Extreme Winter Precipitation Drives Recharge of Mountain Groundwater

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Atmospheric rivers deliver significant water to catchments within the western United States

The good: Significant snowpack accumulation

(AP)

The bad: Potential for destructive flooding

(Reueters)

The ugly: Potentially not enough to offset water loss associated with modern warming?

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How do mountain aquifers respond to extreme winter precipitation?

What is the state of mountain groundwater following the extreme winter of 2023?

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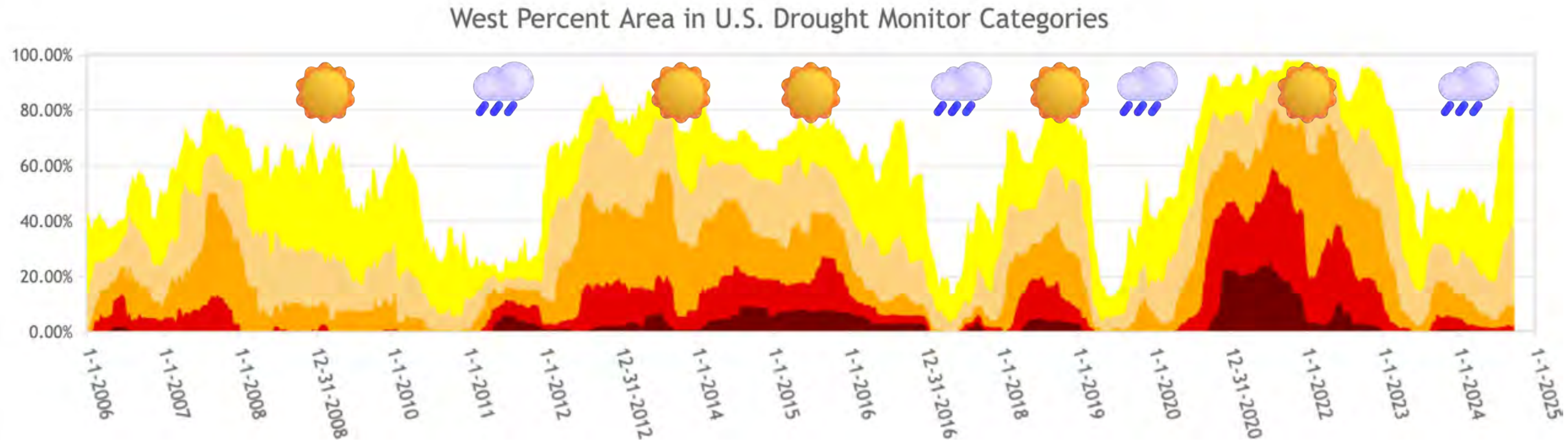
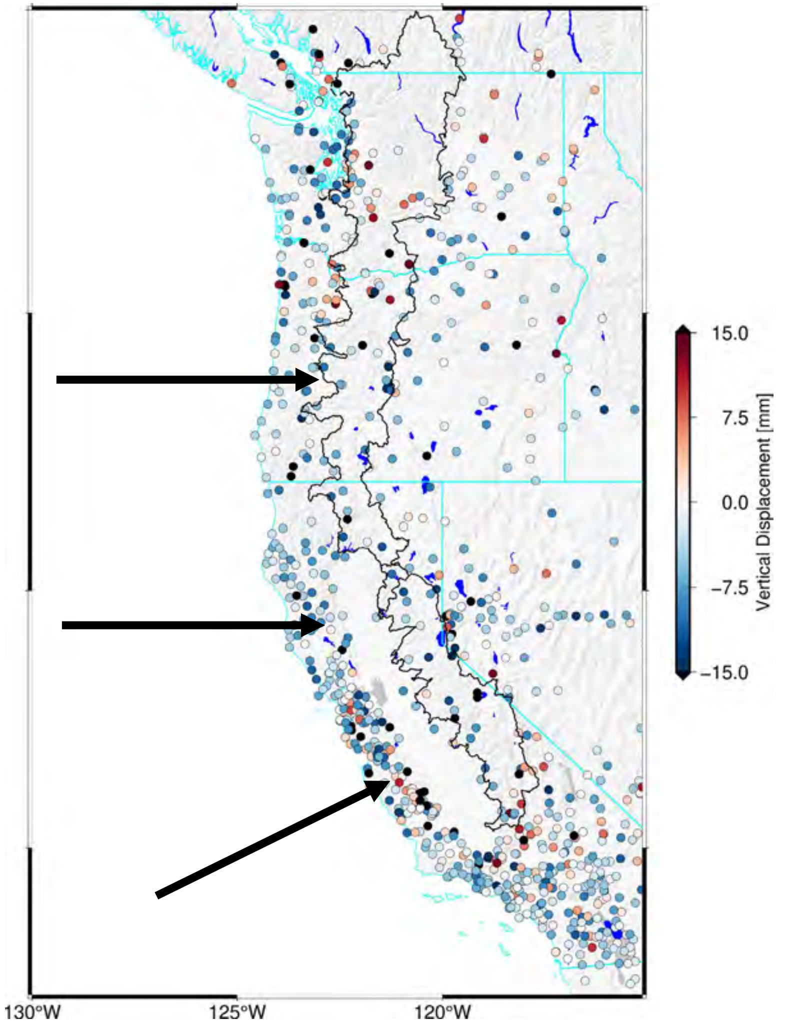


