

1 **China's historical record in the search of tropical cyclones corresponding to**  
2 **ITCZ shifts over the past 2ka**

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15

16 **Abstract**  
17

18 The northwestern Pacific Ocean and south China sea are where tropical cyclones  
19 occur most frequently. Many climatologists also study the formation of Pacific Ocean  
20 warm pools and typhoons in this region. This study collected data of paleotyphoons  
21 found in China's official historical records over the past two thousand years with known  
22 typhoon activity reports. The collected data is then subjected to statistical analyses  
23 focusing on typhoon activity in coastal regions of southeastern China to garner a better  
24 understanding of the long-term evolution of moving paths and occurrence frequency,  
25 especially those typhoons making landfall in mainland China. We analyzed the data  
26 with the year and month of each typhoon event, as well as the number of events in a  
27 ten-year period. The result shows that (1) north/southward migration of typhoon paths  
28 correspond to the north/southward migration of the Intertropical Convergence Zone  
29 (ITCZ) during Medieval Warm Period (MWP) and Little Ice Age (LIA), (2)  
30 paleotyphoons made landfall in mainland China one month earlier during MWP than  
31 those during LIA. This implies a northward shift in ITCZ during MWP. Typhoons tend  
32 to make landfall in Japan during El Nino-like periods and strike the southern coastal  
33 regions of China during La Nina-like stages. According to paleotyphoon records over  
34 the last two thousand years, typhoons made landfall in southeastern China frequently  
35 around 490-510 A.D., 700-850 A.D., and after 1500 A.D. The number of typhoons  
36 striking Guangdong Province peaked during the coldest period in 1660-1680 A.D.;  
37 however, after 1700 A.D., landfall has migrated farther north. The track of tropical  
38 cyclones (TCs) in the northwestern Pacific Ocean is affected by the North Atlantic  
39 Oscillation (NAO) and the Pacific Decadal Oscillation (PDO), which shows a nearly  
40 30-yr and a 60-yr cycle during the LIA.  
41

42 Key word: Tropical cyclone, record, landfall, ITCZ, MWP, LIA, NAO  
43

44 **1. Introduction**  
45

46 Tropical cyclones (TCs) are a serious hazard. According to the Federal Emergency  
47 Management Agency (FEMA) of the USA, the total amount of money spent on flood  
48 recovery programs due to TC activity was greater than that spent on any other natural  
49 catastrophe during the period 2005 to 2015. The level of destruction caused by TCs has  
50 meant they have been the focus of a great deal of current research as well as part of the

51 historical record of China for millennia.

52 Among all tropical cyclones, 37% occur in the northwestern Pacific Ocean (Liang  
53 and Ye, 1993). These TCs are of a greater intensity and likelihood of making landfall  
54 than those making landfall in western Atlantic Ocean. When we searched the historical  
55 records of the Atlantic and Pacific Ocean regions, we found only one notable study of  
56 statistical records in the southeastern coastal region of the United States of America  
57 (Bossak et al., 2014), which discussed regional typhoon occurrence since 1851.  
58 Nevertheless, the historical record of TC occurrence in the northwestern Pacific owns  
59 longer historical records in China. Chan and Shi, (2000) first published the frequency  
60 of typhoon landfall over Guangdong Province of China during the period of 1470 A.D.~  
61 1931 A.D, and then Liu et al. (2001) made an examination of historical records dating  
62 back to 1000 years ago in the Guangdong Province. Fogarty (2004) compiled statistical  
63 records of TC occurrence in southeastern costal China over the last 400 years. While  
64 no study tried to touch the longer period from the China's historical documents, we  
65 attempted to collect more TC data from these documents and discuss why some defect  
66 fragments were not mentioned in this study.

67 A notable important issue related to the frequency of TC landfall had been  
68 discussed by the many meteorological studies. They pointed out that the occurrence and  
69 frequency of TC in the western Pacific Ocean are affected by the ENSO (Lander, 1944;  
70 Wang and Chan, 2002; Chu, 2004;), and ENSO is highly related to the PDO (Pavia et  
71 al., 2006; Feng and Wang, 2013). In addition, the ITCZ position and North Atlantic  
72 Oscillation (NAO) is a main force to drive the storms' pathways (Gil et al., 2006). For  
73 the purpose to track TC pathways in a long-term period, we need the geological records  
74 via the evidences of natural sediment from lake cores and lagoons in widespread coastal  
75 regions. The geological records indicate ancient TC activity were enhanced by the  
76 ENSO activity after middle Holocene, both in Atlantic and Pacific Oceans (Donnelly  
77 and Woodruff, 2007; Woodruff et al., 2009; Chen et al., 2012; McCloskey and Liu, 2012,  
78 2013; McCloskey et al., 2013; Liu et al., 2015). In this study, we attempted to collate  
79 statistics on the landfall frequency of TCs recorded in China's written historical record  
80 with typhoon intensity recorded in the geological record of lake sediments in  
81 northeastern Taiwan to investigate TC path migration in the northwestern Pacific Ocean  
82 region over the last 2 ka.

83

## 84 **2. Paleotyphoon records from China's official historical documents**

85

86 China's historical record is a rich source of documented evidence on climatic  
87 conditions dating back millennia. Anomalous abnormalities in climatic conditions  
88 found in China's records had been successfully applied in the reconstruction of regional  
89 climate changes (Liu et al, 2001; Chu et al., 2002; Chu et al., 2008). Previous research  
90 revealed the term "Jufeng" (cyclone, 颶風) first appeared in the South-North Dynasty  
91 around 420-479 A.D. (Liu et al., 2001). During the following Tang Dynasty (618-907  
92 A.D.) many climate phenomena relating to torrential rainfall and strong winds  
93 resembling typhoons were recorded in poems (Louie and Liu, 2003). After the Northern  
94 Song Dynasty (960-1126 A.D.), Chinese governmental institutions have kept a  
95 continuous record of typhoon strikes reported by local administrative authorities (Louie

96 and Liu 2003, Liu et al. 2003). The term “Typhoon” (颱風) first appeared during the  
 97 Qing Dynasty with documented evidence of typhoon landfall on Taiwan first appearing  
 98 in 1750 A.D.  
 99

### 100 3. Applied method

101 China’s written historical record dates back 3000 years. The statistical records  
 102 used in our study include data from southeastern coastal China and Taiwan (Fig.1). The  
 103 data source upon which our study is based a book titled: A Syllogism of China’s  
 104 “Meteorological Record over the past 3000 Years” (Zhang, 2013). This book consists of  
 105 7813 pieces of documentary evidence from China’s historical documents including  
 106 7713 pieces from local government bodies and another 28 from other historical  
 107 documents. In total, there are more than 220,000 recorded events. After thorough  
 108 verifications of data sources, timing, and event locations found in the record primary  
 109 source reports were kept and duplicates eliminated. This is, by far, the most complete  
 110 and commonly accepted climate record from China’s documented history.

