Replies from the authors to comments by Referee #2 on os-2013-50

We are due thanks to Referee #2 for the work spent on our paper and for constructive comments and suggestions. The specific comments from Referee #2 are discussed below. Comments are in bold italics and replies in regular font.

1 Introduction

1.1 Motivation for the present study

Ref.#2: You provide some background information and explain briefly what you have done, but do not motivate the study or give hypotheses. Also explain in plain words already here the concepts "photopic" and "monochromatic".

We agree that we might have stated more clearly the details of our motivation. On the other hand:
- In the first paragraph of this section we say : "The (Secchi) depth is determined by the optical properties of the water and can therefore be related to these properties. The usefulness of such relationships is the main motivation for this study."
- In the second paragraph we mention that we will estimate the different optical properties appearing in the theoretical expression for the Secchi depth, and then compare the expression to observations. We have now stated explicitly that this test is also a part of our motivation.

We assume that most readers of Ocean Science Journal will understand the concept "monochromatic", while "photopic" perhaps is less clear. Anyhow, these two concepts have now been removed from Sect. 1.1, while brief explanations of them have been added to the second paragraph of Sect. 2.

2 Theory of the Secchi depth

p. 1844, rows 8-12 The theory is presented well and logically, and now you explain what you will be doing next. Yet, at this point it would be appropriate to justify why you have gone through such a vast chain of equations and what will you achieve through the next sections. Please do not refer to "the right hand side" or "the left hand side" of a long equation, but be more precise.

We have rewritten these rows, explaining that we will test Eq. (21) by comparing one side of the equation, the quantity $Z_D(c+K_L)$, to the other side, the sum $\ln(A_1)-\ln(A_2)+\ln(W)-\ln(C_t)$. Secondly we inform the reader how the different parts of the theoretical expression (21) can be used to estimate how colour filters, disk size, sun glitter and waves influence the Secchi depth.

3 Data sets, instruments and environmental conditions

p. 1844, row 15 (and Figure 1) It seems you have some observations from the Kattegat as well. If so, Kattegat should be mentioned here.

Yes, two stations from the northern Kattegat are included in the second data set, and this information has now been added.

In Figure 1, it might be useful to distinguish which data set / combination of data sets the observation points present.

While the Skagerrak/Kattegat locations are all from the second data set, the locations in the Outer Fjord have been applied numerous times by the second and third data set, and the locations in the Inner Fjord have been applied by all three of them. In our opinion a figure with three different location symbols for the three different areas will not really present any new information. We think that the present solution is simpler and thus better: the area of investigation for the different data sets is described in the text. Hopefully our new Table 1 (explained below) will provide the necessary information.

p. 1844, row 16, sentence "...from the surrounding settlements." Please add reference.

The Oslofjord is probably one of the best monitored fjords in the world, and numerous reports in Norwegian from marine research institutes to the Norwegian Environment Agency have been written about the supply of nutrients to the fjord and their concentrations. We have added what we consider to be the most comprehensive reference to the text.

p. 1844, row 20, sentence "...down to the pycnocline." Please add reference.

Two references, describing the position of the pycnocline, have now been added.

p. 1845, rows 1-14 I do not understand why Secchi depth ranges are presented here under "Data sets etc.", nor the relevance of such information, when the observations have been collected from different time-periods and times of year. I would remove this paragraph.

It was pointed out in the Introduction that the Secchi depth is one of several parameters used by environmental authorities to describe water quality. The relevance is thus that the ranges of Secchi depths provide a parameter for water quality, and that this may be of interest to some readers. It is true that the Secchi depth varies with season. That is why we presented ranges instead of e.g. mean values. These ranges are not a part of our test of Eq. (21) (Sections 4-5), neither are they a part of our statistical relationships between Secchi depth and other parameters (Section 6), which to us justify the presentation under the heading "environmental conditions". The information in the rows 6-8 have now been moved to a new Table 1, presented below, together with other information about the environmental conditions. The Secchi depth ranges are now based on the results of Andresen (1993) and Aarup (2002).

