Authors' reply to the reviewers' comments
(manuscript submitted by Sadeghi *et al.*; BGD, 2011, 364)

Dear Emmanuel,
Below you find our detailed answers to the reviewers' comments and suggestions. Here, we follow the given points one by one (in a numbering order) by answering the questions and mentioning the respective changes in the manuscript. Many thanks again for your attentions!

Dear Dr. T. Smyth and the anonymous Referee (#2),
We thank you greatly for your positive feedbacks and appreciate your valuable comments. We found your suggestions very constructive and tried to implement them in the manuscript.
Many thanks for your contributions!

Kind regards,
Alireza Sadeghi,
(on behalf of the co-authors)

[**Abbreviations**: **C** = Reviewers' Comment ; **R** = Authors' Response]

****
* Responses to the Reviewer #1 (RC4939)
****

Responses to the general points (Reviewer #1):
C1. *The detection of coccolithophores is particularly easy from existing satellite platforms, indeed it could be argued that coccolithophores form the only group of phytoplankton that can currently be unambiguously determined from space. The use of a coarser spatial resolution satellite sensor is not improving our knowledge of the biogeography of an already well characterized species.*

R1. Satellite sensors can easily observe coccolithophores in the visible range, as milky-white or turquoise patches in true color images. This is due to the strong backscattering effect of detached coccoliths within the water column [Ackleson and Holligan, 1989; Balch et al., 1991; Holligan and Balch, 1991], which is more pronounced for large blooms. However, this is not a quantitative detection of coccolithophores, and only identifies the spatial distributions of coccolithophore blooms. For instance, Brown and Podesta (1997) applied an image-processing algorithm to the CZCS data in order to classify different ground pixels as “bloom” or “non-bloom” areas, in which specific thresholds of normalized water-leaving radiance (nLw) were imposed for the definition and flagging of coccolithophore blooms, based on empirically derived spectral features.
Additionally, optical effects of some other oceanic constituents (e.g., resuspension of empty -broken up- diatom frustules) can be mistaken as a coccolithophore bloom [Tyrrell and Merico 2004].

On a quantitative level, there are algorithms which estimate the coccolithophore particulate inorganic carbon (PIC) concentrations in bloom and non-bloom waters [Balch et al., 2005; Gordon et al., 2001], pertaining to the total number of detached coccoliths, not the living coccolithophore cells. But , as shown in Balch et al. (2011), above-water PIC measurements can be 2-3 times more than in-water PIC measurement; and additionally, the relation between coccolith concentration and living cell concentration is not a fixed known value, it rather depends on the dominant coccolithophore species, ocean chemistry and also environmental conditions. For instance, even though for *E. huxleyi*, detached coccolith concentrations are typically at least 15-20 times the concentration of plated cells [Balch et al., 1993], it has been shown [Blackburn and Cresswell, 1993] that large coccolithophore blooms can also be dominated by by other species (e.g., *Gephyrocapsa oceanica)* instead of *E. huxleyi.* Hence, overall, the satellite retrieval of coccolithophores is not so straightforward as presumed.

The retrieval method used in our study (PhytoDOAS) has a fundamentally different approach than the coccolithophore PIC algorithms: while the PhytoDOAS is based on the absorption features of living coccolithophore cells, the PIC algorithms are based on the scattering characteristics of the coccolith plates, carried by water-leaving radiance in specific wavelengths (PhytoDOAS use the hyper-spectral information), and do not separate between living and dead material. In contrary, PhytoDOAS enables for the first time to retrieve coccolithophores conc. themselves among other major phytoplankton groups. It is therefore able to detect coccolithophores also in strong mixed phytoplankton conditions and lower concentrations.

Even though the PhytoDOAS method relies on hyperspectral data, currently provided by SCIAMACHY with a coarse spatial resolution (30x60 km^2), the method is in principle applicable to any available hyperspectral sensor (in future), which has moderate or high spatial resolution (e.g., the Sentinel-5-Precursor, planned to launch in 2014 with 7x7 km^2 pixel size and global coverage within 1 to 2 days). While already for ecosystem or biogeochemical modeling studies (e.g. Ye et al. DSR, in press) the SCIAMACHY PhytoDOAS products spatial resolution is sufficient, the proposed future PhytoDOAS products from hyperspectral sensors on the Sentinel mission will enable to detect smaller spatial scale features of phytoplankton groups which are comparable to ocean color sensors -like SeaWiFS or MODIS (which do not deliver conc. of living coccolithophores).

C2. *The validation of the hyperspectral data is only against satellite derived products, which are known to be in error in terms of deriving the higher level products of PIC (rather than just the biogeography described above).*

R2. The reviewer is correct, that the other satellite products are uncertain. The satellite products of total Chl-a bear an uncertainty of about 35% on average which can reach over 50% on regional scales (Lee et al., 2006). Coccolithophore-PIC products also carry different sources of errors, due to optical uncertainties, either from the algorithm or from micro bubbles injection [Zhang, 2002] and also due to non-coccolithophore sources of PIC (for instance, as mentioned before, Balch et al., (2011) reported that remote estimation of PIC can be 2-3 times more than in-water PIC measurement).

However, as an initial evaluation of our retrieval, the satellite products of the total phytoplankton biomass and the coccolithophore-PIC concentration are the only available sources for performing a long-term comparison over the desired oceanic areas. Despite their own sources of errors, by looking over the temporal variations over three larger areas the statistical basis for the comparisons is quite large. We also chose these two products to test the functionality of PhytoDOAS coccolithophore retrieval because of the different scales found between in-situ and satellite observations which are even more severe when comparing in-situ data to the large SCIAMACHY foot prints and long repeat cycle (six days). Comparisons to collocated in-situ samples can introduce errors due to non-uniform distribution of in-situ data (generally they are not uniformly spatially scattered and temporally confined to limited time-frames (for each set of measurements)). On the other hand, as pointed out in the manuscript in the beginning of Chapter 2.1, one in-situ observation technique either only covers part of the coccolithophore groups (e.g. microscope) or the group of haptophytes (e.g. HPLC) or nanoeukaryotes (flow-cytometry) where coccolithophores are only part of the group. (More details are given in R.10)

Responses to the specific points (Reviewer #1):

C3 (P3)**:** *I think the use of the abbreviation coccos is cumbersome and unnecessary.*
R3. We changed that accordingly.

