13C.3A LARGE-SCALE MOISTURE AND THERMODYNAMIC PROPERTIES ASSOCIATED WITH RAPID WEAKENING IN THE EASTERN NORTH PACIFIC

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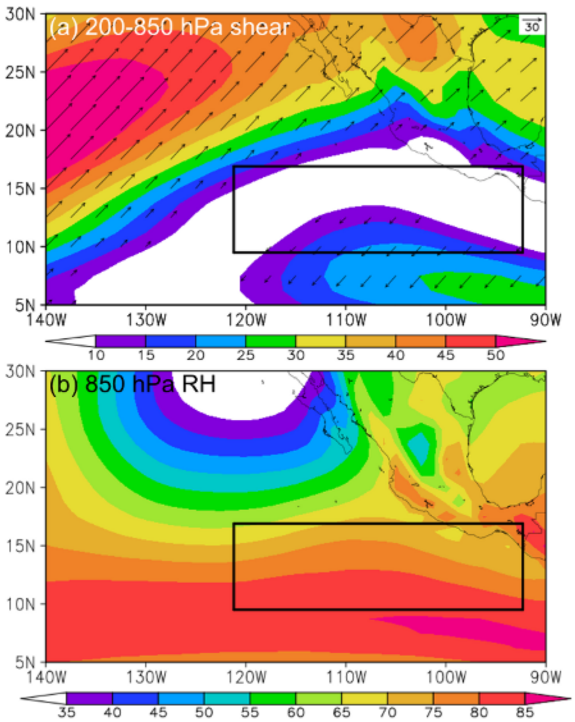
1. INTRODUCTION

The eastern North Pacific (ENP) has the highest density of tropical cyclogenesis of any basin in the world (Molinari et al. 2000). The boxed region in Fig. 1 delineates the area in which 75% of tropical cyclones (TCs) formed from 1981 to 2010. This area is characterized by low vertical wind shear, high low-level relative humidity, atmospheric instability, warm sea surface temperatures (SSTs), and enough distance from the equator to supply sufficient Coriolis force for cyclogenesis (e.g., Gray 1968).

Though many TCs develop near land, the dominant track of ENP TCs is largely westward, and thus away from the coast, due to the influence of the subtropical ridge on the environmental flow in the basin. Once TCs move out of the main genesis region, atmospheric conditions hostile to TC development tend to occur in the form of increasing shear as well as decreasing moisture, convective available potential energy (CAPE), and SSTs (e.g., Fig. 1). The combination of hostile conditions and flow that steers TCs over open ocean limits the number of TCs that make landfall or affect land while the TC center remains over water.



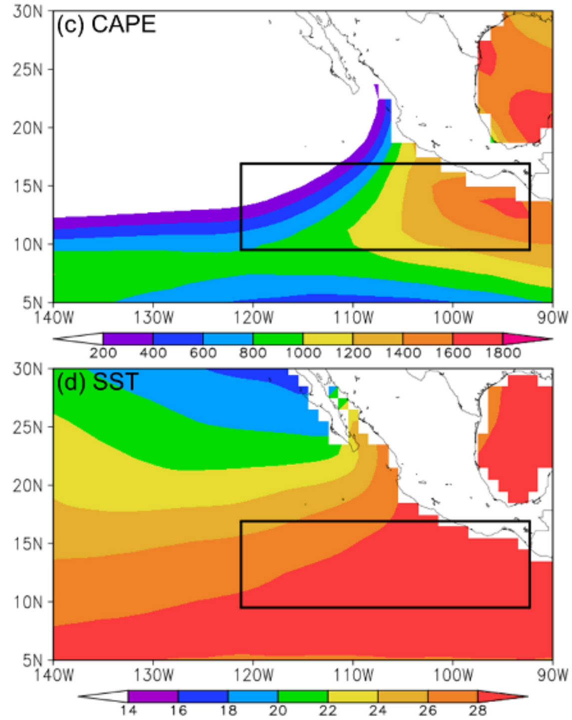


Figure 1. Average July-October 1981-2010 fields from (a)-(c) JRA-55 and (d) COBE SST. The box indicates the region in which 75% of TCs formed from 1981 to 2010.

