Modeled surface salinity and satellite data as proxy for Secchi depth and watercolor of the Gulf of Riga

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Abstract. The present study pays attention to the sea surface salinity field and satellite derived watercolor and Secchi depth datasets in the Gulf of Riga in 1998-2018. The study increases understanding of the river plume's impact on the open part of the Gulf of Riga. Mean watercolor and salinity versus depth had been compared in April and August month. The region with the high mean watercolor and salinity homogeneity consistency had been seen in the deepest part (depth >40m) of the Gulf of Riga in April. The correlation between mean salinity field and watercolor and Secchi depth data sets had been shown. It marks the coastal and transitional region where the current of riverine water on the sea surface dominate the upwelling from the more saline deeper layers. The study distinguishes mean watercolor (in situ observations and derived from satellite) in years with and without seasonal hypoxia in the Gulf of Riga in 2005-2018. Convincing difference between both sets have not been found.

1 Scope

The Gulf of Riga is semi enclosed basin with an average depth 22 m and the maximal depth 58 m connected to the highly brackish waterbody – the Baltic Sea with Irbe strait in west and Suuri strait in north. The salinity of the Gulf of Riga is less than in the open part of the Baltic Sea – 4-6 PSU in its upper and 7-6 PSU in its bottom layer [1]. Tidal amplitudes are negligible – 0.1 m and lower.

Secchi depth has been decreasing in the Gulf of Riga – one of the least transparent basins of the Baltic Sea - during previous decades [2] as well as watercolor in Pt reference units of multiple of the main rivers draining into the Gulf of Riga show increasing trends [3].

The oxygen levels below 2.9 mg/L detected seasonally in 50% of years in 2005-2018 in the Gulf of Riga [4]. The permanent anoxic area that is presently within depth below 70m has emerged since early 1960s in Baltic Proper instead [5].

Despite continuous reduction of nutrient supply to the marine environment [6] – the risks of further eutrophication of the Baltic Sea remain high according [5] where according to the modeled assessment there is internal source released from the sediments of anoxic marine area and its order of magnitude – on average 25 kT/year is close to the assessed total riverine input.

Development of remote sensing methods, technologies and its interpretation allow providing the watercolor and Secchi depth data sets for the world seas, oceans, and main inland lakes for two decades: 1998-2018 [7]. The watercolor of the Gulf of Riga especially in its coastal and transitional area is strongly impacted by longshore sediment transport, chlorophyll *a*, riverine input of colored organic material therefore quantitative interpretation and calibration of available satellite raw data as well as global data products hold multiple unresolved scientific issues there for at first the focus on its open part has been set.

River plumes supply is threat to marine ecosystem. Its risks monitoring methods have been developed for regional application using high-resolution satellite color observations for water quality assessment instead of operational and climatical oceanographical model data analysis and in situ observations [8]. The main long-term aim is increasing understanding of the river plumes in the Gulf of Riga and deriving indicators predicting its spatial extent during different weather conditions (heavy rainfall after drought, etc.).

2 Methodology

2.1 Data

2.1.1 Study site

The study site is shown in Fig. 1. The riverine inflow mainly occurs in southern part where Daugava, Lielupe and Gauja river deltas are located and in the eastern and north – eastern part from Salaca and Parnu rivers.

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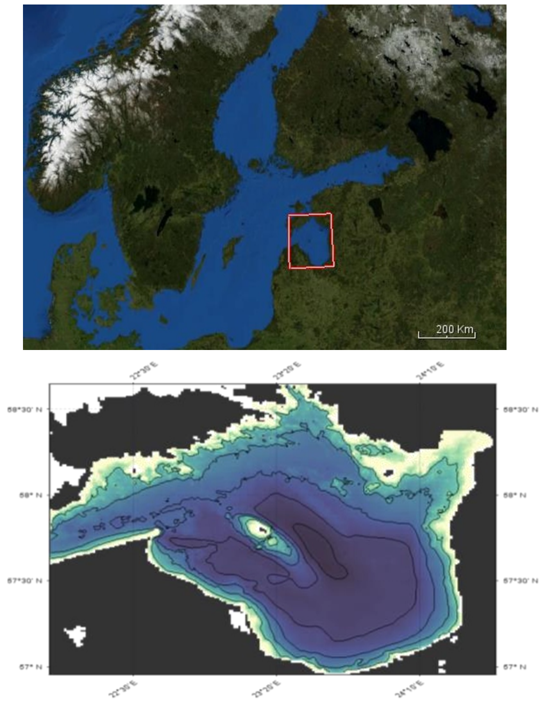

Fig. 1. Location of the study site – the Gulf of Riga, Baltic Sea. Isobaths with 10m step are plotted.

