Revision Log

Updated from the 04 May 2026 version:

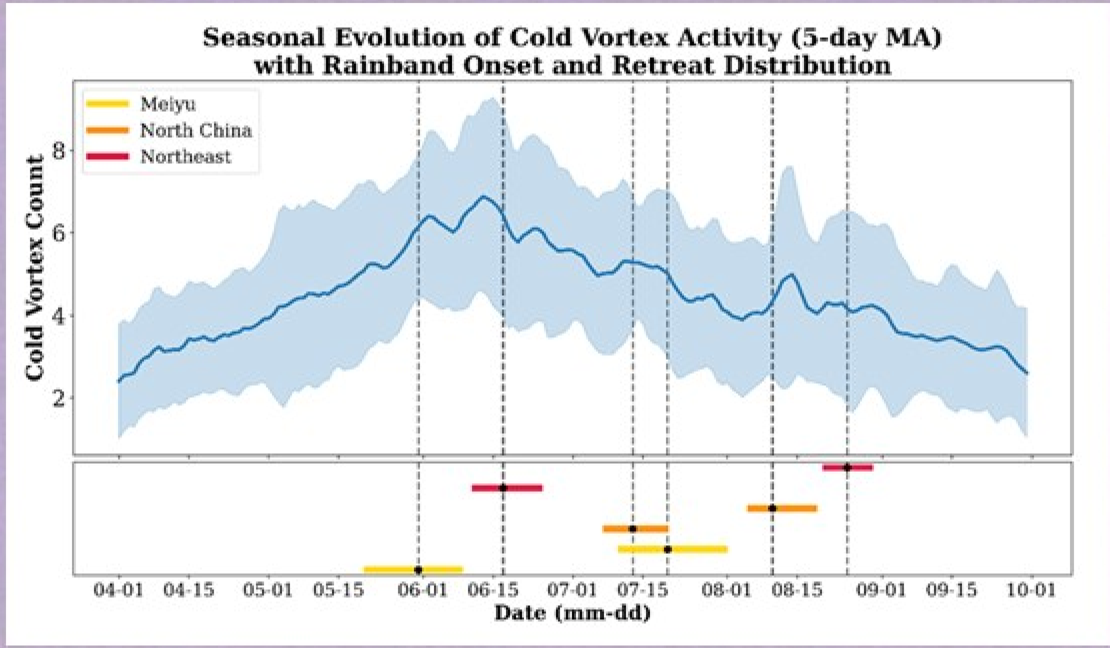
20260513

- Corrected “NCEP5” to “NCEP” on the “NCCV Identification Method” slide.
- Added “Typical Size of a Cut-off Low” to the “NCCV Identification Method” slide.
- Added the data temporal resolution (daily) and spatial resolution to the “Summer Rain-Belt Index Calculation” slide.
- Rephrased and enlarged the reference title on the “Summer Rain-Belt Index Calculation” slide.
- Added the mean onset date, end date, total precipitation of the rain belt on the “Summer Rain-Belt Index Calculation” slide.
- Marked the starting page of the difference analysis, indicating that ERA5 monthly mean data are used in subsequent analyses.

Addition The frequent occurrence period of the Northeast China Cold Vortex coincides with the East Asian summer monsoon rain-belt precipitation period, which provides a basis for this study.

Future work

- Share the methods for calculating the Northeast China Cold Vortex and the main summer rain-belt indices over eastern China, along with the related statistical analyses, as a preprint, and release the code on GitHub.
- Submit this study to a peer-reviewed journal.



EGU26 GENERAL ASSEMBLY

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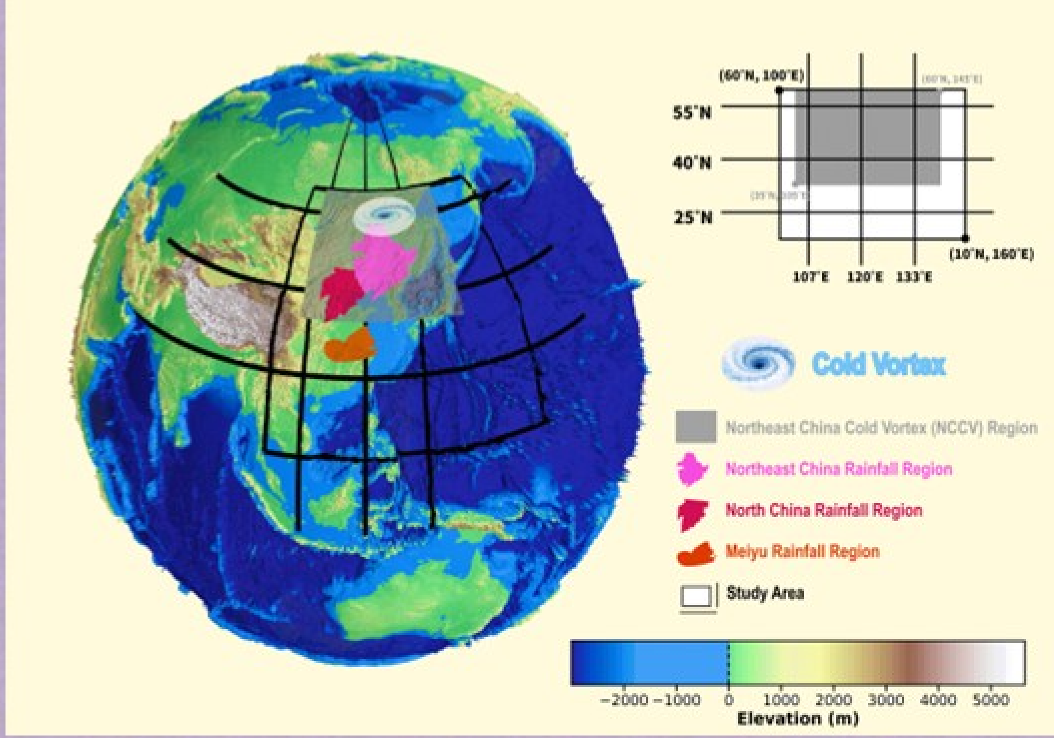

EGU26-8760 | ECS | Orals | AS1.28

Mon, 04 May, 08:55–09:05 (CEST) Room 1.61/62

When Mid–High Latitude Systems Meet the Monsoon:

How the Northeast China Cold Vortex *Regulates* Summer Rain-Belt Timing and Meridional Shifts

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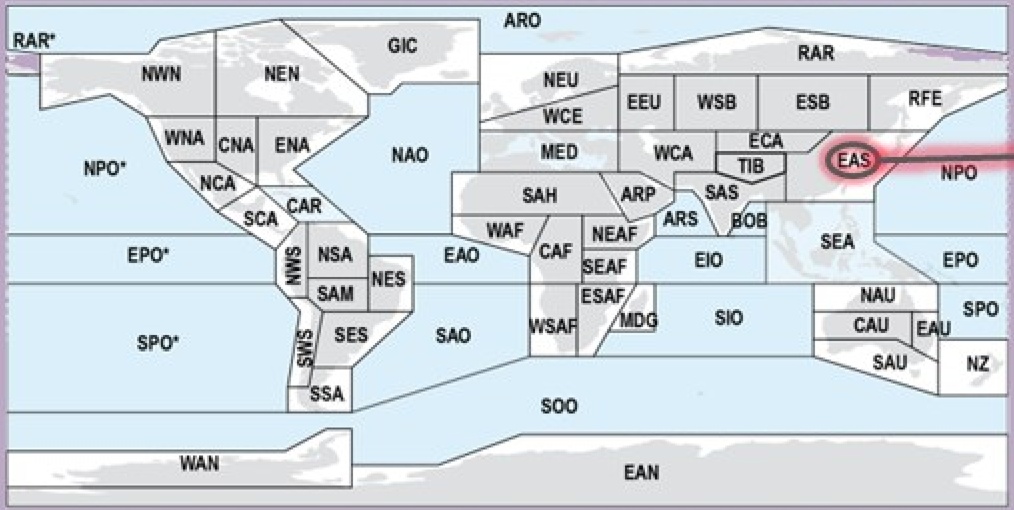
Introduction

I focus on the climate over **East Asia**. The main systems affecting this region are the monsoon and the mid–high latitude westerlies. Both are important parts of the global atmospheric circulation.

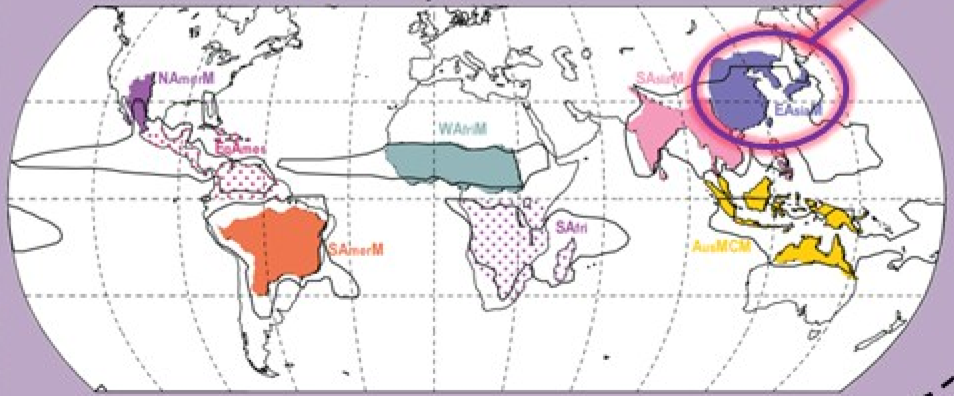
Due to the large Pacific Ocean and the high Himalaya mountains, the East Asian monsoon and cutoff lows in the westerlies are especially active.

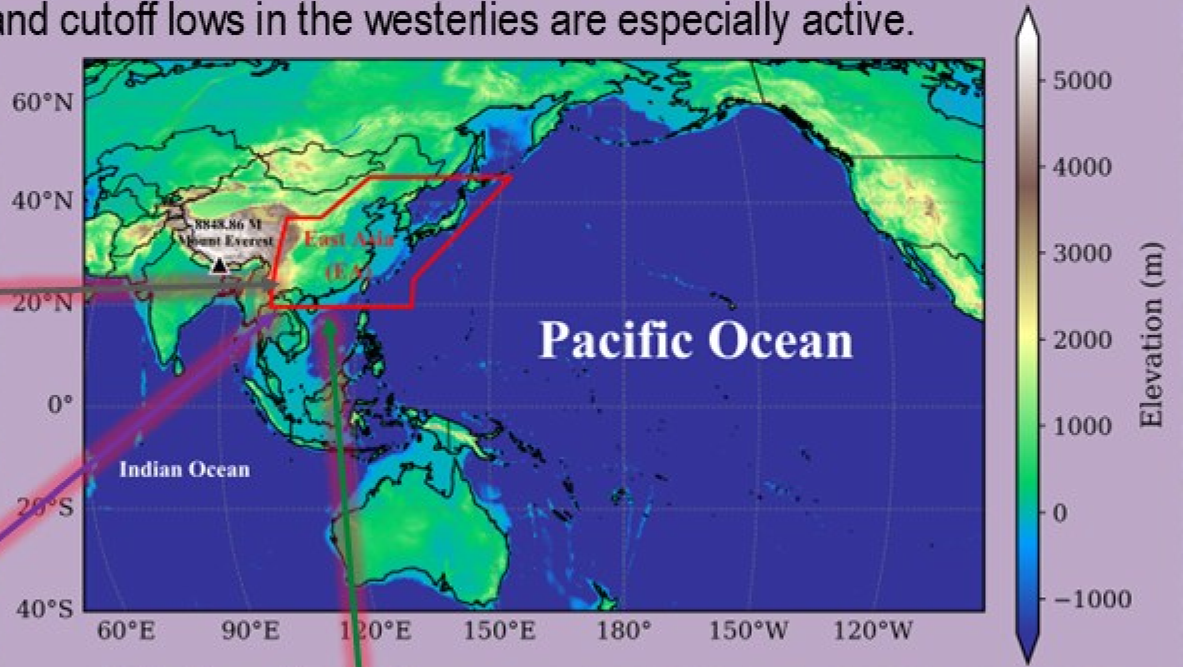
Source: IPCC AR6 (2021)

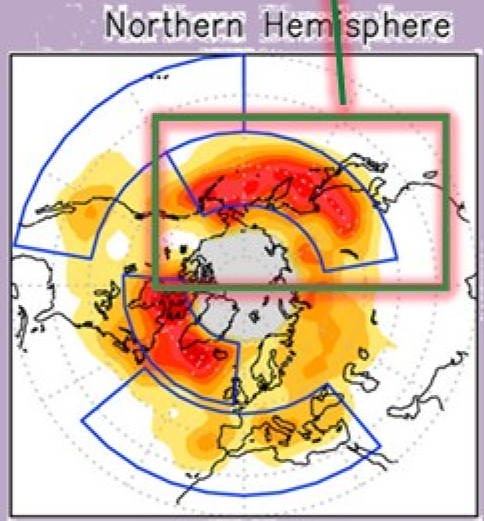
IPCC-AR6 WGI Reference Regions



Global and regional monsoon domains





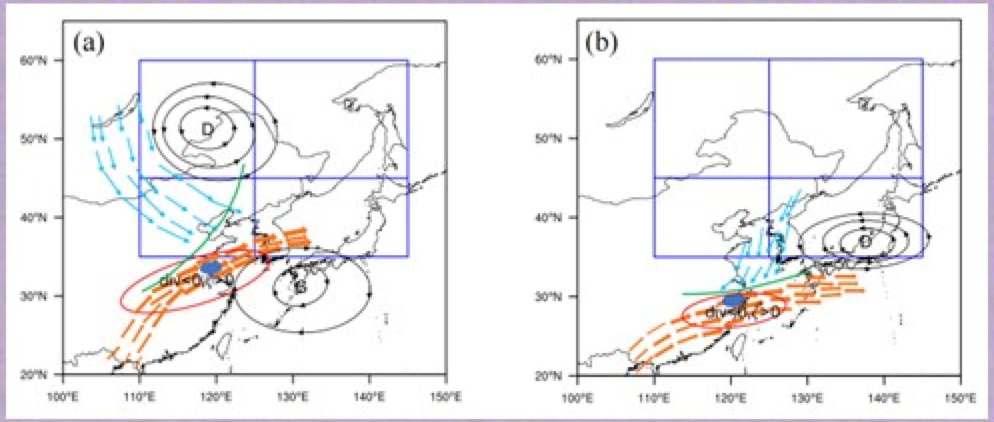


Spatial Distribution of 200-hPa Cut-Off Lows

Cut-off lows are isolated vortices embedded within the westerlies.

