How and why has extreme hourly rainfall (EXHR) changed in the major urban agglomerations over China?

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EGU2020 session “Land–atmosphere interactions and climate extremes"
(CL4.21), 5 May from 14 to 16h

Importance & Poor understanding on changes in extreme sub-daily rainfall

- **Engineering practice & urban infrastructure design demand information about changes in sub-daily rainfall**
- **Long-term observations only at limited regions**
  - Higher density needed
- **Relevance of smaller-scale processes**
  - Mesoscale dynamics & Microphysics
  - Underlying surface (cities, topography, land/sea)
- **Difficult to resolve those processes by coarse-resolution GCMs → need convection-permitting modeling**

(e.g., Lenderink & Meijgaard 2008; Westra et al. 2014; Feng et al. 2016; Prein et al. 2016, 2017; Liu et al. 2017; Zhang et al. 2017)

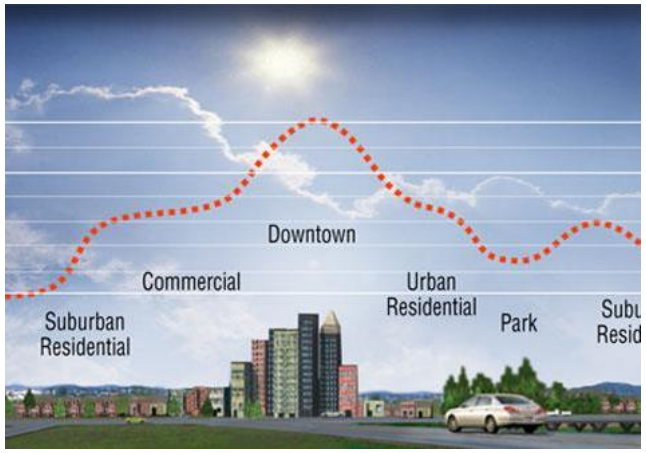
Background: Possible contributors to changes in weather extremes

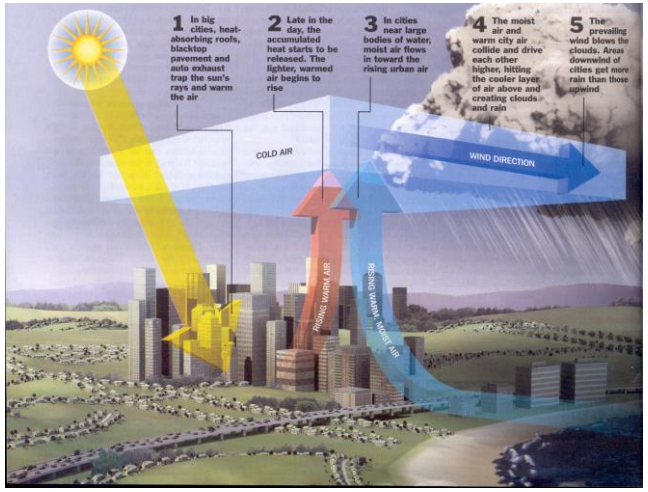
- **Internal climate variability**
- **Changes in external forcing**
  - ✧ **Natural**
    - **Solar irradiance, volcanism**
  - ✧ **Anthropogenic**
    - **Greenhouse gas and aerosol emissions**
    - **Land use & land cover changes**

Seneviratne et al., 2012: Changes in climate extremes and their impacts on the natural physical environment. In: *IPCC Special Report on Extremes.* Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 109-230.

Cities can modify precipitation

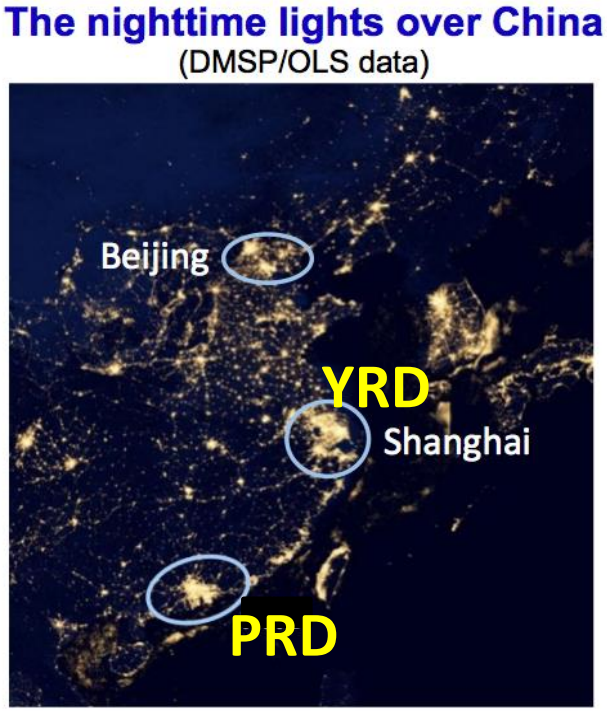
- ✧ **Urban heat island (UHI)**
  - – **"local" vs "advective" UHI**
- ✧ **Anthropogenic aerosol emission**
  - – **CCN → cloud & precipitation microphysics**
  - – **Radiative transfer → air instability**
- ✧ **Urban dynamical effect**
  - – **Building-barrier effects on flow**
  - – **Convergence zones**



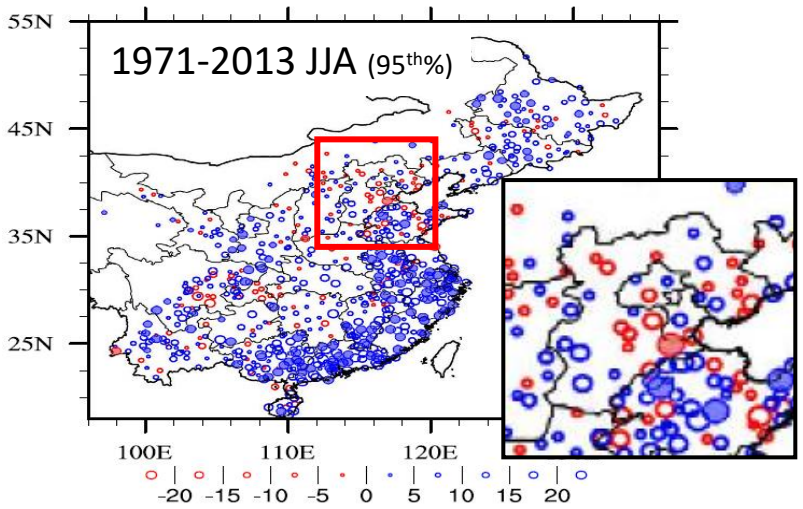


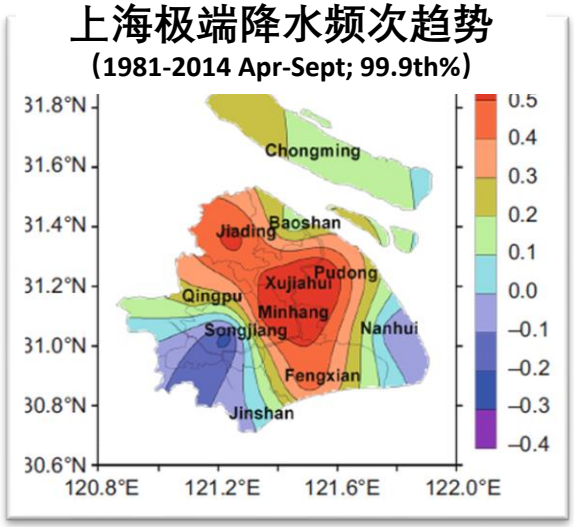
(e.g., Changnon et al. 1969, 1969, 1981; Bornstein, & Lin 2000; Shepherd & Burian 2003; Shepherd 2005; Zhang et al. 2009; Kishtawal et al. 2010; Niyogi et al. 2011; Wan et al. 2013; Liang et al. 2018)

EXHR changes in major urban areas over China

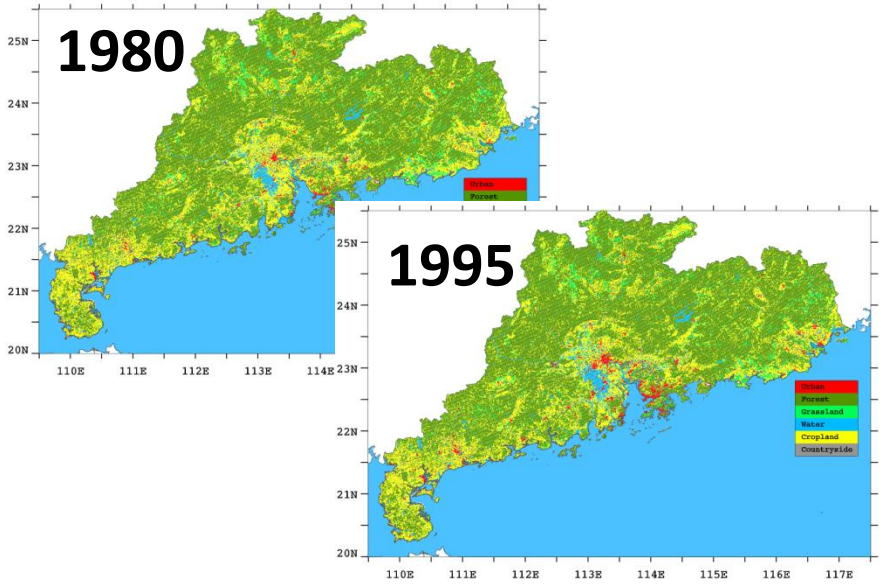


- Beijing-Tianjin-Hebei: no positive or negative trends (Xiao et al., 2016, Sci. Rep.)
- Shanghai: Increasing trends (Liang and Ding, 2016, AAS)
- **Yangtze River Delta (YRD): urban rain-island (Jiang, Luo, Zhang 2020JC)**
- **Pearl River Delta (PRD): urban rain-island (Wu, Luo, Chen 2019JAMC)**

