Characterize the Development and Drivers of Western U.S. Droughts

Speaker: Grace Affram (PhD student)

Collaborators: Wei Zhang, Lawrence Hipps, Cody Ratterman

The 47th NOAA's Climate Diagnostics and Prediction Workshop 10/27/22

College of Agriculture and Applied Sciences
UtahStateUniversity

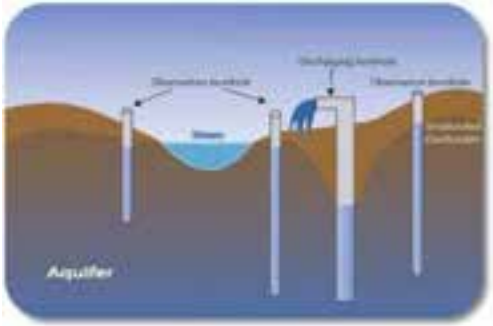
What is a drought?





It is an extended period - a season, year, or several years of deficient rainfall relative to the statistical multi year average for a region (UN, 2000)
But… 'Society is not a passive victim of drought' (Van Loon et al., 2016)

Direct and indirect human causes of drought



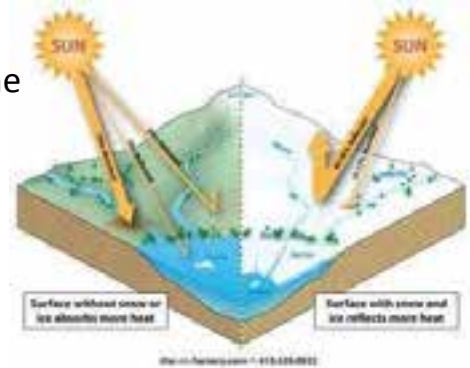
Over abstraction from rivers and groundrock (direct)

Deforestation (indirect)

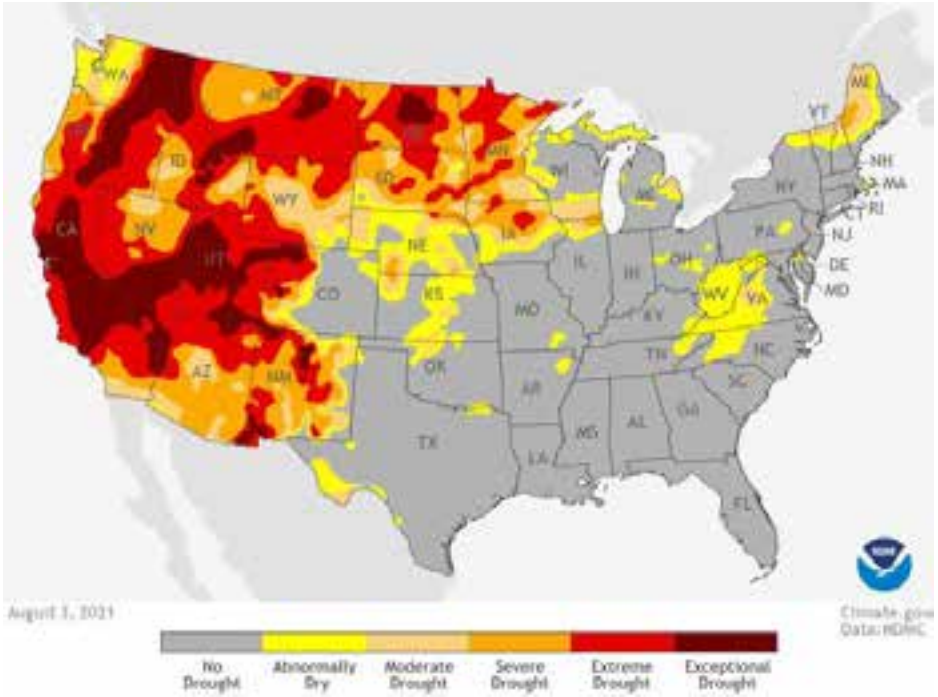
Overgrazing (indirect)

Anthropogenic climate change (indirect)

Changes to the **albedo** (indirect)



Western drought 2021 spotlight



Credit: U.S. drought monitor, 2021

- Arid areas experience drought more often

(e.g.; The Sahel, Australia and the Western U.S.)

