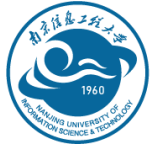


第五届全国中尺度气象论坛 (2023.08.09-08.12)



南京信息工程大学  
Nanjing University of Information Science & Technology

# 二十世纪末以来西北太平洋台风活动变化的 若干事实及可能物理解释

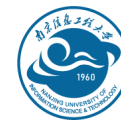
赵海坤

南京信息工程大学大气科学学院/太平洋台风研究中心

[haikunzhao@nuist.edu.cn](mailto:haikunzhao@nuist.edu.cn), [zhk2004y@gmail.com](mailto:zhk2004y@gmail.com)

中国 银川

# 西太台风活动活跃、社会影响大

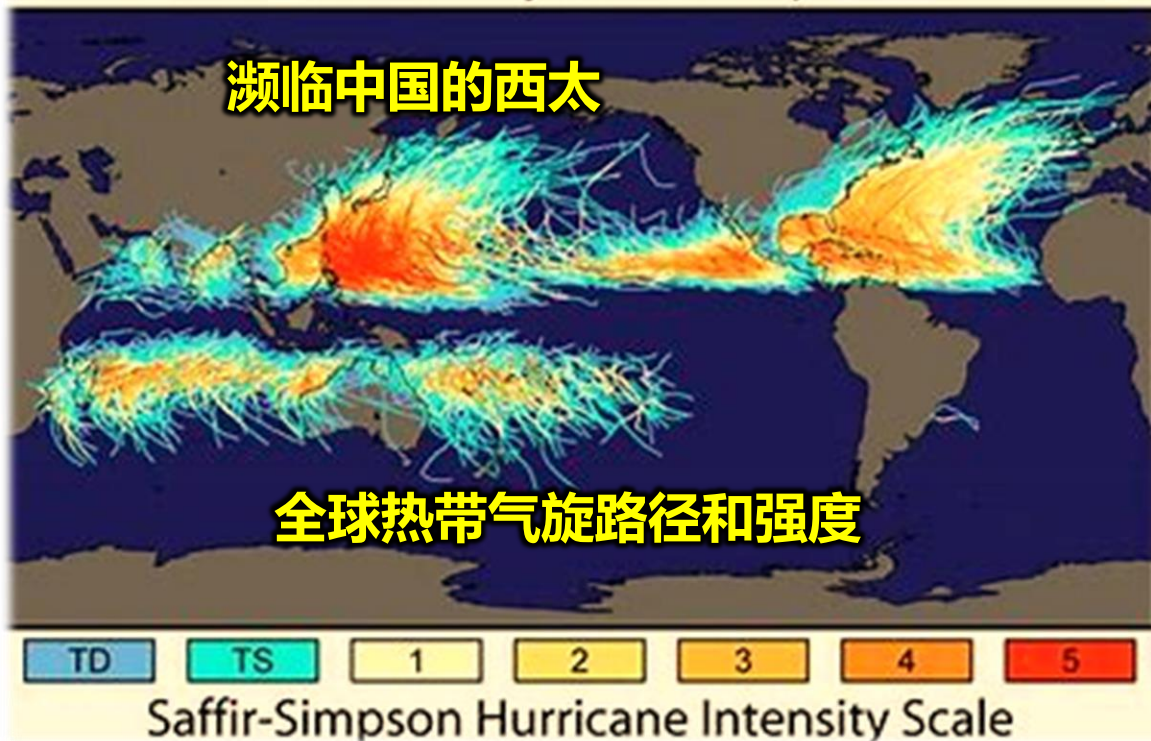


南京信息工程大学  
Nanjing University of Information Science & Technology

西太台风活动全球最频繁、最活跃

西太台风活动影响巨大

Tracks and Intensity of All Tropical Storms



西太台风携带的风雨及其次生风暴潮、泥石流、滑坡等

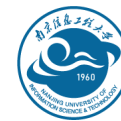


- 生成频数世界之最：~27个，~占全球总数1/3
- 登陆频数世界之最：~9个
- 全球唯一：全年都有台风生成的海域

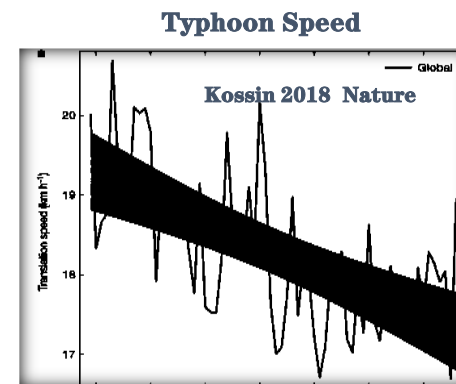
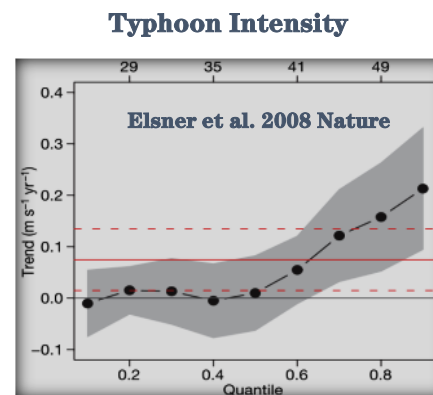
我国“国家中长期科技发展纲要”已将台风灾害列为影响国家公共安全的主要自然灾害之一。



# 全球变暖可能已经影响台风活动但不确定性大



南京信息工程大学  
Nanjing University of Information Science & Technology



➤ **台风最佳路径观测资料的非均匀性和时限性**

**需构建均匀性和更长时间的热带气旋资料**

➤ **模式模式结果的不一致性降低了台风活动未来变化结论的可靠性**

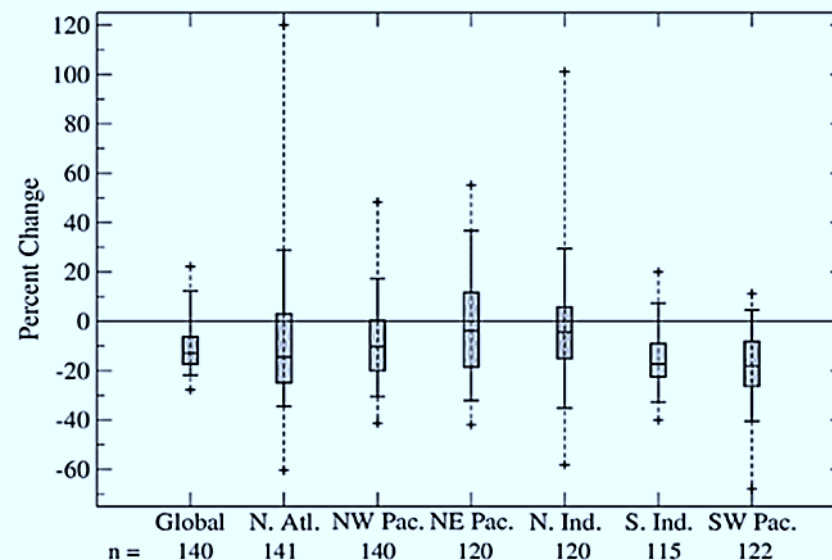
**需提高模式对台风活动的表征能力**

➤ **影响台风活动的物理机制认识的缺乏**

**需从全球尺度至海盆尺度、从天气尺度至气候尺度、从大气海洋至海陆**

**气冰等多圈层、从内部变率至外部强迫展开深入的研究**

b) Tropical Cyclone Frequency Change Projections: By Basin  
Median; interquartile range; 5th/95th percentiles; full range

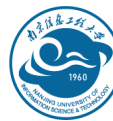


Knutson et al. (2020)





# 20世纪末以来台风活动变化若干事实



南京信息工程大学  
Nanjing University of Information Science & Technology

## Part 1 生成

- 台风频数显著减少
- 台风生成效率显著降低
- 快速增强台风比例显著增加

## Part 2 移动

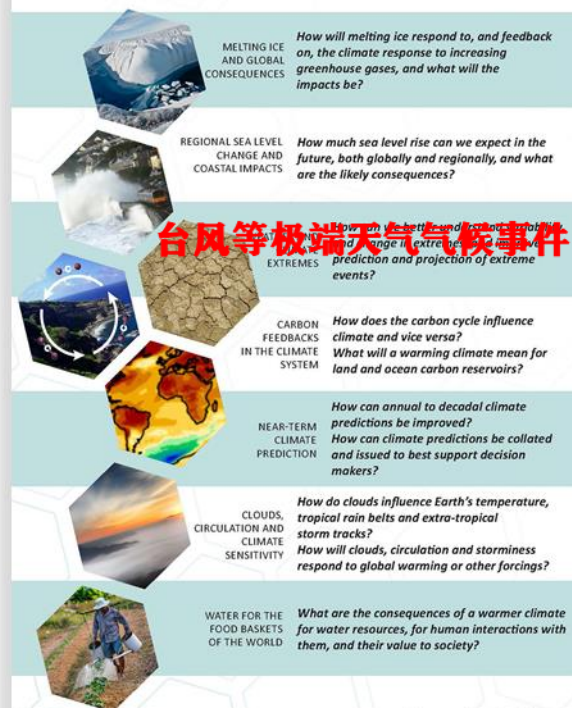
- 台风盛行路径明显的西北偏移
- 台风生命史最大强度位置显著的向极移动

## Part 3 关系

- ENSO 与台风频数的关系显著增强
- 台风生成位置（纬度和经度）共变性显著加强
- 青藏高原积雪与快速增强台风频数的关系显著增强。

### What are the WCRP Grand Challenges?

The WCRP Grand Challenges are highly-focused priority areas of climate science and address specific obstacles to progress. The Grand Challenges provide actionable knowledge for decision makers and compelling storylines for public and media interest. The current WCRP Grand Challenges, and the questions that they address, are:



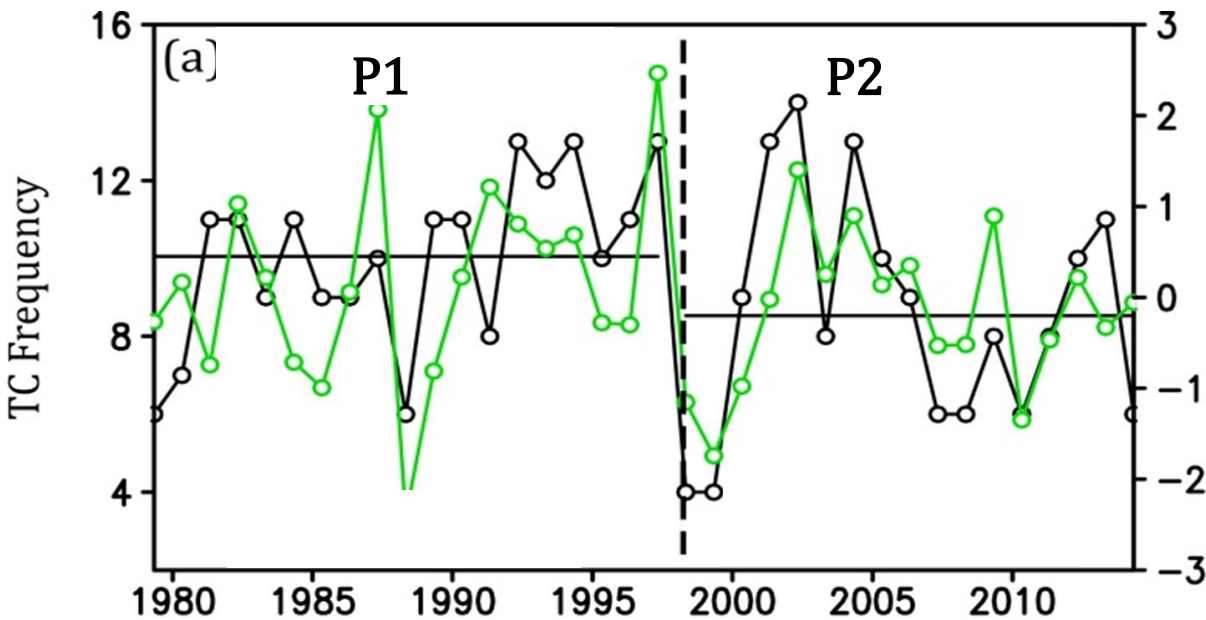
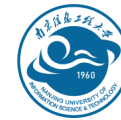
[www.wcrp-climate.org/grand-challenges](http://www.wcrp-climate.org/grand-challenges)

© World Climate Research Programme  
email: wcrp@wmo.int | website: wcrp-climate.org

