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Extreme wet bulb temperatures in China: the significant role of moisture

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2020/3/27

Background

- Under the too humid and warm condition, people have difficulty in sweating. Thus, the environmental and metabolic heat accumulates in the body, which may cause a physical disorder and even death (Budd 2008). Therefore, when thinking of heat stress, it is of great significance to consider not only the extreme dry temperatures, but also involve the other factors such as humidity.

- As a combination of temperature and humidity, the wet-bulb temperature (TW) is an efficient integrated measure to characterize humid heat stress conditions.

- Heat stress in China with the consideration of both temperature and humidity is rarely investigated.

Data and Method

- Daily maximum temperature (T), daily mean pressure, daily mean relative humidity(RH) of 1710 observational sites in China during 1960-2015; the specific humidity (q) is obtained from T and RH.

- The calculation of TW uses the method in Davis-Jones, 2007, ported to Matlab by Dr Robert Kopp (Rutgers, 2016).

- NCEP/NCAR Reanalysis data, including geopotential height, specific humidity, relative humidity, winds and vertical velocity are used to investigate the synoptics during extreme TWs.

Definitions of extreme TW, T and q

- An extreme TW (ex_TW) means the daily maximum TW is higher than the daily threshold. For a specific calendar day, the threshold is the local 90th percentile of a moving 21-day-centered window of daily TWs during 1960-2015.

- An extreme T is similarly defined to the extreme TW, based on only the daily maximum air temperature (Tmax)

- An extreme q is similarly defined to the extreme TW, based on the daily maximum humidity q

Indices to characterize the extreme TWs

- **Frequency(F): the annual occurrences (days) of ex_TW**

- **Maximum duration (D): the annual maximum consecutive days of ex_TWs**

- **Maximum amplitude (A): the annual maximum amplitude of ex_TW**

A=max(TW_i-Th_i), where TW_i is the TW of the i^{th} occurrences of ex_TW. Th_i is the corresponding daily threshold.

Results

a. The climatology of extreme TWs in China

b. The excursion of temperature and moisture to extreme TWs in China

c. Synoptics during extreme TWs and the differences between q-dominated and T-dominated extreme TWs

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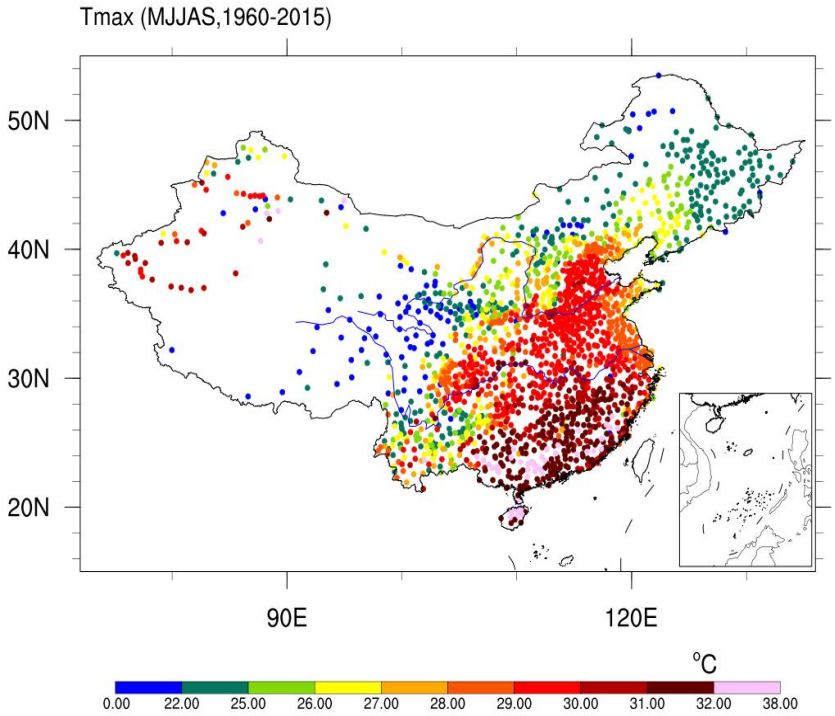
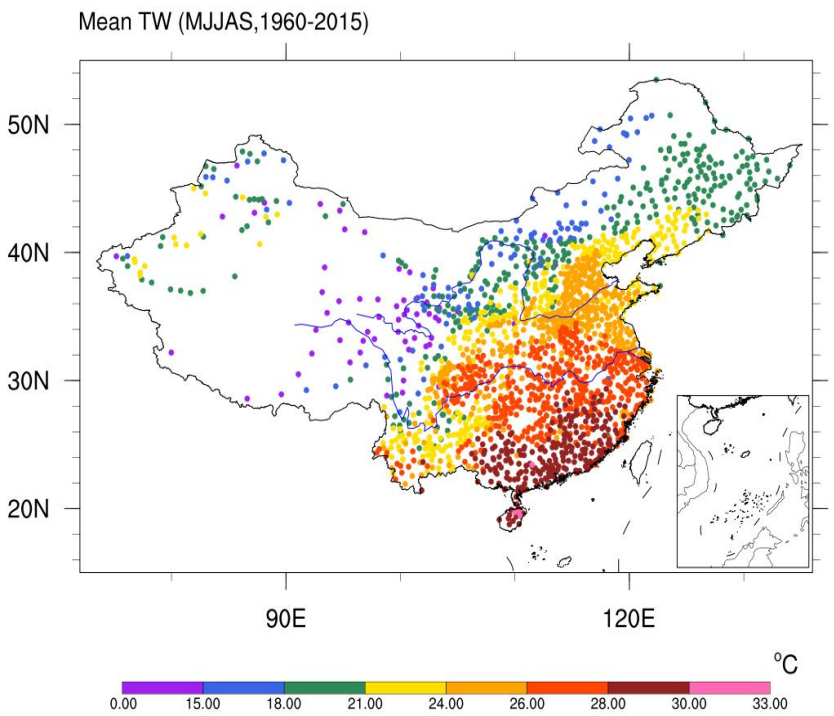
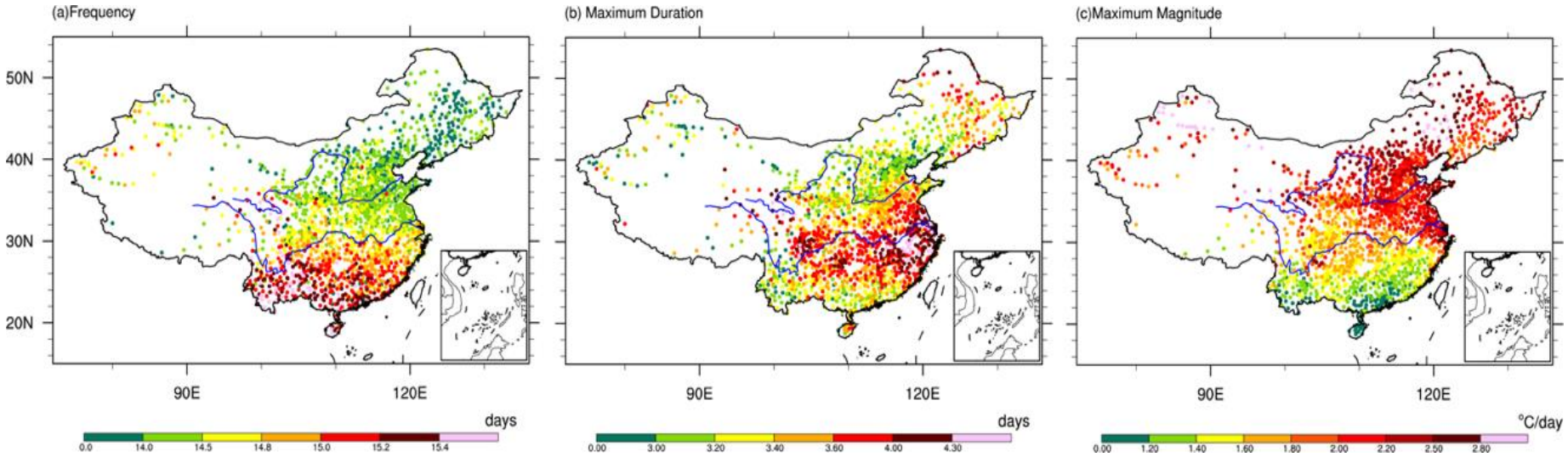
The climatology of Tmax and TW for May to September during 1960-2015





