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Climate of the Past
Discussions

Interactive comment on "Millennial-scale variations of sedimentary oxygenation in the western subtropical North Pacific and its links to the North Atlantic climate" *by* Jianjun Zou et al.

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Anonymous Referee #1 Received and published: 18 July 2019 Review Zou et al 'Millennial-scale variations of sedimentary oxygenation in the westernsubtropical North Pacific and its link to North Atlantic climate.

Zou et al. study sedimentary redox conditions in the Okinawa Trough, and use this as a proxy to infer bottom water oxygen concentrations (I think, it is not always very clear from the manuscript). The title promises more than the paper delivers; the link with North Atlantic climate is only mentioned briefly and explanation is sometimes unclear. The authors present interesting data, but the paper itself needs work. There is so

much information (several times incorrectly referenced), and some information seems irrelevant. There is also a lot of internal discussion within the paper without reaching firm conclusions. While the authors are critical about their own proxy, they are less so about others and this needs to be improved.

Reply#1: We thank Reviewer#1 for the time to review our manuscript with constructive comments, which contribute improving our manuscript. Our work adds an important element to the process in the subtropical North Pacific during the last deglaciation. Our data suggest a substantial impact of NPIW on sedimentary oxygenation in the subtropical North Pacific and also an expansion of oxygen minimum zone in the western North Pacific during the B/A. According to the comments of Reviewers #1 and #2, we have made a thorough revision on our manuscript from the abstract to the conclusions, including Figures 3-7, and use "track changes" to display our revised text in red color (supplement 1). In the revised manuscript (supplement 2), we reworded the abstract, amended the age model (see new Figure 3), rephrased some sentences and paragraphs, and added new evidence of benthic foraminifera abundance of core E017 (see new Figure 6) and added some discussion on the North Atlantic Climate. We hope that the Reviewer will find the new finding clearer. In the following we provide point-by-point response to all the Reviewer's comments as well as excerpts from the manuscript.

Comments: Authors should check that their references are appropriate. Several references are not put in the right context.

Reply#2: Thanks. Checked and Revised. The following references were included in the revised MS: in Line 65 for reference Hoogakker et al., 2015 in Line 74 for reference Addison et al., 2012 in Line 97 for reference Max et al 2017 in Line 100 for reference Rippert et al. 2017 in Line 109 for reference Sibuet et al., 1987 in Line 171 for reference Morford and Emerson, 1999 in Line 336 for references Cartapanis et al., 2011; Lembke-Jene et al., 2017 in Line 351 for reference Shi et al., 2014 in Line 359 for reference Chang et al., 2009 in Line 371 for reference Zhu et al., 2015 in Line 376 for reference Lim et al., 2017 in line 400 for reference Bianchi et al. 2012 in lines 450-451 for references Galbraith and Jaccard, 2015; Moffitt et al., 2015; Praetorius et al., 2015 in line 471 for reference Brewer and Peltzer, 2016 in line 502 for reference Galbraith et al., 2007 in line 536 for reference Lim et al., 2017 in line 541 for reference Andres et al., 2015 in line 557 for reference Kubota et al., 2015 in line 584 for reference Kubota et al., 2015 in line 629 for reference Lynch-Stieglitz, 2017 in lines 631-635 for references Böhm et al., 2015; McManus et al., 2004; Liu et al., 2009; Zhang et al., 2017; Barker et al., 2010; Knorr and Lohmann, 2007; in lines 648 for reference Lohmann et al., 2019 in lines 705-706 for references Galbraith and Jaccard, 2015; Jaccard and Galbraith, 2012; Moffitt et al., 2015

The following original references were removed in the revised MS: in line 65 Lu et al., 2016; in line 400 Savrda and Bottjer, 1991 in line 471 Benson and Krause, 1984 in line 541 Matsumotoet al. (2002) in line 557 Kubota et al., 2010 in line 565 Wang and Wang, 2008 in line 584 Kubota et al., 2010

There are several other studies that deal with the North Pacific and NPIW, which are not referenced here; this includes work by Rippert et al. (2017), Max et al. (2017)

Reply#3: Thanks. These two references have been included in the revised manuscript and compared with their findings. In particular, both two papers highlight the substantial effects of NPIW on subsurface water composition of Eastern Tropical North Pacific and potential roles in regulating global climate. Likewise, the effect of NPIW's ventilation on the western subtropical North Pacific in our study is observed clearly. Our study further validates the role of NPIW in determining its downstream ocean environment.

We have added Lines 97-101 "More recently, Max et al (2017) identified the substantial effects of intensified NPIW on δ13C of deep-dwelling planktic foraminifera Globorotaloideshexagonusin the Eastern Equatorial Pacific during Marine Isotope Stage (MIS) 2. Subsequently, Rippert et al. (2017) confirmed that such enhanced effect of NPIW also occurred during MIS 6. "

Abstract: Lines 44-50: these sentences go around the bushes. Really what you want

to say is that sedimentary oxygenation conditions at mid-depth in the subtropical western North Pacific were more or less similar over the last 50,000 years, apart from the Bolling-Allerod and Pre-boreal. However, it may not be possible to compare with Holocene data, as this may be compromised by ash. This is not made very clear in the manuscript.

