Review of the paper:

"Leeuwin Current dynamics over the last 60kyrs - relation to Australian extinction and Southern Ocean change" by Dirk Nürnberg, Akintunde Kayode, Karl J.F. Meier and Cyrus Karas

Note: Our responses are in blue. All line numbers given here refer to the track-edited versions of the revised manuscript and the revised supplement.

1. Reviewer (Brad Opdyke)
I think this is an excellent paper. The data are detailed and terrific. It is primarily a paleoceanography/paleoclimatology paper, but seems to get starry eyed over the megafaunal dung data. These data, while fun, are not really the focus of the paper, nor should they be. Given the megafauna were probably slaughtered by the early human arrivals, attributing any cause and effect to these paleoceanographic data is drawing a long bow indeed. The dung data need to be de-emphasized and the focus of the abstract and the conclusions should be on the primary paleoceanographic data, which is a high quality data set and should be given top billing!

Many thanks for taking the time to have a look at our manuscript. Following your advice, we toned down the issue on megafaunal extinction. Indeed, our manuscript mainly deals with the paleoceanographic development of the circulation pattern south of Australia. We now omitted the term "Australian extinction" in the title of our manuscript, and shortened the abstract to "We argue that the concerted action of a rapidly changing Leeuwin Current, the ecosystem response in Australia, and human interference since ~50 BP enhanced the ecological stress on the Australian megafauna until its extinction at ~43 ka BP".

We are fully aware of the diverse and longstanding debate on the causes of megafauna extinction, yet we are sure that our "ocean perspective" offers new insights into this topic. Therefore, we have retained a brief subsection on megafauna extinction, because the data on dung fungi from the same sediment core that point to extinction and their compelling correlation with Leeuwin Current and Southern Ocean dynamics cannot remain unconsidered.

Please, also have a look at our reply to the reviewer 2 comments. We considerably improved our manuscript by shortening, re-structuring, and improving the figures.

2. Reviewer (anonymous):
This paper presents a number of high-resolution new data concerning hydrological changes South of Australia, since 60 kyr. Both oxygen isotopes and Mg/Ca of surface dwelling and deep dwelling planktonic foraminifera were measured, to reconstruct Sea surface and thermocline temperature and salinity evolution. The authors present the different currents and water masses influence along the last 60 kyrs and compare their result with different climatic records of the Southern Ocean. They also compare their data with the evolution of atmosphere circulation and South Australia precipitation, pollen and charcoal, to discuss the main factors that conduct to the Australia's megafaunal extinction. This interesting paper thus contains a lot of information, that is not really reflected in the title as not only the Leeuwin current evolution is considered for the oceanic circulation changes. The last part of the paper, dealing with the reasons of the megafauna extinction is well written and easier to follow than the oceanographic discussion.

First, we want to acknowledge the efforts of reviewer 2 for his/her thoroughly review of our manuscript which helped a lot to improve it. We also thank the reviewer that he/her finds our manuscript interesting, stating that it contains a lot of information. In the following we will respond in detail to the reviewer comments.

I would suggest major revisions for two main reasons.

The first one concern the interpretation of the trace element concentration Mg/Ca of the foraminifera. The recent papers that improved a lot the knowledge concerning the factors playing a role in the incorporation of Mg/Ca in foraminifera tests are not taken into account. The authors should take into account those papers by W. Gray, and D. Evans, see Gray and Evans 2019 and reference therein. For the top core sample the temperature reconstructed for the SST for the eastern site is far from the climatologic one. It would be interesting to see the temperature reconstructed using the more recent temperature equation. Taking into account that Mg/Ca will reflect not only temperature change but also salinity and pH changes will change the results. The origin of the surface waters coming mainly from the tropical area, changes in atmospheric CO_2 can be used to take into account pH changes, but for thermocline waters the influence of Subantarctic waters that probably underwent different pH changes due to their Southern Ocean origin might be of importance. The different salinity changes linked also to the changes of the water mass characteristics and the changes in currents strength might complicate the reconstruction.

We apologize for not having considered the recent study of Gray and Evans (2019). We now inserted the following paragraph in our Supplement to discuss in detail the pH-effect on our foraminiferal Mg/Ca data (Supplement Lines 443 ff):

"Gray and Evans (2019) showed by culture experiments that the Mg/Ca-ratios of some planktonic species are sensitive to carbonate chemistry: Foraminiferal Mg/Ca declines with increasing pH (−5 to −9% per 0.1 pH units). These results are mainly in accordance to earlier studies. Lea et al. (1999) claimed that seawater pH changes shell Mg/Ca by -6% per 0.1 pH unit increase. Russell et al. (2004) stated: "Below ambient pH (pH < 8.2), Mg/Ca decreased by 7 $\pm$ 5% (*O. universa*) to16 $\pm$ 6% (*G. bulloides*) per 0.1 unit increase in pH. Above ambient pH, the change in Mg/Ca was not significant for either species." Congruently, Kisakürek et al. (2008) found that the influence of pH on Mg/Ca ratios is negligible at ambient seawater pH (8.1 to 8.3). Below a seawater pH of 8.0, instead, pH has a dominating control on shell Mg/Ca. Hence, Russell et al. (2004) concluded that Mg/Ca-based paleotemperatures for the Quaternary, during which surface-ocean pH has been at or above modern levels, have not been biased by variations in surface-water pH.

