Responses to the reviewer's comments

We sincerely thank the reviewer for giving valuable comments that helped to improve the manuscript. We have revised the manuscript in accordance with your comments and suggestions and provided additional information and interpretation.

(i) Scientific value: Accurate derivation of R from certain inputs are valuable for the purpose of validating and calibrating in situ instruments and satellite sensors and providing an alternative to fill the gap of missing data, etc. The key to such model is to use very limited inputs. However, the proposed approach uses *a*, *bb*, Chl, Kd, and Ku. It means majority of field quantities are required. In particular, to compute Kd and Ku, the profiles of downwelling and upwelling irradiances, Ed and Eu, are needed. As a result, this model becomes redundant because you can easily derive R from Ed and Eu by taking ratios as R=Eu/Ed. The only possible value is to estimate R just beneath surface R(0-,λ) instead of the profiles of R(λ,z) [see (ii)]. I would like the authors to answer: why is this model important and valuable?

This present model, like any other models, estimates $R(0\text{-},\lambda)$ using the IOPs. Most of the other existing models require $a(\lambda)$, $b_b(\lambda)$ and solar angle whereas this model requires additional two inputs namely *Chl* and *a*(412) where *a*(412) which in turn can be obtained from $a(\lambda)$. In the context of remote sensing, *Chl* can be easily obtained from the existing ocean color models. Thus, this model is important for predicting the surface layer *R*. Furthermore, there is no such model available to predict R(0-,λ) for wide optical range from oligotrophic to turbid eutrophic waters.

The calculation of depthwise R(λ,z) requires R(0-,λ), K_u and K_d, where R(0-,λ) comes from IOPs and K_u, K_d are calculated from E_u and E_d. The present work is meant to describe all the possible variations on "*f*" and thus "*R* " throughout the water column.

(ii) Possible but questionable value: As discussed in (i), the remaining value of this model is to estimate R(0-,λ). To estimate R(0-,λ), the required in-water quantities are *a*, *bb*, and Chl. At some cases it is true that you have these three quantities but not R(0-,λ). As a result, this may provide alternative means to derive R(0-,λ) for the purpose of validation of other devices. However, two problems remain. First of all, such model does not account for inelastic processes, which will cause dramatic errors in the red and near-infrared. In addition, it would be easier to make near-surface underwater Ed and Eu measurements and extrapolate to get R(0-,λ) than measuring all *a*, *bb*, and Chl. Therefore, the value of this model exists but limited.

It is true that models developed based on the IOPs do not account for the inelastic processes particularly in the NIR region. Here we have made an attempt to consider unaccounted inelastic processes along with the combined effect of absorption and backscattering for the calculation of *f*(0-,λ) through $(bb/a)^n$.

A separate description has been added to the revised manuscript as follows, "Conversely, the term 'backscattering by absorption ratio' (b_b/a) gives the spectral character to $f(0^-,\lambda)$. The spectral slope is governed by the parameter '*n*', a function of *Chl* [Fig. 2(d)] (Okami et al., 1982). In case of clear oceanic waters, the spectral slope '*n*' is small and thereby produces almost linear $f(0^-,\lambda)$. This is the reason why the case 1 models assume $f(0^-,\lambda)$ as a constant. For

productive waters with elevated C*hl* concentrations, the slope causes large spectral variations in $f(0^-,\lambda)$ [Eq. 6]. For clear waters (assuming *Chl* = 0.1 mg m^{-3}), it takes the value of 0.194, and for turbid productive waters (*Chl* = 72 mg m^{-3}), it takes the value of 0.28. The $(b_b/a)^n$ on $f(0^-,\lambda)$ (Eq. 5) is significant due to the pronounced effect of absorption, fluorescence and backscattering of phytoplankton in the red and NIR regions, particularly at elevated concentrations in productive waters."
In fact, we have examined these effects in all five waters.