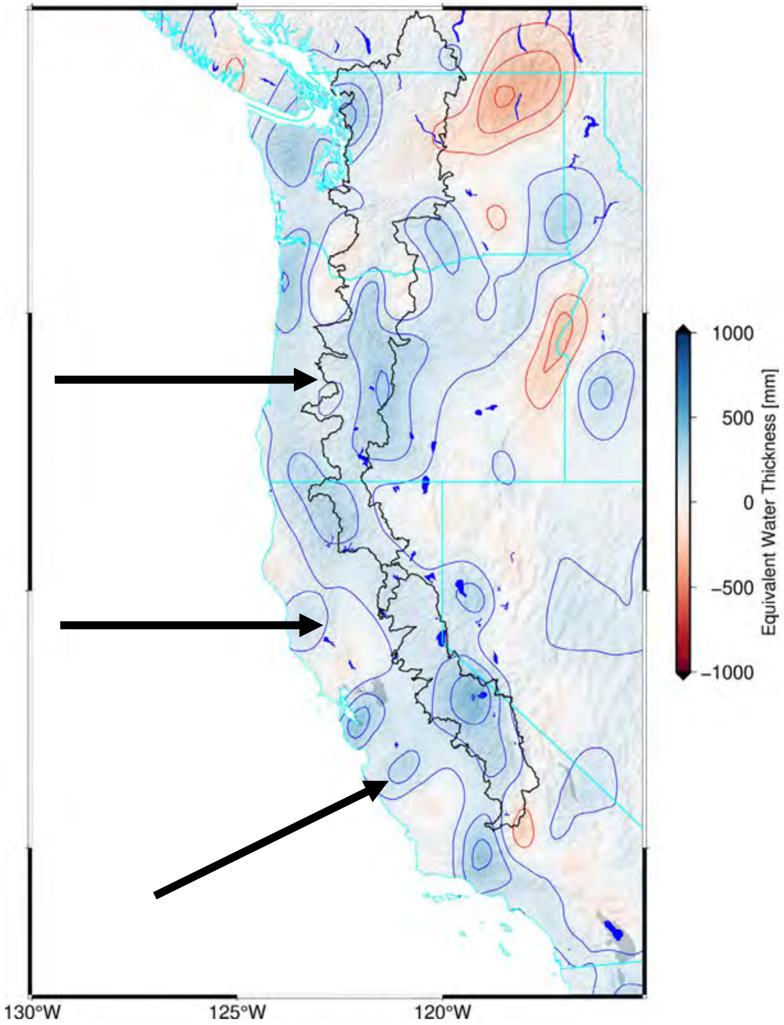
U.S. Drought Monitor

Geodetic methods can quantify water storage gains associated with extreme events such as atmospheric rivers.

