Interactive comment on "Seasonal and interannual variability of coccolithophore blooms in the North East-Atlantic Ocean from a 18-year time-series of satellite water-leaving radiance" *by* L. Perrot et al.

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This paper describes the use of different remote sensing products to detect and quantify the coccolith calcite concentration in the water column along the western European shelves. This is a useful contribution to the subject. However, the manuscript could benefit from structural reorganization, improved focus, and English language editing.

The analyses of the time series was often merely descriptive instead of quantitative. For example, what general trends if any did the coccolithophore blooms show over the 18-year period? Very little space was dedicated to the discussion of the temporal variability of coccolitophore blooms. Instead the paper often reads as a method development paper (which is fine of course but should be advertised as such). The

discussion section includes novel results and does not tackle the results presented in the results section adequately (e.g., Why does the maximum number of coccoliths and SPMfc not coincide in the Celtic Sea area? What is so special about the years 2001 and 2014?). The fact that potential environmental factors such as sea surface temperature, PAR intensity, etc. are not used to explain the temporal and spatial variability of coccolithphore blooms should be mentioned in the introduction section to avoid giving false hopes to the reader (cf. methods paper). The manuscript is rife with typos and inconsistent use of abbreviations and units (e.g., NA-SPM and SPM, Chl and chl-a, liter as l and L; Fig. 10a or Fig.10.a, etc.), which makes it tedious to read. A simple spelling check goes a long way. These errors were for the most part highlighted in yellow in the supplemented pdf. Finally, the abstract does not reflect the goals and results presented in this manuscript.

Response: The article focuses on the application of a novel analytical method to study the variability of coccolihophore blooms along the shel-break in Northeast Atlantic from satellite radiance. It's true that there are two main points in this manuscript, which can be confusing, about the application of the fuzzy method and about the variability of coccolithophore bloom. The phenology of these blooms is not in the center of the paper, as the environmental parameters are not taken into account here to explain the variability. However, the main point is to show that the fuzzy method can be applied to radiance data to discriminate coccolith pixels from suspended particulate matter pixels, and by this way, allows to observe the seasonal variability and the general patterns of coccolithophore blooms in the last 18 years.

To improve the structural organization of the manuscript, the 3 parts of the 'discussion' about the methodology were included in 'results' section. It allows to develop more the discussion about the seasonal and interannual variability of blooms along the shelf-break and to comment with more details the extreme years.

We also added new comments, in the discussion, based on the results of an article in preparation concerning the comparison of satellite SPM to turbidity profiles observed

during the PELGAS cruises (2012-2015). These cruises confirm the main results of this article: satellite-derived SPM on coccolothophores is well related to the surface turbidity, itself well related to coccolithophores. Another interesting fact is that the surface turbidity is a good indicator of the turbidity in the water column in case of cccolithophorides. For these reasons, we confirm that the absence of coccolithophores in the Bay of Biscay in 2014 on the SPM images, hence at surface, was also true in the water column. It gives a higher significance to the results of the present article.

A new paragraph 'Monitoring the coccolithophore blooms' in the discussion chapter, substantially modified, is available at the end of this response.

Specific comments per section: Abstract:

P1 L9: Evaluating ...

Response: The sentence has been changed: "Evaluating the impact of anthropogenic CO2 uptake..."

P1 L13-14: applied to a spectral radiance time series from SeaWiFS (1998-2003) and MODIS (2003-2015).

Response: The sentence has been changed: "...applied to a spectral radiance time series from SeaWiFS (1998-2003) and MODIS (2003-2015)".

P1 L14: please explain 'coccolith pixel'.

Response: Coccolith pixel refers to pixels whose radiance corresponds to a coccolithophore bloom radiance. The sentence has been changed: "After identification of the coccolith radiance for each pixels".

P1 L19: .. the extent of the blooms was highly variable and did not show a consistent seasonal or interannual pattern By bloom extent do you mean area covered or SPM concentration?

