14A.6 SYNOPTIC CONDITIONS ASSOCIATED WITH IMPACTFUL TROPICAL EASTERLY WAVES

Margaret A. Hollis* and Elinor R. Martin
University of Oklahoma, Norman, Oklahoma

1. INTRODUCTION

Tropical easterly waves (TEWs) are a frequently occurring synoptic scale phenomena in the tropical atmosphere. TEWs occur in all basins, and are most active in the basin's respective summertime (Hollis et al. 2024a). TEWs are significant contributors to tropical rainfall seasonally (Berry et al. 2012; Dominguez et al. 2020) and annually (Hollis et al. 2024b), can cause extreme rainfall and flooding (e.g., Engel et al. 2017, Jury 2014), and sometimes serve as precursor disturbances for tropical cyclones (TCs; Chen et al. 2008; Schreck et al. 2011)

This study will examine characteristics of the environments surrounding impactful TEWs, especially those that develop into TCs. This work is done with the goal of furthering our understanding of which TEWs are most likely to develop into TCs or contribute to extreme rainfall, and provide possible physical mechanisms contributing to these processes.

2. DATA AND METHODS

This study utilizes a global database of TEW tracks, described in detail in Hollis et al. (2024a). TEWs in this database were independently tracked at 850 hPa and 700 hPa using curvature vorticity (CV) derived from MERRA-2 wind fields. Using a global database of TEW tracks provides a larger collection of null cases than operational TC formation outlooks, and enables the study of highly precipitating TEWs, but also excludes other types of TC precursor disturbances. TCs have been removed from the TEW tracks, with the tracks of pre-TC TEWs truncating at the final time step before the system is named.

Environmental fields in this study were obtained from MERRA-2 (Gelaro et al. 2017). The near-TEW environment is defined as the box extending 1000 km in each cardinal direction from the TEW track point. Composite average fields are then calculated, with TEWs separated based on impact and basin.

Near-TEW precipitation is derived from the IMERG v6b final run product (Huffman et al. 2019). Unlike the environmental fields, TEW-associated precipitation is defined as precipitation within a 500 km radius of the TEW center. Two definitions of highly precipitating TEWs are used. In the first definition, used in conjunction with the evolution of CV over the wave's life, lifetime precipitation normalized by the wave's lifespan is calculated to define TEWs that produce large amounts of precipitation over the entire life of the system. The rainiest TEWs are those whose normalized lifetime precipitation exceeds the 90th percentile. The second definition, used for environmental composites, identifies individual times with the most area-accumulated precipitation. This second definition uses the 95th percentile to define the rainiest TEWs.

Determination of rainy and pre-TC TEWs is applied independently. Therefore, a wave track in the first definition may meet the rainy threshold and be a pre-TC track. In the section definition, a pre-TC track may contain anomalously rainy times. All analysis is performed independently for TEWs at 850 and 700 hPa, but for brevity only results from 850 hPa are presented here.

3. TIME EVOLUTION OF CURVATURE VORTICITY AT TEW CENTERS

Different categories of TEW exhibit different time evolution of the CV at their center points, as shown in Fig. 1. Differences in evolution of CV at the center of the TEW gives a first-order indication of differences in physical processes occurring around different types of TEWs. Notable differences exist between impactful TEWs and the general population, with impactful TEWs having higher CV through all portions of their life. Rainy and pre-TC TEWs both tend to see increasing CV through the early portions of their lives. Fig. 1 also suggests a substantial overlap between rainy and pre-TC TEWs.

Of the 711 TEW tracks that constitute the rainiest 10% of normalized track-accumulated precipitation, 291 TEWs, or approximately 40% of the rainy TEWs, are also pre-TC TEWs. When

* Corresponding author address: Margaret A Hollis, School of Meteorology, University of Oklahoma, Norman, OK 73072; Email: margaret.a.hollis-1@ou.edu

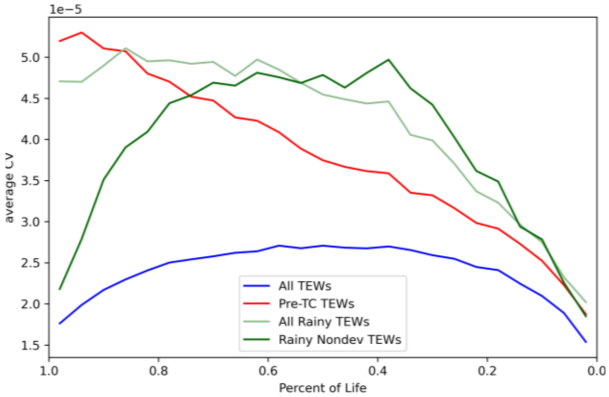

Figure 1*: Mean evolution of CV as a function of percent of TEW life elapsed. Note that the axis should be read from right to left.*

looking only at non-developing rainy TEWs, we see a decrease in CV later in the wave's life, in line with the average non-developing TEW.

