10B.6 The Influence of TUTT Cells on TC Motion

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1. Introduction

The Joint Typhoon Warning Center (JTWC) has repeatedly identified tropical cyclone (TC) interactions with Tropical Upper Tropospheric Trough (TUTT) cells in the northwest Pacific Ocean a type of situation where environmental influences on a TC are poorly forecast or understood. The JTWC's problems with handling TC – TUTT cell interaction scenarios are mostly due to poor numerical model forecasts of a TUTT cell life-cycle and have led to huge forecast errors (1000+ nm) (JTWC 1998). Additionally, numerous researchers have speculated as to whether a TUTT cell can actually affect TC motion (Hodanish and Gray 1993, Holland and Lander 1993, Chen and Chou 1994, Fitzpatrick et al. 1995 and Elsberry 1995). To date, there is no known observational study that proves this type of influence can and does occur nor is there any known operational guidance for such scenarios.

2. Data and Method

Our research is based on similarities with observational binary TC interaction studies (Lander and Holland 1993). ECMWF ReAnalysis (ERA-40) fields are used in conjunction with the JTWC best track data to depict the historical state of the atmosphere from 1994 to 2001. TUTT cell centers are identified at 200 hPa via streamline analysis. With these data, we identify 10 cases in the northwest Pacific Ocean and one Atlantic case. All of these situations had the TC at tropical storm or greater intensity and follow a non-standard track when a TUTT cell was within 2000 km range. Other transient mesoscale or larger atmospheric features known to influence TC motion did not exist within 2000 km of the TC and its path. We use the 11 cases to explore the following questions and to develop operation forecast guidance for the JTWC:

1. How does a TUTT cell directly influence TC motion?
2. Does a TC appear to influence TUTT cell motion?
3. What environmental steering combination (layer, radial band) most closely matches TC motion?
4. What is the maximum separation distance for which an interaction can occur?
5. How does TC and TUTT cell intensity and structure affect an interaction?
6. How long does an interaction last?

3. Results

TUTT cells are found to influence TC motion primarily by contributing flow to a TC's upper layer (100 to 500 hPa) environment which factors into the TC's overall deep layer steering. Poor TUTT cell structure forecasts by numerical models (e.g., NOGAPS) lead to incorrect depiction of the TC's environment. This results in inaccurate forecast guidance during these types of interactions.

Evidence suggests a TC can influence a TUTT cell's motion particularly if the two circulations are of similar scale. In the case of a developed TC, it seems a TUTT cell should be more responsive to a TC's anticyclone, but no evidence of this response is found. Individual track and centroid-relative motion analysis is subject to interpretation based on whether the two circulations are both considered cyclonic or if the TC is viewed as anticyclonic (at ~200 hPa). Satellite imagery supports both a Fujiwhara-type interaction for similarly sized circulations but the interaction appears one-way (TUTT cell to TC) for larger, more intense TUTT cells.

In most of the 11 cases, the 5˚-7˚ radial band of the mass-weighted deep layer mean (DLM) (100 – 1000 hPa) steering flow appear closest to TC motion. This was typically followed closely by the 300 – 850 hPa layer of the 5˚-7˚ radial band. When the TC and TUTT cell are in proximity (< 700 km), however, the DLM 3˚-5˚ radial band often proves to be closer to TC motion during the TUTT cell interaction period.

An influence by a TUTT cell on TC motion is found to occur with a separation distance as great as ~1700 km. This is ~300 km greater than the maximum published distance for binary TC interactions to occur (Brand 1970).

More intense TCs tend to have greater vertical development (Velden and Leslie 1991) and inertial stability (Holland 1983). Greater vertical development of a TC implies a deeper layer of the troposphere is responsible for steering the vortex. In two of our cases with very similar environments during their interaction periods (TUTT cell structure, intensity and orientation), the weaker TC (40 kts) responds much more sluggishly (< 2 m s^{-1}) than the promptly responding (~5 m s^{-1}) more intense TC (90 kts). TC's with greater intensity are more likely to respond to a TUTT cell's influence.

The impacts of TUTT cell intensity and characteristics on these types of interactions will be discussed in the next section.