2.1.2 Reanalysis of the Gulf of Riga

The subregional oceanographic model was set up for the Gulf of Riga (Baltic Sea) for the climatic hindcast run. The characteristics of the run: implementation - UL version of Hiromb-BOOS model; time period - 1993-2021; horizontal resolution - 0.5 nm; vertical resolution - top layer 2m, further depth step 4 m; bathymetry according EMODNET2020; meteorology – ERA5; initial and boundary conditions from Copernicus Marine environmental monitoring service (CMEMS); river discharge of 15 major rivers and 1 channel draining into the Gulf of Riga derived from E-HYPE product according to empirical calibration of the operational model setup for the Gulf of Riga. Monthly means of the reanalysis are provided [9]. Sea surface layer salinity (0-2m) during 1998-2018 had been used in the study.

2.1.3 In situ watercolor measurements

Watercolor in Forel-Ule scale and Secchi depth had been monitored in the Gulf of Riga in long term. The observations carried and provided by Latvian Institute of Aquatic Ecology had been implemented in the study for period 1998-2018: available online in www.latmare.lhei.lv.

There is higher coverage of in situ watercolor and transparency observations in Spring and Summer – because of easier accessibility and longer length of the day – that is essential for visual perception. Data provided in 10 monitoring stations in open waters of the Gulf of Riga with acronyms: *102A*, *107*, *111*, *119*, *120*, *121*, *121A*, *137A*, *142* in the online database had been analysed in the study.

2.1.4 Satellite data of watercolor and Secchi depth

Satellite observations derived global watercolor and Secchi depth product with 4 km spatial resolution and monthly temporal resolution [6] had been implemented in the study. The data product does not provide information in December and January in the study area.

2.2 Research questions

The following research questions were addressed: 1) the specific satellite data product's capability in mean watercolor characterisation of the open waters of the Gulf of Riga and its location emphasizing; 2) correlation between the watercolor and Secchi depth provided by satellite data and sea surface salinity field of the ocean reanalysis for the Gulf of Riga; 3) watercolor changes caused by the seasonal hypoxia in the Gulf of Riga.

2.3 Methods

Open water domain includes area of the Gulf of Riga with the depth above 30 m – in its central part, Fig. 1.

Median and 25% and 75% percentiles have been selected for description of the watercolor seasonality in the Gulf of Riga. In case of observation data median and percentiles had been acquired using all available data entries in the month. In case of satellite derived data – median and percentiles had been calculated from the area means in each year in the selected month. In case spatial variability is higher than interannual variability it is natural to expect higher variability among 25% and 75% percentiles in observations than among 25% and 75% percentiles in satellite data derived watercolor values.

Comparison between the years with seasonal hypoxia reported: (2005, 2012-2015, 2018) and years without seasonal hypoxia reported: (2006-2011, 2016-2017) according to [4] had been done by comparing the means and 25% and 75% percentiles.

The watercolor of the Gulf of Riga has not been previously reported in the scientific literature until now and there are no studies of the watercolor differences potentially caused by the processes during seasonal hypoxia published according to the authors knowledge.

3 Results and discussion

3.1 Annual and seasonal watercolor variability in the open waters of the Gulf of Riga

Fig. 2 illustrate the variability of watercolor according to satellite data in open part of the Gulf of Riga. The first 4 years of the period correspond to lower watercolor mean values than remaining period. The maximum in April occurred in the most part of the years in the study. The increased watercolor in April can relate to increased river runoff after the ice melting – meaning that also open waters of the Gulf of Riga are impacted then.

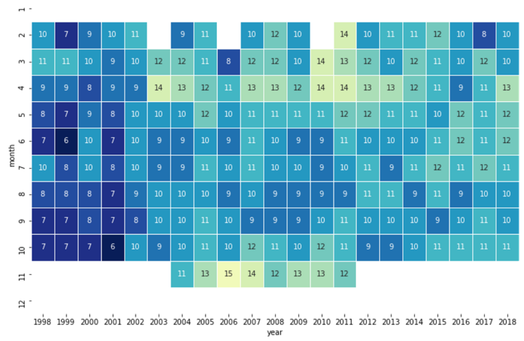

Fig. 2. Watercolor average in each month and year in Forel-Ule scale. The mean value of the nearest data product grid point to selected water stations in the Gulf of Riga has been plotted.