Dec 29-31, 2022



GNSS-Observed ΔZ
Dec 29-31, 2022



GNSS-Inferred ΔTWS
Dec 29-31, 2022

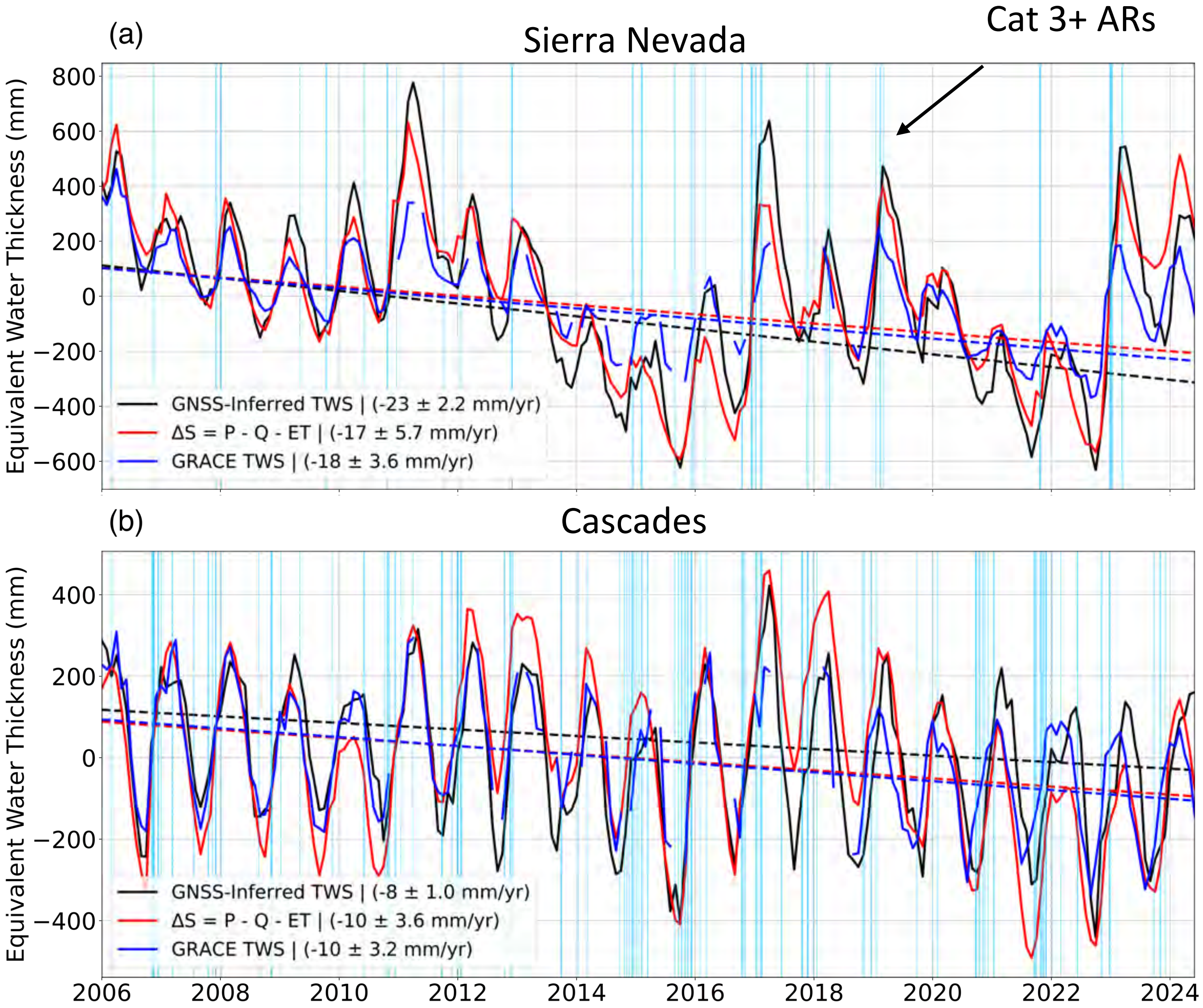
Observed Long-Term Loss of TWS

GNSS, GRACE, and the watershed mass balance independently show that significant water loss has occurred over the past two decades in the Sierra Nevada and Cascades.

Winters with few large storms are associated with multi-year loss of water storage.

Winters with large storms experience significant replenishment of water storage.

