Abstracting ENSO Spatial Patterns' Impact on Atlantic Tropical Cyclone Seasonal Frequency

2012-05-14

Abstract

1 Introduction

Understanding and predicting tropical cyclone (TC) activity is of significant scientific and societal interest. Pacific Ocean sea surface temperatures (SSTs) have well documented global long-range teleconnections, including Atlantic TC activity [10, 4, 5, 6, 13]. The quasi-periodic cycle (2-7 years) of warming and cooling of the near equatorial Pacific Ocean, known as the El-Niño Southern Oscillation (ENSO), is characterized by the warm El-Niño (EN) phase and a cold La Niña (LN) phase. Researchers have traditionally used the phase of ENSO to predict Atlantic TC activity, however, due to the large amplitude variations in seasonal TC counts, the difference in Atlantic TC activity based on the various phases of ENSO is not obvious (see Figure 1).

ENSO has been quantified using warming-based indices where SST anomalies are averaged over regions in the Pacific. Such indices include the Nino 1+2 (0-10S, 90-80W), Nino 3 (5N-5S, 150-90W), Nino 4 (5N-5S, 160E-150W), and Nino 3.4 (5N-5S, 170-120W) regions. Some studies have suggested such indices do not capture ENSO's nature and evolution. Subsequently, more elaborate indices were developed some of which were linear combinations of the above-mentioned indices [17], while others have proposed indices using transformed data or nonlinear combination of indices [14]. Despite the varying degrees of complexity, the majority of works attempting to capture ENSO focus on the intensity of warming in a the tropical Pacific. While such indices might provide valuable insight into weather teleconnections (are there any good examples where ENSO does really well at predicting teleconnections?), they were not designed to capture the physical pathways by which Pacific SSTs may impact the large-scale conditions over the Atlantic, and subsequent Atlantic Tc activity.

We propose a novel spatial ENSO index (S-ENSO) that is designed specifically to capture the physical pathways by which Pacific SSTs may influence Atlantic TC activity. Our approach introduces a distance-based ENSO index that tracks the location of maximum near-tropical Pacific warming anomaly instead of its absolute warming. We will demonstrate the performance of our index by comparing it to traditional warming-based ENSO indices in both predicting seasonal TC frequency as well as discriminating between the large-scale conditions that are favorable for Atlantic cyclogenesis.

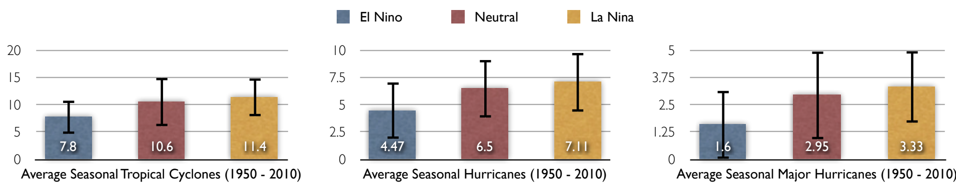

Figure 1: The 1950 – 2010 seasonal mean Atlantic tropical cyclones (a), hurricanes (b), and major hurricane (c) counts for El-Niño, neutral, and La Niña years. Vertical bars denote standard deviation. The overlap between between bars across categories make distinguishing between Atlantic TC activity based on the phase of ENSO uncertain.

2 Spatial ENSO Index (S-ENSO)

An increasing number of studies have suggested changes in the spatial warming patterns of Pacific Ocean (SSTs) [20] and some have linked those changes t o impact U.S. hurricane landfall probabilities [11]. We propose that based on such results, the spatial distribution of Pacific Ocean warming might provide better predictive insights into ENSO-Atlantic TC activity relationship than warming anomalies alone. We propose a distance-based ENSO index that tracks the longitudinal distance between the location of maximum and minimum Pacific tropical warming anomalies instead of the absolute warming of a static region. The S-ENSO index consists of four factors: (i) the longitudinal distance between the warmest and coldest SST anomaly pool in the tropical Pacific, (ii) the mean Outgoing Longwave Radiation (OLR) of the warmest SST anomaly region in the tropical Pacific to monitor atmospheric deep convection, (iii) the mean surface pressure of the warmest SST anomaly region in the tropical Pacific, and (iv) the longitude of the minimal pressure region in the tropical Pacific to approximate Pacific tropical cyclone (typhoon) activity. The S-ENSO index is computed, by first averaging each variable over the March-October then building each of the four indices separately. Then we sum the normalized indices into a single S-ENSO index. For each year from 1979-2011, we search for the region of maximum and minimum warming anomaly in regions of size comparable to that of warming-based ENSO indices. The time series of the longitude of the PWP is then correlated with various quantities that communicate August-October Atlantic TC activity: number of tropical cyclones, number of major hurricanes, potential dissipation index (PDI) [8], accumulated cyclone energy (ACE) [3], and net tropical cyclone energy (NTC) [9].