Response: "Bloom extent" defines the area covered. The sentence has been changed:

"Although a regular pattern in the phenology of the blooms is observed, starting south in April in Biscay and moving northwards until July near Ireland, the bloom extent and the mean concentration of non-algal SPM on the areas identified as coccoliths are higly variable. No major trend can be identified from the time-series, except a slight decrease during the 18 years.."

P1 L21: less than half the average? Which environmental variables were used as predictors for the coccolithophore bloom extent?

Response: The sentence has been changed: "Year 2014 shows very low concentrations of coccoliths from space (less than half average 1998-2015) and anomalies point out the maximum level for 2001" And the comment about environmental variables has been added "Environmental variables are not taken account in this study and the cause of the seasonal and interannual variability of the coccolithophores blooms in this Atlantic region remains an open question."

Introduction:

P1 L29: calcite (throughout the text) should not be capitalized as far as I know.

Response: Words have been changed throughout the text from Calcite to calcite.

P2 L4: in my opinion ocean acidification by increased pCO2 is a chemical fact not a hypothesis.

Response: Yes, the sentence was miswritten, as the hypothesis refered to the acidification of the upper ocean layers and not to the chemical fact. The sentence has been changed: "According to the hypothesis of acidification, due to increasing CO2 in the upper ocean layers (Orr et al., 2005), the calcification, development and extent of the coccolithophore blooms could be positively or negatively impacted (Doney et al., 2009; Beaufort et al., 2011)." .

P2 Âu1: the physiological response of calcification to increased ocean acidification and the change of habitat extent due to changes in the physical/ecological environment

(higher surface temperature, more stratification) are probably two separate phenomena.

Response: Yes, we have to take these details into consideration in the context of this study. The sentence has been changed: "These impacts could depend on the physiological response of coccolithophores and on the future extent of their habitat in relation with the changes in the physical and biological environment."

P2 L12: weird sentence construction. 'Evidenced' using in active tense.

Response: "Evidenced"has been changed to "showed".

P2 L29: ii- detect coccolithophore blooms based on other proxies than chlorophyll.

Response: The sentence has been changed: "ii- detect coccolithophore blooms based on other proxies than chlorophyll as this phytoplankton is not associated with high-biomass blooms (<1μg L-1, Tyrrell and Merico, 2004)."

P4 L8: "we will have a better understanding of the effect of coccolithophores on the non-algal SPM product" this result/goal is not mentioned in the abstract.

Response: This result has been reformulated in the abstract, as the comparison between non-algal SPM in coccolithophore blooms and calcite highlights the differences in optical properties, by the sentence: "However, we observe a factor of 4 between the concentrations of non-algal SPM and calcite, probably due to the high scattering properties of coccoliths not taken into account in the SPM procedure."

P4 L6: Northeast Atlantic: Response: The word has been changed in the text.

P4 last Âu of introduction is only two sentences long. This is a very short paragraph indeed..:

Response: The two last sentences have been modified to be included in the main paragraph: "..By adapting the fuzzy method to a spectra dataset selected on coccolithophore blooms observed in the Northeast Atlantic, the variability of their blooms

across 4 selected regions (Fig. 1a), from South to North along the shel-break, will be investigated from 1998 to 2015. Thus, on the one hand,we will have a better understanding of the effect of coccolithophores on the non-algal SPM product, and on the other hand, we will determine the seasonal and interannual variability of coccolithophore blooms on the margin of the Northeast Atlantic continental shelf."

Methods:

P4 L14&16: "... have been used" for what purpose? Please revicse those sentences and maybe make them active tense.

Response: The global method in this work is based on SeaWifs and MODIS data. The sentences have been changed: "The fuzzy index method is based on SeaWiFS (1998-2003) completed by MODIS-Aqua data (2003-2015).", and "The method uses normalised-leaving radiance L2 products (MODIS and SeaWiFS) and Level 3 images (SPM and calcite)."

P4 L22: define abbreviation for normalised water-leaving radiance (nLw) and use consistently throughout the text; same thing for chlorophyll a concentration, inherent optical properties, etc.

