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RESEARCH LETTER
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Atmospheric and Oceanic Influences on Seasonal Atlantic Tropical Cyclone Landfall Probability

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Key Points:

- El Niño–Southern Oscillation (ENSO) influences the percentage of tropical cyclones (TCs) that make landfall over the Americas and Caribbean
- The number of named storms, landfalling named storms, and probability of landfall increase during La Niña and decrease during El Niño
- ENSO's influence on TC environmental favorability and steering flow work in concert to enhance or reduce TC risk

Supporting Information:

Supporting Information may be found in the online version of this article.

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Abstract Modes of tropical atmosphere-ocean variability, such as the El Niño–Southern Oscillation (ENSO) and Atlantic Meridional Mode (AMM), are useful predictors of seasonal Atlantic tropical cyclone (TC) frequency. However, the percentage of TCs that make landfall has varied widely year-to-year since 1980 (13%–75%) and is weakly correlated with the number of landfalling TCs. In this study, we investigated the relationship between the percentage of TCs that made landfall over the Americas and Caribbean Islands and ENSO and AMM using observations from 1980 to 2025. We found that while ENSO strongly influences landfall probability, the AMM does not. ENSO alters TC steering flow through a Rossby wave train response. Furthermore, ENSO's influence on TC environmental favorability and steering flow work in concert to increase the number of TCs and landfall probability during La Niña, and decrease them during El Niño, highlighting an additional utility of ENSO in seasonal Atlantic TC prediction.

Plain Language Summary It is well known that patterns of tropical atmosphere-ocean variability are useful predictors of seasonal Atlantic tropical cyclone (TC) activity. In particular, the El Niño–Southern Oscillation (ENSO), which is characterized by variations in eastern-central tropical Pacific sea surface temperatures (SSTs), and the Atlantic Meridional Mode (AMM), which is characterized by variations in tropical Atlantic SSTs, strongly influence the number of Atlantic TCs and landfalling TCs. However, the annual percentage of TCs that make landfall has varied widely since 1980 (13%–75%) and is weakly correlated with the number of landfalling TCs. In this study, we investigated the relationship between the percentage of TCs that made landfall over the Americas and Caribbean Islands and ENSO and AMM using observations from 1980 to 2025. We found that while ENSO strongly influences landfall probability, the AMM does not. ENSO alters the prevailing winds that steer TCs through a response in the large-scale atmospheric circulation. Furthermore, ENSO's influence on TC environmental favorability and steering flow work in concert to increase both the number of Atlantic TCs and the probability of landfall during La Niña, and to decrease them during El Niño. This research highlights an additional utility of ENSO in seasonal Atlantic TC prediction.

1. Introduction

Tropical cyclones (TCs) are one of the costliest and deadliest natural disasters in the U.S., accounting for at least 7,211 fatalities and $1.5 trillion in damages from 1980 to 2024 (NOAA National Centers for Environmental Information U.S, 2025). The U.S. and Mexico rank 4th and 5th for the number of landfalling TCs, respectively, averaging 3.3 and 3.2 annually from 1971 to 2011 (Fudeyasu et al., 2014). Seasonal TC forecasts commonly focus on the basin-wide number of TCs by intensity category including named storms (≥34 kts), hurricanes (≥64 kts), and major hurricanes (≥96 kts), however impacts usually correspond to the number of TCs that make landfall. Although many above-average Atlantic hurricane seasons have resulted in above-average landfall frequency, some produce few landfalling TCs. In order to better predict seasonal landfalling TC frequency, it is necessary to understand the atmospheric and oceanic influences on not only the seasonal number of landfalling TCs, but also the percentage of TCs that make landfall.

Modes of tropical atmosphere-ocean variability are useful predictors of seasonal Atlantic TC frequency. These include the El Niño–Southern Oscillation (ENSO), which is characterized by interannual variations in eastern-central equatorial Pacific sea surface temperature (SST), zonal shifts in tropical Pacific deep convection, and changes in upper- and lower-tropospheric wind (Bjerknes, 1969) and the Atlantic Meridional Mode (AMM), which is characterized by interannual variations in the meridional tropical Atlantic SST gradient (Chang

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et al., 1997; Chiang & Vimont, 2004; Servain et al., 1999). During El Niño events, warm eastern-central equatorial Pacific SST anomalies and an eastward shift in tropical Pacific deep convection lead to increased vertical wind shear and upper-tropospheric warming in the tropical Atlantic, inhibiting Atlantic TCs, and vice versa during La Niña (Bove et al., 1998; Camargo et al., 2007; Goldenberg & Shapiro, 1996; Gray, 1984; Landsea et al., 1999; Tang & Neelin, 2004). During the positive phase of the AMM, warm northern tropical Atlantic SST anomalies and cool southern tropical Atlantic SST anomalies lead to increased Atlantic TC activity supported by increased favorability of local (i.e., northern tropical Atlantic) SSTs and reduced vertical wind shear, and vice versa for the negative AMM (Kossin & Vimont, 2007; Vimont & Kossin, 2007). ENSO and the AMM can exert constructive and compensating influences on Atlantic TCs with, for example, La Niña and the positive AMM leading to extremely active Atlantic hurricane seasons (Patricola-DiRosario et al., 2014), such as the catastrophic 2017 season (Klotzbach, Schreck, et al., 2018).