	TCs	Major Hurricanes	NTC	PDI	ACE
S-ENSO	**0.81**	**0.81**	**0.77**	**0.71**	**0.75**
Nino1+2	-0.42	-0.42	-0.40	-0.3	-0.35
Nino 3	-0.44	-0.5	-0.44	-0.39	-0.40
Nino 4	-0.24	-0.41	-0.23	-0.2	-0.2
Nino 3.4	-0.42	-0.53	-0.42	-0.38	-0.40

Table 1: Linear correlation scores between various indices computed over the March-October period and August-October Atlantic TC activity. The highest score for each category is highlighted in **bold**

Given that S-ENSO's performance depends on the month range over which the index is computed, we performed a month range sensitivity analysis to asses the robustness of our results with respect to month range selection. For every possible month range, we computed the S-ENSO, NINO1.2, NINO3, NINO4, and NINO3.4 indeces to correlated them with August-October Atlantic TC activity. Figure **??** shows the month range sensitivity tests for NINO1.2, NINO3, NINO4, NINO3.4, and S-ENSO. Each cell color represents the the linear correlation coefficients between August-October TC Atlantic TC activity and the index computed over a given start and end month. S-ENSO performs significantly better than especially with increased lead times as NINO indices suffer from a "predictability barrier" that make it difficult to use them to predict TC activity before June [18].

2.1 Impact on large-scale conditions over the Atlantic

To propose possible physical pathways by which our index impact Atlantic TC activity, we compute the composites for factors known to influence Atlantic TC activity: SST, central pressure, potential intensity (PI), and vertical wind shear. Each composite was for the August-October period - the peak hurricane season. To compare how well our index resolves the large-scale conditions that are critical to seasonal TC activity we compare our index' composites to those of the seasonal TC count composites (ground truth) and that of the NINO3.4 composites. The rational is that if our index is better able to distinguish between the large-scale conditions for active and inactive hurricane seasons its composite should closely resemble that of the ground truth (i.e. active minus inactive hurricane years).

Figures 2 - **??** show the composites (active years minutes inactive years) for NINO3.4 (top), Combo Index (middle) and ground truth (bottom).

2.1.1 Central Pressure

Tropical cyclones are low pressure systems, therefore seasons with high TC activity tend to have low pressure means as seen in Figure 2. Our index is able to resolve much lower central pressure across the Atlantic Main Development

Region (MDR) than the NINO3.4 index. It is not clear from this composite whether high TC activity is a cause or effect of large-scale low pressure.

2.1.2 Potential Intensity (PI)

Potential intensity is a variable computed by combining the column integrated air temperature and relative humidity. PI has been shown to provide the theoretical upper bound on storm intensity given air temperature and relative humidity [7]. PI has also been used as a proxy of how conducive an environment is for tropical cyclogenesis [6]. As shown in Figure 3 (bottom), active TC seasons tend to have high PI values along the MDR especially right off the West African coast where African Easterly Waves (AEWs) exit the continental mass. Similar to central pressure, our index (Figure 3 middle panel) resolves similar spatial patterns for PI than the ground truth.

2.1.3 Relative Humidity (RH)

In order for TCs to develop a minimal amount of moisture must be present in the vertical column [7]. That is why active TC seasons tend to have high RH in the East Atlantic where most hurricane form (figure 4). While our index resolves the conditions over the Atlantic better than NINO3.4 (Figure 4 top), it over estimate RH in the Western Atlantic. Other moisture variables to look into are precipitable water and saturation deficit.

