THA 2022 International Conference on

Moving Towards Sustainable Water and Climate Change Management After COVID-19

Super Drought Hotspots over East Asia in the Last Decade

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Outline

- **Background and Motivation**
- Data and Methods
- Super Drought Hotspots identification
- Attribution Analysis
- Conclusions

Background and Motivation

UN 2021 report: The global population affected by drought in the first 20 years of the 21st century is estimated to be 1.43 billion

Figure 9

Total number of people affected by disaster type (2000-2019)

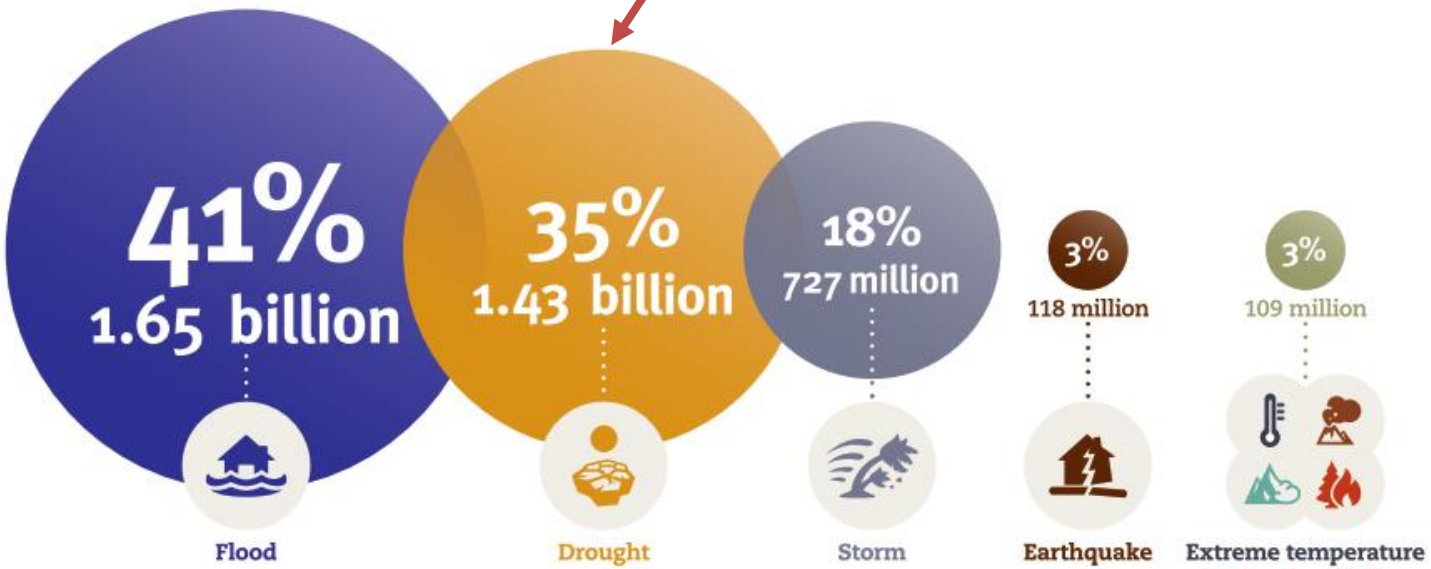
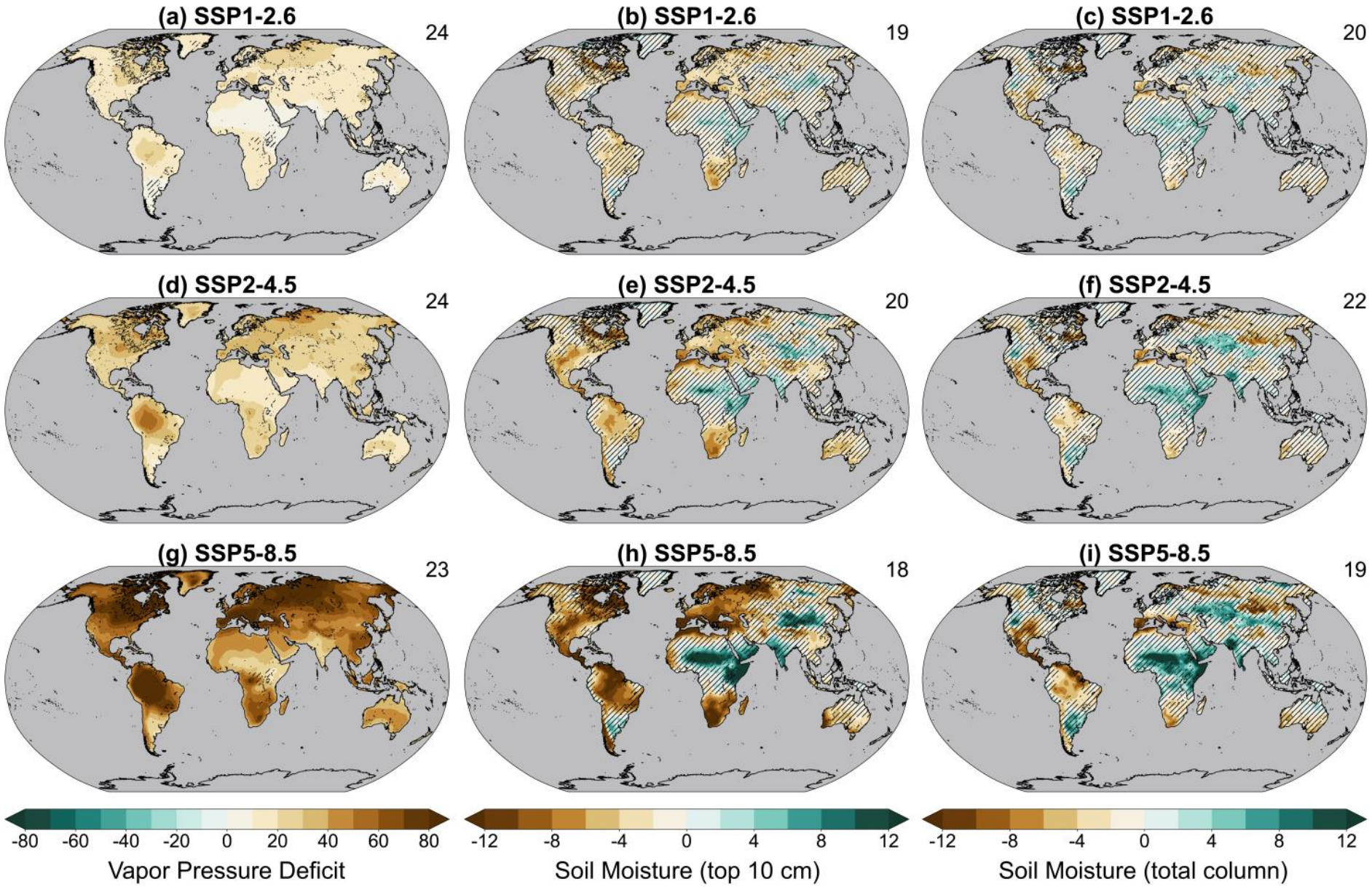


