Responses to Reviewer 1

Reviewer comments are provided in black font, while our replies are in blue.

This article analyzes events of westerly moisture transport across Africa (and nearby regions), and links those events to the phase of the Madden-Julian Oscillation (MJO), and the presence (or lack) of tropical cyclones (TCs) over the Indian Ocean. It finally provides an estimation of the precipitation that can be attributed to those westerly moisture transport events (WMTEs).

The authors developed a detection algorithm, quite similar to those used to monitor atmospheric rivers, to identify the WMTEs. The algorithm is unique in that ARs have a strong poleward component, while inter-tropical WMTEs are mostly zonal. The approach is sound and there was a clear need to have more in-depth understanding of those WMTEs.

The following analyses are less convincing. They remain very descriptive. The authors build samples consisting of different phases of the MJO, combined with the presence or absence of TCs, but the main object proposed in this work (the WMTEs) are not analyzed with more detail than just their presence or absence. Another possible issue comes from the attribution of rainfall to WMTEs: the justifications are not very clear but I understand (Fig. 1) that precipitation extending far beyond the contours of the detected WMTEs can be considered as linked to it. This is clearly not what is usually done when working with those detected moisture transports.

For those reasons, I believe that there is a very good study to be done with those WMTEs, but I think that the current version of the manuscript required major modifications and improvements before it can be accepted for publication. Even though I recommend major corrections, I would like to encourage the authors — there are really great ideas here, we'd just need more physical characterizations (and understanding) of the WMTEs, their properties, and their mechanisms (see detailed comments below).

Thank you very much for your thorough review of our work, for your positive assessment of our manuscript, and for your constructive feedback for improvement. Please find below our responses to each of your comments.

Major comments

1. What are the WMTEs, physically speaking? ARs have been described as "A long, narrow, and transient corridor of strong horizontal water vapor transport that is typically associated with a low-level jet stream ahead of the cold front of an extratropical cyclone" according to the AMS Glossary. This is because ARs are a concept mostly used for extra-tropical climate and weather, where transient disturbances (atmospheric highs and lows) have fronts that separate air masses, where baroclinic instability develops. This definition (and even the schematics that are often provided in some studies) are useful to conceptualize the AR objects, from a physical point of view. The concept of WMTEs strongly differs, even if it is detected by algorithm that are not so different. This is not only because WMTEs are more zonal, but also, because they develop in a tropical climate, where vorticity is very low because of the proximity to the equator. In those regions, large-scale cellular

circulations (that are, partly, conceptual objects) can develop (including zonal ones), as part of the MJO at the intraseasonal timescale, or ENSO at the interannual timescale. Are WMTEs linked, or even part, of those large-scale cells? Do they correspond to “bursts” or transient increases in their lower branch, when moisture convergence is located further east over the Indian Ocean sector (since you use a quite high threshold to define them, you only depict the most intense phases of those westerly circulations)? Do the WMTEs help refine (regionally) the conceptual schemes of the MJO as proposed by Madden and Julian (e.g., Fig. 3 of their 1994 paper, cited in this work), or propose more detailed vertical cross-sections? So, overall: what are WMTEs, physically speaking?

The same could be said about the interannual timescale, especially in OND when the EEA region experiences the Short Rains whose interannual variability is strongly tied to the Walker circulation (= are WMTEs partly driven by changes in the Walker-type circulation ?). See e.g. an (already old) paper by Hastenrath about the detection of those cellular circulations: Hastenrath, S (2000) Zonal circulations over the equatorial Indian Ocean : Journal of Climate 13, 2746-2756.

When reading the article I had a similar question, about their interpretation, when the dominant winds are easterly (usually the case where/when trade winds are well developed) vs. the regions where westerlies prevail (like the northwestern Indian Ocean in boreal summer, due to the monsoonal circulation). In other words, how can the threshold used differentiate transient from seasonal circulations. But the questions raised above are more general and encompass that particular case. All these questions are, in my opinion, super important, to know what are the objects we’re talking about, and that we consider so extensively in this work.

