Replies from the authors to comments by Referee #1 on os-2013-50

We are due thanks to our two referees for the work they have spent on our paper and for their constructive comments and suggestions. The specific comments from Referee #1 are discussed below.

Title

The title does not cover the presented research. Perhaps: Experiments with the Secchi disk and its derivatives

We chose the title because it is short, but it is true that it does not describe all of the contents, except the experimental part. On the other hand we think that the concept of disk derivatives is not clearly defined, and perhaps it would then be better to choose a longer title: "Secchi depth in the Oslofjord-Skagerrak area: theory, experiments and relationships to other quantities".

Abstract

The abstract does not contain any conclusion. As a reader I would like to know the most important outcome of this investigation.

We agree that our abstract has become too short since neither results nor conclusions are mentioned. The abstract has been rewritten.

1 Introduction

In the introduction under motivation for the presented study the authors mention the relation between Secchi depth and optical water properties and the usefulness of studying such relationships. However, these remarks are directly followed by the sentence: 'Observations can never be satisfactory substitute recordings of other optical properties'. In that case, what's the point of doing this research at the first place? I would skip this remark and continue with: Secchi disk observations can serve as 'quick and dirty' (perhaps rephrase) checks of several optical and bio-optical parameters.

Here we disagree. Our complete sentence is: "Observations of the Secchi disk depth can never be satisfactory substitutes for direct recordings of the other optical properties, but they can serve as independent checks of these properties." Thus the last part of this sentence provides one of the reasons for doing Secchi disk observations, while the first part emphasizes that direct recordings of a quantity are better than indirect estimates.

2 Theory of the Secchi depth

Page 1837: Eq.1 The threshold value is not well explained. Is this value 0.0066? (Holmes 1970)

We think that the three lines below Eq. (1) explain what is meant by the threshold value, but we have now added the information that its value varies with the size of the target, the background illumination, the detection probability and the time of exposure, and that it is described in more detail in Section 4.3. It is correct that Holmes (1970) quotes Tyler's (1968) estimate of $C_t \approx 0.66$ %. Tyler's C_t is referred to in Section 4.3.

Page 1840 top: vertical attenuation coefficient (delete s)

Done.

Page 1841: Eq.14 is the constant k 787 m s^{-1}? Please check

Preisendorfer presents his expression on a form that is unpractical for our purposes, and the value of *k* has been calculated by us, based on his equations. We have checked the value.

3 Data sets, instruments and environmental conditions

This chapter could be written more clearly; i) first description of datasets ii) description of instrumentation used (only spectral radiometer data is present in the second dataset) iii) environmental conditions: Especially this part is not well presented. Except some brief notes on salinity and the trophic state of the samples area and pycnocline. I miss remarks on sea state, meteorological conditions (especially remarks on cloud cover and/or sunny conditions. Were the observations performed on the shady side of the ship?). Perhaps it would be better to rename this chapter into Data and methods as in between sentences suddenly HPLC and gravimetrical determined TSM is mentioned.

We agree that this chapter could be better written, and especially the part about the environmental conditions. The chapter has been renamed "Environment, data sets and methods" and has been reorganized and rewritten. There are comments on the sea state and wind in chapters 4.2 and 4.3, but we have now also added such information to this chapter.

Also some results are presented which do not belong in this chapter.

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. We have also presented the ranges of salinity because our Topic Editor thought this information was important. The ranges of Secchi depth were included as well, because they tell something about the water quality. Information about the mean values and variations of the Secchi depth in these areas, based on other sources, has been added to a new Table 1, presented below.

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.

Page 1845: The accuracy of the Secchi depth (add observation) mainly depends on the state of the sea …….. The authors write: in our data the possible error will be in the range 0.2- 0.5m. Please explain

We thought it obvious that in conditions with strong winds the action of the waves and the drift of the ship would make an accurate estimate of the Secchi depth more difficult than in calm weather. The estimated error range of 0.2-0.5 m is based on our experience. This information is now added to the text.

Furthermore Tables 1a and b could better be replaced by graphs to facilitate the reader by presenting the spectral signatures instead of numbers. See Example below.

We agree that a figure is easier to read by a brief glance than a table, and accordingly we have followed the referee's suggestion: omitted the former Table 1 and added a new Figure 2, shown below.