Figure 10

Global drought is projected to increase

IPCC AR6

coherent increases in projected soil moisture drought and vapor pressure deficit



Unprecedented droughts in many parts of the world during the last 20 years

Drought and heat wave in Russia

Drought in Northeast Asia

Drought in Mediterranean

Texas and north Mexico

East African drought

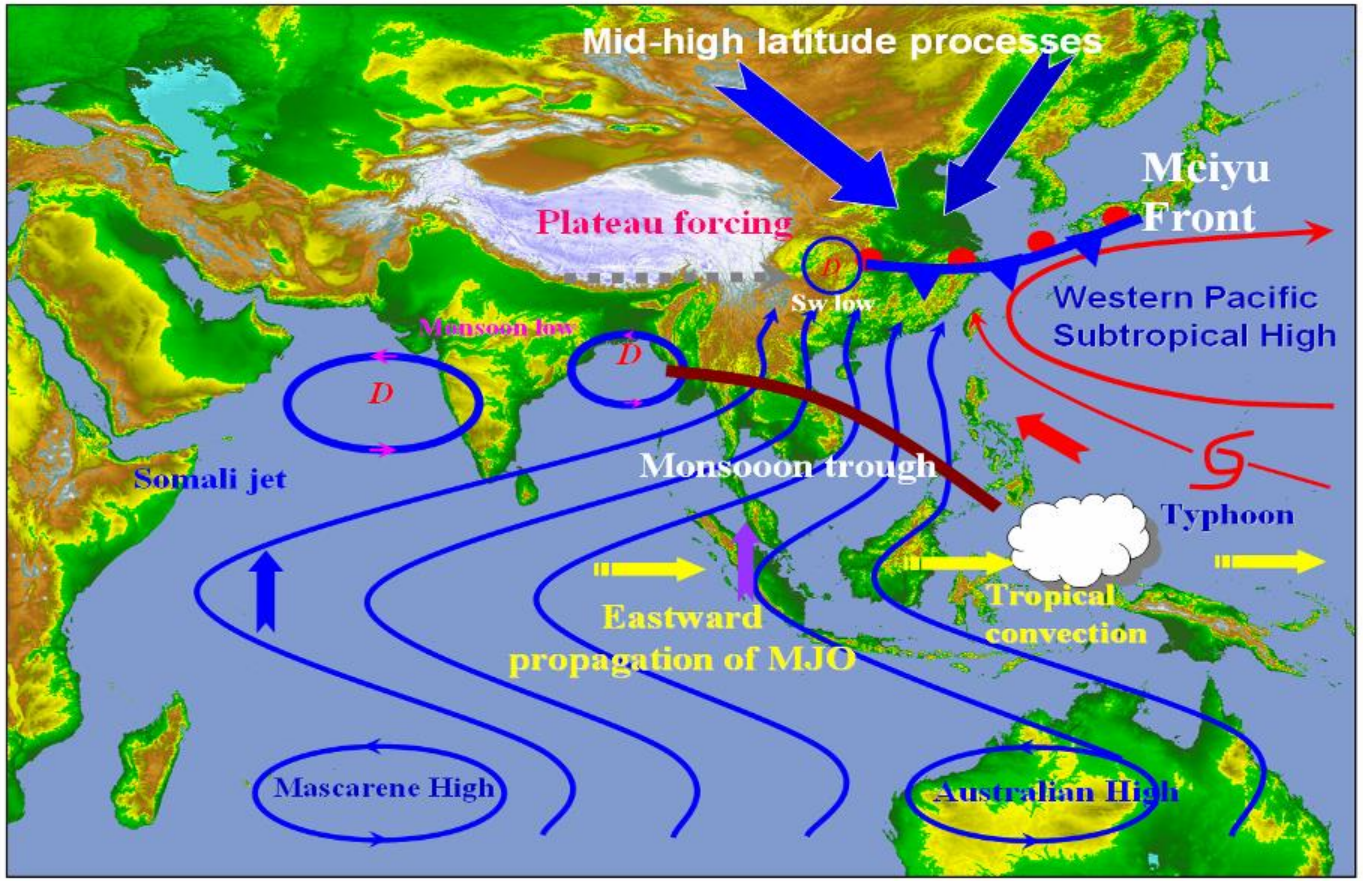
Amazon drought

Drought in Southeast Asia

Australian Drought

Focus on East Asia

- Drought-prone with high vulnerability
- Complex air-sea-land interaction and monsoon climate dynamics



Frequent and extensive droughts in East Asia during last decade

These devastating droughts have not only attracted great concerns from academic sectors and local governments, but also United Nations.

Examples

- Southwest China

2006, 2009-2010, 2011, 2014, 2019

- Mongolia

2017

- Southeast Asia

2015-2017, 2018-2020

Food and Agriculture Organization of the United Nations

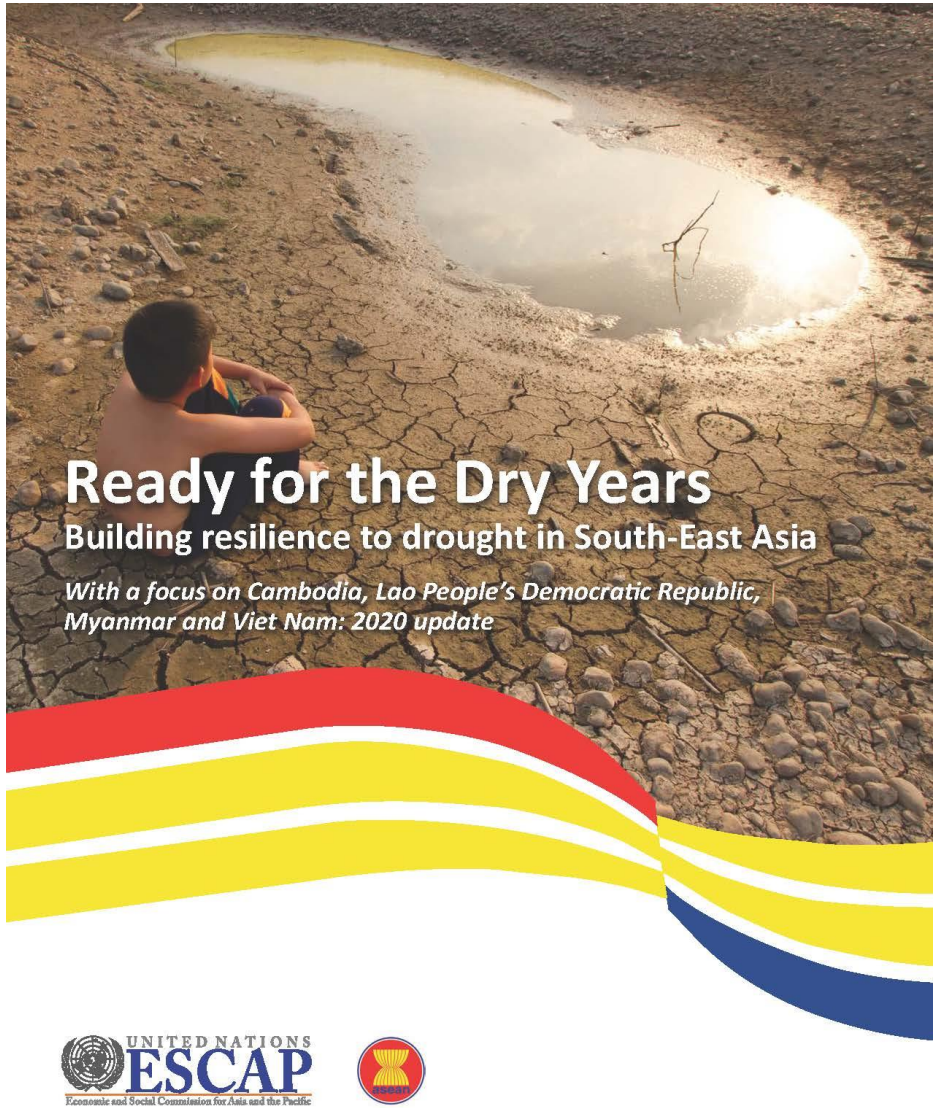
WFP World Food Programme wfp.org

SPECIAL REPORT

FAO/WFP CROP AND LIVESTOCK ASSESSMENT MISSION TO MONGOLIA

22 December 2017

Photographs: ©FAO/C. Coslet, ©FAO/F. Palmeri, ©WFP/A. Wadhwa.



Motivation and Key scientific issues

- Previous efforts are dealing with the following two aspects separately
  - Extremely cases in the recent decade
  - Long-term changes

Key scientific issues

- How has super drought changed since 1960 over East Asia and how was the super drought in the last two decades compared to the preceding decades?
- Where are the hotspots frequently struck by super drought?
- What are the climatic driving factors? To what extent is the super drought governed by internal decadal variability or long-term trend associated with global warming?

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Data

- Observational Data

Data	Variables	resolution	periods	Notes
CRU TS4.04	Precipitation, PET	0.5°	1950-2019	Used for drought index calculation
GLDAS-2.1 GLDAS-2.2	Soil Moisture	1°	1948–1999 2000–2019	Four levels: 0–10cm, 10–40cm, 40–100cm 和100–200cm

- CMIP6 model data

Experiments	Variables	periods	Notes
PiControl	Precipitation and other 10 variables for calculating PET	No less than 500 years	To derive internal variability range
Historical		1850–2019	To derived MME as external forcing 2015–2019 data are obtained from SSP2-4.5 experiments

Methods–SPEI

The SPEI at multiple time scales is used to construct super drought indicator

(1) Calculation of the climatic balance ：

$$D_i = P_i - PET_i$$

(2) Creation of cumulative series at the desired time scale

$$D_n^k = \sum_{i=0}^{k-1}(P_{n-i} - PET_{n-i}), \quad n \geq k$$

where k(months) is the time scale of the aggregation and n is calculation number

(3) Fitting the D_n^k (during calibration period) to a probability distribution function

$$\int_{-\infty}^{D_i} f(x)\mathrm{d}x = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{Z} e^{-x^2/2}\mathrm{d}x$$

