中尺度气象学论坛

2021年12月美国破纪录龙卷事件与西北太平洋台风的联系

蒋宁

中国气象科学研究院 灾害天气国家重点实验室

合作者：刘伯奇，祝从文，陈彦颖

致谢：李明鑫，白兰强

Subseasonal-to-Seasonal S2S Prediction Project

2021年12月份美国发生了破纪录的龙卷事件

National Oceanic and Atmospheric Administration
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The December 2021 tornado outbreak, explained

Focus areas: Weather, Climate Topics: tornadoes, climate change, severe storms

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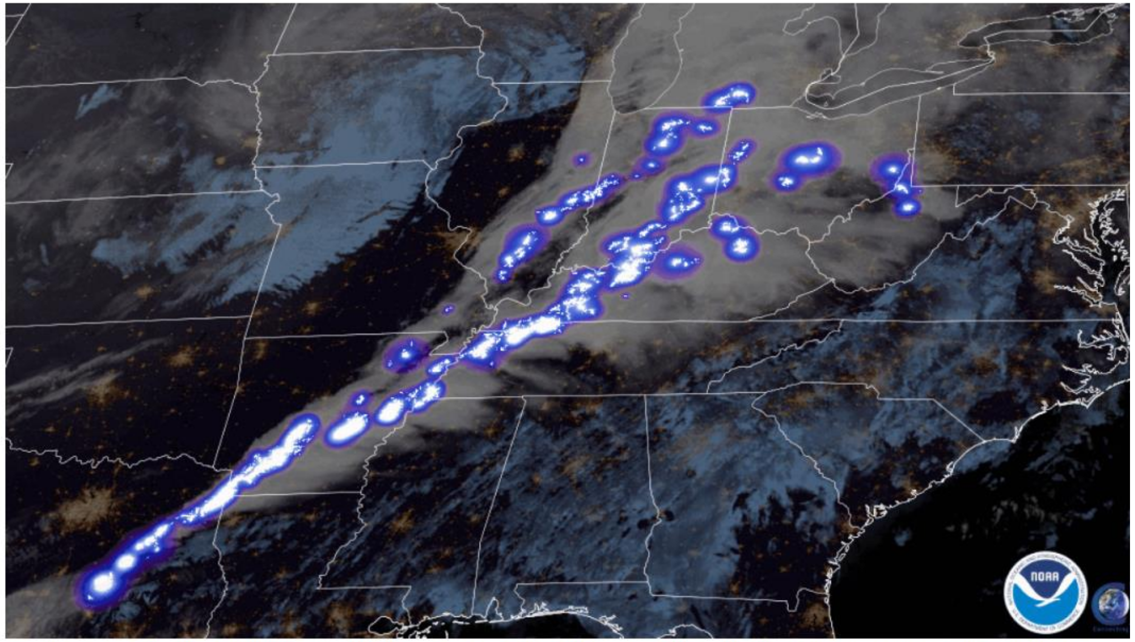
December 20, 2021



A view from NOAA's GOES-16 satellite taken at 11:46 pm CST on December 10, 2021 of the tornado outbreak across the central and southern U.S. NOAA's National Weather Service (NWS) confirmed 61 tornadoes as of December 18, with several long-track tornadoes.
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“雷伊”已致菲律宾375人死亡，台风正变得越来越强？

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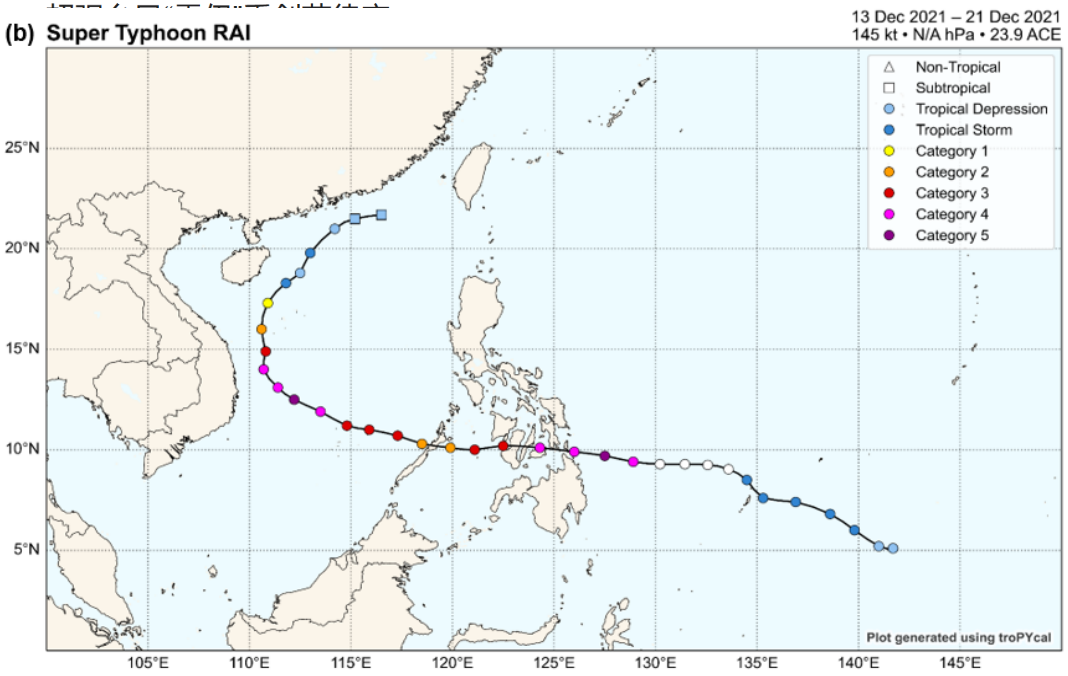

决策服务提供支撑

中国气象科学研究院决策服务信息专报

（2022 年第 1 期，总第 157 期）

中国气象科学研究院
2022 年 1 月 17 日

值班：蒋宁、刘伯奇、马双梅
首席：祝从文
审核：翟盘茂
签发：端义宏

2021 年 12 月美国东南部群发龙卷事件的天气和气候成因分析

摘要： 2021 年 12 月 10 日晚，一次群发性龙卷过程席卷了美国东南部，造成近百人死亡和重大财产损失。研究表明，12 月 10 日，美国东南部冷锋过境令冷暖空气发生强烈相互作用，大气不稳定能量快速释放，直接导致了此次极端龙卷事件。气温持续性偏暖和来自墨西哥湾的暖湿空气向该区域

IOP Publishing Environ. Res. Lett. 18 (2023) 044036 https://doi.org/10.1088/1748-9326/acc880

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LETTER

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Remote linkage of record-breaking U.S. Tornado outbreaks to the tropical cyclone in western North Pacific in December 2021

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Keywords: tornado, ENSO, tropical cyclone, MJO

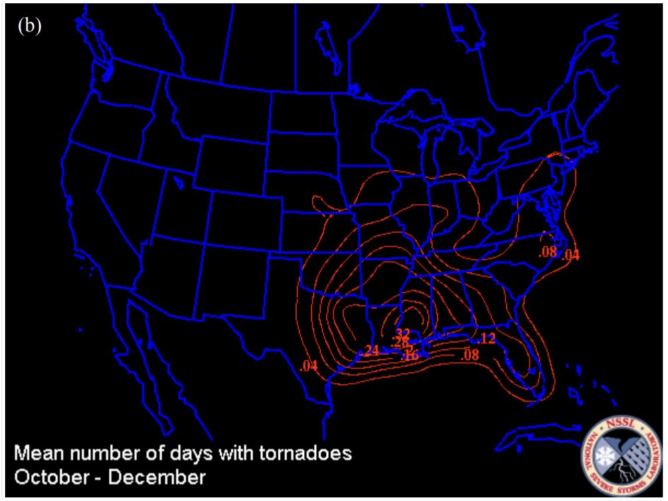
Supplementary material for this article is available online

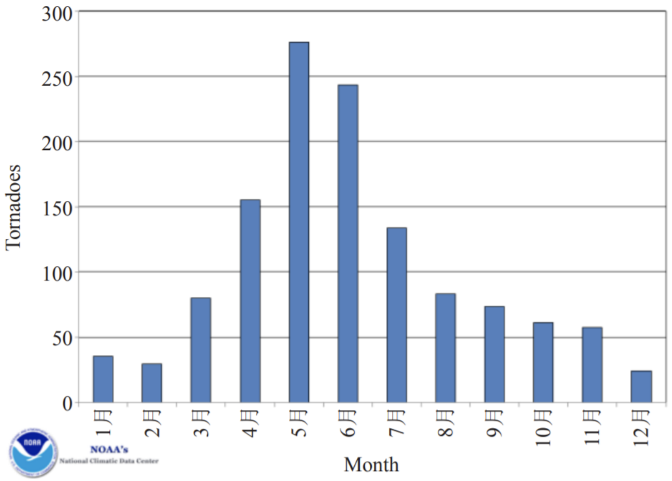
Abstract

The frequency of tornadoes usually peaks during spring to summer rather than winter in climatology. However, the United States (U.S.) experienced more than 200 tornadoes in December 2021, which broke the historical record and caused 87 fatalities. Historically, the frequency of tornadoes in December tends to increase under El Niño conditions. Our results show that the monthly large-scale weather regime conducive to these record-breaking tornado outbreaks under a La Niña condition is closely associated with Typhoon Nyatoh in the western North Pacific. As the tropical cyclone (TC) recurved into the mid-latitudes, its interaction with the extratropical flows has caused distortions in the Asian jet stream and the dramatic development of anomalous anticyclone west of the dateline, which in turn strongly regulated the response of the monthly

