

Tools for developing reproducible climate futures for resource planning

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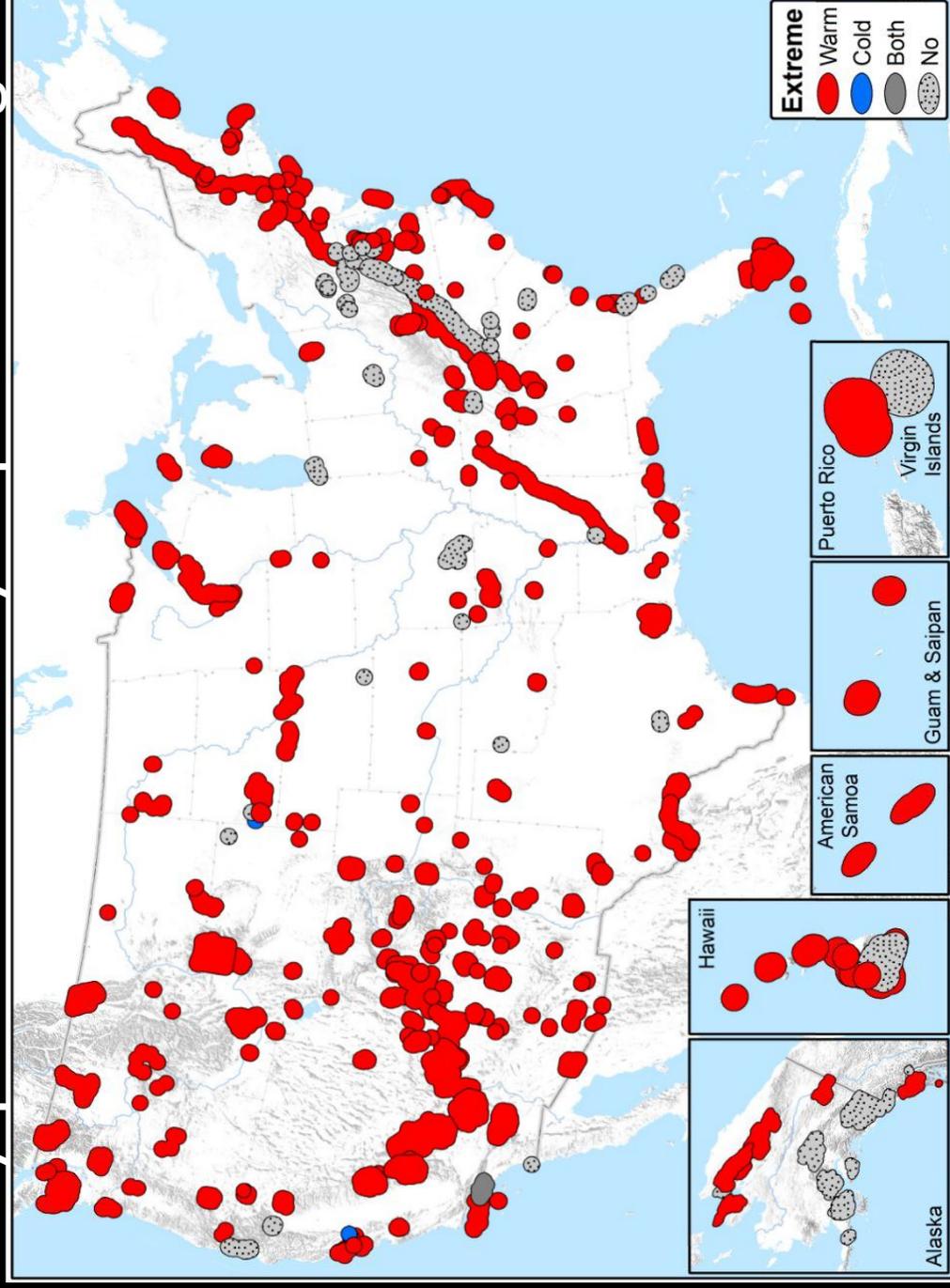


North Central Climate Science Adaptation Science Center, 14 Apr 2022

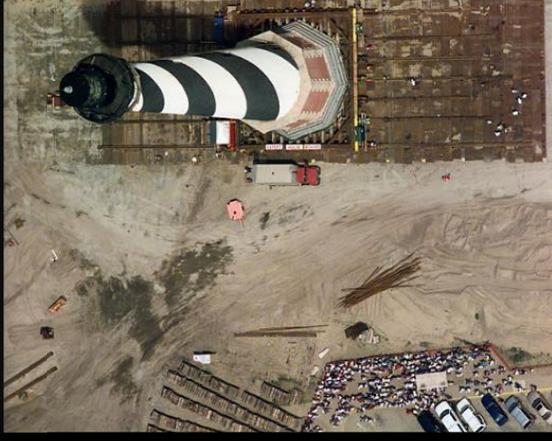
Many parks have already experienced significant warming

81% (235 of 289) of parks already extremely warm*

* Extreme = Parks with recent mean temp greater than 95% of the historical range of conditions



Climate change is impacting parks



More climate change impacts are anticipated

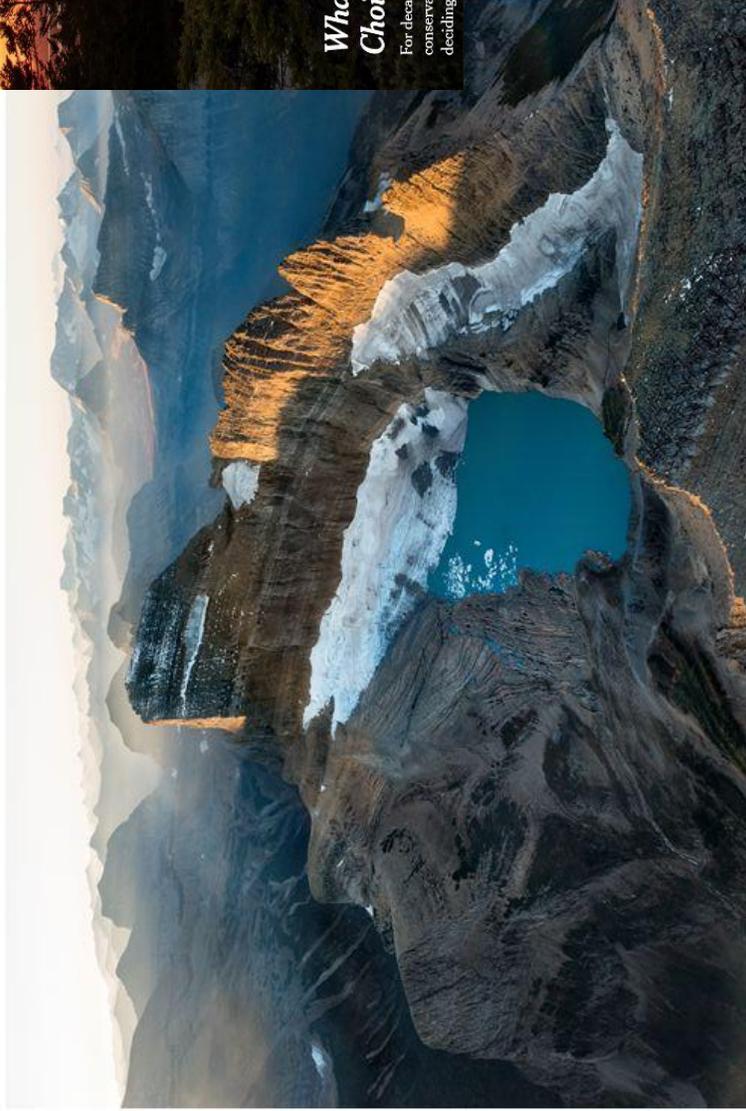
THE POWER OF PARKS |

How the Parks of Tomorrow Will Be Different

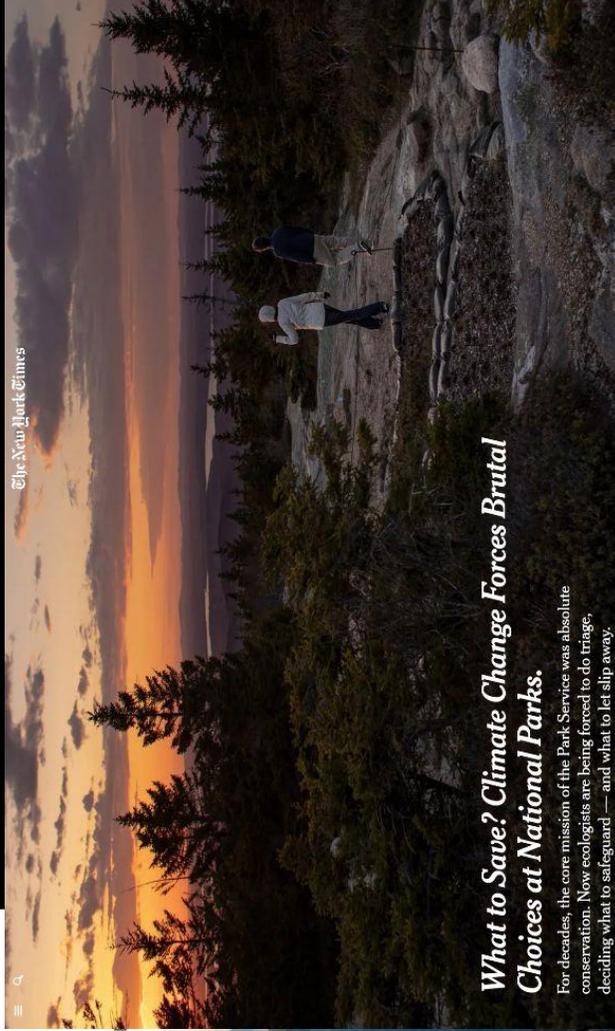
America's most special places will always be beautiful, but a warming climate forces us to accept that they can't be frozen in time.



DECEMBER



The New York Times



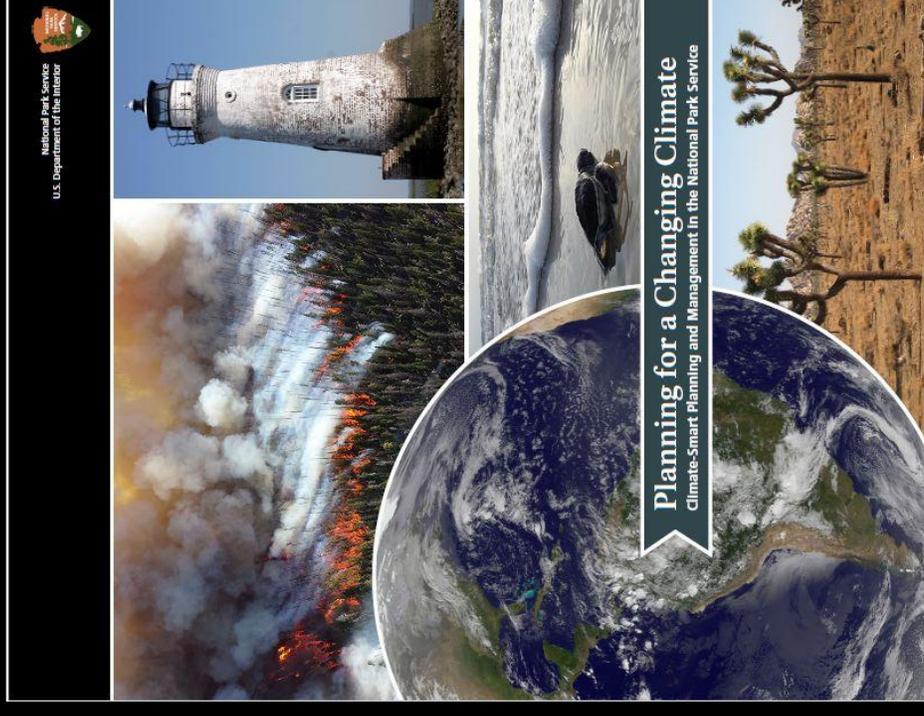
What to Save? Climate Change Forces Brutal Choices at National Parks.

For decades, the core mission of the Park Service was absolute conservation. Now ecologists are being forced to do triage, deciding what to safeguard — and what to let slip away.

Planning for a Changing Climate

Fundamentals of adaptation planning

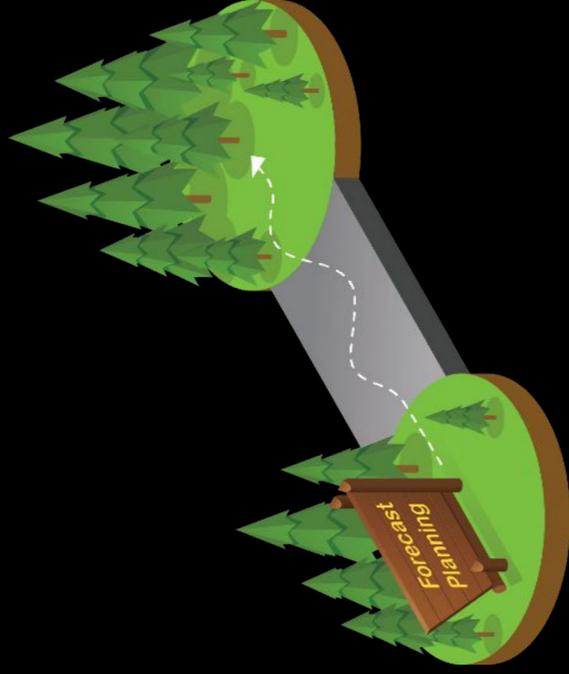
- **Develop forward-looking goals** that consider future climatic conditions
- **Consider more than one scenario** of the future



Planning in uncertain times

Traditional planning

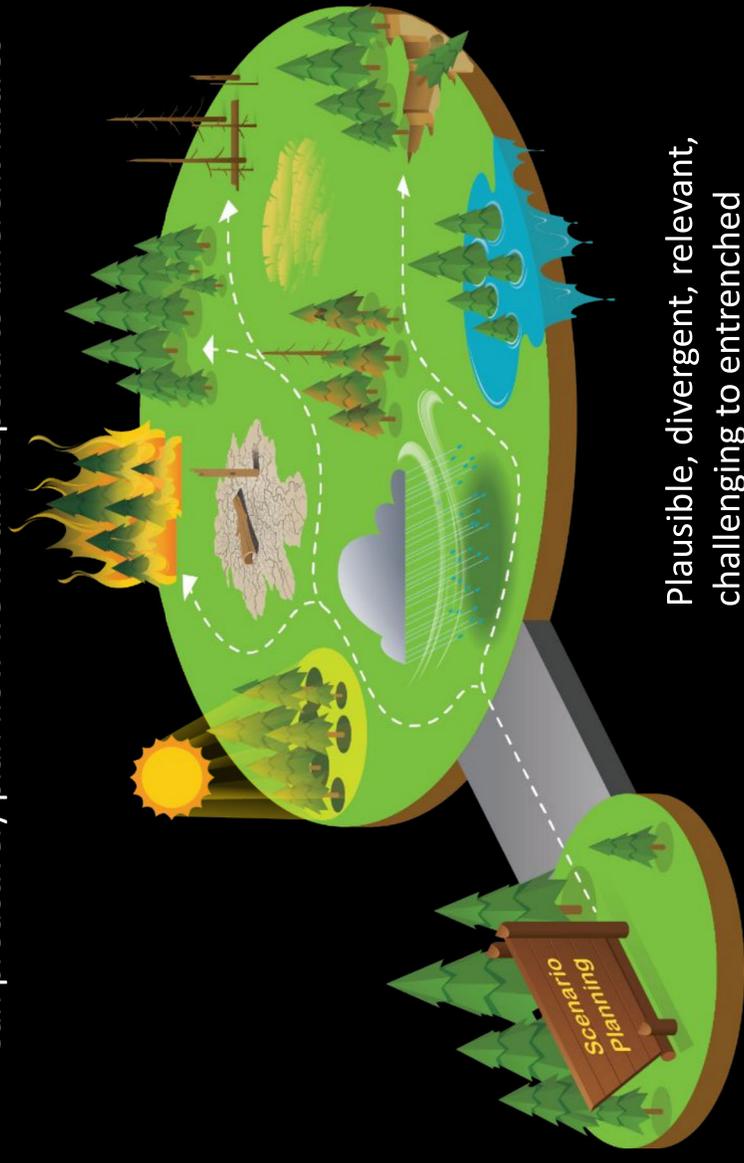
- Assumes the future will look like the past
- Tend to be overconfident in our ability to predict the future
- Tend to think narrowly
- Leave ourselves open to surprises



Planning in uncertain times

Scenario planning

- Not based on the past, but what could happen in the future
- Highly valuable in situations of irreducible uncertainty
- Asks 'what might happen' in a rigorous and creative way
- Encourages thinking broadly, be open-minded about possibilities
- Can proactively plan how we would respond to different futures



Plausible, divergent, relevant,
challenging to entrenched
mindsets

Scenario planning

Organizations that conduct scenario work benefit in the following ways:

- Quicker reactions to a changing world (we've already thought about it)
- More flexible plans
- Innovative ideas
- Early and broad risk identification



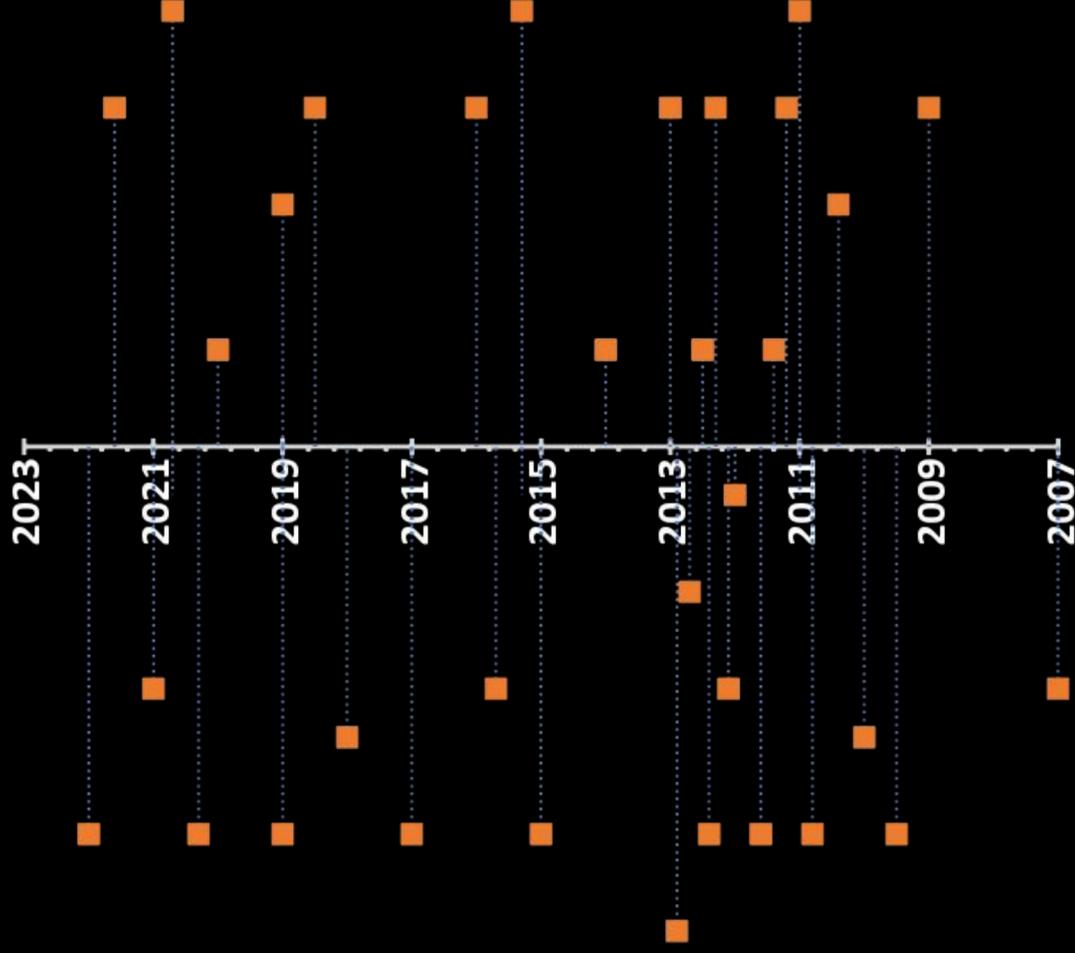
**KEEP
CALM**

IT'S

**DRESS REHEARSAL
TIME!**

NPS Scenario Planning

- Begun in 2007
- Participatory workshops
- More than 30 workshops (2007-present)
- 90+ parks/regions/networks
- 125+ partner organizations represented

