**Editor Decision: Reconsider after major revisions** (19 Nov 2016) by Dr. Thorsten Kiefer
Comments to the Author:

Dear Dr. Mary and co-authors,

Your manuscript had received two very constructive reviews and a short comment, which are in good agreement with each other. They were enthusiastic about the quality of the dataset you have generated, but ask for more elaborate discussion of the mechanisms behind the observed changes, more linguistically accurate expression of thoughts, more background information about the sediment cores, and clearer provision of inferences and conclusions.

I encourage you to submit a revised manuscript version that addresses the reviewers' requests as appropriate. Of course, as Ref#2 mentions and you also rightly point out in your response, this should not lead to an overinterpretation of the evidence.
Thank you for responding to the review of Referee#1 and to the short comment. It seems, however, that you did not respond to Ref#2 yet. Also your responses to Ref#1 were relatively brief and general, not responding systematically to each referee item one by one. When submitting your revised manuscript, I would therefore ask you to please provide a description of the changes you made, or alternatively, a manuscript version with the (relevant) changes tracked. **Moreover, please respond to the comments of Ref#2 in the form of an Author Comment in the Interactive Discussion**.
Thank you for stating that the data will be made available on Pangaea. I encourage you to archive the data there now already (protected if you want) in order to have them ready for release together with publication.
I look forward to receiving your revised manuscript.
Yours sincerely

Thorsten Kiefer

Dear Editor,
Please find below our reply to suggestions and comments formulated by the two reviewers (and also to the comments from Sebastian Luening).
We integrated all the suggestions they provided to improve this new version and hope we satisfy to their review.
Note that an Author comments (in response to James Scourse review) has been posted on the 08 demeber (***- AC2: 'Author Comment to Ref#2', Frederique Eynaud, 08 Dec 2016 and cp-2016-32-supplement).***

Faithfully yours,
Frederique Eynaud (on behalf of my co-authors)

**CPD Interactive comment on "Changes in Holocene meridional circulation and poleward Atlantic flow: the Bay of Biscay as a nodal point" by Yannick Mary et al.**
**Anonymous Referee #1**
Received and published: 27 April 2016

REPLY to Referee #1:
*(see also **CPD** Interactive discussion **- AC1: 'Reply and acknowledgments to Anonymous reviewer # 1', Frederique Eynaud, 02 May 2016 Printer-friendly Version)***

We really appreciate the constructive comments of Reviewer # 1 and the very stimulating questions he raised.
We have considered his/her remarks and suggestions "to boost" our manuscript for the final revision steps. We apologize for the language and the clumsy phrasing of some sections, and agree that our text is sometimes probably too vague and diluted, we want however to underline that it was thoughtfully revised by a native speaker. We will rewrite key parts of our manuscript in a more direct and persuasive style.
We also completely agree with Reviewer # 1 suggestions on our discussion, i.e. that we could have tried to go a step forward, but were cautious in this version to avoid over-interpretations of the data. Considering Reviewer # 1 advices, we tried to go beyond the simple observations and comparisons initially done, and have thus included additional discussions and a Figure (Figure 6) with a conceptual scheme, gathering and reconciling (if possible) the mechanistic functioning of the SPG during the considered period.

Mary et al present an excellent new Holocene SST data set from the Bay of Biscay, including a very high resolution last 1500 years. Good reproducibility is shown between cores and at existing study sites off the Iberian margin, and many of the signals are seen in existing work further north, into the Nordic Seas. The figures are clearly presented. There are numerous instances where the language of the text could be improved, since the meaning is either unclear or very oddly worded, however I trust copy-editing will pick these up. Overall, the methods and results are very good, yet the discussion and interpretation could be improved.
**My main criticism is that the authors often need to be more specific about precisely what the inferred mechanisms driving the changes are, and what their new insight is.**

The authors draw attention to key findings in the conclusion, but not in the abstract.
They interpret their data, alongside existing datasets, as showing regional differences (subpolar versus subtropical) in the timing and trends of temperature trends, notably between Iberian Margin data (subtropical), and the Bay of Biscay and North Iceland (subpolar**). More specific and clearly worded conclusions regarding the drivers of these trends would be useful. The abstract needs improving by including specific key findings/ results and interpretations.** What is the specific important take home message and why is it important? Be precise.

- ⇨ **Reply**: The abstract and conclusion have been rewritten; see now the new version in the revised manuscript (new sentences/ phrasing in red –correction mode).

Discussion of the results and inferred mechanistic scenarios are sometimes rather general ("a gyre-specific expression of the AMOC"). Can the authors go further than simply stating there are some regional differences across the North Atlantic (which has been demonstrated by numerous authors over the years (eg Moros et al 2006, PaleO; Solignac et al 2006, PaleO; deVernal and Hillaire-Marcel 2006, GPC; Thornalley et al 2009, Nature; Giraudeau et al 2010, QSR)? And perhaps of more importance, the addition of a discussion into why there is such good coherence between surface SST records between the Bay of Biscay and the North Iceland shelf, yet quite different trends to the sub-seasonal thermocline data south of Iceland (see comment for L198-200 below). Given that very different trends are observed between the surface and sub-surface south of Iceland, it seems likely the answer lies in different controls on surface versus sub-surface changes, as discussed by Thornalley et al 2009 – the subsurface being controlled by SPG dynamics whereas the surface being controlled by other factors.

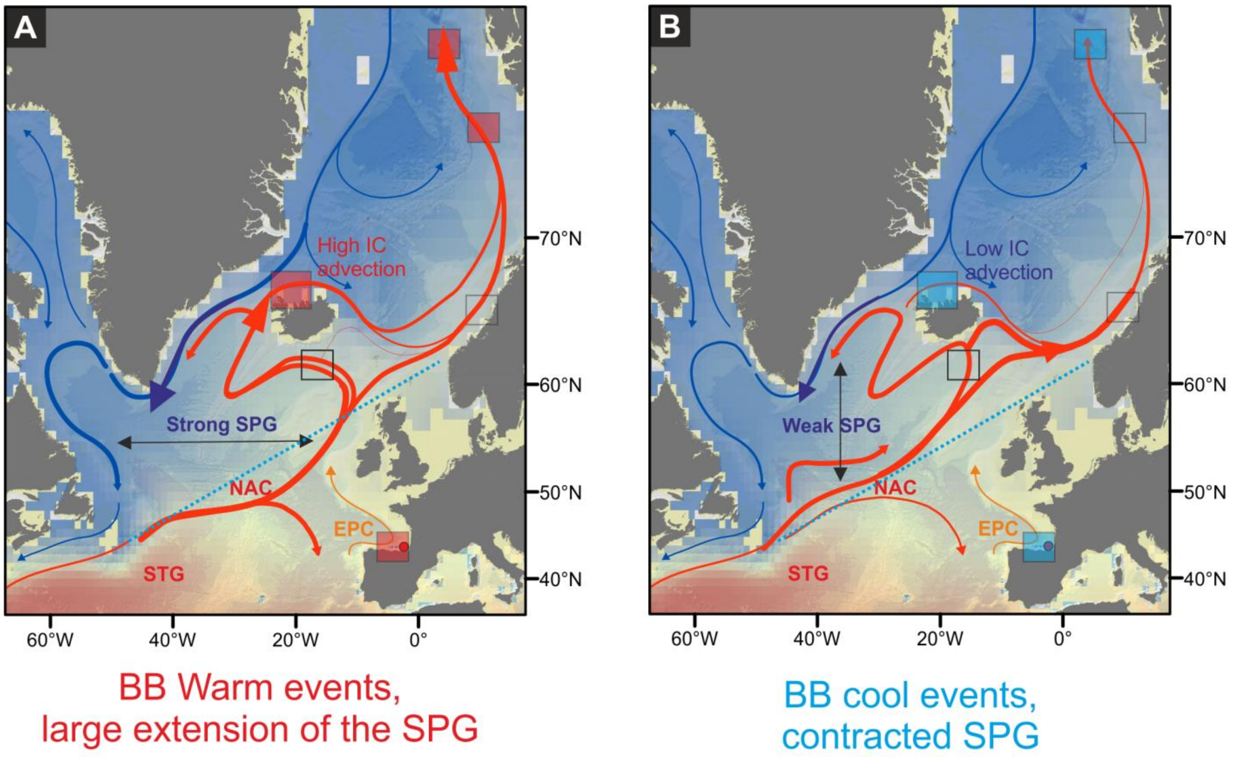
- ⇨ **Reply**: We tried to satisfy this specific remark done by Reviewer 1 by adding new Figures (Figure 5 and 6) compiling additional records and conceptual schemes. Further discussion linked to this new Figures have been introduced in the text (see lines 353 to 374 )

L169-L189 describes these surface changes, including two striking warm intervals, yet there is little discussion about the cause of these events, which are not seen in the subsurface records which are presumably monitoring SPG dynamics. And why is there a good match between the Bay of Biscay SST and the chosen North Iceland Shelf data, but not with numerous other records monitoring the eastern inflow of Atlantic water to the Nordic Seas (see comments for L83-188 below)?

- ⇨ **Reply**: Eastern records have been considered also before our selection, and all depict good resemblance with the Bay of Biscay, even if the pattern is not so clear all over the last 10 ka. As pointed also later by Rev.1, amplitudes are not always comparable and some phasing artefacts due to the age models and to the local context, i.e. important fresh-water and sea-ice advection in the subpolar eastern Atlantic, may bias the comparison. The most resolved ones have been included in the new Figure 5.

This manuscript **could be greatly improved with a little bit more thought and time spent on drawing out the main mechanistic ideas** and how they integrate with broader concepts and existing datasets of North Atlantic Holocene change – trying to be as precise as possible. I strongly encourage the authors to take such efforts since they have a very nice dataset to add to this debate, however, I would find it acceptable if it were published with only minor to its present form, since it does not, in my opinion, have any major factual inaccuracies and does an adequate (albeit limited) job of placing this dataset in context with some existing studies.

⇨ **Reply**: We followed Reviewer 1 advice and have added a conceptual scheme and a Table of bibliographic compilation that will be included in the supplementary information (as Table E2) to tentatively provide a mechanistic scenario. They are also presented below (see the legend in the revised manuscript).




| Forcings/ mechanisms | Bond et al. 2001 | | Thornalley et al. 2009 | | Giraudeau et al. 2010 | | Sorel et al. 2012 | | Staine-Urias et al. 2013 | | Morley et al. 2014 | | Synthesis on BB SST anomalies (This work) integrating the comparison with key Holocene sequences (Fig 4 and 5) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SPG strength**<br>SPG extension | not specified | | "strong "<br>longitudinal (E-W) ↔ | "weak"<br>latitudinal (N-S) ↕ | not specified | | longitudinal (E-W) ↔ | "weak"<br>latitudinal (N-S) ↕ | "strong "<br>longitudinal (E-W) ↔ | "weak"<br>latitudinal (N-S) ↕ | "strong "<br>longitudinal (E-W) ↔ | "weak"<br>latitudinal (N-S) ↕ | "strong" if we follow the consensus but divergent pattern with IC<br>longitudinal (E-W) ↔ | "weak" if we follow the consensus but divergent pattern with IC<br>latitudinal (N-S) ↕ |
| NAO index | | rather NAO- (but not a basin wide expression) | | | NAO like pattern | | NAO+ | NAO- | NAO+ | NAO- | modern conditions | 1930 condtions | NAO+ ? If based on the Medieval anomaly | |
| **Atlantic Inflow in the Nordic seas**<br>IC/ Denmark strait pathway | | | | | low | high | | | not specified | not specified | low inflow | high inflow | high inflow detected at hight latitude of the GIN seas (Barents sea margin)<br>high inflow except at 6 ka | lowest IC inflow |
| South iceland salinity | | | | Saline intervals | | | | | | | | | | saline |
| South iceland upper water stratification | | | | low (negative) density diff | | | | | | | | | Different patterns if late or early Holocene | rather low (negative) density diff |
| Westerlies/ Europe | | | | decreasing wind stress | | | | shifted to the south | strong, warmth/ moist | | | | | |
| **Storms over Europe**<br>Climate over Europe | | | | | | | **low activity** | **high activity**<br>cool events | | | | | **low activity**<br>Warm | **high activity**<br>Coolings |
| Freshening/ export of sea-ice along Greenland | low | high | increase | | low | high | | | | | | | Different patterns if late or early Holocene (residual ice-sheet melting ?) | |
| Solar (nuclide production) | minima | maxima | | | | | | | | | | | Not obvious see reply to Sebastian Luening' comment and Figure 5 | |

**More specific comments:**

L24: Is the Bay of Biscay a nodal position? How so? Often frontal shifts are envisaged shifting about a modal position of Newfoundland...

**Reply**: to reinforce this idea, we have added a zoom on the last centuries which monitor SST changes from different regions and their trends along this period (see also the reply to Rev 2 - First Figure).

L30: I question whether this study actually offers unprecedented resolution (I would remove). Perhaps unprecedented for Bay of Biscay, but certainly not for the North Atlantic

**Reply**: the term "unprecedented" has been changed (see also the reply to Rev 2 ).

Abstract: More generally this should also include a summary of the key findings, rather than just a brief description of the study site and methods.

**Reply**: done, see first reply above.

L37: I find the implication that the AMOC controls the 'frequency' of climate over Europe confusing - what do you mean specifically (and cite ref.)

**Reply**: we rephrased the sentence and introduced references which were deleted with the first sentence of this section (as recommended in Technical corrections of Rev.1).

L46-48: This sentence uses a lot of jargon to say very little.

L47-49: the relevance of this sentence to the study is not that obvious.

**Reply**: deleted.

L56: why is the Bay of Biscay ideally located? One could argue that sites further NW are closer to the STG/SPG boundary and so more sensitive to monitoring these changes.

**Reply**: we hope that the new insert (C) added in Figure 1 monitoring the last centuries will convince Rev 1 and the readers about the key location of the site. Further arguments are also added in the text line 70 to 77.

L139: provide reference for support

**Reply**: done. Line 158

L183-188: There are of course numerous other SST records available from the Nordic Seas under the path of the Inflow and NwAC (eg Risebrobakken et al 2003, Giraudeau et al 2010, Rasmussen and Thomsen 2010) that have not been shown, many of which do not show similar patterns to the Bay of Biscay SST data. It would be interesting to think more about these different records, and more specifically why the Irminger Current/North Iceland shelf shows similar trends to the Bay of Biscay, but not the Faroe branch of the NAC (or at least a more mixed signal is seen in the NwAC and Barents Shelf), especially since one might initially expect a more direct link between the eastern limb extension of the NAC and the eastern located Bay of Biscay.

**Reply**: These records were all considered before the selections. Actually, in the frame of the ANR HAMOC, we have built a database selecting high resolution records notably obtained on the basis on planktonic foraminifera (see http://hamoc-interne.epoc.u-bordeaux1.fr/doku.php?id=start&#news). The new Figure 5 compiles those presented in the Risebrobakken et al., study (MD95-2011 /MD99-2284) in 2013. (see also the reply to Rev 2 ).

L198-200: This is incorrectly worded; more care is needed. The density anomalies in Thornalley et al are a combination of changes due to SPG driven changes in the seasonal sub-thermocline, and other changes in the surface water. Changes in the G. inflate record alone were interpreted as a SPG strength proxy, not the density difference, as plotted by Mary et al. Perhaps a case could be made that by taking the difference between the surface and the sub-thermocline layer removes any larger scale changes in SST and SSS, and helps isolate the SPG strength signal, although this would be at odds with Fig 3 in Thornalley et al 2009.

**Reply**: we have possibly over-interpreted the Thornalley et al., 2009 record but our interpretation was based on their caption in Figure 2 (see below). We reproduced on Figure 4 the density difference curve.

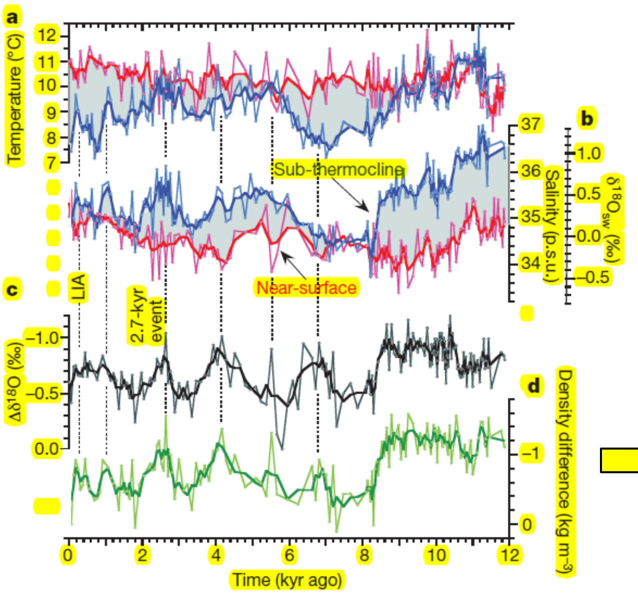
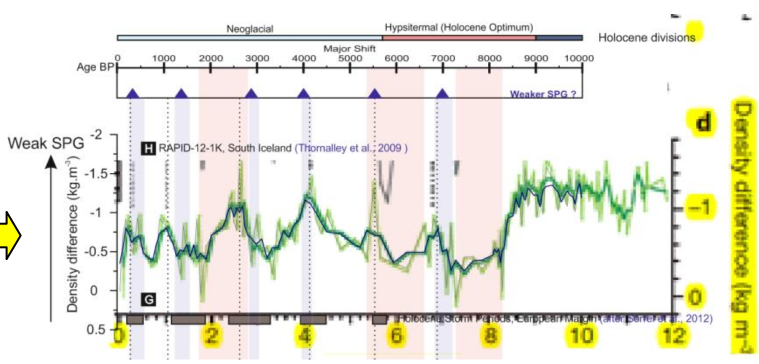



**Figure 2 | Proxy records for RAPiD-12-1K.** **a**, **b**, Mg/Ca-based temperatures (**a**) and salinity estimates derived from paired Mg/Ca–$\delta^{18}O$ measurements (**b**), for near-surface (*G. bulloides*, red) and sub-thermocline (*G. inflata*, blue) waters. Also shown is a scale bar for $\delta^{18}O_{sw}$ values, corrected for whole-ocean ice-volume changes. **c**, **d**, Proxies for upper-water-column stratification (stratification increases upwards) based on the $\delta^{18}O$ difference between *G. bulloides* and *G. inflata* (**c**) and the inferred water density difference between *G. bulloides* and *G. inflata* (**d**), calculated using derived temperatures and salinities. Three-point running means shown in bold. LIA, Little Ice Age.