The negative Mg/Ca vs. pH relationship is balanced by the fact that foraminiferal Mg/Ca is positively correlated with salinity: Nürnberg et al. (1996) already showed from culture experiments that Mg/Ca in *T. sacculifer* changes by 7-10% per salinity unit. Lea et al. (1999) described a 4 $\pm$ 3% change in Mg/Ca per salinity unit for *G. bulloides*, which is rather consistent to the 4 $\pm$ 3% change per psu for *G. ruber*. The Arbuszewski et al. (2010) study referred to an even higher salinity dependence (27 ± 4%). Taken all data together, these results point to a strongly non-linear, positive salinity effect on shell Mg/Ca ratios.

Following Sanyal et al. (1995), who suggested an increase in salinity (by 1 unit) and pH (by 0.2 $\pm$ 0.1) in the oceans during the LGM, Lea et al. (1999) concluded that their opposing effects on shell Mg/Ca should partially cancel each other (also pointed out in Nürnberg, 2000, Science). Since then most Mg/Ca-related studies did neither correct for paleo-salinity nor paleo-pH changes through time.

Gray and Evans (2019) undertook new efforts in this respect. They claim that "the (pH) effect on Mg/Ca is considerably greater than that of salinity, resulting in a large bias in reconstructed temperature if unaccounted for..." They presented the new software package "MgCaRB", which allows to correct foraminiferal Mg/Ca for pH down-core using either atmospheric CO_2 or (preferably) boron isotopes (https://willyrgray.shinyapps.io/mgcarbv1/).

Table S2. For the assessment of the ph-effect on foraminiferal Mg/Ca, MgCaRB requires the input parameters "modern salinity", "modern alkalinity", and the assumed "modern pCO_2 disequilibrium" at the study sites. Modern salinity and alkalinity from the respective core locations and species living depths are from Goyet et al. (2000). For the modern pCO_2 disequilibrium, we tested 3 scenarios (see text).

	Habitat depth (m)	Salinity (psu)	Total alkalinity (µmol/kg)	pCO_2 disequil. (µatm)	
MD03-2614	30-80	34.7	2288	-70 / 0 /+70	*O. universa*
34.7°S 123.4°E	350-400	34.6	2290	-70 / 0 /+70	*G. trunca*
MD03-2609	30-80	34.7	2279	-70 / 0 /+70	*O. universa*
39.4°S 141.5°E	350-400	34.8	2286	-70 / 0 /+70	*G. trunca.*
MgCaRB default settings		35.0	2300	0	.

To better assess a possible bias of changed ocean pH on our reconstructed SST reconstructions off southern Australia, we applied the MgCaRB routines (Gray and Evans, 2019) to our Mg/Ca datasets. When using the program´s CO_2 approach, the relevant input parameters “modern salinity” and “modern alkalinity” where taken from the Ocean Data View (ODV) database from the respective core locations and species living depths (Table S2; Goyet et al., 2000). The resulting $SST_{Mg/Ca}$ records calculated with these modified salinity and alkalinity parameters (Table S2; gray and blue curves in Fig. S10) deviate within error for $SST_{Mg/Ca}$ estimates ($\pm$ ~1°C) from those calculated with the MgCaRB default settings. We hence consider these modifications of minor importance.

MgCaRB offers 3 Mg/Ca vs. temperature calibrations, which might be applied to the *O. universa* Mg/Ca values. The “multispecies” calibration produces unreasonable $SST_{Mg/Ca}$ >24°C far above modern conditions and is hence not considered. The “generic calibration” provides $SST_{Mg/Ca}$, which are ~1-2°C cooler than those calculated with the “species-specific” calibration. Both calibrations provide core-top $SST_{Mg/Ca}$, which refer to austral winter SST. Instead, the Hathorne et al. (2003) calibration specifically established for *O. universa* and used in our study, provides warmer-by-3°C core-top $SST_{Mg/Ca}$, which is basically consistent with the austral summer SST in the area (see Supplement why we opted for the calibration of Hathorne et al., 2003).

Notably, the MgCaRB-derived $SST_{Mg/Ca}$ records exhibit clearly cooler LGM conditions and higher amplitude variations (by 2-3°C) through time than the non-ph-corrected $SST_{Mg/Ca}$ record presented in our study (Fig. S10), which we assume less likely. Further, all MgCaRB calculations provide core-top (~1.3 ka BP) pH-estimates of ~8.18, which are definitely higher than the modern surface ocean pH-value south of Australia (8.105-8.11; Gregor and Gruber, 20021; Raven et al., 2005). Downcore, the pH changes from 8.18 to 8.32 (at MgCaRB default settings). If Kisakürek et al. (2008) are correct, the influence of pH on Mg/Ca ratios in this pH-range is negligible.

For the deep-dwelling *G. truncatulinoides*, MgCaRB only offers the “multispecies” calibration, which produces unrealistic core-top $subSST_{Mg/Ca}$ values being higher-by-3-4°C than the modern subSST conditions. We hence will not continue to discuss the ph-corrected $subSST_{Mg/Ca}$ records.

