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# *Interactive comment on* "Polar Lows – Moist Baroclinic Cyclones Developing in Four Different Vertical Wind Shear Environments" *by* Patrick Johannes Stoll et al.

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Responses to the comments of the first reviewer.

We thank the referee for the thoughtful review, which contains interesting questions and comments. In the following, we answer to each of them.

Reviewer: "I am not familiar enough with the SOM to say if the application of this technique, or of some of the operations that the authors have applied to the meteorological fields in the course of the work, may be in part responsible for this result.



For example I cannot but notice that not only the mid nodes of the 3x3 map based on temperature anomaly (Fig.2 of the paper, better seen in Fig.3 of the supplement), and of the 4x5 map, fig 2 of the supplement, but also the corner node 3 of the map based on full temperature fields (fig 4 of the supplement) have a nice symmetric structure in the center. May the authors comment on the possibility or impossibility of this filtering having occurred in the analysis?"

Response: We formulated a new section to the Supplementary material in order to answer this question:

**5 Evidence for the SOM method to detect characteristic PL environments**

Here we provide more evidence that the applied SOM method is appropriate in detecting characteristic PL environments, whereas simple composites are not sufficient.

The composite fields of meteorological variables in the PL environment may fail to represent a typical PL environment. For example, the composite of all PL time steps in the 850 hPa temperature anomaly features an almost axisymmetrical thermal structure with a warm core (Fig. 1). However, the variability in the temperature anomaly field is large (Fig. 2), especially at some distance from the PL centre. The variability exceeds the magnitude of the composite field, which indicates that PL environments may have a considerably different structure than expressed by the composite of all time steps.

The SOM algorithm is a method to detect coherent patterns of variability. The SOM matrix (e.g. Fig. 2 of paper) shows that most nodes have a different structure from the composite of all time steps. The variability in the temperature anomaly is considerably lower within each SOM node (Fig. 3) than the variability among all time steps (Fig. 2), especially at a distance of more than 100 km from the PL centre. As the variability within each SOM node is rather small and does not exceed the magnitude of

its composite field, each SOM node is considered to be representative for a typical PL environment.

In the following, we discuss why the composite of all time steps features a warm-core structure, and whether PLs can be generally considered warm-core systems. The temperature anomaly most SOM nodes is characterized by strong temperature gradients and is higher at the location of the PL centre as compared to the thermal background field (e.g. Figure 2 of the paper). It can be inferred that a mean over the thermal fields of the SOM nodes (Figure 2 of the paper) is resulting in an axisymmetric warm-core structure captured by the composite of all time steps (Fig. 1), whereas the thermal gradients of different orientation in the SOM nodes cancel out in the composite. The positive temperature anomaly at the centre within each SOM node could be attributed to the release of latent energy, or to the centre that is defined by the relative vorticity maximum, being located close to the updrafts in the warm conveyor belt, an area of low-level potential vorticity production. It is likely a combination the two reasons, possibly with other effects are contributing as well. Hence, PLs appear to be warm-core, but typically embedded in a background field of large thermal contrast.

The SOM algorithm also produces nodes (e.g. node 5 in Figure 2 of the paper) with low thermal gradients, which appears like the composite of all time steps (Fig. 1). The composite of this node features a structure that resembles an axisymmetric warm core (even more recognizable in the 4x5 SOM matrix displayed in the Appendix Figure 2). The averaging of time steps within a node might exaggerate the symmetry in the structure, by the same arguments as for the composite of all time steps. However, different from the situation with all time steps (Fig. 2), the variability is small within the symmetric SOM node (Fig. 3), which indicates that some PLs in fact have time steps with an axisymmetric warm core.

In conclusion, our method shows that axisymmetric PLs occur seldom and PL environments are instead mainly characterized by a horizontal temperature contrast.



