The response to the reviewer #1 comment on manuscript by Meler at al., Ocean Sci. Discuss., doi:10.5194/os-2016-34,

Anonymous Referee #1

General comments

The paper presents very interesting work. Obviously, a lot of careful work has gone into this study and the assessment of model performance is detailed and thorough. It does, however, not become clear what the motivation for of this work is. What are potential applications for each of the presented models and where is the advantage over previously published work? What progress has been made?

Reply: We would like to thank Reviewer 1 for appreciation of our work. We will make effort to explain our motivation and implication of our research and proposed model in the broad context of the possible application in remote sensing, biogeochemistry and carbon cycle studies in enclosed marine basins and estuaries and fresh water lakes. The Reviewer #2 has similar remark therefore we have added a short paragraph in Introduction that fit our research in the broader aspects of applied environmental studies. Proposed new paragraph and references is included below:

"The CDOM absorption coefficient is a very reliable predictor of the dissolved organic carbon concentration in fresh and estuarine waters (Brezonik et al., 2015; Kutser et al., 2015; Toming et al., 2016), and therefore this optical parameter could be easily applied in various aspects of organic carbon biogeochemistry. The ocean color remote sensing offer new operational satellite missions based on medium ground resolution (of the order of 250 m) sensors, like the European Earth Observation Copernicus program Sentinel-3 OLCI mission, and the US Joint Polar Satellite System program VIIRS sensors. These radiometers are particularly suitable for remote sensing observations of inland water bodies and estuaries (Palmer et al., 2015; Kwiatkowska et al., 2016). The optical properties of CDOM, abundant in fresh and estuarine waters at high concentrations, shift the spectral maximum of the water transparency to solar radiation and water leaving radiance towards the longer wavelengths (Darecki et al., 2003; Morel and Gentili, 2009). In extreme cases, in humic boreal lakes, CDOM reduces the water-leaving radiance intensity in the visible spectrum almost to zero (Ficek et al., 2011; Ficek et al., 2012; Ylöstalo et al., 2014). To minimize this effect, the remote sensing algorithm for retrieving bio-optical and biogeochemical variables in optically complex waters has been based on spectral band combinations at longer wavelengths where CDOM absorption is low (e.g. Ficek et al., 2011). Therefore, models need to be developed that enable the complete CDOM absorption spectrum to be reconstructed. Detailed spectral information of CDOM absorption is required, for example, to calculate the spectral indices related to molecular weight, degree of photochemical transformation (Helms et al., 2008) or aromaticity (Weishaar et al., 2003). "

The references list has been updated with those cited in this paragraph.

Specific comments

1. Why was a linear function fitted to the data in Figure 2

Data presented on Figure 2 were showed in the semi – logarithmic scale (the $a_{\mathrm{CDOM}}(400)$ on X-axis is shown in logarithmic scale, the spectral slope S is shown in linear scale). We have used the logarithmic function (equations 10, 11 and 12), to approximate relationship between $a_{\mathrm{CDOM}}(400)$ and S, and therefore graphical representation of logarithmic function in a semi-logarithmic scale, is a straight line.

2. Slope values for the data set presented seem fairly high. What about the quality of the data used to establish the models developed here: is there a dependency of slope values on concentrations which is caused by artifacts due to limited data quality (the use of a short pathlength in combination with relatively low CDOM concentrations)? Low coefficients of determination for the calculation of slope values point towards issues here.

We disagree with the reviewer comment.
The Baltic Sea CDOM absorption data were analyzed twice with focus of on the spectral slope values and its dependency with CDOM absorption coefficient values.
The fist study published by Kowalczuk et al., (2206) presented the differences between spectral slope values calculated with different methods (linear vs. non-linear) and different spectral range used for slope calculations. We have proved in that paper that non-linear fitting methods returns higher slope values compared to linear fit log-transformed absorption data, and that the broader spectral range the smaller uncertainty is slope values would be achieved. The averaged spectral slope value $S_{300\text{-}600}$ (calculated with use of non-linear fitting method) presented in the paper by Kowalczuk et al., (2006) was 0.02334 nm^{-1} (n = 1610, C.V. = 12%)
The second study, published by Kowalczuk et al., (2015), presented most complete to date statistical distribution of the spectral slope values in the function of salinity in the Baltic Sea. This statistical distribution has been derived upon 3636 measured $a_{\mathrm{CDOM}}(\lambda)$ spectra and the spectral slope was calculated with use the same Matlab code and in the same spectral range as we used in the current submission Presented variability range of the spectral slope S, contained within 0.015 to 0.030, plus few point over the value of 0.030. We have also characterized the CDOM optical properties in end members: in the inflowing riverine fresh waters and in marine open Baltic Sea waters. The statistical description CDOM optical properties in open Baltic Sea waters presented in the paper by Kowalczuk et al., (2015) were as follow: salinity at the surface: 7.381 ± 0.209, $a_{\mathrm{CDOM}}(350) = 1.617 \pm 0.233$ m^{-1}, and $S_{300\text{-}600} = 0.0232 \pm 0.0015$ nm^{-1}, (n = 673). The fresh water end member was characterized by following average and standard deviation values: salinity = 0.918 ± 0.546; $a_{\mathrm{CDOM}}(350) = 8.705 \pm 2.842$ m^{-1} and spectral slope coefficient $S_{300\text{-}600} = 0.0185 \pm 0.0008$ nm^{-1}, respectively (n = 30). The Baltic Sea data set used in the current submission were a subset of the data described by Kowalczuk et al. (2015). The same method for spectral slope calculation has been applied in to process the $a_{\mathrm{CDOM}}(\lambda)$ in lakes. In the current manuscript we presented the spectral slope variability range within 0.007 up to 0.30, both in lakes and Baltic Sea, (see, Table 2). The CDOM absorption and spectral slope variability and averaged values were very close to those already reported by Kowalczuk et al., 2006 and 2015. The lower spectral slope values were observed in lake waters, which agrees with current the knowledge about the spectral properties of CDOM absorption (CDOM absorption in fresh water is larger and absorption spectra flatter). The observed inverse dependence of the spectral slope with increasing CDOM absorption has been explained in details in paper by Stedmon and Markager (2003) and explored further in the paper by Kowalczuk et al. (2006).

We were very conservative in while performing $a_{\mathrm{CDOM}}(\lambda)$ data base re-analysis and only those spectral slope values were used in Kowalczuk et al. (2015) paper that were fitted with R^2 at least 0.99. The re-analysis of CDOM absorption data based presented in paper by Kowalczuk et al., (2015), contained CDOM spectra measured with different brands of research grade spectrophotometers and different pathlengths used in measurements. We did not observed any statistical difference related to subset of data measured with different apparatus or different pathlenghts. We can assure that 5 cm cuvette used in CDOM absorption measurement in open Baltic Sea water gave similar results as CDOM absorption spectra measured with use of 10 cm cuvettes. We quite confident in quality of our data and we do not see any issue related to low quality of data.

3. Direct comparison of the different models (presented here and previously published) might be easier if values were presented in separate tables for every statistic metric rather than each model. Similarly, Figure 10 could be re-arranged, so that each panel shows the outputs of all models for a single chlorophyll concentration which would enable a more direct comparison.

Reply: The figure 10 has been re-arranged according to reviewer suggestions.

4. Page 7: It would be helpful to add a short description and purpose of the different statistical metrics.

Reply: The following paragraph has been added to explain statistical metrics used in uncertainty analysis.

Linear metrics are represented by relative mean error and standard deviation were used to measure dispersion of results and asses the modes uncertainty. The relative mean error (Eq. 5a) is the average of all relative deviations between measured and calculated values and it quantified the systematic error. Standard deviation (Eq. 5b) is the dispersion around the average error due to random errors and it quantified the statistical error. Logarithmic metrics were used to better describe the uncertainty in the data ste varying in the range of several orders of magnitude. The standard error factor described how many times the error is deviated from the average value. .

5. The structure, especially of the Discussion section (e.g. paragraph ll. 537.), should be revised as it is difficult to follow the argumentation at times. The Discussion contains paragraphs better suited in the Introduction and Results sections.

The revised manuscript structure will thoroughly corrected in terms of used argumentation and clarity. The whole manuscript will be edited to clarify the English usage, grammar and style.

Technical comments

The language needs to be tidied up thoroughly prior to publication. It distracts from the content.

Reply: We will send the revised manuscript to a English editor prior its submission to a journal editor office.

The symbols for CDOM absorption coefficients and abbreviation for chlorophyll a concentration are used inconsistently throughout the manuscript.

Reply: It has been amended.

Lines 177 – 180: Add reference for protocol used in this work.

Reply: It has been amended.

Line 188/ Eq. 4: Specify at which wavelength chlorophyll specific absorption coefficients calculated.

Reply: It has been amended.

Line 198: The term ’standard deviation’ is slightly mis-leading in this context as Eq. 5b is used as descriptor of the overall error rather than variability in the data.

Line 203: Move symbol definitions to the top of the paragraph, i.e. line 197.

Reply: It has been amended.

Line 264: How are relative RMSE values calculated? If a parameter has a logarithmic distribution, simply dividing the RMSE by the mean value creates a potential bias.

Reply:
All optical parameters values were presented in logarithmic scale, because in this way the relationship between these parameters (which varies with respect to more than two or three orders of magnitude) are more visible. The linear metric were applied to untransformed values of optical and bio-optical parameters. Due to broad range of variability (spanning up to three orders of magnitude) we additionally used the logarithmic metric to reduce to bias due to occurrence of very high values in the data set, that could impact the linear metrics calculations.

Line 452: ‘uncertainty level’ - Which statistical metrics does this refer to?

Reply: “Uncertainty level” in this line is refer to arithmetic metric.

Line 519: This paragraph contains multiple subjective assessments of model performances. It would be helpful to add numbers to support the statements made.

Reply: We will revise the Discussion section to make our statements clear, and to assess the model performances on objective arguments.

The response to the reviewer #2 comment on manuscript by Meler at al., Ocean Sci. Discuss., doi:10.5194/os-2016-34,

Anonymous Referee #2

General comments

An interesting work in which a lot of effort for sampling, analysis and modeling has gone. The motivation for this work is not quite clear. Advantages should be more highlighted, combined with future prospects for its application.

Reply: We would like to thank Reviewer 2 for appreciation of our work. We will make effort to explain our motivation and implication of our research and proposed model in the broad context of the possible application in remote sensing, biogeochemistry and carbon cycle studies in enclosed marine basins and estuaries and fresh water lakes. The Reviewer #1 has similar remark therefore we have added a short paragraph in Introduction that fit our research in the broader aspects of applied environmental studies. Proposed new paragraph and references is included below:

"The CDOM absorption coefficient is a very reliable predictor of the dissolved organic carbon concentration in fresh and estuarine waters (Brezonik et al., 2015; Kutser et al., 2015; Toming et al., 2016), and therefore this optical parameter could be easily applied in various aspects of organic carbon biogeochemistry. The ocean color remote sensing offer new operational satellite missions based on medium ground resolution (of the order of 250 m) sensors, like the European Earth Observation Copernicus program Sentinel-3 OLCI mission, and the US Joint Polar Satellite System program VIIRS sensors. These radiometers are particularly suitable for remote sensing observations of inland water bodies and estuaries (Palmer et al., 2015; Kwiatkowska et al., 2016). The optical properties of CDOM, abundant in fresh and estuarine waters at high concentrations, shift the spectral maximum of the water transparency to solar radiation and water leaving radiance towards the longer wavelengths (Darecki et al., 2003; Morel and Gentili, 2009). In extreme cases, in humic boreal lakes, CDOM reduces the water-leaving radiance intensity in the visible spectrum almost to zero (Ficek et al., 2011; Ficek et al., 2012; Ylöstalo et al., 2014). To minimize this effect, the remote sensing algorithm for retrieving bio-optical and biogeochemical variables in optically complex waters has been based on spectral band combinations at longer wavelengths where CDOM absorption is low (e.g. Ficek et al., 2011). Therefore, models need to be developed that enable the complete CDOM absorption spectrum to be reconstructed. Detailed spectral information of CDOM absorption is required, for example, to calculate the spectral indices related to molecular weight, degree of photochemical transformation (Helms et al., 2008) or aromaticity (Weishaar et al., 2003). "

The references list has been updated with those cited in this paragraph.

Specific comments

Some structures should be revised, especially the discussion. Argumentation is often difficult to follow. Short and concise sentences might be easier. A little bit mixed up with other chapters, especially results.

Reply: The revised manuscript structure will thoroughly corrected in terms of used argumentation and clarity. The whole manuscript will be edited to clarify the English usage, grammar and style.

Fig 10 could be arranged according to chlorophyll a concentrations.

Reply: It has been amended.

To clarify and support statements add numbers (i), (ii), especially in the discussion section.

Reply: This remark is similar to comment by Reviewer #1. We will make effort during manuscript revision to make our statements clear, and to assess the model performances on objective arguments.

Technical comments

The language should be revised prior to publication.
Reply: As we already stated the revised manuscript will corrected by professional English editor.

Sentences are often too long, resulting in confusion.

Reply: The English usage, grammar and style will be corrected by professional English editor.

Formulas should be consistent; the same goes for the description of existing parameters. Symbols and abbreviation are used inconsistently in manuscript, e.g. chl a, CDOM. This should be revised prior to publication.

Reply: It has been amended.

Lines 175ff: Add reference.

Reply: It has been amended.

Line 182ff: Eq 4: At which wavelength was it calculated?

Reply: It has been amended.

Line 203-212: not consistent with others, try to rearrange.

Reply: It has been amended.

Parameterization of the light absorption properties of chromophoric dissolved organic matter in the Baltic Sea and Pomeranian Lakes

Justyna Meler[a*], Piotr Kowalczuk[a], Mirosława Ostrowska[a], Dariusz Ficek[b], Monika Zabłocka[a], Agnieszka Zdun[a]

[a] Institute of Oceanology Polish Academy of Sciences, Powstańców Warszawy 55, 81-712 Sopot, Poland

[b] Institute of Physics, Pomeranian University of Słupsk, Bohaterów Westerplatte 64, 76-200 Słupsk, Poland

[*] corresponding author: jmeler@iopan.pl

Keywords: Baltic Sea; Pomeranian lakes; Chromophoric Dissolved Organic Matter; three alternative models of CDOM absorption; light absorption; ocean optics

Abstract

This study presents three alternative models for estimating~~on of~~ the absorption properties of Chromophoric Dissolved Organic Matter~~,~~ $a_{CDOM}(\lambda)$. For this analysis we used a database containing 556 absorption spectra measured in 2006 – 2009 in different regions of the Baltic Sea (open and coastal waters, the Gulf of Gdańsk and the Pomeranian Bay), at river mouths, in the Szczecin Lagoon and also in three lakes in Pomerania~~n~~ ~~(lakes in~~ Poland) ~~– Lakes~~ Obłęskie, Łebsko and Chotkowskie. ~~Observed~~ The variability range of the CDOM absorption coefficient at 400 nm, $a_{CDOM}(400)$, ~~contained~~ lay within 0.15 – 8.85 m^{-1}. The variability in $a_{CDOM}(\lambda)$ was parameterized with respect to the ~~three orders of magnitude~~ variability over three orders of magnitude in the chlorophyll *a* concentration *Chla* (0.7 – 119 mg m^{-3}). The c~~C~~hlorophyll *a* concentration and ~~CDOM absorption coefficient,~~ $a_{CDOM}(400)$ were correlated, and a statistically significant, non-linear empirical relationship between th~~o~~ese parameters was derived (R^2=0.83). ~~Based on~~On the basis of the ~~observed~~ co-variance between these parameters, we derived two empirical mathematical models that enabled to ~~project~~ design the CDOM absorption coefficient dynamics in natural waters and reconstruct the ~~completed~~ ~~updated~~ complete CDOM absorption spectrum in the UV and visible spectral domains. The input variable in the ~~-~~first model was the chlorophyll *a* concentration, ~~used the chlorophyll *a* concentration as the input variable. The second model used the~~ and in the ~~$a_{CDOM}(400)$, as the input variable~~ second one it was $a_{CDOM}(400)$. Both models were fitted to a power function,

and ~~the~~ a second-~~-~~order polynomial function was used as the exponent. Regression coefficients for ~~derived~~ these formulas were determined for wavelengths from 240 to 700 nm at 5 nm intervals~~-~~. Both approximations reflected the real shape of the absorption spectra with a low level of uncertainty. Comparison of these approximations with other models of light absorption by CDOM ~~proved~~ demonstrated ~~that~~ that our ~~proposed~~ parameterizations were ~~better~~ superior (bias from -1.45% to 62%, RSME from 22% to 220%) for estimati~~o~~ng CDOM absorption in the optically complex waters of the Baltic Sea and Pomeranian lakes.

