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China's historical record when searching for tropical cyclones corresponding to Intertropical Convergence Zone (ITCZ) shifts over the past 2 kyr

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Abstract. The northwestern Pacific Ocean and South China Sea are where tropical cyclones occur most frequently. Many climatologists also study the formation of Pacific Ocean warm pools and typhoons in this region. This study collected data of paleotyphoons found in China's official historical records over the past 2000 years that contained known typhoon activity reports. The collected data are then subjected to statistical analyses focusing on typhoon activity in coastal regions of southeastern China to garner a better understanding of the long-term evolution of moving paths and occurrence frequency, especially regarding those typhoons making landfall in mainland China. We analyzed the data with the year and month of each typhoon event, as well as the number of events in a 10-year period. The result shows that (1) north–southward migration of typhoon paths corresponds to the north–southward migration of the Intertropical Convergence Zone (ITCZ) during the Medieval Warm Period (MWP) and Little Ice Age (LIA) and (2) paleotyphoons made landfall in mainland China 1 month earlier during the MWP than during the LIA. This implies a northward shift in ITCZ during the MWP. Typhoons tend to make landfall in Japan during El Niño-like periods and strike the southern coastal regions of China during La Niña-like stages. According to paleotyphoon records over the last 2000 years, typhoons made landfall in southeastern China frequently around 490–510, 700–850, and after 1500 CE The number of typhoons striking Guangdong Province peaked during the coldest period in 1660–1680 CE; however, after 1700 CE, landfall has migrated farther north. The track of tropical cyclones (TCs) in the northwestern Pacific Ocean is affected by the North Atlantic Oscillation (NAO) and the Pacific Decadal Oscillation (PDO), which shows a nearly 30-year and a 60-year cycle during the LIA.

1 Introduction

Tropical cyclones (TCs) are a serious hazard. According to the Federal Emergency Management Agency (FEMA) of the USA, the total amount of money spent on flood recovery programs due to TC activity was greater than that spent on any other natural catastrophe during the period 2005 to 2015. The level of destruction caused by TCs has meant they have been the focus of a great deal of current research as well as being part of the historical record of China for millennia. Among all tropical cyclones, 37 % occur in the northwestern Pacific Ocean (Liang and Ye, 1993). These TCs are of a greater intensity and make landfall more frequently in this region than those making landfall in the western Atlantic Ocean. People pay a great deal of attention to the frequency and tracks of TCs on Earth. The path of TCs in the Pacific Ocean is driven by the clockwise rotation of the subtropical North Pacific High, and it takes three paths away from this genesis region: (1) a westerly path straight toward south China; (2) a west–northwesterly path curving back to Japan; and (3) a north-oriented path that keeps them out at sea (Elsner and Liu, 2003). Most existing TC records are based on short-term research that covers the past few decades (Wu and Lau, 1992;

Lander, 1994). Short-term weather records indicate that TC paths may be directly influenced by variations in the El Niño Southern Oscillation (ENSO) in the equatorial Pacific region (Chan, 1985; Lander, 1994; Wang and Chan, 2002; Elsner and Liu, 2003; Ho et al., 2004; Chu, 2004), and ENSO is highly related to the Pacific Decadal Oscillation (PDO; Pavia et al., 2006; Feng et al., 2013). Another dynamic forcing influence on the pathways of TCs is related to the Intertropical Convergence Zone (ITCZ) position and North Atlantic Oscillation (NAO) (Gil et al., 2006).

However, climate study literature is severely lacking longer-term studies with more data that cover hundreds of years. For the purpose of tracking TC pathways in the long term, we need geological records from natural sediment from lake cores and lagoons originating in a widespread coastal area. The geological records indicate that ancient TC activity were enhanced by ENSO activity after the middle Holocene, both in the Atlantic and Pacific oceans (Donnelly and Woodruff, 2007; Woodruff et al., 2009; Chen et al., 2012; McCloskey and Liu, 2012, 2013; McCloskey et al., 2013; Liu et al., 2015). Therefore, we attempted to collect more TC data from these documents and understand some of the fragmented historical records. Bossak et al. (2014) discussed the statistical records of regional TC occurrence since 1851 from the southeastern Atlantic coastal region of the United States of America. In addition, the historical record of TC occurrence in the northwestern Pacific has a longer historical record in China. Chan and Shi (2000) first published the frequency of typhoon landfall over Guangdong Province of China during the period of 1470–1931 CE, and then Liu et al. (2001) examined historical records dating back to 1000 years ago in Guangdong Province. Further research also tried to integrate statistical records of TC occurrence in southeastern coastal China over the last 400 years (Fogarty, 2004).

In this study, we attempted to collate statistics on the landfall frequency of TCs recorded in China's written historical record with typhoon intensity recorded in the geological record of lake sediments in northeastern Taiwan to investigate TC path migration in the northwestern Pacific Ocean region over the last 2 kyr.