Source: Muñoz et al. (2020)

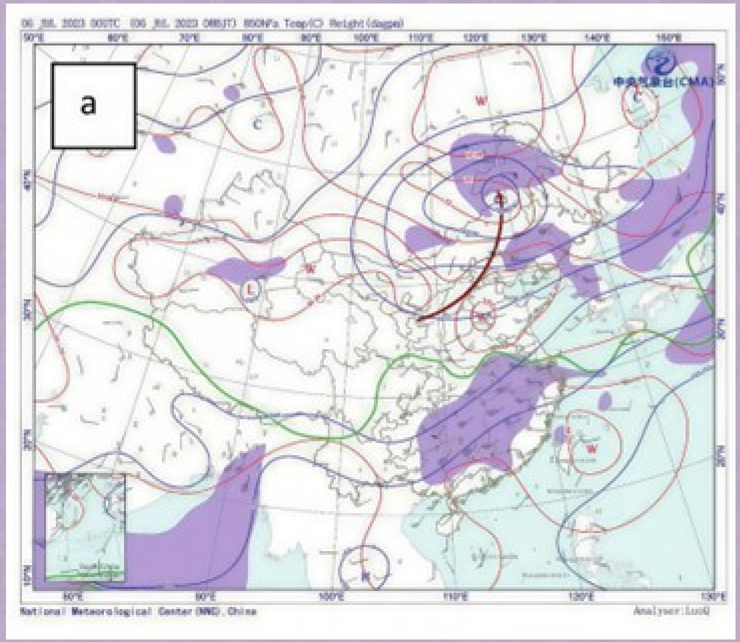
Previous studies show that mid–high latitude systems interact with East Asian summer monsoon rainfall. But the detailed mechanisms are still unclear.



Conceptual model of how NCCV genesis location affects the spatial distribution of Jianghuai Meiyu rainfall

(a) Northwest-shifted NCCV; (b) Southeast-shifted NCCV

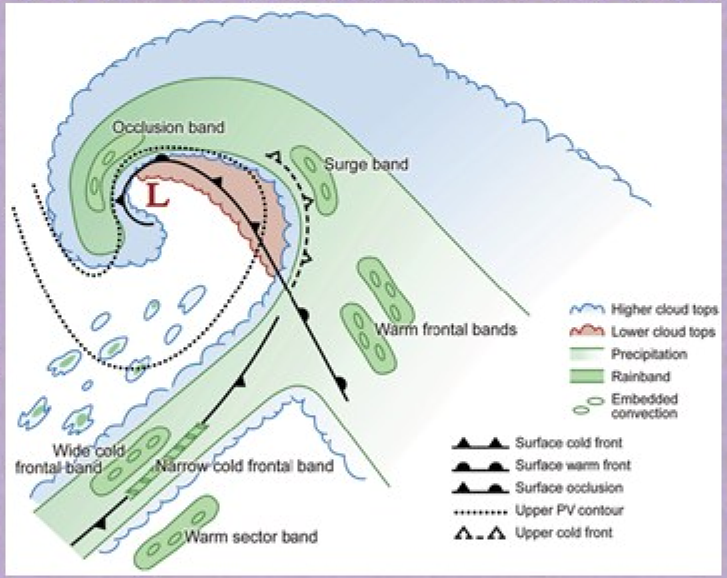
Source: Huang (2020) 黄璇 (2020)



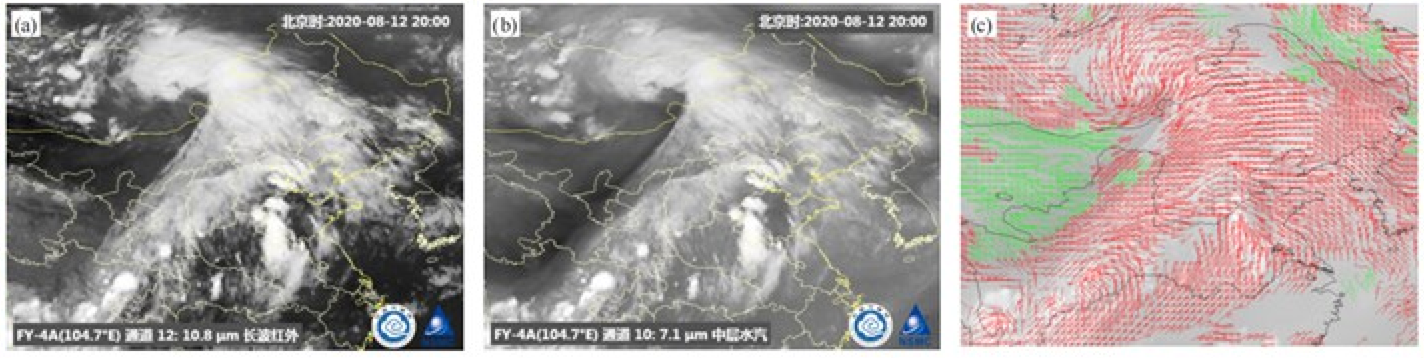
850-hPa synoptic field at 08:00 on 6 July 2023 (a), during an active Northeast China Cold Vortex(NCCV) event

Source: Fu et al. (2024) 付洪泰 (2024)

Idealization of the cloud and precipitation pattern associated with a mature extratropical cyclone.



Source: Houze et al. (2014)



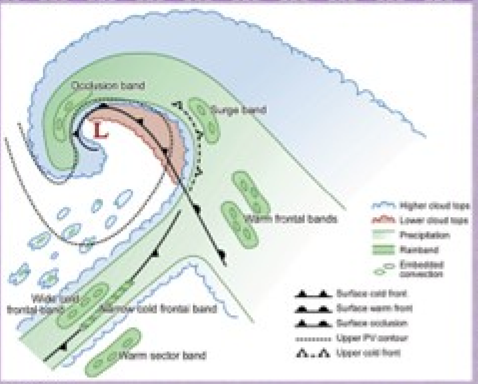
Weather map at 12:00 UTC 12 August 2020

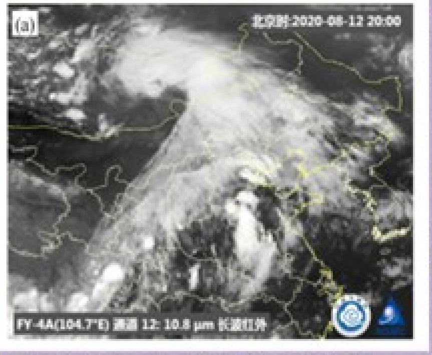
(a) FY-4A 10.8 μm infrared image, (b) FY-4A 7.1 μm water vapor image, (c) FY-2G 6.9 μm water vapour motion wind

Source: Xv (2021) 许建民 (2021)

Idealization of the cloud and precipitation pattern associated with a mature extratropical cyclone.

Source: Houze et al. (2014)





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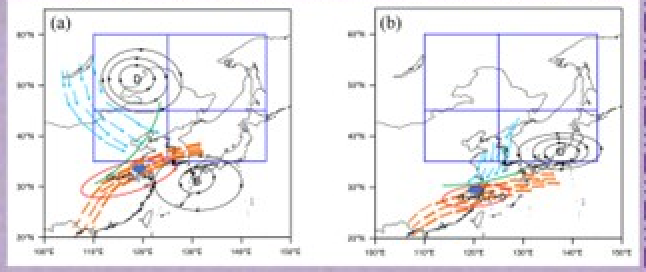

Conceptual model of how NCCV genesis location affects the spatial distribution of Jianghuai Meiyu rainfall

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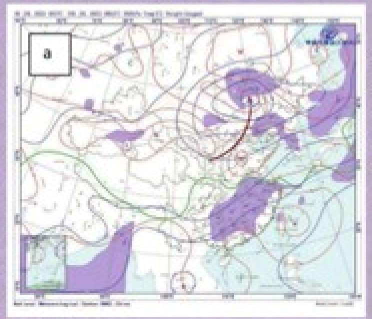
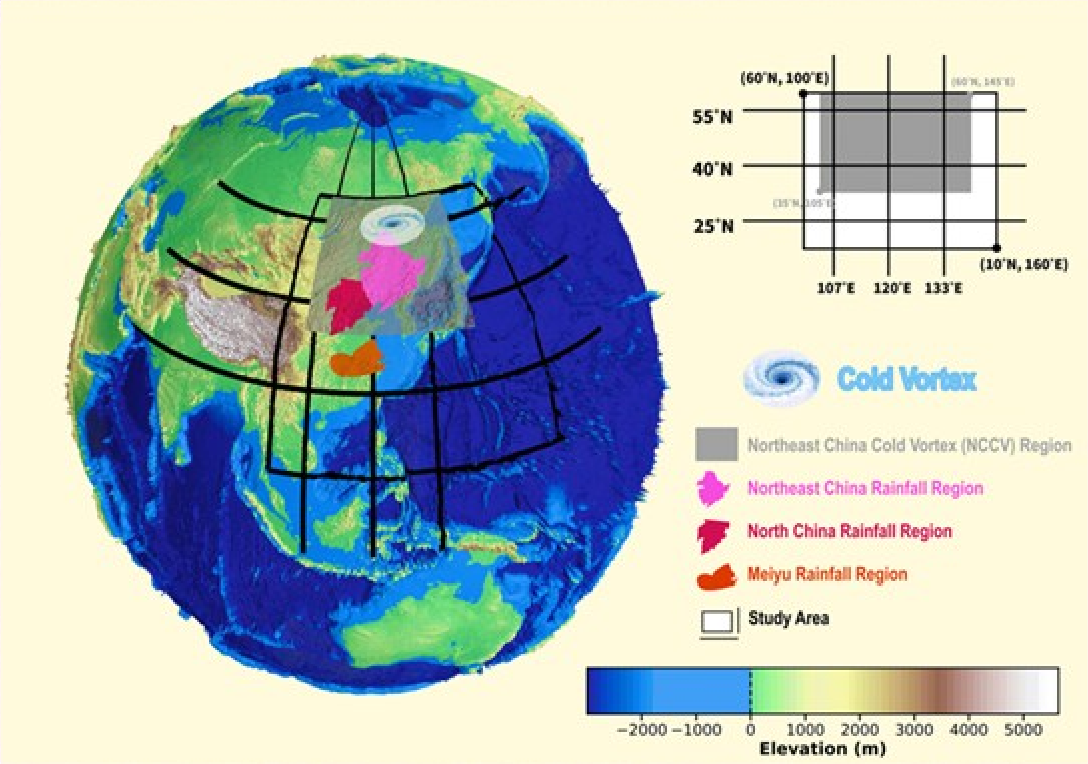
Source: Huang (2020)_黄璇 (2020)



850-hPa synoptic field at 08:00 on 6 July 2023 (a), during an active Northeast China Cold Vortex(NCCV) event

Source: Fu et al. (2024) 付洪泰 (2024)

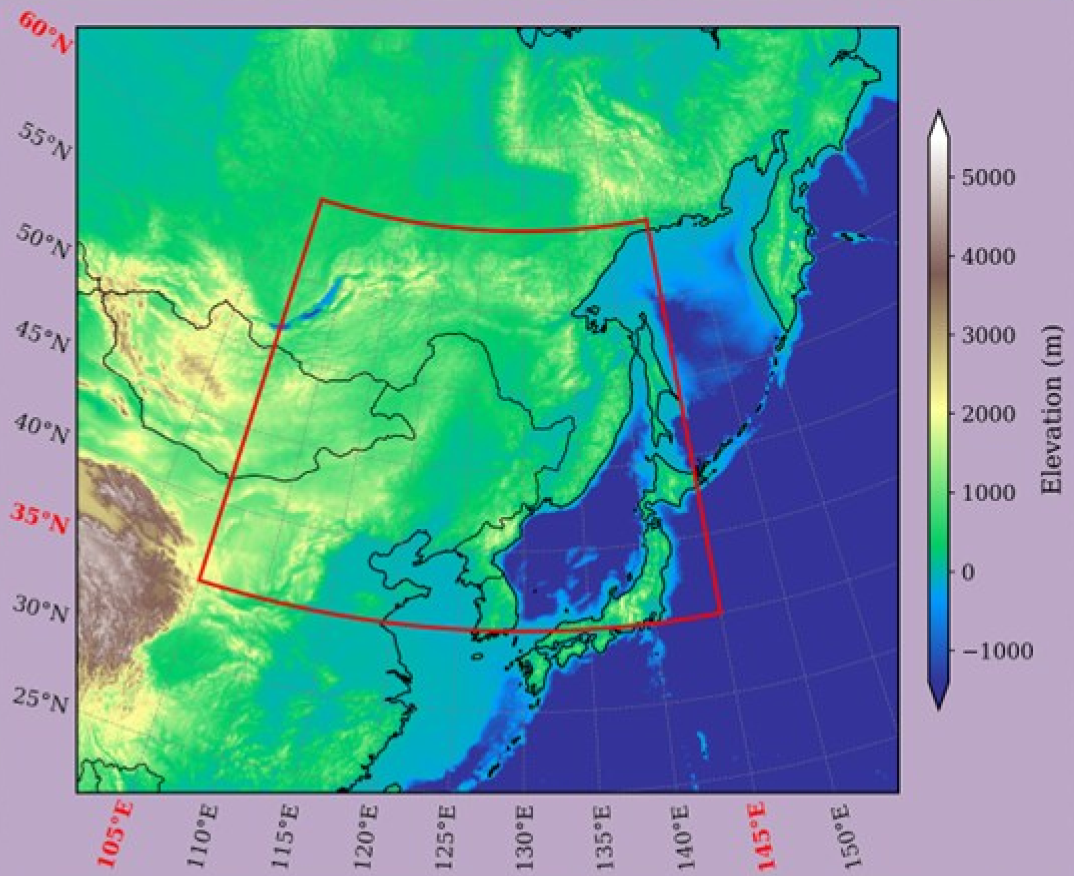


Northeast China Cold Vortex(NCCV) is a cut-off low over East Asia

In this study, we use Northeast China Cold Vortex(NCCV) to represent *cutoff lows*, and the main summer rainfall belts in eastern China to represent the *monsoon*.

