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Interactive Comment

Interactive comment on "Modelling of underwater light fields in turbid and eutrophic waters: application and validation with experimental data" *by* B. Sundarabalan and P. Shanmugam

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We greatly thank the anonymous reviewer for the valuable comments which helped to improve the quality of this manuscript. The responses are given below.

1. Chlorophyll and suspended sediments are identified to be most important in coastal waters, but what is with colored dissolved organic matter CDOM, which is also enhanced especially near river run-offs. It is stated that CDOM absorption is measured.

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Then these values should be included in Table 2 and be further discussed.

The range of the absorption coefficient of CDOM is included and further discussed. CDOM absorption is generally very low in clear and sediment-dominated coastal waters, although being elevated in eutrophic lagoon waters due the in-situ production processes (Shanmugam, 2011b).

2. Regarding Data and methods, it would be helpful to further specify the applied methods to derive chlorophyll concentration, CDOM absorption, etc., since the validation with experimental data is one key point of the work. In this paper we try to minimize the repetition of the methods used to determine Chl and CDOM based on the spectrophotometric methods which are already described in our previous work (Gokul, Shanmugam and Sundarabalan, 2014). The work is also cited in the present study.

3. Some of the equations lack good description. All variables need to be specified for example: Eq. 1 (VSF?), Eq. 28 (Es?..), Eq. 32 (SnLw), Eq. 34 (Cm, zm), Eq. 35 (SSsur, zsur), …. As suggested, all the variables are described in the respective sections.

4. Regarding Eq. 2: "The homogenous and inhomogeneous effects are included in the present RT model (by taking the average of these two terms) to simulate the underwater light fields in a wide variety of waters (including relatively clear, turbid and eutrophic waters)." This is not clear to me. I am not convinced that both parts weight equally: in clear water near the surface the direct component normally dominates; with inhomogeneous insolation conditions, only diffuse radiation occurs. For any type of waters, the direct and diffuse components cannot be fixed, but the weightage of the both components varies disproportionately and the situation is further complicated in turbid coastal waters that are highly dynamic and variable in depth, time and space. Thus, it is difficult to treat these two terms adequately. However, these two terms are calculated independently using different formulations and depending on the input values the magnitudes of these terms are determined. To arrive at some approximate

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solution as both these terms are affected or influenced in the underwater environments, we consider that both terms weigh equally. This solution works well. The use of this weightage value is more appropriate than considering either of one of these terms in existing Radiative transfer models. Furthermore, the impact of this simplification is however distant from that of the inappropriate assumptions associated with the existing RT models.

5. The wave tilt angle is not calculated based on Snell's law. Eq. 5 is the slope of the equation of a line. The tilt angle is calculated from the sea surface slope with respect to normal. But the transmitted angle is calculated using the Snell's law for the modified incident angle (Tilt angle).

6. I am not sure if Eq. 6 is valid for all cases, e.g. if the tilt is negative or smaller than theta. Please check this! The changes in the tilt angle affects the incident angle which modifies the direction of the transmittance. Checked.

7. Regarding surface transmission: What is the exact shape of the used wave surface? What parameterization is assumed, Cox-Munk based wind-dependency? With high standing sun and low or moderate wind speeds (like the cases under consideration in Table 2), a flat surface gives more or less exactly the same irradiance transmission as a strong wind roughened surface. In the introduction it is stated that the model shall overcome key problems with random surface slopes. But what is actually the applied method and what are the effects and advantages? Later it seems to be just one single slope. "The new sea surface boundary condition and the estimated sea surface transmittance have significant effects on the downwelling irradiance (Ed)" (page 2147). Is it possible to account for focusing effects? This major point needs major revision.

The shape of the sea surface is generated using the PM spectrum (refer) based on the measured wind speed which is obtained from the field data. New sea surface boundary condition is based on the random sea surface which is generated using the PM spectrum. The tilt angle is calculated from the sea surface slope with respect to normal. From this the transmitted angle is calculated using the Snell's law for new incident angle (Tilt angle). This overcome the time consuming process based on Cox-Munk which generates the sea surface slope based on the Monte Carlo simulation. The major advantage of this method is to extend the model for spatial analysis of underwater light fields. With this spatial analysis, it is possible to account focusing effects

8. Provide a reference for Gordon's parameter g! Is this parameter for case 1 waters?

A reference paper is included (Gordon et al., 1975; Haltrin, 2003). Gordon parameter "g" is defined as a function of the inherent optical properties (a and bb) which varies with respect to the type of waters (Case 1 or Case 2).

9. Eq. 19: What do the numbers mean? Where do they come from? Is that applicable for optically complex waters? Yes, it is applicable for optically complex waters where it depends on the inherent optical properties of the water column. The values are obtained from Lee et al., 1998; 1999 for shallow waters (Case 2).

10. Comment on the source function: As far as I know, chlorophyll fluorescence is not well understood. It depends on photo-inhibition, cell age, and many other things. This is a potential source of errors. In this study, only chlorophyll fluorescence is considered as the source function. The effects of photo-inhibition, cell age etc is more complex and obvious in time domain and it is difficult to obtain this variation from one time remote sensing data.

