Clim. Past Discuss., 7, C1110–C1122, 2011
www.clim-past-discuss.net/7/C1110/2011/

Climate
of the Past
Discussions

Interactive comment on "High-latitude obliquity forcing drives the agulhas leakage" *by* T. Caley et al.

T. Caley et al.

t.caley@epoc.u-bordeaux1.fr

Received and published: 20 July 2011

We have read the comments published by referee's 1 and would like to clarify all of her/his concerns. In particular, we hope that the following answers will convince referee's 1 to reconsider her/his decision since we demonstrate here that the conditional doubt on our spectral analyses work can be solved.

Referee comment 1

I have two main concerns regarding the concepts the authors put forward and several technical issues that I feel need to be resolved in order to support (or reject) some of the claims the authors make. My first conceptual concern is that I cannot see that the data profiles from core MD96-2048 can serve as robust indicators of Agulhas

leakage variations that occur at the southern tip of Africa, some 10 degrees of latitude to the south of the core position. The leakage is a complex system that is driven by the Agulhas' rotary momentum (i.e., vorticity), wind stress and latitudinal fluctuations of the STC in the south. Obviously, these components are interconnected while, I find it difficult to follow a concept by which hydrographic variability (SST, SSS) is used to infer the rather complex dynamical (=physical) circulation in the Indian-Atlantic gateway.

Response 1

The originality of our study is to document the precursor region of the Agulhas current system. Considering the position of our core, the proxies generated from this site are related to the upstream dynamics of the current and not the leakage at the southern tip of Africa. However, the aim of our study is to investigate the link between the leakage and the upstream dynamics. As say by the referee, the leakage is a complex system but the different components are interconnected. We agree with the referee 1 that it is important to distinguish the hydrographic variability (SST, SSS) and the dynamical circulation and leakage. However, our data support that both of these changes are connected at orbital scale changes and both (the dynamic and hydrographic variability) are important for the AMOC. For example, at terminations, changes in SST and SSS led variations in global ice volume (pp 2203 line 5-13). This is also the case for the transfer (ALF, Peeters et al., 2004) indicating a strong coupling between this both phenomenon, probably linked to the effect of the STC migration and recirculation changes. Another important point is that we used the SST to propose a new hypothesis to link the dynamical circulation between the source region (agulhas strength) and the transfer region (agulhas leakage) of the current (part 4.2): "lateral fluxes and thus the AC were stronger when Agulhas leakage was weaker". Here, the SSTs are not exclusively used to address hydrographic variability but also the dynamical circulation. This hypothesis also established a clear dynamical linked between our core site and the agulhas leakage: "it is in good agreement with some modelling results showing that when the AC is weak, the Indian-Atlantic inter-ocean exchange is larger with westward movement of the Agulhas retroflection (DeRuijter, 1982; Van Sebille et al., 2009)”.

Referee comment 2

My second concern is directly related to the first: I am fairly unconvinced that the SST stack is as robust a mean SST indicator as the authors seem to think it is. The SST stack is built from three SST records that are derived from very different methodologies (and signal carriers): planktic foraminifera, algae, and bacteria, every single one with their own ecological niche, hence recording different kinds of ambient temperature (summer, spring, Fall; surface, sub-surface, etc). As a matter of fact, looking at the individual SST records as displayed in Figure S2A it is quite obvious that they share similar features while they are also quite different from each other in fine-structure (perhaps as a result of different temporal resolution?), in amplitude, and in timing of SST shifts. Hence I do not agree with the reasoning that stacking them into one single record achieves a higher degree of robustness.

Response 2

As explained in the results part, measuring three independent proxies is important to crosscheck temperature variations. All three records are strongly related between each other ($R > 0.5, p < 0.01$) and exhibit typical glacial-interglacial patterns (Fig. S2). As each proxy has some uncertainty related to the calibration, non-temperature influences and lateral advection, the three records were averaged into a single SST stack (Fig. 2b). It is reasonable to assume that the uncertainties are independent between the proxy types. Therefore, the stack is a more accurate temperature reconstruction than the usual interpretation of single temperature proxy records. It also facilitates visual comparisons with other records and strengthens the common down-core patterns. An almost identical temporal variation of the first Principal Component (PC1, 74% variance) and the SST stack ($R > 0.99$) confirms that this record represents the common temporal variation of the three individual SST records. We also discuss in supplementary information the influence of factors other than temperature on SST

proxies, in particular for seasonality. We are thinking that this approach (building a stack) stays actually the better approach for two reasons: (1) As each SST proxy has uncertainties (some are known but some are unknown) we can’t choose one method rather than another one as we won’t be able to say which one is the best and the most robust. (2) Recent work in the Agulhas current system has shown contrasting results between SST proxy (see Martinez-Mendez et al., 2010): “The different SST reconstructions derived from UK’37and Mg/Ca pose a significant challenge to the interpretation of the proxy records”. These results highlight the necessity to check SST reconstruction and the necessity to work on the extraction of a robust SST signal by using a stack.