Response: Abbreviations are defined in Methods part: "normalised water-leaving radiance (nLw)", "chlorophyll a (Chl-a, indicator of the phytoplankton contribution)", and "Inherent Optical Properties (IOPs)", and "Suspended Particulate Matter (SPM)"is defined in abstract. The abbreviation "Non-algal SPM (SPM hereafter)"is defined in Satellite data paragraph to fix the term SPM for the rest of the text. P4 L26: constants defined (see below?). Response: Yes, constants $\alpha 0$ et $\alpha 1$ are defined in the next paragraph below: "Here ïAąïǍř and ïAąïǍś are two constants defined (see below) for each wavelength (555 and 670 nm)."

P5 L5&10: is NA-SPM with an underscore or not?

Response: NA-SPM, which defines Non-Algal Suspended Matters is written with an

underscore. However, it was mentioned before in the text, in page 4 Line 18, "Non-algal SPM (NA-SPM hereafter)". Thus it should be better to change the term NA-SPM to SPM in the text. By this way, the term NA-SPM in formulas in Line 5 and 10 page5 has been changed to the term SPM.

P5 L19: in case of coccolith what?

Response: The sentence has been completed: "In consequence, SPM could be over-estimated in case of coccoliths are present in the middle."

P6 L13: the closer the fuzzy index is to 1, ...

Response: Sentence has been changed: "the closer the fuzzy index is to 1, the higher the probability of a pixel to be a coccolith bloom is."

Results:

P7 L7-8: Revise pieces of sentences to explain what the results are showing. Then point the reader to data in figures.

Response: Sentences have been changed: "Figure 3 illustrates the application of the fuzzy index in the case of the bloom on 25 April 2013 between 44°N/2°W and 47.5°N/6.5°W on Figure 3a. In this area, values of the fuzzy index higher than 0.4 correspond to a high probability of presence of coccoliths. The fuzzy index allows thus to select pixels on SPM image corresponding to coccoliths which are visible in Figure 3b, between 44°N/2°W and 47.5°N/6.5°W."

P7 L13: how was the variability of the fuzzy index assessed?

Response: "The test was done on the number of coccolith pixels on 25 April 2013 (Fig. 4a, blue line) resulting from different thresholds varying between 0.1 (low discriminating value) and 0.9 (high discriminating value) by 0.1 step."

P7 L17-18: so does this mean additional number of spectra does not add information with regard to coccolith pixel identification/classification? Is the second sensitivity test

dependent on the value of the fuzzy factor?

Response: In the second sensitivity test, additional number of spectra does not add significative information for coccolith pixel indentification. As the values of number of coccolith pixels identified have reached a plateau for the number of spectra used in the work, additional number of spectra enhance the robustness of the method but does not add more information. The second sensitivity test is not dependant on values of fuzzy factor. The threshold of fuzzy factor used to select coccolith pixels was fixed at 0.4, as the same value of threshold used in the entire work.

P7 L21: the variability of what?

Response: The sentence has been changed: "To analyse the variability of coccol-ithophore blooms over the 18-year period, a good agreement was required between the results of the fuzzy method applied to SeaWiFS (1998-2003) and MODIS (2003-2015) radiance."

P7 L25: the correlation was significant? (r2=0.89, p=Âǎ?) thus the use of this time series as continuous is warranted in this case.

Response: The correlation is significant: r^2=0.89 with p<0.001 and slope=0.83.

P8 L2: provided an overview of both the coccolithophore bloom's location, areal extent and amplitude.

Response: These informations are added in the text: "After the application of the fuzzy method, the monthly means of coccoliths provided an overview of the areal extent and the amplitude values of the coccolithophore blooms between 1998 and 2014 (Fig. 5) from April to June."

P8 L8: coccoliths don't bloom, the coccolithophores do P8 L9: progresses?

Response: Words are modified in the text: "Coccolithophore bloom starts in 2013 between 44°N and 48°N in the Bay of Biscay (Fig. 5d) and progresses northward".

