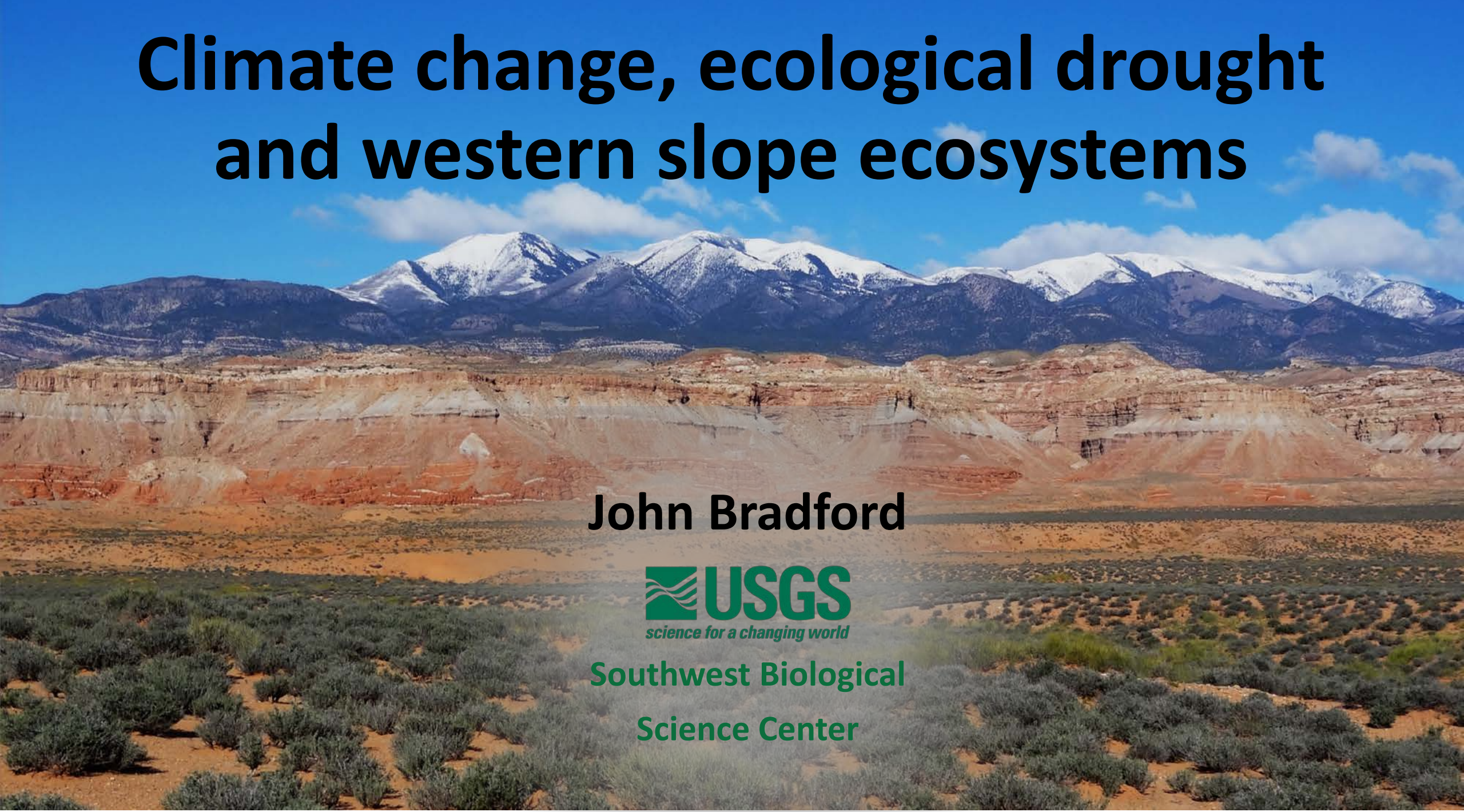
Climate change, ecological drought and western slope ecosystems



John Bradford

USGS
science for a changing world

Southwest Biological
Science Center

Climate Change, ecological drought and western slope ecosystems

Update on climate change information

Implications for ecological drought in drylands of the west

Potential impacts to vegetation

Opportunities for climate adaptation

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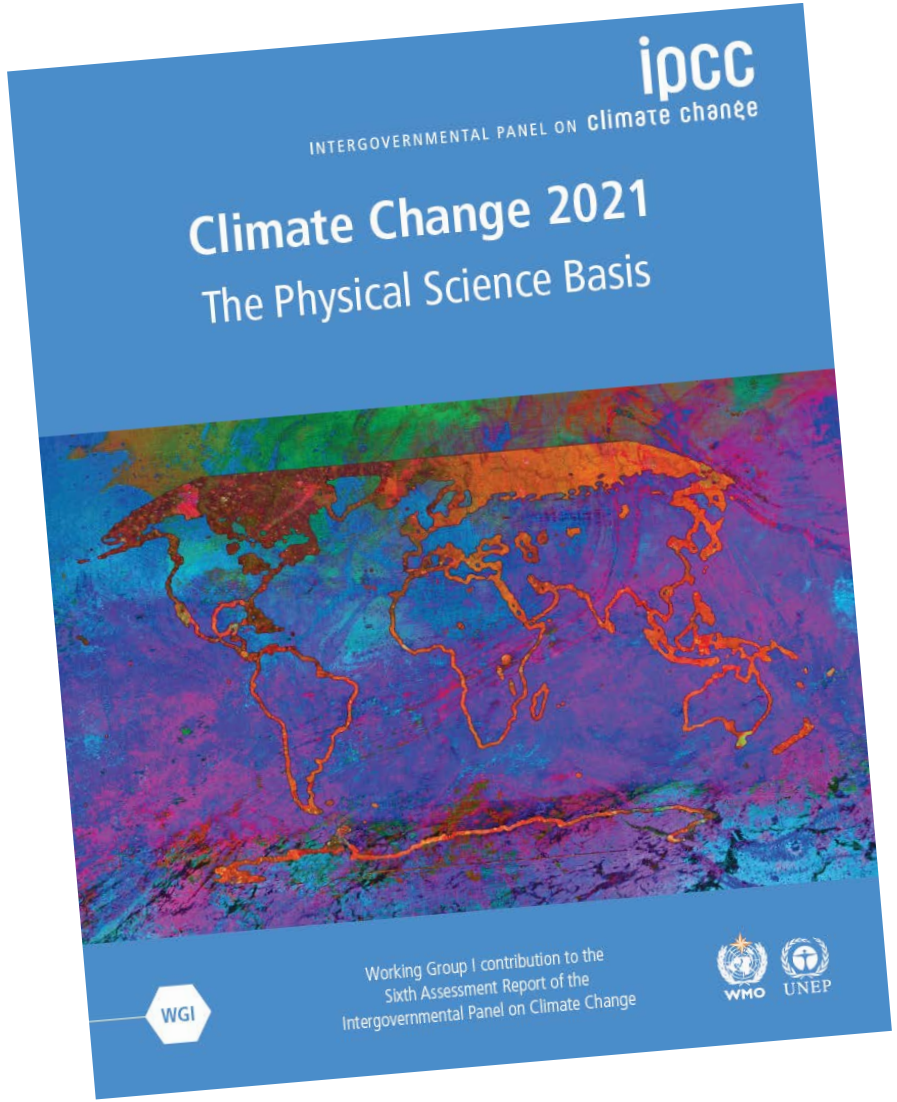
The Physical Science Basis (August 2021)

- climate system & climate change
- advances in climate science
- multiple lines of evidence from paleoclimate, observations, process understanding, and global and regional climate simulations



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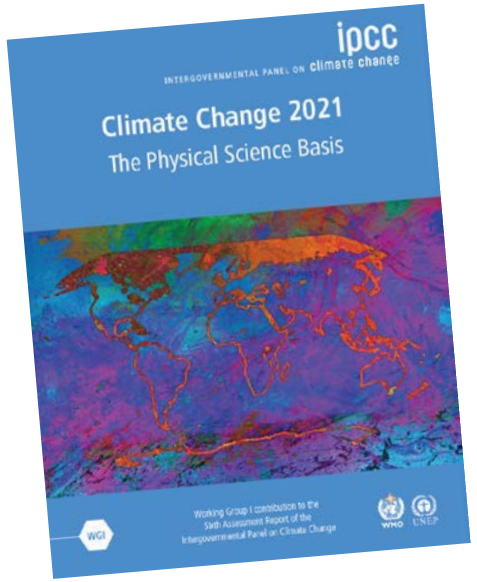

The Physical Science Basis (August 2021)

The Current State of the Climate	
It is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred.	**Humans have definitely warmed the planet.**
The scale of recent changes across the climate system as a whole and the present state of many aspects of the climate system are unprecedented over many centuries to many thousands of years.	Temperatures are rising faster than normal on earth and are now higher than in a LONG time.
Human-induced climate change is already affecting many weather and climate extremes in every region across the globe. Evidence of observed changes in extremes such as heatwaves, heavy precipitation, droughts, and tropical cyclones, and, in particular, their attribution to human influence, has strengthened since AR5.	Changes are occurring everywhere, including extreme events. It's more clear than ever that humans caused this.
Improved knowledge of climate processes, paleoclimate evidence and the response of the climate system to increasing radiative forcing gives a best estimate of equilibrium climate sensitivity of 3°C with a narrower range compared to AR5.	We understand better how much CO2 impacts temperature.

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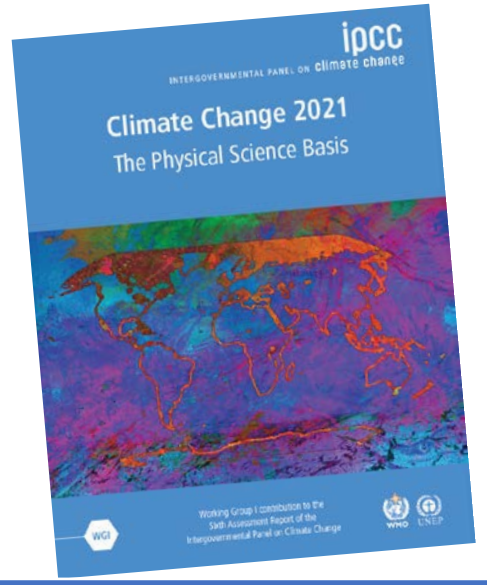

The Physical Science Basis (August 2021)

Possible Climate Futures	
Global surface temperature will continue to increase until at least the mid-century under all emissions scenarios considered. Global warming of 1.5°C and 2°C will be exceeded during the 21st century unless deep reductions in CO2 and other greenhouse gas emissions occur in the coming decades.	Temperatures will keep rising.
Many changes in the climate system become larger in direct relation to increasing global warming. They include increases in the frequency and intensity of hot extremes, marine heatwaves, and heavy precipitation, agricultural and ecological droughts in some regions, and proportion of intense tropical cyclones, as well as reductions in Arctic sea ice, snow cover and permafrost.	Higher temperatures impact many other aspects of climate.
Continued global warming is projected to further intensify the global water cycle, including its variability, global monsoon precipitation and the severity of wet and dry events.	**Rainfall extremes, both wet and dry, will increase.**
Under scenarios with increasing CO2 emissions, the ocean and land carbon sinks are projected to be less effective at slowing the accumulation of CO2 in the atmosphere.	Natural carbon sinks will become less helpful under high emissions.
Many changes due to past and future greenhouse gas emissions are irreversible for centuries to millennia, especially changes in the ocean, ice sheets and global sea level.	We're stuck with many of these changes.

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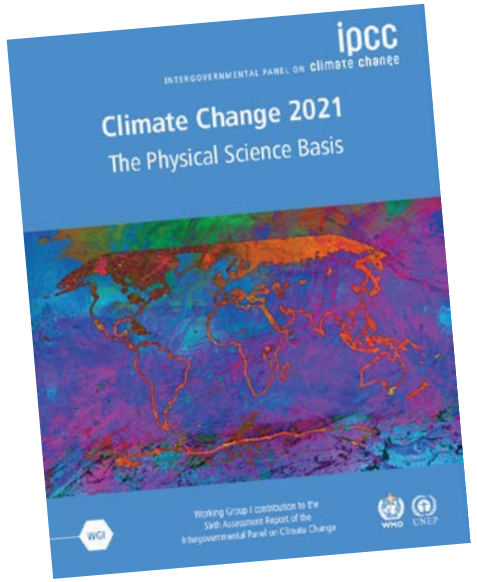

The Physical Science Basis (August 2021)

Climate Information for Risk Assessment and Regional Adaptation	
Natural drivers and internal variability will modulate human-caused changes, especially at regional scales and in the near term, with little effect on centennial global warming. These modulations are important to consider in planning for the full range of possible changes.	Climate change is happening, even if you experience a snowstorm.
With further global warming, every region is projected to increasingly experience concurrent and multiple changes in climatic impact-drivers. Changes in several climatic impact-drivers would be more widespread at 2°C compared to 1.5°C global warming and even more widespread and/or pronounced for higher warming levels.	**The impact of climate change will be greater if temperature goes up more.**
Low-likelihood outcomes, such as ice sheet collapse, abrupt ocean circulation changes, some compound extreme events and warming substantially larger than the assessed very likely range of future warming cannot be ruled out and are part of risk assessment.	Crazy things might happen!

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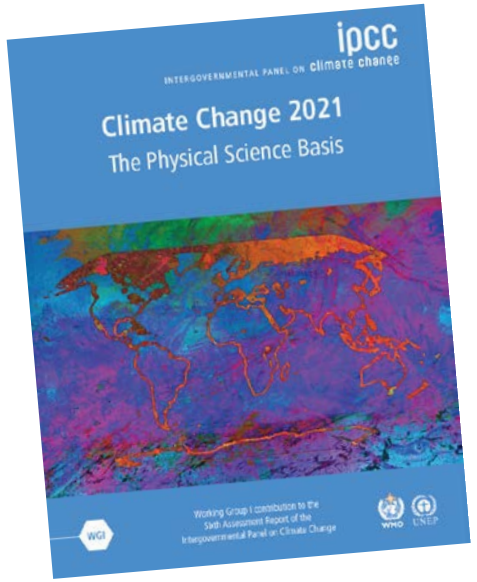

The Physical Science Basis (August 2021)

Limiting Future Climate Change	
From a physical science perspective, limiting human-induced global warming to a specific level requires limiting cumulative CO2 emissions, reaching at least net zero CO2 emissions, along with strong reductions in other greenhouse gas emissions. Strong, rapid and sustained reductions in CH4 emissions would also limit the warming effect resulting from declining aerosol pollution and would improve air quality.	More CO2 or methane will cause more temperature increase
Scenarios with very low or low GHG emissions (SSP1-1.9 and SSP1-2.6) lead within years to discernible effects on greenhouse gas and aerosol concentrations, and air quality, relative to high and very high GHG emissions scenarios (SSP3-7.0 or SSP5-8.5). Under these contrasting scenarios, discernible differences in trends of global surface temperature would begin to emerge from natural variability within around 20 years, and over longer time periods for many other climatic impact-drivers (high confidence).	Limiting carbon emissions could have a big impact on reducing the magnitude of climate change.