We then analyze their relationship and the structure of the corresponding atmospheric circulation.

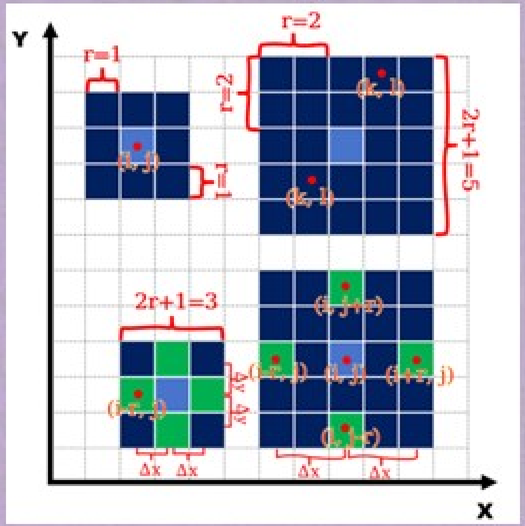
NCCV Identification Method



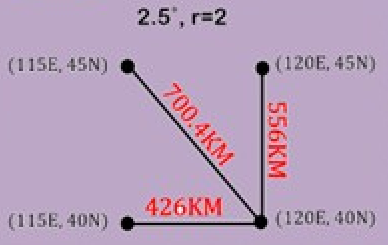
This study identifies Northeast China Cold Vortex events using ERA5, CRA, and NCEP datasets. Based on 500 hPa geopotential height and temperature, a total of 15 sets of cold vortex center frequency are extracted following this method.

- **Data used**

Dataset Name	Spatial Resolution	Temporal Resolution	Time Range	r	α
CRA	0.25° × 0.25°	Daily	1979-2023	1-5	1
ERA5	0.25° × 0.25°	Daily	1940-2024	1-5	1
NCEP/NCAR	2.5° × 2.5°	Daily	1948-2024	1-3	1/0.9/0.75



Typical Size of a Cut-off Low
300KM-800KM



For each grid point (i, j) within the study region, a two-dimensional neighborhood $\mathcal{N}_{(i,j)}(r)$ with radius r is defined, centered at (i, j). This neighborhood contains $(2r+1)\times(2r+1)-1$ surrounding grid points (excluding the center point). The 500-hPa geopotential height at the center is denoted as $Z_{(i,j)}$, and those at neighboring grid points are denoted as $\{Z_{(k,l)}\}$.

$$\frac{1}{|\mathcal{N}_{i,j}(r)|}\sum_{(k,l)\in\mathcal{N}_{i,j}(r)} 1\{Z_{i,j} < Z_{k,l}\} \geq \alpha$$

$$\nabla^2 T_{i,j} = \frac{T_{i+r,j} - 2T_{i,j} + T_{i-r,j}}{(\Delta x)^2} + \frac{T_{i,j+r} - 2T_{i,j} + T_{i,j-r}}{(\Delta y)^2} > 0$$

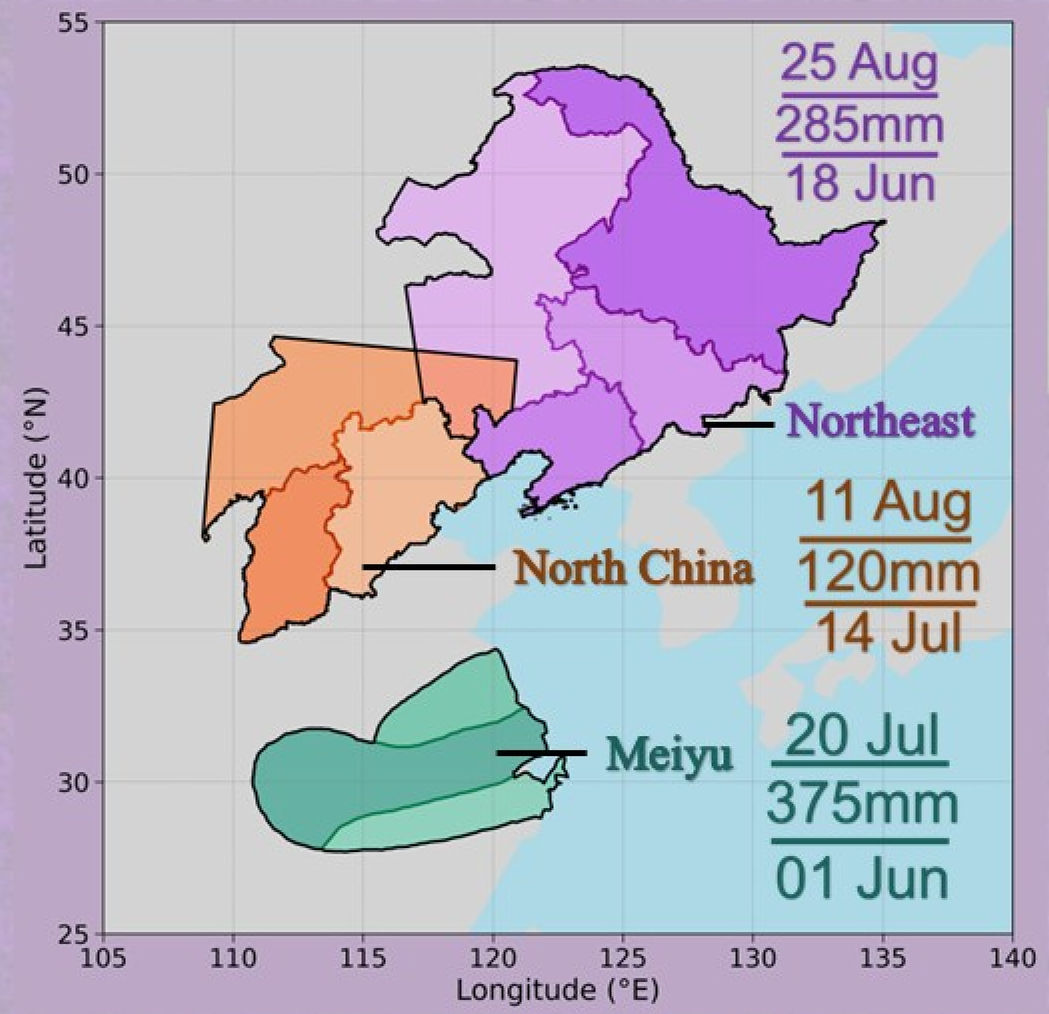
output

CRA： ['C1', 'C2', 'C3', 'C4', 'C5'],
ERA5： ['E1', 'E2', 'E3', 'E4', 'E5'],
NCEP： ['N2', 'N3', 'N4', 'N11', 'N12']

PS: A01, A02

Summer Rain-Belt Index Calculation

The main summer rain belts over eastern China include the Meiyu, the North China rain belt, and the Northeast China rain belt. In this study, we follow the identification method defined by the industry standard issued by the China Meteorological Administration. Five datasets are used in the calculation.



Daily data used to calculate rain-belt indices

Spatial resolution 0.25° \0.1 ° \0.25 ° \0.5 ° \2.5 °

CMA\MSWEP\ERA5\CPC\NCEP

Meiyu monitoring indices

Monitoring indices of rainy season in China—Rainy season in North China

Monitoring indices of rainy season in China—Rainy season in Northeast China

For each rain belt, we obtain the annual start date, end date, rainfall length, total precipitation(rain), and a composite index M.

$$M_j = \frac{L_j}{L_0} + \frac{\frac{R_j}{L_j}}{\frac{P_0}{L_0}} \cdot \frac{1}{2} + \frac{R_j}{P_0} - 2.5$$

Where L_j is the rainfall duration in year j, L_0 is the multi-year mean rainfall duration, $P_0 = R$ is the multi-year mean precipitation intensity, and R_j is the total precipitation intensity in year j.

We study the relationship between multiple Northeast Cold Vortex datasets and different rainfall indices by calculating correlation coefficients.

$$r = \frac{\sum_{i=1}^{n}(X_i-\bar{X})(Y_i-\bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i-\bar{X})^2 \sum_{i=1}^{n}(Y_i-\bar{Y})^2}}$$

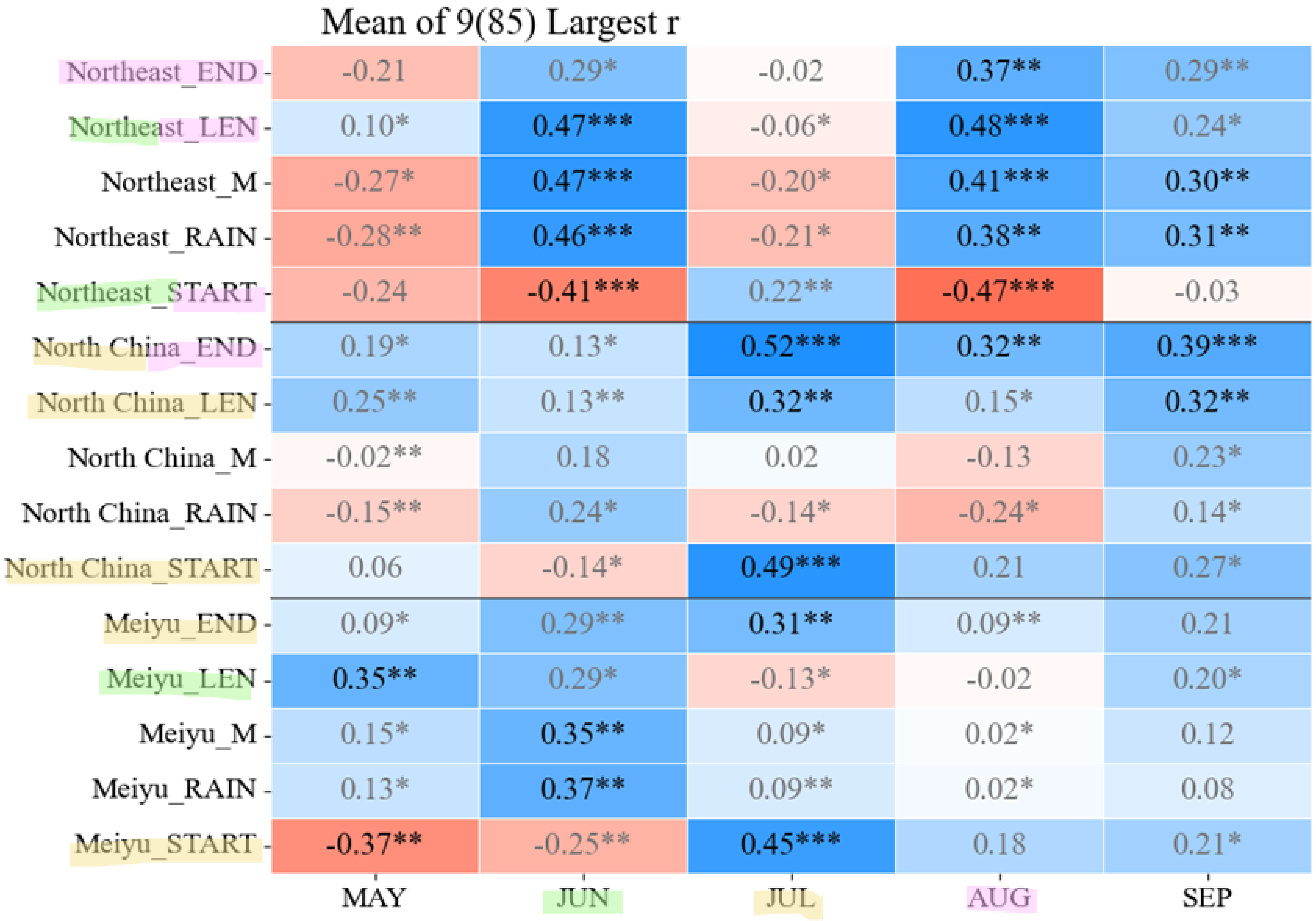
Mean of 9(85) Largest r

	MAY	JUN	JUL	AUG	SEP
Northeast_END	-0.21	0.29*	-0.02	0.37**	0.29**
Northeast_LEN	0.10*	0.47***	-0.06*	0.48***	0.24*
Northeast_M	-0.27*	0.47***	-0.20*	0.41***	0.30**
Northeast_RAIN	-0.28**	0.46***	-0.21*	0.38**	0.31**
Northeast_START	-0.24	-0.41***	0.22**	-0.47***	-0.03
North China_END	0.19*	0.13*	0.52***	0.32**	0.39***
North China_LEN	0.25**	0.13**	0.32**	0.15*	0.32**
North China_M	-0.02**	0.18	0.02	-0.13	0.23*
North China_RAIN	-0.15**	0.24*	-0.14*	-0.24*	0.14*
North China_START	0.06	-0.14*	0.49***	0.21	0.27*
Meiyu_END	0.09*	0.29**	0.31**	0.09**	0.21
Meiyu_LEN	0.35**	0.29*	-0.13*	-0.02	0.20*
Meiyu_M	0.15*	0.35**	0.09*	0.02*	0.12
Meiyu_RAIN	0.13*	0.37**	0.09**	0.02*	0.08
Meiyu_START	-0.37**	-0.25**	0.45***	0.18	0.21*

To highlight stable signals, we average the results with relatively strong correlations, as shown in the heatmap.