Reply#4: Thanks for your suggestion. We have rephrased these sentences in the revised manuscript. The sentence was amended as follows. The text was modified as follows. Lines 42-45: "Our results suggest that enhanced sedimentary oxygenation at mid-depths of the subtropical North Pacific occurred during the cold intervals and after 8.5 ka, while decreased oxygenation during the Bölling-Alleröd (B/A) and Preboreal."

As suggested by the Reviewer, our data suggest well-oxygenated water during cold intervals apart from the B/A and Preboreal. For the Holocene, increased sedimentary oxygenation is ascribed to an intensified Kuroshio system, although discrete volcanic materials, indicating by positive Eu anomaly (Zhu et al., 2015) and more radiogenic Nd isotopes (unpublished data), would dilute the Holocene data. Modern observations suggest the Kuroshio can reach the seafloor at 1200 m in the East China Sea (Andres et al., 2015). In the geological past, both various proxy data and modeling simulations suggest an intensified Kuroshio reentering the OT at early Holocene 9-9.6 ka (Chang et al., 2015; Diekmann et al., 2008; Dou et al., 2016; Lim et al., 2017; Zheng et al., 2016b). In our previous study based on the same core CSH1 (Zhu et al., 2015), we have suggested that the discrete volcanic materials during the Holocene is closely related to enhanced Kuroshio intensity events. Recently, increased total Hg concentration in the sediments from the middle Okinawa since 9.3 ka (Lim et al., 2017) was also suggested and explained by hydrothermal Hg source (due to much higher concentrations than potential terrigenous end-members) brought to the site location via intensified Kuroshio Current. Therefore, Kuroshio Current is the fundamental mechanism to improve the ventilation of the OT, not the effects of volcanic material dilution.

We have now added more information into the section 5.2 Redox-sensitive Elements.

Lines 369-376: "It should be noted that pronounced variations in U concentration since 8.5 ka is related to the occurrence of discrete volcanic materials.A significant positive Eu anomaly (Zhu et al., 2015) together with more radiogenic Nd values (unpublished data) from the same core confirms the occurrence of discrete volcanic materials and its dilution effects on terrigenous components since 7 ka. Occurrence of discrete volcanic material is likely related to intensified Kuroshio Current during the mid-late Holocene, as supported by higher hydrothermal Hg concentrations in sediments from the middle OT (Lim et al., 2017)."

Lines 59-61: how does it seem to be driven? Is this not something you are proposing? Then it is not seem.

Reply#5: Thanks. Revised."seem to be driven" is replaced by "can be driven". Lines 49-51 in the revised MS. The sentence now reads: "The enhanced formation of NPIW during HS1 can be driven by the perturbation of sea ice formation and sea surface salinity oscillation in high-latitude North Pacific."

The authors mix up NADW and the Atlantic Meridional Overturning Circulation. For a good description of AMOC see recent paper by Frajke-Williams et al. (2019).

Reply#6: Thanks. We checked the paper Frajke-Williams et al. (2019). In the revised manuscript, we replaced AMOC by North Atlantic Deep Water and reworded these sentences. Lines 51-57 in the revised MS. The sentences now read: "The diminished sedimentary oxygenation during the B/A due to upwelling of aged, nutrient-rich deep water and enhanced export production, indicates an enhanced CO2 sequestration at mid-depth waters, along with a slight increase in atmospheric CO2 concentration. We attribute these millennial-scale changes to intensified NPIW and enhanced abyss flushing during deglacial cold and warm intervals, respectively, on the basis of background climate change due to shift in North Atlantic Deep Water formation."

Introduction: Lines 70-73: not sure how to interpret this. Where is the respired carbon stored? At the sediment-seawater interface, in sedimentary pore-waters, or in seawa-

ter? The study of Lu et al. (2016) deals with I/Ca in planktic foraminifer in the Pacific Sector of the Southern Ocean, to reconstruct upper ocean oxygenation, the part of respired carbon in their paper refers to a different study (Hoogakker et al., 2015).

Reply#7: We have reworded the first sentence for clearer statement. Additionally, the reference (Lu et al., 2016) was replaced by reference (Hoogakker et al., 2015).

The sentence was amended as follows, Lines 62-66: "The sluggish ocean ventilation and efficient biological pump in the ocean facilitate carbon sequestration in the ocean interior, linking to atmospheric CO2 drawdown, which in turn play a crucial role in regulating sedimentary oxygen on millennial and orbital timescales (Hoogakker et al., 2015; Jaccard and Galbraith, 2012; Sigman and Boyle, 2000)."

Lines 76-83: the study of Cartapanis is from the northeastern Pacific, but not high latitude or subarctic.

Reply#8: The study by Cartapanis et al. (2011) presents high-resolution redox-sensitive trace metals in sediment core from the Eastern Tropical North Pacific and found improved intermediate water oxygenation during Heinrich events. The enhanced ventilation during Heinrich intervals is consistent with our inference. Therefore, we would like to keep this reference in the revised manuscript and rephrased the expression of the context.

Now the sentence reads: "Previous studies from eastern and western North Pacific margins and subarctic Pacific have identified drastic variations in export productivity and ocean oxygen levels at glacial-interglacial timescales using diverse proxies such as trace elements (Cartapanis et al., 2011; Chang et al., 2014; Jaccard et al., 2009; Zou et al., 2012), ..."