In clear oceanic waters, simple extrapolation of near-surface underwater Ed and Eu measurements to get R(0-,λ) may be possible. However, it is not practically possible to simply convert near-surface underwater Ed and Eu measurements and extrapolate to get R(0-,λ) in turbid and productive waters due the reasons explained in Discussion Section 5 Dev, P. J. and Shanmugam, P.: A new theory and its application to remove the effect of surface reflected light in above-surface radiance data from clear and turbid waters, J. Quant. Spectrosc. Ra., 142, 75–92, doi:10.1016/j.jqsrt.2014.03.021, 2014a.

(iii) Scientific rigor: It is understandable and physically verified that the factor *f* is influenced by both solar zenith angle and underwater IOPs, so it can be proportioned to *Sf* and *If*. In fact, the scatter plots in Figure 2 evidently support this. However, how did the authors to know the values of *Sf* and *If* (and *n*) at the first place? There is no way that the values of *Sf*, *If*, and *n* can be known without priori knowledge. It may be not entire correct, but it is guessed that the authors presume a certain relationships (e.g. format of equations) between *Sf* and θs, between *If* and *a*(400) (why choose *a*(400) is also a question to answer), and between *n* and Chl. Then extensive regressions were made to determine the exact equations as shown in Eq. 4-6. If this is true, the relationships in Figure 2 and Eq. 4-6 do not represent the true representation of factor *f*, but only to the dataset the authors have. In addition, if the extensive regressions truly exist, is it still suitable to claim this model as semi-analytical model? Is it still suitable to conclude that this model works universally for different water bodies?

The values of *Sf*, *If*, and *n* cannot be known exactly as these are not the measured quantity. Our measurements and analyses (Figure 2(a)) showed that the quantities (*Sf*, *If*, and *n*) in each type of water followed a distinct pattern although having variations with the solar zenith angle. Dependencies of the IOPs were then observed and we included the absorption term to differentiate this from the solar angle term. Later, we understood that the unaccounted part of the inelastic process along with the combined effect of absorption and backscattering (especially in turbid and productive waters) has an influence on the *f* factor. The introduced coefficients need not to be accurate, but it is true that it follows the functions of *Sf*, *If*, and *n.*

Since we modeled these quantities for a wide range conditions and water types (Table 1), the present model gives R with the relative percent error of less than 25%.

The selection of the wavelength of 400nm has been revised to 412nm. The I_f part of the model equation is changed as follows

$$I_f = 0.0684 * \left(\frac{1}{a(400)} \right)^{0.757}$$ (former I_f)

$$I_f = 0.0671 * \left(\frac{1}{a(412)} \right)^{0.756}$$ (new I_f) (included in the revised manuscript)

Due to the change of wavelength from 400nm to 412nm, the coefficients got slightly changed from 0.0684 to 0.0671 (in magnitude) and 0.757 to 0.756 (in the power). We decided to shift the wavelength from 400 to 412nm because latter one (412nm) has direct applications to remote sensing as most of the ocean color sensors realize its potential applications. Since the present model corresponds to the reflectance (which contain the information of phytoplankton, mineral particles, detritus and CDOM), choosing a wavelength in the lower blue end can give more accurate rather than choosing on the higher wavelength parts particularly>500nm, where pure water absorption dominates. Differences between the constituents (phytoplankton, mineral particles, detritus, CDOM) are more easily predicted and differentiated in the region <443nm. Thus, we have used 412 as an appropriate wavelength.

We do not claim that the present model is universal, but it is well suited for the coastal and associated inland waters environments studied.

(iv) Mathematical and physical issue: In Eq. 7-8, the authors describe how to derive R(λ,z) from R(0-,λ). They claimed that *f*(z) is a function of Kd and Ku. Eq. 7-8 are mathematically valid but not physically. The correct physics is:

$$R(\lambda, z) = \frac{E_u(\lambda, z)}{E_d(\lambda, z)} = \frac{E_u(0^-, \lambda) \times e^{-K_u(\lambda, z) \times z}}{E_d(0^-, \lambda) \times e^{-K_d(\lambda, z) \times z}}$$

$$R(\lambda, z) = R(0^-, \lambda) \times e^{-z[K_u(\lambda, z) - K_d(\lambda, z)]}$$

$$R(0^-, \lambda) = f(0^-, \lambda) \left(\frac{b_b(0^-, \lambda)}{a(0^-, \lambda) + b_b(0^-, \lambda)} \right)$$

As a result, the description within P1889 L18-P1990 L12 are mostly incorrect. In particular, the R (as well as Kd and Ku) are not necessarily constant even in homogeneous water column.