- **TW show negative gradient of mean TW from the southern part of China to the northern part of China.**
- **Differences between TW and T are prominent over Northwest China.**

The climatological characteristics of ex_TW



- **Extreme TWs show high frequency in the southernmost of China while they are longer lasting over southeastern and northeastern China.**

- **Moreover, the magnitude of extreme ex_TWs are higher over Northern China, which may be related to the low climatology of TW over the Northern China**

Results

a. **The climatology of extreme TWs in China**

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q_dominated ex_TW and T_dominated ex_TW

TW changes can result from either or both its components variables (i.e. T and q).

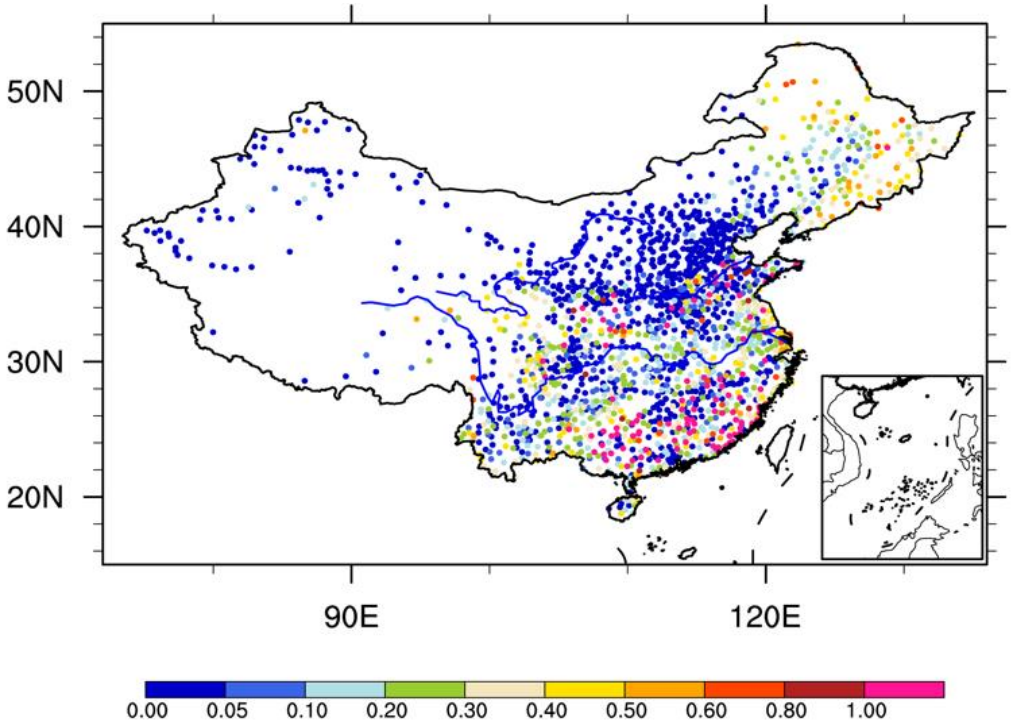
Following Raymond et al., 2017, **the standard anomaly ratio (SAR)** is defined as:

$$SAR=\begin{cases} R1/R2, & R1>0\&R2>0 \\ maximum(SAR), & R1>0\&R2<=0 \\ 0, & R1<=0\&R2>0 \\ 1, & R1<=0\&R2<=0 \end{cases}$$

$R1=[(T-T_c)/T_s]$; $R2=[(q-q_c)/q_s]$, where T/q is the daily maximum dry temperature and specific humidity, and T_c and q_c are the daily threshold for T and q. T_s and q_s are the standard deviations of the time series for T and q during 1960-2015.

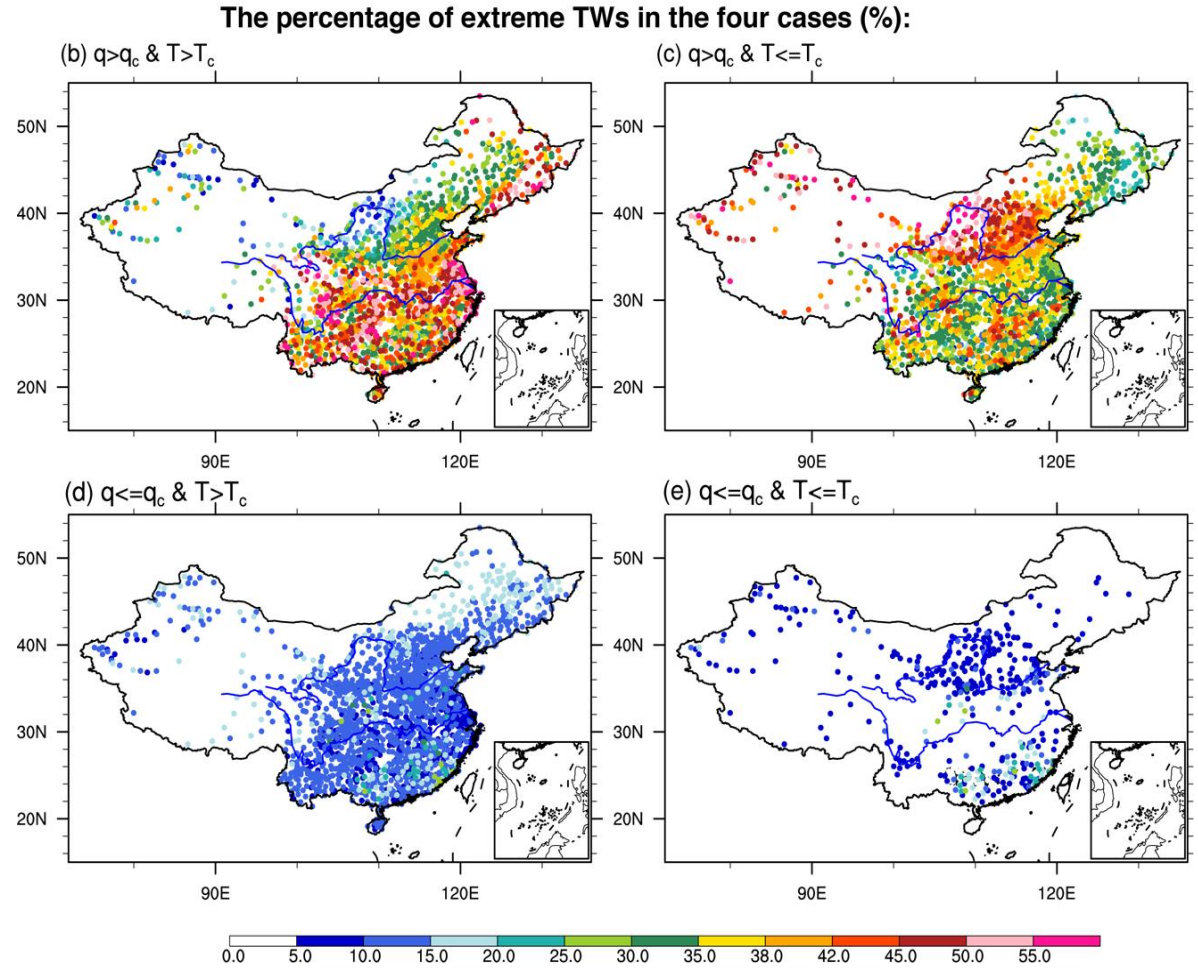
- It is obvious that, for each ex_TW, a higher (smaller) SAR implies that T (q) excursions are of relatively greater importance in controlling extreme TW.