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The Physical Science Basis (August 2021)

Regional fact sheets: www.ipcc.ch/report/ar6/wg1/#Regional

Central and Western North America (CNA and WNA)

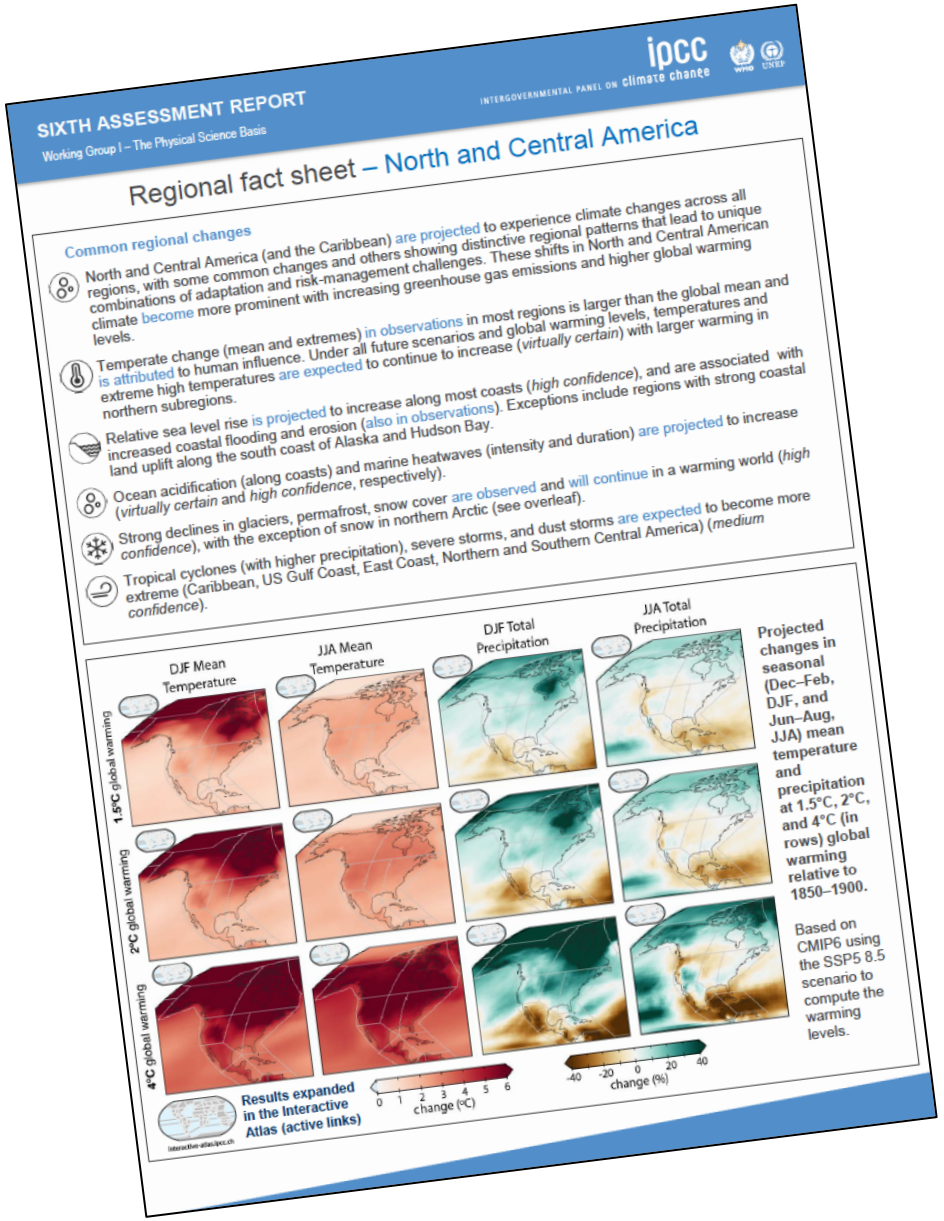
Increases in drought and fire weather in WNA and CNA in observations and will continue to increase in the future particularly at higher warming levels (*high confidence*, but *medium confidence* for fire weather in CNA)

Projected increase in extreme precipitation (*very likely*)

Projected increase in river and pluvial flooding (*medium confidence*)

Projected increases in precipitation in northern part of CNA in winter (*medium confidence*).

Anticipated decrease in NA Monsoon precipitation (*medium confidence*).

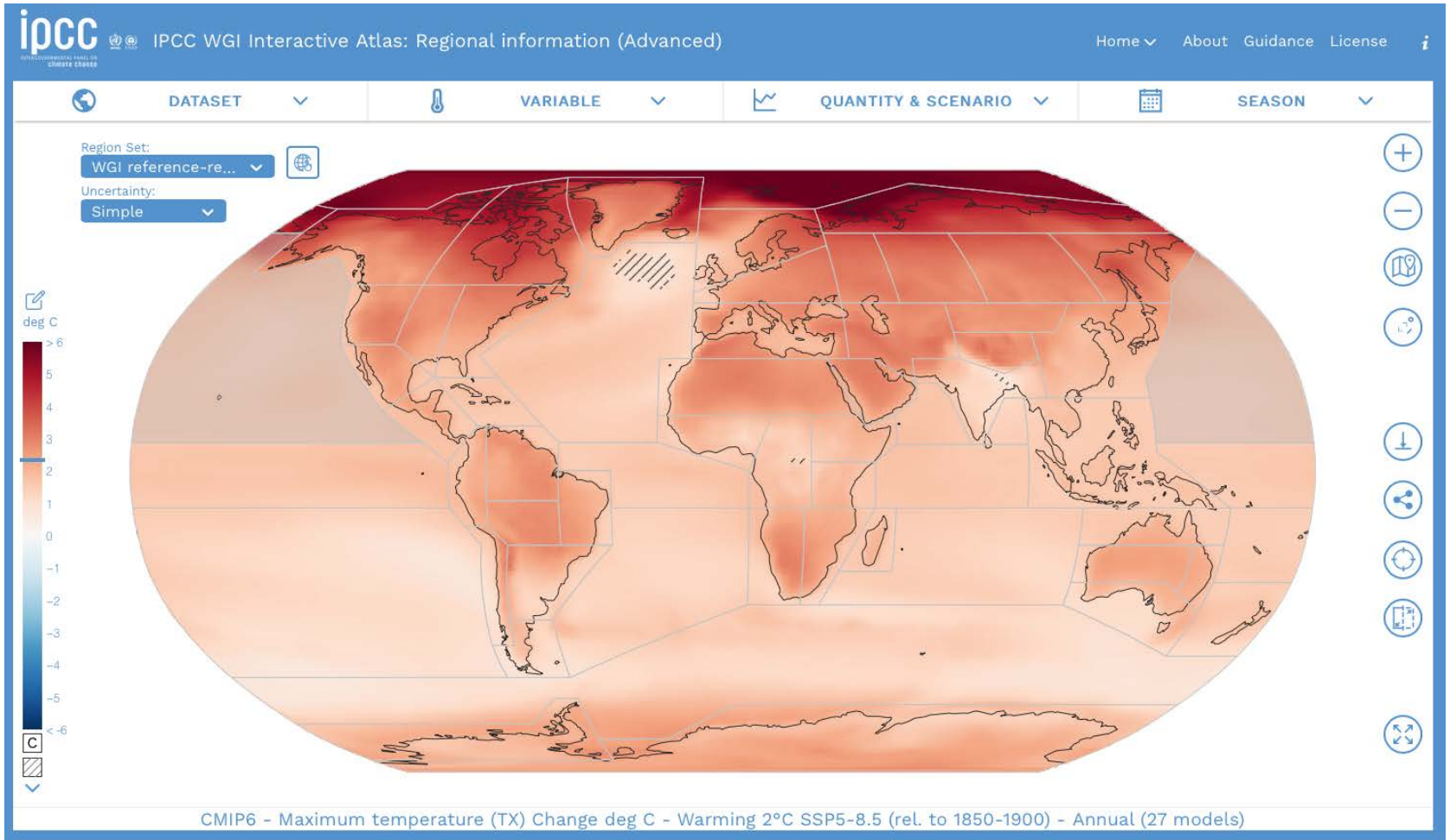


IPCC 6th assessment www.ipcc.ch

The Physical Science Basis (August 2021)

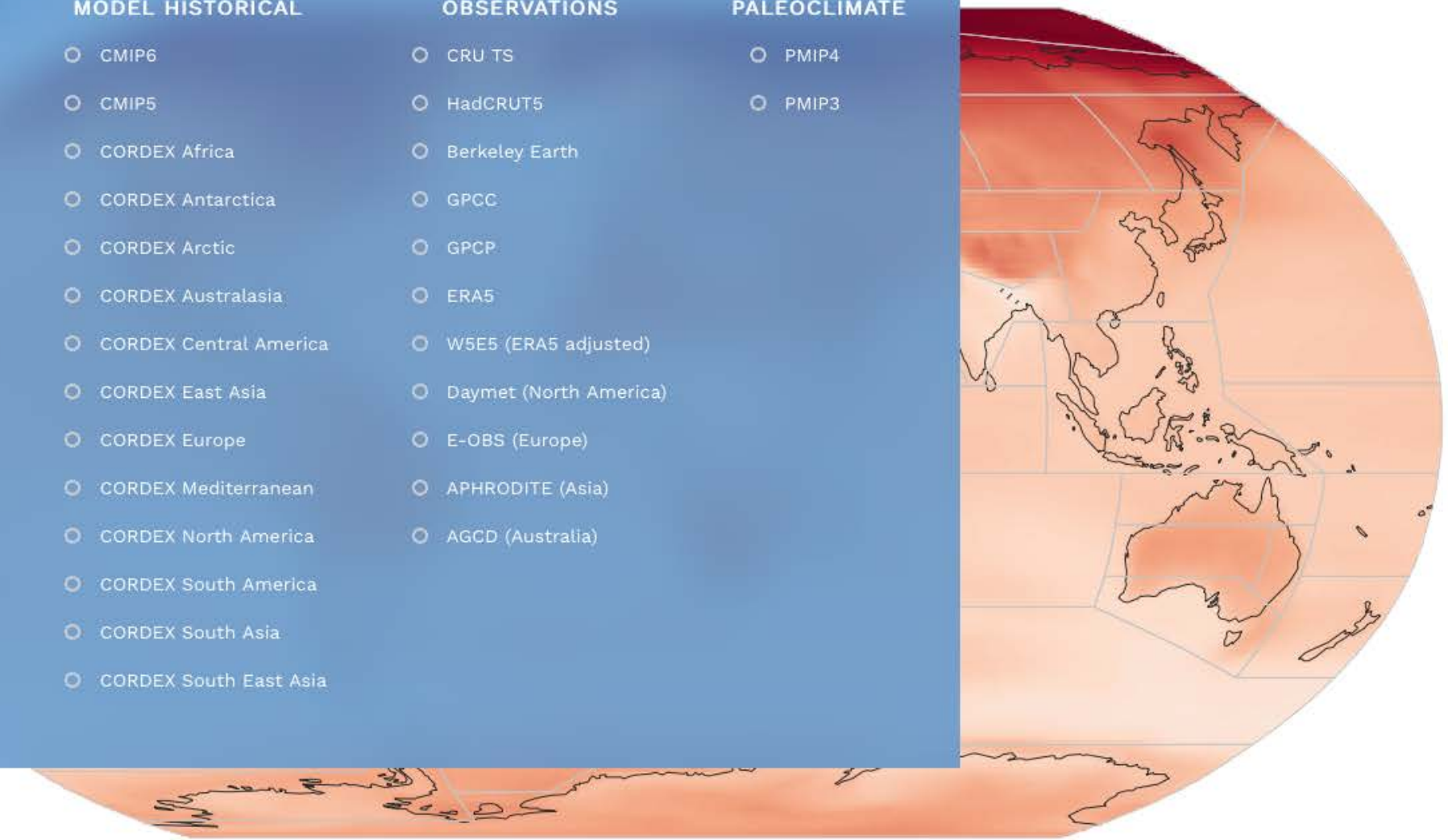
Interactive Atlas:

interactive-atlas.ipcc.ch/

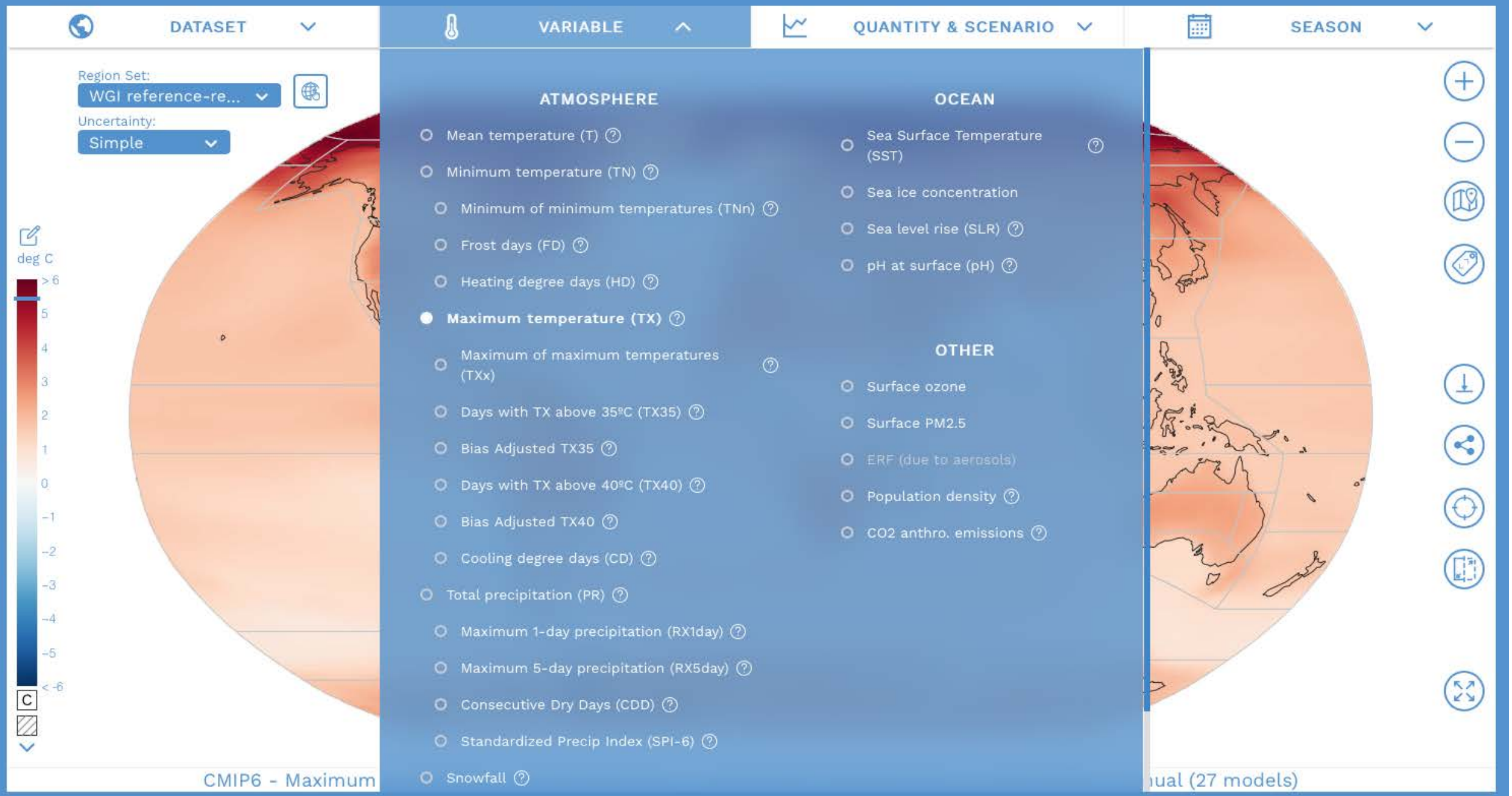


DATASET VARIABLE QUANTITY & SCENARIO SEASON

MODEL PROJECTIONS	MODEL HISTORICAL	OBSERVATIONS	PALEOCLIMATE
● CMIP6	○ CMIP6	○ CRU TS	○ PMIP4
○ CMIP5	○ CMIP5	○ HadCRUT5	○ PMIP3
○ CORDEX Africa	○ CORDEX Africa	○ Berkeley Earth	
○ CORDEX Antarctica	○ CORDEX Antarctica	○ GPCC	
○ CORDEX Arctic	○ CORDEX Arctic	○ GPCP	
○ CORDEX Australasia	○ CORDEX Australasia	○ ERA5	
○ CORDEX Central America	○ CORDEX Central America	○ W5E5 (ERA5 adjusted)	
○ CORDEX East Asia	○ CORDEX East Asia	○ Daymet (North America)	
○ CORDEX Europe	○ CORDEX Europe	○ E-OBS (Europe)	
○ CORDEX Mediterranean	○ CORDEX Mediterranean	○ APHRODITE (Asia)	
○ CORDEX North America	○ CORDEX North America	○ AGCD (Australia)	
○ CORDEX South America	○ CORDEX South America		
○ CORDEX South Asia	○ CORDEX South Asia		
○ CORDEX South East Asia	○ CORDEX South East Asia		



CMIP6 - Maximum temperature (TX) Change deg C - Warming 2°C SSP5-8.5 (rel. to 1850-1900) - Annual (27 models)