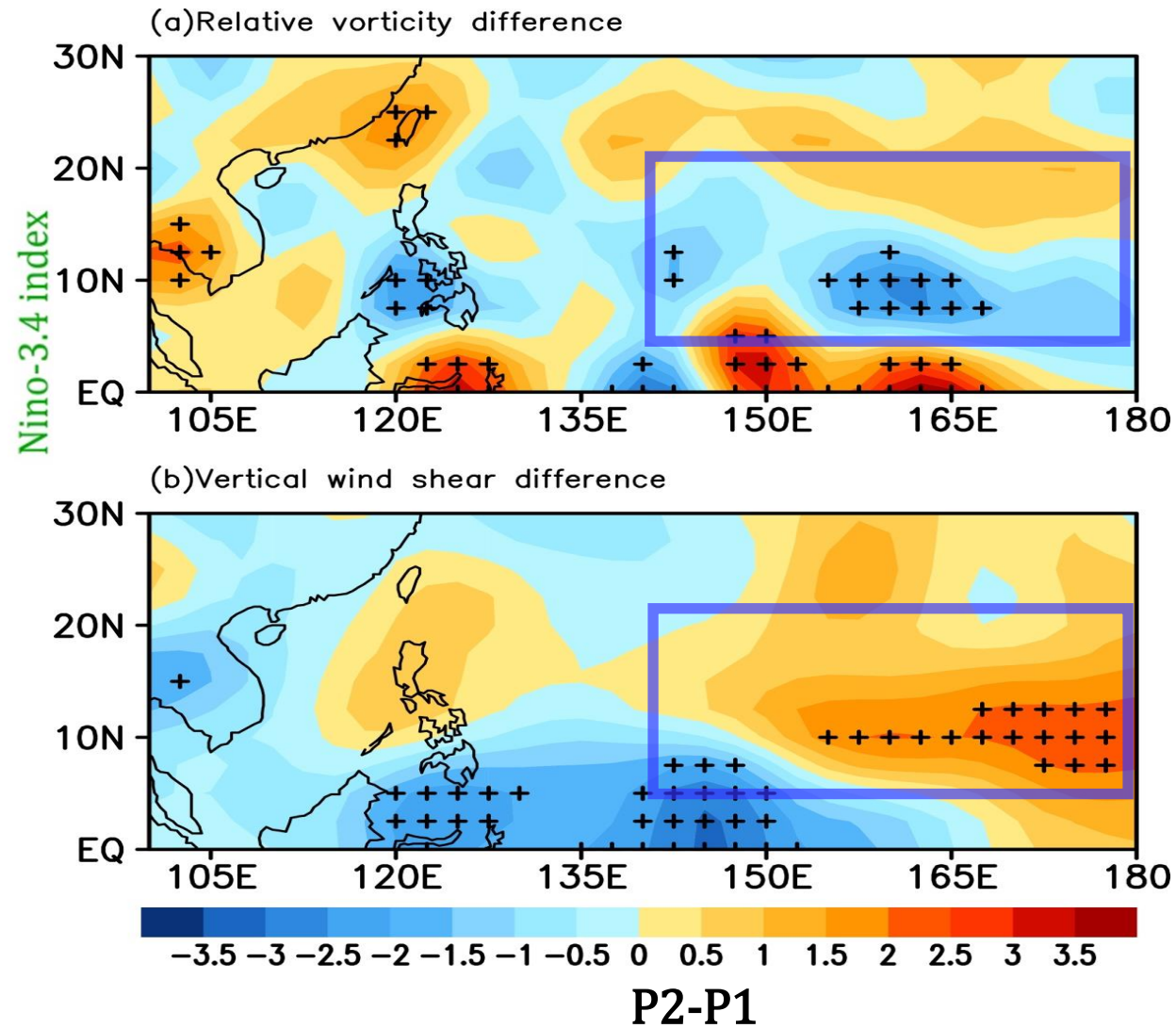


WCRP Grand Challenges

# Part 1-台风频数显著减少

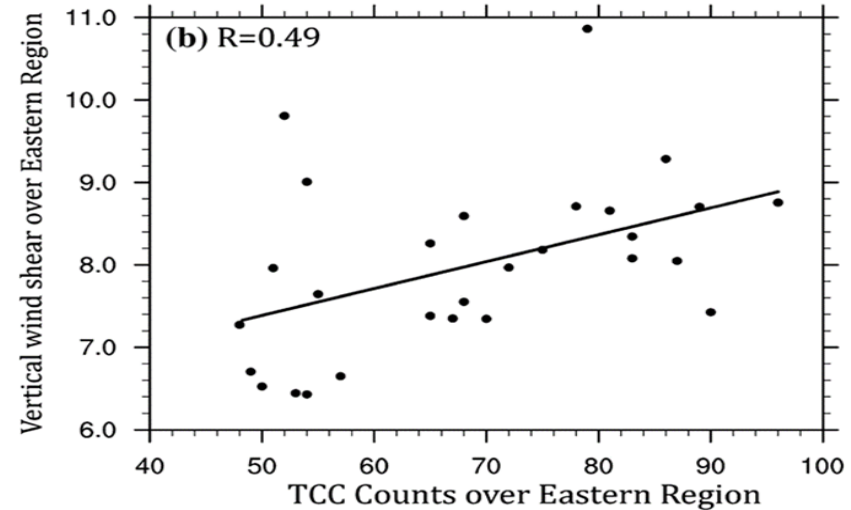
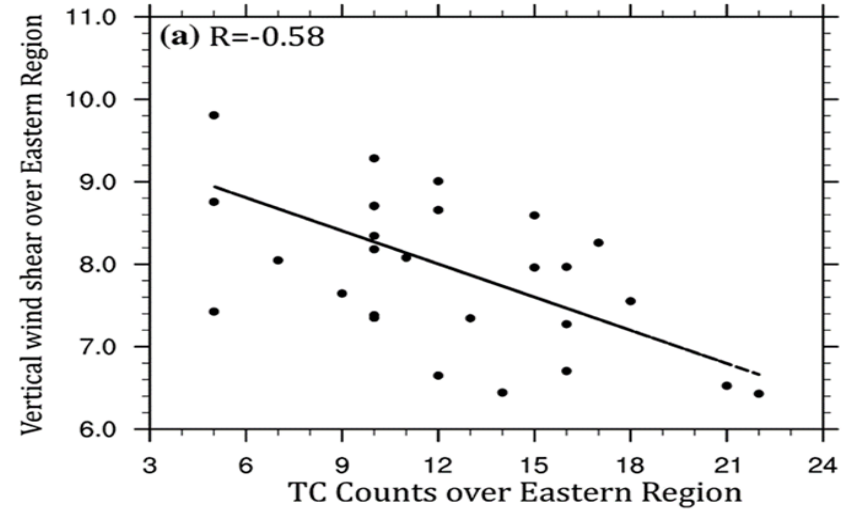
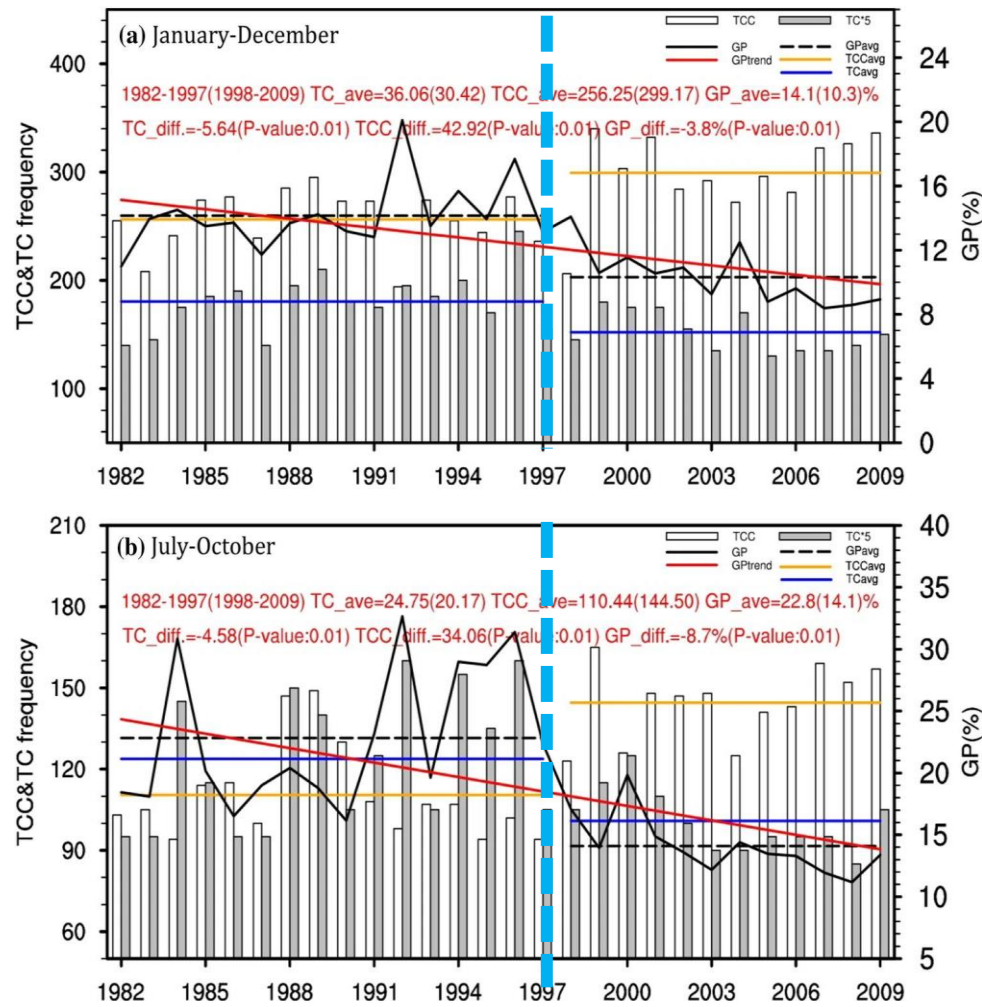
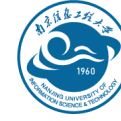


➤ 主要受动力因子控制：垂直切变和低层涡度





# Part 1-台风生成效率显著降低

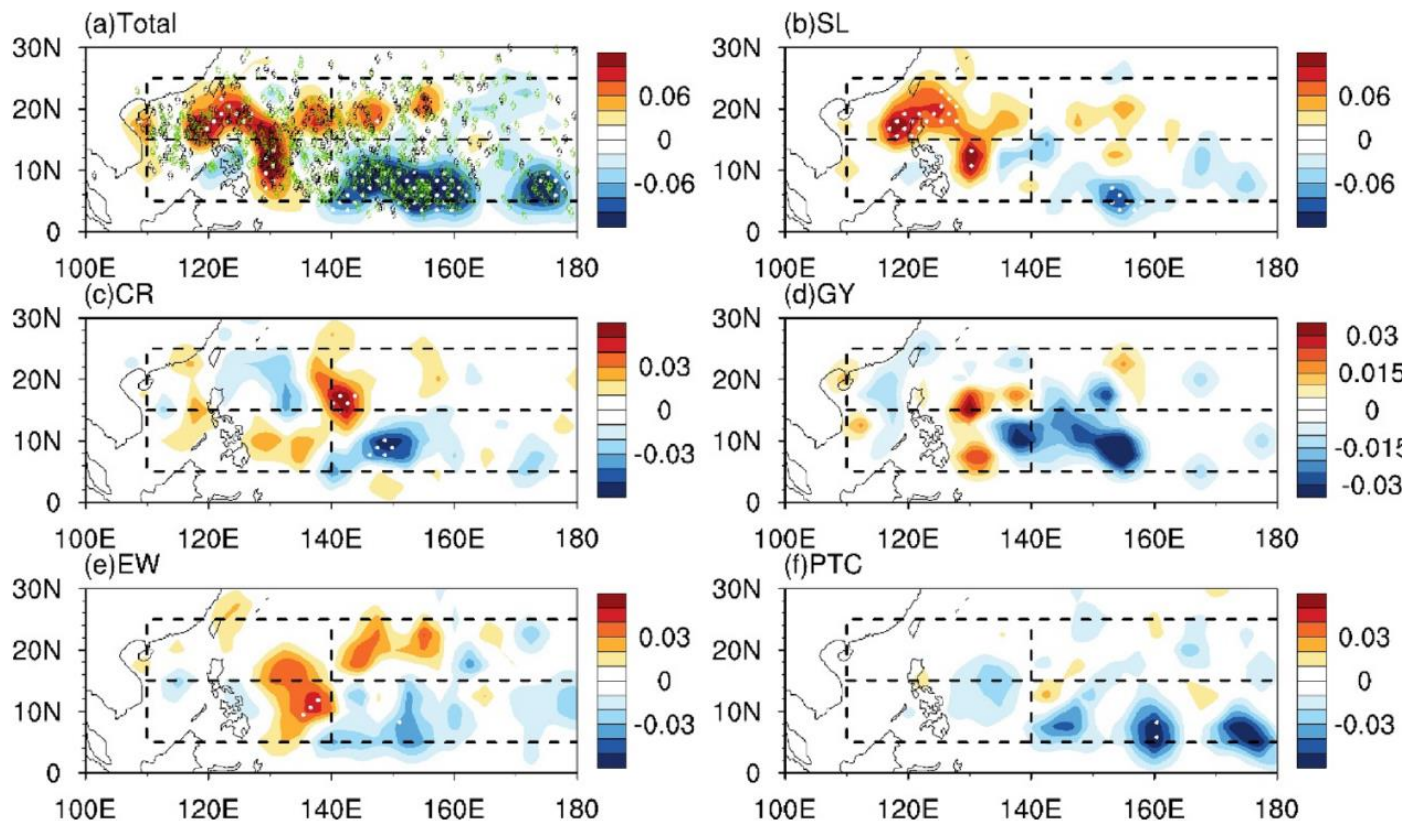


➤ **台风生成效率=台风生成频数/热带云团频数**

**主要受动力因子控制：垂直切变增加有利于热带云团发生，但不利于热带云团发展为台风。**

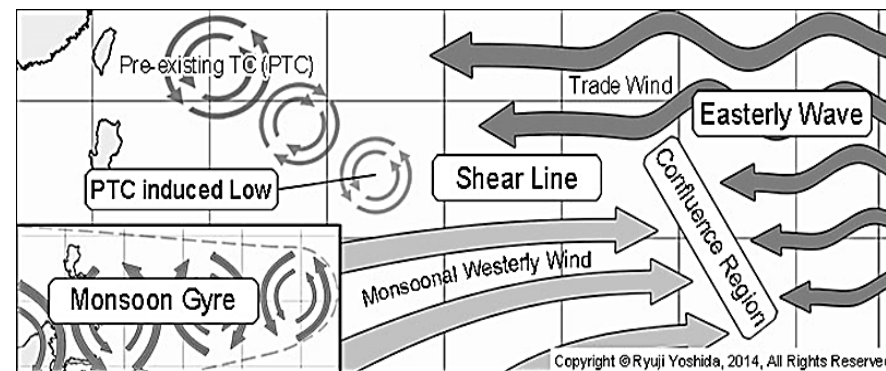
*Zhao et al.(2019, CD)*

# Part 1-与PTC相关台风频数显著减少

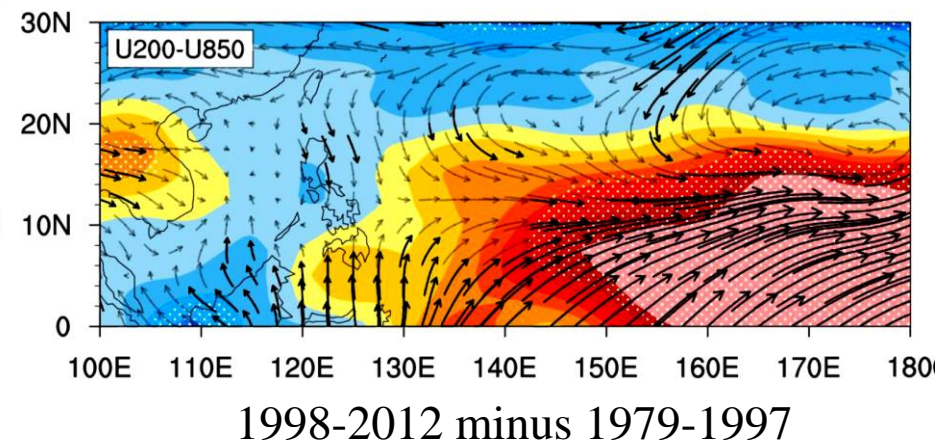


不同大尺度环流型相关的台风生成差值场

Yoshida and Ishikawa (2013)



不同大尺度环流型相关台风生成的分类

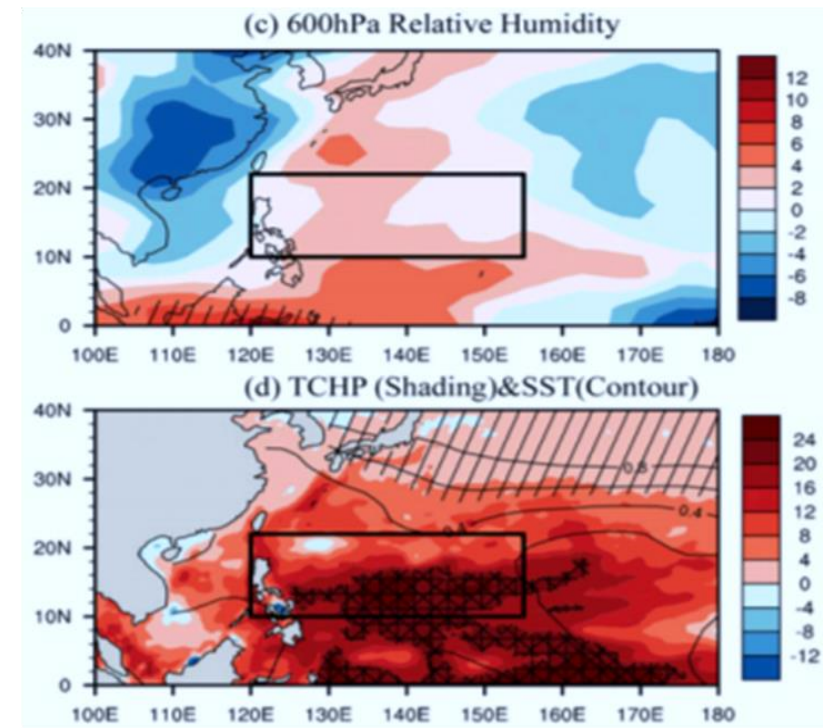
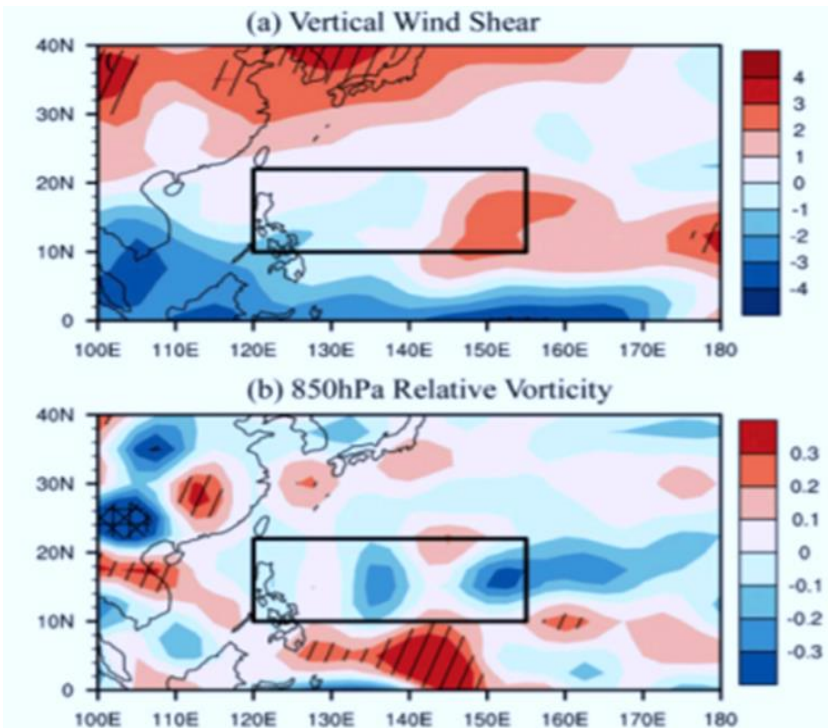
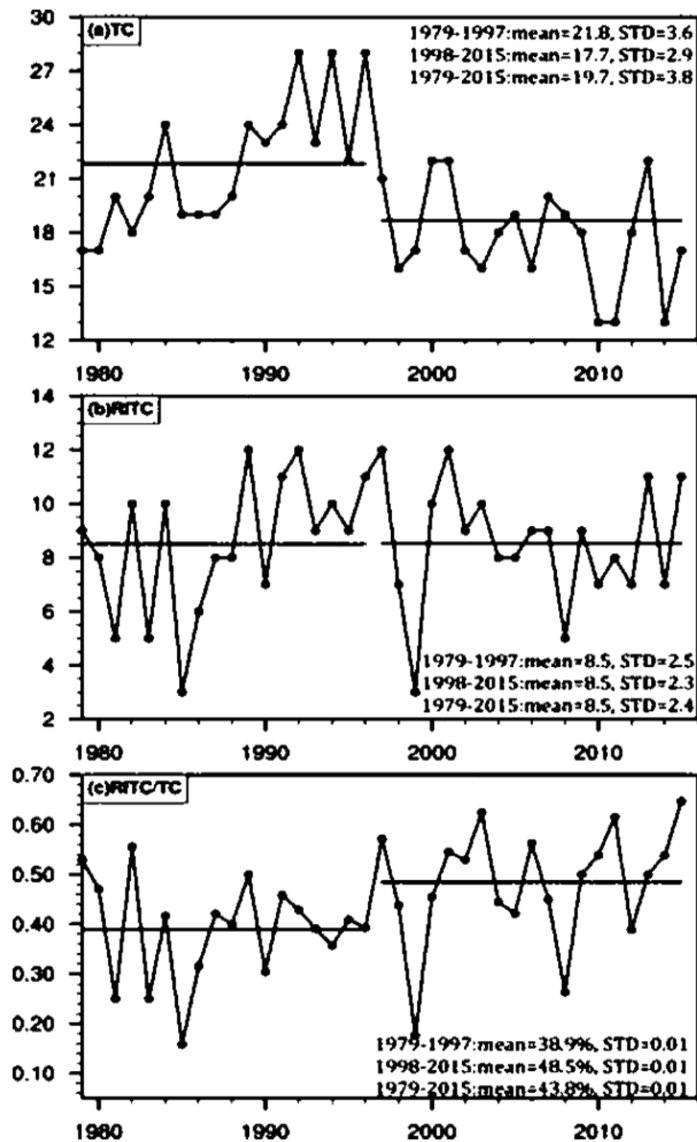
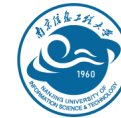