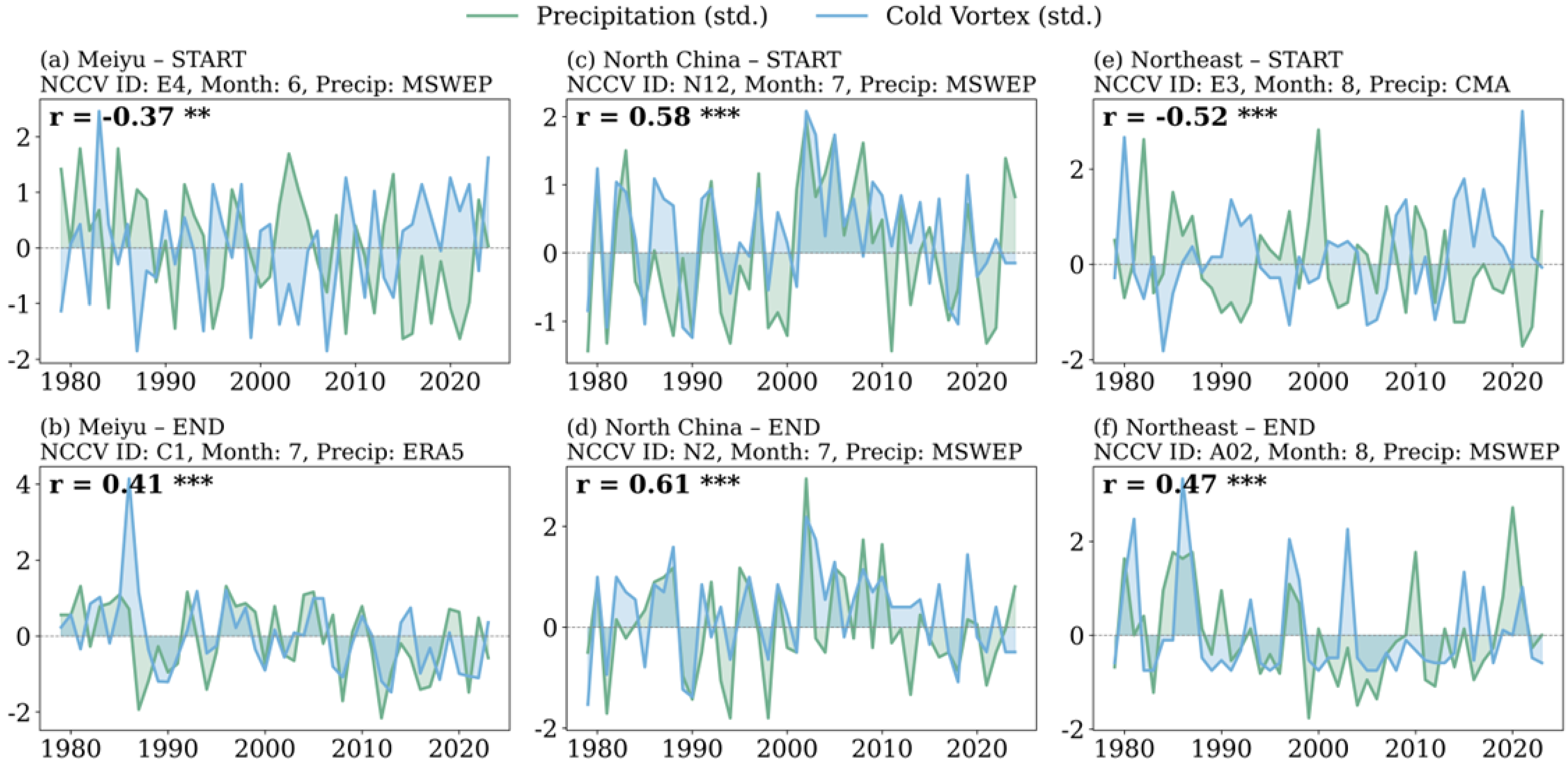
We study the relationship between multiple Northeast Cold Vortex datasets and different rainfall indices by calculating correlation coefficients.

$$r = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2 \sum_{i=1}^{n}(Y_i - \bar{Y})^2}}$$

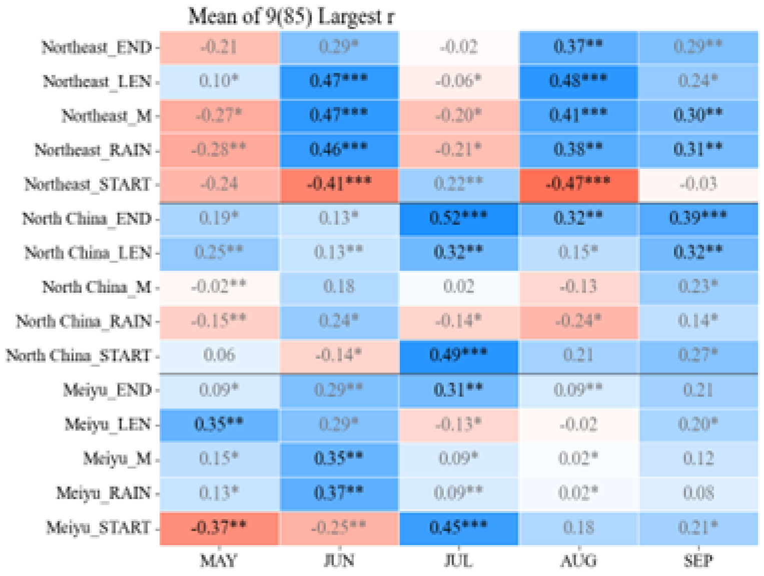


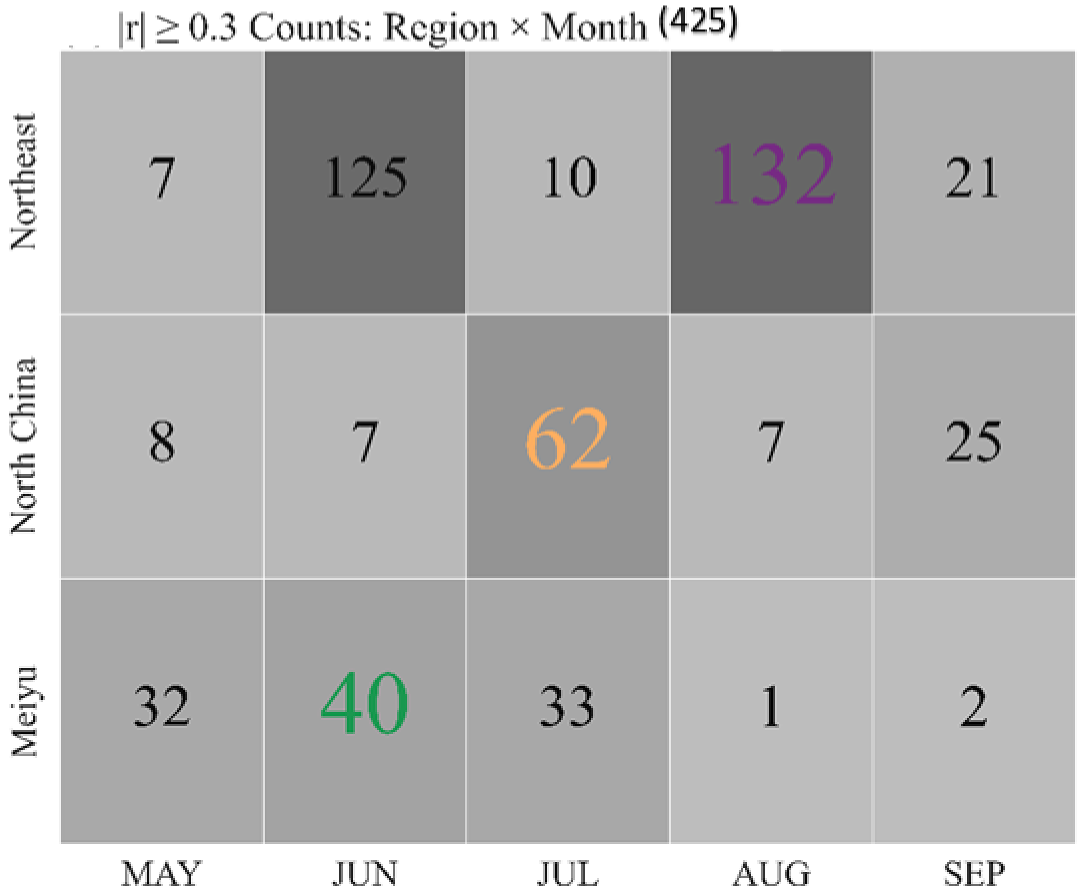
We find that the Northeast Cold Vortex has different levels of connection with Meiyu, North China, and Northeast China rainfall indices. In general, timing-related indices—like start date, end date, and rainfall length—tend to show stronger correlations than rainfall amount.

We show time series from three rainfall belts with the strongest correlations between cold vortex frequency and rainfall start and end dates. The results clearly show a strong relationship between Northeast Cold Vortex frequency and rainfall timing.



Based on the maximum correlation cases, we select three representative time series.
These results show a clear link between cold vortex activity and rainfall changes.





The main results are:

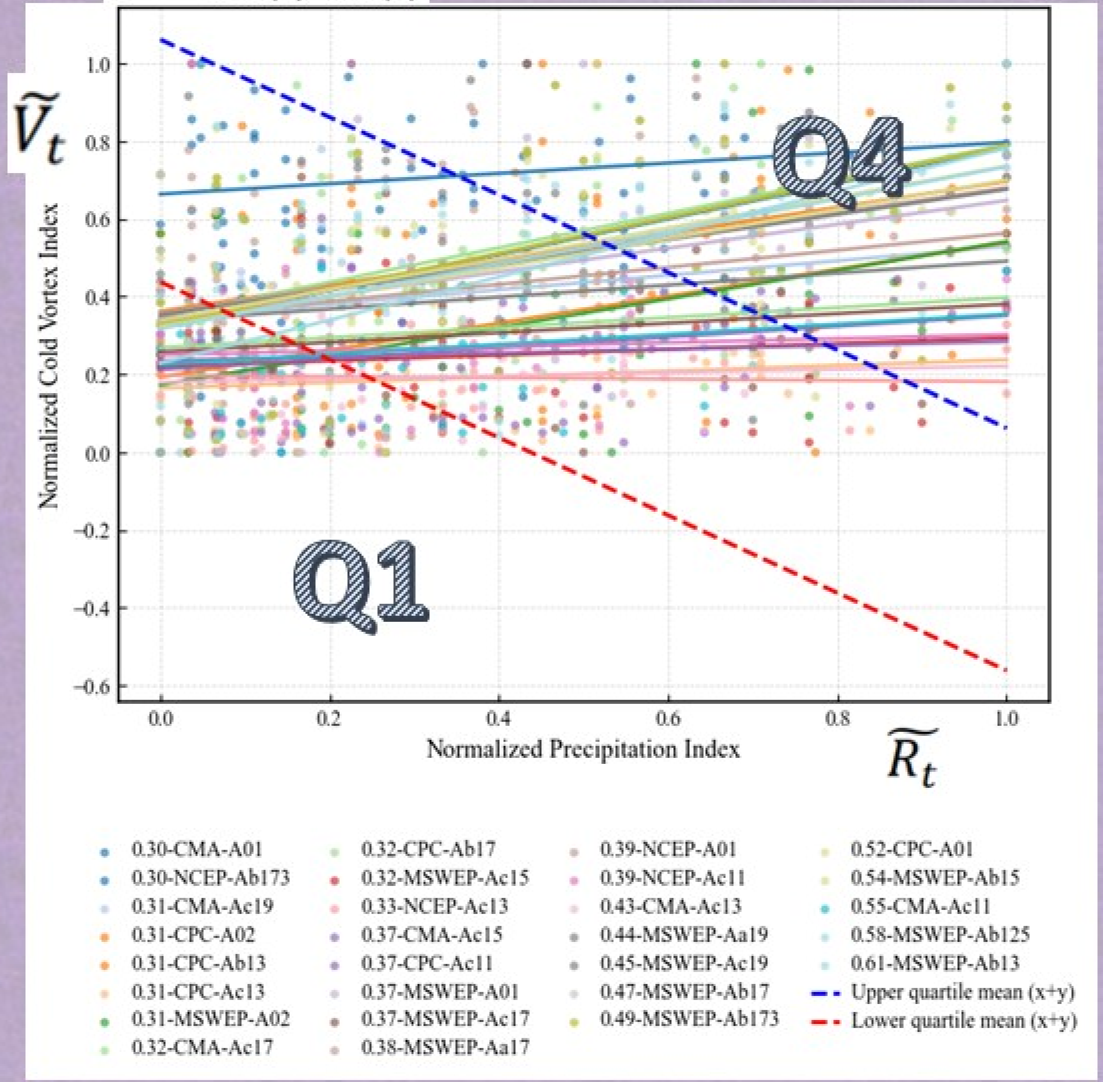
- In **June**, cold vortex frequency is positively related to **Meiyu rain**fall.
- In **July**, cold vortex frequency is positively related to the **end date of North China** rainfall.
- In **August**, cold vortex frequency is positively related to the **rainfall length of Northeast** China rainfall.

Criterion ① : *St* exceeds the upper quartile(Q4) or falls below the lower quartile(Q1)

$$\widetilde{V_t} = \frac{V_t - \min(V)}{\max(V) - \min(V)}, \quad \widetilde{R_t} = \frac{R_t - \min(R)}{\max(R) - \min(R)}$$

$$S_t = \widetilde{V_t} + \widetilde{R_t}$$

St* > *Q4
or
St* < *Q1



To identify the key atmospheric circulation structures, we select representative years based on the following criteria

Criterion ② : Consistent dominant sign combination between residuals and the time derivative of the interannual central difference *St*