Pacific and Atlantic SST variability also influences the frequency of Atlantic TC landfall. Observations from 1900 to 2016 show that La Niña leads to ∼1.75 times more continental U.S. (CONUS) hurricane landfalls than El Niño and that the positive Atlantic Multidecadal Oscillation (AMO), which can excite the AMM on decadal timescales (Vimont & Kossin, 2007), leads to ∼1.3 times more CONUS hurricane landfalls than the negative AMO (Klotzbach, Bowen, et al., 2018). Additional studies similarly found that La Niña tends to increase the probability of U.S. landfalling hurricanes (Bove et al., 1998) and U.S. hurricane losses (Pielke & Landsea, 1999), and vice versa for El Niño. The influence of ENSO on U.S. TC landfall varies by region, with La Niña producing the most pronounced landfall increases along the U.S. East Coast (Klotzbach, 2011; Smith et al., 2007). Balaguru et al. (2025) noted that La Niña favored landfalls along the Atlantic coast of Florida relative to the Gulf Coast of Florida due to modulations in steering flow. Larson et al. (2005) used August–October observations from 1950 to 1998 and found that ENSO influences the percentage of TCs that make landfall over the U.S. and Mexico, with a landfall rate of 19% during El Niño and 31% during La Niña. Similarly, El Niño was 25% more frequent during years with low compared to high U.S. TC landfall counts, whereas La Niña was 18% more frequent during years with high compared to low U.S. TC landfall counts over 1950–2002 (Lyons, 2004). In addition, El Niño is associated with an increase in the percentage of TCs that recurve over the ocean without making landfall, and a decrease in the percentage of TCs that recurve and make landfall based on data from 1950 to 2010 (Colbert & Soden, 2012).

Although the value of modes of tropical climate variability in seasonal TC frequency prediction has been well established, their relationship with the percentage of landfalling TCs over the Americas and Caribbean Islands has not been investigated. The most relevant studies focused on the U.S. and Mexico but did not include the Caribbean Islands, analyzed the peak hurricane season (August–October) rather than the entire season, and/or were performed about three decades ago when substantially fewer reliable observations were available (e.g., Bove et al., 1998; Larson et al., 2005). Furthermore, while the physical mechanisms that explain the relationships between modes of variability and Atlantic TC frequency are well-understood, the mechanisms that explain how climate variability influences the percentage of landfalling TCs are relatively under-studied. Therefore, the purpose of this study is to understand the large-scale atmospheric and oceanic conditions that influence the probability of TC landfall by investigating observed SST patterns (including ENSO and AMM) and large-scale drivers of TC steering flow during Atlantic hurricane seasons characterized by a high and low percentage of landfalling TCs. ENSO is known to initiate extratropical teleconnections through a Rossby wave train response, for example, the Pacific North American pattern (Horel & Wallace, 1981; Wallace & Gutzler, 1981), providing a possible physical mechanism by which tropical Pacific SST can influence TC steering flow in the subtropical Atlantic. We focus on the probability of landfall, as it varies widely from year-to-year and is largely independent of the number of TCs, as shown below. This research provides information that can inform seasonal prediction of landfalling TCs, strengthening the link to TC hazards compared with basin-wide TC frequency.

2. Data and Methods

TC observations were taken from the National Hurricane Center Hurricane Database (HURDAT2) (HRD, 2026; Landsea & Franklin, 2013) as archived in the International Best Track Archive for Climate Stewardship (IBTrACS; Knapp et al., 2010) version 4. We analyzed data from 1980 to 2025 to cover the period with the most reliable records. We considered North Atlantic TCs that reached at least tropical storm intensity (≥34 kts), called "named storms," and included short-lived (<2 days) TCs. A TC was counted as a landfalling TC if it made landfall over the Americas or Caribbean Islands. Landfall information was based on the HURDAT2 database,

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landfall reports from the National Oceanic and Atmospheric Administration (NOAA) Atlantic Oceanographic and Meteorological Laboratory (AOML) Hurricane Research Division (HRD) (HRD, 2026), and the NOAA Hurricane Tracks mapping tool. TCs that had undergone subtropical or extratropical transition before landfall were included in the landfall count. In addition, TCs that reached tropical storm intensity before landfall, but had been downgraded to a tropical depression (<34 kts) at the time of landfall, were also included in the landfall count, as these systems can sometimes still cause significant impacts. TCs that made landfall outside of the Americas or Caribbean (e.g., over Europe, the Azores, or Cabo Verde), without a landfall over the Americas or Caribbean Islands, were not included in the landfall count. In cases where storms made multiple landfalls (e.g., Irma–2017), only one landfall was counted. In this study, we focused on TC frequency and did not analyze TC characteristics at the time of landfall.

In addition to considering the numbers of named storms and landfalling named storms, we calculated the percentage of named storms that made landfall, which notably had a weak correlation ($r = 0.15$) with the number of named storms. We then identified the 8 years with the highest and lowest percentage of landfalling named storms, which corresponds to the top 83rd percentile and bottom 17th percentile, respectively, of the 46 years of observations. We refer to these years as "high landfall probability" and "low landfall probability." In order for a year to be considered, we imposed a criterion that there must be at least 8 named storms, which corresponds to approximately the mean (13.6 named storms) minus one standard deviation (5.4 named storms). This was done to avoid years in which there were very few named storms, which would result in a percentage of landfalling named storms that was sensitive to the number of landfalling storms. For example, while 3 out of 4 named storms that formed in 1983 made landfall, we exclude this season given its extremely low number of named storms. The high landfalling probability years, characterized by 67%–82% of named storms making landfall, were (in order of highest to lowest landfall probability): 1985, 2014, 2002, 1996, 2024, 2007, 1999, and 1988. The low landfalling probability years, which were characterized by 13%–38% of named storms making landfall, were (in order of lowest to highest landfall probability): 1997, 1984, 1980, 2015, 2013, 2025, 2012, and 1991.

