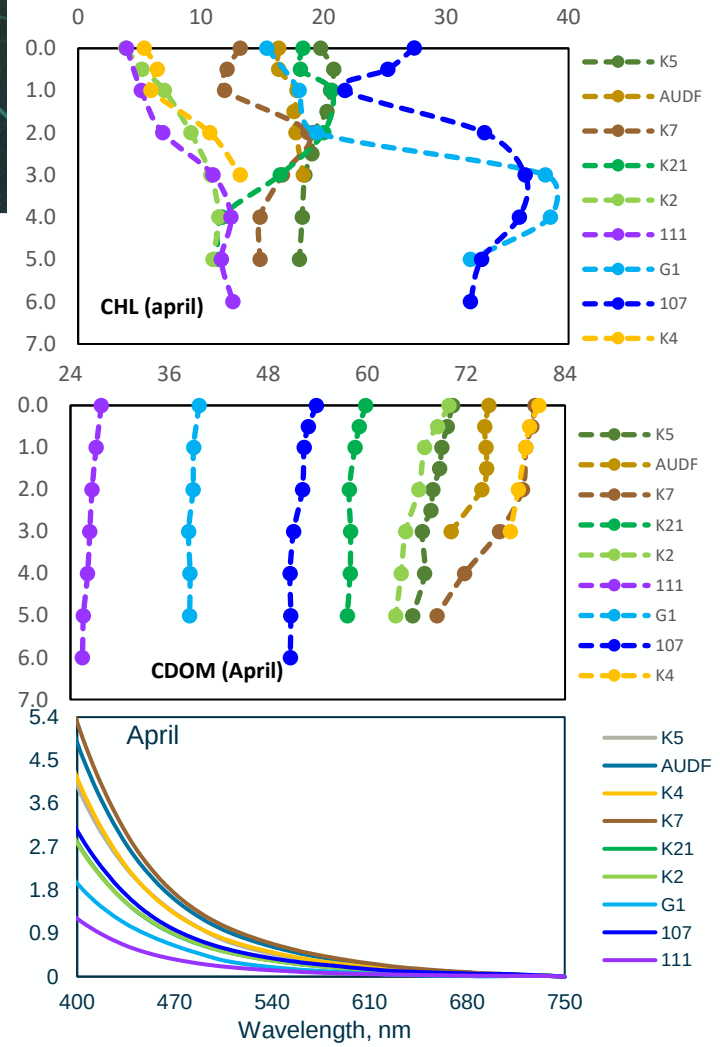


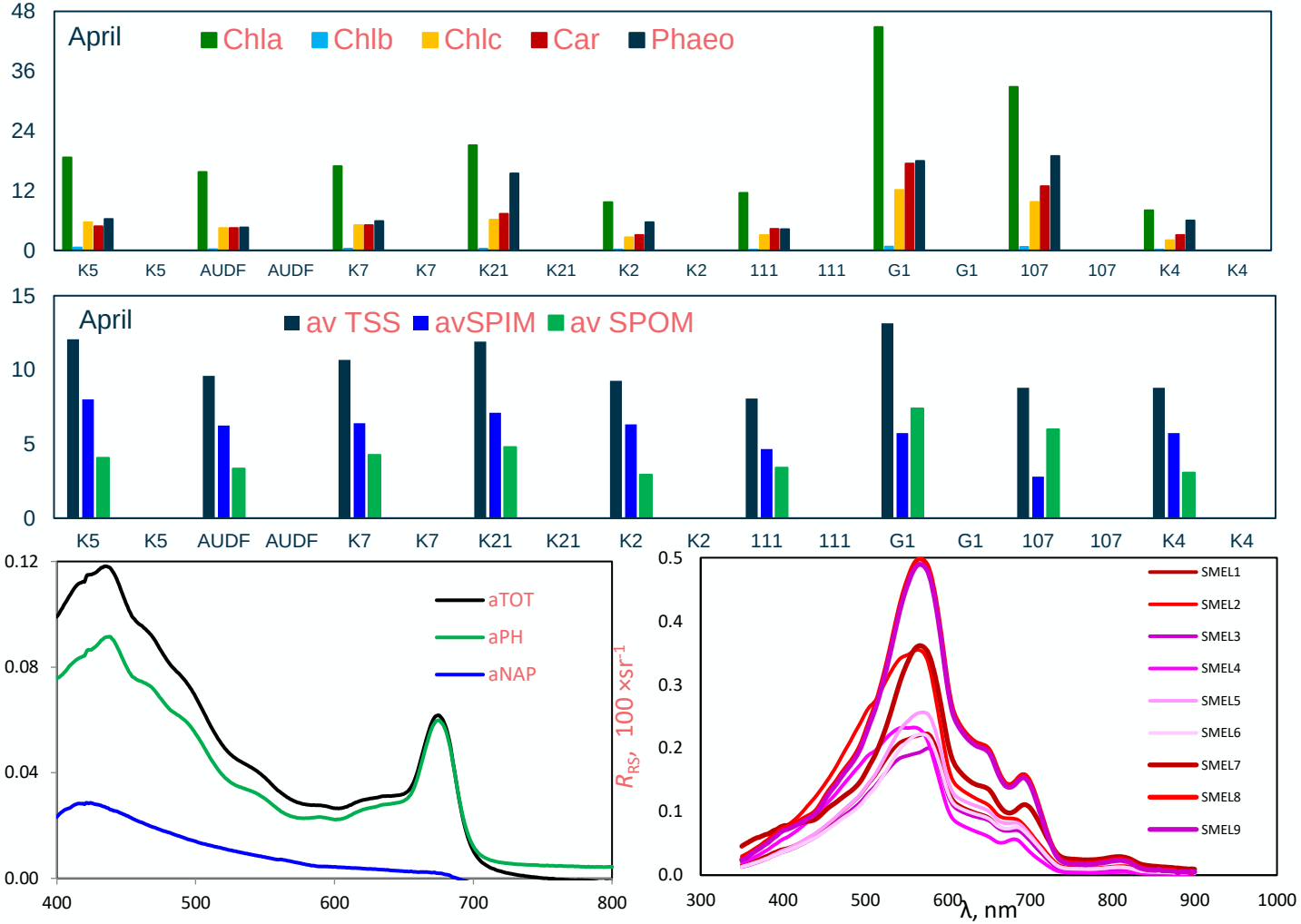
t	13.04.16 – 08.10.21
n	267
Min	0.36
1st Q	2.07
Median	4.87
3rd Q	7.92
Mean	6.89
Max	45.89
StDev	7.69
Range	45.53

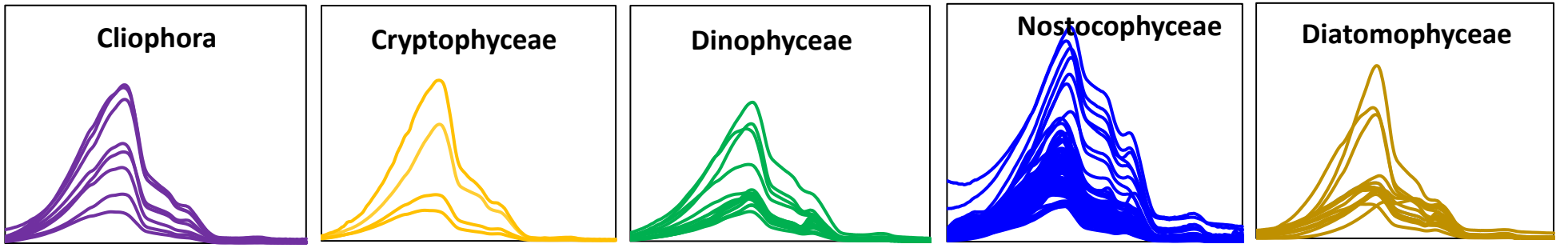


- Chl *a*
- Chl *b*
- Chl *c*
- Car
- Phaeo
- TSS
- SPIM
- SPOM
- *c*
- *b*
- bb
- a_{TOT}
- a_{sphare}
- a_{CDOM}
- a_{PH}
- a_{NAP}
- K_d
- R_{air}
- R_{water}

- CHL fluorescence
- CDOM fluorescence
- Phycocyanin fluorescence
- Phytoplankton species

