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A 40-YEAR CLIMATOLOGY OF EXTRATROPICAL TRANSITION IN THE EASTERN NORTH PACIFIC

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1. INTRODUCTION

The extratropical transition (ET) of tropical cyclones (TCs) is a common process in many of the ocean basins around the world in which TCs occur, including the western North Pacific, the North Atlantic, and the western South Pacific. TCs that transition into extratropical cyclones can re-intensify post-ET and carry damaging winds and heavy precipitation to regions which are rarely impacted by TCs (e.g. Jones et al. 2003). The timing of ET, as well as the strength of the post-ET cyclone, has been historically difficult to forecast.

ET refers to the transition of a symmetric, warm-cored tropical cyclone into an asymmetric, cold-cored extratropical cyclone. This process often occurs as a poleward-moving TC recurves due to the increasing influence of the mid-latitude westerlies, in many cases steered by a mid-latitude trough. As the TC moves poleward, it begins to entrain equatorward-moving dry air into its circulation, eroding deep convection on one side of the storm. The other side of the storm entrains moist, poleward-moving air, allowing that side to maintain convection. Further asymmetry is produced by the increased motion of the storm once it enters the mid-latitude westerlies, which also leads to higher winds on one side of the cyclone. The combination of high winds and rapid motion can lead to hazardous ocean conditions. A mid-latitude trough or mature extratropical cyclone is not necessary to trigger the ET of a TC, but the presence of such a system can enhance its impacts.

In the eastern North Pacific, some TCs will recurve upon interacting with a mid-latitude low pressure system. This interaction often results in these systems entering Mexico and the southwestern United States, bringing associated rainfall (Ritchie et al. 2011). Severe impacts can result from these TCs making landfall along the Mexican or, rarely, the Californian coastlines, resulting in loss of life and millions of dollars in damage (e.g., Blake and Pasch 2010).

Nevertheless, documented cases of ET in the eastern North Pacific have been rare. Jones et al. (2003) noted that the presence of a strong subtropical ridge in this basin precludes ET from occurring. However, Dickinson et al. (2004) explored the ET of Hurricane Lester in 1992 as it moved over land and entered the southwestern United States while still at tropical storm strength. Additionally, Wood and Ritchie (2012) analyzed the ET of Tropical Storm Ignacio in 1997 which contributed to measurable precipitation to the southwestern United States as a tropical storm and brought rainfall to the northwestern United States after completing ET.

This raises the question: how often does ET truly occur in this basin? Potential ingredients for ET include increasing vertical wind shear, decreasing SSTs and sharp SST gradients, and meridional moisture gradients. As these conditions are often present in the eastern North Pacific basin, ET has likely occurred more often than the two documented cases previously mentioned.

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In order to evaluate and quantify the frequency of ET in this basin, this study examines every TC tracked by the National Hurricane Center (NHC) over the 42-y period from 1970 to 2011. Cases of ET are identified using cyclone phase space (CPS), and a climatology of ET in the eastern North Pacific is presented. We discuss the data and methodology used in this study in section 2, cover the climatology of ET in the eastern North Pacific in section 3, compare eastern North Pacific ET to ET in other basins in section 4, and present a summary and conclusions in section 5.

2. DATA AND METHODS

Maximum wind speed and center location every six hours for each eastern North Pacific TC over the 1970-2011 period were extracted from the NHC best track data set. Analysis was restricted to these years in order to only examine those TCs that occurred during the satellite era, resulting in a database of 632 named storms. NHC best track data were also used to examine North Atlantic TCs from 2001-2011, and Joint Typhoon Warning Center (JTWC) best track data were used to examine western North Pacific TCs from 2001-2010.

Atmospheric fields were obtained from the global 6-hourly, T255-(nominally 0.7-degree) resolution European Center for Medium-Range Weather Forecasts (ECMWF) interim reanalysis (ERA-Interim) for 1979-2011 and the global 6-hourly, T85-(nominally 1.4-degree) resolution ERA-40 reanalysis for 1970-1978. Both are hosted by the Research Data Archive (RDA), which is maintained by the Computational and Information Systems Laboratory (CISL) at the National Center for Atmospheric Research (NCAR) at http://dss.ucar.edu.