111 Considering the evolution of typhoon-related keywords over the years, besides  
 112 using the specific keywords “Typhoon” and “Jufeng” to search for records since 1000  
 113 A.D. Related expressions such as “strong wind” (大風), “rainstorm” (暴雨), and “storm  
 114 surge” (風暴潮) were also applied to our search. However, the terms jufeng and  
 115 typhoon rarely appeared in the historical record prior to 1000 B.P. So, for this earlier  
 116 period, we added additional terms that are possibly associated with “typhoon” such as  
 117 “trunk pulling” (拔木), “tree pulling” (拔樹), “collapsed building” (覆屋), and “wind  
 118 storm” (暴風) to our statistical study. We attempt to reconstruct the time of occurrence  
 119 and the location of paleotyphoons along the coastal region in China, and to understand  
 120 the evolution of typhoon development over a long period of time. It is worth to note  
 121 that every episode would be recorded in historical documents due to a significant  
 122 damage or a disaster. As a result, we speculate that the strengths of typhoons would be  
 123 above moderate. All ancient Chinese literatures were listed in the appendix of Liu  
 124 (2015). Table 1 shows some illustrations of original historical source.  
 125

126 Table 1. The historical records of typhoon-related illustrations in China

Occurring time	Descriptions	Locality	Data source
798 A.D. August	Strong wind destroyed the buildings and overturned the boats.	Guangdong	The New Book of Tang , The notes of the Five Elements
1380 A.D. 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 A.D. August	Jufeng and heavy rainfall happened. 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 A.D. August	Strong jufeng destroyed the buildings and the surge smashed several hundreds of merchant ship.	Taiwan	Qing Jiaqing Years, Updated Taiwan County Records, Volume 5, The Fortunate and Abnormal Events.
1831 A.D. July	Jufeng and heavy rainfall caused flooding and seawater intrusion in the coastal range. More than	Shanghai	Qing Guangxu Years, Chongming County Records,

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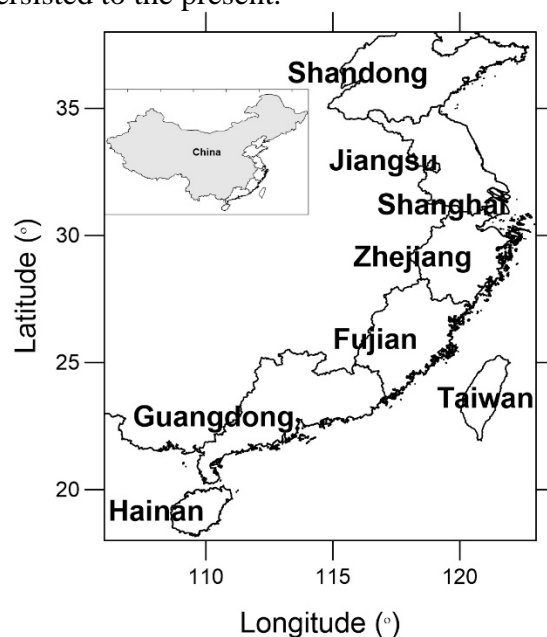
128 **4. Results**

129

130 **4.1 Statistical results on the frequency of typhoon landfall**

131

132 The statistical data collected for the southeastern coastal regions of China includes  
133 data for: Hainan, Guangdong, Fujian, Taiwan, Zhejiang, Shanghai, Jiangsu, and  
134 Shandong (Fig. 1). When we categorized typhoon landfall locations based on latitudes,  
135 Fujian and Taiwan are recognized as one region due to their similarities in latitude and  
136 the same as Jiangsu and Shanghai. It is notable that prior to 2000 years BP the historical  
137 record of China lacks data of typhoon activity. Consequently, this study focuses on data  
138 collected over the past 2000 years. Furthermore, data for the period 1945-2013 A.D.  
139 were collected from the northwestern Pacific Ocean TC records established by the Joint  
140 Typhoon Warning Center (JTWC). The statistical results were divided into three  
141 different time frames based on keyword results and database sources: (1) 0-1000 A.D.;  
142 (2) 1000-1910 A.D.; and (3) 1945-2013 A.D. To plot the number of typhoons occurring  
143 as a function of time, typhoon events in any given decade were collectively plotted to  
144 create an interdecadal bar-graph dating from 1000 AD to the present (Fig. 2). The  
145 number of events which occurred in any given decade relates closely to the age of  
146 historical documents and how well they have been preserved. Records relating to TC  
147 landfall between 1945-2013 A.D. is reliant on satellite acquired data meaning the data  
148 source is highly reliable in terms of its location and intensity. Consequently, Figure 2  
149 shows extreme growth in the number of recorded TCs in the latter years of the twentieth  
150 century. Moreover, Liu et al (2017) published TC landfall data for the northwestern  
151 Pacific Ocean region during 1945-2013 A.D. which corresponds to the results seen here.  
152 The figure 2 shows clearly that TC activity grew extraordinarily at around 1500 A.D.  
153 and has persisted to the present.