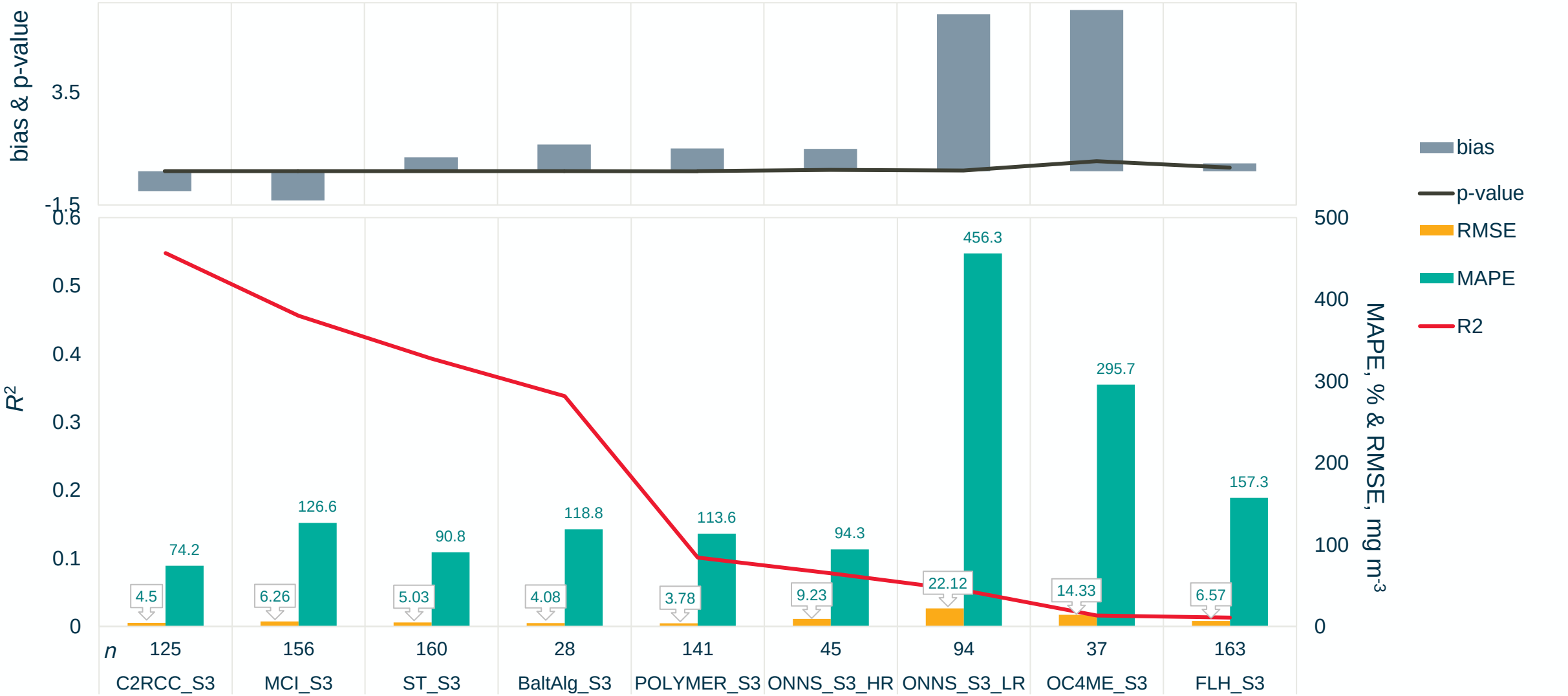






Chl-a products (8/9) based on Sentinel-3 OLCI data

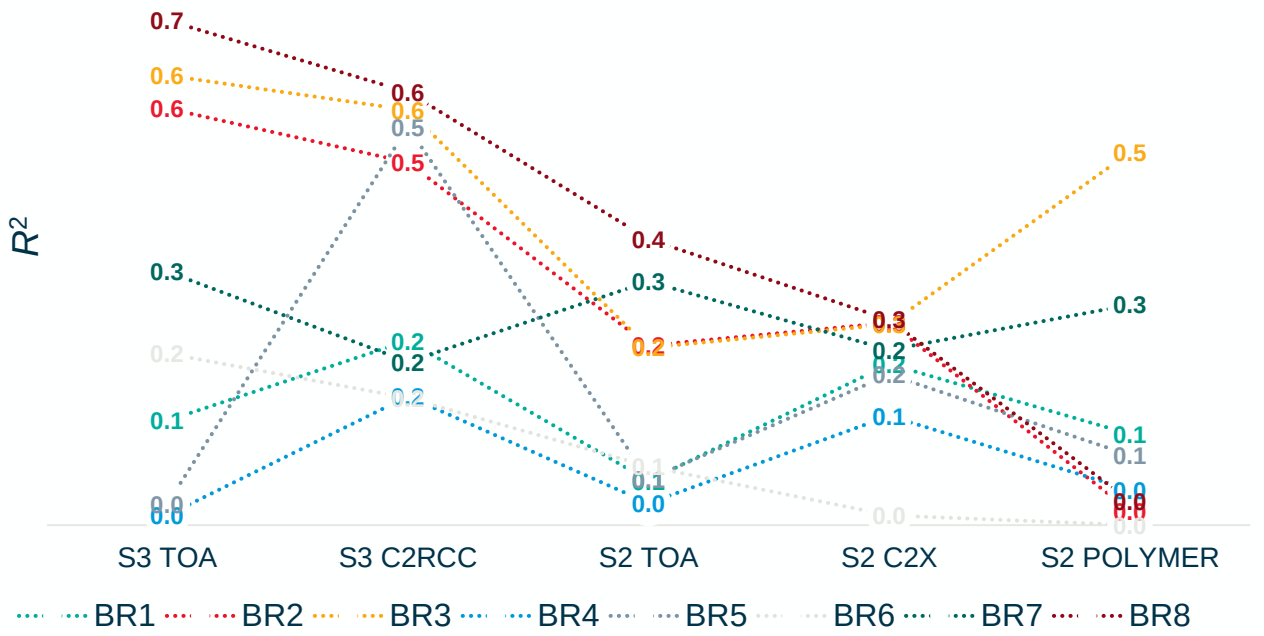
Product name	Data Level	Resolution	Description
C2RCC_S3	Level 1	1x1 300 m	Case-2Regional/CoastColour (C2RCC) atmospheric correction and pixel identification tool (Idepix v1.5) (Brockmann et al. 2016); pixels with following raised flags removed from the study: invalid, sun_glint_risk, cloud_risk, cloud, and cloud_shadow.
POLYMER_S3	Level 1	1x1 300 m	POLYMER L2 v.4.12 atmospheric correction (Steinmetz, Deschamps, and Ramon 2011); pixels with bitmask 0 used in this study.
ST_S3	Level 2	1x1 300 m	EMETSAT product (OLCI WFR) NN: Neural network based approach (Doerffer and Schiller 2007) for turbid waters; pixels with following raised flags removed from the study: cloud, OCNN_fail, AC_fail, highglint, adjac;
OC4ME_S3	Level 2	1x1 300 m	EMETSAT product (OLCI WFR) OC4ME: Maximum Band Ratio (MBR) semi-analytical algorithm (Morel et al. 2007) for clear waters; pixels with following raised flags removed from the study: cloud, OC4ME_fail, AC_fail, highglint, adjac.
MCI_S3	Level 3	1x1 300 m	Maximum chlorophyll index (MCI) (Gower et al. 2005) used to derive Chl-a with linear regression (Chl-a = 7.94 * MCI + 10.05, negative results removed) on OLCI WFR reflectances; pixels with following raised flags removed from the study: invalid, sun_glint_risk, and bright.