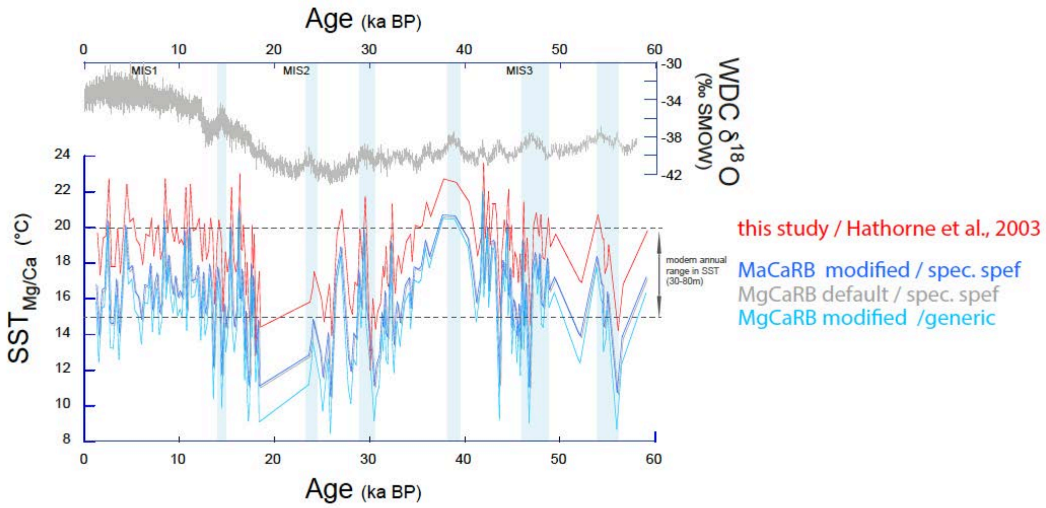

Figure S10. Comparison of differently calculated SST records based on foraminiferal $Mg/Ca_{O.universa}$ from Site MD03-2614. Red: $SST_{Mg/Ca}$ record used in the manuscript, based on the Mg/Ca vs. T-relationship of Hathorne et al. (2003). Gray: $SST_{Mg/Ca}$ record calculated with MgCaRB using the default program settings and the *O. universa* species-specific calibration. Blue and light blue: $SST_{Mg/Ca}$ records calculated with MgCaRB using modified salinity and alkalinity settings (Tab. S-1), and the species-specific (blue) and generic calibrations (light blue) for *O. universa*.

In a further step, MgCaRB offers to include a value for the “modern pCO_2 disequilibrium” at the study site. The “modern pCO_2 disequilibrium” and its effect on the $SST_{Mg/Ca}$ estimates is difficult to assess due to the sparse database south of Australia. We first opted for the MgCaRB default setting of 0, pointing to equal pCO_2 concentrations in surface water and atmosphere. In a second step, we varied the pCO_2 disequilibrium conditions from -70 (suggesting that the surface ocean is a CO_2-sink) to 70 (surface ocean is a CO_2-source). These values are considered as reasonable endmember values for our evaluation (c.f. Takahashi et al., 2009). For the study area, in fact, monthly mean values for sea–air pCO_2 differences are clearly lower and range between ~-10 to ~-40 µatm (Takahashi et al., 2009) pointing to overall CO_2 absorbing (sink) conditions.

When applying MgCaRB, the more negative the pCO_2 disequilibrium is, the more positive will be the according $SST_{Mg/Ca}$ and pH estimates. Fig. S11 shows the core 2614 and core 2609 ph-corrected $SST_{Mg/Ca}$ records at the three different “modern pCO_2 disequilibrium” conditions outlined above: -70 µatm, 0 µatm (default), and +70 µatm. The according errors in $SST_{Mg/Ca}$ amount to on average $\pm$0.9°C.

When assuming that the surface waters at the western Site 2614 originate mainly from tropical ocean areas (CO_2-source; releasing 0.5-1 mol C m^{-2} y^{-1}; McKinley et al., 2017; more positive pCO_2 disequilibrium; c.f. Takahashi et al., 2009; Grenoop et al., 2017) while the eastern site is not, the western core would become even cooler at seasurface, thereby enhancing the $SST_{Mg/Ca}$ difference between the two sites. Instead at subsurface level: When assuming that the subsurface waters at the eastern Site 2609 are fed by subducted southern-sourced surface waters (CO_2-sink; absorbing CO_2 by -1 mol C m^{-2} y^{-1}; McKinley et al., 2017; more negative pCO_2 disequilibrium; c.f. Takahashi et al., 2009; Grenoop et al., 2017), then the $subSST_{Mg/Ca}$ at the eastern location would likely become warmer, reducing the $subSST_{Mg/Ca}$ gradient to the western location. This effect is likely very small, as the deglacial ph of subantarctic surface water never fell below 8.0 (Shuttleworth et al., 2021), with almost negligible effects on foraminiferal Mg/Ca.
We cannot clarify all the issues raised by the Gray and Evans (2019) study, but our considerations imply that the ph-effect on our temperature reconstructions remains such small (<0.9°C; see above) that it has no major implication for our paleoceanographic interpretations.

