Has the Late-season Typhoon Activity over the Western North Pacific changed since 1979?

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Abstract

In 1995 an abrupt shift in the late-season (Oct.–Dec.) typhoon activity over the western North Pacific (WNP) is detected by a Bayesian change-point analysis. Interestingly, a similar change also occurs in the late-season sea surface temperature series over the western Pacific, eastern North Pacific, and portions of the Indian Ocean. All of the counts, lifespans, and accumulated cyclone energy of the late-season typhoons during the 1995–2011 epoch decreased significantly, compared with typhoons that occurred during the 1979–1994 epoch. The negative vorticity anomaly is found to be the leading contributor to the Genesis Potential Index (GPI) decrease over the southeastern sector of the WNP during 1995–2011. To elucidate the origin of the epochal change in the dynamic environmental conditions, a suite of sensitivity experiments is conducted based on the latest version of the Meteorological Research Institute of the Japan Meteorological Agency atmospheric general circulation model (MRI-AGCM). The ensemble simulations suggest that the recent change to a La Niña-like state induces an unfavorable dynamic condition for typhoon genesis over the southeastern WNP. Warming in the Indian Ocean, however, contributes insignificantly to the circulation anomaly related to typhoon genesis over the southeastern WNP.

The frequency of typhoon occurrence reveals a basin-wide decrease over the WNP in the recent epoch, except for a small increase near Taiwan. An empirical statistical analysis shows that the basin-wide decrease in the frequency of the typhoon occurrence is primarily attributed to a decrease in typhoon genesis, while the change in track is of less importance.

Key word: typhoon, Bayesian

1. Introduction

Previous studies have focused on either the variability of annual typhoon counts or tropical cyclone (TC) activity during the peak season (July to September). Very little attention has been paid to the late season (October-December) activity, although the typhoons in this season have considerable impacts (e.g., super-typhoon Haiyan in November 2013). In this study, we will examine whether there are significant changes in typhoons over the western North Pacific (WNP) during the late season, and the mechanisms responsible for any changes. In particular, we will examine how local and remote SST changes on decadal timescales modulate typhoon genesis over the WNP. These issues will be addressed by using the following methodologies: a Bayesian change-point analysis; sensitivity experiments using a new version of the Japanese MRI atmospheric general circulation model (AGCM); and a newly developed empirical statistical analysis for diagnosing typhoon frequency.

2. Data, model, and methodology

The tropical cyclone best track data over the WNP (0–60ºN, 100–180ºE), including the South China Sea (SCS) basin, is obtained from the RSMC－Tokyo Typhoon Center, Japan Meteorological Agency. The timing of extratropical transitions is also included in this dataset. To ensure data reliability, the data for the recent 33-yr satellite period of 1979–2011 is used. Considering the possible inconsistencies among best track datasets, best track data from the Joint Typhoon Warning Center (JTWC 2012) for the same analysis period is also used to confirm the results of the RSMC-Tokyo dataset.

Typhoons are defined as TCs that possess 1-min sustained surface wind speed of over 64 knots. It is noted that the JTWC dataset records a 1-min sustained wind speed, while the RSMC-Tokyo dataset uses a 10-min sustained wind speed. As indicated by Simiu and Scanlon (1978), the strength of the10-min sustained wind is statistically 88% of the 1-min sustained wind. Thus we convert the threshold of 64-kt 1-min mean wind speed to a 56-kt 10-min wind speed threshold for detecting typhoon cases in the RSMC-Tokyo dataset. Because of this conversion, the typhoon strength here is slightly weaker than that from the RSMC-Tokyo official classification.

Typhoon positions are counted for each 2.5º × 2.5º grid box within the WNP domain at 6-h intervals. The typhoon frequency is defined as the total count for each grid box. The location of the typhoon genesis is defined as the first position at which the maximum wind speed exceeds 30 (34) knots in the RSMC-Tokyo (JTWC) dataset. The definition of typhoon lifespan is the period from typhoon genesis to the timing of extratropical transition or of tropical cyclone dissipation.

