9C.5 Downstream Development Associated with the Extratropical Transition of Tropical Cyclones over the Western North Pacific

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1. INTRODUCTION

The movement of a tropical cyclone into the midlatitudes involves interactions among many complex physical processes over a variety of space and time scales. Furthermore, the extratropical transition (ET) of a tropical cyclone may also result in a high-amplitude Rossby-wave response that can extend to near hemispheric scales. After an ET event over the western portion of a Northern Hemisphere ocean basin, the high-amplitude downstream response often forces anomalous midlatitude circulations for periods of days to a week. These circulations may then be related to high-impact weather events far downstream of the forcing by the ET event.

In this study, downstream development following ET events over the western North Pacific is examined. Local eddy kinetic energy analyses are conducted on four cases of North Pacific tropical cyclones of varying characteristics during ET into varying midlatitude flow characteristics during 15 July – 30 September 2005. The goal is to examine the impact of each case on downstream development across the North Pacific during a period in which these events might increase midlatitude cyclogenesis across the North Pacific during a season in which cyclogenesis is typically weak. Cases are chosen to represent the wide spectrum of variability in ET. This includes a case that directly resulted in an intense midlatitude cyclone, a case in which a weak midlatitude cyclone resulted, a case in which the decaying tropical cyclone was absorbed into the midlatitude flow, and a case in which the tropical cyclone decayed under the influence of strong vertical wind shear. The variability in downstream response to each ET case is related to specific physical characteristics associated with the evolution of the ET process and the phasing between the poleward-moving tropical cyclone and the midlatitude circulation into which it is moving.

2. DATA AND METHODOLOGY

In this study, the local K_e analysis is calculated using the National Centers for Environmental Prediction (NCEP) Final (FNL) Global Data Assimilation System analyses. The FNL analysis incorporates observations with a cutoff period of five hours past synoptic time, and utilizes them to make a global analysis plus 3-, 6-, and 9-hour forecasts four times per day. The output fields from the FNL analyses have a horizontal resolution of 1 deg. lat./long., a temporal resolution of six hours and 26 vertical levels from 1000 hPa to 10 hPa. Also, surface variables, sea-level variables, and many other miscellaneous atmospheric and surface observations are contained in the FNL dataset. This study utilizes the 0000 UTC and 1200 UTC analyses of height, relative humidity, vertical velocity, temperature, zonal and meridional wind components, and mean sea-level pressure at vertical levels from 1000 hPa to 100 hPa in 50 hPa increments.

3. ANALYSIS

During 15 July – 30 September 2005, fourteen TCs occurred over the western North Pacific (Fig. 1). Four of these TCs moved poleward of 40^{o}N and began the transformation stage of ET. Two of the ET cases (TY Nabi, 8 September and TS Banyan, 28 July) resulted in re-intensification as extratropical cyclones. One ET case (TY Guchol, 25 August)

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merged with a larger midlatitude trough and TY Saola (27 September) dissipated as it moved into strong upper-level westerly midlatitude flow. In all four ET cases, there was a progression of maxima in the vertically integrated K_e that began over the western North Pacific and proceeded to the eastern North Pacific (Fig. 1).

