P6.2

MEDIUM-RANGE TO SEASONAL PRECURSOR CONDITIONS TO HIGHER LATITUDE LANDFALLS OF EXTRATROPICALLY TRANSITIONING HURRICANES

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1. INTRODUCTION

The extratropical transition (ET) of tropical cyclones (TCs) brings about multiple structural changes leading to a shift of the impacts of a given cyclone, such as that manifest by an expanded region of gale-force winds, the potential for trapped fetch waves due to the increase translation speed of the cyclone, and asymmetric precipitation and wind field distributions. A full overview of the structural changes during ET may be found in the composite paper of Jones et al. (2003). While there have been many works aimed at furthering the understanding of the impacts of a single ET event as well as toward the predictability of post-ET evolution, such as those referenced in Jones et al. (2003), little attention has been focused upon the medium-range to seasonal predictability of ET events.

Previous research by Klotzbach and Gray (2004), among others, has identified climate patterns favorable for TC formation within the Atlantic basin to a reasonable degree of accuracy. Research by Hart and Evans (2001) has shown that the variability in ET event frequency cannot solely be explained by the variability in TC event frequency; in fact, TC frequency explains only about half of the variability in ET frequency. That correlations exist within climatic patterns to TC frequency, however, suggests that such correlations may exist leading to increased predictability of ET frequency within the Atlantic basin.

This work attempts to test for such correlations both on seasonal time scales (e.g. January-July of a given tropical season) as well as on shorter time scales (less than two months) using climatic index correlations, genesis locations and storm tracks, and significant synoptic pattern features, respectively. Such comparisons are also performed with regional composites of ET activity within the north Atlantic basin to isolate the features responsible for a particular track evolution in the higher latitudes. Results from such analyses suggest that robust signals appear on shorter and longer time scales toward understanding the variability in ET frequency and track evolution, particularly as functions of climate indices reflecting enhanced trough activity in the midlatitudes and/or an enhanced potential for tropical cyclone formation within the main development region (Goldenberg and Shapiro 1996) of the Atlantic basin.

2. METHODOLOGY

A list of all TCs that completed ET found within the National Hurricane Center (NHC) Best Track database (Jarvinen et al. 1984) for the north Atlantic basin during the 34-year period from 1970-2003 was extracted and further composited into three higher-latitude composites – storms that approached the New England region of the United States, storms that approached the Canadian Maritime region, and storms that approached Europe – and two higher-latitude compound composites – storms that approached both the Canadian Maritime region and either New England or Europe. A storm was determined to have impacted either New England or the Canadian Maritime region if it came within 300km of their respective coastlines, while it was determined to have impacted Europe if it passed the Prime Meridian (0°E) as a unique entity.

Data from seven major climate indices – Arctic Oscillation (AO), North Atlantic Oscillation (NAO), Quasi-biennial Oscillation (QBO), Southern Oscillation Index (SOI), Madden-Julian Oscillation (MJO), Pacific Decadal Oscillation (PDO), and Pacific-North American (PNA) pattern index – were obtained on monthly time increments from January 1970 through December 2003 (January 1979 to December 2001 for the MJO). Linear correlations were performed between the values of the climate indices and the number of TCs, number of ET events, and percentage of storms that underwent ET in each of the six composites. Such correlations were performed both with respect to seasonal activity, where the values for the aforementioned three variables over an entire tropical season are correlated to the values of the climate indices for each month of the corresponding year; and with respect to monthly activity, where the monthly values of the three storm season values from June-November are correlated to the values of the climate indices for the given month and for each of the preceding three months of the year. A student t-test is applied to the correlations to determine which are significantly different from zero (i.e. a significant linear correlation exists), with the 90% significance threshold set as the minimum value to establish a significant correlation. Results from significance testing upon the composite of all transitioning storms are used to narrow the field of correlations for testing within each of the regional composites; this is done to ensure the robustness of the results toward correctly identifying a higher-latitude impact as also corresponding to an ET event.

