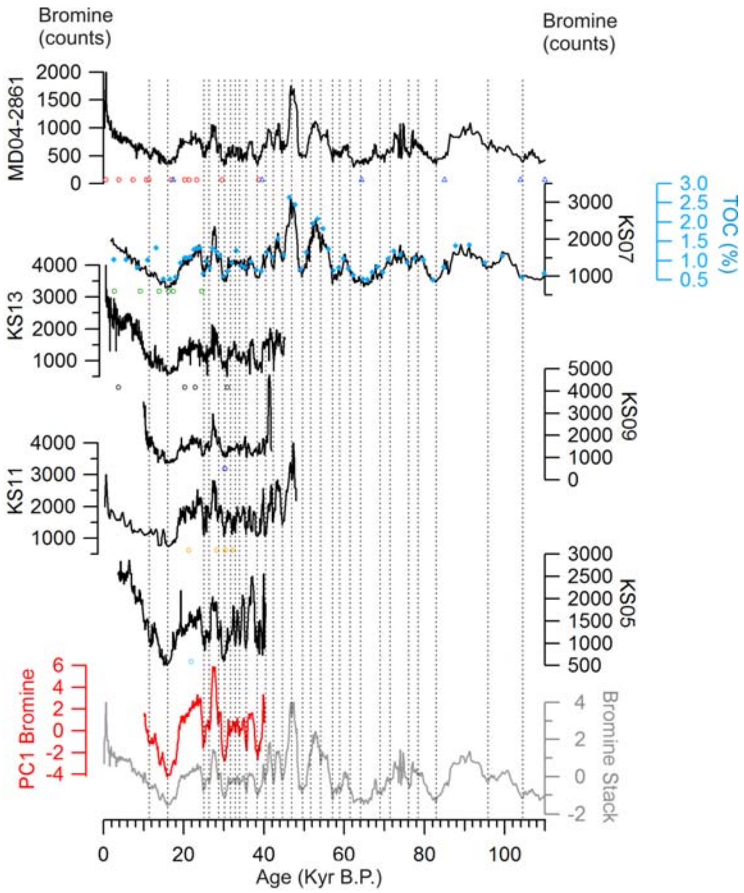
Response Referee 2

We thank the referee 2 for his careful review and comments. They will be helpful for the revision of our paper. Below, we provide point-by-point responses to the referee comments (red text).

This paper employs bromine (Br) to reconstruct surface marine productivity, which is thought to be driven by the intensity of Indian summer monsoon (ISM),in the Arabian Sea during the last glacial period. The authors then investigate the roles of southern hemisphere (SH) and northern hemisphere (NH) temperatures (based on EDML and NGRIP d18O, respectively) in the ISM changes and emphasize upon a potential role of suborbital Antarctica temperature in suborbital-millennial ISM (and also Asian monsoon, AM) changes. They suggest (1) that during 10-16 ka, NH is thought to dominantly control ISM, and (2)that SH temperature plays an important role in ISM during the last glacial (16-40 ka), mainly based on a better correlation between Br and EDML d18O than the correlation between Br and NGRIP d18O.
Increasing researches have highlighted the role of SH climatic variations in monsoon changes at both millennial and orbital timescales(An, 2000; Cai et al., 2006;Rohling et al., 2009; An et al., 2011; Caley et al., 2013).The Br stack record in the manuscript is based on nine marine sediment cores encompassing the whole Arabian Sea. Sedimentary Br contents are assumed as a proxy of surface marine productivity changes, which is linked to ISM changes. These records allow them to make some important findings regarding the importance of suborbital SH dynamic on the ISM changes and then on the regional surface marine productivity in the past. However, I have a number of concerns about the data and their interpretation that raise questions about the conclusions drawn. These concerns are detailed below.

Firstly, large Br differences exist among the cores, although Br patterns seem to be similar. These Br differences can be seen easily from the different coefficient (R2) and P values between Br records with NGRIP and EDML d18O, as listed in Table 2. These are not discussed and are warrant explanation in revision.

As also mentioned by the referee 1, it is interesting to discuss the potential differences between records. This is done in the revised version. We only conserved Bromine records with the highest resolution (close to 120 years or less) to limit its potential influence on the statistical correlation (see new Fig. 3 and Table 2).



