Science and Technology Infusion Climate Bulletin
NOAA's National Weather Service
34th NOAA Annual Climate Diagnostics and Prediction Workshop
Monterey, CA, 26-30 October 2009

The Extratropical Flow Response to Recurving Western North Pacific Tropical Cyclones

Heather M. Archambault, Daniel Keyser and Lance F. Bosart
Department of Atmospheric and Environmental Sciences,
University at Albany, State University of New York

1. Introduction

Case studies of tropical cyclones that recurve and undergo extratropical transition (ET) over the western North Pacific (*e.g.*, Harr and Dea 2009) reveal that recurving TCs can initiate or amplify Rossby wave trains along the North Pacific jet stream. The North Pacific basin is particularly favorable for Rossby wave train activity because of the near year-round occurrence of recurving western North Pacific TCs and the presence of an intense, longitudinally extensive extratropical jet stream (*i.e.*, waveguide) during fall, winter, and spring. Understanding the factors that determine whether a high-amplitude Rossby wave train will be initiated or amplified by a recurving western North Pacific TC is a critical forecasting problem since such wave trains can persist on time scales of a week or more and can act as precursors to extreme weather events over North America.

The downstream response to a recurving western North Pacific TC is believed to depend on a variety of factors, including characteristics of the North Pacific jet stream and the presence of a preexisting upper-level trough or wave packet interacting with the TC. Since the latitude at which a TC recurves is strongly modulated by the strength and latitudinal position of the extratropical jet stream (*e.g.*, Burroughs and Brand 1973), TCs recurving at different latitudes might be expected to produce different downstream responses because of different ambient jet stream characteristics. In this study, the Rossby wave train responses to western North Pacific TCs that recurve at different latitudes are compared using compositing. The compositing technique is detailed in section 2, key results are presented in section 3, and concluding remarks are contained in section 4.

2. Compositing technique

Western North Pacific recurving TCs are selected for compositing from the 413 TC recurvature episodes identified in a 30-year (1979–2008) best-track dataset constructed by the Regional Specialized Meteorological Center Tokyo-Typhoon Center. Based on Fig. 1, which shows the distribution of western North Pacific TC recurvature latitude, the three 5° latitude bands with the most TC recurvatures (15°–20°N, 20°–25°N, and 25°–30°N) are chosen as bins for compositing. To select for like recurving TC cases, additional criteria for compositing are: (i) the TC must be at typhoon strength at the time of recurvature, (ii) the TC must recurve between 125° and 145°E, (iii) the TC must obtain extratropical status at some point in its lifetime (*i.e.*, complete ET), and (iv) the TC must not recurve within 10 days of another TC in the same composite bin. Using these criteria, 24 TCs are obtained for the 15°–20°N bin, 39 for the 20°–25°N

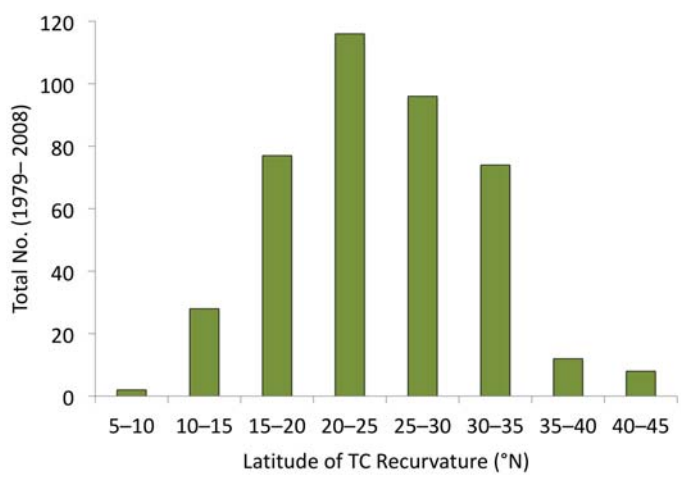

Fig. 1. Histogram of recurvature latitude for all 1979–2008 recurving western North Pacific TCs (n=413).

Correspondence to: Heather M. Archambault, Department of Atmospheric and Environmental Sciences, University at Albany, State University of New York; E-mail: heathera@atmos.albany.edu

bin, and 32 for the 25°–30°N bin. So that each composite bin contains the same number of members, 24 TCs are randomly selected for compositing from the TCs contained in the 20°–25°N and 25°–30°N bins.