1. Introduction

All natural waters contain optically significant constituents that determine~~s~~ their inherent optical properties, i.e. the~~:~~ absorption coefficient, scattering coefficient and beam attenuation coefficient. The total absorption coefficient in the ultraviolet and visible spectral range of the electromagnetic radiation spectrum~~,~~ is almost entirely determined by four main groups of absorbents: water molecules, organic and inorganic suspended particulate matter (SPM)~~,~~ and Chromophoric Dissolved Organic Matter (CDOM). The quantit~~y~~ative and qualitative properties of these absorbents significantly affect the ~~quantity~~ amount and spectral distribution of light in the aquatic environment. The absorption of pure water, as measured by Pope and Fry (1997), is almost constant in natural waters and ~~may~~ can be omitted ~~in further~~ from the following analysis because it does not contribute to ~~a~~ the variability ~~of~~ in the total absorption coefficient. Changes in spectral values of ~~the~~ pure sea water absorption are almost entirely determined by the concentration and ~~the~~ composition of sea salt ions and dissolved gases~~,~~; they ~~and is~~ are ~~mostly~~ pronounced mostly in the UV-A and UV-B spectral regions below 300 nm (Woźniak and Dera, 2007). Spectral properties (values and spectral shape) and the mutual proportions of light absorption coefficients by CDOM~~,~~ (a_{CDOM} (λ)), ~~, by~~ phytoplankton pigments~~,~~ ($a_{ph}(\lambda)$), organic detritus and mineral particles ($a_{NAP}(\lambda)$)~~,~~ determine the spectral shape and magnitude of the total absorption spectrum as well as affect~~ing~~s both the inherent and the apparent optical properties of natural waters (Woźniak and Dera, 2007).

~~The~~ Chromophoric Dissolved Organic Matter (CDOM) is the uncharacterized fraction of the dissolved organic matter pool consisting ~~from~~ of a heterogeneous mixture of water-soluble organic compounds that have the ability to absorb light (Nelson and Siegel, 2002). The effect of ~~the~~ CDOM absorption is mostly visible in the UV and blue spectral range of electromagnetic radiation, where the CDOM contribution to the total non-water absorption ~~could reach~~ can be as much as 90%, even in the clearest natural waters found in South Pacific

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Subtropical Gyre south of~~f~~ Easter Island~~,~~ (Morel et al., 2007; Bricaud et al., 2010; Tedetti et al., 2010). The CDOM absorption band ~~overlaps~~ also overlaps ~~with~~ the primary phytoplankton pigment absorption band in the blue part of the spectrum; this leads to ~~contributing to~~ significant errors of standard algorithms for retrievals of chlorophyll *a*, especially in coastal ocean, ~~-~~and shelf waters and semi-enclosed seas (Darecki and Stramski, 2004; Siegel et al., 2005). Therefore, appropriate quantitative and qualitative descriptions of the optical properties of CDOM ~~is~~ are crucial ~~in~~ for the ocean color remote sensing of aquatic environments.

The CDOM absorption coefficient is a very reliable predictor of the dissolved organic carbon concentration in fresh and estuarine waters (Brezonik et al., 2015; Kutser et al., 2015; Toming et al., 2016), and therefore this optical parameter could be easily applied in various aspects of organic carbon biogeochemistry. The ocean ~~The new ocean~~ color remote sensing offer new operational satellite missions based on medium ground resolution (of the order of 250 m) sensors, like the European Earth Observation Copernicus program Sentinel-3 OLCI mission, ~~and the space sensors of the European Earth Observation Copernicus program~~ and the US Joint Polar Satellite System program VIIRS sensors. These ~~of the US Joint Polar Satellite System program, offered the medium ground resolution (in of the order of 250 m) radiometers, which would~~ are particularly ~~be~~ suitable for remote sensing observations of inland water bodies and estuaries (Palmer et al., 2015; Kwiatkowska~~,~~ et al., 2016). The optical properties of CDOM, abundant in fresh and estuarine waters at high concentrations, shift the spectral maximum of the water transparency to solar radiation and water leaving radiance towards the longer wavelengths (Darecki et al., 2003; Morel and Gentili, 2009). In extreme cases, in humic boreal lakes, ~~the~~ CDOM reduces the water-~~-~~leaving radiance intensity in the visible spectrum almost to ~~null~~ zero (Ficek et al., 2011; Ficek et al., 2012; Ylöstalo et al., 2014). To minimize this effect, the remote sensing algorithm for retrieving~~als of~~ ~~the~~ bio-optical and biogeochemical variables in optically complex waters has been~~were~~ based on spectral band~~s~~ combinations at longer wavelengths where CDOM absorption is low (e.g. Ficek et al., 2011). Therefore, ~~there is a need for development of~~ models need to be developed that ~~that would~~ enable ~~to reconstruct~~ the complete CDOM absorption spectrum, to be reconstructed. ~~The d~~Detailed spectral information of CDOM absorption is required, for example, to calculate the spectral indices related to molecular weight, degree of photochemical transformation (Helms~~,~~ et al., 2008) or aromaticity (Weishaar et al., 2003).

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CDOM ~~plays~~ also plays various ecological roles in aquatic environments: even small concentrations strongly absorb UV radiation, protecting organisms from its destructive action. Higher levels of CDOM absorption~~s~~ limit~~s~~ the amount of radiation available for photosynthesis, ~~and~~ consequently reducing the primary production of organic matter in that water (Górniak, 1996; Wetzel, 2001). CDOM plays an important part in the various biological processes taking place in water bodies: it can affect the species composition, number and size of plankton organisms (Arrigo and Brown, 1996; Campanelli et al., 2009), and in oligotrophic lakes can promote the growth of bacterioplankton (Moran and Hodson, 1994). Several authors have pointed out that CDOM is a potential source of reactive oxygen forms in aquatic ecosystems, which has a considerable influence on a variety of biological processes (Whitehead and de Mora, 2000; Kieber et al., 2003).

CDOM absorption decreases exponentially towards longer wavelengths and can be described by the exponential function (Jerlov, 1976, Bricaud et al., 1981,Kirk 1994):

$$a_{\mathrm{CDOM}}(\lambda) = a_{\mathrm{CDOM}}(\lambda_0)e^{-S(\lambda_0 - \lambda)} \qquad (1)$$

where~~:~~ $a_{\mathrm{CDOM}}(\lambda)$ is the light absorption coefficient for a given wavelength λ, λ_0 is the reference wavelength~~,~~ and S is the slope of the spectrum within a given wavelength interval.

~~The~~ CDOM accumulates in ~~the~~ surface Baltic Sea waters as a combined effect of a very ~~high~~ large inflow of fresh water from rivers, ~~and~~ the limited exchange of waters with the North Sea and the very high productivity ~~of~~ in ~~this marine basin,~~ that sea (Kowalczuk et al., 2006). ~~The~~ ~~S~~systematic studies over the last two decades on the optical properties ~~in the~~ of Baltic Sea waters and its adjoining ~~acent~~ fresh water systems, i.e. ~~–~~coastal lagoons and Pomeranian lakes, have ~~provided~~ yielded evidence that ~~the~~ CDOM is the principal absorbent of solar radiation and the main factor governing their optical properties (Kowalczuk 1999; Kowalczuk et al., 2005a; 2006; 2010; Ficek et al., 2012; Ficek 2013).

We ~~have~~ performed analyses using a combined data set of optical properties of marine and lacustrine water samples, treating the data as a single, pooled set. ~~O~~The optical properties of lacustrine waters ~~displayed a resemblance to~~ resembled ~~marine waters in~~ the Baltic Sea waters, despite the ~~observed~~ differences in the trophic status of th~~e~~ese water bodies. ~~According to~~ In accordance with Choiński (2007), the lake~~s~~ waters were divided into ultra-oligotrophic, oligotrophic, mesotrophic, eutrophic, hy~~i~~pereutrophic and dystrophic. The trophicity ~~i~~was determine~~s~~d ~~by~~ from the concentration of chlorophyll a, the water transparency (~~determined~~ measured ~~by~~ using a Secchi disk)~~,~~ and the concentration of ~~biogenic~~

~~factors~~nutrients, e.g. nitrogen and phosphorus (Carlson, 1977; Kratzer and Brezonik, 1981). The ranges of concentrations of chlorophyll and trophicity-defining nutrients ~~defining trophicity~~ ~~a~~were ~~higher~~ wider in lakes than in ~~marine~~ sea waters. In our modelling approach we ~~have~~ assumed that lakes ~~c~~could ~~ould~~ be treated as a natural extension of coastal, lagoon and river mouth waters.

The main objective of the present work was to derive three alternative parameterization~~s~~ scenarios of the relationships between the CDOM absorption coefficient in ~~the~~ Baltic and Pomeranian lake~~s~~ waters, and physical or biogeochemical variables. The motivation for developing ~~ment of~~ these models was to estimate ~~a~~ the complete spectrum of ~~the~~ CDOM light absorption coefficients by using different input parameters: *i*) ~~in the first scenario the~~ known chlorophyll *a* concentrations in the first scenario, *ii*) ~~in the second scenario~~ known values of the CDOM absorption coefficient at 400 nm, $a_{CDOM}(400)$, in the second scenario, *iii*) and ~~in the third scenario~~ known values of $a_{CDOM}(400)$ and known nonlinear relationships between CDOM absorption coefficient and the spectral slope coefficient *S* in the third scenario. ~~Developed~~ These models can be used to improve the accuracy of ocean colo~~u~~r remote~~s~~ sensing algorithms for retrieving~~al of~~ environmental variables in the Baltic Sea, adjacent ~~estuaries~~ river mouths, ~~and~~ lagoons and fresh-water lakes.

2. Material and methods

2.1 *Sampling area*

Water samples for determining ~~ation of~~ optically significant water constituent~~s~~ concentrations were collected from August 2006 to November 2009 in the southern Baltic and in three lakes in the Pomeranian Lake District (Poland) during the long~~-~~term observation program of inherent and apparent optical properties for calibrati~~o~~ng and validati~~o~~ng ~~of~~ ocean colo~~u~~r satellite imagery products, ~~conducted~~ run by the Institute of Oceanology, Polish Academy of Sciences, Sopot, Poland, (IOPAN). The l~~L~~ocations of the 116 measuring stations~~,~~ where empirical data were gathered (a total of 413 data sets) during 16 cruises of r/v Oceania on the Baltic ~~we~~are shown on Figure 1, and the cruises details ~~is~~ are given in ~~the~~ Table 1. ~~R~~The research cruises were organized so as to capture the dynamics of natural seasonal variability occurring in temperate waters: *i*) at the end of ~~the~~ winter, before the onset of the spring phytoplankton bloom, when wind-driven mixing, the vertical convective thermohaline circulation, reduced biological activity and reduced riverine outflow all result in clearer surface waters; *ii*) in spring, when the spring phytoplankton bloom coincides with the maximum freshwater runoff from the Baltic Sea ~~watershed~~drainage basin; *iii*) ~~and~~ at the end of summer, when ~~at the peak of~~ secondary phytoplankton blooms peak and the ~~period of maximal~~ thermal stratification of waters reaches its maximum extent. The geographical coverage of the samples included the Gulf of Gdańsk, the Pomeranian Bay, the Szczecin Lagoon, Polish coastal waters and the open sea (the Baltic Proper). The coastal sites in the Gulf of Gdańsk and the Pomeranian Bay are under the direct influence of two major river systems, the Vistula and the Odra, respectively, which drain the majority of Poland. Additionally, samples were collected twice a month ~~on~~ at the sampling station ~~at~~ on the Sopot pier (Gulf of Gdańsk), from which 66 sets of data were obtained. Field observations were also carried out from April 2006 to November 2009 ~~on~~ at monthly intervals ~~a month~~ (except the months when the lake surfaces ~~of the lake~~ w~~as~~ere covered with ice) ~~i~~on three Pomeranian lakes (Łebsko, Chotkowskie and Obłęskie) from which 77 data sets were obtained. ~~Selected~~ These lakes are enclosed water bodies with only small rivers flowing in and out of them. Lake Łebsko is a specific case, however: it is a coastal lake, ~~and~~ connected directly to the sea by a short channel~~anal~~. Part of the land around Lake Łebsko ~~area~~ immediately adjacent to the channel ~~anal~~ can, on occasion, be inundated when large backflows of sea water enter the lake. The lake's water level can then rise by 50-60 cm (Chlost and Cieśliński, 2005). Such a situation obviously affects the composition and properties of the lacustrine water. Similar effects, resulting from the great variability of water properties, can be expected at the points where rivers flow into lakes. The lacustrine water in these areas is thus modified by the river water.

2.2 *Sample~~s~~ processing*

Discrete samples of water were taken from the surface layer of the southern Baltic and the three Pomeranian lakes with ~~use of the~~a Niskin bottle. The samples for spectroscopic measurements of CDOM light absorption were filtered twice~~underwent a two-step filtration process~~;~~.~~ ~~The first filtration~~once ~~was~~ through acid-washed Whatman glass fib~~e~~re filters (GF/F, nominal pore size 0.7 µm)~~.~~, then ~~The water was then passed~~ through acid-washed Sartorius 0.2 µm pore cellulose membrane filters to remove fine~~-sized~~ particles. Spectrophotometric scans of CDOM absorption spectra were ~~performed~~ done with ~~use the~~ a Unicam UV4-100 double beam spectrophotometer in the 240-700 nm spectral range; these instruments were installed ~~both~~ in the land ~~base~~ laboratory and on board ~~of~~ the research ship ~~in the 240-700 nm spectral range~~. The cuvette path length was 5 cm and ~~the~~ MilliQ water was used as the

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reference for all measurements. The absorption coefficient $a_{\mathrm{CDOM}}(\lambda)$ was calculated using the following equation:

$$a_{\mathrm{CDOM}}(\lambda) = 2.303 \cdot A(\lambda)/L, \qquad (2)$$

where~~:~~ A(λ)~~,~~ is the optical density~~,~~ and L is the optical path length in meters; ~~and~~ the factor 2.303 is the natural logarithm of 10.