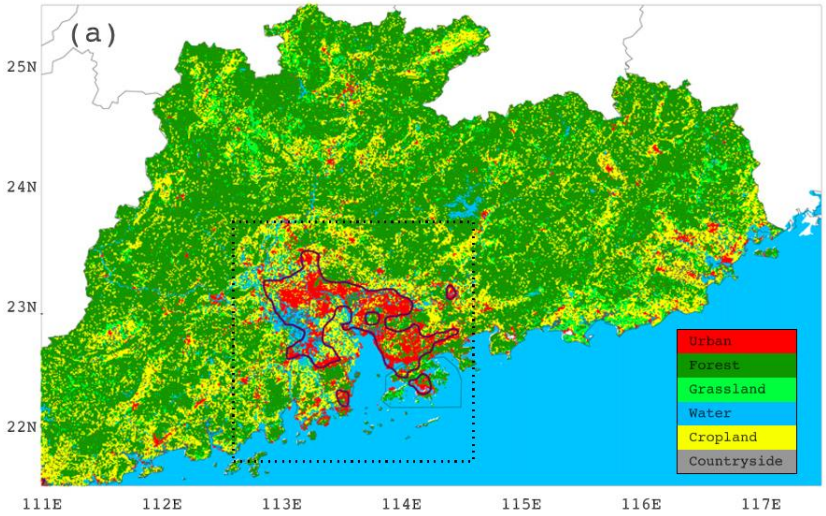




Rapid urbanization over the PRD



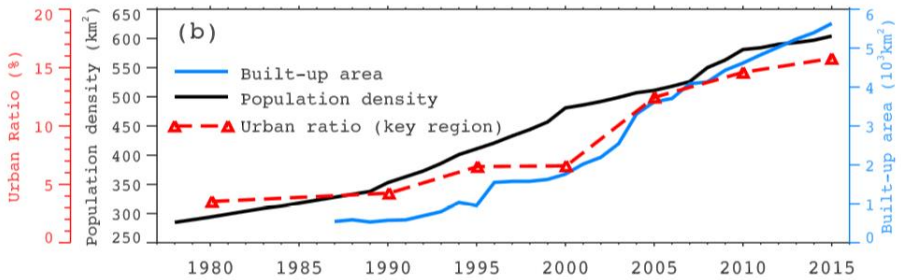
Land use map (2015)



Urban ratio

Population density

Built-up area



1971 **1994** **2015**

Pre era **Rapid urban. era**

Data sources:

- Resources and Environment Scientific Data Center, Chinese Academy of Sciences (http://www.resdc.cn/data.aspx? DATAID598)
- Guangdong Statistical Bureau (2016; http://www.gdstats.gov.cn/)

Trend in EXHR (1971-2016; 95th percentile)

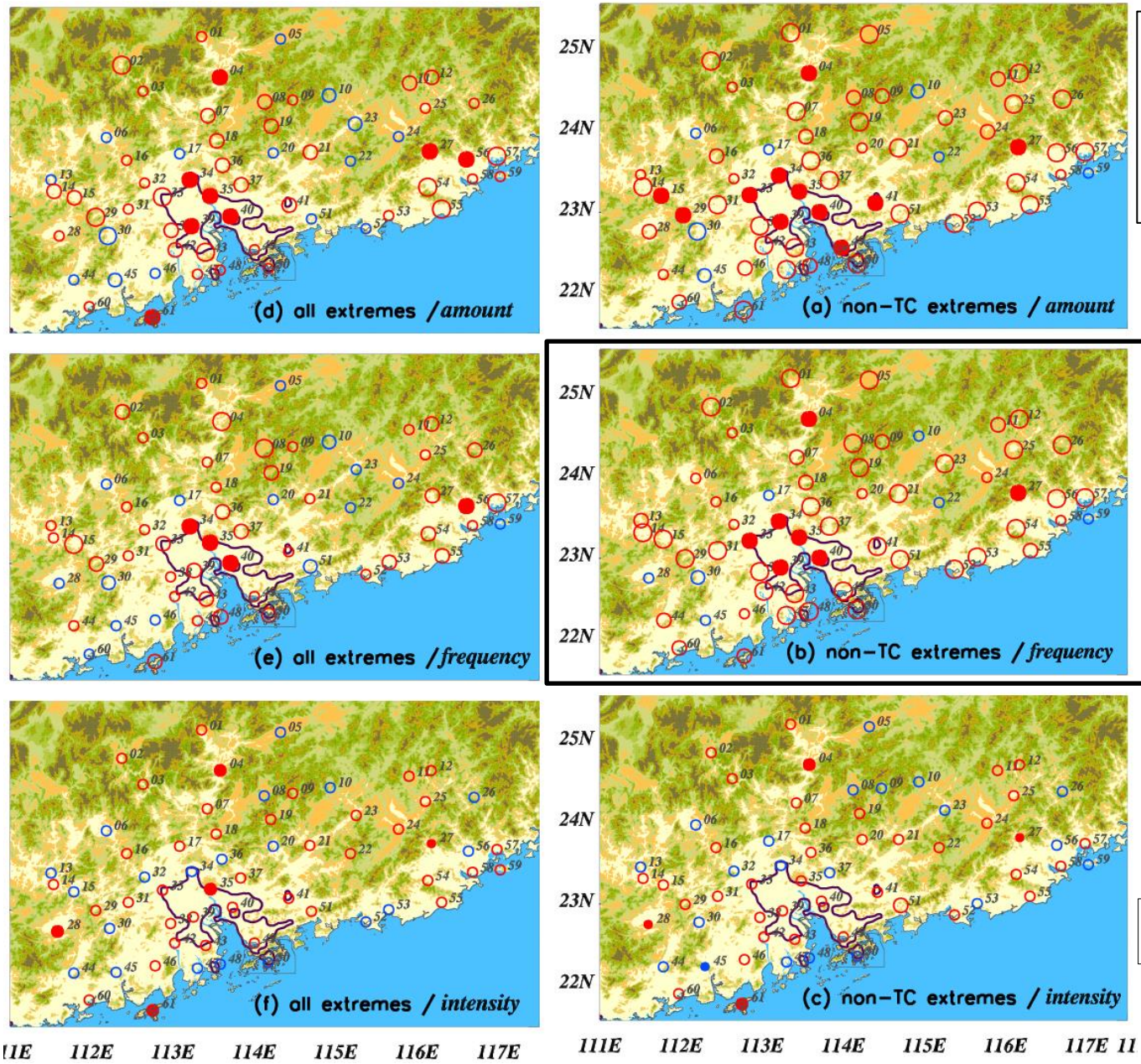
All EXHR

non-TC EXHR (79%)

Amount

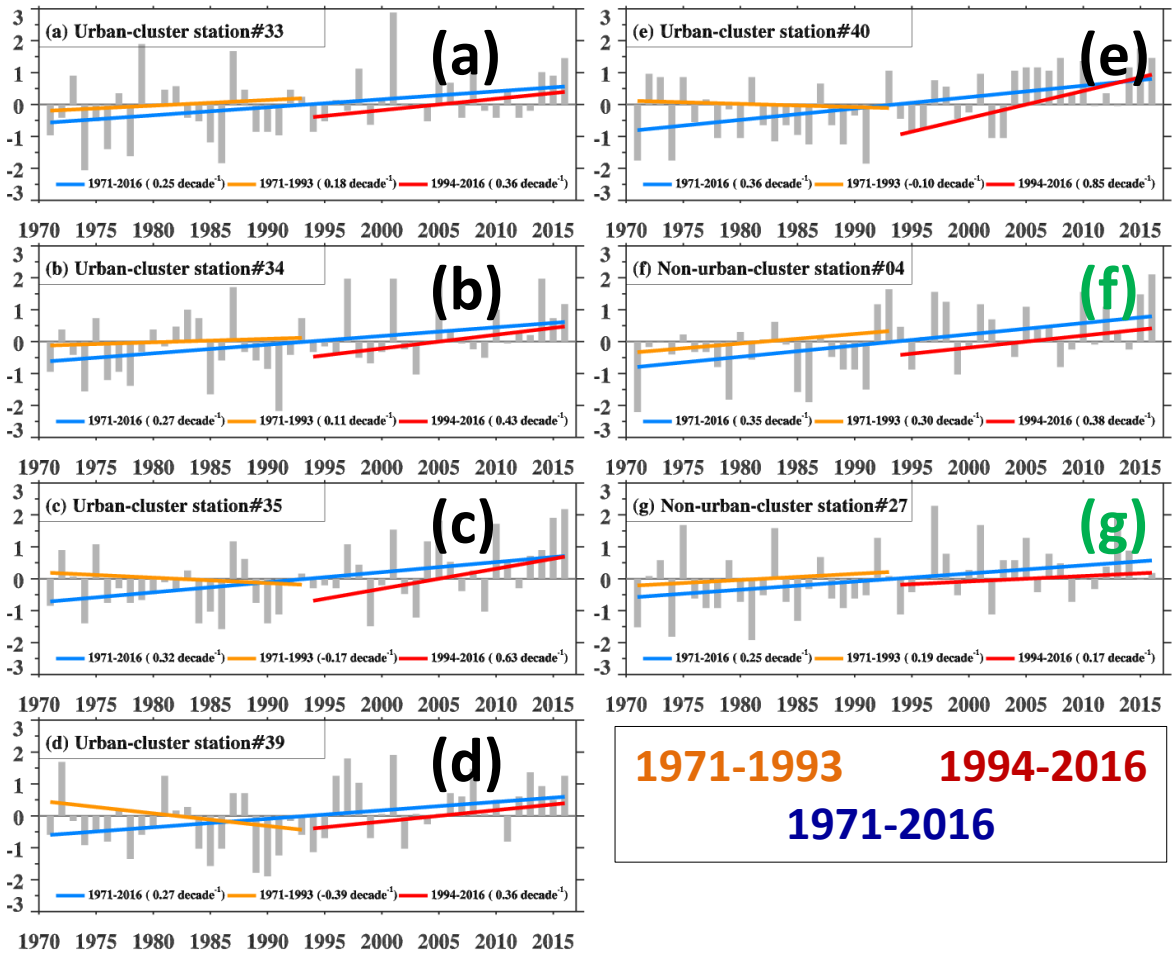
Occur. Freq.