Table 1. Environmental conditions in the Oslofjord-Skagerrak area. S is salinity range between the surface and the Secchi depth, U is mean±standard deviation of wind speed in m s^{-1}, C is mean±sd of cloudiness in octas, and $Z_{D,white}$ is mean±sd of Secchi depth in m.

Area	Inner Fjord north of 59.67° N	Outer Fjord) 59.00°-59.67° N	Skagerrak 57.00°-59.00° N
S:	15-28 (all year) [1]	16-30 (all year) [1]	20-32 (all year) [2]
U:	2.8±0.5 (summer) [3]	6.7±1.1 (summer) [3]	
	2.0±0.7 (winter) [3]	7.9±1.6 (winter) [3]	
C:	5.0±0.8 (summer) [3]	4.8±0.7 (summer] [3]	
	5.5±0.9 (winter) [3]	5.6±0.9 (winter) [3]	
$Z_{D,white}$:	4.4±1.7 (summer) [4]	4.3±1.8 (summer) [4]	8.3±2.8 (all year) [5]
	10.5±2.8 (winter) [4]	11.1±3.2 (winter) [4]	

References: [1] Gade, 1963, 1967; Aure et al., 1996; Staalstrøm et al., 2012; [2] Aarup et al., 1996a; Højerslev et al., 1996; [3] Norwegian Meteorological Institute, pers. comm.; [4] Andresen, 1993; [5] Aarup, 2002.

p. 1845, rows 15-27; p. 1846 and p. 1847, rows 1-8 Please provide more accurate information of the datasets: number of observations, number of stations, specify "different types of Secchi disks", the colours of the filters etc..

The former Table 1 has been substituted by a new figure, as suggested by Referee #1. The additional information suggested by Referee #2 is included in the description of the data sets or presented by the new Table 1. The relevant text on pages 1845 and 1847 has been rewritten.

p. 1847, rows 9-28 (and tables 1a, 1b & 2) Also here, I find it confusing that some results from the data are presented here under "Data sets etc." – it would be easier for the reader if the two

were separated. When presenting results, it would be helpful to refer to one of the datasets introduced earlier.

We agree that it may seem as if we are presenting new results, but they are ten years old. To a similar comment from Referee #1 we replied: "We have presented the spectra of upward radiances and luminances at zero depth, illustrating the greenish colouring of the investigated waters. The spectra were observed in 2002-2003 and constitute a part of our second data set. However, they are not new results, presented here for the first time, but ten years ago they provided important inputs to the validation of remote sensing products within the projects VAMP and REVAMP mentioned in our Acknowledgement. These tests were discussed at meetings in the ESA committee MAVT (MERIS and AATSR Validation Team). Accordingly we think that information about the spectra of the upward radiances belongs to the chapter describing the environment of the Secchi depth recordings rather than in a chapter for new results." The chapter has now been reorganized and rewritten to avoid the confusion of old results and new analyses.

p. 1847 Describe in more detail how the photopic sensitivity of the eye was determined.

In this comment we are not sure which details our referee wants. We have already stated in rows 13-14 that "... the radiance spectra are multiplied by the CIE 1924 photopic efficiency function (e.g. Walsh, 1958) in order to obtain the spectral upward luminances,...",. We assume that we are not expected to describe the different photometric methods used in the papers that the CIE standard curve is based upon. Instead we have tentatively described in more detail what this curve represents and what it looks like in the first paragraph of Chapter 2.

4 Test of Eq. (21) in photopic units

p. 1848, row 11 In a similar way as is done in the beginning of Chapter 5, it would be helpful for the reader to present also in the beginning of Chapter 4 in brief words what is done (perhaps even risking repetition).

We think that the heading of this chapter explains what it is all about, but we have now added some text where we repeat the last lines of Chapter 2 with some more details, and explain why we have chosen this method.

4.1 Values of c_{phot} and $K_{L,phot}$

p. 1849, rows 1-7 It seems you are presenting data from laboratory tests here? Also this data should be presented rather under Chapter 3. Otherwise the reader finds the procedure extremely hard to follow.

We agree and have moved the rows 1-7 on page 1849, describing results from two decades ago, to Chapter 3, while the text in the present chapter have been rewritten.