L203: The assertion that changes in density anomalies reported by Thornalley et al 2009 are synchronous with cold spells in Mary et al's record is unconvincing. Major features are sometimes in phase or out of phase. (The match between periods of storm activity and the SST data of this study is also not that striking.) This is not a major weakness in the paper, and perhaps it simply reflects that the Bay of Biscay SST is only weakly sensitive to expansion/contraction of the subpolar gyre, and at times these signals are dominated/swamped by other controls (perhaps of a more local origin, or of subtropical origin). Or the surface temperature records are less sensitive for monitoring changes in subpolar gyre dynamics than deeper thermocline records. Perhaps it would be worth adding such a caveat, rather than stretching the data comparison too far and inferring close relationships when they don't seem convincing. Yet the similarity between the Bay of Biscay SST and the North Iceland Shelf records is good.
**Reply**: The nuances in the peak to peak correlation have been added in our text line 221.

**The question is therefore how to explain the coherence between the Bay of Biscay and North Iceland SST records**, and the different trends seen in the sub-seasonal thermocline data south of Iceland. Given similar differences are seen between the surface and sub-seasonal thermocline records at the same site south of Iceland (and if anything, the surface temperature data at this site looks more like the Bay of Biscay and North Iceland SST data – albeit not the similar!), rather than the explanation being found in regional differences, it is perhaps likely that it is to do with surface versus subsurface changes.
**Reply**: we expanded our discussion but lack additional subsurface data in the Bay of Biscay to introduce such a debate without over-interpretation. This will be done in a further study as works are ongoing in the frame of the French ANR HAMOC.

L210: please explain this inferred atmosphere-ocean interaction - be more specific. Changed, see line 232

L294: 'a decoupling of subpolar gyre dynamics' from what? This is unclear. Changed, see additional discussion section line 328

L300: please use alternative phrase to 'gyre-specific expression' – in essence you mean there are differing SST changes and trends in the subtropical and subpolar regions (or at least at the sites you discuss). Changed, see line 326

L312: unclear. What is meant by 'contrasted patterns'? Changed, see 361

*Technical corrections:*
L23: add 'in the subpolar North Atlantic to the end of first sentence' Already in the original version but we deleted sub-polar

L34-35: remove this sentence - it adds nothing, and just reads oddly Removed
L49: ’rightly’ should be ’correctly’ The corresponding sentence has been deleted.
L95: replace ‘onwards’ with ‘using a’ Corrected
L173: please refer to figure panel this relates to Done
L191: replace’-1oc’ with ’1oC cooler’, otherwise it might be misread as if the temperature was -1oC! Done
L283: replace ‘extensions’ with ‘expansions’ Done
L605: add labels for what blue triangles are to figure caption Done
L630: the plot is the density difference between the near-surface and base of the seasonal thermocline, not density anomalies at sub-thermocline depths as written in caption. Corrected

**Interactive comment on "Changes in Holocene meridional circulation and poleward Atlantic flow: the Bay of Biscay as a nodal point" by Yannick Mary et al.**

**Sebastian Luening,** luening@uni-bremen.de

Received and published: 30 April 2016

An excellent paper which fills important data gaps. Thanks for this new study. I have two minor points that I would like to raise:

REPLY to Sebastian Luening:
*(see also **CPD** Interactive discussion **- SC2: 'Reply and Comments to Holocene Bond Cycle', Yannick Mary, 04 May 2016)***

We are very grateful for your positive comments and interesting suggestions, and have integrated your comments in the revisions.

1) In the text you cite Mojtahid et al. (2013) which however is not in the reference list and needs to be added.
**Reply**: The reference to the article of Mojtahid et al., (2013) is actually mentioned in the reference list (L454), although not at the correct position. This has been corrected in the final version. We apologize for the mistake and thank you for spotting it.

2) You describe very interesting Holocene millennial-scale cycles. A typical data set from the North Atlantic against which such cycles are usually compared is from Bond et al. 2001. The Bond cycles were demonstrated to be solar-driven. http://science.sciencemag.org/content/294/5549/2130 It would be great if this comparison could be added to the paper.
**Reply**: **The new Figure 5 integrates Bond et al., 2001 data together with the Roth & Joos, 2013 dataset.** Regarding the Solar forcing (as previously mentioned in the interactive discussion), short-lived cold spells recorded in the SST signal of core PP10-07 at 8.2, 7, 4, 2.9 and 1.7 ka BP indeed show similarity with the so-called "Bond cycles", at ca 8, 6, 4.5, 3, 1.8 and 0.5ky (Bond et al., 2001). However, the very short duration of these events in the Bay of Biscay calls for a derived phenomenon rather than a direct influence of solar forcing on SST oscillation. Though, comparing the SST signal of PP10-07 core with Bond cycle proxies, such as drifted ice indices, or directly with solar irradiance signal is a challenging suggestion we were tempted initially to do. This comparison is indirectly done in our paper thanks to the comparison with the Sorel et al. millennial-scale storminess maxima we refer to. These authors concluded that the solar forcing was not a primary trigger but did not excluded its possible influence as a weak external driver. For information, a similar comparison was done and discussed at the scale of the last 2 ka BP in our 2015 paper (Mary et al., 2015).
Moreover, Morley et al., (2014) suggest that the strength of the Latitudinal Thermal Gradient (LTG), driven by contrasting distribution of insolation between polar and tropical latitudes, impacts meridional heat transport by oceanic systems and associated teleconnections. A sharp increase of the LTG occurs around 2000 BP. Such forcing may enhance NAC inflow toward northern latitude, which may explain the large, multi-millennial scale anomalies visible on the Bay of Biscay.

## References

*Bond, G., Kromer, B., Beer, J., Muscheler, R., Evans, M.N., Showers, W., Hoffmann, S., Lotti-Bond, R., Hajdas, I., Bonani, G., 2001. Persistent solar influence on North Atlantic climate during the Holocene. Science 294, 2130–2136.*

*Mary, Y., Eynaud, F., Zaragosi, S., Malaizé, B., Cremer, M. and Schmidt, S.: High frequency environmental changes and deposition processes in a 2 kyr-long sedimentological record from the Cap-Breton canyon (Bay of Biscay), The Holocene, 25, 348–365, doi:10.1177/0959683614558647, 2015.*

*Mojtahid, M., F.J. Jorissen, J. Garcia, R. Schiebel, E. Michel, F. Eynaud, H. Gillet, M. Cremer, P. Diz Ferreiro, M. Siccha and H. Howa, (2013), High resolution Holocene record in the southeastern Bay of Biscay: Global versus regional climate signals. Palaeogeography, Palaeoclimatology, Palaeoecology 377, 28–44. doi:10.1016/j.palaeo.2013.03.004*

*Morley, A., Rosenthal, Y., deMenocal, P., 2014. Ocean-atmosphere climate shift during the mid-to-late Holocene transition. Earth and Planetary Science Letters 388, 18–26. doi:10.1016/j.epsl.2013.11.039*

*Roth, R., Joos, F., 2013. A reconstruction of radiocarbon production and total solar irradiance from the Holocene <sup>14</sup>C and CO<sub>2</sub> records: implications of data and model uncertainties. Climate of the Past 9, 1879–1909. doi:10.5194/cp-9-1879-2013*

*Sorrel, P., Debret, M., Billeaud I., Jaccard S.L., McManus J.F., and Tessier B.: Persistent non-solar forcing of Holocene storm dynamics in coastal sedimentary archives, Nature Geoscience 12, 892–896. doi:10.1038/ngeo1619, 2012.*

**CPD** Interactive comment **on "Changes in Holocene meridional circulation and poleward Atlantic flow: the Bay of Biscay as a nodal point" by Yannick Mary et al., by J. Scourse (Referee)**
Received and published: 17 August 2016

REPLY to James Scourse:
*(see also **CPD** Interactive discussion **- AC2: 'Author Comment to Ref#2', Frederique Eynaud, 08 Dec 2016 and cp-2016-32-supplement)***

We acknowledge the positive review of James Scourse on our paper and thank him for all the good suggestions and perspectives his review brings to our study. All the comments done have been considered for the revision.

JS: Mary et al. present an excellent high resolution record of Holocene palaeoceanographic changes (SST) from the southern Bay of Biscay based on two closely positioned cores. The SST record is based on MAT transfer functions on planktonic foraminiferal assemblages and is compared with other palaeoceanographic records from the Biscay/Iberian margin and the wider North Atlantic. The raw planktonic foram dataset is excellent and the way in which the transfer function has been applied is well explained. The data for the Roman Warm Period interval and their correlation with the wider North Atlantic datasets for this period are impressive. Records of this quality covering the entire Holocene are not common and it is important that the data are published. **However,**
**1. in places I feel there is a tendency to over-interpret the record,**
**2. Sometimes the explanation is not as clear as it might be,**
**3. some fundamental contextual information is lacking,**
**4. independent lines of evidence to corroborate the transfer function SST reconstruction are lacking, and**
**5. most importantly, there are some generalized statements not supported by either numerical model simulations or tests of statistical significance.**

**Reply**: all these flaws are now corrected based on the whole review procedure. We have especially introduced new Figures and text sections to reinforce our observations and findings.

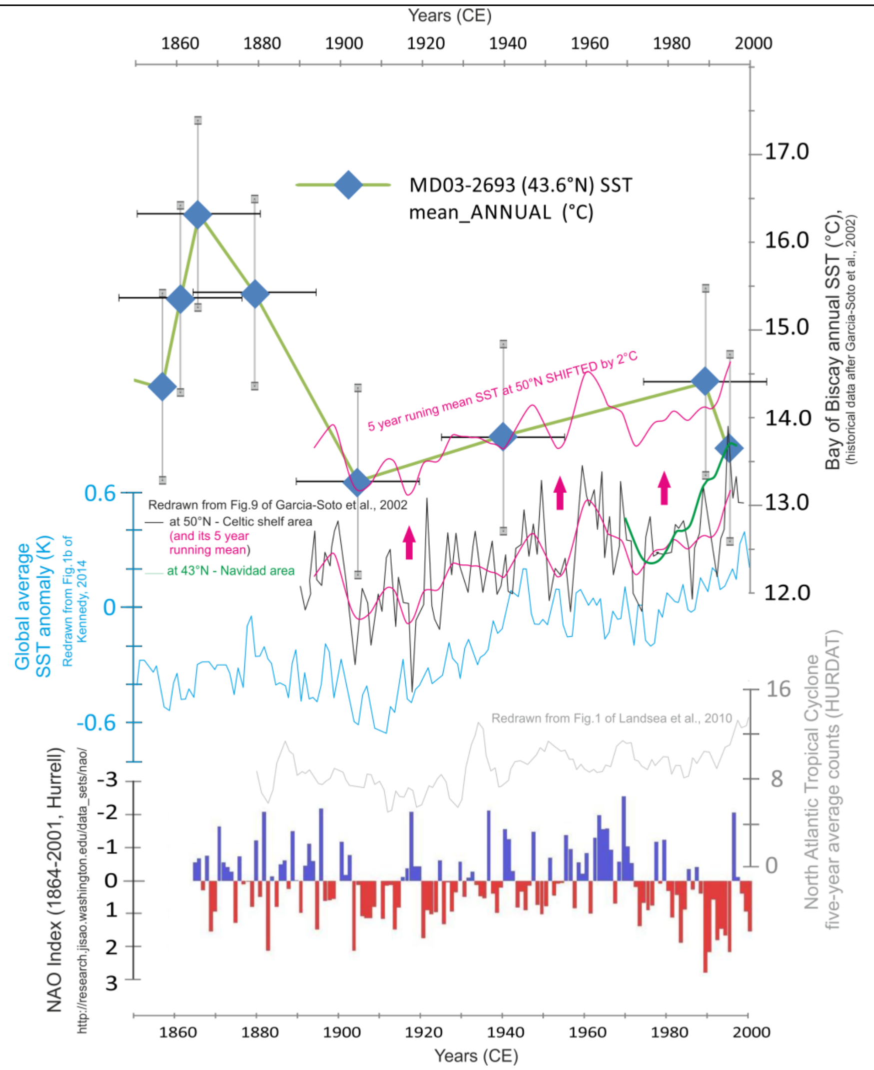
JS: At the outset (and in the Abstract) the authors emphasize **the strategic location of the core sites in the context of the wider North Atlantic circulation/AMOC**. It would be good to support this assertion with some spatial correlation plots between this site and wider North Atlantic SST/SSS fields over the calibration period. **What key elements of the surface circulation correlate with SSTs at this location?** The core locations are actually quite distal from the main centres of North Atlantic hydrographic variability so firming up this relationship with evidence is important. There is significant discussion in the Introduction on the relationships between the regional hydrography and the wider North Atlantic circulation, and with modes of North Atlantic climate variability (AMO/NAO) but this remains (and feels) speculative unless it can be supported by evidence.

**Reply**: many of the questionings legitimately raised by James Scourse about the context of the sites and the related forcings were in fact already considered in details in the Mary et al. (2015) paper - *ref: The Holocene Vol. 25(2) 348-365, DOI: 10.1177/0959683614558647*- which focusses on the MD03-2693 record. A very detailed description of the hydrological and sedimentological contexts is published in this article and we wanted to avoid repetitions in this new paper; we have however documented the modern hydrography and its modulation in the present article as a summary based on modern oceanographer's works (see line 63 to 88). The work of Garcia-Soto, Pingree et al. over the last 15 years are especially worth to consider as tests against the dominant climatic modes were done regarding regional SST data ("Navidad structure and timing", e.g. Garcia-Soto et al. 2002).

**To reinforce the idea of the Bay of Biscay strategic location, an additional Figure has been included within Figure1 (i.e. Figure 1C below) and the citation of Mary et al. 2015 synthesis introduced when needed in the text.** This new Figure 1C is built upon the last centuries and thus compiles the modern contextual hydrography and climate trends. To further test our reconstructions (even of very low resolution at this time scale, done on core MD03-2693, see Mary et al., 2015 for further elements), a 2°C shift in the modern annual SST mean (5 year running average after Garcia-Soto et al., 2002) has been applied for stressing the comparison with our study area. This value of 2 °C is justified by the southern and confined position of our sites within the Bay of Biscay which register the warmest oceanic conditions at this latitude in the North Atlantic (see also our argumentation in ***- AC2: 'Author Comment to Ref#2', Frederique Eynaud, 08 Dec 2016 and cp-2016-32-supplement).***

We tested also this shift values with the WOA sample tool (Table below, http://www.geo.uni-bremen.de/cgi-bin/woasample.pl):

| | LONG | LAT | Modern mean **Annual** SST (°C) | Modern mean **JFM** SST (°C) | Modern mean AMJ SST (°C) | Modern mean **JAS** SST (°C) | Modern mean OND SST (°C) | Nb point | **SST Seasonality modern range (°C)** |
|---|---|---|---|---|---|---|---|---|---|
| PP10-07 | -2.23 | 43.68 | **15.63** | **11.95** | 15.09 | **20.08** | 15.42 | 1 | **8.135** |
| Celtic margin area | - 4 | 50 | **12.322** | **9.705** | 11.078 | **15.369** | 13.135 | 2 | **5.66** |
| FROM: http://www.geo.uni-bremen.de/cgi-bin/woasample.pl, last consult 05/12/2016 | | | | | | | | | |




***New Figure 1C: SST evolution over the last centuries in the Bay of Biscay (from the MD03-2693 sedimentological record and from the compilation of Garcia-Soto et al., 2002) and comparison with the Global SST anomaly (after Kennedy, 2014), the Atlantic Tropical Cyclone Counts (after Landsea et al. 2010) and the NAO index of Hurell (http://research.jisao.washington.edu/data_sets/nao/).***

***REF:*** *Kennedy, J.J., 2014. A review of uncertainty in in situ measurements and data sets of sea surface temperature: IN SITU SST UNCERTAINTY. Reviews of Geophysics 52, 1–32. doi:10.1002/2013RG000434*
*Landsea, C.W., Vecchi, G.A., Bengtsson, L., Knutson, T.R., 2010. Impact of Duration Thresholds on Atlantic Tropical Cyclone Counts*. Journal of Climate 23, 2508–2519.*

This exercise (new compilation in insert FIGURE 1C) shows that (as already stated by physical oceanographers) a poor link exist with the NAO, even if modulations in SST oscillations seem to be coherent from a region to another. Not added on this Figure, but tested also, is the link with the Atlantic Multidecadal Oscillation (AMO) which, as stated by Garcia-Soto & Pingree (2012) is not straightforward but, probably, the most coherent driver of SST changes in the area.