Intensity



Time Series & Trend in EXHR *Frequency*

(a)-(e) PRD city cluster

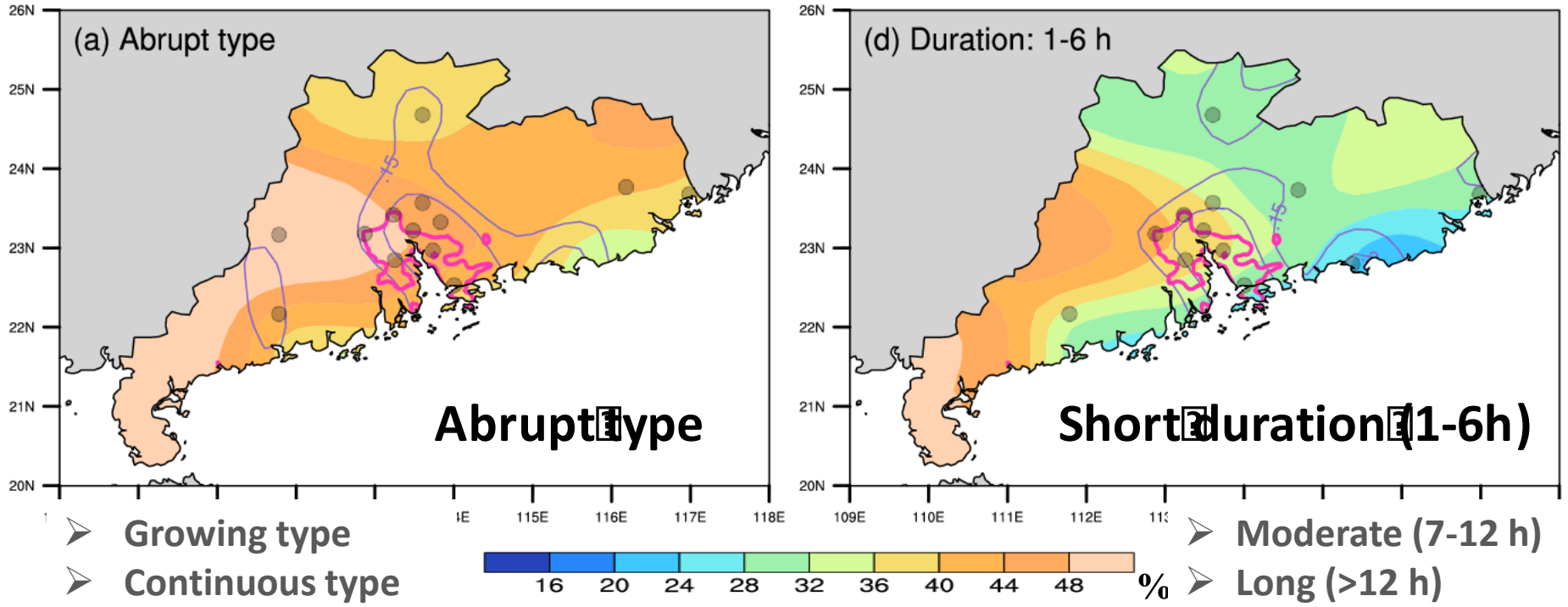


(f)-(g) non-urban region

The comparison between pre- and rapid-urbanization periods at each station remains qualitatively unchanged when any year of 1991-97 is used as the demarcation point.

Significant increase trends in the extreme freq. over the city cluster with a distinct **abrupt, short-duration** characteristic

Duration: Length of a time period with continuous rainfall (>0.1 mm/h) and at least one EXHP at a station.

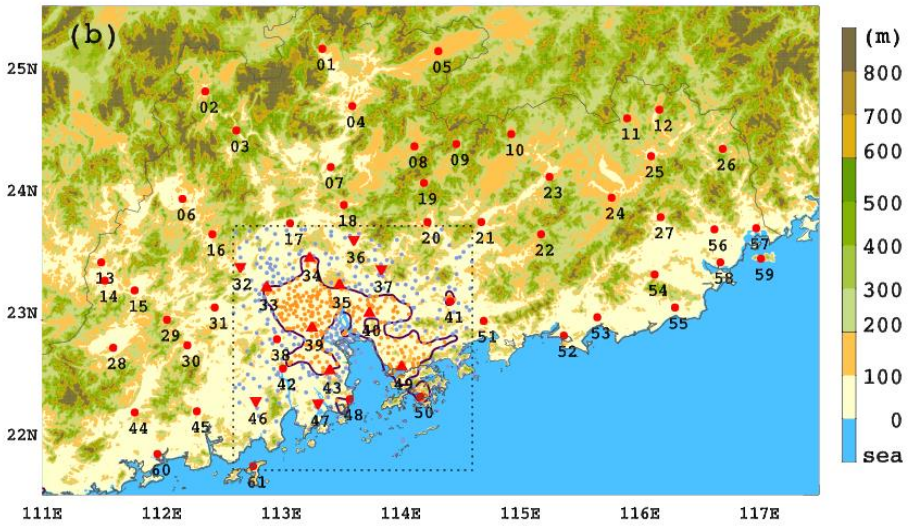


- Contours: Change rate (0.15, 0.2/10y)
- **Dots: Stations with sig. (95%) increase trend**
- Shading: Contribution to total events
- The TC-induced events excluded

- **Not** seen in growing or continuous types, or longer duration events

120 events with EXHP (2011-16 Apr-Sept)

Define an event: A continuous rainy period that contains at least one record of hourly rainfall ≥60 mm in the key region.



Intensity of UHI: $UHII = T_{urban} - T_{rural}$

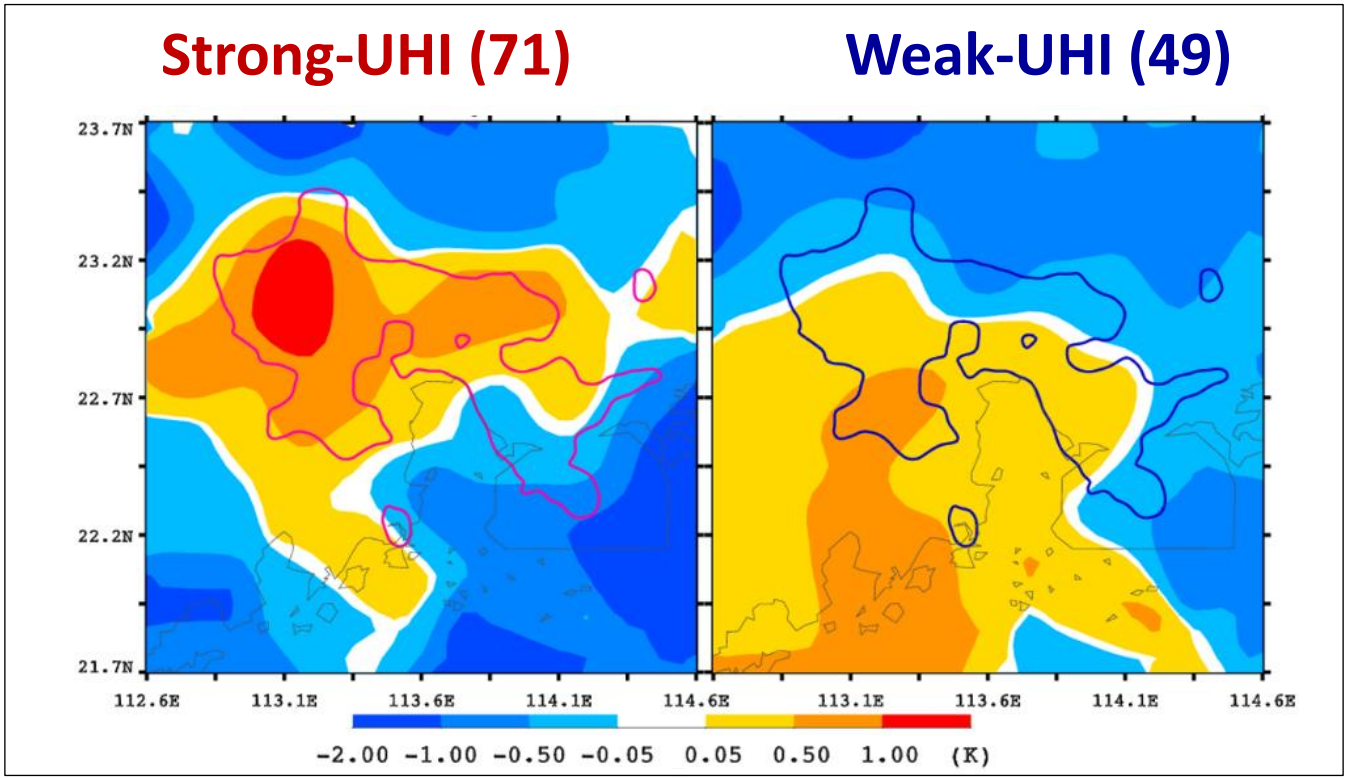
Strong-UHI event:

At least 2h in the 3h pre-event time, $UHII > UHII_{mean}$

Weak-UHI event:

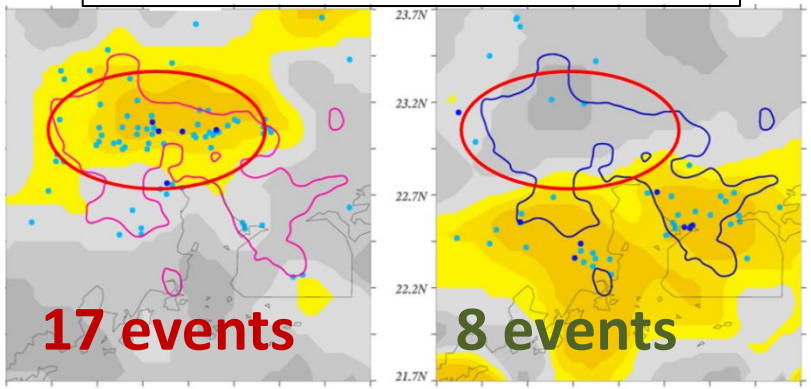
At most 1h in the 3h pre-event time, $UHII > UHII_{mean}$