TC – TUTT cell interactions were found to last from 1 to 2 days (~36 hour average). Interactions ended with the dissipation of the TUTT cell or the separation of the two circulations.

4. TC – TUTT Cell Conceptual Model

A conceptual model is developed to provide operational guidance to the JTWC. The model is based on the deduced or inferred influence of a TUTT cell's wind field on TC motion. Characteristics of the 11 cases are compared based on whether an influence by the TUTT cell is found. Results led to a distinction *primarily* based on TUTT cell intensity (maximum associated 200 hPa relative vorticity (ζ_r) and potential vorticity (PV)) and vertical depth of the TUTT cell's closed circulation below 200 hPa. The model quantifies decision-grade criteria for determining the likelihood of a TUTT cell's influence on TC track with the following six questions:

1. Is the 200 hPa TUTT cell center within 1700 km (~15˚) of the TC?
2. Is the TC and TUTT cell separation distance decreasing?
3. Is the TUTT cell's 200 hPa wind field that is > 25 kts within 430 nm (~7˚) of the TC's center?
4. Has the TUTT cell maintained a maximum 200 hPa intensity of either,
  a. PV $\geq$ 2.5 PVUs (10^{-6} m^2 K s^{-1} kg^{-1})
  b. $\zeta_r \geq 11 \times 10^{-5}$ s^{-1}
5. Does the TUTT cell have a *closed* circulation at or below 400 hPa?
6. Is the TC's intensity > 34 kts?

If all six questions are answered "yes" by a forecaster, an identifiable influence of a TUTT cell's wind field on TC motion is likely. Graphical scenarios (Fig. 1a.) then provide the forecaster with TC track-bias guidance for application on future forecasts. Track bias guidance is based on the forecast model ensemble field (Fig. 1b.). Once an ensemble forecast is developed, a suggested "nudge" (green area in Fig. 1a.) to one side of the ensemble forecast track and/or a speed increase/decrease is then applied. This is intended to reduce forecast errors believed previously to have been caused by poor incorporation of a TUTT cell's wind field into numerical model guidance and/or in-house forecaster techniques. The process can be completed in under a minute for a "situationally aware" forecaster by utilizing a yes/no checklist.

Forecasters are advised not to judge a TUTT cell based on its satellite appearance alone since it can prove to be misleading. For example, Figures 2a-b reveals two TCs (Rex2 and Bart) and their associated TUTT cells above a vertical cross-section of relative vorticity through the circulations. Notice the TUTT cell to the northeast of Rex2 appears impressive in whatever vapor imagery, as does the TUTT cell to the east of Bart. The satellite imagery's corresponding ζ_r cross-sections within the ERA-40 data, however, reveal a shallow and weak TUTT cell associated with Bart. This emphasizes that detailed numerical model analysis is required to more accurately determine the likelihood of an influence by a TUTT cell on TC motion and clearly displays how deceptive satellite imagery can be.

5. Conclusion

Our operational guidance is being implemented at the JTWC and will help to improve TC position forecasts for situations that occur as frequently as binary TC interactions (~1.5/year) in the

a.

b.