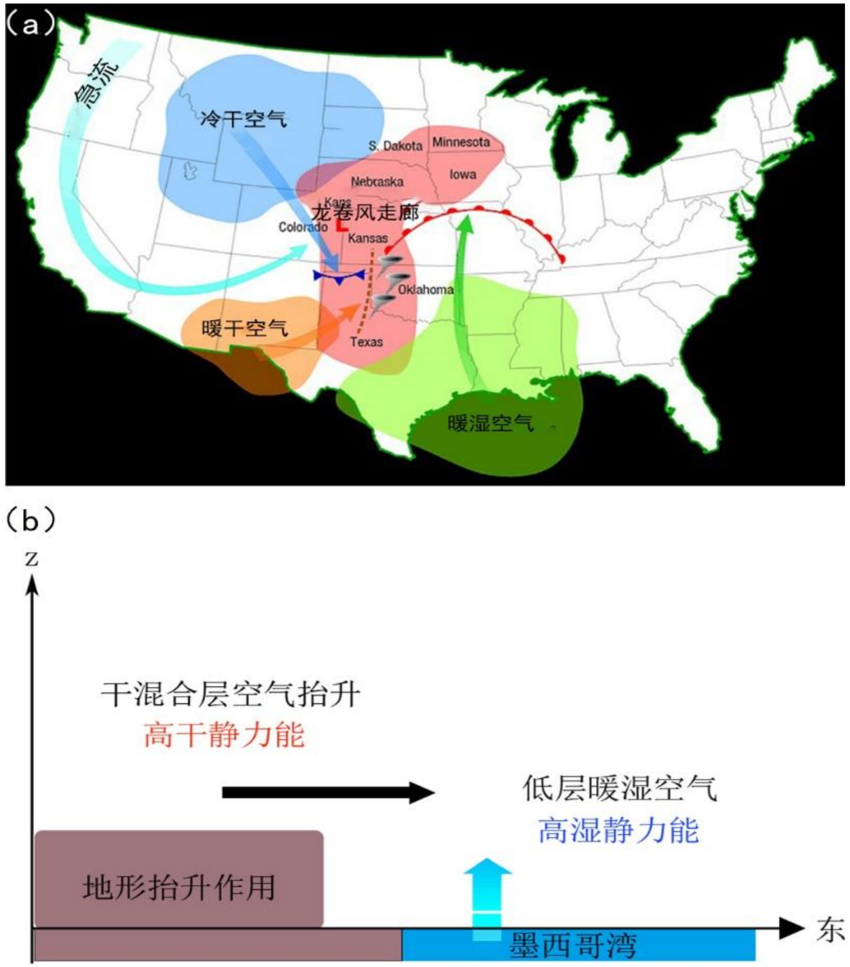
Jiang N., Liu B., Zhu C., Chen Y., 2023: Remote linkage of record-breaking U.S. Tornado outbreaks to the tropical cyclone in western North Pacific in December 2021. ***Environmental Research Letters***, 18, 044036.

美国龙卷事件的统计特征及主要成因





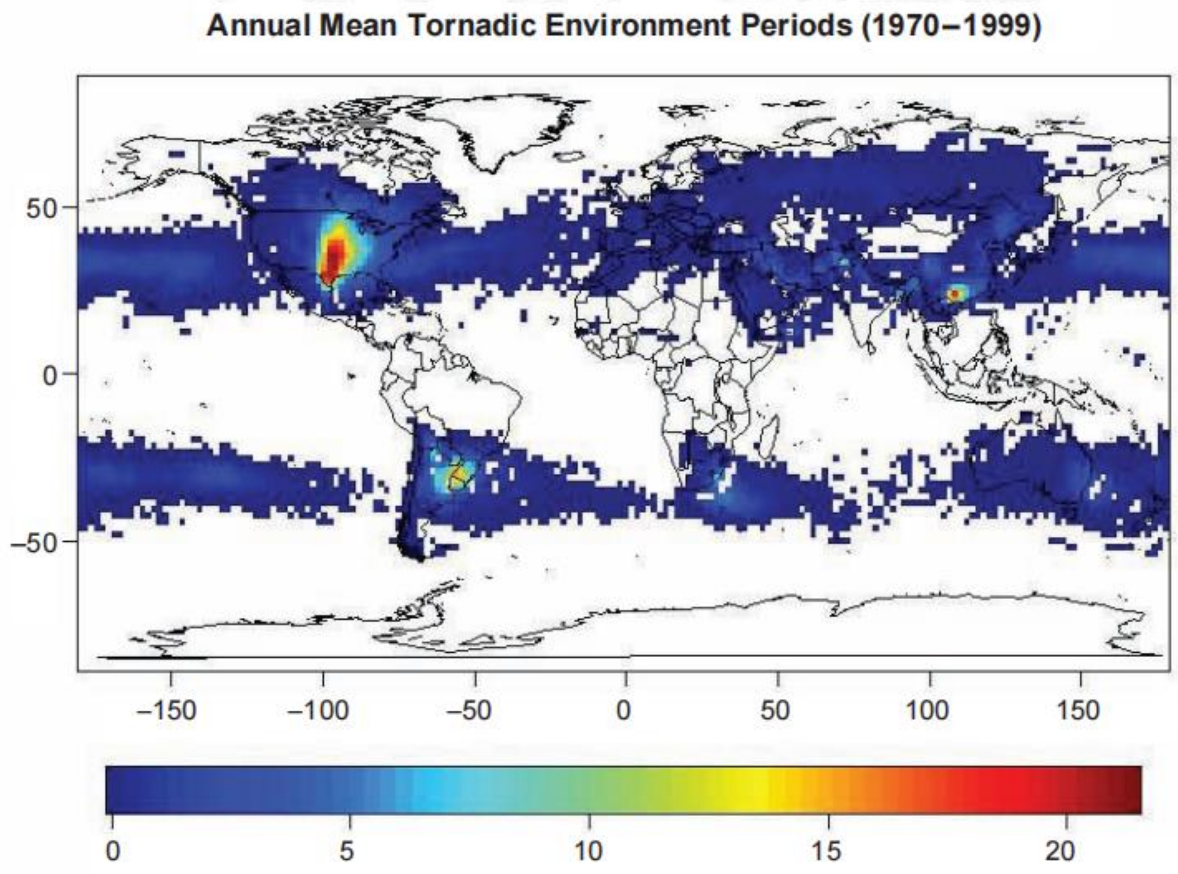
王东海, 李兆慧, 高枞亭,等. 2018. 中国与欧美龙卷统计特征比较分析及研究进展. 气象科技进展, **8**(2):8-23.

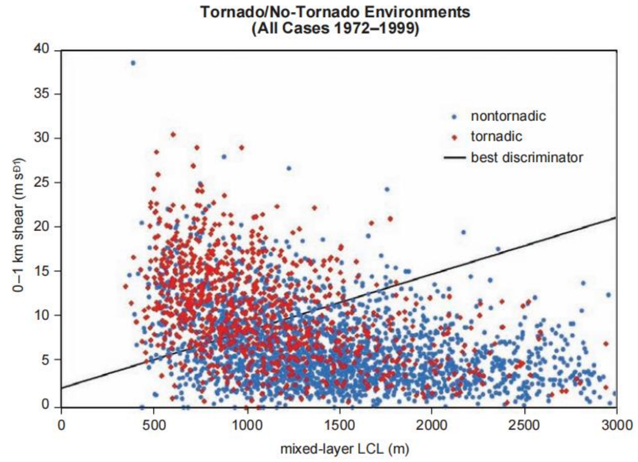


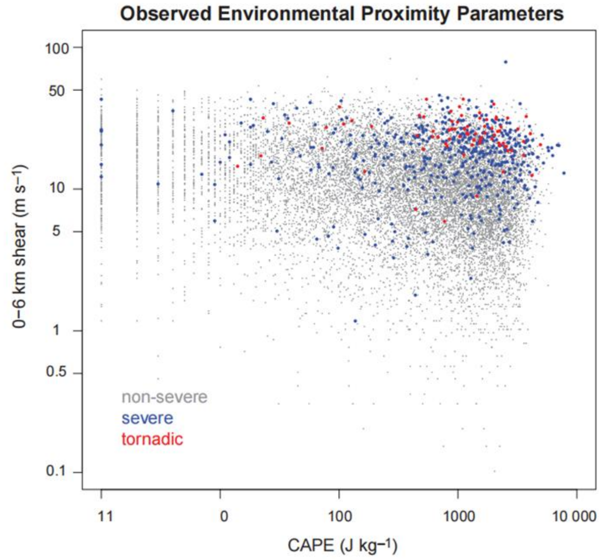
美国龙卷风发生的典型天气环流场和发生机理示意图. (a) 天气环流场（引自：美国国家风暴实验室和天气中心）（b）发生机理（引自：Chavas and Dawson, 2021）

影响美国龙卷发生的主要环境因子

- Convective precipitation
- **Storm Relative Helicity**
- **CAPE**
- CIN
- Lifted index
- Humidity
- **Vertical Wind Shear**







Tippett, M. K., Sobel, A. H., & Camargo, S. J. (2012). Association of U.S. tornado occurrence with monthly environmental parameters. *Geophysical Research Letters*, *39*(2), n/a-n/a. https://doi.org/10.1029/2011GL050368

Mesoscale Meteorology in Midlatitudes
Author(s):Paul Markowski, Yvette Richardson
First published:5 February 2010
Print ISBN:9780470742136 |Online ISBN:9780470682104 |DOI:10.1002/9780470682104
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影响美国龙卷发生的主要天气形势