One feature of many TCs that enter these hostile conditions is rapid weakening (RW), here defined as a decrease in maximum sustained winds of at least 30 kt in 24 hours. Like rapid intensification, rapid weakening can affect intensity forecast errors. It is notable that track forecast errors have greatly improved in the past twenty years, yet intensity forecast improvements have not kept pace (e.g., DeMaria et al. 2014).

An extreme example of RW occurred in the case of Hurricane Jimena (1997), which had an intensity of 115 kt (minimal category 4) at 1200 UTC 28 August yet weakened to 35 kt, or a minimal tropical storm, by 1200 UTC 29 August. This occurred despite the TC never making landfall or even moving near land. Less extreme versions of RW are common in the ENP, and this merits investigation.

This study explores the environmental conditions associated with RW events in the ENP in order to quantify the variables that most strongly affect RW frequency and compare them with extratropical transition (ET) behavior. Observations of these fields available in real time will aid forecasters, particularly when ENP TCs threaten coastal regions.

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2. DATA & METHODS

The National Hurricane Center (NHC) best track (HURDAT2) is used to find all instances of weakening of at least 30 kt in 24 h over the period 1979-2012. Only those RW periods during which the TC center was at least 500 km from land are considered in order to remove potential land effects on the TC's intensity. This resulted in a database of 171 TCs (33% of all cases) (Fig. 2). The North Atlantic (NATL) HURDAT2 is also examined for comparison. A total of 46 TCs (11% of all cases) underwent at least one RW period during 1979-2012 (not shown).

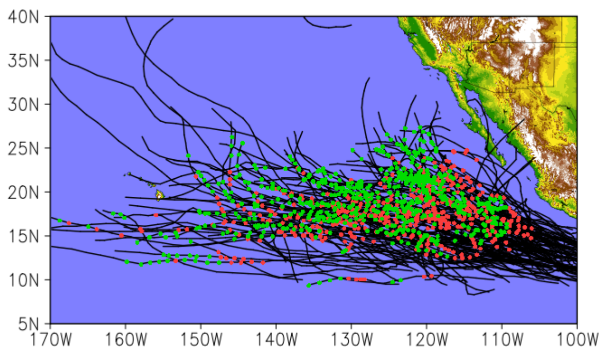

Figure 2. Tracks of 171 TCs that went through at least one RW period while at least 500 km away from the coast. Red dots indicate the TC location at the onset of RW and green the TC location at the end of RW.

The Japanese 55-year Reanalysis (JRA-55; Ebita et al. 2011), the Climate Forecast System Reanalysis (CFSR; Saha et al. 2010), and the NOAA optimum interpolation (OI) SST product are used to investigate environmental conditions associated with RW in both basins. Fields centered on the TC, including relative humidity (RH), CAPE, and SST, are extracted and composited to find dominant patterns and explore the differences in the environment between the onset and end of RW in the ENP.

3. RESULTS

Over the 34-yr period, 615 RW events are observed in the ENP and 113 in the NATL. When breaking them down by monthly percentages, the bulk of the ENP events are found during July-September with a peak in July, while the NATL events are skewed to later in the season with a distinct peak in September (Fig. 3a).

Since a single TC can experience multiple 24-hour periods that qualify as RW, Fig. 3b shows the monthly distribution of RW TCs compared to all TCs that underwent genesis during that month. The ENP again exhibits a number of RW events in July-September, while the NATL is largely restricted to the latter half of the hurricane season.

The mid-season peak of RW in the ENP is largely related to the frequency of hurricane-strength TCs during this time. As the peak intensity of the TC increases, the likelihood of that TC experiencing at least one RW period also increases. In the case of category 5