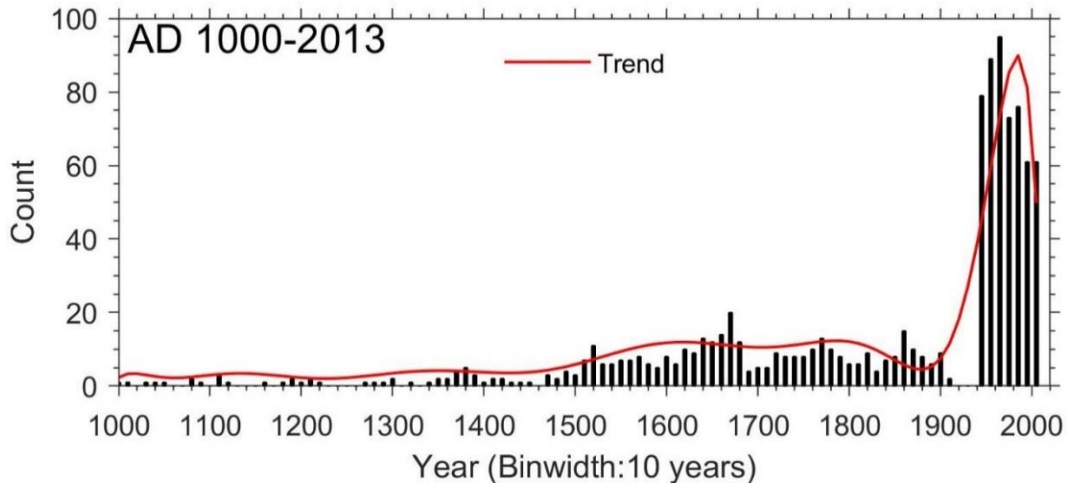


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155

156 Fig. 1 Southeastern coastal regions of China and Taiwan

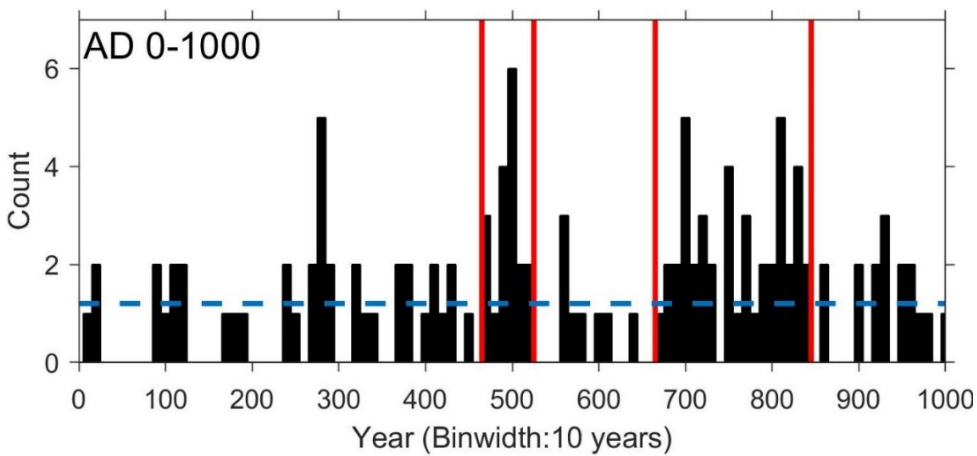
157



158  
 159 Figure 2. Historical paleotyphoon data compiled over the past 1000 years from China’s  
 160 historical record and JTWC data for southeastern China and Taiwan. Each bar  
 161 in the bar-graph represents the collective number of typhoons occurring in any  
 162 given decade.  
 163

164 **4.1.1 Statistic typhoons during 0-1000 A.D.**

165  
 166 The term “Jufeng” did not appear in any historical documents before 1000 A.D.  
 167 Some of the documents, however, only mentioned disaster conditions such as “trunk  
 168 pulling”, “tree pulling”, “collapsed building”, “wind storm” and “torrential rain”. Given  
 169 these limitations, all the typhoon records from 0-1000 A.D. were examined for using  
 170 these assemblage proxies. The original results are listed in Table 1 of the supplementary  
 171 file. There were 124 possible typhoon events found in the records, which have been  
 172 presented in Figure 3. The figure shows for the time period 0-1000 A.D., there were on  
 173 average 1.2 typhoons recorded every 10 years. Based on this result, we define the  
 174 periods that average more than 1.2 typhoons each 10 years plus recorded continuously  
 175 50 years as a high frequency typhoon period. Figure 3 shows that the periods 490-510  
 176 A.D. (South-North Dynasty) and 700-850 A.D. (Tang Dynasty) were periods of  
 177 frequent TC invasions. Our statistic results respond that why many storm damages were  
 178 mentioned in ancient poetries during the Tang Dynasty (Louie and Liu, 2003).  
 179



180  
 181 Fig. 3 Statistics showing the number of typhoons during 0-1000 A.D. The red range  
 182 means high frequent periods of TCs.  
 183

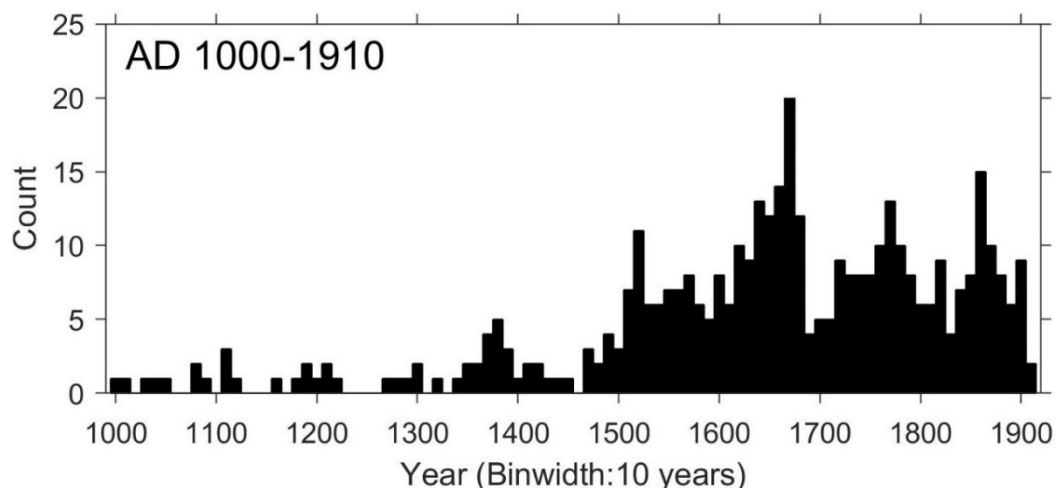
184 **4.1.2 Statistic typhoons during 1000-1910 A.D.**

185

186 Figure 4 gives a total of 408 events relating to the terms “Jufeng” and “Typhoon”  
187 for the period 1000-1910 A.D. Original data are listed in Table 2 of the supplementary  
188 file. Starting from 1460 A.D., TC landfall by suddenly number started to increase  
189 peaking between 1670-1679 A.D. Other periods with substantial numbers of TC  
190 making landfall are: 1520-1529 A.D, 1770-1779 A.D, and 1860-1869 A.D.. During  
191 these times, recorded typhoon landfall was greatest in the Guangdong region (Fig. 6).