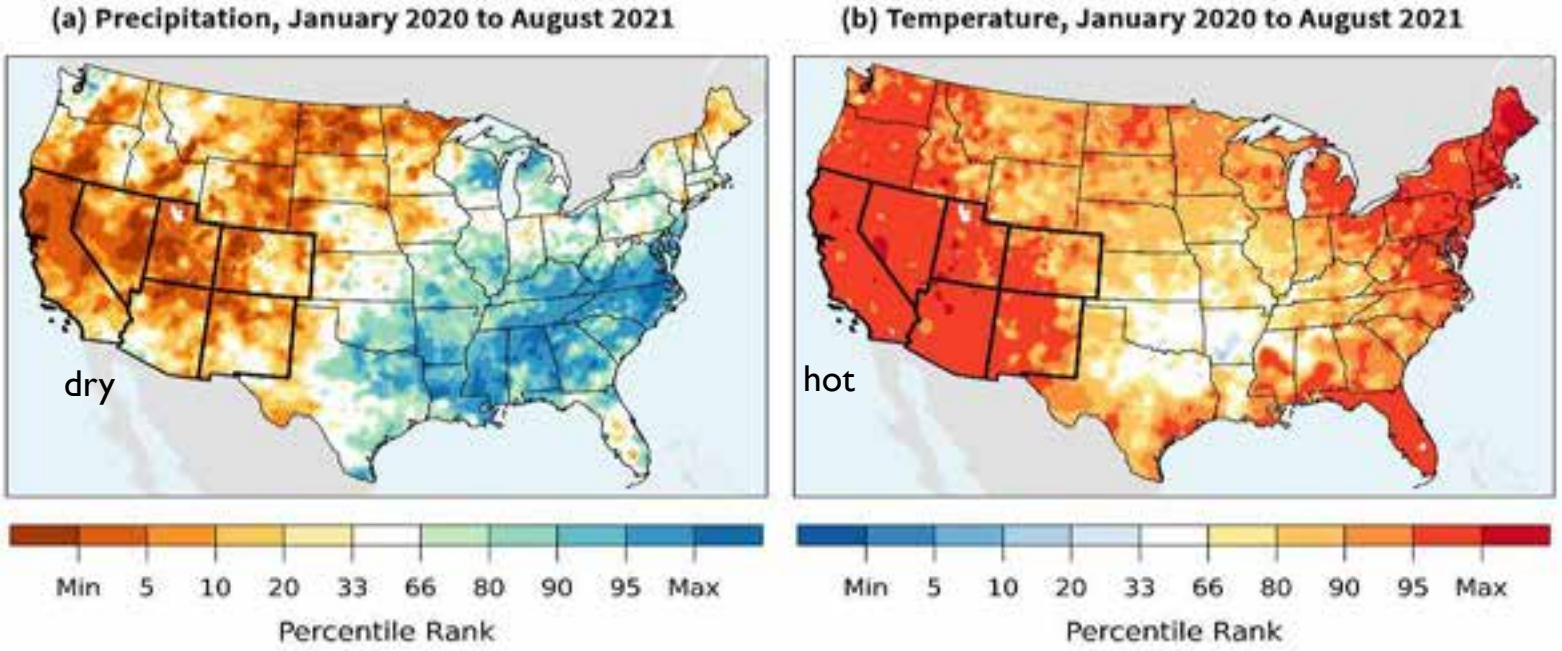
- Feedback loops often exacerbate droughts

(e.g.; Overgrazing and deforestation)

- Intensity & extent of droughts + increase of precipitation extremes may be tied to climate change (Cook et al., 2020)

- The two exceptionally dry years, 2020 & 2021 in history with 2021 alone about 20% drier than expected (Borunda, 2022)

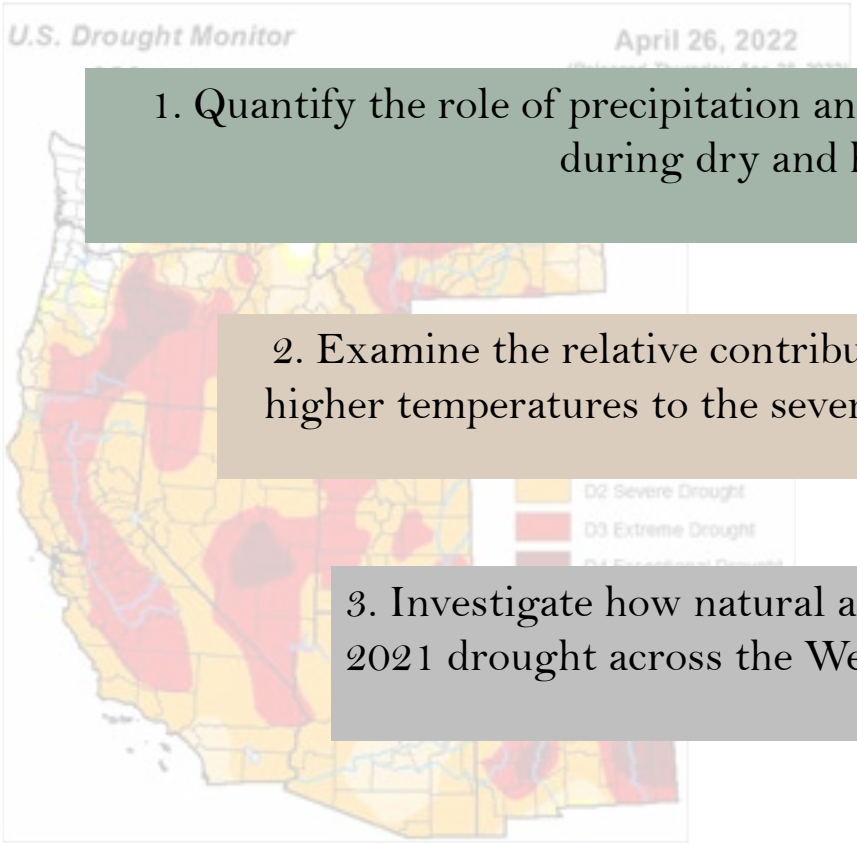
The recent American West megadrought



Credit: NOAA Drought Task Force Report, 2021

- The American West enters a megadrought, particularly in the southwestern region
- Extreme dryness and heat characterized the 2020/2021 drought