Calculation Specification

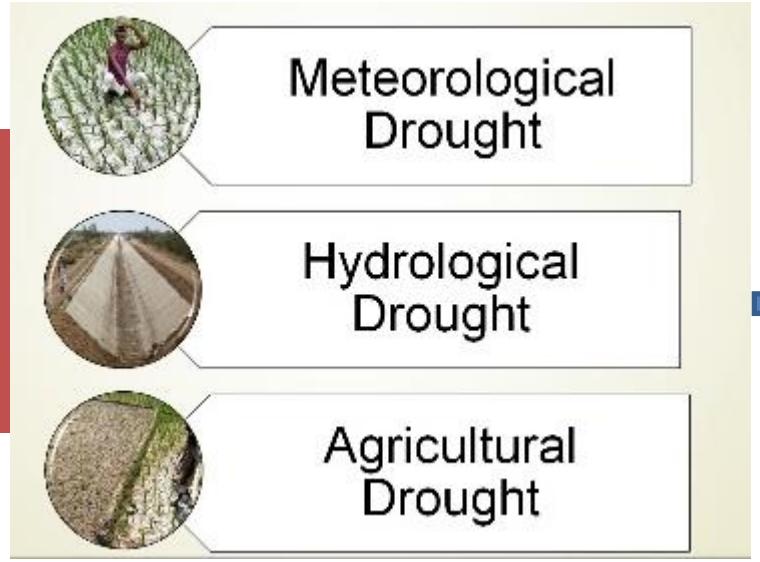
- Time scales: 3, 6, 12, 24
- Fitting distribution：Log-logistic
- Reference period：1960-1999（40 year）
- PET： Penman-Monteith

Methods–Super drought indicator

➢ **Wang and Chen et al. (2016) proposed the concept of super drought**

Wang, L., W. Chen, W. Zhou, G. Huang, 2016: Understanding and detecting super-extreme droughts in Southwest China through an integrated approach and index. Q.J.R. Meteorol. Soc., 142, 529–535, doi: 10.1002/qj.2593.

Super drought
combination of severe/extreme dry states in multiple components of water resources



→ Reinforce the damage

➢ **To detect whether the severe/extreme droughts at multiple time-scales occur alone or in concert.**

Super drought: occurs when the SPEI at timescales of 3, 6, 12, 24 months is all below –1.5

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Super Drought Hotspots identification

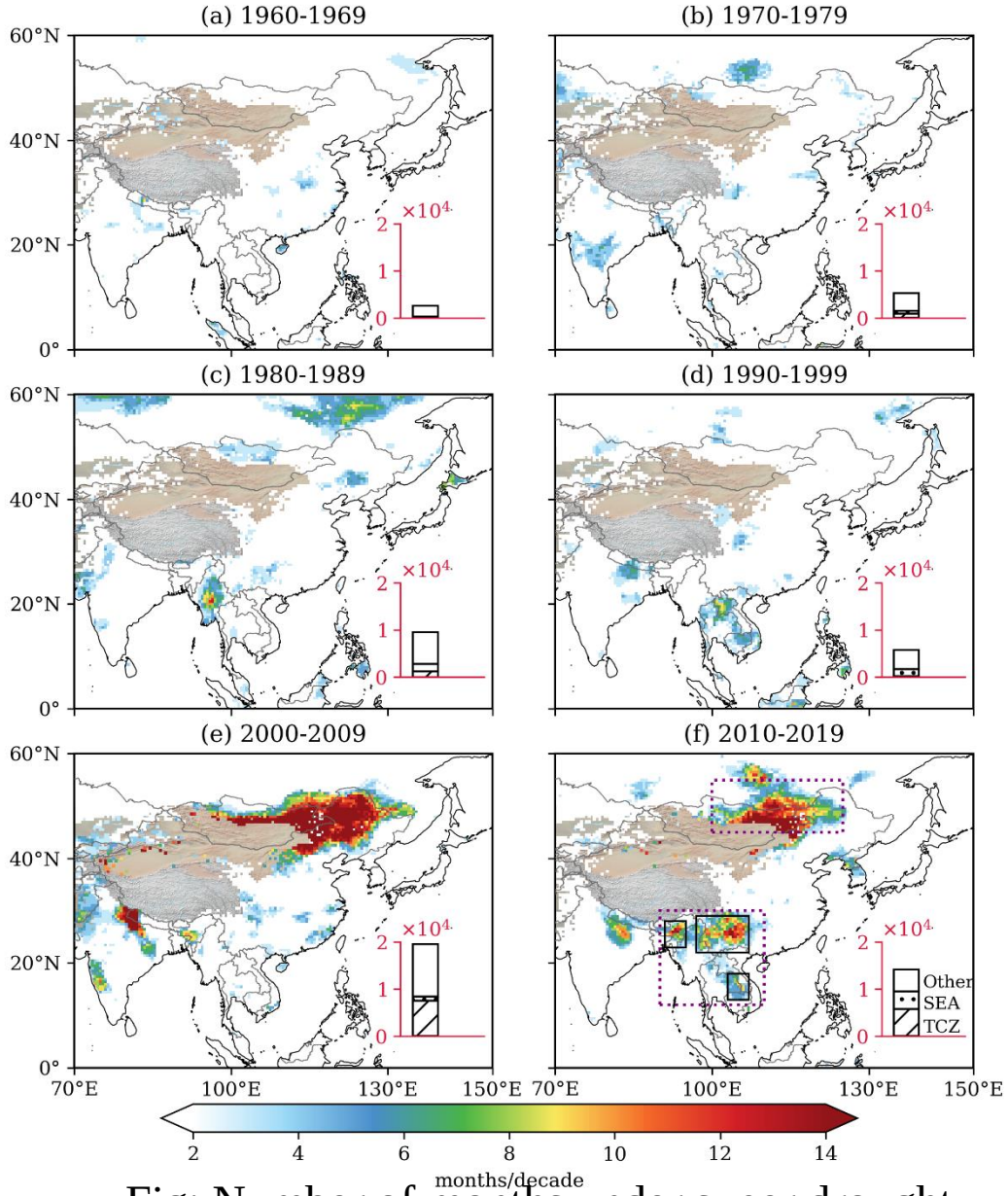

Fig: Number of months under super drought

Two super drought hotspots stand out in the last decade

region		domain
Transitional Climate Zone (TCZ)		45-55°N,100-125°E
Southeast Asian Region (SEA)	Southwest China (SWC)	22-29°N, 97-107°E
	Indo-China Peninsula (ICP)	13-18°N, 103-107°E
	Northeast India (NEI)	23-23°N, 91-95°E

During 2010-2019, TCZ and SEA contribute 40% and 27% of the total amount, respectively, together accounting for 2/3 of the total.

Super Drought Hotspots identification

The results based on GLDAS soil moisture at 10-40cm confirm the two super drought hotspots