P8 L11: is within the bounds of climatological variability?

Response: Yes, the sentence has been reformulated: "The variability of the monthly averages in 2013 is within the bounds of the climatological variability (Fig. 5a,b,c)".

P8 L30-: this sounds like discussion to me, especially considering that no data is shown to back up this statement. Response: This last paragraph is moved in the second part of the Discussion.

P9 L4-5: could you explicitly mention, for the readers not familiar with remote sensing, that cloud-free pixels = pixels with radiance data?

Response: Information to define cloud-free pixels has been added in the text: "The mean bi-weekly number of coccolith pixels over the period 1998-2015 is shown in Fig. 7a. Cloud-free pixels corresponding to pixels for which radiance data is available are taken into account."

P9 L7: 2001 does not show anything, but the number of coccolith pixels in the year 2001 does.

Response: Sentence has been reformulated: "The figure shows the number of coccolith pixels in 2001 shows the largest blooms (Fig. 7a)..".

P9 L23: I assume you want to make sure your signal isn't biased by the data availability and distribution not the effect of cloud-free pixels per se? Is there an overall bias or not?

Response: The sentence has been changed to make it clearer: "To make sure that the signal of coccolith budgets is not biaised by the data availability limited by the number of cloud-free pixels, the time-series of clear pixel numbers (Fig. 8b) was used to normalise the number of coccolith pixels (Fig. 8c)." Whereas there are some differences for some years (as 2006 and 2009), there is not a huge biais between the two-time series as it does not change the extreme years for the coccolithophore blooms. But it allows to see that the trend of time-serie and the variability of blooms is not biaised by the cloud

cover.

P9 L32: consider moving this sentence upward in this section since it is not related to the results presented just before.

Response: This sentence is moved at the end of the first paragraph of the part 3.2.2-Interannual variability.

Discussion:

P10 L4: Comparison of what to in situ data?

Response: The title has been changed: "4.1 Comparison of coccolithophore blooms to the observations of a cruise in the Bay of Biscay in April 1998".

P10 L8: a limited number of samples?

Response: Sentence has been changed: "coccolith and coccolithophore counts were performed in a limited number (33) of samples.".

P10 L14: the concentration of calcite in mg? Carbon maybe?

Response: The concentration calculated here refered to the biomass of coccolithophores and coccoliths in term of calcite. This information has been added: "in terms of calcite mass (in mg)".

P10 firstÂu: probably more suited for the results section. I also expected some kind of correlation coefficient to have a more quantitative sense of agreement between in situ and remote sensing estimates of coccolith calcite concentration.

Response: The paragraph has been moved to Results section. Correlations between SPMfc and in-situ coccoliths and coccospheres calcite concentration have been added: -Correlation between SPMfc and calcite from coccoliths: R^2=0.98, significance $p<0.001$ and slope=0.28 -Correlation between SPMfc and calcite from coccosphere: R^2=0.73, significance p=0.006 and slope=0.1

P10 second Âu: the first part of section 4.2 should probably also be moved to the results section.

Response: The section is moved to Results section.

P13 L6: a good proxy based on your results?

Response: Based on the results, fuzzy-index allows to discriminate coccolith pixels which is a proxy of surface of blooms. It allows to have a quantitative proxy of coccolith abundance through SPM signal corresponding to high fuzzy-index value pixels. The sentence has been reformulated: "In a first step, the fuzzy method, applied to satellite radiance, provides an identification of the coccolithophore blooms during a 18 years period. In a second step, coccolith abundance is assessed from the satellite-derived SPM observed on the coccolith pixels".

P13 L8: that particular time in the bloom evolution is at the end of the bloom sequence, when loose coccoliths accumulate in the surface water, possibly due to high N:P nutrient ratios.

Response: Yes, it's an information added in this part of discussion: "It is worth noticing that, as any other remote-sensing application, this study focuses on a particular moment of the life of the coccolithophore blooms when detached coccoliths, lost by coccolithophores, accumulate in the surface water, possibly due to high N:P nutrient ratios."