Composites of TC tracks for the 8 low landfalling probability years (Figure 1a) and the 8 high landfalling probability years (Figure 1b) show that while there are similar numbers of named storms (97 and 101, respectively), there are relatively few TC tracks in the Caribbean Sea and Gulf of Mexico in the low compared to the high landfalling probability years. In addition, there is a greater occurrence of TC tracks over the central Atlantic during years with low landfall probability. This translates into substantial differences in the number of landfalling named storms, with 28 in the low and 71 in the high landfalling probability composites (Figures 1c and 1d), which corresponds to a composite average landfall probability of 29% and 70%, respectively. For comparison, the average percentage of landfalling named storms over the 1980–2025 period was 51%.

In addition, we analyzed the following modes of climate variability: (a) the AMM using the AMM index, which was calculated by applying Maximum Covariance Analysis to SST and 10-m wind over the tropical Atlantic between 75°E−15°W and 21°S–32°N (Chiang & Vimont, 2004) and (b) ENSO using the Niño3.4 index, calculated as the monthly SST anomaly within 120°W–170°W and 5°S–5°N, the ENSO Longitude Index (ELI; Williams & Patricola-DiRosario, 2018), which represents zonal shifts in tropical Pacific deep convection associated with ENSO, and the relative Oceanic Niño Index (RONI; L'Heureux et al., 2024), which is similar to the Niño 3.4 index but with the average tropical mean (20°S–20°N) SST anomalies subtracted. We used multiple ENSO indices because the Niño3.4 index has been more commonly used historically, whereas the ELI is able to capture spatial variations in ENSO's SST anomalies (e.g., East Pacific vs. Central Pacific El Niño) using one index. The RONI is NOAA's current operational index for classifying ENSO events. We analyzed composites of landfalling TC activity and atmospheric variables for collections of positive/negative AMM and ENSO events. Positive and negative AMM events were defined based on an August–October (ASO) averaged AMM index that was greater than or equal to 2.5 and less than or equal to −0.5. This was done to ensure similar sample sizes ($n = 11$ and $n = 10$ for positive and negative AMM, respectively) due to the asymmetry in the distribution of ASO AMM, which had a median of 1.55. El Niño and La Niña events were defined based on an ASO-averaged Niño 3.4 index of greater than or equal to 0.5 and less than or equal to −0.5, respectively, yielding samples sizes of $n = 12$ and $n = 14$, respectively. The same thresholds were used for ASO-averaged RONI, yielding samples sizes of $n = 13$ for both El Niño and La Niña events. We also considered ENSO events identified using ELI, with El Niño and La Niña events defined as the top and bottom 12 events based on the ASO-averaged ELI, which corresponds to an ELI greater than or equal to 168.8°E and less than or equal to 162.2°E, respectively. Tables S1–S4 in Supporting Information S1 list the years in the AMM and ENSO composites.