* Reported uncertainties represent 95% confidence intervals

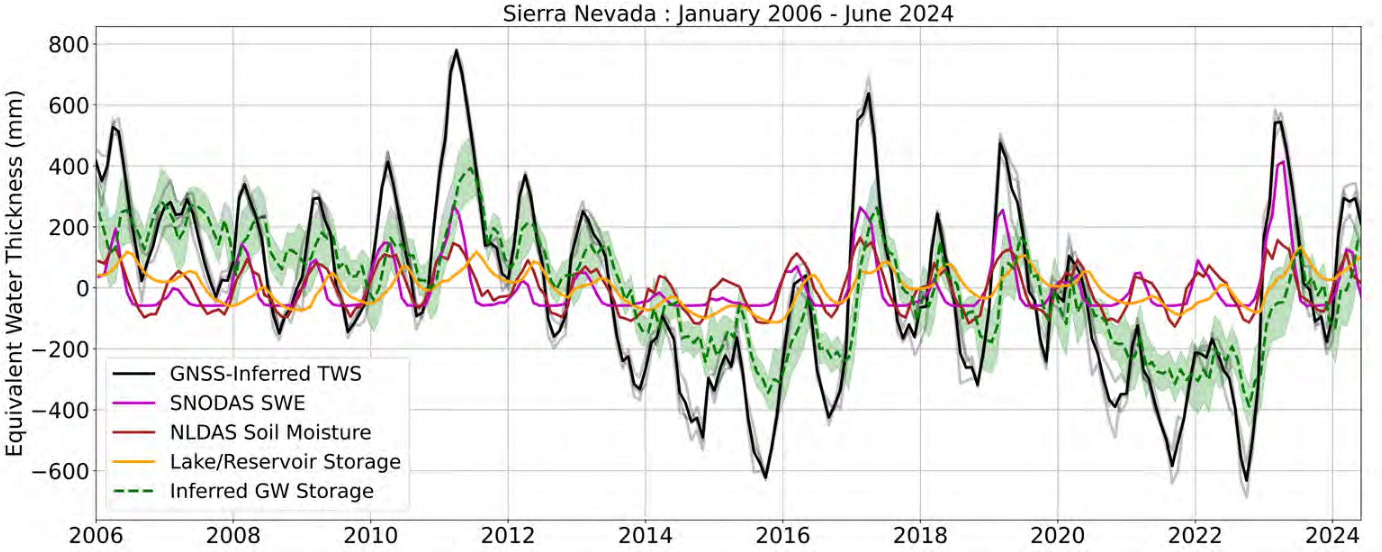


Inferring Changes in Groundwater Storage

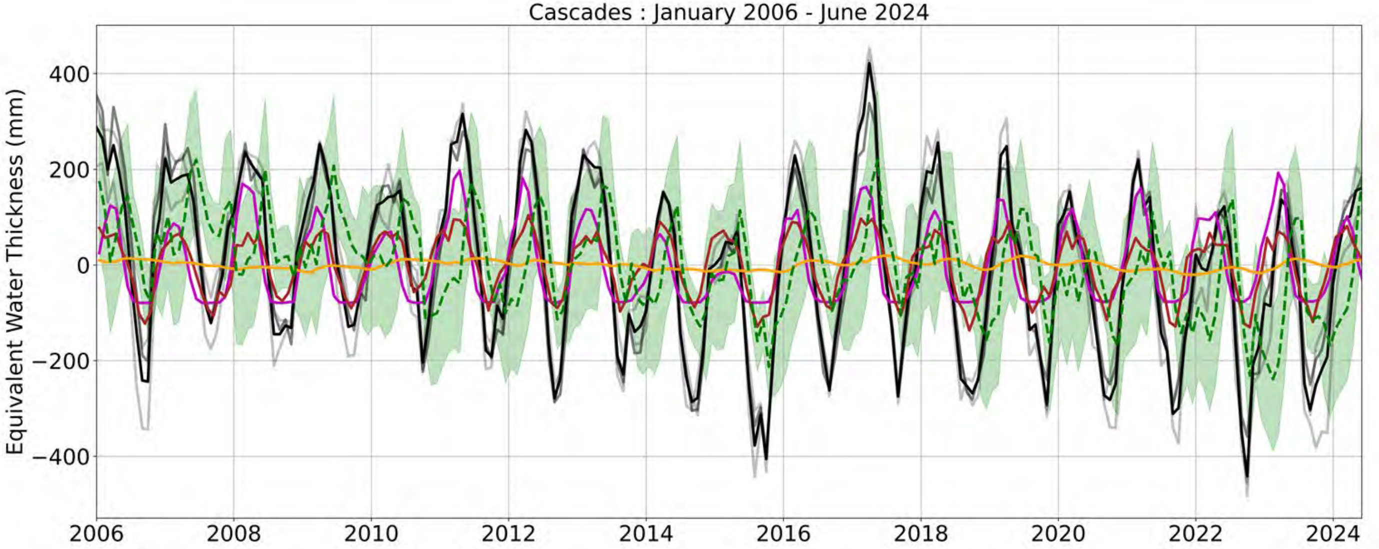
$$\boxed{\Delta GW} = \boxed{\Delta TWS} - \boxed{\Delta SWE} - \boxed{\Delta SM} - \boxed{\Delta SW}$$

ΔTWS	GNSS-inferred terrestrial water storage (TWS)
ΔSWE	SNODAS snow water equivalent (SWE)
ΔSM	NLDAS soil moisture (SM)
ΔSW	CDEC and/or USGS lake and reservoir storage
ΔGW	Inferred groundwater storage