IPCC WGI Interactive Atlas: Regional information (Advanced)
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Guidance
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DATASET
VARIABLE
QUANTITY & SCENARIO
SEASON
Region Set:
WGI reference-re...
Uncertainty:
Simple
deg C
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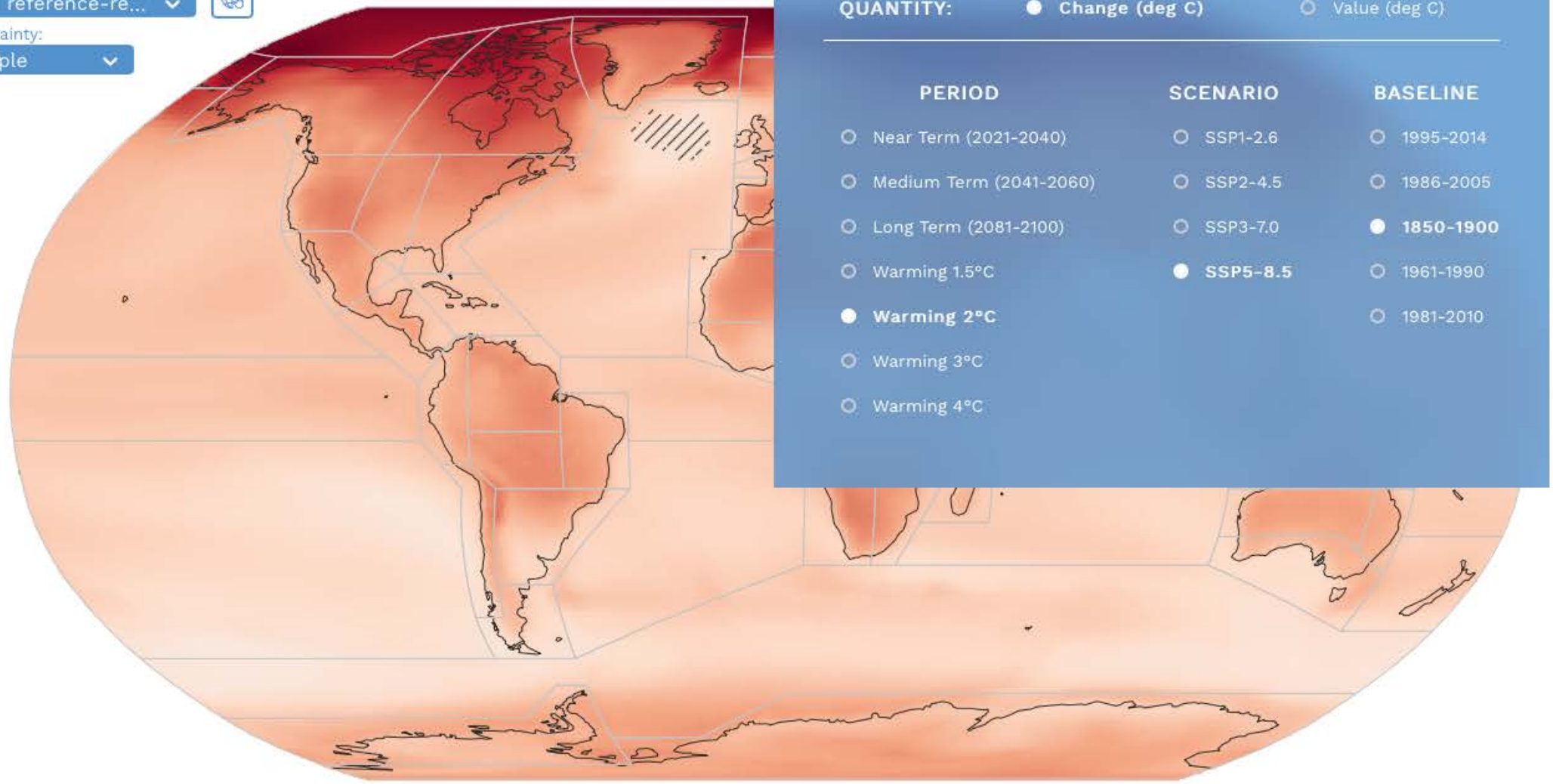
−5
< -6
C
ATMOSPHERE
Mean temperature (T)
Minimum temperature (TN)
Minimum of minimum temperatures (TNn)
Frost days (FD)
Heating degree days (HD)
Maximum temperature (TX)
Maximum of maximum temperatures (TXx)
Days with TX above 35ºC (TX35)
Bias Adjusted TX35
Days with TX above 40ºC (TX40)
Bias Adjusted TX40
Cooling degree days (CD)
Total precipitation (PR)
Maximum 1-day precipitation (RX1day)
Maximum 5-day precipitation (RX5day)
Consecutive Dry Days (CDD)
Standardized Precip Index (SPI-6)
Snowfall
OCEAN
Sea Surface Temperature (SST)
Sea ice concentration
Sea level rise (SLR)
pH at surface (pH)
OTHER
Surface ozone
Surface PM2.5
ERF (due to aerosols)
Population density
CO2 anthro. emissions
CMIP6 - Maximum
ual (27 models)

DATASET VARIABLE QUANTITY & SCENARIO SEASON

Region Set:
WGI reference-re...

Uncertainty:
Simple



QUANTITY: Change (deg C) Value (deg C)

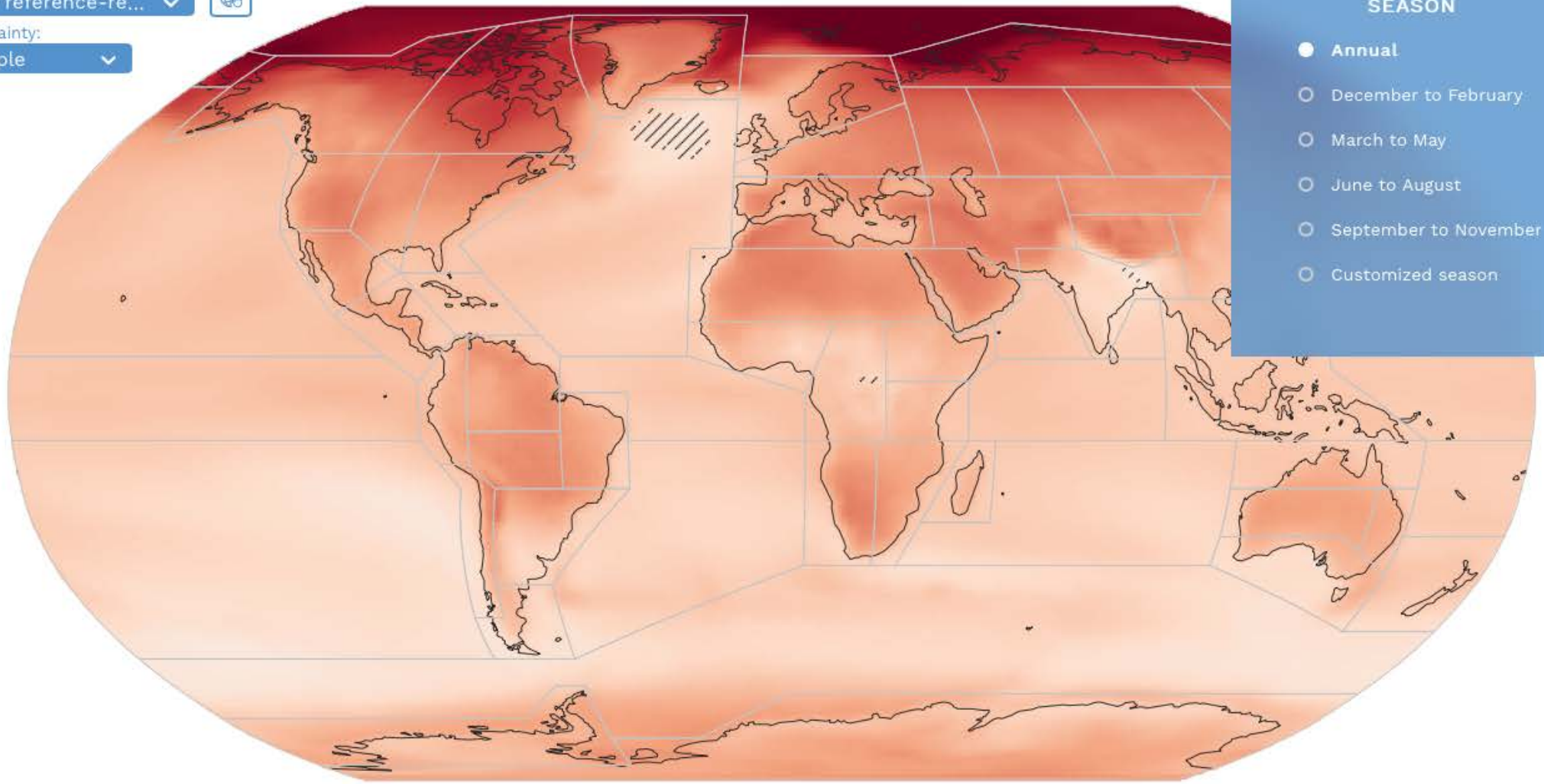
PERIOD	SCENARIO	BASELINE
Near Term (2021-2040)	SSP1-2.6	1995-2014
Medium Term (2041-2060)	SSP2-4.5	1986-2005
Long Term (2081-2100)	SSP3-7.0	**1850-1900**
Warming 1.5°C	**SSP5-8.5**	1961-1990
Warming 2°C		1981-2010
Warming 3°C		
Warming 4°C		

CMIP6 - Maximum temperature (TX) Change deg C - Warming 2°C SSP5-8.5 (rel. to 1850-1900) - Annual (27 models)

DATASET VARIABLE QUANTITY & SCENARIO SEASON

Region Set:
WGI reference-re...

Uncertainty:
Simple



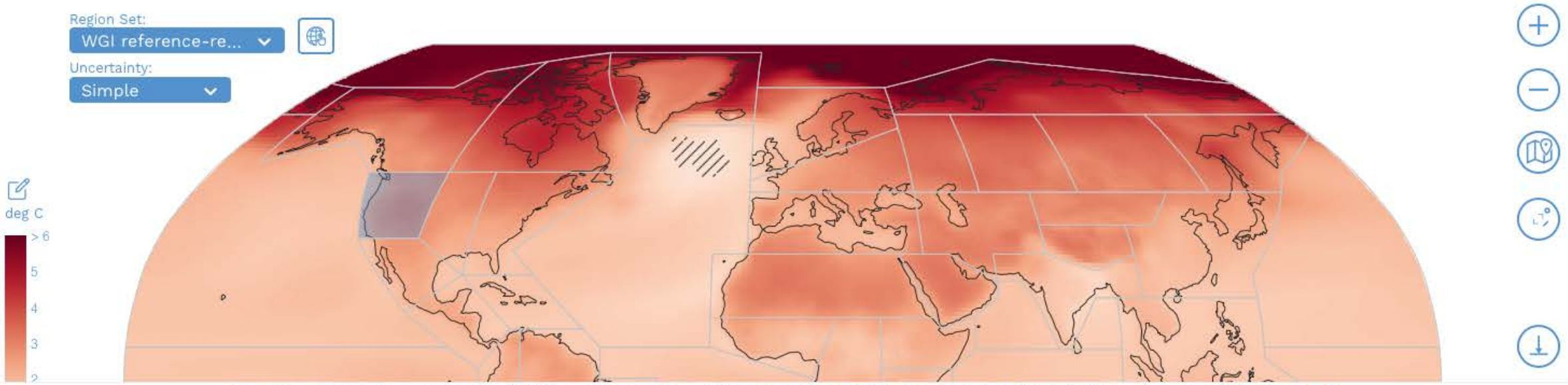
SEASON

- Annual
- December to February
- March to May
- June to August
- September to November
- Customized season

CMIP6 - Maximum temperature (TX) Change deg C - Warming 2°C SSP5-8.5 (rel. to 1850-1900) - Annual (27 models)

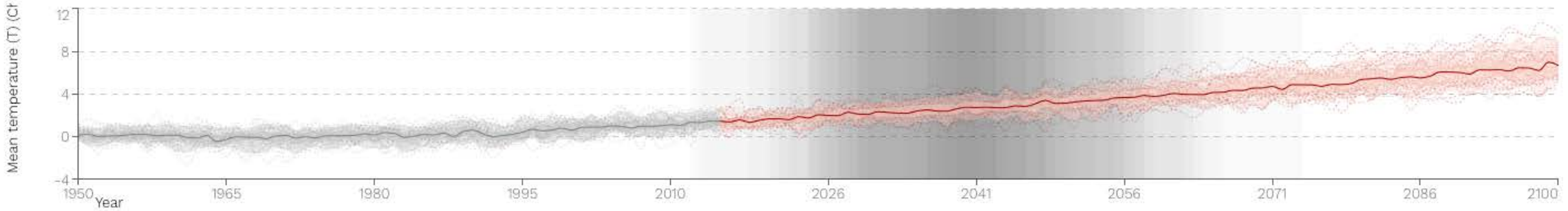
DATASET VARIABLE QUANTITY & SCENARIO SEASON

Region Set: WGI reference-re...
Uncertainty: Simple



CMIP6 - Mean temperature (T) Change deg C - Warming 2°C SSP5-8.5 (rel. to 1850-1900) - Annual (34 models)
Regions: Western North America

Time Series | GWL Plot | Annual Cycle | Scatter Plot | Table Summary | Stripes | Seasonal Stripes



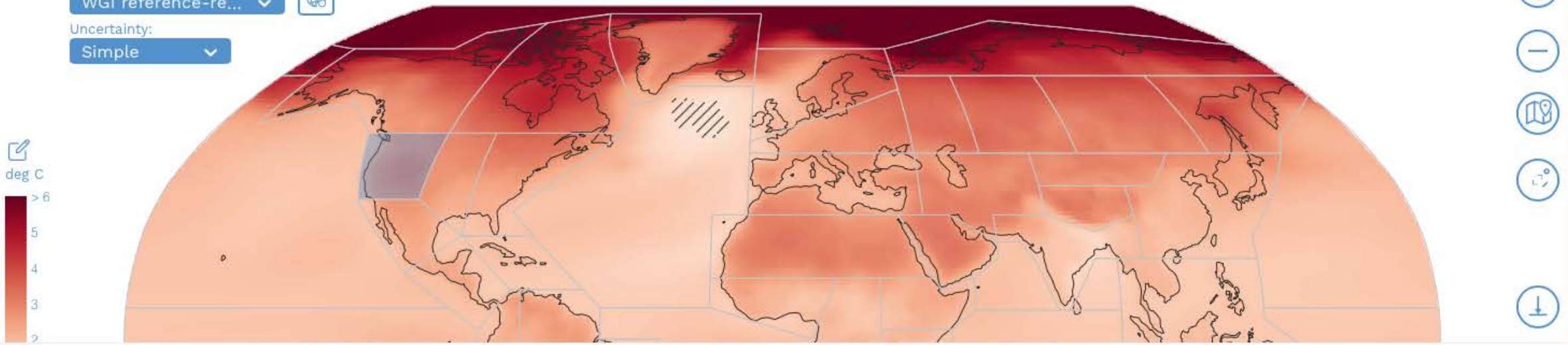
Dotted line: **Model** Solid line: **P50 (Median)** Gray shading: **Selected period** Light / dark area: **Spread P10-P90 / P25-75**

Export PDF | Export PNG | Mask: None | Models

DATASET VARIABLE QUANTITY & SCENARIO SEASON

Region Set: WGI reference-re...

