Interactive comment on “Enhanced western Mediterranean rainfall during past interglacials driven by North Atlantic pressure changes” by Yama Dixit et al.

Anonymous Referee #2

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We cordially thank the reviewer for their constructive comments and helpful suggestions on the manuscript. Our replies to each of the comments are given in blue.

Major comments

The manuscript submitted by Dixit et al to the Climate of the Past journal is a revised version of a manuscript that I reviewed for another journal almost two years ago, and I must say that several of my concerns have not been suitably addressed. Dixit et al. present Mg/Ca and Ba/Ca-based reconstructions of sea surface temperature (SST) and salinity, respectively, for the Tyrrhenian Sea during the last three terminations (TI, TII en TIII) and peak interglacials of MIS 1, MIS 5e, MIS 7e and MIS 7c. From these reconstructions the authors infer changes in Golo River runoff that they interpret to indicate changes in winter rainfall over the northern Mediterranean basin. They observe that the long-term amplitude of the salinity decrease tightly follows eccentricity. They also find that during SST warming putative increases in winter rainfall coincide with increases of African monsoon, increase of Nile River runoff in summer, both developing well-stratified column waters, periods of anoxia and sapropel layers. A comparison of these results with model simulations for the mid-Holocene allows the authors to support the idea of an increased southwesterly moisture transport into the western Mediterranean from the North Atlantic. The first observation is new, and it is interesting to know the factor that may modulate the amplitude of long-term changes in salinity in the Mediterranean Sea; the second finding is not new but supports previous studies explaining sapropel formation (Toucanne et al., 2015, QSR; Grant et al., 2016, QSR) and the origin of the western Mediterranean rainfall during the mid-Holocene (Brayshaw et al., 2011, The Holocene). Therefore, I do not see the real contribution of this manuscript. Moreover, interpreting changes in runoff as direct evidence of changes in seasonal (winter) rainfall seems to me to be inappropriate. Changes in runoff can be the result of changes in vegetation cover with increased runoff during late summer/early autumn in the Mediterranean associated with more erosion, i.e. less forest cover (Durán Zuazo and Rodríguez Pleguezuelo, 2008, Agronomy for Sustainable Development). Additionally, changes in salinity can also result from changes in precipitation-evaporation balance. These issues are not sufficiently discussed in the manuscript.

Reply: We thank the reviewer for acknowledging the novelty of the results inferred from Ba/Ca- runoff record, that the amplitude of the Mediterranean winter precipitation was controlled by eccentricity-modulated precession and that these results provide further support to previous studies explaining the role of Mediterranean winter rain in sapropel formation. Therefore, now we explicitly state in the manuscript both of these points. Lines 1-21 Page 17 now reads

"In this study, we used geochemical proxies to better assess the variation in winter rainfall in the western Mediterranean during the Holocene and the past two interglacials. Our geochemical data suggest increased runoff/ rainfall during the warm periods of the Holocene and the past two interglacials. Proxy data demonstrate that the intensity of the precession-controlled wintertime rainfall in the western Mediterranean was modulated by eccentricity, with times of high eccentricity characterized by higher rainfall and river outflow. These results along with the analysis of Holocene climate simulations support increased winter precipitation sourced from the North-Atlantic in a warmer western Mediterranean during the past. Our data and model results also show that high rainfall events in the northern Mediterranean borderland occurred at times of intensified North African summer monsoon and the sapropel deposition in the Mediterranean basin. This is in agreement with recently published proxy reconstructions for past 1.3 Ma and climate simulations from Lake Ohrid in Central Mediterranean (Wagner et al., 2019). The close chronological correspondence of increased river outflow and winter rainfall to organic carbon deposition and sapropel occurrence supports a causal link. We suggest a close coupling between low and high latitude atmospheric-oceanic processes in triggering anoxia in the basin, with a contribution from, both Nile River outflow changes due to variations in African summer monsoon rainfall as well as North Atlantic climatically-controlled winter-rainfall driving outflow changes in the western Mediterranean."

The main objective of this work was to provide direct geochemical constraints to regional rainfall (salinity) and sea surface temperatures, and to test the hypothesis that increased winter rainfall in the western Mediterranean was North Atlantic- sourced, using PMIP3 model simulations. Increased North Atlantic sourced moisture during past interglacials was previously proposed by some (Kutzbach et al., 2014; Toucanne et al., 2015 and references therein), but contended by several authors (Rohling et al., 2016 for detailed review). We have now stated the aim clearly in the introduction section and also what distinguishes this work from Toucanne et al., 2015. Lines 20-26, Page 3 now reads:

"Mediterranean climates are characterized by strong seasonal contrasts with dry summers and wet and highest precipitation amounts annually during winters from October to March. This winter rain is highly variable in amplitude (Xoplaki et al., 2004). Changes in winter rainfall are critical for regional socioeconomic development for the Mediterranean region, but there still remains a lot of ambiguity on the pattern and mechanism of winter rainfall variability, specifically on Quaternary timescales (IPCC, 2014). Proxy and model studies suggest increased winter rainfall in the western Mediterranean and northern Mediterranean borderland during the Holocene (Carrión, 2002; Fletcher and Sánchez Goñi, 2008; Magny et al., 2011, 2013; Peyron et al., 2011; Zanchetta et al., 2007; Zielhofer et al., 2017) and also during the MIS (Marine Isotope Stage) 5e (Drysdale et al., 2005; Milner et al., 2012; Regattieri et al., 2014) i.e. the warm period of the last interglacial (Railsback et al., 2015). A putative link between high seasonality and increased winter rainfall in the central Mediterranean has also been suggested for the MIS 5e (Milner et al., 2012). This increased winter precipitation in the Mediterranean is attributed to higher air–sea temperature difference and locally induced convective precipitation that dominate changes in the freshwater budget on obliquity timescales (Bosmans et al., 2015; Rohling et al., 2015; references therein). Alternatively, recent study from the oldest lake in Europe, Lake Ohrid in the Balkan Peninsula show that high North Atlantic sourced moisture into the Mediterranean during winters was the primary driver of Mediterranean hydrological changes both on precessional and seasonal timescales during the interglacials of the past 1.36 Ma (Wagner et al., 2019). The Atlantic signature in Mediterranean precipitation is also visible during MIS 10-11 in a leaf-wax isotopic record from Tenaghi Philippon peatland, NE Greece (Ardenghi et al., 2019). In this light, direct rainfall/sea surface salinity (SSS) and sea surface temperature (SST) estimates from well-located, regionally representative archive that cover multiple interglacial periods, is key to addressing long-standing questions regarding the underlying mechanisms and amplitude of winter precipitation variability.

In this study, we bridge the gap by investigating SSS and SST changes in the marine sediment core GDEC-4-2 located off eastern Corsica (Fig. 1). Previously, Toucanne et al. (2015) used sediment characteristics from GDEC-4-2 to propose enhanced North Atlantic-sourced rainfall in the Western Mediterranean during warm intervals of interglacial periods over the last 547 ka BP. Here, we develop independent geochemical record to assess precipitation variability by reconstructing runoff (rainfall/salinity) and temperature changes at the GDEC-4-2 site during the Holocene (MIS 1), the last (MIS 5) and penultimate (MIS 7) interglacials using trace element and stable isotopes of the planktonic foraminifera *Globigerina bulloides* (Fig. 1). We then compare our geochemical proxy records with PMIP model simulations and prominent Mediterranean records, to provide a mechanistic understanding of interglacial precipitation variability."

We agree with the reviewer that changes in runoff could indeed have been affected by seasonal changes in local vegetation, however at longer timescale, sub-orbital in this case, this seasonal effect would be masked by the enhanced precipitation signal which will be reflected in Ba/Ca data. We do concur that the salinity changes can be a result of local evaporation/precipitation, which is the reason why the use of $\delta^{18}O$ is limited in such cases as it is unable to distinguish between the local evaporation/precipitation signal from the global ice-volume and ensuing sea level changes. Therefore, we used Ba/Ca in foraminifera calcite as an independent proxy for local runoff changes. We now discuss this in details on Page 10, lines 20-25 which read
"Difficulties in extracting the local evaporation/precipitation signal from the global ice-volume and ensuing sea level changes, limits the use of $\delta^{18}O_{sw}$ to examine local hydrological changes. Therefore, at GDEC-4-2 site, the $\delta^{18}O_{sw}$ reflect a combined signature of global ice-volume changes and changes in regional precipitation and the Ba/Ca record for river discharge provide independent estimates of the change in SSS for the past interglacials, with high Golo runoff implying increased local precipitation during warm intervals in the western Mediterranean."

Based on previous research in the Mediterranean region, they state that other proxies (pollen and speleothems) are "unable to offer direct insights on the variability in winter rainfall". Contrary to this statement and as far as pollen studies are concerned, we know that present-day changes in Mediterranean forest cover depend on the North Atlantic Oscillation shifts, i.e. on the position and intensity of the westerlies that in turn control winter precipitations in Europe (Gouveia et al., 2008, Int. J. of Climatology). Therefore, pollen-based Mediterranean forest cover changes are direct evidence of changes in winter precipitation as repeatedly shown by data (Fletcher and Sanchez Goñi, 2008, Quat. Res.) and model–data comparisons for different interglacials of the last 800,000 years (Peyron et al., 2017, Climate of the Past;

Oliveira et al., 2018, Climate Dynamics). Moreover, some of these records have allowed for quantitative reconstructions of winter precipitation for TI and the peak of MIS 1 (Fletcher et al., 2010, Climate of the Past; Peyron et al., 2017). I am surprised by the fact that the authors refer to some of these papers in the Discussion section to support their interpretation after criticizing such an approach in the Introduction. Moreover, they justify their work by the inability of this proxy to reconstruct winter rainfall.

Reply: We agree with the reviewer that pollen studies indeed provide direct insights (for example, Fletcher and Sanchez Goñi, 2008, Milner et al., 2012), and have cited these studies in the discussion. However, direct sea surface salinity (SSS) and sea surface temperature (SST) estimates from the western Mediterranean Sea for the past three interglacial including the Holocene, cannot be obtained by palynological studies and is warranted to understand the winter rainfall variability in the Mediterranean. We understand that it was not clearly stated in the previous version, we have now clearly stated that we bridge this gap by presenting new SSS and SST record using marine sediment core GDEC-4-2.