4. NEAR TEW COMPOSITE ENVIRONMENTS

While Fig. 1 suggests that many pre-TC TEWs are also highly precipitating, Fig. 2, showing the composite precipitation around pre-TC TEWs, all highly precipitating TEWs, and TEWs which do not fit either category, further demonstrates the highly precipitating nature of pre-TC TEWs. Pre-TC TEWs on average have a much broader and more intense precipitation field than even other highly precipitating times along TEW tracks. However, when using 700 hPa TEW tracks (not shown), highly precipitating times have a field more comparable to pre-TC TEWs.

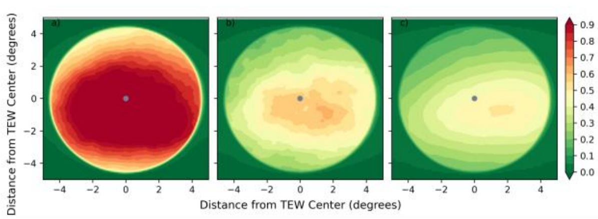

Figure 2*: Composite mean precipitation in the 500 km radius around a) pre-TC TEWs b) rainy TEW times exceeding the 95th percentile and c) non-developing TEWs at non-rainy times.*

The three composite categories shown in Fig. 2 have different centerings to the precipitation field. Pre-TC TEWs have a precipitation field approximately centered on the wave's CV center, while non-rainy non-developing waves on average have the maximum precipitation lagging up to 2° behind the TEW center. Highly precipitating waves, however, are more centered, but still show some lag in precipitation. This suggests environmental differences in the environment, particularly the zonal wind in the vicinity of the system or the shear environment it exists in.

In regional composites of 850 hPa TEWs (not shown), pre-TC precipitation is also zonally centered on the CV center. For highly precipitating TEWs, however, there is some variation in whether the precipitation leads or lags the CV center. In the North Atlantic, precipitation around rainy TEWs lags behind the CV center, while in the North Pacific, precipitation associated with rainy TEWs is more zonally centered on the CV center.

The mid-level vertical velocity in the vicinity of the low-level TEW centers is shown in Fig. 3. Even in global averages, there is a marked difference between all times in pre-TC tracks when compared to either individually rainy times or times that meet neither impactful definition. Somewhat predictably, pre-TC TEWs have greater vertical ascent over a broader area. Despite the fact that their CV evolution is more similar to pre-TC TEWs, rainy TEWs do not exhibit the same degree of

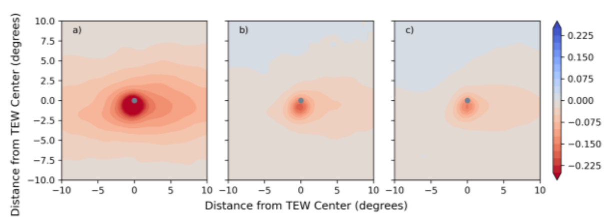

Figure 3*: Composite mean 500 hPa vertical velocity in the 2000 km sided box around a) pre-TC TEWs b) rainy TEW times exceeding the 95th percentile and c) non-developing TEWs at non-rainy times.*

enhancement of mid-level vertical velocity, though the vertical velocity near the TEW center is marginally stronger than it is near non-impactful TEWs.

Similar to the precipitation fields, the vertical ascent field around pre-TC TEWs is the most longitudinally centered of the three categories, while the fields around rainy and non-impactful TEWs have an extended area east of the TEW center, or approximately downshear. Rainy TEWs, however, do show some increased vertical velocity ahead of the CV center. This is especially evident in some regional composites (not shown), such as for the North Indian and North Pacific Oceans.

5. PLANNED WORK

Further planned work on this topic will extend the environmental composites to additional variables. Given that the precipitation and vertical velocity fields surrounding rainy and non-impactful TEWs suggest a difference in vertical wind profiles, we plan to examine both TEW-level zonal wind and vertical wind shear in the atmospheric column. Given the importance of low wind shear for TC formation, and the suggestion of wind shear in Figs. 2 and 3, we believe that there may be some differences in these fields.