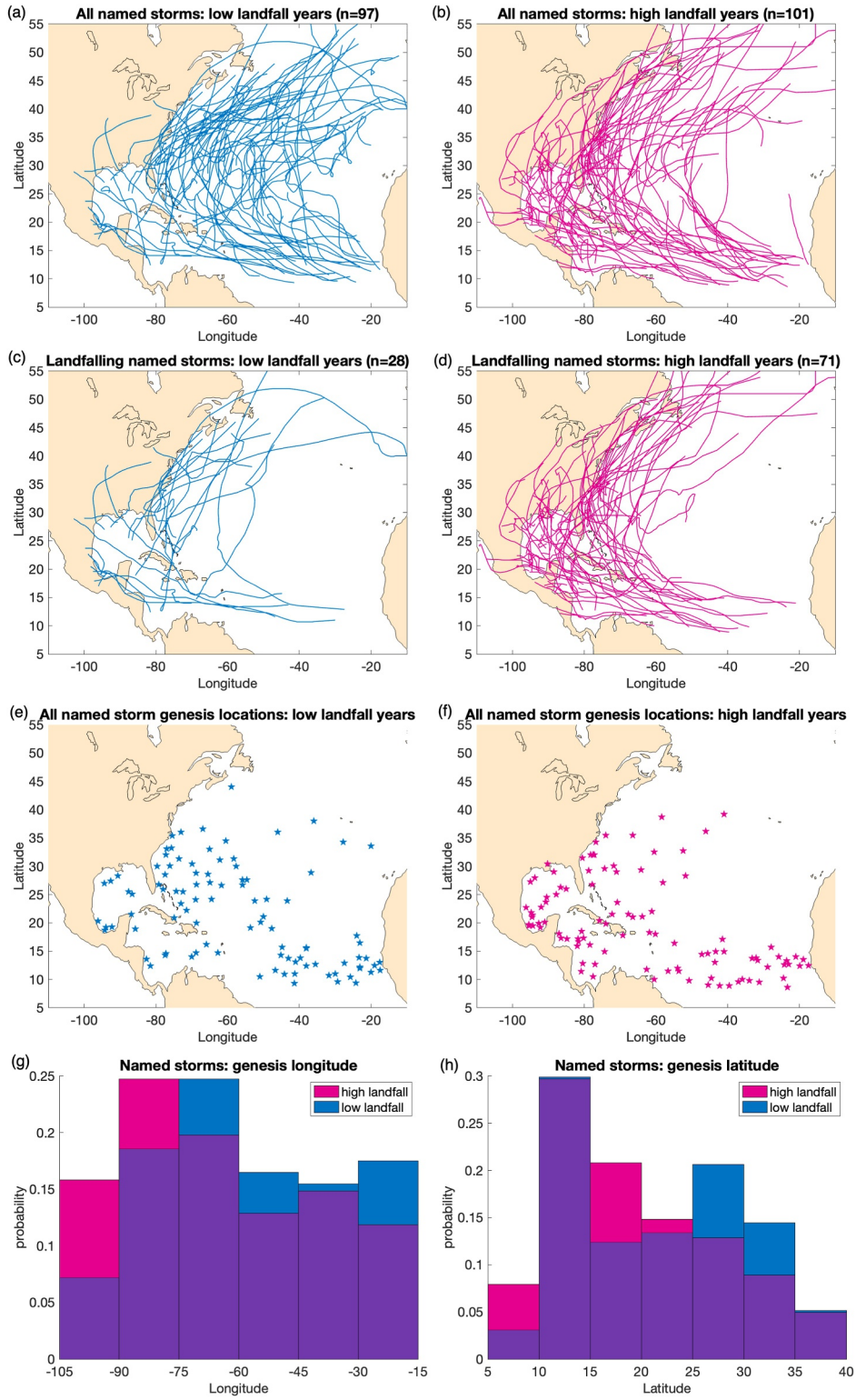

Figure 1. Composites of tropical cyclone (TC) tracks of all named storms during (a) low and (b) high landfall probability years, with the number of tracks labeled. (c) and (d) Same as (a) and (b) but for tracks of landfalling named storms only. Composites of TC genesis locations of all named storms during (e) low and (f) high landfall probability years. The (g) longitude and (h) latitude of TC genesis for all named storms for composites of years with low (blue) and high (magenta) landfalling probability.

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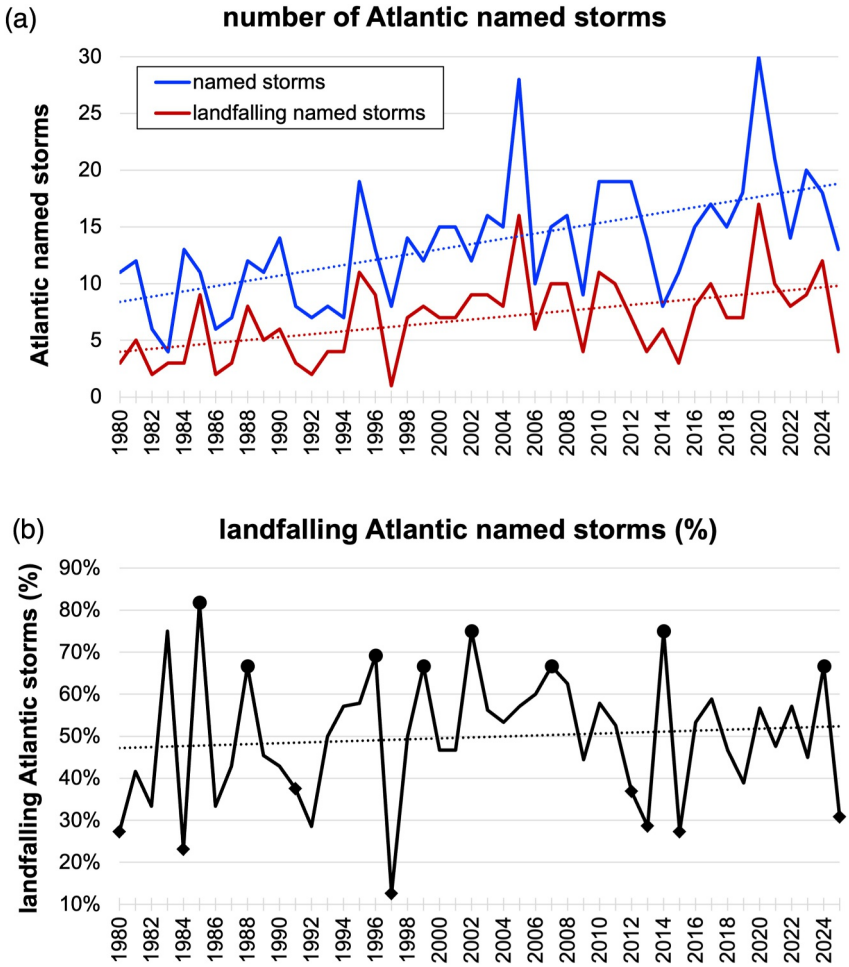

Figure 2. The (a) number of Atlantic named storms (blue) and number of Atlantic named storms that made landfall over the Americas and Caribbean Islands (red) and (b) percentage of Atlantic named storms that made landfall over the Americas and Caribbean Islands based on HURDAT2 observations from 1980 to 2025. In (b), circles denote high landfall probability years and diamonds denote low landfall probability years with at least 8 named storms.