Following the suggestions by the reviewer, we have now rephrased the introduction largely to clearly state previous work done and the aim of this paper. We now state this in lines 1-26, page 3.

Throughout the manuscript the authors are not consistent when they refer to the region of precipitation. Sometimes they refer to northern Mediterranean rainfall, at other times to western Mediterranean rainfall, and they discuss records coming from the east and to the west of this region. This inconsistency is problematic as several studies show that climate during the Holocene in the Mediterranean region presents west-east and north-south gradients (e.g. Dormoy et al., 2009, Climate of the Past).
Reply: We thank the reviewer for pointing this inconsistency; we now refer the region as western Mediterranean throughout the manuscript to maintain homogeneity. Please see lines 16, Page 5; line 2 Page 6; line 12 Page 11, for example.

We do also take note that there is a west-east and north-south gradients in the Mediterranean region, which is in line with our model simulations and this is now mentioned in the text (Page 13, line 16-20). This reads:

“Interestingly, the east-west and north-south gradient in precipitation pattern as noted by previous studies (for example, Dormoy et al., 2009; Magny et al., 2013) is consistent with the increased south-westerly transport in the region, such that the records showing wetter mid-Holocene lie in the stippled area of our simulation results indicating increased moisture.”

I am also concerned by how the authors deal with the timing of Terminations. Terminations are intervals from glacial to interglacial states that generally last a few thousand years and are not events (midpoints) as suggested by Dixit et al. (dashed line in Figures 2 and 3). Terminations should be identified from the 18O of benthic foraminifera, and they are triggered by a combination of ice volume and orbital parameters (Parrenin and Paillard, 2012, Climate of the Past). Cheng et al. (2009, Science) established the timing of marine oxygen isotope terminations (18O of benthic foraminifera) by correlating North Atlantic ice rafted debris (IRD) to radiometrically dated oxygen-isotope cave records from China. The timings of the onset and end of Terminations I, II and III are 18-11 ka, 138-129 ka, 251-243 ka, respectively, and the timing of the midpoint terminations are 14.5 ka, 131 ka, 247 ka. These accurate measurements of the timing of terminations do not coincide with the dates given by Dixit et al. The authors say that the three terminations are centered on 11, 129 and 243 ka, but they do not specify how they established them. With respect to this issue, I invite the authors to look at the recent paper by Barker et al. 2019 in Paleoceanography and Paleoclimatology.

Reply: Based on reviewers’ suggestion, we have now changed the timing of Terminations following the recent Barker et al., 2019 paper, please see lines 10-11, Page 9. Following Barker at al., 2019, we have also now marked the mid-points of terminations in red dashed line on the figures.

Overall, the organization of the manuscript and the order of the figures should be changed, and the English improved.

Reply: We have now enlarged all the figures and also introduced a new Figure 2 (see below), which has the results for GDEC-4-2 only. Consequently, old figure 2 is now Figure 3, which shows the comparison of Last interglacial studies and GDEC-4-2 results on a new age scale from Marino et al., (2015). Original Figure 3 is now Figure 4 showing comparison of all the three interglacials with other studies. We have kept the model simulation results (original Figure 4 now Figure 5) as part of our article, as we think this is important to understand the source of winter rains and complements other model and isotopic studies tracking the source of moisture from the North Atlantic into the Mediterranean, as also discussed above in detail. We have also now checked and corrected the manuscript for any organizational and English grammatical errors. Additionally, we have also modified Figure 1 and its caption and added lake level records used in Figure 4. New Figures 1 and 2 are shown at the end of this document.

For instance, the environmental setting and the studied material are explained twice: at the end of the introduction and at the beginning of the Material and Methods.
Reply: We thank the reviewer for pointing this repetition – this is now corrected.

The introduction should be more focused and clearly explain the gap this work aims to fill and justify the interest of working and comparing the MIS 1, MIS 5e and MIS 7e and MIS 7c warm periods and the related Terminations.
Reply: We have made several changes in the Introduction to clearly state the aims of the paper and the existing gap in our knowledge of hydroclimate variability in the western Mediterranean. Please see previous reply.

Adding model simulations of precipitation changes during contrasting MIS 5e, MIS 7c and MIS 7d interglacials could be relevant.
Reply: We agree with the reviewer that model simulations for MIS 5e, MIS 7c and MIS 7e would have been quite relevant, however, our current understanding of past interglacials is limited because previous coordinated model intercomparisons do not include interglacials older than the Holocene, though this is a topic of active work with PMIP4 simulations will cover the last interglacials available in the coming years (Otto-Bliesner et al., 2016). The idea was, however, recently tested for the interglacials in the past 1.3Ma, from Lake Ohrid on the Balkan Peninsula, together with transient climate model simulations and proxy time series, and they confirm that increased sea surface temperatures during the interglacial amplify local cyclone development and refuel North Atlantic low-pressure systems that enter the Mediterranean when continental ice volume was low and concentrations of atmospheric greenhouse gases were high (Wagner et al., 2019). Therefore, we have added these details to the discussion 1-9, Page 13, with this caveat and pointing out that this will be testable with future simulations. We have now also modified Figure 4 and added recently published pollen data and percent Total inorganic carbon (TIC%) from Lake Ohrid (Wagner et al., 2019,

Nature), which indicate higher aquatic productivity due to warmer conditions and pollen analyses show a simultaneous increase in vegetation cover during early phases of the Last and the Penultimate interglacial periods. This is consistent with our Ba/Ca- river runoff record and PMIP3 model simulations analyzed in our study.

