Second response to reviewers for wcd-2023-6
Strengthening gradients in the tropical west Pacific connect to European summer temperatures on sub-seasonal timescales

Comments of Reviewer 2:

I really appreciate the authors carefully answered and addressed all my questions and comments. I think the manuscript is almost ready to publish. The manuscript is well-written, with most of the details are clear. I have some minor comments/suggestions though, hopefully they would be helpful to improve the accessibility of the paper:

We thank the reviewer for reviewing the manuscript again and making further helpful suggestions. Line numbers refer to lines in the tracked-changes manuscript.

L112: It might be helpful to give the warming rate.
We have added a rate estimate, based on the IPCC AR6 WG1 atlas (Guitierrez et al. 2021), and an additional reference (Dong et al. 2017). See L111:
"In fact, western European summer temperatures have been warming faster than the global average, especially since the 1990's, at a rate of 0.4 to 0.8 °C/decade (Christidis et al., 2015; Dong et al., 2017; Gutiérrez et al., 2021)."

L115: Just want to clarify: four-week-average"d" SST anomalies correlated with four-week-averaged t2m -> do you use rolling-window averaged SST and t2m, so for each year, there are 92 four-week-averaged data point (since its 92 days in JJA)?
That is correct. We already mentioned the use of rolling averages in the data section. We repeat it here for clarity. See L115:
"We correlate four-week-averaged SST anomalies ('SST in week -3 to 0') to the lagged European four-week-averaged response ('t2m in week 3 to 6'). Our use of rolling averages leads to 92 samples per JJA season."

L119-120: consider rephrasing.
We have expanded the text to more clearly explain the construction of the residuals: L120
"First we let a linear regression predict observed SST and t2m anomalies using time and the value of the previous time step (details can be found in van Straaten et al., 2022). These predictions are then subtracted from the observed anomalies, resulting in residual SST and t2m. With the confounding effects of global warming and auto-correlation removed, any correlation that remains significant is more likely to represent a sub-seasonal relation."

L122-125: I think it might be helpful to explain/remind the purpose of this analysis (false discovery rate correction, Fig.2b).
Now explained. L126:
"To mitigate the accumulation of chance-based discoveries when performing multiple significance tests, we applied a false discovery rate correction (Benjamini and Hochberg, 1995) (details can be found in van Straaten et al., 2022)."

L129 & fig.2b: component2 box, it seems like the component2 box does not exactly match the high correlation region, the box seems to be westward. It seems like the box selection is a bit of arbitrary.
You are right that the box does not seem to fully overlap with the correlated region. To explain this better, and to contextualize the current placement, we introduced a new set of Appendix results in the last round of revisions. These show that the region of high correlation is influenced by choices of lag, timescale and data-set length. In this sense, determining the box-placement on any one of

those maps can be considered somewhat arbitrary. The current placement tries to encompass features shared by multiple of those maps. We explain this, and refer to the appendix, in the last part of this section. See L149:
"To test the sensitivity of choices regarding the location of the two boxes, we present additional results in Appendix A. These are additional crossvalidation maps, similar to Fig. 2B, and show that the exact extent and location of the robustly correlated pattern can shift when different combinations of timescales and lags are chosen. The current boxes are positioned such that only the features shared among multiple combinations are captured."

Fig.3b: what does the shaded colors represent? Also, any statistical significant tests for the trends in Fig.3a and correlations in Fig.3b?
The shaded colors represent the magnitude and sign of the correlation values that are also reported as numbers in panels B and C. Because the numbers themselves are reported we do not think that an additional legend is necessary. However, we expand the caption of Figure 3 to explain the meaning of the shading:
"Shading in panels B and C illustrates the sign of the reported correlation values (red: positive, blue: negative) and their magnitude (dark: strong, light: weak)."
Regarding potential significance tests: our goal at this stage is not to prove or disprove an effect but just to highlight potential differences and relatedness among the indices of Pacific variability. One example is the warming of the West Pacific (WNP region) and the absence of warming in the central/eastern tropical Pacific (Nino 4), which is also documented in e.g. Seager et al. 2022 and Wills et al 2022, both of which we cite here. We think that significance tests are therefore not needed.