Composites of the Northern Hemisphere synoptic pattern in each of the 60 days prior to ET or approach for each composite are created utilizing data from the NCAR-NCEP Reanalysis dataset (Kalnay et al. 1996) available on six-hourly intervals at 2.5° by 2.5° horizontal resolution. Five variables are utilized within the analysis – mean sea-level pressure (hPa) and the geopotential height (m) at 250hPa, 500hPa, 700hPa, and 850hPa – across the entire Northern Hemisphere. Mean and standard deviation fields of these variables are created as three-day centered mean fields, such that the synoptic fields lagging the time of approach *t* are averaged utilizing data between *t-1* and *t+1* days prior to approach within one of the composites.

Climatologies for each of the composites are created by constructing a 34-year composite of these synoptic fields at the date and time of ET or approach to a given region. For both the composites and their climatologies, the long-term mean of each of the five synoptic fields is subtracted from each of the members of the composite, such that the comparison is between the mean difference of the climatology field from the long-term mean and the mean difference of the composite field from the long-term mean. A student t-test is again applied to determine whether or not the synoptic patterns associated with each of the composites are significantly different from climatology for each of the five variables in question. Furthermore, a student t-test is applied between each of the composites to determine whether the results from a given composite are unique evolutions leading to a particular higher-latitude storm impact.

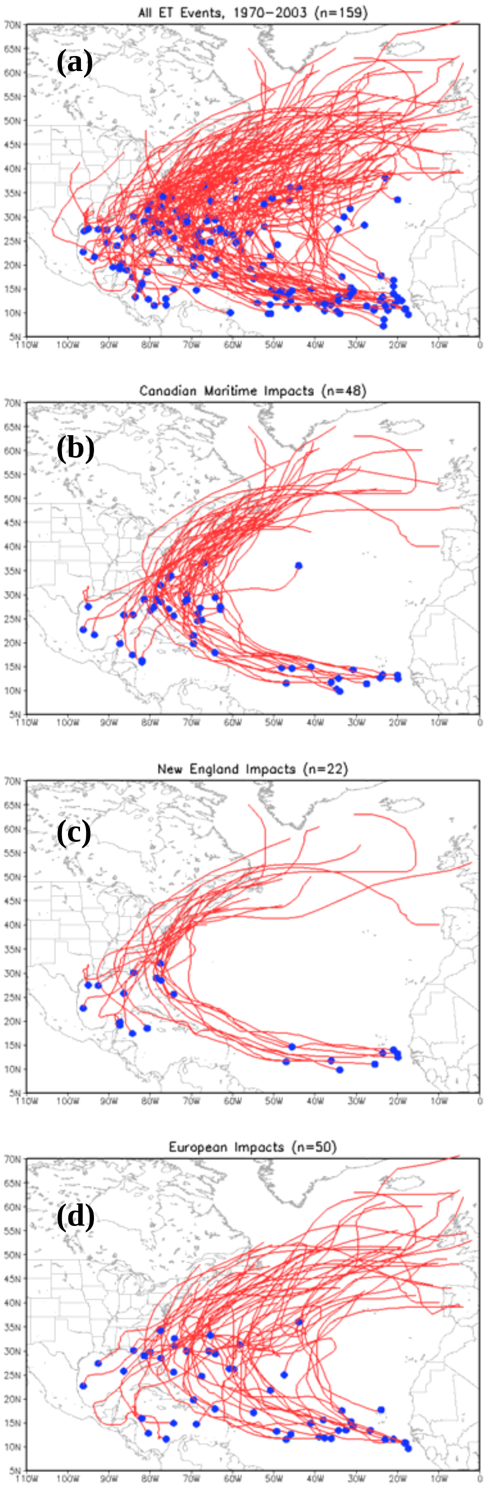

Figure 1: **(a)** Formation point (blue) and tracks (red) of all North Atlantic transitioning TCs from 1970-2003; **(b)** as in (a), except for the Canadian Maritime composite; **(c)** as in (b), except for New England; **(d)** as in (b), except for Europe.

