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Ocean Science Discussions

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10, C100–C107, 2013

Interactive Comment

Interactive comment on "An optical model for deriving the spectral particulate backscattering coefficients in clear and turbid coastal waters" *by* S. P. Tiwari and P. Shanmugam

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Dear Editor,

We thank the reviewers for their valuable comments and suggestions.

Suggested additional references have now been added and referred in the text. The reviewer suggested emphasizing the limitation of a model which use one input to get two outputs, and to explain why bbp and Kd(490) are significantly correlated: A summary description of the problem has now been included, and appropriate references provided. Most of the queries and comments raised by the reviewers are addressed in the revised manuscript. Brief answers and explanations are also provided in this document.

With reference to the IOCCG Report 2013: This model has the potential to derive the particulate backscattering coefficient in oceanic waters (the backscattering coefficient (bb) varies from 0.0003-0.1 m-1 reported in IOCCG Report 2013, pp. 24).

The paper title can be modified in the final revised version due to the limitation of the model over turbid and highly turbid waters. The title can be as follows: "An optical model for deriving the spectral particulate backscattering coefficients in oceanic waters".

Anonymous Referee #4

Major Remarks:

A strong theoretical background is missing to first explain the limitation of a model which use one input to get two outputs, and very importantly to explain why bbp and Kd are significantly correlated (I'm very surprised about that), as Kd is also, and in many cases, driven at first order by the absorption coefficient (Kirk, 198, 1984, 1991, Morel and Loisel, 1998; Lee et al., 2005). For instance, they should discuss the value of their constants in comparison with those appearing in the model of Lee et al. (2005), which provides Kd as a function of a, bb, and sun angle. If we do a parallel with the present model and the Lee et al. (2005)'s model, the offsets (-0.000162 at 532 nm and -0.000157 at 555 nm), should varies as a function of the absorption coefficient, and sun angle. Besides, the problem with absorption, it is well know that Kd is also a strong function of sun angle. How do the performance of the model is affected by sun angle and absorption variations. It is fundamental to examine how the constants values (the two for each wavelength) of the model vary with the absorption coefficient and sun angle.

The proposed model is based on the power function (i.e., f (X) = a [X]ˆb + c), not a simple linear equation. The offset values are considered constants in the present study

OSD

10, C100–C107, 2013

because there is weak dependency of model on solar zenith angle and absorption, only the scattering effects are dominant on Kd at 490 nm.

The relationship between bbp and Kd(490) is derived, exploiting the fact that the inverse spectral dependency exists for particulate backscattering coefficient (bbp) (i.e.,). In such case, the optical variability in the geometric structure of the underwater light field is governed by the relative intensity of 'bbp', whereby leading to the formation of isotropic region. The diffused field so formed becomes less dependent on illumination geometry and solar zenith angle at blue wavelength (Zheng et al., 2002). The dominant effect of scattering over absorption process at Kd(490) relates a very weak dependency of solar zenith angle and absorption on Kd(490). Therefore, it is of prime importance to study the change in apparent optical parameter Kd(490) and the spatial effect induced due to particulate backscattering (bbp) to the geometric structure of the underwater light field, in proper correlation.

Zheng et al. (2002) discussed that a weak dependency of Kd at blue wavelengths based on early experimental (e.g., Hojerslev et al. (1974) in clear water off Sardinia, Nelson and Aas (1977) in turbid Oslofjorden waters, and Baker and Smith (1979) in San Vicente Reservoir near San Diego) and model results reported by different researchers, indicated that the effect of solar elevation on Kd is relatively small. It is also studied that at shorter wavelengths, Kd has been considered to be independent of solar zenith angle. However, more recent experimental results based on the time-series data collected with moored instruments in the upper layer of the Sargasso Sea showed a significant correlation between Kd and solar zenith angle, especially at the red wavelengths (Stramska and Frye, 1997).

