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# Nonstationarity in the terrestrial water cycle assessed by land data assimilation

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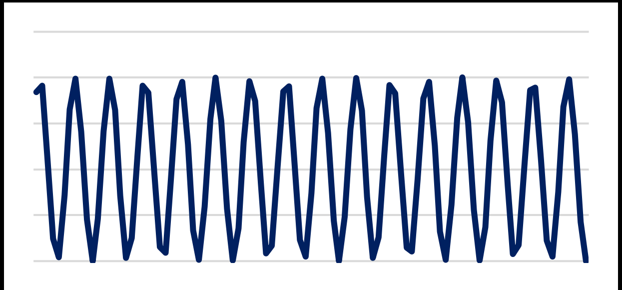
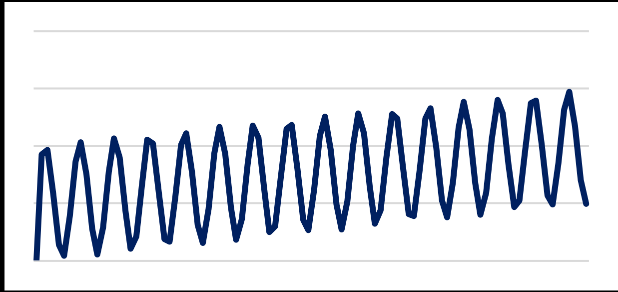
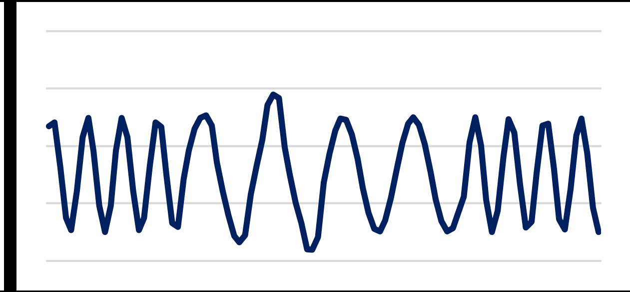
SED Seminar Series
Sep 7, 2023

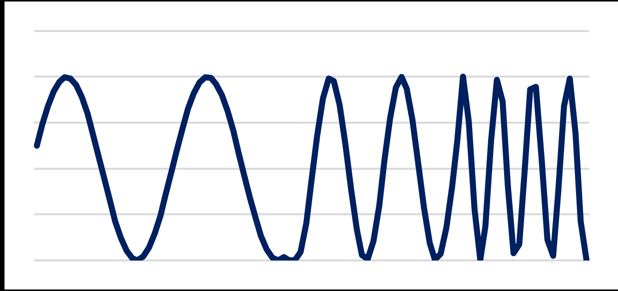


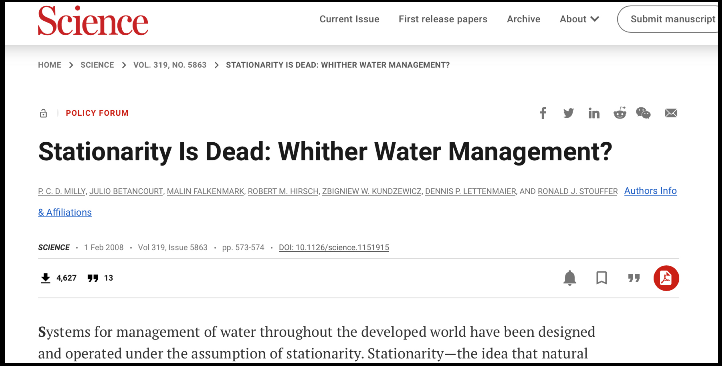
Stationarity assumes that the statistical properties are time-invariant

Different types of non-stationarity ..









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POLICY FORUM

# Stationarity Is Dead: Whither Water Management?

P. C. D. MILLY, JULIO BETANCOURT, MALIN FALKENMARK, ROBERT M. HIRSCH, ZBIGNIEW W. KUNDZEWICZ, DENNIS P. LETTENMAIER, AND RONALD J. STOUFFER Authors Info & Affiliations

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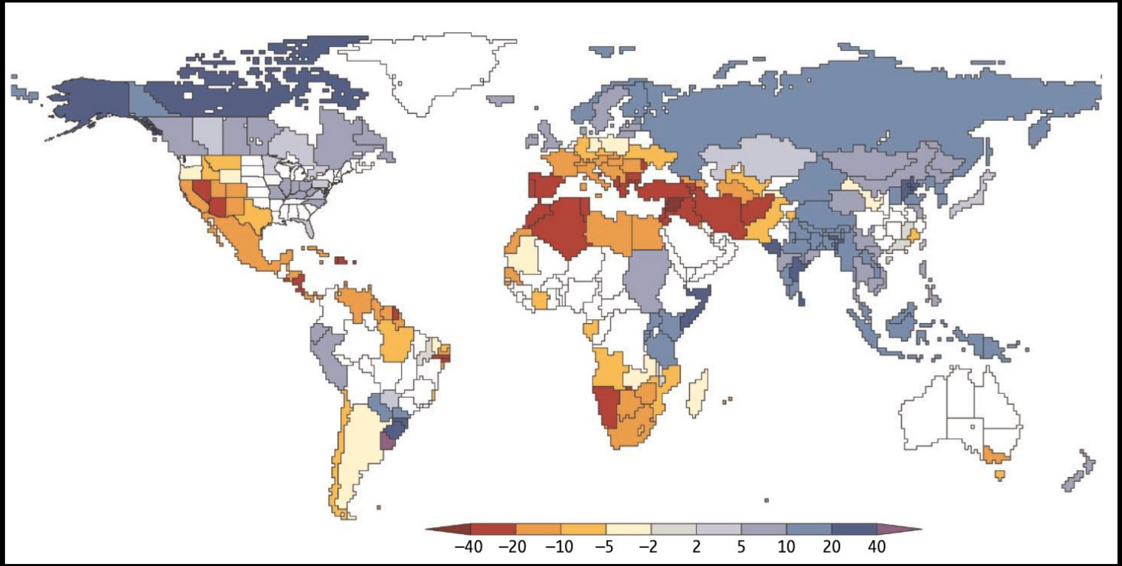
Systems for management of water throughout the developed world have been designed and operated under the assumption of stationarity. Stationarity—the idea that natural




