The storm activities in the West Pacific from 1980 to 2018

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Abstract. The storm is an important weather system that significantly affects socioeconomics and human living. This study uses the global tropical cyclone best track data from IBTrACS, along with other meteorological states from ECMWF ERA-5 reanalysis from 1980 to 2018. In the West Pacific, storms are more likely to occur in summer (July, August and September). During the 39-year period, the occurrence of storm activities tends to be less frequent in summer, accompanied by increased sea surface temperature, total precipitation and total column water. It is also found that the storm number exhibited a high correlation with sea surface temperature, surface pressure, total precipitation and total column water in the middle West Pacific as well as the sea of Okhotsk in summer.

1. Introduction:
Storm, known as a disturbance of the atmosphere, is an important tropical weather system that affects human living and causes huge losses (Smith and Katz 2013). In this case, it quickly became a focusing point for both science community and general public (Pielke et al. 2005; Emanuel 2005).

There are many studies about the influence or the occurrence frequency of storm. For example, by analyzing the amount of water or precipitation increase during the storm reason, it reached the conclusion that storm surge may occur in June to October each year, and mainly concentrate in July to September (Huang et al. 2018). Moreover, other studies have investigated how the storm activities would be altered in a changing climate. According to the clausius-clapeyron theory, global warming increases the amount of water vapor stored in the atmosphere, which also enhances the storm activities (Elisha et al. 2015). Previous studies also showed that storm occurrence has a consistent strong correlation with the large-scale atmospheric circulation in the West Pacific (Ding et al. 1983). More recently, Ye et al. (2019) have studied different kinds of storm track which influence China (Ye et al. 2019). In this study, it was found that these tropical cyclones mainly originated in the region from 5°N to 24°N and from 120°E to 160°E. Aiming to investigate the storm occurrence in the West Pacific, this study provides a comprehensive temporal and spatial analysis of the storm activities and other climate variables in summer (July, August, and September). In particular, this study will focus on the 39-year (1980-2018) record of storm number, sea surface temperature, surface pressure, total precipitation and total column water over the West Pacific region (120°E-180°E, 0°N-60°N). Relationships between the storm and the climate components are examined in both temporal and spatial scales to demonstrate the connection between storm activities and the large-scale meteorological conditions.

2. Data and methodology
In this study, the record of storm occurrence was obtained from the International Best Track Archive
for Climate Stewardship (IBTrACS) version 04 provided by NOAA (National Oceanic and Atmospheric Administration) (Knapp et al. 2014; Knapp et al. 2018; Knapp et al. 2010). This data provides tropical cyclone best track data in a centralized location to aid our understanding of the distribution, frequency, and intensity of tropical cyclones worldwide. The storm number data is available from numerous tropical cyclone dataset in IBTrACS record since 1980, which is the modern era of satellite observations. The data is provided in 0.1° (~10km) spatial resolution and has been interpolated to 3 hourly temporal resolution. The West Pacific covers the area from 120˚E to 180˚E, 0˚ to 90˚N in this study (https://www.ncdc.noaa.gov/ibtracs/index.php?name=ib-v4-access). The climate state data were obtained from the ERA-5 reanalysis from 1979 to present. This data set is the fifth generation of European Centre for Medium-Range Weather Forecasts (ECMWF) atmospheric reanalysis containing model data with observations across the world, which has complete temporal and spatial coverage. The data is provided in a spatial resolution of 0.25°×0.25° with monthly temporal resolution from 1980 to 2018. The meteorological variables we used in this study include sea surface temperature, surface pressure, total precipitation and total column water. The total column water is the total amount of water vapor, liquid water, cloud ice, rain and snow in a column extending from the surface of the Earth to the top of the atmosphere. In the ECWMF Integrated Forecasting System (IFS), the units for total column water are kilograms per square meter (kg/m²). The total precipitation is the accumulated liquid and frozen water, comprising rain and snow, that falls to the Earth’s surface, which is the sum of the large-scale precipitation and convective precipitation. The units of this parameter are depth in meters of water equivalent.

In this study, we first calculated the number of storms for different months, seasons and years. Since the summer is the season with the most occurrence of the storms, we then mainly focus on summer months (July, August and September; JJA). The linear trend of the occurrence of storms in summer has been analyzed. The p-values for each liner trend are also calculated through the two tailed students’ T- test. Then we calculated the spatial correlations between climate state variables with the number of storms in the West Pacific. For each grid box, we averaged the meteorological variables in JJA and then calculate their correlation with the total storm number throughout the 39-year period.

3. Result:

3.1. The climatology of storm occurrence and large-scale meteorological conditions
Based on the Figure 1a, it is clearly that the storm activities are more frequent in summer (July, August, September) than winter (January, February and March) in the West Pacific (Fig.1b).

![Seasonal cycle of average storm number from 1980 to 2018](image1.png)

Fig.1 a. Seasonal cycle of average storm number from 1980 to 2018 in West Pacific
b. The study area: West Pacific Region (0-60N, 120E-180)

Particularly, the monthly average storm number reaches 7 in August, while it reaches minimum in February. The annual averaged number of storms shows a general decreasing trend from 1980 to 2018. Since summer witnesses the most of storms in a year, this season has been selected and it shows a
relatively larger negative trend (Fig.2).