11. I am not sure about the effects of the homogeneous term (3.1.4). Maybe both terms should be compared, to get a feeling of the diffuseness. Combination of diffuse and direct terms were discussed in this study and compared with the in-situ data. This study investigates the combined effect homogeneous and inhomogeneous terms for various types of waters. Here the homogeneous term was obtained from Haltrin (Haltrin, 1998b).

12. Regarding the bio-optical model, isn't it better to use Rrs data even if they are

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small? The random factors in Eq. 30 and 31 are probably depending on skylight diffuseness and may induce errors. Where do they come from? “The coefficients are derived based on the measured Rrs, [Chl]sur and [SS]sur data (Table 3).” This is not clear from Table 3! These two equations (Eq. 30 and 31) are not needed since the conversion of Rrs to nLw is well known. For estimating slopes or relative differences, it is better to use nLw which depict much larger variability compared to the Rrs values (Ahn and Shanmugam, 2006; Shanmugam, 2011b). A small range of values leads to a small range of slope values not adequate for fixing the scenarios. The empirical coefficients presented in this table are derived based on our in-situ data. It is stated in the table caption itself.

13. CDOM profiles are not shown in Figure 3 – but it is said. Fig. 3 is the conceptual graph of chlorophyll profile estimation. CDOM profile is not measured and thus not shown in this study for brevity, although discrete measurements were made for this study.

14. Concerning the use of a specific particulate absorption, what is with the sediment concentration? According Table 2 this makes half of the particulate concentration. I am sure that the specific phytoplankton absorption also works for high concentrations. The absorption should depend on the species and mineral material. How is the empirical relation Eq. 45 derived? The Eq. 45 was derived by relating the particulate absorption coefficients and chlorophyll concentrations which are the dominant factor influencing the particulate populations and hence the remote sensing reflectance of these waters.
15. Page 2141, line 4: Rrs is no slope. Corrected

16. Page 2141, line 21: Figure 7c: it must be more light attenuation towards the sea bed. Corrected

17. Page 2148, line 2: “The bottom reflectance affects the entire water column” in optically shallow water only! Agreed, but in this study the effective bottom reflectance equation is explained as a function of IOPs. This term is expected to significantly

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influence the entire water column in optically shallow waters, not in deep waters and highly turbid shallow waters.

18. Page 2148: “It was found that the predicted underwater light field parameters (Ed, Eu and Lu) from the present RT model using the Pred_IOPs were better consistent with the measured radiometric data as well as those obtained from the same RT model using the in-situ IOP data in clear waters, turbid waters, phytoplankton-dominated waters and eutrophic waters.” This is not clear to me, and I think Figures 11 and 13 show the opposite. The statement is rephrased. The vertical structures of these estimated Chl and SS had good agreement with the measured profile data. It was found that the predicted underwater light field parameters (Ed, Eu and Lu) from the present RT model using the Pred_IOPs are reasonably good when compared with the measured radiometric data as well as those obtained from the same RT model using the in-situ IOP data in clear waters, turbid waters, phytoplankton-dominated waters and eutrophic waters. The differences between the predicted and measured Ed, Eu and Lu may arise from the bio-optical parameterizations used to estimate the IOPs. Perhaps, the non-uniform trend of the chlorophyll pattern along the water column is also expected to cause these differences in the predicted Ed, Eu and Lu by the present RT model.

19. Table 5: Include units and be consistent: wavelengths in nm. Table 1 refers to micro-m. The unit of wavelengths is expressed in μm (micro-m) for consistency

20. Figure 1: Is suspended sediment a potential source? What is the slope of sea surface? Yes, the contribution of suspended sediment is also considered in this study. In this study, the shape of the irregular sea surface is generated based on the wind speed using the PM spectrum which is obtained from the field data. The slope is calculated based on the generated irregular sea surface.

21. Figure 7: What is model and what is measured? Included. Thank you for indicating this.

22. Figure 10 ff.: It would be good to include the specific water depths. And could

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you also include Eu/Ed or Lu/Ed in order to see how AOPs may change with water depth which shouldn't theoretically. Included Depth information were provided in the corresponding Figs as follows: Fig 11 — 2m, 6m, 10m, 14m Fig 12 — 3m, 5m, 7m, 12m Fig 13 — 2m, 3m, 4m, 5m Fig 14 — 1m, 2m, 3m, 4m Fig 15— 0.1m, 0.1m, 0.1m, 0.1m (for four different stations)

23. In the end, there is nothing about the model performance in terms of simplicity and computational time. A statement on this could be helpful. A brief description is included to explain this. The model is implemented in MATLAB 2007 with the computer having 4 gigabyte RAM. The run time for this model is 8 milliseconds for the entire wavelength at one depth. In fact, this can be reduced if the model is implemented in FORTRAN with the high performance computer (Included in the manuscript).

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Kindly see the revised version for further information

Please also note the supplement to this comment:
http://www.ocean-sci-discuss.net/11/C1014/2014/osd-11-C1014-2014-supplement.pdf

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