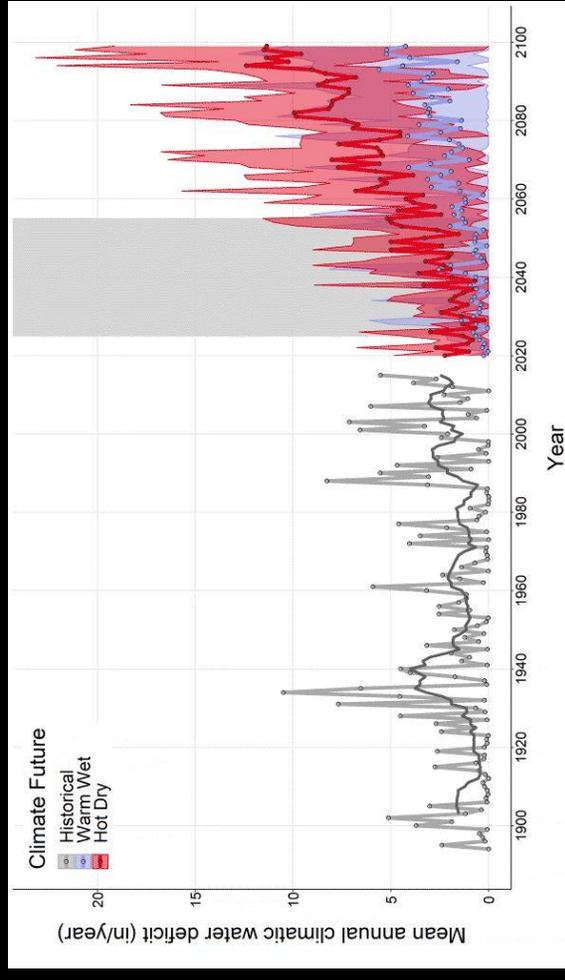
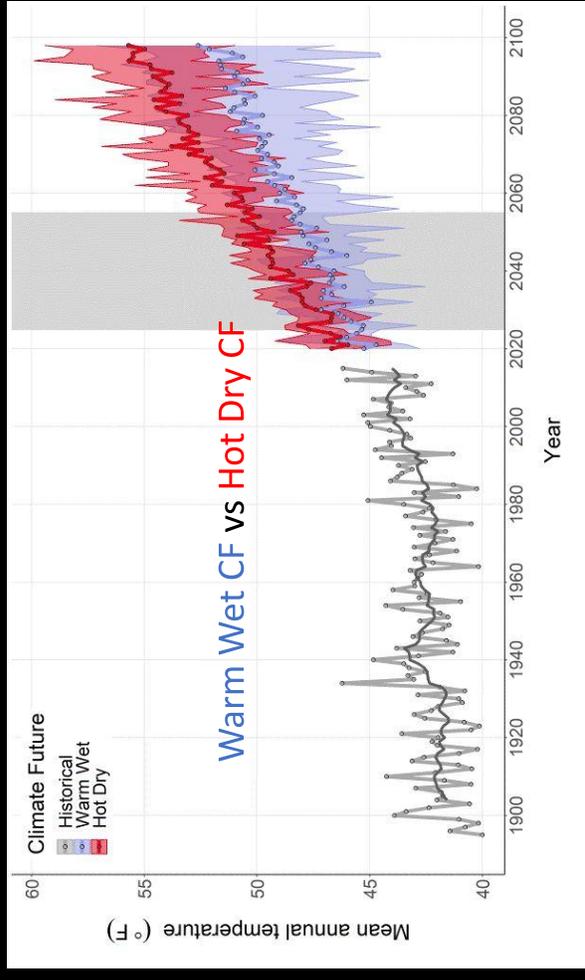


Step 1: Generate Climate Futures

Climate Future - Description of the physical attributes of climate that could plausibly occur at a specific place and time in the future.

Useful climate futures focus on climate metrics that are relevant to resources or decisions.

Multiple climate futures are used to consider the range of ways climate could change.

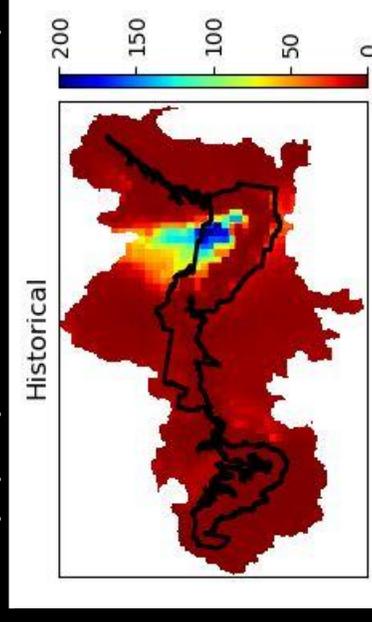


Climate futures

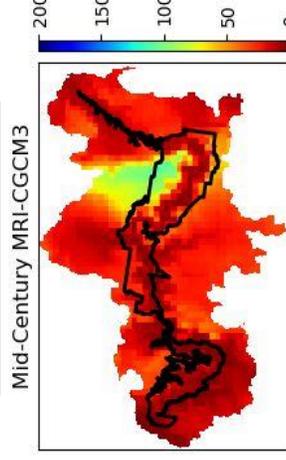
- CF characterize uncertainty
- Divergent CFs describe the broadest potential range of futures we experience
- Divergent CFs support info needs of decision makers by:
 - Allowing them to understand spectrum of change resources may experience
 - Develop strategies robust to the range in potential climate changes
 - Avoid highly consequential surprises

Grand Canyon

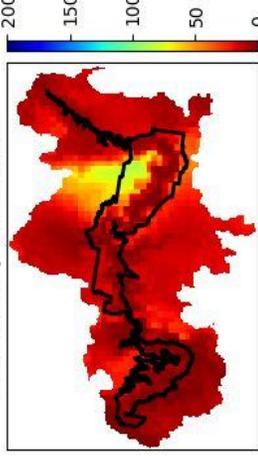
Number of days per year with snow water equivalent > 0



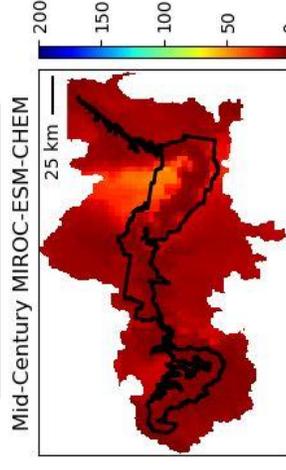
Climate future 1



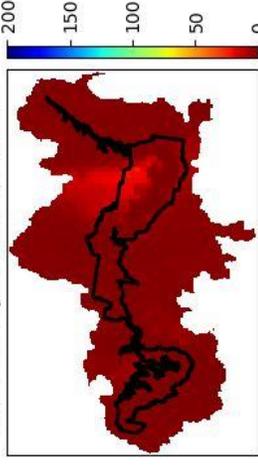
Late-Century MRI-CGCM3



Climate future 2

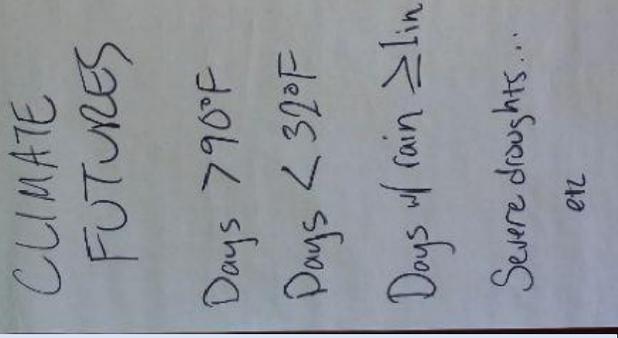


Late-Century MIROC-ESM-CHEM



Climate Future

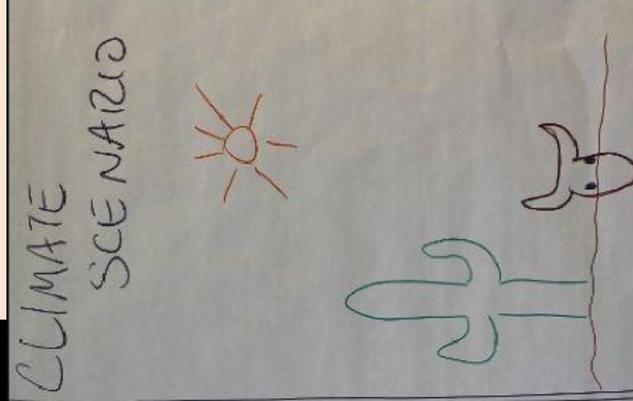
Description of the physical attributes of climate that could plausibly occur at a specific place and time in the future.



Climate-Resource Scenario

Identify potential resource implications of climate futures.

Generally done in collaboration with managers and resource specialists.



Decision Making

Using climate-resource scenarios to develop adaptation strategies.

Use scenarios to inform management decisions and feed them into planning.

Challenges in creating robust climate futures

How do we create climate futures that capture as much relevant uncertainty as possible?

How do we scale up these approaches to help more managers use climate futures?

A story of climate futures in two parts

Chapter I. 2010s: Developing methods that capture as much uncertainty as possible so managers can make robust decisions

Chapter II. 2020s: Developing methods and tools to scale the use of climate futures to meet growing demand

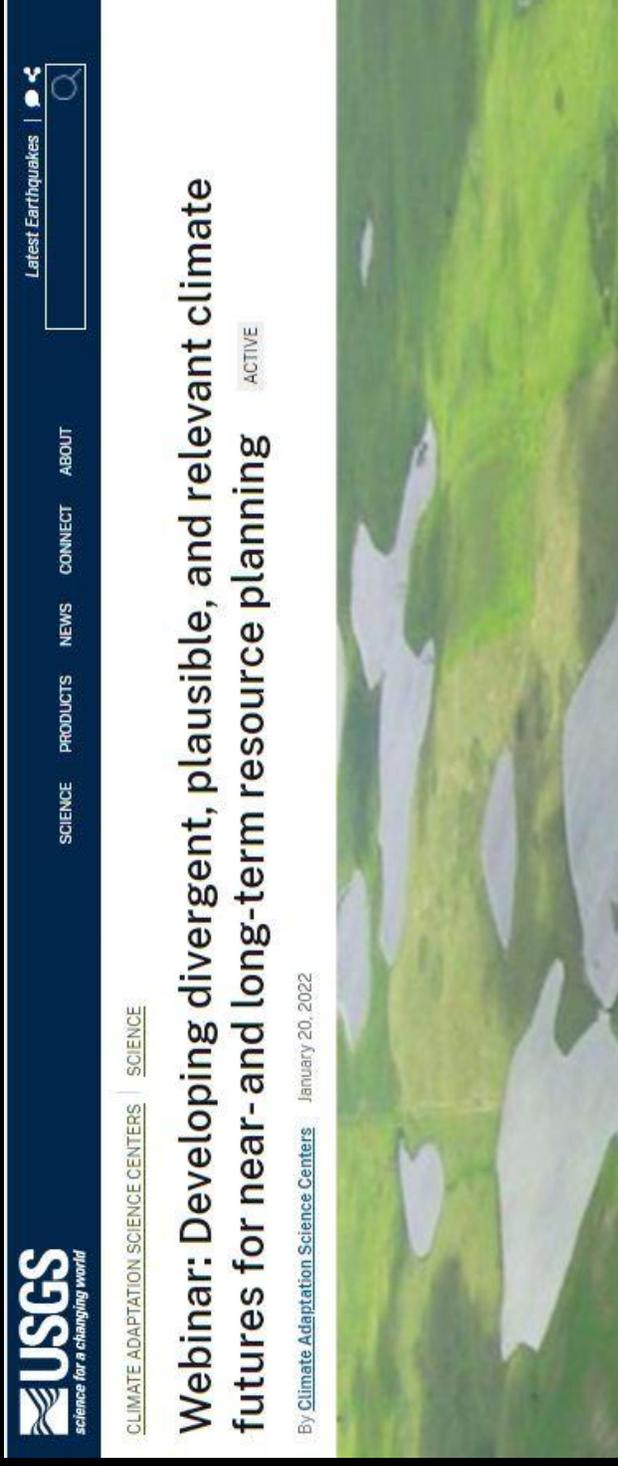
A story of climate futures in two parts

Chapter I. 2010s: Developing methods that capture as much uncertainty as possible so managers can make robust decisions

Chapter II. 2020s: Developing methods and tools to scale the use of scenarios to meet growing demand

CASC webinar 20 Jan 2022

[Developing divergent, plausible, and relevant climate futures for near- and long-term resource planning | U.S. Geological Survey \(usgs.gov\)](#)



The image is a screenshot of a webpage from the U.S. Geological Survey (USGS). At the top left is the USGS logo with the tagline "science for a changing world". To the right of the logo is a navigation menu with links for "SCIENCE", "PRODUCTS", "NEWS", "CONNECT", and "ABOUT". Further right is a search bar with the text "Latest Earthquakes" and a magnifying glass icon. Below the navigation is a breadcrumb trail: "CLIMATE ADAPTATION SCIENCE CENTERS | SCIENCE". The main heading of the page is "Webinar: Developing divergent, plausible, and relevant climate futures for near- and long-term resource planning" with a small "ACTIVE" tag to its right. Below the heading is the text "By Climate Adaptation Science Centers | January 20, 2022". The background of the page features a blurred image of a green, hilly landscape with a winding road.

Climate futures for decision-making

- Introduce Big Bend National Park as an example of developing climate futures for water management planning
- Describe three approaches to generate divergent CFs for use in scenario planning
- Compare range of uncertainty captured by different CF approaches
- Describe key considerations and tradeoffs when selecting a climate future approach

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Climate Change

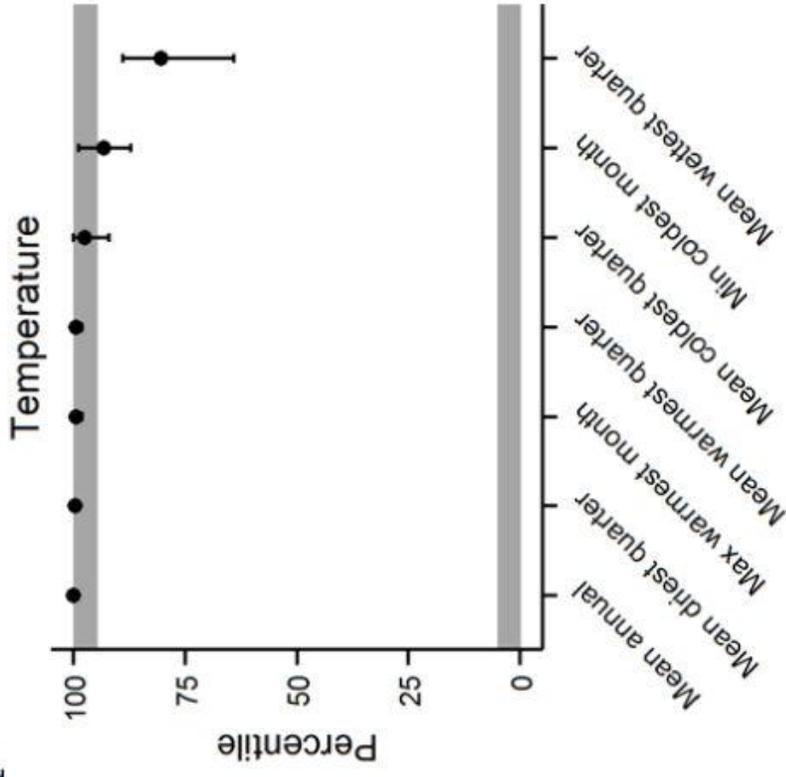
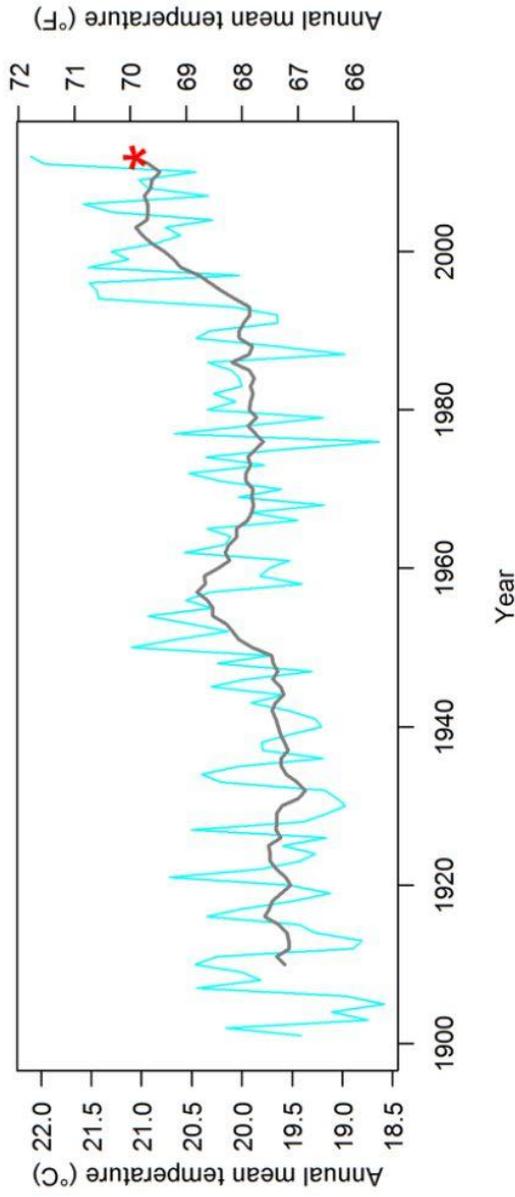
Resource Brief