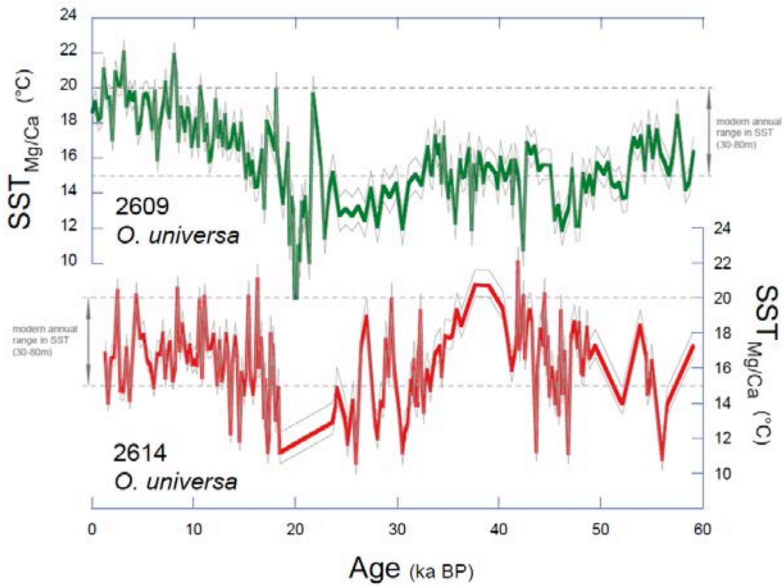

Figure S-2. The core 2614 and core 2609 ph-corrected $SST_{Mg/Ca}$ records (MgCaRB) at the three different “modern pCO_2 disequilibrium” conditions outlined above: -70 µatm (upper gray record), 0 µatm (red and green), and +70 µatm (lower gray record). The hatched lines mark the modern annual range in SST at 30-80 m water depth.

We note, instead, that it is the chosen Mg/Ca vs. temperature calibration, which is most crucial to our study. The choice of an inadequate (not regionally and species-specific calibrated) calibration equation may introduce errors. With respect to the warmer late Holocene $SST_{Mg/Ca}$ at the eastern site compared to the western site – which is basically opposite to what is initially expected from the modern situation - we give to consider that the late Holocene raw $Mg/Ca_{O.universa}$ ratios at the eastern site are undoubtedly higher than at the western location, affording a more differentiated interpretation.”

References are given in the Supplement.

The second reason is the fact that the main part concerning oceanic changes is quite difficult to read. It first relies on an analogy with a simplified description of the modern setting and finally consider much more complicate evolution of currents and influence of the different water masses.

We regret that parts of our manuscript are difficult to read for reviewer 2. Accordingly, we rewrote many parts and considerably changed and improved our manuscript. See where and how we changed the text in detail below.

Some atmospheric considerations appear much later in the discussion as well as some currents and they have not been presented in the modern settings. For example, the subtropical ridge is not presented in the modern setting. It appears for the first time on page 22 where it is still not defined, it is defined on the next page, 23. On fig 6A and on page 32

STR appears but is not defined either. Does it correspond to the Subtropical Ridge? The West Australian Current could be also presented in the modern setting as well as the Est Australian current and the SIOC. The oceanographic area is quite complicated and the assumptions relating the changes in the isotopic and trace elements changes to evolution of water masses and currents influence is not always "direct". This part is thus sometime difficult to follow. A table presenting the implication of the different SST, TT and âˆ†TT and SST evolution for the different periods considered would be most welcome.

We agree and re-structured. As requested, we now provide basic oceanographic and atmospheric information already in Chapter 2.1, and shortened the discussion chapter accordingly. In particular, we discussed in more detail the forcing mechanisms of the Leeuwin Current. This also includes a brief discussion of the atmospheric circulation pattern and the Subtropical Ridge in the Australian area, which are important drivers for the Leeuwin Current System. We added information about the modern West Australian Current and the South Indian Ocean Current. With respect to the East Australian Current: As this current is hardly affecting our study area, we do not go in very much detail in the description.

Accordingly, we changed Chapter 2.1 and Chapter 2.2, and also Chapter 4.3 considerably (please see manuscript, track changes).

We decided to not include a table presenting the SST, TT and ΔT conditions for selected periods in the past, as suggested by the reviewer, as this is done in detail in Fig. 7.

Following are some comments described along the text.

Line 49 : ITW et EGC are not shown on fig.1 suppress fig.1 in this sentence.

Done

Fig.1 SIOC : correct 2607/2609 by 2607/2611

Done

Line 81 ivc not explained (Ice Volume corrected I suppose)

Yes, right, we changed to (Lines 94-100):

"Stable oxygen isotope ($\delta^{18}O$), Mg/Ca-based reconstructions of surface and thermocline temperatures ($SST_{Mg/Ca}$; $TT_{Mg/Ca}$), and the regional ice-volume-corrected $\delta^{18}O$ of seawater ($\delta^{18}O_{sw\text{-}ivc}$ approximating surface and thermocline salinity) from two sediment cores off southern Australia (MD03-2614 and MD03-2609) allow to address the past dynamics of the vertical water column structure south of Australia in response to latitudinal shifts of oceanographic and atmospheric frontal systems, and the impact of the Southern Ocean change in the study area."

Line 326 : Records have been interpolated to calculate gradients. It would be nice to give the sedimentation rate and the resolution of the different records.

We refer to Chapter 3.2., where we provided the following information (Lines 396-399):

"The sedimentation rates in both cores 2609 and 2614 vary from 5-20 cm/kyr over the last 60 kyrs (Fig. 3D), with persistently higher rates and higher-amplitude changes in the western core 2614 for most of the time."

We added the following information (Lines 399-400):

"Sampling of cores 2614 and 2609 was accomplished every 2 cm, providing a temporal resolution of on average ~230 years for core 2614, and ~290 years for core 2609."

Further, Fig. 3D provides the depth/age-relationships of both cores, which basically reflect sedimentation rates.

Line 347, 348. long term analytical precision: add « standards ». What is the reproducibility of G. ruber, G. truncatulinoides and O. universa oxygen isotopes in those cores ?