192 To make sure the historical record accurately reflected climatic conditions for the  
193 period examined, a search of the record was conducted for anomalous climatic events  
194 such as flooding, snow storms, and droughts and so on. It was found that there were  
195 extensive gaps in the data for the periods 1270-1320 A.D. and 1400-1450 A.D.. The  
196 two periods that corresponded to the advent of the Yuan and Ming Dynasties,  
197 respectively. All original data sources are listed in Table 5 of the supplementary file.  
198 The Yuan Dynasty was established by foreign-led dynasty of Kublai Khan of Mongolia.  
199 It was a period described by much internal strife and rebellion. The lack of good climate  
200 data in the historical record for the period 1400-1450 A.D. at first glance might seem  
201 surprising as it is the time of the Yongle Emperor and the promotion of Admiral  
202 Zhenghe, the eunuch commander of the 7 great international tributary voyages across  
203 the South China Sea and Indian Oceans (1405-1430 A.D.). It would seem likely that  
204 weather conditions, especially TC would be of great import to China and this  
205 information would have been carefully recorded. This period is well described in the  
206 book: 1421 (Menzies, 2008). In fact it is thought Zhenghe did record such detail, but  
207 much of it was lost or burned during “Eunuch Conflict” and much internal conflict at  
208 the death of Emperor Yongle. The historical records were terminated in AD 1911  
209 because the Qing Dynasty was overthrown and a civil war was fought in China for a  
210 long period of time. In addition, the World War I happened during 1914-1918 A.D. and  
211 the World War II took place during 1939-1945 A.D. Therefore, China lacks climate  
212 records in the turmoil of war during this period in history.

213



214

215 Fig. 4 The numbers of typhoons occurring per decade for the period 1000-1910 A.D.

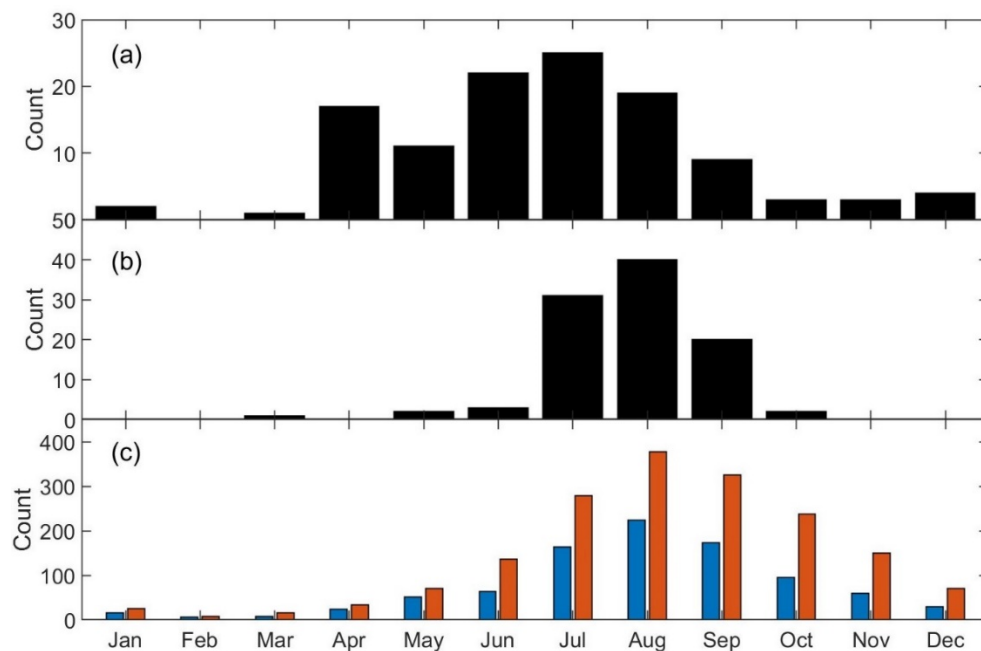
216

217 **4.2 The change in months of the year when typhoons occur**

218

219 To further investigate any changes in the timing of TC landfall occurrence  
220 annually, TC landfall data was collected and analyzed for the three different time  
221 periods: 0-1000 A.D.; 1000-1910 A.D.; and 1945-2013. The results are shown in Figure