Projected changes in runoff volume by the middle of the 21st century

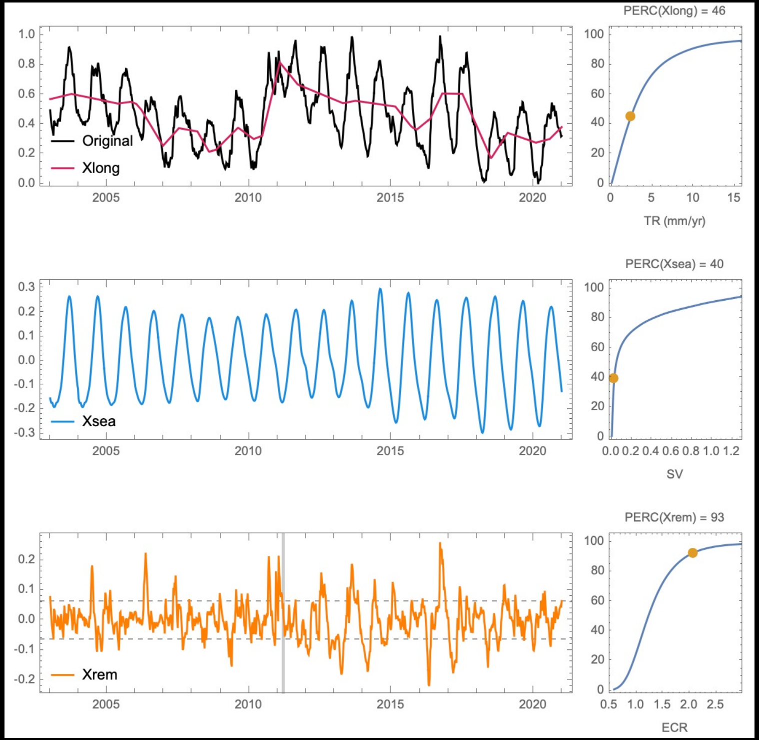
The assumption of a stable climatological pattern is no longer valid, given how the warming climate and anthropogenic disturbances change the terrestrial water cycle

The RobustSTL (seasonal-trend decomposition loess algorithm) is used to decompose the time series into trend, seasonality, and remainder (extremes) components

$X_{long}$

$X_{sea}$

$X_{rem}$



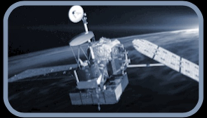

$$X = X_{long} + X_{sea} + X_{rem}$$

The nonstationarity index is then calculated as a normalized measure of the percentile ranking of each of the three component terms

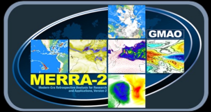
Nie et al. "Nonstationarity in the global terrestrial water cycle and its interlinkages in the Anthropocene", in review

# Global multivariate modeling configuration @ 10km resolution spanning 2003-2020

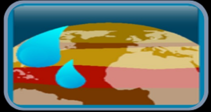
GPM IMERG
Precipitation



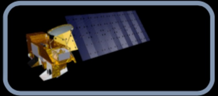
MERRA-2
(T, U, V...)