Several dynamical and thermodynamic variables are derived from the European Centre for Medium Range Weather Forecasts (ECMWF) interim reanalysis (ERA-interim); monthly mean SST from the Met Office Hadley Centre (HadISST1); and monthly mean precipitation from the Global Precipitation Climatology Project (GPCP). The horizontal resolutions of ERA-interim, HadISST1, and GPCP datasets are 1.5º, 1º, and 2.5º latitude-longitude, respectively.

To understand how the regional SST anomalies modulate the critical circulation conditions that affect the epochal changes in typhoon activity, we use an AGCM forced by different boundary conditions. The model used in this study is adapted from the latest version of the Meteorological Research Institute (MRI)-AGCM 3.2 at T_L95 resolution (~200 km).

TY-count (number)	E1 [79-94]	E2 [95-11]	E2-E1	p-value	significance
OND	5.94	3.24	-2.70	0.0002	✓
Oct.	3.13	1.94	-1.19	0.0163	✓
Nov.	1.88	0.88	-1.00	0.0062	✓
Dec.	0.94	0.41	-0.53	0.041	✓
TY-lifespan (days)					
OND	6.61	4.37	-2.24	0.0039	✓
Oct.	7.80	6.18	-1.62	0.1195	
Nov.	7.11	3.64	-3.47	0.0112	✓
Dec.	4.92	3.28	-1.64	0.1056	
TY-ACE (10^3 m^2s^{-2})					
OND	32.69	21.20	-11.49	0.0029	✓
Oct.	40.66	31.50	-9.16	0.1552	
Nov.	36.82	17.36	-19.46	0.0024	✓
Dec.	20.58	14.73	-5.85	0.0843	

Table 1. Seasonal and monthly means of the late-season typhoon counts, lifespans (days) and ACE (10^3 m^2s^{-2}) for the early epoch (1979–1994, E1), recent epoch (1995–2011, E2), and the differences between the two epochs (E2–E1). Tick indicates the epochal change is statistically significant at the 5% level based on the nonparametric Wilcoxon-Mann-Whitney rank-sum test.

A Bayesian paradigm under the one change-point hypothesis is used to objectively detect when a regime shift in TC activity occurs (Chu and Zhao 2004; Tu et al. 2009). The Bayesian analysis provides the probability information of change points rather than a deterministic estimate of the change-point location. This is an advantage over the deterministic approach because the uncertainty inherent in statistical inferences is quantitatively expressed in the probability statement. Expanding from the analytical single change-point analysis, In addition to typhoons, it is also of interest in this study to investigate whether there is an abrupt shift in the SST time series. Because temperature data usually follow a Gaussian distribution rather than a Poisson process, we revised the Poisson-gamma model for typhoon counts by assuming that the mean and variance of the distribution change with time. The conjugate prior for the mean is Gaussian and the conjugate prior for the variance is the inverted gamma distribution. Otherwise the entire structure of the Bayesian inference for abrupt changes in SST is very similar to the typhoon series.

The distribution of typhoon genesis and preferable tracks may both exert influences on the variability of typhoon passage frequency. A new approach, proposed by Yokoi and Takayabu (2013) and Murakami et al. (2013), is applied to assess the relative importance of the typhoon genesis and track anomalies in a given period with respect to the climatology. Because a relatively larger number of typhoon samples help to prevent sampling errors, the analysis is performed with 5º × 5º resolution.

3. Abrupt changes in typhoon activity and SST

Figure 1a compares the time series of typhoon counts in OND over the WNP for the period 1979–2011 that were derived from the RSMC-Tokyo and the JTWC datasets. The two time series are highly consistent with a correlation coefficient of 0.94. The decreasing trends are robust in the two datasets. Both of them show a slope of around -0.1 $year^{-1}$, which exceeds the 95% confidence level based on the Mann-Kendall test. Because the typhoon data shows a very high consistency, we will only delineate the results using the RSMC-Tokyo dataset in the analysis that follows.

