

East Asian Historical Climate Reconstruction Symposium

東亞歷史氣候學術討論會

# 東亞古風暴學的研究倡議

## ***Towards Developing a Paleotempestology Research Agenda for East Asia***

廖淦標

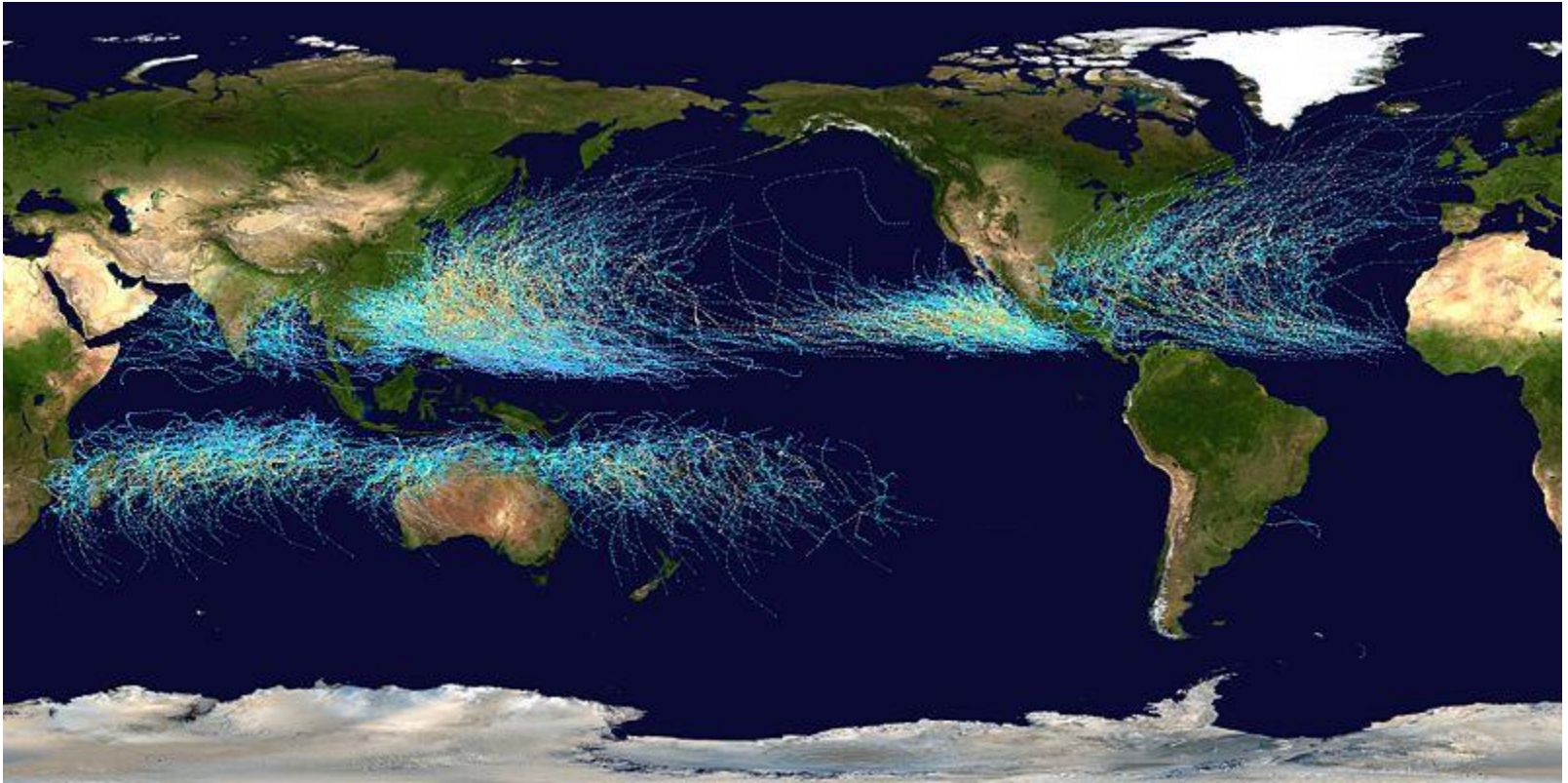
***(Kam-biu Liu)***

***Louisiana State University***

February 13-14, 2017

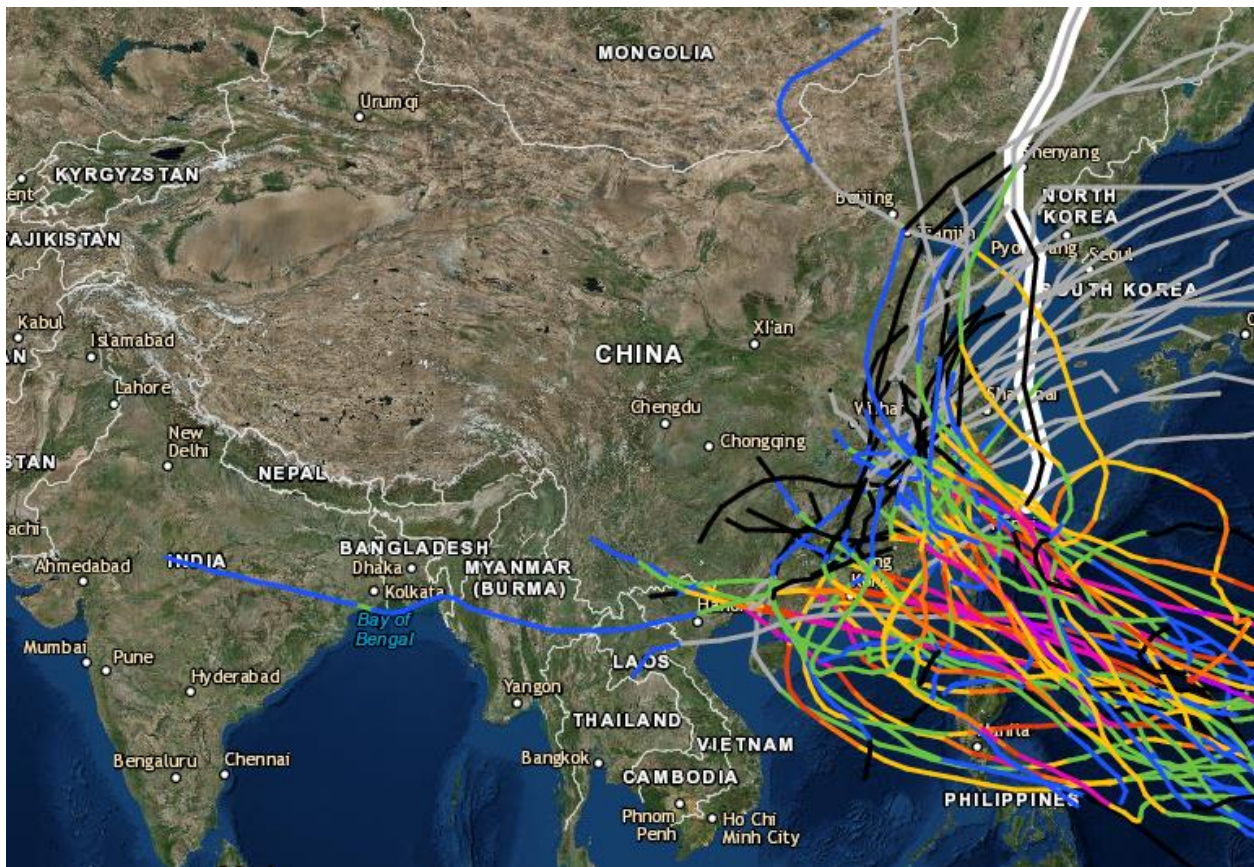
Taipei, Taiwan

**The Western North Pacific region is the most active tropical cyclone basin in the world**



# Intense typhoon landfalls in China (CAT 3-5, 1971-2015)

- 55 in 45 years
- 1.2/yr

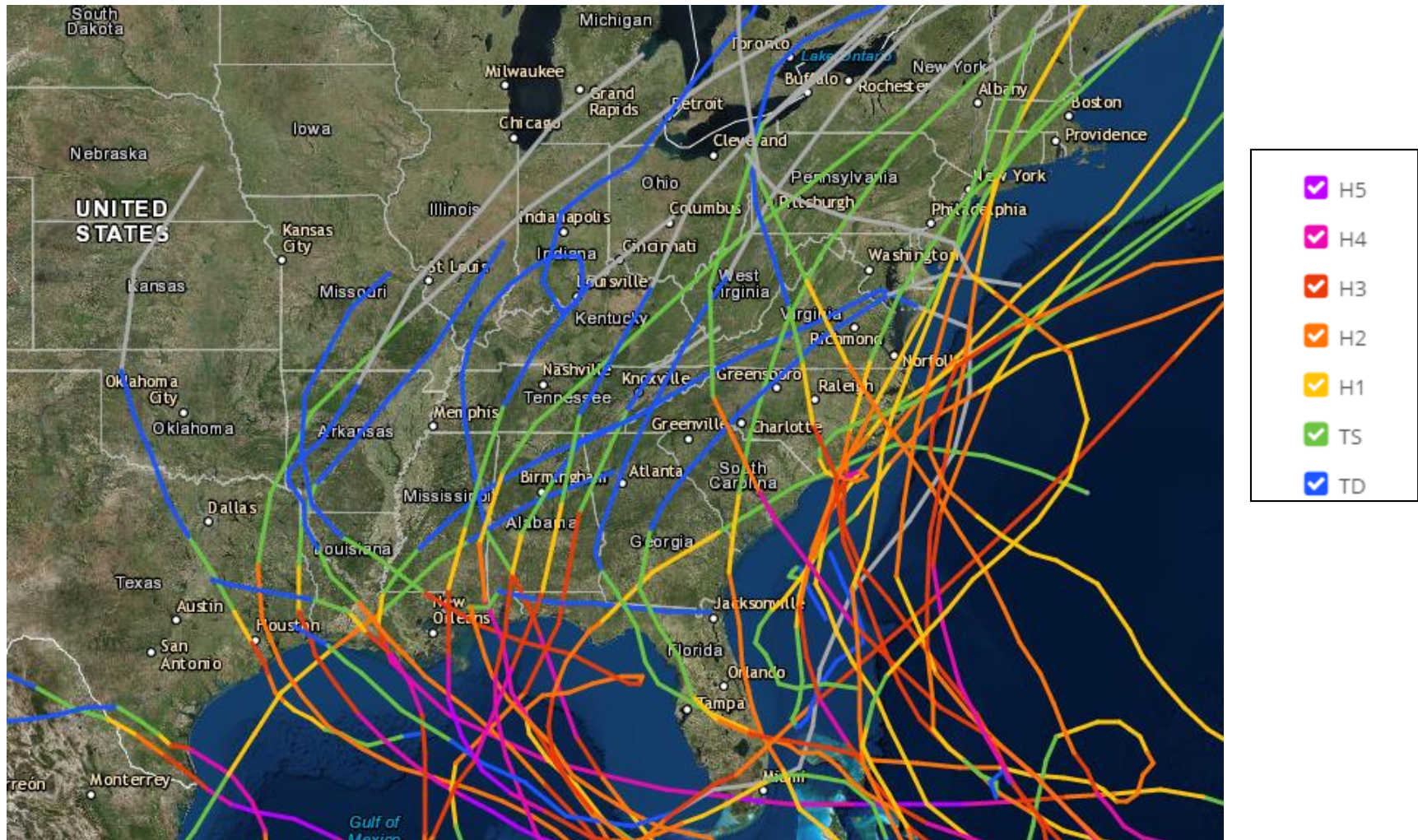


## Ranking of top 5 countries since 1970

1. China
2. Philippines
3. Japan
4. Mexico
5. U.S.A.

# Intense hurricane landfalls in USA (CAT 3-5, 1971-2015)

- 37 in 45 years; 0.8/yr



# Intense hurricane landfalls in U.S. (cat 3-5; 1921-1980)

- 27 in 60 years; = 0.45/yr

- **Geographical variations**

- Gulf Coast = 18
- East Coast = 9

- **Inter-decadal variations**

- 1950s: E. coast landfall
- 1960s: Gulf coast landfall

- **Sea-saw pattern between East Coast & Gulf Coast?**

- NAO

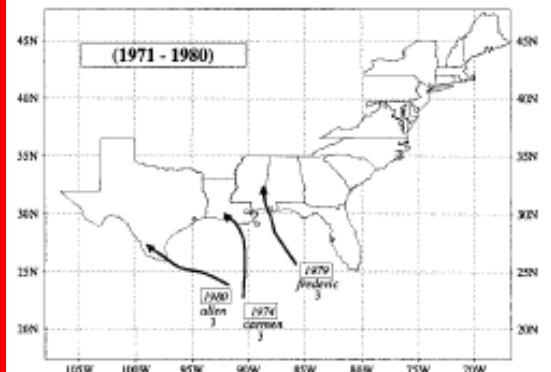
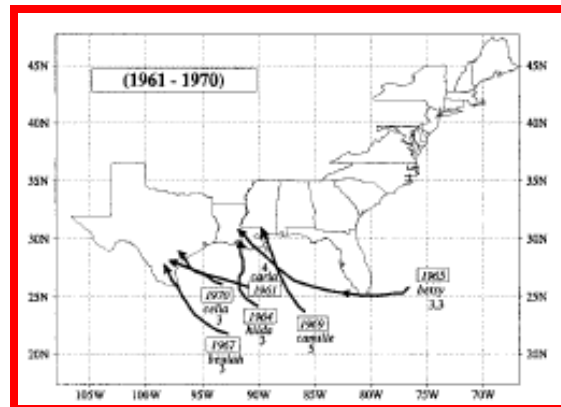
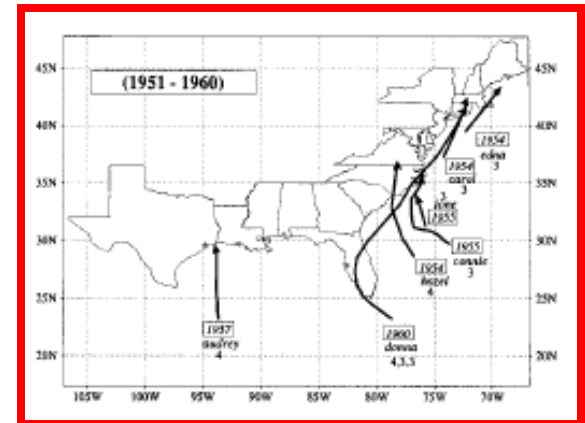
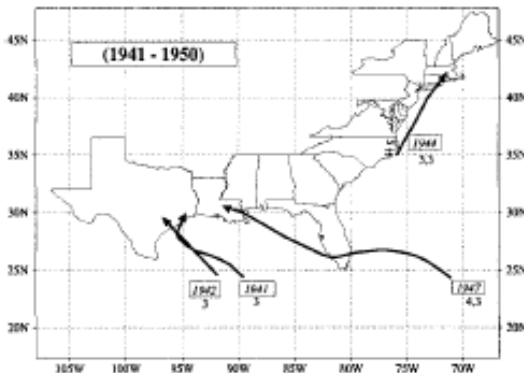
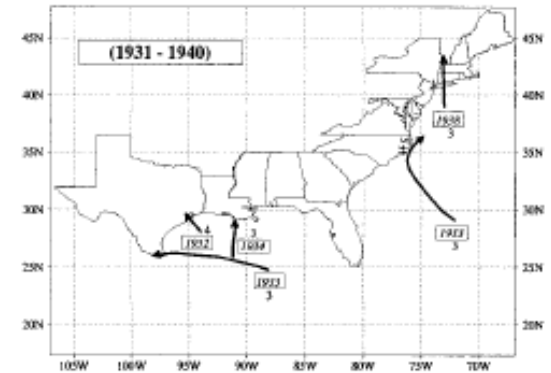
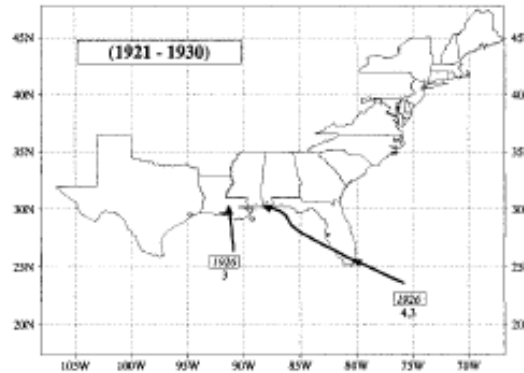


FIG. 8. Major hurricanes along the U.S. coastline (excluding FL, GA, and SC) in 10-yr intervals over the period 1921–80.