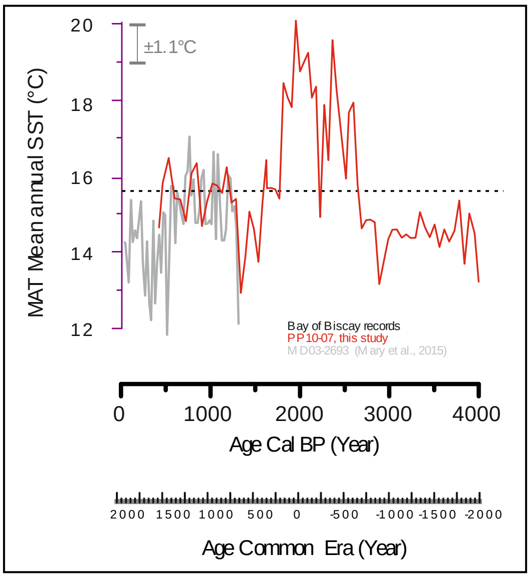
JS: In terms of the excellent reconstructed time-series for the last 2000 years, how do these compare with the CMIP5 simulations, and the earlier data with the CMIP5 mid-Holocene simulations?

**Reply**: This very stimulating question is not trivial as our reconstructed data are regional sea-surface temperatures and none of the products released up to now by CMIP5 (or the related PMIP3 experiment) are thus directly comparable. However, this is also one of the targets of the French ANR HAMOC project – see http://hamoc-interne.epoc.u-bordeaux1.fr/doku.php?id=start&#news - and works are thus ongoing within the involved French teams. This was not possible at this step to include a model-data comparison.

JS: Whilst the quality/resolution of the foram-based transfer function SSTs are not in question**, I would have liked to see some corroboration from independent data (e.g. oxygen isotopes, trace element ratios, alkenones) of at least sections of the record.**

**Reply**: Additional independent data (here XRF elemental ratio measured in PP10-07) have been added on the new Figure 5 (built to support mechanistical interpretations as required by Rev.1): we thus added in the revised article: XRF ratio (Ca/Si, Rb/Sr the latter being a grain-size proxy) and planktonic foraminifera absolute abundances in PP10-07

JS: The PP10-07 long Holocene record is spliced with data for the last 2000 years from MD03-2693; what are the correlation statistics for this overlap?




**Reply**: The overlap is absolutely not "forced": we have not changed anything in the age models to fit or tie our records.
The statistics of the recovery are thus poor but that was not the purpose of the present work. For sure, with additional data and datings a composite record could be built since the coherency of the reconstructed SST is very strong and within the error bar (see the Table and Figures provided with the ***- AC2: 'Author Comment to Ref#2', Frederique Eynaud, 08 Dec 2016 and its cp-2016-32-supplement***).

JS: It is essential to provide some key information about the cores at the start of the Methods section. I note that the water depths are included in Table 1, but what is the geomorphological context of the core locations, why does the sedimentation rate differ so much between the two cores, what are the sediment sources to these locations including biogenic/lithic ratios and, in particular, what is the local hydrographic regime at this location and how does it relate to the wider North Atlantic circulation discussed above? It is also essential at this point to present lithostratigraphic logs for the cores. **Unless these data have been published elsewhere they should be included here, or in the Supplementary info.**

**Reply**: All the geomorphological and sedimentological contexts, as well as the lithostratigraphic descriptions of the cores have already been provided in details in the following references (cited in our article):

Gaudin, M, Mulder, T., Cirac, P., Berne, S., and Imbert P.: Past and present sedimentation activity in the Capbreton Canyon, southern Bay of Biscay, Geo-Marine Letters 26, 331–345, 2006.

Brocheray, S., Cremer, M., Zaragosi, S., Schmidt, S., Eynaud, F., Rossignol L., and Gillet, H.: 2000 years of frequent turbidite activity in the Capbreton Canyon (Bay of Biscay), Marine Geology, 347, 136–152, doi:10.1016/j.margeo.2013.11.009, 2014.

Mojtahid, M., Jorissen, F.J., Garcia, J., Schiebel, R., Michel, E., Eynaud, F., Gillet, H., Cremer, M., Diz Ferreiro, P., Siccha, M., and Howa, H.: High resolution Holocene record in the southeastern Bay of Biscay: Global versus regional climate signals, Palaeogeography, Palaeoclimatology, Palaeoecology, 377, 28–44. doi:10.1016/j.palaeo.2013.03.004, 2013.

Mary, Y., Eynaud, F., Zaragosi, S., Malaizé, B., Cremer, M. and Schmidt, S.: High frequency environmental changes and deposition processes in a 2 kyr-long sedimentological record from the Cap-Breton canyon (Bay of Biscay), The Holocene, 25, 348–365, doi:10.1177/0959683614558647, 2015.

Furthermore, calibration on modern planktonic foraminifera populations have been conducted within the following papers:

Retailleau S., Eynaud F., Mary Y., Schiebel R., Howa H., 2012. An Ocean - Canyon head and river plume: how they may influence neritic planktonic foraminifera communities in the SE Bay of Biscay?, Journal of Foraminifera research 42(3), 257–269

Retailleau S., Howa H., Schiebel R., Lombard F., Eynaud F., Schmidt S., Jorissen F., Labeyrie L., 2009. Planktic foraminiferal production along an offshore-onshore transect in the south-eastern Bay of Biscay. Continental Shelf research 29 (8), 1123-1135

These last references have been added in the text (lines 171-172)

**Detailed comments:**

Some small grammatical/word selection changes are suggested on the attached annotated pdf.
**Reply**: all the detailed comments have been considered for the revision and we thank JS for his patient editing of our manuscript.

JS: Line 30 (and elsewhere): the records are described **as being of “unprecedented” resolution.** This has to be more specific – unprecedented for this region, for the North Atlantic? There are certainly sediment-based records of comparable resolution elsewhere and this record does not compare with annual-banded records of SST (coral, bivalves).
**Reply**: we agree that we have to be more specific but wanted to stress out that, up to now, none comparable SST record exists for a 10 ka long and continuous interval (with such a regular time slice). We have however modulated our sentence.

Line 34: be more specific over the temporal frequency being referred to here. **Reply**: this sentence was deleted (see Rev1 comments)

Line 49: “latitudinal and/or longitudinal migrations”: do you literally mean migrations or intensification/relaxation of gyre circulation? **Reply**: sentence changed, see line 58/59

Lines 53-54: “this paper aims at testing Western European temperate oceanic signals vs. those from a broader North Atlantic view with a focus on the SPG dynamics”: what is meant by “Western European temperate oceanic signals and how are these separated from broader North Atlantic/SPG dynamics. This seems a bit vague/loose to me.
**Reply**: changed by “at testing Western European temperate oceanic signals *vs*. those from a broader North Atlantic…” and simplified, see line 64

Lines 94-96: this sentence requires rephrasing. **Reply**: change by “Here we present past Holocene SST data reconstructed after an ecological transfer function based on the Modern Analogue Technique (see Methods) applied to planktonic foraminiferal assemblages.” The following sentence has also been slightly modified. see line 111

Line 128: what is an “undated point” in a surface sample dataset? **Reply**: changed by “non-stratigraphically constrained”

Line 156: what is meant by “focused” in this context? **Reply**: changed by ”studied”

Line 171: what do you mean by “typical”? **Reply**: changed by ”characteristic”

Line 187: what do you mean by the “modulation of the split” between the SPG and STG? **Reply**: changed and simplified by ”…and to its split between the SPG and the STG”.

Lines 321-323: this is the last line of the Conclusion and I’m not clear what it actually means. **Reply**: reformulated

Figure 1: “seasonal” spelling in figure legend. ? **Reply**: corrected

# Changes in Holocene meridional circulation and poleward Atlantic flow: the Bay of Biscay as a nodal point

Mary, Yannick (1), Eynaud, Frédérique (1), Colin, Christophe (2), Rossignol, Linda (1), Brocheray, Sandra (1, 3), Mojtahid, Meryem (4), Garcia, Jennifer (4), Peral, Marion, (1, 5), Howa, Hélène (4), Zaragosi, Sébastien (1), Cremer, Michel (1)

*(1) Laboratoire Environnements et Paléoenvironnements Océaniques et Continentaux (EPOC) -UMR 5805, Université de Bordeaux, 33615 Pessac, France*
*(2) Laboratoire Géosciences - Université de Paris-Sud, 91405 Orsay Cedex, France*
*(3) now at: Institut Polytechnique LaSalle-Beauvais – Dpt Géosciences, 19 rue Pierre Waguet – BP 30313 – 60026 Beauvais, France*
*(4) UMR CNRS6112 LPG-BIAF, Recent and Fossil Bio-Indicators, Angers University, 2 Bd Lavoisier, 49045 Angers CEDEX 01, France*
*(5) now at Laboratoire des Sciences du Climat et de l'Environnement (LSCE-IPSL), Domaine du CNRS, bât.12 - 91198 Gif-sur-Yvette, France*

***Keywords***

Meridional circulation, Bay of Biscay, Holocene, Sea surface temperature, North Atlantic, Subpolar and Subtropical Gyres

***Abstract***

This paper documents the last 10 ka evolution of one of the key parameters of climate: sea-surface temperatures (SST) in the ~~subpolar~~ North Atlantic. We focus on the southern Bay of Biscay, a highly sensitive oceanographic area ~~because of its strategic and nodal position~~ regarding the dynamics of the North Atlantic subpolar and subtropical gyres (SPG and STG respectively). This site furthermore offers unique sedimentary environments characterized by exceptional accumulation rates, enabling the study of Holocene archives at (infra)centennial scales. Our results mainly derive from planktonic foraminiferal association analysis on two cores from the southern Landes plateau. These associations are used as the basis of Modern Analogue Technique transfer functions~~were used as quantitative tools (thanks to the Modern Analog Technique)~~ to track past hydrographical changes. SST reconstructions were thus obtained at an ~~unprecedented~~ exceptional resolution and compared to a compilation of Holocene records from the north-eastern North Atlantic. From this regional perspective are shown fundamental timing differences between the gyre dynamics, nuancing classical views of a simple meridional overturning cell. Our study highlights that western Europe underwent significant oscillations of (annual) SST during the last 10 ka.

During well know intervals of mild boreal climate, warm shifts of more than 3°C per centuries are accurately concomitant with positive sea-surface temperature anomalies and rise of micropaleontological indicators of gyre dynamics in the northern North Atlantic, pointing to periods of greater intensity of the North Atlantic Current (SPG cell especially) . Conversely, SST signal records short-term cold anomalies which could be related to weaker SPG dynamics.

## 1. Introduction

At climatic and shorter meteorological scales, the key role of the North Atlantic oceanic circulation in climate changes is no longer debatable (e.g., Clark et al., 2002; Bryden et al., 2005). The Atlantic Meridional Overturning Circulation (AMOC) and its dynamics are critical regarding the amplitude and frequency of the modulations of climate (amplitude and frequency) modulations over Europe (westerlies, droughts and/or stormy periods, e.g. Clark et al., 2002; Bryden et al., 2005; Dawson et al., 2007; Magny et al., 2003; Sorrel et al., 2009; Trouet et al., 2012, Van Vliet-Lanoe et al., 2014a and b, Jackson et al., 2015). The two relatedconnected North Atlantic gyres, the subpolar gyre (SPG) and the subtropical gyre (STG) are fundamental for these processes as they transfer heat and salt toward the Nordic seas (e.g., McCartney and Mauritzen, 2001; Perez-Brunius et al., 2004; Hatun et al., 2005; Morley et al., 2014) where convection occurs (e.g. Lozier and Stewart, 2008). Their expansions and contractions notably control the inflow from the North Atlantic Current (NAC) to higher latitudes, thus also affecting the heat budget of the Greenland-Iceland-Norwegian seas, which is critical in the meridional climatic balance (i.e., Hatun et al., 2005, Thornalley et al., 2009). However, complex feedbacks force nonlinear responses within the Earth's radiative budget, preventing climate sciences from providing a precise view of which processes are at play; the incapacity of models to "correctly" represent the last decade of instrumental data is one of the strongest illustrations of this appraisal (e.g., Ba et al., 2014; Karl et al., 2015; Fyfe et al., 2016).

During the late Holocene, changes in the STG and SPG latitudinal and/or longitudinal migrations dynamics contributed to well-known climatic anomalies in Western Europe, such as the Little Ice Age or the Medieval Warm Period/Anomaly, and probably played a major role at longer time scales (Thornalley et al., 2009; Colin et al., 2010; Copard et al., 2012; Sorrel et al., 2012; Staines-Urias et al., 2013; Morley et al., 2014;).

By providing the first Holocene inventory of (infra)centennial hydrographic changes in the inner Bay of Biscay, this paper aims at testing Western European temperate oceanic signals *vs.* those from a broader North Atlantic view with a focus on the SPG dynamics, this latter being seen as a key component of the AMOC variability (e.g. Hatun et al., 2005; Thornalley et al., 2009; Colin et al., 2010). Our study site

**Mis en forme :** Surlignage

(Figure 1) is ideally located under the temperate eastern limb of the NAC, in the southern Bay of Biscay and ~~close~~ not far from the~~to~~ STG/SPG divergence zone (e.g. Planque et al., 2003). This geographic configuration provides to this marine environment a high sensitivity regarding Northern hemisphere climatic signals at present (e.g. Le Cann and Serpette, 2009; Esnaola et al., 2012; Garcia-Soto and Pingree, 2012), echoing pan-Atlantic hydrographical changes, somewhat with amplified responses. Actually, the southern Bay of Biscay records at present the warmest SST (especially in summer) of the mid-latitude temperate band of the North Atlantic with a significant warming trend over the last decades (e.g. Koutsikopoulos et al., 1998; Valencia et al., 2003; deCastro et al., 2009, see also maps at http://www.nodc.noaa.gov/cgi-bin/OC5/woa13fv2/woa13fv2.pl?parameter=t). Previous works done on sedimentary archives in the same area have ~~with some sedimentary archives~~ furthermore ~~evidencing~~ evidenced a strong potential to track down the Holocene variability (Mojtahid et al., 2013; Garcia et al., 2013; Brocheray et al., 2014; Mary et al., 2015).

Today, the Bay of Biscay is characterized by a complex, variable sea-surface circulation with strong seasonal changes, marked by a September-October versus March-April - *SOMA* pattern (e.g., Pingree and Lecann, 1990; Pingree and Garcia-Soto, 2014). The main surface current in the Bay of Biscay is the European Slope Current (ESC), flowing northward along the Armorican Shelf (Figure 1), with important spatial and seasonal variations (Garcia-Soto and Pingree, 2012; Charria et al., 2013). Circulation can reverse during summer along the shelf break, flowing weakly southwestward (Charria et al., 2013). In autumn-winter, the northward flow reaches a maximum, especially when combining with southern intrusions from the Iberian Poleward Current (IPC) which flows along the western Iberian margin (e.g. Peliz et al., 2005) before turning eastward at the Cape Finisterre (NW Spain). The IPC northward extension into the Bay of Biscay is known as the Navidad Current (e.g. Garcia-Soto et al., 2002; Le Cann and Serpette, 2009). The winter mixing of the ~~compound of~~ IPC and ESC is designated as the European Poleward Current (EPC, Garcia-Soto and Pingree, 2012), and drives relatively warm and saline water to the Nordic seas, contributing to their heat and salt budget. The Bay of Biscay is additionally strongly marked by surface water inflow coming from the North Atlantic Current (Figure 1), which enters the Bay from its northwestern boundary (Pingree, 2005; Pingree and Garcia-Soto, 2014;

Ollitrault and Colin de Verdiere, 2014). In contrast with surface circulation of the inner Bay of Biscay, the NAC water inflow shows only limited seasonal variability. At inter-annual time scales however, NAC oscillations are mainly driven by westerly wind regime (Pingree, 2005), and consequently by the North Atlantic Oscillation (NAO), one of the key modes of climatic variability~~oscillation~~ in the North Atlantic. So far, little is known about long term oscillations of the NAC inflow into the Bay. Modern surveys of SST variability over the last 150 years in the Bay of Biscay report that temperature oscillations are mainly controlled by the Atlantic Multi-decadal Oscillation (AMO, Garcia-Soto and Pingree, 2012). The influence of the NAO on SST in the Bay of Biscay is more complex and contributes only little to the observed long term trend, although sharp, inter-annual changes of the NAO index impact annual SST variability (Garcia-Soto and Pingree, 2012, Figure 1C). Moreover, NAO conditions influence large-scale oceanic circulation patterns indirectly responsible for surface temperature anomalies over the Bay (Pingree, 2005; Garcia-Soto and Pingree, 2012, see also the synthesis within Mary et al., 2015).

