北京大學
PEKING UNIVERSITY

中国龙卷远少于美国龙卷的环境背景分析

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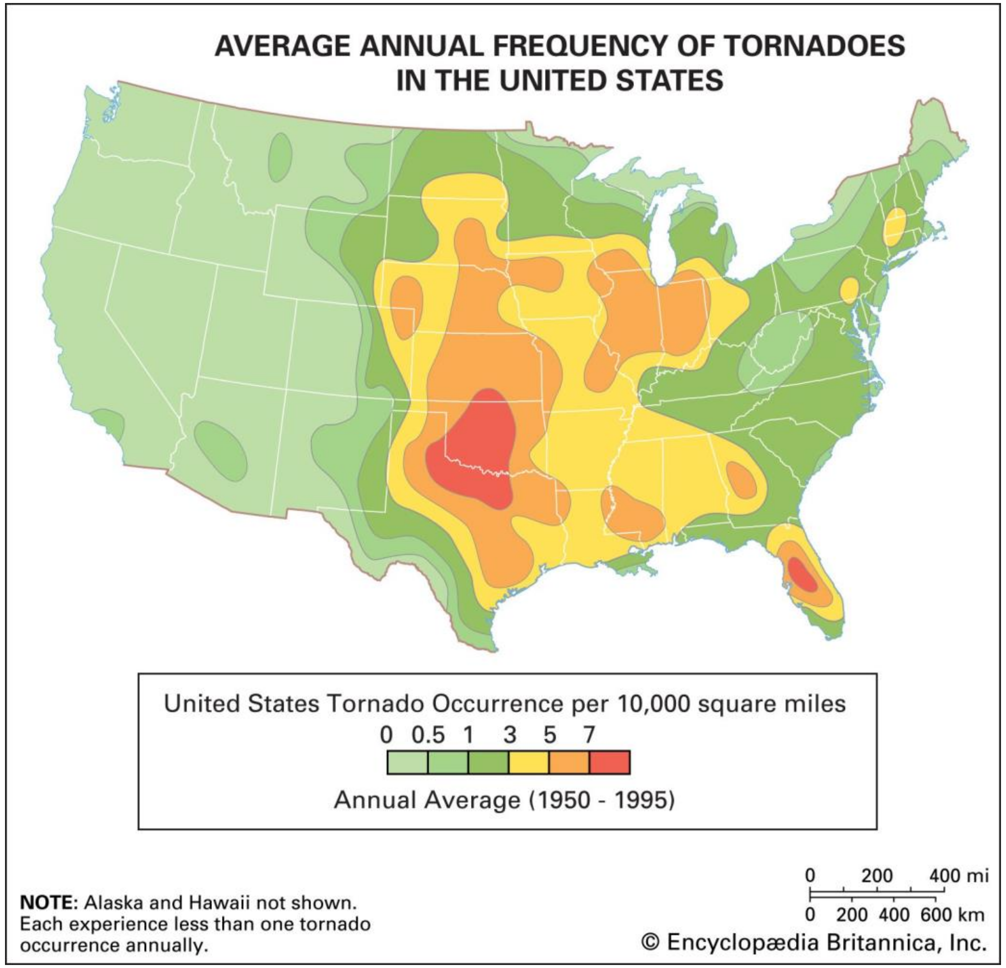
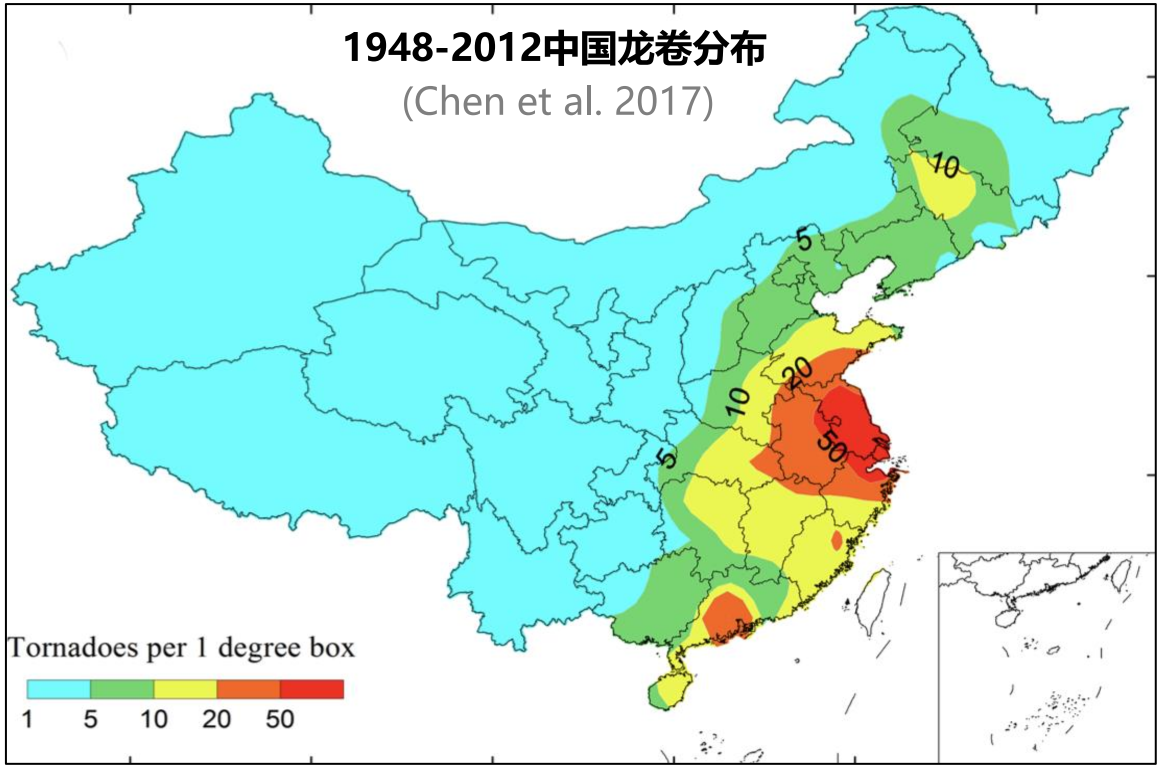
2021年12月10日 银川

中美龙卷活动差异

- **中国龙卷远少于美国:** 中国： 40~150个/年 美国：1200个/年





地形 环境背景分析

龙卷环境背景

➢ **有利于龙卷生成的环境条件** (Romero et al., 2007; Thompson et al., 2012; Anderson-Frey et al., 2018)

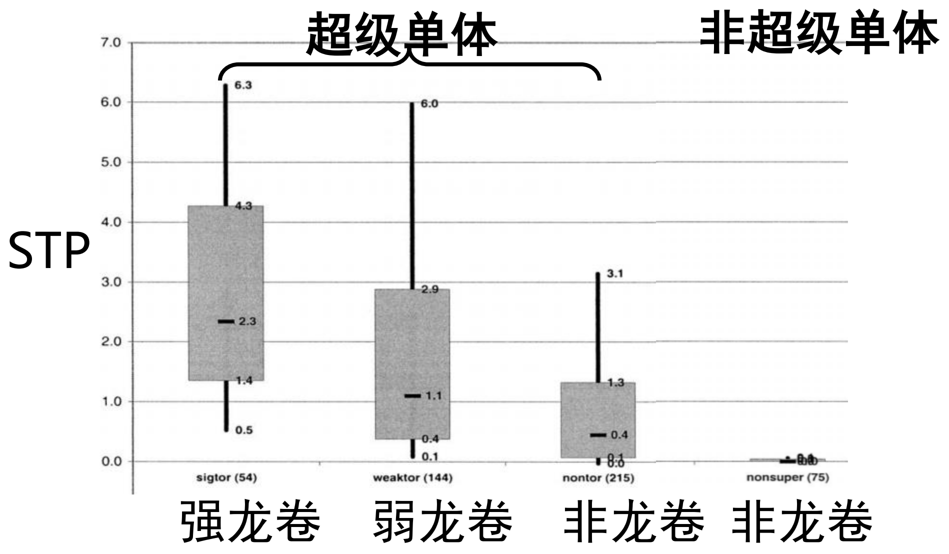
热力环境参量
- 充沛的低层水汽条件：较低的混合层抬升凝结高度（MLLCL）
- 足够的不稳定能量：较高的混合层对流有效位能（MLCAPE）

动力环境参量
- 强垂直风切变：较高的0–6 km垂直风切变（SHR6）
- 强低层顺流涡度：较高的0–1 km风暴相对螺旋度（SRH1）

➢ **最常用的综合参数**

强龙卷参数（Significant Tornado Parameter）

$$\mathrm{STP}=\left(\frac{MLCAPE}{1000\ J\ kg^{-1}}\right)\times\left(\frac{2000\ m-MLLCL}{1500\ m}\right)\times\left(\frac{SRH1}{100\ m^{2}\ s^{-2}}\right)\times\left(\frac{SHR6}{20\ m\ s^{-1}}\right)$$



中国龙卷数据库

➢ 数据来源

- 北京大学**陈家宜研究组的中国龙卷统计数据集**（1948–2012；Chen et al., 2018）
- **《中国气象灾害年鉴》**（2007–2016）
- 已发表的文献，气象业务部门的灾情报告， 网络媒体