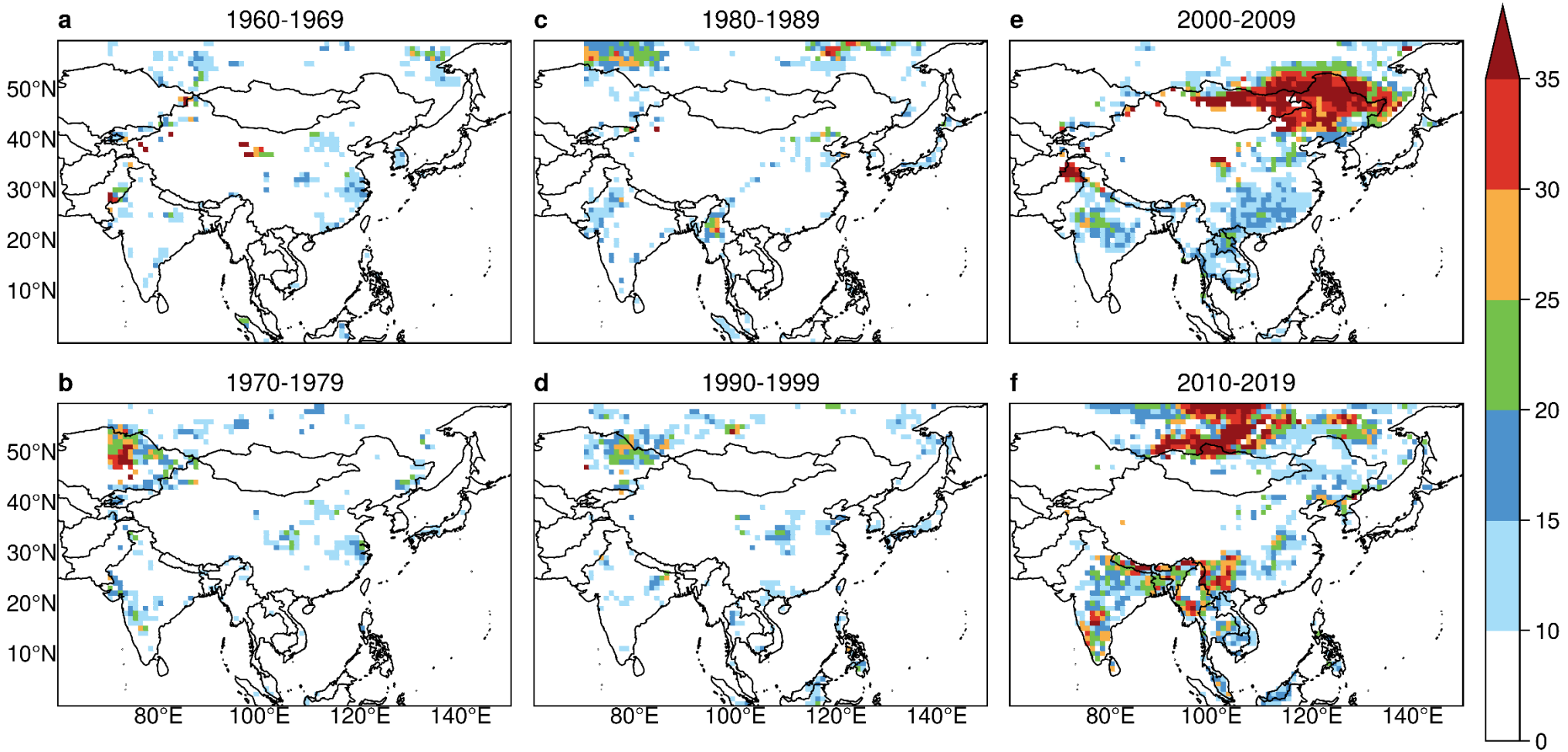

Fig: Number of months under severe soil moisture drought

Temporal and Seasonal features

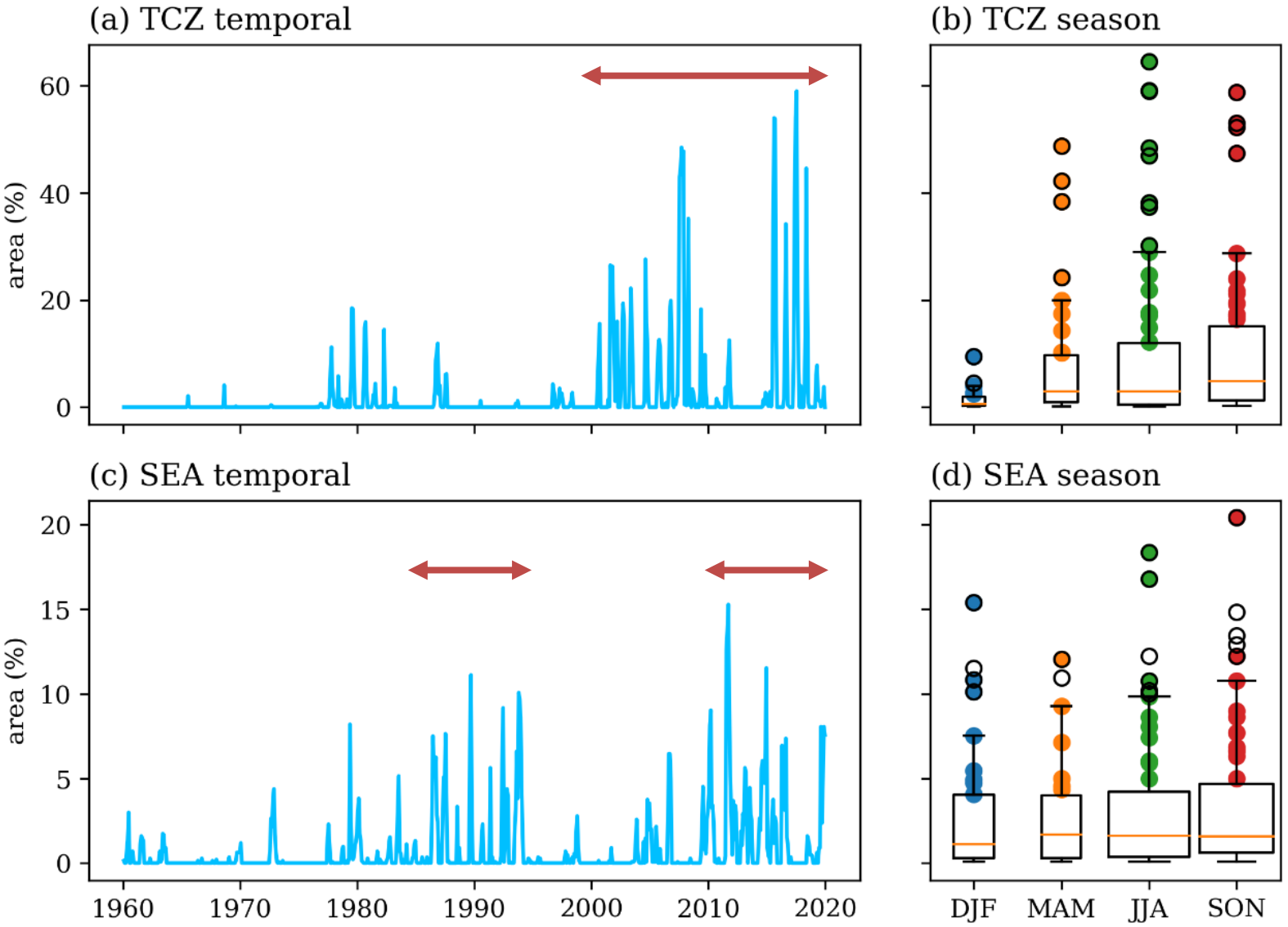

Fig: Temporal evolutions of the percentage area and seasonal distribution

TCZ

- Enhanced super drought after 2000
- 67% in summer and autumn, while only 13% in winter

SEA

- Recent decade and the period around 1990 saw the most widespread super droughts
- Largest contribution from summer (34%) followed by autumn (32%) and then spring (17%) and winter (17%)

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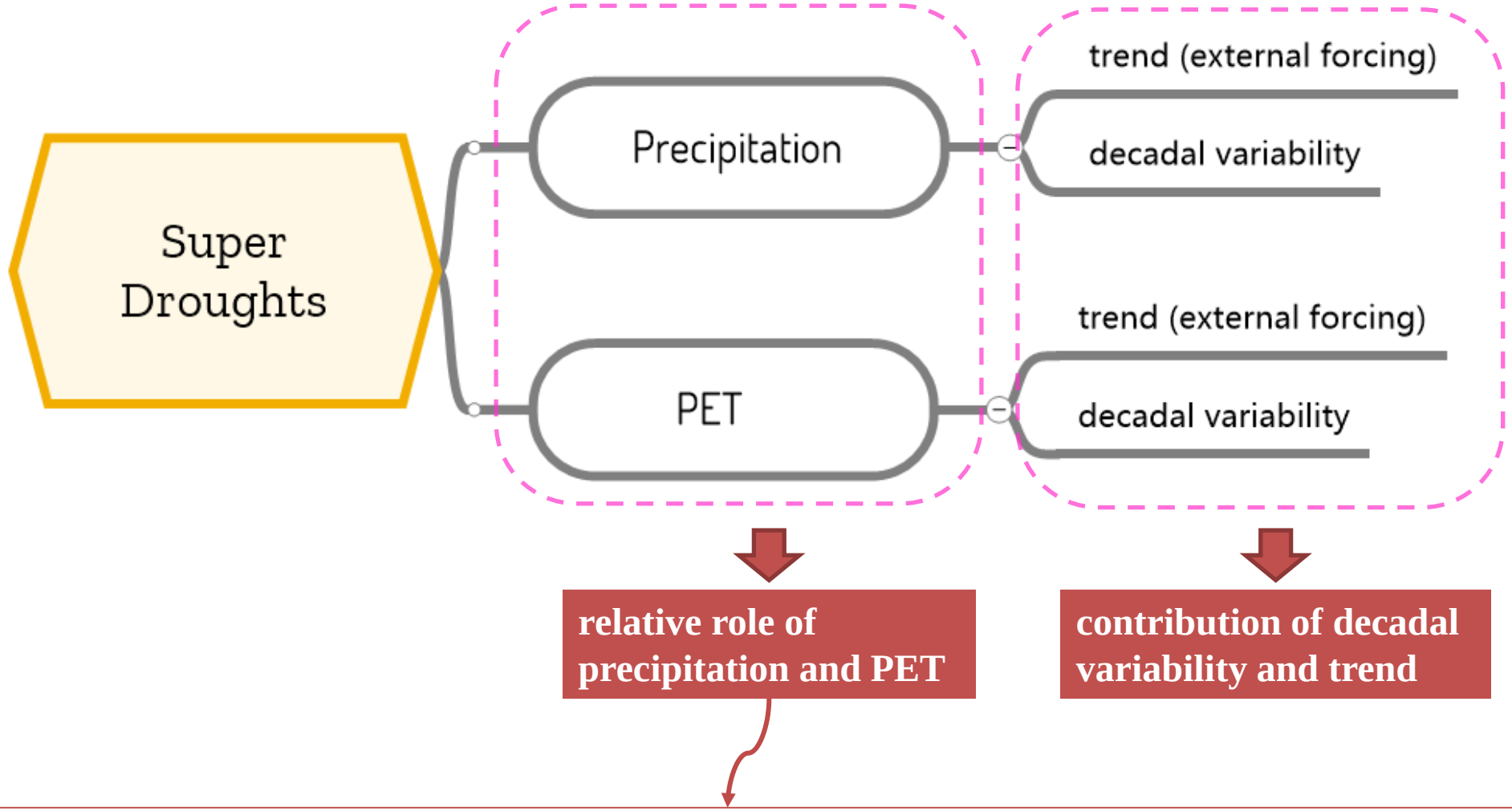
Attribution Analysis