A nonlinear least squares fitting method using ~~a~~ the Trust-Region algorithm implemented in Matlab R2009 was applied (Stedmon et al., 2000, Kowalczuk et al., 2006, 2015) to calculate the CDOM absorption spectrum slope coefficient~~,~~ *S*~~,~~ in the ~~spectral range~~ 300-600 nm spectral range using the ~~following~~ equation:

$$a_{\mathrm{CDOM}}(\lambda) = a_{\mathrm{CDOM}}(\lambda_0)e^{-S(\lambda_0-\lambda)} + K \qquad (3)$$

where~~:~~ λ_0 is 350 nm~~,~~ and *K* is a background constant that allows for any baseline shift caused by residual scattering ~~by~~ due to fine ~~size~~ particle fractions, micro-air bubbles or colloidal material present in the sample, refractive index differences between sample and the reference, or attenuation not due to CDOM. The parameters $a_{\mathrm{CDOM}}(350)$, *S*~~,~~ and *K* were estimated simultaneously ~~via~~ by non-linear regression using Equation 3 (Kowalczuk et al., 2006).

The chlorophyll *a* concentration was determined ~~with use~~by pigment extraction ~~method~~. The p~~P~~igments contained ~~with~~in the suspended particles were collected by ~~filtration of~~ passing the water samples ~~onto~~ through 47-mm Whatman glass-fiber filters (GF/F) under a low vacuum and extracted ~~24 hours~~ in 96% ethanol at room temperature for 24 hours (Wintermans ~~&~~ and De Mots, 1965, Marker et al., 1980). The c~~C~~hlorophyll *a*~~,~~ ~~*Chla*,~~ concentration, *Chla*, was determined spectrophotometrically with a Unicam UV4-100 spectrophotometer ~~(Unicam, Ltd)~~. In this method the optical density (absorbance) of the pigment extract in ethanol at 665 nm was corrected for the background signal in the near infrared (750 nm): $\Delta OD = OD(665\mathrm{nm}) - OD(750\mathrm{nm})$;~~,~~ the absorbance was converted to the chlorophyll *a* concentration~~,~~ using an equation involving the volumes of filtered water (V_w) [dm^3]~~,~~ and ethanol extract (V_{EtOH}) [cm^3], a 2 -cm cuvette path length ~~of cuvette~~ (l), and the ~~chlorophyll *a*~~ specific absorption coefficient of chlorophyll *a* in 96% ethanol [$\mathrm{dm}^3\ (\mathrm{g\ cm})^{-1}$] (for ~~the~~ 665 nm) [Strickland and Parsons 1972; Stramska et al., 2003]:

$$Chla = (10^3 \cdot \Delta OD \cdot V_{EtOH})/(83 \cdot V_w \cdot l)^{-1}. \qquad (4)$$

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During the field~~ surveys~~ work, temperature and salinity profiles were measured with a~~nd~~ SeaBird SB36 CTD probe to provide the background physical conditions ~~during~~ to sampling.

The ~~collected~~ data obtained were analyzed ~~by the~~ useing ~~of~~ a statistical package and data visualization software (SigmaPlot 8.1). As the d~~D~~ynamic range of variability of ~~analyzed~~ the optical parameters ~~values~~ exceeded ~~3~~three -orders of magnitude, ~~therefore~~ logarithmic transformation was applied ~~which allowed~~ for a better presentation of their dynamic~~s~~ changes and to ~~analyze~~ statistically analyze ~~collected~~ the data-set accordingly. ~~F~~The following arithmetic and logarithmic statistical metrics were used to assess the uncertainty of ~~developed~~ the empirical relationships and models ($X_{i,M}$ - measured values; $X_{i,C}$ - estimated values (the subscript M stands for 'measured'; ~~subscript~~ C stands for 'calculated')):

- relative mean error (systematic): $\langle\varepsilon\rangle = N^{-1}\sum_i \varepsilon_i$ (where $\varepsilon_i = \left(X_{i,C} - X_{i,M}\right)/X_{i,M}$); (5a)
- standard deviation (statistical error) of ε (RMSE – root mean square error): $\sigma_\varepsilon = \sqrt{\frac{1}{N}\left(\sum\left(\varepsilon_i - <\varepsilon>\right)^2\right)}$ (5b)
- mean logarithmic error: $\langle\varepsilon\rangle_g = 10^{\left[\left\langle \log\left(X_{i,C}/X_{i,M}\right)\right\rangle\right]} - 1$ (6)
- standard error factor: $x = 10^{\sigma_{\log}}$ (7)
- statistical logarithmic errors: $\sigma_+ = x - 1 \quad \sigma_- = \frac{1}{x} - 1$ (8)
- $\left\langle \log\left(X_{i,C}/X_{i,M}\right)\right\rangle$ - mean of $\log\left(X_{i,C}/X_{i,M}\right)$;
- $\sigma_{\log}$ - standard deviation of the set $\log\left(X_{i,C}/X_{i,M}\right)$.

The linear metrics are represented by the relative mean error, and the standard deviation was~~ere~~ used to measure the dispersion of results and assess the model's uncertainty. The relative mean error (Eq. 5a) is the average of all relative deviations between measured and calculated values and ~~it~~ quantifies~~d~~ the systematic error. ~~S~~The standard deviation (Eq. 5b) is the dispersion around the average error due to random errors and ~~it~~ quantifies~~d~~ the statistical error. Logarithmic metrics ~~we~~are used to better describe the uncertainty in the data s~~t~~et varying ~~in the range of~~ over several orders of magnitude. The standard error factor describes~~d~~ how many times the error ~~is~~ deviates~~d~~ from the average value.

3. Results

3.1 *Variability of ~~analysed~~ the parameters and empirical relationship between* CDOM *absorption and spectral slope coefficient.*

Table 2 lists the ~~V~~variability range and average values of selected optical parameters measured in the study area and used for formulating the empirical model: the light absorption coefficients by CDOM at two wavelengths~~:~~ (375 and 400 nm)~~;~~ – $a_{CDOM}(375)$ and $a_{CDOM}(400)$; spectral slope S, ~~and~~ chlorophyll a concentrations~~,~~ *Chla*.~~;~~ ~~measured in the study area and used for formulation of empirical model have been presented in the Table 2.~~ The ~~minima in of the~~ variability ranges of $a_{CDOM}(375)$, $a_{CDOM}(400)$ and *Chla*~~,~~ ~~were noted~~ reached a minimum in sea waters~~in marine waters~~. The minim~~al~~um ~~values of~~ CDOM absorption coefficients in lacustrine waters were almost ~~an~~ one order of magnitude higher than in ~~marine~~ sea waters, indicating a significant accumulation of CDOM in fresh waters. The maxim~~al~~um values of $a_{CDOM}(375)$, $a_{CDOM}(400)$ and *Chla* were ~~observed~~ recorded in fresh waters~~,~~; these ~~maximal~~ values were approximately ~~two time~~ twice as high as ~~higher than~~ those ~~values~~ of the respective parameters in ~~marine~~ sea waters. Consequently, the average ~~values of the~~ CDOM absorption coefficients~~:~~ ($a_{CDOM}(375)$, $a_{CDOM}(400)$) and~~,~~ chlorophyll a concentrations were higher in fresh ~~waters compared to marine~~ than in sea waters. -The ~~reverse~~ trend ~~is observed~~ was reversed in the case of the CDOM absorption spectrum slope coefficient~~,~~ S~~,~~ and its variability range: both ~~of~~ the ~~minimal~~ maximum and ~~maximal~~ minimum spectral slopes ~~values~~ were lower in the lakes than ~~those observed~~ in the ~~marine~~ sea waters. The average ~~value of the~~ spectral slope coefficient was higher in ~~marine~~ sea waters than in lake waters. These two data sets, measured in the ~~the~~ Baltic Sea ~~waters~~ and Pomeranian lakes, were statistically significantly different, as indicated by the results of simple analysis of variance: (~~p~~ $p = -3.4 \cdot 10^{-38}$). However, their variability ranges were such, that the data from the two different aquatic environments ~~were~~ overlapped,~~ing~~ creating a coherent data set~~,~~ that could be analy~~s~~zed ~~together~~jointly. Our principle assumption ~~for~~ when ~~the derivation of~~ deriving the CDOM absorption model was that~~,~~ the optical properties of lacustrine waters could be treated as if they were an extension of estuarine and ~~marine~~ sea waters.

The spectral slope coefficient was inversely and non-linearly related ~~with~~ to the CDOM absorption coefficient. The highly absorbing samples were spectrally flatter

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(characteri~~s~~zed by a lower S value). ~~Different functional types were used to model this relationships: h~~Hyperbolic (Stedmon and Markager, 2001, Kowalczuk et al., 2006)~~,~~ and ~~or~~ logarithmic (Kowalczuk et al., 2005b) functional types were used to model this relationship. For consistency with Kowalczuk (2001), we ~~have~~ used the log–linear fit to describe the relationship between $a_{CDOM}(400)$ and S. The distribution of the spectral slope ~~in the~~ as a function of the CDOM absorption coefficient in the Baltic Sea (black dots) and Pomeranian lakes (green dots) ~~has been presented~~ is shown ~~o~~in ~~the~~ Figure 2a. The black line represents the log-linear dependence (Equation 9) ~~,~~obtained by Kowalczuk (2001), overlai~~d~~n on our data set:

$$S = log[1.038\, a_{CDOM}(400)^{-0.022}]. \qquad (9)$$

The old re~~a~~lation~~h~~ship work~~ed~~s satisfactorily for part of the Baltic Sea data set (R^2 = 0.76)~~,~~ but ~~it~~ does not cover a large group of CDOM absorption coefficients ~~values larger than~~ > 5 m^{-1}. The values of $a_{CDOM}(400)$ > 5 m^{-1} were measured in the lakes and ~~in~~ estuarine waters, as well as ~~and~~ in the Szczecin Lagoon and where the waters of the Vistula and Odra ~~mouth in~~flow~~ing~~ into the southern Baltic. We ~~have~~ derived a new formul~~e~~a to determine the $a_{CDOM}(400)/S$ relationship that covered the whole range of ~~the~~ $a_{CDOM}(400)$ ~~observed~~ recorded in both ~~the~~ Baltic Sea and ~~in~~ Pomeranian lake~~s~~ waters. The new formul~~e~~a ~~was~~ is ~~marked~~ shown ~~o~~in Figure 2~~.~~a as a red curve and is described by Equation 10~~.~~:

$$S = 0.0213 - 0.003\, ln[a_{CDOM}(400)]. \qquad (10)$$

The new $a_{CDOM}(400)$/S relationship ~~has been found~~ is much better constrained and explain~~ed~~s much more variance (R^2 = 0.79) with less uncertainty (RMSE = 0.1%) compared to the one ~~presented~~ given by Kowalczuk (2001).

Detailed analysis of the spectral slope distribution ~~of spectral slope in the~~ as a function of $a_{CDOM}(400)$ indicated that the data set could be divided ~~in~~ with respect to salinity into two subsets: samples characteri~~s~~zed by salinity ~~above~~ > 5 (mostly Baltic Sea water samples) and those with salinity ~~below~~ < 5, which include waters from river mouths, lakes and the Szczecin Lagoon. The relationship between $a_{CDOM}(400)$ and S derived for the respective data substets ~~we~~are presented ~~o~~in Figure 2~~.~~b and the functional formula~~e~~s ~~we~~are given by Equations 11 (salinity > 5) and ~~Equation~~ 12 (salinity < 5):

$$S = 0.0206 - 0.004\, ln[a_{CDOM}(400)] \qquad (11)$$

$$S = 0.0196 - 0.0009\, ln[a_{CDOM}(400)]. \qquad (12)$$

The suggested ~~Proposed~~ approximations of the $a_{CDOM}(400)/S$ relationships in the two salinity ranges ~~we~~have ~~re characterised by the~~ a higher explained variance (R^2 = 0.78 for Equation 11~~,~~ and ~~lower~~ R^2 = 0.22~~,~~ for Equation 12)~~, respectively~~. In both cases, the estimation uncertainties ~~y:~~ RSME = 0.08% for Equation 11~~,~~ and RSME = 0.09%~~,~~ for Equation 12~~, respectively,~~ – were lower ~~compared to~~ than the approximation ~~presented by~~ given by Equation 10.

3.2. *A model for approximating ~~on of~~the CDOM light absorption spectrum from the empirical dependence on~~y~~ ~~with~~ the chlorophyll a concentration.*

The principle bio-optical assumption on interdependenc~~i~~es among optically significant water constituents in ~~global~~ the world ocean was formulated by Morel and Prieur (1977), who introduced the concept of ~~the~~ Case 1 waters, where the variability ~~i~~of those constituents wa~~i~~s to ~~far~~ a considerable extent correlated with the variability ~~of~~ in the phytoplankton biomass expressed as chlorophyll *a* concentration. ~~The~~ Case 1 waters ~~we~~were mostly open oceanic waters and upwelling regions, ~~at~~ along western continental margins. The ~~marine basins~~ sea areas where th~~ese~~is assumption ~~were~~ was not fulfilled~~,~~ ~~we~~were ~~considered~~ treated as Case 2 waters: mostly semi-enclosed and shelf seas and coastal oceans, where there ~~we~~were sources of riverine waters. It was assumed that changes in the magnitude of optically significant water constituents in ~~the~~ Case 2 waters were independent. This concept was critically reassessed by Siegel et al. (2005), who reanalyzed the global ocean colo~~u~~r imagery data set. They ~~and~~ demonstrated ~~proved~~ that, although ~~in open ocean~~ the bio-optical assumption ~~i~~was still valid in the open ocean, there were significant dependences between chlorophyll *a* and other optically significant water constituents at regional scales ~~in~~ along oceanic continental margins. Even though ~~the~~ CDOM was not thought to be correlated with chlorophyll *a* concentrations in Case 2 waters, there were examples showing that such a relationship~~s~~ ~~were~~ was possible (Ferrari and Tassan, 1992; Vodacek et al., 1997). In ~~the~~ Baltic waters such analyses were carried out by Kowalczuk and Kaczmarek (1996) and Kowalczuk (1999). These authors demonstrated that ~~the correlation between~~ the concentration of chlorophyll *a* and the CDOM absorption coefficient ~~was observed~~were correlated. The positive correlation between light absorption by CDOM and chlorophyll *a* concentration has been confirmed with new data ~~available,~~ from both ~~in marine~~ sea and fresh waters. The ~~clear~~ clearly increasing trend ~~of increase~~ of the CDOM absorption level with ~~increasing~~ phytoplankton biomass ~~has been presented on~~ is shown in Figure 3. The dependence between $a_{CDOM}(400)$ ~~coefficient~~ and ~~the concentration~~ *Chla* obtained by Kowalczuk (2001) has been overlain~~d~~ on the new, ~~currently reported~~ updated empirical data set~~,~~ in Figure 3. It is evident that the

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a_{CDOM}(400)/*Chla* relationship reported by Kowalczuk is applicable to only some of the Baltic Sea data, in the chlorophyll *a*~~-~~ concentration range 0.8 < *Chla* < 10 mg m^{-3}. The ~~old,~~previous power function relationship did not reproduce~~d~~ correctly the a_{CDOM}(400) values for high chlorophyll *a* concentrations, and CDOM absorption data measured ~~in estuaries~~ in river mouths and lakes ~~were lying~~ lay above the model curve. We ~~have~~ proposed a new, statistically significant relationship between ~~the~~ a_{CDOM}(400) and *Chla* ~~which was~~ that is described by a second-degree polynomial ($R^2 = 0.83$, RMSE = 28%, n = 541, p<0.0001).