Research Objectives

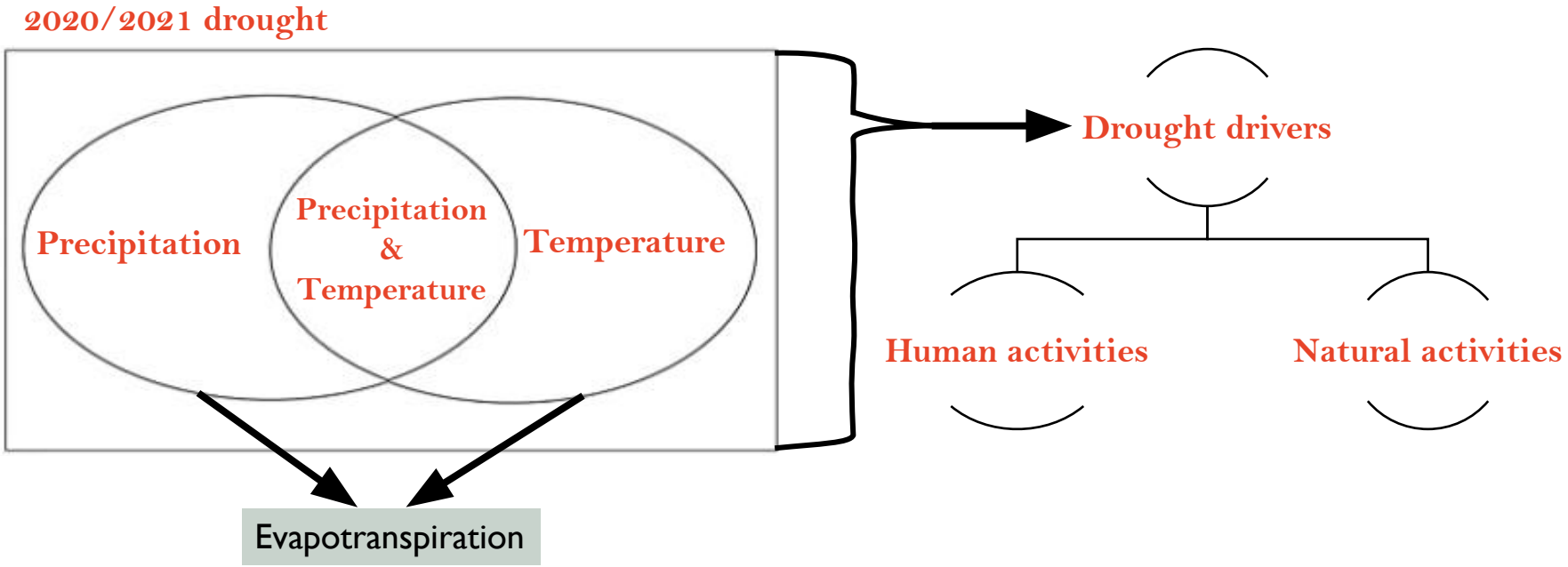


1. Quantify the role of precipitation and temperature to evapotranspiration during dry and hot conditions

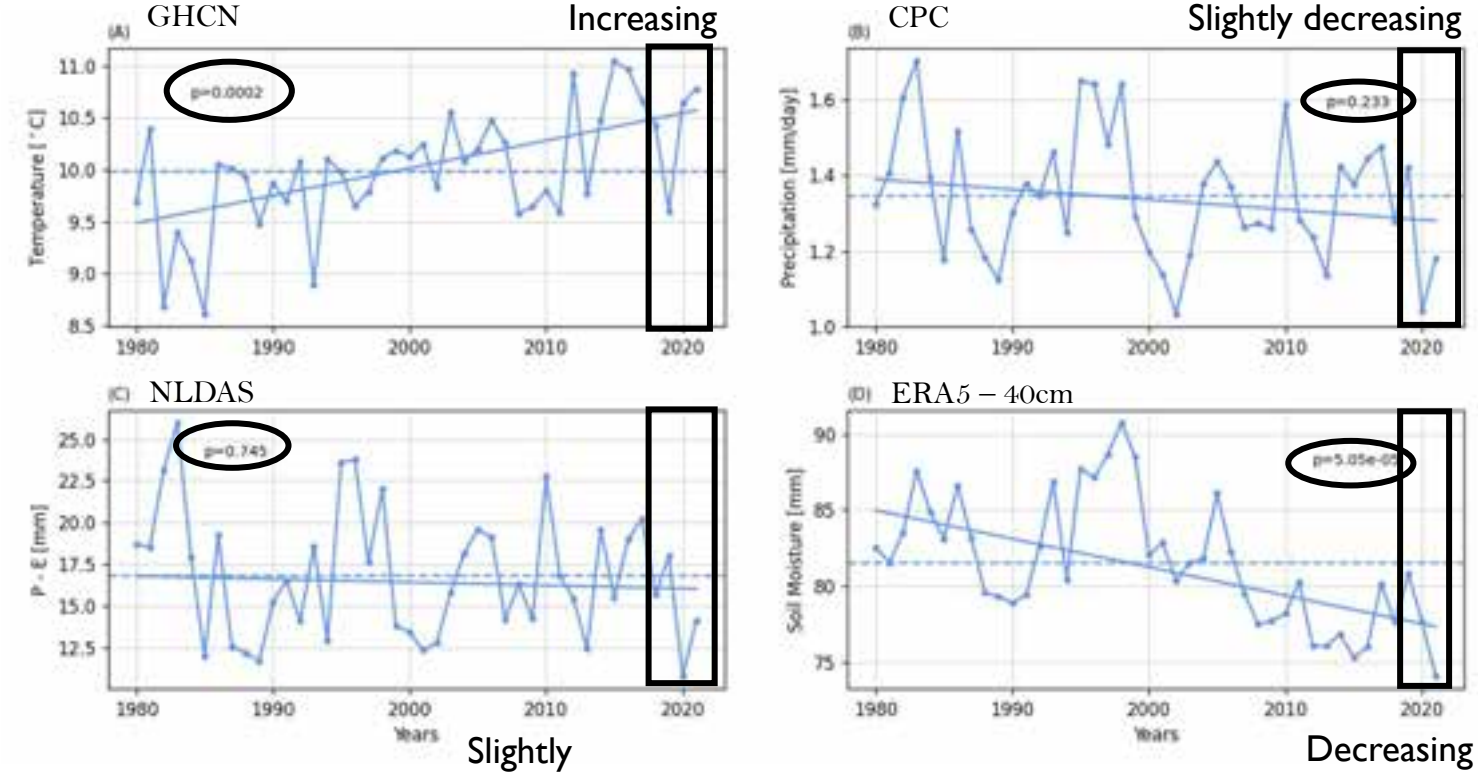
2. Examine the relative contributions of precipitation reductions & higher temperatures to the severe 2021 drought in the western US.