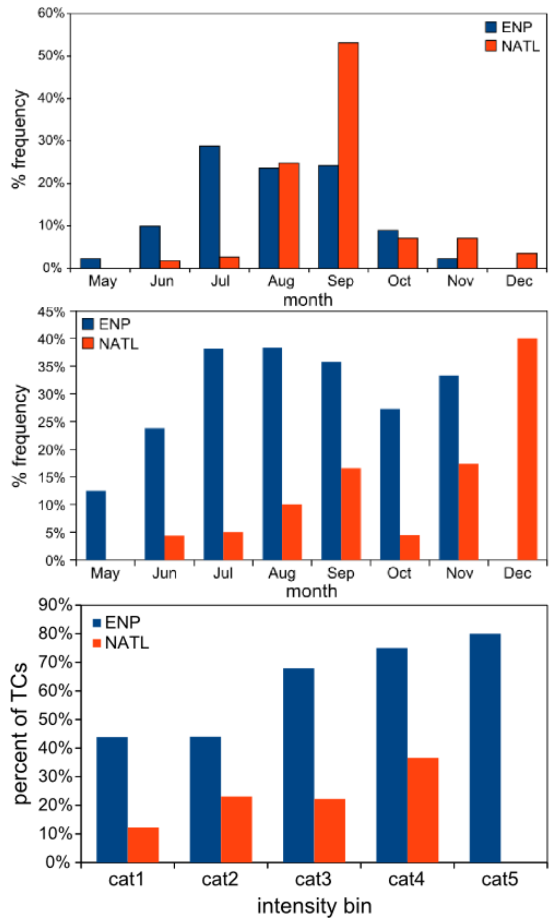

Figure 3. (top) Distribution of individual RW periods in the ENP and NATL. (middle) Seasonal distribution of TCs with at least one RW period. (bottom) Breakdown of RW events by category of peak intensity.

TCs (peak intensity > 137 kt), 80% (8 of 10 cases) underwent at least one RW period. This relationship is similar in the NATL, albeit with lower relative frequencies, though no TC that peaked at category 5 intensity had a RW event. After RW, the majority of TCs had a tendency to continue weakening until dissipation.

As RW events seem to be related to more intense TCs in the ENP, and warmer SSTs have been correlated with more intense TCs (e.g., Emanuel 1988; DeMaria and Kaplan 1994), NINO3 and NINO3.4 region anomalies are compared with RW frequency. Anomalies for the July-August-September period in both NINO

	NINO3	**NINO3.4**
MJJ	0.07	0.18
JJA	0.22	0.22
JAS	**0.55**	**0.59**
ASO	**0.48**	0.46
SON	**0.37**	0.41
OND	0.07	0.04

Table 1. Correlation coefficients between 3-month average NINO3 and NINO3.4 anomalies and RW frequency. Bold values are statistically significant at the 95% level.

regions are positively correlated with RW events and statistically significant at the 95% level, while August-September-October and September-October-November anomalies in the NINO3 region are also positively correlated and statistically significant at the 95% level (Table 1). This supports a relationship between SST anomalies related to the El Niño-Southern Oscillation and RW events that may be due to increased frequency of stronger TCs during El Niño events and suppressed frequency during La Niña events.