National Park Service
U.S. Department of the Interior



Natural Resource Stewardship & Science

Recent Climate Change Exposure of Big Bend National Park



Chisos basin – Big Bend National Park



Oak Spring





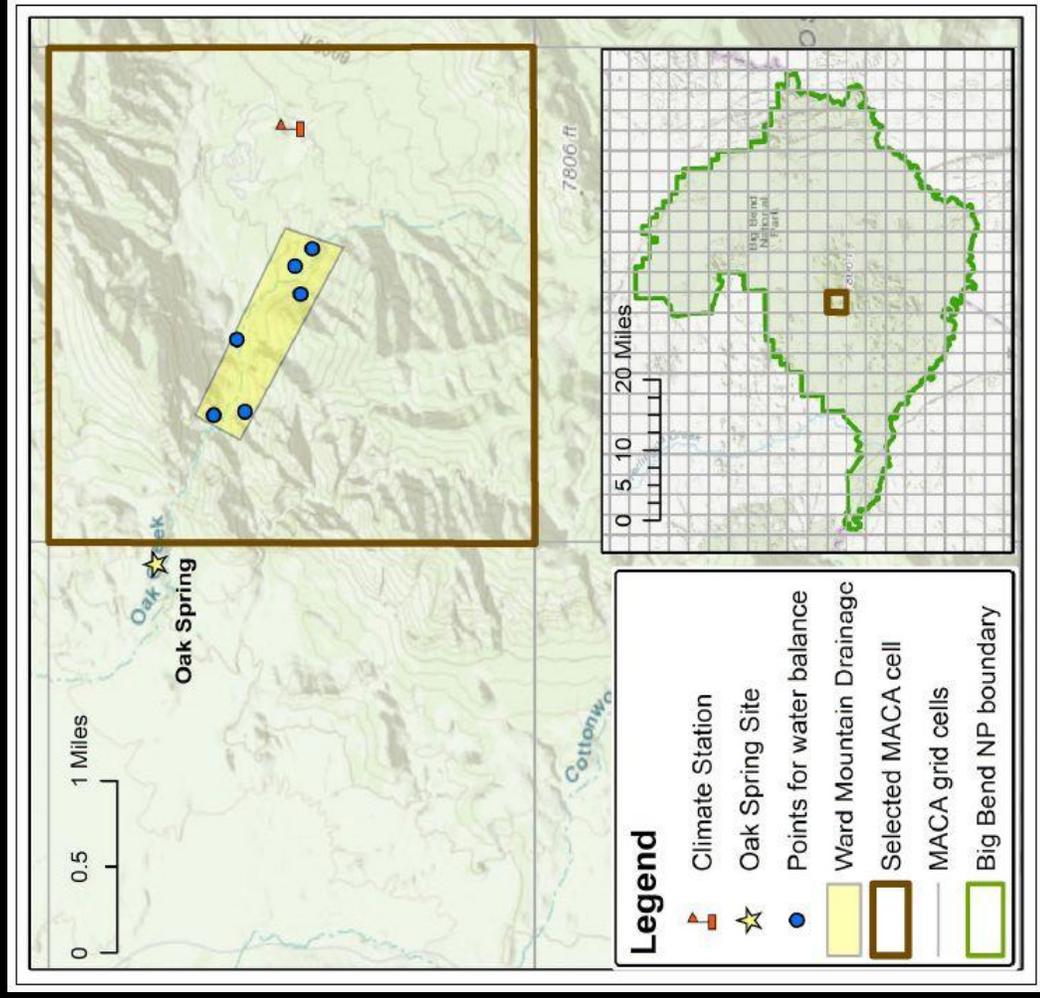
Bob Krumenaker, Superintendent, Big Bend National Park

“We need to understand, not what ‘the’ future will look like, because nobody can predict that, but we do need to understand the range of possible futures”

Climate futures for decision-making

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Generating climate futures



16-km² grid cell overlaying recharge area for Oak Spring

20 GCMs from CMIP5 archive, downscaled using Multivariate Adaptive Constructed Analog method (MACAV2-METDATA)

Each GCM driven by RCP 4.5 and RCP 8.5

Projection = climate model driven by a specific radiative forcing (e.g., IPSL-CM5A-MR; RCP 4.5)

20 GCMs x 2 RCPs = 40 projections

Focused on 30-year climate periods:

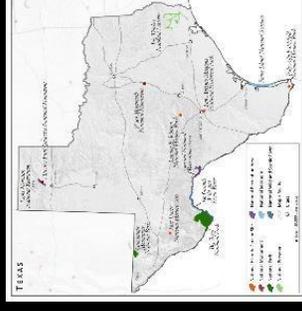
2040s: 2025-2055, near-term

2060s: 2045-2075, mid-term

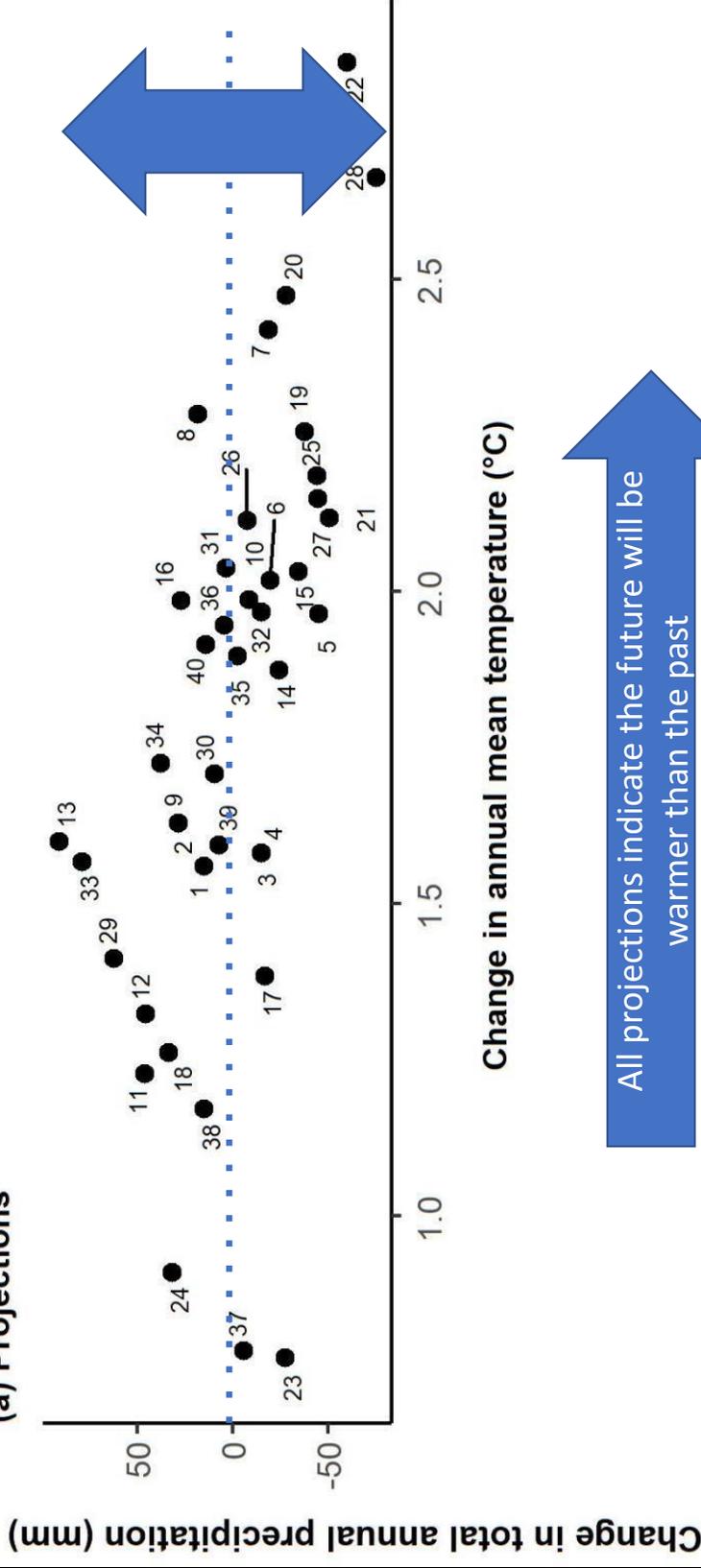
2090s: 2065-2095, long-term

Compared to historical period: 1950-1999

Generating climate futures for Oak Spring recharge area, Big Bend NP, 2040



(a) Projections

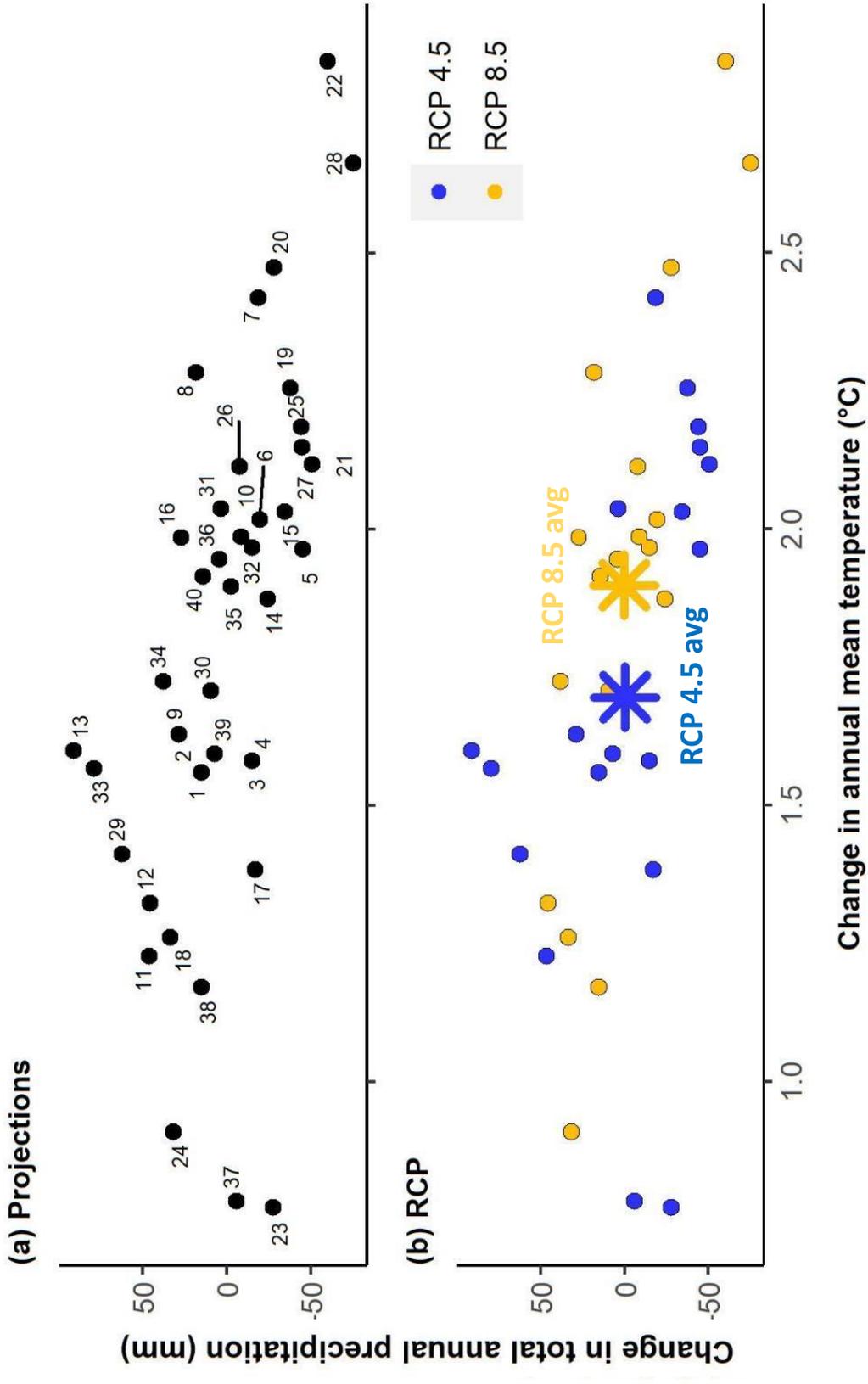


Number	GCM	RCM
1	bcc-csm1-1-m	4.5
2	bcc-csm1-1-m	8.5
3	bcc-csm1-1	4.5
4	bcc-csm1-1	8.5
5	BNU-ESM	4.5
6	BNU-ESM	8.5
7	CanESM2	4.5
8	CanESM2	8.5
9	CCSM4	4.5
10	CCSM4	8.5
11	CNRM-CM5	4.5
12	CNRM-CM5	8.5
13	CSIRO-Mk3-6-0	4.5
14	CSIRO-Mk3-6-0	8.5
15	GFDL-ESM2G	4.5
16	GFDL-ESM2G	8.5
17	GFDL-ESM2M	4.5
18	GFDL-ESM2M	8.5
19	HadGEM2-CC365	4.5
20	HadGEM2-CC365	8.5
21	HadGEM2-ES365	4.5
22	HadGEM2-ES365	8.5
23	inmcm4	4.5
24	inmcm4	8.5
25	IPSL-CM5A-LR	4.5
26	IPSL-CM5A-LR	8.5
27	IPSL-CM5A-MR	4.5
28	IPSL-CM5A-MR	8.5
29	IPSL-CM5B-LR	4.5
30	IPSL-CM5B-LR	8.5
31	MIROC-ESM-CHEM	4.5
32	MIROC-ESM-CHEM	8.5
33	MIROC-ESM	4.5
34	MIROC-ESM	8.5
35	MIROC5	4.5
36	MIROC5	8.5
37	MRI-CGCM3	4.5
38	MRI-CGCM3	8.5
39	NorESM1-M	4.5
40	NorESM1-M	8.5

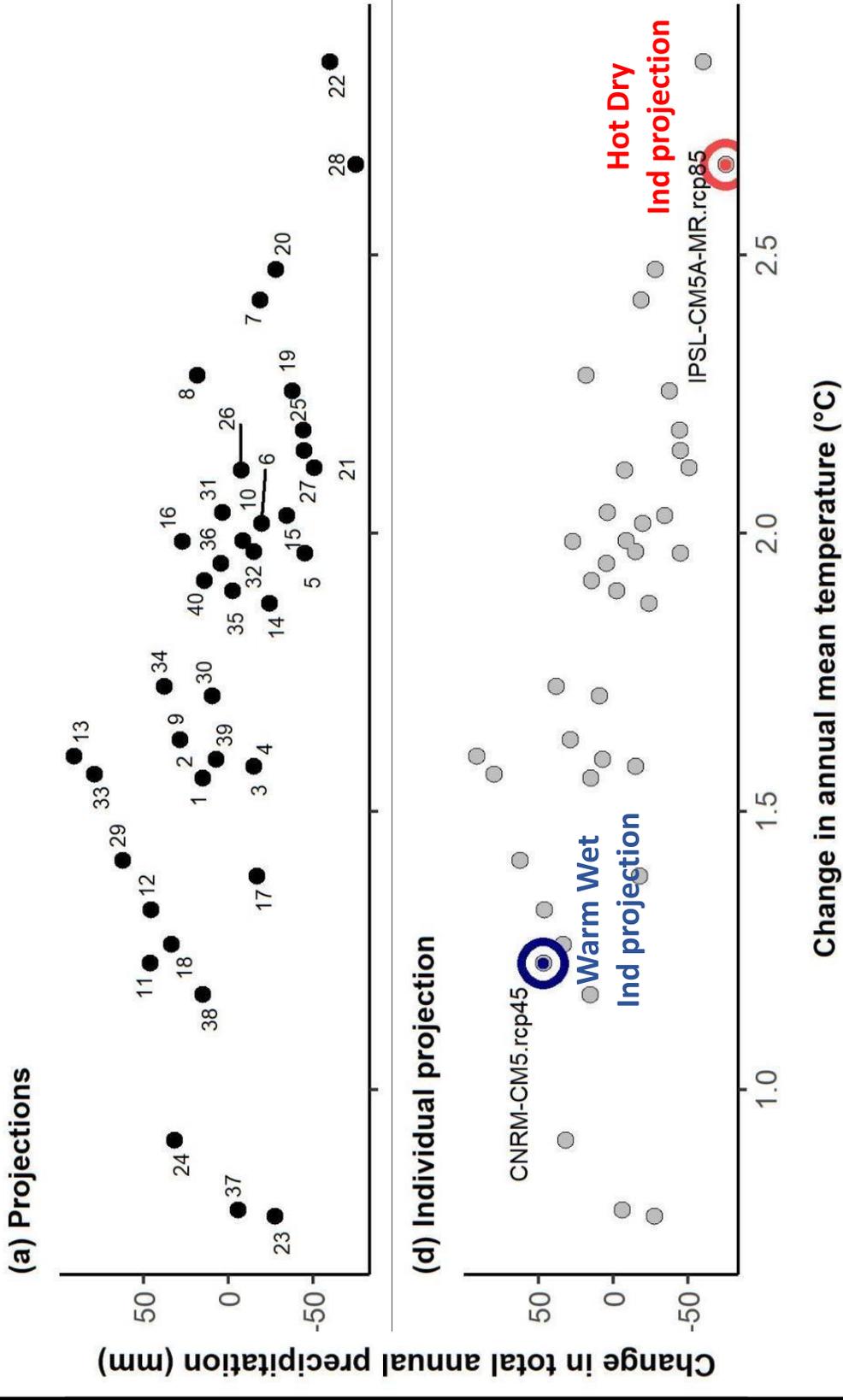
Approach 1: climate futures based on Representative Concentration Pathways (RCPs)

- RCPs – reflect broad range of socio-economic futures
- RCPs represent a range of climate forcings (RCP 2.6, 4.5, 6.0, 8.5), effectively from low to high
- Provide a convenient means to build climate futures
- Divergence among RCP-based CFs represents uncertainty regarding greenhouse gas emissions

Approach 1: RCP-ensemble based climate futures; 2040



Approach 3: Individual projection based climate futures; 2040

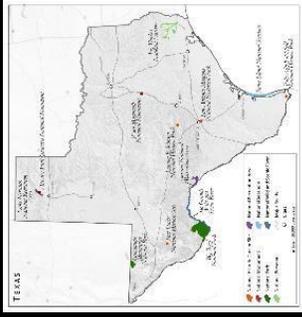


“Warm Wet” – best case CF

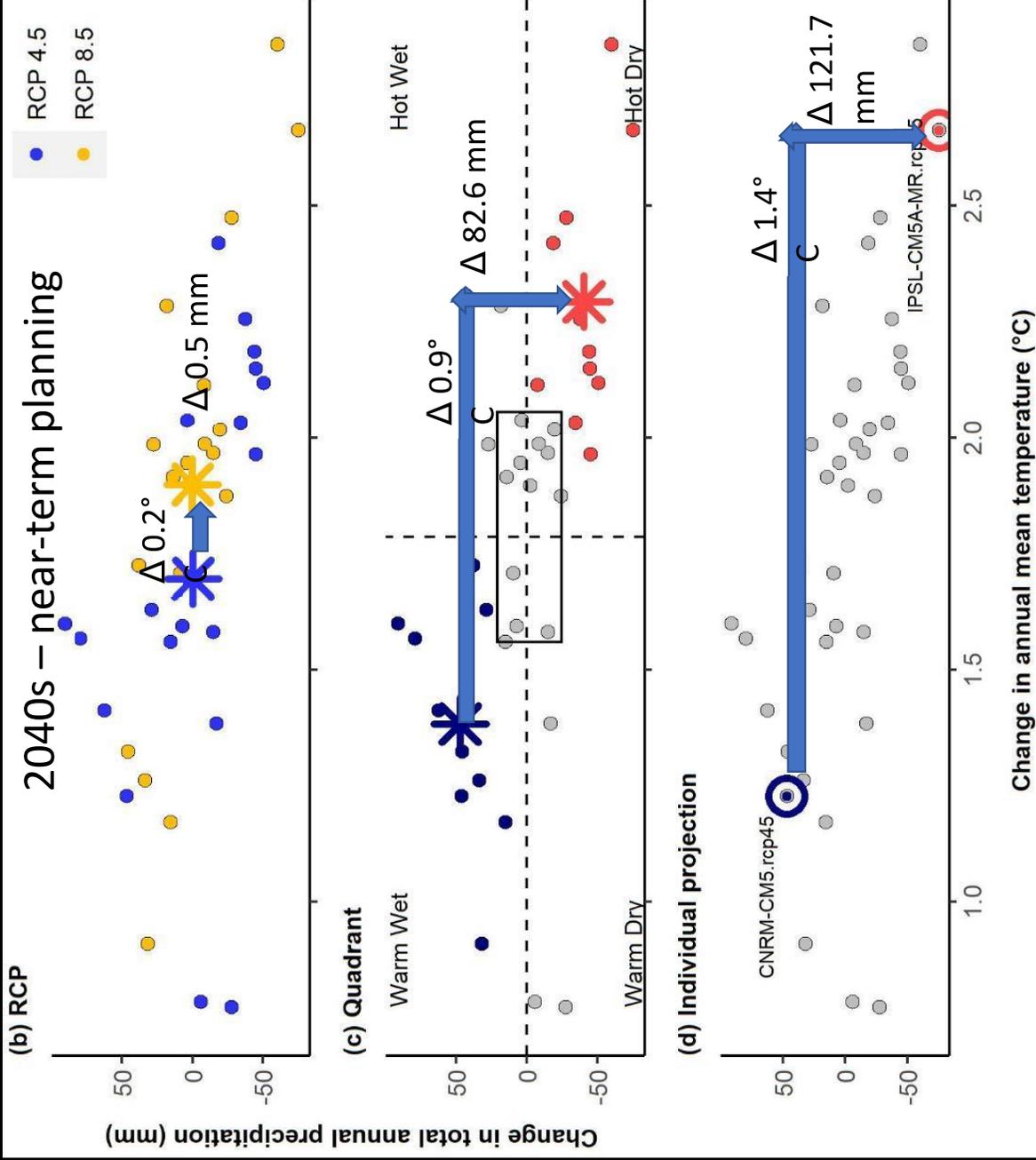
“Hot Dry” – worst case CF

Climate futures for decision-making

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- **Compare range of uncertainty captured by different CF approaches**
- Describe key considerations and tradeoffs when selecting a climate future approach