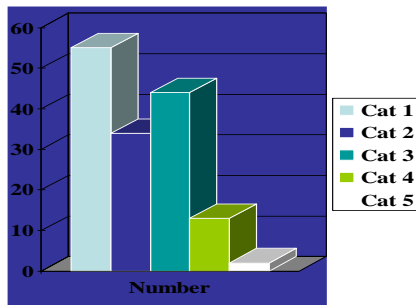
(Elmsler, Liu, & Kocher, 2000)

# Why do we need paleotempestology?

- A long-term perspective is vital for accurate risk assessment.
- Observational record of hurricanes only span the last 160 years.
- Category 4 & 5 hurricanes are extremely rare.
- A long-term perspective is vital to forecasting the return period of the “Big Ones”.
- e.g., Is Hurricane Katrina’s direct hit at New Orleans a 50-yr, 100-yr, or 500-yr event ?



- **What is the probability for a Katrina-like hurricane to hit New Orleans again?**



- **However, New Orleans has never been directly hit by a cat 4 or 5 hurricane in the last 200 years.**

# Research Questions

## to be addressed by paleotempestology

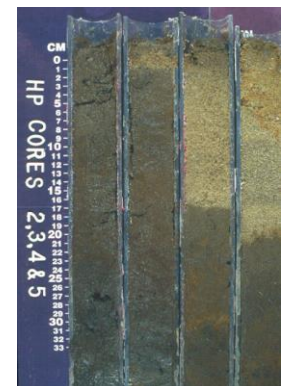
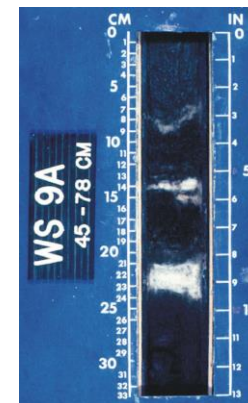
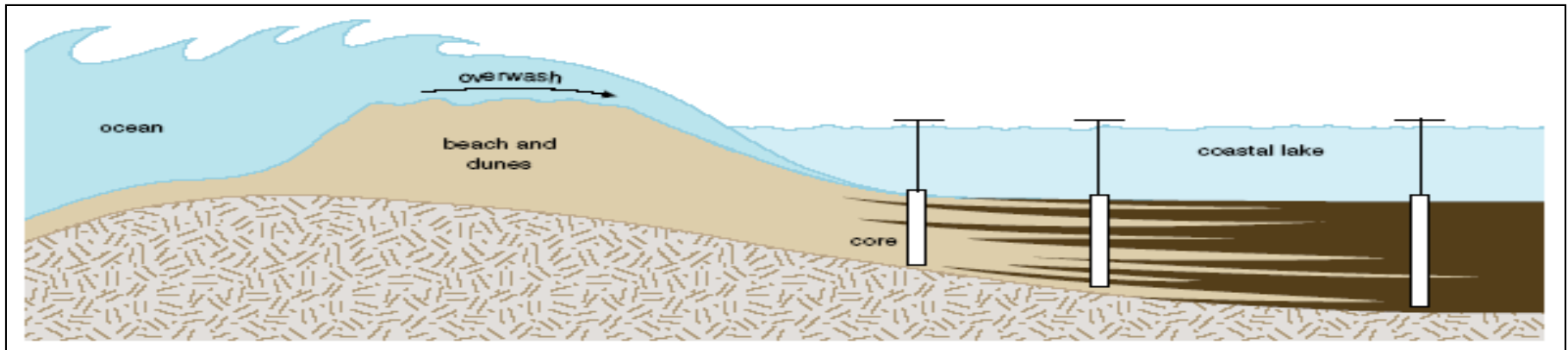
- How does this landfall probability vary spatially and temporally, and at what timescales?
  - Do hurricane risks vary geographically, between north and south, and between one basin and another?
  - Do hurricane activities vary from one century (millennium) to the next?
  - Are the 1940s to 1960s *worst case scenario*? If not, how bad can it be?
- How are these long-term changes in spatial and temporal patterns related to global climate changes? (e.g., *Little Ice Age*, *Medieval Warm Period*)
- How are these changes related to large-scale atmospheric and oceanic conditions? (e.g., ENSO, NAO, PDO, AMO, ITCZ, etc)

# What is Paleotempestology ?

- Paleotempestology is a young field of science that studies **past** hurricane activities by means of geological and archival techniques (Liu, 2004, 2007)

## Principal approach:

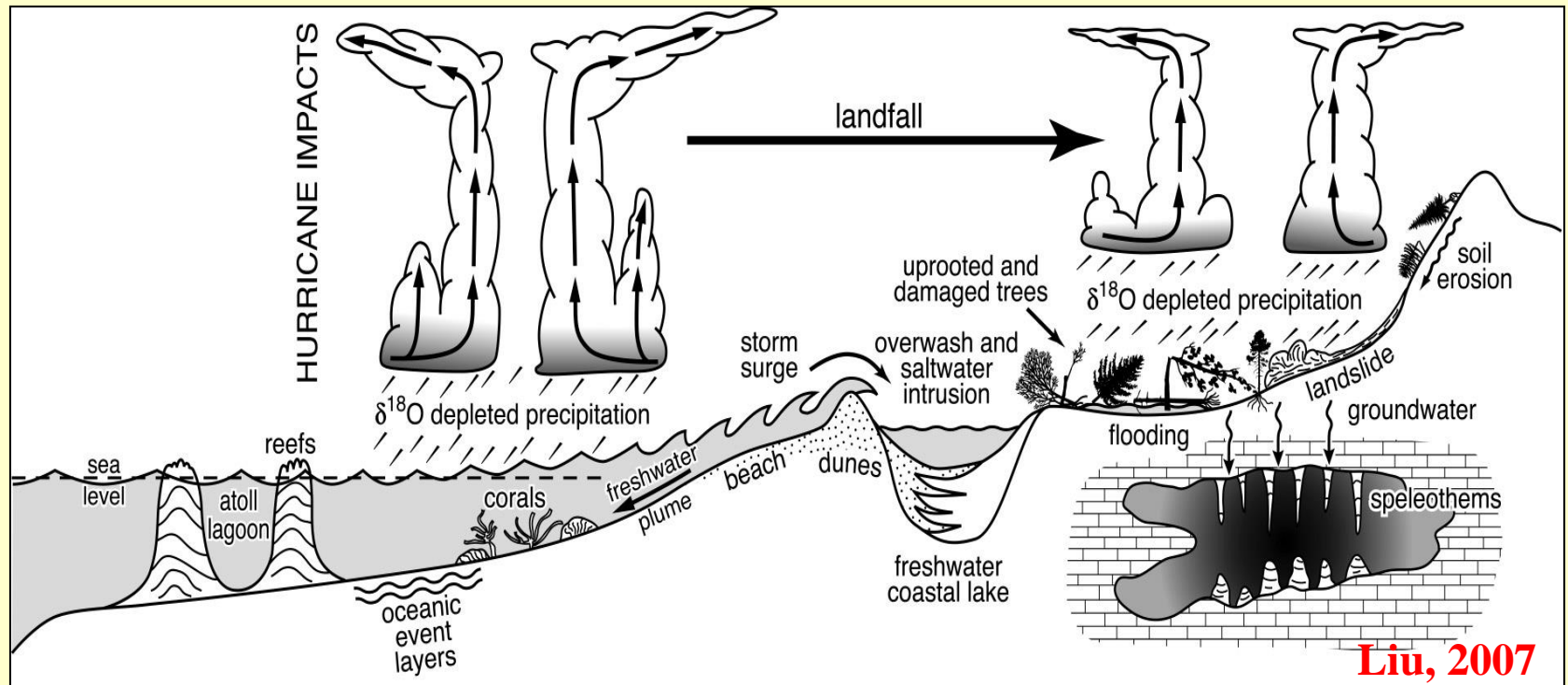
- Detection of overwash deposits in backbarrier lake & marsh sediments





The Expanding Frontiers of Paleotempestology.....

# Multi-proxy Reconstruction of Prehistoric Hurricane Activities



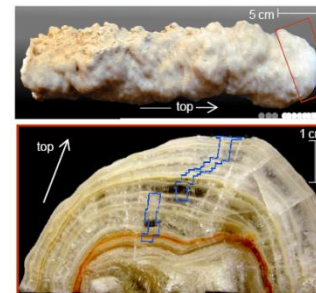
Lake sediments



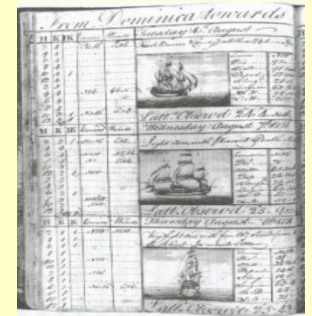
marine sediments



tree rings



speleothems



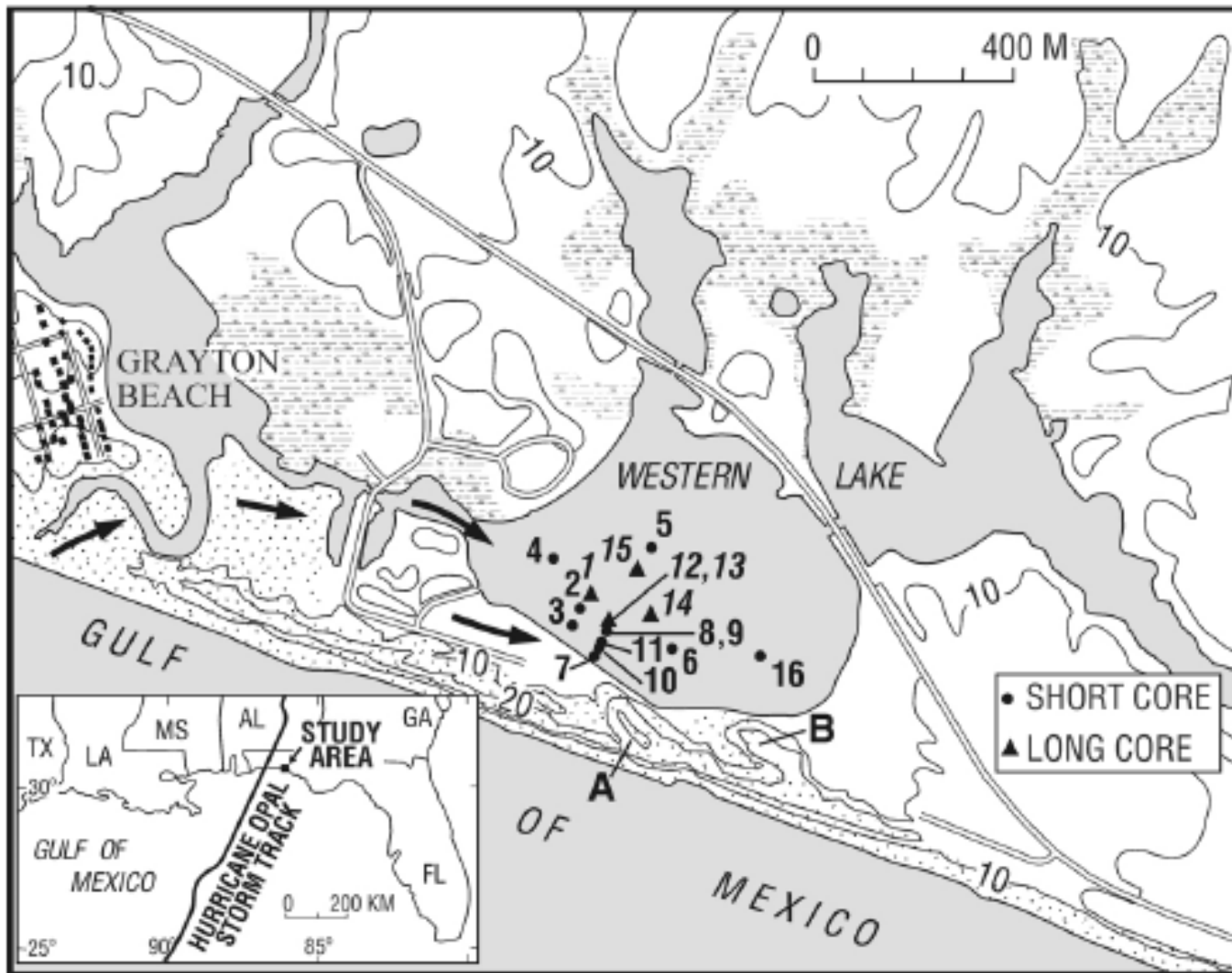
documents

# Western Lake, Florida



Liu, 2007

# Western Lake (NW Florida)



# Western Lake, FL

- Contains 12 sand layers deposited over the last 3800 years (Return period= 300 yr)
- Few events during 5000-3800 yr BP and during the recent millennium (past 1000 yr)
- Multiple strikes by catastrophic storms during “hyperactive period” of 3800-1000 yr BP.

Liu & Fearn, 2000

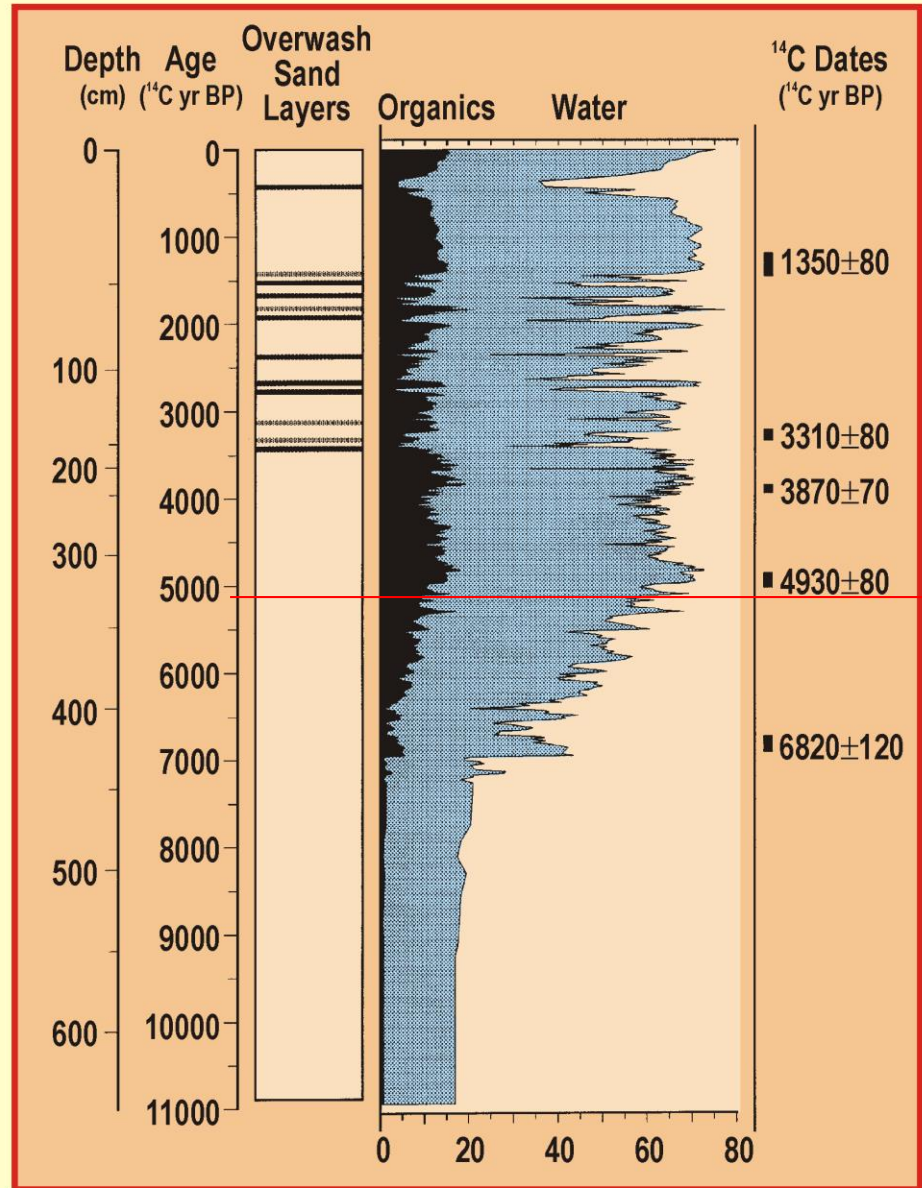
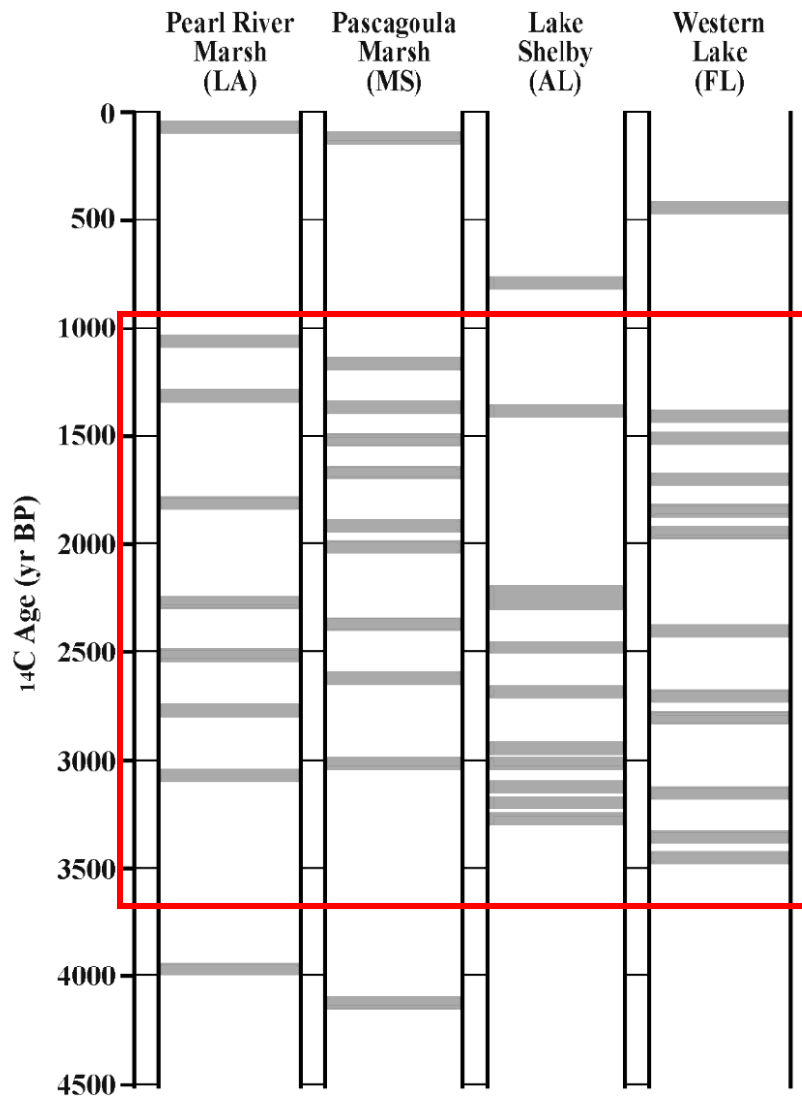