* All time series are set relative to their respective temporal mean



Sierra Nevada : January 2006 - June 2024

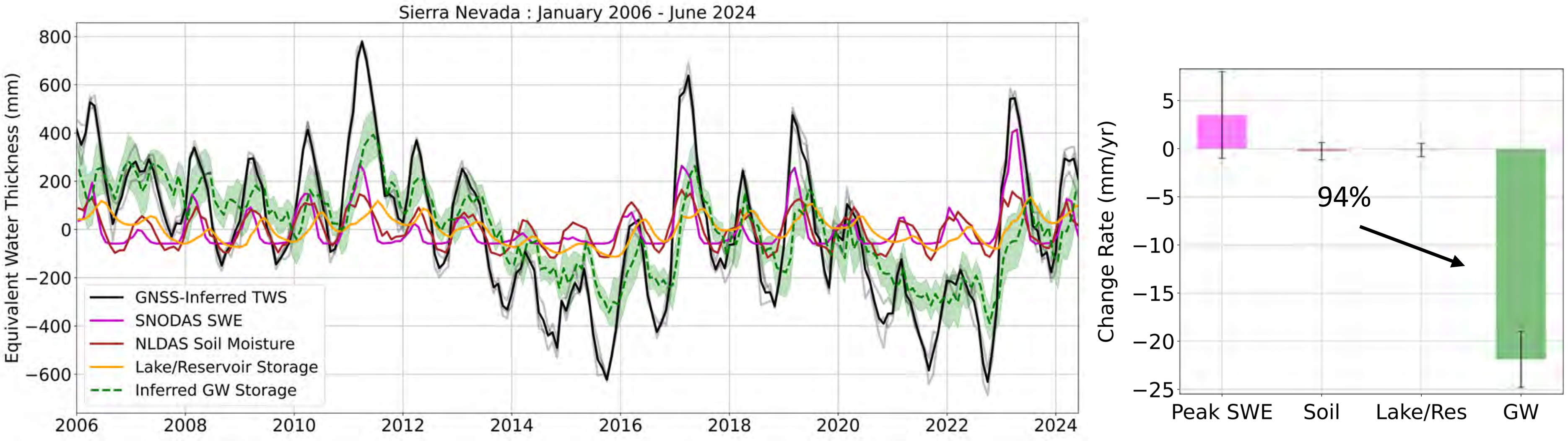


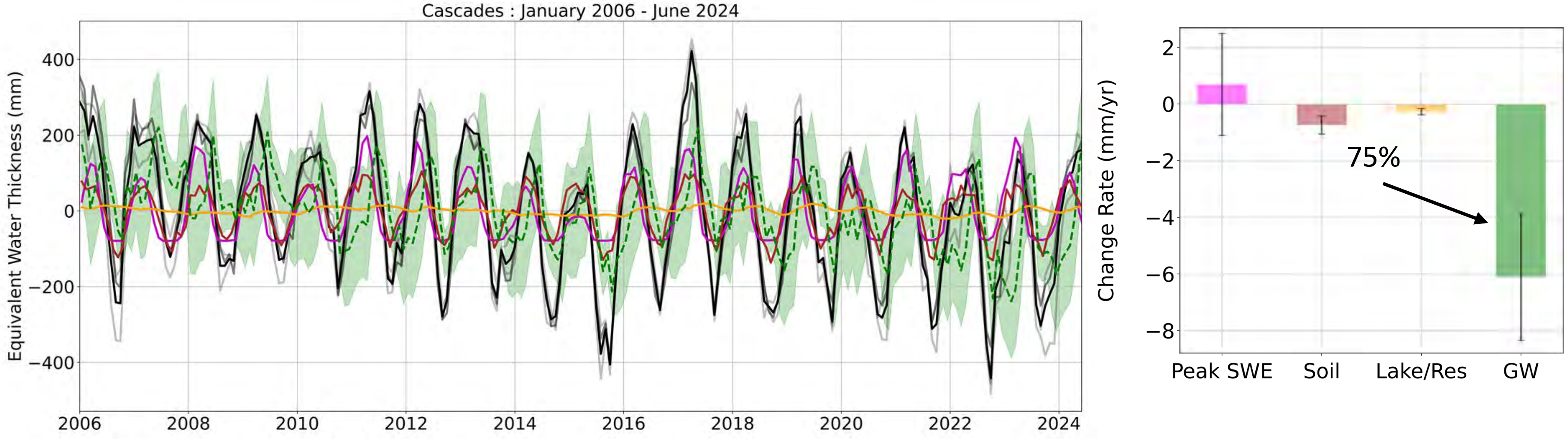
Cascades : January 2006 - June 2024

Observed Long-Term Loss of Groundwater

Declining groundwater storage constitutes nearly all long-term water loss in both regions.

Groundwater depletion is significant during drought periods.





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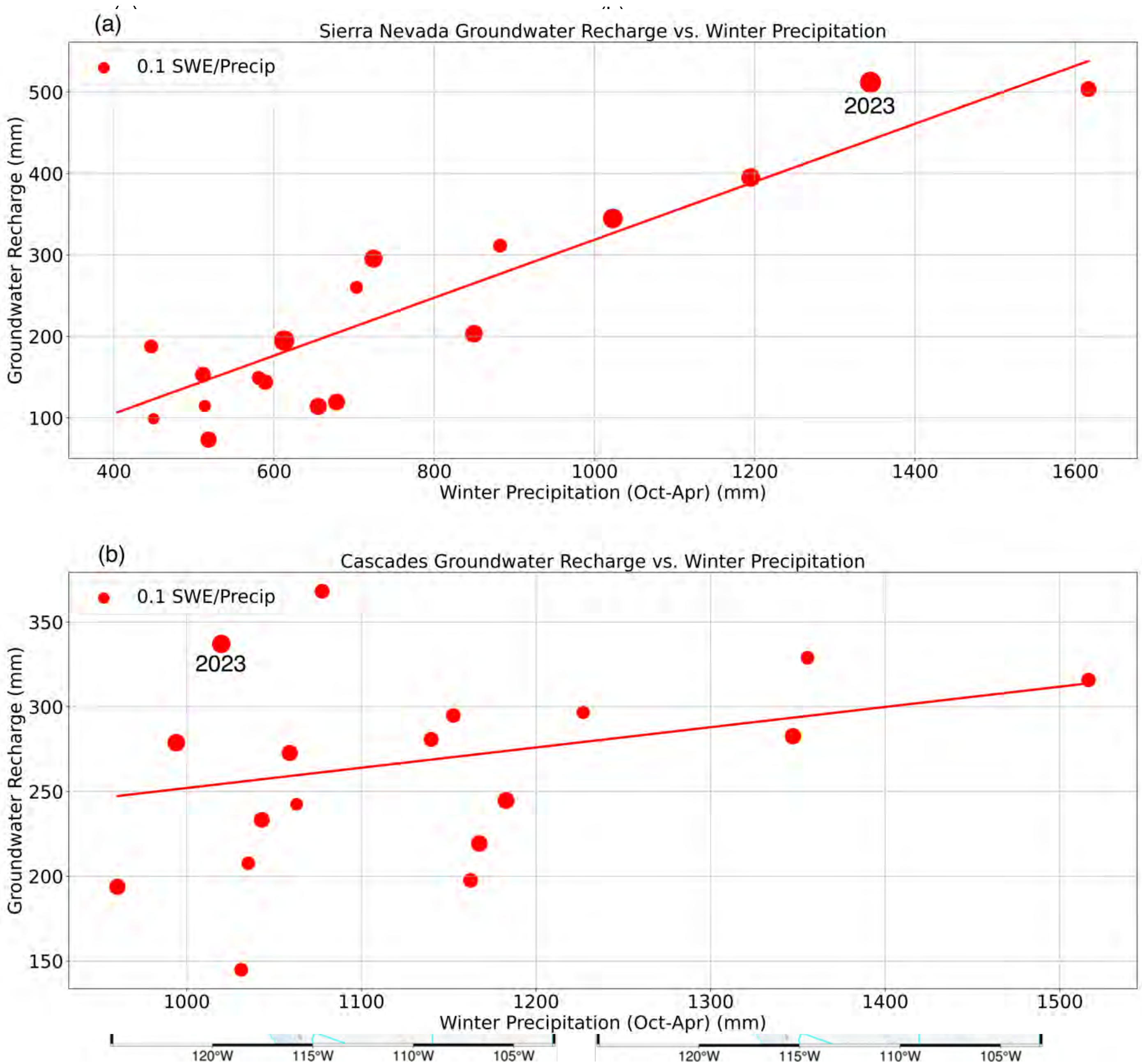
Seasonal Groundwater Recharge

Winter (Oct-Apr) precipitation deposits significant amounts of water in mountainous areas of the west, primarily stored as snowpack and soil moisture.

