Paper: “A model-data comparison of the Holocene global sea surface temperature evolution” by G. Lohmann, M. Pfeiffer, T. Laepple, G. Leduc, and J.-H. Kim, Clim. Past Discuss., 8, 1005-1056, 2012. www.clim-past-discuss.net/8/1005/2012/ doi:10.5194/cpd-8-1005-2012

Response to the reviewer 1

First, we would like to thank the reviewer for the useful and constructive comments. We respond to the three reviewers’ major comments.

1) **Linear regression**

The reviewer suggests to test whether a linear model is appropriate to describe the shape of the Holocene trends. This is a good and sensible suggestion, as the insolation changes are not linear in time, and nonlinear reactions of the climate system might additionally cause deviations from a linear evolution across time. As the reviewer suggested, we analyze the residual plots (standardized residuals of the fit relative to the fitted values) of all sediment records for the alkenones (Figs. 1-3) and Mg/Ca (Fig. 4), as well as the corresponding AOGCM time-series (Figs. 5-8).

In the sediment records, some cores, for example alkenone record BS79-38, show deviations from linearity. This is especially true for alkenone records and less pronounced for the Mg/Ca records. One cannot exclude that this occurs by chance as the alkenone residuals are autocorrelated in time, a point we will later discuss. Across the cores, no clear common pattern in the deviations from linearity is visible which would ask for a non-parametric analysis (Figs. 1-4). We further tested if other parametric models as polynomial models are more appropriate than our linear model: Whereas a polynomial model, as expected, results a higher explained variance, no relation between the deviations from linearity was found in the GCM and the proxies. In the case of fitting a second order polynomial, the nonlinear terms between model and data are uncorrelated.

We therefore continue to favor the linear model. While we acknowledge that this is not a perfect description of the climate response, the linear models provide a good metric to summarize the main behavior, and as we use the same metric for the GCM and the proxy results, potential deviations from linearity would not bias the results. We included a subsection in the results section.

As we mentioned before, these analyses also show, that the residuals are not independent in time for the alkenone records. This is expected, as elements of the climate system, especially the oceans provide some memory. Further, the recording process, as mixing of the sediment by bioturbation, might further increase the autocorrelation. In the revised version, we therefore account for serial correlation by estimating the effective degrees of freedoms $N_{eff} = N(1-r)/(1+r)$, where r is the lag-1 autocorrelation coefficient of the residuals.

2) **Uncertainties in the SST trends**

The serial correlation increases the uncertainty of the slope estimates, especially for the Uk37 records. These recalculated confidence intervals for the slope estimates will be included in the revised manuscript (former Figs. 1 and 2). Because the panels were rather small in the old Fig. 1, we plan to split the former Fig. 1 into 3 sub-figures which are here shown as Figs. 9-11. The figures for the time series include the slope estimates for Alkenones (Figs. 9-11) and Mg/Ca (Fig. 12) and will be included in the revised paper.

Analogous to Figs. 9-12, we display the model data at the core locations where we include the trends plus standard error (Figs. 13-16). Figs. 13-16 show that the uncertainty in the simulated SST trends is very small. As proposed by the reviewer, we include the uncertainty in the trend analysis, by adding error bars in the former CPD Figure 4a,b. These errorbars are shown in Fig. 17 for alkenones and Fig. 18 for Mg/Ca, to be included in the revised paper.

To consider the uncertainties in the SST trends in the model-data comparison, we calculate the weighted correlation between model and proxy data trends, as suggested by the reviewer. The Pearson correlation coefficients were calculated for annual, local winter, and local summer trends. The weights were calculated with $1/sd^2$, where sd is the standard error of the slope in the proxy SSTs. The weighting of the trends with their uncertainty increases the positive correlations between simulated and observed trend patterns in all cases except for local summer where correlation is nearly unaffected by the weighting (table). The significant negative correlations for Mg/Ca and model trend needs to be evaluated in detail in a subsequent study.

	Alkenones		Mg/Ca	
	R	R weighted	R	R weighted
Annual mean	0.45, $p<0.05$	0.53, $p<0.05$	-0.28, $p>0.05$	-0.18, $p>0.05$
Local winter	0.14, $p>0.05$	0.25, $p>0.05$	0.17, $p>0.05$	0.38, $p>0.05$
Local summer	0.44, $p<0.05$	0.42, $p<0.05$	-0.56, $p<0.05$	-0.74, $p<0.05$

3) Model deficiencies

We agree with the reviewer that current climate models have a coarse vertical resolution and crude representation of subgrid-scale processes of the ocean and would like to mention the difficulty of ocean models to properly simulate the seasonal dynamics and mixed layer. In order to get an estimate of the mixed layer depth, we compare the modeled mixed layer depth in the control climate simulation (Fig. 19) with ocean reanalysis data (Fig. 20). The mixed layer depth of the model (HOPE-G) was calculated following the temperature criterion as described in Levitus (1982), which defines the mixed layer as the depth at which the temperature change from the surface temperature is 0.5°C. The same method was used for calculating the mixed layer depth of the ocean reanalysis data (SODA, Carton and Giese, 2008; Carton et al., 2005). Before the calculation of the mixed layer depth, the observational data were vertically interpolated to the HOPE-G model depths. We see similar large-scale pattern in the model and SODA, but also deviations especially in the Southern Ocean. We will insert some cautionary remarks into the new version of the manuscript and emphasize that the representation of the mixed layer will be essential to improve climate simulations and data-model comparisons.

Furthermore, we evaluated the ocean model component of ECHO-G in simulating the seasonal cycle in SST for the core locations (Figs. 21-23, Fig. 24). Again, we split them in different panels: one panel for data located where alkenones have positive trends (Fig. 21), and two panels for those with negative trends (Figs. 22,23), and Fig. 24 for Mg/Ca locations. The black lines represent the modeled seasonal cycle, while the red represent the observational SST seasonal cycle. For the analysis of the model data, we used the last 50 model years of the preindustrial climate simulation and for the observational data we used the full time period (1958-2001). For consistency, we analysed the 10m depth level in both datasets as SST.

We find a general agreement in the shape of the seasonal cycle, but detect a cold bias in the model, especially at high latitudes. We assume that the trends will not be seriously affected by this offset, but will mention in the revised version that deviations in the mean climate state are detected in the model. Parts of this offset could be related to the preindustrial control simulation as compared to present SSTs which are affected by the anthropogenic induced CO_2 increase. At some locations, the ability to simulate the seasonal cycle seems to be limited, especially in the tropics (e.g. in Fig. 21: 52°E,11°N; 11°E,6°S; 82°E, O°S). The result will be used to discuss the ability of climate models to simulate SSTs in the past.

Minor comments:

1) Is rephrased in the revised version
2) Rephrased: “In order to fulfill minimal statistical requirements,“ is not necessary, just deleted
3) Corrected
4) Thanks, done
5) Done
6) Adopted
7) Rephrased as suggested
8) We would like to avoid showing model-data SST difference divided by the model SST trend. We prefer to directly compare the SST trend in the data and model. We adopted your formulation.
9) Rephrased, we want to explain that the median is a better measure than the ensemble mean. We shortened the paragraph.
10) Clarified. Seasonal bias.
11) Done. Related to lines 25-27: we changed the formulation now.
12) We think that we are already criticizing the work directly, especially the pre-selection of proxy-records prior to the correlation estimation.
13) Done
14) We reformulated it. The proxy would record a weaker temperature signal.
15) Done

16) We clarified the sentence and changed the order to make the logical clear.

17) Done

18) Reformulated

19) Done

20) We reformulated orbital forcing. Since obliquity provides the high-low latitude pattern and since precession forcing is zero on the annual mean, we reformulate the sentences.

21) Done

22) Done

23) OK

24) Done

25) Corrected

We update the figures and analyses, and have inserted the comments in the revised manuscript.

References:

Carton, J. A. and Giese, B. S. : A Reanalysis of Ocean Climate Using Simple Ocean Data Assimilation (SODA), Mon. Weather Rev., 136, 2999-3017, 2008.

Carton, J. A., Giese, B. S., and Grodsky, S. A. (2005): Sea level rise and the warming of the oceans in the SODA ocean reanalysis, J. Geophys. Res., 110, art# 10.1029/2004JC002817, 2005.

Levitus, S. : Climatological Atlas of the World Ocean, NOAA Professional Paper 13, U.S. Department of Commerce, 1982.

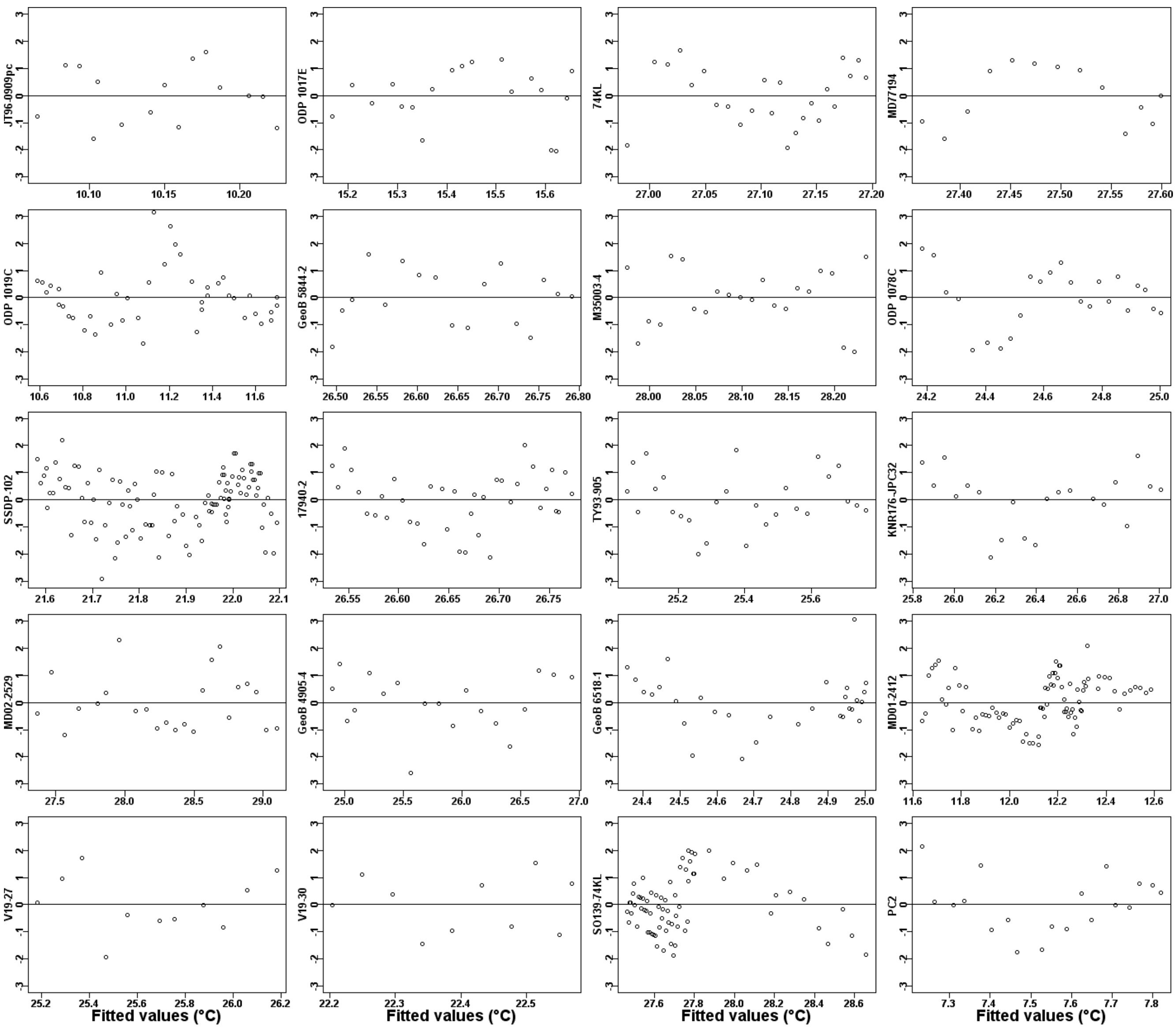

Fig. 1: Standardized residuals of the alkenones plotted against the fitted values at every alkenone core location where the trend is positive.

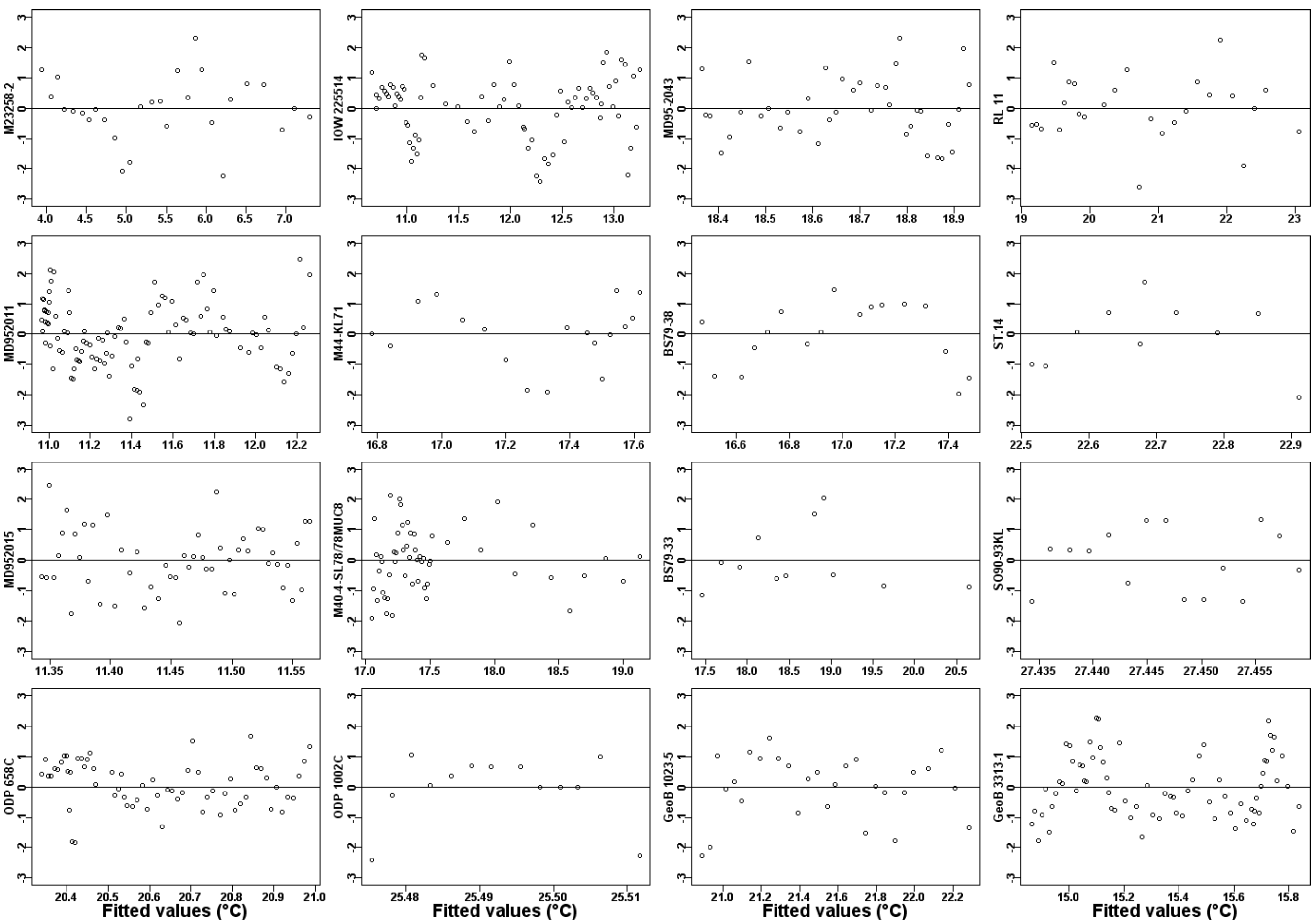

Fig. 2: As Fig. 1, but for the alkenone data where the trend is negative.

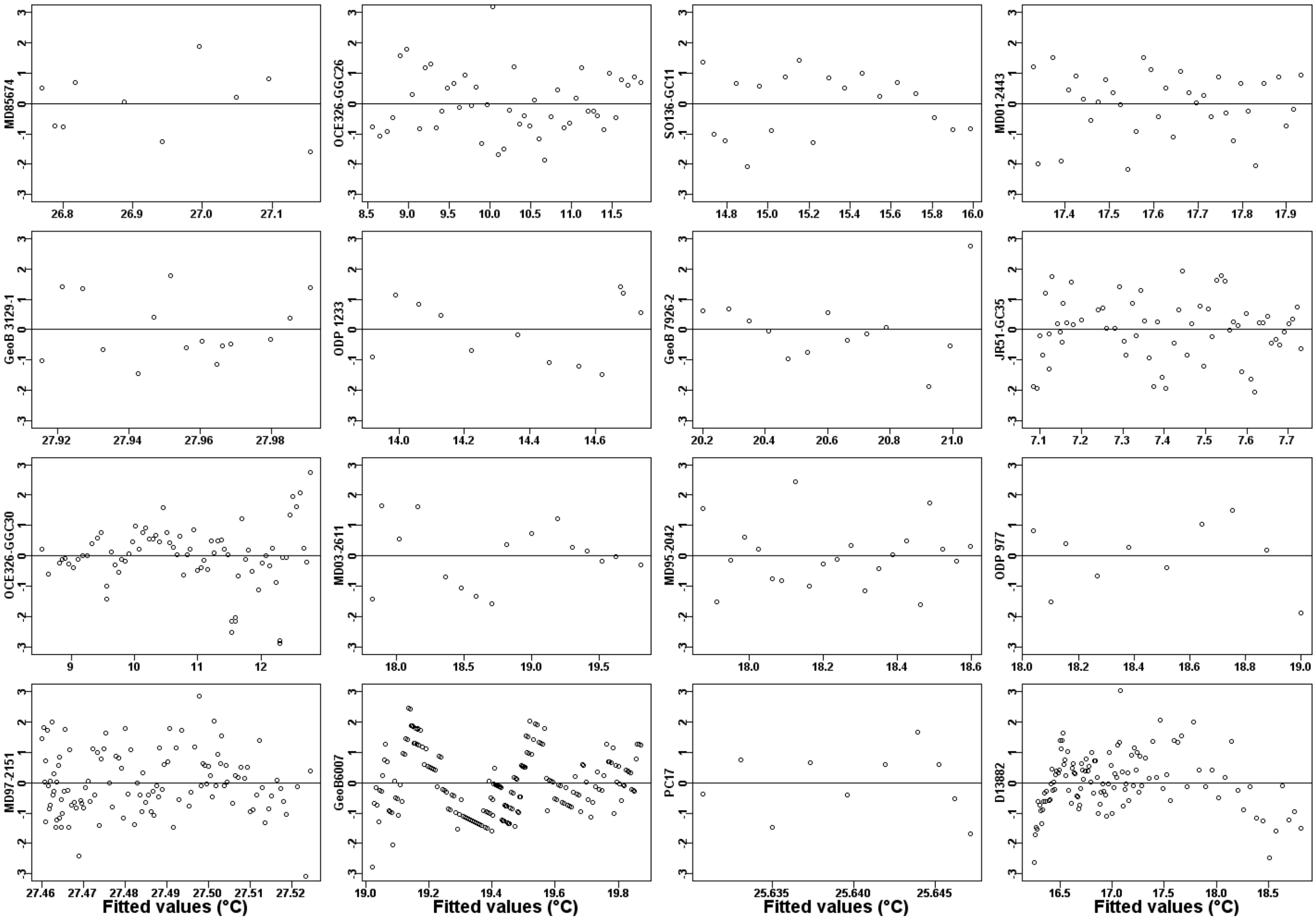

Fig. 3: As Fig. 2, for the remaining cores with negative trends.

