

# Evolution of Tropical Cyclone Characteristics

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## LONG-TERM GOALS

The long-term goals are to understand how variabilities in the large-scale atmospheric environment and the internal tropical cyclone structure influence tropical cyclone track and intensity characteristics and define how these influences differ between developing, mature, and decaying tropical cyclones. During the initial stages of tropical cyclone development, structure and track characteristics can exhibit large variabilities that pose difficult forecast situations. Because decaying tropical cyclones often transition to fast-moving and rapidly-developing extratropical cyclones that may contain gale- or storm-force winds, there is a need to improve understanding and prediction of the extratropical transition phase of a decaying tropical cyclone. Therefore, a tropical cyclone throughout its life cycle has the potential for impacting many fleet components.

## OBJECTIVES

Recent research has concentrated on three primary objectives. Extended periods of increased and reduced tropical cyclone activity occur several times during a typical tropical cyclone season (Harr and Elsberry 1991;1995a,b). If reliable forecasts of extended periods of increased or reduced tropical cyclone activity could be made, maritime operations could be coordinated appropriately. Therefore, increased understanding of the primary factors responsible for initiation, maintenance, and decay of extended periods with tropical cyclone activity or inactivity is a primary objective of the current research.

When a tropical cyclone moves into the midlatitudes, extratropical transition (ET) often results in a fast-moving, rapidly-developing midlatitude cyclone that may contain gale-, storm-, or even typhoon-force winds capable of causing significant damage to coastal and maritime interests. Furthermore, these extreme conditions may occur during summer months when such conditions do not normally occur in association with extratropical cyclones. Based on previous studies of the structural changes of the tropical cyclone during ET (Harr and Elsberry 2000, Harr et al. 2000, Klein et al. 2000), the primary objective of the current research is to define how different types of interactions between the decaying tropical cyclone and midlatitude circulation influence the development of the extratropical cyclone.

Because of the increased need for tropical cyclone forecasts at intervals beyond 72 h, it is possible that a tropical cyclone may form and move a long distance during any given forecast sequence. Because numerical forecast guidance tends to be less accurate during the early stages of the tropical cyclone

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life cycle, a new objective is to identify the capability of operational numerical models to identify circulations that will eventually develop into tropical cyclones.

## **APPROACH**

Tropical cyclone activity/inactivity may be related to mechanisms that act over a variety of space and time scales. It is hypothesized that the mechanisms responsible for clustering of tropical cyclone activity can be put into a framework of interactions between several modes of circulation variability. Low-level circulation and outgoing longwave radiation (OLR) characteristics are partitioned into various modes, then the interactions between modes are examined in relation to tropical cyclone activity/inactivity.

To investigate the structural evolution of a tropical cyclone to an extratropical cyclone, the approach has been to define extratropical transition to occur in two stages, transformation and re-intensification (Klein et al. 2000a). The impact of various factors such as the evolving internal tropical cyclone features (e.g., convective activity, inner-core structure), midlatitude circulation into which the tropical cyclone is moving, and relative roles of upper- and lower-level processes on the transition from a tropical to an extratropical cyclone are then investigated during each stage of the transition process. It is hypothesized that the development of the extratropical cyclone during re-intensification depends on the phasing of the poleward-moving tropical cyclone and a critical region in the midlatitude circulation that contains essential elements for support of extratropical cyclogenesis. The sensitivity of the two-stage process of ET to the interaction between the tropical cyclone and the midlatitude circulation into which the tropical cyclone is moving is examined by numerical experimentation in which only the phasing between the tropical cyclone and midlatitude circulations is altered. The movement of the tropical cyclone into the midlatitudes is then delayed or accelerated to examine the relative roles of tropical and midlatitude features during transformation of the tropical cyclone and re-intensification as an extratropical cyclone.

A catalog of forecast and analyzed circulations will be used to assess the ability of each operational numerical forecast model to predict tropical cyclone formation and initial intensification. The catalog will identify successful forecasts, forecast circulations that never verified, and analyzed circulations that were never forecast.

## **WORK COMPLETED**

A wavelet analysis was used to define the dominant modes of low-level circulation and OLR variability over the western North Pacific in a time-frequency reference. Although the wavelet analysis was applied over the entire data record, the zoom capability of the wavelet transform allows isolation of spectral power during specific time periods and over specific frequency ranges. Of interest in this study is the distribution of spectral power during the June-October period of typhoon activity over the western North Pacific. Partitions have been identified to represent an intraseasonal mode (30-60 days), a western North Pacific monsoon trough mode (10-25 days), and a synoptic mode (2-7 days). A singular value decomposition (SVD) analysis was used to describe the primary patterns of large-scale variability associated with the covariance between circulation features and OLR identified with predominant peaks in spectral power.

The sensitivity of the two-stage process of ET to the interaction between the tropical cyclone and the midlatitude circulation into which the tropical cyclone is moving was examined with the Coupled Ocean Atmosphere Mesoscale Prediction System (COAMPS) developed at the Naval Research Laboratory, Monterey. The sensitivity was examined by modifying the initial conditions of several COAMPS simulations. The original wind, temperature, height, and moisture fields associated with the tropical cyclone were removed and re-located to a specified location. The tropical cyclone-related values were placed into a new location via an iterative statistical interpolation procedure. The new location was chosen based on the desired effect, which may be to either delay or accelerate the motion of the tropical cyclone into the midlatitudes and thus alter the phasing with the midlatitude circulation (Klein et al. 2001).

To examine the capability of operational numerical models to identify circulations that may become tropical cyclones, an algorithm has been developed to detect and track circulations throughout the forecast sequence. A matching technique was used to associate predicted circulations with subsequent analyzed circulations.