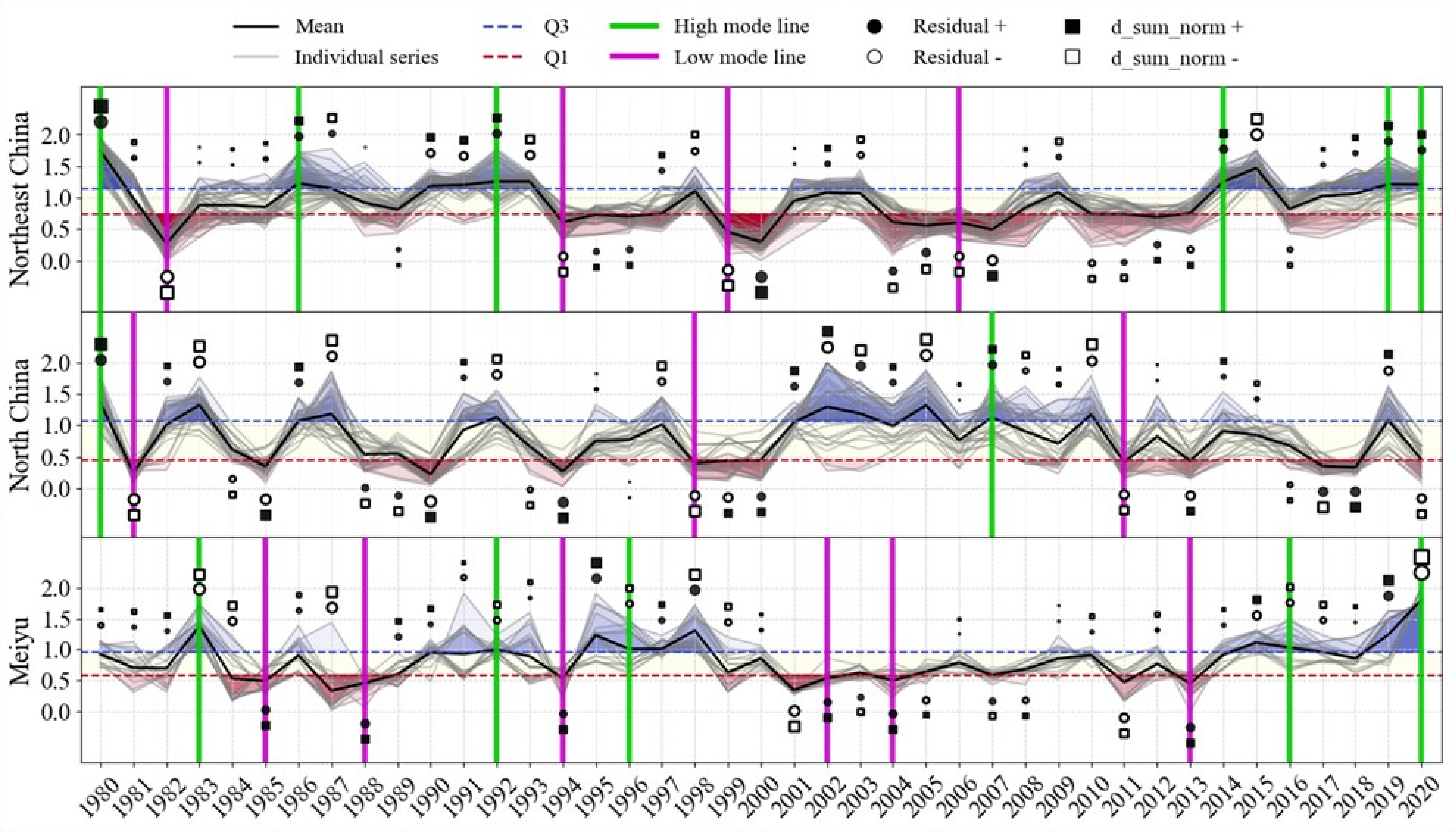
$$\widetilde{V_t} = a\widetilde{R_t} + b$$

$$d_t = \widetilde{V_t} - \left(a\widetilde{R_t} + b\right)$$

$$\frac{dS_t}{dt} \approx \frac{S_{t+1} - S_{t-1}}{2}$$

$$\text{mode}\left[\,\text{sign}(d_t) \cdot \text{sign}\left(\frac{dS_t}{dt}\right)\right] > 0$$

These are the selected years. For each rainfall belt, 2–7 high years and 2–7 low years are selected, ensuring representative sampling for each case.



JUNE- -Meiyu	High Years	1983, 1992, 1996, 2016, 2020
	Low Years	1985, 1988, 1994, 2002, 2004, 2013
JULY- -North China	High Years	1980, 2007
	Low Years	1981, 1998, 2011
AGUGUST- -Northeast	High Years	1980, 1986, 1992, 2014, 2019, 2020
	Low Years	1982, 1994, 1999, 2006

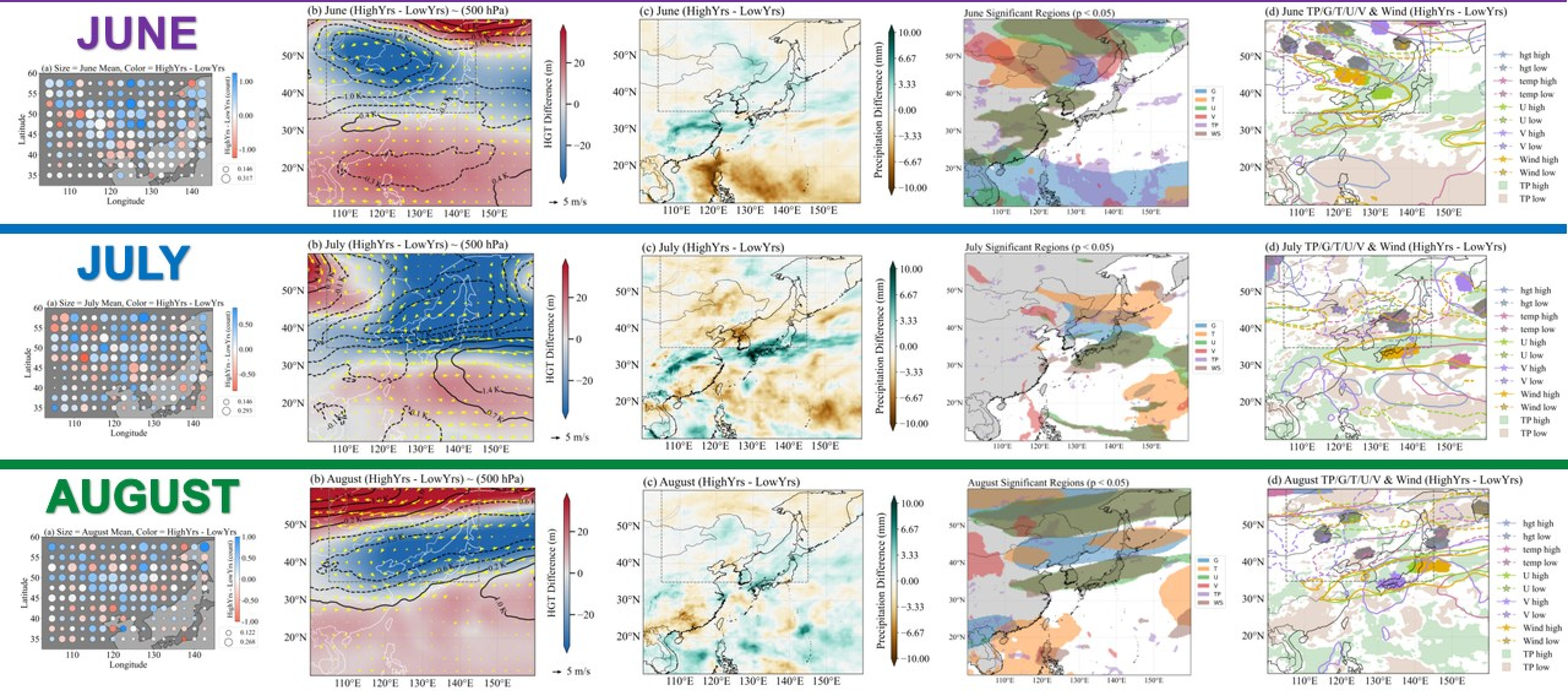
*ERA5 monthly mean data are used from this point onward

Difference (High Years – Low Years)

TO better understand the 3D atmospheric structure associated with Northeast China Cold Vortex rainfall

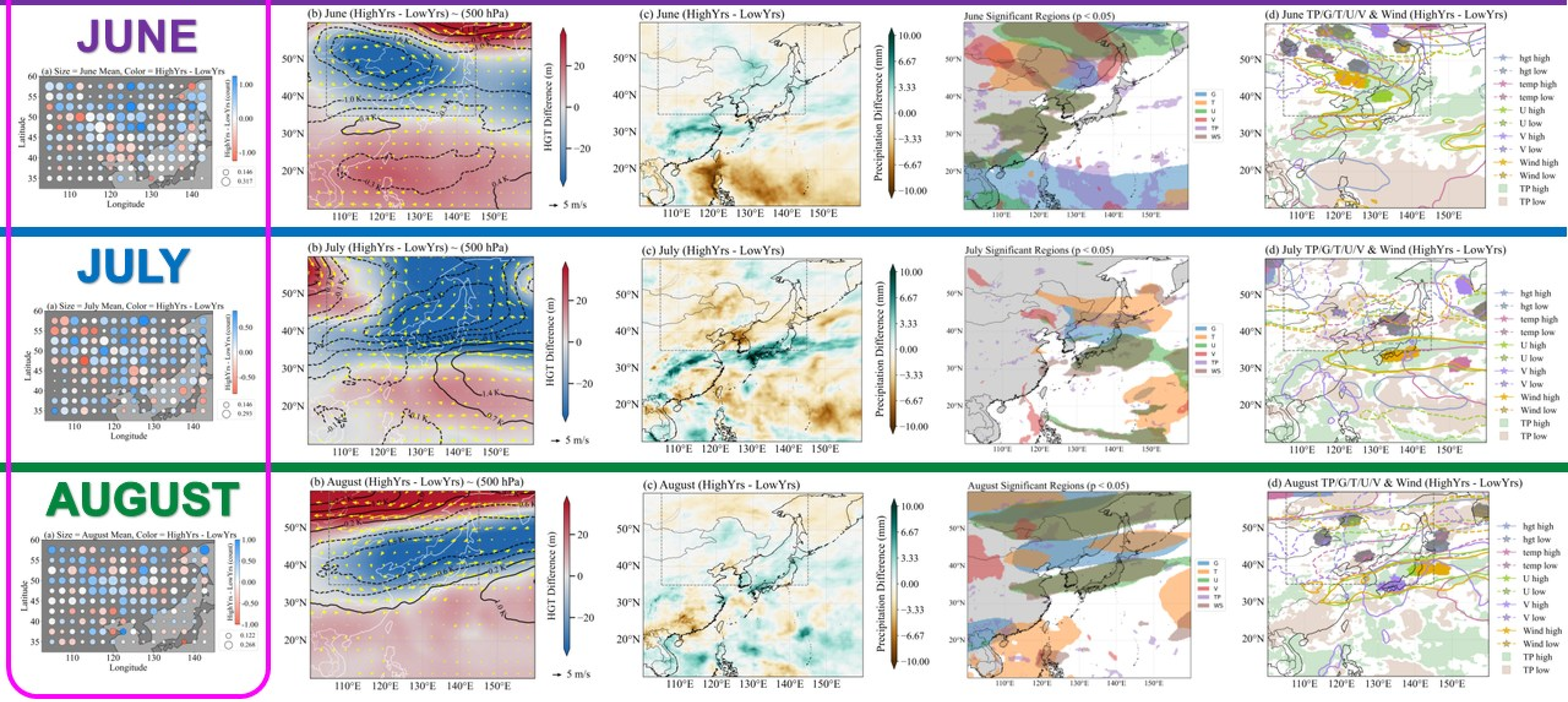
First, East Asian Longitude–Latitude Domain

cold vortex frequency | 500 hPa G/T/U/V | precipitation | Welch's t-test ($p < 0.05$) | extreme composites

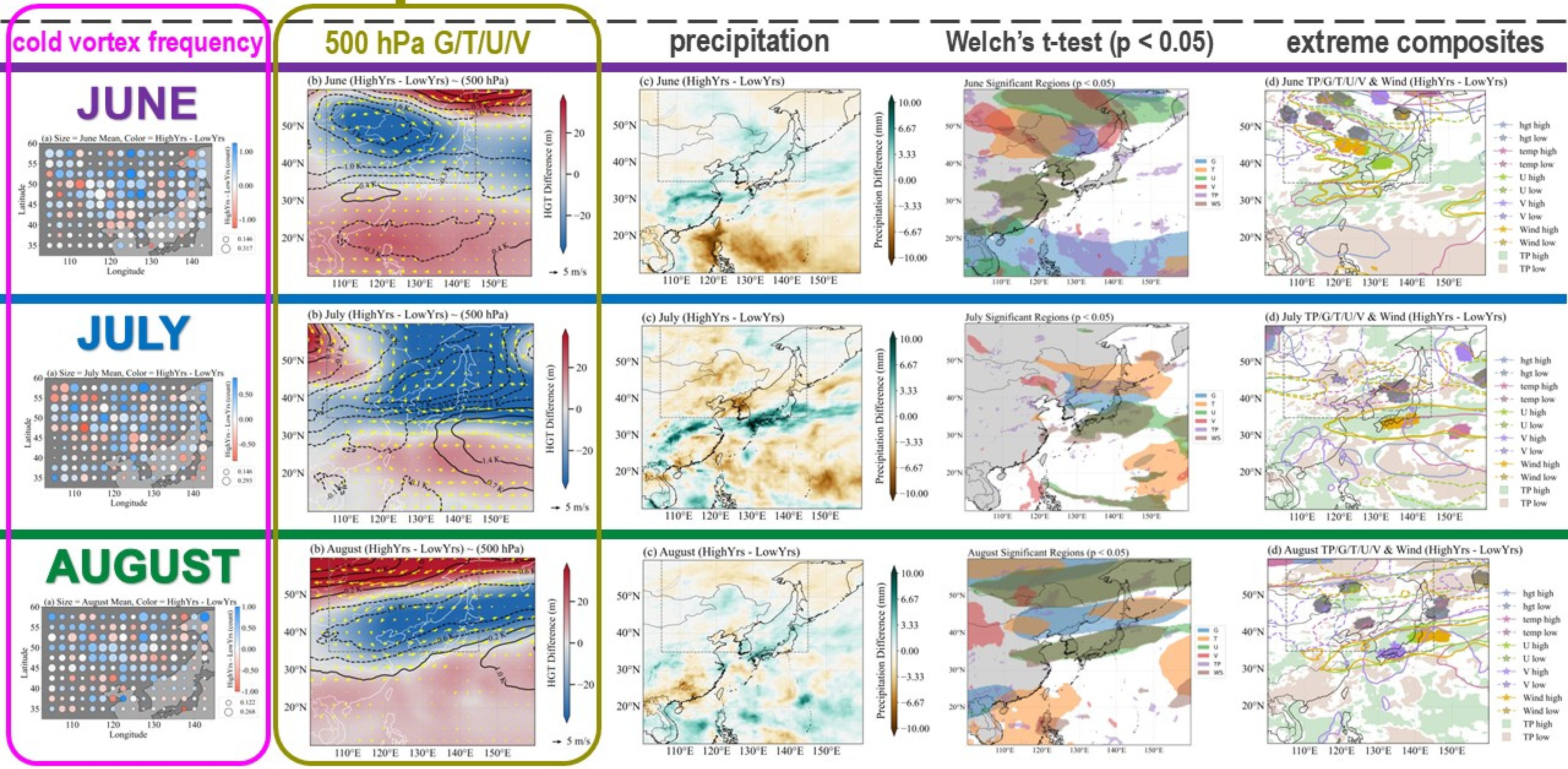


First column: cold vortex frequency differences. Blue means more frequent in active years, red means less frequent. There is no clear spatial pattern, so total frequency seems more important.