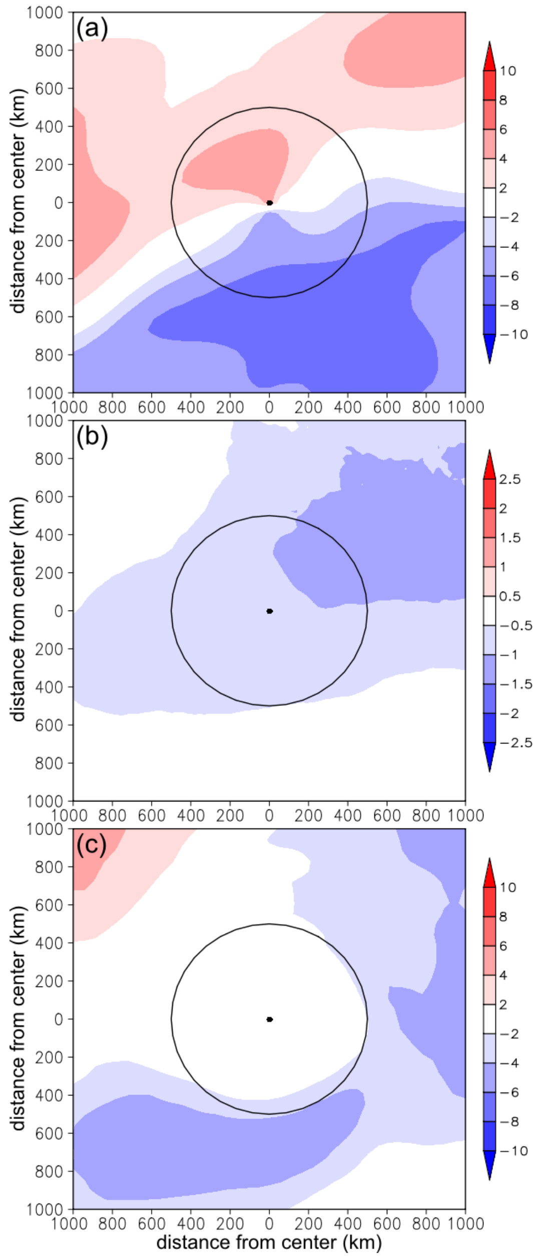

Figure 4. Average difference fields between 0 h and 24 h for (a) 200-850 hPa wind shear (kt), (b) SST (°C), and (c) 850 hPa RH (%).

In order to evaluate the contributions of various fields to the RW process, the composite differences between the TC-centered fields at 0 h and 24 h are calculated. The differences in vertical wind shear, SSTs, and 850 hPa RH are slight (Fig. 4), particularly for 850 hPa RH within a radius of 500 km from the TC center.

Figure 5 shows the fields with greater differences, CAPE and 400-700 hPa RH. The amount of CAPE decreases significantly within the composite TC from 0 to 24 h (Fig. 5a). The composite RH differences (Fig. 5b) show that, during the process of RW, equatorward-moving drier air is being entrained into the TC circulation. Though the RH differences are not co-located with the CAPE differences, the decreases in both of

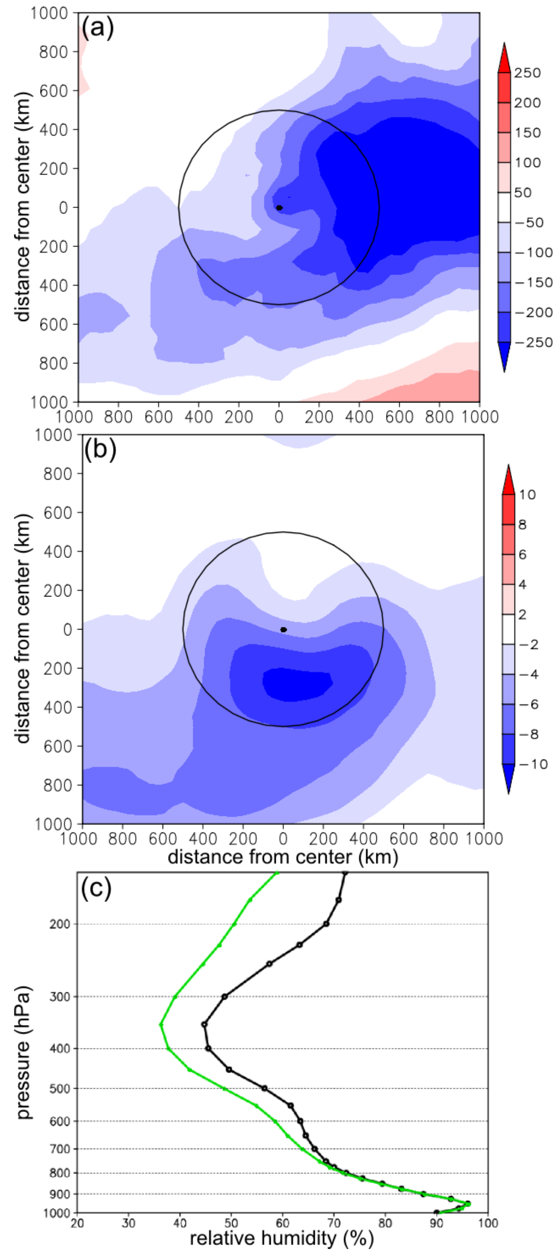

Figure 5. Average difference fields between 0 h and 24 h for (a) CAPE (J kg^{-1}) and (b) 400-700 hPa RH. (c) Average profiles of RH at 0 h (black) and 24 h (green) averaged from 0-500 km from the center of the TC.

these quantities may be related, and they signify an overall increasingly hostile TC environment.

Composite profiles of RH at 0 h and 24 h (Fig. 5c) reveal little change in atmospheric moisture in the lower levels of the troposphere but sizable changes in the middle and upper levels. As these composites are calculated from 615 samples, RW in the ENP appears to be dominated by decreasing CAPE and mid-level humidity and less so by decreasing SSTs and increasing vertical wind shear.