FLH_S3	Level 3	1x1 300 m	Fluorescence line height (FLH) v7.0.0 (Letelier and Abbott 1996) used to derive Chl-a with linear regression (Chl-a = 1235.07 * FLH + 6.52) OLCI OLCI WFR reflectances; pixels with following raised flags removed from the study: invalid, cloud, cloud_ambiguous, cloud_margin, highglint, adjac, and AC_fail.
BalAlg_S3	Level 3	1x1 1000 m	Copernicus Marine Service product OCEANCOLOUR_BAL_CHL_L3_REP_OBSERVATIONS_009_080: BalAlg is an updated version of multilayer perception (MPL) neural network (D'Alimonte et al. 2012).
ONNS_S3_HR	Level 3	1x1 300 m	Copernicus Marine Service product OCEANCOLOUR_BAL_CHL_L3_NRT_OBSERVATIONS_009_049:
ONNS_S3_LR		1x1 1000 m	OLCI Neural Network Swarm (ONNS) v0.9 (Hieronymi, Müller, and Doerffer 2017).


bias & p-value
3.5
-1.5
R^2
0.6
0.5
0.4
0.3
0.2
0.1
0
500
400
300
200
100
0
MAPE, % & RMSE, mg m-3
bias
p-value
RMSE
MAPE
R2
74.2
126.6
90.8
118.8
113.6
94.3
456.3
295.7
157.3
4.5
6.26
5.03
4.08
3.78
9.23
22.12
14.33
6.57
n
125
156
160
28
141
45
94
37
163
C2RCC_S3
MCI_S3
ST_S3
BaltAlg_S3
POLYMER_S3
ONNS_S3_HR
ONNS_S3_LR
OC4ME_S3
FLH_S3

Other available Chl-a products (8/12)