The present paper is based on analyses conducted on two high-resolution well dated cores from the southern part of the inner Bay of Biscay (Figure 1, Table 1): core KS10b (e.g. Mojtahid et al., 2013) and core PP10-07 (e.g. Brocheray et al., 2014). These cores show exceptionally high sedimentation rates for the Holocene, up to 200 cm.ka$^{-1}$ for core PP10-07, and 86 cm ka$^{-1}$ for core KS10b (see detailed description of these archives and of their sedimentological context in the respective references). Here we present ~~reconstructed~~ past Holocene SST data reconstructed ~~derived from~~after an ecological transfer function based on the Modern Analogue Technique (see Methods) applied to planktonic foraminiferal assemblages. These Bay of Biscay sea-surface reconstructions are compared to selected North Atlantic Holocene records using ~~onwards~~ a data mining exercise (referencing sea-surface reconstructions of high time-resolution) done in the frame of the French ANR HAMOC (Holocene North Atlantic Gyres and Mediterranean Overturning dynamic through Climate Changes) project database (see http://hamoc-interne.epoc.u-bordeaux1.fr/doku.php?id=start) ~~and referencing sea-surface reconstructions of high time-resolution~~.

**Mis en forme :** Non Surlignage

# 2. Methods

### 2.1. Age models

Updated age models have been built for the Bay of Biscay cores. All raw $^{14}$C ages were calibrated and converted to calendar ages using the Marine13 calibration curve and the recommended age reservoir of 405 years (Reimer et al., 2013), as no adequate and robust local age reservoir values exist in the area (see Mary et al., 2015 for a discussion). Smooth-spline regression based on the published $^{14}$C dates (n =12 for core Ks10b, Mojtahid et al., 2013) were applied (Figure 2). For core PP10-07, two supplementary $^{14}$C dates were obtained at the top of the sequence (Table 2) and the age model was built using a 5 degree polynomial regression (Figure 2). Core MD03-2693 age model (also exploited in this paper) was built using linear interpolation based on published $^{14}$C and $^{210}$Pb (n=3 and n=8, respectively, Mary et al., 2015). Age-depth modeling and calibration were performed using the dedicated software Clam (Blaauw, 2010), written in the open-source statistical environment R (http://www.r-project.org/).

Code de champ modifié

### 2.2. Past hydrographical parameter quantification

Planktonic foraminifera (PF) assemblages were used to quantify sea-surface parameters: species abundances were determined (counts of 300 specimens at least) on the > 150 µm fraction from sedimentary aliquots retrieved at maximum 10 centimeter-intervals along the studied cores, thus giving a mean time resolution of 50 and 150 years for core PP10-07 and KS10b respectively (see Supplementary material for detailed data). SST reconstructions were calculated using the Modern analogue technique (MAT) a method successfully developed on PF (e.g., Pflaumann et al., 1996; Kucera et al., 2005; Telford and Birks, 2011; Guiot and de Vernal, 2007; 2011). The calculations derive from modern spectra previously compiled and tested separately in the frame of the MARGO exercise for the North Atlantic Ocean and the Mediterranean Sea respectively (Kucera et al., 2005; Hayes et al., 2005). They are based on sediment surface samples analyzed for their contents in PF (specific relative abundances) and thus offer the advantage of already having integrated regional taphonomic processes. At EPOC (Environnements et Paléoenvironnements Océaniques et Continentaux) laboratory, these two MARGO databases were summed to provide larger analogue choices and ambiguous data points were excluded (i.e. ~~undated~~ non-stratigraphically constrained points showing anomalies in the biogeographical distribution), resulting in a final training set of n=1007 modern analogues. Modern sea-surface parameters were extracted from the WOA ATLAS with the sample tool developed by Schäfer-Neth and Manschke (2002). The latter was developed for the MARGO program and interpolates the 10 m World Ocean Atlas WOA - 1998 mean seasonal and mean annual temperatures over the four existing data points surrounding the sample location (see http://www.geo.uni-bremen.de/geomod/staff/csn/woasample.html) thus providing spatio-temporal averaged values of SST (see Kucera et al., 2005 for MARGO analytical developments and Telford and Kucera, 2013 for further considerations).

Calculations were run under the R software with the BIOINDIC package (ReconstMAT script) developed by J. Guiot (https://www.eccorev.fr/ spip.php?article389) using relative abundances of PF with no mathematical transformation (no logarithmic or square root transformations which are frequently used to increase the equitability within assemblages for instance, see Guiot and de Vernal, 2007 for a review). Past hydrological parameter values are derived from a weighted average of the SST values of the five best analogues. The maximum weight is given for the closest analogue in terms of statistical distance (i.e. dissimilarity minimum). The ReconstMAT script furthermore includes the calculation of a threshold regarding this statistical distance which prevents calculation in the case of poor- or non- analogous situations. The degree of confidence of this method allows reconstruction of ~~reconstructing~~ seasonal and annual SST with a maximum root mean square error of prediction (RMSEP) of 1.3°C (see Supplementary material). This method (named MATR_1007PF for Modern Analogue Technique derived from 1007 modern spectra of PF assemblages) was extensively tested at EPOC including comparisons with similar MAT developed regionally on PF (e.g. Salgueiro et al., 2008; 2010) providing very coherent reconstructions along the western European margin (see Eynaud et al., 2013 for further details) and producing pertinent paleoceanographical ~~data~~ series (see Penaud et al., 2011; Sánchez Goñi et al., 2012; Sánchez Goñi et al., 2013 for records also produced with MATR_1007PF). Additionally, our work benefited from modern calibrations conducted on PF from the same area of the Bay of Biscay (i.e. Retailleau et al., 2009; 2012).

**Mis en forme :** Anglais (États Unis)

**Mis en forme :** Anglais (États Unis), Non Surlignage

**Mis en forme :** Non Surlignage

**Mis en forme :** Non Surlignage

**Mis en forme :** Anglais (États Unis), Non Surlignage

## 3. Holocene SST oscillations in the Bay of Biscay

Despite the different bathymetric and physiographic positions of the studied cores (Figure 1, Table 1), reconstructed annual SST in the Bay of Biscay show coherent oscillations of remarkably similar timing (Figure 3a). Small amplitude differences are observed between the two ~~focused~~ studied records, but synchronous warm periods are clearly identified between 8.2-7.4 ka BP and 6.6-5.6 ka BP, these intervals roughly corresponding to the upper and lower limits of the mid-Holocene hypsithermal in the North Atlantic region (e.g. Eynaud et al., 2004; Walker et al., 2012; Tanner et al., 2015).

Mis en forme : Surlignage

On historical time-scales, warm intervals are detected in both cores between 2.6-1.8 ka BP (Roman Warm Period, RWP) and 1.2-0.5 ka BP (Medieval Warm Period, MWP), although less obvious in core KS10b because of the lower time resolution. An offset of up to 4°C above mean annual modern values is observed during a large temperature excursion around ca 2 Ka BP in core PP10-07 only. The amplitude of the warmings detected between 8.2-7.4 ka BP and 6.6-5.6 ka BP reaches ~~concomitantly~~ 2 to 3°C in both records. Such amplitudes in the detected SST warm pulses are especially high in comparison to modern annual values. However, considering the strong modern seasonal SST variations in the Bay of Biscay (as shown on Figure 3a), a 4°C shift of mean annual SST is coherent with a deviation of annual mean temperature toward mean summer values.

Comparison of the southern Bay of Biscay SST reconstructions with other records from the Western European margin (Figure 3, ~~and~~ 4 and 5) suggests that the observed millennial-scaled warm episodes are coherent features which reflect ~~typical~~ characteristic climatic patterns, at least expressed regionally, but also probably more broadly. Indeed, further along the Bay of Biscay margin, other high resolution Holocene archives reveal similar and synchronous episodes (Figure 3C). Concomitantly to the observed warm SST pulses also seen within the seasonal means (see Supplementary material), Holocene pollen assemblages from core VK03-58 bis (pollen data not shown, Naughton et al., 2007) indicate a decrease in mean annual precipitations; this drought being related, according to the authors, to a change in the seasonality with warmer summers especially. In the same way, the evolution of coccolithophorid concentrations in the subpolar North-Atlantic along the Irminger Current pathway, interpreted as

Mis en forme : Surlignage

indicating stronger contribution of NAC water toward the Nordic seas (Andrews and Giraudeau, 2003; Giraudeau et al., 2004, Moros et al., 2012), showed strong similarities with the Bay of Biscay SST signals. Peaks in coccolithophorid abundances in cores B997-330 and MD99-2269 (Figure 4e and f) (see location on Figure 1) were recorded synchronously to the warm pulses in the Bay of Biscay, with especially positively marked anomalies detected around 2 ka BP and 8 ka BP. The Bay of Biscay SST oscillations further correspond with those reconstructed from marine records from the Barents Shelf (see location on Figure 1) from core MSM5/5-712-2 (Werner et al., 2013, Figure 3c) and core M23258 (Sarnthein et al., 2003; Figure 3d). This coherency suggests teleconnections between the southern Bay of Biscay and the Nordic seas, probably due to a common driving mechanism linked to the NAC inflow vigor and ~~to the modulation of~~ its split ~~off Ireland~~ between the SPG and the STG.

Mis en forme : Surlignage

In between the observed warm intervals, SST reconstructions of core PP10-07 and KS10b reveal several low values slightly colder than today (Figure 3a). The time interval between 5.6 and 2.6 ka BP is characterized by temperatures around -1°C cooler compared to the modern ones. This period roughly corresponds to the late Holocene Neoglacial Cooling (e.g. Eynaud et al., 2004; Wanner et al., 2008; Walker et al., 2012). In the same way, short-lived events of 2°C cooling are visible around ca 8.2, 7, 5.5, 4, 2.9 and 1.7 ka BP (Figure 3 and 4). The ~~two~~ three older anomalies are synchronous and well-marked in both KS10b and PP10-07 cores.

The comparison of the timing of these cold spells to other existing Holocene reconstructions from the North Atlantic Ocean reveals that they represent coherent and reproducible features (Figure 4). Interestingly, density anomalies thought to reflect millennial-scale variability in the SPG dynamics (Thornalley et al., 2009; Farmer et al., 2011) were ~~synchronously~~ recorded nearly synchronously (within the age model uncertainties) ~~at sub-thermocline depths~~ in the southern Iceland basin (it is especially obvious before 4ka). These anomalies were interpreted (i.e. Thornalley et al., 2009) as reflecting a strong /*weak*, longitudinally extended/*contracted* SPG thus driving more/*less* vigorous but fresher/*saltier* Atlantic inflow throughout the Faroe current branch and thus modulating the AMOC strength ~~(Thornalley et al., 2009)~~. The good temporal correspondence between the cold spells detected in core PP10-07 (even if shorter) and the density anomalies (core RAPiD-12-1K, Figure 4h) registered in the subpolar North-

Atlantic support, as seen for warm events, a direct teleconnection with the inner Bay of Biscay, probably throughout a STG/SPG seesaw which would influence tracks/intensities of the temperate westerlies. The short lived cold anomalies of PP10-07 are furthermore concomitant with periods of increased storminess identified in various coastal sediments from the NW European margin (Holocene Storm Periods after Sorrel et al., 2012, Figure 3g). These periods have been related to a weakened, westward contracted SPG, involving a rapid feedback in the atmospheric dynamics (e. g. westerlies intensity and/or latitudinal migrations).

In the subtropical North Atlantic, study of benthic foraminiferal stable isotopes in core EUGC-3B (located in the Galician Shelf, Pena et al., 2010; see Figure 1) also showed similar cold anomalies which were interpreted by the authors as suggesting enhanced contribution of colder, NE Atlantic ENACW waters reaching the Iberian margin during these events.

## 4. The European poleward current and the influence of subtropical sourced waters in the Bay of Biscay

Modern surveys (e.g. Garcia-Soto et al., 2002; Lozier and Stewart, 2008; Garcia-Soto and Pingree, 2012) and paleoceanographic time-series (e.g., Mojtahid et al., 2013) recently evidenced the influence of the IPC, and its extension in the Bay of Biscay (i.e. Navidad Current, Garcia-Soto et al., 2002), on surface circulation and hydrological conditions along the European Margin. At present, these incursions of warm waters in the bay occur during winter under specific seasonal wind regimes (of southerly wind off Portugal and westerly wind off Northern Spain, Charria et al., 2013) and negative anomalies of sea level pressure over the North Atlantic (Pingree and Garcia-Soto, 2014). While these conditions were previously related to a negative mode of the NAO (Garcia-Soto et al., 2002), recent analysis of instrumental time-series showed that weather conditions responsible for Navidad current may not always correspond to a fixed value of the NAO index (Pingree and Garcia-Soto, 2014). The Navidad Current occasionally creates warm SST anomalies, enhanced transport of warm water through the pole and could thus be the vector of planktonic exotic (from subtropical origin) faunal invasions in the inner Bay of Biscay (see Mojtahid et al., 2013 and Garcia et al., 2013 for example in the fossil record; see Garcia-Soto and Pingree, 2012 and Pingree and

Garcia-Soto, 2014 for example in instrumental time-series) which could bias our SST reconstructions. In the following, we thus examine the hypothesis of a persistent poleward surface current during the Holocene that would have triggered the observed SST warm anomalies in the PP10-07 and KS10b records.

In order to test the coherency of surface hydrographic features along the temperate and subtropical adjacent portions of the European margin, we compared Bay of Biscay SST reconstructions with existing SST (annual) records produced along the Iberian Margin (Figure 3b and c). We first test this link over historical times, compiling SST high resolution data obtained on the proximal core MD03-2693 (after Mary et al., 2015), which ~~matches~~ accurately complete those from core PP10-07 (see Figure 3a between 0.5 and 1.5 ka and ~~also~~ Figure ~~E4~~ 5a'~~in the Supplementary material~~, even if the cores are not tuned on each other's, i.e. keeping their independent age models; see also - AC2: 'Author Comment to Ref#2', Frederique Eynaud, 08 Dec 2016 and its cp-2016-32-supplement), with additional high resolution records (Figure 3b). The combination of these records reveals a slight warming associated to the Medieval Warm Period and coherent low-amplitude multi-decadal SST oscillations which echoes those of AMO anomalies as reconstructed by Mann et al (2009). Especially striking is the high degree of synchronicity detected between the Iberian margin (core PO287-06 , Abrantes et al., 2011) and the Bay of Biscay at the scale of the last 1.5 ka, despite differences in the proxies used to generate paleo-SST (Alkenones vs MAT on PF respectively) and age-model uncertainties (which probably explain offsets of a few hundred years around 1200 A.D.). The good coherency with AMO reconstructions further supports modern oceanographic assumptions of AMO driving multi-decadal change of SST in the area (Garcia-Soto and Pingree, 2012) and shows that this modulation is at least valid for the late Holocene. Interestingly, modern winter incursions of Iberian water through the Bay of Biscay take place during periods of increasing AMO (Garcia-Soto and Pingree, 2012). During these episodes, warm winter anomalies of up to 1.1° are observed in the Bay of Biscay, which are consistent with the amplitude of the warmings detected in both MD03-2693 and PP10-07 past reconstructions.

However, ~~at a longest~~over the longer Holocene perspective, existing SST records from the Iberian margin do not reveal any coherent patterns with those from the Bay of Biscay over the last 10 ka (Figure 3C). Regardless of the proxies involved in SST reconstructions (Alkenones and MAT), there is no evidence of any earlier distinct SST excursions in the high time resolution data of the Iberian cores

**Mis en forme :** Surlignage

**Mis en forme :** Surlignage

**Mis en forme :** Surlignage

**Mis en forme :** Surlignage

MD99-2331, D13882, MD95-2042 and MD01-2444 (Figure 3c, see also Figure E4 in the Supplementary material) or elsewhere in other lower resolution Holocene records from the same area (Naughton et al., 2007; Martrat et al., 2007; Rodrigues et al., 2009; Voelker and de Abreu, 2011; Chabaud et al., 2014). The early Holocene SST reconstructions in this area show a monotonous long term decrease of SST correlated with the Holocene decline of summer insolation (e.g. Marchal et al., 2002, see also Figure E4) which contrasts strongly with the warm episodes observed in core PP10-07 and KS10b at that time (see Figure E4 in the Supplementary material). Taking into account the similarities between late Holocene records in the Iberian margin and in the Bay of Biscay, our data thus suggests a disconnection between these two regions during the first part of the Holocene, up to 1.5 ka BP. We interpret this divergence as a distinct response of the Bay of Biscay to North Atlantic millennial changes in the NAC/SPF system dynamics (e.g. Perez-Brunius et al., 2004) whereas southwestern Europe has probably undergone a mixed influence of diverse subtropical climatic trends. Sea-surface environments from the Bay of Biscay, located at the interface between the SPG and STG influences may have, as currently observed in frontal regions, recorded an amplified signature of NAC shifts, themselves driven by contraction/extension phases of the whole North-Atlantic gyre system (STP, SPG, and Polar Gyre also). To decipher the role of each of these gyres is at present not possible on the basis of our records only, and requires additional high-resolution comparable marine archives along a latitudinal gradient at least between 30° and 60°N. The analyses of the influence of Mediterranean hydrographic changes (via the Mediterranean outflow export especially) together with those linked to the Eastern North Atlantic Upwelling Region would also be very important to tackle in such a context.

