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Biogeosciences Discussions

Interactive comment on "Coccolithophore response to climate and surface hydrography in Santa Barbara Basin, California, AD 1917–2004" *by* M. Grelaud et al.

M. Grelaud et al.

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We thank Patrizia Ziveri for her constructive criticism that helped to improve the manuscript substantially. We have followed the suggestions in most cases. All relevant parts of the manuscript have been revised in order to clarify issues raised by the P. Ziveri.

The manuscript is presenting high resolution data of six coccolithophore species (relative abundance and carbonate coccolith weight) in the varved sediments of the Santa Barbara Basin (SBB) from approximately the last 80 years. A main goal is to reconstruct past seasonal and annual coccolithophore response to surface hydrographic changes, including the ENSO and PDO anomalies in this region. This is an interesting

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paper but there are several issues that need clear explanations and discussion.

AGE MODEL AND SEASONAL RESOLUTION

1-(section 2.1 pages 4132-33) A new result presented in this paper is the seasonality of coccolithophores inferred from the varves. In order to have this type of resolution it is important to precisely comment on the age model and sampling. The final age model with a mean resolution of about 3 months seems unrealistic (lines 15-17, page 4133).

Answer: there is no bioturbation in that core as evidenced by the presence of laminations. We agree however that it is not possible to give a precise age lower than the semester because of the uncertainty of continuous deposition at the seasonal scale. We therefore changed the expected resolution to sub-annual resolution.

2-The core used in this study is a core B retrieved from a multicore collected in SBB. The core B was sampled every millimeter, not as a function of seasonal varve thickness that is known to be variable, but rather assuming a constant sedimentation rate (?).

Answer: we do not assume that the sedimentation rate is constant in the Santa Barbara Basin, but as it was not feasible to strictly follow varve boundaries because color and textural differences among varves were often indistinct, we prefer to sample core B every millimeter in order to reach the highest resolution possible. The age model provides a mean varve thickness of ˜2.9 mm with a standard deviation of 1.3 mm. These points have been added to the manuscript in section 2.3 Age model.

3-In addition, the dating uncertainty for core A dated in Hughet et al. (2007) (used to establish the age model of core B) is of about 2 years prior to 1980 A.D. and of about 1 year for younger sediment. The fine-tuning of the chronological G. oceanica relative abundance of the core B to the extended NINO3 index needs further explanation.

Answer: we tuned the relative abundance of G. oceanica to the NINO3 index to establish the age model. In De Bernardi et al. (2005), the authors show that this species was particularly well developed in the Santa Barbara Basin (SBB) during the El Niño (EN)

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event of 1997-98. During the period prior the event (i.e. 1996), this species exhibited very low relative and absolute abundances. In their conclusion, the authors argued that the "increase in abundance of G. oceanica during strong EN events could be used as a paleo-EN indicator in the SBB". Moreover, it has been shown that during El Niño years, the tropical convection center move to the central and eastern equatorial Pacific, leading to a weakening of the North Pacific High inducing the warming up of the California borderlands through the intensification of the southern California Countercurrent (Bograd and Lynn, 2001). Since G. oceanica is a tropical species, it seems realistic that this species is brought in the SBB by the California Countercurrent during an El Niño event. It is what we found: with very little change in the timing it is evident that G. oceanica was picking during ENSO years. Therefore with short stretching of the chronology we were able to provide a very good agreement between this proxy and the NINO3 index, this reinsuring both the chronology and the use of that proxy.

4-This tuning is based on previous trap studies showing the relationship of G. oceanica flux with El Nino anomaly in SBB (De Bernardi et al., 2005). However, in the recent study on a SBB core (De Bernardi et al., 2008 Paleoceanography). It was confirmed that the increase in G. oceanica coccolith flux in SBB provides evidence for the poleward transport of El Niño's conditions to higher latitudes. This relationship was mainly shown by G. oceanica fluxes and not by the relative abundances. A strong interannual variability and linkage with PDO and El Niño intensity was also demonstrated.

Answer: in De Bernardi et al. (2008), we can see that the flux of G. oceanica exhibits the same trend as that of the relative abundance: prior the event of 1997-98, the relative abundance as well as the flux of G. oceanica are low, while they increase significantly during the mature El Niño period.

We explained in the manuscript (section 2.2 Coccolith census) that it has been shown that a good correlation exists between coccoliths relative abundance and coccoliths flux (Beaufort and Heussner, 1999), suggesting that these two parameters evolve in the same way. Such relation has been highlighted by Silva et al. (Silva et al., 2008) in

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Lisbon Bay (Portugal), where high flux of G. oceanica are found with high %G. oceanica. Moreover, we prefer use the relative abundance rather than concentration or flux of coccoliths, since the latter depend of dissolution and sedimentation conditions. Finally it is not possible to prepare quantitative slides on such extra small material, excluding the possibility to estimate coccolith fluxes.