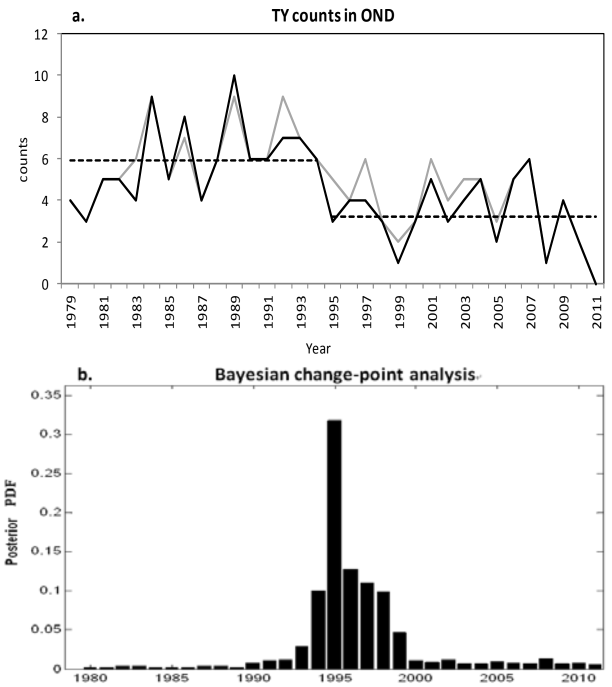

Fig. 1 (a) Time series of late-season (OND) typhoon counts in the WNP from 1979–2011. Black and gray lines illustrate the results from the RSMC-Tokyo and the JTWC datasets, respectively. Dashed lines denote the means for the period 1979–1994 and 1995–2011, respectively. (b) The posterior probability mass function of the change-point as a function of time (year). Source: RSMC-Tokyo.

Figure 1a also shows that the number of late-season typhoon ranges from three to ten during the 1980s, and drops to below five (or even to only one or none) since the late 1990s. The periods of high-versus-low typhoon counts seem to be separated by a sharp transition. In order to objectively detect the occurrence of any abrupt decrease in typhoon counts, we applied the Bayesian change-point analysis, which estimates the posterior probabilities of each observation as a potential change-point. The analysis result indicates an outstanding posterior probability of a shift in 1995 (Fig. 1b), implying that it is more likely that a change would occur in a new epoch with 1995 as the first year.

As shown in Fig. 1a, the average number of the late-season typhoon is 5.94 during 1979–1994 (epoch1 or E1), but is significantly reduced to 3.24 during 1995–2011 (epoch2 or E2). This abrupt drop in the typhoon counts is statistically significant. In addition to the remarkable difference in the number of typhoon geneses, the lifespans of the typhoons also experience a significant epochal change. The duration of a typhoon is on average about five to eight days in the early epoch. In the more recent decade, late-season typhoons tend to be shorter-lived (about three to six days). As a result, the late-season accumulated cyclone energy (ACE), which takes into account the number, strength, and duration of all of the typhoons observed in the OND over the WNP, largely decreases in 1995–2011.

The abrupt change in the WNP typhoon counts may be linked to the tropical SST variability that influences the oceanic and atmospheric conditions for typhoon genesis. To examine if there are any decadal shifts of the late-season SST over the period of 1979–2011, we applied the change-point analysis to the OND-averaged SST in each 5×5 degree point. The temporal and spatial patterns of the SST changes are shown in Fig. 2. A regime shift in the mid-1990s prevails over the tropical oceans, particularly in the western Pacific, eastern North Pacific, eastern South Pacific between the equator and 10ºS, and some portions of the Indian Ocean. In the meantime, limited areas with regime shifts in the 1980s and 2000s are observed in the southwestern Indian Ocean and subtropical southeastern Pacific (south of 15ºS). In the equatorial central-eastern Pacific, however, no significant change-point could be identified.