Reviewer: "I am a bit confused by the numbers on pg. 4. The authors extract 556 tracks from ERA-5, and reduce them to 374 by excluding duplications and mergers. However they state that the Rojo list contains 420 PL events. So my question is are there cases in the Rojo list not found in ERA-5 ? And, secondarily, would a track search not forced to match the Rojo list have found more events in ERA-5"

Response: Answer to the first question: Yes, we state "374 of the 420 PL centres from the Rojo list have at least one associated PL track." So in reverse 46 PL centres from the Rojo list are not found in ERA-5 as a vorticity maxima within a distance of 150 km. However, the PL centres from the Rojo list are identified by the cloud structure, which is to some degree subjective.

Answer to the second question: This highly depends on the construction of the track search. The here applied track search detects a large amount of cyclonic systems, considerably more than in the Rojo list. However, this is not a problem for this study, as the aim of the tracking algorithm is to find the ERA-5 representation of the identified PL from the Rojo list. A study with the aim to reproduce the Rojo list as accurately as possible would need to reduce the amount of detected cyclonic systems, likely by imposing detection criteria.

Reviewer: "pg. 4 ln 112-113. Do you mean all three of initial-middel-final times on land, or just one or two of them ?"

Response: All three of them. An additional word was included: "The latter is defined as when the initial, middle, and final time step of the PL **all** occur on land."

Reviewer: pg.7 ln 180 Has the overbar here the same meaning of area average as for the wind in the previous page, or an average on the square 1000x1000 km area, or is

it a sort of "zonal" mean in that area?

Response: We changed this sentence: The SOM analysis is based on the temperature anomaly field at 850 hPa of each time step $T'(x, y) = T(x, y) - \overline{T}$, with $\overline{T}$ denoting the mean temperature within the PL-centred grid of the time step.

Reviewer: "pg.12 ln 264. Does this QG concept hold on these small scales? In other words, it is not clear to me if this is a statement of principle, or it is the result of the authors study of the meteorological fields."

Response: We tried to clarify this by replacing the sentence with the following: "The thermal wind relation associates the vertical wind shear with the horizontal temperature gradient. This relation is evident for the environmental variables of the different shear categories."

Reviewer: "several typos in the references. eg. ln 488 De Boor, De Boor, De Boor and De Boor; ln 507 Holton, American Journal of Physics (it's a book); ln 510 : what's the title?"

Response: Thanks for spotting these mistakes, we corrected them together with a few others.

Reviewer: "One final observation on the figures. I realize that it would be difficult to carry the same information in less complex figures, but the black dots in Fig.1 are only seen after enlarging the image size, and the 9 (nine!) colored dots of Fig. 4 are a challenge for those who discriminate colors poorly."



Response: Thanks for the remarks. We adapted the mentioned figures.

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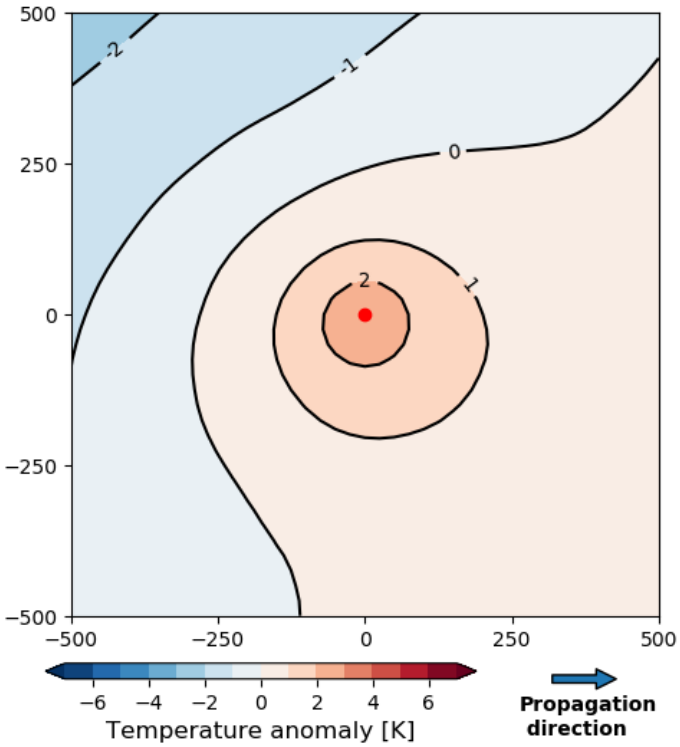


**Fig. 1.** Mean in the 850\,hPa temperature anomaly field in a PL centred perspective with propagation direction towards the right based on all time steps.