Pre-event surface air θ perturbation

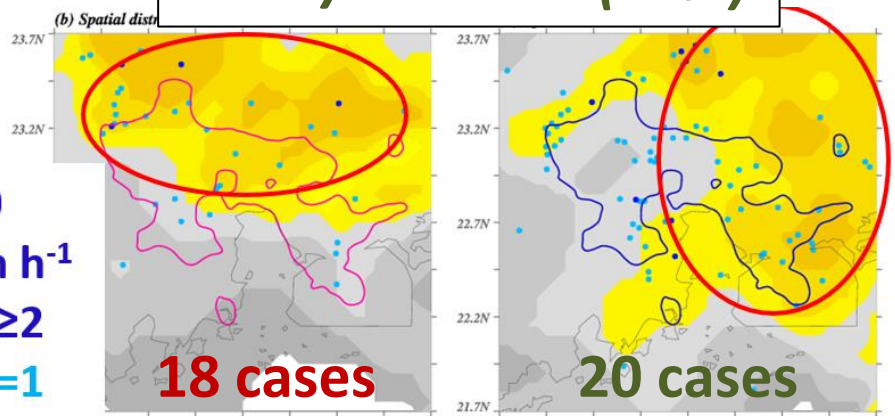


Rainfall under major synoptic patterns: Strong- vs. weak-UHI

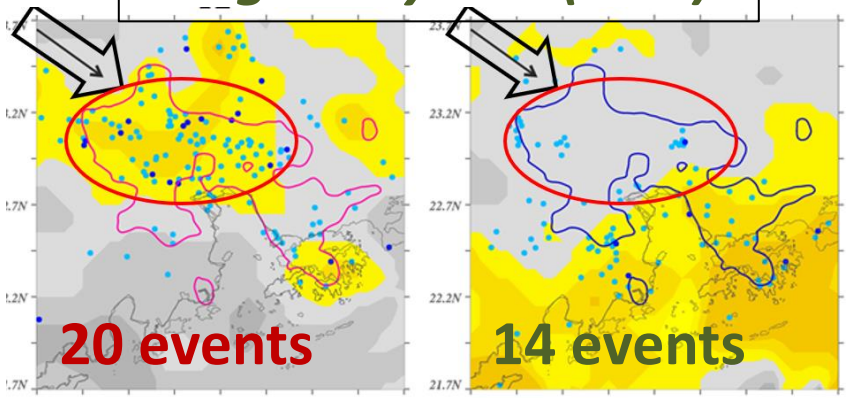
Local/shear line (21%)



Local/SW wind (32%)



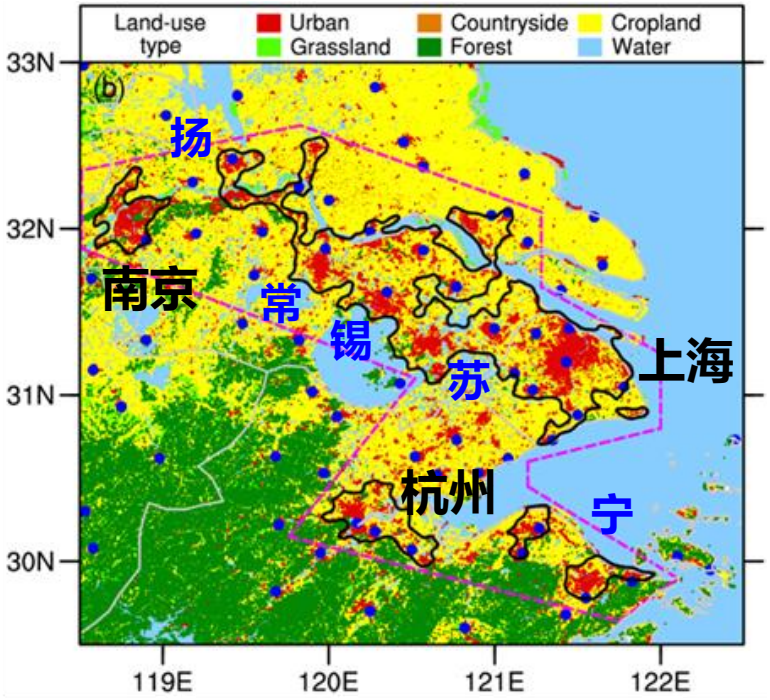
Migratory NW (28%)

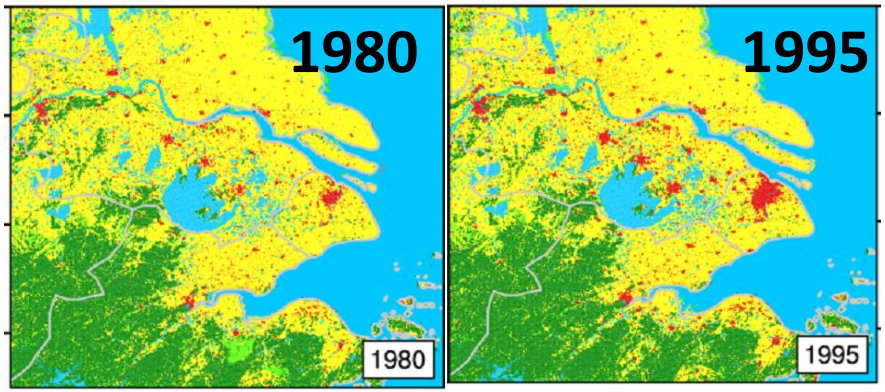


- **81% (97/120) events**

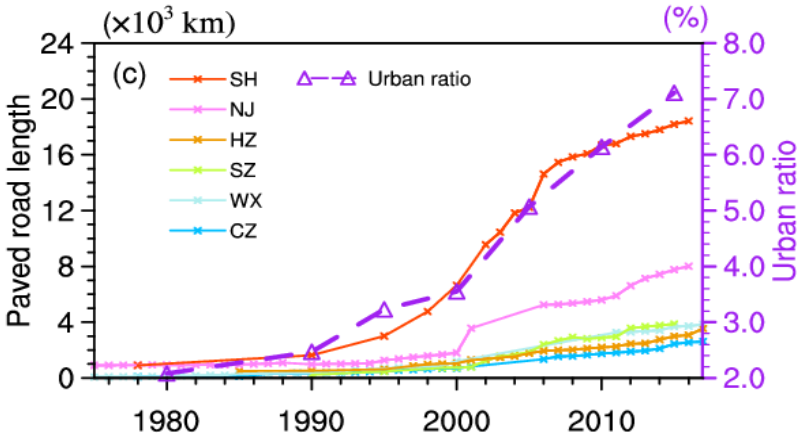
Rapid urbanization over the YRD

Land use map (2015)