The median values of SAR values



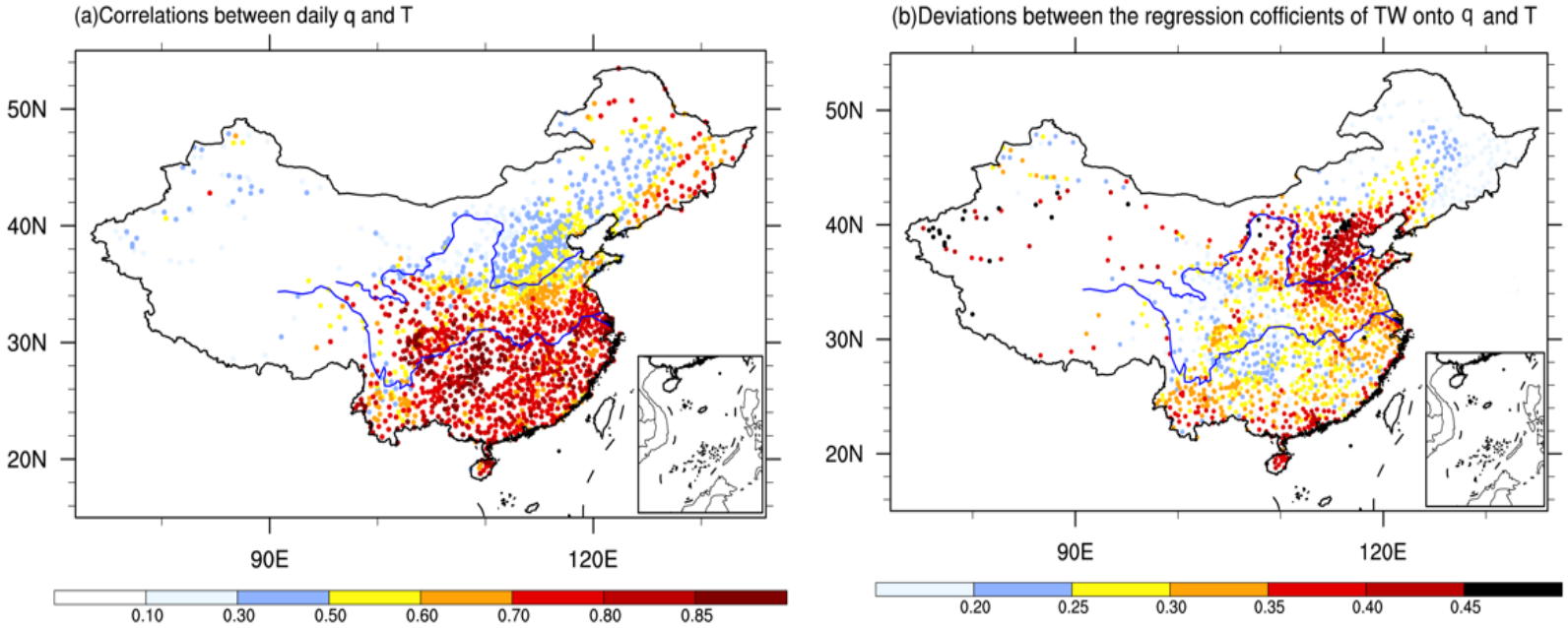
- **Ex_TWs are more possibly q-dominated (median of SAR<1) in most of China, especially in Northwest China and the Northern China (arid and semi-arid regions in China).**

The occurrences of extreme TWs in the above four categories



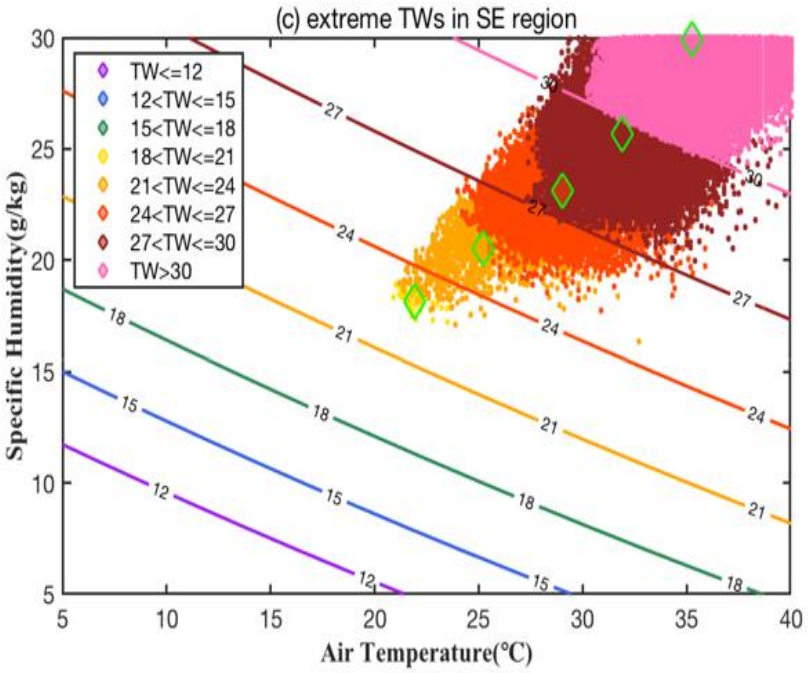
- Anomalous TW usually co-occur with both extreme T and extreme q in southern China.
- Case 2 show higher values over Northwest and Northern China, consistent with the with the lowest SAR values therein.
- Cases 3 is much less compared to case 1 and 2. And case 4 is negligible.

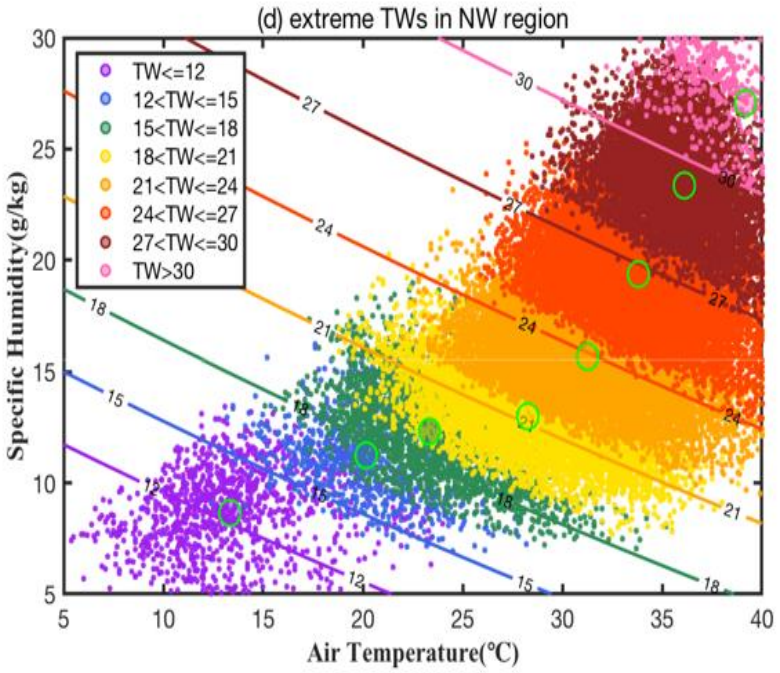
The intrinsic relation among q, T and TW



- The T and q values have a strong linear relation over most of China, especially over the Southern China, consistent with the higher overlap of extreme T and q in Southern China. However, they depict a weak relation over the arid and semiarid region.
- It's notable that one change of q contributes obviously more than one standard change of T to TW changes over most of China, especially over the arid and semiarid China. Therefore, the stronger q-dominance over the arid and semiarid region is driven by the strong dependence of TW changes on q therein.