Uncertainty: Simple



CMIP6 - Mean temperature (T) Change deg C - Warming 2°C SSP5-8.5 (rel. to 1850-1900) - Annual (34 models)
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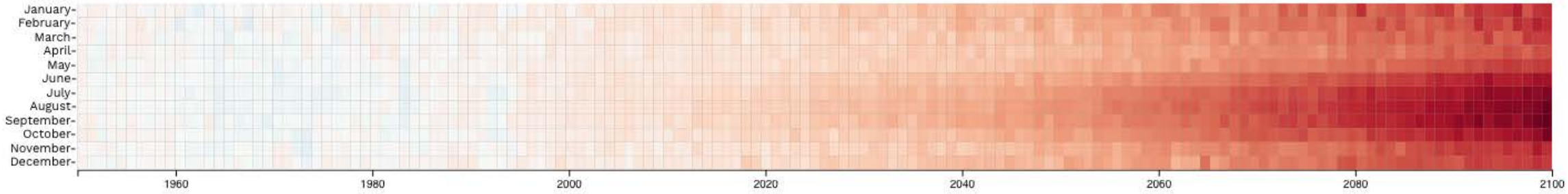
Time Series | GWL Plot | Annual Cycle | Scatter Plot | Table Summary | Stripes | Seasonal Stripes



Seasonal stripes (anomalies rel. to a baseline).: Rows: Ensemble mean monthly value Columns: Years

Export PDF | Export PNG | Mask: None

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- The Physical Science Basis (August 2021)

- Mitigation of Climate Change (March 2022)
  - Emissions
  - Opportunities to decrease greenhouse gases

- Impacts, Adaptation and Vulnerability (February 2022)
  - Ecosystems and ecosystem services
  - Agriculture, Health, poverty, development
  - Regional impacts

Climate Change, ecological drought and western slope ecosystems

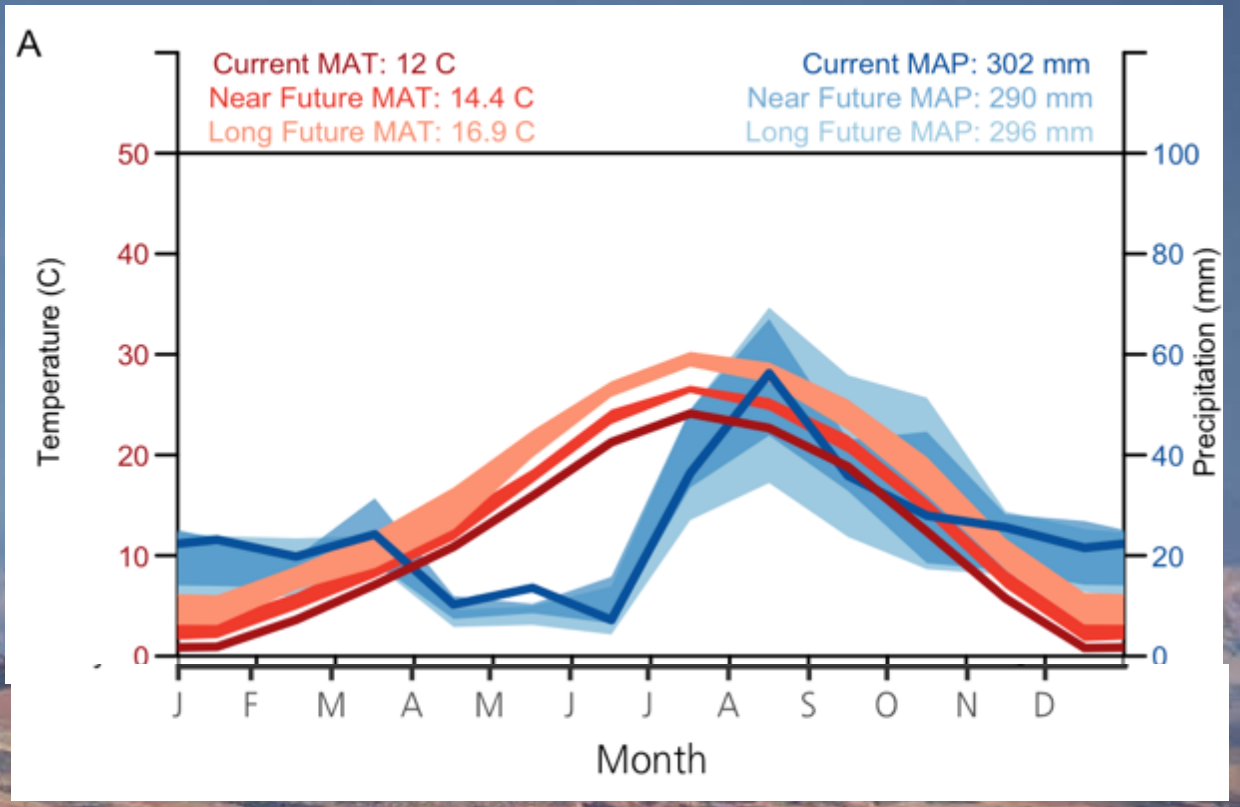
Update on climate change information

Implications for ecological drought in drylands of the west

Potential impacts to vegetation

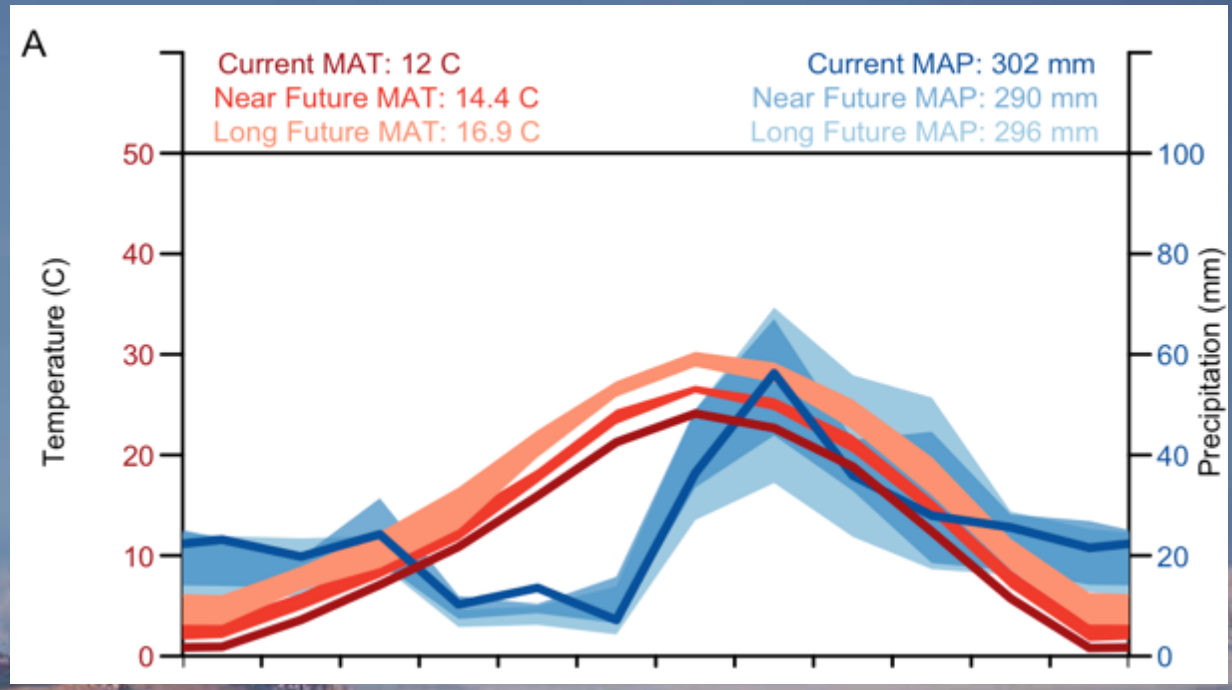
Opportunities for climate adaptation

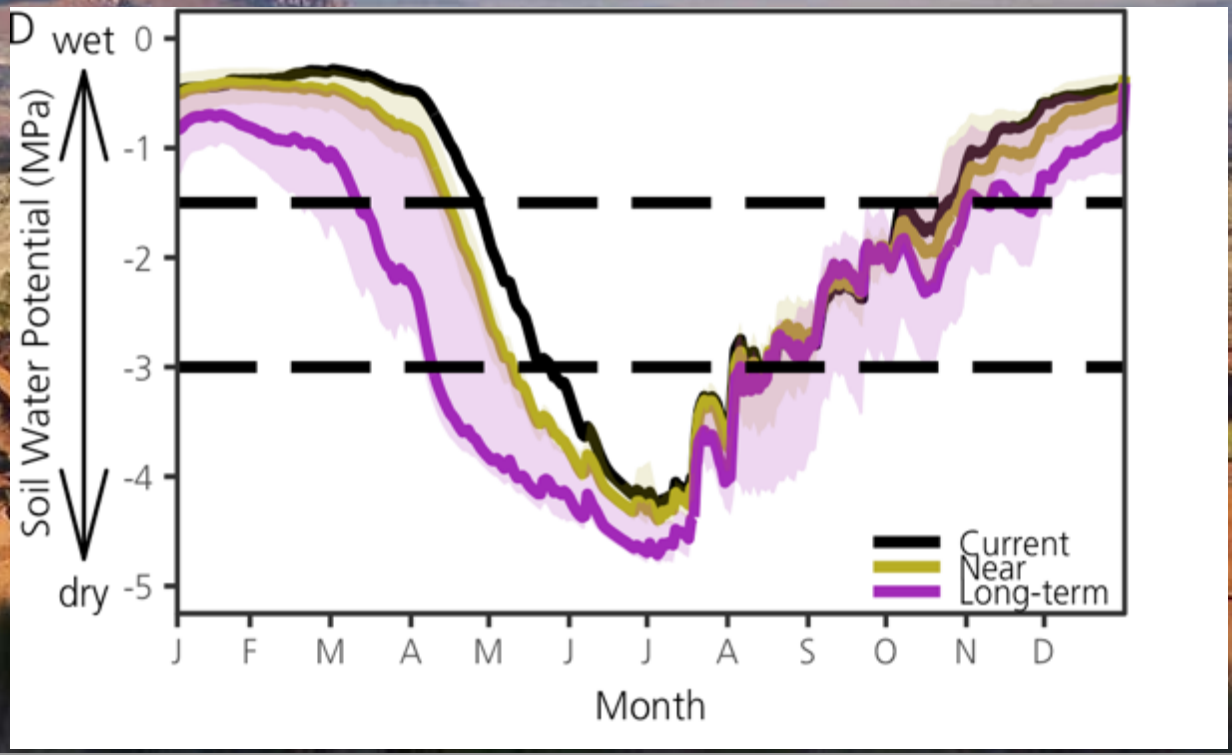
Wupatki National Monument



NPS Photo

Wupatki National Monument





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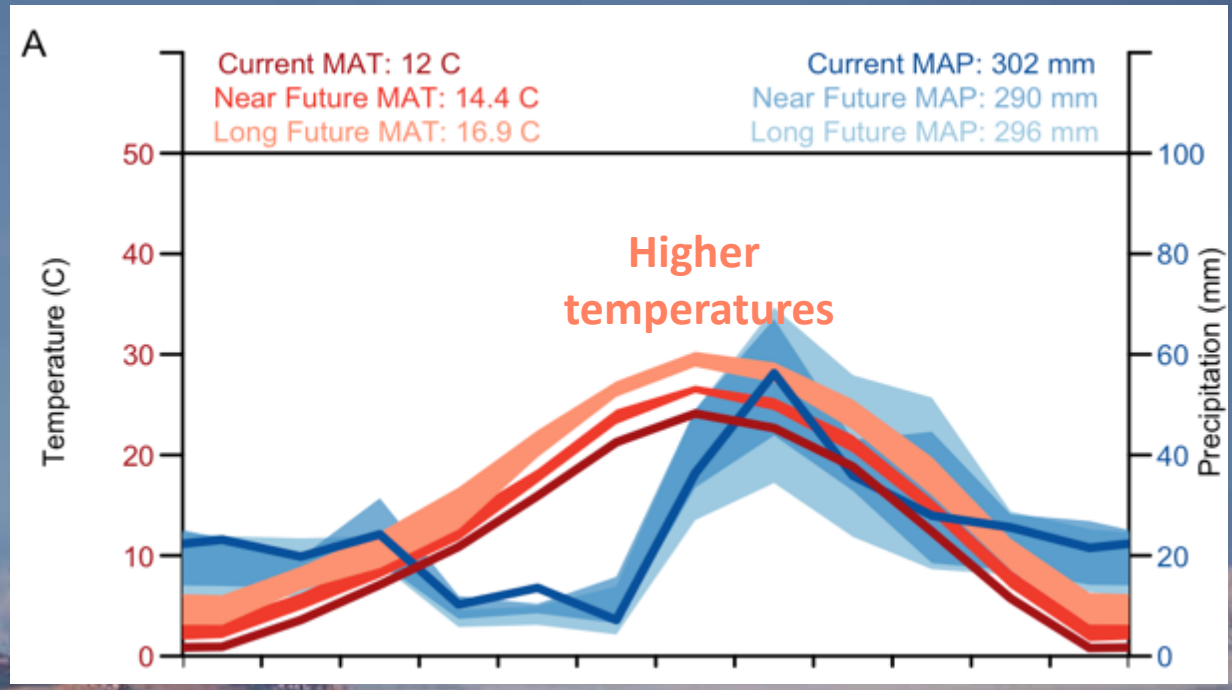
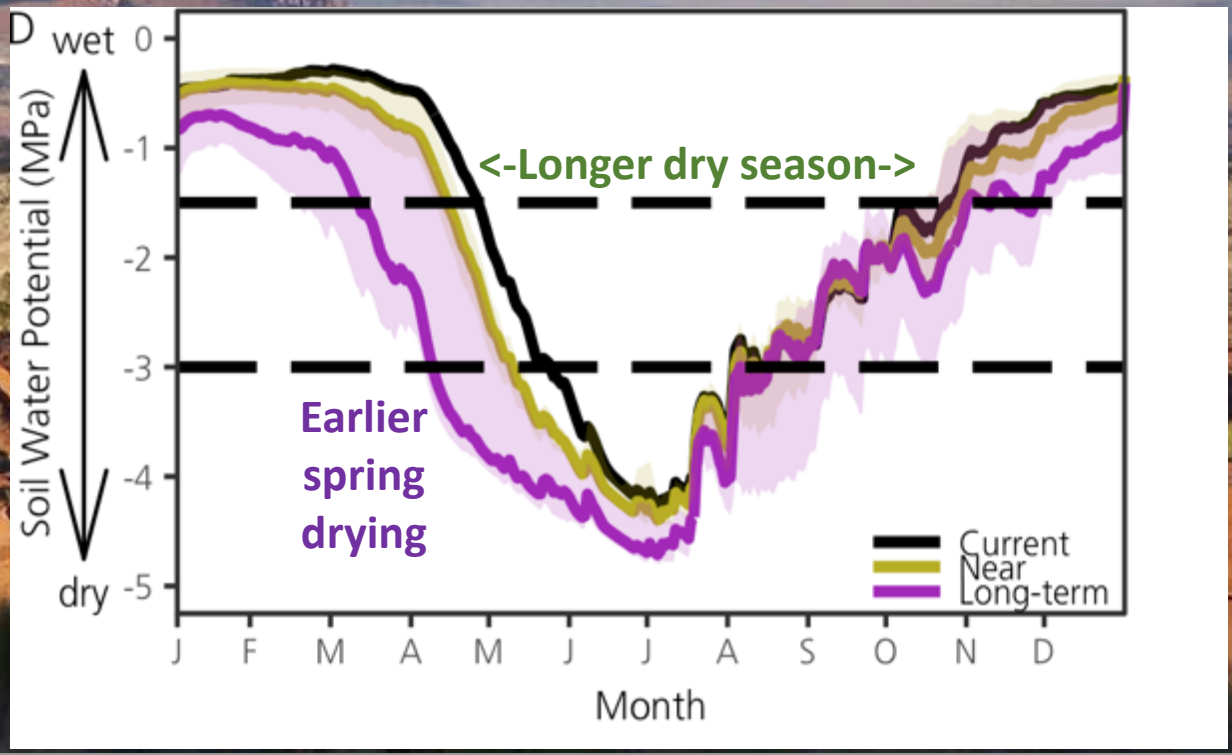
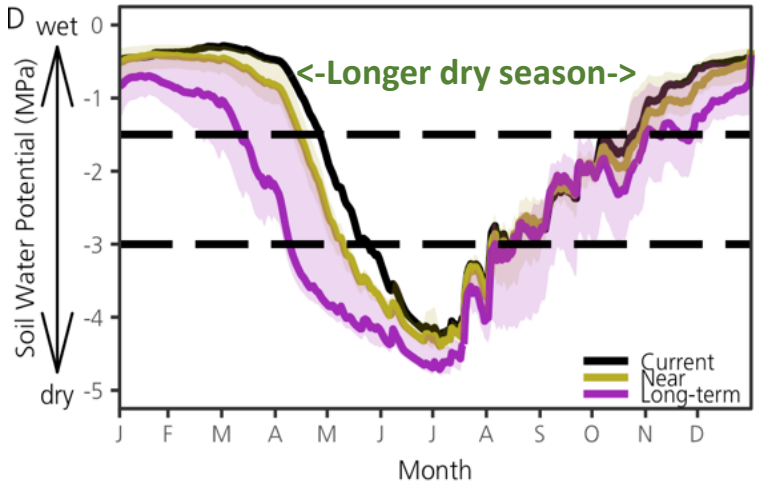
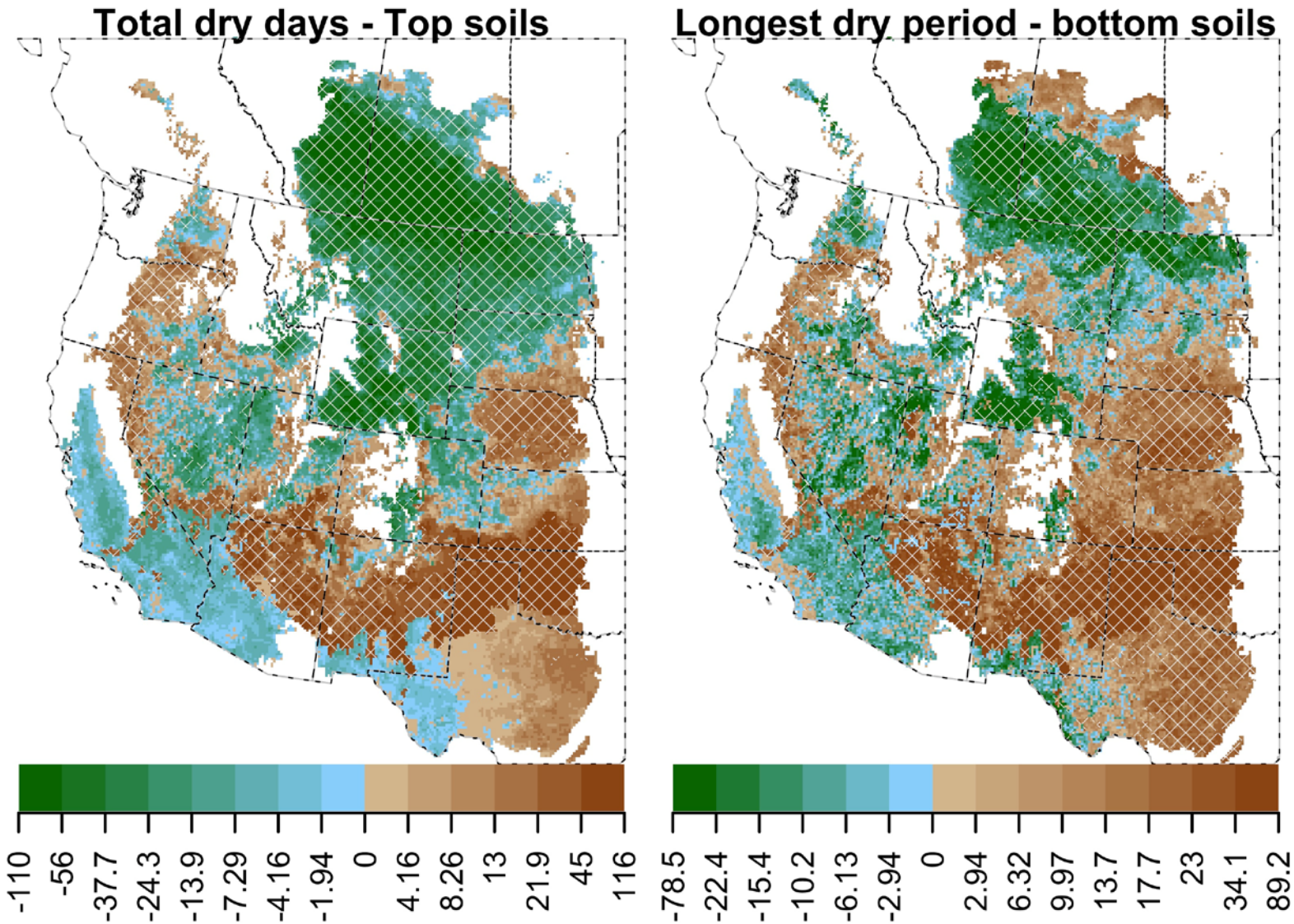




