Tools for developing reproducible climate futures for resource planning

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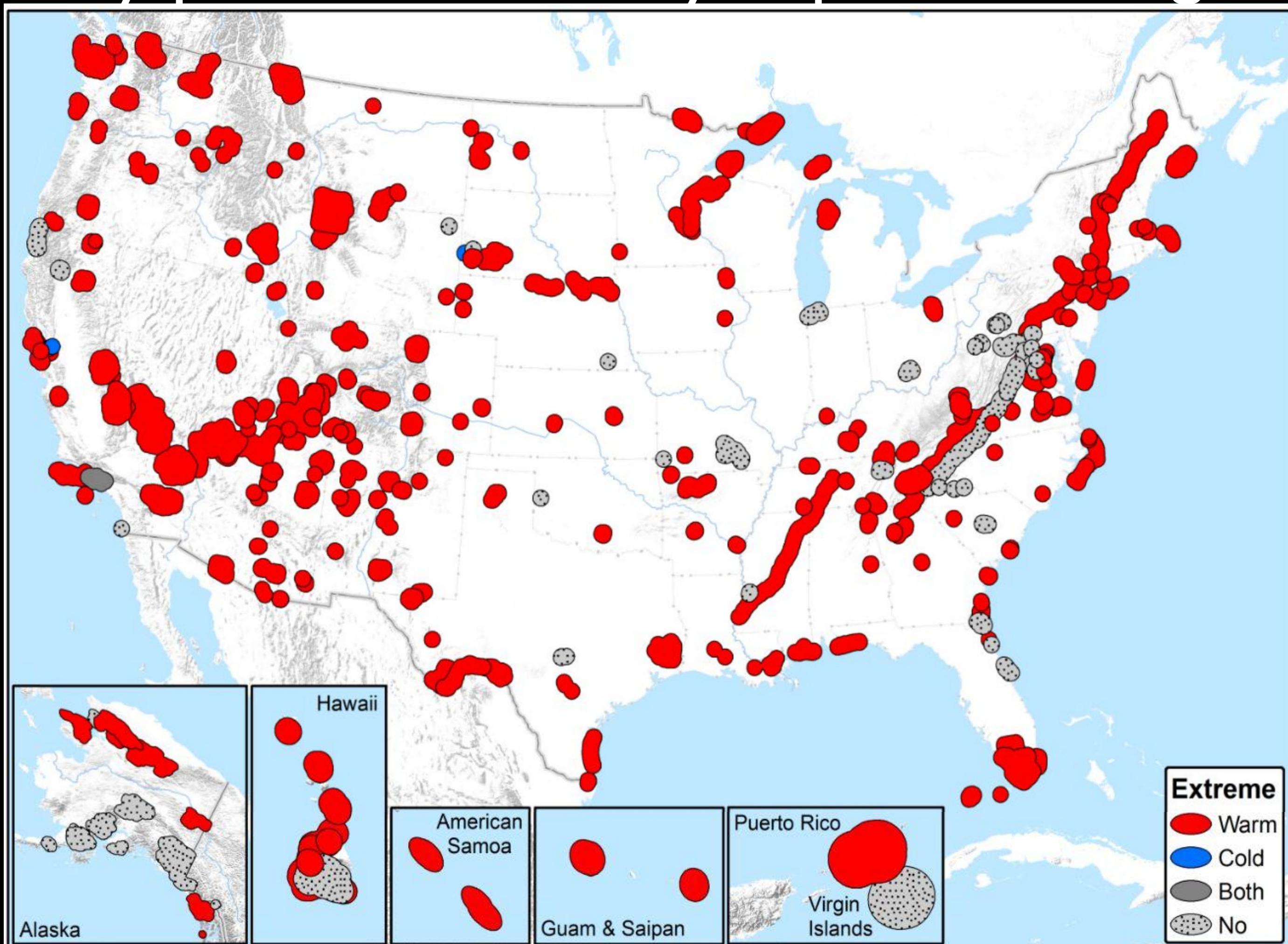
North Central Climate Science Adaptation Science Center, 14 Apr 2022

Many parks have already experienced significant warming



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

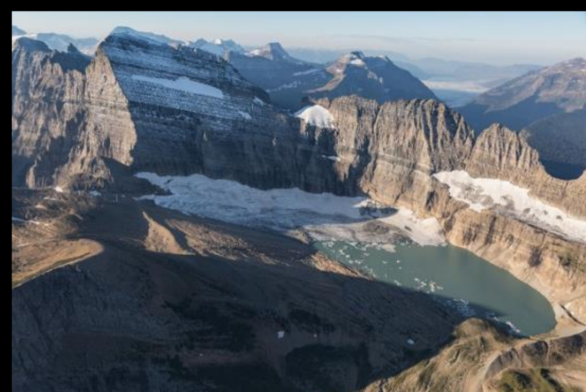
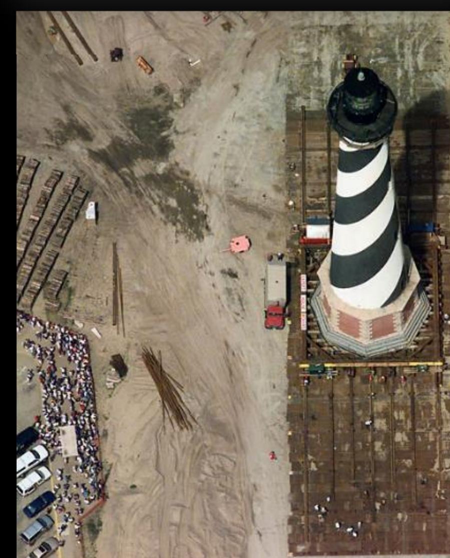
* Extreme = Parks with recent mean temp greater than 95% of the historical range of conditions

Monahan and Fisichelli 2014

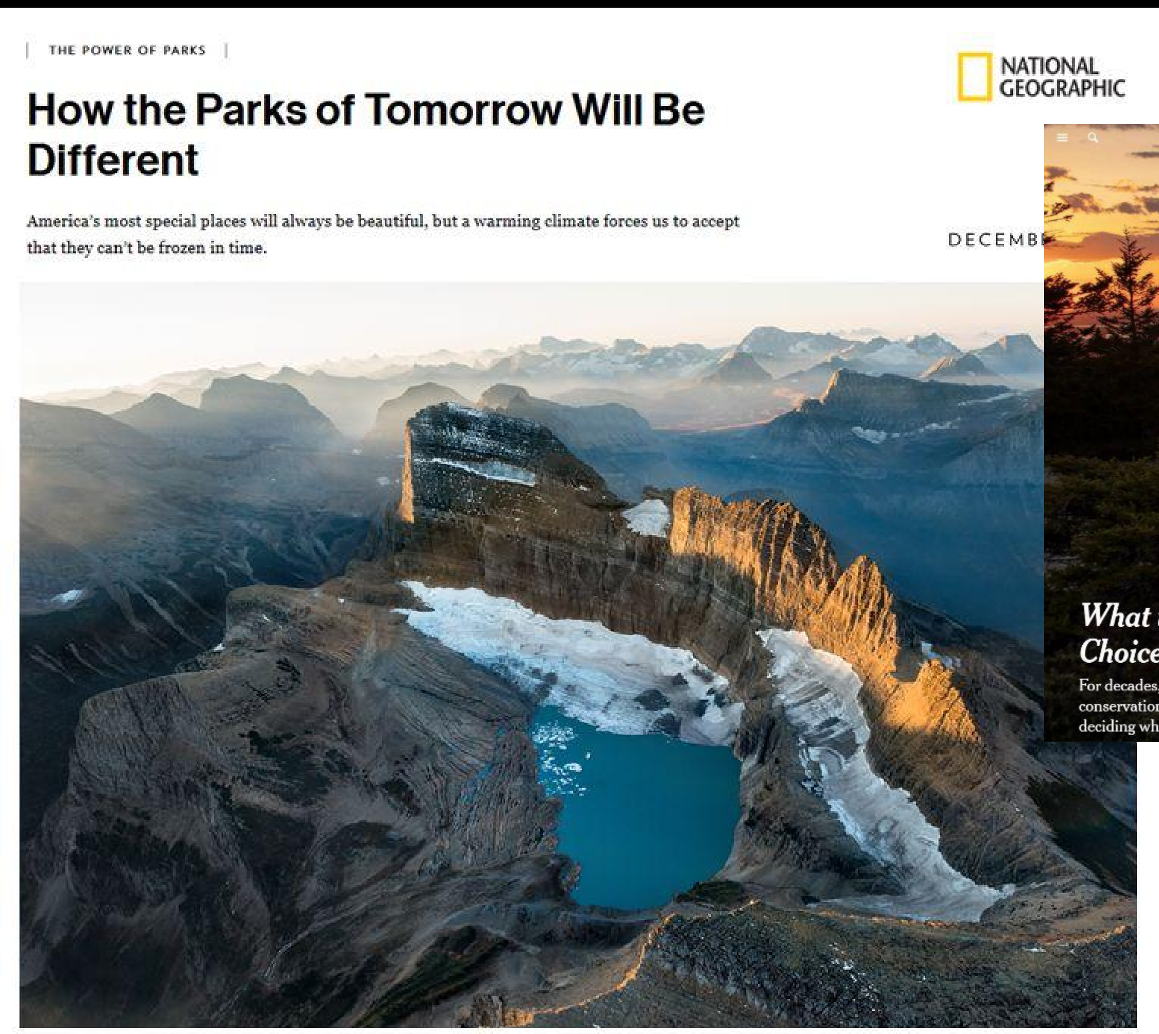
Climate change is impacting parks





More climate change impacts are anticipated


THE POWER OF PARKS

NATIONAL GEOGRAPHIC

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.

DECEMB


The New York Times

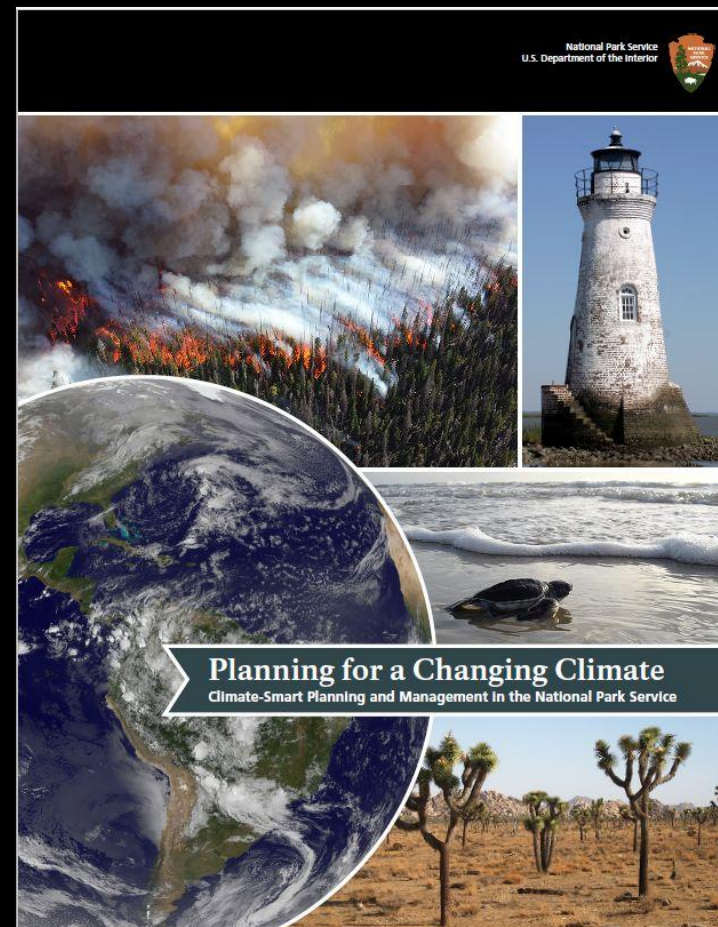
What to Save? Climate Change Forces Brutal Choices at National Parks.

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

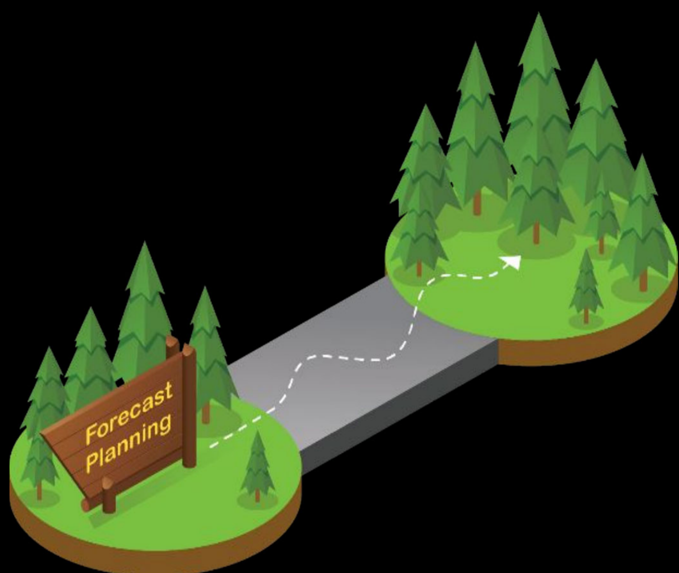
- Develop forward-looking goals that consider future climatic conditions
- Consider more than one scenario of the future



Planning in uncertain times

Traditional planning

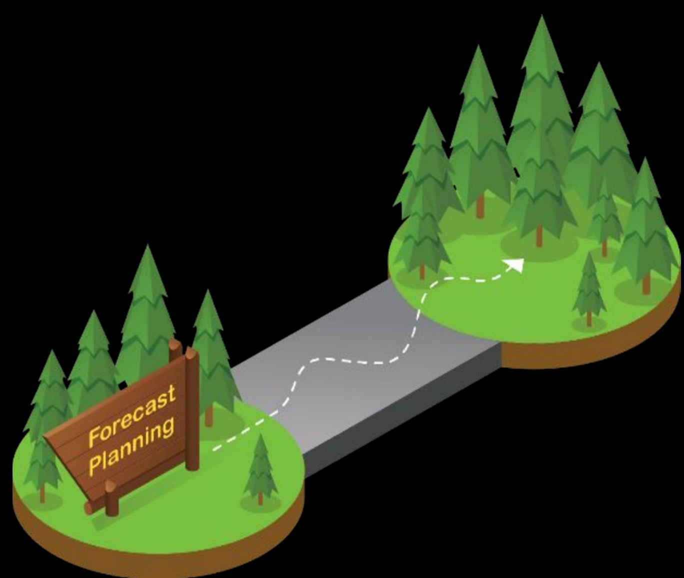
- Assumes the future will look like the past
- Tend to be overconfident in our ability to predict the future
- Tend to think narrowly
- Leave ourselves open to surprises