➢ 质量控制

删除重复的记录
拆解合并的记录
时间地点数字化

- 不同数据来源**逐条交叉对比** → 1121条龙卷记录 （2007–2016）

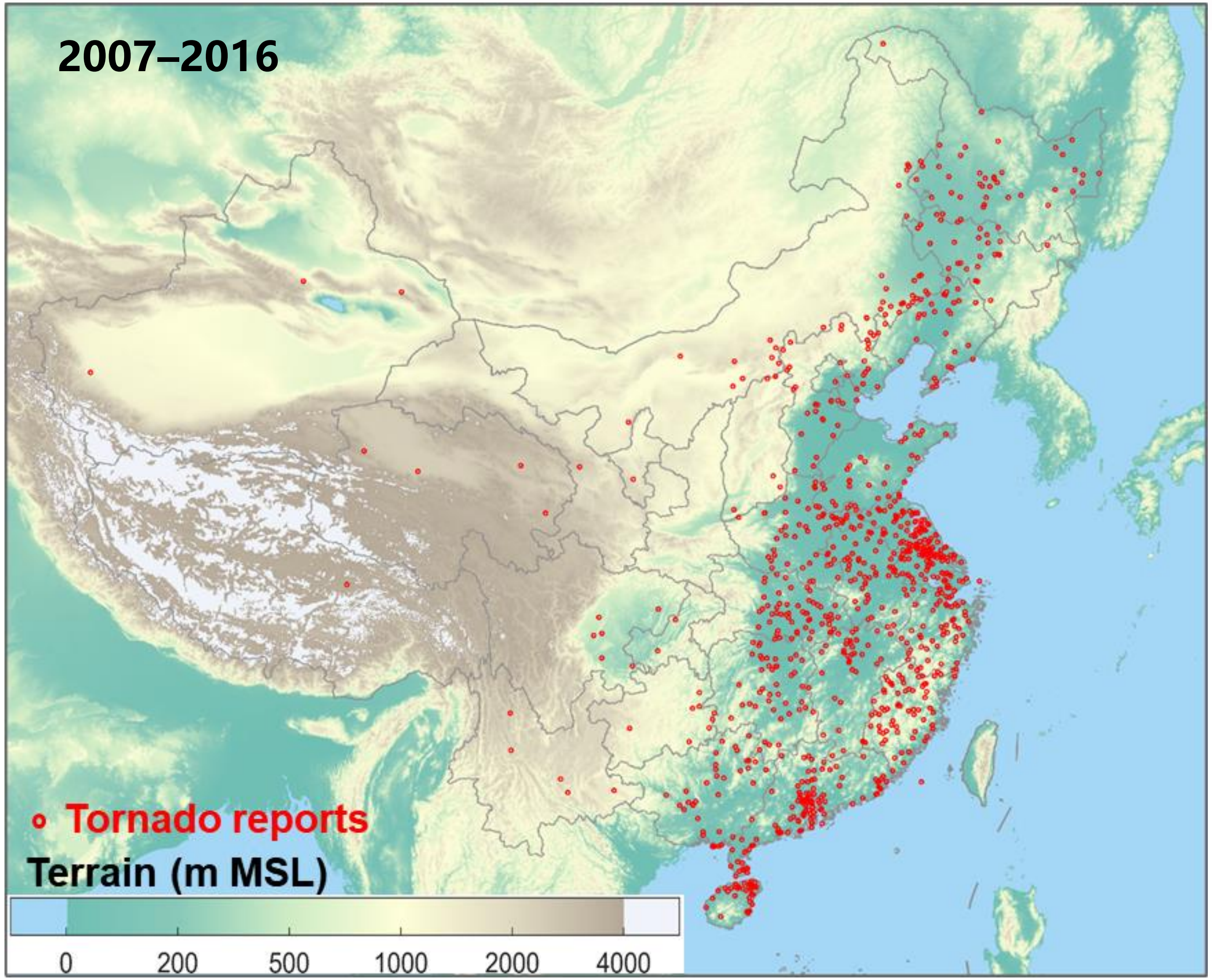
212条无连续雷达数据
909条中138条（~15%）被去除

- 基于雷达资料进行**质量控制** → 983条龙卷记录（2007–2016）

删除无强对流记录
明确时间及地点信息

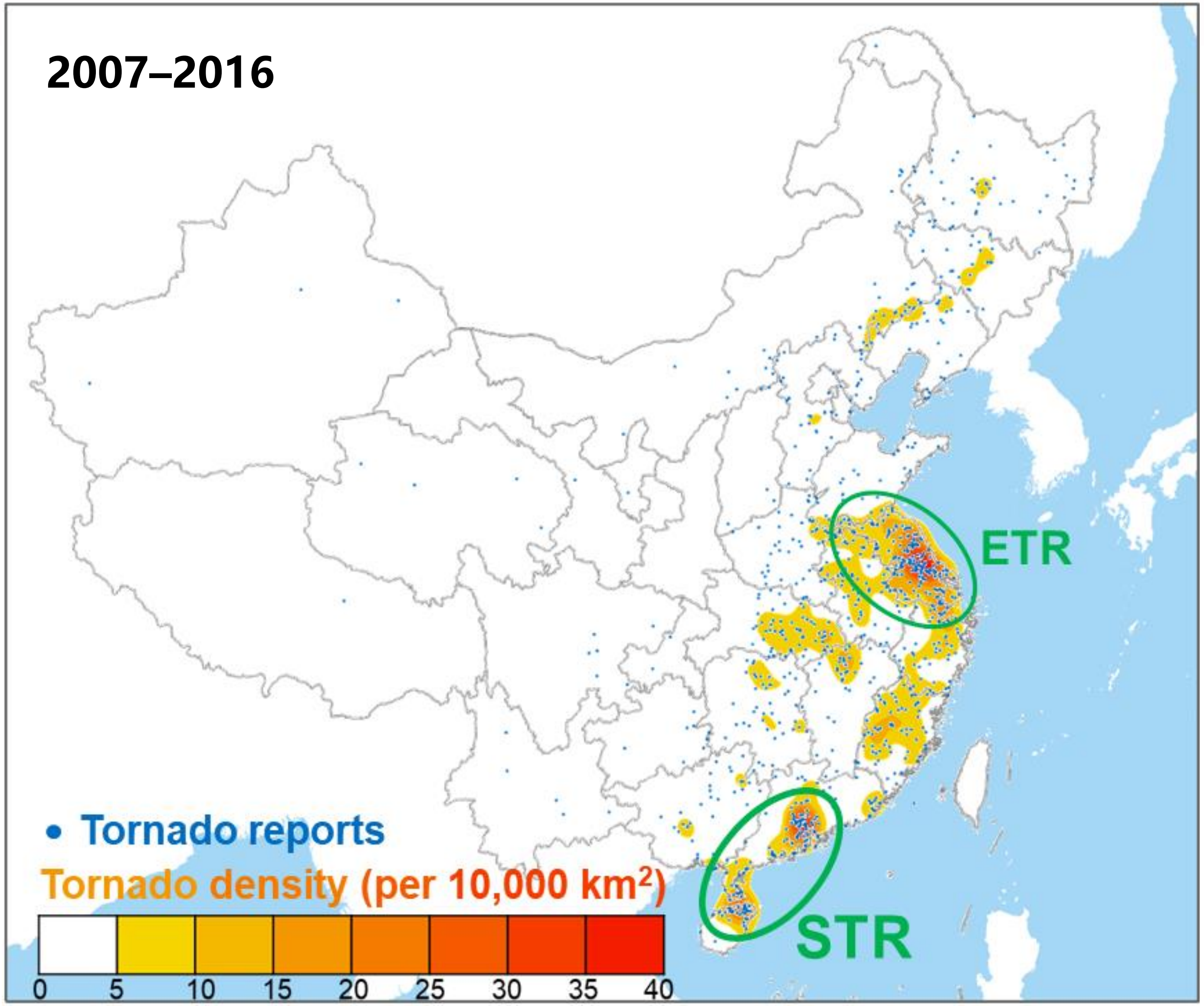
Ruilin Zhou; Zhiyong Meng, 2023, "Tornado Database in China (2017~2020)", https://doi.org/10.18170/DVN/M7PTV9, Peking University Open Research Data Platform, V1, UNF:6:5vqpAispdhQaDuewbT91zA== [fileUNF]

中国龙卷空间分布



- **大多分布在地形较平坦的地区**（华北平原和长江中下游、珠江三角洲附近、海南北部地形平缓地区、东北平原）
- **复杂的地形可能是我国龙卷数偏少的原因之一**

中国龙卷空间分布



- **华东龙卷高发区**

  (**E**astern **T**ornado prone **R**egion)

  江苏及其附近区域：龙卷风密度最高

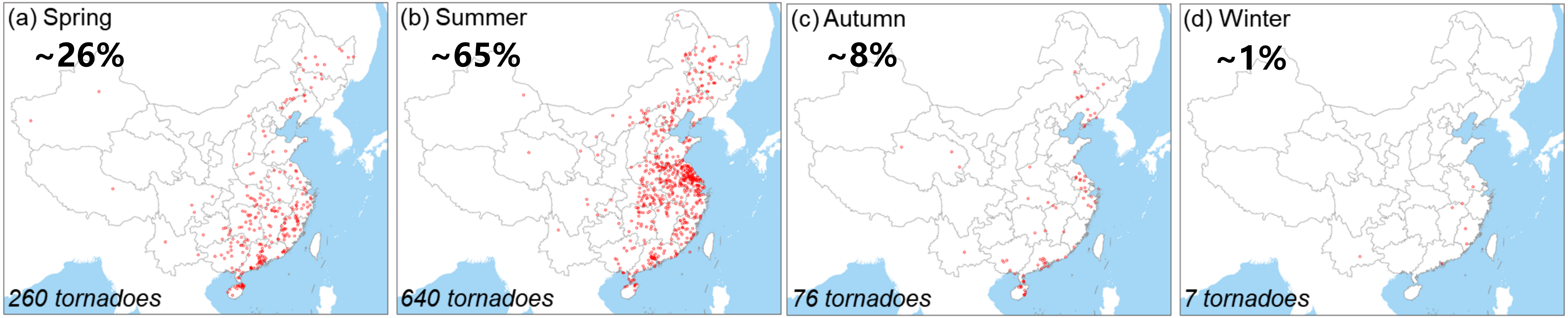
- **华南龙卷高发区**

  (**S**outhern **T**ornado Prone **R**egion)