The compositing procedure is "TC-recurvature-point centered" (*i.e.*, individual member grids are spatially shifted so that the composite members are centered on the centroid of the TC recurvature points). Composite analyses are created using the 2.5° NCEP-NCAR reanalysis dataset (Kalnay *et al.* 1996; Kistler *et al.* 2001), and are shown for Day –1, Day +1, and Day +4 relative to the day of TC recurvature (Day 0). Composite 300-hPa meridional wind anomalies are calculated based on a 1979–2008 climatology, and statistical significance is assessed using a two-sided Student's *t* test.

3. Results

Figures 2–4 illustrate distinct differences between the composite extratropical flow pattern surrounding TC recurvatures within the 15°–20°N, 20°–25°N, and 25°–30°N bands, hereafter lower-latitude (LL), middle-latitude (ML), and higher-latitude (HL) recurving TCs, respectively. One day prior to TC recurvature (Day –1; Fig. 2), an upper-tropospheric trough–ridge–trough pattern (*i.e.*, a Rossby wave train) is apparent over southeastern Asia and the western North Pacific poleward of the TC in the LL composite, whereas no such pattern can be discerned in the ML and HL composites. Additionally, a region of strong upper-tropospheric winds (i.e., at least 65-kt winds) embedded in the western North Pacific jet stream is more expansive and extends farther equatorward in the LL composite than in the ML and HL composites.

Two days later, at Day +1 (Fig. 3), the amplitude and wavelength of the wave train in the LL composite has increased, and the wave train now extends across most of the North Pacific. At this time in the LL composite, southerly upper-tropospheric winds associated with the recurving TC have merged with those associated with a trough embedded in the wave train. A similar wave

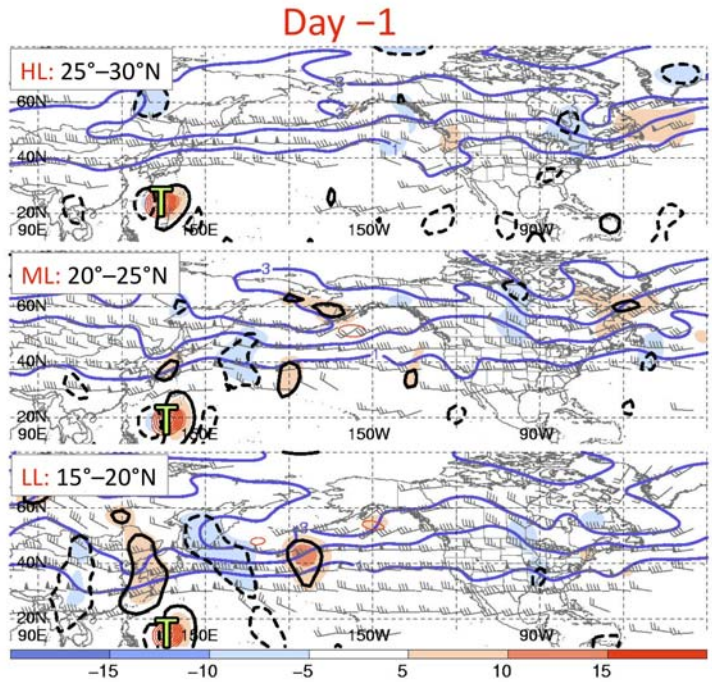

Fig. 2. Day –1 analyses for the 25°–30°N, 20°–25°N, and 15°–20°N composite bins (top, middle, and bottom panels, respectively). Analyses show 925−850-hPa layer-averaged relative vorticity (red contours, every 1×10^{-5} s^{-1}, starting at 2×10^{-5} s^{-1}), 300-hPa meridional wind anomaly (shaded in m s^{-1} according to the color bar, with black closed contours denoting statistical significance at the 95% level), 300-hPa potential vorticity (blue, every 1 PVU), and 300-hPa wind (barbs, >10 m s^{-1} only). Composite locations of the recurving TC are denoted with the "T" symbol.