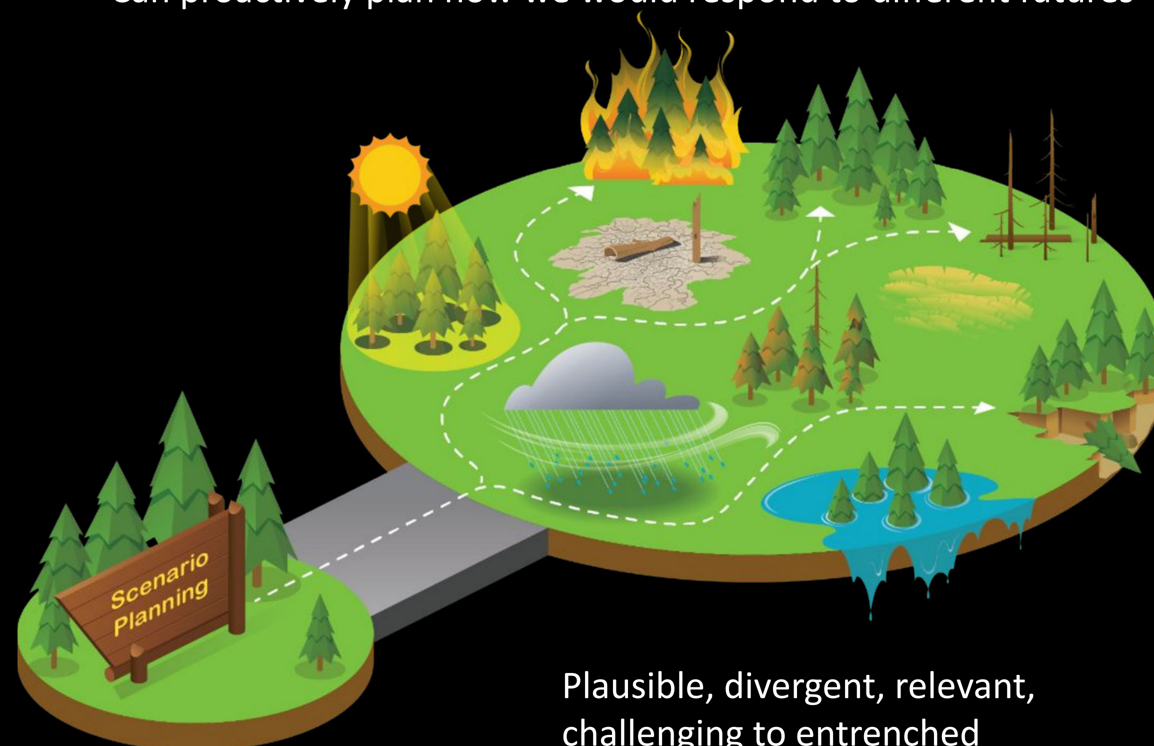


Planning in uncertain times

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

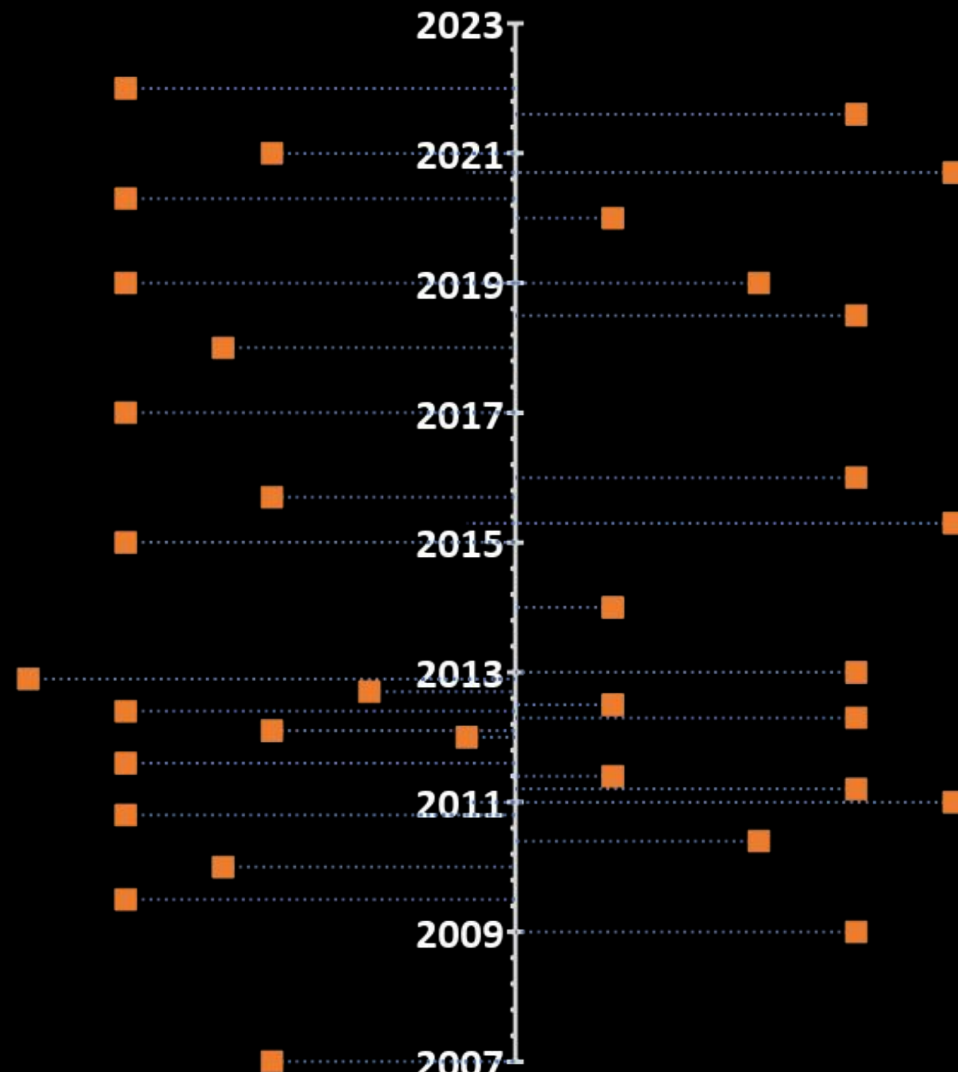
Scenario planning

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

NPS Scenario Planning

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

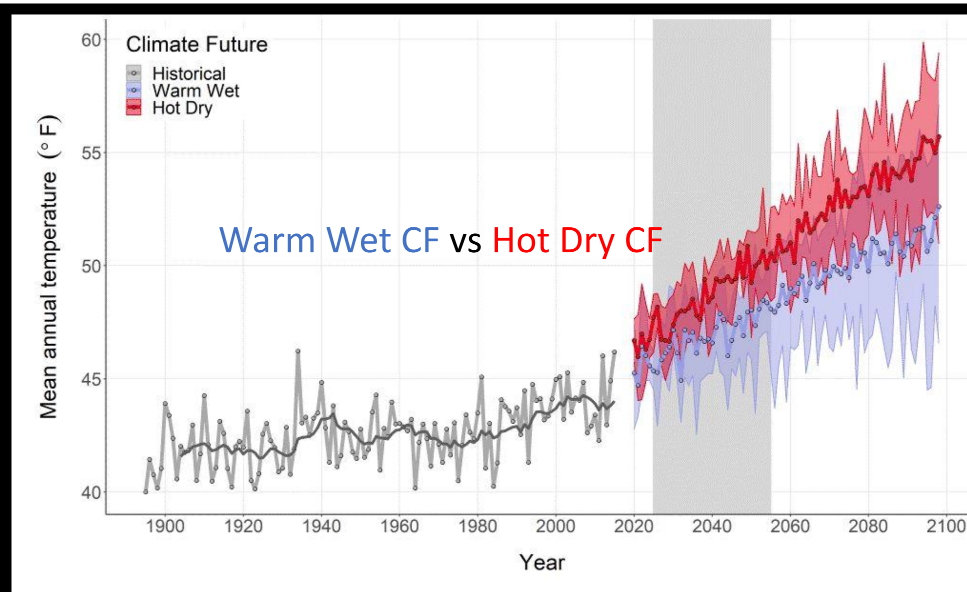


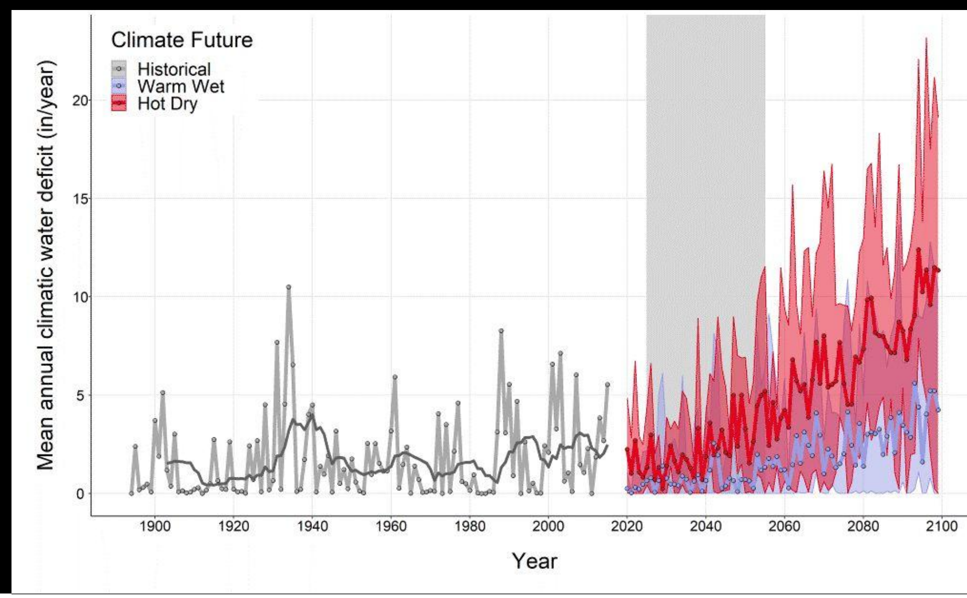
Step 1: Generate Climate Futures

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.

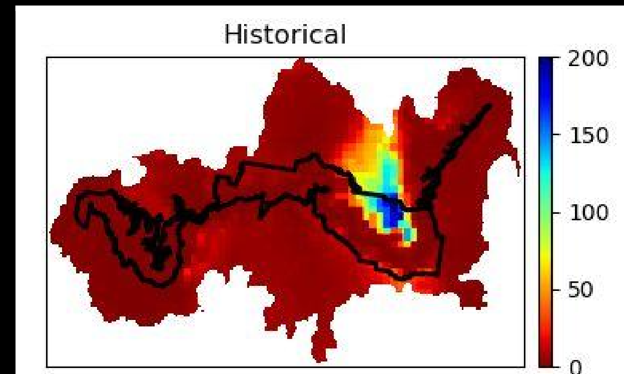




Climate futures

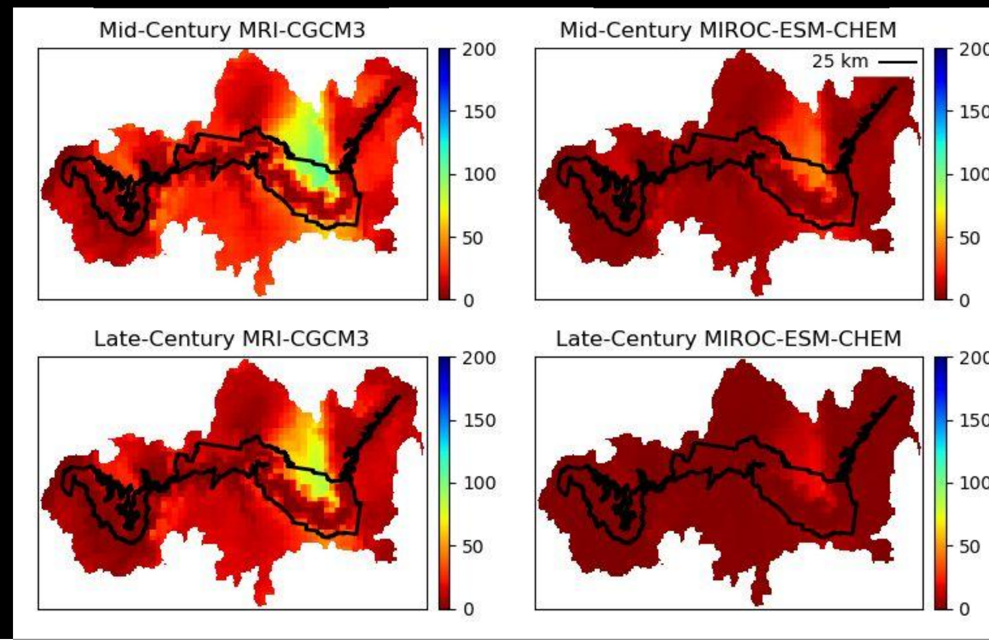
- CF characterize uncertainty
- Divergent CFs describe the broadest potential range of futures we experience
- Divergent CFs support info needs of decision makers by:
  - Allowing them to understand spectrum of change resources may experience
  - Develop strategies robust to the range in potential climate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

Grand Canyon
Number of days per year with snow water equivalent > 0



Climate future 1

Climate future 2



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

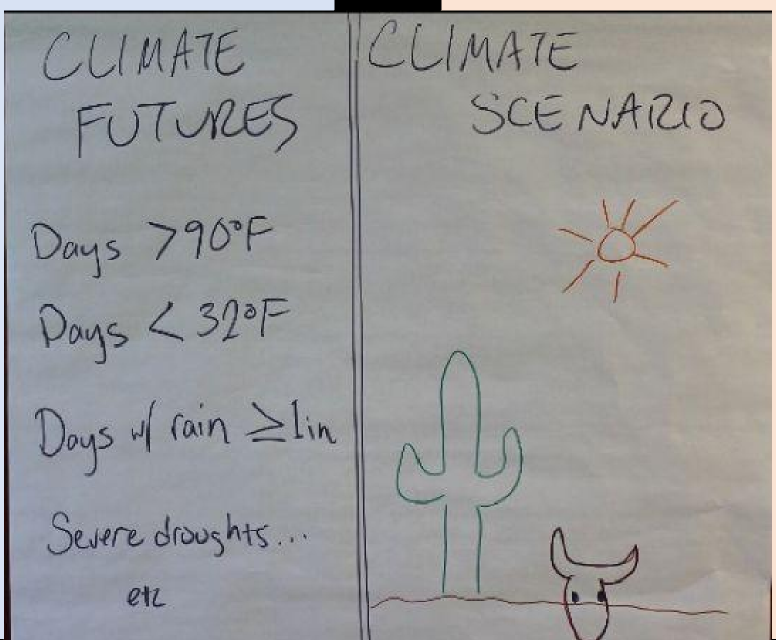
Identify potential resource implications of climate futures.

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

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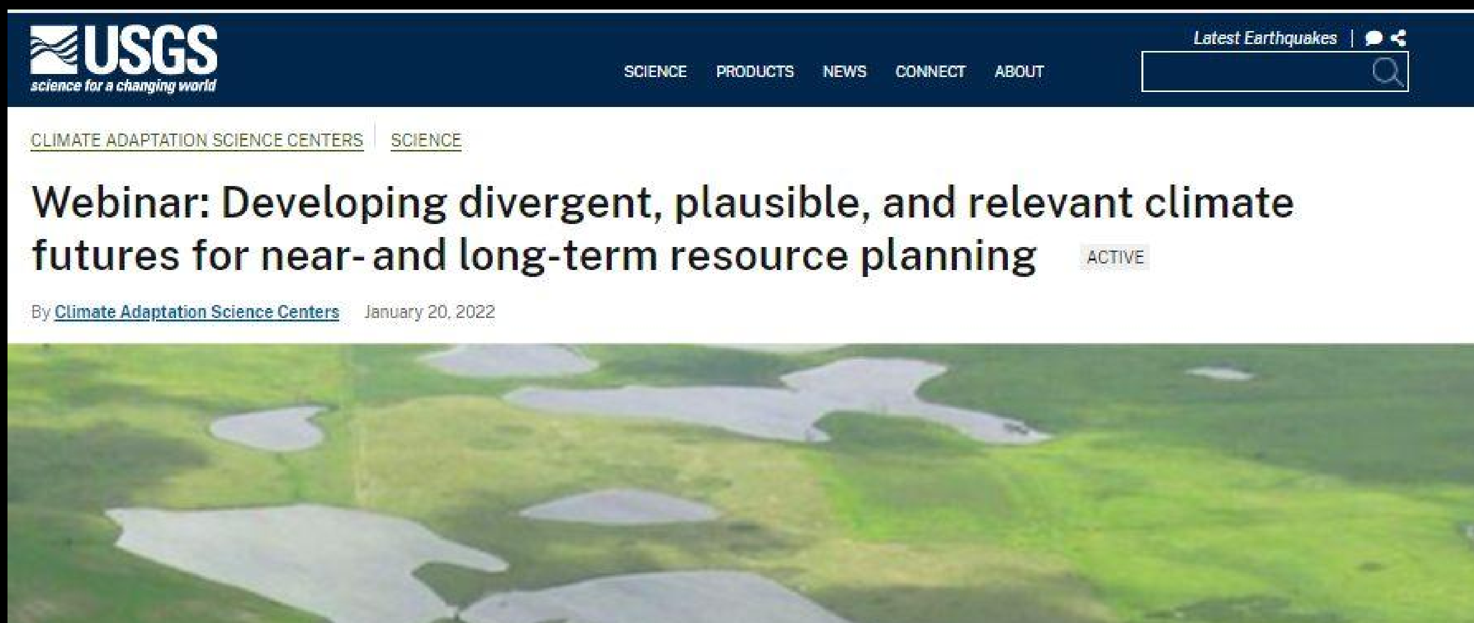
CASC webinar 20 Jan 2022

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



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
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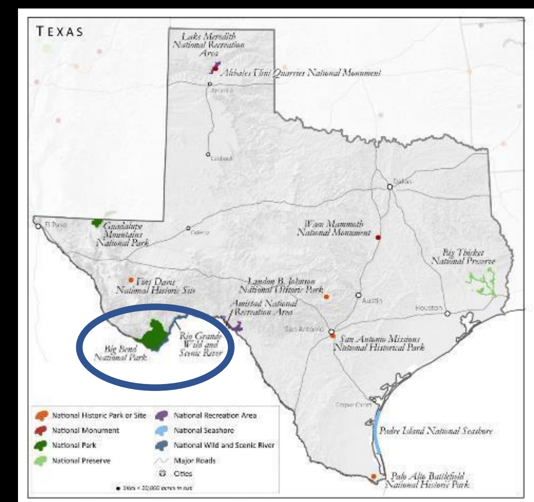
Big Bend National Park



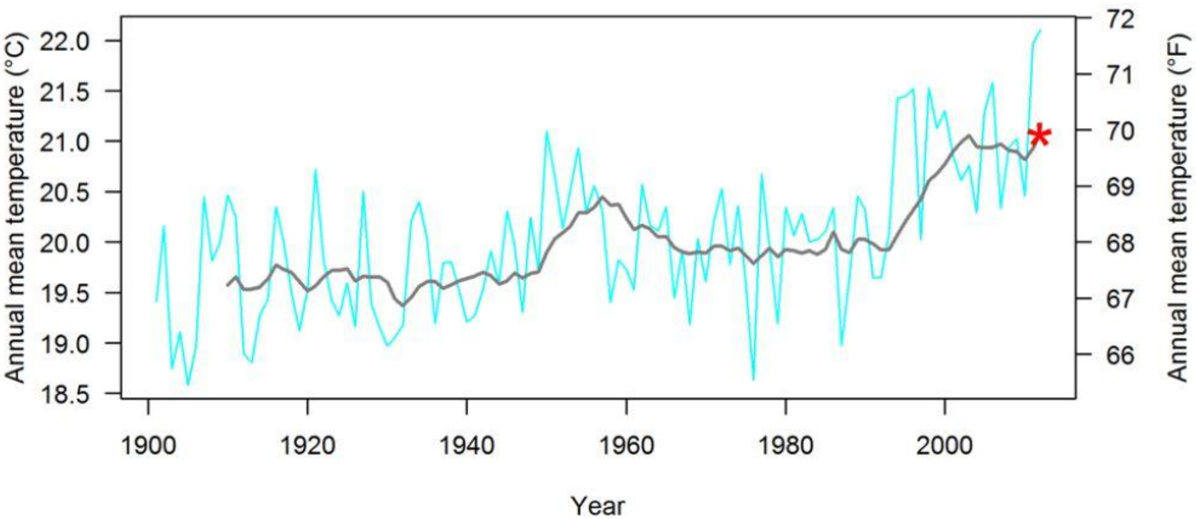
Climate Change

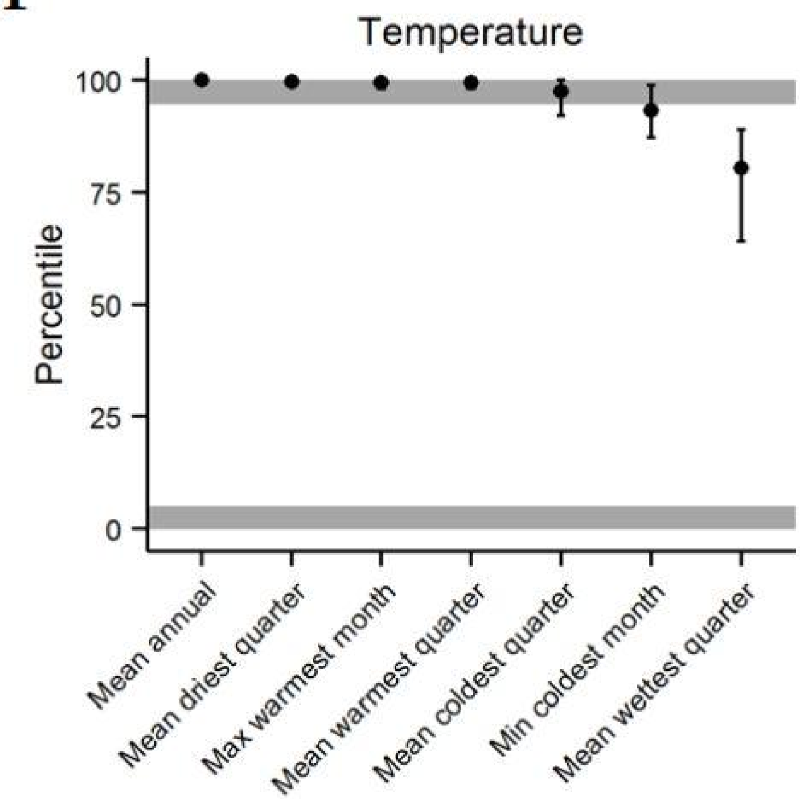
Resource Brief

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"

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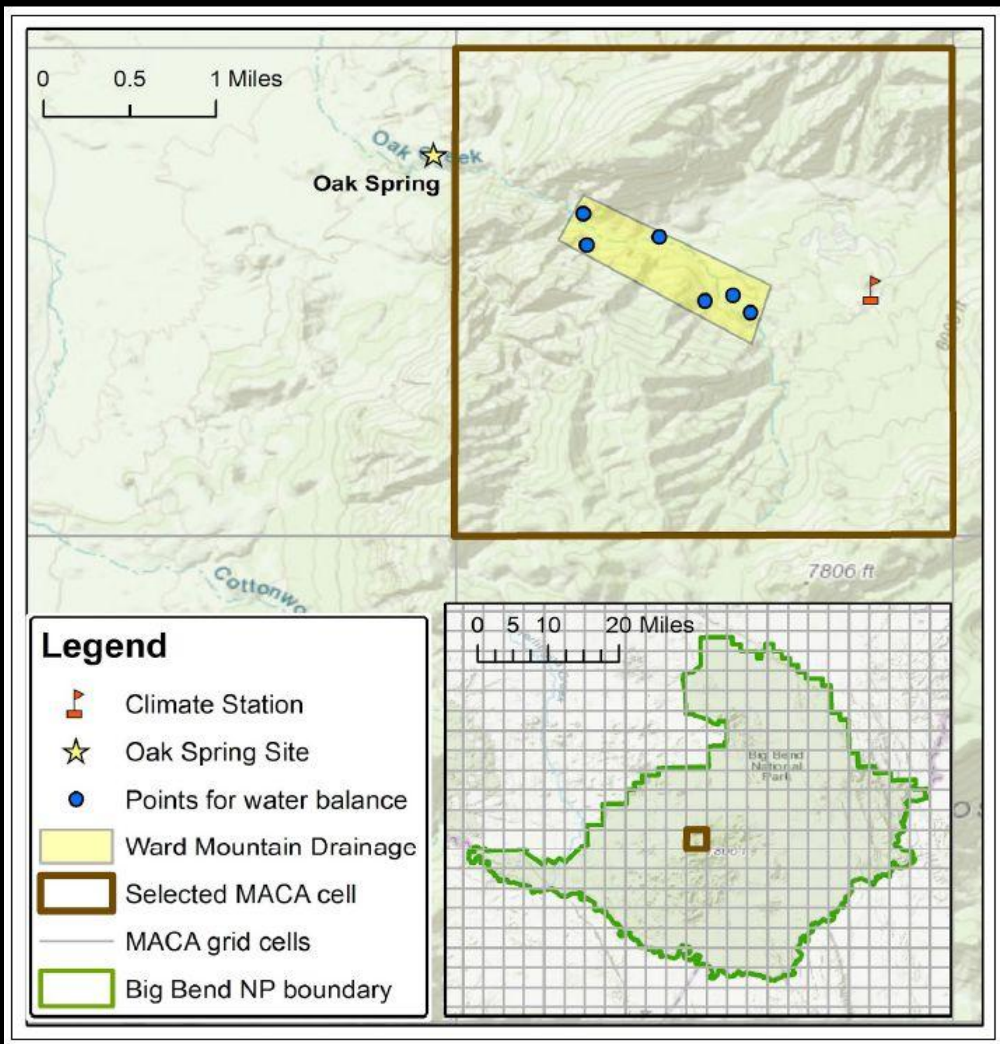
Generating climate futures



16-km^2 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

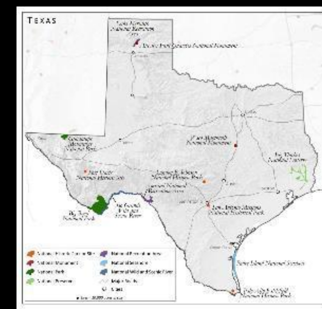
Projection = climate model driven by a specific radiative forcing
(e.g.,IPSL-CM5A-MR; RCP 4.5)