1998-2012 minus 1979-1997

- 发现了近期西北太平洋台风频数显著减少主要是与PTC相关台风显著减少所贡献，西北太平洋东部西风切变增加起主导作用。

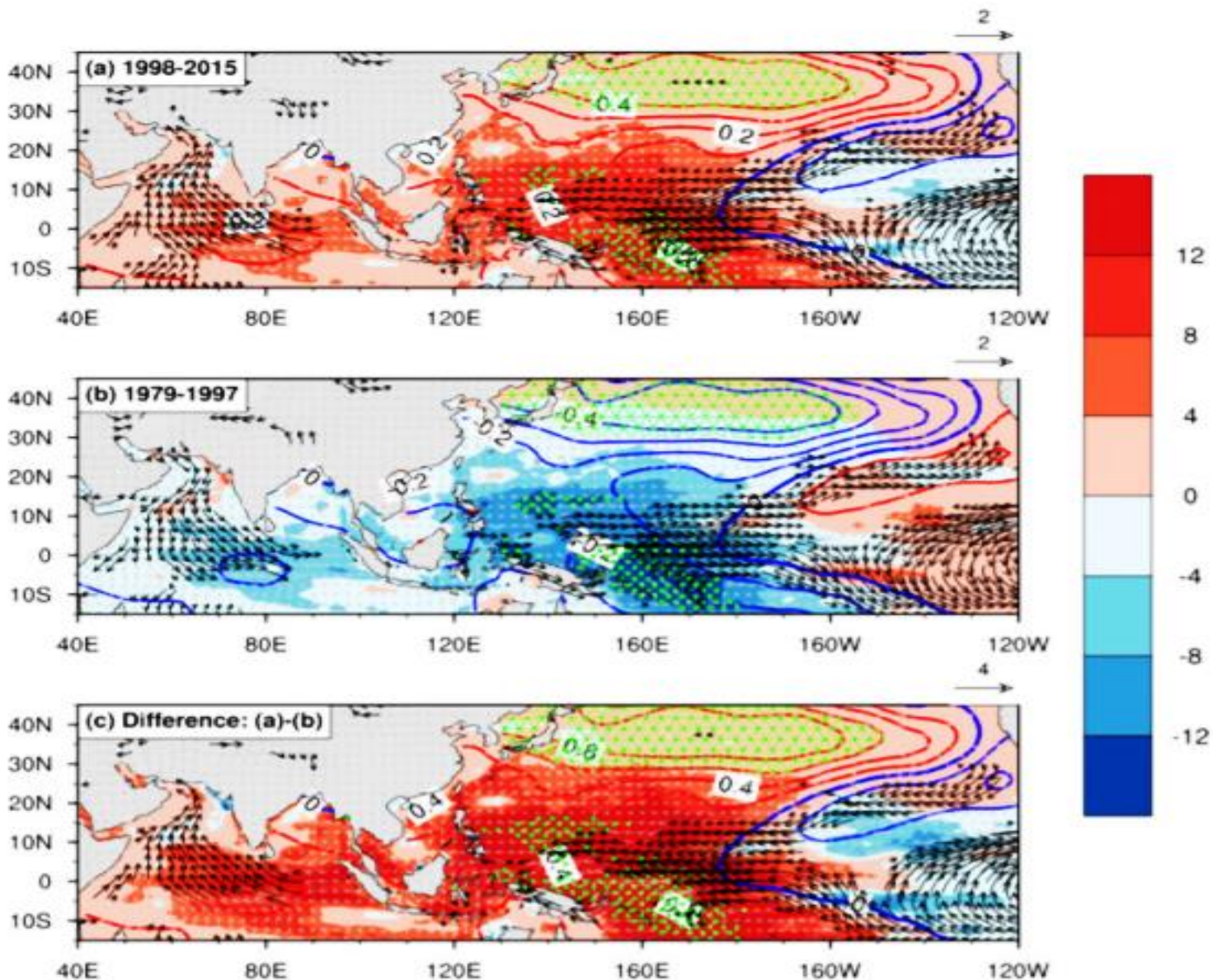
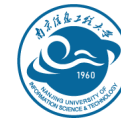


# Part 1-快速增强台风比例显著增加



➤ **主要受热力因子控制：海洋热含量增加、海表面温度升高、中层水汽 增加**

# Part 1-可能的物理成因

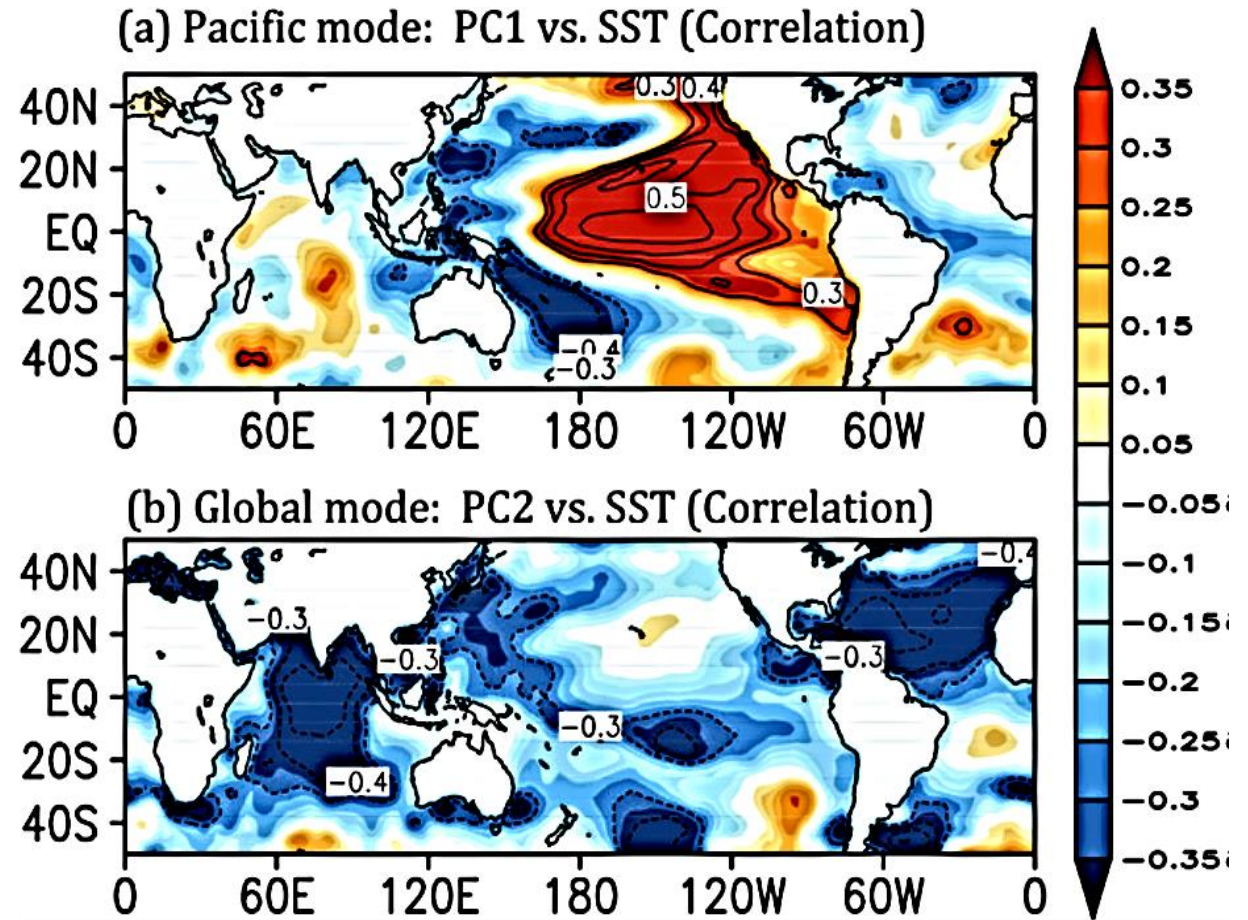
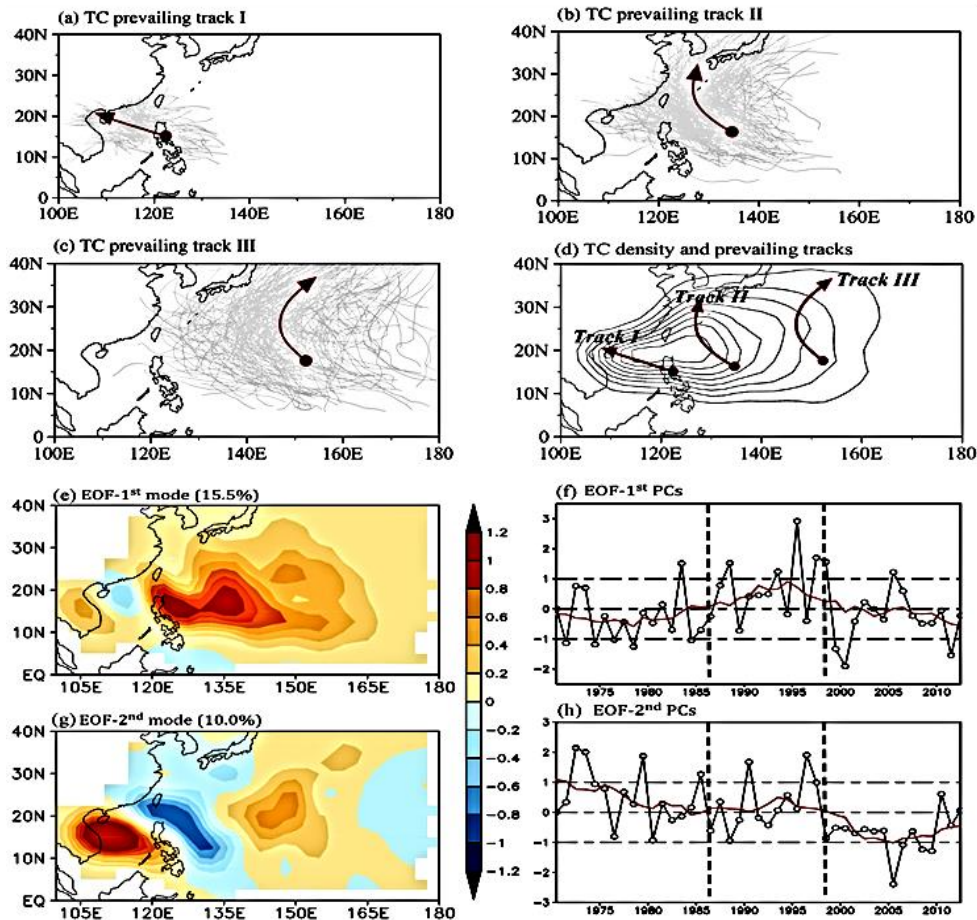
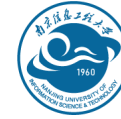


## Mega- La-Niña-like Pattern

- 东风异常
- 垂直切变增加
- 季风环流减弱
- 海洋热含量增加



# Part 2-台风路径显著西北偏移



- 指出了ENSO-like和全球海温一致模态在台风盛行路径变化中占据主导作用，台风盛行路径变化中对大尺度海温模态具有显著的年代际尺度依赖性。



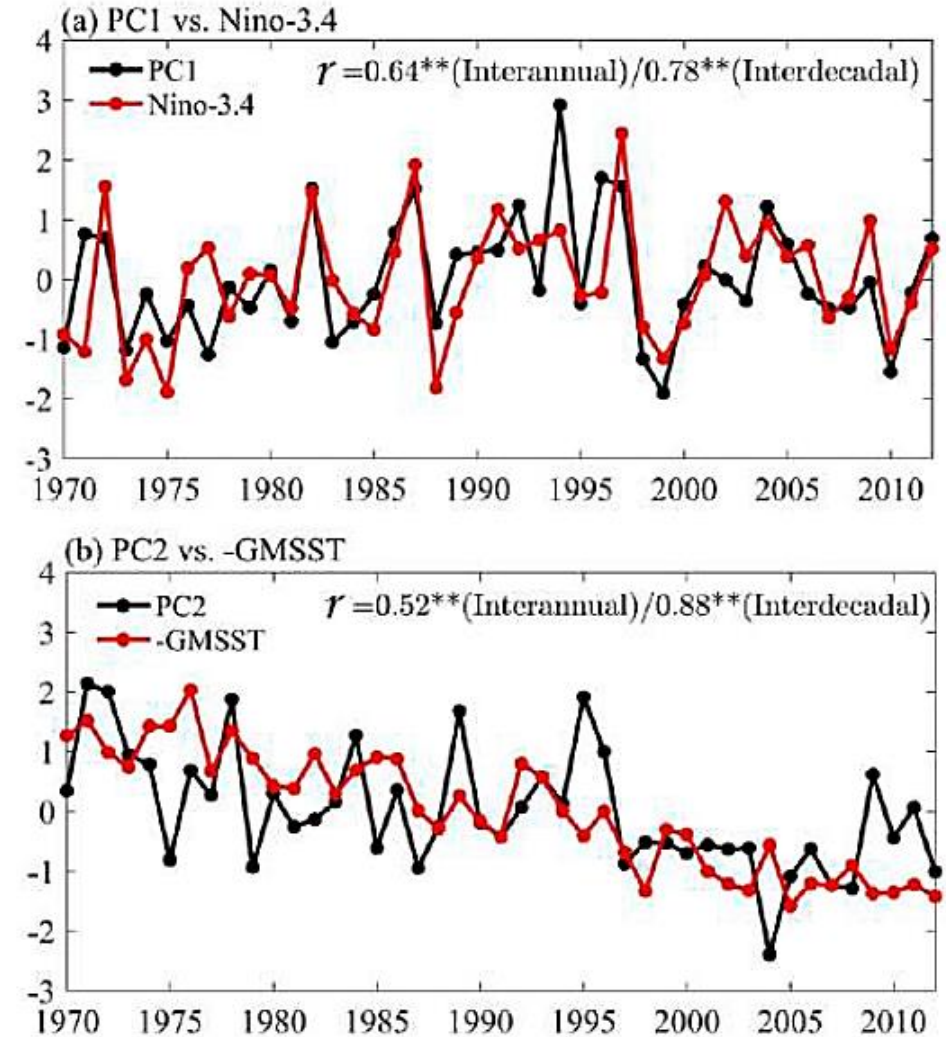
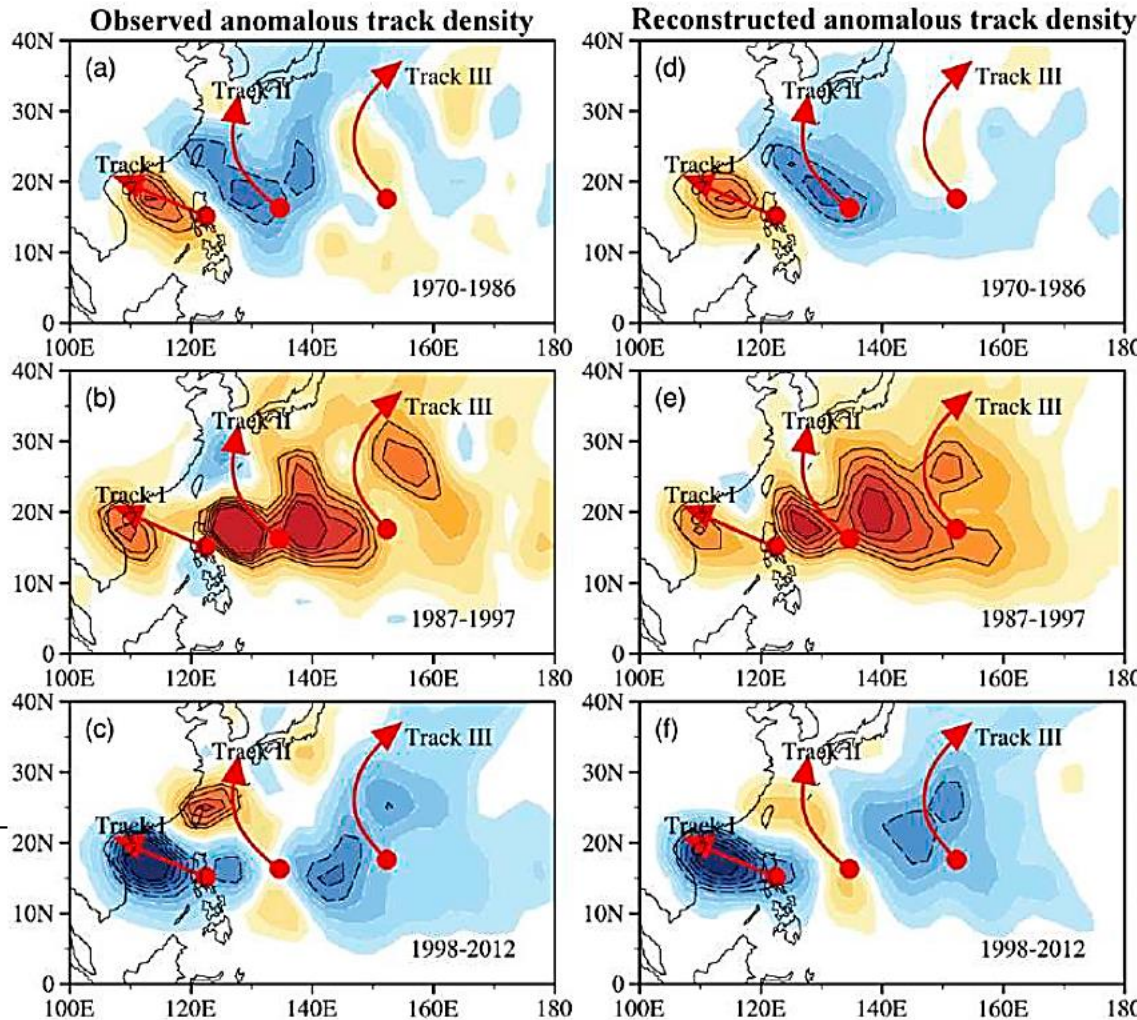
# Part 2-台风路径显著西北偏移



