

Interactive comment on “The role of ocean acidification in *Emiliana huxleyi* coccolith thinning in the Mediterranean Sea” by K. J. S. Meier et al.

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Received and published: 10 March 2014

Major concern

I wonder if the data fully support the authors' major conclusion. i.e. (e.g. page 19715, lines 22-23): “This natural *E. huxleyi* assemblage shows a response to OA”. I find evidence in the dataset which are not in support of this conclusion.

Answer

We thank reviewer 2 for the critical review of our manuscript. We will address the points and be more open to possible other conclusions in the revised manuscript.

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Comment 1

Changes in carbonate chemistry conditions during the 13 years of deployment are extremely small. pH changes by 0.02 units, CO₂ by 1 $\mu\text{mol kg}^{-1}$, and CO₃²⁻ by only 7 $\mu\text{mol kg}^{-1}$ which seems to be too small to explain the prominent decrease in coccolith weight from 5 pg to almost 3.5 pg. Beaufort et al., (2011) report much smaller weight differences over the same CO₃²⁻ range.

Answer

See answer to comment 1 by reviewer 1. Natural assemblages are made up of different types, and therefore may have an element of ecological change along the physiological change. Changes in the relative abundance of types will then lead to a much stronger effect than the physiological response alone.

Comment 2

Measurements from November 1993 to April 1994 reveal similarly low coccolith weights as has been measured at the end of the deployment in 2006. Low weights were also found in summer 2000 and 2004 as well as autumn 2005. It is argued that the three low weight periods in the early 2000s are caused by unusual mixing events and can therefore be excluded. But this does not seem to be the case for the low weight period in winter 1993/1994. So why should these datapoints be excluded from the analysis? There is no sound explanation for that given in the text. If you include these data points in the analysis than there seems to be a fluctuation from low weight until 1994 to higher weight from 1994-2000 and back to low weight in 2000. A consistent negative trend can only be seen when excluding the 1993/1994 data.

Answer

The periods of low weight appear suddenly in the record, which implies that they are not driven by long-term developments. Therefore they must be excluded, if a long-term trend is investigated. Still, it may be, that the long-term weight decrease is caused by

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more frequent events that lead to the short-term disruptions. As a possible mechanism, more frequent deep mixing events are discussed. Temperature sensors from the trap have recorded a sudden temperature change also winter 1993/1994 (Heussner et al. 2006) that may indicate a deep mixing event at the beginning of the record. There are also earlier records of deep convection from winter 1991/1992 (e.g. Schott et al. 1996). See also answer to comment 2 by reviewer 1.

Schott, F., Visbeck, M., Send, U., Fischer, J., Stramma, L. and Desaubies, Y.: Observations of Deep Convection in the Gulf of Lions, Northern Mediterranean, during the Winter of 1991/92, *Journal of Physical Oceanography*, 26(4), 505–524, doi:10.1175/1520-0485(1996)026<0505:OODCIT>2.0.CO;2, 1996.

Heussner, S., de Madron, X. D., Calafat, A., Canals, M., Carbonne, J., Delsaut, N. and Saragoni, G.: Spatial and temporal variability of downward particle fluxes on a continental slope: Lessons from an 8-yr experiment in the Gulf of Lions (NW Mediterranean), *Mar Geol*, 234(1-4), 63–92, 2006.

Comment 3

Fluctuations in carbonate chemistry conditions are much more pronounced on a seasonal scale. CO₃²⁻, for example, fluctuates by almost 30 μmol kg⁻¹ from summer to wintertime which is four times more pronounced than the change from 1993 to 2006. Still, coccolith weight does not follow these fluctuations. In fact, it shows the opposite trend with higher weight at lower CO₃²⁻ concentrations.

Answer

The seasonal amplitude is larger than the long-term change in most environmental variables (see our Figure 7). *E. huxleyi* coccolith weight, pH and atmospheric CO₂ are the only two in which this is not the case. This is why we conclude that ocean acidification (i.e. pH decrease) is the most likely variable that causes the observed weight change.