3. Investigate how natural and anthropogenic forcings shape the 2021 drought across the West

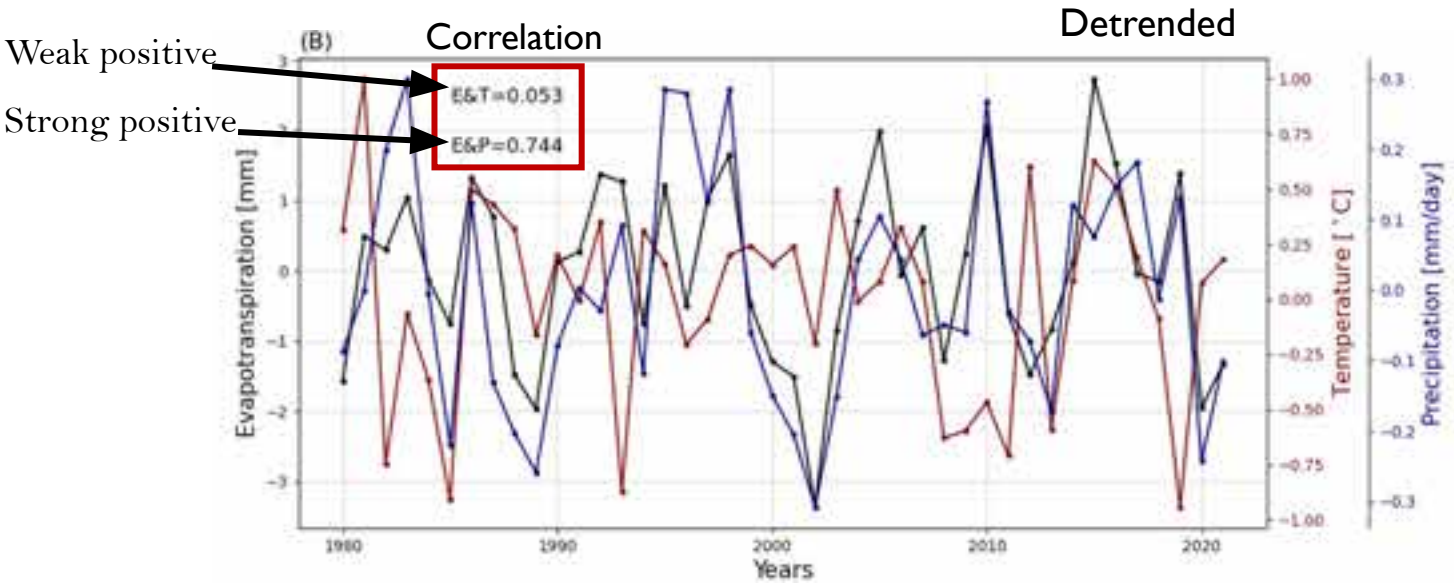
The Venn drought diagram



Inter-annual variability of drought variables