New Figure 3

Core	Lat	Lon	Depth	Last 40 kyr resolution (yrs)	R^2 -EDML (10-16 kyr)	P-value -EDML	R^2 -EDML (16-40 kyr)	P-value -EDML	R^2 NGRIP (10-16kyr)	P-Value NGRIP	R^2 NGRIP (16-40 kyr)	P-value NGRIP
KS05	19.4	60.8	2710	90	0.41	0.00	0.09	0.00	0.16	0.00	0.03	0,05*
KS07	18.0	58.0	2209	130	0.56	0.00	0.25	0.00	0.27	0.00	0.02	0.03
KS09	21.7	61.1	3185	80	0.64	0.00	0.25	0.00	0.36	0.00	0.02	0.01
KS11	20.2	61.3	4004	65	0.24	0.00	0.20	0.00	0.01	0,50*	0.01	0.01
KS13	22.3	60.3	2678	50	0.30	0.00	0.20	0.00	0.42	0.00	0.01	0.03
MD04-2861	24.1	63.9	2049	100	0.15	0.00	0.38	0.00	0.12	0.00	0.00	0,40*
NIOP 463 (Ziegler et al., 2010)	22.5	64.0	920	160	0.01	0,70*	0.12	0.00	0.16	0,10*	0.00	0,30*
SO90-111KL (Schulz et al., 1998)	23.1	66.5	775	90	0.00	0,90*	0.36	0.00	0.38	0.00	0.06	0.00
SO130-289KL (Deplazes et al., 2013)	23.1	66.5	571	annual	0.28	0.00	0.40	0.00	0.77	0.00	0.20	0.00
PC1 Bromine				120	**0.64**	0.00	**0.30**	0.00	**0.38**	0.00	**0.01**	0.00

New Table 2

We added in the revised version in lines 205-214: *"Comparable events of higher bromine values can be observed at 20-24 kyr and centred at 27 kyr (Fig. 3).*

Between 30 and 38 kyr, five events with higher bromine values are documented in each record with the event centred at 37 kyr showing a more pronounced peak in core KS05. The more pronounced peak seems to be a local effect (exported production and diagenesis) as core KS13 is located in the same basin (Owen Basin) and at the same water depth than core KS05 but does not indicate a higher peak of Br (Fig. 1). Core KS09 shows much weak oscillation compared to the other cores that can also result from local effect (Fig. 3). Between 40 and 50 kyr, four comparable bromine peaks are visible in core MD04-2861, KS07 and KS11 with the more pronounced peak centred at 47 kyr (Fig. 3). Between 50 and 110kyr, similar bromine events are observed in core MD04-2861 and KS07 (Fig. 3)."

In order to limit the smoothing effect during the stacking procedure, we used an alternative approach based on principal components analysis (PCA) with the "R" software (http://www.r project.org/) for the time period 10-40 kyr (Fig. 3). The first component (PC1-bromine) of the analysis explains 75% of the variance and confirms the common pattern between Br records as mention by reviewer 2 (Fig. 3).

Furthermore, to assure that our conclusions were not affected by the stacking procedure or PCA we had also presented statistical analyses on individual records, having independent age model (**four of our records** if we exclude core KS05 and KS09 that have only one 14C control point, **Ziegler et al., 2010 and Schulz et al., 1998 records** and **Deplazes et al., 2013 record**) in the new Table 2 of our manuscript. The results support our conclusion based on the initial Bromine stack (Table 2).

We also added in the revised version in lines 322-335: *"We performed regressions underlying the coefficient of determination (R2) and P-values between Arabian Sea marine records and NH NGRIP-SH EDML δ18O ice records over the intervals 16-40 kyr and 10-16 kyr (deglaciation period).*

Although the coefficients of determination and P-values between Br records, NGRIP and –EDML δ18O signals can vary (Table 2) as a consequence of the resolution and local effect for each record, statistical analyses for the interval 16-40 kyr reveal always better correlations between Br records (and PC1-bromine) and the –EDML atmospheric signal than between Br records (and PC1-bromine) and the NGRIP atmospheric signal (Table 2). The same observation is true for the Br record of Ziegler et al. (2010), the TOC record of Schulz et al. (1998) and the reflectance record of Deplazes et al. (2013) on their own age model (Table 2). Note that for the majority of these records, the resolution is high enough (lower or equal to 100 yrs) to allow comparison with the NGRIP record. This is particularly true for the record of Deplazes et al. (2013) that have an annual resolution, therefore even better than the resolution of the NGRIP record."