2 Paleotyphoon records from China's official historical documents

China's historical record is a rich source of documented evidence on climatic conditions dating back millennia. Abnormalities in climatic conditions found in China's records have been successfully applied in the reconstruction of regional climate changes (Liu et al., 2001; Chu et al., 2002, 2008). Previous research revealed that the term *jufeng* (cyclone, 颶風) first appeared in the Southern and Northern dynasties around 420–479 CE (Liu et al., 2001). During the following Tang Dynasty (618–907 CE) many climate phenomena relating to torrential rainfall and strong winds resembling typhoons were recorded in poems (Louie and Liu, 2003). Since the Northern Song Dynasty (960–1126 CE), Chinese governmental institutions have kept a continuous record of typhoon strikes reported by local administrative authorities (Louie and Liu, 2003; Liu et al., 2001). The term "typhoon" (颱風) first appeared during the Qing Dynasty with documented evidence of typhoon landfall on Taiwan first appearing in 1750 CE.

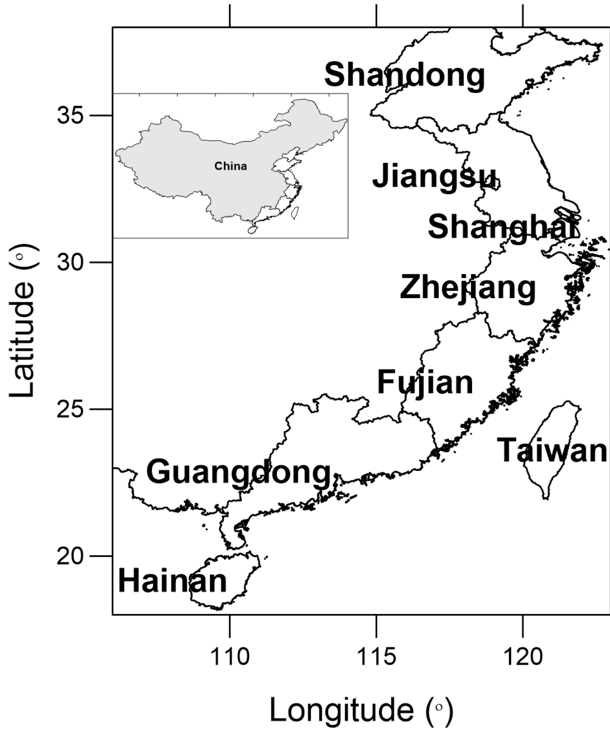

Figure 1. Southeastern coastal regions of China and Taiwan.

China's written historical record dates back 3000 years. The statistical records used in our study include data from southeastern coastal China and Taiwan (Fig. 1). The data source upon which our study is based is a book entitled *A syllogism of China's meteorological record over the past 3000 years* (Zhang, 2013). This book consists of 7813 pieces of documentary evidence from China's historical documents, including 7713 pieces from local government bodies and another 28 from other historical documents. In total, there are more than 220 000 recorded events.

3 Applied method

After thorough verification of data sources, the timing and event locations found in the record primary source reports were kept and duplicates eliminated. Zhang (2013) is, by far, the most complete and commonly accepted climate record from China's documented history.

Table 1. Illustrative quotations from selected historical sources in China.

Occurrence time	Descriptions	Locality	Data source as given in Zhang (2013)
798 CE, August	Strong wind destroyed the buildings and overturned the boats.	Guangdong	The new book of Tang, The notes of the five elements
1380 CE, September	*Jufeng* and heavy rainfall damaged the woods and houses. Many people died in this disaster.	Fujian	Ming Taizu (the first founder of the Ming Dynasty) Memoirs, Volume 133
1673 CE, August	Jufeng and heavy rainfall occurred. The roofs were thrown up and tall trees were snapped off.	Guangdong	Qing Qianlong years, Chaozhou prefecture records, Volume 11, The disastrous and fortunate events
1750 CE, August	Strong *jufeng* destroyed the buildings and the surge smashed several hundreds of merchant ships.	Taiwan	Qing Jiaqing years, updated Taiwan county records, Volume 5, The fortunate and abnormal events.
1831 CE, July	*Jufeng* and heavy rainfall caused flooding and seawater intrusion in the coastal range. More than 9500 people died and the houses floated away in flood.	Shanghai	Qing Guangxu years, Chongming county records, Volume 5, The fortunate and abnormal events.

Considering the evolution of typhoon-related keywords over the years, in addition to using the specific keywords typhoon and *jufeng* to search for records since 1000 CE, related expressions such as "strong wind" (大風), "rainstorm" (暴雨) and "storm surge" (風暴潮) were also applied to our search. However, the terms *jufeng* and typhoon rarely appeared in the historical record prior to 1000 BP. So, for this earlier period, we added additional terms that are possibly associated with typhoon such as "trunk pulling" (拔木), "tree pulling" (拔樹), "collapsed building" (覆屋) and "wind storm" (暴風) to our statistical study. We attempt to reconstruct the time of occurrence and the location of paleotyphoons along the coastal region in China and to understand the evolution of typhoon development over a long period of time. It is worth noting that every episode would be recorded in historical documents due to significant damage or a disaster. As a result, we speculate that the strengths of typhoons would be above moderate. All ancient Chinese literatures was listed in the appendix of Liu (2015). Table 1 shows some of the original historical sources based on Zhang (2013).

