**MWR-D-16-0263 | Bentley et al., Response to Reviewer 3**

The authors thank Reviewer 3 for their thoughtful and thorough review. We have incorporated your recommendations as described below. We have also listed (where appropriate) the sections(s)/line(s) where each change is located in the revised manuscript.

The authors examine different pathways to subtropical cyclogenesis for storms that ultimately undergo tropical transition (TT). A climatology of tropically-transitioning subtropical cyclones compiled by Bentley et al. (2016) is subjectively partitioned into four classes of development: cutoff low (COL); meridional trough (MTRF), zonally oriented trough (ZTRF) and subtropical disturbance (STD). Summary diagnostics of the synoptic environments (principal components, McTaggart-Cowan development pathway and the parameters in Table 1) provide some insights into the characteristics of each class. Storm-centered synoptic composites are used to describe the synoptic evolution leading up to the subtropical cyclogenesis for each storm class; these analyses are intended to demonstrate the “characteristic structures and evolutions between t0 −120 h and t0 that distinguish them from each other.” Anticyclonic wave breaking (AWB) is highlighted as being necessary in three of the four classes. As discussed below, the case is not cleanly made for this choice of four classes.

The reviewer makes an excellent point about the distinctions between the STC categories. Based on the reviewer’s comments, the upper-tropospheric features associated with the formation of NATL STCs that undergo TT were reexamined. This reexamination resulted in the removal of the subtropical disturbance category from the present study. The majority of STCs included in the subtropical disturbance category were re-categorized as zonal troughs. The cutoff low and meridional trough categories are essentially unchanged. Please see responses to the reviewer’s specific points (below) for more information.

The results presented are interesting and worthwhile, however a number of questions in the approach and interpretation deserve consideration.

Data and Methodology

Examples of the four classes are provided in Figure 1, but the MTRF example exhibits a much more negatively tilted trough than is depicted in the schematic in Figure 14. How are the troughs in this class of systems oriented?

Figure 1 has been replaced with new Figs. 1–3, which now highlight the structure and evolution of upper-tropospheric features during the five days prior to STCs forming in association with a cutoff low, meridional trough, and zonal trough. The meridional trough example was selected based on its character-istic evolution of upper-tropospheric features during the five days prior to STC formation and its clear “meridional trough” structure at *t*0. An examination of the 18 STCs included in the meridional trough category reveals that the tilt of meridional troughs ranges from negative, slightly negative, neutral, to slightly positive- averaging out to a slightly negative tilt in the composite analysis. Since meridional troughs included in this study occasionally exhibit a slightly positive tilt, the schematic diagram was given more neutral characteristics than the composite to allow for this possibility.

Page 8 and Figure 2:

The PC analysis doesn’t provide strong support for the four classes highlighted. It is surprising that the four classes don't separate out more. In particular, since the MTRF are identified as not being associated with AWB, I expected to see them discriminated more cleanly.

The authors agree with the reviewer that the original EOF analysis did not support the four classes included in the present study. Based on the reviewer’s comments, the subtropical disturbance category has been removed from the present study and the majority of STCs included in the subtropical disturbance category have been re-categorized as zonal troughs. The cutoff low and meridional trough categories are essentially unchanged. Figure 4 depicts the results of the new EOF analysis, which are much cleaner.

• This led me to ask what led to the choice of 250-150 hPa-averaged PV as the key diagnostic variable?

The 250–150-hPa layer-averaged PV fields were selected as the key diagnostic variable in the present study due to its recent use by Galarneau et al. (2015) and Archambault et al. (2015) to represent upper-tropospheric disturbances interacting with tropical cyclones (their Figs. 9 and 11, respectively).

• How does PC2 vary for STD? this is not discussed in the text and is difficult to discern from the figure (see comments below).

• Expanding the analysis to other summary parameters – the variables in Table 1 and the “McT-C development pathways” – doesn't seem to help. In all cases, ZTRF and STD are barely distinguishable based upon summary parameters; differences in PW and CI between COL and MTRF suggest that these parameters can be helpful discriminators

Excellent comments. As previously stated in responses #1 and #3, the subtropical disturbance category has been removed from the present study. Differences between STCs forming in association with cutoff lows, meridional troughs, and zonal troughs are now more apparent in Table 1 and Figs. 4–8.

