“The Life Cycle of Upper-Level Troughs and Ridges: A Novel Detection Method, Climatologies and Lagrangian Characteristics”

Reply to review #3

We would like to thank Reviewer #3 for the specific and positive comments on how we can improve the presented manuscript. In response to the comments made by you and the other Reviewers, we have made considerable changes to the text and figures, and we will mention the relevant ones in our point-by-point response.

Reviewer: As one of the most important skills of this tracking algorithm is finding the axis of the system, and a lot of the analysis is based on it, more effort should be invested in explaining the notation of cyclonic and anticyclonic tilt, what are the factors controlling the axis orientation and the effect of the axis orientation on the life cycle of the system and it’s interaction with lower-level systems. A cartoon demonstrating these concepts might be helpful.

Authors: The ideal schematic to present the notion of cyclonic and anticyclonic tilt is in our opinion Fig. 12 of Thoncroft et al. (1993), which is shown below. We now reference explicitly this schematic in our introduction.

Further, we added a new Figure that explains the algorithm and, in that schematic, we added a trough axis and point the reader to the orientation of this axis to illustrate the notion of cyclonic and anticyclonic orientation (New Figure 2).

34 C. D. THORNCROFT *et al.*

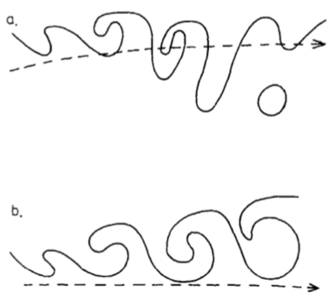

Figure 12. Schematic of a PV-theta contour in an Atlantic storm track sharing its main characteristics with (a) an LC1-type life cycle and (b) an LC2-type life cycle. The dashed line marks the approximate position of the mean jet at each stage.

Reviewer: In the introduction, more attention should be given to explain the open questions addressed in this work (ENSO, midwinter minimum), and how these questions might be addressed using tracking algorithms.

Authors: Good point, we added a new paragraph to the introduction that explains the research questions related to ENSO and the midwinter suppression, which we address in our study. The main literature overview is however presented in the corresponding sections to keep the introduction concise.

Reviewer: Choosing 500 hPa as the main level in which the analysis is done is reasonable, but the authors should add a figure describing the performance of the algorithm as a function of tracking level to give a more general representation.

Authors: Ok, we added the results of the 300 hPa level as a supplement figures and now mention the possibility for the user to choose the level and variable.

Reviewer: The effect of ENSO and the midwinter suppression on the number of eddies is crucial in understanding their overall effect. Although it is challenging to measure as it appears differently depending on the tracking algorithm and the parameter that is tracked. Therefore, the effect of ENSO and the midwinter suppression on the number of tracked eddies as found by the described algorithm should be shown (either in figures 5 and 6 or as additional figures).

Authors: With respect to the influence of ENSO, we focus on the change in the orientation because this was previously inferred based on **E** vectors. We would like to demonstrate the correspondence of the two perspectives. With respect to the midwinter suppression, we fully agree, here the number/frequency of identified objects matters and we added the detection frequencies as yellow contours to the revised Fig. 6.

Reviewer: One of the most commonly used Lagrangian methods is creating composites based on the tracking data. Using this algorithm in order to make composites might be even more useful as the algorithm finds the region associated with the systems, and improved composites can be made. Adding a composite analysis of some field might be very interesting (for example, a composite of the vertical velocity can be made and later compared to the more complicated analysis using LAGRANTO).

Authors: Yes, composites are indeed a major application, which we also foresee for the troughs and ridges. Troughs and ridges could be centered on cyclogenesis or extreme events. We prefer not to add another figure to the paper because the number of Figures is already large. We now have already 10 Figures (1 new, 2 modified) plus 3 new supplementary Figures. We believe that a composite analysis deserves a full-fledged study.

Reviewer: The analysis shown in figure 7 is confusing. These eddies are, to a good approximation, a closed system and therefore mass (and PV) conserving. Looking at the total vertical movement of parcels does not necessarily mean much and the conclusion that vertical processes play a small role in the dynamics might be incorrect. Previous papers (e.g., Booth et al., 2015; Tamarin-Brodsky and Hadas, 2019) have shown (as in figure 8), that there is a small section of rapidly ascending air and a larger section of moderately descending air.

Authors: The trough in Fig.7 is classified as an open trough, because the corresponding geopotential isolines (blue contours in Fig. 7) are not closed. The closed area in Fig. 7 is the region satisfying the curvature threshold (red contours in Fig. 7). We therefore expect a continuous flow in and out of the trough area, which is suggested also by the trajectories. We are not sure in which sense the through constitutes a closed system, for a truly closed system we would expect the trajectories to circle to some degree inside the closed contour.

We however fully agree that analysis of mean quantities can be misleading in particular if the spread among the air parcels is large. Therefore, we added two new histograms to Fig. 7, which show the binned 24-hour changes in PV and pressure. PV changes are for 90% of all air parcels strongly confined to -0.2 to 0.2 PVU/24h. Thus, it is fair to argue that the flow is almost adiabatic with a small fraction of air parcels undergoing diabatic modification (of up to -0.6 PVU/24h). Pressure changes indeed reach up to 60 to 80 hPa/24h for approximately 15% of all air parcels, while ascent of up to -30 to -40 hPa/24h is found for less than 5%. It is therefore correct, as you point out, that embedded in the large-scale descending motion there is a very small fraction of ascending air. Similar examples occur for convection embedded in warm conveyor belts (Martínez-Alvarado et al., 2014; Rasp et al. 2016; Oertel et al. 2019), which itself is the more rapidly ascending fraction of air inside the rising warm sector of an extratropical cyclone. We comment on this in the revised manuscript.

Reviewer: Figure 1 can be reduced to 3 subfigures, combining subfigure b-c and e-f and describe the system's age in the text.

Authors: This is correct. We will check with the copy editor if the figure is too large and reduce it to 3 subfigures but if not, we prefer to keep it.

Reviewer: The use of the phrase "low- (high-) pressure system" (e.g., page 4, line 24) is con- fusing in this context, as it is mostly used to refer to low-level cyclones (anticyclones).

Authors: Yes, this cyclone is also well-marked at the surface. We now mention this in the text, which hopefully clarifies the wording.

Reviewer: The climatology calculations that led to the colours and contours in figure 3 should be better explained.

Authors: We tried to improve the explanation.

Reviewer: Page 11, line 32 to page 12, line 2: These results have been discussed before in the context of extratropical storms, both in simulations (Booth et al., 2015), and observations (Tamarin-Brodsky and Hadas, 2019). A reference should be made.

Authors: Yes, the asymmetry is not an entirely new finding. We added the studies of Sinclair et al. (2020), Tamarin-Brodsky and Hadas (2019), Booth et al. (2015), plus the original literature of O'Gorman (2011), who first explained the asymmetric distribution of vertical motion as a result of the influence of moisture and heating on the static stability. We would argue that the asymmetry is also resulting from moist convection being mostly upward in the atmosphere and not downward.

Reviewer: Page 3, line 17: "The trough and ridge identification algorithm is based on...". Per- haps use "The trough and ridge identification are done on..."

Authors: The corresponding sentence was changed.

Reviewer: Page 4, line 20: Number is unclear.

Authors: The number is the trough/ridge area.