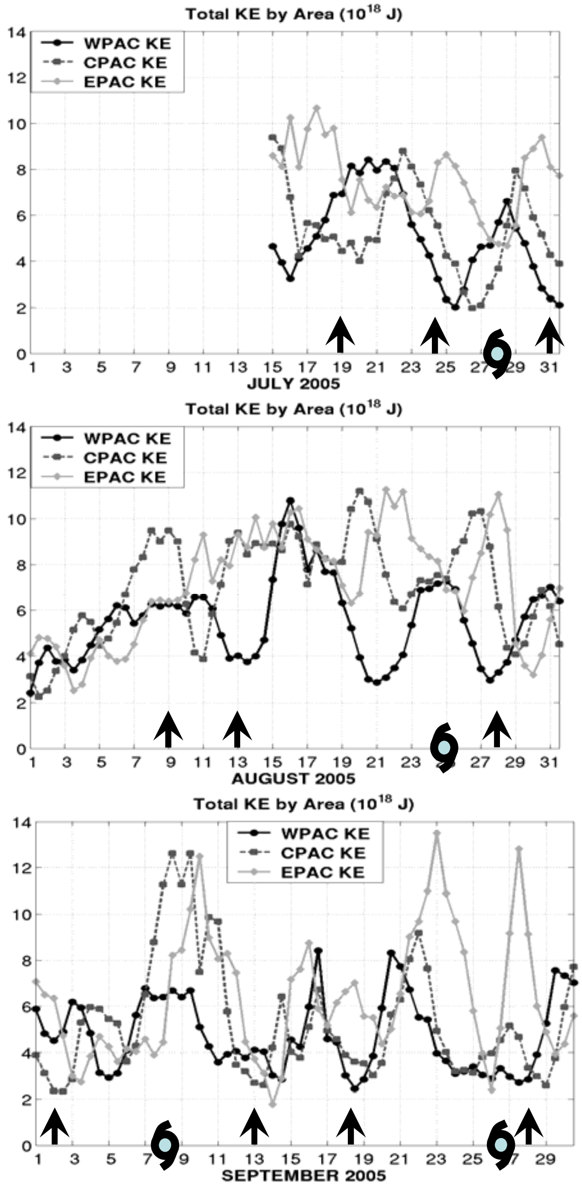

FIG. 1 Volume integrated eddy kinetic energy (10^{18} J) over the North Pacific during 15 July – 30 September 2005. The tropical cyclone symbol marks the dates that tropical cyclones moved poleward of 40^{o}N. The arrows mark the last date associated with a tropical cyclone that stayed south of 40^{o}N. The areas are bounded in latitude by 35^{o}N – 65^{o}N. The western North Pacific extends between 130^{o}E-160^{o}E. The central North Pacific extends between 160^{o}E-160^{o}W. The eastern North Pacific extends between 160^{o}W- 125^{o}W.

The period of study was chosen to examine the influence of ET in downstream development prior to October when the baroclinic energetics increase in association with the strengthening westerly flow. The four cases examined in this study represented a variety of TC characteristics and midlatitude flow patterns in which energetics analyses have been used to describe the characteristics of downstream development associated with the ET of TCs.

The ET of TY Nabi (7 – 9 September) represents what might be considered a typical case in which the decaying TC phases favorably with an upstream midlatitude trough and re-intensifies as a strong extratropical cyclone. Between 6-9 September (Fig. 2), the movement of Nabi into the midlatitudes changed a mostly zonal circulation to a high amplitude pattern of a series of ridges and troughs that extended to the west coast of North America (Fig. 2).

A pronounced downstream development pattern occurred following the ET of Nabi as a trough over the central North Pacific and a separate trough over the eastern North Pacific intensified. During the downstream development, energy export from ex-Nabi maintained the downstream energy center on the western side of the central North Pacific trough longer than might have occurred in a typical downstream development scenario (Fig. 3). Ageostrophic geopotential flux convergence (not shown) deposited K_e poleward of Nabi as it began to move out of the tropics. Instead of a transient transport of energy from the upstream to downstream side of the central North Pacific trough, the dispersion of energy from ex-Nabi provided a prolonged source to the upstream energy center. This is defined in Fig. 1 as a prolonged period of relatively high vertically averaged K_e values over the western and central North Pacific between 7-9 September.

In contrast to TY Nabi, TS Banyan (27 – 29 September) was a large but weak tropical storm that moved poleward during mid-summer. However, the ET of Banyan did result in a strong extratropical cyclone and a pronounced downstream development that was due in part to the poleward transport of warm, rising air. The energy was dispersed via ageostrophic geopotential