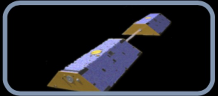

ESA CCI
Soil Moisture



MODIS Aqua/Terra
Leaf Area Index

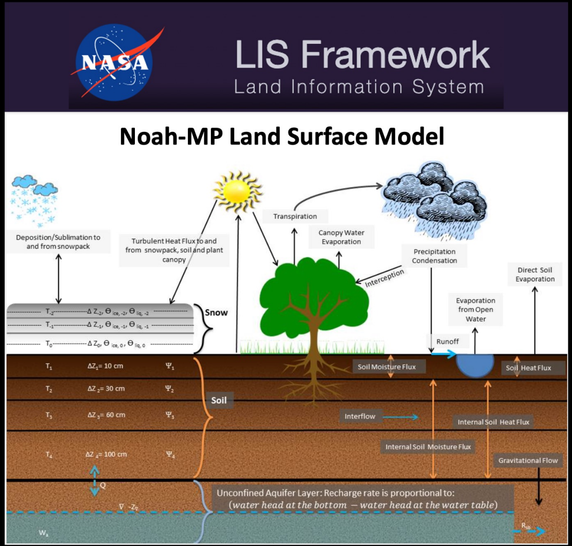


GRACE/GRACE-FO
Terrestrial Water Storage

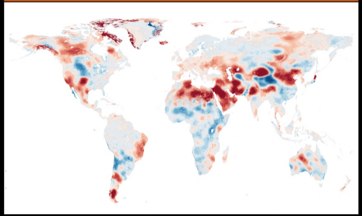


Met-forcing input

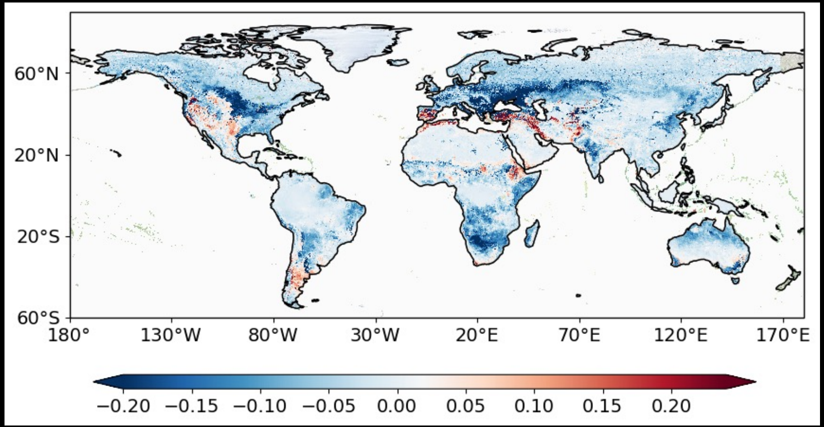
Data Assimilation

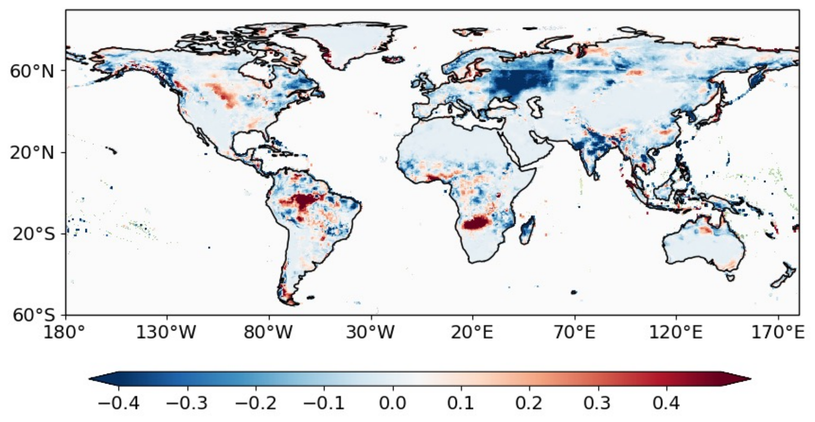



10-km gridded global output of water, energy, and carbon fluxes (2003-2020)

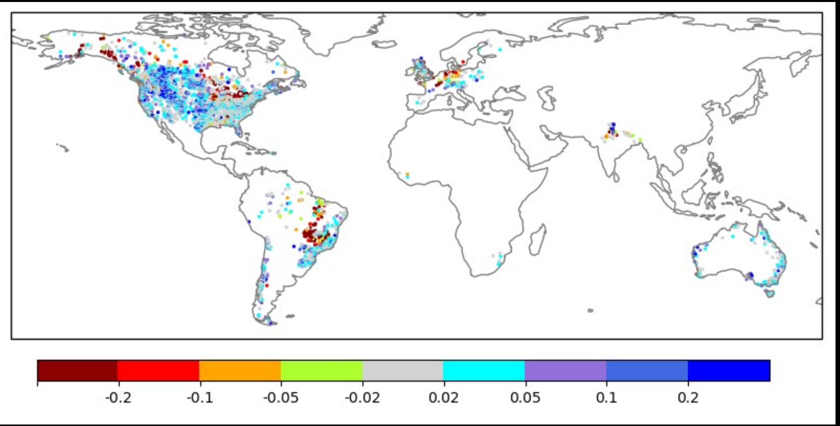


Improvements in ET vs ALEXI (Mutual Information)



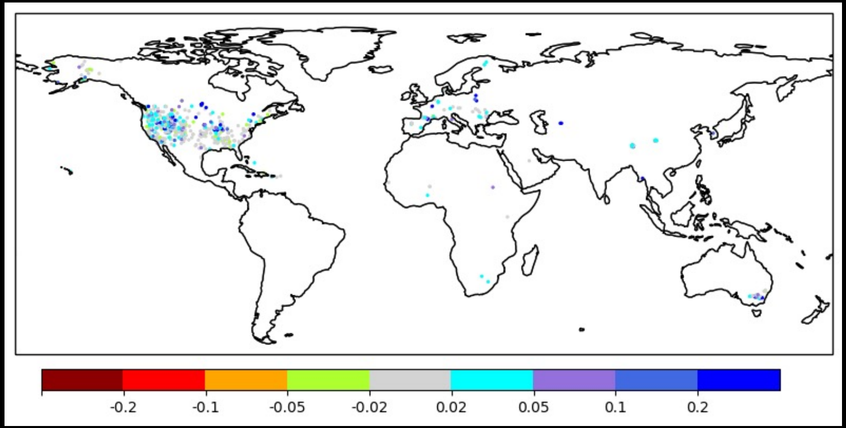



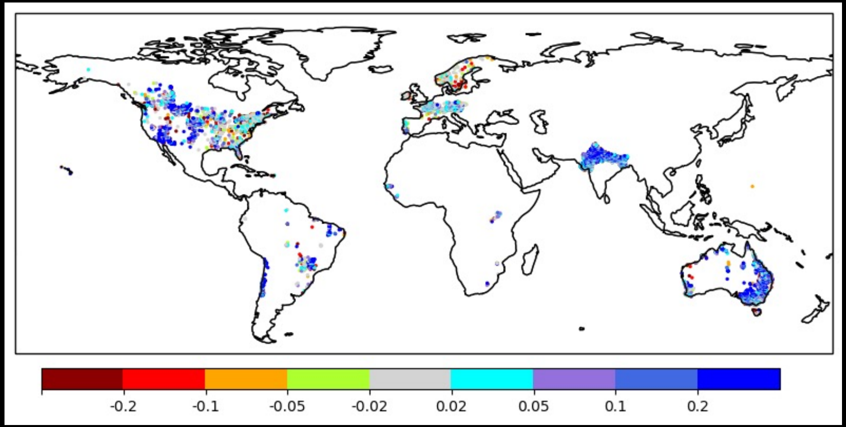

Improvements in Runoff vs RMSE (RMSE)



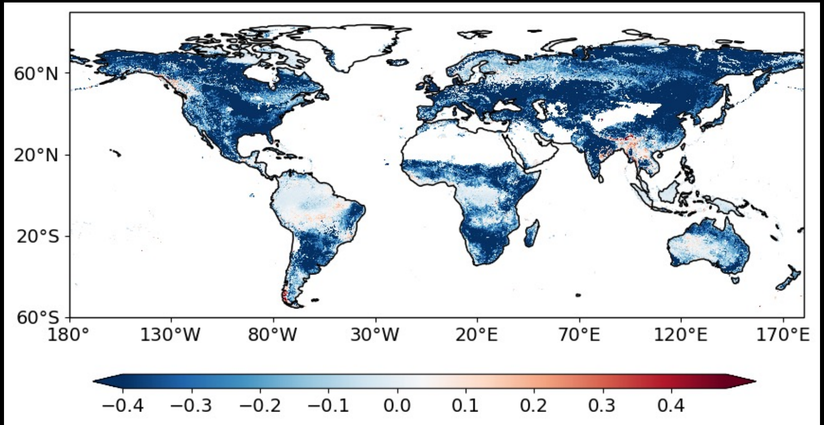

Improvements in streamflow (Mutual Information)