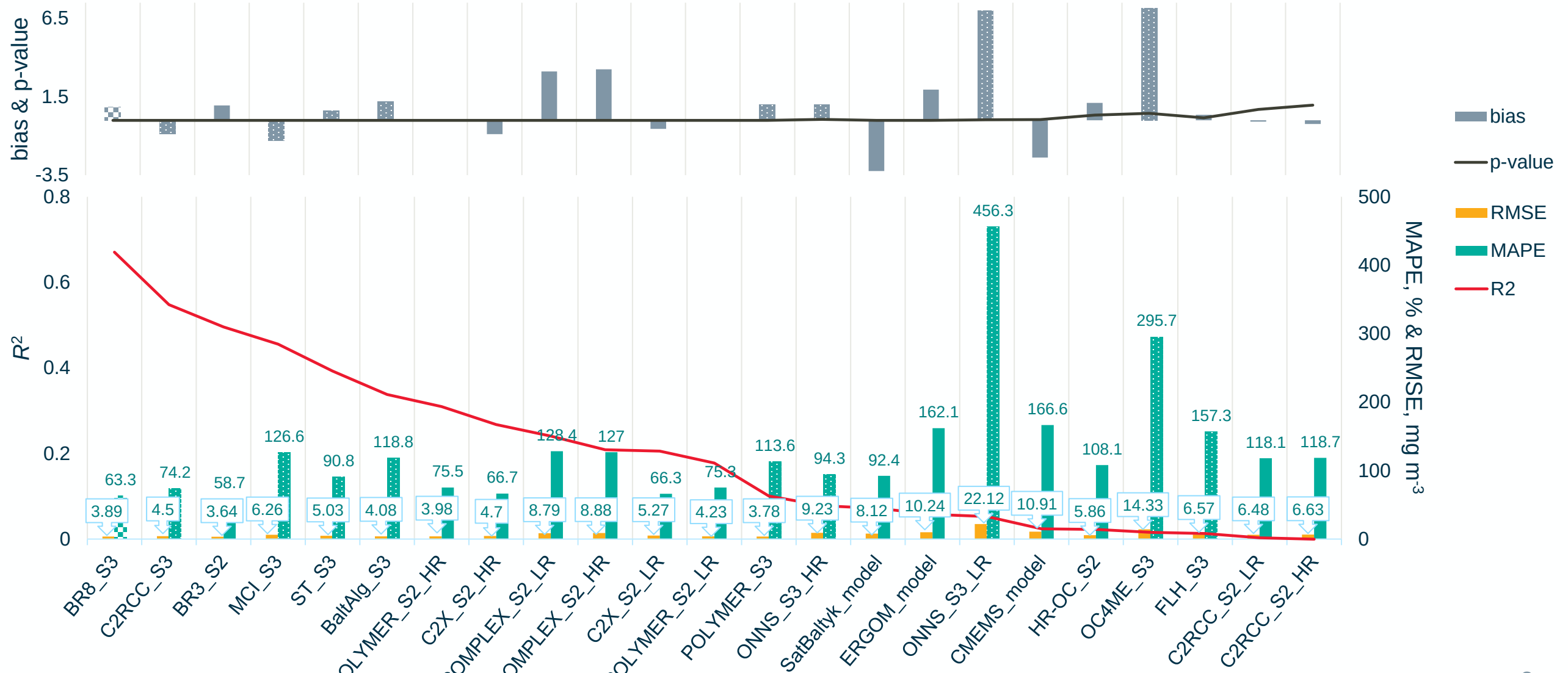
Product name	Satellite	Resolution	Description
C2RCC_S2_HR	Sentinel-2 MSI	3x3 mean 20 m	C2RCC atmospheric correction and Idepix v1.5 (Brockmann et al. 2016); pixels with following raised flags removed from the study: cloud_risk, cloud_shadow, and clear_water (if not raised). In case of two tiles overlapping, the better matching concentration was considered.
C2RCC_S2_LR		3x3 mean 60 m	
C2X_S2_HR	Sentinel-2	3x3 mean 20 m	Case2R/CoastColour-Extreme (C2X) atmospheric correction and Idepix v1.5 (Brockmann et al. 2016); pixels with following raised flags removed from the study: cloud_risk, cloud_shadow, and clear_water (if not raised). In case of two tiles overlapping, the better matching concentration were considered.
C2X_S2_LR		3x3 mean 60 m	
COMPLEX_S2_HR	Sentinel-2	3x3 mean 20 m	Case2R/CoastColour COMPLEX v1.1 atmospheric correction (Brockmann et al. 2016); pixels with following raised flags removed from the study: cloud_risk, agelb_at_max, adet_at_min, and valid_PE (if not raised). In case of two tiles overlapping, the better matching concentration were considered.
COMPLEX_S2_LR		3x3 mean 60 m	
POLYMER_S2_HR	Sentinel-2	3x3 mean 20 m	POLYMER L2 v.4.12 atmospheric correction (Steinmetz, Deschamps, and Ramon 2011); pixels with bitmask 0 used in this study. In case of two tiles overlapping, the better matching concentration was considered.
POLYMER_S2_LR		3x3 mean 60 m	
HR-OC_S2	Sentinel-2	1x1 60 m	Copernicus Marine Service product OCEANCOLOUR_BAL_BGC_HR_L3_NRT_009_202: The High-Resolution Ocean Colour (HR-OC) Consortium contains pixel identification (IdePix), atmospheric correction, in-water processing and merging and the Chl-a is derived by following the approach of Lavigne et al. (2021).
SatBaltyk_model	MODIS, EcoSat	1x1 1000 m	SatBałtyk portal product SatBaltyk: EcoSat eco-hydrodynamic model SatBaltyk using Moderate Resolution Imaging Spectroradiometer (MODIS) and EcoSat data (“SatBałtyk” n.d.).
ERGOM_model	-	1x1 2000 m	Copernicus Marine Service product BALTICSEA_ANALYSISFORECAST_BGC_003_007: Biogeochemical model ERGOM forecast (Neumann 2000).
CMEMS_model	-	1x1 4000 m	Copernicus Marine Service product BALTICSEA_REANALYSIS_BIO_003_012: The Baltic Sea Biogeochemical Reanalysis is using the ice-ocean model NEMO-Nordic coupled with the biogeochemical model SCOBI (Swedish Coastal and Ocean Biogeochemical model) together with a LSEIK data assimilation scheme (Hordoir et al. 2019).