We did not measure replicates on our foraminiferal samples, mainly due to the insufficient numbers of specimens found. However, we provide information on our longterm results of stable oxygen isotope measurements on our MAT253, as it is an established and well-known methodology with known errors. The long-term analytical precision is 0.06 ‰ (1s) for $\delta^{18}O_{VPDB}$ and ±0.05 ‰ for $\delta^{13}C$. In a previous study from the same laboratory, the revealed $\delta^{18}O_{VPDB}$ reproducibility of 148 measurements of *G. truncatulinoides* is ±0.14 ‰ (Nürnberg et al., 2021).

The reproducibility (1s) for the NFHS-2-NP standard (NIOZ Foraminifera House Standard-2-Nano-Pellet; Boer et al., 2022) for $\delta^{18}O_{VPDB}$ is -0.013 ± 0.08 ‰ (number of analyses n = 94); for our inhouse carbonate standard (Carrara Marbel) $\delta^{18}O_{VPDB}$ is -1.86 ± 0.09 ‰ (n = 157); our inhouse foraminifer standard (Manihiki) provides $\delta^{18}O_{VPDB}$ with -0.74 ± 0.17 ‰ (n = 32).

We added the following to the text (Chapter 3.4; Lines 498-501):

"Replicate measurements were not done, due to the low numbers of specimens found. A previous study on the same device revealed a $\delta^{18}O_{VPDB}$ reproducibility of ±0.14‰ from 148 replicate measurements of *G. truncatulinoides* (Nürnberg et al., 2021)."

Line 361 correct ivf by ivc

We replaced "ivf" by "ivc" within the entire text.

Line 370 The notation -0.5-0.5‰ is not very clear. Change maybe for -0.5 to 0.5‰. Furthermore, in the GISS data base there are no values less than 0.25‰ (very few data points) for the first 400 m depth of the area.

We changed to "-0.5 to 0.5‰" in the entire text.

Lines 371 and 374 Mean Holocene should maybe be corrected to Late Holocene if it is a mean of the most recent 5ka.

Done

Lines 407-409 the link between temperature warming and saline conditions comes by the large temperature changes: the isotopes variations are mainly ≤0.5‰, while Mg/Ca temperatures varies by 4 to 10°C. The Mg/Ca temperatures could be noisy.

The reviewer is here addressing the high-amplitude seasurface temperature and salinity development during the last deglaciation. We here fully agree that it is the Mg/Ca-temperature, which causes the large $\delta^{18}O_{sw-ivc}$ (salinity) variations, not the stable oxygen isotope signal.

We note, however, that both the SST and the planktic $\delta^{18}O$-variations are clearly larger in the western core than in the eastern core, which we refer to a more dynamic ocean variability in the western area (see discussion in manuscript).

We also note that the amplitude variations in Mg/Ca during the deglaciation are not significantly larger than during the remaining record, hence not "extremely" noisy for that area.

Lines 413-427 : For the eastern site, the Mg/Ca temperatures are higher than the modern range but for MIS2. For the Holocene they are even higher than temperatures from the western site. Could the authors comment?

We kindly refer to our argumentation (see below) responding to the last but one comment of Reviewer 2.

Fig.2 : The range 50-100 m water depth is indicated for O. universa in the legend, while 30-80 m is indicated on the graphs. Why not keep the usual colors for the two cores: green and

red. And choose other colors for fig.2B, that is the longitudinal profile. Keeping the blue and red colors for 2A and 2B favor confusion.

We corrected figure caption 2 (Lines 239-240): “Presumed calcification depths of foraminiferal species analyzed are indicated by gray shadings: *O. universa* at ~30-80 m water depth …..”. This is congruent to what we show in the figure and stated in the Supplement.

We also followed the advice of the reviewer and changed the colors of the line graphs (Figure 2 A, B).

Lines 446-472 and fig. 6 : Not easy to follow: In the text and on fig. 6A, from 60 to 37 kyr increasing La Niña is indicated, corresponding to a stronger Leeuwin current, while on figure C the trend for that period is a weakening of the Leeuwin current.

We agree to the reviewer that our argumentation is unclear here. We have to admit that the presented relationship between our core 2614 SST record and ENSO strength (former Fig. 6A) is not fully convincing. We hence decided to take out the entire SST-ENSO-issue from our manuscript. The related shortening concerns Chapter 4.1, Chapter 6, and the figure caption of Fig. 6. Fig. 6 was modified accordingly. The shortening does not concern the main conclusions of the paper.

We initially stated and presented in Fig. 6A that the western core $SST_{Mg/Ca}$ record broadly follows the modelled El Niño-Southern Oscillation (ENSO) power, relating enhanced SST conditions to strong La Niña conditions. The reviewer noted a perceived contradiction, however, that from ~60 to ~37 ka BP the gradually increasing La Niña conditions were in line with the weakening of the Leeuwin Current (c.f. former Fig. 6A and 6C).

Based on our paleodata data, we rather make the point that the Leeuwin Current strength is not a direct function of ENSO. A strong Leeuwin Current is not so much reflected by very high SST (as being existent during La Niña), but rather by high thermocline temperatures, a small vertical gradient between SST and TT, and a large W-E gradient of $TT_{Mg/Ca}$ - conditions comparable to the modern austral winter conditions.

In order not to defocus our conclusions on driving mechanisms for the Leeuwin Current, we decided to take out the ENSO-related aspects.