Improvements in root zone soil moisture vs ISMN (Mutual Information)

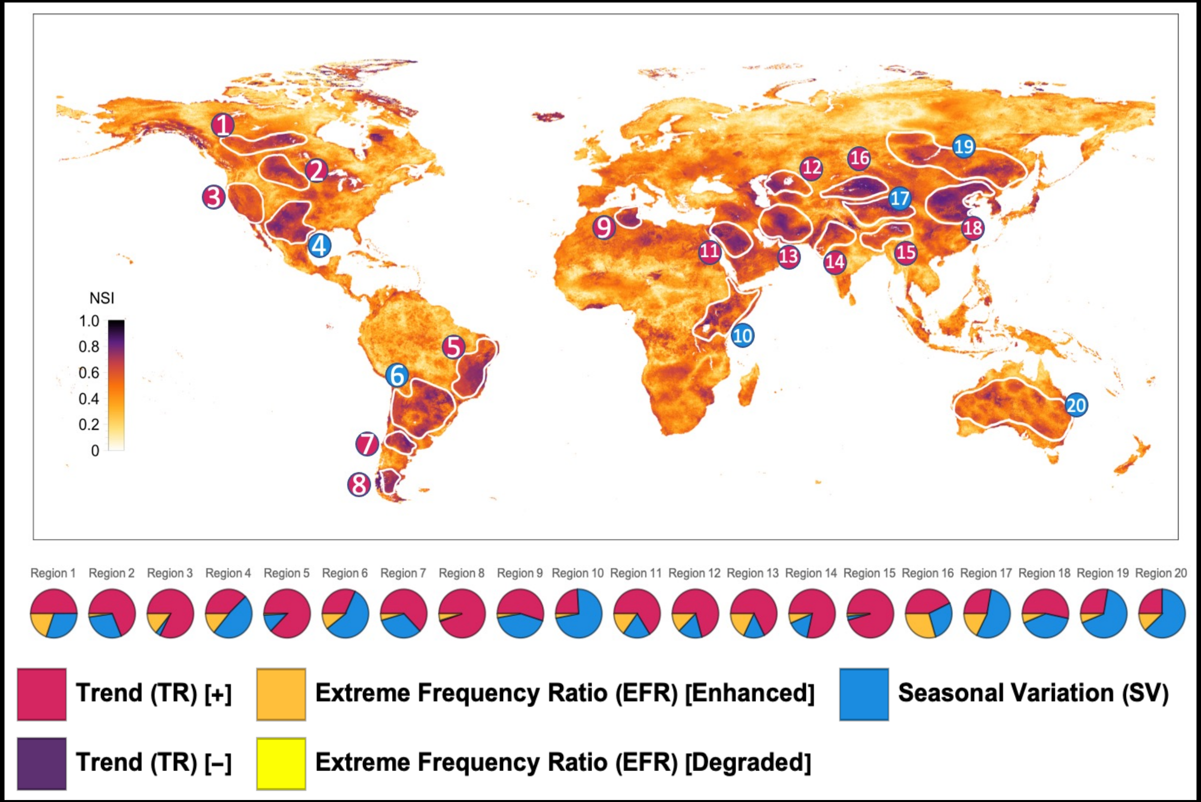



Improvements in groundwater storage vs in-situ (Mutual Information)




Improvements in GPP vs FLUXSAT (Mutual Information)

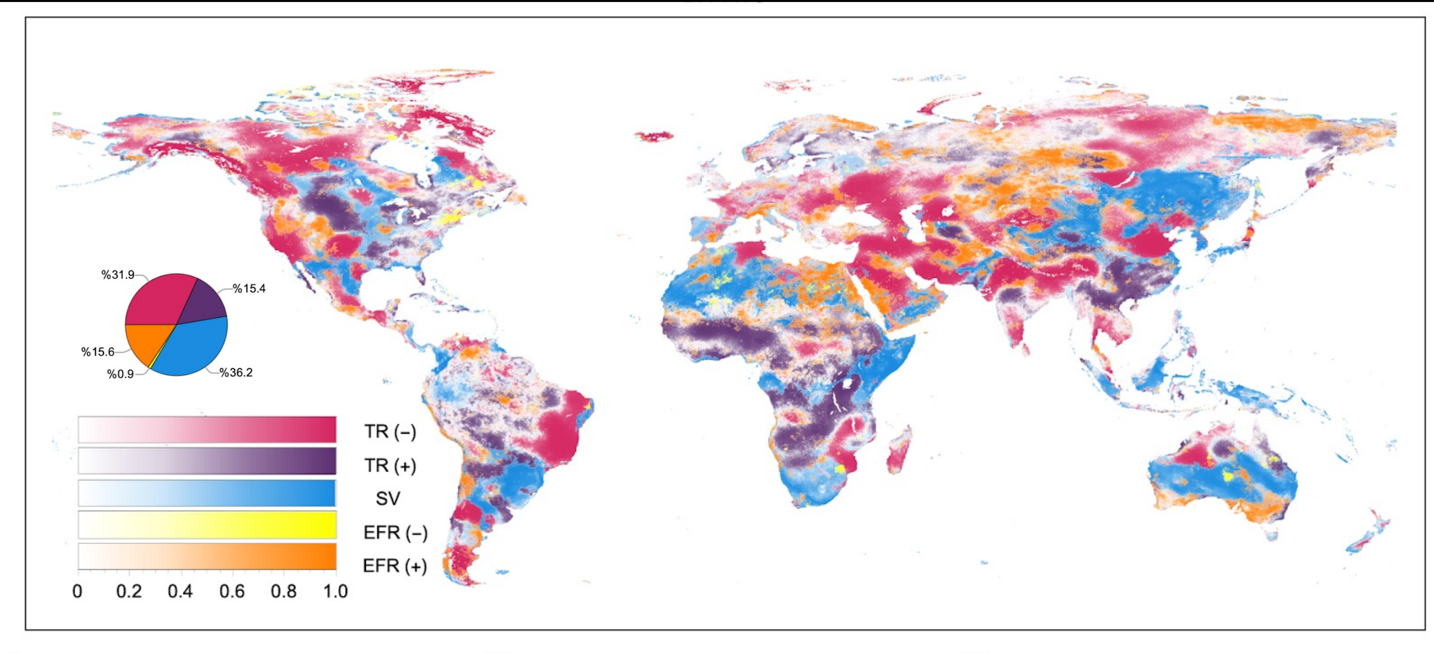



15 out of 20 regions have non-stationary water cycle changes dominated by trend component, with 14 of them showing a depletion.