Extreme TWs in Southeastern (SE) China and Northwest(NW) China





- **The more vertical the average-vector is, the more q_dominated the extreme TWs are.**

Results

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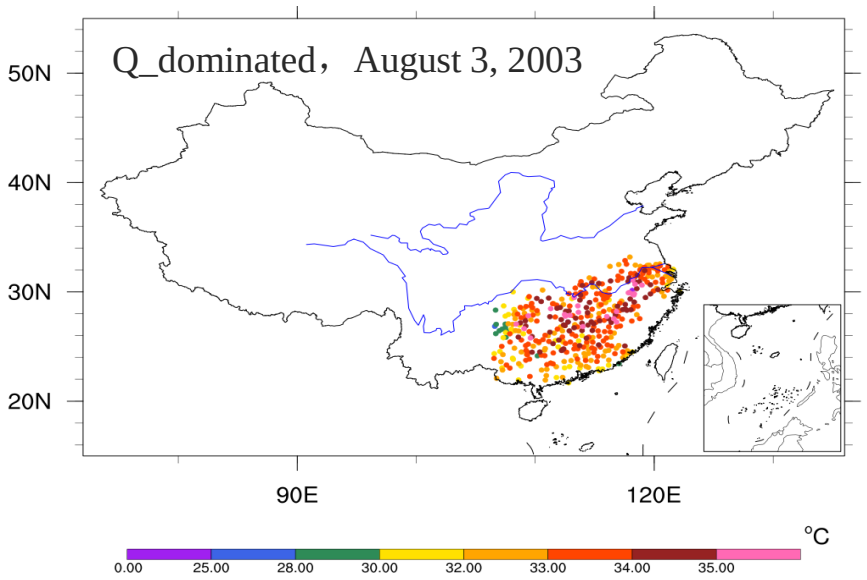
A Regional Extreme TW (Re_TW)

Anomalous temperatures usually influence an area.

High temperatu re + Spatial Extension = A Hot Region

Based on Wang et al., 2017, we defined the regional extreme TW (Re_TW): a hot region consist of more than 20 neighbored sites of ex_TWs , each two of which are within the distance of 250km.



The Classifications of Re_TW

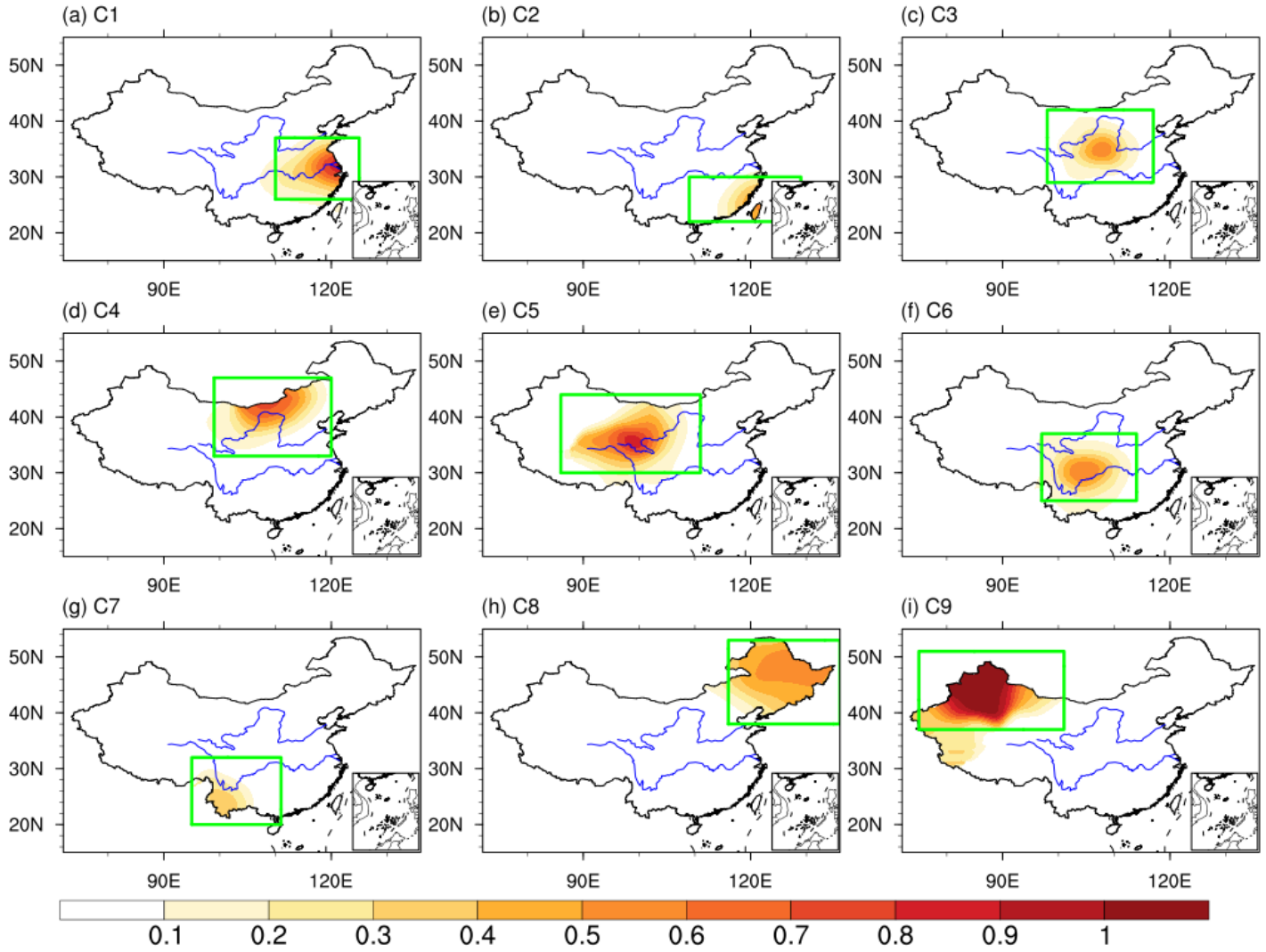
- A Re_TW consists of several hot stations, of which all have a daily SAR values. And the more stations have SAR<1, the more q contribute to the Re_TW, whereas the more stations have SAR >1, the more contribution T has to the Re_TW.
- Therefore, a Re_TW is regarded as q_dominated Re_TW in which most hot stations have SAR values <1 while it is regarded as T_dominated one in which most hots stations have SAR values >1.