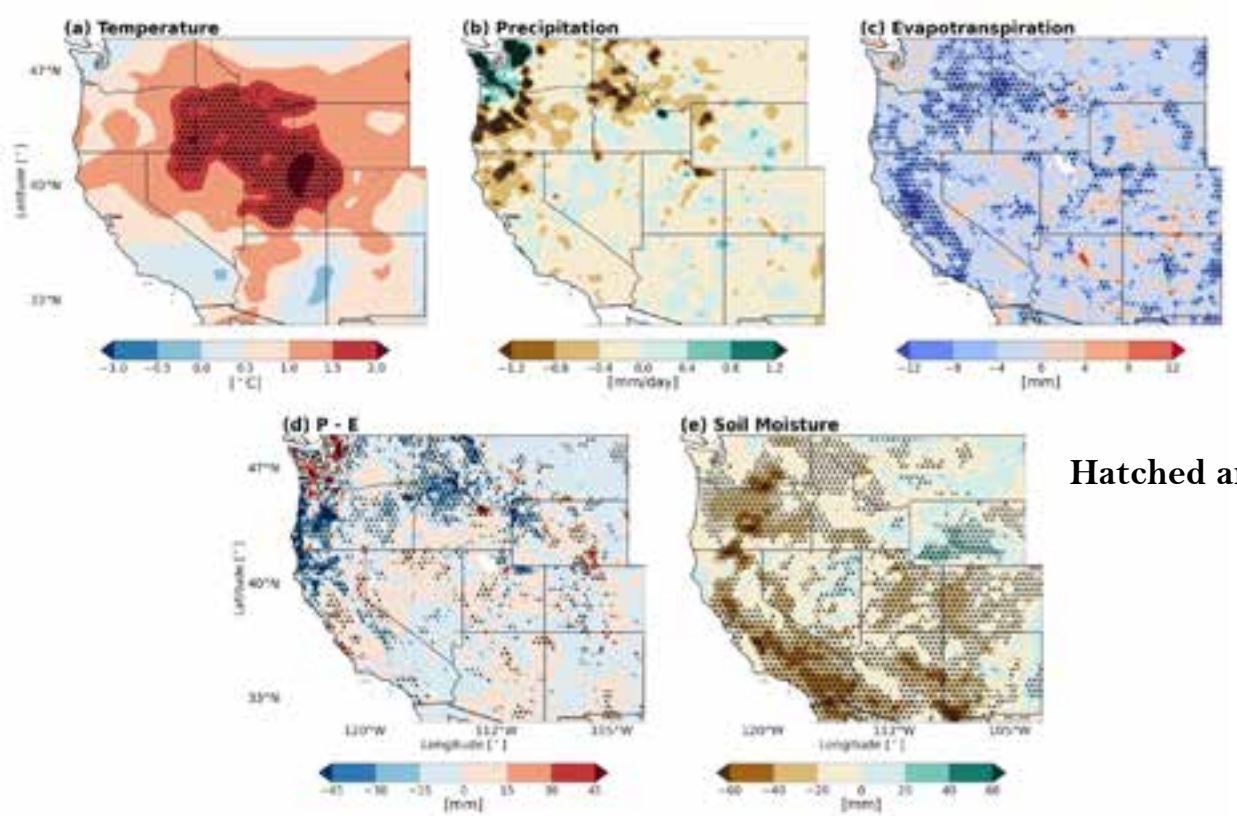


What influences atmospheric evapotranspiration?



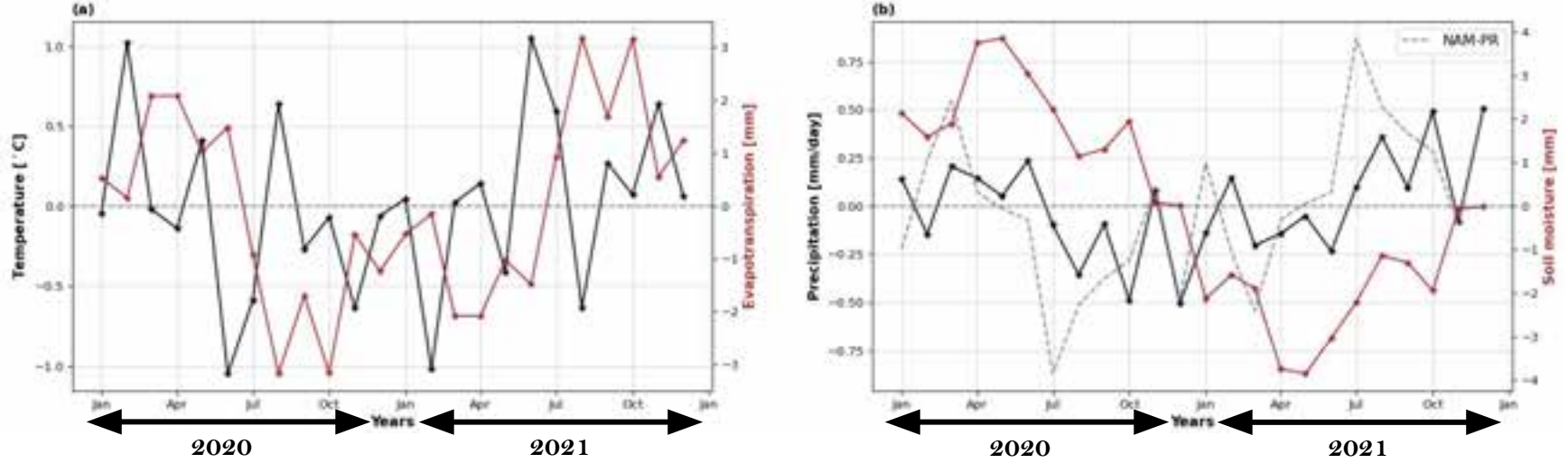
Evaporative demand from warm temperatures can't induce ET due to water limitations