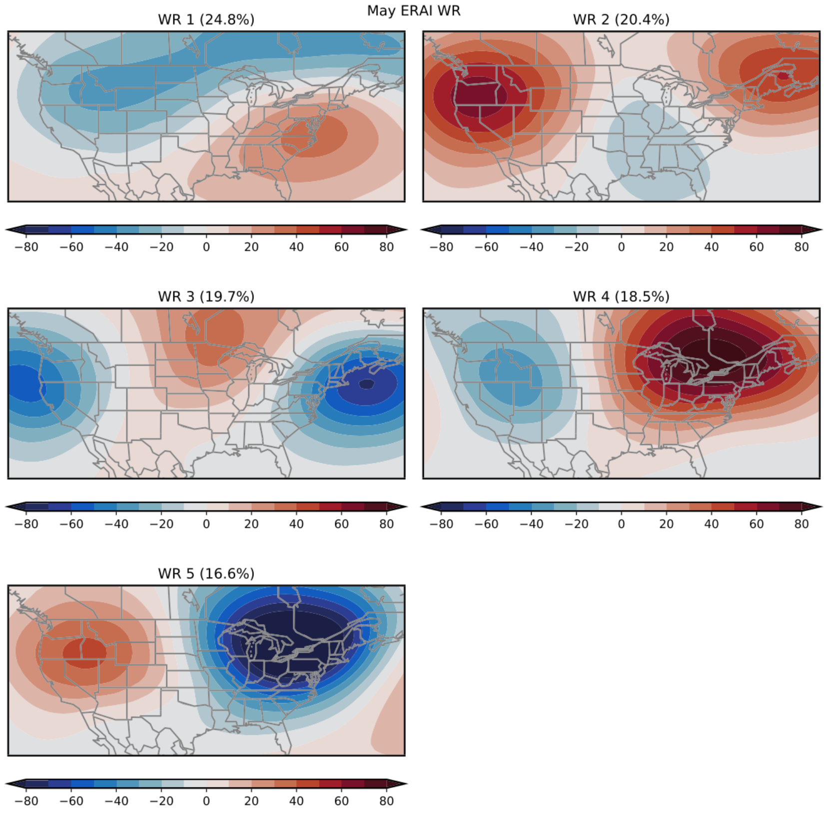


Figure 1. The H500 patterns for five WRs over North America during May ordered from most frequent (WR1) to least frequent (WR5). The frequencies of occurrence are listed at the top of each subfigure.

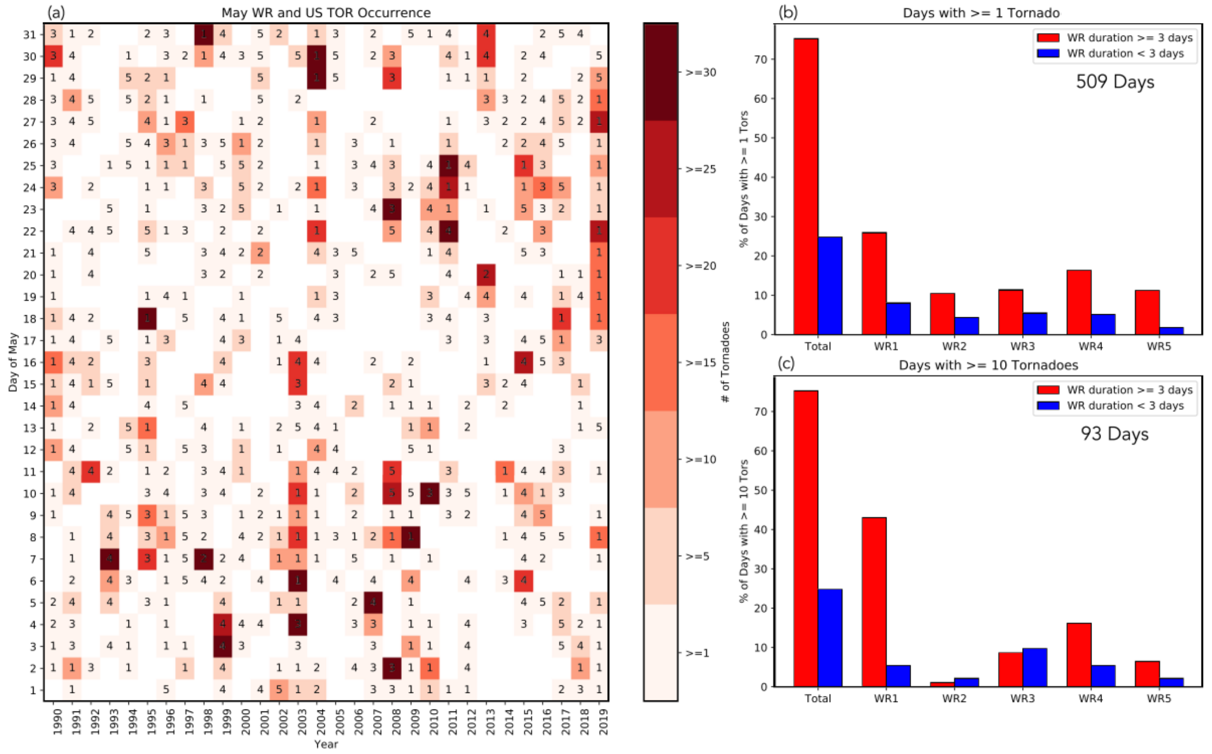


Figure 2. (a) U.S. tornado days (color shading indicates number of tornadoes per day) and WRs (numbers) during May 1990–2019. Non-tornado days are masked with white. Bar charts display the percentage of days with (b) ≥1 tornado and (c) ≥10 tornadoes for persisting (red) and nonpersisting (blue) WRs.

Miller, D. E., Wang, Z., Trapp, R. J., & Harnos, D. S. (2020). Hybrid Prediction of Weekly Tornado Activity Out to Week 3: Utilizing Weather Regimes. *Geophysical Research Letters*, *47*(9), 1–10. https://doi.org/10.1029/2020GL087253

影响美国龙卷发生的主要气候外强迫因子

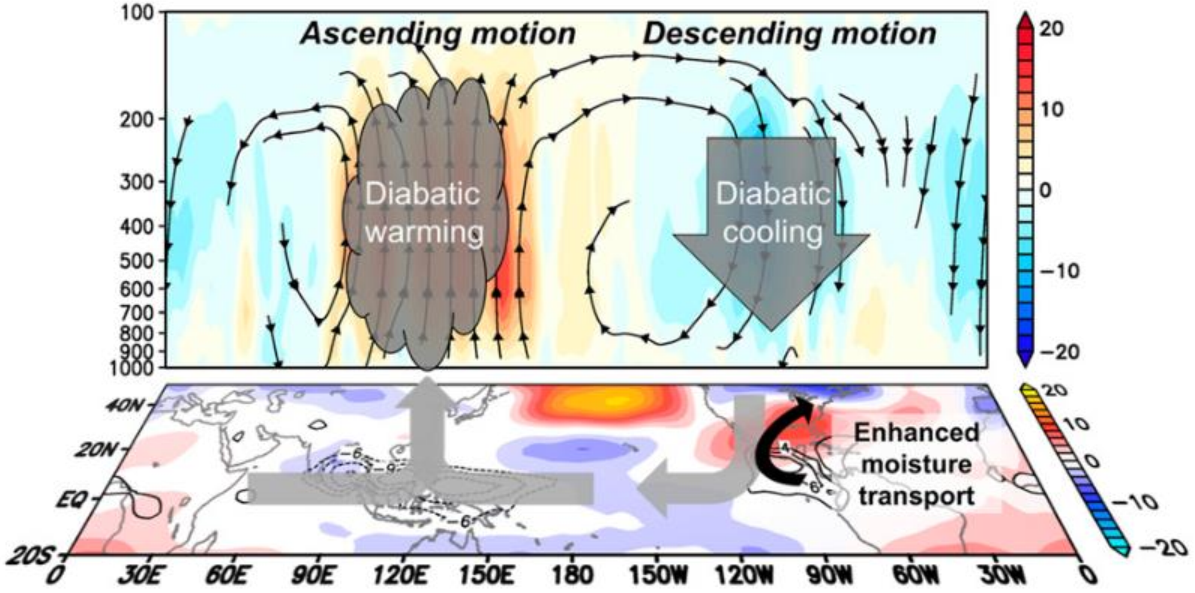


FIG. 9. (top) Schematic of spatially averaged (0°–10°N) anomalous vertical motion (omega; positive value is ascending motion; shaded; 800 Pa s^{-1}) and velocity anomaly (streamlines) during MJO P3456. (bottom) Anomalous geopotential height at 500 hPa (shaded; gpm) and OLR anomalies (contours; W m^{-2}) during MJO P3456.

El Niño-Southern Oscillation (Allen et al., 2015, 2018; Cook & Schaefer, 2008; Lee et al., 2013, 2016)