4 Results

4.1 Statistical results on the frequency of typhoon landfall

The statistical data collected for the southeastern coastal regions of China include data for Hainan, Guangdong, Fujian, Taiwan, Zhejiang, Shanghai, Jiangsu and Shandong (Fig. 1). When we categorized typhoon landfall locations based on latitudes, Fujian and Taiwan are recognized as one region due to their similarities in latitude and the same applies to Jiangsu and Shanghai. It is notable that prior to 0 CE the historical record of China lacks data on typhoon activity. Consequently, this study focuses on data collected over the last 2 kyr. Furthermore, data for the period 1945–2013 CE were collected from the northwestern Pacific Ocean TC records established by the Joint Typhoon Warning Center (JTWC).

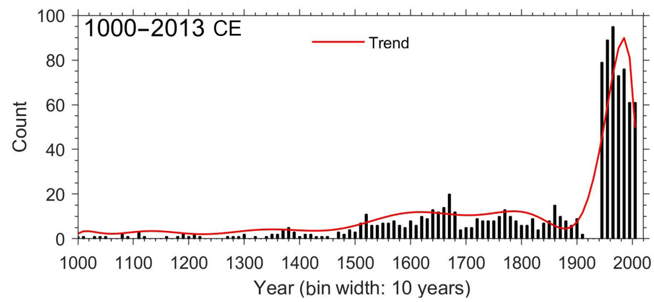

Figure 2. Historical paleotyphoon data compiled over the past 1000 years from China's historical record and JTWC data for southeastern China and Taiwan. Each bar in the bar graph represents the collective number of typhoons occurring in any given decade.

The statistical results were divided into three different time frames based on keyword results and database sources: (1) 0–1000 CE; (2) 1000–1910 CE; and (3) 1945–2013 CE. To plot the number of typhoons occurring as a function of time, typhoon events in any given decade were collectively plotted to create an interdecadal bar graph dating from 1000 CE to the present (Fig. 2). The number of events which occurred in any given decade relates closely to the age of historical documents and how well they have been preserved. Records relating to TC landfall between 1945 and 2013 CE are reliant on satellite-acquired data, meaning the data source is highly reliable in terms of its location and intensity. Consequently, Fig. 2 shows extreme growth in the number of recorded TCs in the latter years of the twentieth century. Moreover, Liu et al. (2017) published TC landfall data for the northwestern Pacific Ocean region between 1945 and 2013 CE, which corresponds to the results seen here. The Fig. 2 shows clearly that TC activity grew to an extraordinary extent at around 1500 CE and has persisted to the present.

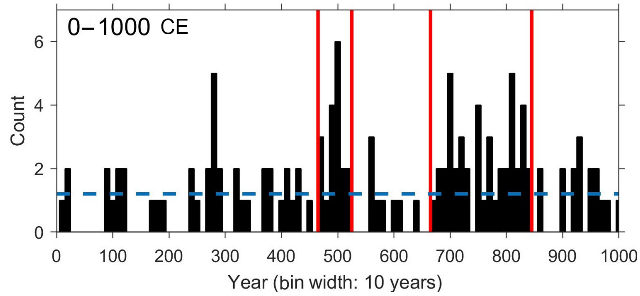

Figure 3. Statistics showing the number of typhoons between 0 and 1000 CE. The red range means high-frequency periods of TCs.

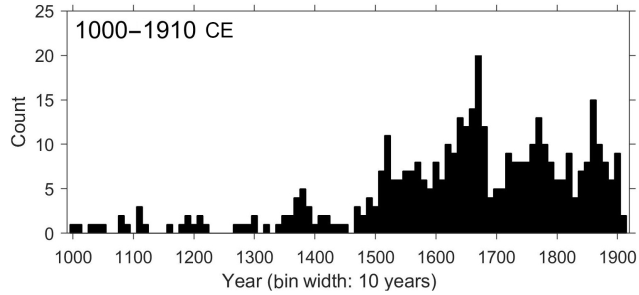

Figure 4. The numbers of typhoons occurring per decade for the period 1000–1910 CE.

4.1.1 Statistical typhoons between 0 and 1000 CE

The term *jufeng* did not appear in any historical documents before 1000 CE. Some of the documents, however, only mentioned disaster conditions such as trunk pulling, tree pulling, collapsed building, wind storm and "torrential rain". Given these limitations, all the typhoon records from 0 to 1000 CE were examined for using these assemblage proxies. The original results are listed in Table S1 of the Supplement. There were 124 possible typhoon events found in the records, which are presented in Fig. 3. The figure shows that, for the time period 0–1000 CE, on average 1.2 typhoons were recorded every 10 years. Based on this result, we define the periods that average more than 1.2 typhoons every 10 years, which were recorded continuously for 50 years, as a high-frequency typhoon period. Figure 3 shows that the periods 490–510 CE (Southern and Northern dynasties) and 700–850 CE (Tang Dynasty) were periods of frequent TC invasions. Our statistical results correspond to the fact that many instances of storm damage are mentioned in ancient poetry from the Tang Dynasty (Louie and Liu, 2003).