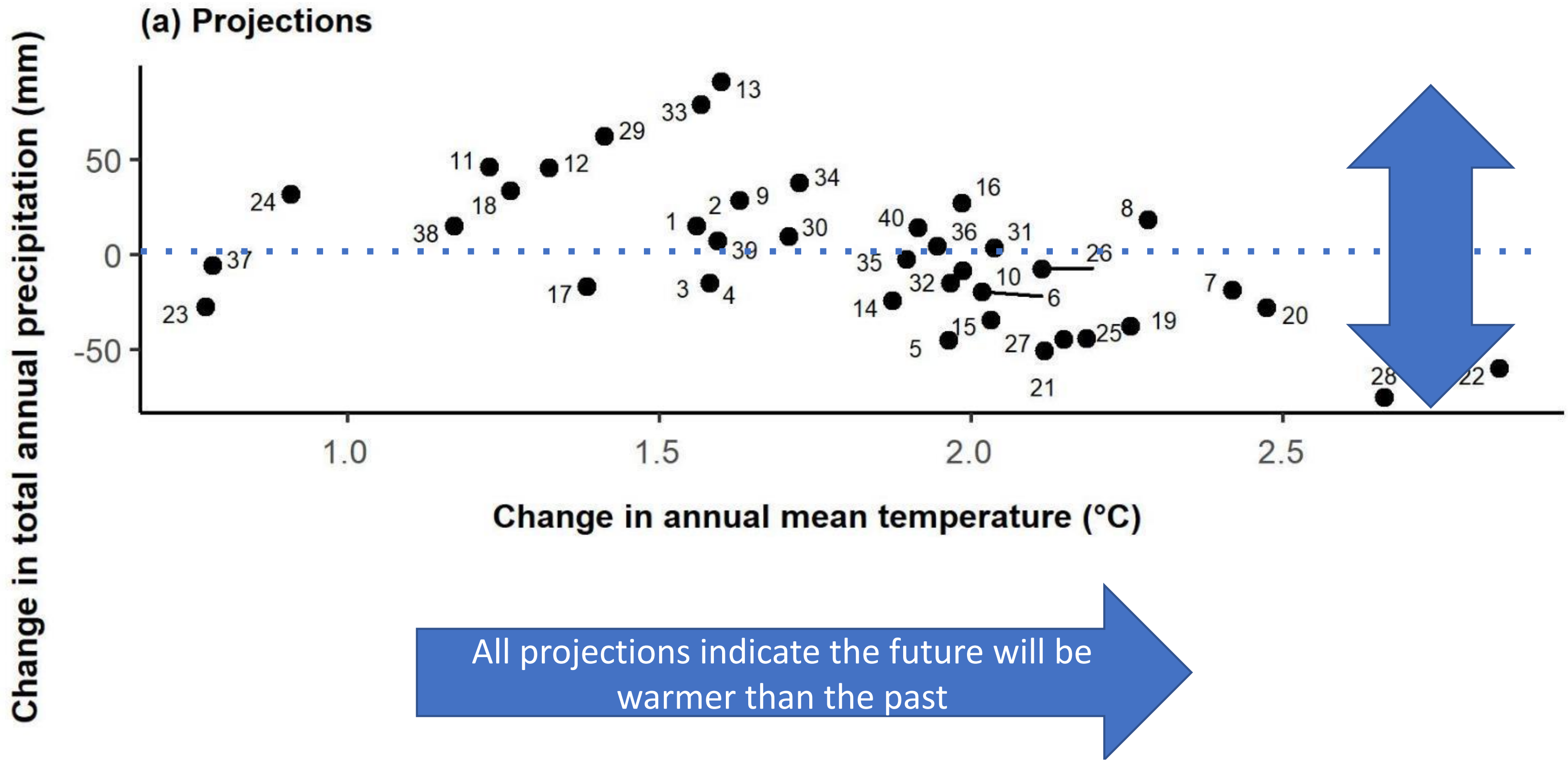
20 GCMs x 2 RCPs = 40 projections

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



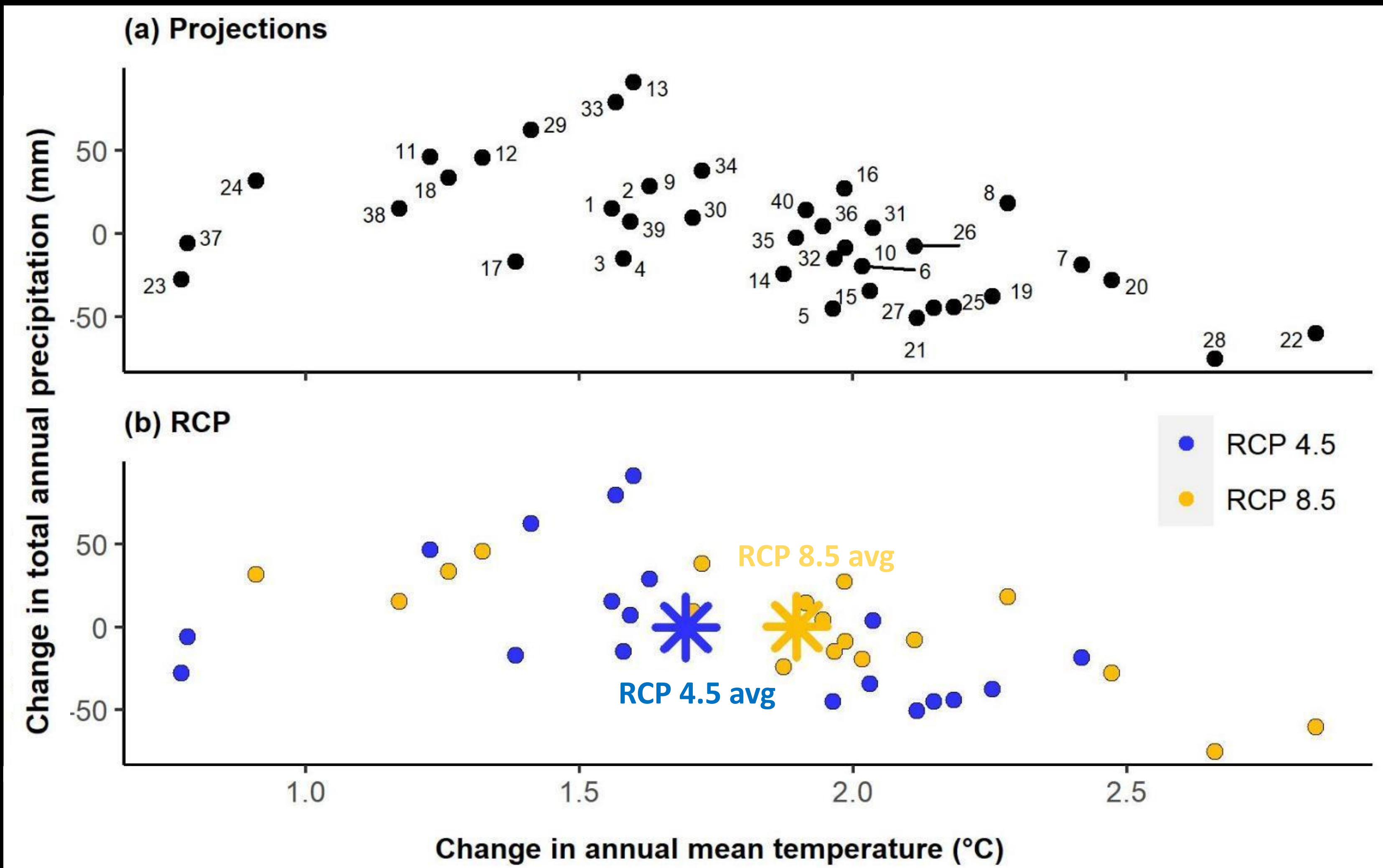


Number	GCM	RCP
1	bcc-csm1-1-m	4.5
2	bcc-csm1-1-m	8.5
3	bcc-csm1-1	4.5
4	bcc-csm1-1	8.5
5	BNU-ESM	4.5
6	BNU-ESM	8.5
7	CanESM2	4.5
8	CanESM2	8.5
9	CCSM4	4.5
10	CCSM4	8.5
11	CNRM-CM5	4.5
12	CNRM-CM5	8.5
13	CSIRO-Mk3-6-0	4.5
14	CSIRO-Mk3-6-0	8.5
15	GFDL-ESM2G	4.5
16	GFDL-ESM2G	8.5
17	GFDL-ESM2M	4.5
18	GFDL-ESM2M	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

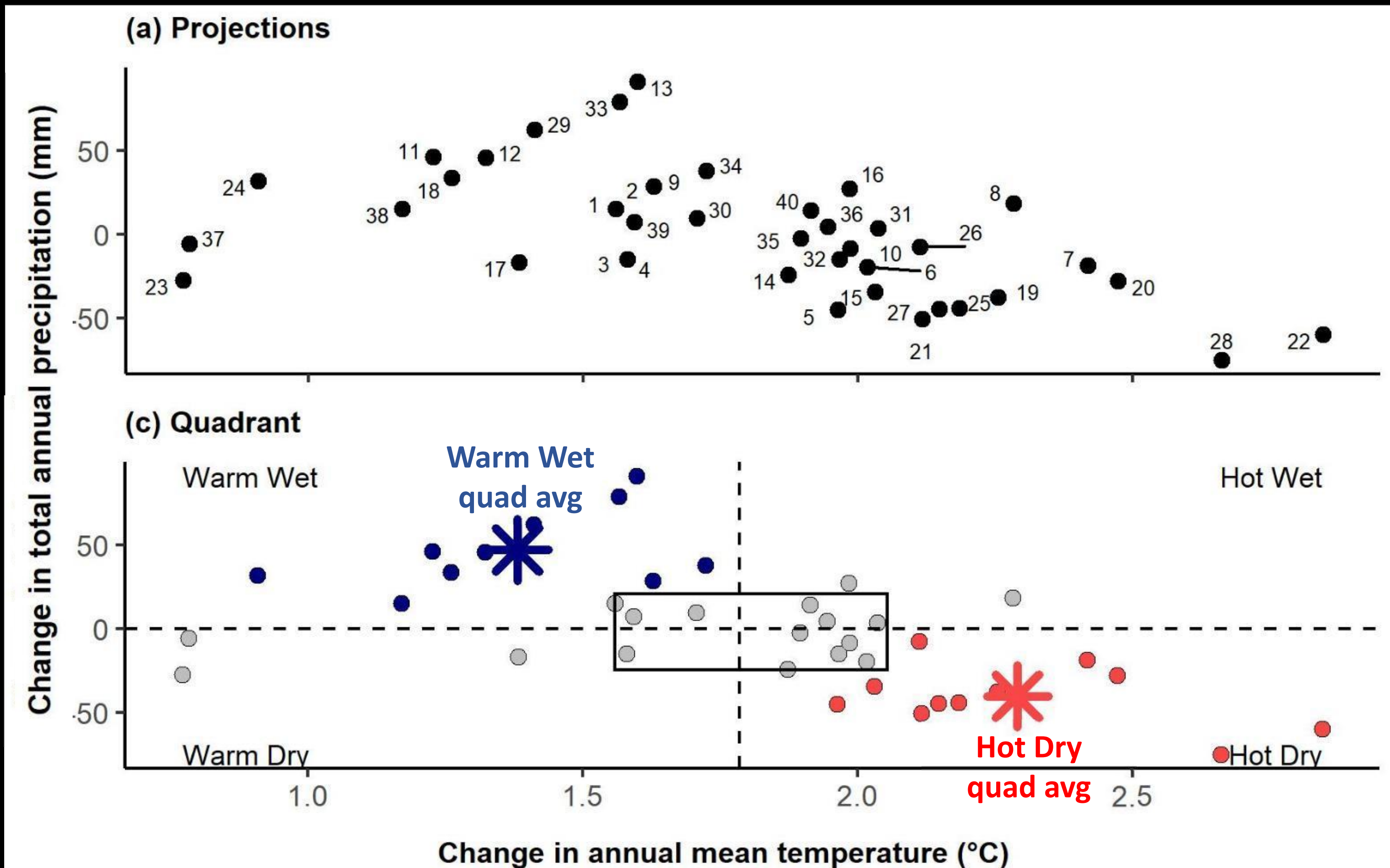
Approach 1: climate futures based on Representative Concentration Pathways (RCPs)

- 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



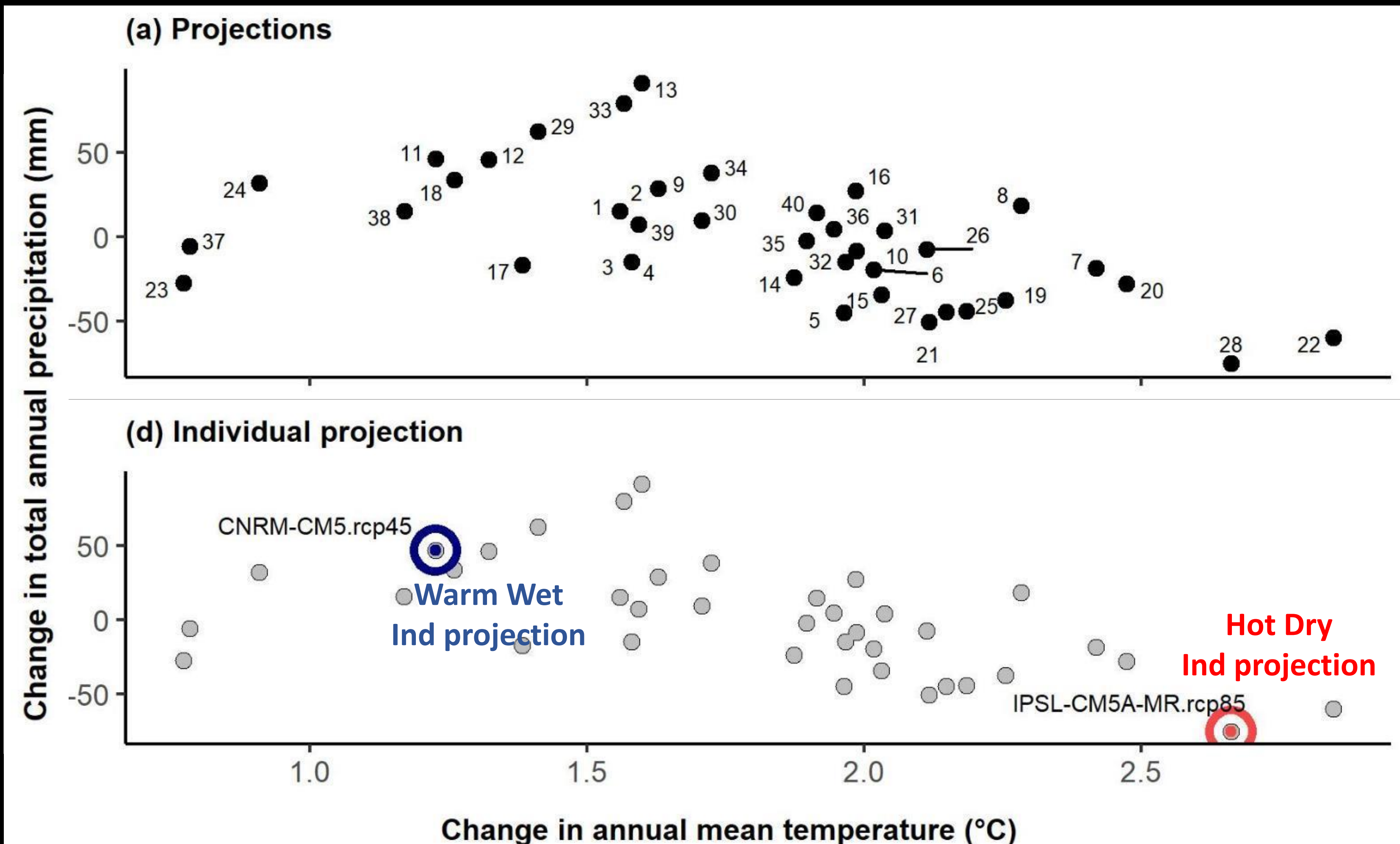
Approach 2: Quadrant-average based climate futures; 2040



"Warm Wet" – best case CF

"Hot Dry" – worst case CF

Approach 3: Individual projection based climate futures; 2040



"Warm Wet" – best case CF

"Hot Dry" – worst case CF

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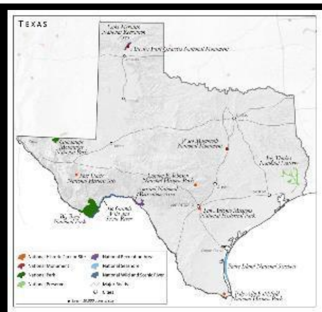
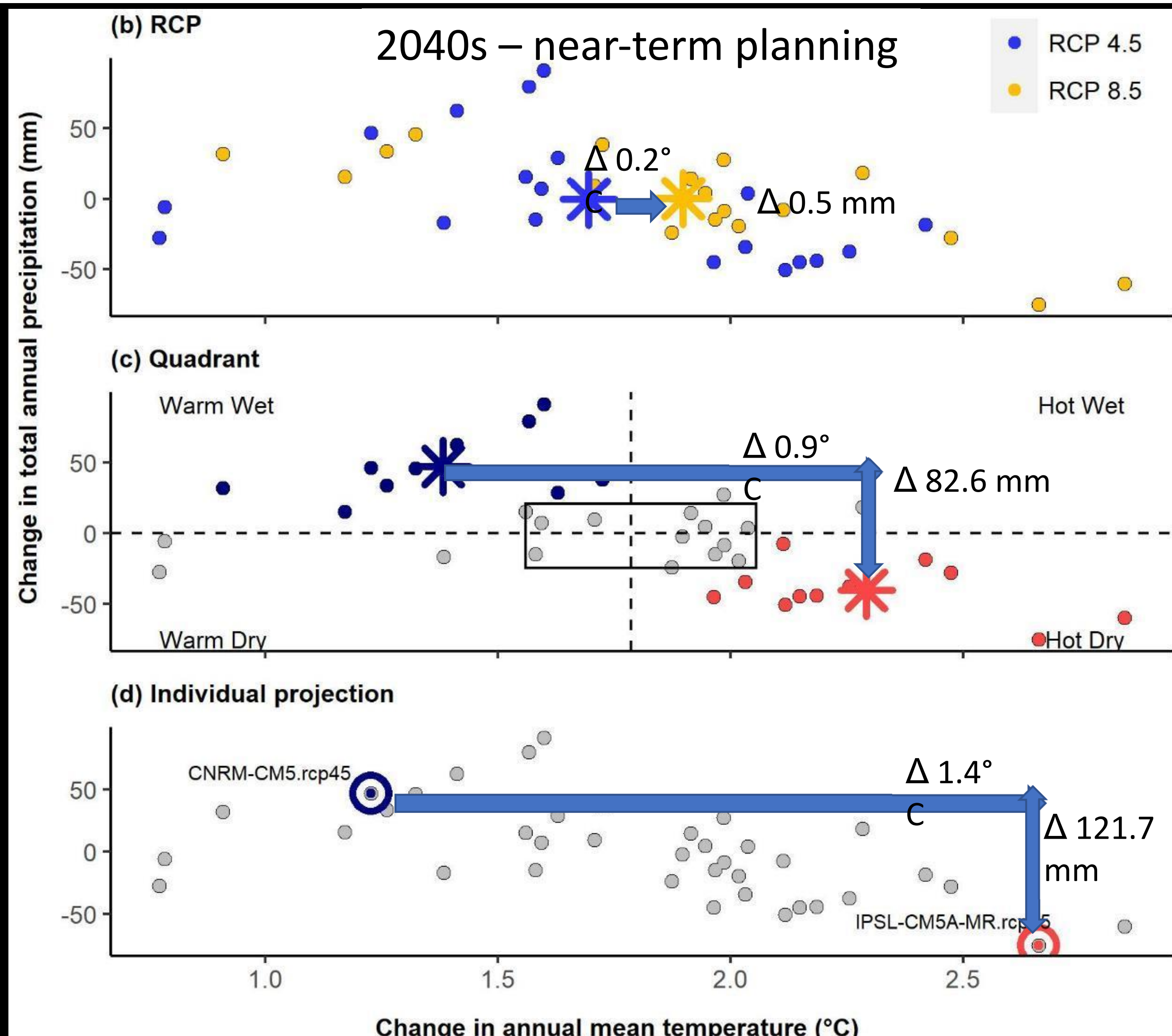


Individual projections and quadrant averages capture a much greater range of uncertainty than RCPs in the 2040s



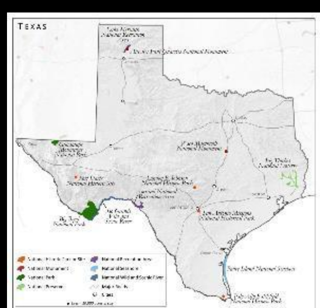
Comparing CF approaches for capturing the range of uncertainty over three time periods