Post-winter (Apr-Jul) melting of snow and dewatering of soils yields concentrated recharge of mountain groundwater.

Extreme winters nearly yield equally significant groundwater recharge events.

Groundwater recharge is highly correlated with winter precipitation in the Sierra Nevada ($R^2=0.91$) and moderately correlated in the Cascades ($R^2=0.4$).



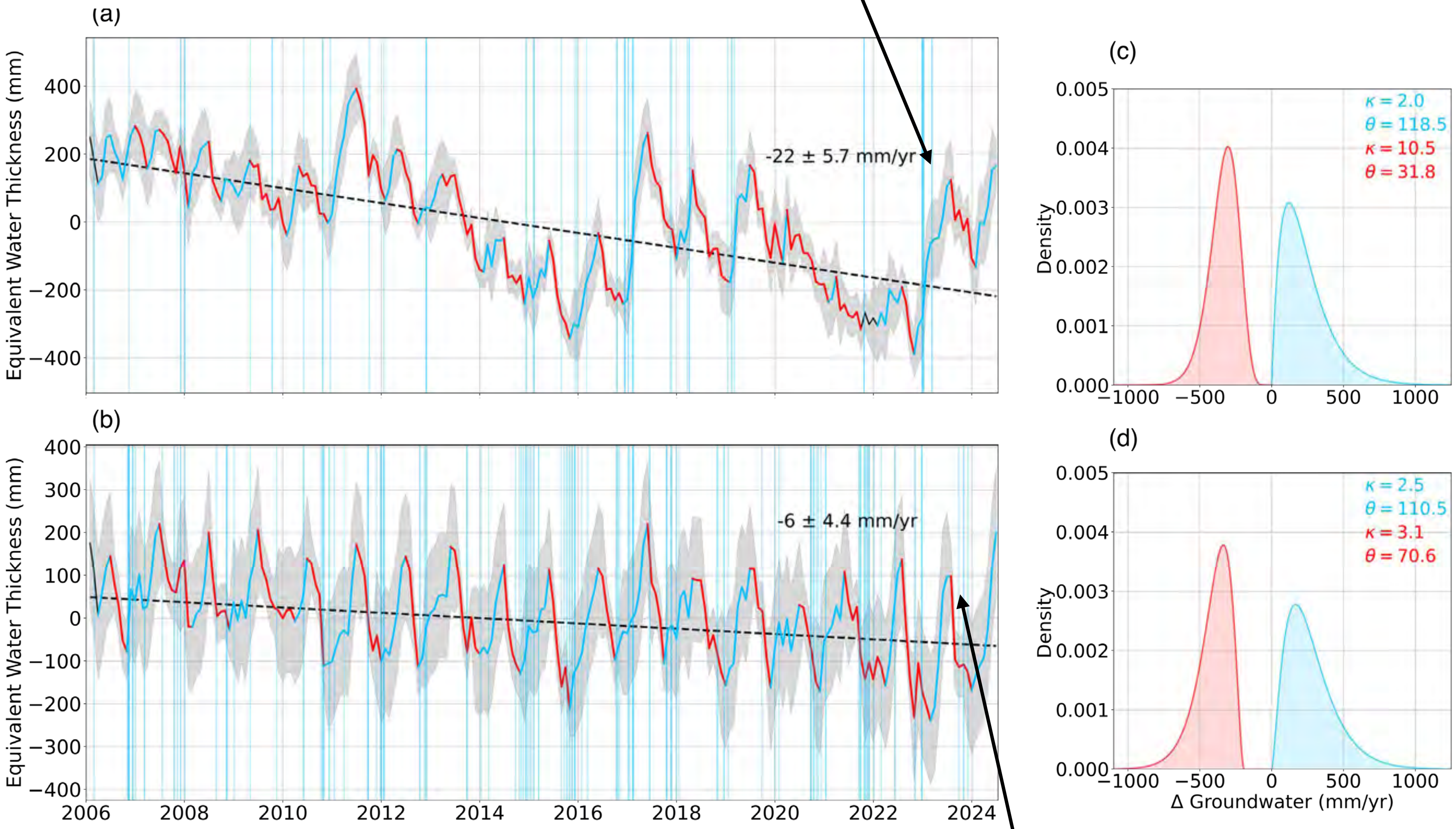
Mountain Aquifer Dynamics

Years with intense atmospheric river activity can yield more than twice the average annual groundwater recharge.

Mountain aquifer recharge is 2-3x more variable than discharge.