2.1.4 Sea Surface Temperatures (SST)

Our index is particularly better at resolving seasonal SSTs compared to NINO3.4.

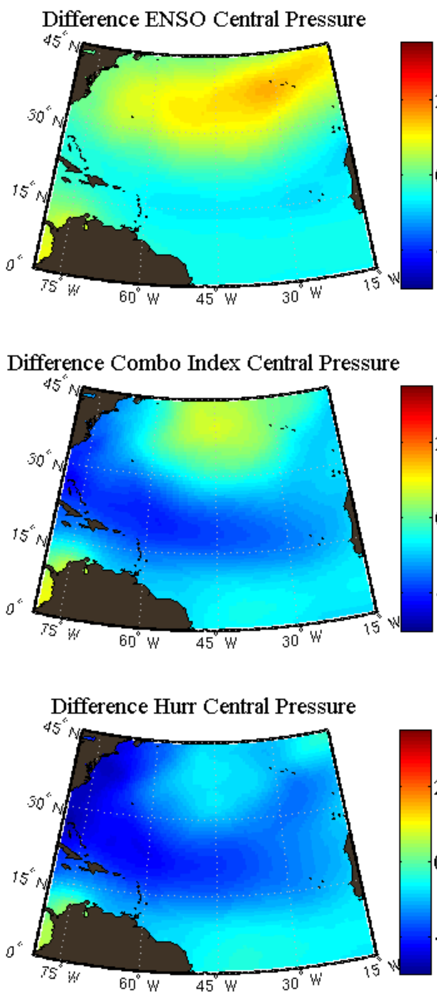

Figure 2: Central pressure composites for NINO3.4 (top), Combo Index (Middle), and Ground Truth (Bottom). Active TC seasons tend to have low pressure.

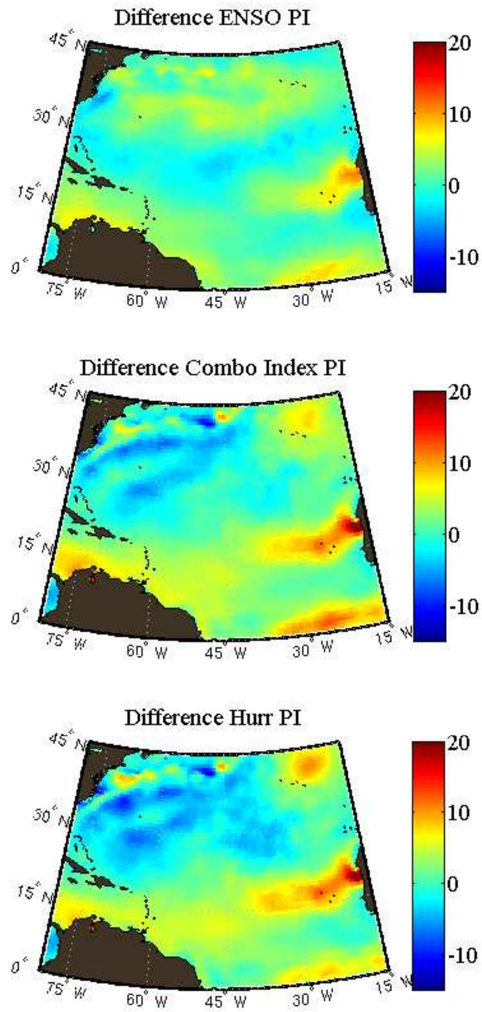

Figure 3: Central pressure composites for NINO3.4 (top), Combo Index (Middle), and Ground Truth (Bottom). Active TC seasons tend to high PI values along the MDR and right off the West African coast.