Individual projections and quadrant averages capture a much greater range of uncertainty than RCPs in the 2040s



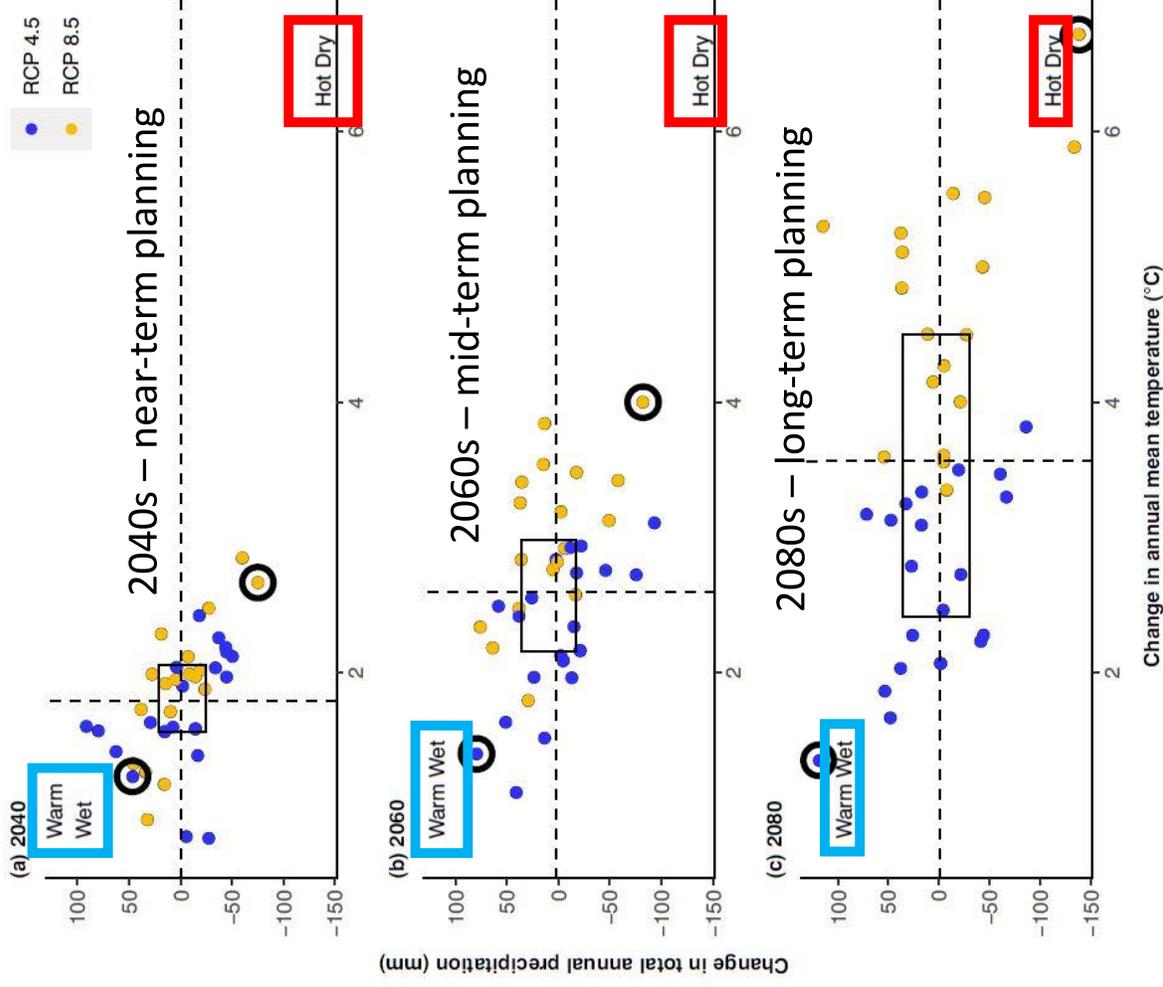
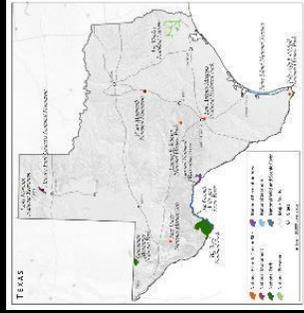
Comparing CF approaches for capturing the range of uncertainty over three time periods

“RCP 4.5” – middle of the road emissions CF

“Warm Wet” – best case CF

“RCP 8.5” – high end emissions CF

“Hot Dry” – worst case CF



Temperature:

2040

Ind projection
$\Delta 1.4^\circ \text{C}$

Individual projections and quadrant averages capture a much greater range of uncertainty than RCPs

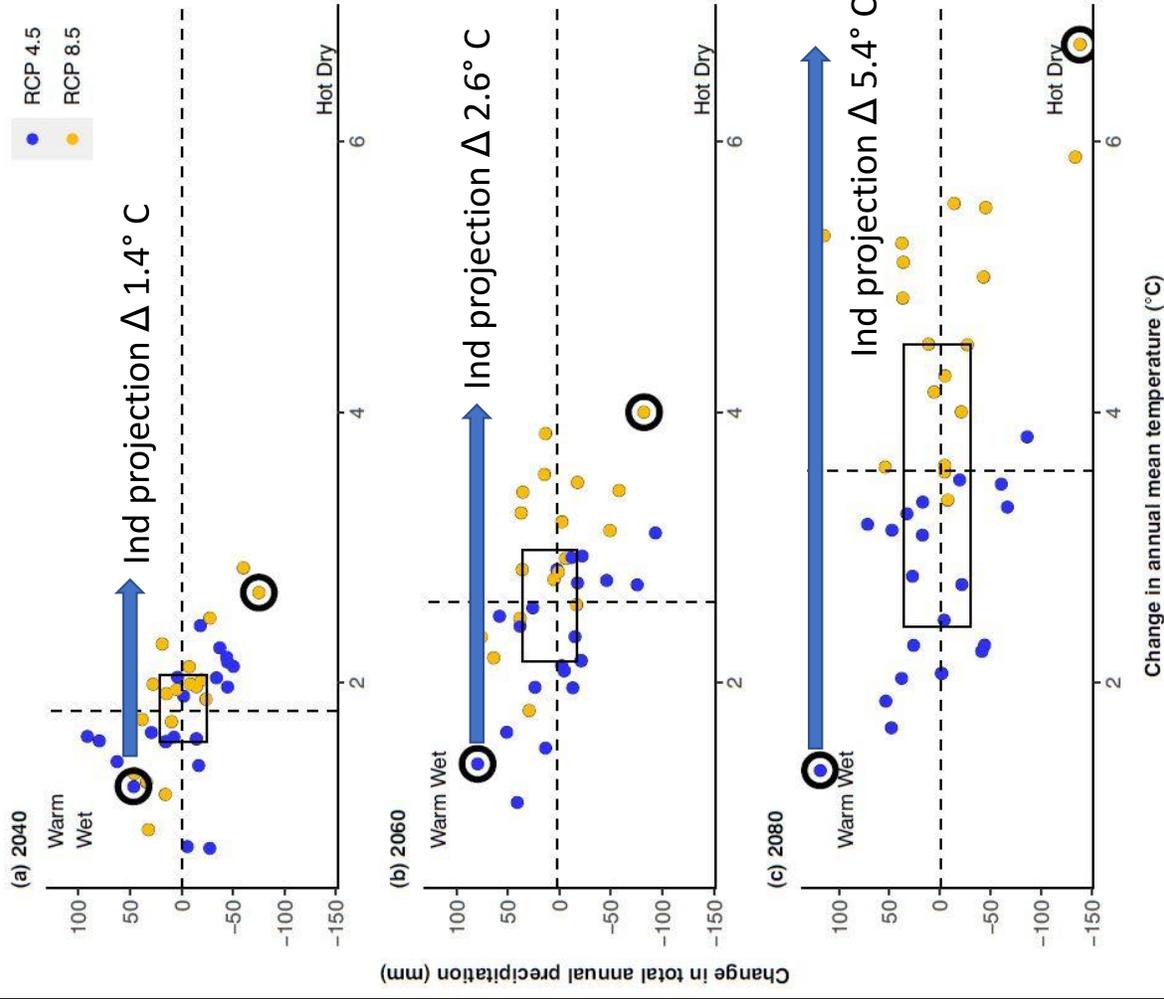
Plausible, divergent, relevant

2060

Ind projection
$\Delta 2.6^\circ \text{C}$

2080

Ind projection
$\Delta 5.4^\circ \text{C}$



Precipitation:

2040

Ind projection
Δ 121.7 mm

Individual projections and quadrant averages capture a much greater range of uncertainty than RCPs

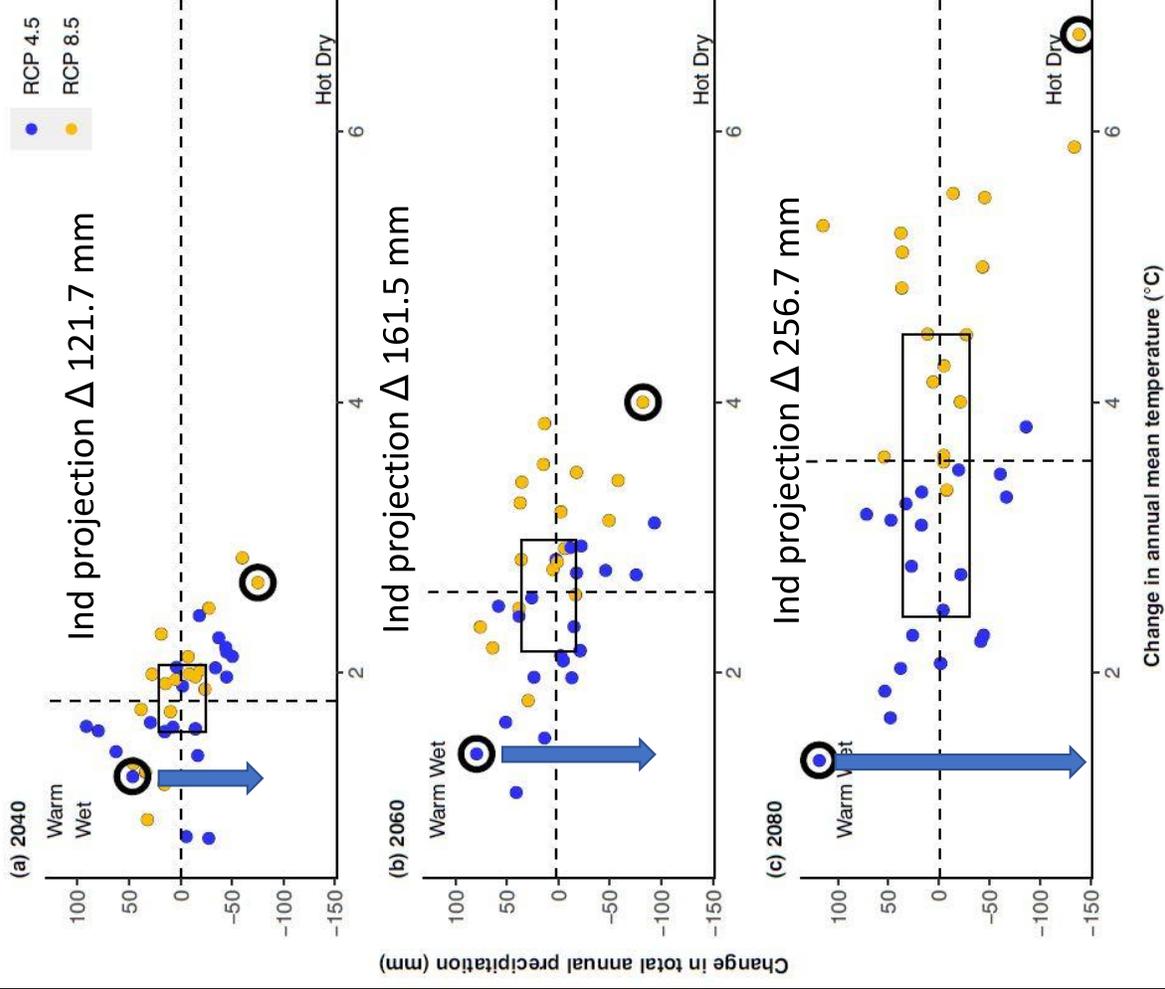
Plausible, divergent, relevant

2060

Ind projection
Δ 161.5 mm

2080

Ind projection
Δ 256.7 mm



Climate futures for decision-making

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Selecting climate future approach

- The choice of climate future approach depends on the decision you are trying to inform, and the time available. It is context-dependent and should not be 'one-size-fits-all'.
- **Mitigation emphasis:** RCP approach
- **Adaptation emphasis:** Quadrant or Individual projection approach
- For **scenario planning** we typically use an approach that results in the following characteristics (plausible, divergent, relevant, challenging to entrenched mindsets)
- **Near term planning:** Individual projection and quadrant approaches capture broader range of uncertainty than the RCP approach
- **Ease / difficulty of approach:** NPS uses quadrant approach as a coarse filter evaluation (simpler planning context), individual projection approach for more detailed investigations (more time for model choice and evaluation)

Other examples of using climate futures for resource management



National Park Service
U.S. Department of the Interior



Implications of Climate Scenarios for
Badlands National Park Resource Management



Badlands National Park (BADL) hosts a myriad of natural and cultural resources, including bison and black-footed ferrets, the mixed grass prairie in which they live, fossils from animals that lived 23-75 million years ago, and historic buildings, trails, and roads. All of these resources are being threatened by the high rates of climate change that will affect each. Due to the scale of this challenge, park resource managers must make forward-looking decisions and act to meet resource management goals.

Fortunately, tools exist to identify strategies and options to help park managers adapt to potential future climate conditions. We used a range of such tools—qualitative scenario planning and quantitative ecological simulation modeling—to anticipate management challenges and identify options for BADL and adjacent federal and tribal lands in the coming decades (through 2050). In corporate and military contexts, scenario planning has long supported effective decision making in the face of

uncertainties about the future, and the National Park Service now applies this technique to address climate change in resource management planning and decisions (Star et al. 2016). Scenario planning is a process that considers multiple plausible futures, a process that is starting to be used for conservation planning in other parks and facilities. Ecological simulation models can help track such complexities of the real world and serve as virtual laboratories for asking “what if...?” questions about how systems might respond under different scenarios.

Here, we summarize results of collaborative work— involving resource managers, subject-matter experts, ourselves, and a larger climate change adaptation team—to identify potential climate impacts and management responses in BADL. Results also include key insights from examining management approaches on adjacent lands. See Fischelli et al. (2016) and Miller et al. (2017) for a more detailed description.



USGS
science for a changing world



This project was conducted under a formal partnership between the USGS and the National Park Service.





National Park Service
U.S. Department of the Interior



Climate Change Scenario Planning for Resource Stewardship: Applying a Novel Approach in Devils Tower National Monument





Natural Resource Report NPS/SSS/CRD/06B—015/2015



National Park Service
U.S. Department of the Interior



Climate Change Scenario Planning for Resource Stewardship at Wind Cave National Park





Natural Resource Report NPS/SSS/NRR—021/2014



National Park Service
U.S. Department of the Interior



Climate Change Scenarios for Wrangell-St. Elias National Park and Preserve





NPS Climate Change Response Program

Conclusions

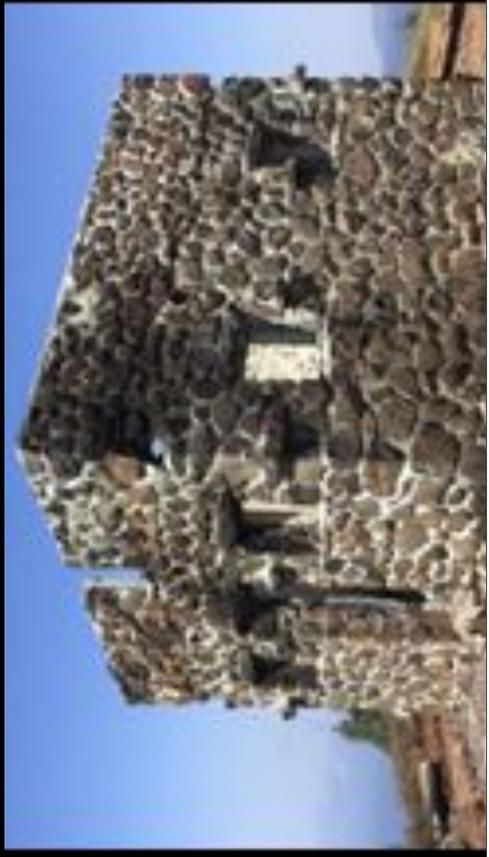
- Divergent and plausible climate futures support decision maker's need to consider the range of potential futures in their decision processes, avoid surprise
- An overarching goal of CFs is to explore relevant uncertainty among projections of change
- A set of divergent, plausible and relevant CFs support scenario-based planning, and help identify strategies that
 - Work across all CFs (robustness vs optimality)
 - Do not work under any CF
 - Are needed to address high consequence vulnerabilities specific to a subset of scenarios
- The individual projection and quadrant average CF approaches capture a much broader range of plausible future conditions compared to the RCP approach, for near and long term projections
- Choosing among the different approaches depends on the application and available resources
- NPS has had success using CFs in scenario planning processes for a wide variety of management contexts



A story of climate futures in two parts

Chapter I. 2010s: Developing methods that capture as much uncertainty as possible so managers can make robust decisions

Chapter II. 2020s: Developing methods and tools to scale the use of scenarios to meet growing demand



Director Sams' Priorities

These priorities reflect my commitment to the workforce, our partners, and the American people. I'm looking forward to working with the NPS deputy directors, senior leadership, and all of you in many programs for these first days.

Chief

1. Connect and empower a thriving and diverse workforce

To better serve communities through our dozens of national programs and care for parks for the next seven generations, we must commit to an inclusive and participatory organizational culture, valuing the diverse ideas, experiences, and background of every individual, and empowering all individuals, leaders, and visitors to realize their potential.

2. Invest in the future of parks

National parks are part of the fabric of our nation. Our duty to preserve and protect these lands on behalf of the American public includes constant innovation and the efficient and effective use of funding to reduce the maintenance backlog, update infrastructure, modernize facilities, and provide visitor amenities that benefit current and future generations.

3. Confront the climate crisis using science and traditional ecological knowledge in stewarding our resources

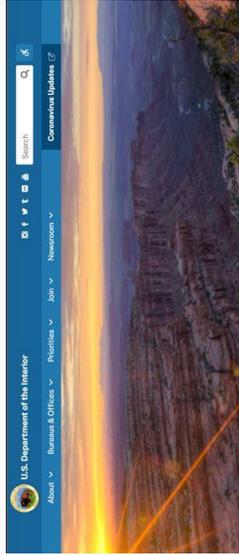
3. Confront the climate crisis using science and traditional knowledge in stewarding our resources

6. Create an NPS experience that meets visitor expectations into the future

For generations, the National Park System has inspired moments of profound discovery and learning and passed transformative experiences to millions of visitors. We will continue to work with our partners to ensure a better experience for all visitors, one that meets the needs of all visitor bodies and into the future.

7. Greatly improve, streamline, and modernize NPS management and business practices, and ensure accountability to ourselves, our partners, and the American people

A wide range of business processes underpin the organizational effectiveness of the National Park Service, including human resources and information technology. We will work with our partners, professional staff, and the public to improve the effectiveness of these organization and administrative functions for the NPS to operate in the 21st century.



