Review of "Interactive 3-D visual analysis of ERA 5 data: improving diagnostic indices for marine cold air outbreaks" by Meher et al.

General comments:

The authors have represented marine cold air outbreaks (MCAO) in three dimensions using the software Met.3D and, using this viewpoint, have defined two new indices, one for MCAO and one for polar lows, which they claim give a more accurate association with polar lows than the previous versions of MCAO indices that depend on a subjectively chosen pressure level. Studying MCAOs in 3-D and their association with polar lows is interesting and new, to my knowledge, and worth being published in WCD. However, to my opinion, the manuscript needs major rewriting and rearranging. The authors should choose where to fully define the indices, either in the method or in the sections where they appear (if the authors want to follow the "workflow"). I found the manuscript hard to follow (especially Section 3.3.3). Some parts of the data and method section felt like a technical report or user guide and not like a scientific article. Moreover, I do not see the point in emphasizing the "workflow" in the first part of the manuscript. These issues are detailed in the specific comments below along with some others, such as some missing explanations/justifications that if added can make the manuscript clearer.

Specific comments:

Introduction:
Line 34: does it mean that machines that don't have GPUs cannot run 3-D software?
Lines 51-52: another index worth mentioning is the difference between the 500-hPa temperature and the sea surface temperature (used for example in Zappa et al. (2014) and the references therein).
Lines 76-77 and lines 77-80: are those two questions pertinent? The answers seem obvious to me: first use a software allowing 3-D visualization, which the authors do, and second yes it can.

Methodology:
The authors point out many times throughout the manuscript that they define and follow a workflow to create new indices for MCAO and polar lows. But isn't that the regular way to reach such a goal? First, study the particular cases and then find a generalization. I suggest to reduce the text about this "workflow" in the whole manuscript. Moreover, I don't see the purpose of Fig.1 and its caption because it is only repeating what is already written in the manuscript. Section 2.3, lines 189-190 can also be removed.
Lines 100-103, 108-116, 125-127, 133-137, 181-185: Why should the reader care about these aspects? I suggest to remove.
Lines 123-124: Why do the authors need to do this comparison of ERA5? Have they found a difference? If not, remove this sentence.
Line 124: What was the original grid of the downloaded data? Why not downloading ERA5 directly on the regular longitude/latitude grid?
Lines 148-151: Rewrite more simply. What does "rasterize" mean?

Line 152: Not clear. Where/Why is this comparison done? I suggest to remove this sentence.

Lines 165-166: Not everybody is expected to know what a "Receiver Operating Characteristic (ROC) curve and accuracy score" are. Can the authors explain what they are?

Lines 167-180: These lines refer to variables (m_theta, m_p, m_tr) that are defined very much further down the manuscript (in Section 3.2). Therefore, this part is confusing.

Line 171: ±12 hours seem long compared to a polar low lifetime. Can the authors justify this choice?

Line 173: Is it really useful to insert the Heaviside function that renders the equation more complicated? Clearly writing which timesteps are considered in this average should be enough.

Results:

Lines 194-195: "MCAOs are resolved in ERA5": why did the authors expect otherwise? MCAOs are a quite large-scale phenomenon.

Lines 197-198 and 272-273: Can the authors give the reasons for the increased MCAO vertical extent when moving south?

Lines 206-208: Remove sentence.

Line 212: Terpstra et al. (2016) used the STARS database and thus seems more appropriate here than Michel et al. (2018).

Line 238: The authors mention the calculation of "other variants of the conventional MCAO index". First, this is very vague, what are those indices? Second, I believe these indices are not shown in the paper, so I would remove this sentence or rephrase it.

Line 273: Please explain what the "conceptual descriptions" are.

Lines 307, 341: Shouldn't p_0 be equal to 1013.25 hPa (instead of 1013.15) that is the standard pressure?

Lines 345-347: Where can the reader see this result? Does this conclusion come from visual inspection? Please precise.

Section 3.3.3 is not very understandable to me and would benefit from a good rewriting. Here are some unclear aspects: What are the critical values of Mi used as thresholds, how are they spread over the "observed" values? Is the "observed binary score of PL occurrence" the same as "the binary empirical data about PL occurrence"? The "observed binary score of PL occurrence" is not a score but rather a mask. Why M_i is "continuous"? It seems to be one map for each polar low track (number i). Remove sentence lines 403-404. On line 407, it is written M_i>0 but it should be M_i=1 because there are no other positive values and it would be consistent with equation 6. What are the "computing sensitivity and specificity for each threshold"? They seem to be associated with Youden's index but it is only mentioned later (and not even explained). What is the "accuracy score"? Is it the same as Youden's index? Line 434 mentions "a particular time" but M_i is the average over several timesteps, isn't it? From the values given on line 449, the Youden's statistic should be equal to 0.78+0.58-1=0.36 which is pretty bad since the perfect value is 1 but the authors still seem to emphasize its good performance. A table recapping all values would be great (specificity, sensitivity, or just Youden's index and accuracy).