- **The contribution of precipitation:** calculated by hold PET as its climatological annual cycle
- **The contribution of PET:** total effects minus the contribution of precipitation

Relative Role of precipitation and PET

TCZ :

- PET plays dramatic role, contributing 41% and 80% in 2000–2009 and 2010–2019, respectively

SEA (SWC, ICP and NEI) :

- PET makes an overall small contribution of less than 20%
- Precipitation rather than PET is the most influential
- The only exception is noted in SWC for the last decade, with PET making a half contribution

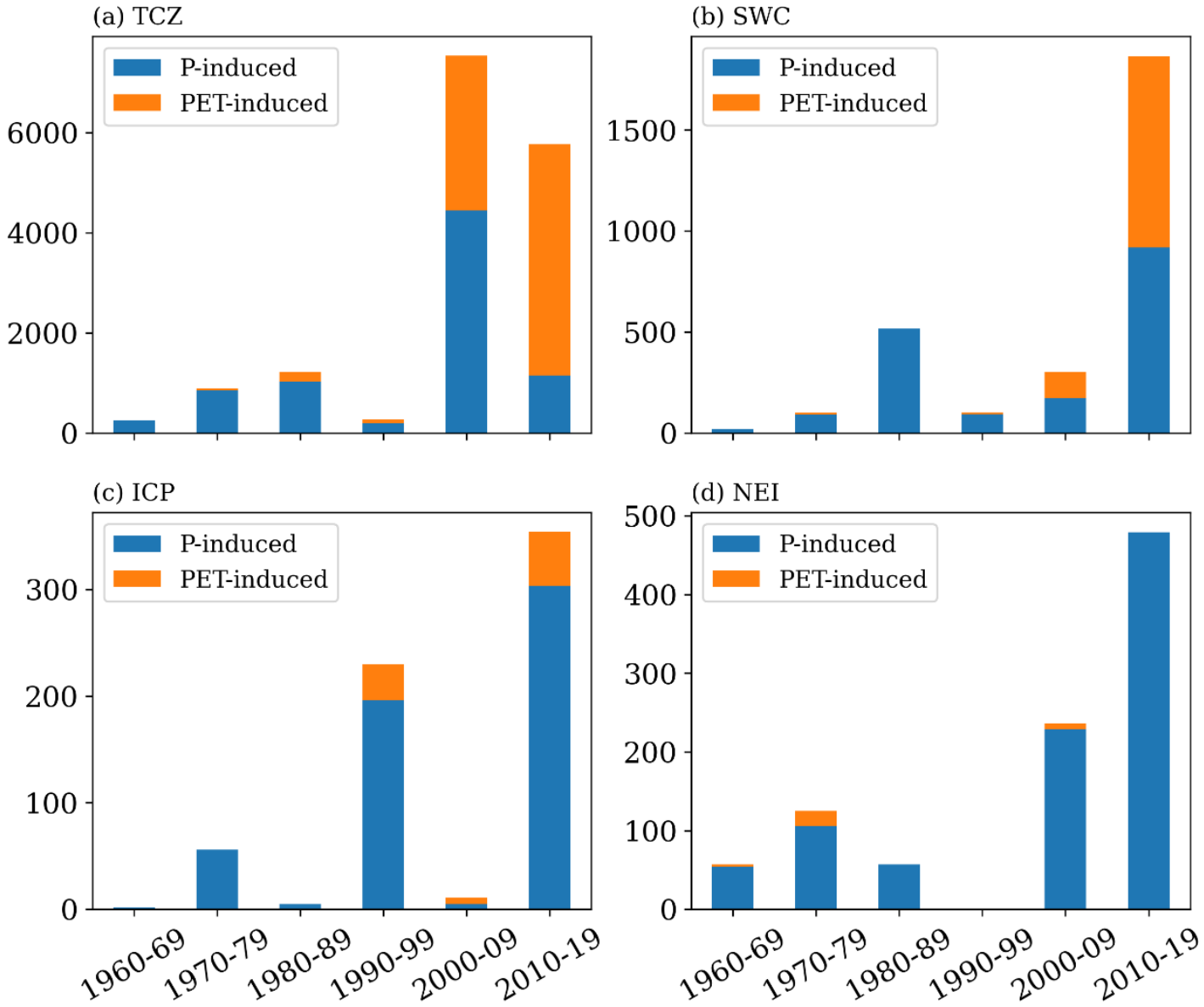
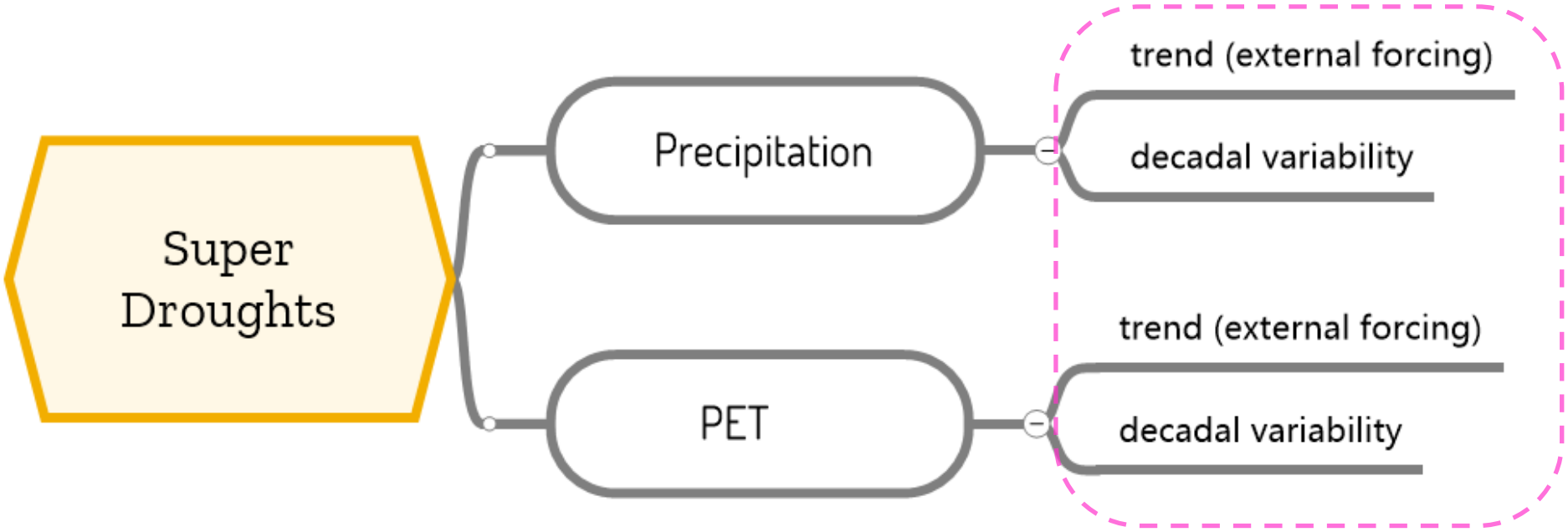


Fig: Contribution of precipitation (blue) and PET (orange)

