Selecting Climate Change Projection Sets for Mitigation, Adaptation, and Risk Management Applications

Alex Ruane & Brock Blevins

Sep 19, 2022

Training Objectives

After participating in the 2-part training, attendees will be able to:

- Understand the differing needs of mitigation, adaptation, and risk management applications
- Recognize the main components and distinguishing factors of climate projection sets
- Summarize the benefits and tradeoffs of different climate projection sets and versions
- Discuss selection of the best climate projection set for various application needs

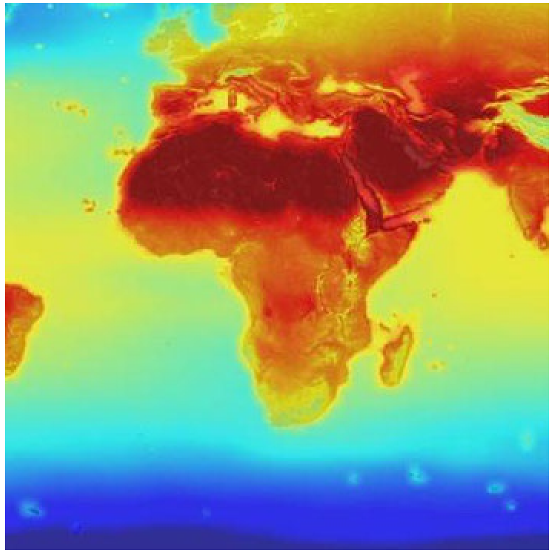
Prerequisites

Fundamentals of Remote Sensing, Session 1

- https://appliedsciences.nasa.gov/join-mission/training/english/arset-fundamentals-remote-sensing

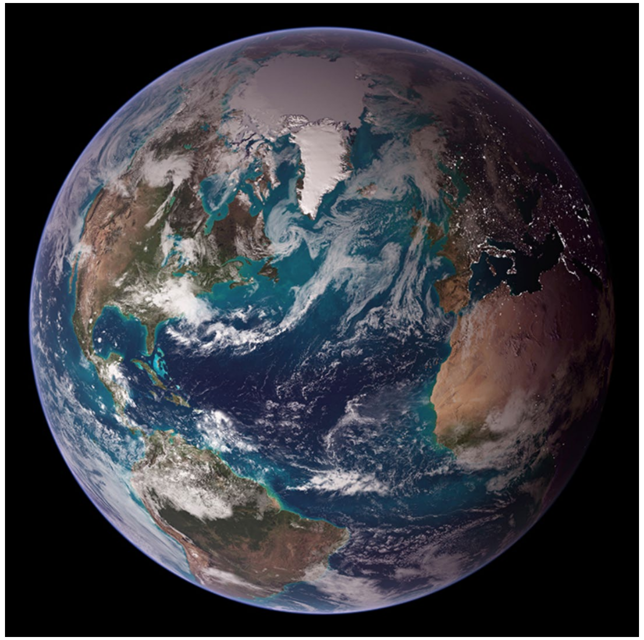
Introduction to NASA Resources for Climate Change Applications

- http://appliedsciences.nasa.gov//join-mission/training/english/arset-introduction-nasa-resources-climate-change-applications



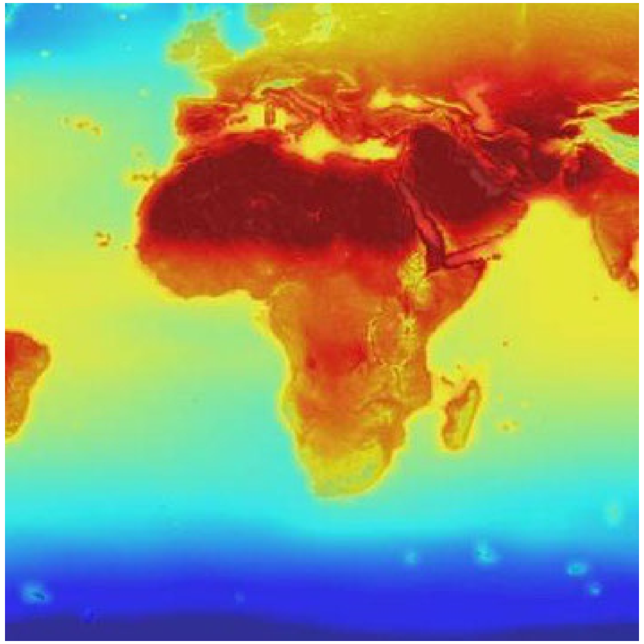
Training Outline

Part 1: What makes projection sets different?



September 19, 2022

Part 2: How do you choose a projection set for your application?



