

Heat extremes in China:
from synoptic behaviors towards urbanization effects

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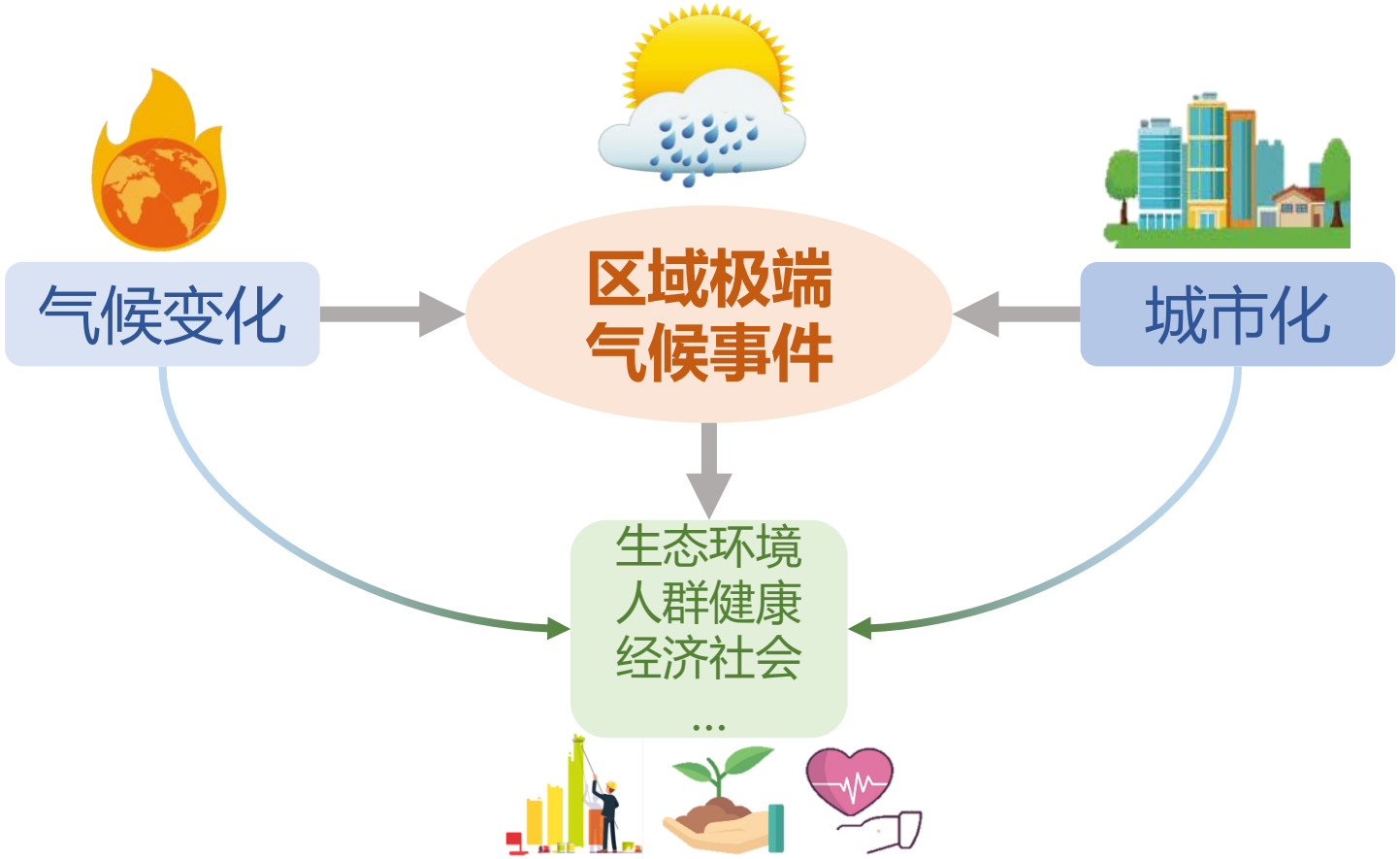
研究方向及个人经历



2007 武汉大学 (遥感)

2010 中科院地理所 (GIS)

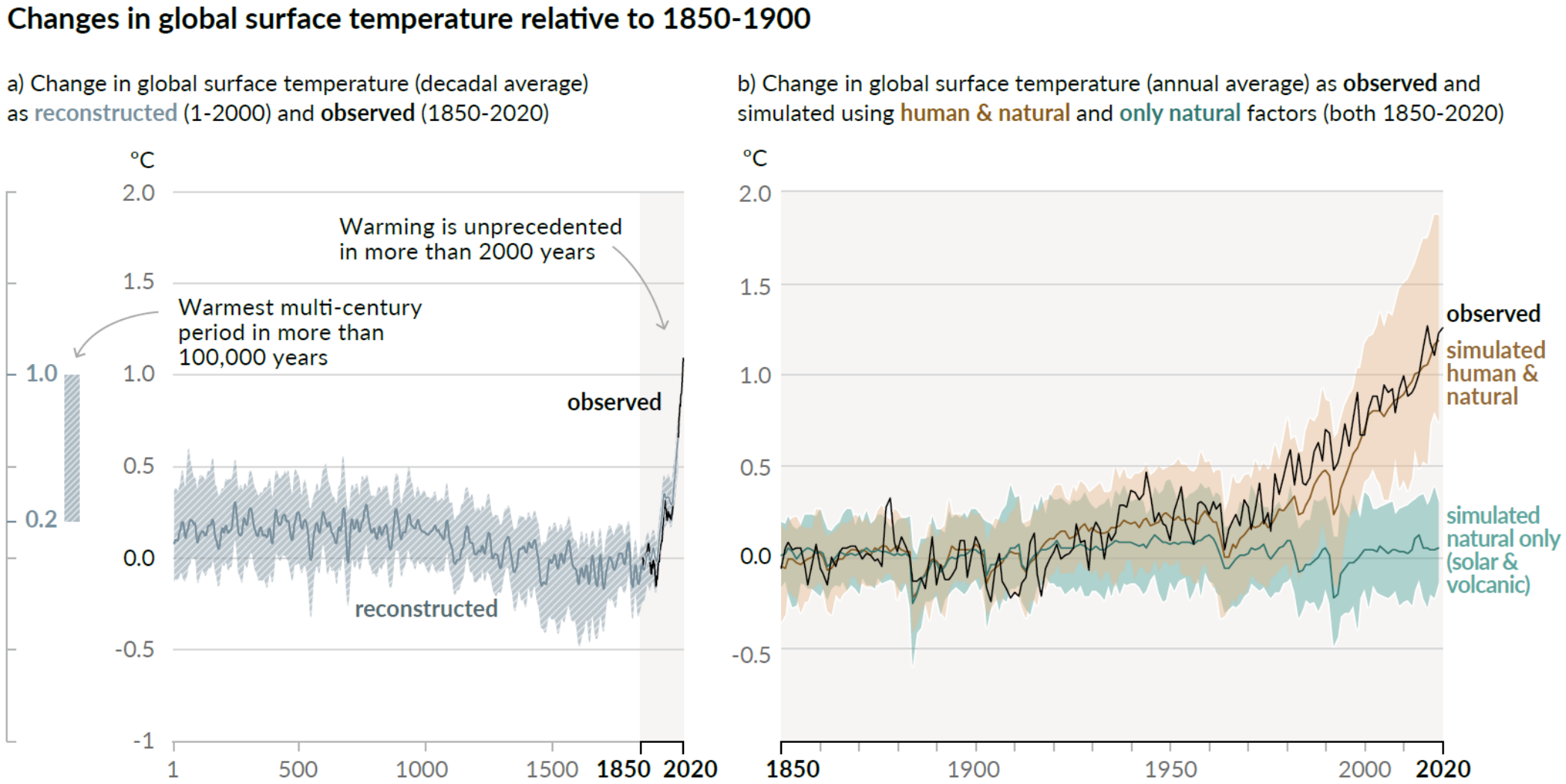
2014 香港中文大学 (地理->大气)

2016 中山大学

Outline

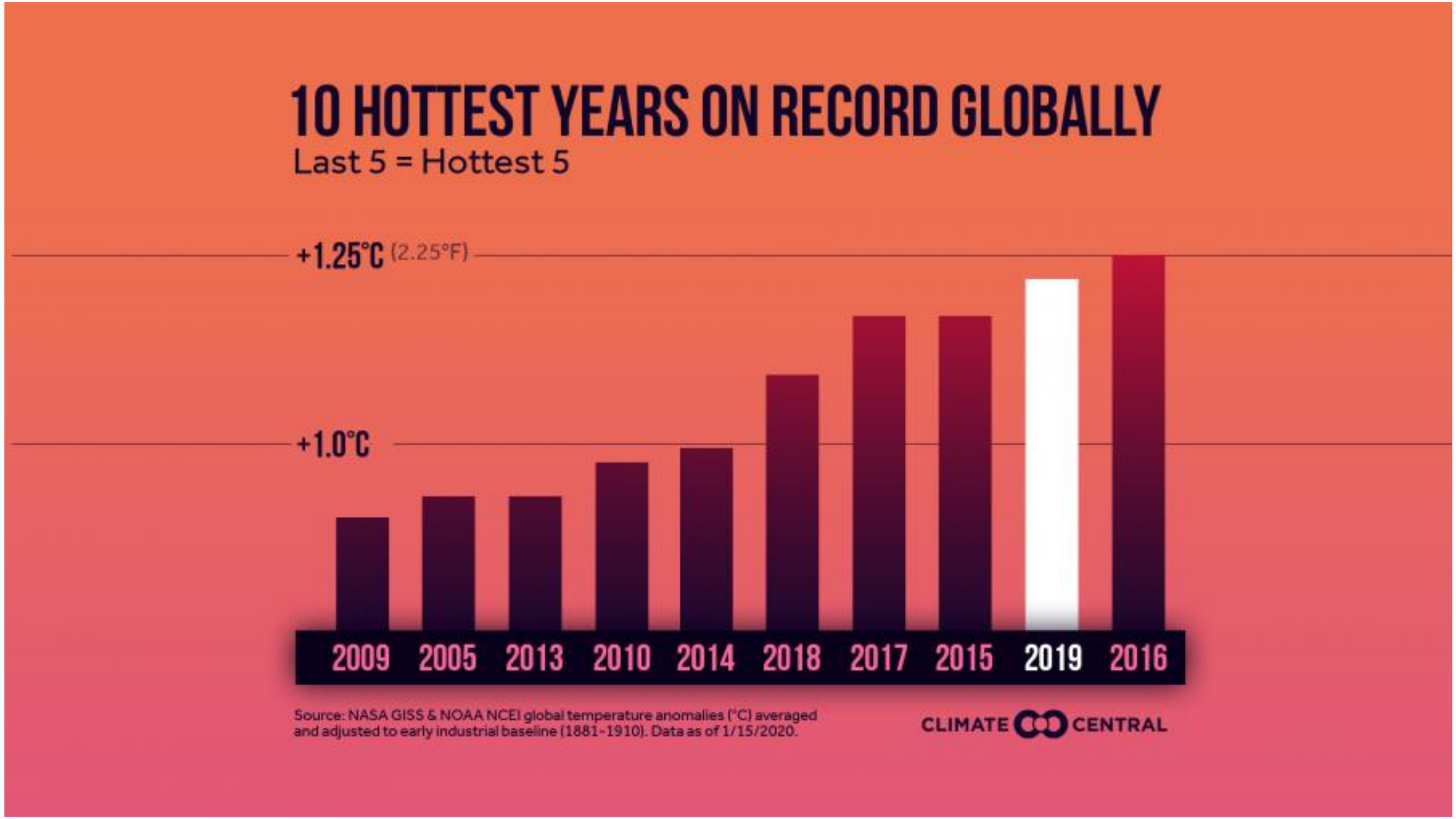
1. Synoptic behaviors and evolution patterns
2. Interannual variabilities in relation to SST anomalies
3. Long-term trends in relation to urbanization effects
4. Human-perceive temperature and urban dry island
5. Summary

Background: A warming world?



(Source: IPCC, 2021)

Top 10 Warmest Years on Record



Heat extremes pose extremely harmful impacts

- 2010 European heatwave: >5500 deaths in Russia (Grumm, 2011)
- 2015: 3275 deaths in France, 2248 deaths in Indian (Tmax=48℃)， 1229 deaths in Pakistan (Tmax=49℃) (Ma et al, 2015)
- **157 million** more people were exposed to heatwave events in 2017, compared with 2000 (Watts, *Lancet*, 2018).

France

India

Pakistan

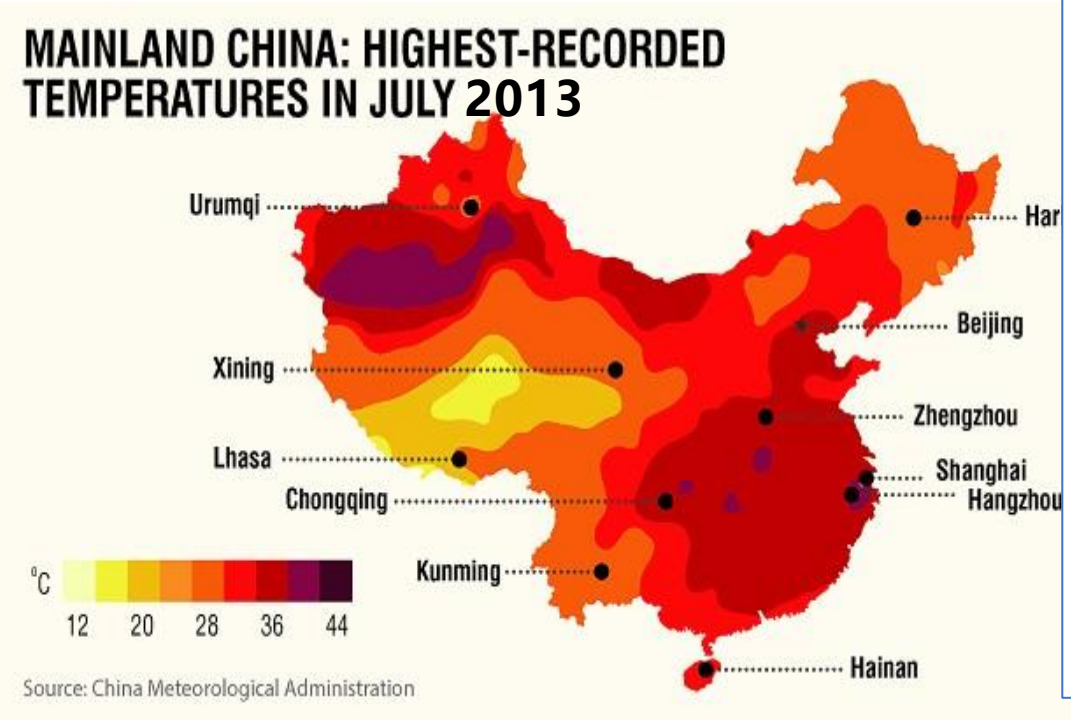
Heat extremes in China

- **2013 heatwave in China: > 5000 heat-related cases**

  (Gu et al., 2015)

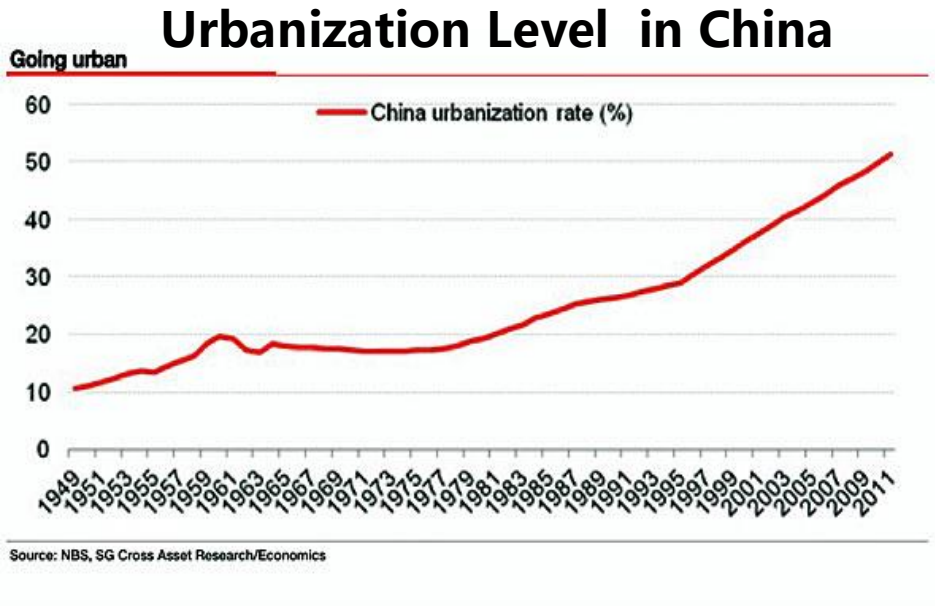
  maximum temperature: 44.1 ℃ in Xinchang, Zhejiang

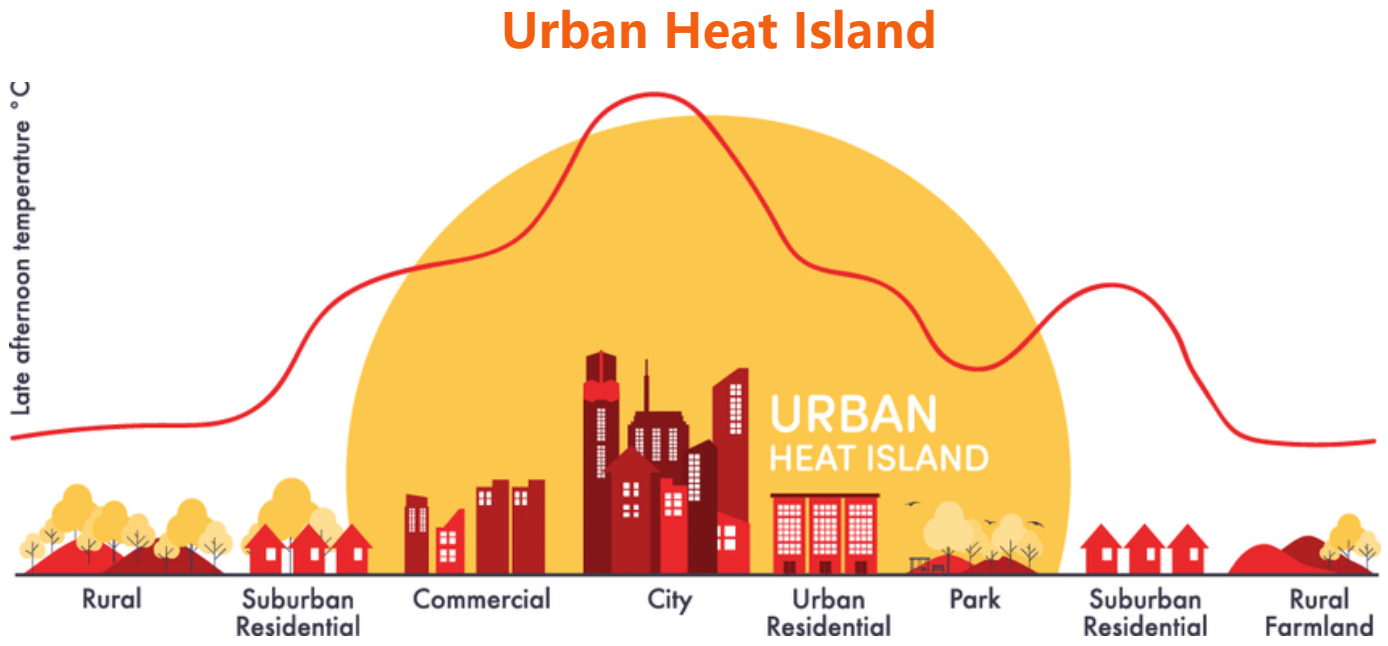
  Hangzhou: >40℃ for consecutive 8 days



Background

Heat extremes would be intensified even more profoundly in **fast-urbanizing** area (e.g., China)





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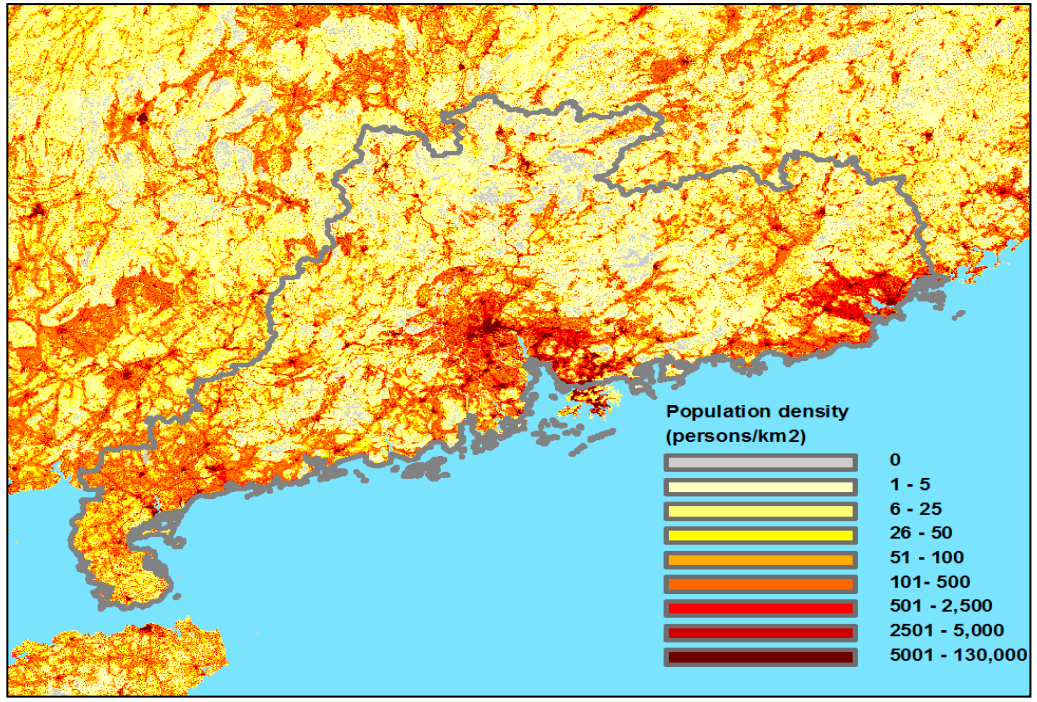
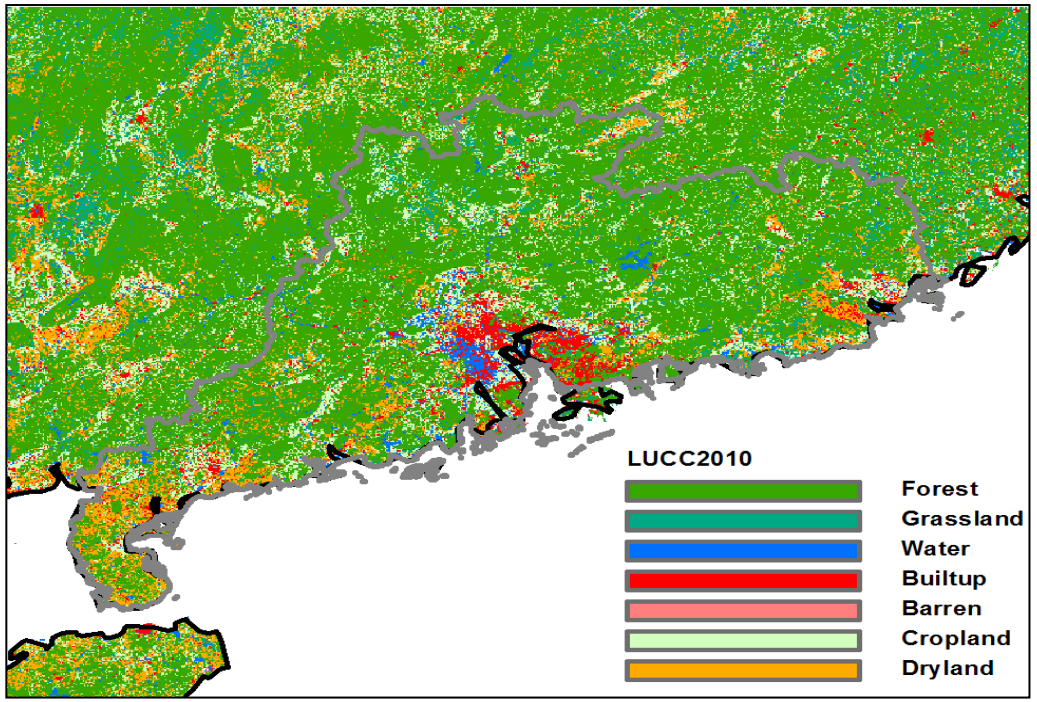
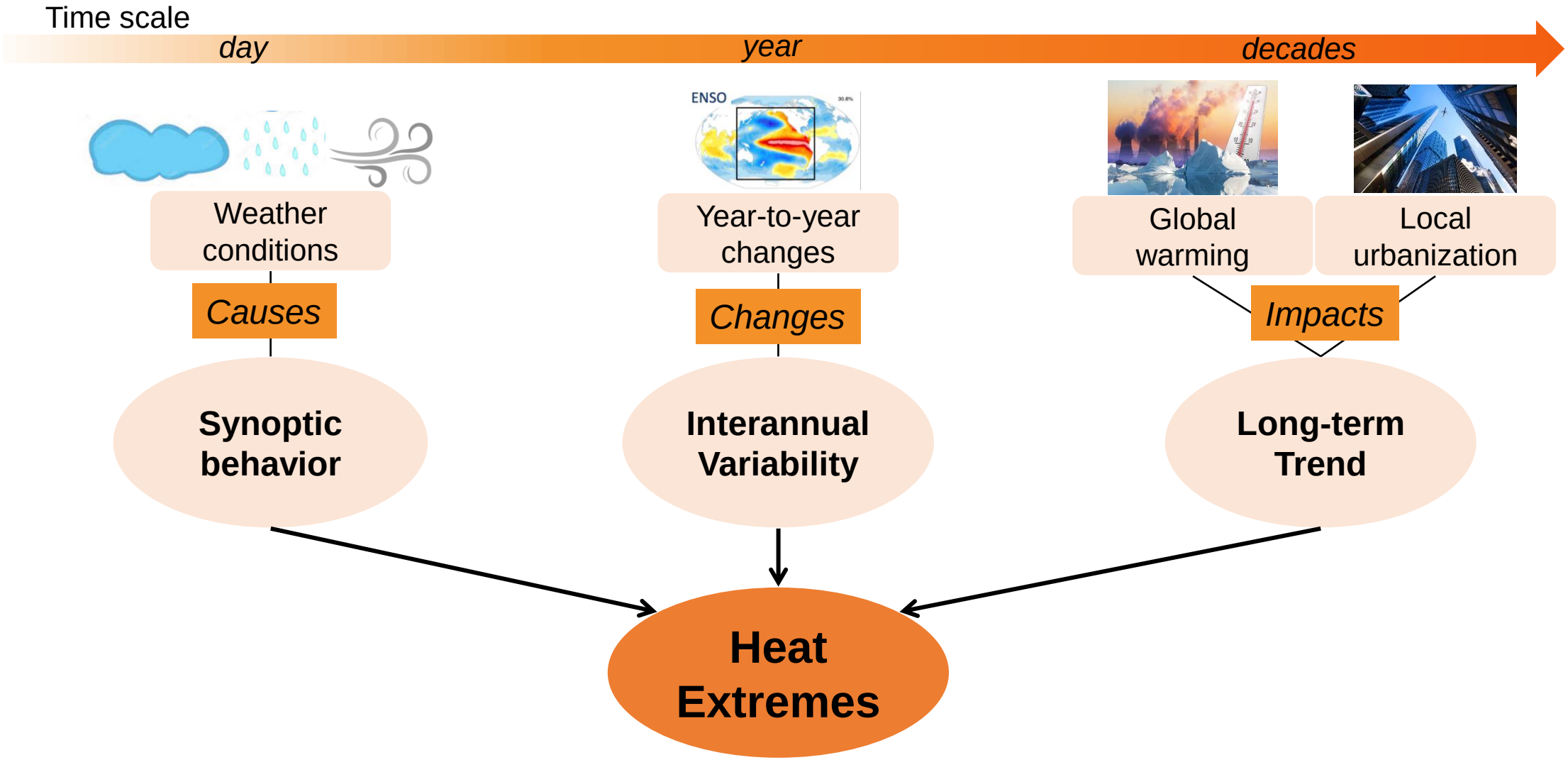