$$0.35 * \text{EOF-1}^{\text{st}} + 0.65 * \text{EOF-2}^{\text{nd}}$$

$$0.64 * \text{EOF-1}^{\text{st}} + 0.36 * \text{EOF-2}^{\text{nd}}$$

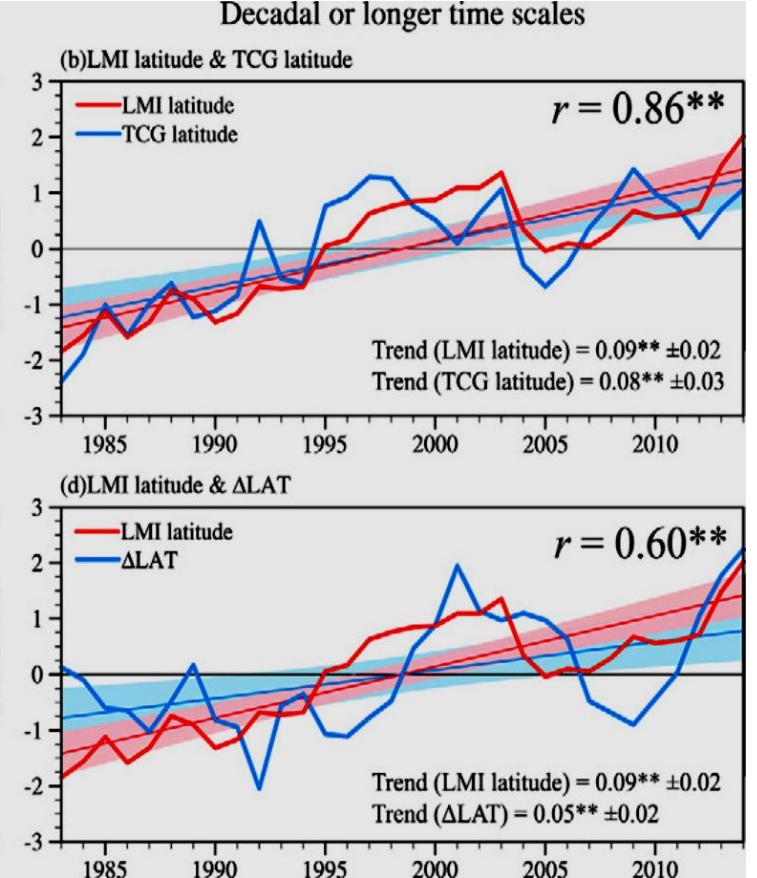
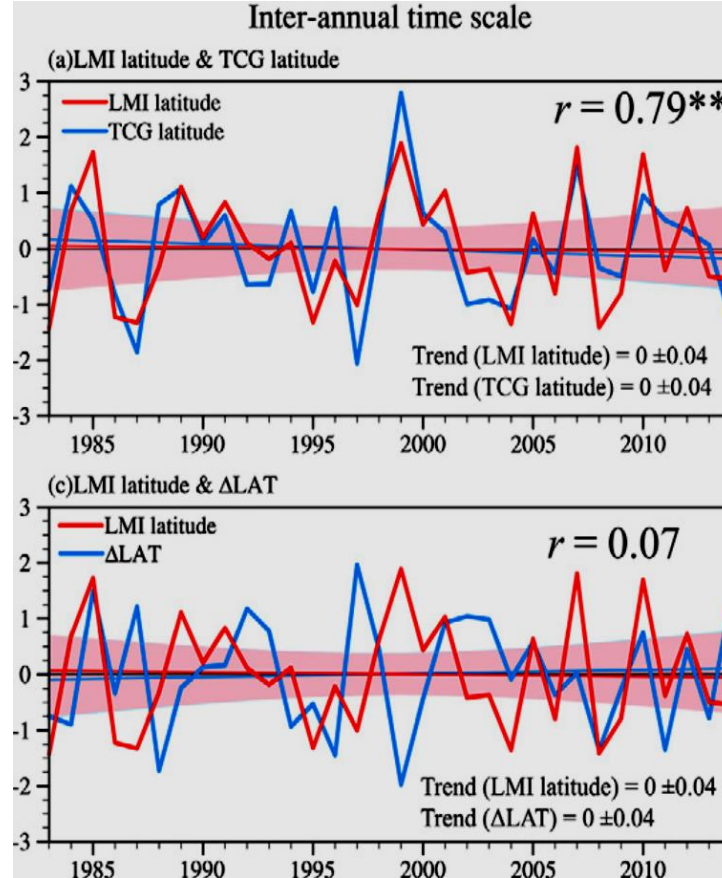
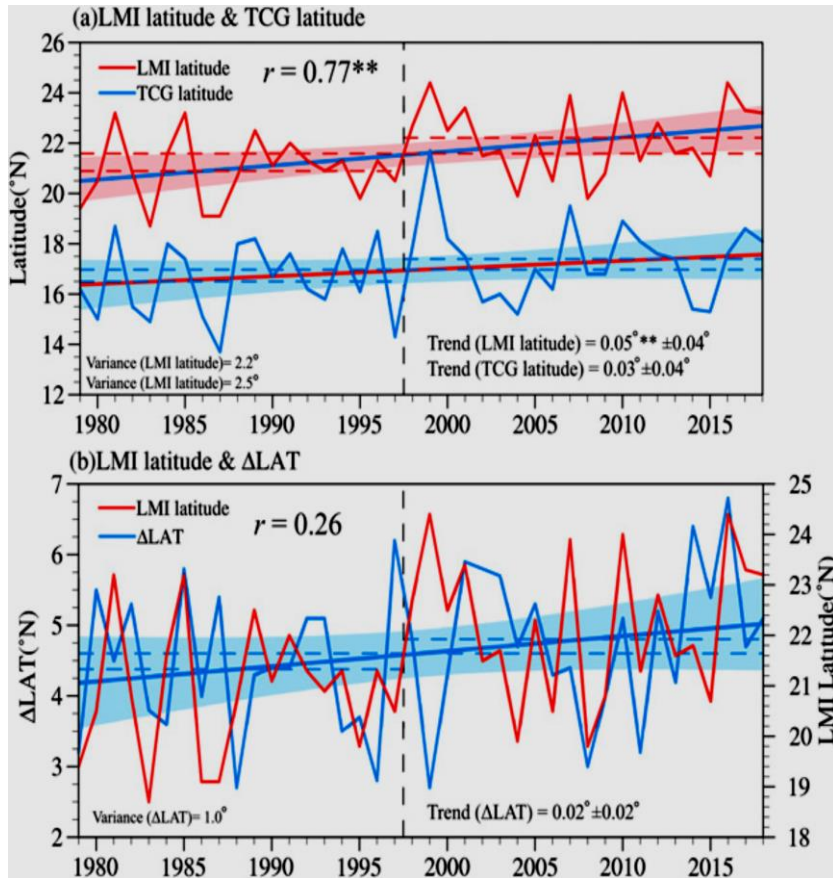
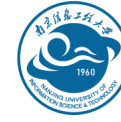
$$-0.30 * \text{EOF-1}^{\text{st}} + -0.70 * \text{EOF-2}^{\text{nd}}$$



➤ 指出了自然变率的主导性，强调了全球变暖在近期台风路径西北偏移的可能重要作用。

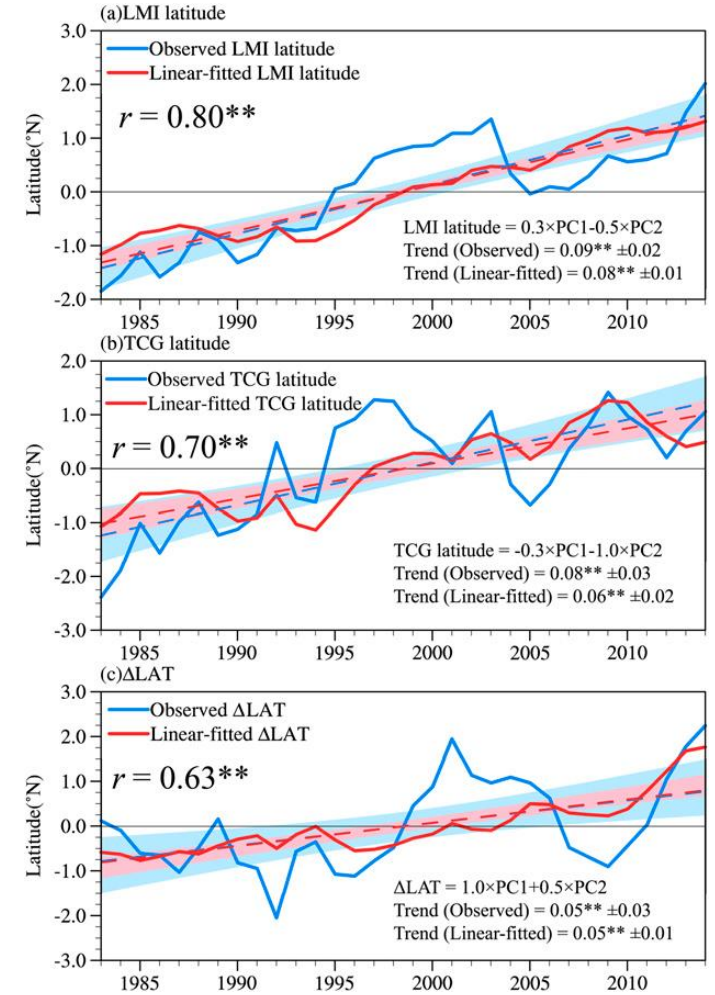
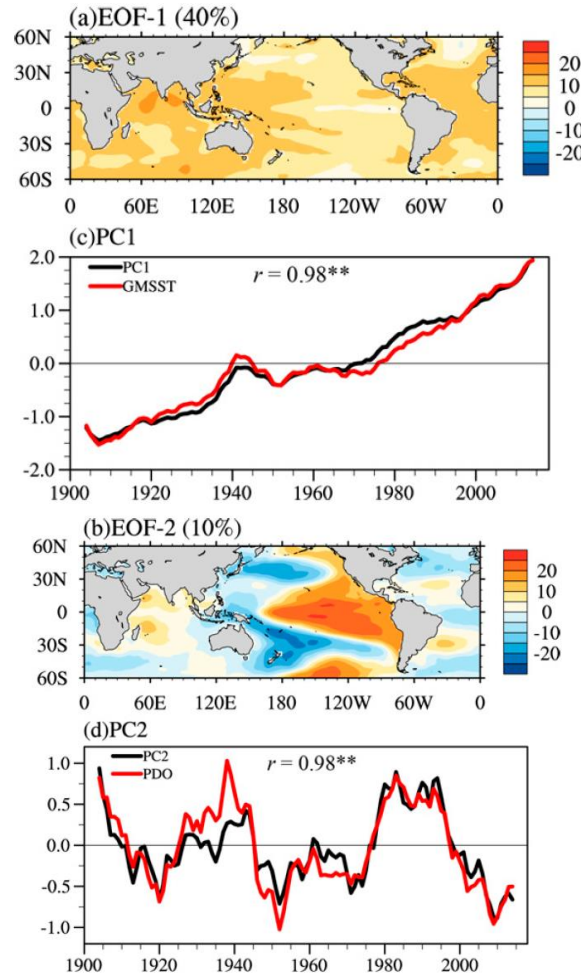
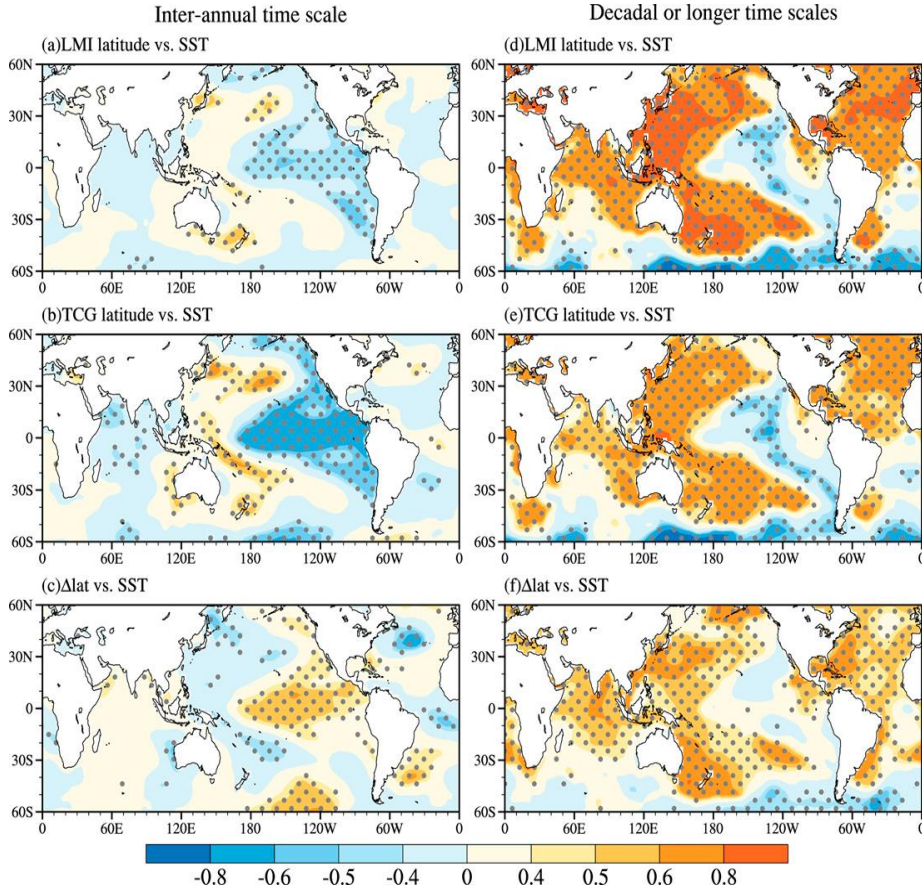
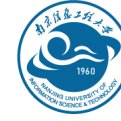


# Part 2-台风最大强度位置显著北移



➤ 从多时间尺度分析了台风最大强度位置变化，年际变化主要受台风生成位置变化主导；年代际及更长时间尺度由台风生成位置和路径变化共同主导。

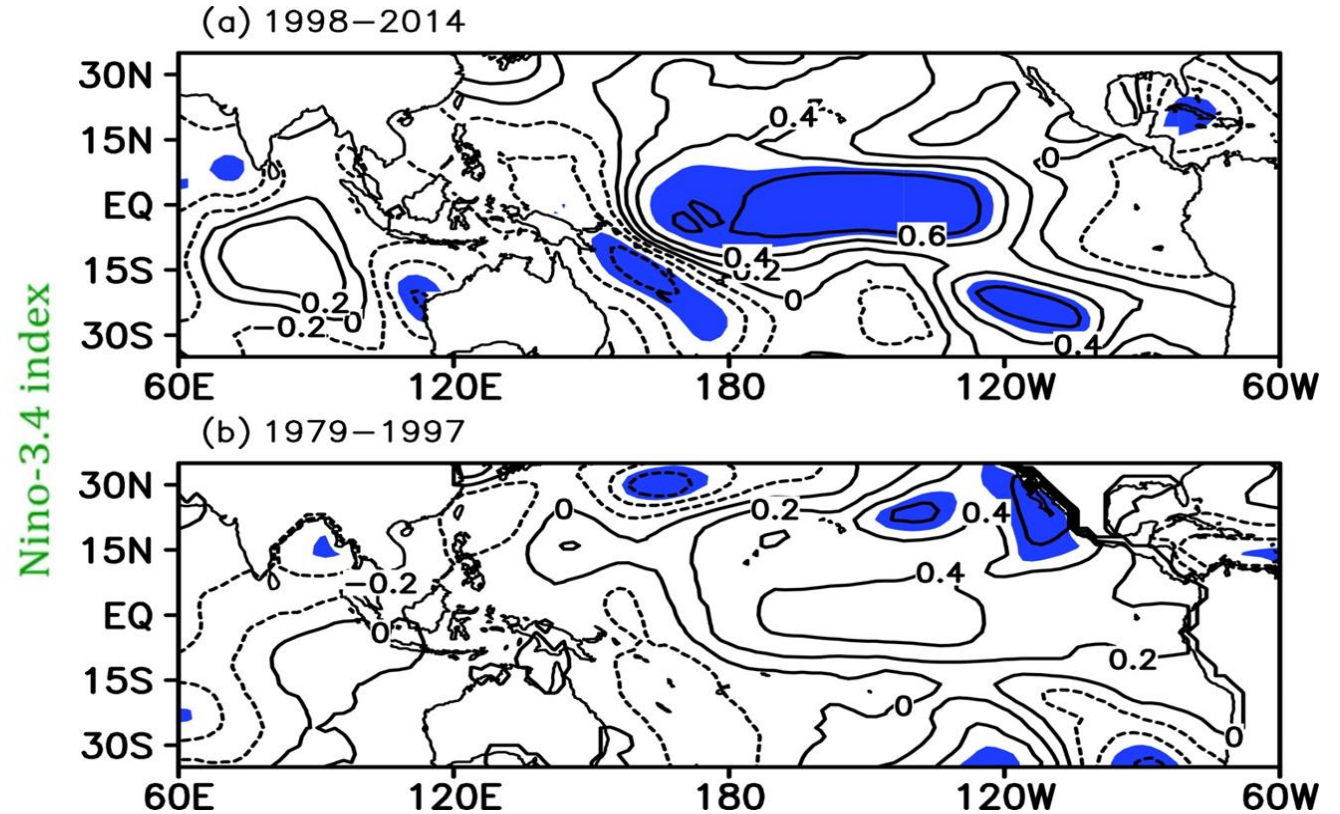
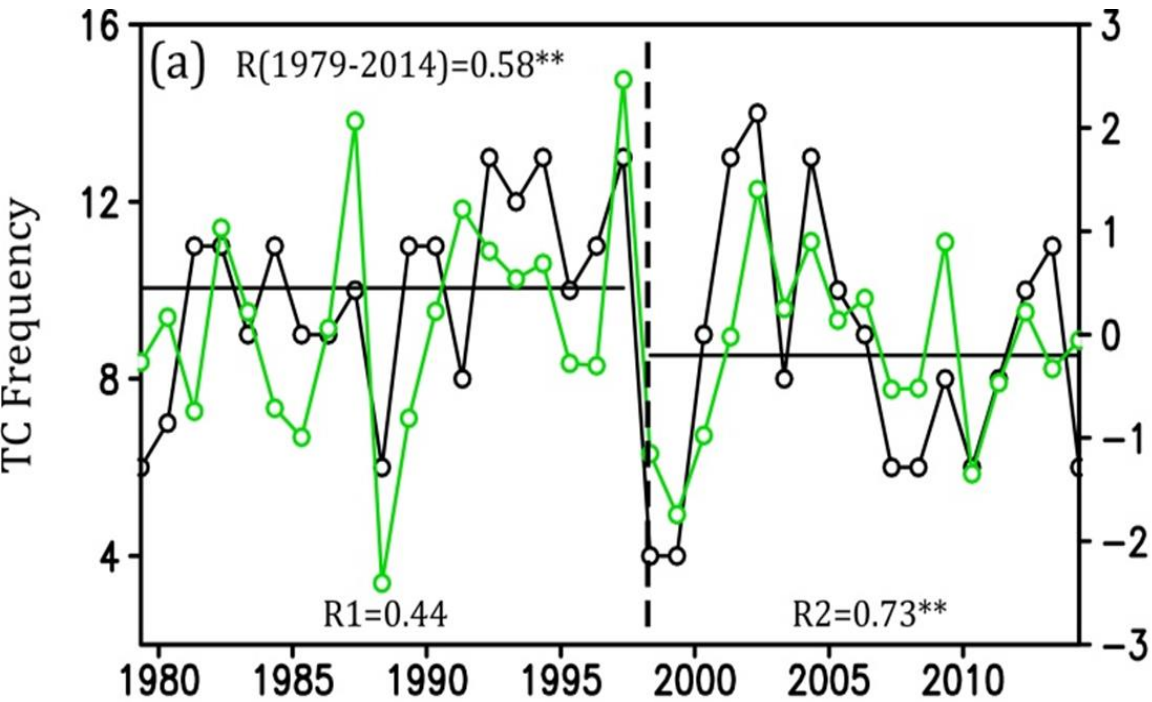
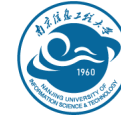
# Part 2-台风最大强度位置显著北移