Open waters have been defined as waters with the depth above 30 m in the study. Fig. 3. visualise the impact of the riverine water in the Gulf of Riga that can be felt till the depth above 40 m in comparison with August when salinity dispersion mainly starts at 30 m depth. Salinity and watercolor narrow peaks for the depth above 40m are highly consistend in April. In case of August – high variability of watercolor starts in larger depth that seen in variability of mean surface salinity.

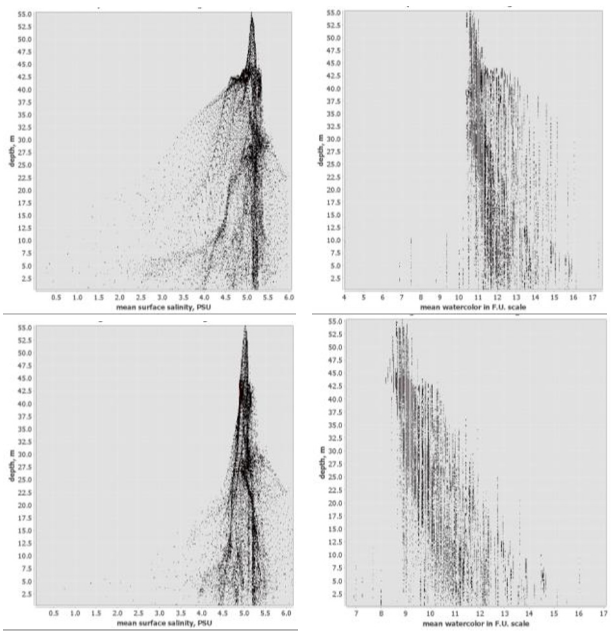

Fig. 3. Mean sea surface salinity in 1993-2021 (left) and mean watercolor in 1998-2018 (right) in April (top row) and August (bottom row).

The consistency of the satellite derived data and in situ watercolor observations is given in Table 1. Observed in situ data characterise the watercolor considering all available data entries for each month. A major part of the data entries corresponds to observations in May and August. Observed watercolor data show the maximum values in April and May: the mean watercolor of all available observation data entries had been below or equal 15 in 75% in measurements done in April during 1998-2018 period. The same situation is true in May. The spring maximum effect is less expressively seen in the satellite derived data – the 75% percentile is 13 in April and 11 in May: there have been 75% of the years in 1998-2018 period with the mean satellite derived watercolor value in the domain equal or below 13 in April. The contrast between month is more expressed in observations on site than in the satellite derived watercolor values. It shows that its spatial variability is more dominant than interannual. The minor peak in autumn possibly connected with stormy weather conditions has been acquired.

Table 1. Watercolor mean in Forel-Ule scale in years 1998-2018 in the open waters of the Gulf of Riga.

	In situ observations				By satellite		
Month	entries	50%	25%	75%	50%	25%	75%
Jan	*19*	9	9	11			
Feb	*26*	11	11	12	10	10	11
Mar	*37*	11	9	13	11	11	12
Apr	*80*	13	9	15	12	9	13
May	*244*	13	9	15	11	10	11
Jun	*60*	9	9	11	10	9	10
Jul	*66*	11	9	13	10	10	11
Aug	*169*	13	11	13	9	9	10
Sep	*66*	9	9	11	10	8	10
Oct	*45*	9	9	9	10	9	11
Nov	*87*	11	9	13	12	12	12
Dec	*21*	9	9	9			

3.2 Correlation of the sea surface salinity and the watercolor and Secchi depth in the Gulf of Riga

The correlation between mean sea surface monthly values and watercolor and Secchi depth values provided by satellite data has been shown in Fig. 4 and Fig. 5. The negative correlation in nearshore regions have been shown for watercolor/salinity – top row in Fig. 4 and positive correlation for Secchi depth/salinity, Fig. 5. Much weaker opposite or no correlation in the central part of the Gulf has been acquired.

The numerical experiment has been done by correlating the years with and without seasonal hypoxia in the Gulf of Riga – middle and bottom rows in Fig. 4 and 5. The results show similar pattern, the stronger correlation in the coastal part is seen. In the years with seasonal hypoxia present – there is also stronger positive correlation seen in northern region of the open part of the Gulf of Riga with interpretation being not obvious.