The subsection "Proxy systematics" should be moved to the Material and Methods section. Furthermore, I do not understand the meaning of "systematics" in this context.
Reply: We have made this modification and have moved the 'Proxy systematics' subsection to Materials and Methods. The term 'Proxy systematics' is used to explain the mechanism of how the temperature and rainfall proxies work.

Figure 3 in which all the results from this study are shown should be Figure 2. Figure 2 is only displaying different records covering TII and MIS 5e in the Mediterranean.
Reply: We have now enlarged all the figures and also introduced a new Figure 2, which has the results for GDEC-4-2 only. Consequently, old figure 2 is now Figure 3, which shows the comparison of Last interglacial studies and GDEC-4-2 results on a new age scale from Marino et al., (2015). Original Figure 3 is now Figure 4 showing comparison of all the three interglacials with other studies. We have also modified Figure 4 and added recent pollen data and weight% Total Inorganic Carbon data from Lake Ohrid in the Central Mediterranean for the studied intervals (Wagner et al., 2019, Nature). We have kept the model simulation results (original Figure 4 now Figure 5) as part of our article, as we think this is important to understand the source of winter rains and complements other model and isotopic studies tracking the source of moisture from the North Atlantic into the Mediterranean, as also discussed above in detail.

Additionally, I have found many inconsistencies throughout the manuscript, sentences difficult to understand, and several typographic mistakes (see below other comments).
In the conclusion section I have one major concern related to the following sentence: "Proxy data placed on a globally synchronous timescale demonstrate that the intensity of the precession-controlled wintertime rainfall: : :": What do the authors mean by "globally synchronous timescale"? How have the authors harmonized the different paleoclimatic records presented in the work: GDEC-4-2, ODP sites 975 and 976, Corchia and Tana Urla speleothems, and the Greek pollen record? The Chronology section is confusing and focuses on how Marino et al. (2015) have dated ODP site 975. The

authors only provide in Table S3 (supplementary information) the common age control points between GDEC-4-2 and ODP 975 for TII and MIS 5e, but they do not refer to the related stratigraphic events. What are the control points for dating TI, TIII and the MIS 1, MIS 5e, MIS 7e, and MIS 7c warming peaks?

Reply: We have now corrected the inconsistencies and typos as pointed by the reviewer. For the chronology, we used the age model constructed by Toucanne et al., 2015 for the Holocene and MIS 7c and 7e, which can be referred for more details regarding tie-points, glacial terminations and warm intervals of MIS 1, MIS 7e and MIS 7c.

For MIS 5e, however, we used the chronology constrained by Marino et al., (2017) as they present a new radiometrically constrained chronology for North Atlantic records of climate variability which they synchronized with ODP sites 976, Corchia and Tana Urla speleothems and also with the marine records from the eastern Mediterranean exploiting the well documented intermediate-water connectivity between the eastern and western Mediterranean Sea. Since we synchronized our MIS 5e chronology with ODP975 chronology, our chronology is in turn synchronized with the records in Figure 3. To clarify, we now state in the text

"We followed the chronology described in Toucanne et al. (2015), which is constrained by aligning the planktonic δ18O, weight percent $CaCO_3$ and XRF-Ca/Ti to the NGRIP ice core $\delta^{18}O$ record from Greenland for the last glacial termination (GICC05 chronology; Rasmussen et al., 2006; Svensson et al., 2008) and to the synthetic Greenland (GLTsyn) record of Barker et al. (2011) from 60 to ~550 ka BP. For penultimate glacial termination T-II and MIS 5, we synchronized $\delta^{18}O$ of G. bulloides to the most up-to-date radiometrically-constrained chronology of ODP Site 975 (Marino et al., 2015) (Fig. 3a; Table S2). Marino et al. (2015) obtained a new radiometrically constrained chronology for ODP975 across T-II and the last interglacial period exploiting the well-documented intermediate-water connectivity between the eastern and western Mediterranean Sea, and the relationship between marine surface water microfossil $\delta^{18}O$ and U-series-dated regional $\delta^{18}O$ speleothem records. This was done to obtain a regionally (both eastern and western Mediterranean) synchronous picture for this time period. The $\delta^{18}O$ of planktonic foraminifera G. bulloides from the site ODP 975 is synchronized to the Soreq Cave speleothem and $\delta^{18}O$ of G. bulloides from marine core LC21 in the eastern Mediterranean, and to $\delta^{18}O$ of G. bulloides of ODP Sites 976, 977 and core MD01-2444 in the western Mediterranean, thereby to the SST and/or IRD records of North

Atlantic climate variability that are archived in the Iberian margin sediment cores (see supplementary information, Table S2).