The classification result:

q_dominated Re_TWs: 67%

T_dominated Re_TWs: 32%

The averaged daily TW anomalies (TW-daily threshold)

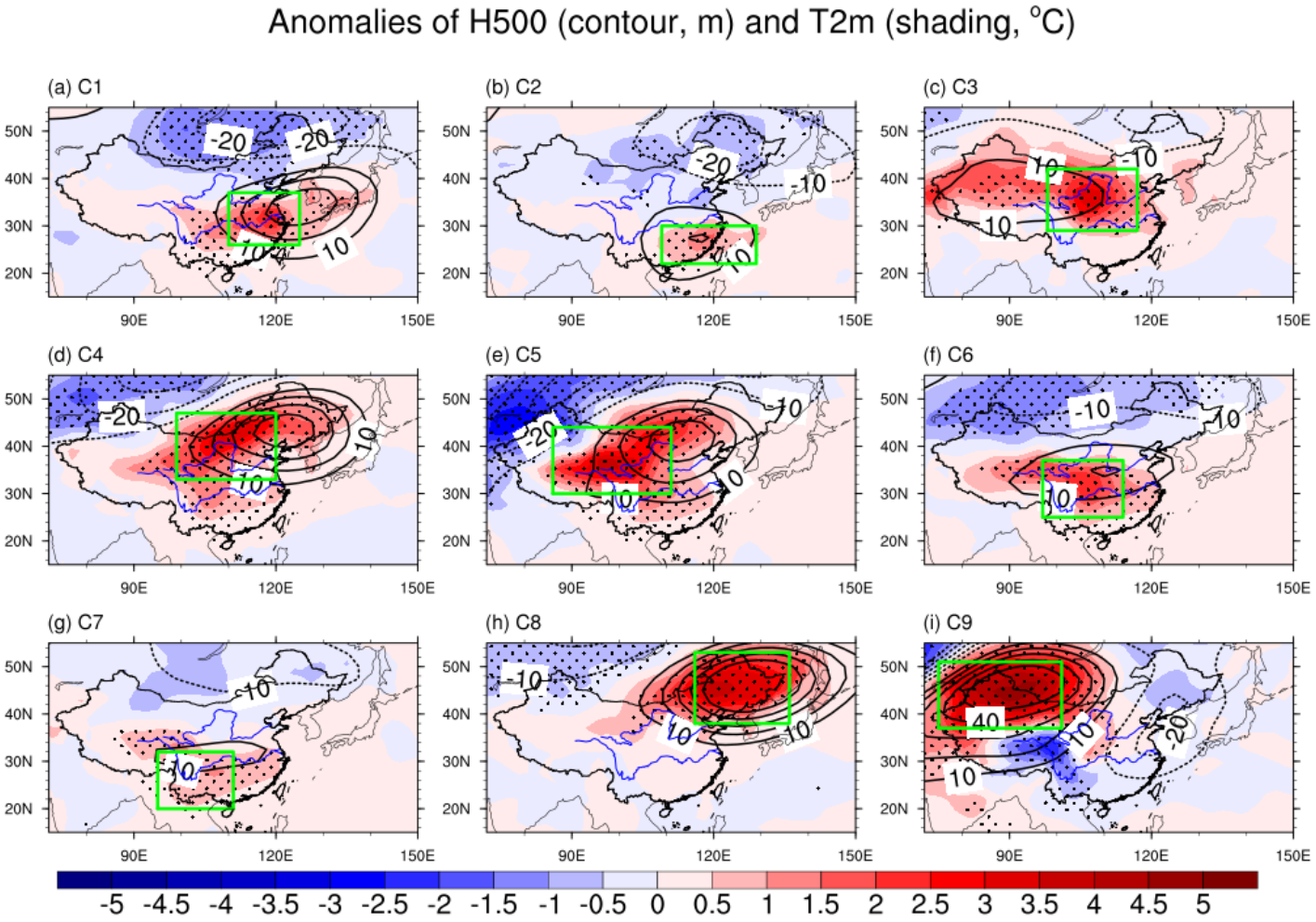


- TW exceedance show higher values in Northern China, which may be related to the low climatology of TW in Northern China. The territories of extreme Re_TWs in each cluster are bounded by green boxes.

The classification of Re_TWs in each cluster

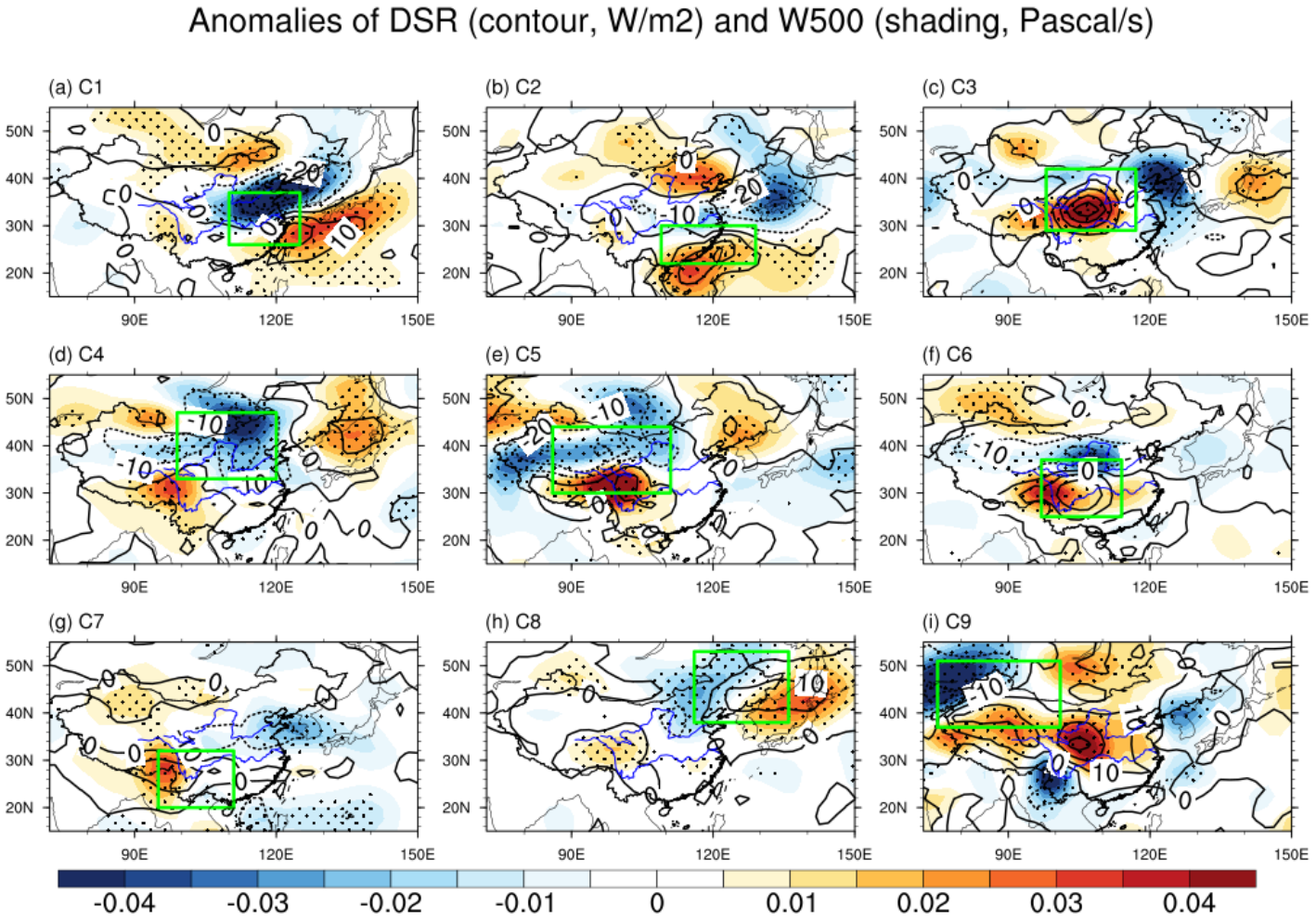
Cluster	1	2	3	4	5	6	7	8	9
q_dominated	72%	53%	53%	82%	77%	67%	66%	62%	65%
T_dominated	28%	45%	45%	16%	21%	33%	30%	38%	34%

- We will also try to specifically compare between the synoptic characteristic during cluster 4, 5 and those during the other clusters such as cluster 2 and 3 to possibly shed a light on the difference of the synoptics between q_domintaed and T_dominated extreme TWs.