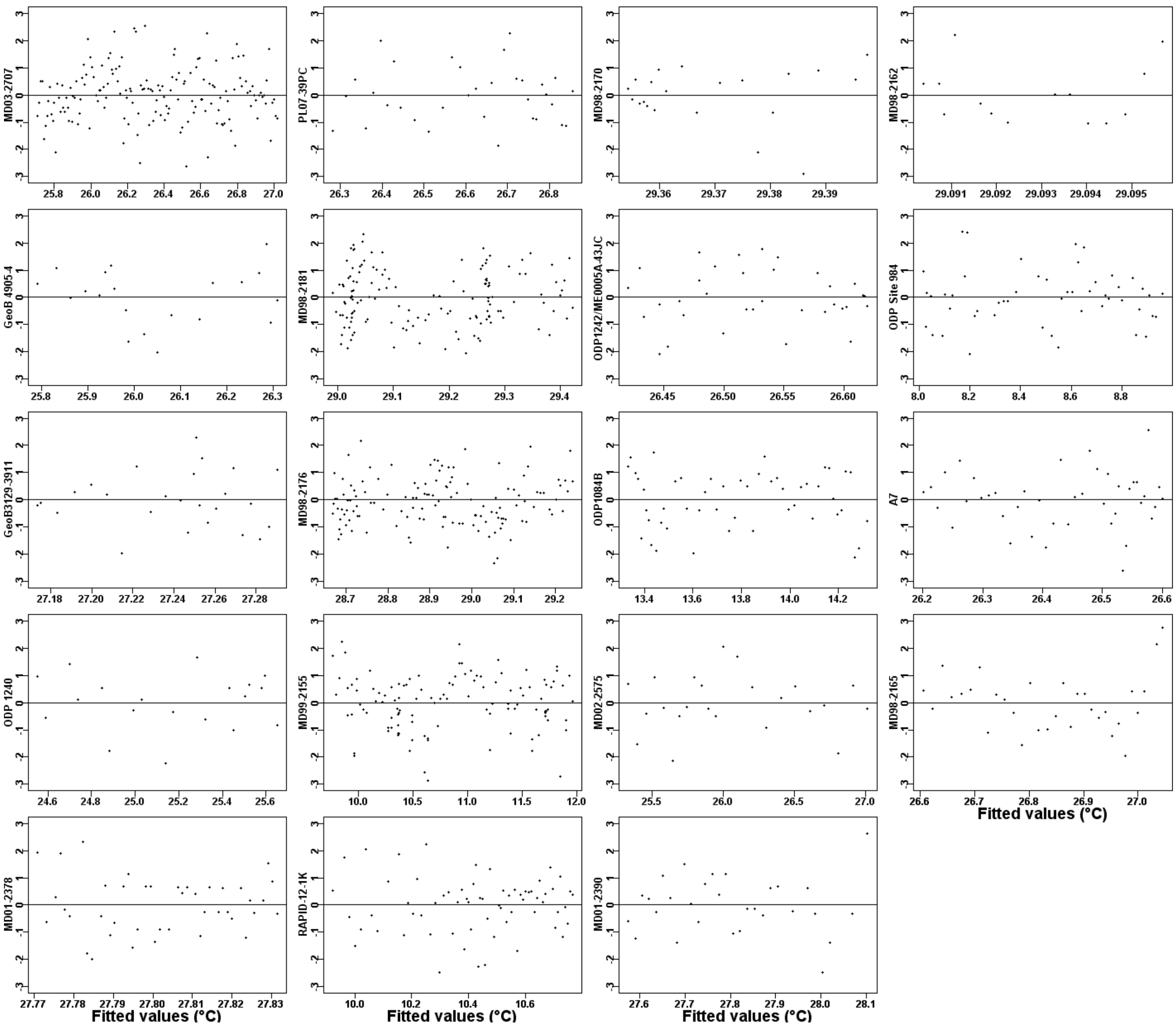

Fig. 4: Standardized residuals of the Mg/Ca plotted against the fitted values at every Mg/Ca core location.

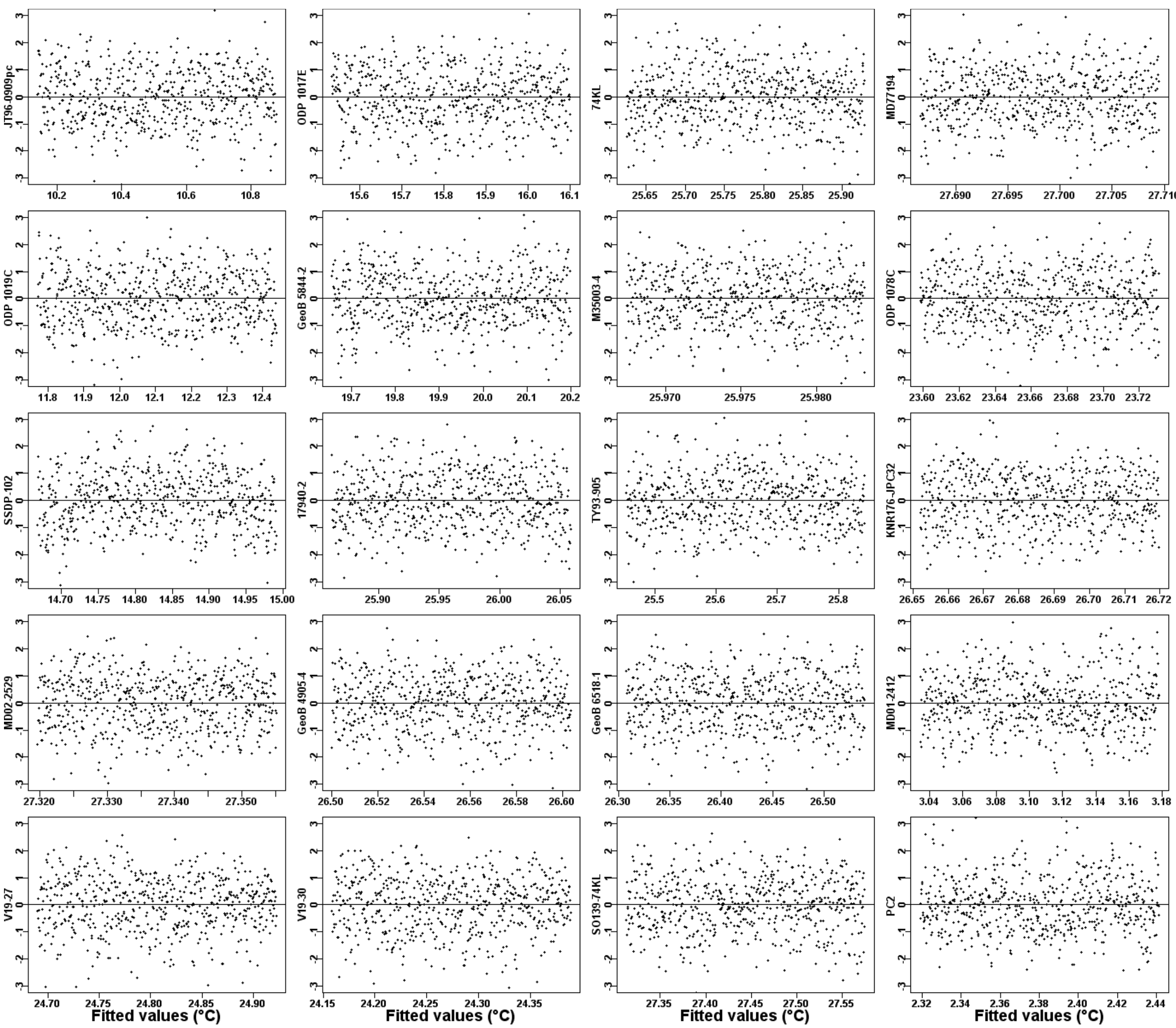

Fig. 5: Standardized residuals of the model at the location of the alkenones where the trend is positive plotted against the fitted values at every alkenone core location (cf. Fig. 1).

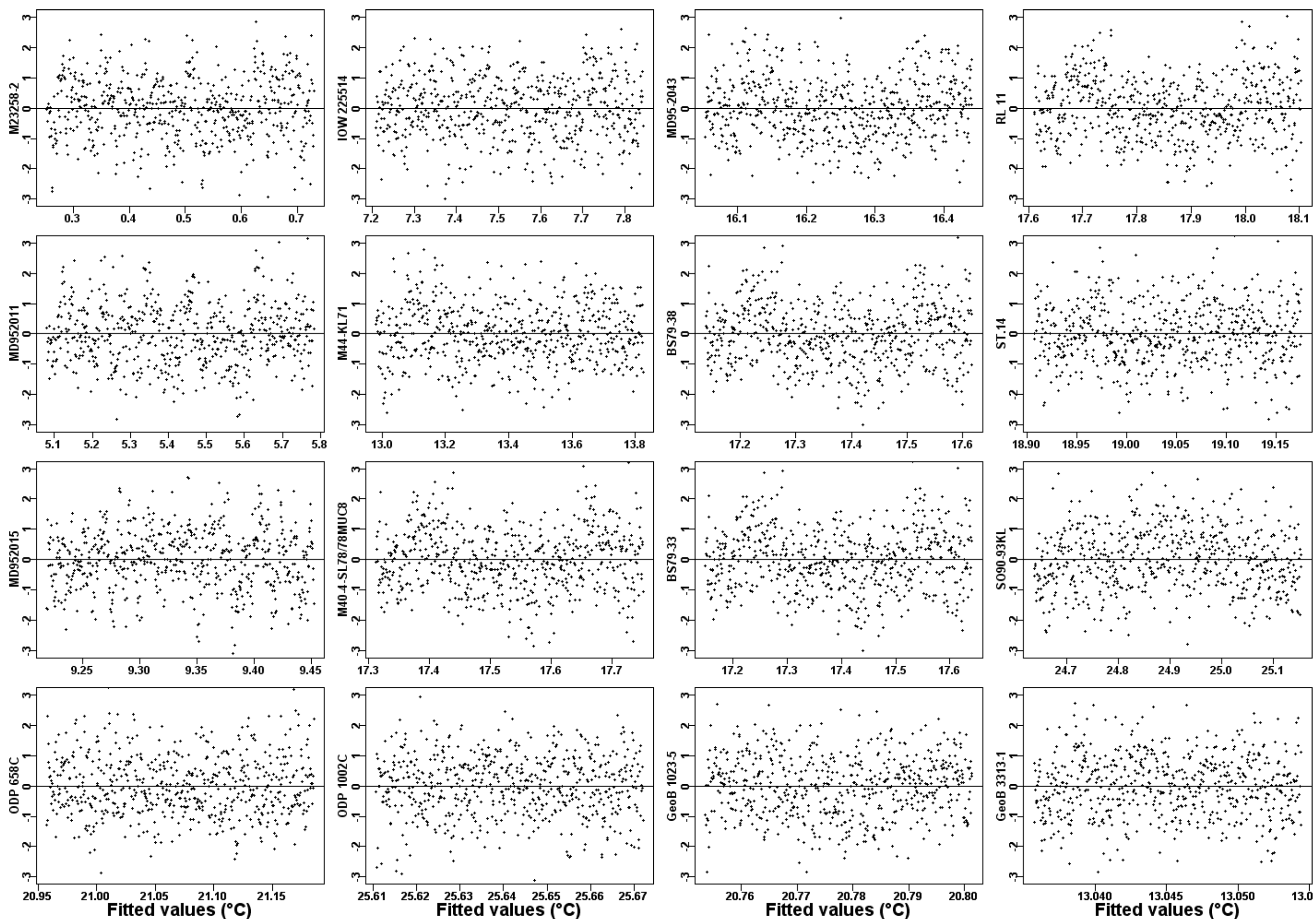

Fig. 6: Standardized residuals of the model at the location of the alkenones where the trend is negative plotted against the fitted values at every alkenone core location (cf. Fig. 2).

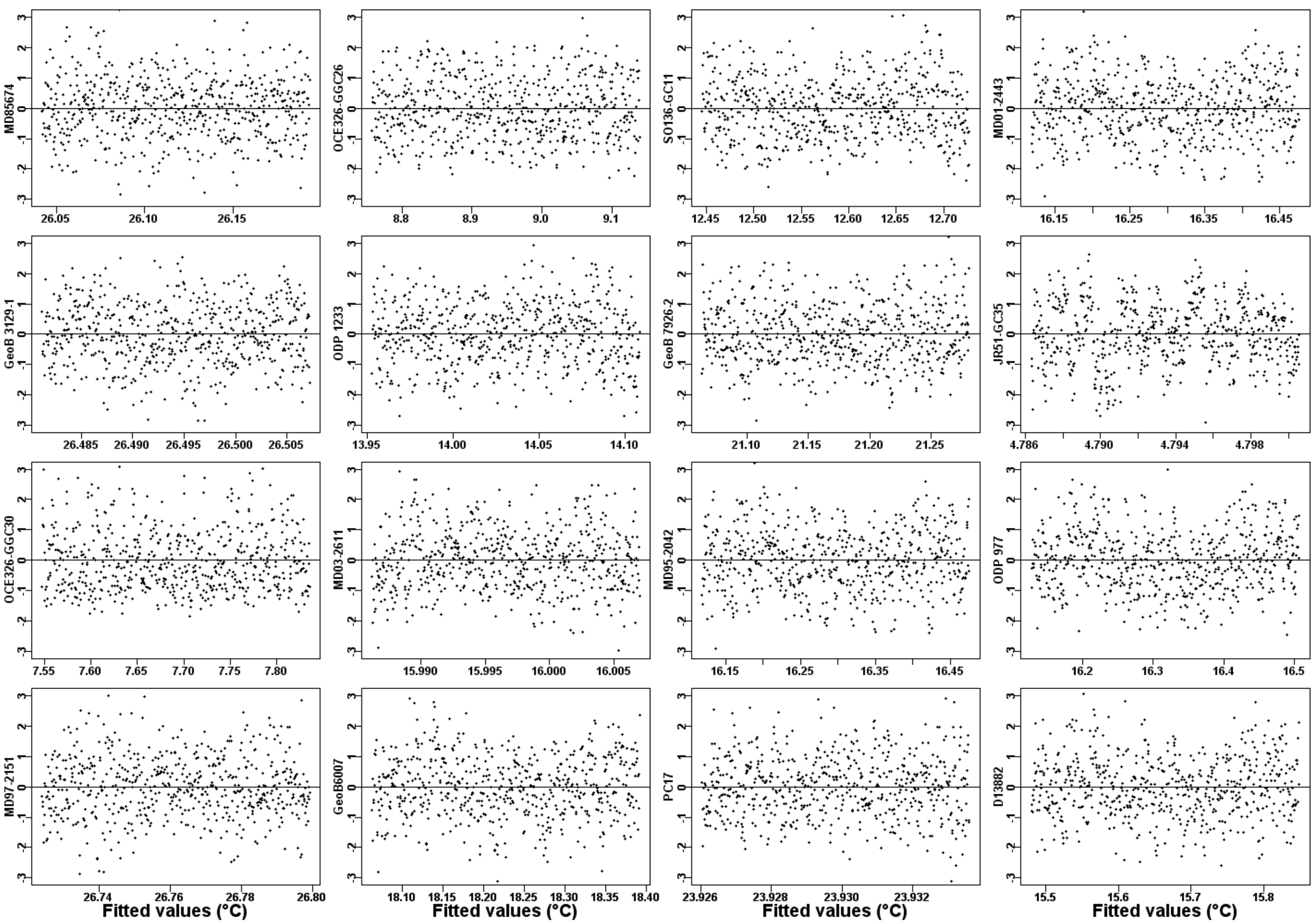

Fig. 7: Standardized residuals of the model at the location of the alkenones where the trend is negative plotted against the fitted values at every alkenone core location (cf. Fig. 3).

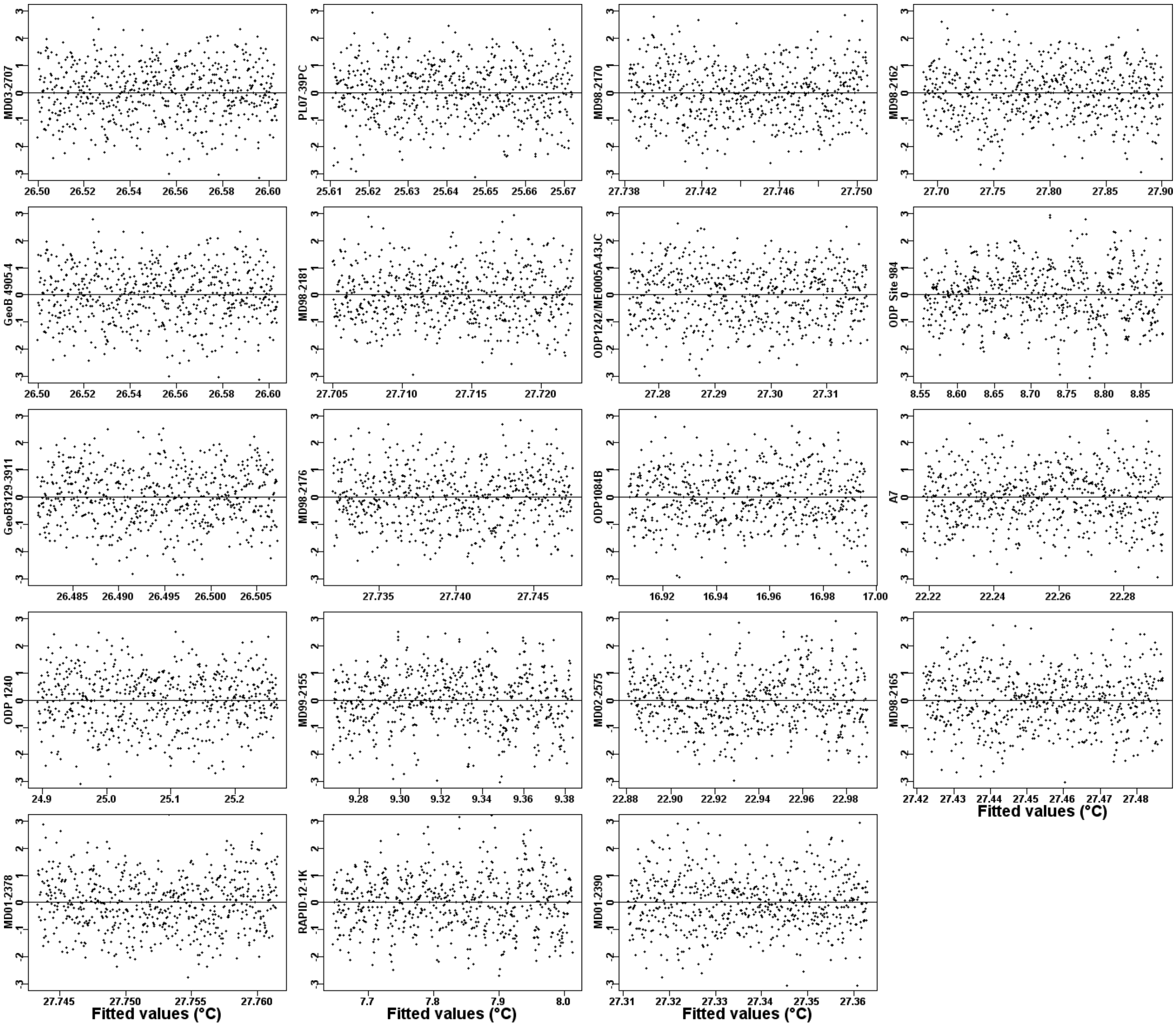

Fig. 8: Standardized residuals of the model at the location of the Mg/Ca plotted against the fitted values at every Mg/Ca core location (cf. Fig. 4).