Other comments

Page 2, line 25 – But Toucanne et al. (2015) suggested that the enhanced rainfall in the western Mediterranean during warm periods of the last interglacial was regional and due to the intensification of winter Mediterranean storm tracks.

Reply: We agree with the reviewer in that Toucanne et al., (2015) did hypothesize that the winter rainfall in the western Mediterranean was due to intensified storm tracks, while Rohling et al., (2015) ruled out any extra Mediterranean moisture source and suggested the winter rainfall is recycled moisture from the basin itself. This is in fact the primary objective of this study to provide quantitative SST and SSS estimates such Toucanne et al. hypothesis can be investigated. We do realize that it was not very clear in our earlier version, hence we have now revised our paper to state this point clearly.

Lines 20-26, Page 3 now read

"In this study, we bridge the gap by investigating SSS and SST changes in the marine sediment core GDEC-4-2 located off eastern Corsican (Fig. 1). Previously, Toucanne et al. (2015) used sediment characteristics from GDEC-4-2 to propose enhanced North Atlantic-sourced rainfall in the Western Mediterranean during warm intervals of interglacial periods over the last 547 ka BP. Here, we develop independent geochemical record to assess precipitation variability by reconstructing runoff (rainfall/salinity) and temperature changes in the western Mediterranean basin during the Holocene (MIS 1), the last (MIS 5) and penultimate (MIS 7) interglacials using trace element and stable isotopes of the planktonic foraminifera Globigerina bulloides (Fig. 1). We then compare our geochemical proxy records with PMIP model simulations and prominent Mediterranean records, to provide a mechanistic understanding of precipitation variability."

Page 3, line 5; Page 4, lines 25-26 – Why do the authors cite Raislback et al., 2015 for MIS 5 and MIS 5e and not for MIS 7c and MIS 7e?

Reply: We have now made corrections in the citations which now reads. "Here, we develop independent geochemical record to assess precipitation variability by reconstructing runoff (rainfall/salinity) and temperature changes in the western Mediterranean basin during the Holocene (MIS 1), the last (MIS 5) and penultimate (MIS 7) interglacials (Railsback et al.,

2015) using trace element and stable isotopes of the planktonic foraminifera Globigerina bulloides (Fig. 1).

Page 3, lines 5-6 – Fletcher and Sánchez Goñi (2008) article presents a marine pollen sequence. Therefore, it is not a lacustrine record as indicated by Dixit et al.
Reply: We have corrected this point now (Page 1, line 23-25) which reads. “Proxy and model studies suggest increased winter rainfall in the Mediterranean during the Holocene (Carrión, 2002; Fletcher and Sánchez Goñi, 2008; Magny et al., 2011, 2013; Peyron et al., 2011; Zanchetta et al., 2007; Zielhofer et al., 2017) and also during the MIS (Marine Isotope Stage) 5e (Drysdale et al., 2005; Milner et al., 2012; Regattieri et al., 2014) i.e. the warm periods of the last interglacial (Railsback et al., 2015).”

Page 4, lines 1-11 – The authors should improve Figure 1 by representing the hydrography affecting GDEC-4-2 site.
Reply: We have now added the text describing the hydrography affecting the site GDEC-4-2. We think that the figure would become very crowded if we add the hydrography along with all the existing records and show the connection with the North Atlantic. Since the hydrography is not directly relevant to the scope of this work, we have now added references (Toucanne et al., 2012, 2015) for detailed information on the hydrography affecting GDEC4-2 and the region in general.
The text now reads “The hydrography at GDEC-4-2 site is mainly influenced by the Levantine Intermediate Water (LIW) circulation (from ca. 200 to 600-1000 m water depth) (see Toucanne et al., 2012 for detail information on hydrography of this region). The LIW is formed in the Levantine Basin (eastern Mediterranean) in a permanent large-scale cyclonic Rhodes gyre through summer evaporation and winter cooling (i.e. buoyancy loss; Lascaratos et al., 1999; Malanotte-Rizzoli et al., 2003; Robinson et al., 1992). It forms the major water mass flowing from the east to west, along with the Aegean and Adriatic water contributions. In the northern Tyrrhenian Sea, a portion of the LIW flows northwards through the Corsica Trough, while the other part flows southwards to the Sardinia Channel, then along the western slope of Sardinia and Corsica before its intrusion into Ligurian Sea. The LIW contributes to the Western Mediterranean Deep Water production after reaching the Gulf of Lion and both water masses contribute to ca. 80% and 20% to the Mediterranean Outflow water (MOW), respectively (Pinardi and Masetti, 2000).

Page 5, line 11 – Add a "," after "sporadically" and "to" before "obtain".

Page 5, line 26; legend of Figure 3 – Replace "precession" with "precision".

Reply: Both the errors are corrected now.

Page 6, lines 22-23 – Delete this sentence. It is a repetition of lines 19-21.

Reply: We have now taken out this sentence to avoid repetition.

Page 6, lines 23-25 – Water temperatures can be also decoupled from local atmospheric temperatures during periods of ice-growth (Sanchez Goñi et al., 2013, Nat. Geosci.), not only during periods of high river discharges.