3. RESULTS

Features in the climate index correlations and synoptic patterns in the one week to eight months preceding an ET event show that the potential for a transitioning TC in the basin is increased, whether in terms of additional transitioning storms or by means of a higher percentage of TCs undergoing transition, under a broad array of conditions. Seasonally, conditions promoting a more southerly midlatitude storm track or an amplified trough along the eastern coast of North American in the winter and early summer promote an enhanced risk of ET events. In particular, values of the AO, NAO, and PNA indices in June and July provide highly significant correlations to season-long ET activity. Monthly index correlations provide a significant means of distinguishing between the synoptic patterns and their reflective climate indices favorable for ET events on month-to-month and up to three month lead time scales (Table 1).

There is no preferred genesis region for transitioning TCs (Figure 1), nor is there any particular time during the season in which ET events occur beyond the normal variance explained by total TC activity. A tendency toward earlier season storms is noted within the New England composite, while the subtropics near the southeast United States and the MDR are preferred genesis regions for this and the Canadian Maritime composites. Over synoptic time and spatial scales for all transitioning storms, regions of below-normal sea level pressure and geopotential heights from Siberia to the Gulf of Alaska and above-normal sea level pressure and geopotential heights from Iceland to Scandinavia and over northern Canada are found near the time of transition (Figure 2). In the two weeks prior to transition, other significant

Month of Climate Index	**Month of Tropical Season**					
	June	**July**	**August**	**September**	**October**	**November**
April	**+MJO**	**+MJO**, *-PDO*, *-SOI*				
May	*-AO*, *-MJO*, *-NAO*	-AO, -MJO, *-MJO*, *-PNA*	**+PNA**, +QBO			
June		-AO, -NAO, **+QBO**, *+QBO*				
July		**+PNA**, *+QBO*, **+QBO**, *+SOI*	-AO	*+PDO*	*-MJO*, **-PDO**	
August			+SOI	**-AO**, *+PDO*	-PDO, -PNA, -PNA, +SOI	**-PNA**, *+SOI*
September				*+PDO*, **+PNA**, *-SOI*		*+MJO*
October					*+MJO*, -PDO, *+QBO*, +SOI	
November						

Table 1: A listing of the significant correlations with climate indices for all transitioning storms. Columns denote the month of the climate index value used, while rows denote the month of ET activity. Normal typeface denotes a correlation with the number of ET events, italics denote a correlation with the percentage of TCs undergoing ET, and boldface denotes a correlation with both. Text in yellow denotes a correlation at 90% or higher; in orange to 95% or higher; and in blue to 99% or higher.

features are noted with above-average pressures and geopotential heights in the subtropical central Pacific Ocean and below-average pressures and geopotential heights near Hudson Bay and in the northeastern Pacific Ocean (not shown). Negative phases of the AO are present in the polar latitudes 21-23 and 36-40 days prior to an ET event, while a positive phase of the MJO is noted starting in the tropical northwestern Pacific 40-44 days prior to an ET event (Figure 3). Only subtle differences emerge within each of the regional composites between each other and the larger ET composite within the synoptic fields (e.g. within the European composite in Figure 4).

4. RESEARCH IMPLICATIONS

The results presented here have implications toward insurance and reinsurance efforts in higher-latitude regions as well as toward operational forecasting of transitioning TCs across the north Atlantic. Knowledge of a heightened level of risk of a higher-latitude TC impact to a particular region – or in general – several months in advance of such an impact allows for risk management and reduction techniques to be implemented across the region. This occurs on both seasonal and monthly time scales, where risk can be minimized for an entire season or for just particular months when indicators do not favor a season-long heightened risk. On shorter time scales, when a TC is already present or just forming within the basin, synoptic-scale indicators may be used to highlight an enhanced risk of a higher-latitude impact well in advance of any operational watches or warnings that may be issued. This allows for the reduction of risk to assets that cannot be manipulated on longer time scales, such as marine vessels, military operations, and even day-to-day human activity cycles. In an operational sense, these findings may be used to highlight regions where additional data observations may be needed (such as in terms of adaptive observations) to improve forecast track errors and whether or not efforts need to be coordinated with the appropriate authorities in a particular region for a TC impact. The findings presented here may be expanded upon with a statistical prediction scheme along the lines of those used for solely TC activity. It will be important to experimentally test such indicators during future tropical seasons to ensure their validity in an operational manner (e.g. to minimize false alarms and erroneous negative responses), an endeavor planned for future exploration.