5 regions have non-stationarity dominated by seasonal shifting.

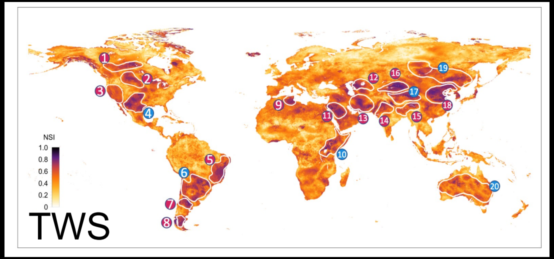
Half of the regions have more than 10% area dominated by extreme frequency ratio, indicating different level of extreme increases with significant abrupt changes.

# Which nonstationarity factors are dominant and where?

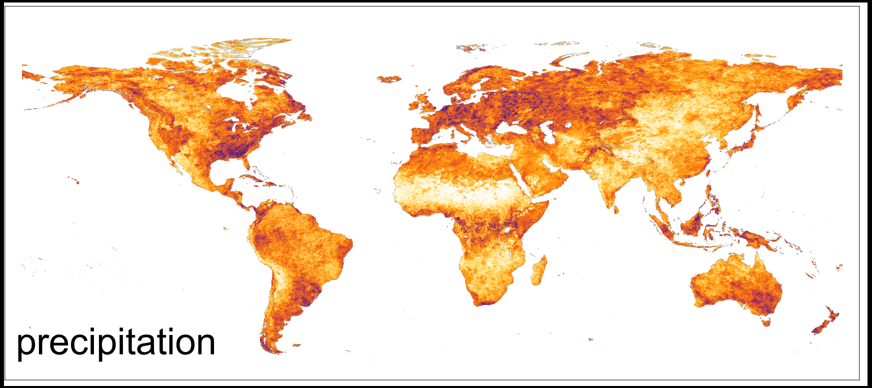



47% of the land are dominated by trend, 36% are dominated by seasonal shift, and 17% dominated by extreme frequency ratio.

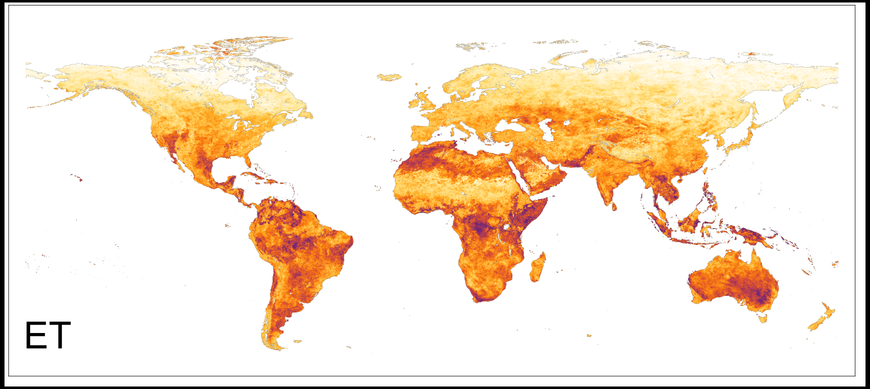
For the 20 hotspot regions, we see a close relationship between TR and EFR, indicating that regions with greater long-term trend are also likely to have abrupt changes with increased extreme frequencies.