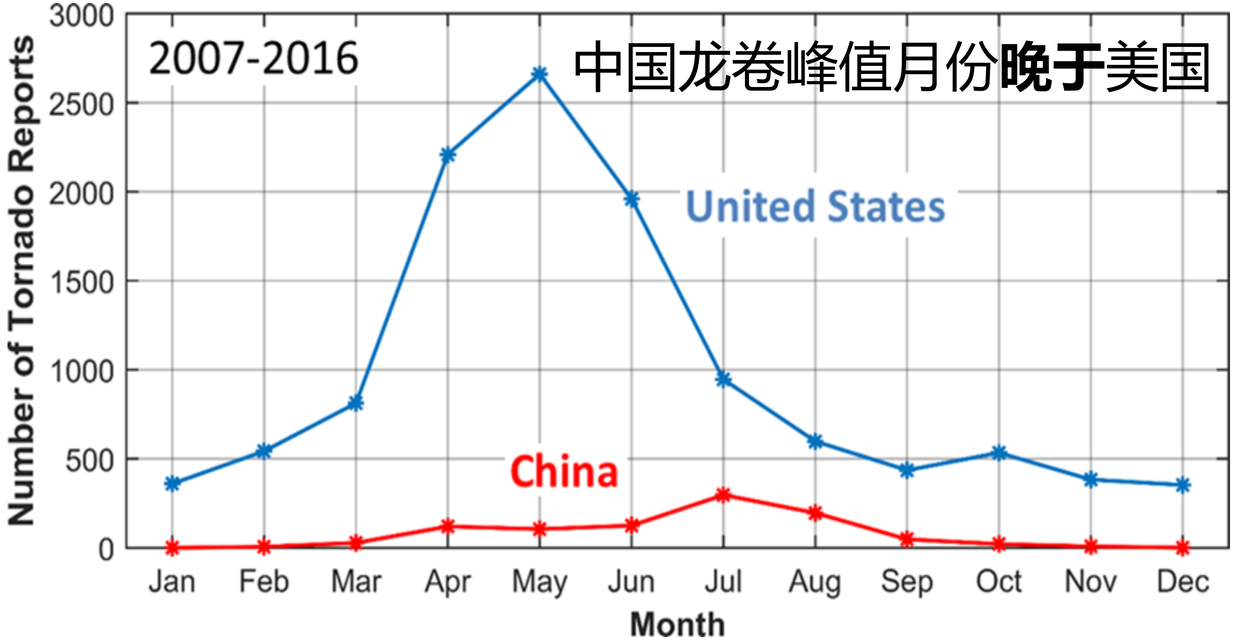
  珠三角及其附近地区、海南北部：

  龙卷风密度较高、高发区域不连续

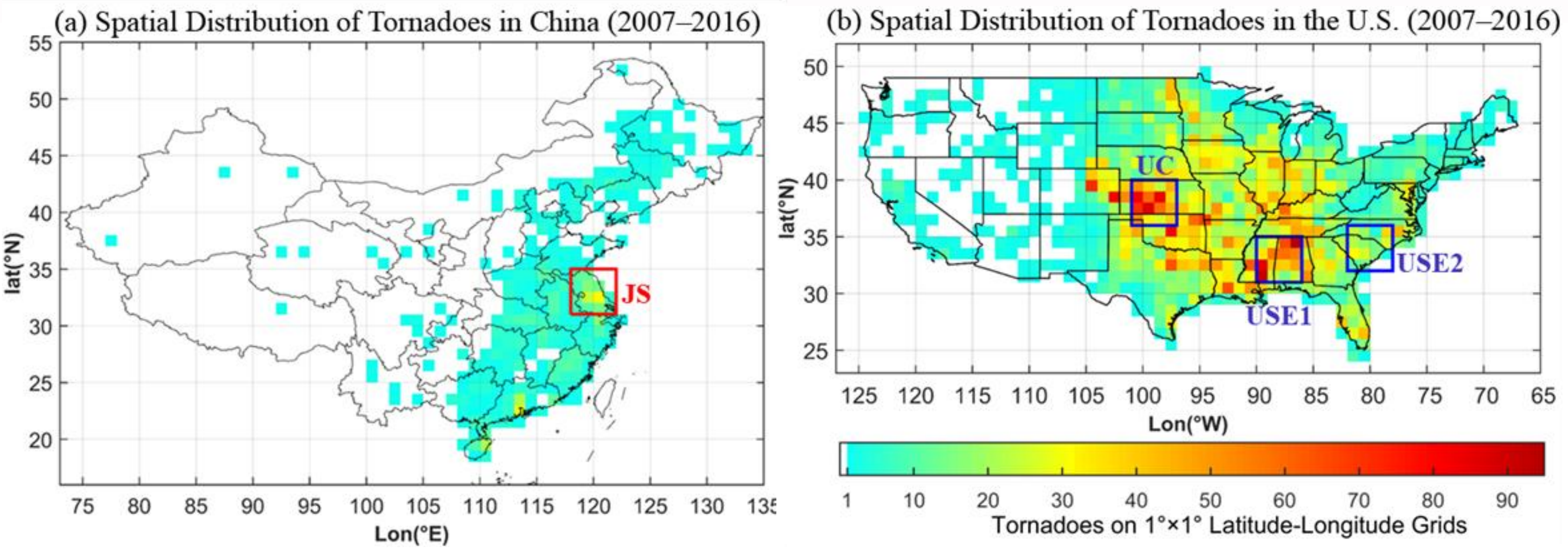
中国龙卷季节分布



- **华东高发区**：夏>春/秋>冬
- **华南高发区**：春>夏>秋>冬



中美代表区域



JS：**华东高发区**核心区域，主要位于**江苏**

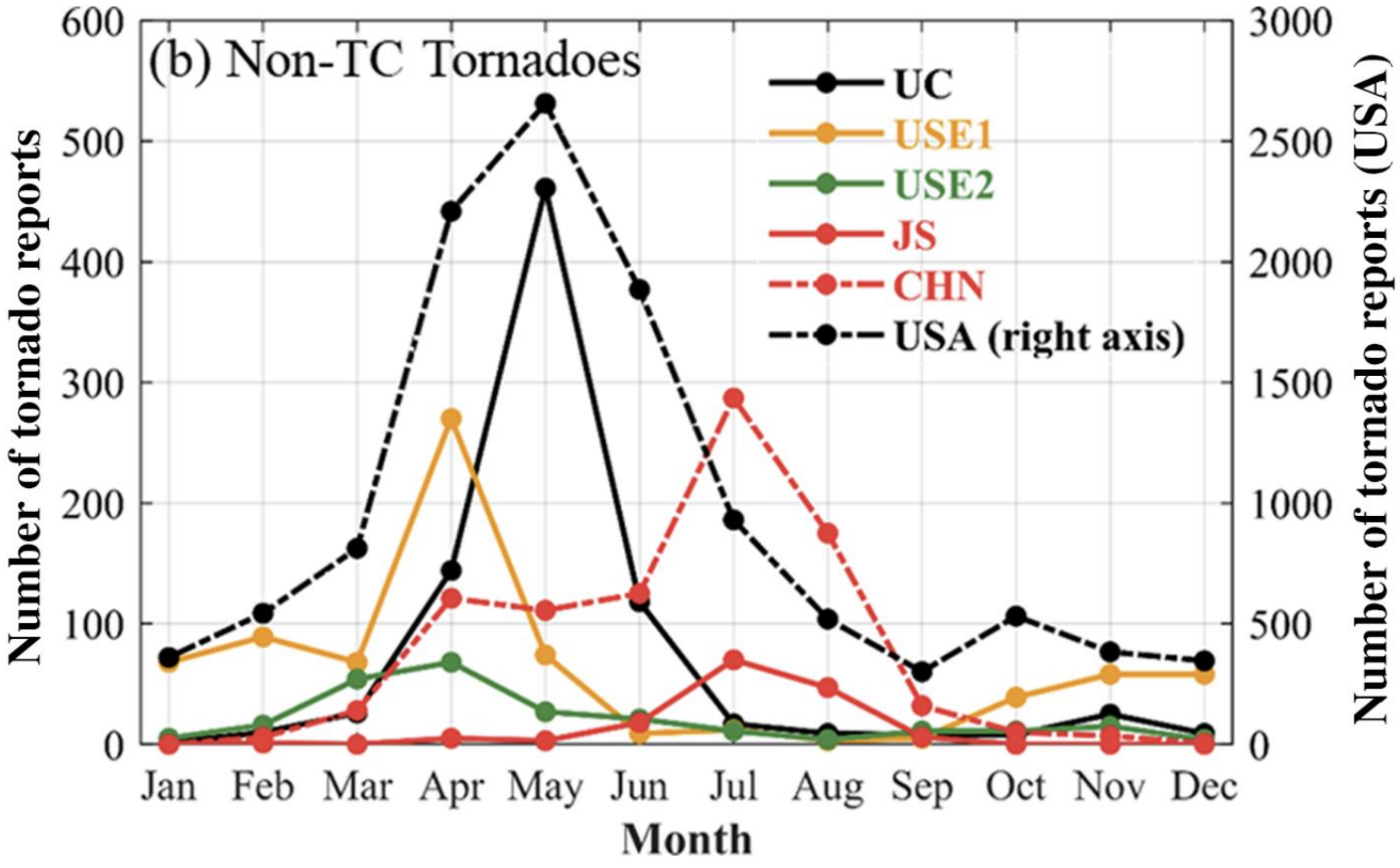
UC：美国**最高发**区，美国**中部**

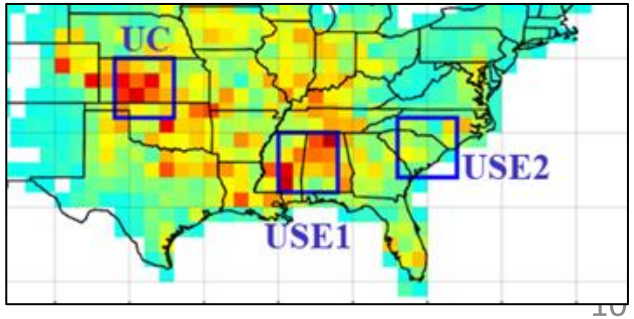
USE1：美国**次高发**区，美国**东南部**

USE2：**与JS类似**，美国**东南部**

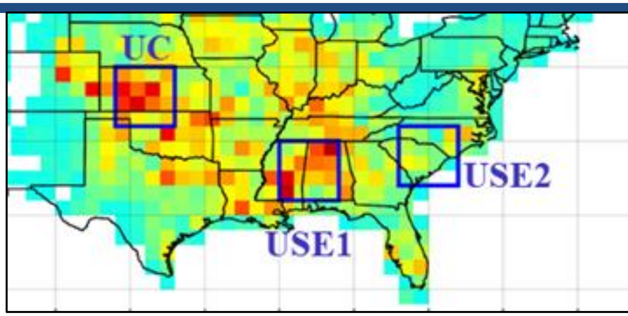
非TC龙卷活动差异

华东龙卷数少、龙卷季偏晚





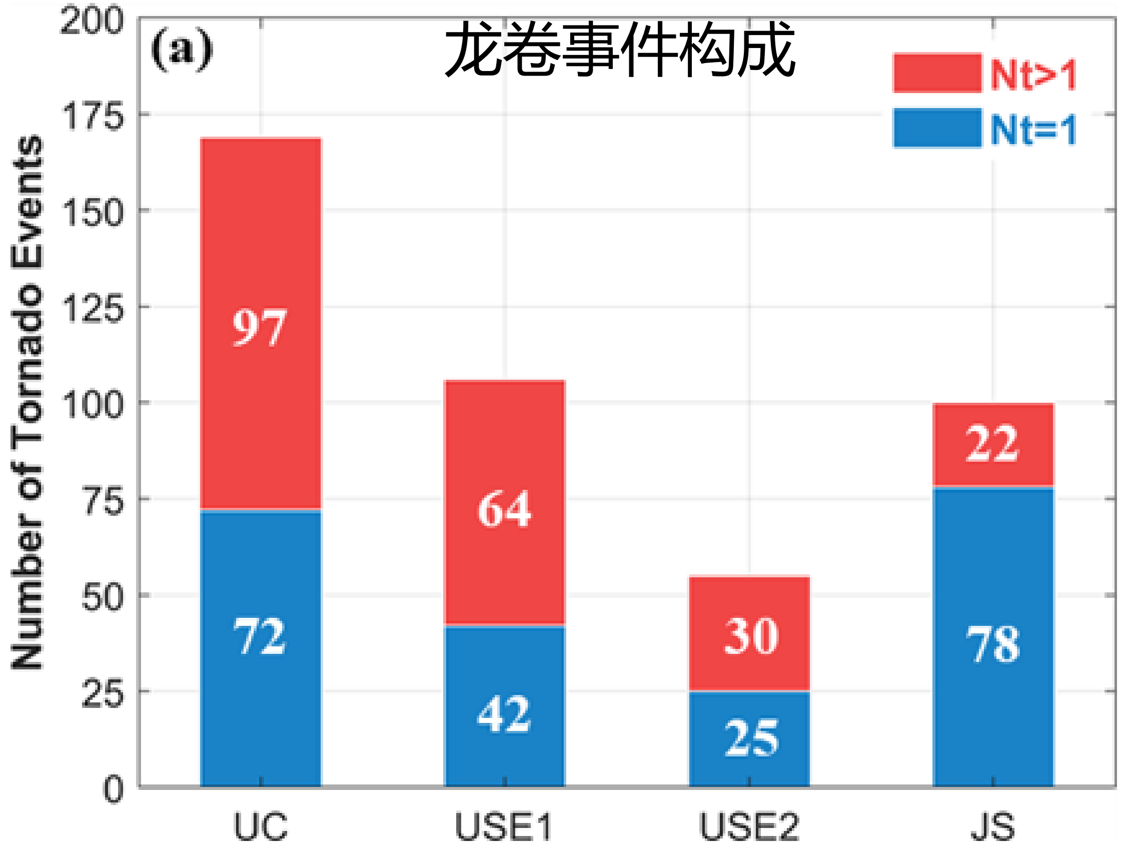
华东龙卷少的原因：华东多龙卷事件显著偏少

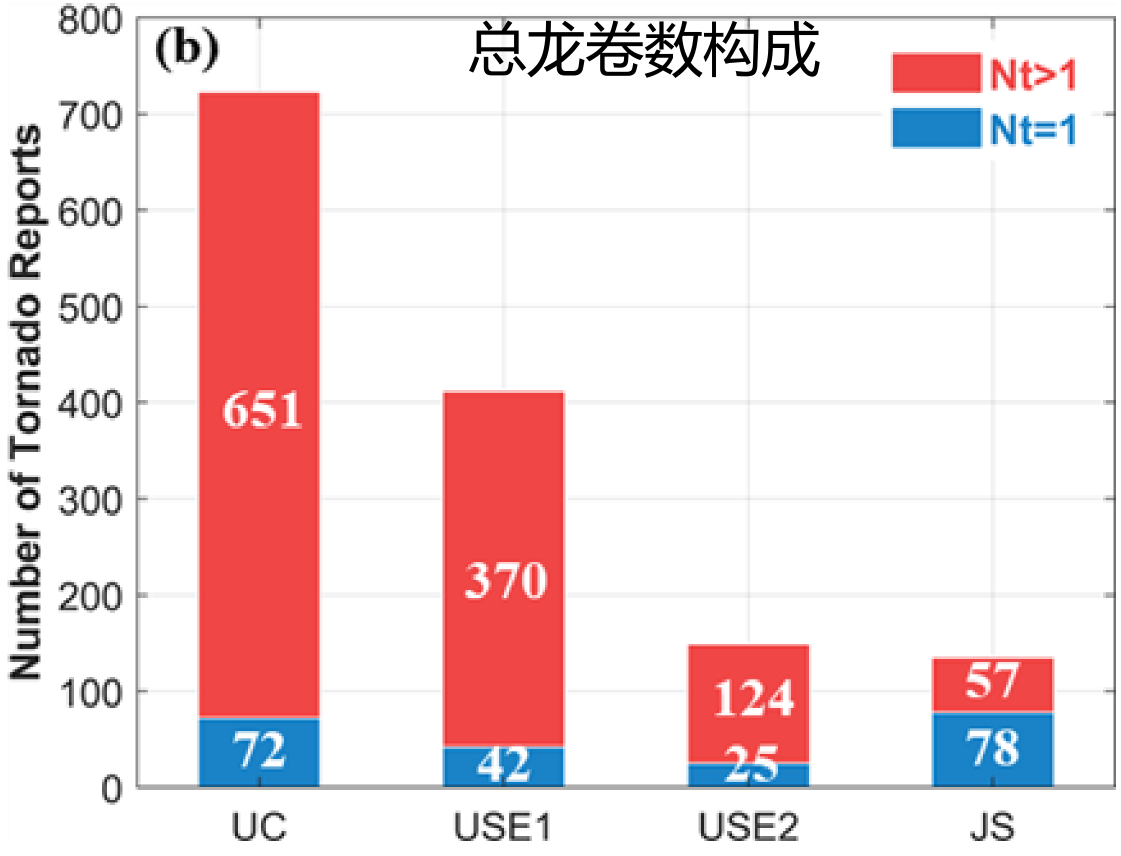


龙卷事件：**约6小时和1°×1°**范围内发生的龙卷

Nt: 1个龙卷事件中的龙卷数。

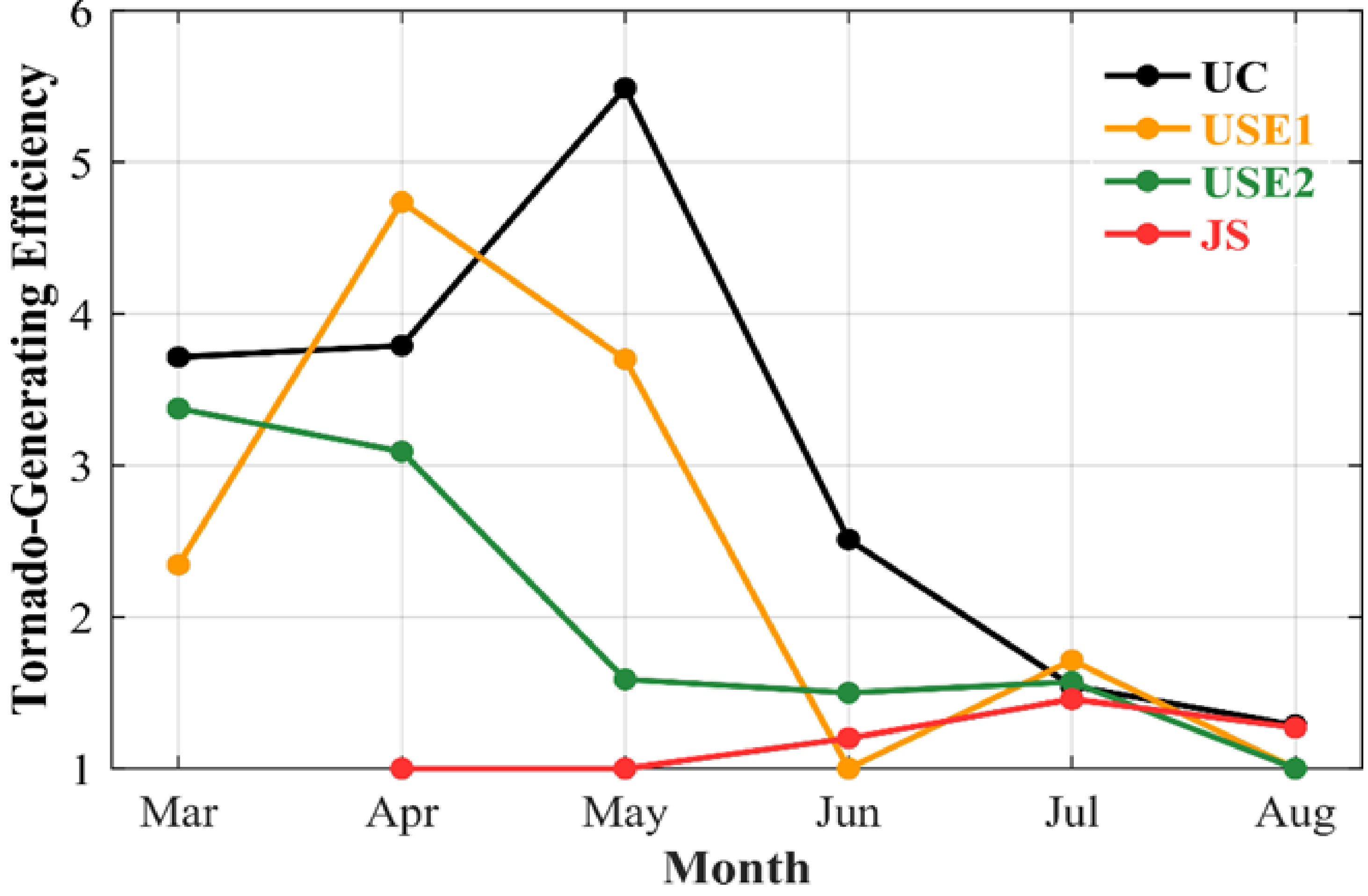
Nt>1: 多龙卷事件　**Nt=1: 单龙卷事件**