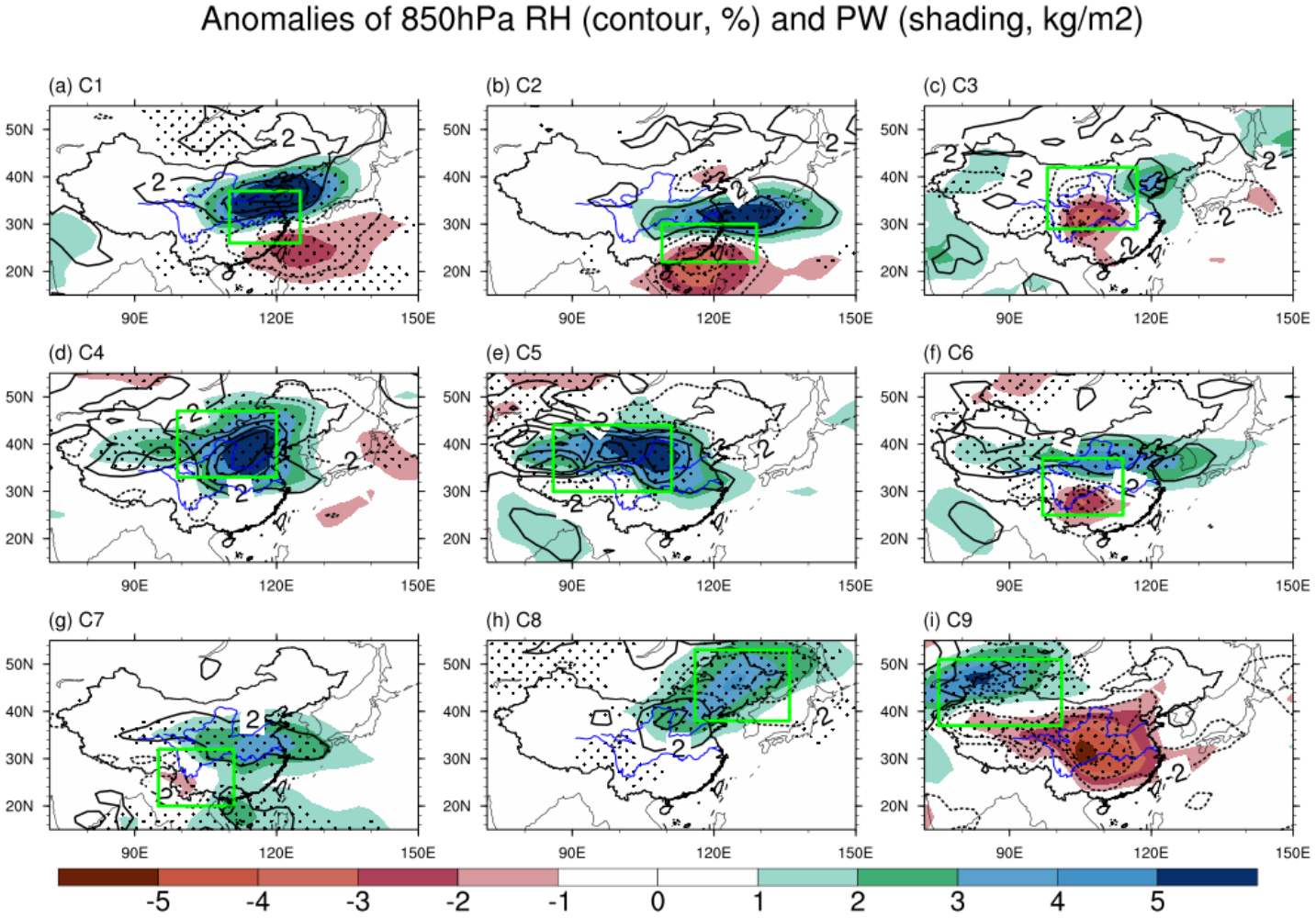
- There are positive T2m anomalies in the territory of extreme Re_TWs (bounded by the green boxes), dominated by extreme high-pressure systems. And such anomalies are stronger in northern part than the southern part of China, consistent with the stronger TW exceedance in the northern part of China.

- However, the increased T2m and H500 are not always co-centered but with notable geographic separation in some clusters. For example, the centers of increased T2m in clusters 4 and 5 are located at the west flank of the anomalous high systems while the center of increased H500 is directly above the center of increased T2m in cluster 8.



- Re_TWs in some cluster (cluster 2 and 3 apparently) are dominated by descending motion and increased DSR, which is helpful to sustain the anomalous high temperatures

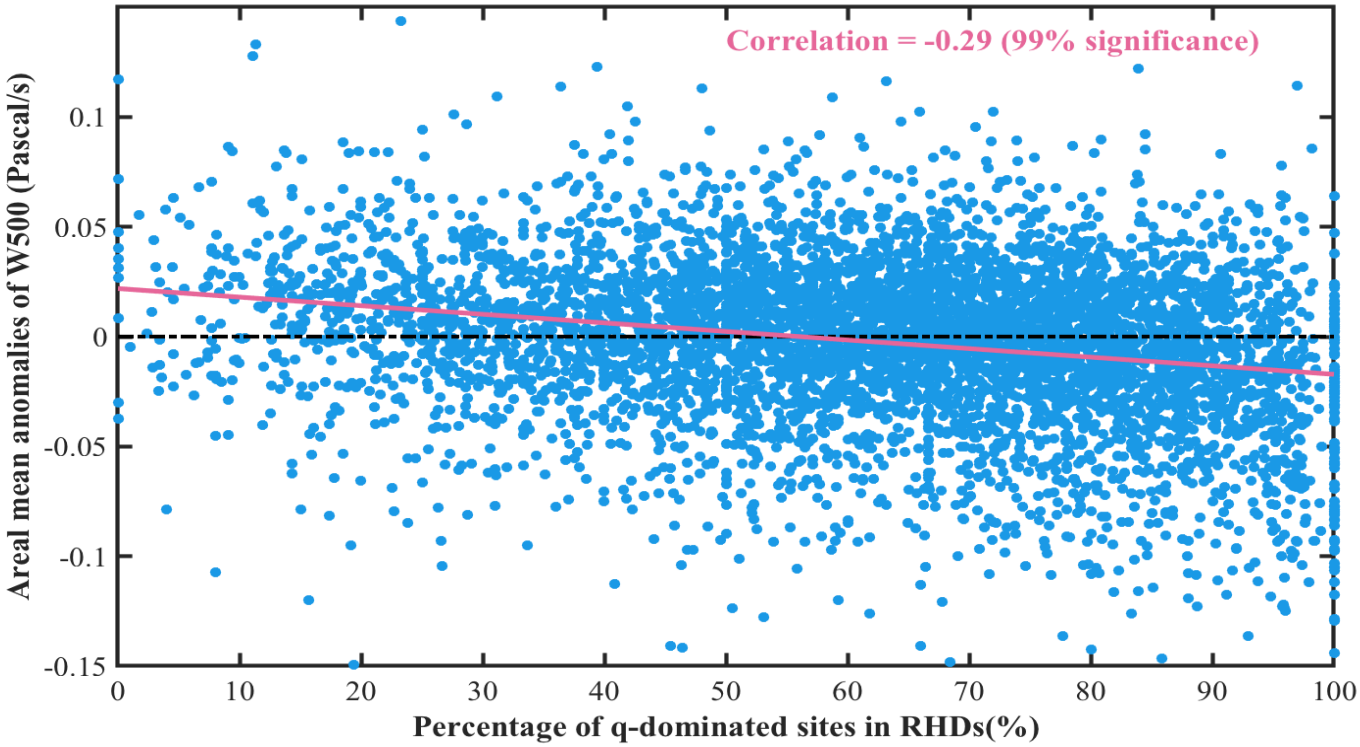
- While some other clusters (especially cluster 4 and 5) are covered aloft by ascending motion and decreased DSR, which does not benefit the extreme temperature maintenance.



