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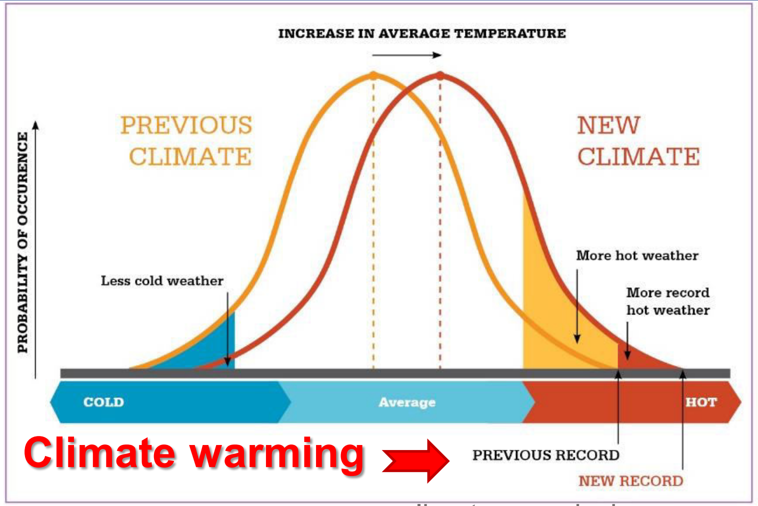
中山大學
SUN YAT-SEN UNIVERSITY

Response of Typical Vegetation Ecosystems to Hotter Droughts under A Changing Climate

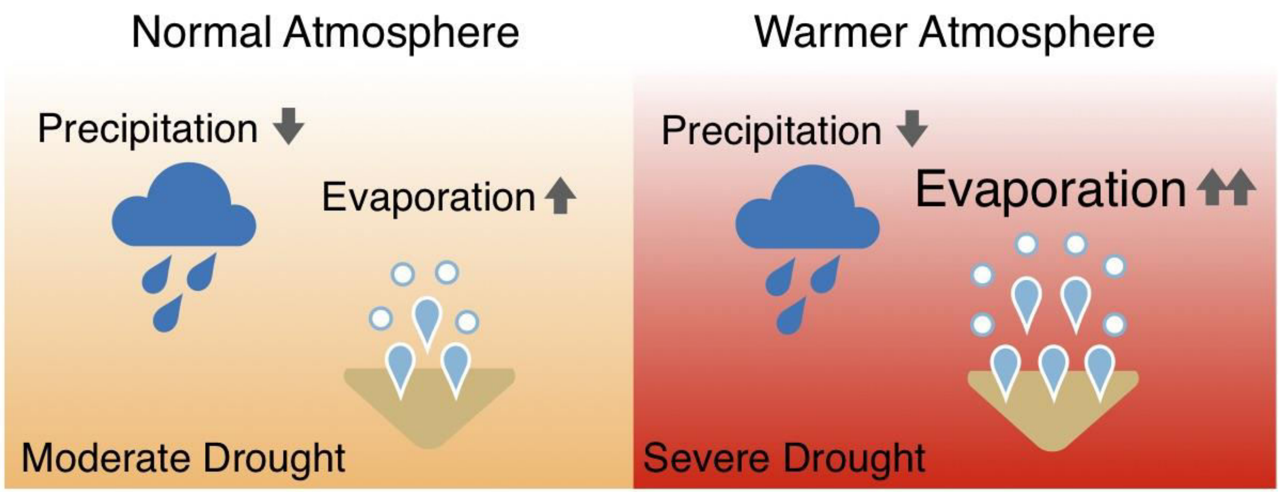
Chunyu Dong, Zhimin Ma, Yu Yan

Sun Yat-sen University

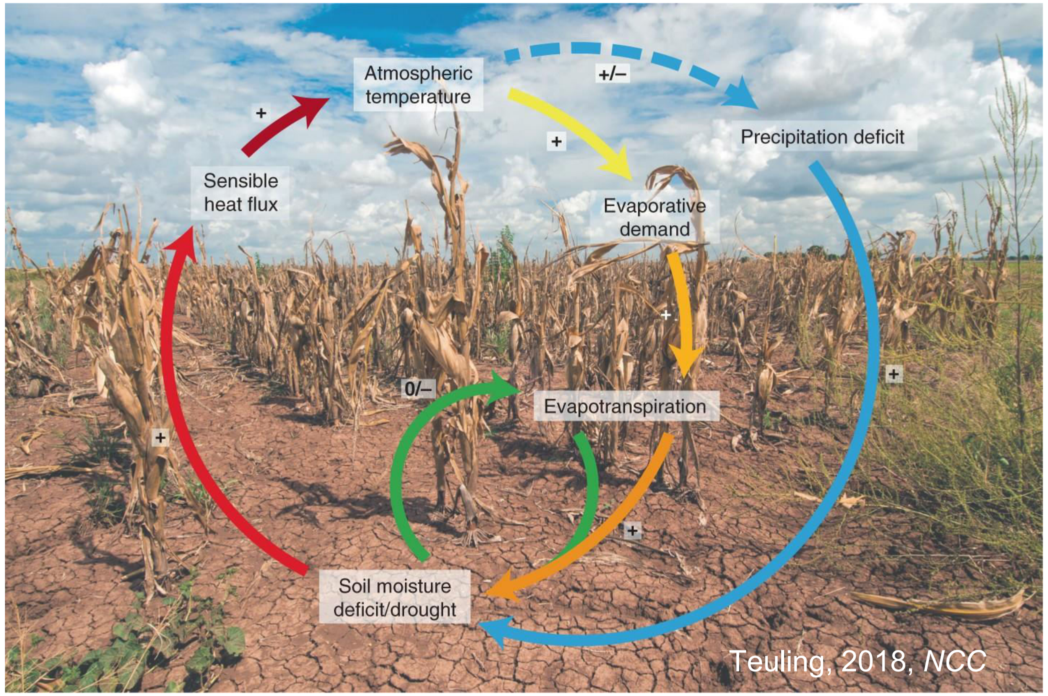
Background: climate warming + drought = hotter drought



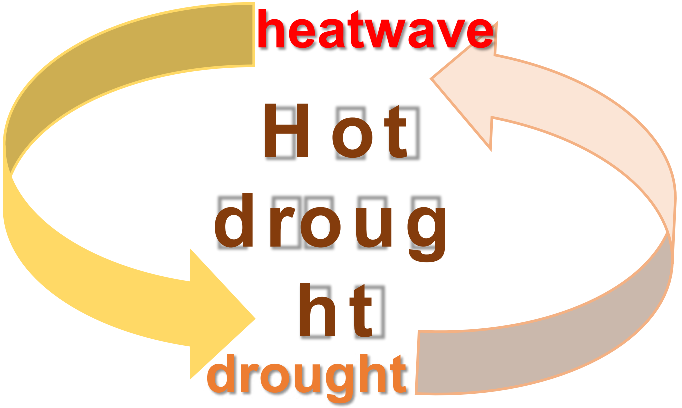
www.climatecommission.gov.au



Jessica Tierney on Twitter

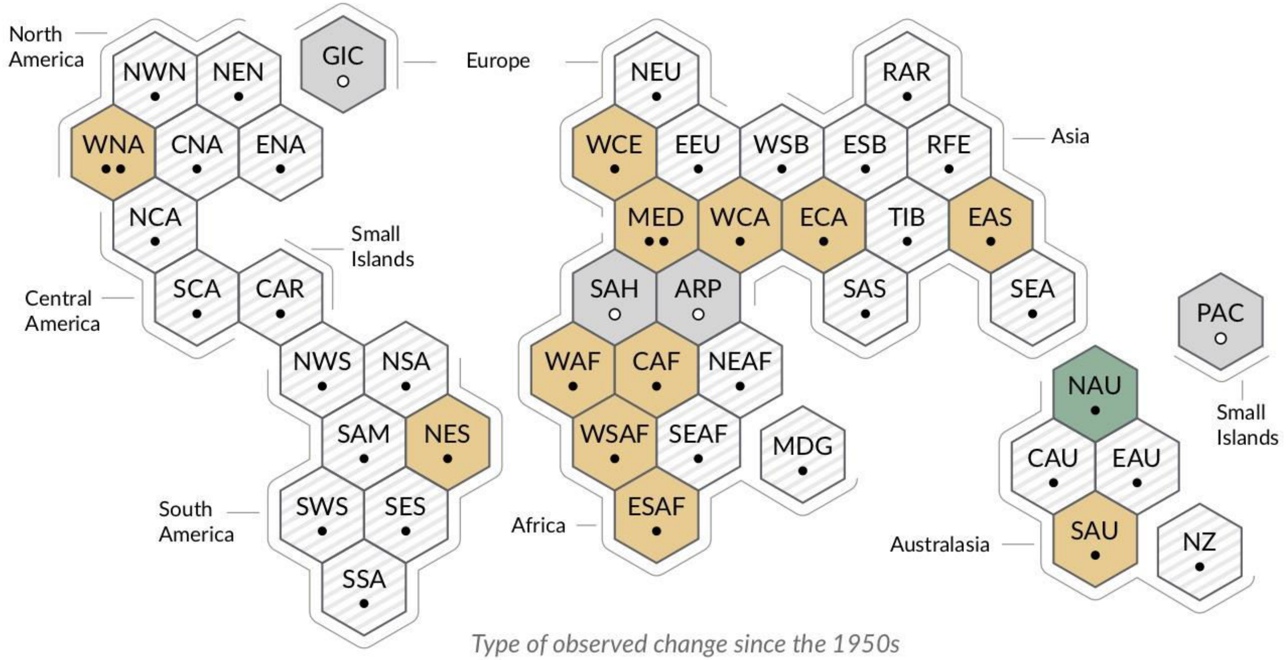


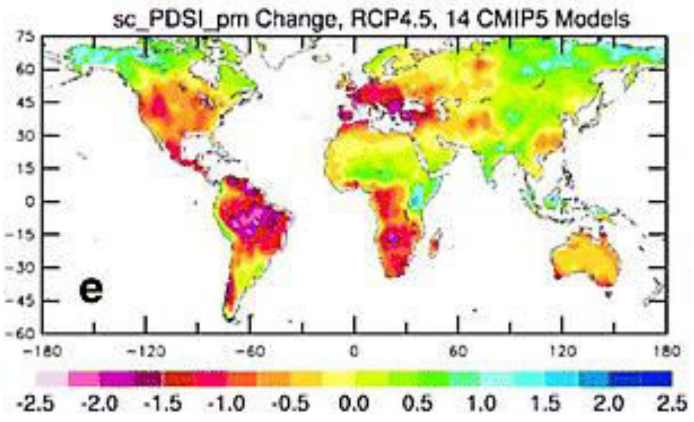
Teuling, 2018, *NCC*

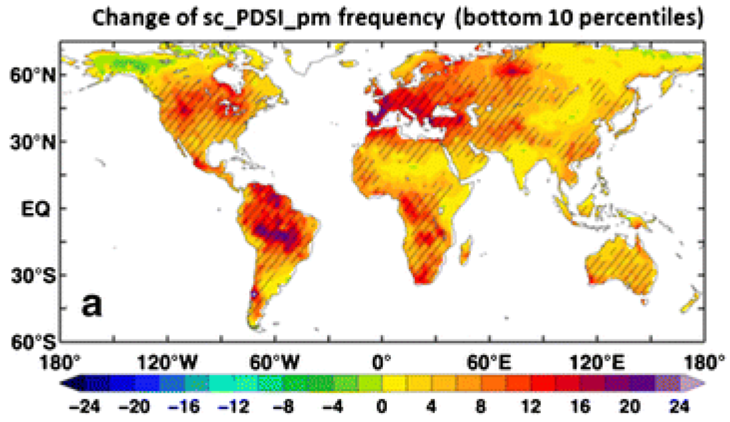


Positive feedback between heatwave & drought

Global warming & drought: past & future



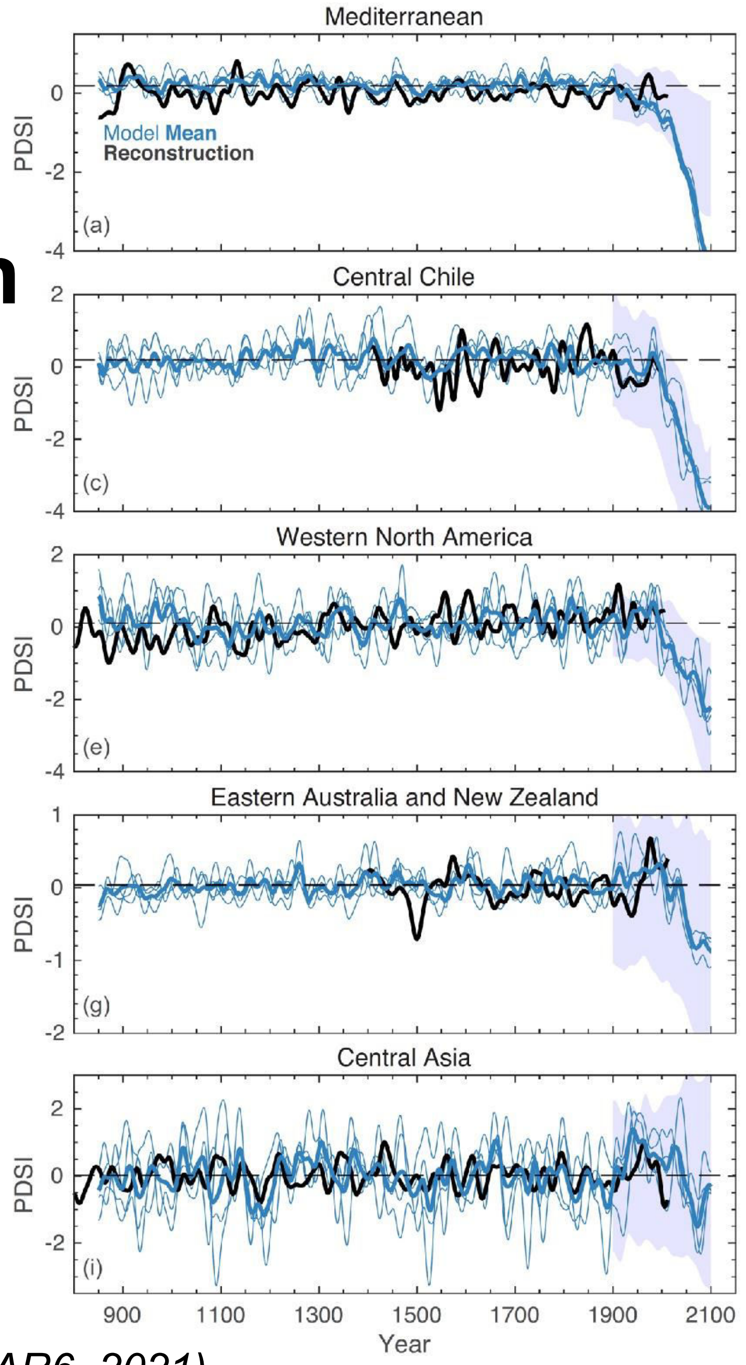




Dai et al. (2018)