4.1.2 Statistical typhoons between 1000 and 1910 CE

Figure 4 gives a total of 408 events relating to the terms *jufeng* and typhoon for the period 1000–1910 CE. Original data are listed in Table S2 of the Supplement. Starting from 1460 CE, the number of TC landfalls suddenly starts to increase peaking between 1670 and 1679 CE. Other periods with substantial numbers of TCs making landfall are 1520–1529, 1770–1779, and 1860–1869 CE. During these times, recorded typhoon landfall was greatest in the Guangdong region (Fig. 6).

To make sure the historical record accurately reflected climatic conditions for the period examined, a search of the record was conducted for anomalous climatic events such as flooding, snow storms, droughts and so on. It was found that there were extensive gaps in the data for the periods 1270–1320 and 1400–1450 CE, which are the two periods that corresponded to the advent of the Yuan and Ming dynasties, respectively. All original data sources are listed in Table S5 of the Supplement. The Yuan Dynasty was established by the foreign-led dynasty of Kublai Khan of Mongolia. It was a period characterized by much internal strife and rebellion. The lack of good climate data in the historical record for the period 1400–1450 CE at first glance might seem surprising as it is the time of the Yongle Emperor and the promotion of Admiral Zhenghe, the eunuch commander of the seven great international tributary voyages across the South China Sea and Indian Ocean (1405–1430 CE). It would seem likely that weather conditions, especially TC would be of great importance to China, and this information would have been carefully recorded. This period is well described in the book *1421: the year China discovered America* (Menzies, 2008). In fact it is thought Zhenghe did record such detail, but much of it was lost or burned during eunuch and internal conflicts at the time of Emperor Yongle. The historical records were terminated in CE 1911 because the Qing Dynasty was overthrown and a civil war was fought in China for a long period of time. In addition, World War I occurred between 1914 and 1918 CE, and World War II took place from 1939 to 1945 CE. Therefore, China lacks climate records in the turmoil of war during this period in history.

4.2 The change in months of the year when typhoons occur

To further investigate any changes in the timing of annual TC landfall, TC landfall data were collected and analyzed for three different time periods: 0–1000 CE; 1000–1910 CE; and 1945–2013. The results are shown in Fig. 5, and monthly statistics are listed in Table S3 of the Supplement. Before 1000 CE, TCs in China mostly occurred in June, July and August (Fig. 5a). However, after 1000 CE, the entire trend in arrival times shifted by 1 month, with TC landfall occurring predominantly in July, August and September (Fig. 5b). The majority of statistics after 1000 CE were collected during the Little Ice Age (LIA; 1400–1850 CE). Figure 5c shows statistics for the period 1945–2013 CE The timing of recent TCs making landfall in southeastern China is quite similar to that which occurred during the LIA period. Recent data show that TC occurrence in the entire northwestern Pacific Ocean re-

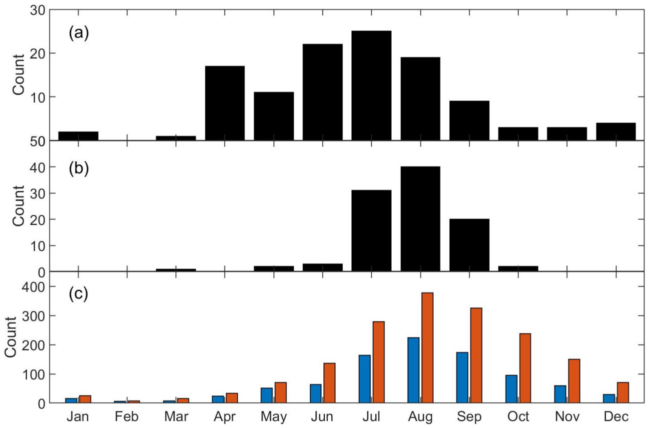

Figure 5. Statistics on TCs that struck China: **(a)** 0–1000 CE; **(b)** 1000–1910 CE; **(c)** 1945–2013 CE. Blue bars indicate the ones that hit China; the red bars indicate the ones that hit the northwestern Pacific Ocean region.

gion can last until as late as October, November and December with TCs making landfall in Vietnam, the Philippines and Thailand after September (Liu et al., 2017). It is assumed that this relates to seasonal changes in the positions of the subtropical high and ITCZ of the northwestern Pacific Ocean region. The ITCZ begins migrating north away from the Equator in March or April. It reaches its northernmost position in August, before migrating south in September (Waliser and Gautier, 1993). The question this study raises is what occurrence shifted the predominant timing of TC arrival in southeastern China from between June and August between 0 and 1000 CE to between July and September after 1000 CE. One likely explanation is that the ITCZ was at a higher latitude before 1000 CE (Rehfeld et al., 2013), resulting in earlier (June–August) TC formation.