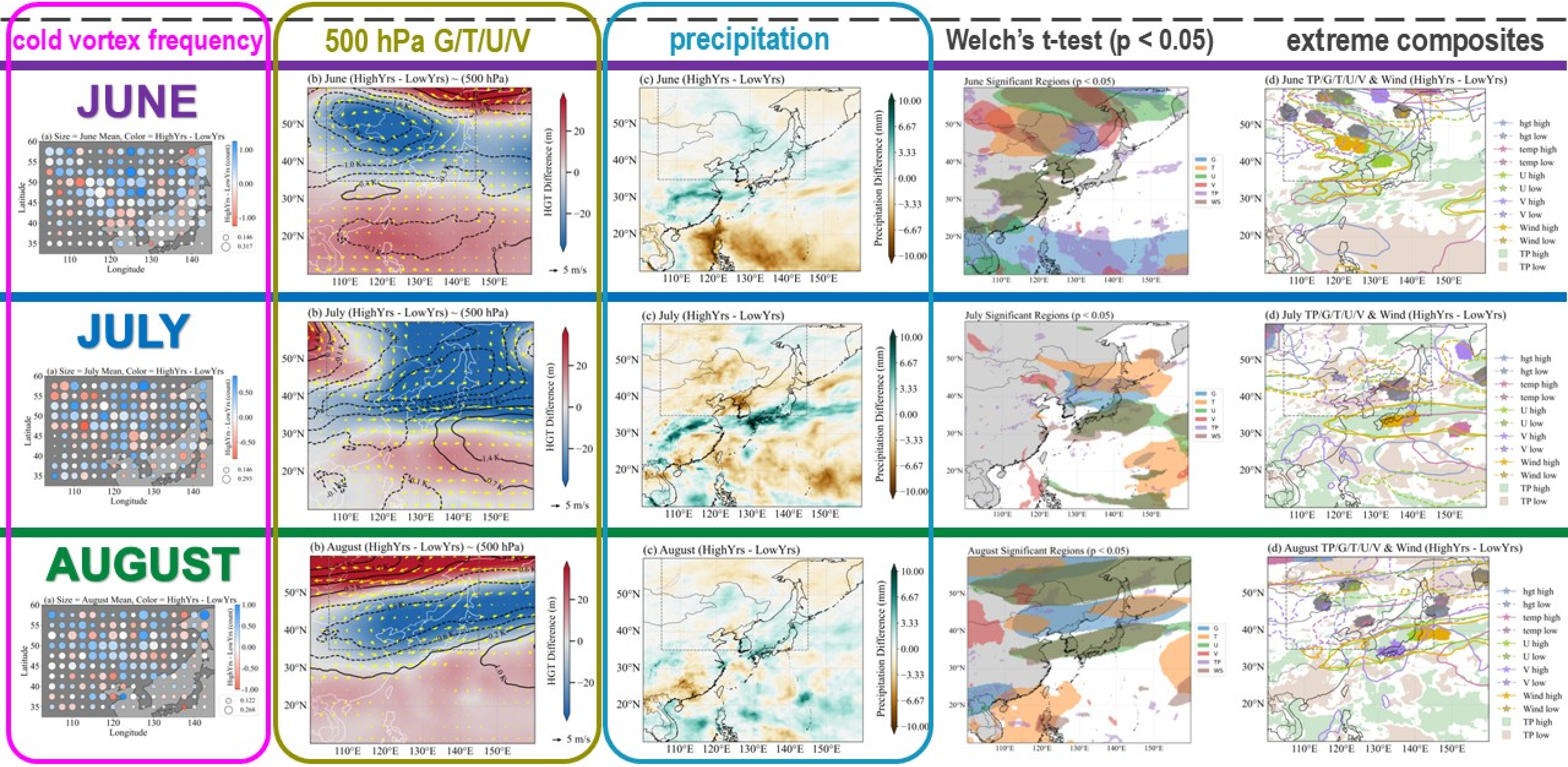
cold vortex frequency	500 hPa G/T/U/V	precipitation	Welch's t-test ($p < 0.05$)	extreme composites



Second column: Composite differences at 500 hPa. Cyclonic circulation structures are clearly evident, with noticeable variations across the three months.



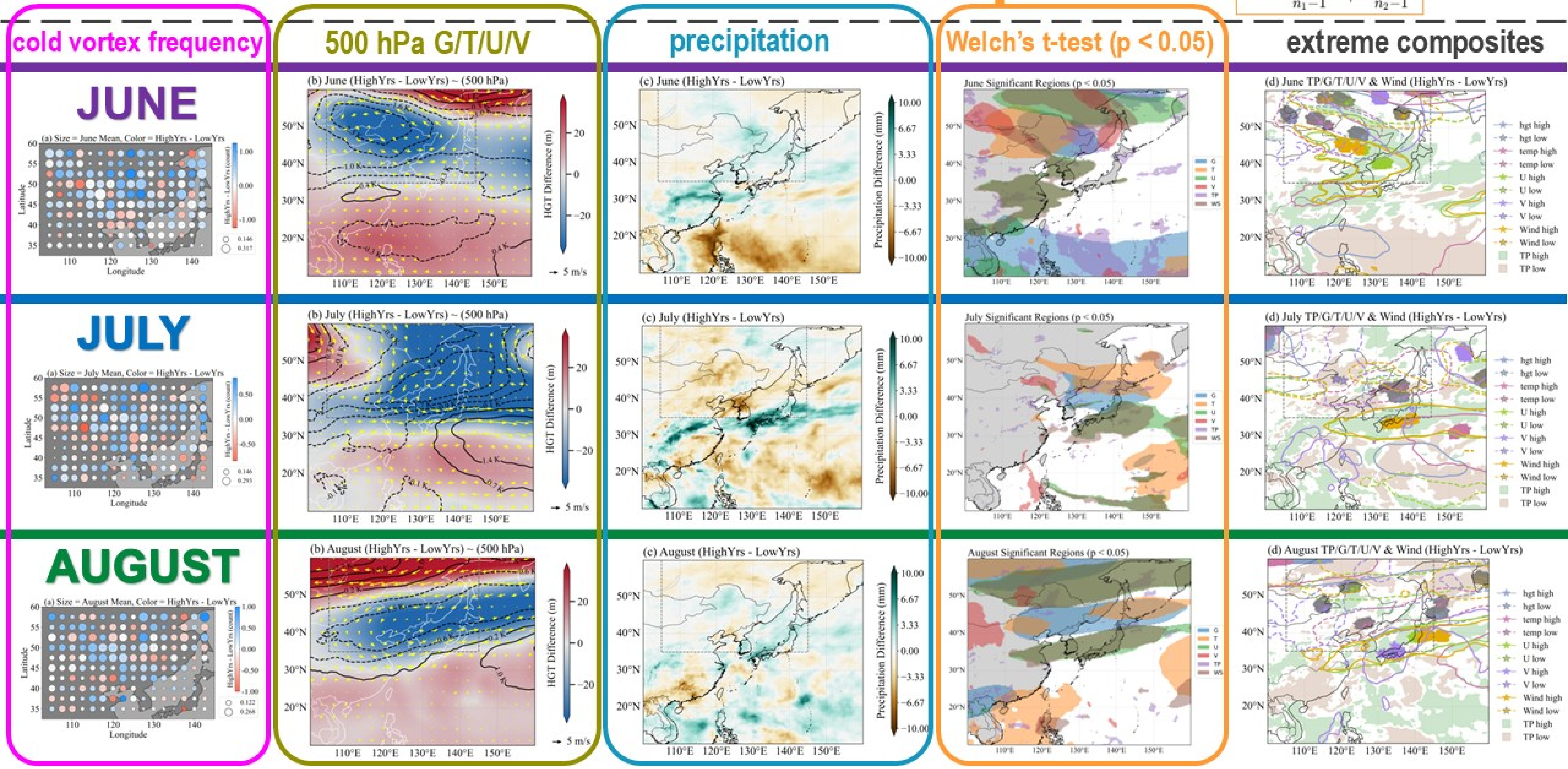
Third column: precipitation differences. Active years bring more Meiyu rainfall and more Northeast China rainfall, but less North China rainfall.



Fourth column: 95% significance based on Welch's t-test. This shows the mid–high latitude circulation has a strong and reliable impact on rainfall belts.

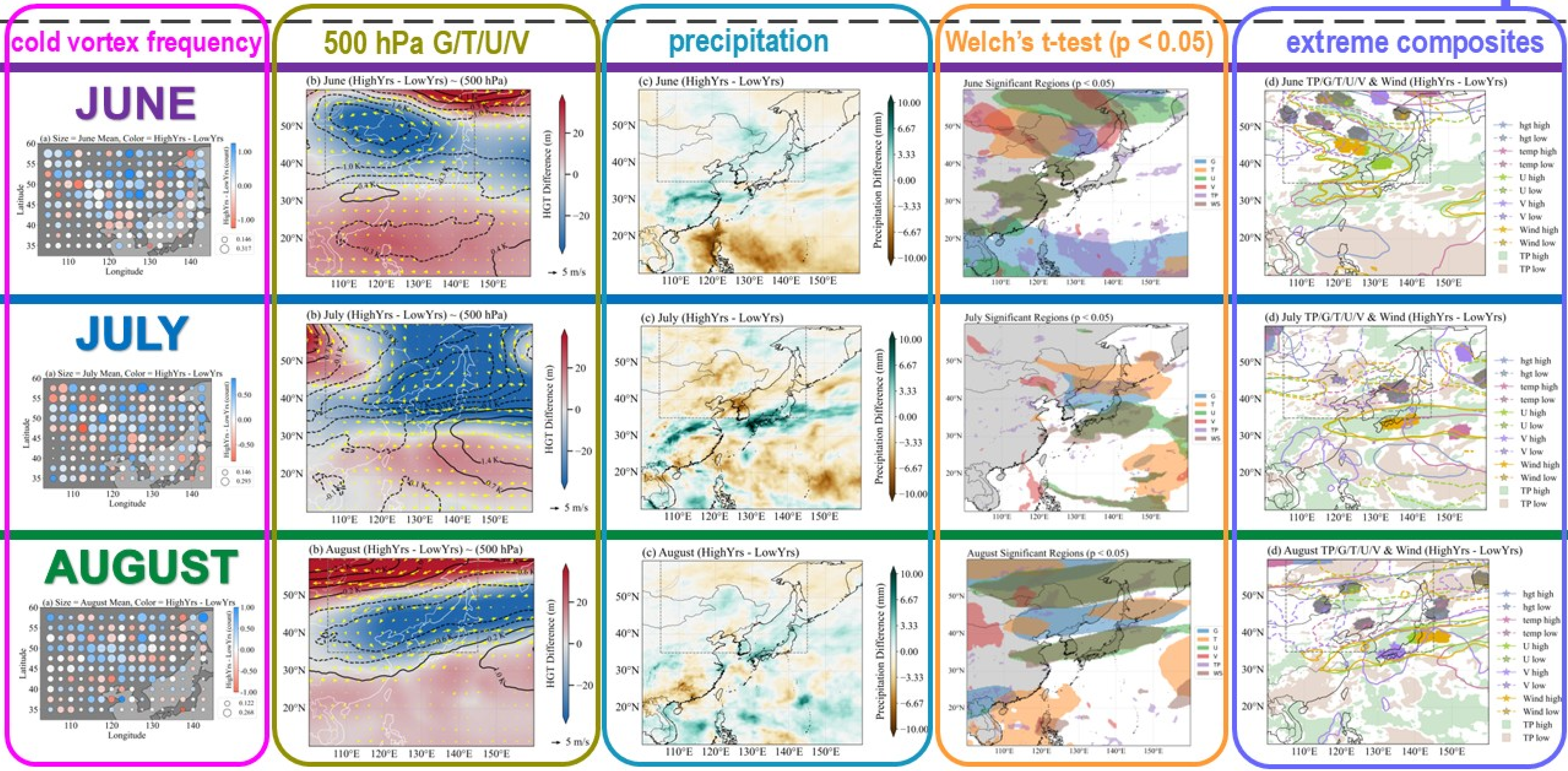
$$t = \frac{\bar{X} - \bar{Y}}{\sqrt{\frac{s_X^2}{n_1} + \frac{s_Y^2}{n_2}}}$$

$$\nu = \frac{\left(\frac{s_X^2}{n_1} + \frac{s_Y^2}{n_2}\right)^2}{\frac{\left(\frac{s_X^2}{n_1}\right)^2}{n_1 - 1} + \frac{\left(\frac{s_Y^2}{n_2}\right)^2}{n_2 - 1}}$$



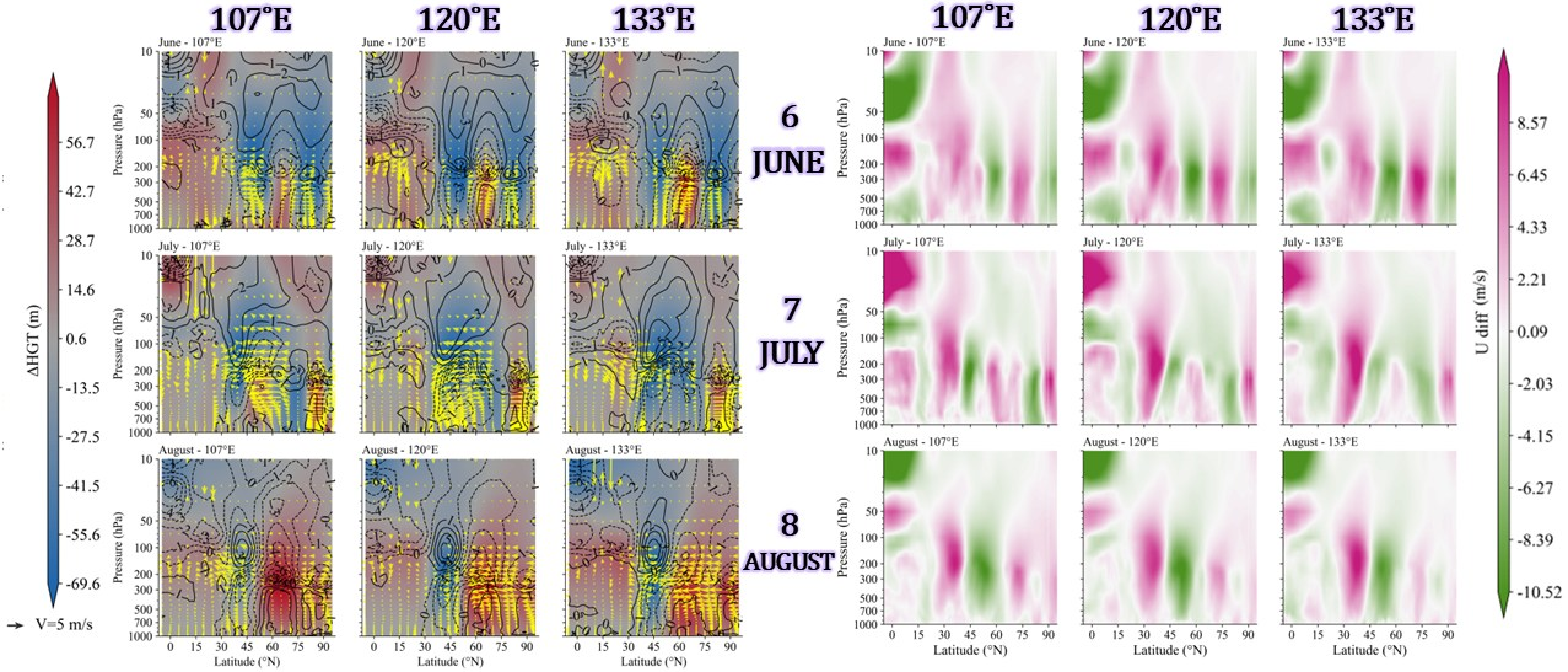
★ 99.8% ★ 0.02% Q4 Q1

Fifth column: extreme composites. We see stronger westerlies, clear wave patterns in mid–high latitudes, and the subtropical high influencing Meiyu and North China rainfall.



