Review of "Moisture transport axes: a unifying definition for monsoon air streams, atmospheric rivers, and warm moist intrusions" by Spensberger et al. submitted to WCD

Thank you for giving me the opportunity to read and review this article on the detection of moisture transport axes. I found it well-written and beautifully illustrated. I really like the proposed new Eulerian method based on one-dimensional moisture transport axes, i.e. lines connecting local maxima in moisture transport. This latitude-independent method allows to identify intense horizontal moisture transport in the atmosphere in an elegant and computationally efficient way, with several advantages compared to other approaches. The advantages I see are: 1) concept-unifying character, 2) region-independent definition, 3) its flexibility with respect to orientation (e.g. no requirement of a westward orientation from a given source region).

I have one major concern with the writing, which is related to the disproportionate focus on atmospheric rivers in the introduction and the slight (certainly unwanted) neglect of the existing tropical and subtropical literature:

1) I found the abstract very convincing in the way the new method is introduced and highlighted as concept-unifying. Really great abstract! But in the introduction, I desperately missed this elegant way to approach the topic of detecting "narrow elongated filaments" comprehending atmospheric rivers, tropical moisture exports, monsoon air stream, warm conveyor belts, warm moist intrusions into polar regions. The introduction focusses entirely on atmospheric rivers. That's a pity, because this fact touches on the characterising advantage and the selling argument for this new method. To introduce moisture transport axes as an atmospheric river detection scheme, raises the question: what is the advantage of this method compared to others? And you bravely address this point at the end of the introduction. There are some practical advantages, indeed. But is your method really just yet another atmospheric river detection scheme? There are so many, and we can reasonably detect these features with the existing methods. In my view, your method is more than that. It's really cool that you can approach the detection of intense moisture transport features from such a "simple" geometric point of view, which has the potential to bring together many different concepts that were either formulated in a region-specific, impact-specific way, or which involves more sophisticated (and computationally expensive) Lagrangian detection methods.
   So in short, I would recommend a rewriting of the introduction in the following way:
   - There are different concepts in the meteorological literature that all characterise narrow elongated filaments of enhanced moisture transport (or total column moisture content), when going from the tropics to the poles: tropical moisture exports (transient features), monsoon air streams (more persistent), atmospheric rivers, cyclone feeder airstreams, warm conveyor belts, warm moist intrusions into polar regions. Some of these concepts overlap, others are distinct due to their regional extent, or due to the specificities of their detection, see *Ralph, Dettinger, Rutz and Waliser, Atmospheric Rivers: Chapter 2, Sodemann et al. 2020: Structure, process, mechanisms*, https://link.springer.com/book/10.1007/978-3-030-28906-5.

- Give a short overview of groups of detection schemes, staying rather general to keep the readership large. What do the existing groups of detection schemes target, resp. what do they miss by definition. Maybe a distinction between Eulerian and Lagrangian methods would also help to put forward the advantages and limitations of the new method? Why is the literature about Lagrangian airstream detection avoided and completely omitted (except for the short mention of warm conveyor belts in the abstract)? To me the moisture transport axes have several useful and complementary advantages compared to Lagrangian air stream definitions.
- Shift the method-specific and rather detailed part of the introduction at L. 46-71 to the method section
- Clearly define the goal of the study: why is it important to detect moisture filaments and why is such a concept-unifying definition useful?
- For the tropical literature I think Knippertz (2007) gives a nice synthesising overview of phenomena at low latitudes.
- In relation to high impact weather the climatology of de Vries (2022) might be relevant. Something that his not mentioned at all but that I find relevant is that the moisture transport axes method focusses on the climatology of coherent, large-scale enhanced moisture transport in the atmosphere but not restricted to precipitation extremes. This allows to study climatological features of moisture transport in the atmosphere and their changes with global warming.

In addition, I have the following minor comments:

2) L.1: could you omit "**extratropical"** and write "**horizontal** water vapour transport is mainly organised in narrow elongated filaments"? Isn't your method globally applicable, as long as the moisture transport is coherent and of a certain minimum spatial extent? I just ask, because I believe your detection method also includes features like tropical moisture exports (Knippertz and Wernli, 2010) and monsoon features, which I would not classify as extratropical.
3) L. 3: I know the "feeder air stream" is the official name in the Dacre et al. studies but for a more general readership, I would find it useful to call it "**midlatitude cyclone** feeder air stream".
4) L. 10: this is really nice because it illustrates the convergence needed to form a strong atmospheric river and further develops the analogy to a river system as defined by the confluence of streams in a catchment. In this sense the moisture transport axis method allows to characterise the substructure of an atmospheric river in a physically meaningful way.
5) I think the paper would benefit from an additional sentence at the end of the abstract to point out what the scientific learnings and broader implications from this study are.
6) L. 24: do the definitions diverge widely or differ in the details?
7) L. 67-71: It reads a bit strange to have "First," and then "Finally". "First," calls for "Second,".
8) L. 74: It requires some effort for me to convert T84 into a length scale in degree or km, if possible, make it easier for readers like me.
9) L. 90: I don't really understand why you do need to include "IVT absolute magnitude" in your threshold. Initially, while reading up to here, I enthusiastically thought that your method would avoid exactly that. Now why do you introduce |IVT| when filtering

out “weak” maxima, nevertheless? Certainly, this is going to remove many moisture transport axes in polar regions. What happens if you omit this and just filter out minima? You get lots of spurious axes? And you cannot filter them out with the minimum length? Do you then get spaghetti-like messy axes? I am very curious about this and would like to understand this better.