Atmospheric variables were analyzed from the monthly 2.5° × 2.5° resolution National Centers for Environmental Prediction/Department of Energy (NCEP-DOE-II) reanalysis (Kanamitsu et al., 2002). Observed SST was analyzed from the monthly 2.0° × 2.0° resolution Extended Reconstructed SST v5 (ERSSTv5; Huang et al., 2017).

3. Results

We first evaluated trends in Atlantic named storms. Figure 2a shows increasing trends during the 1980–2025 period in both the number of Atlantic named storms (2.3 per decade), which is consistent with the trend during 1990–2021 shown by Klotzbach et al. (2022), and the number of landfalling Atlantic named storms (1.3 per decade). Both trends are statistically significant ($p = 0.05$) based on a Mann-Kendall test. On the other hand, there is a weak (1.1% per decade) and statistically insignificant trend in the percentage of Atlantic named storms that made landfall over the Americas and Caribbean Islands (Figure 2b). This makes sense, given that the trend in landfalling named storms is ~56% of the trend in named storms, which is similar to the climatological 51% landfall rate. These results indicate that the increase in landfalling named storms is due to an increase in the number of named storms, rather than an increasing probability of landfall. Our results are in contrast to the findings of Weinkle et al. (2012), who found no trend in landfalling TCs that were hurricane-strength at landfall globally or by basin from 1944 to 2010, which may be explained by the different time periods and TC intensity

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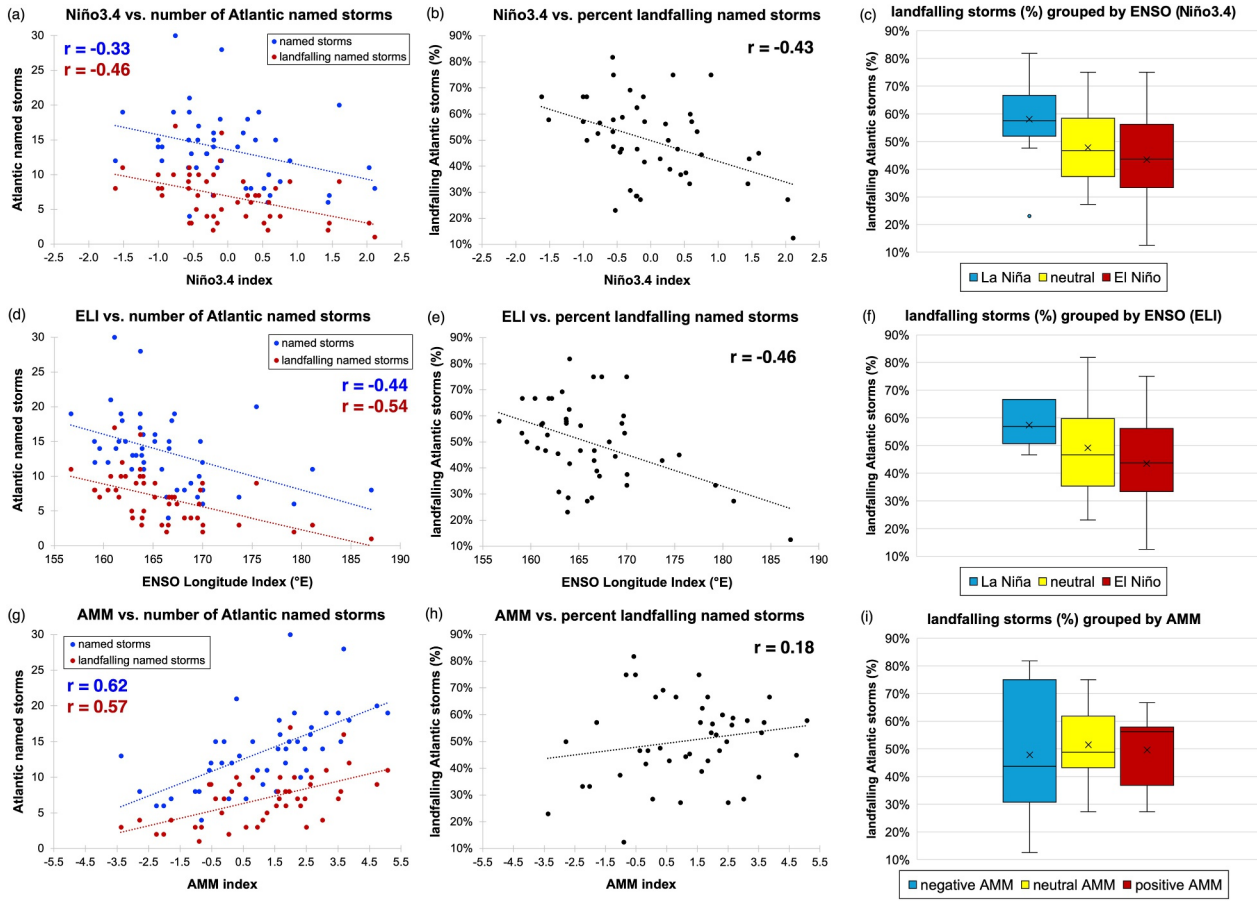

Figure 3. The relationship between the Niño 3.4 index and the (a) number of Atlantic named storms (blue) and number of Atlantic landfalling named storms (red) and the (b) percent of Atlantic named storms that made landfall over the Americas and Caribbean Islands, with linear correlation coefficients (r). Each point represents a year between 1980 and 2025. (c) Boxplots of the percent of named storms that made landfall over the Americas and Caribbean Islands composited according to ENSO phase identified using the Niño 3.4 index. Same as (a, b, and c) but for the (d, e, and f) ENSO Longitude Index (°E) and (g, h, and i) Atlantic Meridional Mode index.

criteria used between the studies. On the other hand, Wang and Toumi (2022) found that globally the number of TCs that made landfall with a landfalling intensity of major hurricane has doubled from 1982 to 2020.