These features are also observed in composite differences of 24 hour periods in which TC intensity decreased by 5 or 10 kt as opposed to the RW criterion of 30 kt, though the magnitude of these differences is much less. For example, the main region of decreasing 400-700 hPa RH is in the southern half of the TC, peaking around 4% less at 24 h compared with 0 h (Fig. 6). The difference for RW cases peaked at 10% in the same region of the storm (Fig. 5b). The dryness of the mid-level air being entrained into the TC circulation does appear to affect the magnitude of the subsequent weakening.

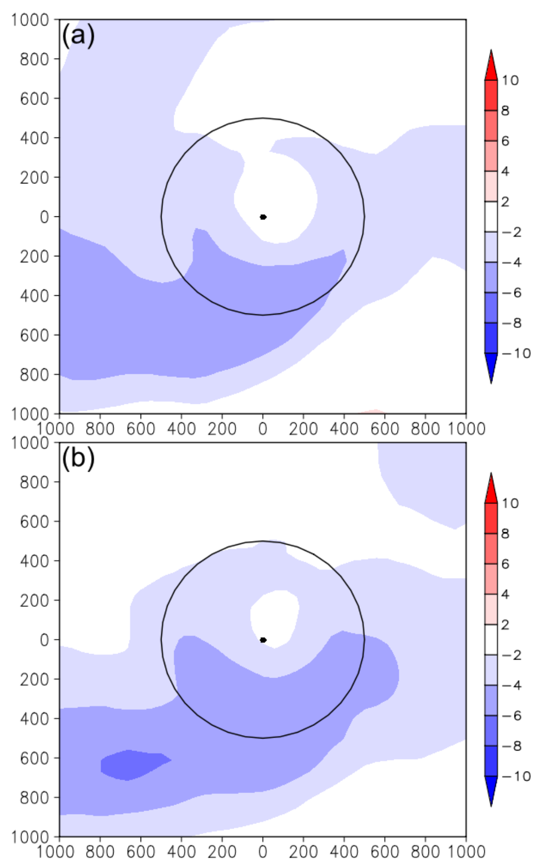

Figure 6. Composite differences of 400-700 hPa RH between 0 h and 24 h for (a) 5 kt weakening and (b) 10 kt weakening.

4. RELATIONSHIP BETWEEN RW AND ET

The frequency of ET in the ENP is much reduced compared with other basins, but the process has been observed for 55 TCs (~9% of cases) in a 42-yr period (Wood and Ritchie 2014). The hostile environmental conditions discussed in section 3, in combination with the subtropical ridge that steers TCs into the region less conducive for TC development, generally inhibits ET in the ENP. Wood and Ritchie (2014) used cyclone phase space (CPS; Hart 2003) to define ET, and Fig. 7 gives a comparison of CPS for those TCs that underwent at least one RW period to those that did not for 1979-2012.

These CPS frequency diagrams imply that RW TCs that undergo ET (where ET is defined by the TC entering the upper-left quadrant) tend to exhibit a weaker ET signature as defined by CPS. In addition, fewer RW TCs maintain their warm core while becoming asymmetric (e.g., lower CPS frequencies are observed in the upper-right quadrant). Those RW TCs that do complete ET tend to experience a slowdown or even cessation of the weakening process after the initial RW period ends. For example, Hurricane Guillermo (1997) moved over warmer SSTs after weakening to a tropical depression and managed to re-intensify around 30°N and 148°W before undergoing ET.