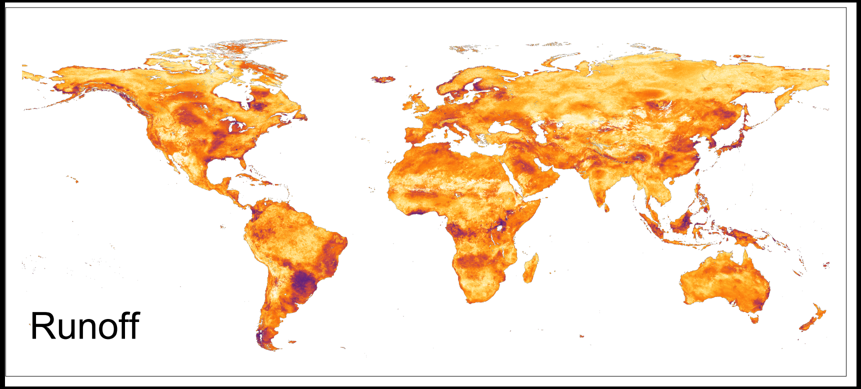


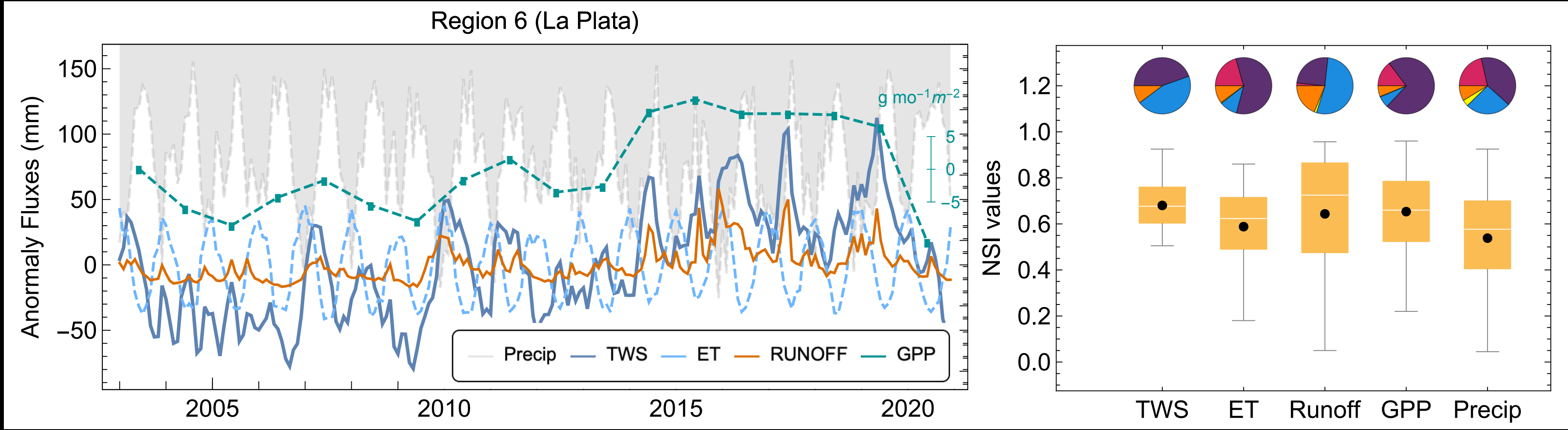

Nonstationarity in the driving meteorology is less strong



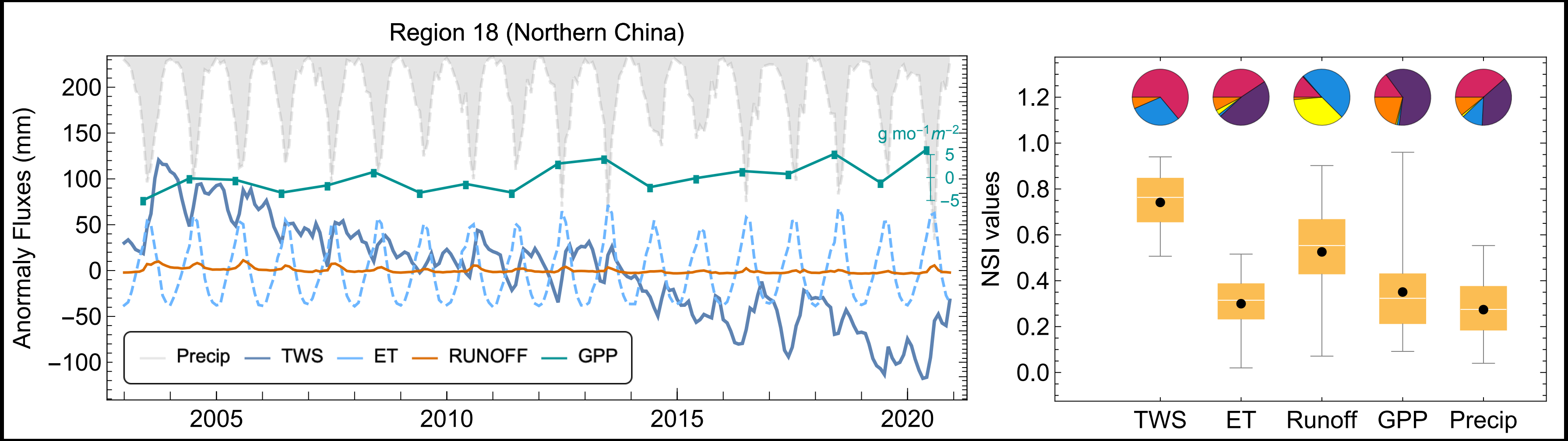

The nonstationarity impacts on ET and runoff are mixed



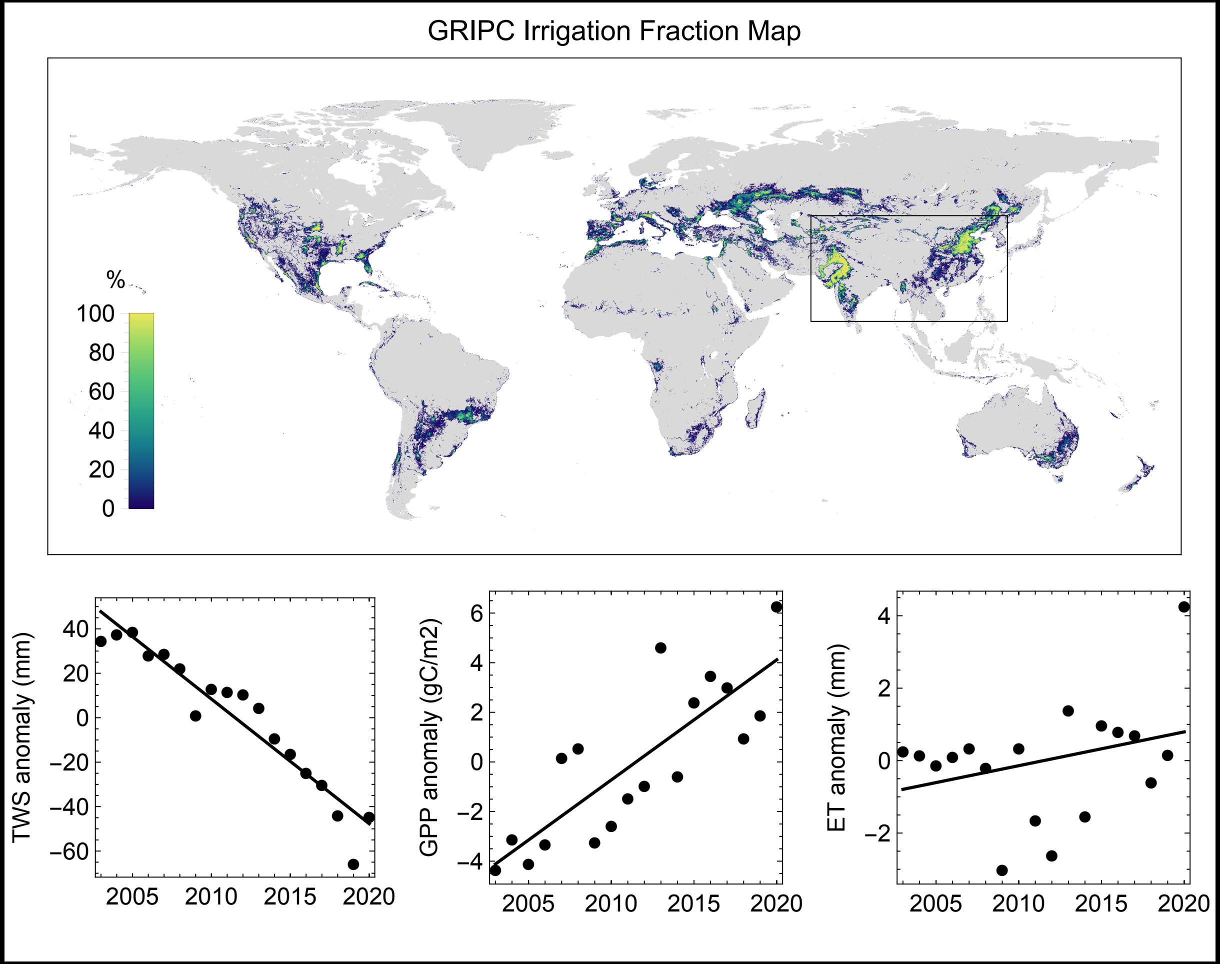





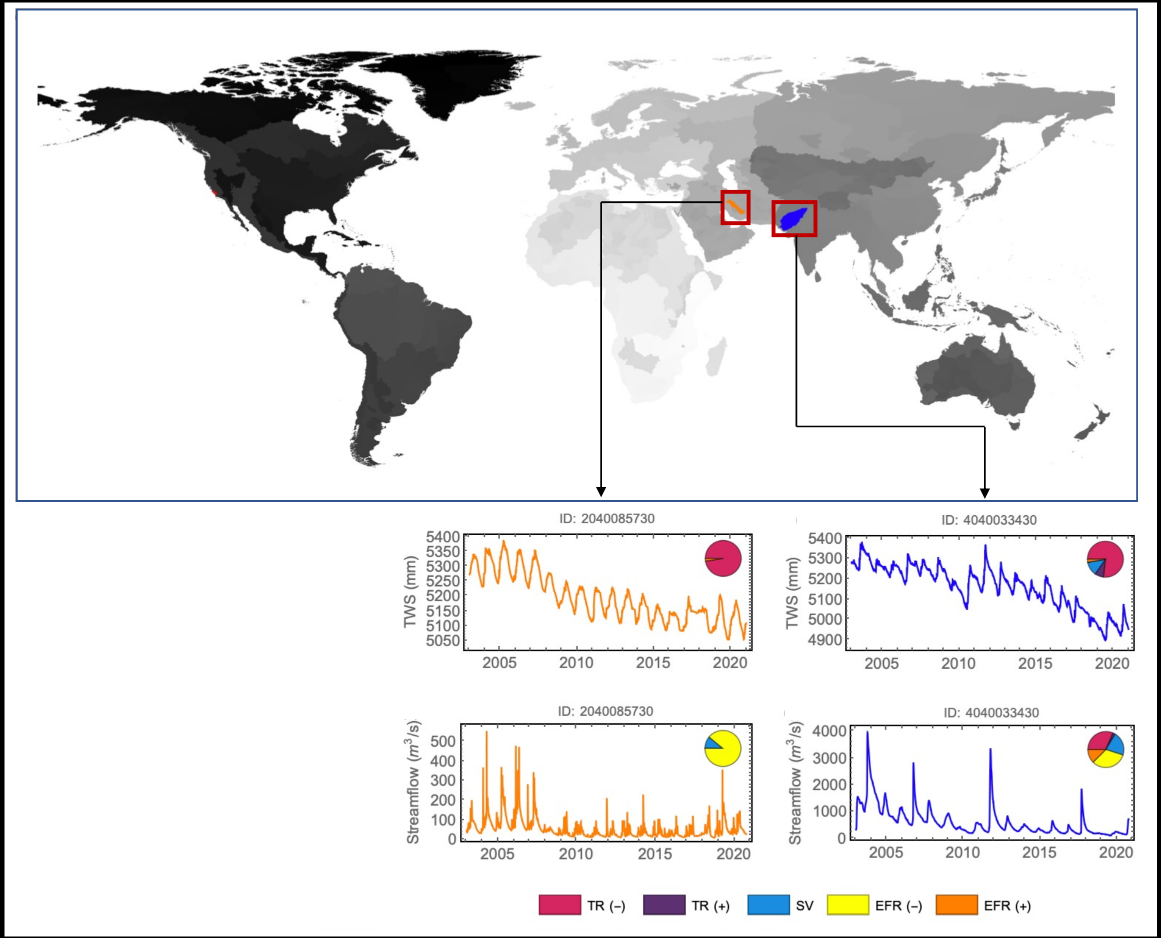

- There is an increasing trend in precipitation
- There is documented evidence for land use change and crop expansion in this area, contributing to a positive trend in GPP
- These two factors drive the nonstationarities in TWS, ET, and Runoff




- TWS non-stationarity dominated by long-term depletion trend.
- No clear trend identified for precipitation, the trend in TWS is mainly attributed to human water use such as irrigation pumping.
- The excessive use of water leads to greening, the sustained crop production leads to low non-stationarity in ET and carbon fluxes when ranked over the global context.