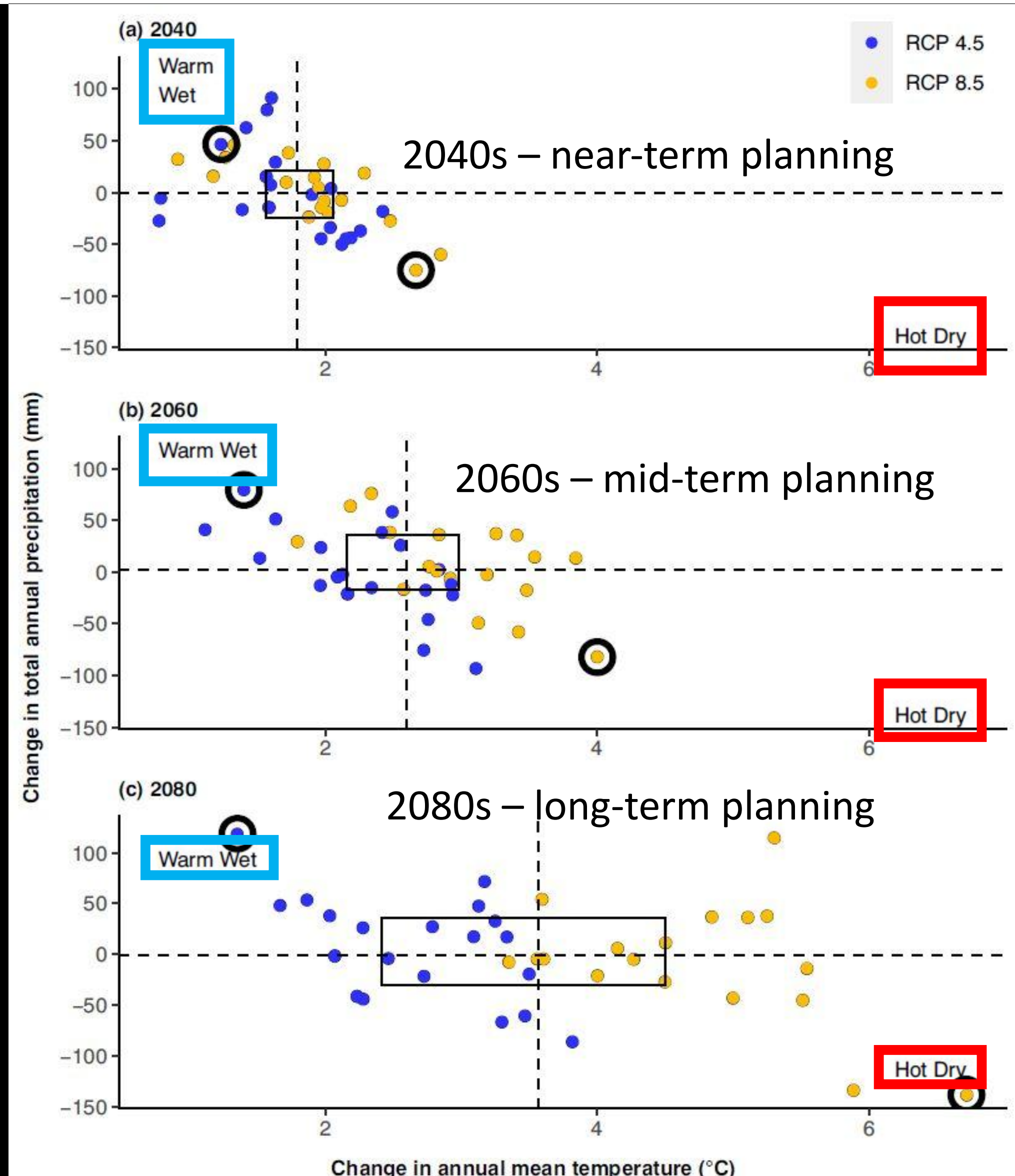
"RCP 4.5" – middle of the road emissions CF

"RCP 8.5" – high end emissions CF

"Warm Wet" – best case CF

"Hot Dry" – worst case CF





Temperature:

2040

Ind projection
Δ 1.4° C

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

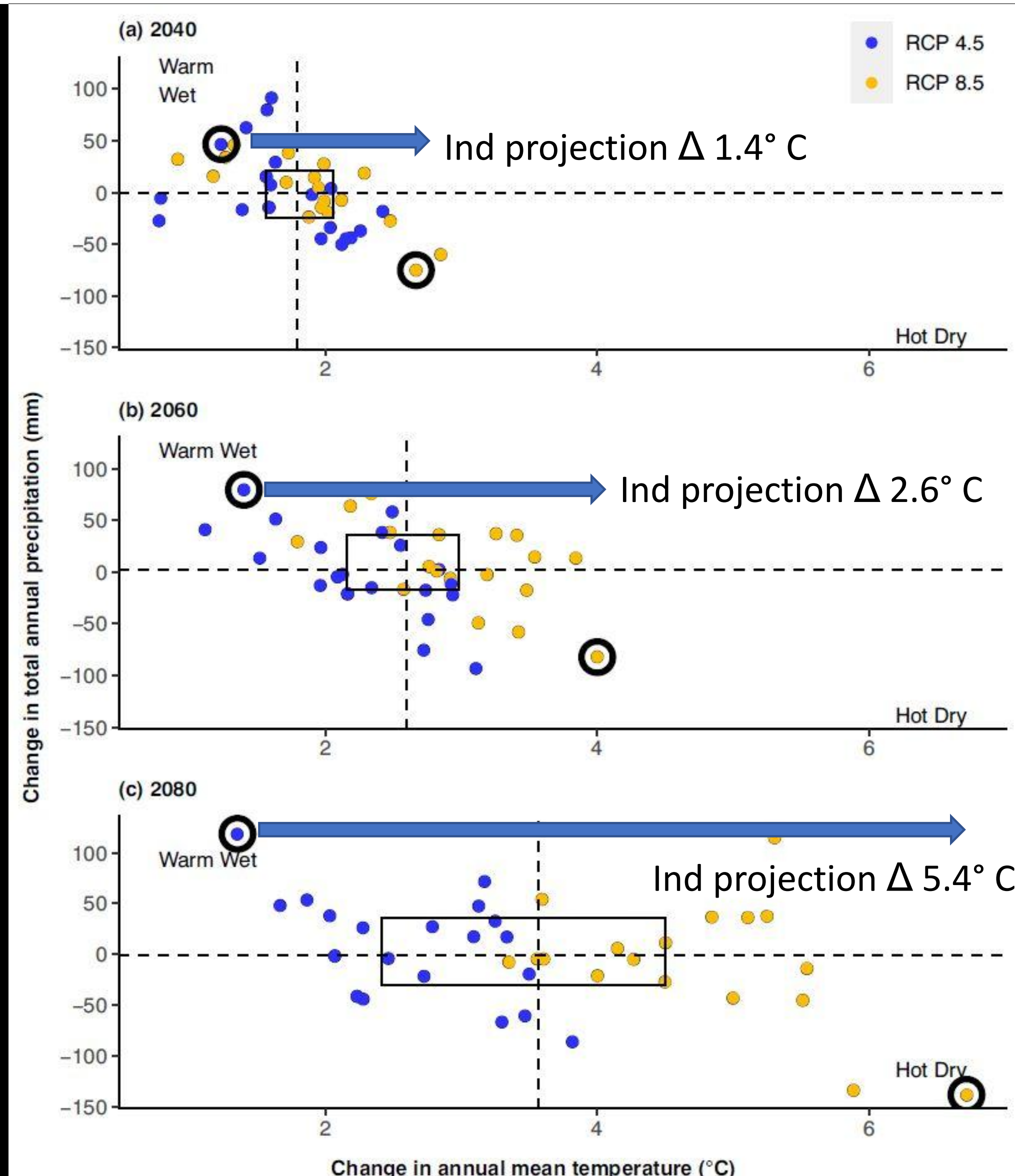
Plausible, divergent, relevant

2060

Ind projection
Δ 2.6° C

2080

Ind projection
Δ 5.4° C



Precipitation:

2040

Ind projection
Δ 121.7 mm

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

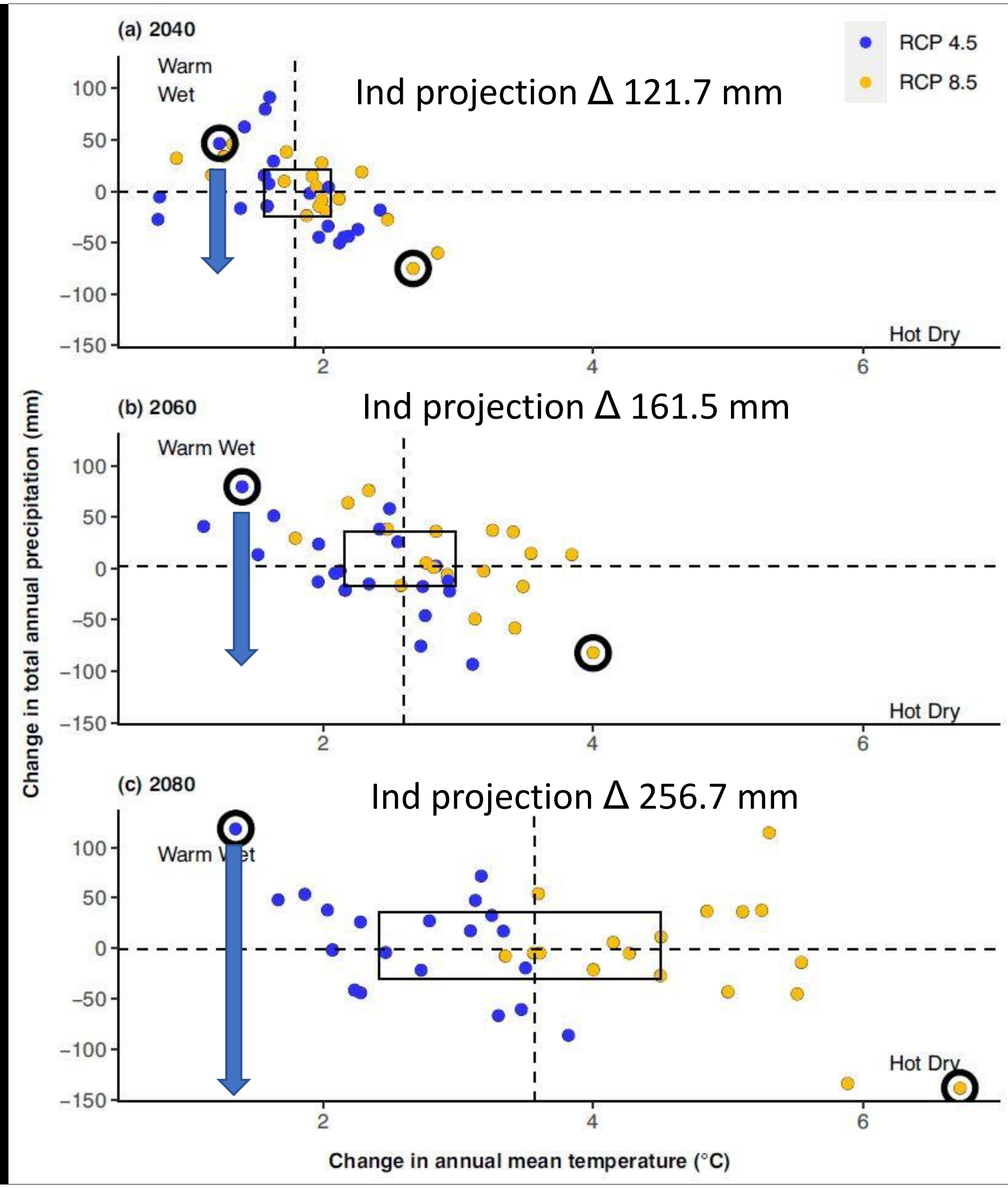
Plausible, divergent, relevant

2060

Ind projection
Δ 161.5 mm

2080

Ind projection
Δ 256.7 mm



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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'.

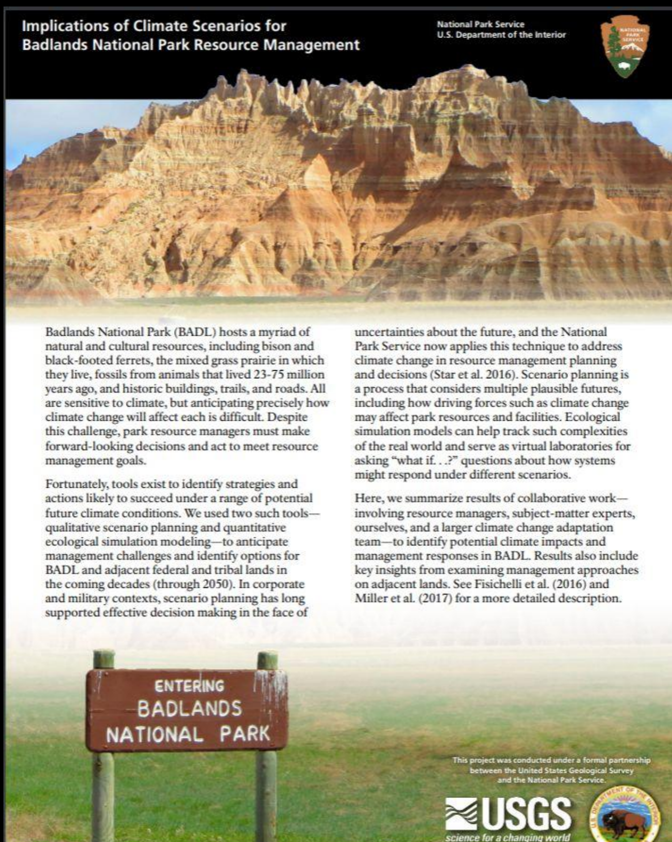
- Mitigation emphasis: RCP approach
- Adaptation emphasis: Quadrant or Individual projection approach

- 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


Implications of Climate Scenarios for Badlands National Park Resource Management

National Park Service
U.S. Department of the Interior

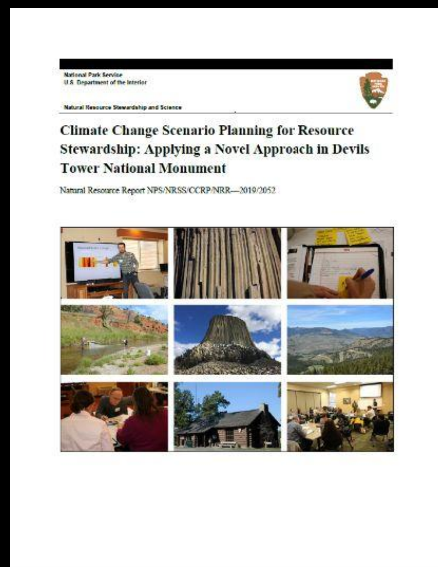
Badlands National Park (BADL) hosts a myriad of natural and cultural resources, including bison and black-footed ferrets, the mixed grass prairie in which they live, fossils from animals that lived 23-75 million years ago, and historic buildings, trails, and roads. All are sensitive to climate, but anticipating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

Fortunately, tools exist to identify strategies and actions likely to succeed under a range of potential future climate conditions. We used two 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, including how driving forces such as climate change may affect park resources 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 Fisichelli et al. (2016) and Miller et al. (2017) for a more detailed description.

This project was conducted under a formal partnership between the United States Geological Survey and the National Park Service.

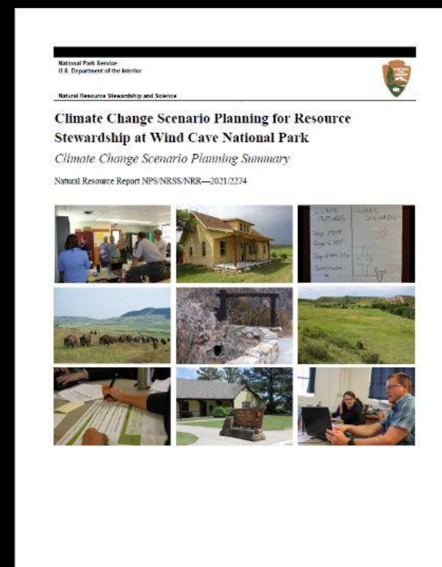
USGS
science for a changing world


National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

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

Natural Resource Report NPS/NRSS/CCRP/NRR—2019/2052

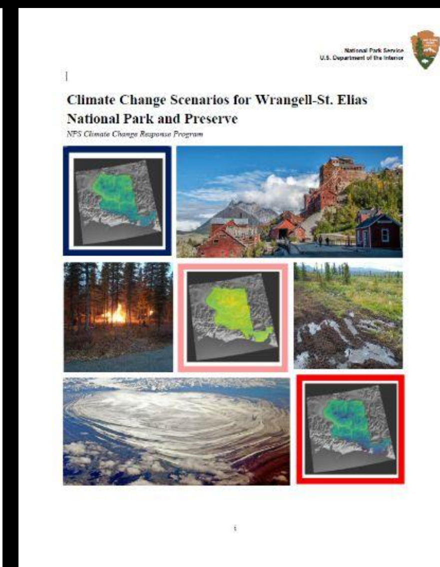

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

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

Climate Change Scenario Planning Summary

Natural Resource Report NPS/NRSS/NRR—2021/2274


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

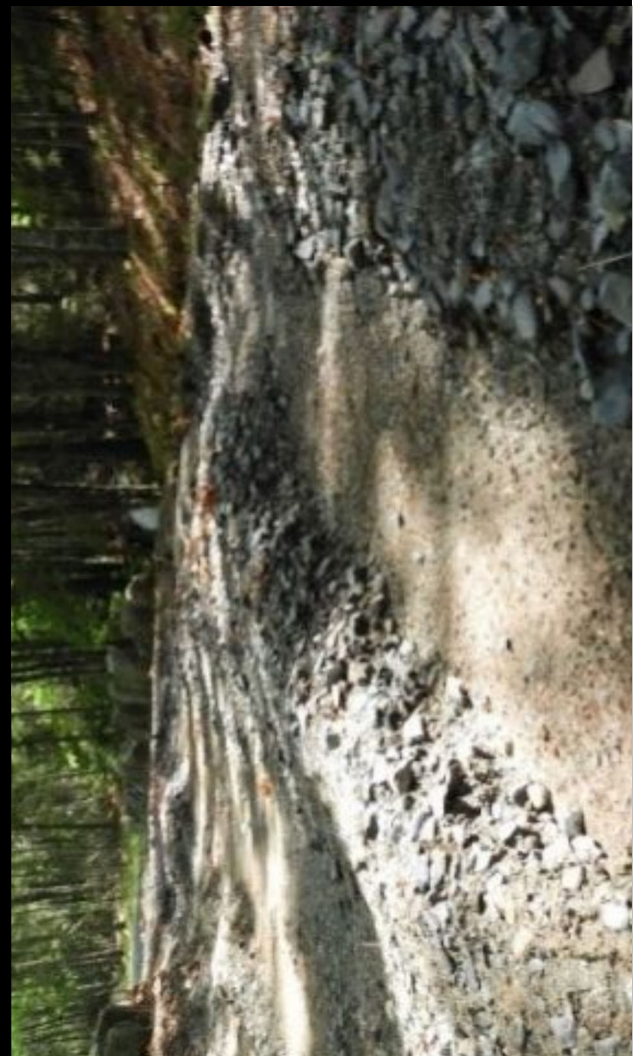
- Choosing among the different approaches depends on the application and available resources

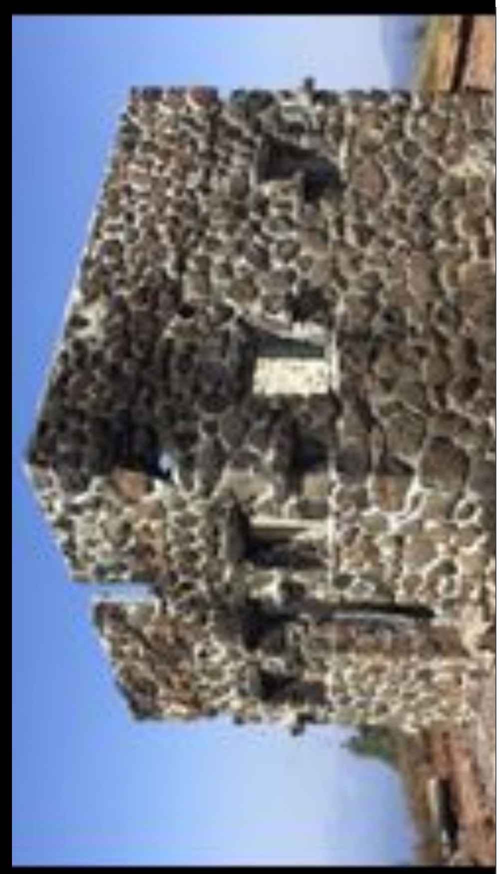
- NPS has had success using CFs in scenario planning processes for a wide variety of management contexts

