1D.2 LARGE-SCALE FLOW RECONFIGURATIONS OVER NORTH AMERICA ASSOCIATED WITH RECURVING WESTERN NORTH PACIFIC TROPICAL CYCLONES

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## 1. INTRODUCTION

In recent years, research on tropical cyclone (TC) recurvature and extratropical transition (ET) has broadened to include investigation of the impact of TC recurvature and ET on the downstream flow pattern. Case studies (e.g., Harr and Dea 2009) and idealized modeling studies (e.g., Riemer et al. 2008; Riemer and Jones 2010) have illustrated that the outflow of a recurving TC impinging upon a midlatitude jet stream can excite and amplify a Rossby wave train. However, the typical observed Rossby wave response to a recurving TC based upon a large number of recurving TC episodes has not been established.

Understanding the typical Rossby wave response to TCs that recurve over the western North Pacific (WNP) is critical because (i) Rossby wave trains migrating from the Pacific are known precursors to large-scale flow reconfigurations and high-impact weather events over North America (e.g., Archambault et al. 2010), and (ii) Rossby wave trains associated with recurving WNP TCs may facilitate the spread of model forecast error and uncertainty downstream to North America (e.g., Anwender et al. 2010).

The purpose of this study is to examine the characteristic downstream response to WNP TC recurvature from a synoptic–dynamic perspective based on 102 cases of recurving WNP TCs occurring between 1979 and 2008. A compositing approach is employed, which is described in section 2. Results showing the excitation and amplification of a Rossby wave train associated with a recurving WNP TC are presented in section 3, and the downstream impact of the Rossby wave train on the flow pattern over North America is illustrated in section 4. Conclusions and proposed future work are offered in section 5.

## 2. METHODOLOGY

To study the characteristic downstream response to recurving WNP TCs, "recurvature-relative" compositing is performed using the 2.5° NCEP–NCAR reanalysis. This compositing procedure entails shifting the reanalysis grids corresponding to each recurving TC case in the composite such that the TC recurvature point for each case is exactly collocated with the mean (composite) TC recurvature point. In this study, recurvature is defined as when a poleward-moving TC changes motion from westward to eastward (i.e., when the TC is at its most westward position). TCs are selected for compositing using the following criteria as identified from the Japan Meteorological Agency best-track dataset: The TC must (i) recurve between 120°E and 150°E, (ii) be a typhoon (TY) at recurvature (i.e., T+0 h), (iii) become an extratropical cyclone (EC) (i.e., complete ET), and (iv) be a tropical storm, TY, or EC at every 6-h interval between T−48 h and T+72 h. In addition, TCs featuring a looping or otherwise irregular track are excluded from the composite. Using the aforementioned selection criteria, 102 recurving WNP TCs for 1979–2008 are obtained for compositing (tracks shown in Fig. 1).

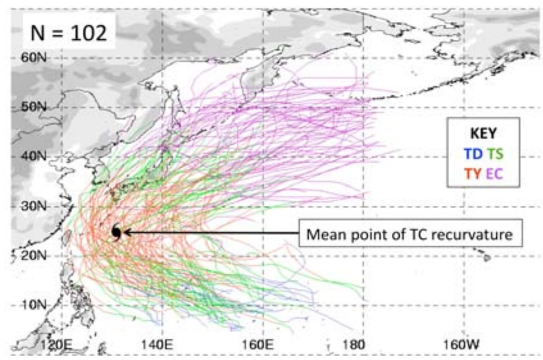


**Figure 1**. Tracks of the 102 recurving WNP TCs included in the composite. The mean point of TC recurvature is given by the TC symbol.

Composite 250-hPa meridional wind anomalies are computed from a recurvature-relative composite climatology constructed from 21-day long-term (1979–2008) mean meridional wind fields corresponding to each case in the composite. The statistical significance of the meridional wind anomalies is assessed using a two-sided Student's *t* test.