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As stated before, seasonal coccolith weight changes may be in part a result of a seasonal change in the population. In the Aegean Sea (Triantaphyllou et al. 2010), heavily calcifying types of *E. huxleyi* occur in late winter/early spring, while lightly-calcifying types are present during the summer. This is very similar to what we observe here. The question is, whether these types are genetically different, or if they are ecophenotypic variations, i.e. whether there is an ecological cause or a physiological cause for the weight change. We cannot answer this question with our methods.

When looking for possible factor controlling this change, it seems that seasonally, the effect of coccolithophore productivity is stronger than the effect of the carbonate chemistry. The main production is in late winter/early spring, and this is when coccoliths are heaviest. On the long-term, productivity does not show strong fluctuations, and thus the effect of carbonate chemistry can be seen. This is already discussed in the manuscript, but we will highlight this more in the revised version.

Triantaphyllou, M., Dimiza, M., Krasakopoulou, E., Malinverno, E., Lianou, V. and Souvermezoglou, E.: Seasonal variation in *Emiliania huxleyi* coccolith morphology and calcification in the Aegean Sea (Eastern Mediterranean), *Geobios-Lyon*, 43(1), 99–110, doi:10.1016/j.geobios.2009.09.002, 2010.

Comment 4

The sediment core data support conclusions by Meier and co-workers because pre-industrial coccolith weight is consistently lower than it is today. However, this evidence seems to be too weak to allow such a critical conclusion. In fact, this conclusion should be backed up by the sediment trap data but this does not seem to be the case as outlined in 1-3.

Answer

Today's values coccolith weight values from the trap lie below sediment core (pre-industrial Holocene) values, and partly below surface sediment (industrial 20th century)

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coccolith weight. When comparing sediment data to seasonal data from the trap, one has to keep in mind, that the data points from sediment samples average over several years, from a few hundred in the pre-industrial Holocene, to 50-80 in the industrial 20th century sample. This cannot be directly compared to monthly samples from the trap. The average coccolith weight from the 12 years of the trap would be similar to the average value in the surface sediment. We see, however, that there is a trend over the trap deployment, that reaches values below this average.

Minor concerns

Abstract.

Lines 4-5.

“The release of several thousands of petagrams of carbon over a few hundred years will overwhelm the capacity of the surface ocean reservoirs to absorb carbon.” This is not fully correct. The ocean cannot be “overwhelmed” with carbon but will always equilibrate with the atmosphere no matter how high the atmospheric pCO₂ will become.

Answer

We will rephrase that sentence.

Line 9.

The term “calcification” should be specified. Do you mean calcification rates or coccolith weight? Please be precise on this throughout the whole manuscript.

Answer

The degree of calcification in coccoliths is defined as “primary variation in amount of biogenic calcite incorporated in a coccolith” (Young et al. 1997). It has been shown, that coccoliths produced from cells with a high calcification rate (i.e. calcite production over time) tend to have a higher degree of calcification and are thus heavier (Bach et al. 2012).

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Bach, L. T., Bauke, C., Meier, K. J. S., Riebesell, U. and Schulz, K. G.: Influence of changing carbonate chemistry on morphology and weight of coccoliths formed by *Emiliana huxleyi*, *Biogeosciences*, 9(8), 3449–3463, doi:10.5194/bg-9-3449-2012, 2012.

Young, J. R., Bergen, J. A., Bown, P. R., Burnett, J. A., Fiorentino, A., Jordan, R. W., Kleijne, A., van Niel, B. E., Romein, A. J. T. and Salis, von, K.: Guidelines for coccolith and calcareous nannofossil terminology, *Palaeontology*, 40(4), 875–912, 1997.

Line 24.

What is meant by coccolithophore production? Please specify.

Answer

This should be coccolithophore productivity.

Introduction.

Page 19703, Line 17.

