S51 A New Metric for Defining the Time of Extratropical Transition of Tropical Cyclones

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1. INTRODUCTION

Almost half of all tropical cyclones (TCs) in the Atlantic basin undergo extratropical transition (ET, Hart and Evans 2001). Re-intensifying ET (RIET) events often result in storm wind fields expanding dramatically with the heaviest precipitation shifting to the left-of-center (LOC, e.g., Atallah et al. 2007; Milrad et al. 2009). RIET events often result in more widespread gale-force winds and inland flash flooding hundreds of kilometers from the cyclone center.

While several objective metrics to track and predict ET have been developed, they rely at least partially on internal tropical cyclone structure, for which numerical models show less skill (Kofron et al. 2010). Furthermore, these metrics fail to account for static stability, which plays a vital role in determining precipitation amounts (Gyakum 2008).

A coupled dynamic and thermodynamic metric using the Eady moist baroclinic growth rate (EMBGR) is proposed to evaluate the time of ET. The EMBGR parameter relies on relatively well-forecast environmental flow characteristics and static stability. The time of ET deduced from the EMBGR is then compared to several existing metrics such as the Cyclone Phase Space (CPS, Hart 2003), TC and mid-latitude tropospheric trough interactions, and precipitation distribution.

2. METHODOLOGY

In total there were 117 Atlantic basin TCs that made landfall between 1979 and 2014 along the East Coast or Gulf Coast of the United States (U.S.). However, the study was limited to 46 TCs that met the following criteria:

- Moved 500 km inland and poleward after landfall.
- Interacted with a mid-latitude upper tropospheric trough.
- Entered the asymmetric warm core sector (AWCS) of their respective CPS.

The National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR, Saha et al. 2010) was chosen for this study given the high resolution (0.5° grid spacing) and reliable precipitation fields. Using the reanalysis data, EMBGR, CPS (track data obtained from NHC Best Track Data (HURDAT2) available at http://www.nhc.noaa.gov/data/#hurdat), vorticity, and precipitation plots were generated.

2.1 *Eady Baroclinic Growth Rates*

Consider the concept of the Eady baroclinic growth rate (EBGR, Eady 1949), defined in Eq. (1) by Hoskins and Valdes (1990).

$$\sigma_{BI} = 0.31\, f\, \frac{\partial \vec{v}}{\partial z} N^{-1}, \qquad (1)$$

where f is the Coriolis parameter, $\partial \vec{v}/\partial z$ is the vertical wind shear, and N the Brunt-Vaisala frequency (static stability). While Eq. (1) essentially measures baroclinicity, it also assumes that the atmosphere is unsaturated, which is not ideal for situations involving heavy precipitation (e.g., TCs) Eq. (1) can be modified by using the moist Brunt-Vaisala frequency (N_m, Durran and Klemp 1982),

$$N_m^2 = \frac{g}{T}\left(\frac{dT}{dz} + \Gamma_m\right), \qquad (2)$$

which accounts for saturated air parcels by incorporating the moist adiabatic lapse rate (Γ_m). Substituting N_m for N in Eq. (1) allows us to define Eq. (3) as the "Eady moist baroclinic growth rate" (EMBGR).

$$EMBGR = 0.31\, f\, \frac{\partial v}{\partial z} N_m^{-1} \qquad (3)$$

2.2 *Tropical Cyclone Phase Space Diagram*

The CPS developed by Hart (2003) is a widely used tool for TCs undergoing ET. However, from a forecasting standpoint, it relies on TC structure for which numerical models show less skill (Kofron et al. 2010).

2.3 *TC and Mid-Tropospheric Trough Interaction*

The time of ET is defined when the 200-300 hPa layer-averaged PV (trough) and 850-700 hPa layer-averaged relative vorticity (TC) first make contact i.e., a vertical shear is being imposed on the TC (e.g., Atallah et al. 2007). Intensity of the interaction is determined by the time tendency of the maximum 850-700 hPa layer averaged relative vorticity (e.g., Milrad et al. 2009).

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3. RESULTS

The time tendency of EMBGR ($d\boldsymbol{EMBGR}/dt$) was plotted as a line graph. The time of trough interaction, AWCS of their respective CPS, landfall, and precipitation distribution were also marked on the line graph. (Reference plots available under the *Handout* link available at: https://ams.confex.com/ams/96Annual/webprogram/Paper291678.html).

In seven (four) cases, an increase in EMBGR occurred simultaneously with a trough interaction (AWCS of CPS). In most of the 46 cases, there was a growth in EMBGR prior to ET (summarized in Table 1). This suggests that utilizing the EMBGR in operational numerical weather prediction (NWP) models could potentially improve ET lead time when compared to CPS (structure dependent) or trough interactions (subjective).

EMBGR VS PV		**EMBGR VS Phase Space**	
EMBGR First	PV First	EMBGR First	Phase Space First
31 cases	8 cases	35 cases	9 cases

Table 1: An increase in the EMBGR was noted in most cases prior to a mid-tropospheric trough interaction or the TC entering its AWCS of the CPS.

In 30 cases (13 cases), trough interaction occurred before (after) the TC went into its respective AWCS of the CPS (summarized in Table 2). Nineteen TCs interacted with a trough around landfall (±12 hours), this is important to note given the forecasting challenge attributed to the increase in friction as the TC moves inland, and change in TC structure and dynamics. Also, given that over 76% of deaths associated with Atlantic TCs are attributed to storm surge and rain (Rappaport 2014), understanding the time and intensity of ET is critical from a precipitation perspective.

PV vs. Phase Space		
PV First *TC interacted with a mid-tropospheric trough*	Phase Space First *TC phase space diagram entered AWCS*	Same Time
30 Storms	*13 Storms*	*3 Storms*
>12 Hours Lead Time	>12 Hours Lead Time	
23 Storms	*7 Storms*	

Table 2: TC interaction with a mid-tropospheric trough is often followed by a TC developing fronts and entering the AWCS of its CPS.

4. SUMMARY AND CONCLUSIONS

Upon studying 13 cases, a strong relation could not be drawn between the time tendency of EMBGR and area of the outer closed isobar. Since the EMBGR is a measure of baroclinicity (frontal formation), $d\boldsymbol{EMBGR}/dt$ may have a much closer relationship with precipitation distribution than wind field size.

Future work includes investigations to systematically demonstrate that $d\boldsymbol{EMBGR}/dt$ predicts LOC precipitation distributions sooner than the CPC or other ET metrics. Storm-relative composite and case study analysis techniques will both be utilized to accomplish this objective.

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