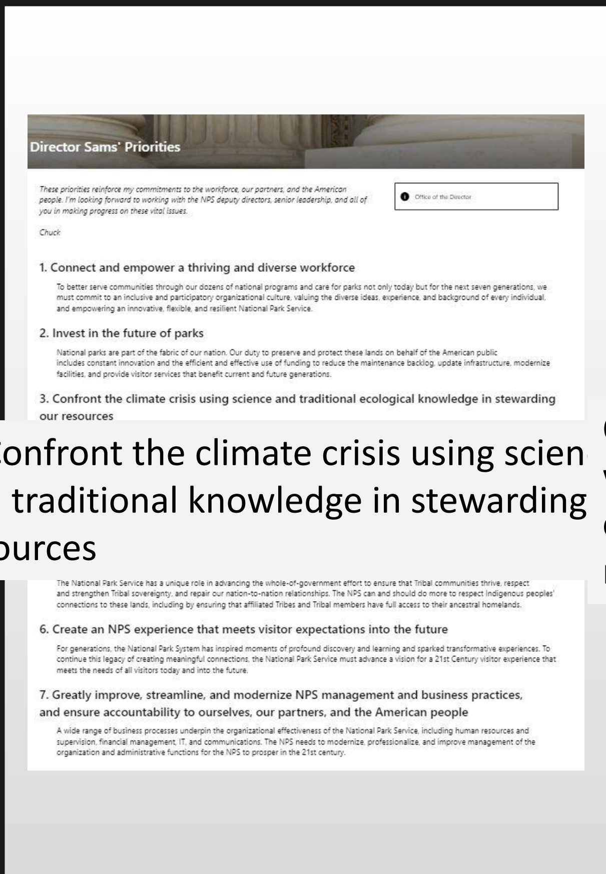
A story of climate futures in two parts

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

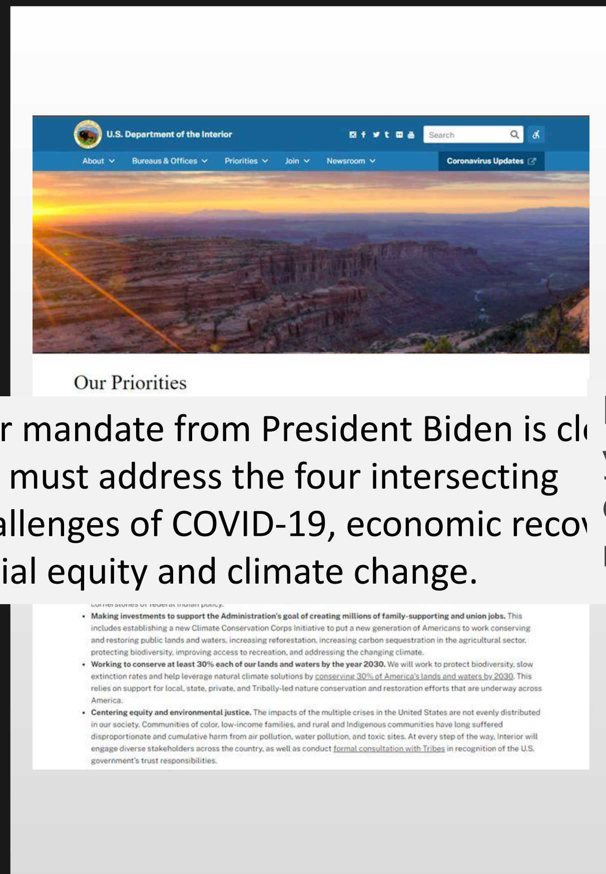
Chapter II. 2020s: Developing methods and tools to scale the use of scenarios to meet growing demand



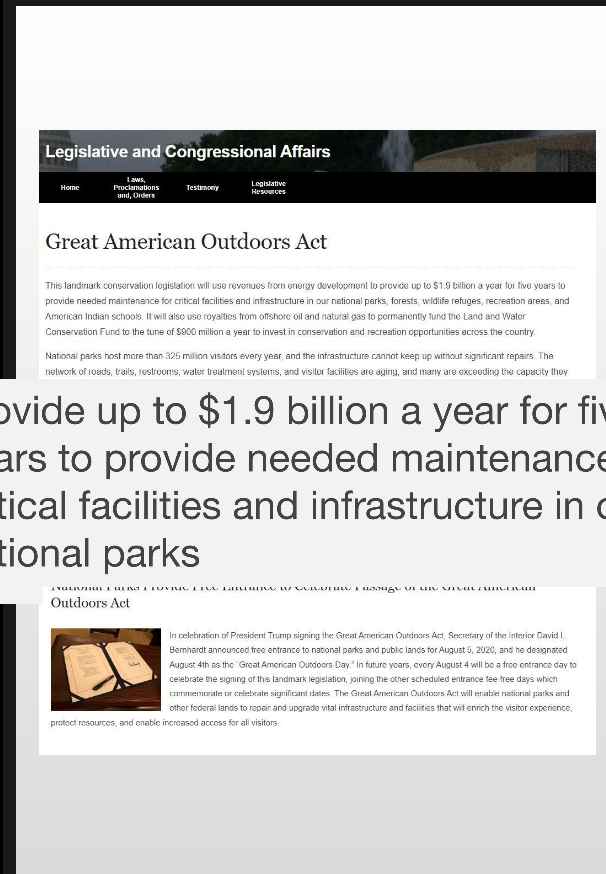




3. Confront the climate crisis using scien and traditional knowledge in stewarding resources

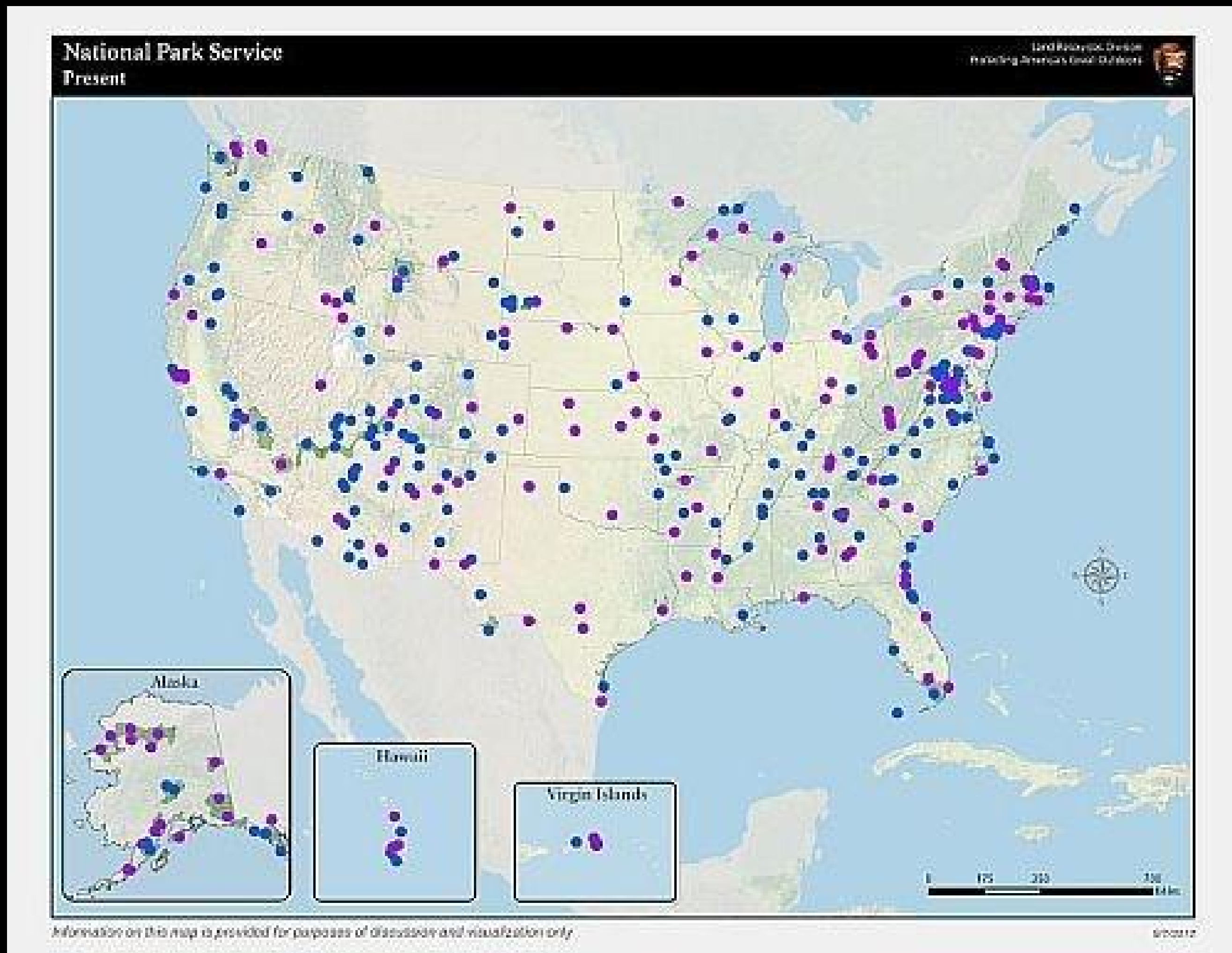


Our mandate from President Biden is cl we must address the four intersecting challenges of COVID-19, economic reco racial equity and climate change.

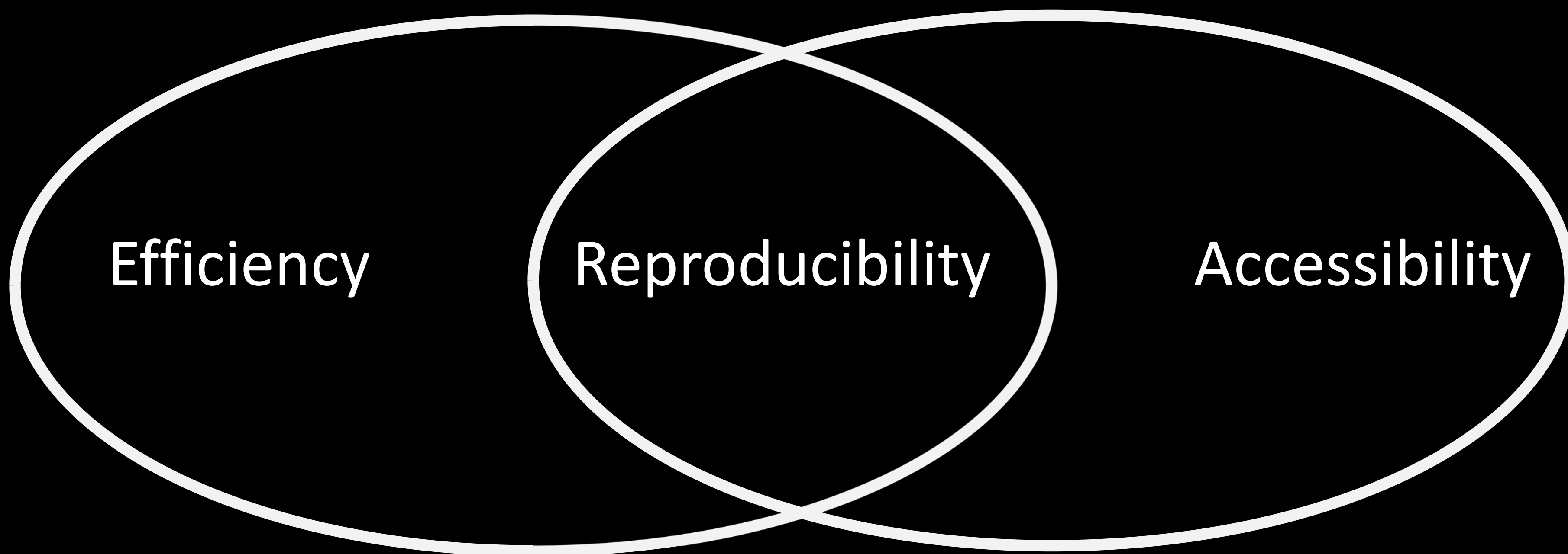


Provide up to $1.9 billion a year for five years to provide needed maintenance for critical facilities and infrastructure in our national parks

New challenges: scaling up CF creation

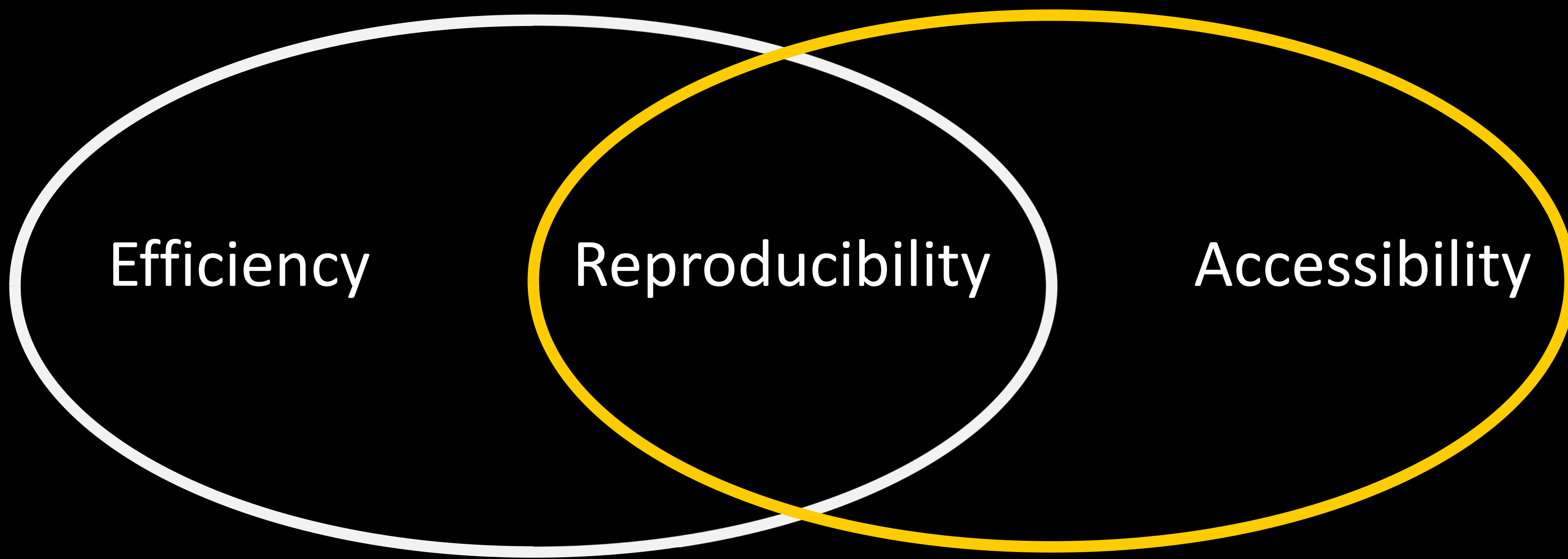


Reproducible Climate Futures



- 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

Reproducible Climate Futures

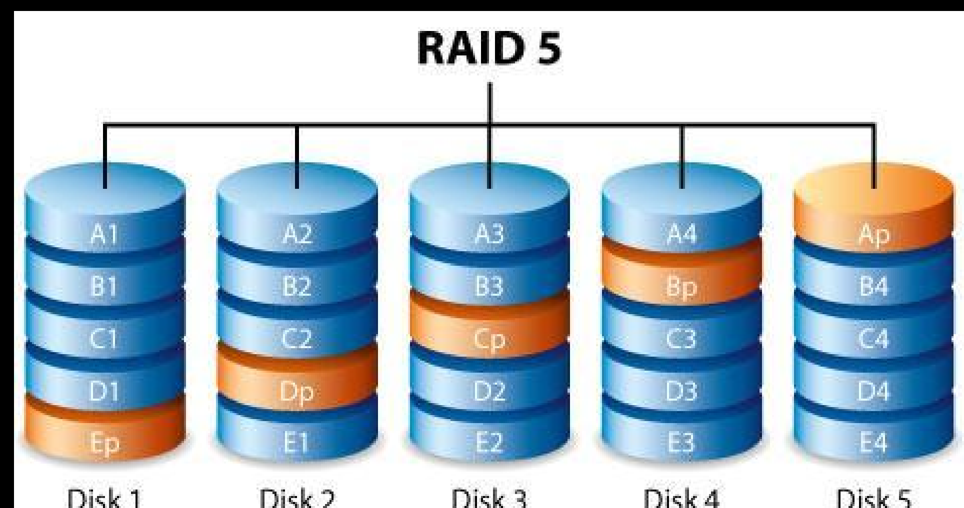


- Streamline workflow to increase efficiency of climate future production
- Design data management processes that enable reproducible science
- Develop tools to increase accessibility and scale analysis

Barriers in climate future accessibility

1. Data access

2. Generating climate futures

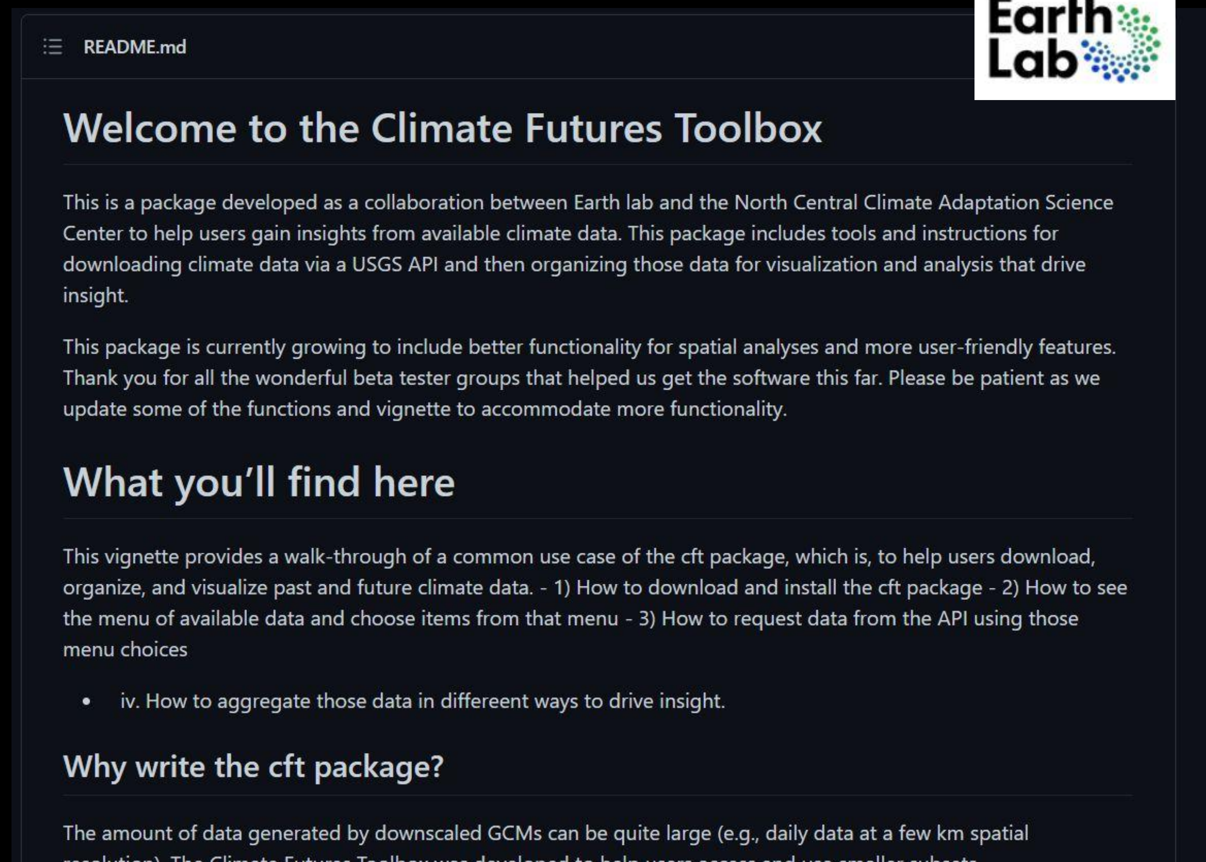


Data Access Solution:

Climate Futures Toolkit (cft) R package

North Central Climate Adaptation Science Center

Earth Lab



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 differeent ways to drive insight.

