REVISED SUBMISSION: RESPONSE TO REVIEWERS
A novel method for objective identification of 3-D potential vorticity anomalies
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We would like to thank the reviewers and the handling topical editor for further comments and feedback on our manuscript. Detailed point-by-point replies (blue font color) to each comment are provided below. Technically, citations of text passages are in italics. Changes made to the text are highlighted in yellow. Minor changes to some figures are described here as well, however, these figures are not included in this answer. Line numbers refer to the resubmitted manuscript.

Handling topical editor:

Dear authors,

The reviewers have recommended minor revisions and acceptance of your work, respectively. Please, check the comments by the Reviewer 1.

Also, I have read with attention your manuscript, and I think that the reviewers have done a great work reviewing it. I think that using a stereographic projection is a very clever idea. My interest comes from the fact that the identification of PV fields is a topic that I researched a few years ago, also related to identifying the tropopause. You can consult it here: https://doi.org/10.1371/journal.pone.0072970

The obligations for editors of GMD state that "Editors themselves should be extra careful in suggesting additional literature." Our publication policy also focuses on avoiding citation malpractice. However, given the topic, I think it is justified to point out my work in this case.

Beyond the PV streamers, in line 38, you mention "cross-equatorial" intrusions. We also found this problem with our algorithm to detect PV fields. In several cases, this happened, and we had to consider it. Somehow, it is similar to the problem of using a longitudinal cartesian projection and dealing with a PV surface cut at a given meridian. We solved it simply by computing surfaces separately and aggregating areas. Our problem was a 2D surface, so simpler than yours.

Also, in lines 145-149, you talk about the discrete nature of algorithms and their impact on the computation. Somehow, this was precisely the problem we addressed with the ROI algorithm instead of piecewise-constant techniques. The improved interpolation and granularity behind the ROI implementation in IDL let us improve the accuracy of the computation of the PV surfaces, independently of the initial horizontal grid, with an increase in precision up to ten times and a computing time up to 9 times faster for a 1,5 degrees grid.

I think that it could be fair and that the point made in your work would benefit from citing our previous results on these two issues, as they show that similar problems have been

faced in the past, and that there is room to improve the solutions when computing this kind of structures.

However, I want to clarify that one referee now recommends accepting your paper as is. Another requests only a few minor modifications and does not consider it necessary to review your work again before acceptance. Therefore, independently of your decision on citing or not the work that I point out, your manuscript is almost sure to be accepted for publication if you address the recommendations of Reviewer 1.

Regards,
Juan A. Añel
Geosci. Model Dev. Executive Editor

We thank the handling topical editor for his remark and for leading the reviewing process. The comments by Reviewer #1 have been addressed. Our responses to these comments are provided below.

The work mentioned by the handling editor uses a region of interest (ROI) approach to significantly improve area measurements, which results in a more precise computation of the equivalent latitude. On the other hand, our work requires a robust measure for distances in a projection following a given field. While the applications are quite distinct, both approaches use higher-order schemes in numerical computation to compensate for distortions, relating these works to each other to some extent.

Regarding the first text passage mentioned by the handling editor (Line 38): We avoid problems at the anti-meridian specifically by choosing a different projection. Furthermore, we are here not specifically interested in areas near the equator. The choice of this specific projection has been extensively discussed in Lines 150-170. We thus do not consider a reference to your previous work at this point to be very helpful.

However, regarding the second text passage (Lines 145-149), we are indeed faced with a similar problem to the one discussed in previous work by the handling editor. While the applications and the solutions are different, the fundamental problem are closely related from the computer-science perspective. Therefore, we agree that our paper benefits from a reference to these previous results and we changed the text as followed:

“Using this concept in real-world environments unfortunately is non-trivial. The distance measure required must follow the domain instead of using a direct spherical distance, as seen in Fig. 2. Most algorithms that satisfy this requirement suffer from metrical errors induced by a discrete representation of the projected grid. Instead, Añel et al. (2013) achieve significant improvements in area computations using a higher-order numerical scheme based on a region-of-interest approach. On the other hand, the present study requires an approach to compute distances (as shown in Fig. 2b), but similarly must compensate for distortions in the field. For more precise results we choose a strategy based on a higher-order numerical scheme also, as outlined in the next section.” (Lines 143-149)

Añel, J. A., Allen, D. R., Sáenz, G., Gimeno, L., and de la Torre, L.: Equivalent latitude computation using regions of interest (ROI), Plos one, 8(9), e72970, https://doi.org/10.1371/journal.pone.0072970, 2013.

Reviewer #1:

General Comments

I appreciate the author's revision and response to both sets of reviewer questions. I believe the paper is nearly ready for publication. Just a few minor comments and suggested technical corrections are listed below. Figure 10 was a very helpful addition to the paper. As I read this, I wondered whether the algorithm could be extended to 4-D, taking the time-evolution into account? Not sure how the "distance" would be calculated in that case, and how exactly the boundaries would be defined. Probably too complicated, but it would be interesting to know whether one could track individual PV anomalies as they flow through time.

This is a very interesting question and remark. Regarding tracking of PV anomalies, we performed some experiments mainly on the 2-D case, however, not adding the time dimension as third dimension to the algorithm but using spatial overlap heuristics and distance measures in the feature vector space to find corresponding anomalies of subsequent timesteps.