We next investigated the relationship between the percentage of named storms that made landfall over the Americas and Caribbean Islands and ENSO and AMM. As expected, there is a statistically significant ($p = 0.05$) inverse relationship between ENSO and both the number of Atlantic named storms ($r = -0.33$, $r = -0.44$, and $r = -0.37$) and the number of landfalling named storms ($r = -0.46$, $r = -0.54$, and $r = -0.49$), with ENSO identified using the Niño 3.4 index (Figure 3a), the ELI (Figure 3d), and RONI (Figure S1a in Supporting Information S1), respectively. Additionally, as expected, there is a significant ($p = 0.05$) relationship between AMM and both the number of named storms ($r = 0.62$) and the number of landfalling named storms ($r = 0.57$) (Figure 3g). Notably, we found that in addition to influencing the number of Atlantic named storms and landfalling named storms, ENSO strongly influences the percentage of named storms that make landfall over the Americas and Caribbean Islands, with significant ($p = 0.05$) correlations of $r = -0.43$ for the Niño 3.4 index (Figure 3b), $r = -0.46$ for the ELI (Figure 3e), and $r = -0.44$ for the RONI (Figure S1b in Supporting Information S1). This is in contrast to the AMM, which like ENSO, has a strong influence on the number of Atlantic named storms and landfalling named storms, but has a weak and insignificant ($p = 0.24$) relationship with the percentage of landfalling named storms (Figure 3h). A composite analysis of the percentage of named storms that make landfall over the Americas and Caribbean according to ENSO state highlights the utility of ENSO in seasonal prediction of the percentage of landfalling named storms. The landfalling probability is substantially and significantly ($p = 0.05$) greater for La Niña events, with a mean of 58%, 57%, and 58% for ENSO classified using the Niño 3.4 index (Figure 3c), ELI (Figure 3f), and RONI (Figure S1c in Supporting Information S1),

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respectively, compared to El Niño events, which had a mean of 43%, 43%, and 44% for ENSO classified using the Niño 3.4 index, ELI, and RONI, respectively.

To understand the physical mechanisms that explain ENSO's influence on the percentage of landfalling named storms, we investigate composites of ocean and atmospheric conditions during Atlantic hurricane seasons with low and high landfall probability. Consistent with the analyses presented in Figure 3, composite SSTAs for seasons with low (Figure S2a in Supporting Information S1) and high (Figure S2b in Supporting Information S1) landfall probability show signals of El Niño (Figure S2c in Supporting Information S1) and La Niña (Figure S2d in Supporting Information S1), respectively, albeit with a weaker magnitude. In addition, there are relatively weak SSTAs in the tropical Atlantic (Figures S2a and S2b in Supporting Information S1). The results so far show that ENSO strongly influences the landfall probability of named storms whereas AMM does not, while both ENSO and AMM influence named storm and landfalling named storm number. This suggests that ENSO influences both TC environmental favorability (Camargo et al., 2007; Goldenberg & Shapiro, 1996; Gray, 1984; Landsea et al., 1999; Tang & Neelin, 2004) and TC steering flow, whereas AMM primarily influences TC environmental favorability (e.g., Kossin & Vimont, 2007; Vimont & Kossin, 2007). Therefore, we next investigate the large-scale 500 hPa circulation response, including TC steering flow near the coasts of the Americas and Caribbean Islands.

Composites of the August–October averaged 500 hPa circulation during Atlantic hurricane seasons with high landfall probability are characterized by a large-scale wave response emanating from the tropical Pacific into the mid-latitudes of North America (Figure 4b), with an anomalous high pressure centered over the southeastern U.S. coast and TC steering flow toward the Gulf Coast, southeast U.S. coast, and Caribbean Islands (Figure 4f). The steering flow anomaly over the eastern U.S. during the high landfall probability years is similar to that found by Saunders and Lea (2005) during July for above-median seasonal U.S. landfalling hurricane activity during 1950–2003. Interestingly, the 500 hPa circulation during the composite of La Niña events exhibits a similar large-scale pattern (Figure 4d) and local steering flow response near the coasts (Figure 4h). This indicates that a Rossby wave response driven by La Niña contributes to more favorable steering flow for TCs to make landfall over the America and Caribbean, similar to the findings of Colbert and Soden (2012). This landfalling TC favorability is combined with the already-established enhanced environmental favorability through decreased vertical wind shear and upper-tropospheric cooling that tends to increase Atlantic TC frequency. We note that the steering flow anomalies during the high landfall probability years and La Niña years resemble the signature of the Central American Gyre over the Yucatan Peninsula (Papin et al., 2017). Atlantic systems forming from the Central American Gyre tend do so in the Caribbean, increasing their chances of making landfall given their close proximity to land.