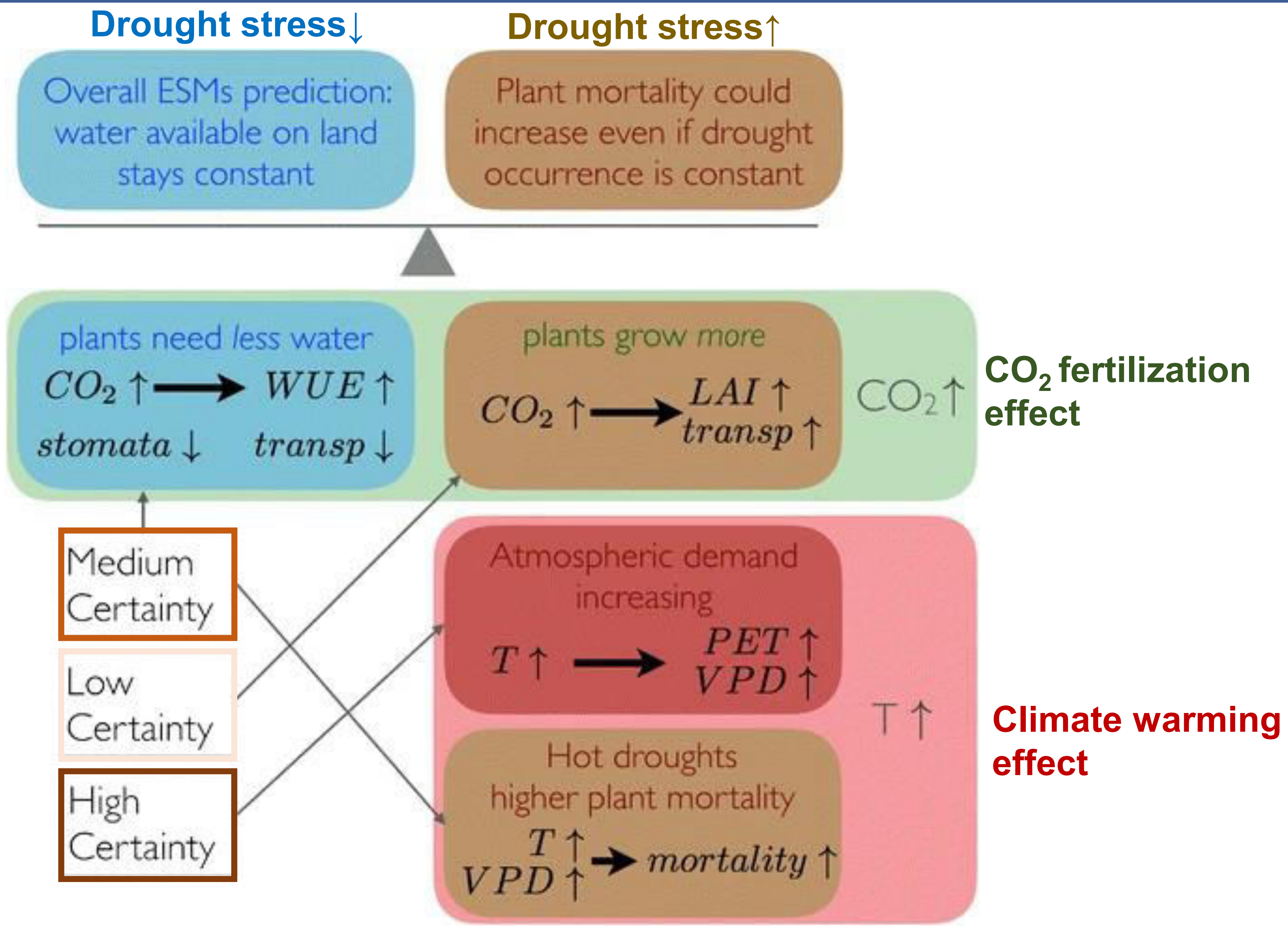
Projection

More and severer droughts



(IPCC AR6, 2021)

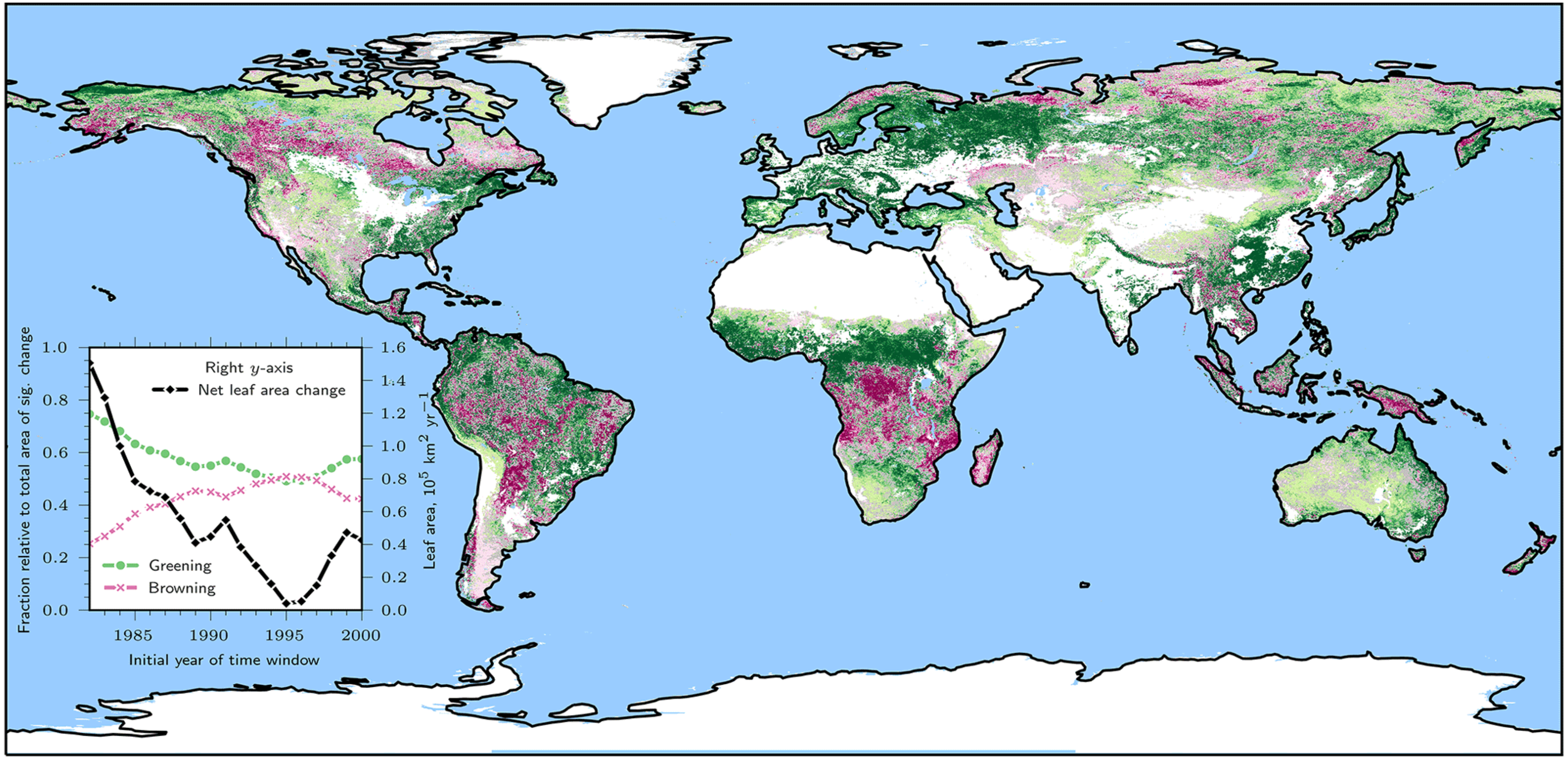
Background: Vegetation's response to future drought



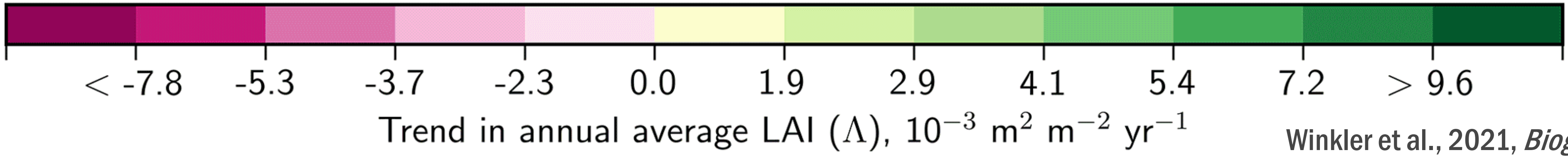
- **High certainty:**
  - warming→ PET and VPD increase
- **Medium certainty:**
  - CO_2 increase→ WUE increase
  - Warming & VPD increase→ mortality increase
- **Low certainty:**
  - CO_2 increase → LAI increase

Swann, CCCR (2018)

Background: continued global greening?



Slow-down of greening + partly browning



Winkler et al., 2021, *Biogeosciences*

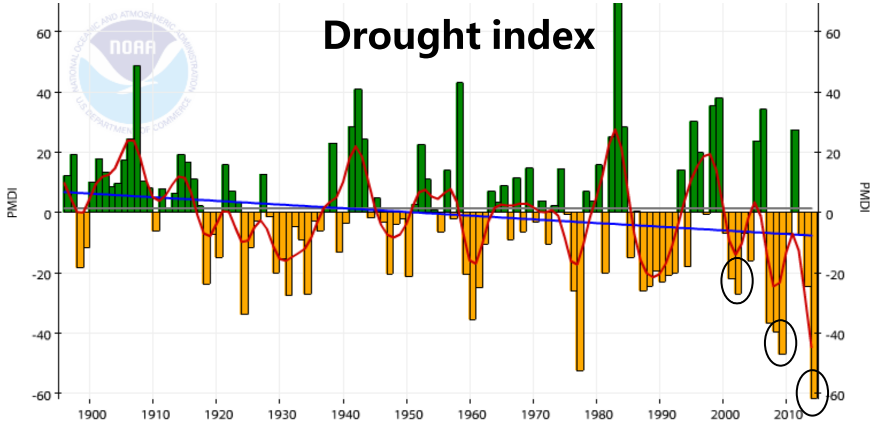
Question

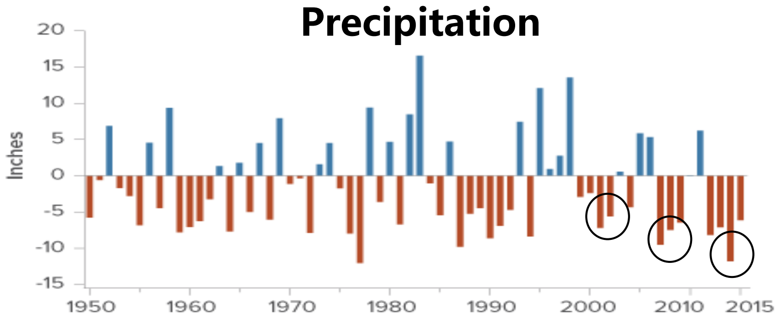
Q1: What are the impacts of hotter droughts on different vegetation ecosystems?

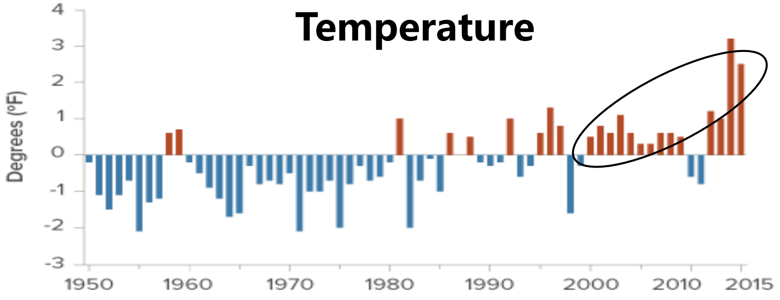
Q2: What are the main drivers for different response of vegetation to drought?