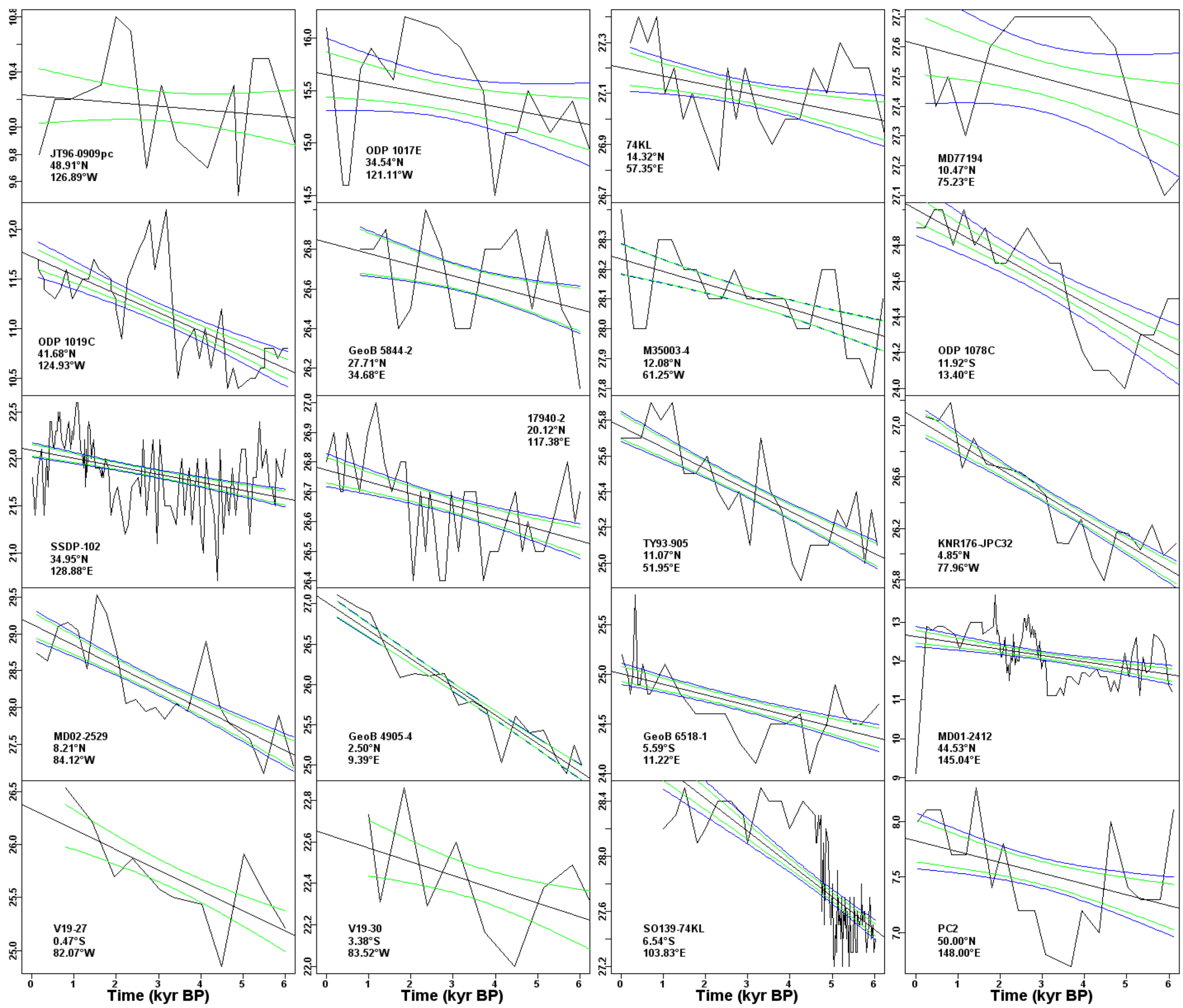

Fig. 9: Alkenones timeseries with positive linear trends and their standard errors (part of Fig. 1 in the CPD paper). The blue curved lines represent the standard error that account for serial correlation, the green ones represent those not accounting for serial correlation.

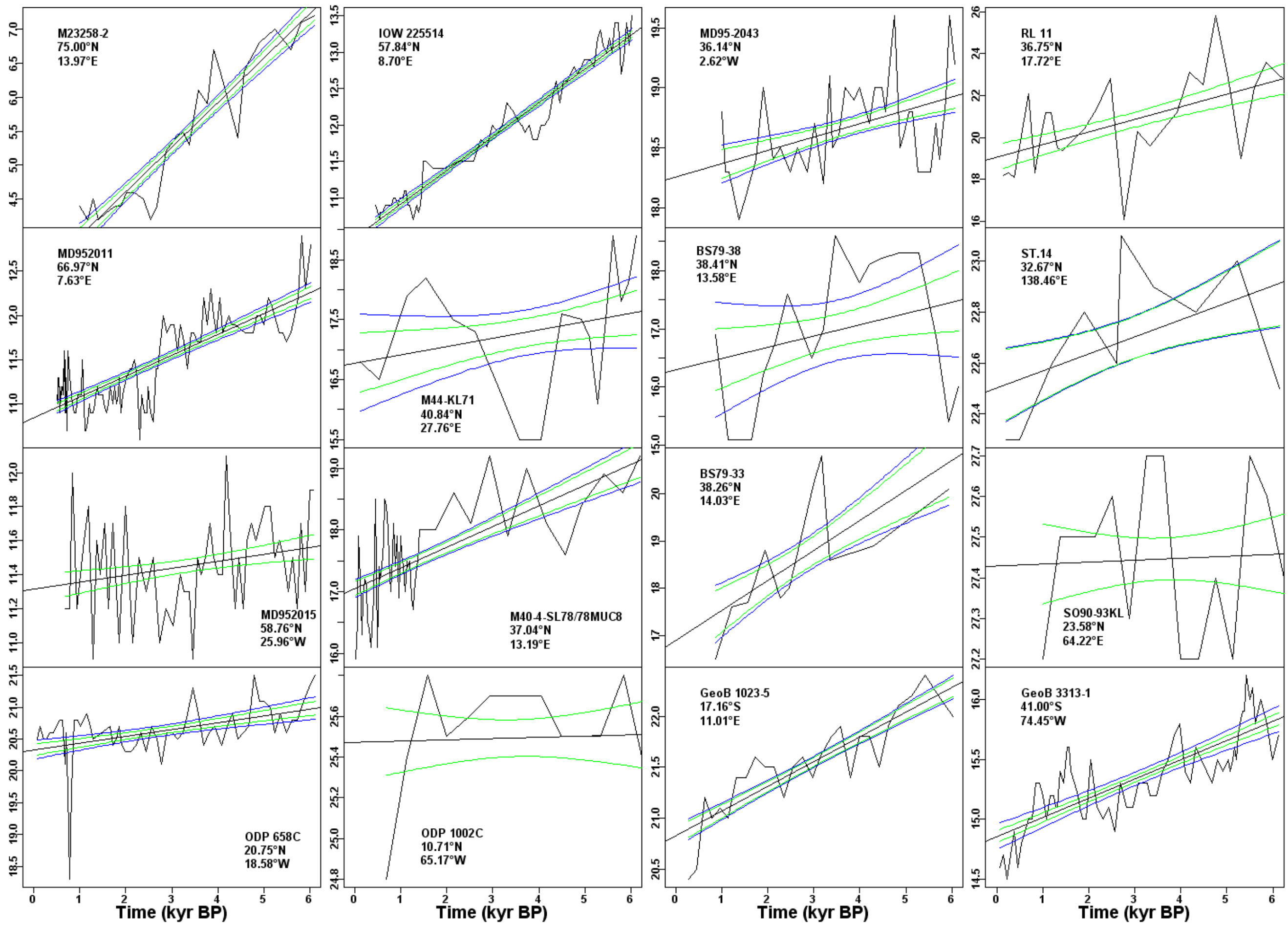

Fig. 10: Alkenones timeseries with negative linear trends and their standard errors.

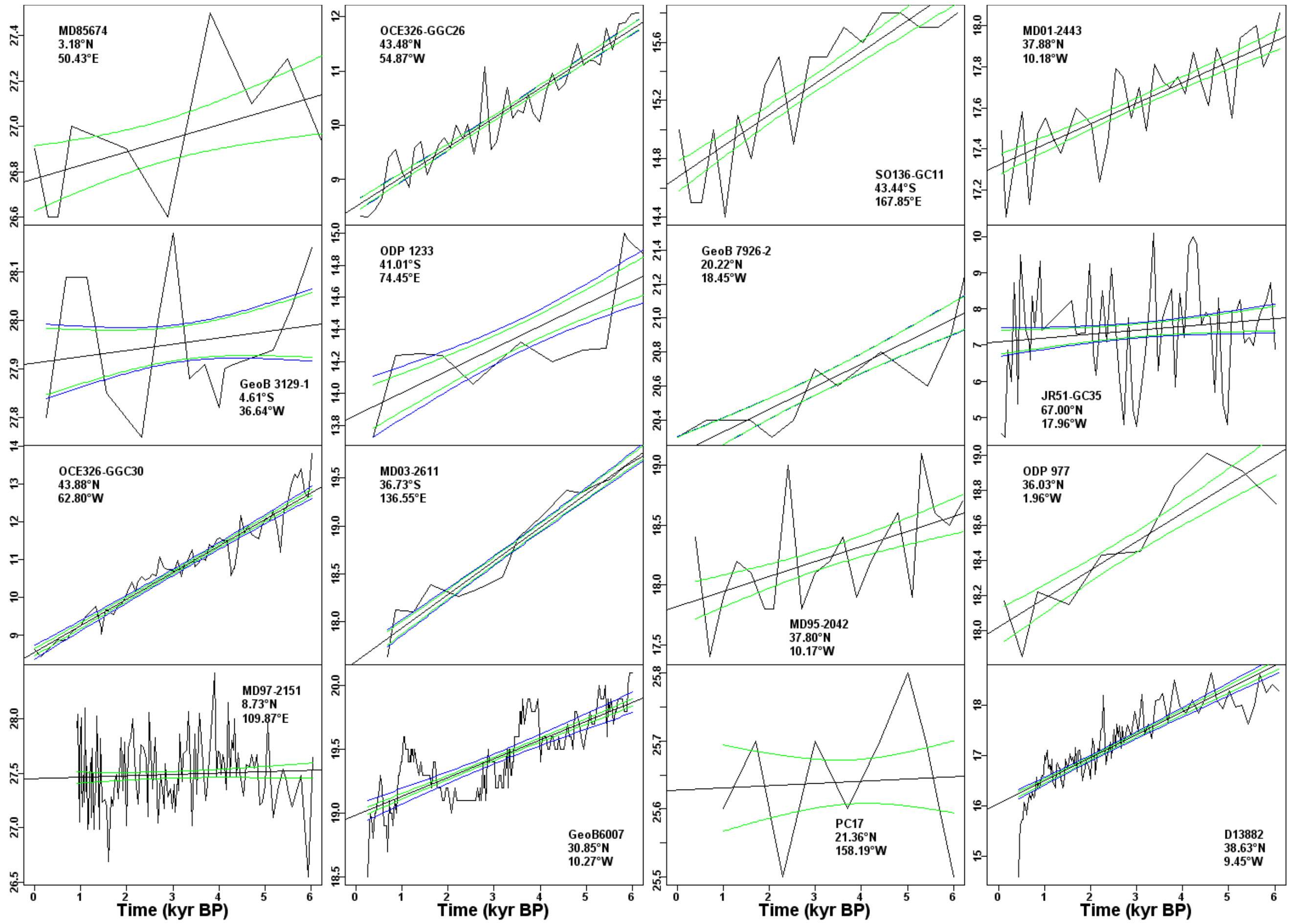

Fig. 11: Continued, as Fig. 10.

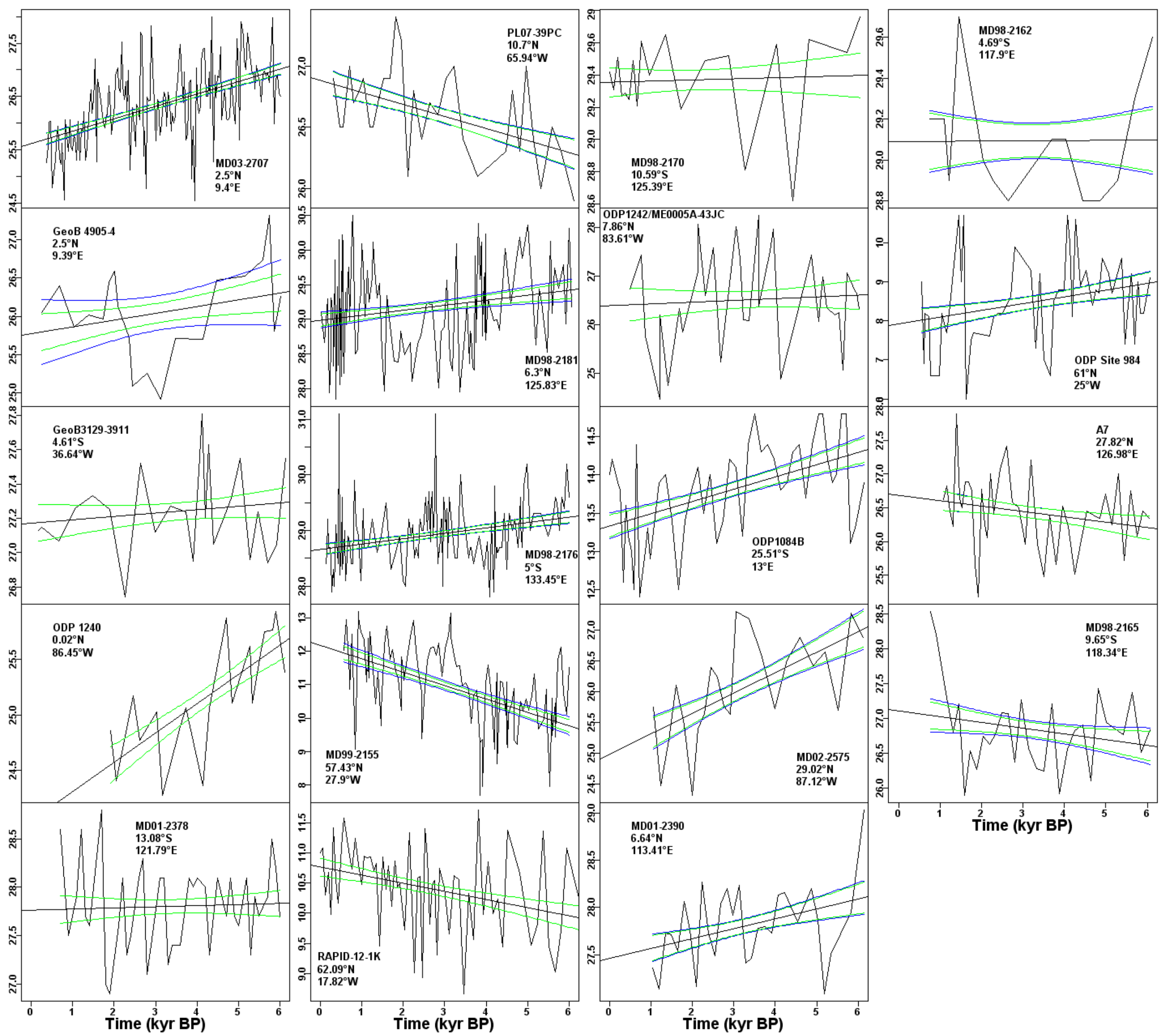

Fig. 12: Mg/Ca timeseries including the linear trends and their standard errors (old Fig. 2 in the CPD paper).

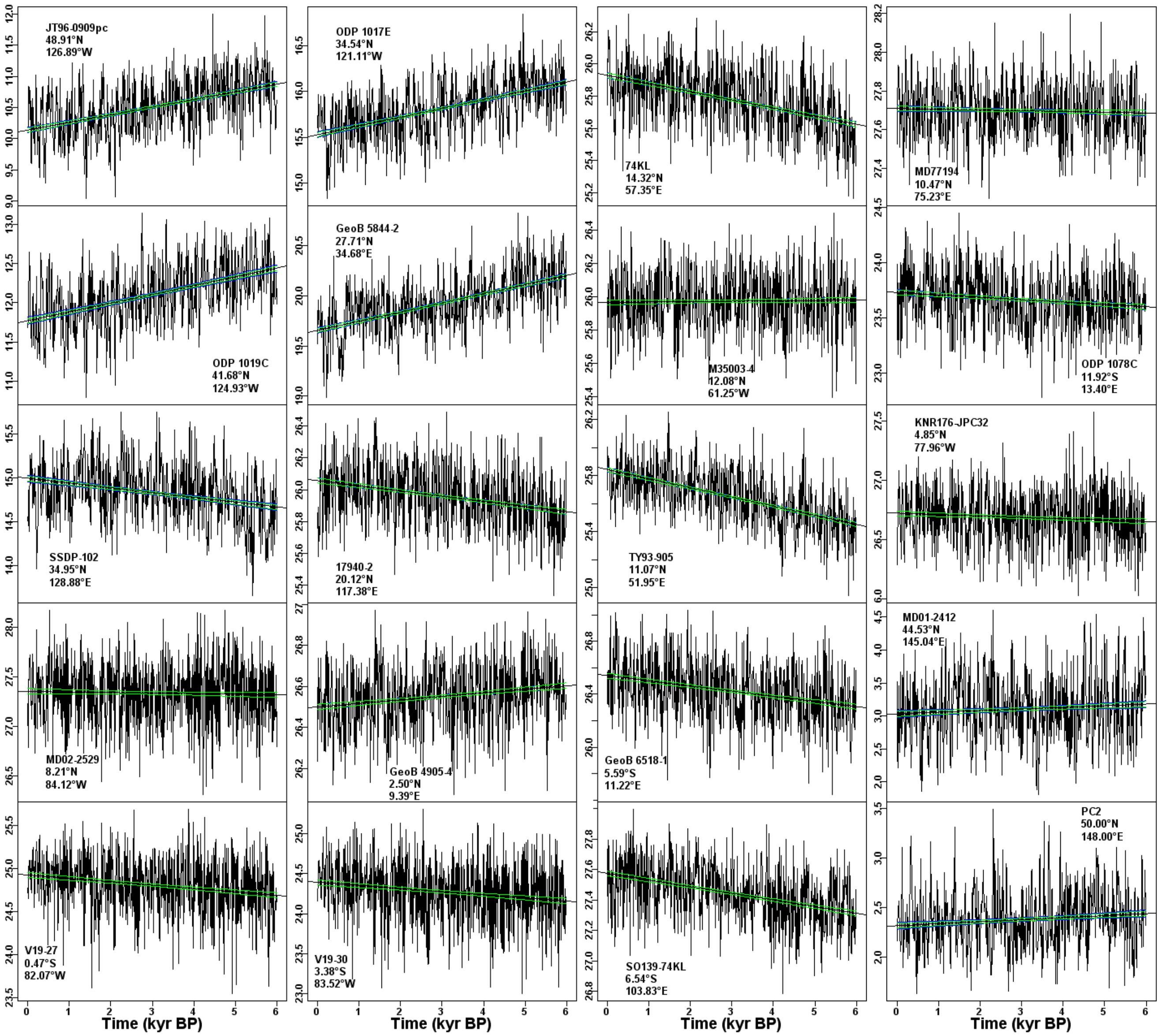

Fig. 13: Model timeseries at the location of the alkenone proxies (that show a positive trend), linear trends and their standard errors (cf. Fig. 9).