(a) Population density in 2010



(b) Land use / land cover types

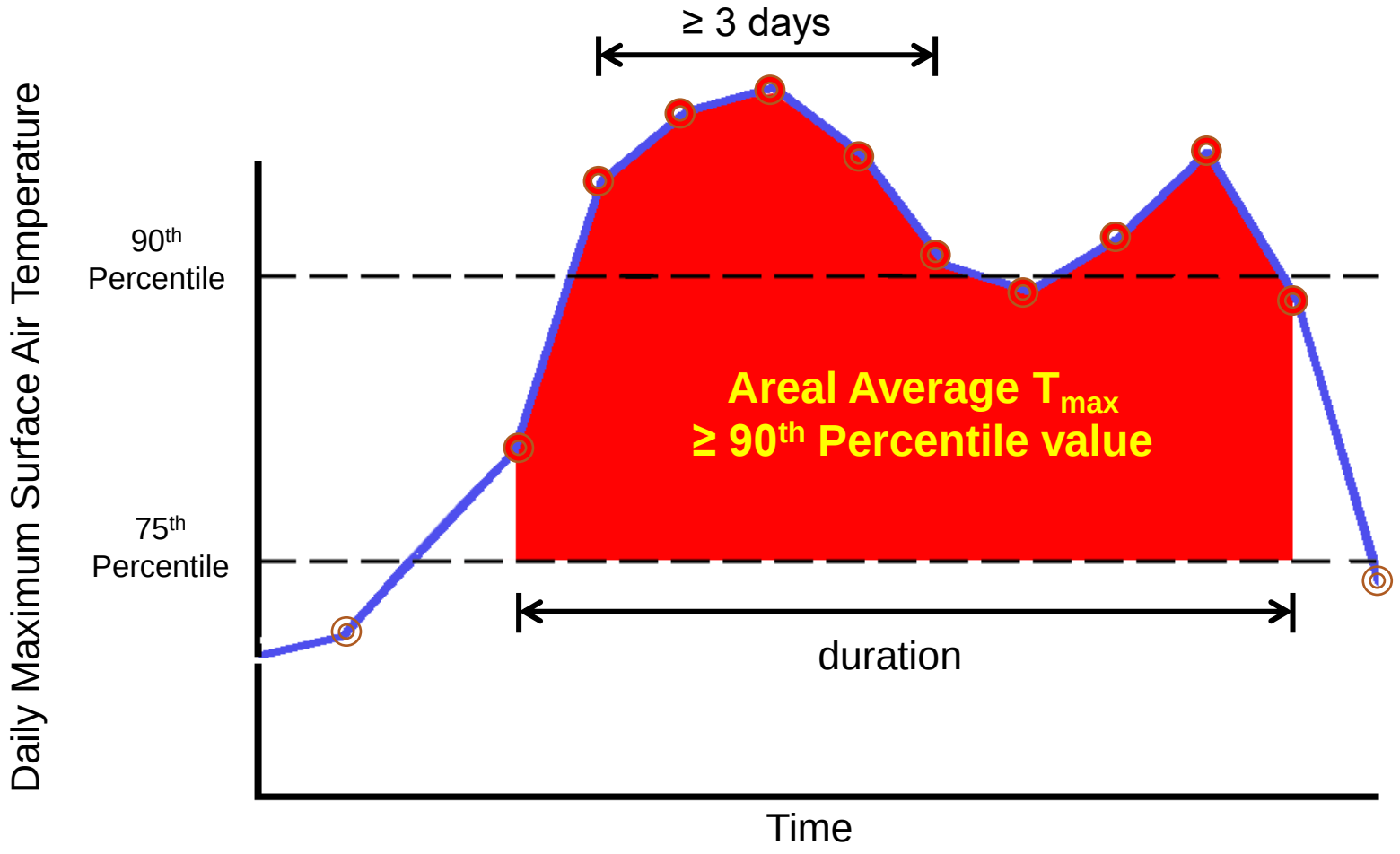
This project



For forecasting, predicting, adapting, mitigating

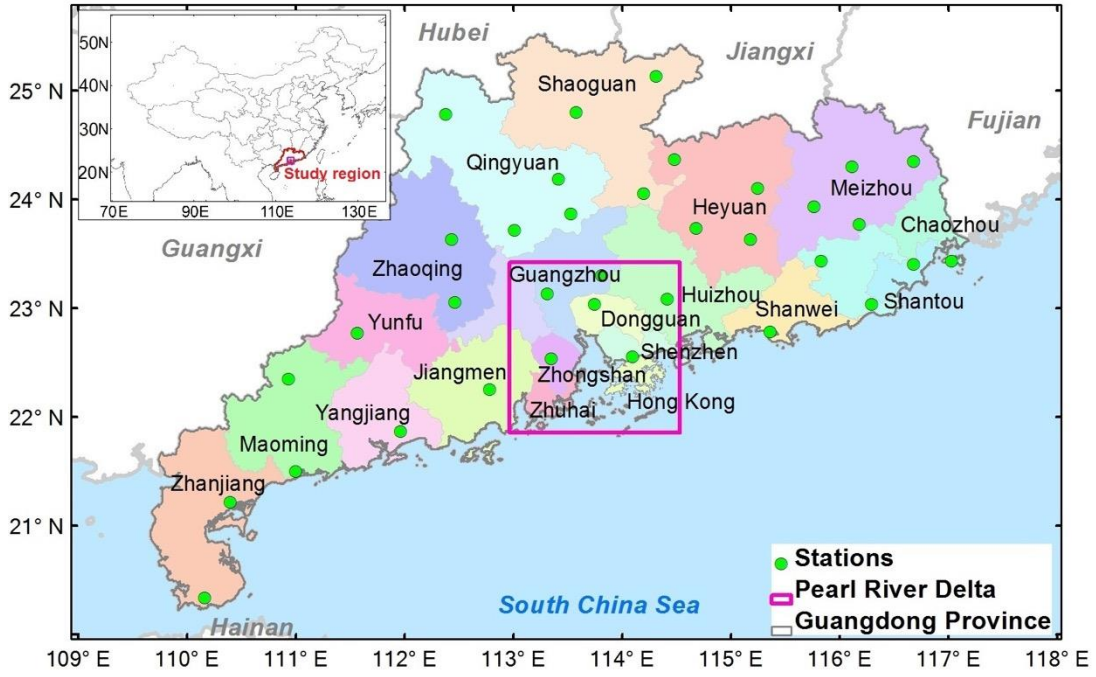
1. Synoptics and Development of Heatwaves

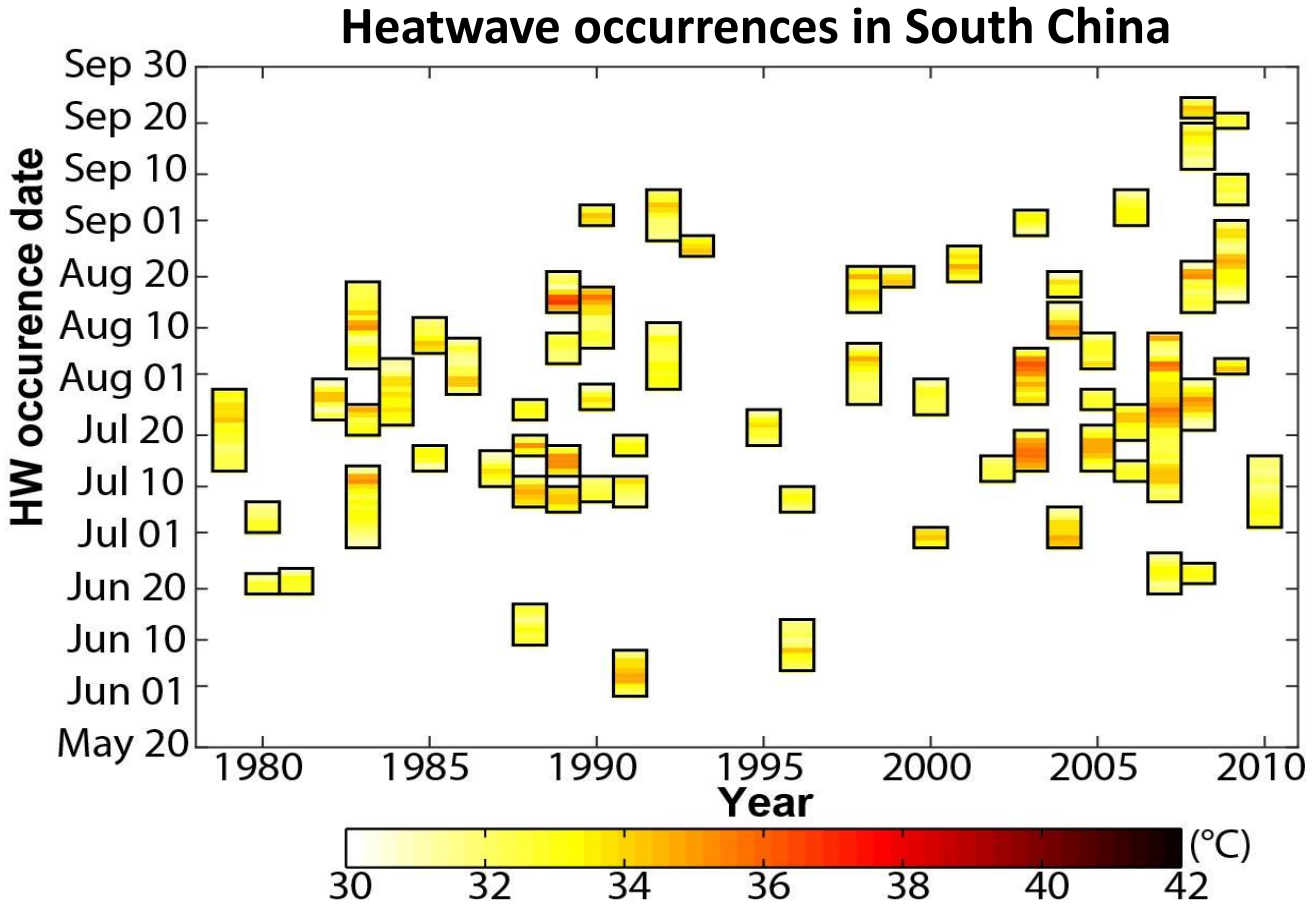
Identification of heatwave



Heatwave is identified by the spatial mean of T_{max} (Lau & Nath, 2012, 2014; Luo & Lau, 2017).

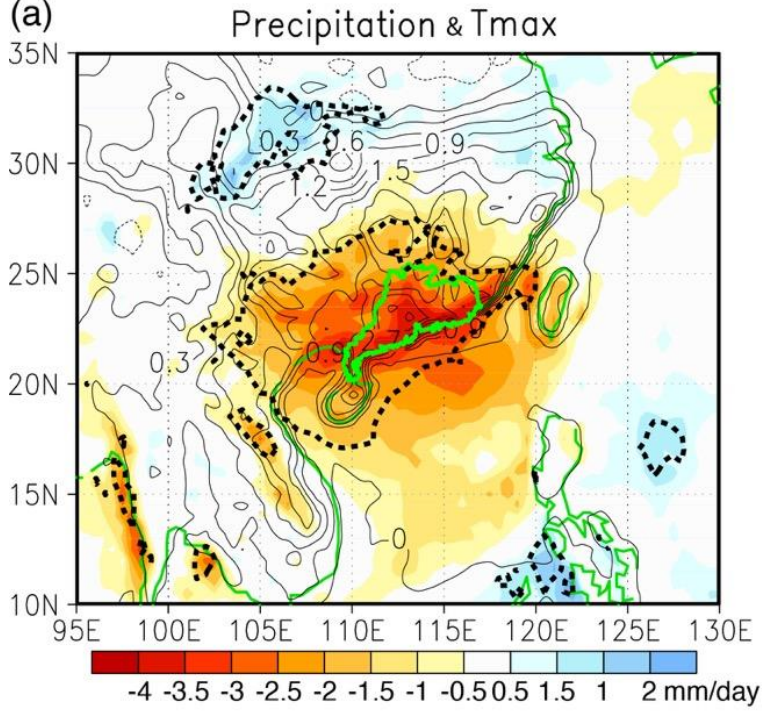
Heatwaves in South China

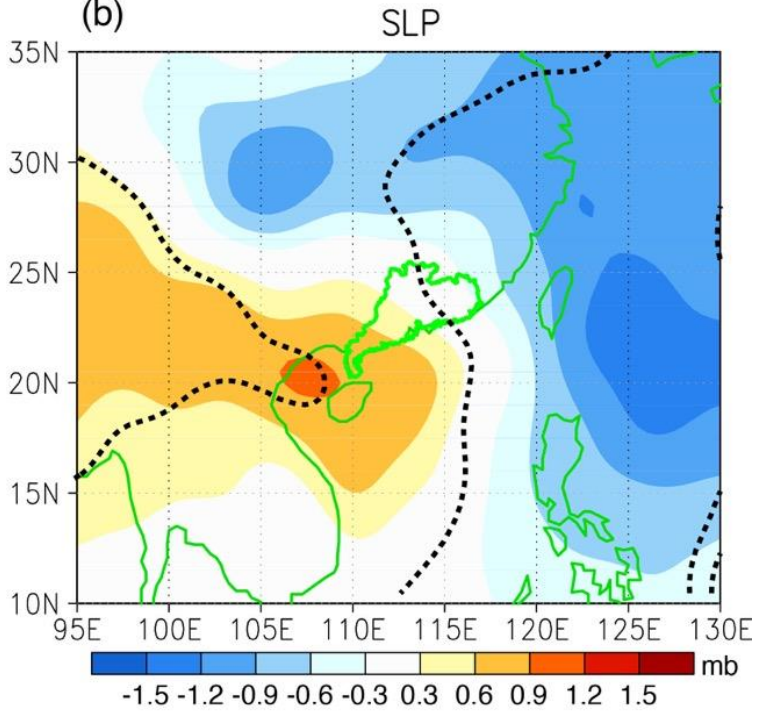




(Luo & Lau, *J. Climate*, 2017)

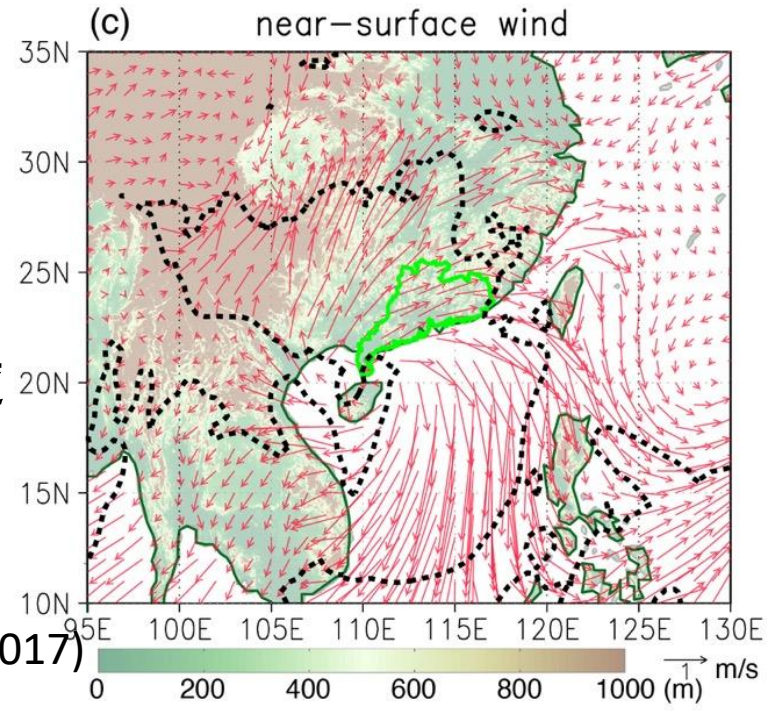
降水减少

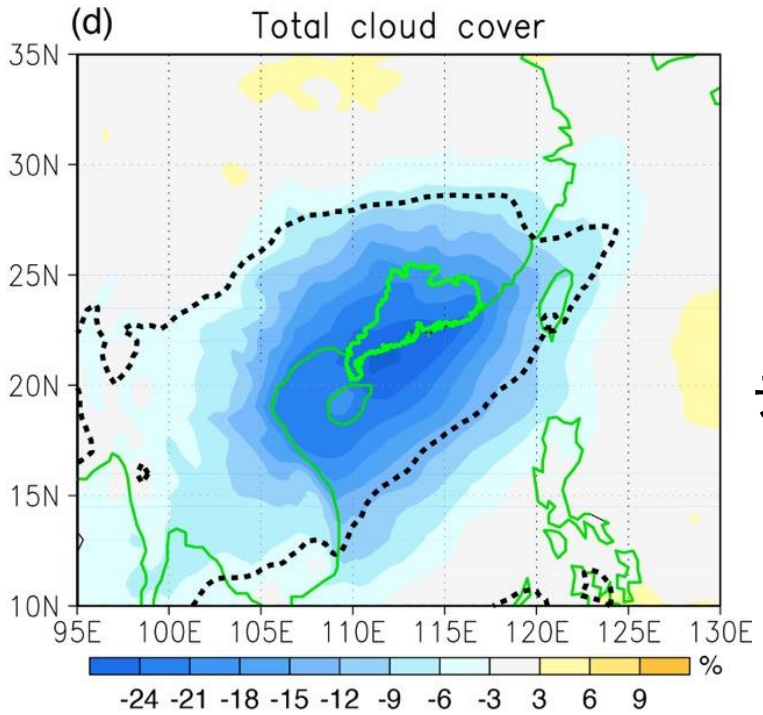




气压增强

近地表反气旋

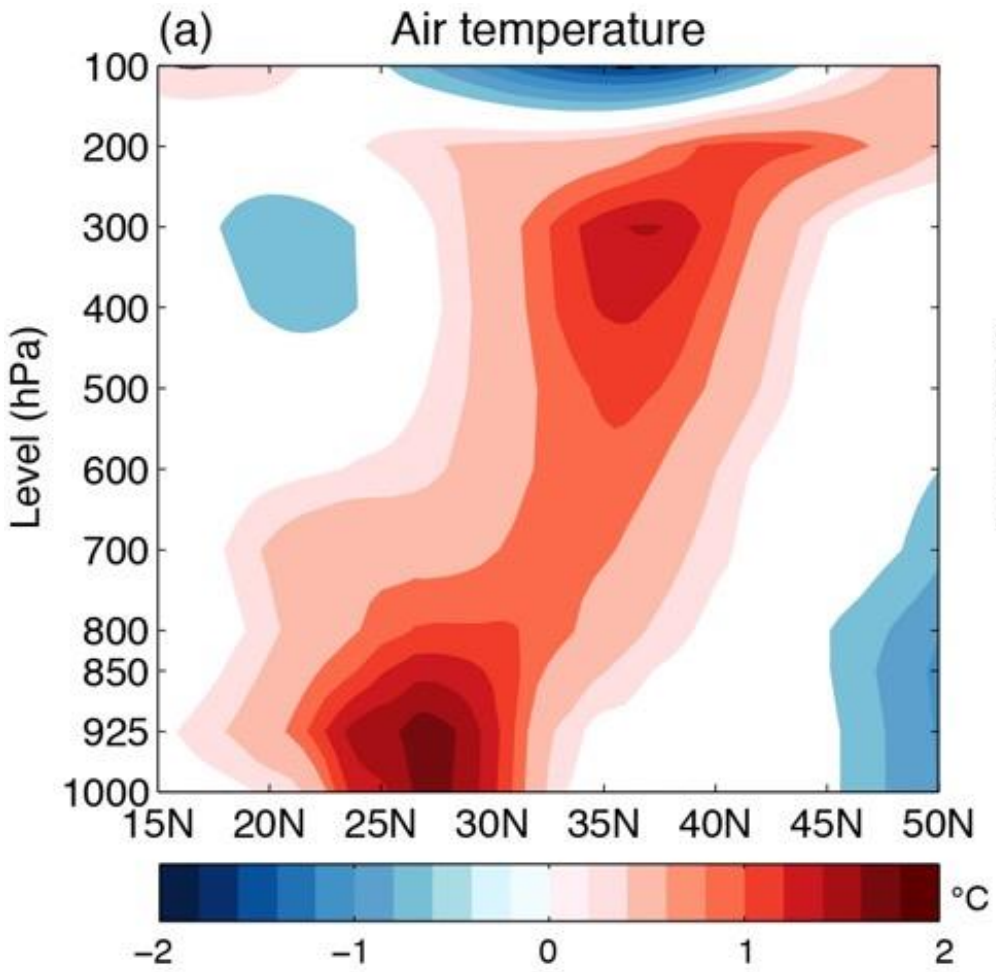


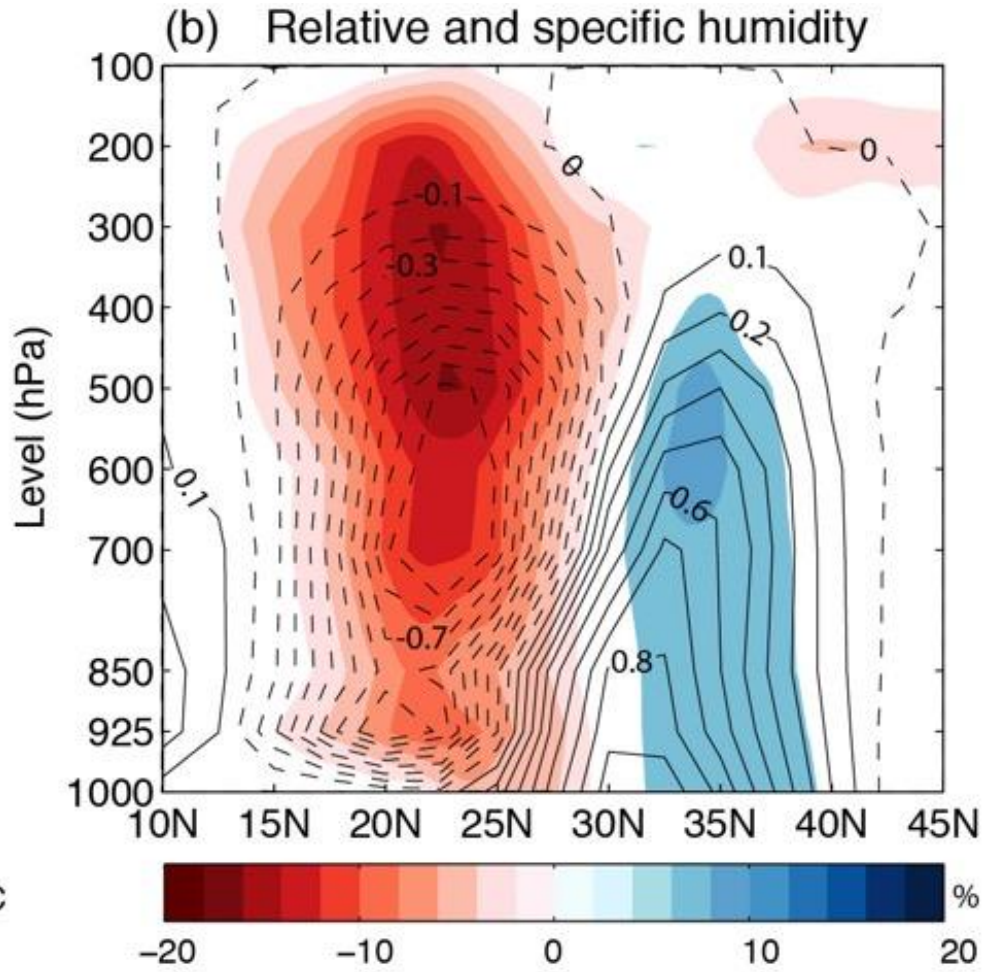


云量减少

(Luo & Lau, *J. Climate*, 2017)

Vertical structure of heatwave in South China

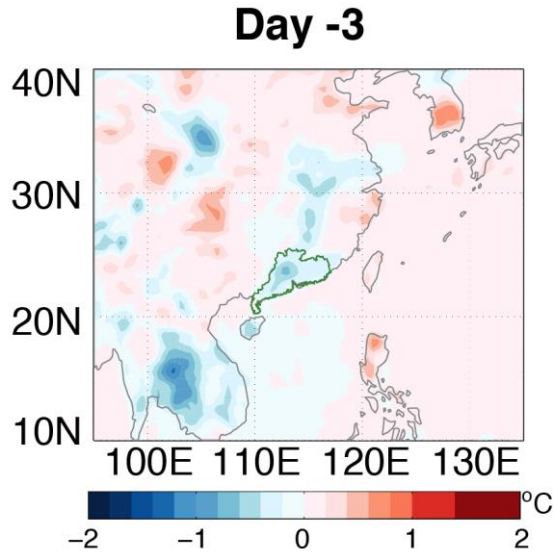




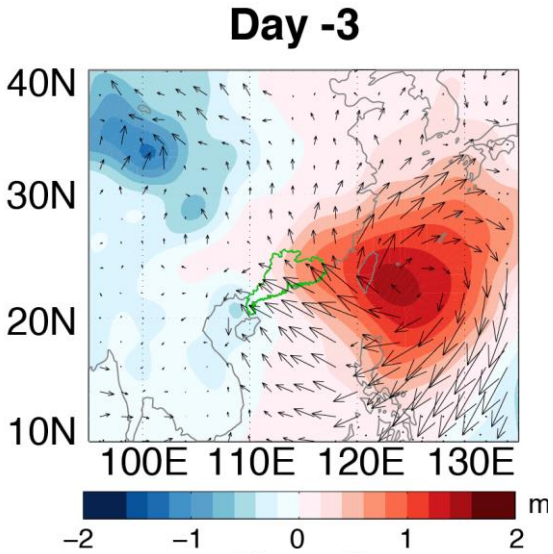
(Luo & Lau, *J. Climate*, 2017)

Development of heatwave in South China

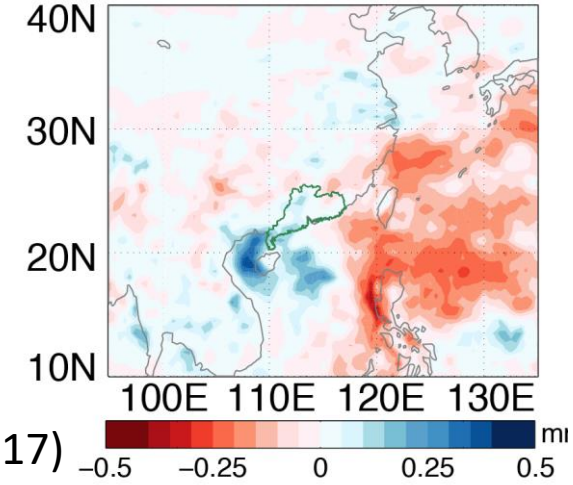
Tmax



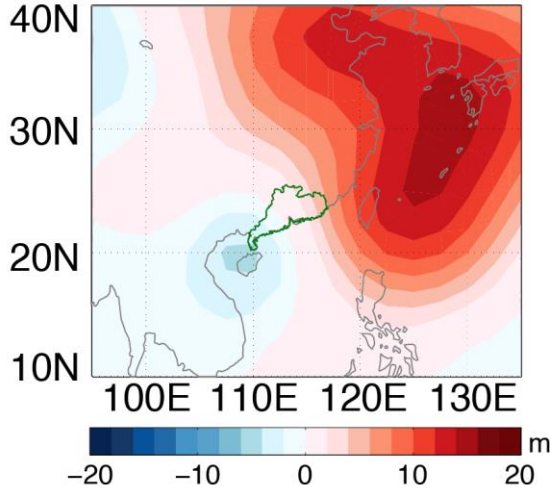
SLP & Wind



Precip.



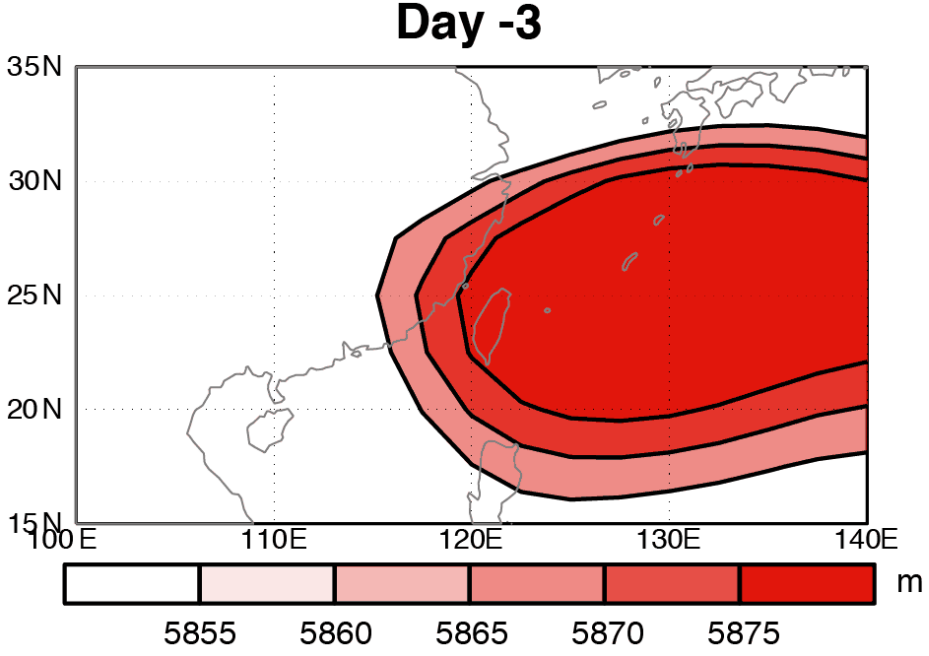
Z500



(Luo & Lau, *J. Climate*, 2017)