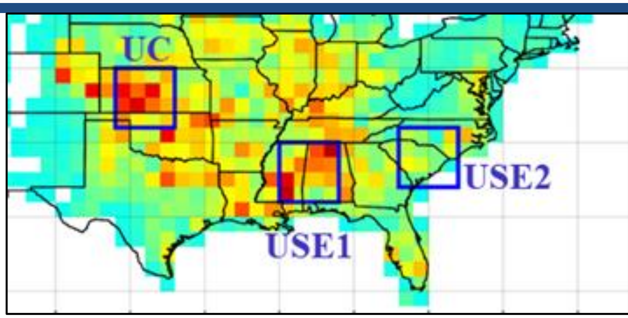
华东龙卷数少的原因：华东龙卷季的龙卷生成效率偏低

龙卷生成效率：平均一次龙卷事件产生龙卷的数目

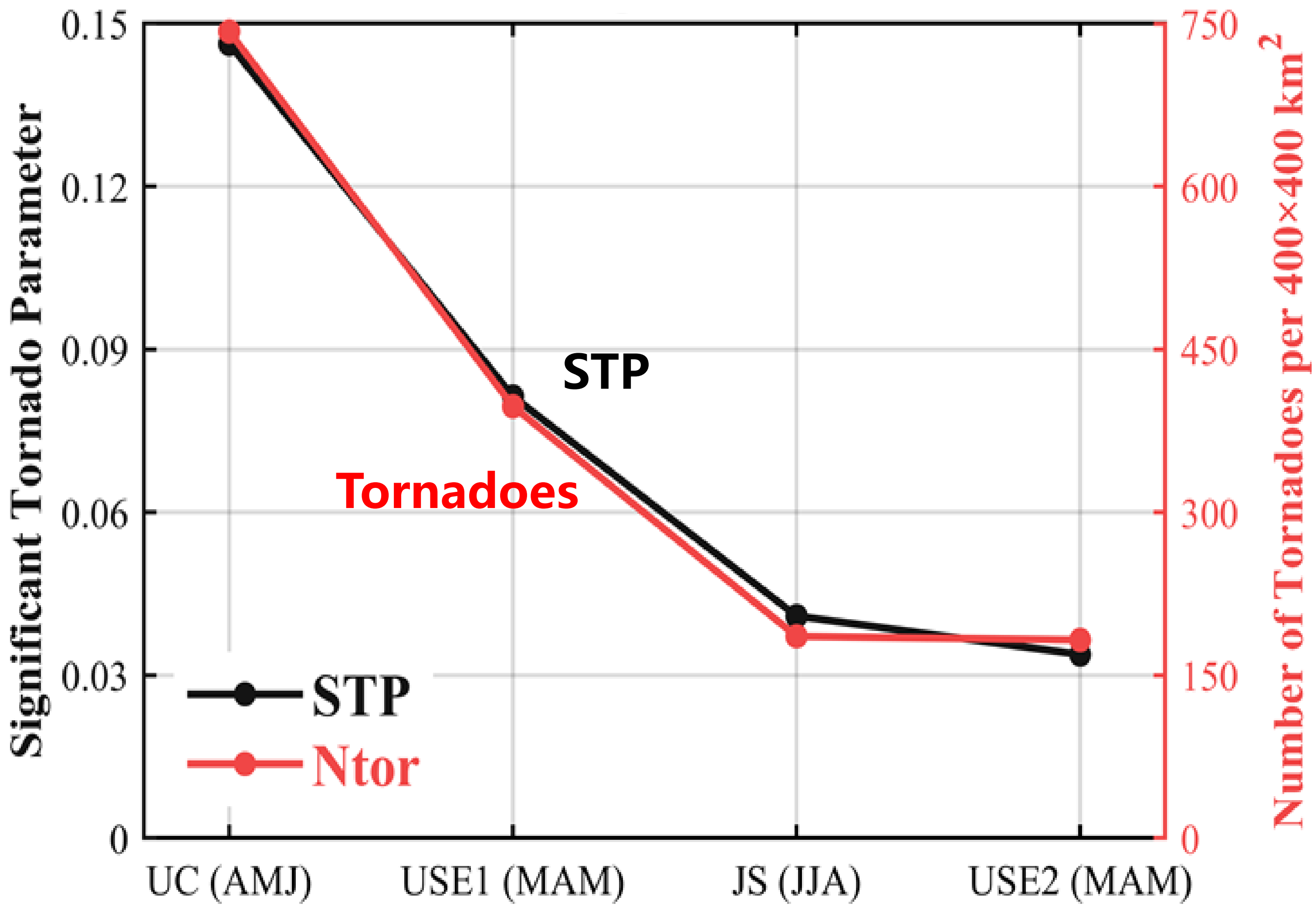


- 春季：美国代表区域>JS
- 夏季：美国代表区域≈JS

华东龙卷数少的原因：STP显著偏低



龙卷季的STP的区域平均值

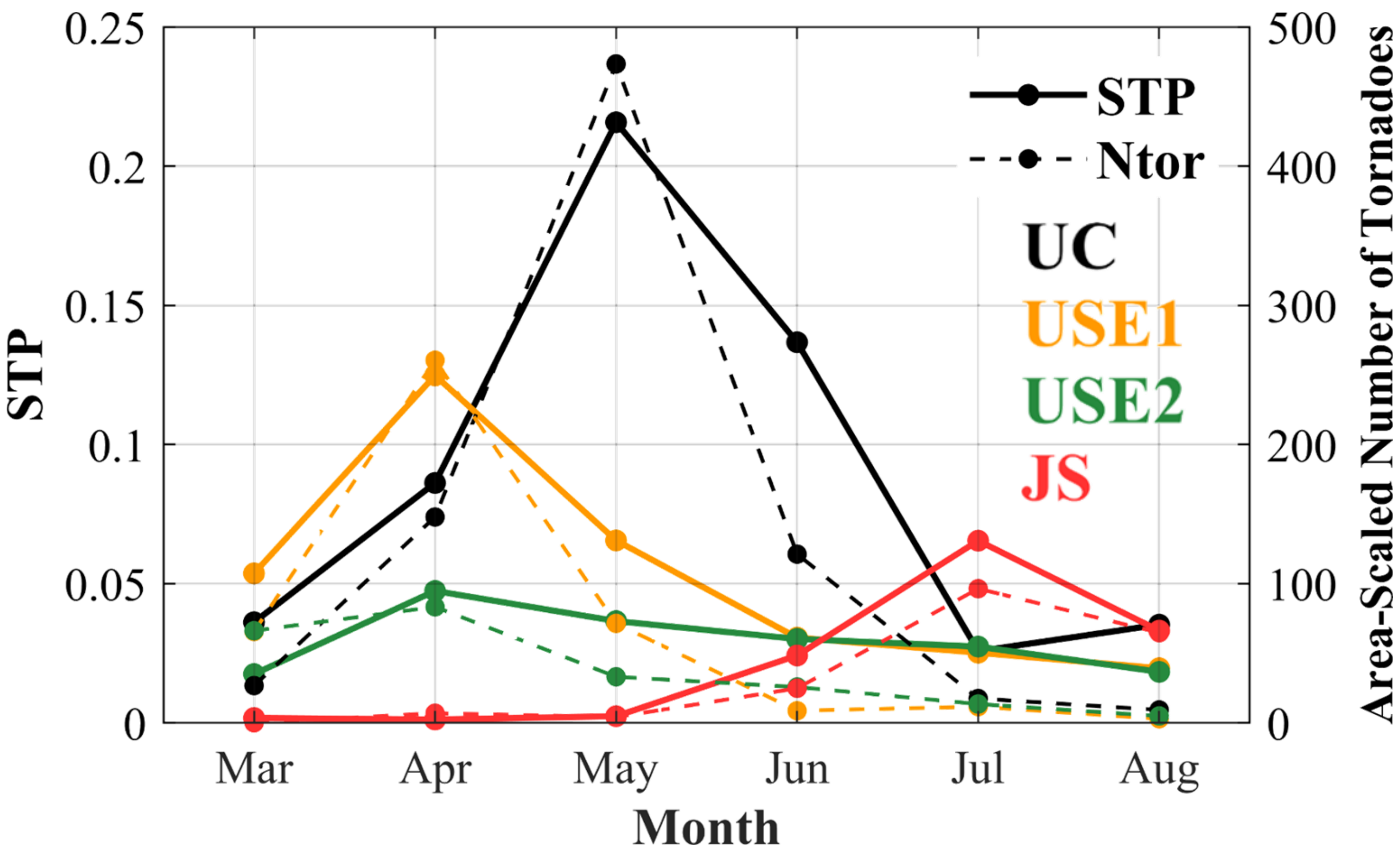


STP与总龙卷数呈单调关系

JS的STP显著偏低

Calculated with NCEP FNL data

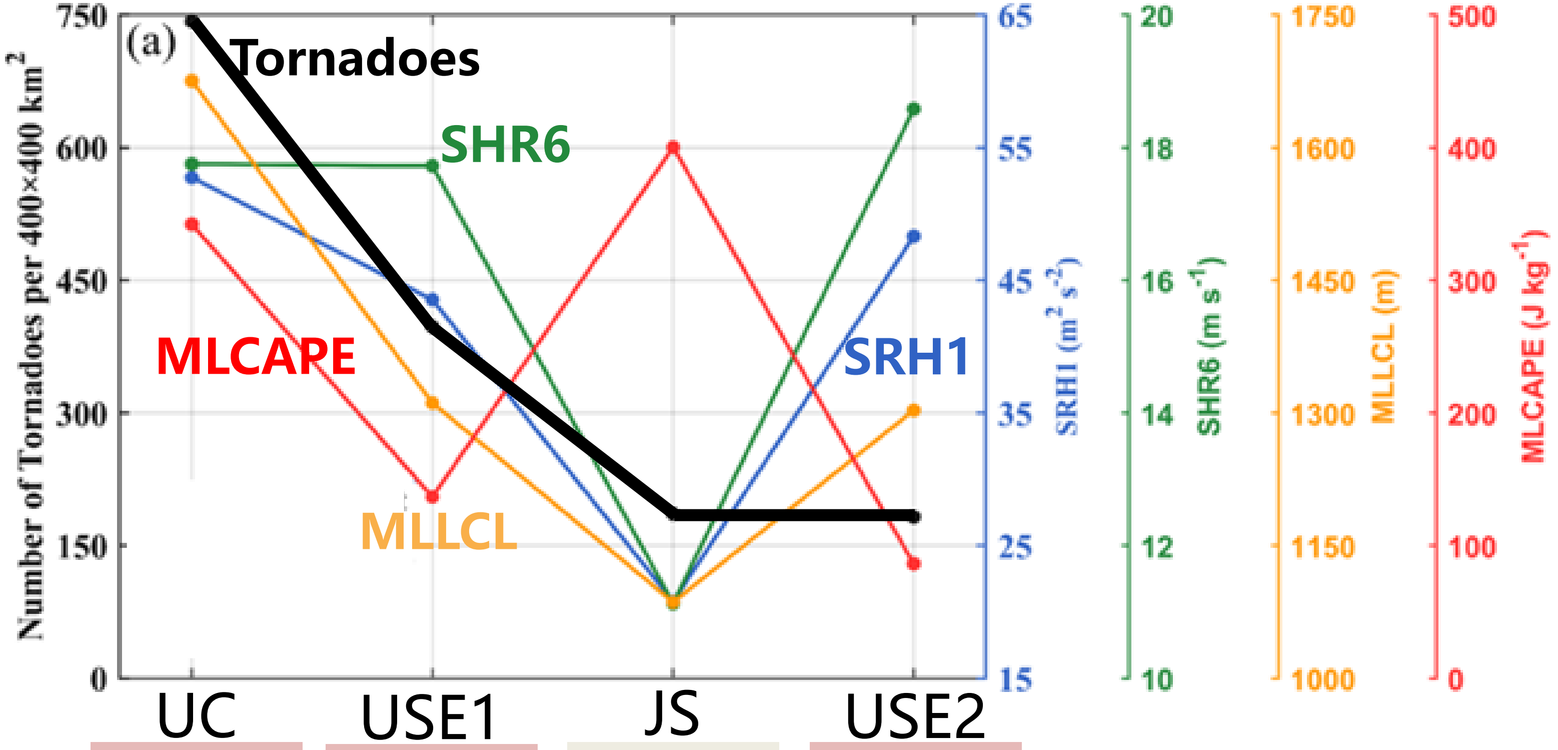
华东龙卷较晚的原因：STP峰值出现较晚



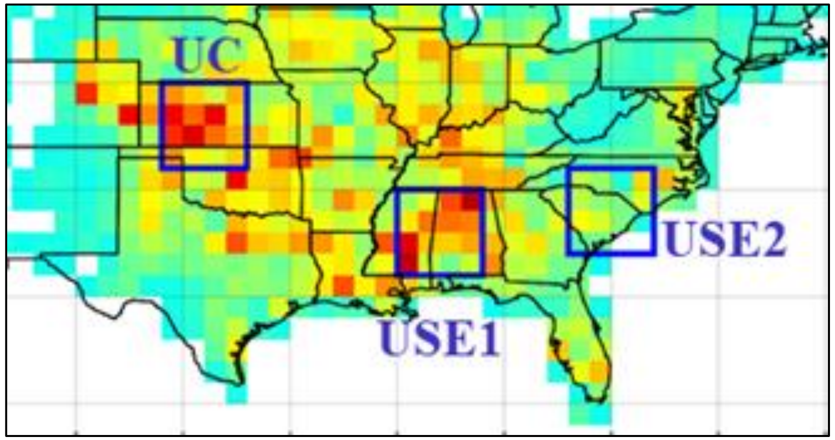
- STP平均值的月变化与龙卷数的月变化一致
- JS的STP峰值出现较晚

华东龙卷数少的原因：龙卷季垂直风切变较弱

龙卷季各环境参数的区域平均值

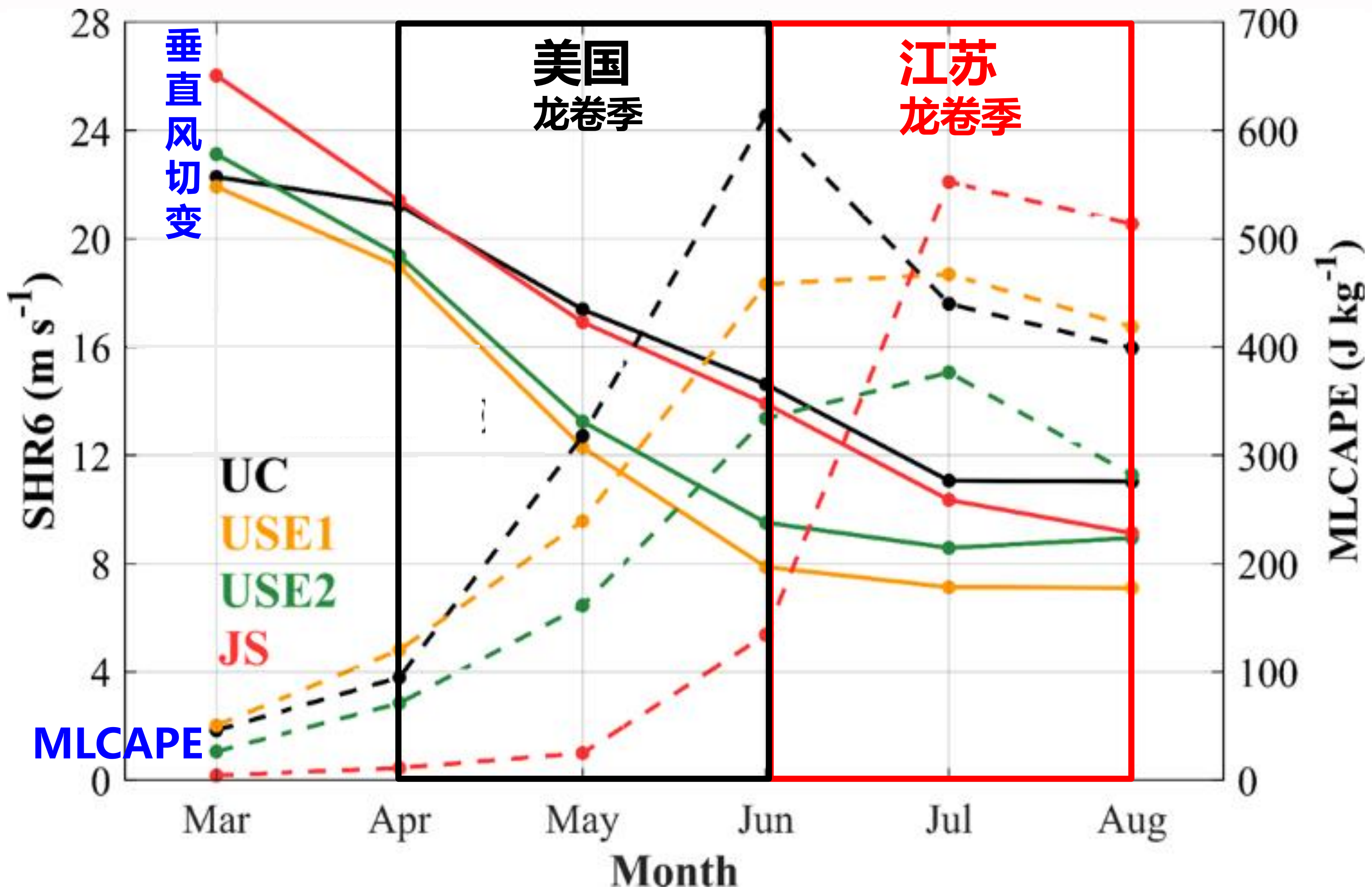


UC	USE1	JS	USE2
高SRH1	高SRH1	低SRH1	高SRH1
高SHR6	高SHR6	低SHR6	高SHR6
高CAPE	低CAPE	高CAPE	低CAPE
高LCL	低LCL	低LCL	低LCL