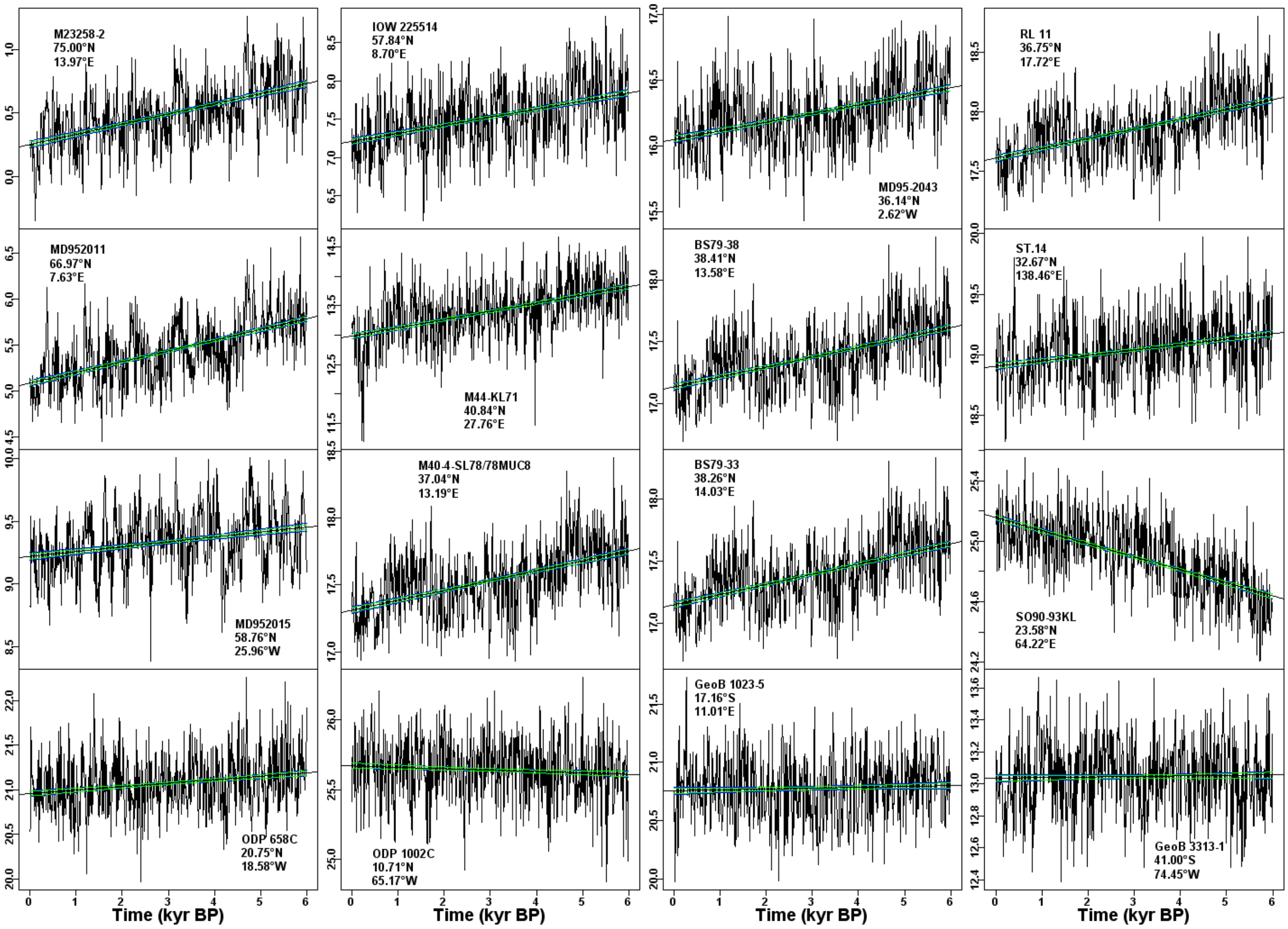

Fig. 14: HOPE-G model timeseries at the location of the alkenone proxies (that show a negative trend), linear trends and their standard errors (cf. Fig. 10).

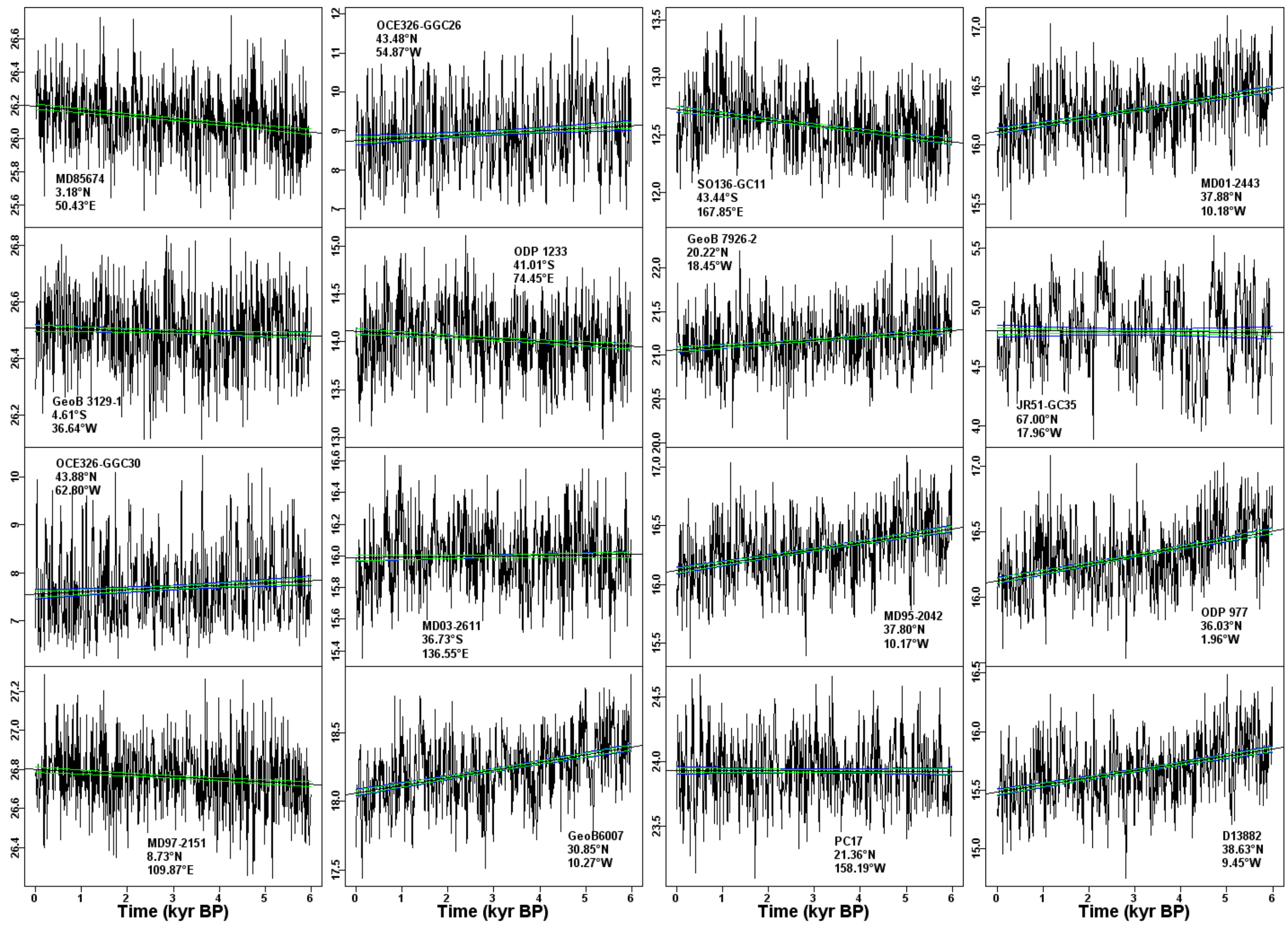

Fig. 15: continued on Fig. 14 (cf. Fig. 11).

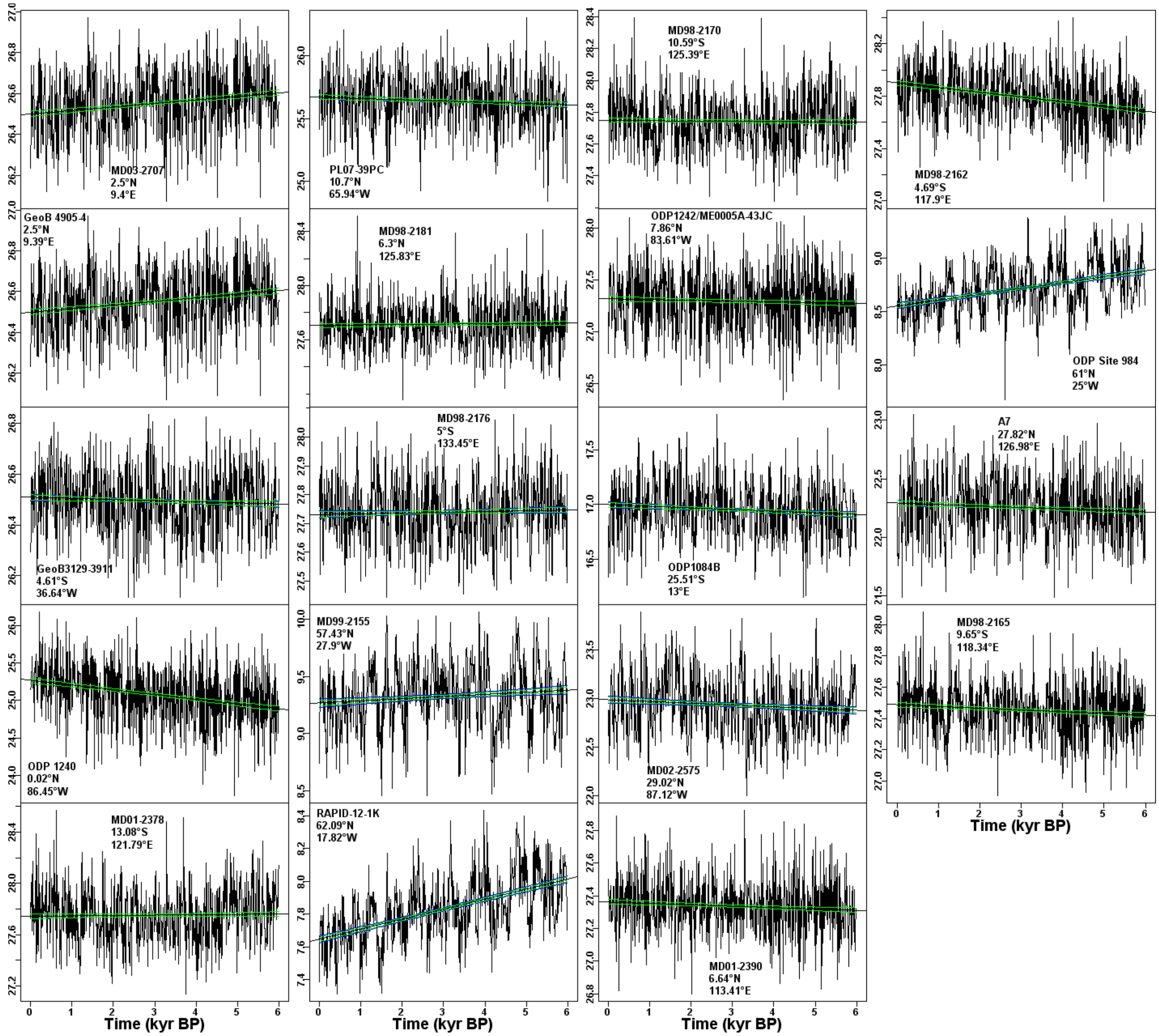

Fig. 16: HOPE-G model timeseries at the location of the Mg/Ca proxies, linear trends and their standard errors (cf. Fig. 12).

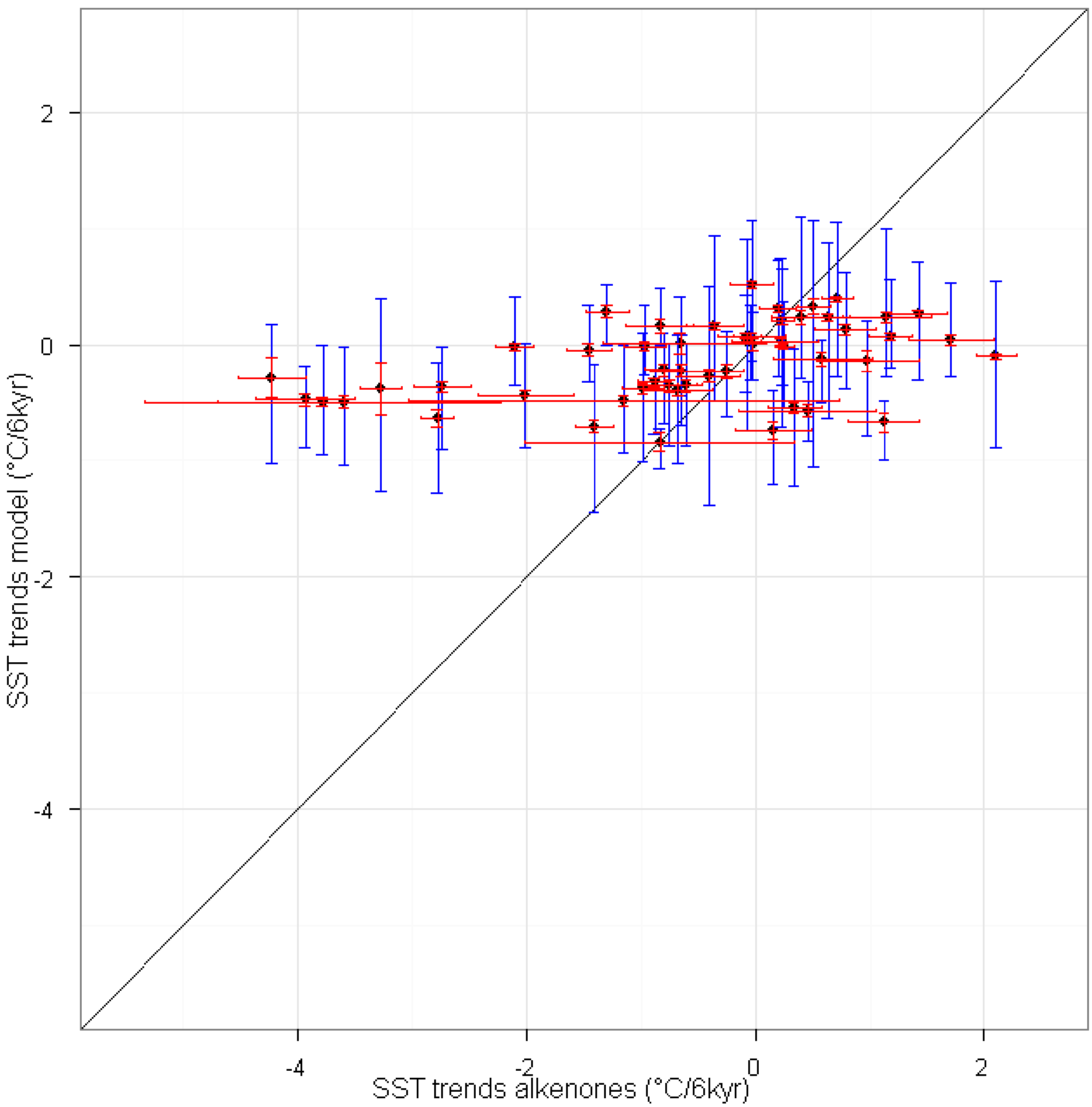

Fig. 17: Alkenone SST trends vs. Model SST trends. Red bars represent the standard error of the slope and blue bars show the modeled seasonal range (maximum and minimum seasonal temperature).

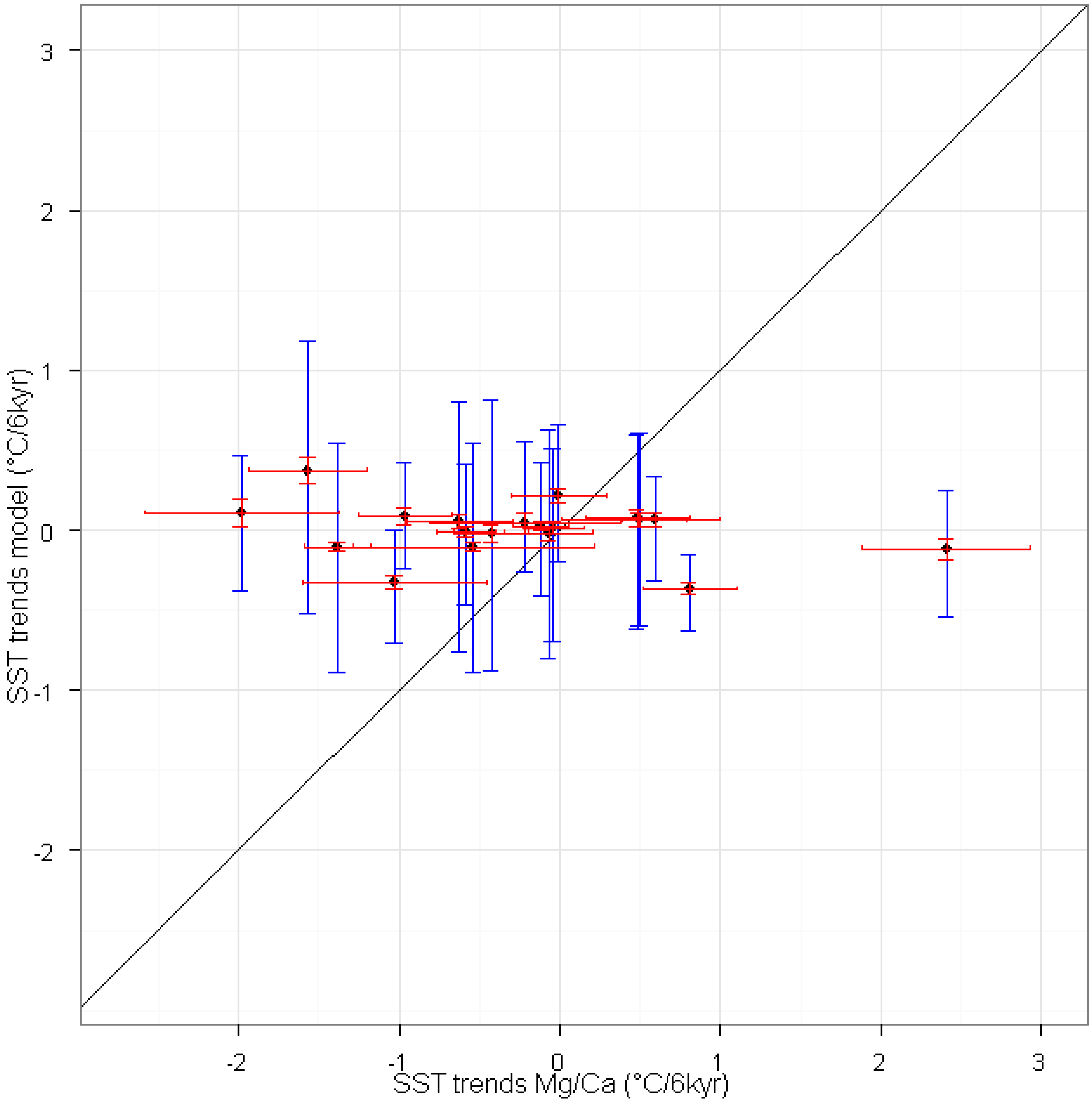

Fig. 18: As Fig. 17, but for Mg/Ca SST trends vs. Model SST trends.