While TEWs must necessarily demonstrate increasing CV when evolving from a wave into a TC, the role of vorticity as a predictive variable is disputed (e.g., Halperin et al. 2017). As shown in Fig. 1, CV alone is not sufficient for the development of a TEW into a TC. Therefore, in addition to comparing the wind and shear surrounding TEWs, we also plan to study the CV at the opposite level to the tracking (700 hPa CV around 850 hPa tracks, 850 hPa CV around 700 hPa tracks). This will approximately demonstrate the vertical depth of the features.

We hypothesize that stronger column CV and weaker vertical wind shear are discriminating factors in the environments around TEWs. In addition to weak wind shear being necessary for TC formation, weak vertical shear around rainy TEWs relative to non-impactful TEWs would provide a possible explanation for the more zonally symmetric rain field seen around rainy TEWs.

6. CONCLUSIONS

Impactful TEWs, defined as those that develop into TCs and those that produce excessive amounts of precipitation, show a markedly different evolution of CV near their centers, with both rainy and pre-TC TEWs typically attaining much higher CV than non-impactful TEWs. Averages of CV by percent of life elapsed suggest that rainy TEWs have higher CV than even pre-TC TEWs in the first two thirds of the wave's life, but statistical testing is needed to confirm this.

Pre-TC TEWs are also frequently highly precipitating, as demonstrated by the fact that they account for approximately 40% of highly precipitating tracks and their composite precipitation fields exceeding 1 mm hr^{-1} across much of the area in the 500 km radius. While the overlap in impactful categories can complicate analysis, it also underscores the importance of identifying both types of impactful TEW.

The composites of mid-level vertical velocity near TEWs show that pre-TC TEWs have the strongest and largest areas of mid-level vertical ascent.

References

Berry, G. J., M. J. Reeder, and C. Jakob, 2012: Coherent Synoptic Disturbances in the Australian Monsoon. *J. Climate*, **25**, 8409–8421, https://doi.org/10.1175/JCLI-D-12-00143.1.

Chen, T.-C., S.-Y. Wang, and A. J. Clark, 2008: North Atlantic Hurricanes Contributed by African Easterly Waves North and South of the African Easterly Jet. *J. Climate*, **21**, 6767–6776, https://doi.org/10.1175/2008JCLI2523.1.

Dominguez, C., J. M. Done, and C. L. Bruyère, 2020: Easterly wave contributions to seasonal rainfall over the tropical Americas in observations and a regional climate model. *Climate Dyn.*, **54**, 191–209, https://doi.org/10.1007/s00382-019-04996-7.

Engel, T., A. H. Fink, P. Knippertz, G. Pante, and J. Bliefernicht, 2017: Extreme Precipitation in the West African Cities of Dakar and Ouagadougou: Atmospheric Dynamics and Implications for Flood Risk Assessments. *J. Hydrometeor.*, **18**, 2937–2957, https://doi.org/10.1175/JHM-D-16-0218.1.

Gelaro, R., and Coauthors, 2017: The Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2). *J. Climate*, **30**, 5419–5454, https://doi.org/10.1175/JCLI-D-16-0758.1.

Halperin, D. J., R. E. Hart, H. E. Fuelberg, and J. H. Cossuth, 2017: The Development and Evaluation of a Statistical–Dynamical Tropical Cyclone Genesis Guidance Tool. *Wea. Forecasting*, **32**, 27–46, https://doi.org/10.1175/WAF-D-16-0072.1.

Hollis, M. A., R. R. McCrary, J. P. Stachnik, C. Lewis-Merritt, and E. R. Martin, 2024: A global climatology of tropical easterly waves. *Climate Dyn.*, **62**, 2317–2332, https://doi.org/10.1007/s00382-023-07025-w.

Hollis, M. A., J. P. Stachnik, C. Lewis-Merritt, R. R. McCrary, and E. R. Martin, 2024: Precipitation Characteristics of Easterly Waves Across the Global Tropics. *J. Geophys. Res.: Atmos.*, **129**, e2023JD039957, https://doi.org/10.1029/2023JD039957.

Huffman, G. J., Stocker, E. F., Bolvin, D. T., Nelkin, E. J., & Tan, J. (2019). GPM IMERG final precipitation L3 half hourly 0.1 degree × 0.1 degree V06, Goddard Earth Sciences Data and Information Services Center (GES DISC), Greenbelt, MD.

Jury, M. R., 2014: Weather–Climate Interactions in the Eastern Antilles and the 2013 Christmas Storm. *Earth Interact.*, **18**, 1–20, https://doi.org/10.1175/EI-D-14-0011.1.

Schreck, C. J., J. Molinari, and K. I. Mohr, 2011: Attributing Tropical Cyclogenesis to Equatorial Waves in the Western North Pacific. *J. Atmos. Sci.*, **68**, 195–209, https://doi.org/10.1175/2010JAS3396.1.