Second, Key Meridional Vertical Cross-Sections in the Northern Hemisphere

we select meridional cross-sections along 107°E, 120°E, and 133°E in the Northern Hemisphere, covering the 100–10 hPa layer. In the left panels, color shading represents geopotential height, contours show potential temperature, and vectors indicate the combined V and W winds. In the right panels, color shading represents the U wind.

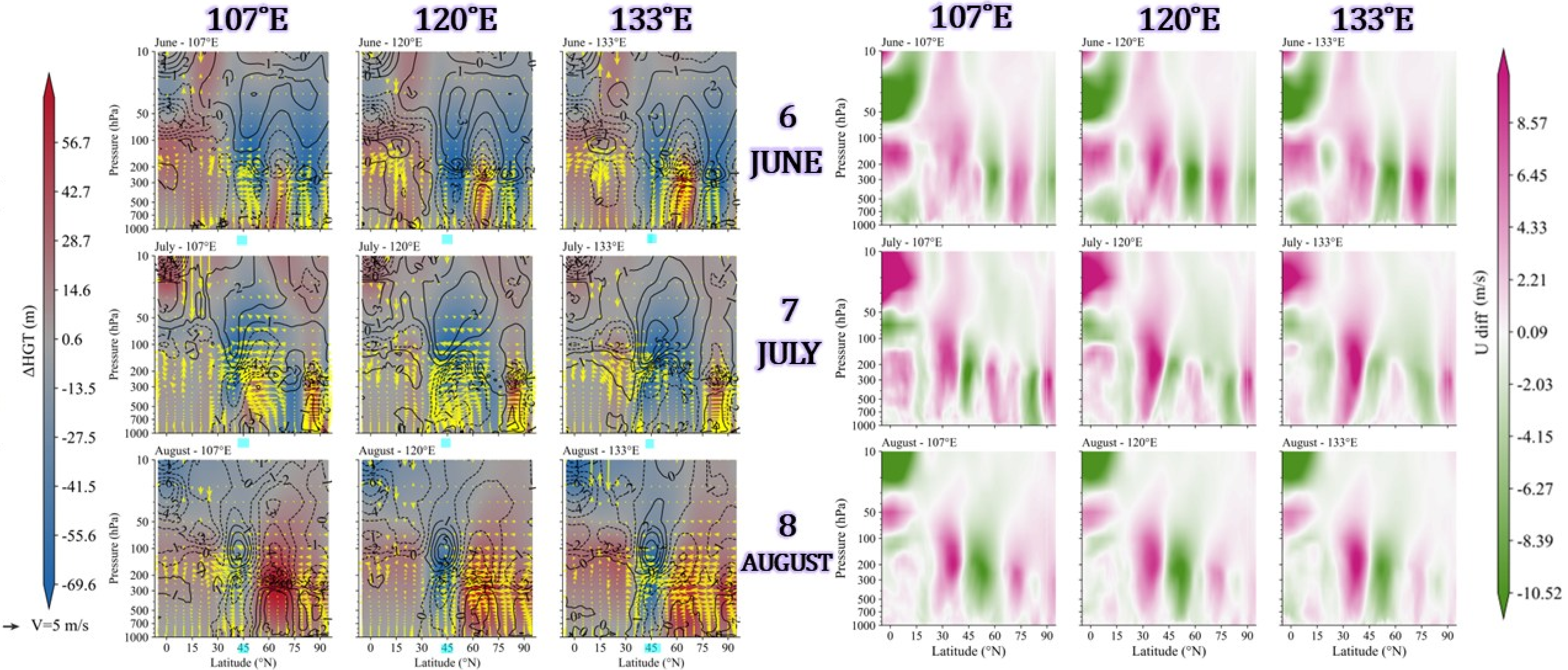


Second, Key Meridional Vertical Cross-Sections in the Northern Hemisphere

A clear region of low geopotential height can be seen around 45°N.

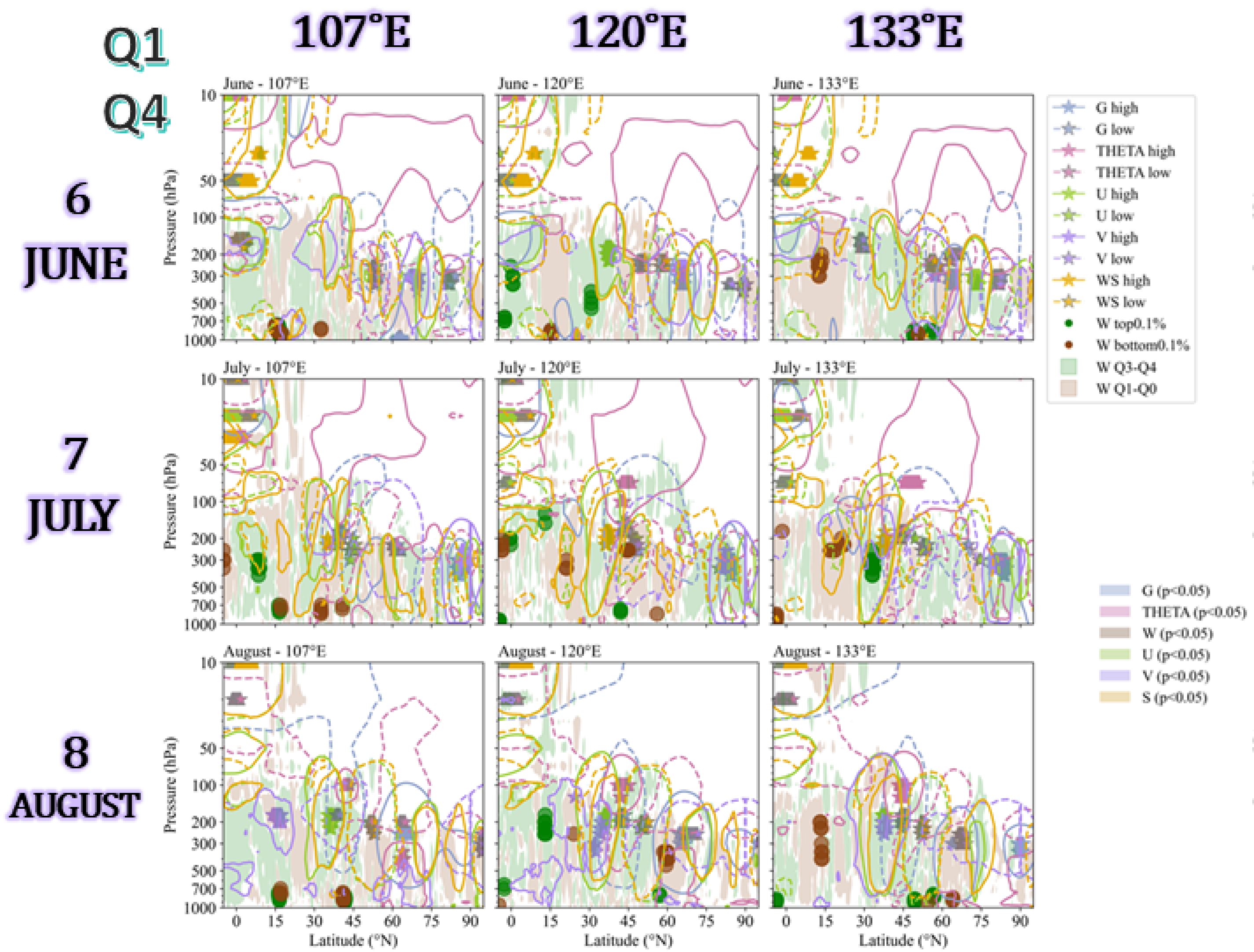
We focus on two key points:

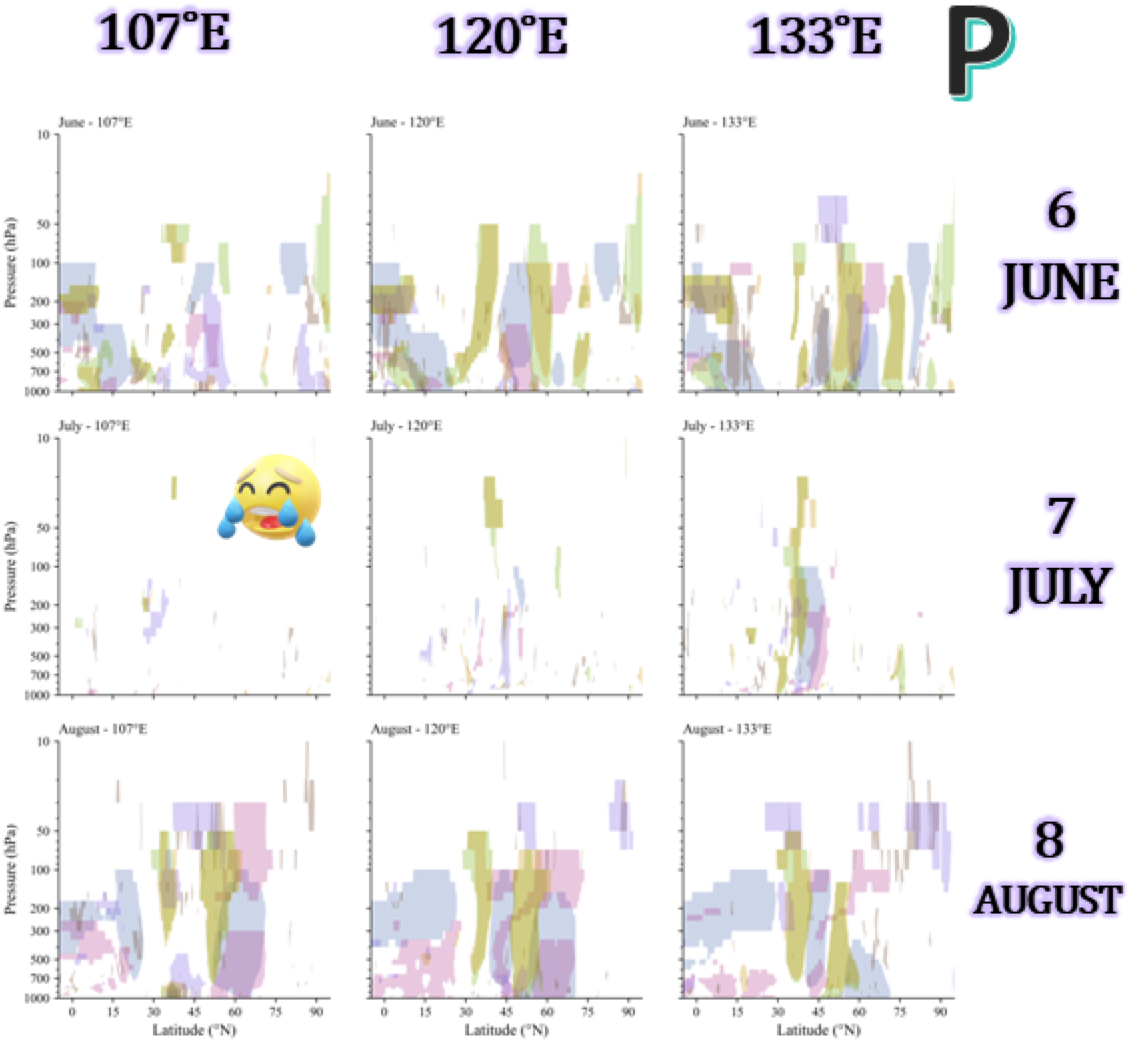
①The meridional direction of the V wind in different months. ②The large values in the tropical stratosphere.