Thank you for these insightful comments about the nature of WMTEs. We agree that the paper would benefit from additional discussion about the physical nature of these events, which we will add to the revised manuscript. We note that we developed the detection framework as part of a project focussed on understanding extreme snowfall events on Kilimanjaro’s glaciers, and to investigate the relation between extremes, WMTEs, the MJO, and TCs. Therefore, providing a definitive answer about the causes of WMTEs is outside the scope of our study but will hopefully be facilitated in future work by our objective timeseries and preliminary analysis

The discussion we will add to the manuscript addressing the main aspects of your comments includes:

1) **Connection to large scale cellular circulations**: it has already been proposed that EEA westerlies are part of the westerly transport into the main area of MJO convergence (e.g., Pohl & Camberlin (2006)). Furthermore, the seasonal cycle of our events is consistent with the seasonal cycle of the MJO: MJO tends to be stronger, with more organised events in DJFM, with a peak in JF (Zhang & Dong, (2004)). Therefore, some WMTEs may potentially be part of the western branch of cellular circulation patterns associated with the MJO.
2) **Connection to the Walker circulation**: the Indian Ocean Walker-like circulation tends to be associated with westerly winds over the central equatorial Indian Ocean rather than directly over EEA, and its influence on EEA rainfall has been mainly been

emphasised for the OND season (Hastenrath, Polzin, & Camberlin (2004), Hastenrath & Polzin (2005), Hastenrath, Polzin, & Mutai (2010)), while our analysis identifies WMTE activity mainly in JF, which we think is related mainly to the MJO activity peak.

3) **Differentiating transient from seasonal circulations**: we showed that the median length of time for a WMTE to persist at a single grid cell is roughly 1-3 days in EEA, and for reviewer 2 we have also added panels showing that in most of EEA, the 95th percentile number of days in a single month with a WMTE peaked at 16-20 days in JF, and therefore believe we identify transient rather than seasonal features. In response to your comment regarding metrics characterising WMTEs, we will add feature tracking in the revised manuscript, which will allow us to accurately calculate the lifetime of these events and more robustly assess their persistence. We also note that the 70th percentile threshold, which varies each month of the year and at each grid box, is somewhat lower than the thresholds normally used in AR studies but should still be high enough to exclude purely seasonal features.

In addition to your suggestions, it has also been proposed that westerlies in EEA are simply associated with a reversal of the zonal pressure gradient across the African continent (also in Pohl and Camberlin (2006)) which could be related to several physical drivers, e.g. the presence of multiple TCs, MJO activity, or persistent continental lows (Webster (2019))

We will add discussion about all of these aspects to the revised manuscript.

2. There are no metrics here to characterize the WMTEs, like their length, width, tilt / direction, duration, integrated moisture transport (and location of the maximum), … The AR community produced tens of articles showing that those descriptors are important to better analyze their impacts on rainfall, and help better understand the mechanisms responsible for rainfall, and its space-time variability (including daily amounts or even extremes). In addition, relating rainfall to the location of the outflow boundary of the WMTEs might give potentially interesting results; similarly, the inflow location might give insight into the moisture sources.

This is a nice suggestion and we agree some analysis of these metrics would give some interesting results. We will therefore implement a feature tracker that will allow us to connect overlapping WMTEs from consecutive days and to analyse some of their properties and relations to the precipitation response.

3. Attribution of precipitation to WMTEs. I understand you've considered the Boolean union of the WMTE and Precipitation > 1mm.day-1 contours and attributed all rainfall falling within that new contour to WMTEs. This would mean that precipitation occurring outside the WMTE contour is yet attributed to it. This would be clearly an issue, especially since WMTE can be linked to the MJO that promoted the development of large-scale convective clusters (some of which can reach 10,000km diameters). This would imply you could attribute MJO-caused precipitation to WMTEs. Considering the Boolean intersection instead of the union would certainly decrease the contribution of WMTE to rainfall totals, but the approach would be more conservative and more robust. This is the one traditionally used by the AR community. Yet, double (or triple!) counts are still possible (i.e., in the worst-case scenario, attributing rainfall to WMTEs, MJO and TCs). See e.g. Dacre's papers about the interactions between

atmospheric rivers, warm conveyor belts and cyclones: 10.1038/s41612-025-00942-z; 10.1029/2023jd040557; 10.1175/JHM-D-18-0175.1.