Reply: We agree with the reviewer that a decoupling between the atmosphere and water temperature does occur during periods of ice-growth, however the decoupling observed in our record occurs during globally warm period and hence we suggest that the decoupling is an artifact of high river discharges. This now reads

"These globally warm periods are characterized by increased Mg/Ca-based-SSTs at GDEC-4-2 with ~18 ºC Holocene values, and MIS 5e being the warmest with temperatures averaging ~24ºC, although at this site, our SST reconstructions indicate increased riverine discharge during MIS 7c and 7e led to local SST being cooler (Fig. S4)."

Page 7, line 12 – Modify the following sentence ": : :a reduced concentration of atmospheric concentrations: : :".

Reply: This sentence is now modified to read "Mid-Holocene conditions differ from the PI period through their orbital configuration and reduced atmospheric greenhouse gas concentrations" on lines 24-25, Page 7

Page 7, line 19 – Replace "isotopes" with "record".

Reply: We have corrected this now.

Page 8 – lines 10-12 – Rephrase this sentence, and move all section 3.1 to section 2

Reply: We have made the changes suggested by the reviewer. The sections now read

"2.5 Proxy systematics

The δ_{18}O in foraminiferal calcite is controlled by calcification temperature and the δ_{18}Osw (Bemis et al., 1998). δ_{18}O sw was estimated using Mg/Ca-based-SST in concert with analysed calcite δ18O (δ_{18}O calcite) for *G. bulloides* (δ_{18}O *G. bulloides*) and temperature - (δ18O calcite - δ_{18}Osw) relationship (Bemis et al., 1998). δ_{18}Osw in turn is controlled by

salinity variations due to river runoff, and changes in the isotopic composition of river water and seawater. The latter in turn reflects changes in precipitation relative to evaporation, advection of surface waters to the site, and continental ice volume changes.
Foraminiferal Ba/Ca is used as an independent proxy for riverine runoff and rainfall changes (Weldeab et al., 2007). Seawater Ba (Basw) concentrations at sites influenced by riverine discharge are highly correlated to salinity because dissolved Ba is high in riverine water and Ba desorbs from suspended sediments in estuaries (Coffey et al., 1997). Ba incorporation in foraminiferal calcite varies linearly with changes in Basw and is therefore independent of temperature and alkalinity (Hönisch et al., 2011). We also attempted to use the modern Ba/Casw-salinity relationship obtained off the Golo River to obtain a first-order estimate of the past runoff-induced SSS variations, as recorded by Ba/Caforam."

"Material and Methods".
Page 9, line 4 – Add "," before "respectively".
Page 9, lines 5-6 – Delete "Ocean Drilling Program" and "s" from "Sites".
Page 9, line 12 – Replace "ice-sheet" with "iceberg".
Page 9, line 22 – Figure S4 is not necessary. The same information is presented in Figure 3.
Reply: We have made all the above changes suggested by the reviewer.

Page 10, lines 13-14 – Contrary to authors' statement, d18Osw values are not shown for site LC21 in Figure 2g. Only d18O values of G. ruber are represented.
Reply: The reviewer is correct, we indeed mean $\delta^{18}O$ of foraminifera and not seawater, which is shown in figure 2g. We have corrected this error now.

Page 10, line 13 – Delete "s" from "sites".
Reply: This has been corrected now.
Page 10, lines 14-16 – Add "through the Nile river".
Reply: We have added "through the Nile River and other north African rivers"

Page 10, line 18 – Delete "at".
Page 10, lines 21-22 – Delete "and sea level changes".

Reply: We have corrected these two points now.

Page 11, lines 3 and 27 – Replace “Fig. 3f” with “Fig. 3e”.

Page 12, line 2 - Replace “Fig. 3f” with “Fig. 3e”.

Reply: We have corrected these two points now.

Page 12, line 16 – Add “during winter” after “North Atlantic region”.

Reply: We have corrected this now.

Page 12, line 24 – Amore et al, 2012 is not listed in the references.

Reply: We have added Amore et al., 2012 reference.

Pge 12, line 27 – The “increased precipitation” of the mid-Holocene occurred in winter?

Reply: We agree with the author, it is indeed “increased winter precipitation during the mid-Holocene”. We have corrected this now.

Page 14, line 3 – Delete “direct”. The geochemical evidence presented by the authors is not a direct evidence for winter precipitation.

Reply: We agree with the author and have corrected this now.

Page 15, line 4 – Replace “analysis” with “analyses”.

Reply: We have corrected this now.

Page 26, line 3 – Replace “: : :for the last MIS 5e” with “for TII and MIS 5e”.

Reply: We have corrected this now

Page 26, lines 7-8 – From where do pollen records come?

Reply: The pollen records come from Tenaghi Philippon peatland in NE Greece. We have added this detail in the figure caption now.

Page 26, lines 9-10 – Vertical orange and yellow bars do not indicate “warmer substages of the last interglacial”. Both bars are within the Marine Isotopic Substage 5e.

