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2 ITCZ shifts over the past 2ka 3 Huei-Fen Chen<sup>1,2</sup>, Yen-Chu Liu<sup>1</sup>, Chih-Wen Chiang<sup>1</sup>, Xingqi Liu<sup>3</sup>, Yu-Min Chou<sup>4</sup> 4 5 6 1. Institute of Earth Sciences, National Taiwan Ocean University, Keelung, Taiwan, 7 R.O.C. 8 2. Center of Excellence for Oceans, National Taiwan Ocean University, Keelung, 9 Taiwan, R.O.C. 10 3. College of Environmental Resources & Tourism, Capital Normal University, 11 Beijing, P.R. China 12 4. Department of Ocean Science and Engineering, Southern University of Science and Technology, Shenzhen, P.R. China 13 14 15 Abstract 16

China's historical record in the search of tropical cyclones corresponding to

17 The northwestern Pacific Ocean and south China sea are where tropical cyclones 18 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 19 20 found in China's official historical records over the past two thousand years with known 21 typhoon activity reports. The collected data is then subjected to statistical analyses 22 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, 23 24 especially those typhoons making landfall in mainland China. We analyses the data with 25 the year and month of each typhoon event, as well as the number of events in a ten-year 26 period. The result shows that (1) north/southward migration of typhoon paths correspond to the north/southward migration of the Intertropical Convergence Zone 27 28 (ITCZ) during Medieval Warm Period (MWP) and Little Ice Age (LIA), (2) 29 paleotyphoons made landfall in mainland China one month earlier during MWP than 30 those during LIA. This implies a northward shift in ITCZ during MWP. Typhoons tend 31 to make landfall in Japan during El Nino-like periods and strike the southern coastal regions of China during La Nina-like stages. According to paleotyphoon records over 32 the last two thousand years, typhoons made landfall in southeastern China frequently 33 around 490-510 A.D., 700-850 A.D., and after 1500 A.D. The number of typhoons 34 35 striking Guangdong Province peaked during the coldest period in 1660-1680 A.D.; 36 however, after 1700 A.D., landfall has migrated farther north.

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38 Key word: Tropical cyclone, record, landfall, ITCZ, MWP, LIA

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# 1. Introduction

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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 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 likelihood of making landfall
than their western Atlantic cousins. Nevertheless, the historical record of TC occurrence





in the northwestern Pacific is limited. Fogarty (2004) compiled statistical records of TC
occurrence in southeastern costal China over the last 400 years and Liu et al. (2001)
made an examination of historical records dating back 1000 years for the Guangdong
region of southeastern China. In the Atlantic Ocean, one notable study of statistical
records in the southeastern coastal region of the United States of America is that of
Bossak et al. (2014), which looked at regional typhoon occurrence since 1851.

57 Studies of TC activity during the Holocene rely heavily on geological studies, 58 which provide evidence of long-term typhoon activity stored in the geological record. 59 Recent studies of ancient TCs show that since the diminishment of the Asian Summer 60 Monsoon and enhancement of ENSO, there has been a gradual growth in the occurrence 61 and impact of TCs (Donnelly and Woodruff, 2007; Woodruff et al., 2009; Chen et al., 62 2012; McCloskey and Liu, 2012, 2013; McCloskey et al., 2013; Liu et al., 2015). This 63 evidence suggests TC activity is controlled by the development of the Pacific Ocean 64 warm pool. Our study collates statistics on the landfall frequency of TCs recorded in 65 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 66 67 northwestern Pacific Ocean region over the last 2 ka.

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

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71 China's historical record is a rich source of documented evidence on climatic conditions 72 dating back millennia. Anomalous abnormalities in climatic conditions found in 73 China's records had been successfully applied in the reconstruction of regional climate changes (Liu et al, 2001; Chu et al., 2002; Chu et al., 2008). Previous research revealed 74 75 the term "Jufeng" (cyclone, 颶風) first appeared in the South-North Dynasty around 76 420-479 A.D. (Liu et al., 2001). During the following Tang Dynasty (618-907 A.D.) 77 many climate phenomena relating to torrential rainfall and strong winds resembling 78 typhoons were recorded in poems (Louie and Liu, 2003). After the Northern Song 79 Dynasty (960-1126 A.D.), Chinese governmental institutions have kept a continuous 80 record of typhoon strikes reported by local administrative authorities (Louie and Liu 2003, Liu et al. 2003). The term "Typhoon" (颱風) first appeared during the Qing 81 82 Dynasty with documented evidence of typhoon landfall on Taiwan first appearing in 83 1750 A.D.