In addition, they compare their records with the Br record of NIOP463, which is also from the Arabian Sea, to confirm Br association to surface productivity changes in Figure 5. Why did they exclude NIOP 463 record from the Br stacking?

Because the machine (XRF core scanner) and protocol (area of the core surface and time of irradiance) are probably different between Ziegler et al. and our work. This could create artefact during the stacking of these records. In addition, the resolution of core NIOP 463 (160 years) is lower than the Bromine record that we conserve in the revised version (close or lower than 120 years) over the last 40ka. This difference is clearly visible in new Figure 6 (see below) and is discussed in detail the revised version in lines 252-307:"*At the moment, there is no clear consensus concerning the effect of oxygen on the preservation of organic matter (Cowie et al., 1999; 2005; Burdige, 2007).*

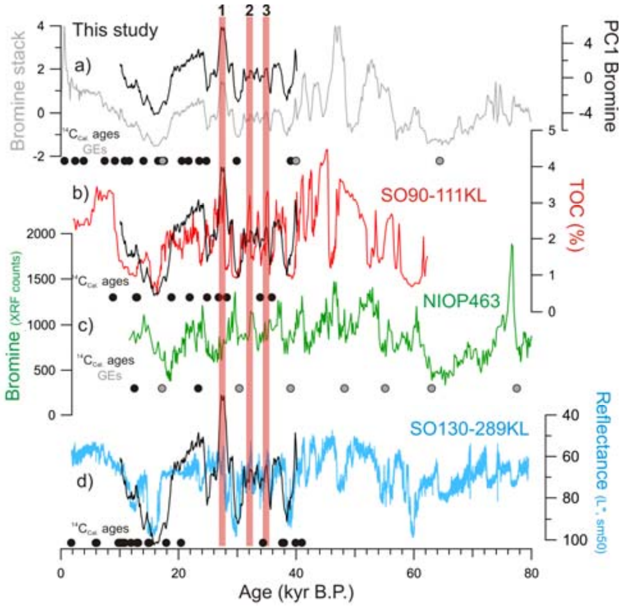
To investigate a potential impact of the absence of oxygen in the OMZ on the preservation of the productivity signal in the Arabian Sea, we compared different published productivity records (Schulz et al., 1998; Ziegler et al., 2010; Deplazes et al., 2013) with our results, covering various water depths (Fig. 1 and Fig. 6). We focus on the interval 10-40 kyr. PC1-bromine (mainly composed of records from below the modern OMZ) and TOC record of core SO90-111KL (Schulz et al., 1998) show a general good agreement (Fig. 6). Slight differences can be observed between 20 and 26 ka and can be related to age model uncertainties. Records can be reconciled by a time shift lower than 2kyr, in agreement with individual marine record uncertainties described previously. The only main differences in term of peaks amplitude can be observed between 32 and 35 ka (Fig. 6) with higher TOC peaks in core SO90-111KL. To investigate the origin of these differences we further compared with Br results from core NIOP463 (Ziegler et al., 2010) and results from core SO130-289KL (Deplazes et al., 2013). Core NIOP463 has a low resolution compared to the other records (Table 2) and only two 14C dates, making difficult to identify and discussed the Br peaks. On the contrary, core SO130-289KL has an annual resolution and is well constrained by 14C dating (Deplazes et al., 2013) (Fig. 6). Results of core SO130-289KL do not indicate extreme productivity peaks at 32 kyr and 35 kyr and the structure of the signal is more comparable to the PC1-bromine signal rather than to the TOC signal in core SO90-111KL. Interestingly, a major peak in organic carbon can be observed at 27 kyr in the PC1-bromine record as well as in the TOC record of core SO90-111KL but not in core SO130-289KL (Fig. 6). These tree main differences (frames on Fig. 6) between Arabian Sea productivity records cannot be attributed to a problem of resolution between records. Concerning a potential effect of the OMZ on the preservation of the productivity signal, we note that some differences exist between records located within the modern OMZ (cores SO90-111KL, SO130-289KL and NIOP463) (Figs. 1 and 6). We also note that records located below the present OMZ fit with some records within the OMZ during such different events (peak at 27 kyr for example) (Fig. 6). In addition, a key argument for a minor role of the OMZ in driving the preservation of organic matter is the observation that records below and within the present OMZ co-varied with other surface productivity records (Reichart et al., 1998; Caley et al., 2011; see also Pichevin et al., 2007).

