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Comment

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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We thank Jorijntje Henderiks for her helpful and critical review. We don't share her enthusiasm on the possibilities of an in-depth statistical analysis, as there is considerable co-variance between the variables, which are all inter-related to a large part. However, we will demonstrate this in the revised manuscript and provide some statistical analysis for our description of the seasonal succession of environmental variables and coccolith weight response.

Comments

Statistical treatment of the data

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(1) The authors need to clarify (1) how they interpolated values for data gaps due to lack of sample availability, and how they dealt with the data gaps created by themselves, by selecting out certain time intervals of “low counts” and “extremely low average weight” (these data are shown in Fig. 2, but omitted in the Supplementary database).

Answer

Interpolation was done in the same way for both the environmental and weight data. As stated in the manuscript, small gaps of up to three months were filled by linearly interpolating between the values before and after the gap. For longer gaps, this could have the disadvantage of creating a linear filling, where a curve would be more appropriate. Therefore, as a basis, the 12-year average of all measured data for the months in the gap was used. However, these average values may not fit into the specific year and would cause a sudden rise or drop compared to the values before or after the gap. Therefore, a correction factor was calculated. For this, the data for the months before and after the gap were compared to the 12-year average values. We have created a new supplementary figure and changed the text in the manuscript accordingly to make this point clearer.

(2) The authors describe the relationships between abiotic factors and *E. huxleyi* mass – by visually evaluating smoothed data and single spectrum analysis (SSA) of the raw data series. This is another major concern: the manuscript lacks any statistical testing of covariation/correlation between the presented time series. For example, statements like “oceanographic features of the NW Mediterranean Sea are well reflected in the weight and length of *E. huxleyi* coccoliths collected by the sediment trap investigated here (Fig. 4).” (p. 19711, section 4.3), and “The seasonal variability in temperature, salinity, nutrient concentration, and the carbonate system parameters is clearly expressed in both the raw measurements and the SSA extraction of the seasonal signal (Figs. 4 and 5)” (same page, l. 11-13), are not substantiated by statistical tests, determining covariation/correlation, but by wordy descriptions of how various parameters “possibly” relate to coccolith length and/or mass (or, rather how previous studies have

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interpreted results).

Answer

In general, I can understand a call for statistical testing. However, the sentence “The seasonal variability in temperature, salinity, nutrient concentration, and the carbonate system parameters is clearly expressed in both the raw measurements and the SSA extraction of the seasonal signal (Figs. 4 and 5)” picked out by reviewer 3 to demonstrate the lack of statistics is a bad example. This sentence needs no testing. There is a clear seasonal variability in the parameters, which can be seen in the raw data (Fig. 4), and in the ssa extraction of the seasonal signal (Fig. 5).

(3) Plotting paired boxplots comparing the latest 2,5 yrs to the decade prior to these, in Fig. 6, may summarize the pooled data, but doesn’t constitute a valid test either.

Answer

These plots are not meant as a test, but have been done in order to compare the only two time periods in which actual carbonate system measurements were available. For everything else we provide the SSA analysis.

(4) Bottom line: all parameters investigated show seasonal patterns and inter-annual variations – the question is how each of these relate to another in this particular, very interesting data set. The fact that seasonal (month-to-month) variations in physico-chemical parameters are much larger than the inter-annual variations calls for an in-depth analysis of these, before jumping to interpreting the “long-term” trends (which, in the end are cooked down to (12-yr) “trends from the SSA”, Figure 7).

Answer

We agree, that statistical testing is important for the validation of our findings. However, the in-depth analysis of the seasonal variation is not the topic of our manuscript. As we are interested in the long-term trend, we have to get rid of the seasonal variation. This is done statistically with a SSA, which decomposes the seasonal and long-term

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trend. Figure 7 shows that in most parameters the seasonal variation is larger than the long-term trend, except for atmospheric CO₂ and pH. This is the basis of our main conclusion, that ocean acidification, i.e. decreasing pH, is the most likely cause for the observed long-term weight change.