Line 92: explain what cabbeling is, not everyone will have heard of the term.

Reply#9: Done. Cabbeling is a mixing process to form a new water mass with increased density than that of parent water masses. We've provided a definition see

Lines 85-86 in the revised MS.

The sentence was changed to: "...... that cabbeling, a mixing process to form a new water mass with increased density than that of parent water masses, is the principle mechanism responsible for ......"

Lines 95- 97: do the data really show this? The one core at 1km is about 0.04 per mil lighter (and within error), but crucially there is no Holocene equivalent for the 0.7 km core.

Reply#10:These two studies show enhanced formation of North Pacific Intermediate Water during the last glaciation. On the basis of >30 sediment cores on the northern Emperor Seamounts and in the Okhotsk Sea with a water depth of 1000 to 4000 m, Keigwin (1998) found that there was a better ventilated water mass above 2000 m in the northwestern Pacific and it was characterized by relatively fresher compared to deep waters. Matsumoto et al. (2002) examined nutrient proxies in sediment cores with water depth of 740m to 3320 m in the North Pacific and found a presence of distinctive water masses below and above 2000m water depth in the glacial Pacific with higher benthic δ13C in the upper 2000m water.

Line2 149-152: do you mean 'is governed by' instead of 'is the balance between'.

Reply#11: Revised. Lines 151-154 in the revised MS.

Now the sentence reads: "Sedimentary redox condition is governed by the rate of oxygen supply from the overlying bottom water and the rate of oxygen removal from pore water (Jaccard et al., 2016), processes that are related to the supply of oxygen by ocean circulation and organic matter respiration, respectively."

Figure 1. O2 map, and locations of cores. Are all the cores discussed in the paper? Is it worrying that the main core CSH1 is from just south of Japan and perhaps should not be considered an open ocean core? What do the letters A to E stand for?

Reply#12: All cores shown in Figure1b have been discussed in this manuscript. For

example, benthic δ13C in core PN-3 was used to indicate ventilation change in the OT. Concentrations of CaCO3 and reactive phosphorus recorded in core MD01-2404 were used to correlate with our productivity proxy. Benthic foraminiferal assemblages in cores E017 and 225 retrieved from the middle and southern OT were used to indicate the ventilation of deep water in the OT. Deep-water temperatures in cores GH08-2004 and GH02-1030, epibenthic δ13C in core PC23A and benthic foraminiferal assemblages in ODP 1617-1017 have implicated the ventilation of North Pacific Intermediate Water.

Core CSH1 is situated in the northern Okinawa Trough at depth of 703 m. In this area, both surface and deep water can be continuously replenished by water mass from open oceans.

Letters A to E stand for sediment cores previously reported in and near the Okinawa Trough and are shown in Table 1.

Setting: Do details of discharge and SSS add anything to this study?

Reply#13: Sea surface salinity (SSS) in the East China Sea is closely related to the precipitation intensity controlled by summer East Asian Monsoon (EAM). Accordingly, a recent study from the northern Okinawa Trough (U1429) has extended this relationship back to 400 ka(Clemens et al., 2018). In order to discern millennial-scale variability, we correlate planktic δ18O of core CSH1 with Chinese stalagmite δ18O, an indicator of summer EAM to establish the age model for core CSH1 in our study. We would like to add the details of discharge and SSS in the manuscript to let the readers know the details.

Material and methods: What causes the high accumulation rates in this core? As the accumulation rates vary significantly, how do these influence the patterns in redox elements etc?

Reply#14: In the northern Okinawa Trough, previous sediment provenance studies suggested the terrigenous sediments are mainly sourced from the Yellow and Changjiang Rivers, from China and short mountainous rivers (Japanese or even Taiwanese rivers) from the surrounding islands, as well as eolian dust, volcanic and hydrothermal materials from Yellow River, Changjiang and part of Korea and Japan Rivers (Beny et al., 2018; Li et al., 2015; Zhao et al., 2018; Zhao et al., 2017). Variation in sedimentation rate has been attributed to changes in eustatic sea level, EAM intensity, path and/or intensity of Kuroshio Current. Generally, sea level is thought to be the first-order factor for controlling linear sedimentation rate changes (Beny et al., 2018; Li et al., 2015; Zhao et al., 2017).

Our data show that there is no coherent relationship between linear sedimentation rate and concentrations of redox sensitive elements. For example, high sedimentation rate between 24.2 ka and 32.4 ka (around 40 cm/ka) corresponds to decreasing concentrations of redox sensitive elements. On the other hand, lower sedimentation between 16 ka and 19.8 ka also corresponds to lower concentrations of redox sensitive elements. Therefore, linear sedimentation rate is not a crucial factor in controlling concentrations of redox sensitive elements in core CSH1.

Lines 339-340: preservation of TOC and CaCO3 are influenced by many factors and not a widely used paleo-export proxy.

