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ITCZ Position Effect on the Tropical Cyclone Genesis in North Atlantic †

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Abstract: The interannual TC frequency variability has not been fully understood. Previous studies have shown that the tropical cyclone (TC) frequency could be regulated by the ITCZ location in idealized models, and the Coriolis parameter is an important determinant. Using observations, the relationship between the ITCZ position and the TC frequency, as well as the ENSO influence, have been examined in this study on interannual timescale over North Atlantic. The results show the significant positive correlation between the ITCZ position and TC frequency over North Atlantic (NA) before and after the ENSO influence is removed. When the ITCZ is further northward, the warmer SST, decreased vertical wind shear, increased relative humidity and cyclonic relative vorticity are all conducive to the increase of the TC frequency in tropical NA.

Keywords: ITCZ position; tropical cyclone frequency; ENSO; interannual variability; observation

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1. Introduction

About 90 tropical cyclones form around the world each year. However, it has not been fully understood what controls this number and its year-to-year variability, nor how the annual TC frequency will change under the warming climate [1]. A clear increase of TC genesis frequency is found under the poleward movement of Intertropical Convergence Zone (ITCZ) in idealized aquaplanet simulations: the ITCZ shifts poleward 0.6° latitude in response to the warming of per kelvin, and the TC frequency increases by 40% with one-degree poleward migration of the ITCZ under the warmer condition but decreases by 10%/K under the warming state with fixed ITCZ position [2]. As the position of maximum SST shift poleward, the ITCZ has poleward migration and the TC genesis frequency increase [3,4]. As the ascending branch of the Hadley circulation, ITCZ is associated with strong low level moisture convergence and heavy precipitation [5]. The strong cyclonic vorticity at the poleward flank of ITCZ is favorable for the TC formation [3]. In idealized aquaplanet simulations, more than 95% of total TCs form over this region [2]. The Coriolis parameter f at the ITCZ location is found to be the critical factor controlling TC frequency, and the cyclogenesis almost has a linear growth with the f in tropical region [4]. In idealized state, the poleward movement of ITCZ could contribute to more TC genesis by increasing TC seeds [6].

It is found that TC genesis frequency is constrained by the TC seeds frequency and the survival rate [6,7]: the TC seed frequency is related to low-level relative vorticity and vertical motion, and the interannual variability of TC frequency could be significantly controlled by TC seeds survival rate which is affected by the large-scale environmental factors. Not only the disturbance caused by ITCZ breakdown could trigger cyclogenesis, but also the ITCZ provides a favorable dynamic and thermodynamic environment with large-scale unstable condition, sufficient background vorticity and moisture, favoring for the TC formation [8].

Basing on the recent studies mentioned above, we hypothesized that as the ITCZ moves poleward, the Coriolis force and cyclonic absolute vorticity increases on the poleward flank of ITCZ where many TCs form, making this region more favorable for cyclogenesis. Most previous studies concentrated on the correlation between TC frequency and ITCZ position in response to varying SSTs forced by climate change in idealized aquaplanet simulations which remove the intricacy caused by the asymmetry of continents and seasonal cycle [2–4]. Both TC formation and ITCZ have their own unique characteristics over different basins. We will test this hypothesis in observations on interannual time scale in North Atlantic Ocean in this study.

The data sets and methods will be described in Section 2 and the annual relationship between ITCZ position and TC frequency will be investigated In Section 3. Section 4 will introduce the ENSO effect on ITCZ position and TC frequency. Section 5 will analyze the relationship between the ITCZ position and the variability of large-scale environmental factors. Finally, Section 6 will provide conclusions, discussion and future work.

2. Data and Methods

The observed TC data set is the IBTrACS (International Best Track Archive for Climate Stewardship) version 4, and the TC records are from USA agencies during 1979–2020 [9]. The TC is defined as the storm whose maximum wind speed Umax ≥ 33 knots and the first record for U ≥ 33 knots is defined as its genesis. We use the observed monthly precipitation data from the GPCP (Global Precipitation Climatology Project) version 2.3 over 1979–2020 with the spatial resolution of 2.5° × 2.5° [10]. The ITCZ positions (θ) is defined by the precipitation centroid:

$$\theta = \frac{\int_0^{20} \varphi \times p \times cos\varphi d\varphi}{\int_0^{20} p \times cos\varphi d\varphi} \quad (1)$$

where φ is the latitude and p is the precipitation. The integral is from 0° to 20° N. The ITCZ positions are calculated at each longitude first and then averaged over the target basin.