C4 (P3)**:** *No need for italics in coccoliths.*
R4. We changed that accordingly.

C5 (P4 line 4): *This is really only one optical effect – high reflectance in the upper ocean causes a shading effect lower down in the water column.*
R5. The phrase has been revised as follows:

"Coccolithophores are known for frequently forming large scale blooms, where due to the strong backscattering effect by coccoliths (detached or attached), they influence the optical behavior of the environment from two aspects: causing a high reflectance from the ocean surface; (and) making a large impact on the light field in upper ocean, by reducing the amount of available light beneath."

C6 (P4 line 11): *I disagree with this – diatoms are not always succeeded by coccolithophores. A great deal of this depends on which niche presents itself at particular times in the season, and to the nutrient availability (or lack thereof).*
R6. Sure, this had to be made clear accordingly. We reduced this generalization by adding proper adverbs and explanatory comments, as follows:

"Studies suggested that coccolithophore blooms, in their most recognized regions of occurrence, often succeed diatom blooms in response to increasing stabilization and nutrient depletion of surface waters (Margalef, 1978; Holligan et al., 1983; Lochte et al., 1993)."

C7 (P4 line 20): *replace with imagery.*
R7. We changed that accordingly.

C8 (P5 line 6): *True phytoplankton functionality depends on things like how they cycle nutrients within the water column. PFTs as defined by satellite algorithms are really only size specific and tell us little about the actual biogeochemical function of phytoplankton.*

R8. The main approaches for classifying phytoplankton groups (beyond the taxonomic method) are based on phytoplankton size classes (PSCs) and phytoplankton functional types (PFTs). According to Nair et al., (2008), these two approaches are not completely independent of each other, because some differences in biogeochemical functions can be attributed to the differences in cell sizes; However, PSCs can not cover appropriately the whole biogeochemical functions, because within a single PSC there might be groups with different functionalities. Therefore, the classification of our interest has been PFT-based approach, which divides all phytoplankton diversities into following types: calcifiers (e.g. coccolithophores), nitrogen-fixers (mostly cyanobacteria), DMS-producers (coccolithophores and dinoflagellates) and silicifiers (e.g., diatoms). Among different bio-optical satellite algorithms, even though PSC-based approaches have been more abundant (as group oriented methods), but there are also some methods focusing on the PFT-based retrieval; e.g., Sathyendranath et al. (2004), Alvain et al. (2005, 2008); Ciotti and Bricaud (2006); Aiken et al. (2007); Bracher et al. (2009) and Sadeghi et al. OSD 2011; Brewin et al. (2010a); Hirata et al. (2011).

C9 (P6 line 2): *replace phenomenal with an alternative word.*
R9. We changed that accordingly by rephrasing the content of bracket with the following:

“in the context of phytoplankton dynamics”

C10 (P6 line 24): *direct comparison with in-situ data is not too difficult (see Smyth et al., 2002 and numerous papers by Gordon et al.) The problem you have here is direct comparison with coincidental data and a data sparsity issue.*

R10. We agree that the core of the difficulties, which prevented so far an in-situ validation, is the data sparsity related to the satellite spatial resolution. As pointed out already in R2, large uncertainties in the total number of coccolithophore cells is also a problem, associated with the limitation of in-situ observations. [More precisely, with analyzing water samples by microscopy or with the Continuous Plankton Recorder (CPR) only the larger cells (> 5 μm and > 10 μm, respectively) can be identified. From HPLC and flow-cytometric analysis only the groups of haptophytes or nano-eukaryotes, respectively can be identified, to both of which coccolithophores belong to. Therefore, coccolithophore group can not be observed properly (along with the cell concentration) through in-situ measurements.]

Since in the former manuscript these two reasons (satellite data sparsity and limitation of in-situ observations) have been stated separately, the idea had been unclear in the former manuscript. Therefore, based on the proposed ideas (in comments C10 , C11), we have reformulated the respecting sentences (P.6, lines: 24-26) as follows:

“Regarding the fact that the whole coccolithophore group cannot be observed through in-situ measurements, and also due to the data sparsity and limited temporal and spatial coverage associated with the coarse spatial resolution of SCIAMACHY, no direct comparison of retrieved to in-situ coccolithophores have been performed. More precisely, with analyzing water samples by microscopy only the cells larger than 5 μm can be identified. Also with the Continuous Plankton Recorder (CPR, see Raitsos et al.,2006), with the mesh size of about 270 μm, only part of the total cells of coccos are detectable, containing those captured on the finer threads of silk that constitute the mesh-weave (Hays et al. 1995).”

C11 (P6 line 26): *reference for the CPR - Raitsos et al (2006). Although need some explanation as to how the CPR can be used. The CPR has a mesh size of 200 μm and coccolithophores are 5 - 20 μm. There is evidence that they stick to the fibers of the CPR (works by Schroder).*
R11. The points mentioned in this comment have been accounted for along with the previous comment (C10) and the respective rephrasing was merged into the R10.

