Study on the shape of tracks of tropical storms in the North West Pacific basin

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Abstract: Quantitative analysis on the sinuosity of 959 tropical storm (TS) tracks is carried out utilizing four decades (1977-2016) of storm data and an established track sinuosity metric in the North West Pacific (NWP) ocean basin. Strong enhancement of storm track sinuosity is observed as we move early to late typhoon season months i.e., from July to October. Significant longitudinal shift (from 110^0–140^0 E to 130^0– 160^0 E) in the positions of genesis points of majority of TSs is observed as the track sinuosity of TSs rises. The warm phase of ENSO is found to be associated with a greater number of TSs with higher sinuous tracks in the NWP basin, which are mostly accumulated in the Eastern part of the NWP basin. The study provides crucial information for disaster risk assessment, mitigation and preparedness.

Keywords: Tropical storm; Sinuosity; Sinuosity Index; North West Pacific.

1. Introduction

Despite great advancements in the forecast accuracy in recent years, the ocean basins of the world still face big disasters every year (Yamaguchi et al., 2017; McAdie et al., 2000; Liou et al., 2019). As Northwest Pacific (NWP) basin possesses maximum (around 30 %) number of storm activities in the world, it becomes a hot spot for investigation of tropical cyclonic activities. This paper provides a new concept of analyzing the storms based on track sinuosity approach. Track sinuosity is the deviation of track of a storm from its ideal straight path. In general, more sinuous nature of the track of a tropical storm with bigger curves and turns, makes it challenging for models to predict its movement. This further leads to more damage due to lack of precise information about their movement in any region. This paper focuses on calculating and correlating the storm track sinuosity results with other fundamental storm parameters and El-Niño southern oscillation phases.

2. Methods

2.1. Data sorting

The data of RSMC-Tokyo was indirectly accessed through the online portal of the International Best Track Archive for Climate Stewardship (IBTrACS) maintained by the US National Oceanic and Atmospheric Administration (NOAA). Year 1977 was the first time when satellite data were started being used dominantly for issuing warning in the NWP region after introduction of Dvorak technique. Thus, 959 storm cases in the NWP basin belonging from four complete decades over the 1977–2016, have been considered. All TD stages of any storm as they belong to storm formation and decay have been omitted from track analysis. The first recorded maximum wind speed ≥35 knots and the last recorded maximum wind speed ≥35 knots, have been considered to make tracks and analysis.

2.2. Track sinuosity calculation

The storm track sinuosity has been measured by dividing the total geodesic track length measured for each storm by the direct geodesic distance between the same storm’s genesis and decay coordinate points. These calculations are done in the GIS environment (ESRI ArcGIS 10.5).

3. Results and Discussions

3.1. Sinuosity

The measured sinuosity values are having high skewness as shown in figure 1 below, which is not good for statistical comparisons. Thus, normalization is done using a combination of cube–root transformation and data shifting to form track sinuosity index (SI). The same method was used for normalization of track sinuosity values in the past for various ocean basins (Terry & Etienne, 2010; Terry & Kim, 2015). The Sinuosity Index (SI) is given as below:

$$SI = \sqrt[3]{S-1} \times 10 \tag{1}$$

where

SI = track sinuosity index value for each storm event, and

S = measured sinuosity value for each storm event

In the equation, subtraction of unity (1) from measured sinuosity value (S) makes the minimum possible sinuosity index value zero (0) for any storm. Hence, a storm with a perfectly straight track will have a SI value of zero (0).

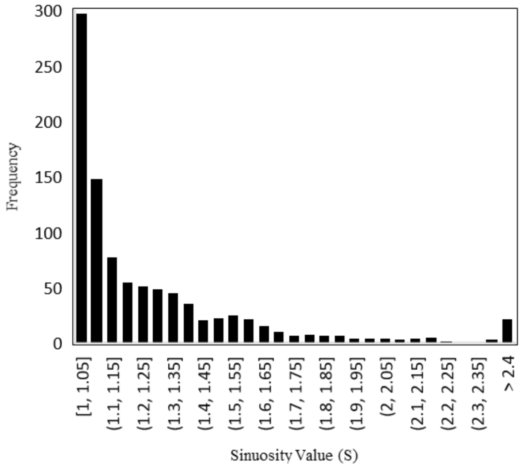

Figure 1. Frequency distribution of sinuosity values of 959 storms over 1977-2016 in NWP basin