Finally, we would like to underline that another recent paper based on the same core (MD96-2048) and dealing with vegetation changes have been submitted (in parallel to ours) to Climate of the Past Discussion (Dupont et al., 2011 Clim. Past Discuss., 7, 2261–2296, 2011 www.clim-past-discuss.net/7/2261/2011/doi:10.5194/cpd-7-2261-2011). This study deals with the pollen records and the authors indicate that “ Comparing the abundances of EM2 – open mountainous scrubland with Fynbos affinities – with the stacked SST curve from our site (Caley et al., 2011) the correlation between the two is striking (Fig. 5)” (pp 2275 line 3-5). If our SST stack was not a robust mean of the three SST indicators, the comparison between these vegetation changes and the SST stack wouldn’t had any chance to fit as well as it is.

Referee comment 3

This then leads to my technical concerns.

A) SST stack. The approach of sampling the Tex86 and Uk37 SST records at the time step of the Mg/Ca record because this “is the SST dataset with the highest time resolution” is statistically wrong; this procedure oversamples the biomarker SST series hence potentially aliasing frequencies that do not exist in the raw records. To apply EOF/PCI to check if the stack “represents the common temporal variation of the three individual SST records" does not rectify this problem.

Response 3

We present the SST stack calculated with following the same time steps as the Tex86 and Uk37 SST records (Biomarker) (Figure 1). With this method, there are no oversamples during the procedure and we can check for potential aliasing frequencies.

By visual inspection, there are no differences between the both different stack (the one based on Mg/Ca and the one based on biomarker time step) and the both PC1 (one for a time step based on the Mg/Ca resolution's and the one with a time step based on the resolution of the biomarkers). We confirm statistically that the results (spectral analyses) are unchanged (Figure 2).

The Figure 2 shows the spectral analyses results obtained with Analyseries software (Paillard et al., 1996) and using two different methods (B-tukey and MTM). Note that the results have been performed for the new SST stack (using the sampling time step of the biomarkers) and with a step for the analysis of 3.5 kyr, which is in accordance with the sedimentation rates of the core. The results clearly demonstrate the important spectral power for the 100 kyr and 41 kyr cycle whereas the 23 kyr cycle (precession) is absent. The F-test obtained by the MTM analyses (red curve) confirms the significance of the 100 and 41 kyr cycles and the non significance of the 23 kyr cycle (precession). As a demonstration, the results are unchanged compared to the results presented in our manuscript. This should confort the main hypothesis of the paper, as there is no significant problem of aliasing frequencies associated to the oversamples during the procedure.

Referee comment 4

B) Spectral analysis, orbital periodicity, phasing : The same sampling issue comes into play again for the spectral analysis: "For spectral analysis all records were sampled at 0.5 kyr intervals." As is mentioned in the Materials and Methods section, mean

sedimentation rates along core MD96-2048 are 2 cm/kyr; the core was sampled every 2-5 cm for isotope and Mg/Ca analysis, yielding time steps between 1-2.5 kyr for d18O and Mg/Ca; the core was sampled every 5–10 cm for alkenone and GDGT, yielding time steps between 2.5-5kyr. Sampling the records at 0.5 kyr intervals for spectral analysis hence oversamples the records by a factor of 2-10. Again, this is illegitimate as it can cause frequency aliasing that then potentially perturb the spectra. I strongly recommend running the spectra on the Mg/Ca record (or SST record derived from it) alone, this is the highest resolved record and directly coincides with the sampling rate of the d18O record. Running spectra for Mg/Ca shall reveal if Mg/Ca-derived SST picks up a precession component that seems absent from the oversampled SST stack.