According to the Kernel Density Estimation (KDE), the fuchsia contour contains 80% of TCs over North Atlantic Ocean (Figure 1). Based on the fuchsia contour, we get the black dotted box which represents the area boundaries for ITCZ location calculation with longitude boundary range of 262° E–345° E, and we use all the TC records in JAS (July–September, red dots) over the whole NA basin.

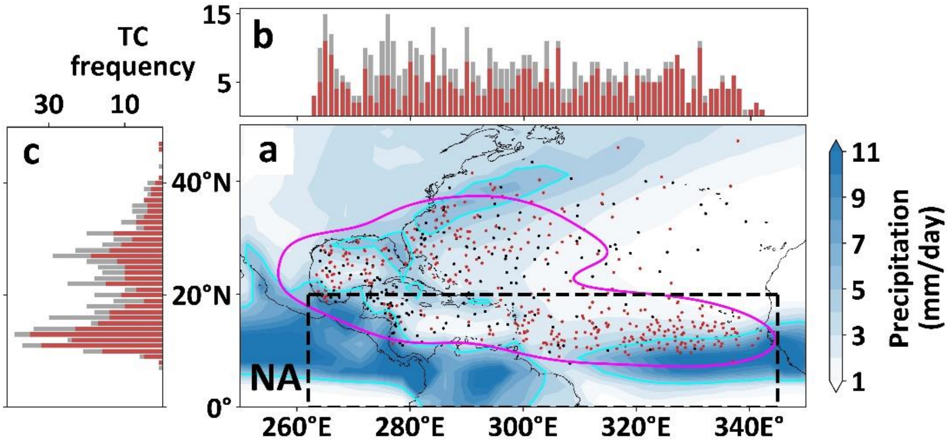

Figure 1. Multiannual (1979–2020) TC genesis and JAS mean precipitation in North Atlantic (NA). The dot represents TC genesis (red dots for JAS, black dots for the rest months) and the shading is the JAS mean rainfall over NA during 1979–2020. The cyan contour represents the rainfall of 5 mm/day, which is also where the ITCZ is located. Fuchsia contour is from the Kernel Density Estimation and it contains 80% of total TCs. The black dotted box represents the area boundaries for ITCZ location calculation, which longitude range is 262° E–345° E. (**b**) Grey bars represent total TC number at 1° longitude interval and red bars represent those in JAS. (**c**) Similar to (**b**), but for latitudinal distribution (in 1° latitude interval).

In this study, the effect of El Niño-Southern Oscillation (ENSO) is represented by Oceanic Niño Index (ONI) in JAS and is obtained from the National Oceanic and Atmospheric Administration (NOAA). The environmental factors such as the SST, relative humidity (at 600 hpa), vertical wind shear (between 200 and 850 hpa) and relative vorticity (at 850 hpa) are all from the ECMWF (European Center for Medium-Range Weather Forecasts) 5th generation reanalysis (ERA5), with 0.25° × 0.25° spatial resolution during 1979–2020 [11].

3. Interannual Relationship between ITCZ Position and TC Frequency

As shown Figure 2a, there is a clear co-variation between ITCZ migration and TC frequency on seasonal cycle in NA. We will explore the relationship between ITCZ position and TC numbers in JAS on interannual time scale during 1979–2020 period (42 years).