Urban vegetation in Los Angeles

Case study: Mediterranean Climate, California

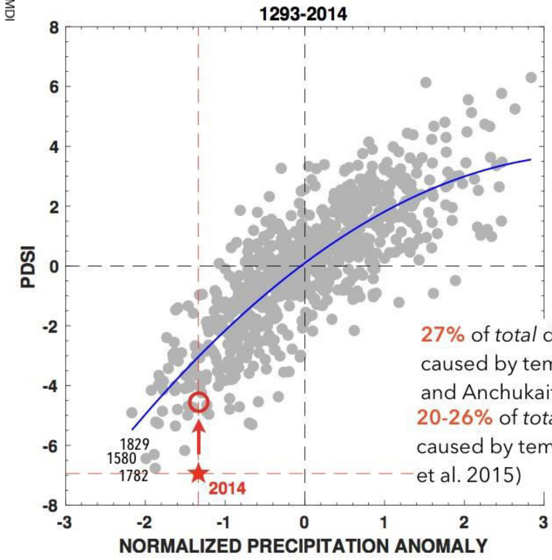






Distribution of P & T anomalies in droughts

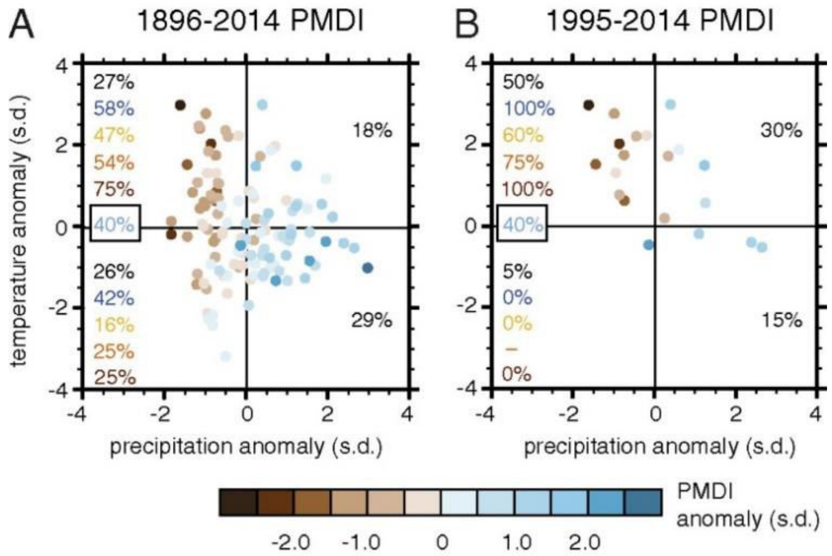
(Diffenbaugh N.S. et al. PNAS 2015)



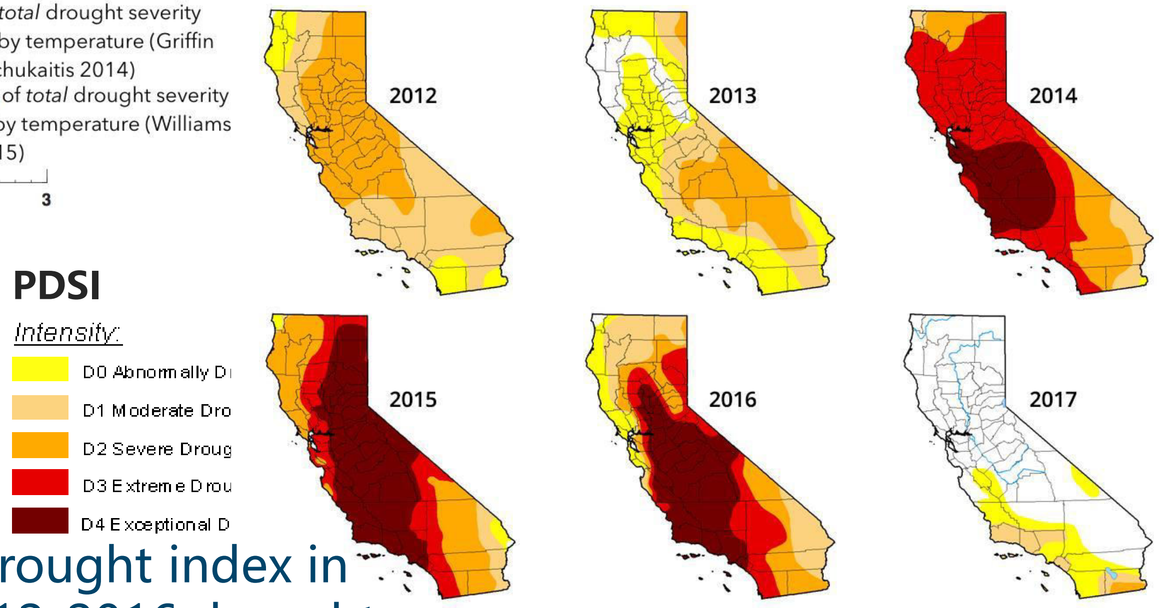
27% of *total* drought severity caused by temperature (Griffin and Anchukaitis 2014)

20-26% of *total* drought severity caused by temperature (Williams et al. 2015)

Jessica Tierney on Twitter



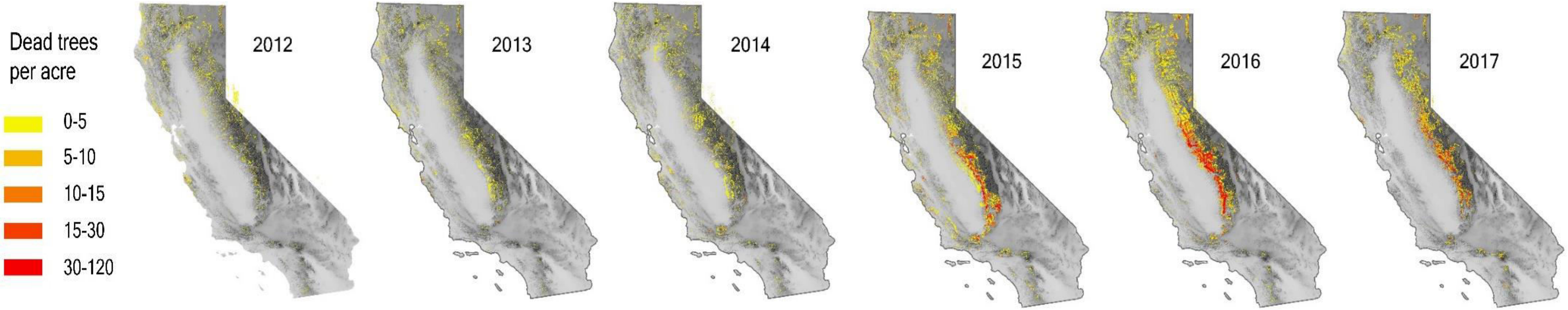
Hotter droughts in recent years



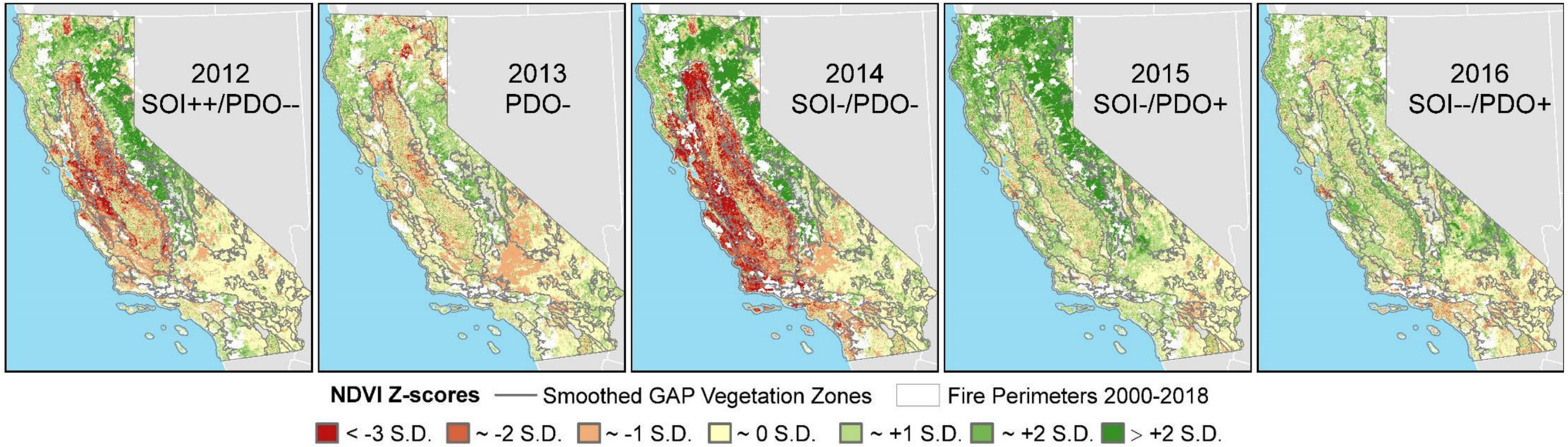
Drought index in 2012-2016 drought

California Drought Monitor Visualizations for March Since 2012

Latitudinal difference of vegetation's response to drought in CA



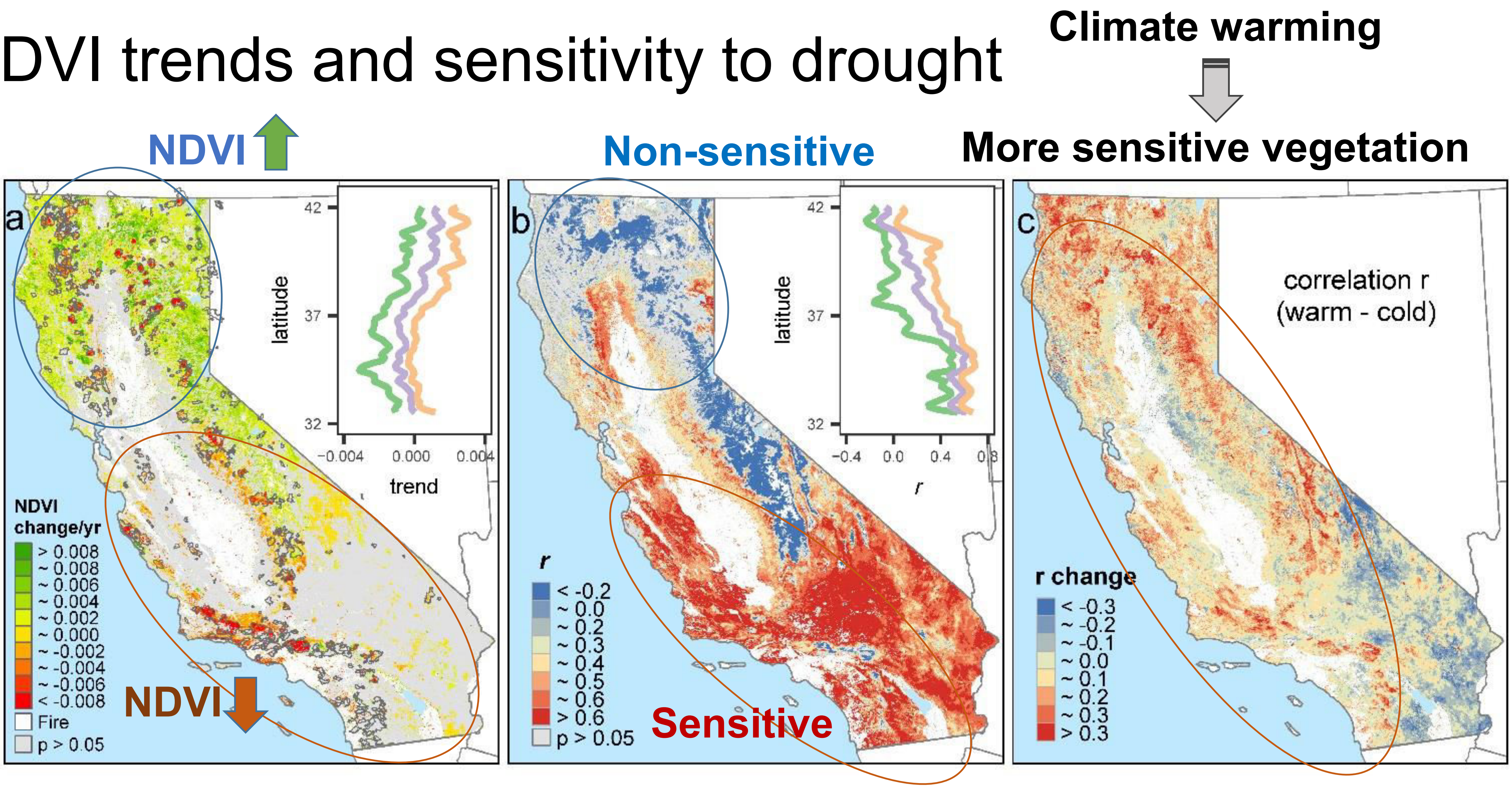
Tree mortality in 2012-2016 CA drought



NDVI change in 2012-2016 drought

Dong et al, GRL (2019)

