# P1.35 EVALUATING THE IMPACTS OF EXTRATROPICAL TRANSITIONING ON TYPHOON LOSSES VIA SYNOPTIC CASE STUDIES

Peter J. Sousounis\* and Mélicie Desflots AIR Worldwide Corporation, Boston, MA

## 1. MOTIVATION FOR THE STUDY

The frequency of Extratropical Transitioning (XTT) in the Northwest Pacific Basin is well known. Extratropical Transitioning frequency or its significance near Japan however is less welldocumented but likely significant. For example, according to the General Insurance Association of Japan (GIAJ), 9 of the top 10 greatest meteorological insured losses in Japan's history have occurred from typhoons that have undergone XTT within 500 km of Japan's Coast (cf. Fig. 1). While the storm track information in Fig. 1 by itself is not conclusive, it is possible that the XTT process contributed to enhanced damage - especially since the process typically begins 24-48 hours before the Japanese Meteorological Agency (JMA) indicates completion.

The significance of this high frequency is illustrated in Fig. 3, which is adapted from Klein (2000) who noted that extratropical transitioning is characterized by a growth in the asymmetry and the size of the circulation and associated cloud and precipitation shields. The asymmetry results from the presence of baroclinicity, which is typically found at higher latitudes and / or at later times of the year.

The economic impacts of XTT in Japan can be dramatic. Buildings and owners in middle and high latitudes and well inland may be less well prepared for storm-force winds and heavy precipitation. Whether due to building codes that are less strict, a lack of evacuation strategies and emergency preparedness, or poor forecasting, a transitioned storm can have serious impacts. Many specific examples are cited in Jones et al. (2003).



Fig. 1. Top nine meteorologically-related losses in Japan history. The numbers in the panels indicate trended losses to 2008 Japanese Yen (¥). The purple circles on tracks to the left indicate times when the storm completed XTT according to the Japanese Meteorological Agency (JMA).

For this study, a simple analysis was performed using 1951-2008 JMA Track Data. Storms that underwent XTT within 500 km of the coast were counted as XTT events and those that came within 500 km but that did not transition were counted as nonXTT events. The yearly frequency is shown in Fig. 2. On average, 55% of storms that came within 500 km of the coast underwent XTT. The frequency is considerably higher over the last 10-20 years.

#### 2. XTT DYNAMICS

The dynamics of XTT are well understood. Various authors have described the XTT process in detail (Klein et al. 2000; Ritchie and Elsberry 2001; Jones et al. 2003; Kitabatake 2007, 2008). As the tropical cyclone (TC) moves poleward, it encounters colder water and increased horizontal temperature gradients. The colder water reduces surface sensible and latent heat fluxes, which are responsible for extracting the energy from the environment (ocean) and converting it to storm energy. Cyclonic flow from the TC distorts the temperature pattern so warm (cold) advection occurs on the east (west) side. The cold advection erodes the convection on the northwest side, causing it to lose its symmetric

<sup>\*</sup> *Corresponding author address:* Peter J. Sousounis, AIR-Worldwide Corporation., 131 Dartmouth Street, Boston, MA 02116; email: psousounis@air-worldwide.com.



Fig. 2. Number of historical XTT and nonXTT events for Japan as defined in text.

appearance. The warm advection on the east side results in warm, moist air being lifted over cold air farther north, which maintains the deep cloudiness and precipitation over the northwest and northeast quadrants. The weakening of the TC and loss of cloud symmetry are characteristic of most XTT events. As the cyclone continues moving northward into stronger baroclinicity, frontogenesis helps lift warm, moist air to cause clouds and precipitation, and helps ventilate the storm aloft, causing the central pressure at the surface to drop. As available potential energy is released, it is converted to storm energy. The transitioning cyclone begins to reorganize and may reintensify.



Fig. 3. Schematic showing evolution of visible cloud as typhoon undergoes XTT near Japan. Adapted from Klein (2000).

Typhoon central pressure and its relationship to wind and subsequent damage is also well understood. Typhoon wind fields can be parametrically determined based on observed central pressure. Damage functions relate wind speed to damage for various types of buildings (Jain 2010).

As XTT progresses, the canonical circular symmetry that characterizes the wind and precipitation footprints of warm-core pre-

transitioned typhoons breaks down. This paper illustrates the impact of XTT on damage extent and distribution from both wind and flood by comparing two typhoons that impacted Japan. Typhoon Etau made landfall in Japan in August 2003 and caused relatively light damage - until it reached Hokkaido - at which point it had transitioned completely. In contrast, Typhoon Tokage made landfall in October 2004 in nearly the same place along Japan's coast and proceeded to cause considerable damage. Both typhoons were very comparable in strength just hours before landfall. It is hypothesized that Tokage maintained strength and increased its damaging footprint because it transitioned much earlier. This paper provides details that support that hypothesis.