Fig. 11. Sediment stratigraphy of Western Lake determined by loss-on-ignition analysis.

## Chronology of Catastrophic Hurricane Strikes along the U.S. Gulf Coast during the last 4500 Years

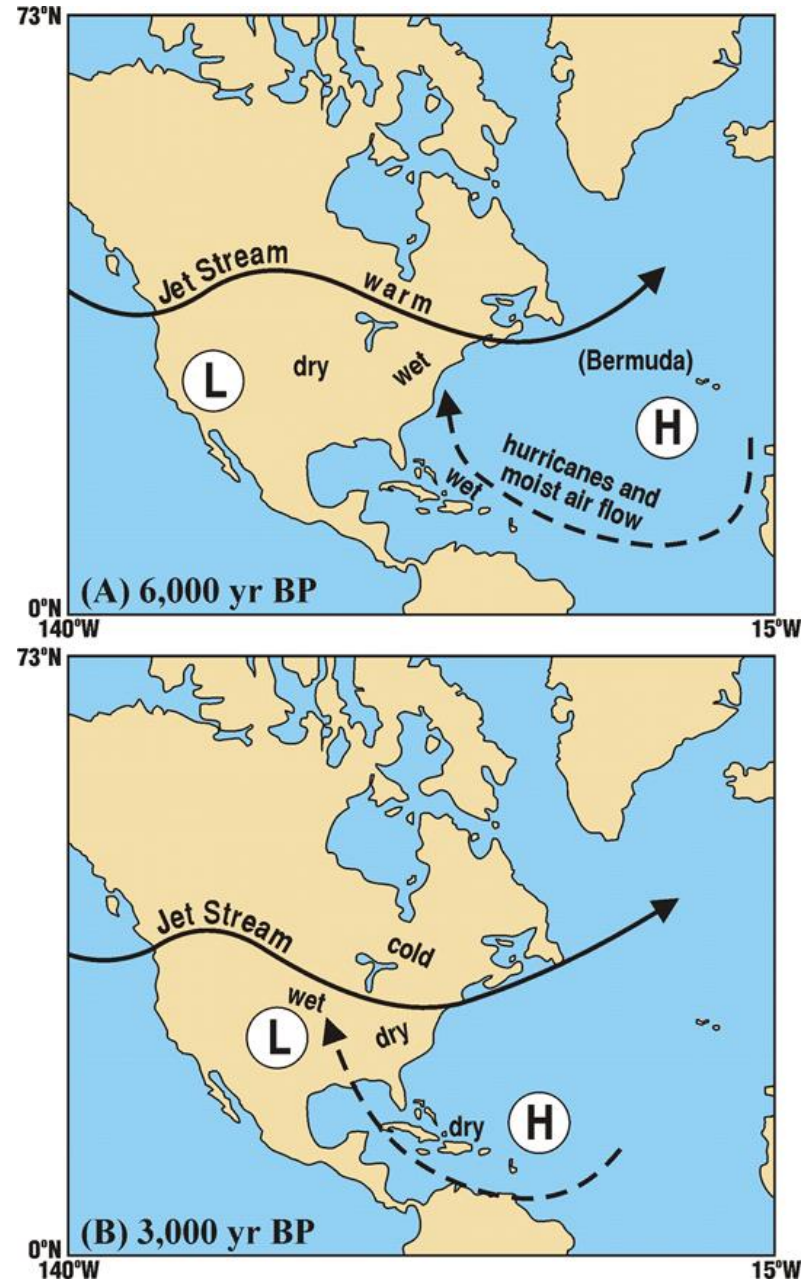


- **Major Findings from Gulf Coast Proxy Records:**
- *Return period* for catastrophic hurricanes = **300 yr**
- Millennial-scale variability
- ***Hyperactive period*** 3800-1000 yr ago
- Past 1000 years: **Quiet**

# The Bermuda High Hypothesis

- Bermuda High provides the steering mechanism that determines hurricane tracks
- A southwestward shift of the Bermuda High at 3800 BP steered more hurricanes towards Gulf coast
- Implication: Hurricane activities along the Gulf coast and Atlantic coast should be negatively correlated (anti-phase pattern)

Liu & Fearn, 2000

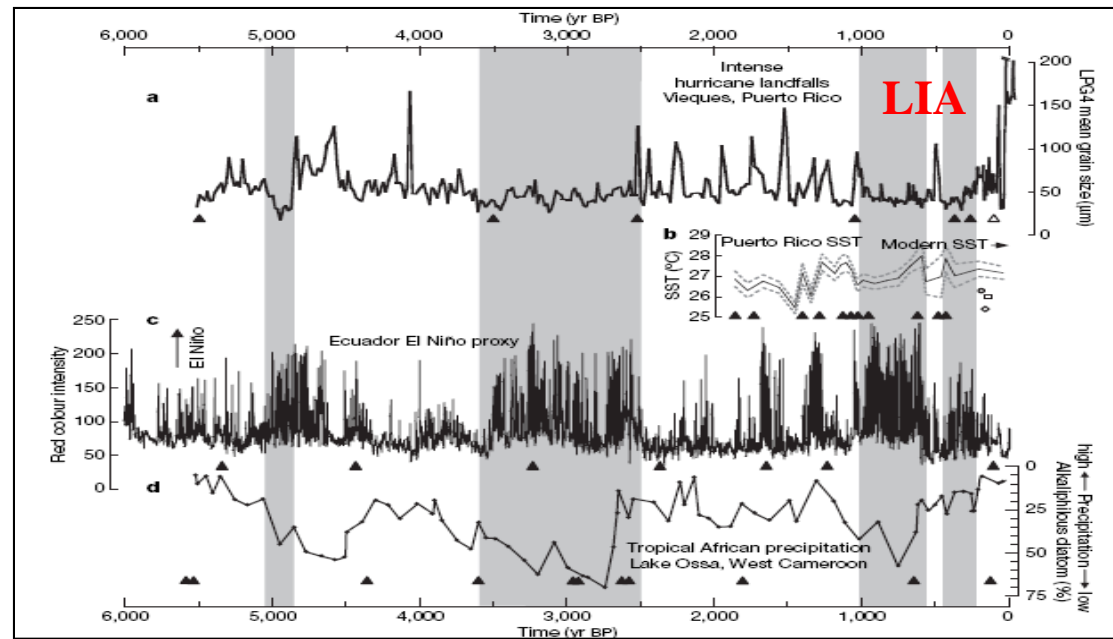


# Proxy record from Laguna Playa Grande, Vieques, Puerto Rico

## Activity regimes

5400 – 3600 yr BP	Active
3600 – 2500 yr BP	Quiet
2500 – 1000 yr BP	Active
1000 – 250 yr BP	Quiet
250 yr BP – present	Active

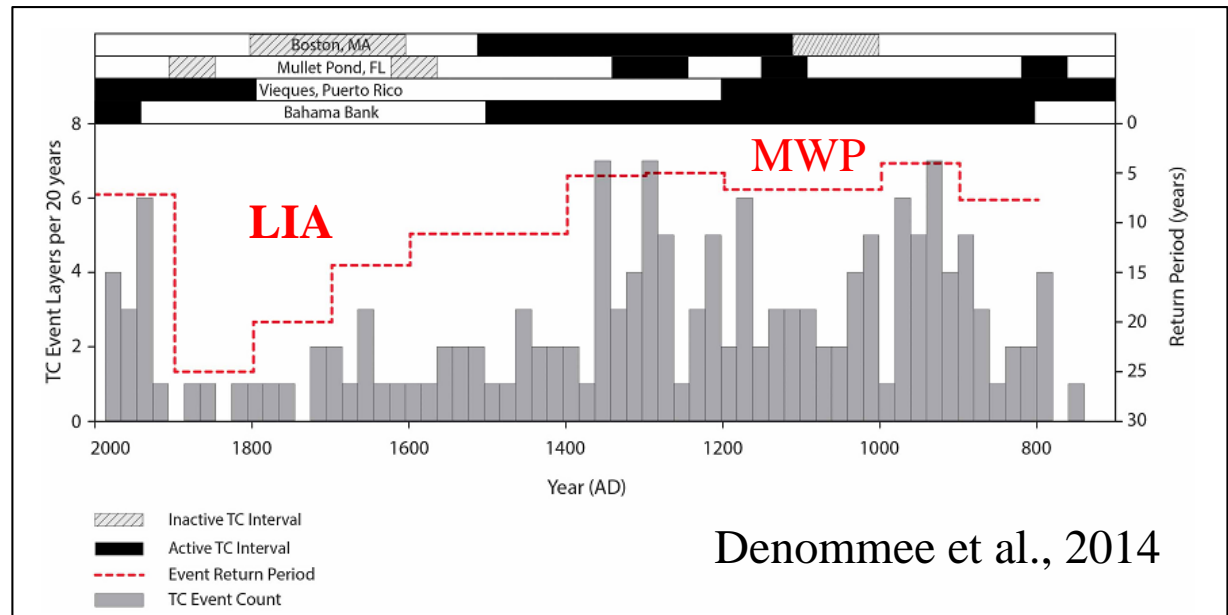
Donnelly & Woodruff., 2007



# Blue Hole Atoll, Belize 1,200-yr marine sediment record



Little Ice Age: Quiet

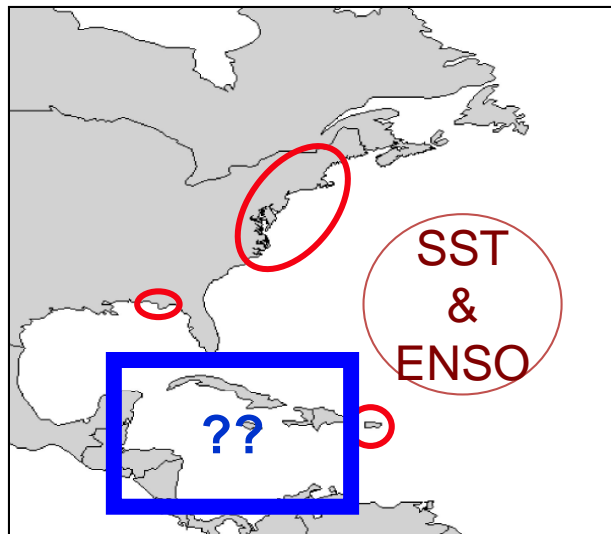


Denommee et al., 2014

# What controls hurricane landfall activity in western Atlantic basin?

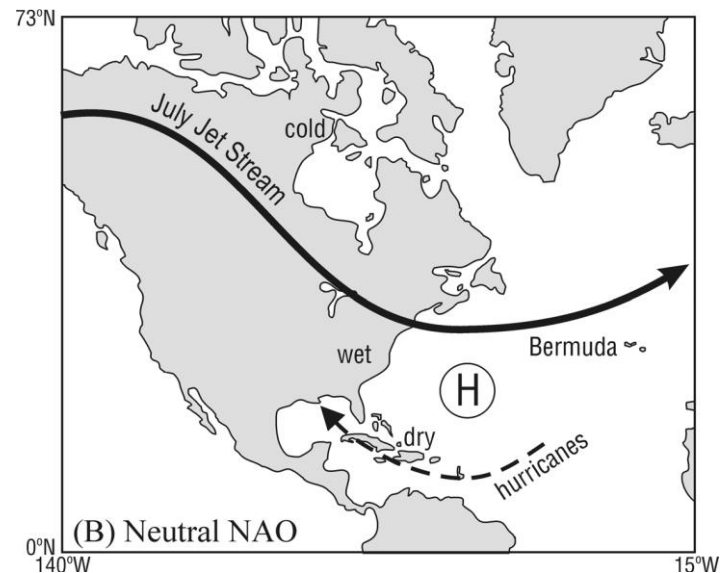
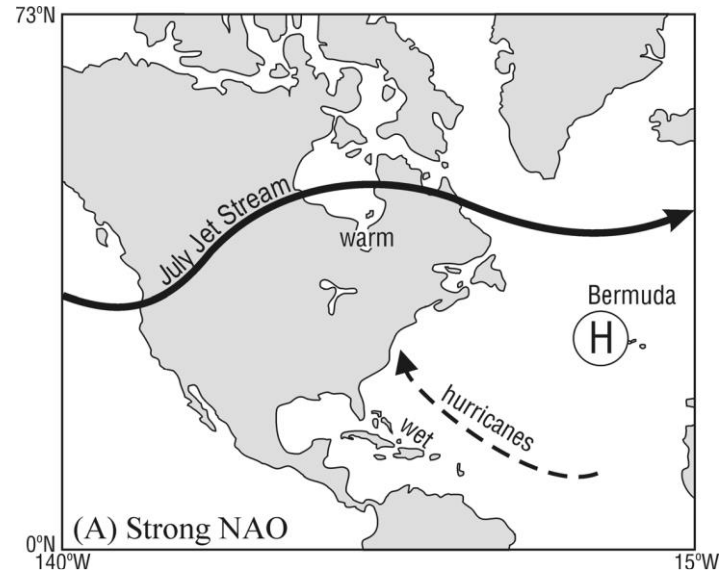
Bermuda High hypothesis  
Vs  
Basin-wide hypothesis

- Are hurricane activity regimes synchronous across the entire coastline from Atlantic Canada to the southern Caribbean?
- Or, are they time-transgressive (i.e., showing see-saw pattern) across the basin?
- Where does Central America & the rest of the Caribbean fit in?