Reply#15: We fully agree that the preservation of TOC and CaCO3 are influenced by many factors, including supply, dissolution, organic matter degradation, terrigenous dilution, etc. Some factors can be ruled out and at times these two proxies have been used to reconstruct export productivity. In this study, C/N molar shows substantial contribution of terrigenous organic matter to total organic carbon, so it is not a suitable proxy for productivity reconstruction.

In the revised manuscript, we showed multiple lines of evidence to support the utility of CaCO3 as a reliable productivity proxy, including (1) strong negative correlation with terrigenous Al of core CSH1; (2) weak dilution effect of terrigenous material on

CaCO3; (3) similar pattern to sea surface temperature of core CSH1 (Shi et al., 2014) (the data have been included in Figure 6); (4) similar deglacial trends in CaCO3 and reactive phosphorus reported in core MD012404 retrieved from the middle OT (Chang et al., 2009; Li et al., 2017). All these lines of evidence support CaCO3 as a proxy for productivity.

We have added these information in lines 342-361 in the revised MS: "Several lines of evidence support CaCO3 as a reliable productivity proxy, particularly during the last deglaciation. The strong negative correlation coefficient ($r = -0.85$, $p<0.01$) between Al and CaCO3 in sediments throughout core CSH1 confirms the biogenic origin of CaCO3 against terrigenous Al (Figure 4f). Generally, terrigenous dilution decreases the concentrations of CaCO3. Inconsistent relationship between percentage CaCO3 and sedimentation rate indicates a minor effect of dilution on CaCO3. Furthermore, the increasing trend in CaCO3 associated with high sedimentation rate during the last deglacial interval indicates a substantial increase in export productivity (Figures 4a and 4d). The high coherence between percent CaCO3 and alkenone-derived sea surface water (SST) (Shi et al., 2014) indicates a direct control on CaCO3 by SST. Moreover, a detailed comparison between CaCO3 concentrations and the previously published foraminiferal fragmentation ratio (Wu et al., 2004) shows, apart from a small portion within the LGM, no clear co-variation between them. These evidence suggest that CaCO3 changes are driven primarily by variations in carbonate primary production, and not overprinted by secondary processes, such as carbonate dissolution through changes in the lysocline depth and dilution by terrigenous materials. Likewise, similar deglacial trend in CaCO3 is also observed in core MD01-2404 (Chang et al., 2009), indicating a ubiquitous, not local picture in the OT. All these lines of evidence thus support CaCO3 of core CSH1 as a reliable productivity proxy to a first order approximation."

Line 354-357: have you checked that it is an extant biological component that makes up the high CaCO3 going from B/A to $\sim$ 8000 years? Can you explain the differences in the LSR figures between Figures 3 and 4? For examples, in Figure 3 highest rates occur centred around 22 kyrs as part of a large interval of high LSR (from 30 to 20), whereas in Figure 4 this occurs earlier (33 to 24 kyrs).

Reply#16: Seven samples at 8.23 ka (120-124 cm), 9.26 ka (144-148 cm), 10.98 ka (184-188 cm), 11.66 ka (200-204 cm), 12.92 ka (232-236 cm), 14.05 ka (264-268 cm), and 15.18 ka (296-300 cm) in core CSH1 were analyzed by Modular Stereo Microscope (Zeiss SteREO Discovery V12) to look into the sediment components. It is clear that abundant biogenic tests, especially foraminiferal tests, are observed during these sediment intervals (Figure A1). On the other hand, increased concentration of CaCO3 is highly coherent with the abundance of planktic foraminifera species G.ruber and SST (Shi et al., 2014), indicating a substantial effect of SST on CaCO3.

In the original manuscript, we made a mistake for LSR in Figure 3. In the revised manuscript, this issue has been corrected (Figure 3).

In addition, high sedimentation (>40-60 cm/ka) in the original manuscript mainly occurred during HS2 and HS3. This can be caused by uncertainties of age control points at 23.476 ka (DO2) and 29.995 ka (H3). In the revised manuscript, these two age control points have been eliminated from the Chinese Stalagmite tuned age model. Even with this more conservative tuning approach, the conclusions on sedimentary oxygenation variations remain the same as before and robust.

Lines 365-266: if U concentrations are affected by volcanic material over the last 8.5 yrs, then surely so are other sedimentary properties? I would like to see an argument in the main text discussing why certain proxy methods are deemed not to be influenced by this volcanic material, whilst others are. If it turns out that interval should not be used than this creates the complication of not being able to compare the down core data with more modern.

Reply#17: The occurrence of volcanic material has been confirmed by positive Eu anomalies and more radiogenic εNd values (unpublished data) and it has substantial effects on concentration of terrigenous materials (Zhu et al., 2015). This argument has

been included in the revised text. Please see Reply#4.

Line 370: change ‘seems’ to ‘may’.

Reply#18: Revised. “seem to” was replaced by “may”. Line 380.

Lines 372-377: are there any other studies that use Mo/Mn ratios as a sedimentary oxygenation proxy, to support your interpretation?

