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

2012-05-14

Abstract

1 Introduction

Pacific Ocean sea surface temperatures (SSTs) have well documented global long-range teleconnections, including Atlantic tropical cyclone (TC) activity [11, 3, 4, 5, 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), has been used to predict Atlantic TC activity for decades. However, due to the large amplitude variations in seasonal TC counts, the difference in Atlantic TC activity based on the phase of ENSO is not obvious (see Figure 1).

Traditionally, ENSO has been quantified using warming-based indices where SST anomalies are averaged over fixed regions in the Pacific Ocean. An increasing number of studies suggest that monitoring static regions may not be enough to capture the complex ENSO phenomenon [18, 1, 20, 12]. Furthermore, other studies proposed that the Pacific Ocean warming patterns are changing - with warm anomalies shifting towards the Central Pacific. Such changes have been attributed to anthropogenic global warming [20] as well as natural climate variability [19]. Based on these findings, it is evident that in order to capture ENSO's long range impact on the tropical Atlantic a new measure of Pacific warming is needed.

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. Tropical Atlantic SST variability west of 40W and extending into the Caribbean is correlated with Pacific ENSO variability, with 50-80% of the anomalous SST variability in the region associated with ENSO [8]. However, a large number of TCs, especially the most intense hurricanes, originate east of 40W (based on the NOAA best track hurricane data). Therefore, it is important for any index to resolve the large-scale conditions over the eastern tropical Atlantic. 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 discriminating between the large-scale conditions that are favorable for Atlantic cyclogenesis.

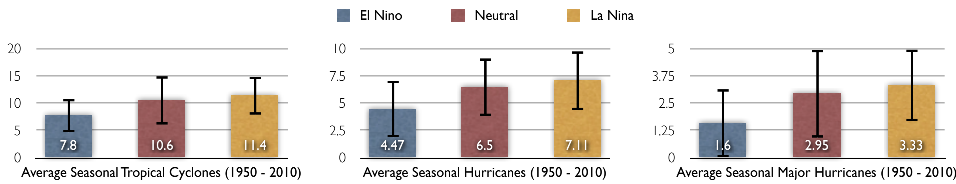

Figure 1: The $1950 - 2010$ seasonal mean Atlantic tropical cyclones (a), hurricanes (b), and major hurricane (c) counts for El-Niño, neutral, and La Niña years. Vertical bars denote standard deviation. The overlap between between bars across categories makes distinguishing between Atlantic TC activity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

2 Spatial ENSO Index (S-ENSO)

We propose that the spatial distribution of Pacific Ocean warming might provide better predictive insights into ENSO-Atlantic TC activity relationship than warming anomalies alone. S-ENSO is a distance-based ENSO index that tracks the longitudinal location of highest SST anomaly in the tropical Pacific. We also track the mean Outgoing Longwave Radiation (OLR) of the identified region to monitor the atmospheric deep convection associated with such anomalies. The S-ENSO index is computed by first averaging the SST anomalies over the March-October period to accurately capture ENSO's evolution prior to and during the Atlantic hurricane season (August-October). We then search the tropical Pacific (5°S-30°N) for a region of similar size than traditional ENSO indices that has the highest mean SST anomaly over the March-October (see figure 2). Once such a region is identified, we compute the mean OLR over that region and use it as a single entry in the index. We repeat this procedure for each year from 1979 to 2010. Table 1 shows S-ENSO's linear correlation coefficients with various quantities that communicate August-October Atlantic TC activity: number of tropical cyclones, number of major hurricanes, potential dissipation index (PDI) [7], accumulated cyclone energy (ACE) [2], and net tropical cyclone energy (NTC) [9].

3 S-ENSO's 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: potential intensity (PI), saturation deficit between the mid- and

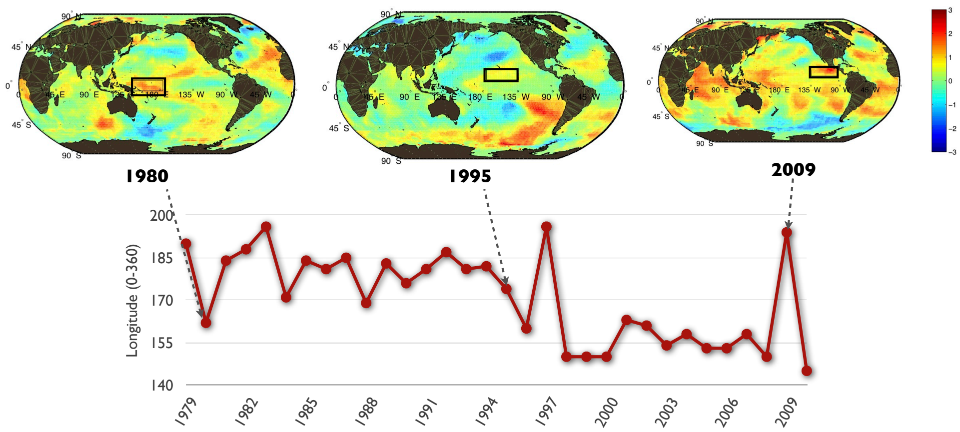

Figure 2: A schematic demonstrating how the S-ENSO index is built. First, SST anomalies over March-October are computed resulting in maps similar to those above. Next, we search the tropical Pacific for the region with the highest mean SST warming anomaly over March-October. Finally, we record the longitude of that region. We repeat this procedure for all years from 1979-2010.