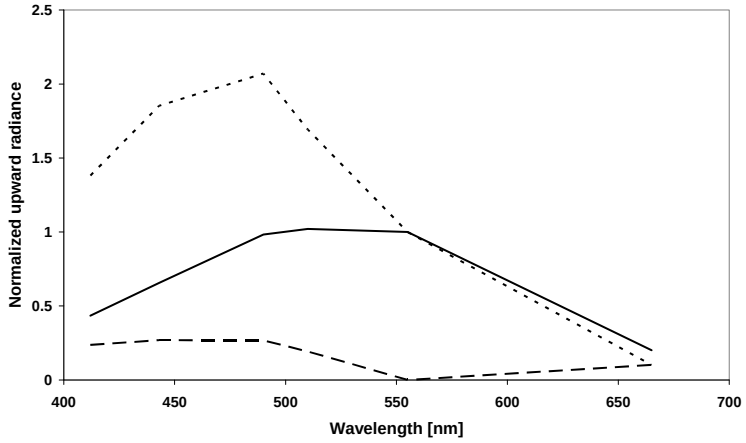


Fig. 2. Upward radiance just beneath the surface, normalized at 555 nm. The solid line is the mean value, based on 48 stations, and the upper hatched line is a station of typical Atlantic water. The lower hatched line is the standard deviation of the normalized spectra.

4 Test of Eq. (21) in photopic units

I would suggest to rename chapter 4 (Test of Eq. 21 in photopic units) into the more general Results

It is true that often today the standard form of a paper follows the IMRAD formula (Introduction, Material and methods, Results And Discussion). However, in the present case we are sure that some readers will be more interested in the statistical relationships between Secchi depth and other optical quantities (chapter 6) than in an academic test of a theory in photopic units (chapter 4), which is why we still think it is better to separate these two exercises into different chapters.

5 The monochromatic assumption

I do not understand the change in chapter number. 5 The monochromatic assumption could be a continuation of the sub chapter numbering under 4. More logical 5 becomes 4.8,

We agree. This chapter is not a direct test of Eq. (21), but a test of an assumption or working hypothesis on which Eq. (21) is based, which is why it was presented as a separate chapter. On the other hand, the test can also be regarded as a part of chapter 4, and accordingly we have followed the referee's suggestion and changed the number to 4.8.

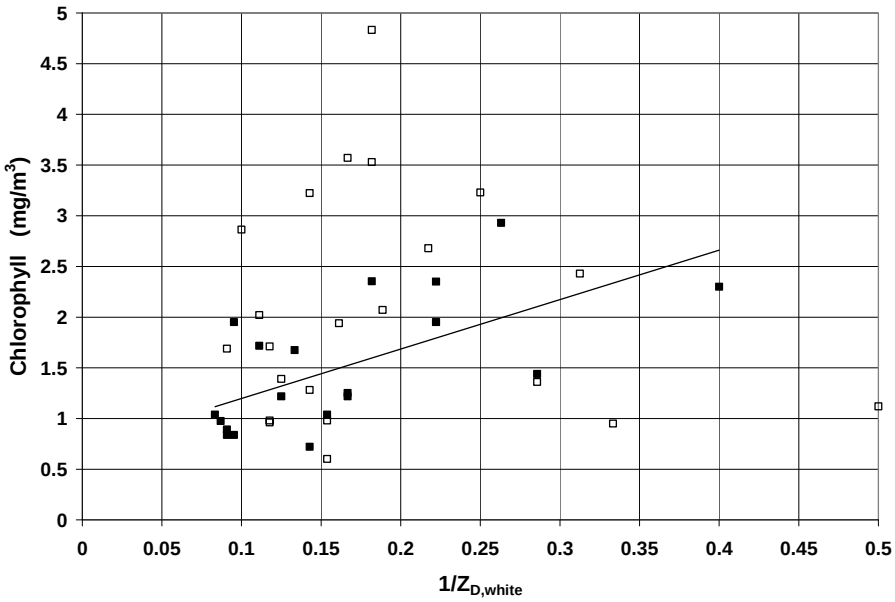
6 Further analyses of the Secchi depths

....delete 6 Further analyses (does not give the reader extra info), let 6.1 be 4.9 and so on until Summary and conclusions are reached.

As pointed out above, we think that for some readers it may be better to have the test of Eq. (21) in one chapter, and the more useful statistical relationships in another one. We have changed the number and heading of this chapter to "5 Relationships between the Secchi depth and other quantities".

The results (Chl as a function of 1/ZD show errors of 30-40% and TSM errors of 50%) presented in the small chapter Chlorophyll a and total suspended material are based upon only 19 stations. Why such a limited number of observations use in this correlation analysis?

It is true that an explanation for the selection of only 19 stations is missing. We wanted to see if there were any differences for the relationships between the Secchi depth measured with the naked eye and with colour filters, when estimating chlorophyll and TSM. This required a complete set of Secchi measurements, and of Chl and TSM. We also wanted to restrict the data to an area that were able to produce useful relationships. This reduced the number of stations to 19.



The problem is what we point out in Section 6.3: "Unfortunately the concentration of chlorophyll *a* is not an optical property." Usually, if there is any correlation between Chl and the Secchi depth, this is due to a covariance between the chlorophyll and the dominant optical properties of the investigated area. If the area encloses too many water types, the correlation is reduced or vanishes. In the figure presented above, the solid squares represent 19 stations north of 58.2°N. The open squares are remaining data from the entire Skagerrak area north of 57.0°N. While the 19 stations show some kind of covariance, represented by the trendline, this property is lost for the larger set of data.