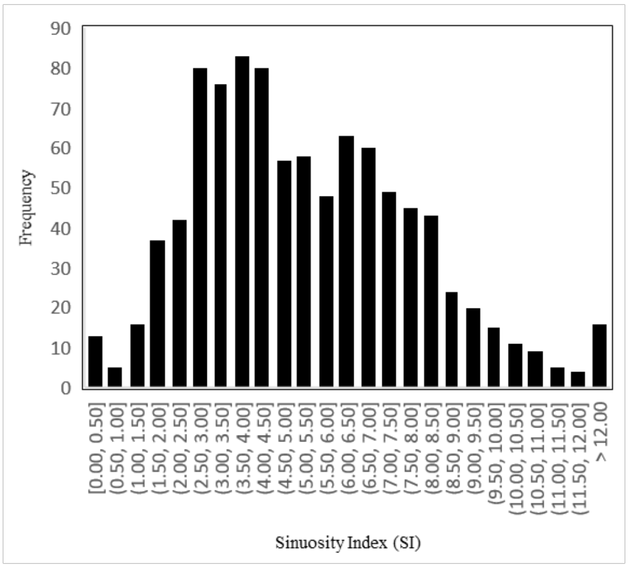

Figure 2. Frequency distribution of sinuosity Index (SI) values of 959 storms over 1977-2016 in the NWP basin

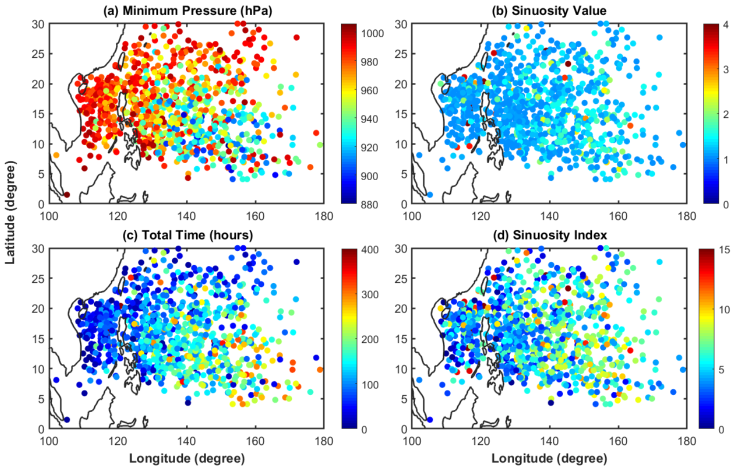

Figure 3. Frequency distribution of SI, Sinuosity Value, Total Time, and Minimum Pressure of 959 storms on map

Figure 3 shows that SI is more capable than sinuosity values to show contrast in storm track sinuosity, which also nicely match with storm's fundamental parameters like, duration and minimum pressure. More SI values (Eastern NWP) have more intense storms with more possibility of their survival.

3.2. Categorization

Table 1 shows the four-quartile based categorization of sinuosity results.

Table 1. Categorization of 4-decade typhoons based on quartiles of SI values

Quartile	Category range			
	Sinuosity	Sinuosity index	Category name	No. of storms
I	1–1.036	0–3.327	Straight	240
II	1.036–1.119	3.328–4.918	Quasi–straight	240
III	1.120–1.344	4.919–7.012	Quasi–sinuous	239
IV	≥1.345	≥7.013	Sinuous	240

The four categories of track sinuosity are named as ‘straight’, ‘quasi–straight’, ‘quasi–sinuous’ and ‘sinuous’, respectively. It is a similar way of categorization used earlier in the other ocean basins (Terry & Etienne, 2010; Terry & Kim, 2015).

3.3. Temporal, month-wise

Data analysis reveals temporal one-to-three years variation in majority of track sinuosity, which is a crucial information for disaster prevention.

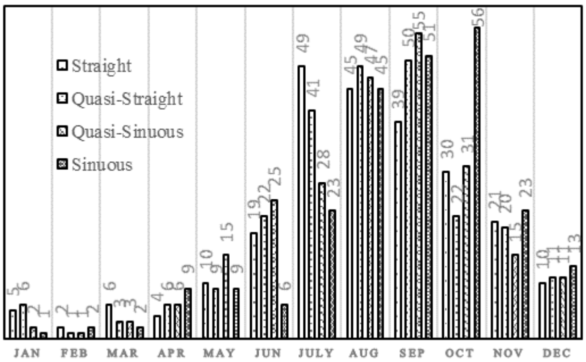

Figure 4. Monthly variations in all four-storm sinuosity category over 1977-2016 in NWP basin

Figure 4 reveals that there is an increasing pattern presence for TSs’ frequency percentage for straight and sinuous tracks from April to July (16–34.8%) and June to October (8.3–40.3%).

3.4. Spatial patterns

Spatial patterns reveal a clear longitudinal eastward shift (from 110^{0}–140^{0} E to 120^{0}–150^{0} E to finally 130^{0}–160^{0} E) in majority of TSs’ origin is observed for TSs with straight tracks to quasi–straight and quasi–sinuous and then finally to sinuous tracks, respectively, whereas there is no such significant latitudinal shift observed in majority of TSs’ origins in between 0^{0}–30^{0} N. Two–sample $\chi 2$ (Chi–square) statistical tests performed for acquiring the results.

3.4. Relationship with storm parameters

Figure 5 verifies the results found in Figure 3 and demonstrates in detail that the stronger storms have more sinuosity index values.