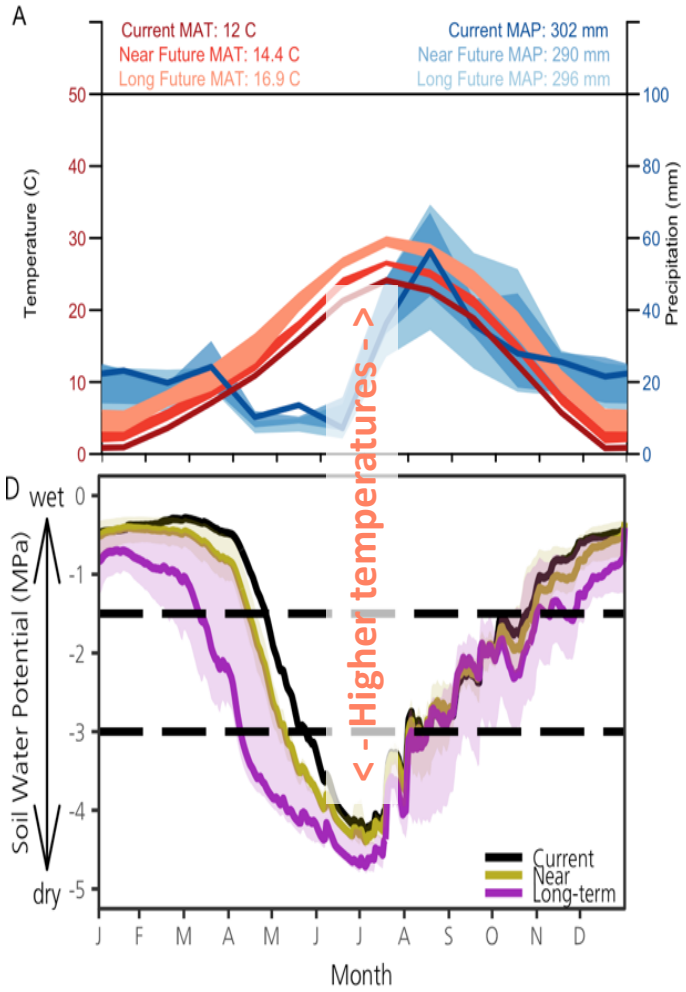
NPS Photo

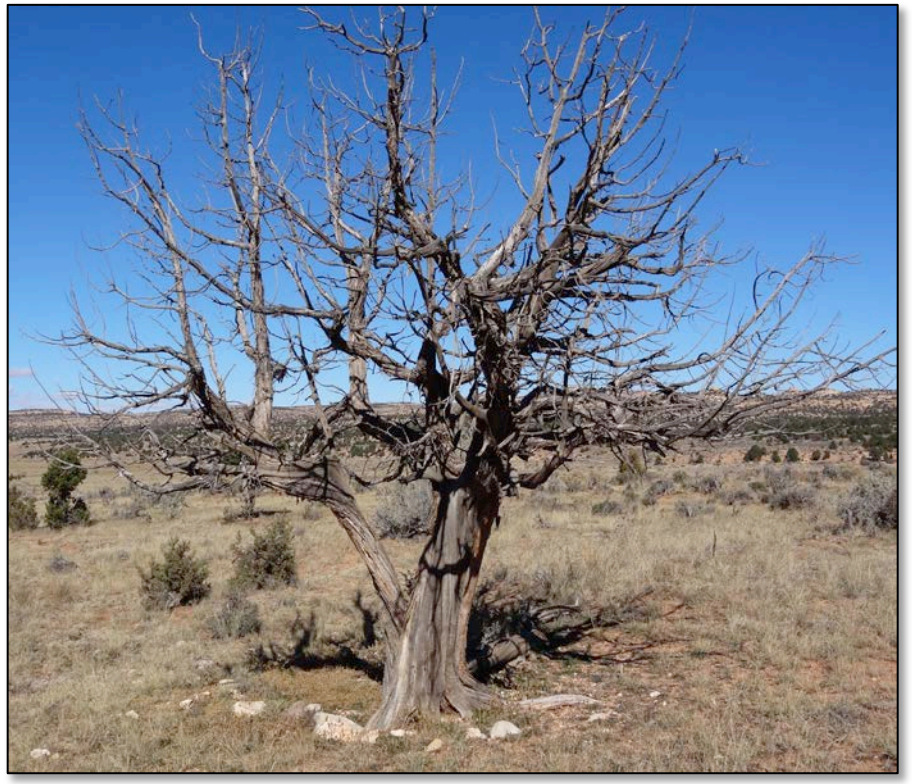




Bradford et al. 2020. *Global Change Biology*

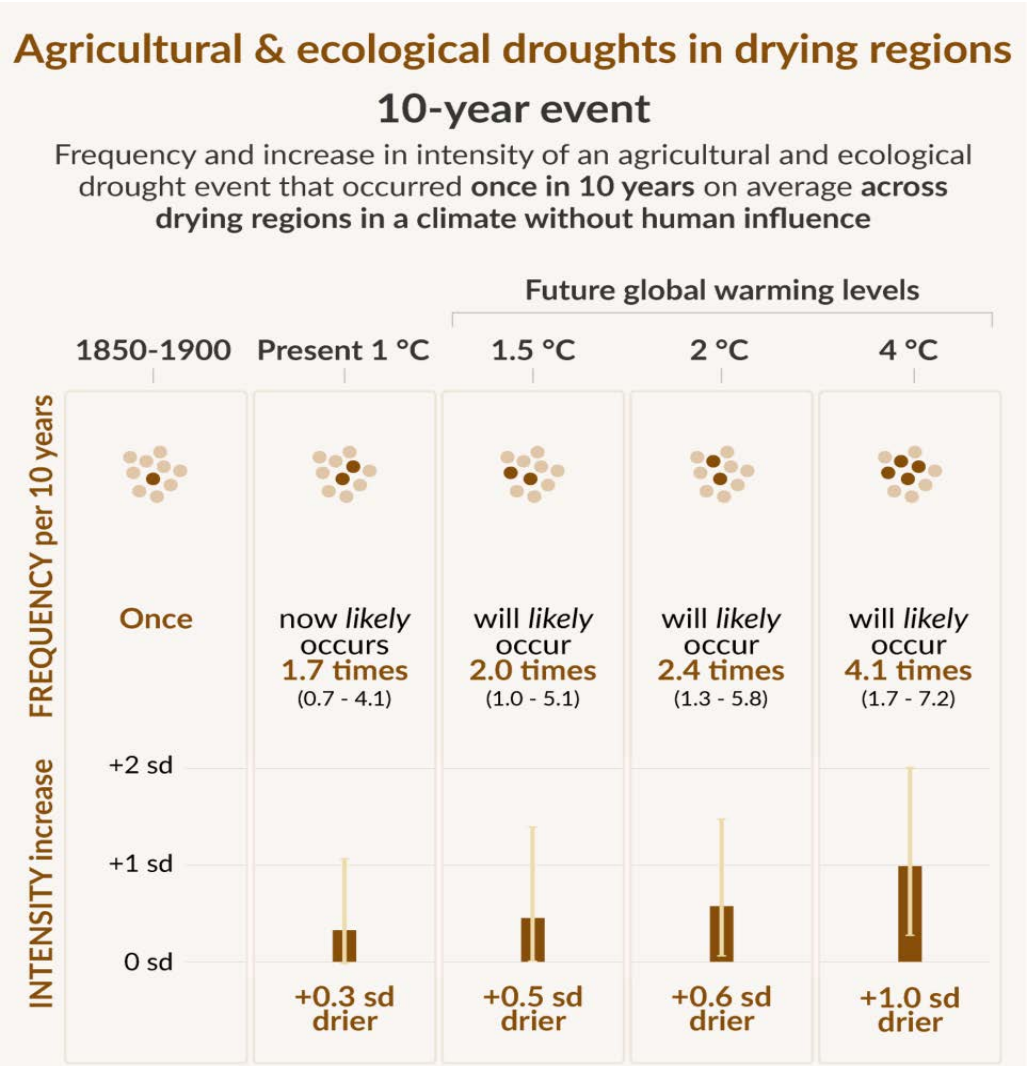
N. American drylands: changing hot-dry stress

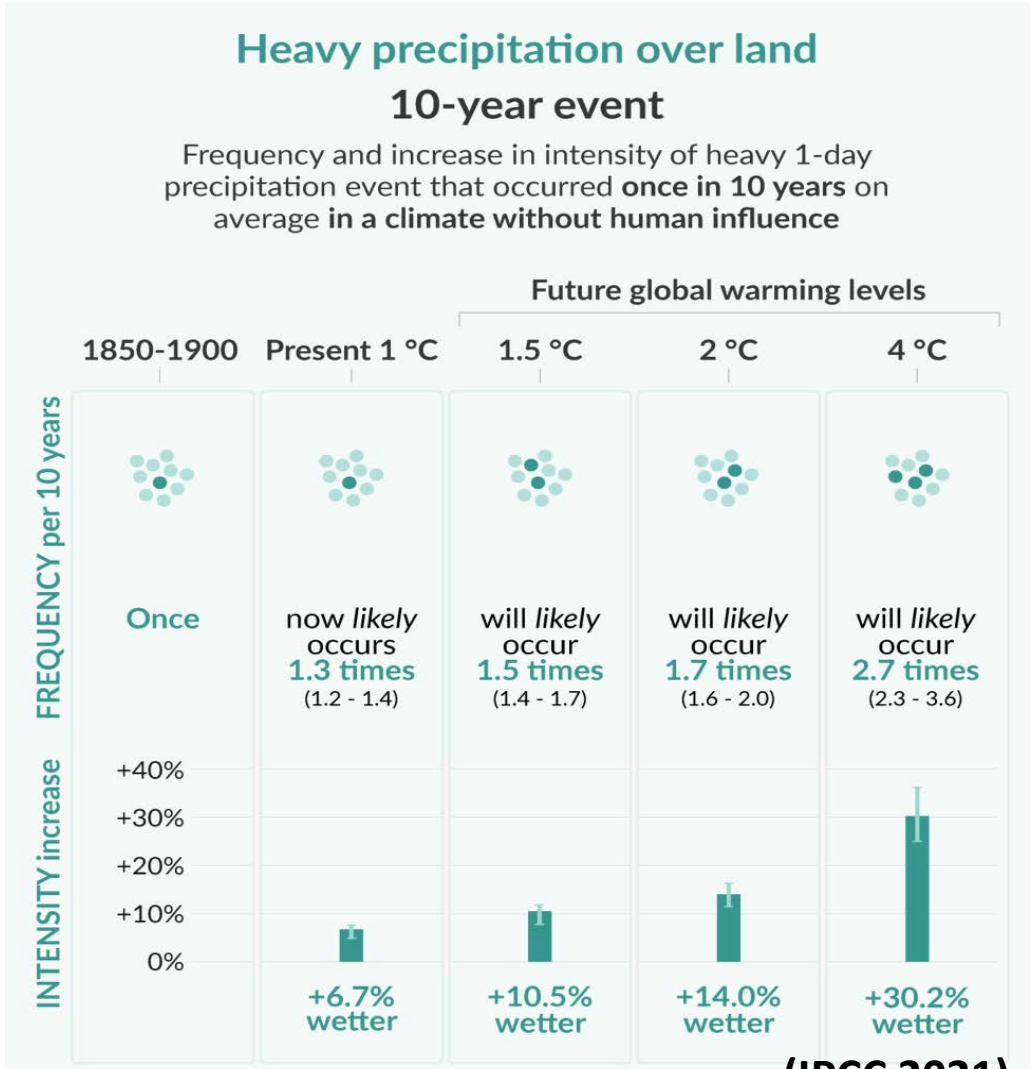




Bradford et al. 2020. *Global Change Biology*

Increasing weather variability … more unusual extreme events.