P14 L2: what is meant here by maximum bloom development?

Response: The maximum bloom development corresponds to the maximum concentration of SPMfc. The sentence has been modified in the text: "the maximum SPMfc concentration corresponds to the period of maximum bloom extent;".

Conclusion:

P14 L4: was the "discrimination method" defined previously?

C11

Response: Yes, the "discrimination methodÂă"refers to the fuzzy index method to discriminate coccolith pixels. The sentence has been changed: "At interannual time scales, the discrimination method, defined here previously, showed differences in the development of the coccolith blooms".

P13 L30: this remarkable conclusion was not even mentioned in the discussion section.

Response: "A conclusion is that the budget of coccolithophores (SPMfc) is twice as strong in the Celtic Sea sub-area than in the Southern and Northern Bay of Biscay sub-areas." This conclusion has been more developed in Results section and in the Discussion section:

-In Results Section, sentences have been modified and added: "The maximum in the second fortnight of May for the Celtic zone shows a two fold higher budget (4.1 104 mg L-1 by pixels) than in the Bay of Biscay." and "This lag between the number of pixels and SPMfc in the Celtic sub-area along the slope relates the difference between the maximum biomass of blooms, described by SPMfc concentration, and the maximum extension of blooms described by the number of coccolith pixels. Blooms in the Celtic sub-area are highly productive (maximum value of SPMfc) in comparison to other sub-areas but does not show the highest value in the number of coccolith pixels. In the Celtic sub-area, the maximum of SPMfc occurred generally a fortnight earlier (in the second part of May) than the maximum extent of coccolith pixels (in the first part of June)"

-In Discussion section, sentences have been added to complete the discussion about the Celtic zone: "The differences in seasonal climatologies between the Celtic zone and the 3 others sub-areas, about the budget of SPMfc twice as strong in Celtic sea than in Bay of Biscay sub-areas, and about the concomitance of maximum bloom extent, which occurs a fortnight later than the maximum concentration, show that coccoliths can be resilient for a long time after the peak of bloom in this area. The difference between Celtic zone and the 3 others sub-areas has to be more investigated, as the

C12

Celtic Sea is a region with a strong internal mixing driven by internal waves (Sharples et al., 2007)."

A new paragraph 'Monitoring the coccolithophore blooms' has been added in the discussion chapter: 4.2 Monitoring the coccolithophore blooms: In a first step, the fuzzy method, applied to satellite radiance, provides an identification of the coccolithophore blooms during a 18 years period. In a second step, coccolith abundance is assessed from the satellite-derived SPM observed on the coccolith pixels. A main result is the seasonal evolution of blooms over the continental slope, which reflects the recurring of coccolihophore blooms along the shelf-break between April and June. Coccolithophore blooms identified show that the area is concerned not by occasional blooms but regular blooms which can last few weeks along the slope.

Seasonal climatologies of SPMfc concentration, and of number of coccolith pixels, point out these regular blooms in the entire area and in the sub-areas. Seasonal climatologies of the number of coccolith pixels in the 4 sub-areas show a temporal evolution suggesting a northward evolution of the blooms with the season, in agreement with the general evolution of the environmental conditions during summer in the full zone. Warmer temperatures, higher solar irradiance and stratification in summer should enhance the development of coccolithophore blooms (Rost and Riebesell, 2004; Tyrell and Merico, 2004). Our 18-time series is relatively far under the classical 30-year period recommended by the World Meteorological Organization (WMO) to build up the mean statistics of a climatic variable. However, the area investigated in this study concerns a place (the continental slope) where the hydrological conditions are mainly driven by the tide and therefore relatively constant from one year to another.