5-The tuning of F. profunda with instrumental monthly summer sea surface temperatures in SBB, mainly based on the ecological study off Bermuda in the N. Atlantic (Haidar and Thierstein, 2001), also needs clarification..

Answer: we explained a little more in the manuscript that: Surface waters of the SBB become stratified and warm in the early summer (mid-June). This phenomenon strengthen through the summer until early fall (Lange et al., 1997). Florisphaera profunda prefers strongly stratified waters (De Bernardi et al., 2005; De Bernardi et al., 2008). De Bernardi et al. (2005) show that F. profunda presents high coccosphere fluxes in fall when the water column was stratified and the thermocline deep. This period correspond to the highest SST recorded in the SBB. Thus we decide to improve the age model by tuning high relative abundance of F. profunda of each year with the highest SST recorded in instrumental data of each year. These periods of high SST correspond roughly to the mid summer and the early fall. Results obtained by Haidar and Thierstein (2001) seem to corroborate our results.

6-It has been shown from time series sediment traps in SBB that F. profunda coccolith fluxes increase during ENSO conditions, when the water column is strongly stratified. It is in fact puzzling why in this paper this species doesn't increase its abundance during the last 30 years of warming

Answer: we agree with the reviewer and add this text, in section 4.3 20th century warming and increasing mass of coccoliths, to explain why: "We did not identify any increase of the relative abundances of tropical coccolithophore species in SBB between ~1917 and 2004, especially during the last 30 years (Figure 3a). The reverse is

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true for the cold species G. muellerae which did not exhibit a decrease of its relative abundances during the same period (Figure 3a). Coccolith assemblages are largely influenced by seasonality and El Niño. SST exhibits amplitude of ˜4°C during a normal year (mean SST amplitude throughout the year for the last century, calculated from the IRI/LDEO Climate Data Library; http://iridl.ldeo.columbia.edu) and a positive SST anomaly of ˜3°C during an El Niño peak in winter (IRI/LDEO Climate Data Library; http://iridl.ldeo.columbia.edu). The regional warming since the 1950s is maximally 1.5°C (Roemmich and McGowan, 1995). This long term SST increase is small in comparison to seasonal or El Niño-induced SST amplitudes and therefore is not clearly recorded in the relative abundance patterns of coccoliths."

COCCOLITH ASSEMBLAGES, HUMAN VERSUS AUTOMATED RECOGNITION

7-There are only very few previous studies on coccolithophores in the SBB and I missed a comparison with a recently published paper that is dealing with the coccolithophore response to the half century of interannual climatic variability in SBB using not an automated recognition software (SYRACO) but human counts (De Bernardi et al., 2008, Paleoceanography). This study is using previous sediment trap data from the same basin to interpret the core record. From this study, it is clear that the main signal is registered in the species flux change and not in the relative abundances.

Answer: we do not totally agree with this point of view. In De Bernardi et al. (2005), the signals carried by flux of G. oceanica and relative abundance of G. oceanica appears to have the same trend: both are low prior the El Niño event of 1997-98, while they increase significantly during the mature El Niño phase. Moreover, in De Bernardi et al. (2008), the relative abundance of G. oceanica increase for most of the El Niño event characterizing the last half century. Finally, Beaufort and Heussner (1999) showed that a good correlation exists between coccoliths relative abundance and coccoliths flux. And again it is not possible to prepare quantitative slides at this resolution.

8-The discrepancy of species percentages of the two counting methods (human versus

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SYRACO) needs to be considered (for example, the relative abundances of E. huxleyi and G. ericsonii). This latest small species (<2.5 micron) could not be so easily identifiable by the automated system since (the bridge crossing the coccolith central area needs to be identified using the rotating stage). Also, different E. huxleyi types with distinct morphological changes and coccolith carbonate quota are present and needs to be considered for the discussion.

Answer: SYRACO main error is that it includes non coccolith specimens in the counts, or to a lesser degree the system has difficulty to distinguish sometimes between the two species (small E. huxleyi and G. ericsonii for example), but this error is reproducible (Beaufort and Dollfus, 2004). In consequence we applied a correction coefficient to each species in order to take into account the addition of noncoccoliths produced by the software. This method has been successfully applied in (Grelaud et al., 2009). It is not possible to distinguish the different E. huxleyi type with SYRACO. But we do not know papers which do so in a paelostudy and in particular the Bernardi et al. (2008) does not approach that problem neither.

COCCOLITH ECOLOGY AND CARBONATE QUOTA IN SBB DURING THE 20th CENTURY WARMING

9-In the presented record the last 30 years warming shown by instrumental records is not shown in the coccolith ecology. A discussion on this should be considered (including the planktonic foraminifera response (Field et al., 2006, Science)).