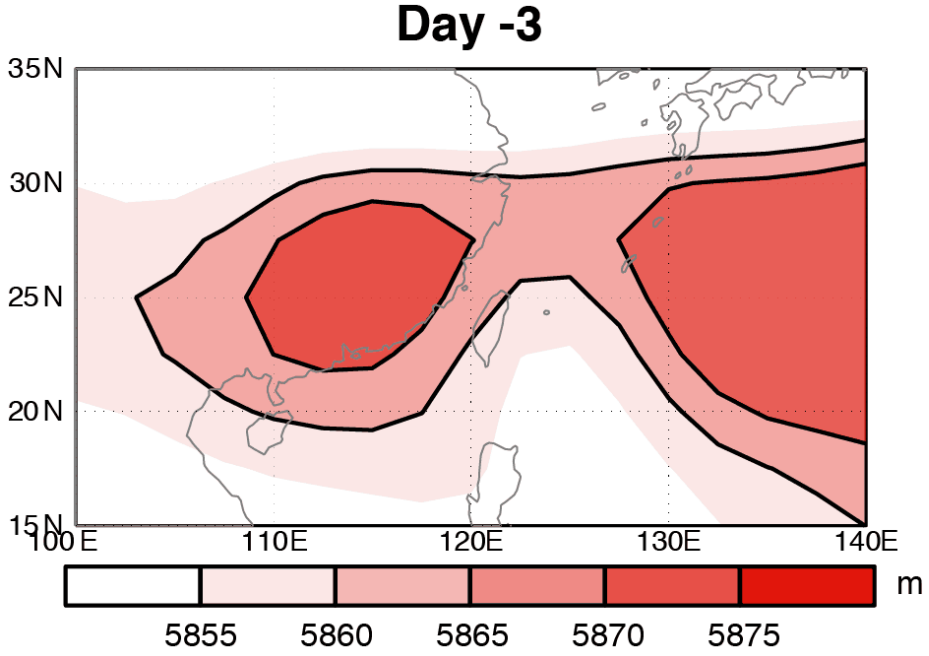
Movement of the WNP subtropical high

Prior to heatwave



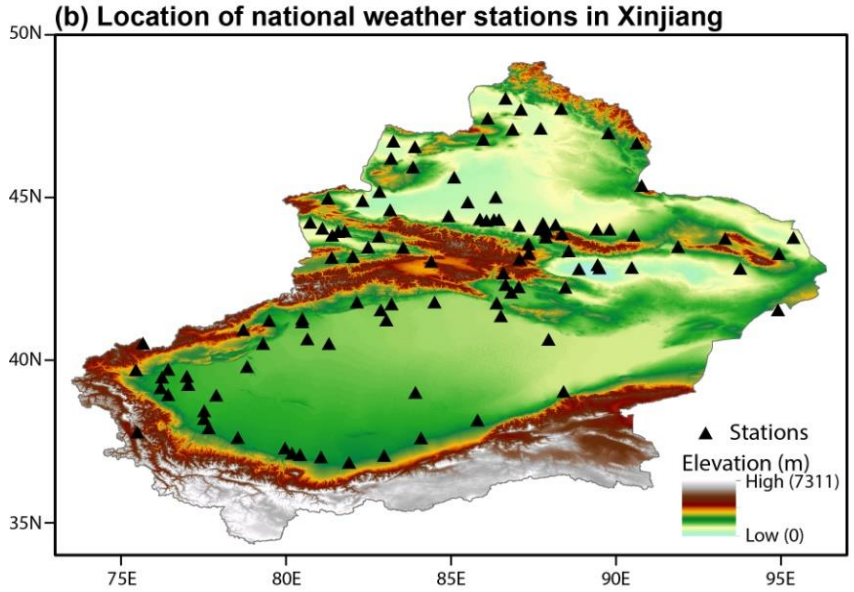
副高西进

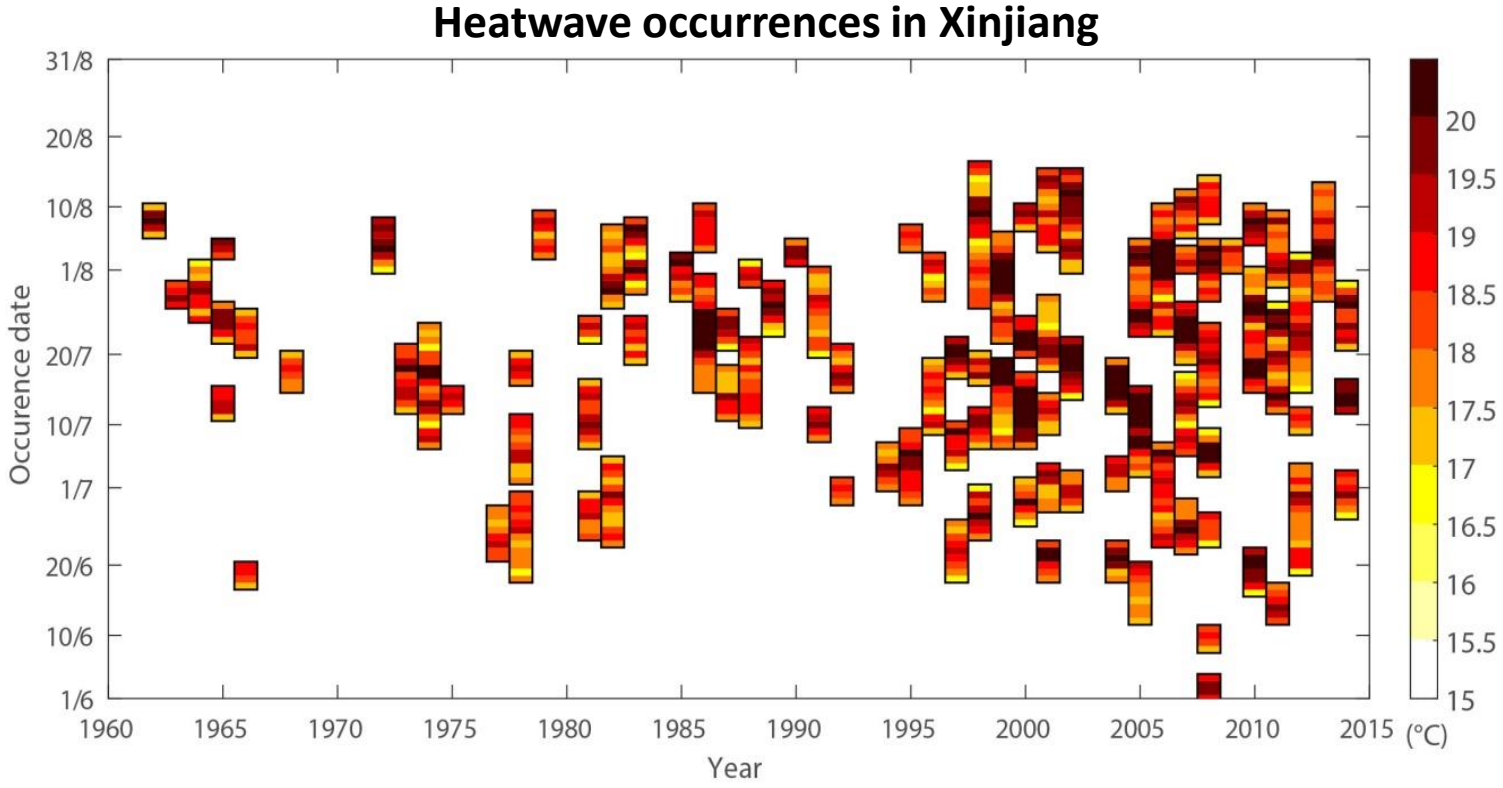
After heatwave ending



(Luo & Lau, *J. Climate*, 2017)

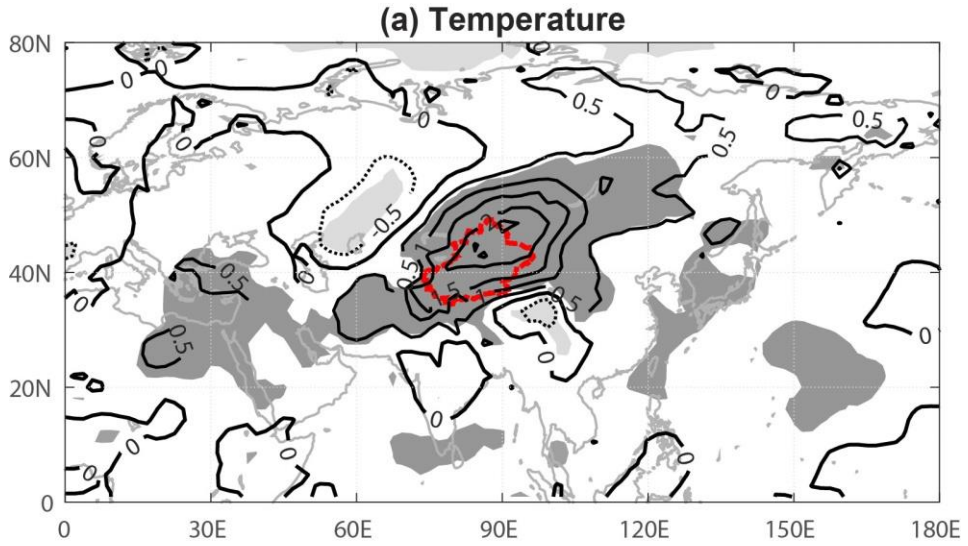
Heatwaves in arid Northwest China

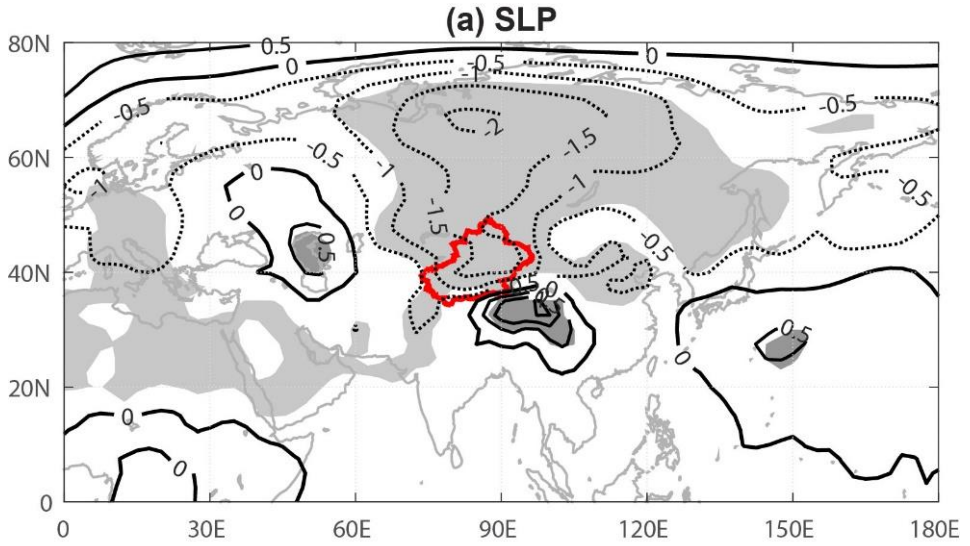


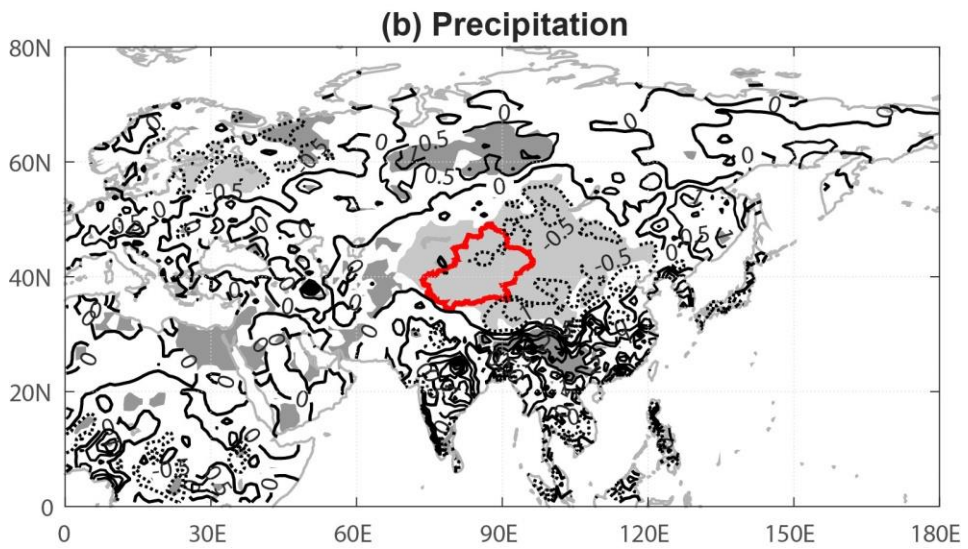


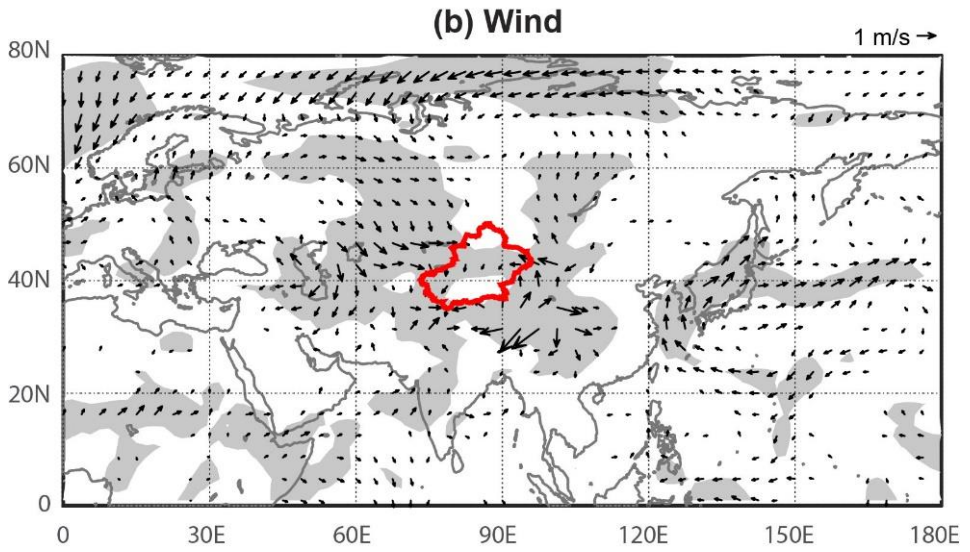
(Luo et al, *Atmos. Res.*, 2020)

Surface pattern of heatwaves in NW China



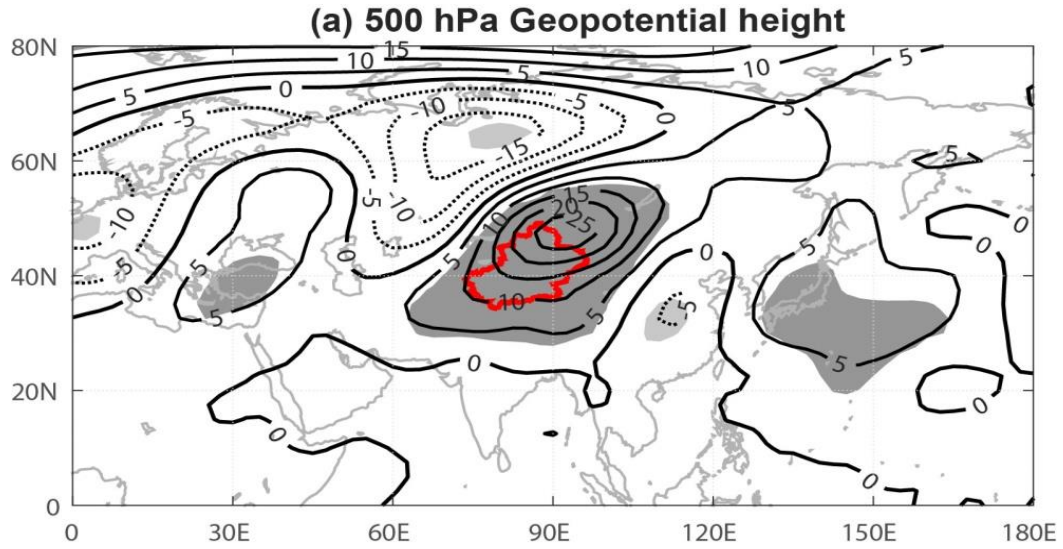


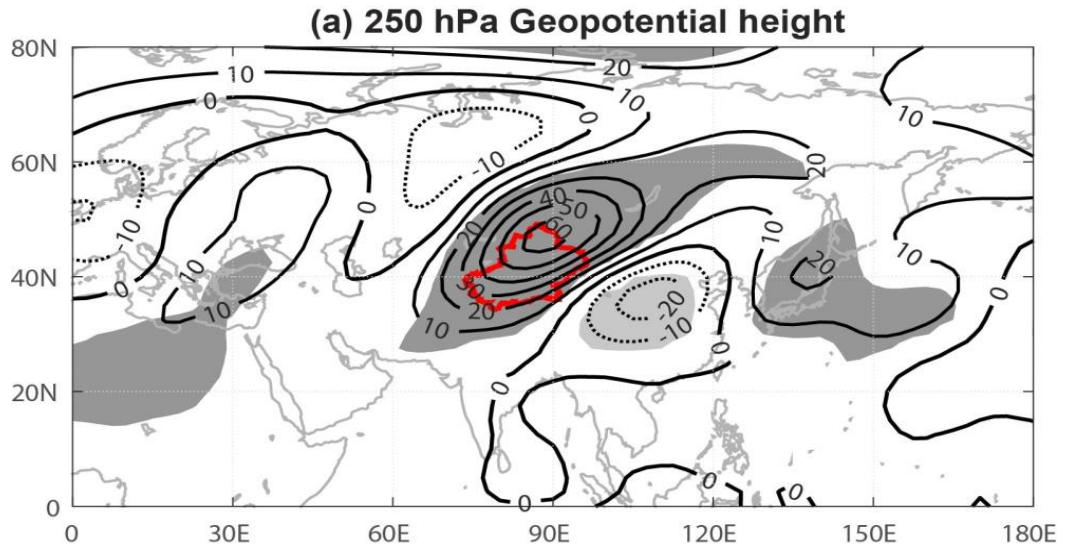


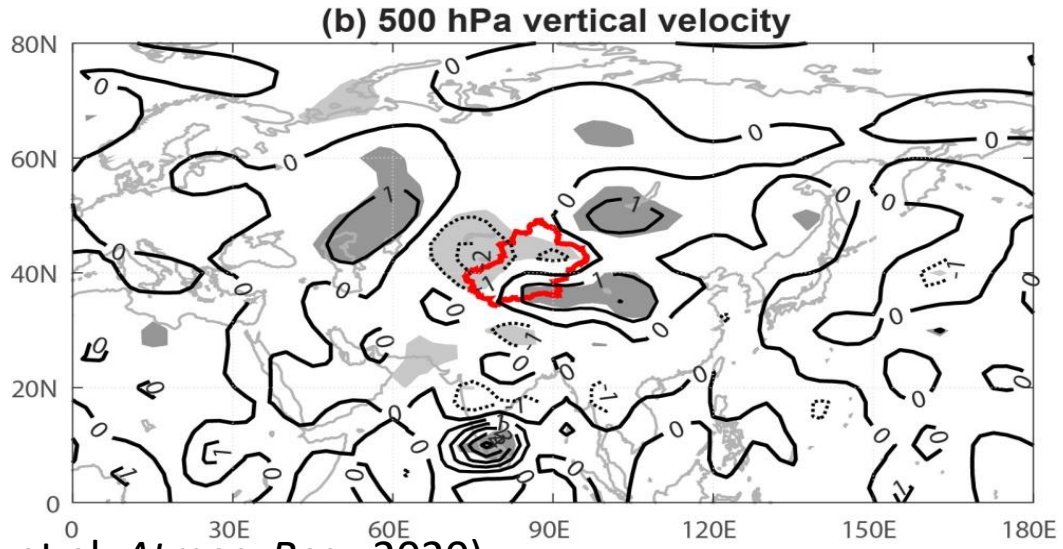


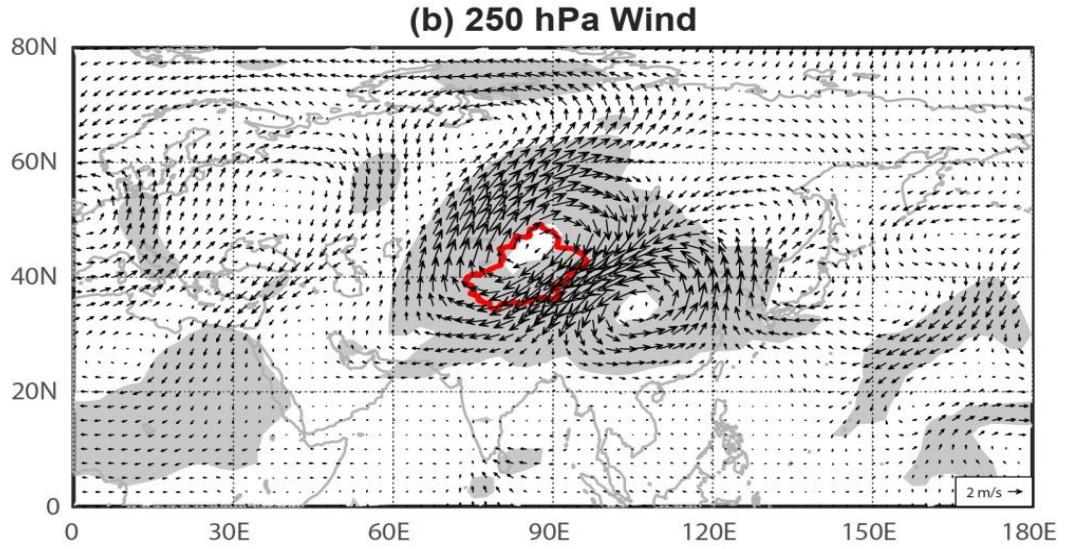
(Luo et al, *Atmos. Res.*, 2020)

Circulation changes of heatwaves in NW China



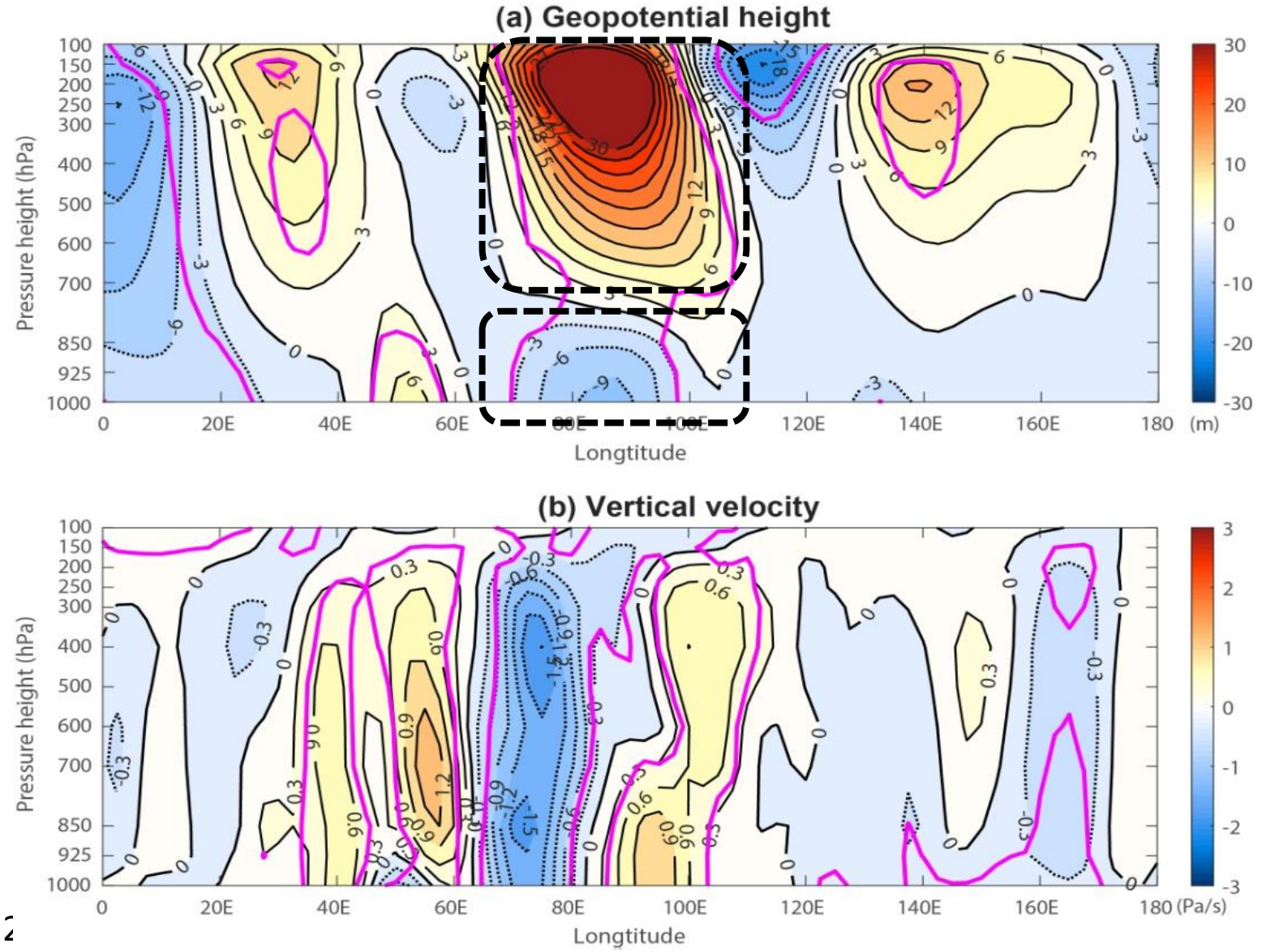






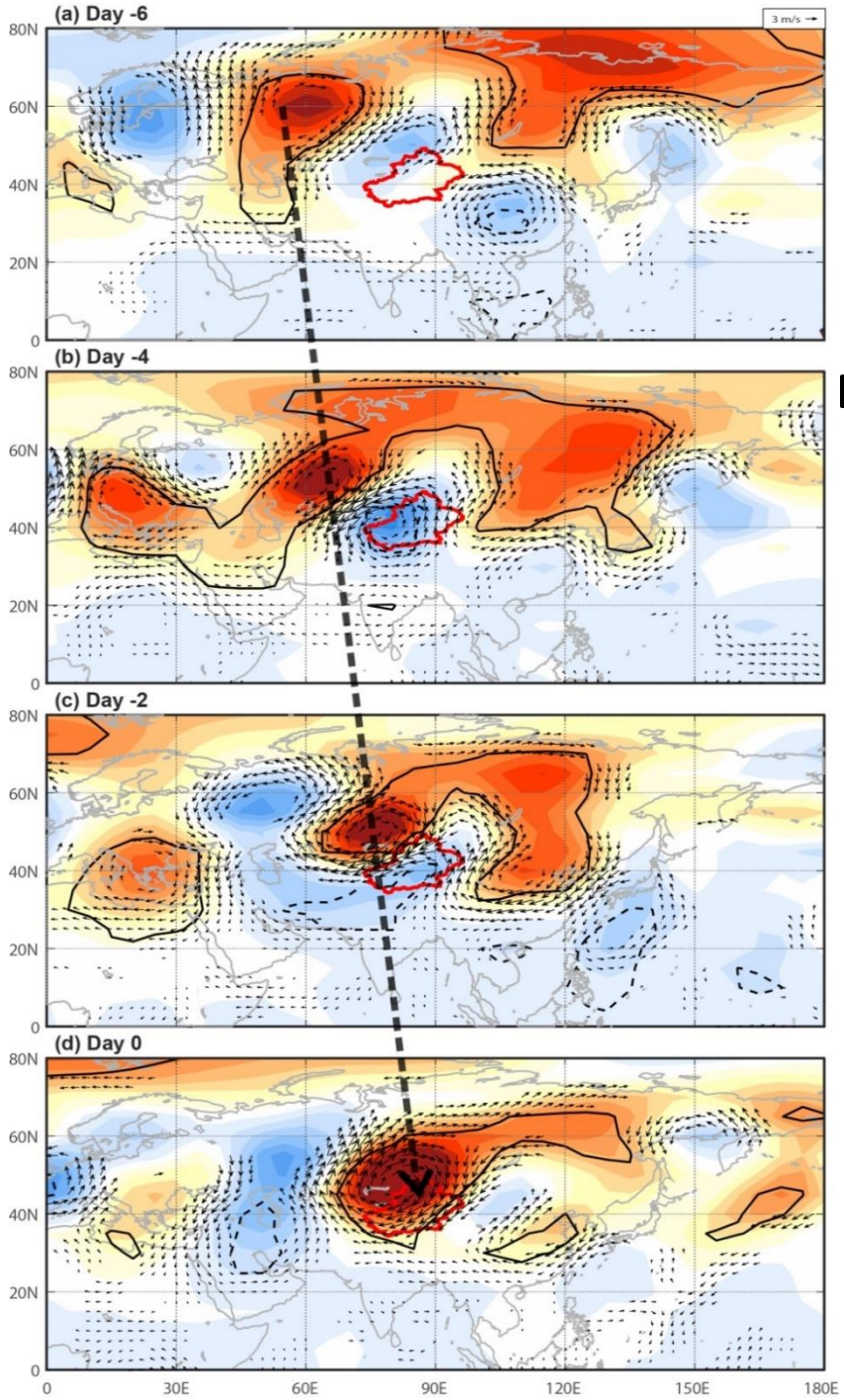
(Luo et al, *Atmos. Res.*, 2020)

Vertical structure of heatwaves in NW China



(Luo et al, *Atmos. Res.*, 2

250-hPa geopotential height & wind



Day (-6)

Day (-4)

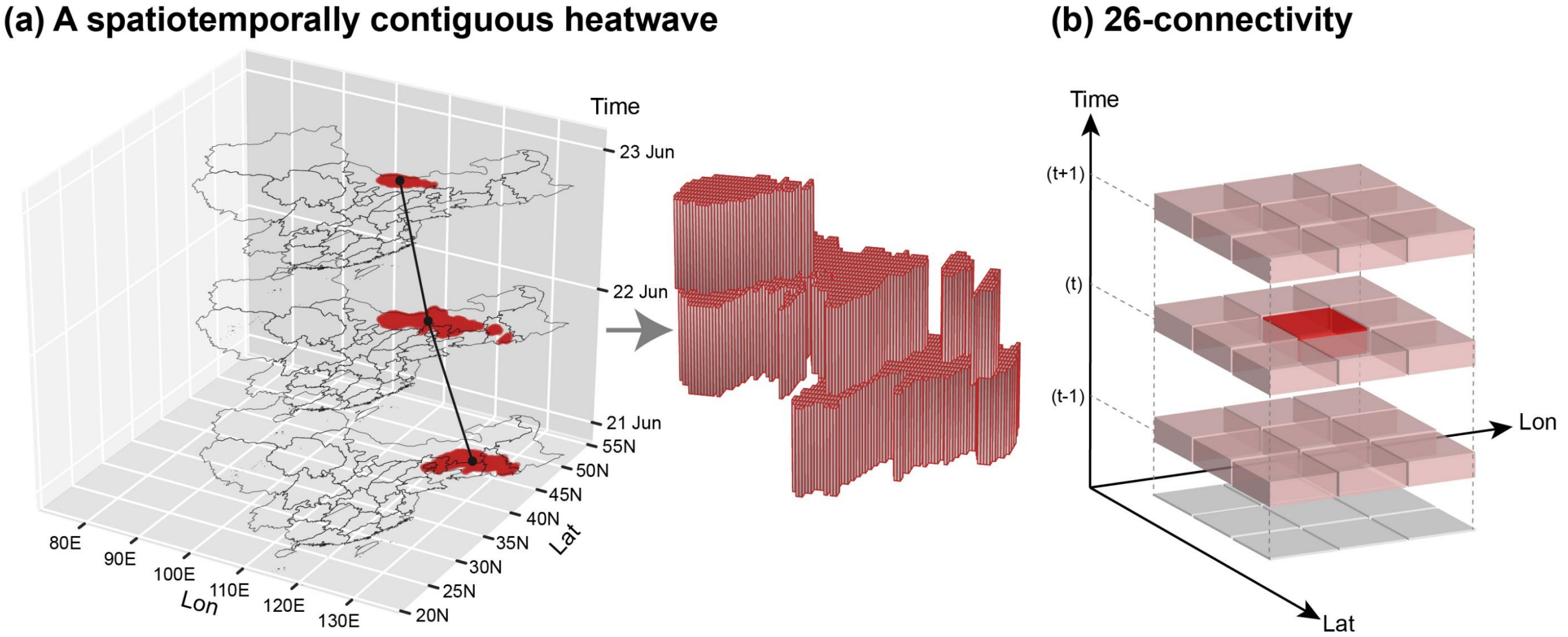
Day (-2)

Day (0)

The development of the heatwaves in northwest China is closely linked to the eastward propagation of a zonal wave train pattern along the midlatitude zone of the Northern hemisphere.