The edges of continental shelves are frequently sites of internal waves and elevated vertical mixing (Sharples et al., 2007) and in the Northeastern Atlantic the internal tide occurs with regular periodicity during the stratified season between April and September (Sharples et al., 2009). As the breaking internal tide is a fundamental control on the structural and functional properties of ecosystems at a shelf edge

(Sharples et al., 2009), the variability of the coccolithophore blooms is probably lower in our area than away from the continental slope. Therefore, the variability of the coccolithophore blooms occurring accasionally in the English Channel in spring and summer (Garcia-Soto and Pingree, 2009), sometimes at a very high level of biomass and in association with dinoflagellates (Smyth et al, 2002), could be higher than in our studied area. It is worth noticing that, as any other remote-sensing application, this study focuses on a particular moment of the life of the coccolithophore blooms when detached coccoliths, lost by coccolithophores, accumulate in the surface water, possibly due to high N:P nutrient ratios. In addition, Sharples et al. (2007) showed that nitrate distributions are enhanced by vertical mixing at the shelf edge of Celtic Sea. The differences in seasonal climatologies between the Celtic zone and the 3 others sub-areas, about the budget of SPMfc twice as strong in Celtic sea than in Bay of Biscay sub-areas, and about the concomitance of maximum bloom extent, which occurs a fortnight later than the maximum concentration, show that coccoliths can be resilient for a long time after the peak of bloom in this area. The difference between Celtic zone and the 3 others sub-areas has to be more investigated, as the Celtic Sea is a region with a strong internal mixing driven by internal waves (Sharples et al., 2007). The interannual variability in the studied area seems to follow a slightly decreasing trend between 2001 and 2015, as shown in Figure 8, but more years of observations are needed to confirm a significant evolution. Coccolithophores were observed in high abundance in all the 4 sub-areas in 2001 whereas they were declining during the last five years in all sub-areas except in the Bay of Biscay in spring 2013. Large-scale and local patterns of variability can be depicted from our time-series of satellite observations but more years are needed to draw conclusions on the effect of climate change on the development of coccolithophore blooms. The quasi absence of coccolithophores in 2014 in the entire area is intriguing. As described in Castelle et al. (2015), the winter of 2013/2014 was characterised by a striking pattern of temporal and spatial extreme storm wave clustering in Western Europe. During this winter, the 110-km long Gironde coast, in the Bay of Biscay, was exposed to the most energetic

wave conditions over the last 18 years. A similar effect was observed in the winter SPM images. However, due to sunny conditions in March, ending a long period of fierce storms, the biological environment recovered quickly to its normal state and stratification occurred even earlier than usual in the Bay of Biscay (Gohin et al., 2015). This absence of coccolithophore was associated to the exceptional development of large patches of gelatinous filter-feeding salps reported in the PELGAS2014 cruise (IFREMER). Salps mucus also impaired the hake fishery of the Bay of Biscay in May and June by clogging the fishing nets. It is quite possible that the salps and other gelatinous plankton trapped coccoliths in their mucus net, gathering them into fecal pellets. As these pellets are large, their sinking rates may reach hundreds of meters per day (Iseki, 1981), much higher than that of detached coccoliths and hence could have favoured the material export from the surface mixed layer. As mentioned in Olson and Strom (2002), grazing by microzooplankton is an important factor in the formation and persistence of coccolithophore blooms. However, an ongoing study shows clearly, from turbidity profiles collected during the 2014 PELGAS cruise, that coccolithophore blooms were almost absent from the waters of the Bay of Biscay in spring 2014 at any depth. This study (Perrot et al., in preparation) also confirms an excellent agreement between satellite SPM and surface turbidity over coccolithophore blooms. It also corroborates the over-estimation of the SPM by the satellite procedure already observed by comparison to the data collected during the April 1998 cruise and to the calcite from NASA products. A factor of 1.7 is observed in May 2013 between the satellite-derived SPM and the in situ Suspended Particulate Inorganic Matter (SPIM), confirming the results of the present study and the fact that the mass-specific backscattering coefficient of the coccoliths is probably higher than the mass-specific coefficient of the particles generally encountered in coastal waters.

Please also note the supplement to this comment:
http://www.ocean-sci-discuss.net/os-2016-13/os-2016-13-AC1-supplement.pdf

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C15