Final Operational Global Analysis (FNL) data from the Global Forecast System (GFS) used by the National Centers for Environmental Prediction (NCEP) were examined to in order to compare the ERA-Interim CPS results over the period 2001-2011. These data were also obtained from the RDA hosted by NCAR.

Each storm in the HURDAT database over the 1970-2011 period was analyzed using the CPS method described in Hart (2003). CPS examines the thermal symmetry of a TC as well as the structure of the thermal wind within the storm and can be used to characterize the structure of any type of cyclone. This measure of thermal symmetry, called the B parameter, can be obtained by computing the difference in 900-600 hPa geopotential thickness between the right and left sides of the storm relative to the TC's direction of motion. Thermal wind is also calculated from geopotential height fields in two different but equivalent mass layers, 900-600 hPa and 600-300 hPa. Phase space can thus be constructed by comparing these parameters. Grid Analysis and Display System (GrADS) scripts provided by Dr. Hart on his web site (http://moe.met.fsu.edu/~rhart/phasescripts/) were utilized to facilitate processing.

In order to confirm whether or not a TC had fully transitioned from one phase to another, a transition zone was established between each quadrant. This was done in response to a number of TCs becoming only very weakly cold core or very weakly asymmetric near the end of their lifetimes and thus skewing the results of statistics computed for individual quadrants. As a result, TCs with final B values between 9 and 11 m and final upper level thermal wind values of -1 to 1 m/s were not included in the analysis discussed below.

Exploration of both the ERA-Interim and the FNL data sets revealed discrepancies in the evaluation of the thermal wind in the 900-600 hPa layer between the two data sets. Conversely, the 600-300 hPa thermal wind values calculated from the two data sets were quite similar. Further investigation revealed that the difference in the treatment of the boundary layer between the two data sets was largely responsible for these discrepancies. As a result, the phase space represented by the 900-600 hPa thickness symmetry and the 600-300 hPa thermal wind will be discussed in this presentation. This change from the methodology presented in Hart (2003) advanced the ET time, the point at which a cyclone entered the asymmetric cold core quadrant of the phase space, by about 6 hours in the eastern North Pacific and by up to 1 day in the North Atlantic.

3. CLIMATOLOGY

Most eastern North Pacific TCs track northwestward or westward under the influence of flow around the subtropical ridge, which is in place for much of the hurricane season (Figure 1). This track brings them over rapidly cooling sea surface temperatures (SSTs), which leads to weakening and eventual dissipation.

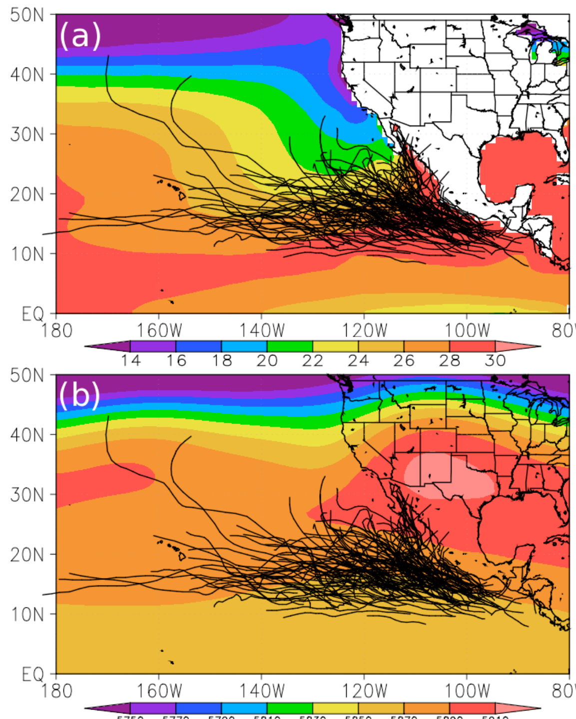

Figure 1. All tracks from 2001 to 2011 superimposed on (a) average 2001-2011 Jul-Sep SSTs (°C) from the 1-degree National Oceanic and Atmospheric Administration (NOAA) optimum interpolation monthly mean data set and (b) average 2001-2011 Jul-Sep 500 hPa geopotential height (m) from the ERA-Interim reanalysis.