The surface pressure reaches its minimum (~1003hPa) in summer and the maximum (~1005hPa) in spring and autumn. The annual averaged surface pressure exhibited an increasing trend with the rate of 0.8 Pa/year during the 39-year period, which is negatively correlated with storm number (Fig.3). Then, we take a step further to do the spatial analysis, with the focus on the winter and summer. It illustrates that the surface pressure is much higher and more uniformly distributed over the ocean than that over the land. In addition, no significant differences were found in winter and summer for surface pressure (Fig.3c, 3d).
Fig. 3  
(a) Seasonal cycle of average Sea Surface Pressure from 1980 to 2018 in West Pacific  
(b) Annual trend of average Sea Surface Pressure from 1980 to 2018 in West Pacific  
(c) Map of average Sea Surface Pressure distribution in winter from 1980 to 2018 in West Pacific  
(d) Map of average Sea Surface Pressure distribution in summer from 1980 to 2018 in West Pacific

The annual sea surface temperature generally increases with time during this 39-year (Fig. 4b) period by about 0.7°C, which shows a negative correlation with the annual averaged storm number. From the Figure 4c and 4d, it shows that the sea surface temperature is relatively low in the northern part of West Pacific, along with a large gradient around 40˚N band. In summer, the sea surface temperature is higher in all regions. In the region 40˚N northward, the sea surface temperature along the coast is much lower than that offshore in winter, while it is reverse in summer.
Fig. 4  

a. Seasonal cycle of average Sea Surface Temperature from 1980 to 2018 in West Pacific  
b. Annual trend of average Sea Surface Temperature from 1980 to 2018 in West Pacific  
c. Map of average Sea Surface Temperature distribution in winter from 1980 to 2018 in West Pacific  
d. Map of average Sea Surface Temperature distribution in summer from 1980 to 2018 in West Pacific

Fig. 5(a) shows that the monthly total column water is much higher in summer (41.8 m) than winter (21.4 m). In fig. 5(b), the averaged total column water exhibits a slight increasing trend with a slope of 0.0038 during 1980-2018. In the West Pacific, the total column water generally decreases from the equator to the mid-latitude. By comparing two seasons, it is found that the distribution of total column water tends to be more uniform in winter and the amount of total column water increased quite rapidly from winter to summer. In summer, the total column water over land is apparently less than that over ocean. (Fig. 5c, 5d). Note that the linear trend and spatial distribution of total precipitation are quite similar to those of the total column water (not shown).
3.2. Correlation between storm number and the meteorological variables

Table 1. The numerical correlation and confident coefficient (p-value) between storm number and climate variable.

| Correlation variable                  | p-value  | correlation |
|---------------------------------------|----------|-------------|
| Number - Total Column Water           | 0.065285 | -0.298113   |
| Number - Surface Pressure             | 0.051102 | -0.314604   |
| Number - Sea Surface Temperature      | 0.039427 | -0.331218   |

By comparing the correlation between the storm number and other meteorological state variables, we found that all variables (total column water, surface pressure and sea surface temperature) show the statistically significant negative correlations with annual averaged storm numbers at 90% confidence level, as shown in Table 1. Moreover, the sea surface temperature shows a relatively stronger negative correlation (~ -0.3) with storm numbers among those variables. For example, the Figure 6a shows the time series of the annual storm number and sea surface temperature. It is obvious that they exhibit the reverse trend and are negatively correlated with each other during 39-year time period.
From the Fig. 6b, we found relatively stronger negative correlations (~ 0.4) between storm number and sea surface temperature in the 30°N zonal band and the sea of Okhotsk. Similarly, the storm number and total precipitation also exhibited a relatively larger positive correlation (0.3-0.4) in the same regions. The strong negative correlation (~ -0.4) of storm number and sea surface pressure can be found in the region in 30°N, from 120°E to 140°E.

These results can be explained by the storm origin regions. According to Ye et al. (2019), they found that the storm in the West Pacific that mostly affecting China were mainly originated from the region 120°E-160°E, 5°N-24°N. And the concentration of storm in this area is mainly caused by the large-scale atmospheric circulation (Ding et al. 1983). This is quite consistent with our findings. As mentioned earlier, in this region with most of storms originated, we found the relatively higher correlations between storm number and sea surface temperature/total precipitation.

4. Conclusion
The IBTrACS and ERA-5 data have been used to investigate the relationship between storm number and other climate components in the West Pacific from 1980 to 2018 in both temporal and spatial
scales. In addition, the spatial distributions of correlations between the storm number and other meteorological state variables are also provided and examined in detail. Through these analyses, we have the following conclusions:

1) In general, the storm appears to be more frequent in summer. While for the other climate factors like sea surface temperature, total precipitation and total column water, they are also relatively higher in summer. In contrast, the surface pressure tends to be the lowest in summer compared to other seasons.

2) Throughout the 39-year period, the storm number showed a decreasing trend, and the negative trend was more prominent in summer. In contrast, all other meteorological state variables (surface pressure, sea surface temperature, total column water) exhibited the increasing trend from 1980 to 2018, which were negatively correlated with the occurrence of storm.

3) For the spatial scale, the correlation between storm number and the climate components appeared to be relatively higher in the middle of West Pacific (130°E-170°E;10°N-30°N) and north of Japan (140°E-160°E;45°N-55°N). This is consistent with previous studies, in which they found a large number of tropical cyclones in the West Pacific have originated from these regions.

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