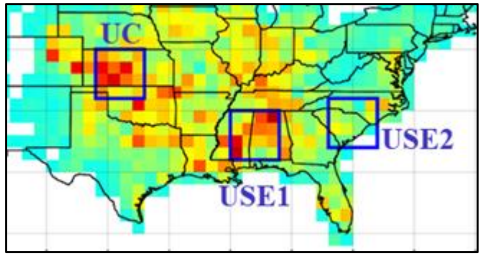
- **单个热力或动力环境参量与龙卷数无线性关系**
- 美国代表区域动力环境较好，
- 华东JS区域热力环境较好，动力环境较差

华东龙卷数少的原因：龙卷季垂直风切变较弱



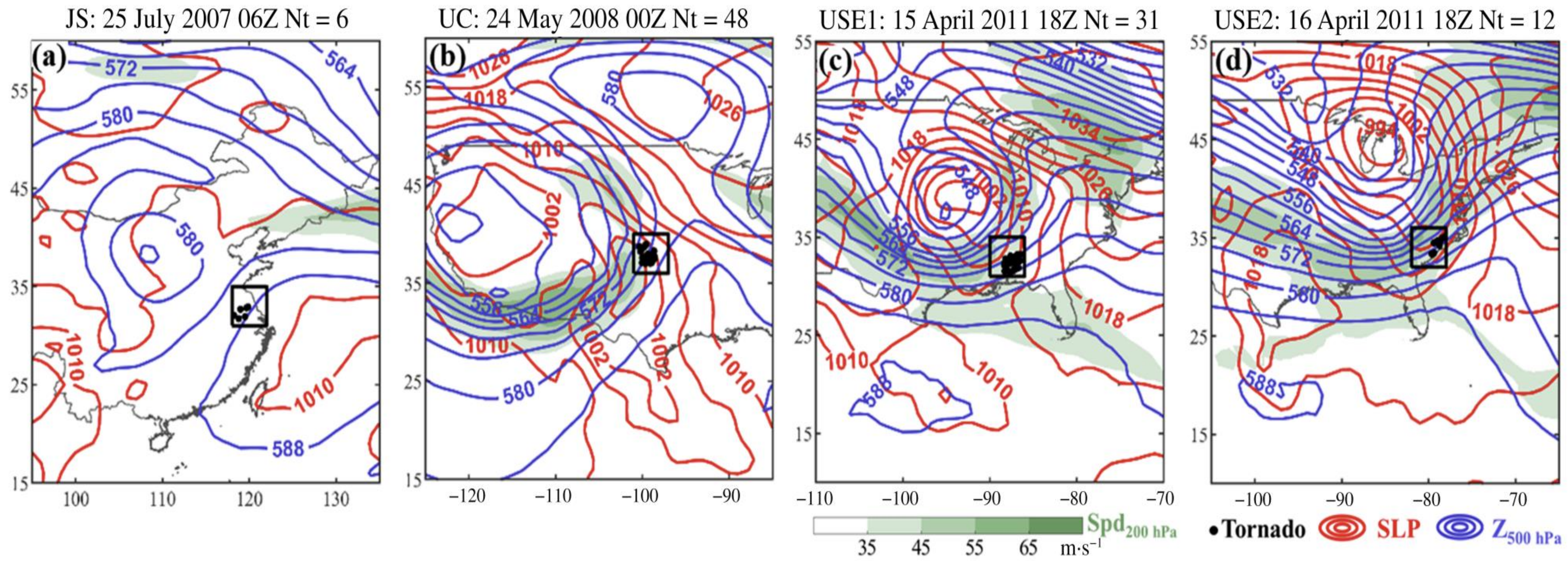
不稳定度增加的较晚

华东龙卷季偏晚

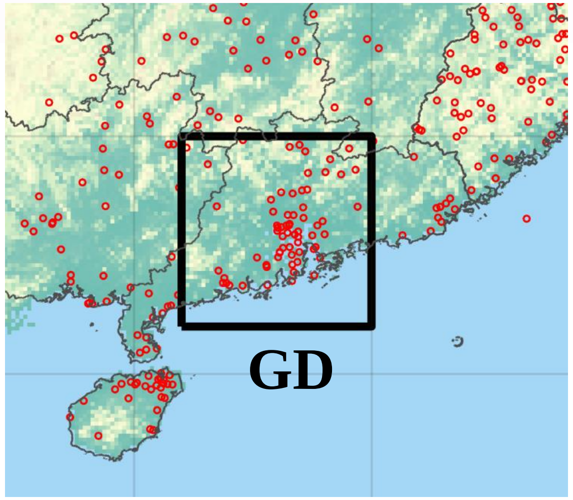


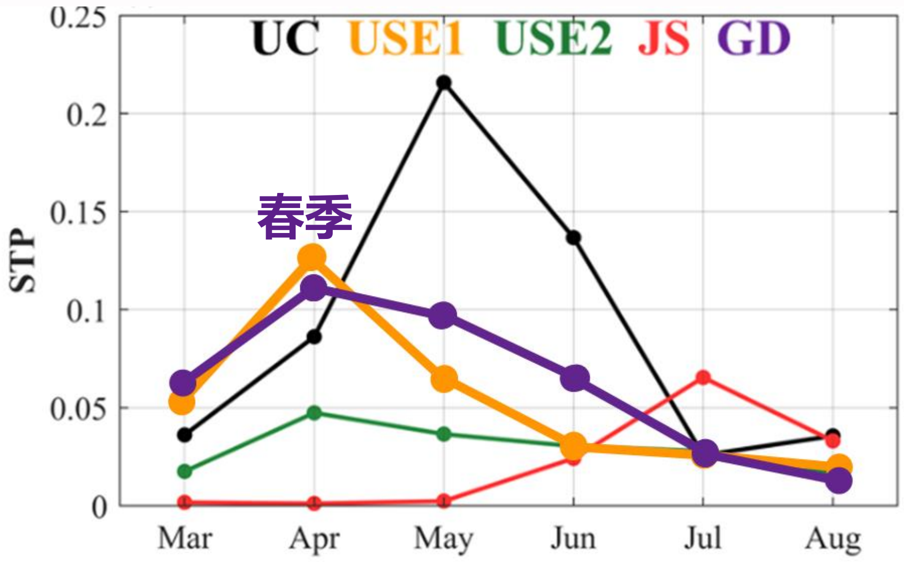
华东龙卷数少的原因：温带气旋偏弱

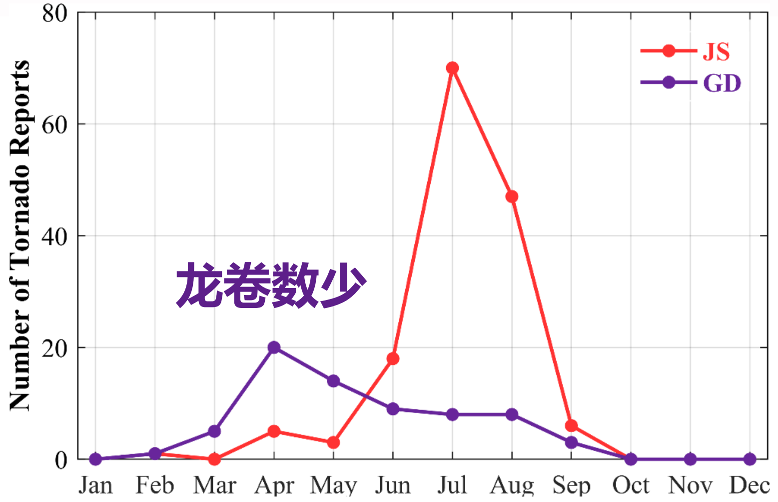
JS　　UC　　USE1　　USE2

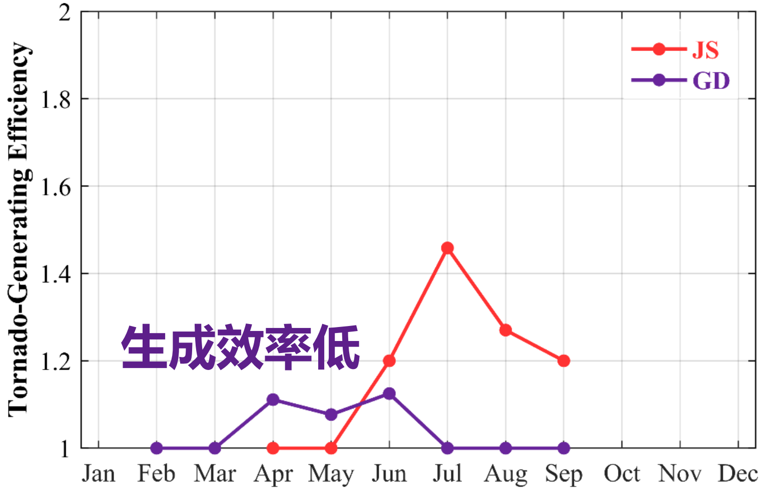


华南：龙卷季早、整体环境与USE1更相似、龙卷数少







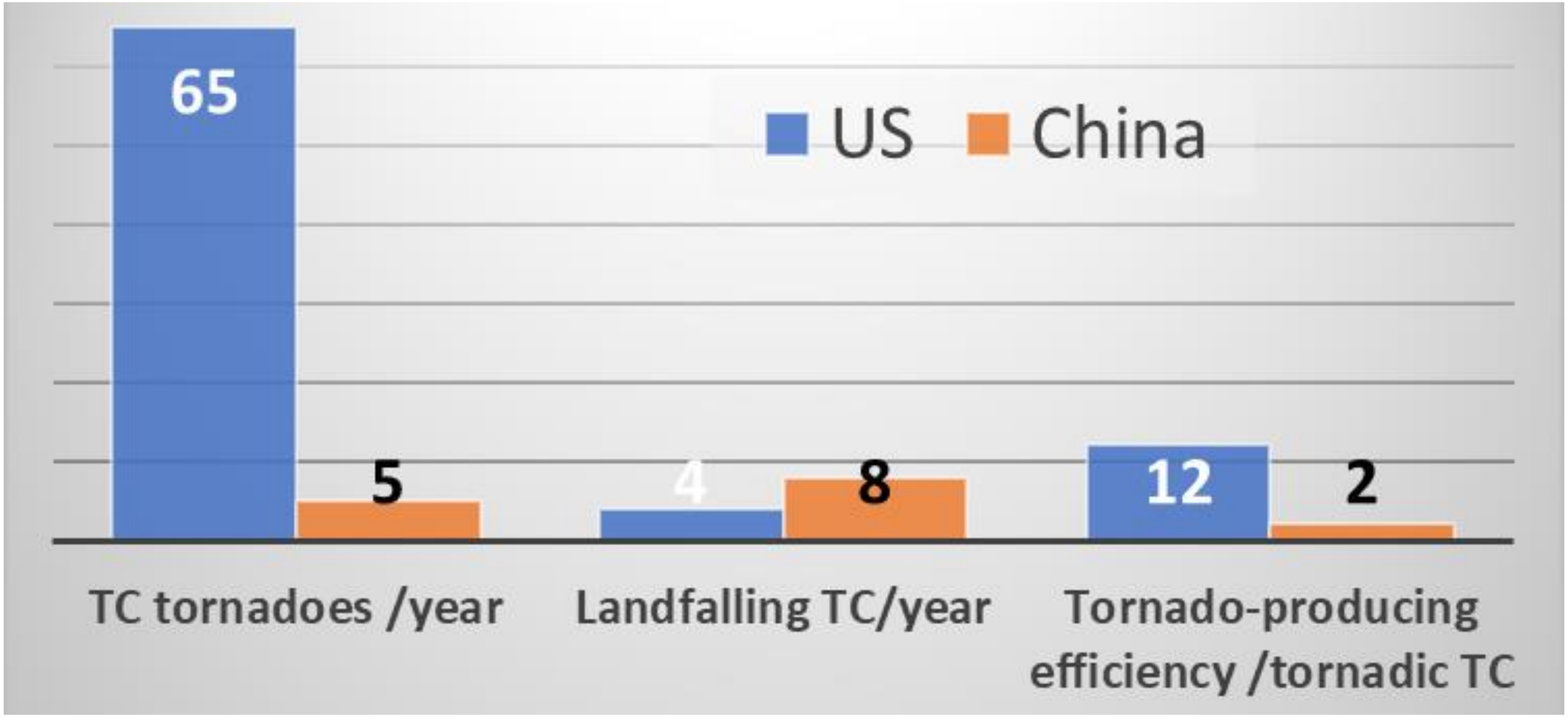


- 华南高发区**高STP，MLCAPE增长较早** **春季**
  高SHR6、SRH1和低MLLCL
- 华南地区**下垫面多丘陵地形**不利于龙卷发生

Zhou R., Z. Meng, L. Bai, 2022: Differences in Tornado Activities and Key Tornadic Environments between China and the United States, International Journal of Climatology, 42(1), 367–384, https://doi.org/10.1002/joc.7248