(IPCC 2021)

Climate Change, ecological drought and western slope ecosystems

Update on climate change information

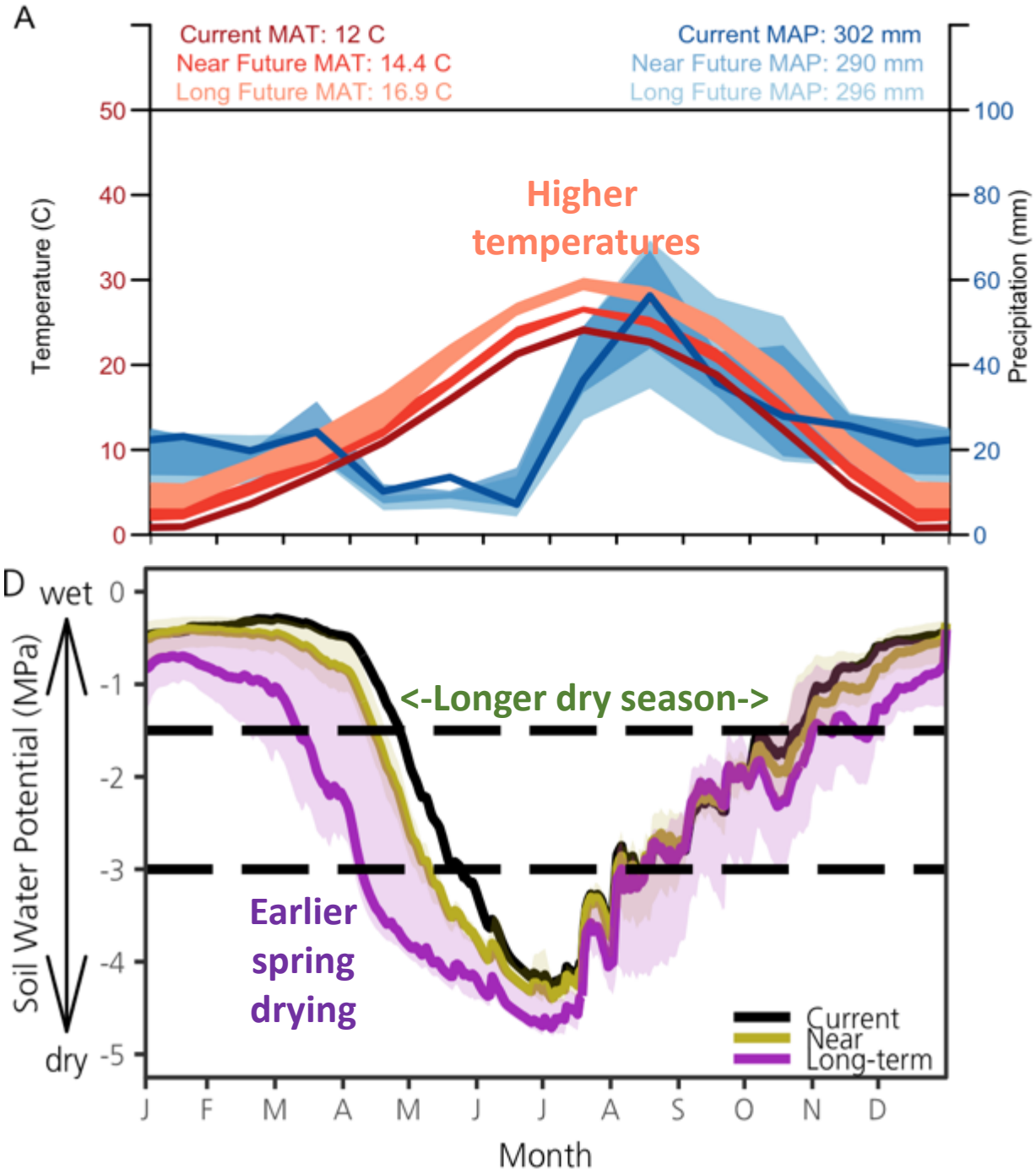
Implications for ecological drought in drylands of the west

Potential impacts to vegetation

Opportunities for climate adaptation

Vegetation impacts

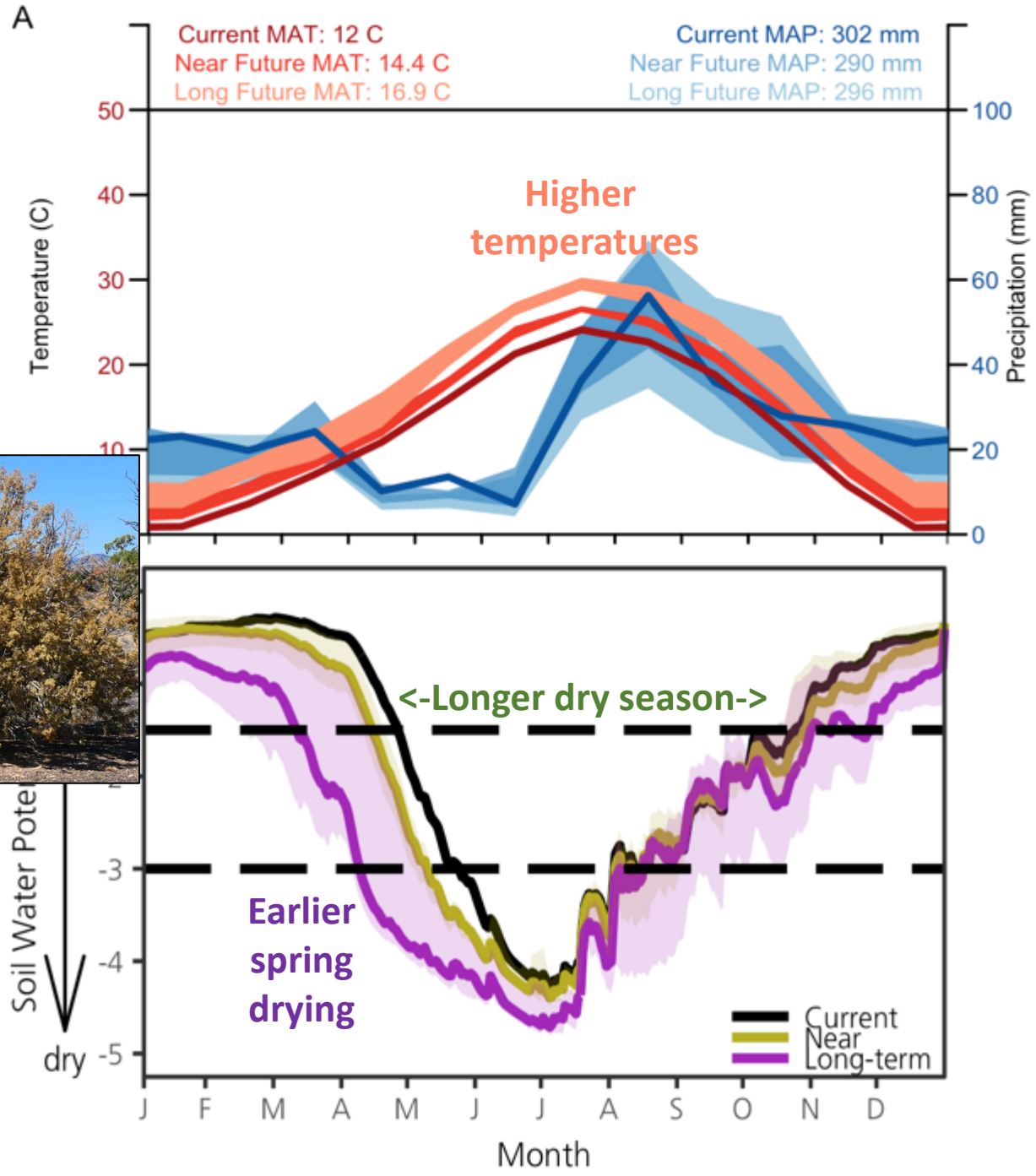
- **Shifting seasonality & phenology**
  - Longer frost-free period
  - Increased plant activity in cool seasons



Vegetation impacts

- Shifting seasonality & phenology

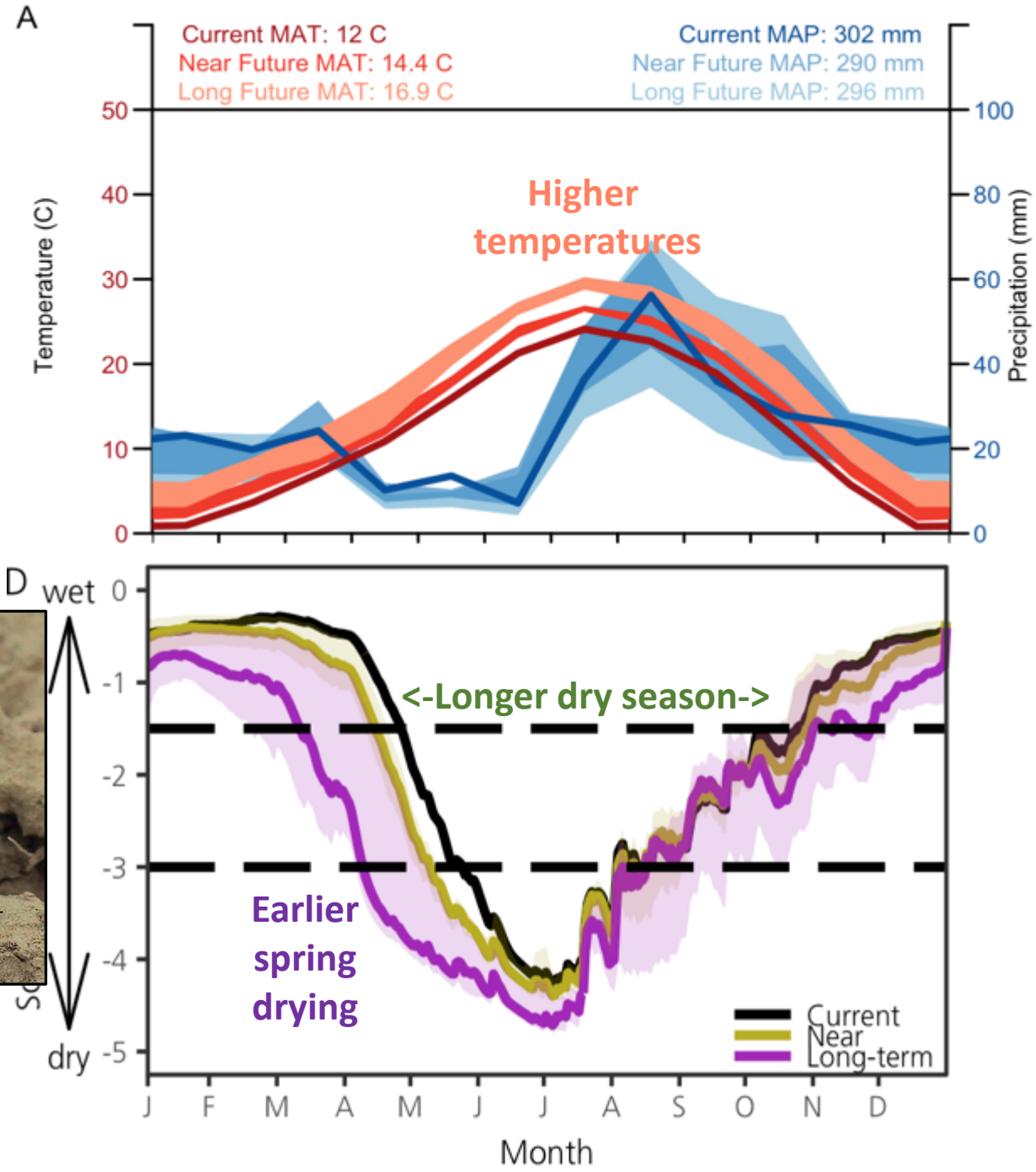
- **Plant mortality & dieback in response to extreme drought & heat**



Vegetation impacts

- Shifting seasonality & phenology
- Plant mortality & dieback in response to extremes

- **Potentially more barriers to plant establishment**



Vegetation impacts

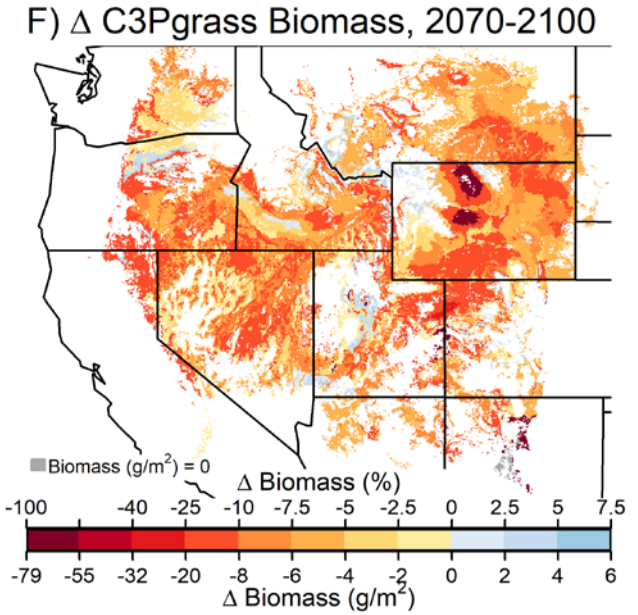
- Shifting seasonality & phenology
- Mortality & dieback in response to extremes
- Potentially more barriers to plant establishment

	Species	Robust change in λ
C3	*A. hymenoides*	-0.006
	E. elymoides	-0.007
	H. comata	-0.057
	P. smithii	-0.019
	P. secunda	-0.010
C4	*A. purpurea*	0.054
	B. eriopoda	-0.103
	B. gracilis	-0.030
	P. jamesii	-0.107
	S. airoides	0.003
	S. cryptandrus	0.148

Decreasing
Increasing

Havrilla et al. in Prep.

- **Long-term changes in plant viability:**
  - Changes in productivity
  - Decreasing for cool-season grasses
  - Mixed changes for warm-season grasses
  - Potential shifts toward deep-rooted woody plants



Palmquist et al. *Global Change Biology* 2021

Vegetation impacts

- Shifting seasonality & phenology
- Mortality & dieback in response to extremes
- Potentially more barriers to plant establishment
- Long-term changes in plant viability

- **Increasing transformations driven by multiple stressors (climate w/wildfire invasions, land use)**

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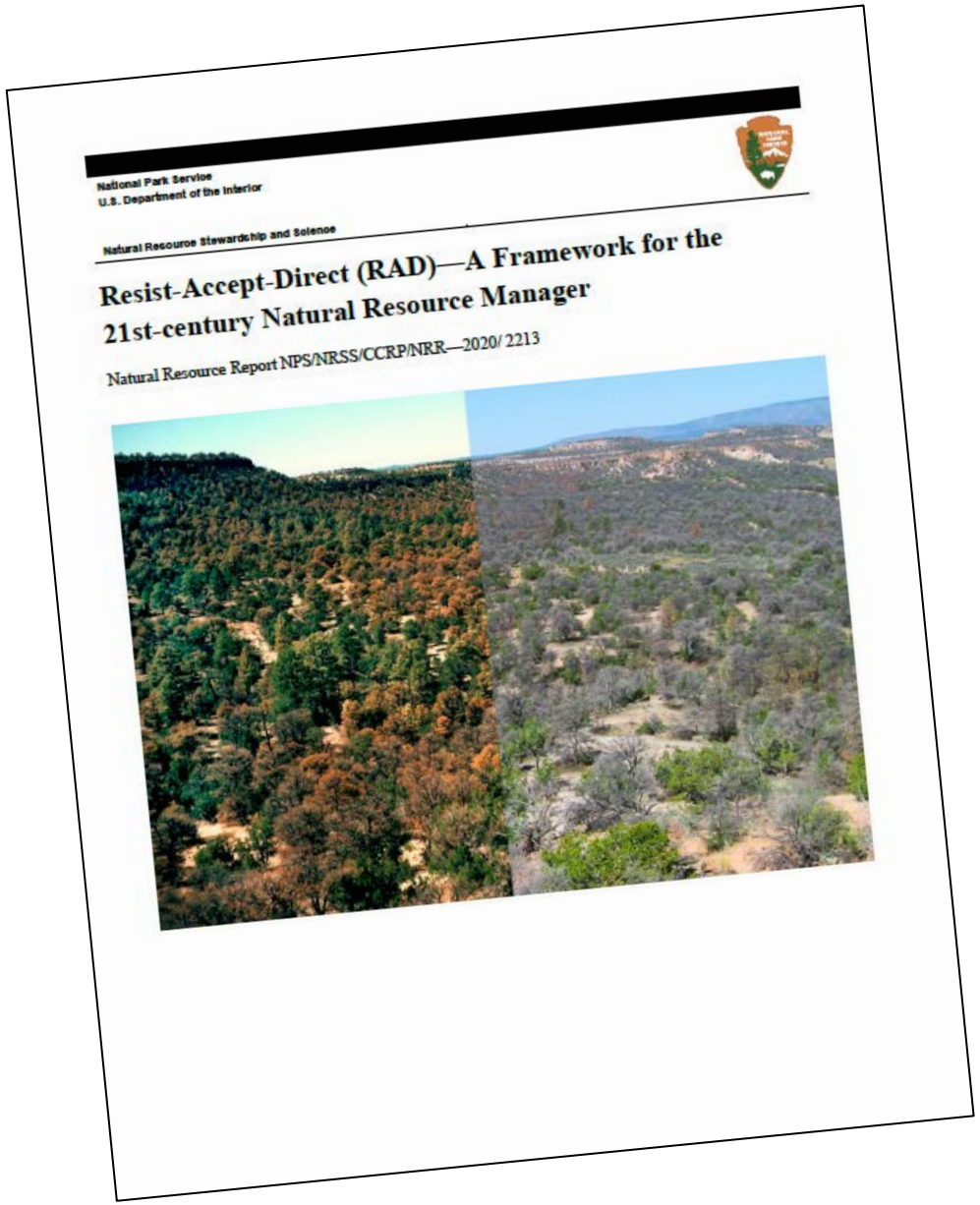
Potential impacts to vegetation