In the revised manuscript, we have rearranged the model equations with required notations (0^-, λ and z). A new section has been used to describe the Ku, Kd variations with respect to the near surface reflectance. In order to examine the phenomenon, it was simulated in the Hydrolight to see the variation of R throughout the water column for varying optical properties. The section has been included in the revised manuscript. The order of the equations are also changed and the manuscript is formatted accordingly.

The model section is rewritten with additional information and more accurate expressions.

3. Model description

Theoretically, diffuse reflectance (R) is regarded as an apparent optical property (AOP), which is the ratio of the upwelling and downwelling irradiances (Eq. 1). In the field of marine optics and remote sensing, the irradiance reflectance can be calculated analytically from the inherent optical properties (IOP) of the seawater (Eq. 3).

$$R(\lambda, z) = \frac{E_u(\lambda, z)}{E_d(\lambda, z)} \qquad (1)$$

$E_{u,d}(\lambda, z)$ at the depth z can be expressed in terms of Beer-Lambert Law as,

$$= \frac{E_u(0^-, \lambda) \times e^{-K_u(\lambda, z) \times z}}{E_d(0^-, \lambda) \times e^{-K_d(\lambda, z) \times z}}$$

$$R(\lambda, z) = R(0^-, \lambda) \times e^{-z[K_u(\lambda, z) - K_d(\lambda, z)]} \qquad (2)$$

where,

$$R(0^-, \lambda) = f(0^-, \lambda)\left(\frac{b_b(0^-, \lambda)}{a(0^-, \lambda) + b_b(0^-, \lambda)}\right) \qquad (3)$$

Here R is related to the IOPs through a factor 'f'(Gordon et al., 1975; Morel and Prieur, 1977). a and b_b denote the absorption and backscattering coefficients respectively, λ the wavelength, 0^- the depth just below the sea surface, and z the depth layer from the surface. In the literature, the factor f is generally parameterized based on the assumptions applicable to clear oceanic waters and holds very little information of the other water types (such as turbid and productive coastal waters). This limits the possibility of extending such models to predict R in coastal and inland waters. In this paper, f is determined just below the water surface and at different depths. As the factor f is dependent partly on the illumination and environmental conditions, analytic solutions for f predictions are not possible (Morel and Gentili, 1991, 1993, 1996). Models with restricted assumptions (such as spectrally invariant, optically homogeneous, zenith sun angle) lower the accuracy of f and hence degrade the predicted reflectance values (Sathyendranath and Platt, 1997). However, based on the experiments conducted in different waters we provided meaningful interpretation about this complex f factor.

The spectral variation of f is found to have dependency (Loisel and Morel, 2001) on absorption and backscattering coefficients (Eq. 4), whereby its magnitude (S_f+I_f) is dependent on the light field available just below the sea level. The entire factor $f(0^-,\lambda)$ seems to follow a power law where its magnitude is the sum of the solar zenith angle function (S_f) and IOP function (I_f). Plotting the S_f+I_f versus solar zenith angle [Fig. 2(a)], the data points seem scattered when they are shown together for all water conditions. However, it can be closely observed that the trend followed by each water type is rather consistent although having a slight shift among the water types [i.e., Type I (blue) & II (purple) lie at the top, Type III (orange) & IV (pink) in the middle, and Type V (green) at the bottom]. Segregating the magnitude term (S_f+I_f) provides an insight into the variation of each function with the solar zenith angle [Fig. 2(b] and (c)]. The term other than the solar zenith angle function (S_f) that seems to influence the f factor is dependent on the IOPs (I_f). We found the relation between this term (I_f) and the inverse of absorption ($1/a(412)$) based on the interpretation of reflectance properties of different waters. The model requires four surface-measured parameters namely the solar zenith angle, *Chl* concentration, absorption and backscattering coefficients. The coefficients denoted with 0^- represent the surface measurements and λ the spectral function. The $a(412)$ in I_f is the surface measured absorption coefficient at 412nm. The model equation is expressed as follows,