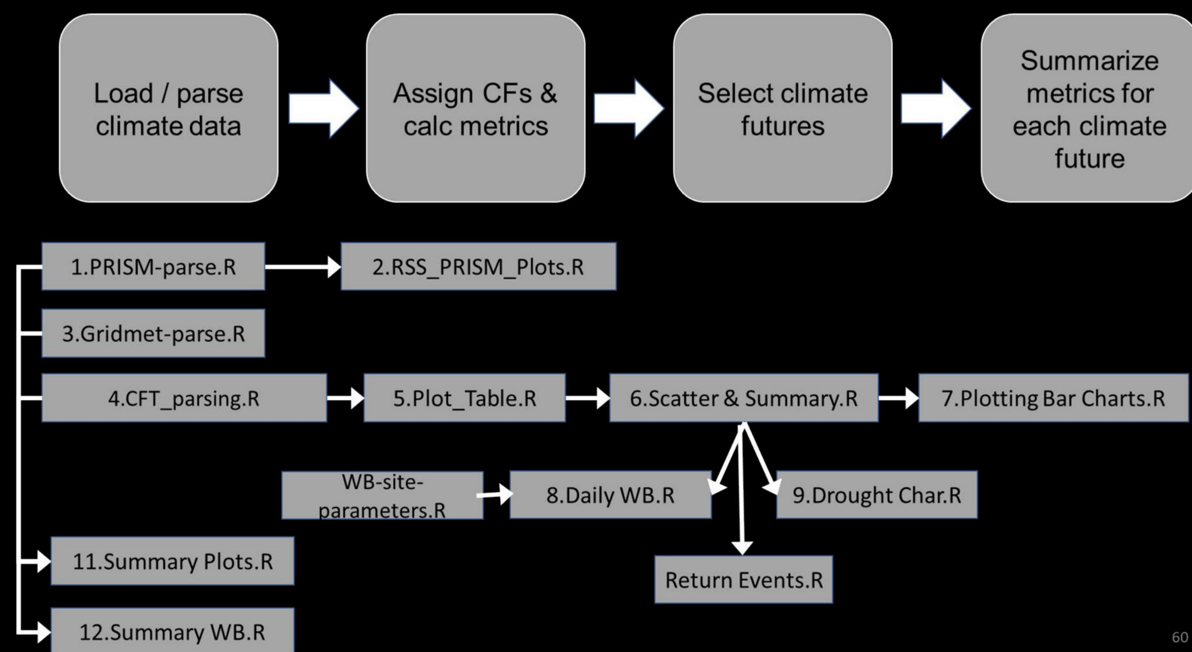
Why write the cft package?

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)

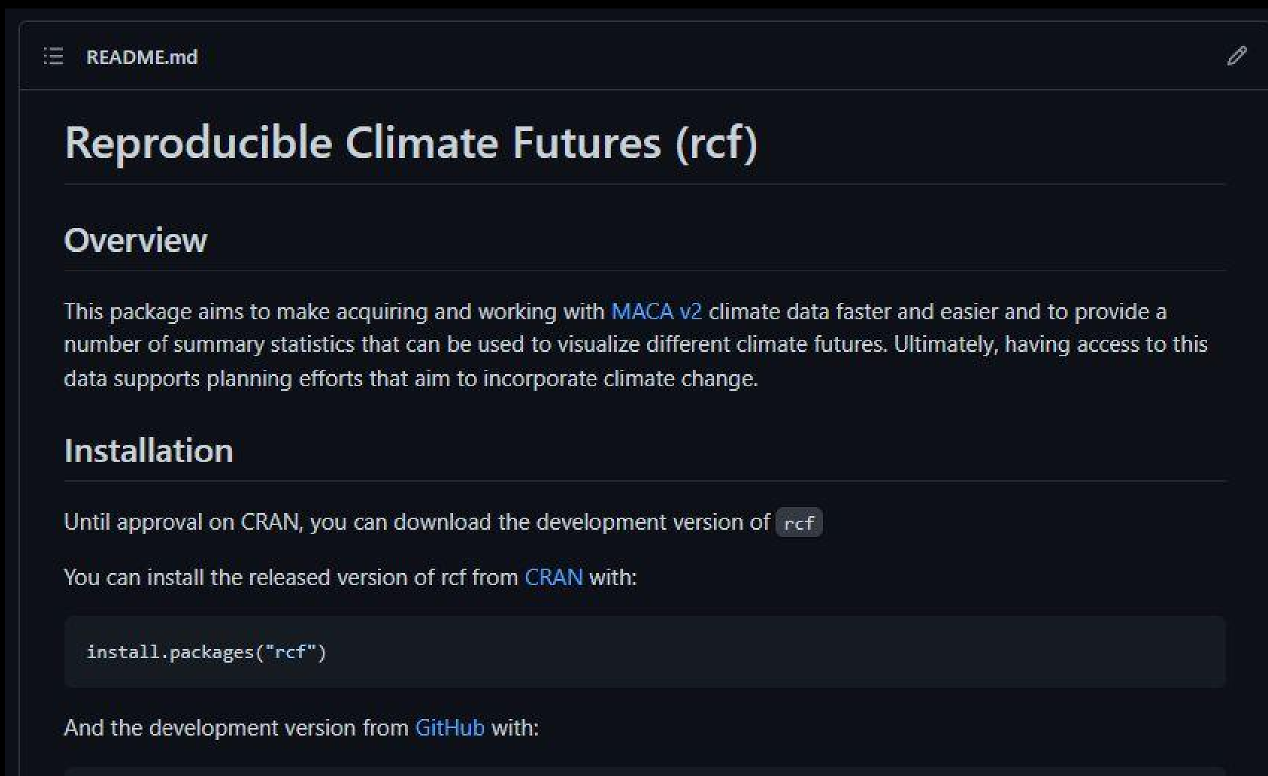
- Near term planning: Individual projection and quadrant approaches capture broader range of uncertainty than the RCP approach

- 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:

National Park Service
U. S. Department of the Interior
Climate Change Response Program

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`

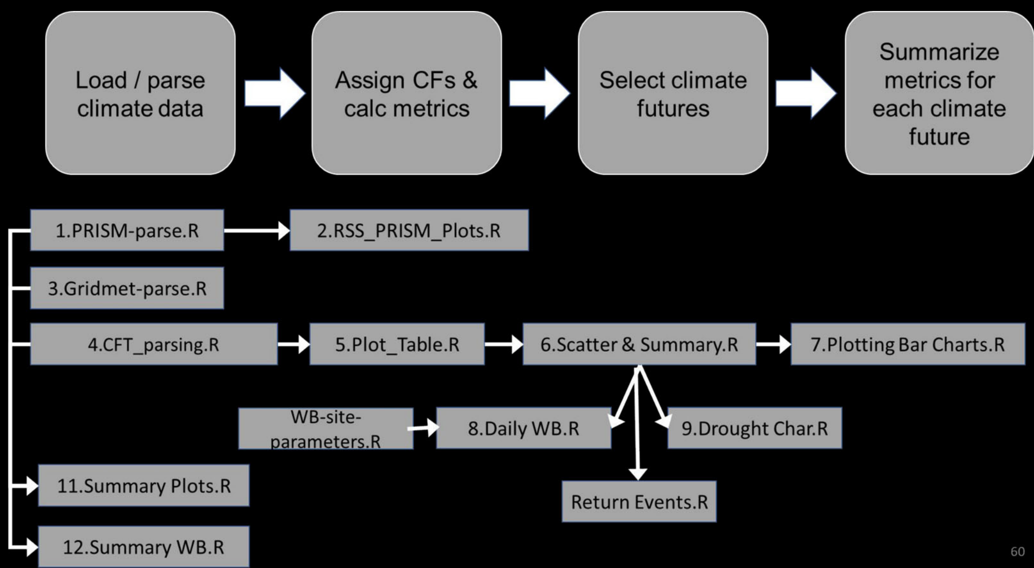
You can install the released version of rcf from CRAN with:

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

And the development version from GitHub with:

Functions for creating quadrant and individual climate futures

rcf Package



60

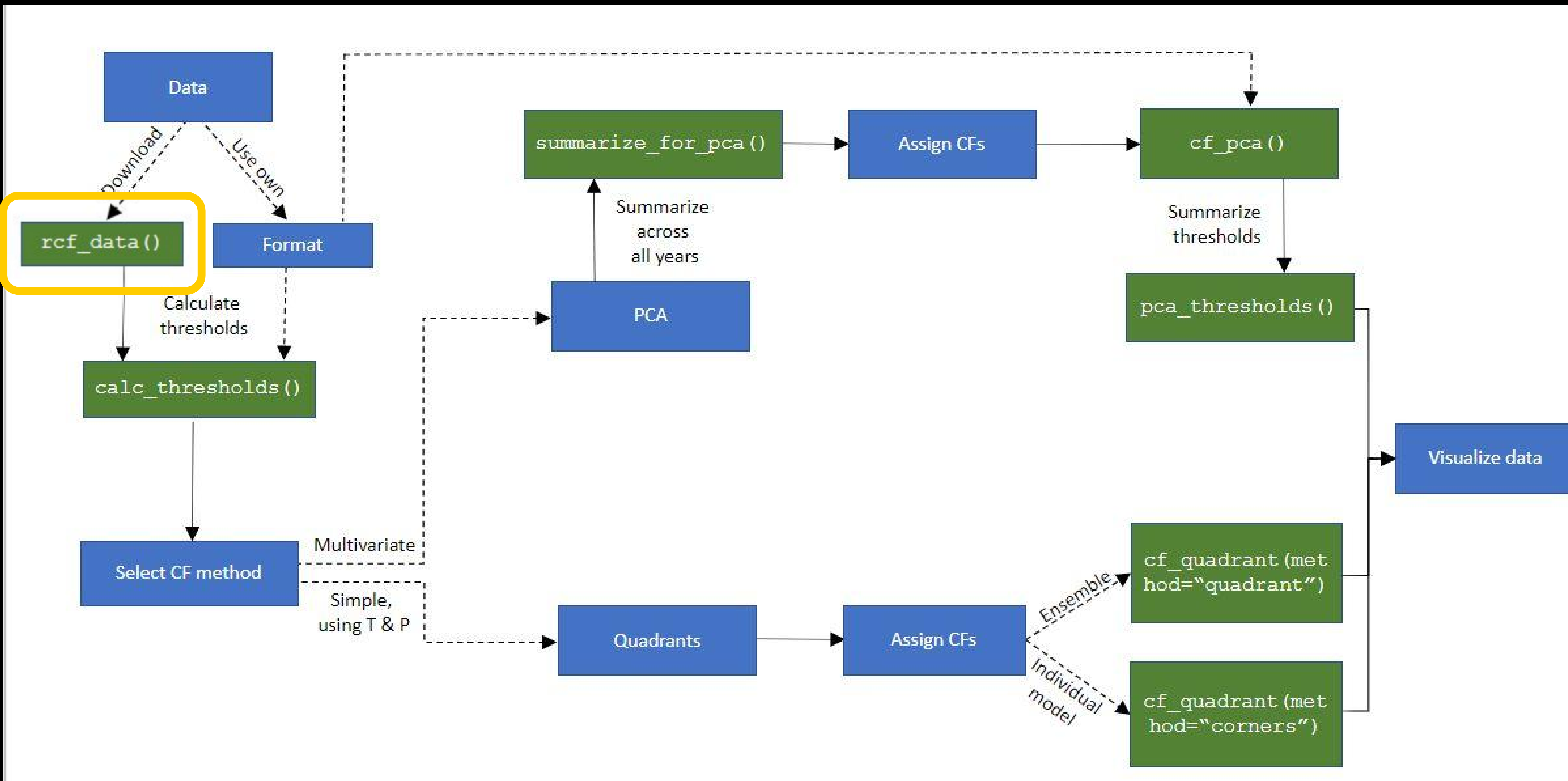
rcf_data()

calc_thresholds()

cf_quadrant()

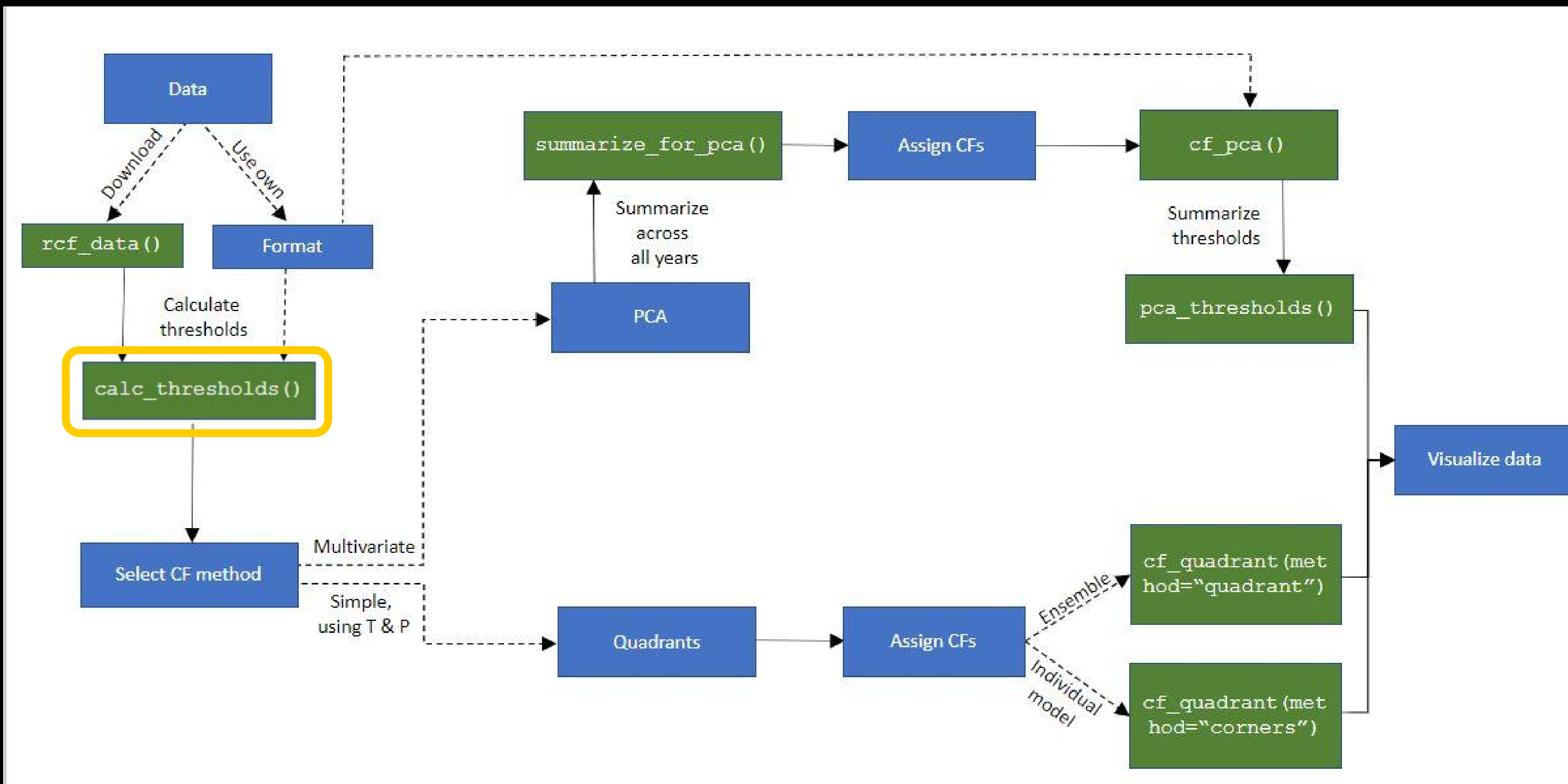
cf_pca()

pca_thresholds()


Data
Download
Use own
rcf_data()
Format
Calculate thresholds
calc_thresholds()
Select CF method
Multivariate
Simple, using T & P
PCA
Summarize across all years
summarize_for_pca()
Assign CFs
cf_pca()
Summarize thresholds
pca_thresholds()
Quadrants
Assign CFs
Ensemble
Individual model
cf_quadrant(method="quadrant")
cf_quadrant(method="corners")
Visualize data

rcf_data()

Wrapper function for cft – downloads MACA data for location of interest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Assign CFs
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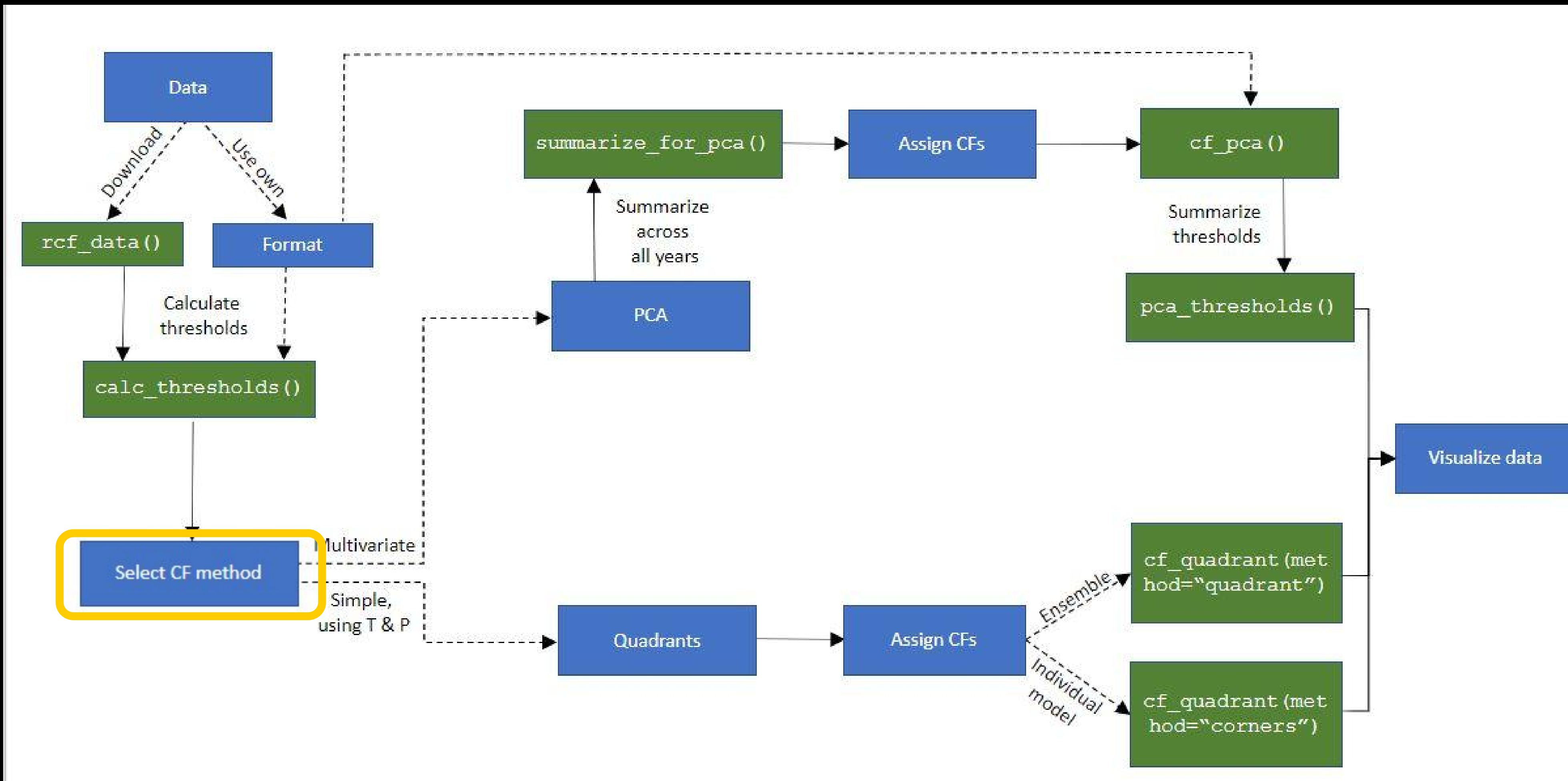
Summarize
thresholds
pca_thresholds()
Quadrants
Assign CFs
Ensemble
Individual
model
cf_quadrant(met
hod="quadrant")
cf_quadrant(met
hod="corners")
Visualize data