The construction and performance of the model are done using the updated version of Mueller (2000) formulation updated versions [http://oceancolor.gsfc.nasa.gov/ANALYSIS/kdv4/]. Mueller (2000) proposed Kd at 490 nm which is derived using the remote sensing reflectance band ratios at two spectral bands 490 and 555 nm. The derived Kd (490) uses as input to estimate

OSD
10, C100–C107, 2013

the bbp at 530 and 555 nm. Theoretically, it is well understood that the effects of absorption properties are more in the shorter wavelength region (e.g., at 412 and 443), there is a severe problem to partitioning individual materials in coastal waters. Furthermore, atmospheric correction errors increase with the decreasing wavelengths, with the 412nm band being the most affected one (Shanmugam, 2012). Therefore, the bands 412 and 443nm are not used in this study. Since there is a minimal effect of CDOM, suspended sediments and other coastal waters materials at 490, 555 and 670nm, these bands are used for modelling. Though several algorithms exist in the literature to estimate the Kd(490), we got maximum number of data sets for Mueller (2000) algorithm. Moreover, the Mueller (2000) model derived Kd(490) values showed excellent agreement against NOMAD-A in-situ data which is used for model parameterizations.

Note: True measured Kd (490) as well as Kd(490) computed by using any other algorithms can also be used to estimate the bbp.

They should test their formulations on the IOCCG synthetic data set which is available (http://www.ioccg.org/groups/OCAG_data.html). This is a truly independent data set, and can be done quickly. The advantage of this data set is that it is error free (synthetic) so can be used to truly assess the performance of the model.

The validation was also performed with IOCCG simulated data set. Results are included in the revised manuscript.

The authors should clearly show the range of variability of the different data sets (histograms of all data sets and parameters in log scale). They should also more carefully check the independence of these different data sets (not sure that they are totally independent). Moreover, they use the data set nomad-A to build their model at 532 and 555 nm, and test the retrieval accuracy on the same data set but at the other available wavelengths. The problem is that in NOMAD, a fit on the data has already been performed, meaning that the bbp values are all dependant, once you have calculated the

OSD
10, C100–C107, 2013

Interactive Comment

slope (calculated using 532 and 555 nm).

The revised manuscript presents the histogram of the particulate backscattering (bbp) coefficients at 530 and 555nm and the remote sensing reflectance at 490 and 555nm from four data sets. (a) NOMAD-A (N = 331), (b) NOMAD-B (N = 125), (c) NOMAD-C (N = 217), and (d) IOCCG Simulated data set (N = 500).

It is not clear whether or not the construction and performance of the model are done using the true measured Kd available in the different data sets, or the estimated Kd using the Mueller formulation. It is well know that this formulation does not work in turbid waters as recently shown in Jamet et al. (2012). How the performance of the model is affected by the Kd retrieval errors? The impact of another algorithm to retrieve Kd should be tested.

Modelled-Kd(490), is used to derive the relationship between the bbp and Kd. Moreover, we have changed the formulation based on the updated Mueller version 9 (http://oceancolor.gsfc.nasa.gov/ANALYSIS/kdv4/).

Minor Remarks:

The authors should give the range of applicability of their models as clear oligotrophic waters generally have bbp values of about 0.0002 to 0.001 m-1 (Antoine et al., 2011; Loisel et al., 2011), and turbid waters have values above 0.03 up to 0.3 m-1 (Neukermanset al., 2011; Boss et al., 2009). Their bbp values presented in this paper cover a restricted range of bbp values: 0.0003 to 0.01 m-1. It does not cover turbid waters. The bbp/Chl value of 0.009 mg-1m2 can be used to discriminate case 1 and Case 2-very turbid waters (Loisel et al., 2010).

Earlier studies have reported that the bbp values vary from 0.0002-0.001 m-1 in clear oligotrophic waters (Antoine et al., 2011; Loisel et al., 2011), and 0.03 up to 0.3 m-1 in turbid waters (Neukermans et al., 2011; Boss et al., 2009). The present model has the potential to estimate the bbp values in oceanic waters, where these values vary from

OSD
10, C100–C107, 2013

0.0003-0.011 m-1 (Figs. 3 and 6).

Introduction should be re-written, as many references are missing, and there are many inaccurate statements which may induce in error the reader. They are listed below:

The authors should explained what they name “clear water”. If it is oligotrophic water, the retrieval of bbp is still very challenging (see Antoine et al., 2011).