➤ 近期台风最大强度位置的北移主要是PDO+全球变暖所影响（全球变暖有利于北移，叠加了PDO位相从暖位相转为冷位相所致的北移）。

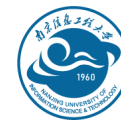


# Part 3-ENSO与台风频数关系增强

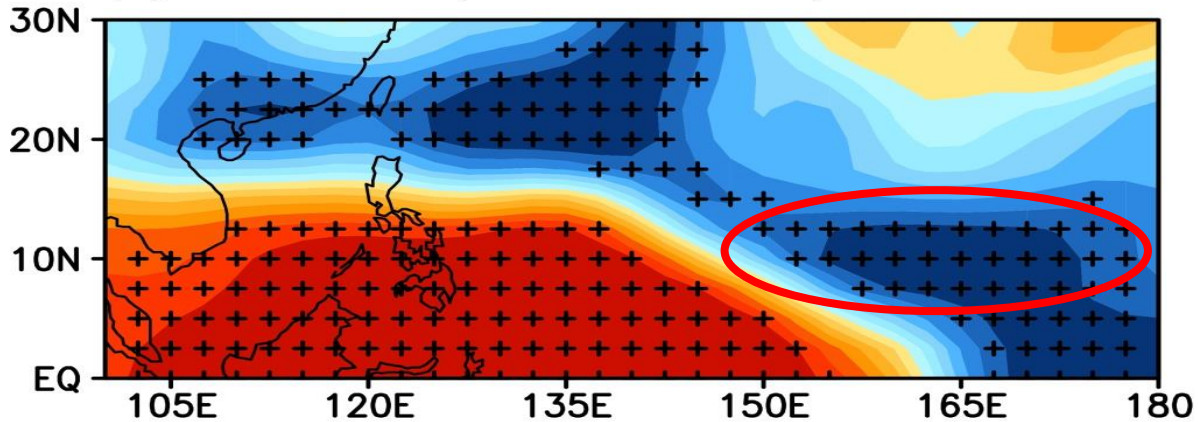


➤ ENSO与台风生成频数关系的显著加强主要是与20世纪末以来发生更多的CP ENSO事件密切相关。

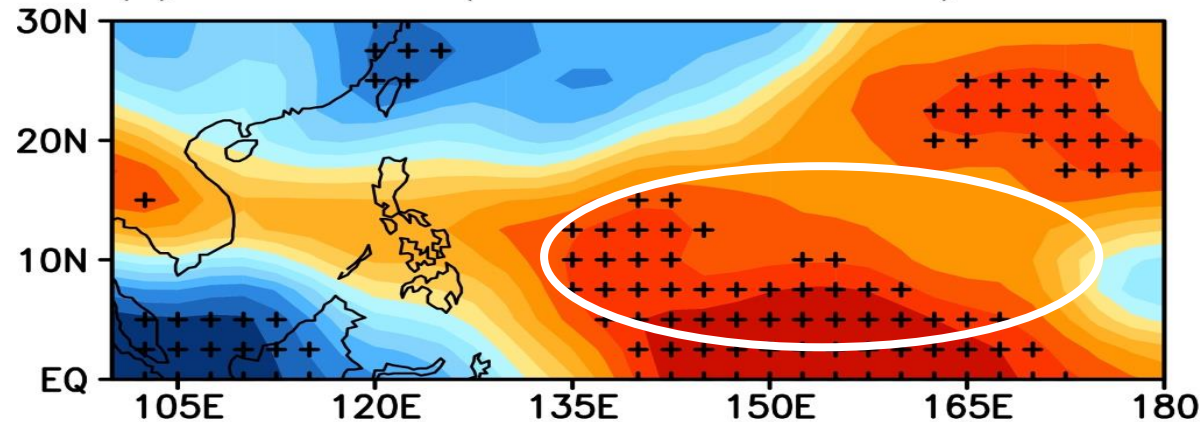
# Part 3-ENSO与台风频数关系增强



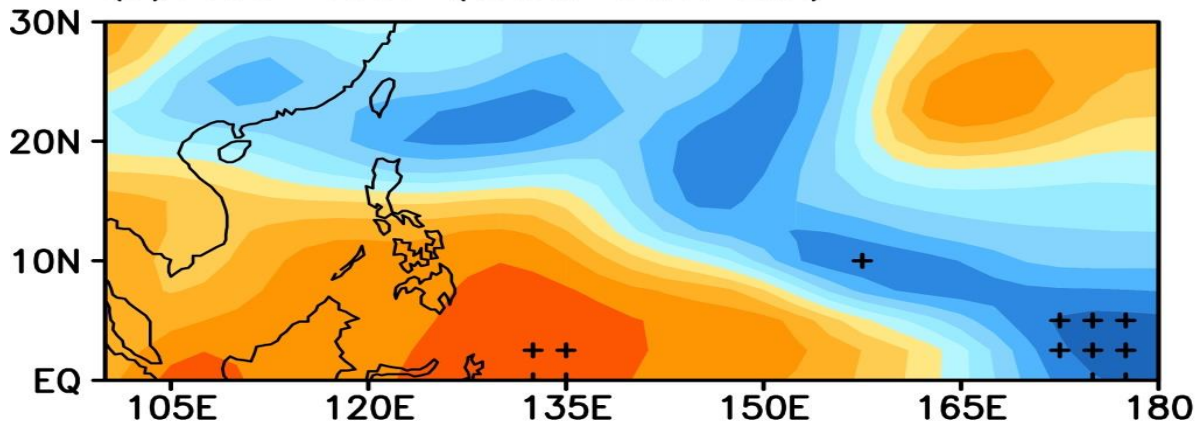
(a)1998-2014 (Shear corr. EMI)



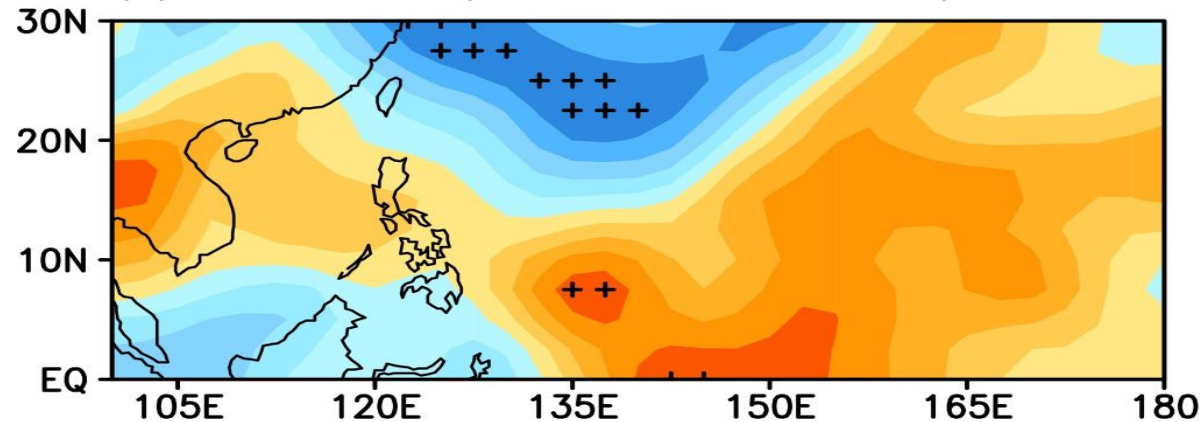
(a)1998-2014 (600hPa RH corr. EMI)



(b)1979-1997 (Shear corr. EMI)



(b)1979-1997 (600hPa RH corr. EMI)

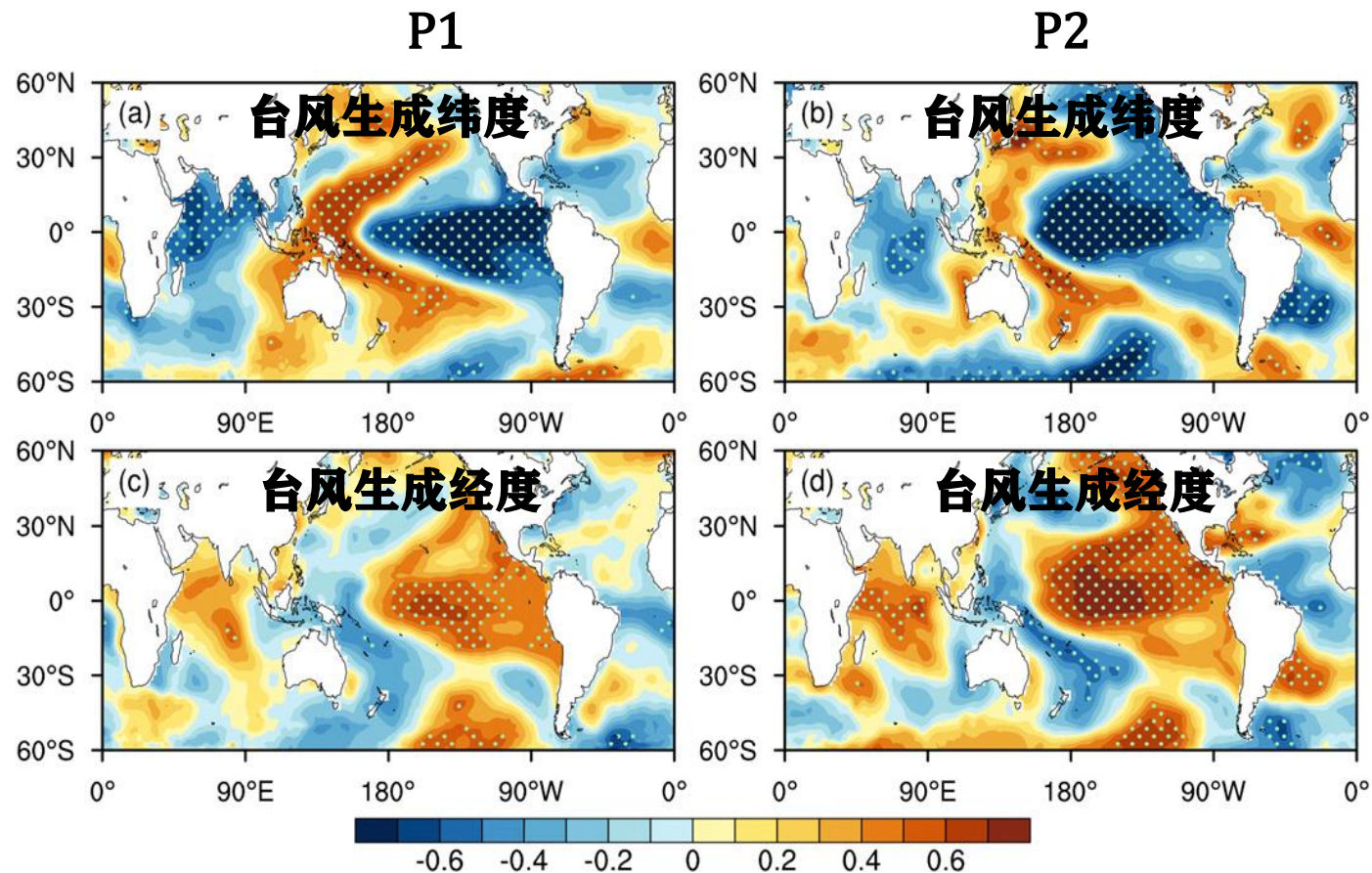
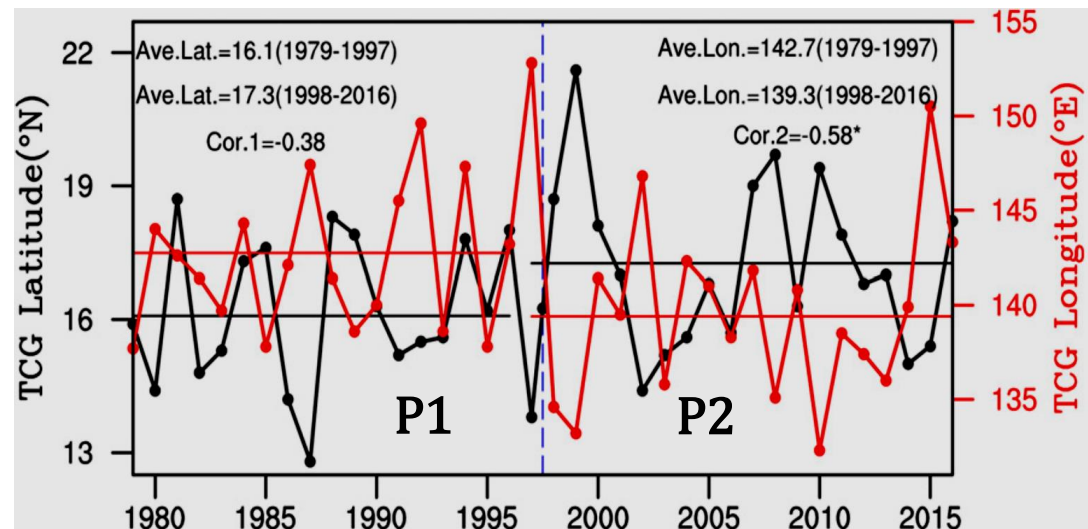


➤ 更多的CP ENSO事件增强了垂直切变和中层相对湿度对台风的效应。



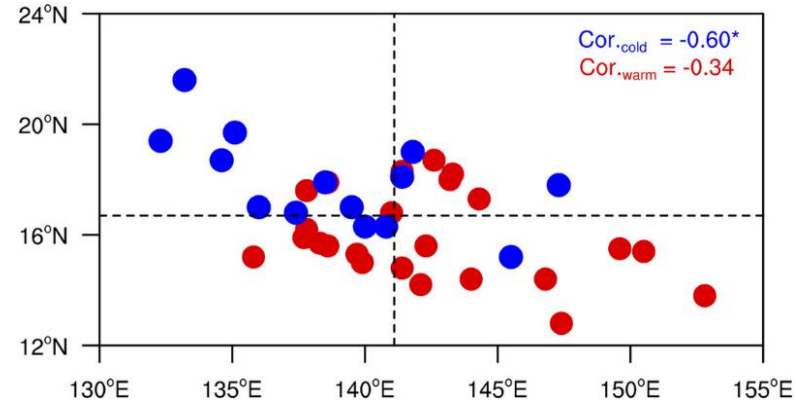
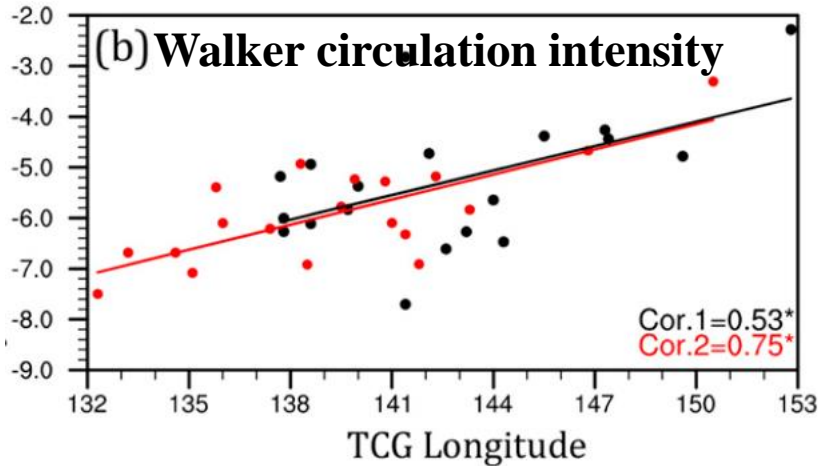
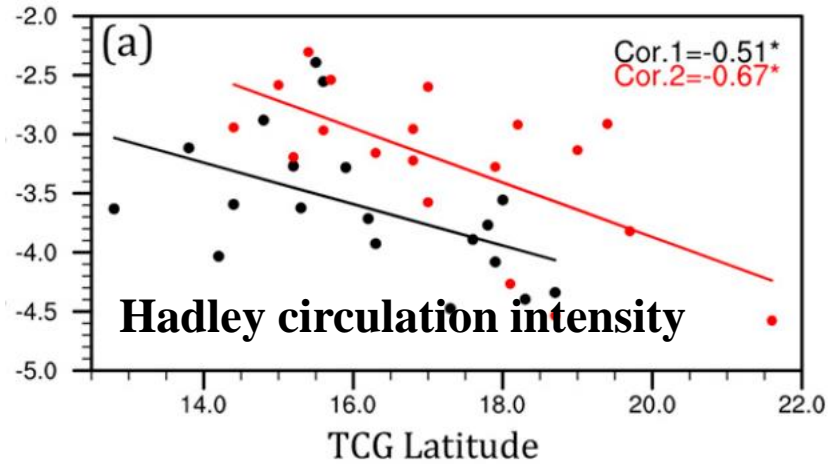
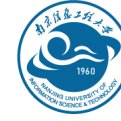
# Part 3-台风生成位置共变性增强

### 台风生成经度和纬度共变关系的年代际变化

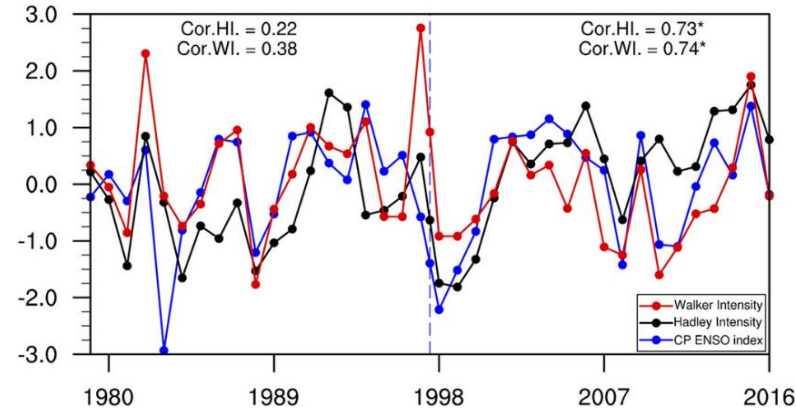


- 20世纪末以来台风生成经度和纬度均与中太平洋海温异常高度相关；
- 20世纪末以前台风生成纬度（经度）与东（中）太平洋海温异常高度相关。

# Part 3-台风生成位置共变性增强



PDO 冷位相  
PDO 暖位相

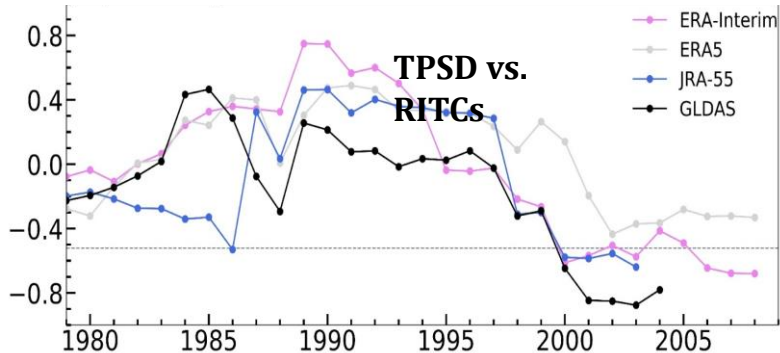
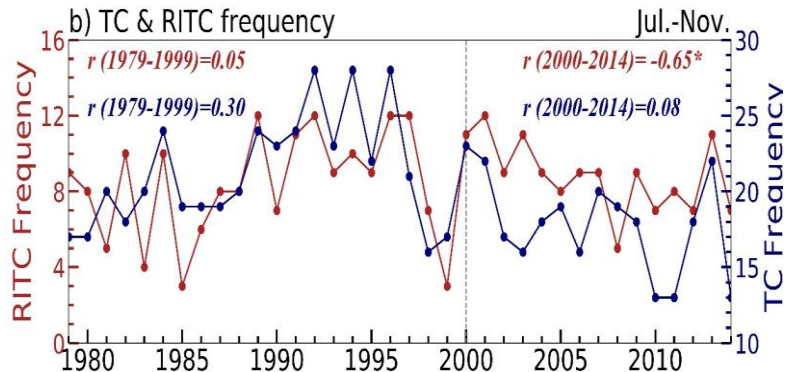
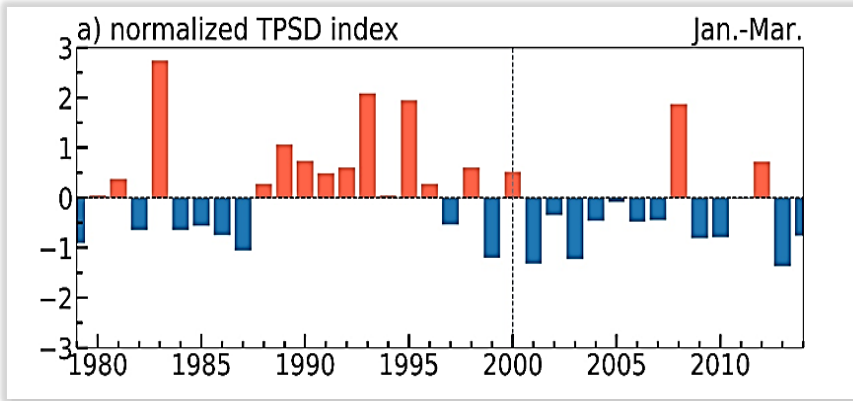
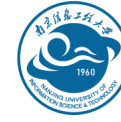