## 3. ROSSBY WAVE TRAIN EXCITATION AND AMPLIFICATION

The excitation and amplification of a Rossby wave train (manifested as a trough–ridge–trough pattern along the midlatitude jet stream) by a recurving WNP TC is examined in a composite analysis shown in Fig. 2. This figure indicates that at the time of TC recurvature the divergent outflow of the TC (represented by the irrotational wind vectors directed radially outward from the region of ascent associated with the TC) acts to advect low-PV air poleward. A check of the same analyses valid every 6 h between T−24 h and T+24 h (not shown) reveals a persistent signature of the poleward advection of low-PV air by the TC outflow into

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the WNP jet stream and meridional PV gradient (i.e., waveguide). This 48-h period coincides with WNP ridge amplification and jet streak development (accompanied by upper-tropospheric frontogenesis, not shown), as well as the formation and amplification of a downstream trough in the exit region of the jet streak. Also of note in Fig. 2 is the presence of an antecedent trough upstream of the amplifying ridge at T+0 h. It is speculated that this trough, which approaches from the northwest between T−48 and T+0 h (not shown), may help to induce TC recurvature and promote advection of low-PV air by the irrotational wind within the developing downstream ridge.

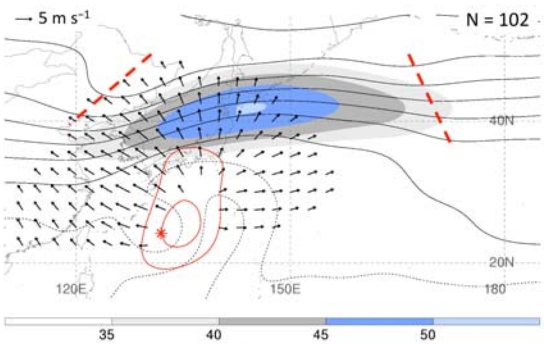


**Figure 2**. Composite analysis of 500-hPa ascent (red, every $1 \times 10^{-3}$ hPa $s^{-1}$), and 200-hPa wind speed (shaded, m $s^{-1}$), PV (solid, every 1 PVU, except dotted for 0.25 and 0.5 PVU), and irrotational wind (vectors, starting at 2.5 m $s^{-1}$) for T+0 h. Red dashed lines denote 200-hPa troughs; asterisk denotes composite TC position.

**4. DOWNSTREAM IMPACT ON NORTH AMERICA**

Examination of the large-scale flow pattern over the North Pacific and North America in the five-day period following TC recurvature reveals the development of significant upper-tropospheric flow perturbations in association with a Rossby wave train. At T+24 h

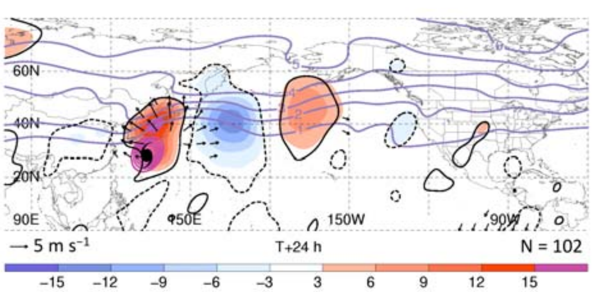


**Figure 3**. Composite analyses of 925–850-hPa relative vorticity (maroon, every $1 \times 10^{-5}$ $s^{-1}$ starting at $2 \times 10^{-5}$ $s^{-1}$), and 250-hPa meridional wind anomaly (shaded, m $s^{-1}$; black contours denote 95% statistical significance), PV (purple, every 1 PVU), and irrotational wind (vectors, starting at 2 m $s^{-1}$) for T+24 h. The TC symbol denotes composite TC position.

(Fig. 3), a Rossby wave train is evident across the western and central North Pacific, with a trough at approximately 120°E, a ridge at 150°E, and a trough axis at the Dateline. By T+72 h (Fig. 4), the Rossby wave train extends across the entire North Pacific and into western North America. In conjunction with downstream development, a ridge has formed over the Gulf of Alaska downstream of a surface cyclone, while farther downstream, a trough has formed over the U.S. Great Basin. The meridional wind anomalies associated with the Great Basin trough feature a slight arcing pattern, suggesting some equatorward dispersion of the energy of the wave train into the subtropics. The same analyses as Figs. 3 and 4 except valid at T+96 and T+120 h (not shown) reveal that significant meridional wind anomalies persist across North America in association with an increasingly arced pattern of meridional wind anomalies.