The same function has been applied to reconstruct the complete CDOM absorption spectrum in the spectral range from 245 to 700 nm with 5 nm resolution~~,~~ (Equation 13):

$$a_{CDOM}(\lambda) = 10^{(A(\lambda)(\log Chla)^2 + B(\lambda)\log Chla + D(\lambda))}, \quad (13)$$

where $A(\lambda)$ [m^5 mg^{-2}], $B(\lambda)$ [m^2 mg^{-1}] and~~,~~ $D(\lambda)$ [m^{-1}] are the regression coefficients.

The spectral distribution of the regression coefficients and determination coefficient ~~have been~~ are presented ~~o~~in Figure 4 and their values ~~we~~are included in Table A in Appendix A. Both regression coefficients $A(\lambda)$ and $B(\lambda)$ ~~showed~~ exhibited a relatively small spectral variation in the UV and part of the visible spectral range. The biggest changes in regression coefficient~~s~~ spectra ~~have been~~ were noted above 580 nm, where a significant increase ~~of the~~ in $A(\lambda)$ was to a large extent ~~has been relatively~~ compensated ~~with~~ by a decrease ~~of the~~ in $B(\lambda)$. ~~S~~The spectral distribution of regression coefficient *A*~~,~~ indicate~~s~~d ~~a~~ the potential influence of ~~the~~ phytoplankton pigment~~s~~ absorption on the CDOM absorption spectrum, as its maximum, situated around 675 nm, overlaps ~~with~~ the long~~-~~-wave maximum of the chlorophyll *a* absorption spectrum. This effect is ~~visible~~ apparent only at longer wavelengths, because the principal~~e~~ chlorophyll *a* maximum at 440 nm~~,~~ is masked by CDOM absorption, especially ~~at~~ in very turbid estuarine and fresh water, where the highest values of CDOM absorption were recorded. The ~~f~~Free term $D(\lambda)$ spectrum, decreas~~es~~ing monotonically with increased wavelength, resembles th~~e~~at of the log~~-~~-transformed CDOM absorption coefficient spectrum corresponding to the average CDOM absorption spectrum at a chlorophyll *a* concentration of 1 mg m^{-3}~~-~~, as shown ~~o~~in Figure 4~~.~~c. The spectral distribution of the determination coefficient ~~values~~ R^2 (~~,~~ ~~presented on~~ Figure 4~~.~~d)~~,~~ shows ~~-demonstrated~~ that~~,~~ the model based on the dependenc~~y~~e between the CDOM absorption coefficient and the chlorophyll *a* concentration~~,~~ explained more than 80% of the variability in $a_{CDOM}(\lambda)$ in the UV and VIS, and that this variability was ~~controlled~~ governed by phytoplankton biomass production. The model's performance deteriorated at wavelengths longer than 550 nm.

The results of the -model uncertainty analysis ~~result~~ for selected wavelengths ~~have been~~ are summarized in Table 3 and ~~presented~~ illustrated ~~o~~in Figure 5. Comparison between estimated ~~vs.~~ and measured $a_{CDOM}(\lambda)$ values at selected wavelengths (260, 350, 440, 500, 550, 600 nm) from the ~~range~~ 240 – 700 nm range ~~we~~are shown on the first six upper panels of Figure 5 (a-f). Histograms of the ratios of ~~between~~ estimated ~~and~~ to measured values at the same wavelengths, ~~we~~are presented ~~o~~in the lower six ~~Figure 5~~ panels of Figure 5 (g-l). The deterioration of model performance with increasing wavelength ~~has been~~ is evident. The overall uncertainty expressed by arithmetic ~~statistics~~ and logarithmic statistics wa~~i~~s satisfactory up to 500 nm, ~~and~~ but then both systematic and statistical estimation errors increased~~d~~ rapidly at longer wavelengths. The arithmetic systematic error ~~has~~ increased~~d~~ from 1.47% at 260 nm to 19.54% at 600 nm, and the arithmetic statistical error ~~has~~ increased~~d~~ from 17.03% at 260 nm~~,~~ to 79.13% at 600 ~~respectively~~. Logarithmic uncertainty metrics indicated~~d~~ that~~,~~ the standard error factor estimated for the entire spectral range from 240 to 700 nm of light absorption coefficients varied~~s~~ from 1.19 to 2.66. This meant~~s~~ that the statistical logarithmic error varie~~s~~d from -62% to +165%. The logarithmic systematic errors throughout ~~in~~ the ~~all~~ 240 - 700 nm range d~~o~~id not exceed 3%.

3.3. *An empirical model for approximating ~~on of~~the -CDOM light absorption spectrum based on the empirical dependence ~~ony with~~ the CDOM absorption coefficient ~~value~~ at 400 nm,* $a_{CDOM}(400)$.

The exponential model for CDOM absorption requires information on two input parameters: the magnitude of CDOM absorption at the reference wavelength and the spectral slope ~~value~~. However, the monotonicity ~~property~~ of the CDOM absorption spectrum ~~determines~~ ensures a ~~the~~ high level of interdependence between ~~y of~~ absorption coefficients ~~values~~ across ~~considered~~ the spectral range in question, so that ~~and allows omit the~~ detailed information on the spectral slope can be omitted. The second model that we have developed is based on the dependence of light absorption by CDOM at any given wavelength and the CDOM absorption coefficient at wavelength 400 nm. Many authors treat this wavelength as a reference for CDOM absorption using the exponential Equation 1 (e.g. Kowalczuk et al., 2005a; Woźniak and Dera, 2007). It was also recommended by Sathyendranath et al. (1989) to distinguish~~ing~~ between absorption by dissolved organic matter ~~absorption~~ from that caused by phytoplankton. In optically complex waters (the Baltic Sea and the lakes), a_{CDOM} (400) makes up ~~the~~ a large proportion of the total absorption of light in water~~,~~ (Kowalczuk, 2001; Ficek, 2013).

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The interdependenc~~y~~e of spectral CDOM absorption values ~~has been~~ was assessed by Kowalczuk (2001), who analy~~s~~zed the linear cross-correlation matrix between $a_{CDOM}(\lambda)$ values measured at different wavelengths. The linear interrelationship between $a_{CDOM}(\lambda)$ deteriorated with increasing spectral distance from the reference wavelength ~~both~~ towards both shorter and longer wavelengths. To better reflect the non-linear property of the CDOM absorption spectrum we ~~have~~ used ~~the~~ a second~~-~~-order polynomial model based on log-transformed $a_{CDOM}(\lambda)$ values as the input variable. The c~~C~~alculations were performed in the ~~spectral range~~ 240 – 700 nm spectral range~~,~~ with a 5 nm resolution. The statistical analyses yielded the formula:

$$a_{CDOM}(\lambda) = 10^{(M(\lambda)(\log(a_{CDOM}(400))^2 + N(\lambda)\log(a_{CDOM}(400)) + O(\lambda))}, \qquad (14)$$

where $M(\lambda)$ [m], $N(\lambda)$ [dimensionless] and $O(\lambda)$ [m^{-1}] are the parameterization coefficients ~~shown graphically~~ illustrated in Figure 6. Their values for the 240 – 700 nm range are listed in Table B (in Appendix A).

The spectral shapes of the regression coefficients $M(\lambda)$, $N(\lambda)$ and the free term $O(\lambda)$, which ~~that~~ were derived for the empirical model ~~that used~~ using the $a_{CDOM}(400)$ value as an independent variable, were quite similar to the spectral shapes of the regression coefficient and the free term of the model based on chlorophyll *a* concentration. ~~The regression~~ $M(\lambda)$~~,~~ and $N(\lambda)$ were also characteriz~~s~~ed by maxima located in the red part of the ~~light~~ spectrum. ~~Similarly~~ As in ~~to~~ the first ~~presented~~ model, the spectral shape of the free term $O(\lambda)$ resembled the log-transformed CDOM absorption spectrum. The spectral distribution of the determination coefficient R^2 indicated that the approximation of $a_{CDOM}(\lambda)$ values based on the magnitude of ~~the~~ CDOM absorption at the reference wavelength was much more accurate than ~~approximation~~ that based on chlorophyll *a* concentration. The R^2 values were ~~over~~ > 0.9 in the ultraviolet part of the spectrum approaching 1, near the reference value, ~~and~~ but dropped ~~felt down~~ to ~~below~~ < 0.8 at 560 nm.

The result of the uncertainty analysis of the second model ~~uncertainty analysis result for~~ at the same wavelengths ~~as previously used, have been~~ are summarized in ~~at~~ Table 4 and presented i~~o~~n Figure 7. ~~Comparison between~~ The estimated ~~vs.~~ and measured $a_{CDOM}(\lambda)$ values at six ~~selected~~ wavelengths ~~were shown~~ are compared on the ~~first six~~ upper six panels of Figure 7 (a-f)~~.~~, and h~~H~~istograms of the ratio between estimated and measured values at the same wavelength ~~were presented~~ are shown on the lower six panels of Figure 7 ~~panels~~ (g-l).

The deterioration of model performance with increasing wavelength ~~h~~was ~~been~~ much smaller than in the case of the CDOM absorption spectrum approximation based on the chlorophyll *a* concentration. The overall uncertainty expressed by arithmetic ~~statistics~~ and logarithmic statistics was much better up to 550 nm. ~~Similarly, to~~ As in the first model, both systematic and statistical estimation errors increased at longer wavelengths. The arithmetic systematic error ~~has~~ increased from 0.38% at 260 nm to 16.64% at 600 nm, and the arithmetic statistical error ~~has~~ increased from 9.11% at 260 nm~~,~~ to 67.45% at 600 nm ~~respectively~~. Logarithmic uncertainty metrics indicate~~d~~d that~~,~~ the standard error factor estimated for the entire spectral range from 240 to 700 nm of light absorption coefficients varie~~s~~d from 1.09 to 1.76. This mean~~s~~t that the statistical logarithmic error varie~~s~~d from -43% to +75%. The systematic error~~s~~ in the 240 - 700 nm interval did not exceed 2%.

3.4 Two-parameter~~ical~~ model for estimating ~~of~~ CDOM absorption in the Baltic Sea and Pomeranian Lakes

Two alternative one-parameter models of CDOM absorption were presented in the previous sections, which ~~that~~ enabled ~~estimation of~~ $a_{CDOM}(\lambda)$ values to be estimated with relatively ~~low~~ small errors. For comparison, we ~~have~~ analyzed the two-parameter model~~,~~ developed by Kowalczuk et al. (2006) for ~~the~~ Baltic Sea waters.~~,~~ This statistical model for estimating~~on of~~ the CDOM absorption coefficient at 375 nm~~,~~ $a_{CDOM}(375)$ ~~at~~ in surface waters was based on the seasons and the chlorophyll *a* concentration, which ~~that~~ acted as a proxy for the autochthonous production of CDOM. We ~~have~~ used the non-linear relationship between the CDOM absorption coefficient $a_{CDOM}(375)$ and the spectral slope to derive S, and ~~used it later for~~ then to reconstruct the CDOM absorption spectrum ~~reconstruction~~ using the classical exponential model (Equation 1).

The dependence between ~~slope~~ *S* and $a_{CDOM}(375)$ ~~coefficient~~ obtained by Kowalczuk et al. (2006) ~~h~~was ~~been~~ overlain~~d~~ on the ~~currently reported~~ empirical data set reported here~~,~~ (Figure 8). The $S/a_{CDOM}(375)$ relationship reported by Kowalczuk et al.~~,~~ (2006) is applicable to most of the Baltic Sea, ~~estuaries~~ river mouth and lake~~s~~ data ~~in~~ within the $a_{CDOM}(375)$ range from 1.5 to– 14.16 m^{-1}. -Th~~at~~is hyperbolic relationship did not ~~reproduced~~ correctly reproduce the *S* values for $a_{CDOM}(375) < 1.5$ m^{-1}, however.~~,~~ ~~S~~The s~~p~~pectral slopes measured in open and coastal Baltic waters ~~were lying~~ lay below the model curve. We ~~have~~ propose~~d~~ a similar hyperbolic, statistically significant, relationship between ~~the~~ *S* and $a_{CDOM}(375)$ which could better fit ~~to~~ the present ~~current~~ data set. The determination coefficient of the updated

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hyperbolic function was very high: R^2 = 0.86, RMSE = 0.08%, n = 541, p<0.0001. The new empirical relationship between the spectral slope *S*~~,~~ and a_{CDOM}(375) is given by formula (15):

$$S = 0.01722 + \frac{0.0057}{0.0407 + a_{CDOM}(375)}. \qquad (15)$$

The new formula~~e~~ was applied Equation 1 to calculate the CDOM absorption spectrum in the spectral range between 240 ~~–~~and 700 nm. The results of the uncertainty analysis ~~result~~ of the exponential model~~,~~, which ~~that~~ used the spectral slope variable estimated from the approximation given by Eq~~a~~uation 15, ~~have been~~ are summarized in Table 5. For comparison, we ~~have~~ also ~~done~~ carried out an uncertainty analysis of the exponential model with the spectral slope ~~variable~~ estimated from the *S* and a_{CDOM}(375) relationships ~~presented~~ given by Kowalczuk et al. (2006). Th~~is~~e ~~uncertainty~~ analysis ~~has~~ revealed that the two-parameter estimate~~ion~~ of the CDOM absorption spectrum was less accurate than the~~t~~ two ~~first~~ one-~~-~~parameter~~s~~ models. The spectral values of CDOM absorption estimated f~~o~~rom the exponential relationship and spectral slope parameterization ~~with use~~ using the empirical formulas of Kowalczuk et al. (2006) and the present one ~~current empirical formulas~~ were systematically overestimated in the UV and underestimated in the visible spectral range. The systematic and statistical errors ~~were~~ increas~~ing~~ed towards the red part of the spectrum. The highest uncertaintie~~sy~~s, ~~that~~ exceed~~ed~~ing 30% in the systematic error and 20% in the statistical error, were noted at wavelengths ~~longer than~~ < 500 nm. The u~~U~~se of the present ~~current~~ empirical spectral slope parameterization enabled ~~estimation of~~ $a_{CDOM}(\lambda)$ ~~values~~ to be estimated with relatively ~~lower~~ smaller errors, compared to the results ~~given~~ obtained by the same approach ~~with use of~~ using the ~~Kowalczuk et al. (2006)~~ slope parameterization of Kowalczuk et al. (2006).

4. Discussion

The ~~Presented~~ dataset presented here is a ~~was~~ subset of the almost 25 year long~~s~~ ~~timer~~ series of bio-optical data collected ~~in~~ by IOPAN in the Baltic Sea. This subset matched the ~~observations conducted~~ measurements obtained ~~in the 2006 - 2009~~ in Pomeranian lakes in 2006 - 2009 by Ficek et al., (2012) and Ficek (2013). ~~Analysed~~ These data ~~were characterized by~~ exhibit a ~~large~~ wide range of dynamic variability~~ range~~, ~~that~~ which in some cases exceed~~sed~~ three orders of magnitude. The s~~S~~ea ~~waters~~ and lake water data~~s~~ were pooled and analyzed jointly~~joint data set~~, despite ~~some~~ certain differences in the compositions of the optically active components ~~of~~ in these waters. We ~~have~~ treated the lakes as a natural extension of marine waters with optical properties resembling the properties of estuaries. Chlorophyll *a* concentrations and a_{CDOM}(λ) values ~~of~~ varied ~~by 3~~ over three orders of magnitude: ~~the~~ *Chla* ~~variability range was found~~ from 0.72 to 119 mg m^{-3}~~-~~, ~~and~~ a_{CDOM}(375) ~~varied~~ from 0.41 to 14.16 m^{-1} and~~,~~ a_{CDOM}(400) ~~varied~~ from 0.15 to 8.85 m^{-1}~~, respectively~~. The s~~S~~pectral slope $S_{300-600}$ in Baltic Sea and lakes ~~was found in the~~ ranged from 0.007 ~~—~~to 0.03 nm^{-1}. ~~R~~The variability ranges of ~~variability of analyzed~~ these parameters correspond~~ed~~ to the ~~data~~ figures given ~~presented~~ in earlier works on the optical properties ~~in the~~ of Baltic Sea waters (Babin et al. 2003, Kowalczuk 1999, Kowalczuk et al. 2005a, 2006, 2010, 2015) ~~or~~ and Pomeranian lakes (Ficek et al. 2012; Ficek 2013). Ficek (2013) reported that ~~in Pomeranian lakes~~ *Chla* ~~concentrations can~~ may be ~~even~~ as high as 336 mg m^{-3} in Pomeranian lakes.

