The Indispensable Role of Evapotranspiration in Driving Terrestrial Water Storage Drought Development

Rutong Liu, Laibao Liu*, Hao Li

Contact: rutongliu@connect.hku.hk

Department of Geography, Institute for Climate and Carbon Neutrality, The University of Hong Kong *laibao@hku.hk

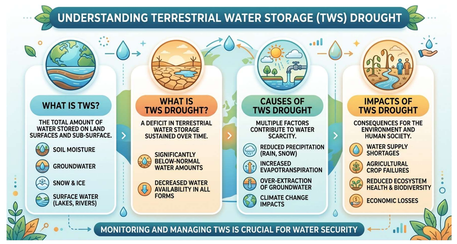
This presentation participates in OSPP

Outstanding Student & PhD candidate Presentation contest

1.Introduction & Motivation

Key Question:

•Is TWS drought mainly caused by **lack of water supply (PR⁻)** or **excessive demand (ET⁺)**?



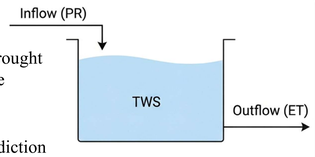
Motivation

1. Unraveling TWS Drought Mechanisms

•Explore how ET and PR anomalies drive TWS drought across global climate gradients from water balance perspective.

2. Refine Drought Frameworks

•New mechanistic view for better monitoring, prediction & management TWS drought.



2. Methodology

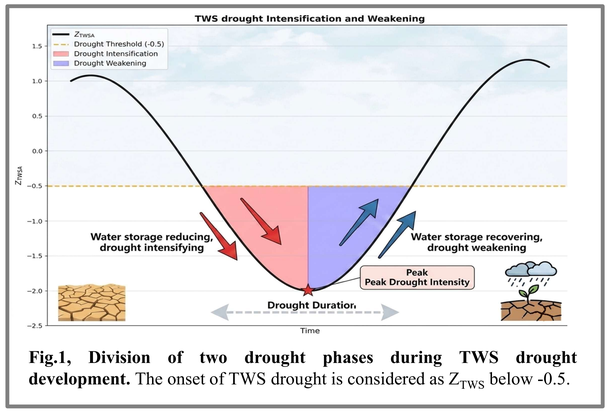
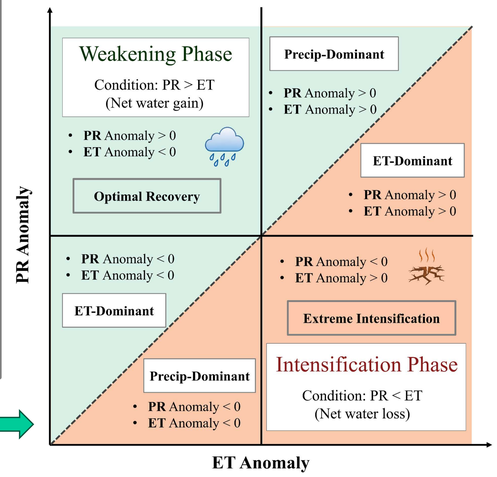


Fig.1, Division of two drought phases during TWS drought development. The onset of TWS drought is considered as Z_{TWS} below -0.5.

Fig.2, Six mechanisms in driving TWS drought development. Based on the sign of anomaly, we divide PR and ET into four quadrants and identified six mechanisms that drive the intensification and weakening of TWS drought.

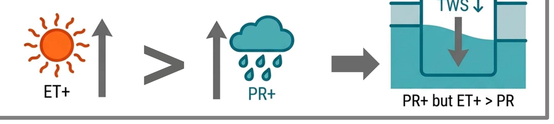


5. Discussion

New perspectives on TWS Drought

Not just "no rain" for TWS depletion

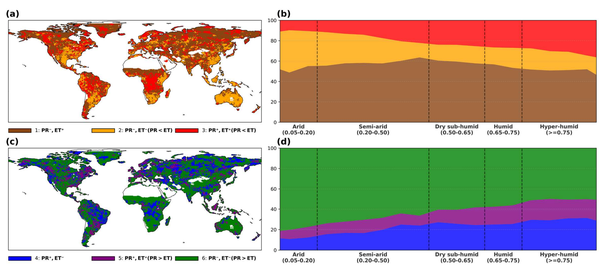
TWS can drop even with **PR above normal** when **ET demand is stronger**



Recovery can come from saving water

TWS drought can weaken mainly via **reducing losses by lower ET**

3.Fequency of 6 mechanisms in TWS drought steps



Six mechanisms

Intensification:

- **1 : Extreme intensification**
- **2 : PR-driven intensification**
- **3 : ET-driven intensification**

Weakening:

- **4 : Optimal weakening**
- **5 : PR-driven weakening**
- **6 : ET-driven weakening**

Fig.3, Frequency of 6 mechanisms in all drought intensification/weakening steps. (a) Map of the most frequent mechanism during drought intensification, excluding hyper-arid regions. (b) Fraction of 3 mechanisms in each climate zones during drought intensification. (c-d) same as (a-b) but during drought weakening.