TC龙卷活动差异

台风龙卷

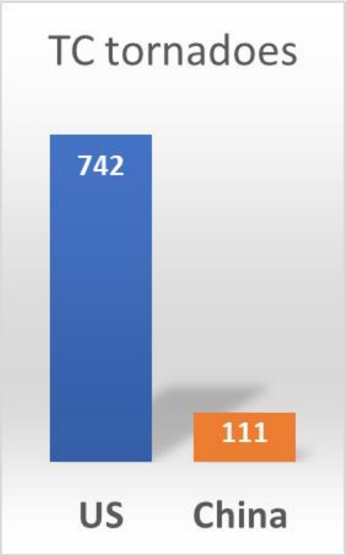


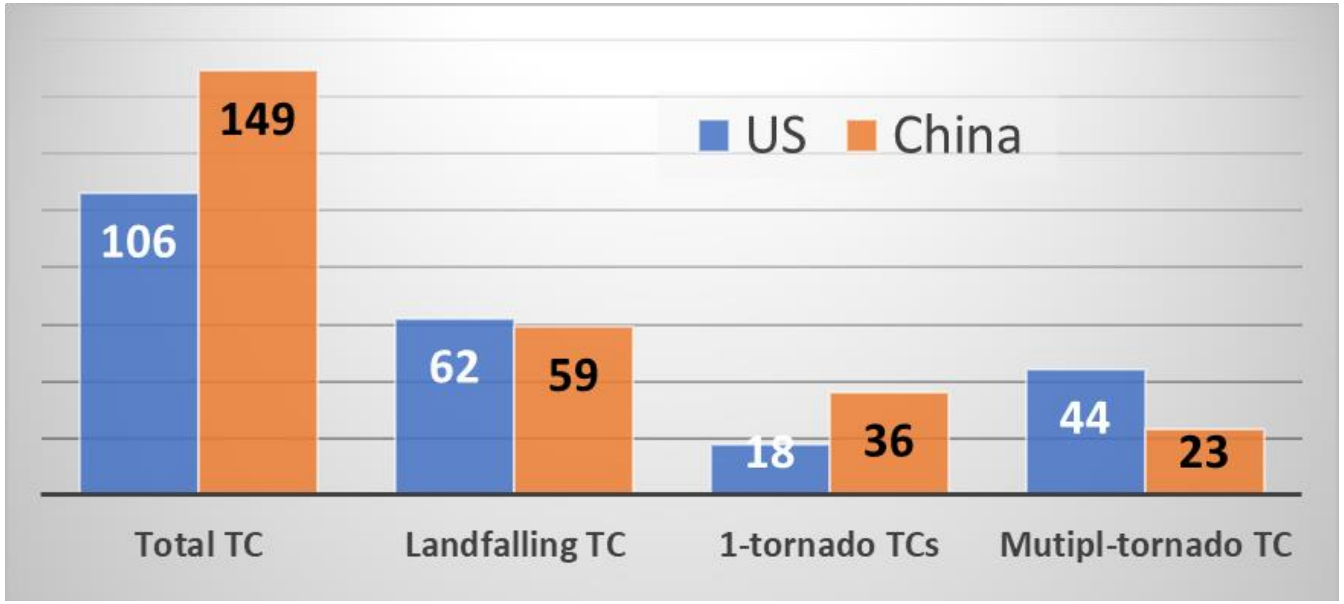
(Edwards and Moister 2022; Bai et al. 2021)

资料和方法

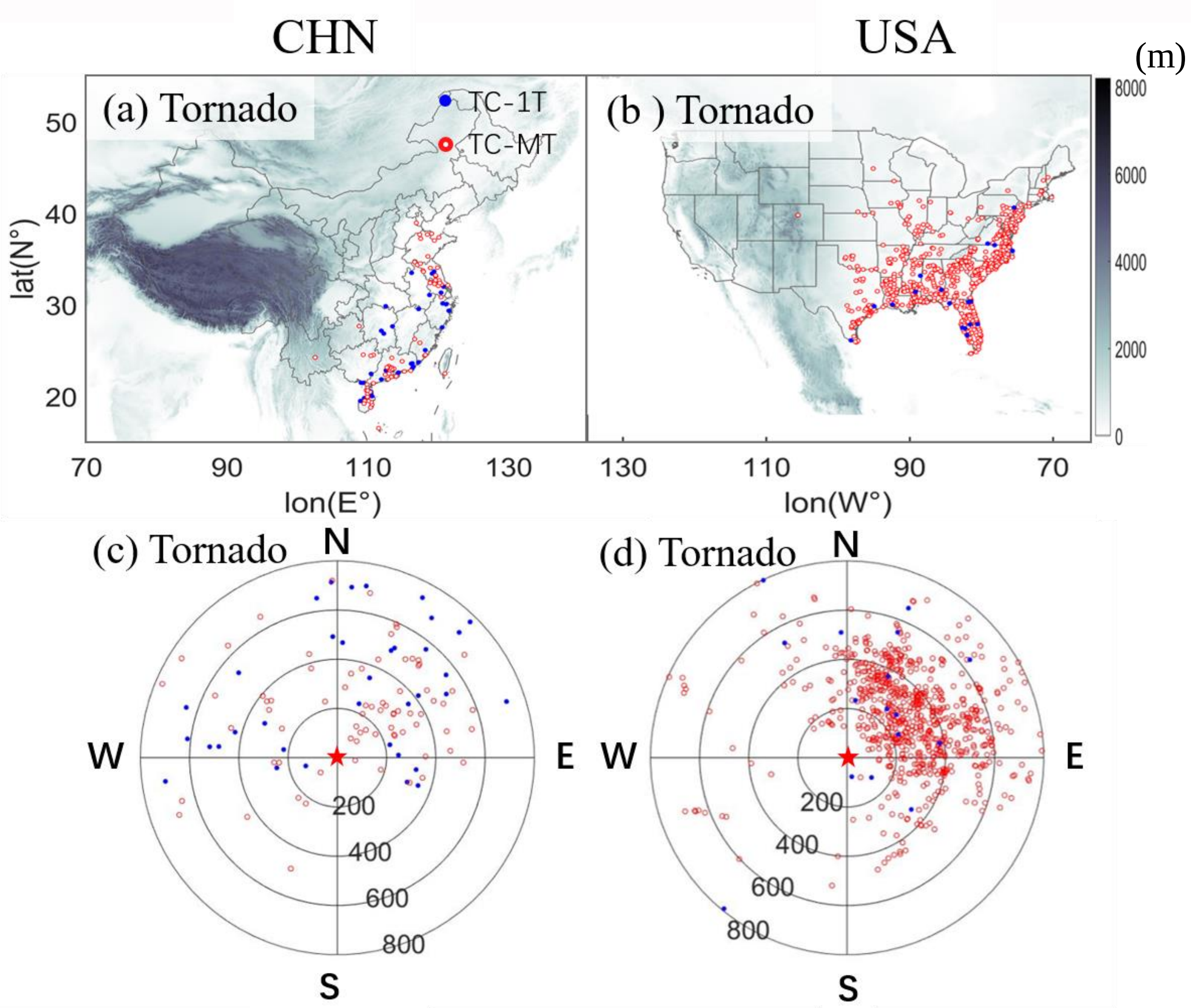
- **Definition of TC tornado**： a tornado situated within 800 km from a TC center
- **TC data**： HURDAT2 database & TC best-track database of CMA
- **Tornado**: NOAA's SPC sever weather database

  Peking University Open Research Data Platform
- **Environment parameters**: calculated with ERA5 (0.25°×0.25°, 1-hr)
- **Time period**: 2007-2021





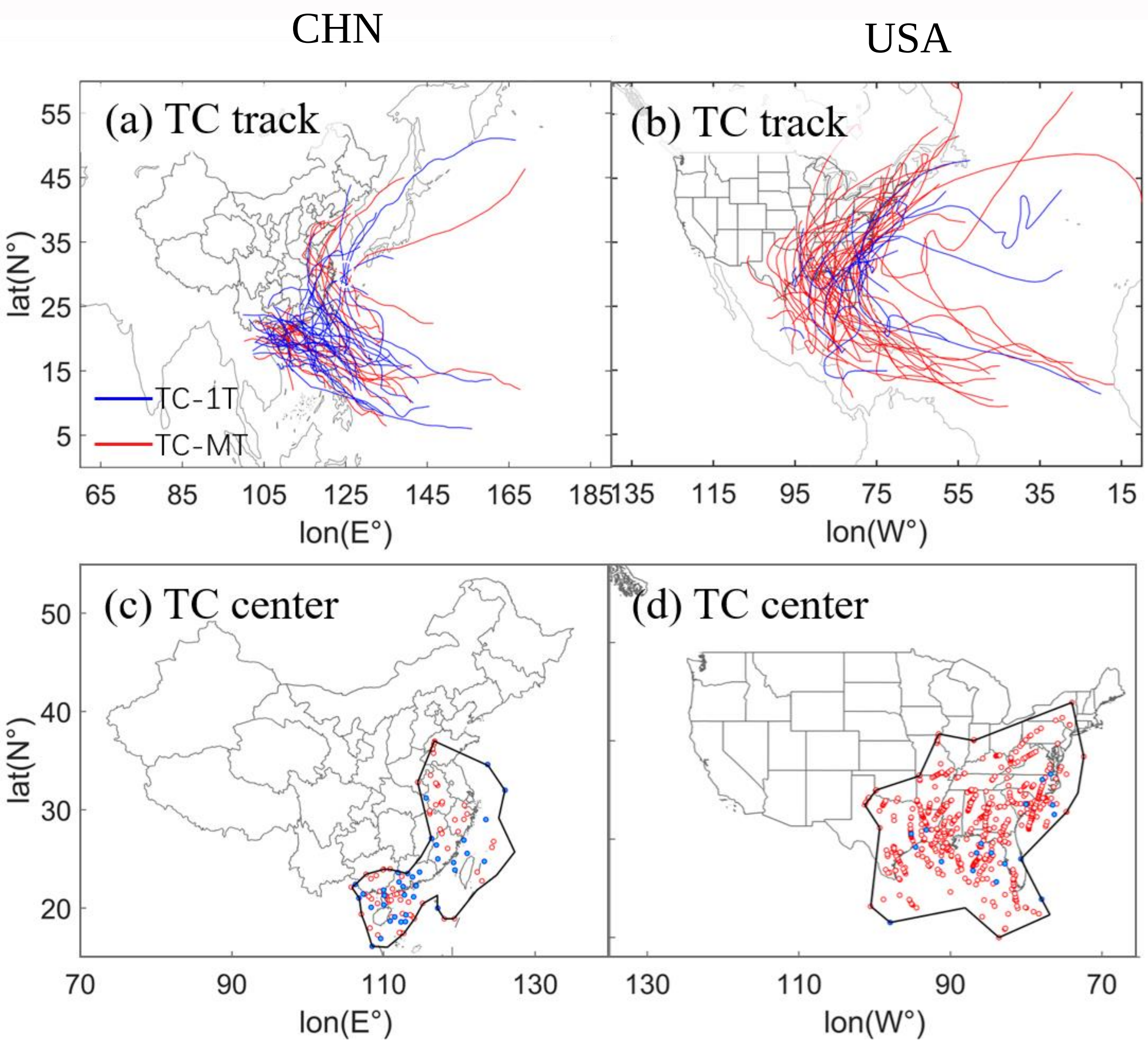
TC龙卷空间分布



- TC tornadoes are along the coastline in China, but in the U.S., they occur both along the coastline and far inland.

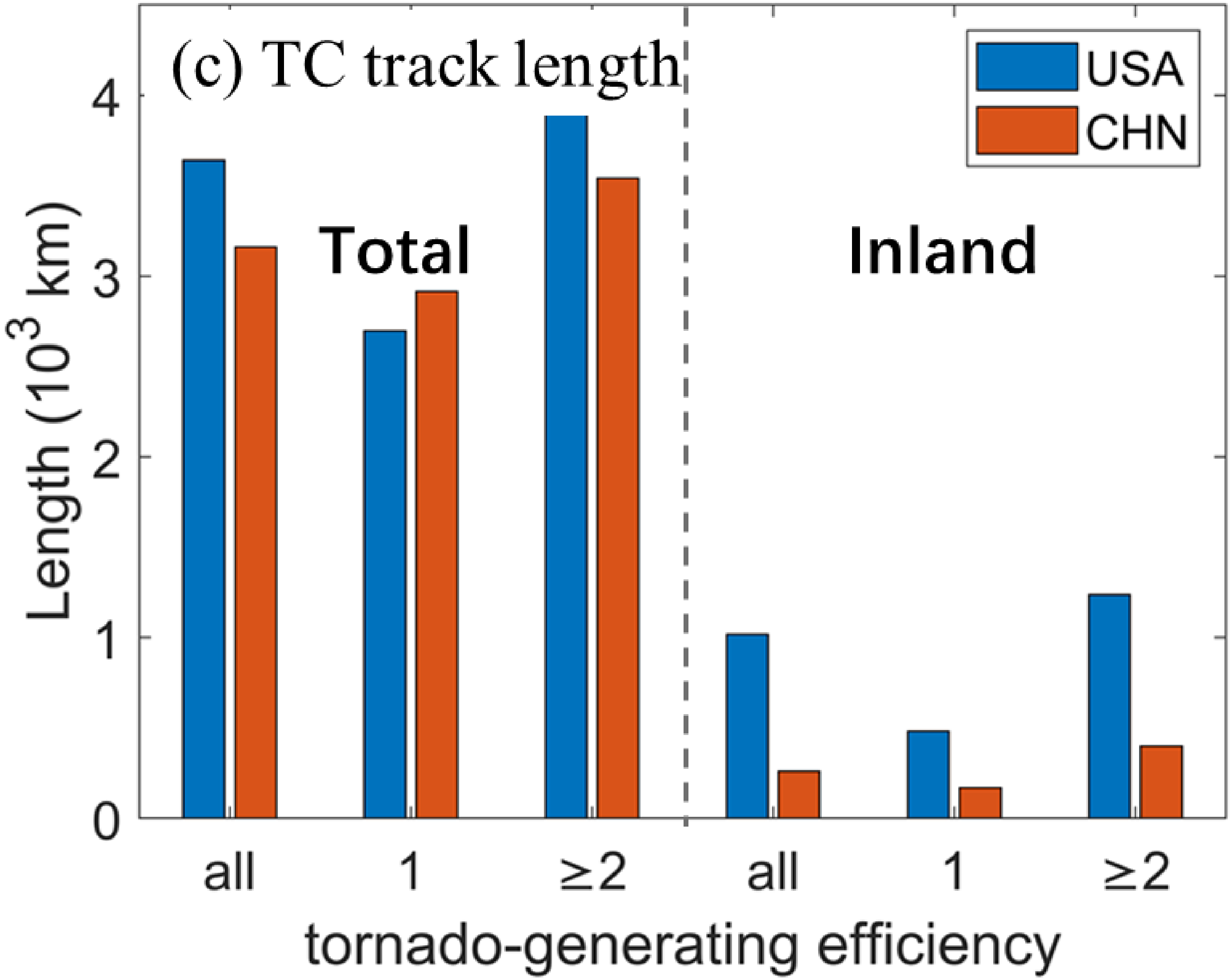
- TC tornadoes occur in the northern half of TC in China, but they mainly in the northeast quadrant of TC in the U.S.