Although the precipitation attribution approach we used was developed for precipitation attribution to various drivers including atmospheric rivers (Konstali et. al., 2024), we repeated our analysis using a conservative attribution approach that only attributes precipitation inside the WMTE mask. Using this approach, precipitation amounts inside the region where WMTEs were common are reduced by around 50%, and as expected, precipitation outside this region decreases considerably (Fig. R1.1). However, we believe that the approach of (Konstali et. al., 2024) is reasonable and provide the following discussion in the text at line 122:

“For comparison, we repeated our analysis using the most conservative possible approach: only attributing precipitation inside the WMTE mask. Using this approach, precipitation amounts inside the region where WMTEs were common were reduced by around 50%, and as expected, precipitation outside this region decreases considerably (Fig. S8). We note that the approach of Konstali et al. (2024) may occasionally lead to over-estimates of attribution (see for example Fig. S5a, f), particularly when other features such as the MJO or TCs are also present in the region. However, we chose to retain our original approach as past work has shown that westerly moisture transport is often associated with enhanced precipitation beyond the margin of the main region with enhanced moisture transport (e.g., Kilavi et al., 2018; Collier et al., 2019) and therefore believe that this provides a reasonable estimate of the impact of WMTEs.”

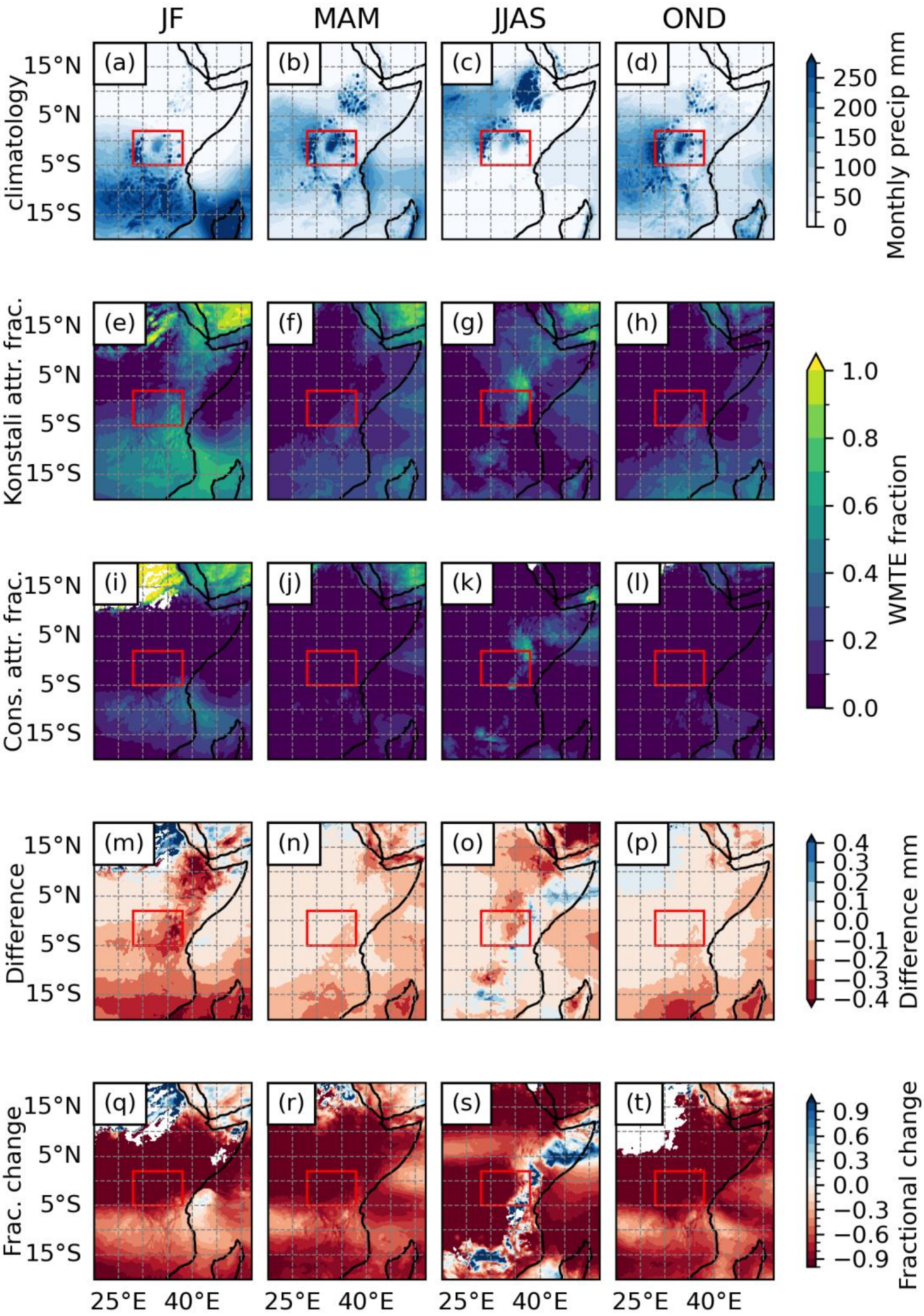

Figure R1.1. Comparison of precipitation attribution approaches. (a-d) The ERA5 average monthly precipitation from 1998 to 2022 in each season. (e–h) The fraction of precipitation that was attributed to WMTEs in each season using the method of (Konstali et al., 2024). (i–l) The fraction of precipitation that was attributed to WMTEs that lay inside the WMTE mask. (m–p) Difference between (i–l) and (e–h). (q–t) Fractional change between (m–p) and (i–l). Small increases in the amount of attributed precipitation in very dry areas are due to removing the wet day threshold for the conservative approach.