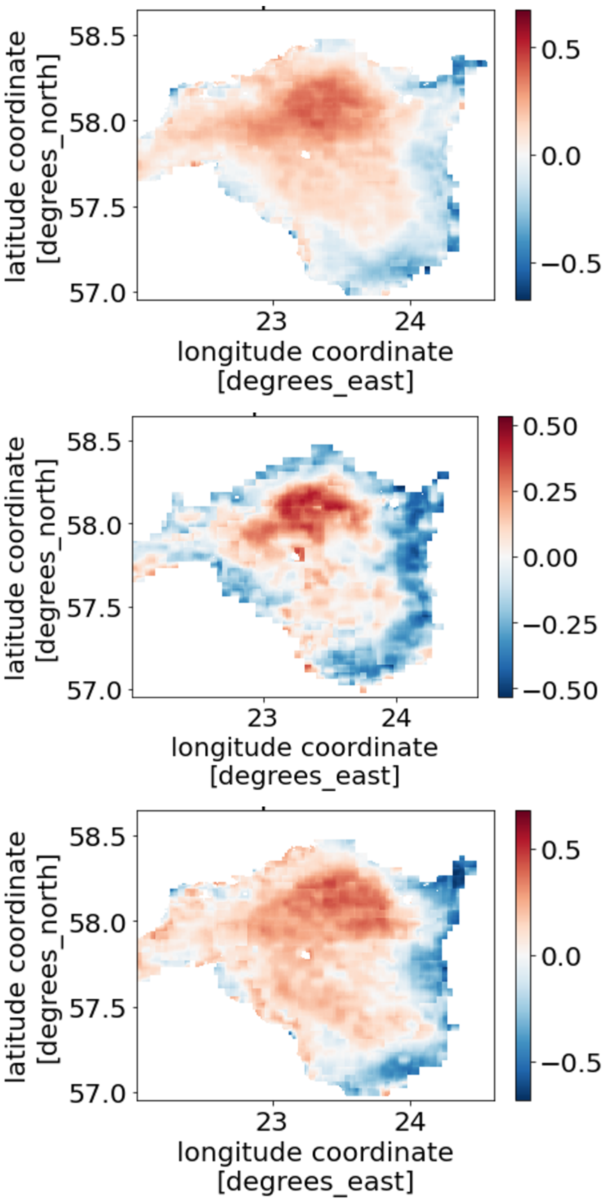

Fig. 4. Correlation between monthly mean surface salinity and satellite derived watercolor: all available monthly values in period 1998-2018 used (top); monthly values from the years with seasonal hypoxia (middle); without seasonal hypoxia (bottom). Correlation drawn in points having more than 30 data points.