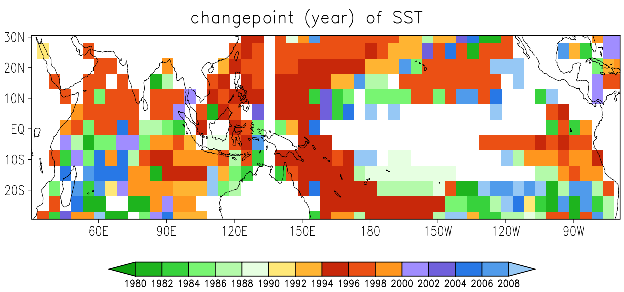

Fig. 2 Change-point analysis of late-season SST during 1979-2011. Shading indicates when (in which year) the maximum probability of regime shift occurs, if the SST exists at a change point during the 33-year time series, in each 5×5 degree point. Blank areas denote no significant change-points.

The epochal changes in the spatial distributions of typhoon genesis and frequency of occurrence are displayed in Figure 3. The monsoon trough retreats southward during the late season and the main genesis regions accordingly shift equatorward. Along with the decadal changes in the monsoon circulation, both the number and locations of the typhoon genesis undergo significant regime shifts. The low-level cyclonic circulation between 130ºE and 160ºE is more enhanced in the early epoch than in the recent epoch (Fig. 3a and b). The weakened cyclonic circulation appears to lead to a significant typhoon genesis decrease in the regions south of 17.5ºN over the WNP and the SCS throughout the period 1995–2011 (Fig. 3b). A slight increase in typhoon genesis can also be found in a few patches of the subtropical regions (Fig. 3c). The frequency of typhoon occurrence also shows significant decreases over most of the WNP basin, with the exception of a small increase in the typhoon frequency that appears near Taiwan in the recent epoch (Fig. 3f). The decreased typhoon genesis (Fig. 3c) may be one of the major contributors to the significant decreases in the typhoon frequency in the recent epoch (Fig. 3f). Another factor possibly affecting the typhoon frequency change may be typhoon track changes.

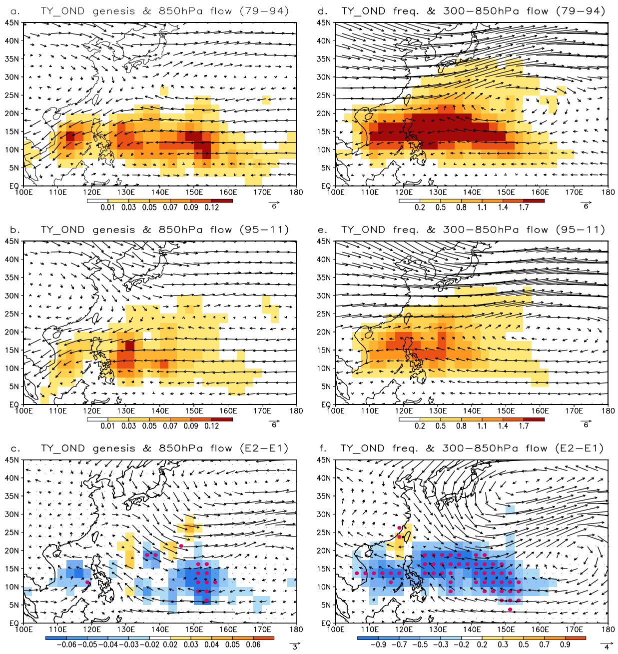

Fig. 3 The frequency of typhoon genesis derived from the RSMC-Tokyo (shading, number per season) and 850-hPa wind field (vector, ms^{-1}) during OND for the period of (a) 1979–1994, (b) 1995–2011, and (c) their difference (1995–2011 minus 1979–1994). (d)-(f) As in (a)-(c) but shading indicates the frequency of typhoon occurrence and vectors present the mass-weighted 300–850 hPa steering flow. The red dots in (c) and (f) mark the regions where the difference in typhoon genesis frequency between two epochs is statistically significant at the 5% level.

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