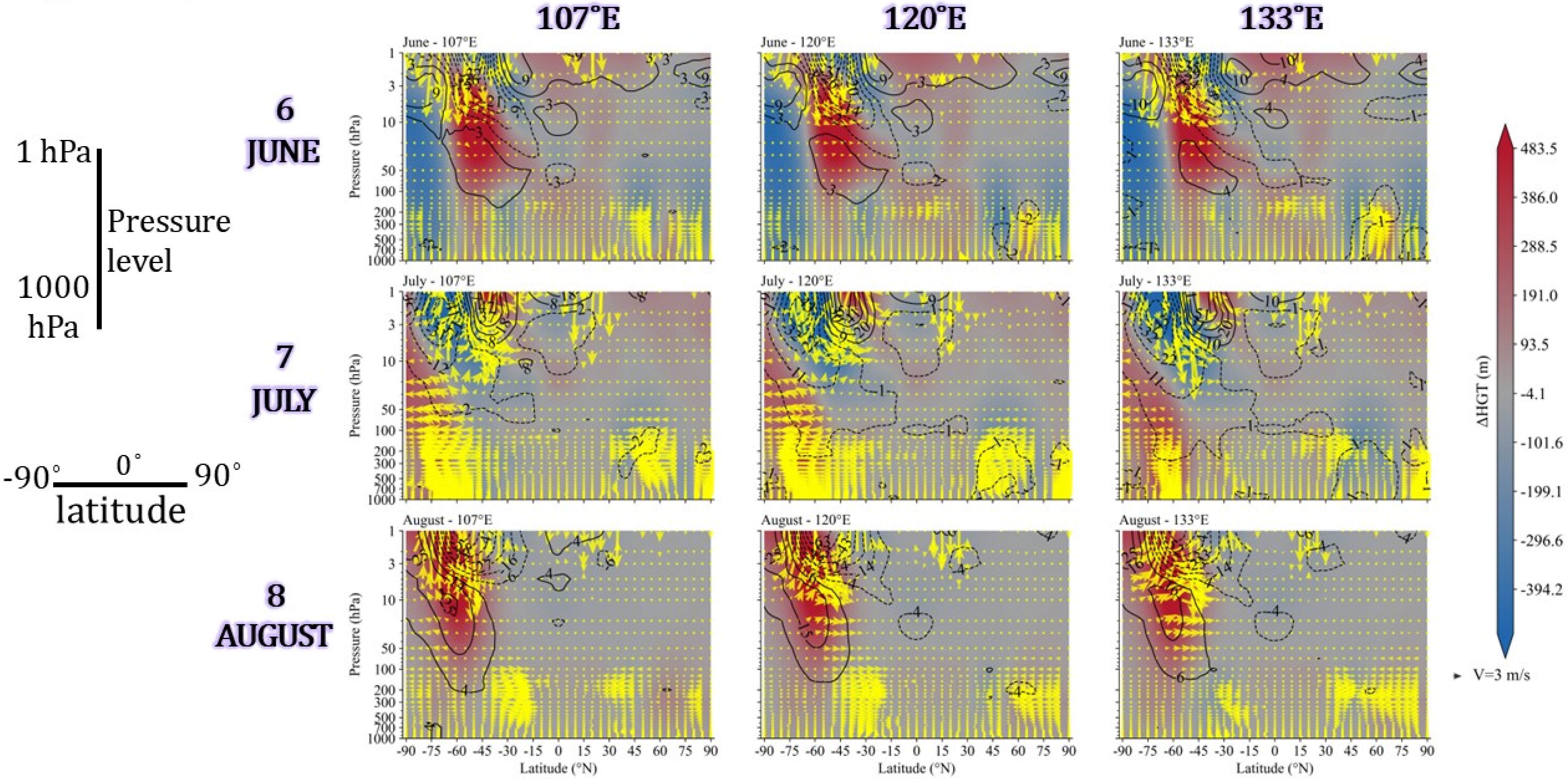
Second, Key Meridional Vertical Cross-Sections in the Northern Hemisphere

The left panels show the extrema of each variable, while the right panels indicate regions where 95% significance based on Welch's t-test. We can observe a staggered and shifting structure among different variables. Although the tropical stratosphere shows large anomalies, these do not pass the 95% significance test.





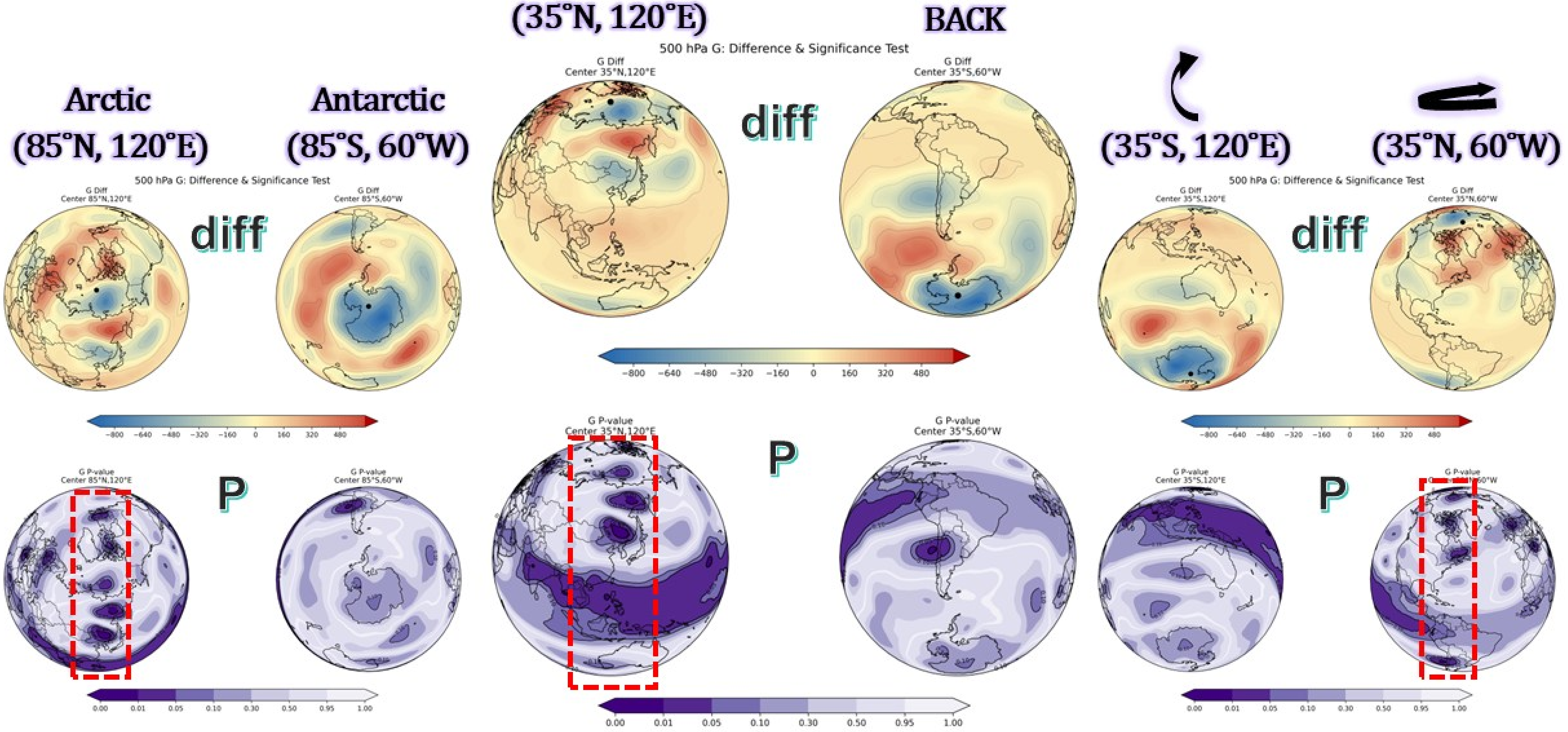
From all three meridians, and considering the full vertical range from 1000 to 1 hPa, a strong signal can be observed in the upper atmosphere over Antarctica.



Third, the 500 hPa global geopotential height difference in June

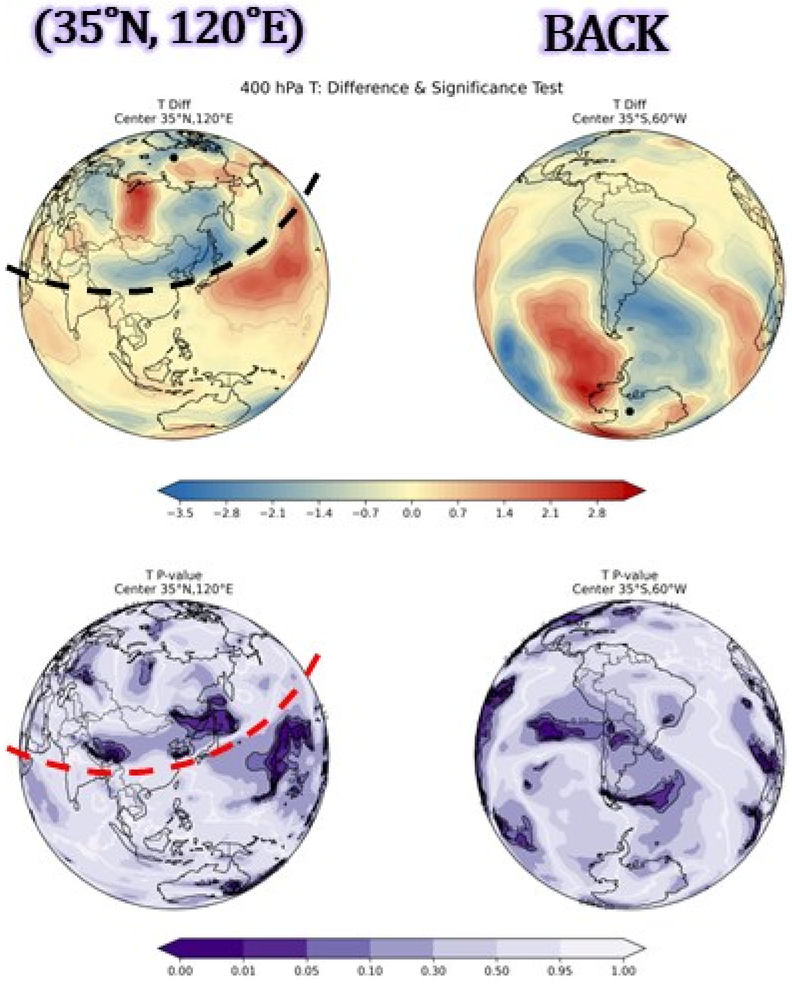
show consistent patterns across the three panels, with differences only in the map projection center.

Both the geopotential height difference and the p-values reveal a continuous quasi-meridional structure on a global scale.

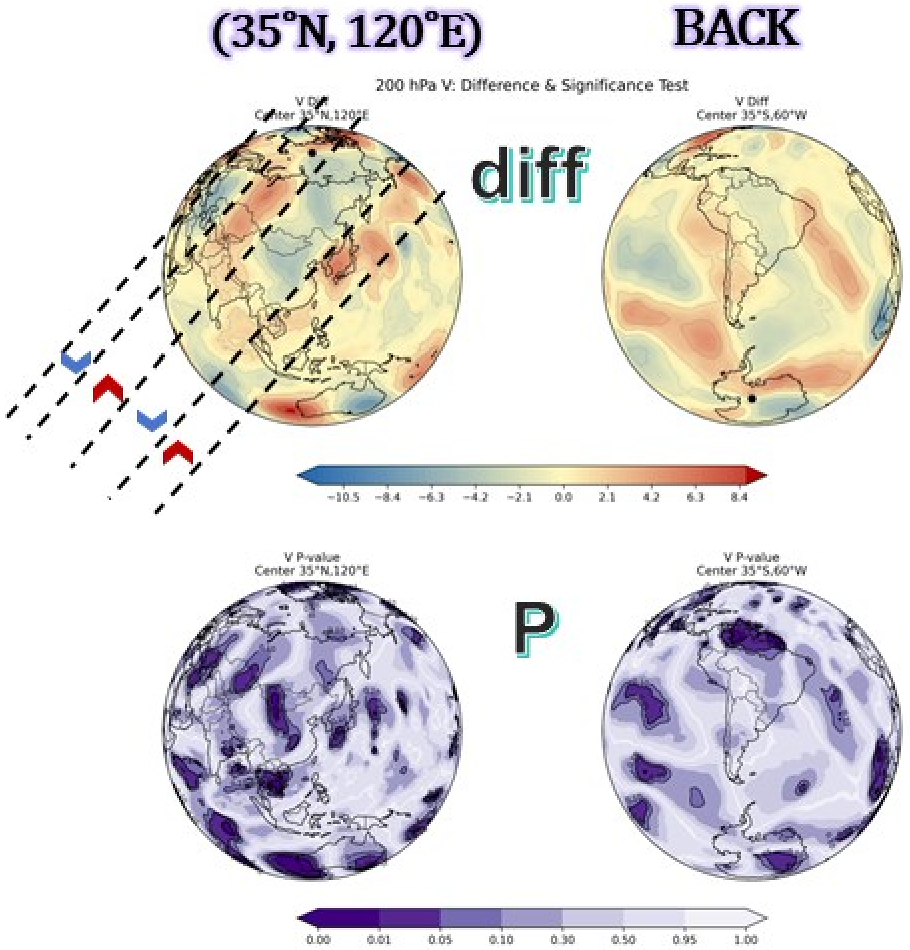


For July and August, as well as for different variables and pressure levels, the structures may vary, but a global-scale response is consistently observed.

JULY 400 hPa T



AUGUST 200 hPa V



MORE...

Summary

- This study analyzes multiple datasets of **Northeast China Cold Vortex** and **the main summer rain belt over eastern China**.
- The relationship between them is quantified using correlation coefficients.
- Based on these correlations, key years in June, July, and August are selected, showing stable circulation patterns.
- At the monthly scale, the results indicate that both the Cold Vortex and summer precipitation are mainly driven by meridional processes with global linkage.

EGU26 GENERAL ASSEMBLY

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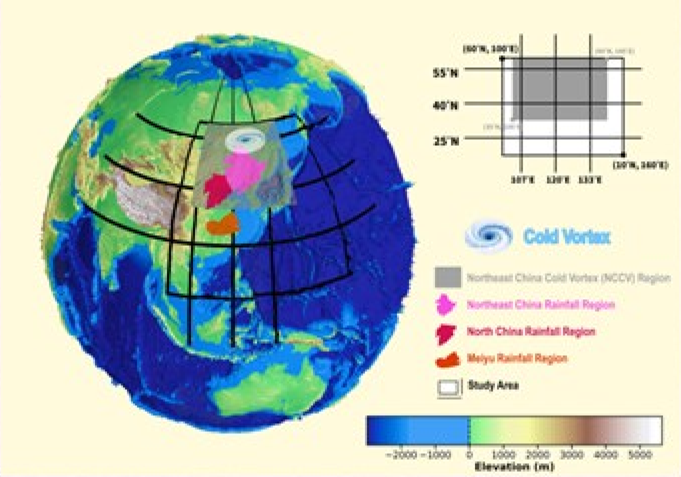

Thanks for your attention!

When Mid–High Latitude Systems Meet the Monsoon:
How the Northeast China Cold Vortex ***Regulates*** Summer Rain-Belt Timing and Meridional Shifts

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