## RESULTS

Based on the SVD analysis, dominant coupled modes of variability between low-level circulation and OLR have been identified for the three time modes defined by the wavelet analysis. Over intraseasonal scales, a global-scale circulation/OLR coupled mode has been associated with the slow eastward propagation of the Madden Julian Oscillation (MJO). Analysis of the SVD coefficients defines considerable variability in the MJO structural characteristics that projects onto circulation modes that act on longer time scales (Chang et al. 2001) and shorter time scales. Over the shorter time scales, the variable MJO-mode amplitude is associated with large variability in the modulation of synoptic-scale features by the intraseasonal events. Therefore, the key to defining potential initiation of intraseasonal periods of tropical cyclone activity or inactivity is identification of the variability in the principal features of the MJO that influence the synoptic scale directly. Over the monsoon trough time scale, the primary coupled circulation/OLR modes define large-scale circulations confined to the western North Pacific. The structure of this mode is related to the northwestward propagation of Rossby waves from enhanced convection over the equatorial western Pacific. Coupled low-level circulation/OLR modes over the synoptic scales define a combination of equatorial waves. Over the central Pacific, a mixed Rossby-gravity (MRG) wave signal is identified. This signal becomes modified over the tropical western North Pacific to be representative of northwestward-moving synoptic-scale waves that have been identified in previous studies (e.g., Chang et al. 1996). Because of the variability associated with each coupled mode, and variability associated with combinations of large-scale and mesoscale factors that influence tropical cyclone activity, the relationship between the various modes and tropical cyclone activity is very complex. However, the unique partitioning of the circulation/OLR modes enables assessment of the amount of variability in tropical cyclone activity that may be explained by each coupled mode.

One aspect of the two-stage process associated with ET is that the transformation stage is rather independent of the tropical cyclone and large-scale circulation characteristics. However, the re-intensification stage is highly dependent on the phasing between the decaying tropical cyclone and the midlatitude circulation into which it is moving. The contributions of the midlatitude circulation and by the tropical cyclone remnants to the outcome of the re-intensification stage of ET are depicted in a matrix (Fig. 1). The midlatitude contribution is based on the degree to which it is favorable for

extratropical cyclogenesis even without the tropical cyclone (Klein et al. 2001). The characterization of the contribution from the decaying tropical cyclone to the re-intensification stage of ET is based on its interaction with the midlatitude circulation. An optimal interaction results in a dynamic coupling of the transformed tropical cyclone with the mid- and upper-tropospheric components of the midlatitude circulation plus the low-level baroclinity such that a deep re-intensification (minimum sea-level pressure less than 980 mb) results. For cases in which the interactions between the transformed tropical cyclone and the midlatitude circulation components is less than optimal, the tropical cyclone contribution is minor. If the transformed tropical cyclone interacts minimally or not at all with the midlatitude circulations, the tropical cyclone contribution is described as none. All contributions are defined from the sensitivity analysis based on modification of the initial conditions in a COAMPS simulation such that the decaying tropical cyclone characteristics are changed to alter the interaction with the midlatitude circulation. The results can be conveyed (Fig. 1) as a shift in the tropical cyclone contribution within the same category of midlatitude contribution.

		Midlatitude Contributions		
		Unfavorable	Neutral	Favorable
TC Contributions	Significant	Little or	Deep and/or Rapid Re-intensification	
	Minor		Moderate	
	None	Decayers		Re-intensification

*Fig. 1: Characterization of the midlatitude circulation and tropical cyclone contributions to the re-intensification stage of ET depicted as a matrix, where the combinations of these contributions may produce three outcomes: (i) deep and/or rapid re-intensification (upper right); (ii) little to moderate re-intensification (within the shaded cells); or (iii) decay of the tropical cyclone without completing ET (lower left).*

The algorithm that allows forecast and analyzed circulations to be cataloged, which has just been completed, will be applied to several operational models to develop a knowledge data base that defines the capability of each model to accurately predict tropical cyclone formation at all forecast ranges.

## **IMPACT/APPLICATIONS**

Identification of the interactions between various modes of tropical circulation variability will lead to a statistical forecast scheme of extended periods of tropical cyclone activity/inactivity. If reliable forecasts of extended periods of inactivity (i.e., at least 20 days with no tropical cyclones) could be made, maritime operations could be coordinated to take advantage of the period of reduced threat from tropical cyclones.

Knowledge of the degree of the midlatitude and tropical cyclone contributions during ET will provide increased forecaster awareness of the potential re-intensification of the extratropical cyclone that results from the completed ET process.

Knowledge of the potential for each operational numerical forecast model for prediction of tropical cyclone formation will lead to a consensus technique for identifying the probability of tropical cyclone formation.

## **TRANSITIONS**

The two-stage model of ET has been incorporated into official training material at the Joint Typhoon Warning Center.

## **SUMMARY**

Results from research of ET conducted under ONR sponsorship at the Naval Postgraduate School has triggered a major sense of awareness of the need for increased understanding of this process (Jones et al. 2001). The primary structural characteristics associated with ET have been identified by Harr and Elsberry (2000), Harr et al. (2000), and Klein et al. (2000,2001). Harr and Elsberry (2001) identified how these characteristics are associated with key weather hazards such as extreme amounts of precipitation. During the next year, results from the examination of the interaction between modes of tropical circulation variability will provide a sound forecast system for assessment of tropical cyclone activity that may be expected over ranges between 10-25 days. Finally, the assessment of the capability of each operation numerical model to predict tropical cyclone formation will provide operational forecasters with information to efficiently assess model guidance.

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