Anomaly = Actual$_{2021}$ - Climatology $_{1981-2010}$



Hatched areas: 0.05 significance level

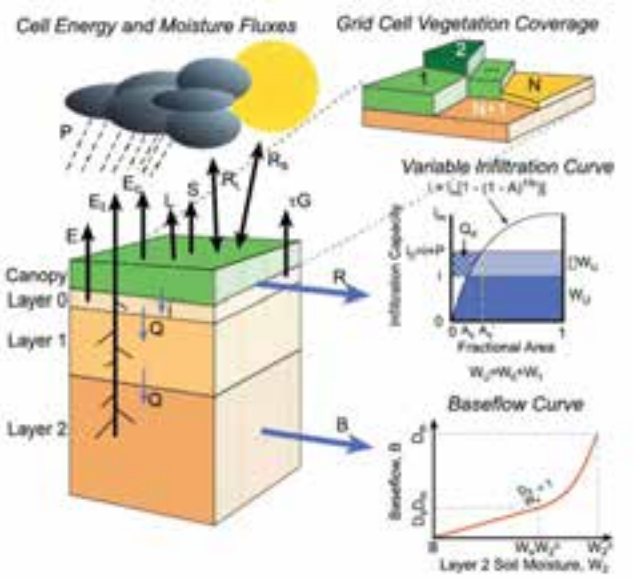
Drought development process (2020-2021)



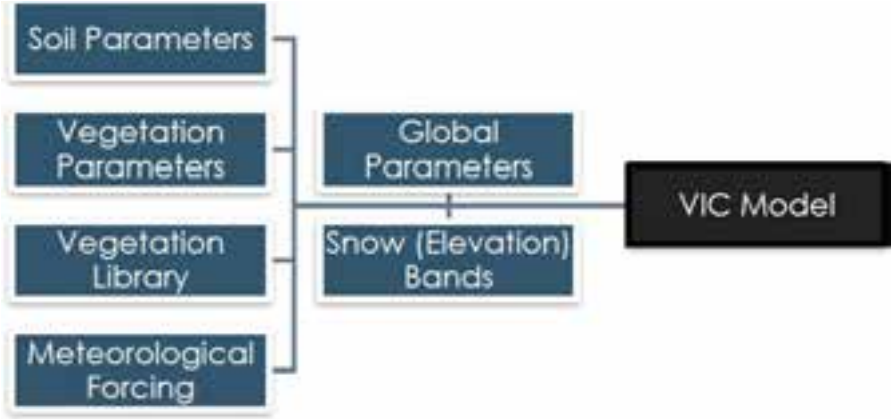
- Co-variations among soil moisture, precipitation and monsoon
- Time lag between precipitation and soil moisture
- Slow recovery of drought in late 2021

Variable Infiltration Capacity Model (VIC) Workflow

- Grid-based land surface representation (Liang et al., 1994)
- Simulates land surface-atmosphere fluxes of moisture and energy
- Developed for coupled Land Surface Model (LSM) – GCM simulations
- Considered a research model and open-source