4.1 *Assessment of the accuracy of one parameter models for for approximating the CDOM light absorption spectrum*

The f~~F~~irst two ~~presented~~ models, each based on a single independent variable, were characterized by a similar arithmetic systematic error. The arithmetic systematic errors calculated for the model which used *Chla* ~~the chlorophyll *a* concentration~~ as the independent variable (Eq. 13) were ~~in~~ of the order of 1.5 - 7% in the UV and the visible spectral range to 500 nm. The arithmetic systematic error calculated for the model ~~which used the~~ using a_{CDOM}(400) as the independent variable (Eq. 14) were ~~in~~ of the order of 0.2 -2.2 % in the same spectral ranges. Based on the arithmetic metrics ~~presented~~ listed in Tables 3 and ~~in Table~~ 4 for model (14), we ~~could~~ concluded~~d~~ that the a_{CDOM}(400) independent variable model ~~was characterized by~~ had a ~~lower~~ smaller uncertainty and higher spectral values of the determination coefficient. Likewise, the standard error factor in the *Chla*~~-~~based model wa~~i~~s higher than in the one based on ~~the~~ a_{CDOM}(400) ~~dependence~~.

Comparison of the data presented in Tables 3, 4 and 5 show~~ed,~~ed that the accuracy of estimation ~~accuracy have~~ deteriorated~~d~~ at wavelengths longer than 550 nm. ~~One possible explanation is t~~The precision of the CDOM measurements might offer a possible explanation. The use of 5 cm cuvettes ~~allowed~~ enabled ~~the~~ reliable detection of CDOM absorption ~~detection~~ at a_{CDOM}(λ) ~~larger than~~ < 0.046 m^{-1}. The spectrophotometer's detection limit ~~has been~~ was usually reached ~~usually~~ at wavelengths ~~longer than~~ <~~-~~ 550 nm in samples ~~collected in~~ of open Baltic Sea waters. Therefore, ~~the~~ modeled values were usually compared to measured values~~,~~ that were heavily impacted by measurement~~s~~ error~~s~~ accuracy. One ~~of the possible~~ way of increasing the spectrophotometric accuracy of CDOM absorption

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measurements would ~~rely on~~ involve increasing the cuvettse path length (the maximum cuvette~~s~~ path length used in most desktop spectrophotometers does ~~would~~ not exceed 10 cm). However, using ~~usage of~~ long ~~measurements~~ path lengths, ~~offered~~ available in optical waveguide spectrophotometer systems (0.2 – ~~÷~~ 2 meters) (D'Sa et al., 1999; Miller et al. 2002), in optically complex waters such as the Baltic Sea and fresh–water lakes, would severely impact the radiometric sensitivity of any spectrophotometer in the UV spectral range.

~~There were~~ A number of regional studies have present~~ing~~ed the dependence between chlorophyll *a* concentration, *Chla*, and CDOM absorption, $a_{CDOM}(\lambda)$, ~~similar~~ using a parameterization similar to that described by Equation 13 (Ferrari and Tassan, 1992, Tassan 1994, Vodacek et al. 1997, Morel et al. 2007, Morel and Gentili 2009, Bricaud et al. 2010, Organelli et al. 2014). We ~~have~~ compared the $a_{CDOM}(\lambda)/Chla$ relationship that we derived ~~by us~~ with some of the ~~elected~~ relationships between ~~CDOM absorption coefficients~~ $a_{CDOM}(\lambda)$ and *Chla* ~~developed~~ derived by ~~different~~ various authors for different water types. Selected model outputs were overlai~~d~~n on the observed distribution of $a_{CDOM}(\lambda)$ ~~in the~~ as a function of *Chla*~~,~~ ~~(presented on~~ Figure 9). In all cases, ~~T~~these relationships ~~in all cases~~ were approximated by power functions~~,~~ and assumed different rates of increase of ~~the~~ $a_{CDOM}(\lambda)$ ~~value~~ with increasing *Chla* (Tassan, 1994; Morel et al., 2007; Morel and Gentili 2009; Bricaud et al. 2010). The ~~R~~relationships ~~developed~~ derived by other authors~~,~~ were ~~not~~ found unsuitable for estimating CDOM absorption in the Baltic Sea ~~waters~~ and lake~~s~~ waters. The ~~E~~empirical relationships derived ~~developed~~ by Tassan~~,~~ (1994), Morel et al., (2007), Morel and Gentili (2009) and Bricaud et al. (2010) all underestimated ~~the~~ CDOM absorption in the Baltic Sea. Such a ~~large mismatch~~great discrepancy between estimated and observed CDOM absorption values ~~certainly will~~ have resulted from the fact that these relationships were developed for clear~~n~~ oceanic waters, where the contribution of dissolved organic material to the total light absorption ~~light~~ was ~~lower~~ less than in the Baltic Sea and the concentration of *Chla* did not exceed 40 mg m^{-3}. For example, Bricaud et al. (2010) ~~have~~ based their empirical model on measurements from mesotrophic waters around the Marquesas Islands to hyperoligotrophic waters in the subtropical gyre and eutrophic waters in the upwelling area west off the Chilean coast (South Pacific). ~~Reported~~ The *Chla* concentrations they reported spanned more than two orders of magnitude (0.017 to 1.5 mg m^{-3}) in the surface layer, values of ~~;~~ the spectral slope~~,~~ *S*~~,~~ ~~values contained~~ lay within the ~~range of~~ 0.007 - 0.032 nm^{-1} range~~;~~, and ~~while observed~~ the $a_{CDOM}(440)$ values were from 0.0003 to 0.038 m^{-1}. Morel et al. (2007) carried out measurements in hyperoligotrophic waters in the South Pacific gyre (near Easter

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Island), where ~~observed~~ *Chla* concentrations ~~were within~~ ranged from ~~of~~ 0.022 to 0.032 mg m^{-3} in the surface layer. Tassan (1994) reported two relationships between $a_{CDOM}(\lambda)$ and *Chla* (one for Gulf of Naples waters and second for the Adriatic Sea)~~,~~ and then used these relationships ~~for estimation of~~ to estimate CDOM absorption coefficients ~~values~~ at different ranges of *Chla* ~~concentrations~~ (0.25 do 40 mg m^{-3}). Morel and Gentili (2009) tested ~~developed~~ a satellite ocean color algorithm they derived for ~~enabling~~ determin~~ation~~ing ~~of the~~ CDOM absorption and ~~the~~ *Chla* concentrations from satellite imagery ~~in~~ of Mediterranean waters, where *Chla* varied ~~within the range~~ from 0.01 to 0.5 mg m^{-3}. The eutrophic Baltic Sea waters and super~~te~~hutrophic lake~~s~~ waters were characterized by significantly higher *Chla* concentrations. The total absorption in our study area w~~ere~~as dominated by the absorption of CDOM ~~organic dissolved substances~~ (Woźniak et al., 2011; Ficek et al., 2012)~~,~~; therefore, ~~observed~~ measured $a_{CDOM}(\lambda)$ values per unit ~~of~~ chlorophyll *a* concentration~~s~~ were almost twice as ~~much~~ high in the Baltic Sea and Pomeranian lakes, as ~~compared to those observed~~ in Pacific Ocean and Mediterranean and Adriatic Sea waters~~oceanic waters in the Pacific and marine water in the Mediterranean and Adriatic~~. These findings underline the~~d~~ need ~~for~~ to derive ~~development of~~ regional algorithms and bio-optical models, because ~~one~~ those derived for ~~developed in~~ other regions ~~did~~ do not account for~~ed~~ the constant, ~~and~~ very high background ~~in~~ CDOM absorption ~~persistently~~ prevalent in the Baltic Sea and fresh waters in the temperate climatic zone.

The uncertainty analysis showed ~~proved~~ that~~,~~ both the mathematical, single independent variable CDOM absorption estimates ~~ions~~ presented in this paper performed better~~,~~ than the classical exponential model, with variable slope parameterized with the relationship derived by Kowalczuk et al. (2006) and its modification ~~presented~~ given in Equation 15~~.~~. The two~~-~~-parameter~~s~~ exponential model significantly underestimated $a_{CDOM}(\lambda)$ at longer wavelengths. The s~~S~~tandard error factor *x* wa~~i~~s lower in the Kowalczuk et al. (2006) model and our modification of this model than in approximations (13) and (14). But the systematic errors, both arithmetic and logarithmic, we~~a~~re much higher. For example, in the model~~s~~ by Kowalczuk et al. (2006) for the 440 nm wavelength, the arithmetic systematic error took~~akes~~ an average value of -16% and the average logarithmic systematic error ~~takes average value~~ was -17%, ~~while~~ whereas with ~~using the~~ formula (13)~~,~~ we had~~ve~~ 4% and 0.01%, and ~~for the~~ with formula (14) 0.4% and 0.003%, respectively. Morel and Gentili (2009) and Morel et al. (2010) derived a two-component model for ~~description of~~ describing ~~the~~ CDOM absorption properties, ~~and they~~ modeling ~~lled~~ the spectral slope values using its empirical

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relationship with the chlorophyll *a* concentration. These models were based on data sets collected in clear oceanic waters, so their applicability to Baltic Sea conditions would probably be questionable, as ~~it was~~ in the case of the $a_{CDOM}(\lambda)/Chla$ relationships.

4.2 Assessment of the accuracy of two parameters models for for approximating the CDOM light absorption spectrum

Finally, we ~~have~~ compared the performance in the retrieval of the CDOM absorption spectrum in ~~the~~ Baltic Sea conditions of ~~two~~ three standard exponential models broadly used in optical oceanography: *i)* ~~model~~ the one by Bricaud et al. (1981) with spectral slope $S_{375-500}$ and CDOM absorption reference wavelength λ_0 = 375 nm~~,~~; *ii)* ~~model~~ the one by Babin et al. (2003) with spectral slope~~,~~ $S_{350-500}$ and CDOM absorption reference wavelength λ_0 = 443 nm~~)~~; and *iii)* the model by Kowalczuk et al. (2006). The modelled spectra ~~we~~are presented ~~o~~in Figure 10, together with measured CDOM absorption spectra and those calculated from the one-parameter models expressed by Equations 13 and 14 for ~~determined~~ measured *Chla* ~~concentrations~~. ~~E~~The empirical model developed for the Baltic Sea and inland waters (-Equations 13 and 14), based on locally observed variabilities~~ty~~ in biogeochemical and optical variables, adequately reflected the measured light absorption coefficients in the spectral range 240-600 nm. The model based on the dependence of the chlorophyll *a* concentration, Equation 13, fitted best ~~the~~ the $a_{CDOM}(\lambda)$ from 240 to 600 nm, and could be applied ~~in~~ to a variety of water bodies with contrasting trophic status. From this point of view, it ~~has~~ outperformed ~~to~~ the models derived by Bricaud et al. (1981) ~~or~~ and Babin et al. (2003), which were developed ~~either~~ for oligotrophic or mesotrophic oceanic waters, and European coastal waters, respectively. The ~~M~~model by Kowalczuk et al. (2006) underestimated ~~values of~~ $a_{CDOM}(\lambda)$ for *Chla* concentrations ~~below~~ < 5 mg m^{-3} (see Figure 10). For *Chla* ~~greater than~~ > 20 mg m^{-3} the shapes of all the modeled spectra ~~for~~ were similar.

In order to compare the performance of two parameters models developed by Bricaud et al., (1981) and Babin et al., (2003) ~~above-mentioned models~~, we adapted them to the empirical data set presented in this study within the spectral range from 240 to 700 nm~~,~~ and then ~~we have~~ applied the same statistical metrics to assess their uncertainty. The c~~C~~alculated errors for selected wavelengths ~~we~~are listed in Table 6 ~~for selected wavelengths~~. The systematic errors in arithmetic statistics were higher for the models by ~~ouput~~ Bricaud et al. (1981) and Babin et al. (2003) compared to the errors calculated for the parameterizations given by Equations 13 and 14. The systematic errors calculated for the CDOM absorption model by Babin et al.~~,~~ (2003) were significantly higher ~~in~~ at all the ~~selected~~ wavelengths compared to those ~~presented~~ listed in Tables 3 and 4. ~~The~~ CDOM absorption could be estimated ~~by~~ using the empirical model based on the ~~a the~~ $a_{CDOM}(\lambda)/Chla$ ~~dependency~~ relationship with ~~the~~ a systematic error of 3.13 % at λ = 350 nm, whereas the model by Babin et al.~~,~~ (2003) ~~model~~ estimated ~~the~~ CDOM absorption at the same wavelength with a systematic error of -33.70%. ~~C~~The calculated statistical errors of the estimates ~~with use of~~ using the models by ~~the~~ Bricaud et al. (1981) and Babin et al. (2003) ~~models~~ were very large compared to the results obtained with models expressed by Equations 13 and 14. Whereas the standard error factors are quite good for Bricaud's model (from 1 to 2.43), they are much higher for Babin's model (from 1.045 to 3.58). However, in both cases, the systematic errors ~~we~~are significant : -59% to 144 and 79% to +400%, respectively.

5. Conclusions

We ~~have~~ demonstrated that CDOM absorption was ~~non-linearly~~ correlated non-linearly with chlorophyll *a* concentration ~~in~~ over a broad range of variability ~~range~~ spanning ~~over~~ three orders of magnitude in ~~marine~~ waters of the Baltic Sea, its estuaries, coastal lagoons and in ~~the~~ fresh water lakes ~~characterised by~~ of different t~~h~~rophic status. ~~The~~ A second-order polynomial approximation of the relationship between chlorophyll *a* concentration and $a_{CDOM}(400)$ ~~could be~~ was used ~~to~~ with respect to ~~in~~ both ~~marine~~ sea and fresh water, and was much more accurate than the one derived for Baltic Sea waters by Kowalczuk (2001). This relationship ~~has~~ also ~~proved~~ demonstrated that the optical and bio-optical properties of ~~marine~~ sea and fresh waters ~~could~~ could be regard~~s~~ed as a~~n~~ continuum in regard of CDOM absorption and chlorophyll *a* concentration. We ~~have had~~ derived models for estimating ~~of~~ the CDOM light absorption ~~by~~ spectrum in the spectral range 240-700 nm non-linearly from chlorophyll *a* concentrations *Chla* or from coefficients of light absorption by CDOM for wavelength 400 nm ($a_{CDOM}(400)$). For comparison, we ~~have~~ also~~,~~ tested the classical exponential model for approximating the CDOM absorption spectrum, where the spectral slope coefficient was determined from the nonlinear relationship between the spectral slope coefficient and ~~values of~~ $a_{CDOM}(375)$. The result of the uncertainty analysis ~~results proved~~ showed that~~,~~ the one-parameter~~ic~~, second-order polynomial function of the chlorophyll *a* concentration~~,~~ *Chla*~~,~~ enabled ~~estimation of~~ spectral values of the CDOM absorption coefficient~~,~~ $a_{CDOM}(\lambda)$ to be estimated with just a slightly lower accuracy than~~,~~ its estimat~~ion~~e based on a second-order polynomial function of the CDOM absorption

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coefficient at wavelength 400 nm $a_{CDOM}(400)$. The models presented here, ~~Presented models,~~ optimized for the specific optical and bio-optical conditions of the Baltic Sea and fresh water bodies ~~specific optical and bio-optical conditions~~, ~~were characterized with~~ had significantly lower estimation errors ~~of estimations~~ compared to the widely used CDOM absorption models ~~proposed~~ developed by other authors. The CDOM absorption models presented in this study~~,~~ ~~could~~ can be used for improving ~~ements of~~ remote sensing algorithms designed for retrieving ~~als of~~ various optical and bio-optical parameters ~~needed~~ required for characterizing ~~ation~~ and monitoring ~~of~~ the state and functioning of the Baltic Sea and Pomeranian lake~~s~~ ecosystems. Validation of these models showed that they can be reliably applied in monitoring surveys~~,~~ when a rapid~~,~~ approximation of the light absorption spectrum is needed.