4. Relationship between WMTEs and TCs: is it a "chicken and egg" problem? Do the WMTEs feed TCs with moisture, or do WMTEs respond to the development of TCs (or convection, more generally) through ageostrophic circulations? While the causality itself

might deserve dedicated studies, it would be quite straightforward to see whether the WMTEs develop before, or after the TC. This could be useful as a first clue to understand how both circulations behave and interact.

This is a very nice question, which we will answer and discuss in the revised manuscript once we implement the feature tracking.

Minor points. There are not many of them because I mostly focused this first review on the main points listed above.

l. 92. How precisely is the 70th percentile of moisture transport calculated? By considering both signs (i.e. easterly and westerly), or just westerly transport occurrences?

The 70th percentile is computed considering both signs. We amended line 92 to make this clear: “the magnitude of moisture transport exceeded the 70th percentile of all magnitudes recorded at that location, for that month, from 1980 to 2022 (including non-westerly days)”

Figure 2. If the main interest in this work is to assess westerly moisture transport across Africa and reaching the EEA region, then the choice of the domain is a bit strange — shifted eastwards, and giving more importance to the Indian Ocean region. Previous work (e.g. on the regional influence of the MJO) discussed zonal moisture convergence between the Congo basin and the Indian sector, so the WMTEs of interest, advecting moisture towards EEA, should be placed over inter-tropical or equatorial Africa. Moisture sources might be continental (Congo basin) or oceanic (Atlantic sector). Why such an eastward-shifted domain? WMTEs have lesser importance for EEA if they occur east of it?