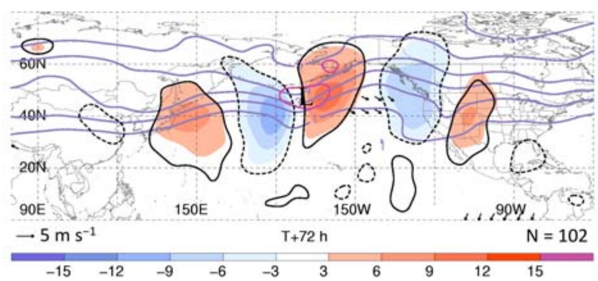


**Figure 4.** Same as in Fig. 3, except for T+72 h. The "L" symbol denotes a surface cyclone that forms downstream of the recurving WNP TC.

A composite Hovmöller plot of 250-hPa meridional wind anomalies is presented (Fig. 5) to summarize the characteristics of the composite Rossby wave train associated with a recurving WNP TC. This plot shows that the wave train persists for ~6 days and traverses ~135° of longitude. The mean zonal group speed of the wave train through its lifetime is estimated to be 45° $d^{-1}$, or 40 m $s^{-1}$. However, based on Fig. 5, the zonal group speed of the wave train appears to be slower over the eastern North Pacific compared to over the WNP. A tendency for the group speed of the Rossby wave train to slow as it crosses the eastern North Pacific is consistent with the presence of a climatologically weaker jet stream and waveguide over the eastern North Pacific region relative to the WNP (not shown).

**5. CONCLUSIONS AND FUTURE WORK**

A TC recurvature-relative composite analysis of 102 recurving WNP TCs is performed using the 2.5° NCEP–NCAR reanalysis to investigate the characteristic downstream response to recurving WNP TCs. The composite analysis reveals that outflow from the recurving WNP TC acts to perturb the WNP jet stream such that a long-lived Rossby wave train is excited. The

Rossby wave train is seen to amplify as it crosses the North Pacific in conjunction with surface cyclogenesis over the central North Pacific. This wave train is found to result in the onset of a western/central U.S. trough approximately 3 days after WNP TC recurvature.

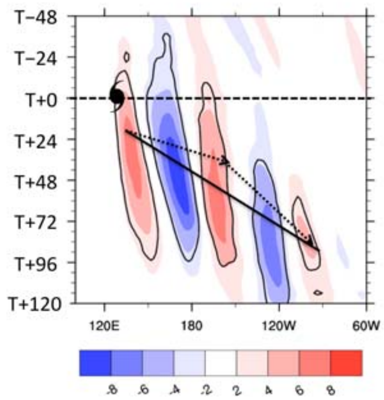


**Figure 5.** Composite Hovmöller plot of 30°–60°N-averaged 250-hPa meridional wind anomaly (shaded, m $s^{-1}$) and 95% statistical significance (black) for T−48 h to T+120 h. The solid lines denotes the mean zonal group speed of the wave train, which is estimated to be 45° $d^{-1}$, or 40 m $s^{-1}$. The dotted arrows denote group speeds of the wave train at different periods in its lifetime. The TC symbol denotes composite TC longitude at recurvature.

The findings of this study that Rossby wave trains associated with recurving WNP TCs tend to persist on a time scale of a week and can migrate well downstream to North America suggest that recurving WNP TCs can exert considerable influence on the intraseasonal climate of the midlatitude NH. Further, these findings motivate investigation of how frequently such wave trains act as precursors to high-impact weather over North America. For example, the finding that the development of a western–central U.S. trough is favored in the days following a recurving WNP TC episode raises the possibility that recurving WNP TCs could serve as precursors to severe weather outbreaks or early-season cold-air outbreaks over the U.S. Plains.

The factors favoring the excitation, amplification, and downstream development of long-lived, high-amplitude Rossby wave trains associated with recurving WNP TCs is a topic of ongoing research. Preliminary findings suggest that compared to WNP TCs that recurve in summer and early fall when the WNP jet stream is relatively weak, WNP TCs that recurve in spring and late fall when the jet stream is relatively strong may favor the development of longer-lived, higher-amplitude Rossby wave trains that yield a more pronounced trough and associated high-impact weather events over the western/central U.S.

## 6. REFERENCES

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