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Table 1. Dates, numbers of samples collected and parameters measured during cruises and field experiments ~~made~~ carried out for this study.

Dates of cruises	Number of samples	Parameters measured	Region
24-31 Aug. 2006	20	$a_{CDOM}(\lambda)$, *Chla*, CTD	southern Baltic Proper, Gulf of Gdańsk
24-29 Sept. 2006	12	$a_{CDOM}(\lambda)$, *Chla*, CTD	southern Baltic Proper, Gulf of Gdańsk
18-28 Oct. 2006	30	$a_{CDOM}(\lambda)$, *Chla*, CTD	southern Baltic Proper, Gulf of Gdańsk, Pomeranian Bay
21-31 March 2007	36	$a_{CDOM}(\lambda)$, *Chla*, CTD	southern Baltic Proper, Gulf of Gdańsk, Pomeranian Bay, Szczecin Lagoon
21-31 May 2007	38	$a_{CDOM}(\lambda)$, *Chla*, CTD	southern Baltic Proper, Gulf of Gdańsk
20-28 Oct. 2007	26	$a_{CDOM}(\lambda)$, *Chla*, CTD	southern Baltic Proper, Gulf of Gdańsk
01-11 March 2008	29	$a_{CDOM}(\lambda)$, *Chla*, CTD	southern Baltic Proper, Gulf of Gdańsk, Pomeranian Bay
11-18 April 2008	22	$a_{CDOM}(\lambda)$, *Chla*, CTD	southern Baltic Proper, Gulf of Gdańsk
06-14 May 2008	23	$a_{CDOM}(\lambda)$, *Chla*, CTD	southern Baltic Proper, Gulf of Gdańsk
01-09 Sept. 2008	26	$a_{CDOM}(\lambda)$, *Chla*, CTD	southern Baltic Proper, Gulf of Gdańsk, Pomeranian Bay, Szczecin Lagoon
25-29 Nov. 2008	18	$a_{CDOM}(\lambda)$, *Chla*, CTD	Gulf of Gdańsk
04-12 March 2009	14	$a_{CDOM}(\lambda)$, *Chla*, CTD	Gulf of Gdańsk, Gotland Basin
15-21 April 2009	29	$a_{CDOM}(\lambda)$, *Chla*, CTD	southern Baltic Proper, Gulf of Gdańsk
20-28 May 2009	34	$a_{CDOM}(\lambda)$, *Chla*, CTD	southern Baltic Proper, Gulf of Gdańsk, Pomeranian Bay, Szczecin Lagoon
07-16 Sept. 2009	35	$a_{CDOM}(\lambda)$, *Chla*, CTD	southern Baltic Proper, Gulf of Gdańsk
06-10 Oct. 2009	21	$a_{CDOM}(\lambda)$, *Chla*, CTD	southern Baltic Proper, Gulf of Gdańsk
Dec. 2006 – Sept.	66	$a_{CDOM}(\lambda)$, *Chla*	Sopot Pier

April – Dec. 2007	10	$a_{CDOM}(\lambda)$, *Chla*	Lake Łebsko
April – Sept. 2008	8	$a_{CDOM}(\lambda)$, *Chla*	Lake Łebsko
June – Oct. 2009	9	$a_{CDOM}(\lambda)$, *Chla*	Lake Łebsko
March – Dec. 2007	10	$a_{CDOM}(\lambda)$, *Chla*	Lake Chotkowskie
Feb. – Sept. 2008	8	$a_{CDOM}(\lambda)$, *Chla*	Lake Chotkowskie
April – Nov. 2009	8	$a_{CDOM}(\lambda)$, *Chla*	Lake Chotkowskie
March – Dec. 2007	9	$a_{CDOM}(\lambda)$, *Chla*	Lake Obłęskie
Feb. – Sept. 2008	8	$a_{CDOM}(\lambda)$, *Chla*	Lake Obłęskie
May – Nov. 2009	7	$a_{CDOM}(\lambda)$, *Chla*	Lake Obłęskie
All data	556		

Table 2. Range of variability of the spectral slope $S_{300-600}$, ~~the~~ coefficients of light absorption by CDOM for wavelengths λ = 375 nm and 400 nm, a_{CDOM} (375) and a_{CDOM} (400), and concentrations of chlorophyll *a*, *Chla*, calculated for the empirical data ~~analysed here~~.

Study area	range of variability	mean value	SD
		$S_{300-600}$ [nm^{-1}]	
Baltic	0.014 – 0.03	0.022	0.0021
lakes	0.007 – 0.02	0.017	0.0030
all	0.007 – 0.03	0.021	0.0022
		a_{CDOM}(375) [m^{-1}]	
Baltic	0.41 – 7.92	1.61	1.17
lakes	2.11 – 14.16	7.11	3.36
all	0.41 – 14.16	2.06	2.17
		a_{CDOM}(400) [m^{-1}]	
Baltic	0.15 – 4.79	0.997	0.73
lakes	1.28 – 8.85	4.47	2.07
all	0.15 – 8.85	1.35	1.41
		Chla [mg m^{-3}]	
Baltic	0.72 – 76.94	8.77	11.61
lakes	1.48 – 118.97	39.11	34.15
all~~r~~	0.72 – 118.97	13.09	19.78

Table 3. Relative errors of the empirical model ~~expressed~~ given by formula (13) for determining~~enabling~~ ~~the determination of~~ spectral values of CDOM absorption coefficients ($a_{CDOM}(\lambda)$) at selected wavelengths.

Wavelength [nm]	Arithmetic statistics		Logarithmic statistics			
	systematic error	statistical error	systematic error	standard error factor	statistical error	
	$\langle\varepsilon\rangle$ [%]	σ_ε [%]	$\langle\varepsilon\rangle_g$ [%]	x	σ_+ [%]	σ_- [%]
260	1.47	17.03	0.00	1.19	19.06	-16.01
350	3.13	25.16	-0.01	1.29	29.01	-22.49
440	4.01	29.37	-0.01	1.33	32.71	-24.65
500	6.54	39.43	0.01	1.42	42.45	-29.80
550	11.03	55.07	0.00	1.57	57.40	-36.47
600	19.54	79.13	-0.09	1.83	83.43	-45.48

Table 4. Relative errors of the empirical model ~~expressed~~ given by formula (14) ~~enabling~~ for determining ~~the determination of~~ spectral values of CDOM absorption coefficients ($a_{CDOM}(\lambda)$) at selected wavelengths.

Wavelength [nm]	Arithmetic statistics		Logarithmic statistics			
	systematic error	statistical error	systematic error	standard error factor	statistical error	
	$\langle\varepsilon\rangle$ [%]	σ_ε [%]	$\langle\varepsilon\rangle_g$ [%]	x	σ_+ [%]	σ_- [%]
260	0.38	9.11	0.00	1.09	8.94	-8.21
350	0.20	6.43	-0.01	1.07	6.86	-6.42
440	0.42	9.51	0.00	1.09	9.39	-8.59
500	2.21	22.11	0.01	1.23	23.01	-18.71
550	6.24	37.86	0.00	1.42	41.79	-29.47
600	16.61	67.45	-0.01	1.76	75.88	-43.14

Table 5. Relative errors of the empirical models ~~expressed~~ given by formulas ~~dependence~~ (15) and (1) for determining~~enabling~~ ~~determination of~~ spectral values of CDOM absorption coefficients ($a_{CDOM}(\lambda)$) at selected wavelengths.

Wavelength [nm]	Arithmetic statistics		Logarithmic statistics			
	systematic error	statistical error	systematic error	standard error factor	statistical error	
	$\langle\varepsilon\rangle$ [%]	σ_ε [%]	$\langle\varepsilon\rangle_g$ [%]	x	σ_+ [%]	σ_- [%]
260	2.81	14.14	1.82	1.15	15.33	-13.29
350	3.69	4.46	3.59	1.04	4.49	-4.30
440	-14.74	14.13	-15.86	1.18	17.53	-14.92
500	-31.15	22.06	-34.44	1.37	36.54	-26.76
550	-43.73	31.25	-50.93	1.67	67.41	-40.27
600	-36.05	50.48	-50.16	2.01	101.01	-50.25
Kowalczuk et al. 2006						
260	9.32	11.48	8.62	1.13	13.02	-11.52
350	5.14	4.70	5.04	1.05	4.68	-4.47
440	-18.16	13.96	-19.29	1.18	17.90	-15.18
500	-35.34	21.93	-38.71	1.38	38.23	-27.66
550	-47.27	27.17	-53.46	1.65	64.71	-39.29
600	-41.25	46.17	-54.77	2.05	104.97	-51.21

Table 6. Relative errors of the models of Bricaud et al. (1981) and Babin et al. (2003) ~~models~~ for determining~~enabling determination of~~ spectral values of CDOM absorption coefficients ($a_{CDOM}(\lambda)$) at selected wavelengths.

Wavelength [nm]	Arithmetic statistics		Logarithmic statistics			
	systematic error	statistical error	systematic error	standard error factor	statistical error	
	$\langle\varepsilon\rangle$ [%]	σ_ε [%]	$\langle\varepsilon\rangle_g$ [%]	x	σ_+ [%]	σ_- [%]
Bricaud et al. 1981						
260	-35.74	20.98	-38.79	1.36	35.97	-26.46
350	-6.95	3.64	-7.02	1.04	3.98	-3.82
440	11.10	8.51	10.78	1.08	7.95	-7.37
500	14.24	19.13	12.82	1.17	16.72	-14.32
550	11.21	30.85	7.70	1.28	27.77	-21.74
600	51.80	90.23	33.10	1.64	64.00	-39.03
Babin et al. 2003						
260	-58.45	27.26	-65.30	1.78	77.78	-43.75
350	-33.70	13.85	-35.08	1.23	22.59	-18.43
440	-4.69	4.10	-4.78	1.04	4.45	-4.26
500	12.87	18.23	11.40	1.18	17.77	-15.09
550	26.12	42.51	19.30	1.40	40.12	-28.63
600	92.38	137.52	55.82	1.95	95.05	-48.73

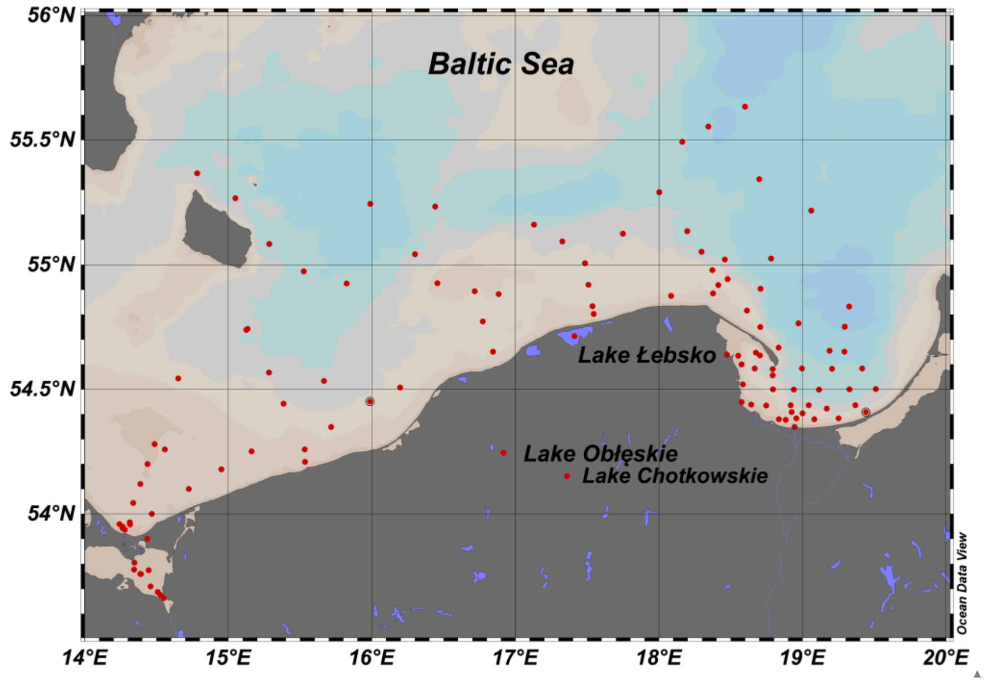

Figure. 1. ~~Location~~ Positions of the measurement stations in 2006 – 2009.

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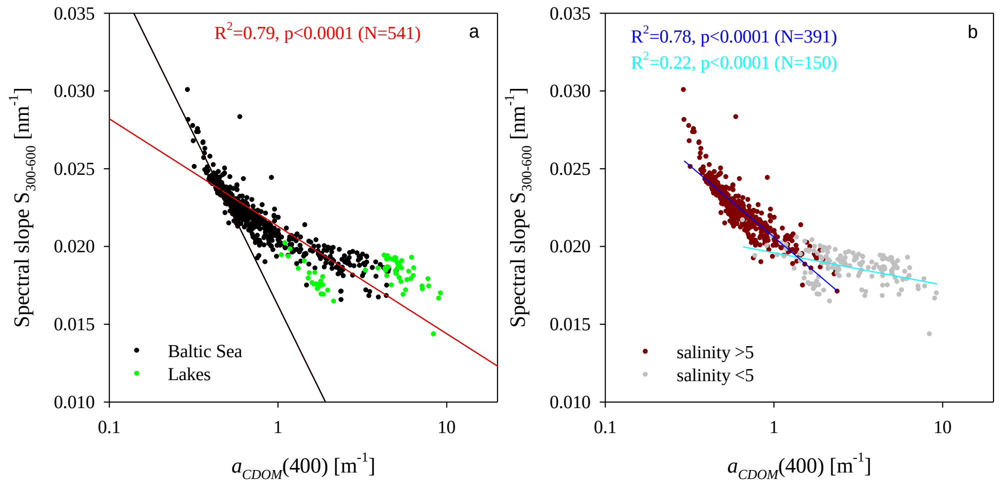

Figure 2. Relationship between the spectral slope $S_{300-600}$ and the coefficient of light absorption by CDOM for wavelength 400 nm, $a_{CDOM}(400)$~~,~~ in the semi-log scale (a) in the Baltic (black dots) and lakes (green dots). The black curve is the approximation obtained by Kowalczuk (2001), the red line represents the approximation ~~expressed~~ given by Equation 10; (b) for samples with salinity ~~above~~ > 5 (most of the sea water samples) and with salinity ~~below~~ < 5 (samples from lakes, river mouths, the Szczecin Lagoon). The blue line represents the approximation given ~~expressed~~ by Equation (11)~~,~~ and the cyan line the approximation given by Equation (12).