Manuscript is greatly improved. All the minor corrections are incorporated in the revised manuscript, and also inexact sentences are rephrased.

As suggested, we have made a major revision with better clarity and figures are re-drawn in the revised manuscript.

Missing references are inserted in the reference list.

P262 Line 21-24: Should be reformulated as bbp depends, at first order, to the particulate concentration, and to second order to the chemical composition (index of refraction), PSD, and structure of the bulk particulate matter (Stramski et al., 2004).

Rephrased in the revised manuscript

Line 24-24: Recent field measurements showed that particles smaller than 3 microns contribute to about 50% of bbp, in contrast to the results based on Mie scattering theory (Dall’Olmo et al., 2009).

Rephrased in the revised manuscript

P263 Line 1-5: Inexact sentence, it should be reformulated. It is not only the proportion of the living vs. non-living fraction which explain bbp, but first the concentration.

Rephrased in the revised manuscript

Line 7: Atmospheric deposition can occur in open ocean waters (see Loisel et al., 2011 about the particulate backscattering anomalies).

Rephrased in the revised manuscript

OSD
10, C100–C107, 2013

Line 18: You should give the references where it is stated that empirical algorithms give “An better estimates of bbp in clear ocean waters”.

Rephrased in the revised manuscript

P264/265 The authors used the Smith and Baker bw values. They should discuss their choice, as new and more accurate measurements (the more recent ones are those of Zhang et al., 2009) are now available for pure sea water; which can make a big difference in clear waters (see discussion in Twardovski et al., 2007). They should check which bbw values have been used in the NOMAD data set during the processing of the data.

We have used bbw values obtained from the NASA website which includes constant bbw from Smith and Baker (1981). More information is available on the below link. http://oceancolor.gsfc.nasa.gov/REPROCESSING/R2009/sources/water_coef.txt

P266: Note that the model of Loisel et al. (2006) allows bbp to be retrieved at different wavelengths because it is not based on prior spectral assumptions on the bbp spectral shape.

Rephrased in the revised manuscript

P273: "Though several models are available to retrieve bbp as the function of chlorophyll concentration or spectral remote sensing reflectance, none of these models provide bb values over the entire visible spectral bands that are available with satellite sensors such as SeaWiFS, MODIS and MERIS". This statement is wrong, as QAA and GSM (actually done for this paper), and many other inverse methods, provide also bbp at different wavelengths.

Reformulated Though several models are available to retrieve bbp as the function of chlorophyll concentration or spectral remote sensing reflectance, there is a lack of models to provide accurate estimate of the bbp values over the visible wavelengths with satellite ocean colour sensors such as SeaWiFS, MODIS and MERIS.

OSD
10, C100–C107, 2013

P274: "The present study is expected to form the basis for robust relationships between bbp and Kd in a wide range of coastal and open ocean waters. More measurements of these optical properties in typical coastal waters will allow the refinement of the new model which can be used to derive information on the refractive index and particle size distribution based on certain optical models to study the particle populations and their characteristics in coastal waters". Prior to any refinement based on new measurements, the authors should first examine the effect of a and sun angle on their relationships.

Diffuse attenuation coefficient at 490 nm was used as an input to estimate the bbp at two selected 530 and 555 nm wavelengths. As it is clear from Lee et al. (2005) Kd is also dependent on the absorption and solar zenith angle, in principle the effects of absorption and solar zenith angle on Kd(490) is very weak while the scattering process being dominant. Based on this fact we have correlated the bbp at two selected wavelengths with Kd(490) for estimating the slope. It is noted that our input remain the same for both the selected wavelengths 530 and 555 nm.

In this study, effects of solar zenith angle and absorption on the formulation of the model are considered very weak (or negligible).

The authors wish to thank the reviewer for his insightful efforts and positive contribution to the outcome of this paper.

Please also note the supplement to this comment:
http://www.ocean-sci-discuss.net/10/C100/2013/osd-10-C100-2013-supplement.pdf

Interactive comment on Ocean Sci. Discuss., 10, 261, 2013.

OSD

10, C100–C107, 2013

Interactive Comment