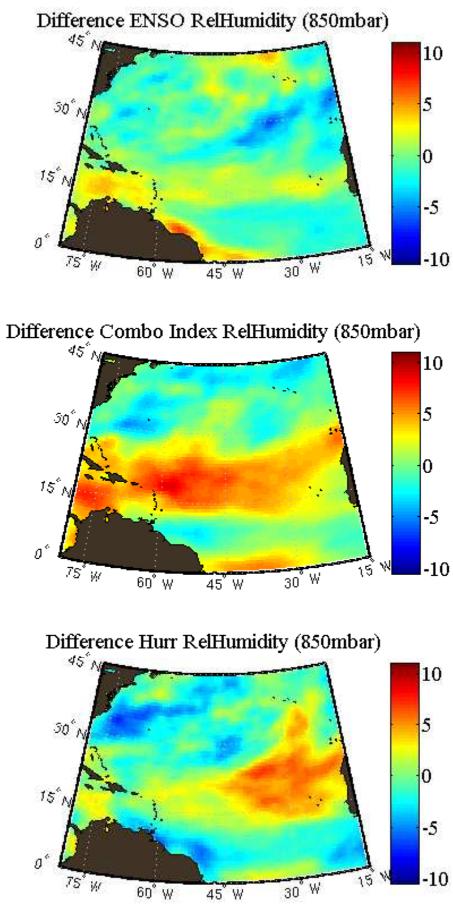

Figure 4: 850 mb Relative Humidity composites for NINO3.4 (top), Combo Index (Middle), and Ground Truth (Bottom). Active TC seasons tend to have high RH along the MDR.

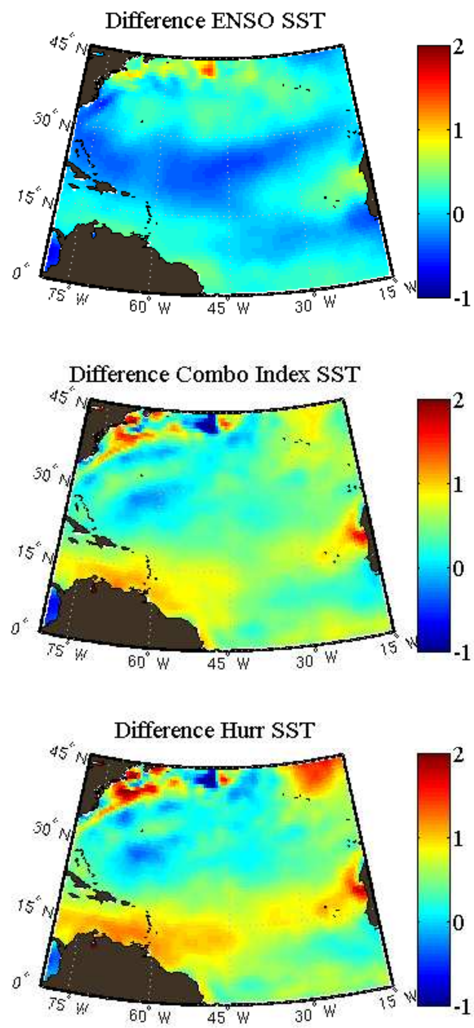

Figure 5: SST Composites for NINO3.4 (top), Combo Index (Middle), and Ground Truth (Bottom). Active TC seasons tend to have high SSTs along the MDR and in the North Atlantic.

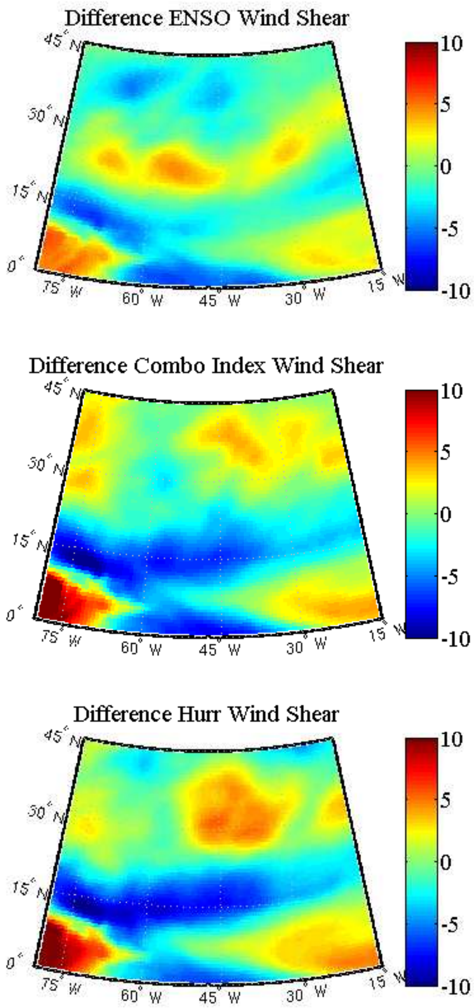

Figure 6: Vertical wind shear (VWS) Composites for NINO3.4 (top), Combo Index (Middle), and Ground Truth (Bottom). Active TC seasons tend to have low VWS along the MDR.