Riebesell et al., (2000) investigated two different species but not two different strains.

Answer

We will delete that citation here.

Page 19703, Lines 17-23.

It is argued in this section that a particular haplotype is responsible for increasing calcification rates measured in some experiments. I think this description is overly simplistic. Things are probably much more complex than that (compare e.g. Iglesias-Rodriguez et al., 2008 and Hoppe et al., 2011).

Answer

It has recently been shown that the presence of a heavily calcified morphotype can largely influence the response of natural assemblages (Berger et al. 2014). We will

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focus the discussion on that and avoid implying that a single haplotype is responsible for different responses in culture.

Berger, C., Meier, K. J. S., Kinkel, H. and Baumann, K. H.: Changes in calcification of coccoliths under stable atmospheric CO₂, *Biogeosciences*, 11(4), 929–944, doi:10.5194/bg-11-929-2014, 2014.

Page 19703, Line 28.

Beaufort et al. (2011) did not measure calcification rates. The reference should not be used here.

Answer

Reference will be deleted.

Page 19704, Line 25.

“These oceanographic features. . . .” I think these are rather chemical than “oceanographic” features.

Answer

Will be changed to chemical.

Page 19704, Lines 24-26.

“These oceanographic features make the Mediterranean a natural laboratory to study the effect of anthropogenic acidification on calcifying organisms.” In fact, CO₂ invades the ocean not only in the Mediterranean. That is why it is misleading to call it a “natural laboratory”. Furthermore, the Mediterranean is a rather unrepresentative ocean basin to study the effect of OA on marine organisms because of its high total alkalinity. This sentence could be rephrased.

Answer

We will rephrase the sentence.

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Material and methods.

Page 19707, Lines 21-22.

“Missing measurements were replaced with values obtained from linear regression of the measurements from above and below.” I do not understand what is meant by “above and below”. Calculations of the carbonate system should be explained in more detail. They are not described particularly well in the current version of the manuscript.

Answer

We will rephrase that section. Please see also supplementary Figure 1 in answer to comment 1 by reviewer 3.

Results and discussion.

Paragraph 4.3.1.

The detection of a regular seasonal pattern in coccolith weight is highly interesting and deserves to be highlighted. The correlation between coccolith weight and nutrient/productivity patterns is also good enough to speculate that there may be a connection. I wonder, however, if the Authors could extend their discussion on this topic. Seasonality is a very broad term. What could specifically be responsible for the regular pattern. Are there different *E. huxleyi* populations with one dominating in spring/summer and the other dominating during autumn/winter time?

Answer

Yes, there might be. A study from the Aegean suggests the dominance of a highly calcified morphotype in winter/spring (Triantaphyllou et al. 2010). We will include this in the discussion.

Triantaphyllou, M., Dimiza, M., Krasakopoulou, E., Malinverno, E., Lianou, V. and Souvermezoglou, E.: Seasonal variation in *Emiliania huxleyi* coccolith morphology and calcification in the Aegean Sea (Eastern Mediterranean), *Geobios-Lyon*, 43(1), 99–110,

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doi:10.1016/j.geobios.2009.09.002, 2010.

Paragraph 4.3.2. Page 19714, Lines 12- 18.

“ The SSA analysis conducted on this data, coccolith weight and other environmental data reveals significant trends only for coccolith weight and carbonate system parameters, whereas temperature, nutrients, and salinity present a limited variability (Fig. 7). Therefore, the most likely cause for the observed mass loss of *E. huxleyi* coccoliths is the observed change in surface water carbonate chemistry.” I wonder why changes in carbonate chemistry are the most likely cause for the observed decrease in weight? There can be many other parameters (which have not been measured in this study) which can explain the decreasing trend.

Answer

Yes, this is true, and we will mention possible alternatives, e.g. light, turbidity.

Paragraph 4.3.1.

See major concerns.

Answer

see answers before

Interactive comment on Biogeosciences Discuss., 10, 19701, 2013.