Contribution of decadal variability and trend

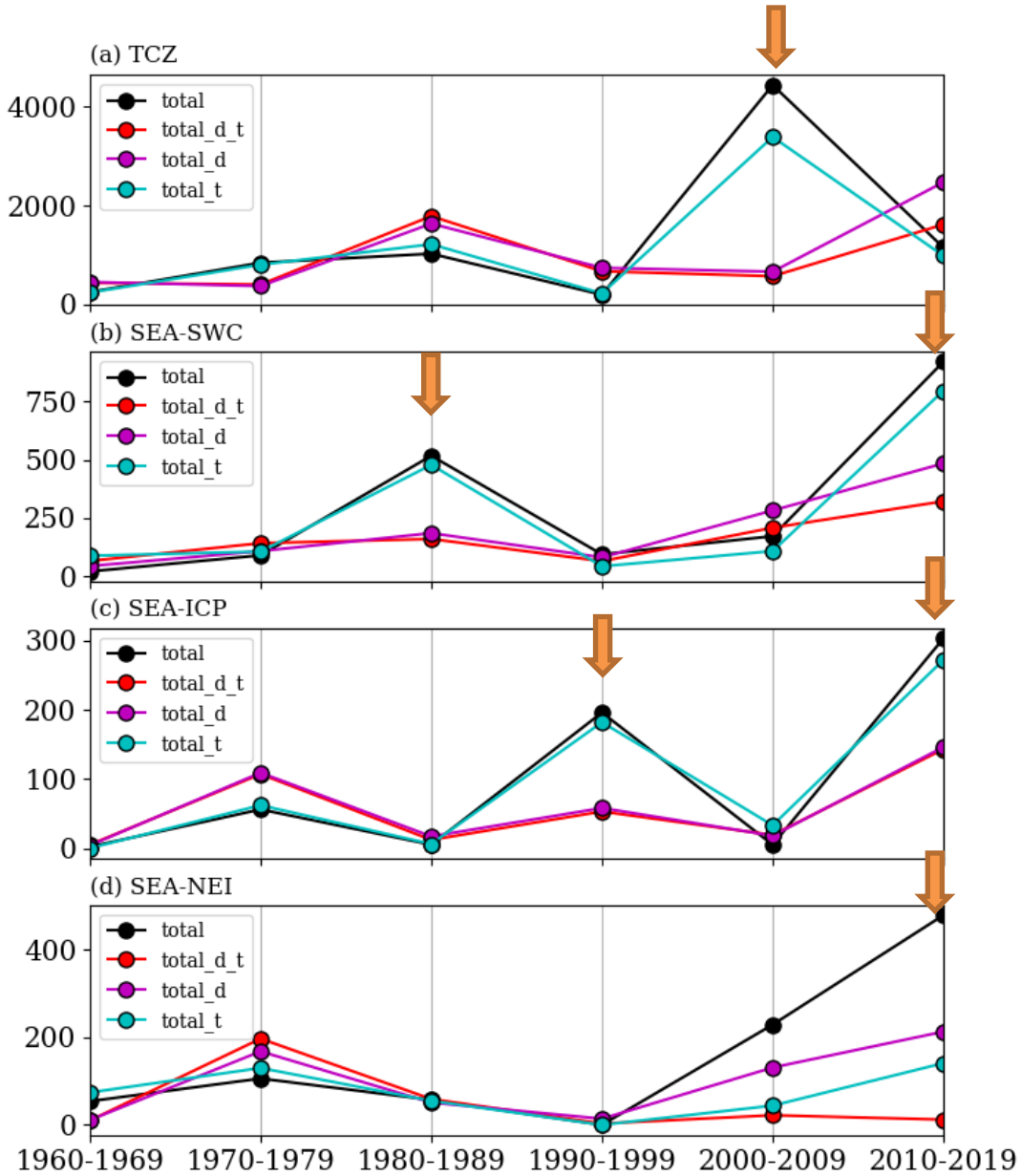


Statistical-based Method (Primary)
CEEMDAN (Complete Empirical Mode Decomposition with Adaptive Noise): to separate the long-term trends and internal decadal variability
Model-based simulations (For validation purpose)
External forcing: Multimodel ensemble mean for Hist simulation **Internal decadal variability:** the range between the maximum and minimum values across the entire piControl runs

precipitation-induced super drought: contribution of trend and decadal variability

- Four sets of calculation by removing specific EMD modes
  - benchmark
  - decadal oscillation and trend removed
  - decadal oscillation removed
  - trend removed

Region	Leading mode	contribution
TCZ	decadal	2000-2009：85%
SEA-SWC	decadal	1980-1989：64% 2010-2019：47%
SEA-ICP	decadal	1990-1999：70% 2010-2019：51.9%
SEA-NEI	decadal and trend	2010-2019：97%



precipitation-induced super drought: contribution of trend and decadal variability

Linear trends in most parts of East Asia failed statistical test

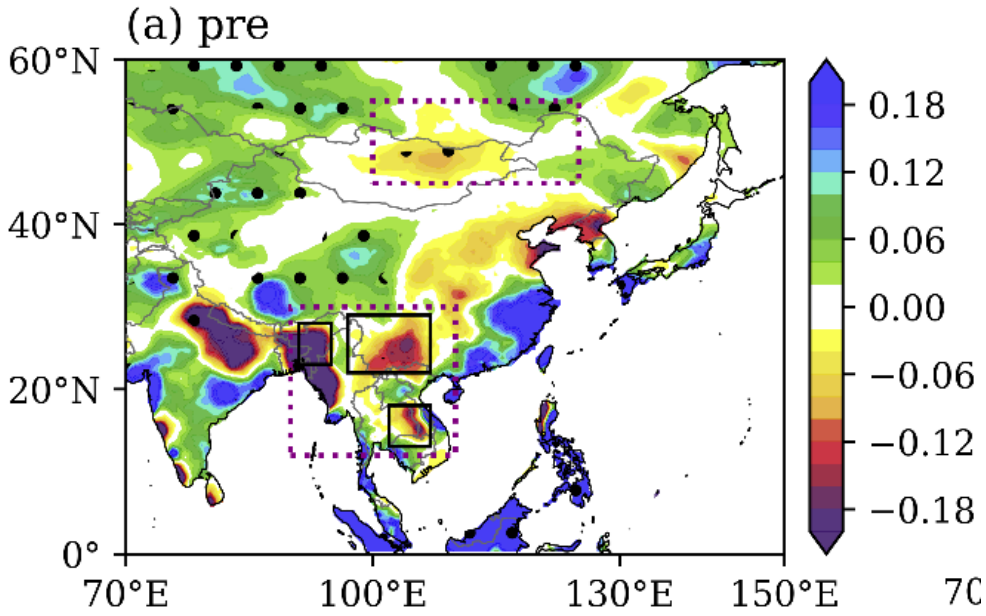


Fig: Linear trends of precipitation from 1960–2019

The external forcing induced anomalies in the recent decade is –0.81, only 15% of the unforced amplitude