Response 4

First, we would like to indicate that the spectrum for Mg/Ca record alone is already available in SI Fig S5 and that the results confirm the absence of the precession (pp 2200 line 22-25 "Regardless of whether the statistical analysis is performed using an alternative age model (Fig. S4), or with the individual SST records (Fig. S5), the important ïňĄnding remains that all records vary in phase with changes in high-latitude obliquity".

In addition, we proposed (Figure 3, 4 and 5) the spectral analyses results for all the individual SST records with a time step for the analyses in accordance to the sedimentation rates of the core: that is 2 kyr for Mg/Ca and 3.5 kyr for alkenone and GDGT. All the results clearly confirmed the important spectral power for the 100 kyr and 41 kyr cycle whereas the 23 kyr cycle (precession) is absent.

All the spectral analyses results (the one already in the SI, as well as the new ones presented here) confirm the main conclusion of the manuscript, as there is no significant problem of aliasing frequencies associated to the oversamples during the procedure for each of the individual SST records. The results of the individual records are the same that for the SST stack (important spectral power for the 100 kyr and 41 kyr cycle whereas the 23 kyr cycle (precession) is absent).

In the light of these results, we would like to request referee 1 to reconsider his/her decision to reject the paper as it seems that the final decision was mainly linked to the potential spectral problem and stays conditional (reviewer's 1 last sentence “As for the final recommendation I am drawn between “reject” and “major revisions”. In the end I opt for the “reject” on grounds that the data processing both for the SST stack and the time series analysis is inadequate to the extent that the spectra may come out quite differently if the sampling rate is corrected, and the spectra are run for the highest-resolving of the records only i.e., Mg/Ca. This may change the main conclusions of the paper and give it a different direction, which in my view warrants a “reject”). Our main conclusions stay unchanged.

Referre comment 5

The observation that “...SST stack and d18Osw records are nearly in phase with changes in high-latitude annual mean insolation” may well be true while the amplitude modulation is off, as is visible in Fig. 2E. Therefore, an immediate mechanistic linking with obliquity modulation of northern hemisphere insolation cannot be claimed without a further discussion of the factors that may have shifted the amplitude away from that of the input signal.

Response 5

In our manuscript, we do not claim that obliquity plays an immediate mechanism to control SST and SSS changes. We mention pp2001 line 11-17: “Changes in high latitude insolation driven by obliquity variations may have controlled the position of the STC along with the shift of the Southern Hemisphere westerlies (Bard and Rickaby, 2009; Biastoch et al., 2009), changes in heat export from the tropics (Jouzel et al., 2007), and sea ice coverage (Knorr and Lohmann, 2003). Poleward shifts of the STC modify recirculation in the Indian subtropical gyre (Bard and Rickaby, 2009),which intensifies heat and salt transfer from the Indian Ocean to the South Atlantic, thus increasing SSTs and SSSs of the AC”. This explanation indicates that the effect of obliquity is not immediate but affects the SST and SSS through different processes: changes in westerlies, heat export, sea ice, STC and recirculation. All these intermediate processes can explain the amplitude modulation from that of the input signal.

Interactive comment on Clim. Past Discuss., 7, 2193, 2011.

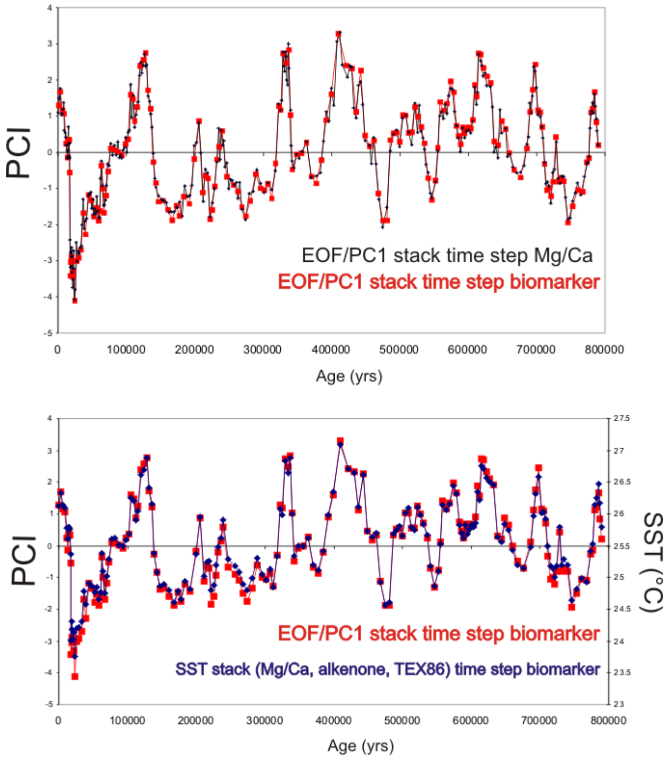
PCI
EOF/PC1 stack time step Mg/Ca
EOF/PC1 stack time step biomarker
Age (yrs)
PCI
SST (°C)
EOF/PC1 stack time step biomarker
SST stack (Mg/Ca, alkenone, TEX86) time step biomarker
Age (yrs)
0
100000
200000
300000
400000
500000
600000
700000
800000