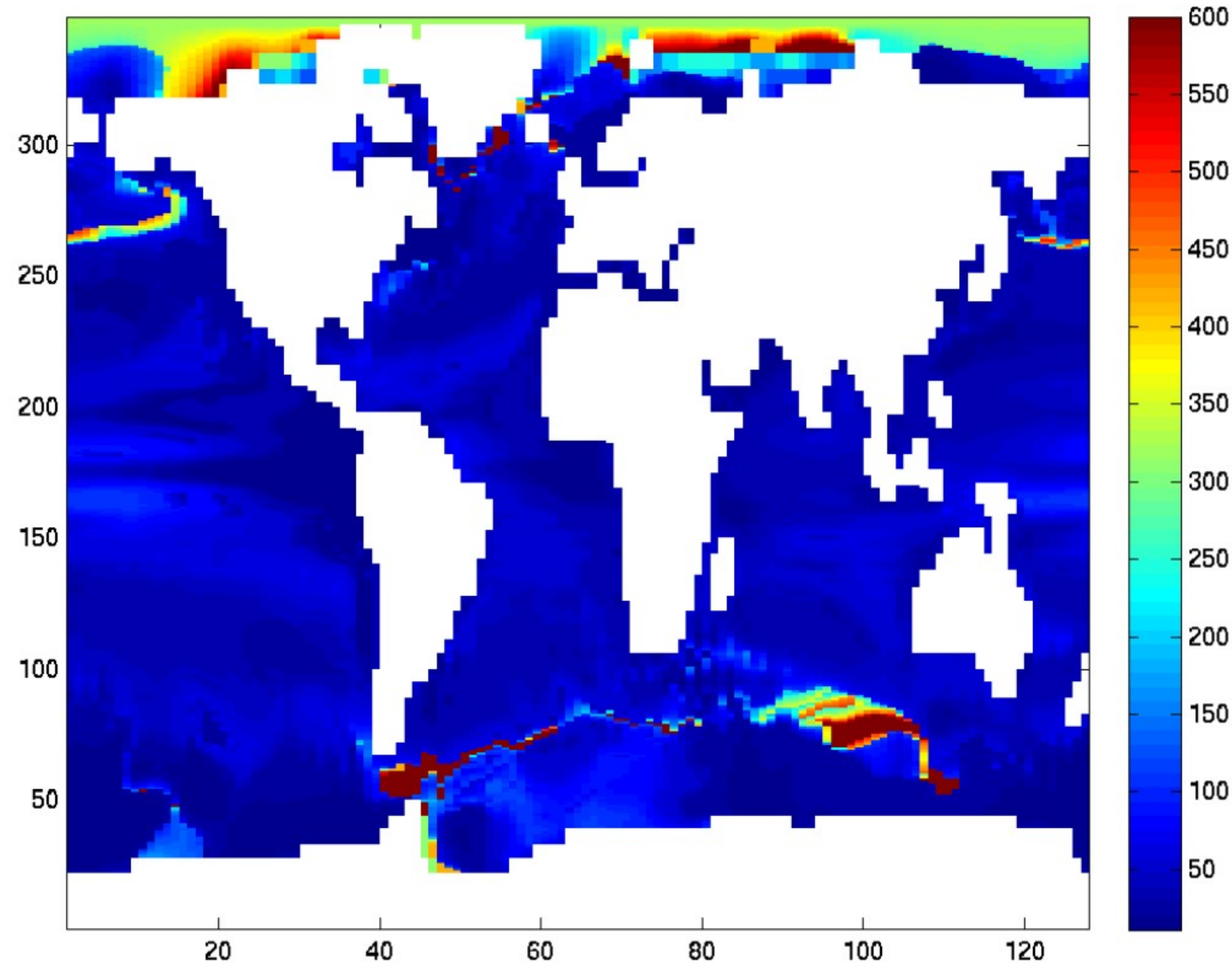

Fig. 19: HOPE-G annual mean mixed layer depth (m).

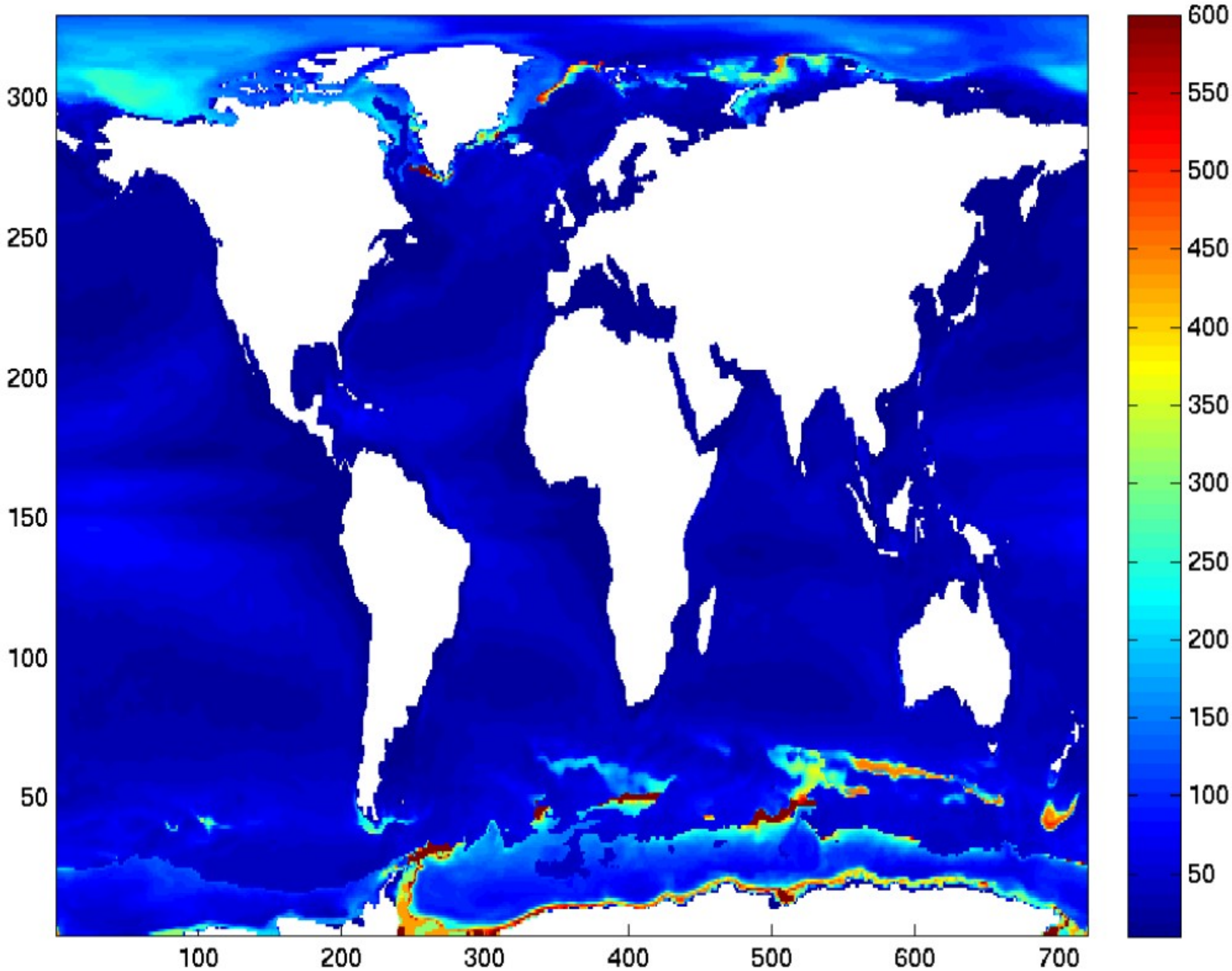

Fig. 20: Same as Fig. 19, but for the SODA data set.

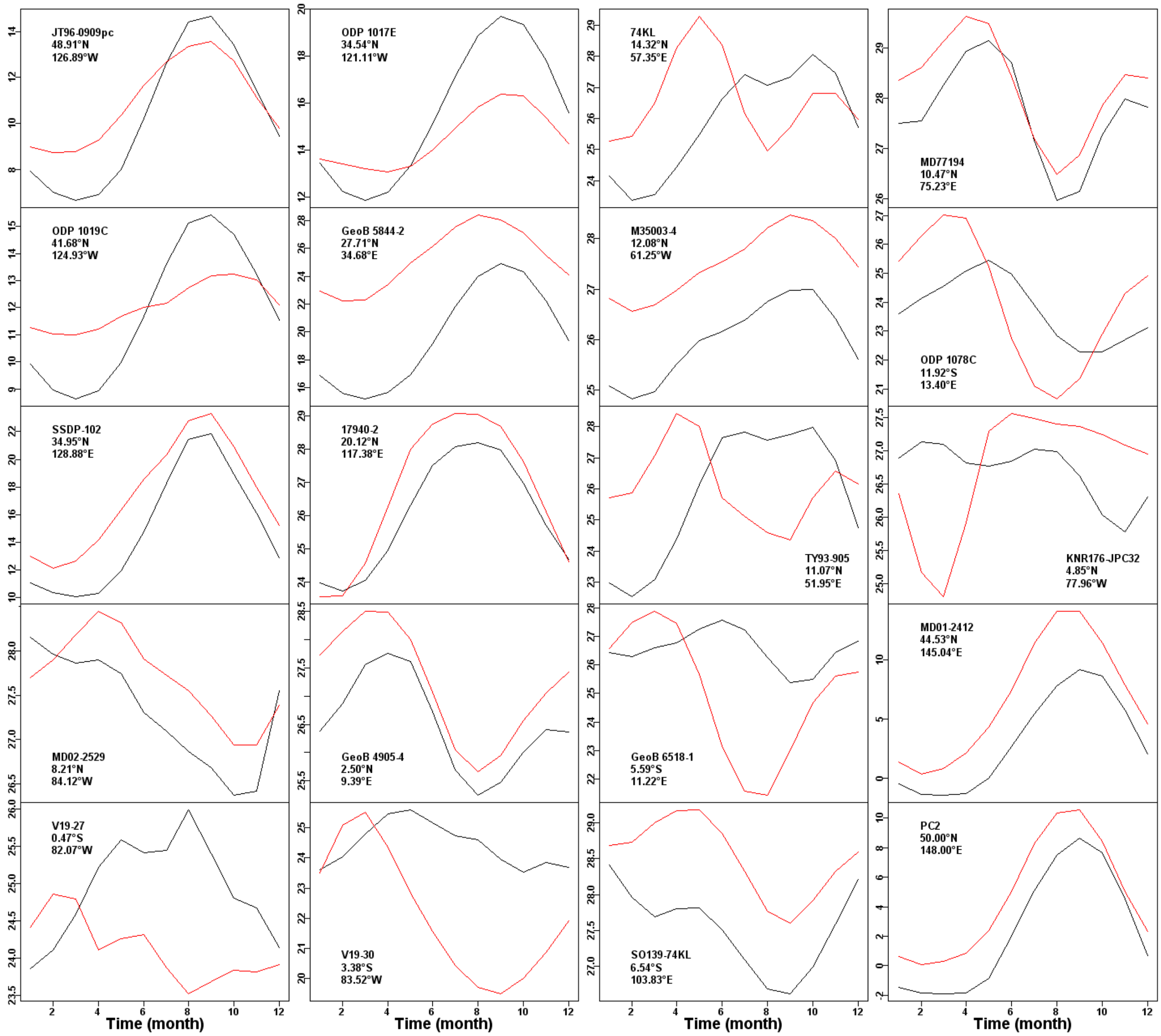

Fig. 21: Seasonal cycle at the Alkenones core locations (cf. Fig. 9). The black lines represent the modeled seasonal cycle, while the red represent the observational SST seasonal cycle.

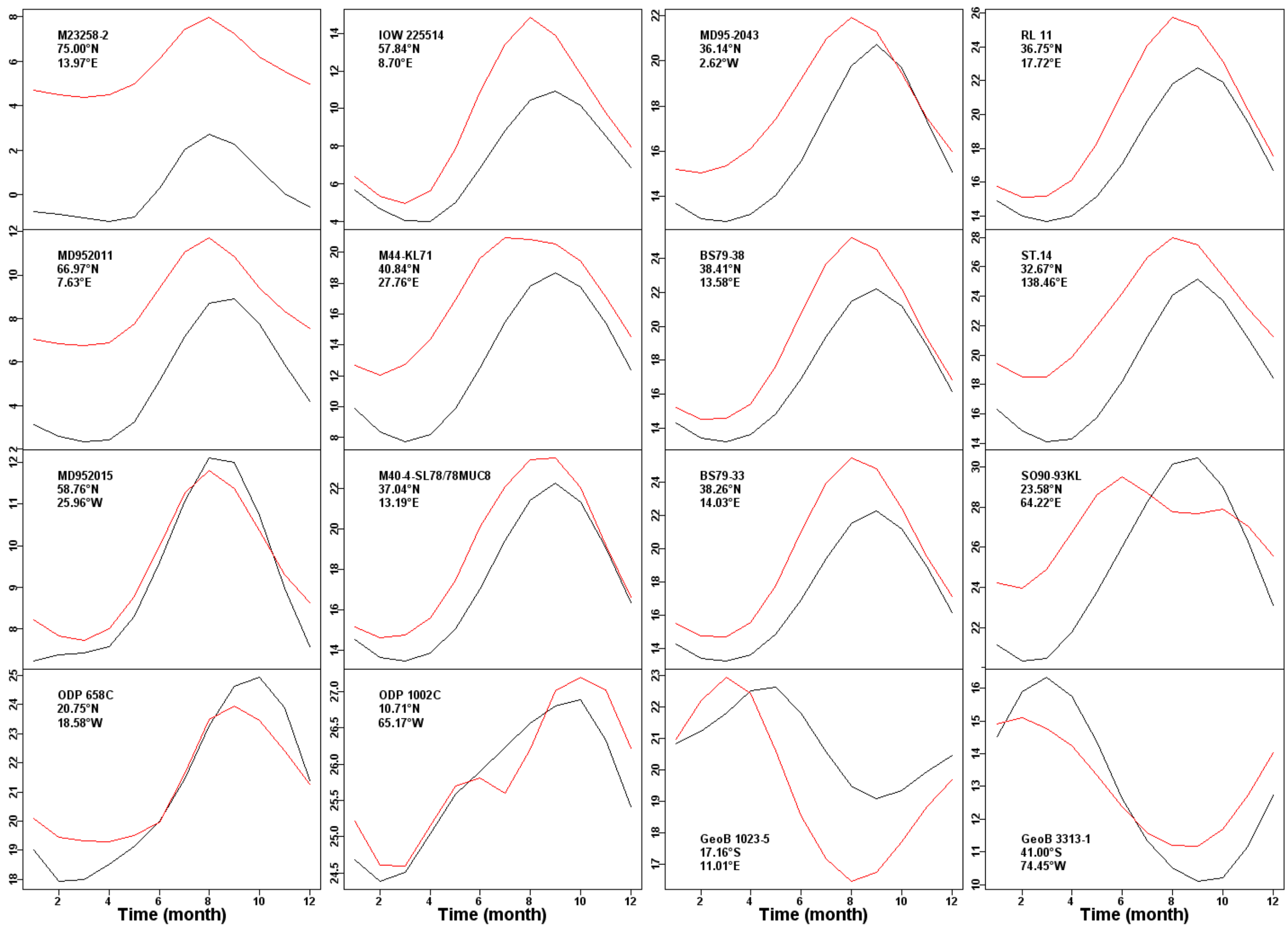

Fig. 22: As Fig. 21, but related to the core locations from Fig. 10.

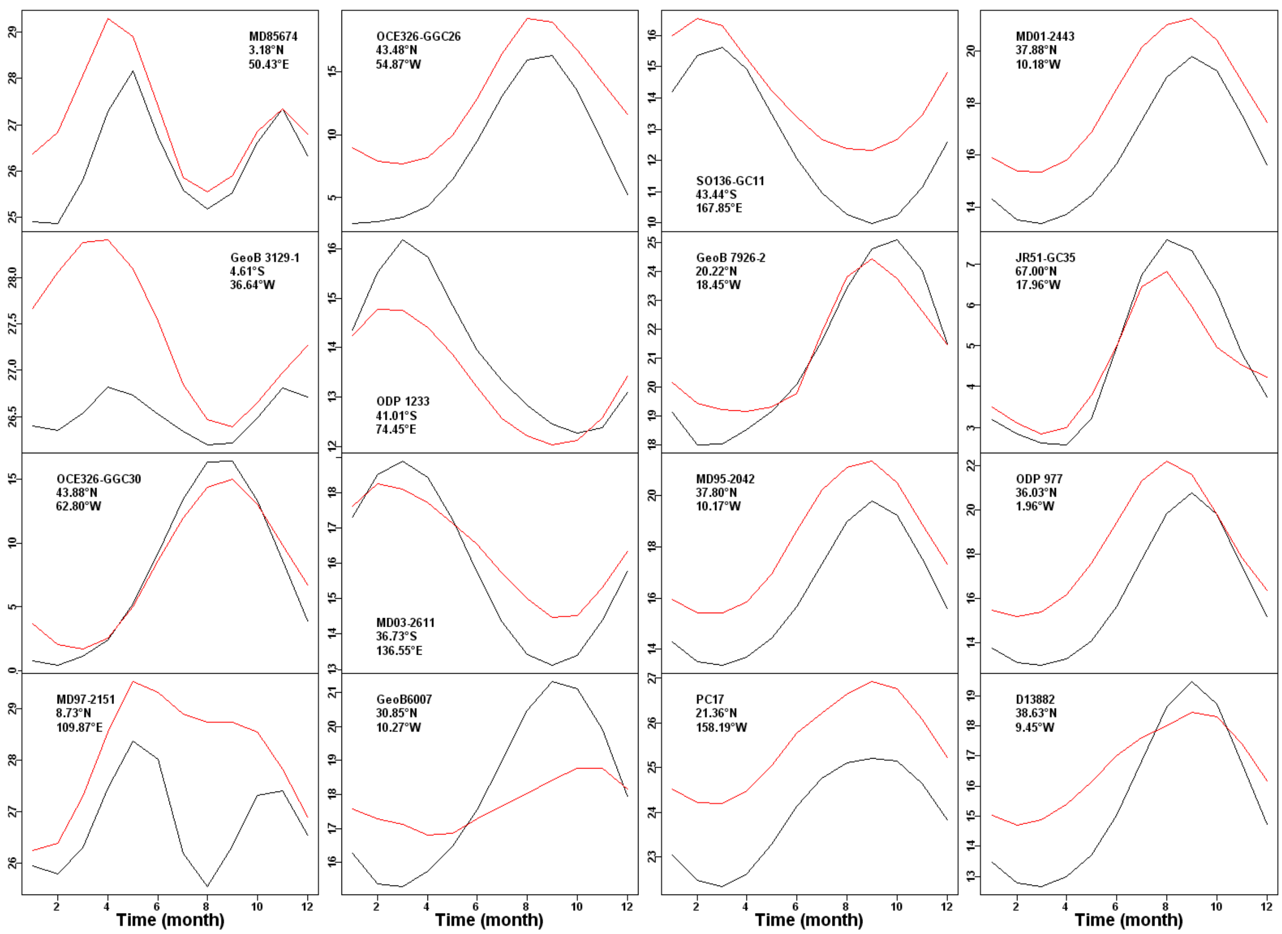

Fig. 23: As Fig. 21, but related to the core locations from Fig. 11.