L160-162: I think the description is not accurate. The change in the climatological background state of the Pacific is "La Nina-like", meaning the western tropical Pacific has been warming fast, while the eastern tropical Pacific has been warming slowly even slightly cooling. This change in SST-pattern can lead to strengthening Walker Circulation. It does not mean the change in the basic-state "interacts with La Nina to produce stronger Walker Circulation".
I understand that this description is from Funk and Hoell 2015 Discussion, but in the more recent studies regarding the trend of the tropical Pacific basic-state (e.g., Seager et al. 2019, 2022; Lee et al. 2022 review paper), they did not mention that the La Nina-like warming basic-state "interacts with La Nina events to produce stronger Walker Circulation".
This language was the result of us trying to accommodate the concerns of Reviewer #1 in the first round of revisions. The reviewer raised that the 'La Nina like' changes in the background state are not entirely interchangeable with the western Pacific warming mode diagnosed by Funk and Hoell 2015. We replied that they indeed have a different spatial emphasis, but that the result is highly equivalent, namely a strengthening of the Walker circulation. However, we do agree with the current concern that the 'interact' language is a bit awkward. We adapt our formulation. L164:
"These opposing trends reflect documented warming in the western Pacific, while the central to eastern tropical Pacific has not warmed (Wills et al., 2022; Seager et al., 2022; Sun et al., 2022; Lee et al., 2022). The result is that the zonal SST gradient over the tropical Pacific has increased, which is generally referred to as a 'La-Niña-like' change in the Pacific 'background state', and has been linked to a stronger Walker circulation (Lee et al., 2022; Seager et al., 2022). Also the west Pacific warming mode, visible as the warming in the WNP region, enhances the climatological background-gradient over the Pacific, and is linked to a strengthening of the Walker circulation, […]"

Fig.4: It might be helpful to include a legend in the panel A.

Now included, for both panel A and B. See Fig. 4.

Fig.4 & Section 4: It might be helpful to briefly mention why 21-year rolling window is used here.
We now explain in the text of Section 4 why a rolling window of this length was used: sufficiently short that it allows for non-stationarity in the teleconnection (see e.g. Bahaga 2013 for an investigation of different lengths) but certainly longer than the timescale of ENSO. L184:
"A window length of 21 summers was deemed sufficiently short to adapt to non-stationarity in the roughly 72-year dataset, but sufficiently long not to be affected by inter-annual variability."

L278-284: I am not familiar with these studies and the coupling between ocean and jet stream in the North Atlantic, but did these work focus on the same timescales (subseasonal)?
The studies describe a coupling that develops from late-winter and spring into summer. In that sense it is a seasonal phenomenon, because consequences in July and August can be linked to patterns in March and April. In text we already mention this seasonal aspect, which interacts with changes on a shorter timescale such as the month-to-month migration of the jet-stream, and of course also with the sub-seasonal teleconnection from the Pacific (this is why we place the discussion of this phenomenon in the 'modulation' section). To make the seasonal character a bit clearer we amend the text as follows. L288:
"The tripole pattern spans multiple seasons and can occur already in late winter and early spring. From that moment onward it is known to precede the summertime pattern with a strong low pressure anomaly positioned south of Greenland and west of the British Isles (Fig. 5G)"
and L298:
"We therefore deduce that the seasonal interplay of SST tripole and Atlantic jet could modulate the sub-seasonal teleconnection by longitudinally guiding QSRWs from the west Pacific towards Europe."

L301: stronger "equatorial" and meridional SST gradients: zonal?
That is correct. Changed to 'zonal'. L312

L322: "To a smaller extent also Western European t2m has been increasing" -> consider rephrasing. "smaller extent" -> I am not sure what this means, spatial extent? "increasing" -> warming?
Indeed confusing, this concerns the degree of warming and not spatial extent. We replaced the text L336:
"The warming of Western European average summer t2m has been less severe, though still highly significant (Christidis et al., 2015; Gutiérrez et al., 2021)."