Reply#19: To our knowledge, Mo/Mn ratios are not used as sedimentary oxygenation proxy in previous studies. In this study, we use both Mo/U ratio and excess U concentration to reconstruct sedimentary oxygenation changes. Among these, excess U concentration has been widely used for past sedimentary oxygenation changes (Jaccard and Galbraith, 2013; Jaccard et al., 2016; Jaccard et al., 2009). The strong positive correlation coefficient between excess U and Mo/Mn ratio in core CSH1 indicates its reliability and supports our interpretation. In addition, we also examined the Mo/Mn ratio in sediment cores from the Sea of Japan (KCES1, unpublished data), subarctic Pacific (LV76-18, unpublished data), and the Norwegian Sea (BB03, unpublished data). These data lend strong support for us to view the Mo/Mn ratio as a reliable proxy in reconstructing sedimentary oxygenation changes.

Line 380: define oxygen deficient. Reply#20:In the revised manuscript, "oxygen-deficient" was replaced by "deoxygenated".

The sentence now reads as follows, Lines 391: "...... together with lower Mn concentrations suggest a deoxygenated depositional condition during the late deglacial period (15.8 kaâĂŠ9.5 ka)......" The oxygen thresholds are given in lines 399-401.

Discussion: Lines 387-392: I would recommend the authors to use more appropriate scheme that is used for sea-water that includes hypoxic, for example as defined by Bianchi et al. (2012). You will also found that suboxic is classified as < 2-10 μmol/l.

Reply#21: Thanks. The oxygen content scheme for seawater developed by Bianchi et al.(2012) has been adopted in the revised manuscript. Lines 400-402 in the revised

MS.

Following the Reviewer's suggestion we changed the sentence to: "Here, we adopt the definition of oxygen thresholds by Bianchi et al. (2012) for oxic (>120 μmol/kg O2), hypoxic (<60–120 μmol/kg O2) and suboxic (<2–10 μmol/kg O2) conditions, whereas anoxia is the absence of measurable oxygen."

Lines 403-405: I do not understand this reasoning. You have not linked weakly restricted basin settings with euxinia?

Reply#22: We thank the reviewer for this suggestion. The previous manuscript had an inaccurate statement. Now, we changed this sentence to make it more explicit. The sentence was amended as follows. Lines 413-415 in the revised MS. "Given that the northern Okinawa Trough is located in the open-ocean settings, we use the above mentioned two proxies to evaluate the degree of oxygenation in sediments."

It is confusing talking about ppm in the main text, whilst Figure 4 gives concentrations in μg/g.

Reply#23: Corrected.

In the revised manuscript, the uniform concentration unit, μg/g has been used for all trace elemental concentrations in the main text. Lines 416 and 421 in the revised MS.

Lines 406-412: Mo/U ratios are not shown in the manuscript. This is out of the blue.

Reply#24: Revised.

Mo/U ratio has been included in Figure 4m.

Lines 413-425: two studies. More importantly though, Figure 4 shows no benthic foraminifera data, and it is therefore impossible to confirm this claim of ventilation pattern from benthic foraminiferal assemblages to be similar to that of the RSEs. It would also be good to see a more critical discussion about this proxy.

Reply#25: We understand the point raised by the Reviewer. In this study, the benthic foraminiferal species are not counted in core CSH1. The benthic foraminiferal census data in cores E017 (1826 m water depth), 255 (1575 m water depth) are used to indicate the variations in ventilation of the middle and southern OT. The age model for core 255 (core length 655cm) was determined by two AMS 14C dates of N.dutertrei at depth 370 cm (9.17 ka) and 590 cm (18.8 ka) (Jian et al., 1996), whereas the age model for core E017 was established by 6 age points (Li et al., 2005). Although the downcore abundance of hypoxia-like species in both studies are similar to each other(Li et al., 2005), here we focus on the benthic foraminiferal census data in core E017. We recalibrated the AMS 14C dates using CALIB 7.04 software with Marine 13 calibration dataset (Reimer et al., 2013) and compare the profiles of oxygen-like species and hypoxia-like species with our Mo/Mn and excess U. For the sake of simplicity, the abundance of Bulimina aculeata (hypoxia-like species) and Cibicidoides hyalina (oxygen-like species) have been included in Figure 6 in the revised manuscript. High relative abundance of B.aculeata and low C. hyalina suggest the dominance of hypoxic environment, whereas the oxic condition is prevailed after ∼7 ka. This is consistent with our RSEs data, suggesting a widespread occurrence of oxygen-depleted water in the Okinawa Trough during the last deglaciation.

Lines 425-428: No. There is at least 800 meter water depth difference between your core and the others. The core of the current study is situated just above the low oxygen zone, whereas those of the other two studies are in /below the low oxygen zone.

Reply#26: Thanks for your comments. The seafloor bathymetry is much deeper in the southern OT, and shoals gradually toward the northern OT. Although our core is above the sill depth (1100m), while others below (1100m), previous investigations show the hydrographic characteristics in the mid-depth and deep OT are mainly regulated by the NPIW in the western boundary region of the Philippine Sea that flows into the OT through the Kerama Gap (1100 m) and the channel east of Taiwan (775 m) (Nakamura et al., 2013). Thus, ventilation signals recorded in these cores are mainly controlled by the same physical processes, though export productivity in different areas also exerts some impacts on deepwaters and sedimentary oxygenation.

Lines 439-448: why are you looking at one NE Pacific to find out what is happening at your core site? There are several studies from across the Pacific that show something happening around the same time period (for example see Moffit et al., 2015), and Galbriath and Jaccard (2015), so rather than repeating the same discussion for a very small area, it would be easier to build up on those results.