Band Ratios (BR) applied on top- and bottom-of-atmosphere reflectances (R)



	BR1	BR2	BR3	BR4	BR5	BR6	BR7	BR8
Sentinel-3	R665/R560	R665/R709	R709/R674	R709	R754/R665	(R665-R709)*R754	R709-(R665+R754)/2	**R754/R709-R754/R665**
Sentinel-2	R665/R560	R665/R704	**R704/R665**	R704	R740/R665	(R665-R704)*R740	R704-(R665+R740)/2	R740/R704-R740/R665

All results


bias & p-value
6.5
1.5
-3.5
bias
p-value
RMSE
MAPE
R2
R^2
0.8
0.6
0.4
0.2
0
500
400
300
200
100
0
MAPE, % & RMSE, mg m^{-3}
63.3
74.2
58.7
126.6
90.8
118.8
75.5
66.7
128.4
127
66.3
75.3
113.6
94.3
92.4
162.1
456.3
166.6
108.1
295.7
157.3
118.1
118.7
3.89
4.5
3.64
6.26
5.03
4.08
3.98
4.7
8.79
8.88
5.27
4.23
3.78
9.23
8.12
10.24
22.12
10.91
5.86
14.33
6.57
6.48
6.63
BR8_S3
C2RCC_S3
BR3_S2
MCI_S3
ST_S3
BaltAlg_S3
POLYMER_S2_HR
C2X_S2_HR
COMPLEX_S2_LR
COMPLEX_S2_HR
C2X_S2_LR
POLYMER_S2_LR
POLYMER_S3
ONNS_S3_HR
SatBaltyk_model
ERGOM_model
ONNS_S3_LR
CMEMS_model
HR-OC_S2
OC4ME_S3
FLH_S3
C2RCC_S2_LR
C2RCC_S2_HR

Take home

- 21 different available Chl-a products of the Baltic Sea, from witch 9 are based on Sentinel-3 data
- 8 different empirical band ratio type algorithms
- The best performing Chl-a product was C2RCC of Sentinel-3 OLCI data
- The empirical band ratio algorithms with Sentinel-3 data were more successful than any of the available product
- High uncertainties of the results shows that there is still room for improvement for atmospheric correction methods

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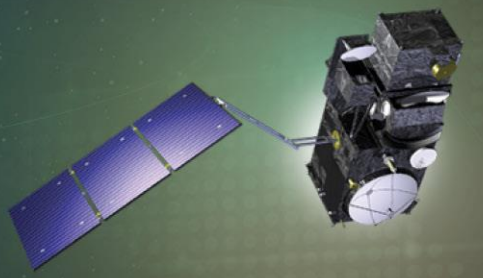

Thank you!