4.3 The spatial distribution of the typhoons – the relationship between landfall locations and occurrence frequencies

Not all historical records gave details on where TCs struck before 1000 CE; therefore, this study focuses solely on the landfall locations of paleotyphoons between 1000 and 1910 CE. The number of typhoons that struck each province in China is shown in Fig. 6. Table S4 of the Supplement gives additional details on landfall locations. For the period 1000–1910 CE, Guangdong was struck by the most TCs. On the whole, the number of TCs making landfall increased dramatically after 1500 CE, with the number of typhoons hitting Guangdong peaking between 1660 and 1680 CE. By contrast, regions north of Fujian did not record any increase in typhoon activity during this time period. The number of typhoons striking Zhejiang and Jiangsu, however, did start to increase after 1700 CE.

Newton et al. (2006) proved that the warmest temperatures in the Indo-Pacific Warm Pool occurred during the Medieval Warm Period while the coolest temperatures occurred during the Little Ice Age. In particular, the lowest temperatures occurred around 1660–1680 CE within the period of the Maunder Minimum (1645–1715 CE). Therefore, it is thought that the sudden change in TC tracks around 1700 CE may relate to a change in temperature lows in the Northern Hemisphere and a shift in the location of the ITCZ.

5 Discussions

5.1 Northwestern Pacific Ocean paleotyphoon track changes during the MWP and LIA

Conserving historical documents has always been a difficult task. Racial conflicts, war, rebellion and inter-court feuds could all result in precious data being damaged, destroyed or lost during certain periods in history. Consequently, statistics on paleotyphoons recorded in the historical record are only semiquantitative. On the other hand, they are very useful in terms of noting the location of landfalls and the precise timing of such events. To help overcome any anomalies in the typhoon record lost to documented history and to avoid any confusion regarding the intensity of events, this study also looked at the geological record of paleotyphoons derived from lake sediments in northeastern Taiwan (Chen et al., 2012; Yang et al., 2014; Wang et al., 2013, 2014, 2015). Since the topography of northeastern Taiwan's Yilan region is quite unique, with the summer monsoon being blocked by mountains and rainfall being mainly supplied by the winter monsoon and typhoons (Chen et al., 2012), the region is very helpful for studying TC in the northwestern Pacific. In fact, large-scale river terraces have occurred due to typhoon rainfall, and this record has been preserved in the mountain areas of Yilan since 2.7 ka (Hsieh, 2017).

In order to correlate the number of paleotyphoons from historical data with the geological record of lake sediments, the Southern Oscillation Index (SOI), the intensity of paleotyphoons determined from sedimentary particle size at Taiwan's Lake Dahu and paleotyphoon signals from lagoon sediments in Kyushu, Japan (Fig. 7), are referenced and compared. Results suggest that typhoons struck Taiwan and the southeastern coastal region of China mostly during La Niña-like stages (Fig. 7a, b, c) (Chen et al., 2012). This outcome matches that mentioned by historical maritime disaster events caused by paleotyphoons in the last 1000 years in Liu et al. (2017). According to Liang and Zhang (2007), the chances of a typhoon making landfall in the southeastern coastal region of China during La Niña years is higher than that during El Niño years. If we started entering an El Niño-like stage after 1900 CE, this means the number of typhoons striking Japan in the future will very likely increase compared to what we see now. This trend in the data since 1700 CE shows a gradual increase in typhoon numbers mov-

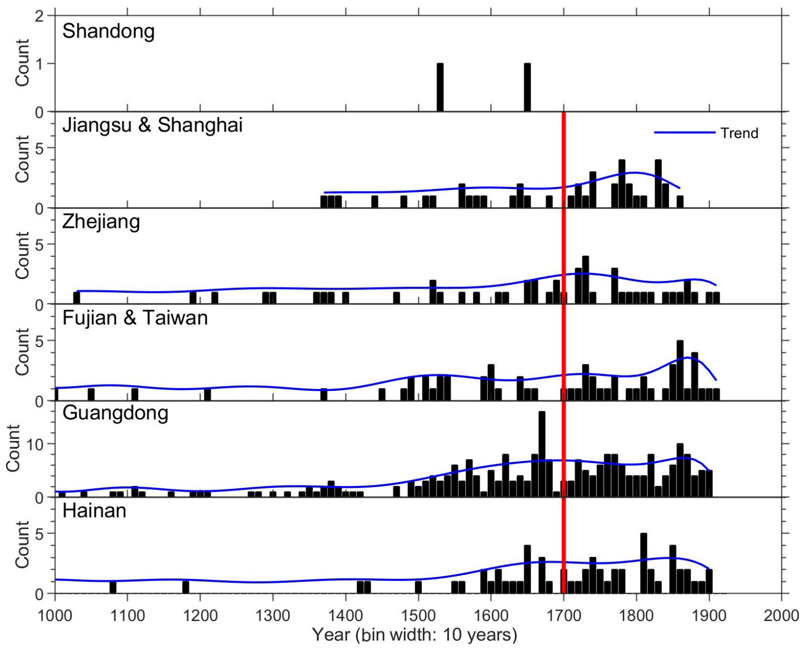

Figure 6. The number of typhoons that struck the southeastern regions of China and Taiwan between 1000 and 1910 CE. (Red line means the time boundary of 1700 CE. More TCs made landfall in Guandong before this time, but more TCs made landfall to northward after this time.)