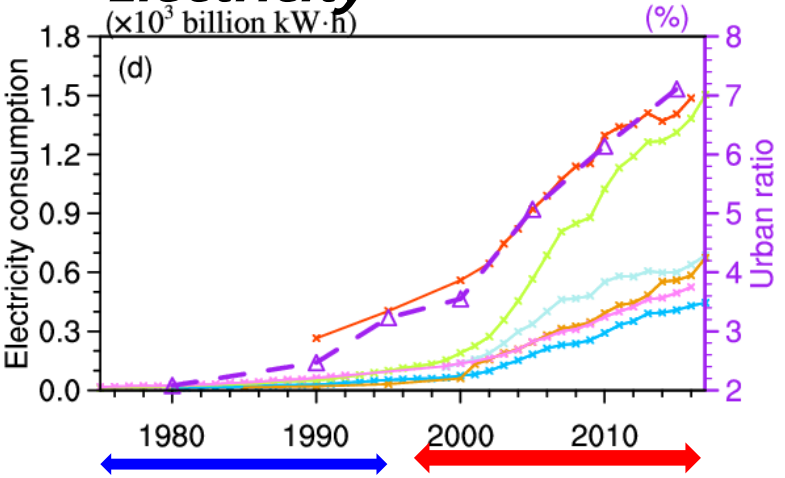




Paved road ***Urban ratio***



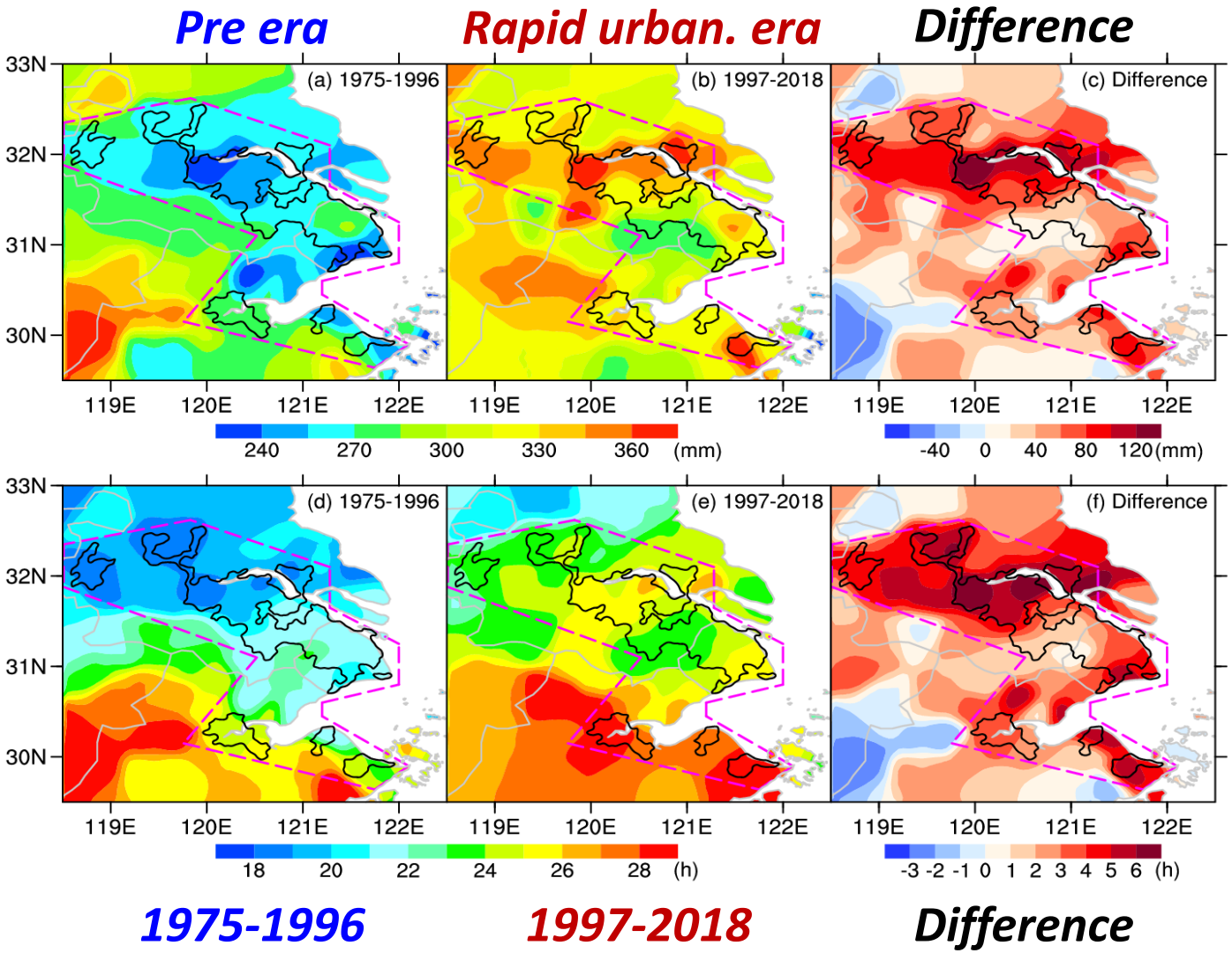
Electricity ***Urban ratio***



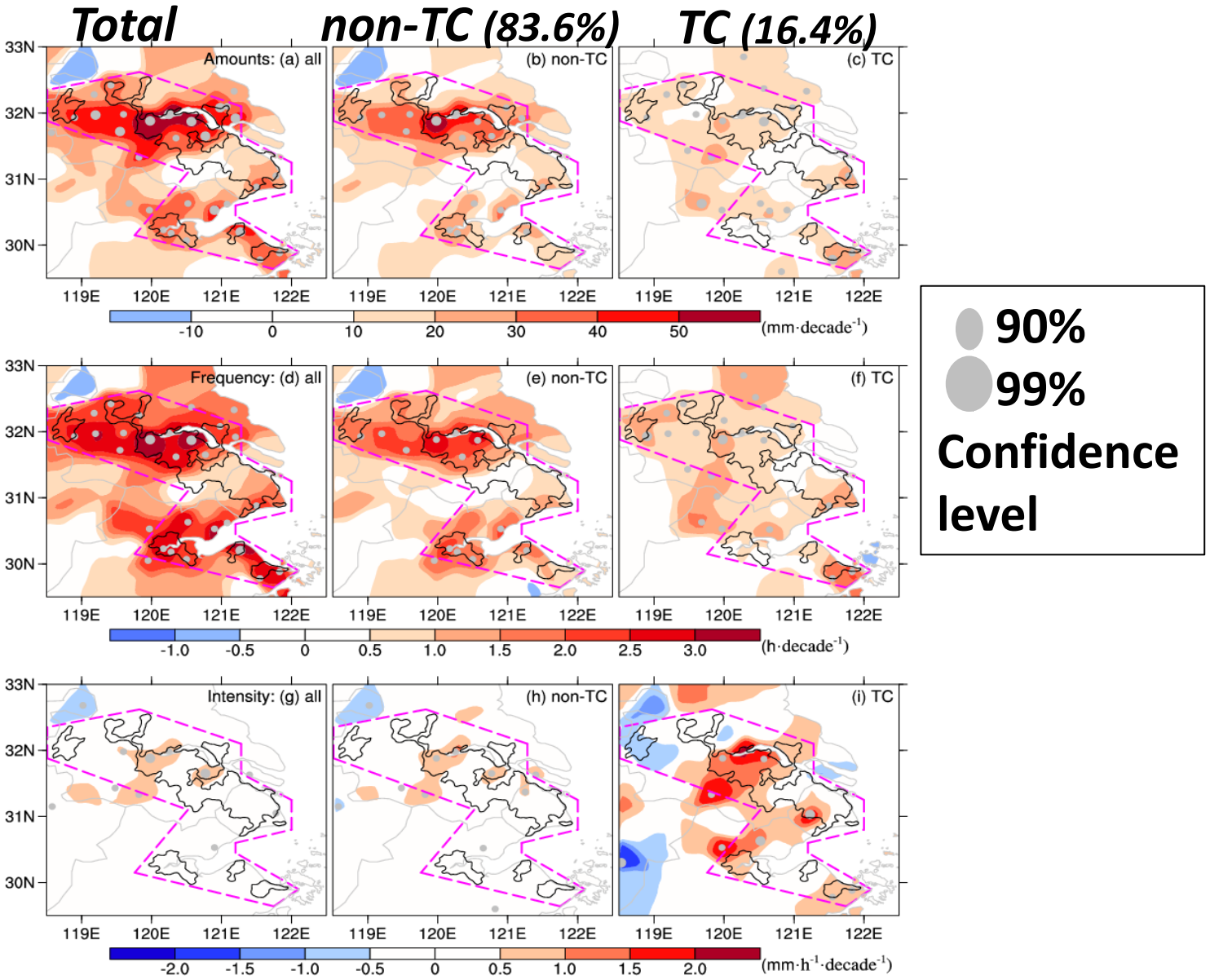
Pre era **Rapid urban. era**

1975 **1996** **2018**

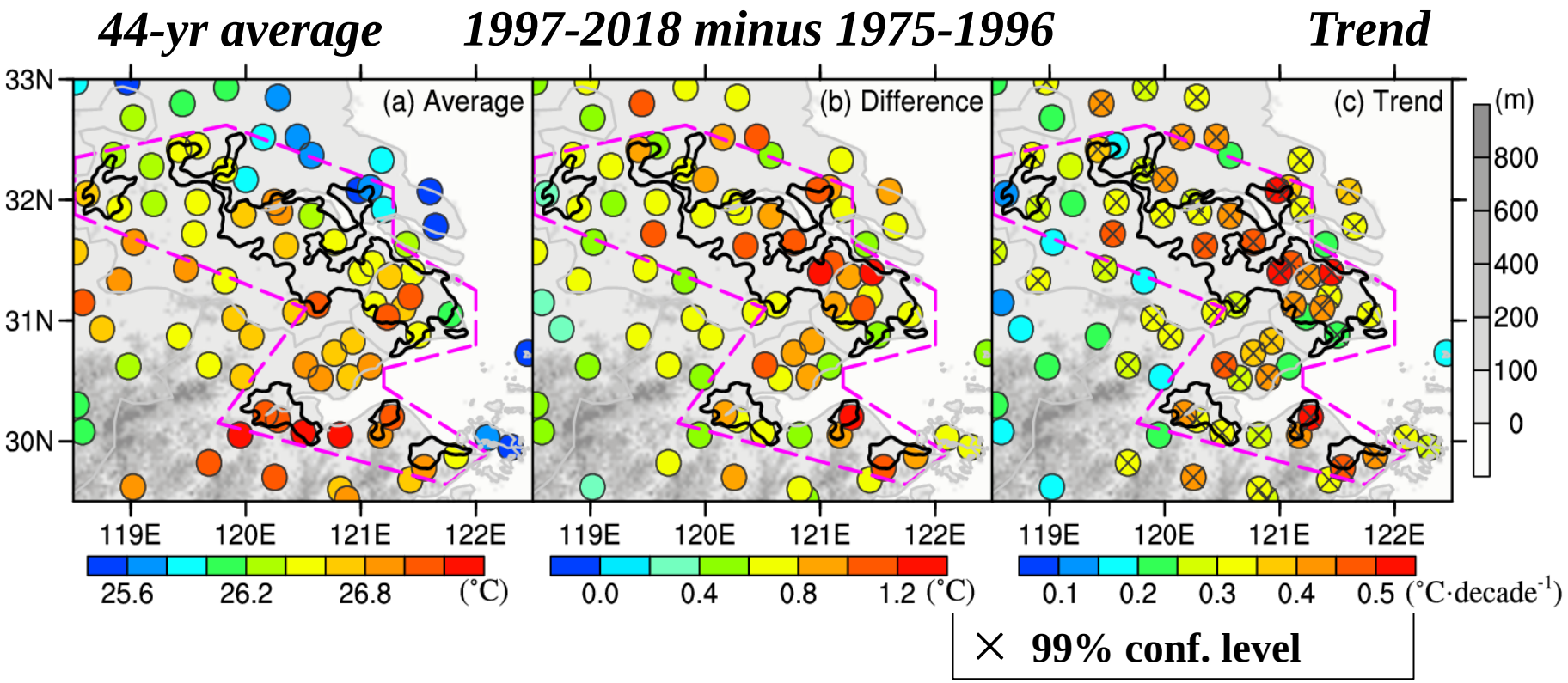
Summer EXHR over the YRD



Trends of EXHR over the YRD (1975-2018)

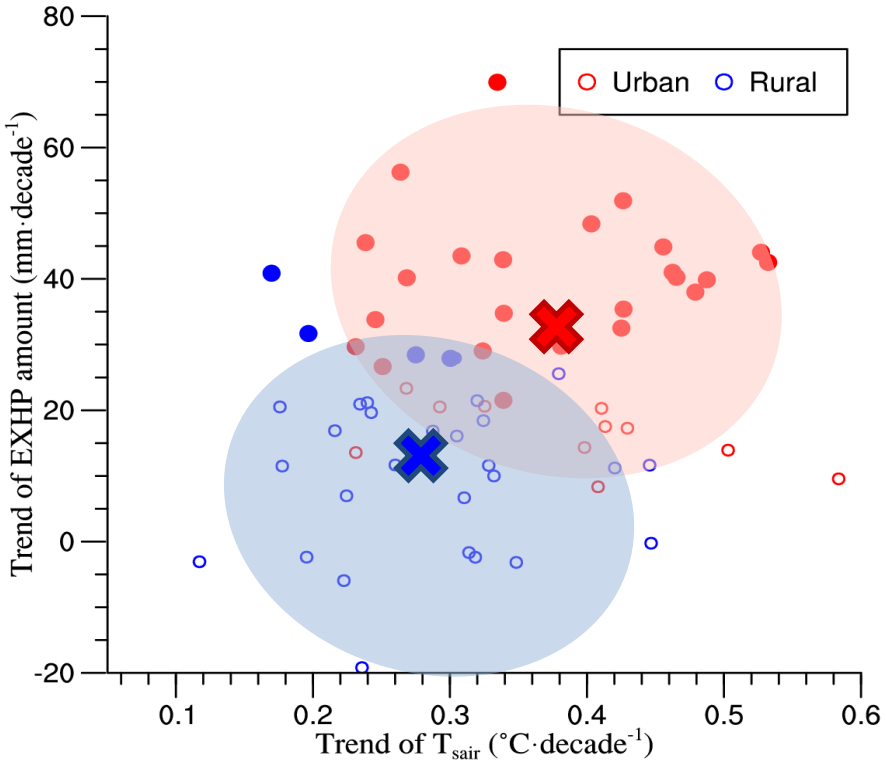


JJA daily mean temperature (T_{sair})