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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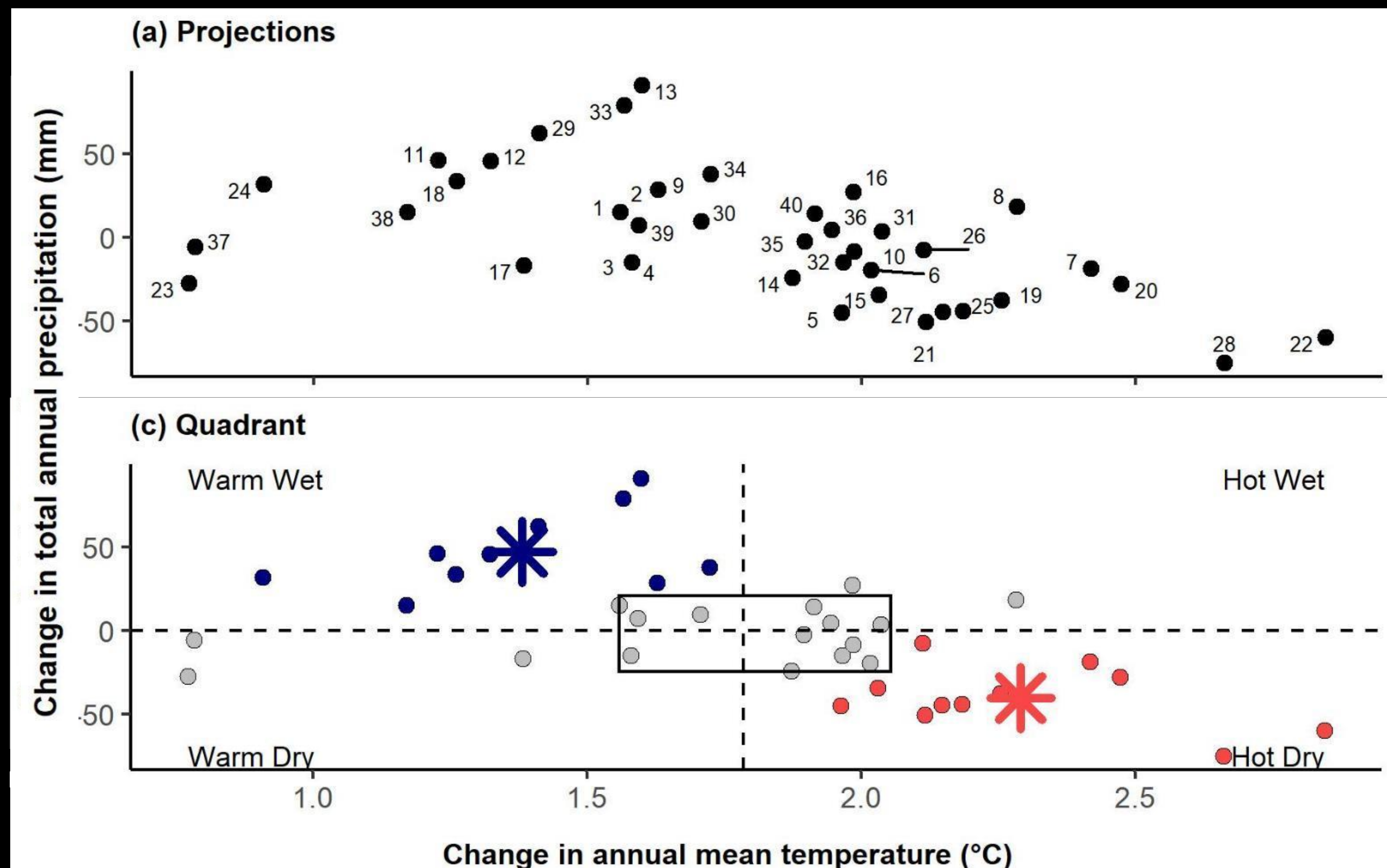
pca_thresholds()
Quadrants
Assign CFs
Ensemble
Individual
model
cf_quadrant(met
hod="quadrant")
cf_quadrant(met
hod="corners")
Visualize data

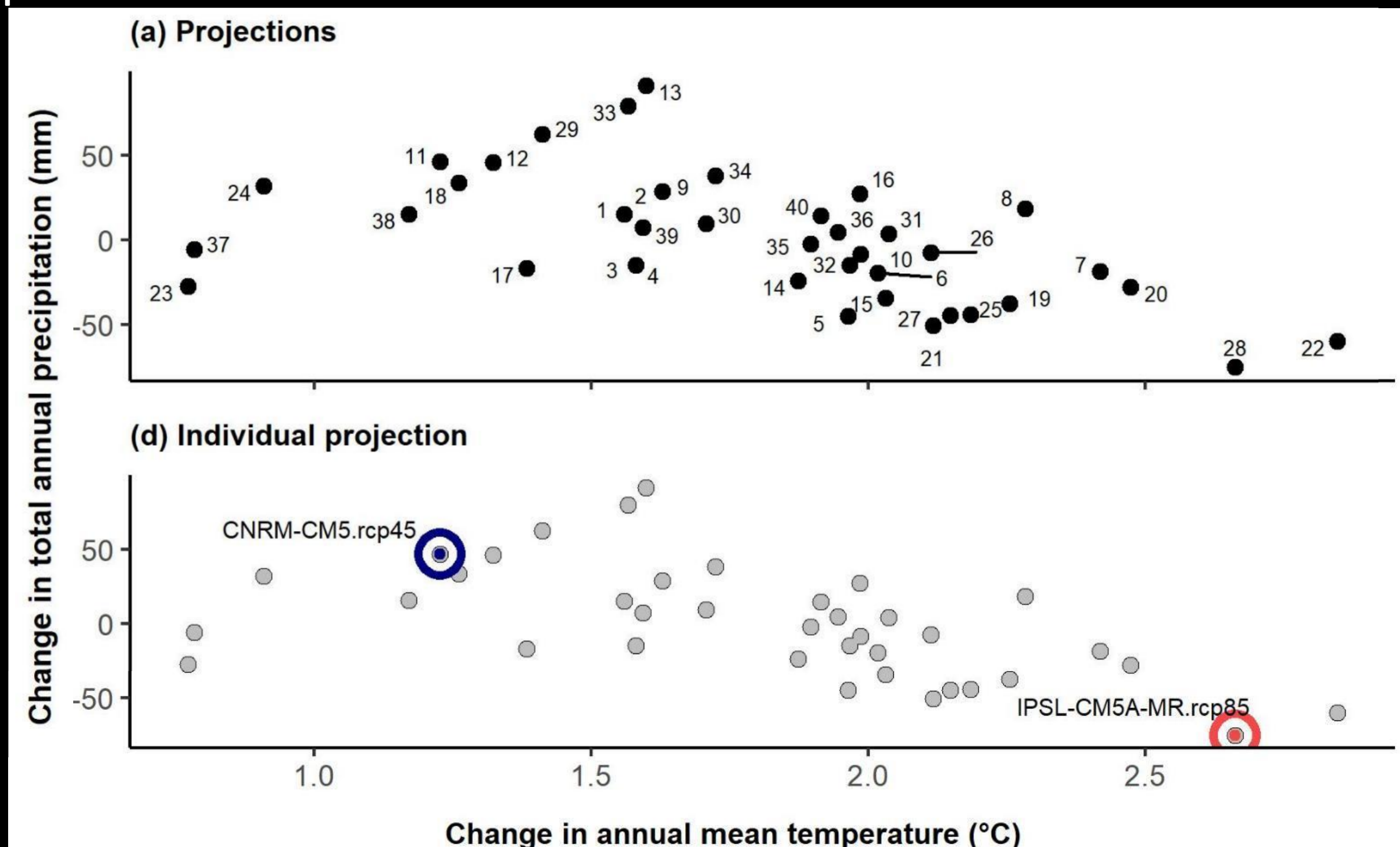
cf_quadrant()

Method = 'quadrant'



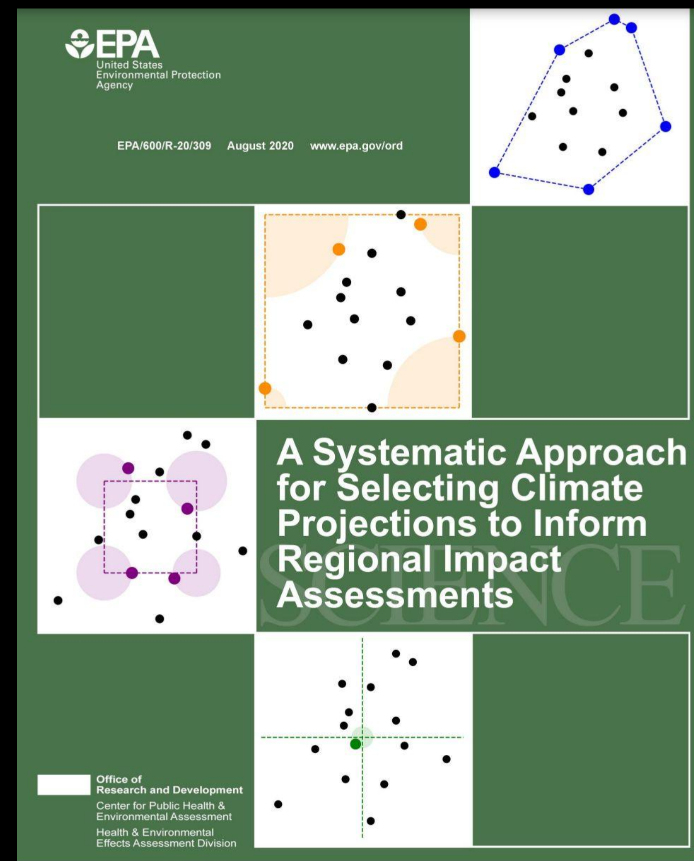
cf_quadrant()

Method = ‘individual’



Algorithms for selecting divergent individual climate future projections

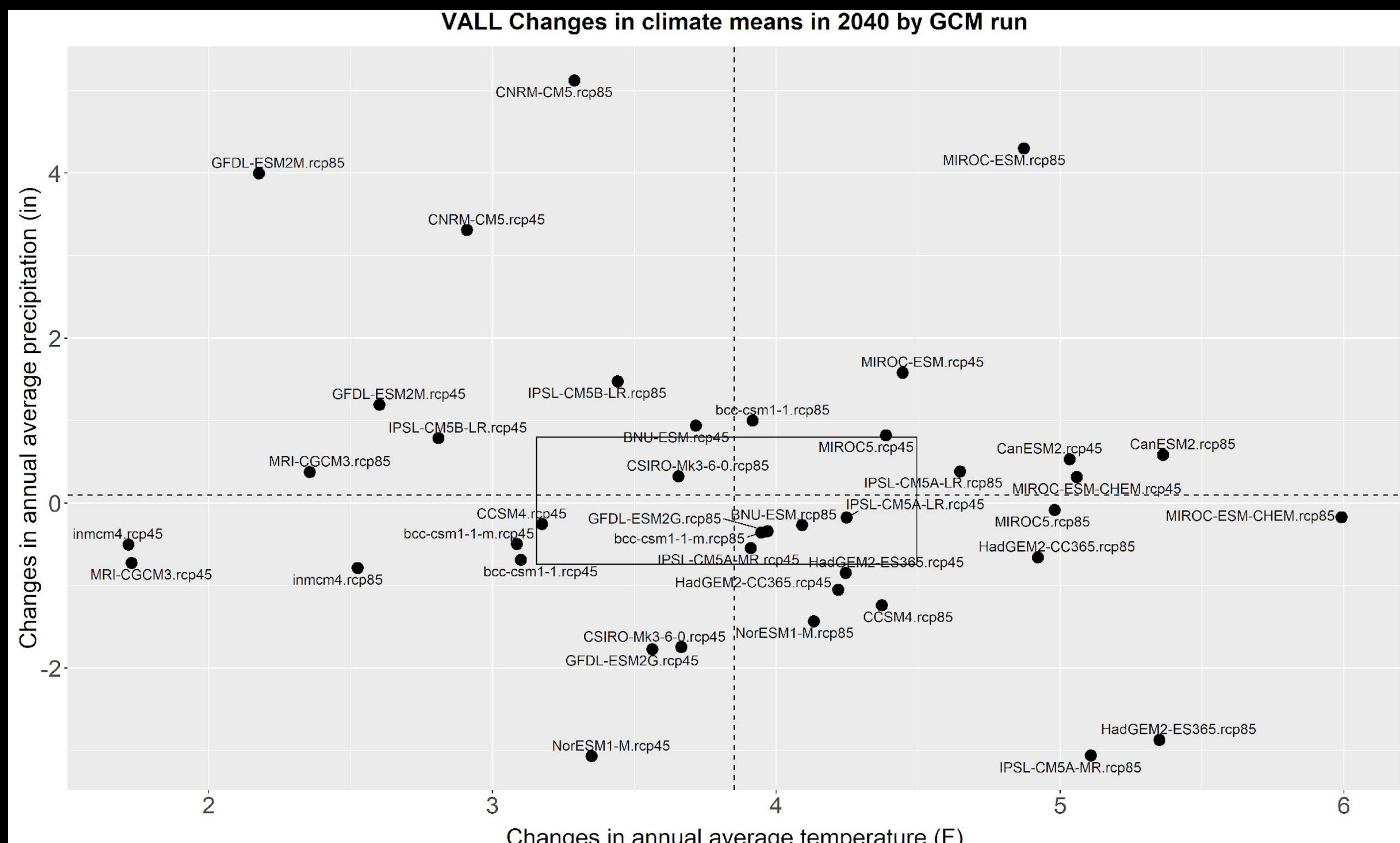
1. ‘ Corners’ method – bivariate selection



https://lasso.epa.gov/strategies

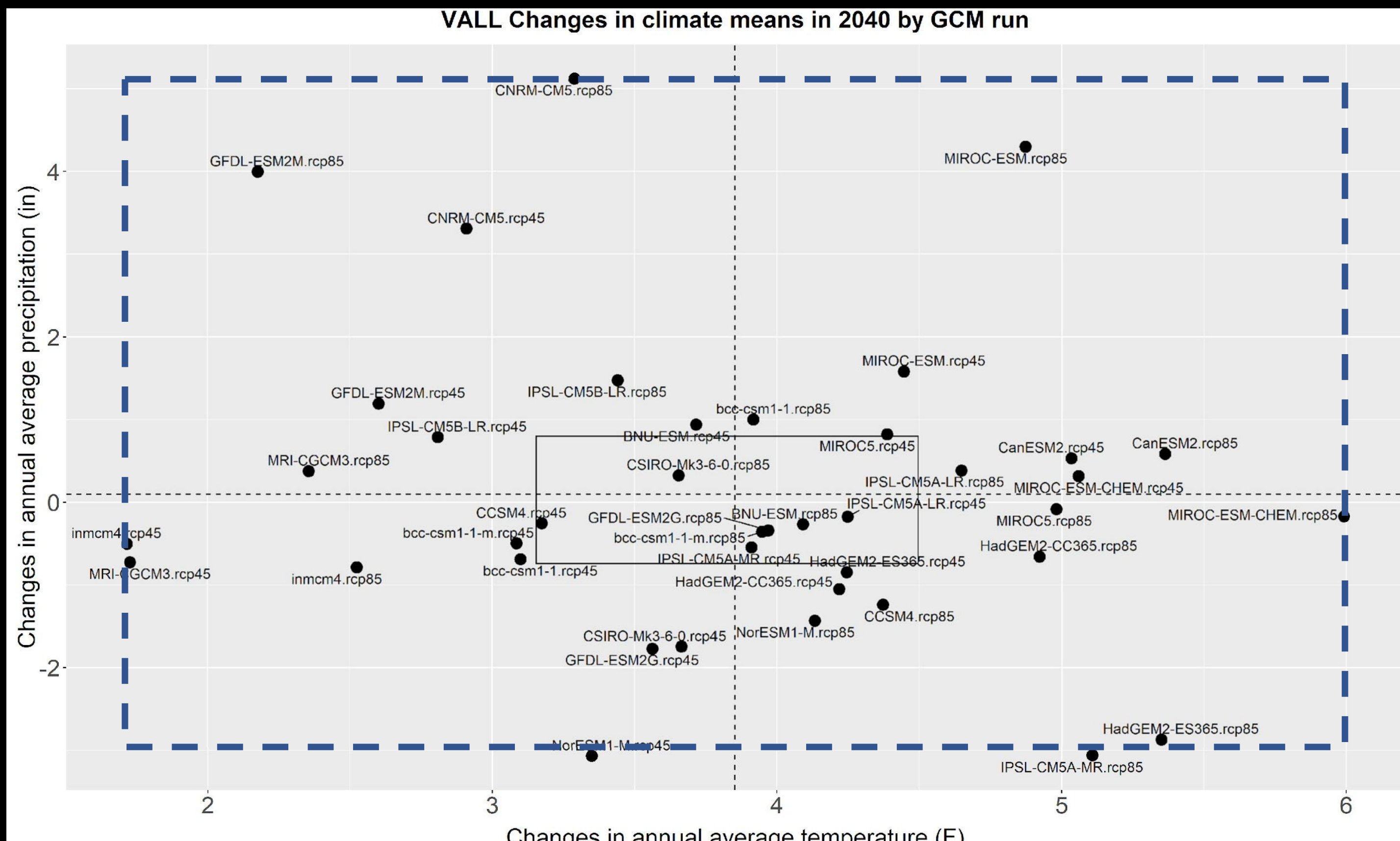
Algorithms for selecting divergent individual climate future projections

1. ‘ Corners’ method



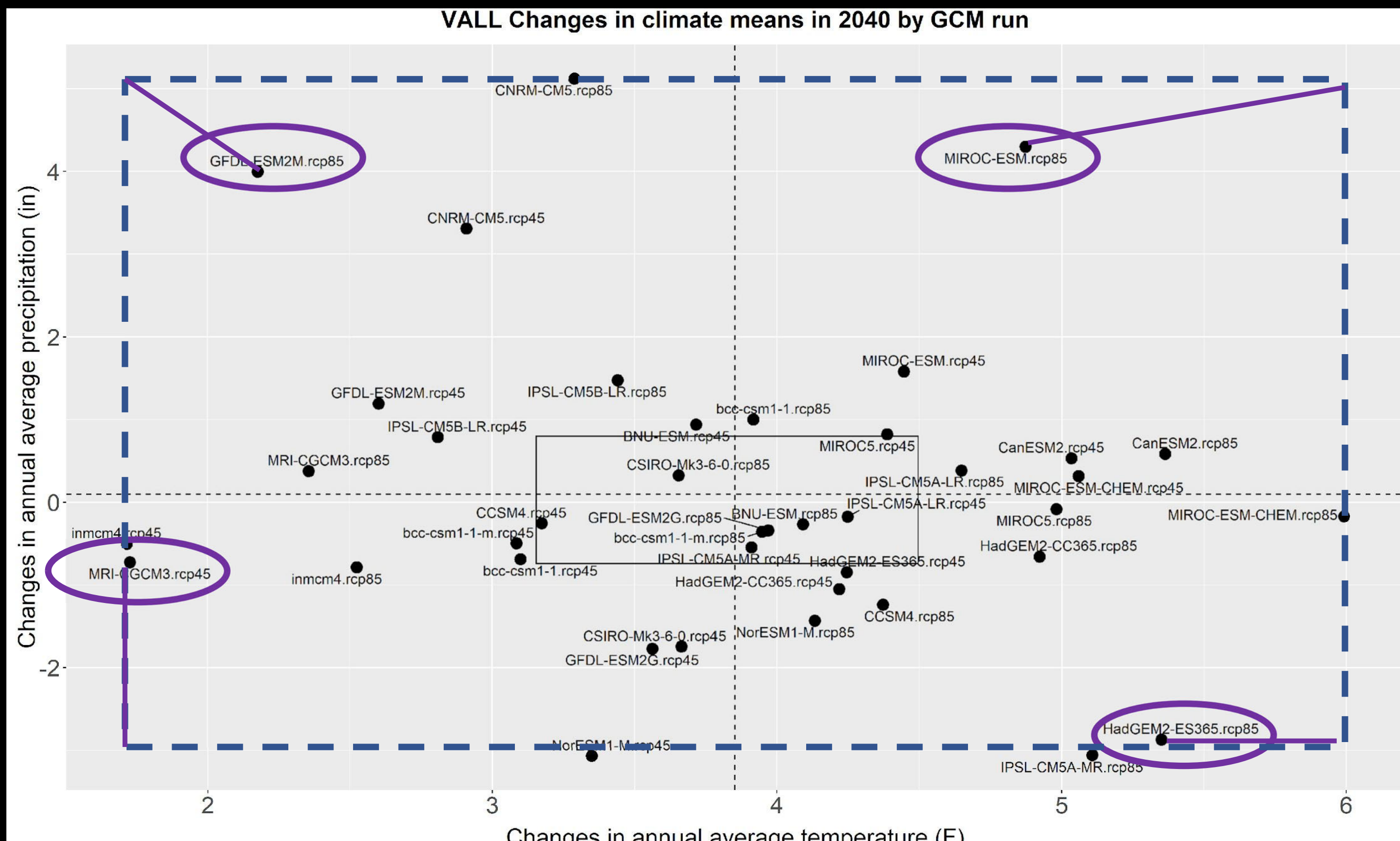
Algorithms for selecting divergent individual climate future projections