### 3. TYPHOONS ETAU AND TOKAGE OVERVIEW

Typhoon Etau formed in August 2003. It reached maximum intensity just after by-passing Okinawa, Japan at 0600 UTC on August 07 with a minimum central pressure of 945 mb and (10 min) maximum sustained winds of 85 kts according to the JMA. Etau weakened slightly just prior to landfall but then weakened more dramatically after landfall as it traveled up the spine of Honshu. Damage was minor except in Hokkaido, where damage to timber occurred from



Fig. 4. Tracks of Etau 2003 (upper) and Tokage 2004 (lower) from Digital Typhoon.



Fig. 5. NHC Enhanced satellite imagery (from Digital Typhoon) for Typhoons Etau 2003 (upper row) and Tokage 2004 (lower row) at times shown.

flooding and mudslides as the storm was transitioning. Enhanced satellite imagery in Fig. 5 shows Typhoon Etau remaining tropical through at least 0000 UTC on August 08 (note presence of eye at that time). Afterwards, interaction with an approaching weak trough began the transitioning process (note comma head and tail).

Table 1. Summary of housing damage from Typhoons Etau 2003 and Tokage 204.

Housing Damage	Etau	Tokage
Completely destroyed	28	909
Halfly destroyed	27	7776
Partially destroyed	559	10955
Inundation above floor	389	14323
Inundation below floor	2009	41132
Insured Loss (B ¥)	10	187

Typhoon Tokage formed in October 2004 and reached maximum intensity on October 17 with (10 min) maximum sustained winds of 85 kts and minimum central pressure of 940 mb according to the JMA. While it is not unusual for the Joint Typhoon Warning Center (JTWC) to report different intensities for storms than the JMA, in the case of Tokage and Etau, the JTWC reported that Tokage was stronger than Etau 24 hours before landfall but considerably weaker at landfall. JMA showed that Tokage and Etau were the same strength 24 hours before landfall. Tokage was the worst storm to strike Japan since Typhoon Mireille in 1991. There were 69 deaths from the high winds, flooding and mudslides, and 17 persons were still unaccounted for several days after the storm.

Enhanced satellite imagery (Fig. 5) shows Typhoon Tokage beginning transition between October 19 and 20. By 0000 UTC October 20, the southwest erosion of the cloud mass indicates that the cold advection is already in progress. The satellite imagery shows a Tokage with a well defined comma head and tail just after it exits Honshu.

Damage from Tokage was severe from flooding – especially in some of the interior and prefectures on the Sea of Japan (northern) side. Inspection of Table 1 shows that Tokage clearly resulted in more damage from both wind (indicated by destroyed) and flood (indicated by inundation) than Etau.

#### 4. DIAGNOSING THE DIFFERENCES

Six-hourly data from the Japanese 25-Year ReAnalyisis Project (JRA-25) at 20 km resolution and 3-hourly data from the Tropical Rainfall Measurement Mission (TRMM) at 0.25 degree resolution is used to evaluate Etau and Tokage. For each storm, the panels in Fig. 6 show sealevel pressure, six-hourly accumulated precipitation (centered on the times for each storm show the conditions at landfall, while the left panels show the pre-landfall conditions when the storms are near Okinawa and beginning to curve towards the northeast. Note that Tokage is



*Fig. 6. Sea-level pressure and precipitation for Etau and Tokage for times shown. Heavy contour shows 35 kt isotach. See text for more details.* 

moving more quickly than Etau, which is likely associated with its transitioning. The pre-landfall comparison from the JRA perspective shows that Etau is about 10 mb weaker even though the JMA shows the storms to have nearly identical central pressure. The extent of the 35 kt winds is comparable in both – although the Tokage footprint is a bit wider in the east-west direction. The pre-landfall precipitation footprint for Etau is noticeably smaller and more symmetric. At landfall, the wind and precipitation footprints are markedly different. Specifically, Etau has shrunk from both perspectives, while Tokage has remained the same size if not expanded slightly. A noteworthy feature of the Tokage windspeed footprint is that it extends on the left hand side over the Sea of Japan. Precipitation is also considerably heavier, which was likely attributable primarily to frontal uplift.

According to the phase space diagrams for typhoons Etau (2003) and Tokage (2004) shown in Fig. 7, which were derived following the methodology described in Hart (2003) and using the 6 hourly JRA-25 reanalysis fields, Etau made landfall as a tropical system while Tokage was already exhibiting extratropical characteristics. As indicated by the cool colors, while Typhoon Tokage was making landfall, its maximum wind speed was located mainly on the left hand side (LHS) of the storm track.

Vertical north-south cross sections through the storm center for selected times (not shown) illustrate the lateral extent of the wind field as well as the strength of horizontal (potential) temperature gradients. Both storms were associated with an upper level jet streak as is shown in Fig. 8. For Etau, however, this feature proved to be inconsequential as is evidenced by its weakening with time. Even though the storm moved into a region of slightly higher baroclinicity, the wind speeds weakened considerably at landfall. For Tokage, the jet streak was much stronger and even strengthened a bit more at landfall. Baroclinicity was also considerably higher. These ingredients likely played a role in maintaining the intensity and horizontal extent of Tokage as it began undergoing XTT.