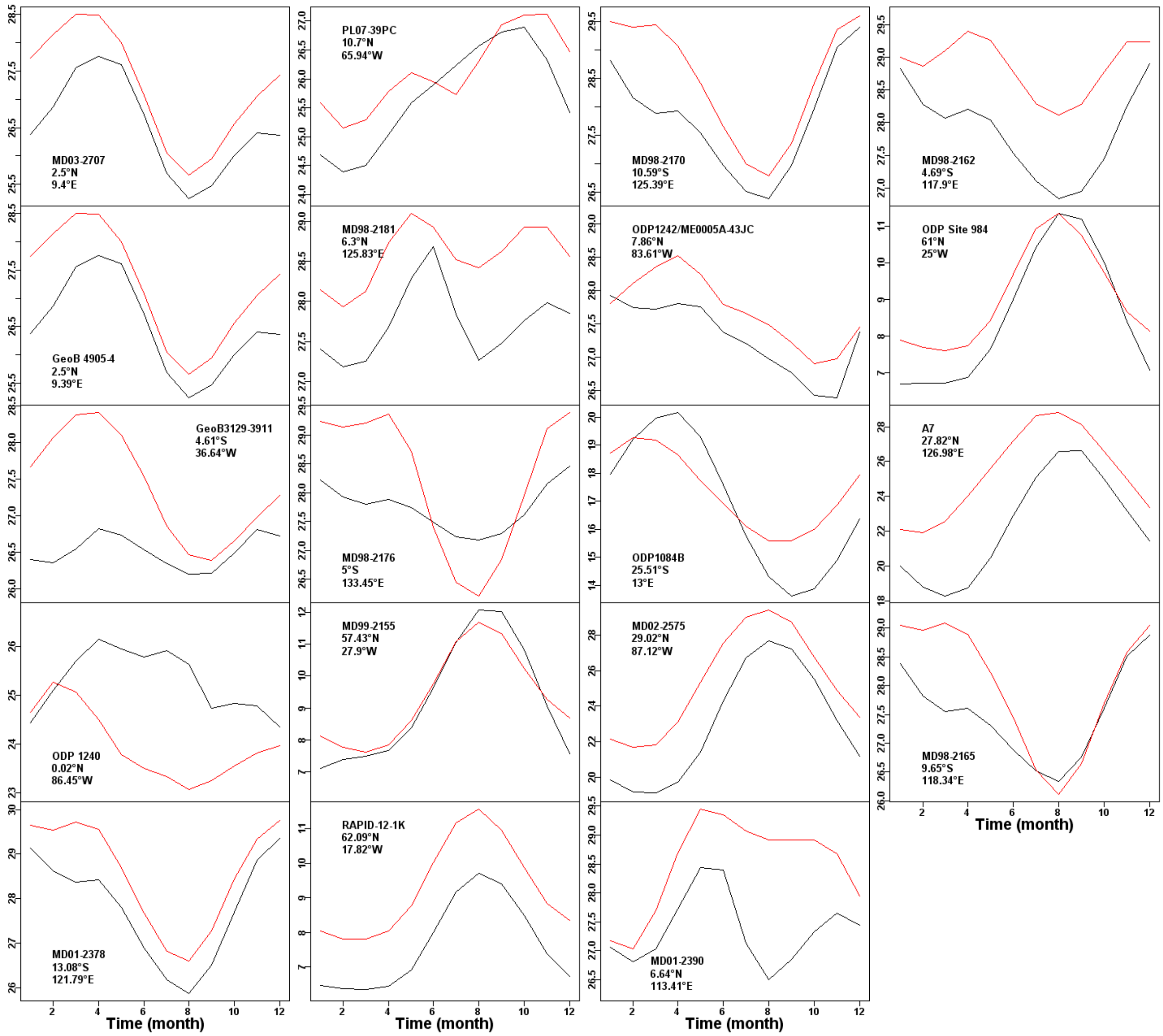

Fig. 24: Seasonal cycle at the Mg/Ca core locations (cf. Fig. 12). The black lines represent the modeled seasonal cycle, while the red represent the observational SST seasonal cycle.

Paper: “A model-data comparison of the Holocene global sea surface temperature evolution” by G. Lohmann, M. Pfeiffer, T. Laepple, G. Leduc, and J.-H. Kim, Clim. Past Discuss., 8, 1005-1056, 2012. www.clim-past-discuss.net/8/1005/2012/ doi:10.5194/cpd-8-1005-2012

Response to the reviewer 2

First, we would like to thank the reviewer for the useful and constructive comments. We respond first to the reviewers’ major comments.

1) Data sets
    a. Correct. We provide now the bibliography of the data sets and include an extra table. There we provide the source of information for our paper. In a similar way, we include now the information of the PMIP3 model results.

    b. We deliberately avoid to give the authors’ comment of potential seasonal bias. Instead, we want to elaborate from the analyses which season is fitting best to the model trends.

    c. Aliasing: The number 10 within 6000 years is arbitrary, but we have chosen this number to estimate the trends (including their errors).

In the new figures, it is now clear that PC17 has 10 values. We also calculated the uncertainties in the trends (Figs. 1-4) and evaluate their residuals (standardized residuals of the fit relative to the fitted values) as shown in Figs. 5-8. Across the cores, no clear common pattern in the deviations from linearity is visible which would ask for a non-parametric analysis.

2) Correct. The data with more than 2°C are mainly at high latitudes. We expect that the alkenone method has its limitations in these areas. We include a sentence in the new manuscript.
3) We evaluated the ocean model component of ECHO-G in simulating the seasonal cycle in SST for the core locations (Figs. 9-12). If the recorder system changes over time, the system may record another time of the year in the mid-Holocene compared to PI. Your are right. To make an example, a time shift of 30 days mean that a seasonal

correlation centred on JJA is then centered on JAS or MJJ. We included this into the methods section. Also some formulations were modified as suggested.

Minor points:

1) we want to keep the title as it is
2) We reformulated the sentences. For example:

1025: „Paleoclimate information gathered from model-data comparisons are difficult to be put into a context which goes beyond a description of observed model-data discrepancies, as both climate models and proxy reconstructions are imperfect and have very different characteristics.“

1027: „It means that refining Mg/Ca interpretation in light of the foraminiferal seasonal preferences may theoretically be undertaken by field studies.“

3) We include now the recent compilations in the introduction: A recent compilation of land proxy data and models (Branonnot et al., 2012) shows mean annual temperature anomalies of 2-5 K during the mid-Holocene over large parts of northern and middle Europe, parts of northern Asia, as well as southern Africa. In the Mediterranean and the subtropical regions, the data shows a cooling of 1-2 K, as seen from pollen and plant macrofossil data (Bartlein et al., 2011). Furthermore, we included more information in the discussion and conclusion section.
4) The environmental conditions are not systematically known. We try to avoid a discussion of individual cores, although we are aware that paleoclimatologist may have core-specific knowledge about habitat depth and seasonality.
5) This is indeed confusing that there is a significant negative relation for Mg/Ca. We guess that the relatively small sample size und unknown environmental effects are re-

sponsible for this inverse relationship. We modified the sentence.

6) We modified the sentence and add: This suggests that the nutrient supply from deeper waters is an important influence on the alkenone production as hypothesized by Ohkouchi, et al., 1999.

7) Thanks, modified
8) Modified
9) Thanks, a valid suggestion. We moved the section and introduced more subsections.
10) We also evaluated Mg/Ca and want to leave the formulation.
11) Done.
12) The matches are featureless because they do not reflect large-scale pattern. We inserted this into the manuscript.
13) Good suggestion, adopted: Comparing the reconstructed Holocene temperature trends to the model levels of the upper 100m does not remove the discrepancy between models and proxies.

14) We followed your suggestion.
15) Done.
16) Done.
17) Done.
18) Because the signal would be smoothed.
19) Ok, we reformulated the sentence.
20) Done.
21) Done.
22) Done.
23) Done.

24) Done.

25) Done.

26) Done.

27) Done.

28) Done.

29) We modified the color scale.

30) Right. More information is now given in the caption. The number of points may not be identical because of missing values or the values are out of range in the vertical.

31) Done, now we state explicitely the meaning of the triagles and diamonds.

32) Re-done.

Final remark: we included also the PMIP3 data into our compilation and made an additional figure.

References:

Bartlein, P.J., Harrison, S. P., Brewer, S., Connor, S., Davis ,B. A. S., Gajewski, K., Guiot, J., Harrison-Prentice, T. I., Henderson, A., Peyron, O., Prentice, I. C., Scholze, M., Seppä, H., Shuman, B., Sugita, S., Thompson, R. S., Viau, A. E., Williams, J., and Wu, H.: Pollen-based continental climate reconstructions at 6 and 21 ka: a global synthesis, Clim. Dynam., 37 (3), 775 – 802. DOI 10.1007/S00382-010-0904-1, 2011.

Braconnot, P., Harrison, S., Kageyama, M., Bartlein, P., Masson-Delmotte, V., Abe-Ouchi, A., Otto-Bliesner, B., and Zhao, Y: Evaluation of climate models using palaeoclimatic data, Nature Climate Change 2, 417–424 (2012) doi:10.1038/nclimate1456

Ohkouchi, N., Kawamura, K., Kawahata, H., and Okada, H.: Depth ranges of alkenone production in the central Pacific Ocean, Global Biogeochem. Cycles, 13, 695–704, 1999.

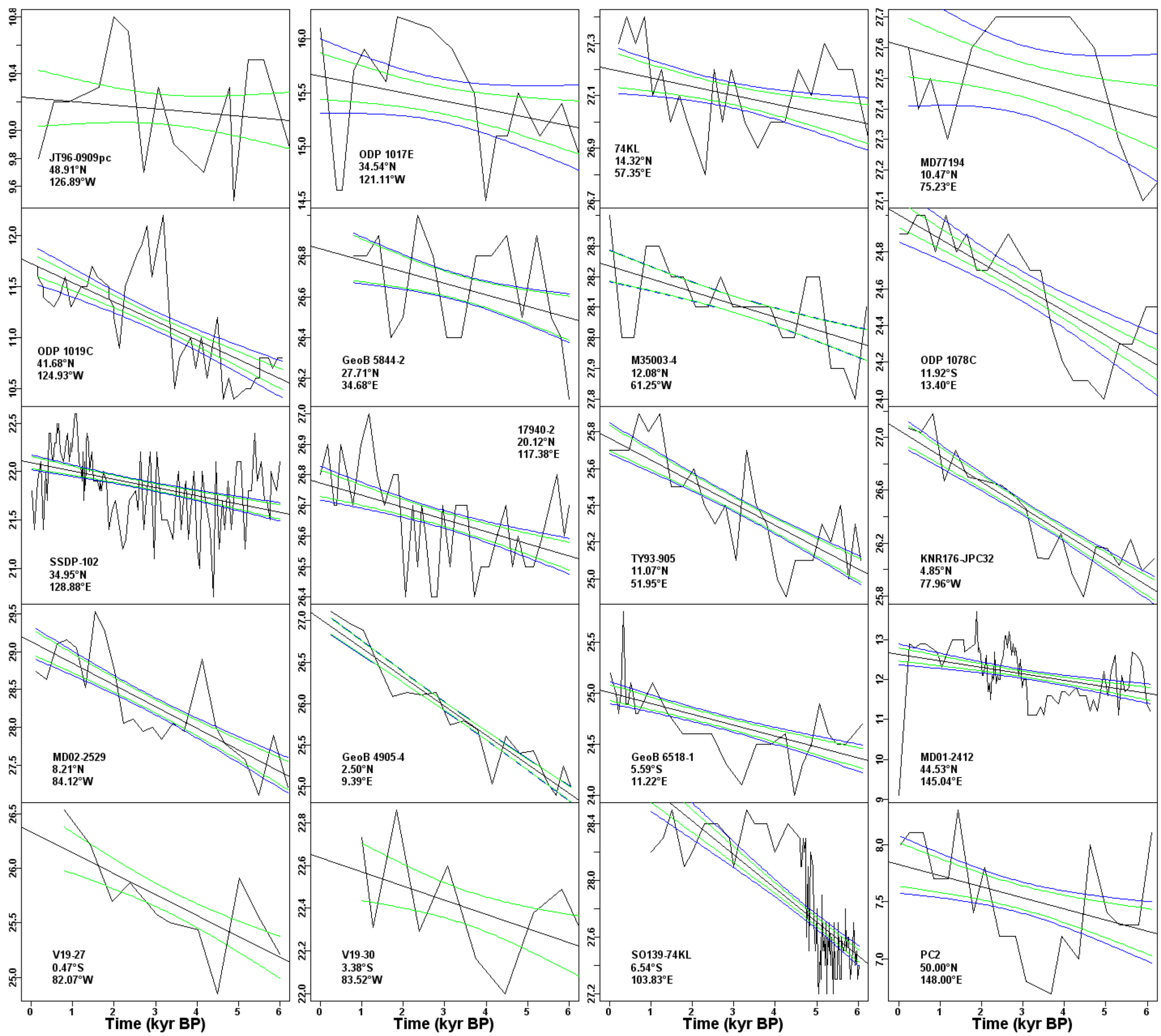

Fig. 1: Alkenones timeseries with positive linear trends and their standard errors (part of Fig. 1 in the CPD paper). The blue curved lines represent the standard error that account for serial correlation, the green ones represent those not accounting for serial correlation.

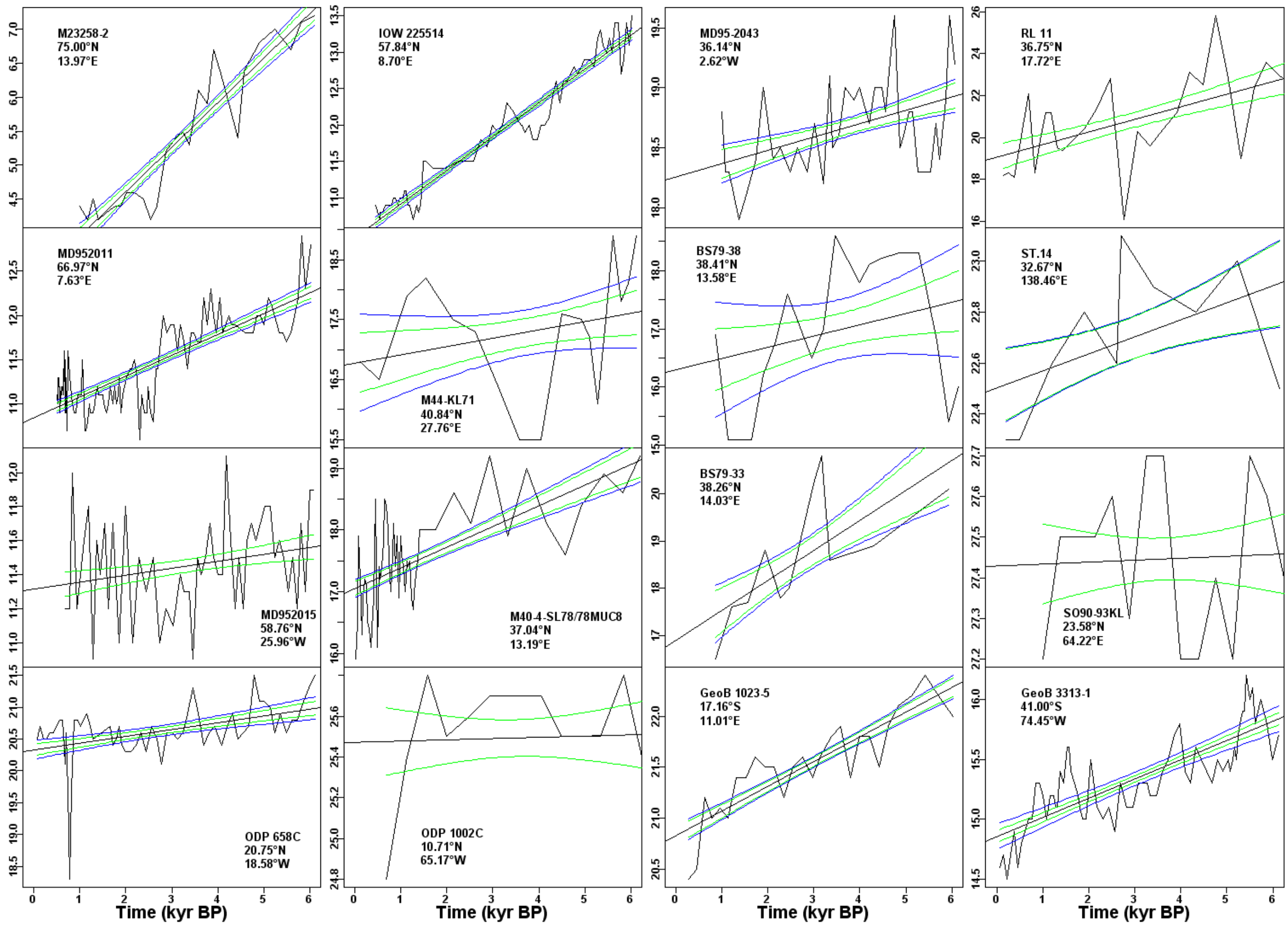

Fig. 2: Alkenones timeseries with negative linear trends and their standard errors.