Mis en forme : Couleur de police : Accent 1

## 5. Implication for Holocene climate dynamics

In agreement with modern climate observations (e.g. Ba et al., 2014), North Atlantic paleoceanographic studies describe a strong impact of the Subpolar gyre (SPG) dynamics on the NAC inflow toward high-latitudes and global circulation during the Holocene (Bianchi and Mc Cave, 1999; Oppo et al., 2003; Perez-Brunius et al., 2004; Thornalley et al., 2009; Giraudeau et al., 2010; Moros et al., 2012; Staines-Urías, 2013; Morley et al., 2014). Freshwater fluxes in the Labrador Sea and wind stress over the North

Atlantic are key drivers of eastern expan~~ten~~sions/contractions of the SPG (Hatun et al., 2015), thus also controlling the salinity balance over the North Atlantic, boreal deep-water convection and North hemisphere climate patterns. The compilation of proxy-records from further south in the Bay of Biscay indicates that the Holocene relatively long-term periods of warming ~~in the Bay of Biscay~~ are interbedded/superposed to rapid, millennial cold anomalies of SPG origin (Figure 4). In agreement with other North Atlantic records, strong NAC occurs preferentially during the Holocene optimum (Berner et al., 2007; Solignac et al., 2008), and during the Roman Warm Period (Werner et al., 2012). In contrast, the occurrences of cold anomalies in the North Atlantic follow a 1500 years periodicity during the Holocene (e.g., Thornalley et al., 2009; Debret et al., 2007; Sorrel et al., 2012), and are accurately reflected by the SST PP10-07 record (Figure 4f).

As also suggested by recent studies of modern time-series (Lozier et al., 2010; Lozier, 2012), Holocene SST records from the Bay of Biscay evidence a decoupling of gyre dynamics, and a potential gyre-specific expression of the AMOC. Model studies similarly question the meridional coherence of the AMOC, revealing an inherent character of its mid-latitude variability at decadal time-scales (Bingham et al., 2007), mainly driven by wind forcing and eddy variability. While our findings support coherent sea-surface hydrographical patterns between subtropical and temperate environments along the western European margin, suggesting a coupled SPG/STG gyre dynamics over the last 1.5 to 2 ka, earlier Holocene contexts seem to have been rather favorable to a gyre-specific expression, i.e. each gyre being related to intrinsic forcings mainly due to their latitudinal position and to proximal saline/fresh water intrusions~~, as seen at least from SST reconstructions~~.

To tentatively go further in the interpretations, we have compiled bibliographic sources dealing with the Holocene climatic variability. Many of the relevant records are considered on Figures 4 and 5, with a zoomed representation over the last 4 ka in Figure 5(5a' to 5e') which gathers proximal European records. Related interpretations and elements regarding the SPG/STG (and other ocean and climate features when existing) were also compiled as a Table (see Table E2 in Supplementary material) to provide a comprehensive summary which is conceptualized on Figure 6. With this exercise, is confirmed that no definitive trend could be assessed over the whole Holocene. It seems rather that the delimitation of the mid-Holocene is of high relevance regarding the latitudinal coherence of climatic events. Probably in relation with the influence of relict ice-sheet melting (and thus fresh-water injection in the SPG) and the related sea-level rise stop, key connections and feedbacks may have took place after 6/5 ka only, thus triggering modern oceanographic and climatic modes. Actually, when focusing on the early Holocene, warm anomalies in the Bay of Biscay coincide with signals of significant NAC inflow in the GIN seas (Figures 4 and 6a), but are not clearly seen on records close from European ice-sheets (Figure 5e). At a millennial scale, these events seem to be in phase with evidences of solar activity changes (Figure 5f – reverted scale) and important pulses of ice-drifting in the North Atlantic (after Bond et al., 2001, Figure 5g). The centennial evolution within each event is however more complex. Over the last 5 ka, trends seem to be more clearly expressed with, especially during the last millennia, good coherency at the local and regional scales (Figure 5a' to 5e'). Warm/cold shifts occur in a well-defined temporal frame, relevant at least over Europe, but hardly attributable on the basis of our work to a preferential radiative forcing (internal as external).

To understand climatic processes behind these observations and test their coherency region per region, a pan-(North)-Atlantic view is however required, emphasizing the need~~urging~~ for comprehensive data compilation efforts as those undertaken for instance in the work conducted for the Ocean2k SST synthesis (e.g. McGregor et al., 2015) or the PAGES 2K Network consortium (http://pastglobalchanges.org/ini/wg/2k-network/intro). SST records should however ~~been~~ be supplemented~~incremented~~ by complementary parameters when possible, especially to document hydrographic processes at various depths, in order to better understand the 3D articulation of the oceanic thermal and dynamic responses to various Holocene forcings (e.g. changes in insolation, sea-level - gateway connection, volcanism, or even anthropogenic related, which could have been cumulative or not).

## 6. Conclusion

Our study, which documents Holocene surface hydrographical changes at unprecedented time-scales in the Bay of Biscay, reveals contrasted patterns (warm *vs* cool SST) which correlate with other

**Mis en forme :** Police :Italique

North Atlantic proxy records interpreted to be responding to North Atlantic gyre dynamicsaccurately reflect the variability of the North Atlantic gyre dynamics. Coherently with stronger NAC inflow in the Nordics seas as detected in other archives from the northern North Atlantic, our high-resolution sedimentary records identify specific warm periods during the early Holocene and at ca. 2 ka BP and reveal that northward advection of subtropical waters may have influenced SST oscillations in the Bay of Biscay during the last 1.5 ka BP. In addition, SST signals from the Bay of Biscay show the occurrences of short-term cold anomalies, interpreted here as the signature of changes in SPG dynamics. The influence of the two main North Atlantic gyres, i.e STP vs SPG, observed asynchronously over most of the Holocene in the Bay of Biscay, indicate fundamental differences in the temporal variability of their dynamics, contrasting with the idea of a coherent, basin-wide-driven, overturning cell in the North-Atlantic. Our results suggest a gyre-specific expression of the AMOC where intrinsic salinity valves, linked to the latitudinal and geographical contexts, are of major importance.Our results suggest a gyre-specific expression of the AMOC, which That may contribute to strong regionalisms in the response of the North Atlantic hydrography to Holocene climatic changes and imply to be as precise as possible when modeling this key component in the Earth climate system. This urges also for a densification (and maybe diversification) in the coverage of past Holocene archives.may contribute to strong regionalisms in the response of the North Atlantic hydrography to Holocene climatic changes.

**Mis en forme :** Surlignage

**Mis en forme :** Surlignage


## 7. Acknowledgments

Analyses documented in this study have been supported by the French ANR HAMOC. We are grateful to the captain and crew of the RV *Pourquoi Pas?* and to the scientific team of the 2010-SARGASS cruise. This work beneficiated from $^{14}C$ AMS measurement facilities thanks to the ARTEMIS French project. We thank Giovanni Sgubin, Didier Swingedouw and Eleanor Georgiadis for useful discussions and comments on the manuscript. This is an UMR EPOC contribution. Data will be set on http://www.pangaea.de/.

M.Y. and E.F. designed the study and wrote the paper in the frame of the ANR HAMOC project coordinated by C.C..

E.F., R.L., M.M., G.J., P.M., H.H. performed and/ or supervised planktonic foraminifera assemblage analyses and picking for the datings. E.F. ran the transfer function. M.Y. performed age modelling with the help of E.F. and M.M.. B.S, S.Z. and C.M. investigated the sedimentology of core PP10-07. All authors contributed to discussions and interpretation of the results. The authors declare no competing financial interests.

## 8. References

Abrantes, F., Rodrigues, T., Montanari, B., Santos, C., Witt, L., Lopes, C. and Voelker, A.: Climate of the last millennium at the southern pole of the North Atlantic Oscillation: an inner-shelf sediment record of flooding and upwelling, Climate Research 48, 261–280, doi:10.3354/cr01010, 2011. - *Data available from http://doi.pangaea.de/10.1594/PANGAEA.761849*.

Andrews, J.T. and Giraudeau, J.: Multi-proxy records showing significant Holocene environmental variability: the inner N. Iceland shelf (Hunafloi), Quaternary Science Reviews 22, 175–193, 2003.

Ba, J., Keenlyside, N. S., Latif, M., Park, W., Ding, H., Lohmann, K., Mignot, J., Menary, M., Otterå, O. H., Wouters, B., Salas y Melia, D.,Oka, A., Bellucci, A., and Volodin, E.: A multi-model comparison of Atlantic multidecadal variability, Climate Dynamics 43, 2333–2348, 2014.

Berner, K.S., Koç, N., Godtliebsen F., and Divine, D.: Holocene climate variability of the Norwegian Atlantic Current during high and low solar insolation forcing, Paleoceanography 26, n/a–n/a., 2011.

Bianchi, G.G. and Mc Cave, I.N.: Holocene periodicity in North Atlantic climate and deep-ocean flow south of Iceland, Nature 397, 515–517, 1999.

Bingham, R.J., Hughes, C.W., Roussenov, V., and Williams R.G.: Meridional coherence of the North Atlantic meridional overturning circulation. Geophysical Research Letters 34, n/a–n/a. 2007.

Blaauw, M.: Methods and code for 'classical' age-modelling of radiocarbon sequences, Quaternary Geochronology 5, 512-518, 2010.

Brocheray, S., Cremer, M., Zaragosi, S., Schmidt, S., Eynaud, F., Rossignol L., and Gillet, H.: 2000 years of frequent turbidite activity in the Capbreton Canyon (Bay of Biscay), Marine Geology, 347, 136–152, doi:10.1016/j.margeo.2013.11.009, 2014.

Bryden, H. L., Longworth, H. R., and Cunningham, S. A.: Slowing of the Atlantic meridional overturning circulation at 25° N, Nature 438, 655–657, 2005.

Chabaud, L., Sanchez Goni, M.F., Desprat, S., and Rossignol, L.: Land-sea climatic variability in the eastern North Atlantic subtropical region over the last 14,200 years: Atmospheric and oceanic processes at different timescales, The Holocene 24, 787–797, 2014.

Charria, G., Lazure, P., Le Cann, B., Serpette, A., Reverdin, G., Louazel, S., Batifoulier, F., Dumas, F., Pichon, A., and Morel Y.: Surface layer circulation derived from Lagrangian drifters in the Bay of Biscay, Journal of Marine Systems 109-110, S60–S76. doi:10.1016/j.jmarsys.2011.09.015, 2013.

Clark, P.U., Pisias, N.G., Stocker, T.F., and Weaver A.J.: The role of the thermohaline circulation in abrupt climate change, Nature 415, 863–869, 2002.

Copard, K., Colin, C., Henderson, G.M., Scholten, J., Douville, E., Sicre, M.-A., and Frank, N.: Late Holocene intermediate water variability in the northeastern Atlantic as recorded by deep-sea corals, Earth and Planetary Science Letters, 313-314, 34–44. doi:10.1016/j.epsl.2011.09.047, 2012.

Colin, C., Frank, N., Copard, K., Douville, E.: Neodymium isotopic composition of deep-sea corals from the NE Atlantic: implications for past hydrological changes during the Holocene, Quaternary Science Reviews, 29, 2509–2517, doi:10.1016/j.quascirev.2010.05.012,2010.

Debret, M., Bout-Roumazeille, V., Grousset, F., Desmet, M., McManus, J. F., Massei, N., Sebag, D., Petit, J.-R., Copard, Y., and Trentesaux A.: The origin of the 1500-year climate cycles in Holocene North-Atlantic records. Climate of the Past 3, 569–575, 2007.

deCastro, M., Gómez-Gesteira, M., Alvarez, I., Gesteira, J.L.G. : Present warming within the context of cooling–warming cycles observed since 1854 in the Bay of Biscay, Continental Shelf Research, 29, 1053–1059, doi:10.1016/j.csr.2008.11.016, 2009.

Esnaola, G., Sáenz, J., Zorita, E., Fontán, A., Valencia, V., and Lazure, P.: Daily scale winter-time sea surface temperature variability and the Iberian Poleward Current in the southern Bay of Biscay from 1981 to 2010. Ocean Science Discussions 9, 3795–3850, 2012.

Eynaud, F., Turon, J.L., and Duprat, J.: Comparison of the Holocene and Eemian palaeoenvironments in the South Icelandic Basin: Dinoflagellate cysts as proxies for the North Atlantic surface circulation, Review of Palaeobotany and Palynology, 128, 55–79, 2004.

Eynaud, F., Malaizé, B., Zaragosi, S., de Vernal, A., Scourse, J., Pujol, C., Cortijo, E., Grousset, F.E. Penaud, A., Toucanne, S., Turon, J.-L. and Auffret, G.: New constraints on European glacial freshwater releases to the North Atlantic Ocean, Geophysical Research Letters, 39(15). L15601, 2012.

Farmer, E.J., Chapman, M.R., and Andrews, J.E.: Holocene temperature evolution of the subpolar North Atlantic recorded in the Mg/Ca ratios of surface and thermocline dwelling planktonic foraminifers, Global and Planetary Change, 79, 234–243, 2011.

Garcia, J., Mojtahid, M., Howa, H., Michel, E., Schiebel, R., Charbonnier, C., Anschutz, P., and Jorissen F.J.: Benthic and planktic foraminifera as indicators of late glacial to Holocene paleoclimatic changes in a marginal environment: An example from the southeastern Bay of Biscay, Acta Protozool, 52, 163–182, 2013.

Garcia-Soto, C., Pingree, R. D., and Valdés, L.: Navidad development in the southern Bay of Biscay: Climate change and swoddy structure from remote sensing and in situ measurements, Journal of Geophysical Research, 107, 2002.

Garcia-Soto, C. and Pingree, R.D.: Atlantic Multidecadal Oscillation (AMO) and sea surface temperature in the Bay of Biscay and adjacent regions, Journal of the Marine Biological Association of the United Kingdom, 92, 213–234, 2012.

Gaudin, M, Mulder, T., Cirac, P., Berne, S., and Imbert P.: Past and present sedimentation activity in the Capbreton Canyon, southern Bay of Biscay, Geo-Marine Letters 26, 331–345, 2006.

Giraudeau, J., Jennings, A. E., and Andrews, J.T.: Timing and mechanisms of surface and intermediate water circulation changes in the Nordic Seas over the last 10,000 cal years: a view from the North Iceland shelf, Quaternary Science Reviews, 23, 2127–2139, 2004.

Giraudeau, J., Grelaud, M., Solignac, S., Andrews, J.T., Moros, M., and Jansen, E.: Millennial-scale variability in Atlantic water advection to the Nordic Seas derived from Holocene coccolith concentration records, Quaternary Science Reviews, 29, 1276–1287. doi:10.1016/j.quascirev.2010.02.014, 2010.

Guiot, J. and de Vernal, A.: Transfer functions: Methods for quantitative paleoceanography based on microfossils. In: Hillaire-Marcel C. and de Vernal A. (eds), Proxies in Late Cenozoic Paleoceanography, Amsterdam: Elsevier, pp. 523–563, 2007.

Guiot, J. and de Vernal A.: Is spatial autocorrelation introducing biases in the apparent accuracy of paleoclimatic reconstructions?, Quaternary Science Reviews, 30, 1965–1972, 2011.

Hatun, H., Britt Sandø, A., Drange, H., Hansen, B. and Valdimarsson, H.: Influence of the Atlantic Subpolar Gyre on the Thermohaline Circulation, Science, 309, 1841–1844, 2005.

Hayes, A., Kucera, M., Kallel, N., Sbaffi, L. and Rohling, E. J.: Glacial Mediterranean sea surface temperatures based on planktonic foraminiferal assemblages, Quaternary Science Reviews, 24, 999–1016, 2005.

Jackson, L.C., Kahana, R., Graham, T., Ringer, M. A., Woollings, T., Mecking, J. V., and Wood, R. A.: Global and European climate impacts of a slowdown of the AMOC in a high resolution GCM, Clim Dyn, 1–18, doi:10.1007/s00382-015-2540-2, 2015.

Kennedy, J.J.: A review of uncertainty in in situ measurements and data sets of sea surface temperature, Reviews of Geophysics, 52, 1–32, 2014. doi:10.1002/2013RG000434

Kennett, J.R., Allen, M., Beer, J., Grootes, P., Laj, C., McManus, J., and Ramesh, R.: Decadal-to-millennial-scale climate variability—chronology and mechanisms: summary and recommendations, Quaternary Science Reviews 21, 1121–1128, 2002.

Koutsikopoulos, C., Beillois P., Leroy C., Taillefer F.: Temporal trends and spatial structures of the sea surface temperature in the Bay of Biscay, Oceanologica Acta, 21 (2), 335-344, 1998.

Kucera, M., Weinelt, M., Kiefer, T., Pflaumann, U., Hayes, A., Weinelt, M., Chen, M.-T., Mix, A.-C., Barrows, T.T., Cortijo, E., Duprat, J., Juggins, S., and Waelbroeck, C.: Reconstruction of sea-surface temperatures from assemblages of planktonic foraminifera: multi-technique approach based on geographically constrained calibration data sets and its application to glacial Atlantic and Pacific Oceans, Quaternary Science Reviews, 24, 951–998, doi:10.1016/j.quascirev.2004.07.014, 2005.

Landsea, C.W., Vecchi, G.A., Bengtsson, L., Knutson, T.R.: Impact of Duration Thresholds on Atlantic Tropical Cyclone Counts*, Journal of Climate, 23, 2508–2519,2010.

Le Cann, B., and Serpette, A.: Intense warm and saline upper ocean inflow in the southern Bay of Biscay in autumn–winter 2006–2007, Continental Shelf Research, 29, 1014–1025, doi:10.1016/j.csr.2008.11.015, 2009.

Lherminier, P., and Thierry, V.: The Reykjanes Ridge Experiment, http://wwz.ifremer.fr, 2015.

