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A New Dynamic-based Metric to Explore the Time and Intensity 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, onset and intensity 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, 73 TCs that met the following criteria were considered for this study:

- Moved 500 km inland and poleward after landfall.
- Interacted with a mid-latitude upper tropospheric trough.

Twenty-five cases exhibited a LOC precipitation distribution and 34 cases either retained or exhibited a ROC precipitation distribution (e.g., Milrad et al. 2009). Precipitation distribution could not be determined in 14 cases and these were excluded from the analysis.

2.1 *Data*

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 HURDAT), vorticity, and precipitation plots were generated. CFSR precipitation distribution was compared with the NCEP North American Regional Reanalysis (NARR; Mesinger et al. 2006) and found to be similar.

2.2 *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).

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

EMBGR plots were obtained by taking the 850-600 hPa layer average N_m and the corresponding 850-600 hPa $\partial\vec{v}/\partial z$.

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2.3 *TC and Mid-Tropospheric Trough Interaction*

Using this metric, the time of ET is defined when the 200-300 hPa layer-average PV (trough) and 850-700 hPa 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 (Milrad et al. 2009).

2.4 *Precipitation Distribution*

The precipitation shift from symmetric or ROC to LOC is a common occurrence during ET (e.g. Atallah et al., 2007 and Milrad et al., 2009). Time of precipitation shift for LOC cases was defined when the precipitation distribution shifted from symmetric or ROC to LOC. The precipitation shift in all 25 LOC cases occurred within ±24 hours when compared to the time of TC and trough iteraction. ROC cases were usually associated with decaying ET cases (Milrad et al. 2009) and the nature of precipitation distribution shifted from symmetric or weak ROC to a well-defined ROC. The time of TC and trough interaction was used instead as the time of precipitation shift for ROC cases.

Storm-relative composite plots were produced for 20 randomly selected LOC and ROC cases from 36 hours before precipitation shift to 24 hours after, inclusive. Evaluated composite fields and trends include EMBGR, precipitation, and upper-tropospheric trough-TC interaction.

3. RESULTS

Preliminary results for time of ET are presented in the *Manuscript* link available at: https://ams.confex.com/ams/96Annual/webprogram/Paper291678.html (Raghavendra and Milrad 2016).

REFERENCES

Atallah, E. H., L. F. Bosart, and A. R. Aiyyer, 2007: Precipitation distribution associated with landfalling tropical cyclones over the eastern United States. *Mon. Wea. Rev.*, **135**, 2185–2206.

Durran, D. R., and J. B. Klemp, 1982: On the effects of moisture on the Brunt-Vaisala frequency. *J. Atmos. Sci.*, **39**, 2152-2158.

Eady, E., 1949: Long waves and cyclone waves. *Tellus*, **1**, 33-52.

Gyakum, J. R., 2008: The Application of Fred Sanders' Teaching to Current Research on Extreme Cold-Season Precipitation Events in the Saint Lawrence River Valley *Region. Meteorological Monographs*, **33**, 241–250.

Hart, R. E., and J. L. Evans, 2001: A Climatology of the extratropical transition of Atlantic tropical cyclones. *J. Climate*, **14**, 546–564.

Hart, R.E., 2003: A Cyclone Phase Space Derived from Thermal Wind and Thermal Asymmetry. *Mon. Wea. Rev.*, **131**, 585–616.

Hoskins, B. J., and P. J. Valdes, 1990: On the existence of storm-tracks. *J. Atmos. Sci.*, **47**, 1855-1864.

Kofron, D. E., E. A. Ritchie, and J. S. Tyo, 2010: Determination of a consistent time for the extratropical transition of tropical cyclones. Part I: Examination of existing methods for Finding "ET Time". *Mon. Wea. Rev.*, **138**, 4328–4343.

Milrad, S. M., E.H. Atallah, and J.R. Gyakum, 2009: Dynamical and precipitation structures of poleward moving tropical cyclones in eastern Canada, 1979 -- 2005. *Mon. Wea. Rev.*, **137**, 836-851.

Raghavendra, A., and S.M. Milrad, 2016: New Metric for Defining the Time of Extratropical Transition of Tropical Cyclones. 15th Annual Student Conference, New Orleans, LA, Amer. Meteor. Soc., S51. [Available online at https://ams.confex.com/ams/96Annual/webprogram/Paper291678.html]

Rappaport, E. N., 2014: Fatalities in the United States from Atlantic tropical cyclones: New data and interpretation. *Bull. Amer. Meteor. Soc.*, **95**, 341–346.

Saha, S., and Coauthors, 2010: The NCEP Climate Forecast System Reanalysis. *Bull. Amer. Meteor. Soc.*, **91**, 1015-1057.