Fig.6: STR is not defined; it is not possible to read what is on fig. 6.B

We changed Fig. 6 and the according figure caption (now Lines 1038-1050). Most importantly, we removed the SST and ENSO records in Fig. 6A.

STR is no longer mentioned in Fig. 6. The Subtropical Ridge (STR) is now described in Chapter 2.1 (Lines 141-150).

Line 482 : The average looks closer to 20°C than 18°C at 60ka BP

We agree with the reviewer. We re-calculated the $TT_{Mg/Ca}$ average, which is 20.2°C. We changed the text accordingly (Line 685).

Line 493 : 10-12°C is the modern range for the western site. For the eastern site, it is 9-10°C (WOA) maybe indicate cooler by 2-3°C than the core top.

If we define MIS 3 from ~57 to 29 ka BP (c.f. Lisiecki and Raymo, 2005), the $TT_{Mg/Ca}$ range at the eastern site is 7-11°C. The modern TT range is 9-11°C (c.f. Fig. 2). We hence modified our text to (Lines 694-695):

“In the eastern core 2609, the MIS3 $TT_{Mg/Ca}$ range between ~7°C and 11°C, which is cooler by max. 2°C than the modern TT range (9-11°C, c.f. Fig. 2).”

Lines 493-495 : the ^{18}O axis is reverse so the curve indicate more positive and not “more negative” conditions and during LGM the conditions are not fresher but more saline.

Yes, the reviewer is right, we messed it up here – maybe due to our insufficient wording. We modified to (Lines 695-701):

"The thermocline depth $\delta^{18}O_{sw-ivc}$ values (-0.5 to ~0.5 ‰) are mostly equal or more positive than the modern value (Richardson et al., 2019; c.f. Fig. 4), but remain clearly fresher by up to 2‰ and less variable than at the western core (0-2 ‰). During MIS 2 and in particular during the LGM, the conditions at thermocline depth at core 2609 are cooler-than-modern by ~2°C, while remaining fresher and lower in amplitude compared to the clearly more variable and warmer thermocline conditions at core 2614 (Fig. 5 C, D)."

Lines 534-538: could be in the modern setting part.

Yes, we agree with the reviewer and moved that part to the Chapter 2.2. (Lines 269-274):

"Along the southern Australian margin, the boundary between the top surface of SABCW (as part of the Central Water) and the overlying STSW defines the interface between the eastward-directed Leeuwin Current System transporting subtropical waters and the westward flow of the Flinders Current System, which brings subantarctic waters into the region (SABCW coupled to Tasmanian Subantarctic Mode Water (TSAMW) and Tasmanian Intermediate Water (TIW)) (Fig. 2 B; Richardson et al., 2019)."

We shortened the initial part to (Lines 787-789):

"The boundary between STSW and Central Water defines the interface between the eastward-directed Leeuwin Current System and the westward flow of the Flinders Current System (c.f. Fig. 2 B; see Chapter 2.2)".

Lines 543-545: strong stratification should be associated with high ΔT_{SST-TT}?

We modified our initial sentence to (Lines 792-795):

"The vertical temperature gradient (ΔT_{SST-TT}) provides insight into the thermocline depth, with small (large) ΔT_{SST-TT} pointing to a shallow (steep) thermal gradient and a deep (shallow) thermocline with accompanying strong (weak) vertical mixing."

Lines 553-567 : difficult to read, rephrase the English? What does the authors mean by "compare to the modern situation"? idem for "with a rather equalized vertical temperature gradient" and "The oceanographic setting as existent today was considerably different". Furthermore, the latest Holocene SST reconstructed from the two cores does not really look alike the modern situation as the reconstructed SST of the eastern site is ~21°C instead of within the range 13-16°C. The atmosphere circulation has not been presented in the modern settings and as for STR, it would have been nice to read about the role of the "opposing winds" before.

We agree with the reviewer and re-structured this paragraph. The information on the modern oceanographic setting has been moved to Chapter 2.2, which led to further shortening of the paper.

We address in detail the deviation of the reconstructed $SST_{Mg/Ca}$ of the eastern site from the modern SST conditions in Chapter 4.3 (Holocene). We here noted (Lines 1198-1205):

"The differential behaviour at surface and thermocline depths became most pronounced after ~6 ka BP, when the thermocline at the eastern core location 2609 became distinctly shallower than in the western study area, while $SST_{Mg/Ca}$ continued to increase. We relate the warmer and more saline late Holocene conditions at sea surface in the east (Fig. 4 B, D) to intensified surface heating near the eastern edge of the Great Australian Bight during austral summer (c.f. Herzfeld and Tomzcak, 1997). These shallow waters then spread eastward over the shelf and continued to flow as South Australian Current towards Bass Strait (Middleton and Platov, 2003; Ridgeway and Condie, 2004)."

We also argue that during the Holocene, "…the East Australian Current re-invigorated flowing south down the east coast of Australia and seasonally affecting the south coast…" (Lines 1195-1196) synchronous to "…increasing air temperature and a spatially heterogeneous hydroclimate with increased effective precipitation…" across the Australian temperate region (see Lines 1192-1193).

See also our comments further below on the high SSTs in the eastern area.

A short discussion of the atmospheric circulation pattern and its role for the ocean currents is added to Chapter 2.1 (now lines 141-150).

Line 568: yes for TT waters not for the surface ones.