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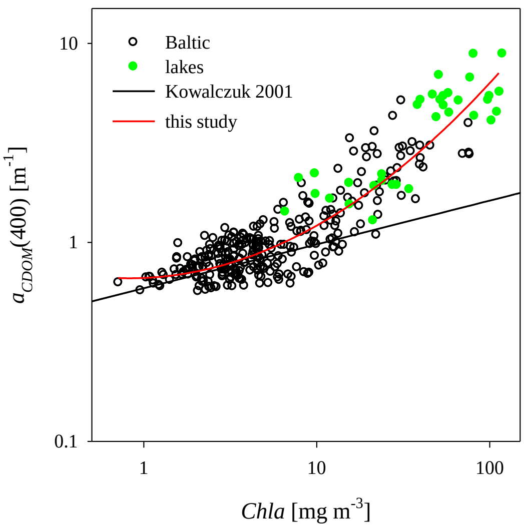

Figure 3. Dependence between coefficients of light absorption by CDOM a_{CDOM}(400) and chlorophyll *a* concentration. The black line shows the approximation obtained by Kowalczuk (2001) and the red line shows the second-degree polynomial approximation ~~second-degree polynomial io~~n the log-log scale.

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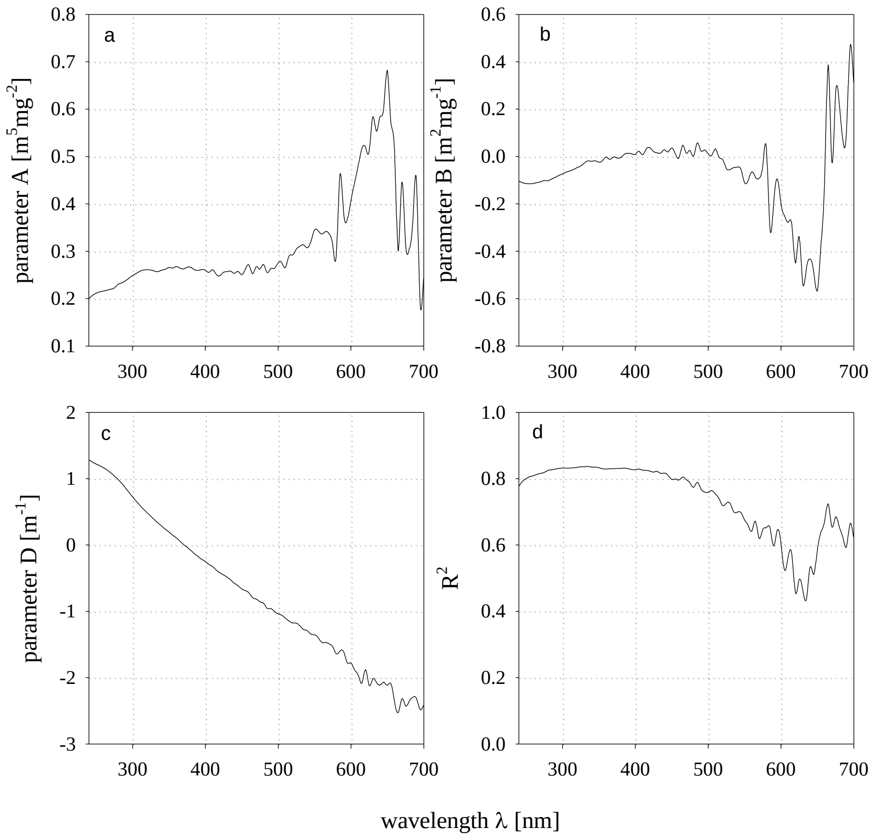

Figure 4. Spectral dependence of the model (expressed by Equation 13) regression coefficients (panels a and b), free term (panel c) and determination coefficient~~,~~ (panel d).

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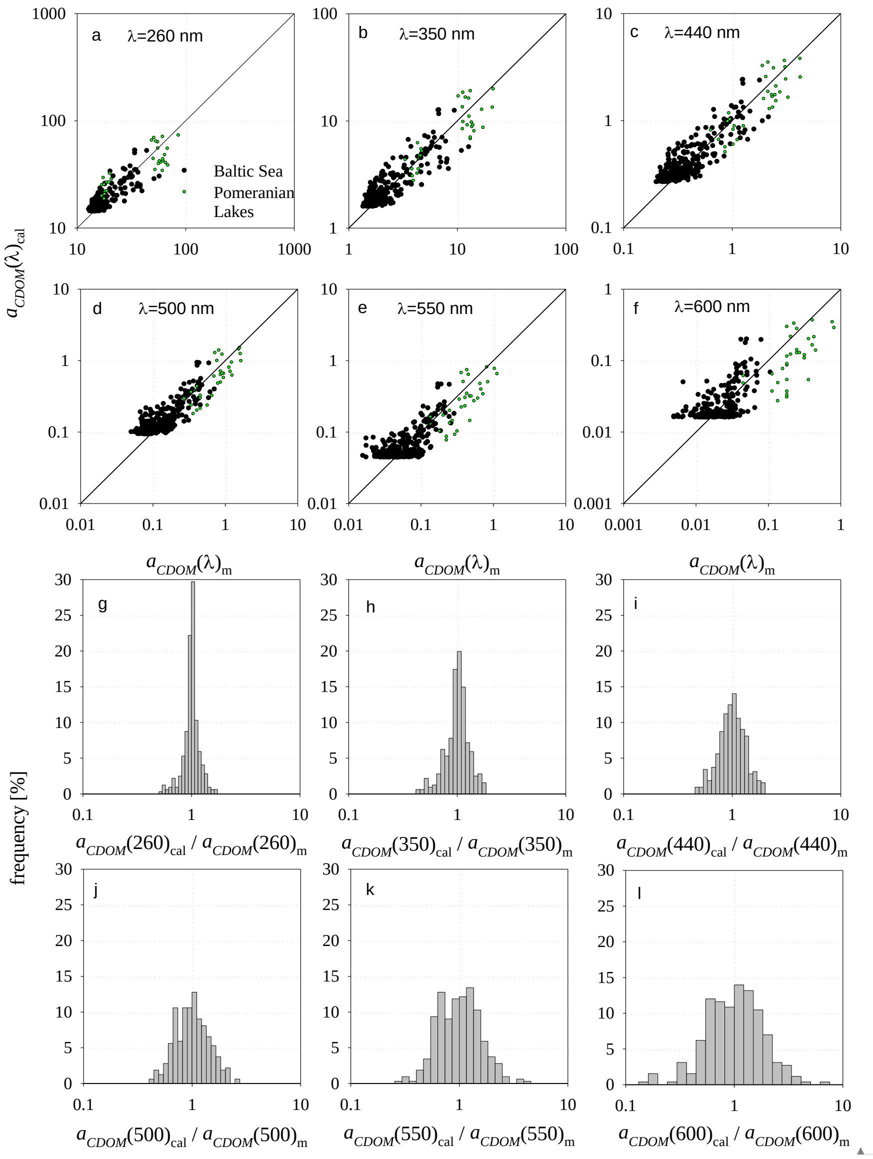

Figure 5. Comparison of light absorption coefficients calculated ($a_{CDOM}(\lambda)_{cal}$) using model (13) and measured ($a_{CDOM}(\lambda)_m$) in the Baltic (black dots) and Pomeranian lakes (green dots) for selected wavelengths: (a) 260 nm; (b) 350 nm; (c) 440 nm; (d) 500 nm; (e) 550 nm; (f) 600 nm. The solid line shows the function $a_{CDOM}(\lambda)_{cal} = a_{CDOM}(\lambda)_m$. ~~And~~ T~~t~~he probability density distributions of the ratio of calculated $a_{CDOM}(\lambda)_{cal}$ to measured $a_{CDOM}(\lambda)_m$ light absorption coefficients for selected wavelengths: (g) 260 nm; (h) 350 nm; (i) 440 nm; (j) 500 nm; (k) 550 nm; (l) 600 nm.

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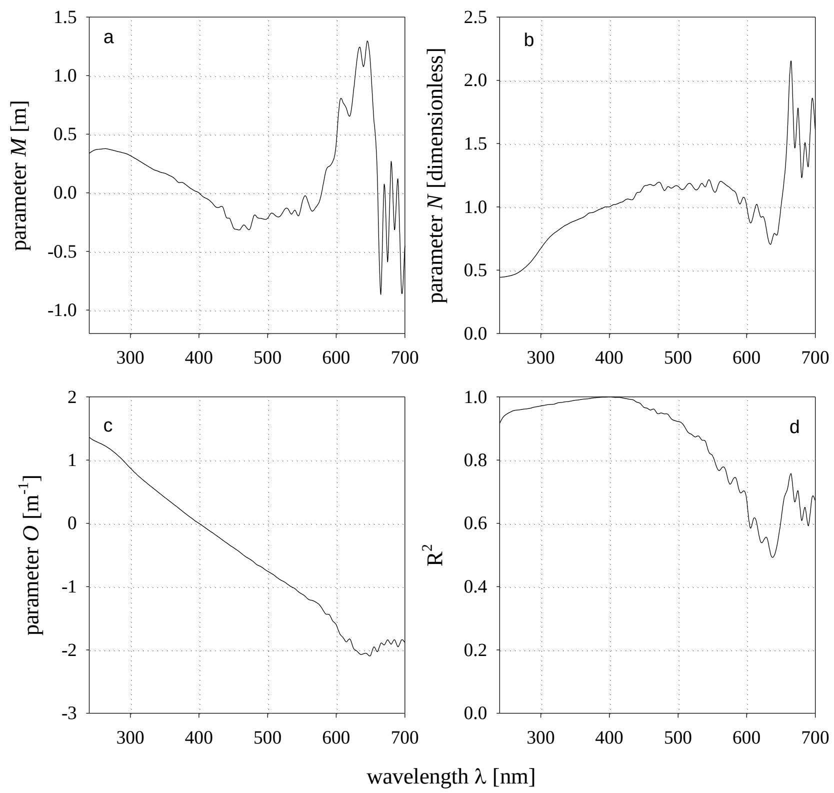

Figure 6. Spectral dependence of the model (expressed by Equation 14) regression coefficients (~~–~~panels a and b), free term (panel c) and determination coefficient~~,~~ (panel d).

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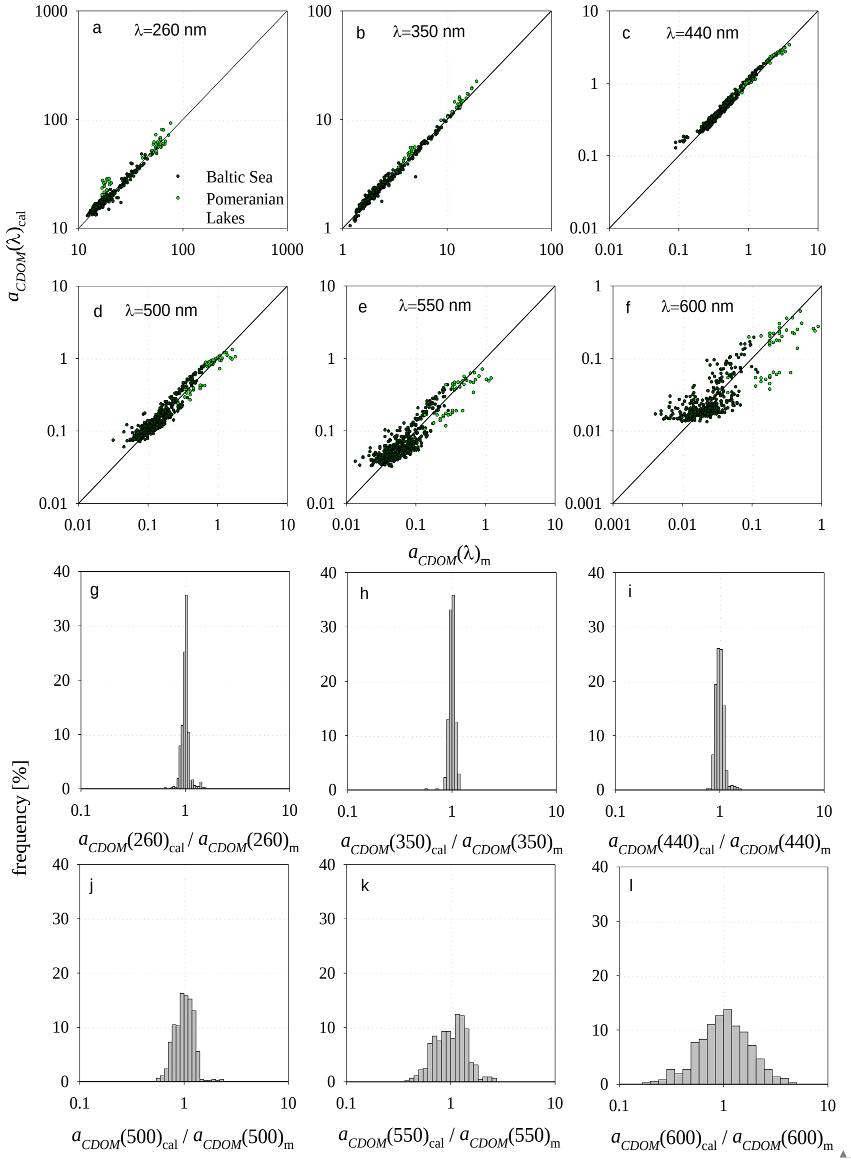

Figure 7. Comparison of light absorption coefficients calculated ($a_{CDOM}(\lambda)_{cal}$) using model (14) and measured ($a_{CDOM}(\lambda)_{m}$) in the Baltic (black dots) and Pomeranian lakes (green dots) for selected wavelengths: (a) 260 nm; (b) 350 nm; (c) 440 nm; (d) 500 nm; (e) 550 nm; (f) 600 nm. The solid line represents the function $a_{CDOM}(\lambda)_{cal}$ = $a_{CDOM}(\lambda)_{m}$ ~~–~~. ~~And T~~the probability density distribution of the ratio of calculated $a_{CDOM}(\lambda)_{cal}$ to measured $a_{CDOM}(\lambda)_{m}$ light absorption coefficients for selected wavelengths: (g) 260 nm; (h) 350 nm; (i) 440 nm; (j) 500 nm; (k) 550 nm; (l) 600 nm.

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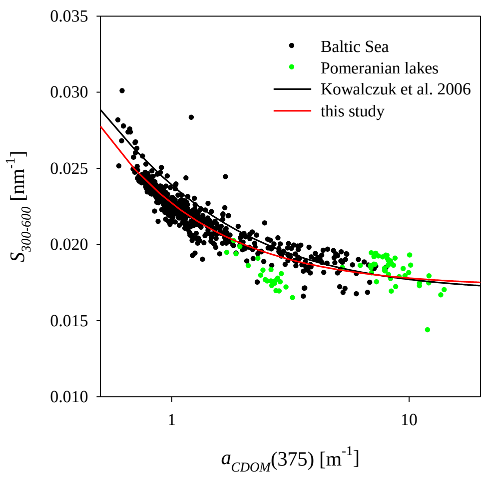

Figure. 8. The relationship between the spectral slope coefficient S, and a_{CDOM}(375) in the Baltic (black dots) and lakes (green dots). The b~~B~~lack line indicates the model of Kowalczuk et al. (2006), ~~and~~ the red one ~~indicates~~ our new approximation (15).