C12 (P7 line 5): *Therefore this paper is a satellite algorithm versus satellite algorithm comparison.*
R12. We attached the suggested sentence to the initial sentences, with some minor changes:

“Therefore, with respect to coccolithophores, the comparison presented in this paper is a satellite algorithm versus satellite algorithm approach. Practically, the PhytoDOAS coccos,, were compared to the global distribution of PIC obtained from the MODIS-Aqua level-3 products (after the preliminary comparisons with the NOBM coccos modeled data).”

C13 (P8 line 1): *the Great Calcite Belt is still only a hypothesis. Balch et al. (2011) readily admit that the GCB is still only a hypothesis, with a few in situ observations to support it. Other factors in the Southern Ocean include elevated levels of bubble production, which in turn cause the PIC algorithm to overestimate PIC by a factor of up to three. You should not present a hypothesis as grounded fact.*
R13. We agree. The whole sentences (P.8, lines: 1-3) have been rephrased as below:

“As shown in Fig. 2 on a background of the MODIS-Aqua PIC product, two regions (*sAtl* and *sPac*) are located in a wide latitudinal belt of elevated PIC concentrations. This area, characterized by an almost permanent high reflectance, has been hypothesized (Balch et al., 2005, 2011) to be associated with elevated coccolithophores, and hence is is referred to as *Great Calcite Belt.”*

C14 (P9 lines 4 - 12): *There is possibly a good case for a more consistent dataset here. Options are: MODIS Aqua chlorophyll (from Ocean Color Web site) together with MODIS Aqua PIC or; GlobColour Chlorophyll and GlobColour radiances to derive the PIC product.*

R14. We agree that the sets of satellite products proposed here as alternative comparison options, are more consistent. But it was also in our interest to select a satellite product where Chl-a data are as complete as possible (as it is fulfilled by GlobColour Chl-a data, as merging measurements from three different sensors). Having different Chl-a algorithms included provides also a more general comparison.

Since PIC is regarded as a proxy for coccolithophores, and satellite PIC results have been often discussed in literature by referring to the PIC product of MODIS-Aqua (e.g., in several papers of Balch et al.,), we have chosen this product of PIC and did not calculate PIC from the merged GlobColour reflectances.

C15 (P11 line 29): *low phytoplankton activity in wintertime. This is not just due to the deep winter mixed layer! This highlights often encountered problems with Remote Sensing papers: a lack of appreciation for the way the ocean works. The north Atlantic will have very low levels of light at this time of year which obviously affect photosynthesis. In April there is still a deep mixed layer depth (see your graphs), but productivity is increasing due to increasing light levels. It is also worth looking at the Behrenfeld (2010) paper and the ideas of Sverdrup.*

R15. That's true; we forgot to mention that before. Phytoplankton activity is certainly besides nutrients primarily dependent on light intensity which is too low in the winter. However the MLD influences the amount of the light exposed to the phytoplankton existing in the upper part of the water column (due to the permanent turbulence in the mixed layer; leading to the concept of the critical depth (proposed by Sverdrup, 1953), associated with the initiation of the spring blooms. We have corrected the referred sentences as follows:

“The North Atlantic is generally characterized by an extremely deep winter mixed layer and also a very low phytoplankton activity in wintertime, both features can be seen clearly in Fig. 3 (however, the low phytoplankton biomass in wintertime is a result of the dramatic reduction in solar radiation, which in turn is reflected at the low SST values, shown too in Fig. 3).”

C16 (P12 lines 1 - 5): *Higher SSTs are associated with a stratified water column, which then leads to changes in the nutrient dynamics such as nutrient exhaustion.*

R16. We do not see any conflict between your comment and what has been stated in the mentioned lines. Rather, this statement would improve the interpretation of the result, regarding comparison between the times series of phytoplankton-based products and SSTs. Particularly, it explains well the reason why peaks of phytoplankton activities occur always before the peaks of SSTs. Therefore, we have added this statement to the original sentences, with some additional explanations:

“The phytoplankton and PIC maxima coincide with the high positive gradient of SST; i.e., SST peaks always appear delayed to the phytoplankton peaks, which is in accordance with the results of Raitsos et al. (2006). Furthermore, higher SSTs are associated with a stratified water column, which then leads to changes in the nutrient dynamics such as nutrient exhaustion. This can be pronouncedly observed over a period in summertime, when there is a significant gap of productivity between the spring bloom and the fall bloom."

C17 (P12 line 16): *need evidence or a reference here for the temporal rhythm of phytoplankton dynamics.*
R17. By replacing the last line with the following statement, we have tried to provide argument for supporting the idea (the advantage of a weekly-based analysis):

"The period of one-month is probably larger than the real, because of the life-time of phytoplankton cells (few days) and also changes in the environmental conditions, which might involve rapid changes in specific factors, due to the regional geophysical and biological characteristics. Therefore, weekly-based analysis would lead to a more precise investigation of the temporal rhythm of phytoplankton dynamics."

C18 (P12 line 20): *high wind speeds could also explain why the water appear white, therefore triggering the coccolith flag . . .*
R18. In fact there is a hypothesis (Zhang et al., 2002) suggesting that the storm-induced micro-bubble injection might explain the high reflectance in the region between the Subtropical Front (STF) and the northern part of the Subantarctic Front (SAF). But this feature can not explain the observations of elevated coccolithophores in large regions of the global ocean, whose results follow a relatively regular basis. On the other hand, according to Koepke (1984), the spectral footprint of the wind-driven white caps is almost flat in the visible range, therefore it is Moreover, the values shown in the wind-speed time series are not as big as wind-speed ranges of stormy conditions, rather showing only irregularities. In fact (regarding Fig. 3, Fig. 4 and Fig. 5), while the wind-speed in *nAtl* reaches up to *15 m/s*, its maximum levels in s*Atl* and *sPac* are *10 m/s* and *12 m/s*, respectively.
However, as a possible factor which can partly explain one error source of the coccolithophore retrievals, we have introduced this statement on the manuscript (P12, end of line 22) as follows:

"It should be mentioned that strong surface winds also cause whiteness of the water surface, namely high reflectance. Within the PhytoDOAS retrieval such pixels are flagged and not processed by the differential absorption method, because the spectral footprint of the wind-driven whitecaps is almost flat in the visible range (Koepke, 1984). Moreover, Zhang et al., (2002) suggested that the storm induced micro- bubble injection might explain the high reflectance in the so-called region of *Great Calcite Belt* (between the Subtropical Front and the northern part of the Subantarctic Front). However, looking at the two regions of our study within the *Great Calcite Belt*, PhytoDOAS coccolithophore results prove that in these regions coccolithophores are highly abundant."