Walker 环流和Hadley 环流与 CP ENSO 共变关系的年代际变化

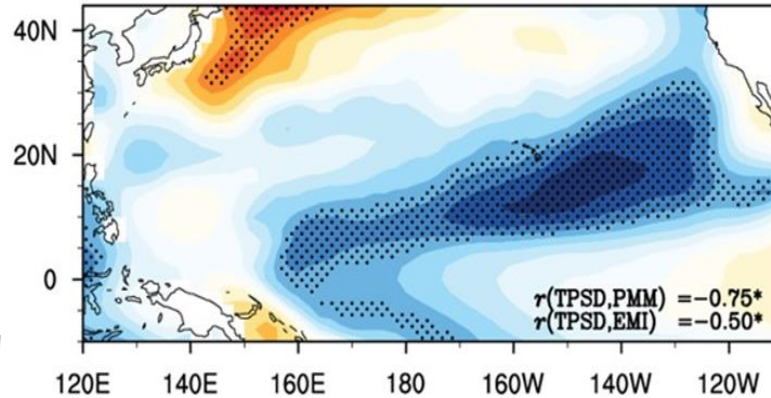
➤ PDO位相转变+ENSO状态变化显著调制沃克环流和哈德来环流的协同影响调制台风生成位置的共变性。



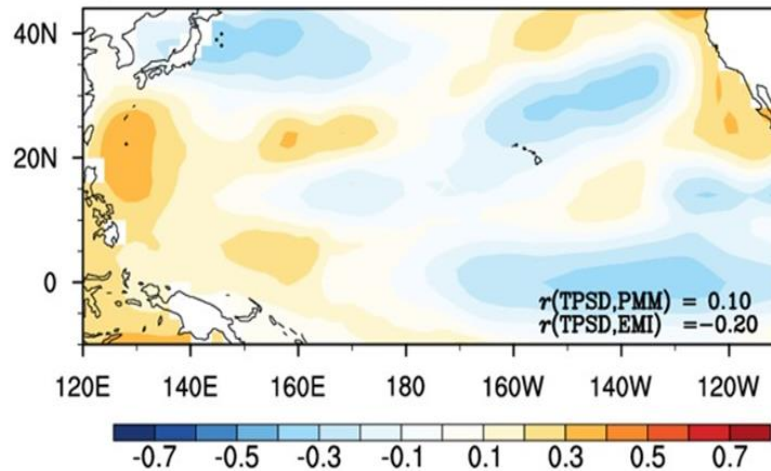
# Part 3-青藏高原积雪影响快速加强台风



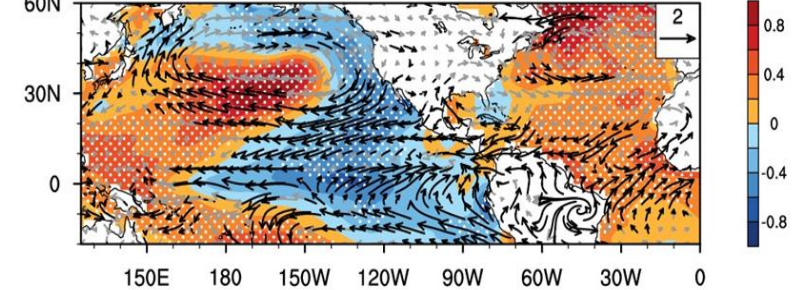
a) 2000-2014 TSPD vs. SST



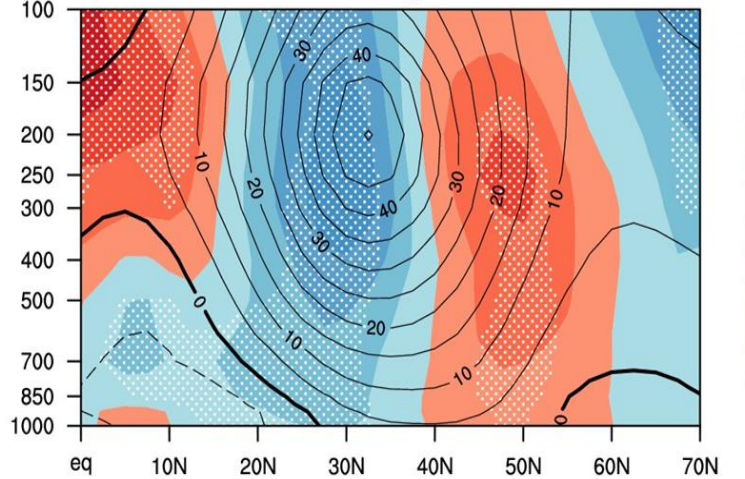
b) 1979-1999



a) Difference of SSTA&UV850

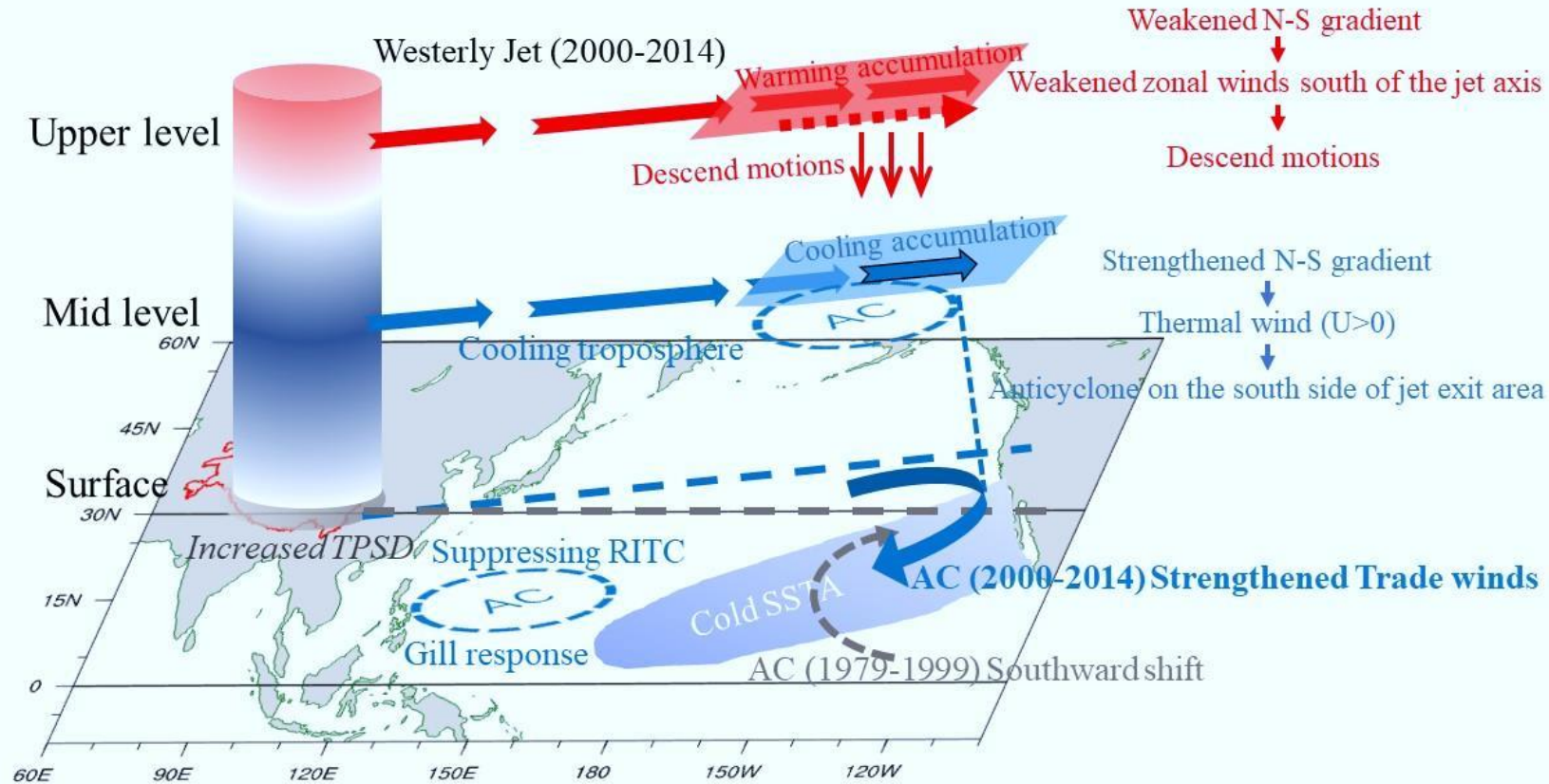
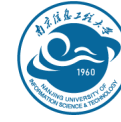


b) U: Difference and Climatology



➤ 提出了TP积雪通过影响中纬度急流触发太平洋经向模态影响RITC。

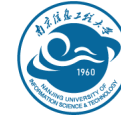
# Part 3-青藏高原积雪影响快速加强台风



青藏积雪影响快速加强台风的可能物理机制示意图

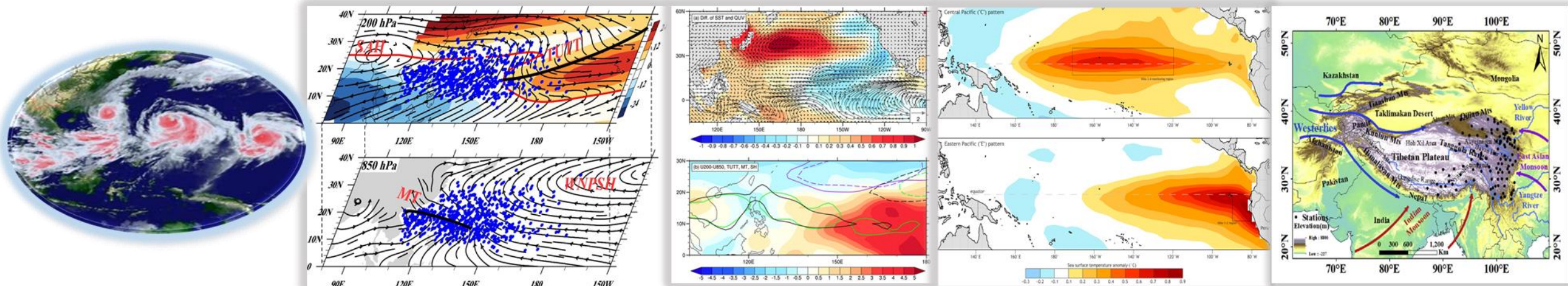


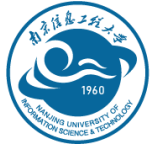
# Part 4-主要结论



- 海洋和陆面热力状态改变：PDO 位相由暖变冷、AMO位相由冷变暖、更多CP ENSO、TP积雪减少；
- 大尺度环流系统改变：季风减弱、副高西伸、TUTT西伸、高空急流北移；
- 大尺度环境因子改变：垂直切变增加、低层涡度减弱、中层水汽增大、OHC增加。

- 环境因子+大尺度环流系统：构建从大尺度环流系统变化的角度系统理解台风活动变化的框架；
- 多圈层影响：重视海-陆-气相互作用对台风活动及其遥相关的协同效应；
- 多时间尺度过程：从天气 ( TC seeds)至气候尺度加深对台风活动气候变化的物理认识。





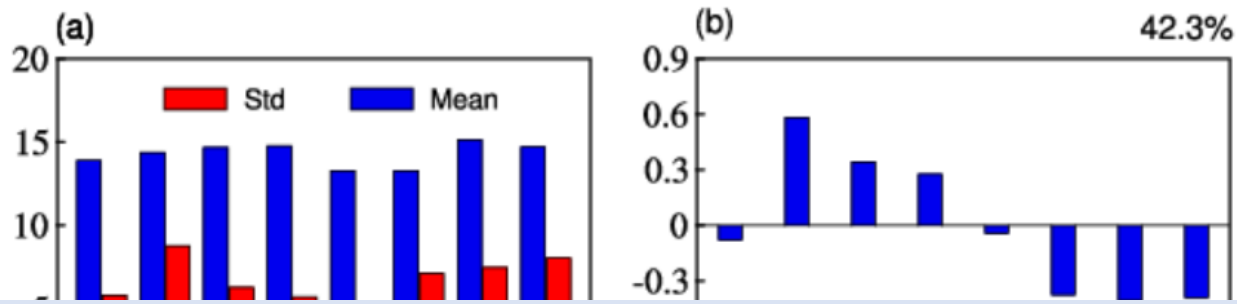
# 谢谢!

## 敬请批评指正!

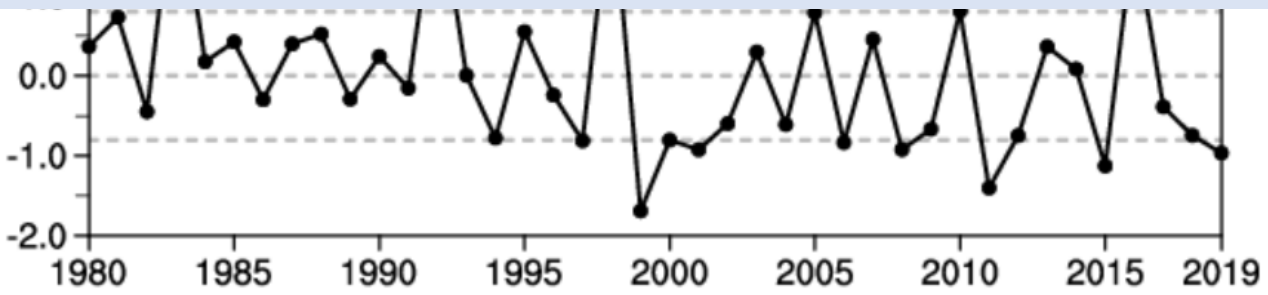
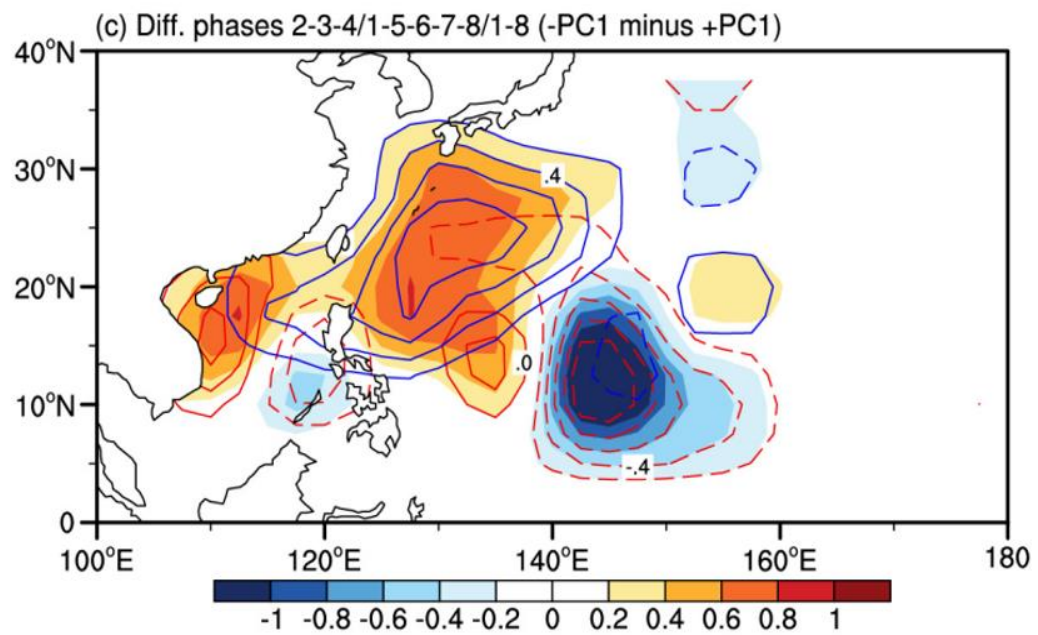
- Cai Y., Han, X., **Zhao, H.\***, et al., 2022: Enhanced Predictability of Rapidly Intensifying Tropical Cyclones over the Western North Pacific Associated with Snow Depth Changes over the Tibetan Plateau. *J Climate*, **35**, 2093–2110.
- Zhao K, **Zhao H.\***, et al., 2021: Changes in extended boreal summer tropical cyclogenesis associated with large-scale flow patterns over the western North Pacific in response to the global warming hiatus. *Clim. Dyn.*, **56(1)**, 515-535.
- **Zhao, H.\***, et al., 2020: Dominant Influence of ENSO-Like and Global Sea Surface Temperature Patterns on Changes in Prevailing Boreal Summer Tropical Cyclone Tracks over the Western North Pacific, *J Climate*, **33(22)**, 9551-9565.
- **Zhao H.\***, et al., 2019: Recent increased co-variability of tropical cyclogenesis latitude-longitude over the western North Pacific during the extended boreal summer. *J Climate*, **32 (23)**, 8167-8179.
- **Zhao H.\***, et al., 2019: Recent Strengthening of the Relationship between the Western North Pacific Monsoon and Western North Pacific Tropical Cyclone Activity during the Boreal Summer. *J Climate*, **32 (23)**, 8283-8299.
- **Zhao H.\***, et al., 2019: Recent decrease in genesis productivity of tropical cloud cluster over the western North Pacific, *Clim. Dyn.*, **52 (9)**, 5819-5831.
- **Zhao H. \***, et al., 2018: Changes in Characteristics of Rapidly Intensifying Western North Pacific Tropical Cyclones Related to Climate Regime Shifts, *J Climate*, **31 (19)**, 8163-8179.
- **Zhao H.** and C. Wang\*, 2018: On the relationship between ENSO and tropical cyclones in the western North Pacific during the boreal summer, *Clim. Dyn.*, **52 (1)**, 275-288.