L324 & 327: (Fig.8A) -> Figs.4A and 8A. (Fig.8C) -> Figs.4A and 8C
Fig.8: Please consider either to include title in each panel, or change the y-axis. It is not easy to read the figure.
We have simplified the Y-axes for Figure 4 (panels a and b) by including titles and a legend (as per your comment on Figure 4 above.
We also re-arranged the panels in Figure 8 such that y-axes are shared and need only one label. We have added clarifying titles to the columns in Figure 8.

L322-L333: I think these two paragraphs are convoluting. It may be helpful to polish or edit a bit. My understanding is that the authors want to state the discrepancy between "more frequent negative t2m on subseasonal timescales" and "the warming trend of seasonal t2m over Western Europe": if the more frequent negative t2m on subseasonal timescales is due to change in circulations, then there must be other factors (other than the WPD-Europe teleconnections) that cause the warming trend of seasonal t2m.
Your latter comment is indeed what we try to convey. We have now reordered the sentences in these two paragraphs to a more logical structure, and we also adopt your phrasing. L327-345:

“The emergence of a significant teleconnection in recent decades provides a lens through which recent summer circulation changes over Europe can be interpreted. This is relevant because warming trends are the consequence of multiple factors such as direct forcing by greenhouse gases and aerosols (Dong et al., 2017), but also circulation changes (Deser et al., 2016; Faranda et al., 2023). The changes diagnosed in this study are an increased occurrence of negative WPD and a reduced occurrence of positive WPD, each with a respective QSRW response. The increased frequency of the negative WPD phase (Fig. 4A), would, according to its corresponding QSRW, induce a warming in eastern Europe and Russia (Fig. 5M). Indeed, high pressure has become more prevalent in this region (Lee et al., 2017; Kim and Lee, 2022; Teng et al., 2022), associated with a very strong increase in heat waves (Rousi et al., 2022), with average summer t2m increasing more than in our Western European target region (Teng et al., 2022).

The warming of Western European average summer t2m has been less severe, though still highly significant (Christidis et al., 2015; Gutiérrez et al., 2021). A precise quantification of the contribution from changes in WPD to this trend is beyond the scope of this study (and is also hindered by the methodological necessity to isolate the sub-seasonal teleconnection from the trend by using 21-year rolling window distributions of t2m, see section 4). But relative to the trend, two things can be said. First, during the time that negative WPD has roughly doubled in frequency (Fig. 8A), it remained consistently related to the cold Western European t2m tercile (Fig. 8B). This means that Western European warming is likely caused by other factors.

Second, one of these factors could be positive WPD. […].”

L325-326 “This means that if the teleconnection is influencing Western Europe through circulation changes, then its effect among all other factors, would be a dampening of the warming.” This sentence confuses me.

We have adapted this paragraph. See our reply above.

Author provided references:

Bahaga, T. K., Fink, A. H., & Knippertz, P. (2019). Revisiting interannual to decadal teleconnections influencing seasonal rainfall in the Greater Horn of Africa during the 20th century. *International Journal of Climatology*, *39*(5), 2765-2785.

Dong, B., Sutton, R. T., & Shaffrey, L. (2017). Understanding the rapid summer warming and changes in temperature extremes since the mid-1990s over Western Europe. *Climate Dynamics*, *48*, 1537-1554.

Gutiérrez, J.M., R.G. Jones, G.T. Narisma, L.M. Alves, M. Amjad, I.V. Gorodetskaya, M. Grose, N.A.B. Klutse, S. Krakovska, J. Li, D. Martínez-Castro, L.O. Mearns, S.H. Mernild, T. Ngo-Duc, B. van den Hurk, and J.-H. Yoon, 2021: Atlas. In *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1927–2058