Yes, the reviewer is right. We now defined the discussed time interval to ~60-45 ka BP, and changed our text (Lines 849-854):

"The oceanographic setting as existent today was considerably different during the early MIS3 (~60-45 ka BP) with tangible differences between both regions. The thermocline was generally deeper (Fig. 6 A), and the thermocline waters were considerably warmer and more saline in the western than in the eastern region (Figs. 5 C, D), pointing to an overall thick STSW in line with a strong Leeuwin Current. The $SST_{Mg/Ca}$ conditions were rather similar in both areas during these times (Figs. 4 C, 6 A)."

Line 575: is it really "dislocation" or shift?

What we meant here is the poleward movement of the location of the front. We changed to "shift" (now Line 859).

Line 580 correct for "between core 2614 ΔT_{SST-TT} and $\Delta TT_{west-east}$"

Done (Line 864)

Line 625 similar would be more appropriate than equalized?

We changed to the following, which better expresses what we mean (Lines 941-944):

"Approaching $SST_{Mg/Ca}$ conditions at both study sites with according $\Delta SST_{Mg/Ca}$ minima occurred consistently during the MIS 3 warming periods 7, 6, 5, and 3, implying that the formation of the South Australian Current intensified at times of a strong Leeuwin Current (Fig. 6 B)."

Line 652 again replace "equalized", that does not go well with gradient.

The reviewer is right. We changed to the following (Lines 971-974):

"Overall, we note a shallow thermocline at site 2609 (Fig. 6 A) and a low West-East gradient at thermocline depth (Fig. 6 B), pointing to a narrower, shallower and weaker Leeuwin Current influencing the western study area."

Line 722 the vertical ΔT gradient decrease at the west site linked to increased LC, it increases at the east site.

The reviewer is correct. We changed to the following (Lines 1134-1138):

"The enhanced lateral temperature gradient at thermocline depth ($\Delta T_{West-East}$) and the lowered vertical (ΔT_{SST-TT}) temperature gradient at the western core 2614 (Fig. 6 A, B) point to the rapid formation of a deep thermocline in response to a strengthened Leeuwin Current, and the greater influx of ITW waters at the expense of SICW contributions during the times of poleward migration of the STF."

Lines 744-745 and following lines: for the late Holocene, in the core SST reconstruction the vertical temperature gradient and the SST is larger at the east site than at the west site. It does not correspond to the modern setting. What confidence in the east site reconstructed SST signal?

We here add the line of argumentation to justify our SST reconstruction in particular for the eastern study area. We initially wrote with respect to the Holocene SST development (Lines 1189-1190): "At the sea surface, the eastern study area was apparently warmer and more saline than the western area..."

We give to take into consideration, most importantly, that it is the clearly higher Mg/Ca ratios of the shallow-dwelling *O. universa* from the eastern core, which lead to the high $SST_{Mg/Ca}$ when applying the same calibration equation as in the western core (c.f. Supplement: Foraminiferal Mg/Ca-paleothermometry). This is in fact not the case for the Mg/Ca ratios of the deep-dwelling *G. truncatulinoides*, which are definitely lower in the eastern than in the western core. Hence, independent from the applied calibration equation, the *O. universa* signal in the east is warmer than in the west, while the *G. truncatulinoides* signal is cooler in the east than in the west. This differential pattern leads us to argue that dissolution and/or diagenetic issues, which should affect the foraminiferal tests similarly, do not play a role here (a discussion on dissolution/diagenetic issues is given in the Supplement).

We hence hold on our interpretation that the seasurface in the east must have been warmer than in the west during the late Holocene. This may be due to reasons, which we discussed in our manuscript in high detail.

We have to acknowledge that our SST-estimates rely on the (available) species-specific Mg/Ca-vs-temperature calibration, which may introduce considerable error, indeed. We wrote in Chapter 3.3 (Lines 453-457) that "…the (applied) calibration (of Hathorne et al., 2003) provides a mean Holocene (<10 ka BP) $SST_{Mg/Ca}$ estimate of ~20.5°C in the eastern core 2609, which exceeds the modern annual SST conditions by ~3-5˚C °C (c.f. Fig. 4 C). In the western core 2614, the $SST_{Mg/Ca}$ estimate of ~19.6°C (Fig. 4 C) is in broad agreement with the modern austral summer SST range at 30-80 m water depth in the upper thermocline/mixed layer…".

We also wrote (Lines 473-489): "Even though the calibrations were carefully chosen, there remains considerable uncertainty in the absolute temperature values over time. First, calibrations should ideally be region-specific to allow for best reconstructions. None of the calibrations applied, however, were developed for the region south of Australia. Second, the range in downcore temperature amplitudes highly depends on the applied calibration. The less exponential the calibration, the larger the downcore amplitude variations. These imponderabilities cannot be solved in this context."

Our study implies that a potential seasonal bias in foraminiferal growth and hence, proxy formation, has to be taken into account. We stated in our Supplement (Lines 361-437): "Growth seasonality is a relevant factor, which influences planktonic foraminiferal proxies and creates seasonal biases in the proxy signal recorded in a fossil assemblage (Jonkers and Kučera, 2015). The Holocene $SST_{Mg/Ca}$ estimates from the eastern core region are ~3-5˚C warmer than the modern annual temperature range in the region. We take this as indication that the derived $SST_{Mg/Ca}$ values represent the austral summer range during the Holocene" (see comments above).