Mis en forme : Anglais (États Unis)

Code de champ modifié

Lozier, M.S. and Stewart, N. M., On the Temporally Varying Northward Penetration of Mediterranean Overflow Water and Eastward Penetration of Labrador Sea Water, Journal of Physical Oceanography, 38, 2097–2103, 2008.

Lozier, M.S., Roussenov, V., Reed, M.S.C. and Williams, R.G.: Opposing decadal changes for the North Atlantic meridional overturning circulation, Nature Geoscience 3, 728–734, 2010.

Lozier, M.S.: Overturning in the North Atlantic, Annual Review of Marine Science 4, 291–315, 2012.

Magny, M, Bégeot, C, Guiot, J. et al. Contrasting patterns of hydrological changes in Europe in response to Holocene climate cooling phases, Quaternary Science Reviews, 22, 1589-1596, 2003.

Mann, M.E., Zhang, Z., Rutherford, S., Bradley, R. S., Hughes, M. K., Shindell, D., Ammann, C. Faluvegi, G. and Ni F.: Global signatures and dynamical origins of the Little Ice Age and Medieval Climate Anomaly, Science, 326: 1256–1260, 2009. *Data available from* *http://www.meteo.psu.edu/holocene/public_html/supplements/MultiproxySpatial09/*

Marchal, O., Cacho, I., Stocker, T.F., Grimalt, J.O., Calvo, E., Martrat, B., Shackleton, N., Vautravers, M., Cortijo, E. and van Kreveld S.: Apparent long-term cooling of the sea surface in the northeast Atlantic and Mediterranean during the Holocene, Quaternary Science Reviews, 21, 455–483, 2002.

Martrat, B., Grimalt, J.O., Shackleton, N.J., de Abreu, L., Hutterli, M.A. and Stocker, T. F.: Four Climate Cycles of Recurring Deep and Surface Water Destabilizations on the Iberian Margin. Science 317, 502–507. *Data available from* *http://doi.pangaea.de/10.1594/PANGAEA.771894*, *2007.*

Mary, Y., Eynaud, F., Zaragosi, S., Malaizé, B., Cremer, M. and Schmidt, S.: High frequency environmental changes and deposition processes in a 2 kyr-long sedimentological record from the Cap-Breton canyon (Bay of Biscay), The Holocene, 25, 348–365, doi:10.1177/0959683614558647, 2015.

~~Mojtahid, M., Jorissen, F.J., Garcia, J., Schiebel, R., Michel, E., Eynaud, F., Gillet, H., Cremer, M., Diz Ferreiro, P., Siccha, M., and Howa, H.: High resolution Holocene record in the southeastern Bay of Biscay: Global versus regional climate signals, Palaeogeography, Palaeoclimatology, Palaeoecology, 377, 28–44. doi:10.1016/j.palaeo.2013.03.004, 2013.~~

McCartney, M.S., and Mauritzen, C.: On the origin of the warm inflow to the Nordic Seas, Progress in Oceanography, 51, 125–214, 2001.

**Code de champ modifié**

McGregor, H.V., Evans, M.N., Goosse, H., Leduc, G., Martrat, B., Addison, J.A., Mortyn, P.G., Oppo, D.W., Seidenkrantz, M.-S., Sicre, M.-A., Phipps, S.J., Selvaraj, K., Thirumalai, K., Filipsson, H.L., Ersek, V.: Robust global ocean cooling trend for the pre-industrial Common Era. Nature Geoscience 8, 671–677. doi:10.1038/ngeo2510, 2015.

Mojtahid, M., Jorissen, F.J., Garcia, J., Schiebel, R., Michel, E., Eynaud, F., Gillet, H., Cremer, M., Diz Ferreiro, P., Siccha, M., and Howa, H.: High resolution Holocene record in the southeastern Bay of Biscay: Global versus regional climate signals, Palaeogeography, Palaeoclimatology, Palaeoecology, 377, 28–44. doi:10.1016/j.palaeo.2013.03.004, 2013.

Morley, A., Rosenthal, Y., deMenocal, P.: Ocean-atmosphere climate shift during the mid-to-late Holocene transition, Earth and Planetary Science Letters 388, 18–26, doi:10.1016/j.epsl.2013.11.039, 2014.

Moros, M., Jansen, E., Oppo, D.W., Giraudeau, J., and Kuijpers, A.: Reconstruction of the late-Holocene changes in the Sub-Arctic Front position at the Reykjanes Ridge, north Atlantic, The Holocene, 22, 877-868, 2012.

Naughton, F., Bourillet, J.F., Sanchez Goni, M.-F., Turon J.-L., and Jouanneau J.-M.: Long-term and millennial-scale climate variability in northwestern France during the last 8850 years, The Holocene, 17, 939–953, 2007a.

Naughton, F., Sanchez Goñi, M.F., Desprat, S., Turon, J.-L., Duprat, J., Malaizé, B., Joli, C., Cortijo, E., Drago T. and Freitas, M.C.: Present-day and past (last 25000 years) marine pollen signal off western Iberia, Marine Micropaleontology, 62, 91–114,doi:10.1016/j.marmicro.2006.07.006, 2007b.

Ollitrault, M. and Colin de Verdière A.: The ocean general circulation near 1000 m depth, J. Phys. Oceanogr. 44, 384–409, 2014.

Peliz, Á., Dubert, J., Santos, A.M.P., Oliveira, P.B., Le Cann, B.: Winter upper ocean circulation in the Western Iberian Basin—Fronts, Eddies and Poleward Flows: an overview, Deep Sea Research Part I: Oceanographic Research Papers, 52, 621–646, doi:10.1016/j.dsr.2004.11.005, 2005.

Pena, L.D., Francés, G., Diz, P., Esparza, M., Grimalt, J.O., Nombela, M.A. and Alejo, I.: Climate fluctuations during the Holocene in NW Iberia: High and low latitude linkages, Continental Shelf Research, 30, 1487–1496, doi:10.1016/j.csr.2010.05, 2010.

Penaud, A., Eynaud, F., Sánchez-Goñi, M.F., Malaizé, B., Turon, J.L., and Rossignol L.: Contrasting sea-surface responses between the western Mediterranean Sea and eastern subtropical latitudes of the North Atlantic during abrupt climatic events of MIS 3, Marine Micropaleontology, 80, 1-17, 2011.

Pérez-Brunius, P., Rossby, T., Watts, D.R.: Absolute transports of mass and temperature for the North Atlantic Current-Subpolar Front system, Journal of physical oceanography, 34, 1870–1883, 2004.

Pflaumann, U., Duprat, J., Pujol, C,. and Labeyrie, L. D.: SIMMAX: A modern analog technique to deduce Atlantic sea surface temperatures from planktonic foraminifera is deep-sea sediments, Paleoceanography, 11, 15–35, 1996.

Pingree, R.: North Atlantic and North Sea climate change: curl up, shut down, NAO and ocean colour, Journal of the Marine Biological Association of the United Kingdom, 85, 1301–1315, 2005.

Pingree, R. D. and Garcia-Soto, C.: Plankton blooms, ocean circulation and the European slope current: Response to weather and climate in the Bay of Biscay and W English Channel (NE Atlantic), Deep Sea Research Part II: Topical Studies in Oceanography, 106, 5–22, 2014

Pingree, R.D. and Le Cann B.: Structure, strength and seasonality of the slope currents in the Bay of Biscay region, Journal of the Marine Biological Association of the United Kingdom, 70, 857–885, 1990.

Planque, B., Beillois, P., Jégou, A.-M., Lazure, P., Petitgas, P., Puillat, I.: Large-scale hydroclimatic variability in the Bay of Biscay: the 1990s in the context of interdecadal changes, in: ICES Marine Science Symposia, 61–70, 2003.

Reimer, P.J., Bard, E., Bayliss, A., Beck, J. W., Blackwell, P. G., Ramsey, C. B., Buck, C. E., Cheng, H., Edwards, R. L., Friedrich, M., Grootes, P. M., Guilderson, T. P., Haflidason, H., Hajdas, I., Hatté, C., Heaton, T. J., Hoffmann, D. L., Hogg, A. G., Hughen, K. A., Kaiser, K. F., Kromer, B., Manning, S. W., Niu, M., Reimer, R. W., Richards, D. A., Scott, E. M., Southon, J. R., Staff, R. A., Turney, C. S. M. and van der Plicht, J.: IntCal13 and Marine13 Radiocarbon Age Calibration Curves 0-50,000 Years cal BP, Radiocarbon, 55(4), 2013.

**Mis en forme :** Anglais (États Unis)

Retailleau S., Howa H., Schiebel R., Lombard F., Eynaud F., Schmidt S., Jorissen F., Labeyrie L.: Planktic foraminiferal production along an offshore-onshore transect in the south-eastern Bay of Biscay, Continental Shelf research, 29 (8), 1123-1135, 2009.

Retailleau S., Eynaud F., Mary Y., Schiebel R., Howa H.: An Ocean - Canyon head and river plume: how they may influence neritic planktonic foraminifera communities in the SE Bay of Biscay?, Journal of Foraminifera research, 42(3), 257–269, 2012.

Risebrobakken, B., Dokken, T., Smedsrud, L.H., Andersson, C., Jansen, E., Moros, M., Ivanova, E.V.: Early Holocene temperature variability in the Nordic Seas: The role of oceanic heat advection versus changes in orbital forcing, Paleoceanography, 26, 2011. doi:10.1029/2011PA002117

Rodrigues, T., Grimalt, J.O., Abrantes, F.G., Flores, J.A. and Lebreiro, S.M.,—:(Holocene interdependences of changes in sea surface temperature, productivity, and fluvial inputs in the Iberian continental shelf (Tagus mud patch), Geochemistry, Geophysics, Geosystems 10, n/a–n/a. doi:10.1029/2008GC002367, 2009. *Data available from* *http://doi.pangaea.de/10.1594/PANGAEA.761812*

Salgueiro, E., Voelker, A., Abrantes, F., Meggers, H., Pflaumann, U., Loncaric, N., GonzÃlez-Ãlvarez, R., Oliveira, P., Bartels-JÃ3nsdÃ3ttir, H.B., Moreno, J. and Wefer, G.: Planktonic foraminifera from modern sediments reflect upwelling patterns off Iberia: Insights from a regional transfer function, Marine Micropaleontology 66, 135–164, 2008.

Salgueiro, E., Voelker, A.H.L., de Abreu, L., Abrantes, F., Meggers, H., Wefer, G.: Temperature and productivity changes off the western Iberian margin during the last 150Â ky, Quaternary Science Reviews 29, 680–695, 2010.

Sánchez Goñi, M.F, Bakker, P., Desprat, S., Carlson, A. E., Van Meerbeeck, C. J., Peyron, O., Naughton, F., Fletcher, W. J., Eynaud, F., Rossignol, L. and Renssen, H.: European climate optimum and enhanced Greenland melt during the Last Interglacial, Geology, 40, 627-630, 2012.

Sánchez Goñi, M.F., Bard, E., Landais, A., Rossignol, L., d'Errico, F.: Air–sea temperature decoupling in western Europe during the last interglacial–glacial transition, Nature Geoscience 6, 837-841, doi:10.1038/ngeo1924, 2013.

Sarnthein M., Van Kreveld, S., Erlenkeuser, H., Grootes, P. M., Kucera, M., Pflaumann, U., Schulz, M.: Centennial-to-millennial-scale periodicities of Holocene climate and sediment injections off the western Barents shelf, 75°N , Boreas, 32, 447–461. doi:10.1080/03009480310003351, 2003.

Schäfer-Neth, C. and Manschke, A., WOA-Sample tool, http://www.geo.uni-bremen.de/geomod/staff/csn/woasample.html, 2002. last access: January 2016.

Code de champ modifié

Staines-Urías, F., Kuijpers, A., and Korte, C.: Evolution of subpolar North Atlantic surface circulation since the early Holocene inferred from planktic foraminifera faunal and stable isotope records. Quaternary Science Reviews 76, 66–81, 2013.

Solignac, S., Grelaud, M., de Vernal, A., Giraudeau, J., Moros, M., McCave N. and Hoogakker, B.: Reorganization of the upper ocean circulation in the mid-Holocene in the Northeastern Atlantic, Can. J. Earth Sci. 45, 1417-1433, 2008.

Sorrel, P., Debret, M., Billeaud I., Jaccard S.L., McManus J.F., and Tessier B.: Persistent non-solar forcing of Holocene storm dynamics in coastal sedimentary archives, Nature Geoscience 12, 892–896. doi:10.1038/ngeo1619, 2012.

Tanner, B.R., Lane, C.S., Martin, E.M., Young, R. and Collins, B.: Sedimentary proxy evidence of a mid-Holocene hypsithermal event in the location of a current warming hole, North Carolina, USA. Quaternary Research 83, 315–323. doi:10.1016/j.yqres.2014.11.004, 2015.

Telford, R.J. and Birks, H.J.B.: Effect of uneven sampling along an environmental gradient on transfer-function performance, Journal of Paleolimnology 46, 99–106, 2011.

Telford, R. J., Li, C., and Kucera M.: Mismatch between the depth habitat of planktonic foraminifera and the calibration depth of SST transfer functions may bias reconstructions, Climate of the Past, 9, 859-870, 2013.

Thornalley, D. J. R., Elderfield, H. and McCave, I.N.: Holocene oscillations in temperature and salinity of the surface subpolar North Atlantic, Nature 457, 711–714, 2009.

Trouet V., Scourse, J.D. and Raible, C.C.: North Atlantic storminess and Atlantic Meridional Overturning Circulation during the last Millennium: Reconciling contradictory proxy records of NAO variability, Global and Planetary Change, 84–85, 48-55, 2012.

Valencia, V., Borja, Å., Fontån, A., Pérez, F. F., and Rios, A. F.: Temperature and salinity fluctuations along the Basque Coast (southeastern Bay of Biscay), from 1986 to 2000, related to climatic factors, ICES Journal of Marine Science, 219: 340-342, 2003.

Van Vliet-Lanoe, B., Goslin, J., Hallegouet, B., Henaff, A., Delacourt, C., Fernane, A., Franzetti, M., Le Cornec, E., Le Roy, P., Penaud, A.: Middle- to late-Holocene storminess in Brittany (NW France): Part I - morphological impact and stratigraphical record, The Holocene, 24, 413–433, doi:10.1177/0959683613519687, 2014a.

Van Vliet-Lanoe, B., Penaud, A., Henaff, A., Delacourt, C., Fernane, A., Goslin, J., Hallegouet, B., Le Cornec, E.: Middle- to late-Holocene storminess in Brittany (NW France): Part II - The chronology of events and climate forcing, The Holocene, 24, 434–453, doi:10.1177/0959683613519688, 2014b.

Voelker, A.H.L., de Abreu, L.: A Review of Abrupt Climate Change Events in the Northeastern Atlantic Ocean (Iberian Margin): Latitudinal, Longitudinal, and Vertical Gradients, in: Rashid, H., Polyak, L., Mosley-Thompson, E. (Eds.), Geophysical Monograph Series. American Geophysical Union, Washington, D. C., pp. 15–37, 2011.

Wanner, H., Beer J., Bütikofer J., Crowley T.J., Cubasch U., J. Flückiger, H. Goosse, M. Grosjean, F. Joos, J.O. Kaplan, M. Küttel, S.A. Müller, Prentice I.C., Solomina O., Stocker T.F., Tarasov P., Wagner M. and Widmann M.: Mid- to Late Holocene climate change: an overview, Quaternary Science Reviews 27, 1791–1828. doi:10.1016/j.quascirev.2008.06.013, 2008.

Walker, M. J. C., Berkelhammer, M., Björck, S., Cwynar, L. C., Fisher, D. A., Long, A. J., Lowe, J. J., Newnham, R. M., Rasmussen S. O., and Weiss, H.: Formal subdivision of the Holocene Series/Epoch: a Discussion Paper by a Working Group of INTIMATE (Integration of ice-core, marine and terrestrial records) and the Subcommission on Quaternary Stratigraphy (International Commission on Stratigraphy), Journal of Quaternary Science, 27, 649–659, 2012.

Werner, K., Spielhagen, R.F., Bauch, D., Hass, H.C. and Kandiano, E.S.: Atlantic Water advection versus sea-ice advances in the eastern Fram Strait during the last 9 ka: Multiproxy evidence for a two-phase Holocene, Paleoceanography, 28(2), 283-295, Data available from http://doi.pangaea.de/10.1594/PANGAEA.810415, 2013.