222 5 and monthly statistics listed in Table 3 of the supplementary file. Before 1000 A.D.,  
 223 TCs in China mostly occurred in June, July, and August (Fig. 5a). However, after 1000  
 224 A.D., the entire trend in arrival times shifted by one month with TC landfall occurring  
 225 predominantly in July, August, and September (Fig. 5b). The majority of statistics after  
 226 1000 A.D. were collected during the LIA (1400-1850 A.D.). Figure 5c shows statistics  
 227 for the period 1945-2013 A.D. The timing of recent TCs making landfall in southeastern  
 228 China is quite similar to that which occurred during the LIA period. Recent data shows  
 229 that TC occurrence in the entire northwestern Pacific Ocean region can last until as late  
 230 as October, November, and December with TCs making landfall in Vietnam,  
 231 Philippines, and Thailand after September (Liu et al., 2017). It is assume that this relates  
 232 to seasonal changes in the positions of the subtropical high and ITCZ of the  
 233 northwestern Pacific Ocean region. The ITCZ begins migrating north away from the  
 234 equator in March or April. It reaches its northernmost position in August, before  
 235 migrating south in September (Waliser and Gautier, 1993). The question this study  
 236 raises is what happened to shift the predominant timing of TC arrival in southeastern  
 237 China from between June~August during 0-1000 A.D. to between July~September after  
 238 1000 A.D. One likely explanation is the ITCZ being at a higher latitude before 1000  
 239 A.D. (Rehfeld et al., 2013), resulting in earlier (June~August) TC formation.  
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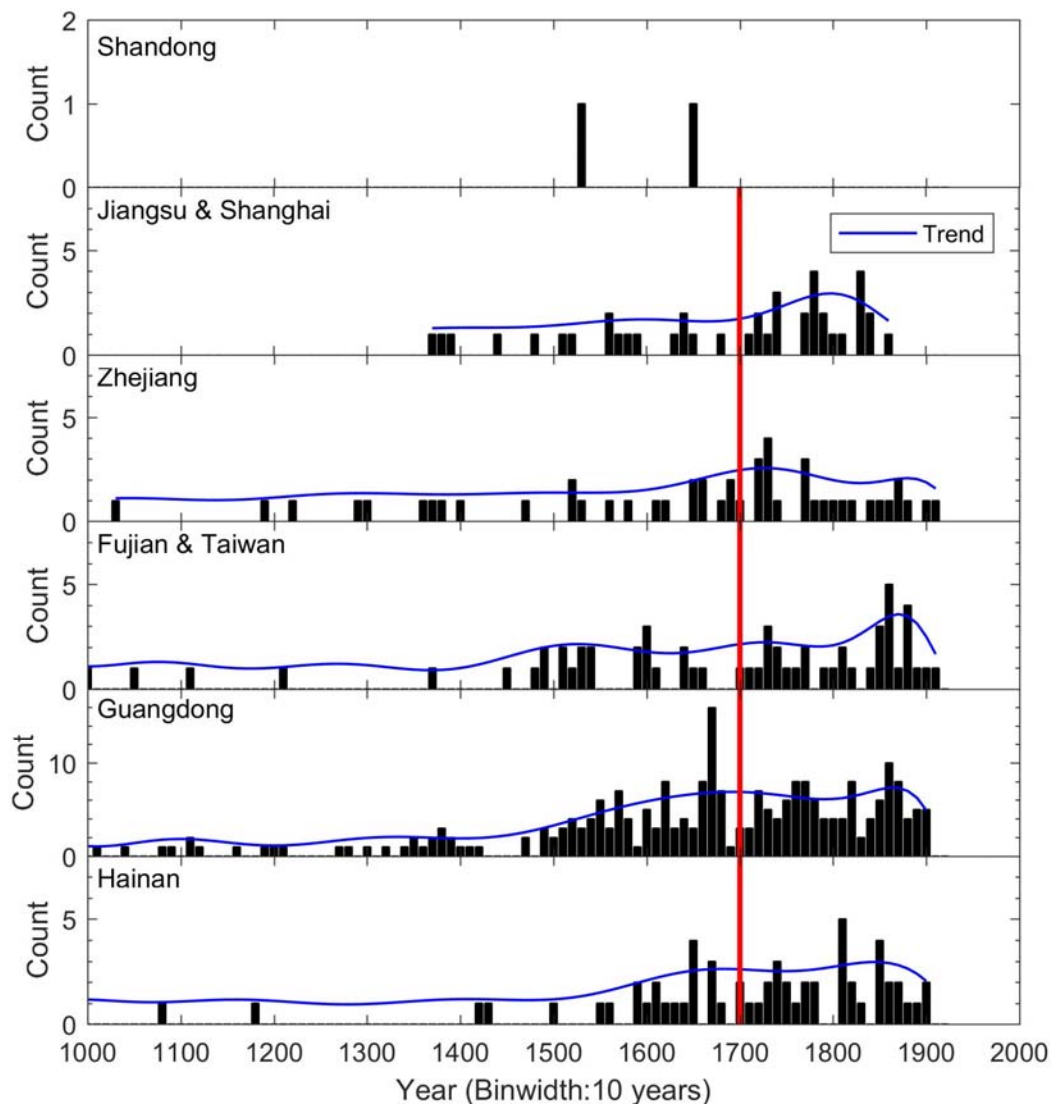
241  
 242 Fig. 5 Statistics on TCs that struck China (a) 0-1000 A.D. (b) 1000-1910 A.D. (c) 1945-  
 243 2013 A.D. Blue bars indicate the ones that hit China; the red bars indicate the ones that  
 244 hit the north-western Pacific Ocean region.  
 245

246 **4.3 The spatial distribution of the typhoons - the relationship between landfall**  
 247 **locations and occurrence frequencies**  
 248

249 Not all historical record gave detail on where TCs struck until 1000 A.D.;  
 250 therefore, this study focuses solely on the landfall locations of paleotyphoons between  
 251 1000 and 1910 A.D. The number of typhoons that struck each province in China are  
 252 shown in Figure 6. Table 4 of the supplementary file gives additional detail on landfall  
 253 locations. For the period 1000-1910 A.D., Guangdong was struck by the most TCs. On  
 254 the whole, the number of TCs making landfall increased dramatically after 1500 A.D.

255 with the number of typhoons hitting Guangdong peaking between 1660-1680 A.D. By  
 256 contrast, regions north of Fujian did not record any increase in typhoon activity during  
 257 this time-period. The number of typhoons striking Zhejiang and Jiangsu, however, did  
 258 start to increase after 1700 A.D.

259 Newton et al. (2006) proved that the warmest temperatures in the Indo-Pacific  
 260 Warm Pool occurred during the Medieval Warm Period while the coolest  
 261 temperatures occurred during the Little Ice Age. In particular, the lowest temperatures  
 262 occurred around 1660-1680 A.D. within the period of the Maunder Minimum (1645-  
 263 1715 A.D.). Therefore, it is thought that the sudden change TC tracks around 1700  
 264 A.D. may relate to a change in temperature lows in the northern hemisphere and a  
 265 shift in the location of the ITCZ.  
 266



267  
 268 Fig. 6 The number of typhoons that struck the southeastern regions of China and  
 269 Taiwan during 1000-1910 A.D. (Red line means the time boundary of 1700 A.D.  
 270 More TC made landfall in Guangdong before this time, but more TC made landfall to  
 271 northward after this time)  
 272

## 273 5. Discussions

274

275 **5.1 Northwestern Pacific Ocean paleotyphoon track changes during the MWP**  
276 **and LIA**