1. ‘ Corners’ method

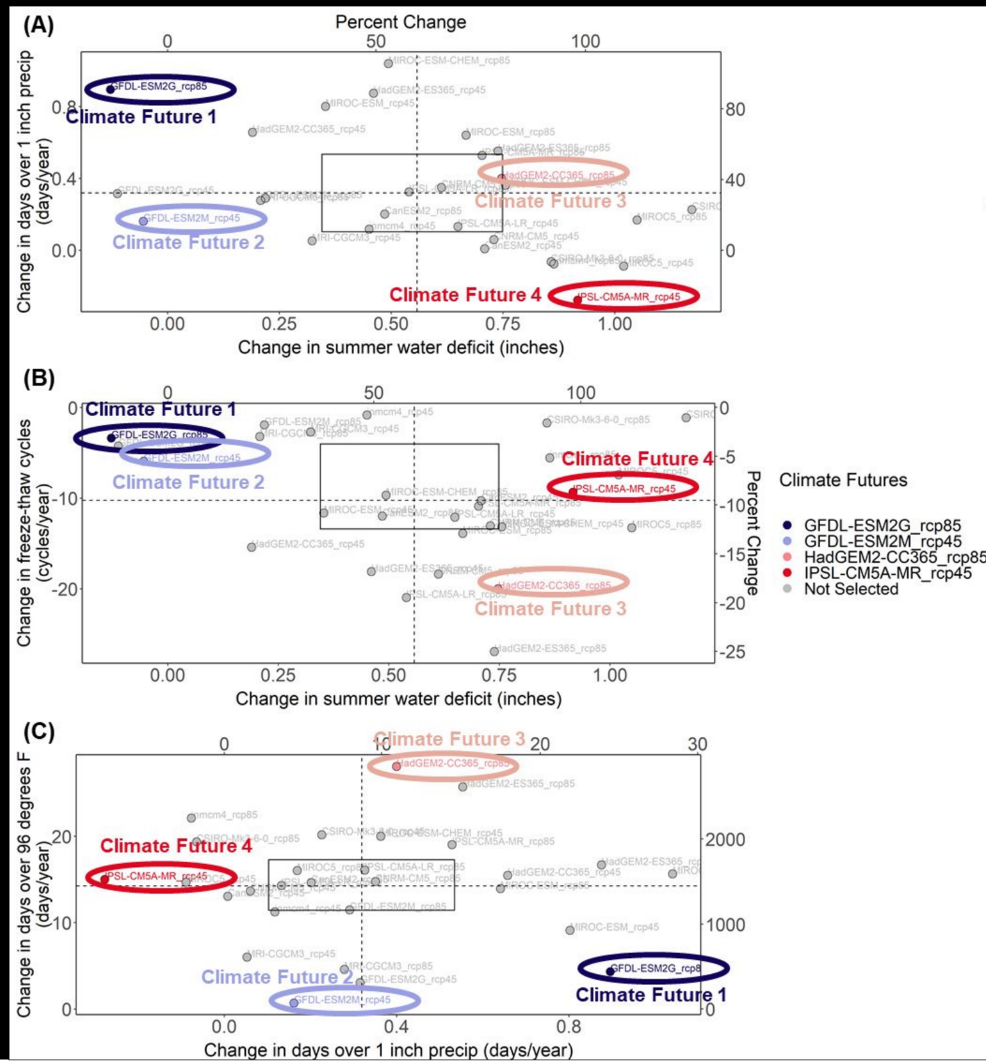


Algorithms for selecting divergent individual climate future projections

1. ‘ Corners’ method

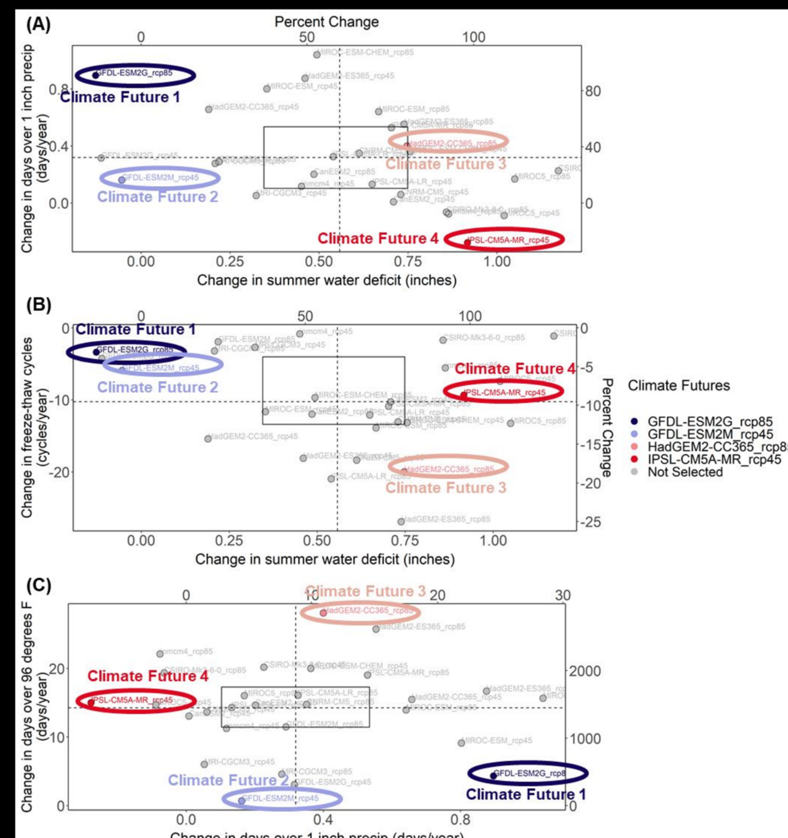


Algorithms for selecting divergent individual climate future projections



Algorithms for selecting divergent individual climate future projections

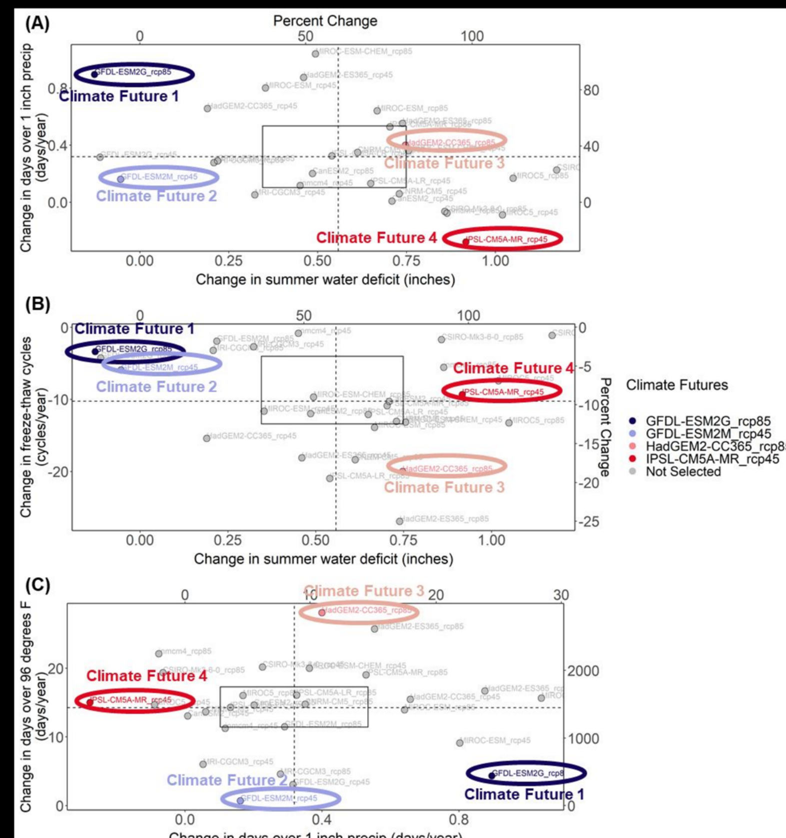
Concern	Based on
Historical structures, tower exfoliation	Freeze-thaw cycles (primary), Extremely hot days (secondary)
Vegetation	Mean (primary) and maximum (secondary) summer water deficit
Erosion	>1-inch precipitation events
Tower exfoliation, visitor and staff safety	Extremely hot days



Algorithms for selecting divergent individual climate future projections

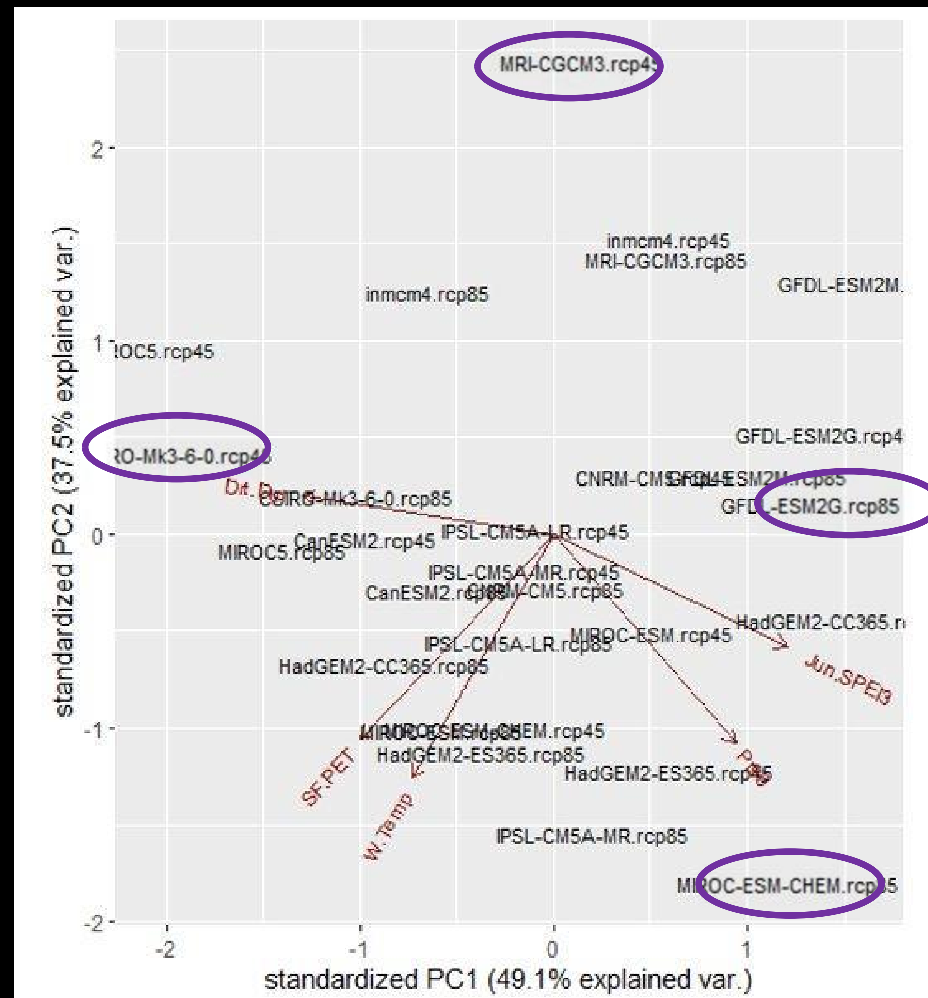
2. Principal Component Analysis – multivariate selection

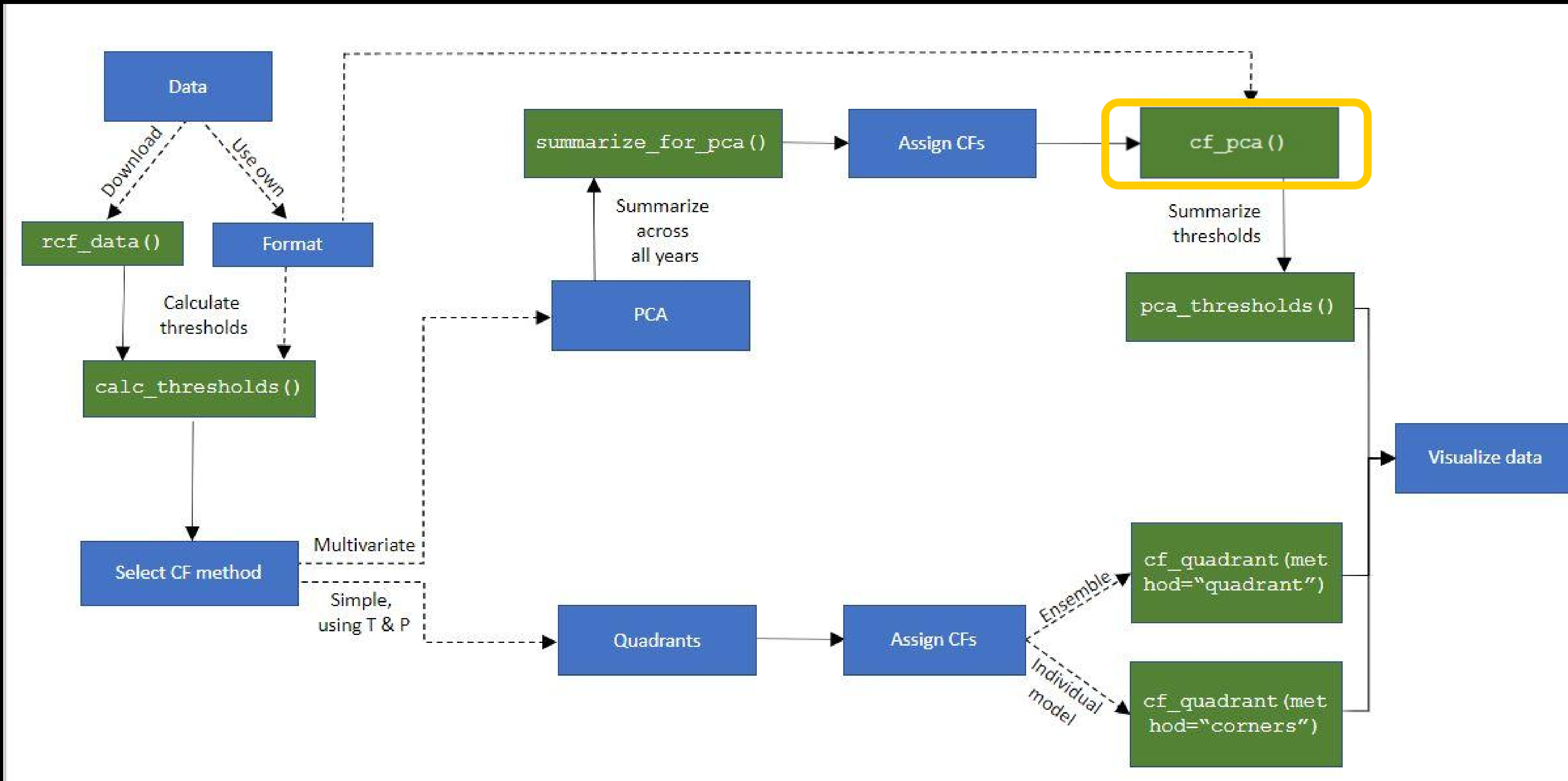
Concern	Based on
Historical structures, tower exfoliation	Freeze-thaw cycles (primary), Extremely hot days (secondary)
Vegetation	Mean (primary) and maximum (secondary) summer water deficit
Erosion	>1-inch precipitation events
Tower exfoliation, visitor and staff safety	Extremely hot days



Principal Component Analysis (PCA)

- What is PCA?
- Why use PCA for model selection?




Data
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Quadrants
Assign CFs
Ensemble
Individual
model
cf_quadrant(method="quadrant")
cf_quadrant(method="corners")
Visualize data


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 make 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 knowlege 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:

- 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://irmadev.nps.gov/DataStore/DownloadFile/660685")
#> Rows: 2191480 Columns: 10
```

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

Thank you!

Contact: amber_runyon@nps.gov

[redacted]

Resources

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. Lawrence[1] · Amber N. Runyon[1] · John E. Gross[1] · Gregor W. Schuurman[1] · Brian W. Miller[2]

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

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

1 Climate Change Response Program, National Park Service, Fort Collins, CO, USA

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	• Add 5^{th} and 95^{th} 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:

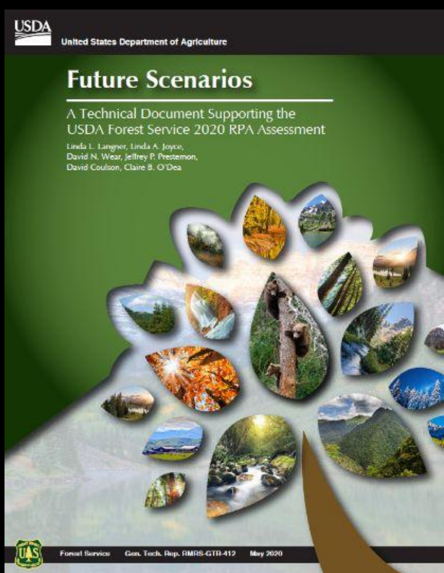
```
install.packages("rcf")
```

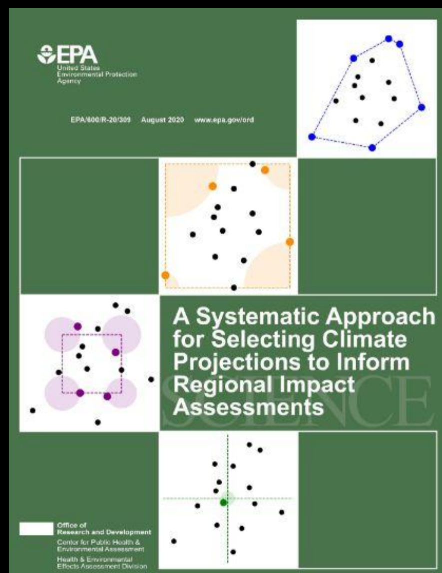
And the development version from GitHub with:

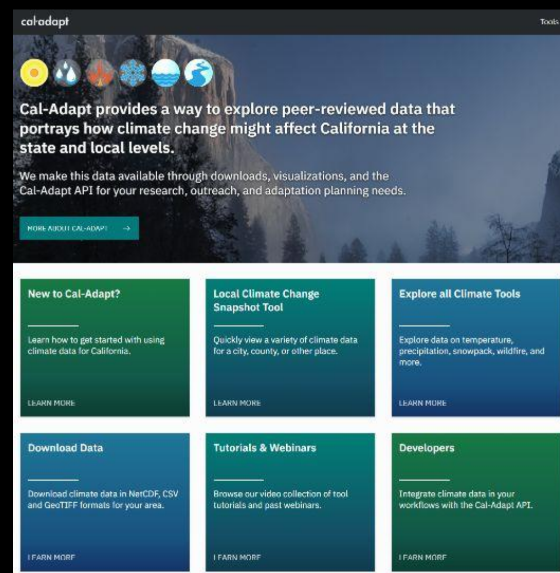
```
# install.packages("devtools")
devtools::install_github("nationalparkservice/rcf")
```

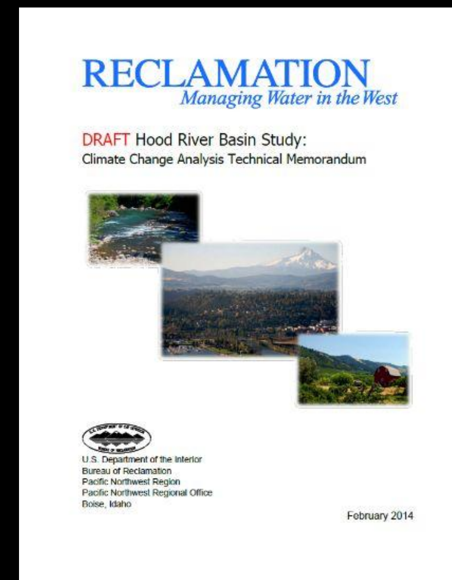
For more information:
Amber_Runyon@nps.gov

Resources for generating climate futures

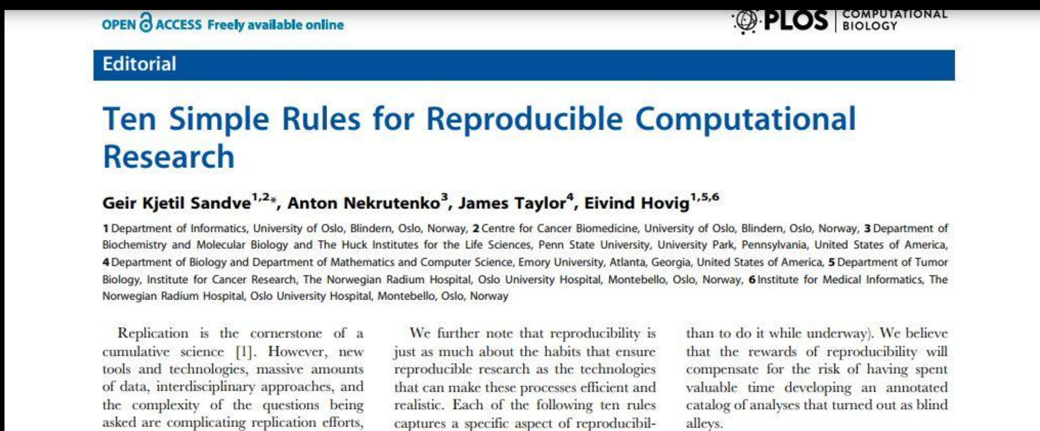








Standards for reproducible research


OPEN ACCESS Freely available online

PLOS | COMPUTATIONAL BIOLOGY

Editorial

Ten Simple Rules for Reproducible Computational Research

Geir Kjetil Sandve[1,2]*, Anton Nekrutenko[3], James Taylor[4], 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,

We further note that reproducibility is 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 reproducibil-

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.

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