## Table caption

**Table 1**: Location and references of the southern Bay of Biscay cores used in this study.

**Table 2**: Summary of AMS $^{14}C$ ages of core PP10-07 with calendar correspondences.

| *Cruise, Core label* | *Latitude (°N)* | *Longitude (°E)* | *Water depth (m)* | *Longitudinal distance (km) from the shore* | *Datasources and references* |
|---|---|---|---|---|---|
| SARGASS, PP10-07 | 43.677 | -2.228 | 1472 | 58 | **This work,** Brocheray et al., 2014 |
| PROSECAN IV, KS10b | 43.833 | -2.050 | 550 | 50 | **This work,** Mojtahid et al., 2013 |
| SEDICAR/PICABIA, MD03-2693 | 43.654 | -1.663 | 431 | 15 | **This work,** Gaudin et al., 2007, Mary et al., 2015 |

**Table 1:** Location and references of the southern Bay of Biscay cores used in this study.

| **Depth in core PP10-07 (cm)** | Sample | Material | Ref Number | mg C | $d^{13}C$ | pMC corrected | | | **RAW 14C Age yr BP** | | | *corrected reservoir age / -400 yr BP* | **Calibrated age (median age) CLAM yr BP** | ***-2σ yr*** | ***+2σ yr*** | *Error yr* | *Confidence %* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **4,5** | PP10-07, 3-6 cm (TR1) | Bulk planktonic foraminifera | SacA39103 | 0,572 | 0,12 | 90,6 | ± | 0,24 | **790** | ± | 30 | *390* | ***423*** | *353* | *493* | *70* | *92,6* |
| **124,5** | PP10-07 124-125 cm (TR2) | Bulk planktonic foraminifera | SacA39104 | 0,455 | -1,1 | 82,1 | ± | 0,24 | **1590** | ± | 30 | *1190* | ***1149,5*** | *1063* | *1236* | *86,5* | *95* |
| **219,5** | PP10-07 218-221 | Bulk planktonic foraminifera | SacA 29590 | 0,7 | 0,2 | 77,5 | ± | 0,19 | **2050** | ± | 30 | *1650* | ***1618*** | *1533* | *1702* | *85* | *95* |
| **380** | PP10-07 / 380 | Bulk planktonic foraminifera | SacA 26975 | 0,78 | -4,6 | 72,2 | ± | 0,24 | **2615** | ± | 30 | *2215* | ***2271*** | *2175* | *2366* | *96* | *95* |
| **720,5** | PP10-07 / 720-721 | Bulk planktonic foraminifera | SacA 26976 | 1 | -0,9 | 58,8 | ± | 0,22 | **4265** | ± | 30 | *3865* | ***4380*** | *4272* | *4487* | *108* | *95* |
| **1050** | PP10-07 / 1050 | Bulk planktonic foraminifera | SacA 26977 | 1,1 | -5,2 | 49,4 | ± | 0,17 | **5660** | ± | 30 | *5260* | ***6070*** | *5970* | *6170* | *100* | *95* |
| **1180** | PP10-07 1180 | Bulk planktonic foraminifera | SacA 29591 | 0,69 | -0,3 | 44,6 | ± | 0,14 | **6490** | ± | 30 | *6090* | ***7007*** | *6897* | *7116* | *110* | *95* |
| **1540** | PP10-07 / 1537-1543 | Bulk planktonic foraminifera | SacA 26978 | 1,17 | -1,9 | 33,8 | ± | 0,17 | **8705** | ± | 40 | *8305* | ***9371*** | *9276* | *9466* | *95* | *95* |
| **1731,5** | PP10-07 1730-1733 | Bulk planktonic foraminifera | SacA 29592 | 0,84 | -0,8 | 33 | ± | 0,12 | **8900** | ± | 30 | *8500* | ***9556*** | *9477* | *9635* | *79* | *95* |
| **1981,5** | PP10-07 1980-1983 | Bulk planktonic foraminifera | SacA 29593 | 1 | -1,5 | 31,6 | ± | 0,12 | **9270** | ± | 30 | *8870* | ***10093*** | *9992* | *10193* | *101* | *92* |

**Table 2:** Summary of AMS $^{14}C$ ages of core PP10-07 with calendar correspondences.

**Mis en forme :** Police :+Corps (Calibri)

**Mis en forme :** Police :+Corps (Calibri), 8 pt, Anglais (États Unis)

**Mis en forme :** Police :+Corps (Calibri)

**Figure caption**

**Figure 1: A)** : map showing the regional scheme of the main surface currents in the Bay of Biscay, drawn after the compilation of modern hydrological survey from Pingree and Garcia-Soto (2014). North Atlantic Current (NAC), Iberian poleward Current (IPC), and European Slope Current (ESC) are respectively represented by the red and orange arrows. The studied sedimentary cores PP10-07 and KS10b from the inner Bay of Biscay are shown in red. Additional Holocene records cited in the text are displayed by green squares. **B**:) North Atlantic general circulation pattern (SPG: Subpolar Gyre, STG: Subtropical Gyre, EPC: European Poleward Current, after Lherminier and Thierry, 2015) with the location of the northern and southern sedimentary records discussed in the text. Core references: **1-**Brocheray et al., 2014; **2-**Mojtahid et al., 2013; **3-**Gaudin et al., 2006; Mary et al., 2015; **4-**Naughton et al., 2007a; **5-**Pena et al., 2010; **6-**Werner et al., 2013; **7-**Sarnthein et al., 2003; **8-**Giraudeau et al., 2004; **9-**Andrews and Giraudeau, 2003; **10-**Thornalley et al., 2009; **11-** Naughton et al., 2007b; **12-**Abrantes et al., 2011; **13-**Chabaud et al., 2014; **14-** Rodrigues et al., 2009; **15-** Martrat et al., 2007; **16-** Risebrobakken et al., 2011; **17-** Cisneros et al., 2016. **C**: SST evolution over the last centuries in the Bay of Biscay (from the MD03-2693 sedimentological record and from the compilation of Garcia-Soto et al., 2002) and comparison, from the top to the bottom with: the Global SST anomaly (after Kennedy, 2014), the Atlantic Tropical Cyclone Counts (after Landsea et al. 2010) and the NAO index of Hurell (http://research.jisao.washington.edu/data_sets/nao/).

**Figure 2:** Revised age models for cores KS10b, MD03-2693, and PP10-07 (left panels) compared to previous published age models (right panels with original references).

**Mis en forme :** Police :Gras

**Mis en forme :** Police :Gras

**Mis en forme :** Police :Gras, Anglais (États Unis), Surlignage

**Mis en forme :** Anglais (États Unis), Surlignage

**Mis en forme :** Anglais (États Unis)

**Mis en forme :** Anglais (États Unis)

**Figure 3:** Mean Annual sea surface temperature (SST) records from the Western European margin. **A**~~)~~: Holocene SST signals from cores PP10-07 and KS10b (this study) reconstructed using the Modern Analogue Technique (MAT) based on planktonic foraminifera (see Methods), and compared to SST signal of the adjacent core MD03-2693 (Mary et al., 2015). Black dots identify $^{14}C$ age control points. **B**~~)~~: SST signals spanning the last 1500 years in the Bay of Biscay (core MD03-2693) based on MAT and from the Iberian Margin (core PO287-06, Abrantes et al., 2011) using alkenones. Reconstructed signals are compared with the AMO reconstruction of Mann et al., (2009). The dotted curve represents core MD03-2693 signal transposed on top of the two other curves. **C**~~)~~: Holocene SST signals from the Iberian Margin using MAT based on planktonic foraminifera for cores MD99-2331 (after Naughton et al., 2007b) and MD95-2042 (after Chabaud et al., 2014) and Alkenones for cores D13882 (after Rodrigues et al., 2009) and MD01-2444 (after Martrat et al., 2007).

**Figure 4:** Comparison of annual SST Holocene signals from the Bay of Biscay (**A** and **B**) with records from the northern North Atlantic highlighting variations of the NAC intensity and SPG dynamics; **C**~~)~~: SST signal of core MSM5/5-712-2 (Fram strait, Werner et al., 2013) and of **D**~~)~~: core M23258 (Barents shelf, after Sarnthein et al., 2003), both reconstructed using the Modern Analogue Technique (MAT) based on planktonic foraminifera; **E**~~)~~: Concentration of NAC indicator coccolith species in core MD99-2269 (North Iceland Shelf, after Giraudeau et al., 2004) and in **F**~~)~~: core B997-330 (North Iceland Shelf, after Andrews and Giraudeau, 2003); The PP10-07 record is here also plotted by a thin dotted red line to underline the comparison; **G**~~)~~: Holocene Storm Periods (after Sorrel et al., 2012) reconstructed from sedimentological evidence from a compilation of coastal cores in North-western Europe; **H**~~)~~: core Rapid-12-1K (Thornalley et al., 2009) proxy for upper-water column stratification, calculated using derived Mg/Ca and $\delta^{18}O$ temperatures and salinities of

Mis en forme : Police :Gras
Mis en forme : Police :Gras
Mis en forme : Police :Gras
Mis en forme : Police :Gras
Mis en forme : Police :Gras
Mis en forme : Police :Gras
Mis en forme : Police :Gras
Mis en forme : Police :Gras
Mis en forme : Police :Gras
Mis en forme : Police :Gras

*G. bulloides and G. inflata*. Dotted vertical lines point out events of density difference between the near-surface and base of the seasonal thermoclinedensity anomalies at sub-thermocline depths in the southern Iceland basin. The topmost dark blue triangles and light blue vertical bands point to cold anomalies recorded in the southern Bay of Biscay (potentially corresponding to a weak SPG).. Pink bands conversely highlight periods of warmth which also correspond to enhanced NAC activity North of Iceland.

Changes in gyre circulation dynamics are compared with the Holocene division of Wanner et al. (2008).

**Figure 5:** Gathering data and forcings: comparison of the Bay of Biscay (BB) signals (**A**: annual SST, **B**: XRF ratio in PP10-07, **C**: planktonic foraminifera absolute abundances in PP10-07, **D**: annual SST anomalies vs modern mean in PP10-07), with key Holocene records, i.e.: **E**: Bond et al. 2001 record; **F**: total solar irradiance reconstruction after Roth & Joos, 2013; **G**: annual SST anomalies in the Nordic seas (Eastern) digitized from Risebrobakken et al., 2013. The dark blue triangles and light blue vertical bands point to cold anomalies recorded in the BB (potentially corresponding to a weak SPG).

On the left side are compiled data zooming over the last 4 ka with **A'**: BB annual SST; **B'**: reconstruction of the European temperature anomalies (from 30-year averages) of the PAGES 2k Network (2013); **C'**: Cantabrian speleothem $\delta^{13}C$ stack reflecting 4ka land surface temperature changes, digitized after Martín-Chivelet et al. 2011; **D'**: temperate pollen tree influx from the proximal Ria de Vigo, redrawn after Desprat et al., 2003, **E'**: Mg/Ca SSt anomaly in Minorca and related historical events after Cisneros et al. 2016 (Talaiotic Period -TP, Roman Period -RP, Dark Middle Ages -DMA, Medieval Climate Anomaly -MCA, Little Ice Age -LIA).

**Mis en forme :** Police :Gras

**Mis en forme :** Police :Gras

**Mis en forme :** Police :Gras

**Mis en forme :** Police :Gras

**Mis en forme :** Police :Gras

**Mis en forme :** Police :Gras

**Mis en forme :** Anglais (États Unis)

**Mis en forme :** Police :Gras

**Mis en forme :** Exposant

**Figure 6:** tentative scheme of North Atlantic oceanic circulation changes associated to contrasted BB SST scenarios (**A**: BB warm anomalies, **B**: BB cool events). This Figure, primarily based on the Figure 1B, was constructed compiling previous works of Staine-Urias et al., 2013 and of Morley et al., 2014 (see also table E2). Squares identify the key records used in Figure 4 and 5 with colors pointed to warm/cool situation or empty when no clear trend is detectable.

**Mis en forme :** Police :Gras

**Mis en forme :** Police :Gras

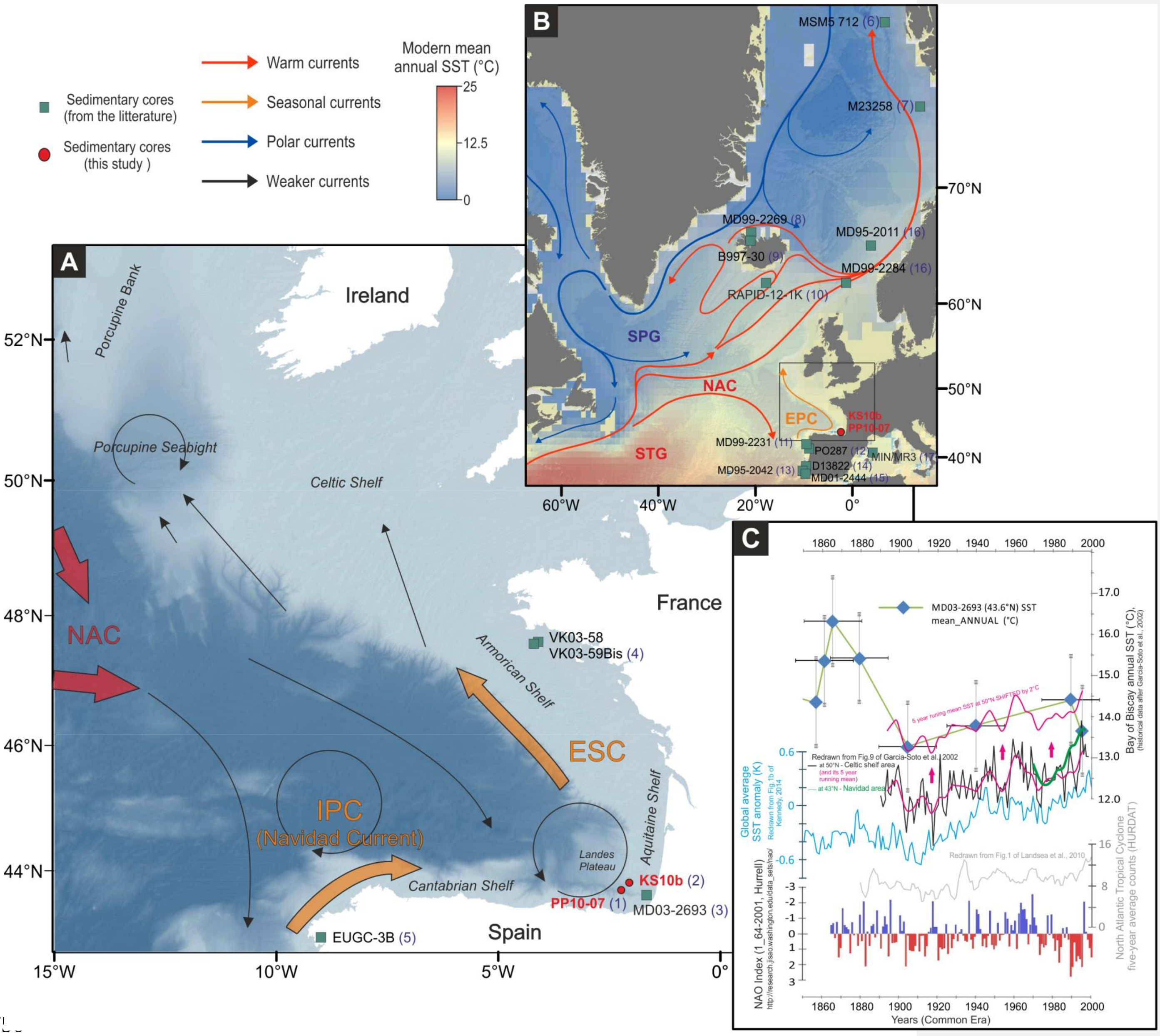
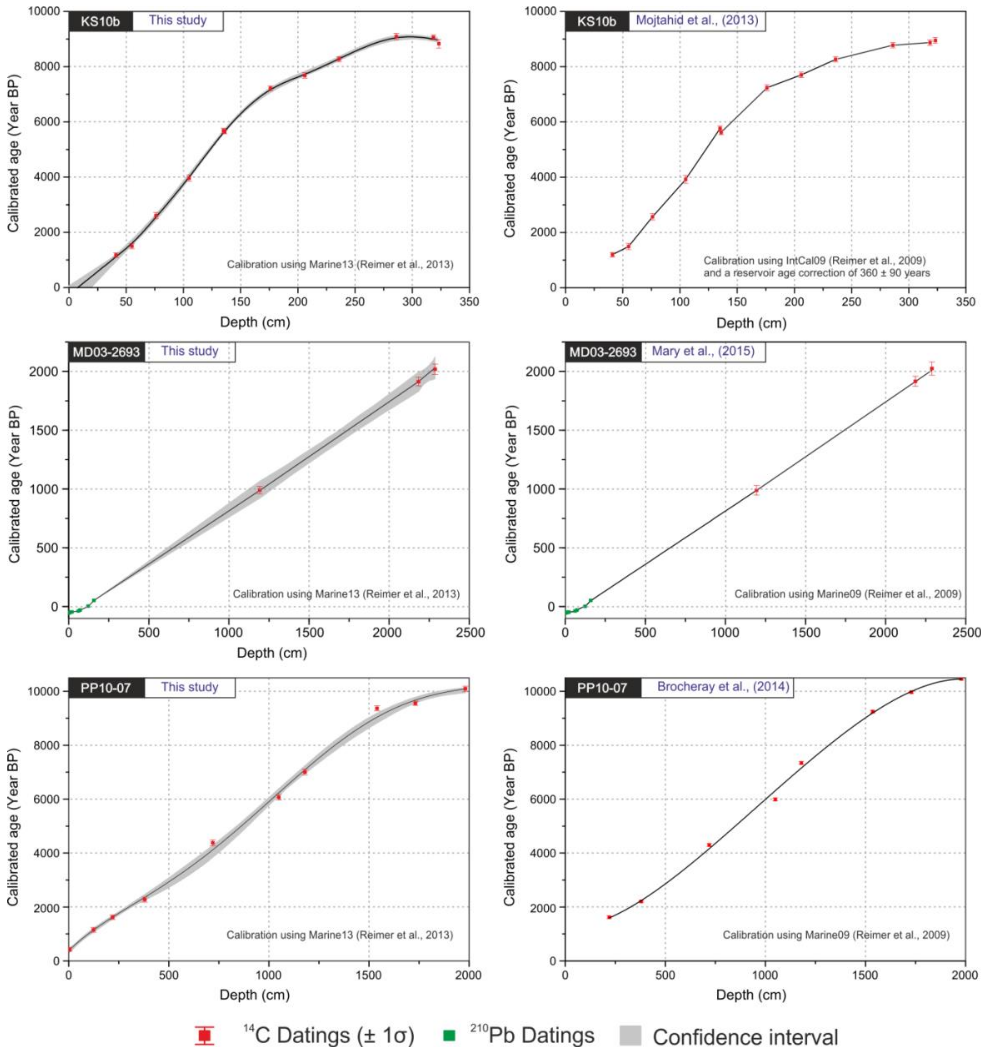