However, some TCs move far enough northward to enter the mid-latitude westerlies due to weaknesses that occur in the subtropical ridge either from a trough passing far to the north of the TC or the TC itself becoming strong enough to move along the planetary vorticity gradient. Other TCs directly interact with troughs that have begun to dig farther southward later in the hurricane season, generally in the months of September and October (e.g. Ritchie et al. 2011). In order to quantify how often ET does occur in the eastern North Pacific, every TC tracked by the NHC was analyzed using the two ERA data sets and cyclone phase space.

The resulting frequency of all 632 TCs in the phase space of upper-level (600-300 hPa) thermal wind compared with lower-level (600-900 hPa) geopotential thickness symmetry is given by Figure 2a. This figure shows that eastern North Pacific TCs tend to remain symmetric throughout their lifetimes, but there is a split between the cold core and warm core phases.

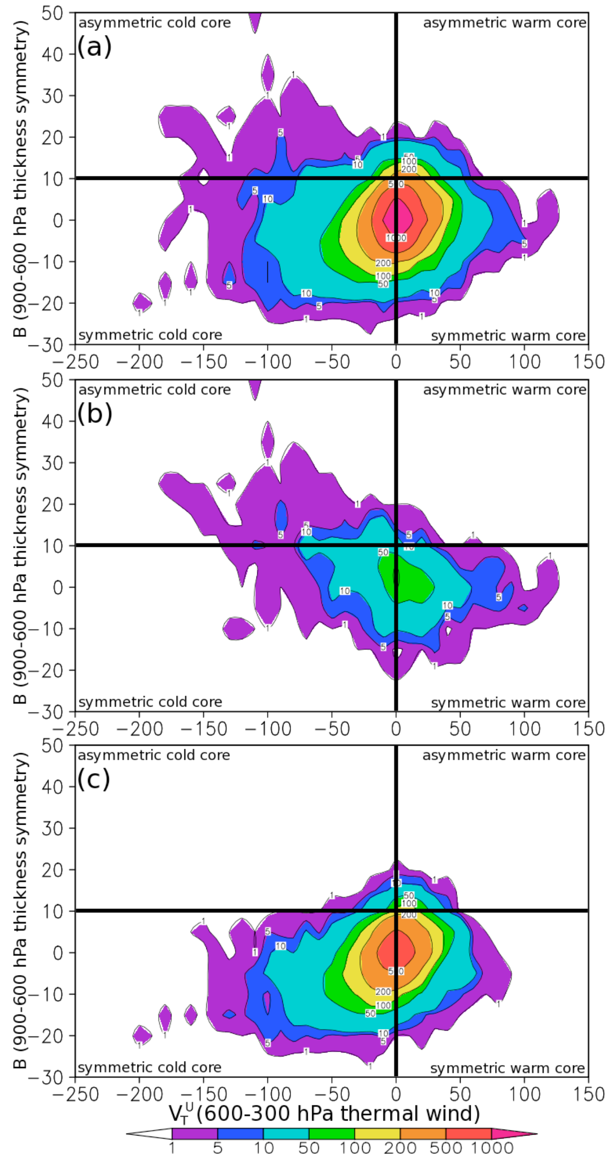

Figure 2. Phase space frequency distribution of (a) all TCs, (b) TCs that complete ET, and (c) cold core dissipators according to 600-300 hPa thermal wind and 900-600 hPa geopotential thickness symmetry.