Adding statistics on the seasonal variation would not help get rid of the “wordy descriptions”, as there is considerable co-variation between the data. This makes it necessary to discuss the seasonal succession of events that lead to the observed weight patterns. The correlation between the data can be seen by just looking at the data (Fig. 5 shows the seasonal signals). We have now added a figure for the correlation between the parameters in our time series (Suppl. Figure 2).

However, in time series a direct correlation of the variables may not be correct, a a lagged response may occur. Therefore we have also calculated a cross-correlation between the variables, which show that correlation may be improved if a lagged response is assumed. This can be seen in a PCA analysis (gradients are short, which is why a RDA is not advisable) on the combined seasonal and trend signal from the SSA (Suppl. Figure 3).

The question why the seasonal variation is larger than the long-term trend can be answered by a change in *E. huxleyi* morphotypes during the year. See answer to comment 3) by reviewer 2.

Missing out on alternative interpretations?

(5) The information that was culled from the final data analysis (“low counts” in years 2000, 2004 and 2005) may indeed reveal some very interesting clues on ecological dynamics in addition to (seasonal) abiotic influences on *E. huxleyi* (see Fig. 2 and p. 19709, l.16-29). Could this time series potentially reflect an overall “regime” shift after the summer of 2000, as mean weight and size became overall lower/smaller and you infer “decreased seasonality” (yellow bars in Fig. 2) since then (and not before)? The frequency of such “disturbance” periods is arguably increasing. What were the

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conditions at the start of the trap deployment, 1993/94, when you record similarly low counts? Could we be looking at some threshold/step changes, rather than a “long-term trend” as implied in your conclusions? Also, please define what you deem the “normal” seasonal development of *E. huxleyi* in this area (p. 19710, l. 5-13).

Answer

Temperature measurements at the trap show a drop during mixing events. There is a temperature drop in winter 1993, indicating a deep mixing event (Heussner et al. 2006). Taking this into consideration, it seems that also the low count/low weight values at the beginning of the record are due to an event. These events clearly become more frequent, and only small and lightly calcifying morphotypes of *E. huxleyi* are left in low numbers during and after these events, while diatoms seem to benefit from these conditions. The “normal” seasonal development can be seen in years with no events. It is possible, that a regime shift in the phytoplankton community towards a diatom dominated system will affect the *E. huxleyi* population composition. We will discuss this in the revised version.

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.

Minor points and recommendations (at this stage non-exhaustive)

(6) “Thinning” of *E. huxleyi* coccoliths (p. 19709, l. 1-15). In order to substantiate your conclusion that *E. huxleyi* is becoming lighter in mass through “thinning” (rather than size decrease alone), you could calculate the theoretical shape factor ($ks = \text{mass}/(2.71 \cdot \text{length}^3)$; cf. Young and Ziveri, 2000) for each sampled population and show these data either as an additional time series and/or cross plots.

Answer

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As the length data is binned in 0.15 μm intervals due to the methodological restrictions this is not advisable.

(7) Abstract Shorten. Focus on the fact that this study offers a (unique) 12-yr sediment trap-derived time series from the Mediterranean (Gulf of Lions), what's special about the Mediterranean, and your main findings. Most of lines 1-16 could be integrated in the Introduction (you already do).

Answer

An abstract should also give some rationale for the study, which we do in lines 1-16.

Figures

(8) Fig. 3: rephrase: "coccolith concentration vs. total mass flux in the trap material." Reading the figure caption alone, it is not clear what the point of this comparison is (section 4.2. Sediment transport, explains a sediment resuspension argument). Nor is it clear what is meant by the grey "intervals". The phrasing "indicating small influence of mass flux on coccolith weight" raises the questions "why would it?" and "is this a plot of coccolith weight, or coccolith concentration (as on y-axis)?"

Answer

There is an error in the caption. The caption will be rephrased to make it more understandable.