In theory, the presented algorithm could also be applied to 4-D, but this stresses the authors' limits of visual thinking. The 2-D and 3-D strategy handles "intrusions in the spatial dimension". These can be clearly visualized and thought of, as described in the paper. The fourth dimension would add "intrusions in time". First, note that identified objects are labeled by coherence. Therefore, the tracking can essentially be thought of a form of overlap tracking. However, to decide which areas to consider as anomalies, the operators (dilation and erosion in the time dimension) would also highlight structures that are "short-lived" (c.f. thin structures in the spatial domain $\cong$ short-lived structures in the temporal domain). Therefore, this leads to the addition of short-lived anomalies in areas which are broad and not spatially covered by the anomalies. It is questionable, yet debatable, if such structures are of interest, and it opens a variety of questions regarding the distance measure and the filtering process.

All in all, considering time as fourth dimension can be useful, and it can combine identification and tracking in one cohesive process. For our specific use case, the extension of the used operators to 4-D is possible, but would become very complicated, difficult to interpret, and would lead to more questions than it would solve. Not applying the dilation and erosion operators along the time dimension would yield a simple overlap tracking, which might already give good results if the temporal resolution is chosen wisely. We hence refrain from mentioning a possible generalization to 4-D in this study, but keep in mind this interesting thought for future work.

Specific Comments

Lines 127-8: In the erosion exercise in Fig. 1, it looks like the mask is small enough that there would be some part of the extended PV intrusion that would be kept and should show up as a greyed out area in panel (b). Is this true, and if so does the algorithm remove these type of cutoffs during the erosion? Later, lines 261-3, you say “Generally, this inner core may contain multiple disjunct areas. In these cases we pick the biggest one as the core to proceed with, defined by its area.” I assume a similar process is done for this figure. If so, you may want to state that explicitly to avoid any confusion. It might actually be helpful if you greyed out the smaller inner core area (if it does indeed exist) to illustrate this.

The figure in question has been generated in a manner that the orange mask should be big enough to not result in any left-over greyed area within the anomaly. The idea of this section is to provide a quick introduction to the operators used in the algorithm while sticking to a simple example. As noted by the reviewer, it is essential to pick only the biggest “inner core” after the erosion. We decided to not include such a specific case in this introduction.
However, after reviewing the figure, we agree that the orange mask in Fig. 1a-c does not quite cover the entirety of the displayed anomaly. The size of the displayed orange mask has been adjusted, and the figure has been revised accordingly to match the actual used size.

Fig. 4h: This is a very minor point, but I’m not sure what the green and red symbols represent. Are they supposed to be funnels? Maybe a green check mark and a red X would make more sense to the reader?

Yes, these funnels should symbolize the filtering process. However, we agree that a check mark and a X would be more intuitive and would also be the better choice regarding the color accessibility guidelines. Therefore, the figure has been revised by changes the funnels to green check marks and red crosses.

Page 19: When I first read the revision, I wondered why the paragraph starting “Figure 9a...” had been moved from its previous position. In the original submission it was placed after the description of the 3-D algorithm. Now it is before the description, and the new Figure 10 is referred to in the algorithm description. After reading this section several times, I think I understand that you’re trying to orient the reader to the 3-D rendering of the tropopause with this figure. If so, would it make sense to not highlight the PV anomalies in Figure 9, but just show the tropopause, as in Figure 4c? Then later, after describing the algorithm, you could show this figure again with the anomalies identified, as in Figure 4g? Just a suggestion, because it is a bit confusing to see the anomalies in this figure, but then later explain how the anomalies are identified.

We thank the reviewer for this comment. With Figure 9, we want to give the reader an overview and a visual introduction to both the entirety of the tropopause in 3-D, but also the structure, distinctness, and locations of the anomalies. In the mentioned section, we first introduce the tropopause displayed in the figure, then we show how the anomalies are situated in relation to the tropopause. We think doubling this figure, one with and one without anomalies, is not necessary and that it is sufficiently clear in this case.

Is Figure 9 for 24 July 2015, as in Figure 10? May want to include the date/time in the caption.

We thank the reviewer for pointing out the missing reference on how to reproduce this display. Indeed, the same time step has been chosen. We added at the end of the caption of Fig. 9: *"Displayed on both panels is the ERA5 reanalysis at 24 July 2015, 00 UTC."*

Line 467: Was Met.3D used for the previous visualizations? If so, you might want to move this statement above to where you first use this software (Figure 9 description).

Yes, Met.3D has also been used for the previous visualizations. Although we already introduced the tool in the introduction (Lines 105-111), we agree that there should be a further remark when referencing the first figure making use of Met.3D instead of the second one. Therefore, we removed the reference to Met.3D in Line 468 and added: *"Figure 9a shows a 3-D visualization using the open-source visualization framework Met.3D (Rautenhaus et al., 2015b) of the tropopause (defined by the 2-PVU isosurface) and the identified anomalies."* (Lines 388-389)

Suggested Technical Corrections

These are mainly stylistic suggestions that you can take or leave as you see fit.

Line 44: change to "objective identification of PV structures"
Lines 47,48, 78, etc.: change to "e.g.," to be consistent with other uses of e.g.
Line 66: change to "Bithell et al. (1999)"
Line 99: change "that base on" to "that are based on"
Line 153: change "south pole" to "South Pole" for consistency
Line 175: does "resp" mean "respectively"?
Line 208: capitalize "Euclidean"
Line 216: change "of a measure" to "of as a measure"
Line 229: Do you want to capitalize Seasonal, since Subseasonal is capitalized?
Line 286: "Depending on the use case", do you mean "Depending on the case"?
Line 293: change "Besides as filtering" to "Besides a filtering"
Line 380: Do you want "for cutoffs" within parentheses?
Line 398: change "independently on" to "independently of"
Line 405: change to "Bithell et al. (1999)"

We thank the reviewer for these technical and mainly stylistic suggestions. Text changes have been done where the authors deem them appropriate. We refer the reviewer to the uploaded Author’s track-changes file for the changes made.