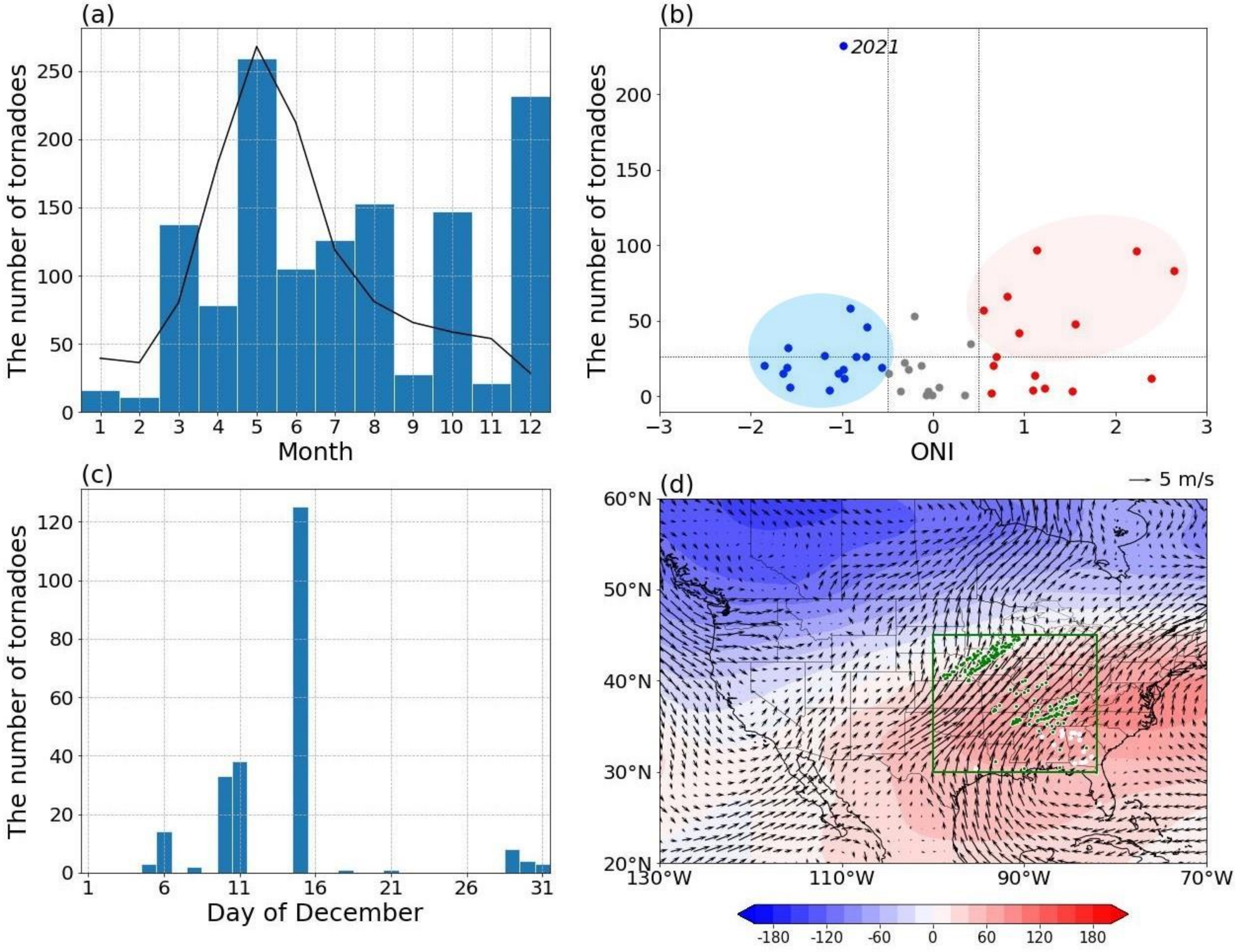
Madden-Julian Oscillation (Baggett et al., 2018; Barrett & Gensini, 2013; Barrett & Henley, 2015; Gensini et al., 2019, 2020; Kim et al., 2020; Miller et al., 2022; Moore & McGuire, 2020; Thompson & Roundy, 2013; Tippett, 2018)

Arctic ice (Trapp & Hoogewind, 2018)

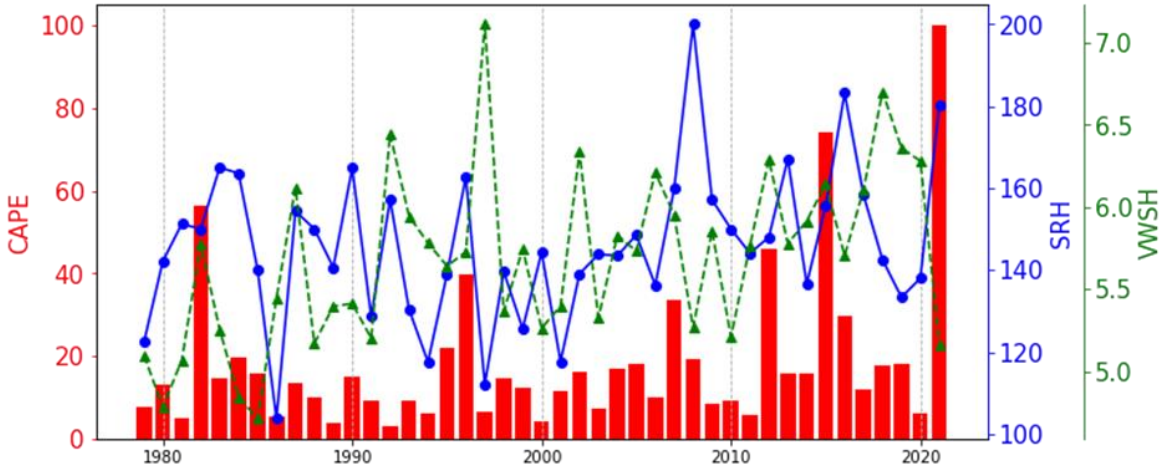
global atmospheric angular momentum (AAM) (Gensini & Marinaro, 2016; Moore & McGuire, 2020)

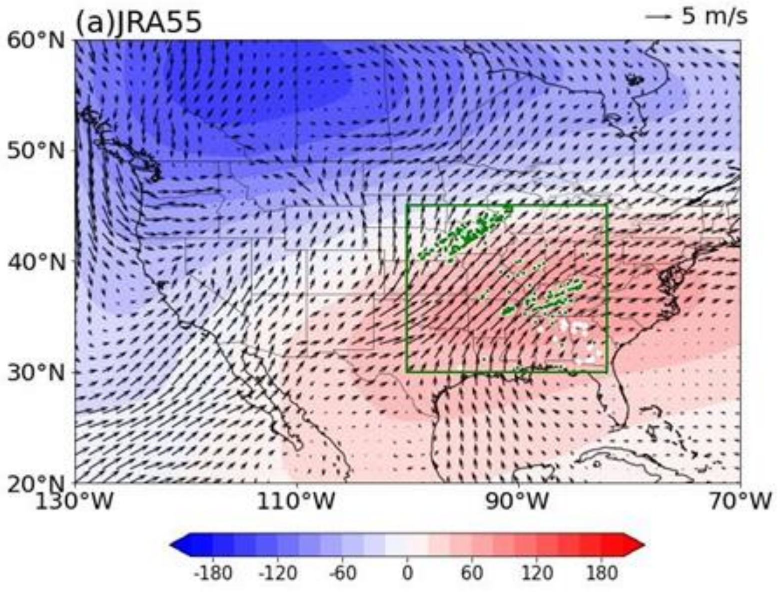
Kim, D., Lee, S.-K., & Lopez, H. (2020). Madden–Julian Oscillation–Induced Suppression of Northeast Pacific Convection Increases U.S. Tornadogenesis. *Journal of Climate*, *33*(11), 4927–4939. https://doi.org/10.1175/JCLI-D-19-0992.1