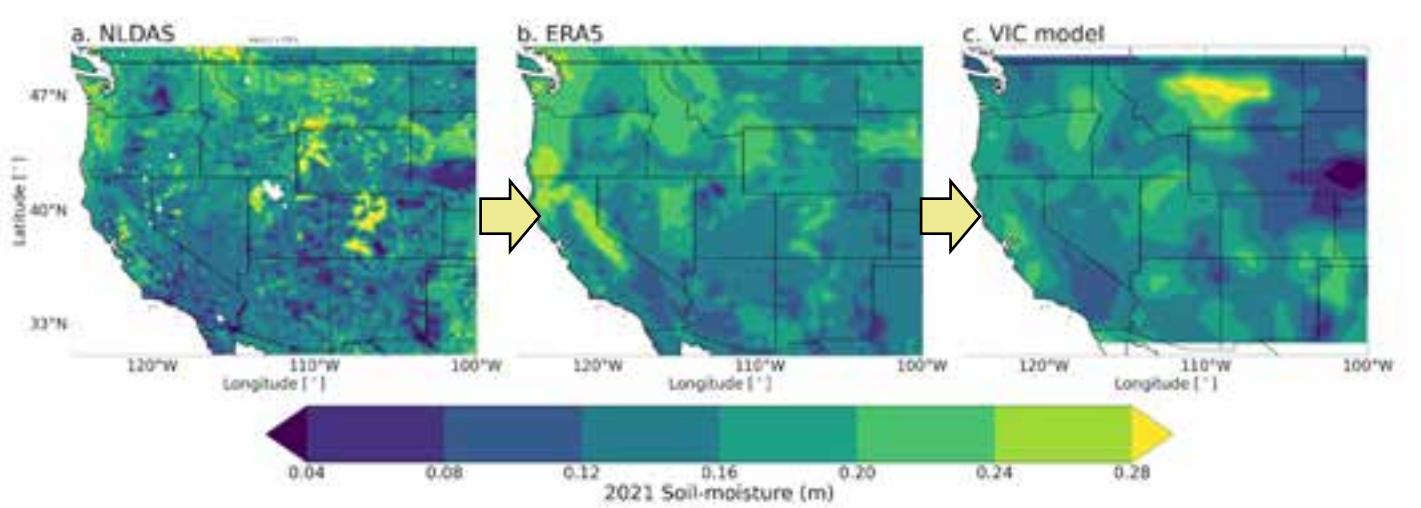
Inputs



Outputs

- Soil Moisture
- Evapotranspiration
- Runoff/Streamflow
- Snow Water Equivalent

Soil moisture performance from observations and model simulation



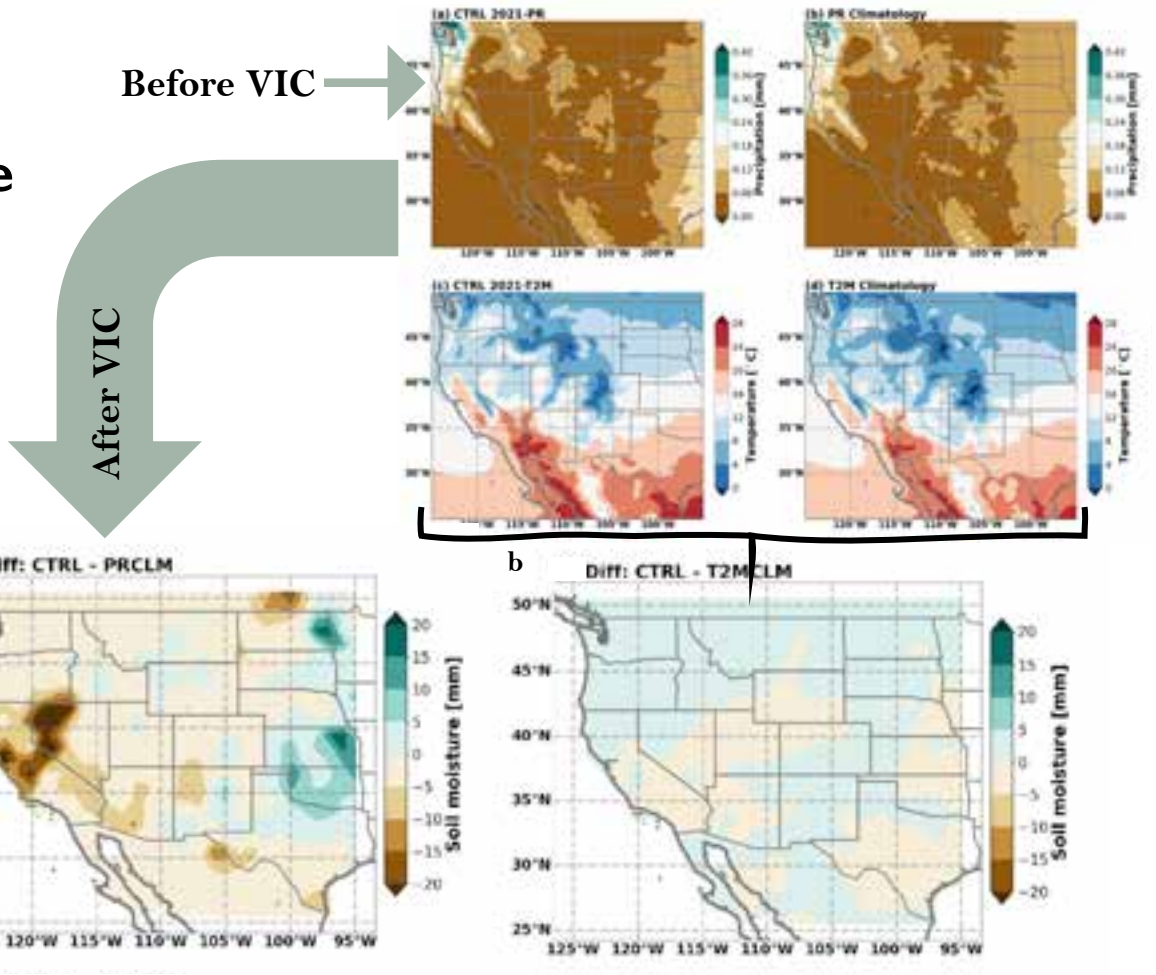
Methodology

- CTRL – Forced by met forcings for the entire 2021 year across the western U.S.
- PRCLM – Substituted precipitation in CTRL with 3-hour climatological precipitation (1981-2010)
- T2MCLM – Same as above but for temperature

Roles of precipitation and temperature in driving the 2021 drought

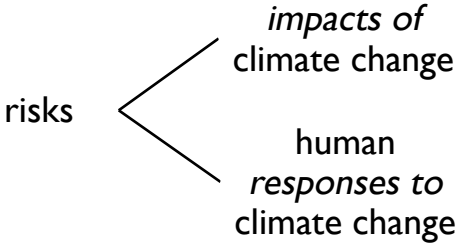
- Before model run -- Low precipitation and high temperature in ctrl experiment

- After model run -- Low soil moisture was mainly induced by reduced precipitation in 2021



Concept of Risk in human or ecological systems

- Risk is defined as **the potential for adverse consequences** (IPCC, 2020)
- Fraction of attributable risk assesses the changing magnitude of an impact driver
- Changes can be natural, unintended/deliberate (anthropogenic)
- Risk is a combination of hazard, exposure and vulnerability
- Escalates with higher temperatures causing irreversible impacts (IPCC, 2020)