Our Priorities

Our mandate from President Biden is clear: we must address the four intersecting challenges of COVID-19, economic recession, racial equity and climate change.

- Making investments to support the Administration's goal of creating millions of family-supporting and union jobs. This includes supporting public lands and waters, increasing reforestation, increasing carbon sequestration in the agricultural sector, protecting biodiversity, improving access to recreation, and addressing the changing climate.
- Working to conserve at least 20% each of our lands and waters by the year 2030. We will work to protect biodiversity, slow climate change, and support local, state, private, and Tribal-led nature conservation and restoration efforts that are underway across America.
- Centering equity and environmental justice. The impacts of the multiple crises in the United States are not evenly distributed. We will work to ensure that our actions do not disproportionately harm communities of color, low-income communities, and people of color. We will engage diverse stakeholders across the country, as well as conduct formal consultation with Tribes in recognition of the U.S. government's trust responsibilities.

Legislative and Congressional Affairs

Home | Pressroom | Field Offices | Testimony | Publications | Information

Great American Outdoors Act

This landmark conservation legislation will use revenues from energy development to provide up to \$1.9 billion a year for five years to provide needed maintenance for critical facilities and infrastructure in our national parks, forests, wildlife refuges, recreation areas, and American Indian schools. It will also use royalties from offshore oil and natural gas to permanently fund the Land and Water Conservation Fund to the tune of \$800 million a year to invest in conservation and recreation opportunities across the country.

National parks host more than 325 million visitors every year, and the infrastructure carried heavy use without significant repairs. The network of roads, trails, restrooms, water treatment systems, and visitor facilities are aging, and many are exceeding the capacity they

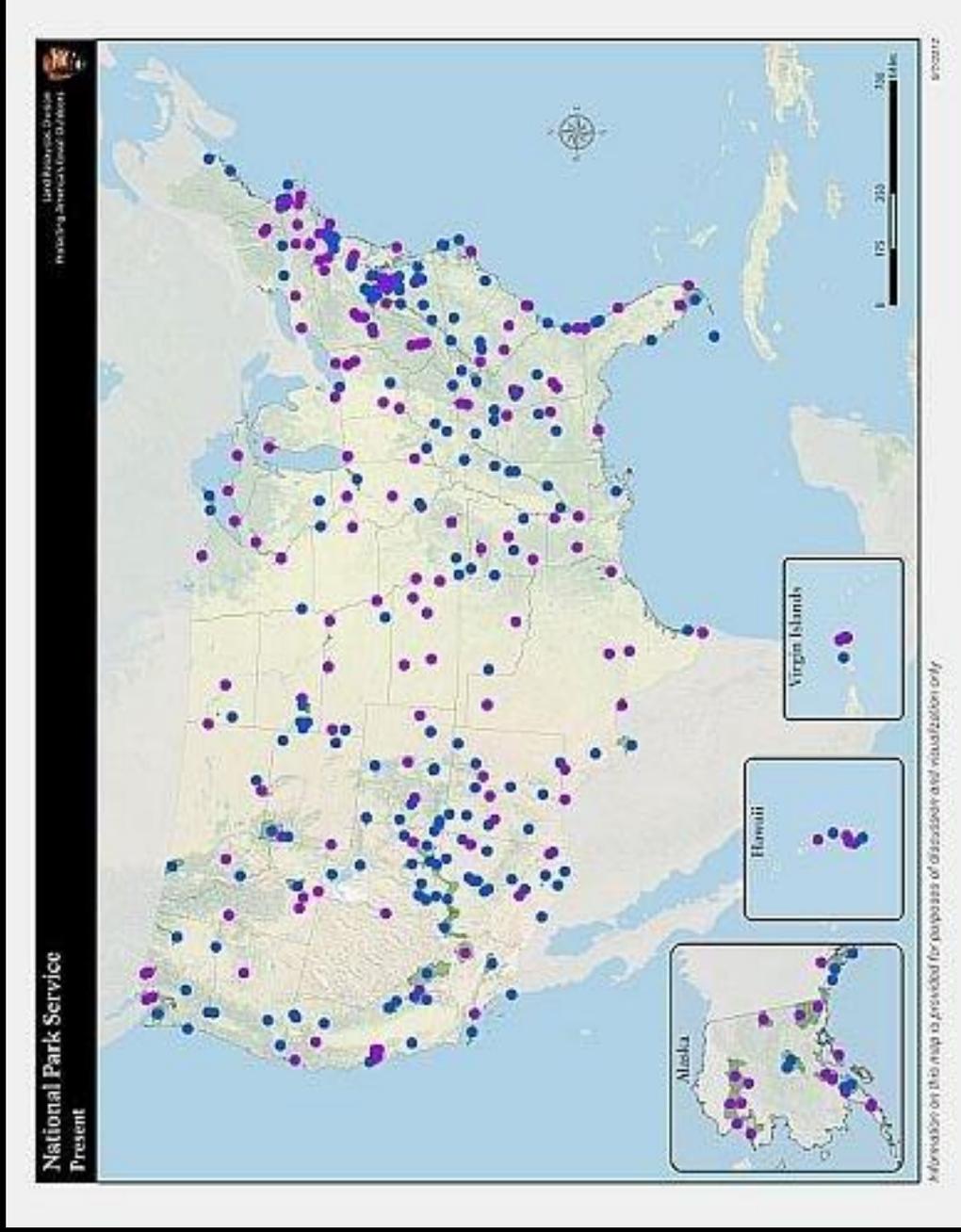
Provide up to \$1.9 billion a year for five years to provide needed maintenance for critical facilities and infrastructure in our national parks

Outdoors Act

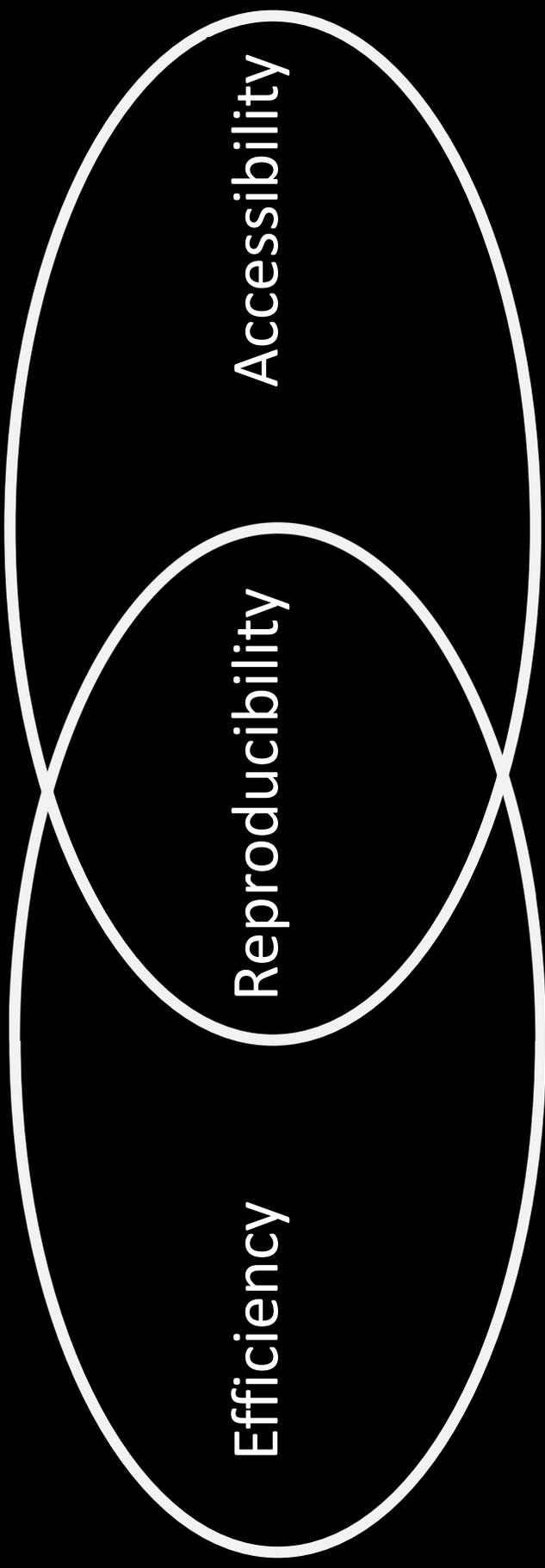


In celebration of President Trump signing the Great American Outdoors Act, Secretary of the Interior David L. Bernhardt announced free entrance to national parks and public lands for August 5, 2020, and he designated August 4th as the "Great American Outdoors Day." In future years, every August 4 will be a free entrance day to celebrate the signing of this landmark legislation, joining the other scheduled entrance free days which commemorate or celebrate significant dates. The Great American Outdoors Act will enable national parks and public lands to receive an average of \$1.9 billion annually to upgrade and maintain infrastructure and facilities that protect, protect resources, and enable increased access for all visitors.

New challenges: scaling up CF creation

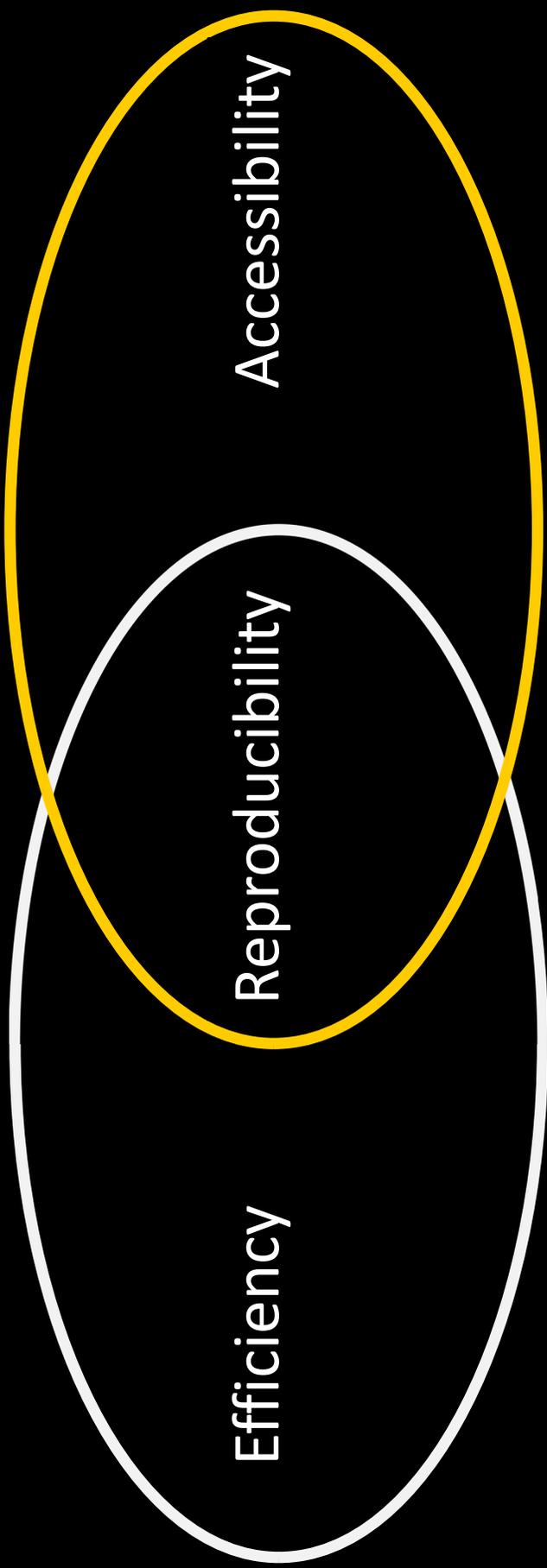


Reproducible Climate Futures



- Streamline workflow to increase efficiency of climate future production
- Design data management processes that enable reproducible science
- Develop tools to increase accessibility and scale analysis

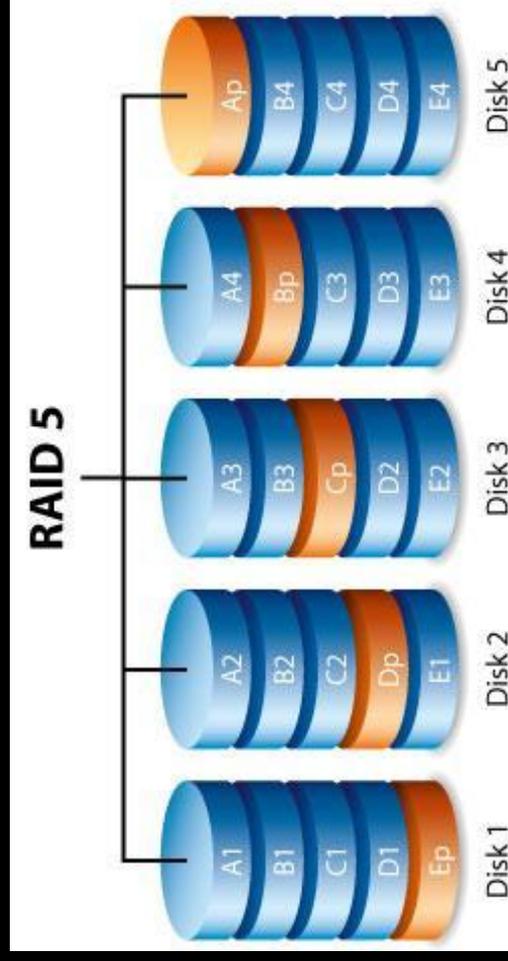
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- Streamline workflow to increase efficiency of climate future production
- Design data management processes that enable reproducible science
- Develop tools to increase accessibility and scale analysis

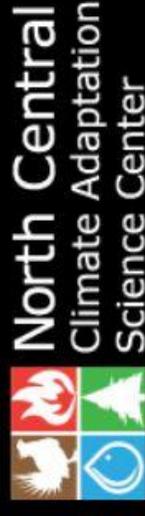
Barriers in climate future accessibility

1. Data access
2. Generating climate futures



Data Access Solution:

Climate Futures Toolkit (cft) R package



☰ README.md

Welcome to the Climate Futures Toolbox

This is a package developed as a collaboration between Earth lab and the North Central Climate Adaptation Science Center to help users gain insights from available climate data. This package includes tools and instructions for downloading climate data via a USGS API and then organizing those data for visualization and analysis that drive insight.

This package is currently growing to include better functionality for spatial analyses and more user-friendly features. Thank you for all the wonderful beta tester groups that helped us get the software this far. Please be patient as we update some of the functions and vignette to accommodate more functionality.

What you'll find here

This vignette provides a walk-through of a common use case of the cft package, which is, to help users download, organize, and visualize past and future climate data. - 1) How to download and install the cft package - 2) How to see the menu of available data and choose items from that menu - 3) How to request data from the API using those menu choices

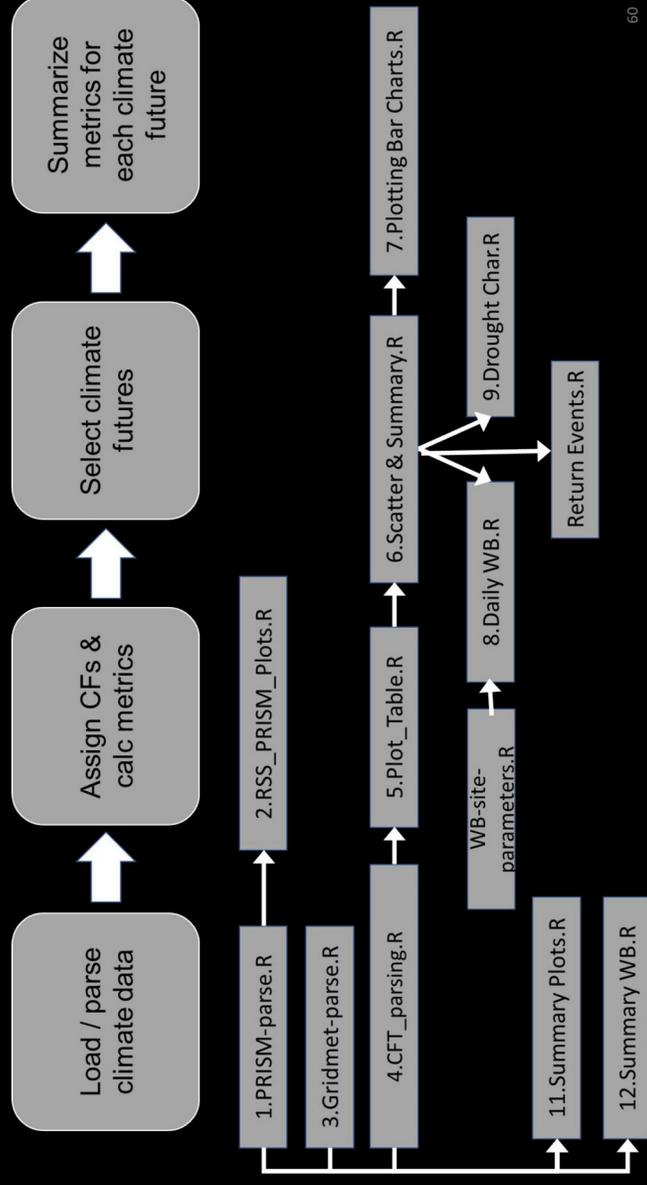
- iv. How to aggregate those data in different ways to drive insight.

Why write the cft package?

The amount of data generated by downscaled GCMs can be quite large (e.g., daily data at a few km spatial resolution). The Climate Futures Toolbox was developed to help users access and use smaller subsets.

Barriers in climate future accessibility

1. Data access
2. Generating climate futures



Selecting climate future approach

- The choice of climate future approach depends on the decision you are trying to inform, and the time available. It is context-dependent and should not be 'one-size-fits-all'.
- Mitigation emphasis: RCP approach
- Adaptation emphasis: Quadrant or Individual projection approach
- For **scenario planning** we typically use an approach that results in the following characteristics (plausible, divergent, relevant, challenging to entrenched mindsets)
- **Near term planning**: Individual projection and quadrant approaches capture broader range of uncertainty than the RCP approach
- **Ease / difficulty of approach**: NPS uses quadrant approach as a coarse filter evaluation (simpler planning context), individual projection approach for more detailed investigations (more time for model choice and evaluation)

Climate Future Generating Solution:

Reproducible Climate Futures (rcf) R package



☰ README.md

Reproducible Climate Futures (rcf)

Overview

This package aims to make acquiring and working with [MACA v2](#) climate data faster and easier and to provide a number of summary statistics that can be used to visualize different climate futures. Ultimately, having access to this data supports planning efforts that aim to incorporate climate change.