Fig. 1.

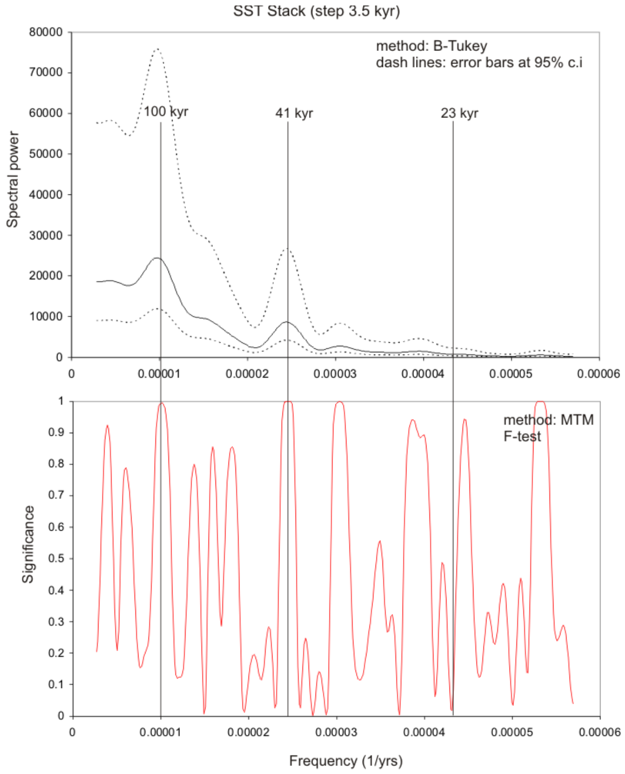
SST Stack (step 3.5 kyr)
method: B-Tukey
dash lines: error bars at 95% c.i
100 kyr
41 kyr
23 kyr
Spectral power
method: MTM
F-test
Significance
Frequency (1/yrs)
0
0.00001
0.00002
0.00003
0.00004
0.00005
0.00006

Fig. 2.

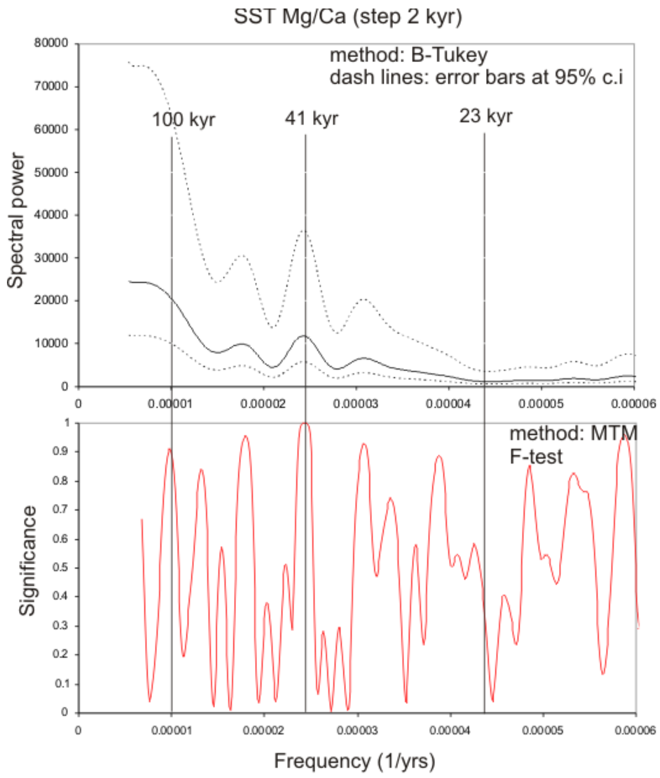
SST Mg/Ca (step 2 kyr)
method: B-Tukey
dash lines: error bars at 95% c.i
100 kyr
41 kyr
23 kyr
Spectral power
80000
70000
60000
50000
40000
30000
20000
10000
0
0
0.00001
0.00002
0.00003
0.00004
0.00005
0.00006
method: MTM
F-test
Significance
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.00001
0.00002
0.00003
0.00004
0.00005
0.00006
Frequency (1/yrs)

Fig. 3.