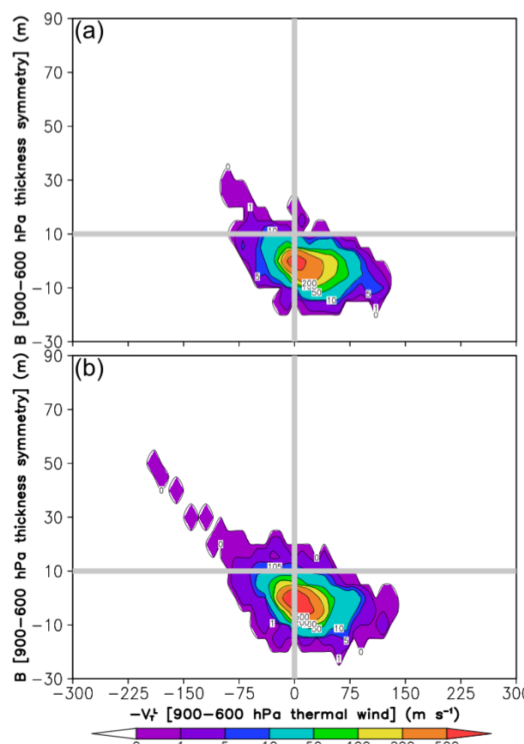

Figure 7. Cyclone phase space frequency from the JRA-55 for (a) all TCs that experience at least one RW period and (b) all other TCs during 1979-2012.

Though the average strength of ET differs as defined by CPS, there is not a significant difference between the frequency of ET for RW TCs and non-RW TCs. For RW cases, 8.2% (14 of 171 TCs) complete ET during 1979-2012, while 9.0% of non-RW cases (45 of 344 TCs) complete ET. This is likely related to the fact that most ENP TCs that undergo ET tend to be at tropical depression or tropical storm intensity at the onset of ET regardless of their earlier peak intensity or the rate at which they weakened to that lower intensity.

5. DISCUSSION & SUMMARY

The process of rapid weakening is frequently observed in the ENP, with nearly 33% of TCs that existed from 1979 to 2012 experiencing at least one RW period in their lifetime. In contrast, only 11% of NATL TCs experienced a period of RW. The most intense TCs experience the highest proportion of RW events (Fig. 3), which implies two things: 1) a more intense TC has a greater chance of experiencing RW; and 2) once a mature ENP TC leaves the conducive genesis environment, it is difficult for the storm to maintain its structure in the hostile ENP environment northwest of the main genesis region.

Increasing vertical wind shear, decreasing SSTs, and decreasing humidity are each associated with weakening in TCs, and the composite environment associated with RW events generally exhibit all of these characteristics. The strongest influence appeared to be from decreasing 400-700 hPa relative humidity, showing that dry air entrainment in the mid-troposphere is likely a significant factor in TC rapid intensity decreases.

These conditions hostile to TC development generally exist north and northwest of the main development region in the ENP, which contributes to the relative infrequency of land impacts from ENP TCs despite the proximity of the genesis region to the coastline. The other main factor is the steering flow caused by the subtropical ridge, which exerts a dominantly westward component to ENP TC tracks. This combination also limits the frequency of ET in this basin (Wood and Ritchie 2014). The completion of ET is only slightly less frequent for the subset of TCs that experience RW than for the subset that do not.

Future work involves further quantification of the relative contribution of these factors to RW in the ENP. As this study focused on reanalysis data sources, the next step involves the exploration of currently available satellite observations to identify regions where one or more of these negative conditions exist in order to aid future real time forecasts.

6. REFERENCES

DeMaria, M., and J. Kaplan, 1994: Sea surface temperature and the maximum intensity of Atlantic tropical Cyclones. *J. Climate*, **7**, 1324–1334.

Ebita, A., and Coauthors, 2011: The Japanese 55-year Reanalysis “JRA-55”: An interim report. *SOLA*, **7**, 149-152.

Emanuel, K. A., 1988: The maximum intensity of hurricanes. *J. Atmos. Sci.*, **45**, 1143-1155.

Gray, W. M., 1968: Global view of the origin of tropical disturbances and storms. *Mon. Wea. Rev.*, **96**, 669-700.

Hart, R.E., 2003: A cyclone phase space derived from thermal wind and thermal asymmetry. *Mon. Wea. Rev.*, **131**, 585-616.

Molinari, J., D. Vollaro, S. Skubis, and M. Dickinson, 2000: Origins and mechanisms of eastern Pacific tropical cyclogenesis: A case study. *Mon. Wea. Rev.*, **128**, 125-139.

Saha, S., and Coauthors, 2010: The NCEP Climate Forecast System Reanalysis. *Bull. Amer. Meteor. Soc.*, **91**, 1015–1057.

Wood, K. M., and E. A. Ritchie, 2014: A 40-year climatology of extratropical transition in the eastern North Pacific. *Revised for J. Climate.*