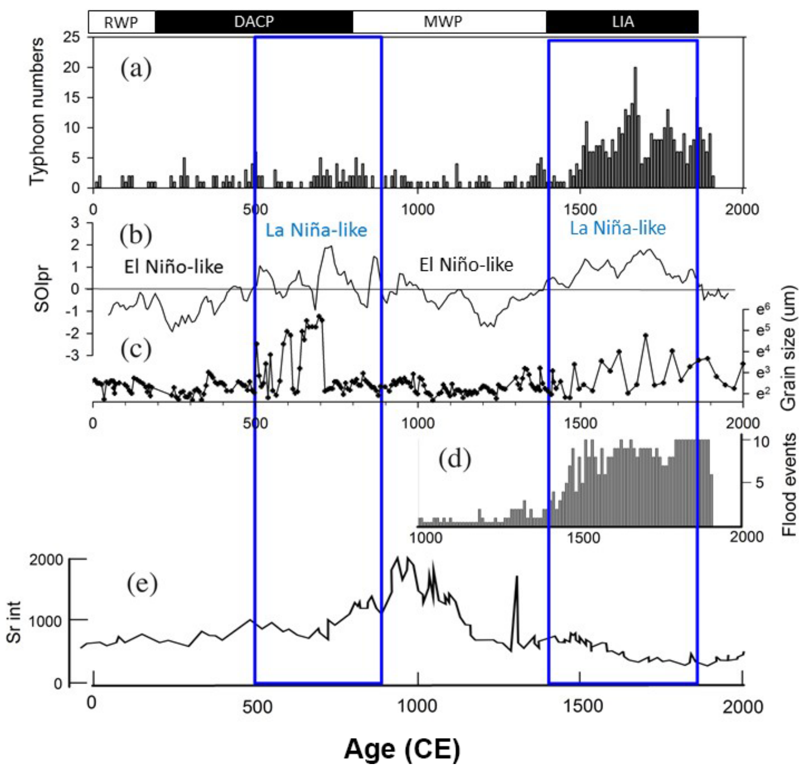

Figure 7. Correlations between typhoon events and ENSO. **(a)** Number of typhoons recorded in Chinese historical documents for the last 2000 years. **(b)** SOI_{pr} (Southern Oscillation Index from precipitation proxies; Yan et al., 2011). **(c)** The change in particle sizes from lake sediments from Yilan, Taiwan, indicating the change in magnitude of typhoon rainfall (Chen et al., 2012). **(d)** Number of flooding events recorded in Chinese historical documents (Chu et al., 2002). **(e)** Variation in Sr in lagoon sediments from Kyushu, Japan, indicating influences from exceptionally strong typhoons (Woodruff et al., 2009). RWP: Roman Warm Period; DACP: Dark Ages Cold Period.

ing north and away from Guangdong (Fig. 6). It has also been shown that the number and intensity of typhoons recorded in Taiwan's lake sediments has grown since the LIA (1400 CE) which seems to match the general trend in the recorded number of historical events pretty well (Fig. 7a and c). This period also coincided with the timing of flooding events in southern China (Fig. 7d). Park et al. (2017) investigated the records of lake sediments in the East Asia region. Their study noted that along coastal regions including Jeju Island (Korea), lakes in Yilan (Taiwan), Lake Huguangyan in Guangdong, and lakes on Hainan Island relatively drier conditions prevailed during the MWP and wetter conditions during the LIA. This may be due to an increase in rainfall caused by typhoons along the coast.

This study, therefore, finds that the northward migration of the ITCZ during the MWP caused typhoons to move north toward Japan. In contrast, typhoons moved toward southern China during the LIA due to the southward transition of the ITCZ. This seems to be a reasonable explanation and is not out of step with other regional studies (Rehfeld et al., 2013; Chen et al., 2015; Xu et al., 2016).