NDVI trends and sensitivity to drought



NDVI trends

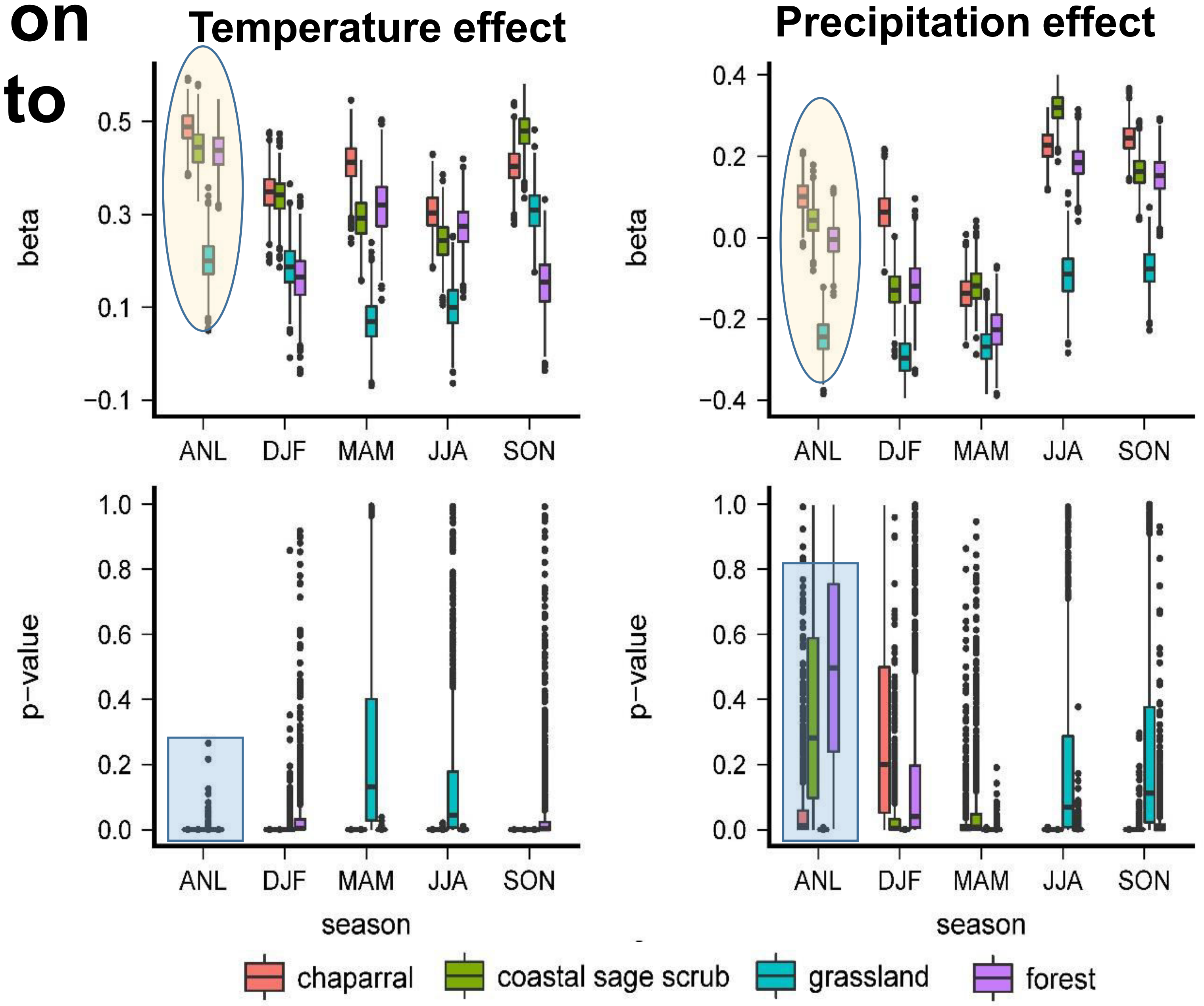
NDVI-PDSI correlation *r*

Δ(NDVI-PDSI correlation *r*)
(warm period-cold period)

Dong et al., 2019, *GRL*

Impact of T & P change on vegetation's sensitivity to drought

- Warming can increase all vegetation's sensitivity to drought
- Shrubs are most vulnerability
- Grasses will be less affected



ANL: annual, DJF: winter, MAM: spring, JJA: summer, SON: fall

Dong et al., 2019, *Remote Sens.*

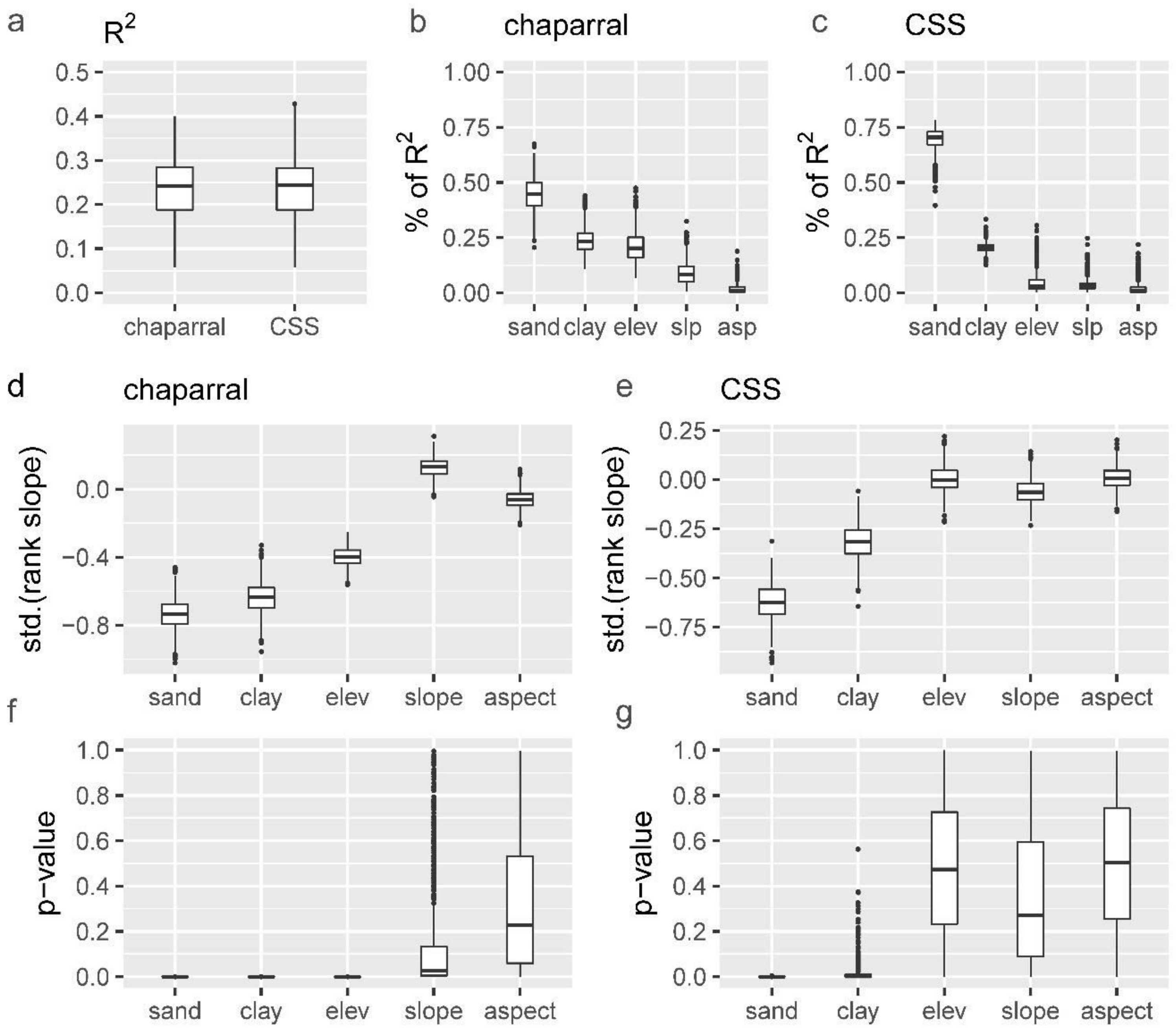
Impact of topography & soil on vegetation's sensitivity to drought

- Higher soil moisture holding capacity

  -> less sensitive to drought

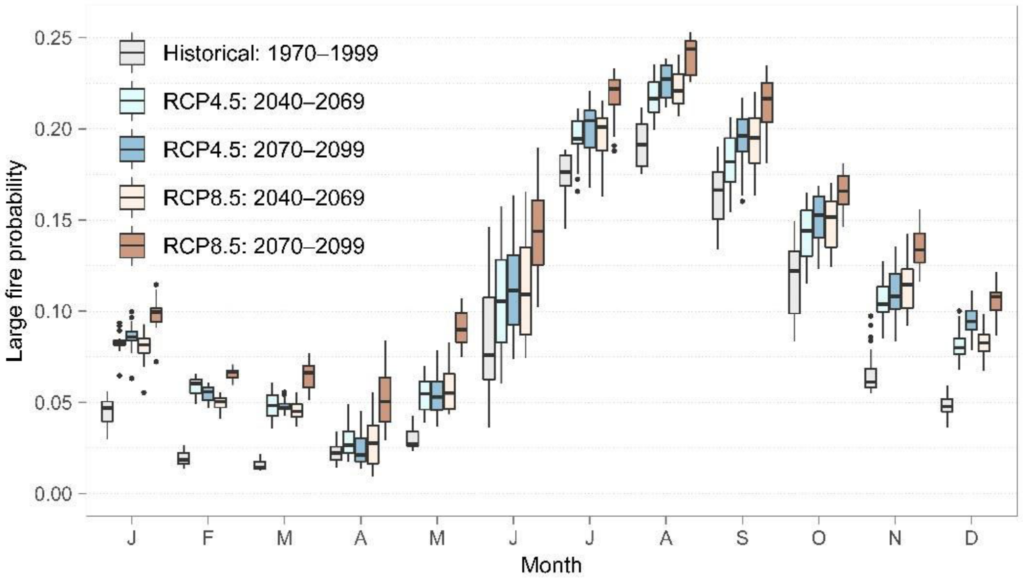
- Higher elevation and/or lower slope

  -> less sensitive to drought

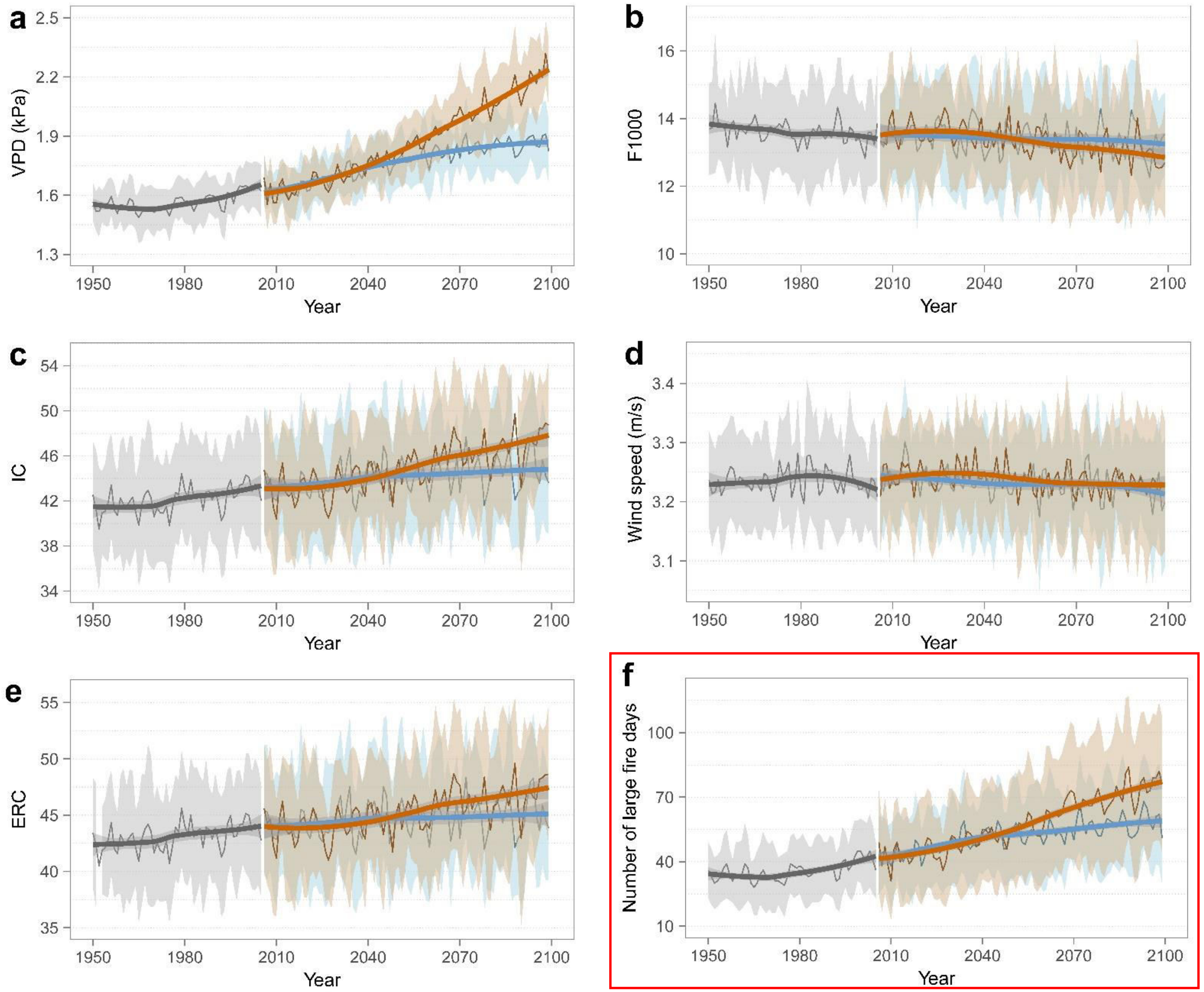


Okin & Dong et al., 2018, *JGR: Biogeosciences*
Gillespie, Ostermann-Kelm, Dong et al., 2018, Ecological Indicators