Reply: We have reworded the sentence to read “Vertical light yellow bars indicate interglacial conditions *s.l.* and dark yellow bars denote interglacials warm intervals and the interglacial *s.s.*”

Page 27, lines 7-8 – Contrary to the authors' statement, vertical orange and yellow bars do not indicate stadials during MIS 1 and MIS 5. Also there is no orange bar. Please harmonize the colors between figures 2 and 3.

Reply: We have made these corrections in the figures now.

In Figure 2, the blue band indicating the HS1 should be enlarged and start at 18 ka and not at 17 ka as shown.

Reply: We have now corrected HS1 in Figure 3.

Modified Figure 1 and new figure 2:

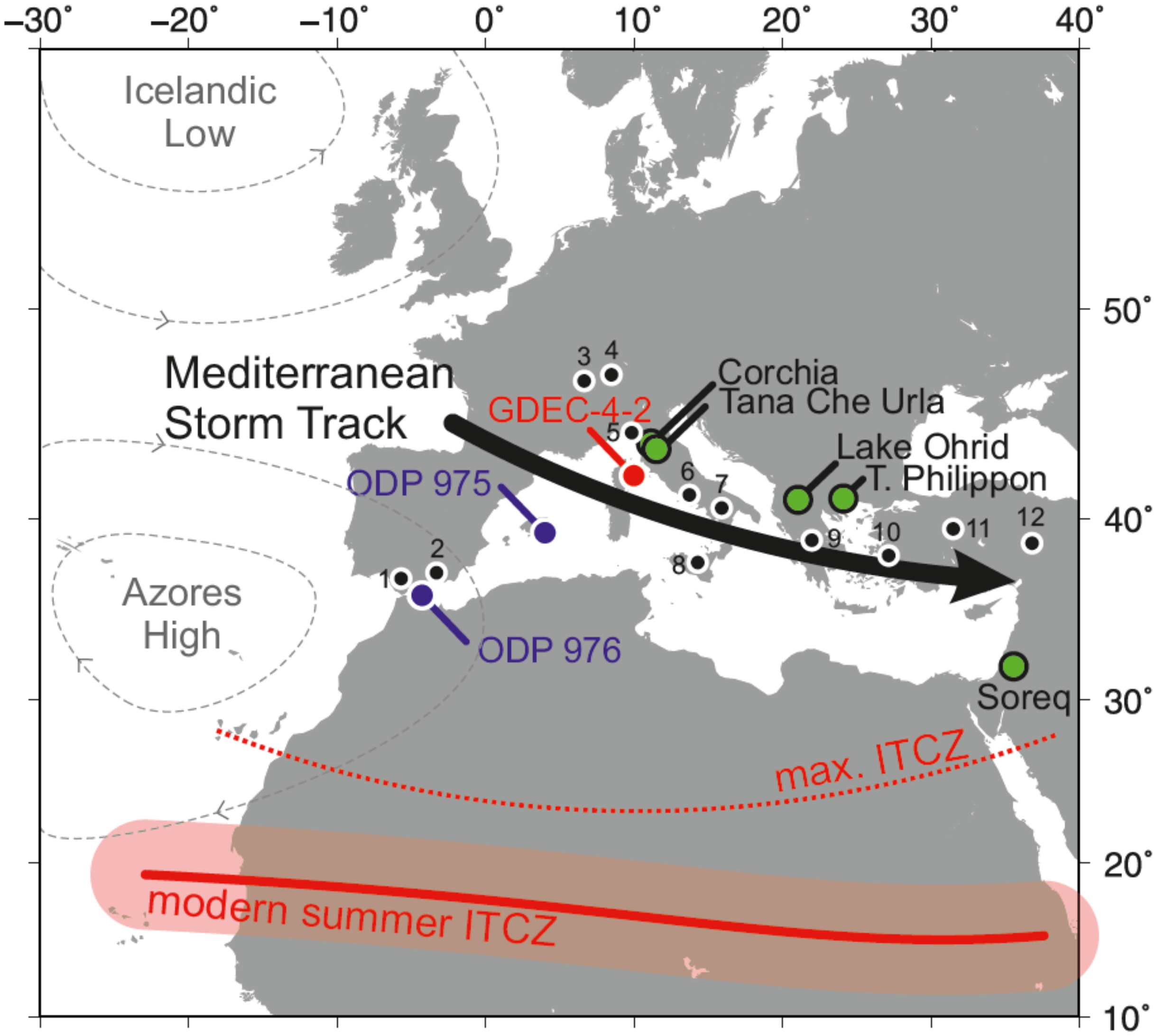

Figure 1: Location of GDEC-4-2 (red) in the Northern Tyrrhenian Sea and other marine (blue) and terrestrial archives (green). Numbers and black dots denote the lake level records used to compare results with model simulations in Figure 5. 1) Lake Medina in southern Spain (Reed et al., 2001); (2) Lake Siles in southern Spain (Carrión, 2002); (3) Lake Cerin (Magny et al., 2011); (4) Lake Ledro in northern Italy (Magny et al., 2012); (5) Lake Accesa in central Italy (Magny et al., 2007); (6) Lake Grande diMonticchio in Basilicata, southern Italy (Allen et al., 1999); (7) Lake Albano and Lake Nema (Ariztegui et al., 2000); (8) Lake Preola in Sicily (Magny et al., 2011); (9) Lake Xinias in northern Greece (Digerfeldt et al., 2007); (10) Lake Golhisar in south-western Turkey (Eastwood et al., 2007); (11) Lake Eski Acigol in central Turkey (Turner et al., 2008); (12) Lake Van in Turkey (Pickarski and Litt, 2017). Red band and red dotted line denotes the extent of modern summer ITCZ and the maximum northward reach of ITCZ in the past respectively (Tuenter et al., 2003). Also shown are the sea-level pressures in North Atlantic and the direction of Mediterranean storm tracks (black).