(Luo et al, *Atmos. Res.*, 2020)

3D Propagation of Contiguous Heatwaves



(Luo et al, *GRL*, 2022)

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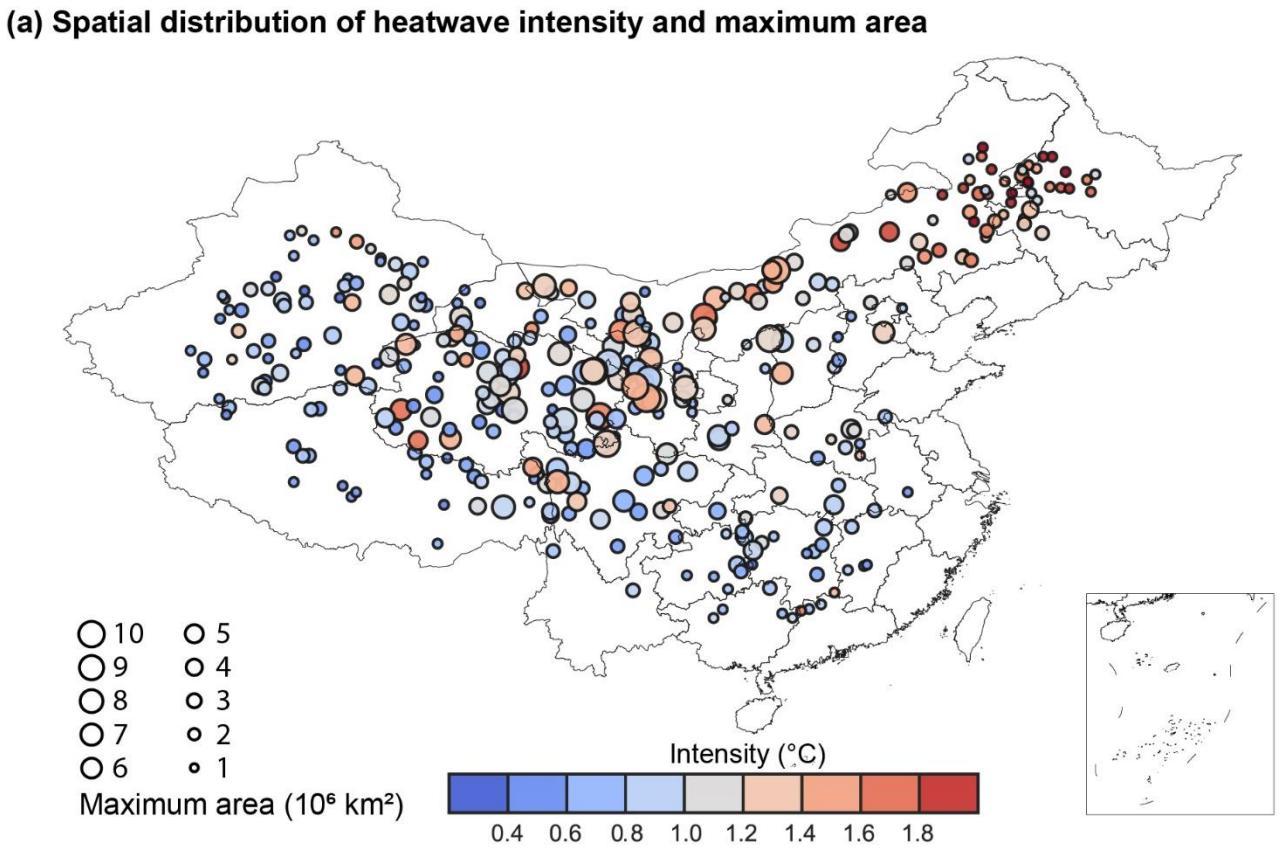
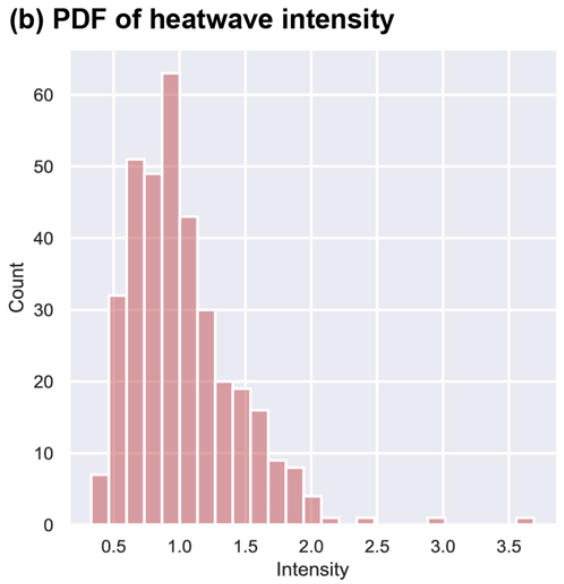
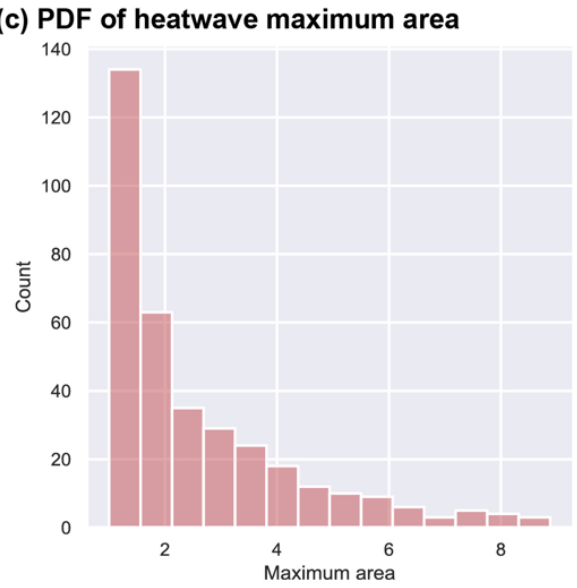
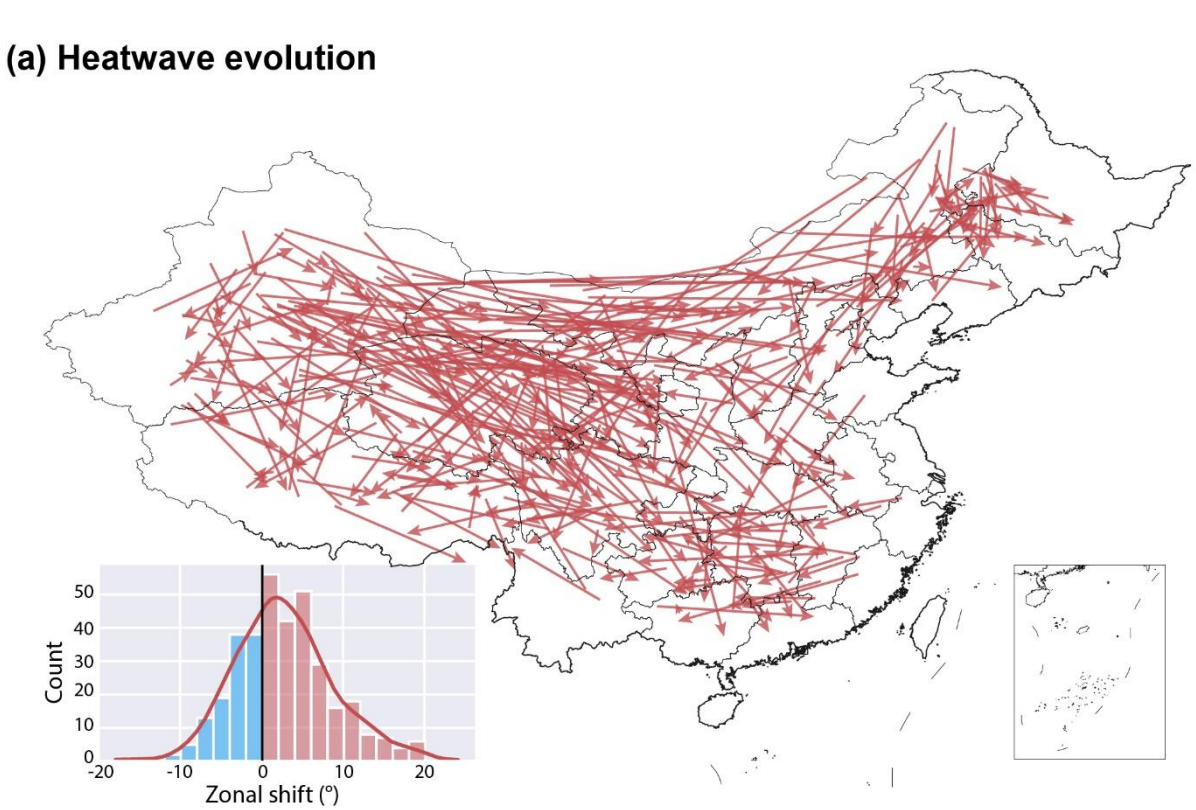


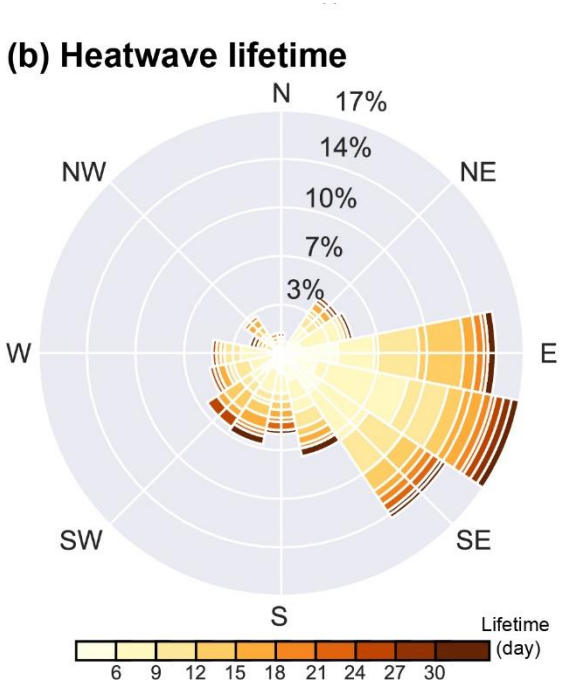


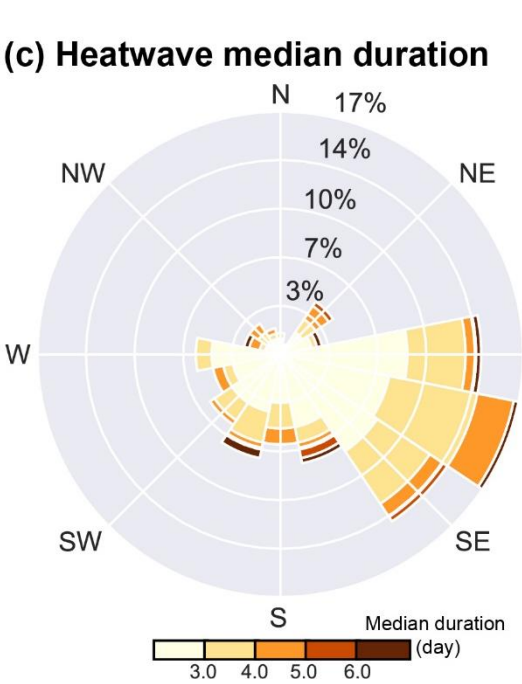


(Luo et al, *GRL*, 2022)

3D Propagation of Contiguous Heatwaves

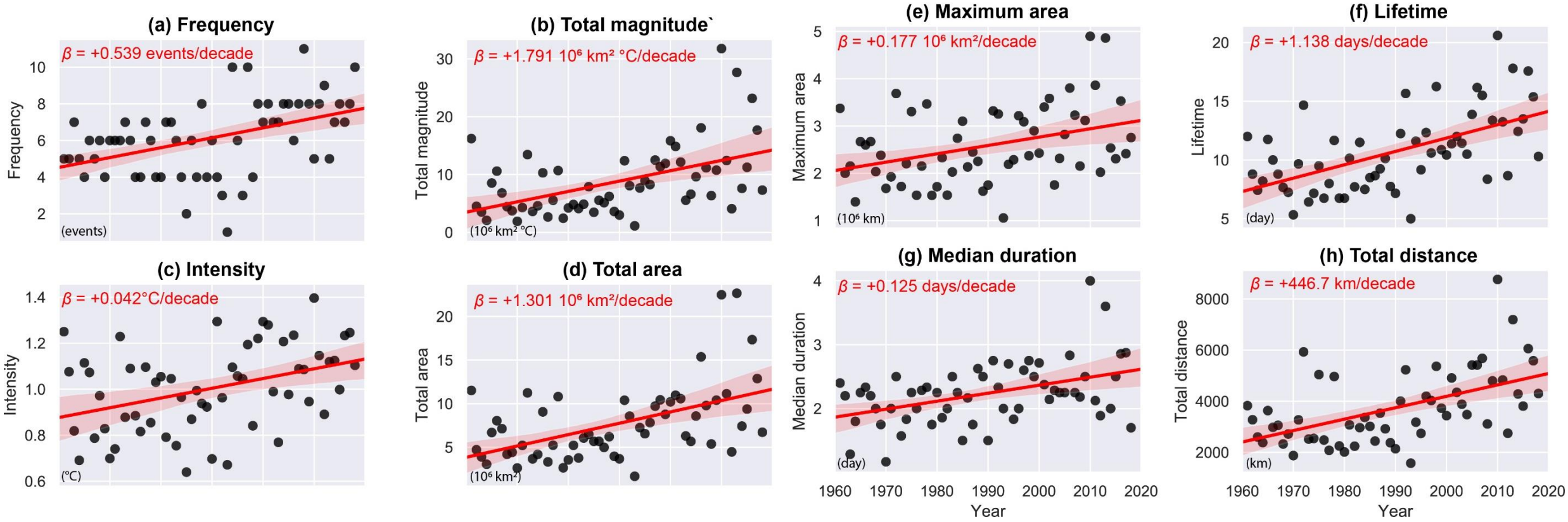






(Luo et al, *GRL*, 2022)

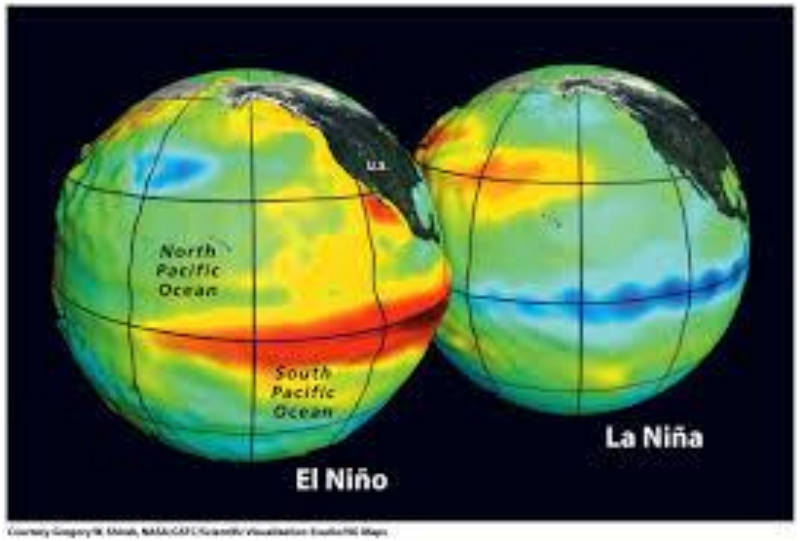
Long-term trends of contiguous heatwaves

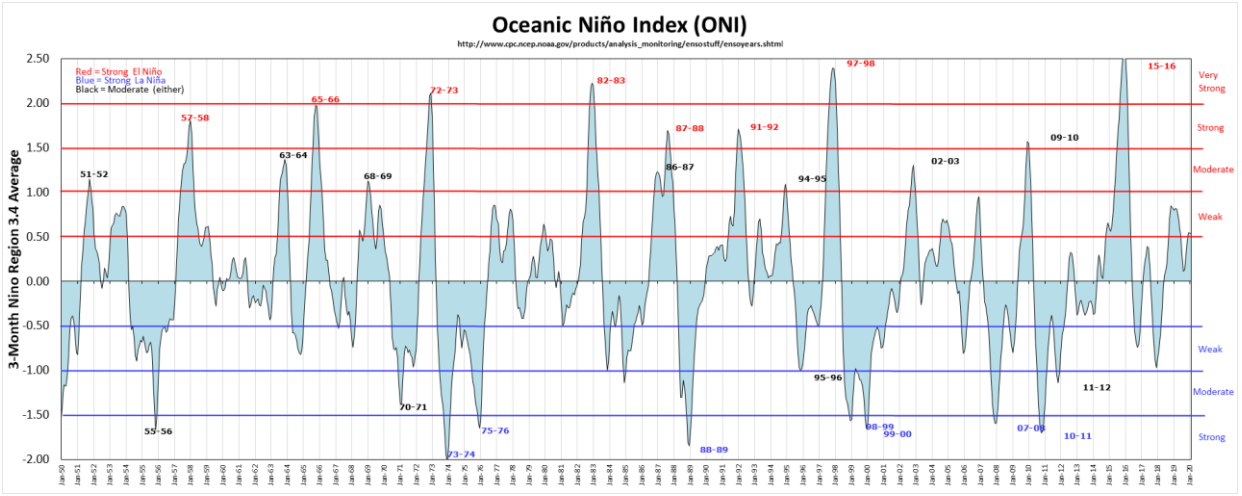


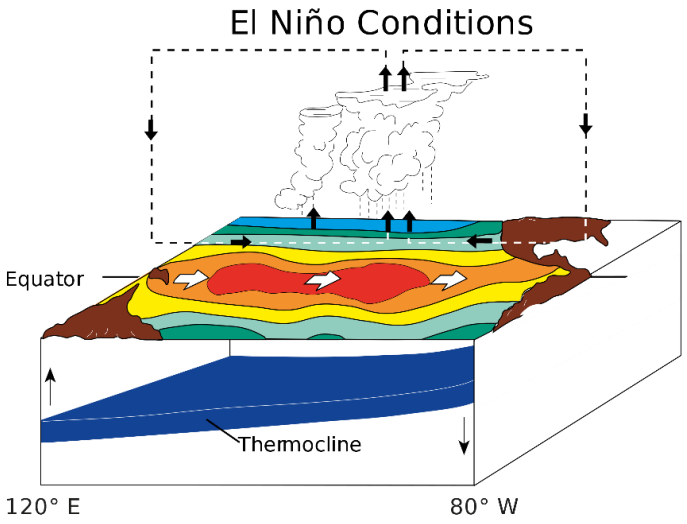
(Luo et al, *GRL*, 2022)

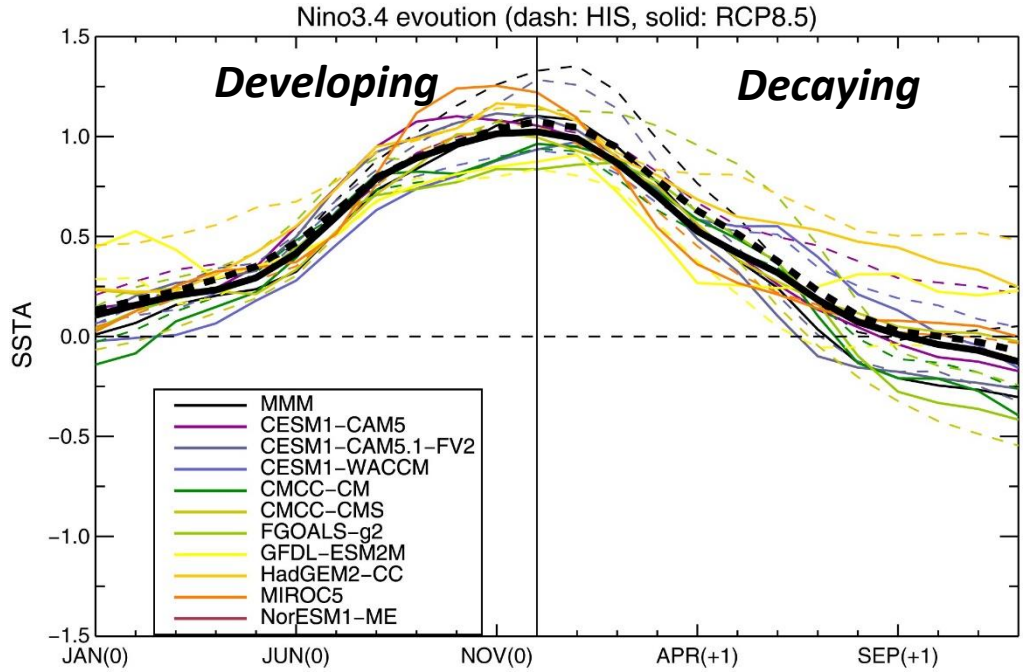
2. Interannual Variabilities of Heatwaves in Relation to SST Anomalies

El Niño/Southern Oscillation (ENSO)









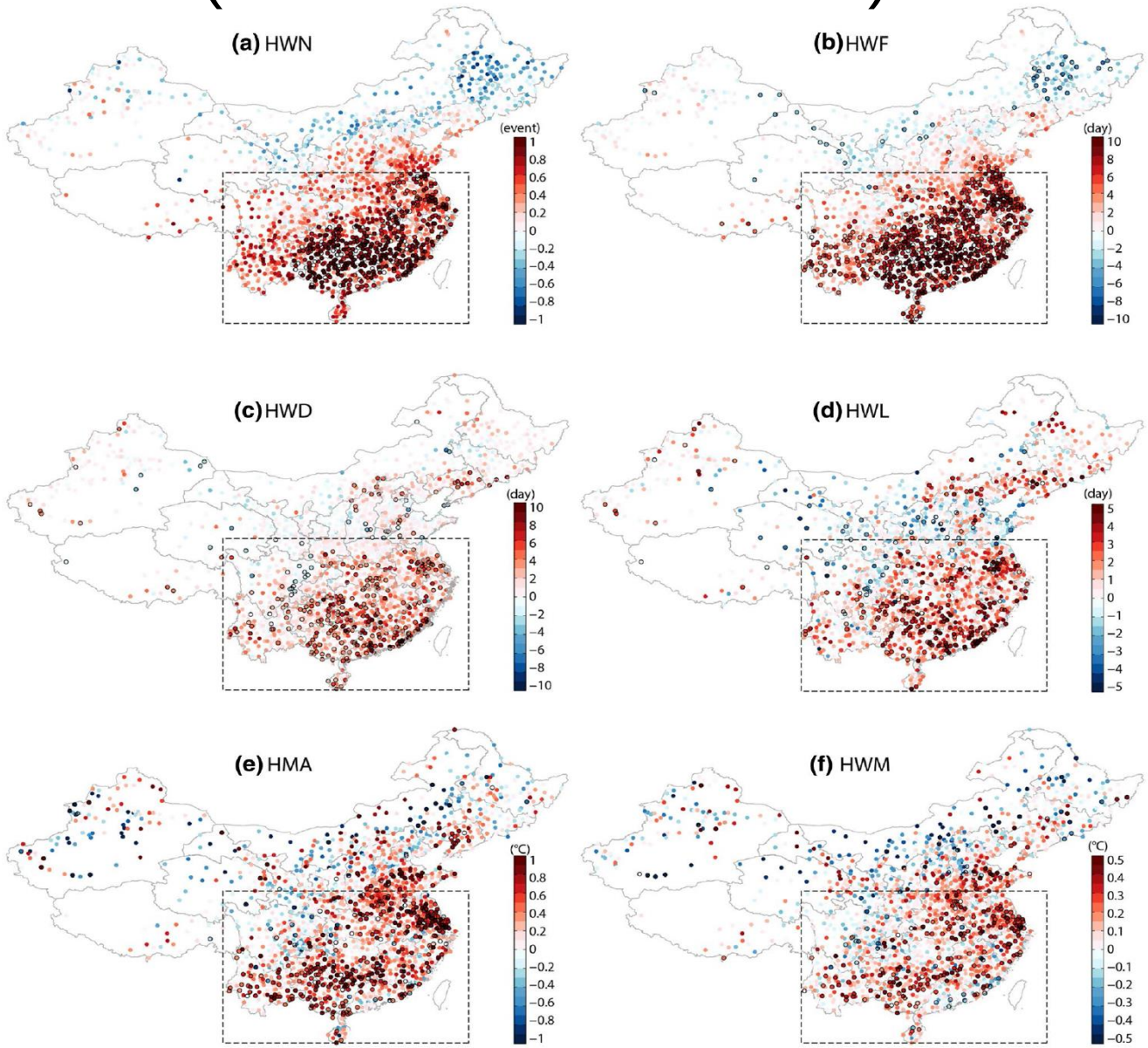
Heatwave differences between El Nino and La Nina years

(El Nino *minus* La Nina)

Frequency

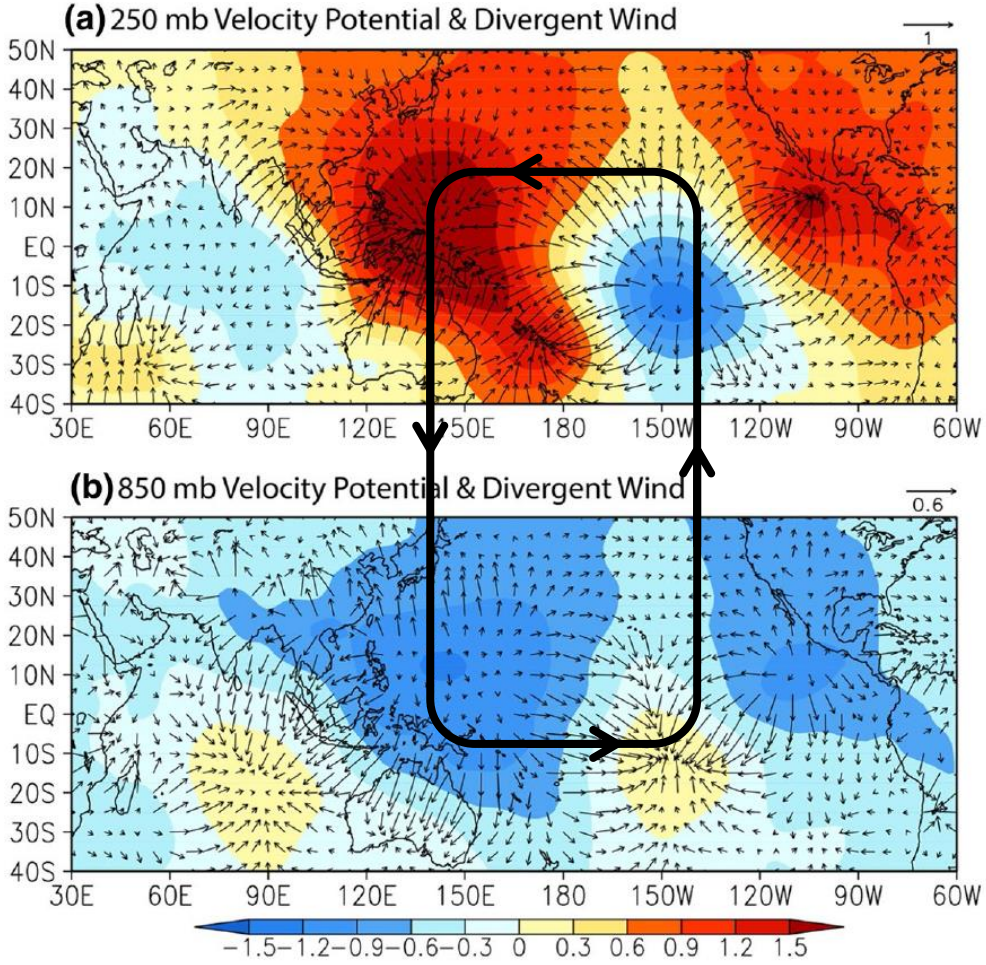
Duration

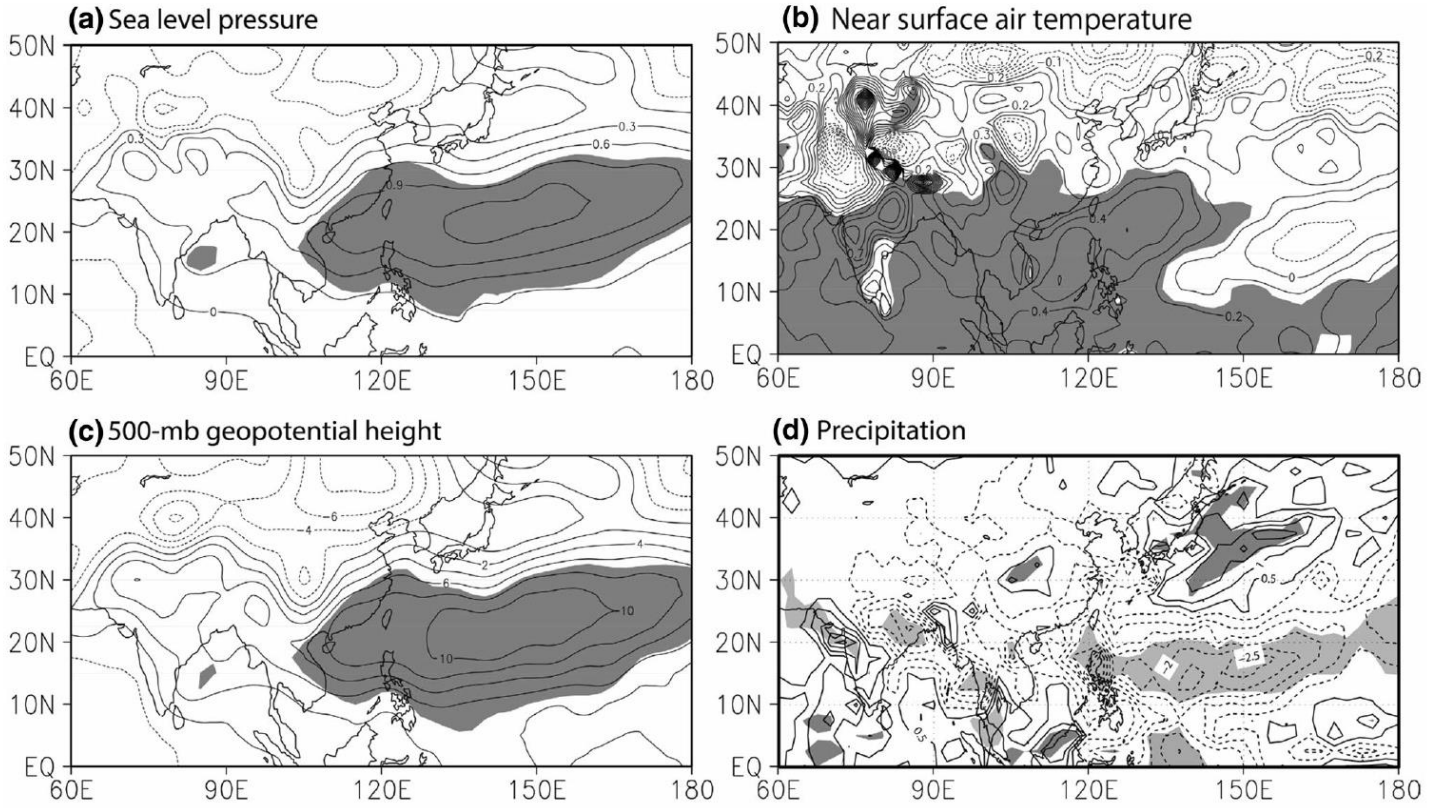
Magnitude



(Luo & Lau, *Clim. Dyn.*, 2018)