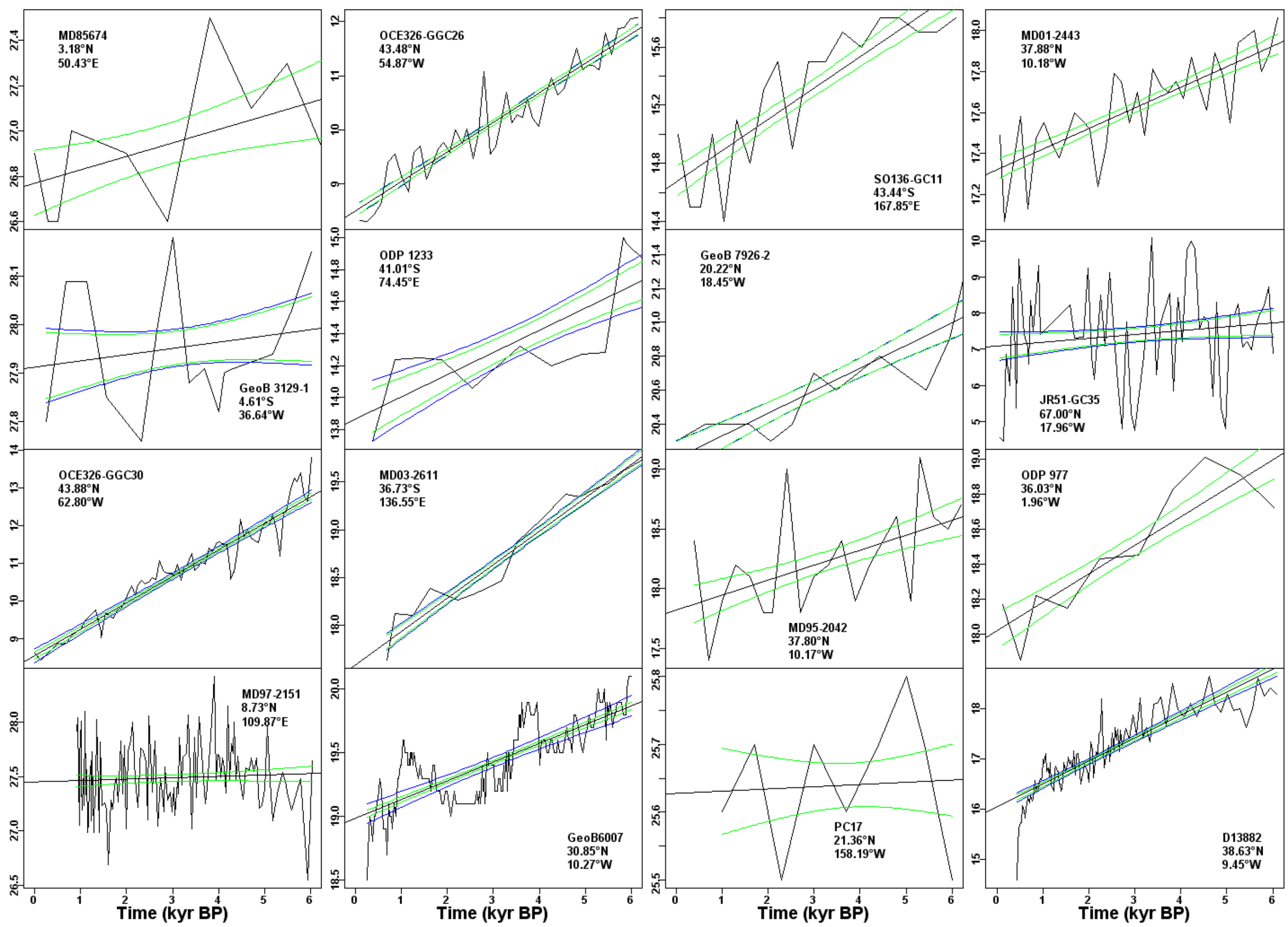

Fig. 3: Continued, as Fig. 2.

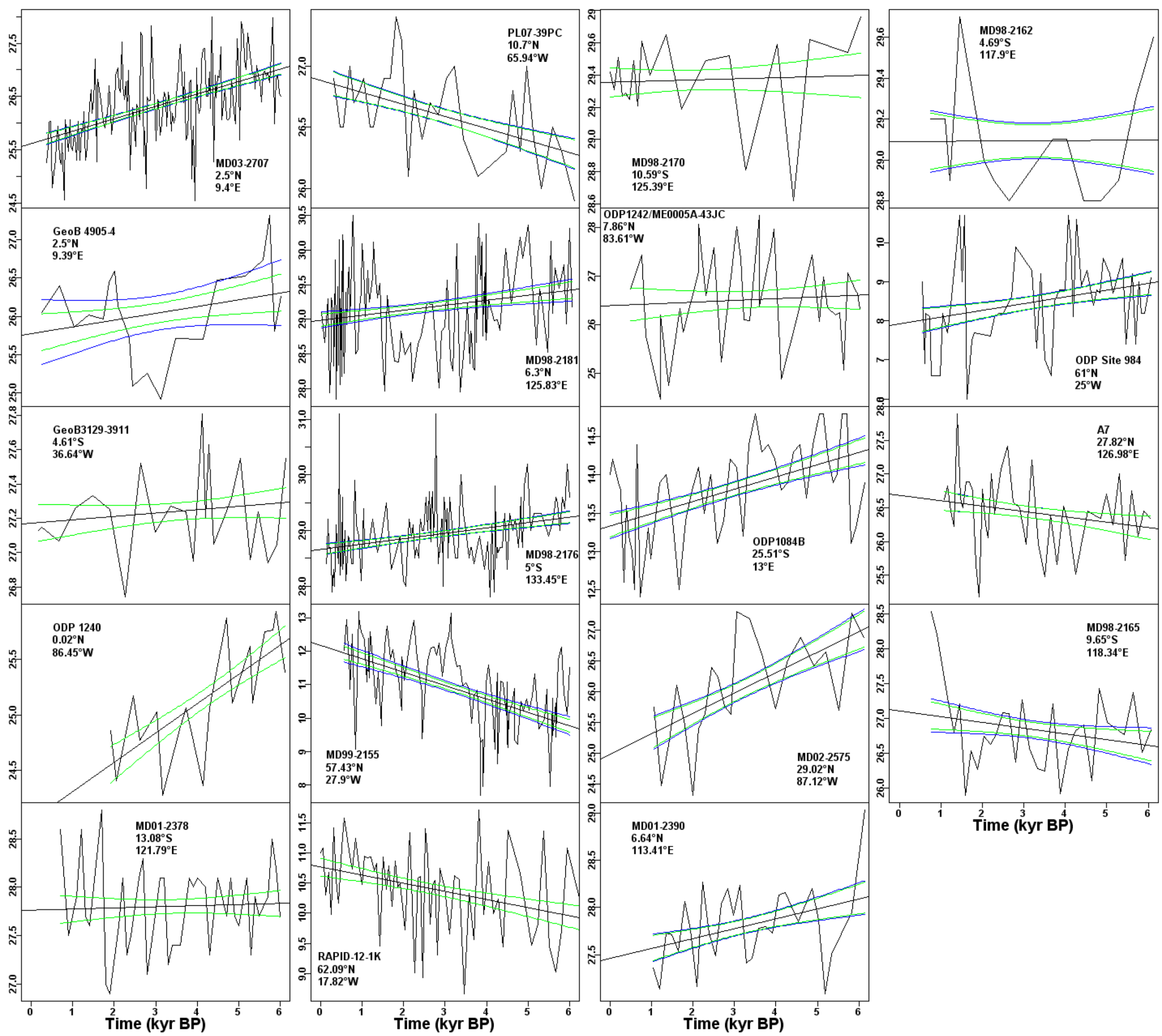

Fig. 4: Mg/Ca timeseries including the linear trends and their standard errors (old Fig. 2 in the CPD paper).

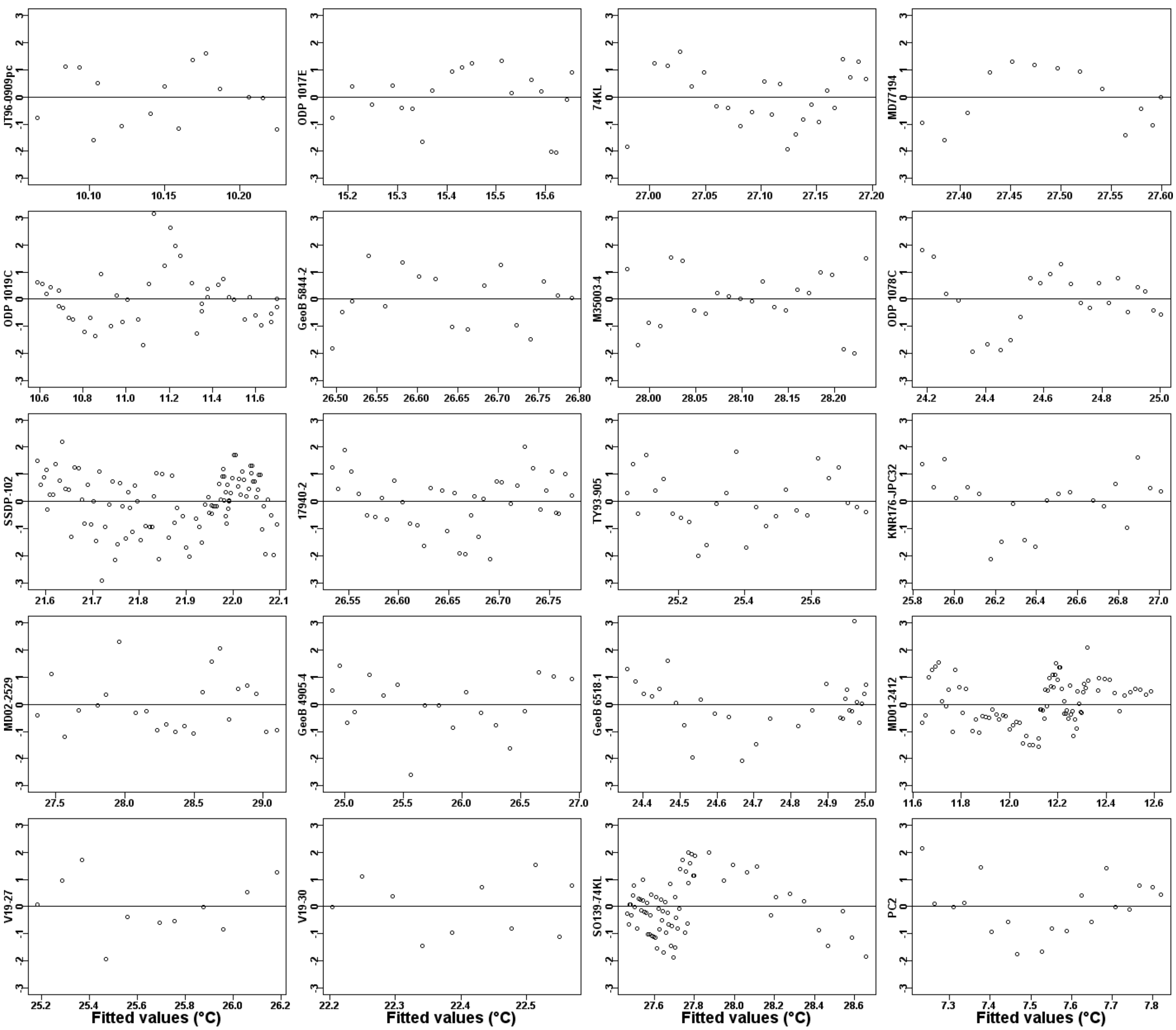

Fig. 5: Standardized residuals of the alkenones plotted against the fitted values at every alkenone core location where the trend is positive.

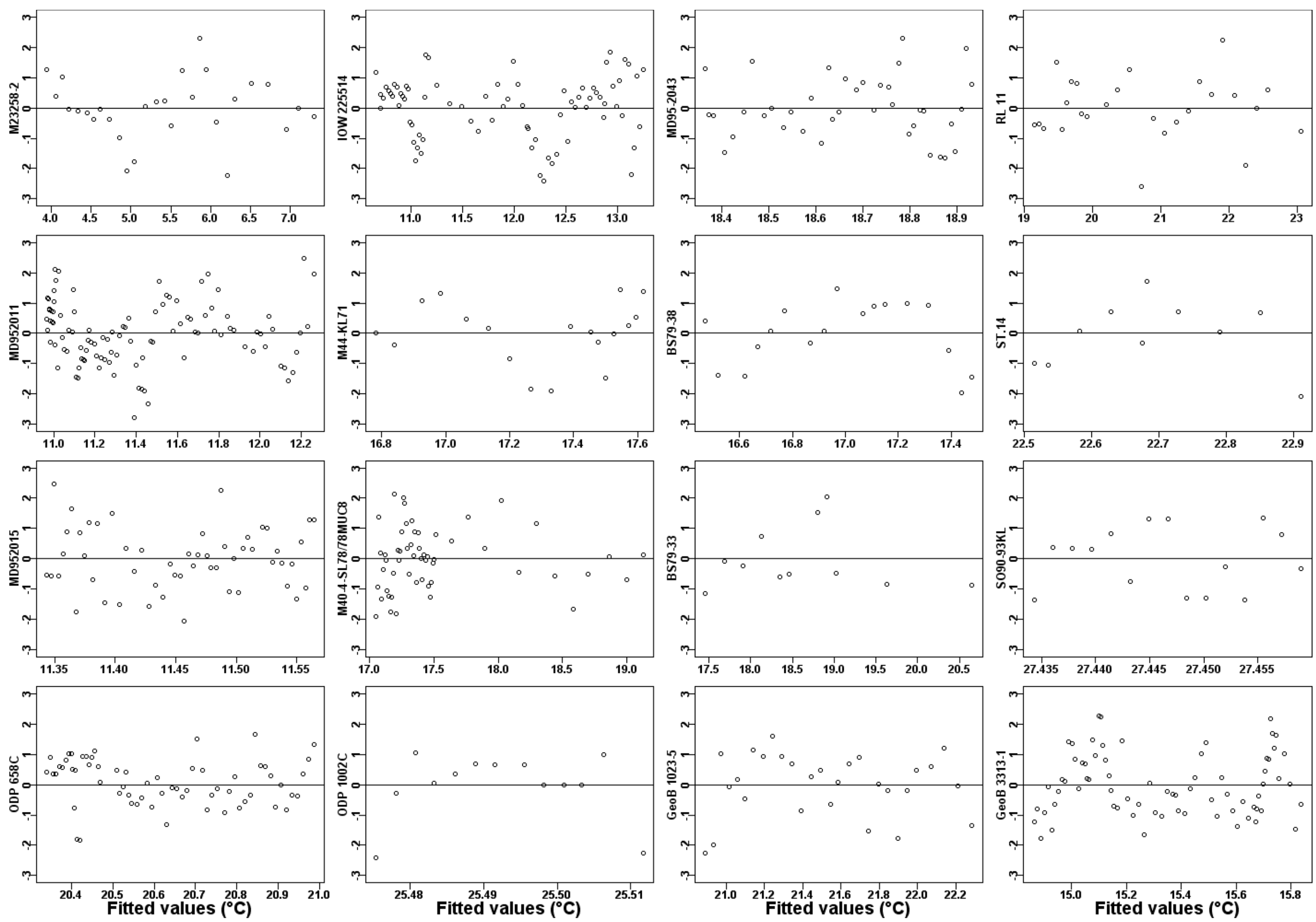

Fig. 6: As Fig. 5, but for the alkenone data where the trend is negative.

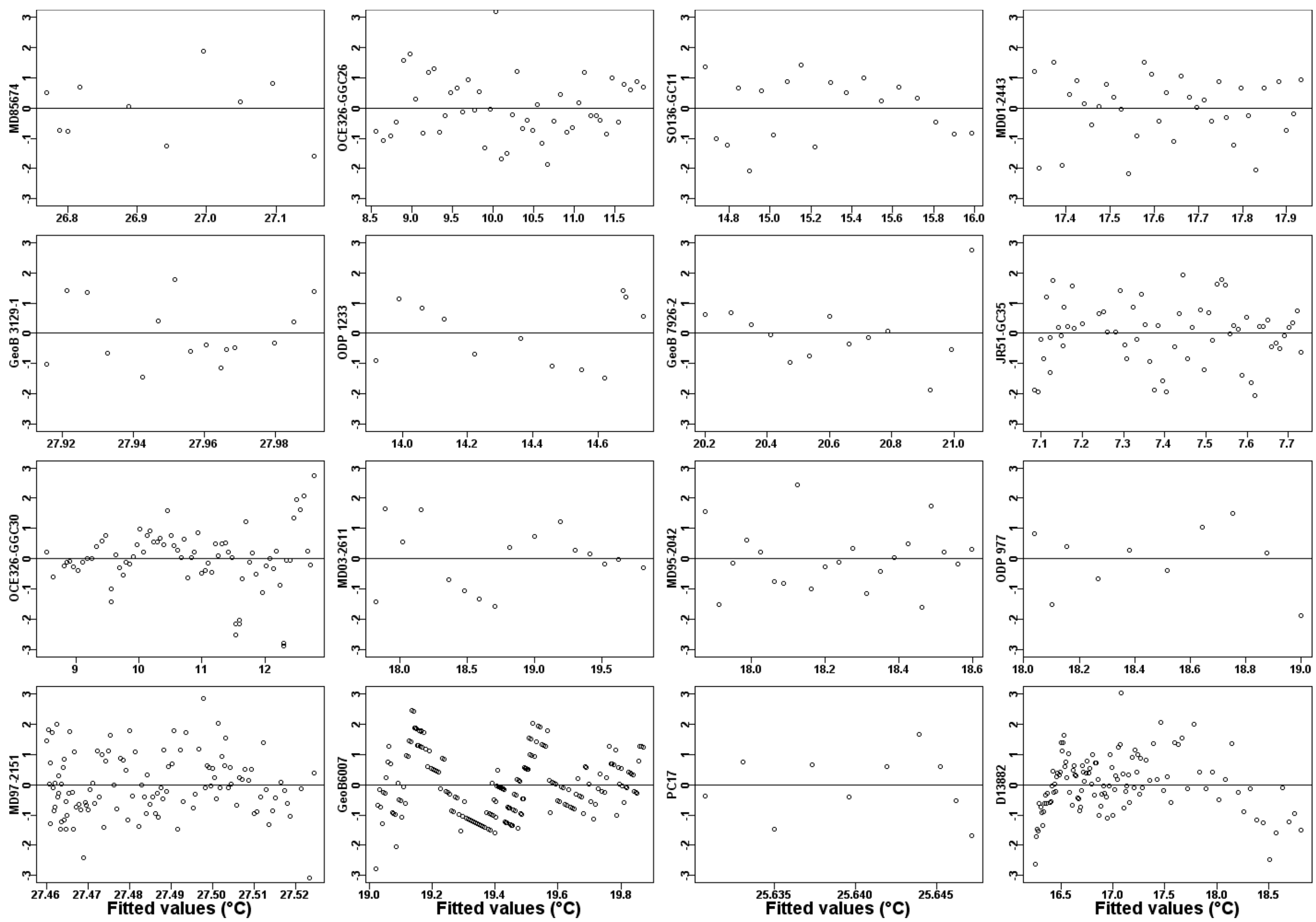

Fig. 7: As Fig. 6, for the remaining cores with negative trends.