We finally compared our $SST_{Mg/Ca}$-reconstruction to other SST reconstructions from the area. In Lines 606-616 we mentioned: "We also note that the youngest *O. universa*-derived $SST_{Mg/Ca}$ estimate from core 2609 matches the SST_{LDI} estimate of ~22°C from nearby core MD03-2607 (Lopes dos Santos et al., 2013; close to the Murray Canyon; 36˚57.64'S 137˚24.39'E)) (Fig. 4 C). The SST_{LDI} estimates are based on long-chain diols, and LDI-inferred temperatures supposedly reflect SSTs of the warmest month (Lopes dos Santos et al., 2013).

Further in Lines 668-675. "We hence hypothesize that the *O. universa* $SST_{Mg/Ca}$ signal is seasonally biased towards the austral summer season. We note also that the entire core 2609 $SST_{Mg/Ca}$ record matches the SST_{LDI} record from nearby core MD03-2607 reasonably well, with similar absolute temperature estimates (~11-24°C) and in particular, similar deglacial amplitudes of up to 7°C (Fig. 4 C). Both, the SST_{LDI} and $SST_{Mg/Ca}$ estimates are warmer by 4°C than the alkenone-based $SST_{Uk'37}$ estimate from cores MD03-2607 (Lopes dos Santos et al., 2012) and MD03-2611 (Calvo et al., 2007; 36°44'S, 136°33'E) (Fig. 1), likely due to the fact that $SST_{Uk'37}$ reflect the cooler early spring conditions."

We hence argue that our $SST_{Mg/Ca}$-reconstruction is rather robust. We provided a reasonable oceanographic explanation for the "warm" eastern area in Chapter 4.3 (Lines 1200-1205):

"We relate the warmer and more saline late Holocene conditions at sea surface in the east (Fig. 4 B, D) to intensified surface heating near the eastern edge of the Great Australian Bight during austral summer (c.f. Herzfeld, 1997). These shallow waters then spread eastward over the shelf and continued to flow as South Australian Current towards Bass Strait (Middleton and Platov, 2003; Ridgeway and Condie, 2004) (c.f. Fig. 1)."

The impact of pH on foraminiferal Mg/Ca is discussed in detail in the Supplement (Lines 443 ff):).

Supplementary :

182 : "$\delta^{18}O$ *G.* ruber values are on average higher by ~0.5‰" replace "higher" by "lighter"

Done

Additional remarks:

Please note that all figures have been improved.

Please note that we meanwhile accomplished 3 AMS^{14}C datings on core MD03-2609, which support the initial age model. Only minor corrections became necessary. We added the following in Chapter 3.2 Chronostratigraphy (Lines 359-365):

"The core 2609 age model is supported by 3 radiocarbon (AMS^{14}C) datings (Fig. 3; c.f. Supplement Table S2), for which a mix of shallow-dwelling planktonic foraminiferal tests was selected. The measurements were accomplished by Beta Analytic, Inc., Florida, USA (info@betalabservices.com). All AMS^{14}C dates were calibrated applying the BetaCal4.20 software, using the MARINE20 database. The marine calibration incorporates a time-dependent global ocean reservoir correction of ~550 ^{14}C yr at 200 cal BP to ~410 ^{14}C at 0 cal BP (Heaton et al., 2020)."

And Lines 388-390: "To account for local effects, the difference ΔR in reservoir age of the study area south of Australia and the model ocean was additionally considered. The Calib7.1 marine reservoir correction database provides a ΔR-value of -84 ± 65 years (Stuiver and Reimer, 1993)."

Figure 3 and the figure caption were modified accordingly. A detailed presentation and discussion of the data are given in the Supplement (Lines 459-573).

"The age model *of* core MD03-2609 is primarily based on the tuning of multiple planktonic $\delta^{18}O$ records to those of the well-dated reference core 2614 (van der Kaars et al., 2017). The tuning is further supported by 3 radiocarbon (AMS^{14}C) datings (Fig. 3; c.f. Table S3), for which a mix of shallow-dwelling planktonic foraminiferal tests was selected. The measurements were accomplished by Beta Analytic Radiocarbon Dating Laboratory, Florida, USA (info@betalabservices.com). All AMS^{14}C dates were calibrated applying the BetaCal4.20 software, using the MARINE20 database. The marine calibration incorporates a time-dependent global ocean reservoir correction of ~ 550 ^{14}C yr at 200 cal BP to ~410 ^{14}C at 0 cal BP (Heaton et al., 2020). To account for local effects, the difference ΔR in reservoir age of the study area south of Australia and the model ocean was additionally considered. The Calib7.1 marine reservoir correction database provides a ΔR-value of -84 ± 65 years (Stuiver and Reimer, 1993)."

Table S3. Radiocarbon (AMS^{14}C) datings performed on sediment core MD03-2609.

Core MD03-2609	Remark	Lab code	Sample type	^{14}C age raw	Age error	Calibrated median age	Age error	Reference
Depth (cm)				(yrs BP)	+/- (yrs)	(yrs BP)	+/- (yrs)	
164	AMS^{14}C	BETA – 626880	mixed planktic	18610	60	19040	60	this study
230	AMS^{14}C	BETA – 626881	mixed planktic	32530	230	32970	230	this study
304	AMS^{14}C	BETA – 626882	mixed planktic	40820	530	41250	530	this study
314	not considered	BETA – 626882	mixed planktic	40820	520	41240	520	not considered