Final response to the editor

We thank Michael Riemer, the editor, for his constructive comments and suggestions. In the light of the editor's suggestions, we have omitted the QRA metric and the accompanying analyses from the revised version of the manuscript. The revised title reads as "Recurrent Rossby waves and south-eastern Australian heatwaves".

Another major comment raised by the editor and reviewer #1 was on the issue of correlation vs causation. Both the reviewer #1 and the editor interpret that from the "co-occurrence" or "co-variability" of R-metric with SEA heatwaves, we conclude that RRWPs increase the duration heatwaves. We noted in our previous response that there were indeed some misleading statements in the text, and we have removed those in the revised manuscript. We clarify the following points: the analysis from Weibull regression, where we evaluate the hypothesis whether increase in R-metric is statistically associated with increased duration of hot spells, shows that increase in R-metric is associated with statistically significant increase in hot spells, including over south-eastern Australia (SEA). This information is combined with process knowledge gathered in the published literature highlighting the important role of upper-level ridges and associated subsidence for the formation of heatwaves. We supplement this analysis with discussion of the two persistent and extreme heatwaves where we show how recurrent Rossby waves play a role to form recurrent ridges over SEA. Apparently, this point did not come out clearly from the manuscript for both reviewer#1 and the editor. So, we have stressed this point more in the revised manuscript. We again take up this point in the discussion. We have further included a short discussion on a potential soil moisture feedback.

Furthermore, reviewer #1 and the editor present an alternate causal pathway where the surface anomalies may be driving the amplified waves. We thank them for this suggestion as this possible pathway was missing from our discussion so far. We have now added a discussion of this point in the revised manuscript. Based on idealised simulations by Martius et al. (2021) we argue that the effect of the surface temperature anomalies on the upper-level flow and hence the R metric is very small. Martius et al. (2021) investigates the effects of soil moisture anomalies over Australia on the local and remote flow. An ensemble of 50 CESM simulations with soil moisture set to -1 and +1 STD over Australia are analysed. The soil moisture anomalies result in surface temperature anomalies of up to 4°C and can hence serve as a proxy for a heat wave (see Fig.1a below). The temperature anomalies do have a significant effect on the geopotential height at 250hPa (Fig.1b below) and the meridional wind (Fig. 2), however the absolute anomalies are small. The meridional wind anomalies are on the order of 0.5 to 1 m/s locally. Considering that the meridional wind is averaged latitudinally for the computation of the R metric, the absolute effect on the R-metric is very small. The link between the surface temperature anomalies and upper-level flow anomalies were derived using a model and not "simply" a hypsometric equation and therefore, include feedback processes between the temperature anomaly and the circulation such as changes in precipitation and therefore diabatic heating.

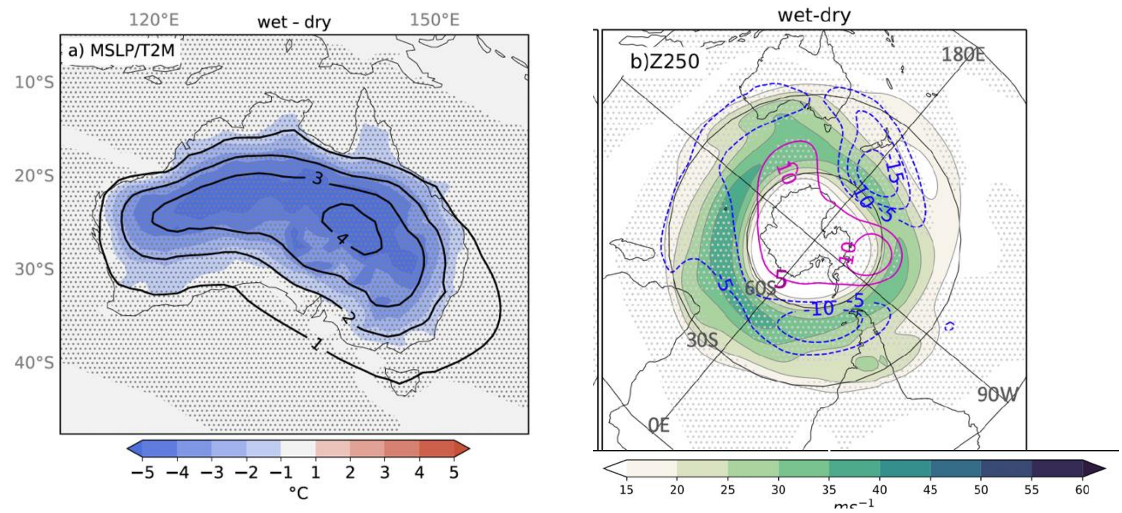

Fig. 1: a) adapted from Fig.2 in Martius et al. (2021). Colours show the ensemble two-meter temperature difference between the wet and the dry simulations, solid contours show the mean sea level pressure difference. b) adapted from Fig. 6 in Martius et al. (2021). Colours show the zonal wind in m/s and dashed lines the difference in geopotential height at 250hPa (5,10 m magenta, -5,-10m blue lines) between the wet and the dry simulations

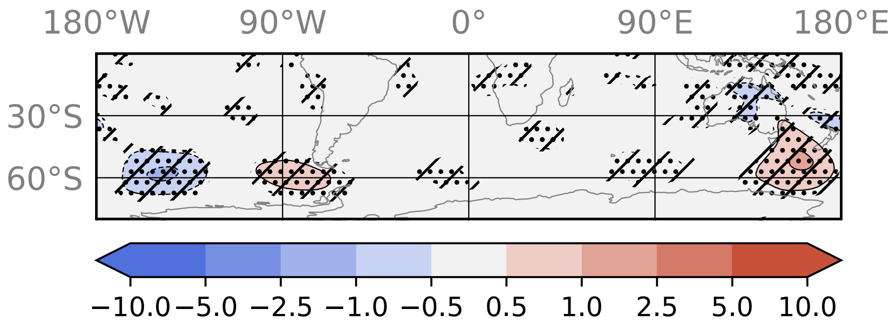

Fig. 2: Colours show the difference in meridional wind (m/s) at 250hPa between the wet and the dry simulations

These points have been taken up further in the discussion section of the revised manuscript.

Lastly, the editor also made an interesting outlook statement on the use of causal networks based on a Bayesian framework in climate sciences. In general, we agree with the remark. We add a further point below extending the editor’s statement.

As is the case with any correlation or regression-based analysis, the selection of the exposure (R in our case) and outcome variables (length of hot spells) should be carefully made with the underlying theoretical knowledge of the system. Spurious causal links between exposure and outcome may occur for example, due to confounders, that are hidden variables in the system driving both the exposure and the outcome. Such problems can indeed be addressed by using causal networks approach (Pearl 2009). As the editor points out causal networks have been applied in Climate Sciences recently to quantify causal processes, but only for process acting on a longer timescale from a week to month (e.g., Runge et. al, 2019). Some studies are, in parallel, attempting to apply causal networks on a sub-weekly scale (e.g., Ali et al., 2022). However, it should be stressed that even with a causal network approach used in the studies above, the network cannot account for hidden confounders by itself if the hidden variables are not included in the causal network setup. Although, the causal networks are mathematically quite robust and an upgrade to the currently used correlation-based approaches prevalent in climate science but, the theoretical knowledge of the system is still vital in designing and implementing any data-driven approach including causal inference.

References:

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