Reply#27: At present, a contrasting distribution of dissolved oxygen concentration of the subsurface water can be observed in the eastern and western North Pacific margins (Figure 1), which is characterized by strong Oxygen Minimum Zone in the eastern margin and oxic condition in the western margin. The benthic foraminiferal assemblages from ODP site 1017 exhibit strengthening of OMZ during warm periods and weakening during cold periods (Cannariato and Kennett, 1999). The question that whether expanded OMZ can extend toward the western NW Pacific remains elusive in the geological past during warming intervals. In fact, the key question involved is how to explain the cause of oxygenation variation on basin- wide scale. Comparison of our results from the western North Pacific with those of the eastern North Pacific aids to understand the mechanism behind sedimentary oxygen changes.

We have added more information into the section 6.2 and all these references have been included in Lines 448-463. "These processes have been invoked in previous studies to explain the deglacial Pacific-wide variations in oxygenation by either one or a combination of these factors (Galbraith and Jaccard, 2015; Moffitt et al., 2015; Praetorius et al., 2015). Our data also suggest drastic variations in sedimentary oxygenation over the last 50 ka. However, the mechanisms responsible for sedimentary oxygenation variations in the basin-wide OT and its connection with ventilation of the open North Pacific remain unclear. In order to place our core results in a wider regional context, here, we compare our proxy records of sedimentary oxygenation (Uexcess concentration and Mo/Mn ratio) and export productivity (CaCO3) (Figures 6a, b, c) with

abundance of Pulleniatina obliquiloculata (an indicator of Kuroshio strength) and sea surface temperature (Shi et al., 2014), bulk sedimentary nitrogen isotope (an indicator of denitrification) (Kao et al., 2008), benthic foraminifera δ13C (a proxy for water mass) in cores PN-3 and PC23A (Rella et al., 2012; Wahyudi and Minagawa, 1997), abundance of benthic foraminifera (an indicator of hypoxia) in core E017 (Li et al., 2005) and ODP167 site 1017 (Cannariato and Kennett, 1999) (Figures 6d-k)."

Lines 454-457: no, at those high temperatures you would only get a reduction in O2 of $\sim$ 3 for one degree warming, and 15 for a four degree warming (assuming no large salinity changes). Higher glacial salinity would cause less reduction in O2.

Reply#28: Corrected. The reference by Brewer and Peltzer (2016) has been included in the revised manuscript. Lines 469-473.

The sentence was changed to: "Based on thermal solubility effects, a hypothetical warming of 1°C would reduce oxygen concentrations by about 3.5 μmol/kg at water temperatures around 22°C (Brewer and Peltzer, 2016), ..."

Lines 457-458: sentence does not make sense. Reply#29:We have removed the sentence in the revised manuscript.

Lines 848-846ïijĹ484-486ïij§ïijĽ: does not make sense. How does subsurface water oxygen consumption lead to lower oxygen concentrations in deeper waters?

Reply#30: Thanks for your suggestion. We have removed the sentence in the revised manuscript. The replenishment of oxygen in deep water is controlled by both lateral advection and vertical supply. The oxygen consumption in subsurface water would reduce the oxygen concentration, thus lead to a less penetration of oxygen into deeper waters.

Lines 491-494: again not taking into account other factors that influence CaCO3 accumulation and preservation in sediments. For discussion on Kuroshio Current: see Lim et al. (2017).

Reply#31: Please see Reply #16 for CaCO3. Total Hg concentrations (Lim et al., 2017) has been invoked to explain variations in the intensity of Kuroshio. Interestingly, they concluded that the intensity of Kuroshio strengthened rapidly since 9.3 ka, whereas weakening and/or changing path of Kuroshio occurred during the last glaciation (20 ka - 9.3 ka). This conclusion further confirms weakening effect of Kuroshio on ventilation during the glacial period but an increase since 8.5 ka, consist with our inference.

We have added Lines 534-537. "More recently, lower hydrothermal total Hg concentration during 20 ka - 9.6 ka, associated with reduced intensity and/or variation in flow path of KC, relative to that of Holocene recorded in core KX12âĂŘ3 (1423 water depth) (Lim et al., 2017), further validates our inference."

Line 544-550: coined? Matsumoto et al. (2002) discuss one radiocarbon age from the Santa Barbara basin in relation to oxygen content, but at no point do they propose that GNPIW was stronger oxygenated. Cartapanis et al. (2011) and Ohkushi et al. (2013) discuss that the NE OMZ Pacific strengthened and weakened at millennial time scales, not glacial interglacial timescales. Also around the equatorial Pacific it is suggested that there was no difference in intermediate water oxygenation between the last glacial and Holocene (Hoogakker et al., 2018). Further down in the South Pacific Lu et al. (2016) suggest that upper waters were depleted in oxygen during the last glacial period.