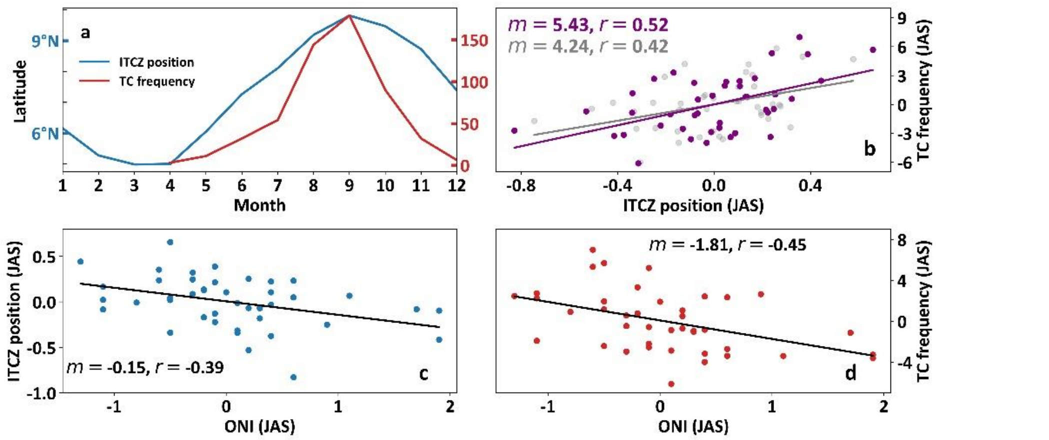

Figure 2. (**a**) Monthly climatology (1979–2020) of ITCZ position and TC frequency in NA; (**b**) Scatter plot between the detrended ITCZ position and TC frequency in JAS over 1979–2020; (**c**) The correlation between JAS ONI and detrended ITCZ position in NA during 1979–2020; (**d**) as (**c**), but for the correlation between the JAS ONI and detrended TC frequency.

The relationship between detrended ITCZ position and detrended TC frequency over NA is shown by the purple label and line in Figure 2b, with their Pearson correlation (r) and linear regression slope (m). As expectation, the correlation (purple number, r = 0.52) is positive, implying the increase of about 5 TCs/degree poleward movement of the ITCZ.

4. ENSO Effect on ITCZ Position and TC Frequency over North Atlantic

ENSO could have strong effect both on the ITCZ (Figure 2c) and TC activities (Figure 2d) on interannual timescale. During El Niño episodes, the tropical Central-Eastern North Pacific become warmer and ITCZ have equatorward migration [5], and there are fewer TCs in JAS over NA during El Niño because of the stronger vertical wind shear. ENSO could also adjust low level convergence and middle troposphere relative humidity, affecting TC frequency [12].

In order to check the ENSO effect on the relationship between ITCZ position and TC frequency, we also removed the ENSO regression from the detrended ITCZ position and detrended TC frequency, and then recalculate this relationship, which is shown by the grey label and line in Figure 2b. Although ENSO significantly adjusts ITCZ position and TC activities respectively, and to some extent it does promote the relationship between ITCZ position and TC frequency. The correlation remains significant in NA even after ENSO signal removed.

5. Spatial Correlation Distribution with Environmental Factors

Previous studies have revealed the environmental conditions required for cyclogenesis, such as the warm tropical SST, weak vertical wind shear, sufficient moisture and cyclonic absolute vorticity [13]. The north-south displacement of ITCZ also could reduce the vertical wind shear to adjust the TC activity in Caribbean Sea [14], increasing the genesis probability and survival rate.

Figure 3 is the correlation between the environment factors time series in each spatial grid point and NA ITCZ position in JAS from 1979–2020. There are total 42 years and the degree of freedom is 40 with the Pearson correlation critical value of 0.304 at 95% significance level. For tropical NA, the warmer SST, decreased vertical wind shear, increased relative humidity and cyclonic relative vorticity (Figure 3a–d), are all conducive to TC increase during the ITCZ northward period.