For clarity, I suggest to move Section 3.2.1 into Section 3.1 with Section 3.2 focusing only on the new indices (3.2.1 would be the new MCAO index, 3.2.2 about the new polar low index, 3.2.3 about the evaluation of the new indices and their association with polar lows, 3.2.4 about the region-specific index). To emphasize the usefulness of the new index, I think the authors should perform a composite of the new MCAO index for the polar low dates (as a

map) with the actual positions of the polar lows superimposed (such as the tracks shown in Terpstra et al. (2016) or only the genesis points with the 32 uncaught polar lows in another color).

Conclusions:
Lines 521-522: The sentence "Terpstra,,, initiation" is not clear, please rephrase. Does it mean that a MCAO that lasts for a long time does not promote more polar lows than a short-duration MCAO?
Lines 523-526: Can't polar low genesis happen both inside and at the outer edge of a MCAO? Moreover, the comparison between this study and previous studies might not be fair since the present study tends to average the index over the polar low duration when previous studies focused on the polar low genesis time.
Lines 531-539: The authors highlight the less computationally expensive 2-D new MCAO index but still advise to perform a first empirical study to determine the critical pressure, hence losing the advantage of the new index. Can't the authors give the best critical pressure to use in future studies?

Figure 3: What are the "typical 2-D wind-patterns during PLs" the authors refer to? Terpstra et al. (2016) seems a more appropriate reference here as it dealt with the STARS polar lows. On line 205, it is written that the polar low "formed east of the coast of Novaya Zemlya during the 19-20th December 2002". However, on the inlay of panel (a), the polar low is located west of Novaya Zemlya. Can the authors clarify? Could it be relevant to mention if the two polar lows selected formed in a forward or reverse shear environment?

Figure 5: The polar low location does not seem to move from one panel to the other whereas the time is not the same. The same comment applies to Movies 4 and 5. Is that normal?
Caption: the sentences "Movie 6 … in Fig. 2." "We count … (see Fig. 6 and 7)." seem both out of place here.

Figure 6: The authors wrote "the time of the PL on the 24th of March, 2011". What is the timestep?
For panels (b,e,f), there are no polar lows in the domain but is there any cold air outbreak?
Can the authors provide an error bar for the pseudo-events hit rate? For example, the authors could randomly draw 132 timesteps, count the number of matches and repeat those steps 1000 times to get a distribution of hit rates.
One may wonder what the MCAO looks like (in 3-D) when the MCAO cannot be associated with a polar low (e.g., one of the 32 polar low cases missed by the index in Fig. 6f).
How is the area of pseudo-events defined (used in panels c,f,i)?

The authors may consider changing the title of the manuscript to include the polar lows as estimating favorable environments for their formation is the end goal of the study if I am not mistaken.

Technical corrections (non-exhaustive list):

Line 22: infrastructure -> infrastructures
Line 65: differs -> differ
Line 147: Sea -> Seas
Line 197: Fig 2a-c -> Fig. 2c-e
Line 200: underline -> underlines
Lines 220-225: (3.2.1) -> (Section 3.2.1) and so on for 3.2.2, 3.2.3, and 3.2.4
Line 242: decreases -> decrease
Line 247: Fig. 4 -> Fig. 4a-c
Lines 247-248: "The magnitude of …pressure level" is a repetition of the sentence on line 241 so consider changing one of the two sentences.
Line 260: Fig.4 -> Fig. 4d-f
Line 287: removes the [] around the unit.
Line 316: at 2 PVU -> by the 2 PVU surface
Line 331: How are the within and outside areas defined?
Line 333: Fig. 6e -> Fig. 6b
Lines 334, 336: Fig. 6b,h -> Fig. 6e,h
Line 345: Fig. 6 -> Fig. 6h
Line 346: remove the word percent
Line 356: location -> locations
Line 385: remove "for details,"
Line 423: Youdens -> Youden's
Line 526: develop -> developing
Line 550: front -> forward
Figure 1: to be removed?
Figure 2: consider removing Fig, 2b. Is it correct that the 257-K isentrope is shown on the left panels (c-e) and the 267-K isentrope on the right panels (f-h)? It is not very clear. The contours on the cross-sections are not very visible. The caption should be simplified. Nordic Sea -> Nordic Seas. Remove [] around kg/kg. Remove "Fig. 3 illustrates … depicted here."
Figure 3: Maybe remove the dotted lines between the inlay and the 3-D picture for clarity.
Figure 4: (d-f) Vertical profile -> (d-f) Vertical profiles
Figure 6 panel (g): shouldn't it be 5th percentile instead of 95th for the polar low index?
Figures' caption: Does the description of the figures belongs to the caption or to the text? For example, in Fig. 2: "Before the start of the MCAO in case 1 (c), the cold air is located above sea-ice; it is then transported … over warmer oceans (d-e)." or in Fig. 3 "no symmetric slow wind eye is observed in the lower troposphere…further south."

References:
Terpstra, A., C. Michel, and T. Spengler, 2016: Forward and reverse shear environments during polar low genesis over the northeast Atlantic. Mon. Wea. Rev., 144, 1341–1354, https://doi.org/10.1175/MWR-D-15-0314.1.
Zappa, G., L. Shaffrey, and K. Hodges, 2014: Can polar lows be objectively identified and tracked in the ECMWF operational analysis and the ERA-Interim reanalysis? Mon. Wea. Rev., 142, 2596–2608, https://doi.org/10.1175/MWR-D-14-00064.1.