Mann et al., 2009

## Bermuda High hypothesis

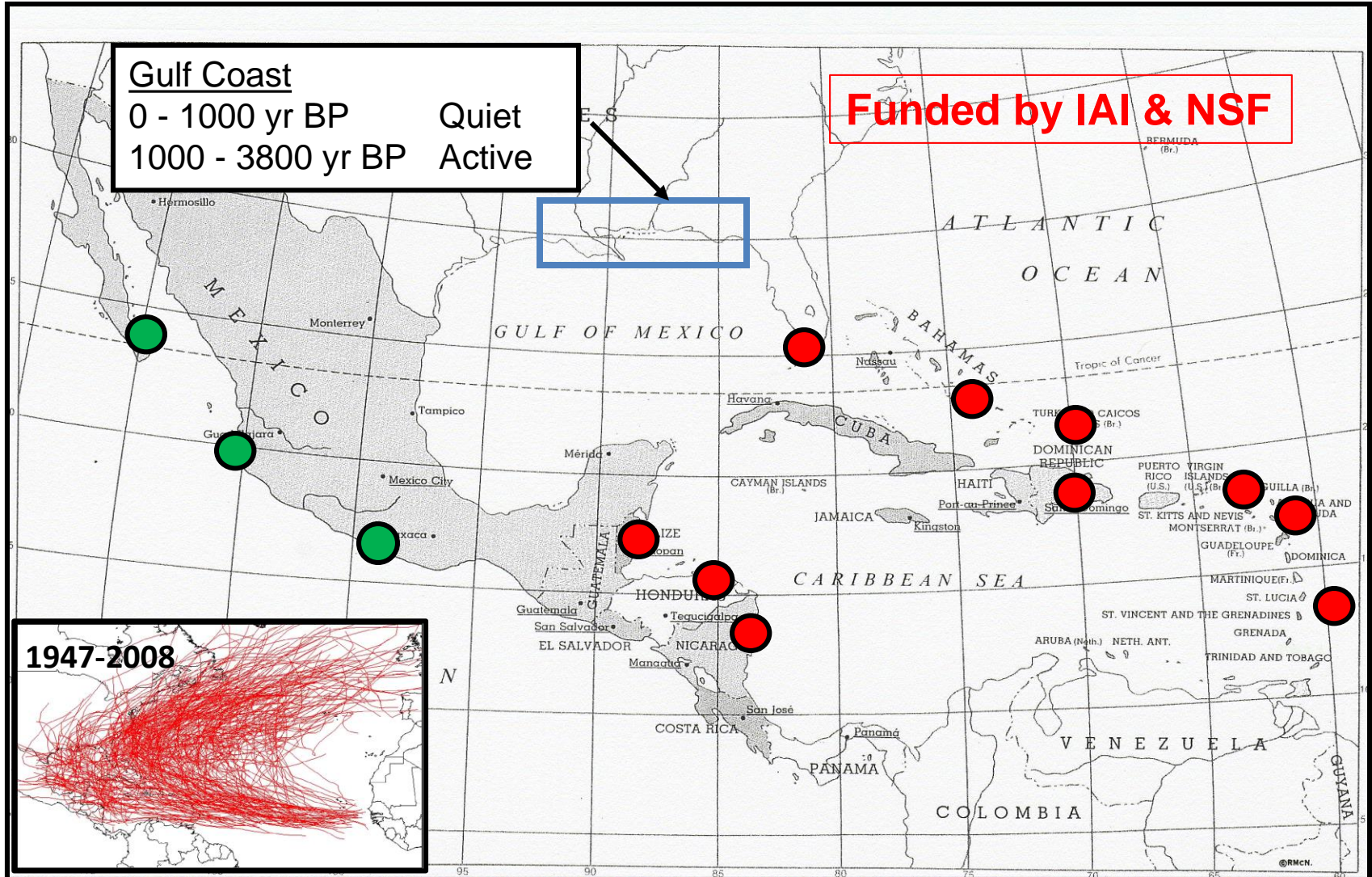


Liu & Fearn, 2000; Elsner et al., 2000

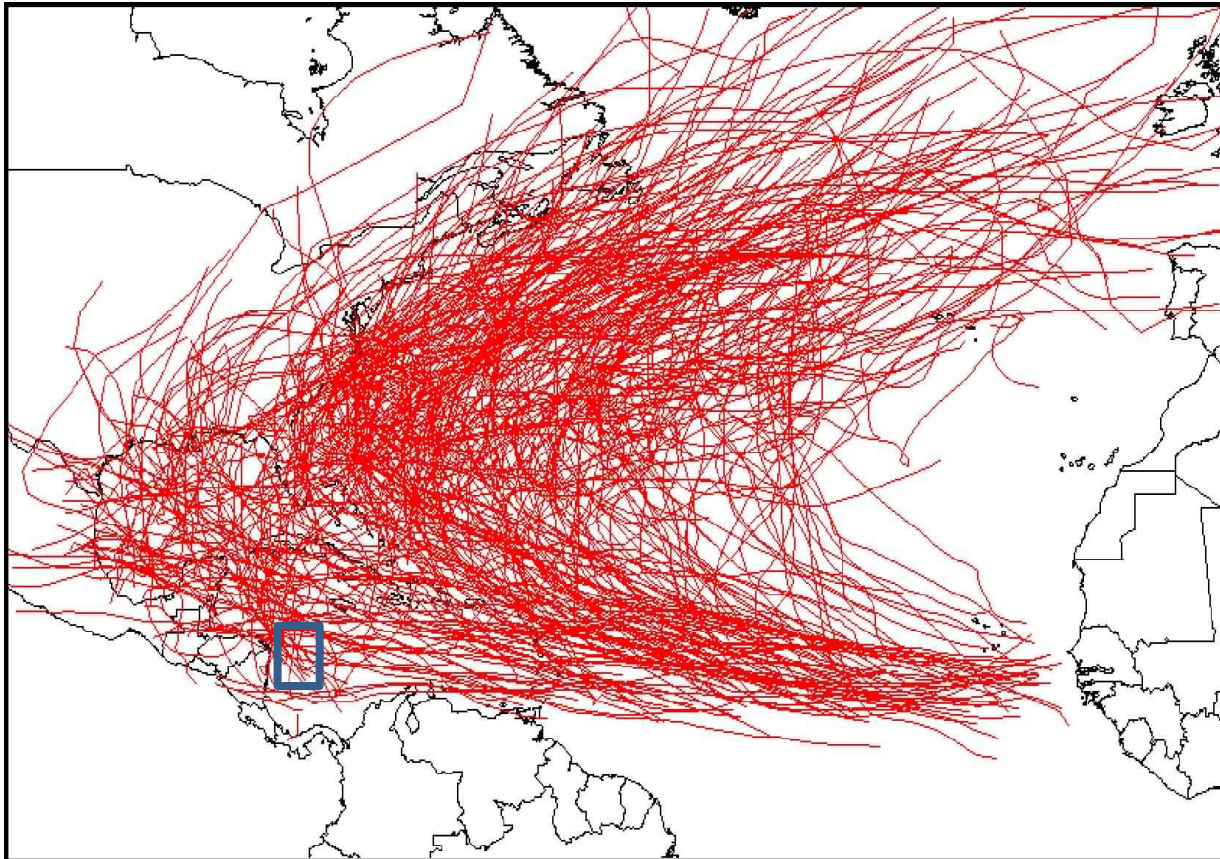


# Paleotempestology

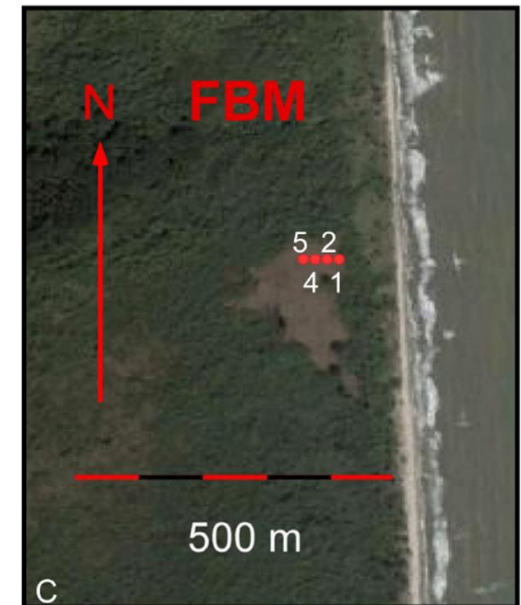
## LSU's fieldwork locations & new proxy records



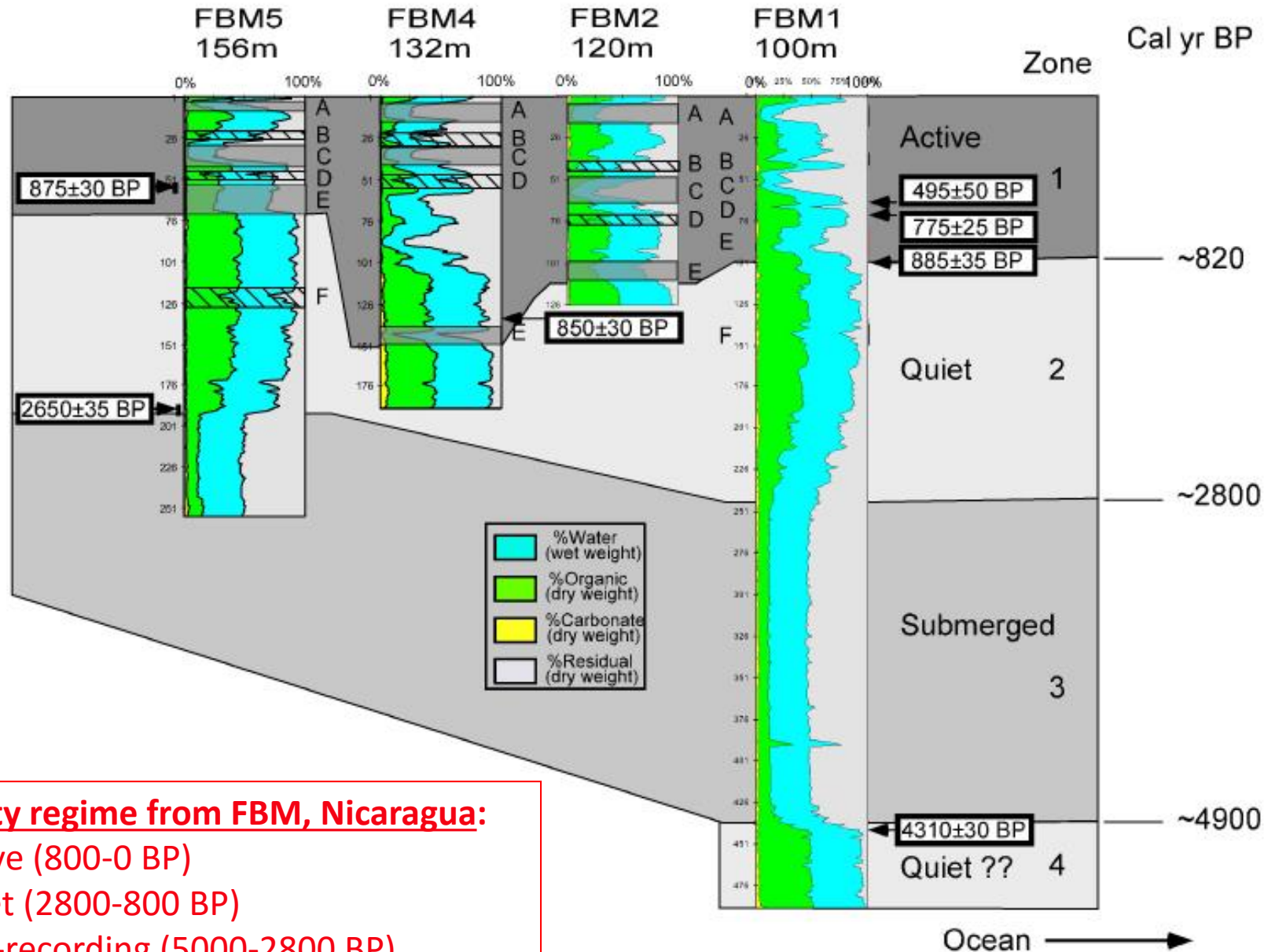
# Nicaragua: Southernmost limit of Atlantic hurricane activity



All North Atlantic Tropical cyclones 1947-2008



# Falso Bluff Marsh

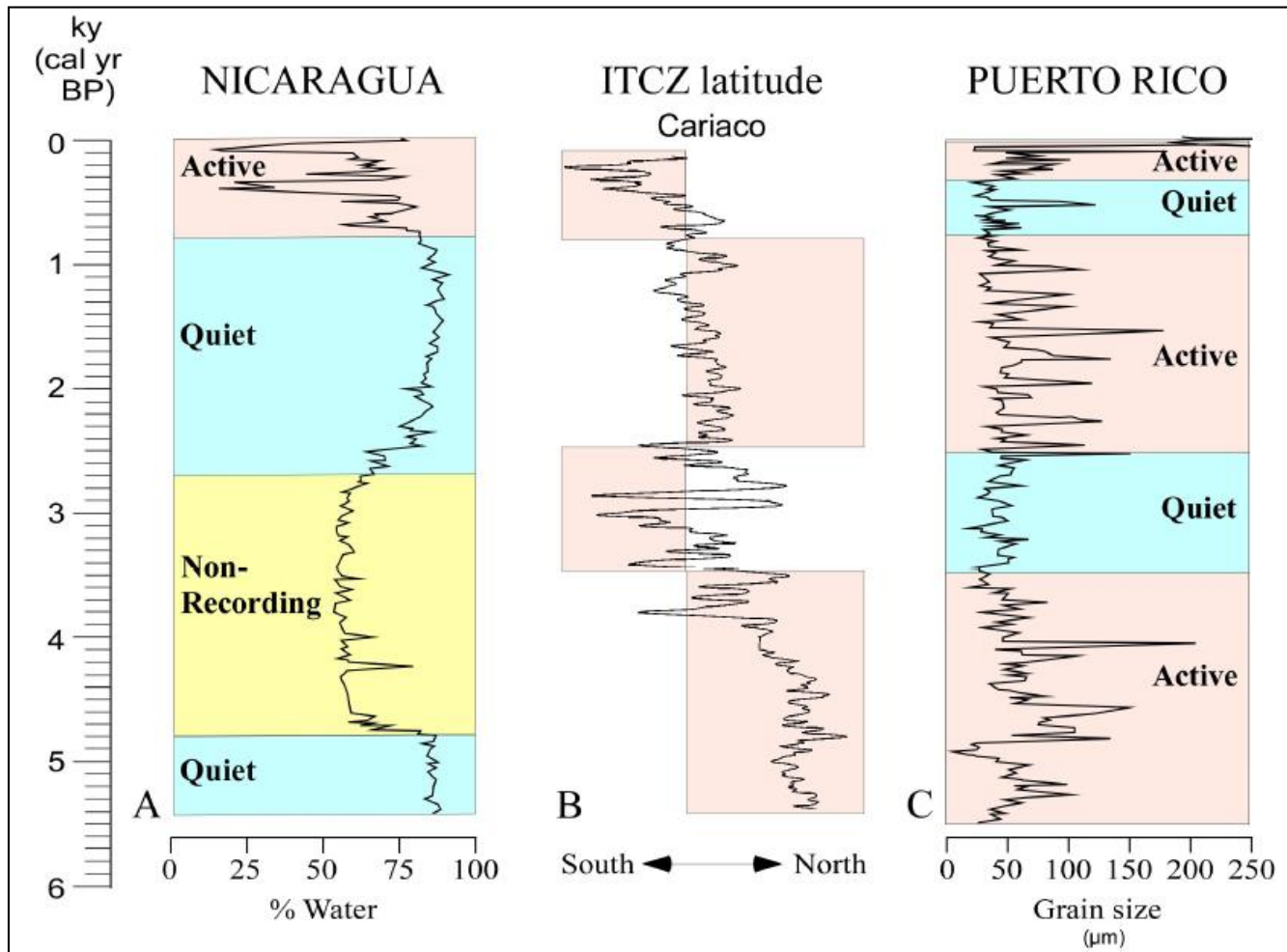


## Activity regime from FBM, Nicaragua:

- Active (800-0 BP)
- Quiet (2800-800 BP)
- Non-recording (5000-2800 BP)
- Quiet ?? (5500-5000 BP)

## Findings from Nicaragua:

- Activity regime in Nicaragua is **anti-phase** with those recorded in Puerto Rico.
- Enhanced hurricane activity in Nicaragua is correlated with southward shift of the ITCZ and Bermuda High.
- FBM data do not support the **Basin-wide Hypothesis**.
- Conclusion needs to be confirmed due to **non-recording period**, 4800-2800 cal yr BP
- New data (unpublished) from northern Nicaragua confirmed anti-phase pattern.