(9) Very hard to read all the details contained in Figure 4. I also prefer the "seasonal" data presented in Fig. 5 over those in Fig. 4 Right-hand side. I understand the latter holds all the raw scatter and additional water depths for some parameters, but this is not explained in the caption (nor discussed in the text). You highlight the period Feb-May in Fig. 4, but not in Fig. 5 – what is the rationale (interpretation) behind the highlights? May want to explain this in the caption as well.

Answer

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The data from different water depths shows that the main variability is in the upper water column, where most of the haptophyte production takes place (see text). The period from Feb-May highlights the period, where coccolith weight reaches the maximum.

Figure 5 is very informative on the monthly (seasonal) AND interannual variations (through the annual deviations from the 12-yr mean).

(10) Fig. 6: shows paired box plots, comparing data from different segments of the time-series; before August 2003 (from Dec 1993; 10 yrs, 8 months of data) and after (until Dec 2005 (or Jan 2006?); 2 yrs, 4-5 months). This is not time series analysis, but a comparative approach to illustrate average shifts in the distribution of data (mean and variance). I am not convinced that the comparison between a decade vs. 1/4 decade worth of data is a fair comparison.â€

Answer

This Figure is necessary in order to compare the available data. The time intervals were chosen due to the availability of the carbonate system data, of which only two periods of measurements exist. All further analysis is based on the averaged time-series, with filled gaps, and the calculated carbonate system. We think that the comparison of “real” data with the processed series is important in order to show that there is no artificial error in the processed series.

(11) Fig. 7: Comparing and correlating long-term trends is very different from actual time series analysis (see e.g. Hannisdal et al., 2012; Reitan et al., 2012). Again, this representation of data leaves the authors (and readers) only with visual speculations, no statistical test of the relationships between the various parameters in these SSA plots.

Answer

Single spectrum analysis is a statistical method method for time-series analysis. Please see Golyandina and Korobeynikov (2014) on how exactly the analysis was

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done. For our purpose of decomposing the trend from the seasonal signal this method is sufficient.

Golyandina, N., and Korobeynikov, A.: Basic Singular Spectrum Analysis and Forecasting with R, Computational Statistics and Data Analysis, 71, 934-954, doi: 10.1016/j.csda.2013.04.009, 2014.

(12) Fig. 8: This is a nice overview figure (note that the blue shading for the pre-industrial Holocene range is not visible in b&w print). However, what is your explanation (or point) for the overlapping range between the pre-industrial Holocene and the mean weight values during 1994-1999 (clearly part of Industrious Times and CO₂ values 355-370, according to Fig. 7)? It is interesting that the most recent trap samples reveal even lower mass than the Gulf of Lions Recent sediments. However, data from 1993-1994 revealed similarly low values (but are omitted here – compare Fig. 2A).

Answer

See answer to comment 4 by reviewer 2.

Captions for Figures:

Supplementary Figure 1: Gap filling methods. A theoretical environmental variable over the course of a year with two gaps (May to June and October) is shown (blue line with squares). Short gaps were filled by linear interpolation (green dashed line). Where a linear interpolation would be inappropriate, the 12-year average (red line with circles) was used and adjusted for the specific year. The difference between the measurements and the 12-year averages were calculated for the months before and after the gap ($\Delta_{\text{before gap}}$, $\Delta_{\text{after gap}}$, orange triangles). The slope between these values was used to calculate correction values for the values in the gap (open triangles). These were added to the 12-year average values in order to obtain the gap filling (green line and diamonds).

Supplementary Figure 2: Correlogram showing correlation coefficients between vari-

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ables from the time series (average of upper 50 m water column). Lower panel shows pie diagrams with positive (blue) and negative (red) correlation. Upper panel gives the exact values with 95% confidence interval below. *E. huxleyi* coccolith weight shows small correlation with pH, atmospheric CO₂, phosphate, temperature and nitrate. Only the correlation with pH and atmospheric CO₂ are statistically significant (see P-values in Supplementary Table 1).