Climate change increases vegetation degradation and wildfire risk in CA

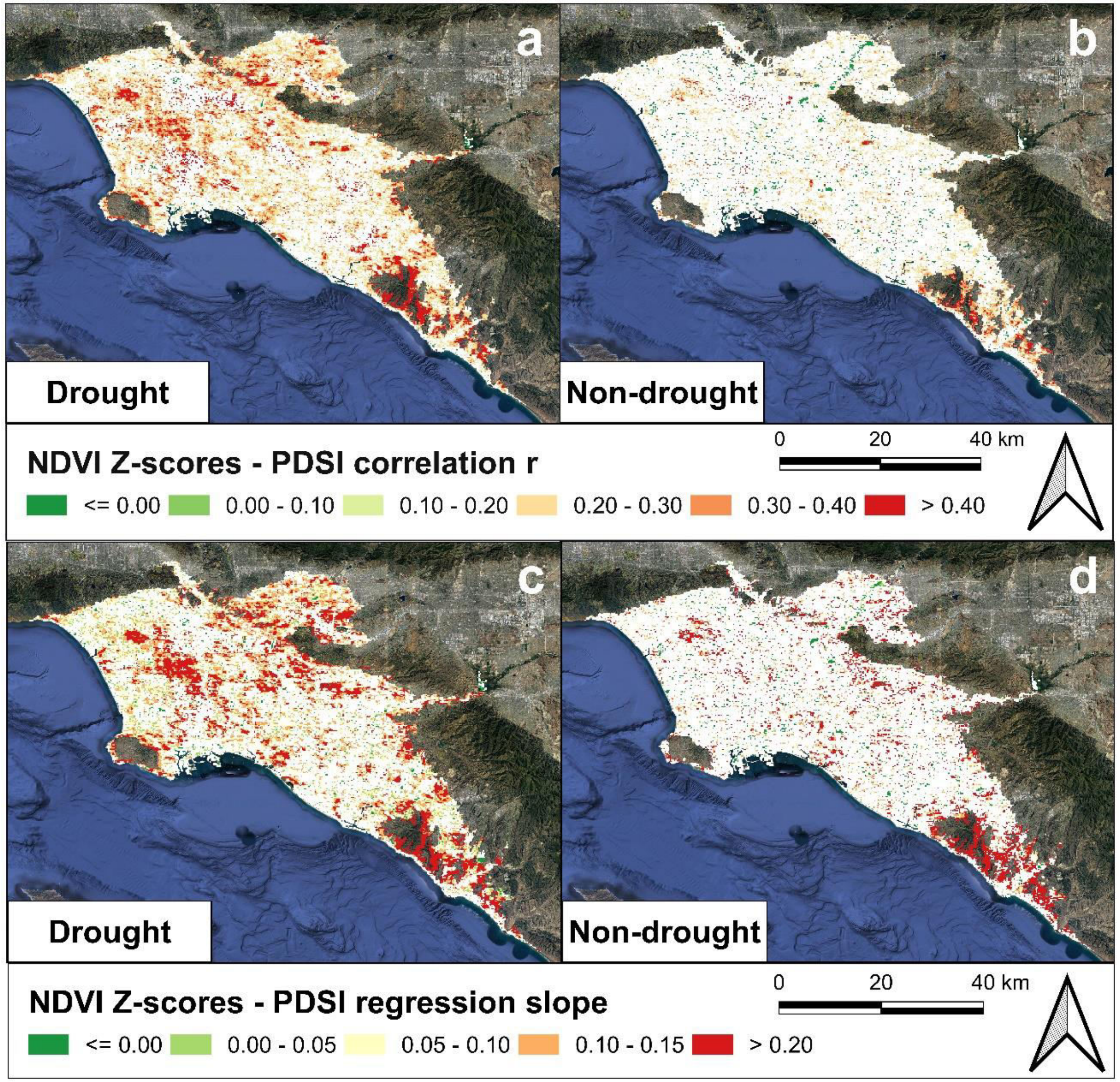


- Higher GHG emission
→ Increased hotter droughts
→ Prolonged fire season & large-fire days

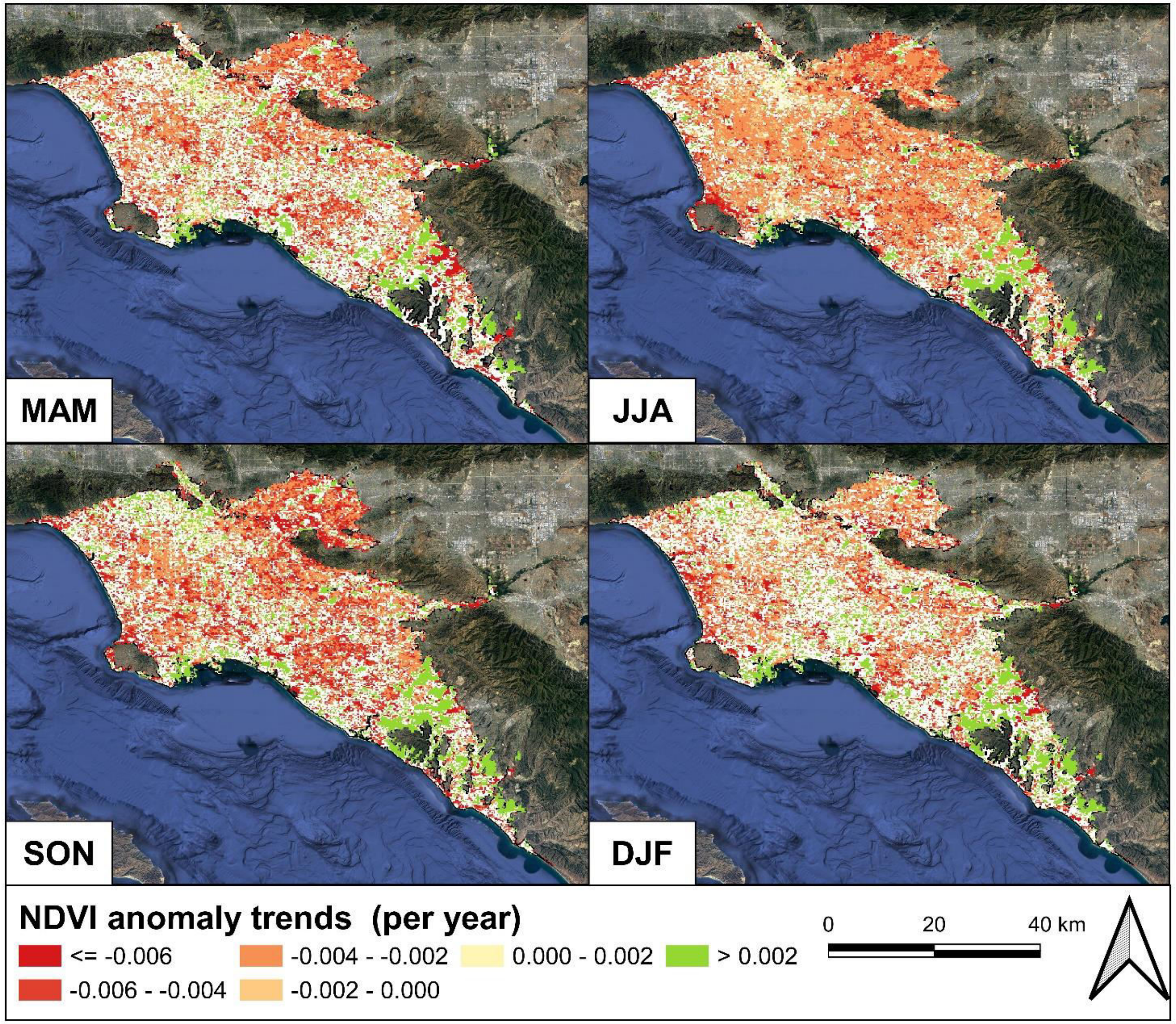


Dong et al., 2022, *Communications Earth & Environment*

Diverse urban vegetation response in hotter droughts

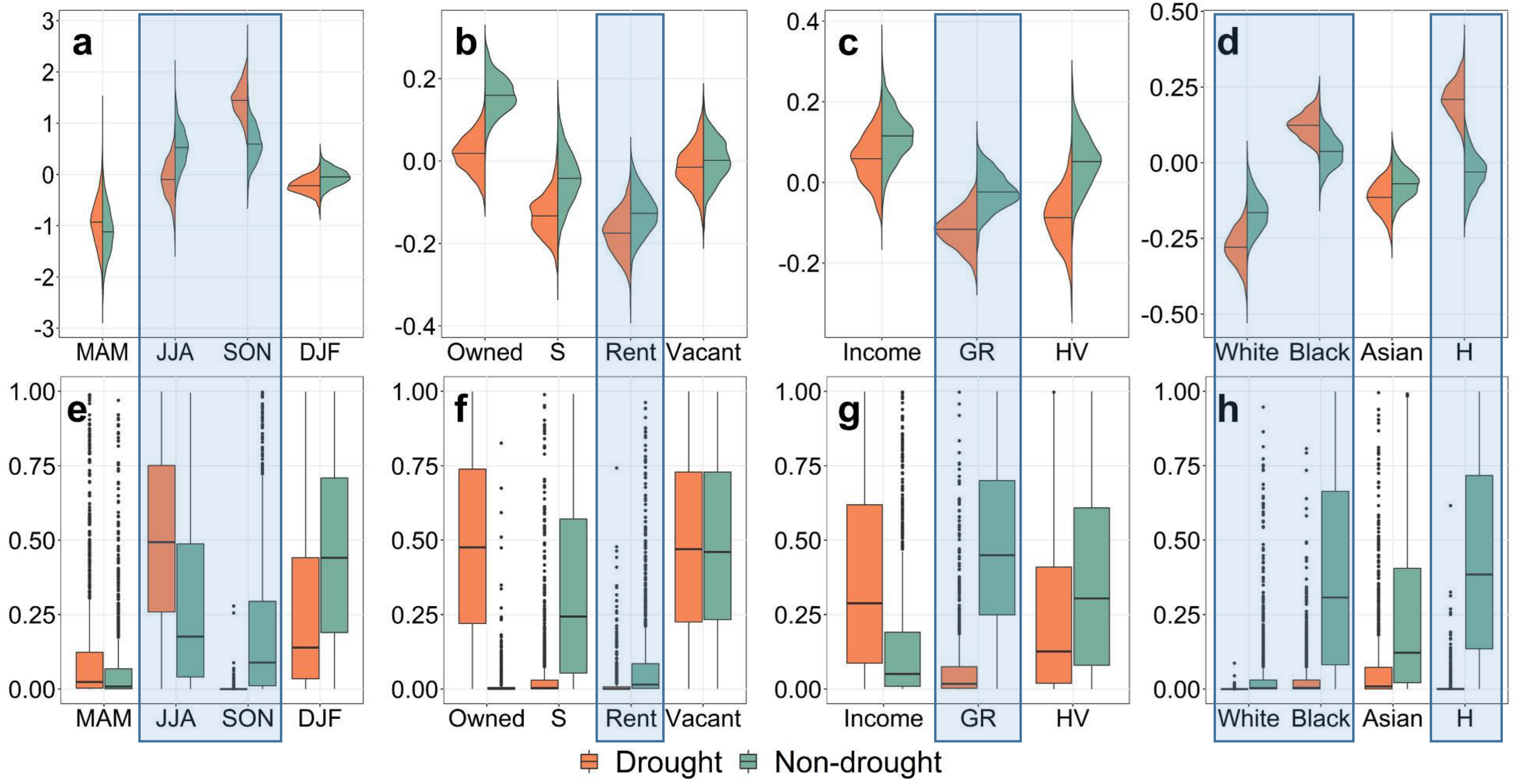


Greenness's sensitivity to drought in LA



Greenness trends in LA

Drivers of different urban vegetation's sensitivity to hotter drought



- Higher dry season T, more sensitive vegetation to drought
- Higher rent, lower sensitivity
- More White population, lower sensitivity
- More Black and/or Hispanic population, higher sensitivity

MAM: spring T; JJA: summer T; SON: fall T; DJF: winter T; S: seasonal use; GR: gross rent; HV: house value; H: Hispanic population

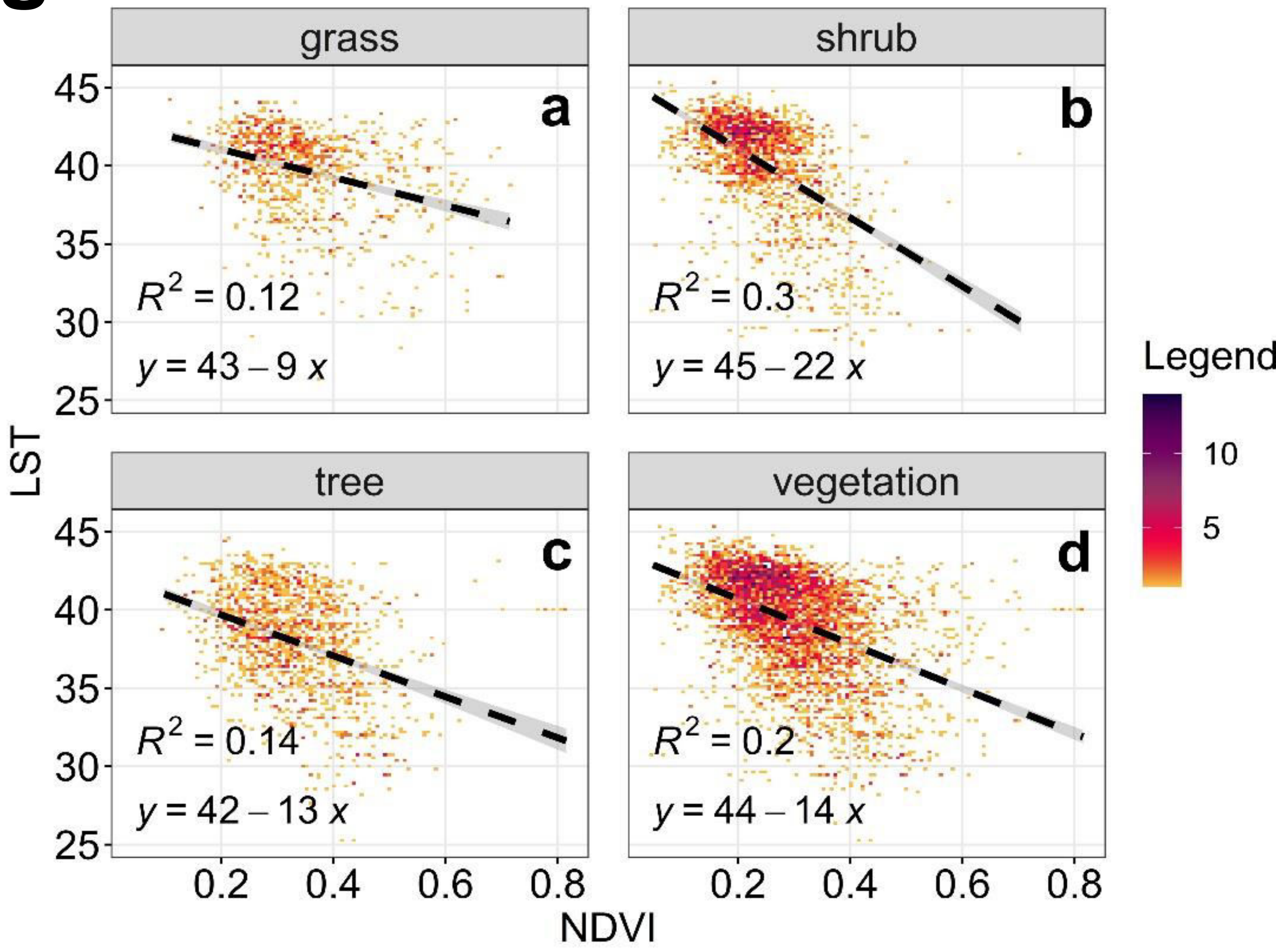
Dong et al., 2023, *Sustainable Cities and Society*