10) L. 95: It was exactly when thinking about long climate model simulations that I thought that a |IVT|-independent threshold (i.e. one that would just filter out minima) would be very valuable.
11) L. 107: Is this similar to what is done in front detection? Are there any parallels to front detection schemes in your method that would be worthwhile mentioning?
12) L. 119: When looking at your case studies, I note that the features you detect with the moisture transport axes are coherent large-scale phenomena which are of meteorological relevance. Some properties of the detected moisture transport axes also reveal meso-scale features in addition, which are to date not well studied but which are likely relevant for the understanding and adequate prediction of these systems (among others atmospheric rivers) and their impact.
13) L. 127: does this relate to the two types of WCB outflow branches (cyclonic and anticyclonic outflow?) see Heitmann et al. 2024.
14) L. 132 and elsewhere: “pick up” sounds a bit like slang. Can you reformulate?
15) L. 133: “picked up by one to three of the six global detection algorithms” I don’t understand what this means. Why writing “one to three” and not mentioning a clearly defined number of algorithms?
16) L. 137: “expulsion of Tropical moisture” and at L. 320: “extrusions of moisture from the deep tropics”. I would use an existing term such as tropical moisture export.
17) L. 131-140: Here you already compare your method to existing atmospheric river detection schemes, and you do this sort of evaluation again in Section 5. I would recommend to group all the comparison effort to existing methods in one method evaluation section, which I would personally prefer to have before the more phenomenological and scientific discussion about the relationship of moisture transport axes to different tropical, midlatitude and polar features.
18) L. 176: MTA is not defined, and I preferred the written out version “moisture transport axes”.
19) L. 202: off -> of
20) L. 206-207: I don’t understand this sentence.
21) Section 5: I find the discussion around the detection of atmospheric rivers very technical and sometimes difficult to follow. The panel d in Figures 5-9 only show a few contours from the existing atmospheric river detection in the climatological plots and the chosen way of illustrating this intercomparison makes it difficult to compare the new method quantitatively with existing ones. If possible, I would separate the evaluation of the method based on a comparison to others from the scientifically interesting discussion of what the new method detects and what we can learn from it about atmospheric river dynamics.
22) L. 262-269: I find this way of approaching the identified tropical phenomena a bit awkward. Indeed, there are more persistent features linked to the Monsoon systems but there are also many transient features such as tropical plumes (Rubin et al. 2007) or tropical moisture exports (Knippertz, 2007), often times these systems are related to Rossby wave breaking and are relevant for extreme precipitation in the subtropics (de Vries, 2021).

23) L. 286-287: are these barrier winds? What does the direction of transport depend on? Are these relevant questions for forecasting in these regions? And can you see and propose how one could address them by using moisture transport axes?
24) L. 295: I think here one could establish a link with the West African Monsoon (Fink et al. 2017).
25) L. 297: Yes, indeed, that is also, when most precipitation falls in the Sahara (Armon et al. 2024).
26) Fig. 3 and others: Probably it is just my printer but the delimitation of the continents is barely (not) visible and makes it a bit difficult to orient
27) L. 305 recycling vs. large-scale transport: A large share of moisture in cyclone precipitation is fed through the cyclone feeder airstream and originates from the cold sector of previous cyclones as well as the cyclone-anticyclone interaction zone (see, Papritz et al. 2021). Could moisture transport axes be combined with cyclone masks and tracks to study the cyclone-to-cyclone moisture hand over and multi-cyclone association of intense moisture transport in more detail? What about the temporal evolution of moisture transport axes? Can two subsequent moisture transport axes be related to each other?
28) L. 307-311: Yes, the tracing of the moisture filaments further into the subtropics, continents and/or polar regions is a very nice characteristic of the new method but here I think the Eulerian vs. Lagrangian aspect should be mentioned and discussed as a caveat resp. as a possible outlook: this of course does not mean that you suggest that moisture transport in the atmosphere is generally occurring over longer distances or timescales. A combination with a trajectory-based diagnostic would be required for investigating the moisture cycling aspect along these moisture filaments.
29) L. 311: yes, and I think this is really exciting because it allows to study the substructure of atmospheric rivers in more detail, in particular the relevance of moisture recycling through precipitation evaporation and the importance of cold pool-like circulations within the complex cloud-systems.
30) L. 320: "extrusions of moisture from the deep tropics"->tropical moisture exports? Or is the feature you describe something meteorologically different?
31) L. 324-331: yes, exactly, very nice and convincing concluding paragraph, that's the framing I would also strongly encourage to adopt for the introduction.
32) I miss a serious discussion of the caveats of the method in the conclusions and an outlook about which scientific questions could be addressed with this new valuable detection scheme.
33) L. 339: TWe -> We
34) L. 333: I commend the authors on their plan to make their climatology of moisture transport axes publicly available. MTAs have not been introduced as an abbreviation -> write it out?

References:

Armon, M., de Vries, A. J., Marra, F., Peleg, N., and Wernli, H. (2024): Saharan rainfall climatology and its relationship with surface cyclones, Weather and Climate Extremes, 131, 100 638, https://doi.org/10.1016/j.wace.2023.100638.

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Ralph, Dettinger, Rutz and Waliser (2020): Atmospheric Rivers, https://link.springer.com/book/10.1007/978-3-030-28906-5#about-this-book. And from this book I particularly recommend:

Sodemann, Wernli, Knippertz, Corderia et al., Chapter 2: Structure, Process, and Mechanism.

Rubin, S., B. Ziv, and N. Paldor (2007): Tropical Plumes over Eastern North Africa as a Source of Rain in the Middle East. Mon. Wea. Rev., 135, 4135–4148, https://doi.org/10.1175/2007MWR1919.1.