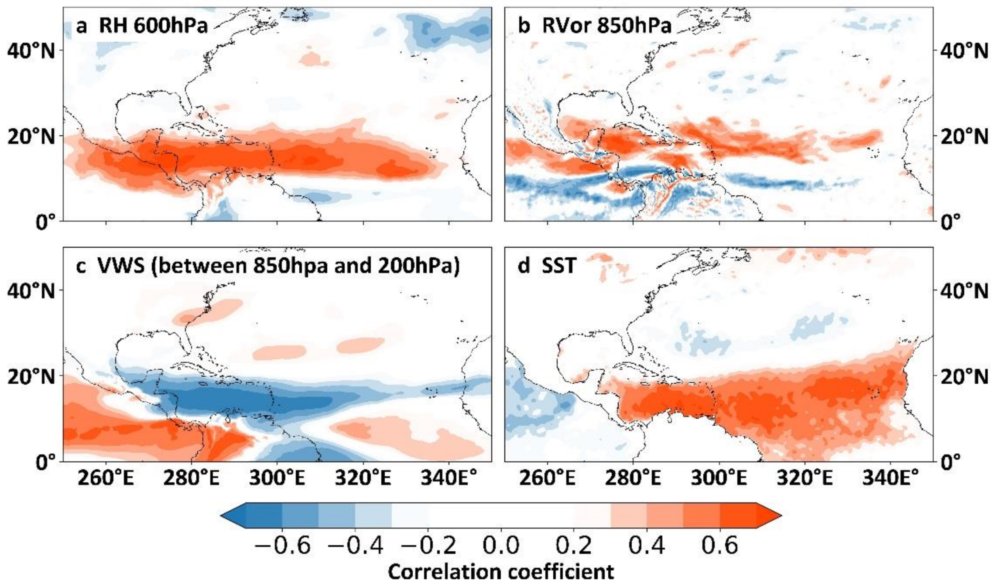

Figure 3. (**a**) Spatial correlation coefficient distribution between JAS ITCZ position and relative humidity at 600 hpa over North Atlantic; (**b**–**d**) as (**a**), but for relative vorticity at 850 hpa, vertical wind shear (between 850 hpa and 200 hpa) and SST.

By contrast, in the subtropical North Atlantic, the ITCZ have little effect to the environment. This implies that the ITCZ position is mainly associated with the TCs generated in the tropical area, and there is different kind of genesis for the TCs in subtropical North Atlantic, such as baroclinicity.

6. Conclusions and Discussion

The annual TC frequency variability is not fully understood, nor how it will change under climate warming [1]. In idealized aquaplanet simulation, as the position of maximum SST shift poleward, the ITCZ has poleward migration and the TC genesis frequency increase with the key effect of Coriolis parameter [4]. In idealized state, the poleward movement of ITCZ could contribute to more TC genesis by increasing TC seeds [6]. Basing on previous studies, we hypothesized that as the ITCZ moves poleward, the Coriolis force and cyclonic absolute vorticity increases on the poleward flank of ITCZ where many TCs form, making this region more favorable for cyclogenesis, and test this hypothesis on interannual time scale in North Atlantic.

Our results show the significant positive correlation between ITCZ position and TC frequency in North Atlantic on interannual time scale, supporting the hypothesis. Additionally, ENSO have significant effect both on ITCZ position and TC frequency on interannual time scale in NA, since they are all related to tropical SST (sea surface temperature) spatial distributions. During La Niña episodes, the ITCZ moves poleward and TC genesis increases. But the ENSO seems to have little impact on the relationship between ITCZ position and TC frequency because their correlation remains significant even after ENSO regression removed. We also tried others definitions for ITCZ calculation and got the similar correlation results, indicating the robustness of this result. We also show the northward migration of ITCZ could adjust the large-scale environment distribution, such as relative humidity (at 600 hpa), vertical wind shear (between 850 hpa and 200 hpa) and relative vorticity (at 850 hpa), favoring the increase of the TCs over tropical NA.

Although we get the expected correlation that the TC increases as ITCZ poleward, we couldn't make clear that how much contribution of the TC frequency increase is due to Coriolis effect and how much is due to the large-scale environment. The casual relationship between ITCZ and TC is difficult to distinguish because the ITCZ could be partly affected by the TC rainfall.

We have the ongoing work investigating if the correlation between ITCZ position and TC frequency remains after the TC rainfall is removed from the total precipitation. Recent studies [6,7] show that TC genesis frequency is constrained by the TC seeds frequency and the survival rate. The TC seed frequency is related to low-level relative vorticity and vertical motion, and TC seeds survival rate is affected by the large-scale environmental factors. The influence of ITCZ and the large-scale environmental factors on TC seed frequency and survival rate will be further studied in future work.

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Data Availability Statement: The IBTrACS data can be downloaded at https://www.ncei.noaa.gov/products/international-best-track-archive?name=ib-v4-access and The GPCP data are available at https://psl.noaa.gov/data/gridded/data.gpcp.html from National Oceanic and Atmospheric Administration (NOAA), Niño 3.4 region, available at https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php. The ERA5 reanalysis data are downloaded at https://cds.climate.copernicus.eu/cdsapp#!/search?type=dataset.

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Conflicts of Interest: The authors declare no conflict of interest.

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