Opportunities for climate adaptation: frameworks, resources & tools

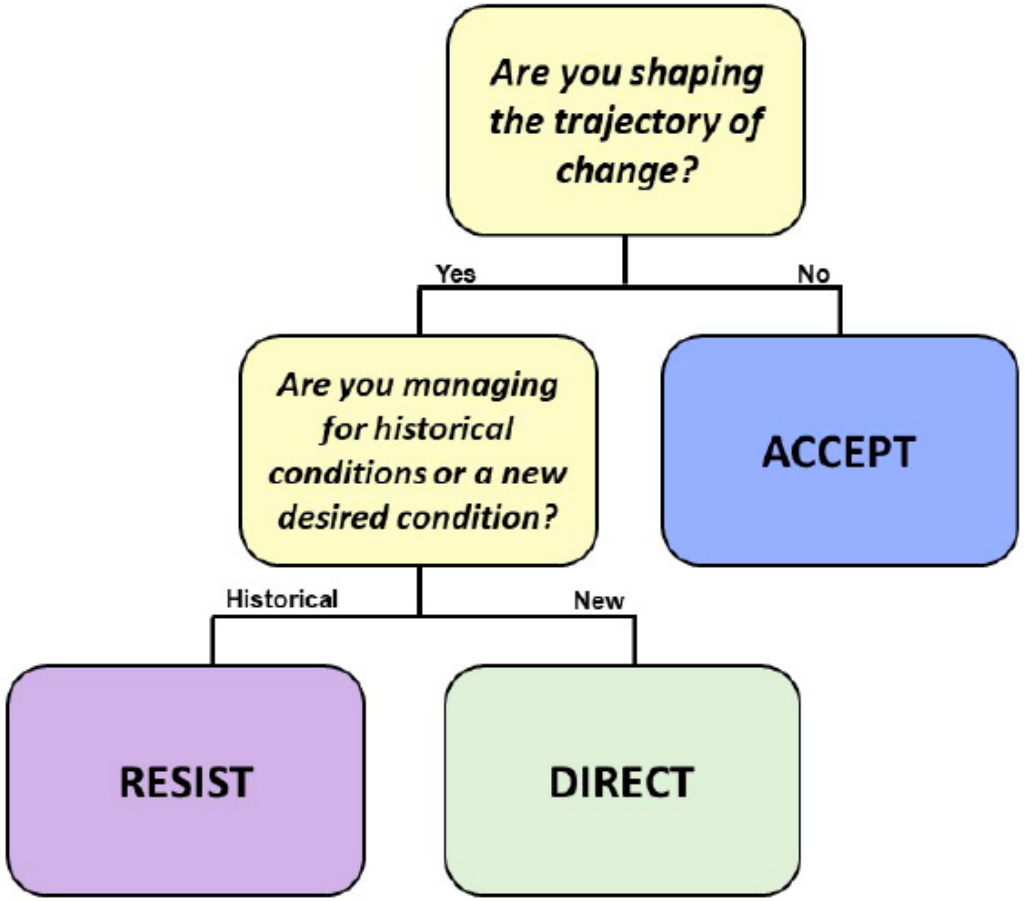
Climate adaptation: conceptual frameworks


National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

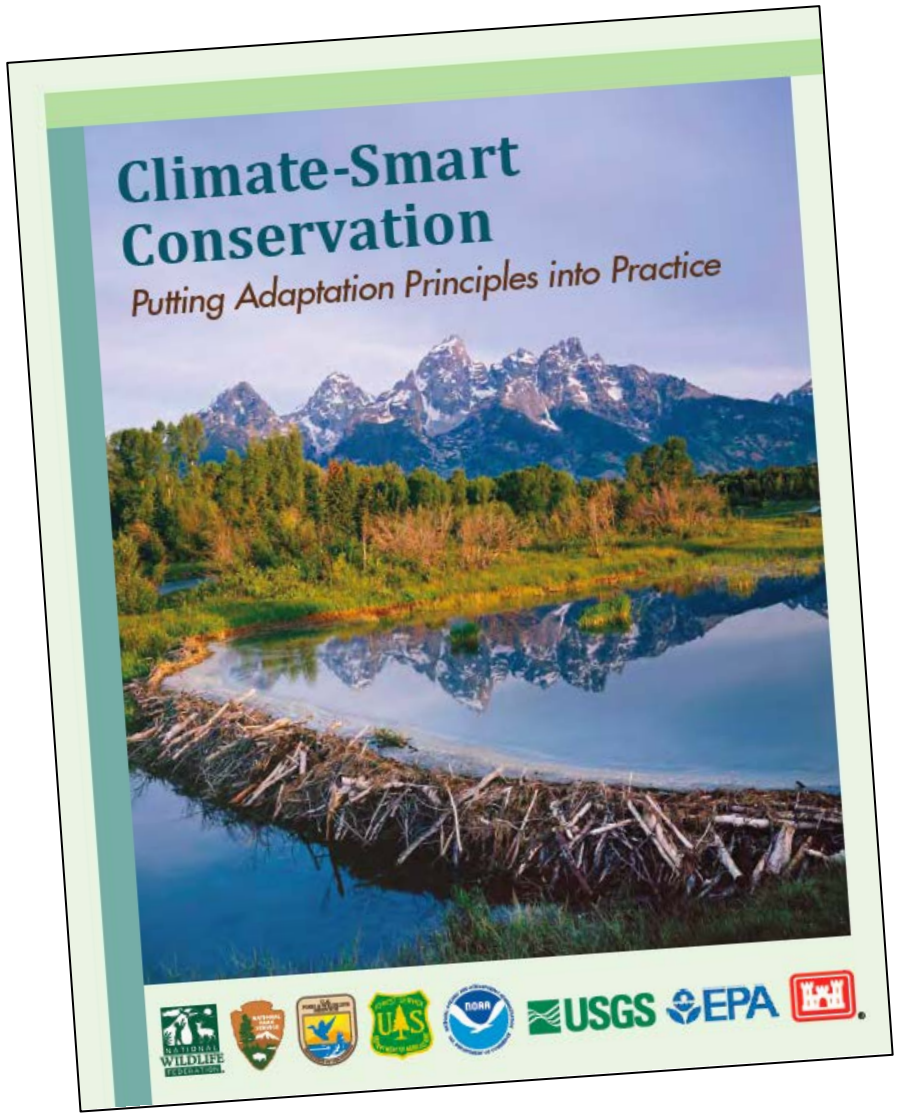
Resist-Accept-Direct (RAD)—A Framework for the 21st-century Natural Resource Manager

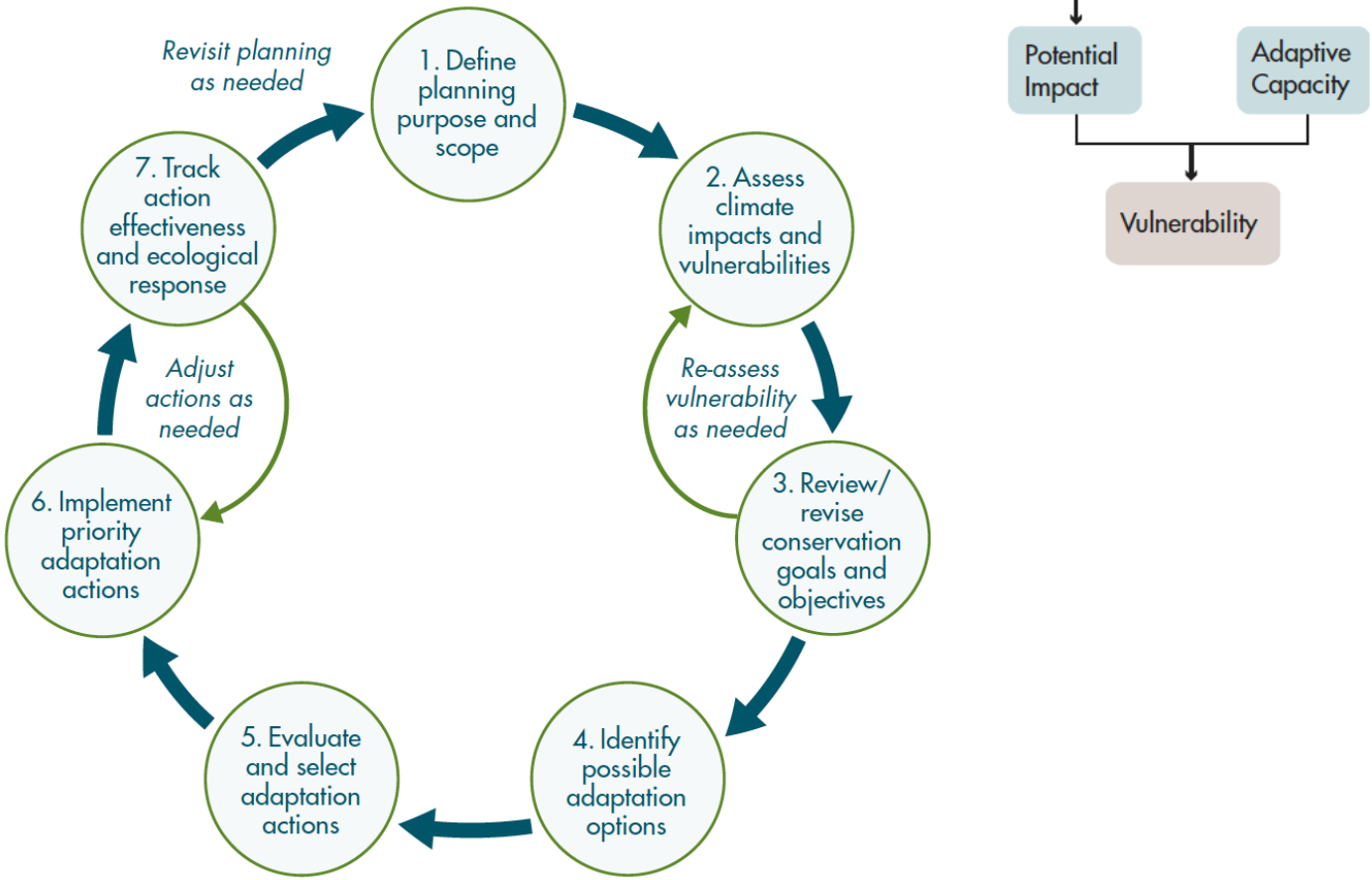
Natural Resource Report NPS/NRSS/CCRP/NRR—2020/2213



https://www.nps.gov/subjects/climatechange/radframework.htm

Climate adaptation: conceptual frameworks





https://www.nwf.org/ClimateSmartGuide

What is the resource of concern?

Identify focal resources for the rest of the project.

What is changing?

Estimate exposure to long-term aridification.

What are the impacts?

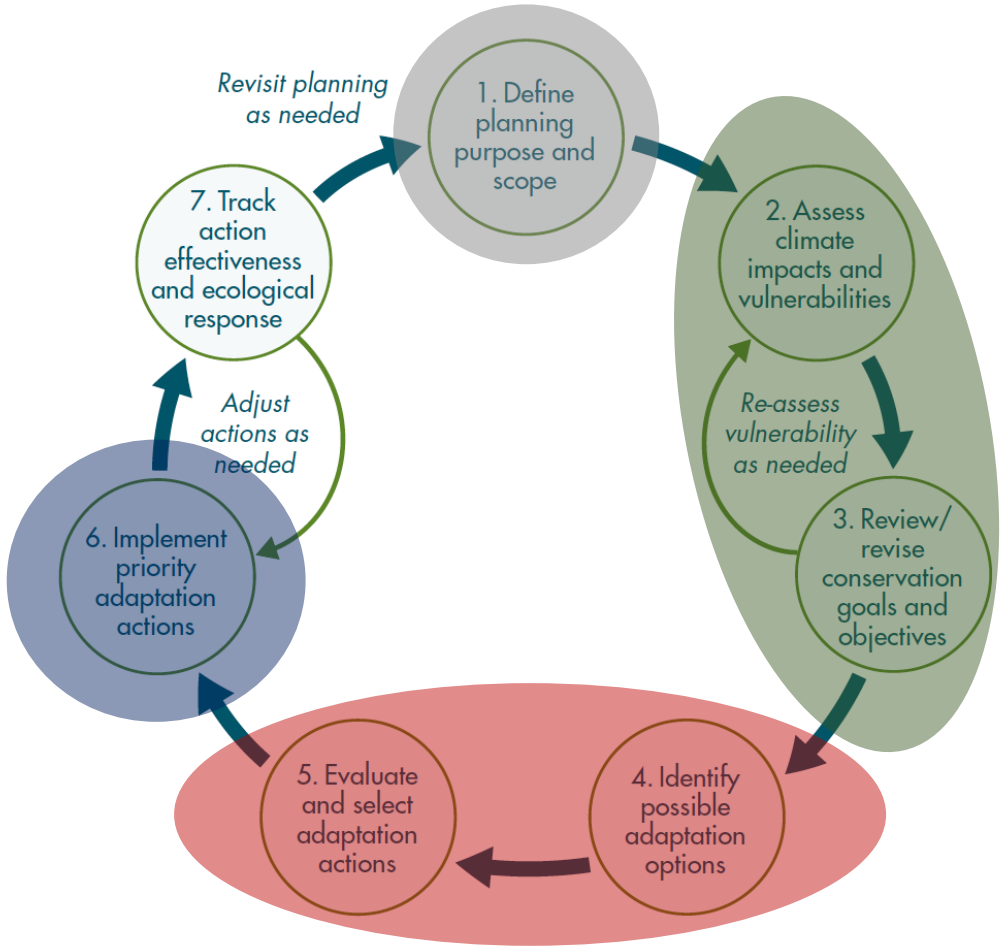
Synthesize knowledge about vegetation sensitivity to aridification.

What can we do?

Identify short- and long-term management strategies that enhance adaptive capacity.

How do we make it happen?

Incorporate strategies into management plans and actions.