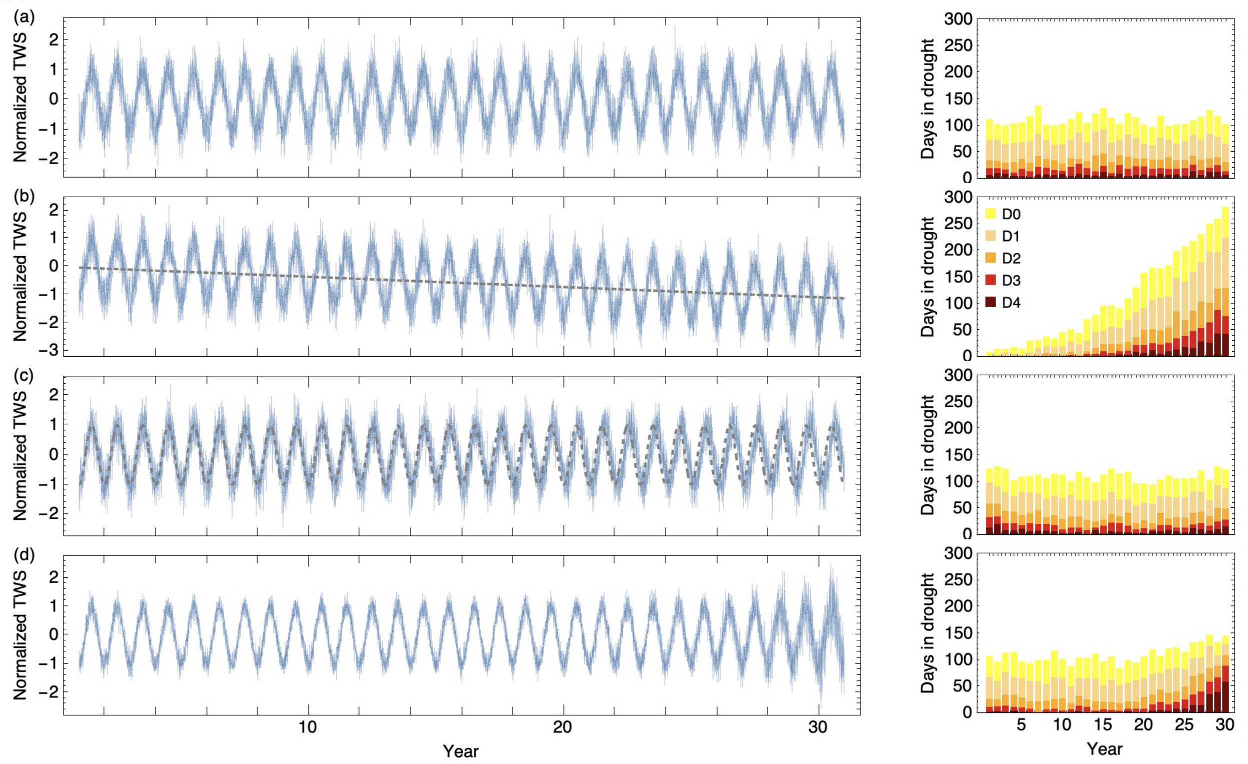



For irrigated south Asia, depletion of TWS due to GW pumping has supported crop growth. The reduced water availability and increased vegetation leads to mixed impacts in ET.




TWS depletion has led to overall damping of runoff extremes in many places in the world

# What does this mean for quantification of extremes?



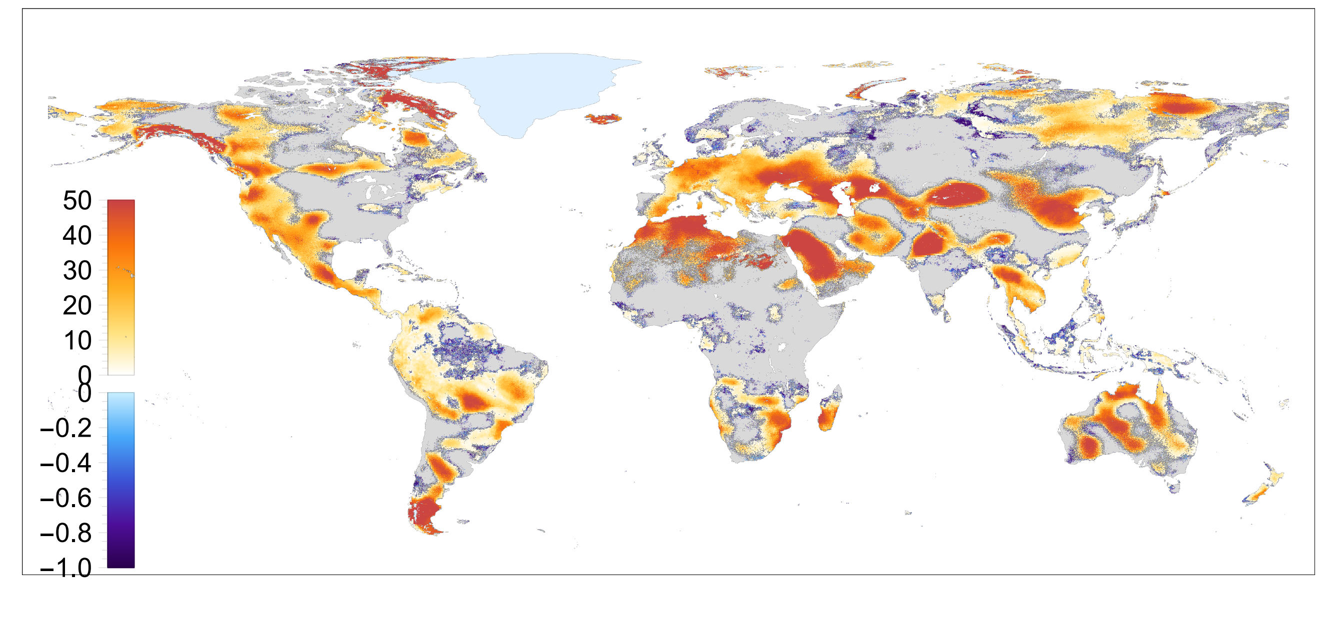

Stationary

Nonstationarity from trends

Nonstationarity from seasonal shifts

Nonstationarity from extreme frequency changes

# Large errors in drought estimation when nonstationarity is not acknowledged!




Several (~100) scenarios for estimating drought were considered, using different periods for reference data and climatology

Median bias in drought estimation across the ensemble members relative to a stationary assumption

# Summary

- Multivariate land remote sensing analysis reveals significant nonstationarities in the terrestrial water cycle with nearly half the world dominated by long-term trends (47%), followed by seasonal shifts (36%) and extreme changes (17%).
- Hotspot regions with intensive human disturbances show larger trends collocated with increased extreme frequencies.
- Nonstationarity changes must be incorporated for developing strategies related to the management of water availability and extremes.