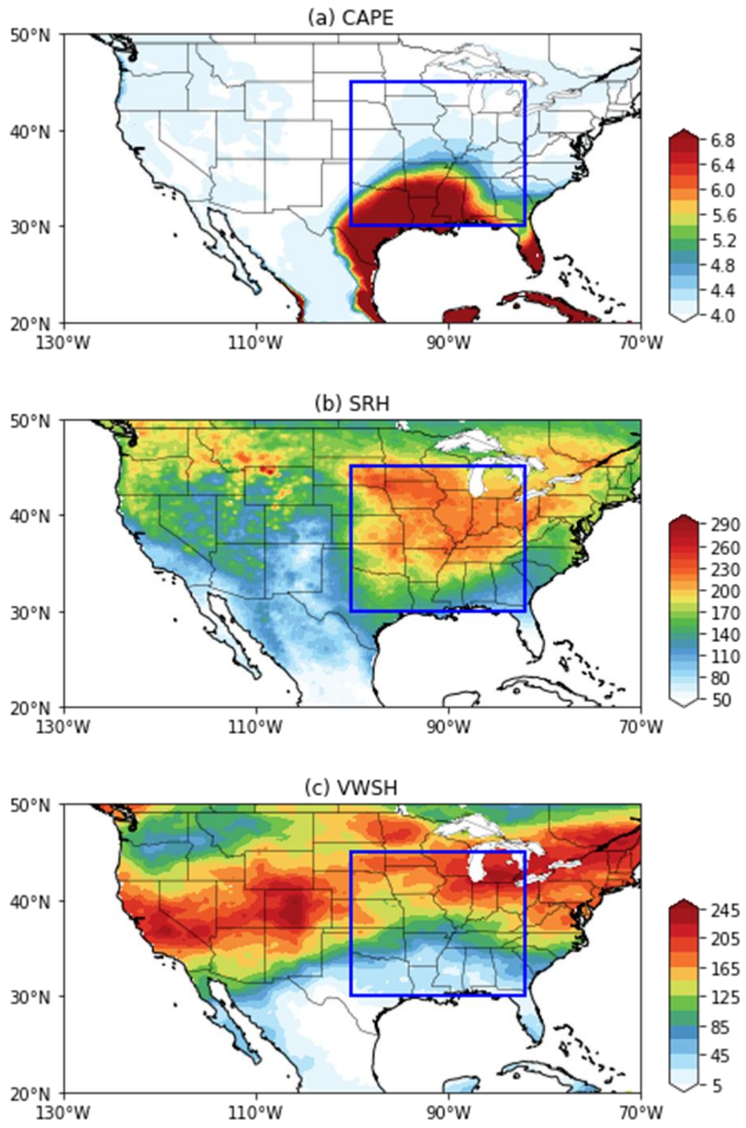
2021年12月-美国龙卷发生的主要特征



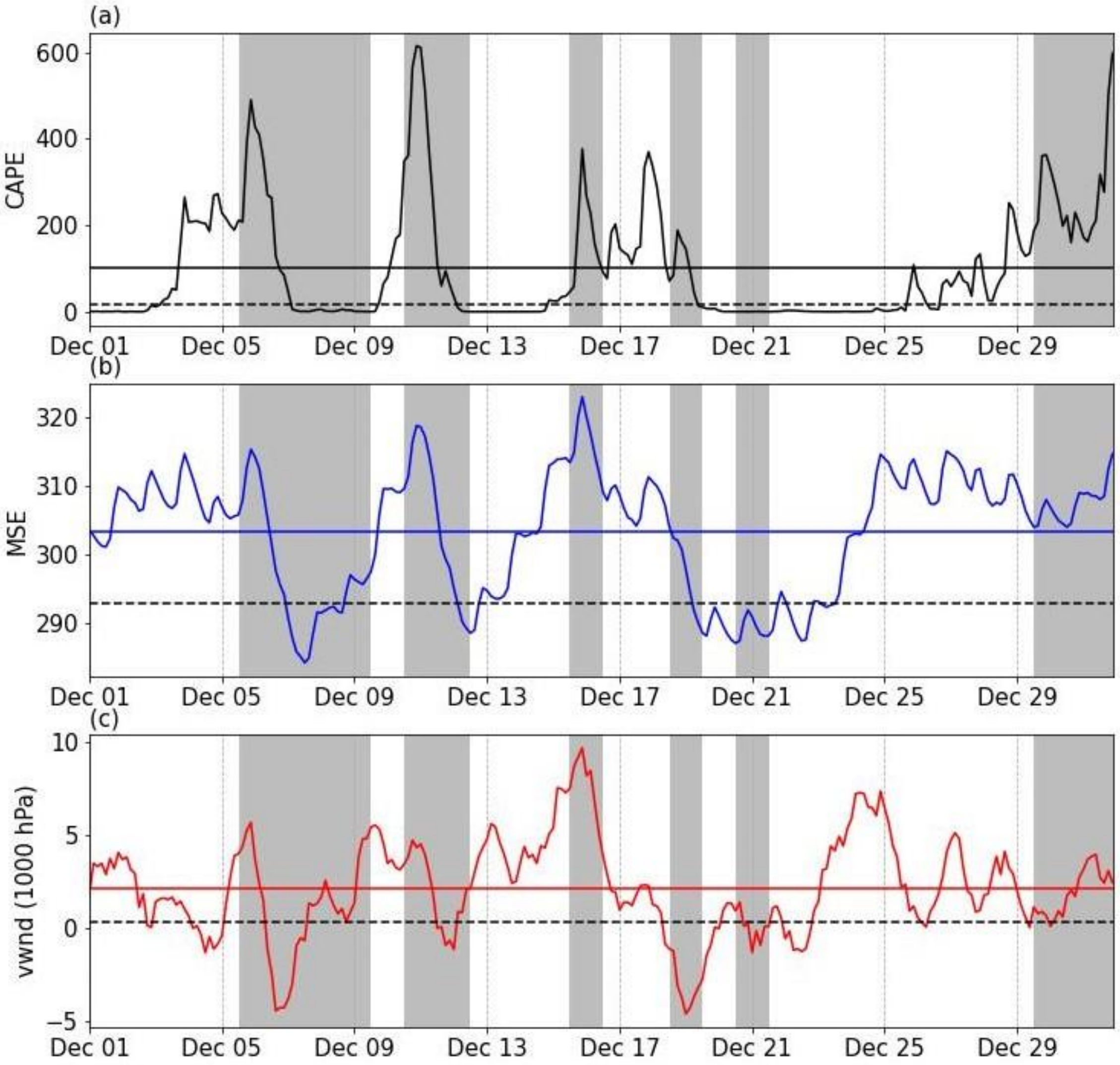
2021年12月-美国龙卷发生的主要特征







2021年12月-美国龙卷发生的主要特征



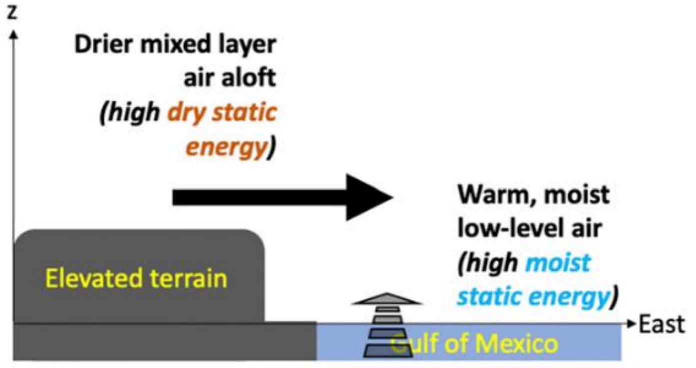


FIG. 1. Conceptual diagram of how an environment with large CAPE is generated east of the Rocky Mountains, in a static energy framework following AE17.

$$M = C_p T + L_v r + gz,$$

$$D = C_p T + gz.$$

$$\mathrm{CAPE} \sim (M_{\mathrm{BL}} - D_{\mathrm{FT}}) \ln(T_{\mathrm{LFC}}/T_{\mathrm{LNB}}).$$

Chavas, D. R., and D. T. Dawson, 2021: An idealized physical model for the severe convective storm environmental sounding. *J. Atmos. Sci.*, **78**, 653–670, https://doi.org/10.1175/JAS-D-20-0120.1.

ENSO对美国龙卷发生的影响

LETTERS
PUBLISHED ONLINE: 16 MARCH 2015 | DOI: 10.1038/NGEO2385
nature geoscience

Influence of the El Niño/Southern Oscillation on tornado and hail frequency in the United States

John T. Allen[1]*, Michael K. Tippett[2,3] and Adam H. Sobel[2,4]

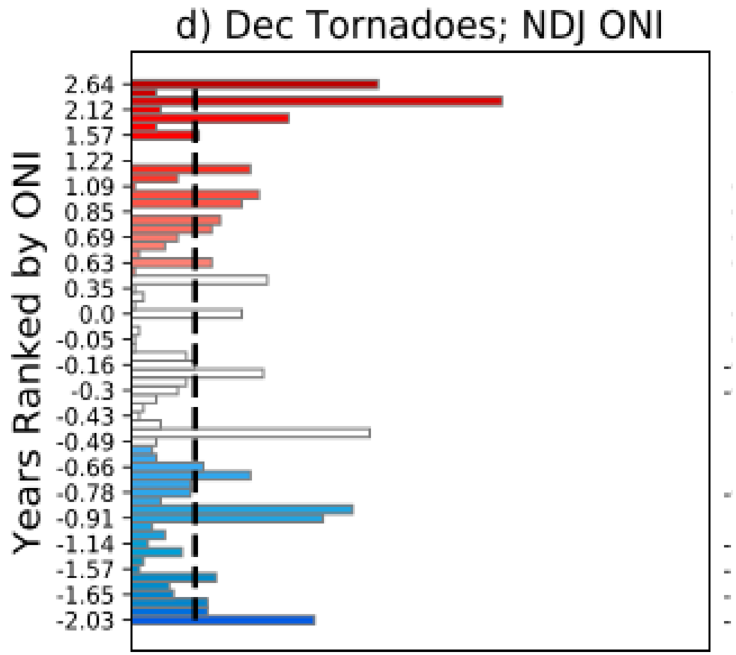
AGU100 ADVANCING EARTH AND SPACE SCIENCE
Geophysical Research Letters
RESEARCH LETTER
10.1029/2018GL077482

Key Points:
- El Niño–Southern Oscillation modulates both the timing and magnitude of the annual cycle for tornadoes
- Climate variability plays a substantial role in the characteristics of the annual cycle of tornadoes

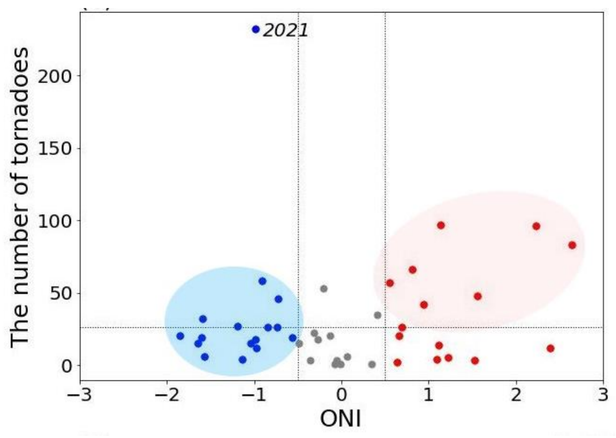
Modulation of Annual Cycle of Tornadoes by El Niño–Southern Oscillation

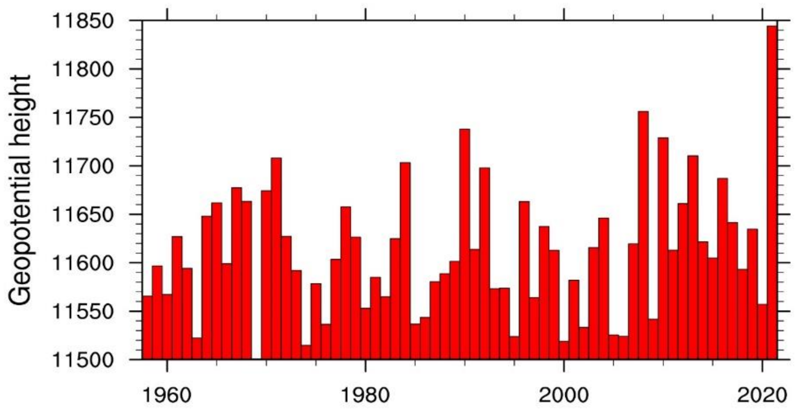
John T. Allen[1], Maria J. Molina[1], and Vittorio A. Gensini[2]