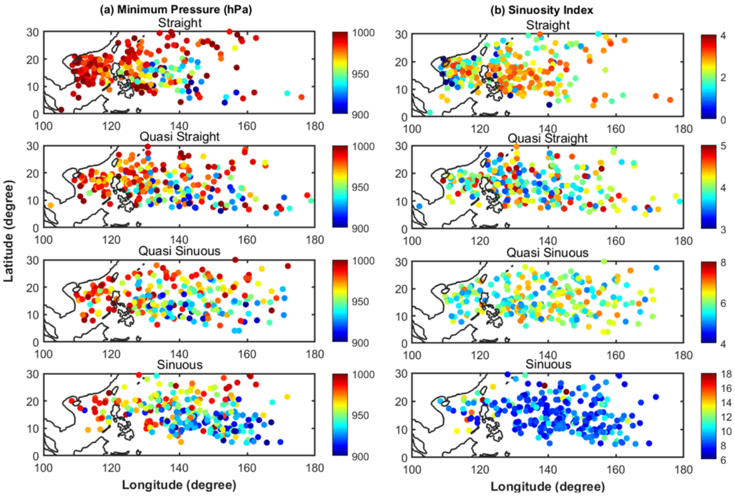

Figure 5. Spatial distribution of minimum pressure and SI in different sinuosity categories

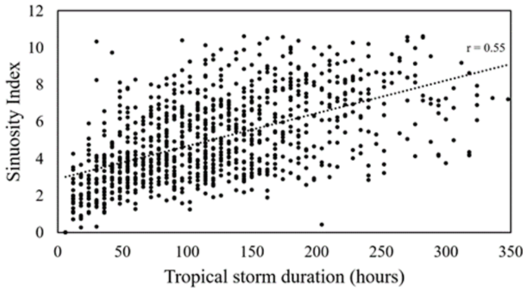

Figure 6. Relationship between SI and storm duration

Figure 6 reveals that correlation between storm time duration and SI and found that the correlation is 0.55, whereas, correlation between track length and SI is 0.48. For results, Pearson’s correlation between track sinuosity index (SI) and various fundamental storm parameters was done along with using Student’s t-test for measuring level of significance.

3.5. Relationship with ENSO phases

ENSO can be described by single variable ENSO indices such as Southern Oscillation Index (SOI) or Niño 3.4 Sea Surface Temperature (SST) but the Multivariate ENSO Index (MEI) is considered as the most representative since it combines both oceanic and atmospheric variables. MEI facilitates a more complete and flexible description of ENSO by linking six different meteorological parameters measured over the tropical Pacific.

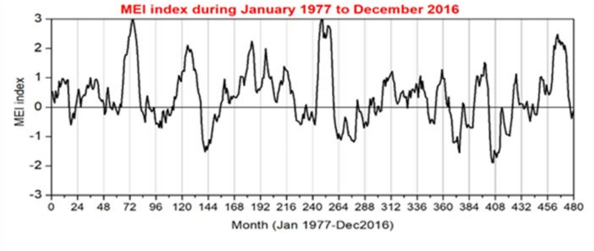

Figure 7. MEI index over 4 decades (1977-2016)

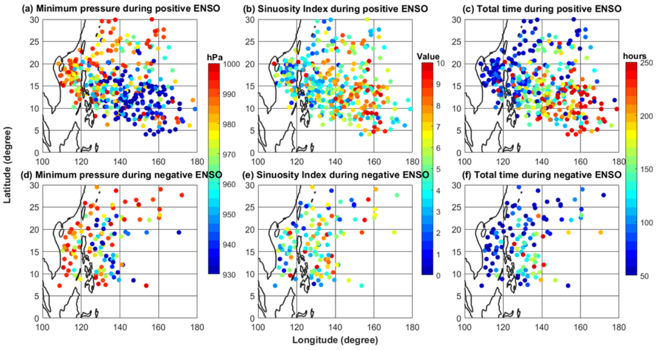

Figure 8. ENSO phases relationship with strength, duration, and SI values of storms

Figure 8 reveals that the warm phase of ENSO is more associated with a greater number of TSs with higher sinuous tracks in the NWP basin. These are mostly accumulated in the Eastern part of the NWP basin.

4. Conclusions

Strong enhancement of storm track sinuosity is observed as we move early to late typhoon season months i.e., from July to October. A short term (one- to three-year) cyclic pattern of varying track sinuosity of TSs is detected in the NWP basin. Significant longitudinal shift (from 110^0–140^0 E to 130^0– 160^0 E) in the positions of genesis points of majority of TSs is observed as the track sinuosity of TSs rises. Investigation of track sinuosity based on the warm/cold phase of the El Niño/Southern Oscillation (ENSO) reveals crucial information. The warm phase of ENSO is found to be associated with a greater number of TSs with higher sinuous tracks in the NWP basin, which are mostly accumulated in the Eastern part of the NWP basin. The study provides crucial information for disaster risk assessment, mitigation and preparedness.

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