Figure 2b shows the frequency distribution of only those TCs that dissipated after entering the asymmetric cold core phase, the phase that defines ET. These cases comprise 57 (9%) of the TCs examined over the 42-y period. Most of these became symmetric cold core before completing ET. This set of storms includes Hurricane Lester from the 1992 season (Dickinson et al. 2004) and Tropical Storm Ignacio from the 1997 season (Wood and Ritchie 2012). Almost all of these ET events took place in August or later. An average of 1.4 TCs underwent ET every year over the 42-y period. These TCs tend to follow a recurving track pattern (Figure 3a).

Figure 2c highlights 343 TCs that, instead of completing ET, dissipated after becoming cold core. Most of these TCs began as symmetric or asymmetric warm core systems that then lost their warm core characteristics as they moved over cooler SSTs. In general, these storms weakened due to increasing vertical wind shear that eroded the convection near the center of the storm. However, these storms maintained their thermal symmetry rather than becoming asymmetric prior to dissipation. These “cold core dissipators” occur throughout the hurricane season, though the number does vary greatly from year to year (Figure 4). The percentage of cold core dissipators each year also varied, so there does not seem to be a correlation between the number of TCs in a given season and the number of cold core dissipators. An average of 8.2 TCs followed this pattern each year over the 42-y period. Most cold core dissipators follow the general westward track, but some recurve northward before dissipating (Figure 3b).

169 TCs (27%) retained tropical characteristics throughout their lifetimes, an average of 4 TCs per year. 19 TCs (3%), about one every two years, were “warm core dissipators” that kept their warm core but became asymmetric prior to dissipation. The 44 TCs (7%) that dissipated in the transition region between quadrants were not included in the analysis presented here.

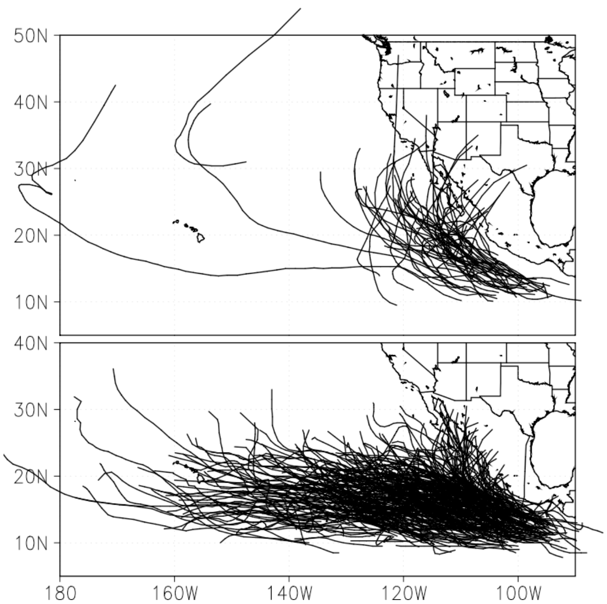

Figure 3. (a) Tracks of 57 TCs that completed ET. (b) Tracks of 343 cold core dissipators.

The frequency of ET and cold core dissipators was also compared to the El Niño-Southern Oscillation (ENSO) using NOAA's Oceanic Nino Index (ONI). Years entering ENSO phases which exceeded 1.0 or went below -1.0 on this index were chosen for comparison, producing eight El Niño and nine La Niña years over the 42-y period. More TCs went ET or became cold core dissipators in El Niño years, and more TCs remained tropical throughout their lifetimes in La Niña years. There were an equal number of warm core dissipators in both types of years. Overall, more TCs occurred in the El Niño years examined than in the La Niña years.