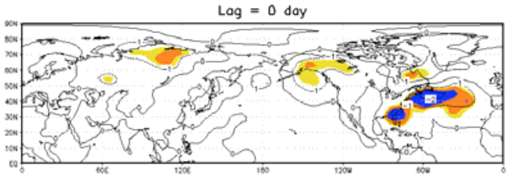

Figure 2: Anomalies (hPa; negative values dashed) in the mean sea-level pressure field for the composite of all transitioning storms at the time of transition. Significant fields are denoted in color shading as in Table 1.

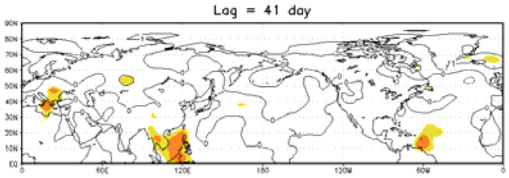

Figure 3: As in Figure 2, but for 41 days prior to transition.

5. ACKNOWLEDGEMENTS

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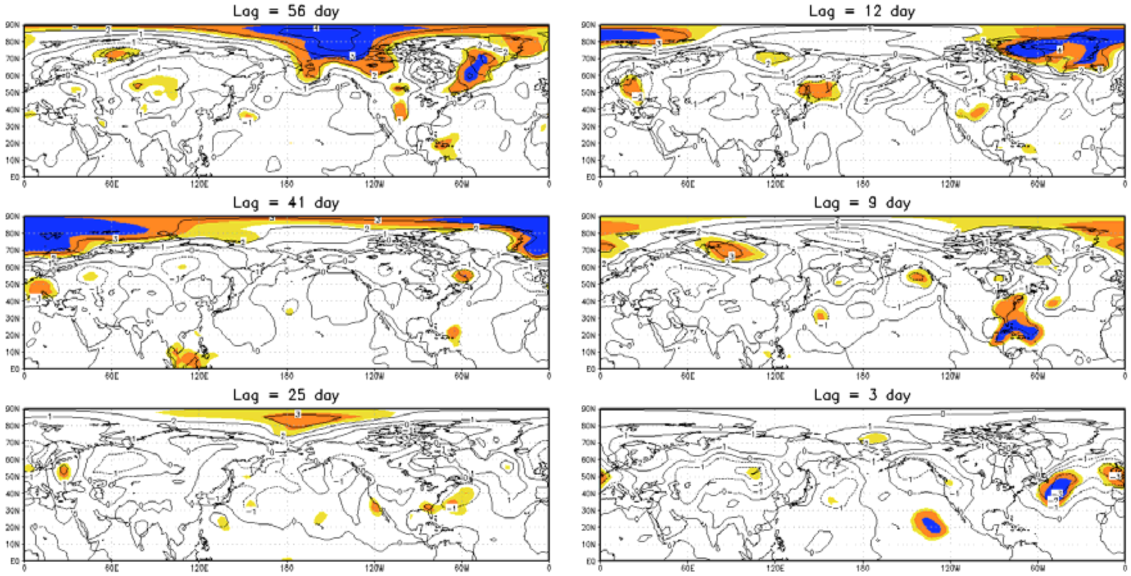

Lag = 56 day

Lag = 12 day

Lag = 41 day

Lag = 9 day

Lag = 25 day

Lag = 3 day

Figure 4: Lag correlations in the mean sea-level pressure field for the European composite from 3-56 days prior to approach to the region. Significance shading is as in Table 1 and anomalies from the climatological mean are contoured (hPa; interval: 1hPa).

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