Supplementary Figure3: PCA of the combined seasonal and trend data from the SSA. The first PCA axis explains 62% of the variance, the second axis 31%. The data clusters in months (represented by grey numbers), and the arrows point into the direction of the maximum values. The main coccolithophore production season from February to May is marked in green. At the beginning of the season, nutrients and [CO₂] are highest, while temperature, [CO₃²⁻] and Ω Calcite are lowest. A two month lag between these initial conditions and the maximum in coccolith weight is observed.

Please also note the supplement to this comment:

<http://www.biogeosciences-discuss.net/10/C9144/2014/bgd-10-C9144-2014-supplement.pdf>

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

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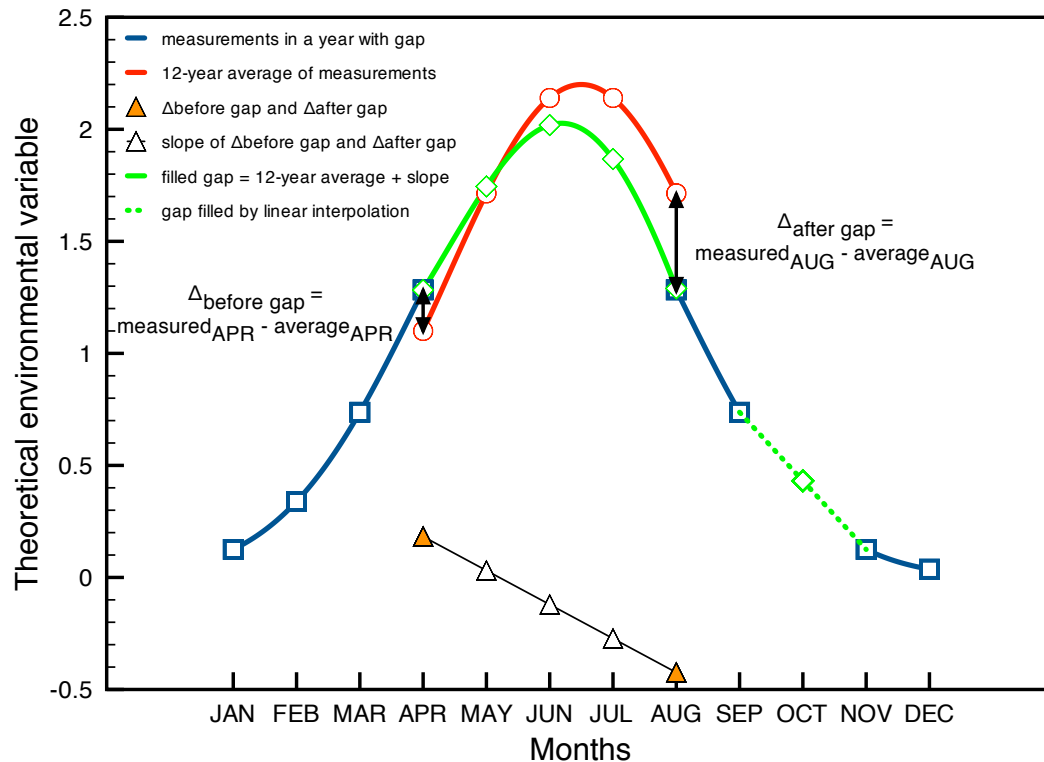


Fig. 1. Gap filling methods.