5.2 The linkage between ancient TCs of the northern Atlantic Ocean and northern Pacific Ocean

Donnelly and Woodruff (2007) first suggested that the number of hurricanes in the Caribbean area has been increasing over the last 4000 years. According to ancient hurricane research along the Gulf Cost and Caribbean Sea to Puerto Rico, hurricane tracks show an antiphase in time series data (McCloskey and Liu, 2012, 2013; McCloskey et al., 2013; Liu et al., 2015). During the MWP, more TCs made landfall in the Gulf Coast as the strength of the Bermuda High enhanced and the ITCZ moved northward. During the LIA, more TCs made landfall in the Caribbean Sea (McCloskey and Knowles, 2009; McCloskey and Liu, 2012, 2013; McCloskey et al., 2013). In 1650 CE, TC frequency reached a peak, and after 1850 CE TCs began to move toward Florida and Bermuda with the northward movement of the ITCZ (Baldini et al., 2016). Ancient lake sediment data from Yilan, Taiwan, reveals the period in history when paleotyphoons occurred most frequently. This timing correlates highly with the time of paleohurricanes recorded in Belize from McCloskey and Liu (2013). This suggests that the migration paths of TCs in both the northwestern Pacific Ocean region and the northwestern Atlantic Ocean region are closely related. TC activity occurred between 200 and 600 and between 1450 and 2600 yr BP in Belize, and it occurred between 200 and 500, 1300 and 1500, and 2000 and 2300 yr BP in Taiwan's lakes (Chen et al., 2012). This phenomenon indicates a close association between TC activity in the North Pacific Ocean and the North Atlantic Ocean.

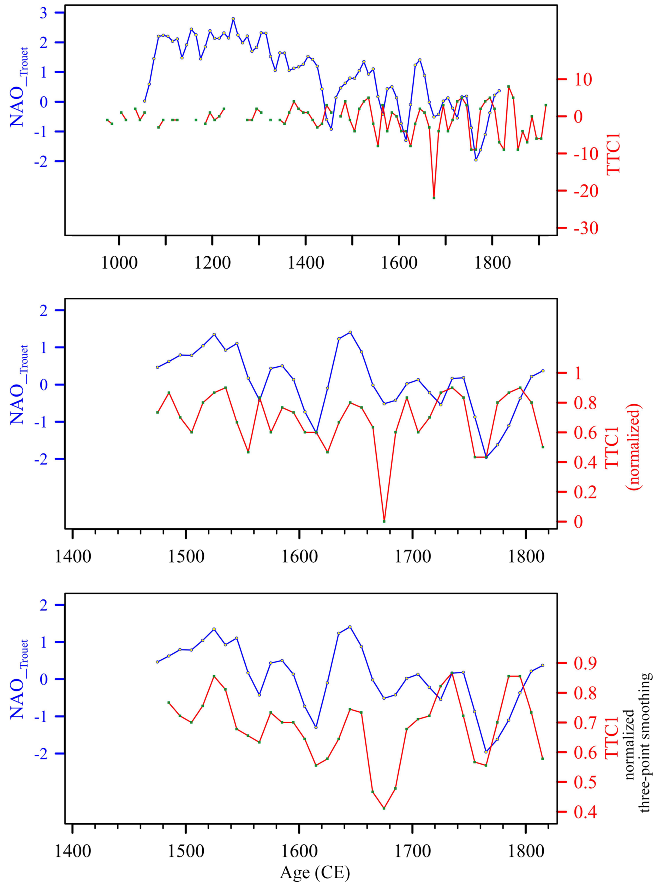

Figure 8. The relation between the NAO_{Trouet} (Trouet et al., 2009) and the TTC1.

5.3 The tracks of TCs corresponding to the NAO during the LIA

Since the ITCZ and westerlies are both linked to the Hadley Cell, and the position of midlatitude storms are determined by the westerlies, which are influenced by the North Atlantic Oscillation (NAO) (Hurrell, 1995; Morley et al., 2014), we compared the NAO record with the track of TCs. In order to compare our tracks of TCs with the NAO, we created an index called TTC1 to represent the track of TCs that either move toward southern China or toward northern China ($TTC1 = \sum X_i F_i$). X_i is the number of typhoons that had made landfall in a particular province, and F_i means the location factor of the landfall locality (Table 2). When the value of TTC1 is higher, it indicates a larger amount of typhoon landfalls in northern China (Fig. 8). The TTC1 can also be normalized to values between 0 and 1. Furthermore, we used digitalization to retrieve the average data of 10 years from the 2 kyr NAO index according to the results of Trouet et al. (2009) and Ortega et al. (2015). The results calculated from Trouet et al. (2009) and our TTC1 agree quite well (Fig. 8). However, our records were fragmentary before 1470 CE, and we lack the historical data from Japan. The re-

Table 2. Location factor (F_i) of various geographical locations in China.