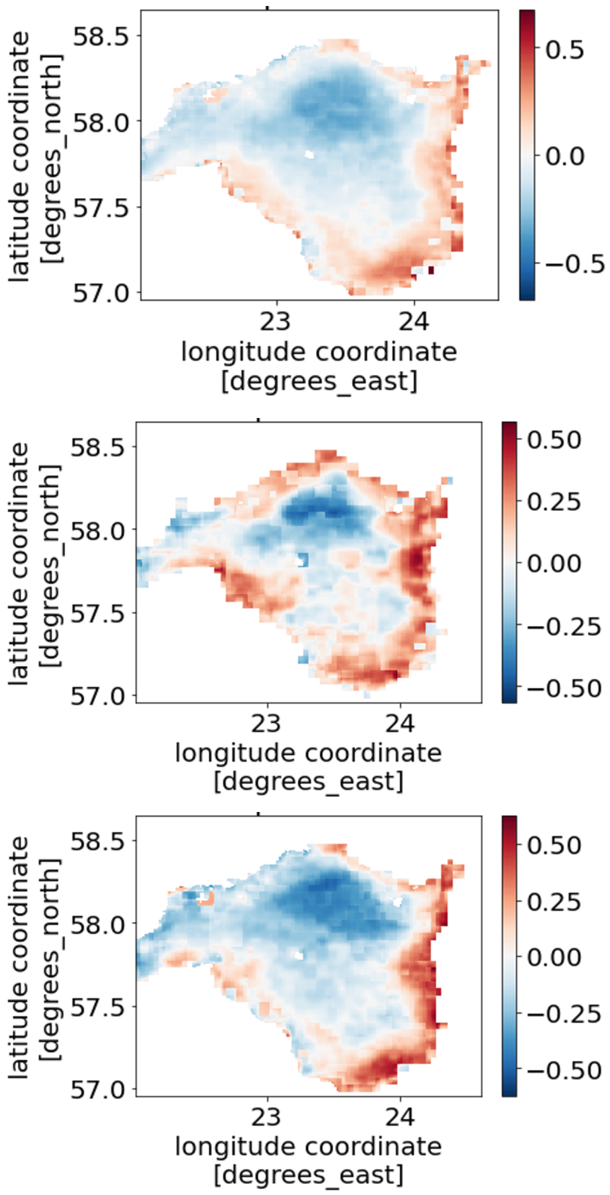

Fig. 5. Correlation between monthly mean surface salinity and satellite derived Secchi depth: all available monthly values in period 1998-2018 used (top); monthly values from the years with seasonal hypoxia (middle); without seasonal hypoxia (bottom). Correlation drawn in points having more than 30 data points.

3.3 Watercolor in open waters of the Gulf of Riga in years with and without seasonal hypoxia observed

Convincing difference between both watercolor sets has not been found, Tables 2, 3. Minor differences seen: 1) higher mean in July and August; lower mean in October; lower 75% percentile in November are distinguishable in satellite data with the seasonal hypoxia, Table 2; 2) lower mean in situ observed watercolor in May in years with seasonal hypoxia, Table 3.

Table 2. Watercolor mean in the open waters of the Gulf of Riga in years with/without seasonal hypoxia.

	Satellite derived					
	with			without		
Month	50%	25%	75%	50%	25%	75%
Feb	10	10	11	10	10	11
Mar	11	11	12	12	11	12
Apr	12	12	12	12	11	13
May	11	10	12	11	11	11
Jun	10	10	10	10	9	11
Jul	11	10	11	10	10	10
Aug	10	10	10	9	9	10
Sep	10	9	10	10	9	10
Oct	10	9	11	11	11	11
Nov	12	12	12	12	12	13

Table 3. Watercolor mean in the open waters of the Gulf of Riga in years with/without seasonal hypoxia. Observation data entry analysis.

	In situ observations							
	with				without			
Month	entries	50%	25%	75%	entries	50%	25%	75%
May	*49*	13	11	19	*79*	15	12	19
Aug	*52*	13	11	13	*42*	13	11	15
Nov	*18*	11	9	13	*24*	12	9	13

4 Conclusions

The seasonality of the watercolor in open waters - less affected by longshore sediment transport and estuaries carried nutrients and colored organic matter than transitional and coastal waters of the Gulf of Riga - has been shown.

The highest watercolor in open waters is usually observed in Spring. The river impact reaching the marine surface regions with the depth below 30m has been clearly shown in April. The high homogeneity in the mean sea surface salinity and watercolor in the region with the depth >40 m in April has been shown. Relatively stable mean surface salinity is seen in the region with the depth >30 m in August instead.

Negative correlation between monthly mean surface salinity and satellite derived watercolor and positive correlation between monthly mean surface salinity and satellite derived Secchi depth has been shown in coastal region of the Gulf of Riga.

Potential impact of seasonal hypoxia on the watercolor in the Gulf of Riga has been analysed.

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References

1. A. Omstedt, L.B. Axell, Cont. Shelf Res. **23**, 265 (2003)
2. V. Fleming-Lehtinen, M. Laamanen, Estuar., Coast. and Shelf Sci. **102–103**, 1 (2012)
3. I. Kokorite, M. Klavins, V. Rodinov, G. Springe, Environ. Monit. Assess. **184**, 4999 (2012)
4. S.T. Stoicescu, J. Laanemets, T. Liblik, M. Skudra, O. Samlas, I. Lips, U. Lips, Biogeosciences **19**, 2903 (2022)
5. A. Stigebrandt and A. Andersson, Front. Mar. Sci. **7**, 572994 (2020)
6. Helcom Baltic Sea Environment factsheet. (2020)
7. J. Pitarch, H.J. van der Woerd, R.J.W. Brewin, O. Zielinski, *PANGAEA* (2019)
8. C. Petus, C.J. Collier, M. Devlin, M. Rasheed, S. McKenna, Mar. Environ. Res. **137**, 163 (2014)
9. V. Frishfelds, D. Cepīte- Frišfelde, A. Timuhins, U. Bethers, & J. Sennikovs, Zenodo. (2023)