- **44-yr average: decreases with latitude, lower at the coasts**
- **Difference: positive, larger over urban areas**
- **Trend: significant increase (>0.3°C·decade^{-1}) mostly over urban areas**
  - ***Global land T_{sair}: 1.53°C increase from 1850-1900 to 2006-2015 (IPCC, 2019)***

EXHP and T_{sair} Trends: Urban vs. Rural stations



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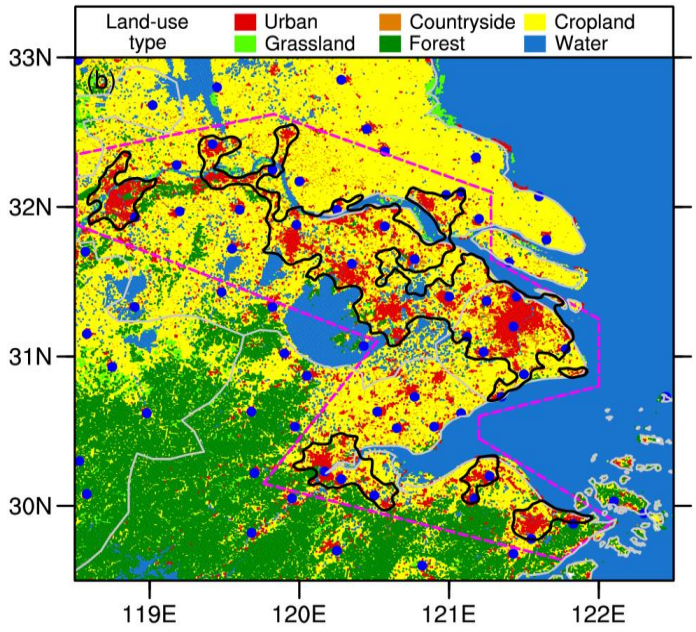
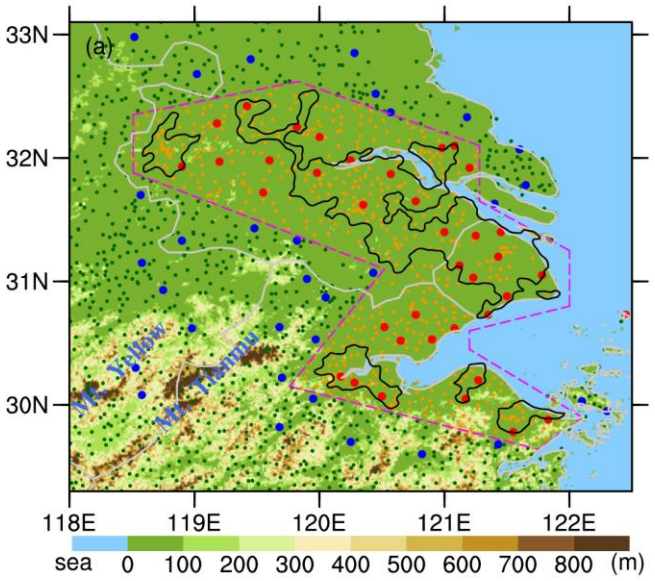


Mean trend	T_{sair} (℃·decade^{-1})	EXHR amount (mm·decade^{-1})
Rural	0.28	12.8
Urban	0.38	32.6

113 events with EXHP (2011-2018 JJA)

Define an event:

- **At least one record of hourly rainfall ≥23.7 mm (99th%) in the urban agglomeration**
- **Convection developed locally, without apparent rainfall in the 6h pre-event time**



Intensity of UHI: UHII = T_{urban} - T_{rural}

Strong-UHI event:

At least 2h in the 3h pre-event time, UHII > $UHII_{mean}$

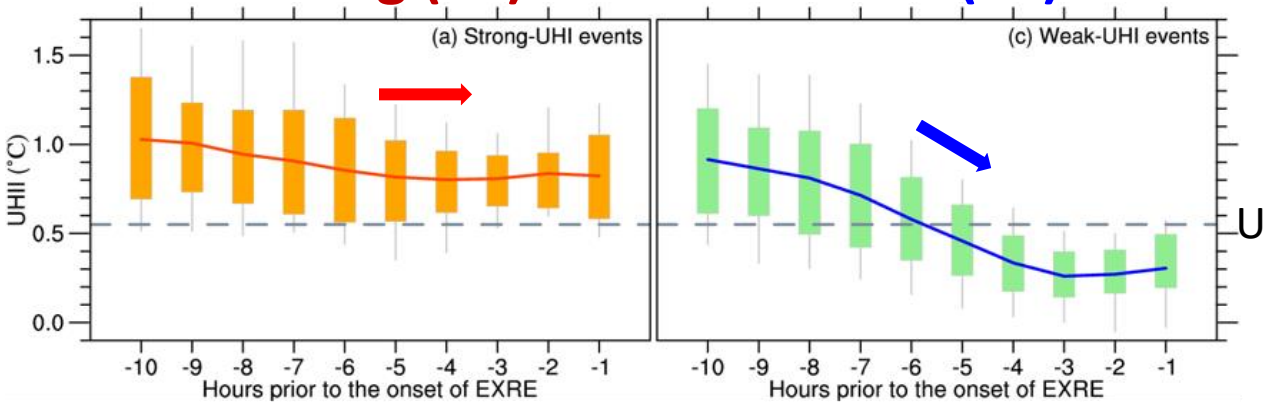
Weak-UHI event:

At most 1h in the 3h pre-event time, UHII > $UHII_{mean}$

Strong- vs. weak-UHI events (2011-2018)

Strong (56) **Weak(57)**

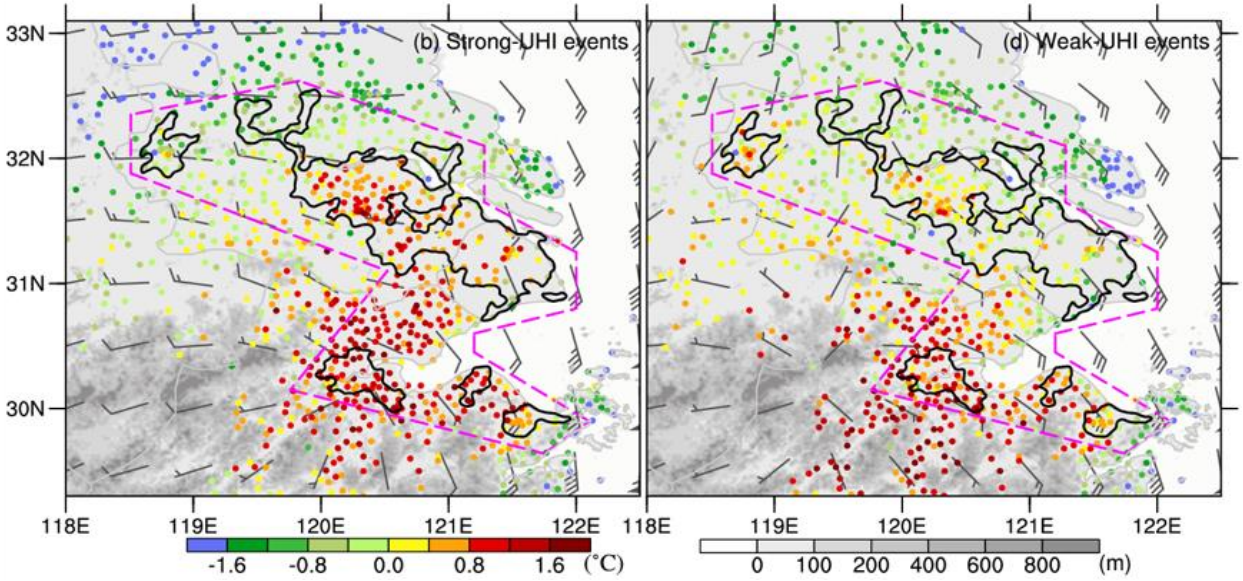
UHII



$UHII_{mean}$

***T_{sair}* perturbation,**

975 hPa wind



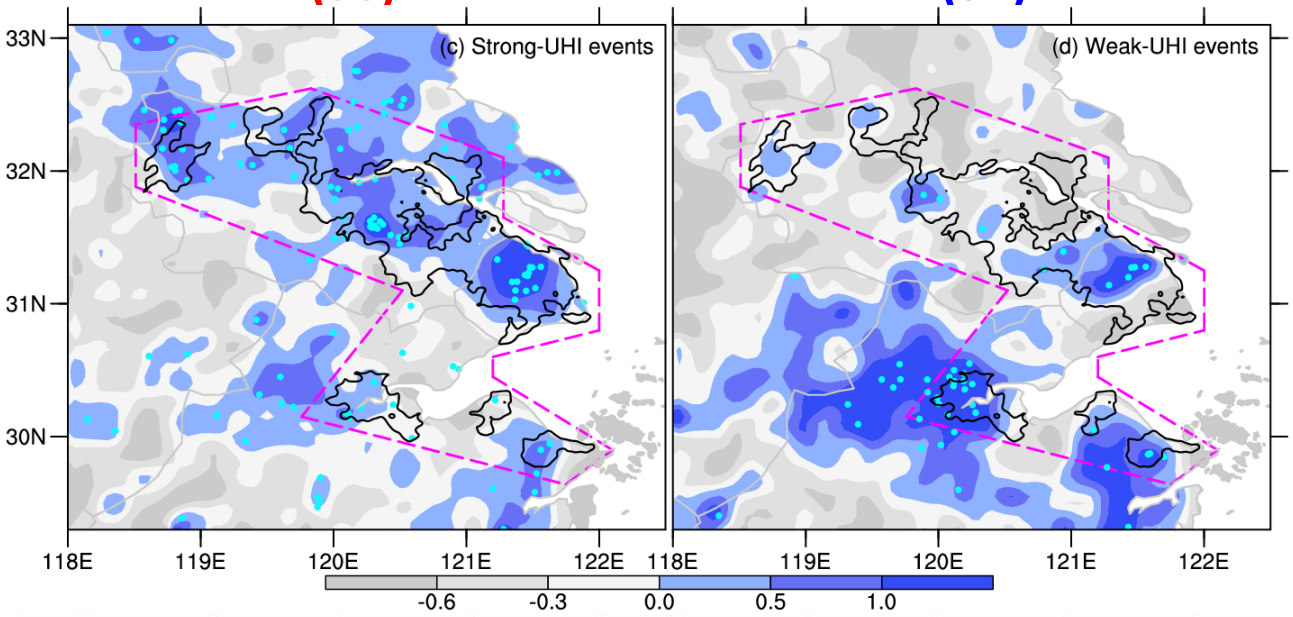
T_{sair} is 3h pre-event averaged. Wind is at 1400 LST.