Lines 201 – 211: I don't understand this paragraph. A few questions raised here include:

• Why does the use of a single time partially explain the discrepancies? If this is a solution, why isn’t it used to make the distinctions between the classes clearer in PC space?

This paragraph has been rewritten to provide a better explanation of small regions of overlap in the PC1–PC2 phase space now observed after removing the subtropical disturbance category from the present study (L215–228). STCs are subjectively categorized in the present study based on the evolution of the upper-tropospheric features associated with their formation between *t*0 − 120 h and *t*0. The EOF analysis, performed on the 250–150-hPa layer-averaged PV fields at *t*0 only, knows nothing about the evolution of these upper-tropospheric features between *t*0 − 120 h and *t*0. STCs overlapping in the PC1–PC2 phase space are included in separate categories due to the distinct evolution of their upper-tropospheric features between *t*0 − 120 h and *t*0 that cannot be captured by the EOF analysis performed exclusively at *t*0.

• Since AWB is credited with being critical in 3/4 classes of subtropical cyclogenesis (37/52 classified cases), should the reader be concerned that there’s no signature of AWB being picked up in the EOF analysis?

Figure 4c reveals that EOF2 is picking up the signature of AWB occurring to the north of the location of STC formation in the EOF analysis. EOF2, as well as the signature of AWB, is discussed in detail on L179–192 and L202–214.

Section 2b: Cyclone-relative compositing

Subtropical genesis locations plotted in Figure 4 show that

• **COL and MTRF** genesis can occur at almost any longitude in the basin (and generally further poleward). **ZTRF and STD** only occur west of 50°W. Correct

• **ZTRF and STD** are essentially indistinguishable based on geographic distribution and on all of the summary metrics (e.g. lines 321-322). Why should an investigator want to include an extra classification into their analysis? How do the differences between the storm-centered composites compare with the intra-class (within STD, etc.) variability?

• The case needs to be made for two classes here, rather than one class – or perhaps two differently partitioned classes.

As previously discussed, the similarities between STCs included in the zonal trough and subtropical disturbance categories caused these two categories to be reexamined and the subtropical disturbance class to be removed from the present study. STCs included in each individual category are more similar to each other than to STCs included in another category, which was not necessarily the case prior to the recategorization of the subtropical disturbance category.

• Creating cyclone-relative composites makes sense, however, given the range of background states due to the geographic variability, interpreting the COL and MTRF composites is not straightforward.

Please see the authors’ response to “Sections 4a and 4b” (below).

Catalogue of storms and Figure 5

In trying to understand how the two partitioning approaches [the 4 classes here and the 3 McT-C TT pathways] interacted, I compared Figure 11 of Bentley et al. (2015) with Figure 5 in this manuscript. One April and 4 October storms that were included in the 2015 paper are not included in the 62 storms being analyzed in this work. It would be helpful to provide the catalogue of storms and how they are classified, in both partitioning approaches.

The reviewer appears to be referencing a version of Bentley et al. (2016) that was written prior to the version that was published in MWR in May 2016. At the request of the editor, the five STCs identified by the reviewer above were removed from Bentley et al. (2016) because they never underwent TT and became tropical cyclones. The authors believe that the discrepancies identified by the reviewer will not appear when the published version of Bentley et al. (2016) and the present study are compared. Figures 6 and 7 in the present study can be compared with Figs. 9 and 11 in Bentley et al. (2016), respectively.

Lines 331 – 334: This paragraph doesn’t provide an explanation for why the lower mean CI values for ZTRFs are associated with the higher mean PW and higher 850 hPa qe. Is the difference between the PW means for the ZTRFs and STDs statistically significant? In addition, while the means vary as described, there’s no constraint that each element of this variation hold for an individual storm.

The authors agree with the reviewer. Due to their similar characteristics, STCs included in the subtropical disturbance category were partially combined with STCs included in the zonal trough category (see previous responses). No reference to equivalent potential temperature is made in the present study.