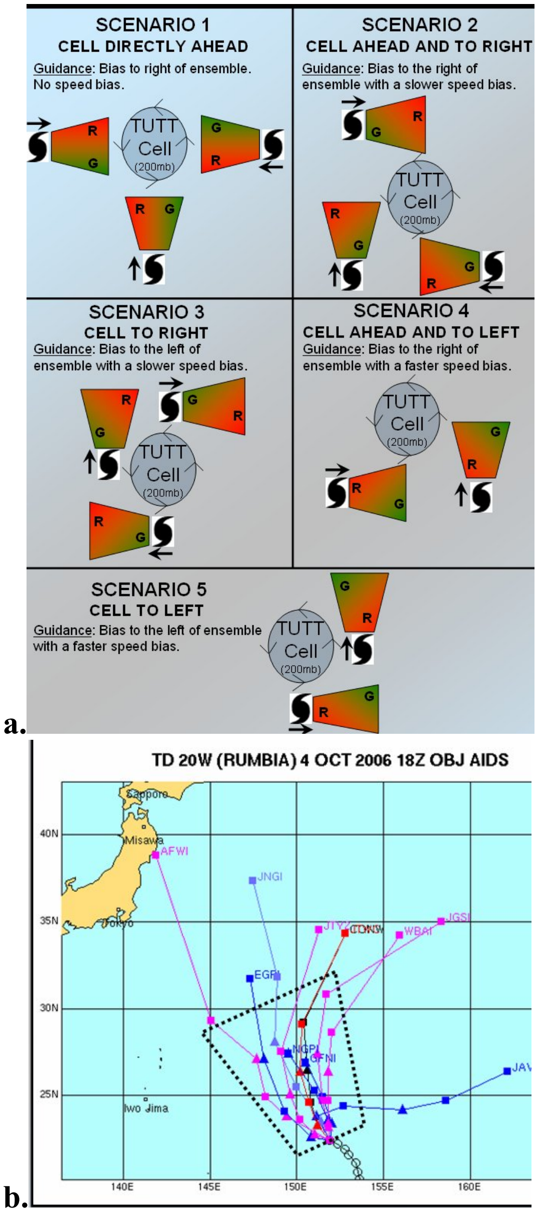
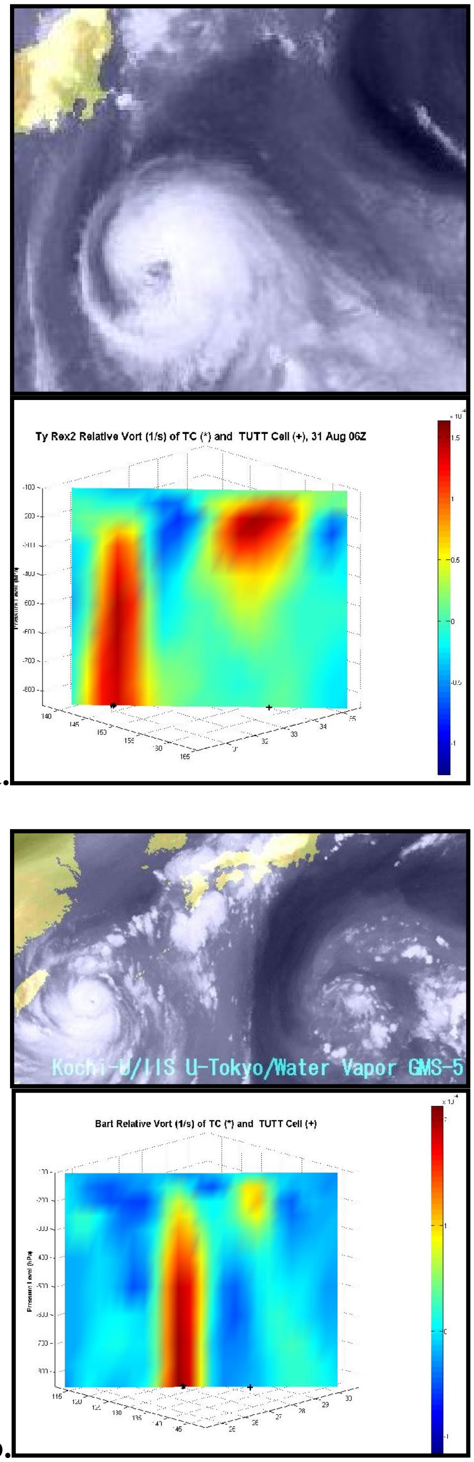


Fig. 1. a) Graphical portion of TC – TUTT cell conceptual model for TC forecasters and b) a sample TC forecast ensemble field (dotted trapezoid) from the JTWC.

northwest Pacific Ocean. We believe our results provide credence to the numerous researchers that speculated about the influence of a TUTT cell on TC motion and help the operational community improve TC track forecasts.



a. **b.**

Fig. 1. a) Rex2 and a TUTT cell (to the NE) in water vapor imagery (top) and associated relative vorticity cross-section (bottom) from 100 to 850 hPa. b) As in 2a but for Bart.

7. References

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