Region-normalized rainfall

- At least 4 EXHRs (>23.7 mm/h)

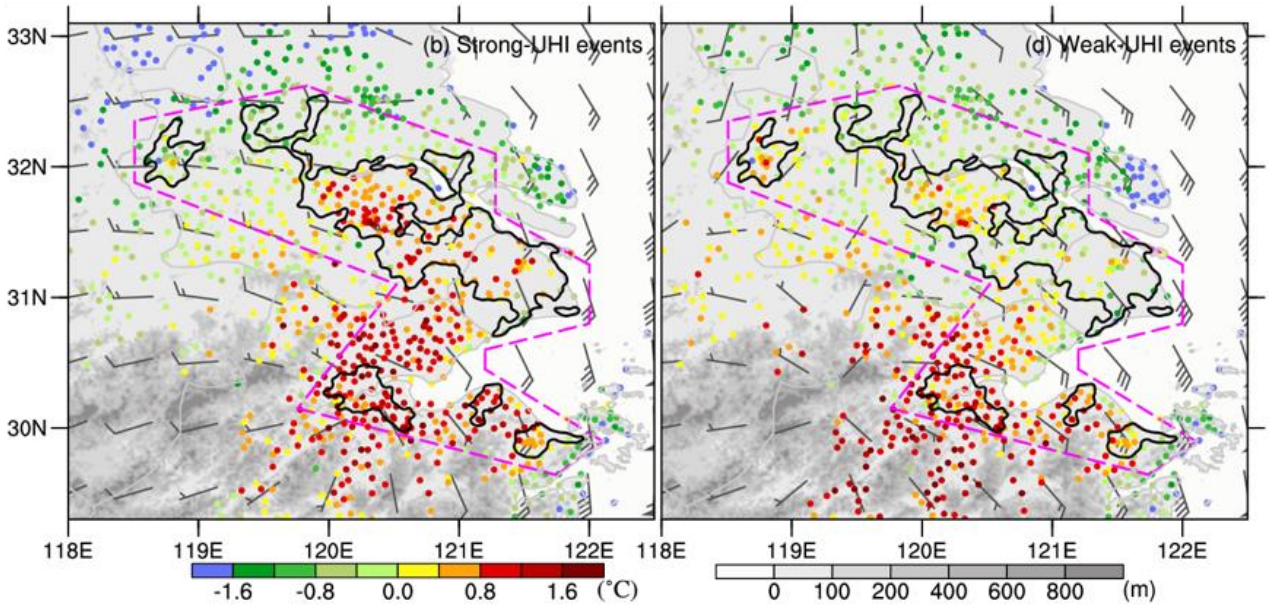
Strong-UHI events (56)

Weak-UHI events (57)



T_{sair} perturbation,

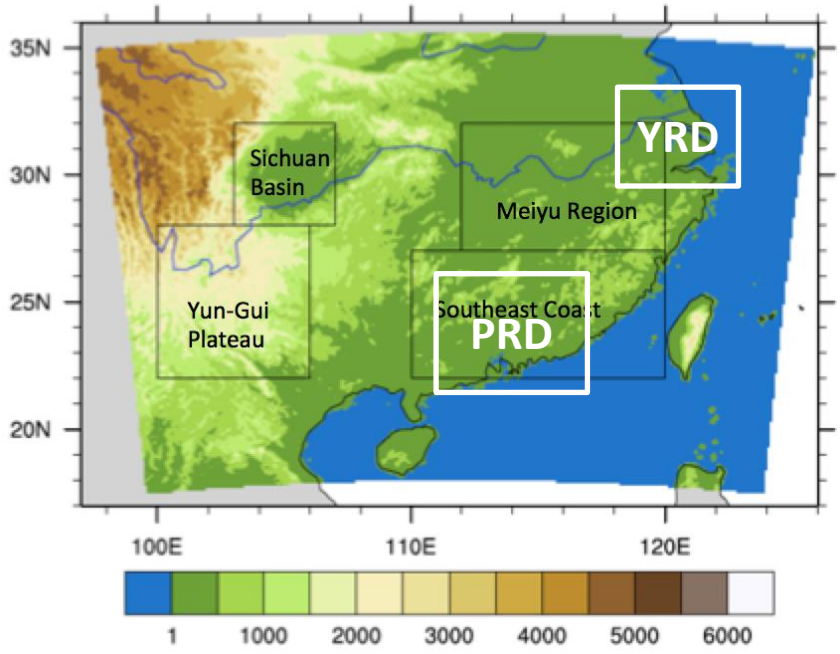
975hPa wind



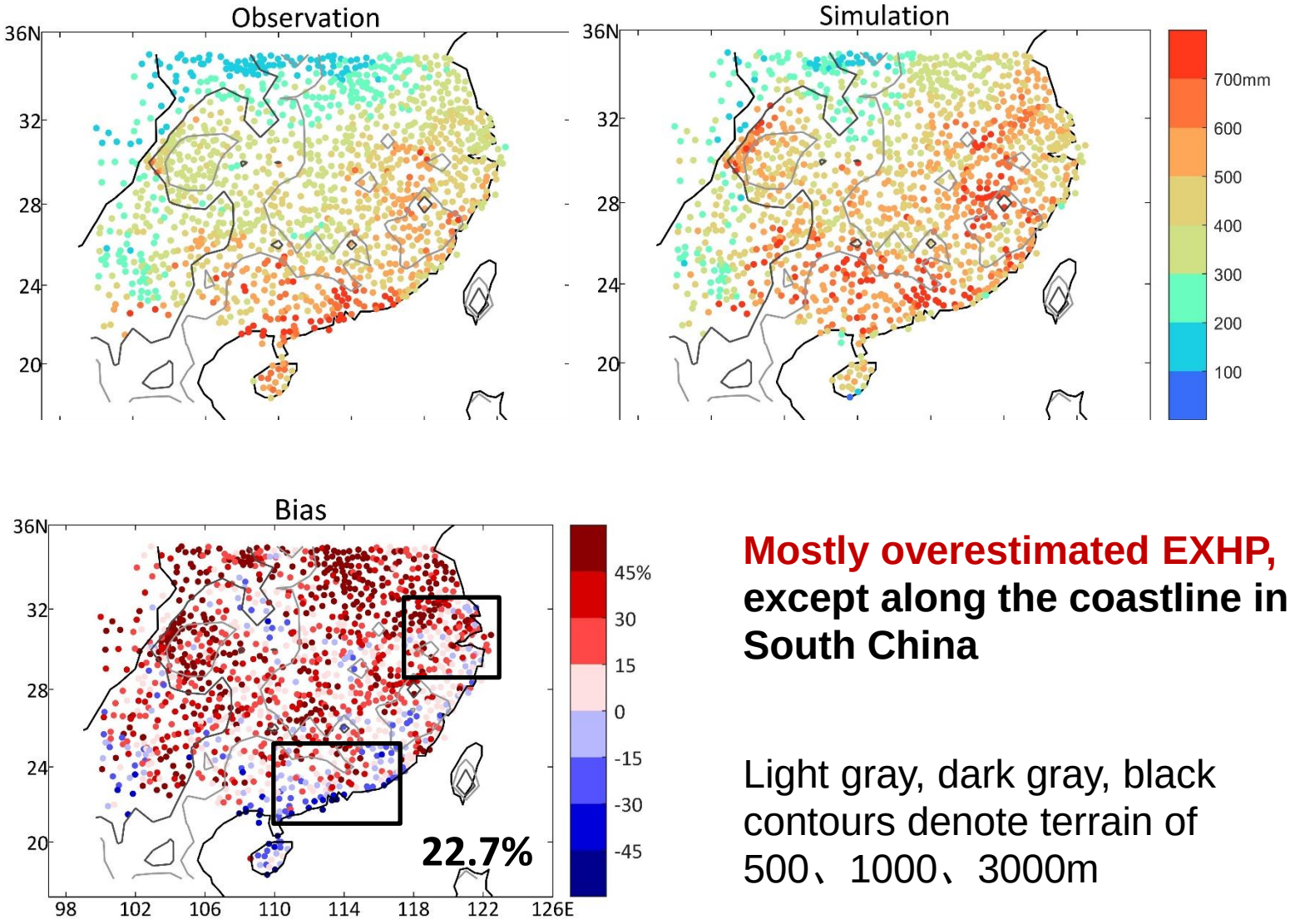
Using convection-permitting modeling to study EXHR over Eastern China

(Yun et al., *Climate Dynamics* 2020)

- WRF model (V3.9.1.1)
- 3km grid spacing, 51 vertical levels
- Physics options
  - Microphysics: Morrison
  - PBL: MYJ
  - Radiation: RRTMG
  - Land surface: Noah-MP
- Initial and boundary forcing
  - ERA5
- Simulation time
  - 10 warm seasons (2008-2017)



EXHP amount (95th%; May-Sept 2008-17)