中国TC龙卷少的原因：转向路径少 整体偏南



- TCs in China mostly have southeast-northwest oriented tracks, but TCs in the U.S. mostly have recurving tracks.
- Average latitude:
  CHN: 24.6° N USA:31.4° N

中国TC龙卷少的原因：TC路径偏短



- TCs in the U.S. have longer tracks than those in China, providing more opportunity to produce tornadoes.

中国TC龙卷少的原因：环境参数分析

- **E-CAPE: entraining convective available potential energy**

$$\mathrm{CAPE} = \int_{\mathrm{LFC}}^{\mathrm{EL}} \frac{T_v{}' - T_v}{T_v} \mathrm{g}\, dz$$

updating Tv' considering the effect of entrainment with a mass entrainment rate of 40%

- **SHR6: 0-6-km vector shear magnitude**

- **SRH1: 0-1-km storm relative helicity**

$$\mathrm{SRH} = \int_0^{\mathrm{H}} (V_h - C) \cdot \left(\boldsymbol{k} \times \frac{\partial V_h}{\partial z} \right) dz$$

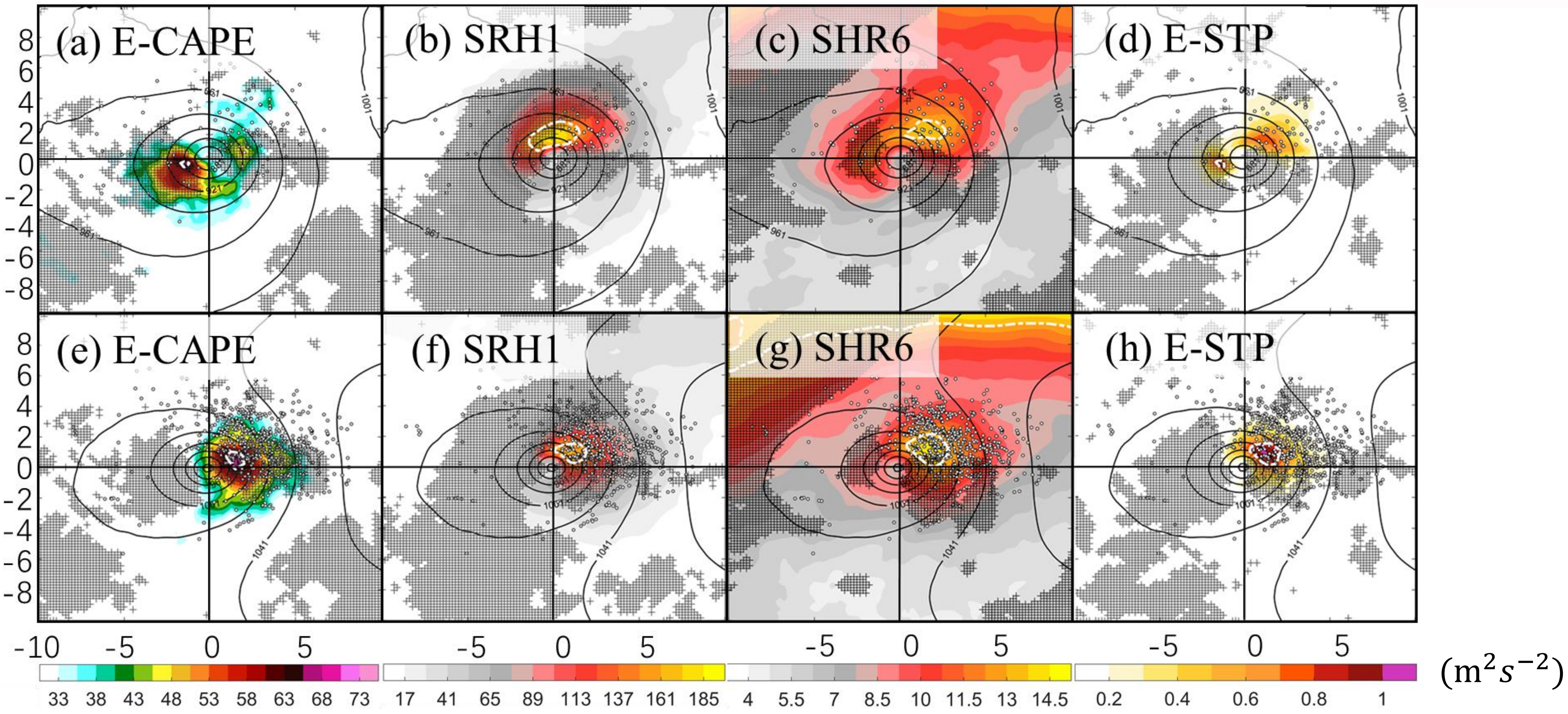
- **E-STP: entraining significant tornado parameter**

$$\text{E-STP} = \frac{\text{E-CAPE}}{1000} \times \frac{\mathrm{MLCAPE_{max}}}{\text{E-CAPE}_{\max}} \times \frac{\mathrm{SHR6}}{20} \times \frac{\mathrm{SRH1}}{100} \times \frac{(2000 - \mathrm{MLLCL})}{1500}$$

中国TC龙卷少的原因：E-CAPE和SRH大值区不重叠

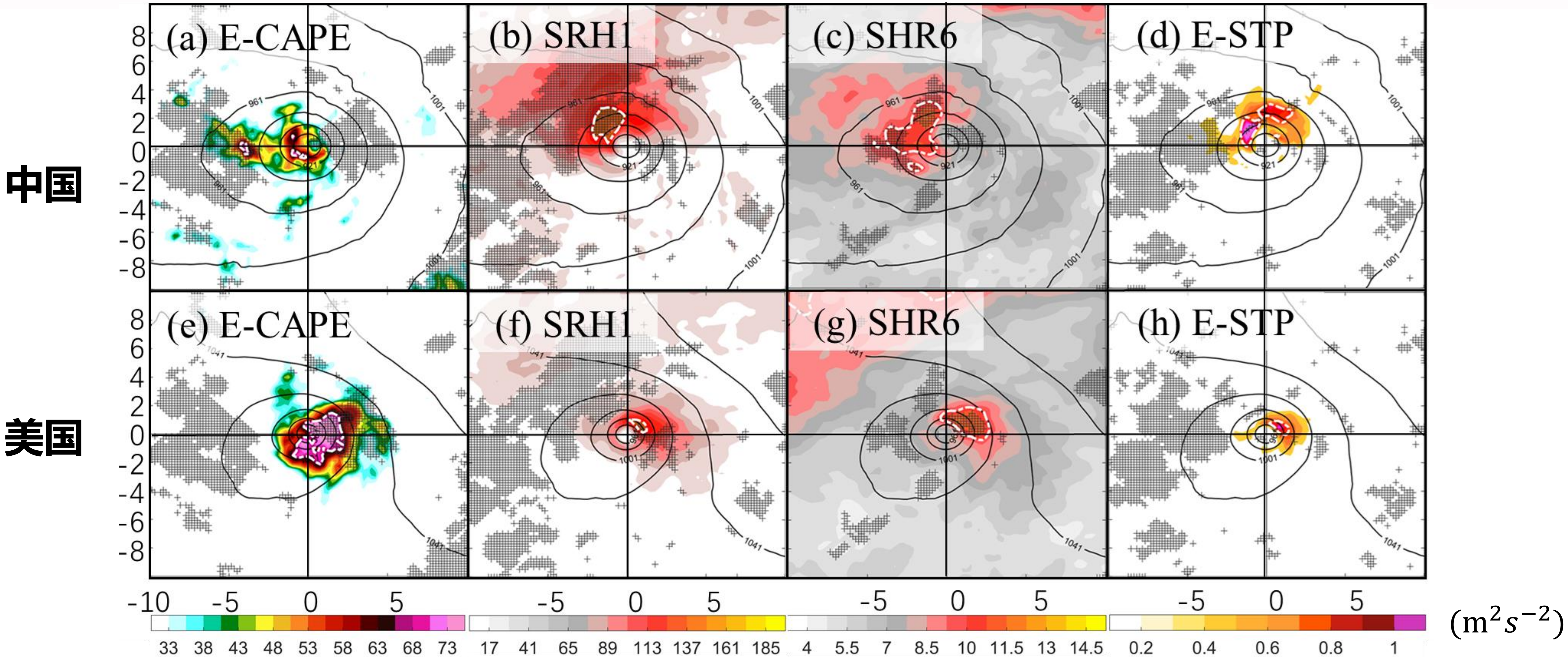
中国

美国



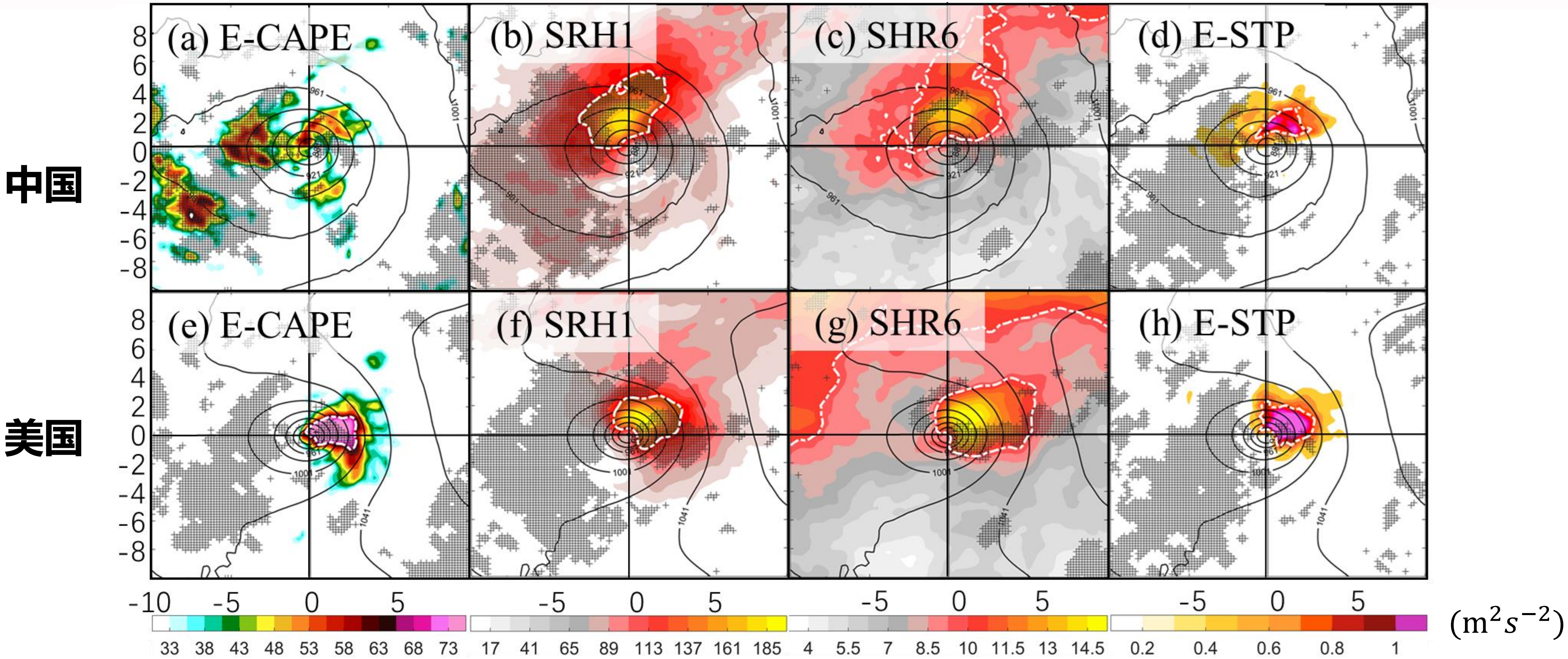
- Mismatch between the most thermodynamically and kinematically beneficial regions of TC in China ➡ lower E-STP

TC登陆之前：中国TC的E-CAPE和SRH大值区重叠！



- Before landfall, the environment of (tornadic) TCs in China is as (more) beneficial for tornado formation as (than) that in the U.S.