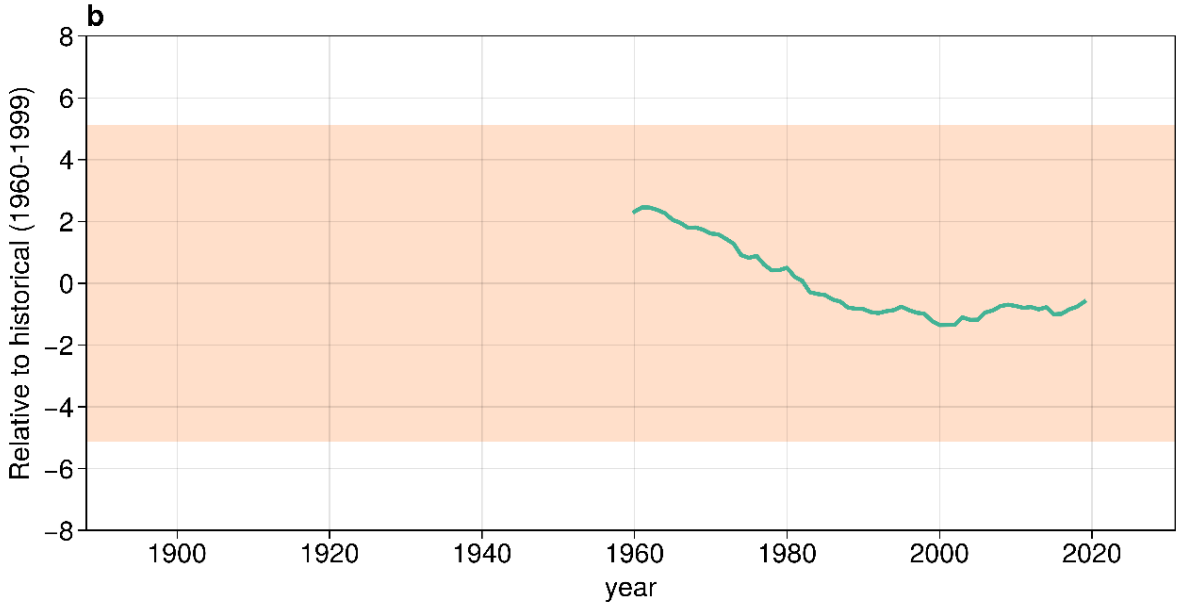


Fig: green line for Hist MME, shaded area for internal variability range

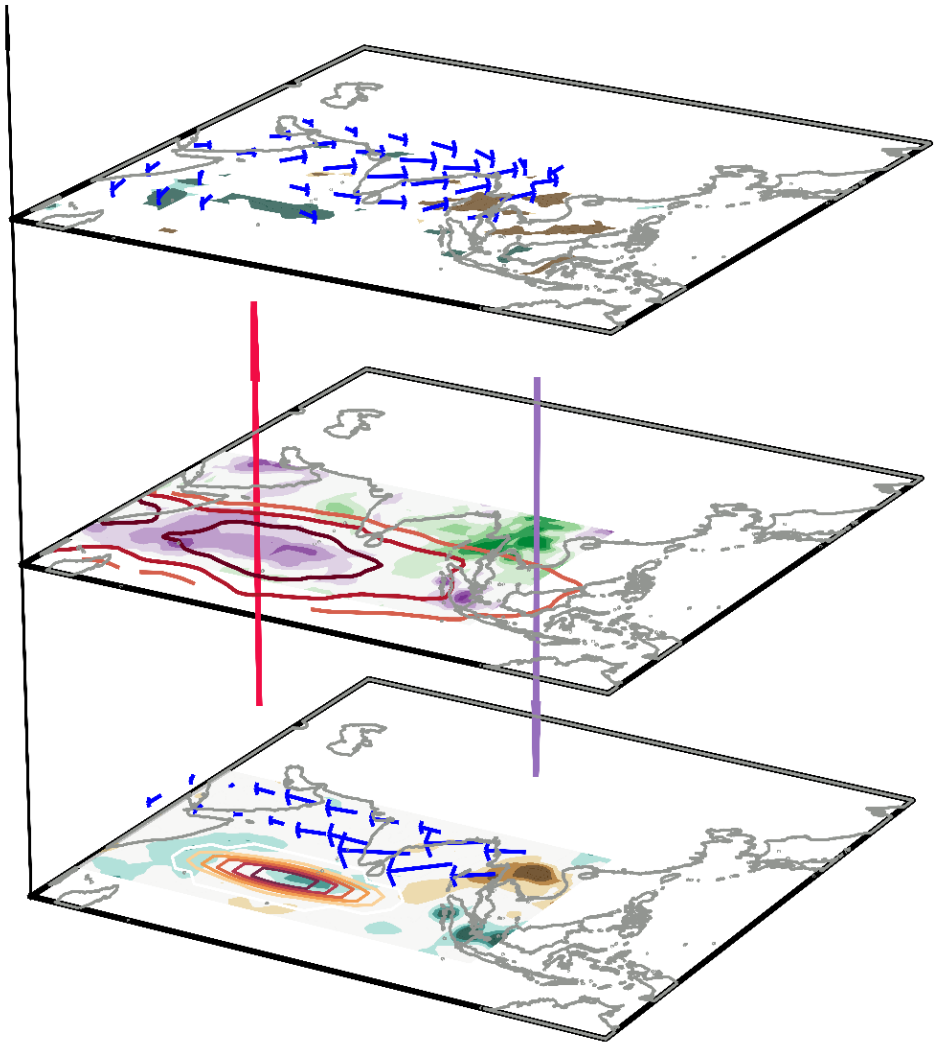
Out of the total variability in precipitation, more than half of the super droughts in the recent decade is caused by decadal variability, while the trend mode has marginal influence

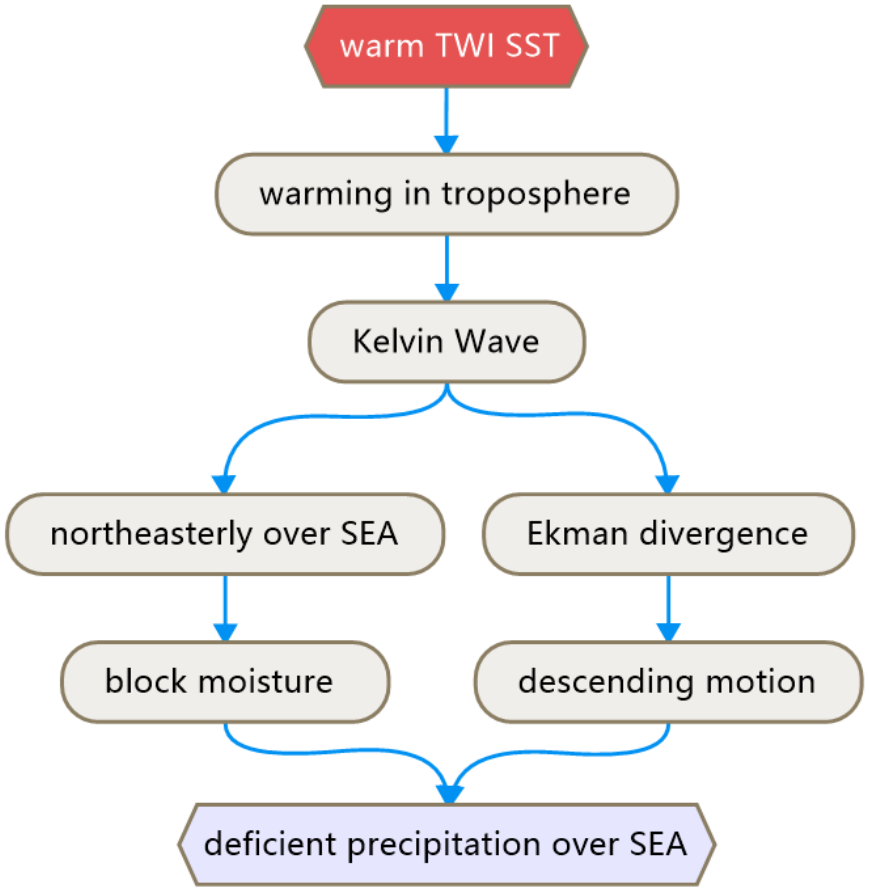
What causes the internal decadal variability of precipitation in SEA?

Tropical West Indian Ocean SST

ENSO

Decadal variation of precipitation in SEA





Wang Lin, Huang Gang, Chen Wen, Wang Ting, Chakrit Chotamonsak, Atsamon Limsakul, 2022: Decadal background for active extreme drought episode in the decade of 2010–2019 over southeastern mainland Asia. *Journal of Climate*.

PET-induced super drought: contribution of trend and decadal variability

- For PET, the trend component is dominant, while the overall effect of decadal component is weak
- Global warming signal can explain 90% of the local PET upward trend