Therefore, it can be suggested that (1) the dynamics of the OMZ in the past is not the main driver of the organic carbon preservation signals observed in marine records and (2) the potential effect of bioturbation under the OMZ is weak.

As the terrestrial organic matter is poor in Br compared to the marine (Mayer et al., 2007), a preferential input or degradation of terrestrial organic matter affecting the TOC record in cores located close to the Indus river (SO90-111KL and SO130-289KL) could explained some differences with Br records (Fig. 1 and 6). However, core SO90-111KL and SO130-289KL exhibit some differences in term of amplitude of events whereas they are at the same location, close to the Indus River (Fig. 1 and 6). In addition, the similarity between PC1-bromine event at 27 kyr with that of core SO90-111KL together with the similarity between PC1-bromine event *at 32kyr and 35kyr and thus of core SO130-289KL (Fig. 6) argue against a preferential input or degradation of terrestrial organic matter.*

We suggest that the discrepancies between records reflect the effect of local particularities (mostly exported production, and secondly diagenesis) that can induce signal bias. If true, our strategy based on the extraction of the common variance between different records appears to be a good strategy and the obtained results more susceptible to be compared with other records. Indeed, our results based on PC1-bromine capture the peaks of core SO130-289KL at 32 and 35 kyr which are different in core SO90-111KL but also capture the major peak at 27 kyr which is visible in core SO90-111KL and in our six separated bromine records (Fig. 3) but not in core SO130-289KL.

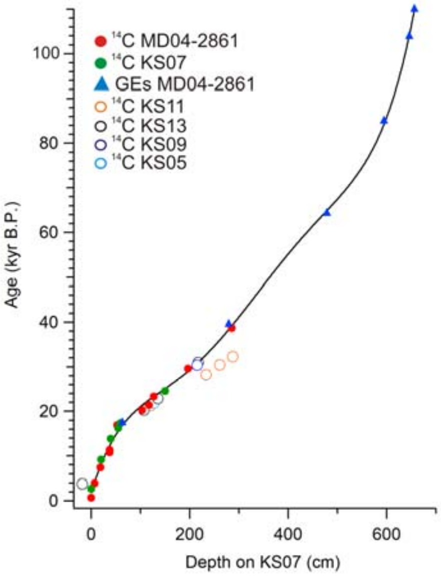
To resume, SH ventilation changes and the dynamic of the OMZ can't be invoked as the main driver of the generation and preservation of productivity signals in the Arabian Sea. Indian summer monsoon dynamic induce variability in upwelling seems to be the good candidate to explain the productivity signals recorded."



New Figure 6

For age constrains, the authors only list and discuss the 14C and GEs in Table 1, but no information is provided for other cores. Age constrains for other cores should be provided. Are the age models for these cores better than +/-5 or +/-10 kyr? If so, some sensitivity test is needed for statements in lines 13-17 on Page 9322.

Ages for other cores have not been provided because the sedimentation is not composed of constant hemipelagic material. Nonetheless, the addition of all available 14C dates (core KS13 and KS11, KS09 and KS05) on the new Figure 2 (added in the revised version) indicates no violation of our initial age model.



New Figure 2

From these new results, we can state that the accuracies of the age model for cores KS13 and KS11 is better than +/-5 ka over the last 35 ka. Also, based on the comparison with three records with their own C14 age models (Fig. 6) we can conclude that the accuracies of the age model of our PC1-Bromine is better than 2 ka for the time period 10-40 ka.

Secondly, they use XRF Br counts as a proxy of surface marine productivity by its correlation with total organic carbon (TOC) from the core KS07 (Fig. 4). If so,why not directly use TOC as a proxy of surface marine productivity?