$$f(0^-,\lambda) = (S_f + I_f)*\left(\frac{b_b(0^-,\lambda)}{a(0^-,\lambda)}\right)^n \qquad (4)$$

$$f(0^-,\lambda) = \left\{0.03*\exp^{(0.0462*\theta_s)} + 0.0671*\left(\frac{1}{a(412)}\right)^{0.756}\right\}\times\left(\frac{b_b(0^-,\lambda)}{a(0^-,\lambda)}\right)^n \qquad (5)$$

where, $n = 0.03\times\log(Chl) + 0.2243$. (6)

As shown mathematically in Eq. (5) and schematically in Fig. 2(b) and (c), S_f increases exponentially with the increase of solar zenith angle and I_f follows a power function which decreases with increasing *a(*412*nm)*. The absorption coefficient at 412nm is chosen because significant variations in the absorption spectra are evident within this spectral region, whereas at longer wavelengths the absorption due to the pure seawater dominates. The wavelength 412 nm has direct applications to remote sensing as most of the ocean color sensors included this band to realize its potential applications. Since the present model corresponds to the reflectance (which contain the information of phytoplankton, mineral particles, detritus and CDOM), choosing a wavelength in the lower blue end can give more accurate information about the water column properties rather than choosing a longer wavelength beyond 500nm. Consequently both the S_f and I_f terms determine the magnitude of $f(0^-,\lambda)$.

Conversely, the term 'backscattering by absorption ratio' (b_b/a) gives the spectral character to $f(0^-,\lambda)$. The spectral slope is governed by the parameter '*n*', a function of *Chl* [Fig. 2(d)] (Okami et al., 1982). In case of clear oceanic waters, the spectral slope '*n*' is small and thereby produces almost linear $f(0^-,\lambda)$. This is the reason why the case 1 models assume $f(0^-,\lambda)$ as a constant. For productive waters with elevated C*hl* concentrations, the slope causes large spectral variations in $f(0^-,\lambda)$ [Eq. 6]. For clear waters (assuming *Chl* = 0.1 mg m^{-3}), it takes the value of 0.194, and for turbid productive waters (*Chl* = 72 mg m^{-3}), it takes the value of 0.28. The $(b_b/a)^n$ on $f(0^-,\lambda)$ (Eq. 5) is significant due to the combined effect of absorption, fluorescence and backscattering of phytoplankton in the red and NIR regions, particularly at elevated concentrations in productive waters. The high chlorophyll effect is thus accounted in $f(0^-,\lambda)$. Considering all the water types, the predicted S_f+I_f values are in excellent agreement with *in situ* S_f+I_f determinations (Fig. 2(e)).

Irradiance reflectance as a function of depth, $R(\lambda,z)$ can be calculated by combining Eqs. (2) and (3),

$$R(\lambda,z) = f(0^-,\lambda)\left(\frac{b_b(0^-,\lambda)}{a(0^-,\lambda)+b_b(0^-,\lambda)}\right)\times e^{-z[K_u(\lambda,z)-K_d(\lambda,z)]} \qquad (7)$$

$$R(\lambda,z) = f(\lambda,z)\left(\frac{b_b(0^-,\lambda)}{a(0^-,\lambda)+b_b(0^-,\lambda)}\right) \qquad (8)$$

where, $f(\lambda,z) = f(0^-,\lambda)\times e^{-z[K_u(\lambda,z)-K_d(\lambda,z)]}$. (9)

Clearly, the depth wise *f* function [$f(\lambda,z)$] is largely dependent on the *f* just below the surface [$f(0^-,\lambda)$]. As noted earlier, the $f(0^-,\lambda)$ is a function of light field available at just below the water surface which is approximated on the basis of the solar zenith function and IOPs. In case, if the oceanic water is homogeneous, *R* throughout the water column must be uniform without any fluctuations. This in turn sheds light on the *f* function of both 0^- and *z*. For the uniform *R* throughout the vertical column, $R(0^-,\lambda)$ must be equivalent to $R(\lambda,z)$. Since most of the natural waters are non-homogeneous (because the water constituents are not homogeneously distributed in general) the fluctuations of R are expected. The fluctuations in R are replicated on the f. Since f is a function of light field available in the water column, it tends to decrease with depth as denoted by $-z$ (minus z) in Eq. 9. The term $(K_u\text{-}K_d)$ is the difference in the upwelling and downwelling diffuse attenuation coefficients that induce the corresponding change (increase or decrease) in $f(\lambda,z)$. Thus, any underwater fluctuations in R depend on the change in the upwelling and downwelling diffuse attenuation coefficients (Eqs. 7 and 8).