How El Nino affects heatwaves in China



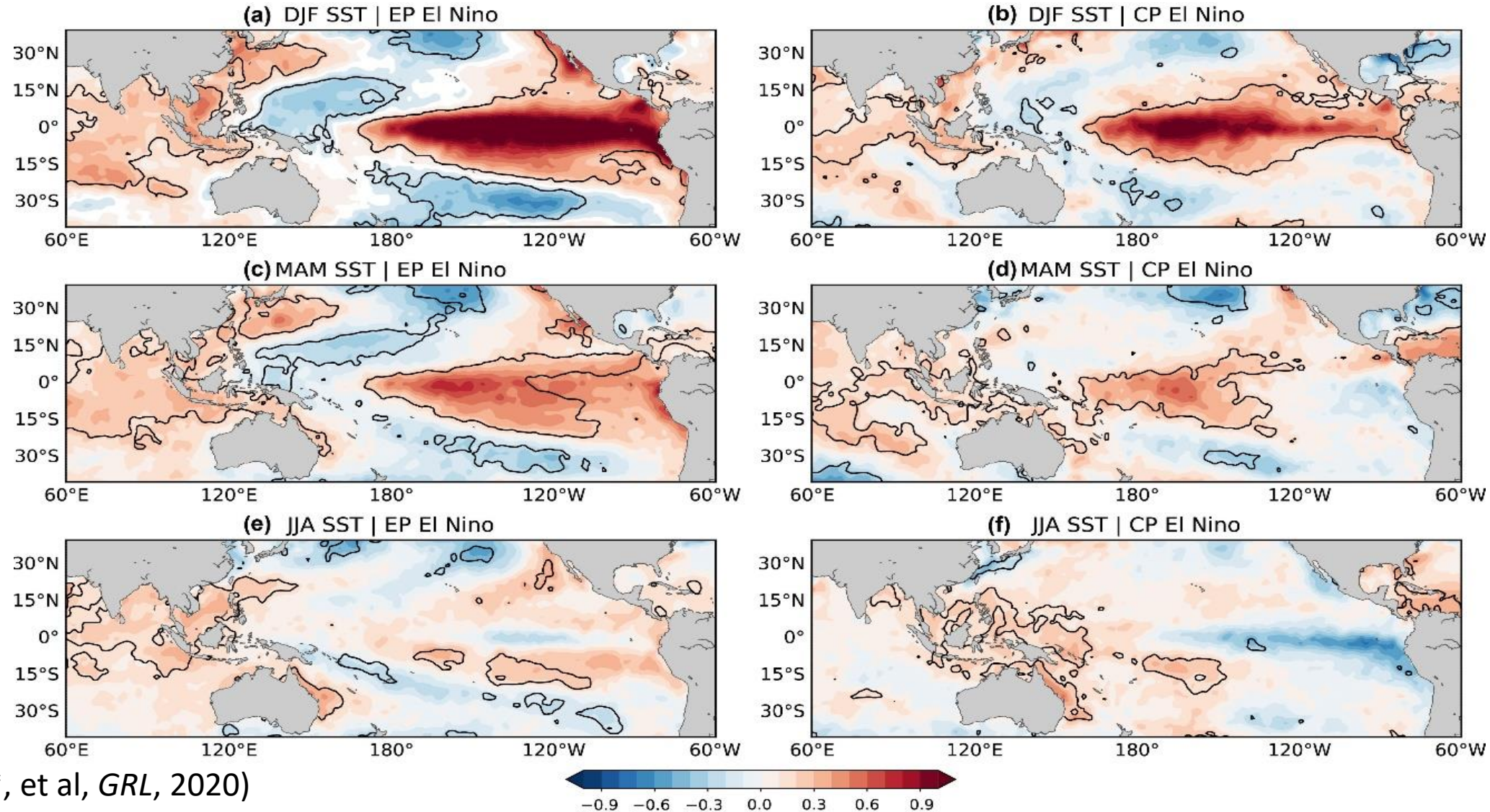


(Luo & Lau, *Clim. Dyn.*, 2018)

Two El Nino Types

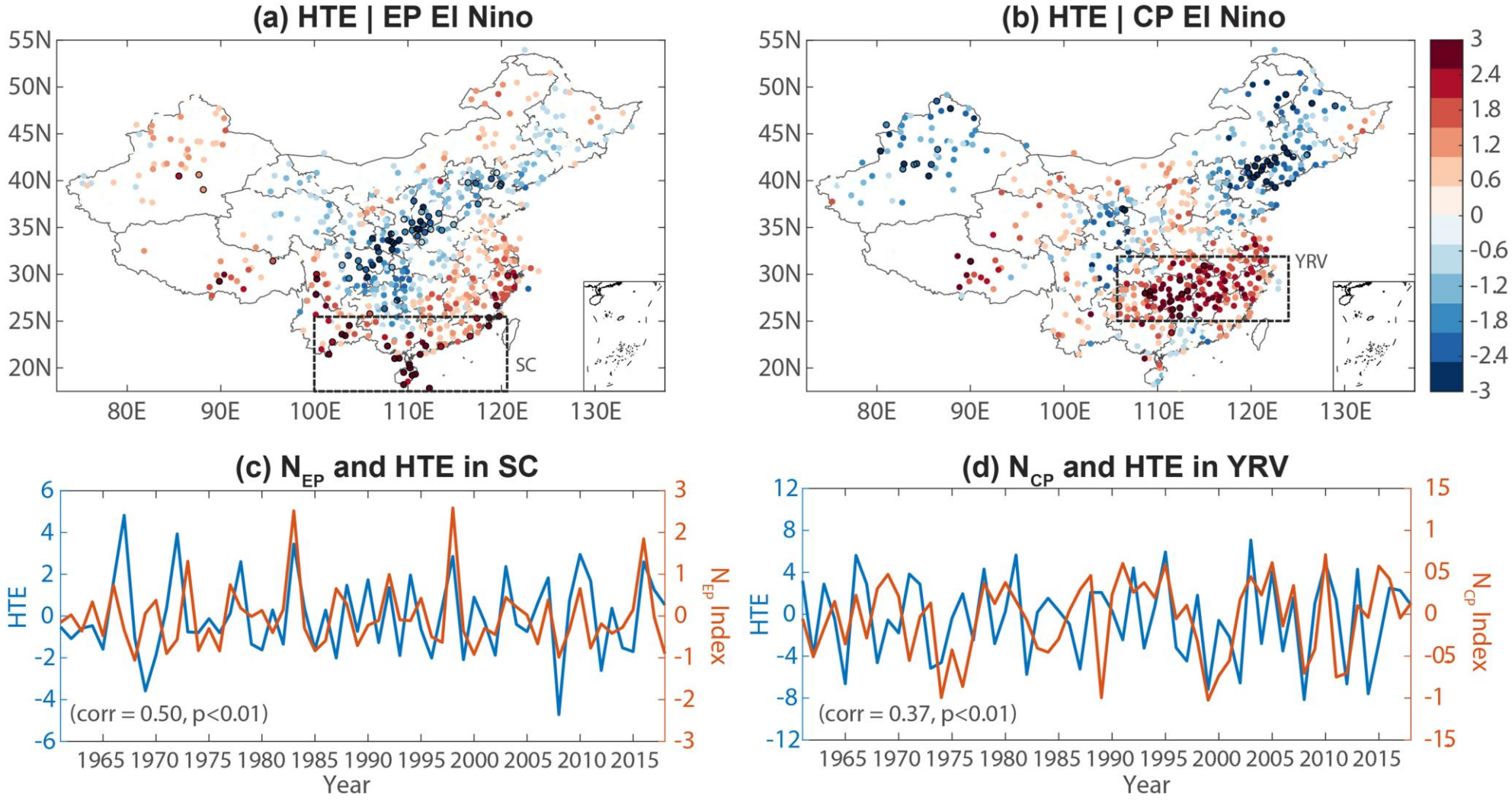
Eastern-Pacific (EP) El Nino

Central-Pacific (CP) El Nino



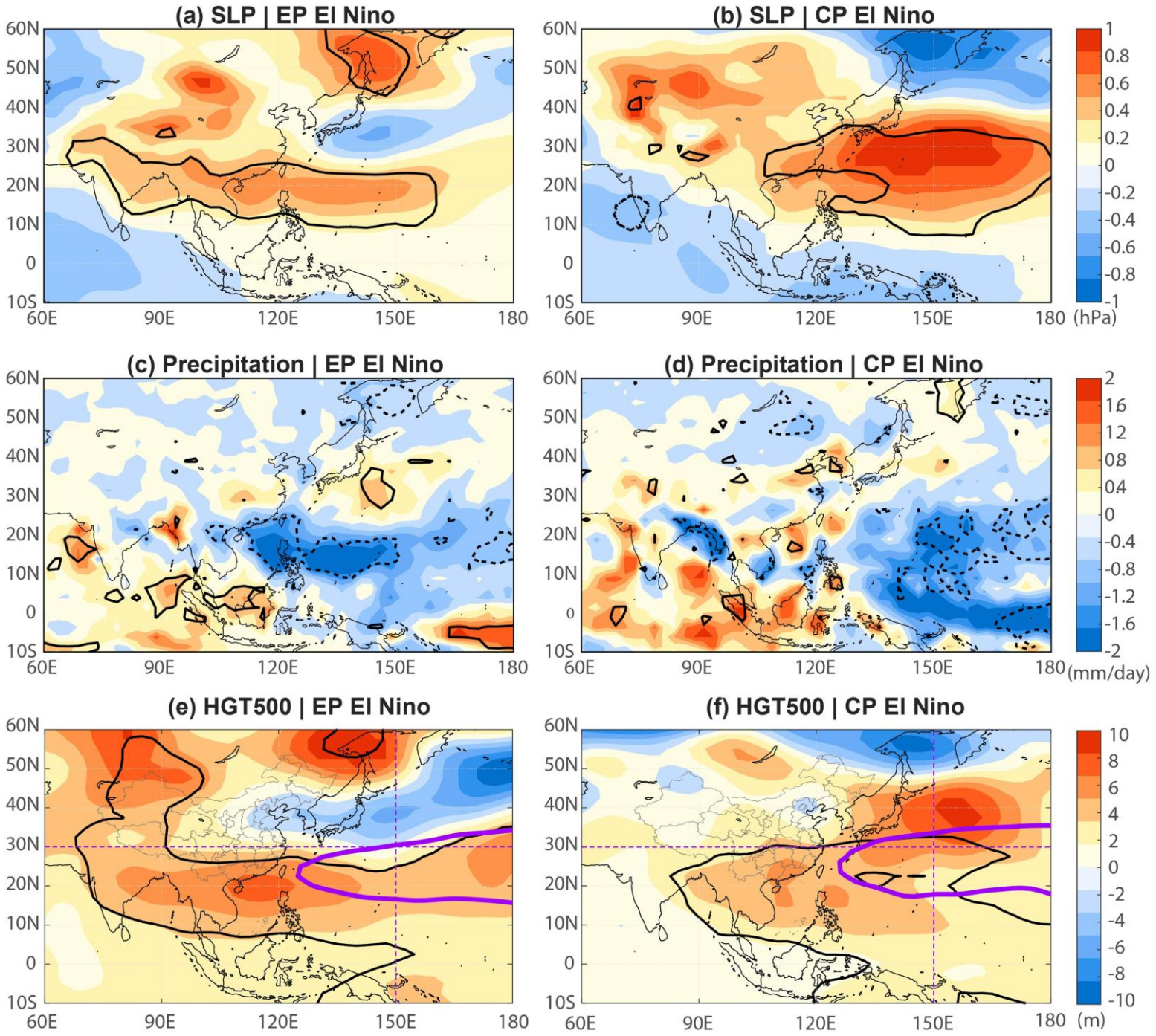
(Gao, Luo*, et al, *GRL*, 2020)

Two El Nino types and heat extremes in China



EP (CP) El Niño increase hot spells in South (East) China.

(Gao, Luo*, et al, *GRL*, 2020)

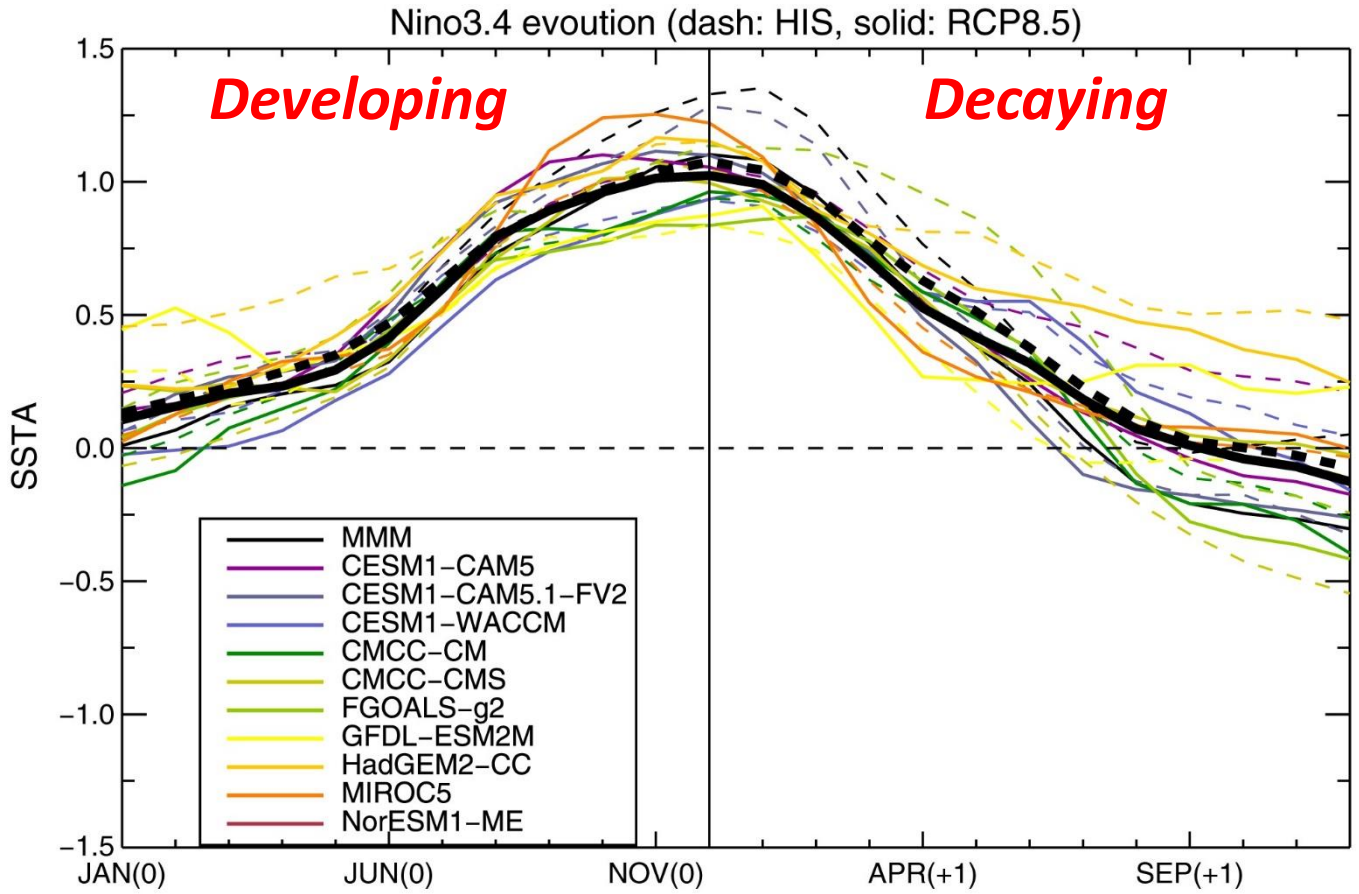


EP (CP) El Niño events are coincident with southwestward (northeastward) displacement of the North Pacific subtropical high pressure belt.

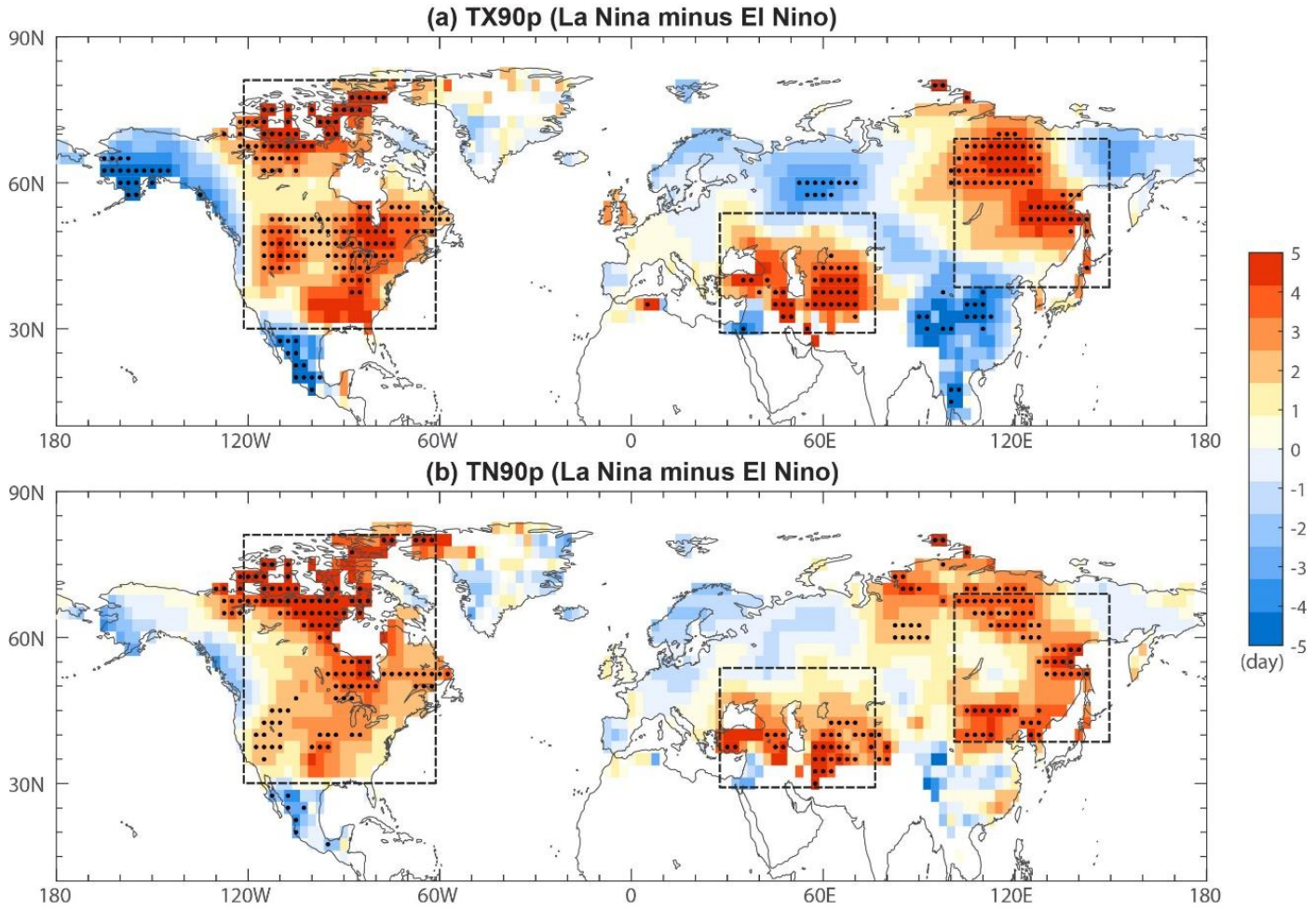
EP (CP) El Niño are accompanied by a southward (poleward) shift of the upper-tropospheric jet stream over the Asian continent (Pacific Ocean).

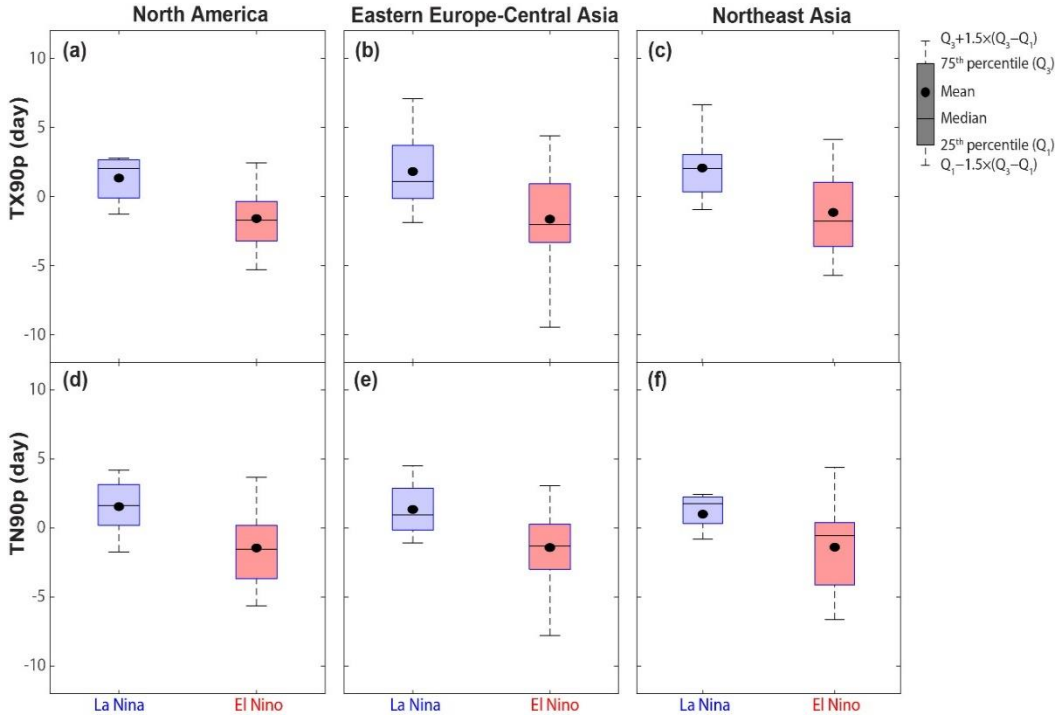
(Gao, Luo*, et al, *GRL*, 2020)

Developing ENSO and heat extremes



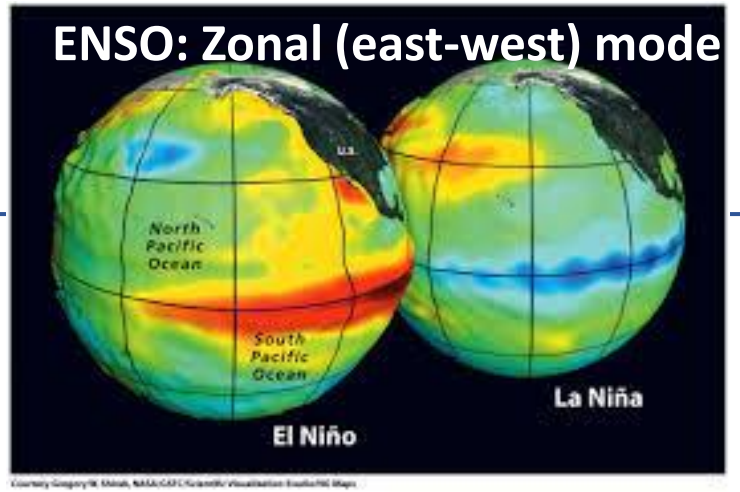
Developing ENSO and heat extremes



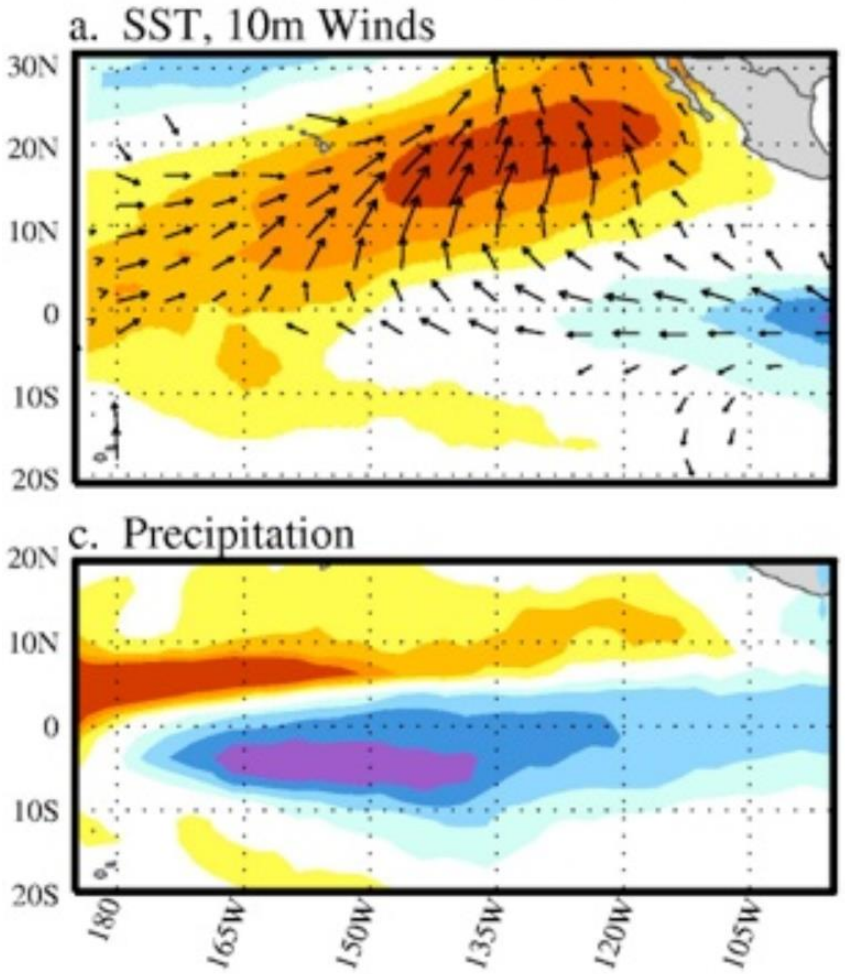


(Luo & Lau, *ERL*, 2020)

PMM and heat extremes



Pacific Meridional Mode (PMM)

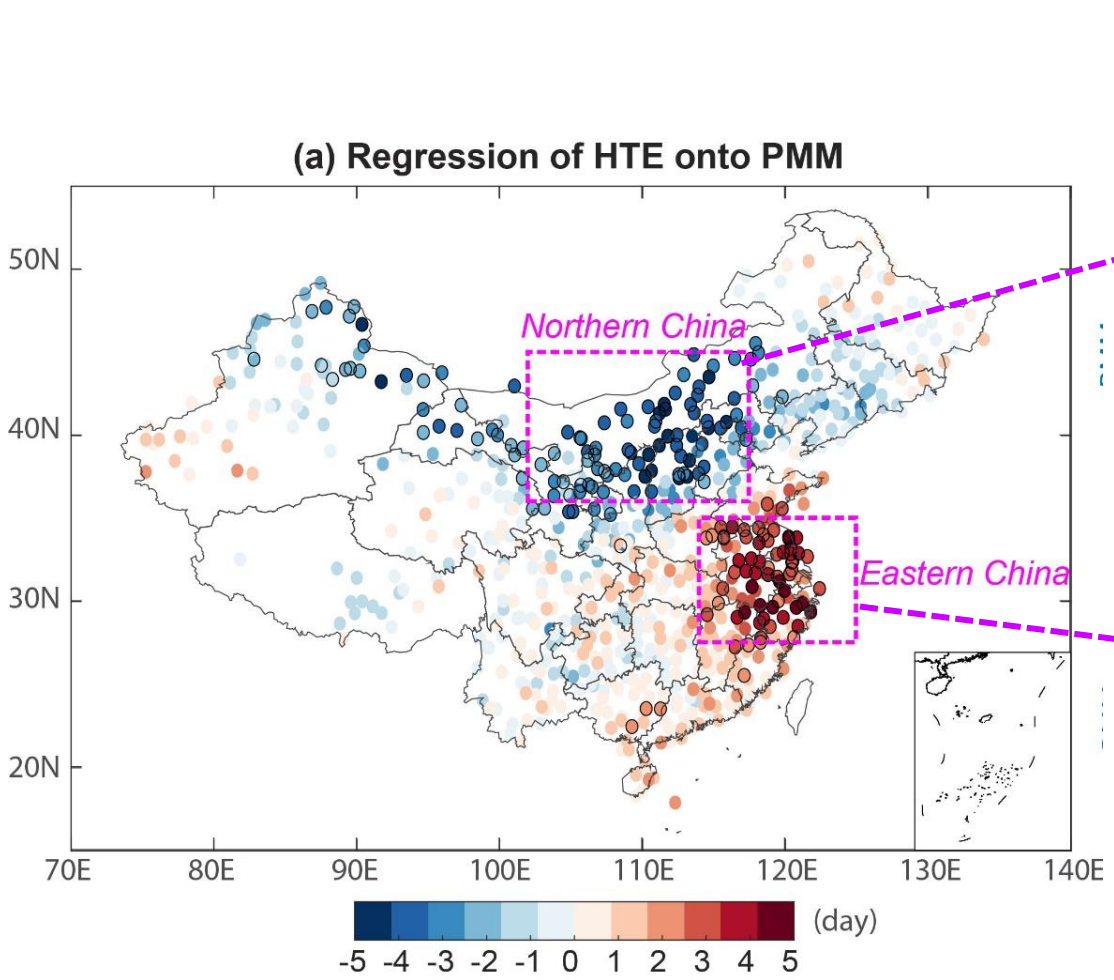


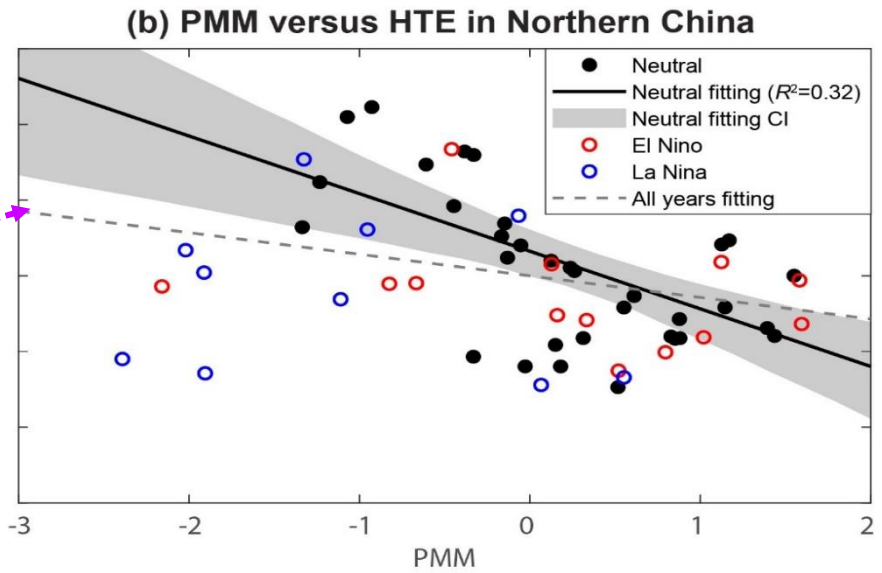
Source: Chiang and Vimont (2004)

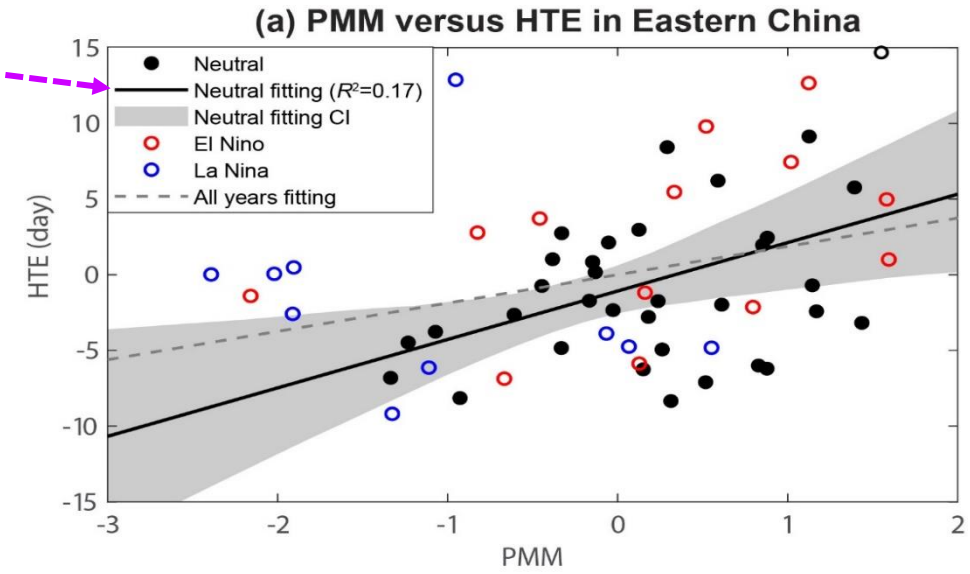
- Meridional (North-South) mode in the Pacific ocean.
- Peaks in late spring season.