TC登陆附近：中国TC的E-CAPE和SRH大值区错位！

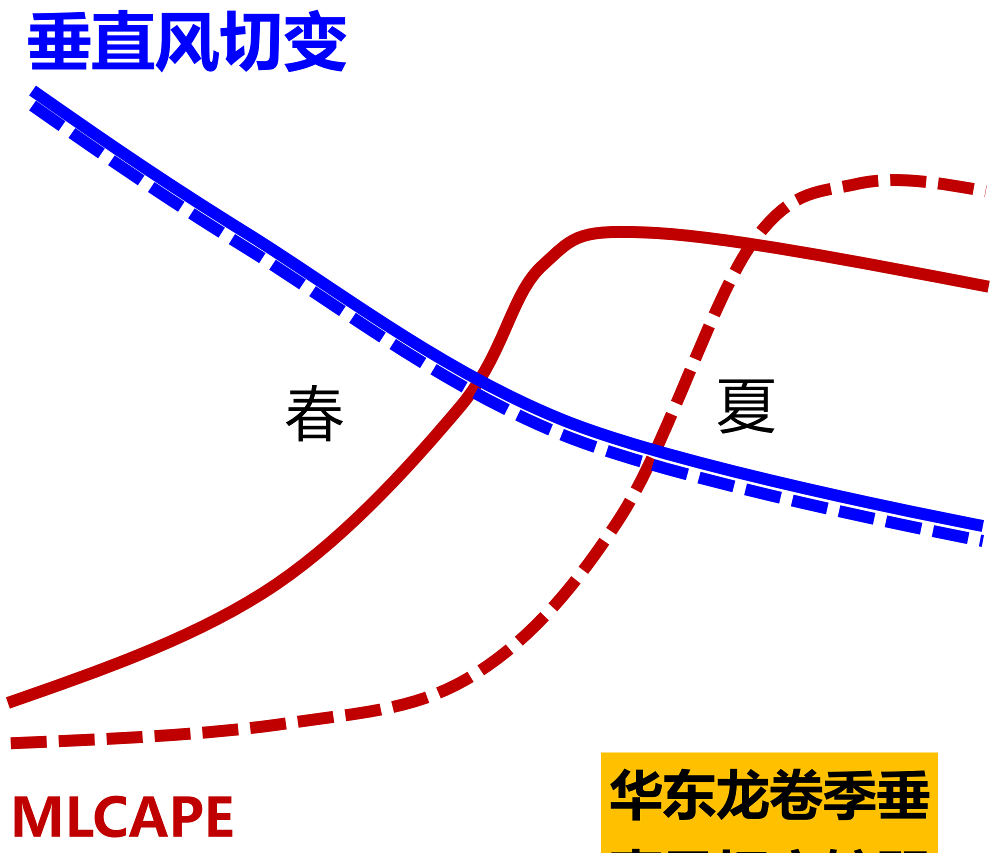


- Around landfall, the environment of TCs in China become less beneficial for tornado formation than that in the U.S.

小结

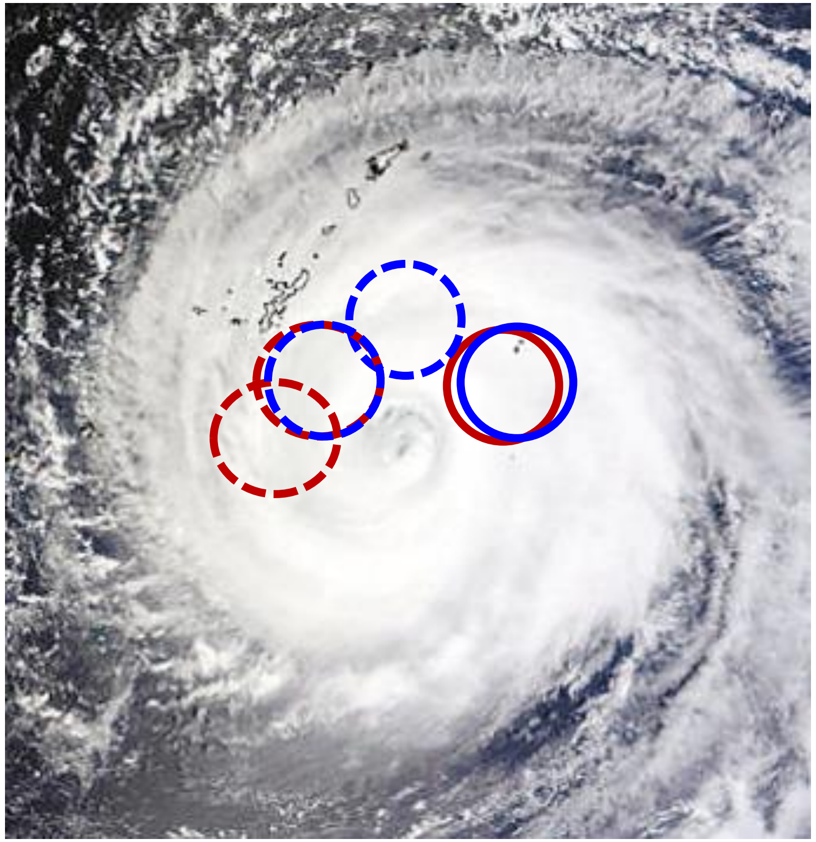
美国 ——
中国 - - -

非TC龙卷环境



华东龙卷季垂直风切变较弱

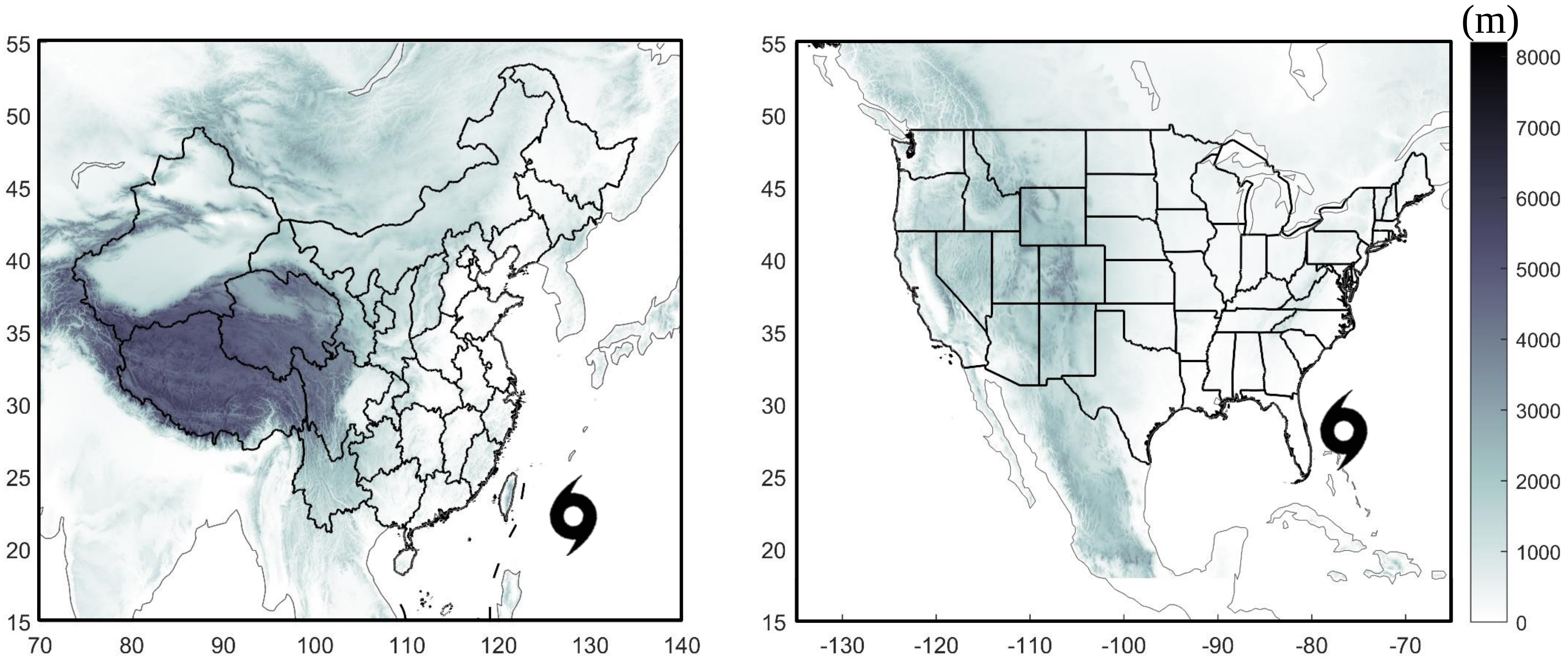
TC龙卷环境



中国龙卷性TC的垂直风切变和ECAPE大值区错位

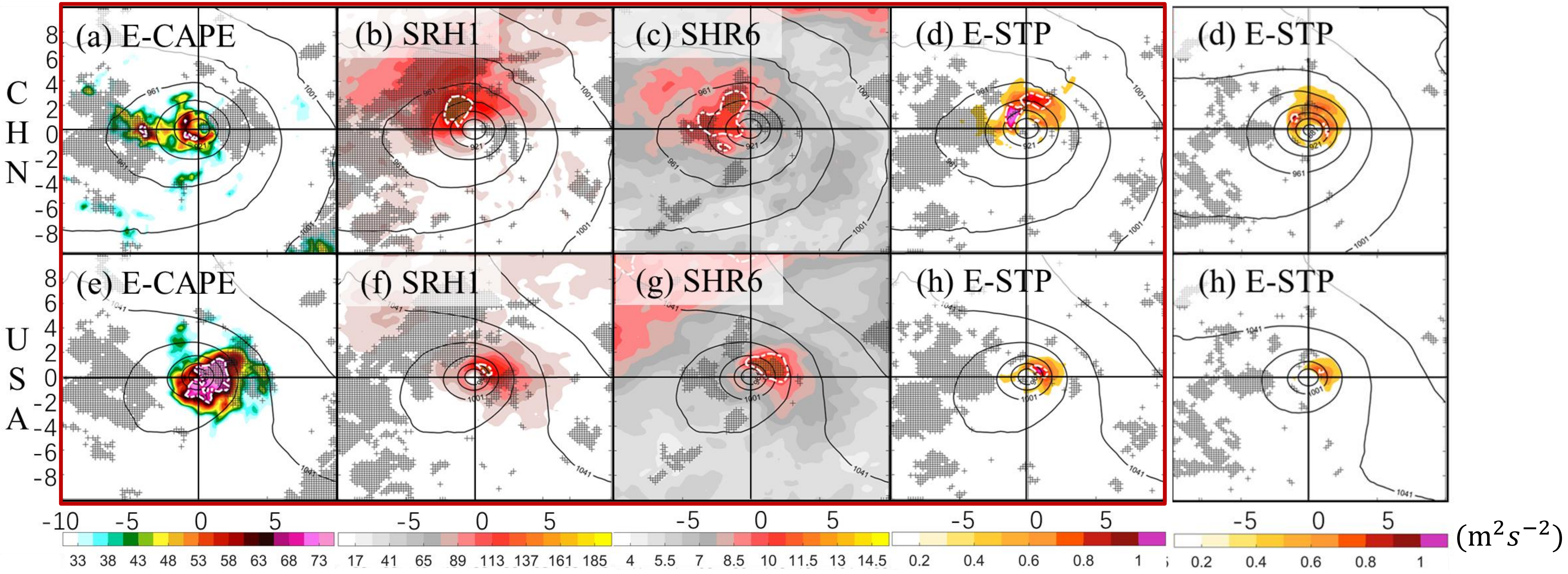
TC龙卷

The U.S. has the largest frequency of TC tornadoes in the world, followed by China.



- Middle latitudes → large vertical wind shear → tornadoes
- Long coastal lines → TC strikes

TC登陆之前：中国TC的E-CAPE和SRH大值区重叠！



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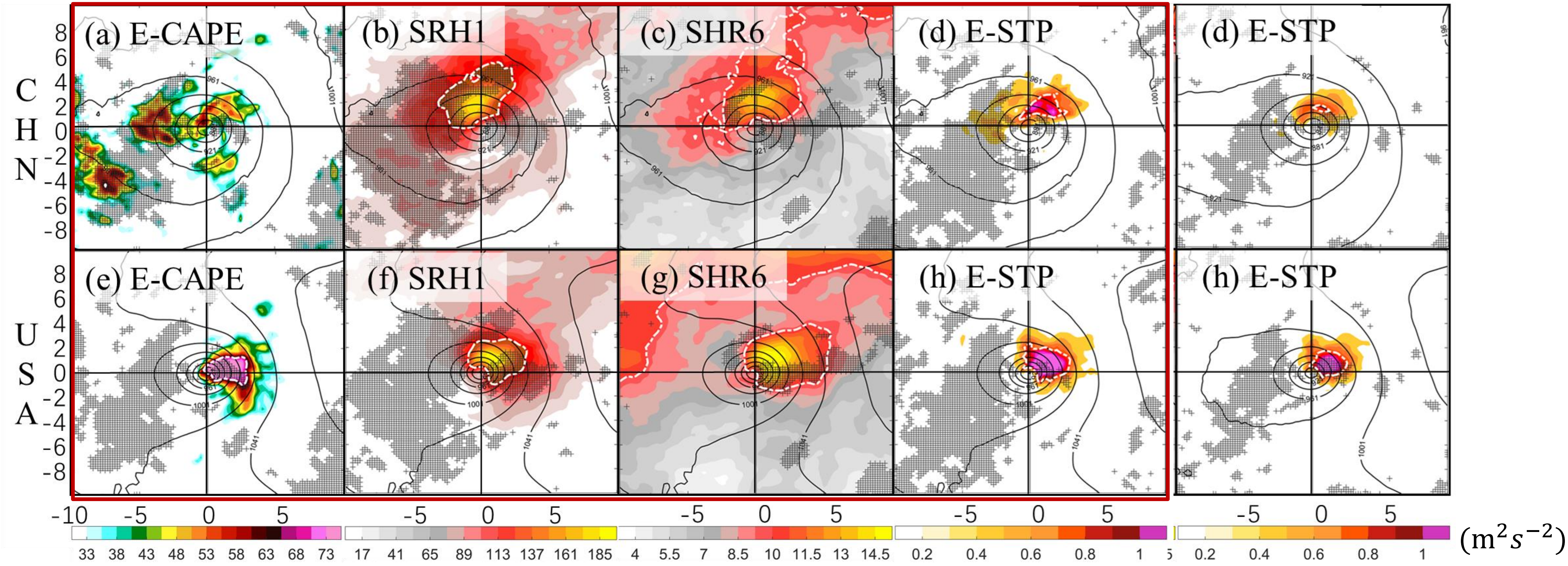
TC登陆附近：中国TC的E-CAPE和SRH大值区错位！



- Around landfall, the environment of TCs in China become less beneficial for tornado formation than that in the U.S.