Discharge from mountain groundwater systems is relatively constant year over year

512 mm of groundwater recharge ≈ 2.2x average recharge

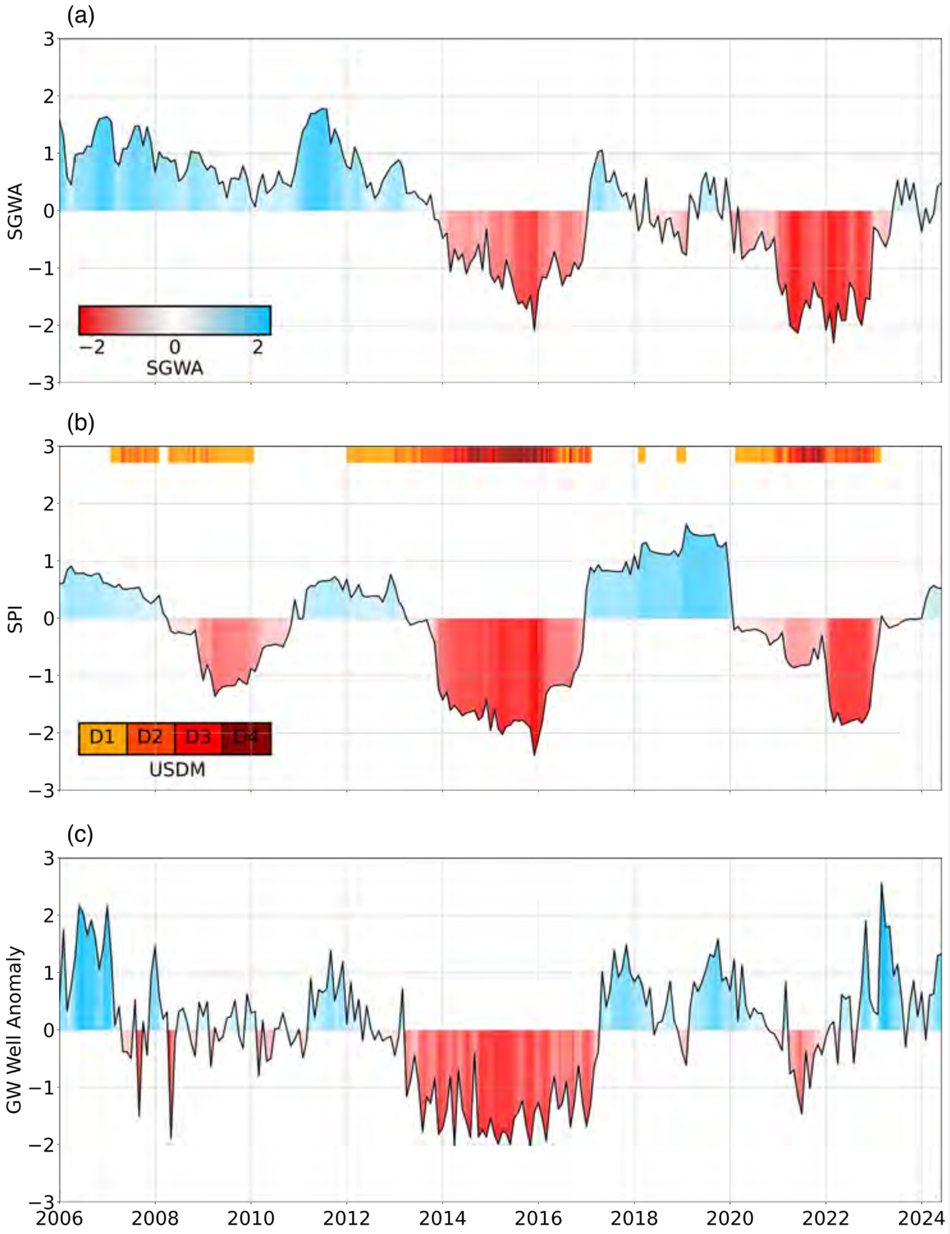


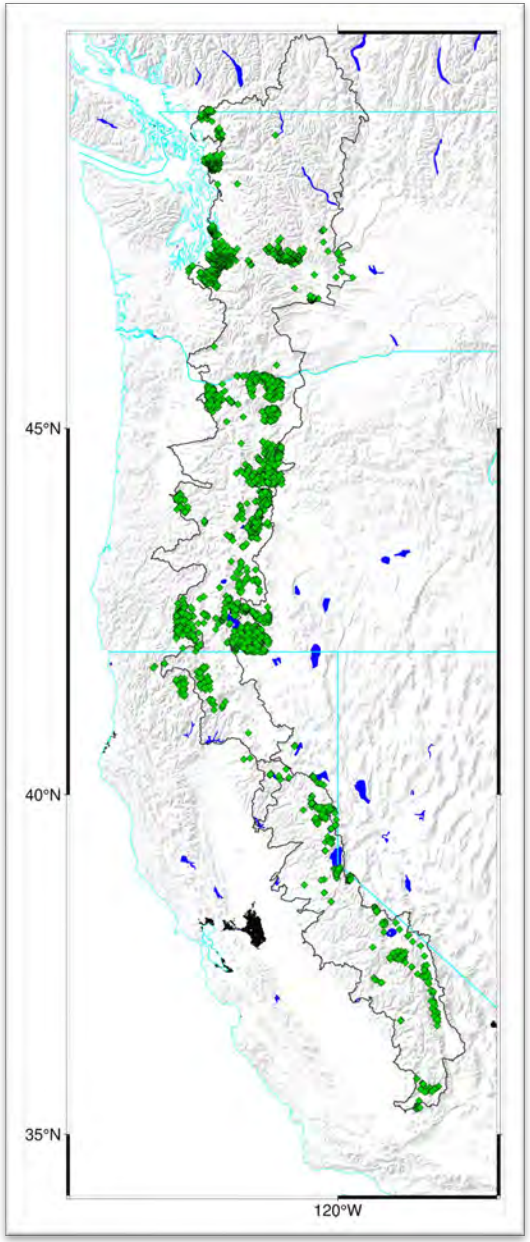
337 mm of groundwater recharge ≈ 1.3x average recharge