4.2 Values of ρ_{DL}, R_L, $\Re$, $\bar{\rho}_{L,air}$, $\ln(A_1)$ and $\ln(A_2)$

p. 1850, rows 5-8 (and table 3) Looking at the table, the reader assumes, that the coloured filters are used to observe the white disk, but this should nevertheless be confirmed in the table text.

We agree, and this detail has been added.

p.1850, rows 24-26 Again a new dataset is presented. If the dataset first introduced in Aas (2010) is used here to present new results, please introduce also this dataset in Chapter 3 with reference to the original paper. Or (as it seems), if you are referring only to results already presented in Aas (2010), please do not introduce the dataset again here.

A conclusion in the summary by Aas (2010) was that the reflected radiance L_r at the sea surface could be determined from observations of four variables: the downward irradiance in air (E_{air}), the wind speed (U), the radiance in air from zenith and the solar zenith angle. Our main data set from 2002-2003 contains these variables, and L_r can then be calculated by using the polynomials presented by Aas (2010), and the reflectance $\overline{\rho}_{L,air}$ can be found from Eq. (17). We have now omitted the words "data set" and rewritten the text.

4.4 Value of ln(A) and comparison to observations of $Z_{D,white}(c+K_L)_{phot}$

p. 1854, rows 15-18 (and Figure 2) Extrapolating the non-linear function to values ZD,white < 2, after removing all such values is not justified. Either remove the trendline at low x-values or completely. Please also provide R2 of trend-line.

This is a misunderstanding. On p. 1854, rows 6-7, it is explained that the mean value of the product $Z_{D,white}(c+K_L)_{phot}$, representing the left hand side of Eq. (21), is 7.0. The line $(c+K_L)_{phot}$ = 7.0/$Z_{D,white}$ is thus not a trendline based on the least squares method, but represents this mean value. It is also stated in rows 9-11 that for $Z_{D,white}$ in the range 1-2 m, the product tended to increase to 10-14, that is $(c+K_L)_{\mathrm{phot}}$ was close to 10 m^{-1}. Accordingly the line was extended down to $Z_{D,white}$=0.7 m to show to the reader how this line would underestimate the values of $(c+K_L)_{\mathrm{phot}}$ if $Z_{D,white}$ had been in the range 1-2 m. In order to avoid misinterpretations of the solid line, the figure legend now suggests that the reader should read the text in Chapter 4.4 for further explanation.

We are not sure if it is a good idea to introduce the coefficient of determination R^2 related to the chosen trendline, because the R may by some readers be confused with the correlation coefficient r. The correlation coefficient r is independent of the trendline and is defined by $r = S_{x,y}/(s_x\ s_y)$, where $S_{x,y}$ is the covariance of the data set (x,y), and s_x and s_y are the standard deviations of x and y. The R^2 coefficient, on the other hand, would in our notation have the general definition $R^2 = 1 - (N/(N-1))\ (\varepsilon^2/s_y^2)$, where N is the number of observations, and ε is the root-mean-square error between y and the chosen trendline. Only if the trendline is on the form $y=A+Bx$, will $r^2 = R^2$. However, we agree that it could be of interest to some readers that the coefficient of determination for the line $(c+K_L)_{phot}$ = 7.0/$Z_{D,white}$ in Fig. 2 is R^2 = 0.87, even if the line is not a regular trendline, and accordingly this information has now been added to the figure. The correlation coefficient for the data set (1/$Z_{D,white}$, $(c+K_L)_{phot}$) is r = 0.95, and this information has been included in Chapter 4.4. Definitions of R^2 and r have also been added to the chapter.

4.5 Effect of colour filters and the black disk

p. 1856, rows 5-20 (and Table 4) You are presenting here a new parameter, ZB, which has not been introduced in the list of acronyms (Table 10). The bowl has not either been mentioned in Chapter 3 where datasets and their collection is explained.

It is correct that $Z_{B,black}$ is missing in Table 10. It has now been added to this list of symbols. The bowl is described in Chapter 3, p. 1845, rows 24-27.

When presenting A, B and B0 of the linear relationship, the statistical significance should also be given.