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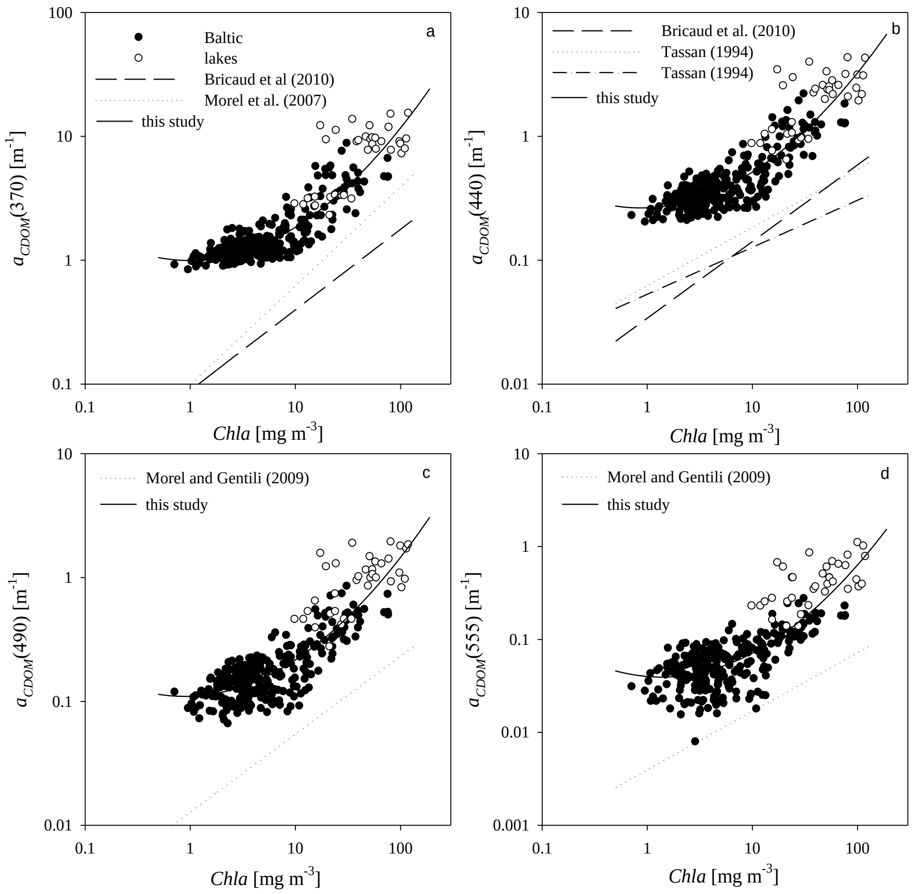

Figure 9. Comparison of the relationships between $a_{\mathrm{CDOM}}(\lambda)$ and *Chla* ~~developed~~ derived in this work and obtained by different authors for different waters adapted to the data analyzed in this work.

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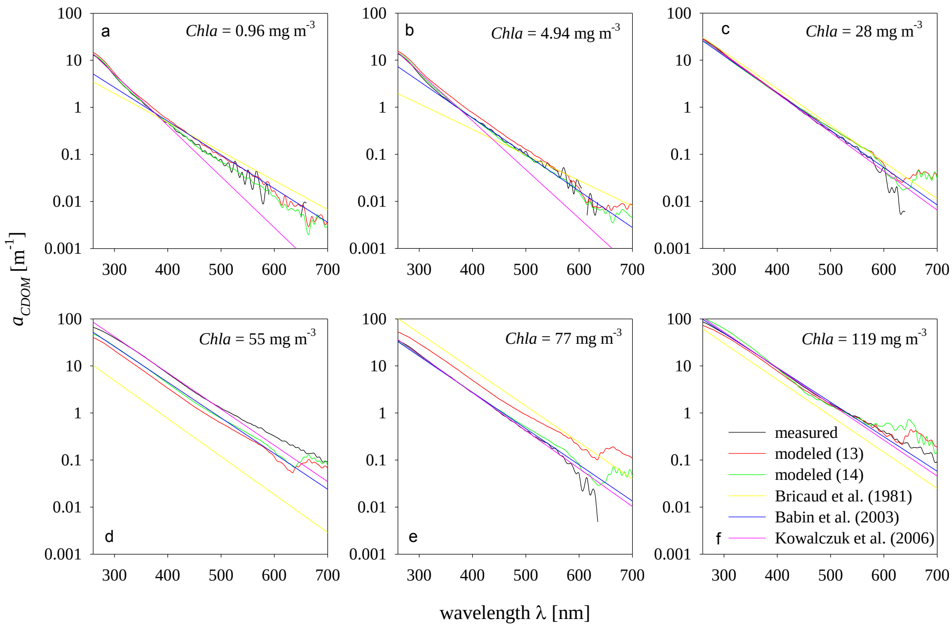

Figure 10. CDOM light absorption spectra (empirical, modeled using Eqs. 13 and 14, calculated using the models of Bricaud et al. (1981), Babin et al. (2003), Kowalczuk et al. (2006) for the following concentrations of chlorophyll *a* *Chla*: (a) ~~*Chla* =~~ 0.96 mg m^{-3}; (b) ~~*Chla* =~~ 4.94 mg m^{-3}; (c) ~~*Chla* =~~ 28 mg m^{-3}; (d) ~~*Chla* =~~ 55 mg m^{-3} (e) ~~*Chla* =~~ 77 mg m^{-3} (f) ~~*Chla* =~~ 119 mg m^{-3}.

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Appendix A.

Table A. Model parameters for light absorption by CDOM (13) for the wavelength range 240 - 700 nm shown for intervals of 5 nm

wave-length [nm]	*A* [m^5 mg^{-2}]	*B* [m^2 mg^{-1}]	*D* [m^{-1}]	R^2	wave-length [nm]	*A* [m^5 mg^{-2}]	*B* [m^2 mg^{-1}]	*D* [m^{-1}]	R^2
1	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*
240	0.200	-0.104	1.286	0.78	**475**	0.262	0.027	-0.857	0.79
245	0.207	-0.110	1.250	0.79	**480**	0.272	0.002	-0.880	0.77
250	0.211	-0.114	1.221	0.80	**485**	0.255	0.057	-0.956	0.79
255	0.214	-0.115	1.195	0.81	**490**	0.263	0.024	-0.959	0.77
260	0.216	-0.114	1.166	0.81	**495**	0.264	0.028	-1.003	0.76
265	0.218	-0.110	1.131	0.81	**500**	0.275	0.010	-1.038	0.76
270	0.220	-0.107	1.090	0.82	**505**	0.277	0.005	-1.059	0.76
275	0.222	-0.101	1.041	0.82	**510**	0.265	0.032	-1.105	0.75
280	0.230	-0.102	0.990	0.83	**515**	0.290	-0.003	-1.147	0.74
285	0.233	-0.095	0.931	0.83	**520**	0.292	-0.013	-1.177	0.72
290	0.237	-0.088	0.865	0.83	**525**	0.304	-0.050	-1.178	0.73
295	0.243	-0.080	0.795	0.83	**530**	0.310	-0.055	-1.221	0.73
300	0.249	-0.074	0.727	0.83	**535**	0.313	-0.047	-1.275	0.70
305	0.253	-0.066	0.660	0.83	**540**	0.307	-0.045	-1.292	0.70
310	0.258	-0.061	0.599	0.83	**545**	0.320	-0.054	-1.345	0.70
315	0.260	-0.055	0.541	0.83	**550**	0.344	-0.110	-1.354	0.68
320	0.261	-0.047	0.487	0.83	**555**	0.344	-0.101	-1.398	0.66
325	0.261	-0.040	0.435	0.84	**560**	0.337	-0.065	-1.470	0.64
330	0.258	-0.027	0.382	0.84	**565**	0.341	-0.087	-1.468	0.67
335	0.257	-0.019	0.332	0.84	**570**	0.337	-0.091	-1.491	0.62
340	0.260	-0.020	0.286	0.84	**575**	0.314	-0.040	-1.537	0.65
345	0.262	-0.018	0.238	0.84	**580**	0.291	0.036	-1.641	0.65
350	0.266	-0.024	0.196	0.83	**585**	0.462	-0.307	-1.597	0.65
355	0.265	-0.018	0.150	0.83	**590**	0.382	-0.195	-1.612	0.60
360	0.268	-0.022	0.108	0.83	**595**	0.367	-0.095	-1.776	0.65
365	0.265	-0.012	0.059	0.83	**600**	0.405	-0.198	-1.778	0.61
370	0.263	-0.002	0.008	0.83	**605**	0.444	-0.251	-1.886	0.52
375	0.266	-0.007	-0.035	0.83	**610**	0.480	-0.278	-1.963	0.57
380	0.266	-0.004	-0.081	0.83	**615**	0.516	-0.288	-2.083	0.57
385	0.261	0.009	-0.131	0.83	**620**	0.520	-0.450	-1.879	0.46
390	0.260	0.014	-0.174	0.83	**625**	0.510	-0.337	-2.118	0.50
395	0.261	0.012	-0.216	0.83	**630**	0.584	-0.538	-2.015	0.46
400	0.260	0.009	-0.248	0.83	**635**	0.553	-0.471	-2.075	0.44
405	0.255	0.022	-0.294	0.83	**640**	0.585	-0.434	-2.110	0.53
410	0.261	0.008	-0.326	0.83	**645**	0.600	-0.487	-2.069	0.51

415	0.252	0.032	-0.379	0.83	**650**	0.682	-0.567	-2.115	0.59
420	0.248	0.037	-0.418	0.82	**655**	0.572	-0.371	-2.096	0.64
425	0.255	0.021	-0.451	0.82	**660**	0.512	-0.099	-2.375	0.67
430	0.257	0.016	-0.486	0.82	**665**	0.301	0.387	-2.524	0.72
435	0.258	0.015	-0.529	0.82	**670**	0.446	-0.024	-2.320	0.66
440	0.253	0.028	-0.577	0.82	**675**	0.319	0.264	-2.428	0.69
445	0.258	0.019	-0.614	0.81	**680**	0.305	0.224	-2.352	0.66
450	0.251	0.036	-0.662	0.80	**685**	0.360	0.072	-2.297	0.62
455	0.262	0.011	-0.688	0.80	**690**	0.452	0.103	-2.314	0.60
460	0.271	-0.005	-0.723	0.80	**695**	0.191	0.466	-2.481	0.67
465	0.253	0.048	-0.795	0.81	**700**	0.243	0.310	-2.412	0.62
470	0.267	0.014	-0.815	0.80					

Table B. Parameters of the model of light absorption by CDOM (14) for the wavelength range 240 - 700 nm, shown for intervals of 5 nm

wave-length [nm]	*M* [m^5 mg^{-2}]	*N* [m^2 mg^{-1}]	*O* [m^{-1}]	R^2	wave-length [nm]	*M* [m^5 mg^{-2}]	*N* [m^2 mg^{-1}]	*O* [m^{-1}]	R^2
1	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*
240	0.337	0.444	1.360	0.92	**475**	-0.300	1.184	-0.572	0.95
245	0.356	0.445	1.323	0.94	**480**	-0.195	1.129	-0.613	0.95
250	0.369	0.450	1.294	0.95	**485**	-0.211	1.159	-0.657	0.95
255	0.372	0.455	1.269	0.95	**490**	-0.217	1.147	-0.682	0.93
260	0.375	0.463	1.243	0.96	**495**	-0.226	1.163	-0.720	0.93
265	0.376	0.474	1.213	0.96	**500**	-0.218	1.163	-0.756	0.92
270	0.370	0.490	1.177	0.96	**505**	-0.176	1.138	-0.787	0.92
275	0.363	0.511	1.136	0.96	**510**	-0.187	1.150	-0.823	0.90
280	0.355	0.535	1.091	0.96	**515**	-0.206	1.183	-0.867	0.89
285	0.348	0.562	1.042	0.96	**520**	-0.188	1.174	-0.901	0.88
290	0.340	0.596	0.988	0.97	**525**	-0.140	1.137	-0.929	0.87
295	0.332	0.633	0.930	0.97	**530**	-0.139	1.149	-0.969	0.88
300	0.317	0.672	0.873	0.97	**535**	-0.182	1.186	-1.005	0.86
305	0.300	0.709	0.819	0.97	**540**	-0.148	1.158	-1.033	0.86
310	0.283	0.743	0.767	0.98	**545**	-0.197	1.215	-1.082	0.83
315	0.265	0.771	0.718	0.98	**550**	-0.092	1.150	-1.116	0.82
320	0.247	0.794	0.673	0.98	**555**	-0.025	1.119	-1.155	0.79
325	0.229	0.813	0.628	0.98	**560**	-0.097	1.192	-1.204	0.77
330	0.212	0.833	0.584	0.98	**565**	-0.157	1.195	-1.217	0.78
335	0.195	0.851	0.541	0.98	**570**	-0.126	1.174	-1.243	0.76
340	0.185	0.865	0.497	0.99	**575**	-0.081	1.154	-1.282	0.73
345	0.174	0.880	0.454	0.99	**580**	0.036	1.130	-1.355	0.74
350	0.167	0.890	0.411	0.99	**585**	0.187	1.101	-1.434	0.74
355	0.154	0.902	0.370	0.99	**590**	0.227	1.022	-1.444	0.70

360	0.139	0.913	0.328	0.99	**595**	0.267	1.075	-1.543	0.70
365	0.119	0.928	0.286	0.99	**600**	0.420	1.009	-1.601	0.68
370	0.089	0.950	0.244	0.99	**605**	0.774	0.876	-1.742	0.59
375	0.089	0.955	0.200	1.00	**610**	0.771	0.937	-1.804	0.61
380	0.073	0.965	0.157	1.00	**615**	0.719	1.020	-1.873	0.60
385	0.050	0.979	0.115	1.00	**620**	0.656	0.924	-1.827	0.54
390	0.030	0.990	0.076	1.00	**625**	0.853	0.918	-1.969	0.55
395	0.014	1.001	0.035	1.00	**630**	1.122	0.784	-2.016	0.55
400	0.000	1.000	0.000	1.00	**635**	1.238	0.704	-2.069	0.50
405	-0.029	1.015	-0.038	1.00	**640**	1.078	0.787	-2.061	0.50
410	-0.046	1.021	-0.075	1.00	**645**	1.293	0.784	-2.060	0.54
415	-0.063	1.033	-0.115	1.00	**650**	1.090	0.999	-2.088	0.61
420	-0.092	1.042	-0.151	1.00	**655**	0.620	1.229	-1.952	0.68
425	-0.122	1.060	-0.190	0.99	**660**	0.130	1.655	-2.029	0.71
430	-0.123	1.059	-0.228	0.99	**665**	-0.868	2.149	-1.893	0.76
435	-0.125	1.063	-0.269	0.99	**670**	0.075	1.468	-1.922	0.67
440	-0.210	1.111	-0.307	0.98	**675**	-0.590	1.782	-1.839	0.70
445	-0.221	1.118	-0.346	0.98	**680**	0.268	1.233	-1.910	0.61
450	-0.297	1.161	-0.382	0.97	**685**	-0.316	1.508	-1.839	0.65
455	-0.312	1.171	-0.419	0.96	**690**	0.117	1.321	-1.951	0.59
460	-0.314	1.177	-0.458	0.96	**695**	-0.832	1.847	-1.843	0.68
465	-0.275	1.169	-0.503	0.96	**700**	-0.453	1.610	-1.882	0.67
470	-0.302	1.190	-0.540	0.95					