Does PMM link with heat extremes in China?

PMM and heat extremes in China

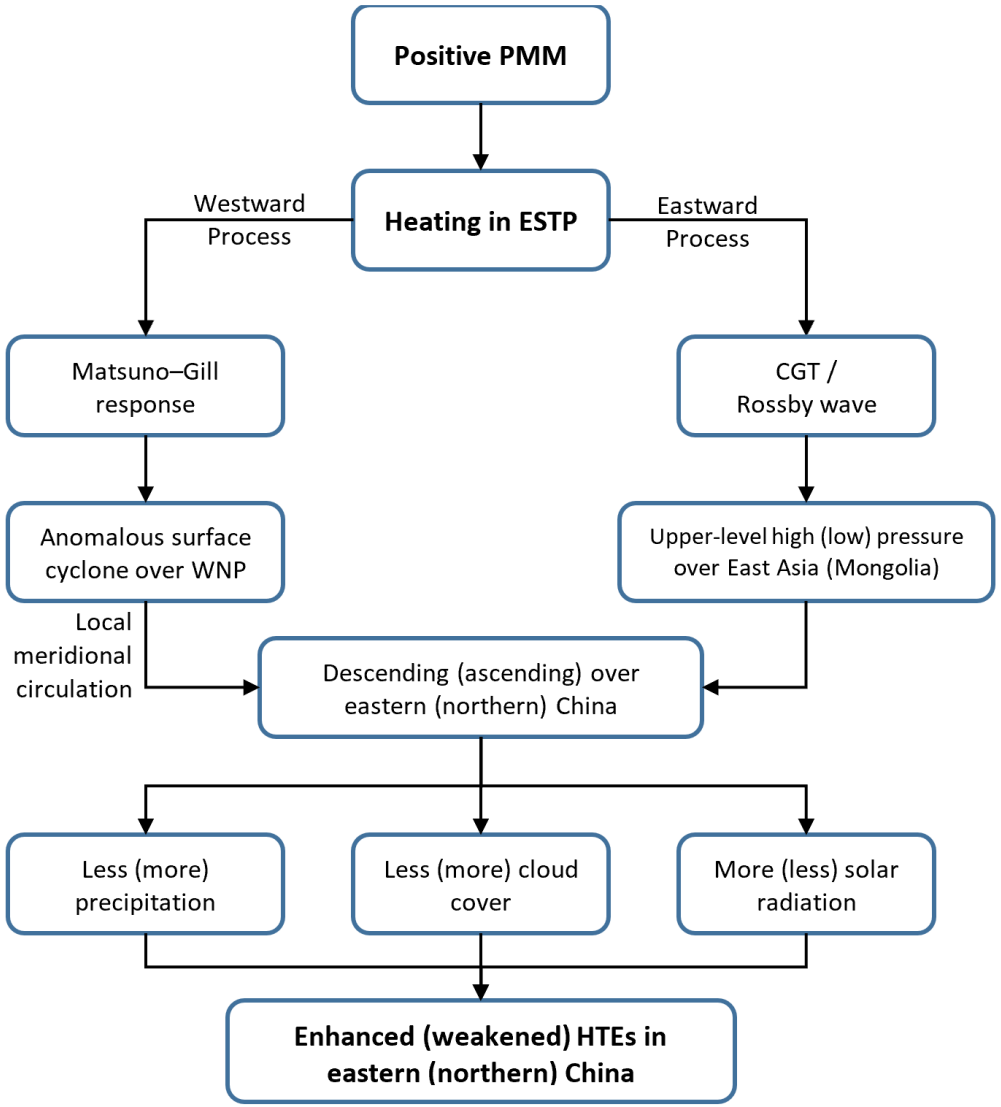


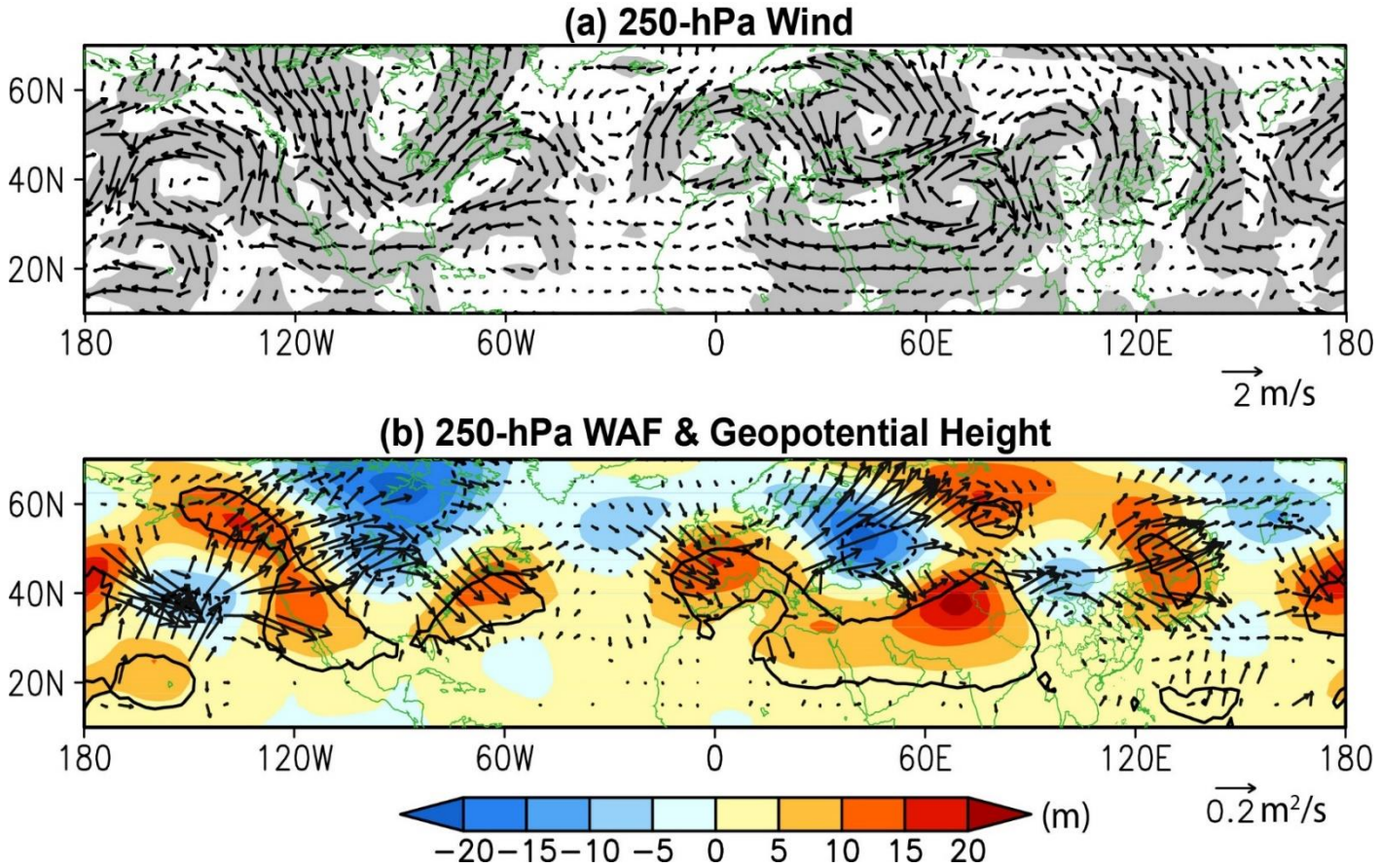




(Luo et al, *J. Clim.*, 2020)

PMM and heat extremes



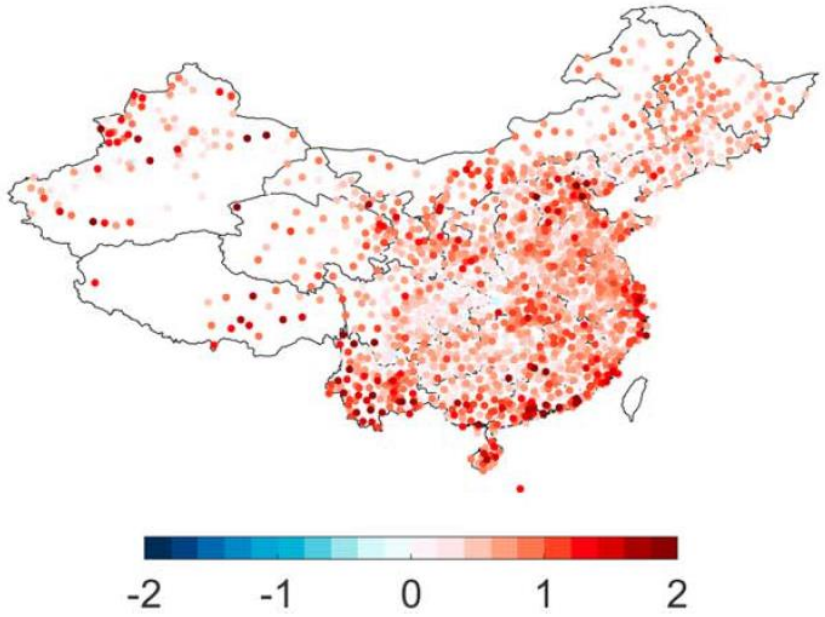


(Luo et al, *J. Clim.*, 2020)

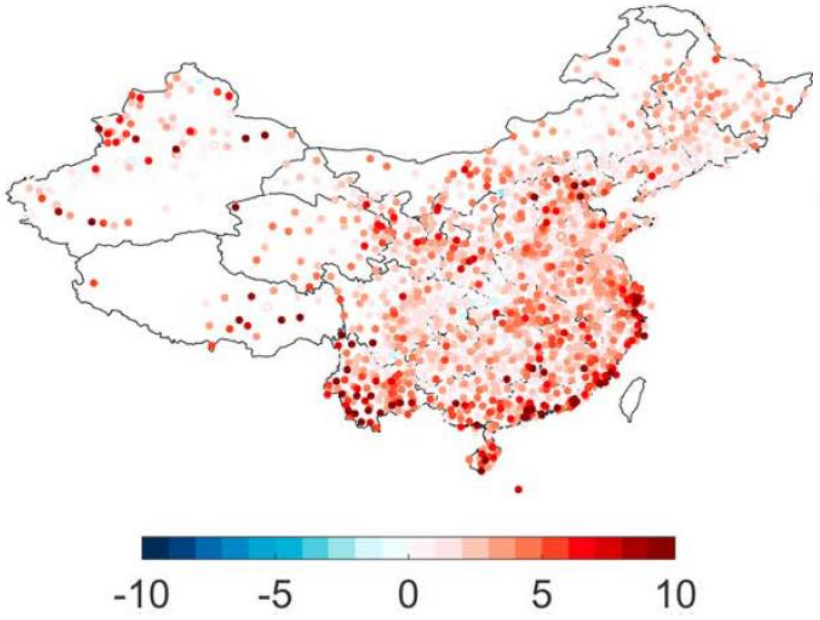
3. Long-term Trends of Heatwaves in Relation to Urbanization Effects

Long-term trend of heatwaves in China

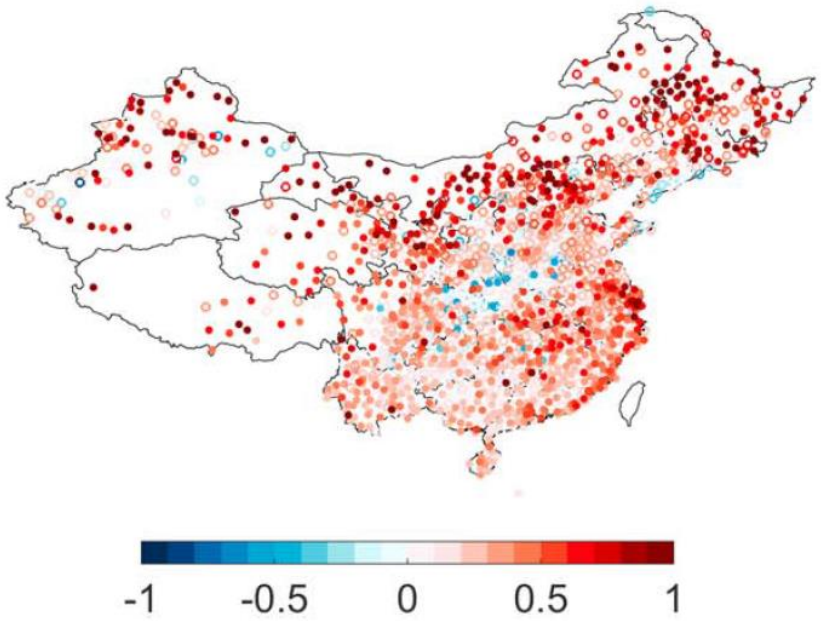
Frequency



Participating days

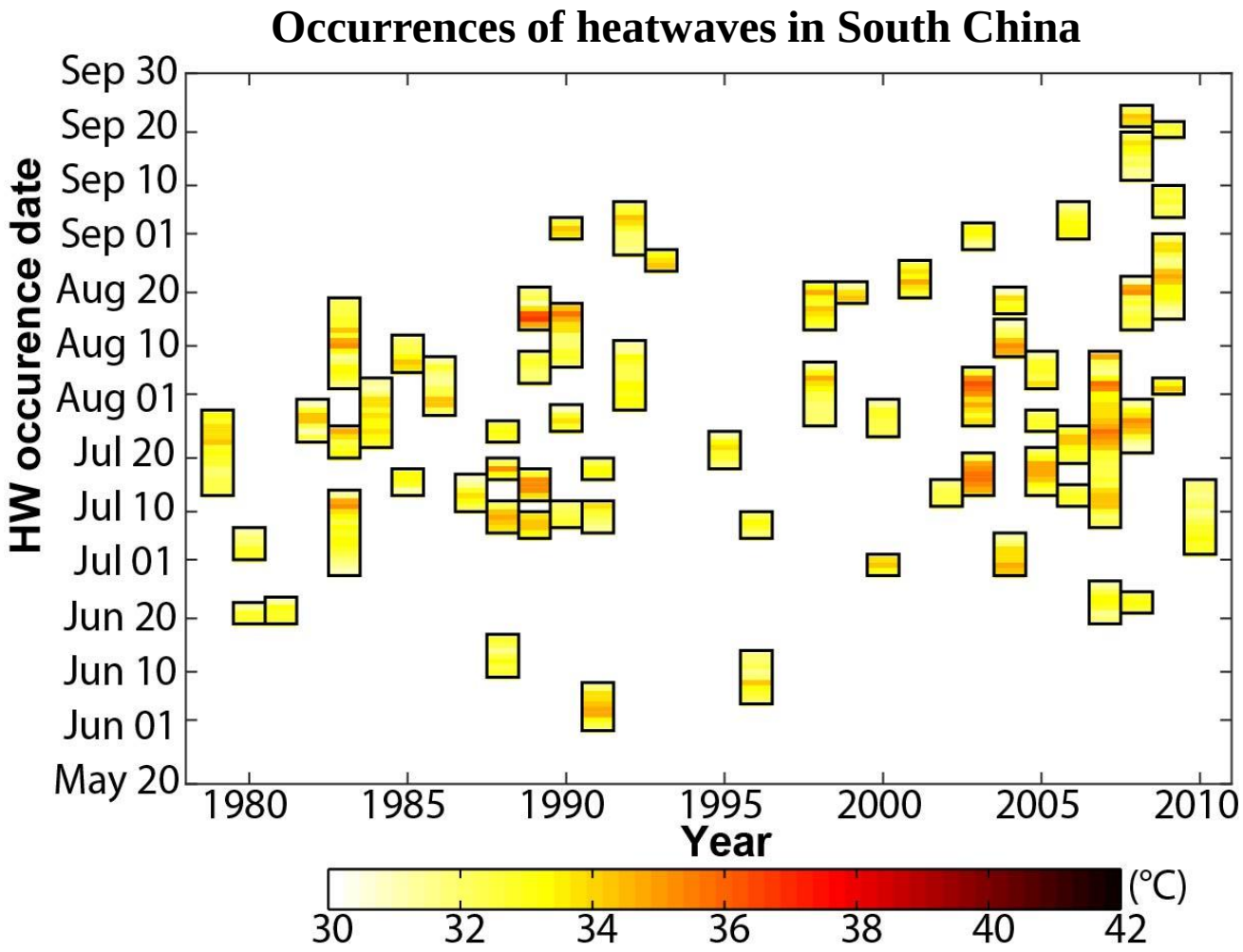


Amplitude



(Liao et al, *GRL*, 2018)

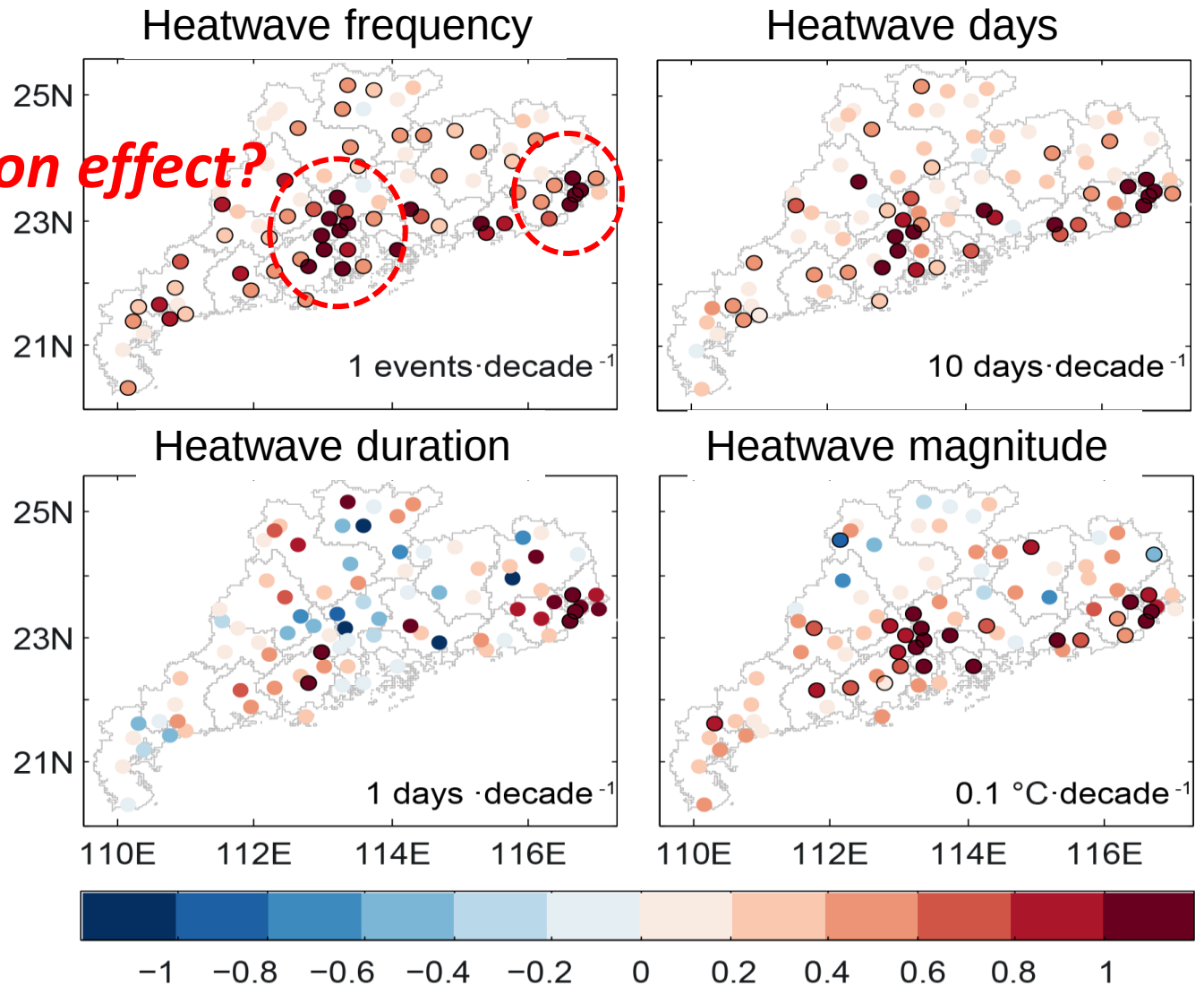
Heatwaves occurrences in South China



(Luo & Lau, *J. Climate*, 2018)

Heatwave trends in South China

Urbanization effect?



(Ye, …, Luo*, *IJOC*, 2018)

Estimation of urbanization effect

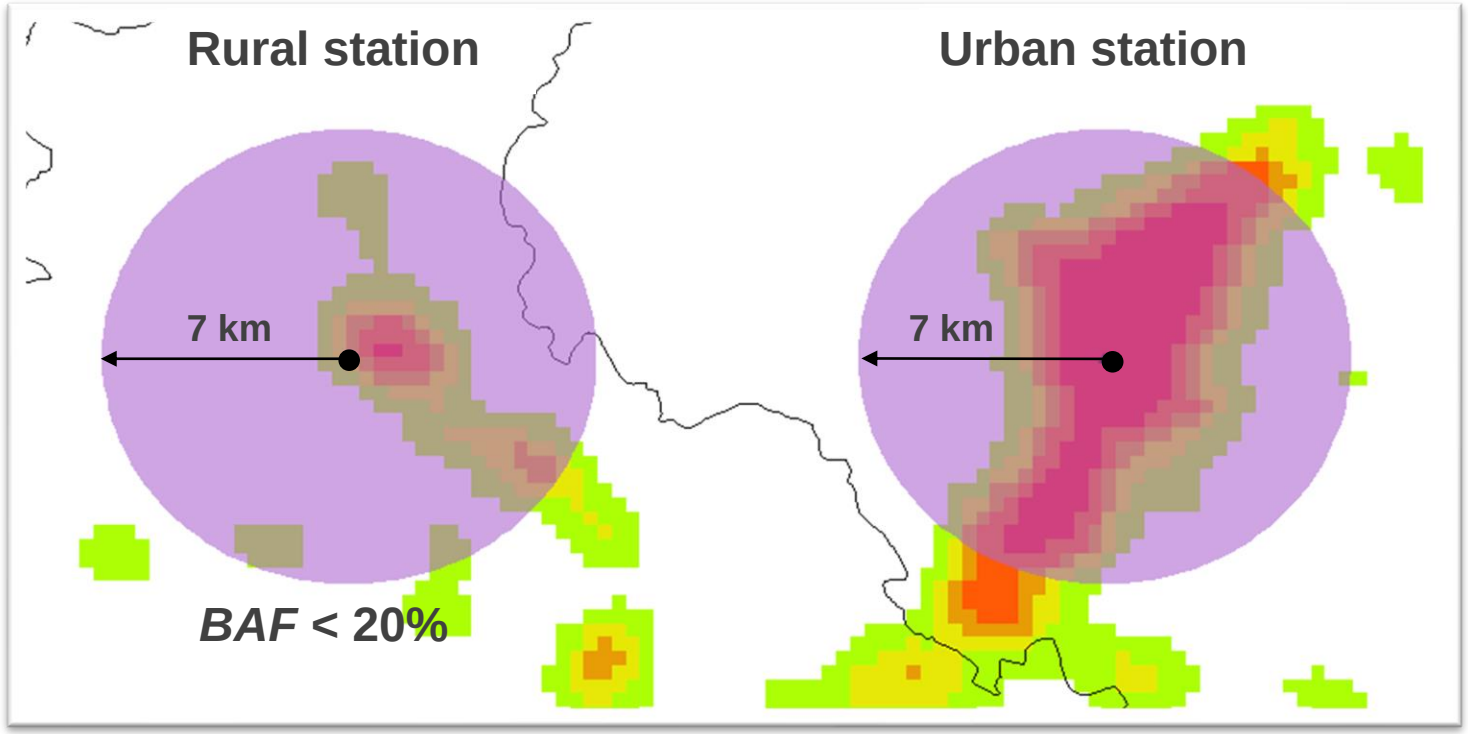
Urbanization Effect ($\Delta T_{u\text{-}r}$) is defined as the difference between the urban trend (T_u) and rural trend (T_r) (Ren et al., 2014):

$$\Delta T_{u-r} = T_u - T_r$$

Urbanization effect — Urban trend — Rural trend

Relative contribution (%): $$C_{u-r} = \left| \frac{T_u - T_r}{T_u} \right| \times 100\%$$

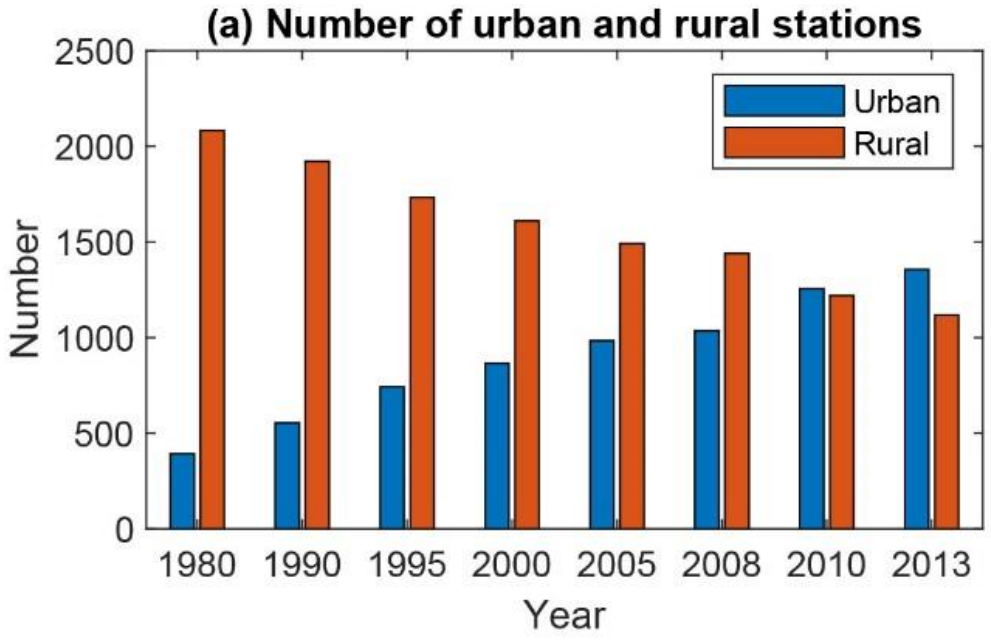
Classification of urban/rural stations

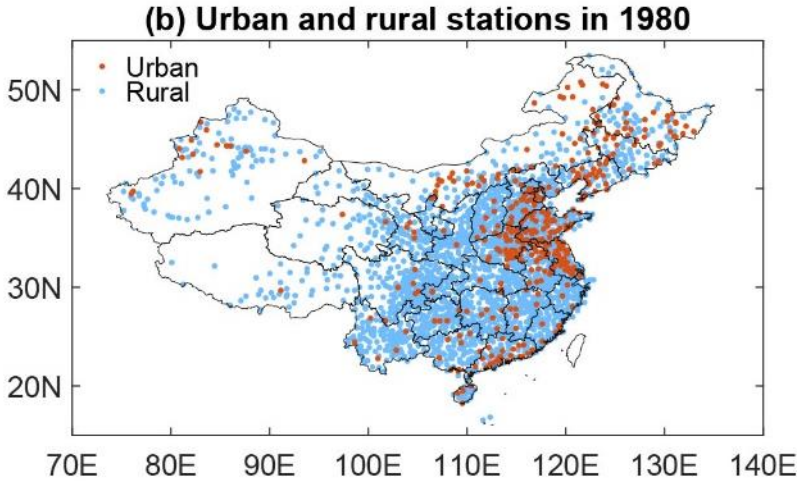


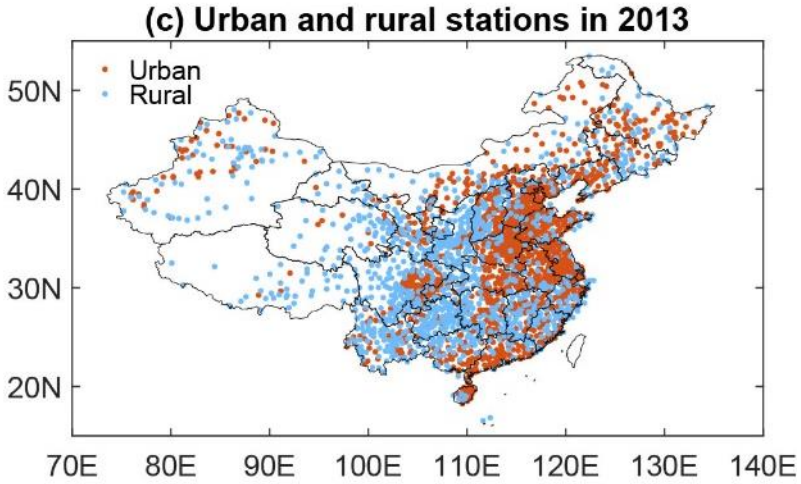
$$BAF = \frac{Area_{Artificial\ surfaces}}{Area_{Buffer}}$$