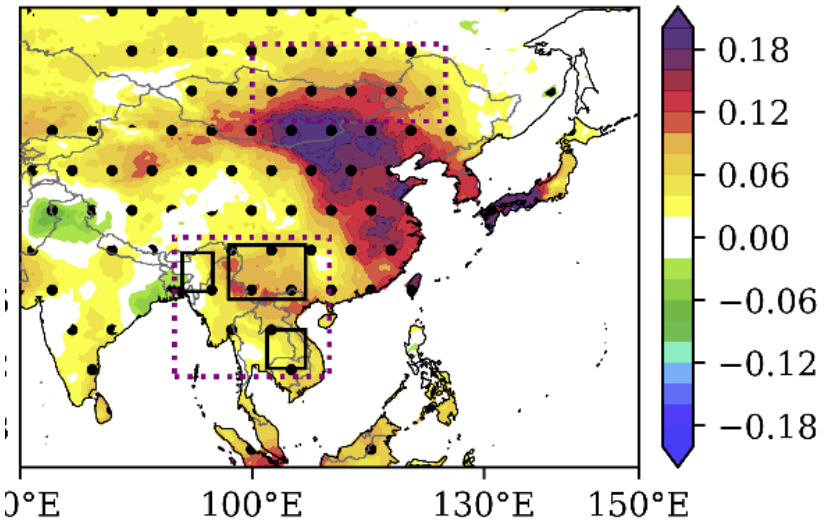


Fig: Linear trends of PET from 1960–2019

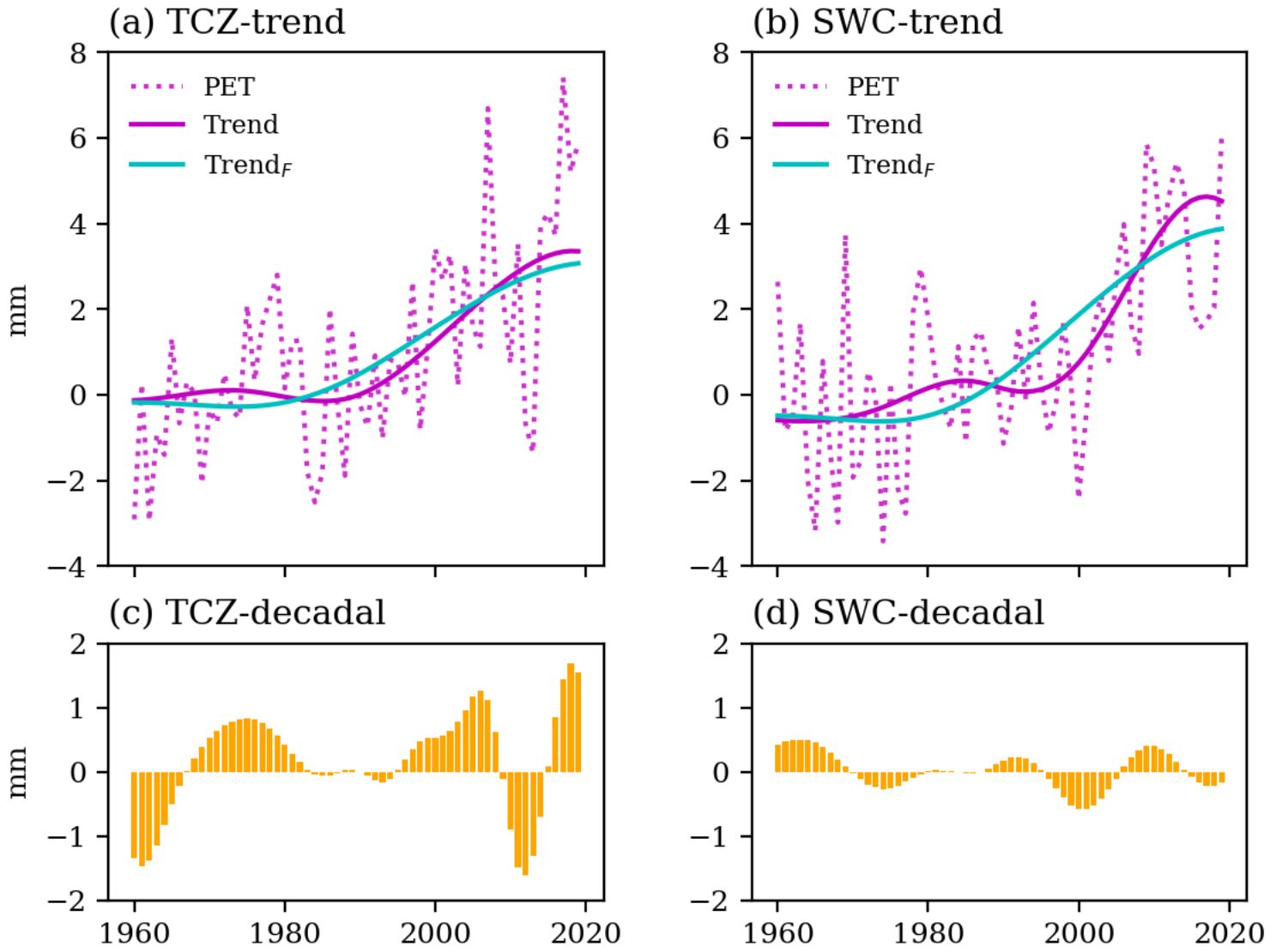


Fig: Upper: The PET (dotted pink), the trend component (solid pink) and forced trend component (solid blue). Bottom: The decadal component of PET

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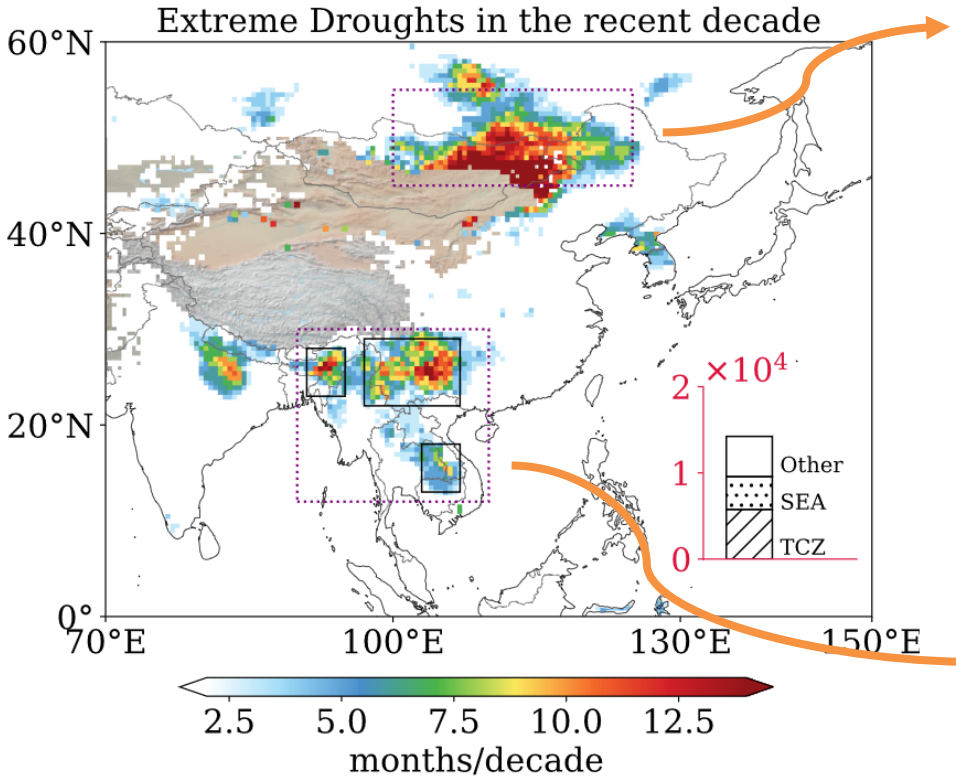
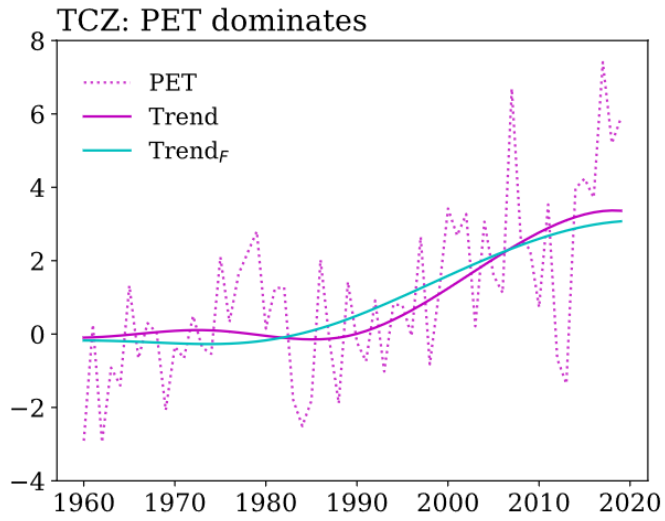
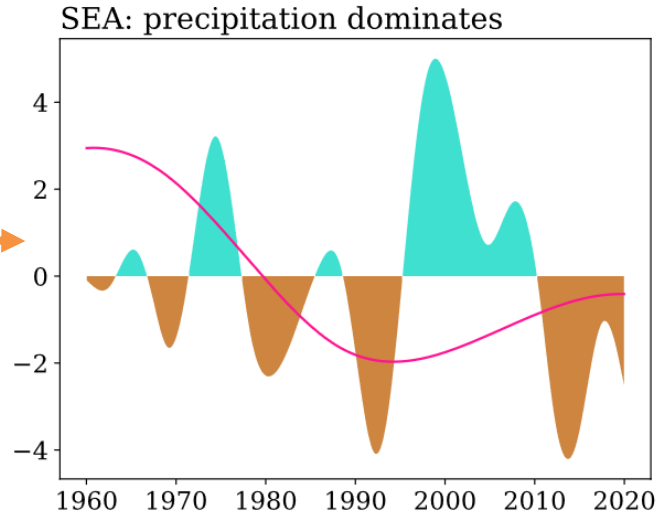
Conclusions

- **Super drought hotspots in the last decade: TCZ and SEA**
- **TCZ: primarily driven by global warming induced PET increase**
- **SEA: mainly caused by decadal variability of precipitation**







Wang Lin, Chen Wen, et al., 2021. Super Droughts over East Asia since 1960 under the Impacts of Global Warming and Decadal Variability. *Int J Climatol*, doi: 10.1002/joc.7483.

Wang Lin, Chen Wen, et al., 2022: Decadal background for active extreme drought episode in the decade of 2010–2019 over southeastern mainland Asia. *Journal of Climate*. Under review

Thanks for your attention!