C19 (P15 lines 1 - 19): *need to unpackage the chlorophyll algorithm issue in the presence of coccolithophores: the reason for an overestimate in chlorophyll is because coccolithophores make fundamental changes to the band ratio algorithms.*
R19. We agree. We changed accordingly and added some explanation to this page (P15, after line 16):

"The overestimation of coccolithophores observed in Fig. 7 may be assigned to the proposed underestimation of Chl-a during the coccolithophore blooms for the GlobColour data set. The reason for an overestimate in Chl-a is because coccolithophores make fundamental changes to the band ratio algorithms: coccolithophores increase the radiance uniformly in both the blue and green [Gordon et al., 1988], leading to the ‘‘flattening’’ of the reflectance spectrum. This flattening effect is more pronounced over the coccolithophore blooms, implying that the standard ratio pigment algorithms [Gordon and Morel, 1983] will not provide correct pigment retrievals within the blooms [Balch et al., 1989].”

C20 (P17 **-** 19): *I am always a little dubious about invoking trends and climatologies from such a short time series.*

R20. Of course, the trend results extracted from short-term time series are not promising. But we have been limited by the data availability of SCIAMACHY and MODIS, which have been operating since 2002. As an ongoing work, it might be of help to apply different approaches, as proposed here, for trend calculations. Furthermore, even with this short-time trends, comparison with the respective trends of other satellite products, has provided some informative results with respect to tracking the possible differences. For instance, when comparing the trends of different variables in *nAtl* and *sAtl* (Fig. 10, left panel), MODIS- PIC and GlobColour Chl-a do not show any change in the sign, while the trend signs of coccolithophores, SST and wind-speed do change. If SST and wind-speed (both important factors for phytoplankton dynamics) are assumed to be more trustful than other satellite products (due to their more direct observation process), then it would be a meaningful question: why the trend of coccolithophores follows the changes in these parameters, while MODIS- PIC and GlobColour Chl-a do not?

Accordingly, we mentioned this limitation at the beginning of the respective discussion (P. 17 , line 19) as follows:

“It should be noted that the information extracted from this eight-year trend analysis is not highly promising, due to the relatively short period of monitoring. However, the analysis highlight that some results are consistent with the well-known relationships between the variables. For instance, when comparing the trends of different variables in *nAtl* and *sAtl* (Fig. 10, left panel), MODIS-PIC and GlobColour Chl-a surprisingly do not show any change in the sign, while the trend signs of coccolithophores, SST and wind-speed do change, accordingly. Moreover, this trend analysis is also aiming to investigate an optimal approach for estimation of phytoplankton trend.”

****

*   **Responses to the Reviewer #2 (RC5479)**

****

Responses to the general points (Reviewer #2):

C21. *While the use of hyperspectral data in the field of sea-surface remote sensing is indeed promising, I am not convinced that the methodology used here has any advantage on standard ocean color products, which have a much better spatial resolution.*

This is emphasized by the fact that, as mentioned by the authors, the PhytoDOAS coccolithophore retrieval is actually validated against MODIS PIC data. On the other, the very low spatial resolution associated with the SCIAMACHY data is likely to filter out much of the spatial information which is of great importance when trying to to study variations in plankton dynamics.

R21. We have found the content of this remarkable comment the same as what has been given by the Reviewer 1 in his first general comment (C1.). Therefore, we should refer to the respective answer (R1.), which is also repeated in below:

Satellite sensors can easily observe coccolithophores in the visible range, as milky-white or turquoise patches in true color images. This is due to the strong backscattering effect of detached coccoliths within the water column [Ackleson and Holligan, 1989; Balch et al., 1991; Holligan and Balch, 1991], which is more pronounced for large blooms. However, this is not a quantitative detection of coccolithophores, and only identifies the spatial distributions of coccolithophore blooms (e.g., Brown and Yoder, 1994). For instance, Brown and Podesta (1997) applied an image-processing algorithm to the CZCS data in order to classify different ground pixels as “bloom” or “non-bloom” areas, in which specific thresholds of normalized water-leaving radiance (nLw) were imposed for the definition and flagging of coccolithophorid bloom, based on empirically derived spectral features.
Additionally, optical effects of some other oceanic constituents (e.g., resuspension of empty -broken up- diatom frustules) can be mistaken as a coccolithophore bloom [Tyrrell and Merico 2004].

On a quantitative level, there are algorithms which estimate the coccolithophore particulate inorganic carbon (PIC) concentrations in bloom and non-bloom waters [Balch et al., 2005; Gordon et al., 2001], pertaining to the total number of detached coccoliths, not the living coccolithophore cells. But , as shown in Balch et al. (2011), above-water PIC measurements can be 2-3 times more than in-water PIC measurement; and additionally, the relation between coccolith concentration and living cell concentration is not a fixed known value, it rather depends on the dominant coccolithophore species, ocean chemistry and also environmental conditions. For instance, even though for *E. huxleyi*, detached coccolith concentrations are typically at least 15-20 times the concentration of plated cells [Balch et al., 1993], it has been shown [Blackburn and Cresswell, 1993] that large coccolithophore blooms can also be dominated by by other species (e.g., *Gephyrocapsa oceanica)* instead of *E. huxleyi*. Hence, overall, the satellite retrieval of coccolithophores is not so straightforward as presumed.