Dynamic classification of urban/rural stations

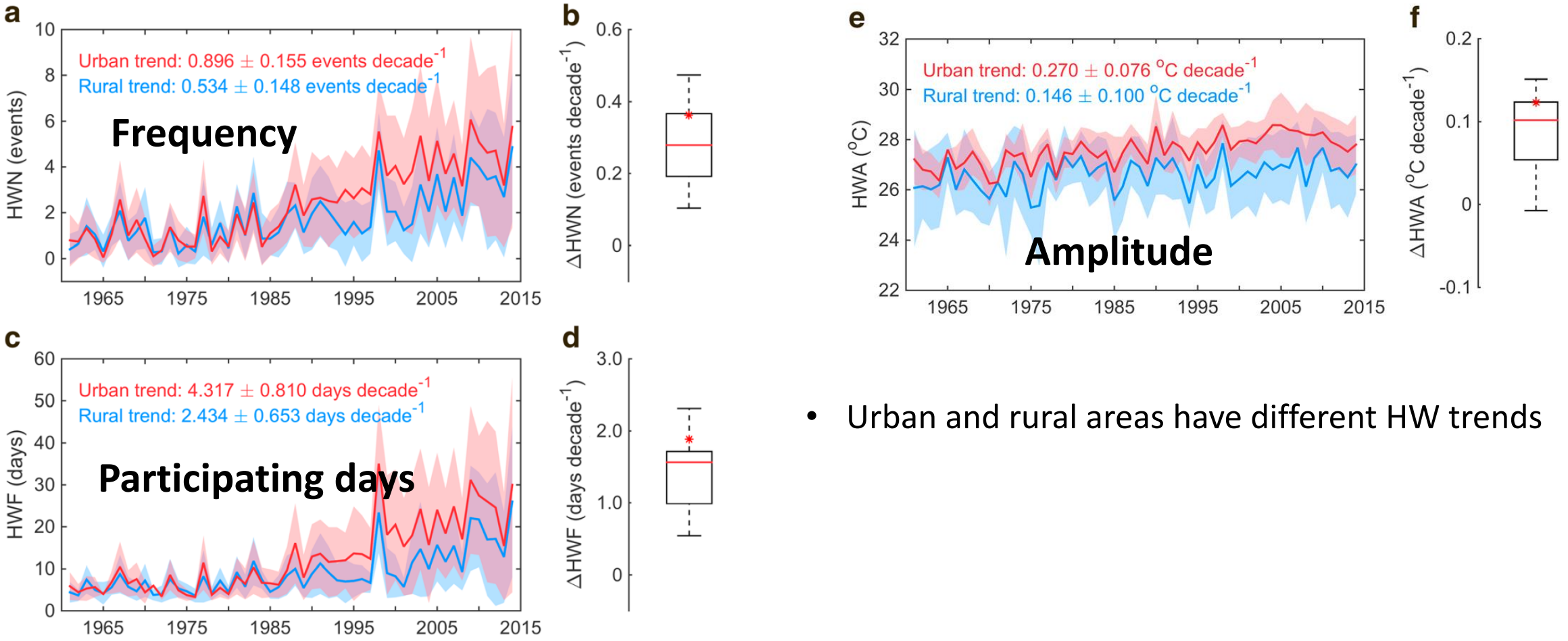
Considering the ***rural–urban conversion*** during the urbanization process, the BAF and the station classification are updated **dynamically**.







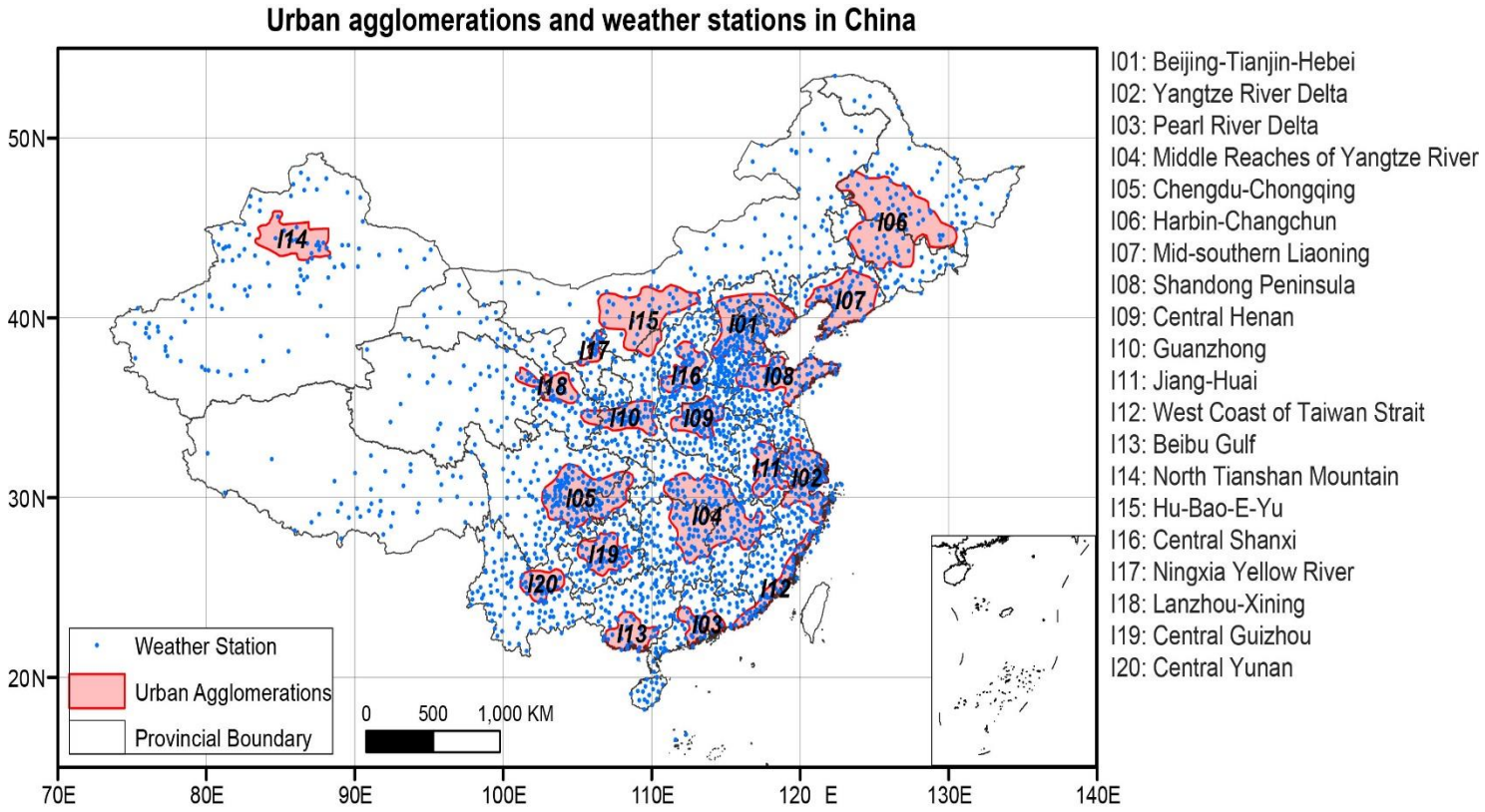
Urbanization effect on heatwave in China

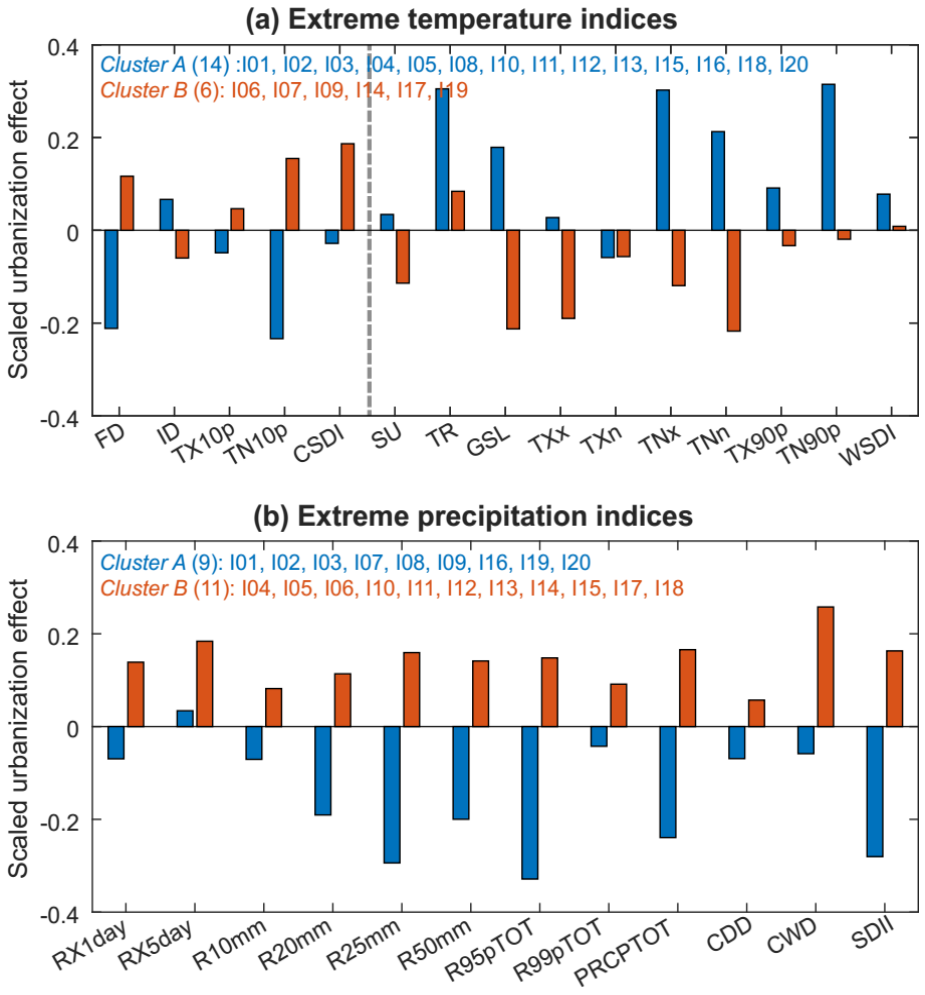


- Urban and rural areas have different HW trends

(Liao et al, *GRL*, 2018)

Urbanization effects on extreme climate events

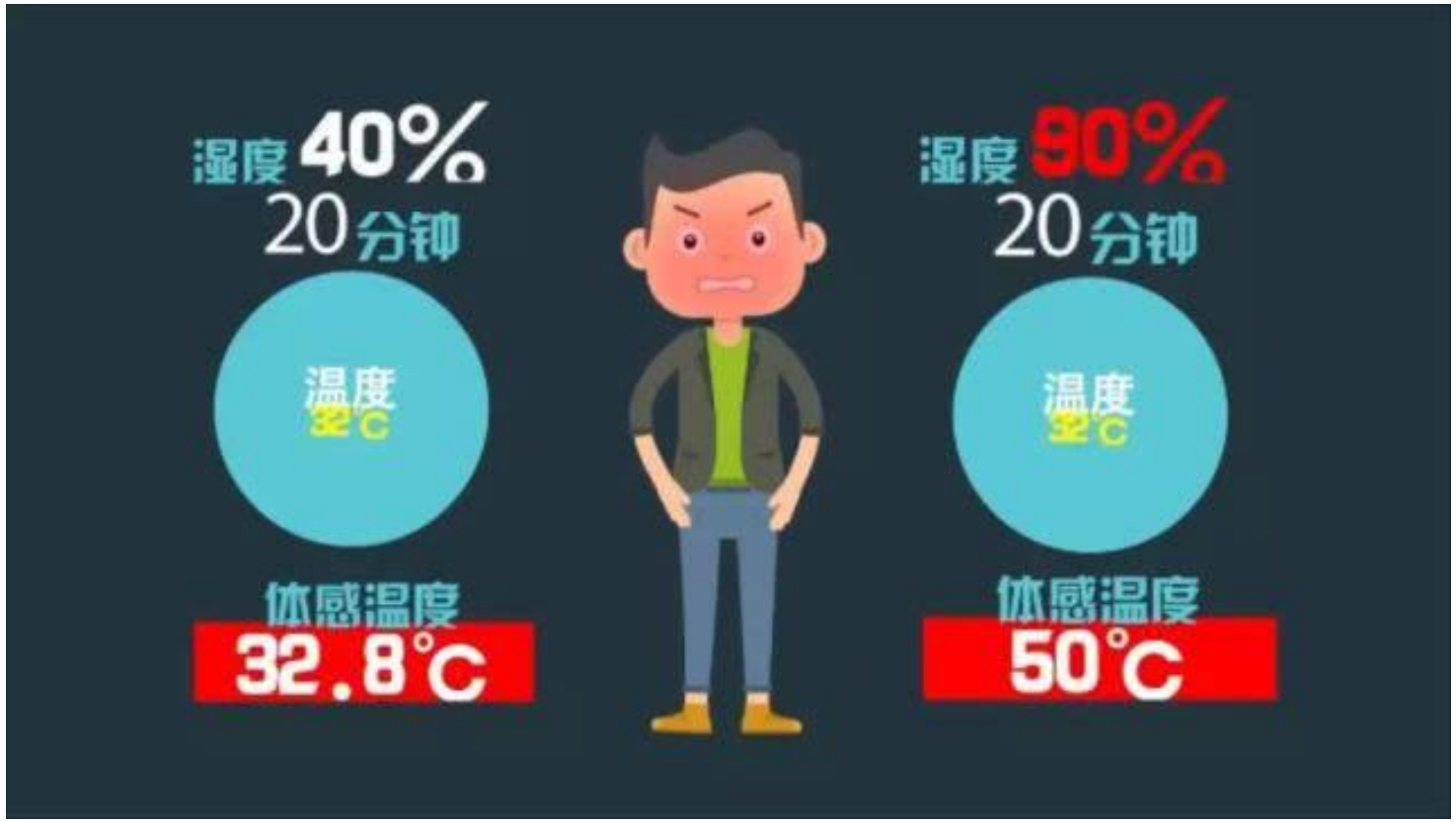




(Lin, Luo*, et al., *Sci. Total. Envi.*, 2020, under review)

4. Human Perceived Temperature Changes

Human-perceived temperature

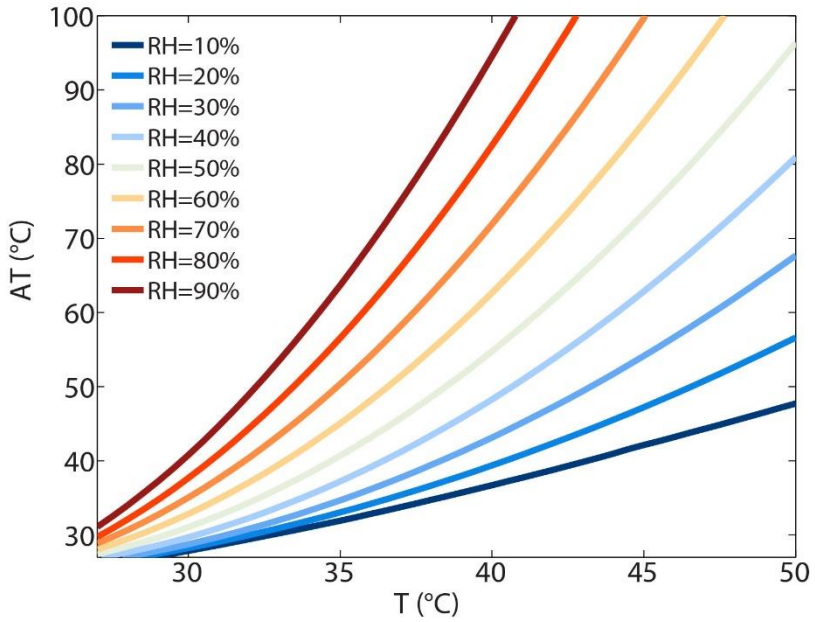


Heat index

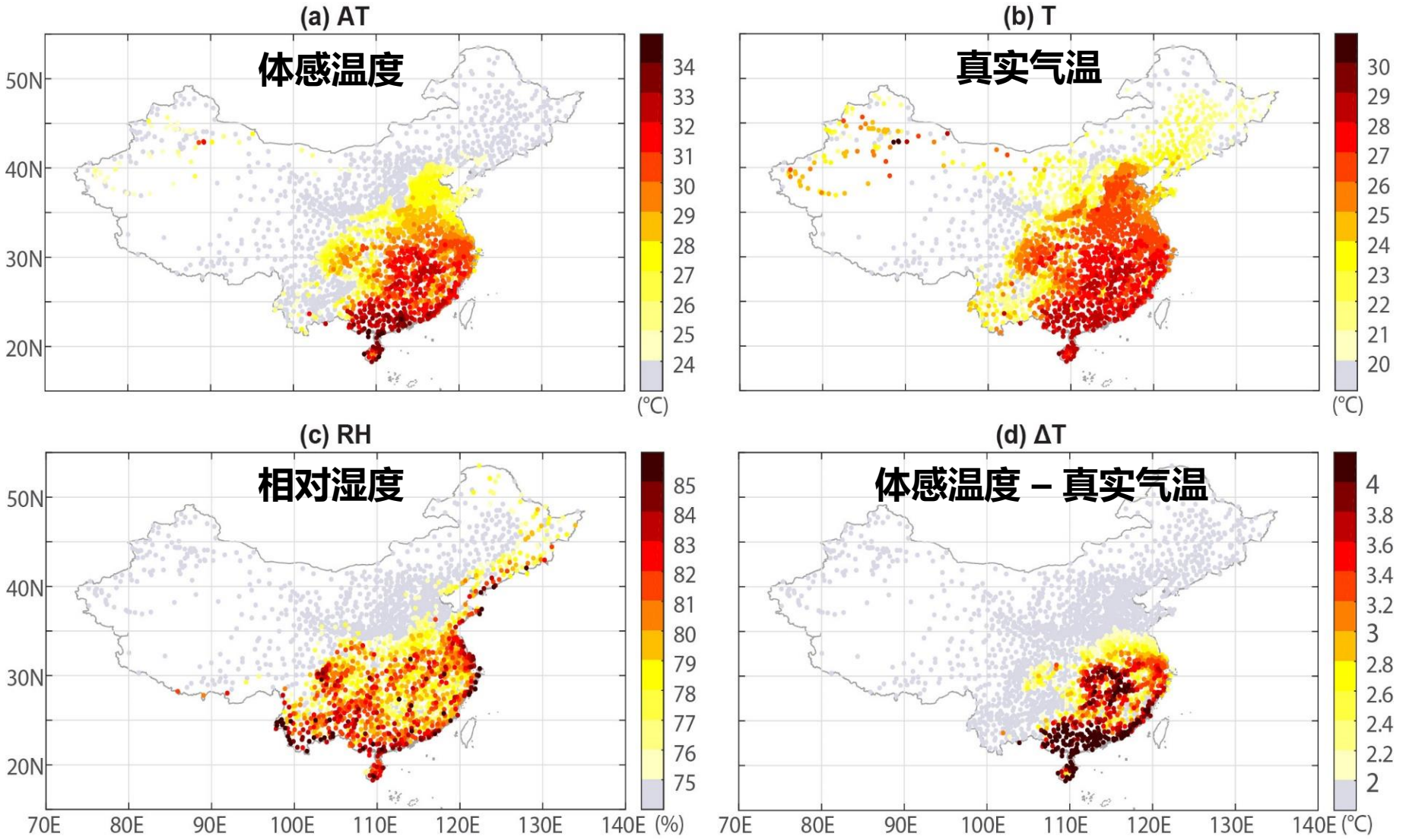
NOAA national weather service: heat index

Relative humidity	Temperature															
	80 °F (27 °C)	82 °F (28 °C)	84 °F (29 °C)	86 °F (30 °C)	88 °F (31 °C)	90 °F (32 °C)	92 °F (33 °C)	94 °F (34 °C)	96 °F (36 °C)	98 °F (37 °C)	100 °F (38 °C)	102 °F (39 °C)	104 °F (40 °C)	106 °F (41 °C)	108 °F (42 °C)	110 °F (43 °C)
40%	80 °F (27 °C)	81 °F (27 °C)	83 °F (28 °C)	85 °F (29 °C)	88 °F (31 °C)	91 °F (33 °C)	94 °F (34 °C)	97 °F (36 °C)	101 °F (38 °C)	105 °F (41 °C)	109 °F (43 °C)	114 °F (46 °C)	119 °F (48 °C)	124 °F (51 °C)	130 °F (54 °C)	136 °F (58 °C)
45%	80 °F (27 °C)	82 °F (28 °C)	84 °F (29 °C)	87 °F (31 °C)	89 °F (32 °C)	93 °F (34 °C)	96 °F (36 °C)	100 °F (38 °C)	104 °F (40 °C)	109 °F (43 °C)	114 °F (46 °C)	119 °F (48 °C)	124 °F (51 °C)	130 °F (54 °C)	137 °F (58 °C)	
50%	81 °F (27 °C)	83 °F (28 °C)	85 °F (29 °C)	88 °F (31 °C)	91 °F (33 °C)	95 °F (35 °C)	99 °F (37 °C)	103 °F (39 °C)	108 °F (42 °C)	113 °F (45 °C)	118 °F (48 °C)	124 °F (51 °C)	131 °F (55 °C)	137 °F (58 °C)		
55%	81 °F (27 °C)	84 °F (29 °C)	86 °F (30 °C)	89 °F (32 °C)	93 °F (34 °C)	97 °F (36 °C)	101 °F (38 °C)	106 °F (41 °C)	112 °F (44 °C)	117 °F (47 °C)	124 °F (51 °C)	130 °F (54 °C)	137 °F (58 °C)			
60%	82 °F (28 °C)	84 °F (29 °C)	88 °F (31 °C)	91 °F (33 °C)	95 °F (35 °C)	100 °F (38 °C)	105 °F (41 °C)	110 °F (43 °C)	116 °F (47 °C)	123 °F (51 °C)	129 °F (54 °C)	137 °F (58 °C)				
65%	82 °F (28 °C)	85 °F (29 °C)	89 °F (32 °C)	93 °F (34 °C)	98 °F (37 °C)	103 °F (39 °C)	108 °F (42 °C)	114 °F (46 °C)	121 °F (49 °C)	128 °F (53 °C)	136 °F (58 °C)					
70%	83 °F (28 °C)	86 °F (30 °C)	90 °F (32 °C)	95 °F (35 °C)	100 °F (38 °C)	105 °F (41 °C)	112 °F (44 °C)	119 °F (48 °C)	126 °F (52 °C)	134 °F (57 °C)						
75%	84 °F (29 °C)	88 °F (31 °C)	92 °F (33 °C)	97 °F (36 °C)	103 °F (39 °C)	109 °F (43 °C)	116 °F (47 °C)	124 °F (51 °C)	132 °F (56 °C)							
80%	84 °F (29 °C)	89 °F (32 °C)	94 °F (34 °C)	100 °F (38 °C)	106 °F (41 °C)	113 °F (45 °C)	121 °F (49 °C)	129 °F (54 °C)								
85%	85 °F (29 °C)	90 °F (32 °C)	96 °F (36 °C)	102 °F (39 °C)	110 °F (43 °C)	117 °F (47 °C)	126 °F (52 °C)	135 °F (57 °C)								
90%	86 °F (30 °C)	91 °F (33 °C)	98 °F (37 °C)	105 °F (41 °C)	113 °F (45 °C)	122 °F (50 °C)	131 °F (55 °C)									
95%	86 °F (30 °C)	93 °F (34 °C)	100 °F (38 °C)	108 °F (42 °C)	117 °F (47 °C)	127 °F (53 °C)										
100%	87 °F (31 °C)	95 °F (35 °C)	103 °F (39 °C)	112 °F (44 °C)	121 °F (49 °C)	132 °F (56 °C)										

Key to colors: Caution | Extreme caution | Danger | Extreme danger

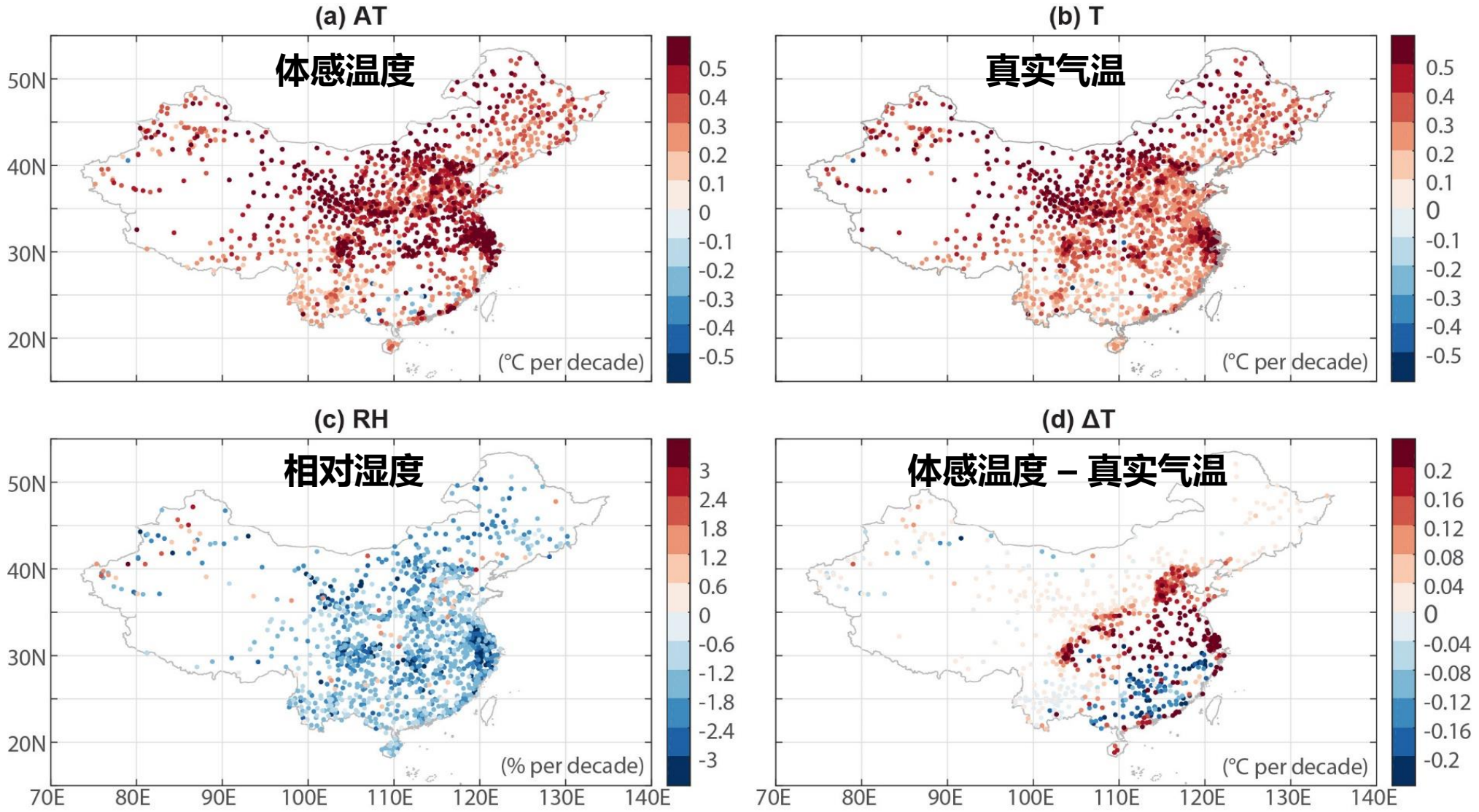


Heat stress in China



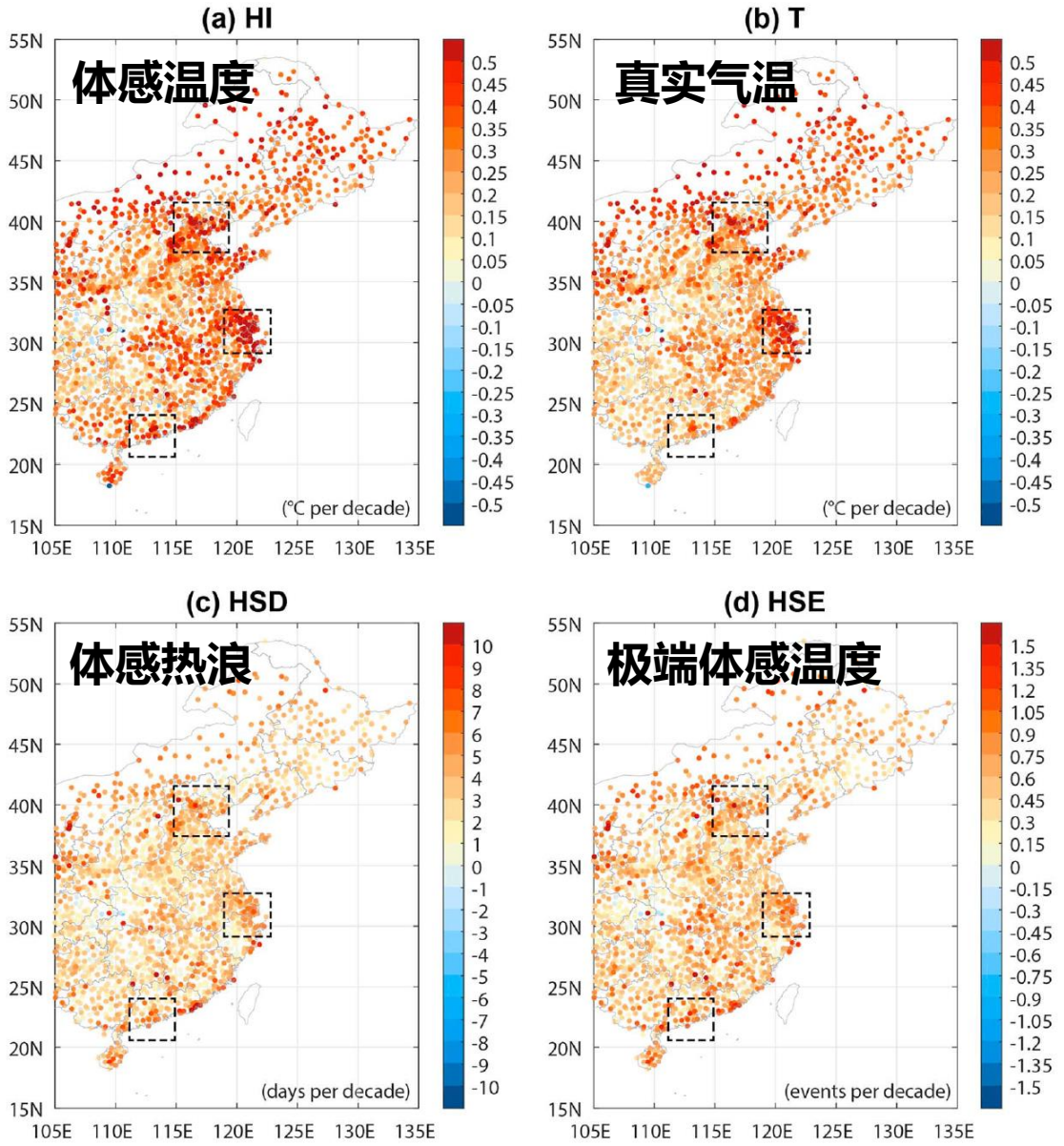
(Luo & Lau, *Clim. Dyn.*, 2019)