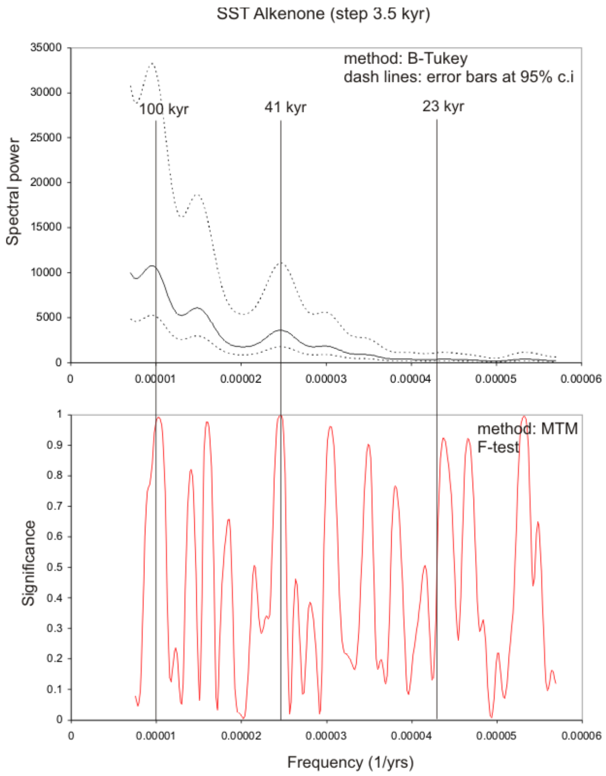
SST Alkenone (step 3.5 kyr)
method: B-Tukey
dash lines: error bars at 95% c.i
100 kyr
41 kyr
23 kyr
Spectral power
35000
30000
25000
20000
15000
10000
5000
0
0
0.00001
0.00002
0.00003
0.00004
0.00005
0.00006
method: MTM
F-test
Significance
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.00001
0.00002
0.00003
0.00004
0.00005
0.00006
Frequency (1/yrs)

Fig. 4.

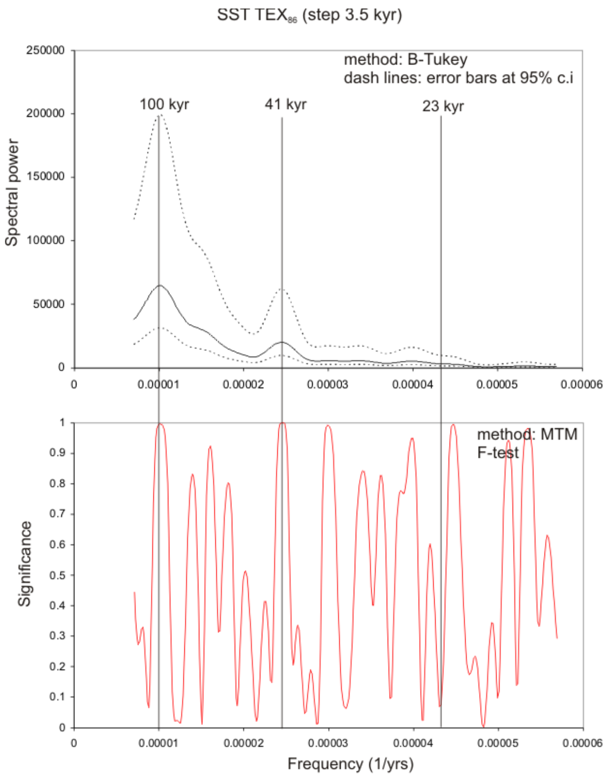
SST TEX$_{86}$ (step 3.5 kyr)
method: B-Tukey
dash lines: error bars at 95% c.i
100 kyr
41 kyr
23 kyr
Spectral power
250000
200000
150000
100000
50000
0
0.00001
0.00002
0.00003
0.00004
0.00005
0.00006
method: MTM
F-test
Significance
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Frequency (1/yrs)

Fig. 5.