The 500 hPa circulation response for the composites of low landfall probability years (Figures 4a and 4e) and El Niño years (Figures 4c and 4g) shows opposite-signed anomalies compared to those for the high landfall probability years and La Niña. Our finding that ENSO's influence on TC steering flow and environmental favorability work in concert to decrease (during El Niño) or increase (during La Niña) both TC frequency and the percentage of TCs that make landfall explains the relationships between ENSO and the number of named storms, number of landfalling named storms, and percentage of landfalling storms (Figure 2). Our findings make sense in the context of Lyons (2004), who inferred that steering flow was more efficient at guiding TCs to the coast during years with high landfall frequency, based on the result that the percentage of Atlantic TCs that made U.S. landfall was higher during years with a high compared to a low landfall frequency.

During August–October, La Niña years tend to be colder than neutral and El Niño years across most of the tropics (Hogikyan et al., 2022), resulting in anomalously low geopotential heights (Figures 4d and 4h). These lower tropical geopotential heights, combined with higher geopotential heights in the subtropics across the western Atlantic, result in anomalous easterly winds across the western Atlantic, favoring landfall in the Caribbean and the Americas (Figures 4d and 4h). In El Niño years, the opposite circulation anomalies occur, disfavoring landfalls (Figures 4c and 4g).

Finally, we present differences in the location of TC genesis during years with low and high landfall probability (Figures 1e and 1f) that, together with the steering flow responses, contribute to landfall probability. Low landfall probability years experienced an eastward and northward shift in the relative probability of TC genesis compared to years with high landfall probability (Figures 1g and 1h). This is consistent with the observational analysis of Lyons (2004), who found that years with high U.S. landfall frequency experienced increased TC genesis in the

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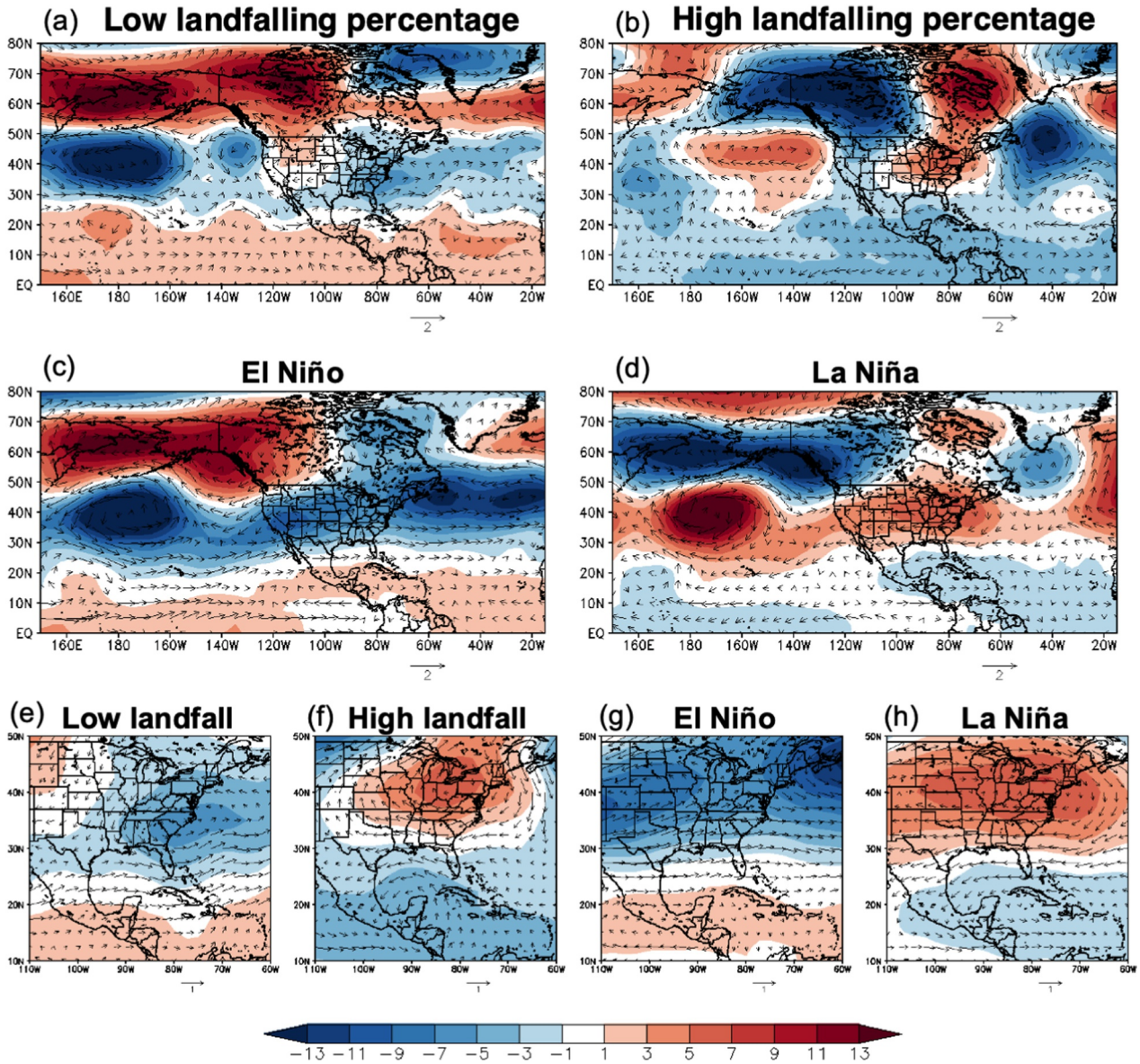

Figure 4. Composites of August-October averaged 500 hPa geopotential height (m; shaded) and wind vectors (m s^{-1}; vectors) for Atlantic hurricane seasons with a (a) low and (b) high percentage of named storms that made landfall over the Americas and Caribbean Islands, and for (c) El Niño and (d) La Niña. (e)–(h) Same as (a)–(d), but zoomed in over the coastlines.