Sections 4a and 4b: COL and MTRF cyclone-relative composite discussion

Retaining the maps on the COL and MTRF composite plots (Figs. 7 – 10) is problematic, since the storms in each sample are fairly uniformly distributed on a spectrum from open ocean to close to land. By retaining the map and a single composite for each class, it can deceive the reader into attributing effects of topography, SST gradients and landsea contrasts to the evolution of the Rossby wave pattern as the trough of interest “traverses North America.”

The reviewer’s point is well taken. In order to explain the inclusion of geographical features in each cyclone-relative composite and to prevent the reader from being deceived, text has been added to section 2b (i.e., “cyclone-relative compositing methodology”) that discusses the concerns raised by the reviewer. L247–253 state that the position of geographic features relative to the location of STC formation within each category at *t*0 is displayed in each cyclone-relative composite for reference. However, it is noted that the geographical features displayed in each cyclone-relative composite are not representative of all STCs included within each category due to differences in the location of STC formation within each category (Fig. 6). For this reason, the effects of topography, land-sea contrasts, and SST gradients on the precursors to STC formation will not be discussed in the present study.

Lines 365 – 366: Is the argument that AWB is occurring because of the cutoff low? Or that it is inferred from the development of the cutoff low?

AWB is said to lead to the development of a cutoff low over the location of STC formation (L381–384). AWB is inferred from the evolution and structure of the upper-tropospheric meridional wind pattern, as well as the tilt of the upper-tropospheric ridge, during the five days prior to STC formation (Fig. 9).

Lines 376, Figure 8: As this upper-tropospheric trough moves eastwards, it appears to be digging southwards in the composite. Is this evident in the individual MTRF cases? Have increasing negative tilt in composite as approach t0 (e.g. lines 399-400); this would be associated with weaker shear (all else equal). But the shear at t0 for MTRF cases is as strong as shear for the cutoff lows. What is going on here?

Yes, the amplification of the upper-tropospheric trough as it moves eastward is evident in the individual cases included in the meridional trough category. As stated in a previous response, the tilt of individual meridional troughs ranges from negative, slightly negative, neutral, to slightly positive- averaging out to a slightly negative tilt in the composite analysis. Because each individual meridional trough does not exhibit a negative tilt, weaker mean VWS value is not observed at *t*0.

Figure 9: The caption description of the vertical motion is confusing: “600–400-hPa layer averaged ascent (red contours, every 0.5 x 10-3 starting at −1.0 x 10-3 hPa s-1)” seems to imply that −1.0 x 10-3 hPa s-1 is the most negative value. But we are interested in ascent and ascent is going to be negative (hPa s-1).

Great catch. This caption was confusing and has been changed to say “600–400-hPa layer-averaged ascent (red contours, every 0.5 × 10−3 hPa s−1 less than or equal to −1.0 × 10−3 hPa s−1)” to indicate that ascent is negative.

Figures 7, 8, 11 and 12: What are the surface cyclones like in each class? The only partition in which an isolated system is evident in these upper-tropospheric analyses is the cutoff lows (unsurprising).

Excellent question. Figures 10, 12, and 15 now depict the 925–850-hPa layer-averaged relative vorticity field in an effort to examine the lower-tropospheric cyclonic circulation associated with STC formation. Figures 10, 12, and 15 reveal that the lower-tropospheric cyclonic circulation associated with STC formation develops in association with the upper-tropospheric disturbance and not due to the favorable interaction of the upper-tropospheric disturbance and preexisting lower-tropospheric cyclonic circulation.

Figures 13 – 16: Are these schematics of a short period centered on the subtropical cyclogenesis time, or in advance of genesis?

Figures 16–18 represent a short period of time centered on the time of STC formation (*t*0).

Figures 1b, 8 and 14: The trough providing the forcing in the region of genesis appears to be negatively tilted in the example (Fig. 1) and in the evolution of the southern tilt of the trough near t0 (Fig. 8), but is depicted as nearly neutral in the schematic (Fig. 14). Is there any uniform behavior in the tilt of the trough in this (MTRF) class?