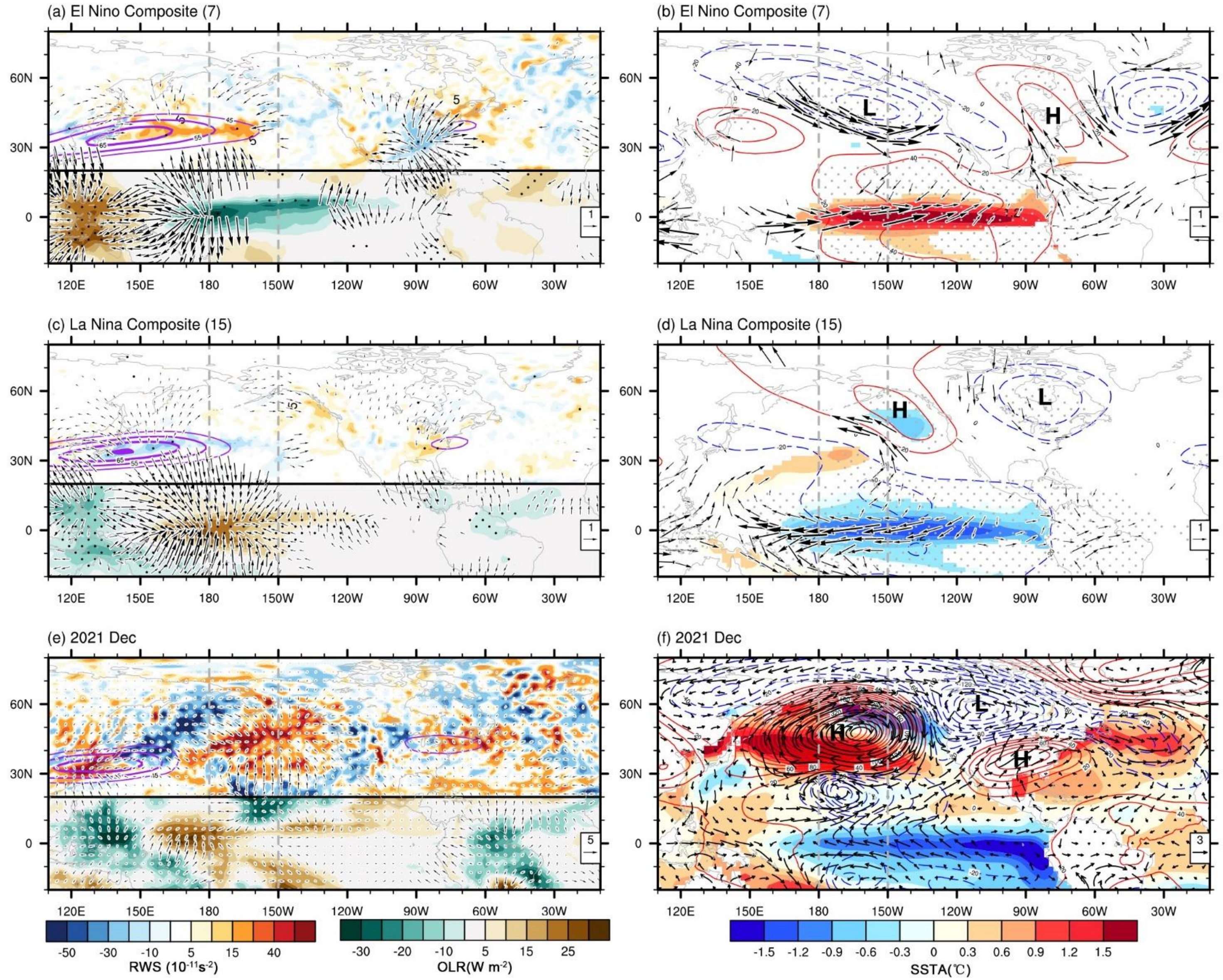
[1]Department of Earth and Atmospheric Sciences, Central Michigan University, Mount Pleasant, MI, USA, [2]Department of Geographic and Atmospheric Sciences, Northern Illinois University, DeKalb, IL, USA