84 China's written historical record dates back 3000 years. The statistical records used 85 in our study include data from southeastern coastal China and Taiwan (Fig.1). The data 86 source upon which our study is based a book titled: "A Syllogism of China's 87 Meteorological Record over the past 3000 Years" (Zhang, 2013). This book consists of 88 7813 pieces of documentary evidence from China's historical documents including 89 7713 pieces from local government bodies and another 28 from other historical 90 documents. In total, there are more than 220,000 recorded events. After thorough 91 verifications of data sources, timing, and event locations found in the record primary source reports were kept and duplicates eliminated. This is, by far, the most complete 92 93 and commonly accepted climate record from China's documented history. 94

### 3. Results

# 97 **3.1 Statistical results on the frequency of typhoon landfall**

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In order to search the historical record comprehensively, a keyword search was





conducted for the terms "typhoon" and "jufeng" as well as associated expressions such
as "strong wind", "rainstorm", "storm surge" and so on. The terms typhoon and jufeng
rarely appeared in the historical record prior to 1000 BP so for this earlier period we
added additional terms such as "trunk pulling", "tree pulling", "collapsed building",
"wind storm" and "torrential rain". Once the data was collected, all long-term data for
the southeast costal region of China was examined and integrated into the study to help
reconstruct the timing and evolution of paleotyphoons in terms of their location.

107 The statistical data collected for the southeastern coastal regions of China includes 108 data for: Hainan, Guangdong, Fujian, Taiwan, Zhejiang, Shanghai, Jiangsu, and 109 Shandong. When we categorized typhoon landfall locations based on latitudes, Fujian 110 and Taiwan are recognized as one region due to their similarities in latitude and the 111 same as Jiangsu and Shanghai. It is notable that prior to 2000 years BP the historical 112 record of China lacks data of typhoon activity. Consequently, this study focuses on data 113 collected over the past 2000 years. Furthermore, data for the period 1945-2013 A.D. were collected from the northwestern Pacific Ocean TC records established by the Joint 114 115 Typhoon Warning Center (JTWC). The statistical results were divided into three 116 different time frames based on keyword results and database sources: (1) 0-1000 A.D.; 117 (2) 1000-1910 A.D.; and (3) 1945-2013 A.D. To plot the number of typhoons occurring 118 as a function of time, typhoon events in any given decade were collectively plotted to 119 create an interdecadal bar-graph dating from 1000 AD to the present (Fig. 2). The 120 number of events which occurred in any given decade relates closely to the age of 121 historical documents and how well they have been preserved. Records relating to TC 122 landfall between 1945-2013 A.D. is reliant on satellite acquired data meaning the data 123 source is highly reliable in terms of its location and intensity. Consequently, Figure 2 124 shows extreme growth in the number of recorded TCs in the latter years of the twentieth 125 century. Moreover, Liu et al (2017) published TC landfall data for the northwestern 126 Pacific Ocean region during 1945-2013 A.D. which corresponds to the results seen here. 127 The figure 2 shows clearly that TC activity grew extraordinarily at around 1500 A.D. 128 and has persisted to the present.





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Fig. 1 Southeastern coastal regions of China and Taiwan







Year (Binwidth:10 years)
 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.

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### 138 3.1.1 Statistic typhoons during 0-1000 A.D.

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140 The term "Jufeng" did not appear in any historical documents before 1000 A.D. 141 Some of the documents, however, only mentioned disaster conditions such as "trunk 142 pulling", "tree pulling", "collapsed building", "wind storm" and "torrential rain". Given these limitations, all the typhoon records from 0-1000 A.D. were examined for using 143 144 these assemblage proxies. The original results are listed in Table 1 of the supplementary 145 file. There were 124 possible typhoon events found in the records, which have been 146 presented in Figure 3. The figure shows for the time period 0-1000 A.D., there were on average 1.2 typhoons recorded every 10 years. Based on this result, we define the 147 periods that average more than 1.2 typhoons each 10 years plus recorded continuously 148 149 50 years as a high frequency typhoon period. Figure 3 shows that the periods 490-510 150 A.D. (South-North Dynasty) and 700-850 A.D. (Tang Dynasty) were periods of 151 frequent TC invasions. Our statistic results respond that why many storm damages were 152 mentioned in ancient poetries during the Tang Dynasty (Louie and Liu, 2003).