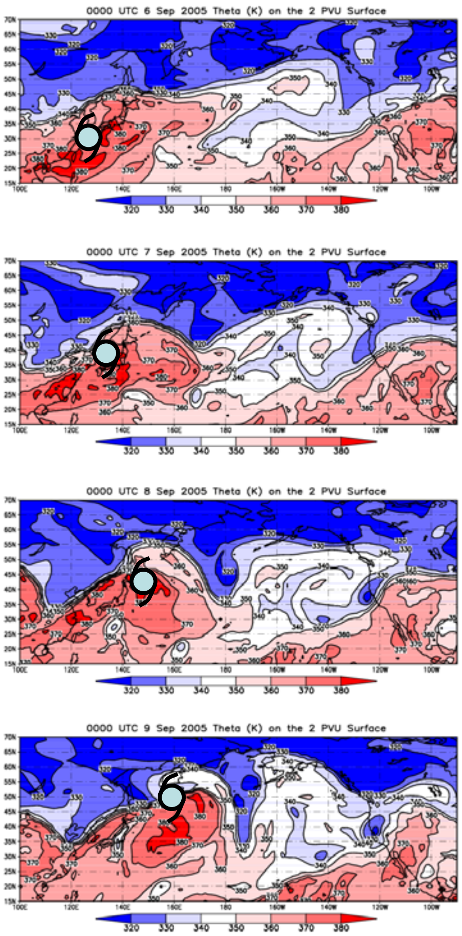

FIG. 2 Potential temperature (K) on the 2 PVU surface. The tropical cyclone symbol marks the location of Nabi at each time.

fluxes (not shown) into the weak midlatitude flow and contributed to downstream development over the central and eastern North Pacific (Fig. 4). Because of the weak baroclinic environment across the western North Pacific at the start of the transformation stage of ET during TS Banyan, significant downstream progression of K_e did not begin until the remnants of Banyan had re-intensified as an extratropical cyclone (Fig. 4). For this region, relative maxima in vertically integrated K_e across the western and central North Pacific during Banyan are short lived (Fig. 1). However, energy from the ex-Banyan contributed to the development of the trough over the eastern North Pacific as it extended toward western North America.

Typhoon Guchol (26 – 27 August) was a very small typhoon that did not complete ET and became absorbed into a midlatitude trough (Fig. 5). Because of the strength of the midlatitude trough, the vertically integrated K_e over the western North Pacific had increased by 1200 UTC 23 September, which was prior to the ET of Guchol (Fig. 1). However, the sudden increase in K_e over the central then eastern North Pacific occurred following the absorption of Guchol into the midlatitude trough.

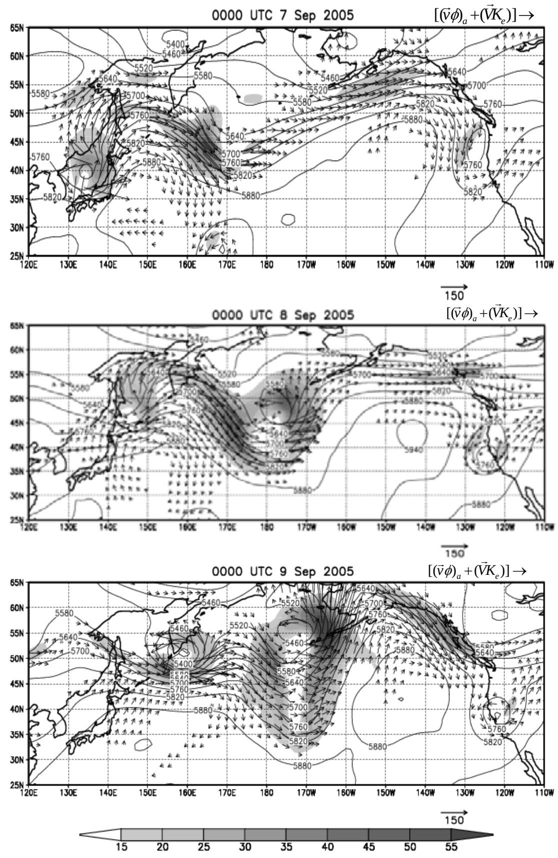

FIG. 3 Vertically averaged K_e (shaded in units of 10^5 J m^{-2}), energy flux vectors (reference vector in lower right, units of 10^5 W m^{-1}), and 500 hPa heights (contours, 60 m intervals).

Finally, TY Saola (26 – 28 September) began ET as it encountered very large vertical wind shear and strong zonal flow over the western North Pacific. These factors led to the dissipation of the ex-Saola circulation. However, extension of the warm, moist tropical air into the strong zonal flow led to the production of K_e by baroclinic processes immediately downstream of Saola (Fig. 6). This energy was dispersed into the midlatitude flow and may have had a minor impact on a large