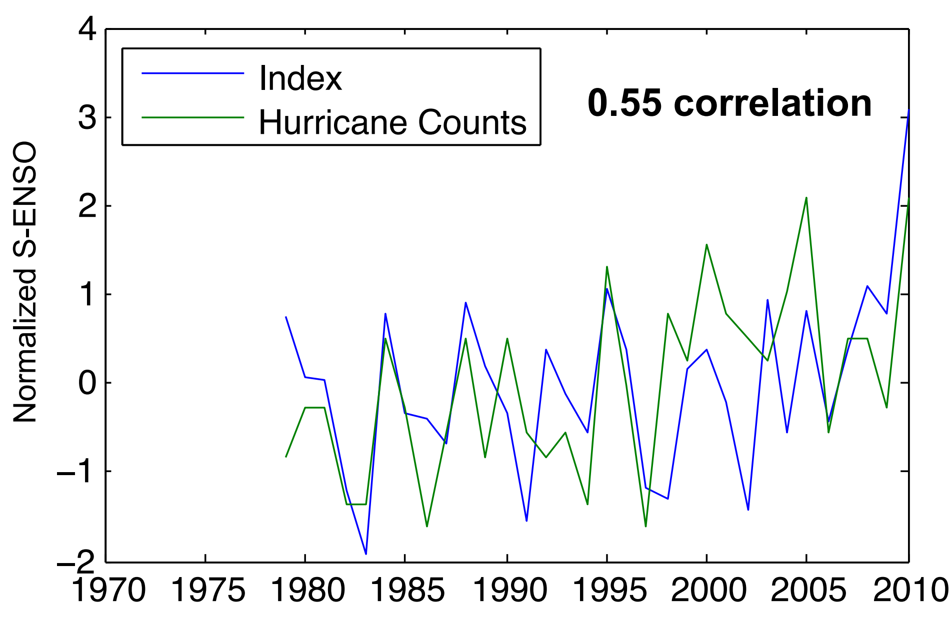

Figure 3: The time-series of S-ENSO along with annual August-October Atlantic TC counts.The mean OLR of the the warmest Pacific SST anomaly region and August-October Atlantic TC counts (0.55 linear correlation). There is a notable shift in the SST anomaly signal after 1997.

	TCs	Major Hurricanes	NTC	PDI	ACE
S-ENSO	**0.55**	**0.57**	0.50	**0.46**	**0.48**
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 coefficients between the March-October S-ENSO and August-October Atlantic TC activity. The highest score for each category is highlighted in **bold**

lower-troposphere and vertical wind shear between 850 and 200 hPa. (also not shown we have composites for SST, central pressure, geopotential height and precipitable water). 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 (baseline) and those of the most common warming-based ENSO index: NINO3.4. The idea is that if our index is better able to distinguish between the large-scale conditions for active and inactive hurricane seasons its composites should closely resemble those of the baseline (i.e. active minus inactive hurricane years). Furthermore, Recent hurricane downscaling studies [14, 6] as well as genesis indices [16] have shown that the large scale environment over the Atlantic might play a dominant role in modulating Atlantic TC activity than precursor disturbances, since these simulations do not model such disturbances yet are able to reproduce Atlantic TC climatology with significant accuracy.

Previous work investigating the ENSO-Atlantic TC teleconnection proposed that enhanced convection as a result of anomalous Pacific Ocean warming during the El Niño phase is associated with strong westerly upper tropospheric wind over the Caribbean basin and tropical Atlantic, resulting in low TC activity during ENSO's warm phase (El Niño) events and high TC activity during its cold phase (La Niña). Warm eastern Pacific SST and negative (drought) Sahelian rainfall anomalies are associated with suppressed Atlantic basin tropical cyclone activity through an equatorially confined near-zonal circulation with upper-level westerlies and lower-level easterlies that act to increase the climatological westerly vertical shear in the main development region [10]. Other studies have suggested that ENSO impact Atlantic TC activity via tropospheric warming [17], since warm free tropospheric temperatures that are spread eastward from the Pacific by equatorial wave dynamics (e.g. Kelvin waves) can inhibit TC activity by providing a too weak vertical temperature gradient for TC activity to occur. Analogous to reduced vertical temperature gradient, a reduced vertical gradient of saturation deficit suppresses vertical mixing and thus negatively affects TC activity.

However, it seems that by monitoring the deep convection associated with the region with the highest Pacific SST warming anomaly, we succeed to observe the strength and location of updrafts related to this convection and the resulting strength and location of the zonal Walker circulation, as well as its impact on the tropical Atlantic circulation, as described in e.g. [15], who suggest that the remote impact contributes to nearly half of the variance of the tropical Atlantic SST variability at interannual and decadal time scales. Updrafts over the eastern and central Pacific during El Niño result in downdrafts and therefore reduced TC activity over the tropical Atlantic, whereas updrafts over the western Pacific during neutral and La Niña years result in downdrafts over the eastern tropical Pacific and updrafts over the Atlantic, thus leading to increased TC activity.