If we use all stations north of 57.0°N, Table 9 will change to the result below:

Table 9. Relationships on the forms $y=A+Bx$ and $y=B_0x$ obtained by correlation analysis of chlorophyll *a* (Chl), total suspended material (TSM) and inverse Secchi disk depths ($1/Z_D$) observed with the open eye and with blue, green and red glass filters. The concentrations of Chl and TSM are averages over the depth range 0-$Z_{D,white}$, and r is the correlation coefficient. The error ε is the root-mean-square of the deviations (y-A-Bx), and ε_0 is the rms of (y-B_0x). The analysis is based on 41 (Chl) and 51 (TSM) stations north of 57.0°N.

y	x	r	A [mg m^{-3}]	B [mg m^{-2}]	B_0 [mg m^{-2}]	$(y/x)_{mean\pm sd}$ [mg m^{-2}]	y_{mean} [mg m^{-3}]	ε [mg m^{-3}]	ε_0 [mg m^{-3}]	
Chl	$1/Z_{D,white}$	0.16	1.50	1.7	8.5	11.5±6.2	1.8	0.9	1.1	
Chl	$1/Z_{D,blue}$	0.16	1.50	1.0	5.0	5.8±3.1	1.8	1.0	1.7	
Chl	$1/Z_{D,green}$		0.09	1.71	0.3	3.0	8.0±4.1	1.8	0.9	1.4
Chl	$1/Z_{D,red}$	0.24	1.33	1.5	4.9	6.2±3.1	1.8	0.9	1.1	
y	x	r	A [g m^{-3}]	B [g m^{-2}]	B_0 [g m^{-2}]	$(y/x)_{mean\pm sd}$ [g m^{-2}]	y_{mean} [g m^{-3}]	ε [g m^{-3}]	ε_0 [g m^{-3}]	
TSM	$1/Z_{D,white}$		0.76	0.12	6.2	6.8	7.1±3.0	1.2	0.5	0.5
TSM	$1/Z_{D,blue}$	0.54	0.71	1.4	2.5	3.6±1.9	1.2	0.6	0.8	
TSM	$1/Z_{D,green}$		0.68	0.27	3.8	4.6	5.1±2.4	1.2	0.5	0.6
TSM	$1/Z_{D,red}$	0.73	0.08	3.6	3.8	4.0±1.8	1.2	0.5	0.5	

The errors of the chlorophyll estimates are now in the range 50-90 %, relative to the mean value, while in the first version of the table the error range was 30-40 %. The inclusion of more stations and more water types, like in the last table, reduces the correlation between Secchi depth and chlorophyll content to almost nil. The best correlation is now obtained for the Secchi depth observed through a red glass filter. In this spectral range the varying yellow substance content will have its minimum influence on the light conditions.

It is interesting that the relationships for the TSM change far less for the larger area and the greater number of stations. In fact, the mean value of the TSM remains the same. The overall difference is that the accuracy of the estimates of TSM is better for the larger area.

We have then decided to use the last version of this table, because it illustrates more of the problems involved by trying to find relationships between chlorophyll and optical properties. In the text we have added information about the possible influences of the number of samples on the correlation coefficient for chlorophyll versus Secchi depth.

This outcome only holds for the investigated eutrophic area (see also comment at the end). ..... The authors should point out that the found relations hold/are applicable for the Skagerrak and Oslo fjord only.

We agree that the results are only valid in the area from which the data have been obtained, which is why our last sentence in the summary sounds: "We assume that there may be regional differences for the found relationships." This information has now also been added to the former chapter 6 (now 5).

7 Summary and conclusions

I miss Recommendations .....It would be recommendable to repeat the analysis using a more varied dataset, i.e. a more balanced dataset based on different water types (including open ocean observations). Especially the outcome of the investigated relation of Chl and TSM as a function of the reciprocal Secchi depth could benefit.

This is an interesting topic, and as explained in our reply above to the comment on the chlorophyll and TSM analysis, our experience so far tells us that chlorophyll estimates are

more useful for a smaller than for a larger area. We have now recommended that similar statistical relationships should be tested out for other water types and areas.

Tables

During a first reading of the paper the reader could easily be overwhelmed be the number of Tables containing lots of regression coefficients etc.. The authors should think of a way to either present the best results, not all and mention some in the text or should make use of graphs which makes the article much more comprehensible.

We agree that all the tables make the paper more difficult to read, and it would be more reader-friendly to substitute some of them by figures. However, for those readers who are interested in following the recommendation of making similar experiments in other oceanic areas, tables with numerical values will be more useful than figures. The best results are already presented by figures.

We have added two figures: a new Fig. 2 illustrating the spectral colouring of upward light in the area of investigation, and a new Fig. 10 presenting Chl and TSM versus $1/Z_{D,white}$.