The retrieval method used in our study (PhytoDOAS) has a fundamentally different approach than the coccolithophore PIC algorithms: while the PhytoDOAS is based on the absorption features of living coccolithophore cells, the PIC algorithms are based on the scattering characteristics of the coccolith plates, carried by water-leaving radiance in specific wavelengths (PhytoDOAS use the hyper-spectral information), and do not separate between living and dead material. In contrary, PhytoDOAS enables for the first time to retrieve coccolithophores conc. themselves among other major phytoplankton groups. It is therefore able to detect coccolithophores also in strong mixed phytoplankton conditions and lower concentrations.

Even though the PhytoDOAS method relies on hyperspectral data, currently provided by SCIAMACHY with a coarse spatial resolution (30x60 km^2), the method is in principle applicable to any available hyperspectral sensor (in future), which has moderate or high spatial resolution (e.g., the Sentinel-5-Precursor, planned to launch in 2014 with 7x7 km^2 pixel size and global coverage within 1 to 2 days). While already for ecosystem or biogeochemical modeling studies (e.g. Ye et al. 2012, in press) the SCIAMACHY PhytoDOAS products spatial resolution is sufficient, the proposed future PhytoDOAS products from hyperspectral sensors on the Sentinel mission will enable to detect smaller spatial scale features of phytoplankton groups which are comparable to ocean color sensors -like SeaWiFS or MODIS (which do not deliver conc. of living coccolithophores).

C22. *I find the coarse spatial and temporal resolution used in this research, which is somewhat imposed the instrument used, inadequate for deriving robust insights on the processes controlling the evolution of a single plankton group. This is emphasized by a careful examination of Fig. 8 that shows very little (and sometimes not at all) difference between the evolution of coccolithophores and diatoms. This implies that many of the results and conclusions are also applicable to diatoms.*

R22. We agree that a finer spatial resolution (than what we have been limited to) could result in a better investigation of spatial distributions of diatoms and coccolithophores. We think, however, the reason that coccolithophores and diatoms (as depicted in Fig. 9 – it was mistakenly referred to as Fig. 8 in this comment) show fairly similar patterns (though with different ranges of Chl-a) is mostly due to the temporal resolution (monthly averages) utilized in this study. We referred to this weak point on P. 11741 (lines 10-15) and addressed in the *Conclusions* (P. 11744, lines 24-26) the reason for not having used the shorter averaging time-scales, where we also mentioned (P. 11745, lines 2-3) a weekly-based retrieval as an alternative approach for the PhytoDOAS PFT retrievals in its future applications. However, it should be noted that, both in spatial and temporal basis, coccolithophores and diatoms do have some overlaps: it is believed that coccolithophore blooms succeed diatom blooms (Margalef, 1978; Holligan et al., 1983; Lochte et al., 1993), which has a twofold implication: there are some common habitats for these two PFTs; and their activity periods are close to each other.
Furthermore, regarding Fig. 9, the temporal patterns of diatoms and coccolithophores in *nAtl* show more differences than in *sAtl* and *sPac*, which needs to be speculated. The study by Eynaud et al., (1999) sheds light on the complexities associated with the distributions of diatoms and coccolithophores in the austral oceanic areas, which are affected by the geostrophic circulation patterns of the Southern Ocean:

"*The geostrophic circulation patterns of the Southern Ocean produce extended zones with relatively uniform hydrographic characteristics. Furthermore, frontal boundaries are believed to influence biological dispersal between and containment within these zones. The phytoplankton of this ocean has been studied for more than 50 years. In the microplankton and nanoplankton size-groups (2-200 μm), diatoms and coccolithophores are among the most studied. Diatoms are usually considered to be dominant in the Southern Ocean (Hasle, 1969; Fenner et al., 1976; Jacques, 1981; Pichon, 1985). These organisms are particularly well adapted to Antarctic waters, where light, temperature and nutrient availability are thought to be favorable to their growth. Northward, in the Subantarctic zone, coccolithophores become the major group (Hasle, 1969).*"

Much of the biology in the austral oceanic regions occurs along the major fronts; i.e., the Subtropical, the Subantarctic, and the Antarctic Polar fronts, which are areas associated with well defined temperature changes. Some studies suggest that size and distribution of phytoplankton are also related to fronts. Microplankton (> 20 μm) are found at fronts and at sea ice boundaries, while nanoplankton (< 20 μm) are found between fronts [Knox, 2007].

Overall, due to the influence of geostrophic currents, there is no clear evidence about the unique domains (on large scales) of single species blooms in southern parts of the austral waters. For instance, while some studies (e.g., Smetacek et al. 2002) suggest that the Antarctic Circumpolar Current is dominated by diatoms, and the Weddell Sea has abundant coccolithophores, there are also other studies (e.g., Eynaud et al. ,1999) suggesting that coccolithophores are abundant in the northern regions adjacent to the Southern Ocean, where diatoms are dominated.

Therefore, it might be also a case that the large study areas (10° by 10°) selected in the southern hemisphere (i.e., *sAtl* and *sPac*), contain separate areas affected by different fronts and hence, covered simultaneously by diatoms and coccolithophores. This might also partly justify the similar patterns observed by PhytoDOAS for these regions.

Nevertheless, we addressed this feature on the manuscript, where we replaced the whole paragraph (P 11741, lines: 5-15) by new ones, collected from the above arguments. In this way we emphasize the mentioned feature along with providing further explanations about that. To shorten this answer the alternative paragraphs are given in our response to C33 (i.e., in R33), which is referring to the same issue with respect to Fig. 9.