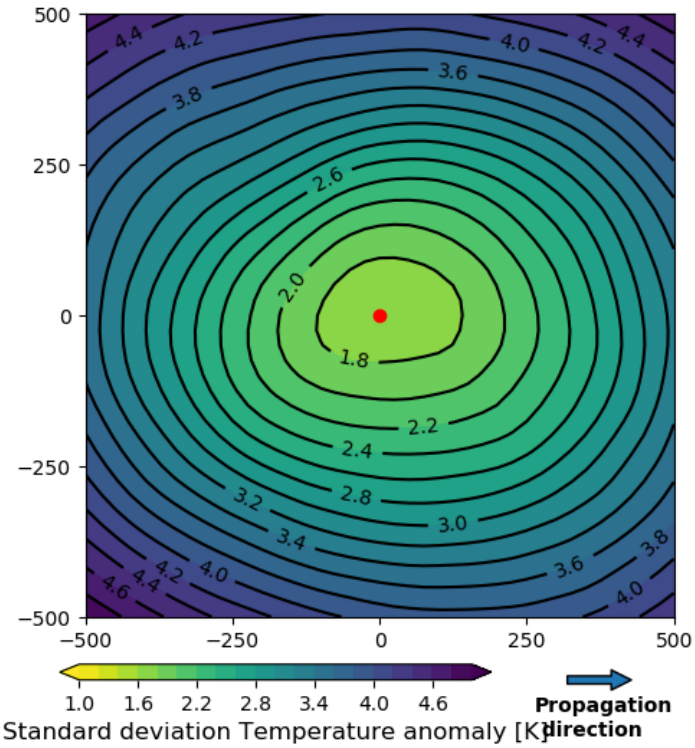


**Fig. 2.** Standard deviation in the 850\,hPa temperature anomaly field in a PL centred perspective with propagation direction towards the right based on all time steps.

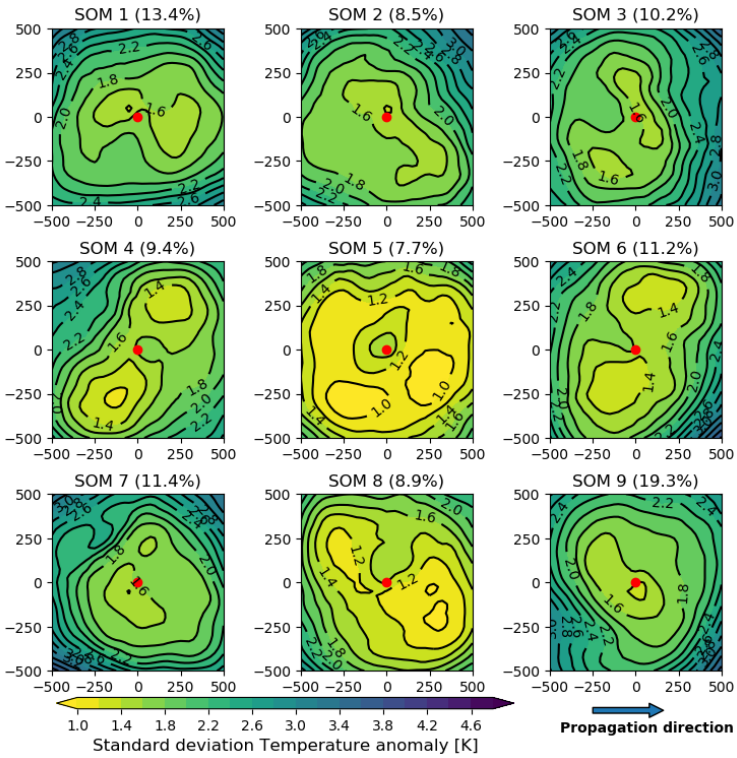


**Fig. 3.** Standard deviation in the temperature anomaly at 850\,hPa for all time steps with the same SOM node. The SOM matrix is calculated as presented in Figure 2 of the paper.