Reply#32: In Matsumoto et al. (2002), published in Quaternary Science Reviews (2002, 21, 1693-1704), they used a compilation of benthic foraminiferal δ13C to reveal the deep hydrography of the North Pacific. On page 1700 of this paper, they stated that "Although a water mass that reaches 2000 m should not be called intermediate water in the sense of modern physical oceanography, here we will refer to it as glacial NPIW (GNPIW) for the lack of a better name." According to our understanding, GNPIW refers to the nature of NPIW during cold intervals in the geological past, which is used to describe the state of NPIW at a variety of timescales, such as glacials, stadials, and Heinrich cold events. It should be noted that, since then, this term have been widely used in the literature related to NPIW (Cartapanis et al., 2011; Max et al., 2017; Worne

et al., 2019).

Cartapanis et al. (2011) stated in the abstract that "...... intermediate water oxygenation improved during H events, but slightly deteriorated during late Marine Isotope Stage (MIS) 3 and MIS 2." and they attributed to reorganization in regional intermediate oceanic circulation.

Ohkushi et al. (2013) revealed millennial-scale changes of OMZ of the NE Pacific with an increase at warming interval and a decrease at cold interval during the last deglaciation. They also found that "the middle to late Holocene (6–0 ka) was less dysoxic than the early Holocene."

Around the Eastern Equatorial Pacific, Hoogakker et al. (2018) suggested a persistent oxygen depletion of shallow depths during the last glacial period and the Holocene. Lu et al. (2016) concluded that the oxygen depletion in upper waters is closely related to poor ventilation and storage of respired carbon. Our data show increased ocean oxygenation at intermediate depth during the last glacial period and we attribute to enhanced NPIW formation at that time. Such spatial discrepancy in ocean oxygenation is ascribed to regional ocean circulation and export production.

Lines 550-556: generalised comment, what about brine (aka Kim et al. 2011).

Reply#33: Thanks. In the revised Manuscript, we shorten these sentences. Lines 568-570 in the revised MS.

The sentence now was changed to: "The intensified formation of GNPIW due to the displacement of source region to the Bering Sea was proposed by Ohkushi et al. (2003) and then is confirmed by Horikawa et al. (2010)."

Lines 556-559: what is intensified GNPIW?

Reply#34:"intensified GNPIW" means improved ventilation and deeper penetration of NPIW. Here, we also use enhanced NPIW formation to replace intensified GNPIW. Lines 575-576 in the revised MS.

The sentence was amended as follows. "......validate such inference, suggesting pronounced effects of intensified NPIW formation in the OT."

Discussion lines 560-571: needs tightening, it is unclear where this goes and how it relates to this study?

Reply#35: We have rewritten these sentences together with lines 572 - 581 (in the original manuscript). In the revised manuscript, the aim of this paragraph is to clarify the process of intensified GNPIW during HS1 and its substantial control on sedimentary oxygenation of the northern OT. Lines 577-592 in the revised MS.

We have changed the sentences as follows: "During HS1, a stronger formation of GNPIW was supported by proxy studies and numerical simulations. For example, on the basis of paired benthic-planktic (B-P) 14C data, enhanced penetration of NPIW into a much deeper water depth during HS1 relative to the Holocene has been revealed in several studies (Max et al., 2014; Okazaki et al., 2010; Sagawa and Ikehara, 2008), which was also simulated by several models (Chikamoto et al., 2012; Gong et al., 2019; Okazaki et al., 2010). On the other hand, increased intermediate water temperature in the subtropical Pacific recorded in core GH08-2004 (1166 m water depth) (Kubota et al., 2015) and young deep water observed in the northern South China Sea during HS1 (Wan and Jian, 2014) along downstream region of NPIW are also related to intensified NPIW formation. Furthermore, the pathway of GNPIW from numerical model simulations (Zheng et al., 2016a) was similar to modern observations (You, 2003). Thus, all these evidence imply a persistent, cause and effect relation between GNPIW ventilation, the intermediate and deep water oxygen concentration in the OT and sediment redox state during HS1. In addition, our RSEs data also suggested a similarly enhanced ventilation in HS2 (Figures 6b and 6c) that is also attributed to intensified GNPIW."

Line 629: what is ocean ventilation seesaw? There is hardly any explanation for this in the main text, and Figure 7 shows strength of AMOC in the Atlantic and compares this

with the current study.

Reply#36: In the revised manuscript, the "ocean ventilation seesaw" has been replaced by "the mechanism behind such out-of-phase pattern between the ventilation in the subtropical North Pacific and the North Atlantic deep water formation" Lines 653-655 in the revised MS.

In addition, we also have added some discussion about the North Atlantic Climate in the 1st paragraph of section 6.3 and modified the text of the following sections to make it more logical.

Lines 625-636 "One of the characteristics climate features in the Northern Hemisphere, in particular the North Atlantic is millennial-scale oscillations during the glacial and deglacial periods. These abrupt climatic events have been widely thought to be related to varying strength of Atlantic Meridional Overturning Circulation (AMOC) (Lynch-Stieglitz, 2017). One of dynamic proxies of ocean circulation, 231Pa/230Th reveals that severe weakening of AMOC only existed during Heinrich stadials due to increased freshwater discharges into the North Atlantic (Böhm et al., 2015; McManus et al., 2004). On the other hand, several mechanisms, such as sudden termination of freshwater input (Liu et al., 2009), atmospheric CO2 concentration (Zhang et al., 2017), enhanced advection of salt (Barker et al., 2010) and changes in background climate (Knorr and Lohmann, 2007) were proposed to explain the reinvigoration of AMOC during the B/A."