277

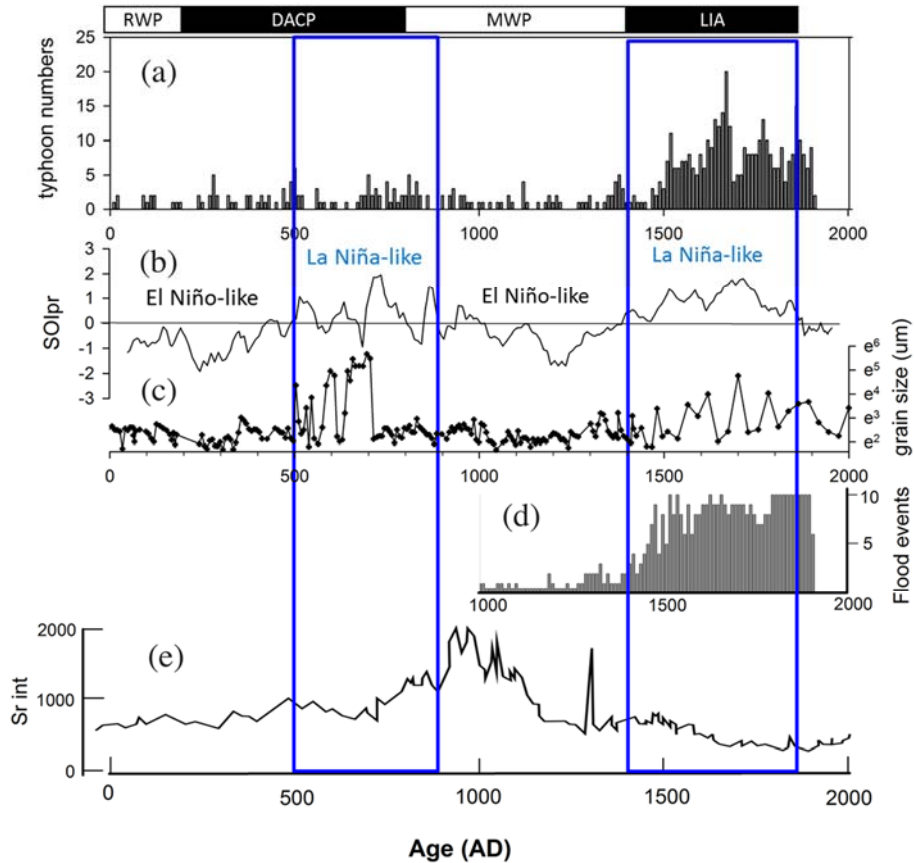
278 Conserving historical documents has always been a difficult task. Racial conflicts,  
279 war, rebellion, and inter-court feuds could all result in precious data being damaged,  
280 destroyed or lost during certain periods in history. Consequently, statistics on  
281 paleotyphoons recorded in the historical record are only semi-quantitative. On the other  
282 hand, they are very useful in terms of noting the location of landfalls and the precise  
283 timing of such events. To help overcome any anomalies in the typhoon record lost to  
284 documented history and avoid any confusion regarding the intensity of events, this  
285 study also looked at the geological record of paleotyphoons derived from lake  
286 sediments in northeastern Taiwan (Chen et al., 2012; Yang et al., 2014; Wang et al.,  
287 2013, 2014, 2015). Since the topography of northeastern Taiwan's Yilan region is quite  
288 unique with the summer monsoon being blocked by mountains and rainfall being  
289 mainly supplied by the winter monsoon and typhoons (Chen et al., 2012), the region is  
290 very helpful for studying TCs tracking in the Northwestern Pacific. In fact, large-scale  
291 river terraces have occurred due to typhoon rainfall and this record is preserved in the  
292 mountain areas of Yilan since 2.7 ka BP (Hsieh, 2017).

293 In order to correlate the number of paleotyphoons from historical data with the  
294 geological record of lake sediments, the Southern Oscillation Index (SOI), intensity of  
295 paleotyphoons determined from sedimentary particle size at Taiwan's Lake Dahu, and  
296 paleotyphoon signals from lagoon sediments in Kyushu, Japan (Fig. 7) are referenced  
297 and compared. Results suggest that typhoons struck Taiwan and the southeastern  
298 coastal region of China mostly during La Nina-like stages (Figs. 7a, b, c) (Chen et al.,  
299 2012). This outcome matches that mentioned by historical maritime disaster events  
300 caused by paleotyphoons in the last 1000 years in Liu et al. (2017). According to Liang  
301 and Zhang (2007), the chances of a typhoon making landfall in the southeastern coastal  
302 region of China during La Nina years is higher than that during El Nino years. If we  
303 started entering an El Nino like stage after 1900 A.D., this means the number of  
304 typhoons striking Japan in the future will very likely increase compared to what we see  
305 now. This trend in the data since 1700 A.D. shows a gradual increase in typhoon  
306 numbers moving north and away from Guangdong (Fig. 6). It has also been shown that  
307 the number and intensity of typhoons recorded in Taiwan's lake sediments has grown  
308 since the LIA (1400 A.D.) which seems to match the general trend in the recorded  
309 number of historical events pretty well (Fig. 7a and c). This period also coincided with  
310 the timing of flooding events in southern China (Fig. 7d). Park et al. (2017) investigated  
311 the records of lake sediments in the East Asia region. Their study noted that along  
312 coastal regions including Jeju Island (Korea), lakes in Yilan (Taiwan), Lake  
313 Huguangyan in Guangdong, and lakes on Hainan Island relatively drier conditions  
314 prevailed during MWP and wetter conditions during the LIA. This may be due to an  
315 increase in rainfall caused by typhoons along the coast.

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

321

322



323 Fig.7 Correlations between typhoon events and ENSO. (a) Number of typhoons  
 324 recorded in Chinese historical documents for the last 2000 years. (b) SOI (Yan et al.,  
 325 2011). (c) The change in particle sizes from lake sediments from Yilan, Taiwan  
 326 indicating the change in magnitude of typhoon rainfall (Chen et al., 2012). (d) Number  
 327 of flooding events recorded in Chinese historical documents (Chu et al., 2002). (e)  
 328 Variation of Sr in lagoon sediments from Kyushu, Japan indicating influences from  
 329 super strong typhoons (Woodruff et al., 2009).