(v) Missing comparison with other models: It is not convincing that the newly proposed model is better than existing ones unless the model is compared to them, at least with model by Dev and Shanmugam (2014b).

Comparison is made with the Dev & Shanmugam (2014b) and below text has been included in the revised manuscript.
"Comparing with the existing models, it should be noted that the existing models are designed with certain assumptions to predict R in case 1 waters or coastal (case 2) waters. For instance, a model that is originally developed for clear oceanic case 1 waters (Gordon et al., 1975; Morel and Prieur, 1977, Kirk, 1984) gives biased reflectance values in turbid coastal and productive water types. A model of case 2 waters (Albert and Mobley, 2003) is restricted to case 2 waters (Dev and Shanmugam, 2014b). Thus, it is more appropriate to compare the results of this study with our previous model since both the models are designed for both marine and inland waters. Figure 5(a)-(d) shows the scatter plots comparing the model R (from the model of Dev and Shanmugam (2014b) and this study) with *in-situ* R for all the water types, where the blue dots represent the previous model (Dev and Shanmugam, 2014b, denoted as *DS* in Table 3) and the orange dots represent the present model (denoted as *PM* in Table 3) for the key wavelengths 412, 443, 488, 531, 555, 650, 685, 715nm. In Fig. 5(a), results from both the models are nearly identical although the previous model slightly performs better (relative error 18.8%) than the present model (relative error 21.3%). These differences are noticeable in the range below 0.001 where the instrument noise could cause errors in clear oceanic waters when the reflectance values are almost zero in the NIR. In type II relatively clear waters, results from the present model start improving upon those of the previous model (Figure 5(b)), with the relative error of 18.2% for the present model and 15.3% for the previous model. The present model gives better results for the moderately turbid type III waters than the previous model (see the orange dots falling on the 1:1 line in Figure 5(c)). The relative error percentage of the present model is 10.5% when compared to 12.8% for the previous model. In Type IV sediment dominated turbid waters (Figure 5(d)), the present model yields the error percentage of <6% whereas the previous model yields around 21.3%. In the turbid productive type V waters, results from the present model are closer to the *in-situ* data (Figure 5(e)), thereby yielding the relative percentage error of less than 9% over 48% for the previous model. These results suggest that the model is well suited for optically complex coastal and inland waters with high organic and inorganic contents. These validation results clearly emphasize the importance of the present model for predicting R in a wide variety of waters without involving the spectral constants with the previous model. The additional parameters with the present model increase its potential and wider applicability".

Additional comments:

1. Title: What is the definition of diffuse reflectance? Many claims about R may not be correct depending on the exact definition. Is there any component in this paper related to inland waters?

It is understood that R can be referred to as the diffuse reflectance when it is evaluated just beneath the water (sea or lake) surface. Since the present work focuses on R at depths, the more correct expression for R is “Irradiance reflectance” or “Subsurface reflectance” as already noted in our earlier paper. Hence, the “diffuse reflectance” term is replaced by “Irradiance reflectance” to follow exact physics.

Definition of R has been added to the abstract as follows, “Irradiance reflectance (*R*) is the ratio of the upwelling to the downwelling irradiances that can be related to the Gordon’s parameter $(b_b/(a+b_b))$ through a proportionality factor ‘*f*’.”
In the revised manuscript, the sentence is rephrased as: “The model is applicable for both marine and inland waters.”

2. Abstract: it mentioned that this newly proposed work eliminate Kchl and Kss, which were used in Dev and Shanmugam (2014b). It thereafter never appeared in the main text of the paper. However, I think this should be an important component in the introduction and discussion sections. Or else how can your motivation and scientific basis be clear?
A separate paragraph has been added on the revised manuscript along with the inter-comparison of previous model and present model with the measured data.