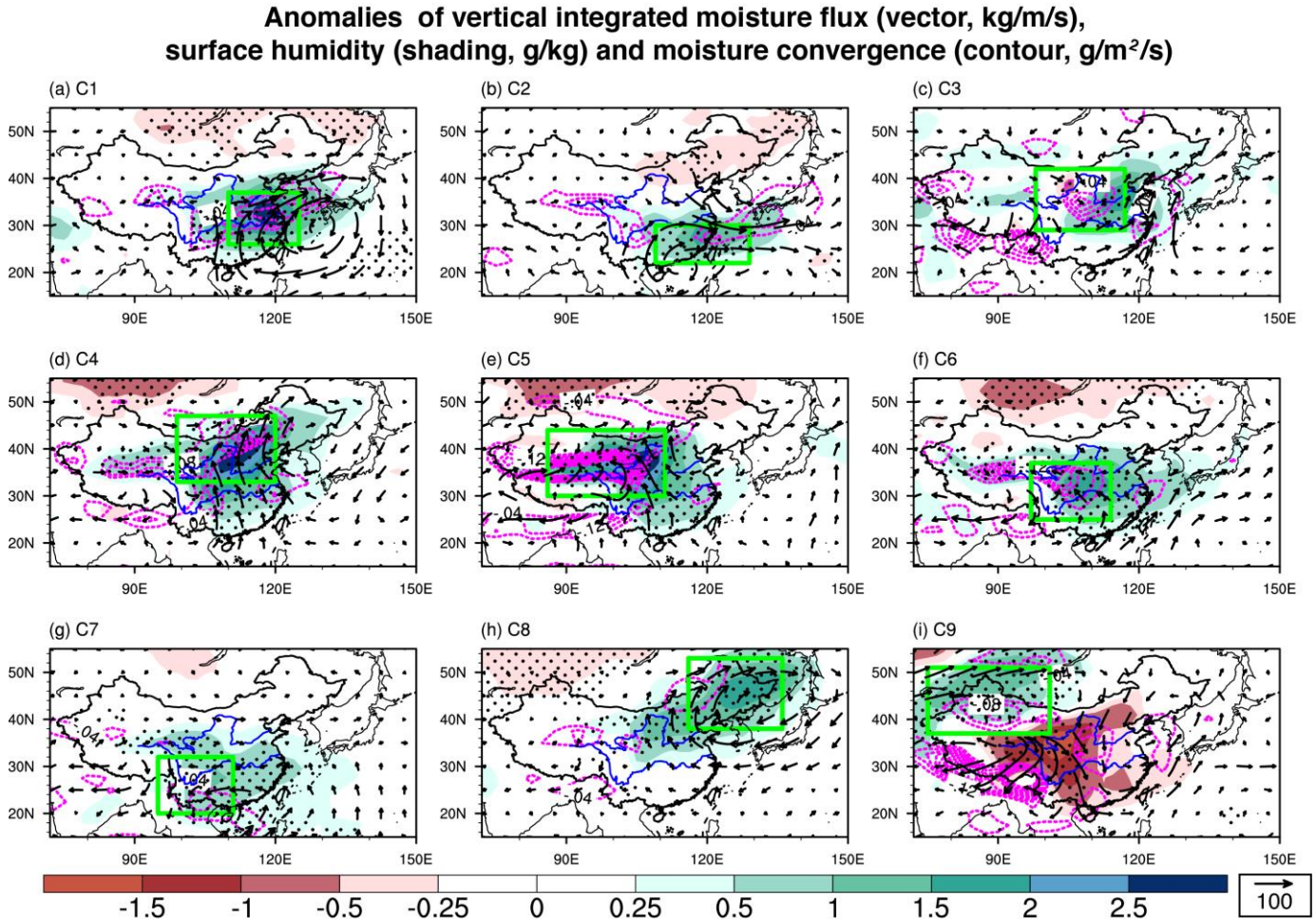
- In cluster 2 and 3, cluster 6 as well, it is reduced precipitable water while the precipitable water is apparently increased in the other cluster, especially cluster 4 and 5.

- Thus, we suspect that the synoptic environment during q_dominated Re_TWs is convection-favored while it is convection-inhibited during the T_dominated extreme Re_TWs.

Relationship between convection and SAR values



- **The more q-dominated sites, the stronger convection it is, which means the higher (lower) the q_dominance (T_dominance) is, the stronger the convection would be.**



- There are specific humidity increases near the territory of each cluster, generally co-located with the moisture flux convergence. The moisture flux convergence is stronger in cluster 4 and 5 where q-T relationship is weak, indicating the water transport primarily contributes to the humidity increase therein. And the effect of humidity increase is higher than the effect of T increase (q_s increase) as the near surface relative humidity is increased.
- However, in the other clusters (especially cluster 2 and 3), the near surface relative humidity is decreased over the territory of TW exceedance, indicating the T increases (q_s increases) are stronger than q increases.

Further verification: a canonical view

- It can be inferred the synoptic environment during q_dominated Re_TWs tends to be convection-favored and it tends to be convection-inhibited during the T_dominated extreme Re_TWs. And the higher (lower) the q_dominance (T_dominance) is, the stronger the convection would be.

- Therefore, to distinctively illustrate the difference between q_dominated and T_dominated Re_TWs, we further compare between the synoptics during the extreme cases of q_domianted Re_TWs of which most sites are of extreme q but normal T and those during the extreme cases of T_dominated Re_TWs of which most sites are of extreme T but normal q.