331

## 332 5.2 The linkage between ancient TCs of the northern Atlantic Ocean and 333 northern Pacific Ocean

334

335 Donnelly and Woodruff (2007) first suggested that the number of hurricanes in  
 336 the Caribbean area has been increasing over the last 4000 years. According to ancient  
 337 hurricane research along the Gulf Coast, Caribbean Sea to Puerto Rico, hurricane tracks  
 338 show an antiphase in time series data (McCloskey and Liu, 2012, 2013; McCloskey et  
 339 al., 2013; Liu et al., 2015). During the MWP, more TCs made landfall in the Gulf Coast  
 340 as the strength of the Bermuda High enhanced and the ITCZ moved northward. During  
 341 the LIA, more TC made landfall on the Caribbean Sea (McCloskey and Knowles, 2009;  
 342 McCloskey and Liu, 2012, 2013; McCloskey et al., 2013). In 1650 A.D., TC frequency  
 343 reached a peak, and after 1850 A.D. TCs began to move toward Florida and Bermuda  
 344 with the northward movement of the ITCZ (Baldini et al., 2016). Ancient lake sediment  
 345 data from Yilan, Taiwan reveals the period in history when paleotyphoons occurred  
 346 most frequently. This timing highly correlates to the time of paleohurricanes recorded  
 347 in Belize (McCloskey and Liu, 2013). This suggests that the migration paths of TCs in  
 348 both the northwestern Pacific Ocean region and the northwestern Atlantic Ocean region

349 are closely related. The TC activity happened during 200–600 yr BP and 1450–2600 yr  
 350 BP in Belize, and it occurred during 200-500 yr BP, 1300-1500 yr BP and 2000-2300  
 351 yr BP in Taiwan’s lakes (Chen et al., 2012). This phenomenon indicates a close link  
 352 between TC activity in the North Pacific Ocean and the North Atlantic Ocean.

353

### 354 **5.3 The Track of TCs corresponding to the NAO during the LIA**

355

356 Since the ITCZ and Westerlies both link to the Hadley Cell, and the position of  
 357 middle-latitude storms are dragged by the westerlies which is influenced by the North  
 358 Atlantic Oscillation (NAO) (Hurrell, 1995; Morley et al., 2014), we compared the  
 359 NAO record with the track of TCs. In order to compare our tracks of TCs with the  
 360 NAO, we created an index of TTC1 to represent the track of TCs that either move  
 361 toward southern China or toward northern China ( $TTC1 = \sum X_i F_i$ ).  $X_i$  is the number of  
 362 typhoons that had made landfall in that certain province, and  $F_i$  means the location  
 363 factor of the landfall locality (Table 1). When the value of TTC1 is higher, it indicates  
 364 a larger amount of typhoon landfalls in northern China (Fig. 8). The TTC1 can also be  
 365 normalized to values between 0~1. Furthermore, we used digitalization to retrieve the  
 366 average data of 10-year from 2ka NAO index according to the results of Trouet et al.  
 367 (2009) and Ortega et al. (2015). The results calculated from Trouet et al. (2009) and  
 368 our TTC1 agree quite well (Fig. 8). However, our records were fragmentary before  
 369 1470 A.D. and we lack the historical data from Japan. The results in Figure 8 reveals  
 370 that our normalized TTC1 corresponding to the  $NAO_{\text{trouet}}$  during the LIA stage, and  
 371 the 3-point smoothing of the TTC1 shows a very good correlation with the  $NAO_{\text{trouet}}$ .  
 372 This result proves that the NAO influences the migration of the westerlies and it also  
 373 gently affects the tracks of the TCs.

374

375 Table 1. Location factor ( $F_i$ ) of various geographical locations in China

Landfall Locality	Hainan	Guangdong	Fujain & Taiwan	Zhejiang	Jiangsu & Shanghai	Shandong
Location factor ( $F_i$ )	-2	-1	1	2	3	4