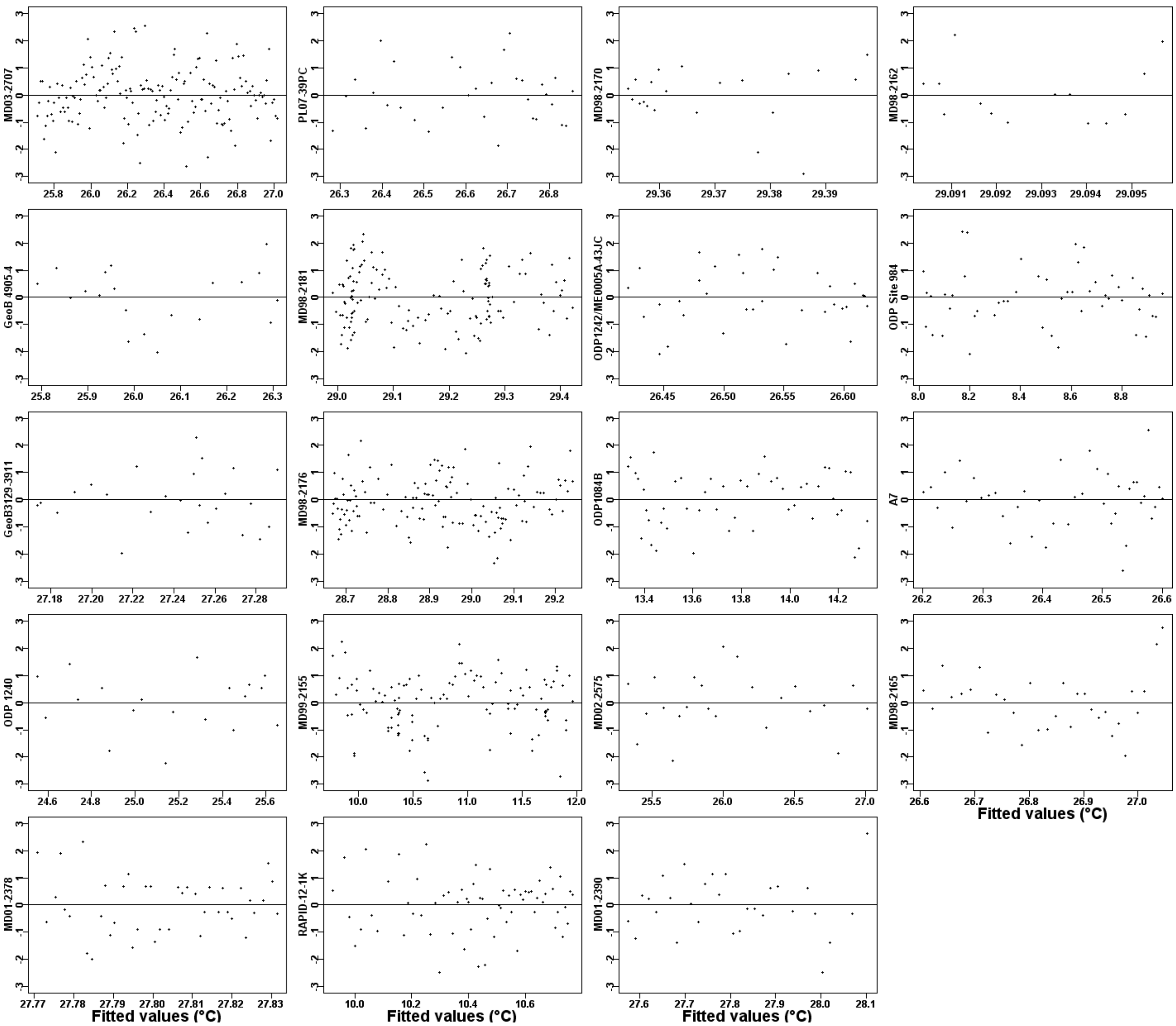

Fig. 8: Standardized residuals of the Mg/Ca plotted against the fitted values at every Mg/Ca core location.

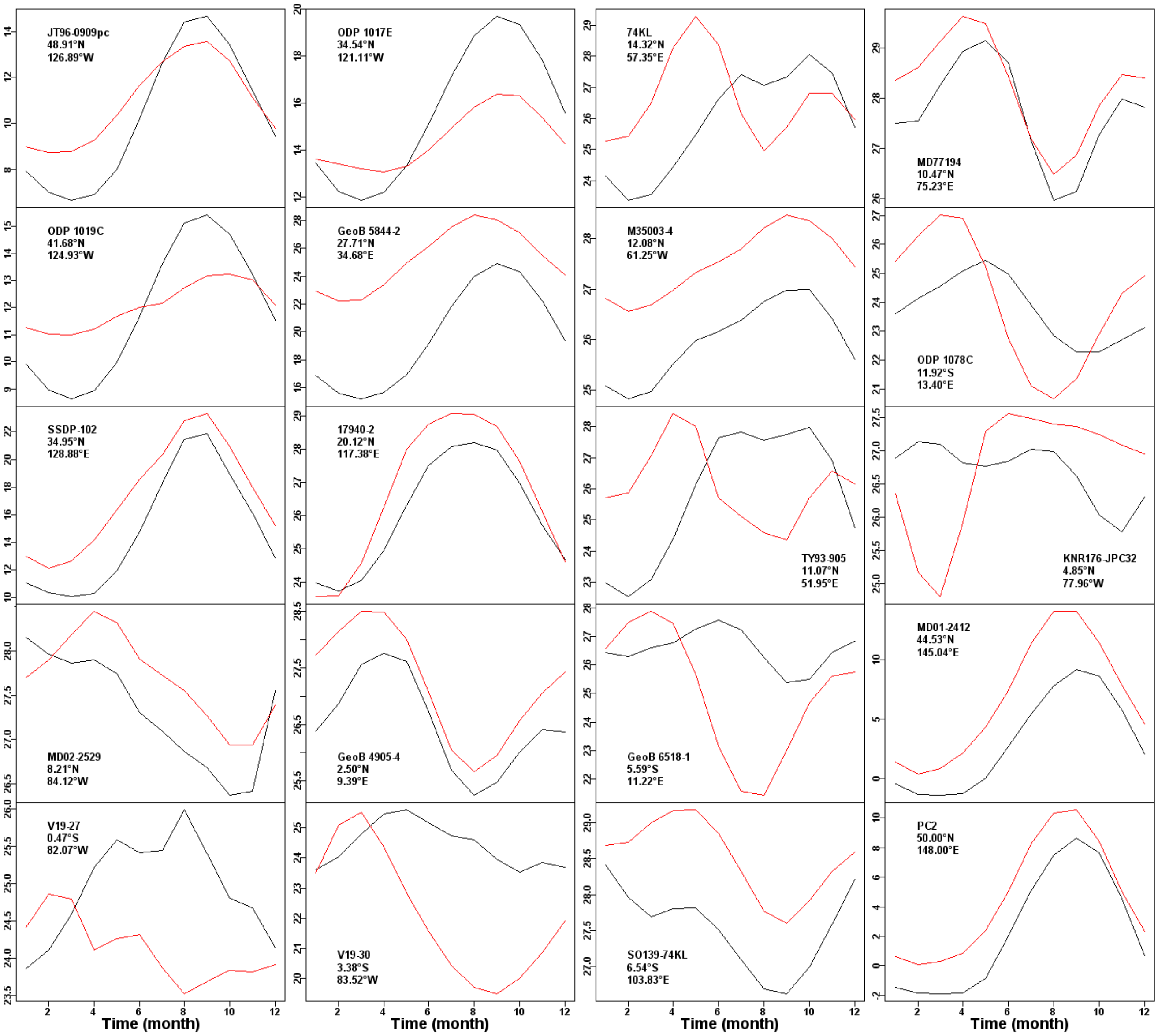

Fig. 9: Seasonal cycle at the core locations (cf. Fig. 1). The black lines represent the modeled seasonal cycle, while the red represent the observational SST seasonal cycle.

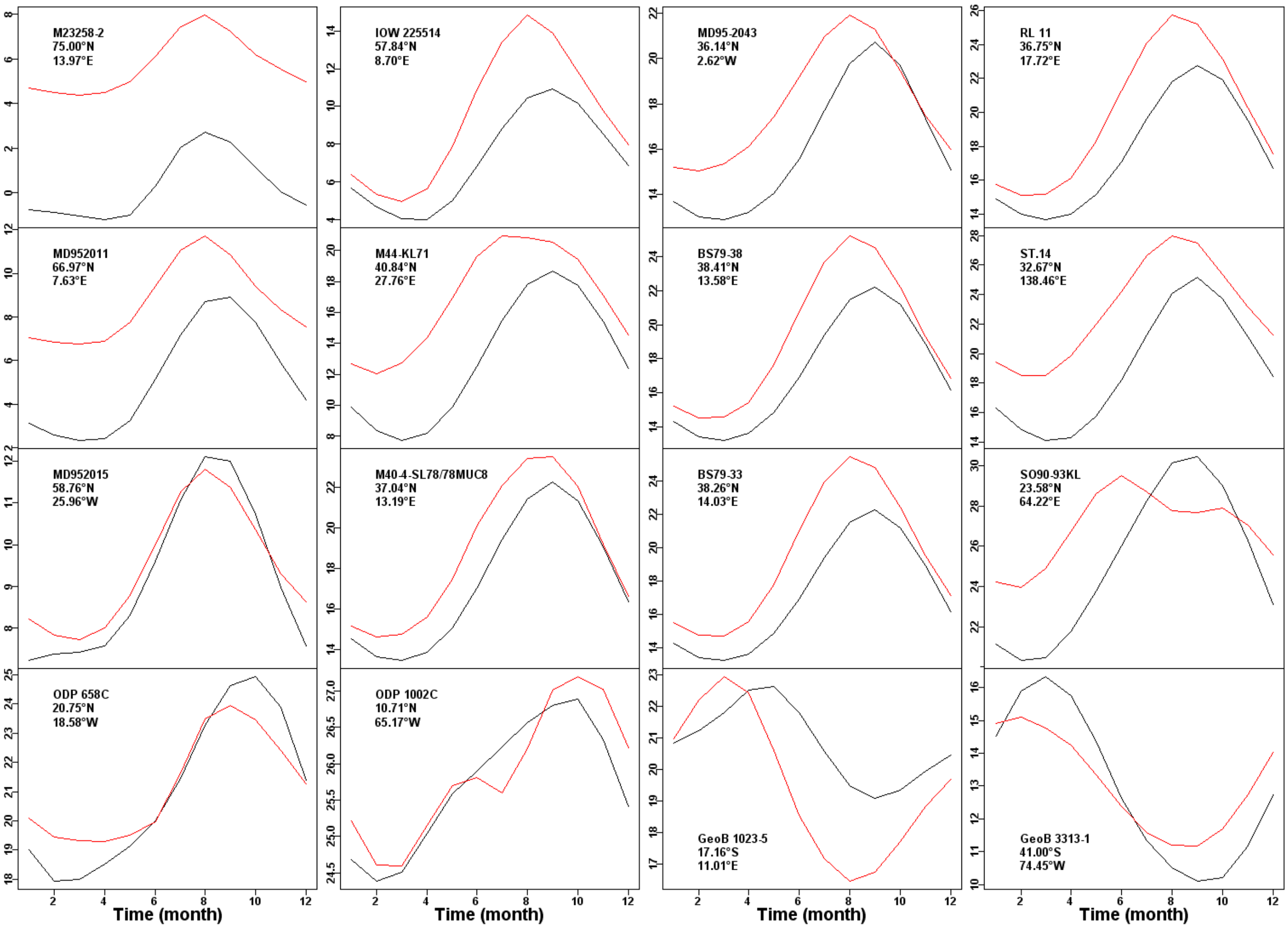

Fig. 10: As Fig. 9, but related to the core locations from Fig. 2.

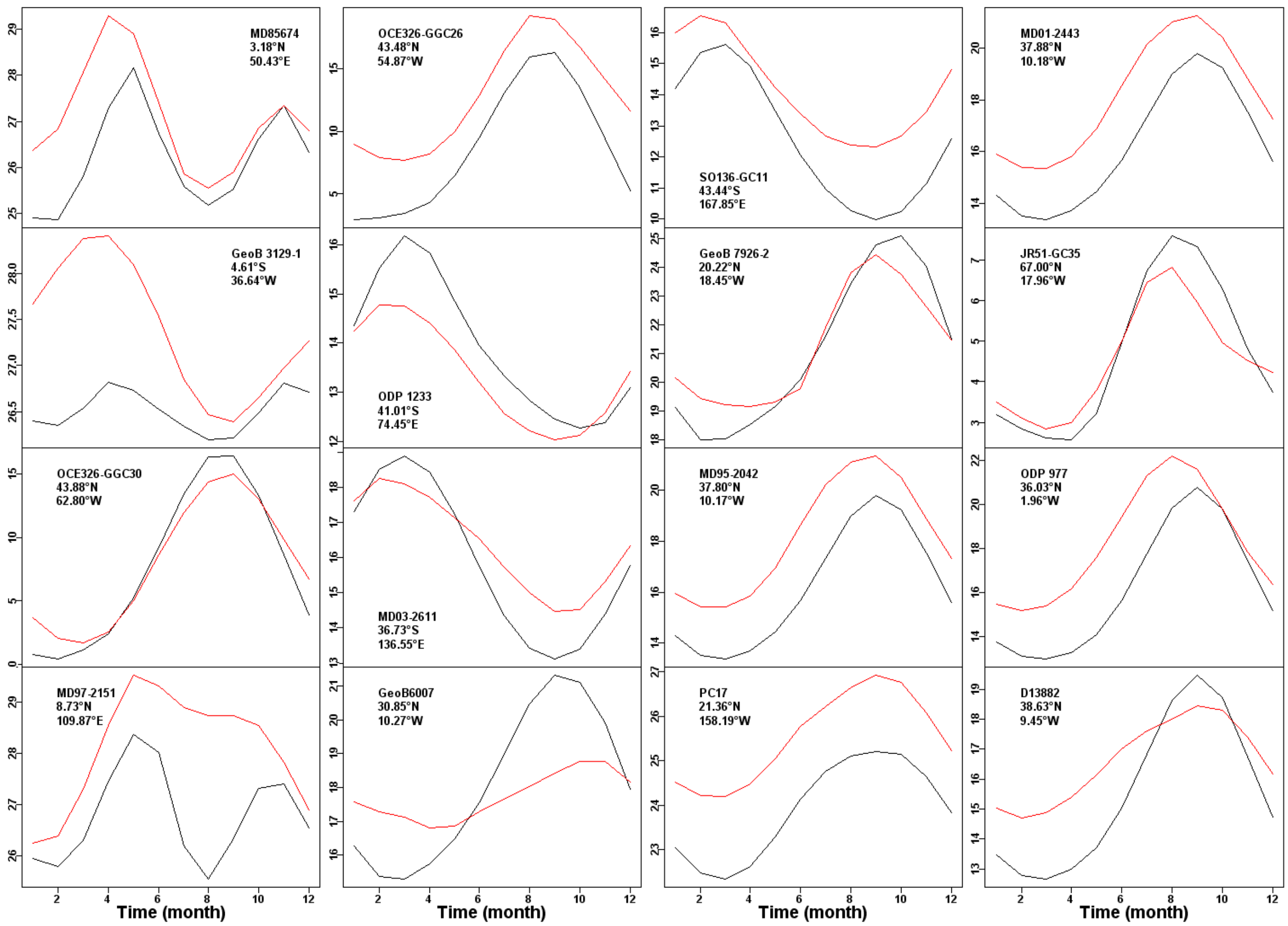

Fig. 11: As Fig. 9, but related to the core locations from Fig. 3.

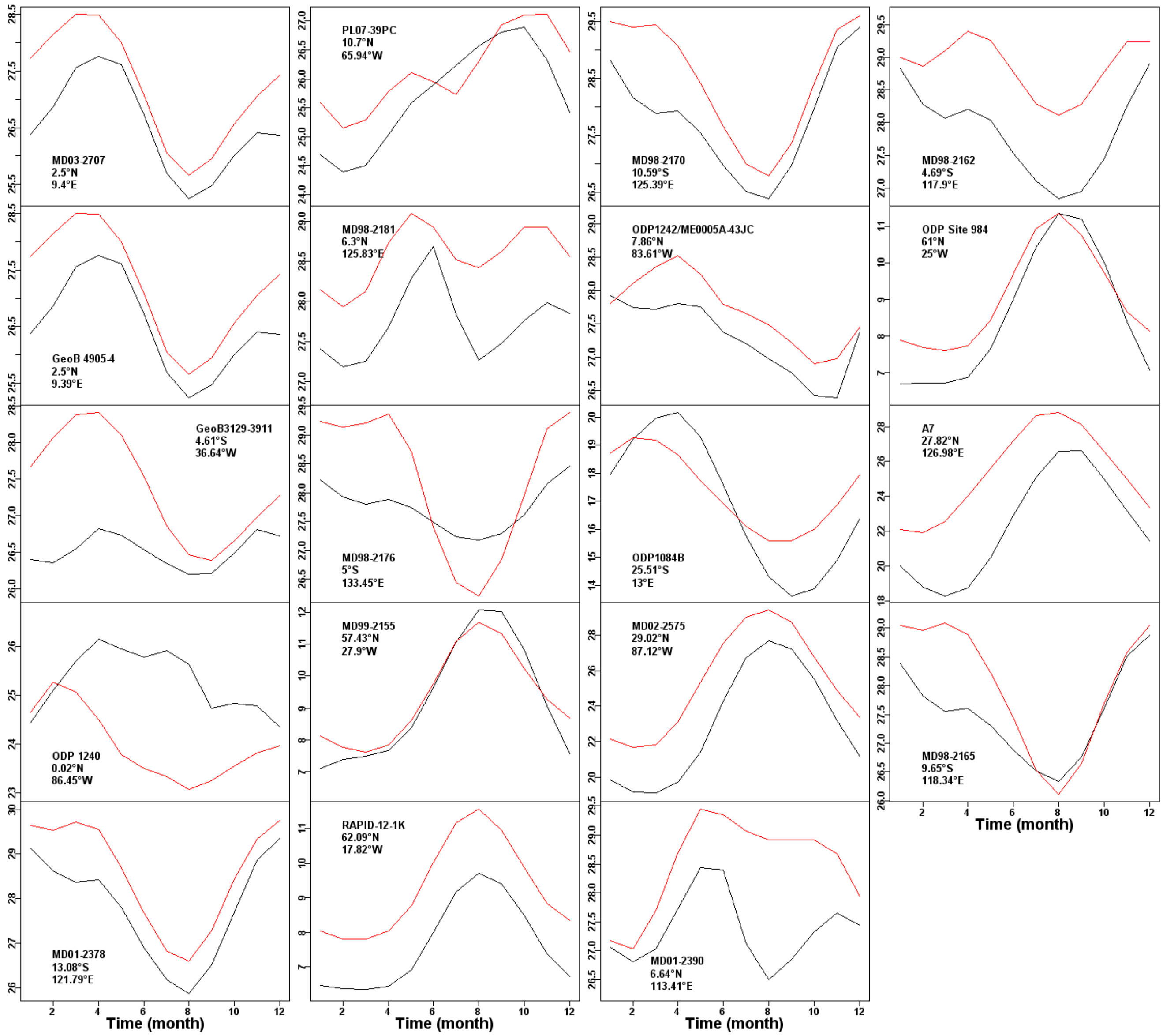

Fig. 12: Seasonal cycle at the Mg/Ca core locations (cf. Fig. 4). The black lines represent the modeled seasonal cycle, while the red represent the observational SST seasonal cycle.