Installation

Until approval on CRAN, you can download the development version of `rcf`

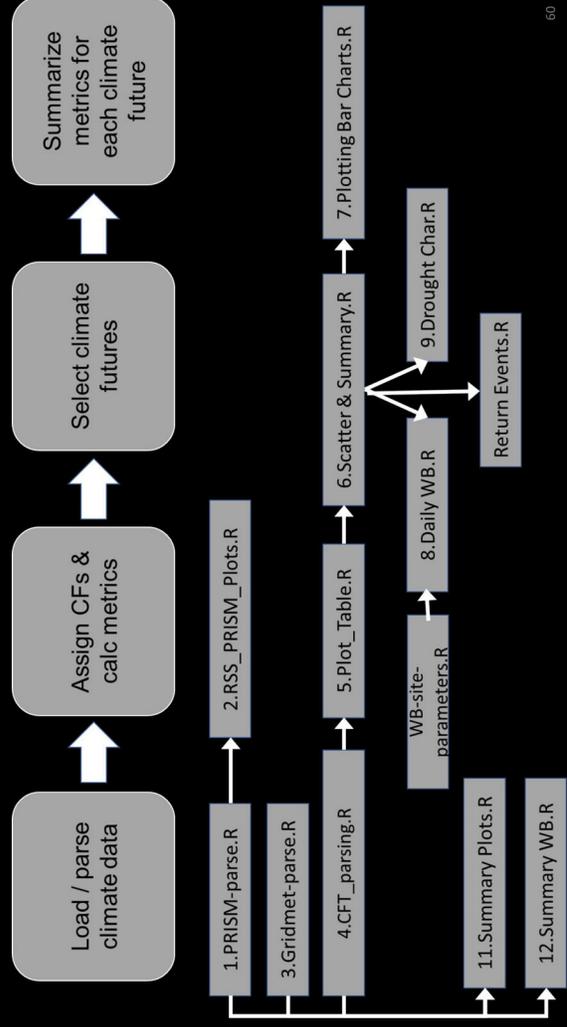
You can install the released version of `rcf` from CRAN with:

```
install.packages("rcf")
```

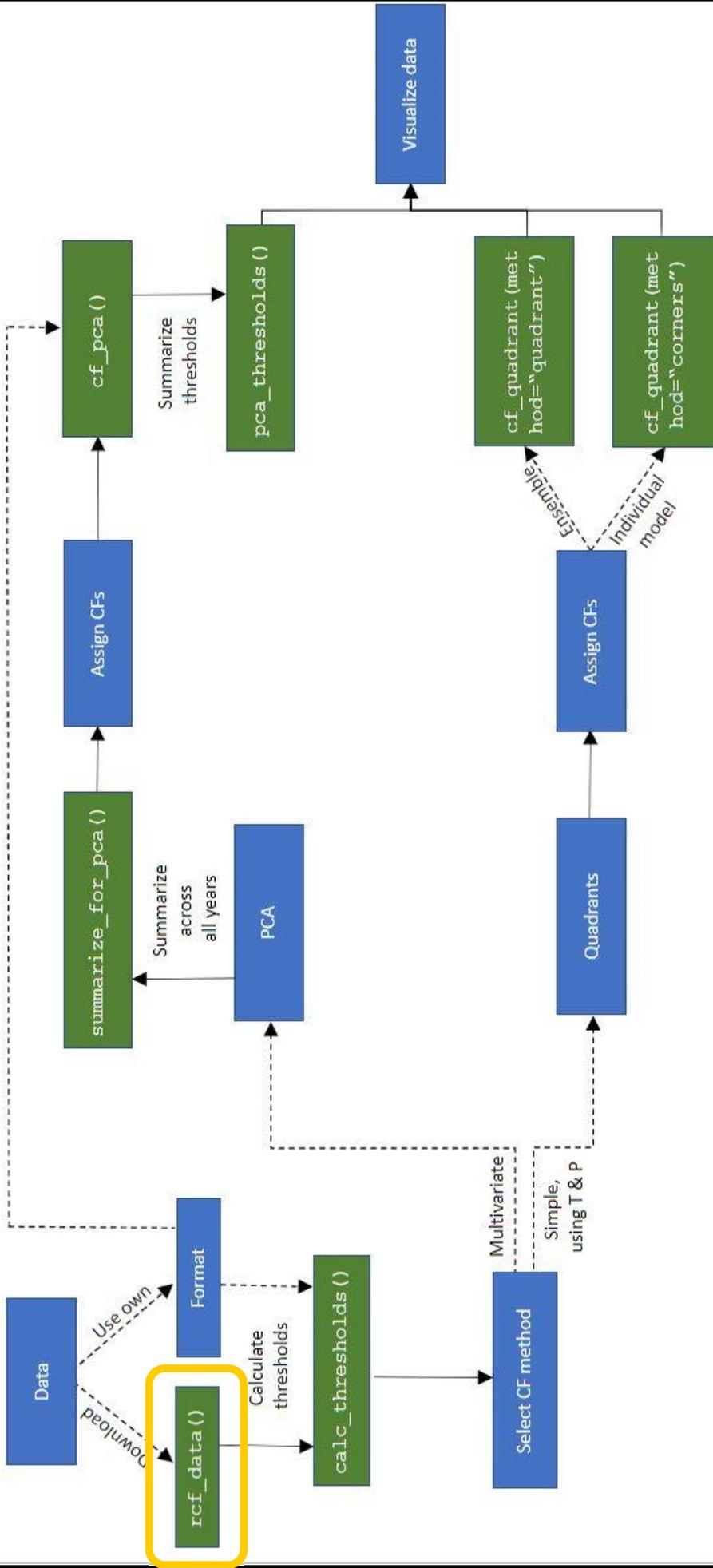
And the development version from [GitHub](#) with:

Functions for
creating quadrant
and individual
climate futures

rcf Package

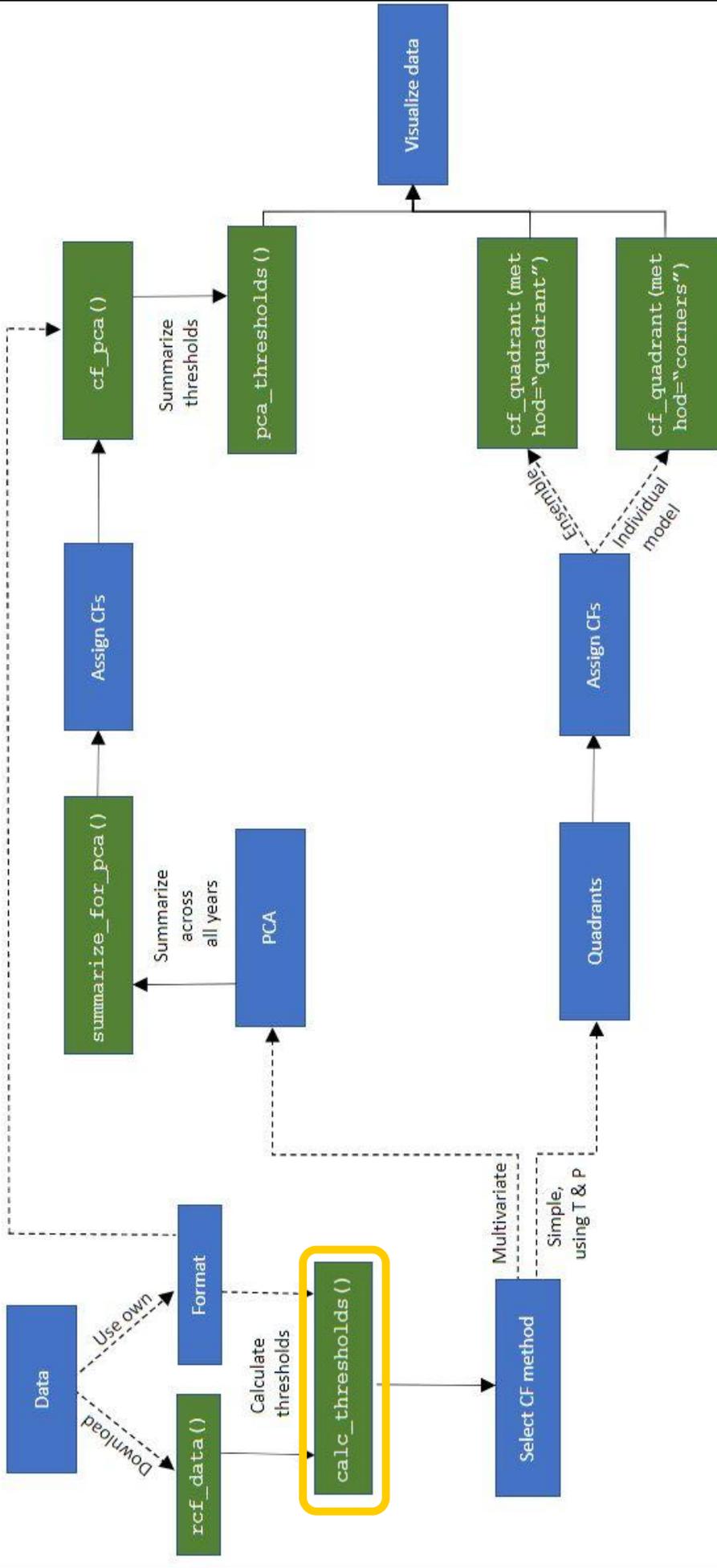


rcf_data()
calc_thresholds()
cf_quadrant()
cf_pca()
pca_thresholds()



```
rcf_data()
```

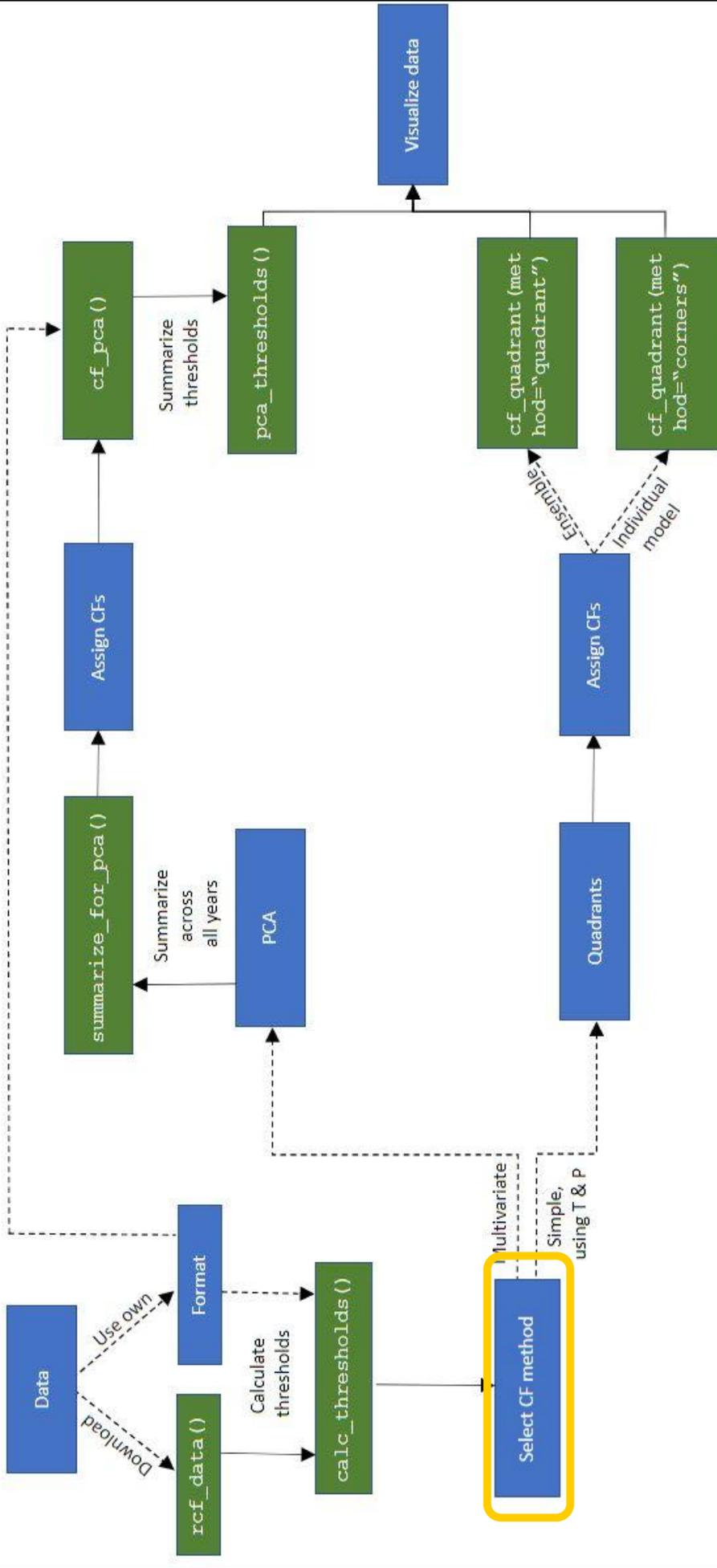
Wrapper function for cft – downloads MACA data for location of interest



calc_thresholds()

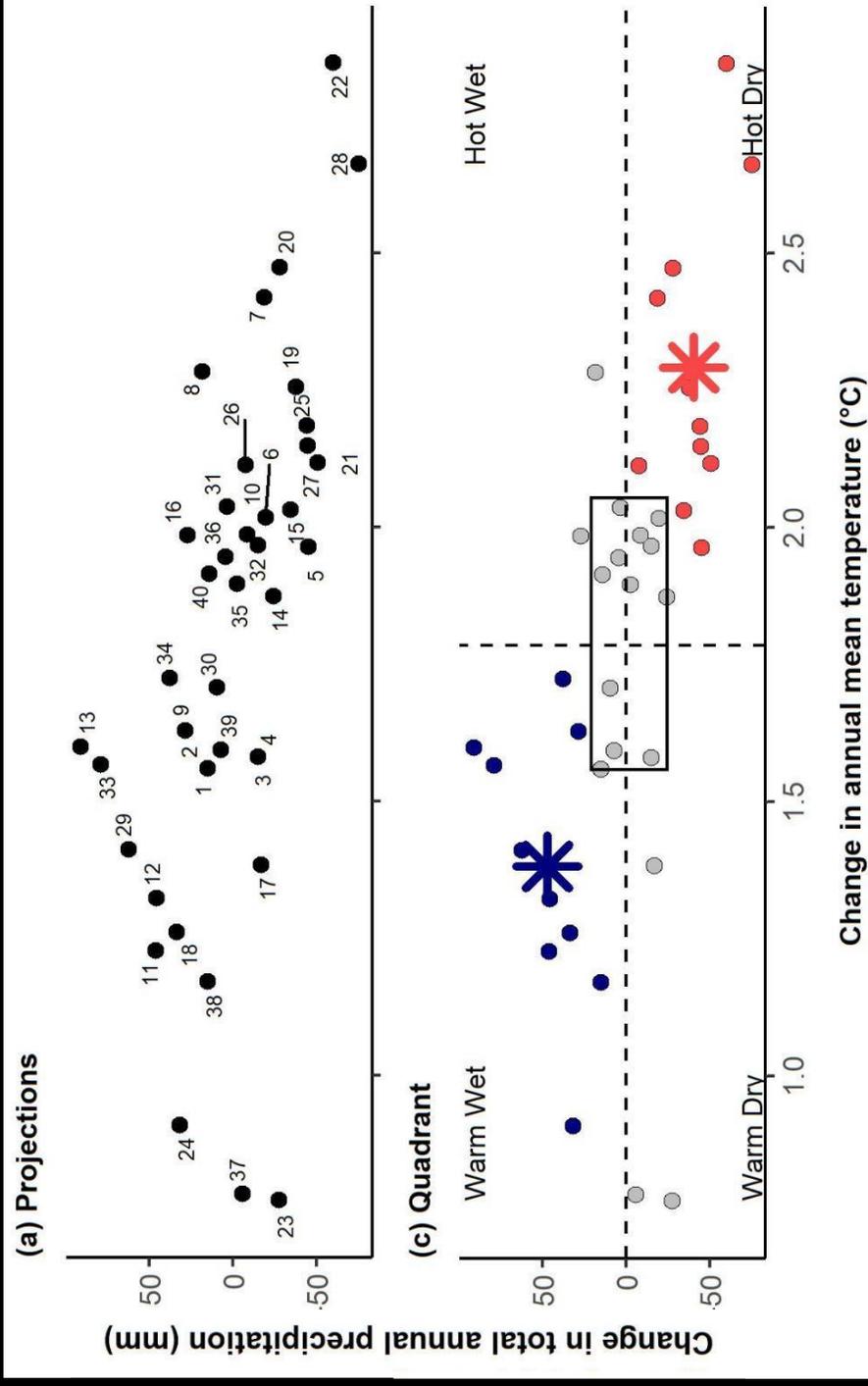
Calculates 21 threshold variables

Variable Name	Column Name	Variable Calculation
Minimum temperature	tmin	Downloaded data
Maximum temperature	tmax	Downloaded data
Precipitation	precip	Downloaded data
Heavy precipitation	precip_heavy	Precipitation greater than 2 in or 50 mm
Freeze thaw	freeze_thaw	Minimum temperature below 28F or -2.2C, maximum temperature above 34F or 1.1C
Growing degree day	gdd	Temperature exceeds 41F or 5C
Growing degree day length	gdd_count	Consecutive growing degree days
Non growing degree day length	not_gdd_count	Consecutive non growing degree days
Frost	frost	Growing degree day with minimum temperature below 32F or 0C
Growing season length	grow_length	Growing season length



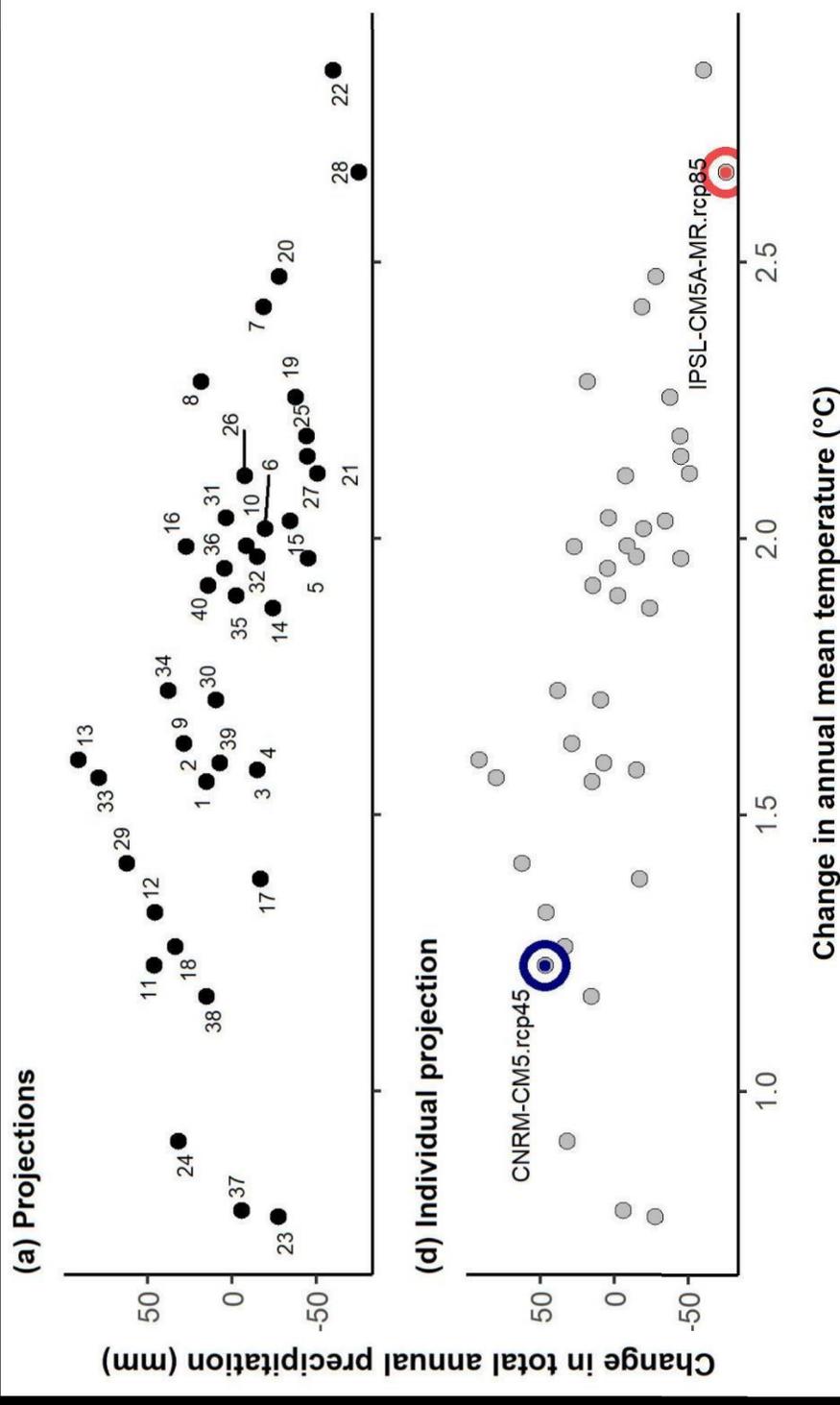
cf_quadrant()

Method = 'quadrant'