Here we are not sure what kind of statistical information the referee is missing, since statistical significance can be tested and expressed in different ways. We have now added the standard deviation s_y of y as well as the rms errors ε and ε_0 to Table 4, and the specially interested reader should then be able to make the wanted statistical tests.

4.6 Effect of size

p. 1857, rows 9-11 (and Figure 3) The fit of a broken trend-line should be tried as well. Visually it seems, that a line ZD10cm = ZD,30cm would fit better at low values (for example <6m). Please also provide R2 of trend-line.

Yes, we agree that for the lower range of Z_D a slightly greater slope may seem to produce a better fit. However, in the present case we are not in favour of splitting up the data set in order to obtain best fits for different ranges. Our intention is to estimate the overall effect on the Secchi depth of a size reduction from 30 to 10 cm disk diameter, and then we find that the chosen method is better. We have added $R^2 = 0.95$ to the figure, and s_y, ε and ε_0 to Table 4.

4.7 Effects of sun glitter, water telescope and ship shadow

p. 1857, rows 13-27 (and Figure 4) The fit of a broken and possibly also non-linear trend-line should be tried as well, and the one with best fit chosen. Visually it seems, that a line ZD10cm,tel = ZD,10cm would fit better at low values. Please also provide R2 of trend-line.

Here our reply is the same as to the comment above. We have added $R^2 = 0.92$ to the figure.

p. 1858, rows 14-17 (and Fig. 5) Please provide R2 of fit.

We have added $R^2 = 0.91$ to the figure.

6 Further analyses of the Secchi depths

6.1 Estimates of monochromatic coefficients

p. 1861, rows 19-22 (and Fig. 6) Please provide R2 of fit.

We have added $R^2 = 0.74$ for $K_{d,665}$ and $R^2 = 0.54$ for $K_{d,555}$ to the figure.

6.2 Quanta irradiance − PAR

p. 1863, rows 21-23 and Table 8 For consistency of terminology throughout the paper, please use 'Secchi depth' instead of 'Secchi disk depth' also here.

We have omitted "disk" from Table 8 and checked the rest of the paper.

p. 1864, rows 18-24 (and Fig. 7) Please also provide R2 of trend-line.

We have added $R^2 = 0.28$ to the figure.

p. 1865, rows 11-13 (and Figure 8) To help the reader, explain what is Zq and p also in the figure text. Please also provide R2 of trend-lines.

We have added an explanation of the symbol $Zq(p\%)$ to the figure legend, and have also included in the figure the values of R^2 for the lines through the origin.

6.3 Chlorophyll *a* and total suspended material

p. 1865, rows 20-27, p. 1866, rows 1-5 (and table 9) What is the justification for using 1/ZD as explanatory variable (x) instead of the response variable (y)? As you state here, chl and TSM are not optical properties but matter causing attenuation (or proxy of such matter, in the case of chl), and thus logically not functions of 1/ZD (Preisendorfer, 1986, 1st law of Secchi disk).

The justification is offered in the mentioned rows 20-27: "The chlorophyll content is perhaps the most used concept when the amount of algae in the sea shall be described. ...our estimates....have average errors of 30-40%.....Even less accurate are the estimates of total suspended matter (TSM)...Still such relationships provide useful checks because they quantify the order of magnitude of the concentrations." It is true that Chl and TSM cause Z_D to vary, and not the other way around, but that does not imply that it is worthless to test how accurately Chl and TSM can be estimated from observed Z_D.

Instead of regarding these parameters separately, one might test their combined effect – yet acknowledging the other important parameters such as CDOM (as indicated in p. 1848, rows 1-10).

We agree that it would be interesting to test how the combined Chl and TSM (and even yellow substance) influence the Secchi depth, but that will not be done in this paper. As we just pointed out above, the purpose of our exercise is to find simple relationships that quantify the order of magnitude of Chl and TSM from observed Z_D.

In figure text, for consistency of terminology throughout the paper, please use 'Secchi depth' instead of 'Secchi disk depth' also here.
We have changed "Secchi disk depth" to "Secchi depth" throughout the paper.