The domain used for WMTE detection (22◦ W to 102◦ E and from 40◦ N to 37◦ S) includes both the Congo basin and a part of the Atlantic sector. We also extended the domain eastwards so that we could investigate the interaction of WMTEs with TCs anywhere in the Indian Ocean. Most of the figures in the paper do not include the Atlantic part of the domain because the identified WMTEs did not occur there. We briefly mentioned this in the preprint at line 83: “The area used in our detection algorithm included all of Africa and the Indian Ocean, extending from 22◦ W to 102◦ E and from 40◦ N to 37◦ S. However, we focus our results and discussion on the regions of eastern Africa and south-west Indian 85 Ocean where our phenomenon of interest occurs”, but we will add a sentence in the revised manuscript justifying this more clearly.

Figure 3. Why show the curl of the moisture fluxes, rather than their convergence? I’m not saying this is wrong, but this needs to be explained. Moisture convergence may make more sense for rainfall analysis. Vorticity is certainly more meaningful when assessing the links with cyclogenesis.

We show the curl to demonstrate the connection of westerly events to flow curvature over East Africa and cyclonic activity in the SWIO. We have amended line 142 to make this clearer: “To identify possible connections between WMTEs and cyclonic activity, we also show the curl of the moisture transport field.”

The quantity we show is therefore equivalent to the relative vorticity but for the moisture transport. We will check the relative vorticity field in case it makes any significant change to the interpretation.

l. 156. TCs themselves are not independent of the MJO. The authors did not discuss this point.

Bessafi, M. & Wheeler, M. C. (2006) Modulation of south Indian Ocean tropical cyclones by the Madden-Julian Oscillation and convectively coupled equatorial waves. Mon. Weather Rev. 134, 638–656

Klotzbach, P. J. (2014) The Madden-Julian Oscillation's Impacts on Worldwide Tropical Cyclone Activity. J. Clim. 27, 2317–2330

Diamond, H. J. & Renwick, J. A. (2015) The climatological relationship between tropical cyclones in the southwest pacific and the Madden-Julian Oscillation. Int. J. Climatol. 35, 676–686

Thank you for pointing out this association which was part of our motivation of breaking down the TC analysis by MJO phase. We have added the following text at line 172: "TC activity is itself influenced by the MJO phase: Liebmann et al. (1994) showed that TC genesis in the Indian Ocean is enhanced when the centre of MJO convection lies over the Indian Ocean (phases 2–4), while Klotzbach (2014) showed that cyclogenesis in also enhanced, particularly in the eastern Indian Ocean, during phase 5. Since we expected TCs further east to have less impact on WMTEs over EEA, we controlled for the effect of MJO on TC genesis by subdividing our analysis using the same classification as in previous sections, with phases 2–4 described as favourable and 5–1 as unfavourable."

Figure 6. What is the use of defining an EEA region like in Finney et al. if it's not used in this work, e.g. to compute regional indices?

We included the EEA region from Finney et al. because it is the most comprehensive existing study of this interplay between MJO, TCs, and westerly moisture transport in driving EEA precipitation and we wanted to compare our findings. We have clarified that we show the box only to allow comparison between the studies in the text and added some discussion of the differences in methodology and results between the studies

References

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Hastenrath, S., Polzin, D., & Camberlin, P. (2004). Exploring the predictability of the "short rains" at the coast of East Africa. *Int. J. Climatol., 24*, 1333--1343.

Hastenrath, S., Polzin, D., & Mutai, C. (2010). Diagnosing the droughts and floods in equatorial East Africa during boreal autumn 2005-08. *J. Climate, 23*, 813--817.

Webster, E. M. (2019). *A synoptic climatology of Continental Tropical Low pressure systems over southern Africa and their contribution to rainfall over South Africa.* Master Thesis, University of Pretoria, Pretoria.

Zhang, C., & Dong, M. (2004). Seasonality in the Madden–Julian Oscillation. *J. Climate*(17), 3169–3180. doi:https://doi.org/10.1175/1520-0442(2004)017<3169:SITMO>2.0.CO;2