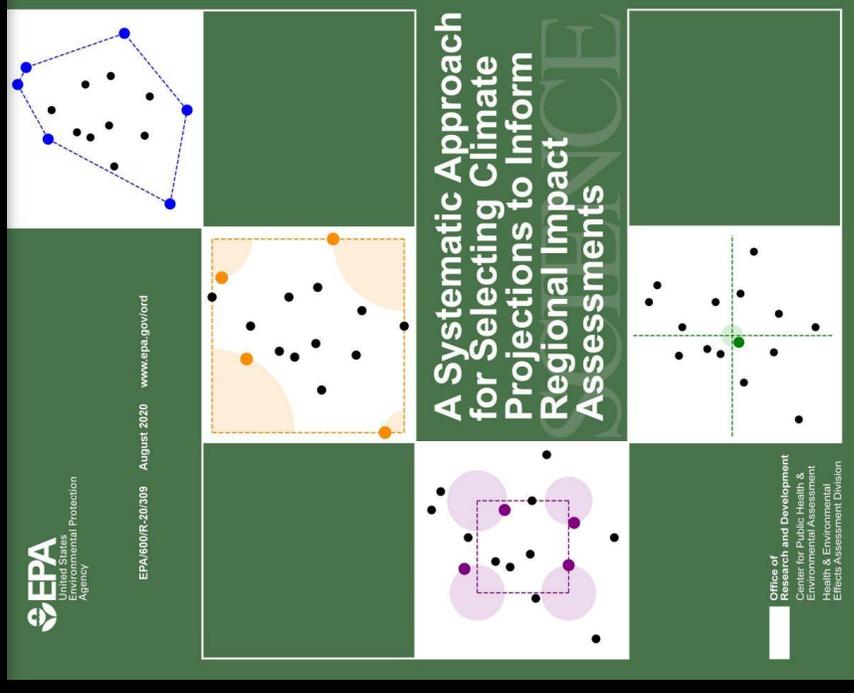
cf_quadrant()

Method = 'individual'



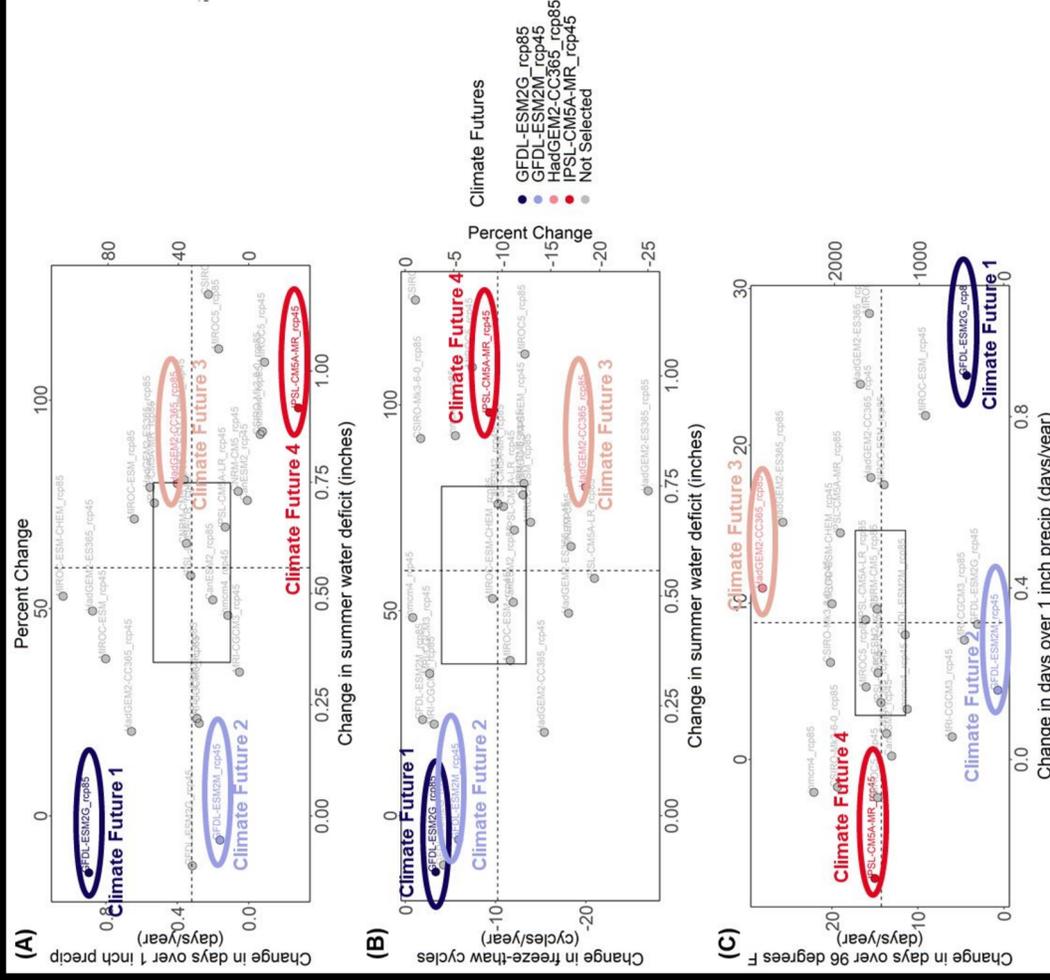
Algorithms for selecting divergent individual climate future projections

1. 'Corners' method – bivariate selection



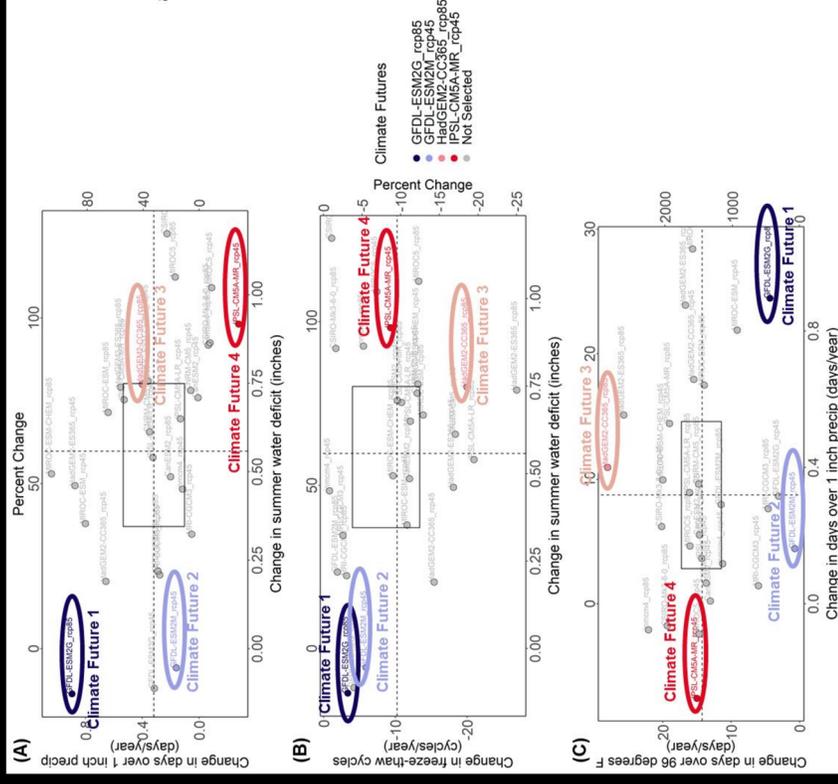
<https://lasso.epa.gov/strategies>

Algorithms for selecting divergent individual climate future projections



Algorithms for selecting divergent individual climate future projections

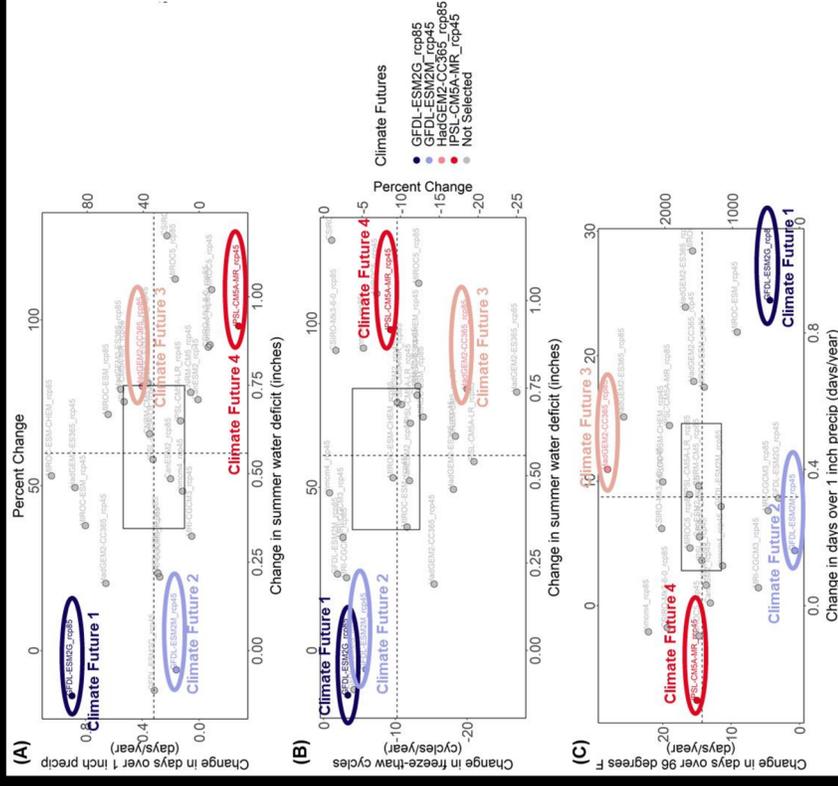
Concern	Based on
Historical structures, tower exfoliation	Freeze-thaw cycles (primary), Extremely hot days (secondary)
Vegetation	Mean (primary) and maximum (secondary) summer water deficit
Erosion	>1-inch precipitation events
Tower exfoliation, visitor and staff safety	Extremely hot days

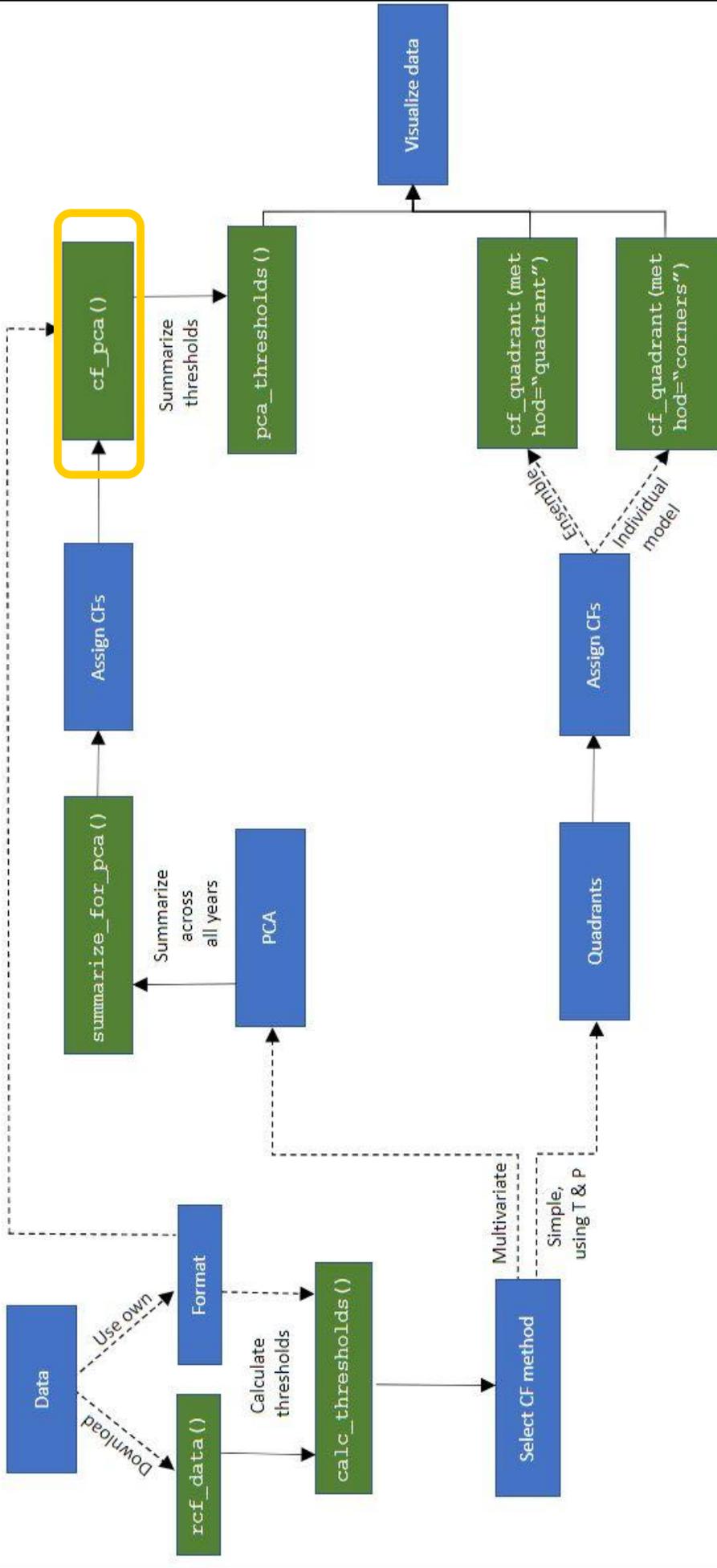


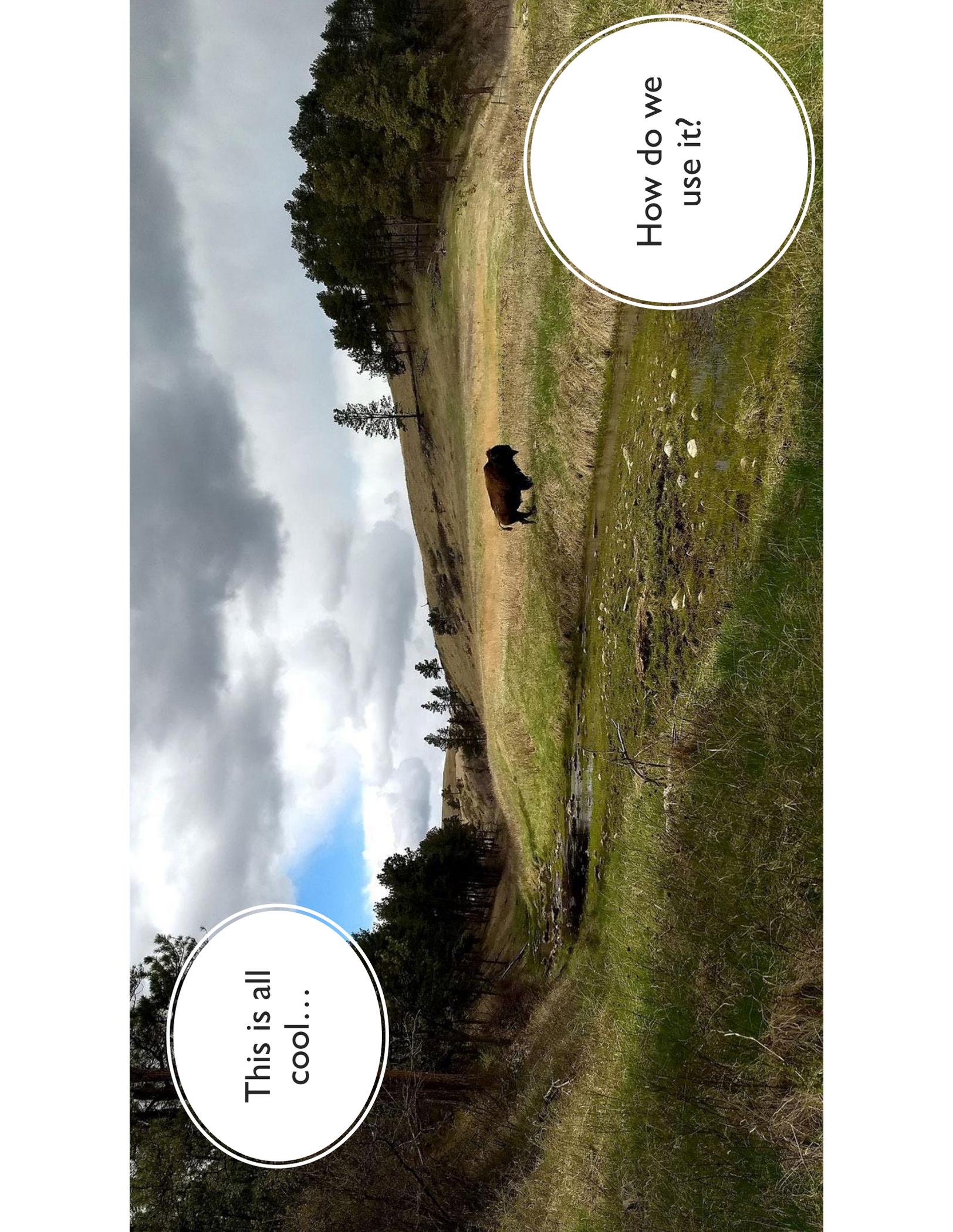
Algorithms for selecting divergent individual climate future projections

2. Principal Component Analysis – multivariate selection

Concern	Based on
Historical structures, tower exfoliation	Freeze-thaw cycles (primary), Extremely hot days (secondary)
Vegetation	Mean (primary) and maximum (secondary) summer water deficit
Erosion	>1-inch precipitation events
Tower exfoliation, visitor and staff safety	Extremely hot days





A landscape photograph showing a bison standing in a grassy field. In the foreground, there is a stream with rocks. The background features a line of trees and a sky with large, grey clouds. Two white circular callouts with black borders are overlaid on the image.

This is all
cool...

How do we
use it?

Training and resources

An Introduction to the Reproducible Climate Futures package

Janelle Christensen

8-20-2021

About this tutorial

This vignette will walk through how to use the `rcf` package. Using the functions in this package will enable users to be made the choice to automatically select Global Circulation Models (GCMs) that are most representative of 4 climate futures (CFs) - Warm Wet, Warm Dry (or Damp), Hot Wet, and Hot Dry (or Damp)*.

It can also be used to manipulate the data to produce summaries of threshold values for 25 variables using one of three methods (quadrant, corner, or PCA) and duration (month, season, or year).

*GCMs will be labeled as "damp" rather than "dry" if the mean of future precipitation for climate futures labeled as "dry" in that location are greater than zero.

Expected knowledge

This package expects that you have a basic understanding of GCMs and that each one represents a plausible climate future. The GCMs in this package are based off of the downscaled climate model `MACA` (Multivariate Adaptive Climate Analog) Version 2. Additionally, this vignette assumes you have some knowledge of packages in the `tidyverse` specifically `readr` and the `read_csv()` function, `dplyr` functions such as `filter()`, `mutate()` and `select()` as well as some understanding of how to use `ggplot2`.

Learning goals of this vignette

At the end of this tutorial, you should be able to understand:

- o the workflow of the `rcf` package

What is PCA and why use it?

Principal components analysis (PCA) is a statistical tool that can help to visualize the variance of more than 2 variables. In traditional model selection methods, we select models using just temperature and precipitation, but PCA allows us use as many variables as we would like to select models that best represent the climate futures we are interested in. If we want to select which models will best show changes in temperature, precipitation, relative humidity, growing degree days and freeze thaw cycles, PCA is the best tool to use. It essentially is able to condense the variance of all 5 of those variables into an x-y plot, and we can select which models show the most variability on that plot. A more in-depth explanation of PCA can be found [here](#).

PCA in the rcf package

For more advanced users of the `rcf` package, models can be selected using PCA with a somewhat adjusted workflow. You can either use your own data and start at the `cf_pca()` function, or you can use the threshold values to calculate which models are most representative of the variables you are interested in.

If you would like to use your own data to calculate the PCA, you can skip down to the "PCA Calculation" section below.