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

# 3.1.2 Statistic typhoons during 1000-1910 A.D.

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Figure 4 gives a total of 408 events relating to the terms "Jufeng" and "Typhoon"
for the period 1000-1910 A.D. Original data are listed in Table 2 of the supplementary
file. Starting from 1460 A.D., TC landfall by suddenly number started to increase
peaking between 1670-1679 A.D. Other periods with substantial numbers of TC
making landfall are: 1520-1529 A.D, 1770-1779 A.D, and 1860-1869 A.D.. 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 166 167 period examined, a search of the record was conducted for anomalous climatic events such as flooding, snow storms, and droughts and so on. It was found that there were 168 169 extensive gaps in the data for the periods 1270-1320 A.D. and 1400-1450 A.D. two 170 periods that corresponded to the advent of the Yuan and Ming Dynasties, respectively. 171 The Yuan Dynasty was established by Kublai Khan of Mongolia, making it the first 172 foreign-led dynasty. It was a period described by much internal strife and rebellion. During this period record keeping and the traditional stewardship of the Han people 173 174 over accurate records was put in doubt. The lack of good climate data in the historical 175 record for the period 1400-1450 A.D. at first glance might seem surprising as it is the 176 time of the Yongle Emperor and the promotion of Admiral Zhenghe, the eunuch 177 commander of the 7 great international tributary voyages across the South China Sea 178 and Indian Oceans (1405-1430 A.D.). It would seem likely that weather conditions, 179 especially TC would be of great import to China and this information would have been 180 carefully recorded. This period is well described in the book: 1421 (Menzies, 2008). In 181 fact it is thought Zhenghe did record such detail, but much of it was lost or burned 182 during "Eunuch Conflict" and much internal conflict at the death of Emperor Yongle.









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

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### 188 **3.2** The change in months of the year when typhoons occur

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190 To further investigate any changes in the timing of TC landfall occurrence 191 annually, TC landfall data was collected and analyzed for the three different time 192 periods: 0-1000 A.D.; 1000-1910 A.D.; and 1945-2013. The results are shown in Figure 193 5 and monthly statistics listed in Table 3 of the supplementary file. Before 1000 A.D., 194 TCs in China mostly occurred in June, July, and August (Fig. 5a). However, after 1000 195 A.D., the entire trend in arrival times shifted by one month with TC landfall occurring 196 predominantly in July, August, and September (Fig. 5b). The majority of statistics after 197 1000 A.D. were collected during the LIA (1400-1850 A.D.). Figure 5c shows statistics 198 for the period 1945-2013 A.D. The timing of recent TCs making landfall in southeastern 199 China is quite similar to that which occurred during the LIA period. Recent data shows 200 that TC occurrence in the entire northwestern Pacific Ocean region can last until as late 201 as October, November, and December with TCs making landfall in Vietnam, 202 Philippines, and Thailand after September (Liu et al., 2017). It is assume that this relates 203 to seasonal changes in the positions of the subtropical high and ITCZ of the 204 northwestern Pacific Ocean region. The ITCZ begins migrating north away from the 205 equator in March or April. It reaches its northernmost position in August, before 206 migrating south in September (Waliser and Gautier, 1993). The question this study 207 raises is what happened to shift the predominant timing of TC arrival in southeastern 208 China from between June~August during 0-1000 A.D. to between July~September after 209 1000 A.D. One likely explanation is the ITCZ being at a higher latitude before 1000 210 A.D. (Rehfeld et al., 2013), resulting in earlier (June~August) TC formation. 211







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Fig. 5 Statistics on TCs that struck China (a) 0-1000 A.D. (b) 1000-1910 A.D. (c) 1945-213 2013 A.D. Blue bars indicate the ones that hit China; the red bars indicate the ones that 214 215 hit the north-western Pacific Ocean region.

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#### 3.3 The spatial distribution of the typhoons - the relationship between landfall 217

#### 218 locations and occurrence frequencies

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220 Not all historical record gave detail on where TCs struck until 1000 A.D.; 221 therefore, this study focuses solely on the landfall locations of paleotyphoons between 222 1000 and 1910 A.D. The number of typhoons that struck each providence in China are 223 shown in Figure 6. Table 4 of the supplementary file gives additional detail on landfall 224 locations. For the period 1000-1910 A.D., Guangdong was struck by the most TCs. On 225 the whole, the number of TCs making landfall increased dramatically after 1500 A.D. 226 with the number of typhoons hitting Guangdong peaking between 1660-1680 A.D. By 227 contrast, regions north of Fujian did not record any increase in typhoon activity during 228 this time-period. The number of typhoons striking Zhejiang and Jiangsu, however, did 229 start to increase after 1700 A.D.

230 Newton et al. (2006) proved that the warmest temperatures in the Indo-Pacific 231 Warm Pool occurred during the Medieval Warm Period while the coolest

temperatures occurred during the Little Ice Age. In particular, the lowest temperatures 232 233 occurred around 1660-1680 A.D. a period of reduced solar intensity known as the

Maunder Minimum. Therefore, it is thought that the sudden change TC tracks around

234 235 1700 A.D. may relate to a change in temperature lows in the northern hemisphere and

- 236 a shift in the location of the ITCZ.
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Fig. 6 The number of typhoons that struck the southeastern regions of China andTaiwan during 1000-1910 A.D.