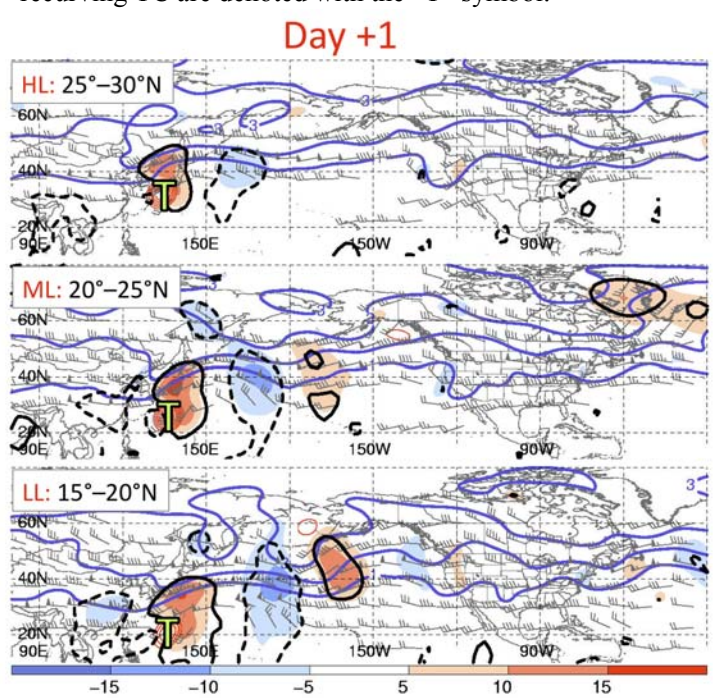

Fig. 3. Same as in Fig. 2, except for Day +1.

train has also emerged in the ML composite over the western and central North Pacific, although the southerly winds on the leading edge of the wave are weaker and the wavelength of the wave train is slightly shorter. In contrast to the other two composites, a wave train is absent from the HL composite: only a ridge has amplified along the western North Pacific jet stream as the recurving TC moves poleward. In all three composites, the maximum wind speed of the western North Pacific jet stream increases between Day –1 and Day +1, from 90 kt to 105 kt, 70 kt to 95 kt, and 65 kt to 70 kt for the LL, ML, and HL composites, respectively.

By Day +4 (Fig. 4), the wave trains in the LL and ML composites have advanced downstream, yielding a ridge near the western North American coast and trough over the U.S. Great Basin. Accompanying ridge amplification along the western North American coast is warm air advection over western Canada and southern Alaska (not shown) in association with a Gulf of Alaska surface low (Fig. 4). The HL composite does not indicate a pronounced ridge–trough couplet over the eastern North Pacific and western North America: instead, only a weak trough over the western U.S. is evident within a relatively low-amplitude, short-wavelength wave train.

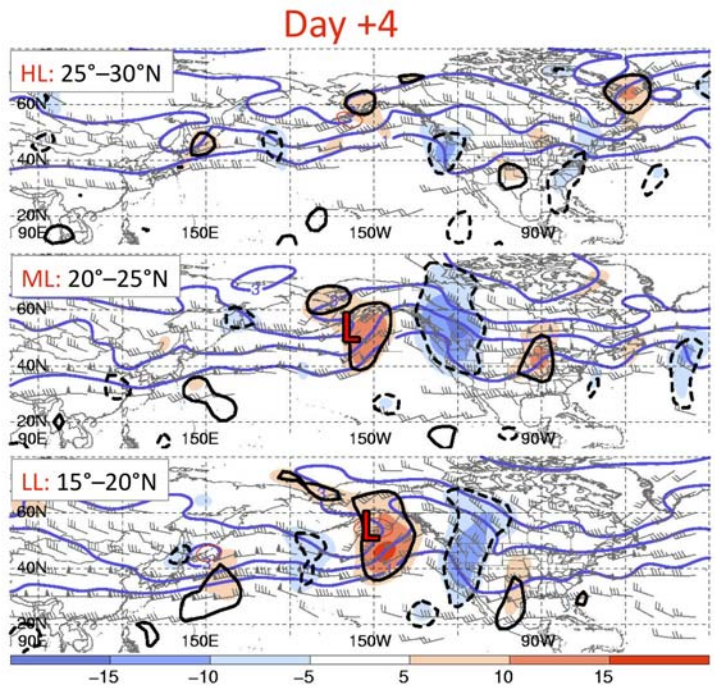

Fig. 4. Same as in Fig. 2, except for Day +4. Composite locations of key surface lows are denoted with an "L" symbol.