4 Acknowledgments

We thank Prof. David Nolan for providing us with the MATLAB routines to compute potential intensity (PI) from reanalysis data.

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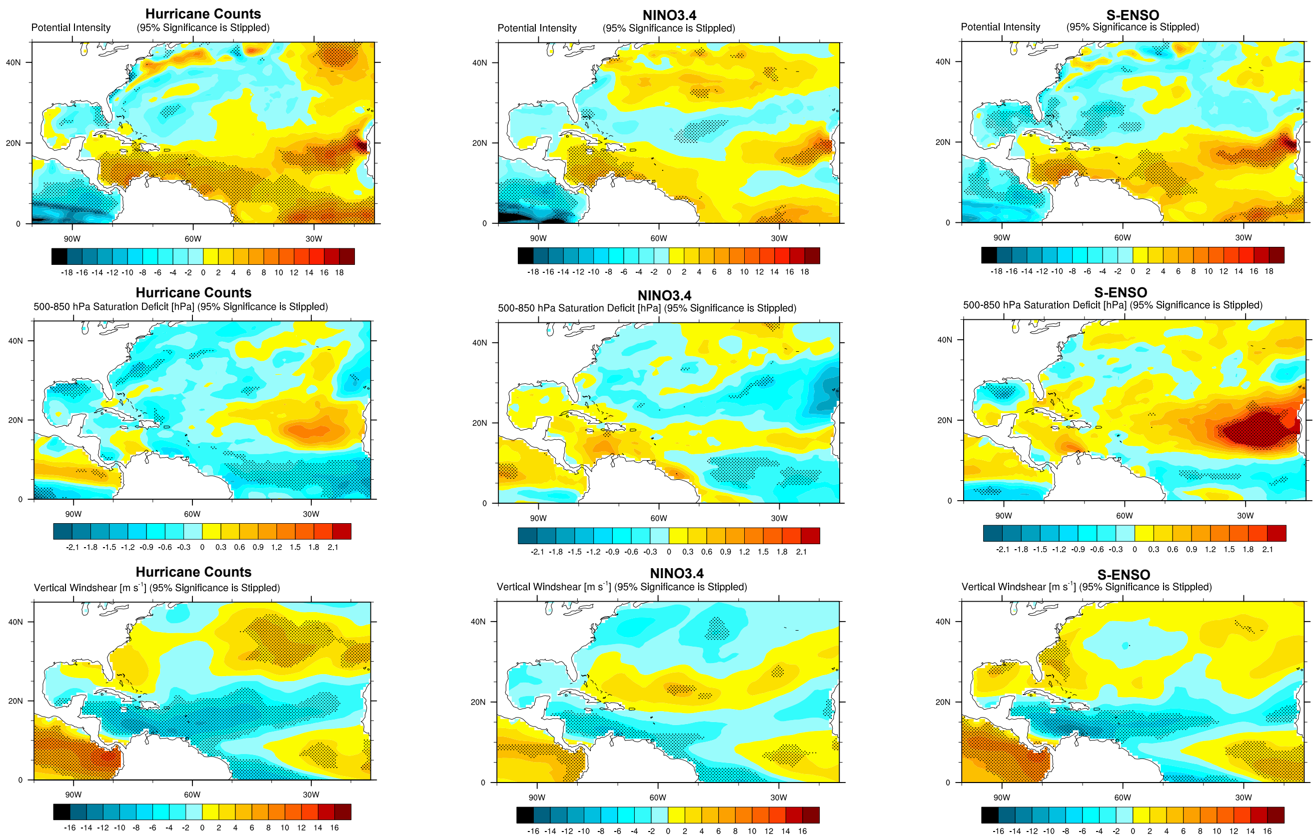

Figure 4: composites for PI (top row), the difference in saturation deficit between 500 and 850 hPa (middle row), and vertical wind shear between 200 and 850 hPa (bottom) row. Each column shows the composites for hurricane counts (left), NINO3.4 (middle), and S-ENSO (right). 95% significance intervals are shaded. Shaded area represents 95% significance level. The hurricane count positive years (6) are: 1995, 2001, 2003, 2005, 2008, and 2010. The hurricane count negative years (8) are: 1982, 1983, 1986, 1987, 1992, 1993, 1994, 1997 and 2002. The NINO3.4 positive years (8) are: 1981, 1984, 1985, 1988, 1999, 2000, 2007, and 2008. The NINO3.4 negative years (6) are: 1982, 1987, 1991, 1992, 1997, 2002. S-ENSO positive years (6) are: 1989, 1995, 2003, 2005, 2008, 2010. S-ENSO negative years (6) are: 1982, 1983, 1991, 1997, 1998, 2002. For all three variables, S-ENSO reproduces the large scale environment over the Atlantic better than the traditional warming-based ENSO index NINO3.4

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