Because XRF counts allow the fast estimation of down core TOC profiles at high resolution (Ziegler et al., 2008) and because this method is non destructive. Also, the Bromine is related to marine organic carbon whereas TOC can also be influences by terrestrial organic carbon. Nonetheless, in our study in the Arabian Sea as well as in Ziegler et al., 2008 results, a good relationship is found between TOC and Br suggesting that the TOC is mainly linked to marine organic carbon. This is discussed in the revised version in lines 286-294: *"As the terrestrial organic matter is poor in Br compared to the marine (Mayer et al., 2007), a preferential input or degradation of terrestrial organic matter affecting the TOC record in cores located close to the Indus river (SO90-111KL and SO130-289KL) could explained some differences with Br records (Fig. 1 and 6). However, core SO90-111KL and SO130-289KL exhibit some differences in term of amplitude of events whereas they are at the same location, close to the Indus River (Fig. 1 and 6). In addition, the similarity between PC1-bromine event at 27 kyr with that of core SO90-111KL together with the similarity between PC1-bromine event at 32kyr and 35kyr and thus of core SO130-289KL (Fig. 6) argue against a preferential input or degradation of terrestrial organic matter."*

The origin of Br and its preservation are not discussed.

We added in the revised version in lines 112-119: *"Although the chemical nature or origin of the association is unknown, bromine in the particulate phase of sediments is probably associated entirely with organic matter (Harvey, 1980; Pedersen and Price, 1980; Calvert and Pedersen, 1993; Mayer et al., 2007), it behaves conservatively within the water column and is not affected by redox changes in the water column and within the sediments (Shimmield and Pedersen, 1990, and refs. therein). Primary producers, especially macroalgae (Gribble, 1998), and heterotrophic organisms (invertebrates and bacteria) (Gribble, 1998; Van Pée, 1996) are known to synthesize brominated organic compounds and the Br preservation may be subject to normal diagenetic loss of organic carbon during progressive burial (Calvert and Pedersen, 1993; Mayer et al., 2007). Nonetheless, it seems that Br is less labile during diagenesis than the bulk of buried organic matter (Shimmield and Pedersen, 1990). Previous study has demonstrated a good correlation between Br and sedimentary MOC in different productive oceanic settings like for instance the Panama basin (Pedersen and Price, 1980), the Namibian margin (Calvert and Price, 1983), the northwest African margin (Martinez et al., 1999), the Californian margin (Hendy and Pedersen, 2005) and the Arabian Sea (Ziegler et al., 2008)."*

On the other hand, what is the correlation for other cores? It appears that the Br stack and TOC of the core SO90-111KL (Fig. 5) are very different.

The correlation between TOC and Br is employed as a tracer for marine vs. terrestrial organic carbon (Mayer et al., 2007). Although the study of this balance is very interesting, this is not the scope of our paper. Here, we are interested by marine organic carbon which can be associated to surface productivity linked upwelling changes induced by monsoonal winds. The calibration with the TOC for core KS07 just confirm a reduced influence of terrestrial organic carbon in the region and that Br is a proxy for marine organic carbon (Ziegler et al., 2008). The PC1-bromine and TOC of the core SO90-111KL are not very different on the interval 10-40 ka (Fig. 6). Two main differences can be observed and they are discussed in detail in the revised version in the new paragraph 3.3 (lines 252-307).

In addition, both Br and TOC are affected by sediment dilution. It is important to use 230Th-normalization, at least for some key time intervals, to be sure that sediment focusing or dilution does not affect both of the Br or TOC signals.

To ensure that there is no major problem of dilution, we presented in supplementary information the normalization of the Br to other elements. This is also mentioned in the text. I quote from the SI : *"In addition to the bromine stack (Br), two other stacks have been computed following the same procedure describe in the method part but after normalization of the bromine signal by Calcium counts (Ca) and Titanium counts (Ti) obtained with the XRF core scanner. The comparison of the stacks allows the discussion of potential dilution effect for the bromine signal by the input and preservation of biogenic carbonate (documented by Ca counts) or terrestrial material (documented by Ti counts) (Richter, 2006). From this comparison, no significant dilution effect by the input and preservation of biogenic carbonate and terrestrial material can be found. The structure of the signal is conserved, particularly for the interval 10-40 ka. Some amplitude differences occur*

between 60 and 110 ka, but this does not affect the timing of events at the orbital scale discussed in this study".
In addition, at the paleoscale, bromine record of core MD04-2861 co-varied with other surface productivity record such as foraminifera assemblages (Caley et al., 2011), suggesting a common vector with no major lateral advection.