Lines 637-638 "Our RSEs data in the Northern OT and epibenthic δ13C in the Bering Sea (Figures 7a-c) both......"

Lines 653-655 "However, the mechanism behind such out-of-phase pattern between the ventilation in the subtropical North Pacific and the North Atlantic deep water formation remains unclear."

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Captions Figure A1 Photomicrographs with Modular Stereo Microscope (Zeiss SteREO Discovery V12) show that both detrital and biogenic components of sediment coarse fraction (>63 μm) for 8.23 ka (120-124 cm), 9.26 ka (144-148cm), 10.98 ka (184-188 cm), 11.66 ka (200-204 cm), 12.92 ka (232-236 cm), 14.05 ka (264-268 cm), and 15.18 ka (296-300 cm) in core CSH1 at 200X magnification.

Figure 3. (a) Lithology and oxygen isotope (δ18O) profile of planktic foraminifera species Globigerinoides ruber (G.ruber) in core CSH1. (b) Plot of ages versus depth for core CSH1. Three known ash layers are indicated by solid red rectangles. (c) Time series of linear sedimentation rate (LSR) from core CSH1. (d) Comparison of age model of core CSH1 with Chinese Stalagmite composite δ18O curve of (Cheng et al., 2016). Tie points for CSH1 core chronology (Table 2) in Figures 3c and 3d are designated by colored crosses.

Figure 6. Proxy-related reconstructions of mid-depth sedimentary oxygenation at site CSH1 (this study) compared with oxygenation records from other locations of the North Pacific and published climatic and environmental records from the Okinawa Trough.

Please also note the supplement to this comment:
https://www.clim-past-discuss.net/cp-2019-70/cp-2019-70-AC1-supplement.zip

Interactive comment on Clim. Past Discuss., https://doi.org/10.5194/cp-2019-70, 2019.

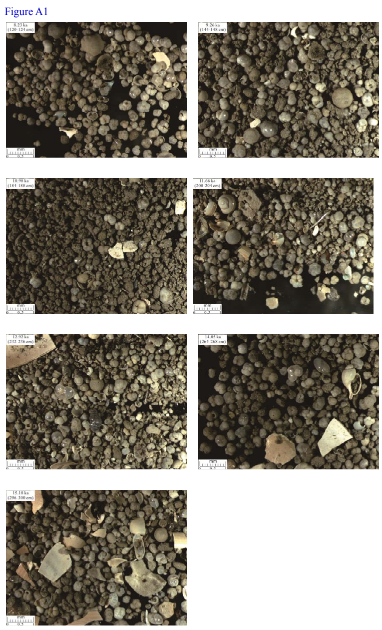

Fig. 1. Figure A1

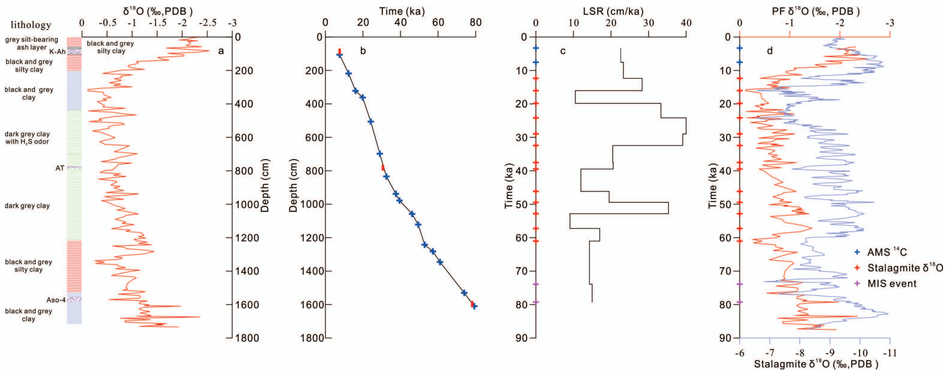

Fig. 2. Figure 3

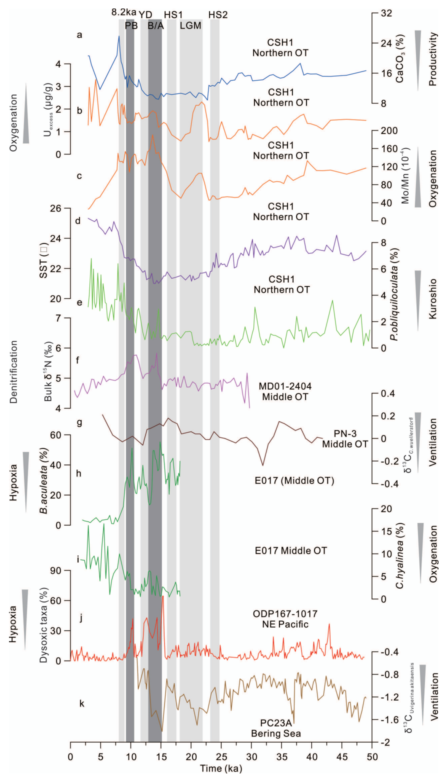

Fig. 3. Figure 6