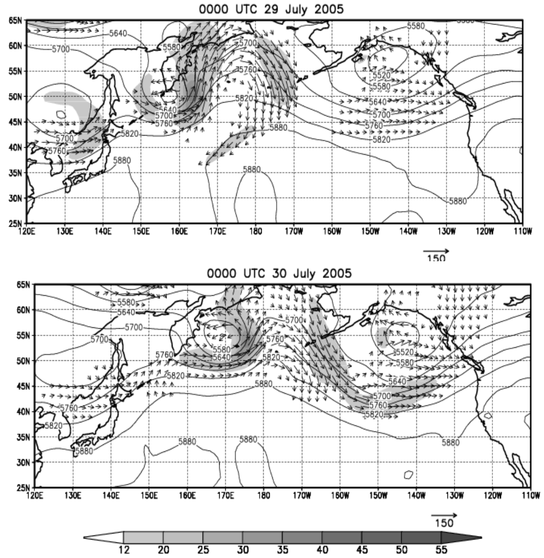

FIG. 4 Vertically averaged K_e (shaded in units of 10^5 J m^{-2}), energy flux vectors (reference vector in lower right, units of 10^5 W m^{-1}), and 500 hPa heights (contours, 60 m intervals).

downstream development event that occurred over the eastern North Pacific

4. Conclusions

In just this limited sample, a variety of TC and midlatitude flow characteristics were identified with downstream development. It is not necessary for the ET process to result in a re-intensifying extratropical cyclone for there to be a significant influence on downstream development. Because of the many dynamic and thermodynamic processes involved during ET, the impact of ET on downstream development is typically not forecast well. One key to improving predictability is increased understanding of the role(s) of various processes associated with ET. However, an equally important key is to explain the variability caused by the many ways in which a poleward-moving, decaying TC may interact with the midlatitude flow into which it is moving.

Acknowledgments

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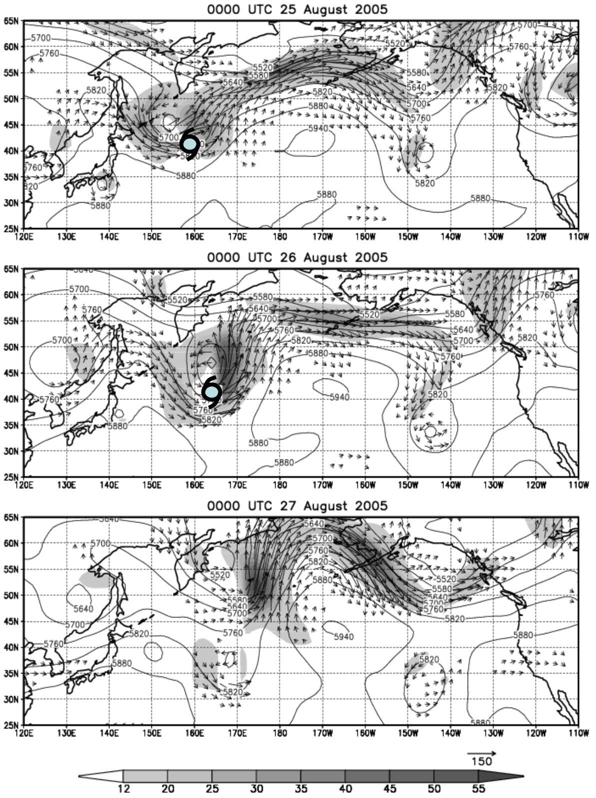

FIG. 5 Vertically averaged K_e (shaded in units of 10^5 J m^{-2}), energy flux vectors (reference vector in lower right, units of 10^5 W m^{-1}), and 500 hPa heights (contours, 60 m intervals). The tropical cyclone symbols mark the location of TY Guchol as it becomes absorbed into the midlatitude trough.

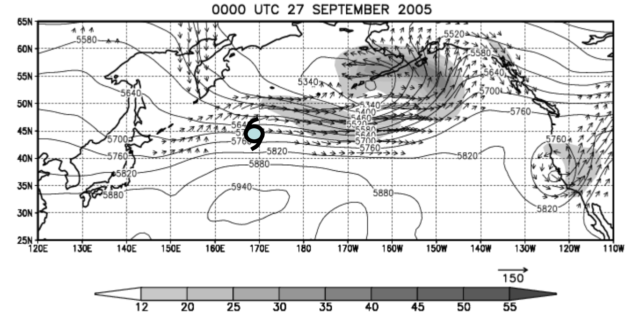

FIG. 6 Vertically averaged K_e (shaded in units of 10^5 J m^{-2}), energy flux vectors (reference vector in lower right, units of 10^5 W m^{-1}), and 500 hPa heights (contours, 60 m intervals). The tropical cyclone symbol marks the location of the ex-TY Saola.