Mostly overestimated EXHP, except along the coastline in South China

Light gray, dark gray, black contours denote terrain of 500、1000、3000m

Including aerosol-radiation and aerosol-cloud interactions reduces wet bias

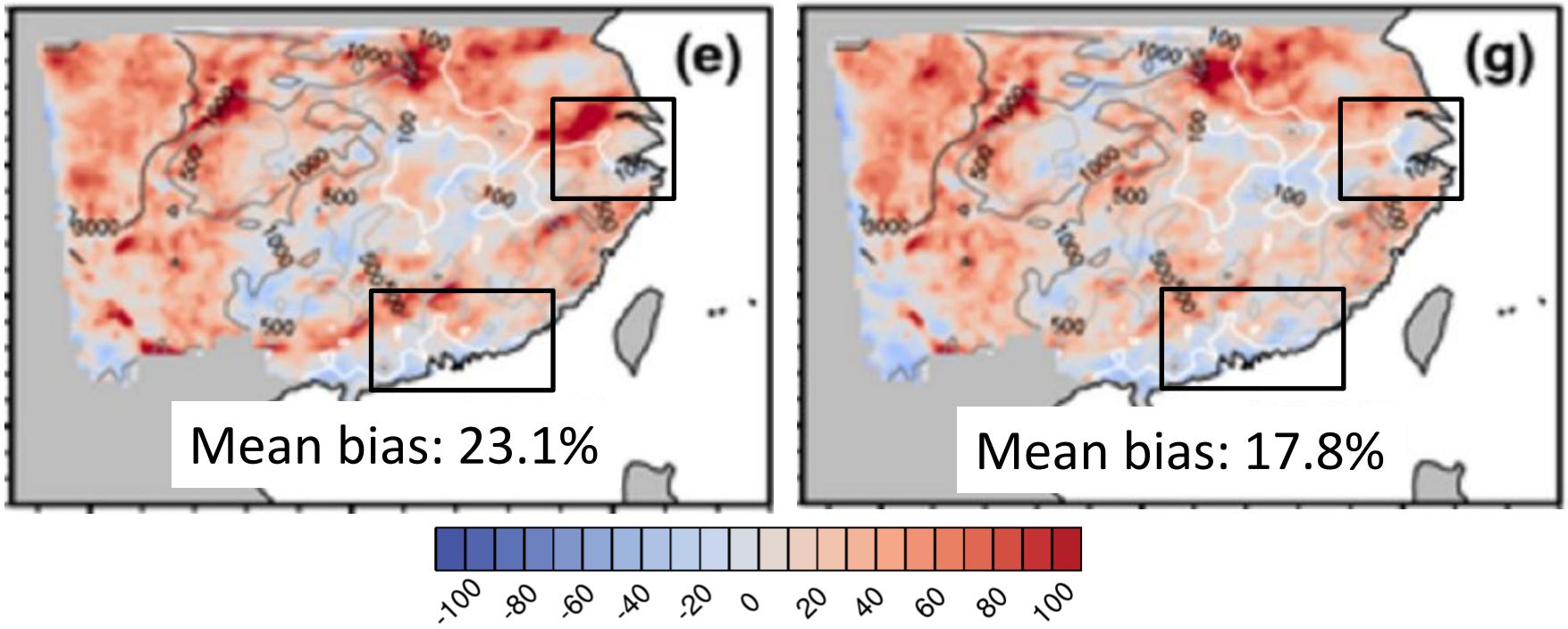
Difference (%): Model – Obs

(2008 warm-season mean precipitation)

Original

Aerosol-aware

(Thompson & Eidhammer, 2014)



UK Met Office Unified Model (UM) simulations

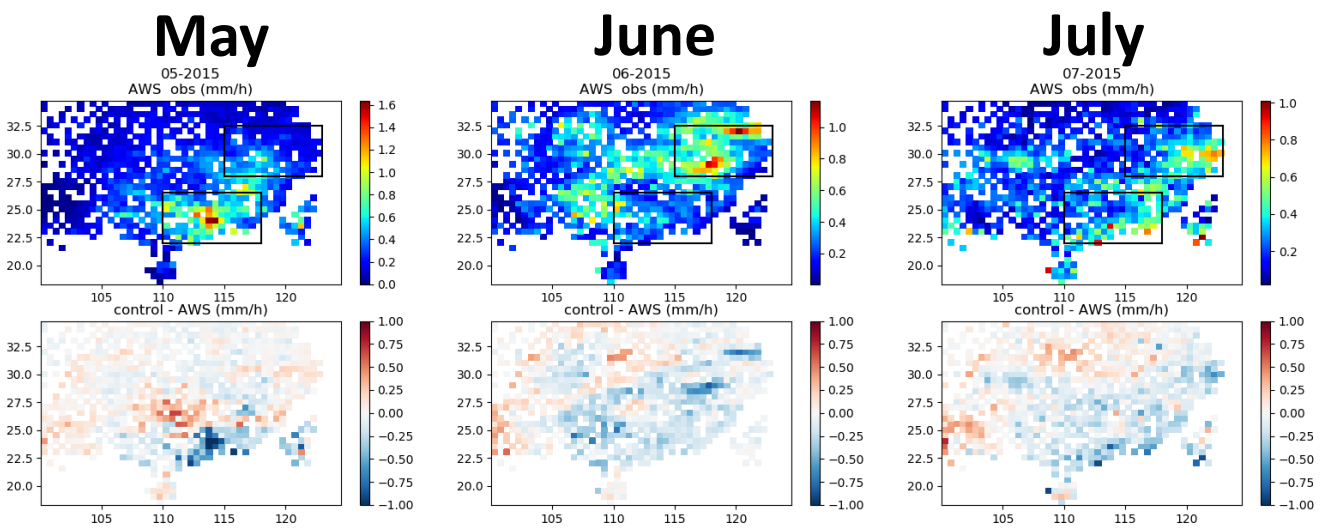
- Convection permitting (3km) Unified Model simulations with "UKCA-CASIM"
- Atmospheric composition & chemistry (UKCA, with offline-oxidants)
- 4 soluble modes, 2 insoluble
- Cloud microphysics : double moment, five species

- **Control** : Sea salt, black carbon, organic carbon and sulphates

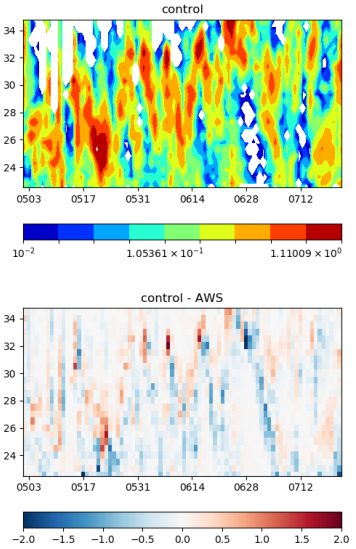
- **Expt. "No B/OC"** : without anthropogenic black or organic carbon

Unified Model (UM) simulations

- Simulations have **warm-sector dry biases**
- Particularly over urban areas, e.g., PRD, YRD



Evolution of 2015 EASM



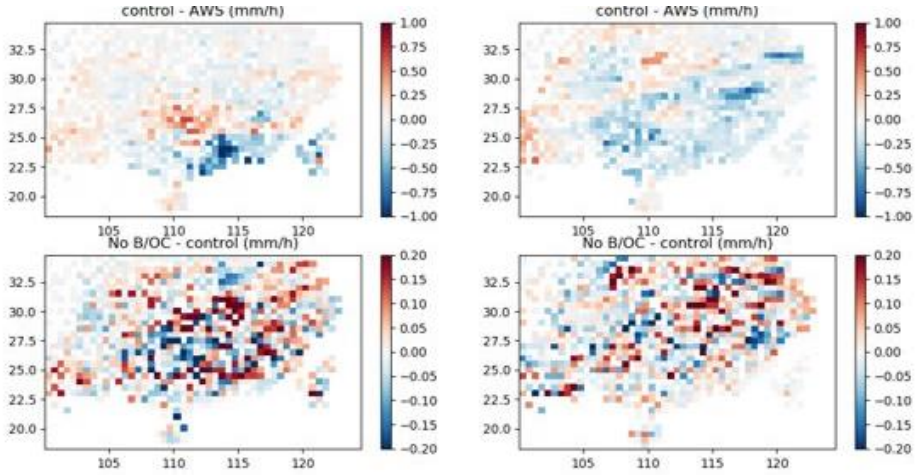
Top: AWS obs of monthly mean rainfall amounts (mm/h), for rainfall > 0.1 mm/h

Bottom: control model biases

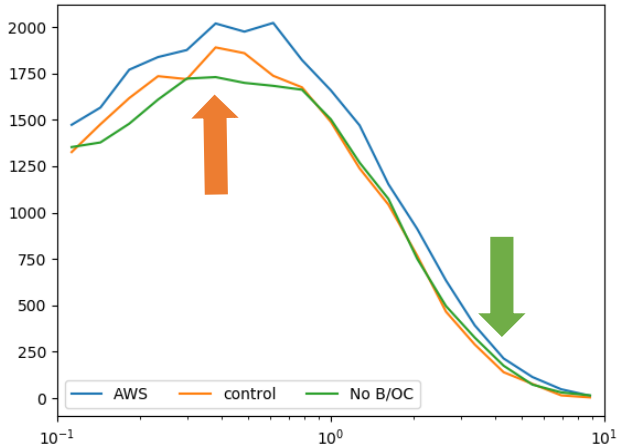
Removing carbonaceous components

- **No carbon aerosols: reduced light rain**
- **increased heavy rain *?***
- ***Signal-to-noise is large: more years needed ...***

May June



Top: control - AWS
Bottom: No B/OC - control



Daily-mean rainfall rate (mm/h)

Conclusions

- **Increasing trends in occurrence frequency and amount of the EXHR over the coastal urban agglomerations**
  - non-TC EXHP: PRD +, YRD +
  - TC-induced: PRD – (due to less landing TC), YRD +
- **Statistically significant larger increasing trends in EXHR and surface temperature during rapid urbanization era than the pre-era, and in cities than those in rural areas**
- **Contrasting EXHR distributions between strong- and weak-UHI events.**

✓ **UHI-effect seems to contribute to more frequent EXHR**

- **Convection-permitting WRF & UM simulations largely produce wet & dry biases, respectively; but both seem to underestimate rainfall in coastal SC**
- **We need to further the understanding of nexus between global warming, circulation change, TC, urbanization, and EXHR**

Thanks!

- Jiang, X., Y. Luo, D.-L. Zhang, M. Wu, 2020: Urbanization Enhanced Summertime Extreme Hourly Precipitation over the Yangtze River Delta. *J. Climate*, in press.
- Wu, M., Y. Luo, F. Chen, W. K. Wong, 2019: Observed Link of Extreme Hourly Precipitation Changes to Urbanization over Coastal South China. *J Appl. Meteor. Clim.*, 58, 1799-1819.
- Yun, Y., C. Liu, Y. Luo, X. Liang, L. Huang, F. Chen, R. Rasmmusen, 2020, Convection-Permitting Regional Climate Simulation of Warm-Season Precipitation over Eastern China. *Climate Dynamics*, https://link.springer.com/article/10.1007/s00382-019-05070-y.