An examination of the 18 STCs included in the meridional trough category reveals that the tilt of meridional troughs ranges from negative, slightly negative, neutral, to slightly positive- averaging out to a slightly negative tilt in the composite analysis. Since individual meridional troughs included in this study occasionally exhibit a slightly positive tilt, the schematic diagram was given more neutral characteristics than the composite to allow for this possibility.

Lines 465 – 470: The mean CI for the STD composite is described as maintaining near threshold

values (~20–22° C) over 5 days. Is this true by storm? How can the threshold be understood relative to a composite? While the genesis region may be favorable for convective initiation prior to the upper-level feature arriving, the irrotational winds are much weaker than for MTRF (which had the same mean CI and larger variance).

The subtropical disturbance category was removed from the present study due to its similarities with the zonal trough category, with the discussion referenced above removed as well. Individual CI values at the time of STC formation are given in Fig. 8. Composited CI values are shaded in the new Figs. 10 and 15 to facilitate the discussion of the role of reduced bulk tropospheric stability in STC formation in the cutoff low and zonal trough categories.

Discussion

Conclusions that a cold upper troposphere and weak thermal stability is favorable for subtropical cyclone development confirms Evans and Guishard (2009, p 2072).

Correct. Reference has now been made to Evans and Guishard (2009) on L498.

The contrast between the roles of cold upper troposphere and thermal stability in cyclogenesis in the tropics and subtropics is really interesting, yet is only mentioned in passing. The information provided on the four classes could be distilled to explore/elaborate on this. For example, is this cold upper tropospheric air and moderate vertical wind shear a signature for a TUTT?

The authors agree with the reviewer that this contrast is really interesting, and wanted to make sure that it was stated explicitly as a means of suggesting the topic of a subsequent study. The authors believe that cold upper-tropospheric air and moderate vertical wind shear could certainly be the signature of a TUTT, which is noted on L40–41 as another name for an upper-tropospheric disturbance forming in conjunction with AWB. A fellow graduate student at the University at Albany is currently investigating the environment surrounding upper-tropospheric disturbances associated with TC formation in the NATL basin, so a subsequent study concerning this topic may already be in the works.

**Graphics**

Figure 2: Color choice is problematic in distinguishing between the last three classes in this figure (ZTRF, STD, unclassified), but especially for STD versus unclassified. Suggest either changing the colors, or using a different symbol for unclassified systems.

Excellent comment. Colors have been modified in Figs. 4 to make them easier to distinguish.

Figure 4: Once again, it is problematic to distinguish between ZTRF, STD and unclassified. Perhaps use open circles for unclassified here? Additional (and very useful) information could be included in this figure if the color coding for storm class was maintained, but different symbols were used to represent strong, weak and trough induced TT (even just S, W and T). This combines the upper tropospheric classification, TT evolution and geographic distribution.

Excellent comment. Colors have been modified in Figs. 5–8 to make them easier to distinguish. Unclassifiable STCs are indicated using open circles, as the reviewer suggested. Attempts were made to include the McTaggart-Cowan et al. (2013) development pathway designation on Fig. 6 (see below). Unfortunately, the authors felt that these labels made the figure appear too cluttered in regions where STCs overlap (e.g., the western NATL), causing it to not be used. The same information can be gathered, albeit less conveniently, by comparing Fig. 6 in the present study to Fig. 9 in Bentley et al. (2016).