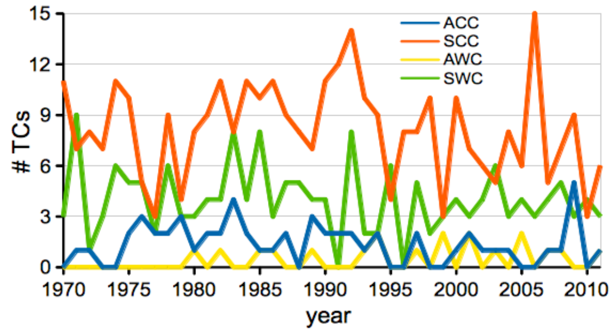

Figure 4. Number of TCs ending in a particular phase space quadrant per year. ACC refers to TCs that went ET, SCC refers to cold core dissipators, AWC refers to warm core dissipators, and SWC refers to TCs that remained tropical throughout their lifetimes.

4. BASIN COMPARISON

North Atlantic TCs that undergo ET tend to lose their thermal symmetry prior to converting from a warm core to a cold core system as shown by cyclone phase space (Figures 5a, 6b). These systems are moving poleward into the mid-latitude flow when ET occurs. This has been documented in a number of previous studies (e.g., Hart 2003). The FNL analysis for the lower level parameters of CPS is shown in order to easily compare with results from previous studies that used 1-degree data.

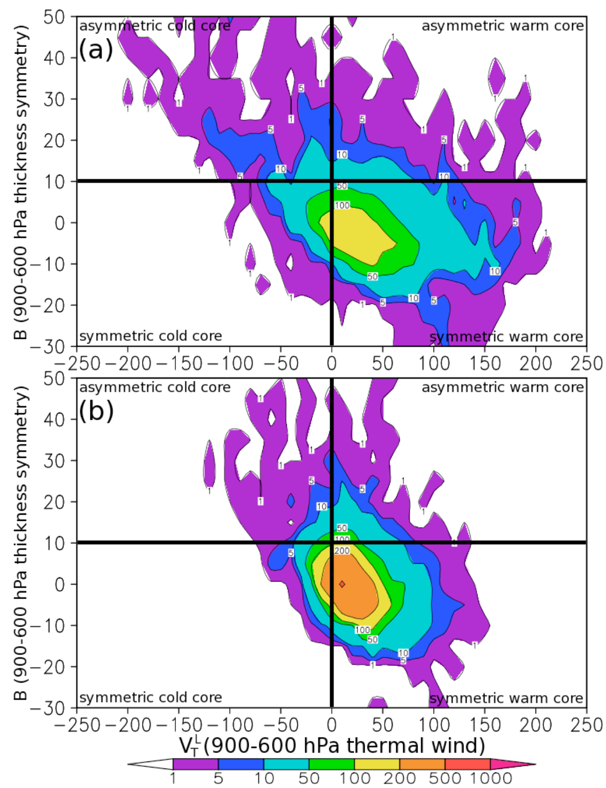

Figure 5. Lower-level (900-600 hPa) phase space frequency distribution using FNL analysis data for (a) 174 North Atlantic TCs tracked by the NHC from 2001-2011 and (b) 259 western North Pacific TCs from the JTWC best tracks for 2001-2010.

North Atlantic TCs spend most of their lifetimes in the symmetric warm core quadrant, some of which dissipate without ever making a transition to another quadrant. The same is true of western North Pacific TCs (Figure 5b), with a strong peak for TCs that remain tropical and do not transition between quadrants.

Conversely, eastern North Pacific TCs that weaken after moving over cooler SSTs tend to become cold core dissipators (Figure 5a). They also generally follow a westward or northwestward path rather than turning northward prior to dissipation (Figures 1, 3b). Some TCs do recurve, but this pattern is far less frequent in this basin compared to the Atlantic and western North Pacific basins (e.g., Figure 1, Jones et al. 2003).