**Figure 1 (revised)**



KS10b
This study
Calibrated age (Year BP)
Depth (cm)
Calibration using Marine13 (Reimer et al., 2013)
KS10b
Mojtahid et al., (2013)
Calibration using IntCal09 (Reimer et al., 2009)
and a reservoir age correction of 360 ± 90 years
MD03-2693
This study
Calibration using Marine13 (Reimer et al., 2013)
MD03-2693
Mary et al., (2015)
Calibration using Marine09 (Reimer et al., 2009)
PP10-07
This study
Calibration using Marine13 (Reimer et al., 2013)
PP10-07
Brocheray et al., (2014)
Calibration using Marine09 (Reimer et al., 2009)
14C Datings (± 1σ)
210Pb Datings
Confidence interval


**Figure 2**

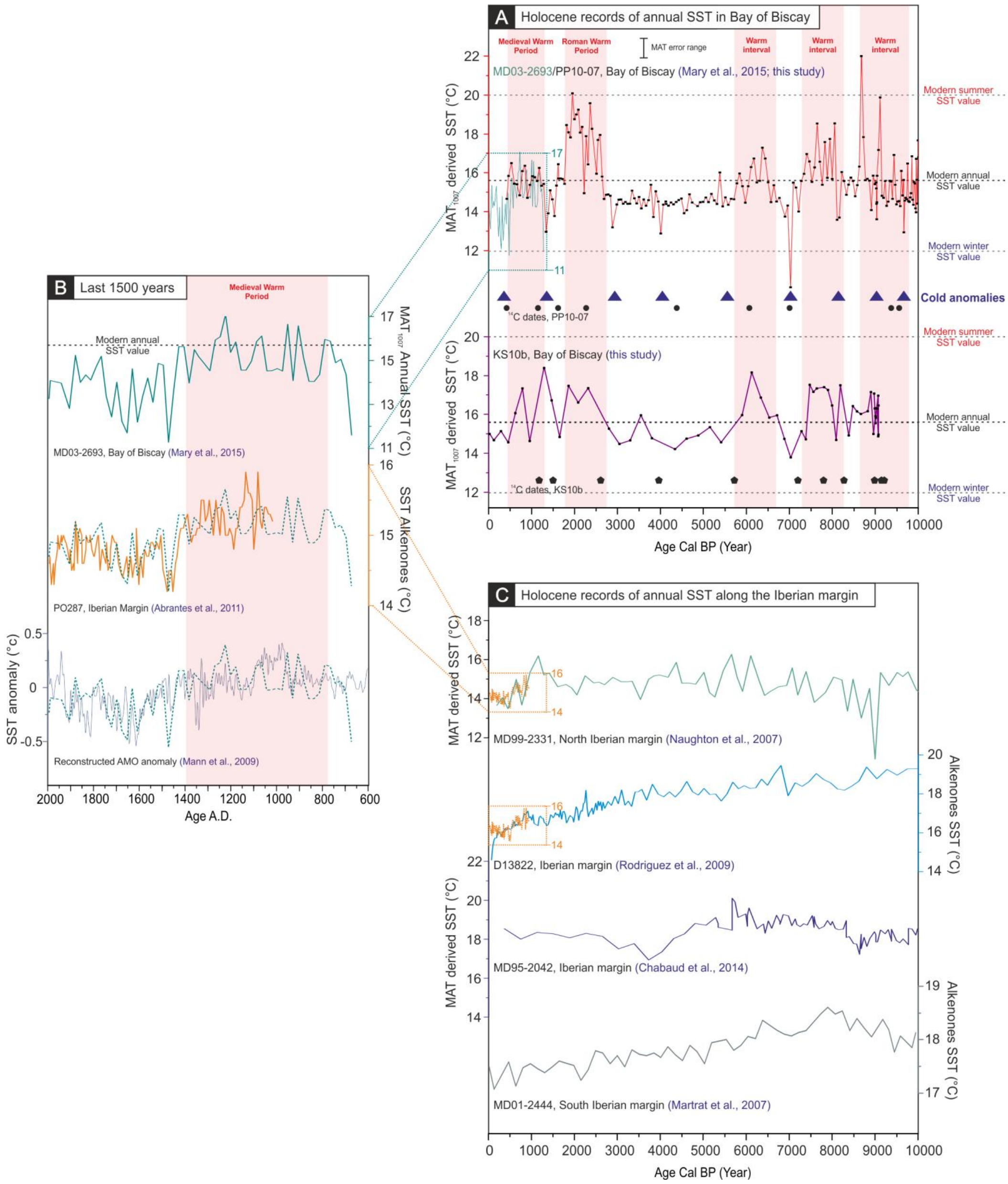
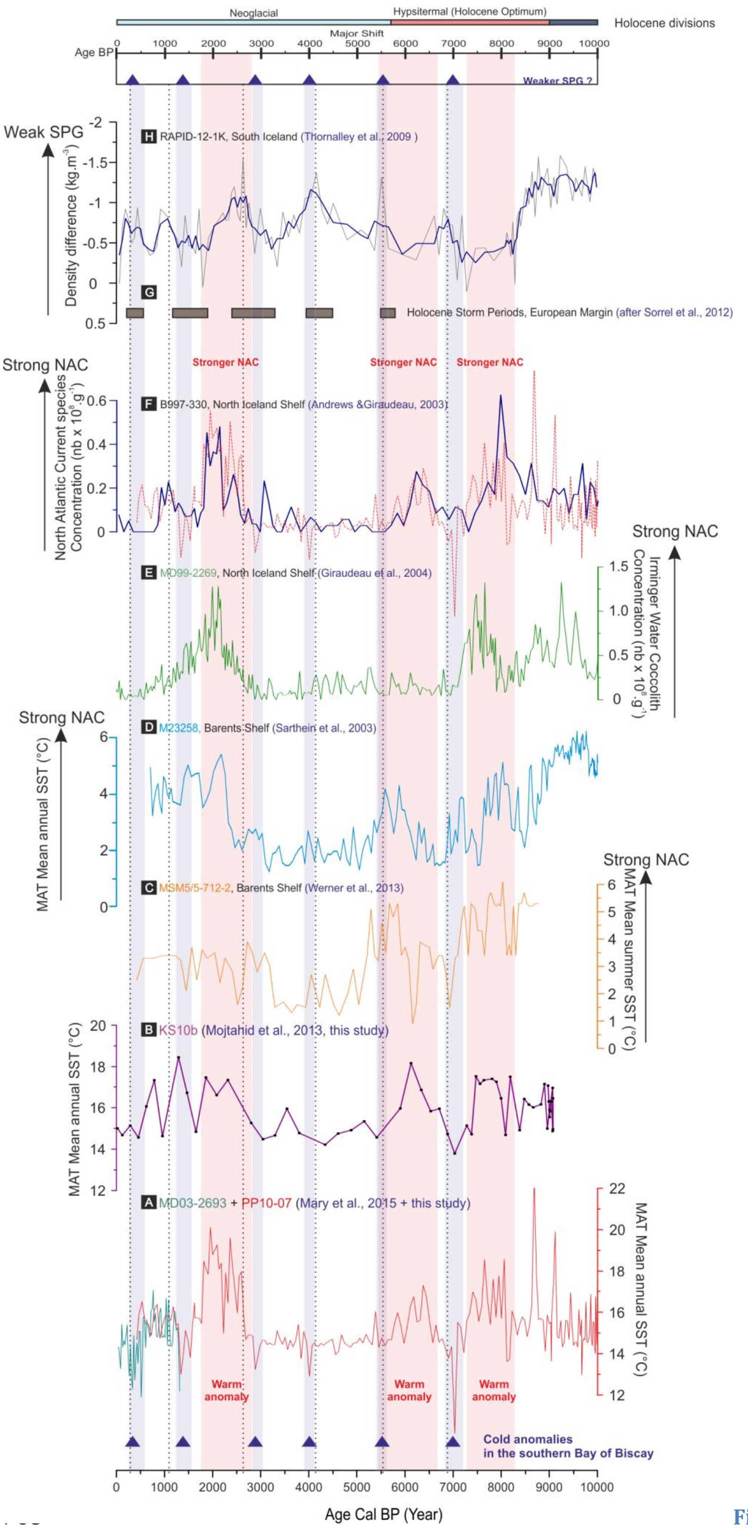

A Holocene records of annual SST in Bay of Biscay
Medieval Warm Period
Roman Warm Period
MAT error range
Warm interval
Warm interval
Warm interval
MD03-2693/PP10-07, Bay of Biscay (Mary et al., 2015; this study)
Modern summer SST value
Modern annual SST value
Modern winter SST value
Cold anomalies
14C dates, PP10-07
KS10b, Bay of Biscay (this study)
14C dates, KS10b
MAT1007 derived SST (°C)
Age Cal BP (Year)
B Last 1500 years
Medieval Warm Period
Modern annual SST value
MD03-2693, Bay of Biscay (Mary et al., 2015)
MAT1007 Annual SST (°C)
SST Alkenones (°C)
PO287, Iberian Margin (Abrantes et al., 2011)
SST anomaly (°c)
Reconstructed AMO anomaly (Mann et al., 2009)
Age A.D.
C Holocene records of annual SST along the Iberian margin
MAT derived SST (°C)
MD99-2331, North Iberian margin (Naughton et al., 2007)
Alkenones SST (°C)
D13822, Iberian margin (Rodriguez et al., 2009)
MD95-2042, Iberian margin (Chabaud et al., 2014)
MD01-2444, South Iberian margin (Martrat et al., 2007)
Age Cal BP (Year)

**Figure 3**



Neoglacial
Hypsitermal (Holocene Optimum)
Holocene divisions
Major Shift
Age BP
Weaker SPG ?
Weak SPG
H RAPID-12-1K, South Iceland (Thornalley et al., 2009 )
Density difference (kg.m-3)
G
Holocene Storm Periods, European Margin (after Sorrel et al., 2012)
Stronger NAC
Stronger NAC
Stronger NAC
Strong NAC
F B997-330, North Iceland Shelf (Andrews &Giraudeau, 2003)
North Atlantic Current species Concentration (nb x 10^6.g^-1)
Strong NAC
E MD99-2269, North Iceland Shelf (Giraudeau et al., 2004)
Irminger Water Coccolith Concentration (nb x 10^9.g^-1)
Strong NAC
D M23258, Barents Shelf (Sarthein et al., 2003)
MAT Mean annual SST (°C)
Strong NAC
C MSM5/5-712-2, Barents Shelf (Werner et al., 2013)
MAT Mean summer SST (°C)
B KS10b (Mojtahid et al., 2013, this study)
MAT Mean annual SST (°C)
A MD03-2693 + PP10-07 (Mary et al., 2015 + this study)
MAT Mean annual SST (°C)
Warm anomaly
Warm anomaly
Warm anomaly
Cold anomalies in the southern Bay of Biscay
Age Cal BP (Year)


**Figure 4**

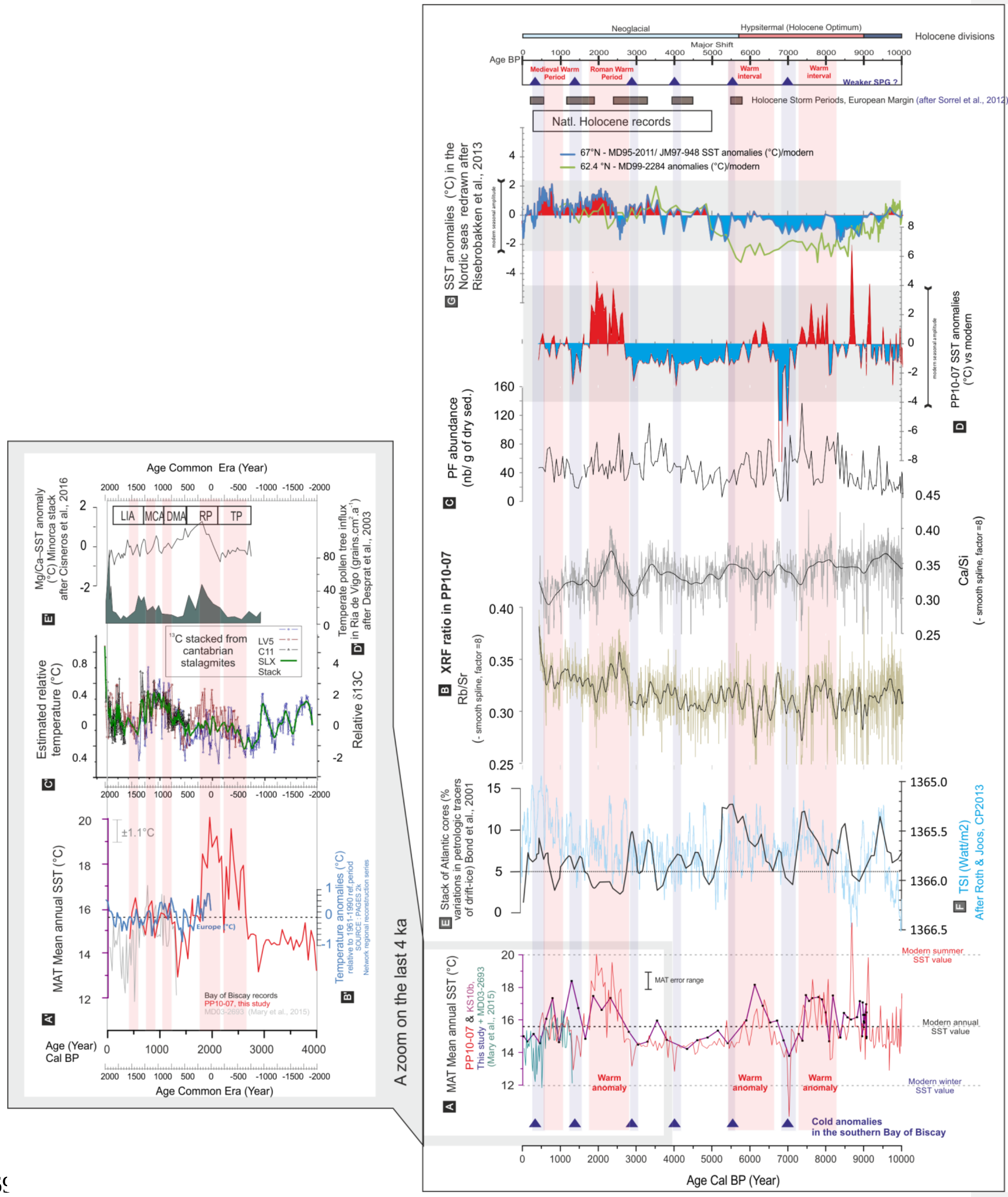
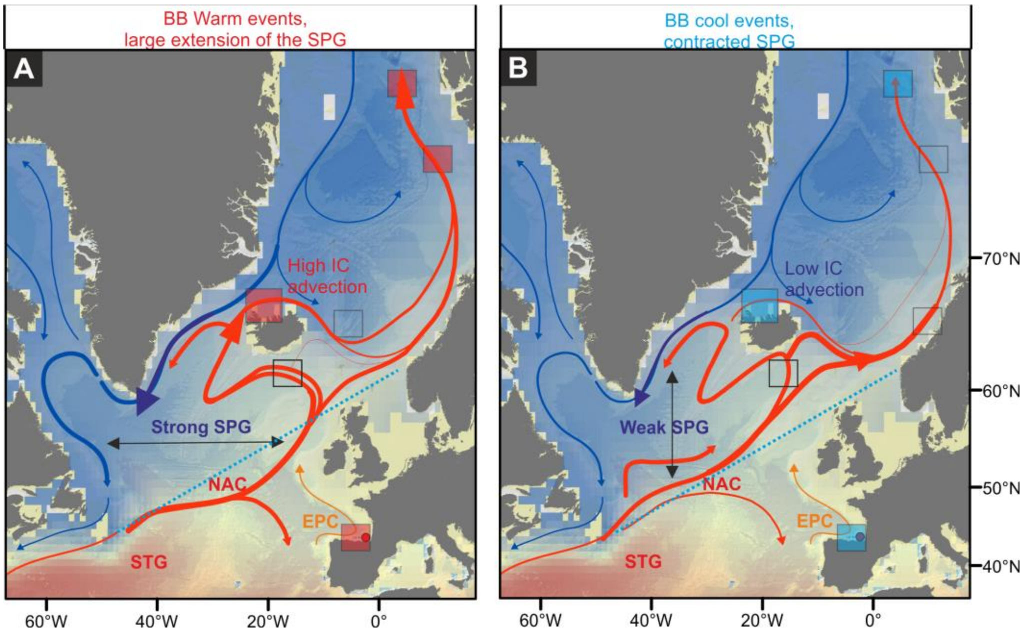



**Figure 5 (new Figure)**

772




773 **Figure 6 (new Figure)**