Answer: this point had been tackled in the two first paragraphs of section 4.3 20th century warming and increasing mass of coccoliths. Moreover, the signal carried by the coccoliths assemblage is largely influenced by seasonality and El Niño. We therefore added this few sentence for clarification : "SST exhibits amplitude of ˜4°C during a normal year (mean SST amplitude throughout the year for the last century, calculated from the IRI/LDEO Climate Data Library; http://iridl.ldeo.columbia.edu) and a positive SST anomaly of ˜3°C during an El Niño peak in winter (IRI/LDEO Climate Data Li-

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brary; http://iridl.ldeo.columbia.edu). The regional warming since the 1950s is maximally 1.5°C (Roemmich and McGowan, 1995). This long term SST increase is small in comparison to seasonal or El Niño-induced SST amplitudes and therefore is not clearly recorded in the relative abundance patterns of coccoliths."

10-The increase in individual E. huxleyi and G. oceanica coccolith weight shown by the line regression (figure 5b page 4159) is intriguing. It is surprising the attempt to link these results with the warming, since no other ecological changes in the assemblages are observed.

Answer: southern California experienced an increase of at most 1.5°C since the 1950's. As we do not observed changes in coccoliths relative abundances during this period, we analyzed coccoliths morphometry in order to check the possible impact of warming on coccolithophores. As the increase of the mean weight of Isochrysidales follows that of SBB SST during the last century (Figure 5B), we hypothesized that SST warming could reinforce coccolithophores calcification.

11-In addition, there is a very high variability in the coccolith weight that needs a discussion. (lines 12-19)

Answer: We prefer discuss of long term variability of coccoliths mass rather than high frequency variability such as El Niño or PDO, but, we added a paragraph in section 4.3 stipulating that :"between the 1940's and the 1970's, weights of E. huxleyi and G. oceanica decreased (Figure 5a). This period corresponds to the cool phase of the PDO, which implies cooler SST along the North American Pacific margin. This aspect reinforces our supposition that warm SST is able to enhance Isochrysidales mass. In this context it is possible to suppose that high frequency variability in weight of E. huxleyi and G. oceanica during the 20th century could be linked to El Niño variability, with an increase of mass during warm episodes."

12-An increase in calcification rate (without an associated increase in organic carbon production) would increase the surface CO2 concentration, acting as a positive feed-

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back on CO2. Also note that the increase in coccolith calcite production would not necessarily be shown in more heavily calcified individual coccoliths (so no conclusions on calcite production and feedbacks can be claimed).

Answer: "The increase in coccolith calcite production would not necessarily be shown in more calcified individual coccoliths." If calcification increases but not the weight of a coccolith, it means that the coccolithophore produces more coccoliths. However, it has been shown that the number of coccoliths per coccosphere remains constant from the centre of the South Pacific Gyre to the Marquesas archipelago to the Peru-Chile upwelling (Beaufort et al., 2008). We supposed then that an increase in calcite production by coccolithophores will lead to an increase of individual coccolith weight. Finally and more importantly, we never discuss in this manuscript the "calcite production and feedbacks".

13-Since these results are based on an automated recognition it would be critical to check if the system didn't mislead differerent carbonate quota with a change in assemblages (for example E. huxleyi to small Gephyrocpasa spp.).

Answer: the estimate of morphometric parameters are realized with the files produced by SYRACO during species recognition. We estimated the inclusion of non-coccoliths or the confusion between different species (i.e. E. huxleyi and G. ericsonii). The bias linked to this "intrusion" is then limited when SYRACO analyzes morphometric parameters.

14-It is hard to conclude anything about G. oceanica ecology in this paper since the record has been tuned with the El Niño to obtain the high resolution age model.

Answer: we found that before tuning the %G. oceanica resemble the ENSO record. This is what was expected from the literature. We do not conclude much more.

15-There is no discussion on the coccolithophore response to the intensity of El Niño and PDO variability.

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Answer: we found that coccoliths are good marker of the event, but that the intensity of these event are more difficult to estimate, and we preferred to not enter into that problem in detail because of too much uncertainty.

Other remarks:

16-When the name of a species is mentioned at the beginning of a sentence it is conventional to write the full genus name (for example Emiliania huxleyi and not E. huxleyi).

Answer: it has been corrected.

17-Line 1-2 page 4131: ". . . coccolithophores consist of $<$10 micron calcareous plates" This is not correct since there are species such as C. pelagicus, and C. leptoporus, that could have a larger size

Answer: it has been corrected: 10 has been replaced by 20

18-Line 14: "southern species" should be changed with tropical species

Answer: the term has been changed.

19-Line 25, page 4138: Kincaid et al., 2000, doesn't present any coccolith data.

Answer: this reference was used here to highlight the stratification of surface waters during summer. The sentence was ambiguous and has been reworded as follow: "Florisphaera profunda's preference for stratified waters is well suited for the SBB during summer (De Bernardi et al., 2005) when its highest abundance is observed (Figure 3c) and when the SBB is well stratified (Kincaid et al., 2000)."

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