Responses to the specific points (Reviewer #2):

C23 (P 11729 line 26): *The authors should be much clearer in stating their objectives. If the main objective is "to apply the PhytoDOAS method for quantitative remote sensing of coccos using satellite data", the comparison with geophysical parameters (which I find potentially interesting), is redundant.*
R23. We agree that the statement mentioned as the main objective does not express alone the whole work presented by the manuscript. Therefore, we have reformulated this statement as follows:

"The main interest of this study was to show the capability of the PhytoDOAS method for quantitative remote sensing of coccolithophores (using satellite data) and also its application for studying the phytoplankton dynamics, which is necessarily connected to the study of environmental factors."

C24 (P 11731 line 28): *Missing units for the area. Also, the authors should explain using this size of region of interest.*
R24. We changed it accordingly.

"The regions were selected to be geographically 10° × 10° areas, which regarding their latitudinal distributions means almost the same geometrical areas for *sAtl* and *sPac* and a slightly smaller area for *nAtl*."

C25 (P 11735 lines 1-5): *Not clear what are the missing points in the PhytoDOAS time series – they seem to be continuous.*
R25. We replaced the respective figures (i.e., Fig. 3, Fig.4 and Fig.5) in order to depict the gaps; we also changed the explanations about the missing points (P 11735 lines 1-5), accordingly:

"In the time-series of the PhytoDOAS coccolithophores there are some missing points, due to the post-processing of the retrieved data. More precisely, the fit-quality was controlled by applying a Chi-square (χ) filter (on the overall Chi-square of the retrievals) and the quality of the averaging process was conditioned by inserting a threshold value for the available number of ground pixels. Due to these gaps the coccolithophore time-series, compared to the time-series of the other parameters, seem noncontinuous, which was necessary to avoid artifact features."

C26 (P 11735 lines 7): *The author should specify the spatial resolution of SCIAMACHY; "coarse" is too vague.*
R26. We changed it accordingly.

C27 (P 11738 line 27): *It seems that the term "spatial" is mistakingly used.*
R27. Here the term "spatial variations" refers to the variations induced by different geographical habitats. For more clarity, however, we replaced the whole sentence by the following:

"All together, these samples show variations in phytoplankton absorption within the same phytoplankton group, originated from their different geographical habitats."

C28 (P 11738 line 3): *If cocsos-Chl is higher than the total Chl it definitely overestimated, and not "seems to be" overestimated.*
R28. Since on the former manuscript the possible causes of this difference (between GlobColour Chl-a and PhytoDOAS coccolithophores) has been explained a few sentences below this line , we rephrased accordingly the mentioned sentence (P 1173**9** line 3) as follows:

"The retrieved *chl-a* of coccolithophores are higher than GlobColour total *chl-a* in many months (which are illustrated by values less than one)"

C29 (P 11745 line 4): *I don't see how "The outcome of the study proves that the PhytoDOAS coccos data show valuable results ". Overall, it seems that similar conclusion as the one presented here, would be valid for MODIS retrievals of PIC or chlorophyll.*
R29. In order to be more informative on the context of the study outputs, we reformulated the above sentence with the following:

"The outcome of the study indicates that the PhytoDOAS method can detect quantitatively the living coccolithophore cells (in term of *chl-a* content). The resulting data show similar patterns to the distribution of coccolithophore-PIC product of MODIS-Aqua, as well as showing consistency with the environmental conditions associated with coccolithophore blooms."

C30 (Figure 1): *Message is not clear. The authors should point out (in the text and/or in the figure caption) what are the main similar patterns. For the middle panel I recommend changing the dynamical range so that it emphasize more features.*
R30. To address this issue following statement has been added to the text (P. 11731, line 16):

" The similarities observed between distribution patterns of coccolithophores and PIC are pronounced in the North Atlantic and North Pacific; but partial similarities are also seen in the Mid-Pacific, South Atlantic and northwest and southwest of the Indian Ocean."

C31 (Figures 3-5, 11): *For more clarity I recommend changing the order of panels, starting at the top (panel a) and ending at the bottom.*
R31. We changed the figures accordingly.

C32 (Figure 8): *The authors should be more clear in distinguishing between left and right panels – both graphically and in the caption.*

R32. We changed accordingly the captions of Fig. 8 and Fig. 10 and respective sentences referring them in the text.

C33 (Figure 9): *The remarkable similarity between the time series suggests that the algorithms have little success in correctly distinguishing between the plankton groups – I recommend the authors address this issue in the text.*

R33. We have explained the possible reasons for this similarity in R22. Accordingly, based on the arguments given in R22, we changed the whole paragraph on the manuscript (P. 11741, lines: 5-15) to address this feature and its possible causes:

"As it is believed that coccolithophore blooms often follow diatom blooms (Margalef, 1978; Holligan et al., 1983; Lochte et al., 1993), time series of diatoms and coccolithophores for the study regions have been compared in Fig. 9. Regarding Fig. 9, diatoms show always higher *chl-a* contents in all regions, as it is expected (e.g., Goldman, 1993; Clark et al., 2002). However, while the temporal patterns of diatoms and coccolithophores in *nAtl* show clear differences, these differences are not as pronounced in *sAtl* and *sPac.* The following may explain these features:

Firstly, it should be noted that, both spatially and temporally, coccolithophores and diatoms have some overlaps, originated from their bloom successions: this has a twofold implication, referring to some common habitats for the two PFTs, where their activity periods are close to each other. The latter factor suggests shorter averaging period to reach an improved identification, which can not be resolved by the current PhytoDOAS monthly products (based on the SCIMACHY data availability). As another side-effect of current averaging, monthly-mean *chl-a* maxima of coccolithophores and diatoms are probably smaller than the absolute maxima they reach during the blooms.