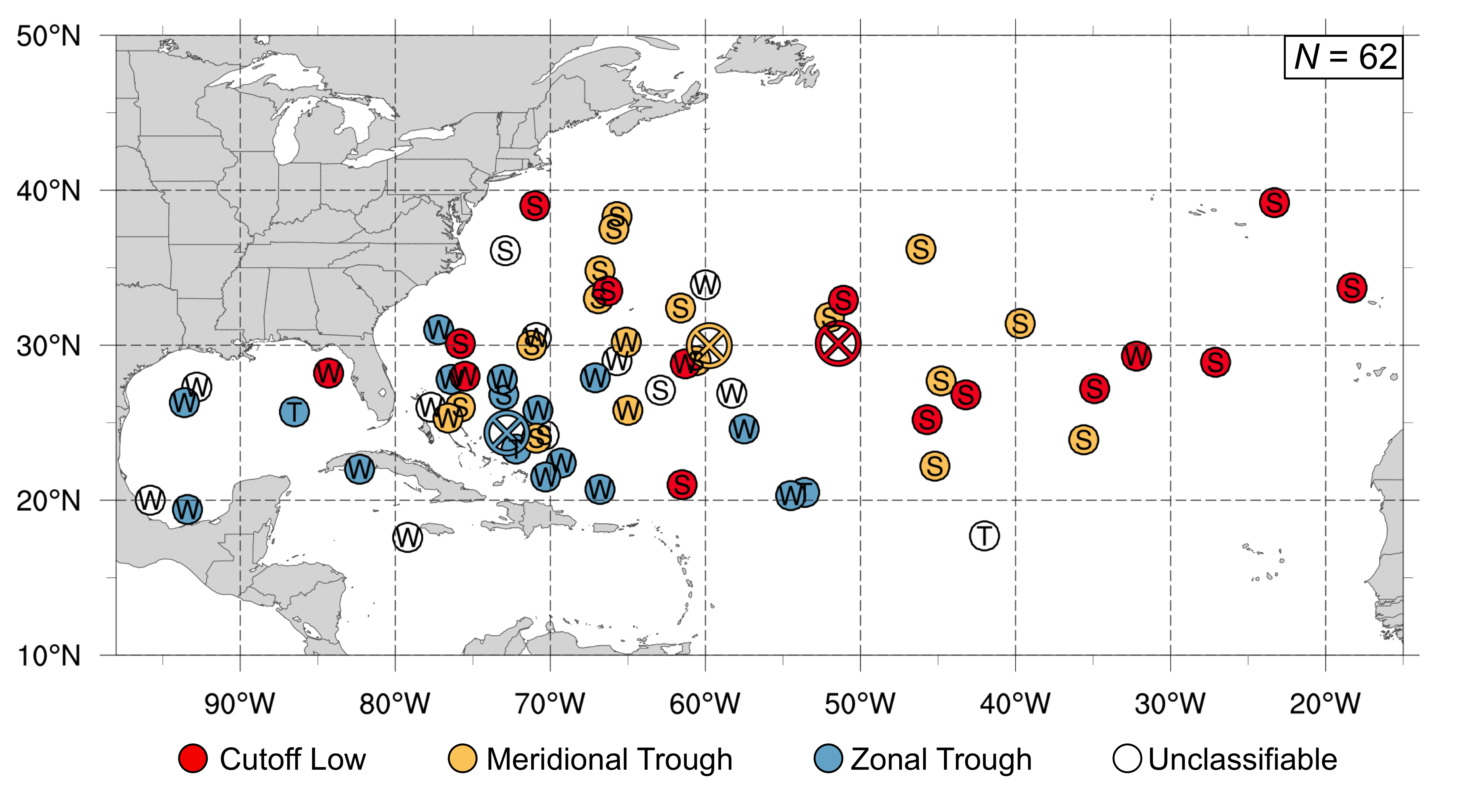


Figure 6: Since the 22.5°C CI threshold is used throughout, it is worth showing the reader how many storms in the 20-29.9 category are below the threshold.

The number of storms below the 22.5°C CI threshold is specifically stated on L328–330 for the coupling index category (i.e., all 15 STCs). Four STCs in the meridional trough category and 3 STCs in the zonal trough category exceed the 22.5°C CI threshold, with CI ranges given on L335 and L346.

**Editorial**

Lines 248 – 249: That the COL and MTRF classes form further northward has been documented (e.g. Figure 4), so the fact that they are typically associated with weak TT agrees with this result – it doesn't suggest it.

The reviewer’s point is well taken. However, Fig. 6 has not been introduced yet as of L270–274, so the results of the McTaggart-Cowan et al. (2013) classification still only suggest this result at this time.

Lines 262 – 263: Remove “to STCs forming in association with cutoff lows and meridional troughs” for clarity.

Good suggestion. L284 has been shortened to say “In contrast, …” in order to be more clear.