3. Page 1895 L11-13: more context is needed to introduce the factor *f*.

This section is rewritten to explain adequately about the *f* factor in the revised manuscript.

4. In all equations: please specify the dependence on z and λ by *a*, *bb*, Kd, and Ku.

Dependencies on z and λ by *a*, *bb*, Kd, and Ku are added to the equations.

5. Page 1900 L21-L24: Place in the captions of Figure 3.

Figure captions are placed in Figure 3.

6. Page 1901 L2 (and other places): In general, it does not say "higher" wavelengths. Instead "longer" or "greater" may be used.

The word ‘higher wavelengths’ is replaced by ‘longer wavelengths’ in 3 places in the manuscript.

7. Page 1903 L22-24: What is your basis to claim this model would work for homogeneous water? Does "inhomogeneous" include "stratified"? What are the real value of this model? [please see (i) and (ii)].

Since, the stratified includes the inhomogeneous conditions, the word “stratified” has been removed from the revised manuscript.

8. Table 1: For what stations? Could you please include information such as *a*, *bb*, Chl, TSM as well?

A table (table 1) is provided to show the optical properties range corresponding to Figure 3. (Table has been added to the revised manuscript).

Water Type	*Figure 3*	*a(412)* (m^{-1})	b_b*(412)* (m^{-1})	*Chl* (mg m^{-3})	*Turbidity* (NTU)	*solar zenith angle* (deg)
Type I	a_1	0.129	0.0154	0.2	0.59	41.15
	a_2	0.132	0.016	0.23	0.6	25.52
Type II	b_1	0.385	0.0481	1.99	2.03	33.59
	b_2	0.493	0.0325	1.68	1.43	39.47
Type III	c_1	1.234	0.0383	17.72	1.86	42.38
	c_2	1.183	0.0471	16	2.23	53.8
Type IV	d_1	0.928	0.232	1.25	8.66	19.39
	d_2	0.56	0.1467	1.09	5.64	31.92
Type V	e_1	8.1	0.29	49.28	7.66	20.94
	e_2	6.56	0.24	44.64	7.79	54.91

9. Figure 4a: R is missing between surface and ~20 cm. What is the causes of the missing R? Are *a*, *bb*, and Chl available between surface and 20 cm? If not, how did you derive *f*(0-,λ) and R(0-,λ)? As explained in (iv), the R(λ,z) solely depends on R(0-,λ) when Kd and Ku are in situ determined. It is critical to know how could you derive R(λ,z) from R(0-,λ) when there are missing data below surface. I assume Ku and Kd within 0 – 20 cm layer is not available as well. What are the additional assumptions did you make to predict R(λ,z) under such case? In fact, this is very critical because data are often missing within top 50 cm or so. If you make additional assumptions, please include them in the paper and discuss its potential influence on the model.

The following text has been added to the revised manuscript. “Measurements were taken approximately 20cm from the sea surface. It is assumed that the IOPs are uniform in the first half meter of the water column from the surface. Note that one cannot measure the radiance or irradiance or any IOPs exactly just below the sea surface due to the wave action. Though the measurements of radiance or irradiance from just below the sea surface (below 20 cm) might contain errors (due to waves and possible titling of instrument), such errors are cancelled out when taking the irradiance ratio to calculate the reflectance values”.
We have not made measurements within 0-20 because of the wave conditions. Measurements taken below this depth were reliable because the instruments (Trios Radiometers) were stable and ship position was adjusted to make the conditions favorable for profiling measurements without ship shadowing effects and wave effects.

For depth case, we have also shown results using Hydrolight simulations (R, Kd and Ku) for given wind speeds (with zero wind speed case, an example is shown in figure 4).

10. Figure 5: Are R from all depths included?

Figure 5 is replaced with new figure, with the comparisons of the previous model (Dev & Shanmugam, 2014b). Since the Ku and Kd are derived from irradiances, it generally gives 1:1 correspondence R(λ,z). This plot includes all data including depth profile data.