Secondly, according to Eynaud et al.,(1999), with respect to the distributions of diatoms and coccolithophores in the austral oceanic areas (including *sAtl* and *sPac*}, there are complexities induced by the geostrophic circulation patterns of the Southern Ocean (e.g., Antarctic Circumpolar Current, ACC): the geostrophic circulation patterns of the Southern Ocean produce extended zones with relatively uniform hydrographic characteristics, inducing frontal boundaries (e.g., the Subantarctic, and the Antarctic Polar fronts). Furthermore, the frontal boundaries, which are areas associated with well defined temperature changes, are believed to influence biological dispersal between and containment within these zones. Hence, due to the influence of geostrophic currents and frontal boundaries, there is no clear evidence for unique domains (on large scales) of single species blooms in the southern parts of austral waters. For instance, while some studies (e.g., Smetacek et al. 2002) suggest that the ACC is dominated by diatoms and the Weddell Sea has abundant coccolithophores, there are other studies (e.g., Eynaud et al.,(1999)) suggesting that coccolithophores are also abundant in the northern regions adjacent to the Southern Ocean (where diatoms are dominating). Therefore, it might be that the large study areas (10° by 10°) selected in the southern hemisphere (i.e., *sAtl* and *sPac*), contain sub-areas affected by different fronts (or geostrophic currents) and hence, the selected area is covered simultaneously by diatoms and coccolithophores. This might also partly justify the similar patterns observed by PhytoDOAS for these two regions

Overall, it seems that utilizing smaller study regions and also shorter averaging periods (e.g., weekly-based averaging instead of monthly-based one) would lead to more distinguishable time series for diatoms and coccolithophores than what is shown in Fig. 9. However, these too options are not achievable by SCIAMACHY data due to its temporal data-sparsity and its coarse spatial resolution (as described before). Nevertheless, the application of PhytoDOAS to future hyperspectral satellite sensors with improved spatial and temporal resolution will be enable such analysis."

C34 (Figure 11): *The legend should not include the line-type.*
R34. We changed it accordingly on respective figures.

****

References:

Ackleson, S. G. and Holligan, .P. M.: AVHRR observations of a Gulf of Maine coccolithophorid bloom. Photogramm. Eng. Remote Sensing, 55, 473-474, 1989.

Aiken, J., Fishwick, J. R., Lavender, S. J., Barlow, R., Moore, G., and Sessions, H.: Validation of MERIS reflectance and chlorophyll during the BENCAL cruise October, 2002: Preliminary validation of new products for phytoplankton functional types and photosynthetic parameters. International Journal of Remote Sensing, 28., 2007.

Alvain, S., Moulin, C., Dandonneau, Y., and Breona, F. M.: Remote sensing of phytoplankton groups in case 1 waters from global SeaWiFS imagery. Deep-Sea Research, 52. 2005.

Alvain, S., Moulin, C., Dandonneau, Y., and Loisel, H.: Seasonal distribution and succession of dominant phytoplankton groups in the global ocean: A satellite view. Global Biogeochemical Cycles, 22. 2008.

Balch, W. M., Eppley, R. W., Abbott, M. R., and Reid, F. M. H.: Bias in satellite-derived pigment measurements due to coccolithophores and dinoflagellates, J. Plankton Res., 11, 575-581, 1989.

Balch, W. M., Holligan, P. M., Ackleson, S. G., and Voss, K. J.: Biological and optical properties of mesoscale coccolithophore blooms in the Gulf of Maine, Limnol. Oceanogr., 36, 629-643, 1991.

Balch, W. M., Kilpatrick, K. A., and Holligan, P. M.: Coccolith formation and detachment by Emiliania huxleyi (Prymnesiophyceae), J. Phycol., 29, 566–575, doi:10.1111/j.0022-3646.1993.00566.x, 1993

Balch, W. M., Gordon, H. R., Bowler, B. C., Drapeau, D. T., and Booth, E. S.: Calcium carbonate measurements in the surface global ocean based on moderate-resolution imaging spectroradiometer data, J. Geophys. Res., 110, C07001, doi:10.1029/2004JC002560, 2005.

Balch, W. M., Drapeau, D. T., Bowler, B. C., Lyczskowski, E., Booth, S., and Alley, D.: The contribution of coccolithophores to the optical and inorganic carbon budgets during the Southern Ocean gas exchange experiment: new evidence in support of the Great Calcite Belt hypothesis, J. Geophys. Res., 116, C00F06, doi:10.1029/2011JC006941, 2011.

Blackburn, S.I, and Cresswell, G. : A coccolithophorid bloom in Jervis Bay, Australia, Australian J. Mar. Freshwater Res., 44 , pp. 253-260, 1993.

Bracher, A., Vountas, M., Dinter, T., Burrows, J. P., Rttgers, R., and Peeken, I.: Quantitative observation of cyanobacteria and diatoms from space using PhytoDOAS on SCIAMACHY data, Biogeosciences, 6, 751-764, doi:10.5194/bg-6-751-2009, 2009.

Brewin, R. J. W., Lavender, S. J., Hardman-Mountford, N. J., and Hirata, T.: A spectral response approach for detecting dominant phytoplankton size class from satellite remote sensing. Acta Oceanol Sin., 29:14-32, 2010a.

Brown, C. W. and Yoder, J. A.: Coccolithophorid blooms in the global ocean, J. Geophys. Res., 99(C4), 7467-7482, 1994a.

Brown, C. W. and Podesta, G. P.: Remote sensing of coccolithophore blooms in the Western South Atlantic Ocean, Remote Sens. Environ., 60, 83-91, 1997.

Ciotti, A. M. and Bricaud, A.: Retrievals of a size parameter for phytoplankton and spectral light absorption by coloured detrital matter from water-leaving radiances at SeaWiFS channels in a continental shelf off Brazil. Limnology and Oceanography: Methods, 4:237-253., 2006.

