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Interactive comment on "Nutrient utilization and diatom productivity changes in the low-latitude SE Atlantic over the past 70 kyr: Response to Southern Ocean leakage" *by* Katharine Hendry et al.

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1 Response to Reviewer 2

The authors present new Si isotope data from core GeoB3606-1 from the Benguela Upwelling System covering the past âĹij70 kyr, since MIS 3-4, which is influenced by variations in water supply/leakage of nutrient-rich waters from the Southern Ocean via Antarctic Intermediate Water. This is generally a very interesting paper. As nicely

outlined in the manuscript, leakage of nutrient-rich waters from the Southern Ocean has been studied and discussed widely in the past in order to explain variations in CO2- drawdown during cold climate periods. However global records between ocean basins and regions vary widely, some indicating addition of nutrients and stimulation of primary production in the lower latitudes, whereas others do not. Eastern boundary upwelling systems, and here especially the Benguela upwelling system, are ideal regions to study leakage theories, because it receives direct water supply from the Southern Ocean via shoaling/upwelling of nutrient-rich Antarctic water. This nutrient rich water is source for intense primary production. And diatoms in upwelling regions have been shown before to react very sensitive to changes in nutrient supply, whereby stable Si isotopes can be used to reconstruct relative utilization of the available nutrient pool. Therefore, the study presented here is of very wide interest and can potentially provide highly useful information for paleoceanographers and paleoclimate studies providing important in- formation on the response of the Benguela upwelling region to nutrient leakage from the Southern Ocean and its effect on the global climate system. Specifically, the paper presents Si isotope data from two large diatom species, which were hand-picked from the sediment samples in order to prevent influence of changing diatom assemblages due to variable environmental conditions and potential species-specific fractionation effects. Furthermore, the Si isotope data are interpreted in context of existing records for bSi content/accumulation, sea surface temperatures (upwelling intensity) etc. Although I generally appreciate the study and the applied methods very much, I have two major concerns about details of the method and interpretation of the Si isotope data that need to be addressed before publication in Climate of the Past.

We would like to thank the reviewer for their positive comments and will address their recommendations for modifications below.

Major Comments: The authors present a "species-specific" diatom Si isotope record, consisting of two diatom species (*A. curvatulus and C. radiatus*), which, as far as I understand, grow under and therefore represent different environmental conditions concerning nutrient status, temperature preference, etc. The Si isotope data are, however, presented as a single isotope record. The diatoms were hand-picked from the record. I generally think is a very good approach for the area and the research question, but it is completely unclear to me how the authors "mixed" the specimens in each sample, i.e. did they made sure to always have the same exact number of specimens from each of the two species in each sample? Could there have been an imbalance according to variations in the relative number of specimens or variations in their size/silicification in each sample over time? The authors acknowledge themselves that we have indications for species-specific fractionation effects for Si isotope in diatoms.

We thank the reviewer for these valid comments. Whilst it is not ideal to mix two species we justify the approach here because i) we needed to obtain sufficient material for analysis and ii) these species are both large centric diatoms with similar ecologies. In the region of the BUS, the major ecological divide for phytoplankton relates to whether or not the species in question resides inside or outside of the main upwelling zone. Both of the diatom species in question here are common in more pelagic waters outside of the upwelling zone.
This has now been emphasised on line 90:
"Compared to A. curvatulus, it represents a more "pelagial" signal. However, both species can be considered as occupying niches outside of the main upwelling zone"
We have also removed reference to the term 'species-specific' where this could be interpretated as referring to our records (abstract and line 273). We have also emphasised on line 104:
"Valves of the two diatom species were combined to allow for enough ma-

terial and because the species diatoms are indistinguishable under a low-magnification binocular microscope (note that low MIS2 data resolution was due to limited valve availability). They were the two only large centric diatoms present in the washed/sieved samples of GeoB3606-1."

Also, the fractionation behaviour for diatoms might change significantly under variable environmental conditions (high/low nutrient concentrations in the surrounding seawater with effects on the influx:efflux ratio of dissolved Si for single diatom cells, potentially affecting the preserved Si isotope ratios). We agree entirely, and we explore these potential changes in environmental conditions in the modelling thought-experiments. The latter suggestion of investigating the impact of influx:efflux on silicon isotope ratios is very poorly constrained in biological systems and we feel this is out of the scope of this study.
The total variation in the d30Si record is 3 per mil, ranging from -1.5 to +1.5. This range is huge compared to any other diatom record published so far. Admittedly, single-species record can have larger variations compared to mixed-species, where variations are rather flattened out. However, to me the explanation/interpretation of this range, and especially the negative values, is quite superficial. The authors assume a constant diatom Si isotope fractionation of -1.1 per mil, and also acknowledge larger possible species-specific fractionation. That's okay. However, assuming the -1.1 per mil fractionation, the most negative values in the record would imply surface water $\delta^{30}Si$ values of -0.4 per mil. This is completely unrealistic. Even in combination with a larger isotope fractionation between diatoms and seawater and other environmental effects in the upwelling region (only mentioned very broadly), I don't see how this is possible. Please explain.