Heat stress trends



(Luo & Lau, *Clim. Dyn.*, 2019)

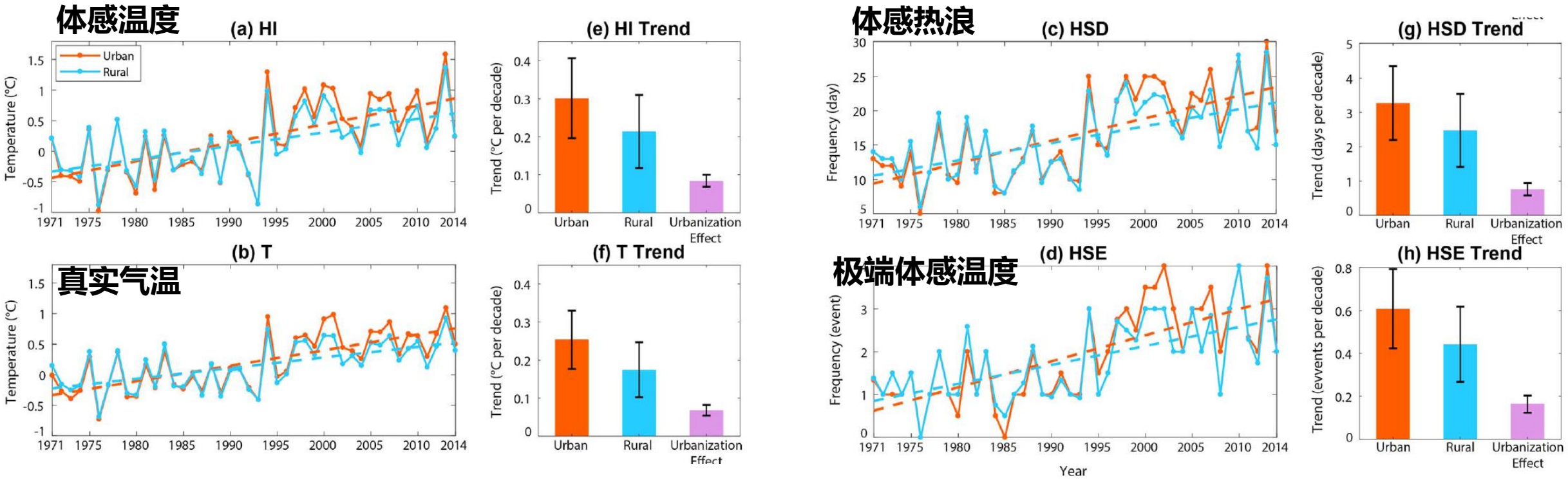
Urbanization and heat stress in eastern China



- **Perceived heat stress increases faster than air temperature across eastern China;**
- **Both of them increase faster in urban than in rural areas**

(Luo & Lau, *GRL*, 2018)

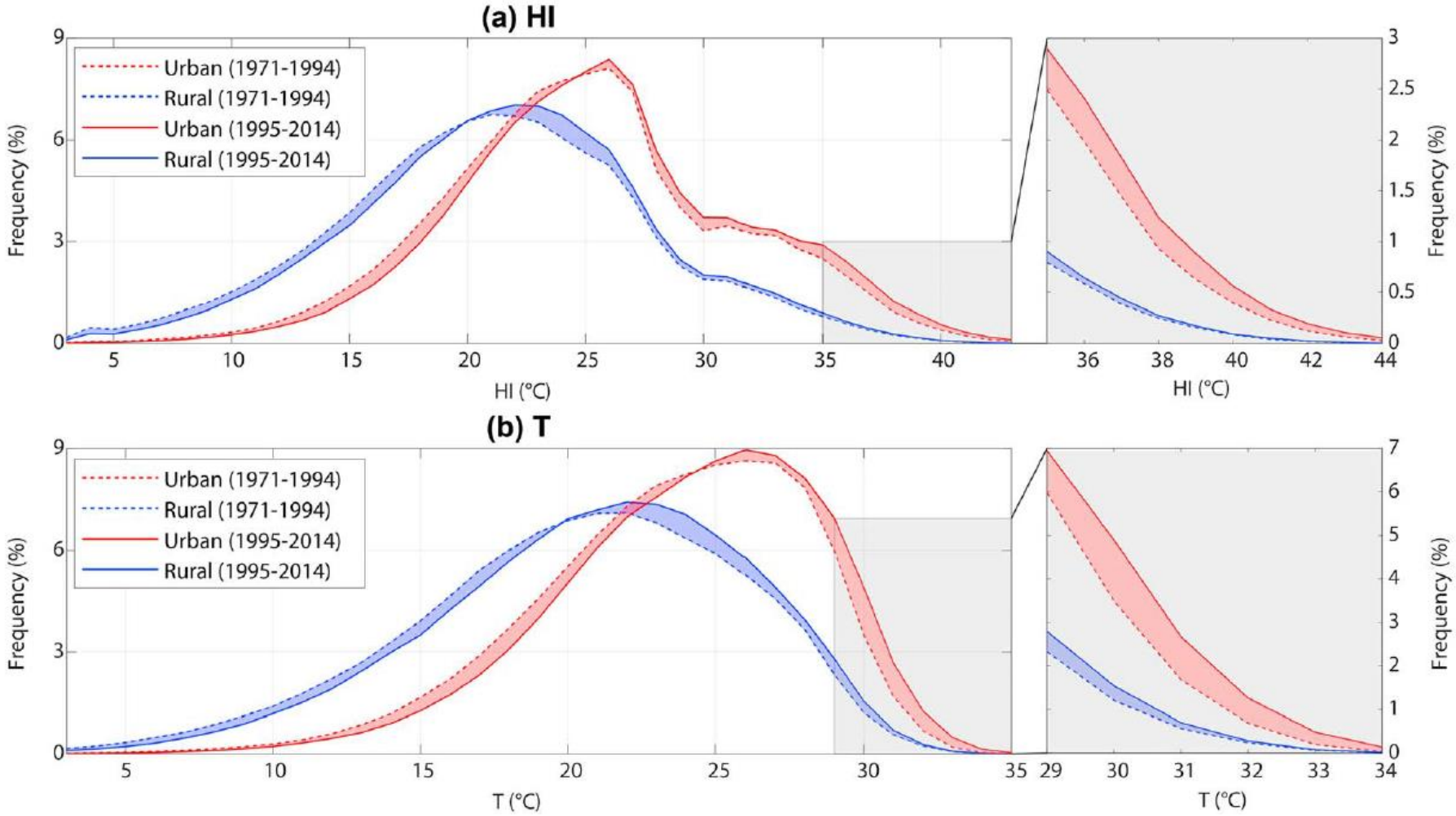
Urbanization effects



Urbanization contributes ≈30% to the increase in mean heat stress and the frequencies of extreme heat stress days and consecutive events in the urban areas.

(Luo & Lau, *GRL*, 2018; Luo et al., *Earth's Future*, 2021)

PDFs of daily temperature in urban/rural areas



The probability distributions of extreme heat stress and temperature in urban areas exhibit larger shifts toward higher values.

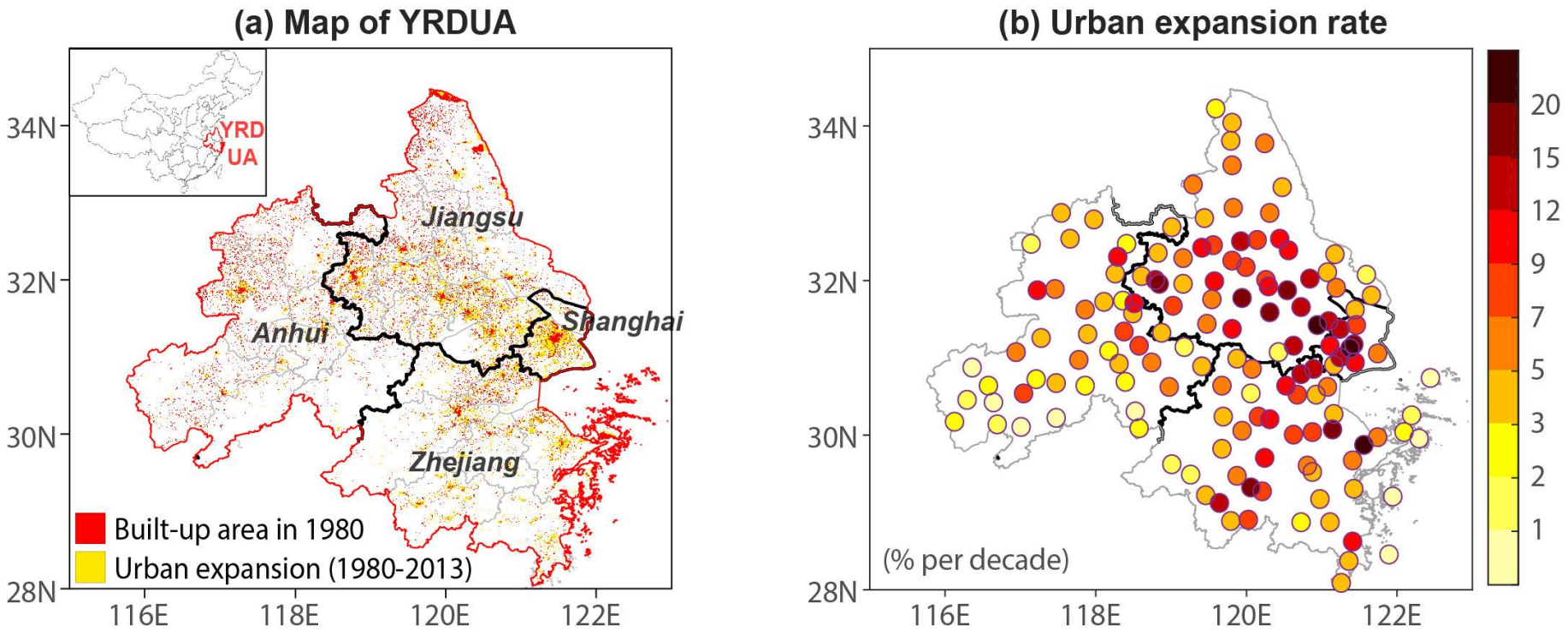
(Luo & Lau, *GRL*, 2018; Luo et al., *Earth's Future*, 2021)

5. Urban Dry Island and Urbanization

What about moisture?



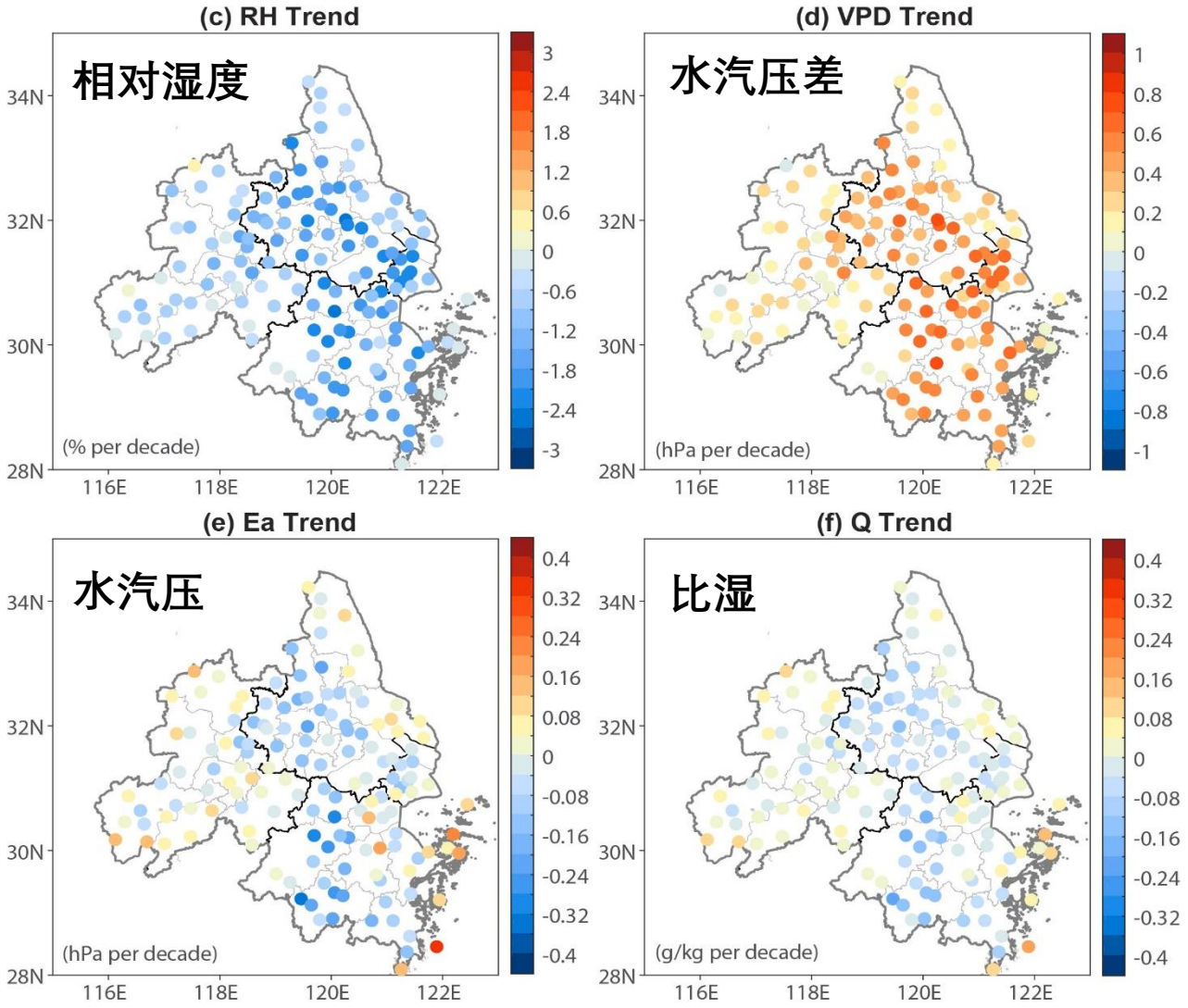
Urban dry island?

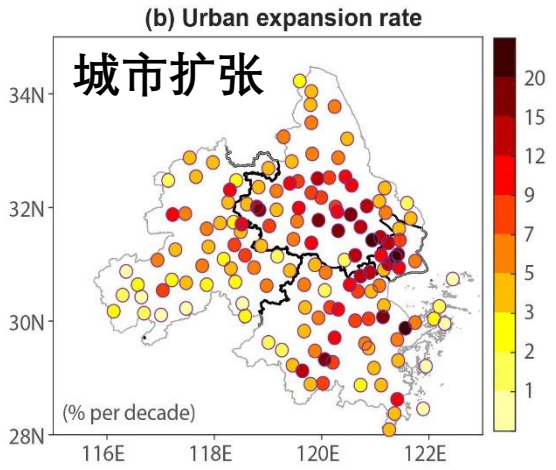


10.1% in 1980 → 32.1% in 2013

(Luo & Lau, *GRL*, 2019)

Urban dry island?



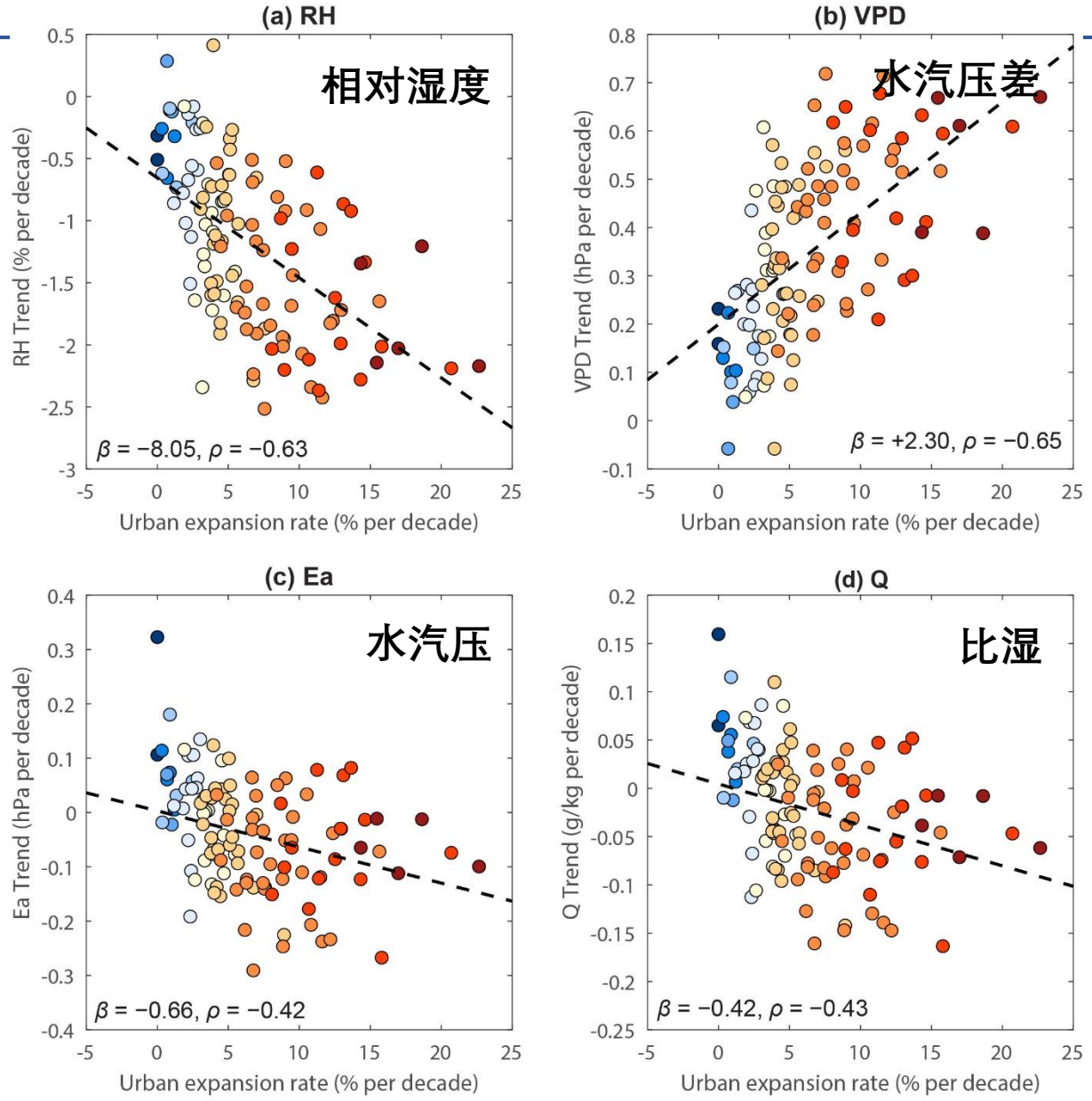


Local urban expansion may accelerate the drying climate trends in YRDUA.

(Luo & Lau, *GRL*, 2019)

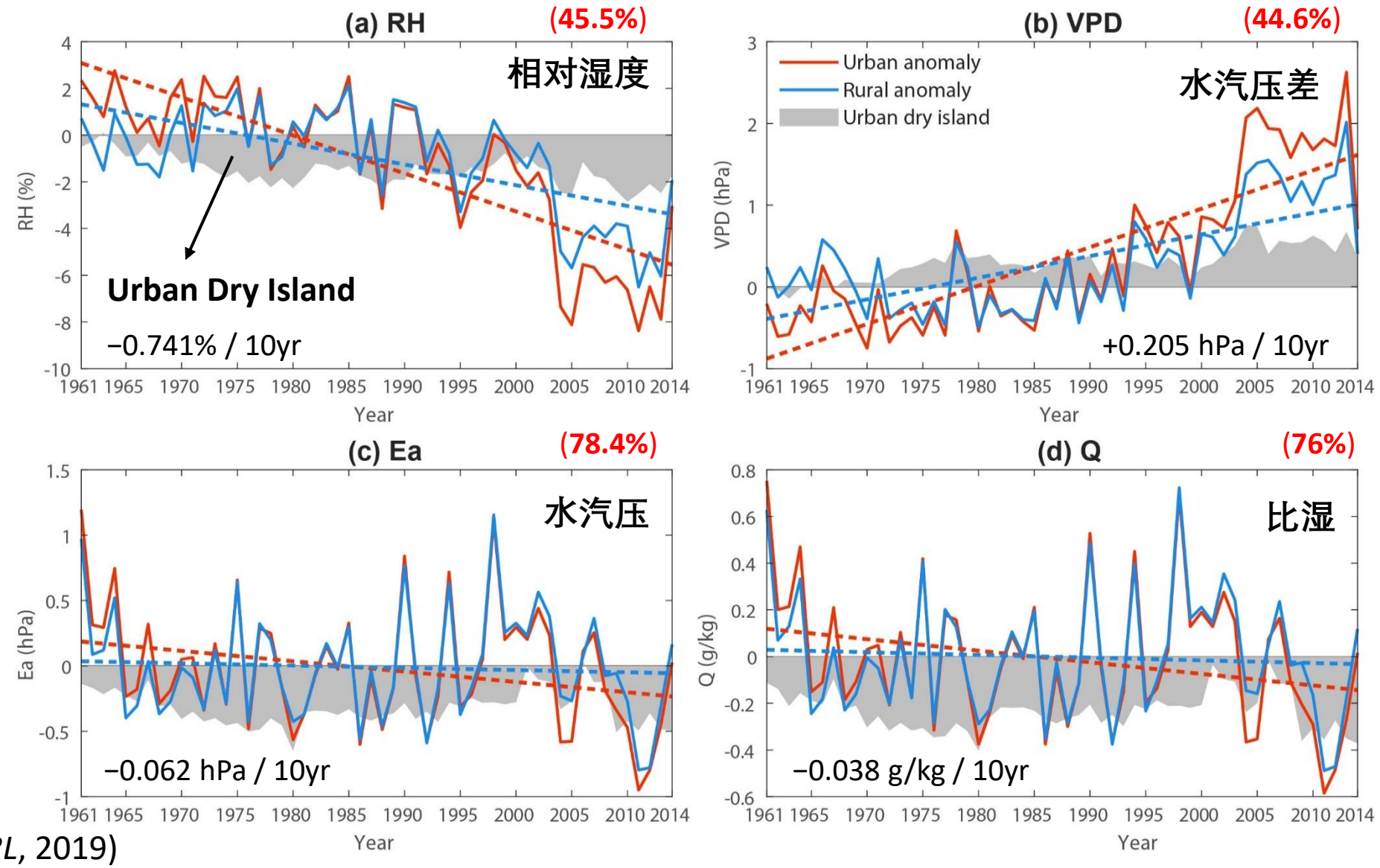
UDI intensified by urbanization

Stronger drying trends in faster-urbanized areas.



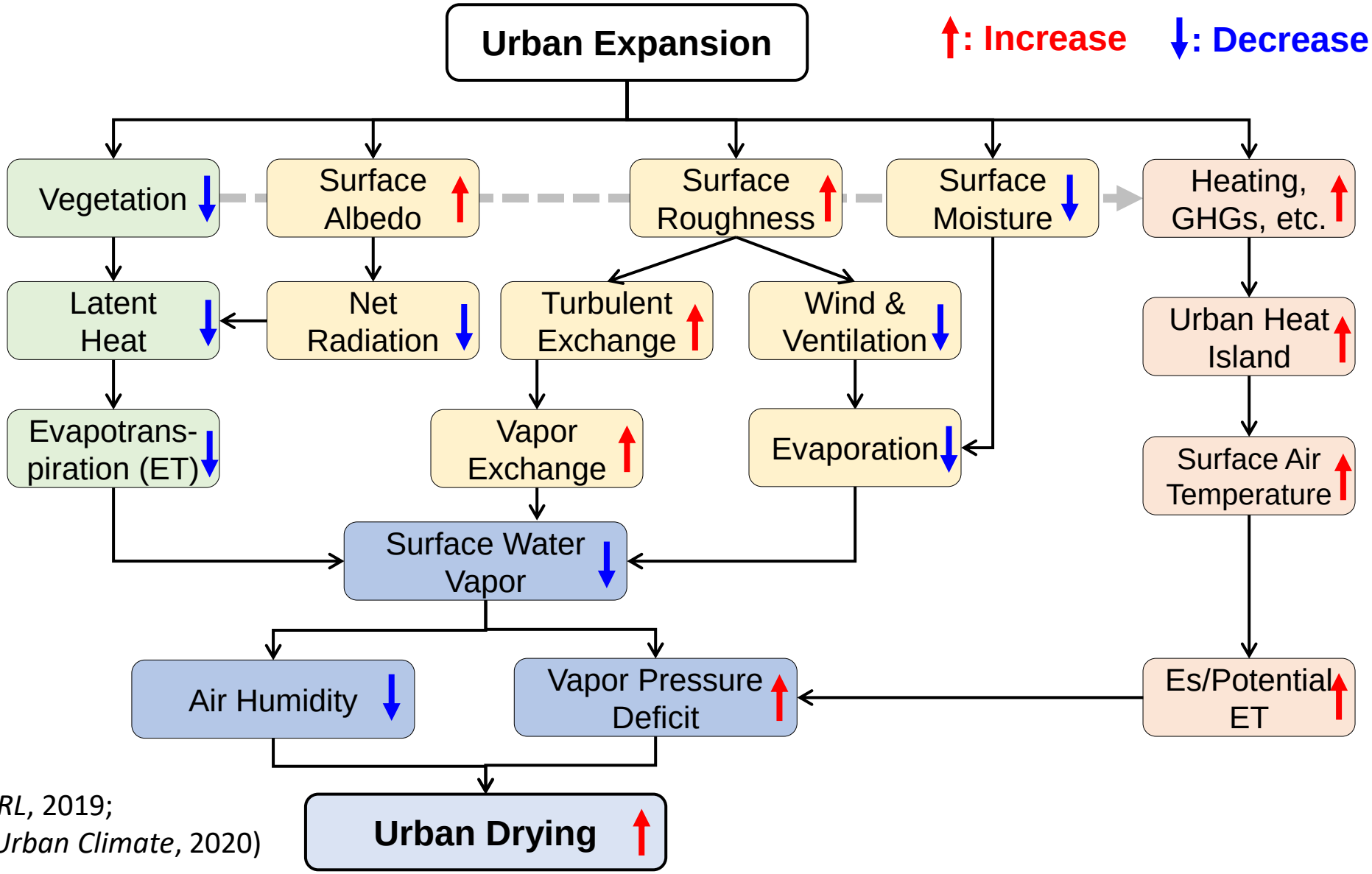
(Luo & Lau, *GRL*, 2019)

Faster drying trend in urban than rural area



(Luo & Lau, *GRL*, 2019)

Possible processes



(Luo & Lau, *GRL*, 2019;
Lin, …, Luo*, *Urban Climate*, 2020)

Summary

Causes and synoptic weather conditions

- Reduced precipitation and cloud, increased pressure, surface cyclone/anticyclone, sinking air motion, etc.
- Different mechanisms for heatwaves in different subregions.

weather forecast

Interannual variations

- Influenced by both zonal (ENSO) and meridional (PMM) modes of the Pacific ocean via different processes.

seasonal forecast

Long-term trend and urbanization effects

- Intensifying frequency, duration, and intensity across China;
- Urbanization contributes to ≈ 50% of the total trend in urban area.

climate prediction & mitigation

Urban dry island intensified by urban expansion

THANKS

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