Clark, D. R., Flynn, K. J., and Owens, N. J. P.: The large capacity for dark nitrate-assimilation in diatoms may overcome nitrate limitation of growth, New Phytol., 155, 101-108, 2002.

Eynaud, F., Giraudeau, J., Pichon, J.-J., and Pudsey, C. J.,: Sea-surface distribution of coccolithophores, diatoms, silicoflagellates and dinoflagellates in the South Atlantic Ocean during the late austral summer 1995, Deep-Sea Research I (46), p 451-482, 1999.

Fenner, J., Schrader, H.J., Wienigk, H.,: Diatom Phytoplankton studies in the Southern Pacific Ocean, composition and correlation to the Antarctic convergence, and its Paleological Significance. Initial Reports of DSDP Leg 35, 757-813, 1976.

Goldman, J. C.: Potential role of large oceanic diatoms in new primary production, Deep-Sea Res. Pt. I, 40, 159-68, 1993.

Gordon, H. R. and Morel, A.: Remote Assessment of Ocean Color for Interpretation of Satellite Visible Imagery: a Review, Springer-Verlag, New York, 1983.

Gordon, H. R., Brown, O. B., Evans, R. H., Brown, J. W., Smith, R. C., Baker, K. S., and Clark, D. K.: A semi-analytic radiance model of ocean color, Geophys. Res., 93, 10909-10924, 1988.

Gordon, H. R., Boynton, G. C., Balch, W. M., Groom, S. B., Harbour, D. S., and Smyth, T. J.: Retrieval of coccolithophore from SeaWiFS imagery calcite concentration, Geophys. Res. Lett., 28(8), 1587-1590, 2001.

Hasle, G.R.,: An analysis of the phytoplankton of the Pacific Southern Ocean: abundance, composition and distribution during the Brategg Expedition 1947-1948. Halvaradets Skr. Science of Royal Marine Biology Research 52, 168. 1969.

Hirata, T., Hardman-Mountford, N. J., Brewin, R. J. W., Aiken, J., Barlow, R. G., Suzuki, K., Isada, T., Howell, E., Hashioka, T., Noguchi-Aita, M., and Yamanaka, Y.: Synoptic relationships between surface chlorophyll-a and diagnostic pigments specific to phytoplankton functional types. Biogeosciences, 8:311-327, 2011.

Holligan, P. M., Viollier, M., Harbour, D. S., and Champagne-Philipe, M.: Satellite and ship studies of coccolithophore production along a continental shelf-edge, Nature, 304, 339-342, 1983.

Holligan,P.M., and Balch,.W.M. :From the ocean to cells: coccolithophore optics and biogeochemistry In Demers. S. (ed.), Particle Analysis in Oceanography. Springer-Verlag, Berlin, pp. 301-324.

Jacques, G., Minas, M.: Production Primaire dans le secteur indien de l'ocean Antarctique en fin d'ete. Oceanologica Acta 4, 33-41, 1981.

Knox, G.A.: Biology of the Southern Ocean. CRC Press 2007. pg 23

Koepke, P.,: Effective reflectance of oceanic whitecaps, *Applied Optics*, Vol. 23, Issue 11, pp. 1816-1824 doi:10.1364/AO.23.001816, 1984.

Lochte, K., Ducklow, H. W., Fasham, M. J. R., and Stienen, C.: Plankton succession and carbon cycling at 47-degrees-N-20-degrees-W during the JGOFS North Atlantic bloom experiment, Deep-Sea Res. Pt. II, 40(1-2), 91-114, 1993.

Margalef, R.: Life-forms of phytoplankton as survival alternatives in an unstable environment, Oceanol. Acta, 1, 493-509, 1978.

Nair, A., Sathyendranath, S., Platt, T., Morales, J., Stuart, V., Forget, M.-H., Devred, E., and Bouman, H.:

Remote sensing of phytoplankton functional types, Remote Sens. Environ., 112, 3366-3375, 2008.

Pichon, J.,: Les diatomees traceurs de l'evolution climatique et hydrologique de l'Ocean Austral au cours du dernier cycle climatique. These de 3e cycle, Universite de Bordeaux I, 279, 1985.

Raitsos, D. E., Lavender, S. J., Pradhan, Y., Tyrrell, T., Reid, P. C., and Edwards, M.: Coccolithophore bloom size variation in response to the regional environment of the subarctic North Atlantic, Limnol. Oceanogr., 51, 2122-2130, 2006.

Sathyendranath, S., Watts, L., Devred, E., Platt, T., Caverhill, C., and Maass, H.: Discrimination of diatoms from other phytoplankton using ocean-colour data. Marine Ecology Progress Series, 272, 2004.

Smetacek, V., Klaas, C., Menden-Deuer, S. and Rynearson, T.A.: Mesoscale distribution of dominant diatom species relative to the hydrographical field along the Antarctic Polar Front. Deep-Sea Research II, 49, 3835-3848, 2002.

Tyrrell, T. and Merico, A.: Emiliania huxleyi: Bloom Observations and the Conditions that Induce Them, in: Coccolithophores from Molecular Processes to Global Impact, edited by: Thierstein, H. R. and Young, J. R., Springer, New York, 75-97, 2004.

Ye Y., Voelker C., Bracher A., Taylor B,Wolf-Gladrow D. (in press, available online since 20-1-2012) Environmental controls on N2 fixation by Trichodesmium in the tropical eastern North Atlantic. Deep Sea Research I: doi: 10.1016/j.dsr.2012.01.004.

Zhang, X., Lewis, M., Lee, M., Johnson, B., and Korotaev, G.: The volume scattering function of natural bubble populations, Limnol. Oceanogr., 47, 1273–1282, doi:10.4319/lo.2002.47.5.1273, 2002.