McCloskey & Liu,  
2012

A new 450-year stalagmite record of western Caribbean hurricane activity from *Yok Balum Cave (YOK-G)*, Belize (16°12' N) (AD 1550-1983)

Baldini et al., 2016, *Scientific Reports*



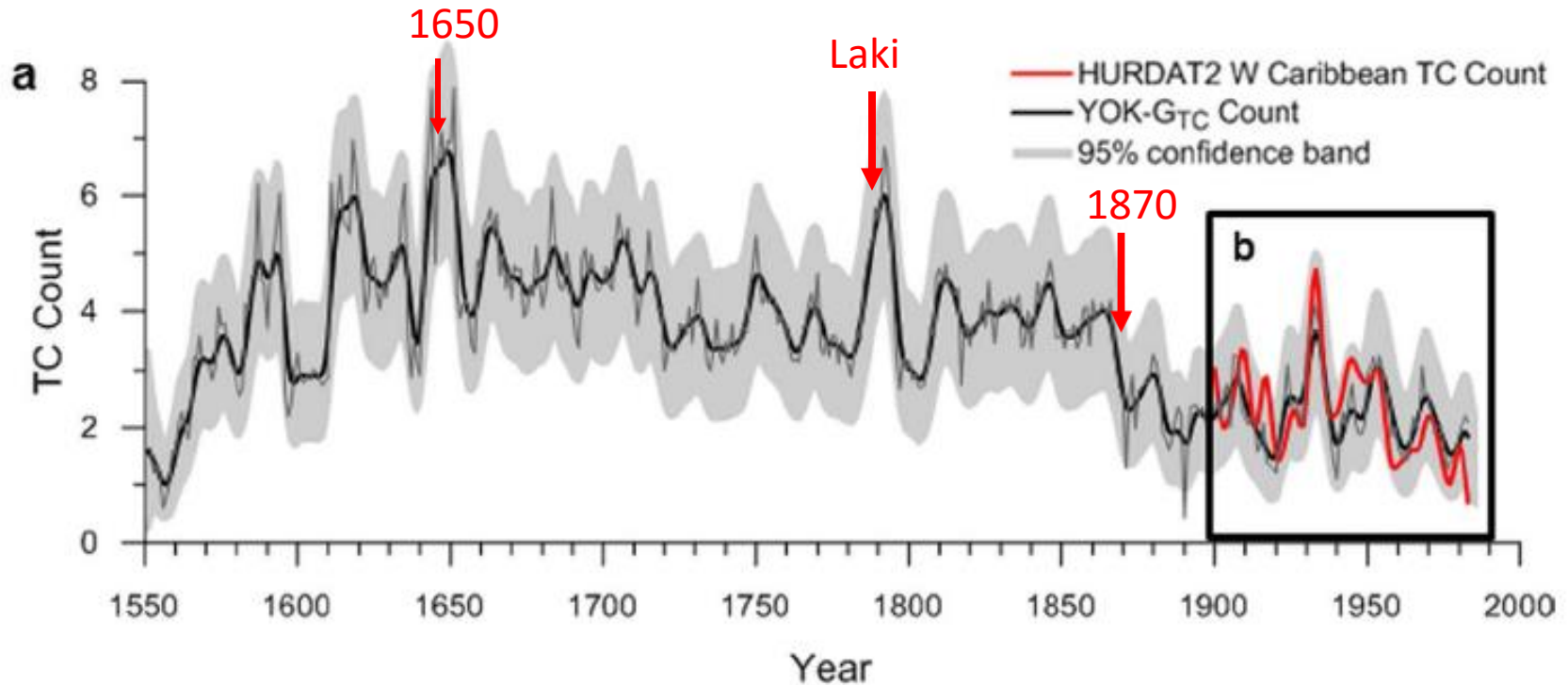
<http://cavingnews.com/20150211>



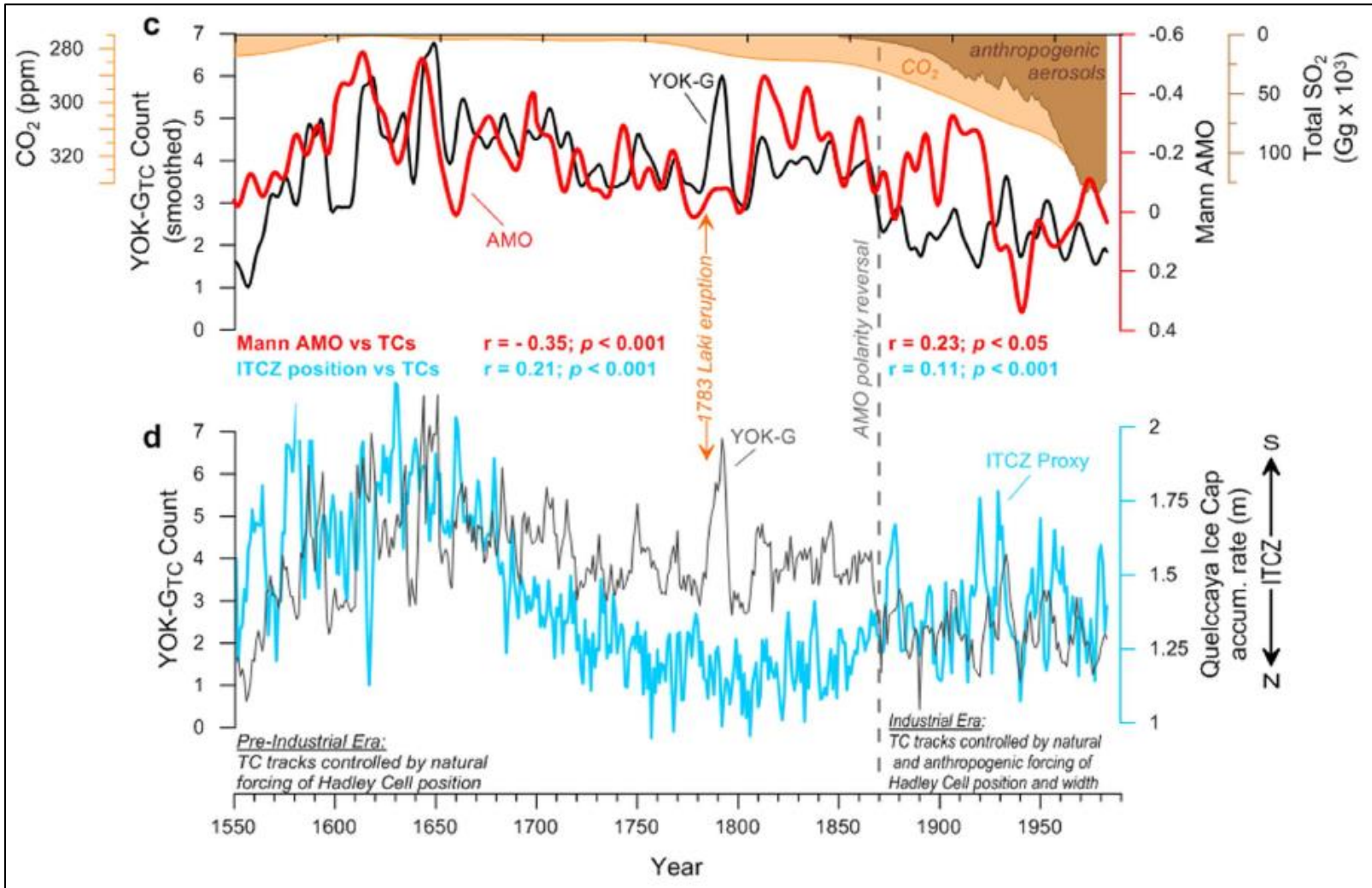
<https://www.dur.ac.uk/earth.sciences/research/projects/hurricane/>

# A new 450-year stalagmite record of western Caribbean hurricane activity from Yok Balum Cave (YOK-G), Belize (16°12' N) (AD 1550-1983)

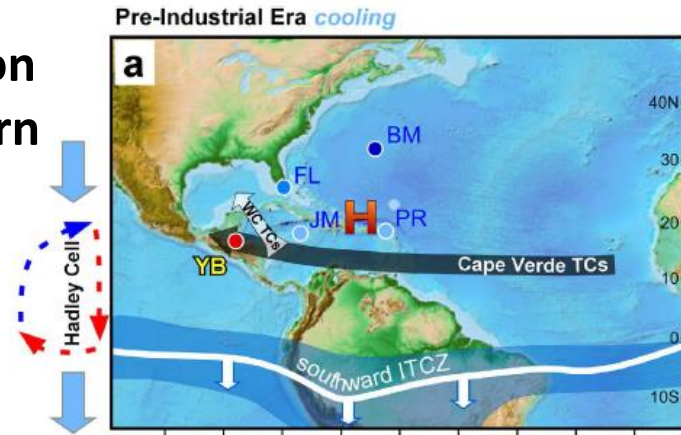
- YOK-G TC counts for 1900-1983 well-correlated with HURDAT2 TC counts for w Caribbean
- TC activity peaked at AD 1650, coincident with max LIA cooling; southernmost ITCZ & Hadley Cell & BH
- Declined afterwards, suggesting northward shift of storm track due to AMO warming
- Sharp spike in 1783 after Laki volcanic eruption, suggesting sensitivity to sulphate aerosols
- Declined (from 4 to 2) abruptly after 1870



- TC activity negatively correlated with AMO before 1870; positively after 1870
- Polarity shift coincident with widespread industrialization (GHGs & sulphate aerosols)
- Rising GHGs expanded Hadley Cell & BH northward, reducing TC counts in Belize
- Rising sulphate aerosols shifted MDR & ITCZ southward
- Combined effect: More recurving storm tracks; greater risk to NE Atlantic coast

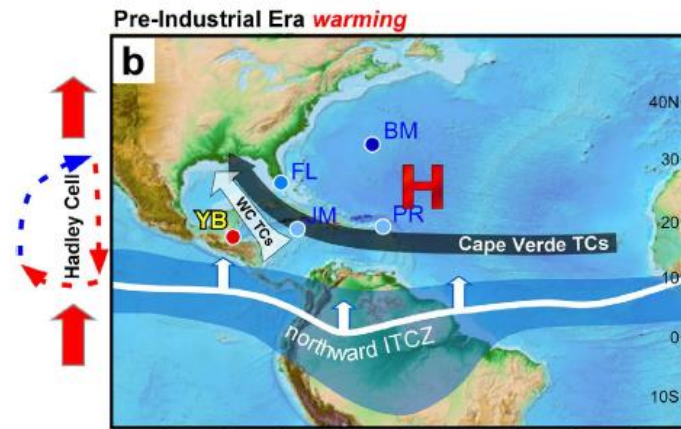


# A 450-yr reconstruction of Caribbean & western Atlantic hurricane activity: A mapped perspective



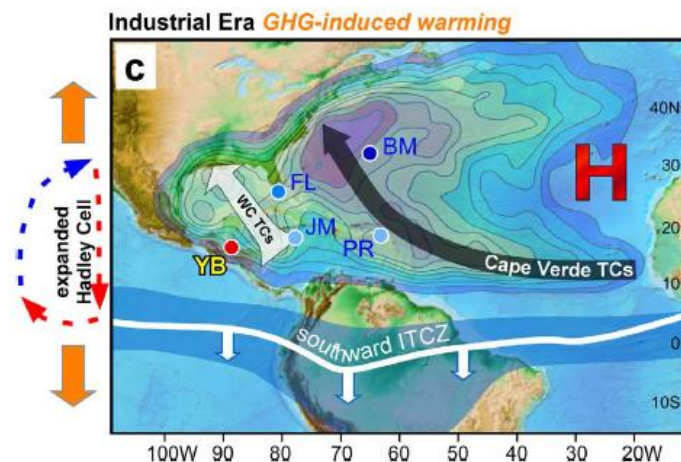
Ca. 1650

- Max LIA cooling
- Southernmost position of ITCZ
- Max Belize TC



1650 - 1870

- Gradual warming
- ITCZ shifts north
- Storm tracks shift north
- Belize TC decreases



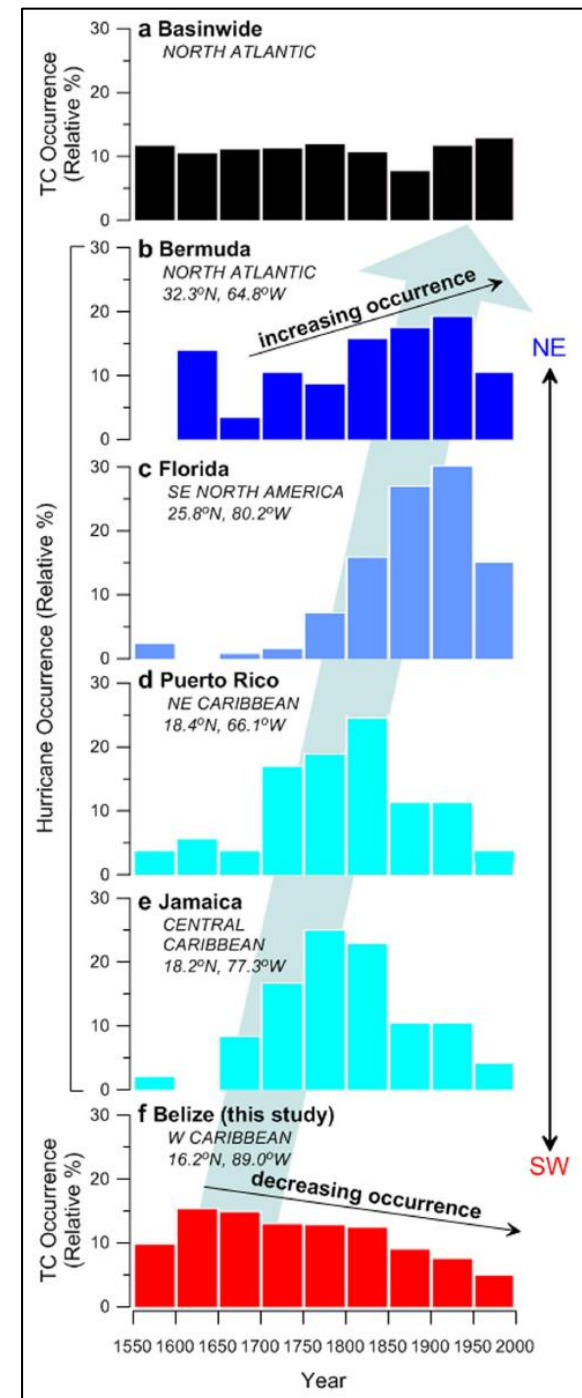
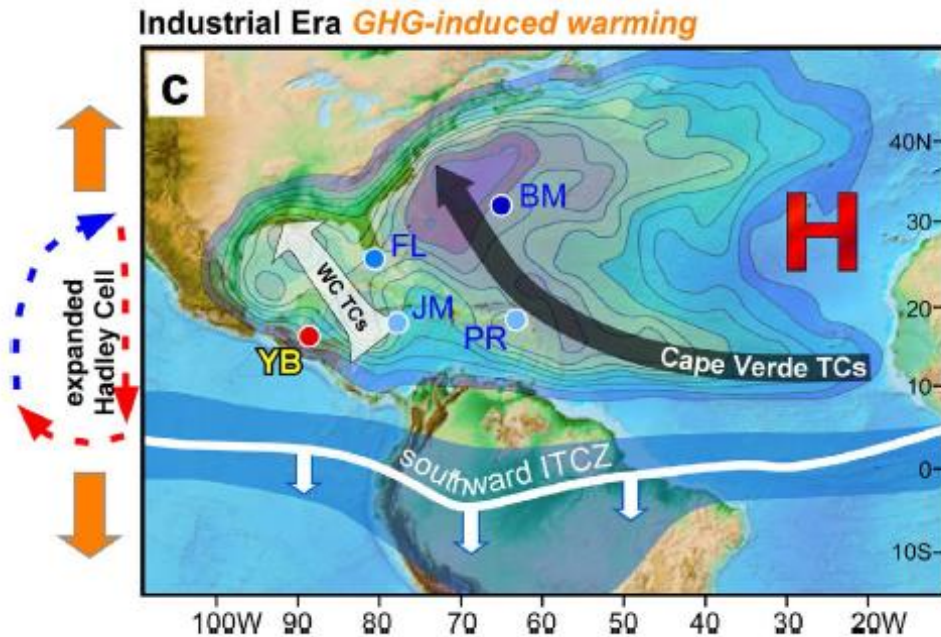
Post-1870