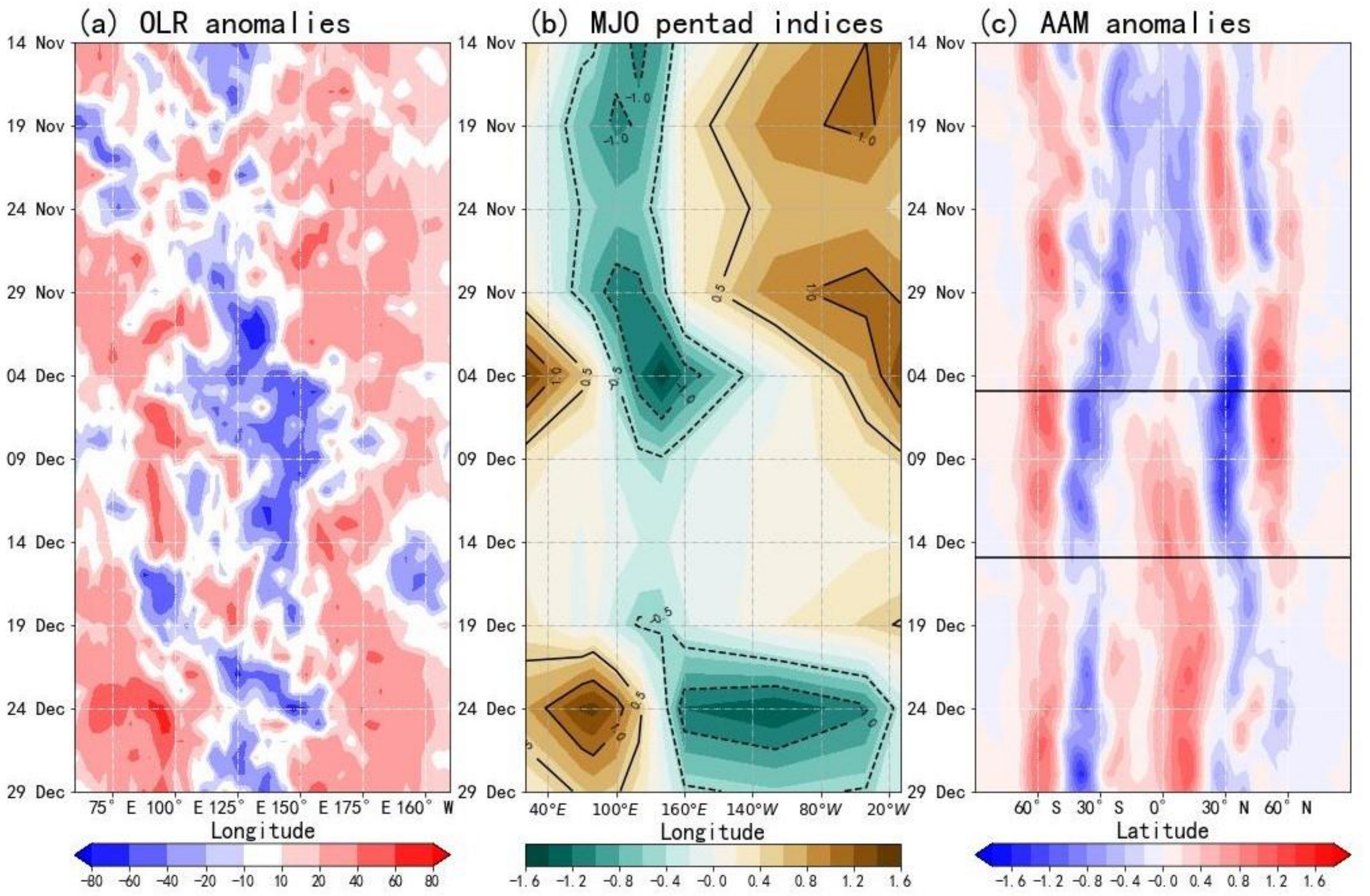
ENSO对美国龙卷发生的影响







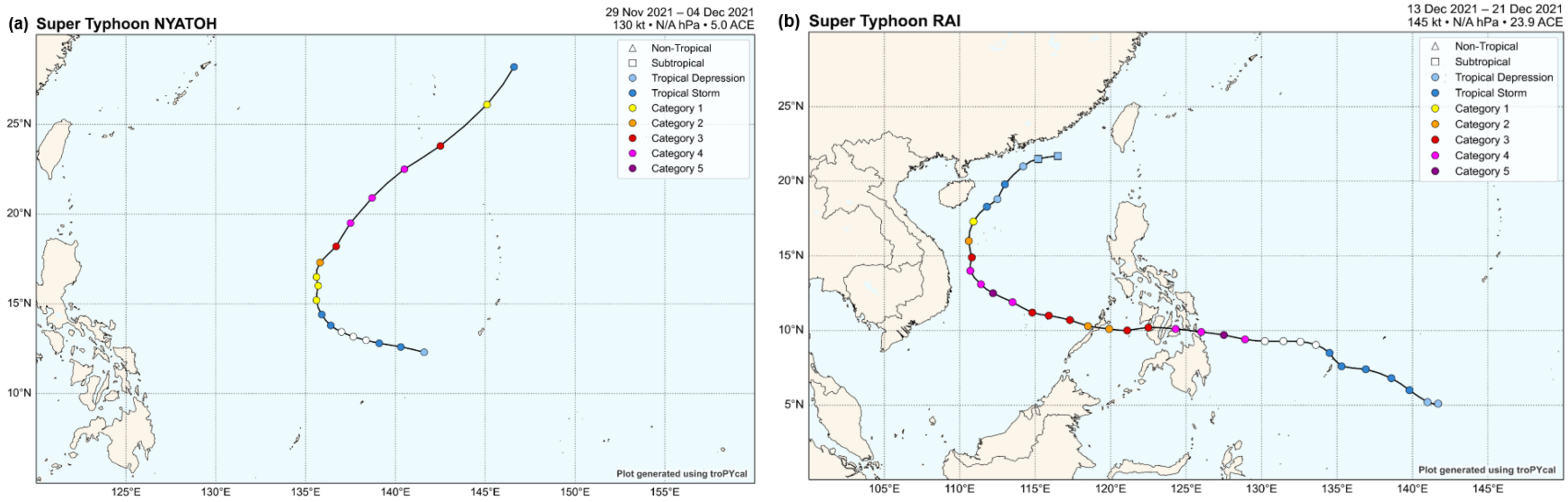
次季节演变特征

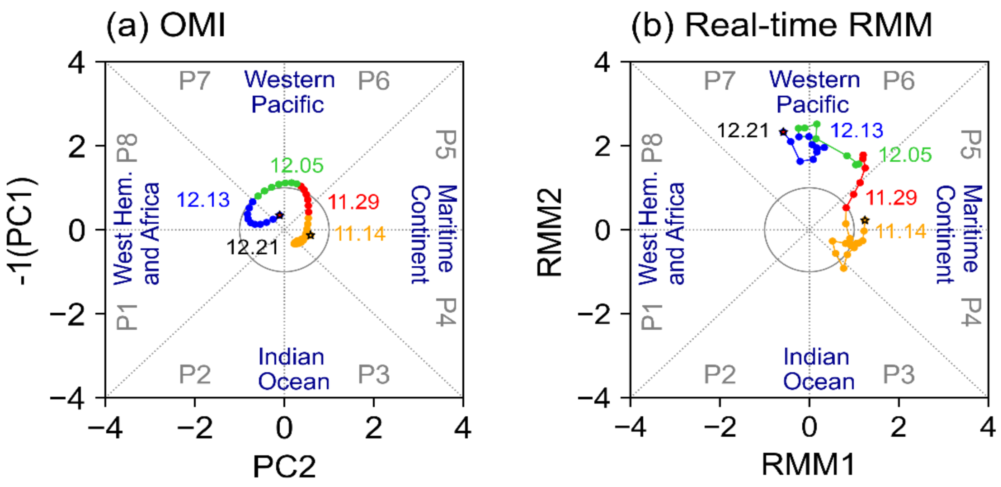


Gensini, V. A., Barrett, B. S., Allen, J. T., Gold, D., & Sirvatka, P. (2020). The extended-range tornado activity forecast (ERTAF) project. *Bulletin of the American Meteorological Society*, *101*(6), E700–E709.

Miller, D. E., Gensini, V. A., & Barrett, B. S. (2022). Madden-Julian oscillation influences United States springtime tornado and hail frequency. Npj Climate and Atmospheric Science, 5(1).

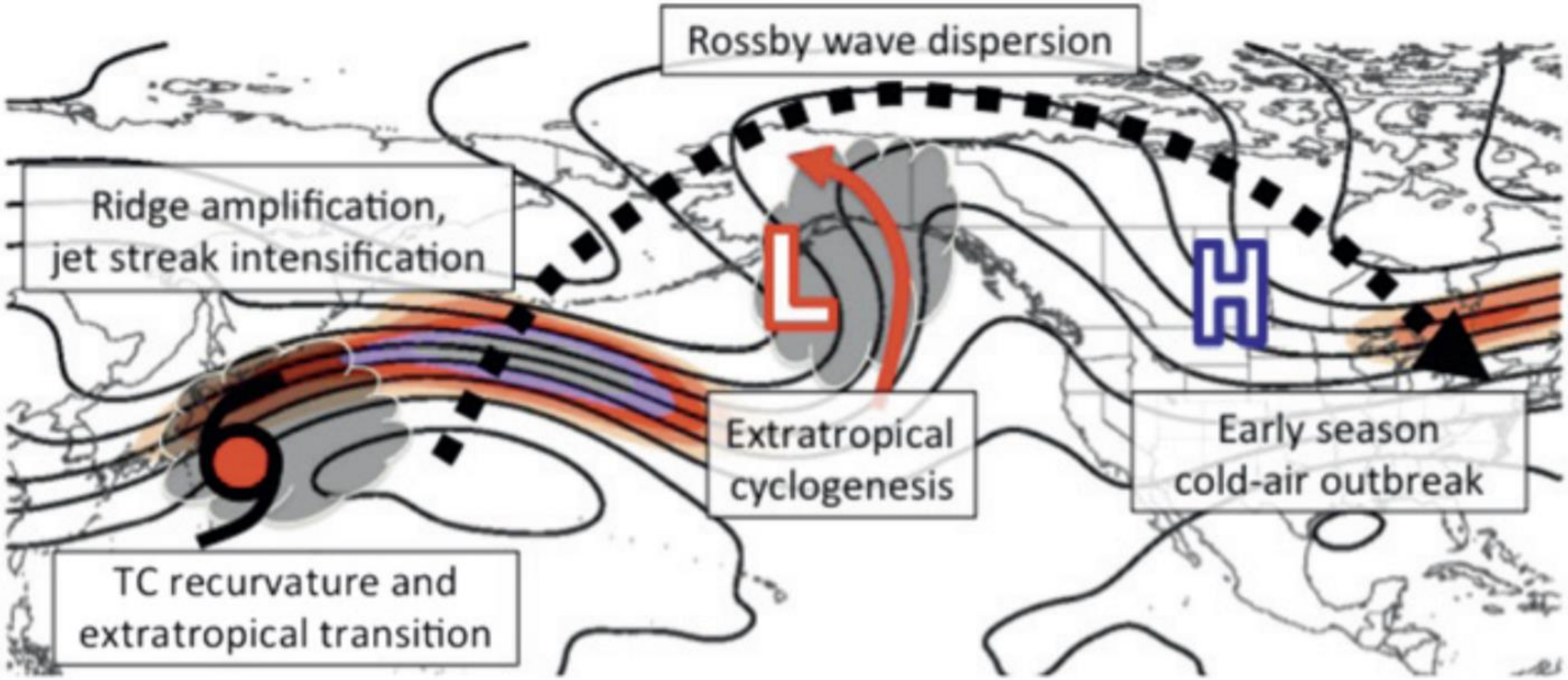
次季节演变特征





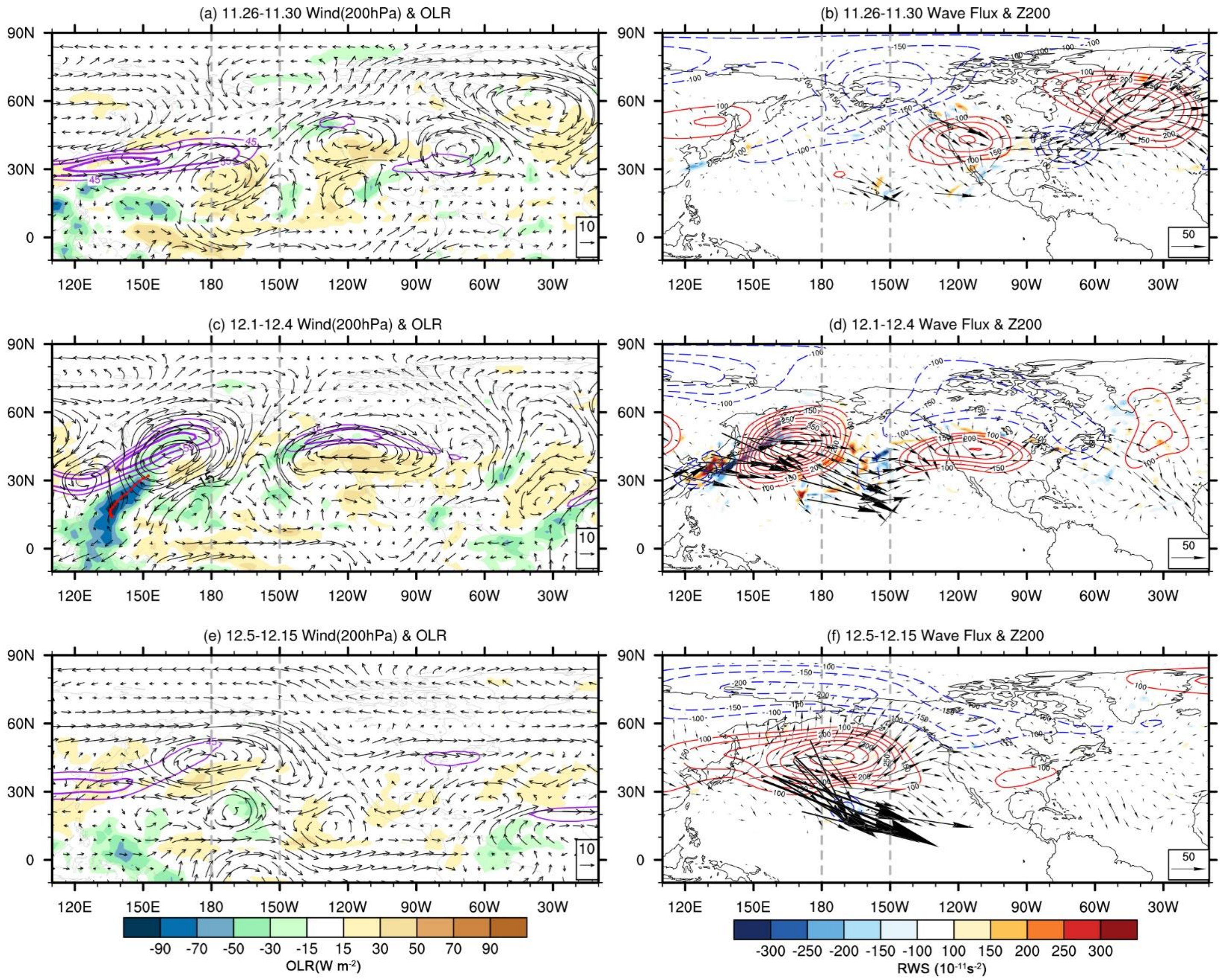
Kiladis, G. N., Dias, J., Straub, K. H., Wheeler, M. C., Tulich, S. N., Kikuchi, K., Weickmann, K. M., & Ventrice, M. J. (2014). A comparison of OLR and circulation-based indices for tracking the MJO. *Monthly Weather Review*, *142*(5), 1697–1715. https://doi.org/10.1175/MWR-D-13-00301.1