We agree that the record shows very large isotopic variability. As there is no straightforward explanation, we decided to explore possible explanations

with the modelling thought-experiments. We conclude that it's only possible to explain the very light isotope ratios through a combination of changes in upwelling and a divergence fractionation factor (see line 236).
We have emphasised the motivation behind the modelling on line 226:
"Our downcore record reveals strong variability in silicon isotope systematics in the BUS over the late Quaternary, which is challenging to interpret by simple changes one of the many different potential environmental driving mechanisms (e.g. upwelling intensity, biological productivity, oceanic end-member compositions)"
And discussed the challenges with interpreting the light isotopic signature (and, so, the range in isotopic values) on line 235:
"A combination of changes in upwelling intensity, stratification, seawater input and utilisation can act together to change the isotopic differentiation of shallow and deep-water masses. The experiment results also indicate that, in order to achieve the extremely low $\delta^{30}Si_{CA}$ values observed downcore, isotopic fractionation during DSi uptake by A. curvatulus and C. radiatus is likely to be greater than generally assumed, up to -2 , as observed in some diatom cultures of other species. . ."

Additional minor comments: L. 116: delete "(multi-collector-inductively coupled plasma mass spectrometer)", abbreviation has been introduced before

Done.

L. 198: "Quantifying changes to the . . ." I'm not sure that I see the "quantification" in this section.

This has been changed to "Exploring changes to the. . ." (now in line 225).

L. 200: is river input a significant source for dSi in the BUS? Also, what about dust from the arid hinterland? Dust storms towards the upwelling region/open ocean are a regular seasonal feature in the region at least nowadays. Any proposed changes over time there? Could there be variations in Si utilization due to changes in Fe fertilization from dust directly in the region, not just leakage?

This is a good point, which we are happy to discuss and clarify. There is no evidence for a significant fluviatile input along the Namibian coast during the late Quaternary (Shi et al., 2001). Regarding winds, sedimentological studies conducted on the upper Namibian slope (core drilled around 1,000 m water depth, shallower than GeoB3606-1; Pichevin et al., 2005) shows a strong match between stronger wind/drier land conditions and the overall trend of highest diatom values at site GeoB3606-1 from 70 kyr to 36 kyr is evidence for a trade wind effect on the diatom production. Similarly, the increase of SST at site GeoB3606-1 (Romero et al., 2015) corresponds well with the weakened trades intensity after 36 kyr. Although the strength of the trade winds remained strong during MIS2 (Shi et al., 2001), upwelling conditions in surface waters overlying the lower slope off SW Africa became less favourable for diatom production. In other words, the diatoms are responding to upwelling and DSi input more than the trade winds (i.e. the dust supply is not sufficient to promote diatom production).

We have added to the methods section on line 145:

"There is no evidence for a significant fluviatile input along the Namibian coast

during the late Quaternary (Shi et al., 2001). As such, relatively low terrestrial DSi inputs were set as a constant in the model."

We have added the following on line 179:

"The high DSi supply could also have been promoted by strong trade winds, due to enhanced dust supply as a result of drier conditions on land in addition to upwelling of marine sources (Shi et al., 2001; Pichevin et al., 2005)."

And on line 205:

"Although upwelling conditions in surface waters overlying the lower slope off SW Africa became less favourable for diatom production, the strength of the trade winds remained strong during MIS2 (Shi et al., 2001), indicating that dust supply is a secondary control on diatom activity in the Late Quaternary in the SE Atlantic."

Additional references:

Pichevin, L., Cremer, M., Giraudeau, J., Bertrand, P., 2005b. A 190 kr record of lithogenic grain-size on the Namibian slope: Forging a tigh link between past wind-strength and coastal upwelling dynamics. Marine Geology 218, 81-96.

Shi, N., Schneider, R.R., Bueg, H.-J., Dupont, L.M., 2001. Southeast trade wind variations during the last 135 kyr: evidence from pollen spectra in eastern South Atlantic sediments. Earth Planet. Sci. Lett. 187, 311-321.