Vegetation's cooling effect change in hotter drought

- Cooling effect：

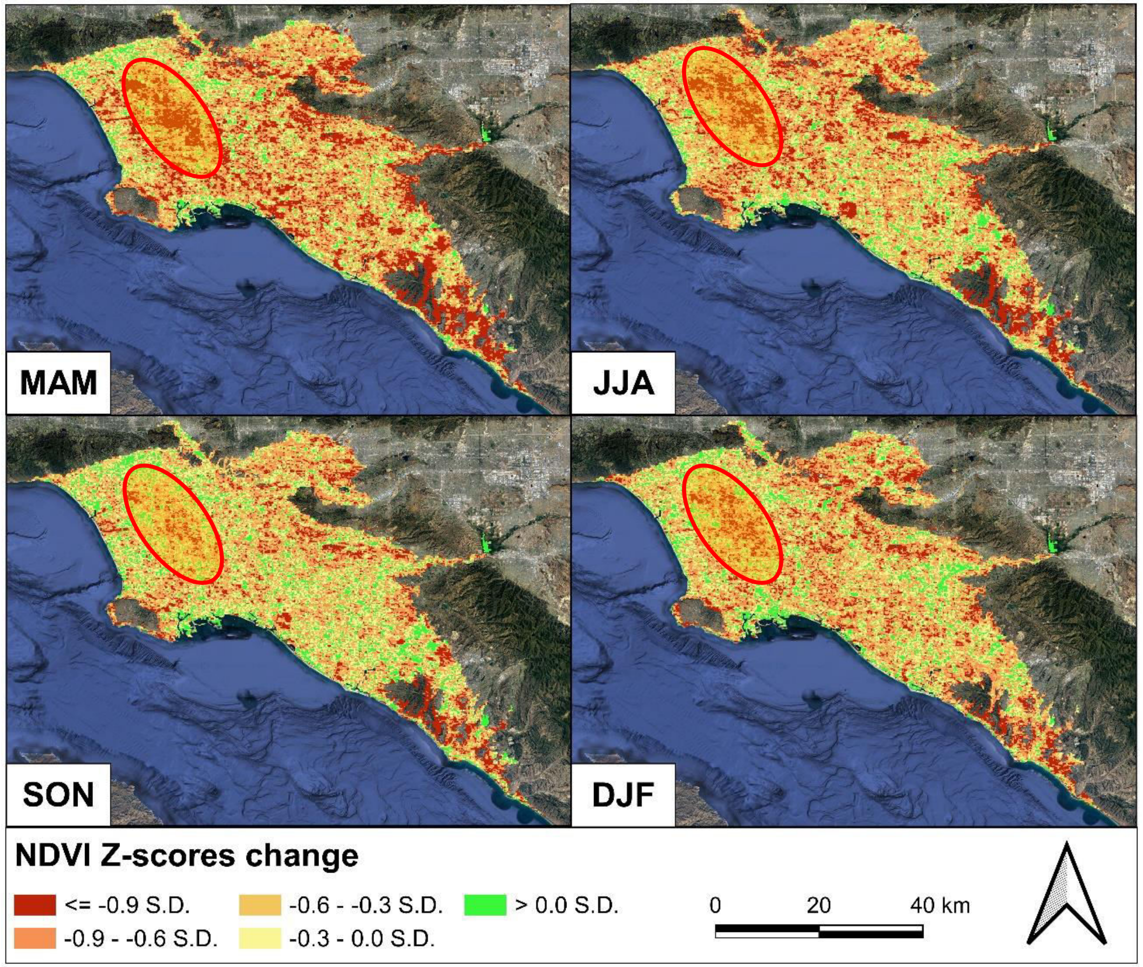
  shrub > tree > grass

- NDVI ↑， Cooling effect ↑



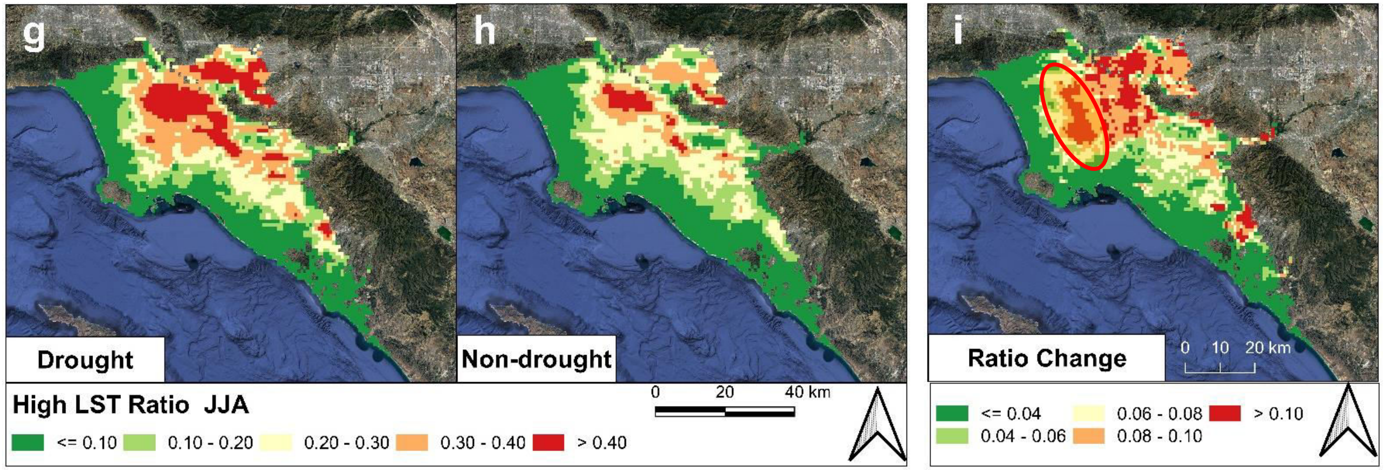
LST~NDVI regressions

Comparisons between NDVI & heatwave change in drought



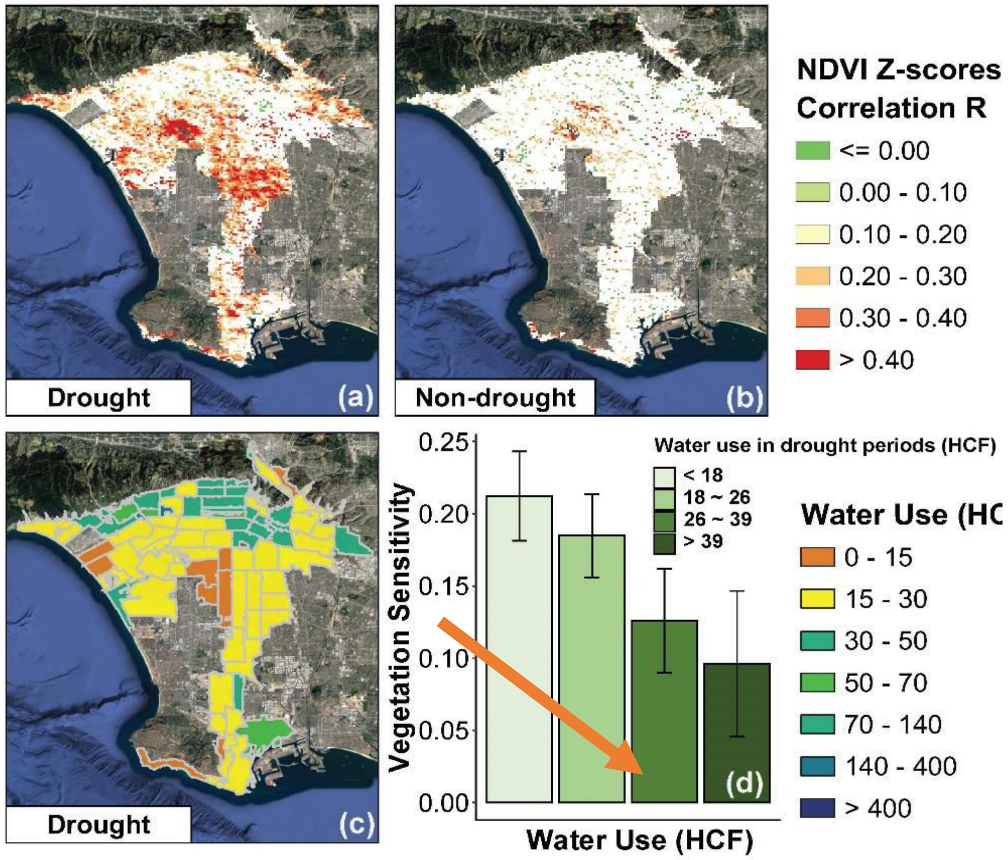
NDVI change

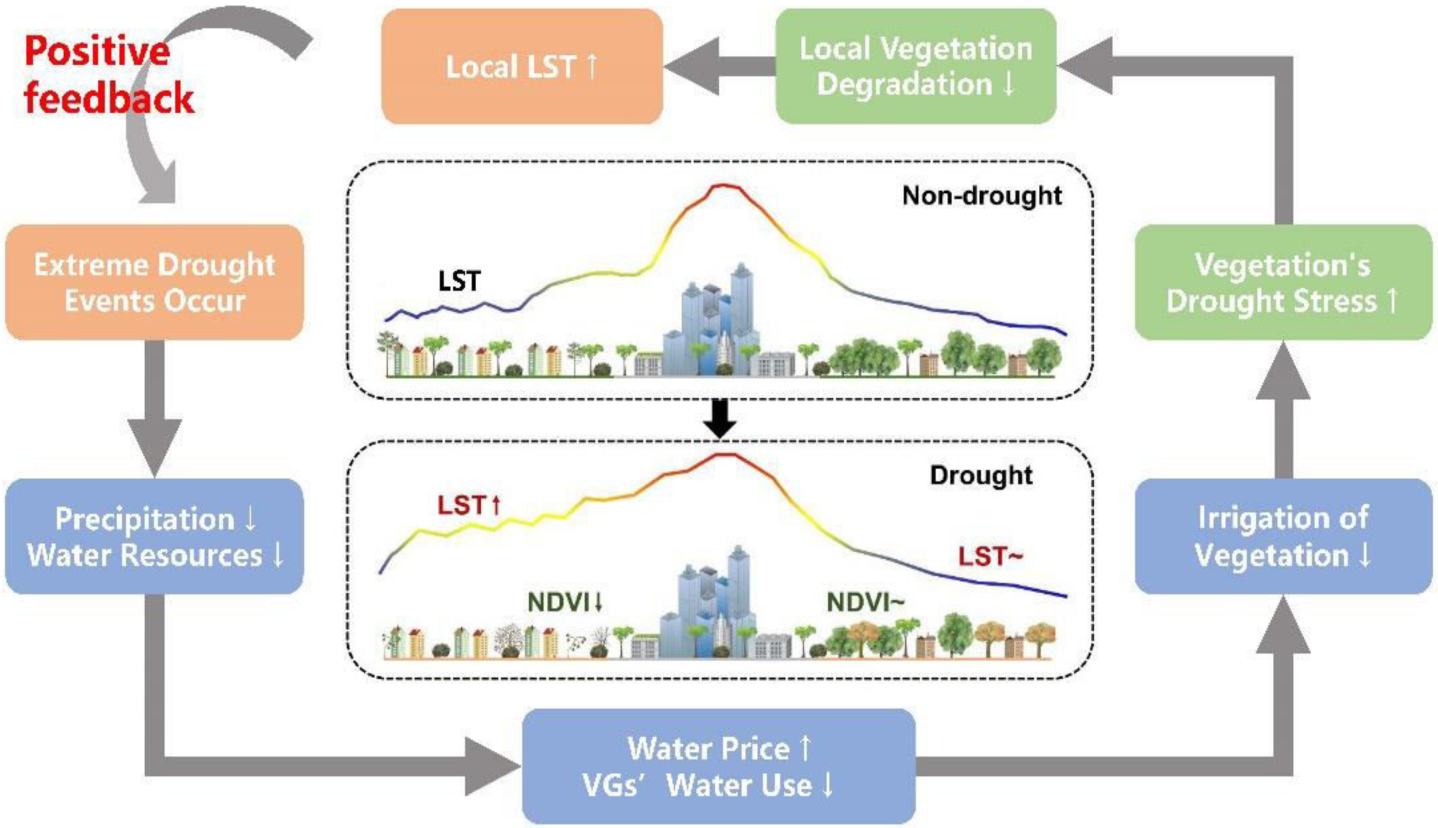
干旱期高温比例　　非干旱期高温比例　　比例变化（干旱-非干旱）



- NDVI declines —> heatwave increase
- —> More NDVI declines
- Mostly occurred in disadvantaged communities