Beyond Precipitation Deficits During Drought Intensification

- •Conventional view ("drought = PR < 0") is **insufficient,** TWS can **decline even when PR > 0** → Excessive ET demand overrides precipitation surplus
- •**"Excessive demand" (ET⁺)** frequently controls drought intensification
- •Most critical in **humid regions**

Asymmetric Mechanisms

- •Intensification → Driven by **positive ET anomaly (ET⁺)**
- •Weakening → Driven by **negative ET anomaly (ET⁻)**
- •The two phases are **not simple opposites**

Climate-Dependent Patterns

- •TWS can recover **even when precipitation remains below normal**
- •**Arid/Semi-arid**: Weakening dominated by **ET- (demand relief)**
- •**Humid regions**: Highly vulnerable to **ET⁺ (excessive demand)**

4. Relative importance of PR and ET in drought events

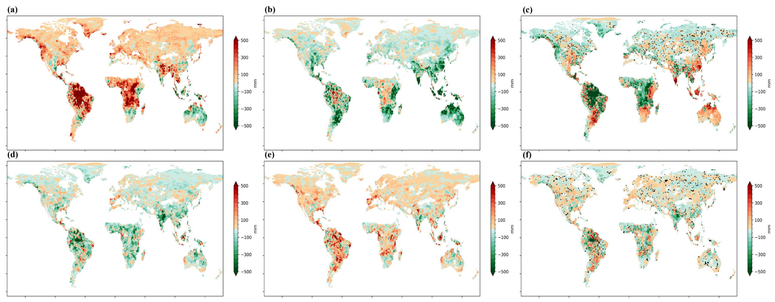


Fig.4, Relative importance of PR and ET over all drought events. (a) Cumulative flux of ET in drought events during drought intensification (b) Cumulative flux of PR in drought events during drought intensification. (c) The difference in absolute values between PR and ET during drought intensification . The black dots indicate unrobust grids where the difference is less than 5% of its maximum absolute value. (d-f) same as (a-c) but during drought weakening.

ET vs. PR: ET as Magnitude Leader

- **•ET holds the largest flux anomaly** during drought intensification, especially in **energy- and vegetation-rich regions.**

Weakening ≠ "more precipitation"

- **•Reduced atmospheric demand (ET⁻)** is equally or more important than PR during drought weakening.

Robust Attribution

- •Only grids where |ET| vs. |PR| difference is **statistically significant is robust.**

6. Conclusion

- **•Dominance of ET in driving TWS drought:** ET anomalies frequently exceed PR anomalies in magnitude within humid and transitional climate zones, dictating the net TWS trend.
- **•Asymmetrical role of ET in two drought phases: ET⁺** speeds up water loss during drought intensification; **ET⁻** supports TWS recovery during drought weakening.
- **•Policy Implication:** Future drought monitoring and early-warning systems should prioritize **ET-based metrics** alongside precipitation data to accurately predict water resource security in a changing hydroclimate.

Reference

Padrón, R.S., et al., 2020. Observed changes in dry-season water availability attributed to human-induced climate change. Nat. Geosci. 13, 477–481. https://doi.org/10.1038/s41561-020-0594-1

Seneviratne, S.I., et al., 2012. Swiss prealpine Rietholzbach research catchment and lysimeter: 32 year time series and 2003 drought event. Water Resources Research 48. https://doi.org/10.1029/2011WR011749

Tapley, B.D., et al., 2019. Contributions of GRACE to understanding climate change. Nat. Clim. Chang. 9, 358–369. https://doi.org/10.1038/s41558-019-0456-2

Wankmüller, F.J.P., et al., 2024. Global influence of soil texture on ecosystem water limitation. Nature 635, 631–638. https://doi.org/10.1038/s41586-024-08089-2

Zhao, M., et al., 2022. Evapotranspiration frequently increases during droughts. Nat. Clim. Chang. 12, 1024–1030. https://doi.org/10.1038/s41558-022-01505-3