September 20, 2022

Certificate of Completion

- A certificate of completion will be awarded to those who:
  - Attend the 2 live parts of the webinar
  - You will receive a certificate approximately two months after the completion of the course from: marines.martins@ssaihq.com
- *There will not be a homework associated with this training*

About ARSET

- *ARSET provides accessible, relevant, and cost-free training on remote sensing satellites, sensors, methods, and tools.*
- Our trainings are:
  - Online and in-person
  - Open to anyone
  - Live, instructor-led or self-guided
  - Tailored to those with a range of experience in remote sensing, from **introductory** to **advanced**

- ARSET offers trainings for:
  - Disasters
  - Health & Air Quality
  - Land Management
  - Water Resources
  - Climate

For more information, visit appliedsciences.nasa.gov/arset

Selecting Climate Change Projection Sets for Mitigation, Adaptation, and Risk Management Applications

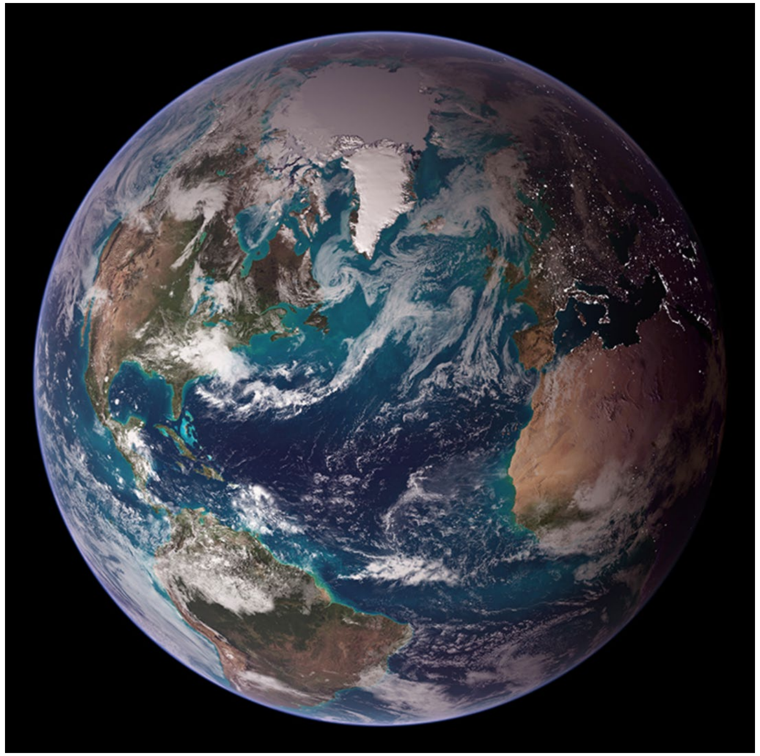
Alex Ruane and Meridel Phillips, NASA Goddard Institute for Space Studies, New York

Part 1: September 19, 2022

Part 2: September 20, 2022

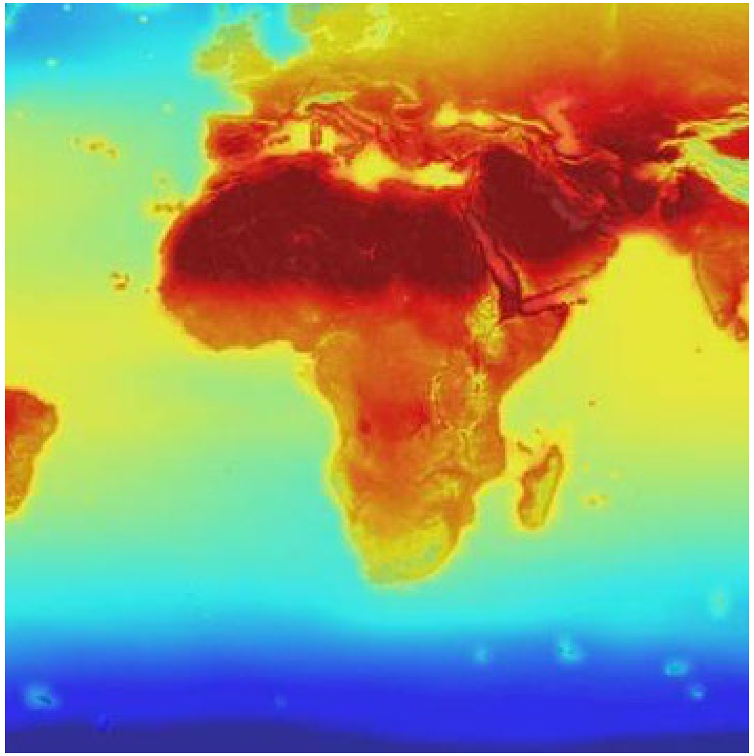
Important Context from Previous ARSET Sessions

Part 1: Climate Change Monitoring & Impacts Using Remote Sensing and Modeled Data



September 29, 2021

Part 2: Climate Change Future Scenarios, Impact Forecasting, and Adaptation



October 6, 2021

Dealing with a Firehose of Climate Data

Our aim is to help experts and stakeholders make sense of the huge variety of climate information to select climate projection sets suitable for an application.