* Reported uncertainties represent 95% confidence intervals

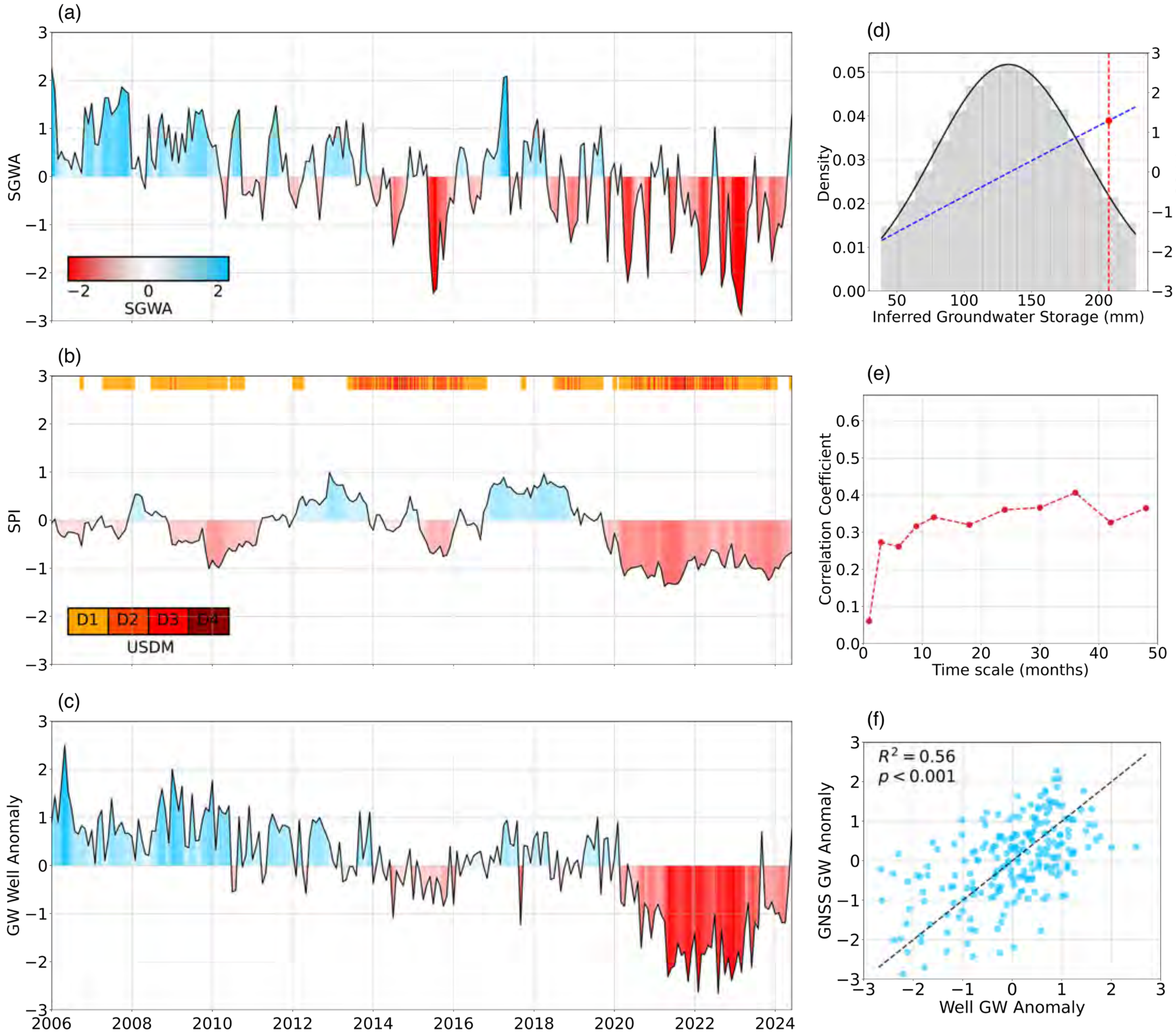
State of Sierra Nevada Groundwater

The state of groundwater rose near or above normal conditions following winter 2023 and appears to be durable despite a modest winter in 2024.





State of Cascades Groundwater



The state of groundwater rose near or above normal conditions following winter 2023 but quickly returned to a state of deficit.

- **Differences may portray role of hydraulic properties of these groundwater systems**

Takeaways and Concluding Remarks

The good: Mountain groundwater systems respond rapidly to periods of extreme precipitation and storage gains appear to be durable, especially within the Sierra Nevada

- **As intense atmospheric river events are projected to become more frequent (e.g., Gershunov et al., 2019), we hypothesize that mountain groundwater may be sustained by extreme precipitation events in the future.**

The bad: Groundwater storage has declined significantly over the past two decades and constitutes nearly all long-term water loss within mountainous regions

The ugly: Shifting precipitation regimes make the future recharge potential of these extreme events uncertain

Thanks !

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