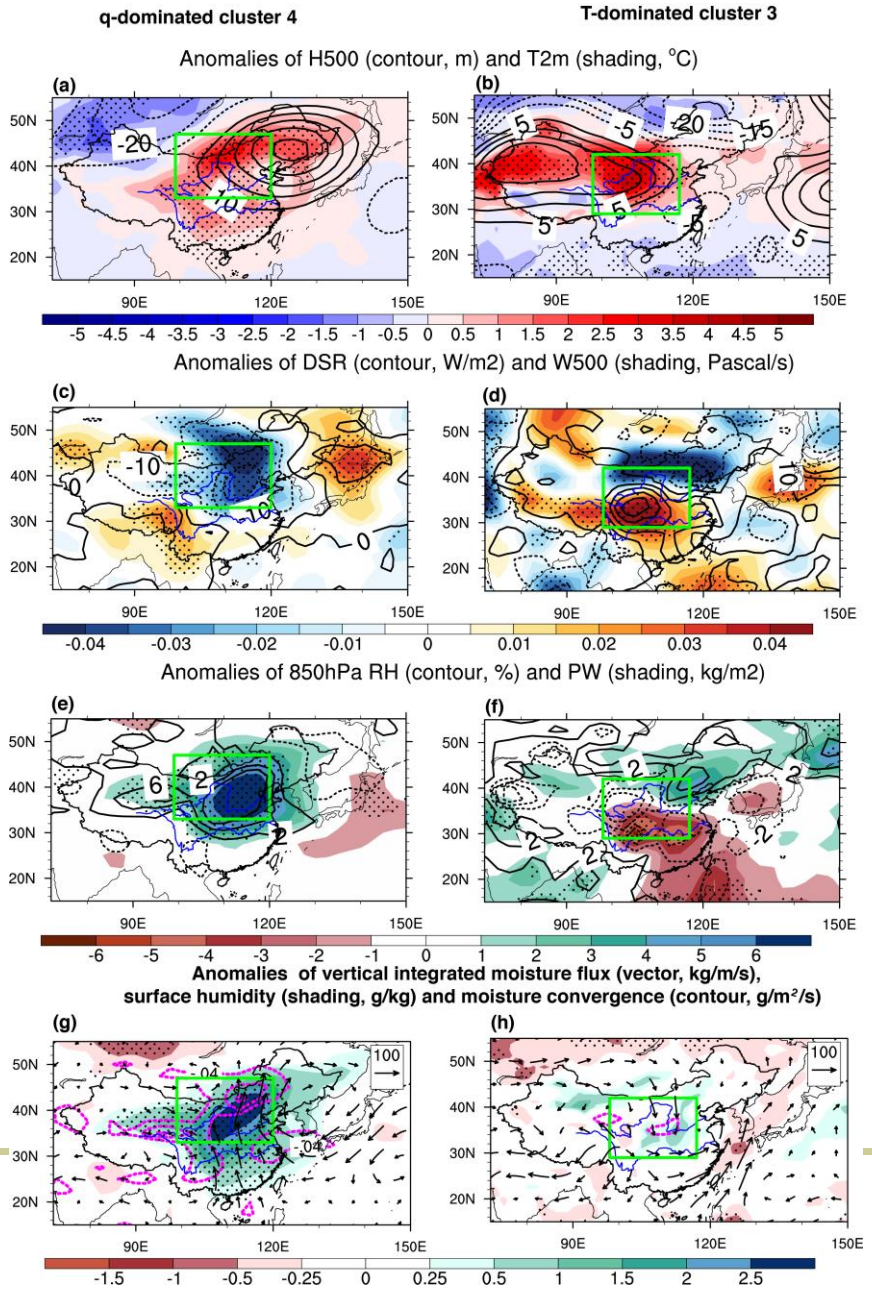
Further classification of each cluster

Cluster	1	2	3	4	5	6	7	8	9
q_dominated (extreme cases)	18.89	14.46	15.74	64.38	30.97	17.72	17.05	22.63	29.94
T_dominated (extreme cases)	1.73	11.57	25.38	5.56	1.55	3.99	2.58	9.17	9.58

- Cluster 4 have relatively more extreme cases of q_dominated Re_TWs.
- Cluster 3 have relatively more extreme cases of T_dominated Re_TW.

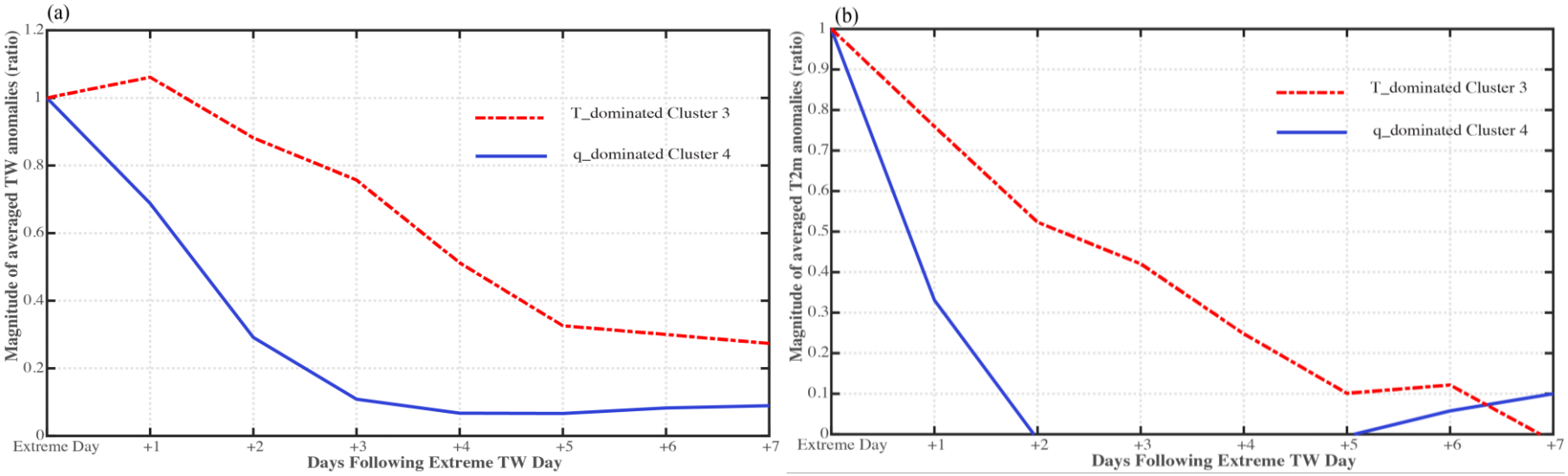
Therefore, the followings analyses compare between the synoptics during the extreme cases of q_dominated Re_TWs in cluster 4 and those during the extreme cases of T_dominated Re_TWs in cluster 3.

Extreme cases of T_dominated(q_dominated) Re_TWs in cluster 3 (4)



- For both q_dominated and T_dominated TWs, the territories of extreme Re_TWs are accompanied by increase T and high-pressure system.
- Ascending motions with decreased DSR and increased precipitable water are seen for q_dominated cluster 4, which implies a convection-favorable environment. Moreover, specific humidity shows apparent increase over the center of TW increases, accompanied by strong water vapor transport. The q increases are stronger than the T increases, thus RH is increased. Also, the strong low-level wind convergence and high relative humidity may benefit the convection activity.
- Besides, descending motions with increased DSR and decreased precipitable water are seen, which benefit the maintenance of high temperature. Moreover, specific humidity q shows weak increase. The relative humidity is decreased as T increases are stronger.

The evolutions of extreme TW days



Daily evolution of the ratio of averaged TW anomalies posted to the specific dates of the extreme cases of q-dominated RHDs in cluster 4 and the T-dominated RHDs in cluster 3. The TW and T2m anomalies are averaged over the territories of RHDs.

- **The anomalous TW/T of T_dominated TW extremes tend to last longer than the q_dominated TW extremes. This is consistent with the spatial pattern of ex_TW durations, which show longer duration in southern China while shorter duration in Northwest and Northern China.**

Summary

- Extreme TWs show high occurrences in southern China and they are longer lasting over the southeastern and northeastern China. Moreover, the magnitude of extreme TWs is higher over the northern part of China than those in the southern part.

- Anomalous T, q and TW are generally co-occur in southeastern China while extreme TW/T show less overlap in Northern and Northwest China. Therefore, focusing on only high dry temperatures will miss most of extreme TW in Northwest and Northern China.

- Based on the excursion of q and T to the extreme TWs, ex_TWs are classified into q_dominated and T_dominated ones. q shows higher dominances in arid and semi-arid regions.

- The territories of extreme TWs are generally accompanied by increased T2m and influenced by anomalous high-pressure system.

- However, the synoptic environments during q_dominated ex_TWs tends to be convection-favored. In contrast, it tends to be convection-inhibited during T_dominared ex_TWs.

- T_dominated ex_TWs are likely to sustain a longer time than the q_dominated extreme TWs.

Thank you!