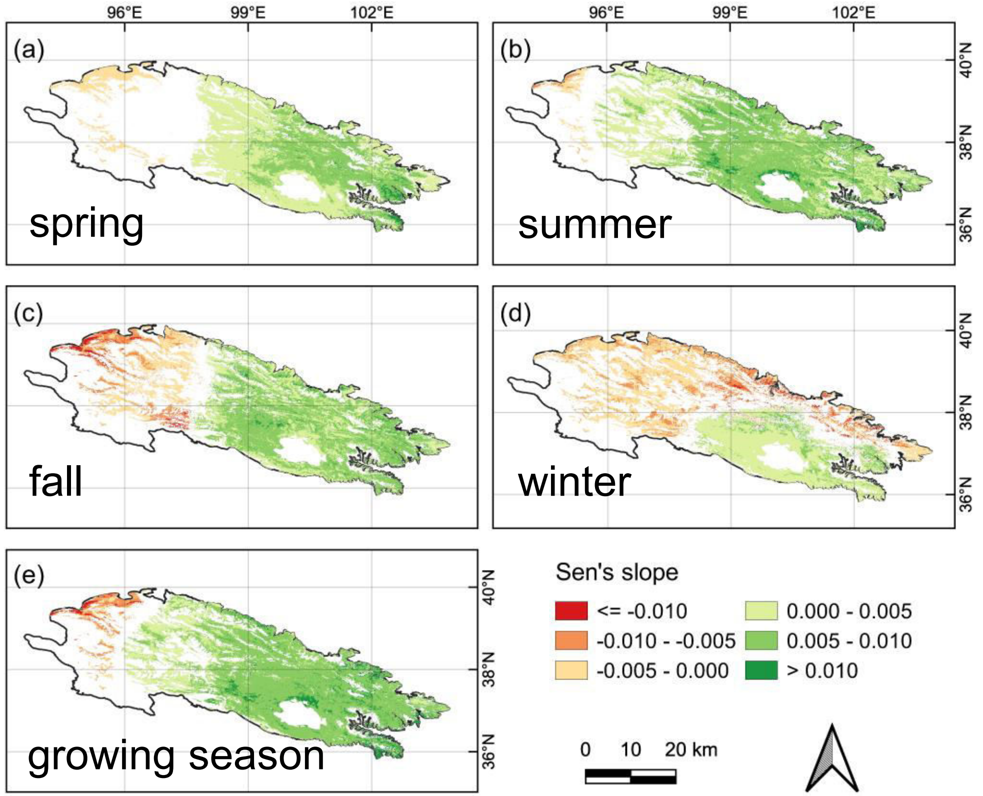
Positive feedback of vegetation-water-heatwaves in cities





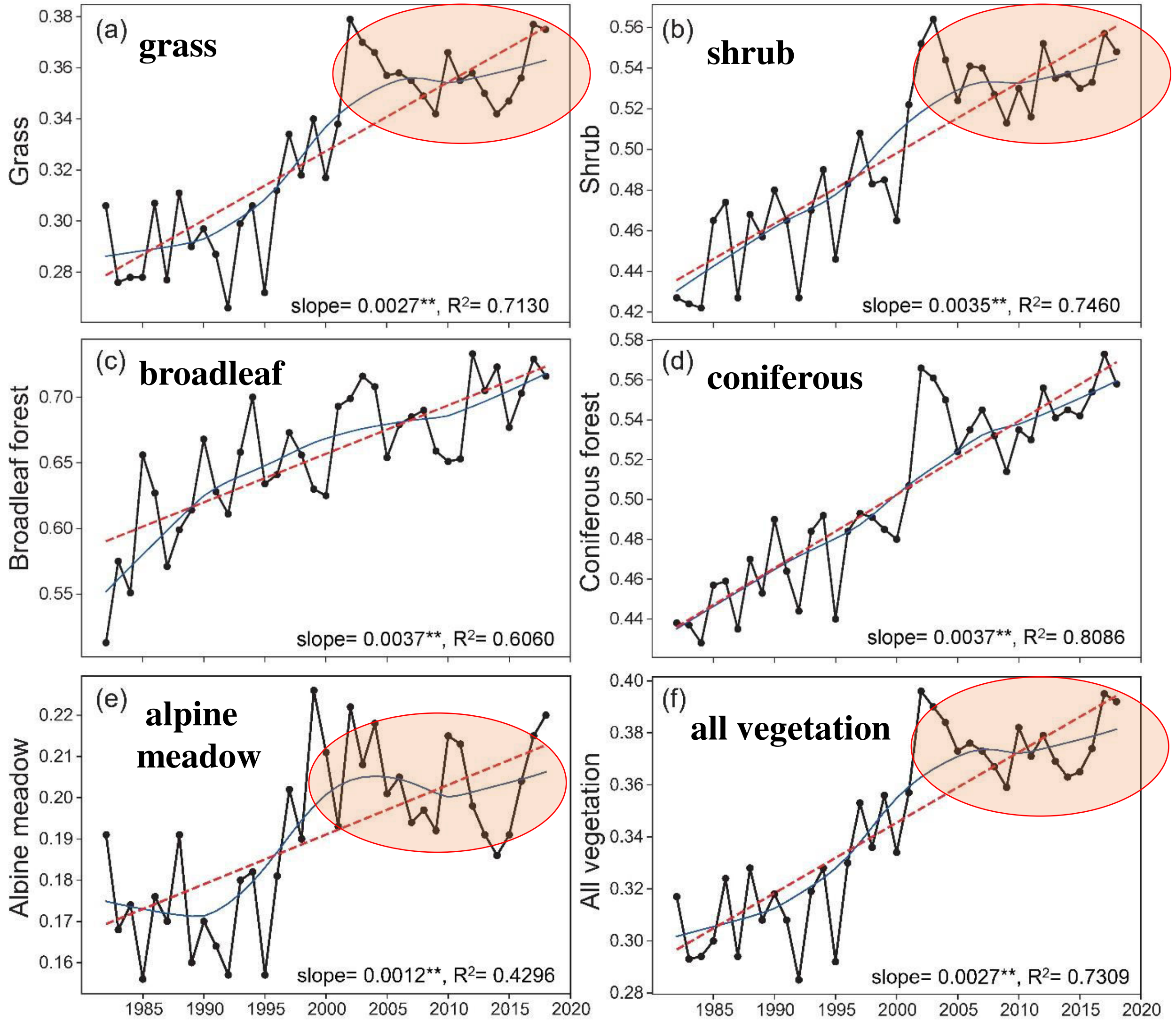
irrigation ↑ **sensitivity to drought** ↓

Case study: Qilian Mountains (QLMs), NW China



Seasonal NDVI trends

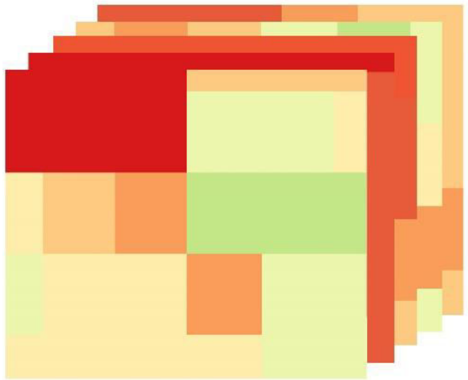
- Greening in east & browning in west
- Fast greening during 1995~2005
- Slow-down of greening since 2005



Ma & Dong et al., 2023, *J. Hydrol.*, under review

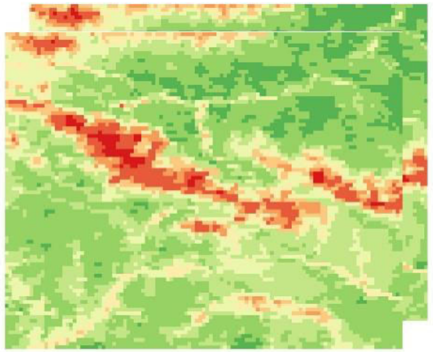
Development of an NDVI downscaling algorithm

Low resolution
Long series
NDVI (coarse)



AVHRR
(0.05°, daily, 1981-2018)

High resolution
Short series
NDVI (fine)

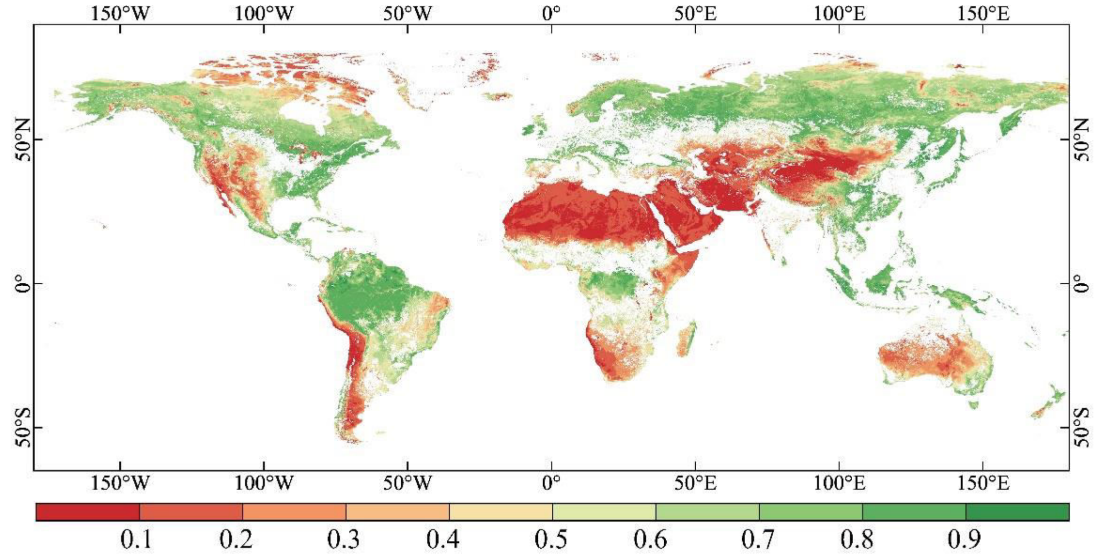


MODIS
(250 m, 16d, 2001-2018)

$$NDVI_{downscaled} = f(NDVI_{coarse}, NDVI_{fine}, CV)$$

Google Earth Engine

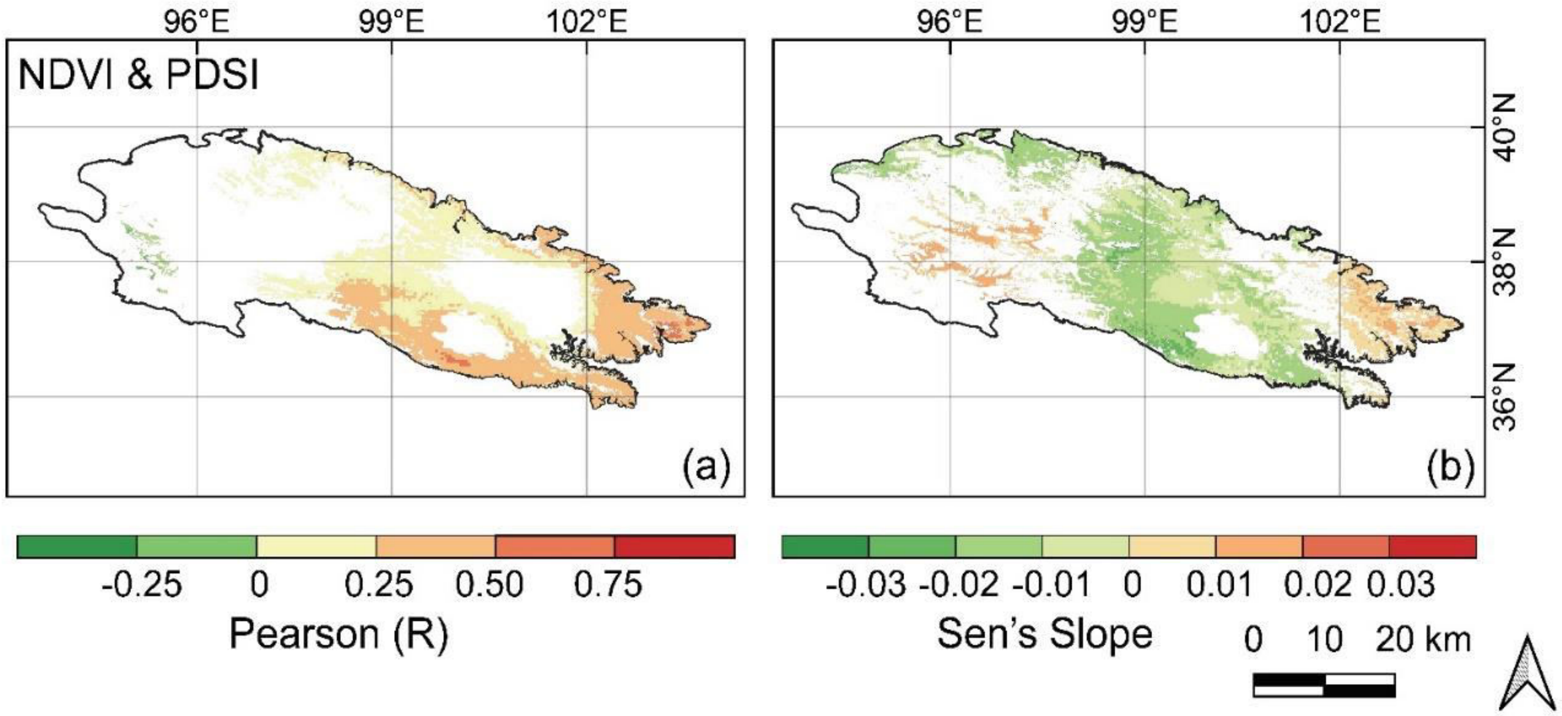
High resolution
Long series



Global Downscaled NDVI
(250 m, monthly, 1982-2018)