If you want to use the data that is created from the threshold values, the first two steps in using PCA are exactly the same as using the quadrant method:

1. Download data using `rcf_data()`
2. Calculate threshold values using `calc_thresholds()`

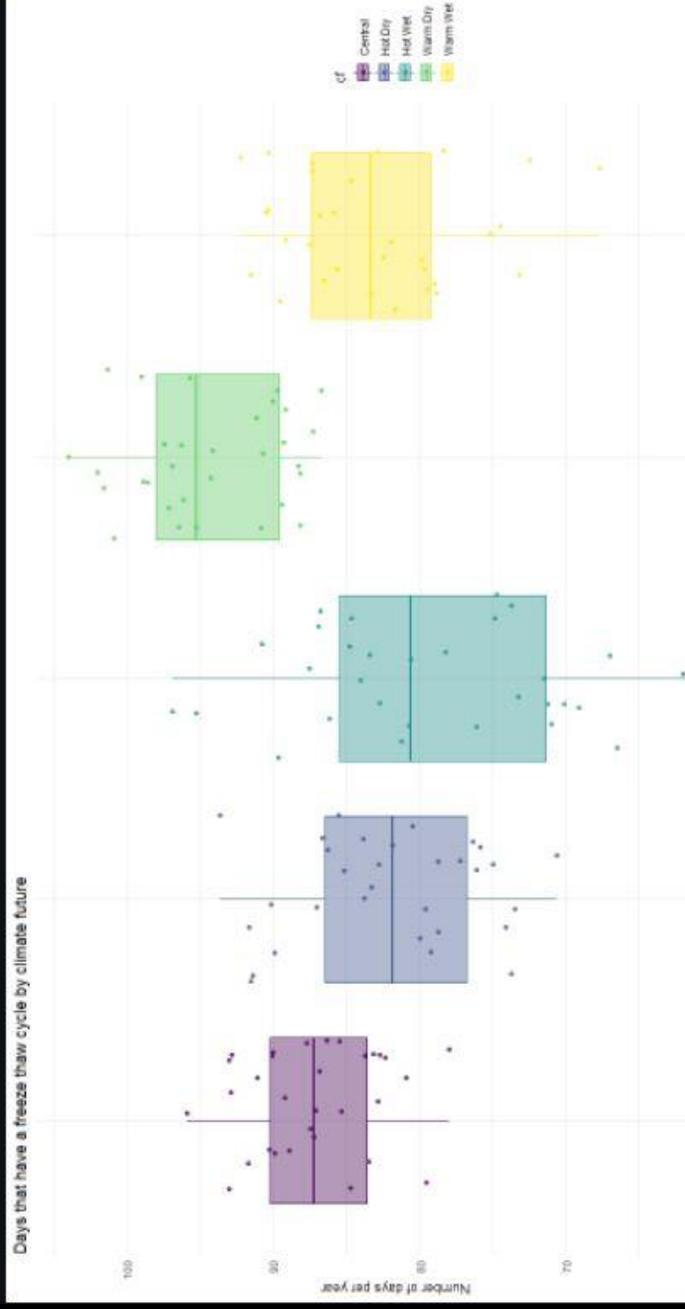
To see how to do this, you can follow along with [An Introduction to the Reproducible Climate Futures package](#)(INSERT LINK).

```
# raw_data <- rcf_data(siteID = "BAND",  
#                       latitude = 35.75758546,  
#                       longitude = -106.3054344,  
#                       directory = my_directory,  
#                       units = "imperial")
```

```
raw_data <- read_csv("https://irma.dev.nps.gov/DataStore/DownloadFile/6666685")  
#> Rows: 2191480 Columns: 10  
#> Column names: file_start
```

Training and resources

```
scale_color_viridis_d() +  
labs(y = "Number of days per year",  
      title = "Days that have a freeze thaw cycle by climate future") +  
theme(axis.title.x = element_blank()) +  
theme_minimal()
```



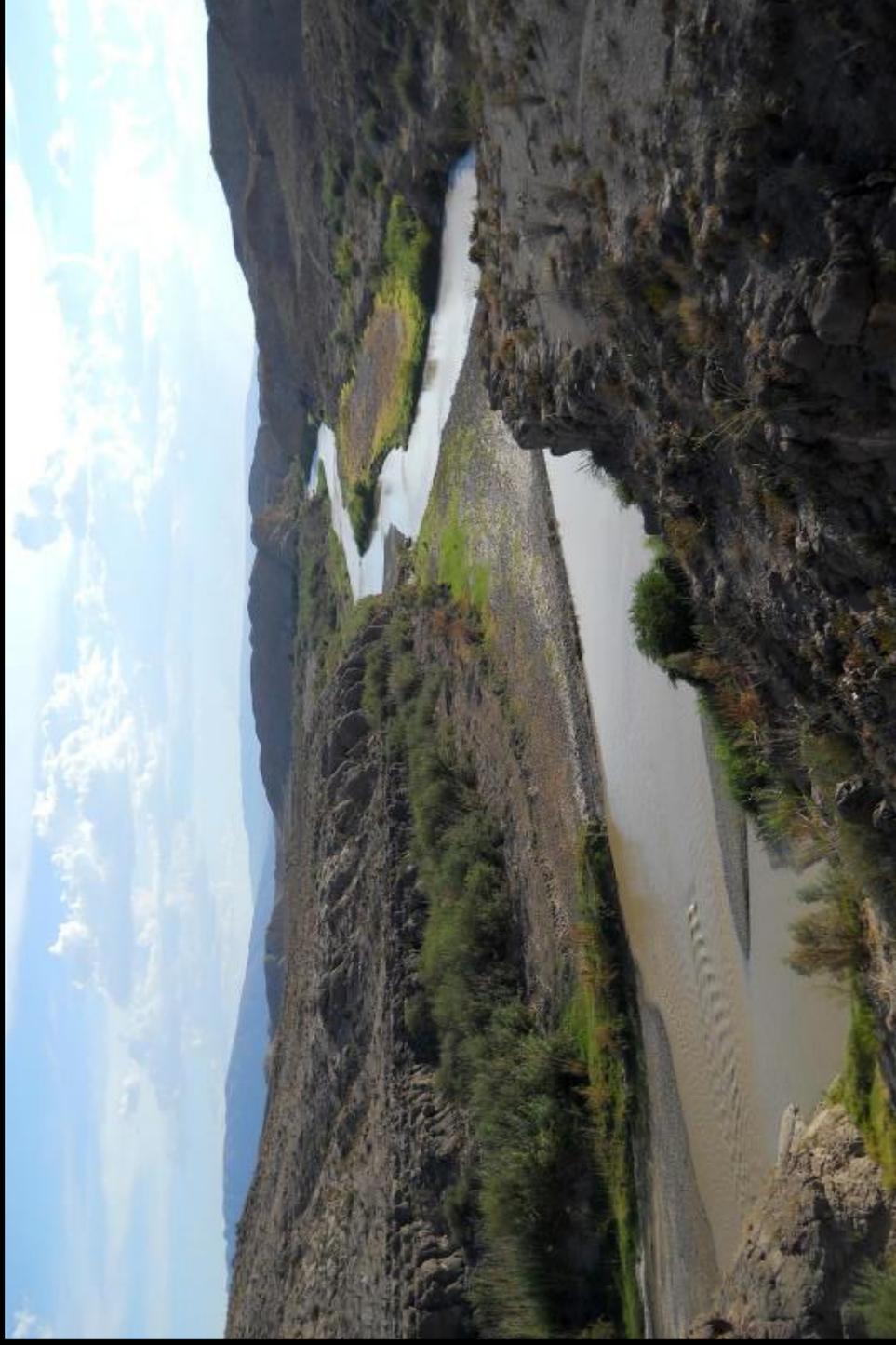
Training workshops

Hands-on training workshops to be held in coming months (Summer 2022)

If interested reach out to me and will put on distribution list

Acknowledgements

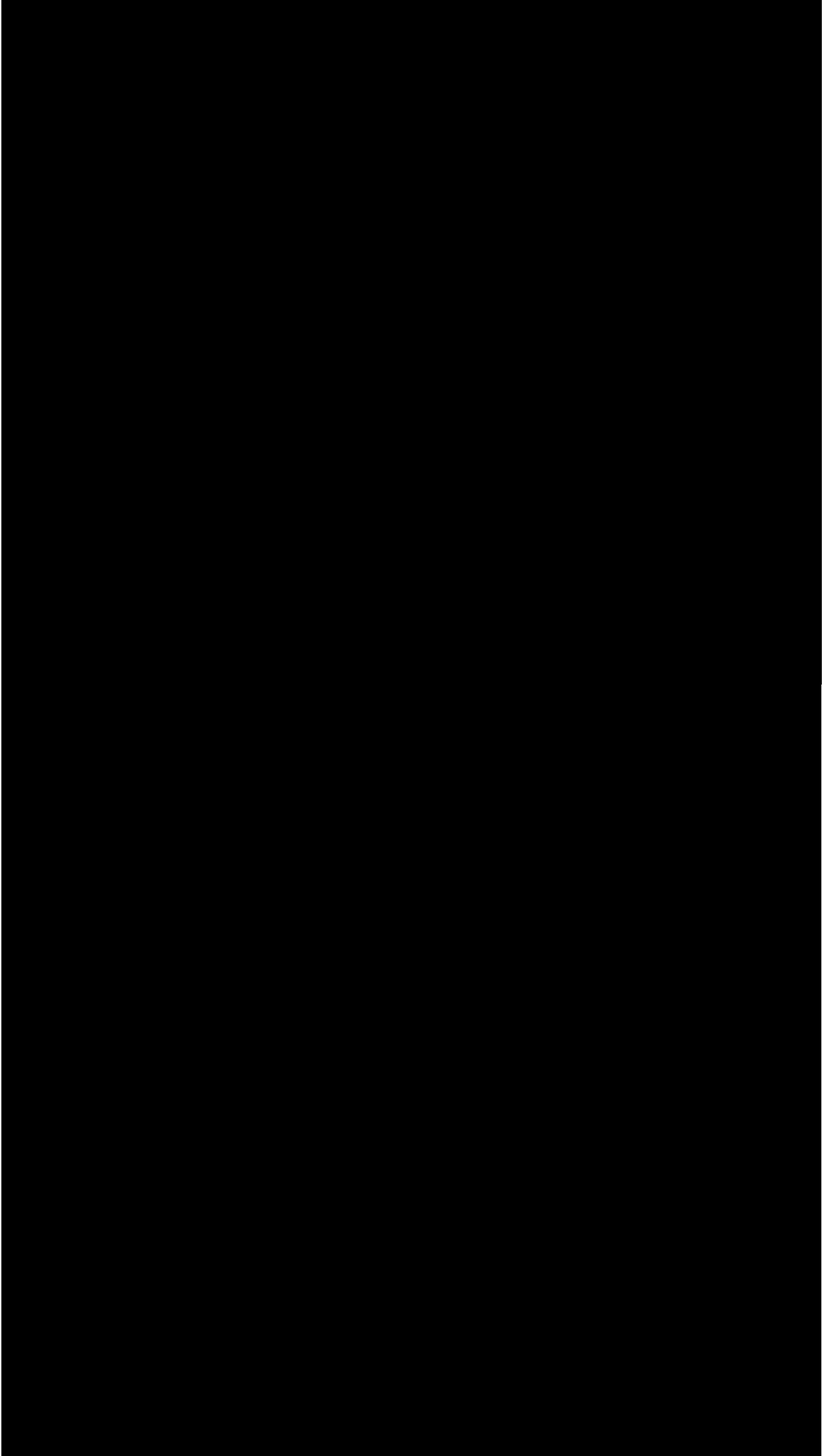
- Joel Reynolds
- Cat Hawkins Hoffman
- Amy Symstad
- Leigh Welling
- Imtiaz Rangwala
- Nick Fisichelli
- Amanda Carlson
- Annie Kellner
- Megan Sears
- Garrett Knowlton
- Janelle Christensen



NPS Climate Change Response Program



Contact: amber_runyon@nps.gov



Resources

The image shows a YouTube video player interface. At the top left is the YouTube logo and a search bar. The video title is "Warming Up to Adaptation: Big Bend National Park". The video content shows a desert landscape with a large rock formation and a saguaro cactus. A National Service logo is in the top right corner of the video. The video player includes standard controls: play/pause, volume, full screen, and a progress bar showing 1:00 / 6:11. Below the video, there are engagement icons for likes (4), dislikes, share, save, and a menu icon. The video description below the player reads: "Warming Up to Adaptation: Big Bend National Park" and "394 views • May 5, 2021".

Climatic Change (2021) 167:38
<https://doi.org/10.1007/s10584-021-03169-y>



Divergent, plausible, and relevant climate futures for near- and long-term resource planning

David J. Lawrence¹ · Amber N. Runyon¹ · John E. Gross¹ · Gregor W. Schuurman¹ · Brian W. Miller²

Received: 4 January 2021 / Accepted: 7 July 2021 / Published online: 13 August 2021
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Abstract

Scenario planning has emerged as a widely used planning process for resource management in situations of consequential, irreducible uncertainty. Because it explicitly incorporates uncertainty, scenario planning is regularly employed in climate change adaptation. An early and essential step in developing scenarios is identifying “climate futures”—descriptions of the physical attributes of plausible future climates that could occur at a specific place and time. Divergent climate futures that describe the broadest possible range of plausible conditions support information needs of decision makers, including understanding the spectrum of potential resource responses to climate change, developing strategies robust to that range, avoiding highly consequential surprises, and averting maladaptation. Here, we discuss three approaches for generating climate futures: a Representative Concentration Pathway (RCP)-ensemble, a quadrant-average, and an individual-projection approach. All are designed to capture relevant uncertainty, but they differ in utility for different applications, complexity, and effort required to implement. Using an application from Big Bend National Park as an example of numerous similar efforts to develop climate futures for National Park Service applications over the past decade, we compare these approaches, focusing on their ability to capture among-projection divergence during early-, mid-, and late-twenty-first century periods to align with near-, mid-, and long-term planning efforts. The quadrant-average approach and especially the individual-projection approach captured a broader range of plausible future conditions than the RCP-ensemble approach, particularly in the near term. Therefore, the individual-projection approach supports decision makers seeking to understand the broadest potential characterization of future conditions. We discuss tradeoffs associated with different climate future approaches and highlight suitable applications.

✉ David J. Lawrence
david_james_lawrence@nps.gov

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² U.S. Geological Survey, North Central Climate Adaptation Science Center, Fort Collins, CO, USA

Selecting climate future approach

	RCP ensemble	Quadrant average	Individual projection
Mitigation vs adaptation focus	Mitigation	Adaptation	Adaptation
Effort required (time, expertise)	Simple	Simple	Moderate
Uncertainty characterization	Emissions uncertainty	Emissions + GCM uncertainty combined	Emissions + GCM uncertainty combined
Planning time frame	Mid to long-term (>2050)	Near, mid, and long term	Near, mid, and long term
Supports annual (time series) analysis?	Yes, daily	No, projections may move quadrants through time	Yes, daily
Proportion of uncertainty captured	Low	Moderate	Most
Ways to enhance characterization of uncertainty	<ul style="list-style-type: none"> • Add 5th and 95th percentile model estimates • Show individual models along with ensemble • Show max/min of models along with ensemble 	Switch to individual projection approach	Select projections that span greatest range for climate metric(s) of interest
Examples	Ficklin and Novick 2017 Hoestler et al. 2021	Runyon et al. 2019	Lawrence and Runyon 2019 Miller et al. 2017

RCF package

Spring 2022 release

Developing an R package that generates CFs and calculates thresholds for 30 metrics

- Individual or quadrant CF selection
- CFs selected from temperature and precipitation OR multiple metrics using principle component analysis

Trainings on climate future creation will be announced in spring 2022

Reproducible Climate Futures (rcf)

Overview

This package aims to make acquiring and working with [MACA v2](#) climate data faster and easier and to provide a number of summary statistics that can be used to visualize different climate futures. Ultimately, having access to this data supports planning efforts that aim to incorporate climate change.

Installation

Until approval on CRAN, you can download the development version of `rcf`

You can install the released version of `rcf` from CRAN with:

```
install.packages("rcf")
```

And the development version from GitHub with:

```
# install.packages("devtools")  
devtools::install_github("nationalparkservice/rcf")
```

For more information:
Amber_Runyon@nps.gov

Resources for generating climate futures

EPA
Environmental Protection Agency
EPA/600/R-20/001 August 2020 www.epa.gov/clm

A Systematic Approach for Selecting Climate Projections to Inform Regional Impact Assessments

Office of Research and Development
Center for Public Health & Environmental Health & Environmental Effects Assessment Division

United States Department of Agriculture
USDA

Future Scenarios

A Technical Document Supporting the USDA Forest Service 2020 RPA Assessment
David A. Weaver, John P. Peterson, David Coulson, Clara B. O'Brien

Forest Service | Case, Tech. Rep. RMRS-471-1-17 | May 2009

RECLAMATION Managing Water in the West

DRAFT Hood River Basin Study:
Climate Change Analysis Technical Memorandum

U.S. Department of the Interior
Bureau of Reclamation
Northwest Division
Pacific Northwest Regional Office
Boise, Idaho

February 2014

caladapt

Tools

Cal-Adapt provides a way to explore peer-reviewed data that portrays how climate change might affect California at the state and local levels.

We make this data available through downloads, visualizations, and the Cal-Adapt API for your research, outreach, and adaptation planning needs.

View About Cal-Adapt

- New to Cal-Adapt?**
Learn how to get started with using climate data for California. [LEARN MORE](#)
- Local Climate Change Snapshot Tool**
Quickly view a variety of climate data for a city, county, or other place. [LEARN MORE](#)
- Explore All Climate Tools**
Explore data on temperature, precipitation, streamflow, wildfire, and more. [LEARN MORE](#)
- Download Data**
Download climate data in NetCDF, CSV and GeoTIFF formats for your area. [LEARN MORE](#)
- Tutorials & Webinars**
Browse our video collection of tool tutorials and past webinars. [LEARN MORE](#)
- Developers**
Integrate climate data in your workflows with the Cal-Adapt API. [LEARN MORE](#)

Standards for reproducible research

1. For every result, keep track of how it was produced
2. Avoid manual data manipulation steps
3. Archive the exact version of all external programs used
4. Version control all custom scripts
5. Record all intermediate results, when possible in standardized formats
6. For analysis that include randomness, note underlying random seeds
7. Always store raw data behind plots
8. Generate hierarchical analysis output, allowing layers of increasing detail to be inspected
9. Connect textual statements to underlying results
10. Provide public access to scripts, runs, and results

OPEN ACCESS Freely available online

PLOS COMPUTATIONAL BIOLOGY

Editorial

Ten Simple Rules for Reproducible Computational Research

Geir Kjetil Sandve^{1,2*}, Anton Nekrutenko³, James Taylor⁴, Eivind Hovig^{1,5,6}

¹ Department of Informatics, University of Oslo, Blindern, Oslo, Norway, ² Centre for Cancer Biomedicine, University of Oslo, Blindern, Oslo, Norway, ³ Department of Biochemistry and Molecular Biology and The Huck Institutes for the Life Sciences, Penn State University, University Park, Pennsylvania, United States of America, ⁴ Department of Biology and Department of Mathematics and Computer Science, Emory University, Atlanta, Georgia, United States of America, ⁵ Department of Tumor Biology, Institute for Cancer Research, The Norwegian Radium Hospital, Oslo University Hospital, Montebello, Oslo, Norway, ⁶ Institute for Medical Informatics, The Norwegian Radium Hospital, Oslo University Hospital, Montebello, Oslo, Norway

Replication is the cornerstone of a cumulative science [1]. However, new tools and technologies, massive amounts of data, interdisciplinary approaches, and the complexity of the questions being asked are complicating replication efforts,

just as much about the habits that ensure reproducible research as the technologies that can make these processes efficient and realistic. Each of the following ten rules captures a specific aspect of reproducibility.

We further note that reproducibility is than to do it while underway). We believe that the rewards of reproducibility will compensate for the risk of having spent valuable time developing an annotated catalog of analyses that turned out as blind alleys.