Gulf of Mexico and western Caribbean. Combined with the steering flow responses shown above, these changes in TC genesis location explain the tendency for TC tracks to recurve away from land or continue westward and make landfall (Figures 1a–1d).

4. Discussion and Conclusions

In this study, we investigated the relationship between modes of tropical climate variability and the annual percentage of Atlantic TCs that made landfall over the Americas and Caribbean Islands using observations from 1980 to 2025. We found that the percentage of landfalling TCs varied widely from year-to-year (13%–75%) and is largely independent from the number of Atlantic TCs, motivating the focus on the percentage of landfalling TCs, rather than the number of landfalling TCs. Trends in the number of Atlantic named storms (2.3 per decade) and number of landfalling Atlantic named storms (1.3 per decade) were significant ($p = 0.05$) over the 1980–2025 period, whereas the trend in the percentage of landfalling named storms was weak and insignificant, indicating that the increasing

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trend in the number of landfalling named storms was due to an increase in the number of named storms, rather than an increasing probability of landfall. In addition, we discovered that ENSO significantly ($p = 0.05$) influences the percentage of landfalling named storms, with 58% of named storms making landfall during La Niña events and 43% during El Niño events. On the other hand, the AMM has minimal influence on the percentage of landfalling named storms. This indicates that ENSO influences both TC environmental favorability (which influences the number of named storms and has been established by previous studies) and TC steering flow (which influences the probability of TC landfall and was shown in this study). On the other hand, the AMM primarily influences TC environmental favorability as opposed to TC landfall probability. We found that the physical mechanism that explains ENSO's influence on the percentage of landfalling TCs is a large-scale Rossby wave response that emanates from the tropical Pacific into the mid-latitude North Atlantic and influences the TC steering flow near the American coasts and Caribbean Islands. Notably, we discovered that ENSO's influence on TC environmental favorability and steering flow work in concert to increase both the number of Atlantic TCs and landfall probability, respectively, during La Niña, and to decrease them during El Niño.

Valuable avenues for future research include investigating how the type of El Niño (e.g., East Pacific and Central Pacific) influences Atlantic TC landfall probability and the large-scale circulation and regional steering flow response. Previous research found that the location of SST warming during El Niño is important for the Atlantic TC frequency response. Specifically, atmospheric model simulations showed that the strongest observed Central Pacific El Niño SST pattern is less effective than the strongest observed East Pacific El Niño SST pattern at suppressing Atlantic TCs, owing to a weaker eastward shift in tropical Pacific deep convection and associated tropical Atlantic vertical wind shear response (Patricola-DiRosario et al., 2016). Given those findings, we anticipate that the percentage of landfalling Atlantic TCs would be reduced more by East Pacific El Niño than Central Pacific El Niño, with stronger steering flow away from the Americas and Caribbean in the former. Investigating this using observations would require a longer record in order to have sufficient sample sizes of each El Niño type, whereas investigating this using model simulations would require consideration of any model biases in steering flow, which would be critical for representing the percentage of landfalling TCs. It may also be useful to consider how subseasonal modes of tropical variability, for example, the Madden-Julian Oscillation (MJO), can modulate landfall percentage for the Americas and Caribbean. While the steering flow modulation impact of the MJO on landfall percentage was relatively low over the continental U.S (Klotzbach et al., 2023), the relationship between the MJO and landfall rates over the larger region explored here has yet to be investigated in detail.

This research has important implications for seasonal Atlantic TC prediction by uncovering an additional utility of ENSO. Specifically, it reveals that La Niña not only tends to increase the numbers of Atlantic TCs and landfalling TCs, but also tends to increase the probability of landfall, and vice versa for El Niño, whereas the AMM only influences the numbers of Atlantic TCs and landfalling TCs.

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Availability Statement

Data are available at the following:

- Atlantic Hurricane Database (HURDAT2): Landsea and Franklin (2013) and HRD (2026) https://www.nhc.noaa.gov/data/#hurdat
- National Oceanic and Atmospheric Administration (NOAA) Historical Hurricane Tracks. https://coast.noaa.gov/hurricanes
- NCEP-II reanalysis: Kanamitsu et al. (2002) https://psl.noaa.gov/data/gridded/data.ncep.reanalysis2.html
- ERSSTv5: Huang et al. (2017) https://psl.noaa.gov/data/gridded/data.noaa.ersst.v5.html
- AMM index: https://psl.noaa.gov/data/timeseries/month/DS/AMM/
- Niño3.4 index: https://psl.noaa.gov/data/timeseries/month/DS/Nino34/
- ENSO Longitude Index (ELI): Williams and Patricola-DiRosario (2018).
- RONI: L'Heureux et al. (2024) https://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php

Code available at C. Patricola-DiRosario (2026).

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