Ma & Dong* et al., 2022, *Remote Sens.*

Spatial variability of vegetation's sensitivity to drought



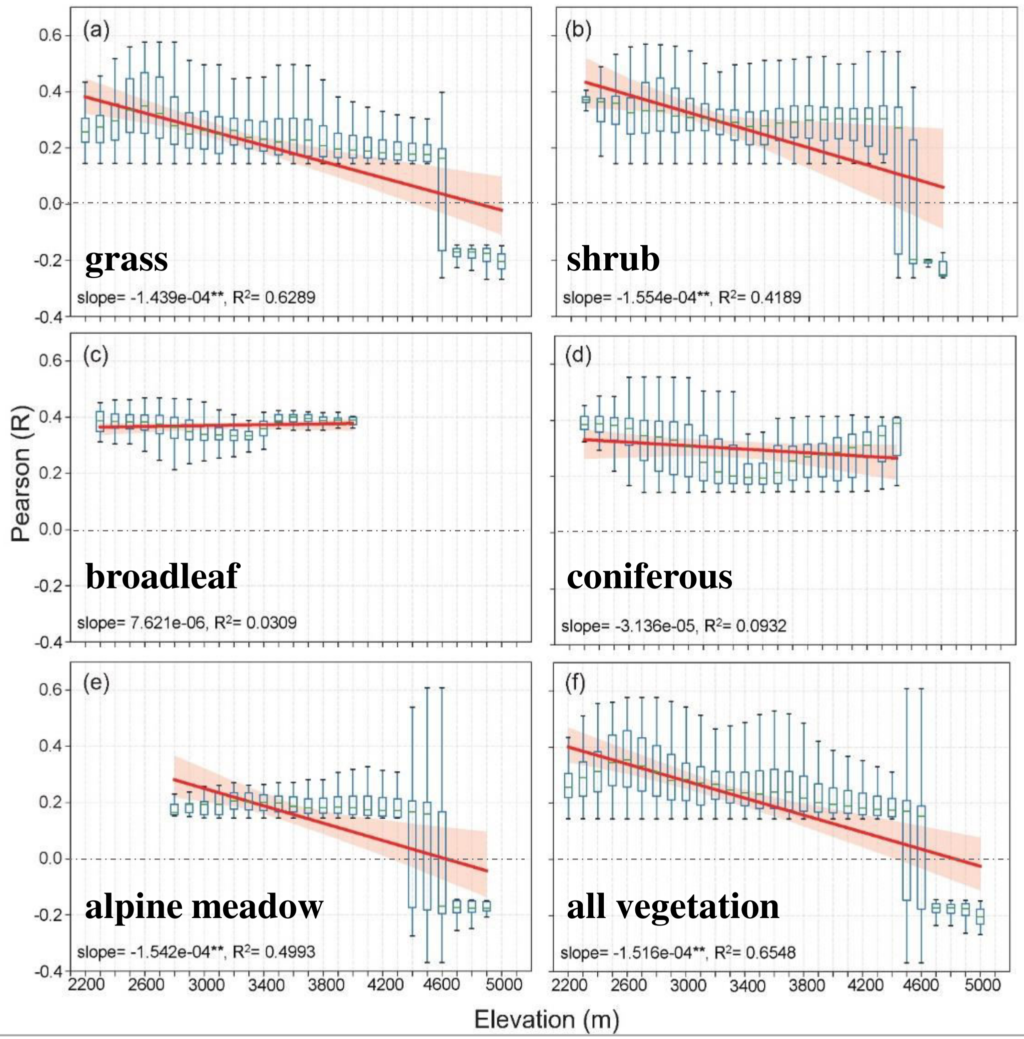
Sensitivity to drought

Trends of sensitivity to drought

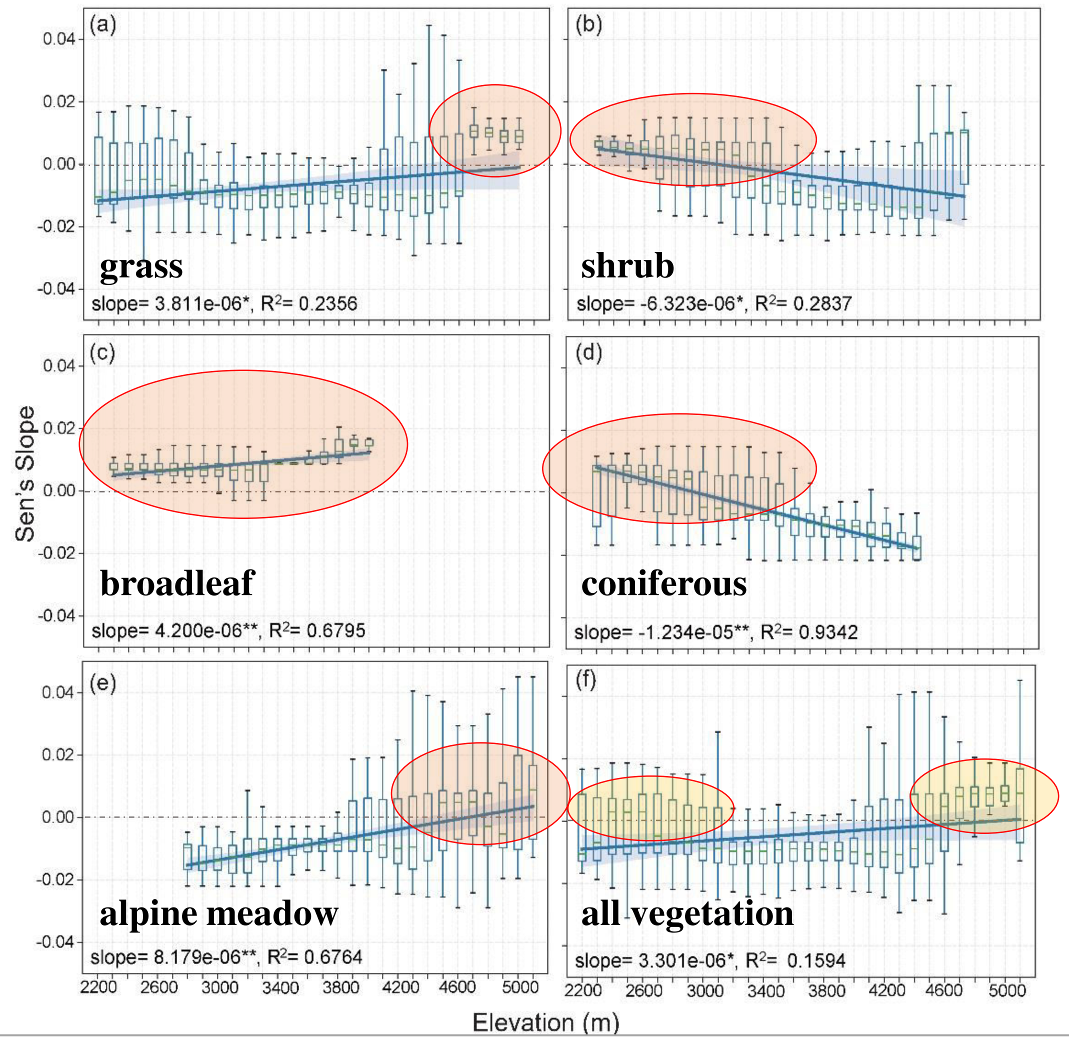
- High sensitivity to drought for vegetation in the east, and low sensitivity in the west;
- High sensitivity for the low and medium elevations;
- Decreasing sensitivity for the central areas, and increased sensitivity for the eastern and western parts.

Varied vegetation's response to drought along elevations

Sensitivity to drought

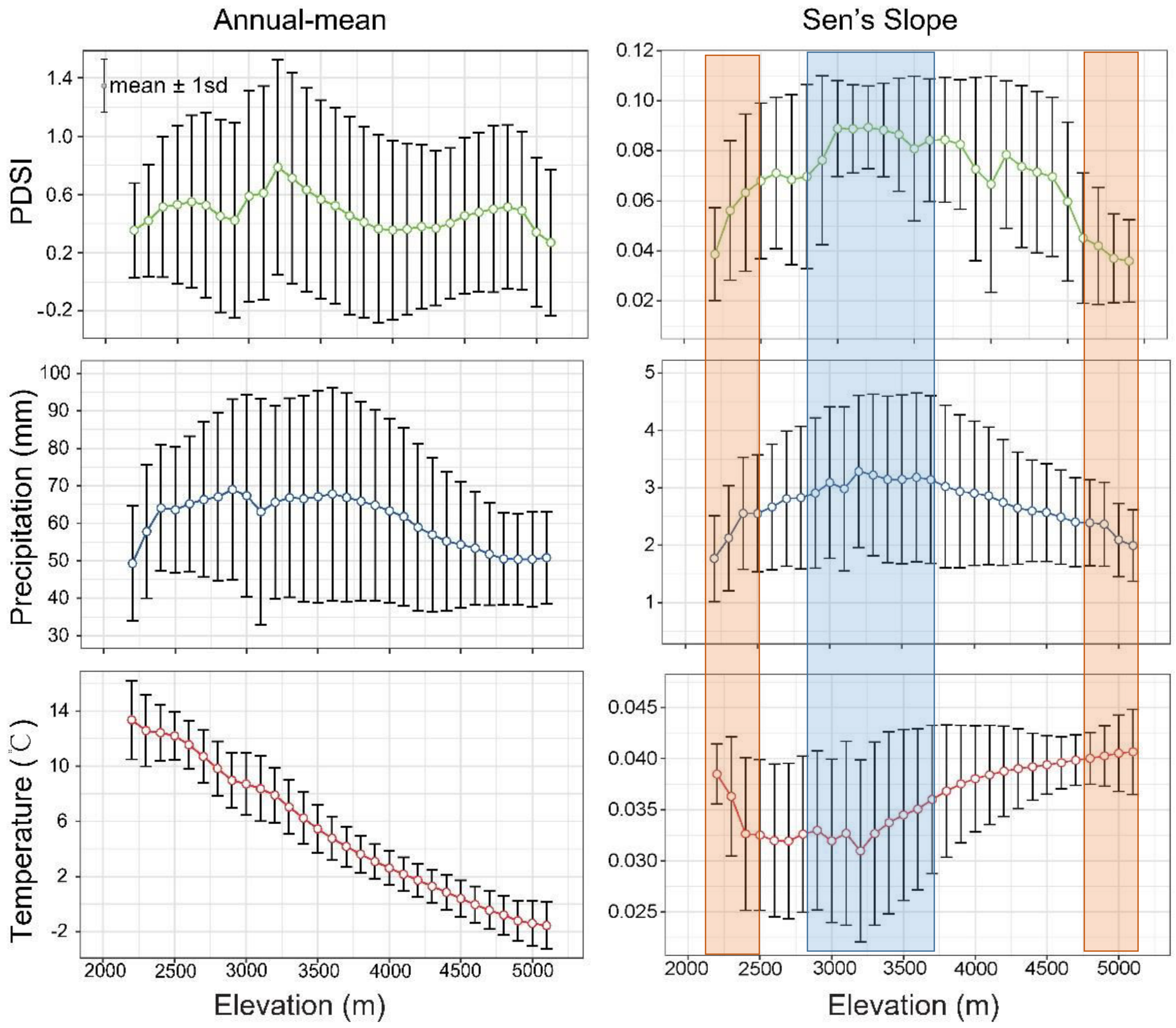


Trends of sensitivity to drought



- Increased sensitivity for the low and high elevations, decreased sensitivity for the middle elevations;
- Highest and increased sensitivity for broadleaf forests.

Reasons for the varied response of vegetation at different elevations



Climate change trends at different elevations

- **High and low elevations:**
- Fastest warming & slowest wetting -> slowest PDSI increase

- **Middle elevations:**
- Slowest warming & fastest wetting -> fastest PDSI increase

Summary

- The **ecosystems in lower-elevated and warmer areas** dominated by moisture-limited vegetation were relatively **more sensitive to hotter drought**;
- The **ecosystems in higher-elevated and colder areas** dominated by heat-limited vegetation were relatively **insensitive to hotter drought**;
- The **warming climate has led to an increased sensitivity** of many vegetation communities to drought;
- The response of **urban vegetation** to hotter drought is largely driven by differences in irrigation water use and the underlying socioeconomic factors, leading to **increased environmental injustice.**

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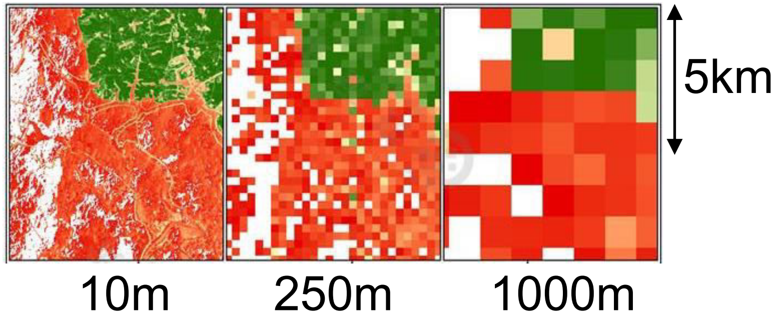
Thanks!

Q & A

Chunyu Dong
dongchy7@mail.sysu.edu.cn

Downscaling algorithm

Coefficient of variation $CV = \sigma/\mu$



Key equations

2001-2018:

$$NDVI_{H,x,y,t} = NDVI_{H,x,y,bl} \times (1 + K_{x,y,t} \times R_{CVx,y,m}) + \varepsilon_{x,y,t}$$

1982-2000:

$$NDVI_{H,x,y,t} = NDVI_{H,x,y,bl} \times \left(1 + K_{x,y,t} \times R_{CVx,y,m} \times R_{CVx,y,n}\right) + \varepsilon_{x,y,t}$$

in which, $NDVI_{H,x,y,t}$ is the downscaled high-resolution NDVI, $NDVI_{H,x,y,bl}$ is the monthly median MODIS NDVI during the baseline period of 2001~2018, $\varepsilon_{x,y,t}$ is random error.

Extraction of spatial information

$$R_{CVx,y,m} = MODIS\_CV / AVHRR\_CV_{post}$$

in which, $MODIS\_CV$ and $AVHRR\_CV_{post}$ refer to pixel-wise coefficients of variation (CVs) of MODIS and AVHRR NDVI.

$$R_{CVx,y,n} = AVHRR\_CV_{post} / AVHRR\_CV_{pre}$$

in which, $AVHRR\_CV_{pre}$ and $AVHRR\_CV_{post}$ refer to pixel-wise coefficients of variation (CVs) of AVHRR NDVI for the two periods of 1982~2000 and 2001~2018.

Extraction of temporal information

$$K_{x,y,t} = \left(NDVI_{L,x,y,t} - NDVI_{L,x,y,bl}\right) / NDVI_{L,x,y,bl}$$

in which, $NDVI_{L,x,y,t}$ is the monthly AVHRR NDVI (1982~2018), $NDVI_{L,x,y,bl}$ is the monthly median AVHRR NDVI during the baseline period (2001~2018).

Ma & Dong* et al., 2022, *Remote Sens.*