Landfall locality	Hainan	Guangdong	Fujain and Taiwan	Zhejang	Jiangsu and Shanghai	Shandong
Location factor (F_i)	−2	−1	1	2	3	4

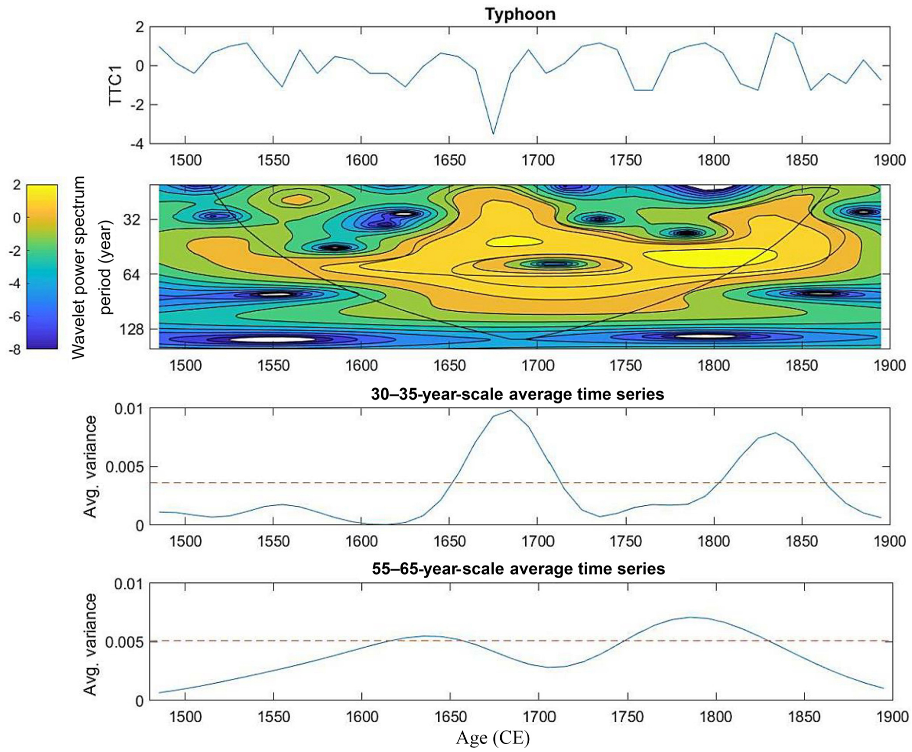

Figure 9. The wavelet analysis of the TTC1 during the LIA.

sults in Fig. 8 reveal that our normalized TTC1 corresponding to the NAO_{Trouet} during the LIA stage, and the 3-point smoothing of the TTC1 shows a very good correlation with the NAO_{Trouet}. This result indicates that the NAO influences the migration of the westerlies, and it may also gently affect the tracks of the TCs.

After we performed the wavelet analysis, we found that the TTC1 shows both 30–35- and 55–65-year cycles during the LIA stage (Fig. 9). This result is also consistent with the frequency of typhoon landfall over Guangdong Province of China during the period of 1470–1931 CE based on a different data source (Chan and Shi, 2000). The 60-year cycle is clearly present in the PDO and the Atlantic Multi-decadal Oscillation (AMO), with phases coherent with a planetary signal since at least 1650 to 1850 CE (Scafeta, 2012; Solheim, 2013). This implies that the PDO also affects the TTC1 cycle.

6 Conclusions

We statistically analyzed Chinese historical documents to understand the relationship between the MWP, LIA and movements in the ITCZ. Our conclusions are very similar to those found in previous studies, indicating that China's documented historical record is an invaluable asset in the study of climatological phenomena. The conclusions are as follows:

1. Before 1000 CE, TCs struck China mostly in June, July and August. The timing of TC landfall shifted to July, August and September after 1000 CE.

2. Statistical analyses of China's historical documents show that there was a sudden increase in the frequency of paleotyphoons in 490–510, 700–850 CE and since the beginning of the LIA (1400 CE).

3. Correlating lake core records from Taiwan and Japan proved that more typhoons made landfall in Guangdong and Taiwan during the LIA, whereas, more typhoons made landfall in Japan during the MWP.

4. Most typhoons made landfall in Guangdong in the coldest period of the LIA. Typhoon tracks started migrating towards Fujian and farther north after 1700 CE, indicating that there is a northward trend in typhoons towards Japan.

5. The track of TCs has 30–35- and 55–65-year cycles during the LIA stage; the result is consistent with the variation in the NAO and the PDO cycles.

Paleoclimate research covering the last 2000 years since the late Holocene mainly focuses on three drastic temperature fluctuation periods, i.e., the MWP, LIA and the global warming of the past 200 years. Our study shows that the paths of paleotyphoons between the MWP and LIA are closely related to the migration of the ITCZ. The results also demonstrate that the migration paths of TCs in the northern Pacific Ocean and the northern Atlantic Ocean are highly correlated with the NAO and the PDO cycles.

Data availability. We show all data in the Supplement.

Supplement. The supplement related to this article is available online at: https://doi.org/10.5194/cp-15-279-2019-supplement.

Author contributions. HFC coordinated and wrote this paper; HFC conceived the present idea and explained the conclusions; YCL read all records and obtained statistical results; XL and YMC contributed original books and helped collect data; CWC and HJP drew some of the figures and did the wavelength analysis.

Competing interests. The authors declare that they have no conflict of interest.

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