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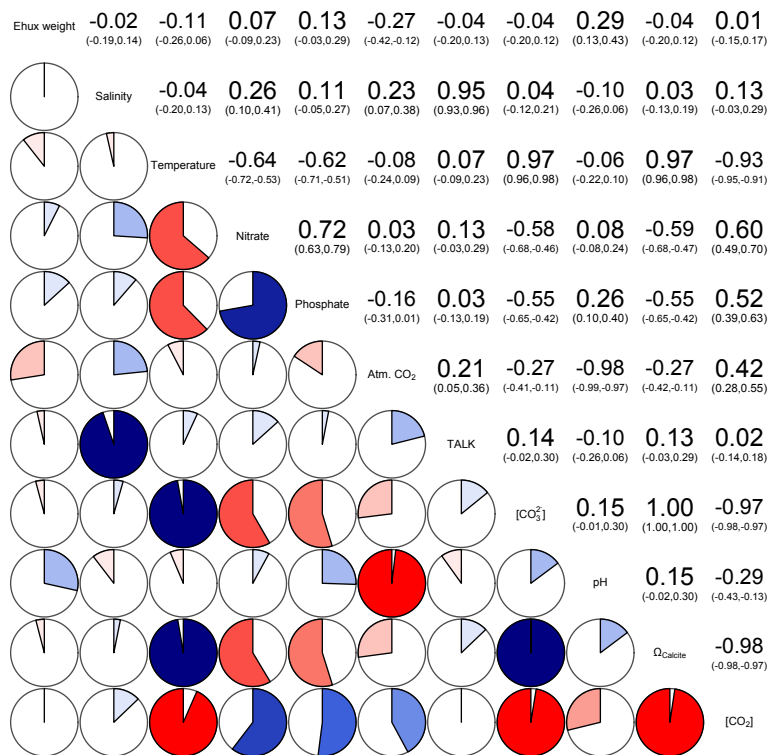


Fig. 2. Correlation matrix.

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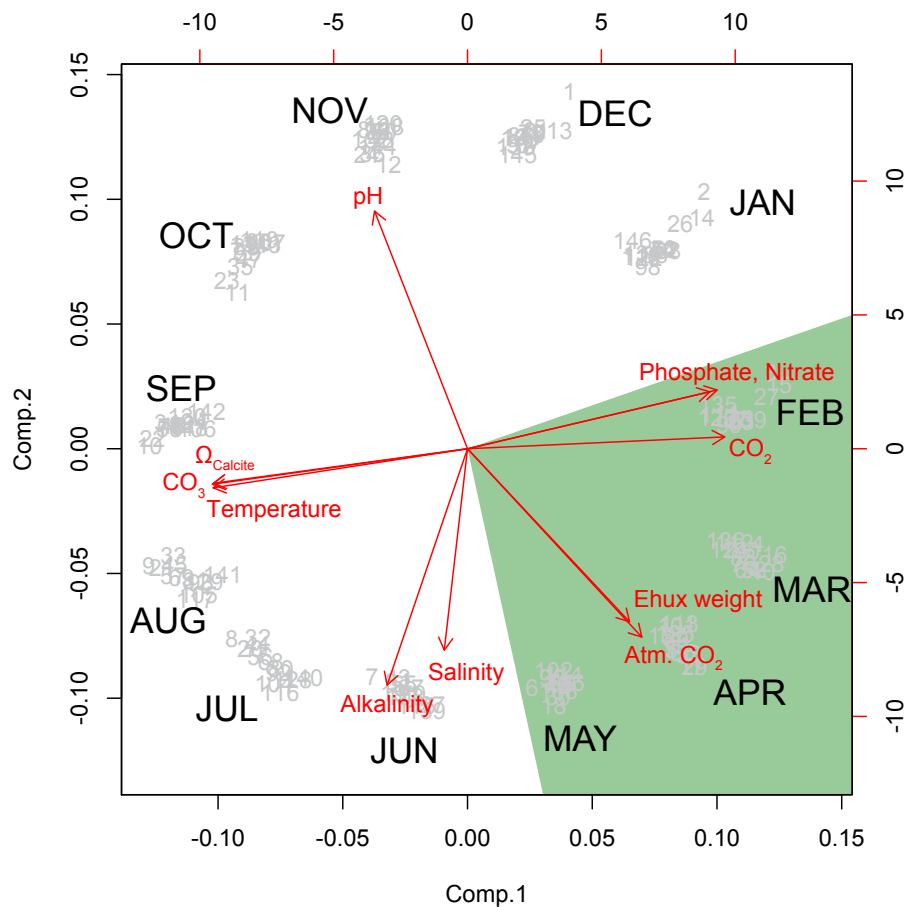


Fig. 3. PCA of the combined seasonal and trend data from the SSA. The first PCA axis explains 62% of the variance, the second axis 31%.

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