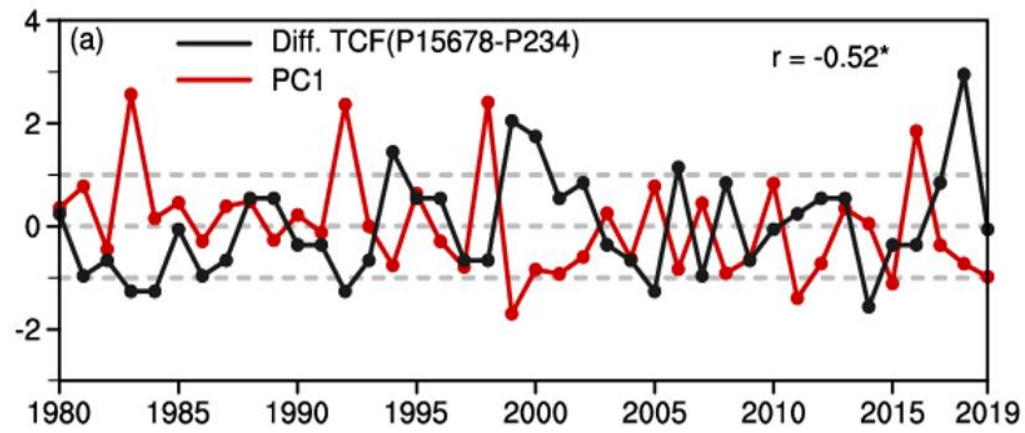
# BSISO位相天数变化对TC生成的影响



+PC1: 偏南Days ↑, 南部TCs ↑  
 -PC1: 偏北Days ↑, 北部TCs ↑

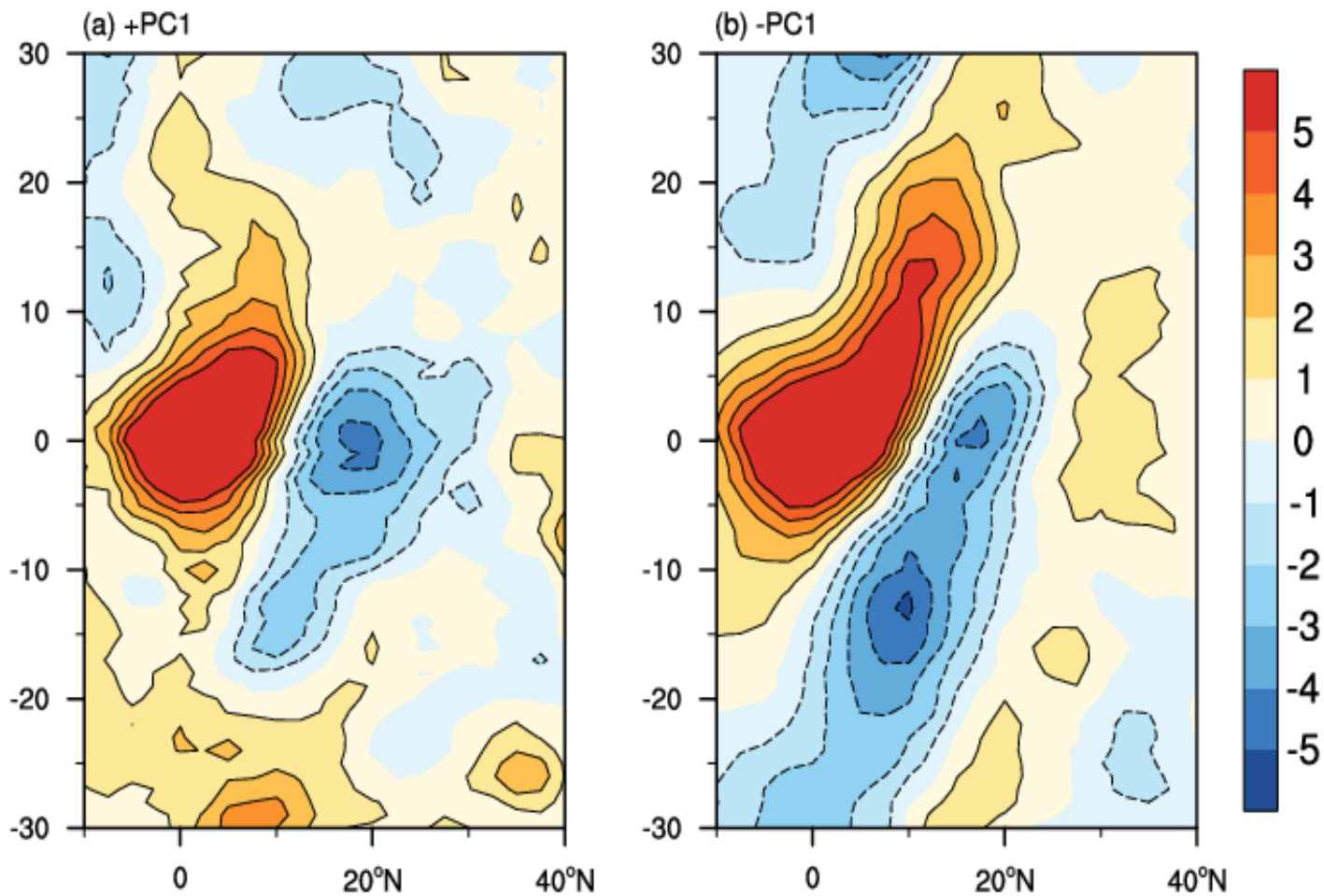


不同位相发生频数的EOF分解





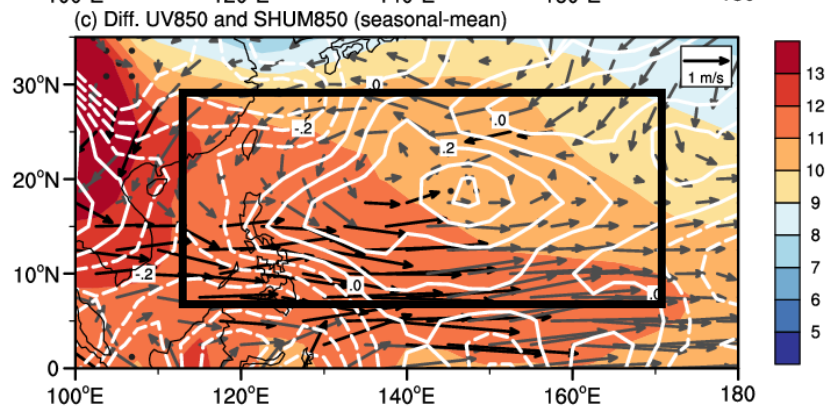
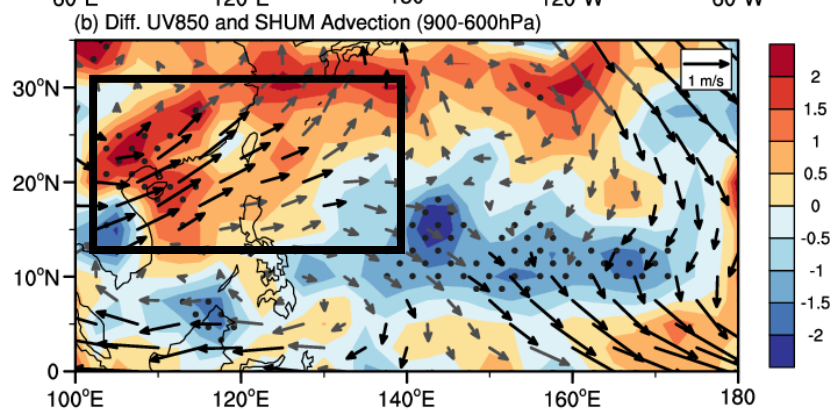
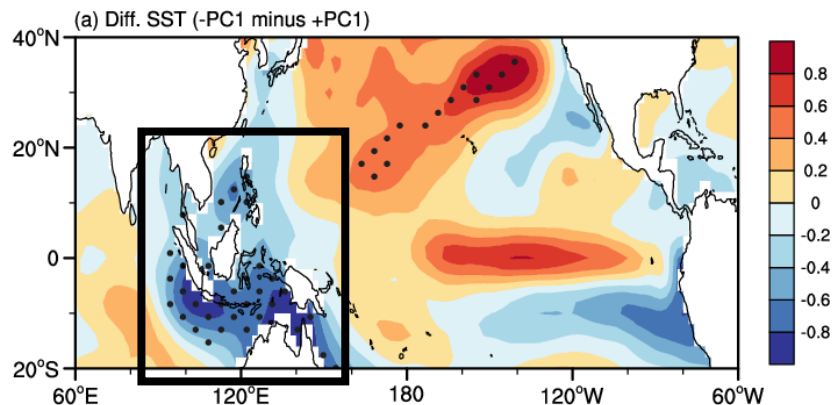
# BSISO影响TC生成的关键因素



BSISO位相频数年际变化  
与BSISO传播方向相关

超前滞后回归的90-150°E平均的OLR异常 ( $W m^{-2}$ ) 的时间-纬度剖面图



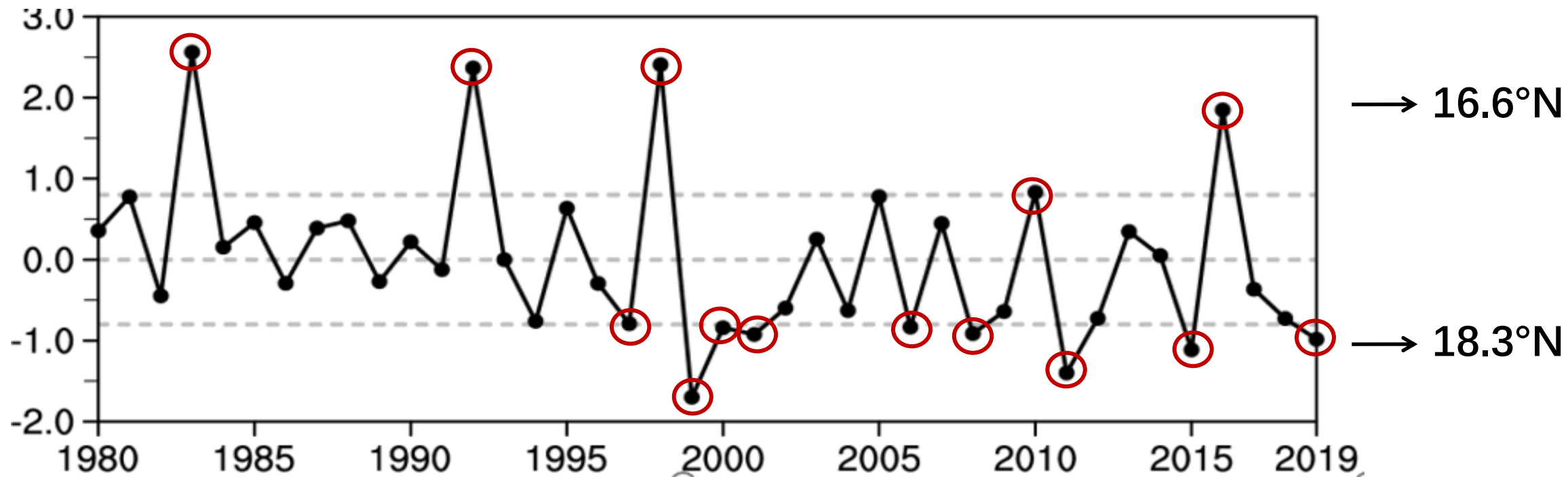


海温异常

正的水汽平流异常

季节平均湿度增加

## 对近期TC生成位置北移的贡献



0.8 个标准差

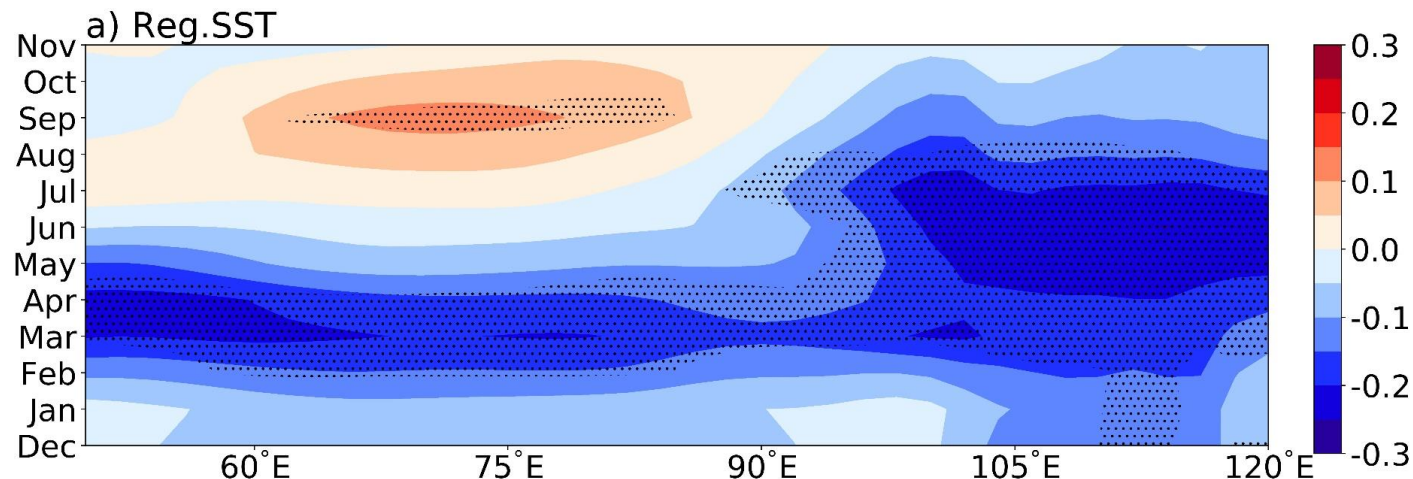
5个强+PC1年: 1983, 1992, 1998, 2010, 2016

9个强-PC1年: 1997, 1999, 2000, 2001, 2006, 2008, 2011, 2015, 2019



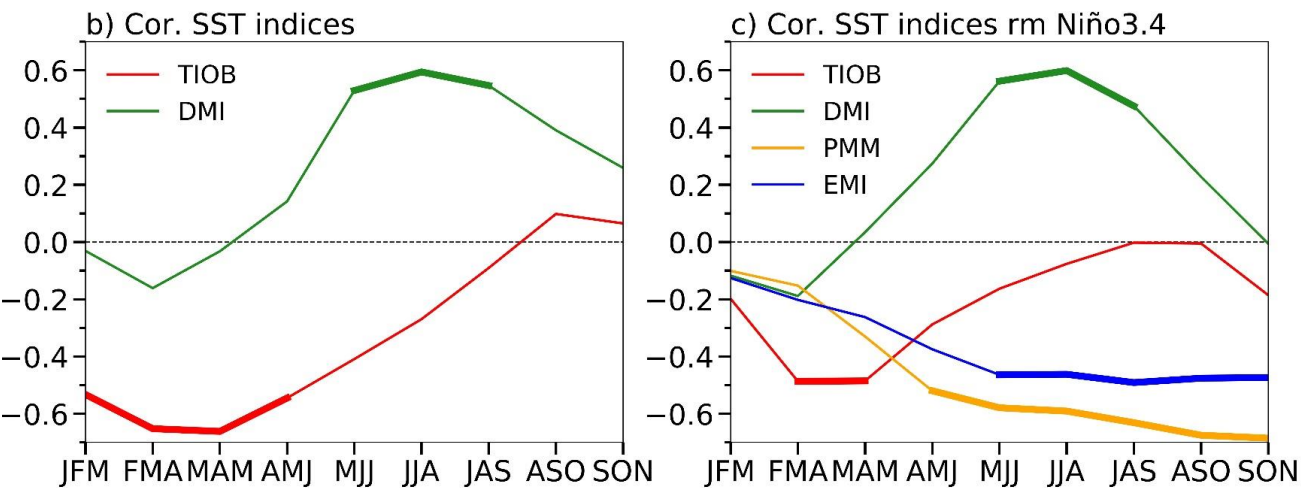
# 印度洋海温演变

TPSD回归的印度洋海温时间演变&各指数滞后相关



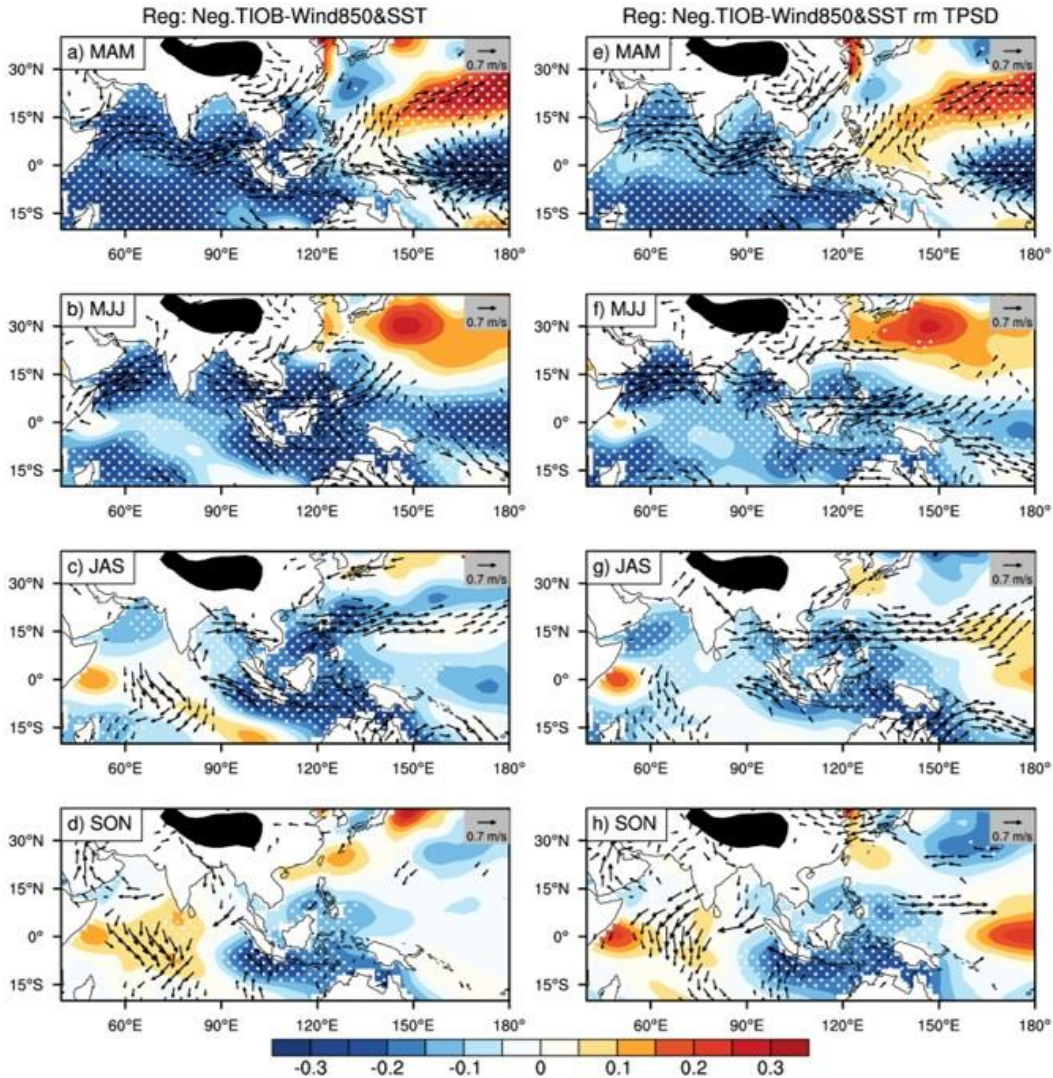
春季：印度洋海盆一致异常<sup>1</sup>  
 $r(TIOB, RITC) = 0.04$