In fact, the juxtaposition of not one but three separate jet streaks at 300 mb during the period when Tokage was approaching and making landfall, likely assisted the enhancement of its surface wind field especially on the left hand



Fig. 7. XTT phase space diagrams for Typhoons Etau and Tokage.



Fig. 8. 300 hPa geopotential heights and windspeeds for times shown. White circles and arrows indicate ageostrophic flow. Plus and minus signs indicate ascent and descent. Purple arrow indicates surface ageostrophic flow.

(north) side. Specifically, Tokage was moving towards the northeast and approaching the right entrance region of the main jet, which is typically an area of enhanced upper level divergence and ascent (circled + sign) as shown in Carlson (1991). the presumed ageostrophic Additionally circulation associated with this feature probably resulted in enhanced southerly (northerly) flow at 300 mb (the surface) as indicated by the white (purple) arrow and was likely primarily responsible for maintaining the strength of Tokage's wind field at the surface. The approach and positioning of the other two jet streaks also constructively enhanced the impact of the main jet streak, resulting in a broad region of upper level divergence and ascent that surrounded Tokage. Etau did not enter such an environment, which is less probable during summer months and so was susceptible to the typical post landfall deterioration from friction and its loss of surface heat fluxes.

#### 5. LOSS COMPARISON

The loss estimates for Typhoon Etau (2003) and Typhoon Tokage (2004) were obtained using the AIR Japan typhoon model with the wind speeds from the JRA-25 20 km re-analysis data and the precipitation estimates from the TRMM satellite and an industry exposure distribution developed at AIR (Fig. 9). The extratropical structure of Typhoon Tokage and its evolution around landfall time, lead to far greater observed and modeled losses than Typhoon Etau (compare Figs. 10 and 11). The two typhoons inflicted comparable losses to prefectures of high exposure, namely Osaka (for Typhoon Etau) and Tokyo (for Typhoon Tokage). However, the expanded wind and precipitation of Typhoon Tokage reached and affected most of the prefectures in Japan. The atypically strong winds and precipitation on the left hand side of the track of Typhoon Tokage induced significant losses in the prefectures facing the Sea of Japan.

Despite the fact that Typhoon Tokage (2004) made landfall with approximately the same central pressure as Typhoon Etau (2003) and despite its faster filling rate than Typhoon Etau, the winds of Typhoon Tokage were higher than the ones from Typhoon Etau over the main islands of Japan.

The significant enhancement of the winds and precipitation on the left hand side of Typhoon Tokage were probably a response to the interaction between the extratropical system and a strong jet, which was present over Northern Japan hours prior to landfall of Tokage. The resulting structure of the wind and precipitation fields of Typhoon Tokage produced significant losses in Japan making Tokage the fifth highest loss by typhoon in Japan. according to GIAJ.

Additional experiments are planned to evaluate specific impacts of track, size, or intensity differences not associated with the XTT process.



Fig. 9. Spatial distribution of industry exposure for Japan.



Fig. 10. Insured loss distribution for Typhoon Etau using AIR Japan Typhoon Model with analyzed wind and precipitation fields. JRA-25 20km reanalysis derived Surface windspeed (mph) footprint (upper left). TRMMderived precipitation (mm) footprint (upper right). Model estimated losses from wind damage (lower left). Model estimate losses from flood damage (lower right).

A transitioning typhoon over Japan can have a social impact comparable to or more significant than a non-transitioning typhoon. As each year, 5 out of 8 storms that come within 500 km of the Japanese coast undergo extratropical transition and as shown by the significant losses induced by Tokage as the system made landfall in Japan as an extratropical cyclone, a better understanding of the extratropical transition process might help to develop more accurate building codes and ultimately save lives.

#### Acknowledgements

We gratefully acknowledge the availability and use of JRA25-20 km Reanalysis Data and TRMM Data for this study.

#### REFERENCES

Carlson, T. N., 1991: Mid-latitude Weather Systems. Routledge, New York, 507 p.

Harr, P. A., R. L. Elsberry and T. F. Hogan, 2000: Extratropical transition of tropical cyclones over the western North Pacific, Part II: The impact of midlatitude circulation characteristics. Mon. Wea. Rev., 128, 2634-2653.

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

Jones, S., and Coauthors, 2003: The extratropical transition of tropical cyclones: Forecast challenges, current understanding, and future directions. *Wea. Forecasting*, **18**, 1052–1092.

Kitabatake, N., 2008: Extratropical transition of tropical cyclones in the western North Pacific: Their frontal evolution. *Mon. Wea. Rev.*, **136**, 2066-2090.

Klein, P. M., P. A. Harr and R. L Elsberry, 2000: Extratropical transition of western North Pacific tropical cyclones: An overview and conceptual model of the transformation stage, *Wea. Forecasting*, **15**, 373-396.

Ritchie, E. A. and R. L. Elsberry, 2001: Simulations of the transformation stage of the extratropical transition of tropical cyclones. *Mon. Wea. Rev.*, **129**, 1462-1480.



Fig. 11. Similar to Fig. 10 but for Typhoon Tokage.