3 Appendix

3.1 ENSO Overview

The quasi-periodic cycle (2-7 years) of warming and cooling of the near equatorial Pacific Ocean, known as the El-Niño Souther Oscillation (ENSO) is associated with anomalous atmospheric circulation and alterations to the Eastern Pacific thermocline (the subsurface boundary between upper warm waters and deep cool waters). During its warm, El-Niño (EN) phase, the equatorial Pacific Ocean experiences weak easterly winds causing an increase in Eastern Pacific SSTs, that in turn alters the atmospheric zonal (Walker) circulation, generally resulting in prevailing westerlies. ENSO's cold, La Niña (LN) phase, is characterized by the opposite atmospheric conditions – with cold SST anomalies along the Eastern Pacific and warm ones near the Western Pacific as a result of prevailing easterly winds (see Figure 12). The mechanisms that control the reversal to the opposite LN phase are not fully understood [12, 15]. Recent research has suggested that to fully capture ENSO activity, it is no longer sufficient to monitor the warm and cold phases in the Eastern Pacific. Instead, warming patterns in the Central Pacific must be monitored as well [1]. Warming in the Central Pacific, known as El Niño Modoki, where a warm waters are surrounded by cold ones has been observed with increased frequency since the 1990s. Such changes have been attributed to anthropogenic global warming [20] as well as natural climate variability [19].

Enhanced convection as a result of anomalous Pacific Ocean warming is associated with strong westerly upper tropospheric wind over the Caribbean basin and tropical Atlantic, resulting in low TC activity during EN events and high TC activity LN [10]. Other studies have suggested that ENSO impact Atlantic TC activity via tropospheric warming [16].

3.2 Combo Index Cross Validation Month Range Sensitivity Experiment

In this section we compute the combination index in the same fashion as described in the previous section. These results are for building the index with varying month ranges, and then performing leave one-out cross validation with the combination index and 5 different hurricane statistics