Climate adaptation: resources

NIACS NORTHERN INSTITUTE OF APPLIED CLIMATE SCIENCE

www.niacs.org/

CLIMATE CHANGE
RESPONSE FRAMEWORK

www.forestadaptation.org

USDA
U.S. FOREST SERVICE
Caring for the land and serving people
United States Department of Agriculture

CLIMATE CHANGE RESOURCE CENTER

CLIMATE CHANGE RESOURCE CENTER

EDUCATION TOPICS ADAPTATION TOOLS LIBRARY

www.fs.usda.gov/ccrc/

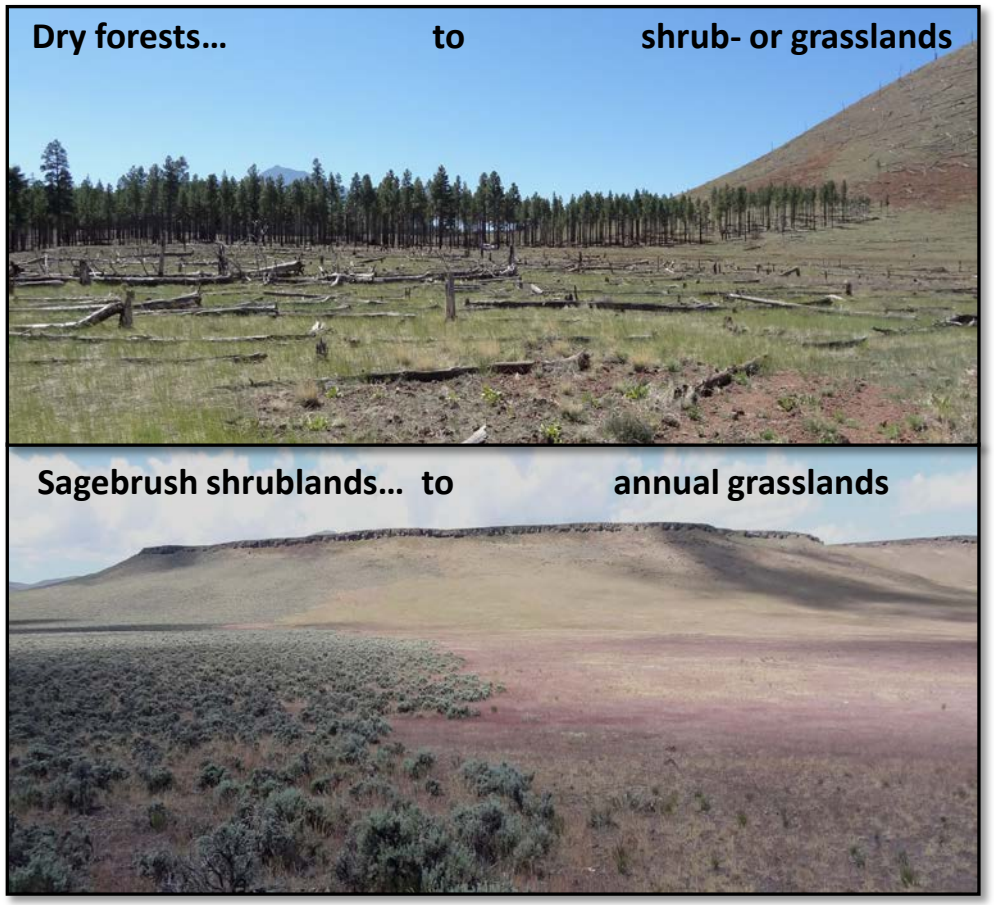
Climate adaptation: tools

- https://toolkit.climate.gov/tools
- https://www.climatehubs.usda.gov/hubs/northern-forests/adaptation-tools
- https://www.fs.usda.gov/ccrc/tools
- https://climatetoolbox.org/
- https://training.fws.gov/courses/alc/alc3184/resources/tools/CCToolMatrix.pdf

- **Many** other more specific tools are emerging: e.g. ecological drought forecasts to enhance dryland restoration success:
- https://chsapps.usgs.gov/apps/land-treatment-exploration-tool/map

Forecasting dryland plant establishment to enhance restoration success

Drylands are transforming



Restoration is widespread but success is not!

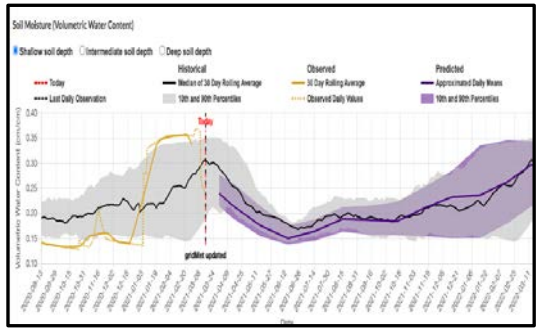
Plant establishment is often limited by dry conditions

Establishment requirements are *reasonably* well recognized

Soil moisture details are critical (depth & seasonal timing of moisture)
Some quantitative models exist

We are forecasting soil moisture & plant establishment

Using NOAA's seasonal temperature & precipitation anomaly forecasts with ecosystem water balance modeling and establishment models.



Opportunities for improvement

- Gather & integrate monitoring data of seeding outcomes to iteratively improve ecological models
- Build establishment models for more species, genotypes, & seed sources
- Increased confidence in anomaly forecasts confidence will constrain forecast uncertainty
- Forecasts are currently point-based, need to created gridded products for landscape and regional planning

John Bradford (USGS): jbradford@usgs.gov

https://chsapps.usgs.gov/apps/land-treatment-exploration-tool/map

Plan Treatment | Layers/Legend

Step 1: Describe proposed treatment

Project Name:

Type a descriptive name for your project e.g., Cougar Canyon Wildfire Aerial Seeding Rehabilitation 2018.

What kind of treatment are you planning?

Select what type of treatment you are planning from the drop down list.

File Name:

Type a file name to be used for each exported product. To use the Project Name, check the box for 'same as project name'.

same as project name

Next Step >>

Step 2: Select treatment boundary

Step 3: Explore site characteristics

Step 4: Summarize your proposed treatment area

Step 5: Select search parameters

Step 6: Compare to LTDL treatments

Planning Map | Site History | Results | Report | USFWS IPaC | **Drought Forecast**

Print Report

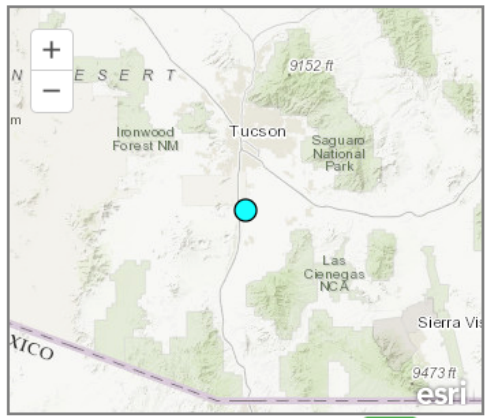
Seasonal Ecological Drought Forecast

Weather variability is well known to have strong effects on land treatment application and outcomes particularly in dryland ecosystems. Intra-annual variations in seasonal water and temperature is especially important, such as those driven by particular storms or short-term events that last weeks or months. Past research has demonstrated the importance of weather, and drought in particular, on the success or failure of dryland restoration (e.g. Brabec et al. 2017; Hardegree et al. 2018, Shriver et al. 2018, Moffett et al. 2019).

This tool forecasts seasonal weather and soil water availability to help plan treatments such as herbicide or seeding after wildfires. The forecasts may help in understanding past treatment results, and/or evaluate climate and weather effects on treatments.

Overview of tool

The Seasonal Ecological Drought Forecast Tool estimates soil moisture conditions for 12 months into the future by integrating National Weather Service regional seasonal temperature and precipitation forecasts, including uncertainty, with an ecosystem water balance model. Users select a point location and can specify soil texture or use gridded soils data SSURGO and STATSGO. The Seasonal Ecological Drought Forecast tool generates site-specific temperature, precipitation and soil moisture forecasts and compares forecasted conditions to historical conditions at 4km resolution. These forecasts can help assess the potential impact of drought on land treatments in the next 12 months. The Seasonal Ecological Drought Forecast tool also forecasts sagebrush establishment success for the coming season. Metrics for additional plant species are planned for future versions of the tool.



click button to change the point: Point

Instructions for using the tool

The latitude and longitude shown in the map box to the left represents a central point for the planned treatment boundary created in Step 2. The point can be changed by clicking on the 'Point' button below the map to clear the current selection and clicking a new point on the map. The Seasonal Ecological Drought Forecast tool is set by default to use gridded soils data to determine the percent clay and sand for the location. Click the 'Specify Soils' radio button to show fields to specify values for the percent clay and sand. Click the 'Calculate' button when location and soils selections are complete. It may take 3-5 minutes for the Seasonal Ecological Drought Forecast tool to return a report. The results will display below and consist of a summary, shown first, and overview graphs of soil moisture, air temperature, and precipitation. Clicking the section headers opens detailed sections for each metric. See the User Guide Drought Forecast tab for more detailed instructions on how to use this tool and interpret its results.

Use Gridded Soils Data

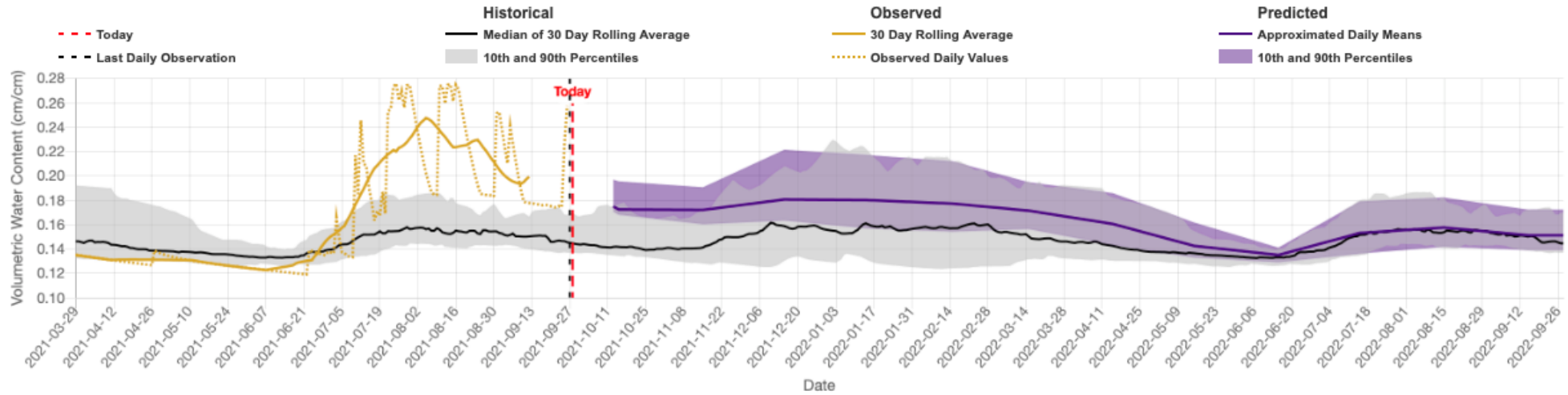
Specify Soils

Calculate

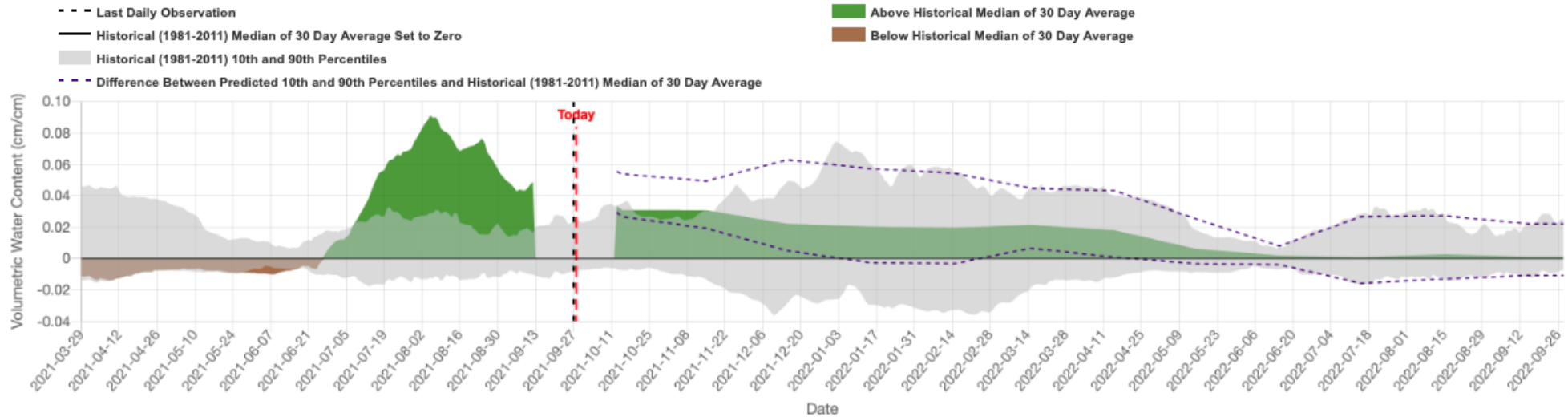
Soil Moisture

Soil Moisture (Volumetric Water Content)

Shallow soil depth | Intermediate soil depth | Deep soil depth



The figure above shows an 18-month time series of soil moisture (volumetric water content) values in Shallow (0-15cm) soils. The time series includes recent (the last 6 months) observations on the left and forecasted values (the next 12 months) on the right. Variability in forecasted values is a result of uncertainty in the seasonal outlooks for temperature and precipitation. *toggle long description*



The figure above shows an 18-month time series of soil moisture (volumetric water content) deviations from the long-term site median of the 30-day rolling average in Shallow (0-15cm) soils. The vertical, dashed red line on the figure is today's date and the vertical, dashed black line is the date of the most recent data from gridMet. The time series includes recent (the last 6 months) observations on the left and forecasted values (the next 12 months) on the right. The long-term historical normal for each day is plotted in the background to help compare the recent past and future to reference conditions. This figure helps users determine if soils are expected to be wetter or drier than normal. *toggle long description*

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Climate change information: New IPCC report(s) & resources

- Projections similar to previous reports: warmer temperatures, variable precipitation
- Greater confidence about processes, human influence, and weather extremes

Implications for ecological drought in drylands of the west

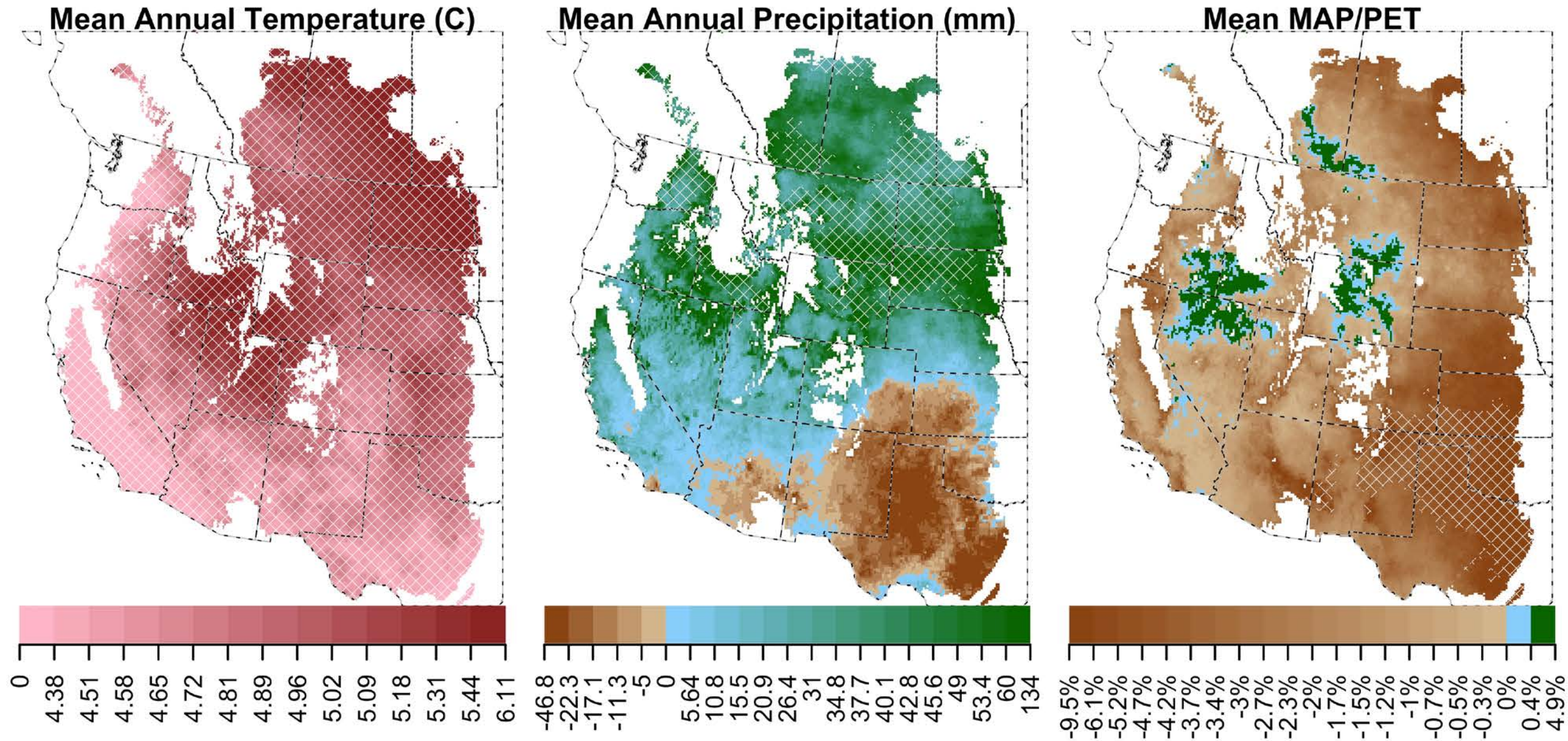
- Warmer (perhaps wetter) cool season
- Earlier spring drying, longer and hotter summers & more variability

Potential impacts to vegetation

- Shifting seasonality & increased mortality
- Changes in viability and transformations

Opportunities for climate adaptation

- Conceptual frameworks exist
- Practical resources are available….tool for adaptation to drought & climate changes are growing



Bradford et al. 2020. *Global Change Biology*