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# 4. Discussions

- 245 4.1 Northwestern Pacific Ocean paleotyphoon track changes during the MWP
- 246 and LIA

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248 Conserving historical documents has always been a difficult task. Racial conflicts, 249 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 250 251 paleotyphoons recorded in the historical record are only semi-quantitative. On the other 252 hand, they are very useful in terms of noting the location of landfalls and the precise 253 timing of such events. To help overcome any anomalies in the typhoon record lost to 254 documented history and avoid any confusion regarding the intensity of events, this 255 study also looked at the geological record of paleotyphoons derived from lake 256 sediments in northeastern Taiwan (Chen et al., 2012; Yang et al., 2014; Wang et al., 257 2013, 2014, 2015). Since the topography of northeastern Taiwan's Yilan region is quite 258 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 TCs tracking in the Northwestern Pacific. In fact, large-scale
river terraces have occurred due to typhoon rainfall and this record in preserved in the
mountain areas of Yilan since 2.7 ka BP (Hsieh, 2017).

In order to correlate the number of paleotyphoons from historical data with the 263 264 geological record of lake sediments, the Southern Oscillation Index (SOI), intensity of 265 paleotyphoons determined from sedimentary particle size at Taiwan's Lake Dahu, and 266 paleotyphoon signals from lagoon sediments in Kyushu, Japan (Fig. 7) are referenced 267 and compared. Results suggest that typhoons struck Taiwan and the southeastern 268 coastal region of China mostly during La Nina-like stages (Figs. 7a, b, c) (Chen et al., 269 2012). This outcome matches that mentioned by historical maritime disaster events 270 caused by paleotyphoons in the last 1000 years in Liu et al. (2017). According to Liang 271 and Zhang (2007), the chances of a typhoon making landfall in the southeastern coastal 272 region of China during La Nina years is higher than that during El Nino years. If we 273 started entering an El Nino like stage after 1900 A.D., this means the number of 274 typhoons striking Japan in the future will very likely increase compared to what we see 275 now. This trend in the data since 1700 A.D. shows a gradual increase in typhoon 276 numbers moving north and away from Guangdong (Fig. 6). It has also been shown that 277 the number and intensity of typhoons recorded in Taiwan's lake sediments has grown 278 since the LIA (1400 A.D.) which seems to match the general trend in the recorded 279 number of historical events pretty well (Fig. 7a and c). This period also coincided with 280 the timing of flooding events in southern China (Fig. 7d). Park et al. (2017) investigated 281 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 282 Huguangyan in Guangdong, and lakes on Hainan Island relatively drier conditions 283 284 prevailed during MWP and wetter conditions during the LIA. This may be due to an 285 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).





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Fig.7 Correlations between typhoon events and ENSO. (a) Number of typhoons
recorded in Chinese historical documents for the last 2000 years. (b) SOI (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 of Sr in lagoon sediments from Kyushu, Japan indicating influences from
super strong typhoons (Woodruff et al., 2009).

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# 302 4.2 The linkage between ancient TCs of the northern Atlantic Ocean and

## 303 northern Pacific Ocean

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305 Donnelly and Woodruff (2007) first suggested that the number of hurricanes in the 306 Caribbean area has been increasing over the last 4000 years. According to ancient hurricane research along the Gulf Cost, Caribbean Sea to Puerto Rico, hurricane tracks 307 show an antiphase in time series data (McCloskey and Liu, 2012, 2013; McCloskey et 308 309 al., 2013; Liu et al., 2015). During the MWP, more TCs made landfall in the Gulf Coast 310 as the strength of the Bermuda High enhanced and the ITCZ moved northward. During 311 the LIA, more TC made landfall on the Caribbean Sea (McCloskey and Knowles, 2009; 312 McCloskey and Liu, 2012, 2013; McCloskey et al., 2013). In 1650 A.D., TC frequency reached a peak, and after 1850 A.D. TCs began to move toward Florida and Bermuda 313 314 with the northward movement of the ITCZ (Baldini et al., 2016). Ancient lake sediment 315 data from Yilan, Taiwan reveals the period in history when paleotyphoons occurred 316 most frequently. This timing highly correlates to the time of paleohurricanes recorded 317 in Belize (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. The TC activity happened during 200–600 yr BP and 1450–2600 yr
BP in Belize, and it occurred during 200-500 yr BP, 1300-1500 yr BP and 2000-2300
yr BP in Taiwan's lakes (Chen et al., 2012). This phenomenon indicates a close link
between TC activity in the North Pacific Ocean and the North Atlantic Ocean.

## 324 5. Conclusions

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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.
- 333 (2) Statistical analyses of China's historical documents show that there was a
  334 sudden increase in the frequency of paleotyphoons in 490-510 A.D., 700-850
  335 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.
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Paleoclimate research covering the last 2000 years since the late Holocene mainly
focuses on three drastic temperature fluctuation periods, including 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 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.

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- 356

# 357 Appendix A. Supplementary data

358 359 Supplementary data related to this article can be found at xxx.

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