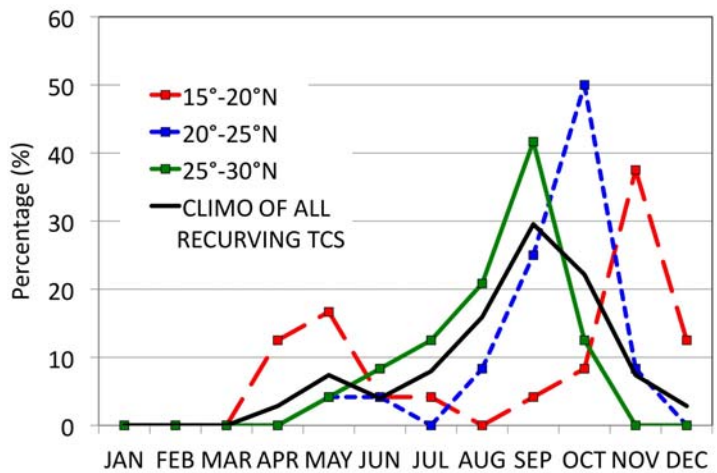

Fig. 5. Monthly frequency of recurving western North Pacific TCs for the three composite bins (n=24) and for the 1979–2008 climatology (n=413).

To examine whether recurving TCs contained in the LL, ML, and HL composites are favored at particular times of the year, the monthly frequency of recurving TCs is plotted in Fig. 5 for the three composite bins and the overall (1979–2009) recurving TC climatology. This figure reveals that recurving TCs contained in each of the composite bins tend to be favored at different times of the year: The HL recurving TCs occur near the climatological peak in recurving TC activity (September), the ML recurving TCs tend to occur slightly later in the season (October), and the LL recurving TCs tend to occur even later, as well as substantially earlier, in the season (November and May, respectively).

4. Concluding remarks

The results of the composite analysis suggest that LL and ML recurving TCs over the western North Pacific tend to induce or amplify Rossby wave trains that are characterized by higher amplitudes and longer wavelengths than HL recurving TCs. The LL and ML recurving TCs tend to favor the amplification of a ridge along the western North American coast and a downstream trough over the U.S. Great Basin

approximately four days after TC recurvature. The composite analysis also suggests that LL recurving TCs may be more likely to be associated with a preexisting wave packet over eastern Asia and the western North Pacific than ML and HL recurving TCs.

The composite analysis illustrates that western North Pacific TCs that recurve closer to the equator tend to do so in the presence of a jet stream that is relatively strong and displaced equatorward, suggesting that TCs that recurve closer to the equator may be favored in late fall or in spring rather than in peak recurving TC season (i.e., late summer and early fall). A relationship between TC recurvature latitude and time of year is corroborated by the increased number of spring and late fall TCs in the composite bins as the latitude of the TC recurvature bin decreases.

In conclusion, the findings of this study suggest that western North Pacific TCs that recurve in late fall or in spring, when the North Pacific jet stream is relatively strong and displaced equatorward, may be more likely to induce or amplify a Rossby wave train that impacts North America than TCs that recurve in late summer or early fall when the North Pacific jet stream is relatively weak and displaced poleward. Future work will investigate the extent that forecast skill and uncertainty associated with the downstream extratropical response to a western North Pacific recurving TC depend upon the latitude at which the TC recurves.

References

Burroughs, L. D., and S. Brand, 1973: Speed of tropical storms and typhoons after recurvature in the western North Pacific Ocean. *J. Appl. Meteor.*, **12,** 452–458.

Harr, P. A., and J. M. Dea, 2009: Downstream development associated with the extratropical transition of tropical cyclones over the western North Pacific. *Mon. Wea. Rev.*, **137,** 1295–1319.

Kalnay, E., and Coauthors, 1996: The NCEP/NCAR 40-Year Reanalysis Project. *Bull. Amer. Meteor. Soc.,* **77,** 437–471.

Kistler, R., and Coauthors, 2001: The NCEP–NCAR 50-Year Reanalysis: Monthly means CD-ROM and documentation. *Bull. Amer. Meteor. Soc.,* **82,** 247–267.