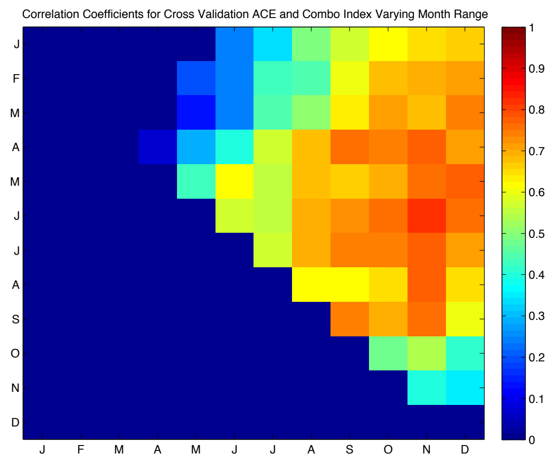

Figure 7: Corr Combo Index vs. ACE

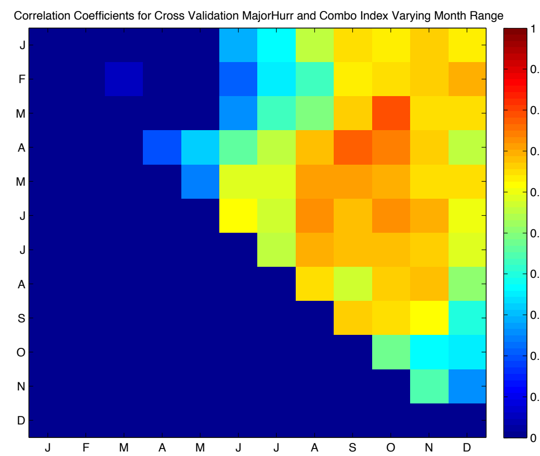

Figure 8: Corr Combo Index vs. Major Hurr

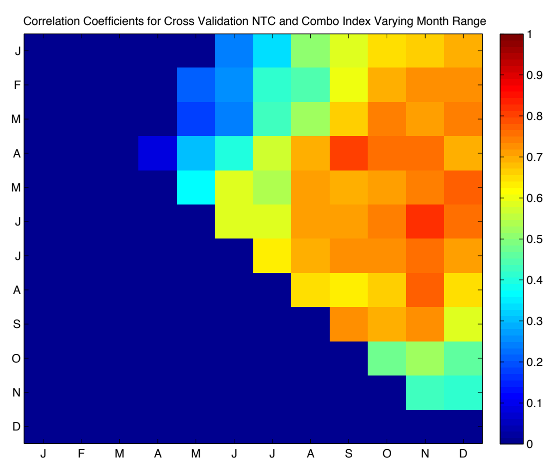

Figure 9: Corr Combo Index vs. NTC

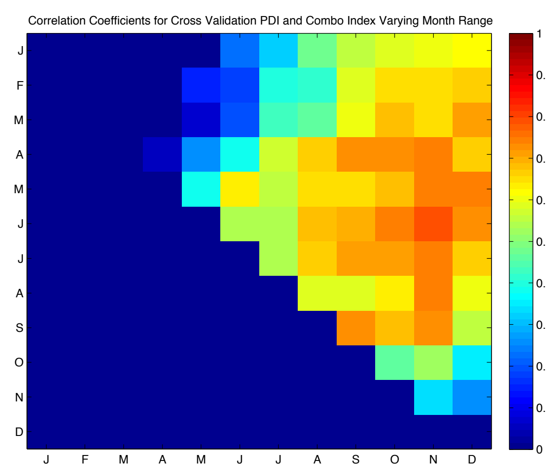

Figure 10: Corr Combo Index vs. PDI

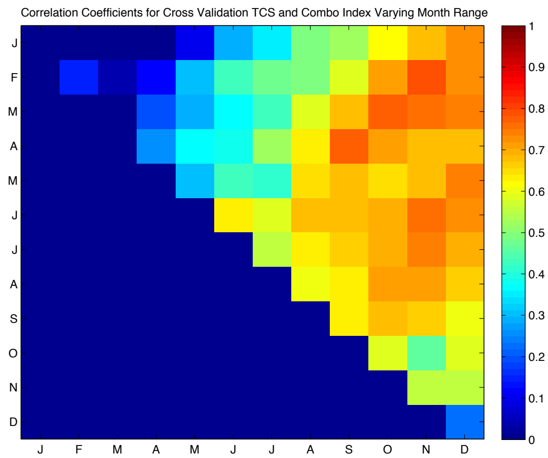

Figure 11: Corr Combo Index vs. TCs

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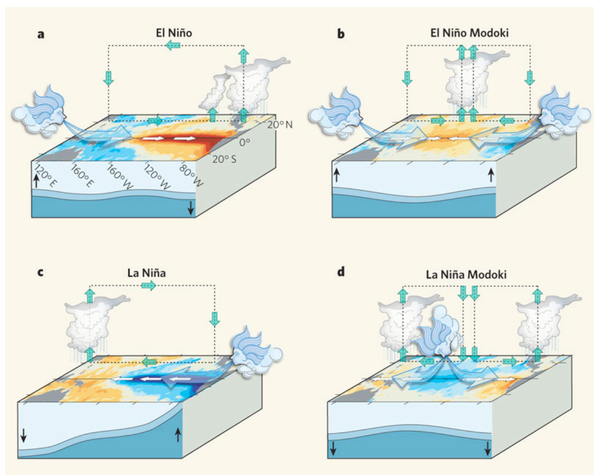

Figure 12: (a), An El Niño event is produced when the easterly winds weaken; sometimes, in the west, westerlies prevail. This condition is categorized by warmer than normal sea surface temperatures (SSTs) in the east of the ocean, and is associated with alterations in the thermocline and in the atmospheric circulation that make the east wetter and the west drier. (b), An El Niño Modoki event is an anomalous condition of a distinctly different kind. The warmest SSTs occur in the central Pacific, flanked by colder waters to the east and west, and are associated with distinct patterns of atmospheric convection. (c), (d), The opposite (La Niña) phases of the El Niño and El Niño Modoki respectively. Image and caption used for illustration purposes only taken from [2]

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