- Industrialization
- GHG-warming expanded Hadley Cell & BH
- ITCZ shifts S due to aerosols
- More recurving storm tracks
- Fewer Belize TC



*Historical data support interpretation of paleotempestology record.....*

**The southwest-to-northeast shift in storm tracks is supported by documentary TC records from Jamaica, Puerto Rico, Florida, and Bermuda**



# Paleotempestology data verify historical record .....

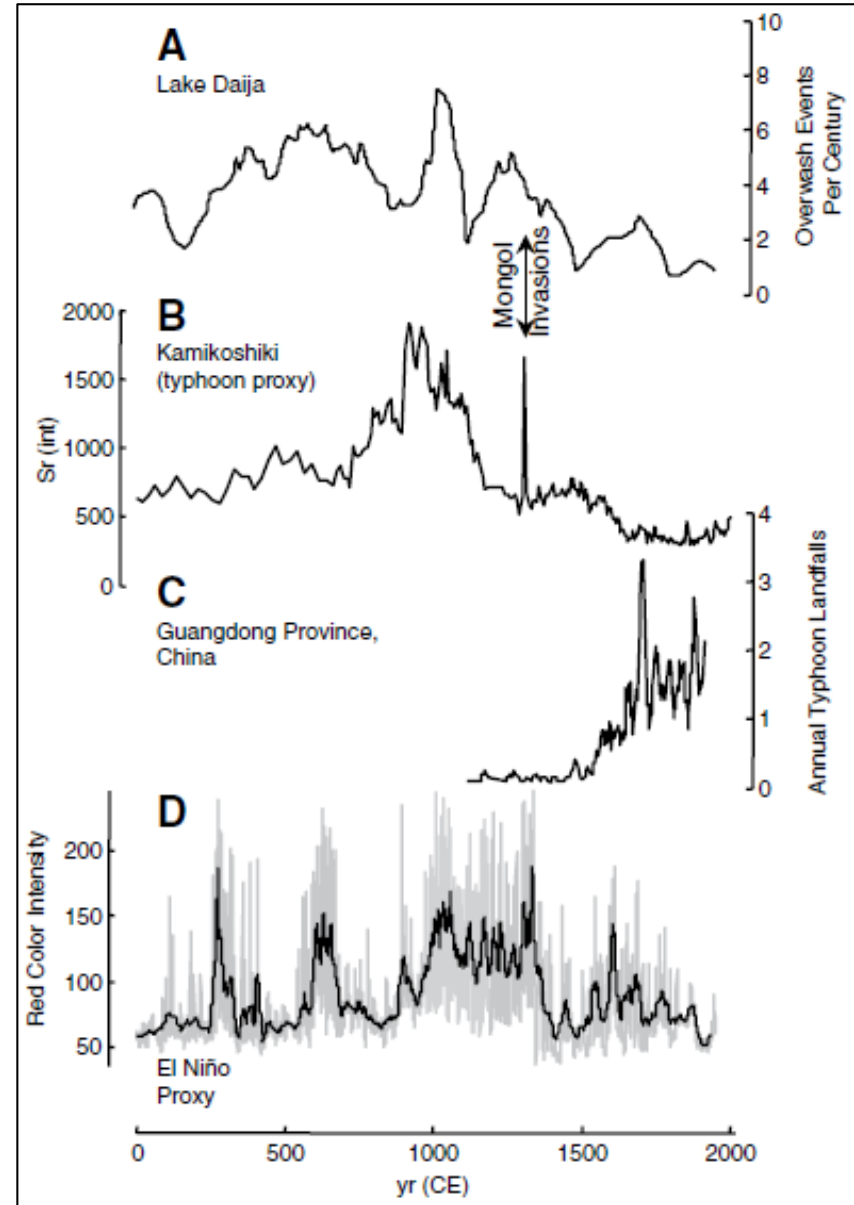
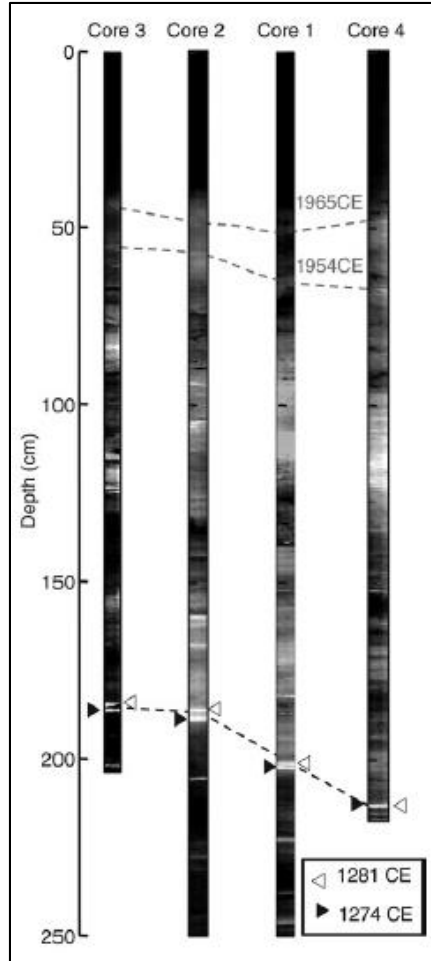
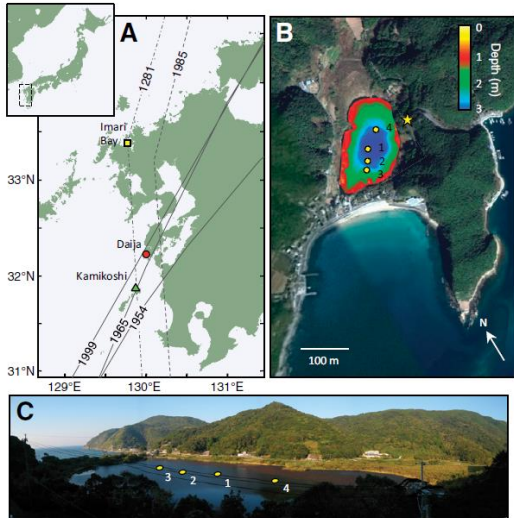
Depositional evidence for the Kamikaze typhoons and links to changes in typhoon climatology

J.D. Woodruff<sup>1\*</sup>, K. Kanamaru<sup>1</sup>, S. Kundu<sup>1</sup>, and T.L. Cook<sup>2</sup>

<sup>1</sup>Department of Geosciences, University of Massachusetts, Amherst, Massachusetts 01003, USA

<sup>2</sup>Worcester State University, Worcester, Massachusetts 01602, USA

- Evidence from paleo-tempestology supports legends of two typhoon events destroying the invading fleets of Kublai Khan in AD 1274 and 1281 (Woodruff et al., 2015)



# The term “Jufeng” first appeared in the 5<sup>th</sup> century AD



Jufeng

狀如狸以鐵椎捶其頭數十下乃死張口向風須臾即起  
 風土記曰南中六月則有東南長風風六月止俗號黃  
 雀長風時海魚變為黃雀因為名也  
 庚仲雍湘州記曰零陵山有石鷲遇風雨則飛雨止還  
 化為石  
 交州記曰風山在九真郡風門在山頂上常有風  
 又風母出九德縣風母似猿見人若慙而屈頸若打殺  
 欽定四庫全書  
 太平御覽  
 卷九  
 十  
 之得風還活  
 南越志曰熙安間多颶音具風颶者具四方之風也一日  
 懼風言怖懼也常以六七月興未至時三日雞犬為之  
 不鳴大者或至七日小者一二日外國以為黑風  
 盛宏之荊州記曰宜都佷山縣山有風穴張口大數尺  
 名曰風井夏則風出冬則風入風出之時吹拂左右常  
 淨如掃暑月經之凜然有衣裘想宜都山記曰泰山松  
 以六月至此穴便思

“Many *jufeng* (typhoons) occur around Xi’an County. *Ju is a wind (or storm) that comes in all four directions.* Another meaning for *jufeng* is that it is a scary wind. It frequently occurs in the 6<sup>th</sup> and 7<sup>th</sup> (lunar) months. Before it comes, roosters and dogs are silent for three days. Major ones may last up to seven days. Minor ones last one or two days. These are called *heifeng* (black storms/winds) in foreign countries.”

Shen Huai-yuan, *Nan Yue Zhi* (ca. AD 470)

# AD 816 – Earliest typhoon landfall recorded in Chinese history

- “On *mu-shen* day of the 8<sup>th</sup> (lunar) month (of the 11<sup>th</sup> year of *Yuanhe* Reign)<sup>1</sup>, *Mizhou*<sup>2</sup> reported that a *jufeng* occurred and the seawater damaged the city wall”.

Old Tang History, Chapter 15

Xian Zong Ben Ji (Basic Annals of Emperor Xian Zong)

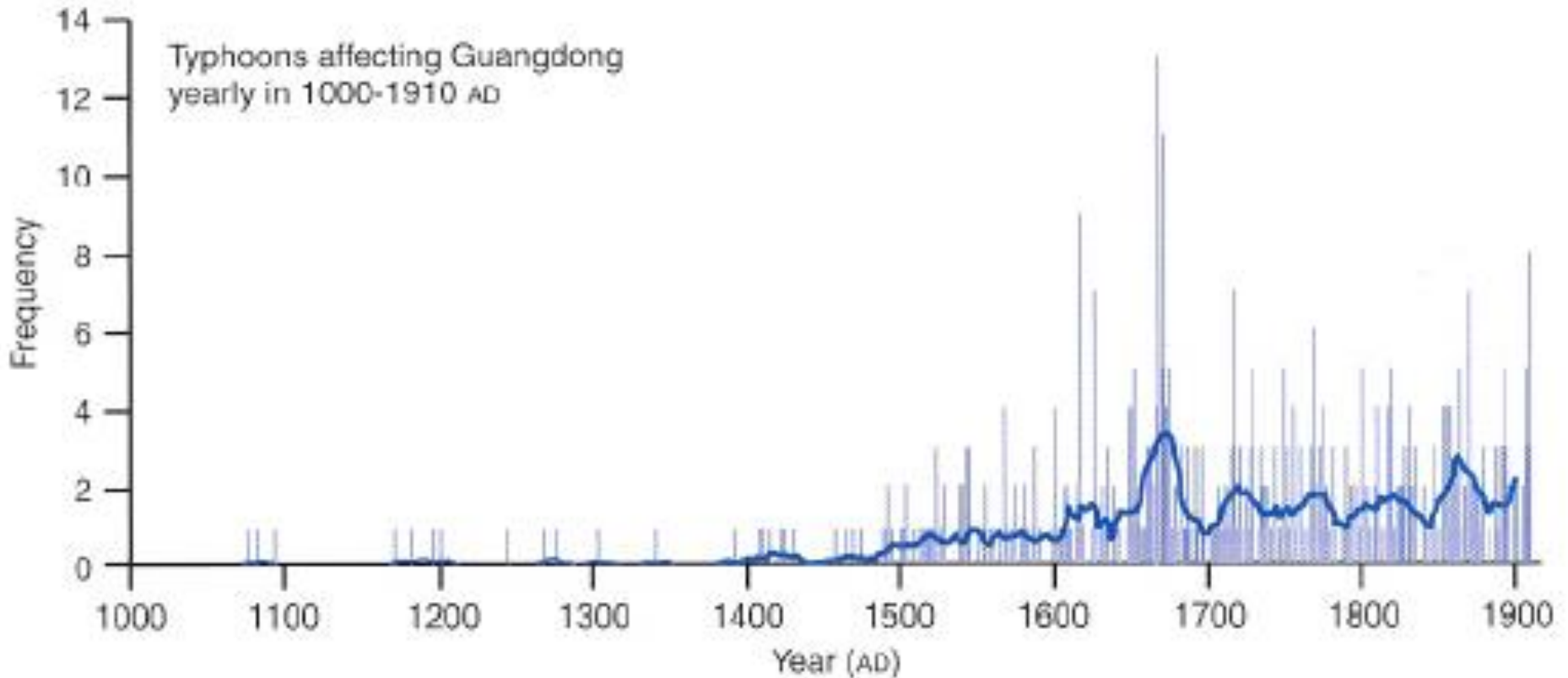
- <sup>1</sup> AD 816, June 29-July 28
- <sup>2</sup> Gaomi, Shandong Province



容 密

Louie & Liu, 2003, *J. Historical Geog.*

# Typhoons Affecting Guangdong in 1001-1900



## Major findings:

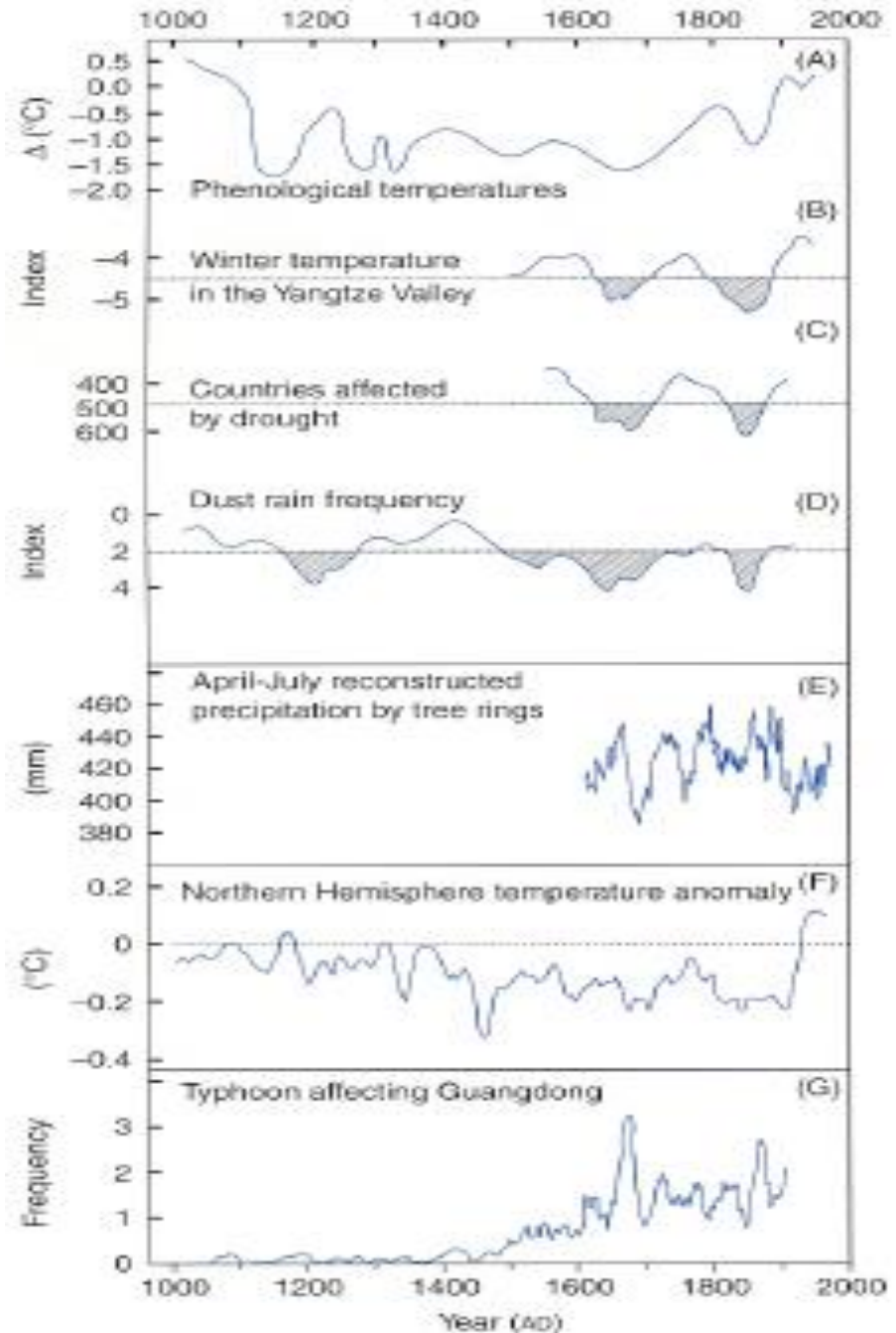
- Most active decades: AD 1660-1680, 1850-1880
- Approximately 50-year periodicity