夏秋：北印度洋偶极子<sup>2</sup>  
 $r(IOD, RITC) = -0.24$



**1 TIOB**: 热带印度洋区域 (40E-110E, 20S-20N) 的平均SSTA (Xie et al. 2009)

**2 IOD** : 热带西印度洋(50-70E, 10S-10N) 与东印度洋(90-110E, 10S-Equator)平均海温之差(DMI; Saji et al. 1999)



3-5月、6-8月TIOB指数、7-9月DMI与TC频数、RITC频数的偏相关系数；“\*”号表示相关性通过90%显著性检验；其中TPSD的线性关系被去除

	TIOB index		DMI
	MAM	JJA	JAS
TC	-0.48*	-0.64*	-0.05
RITC	-0.68*	-0.68*	0.18

- 在2000年以后，**春季冷海温**容易在台风季节发展成**印度洋偶极子模态**；
- 而剔除高原雪深的信号后，西印度洋海温不显著，仅东印度洋与海洋大陆的冷海温通过激发**开尔文波**影响WNP环流，影响**RITCs**活动

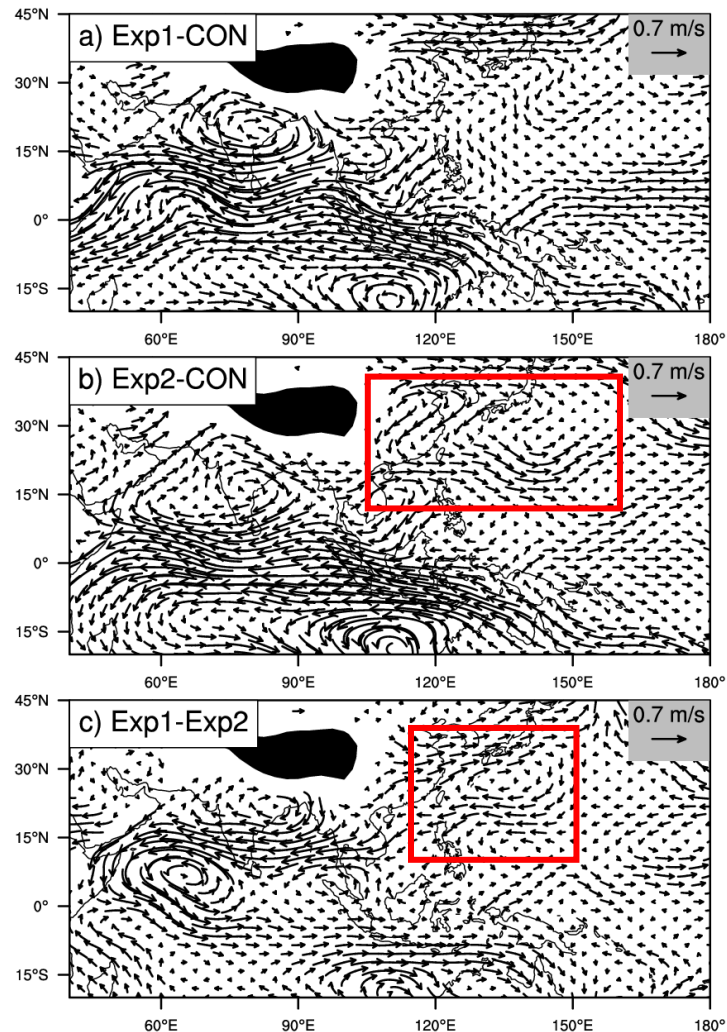
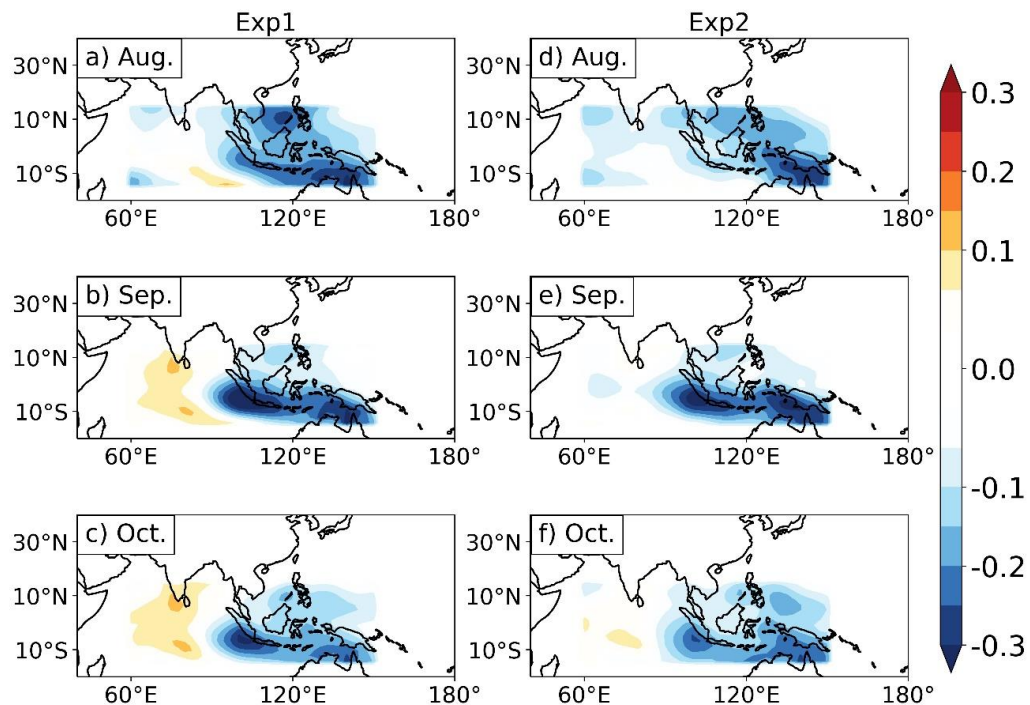


## CAM5试验

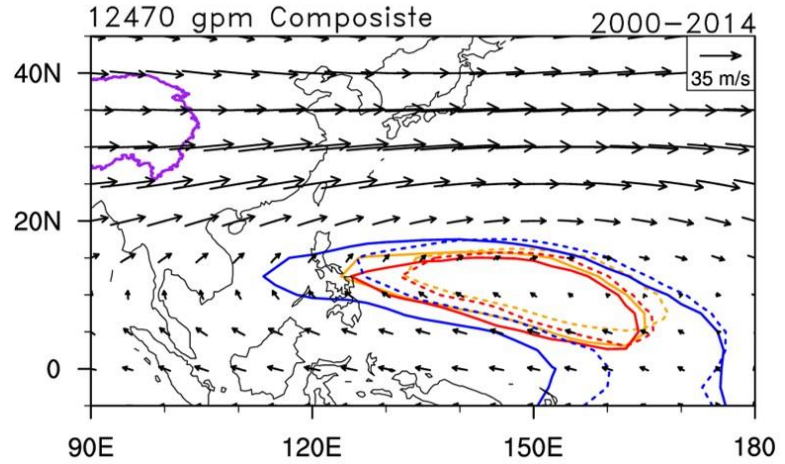
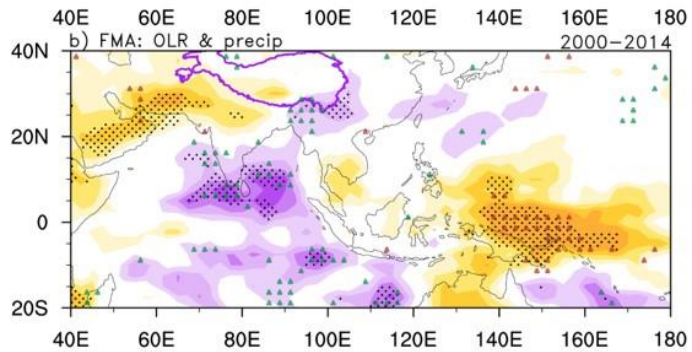
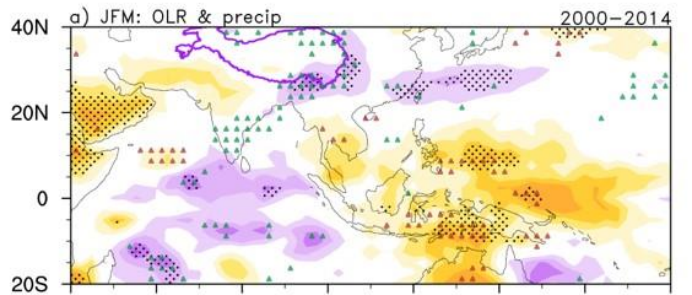
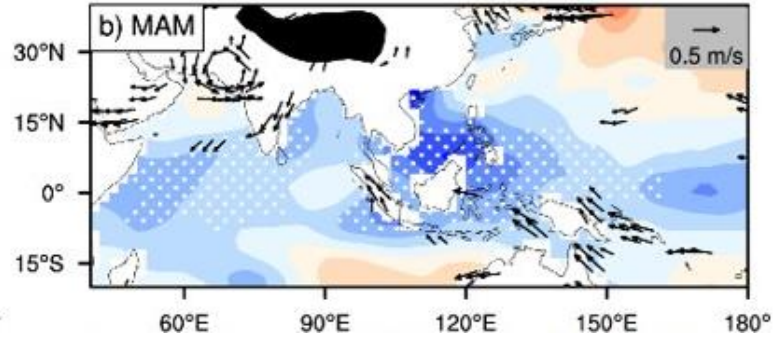
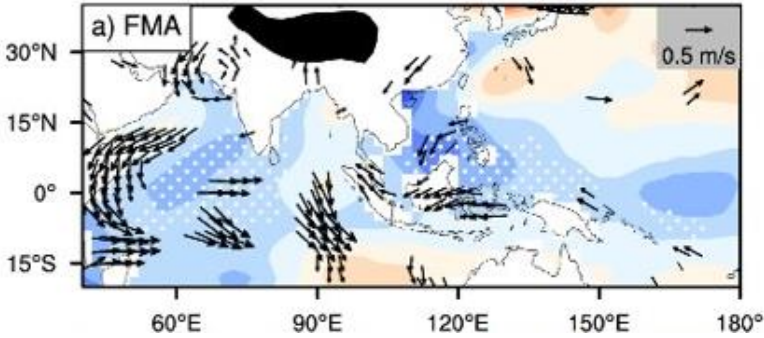
表 2.1 CESM 模式试验设计

试验名称	设计
CON	全球 SST 的气候平均
Exp1	全球 SST 的气候平均叠加由春季 TIOB 指数回归得到的印太地区海温异常
Exp2	全球 SST 的气候平均叠加由春季 TIOB 指数回归得到的印太地区海温异常 (其中 TPSD 信号被滤除)

其中印度-太平洋地区为-15°S-15°N, 60°-150°E, 季节为 8-10 月份

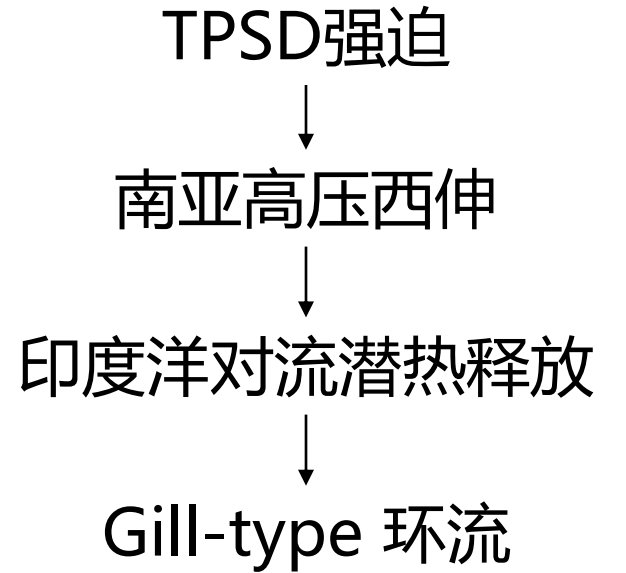


SSTA & Wind850



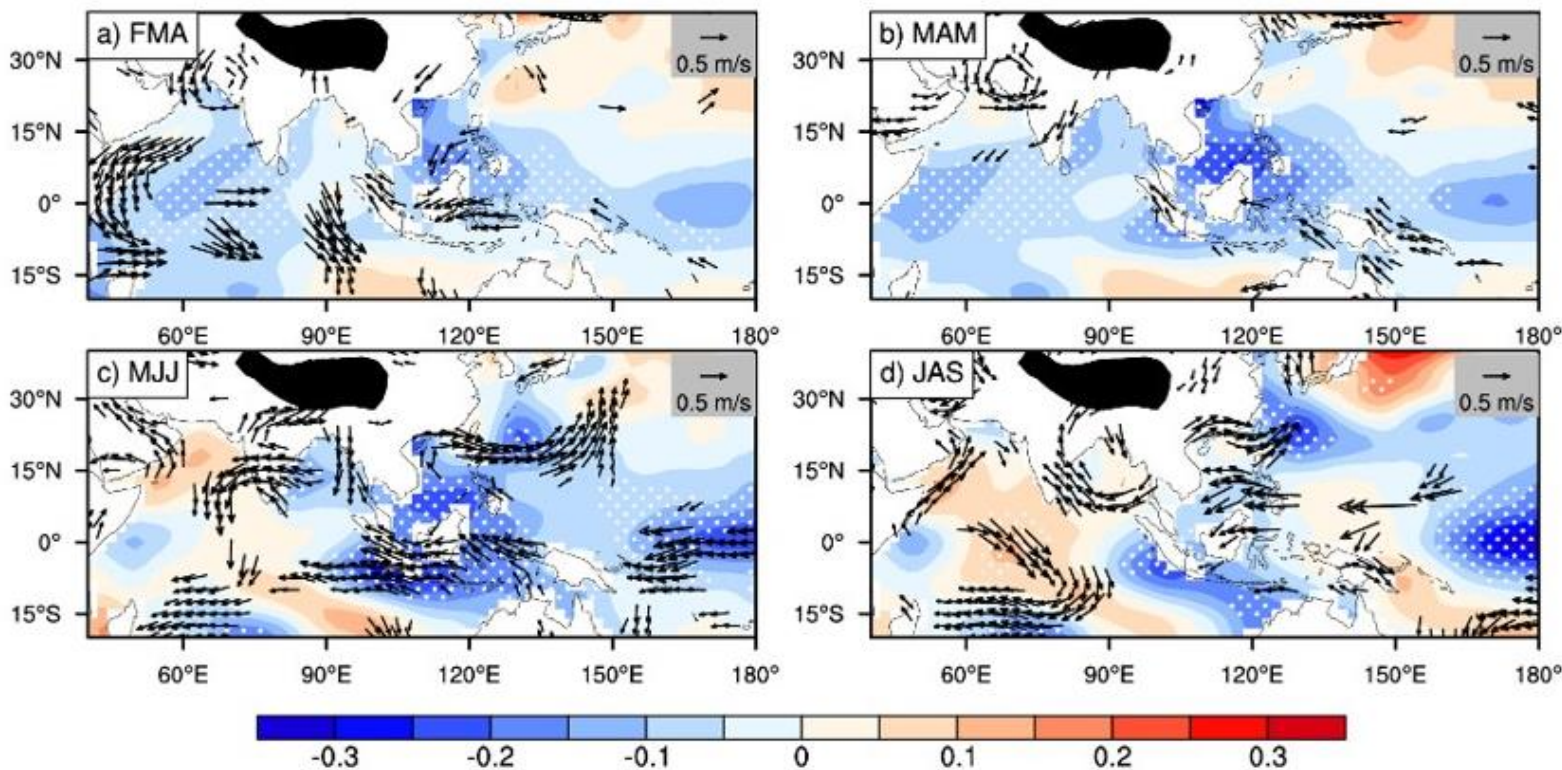
Blue: reduced TPSD years: 2001,2009,2013,2014 (< 0.6std)  
 Red: excessive TPSD years : 2005, 2008, 2012 (> 0.6std)  
 Yellow : climatological during 2000-2014

冬-春:





SSTA & Wind850



季风季节-台风季节

- 季风减弱→蒸发减少
- 纬向差异大→印尼离岸风
- 东风异常→海洋Rossby波

⇒ ⇒ **冷水东缩，西侧增暖**

- 在2000年以后，青藏高原积雪深度影响下，通过调制南亚高压的强度影响春季海盆尺度的海温异常，而在季风季节到台风季节，由于夏季风减弱，通过风-蒸发反馈机制形成印度洋偶极子模态