Thirdly, on page 9322, the authors state that a distinct structure in the Br stack from about 22 to 16 kyr BP is not visible in NGRIP but is similar to that recorded in the EDML18O ice record (Fig. 7). This should be the key finding of the paper. Although I do not doubt that there is a distinct structure in the Br stack, the authors do not describe what kind of distinct structure and do not argue why these similarities can be used to indicate that SH changes might play an important role in ISM dynamics. Furthermore, I can not follow why this distinct structure is challenging the traditional views of a strict NH control.
The distinct structure is characterized by a distinct gradual shift in the PC1 of bromine records, which is not visible in NGRIP but clearly observed in –EDML. Therefore, enhanced monsoon intensity coincided with cold intervals in Antarctic climate records. I quote from the text: *"lower Antarctic temperatures lead to a stronger high pressure system over the Mascarene region. Indeed, the Mascarene high is forced by the subsiding branch of the Southern SH Hadley cell owing to the Equator-to-Antarctica temperature gradient. This strengthens the cross-equatorial Somali jet leading to increased intensity of Indian summer monsoons (Xue et al., 2004)."*
This suggest a role (imprint) of the SH and not a strict NH control. Nonetheless, it does not exclude a role of the NH as we observe, although weaker, significant correlations with NGRIP (Table 2). We explained more clearly this point in the revised version.

Other factors may be important on this kind of the distinct structure, such as age control and Br sources. In particular, this distinct structure appears only during the AIM1 (22 to 16 kyr BP), why not during the periods of AIMs 4, 8, and 12 (Fig. 7)?Again, Fig 7B heavily relies on the age model. Are the age models better than +/-5 kyr?
Uncertainties for the age models are described in part 3.2 of the text in details (now in the new part 2.3.1). Age model are better than +/-5 ka (Fig. 6). The structure is not related to Br sources because it is also visible in the Deplazes et al., 2013 record that reflect the alternance of laminated organic-carbon-rich strata and bioturbated sediments and in Schulz et al., 1998 record (TOC). The significant correlation between –EDML and PC1 Bromine records suggests that the structure also appear during AIMs 4, 8 (Table 2 and Fig. 7). The fact that the structure is more expressed during 22-16ka could be a consequence of the specific configuration, i.e the changes from a minimum toward a maximum of Antarctic temperature (Fig. 7) with a large ice volume (An et al., 2011; Caley et al., 2013).

Finally, and the most importantly, when they argue the pressure system of ISM, only the Mascarene high is considered, but not for the Indian low. As discussed by An et al. (2011), strong ISM (high cross-equatorial pressure gradient) during interglacial coinciding low NH ice volume and warm SH temperature is mainly owing to strong Indian low. Similar scenario would occur during the DO stadials. However, a weak ISM during DO stadials is shown in Figure 8b and an unchanged Indian low is shown. In fact, the NH still plays a more significant roleduring the lastdeglaciation as stated in the paper itself and in An et al. (2011), though SH temperature changes affect on the ISM during the glacial periods.

We agree with the reviewer that we need to discuss more in detail the Indian low in parallel to the Mascarene high. However, the interglacial conditions can't be directly compared to our study focussed on glacial conditions. During glacials, the Indian low is weak overall (An et al., 2011). We modified the figure 8 to indicate the role of the Indian low and revised the text accordingly in lines 386-395: *"During SH cooling, the monsoon circulation is enhanced as the results of a less weak Indian low caused by NH temperature increase characteristic of interstadials and the Mascarene high increase (Fig. 8). This produce important energy transfers to the NH, which can, in turn, amplify/modulate DO interstadials (Fig. 7 and Fig. 8). This atmospheric teleconnection has already been suggested for DO interstadials 12, 8, and 1 (Rohling et al., 2003). Conversely, when the SH temperature increases (AIMs), the reduced Indo-Asian monsoon circulation caused by a weaker Indian low and weaker Mascarene high can constitute a positive feedback to the observed stadials recorded in the NH (Fig. 7 and Fig. 8). As atmospheric processes are faster than oceanic processes, the monsoon is an ideal candidate to amplify inter-hemispheric asymmetric patterns during millennial scale changes."*