376

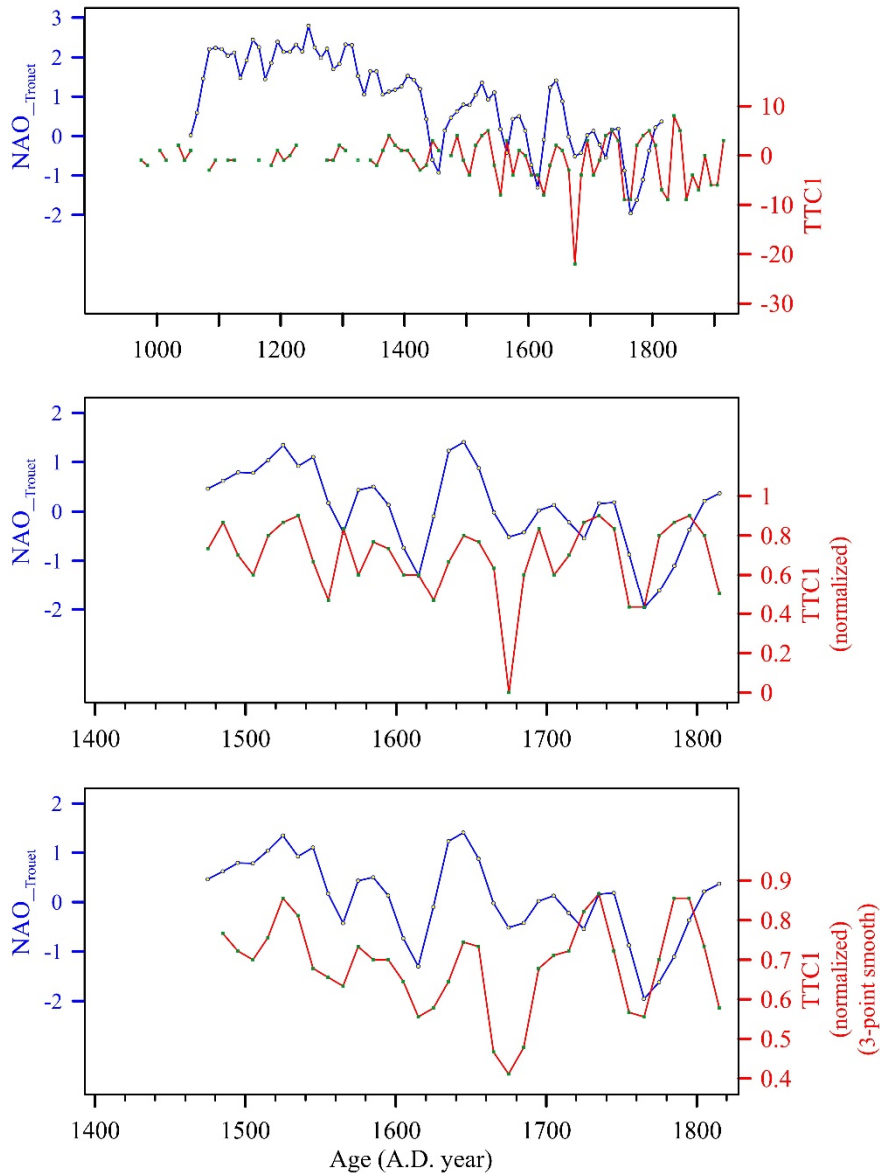


Fig. 8 The relation between the  $NAO_{\text{trouet}}$  (Trouet et al., 2018) and the TTC1

377  
378  
379

380 After we performed the wavelet analysis, we found that the TTC1 shows both 30-  
381 35 yr and 55-65 yr cycles during the LIA stage (Fig. 9). This result is also consistent  
382 with the frequency of typhoon landfall over Guangdong Province of China during the  
383 period of 1470 A.D.~ 1931 A.D. based on a different data source (Chan and Shi, 2000).  
384 The 60 yr cycle is clearly present in the Pacific Decadal Oscillation (PDO) and the  
385 Atlantic Multi-decadal Oscillation (AMO), with phases coherent with a planetary signal  
386 since at least 1650 A.D. to 1850A.D. (Scafeta, 2012; Solheim, 2013). This implies that  
387 the PDO also affects the TTC1 cycle.

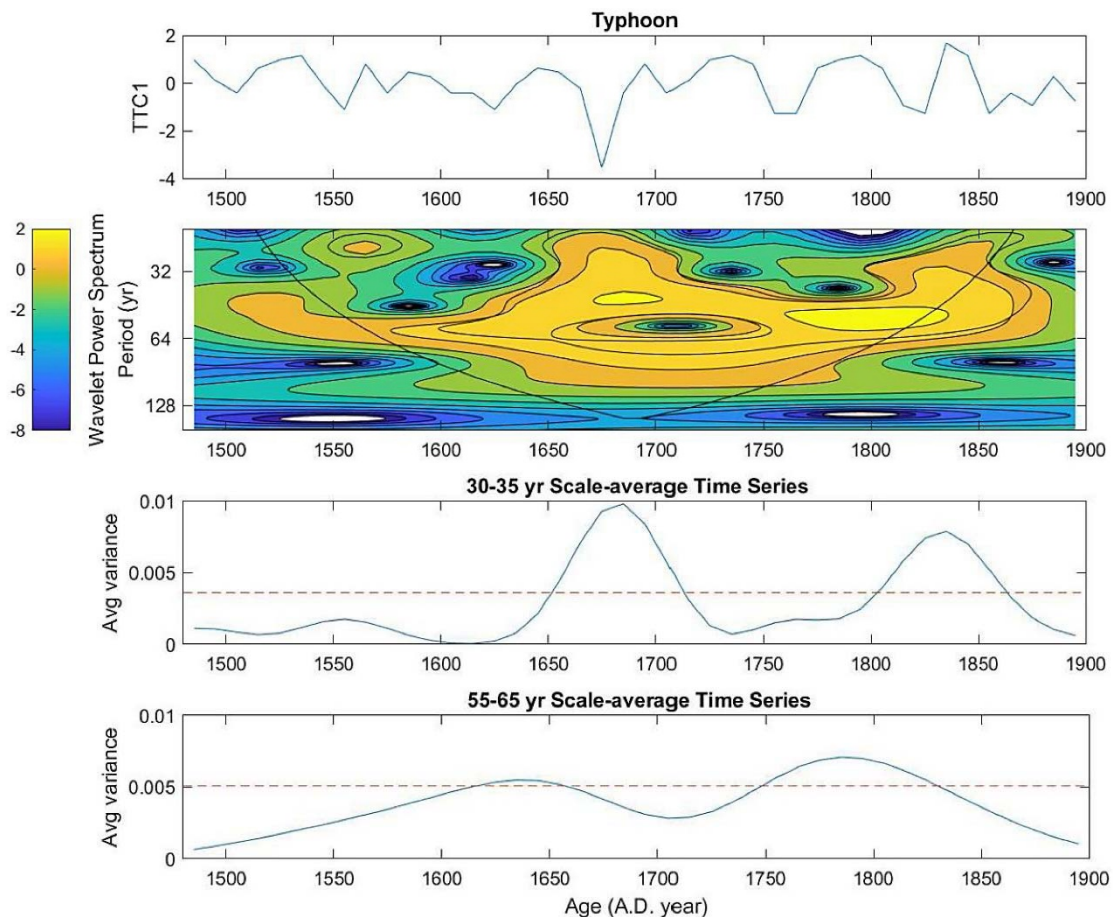


Figure 9. The wavelet analysis of the TTC1 during the LIA

## 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 A.D., TCs struck China mostly in June, July, and August. The timing of TC landfall shifted to July, August, and September after 1000 A.D.
- (2) Statistical analyses of China's historical documents show that there was a sudden increase in the frequency of paleotyphoons in 490-510 A.D., 700-850 A.D. and since the beginning of the LIA (1400 A.D.).
- (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 at the coldest era of LIA. Typhoon tracks started migrating towards Fujian and farther north after 1700 A.D., indicating that there is a northward trend in typhoons towards Japan.
- (5) The track of TCs has 30-35 yr and 55-65 yr cycles during the LIA stage, the result is consistent with the variation of 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, including the MWP, LIA, and

414 the global warming of the past 200 years. Our study shows that the paths of  
415 paleotypoos between the MWP and LIA closely related to the migration of the ITCZ.  
416 The results also demonstrate that the migration paths of TCs in the northern Pacific  
417 Ocean and the northern Atlantic Ocean are highly correlated with the NAO and the  
418 PDO cycles.

419

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426

## 427 **Appendix A. Supplementary data**

428 Supplementary data related to this article can be found at xxx.

429

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