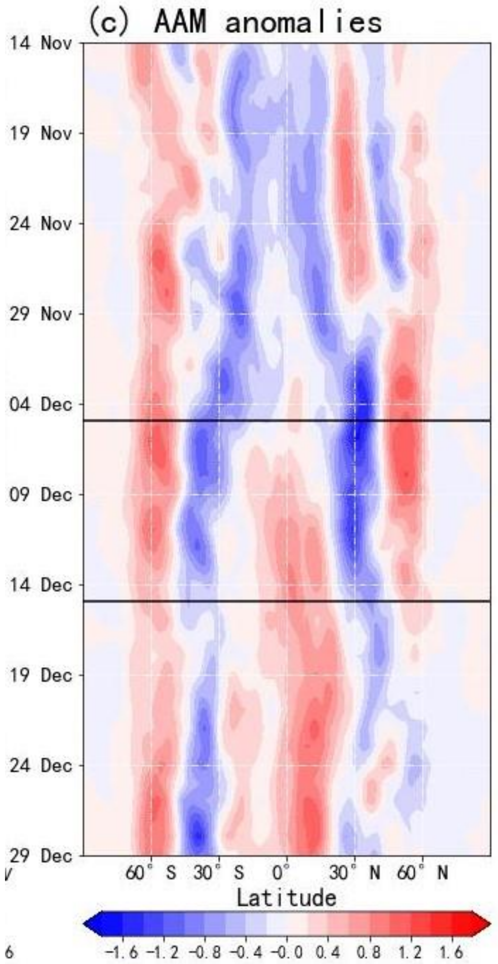
次季节演变特征



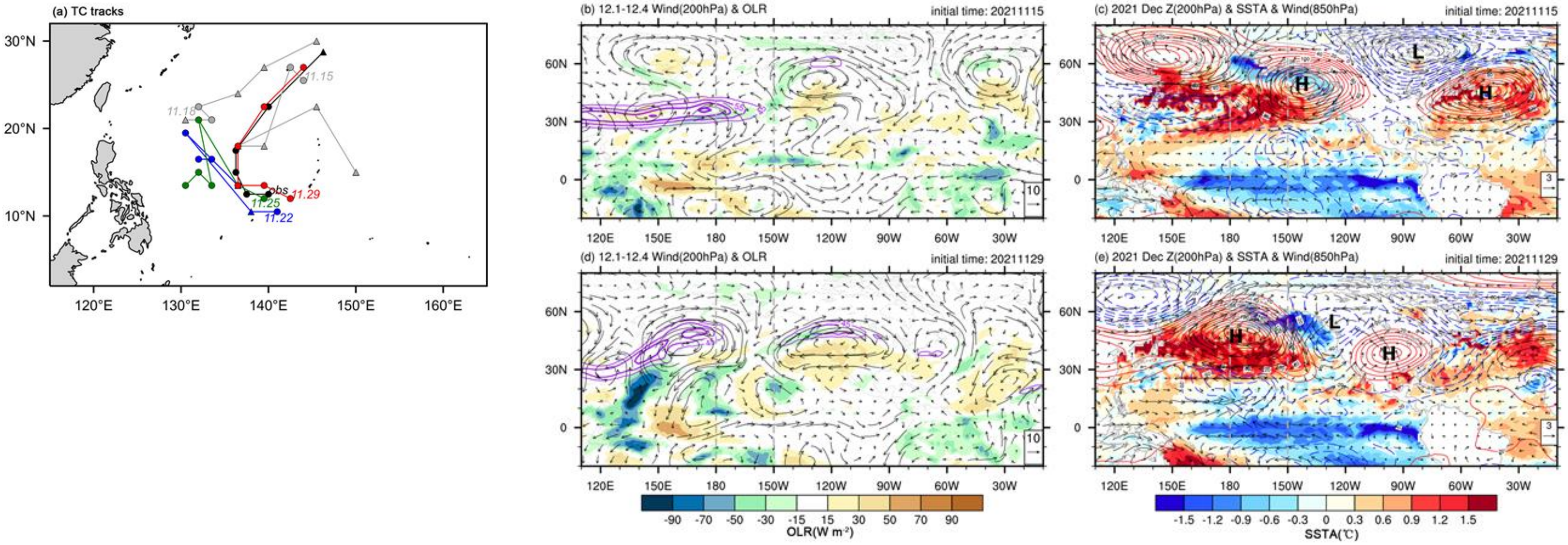
Archambault, H. M., Bosart, L. F., Keyser, D., & Cordeira, J. M. (2013). A Climatological Analysis of the Extratropical Flow Response to Recurving Western North Pacific Tropical Cyclones. *Monthly Weather Review*, *141*(7), 2325–2346. https://doi.org/10.1175/MWR-D-12-00257.1

次季节演变特征


(a) 11.26-11.30 Wind(200hPa) & OLR
(b) 11.26-11.30 Wave Flux & Z200
(c) 12.1-12.4 Wind(200hPa) & OLR
(d) 12.1-12.4 Wave Flux & Z200
(e) 12.5-12.15 Wind(200hPa) & OLR
(f) 12.5-12.15 Wave Flux & Z200
90N 60N 30N 0
120E 150E 180 150W 120W 90W 60W 30W
-90 -70 -50 -30 -15 15 30 50 70 90
OLR(W m-2)
-300 -250 -200 -150 -100 100 150 200 250 300
RWS (10-11s-2)

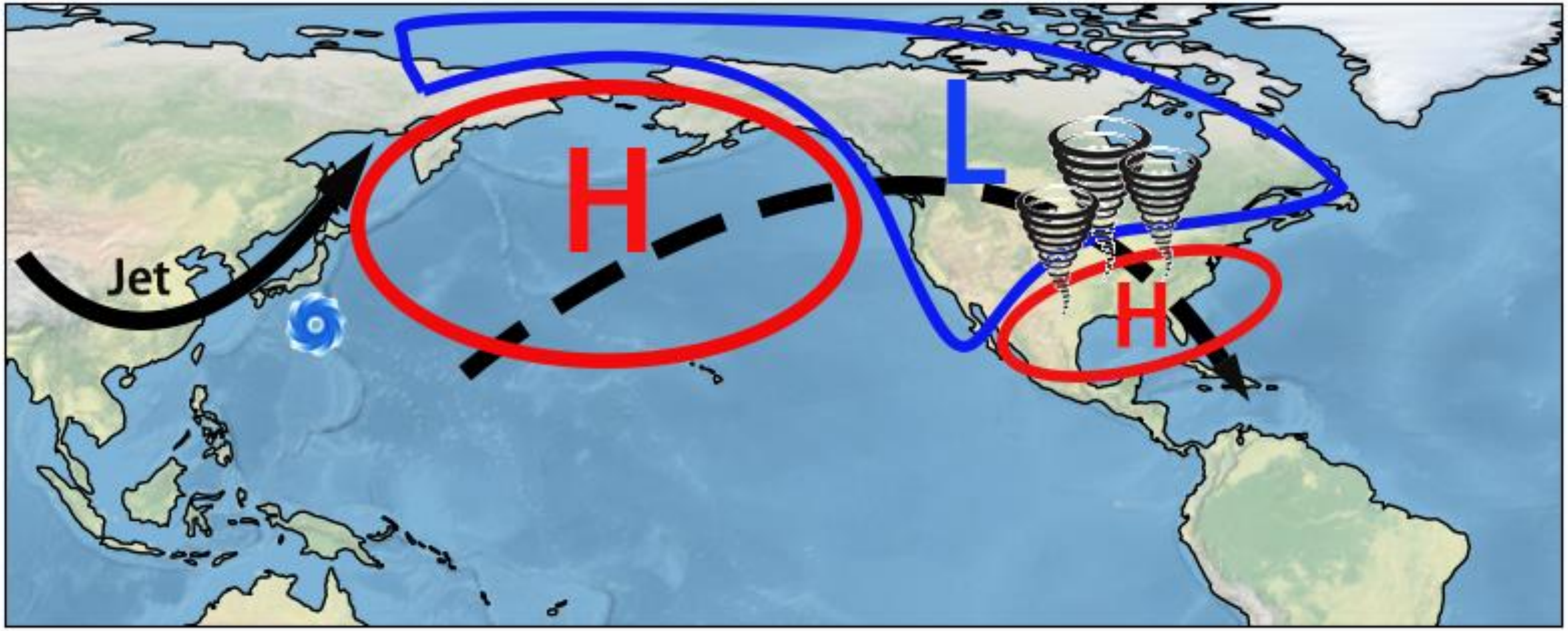

(c) AAM anomalies
14 Nov
19 Nov
24 Nov
29 Nov
04 Dec
09 Dec
14 Dec
19 Dec
24 Dec
29 Dec
60° S 30° S 0° 30° N 60° N
Latitude
-1.6 -1.2 -0.8 -0.4 -0.0 0.4 0.8 1.2 1.6

次季节演变特征



(a) TC tracks
30°N
20°N
10°N
120°E
130°E
140°E
150°E
160°E
11.15
11.18
11.22
11.25
11.29
obs
(b) 12.1-12.4 Wind(200hPa) & OLR
initial time: 20211115
(c) 2021 Dec Z(200hPa) & SSTA & Wind(850hPa)
initial time: 20211115
(d) 12.1-12.4 Wind(200hPa) & OLR
initial time: 20211129
(e) 2021 Dec Z(200hPa) & SSTA & Wind(850hPa)
initial time: 20211129
60N
30N
0
120E
150E
180
150W
120W
90W
60W
30W
H
L
-90 -70 -50 -30 -15 15 30 50 70 90
OLR(W m⁻²)
-1.5 -1.2 -0.9 -0.6 -0.3 0 0.3 0.6 0.9 1.2 1.5
SSTA(℃)

总结



Jiang N., Liu B., Zhu C., Chen Y., 2023: Remote linkage of record-breaking U.S. Tornado outbreaks to the tropical cyclone in western North Pacific in December 2021. *Environmental Research Letters*, 18, 044036.