Liu et al., 2001

# Comparison between Guangdong typhoon record with other paleoclimatic proxy records from China

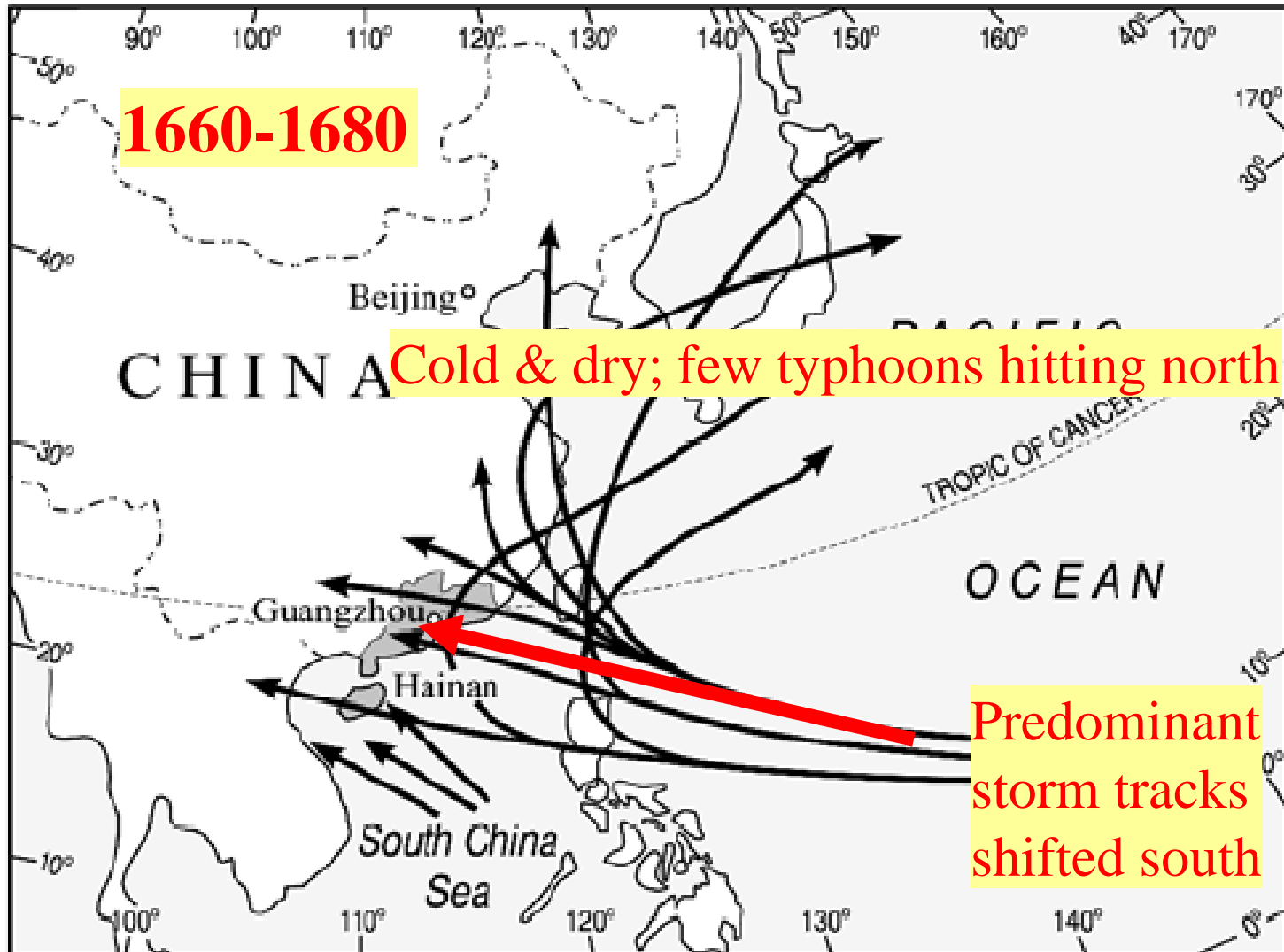
- Little Ice Age cold period has two temperature minima
- Two active periods in Guangdong coincide with two of coldest & driest periods in north & central China
- Multi-decadal variability

Liu et al., 2001



## Hypothesis:

### Southward shift of typhoon tracks during AD 1660-1680



## ENSO affects TC tracks & life span

### During El Nino years:

- TCs form further to the east;
- TCs have longer life span;
- Tracks more likely to recurve:
  - Subtropical high shifts eastward;
  - More likely to interact with mid-latitude synoptic systems.
- Japan at greater risk of landfall.

### During La Nina years:

- TCs have shorter life span (formed closer to land);
- Westward-moving track predominant
- South China & Philippines at greater risk of landfall.

**Hypothesis:** Peak TC activity in Guangdong during 1660-1680 may be due to enhanced La Nina conditions?

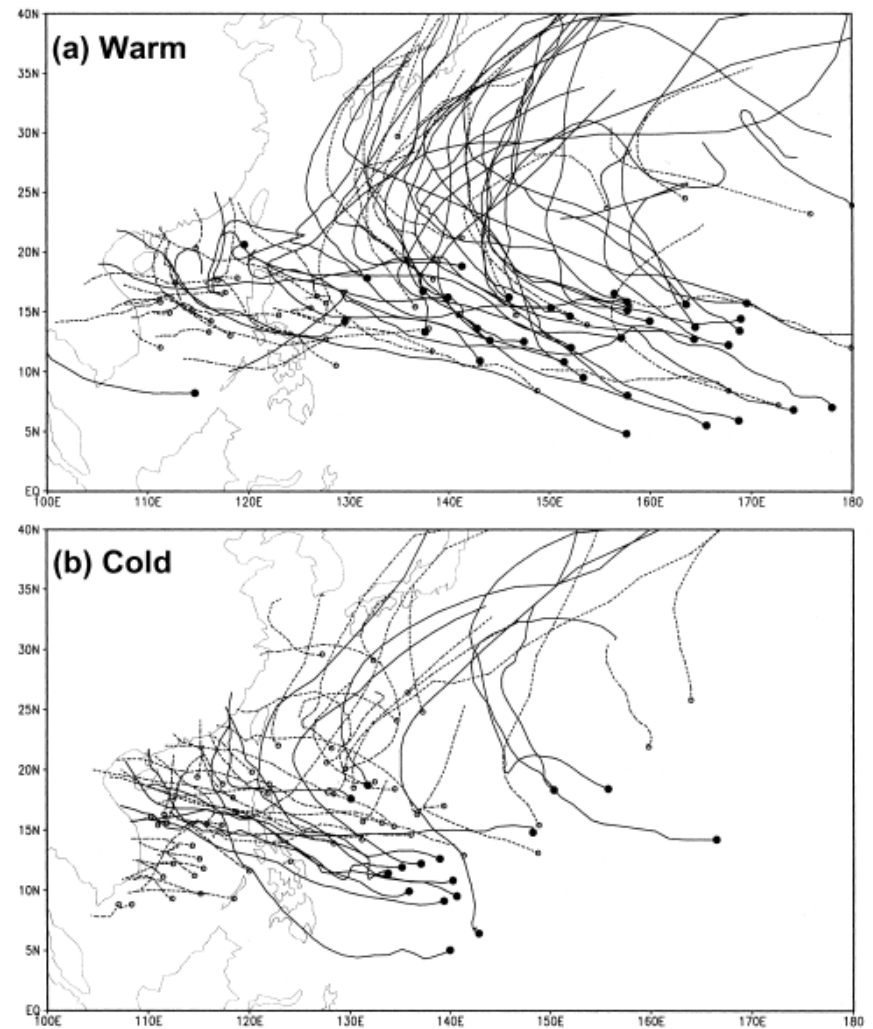
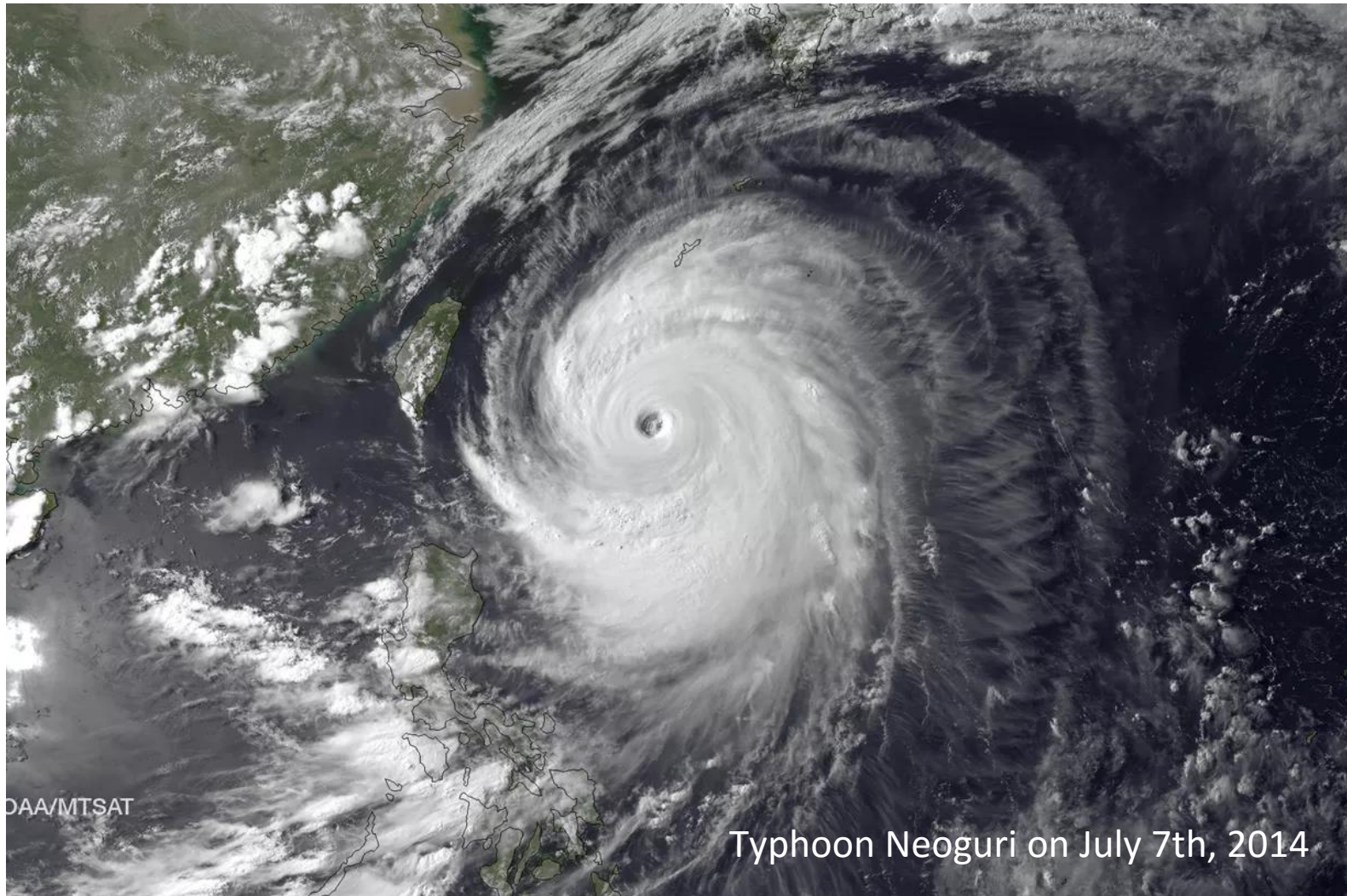


FIGURE 10.13 September to November tropical cyclone tracks: (a) during the six strongest warm years examined for this study (1965, 1972, 1982, 1987, 1991, 1997); (b) during the six strongest cold years (1970, 1973, 1973, 1975, 1988, 1998, 1999). Genesis locations (tracks) of the long-lived tropical storms are marked by heavy solid dots (solid lines). A long-lived tropical storm has a life span exceeding seven days. Genesis locations (tracks) of other storms are denoted by open circles (dashed lines) (adapted from Wang and Chan 2002, by permission of the American Meteorological Society).



## Examples of some recent paleotempestology work in China:

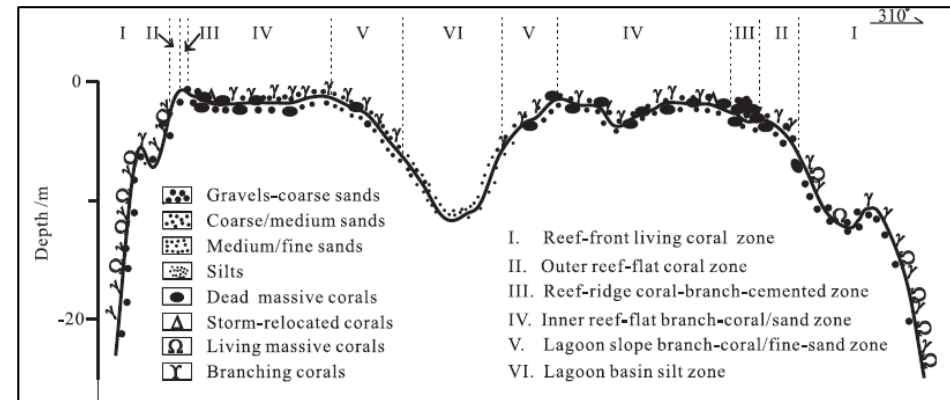
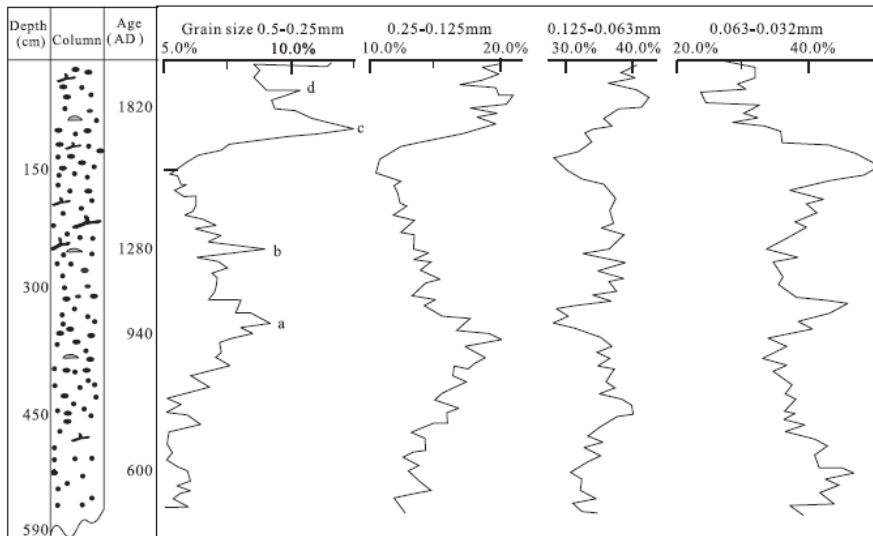
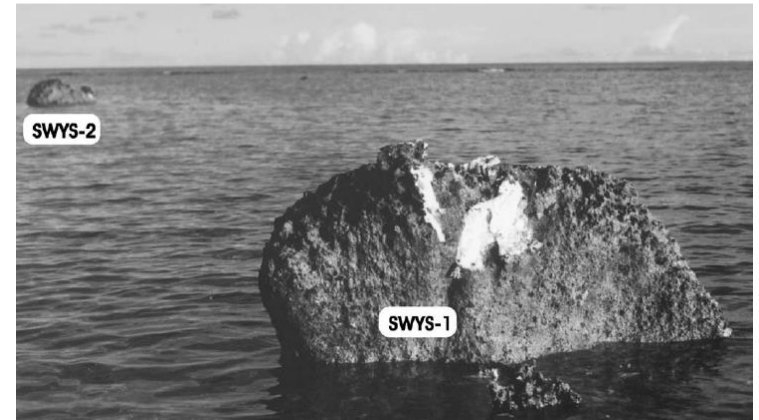
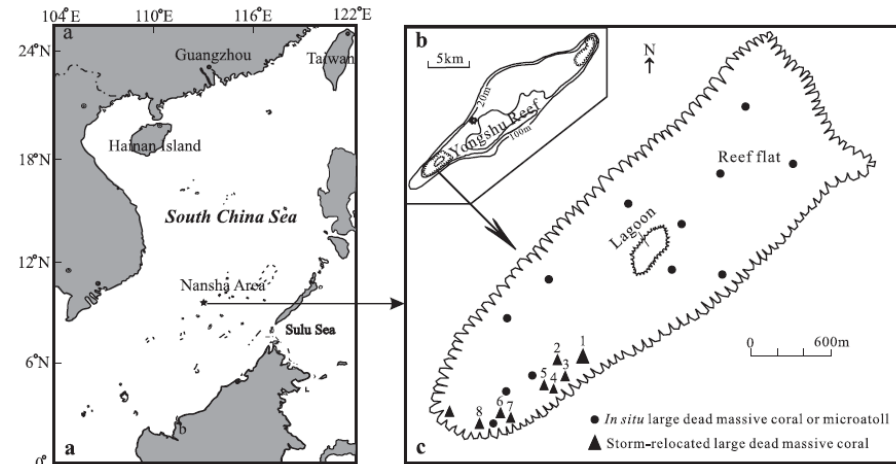