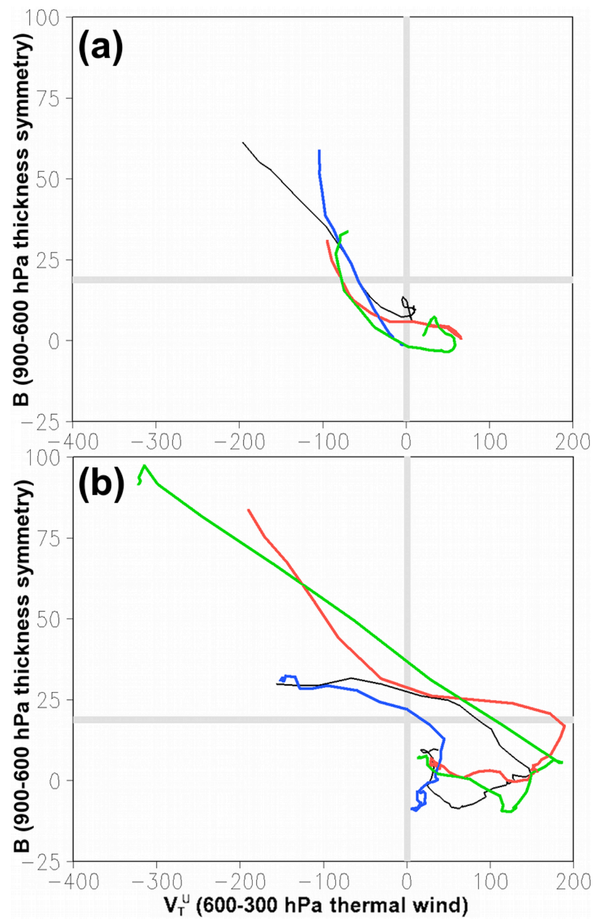

Figure 6. (a) Examples of Eastern North Pacific TCs that underwent ET: 1978 Norman (black), 1992 Lester (red), 1997 Ignacio (blue), and 2002 Elida (green). (b) Examples of North Atlantic TCs that underwent ET: 2003 Fabian (black), 2005 Wilma (red), 2006 Ernesto (blue), and 2009 Bill (green). Both panels were produced using the ECMWF reanalyses.

Eastern North Pacific ET tends to be weaker than that of its North Atlantic and western North Pacific counterparts, as shown by the above examples. North Atlantic ET is often assisted by a trough that has developed and/or intensified over the North American continent before interacting with the TC. Warmer SSTs in place along the eastern coast of the United States due to the Gulf Stream also contribute energy farther north. This allows Atlantic TCs to maintain their intensity farther northward, and it contributes to gradients in moisture and SST that can help cyclones intensify post-ET.

5. SUMMARY AND CONCLUSIONS

The eastern North Pacific hurricane season is dominated by a strong ridge centered over Mexico and the southwestern United States. This ridge provides a steering flow that generally directs TCs westward away from land and over cooler waters, where they dissipate. However, some of these TCs do complete ET over open ocean as shown by cyclone phase space. ET-ing TCs in the eastern North Pacific tend to recurve, often impacting Mexico and the southwestern U.S. as a result. Many TCs that do not undergo ET become cold core dissipators rather than retaining their tropical characteristics before dissipating. Over half of the eastern North Pacific TCs examined in this study were cold core dissipators.

Additionally, the process of ET differs from that seen in the North Atlantic and western North Pacific. In the North Atlantic, TCs retain their warm core while becoming asymmetric before undergoing ET, a signature found even more strongly in the western North Pacific. However, eastern North Pacific TCs tend to retain their symmetry rather than their warm core before undergoing ET. Cool SSTs to the north and west of the main development region in this basin contribute to these structural changes.

None of the TCs in this study were tracked beyond the data provided by the NHC or JTWC. Many recurving TCs that impacted Mexico and the southwestern United States may have completed ET over land but instead were diagnosed as cold core dissipators due to the lower-level circulation eroding after landfall. Future work will track these systems beyond the NHC best track to determine how often TCs complete ET over land. Over-ocean recurving cold core dissipators will also be tracked further to determine whether or not they eventually complete ET. The evolving structure of TCs that complete ET as well as that of cold core dissipators will also be further explored.

The eastern North Pacific is a unique basin and less well-behaved than it appears at first glance. TCs that do not follow the traditional westward track exhibit unusual behavior worthy of further study, including the examples described in this paper.

6. REFERENCES

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