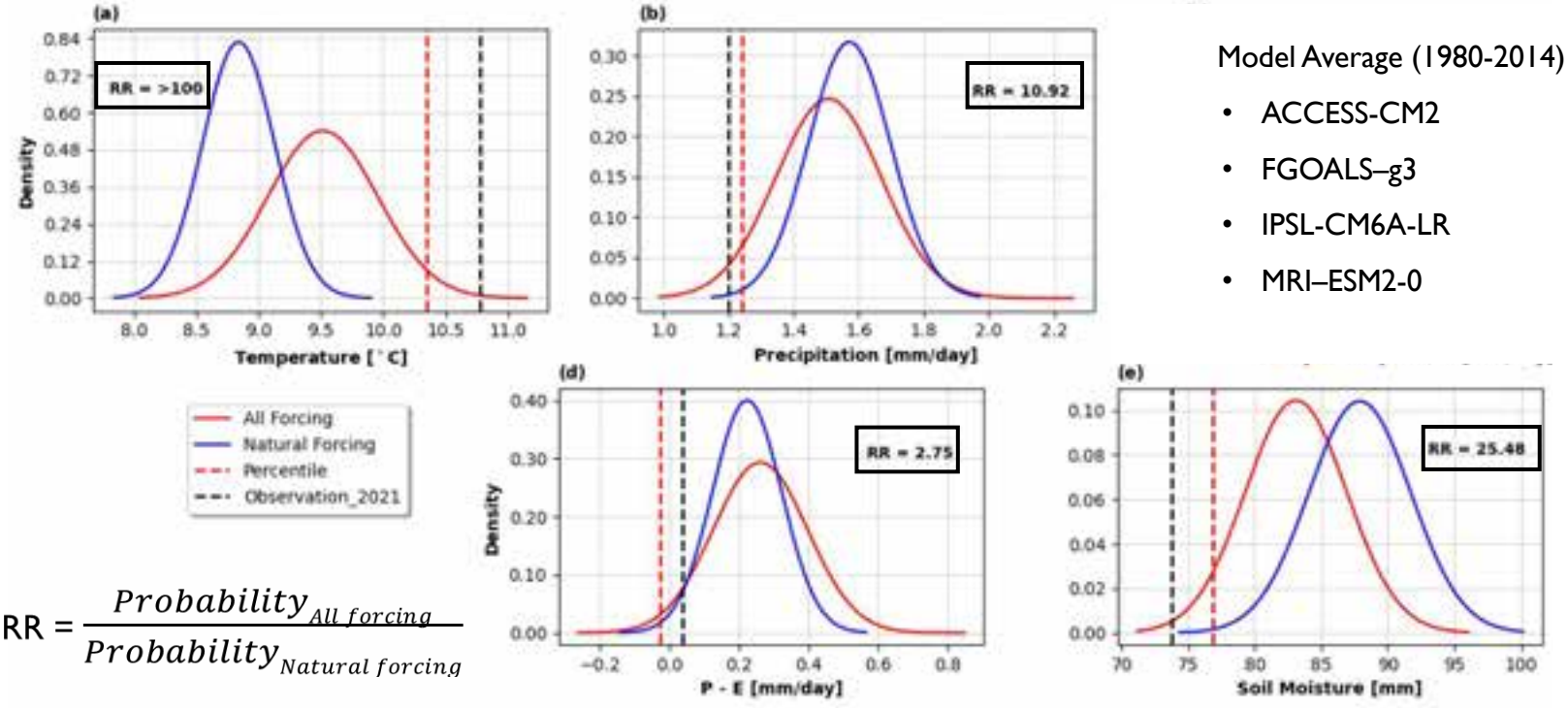
Risk Ratio (RR) =

$$\frac{Probability_{All\ forcing}}{Probability_{Natural\ forcing}}$$

Limitations

- Potential means uncertainty/incomplete knowledge -- future is always uncertain
- Risk refers to only negative ("adverse") consequences – Can't define the potential of positive outcomes

Is drought naturally caused or human-induced?



Model Average (1980-2014)

- ACCESS-CM2
- FGOALS–g3
- IPSL-CM6A-LR
- MRI–ESM2-0

$$RR = \frac{Probability_{All\ forcing}}{Probability_{Natural\ forcing}}$$

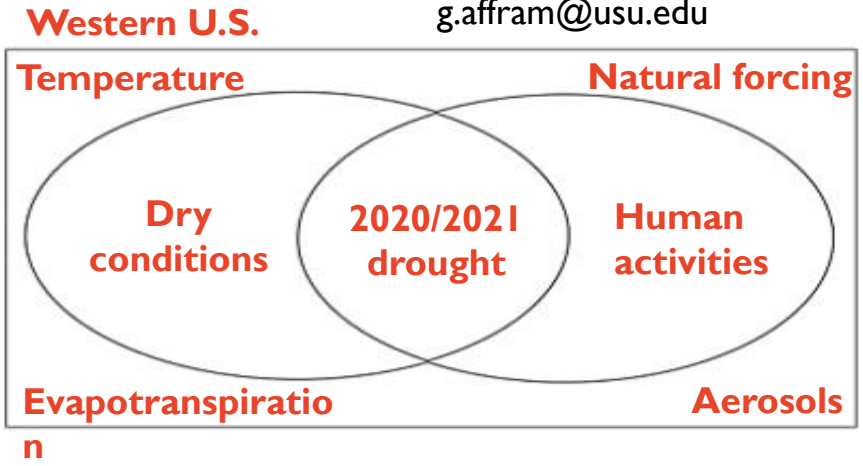
Anthropogenic = All – Natural forcing

RR > 1: Anthropogenic forcing increases the risk of extreme event

TAKE HOME MESSAGE

- Extreme risk ratios indicates high contributions from human activities to severity of this drought by approximately 25 times in terms of soil moisture
- The 2021 extreme drought event is largely attributed to low precipitation, and less so to warmer temperatures
- High temperatures in 2021 did not lead to excessive evapotranspiration due to limited water availability

Contact:
g.affram@usu.edu



"We still have the ability to limit climate change and to help communities around the world adapt to the changes that have already occurred. Every fraction of a degree counts. Let's go change the world!" – IPCC, 2022.