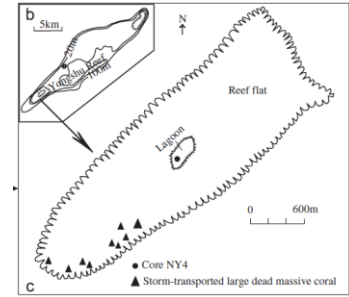
## Storm cycles in the last millennium recorded in Yongshu Reef, southern South China Sea

Ke-Fu Yu<sup>a,b,c,\*</sup>, Jian-Xin Zhao<sup>b,1</sup>, Kenneth D. Collerson<sup>b,2</sup>, Qi Shi<sup>a,3</sup>, Te-Gu Chen<sup>a,4</sup>, Pin-Xian Wang<sup>c,5</sup>, Tung-Sheng Liu<sup>d,6</sup>

- Large wave-transported *Porites* coral boulders dated to AD 1064, 1218, 1336, 1443, 1682, & 1872
- return period 160 (110-240) years

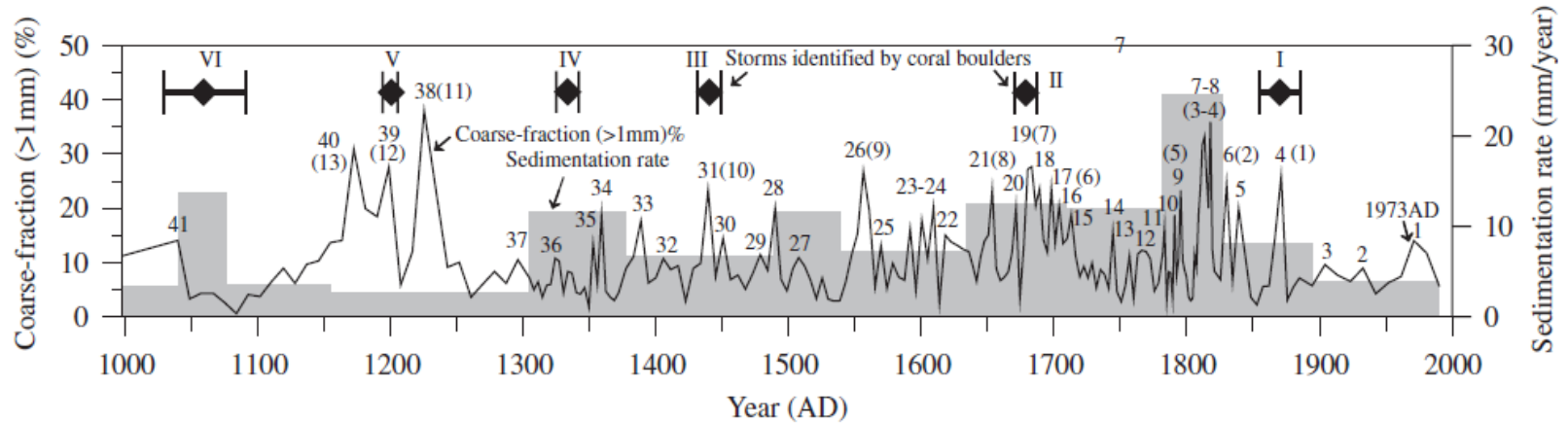
(Yu et al., 2004)





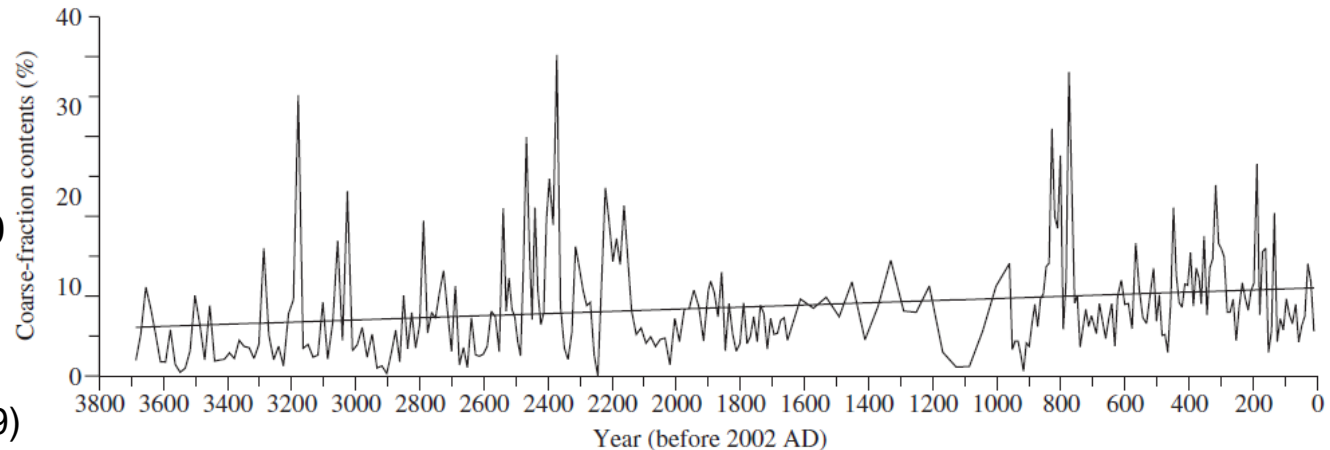
# Reconstruction of storm/tsunami records over the last 4000 years using transported coral blocks and lagoon sediments in the southern South China Sea

Ke-Fu Yu<sup>a,b,\*</sup>, Jian-Xin Zhao<sup>a,b,\*</sup>, Qi Shi<sup>a</sup>, Qing-Shan Meng<sup>c</sup>



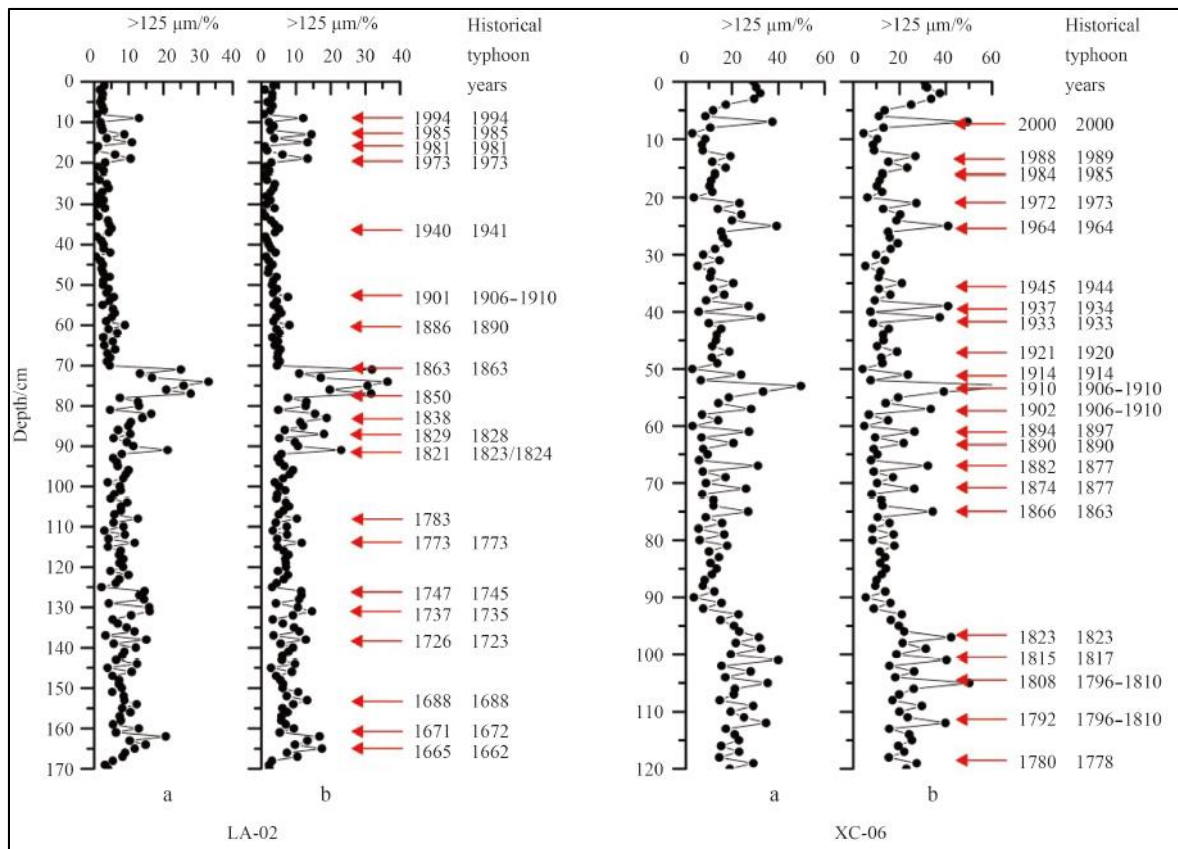
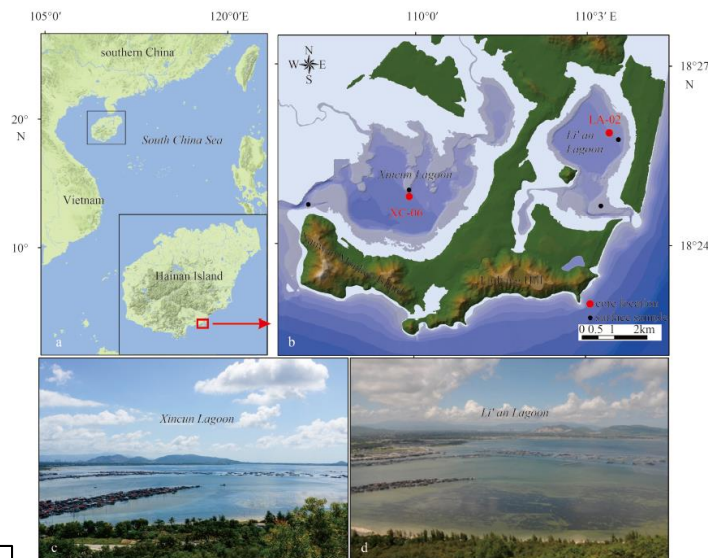
- Core from center lagoon
- 77 grain-size peaks in 4000 years
- 3 stormy episodes:
  - AD 800, 400 BC, 1200 BC
- TC or tsunamis?

(Yu et al., 2009)



## Typhoon events recorded in coastal lagoon deposits, southeastern Hainan Island

ZHOU Liang<sup>1,2</sup>, GAO Shu<sup>1,2\*</sup>, YANG Yang<sup>1,2</sup>, ZHAO Yangyang<sup>1,2</sup>, HAN Zhuochen<sup>1,2</sup>, LI Gaocong<sup>1,2</sup>, JIA Peihong<sup>1,2</sup>, YIN Yong<sup>1,2</sup>



A 350-year sedimentary proxy record based on grain-size analysis and Pb-210 dating

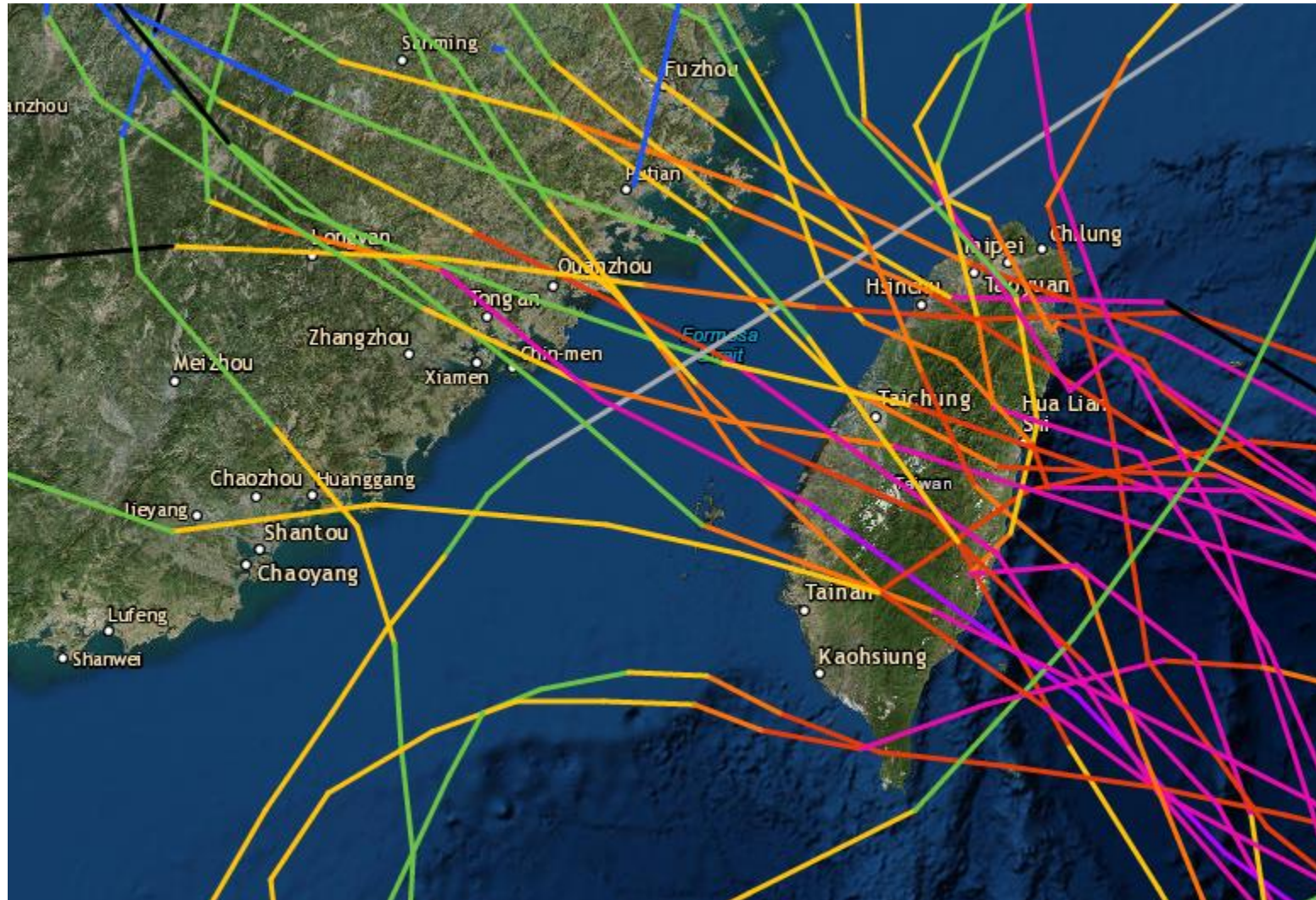
(Zhou et al., 2016)



*Paleotempestology is needed for Taiwan too.....*

## Intense typhoon record of Taiwan (CAT 3-5, 1971-2015)

25 intense typhoons in 45 years; 0.6/yr



# Conclusions

## Research opportunities and potential for paleotempestology in China:

- A long-term record is needed to predict future typhoon activity
- Paleotempestology is still at its infancy in China
- Atlantic paleotempestology can help formulate research questions for E. Asia
- Historical documentary record can be used to support geological record
- Coral atolls in South China Sea provide promising records
- Ideal backbarrier lakes hard to find, but coastal wetlands possible
- Speleothems need to be further explored