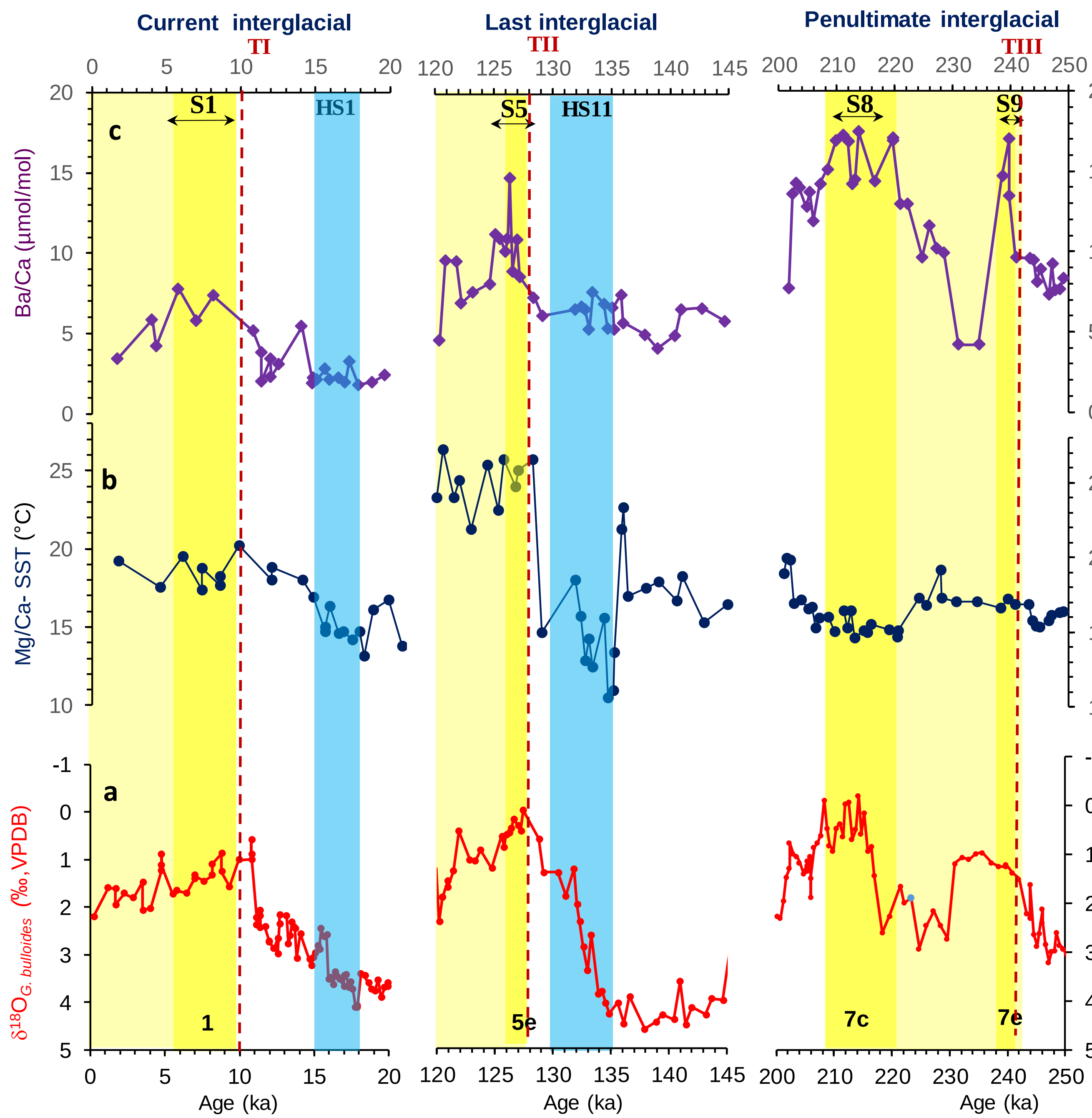

Figure 2: GDEC-4-2 results for the last three interglacials. (a) δ18O *G. bulloides*; (b) Mg/Ca-based SSTs from *G. bulloides* (blue); (c) Ba/Ca in foraminifera as a proxy of river discharge. Vertical light yellow bars indicate interglacial conditions *s.l.* and dark yellow bars denote interglacials warm intervals and the interglacial *s.s.* Sapropel deposition intervals, Heinrich stadials (blue bar) and mid-points of glacial terminations (dashed red line, following Barker et al., 2019) shown on top.