Note that we will not be giving you one recommendation, but aim to empower you in your selection process.

Photo from US Navy, Available on Wikimedia Commons

Goals for this ARSET Session

How do we select a set of climate projections to use for our mitigation, adaptation, or risk management application?

Part 1: What makes projection sets different?

- Context of applications areas (mitigation, adaptation, risk)
- Where climate projection sets come from
- Key distinguishing features

Part 2: How do you choose a projection set for your application?

- Matching projection set characteristics to a given application's needs
- Advantage of using more updated versions
- Tradeoffs in using more complex projection sets
- Supporting materials that make a projection set more appealing

Part 1: What makes projection sets different?

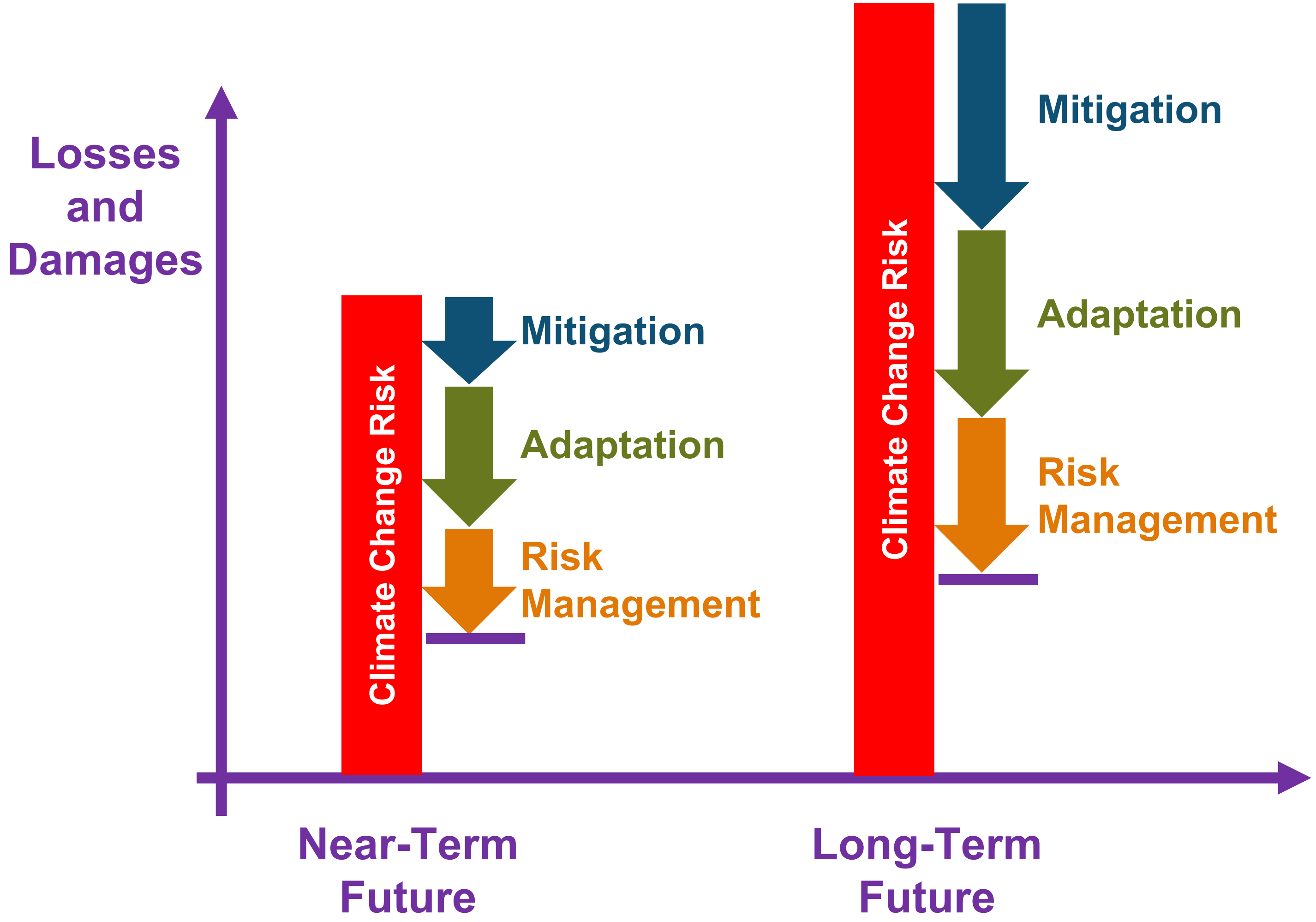
Context of Climate Application Areas

Overview of Application Areas

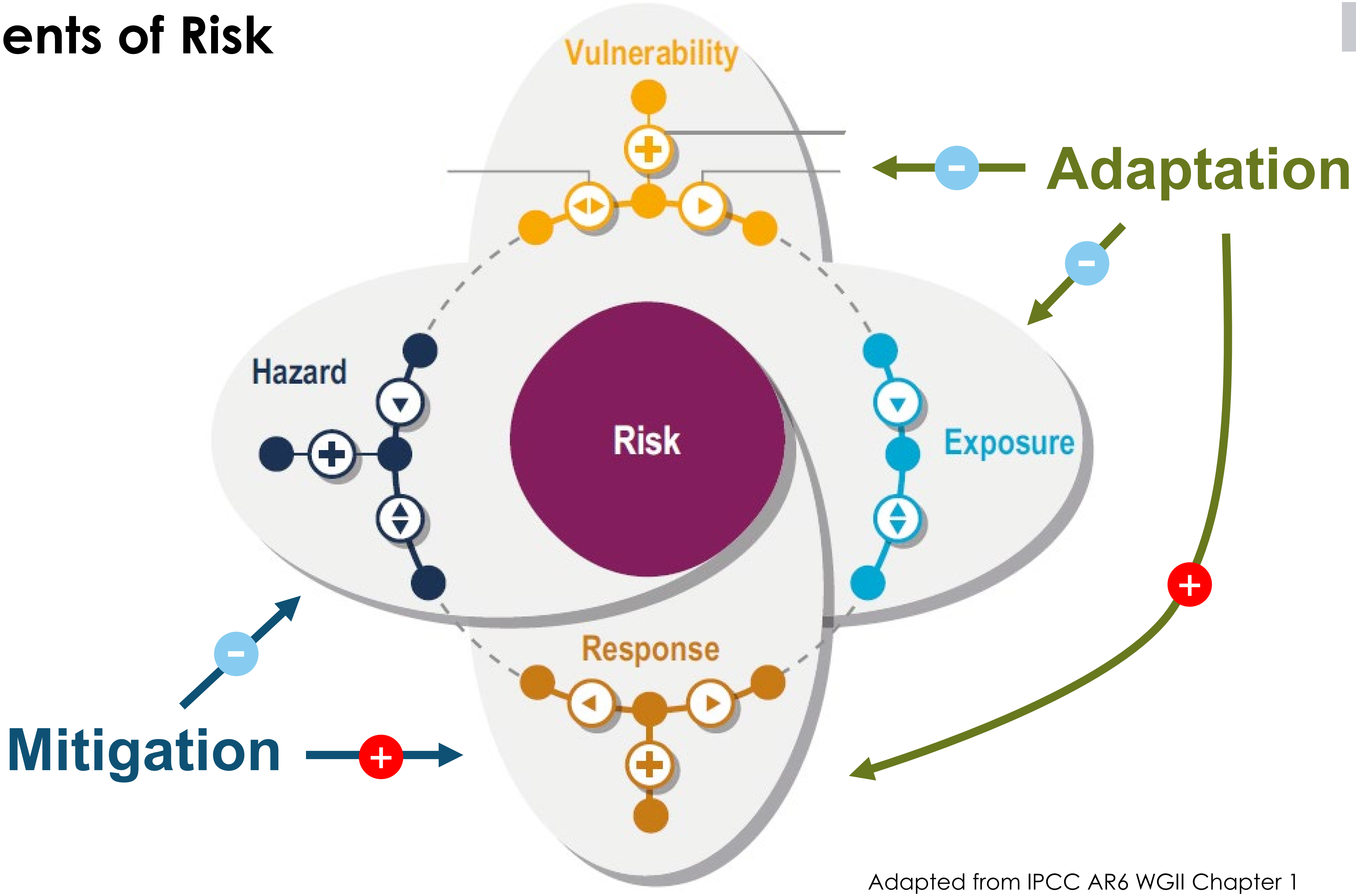
Three options in the face of climate change:
Mitigate, **adapt**, or
manage the leftover risk

Likely need combination of all three:

- Losses and damages can occur even with substantial interventions
- Substantial costs and limits for adaptation and risk management
- Risks and options grow over time, depending on our actions



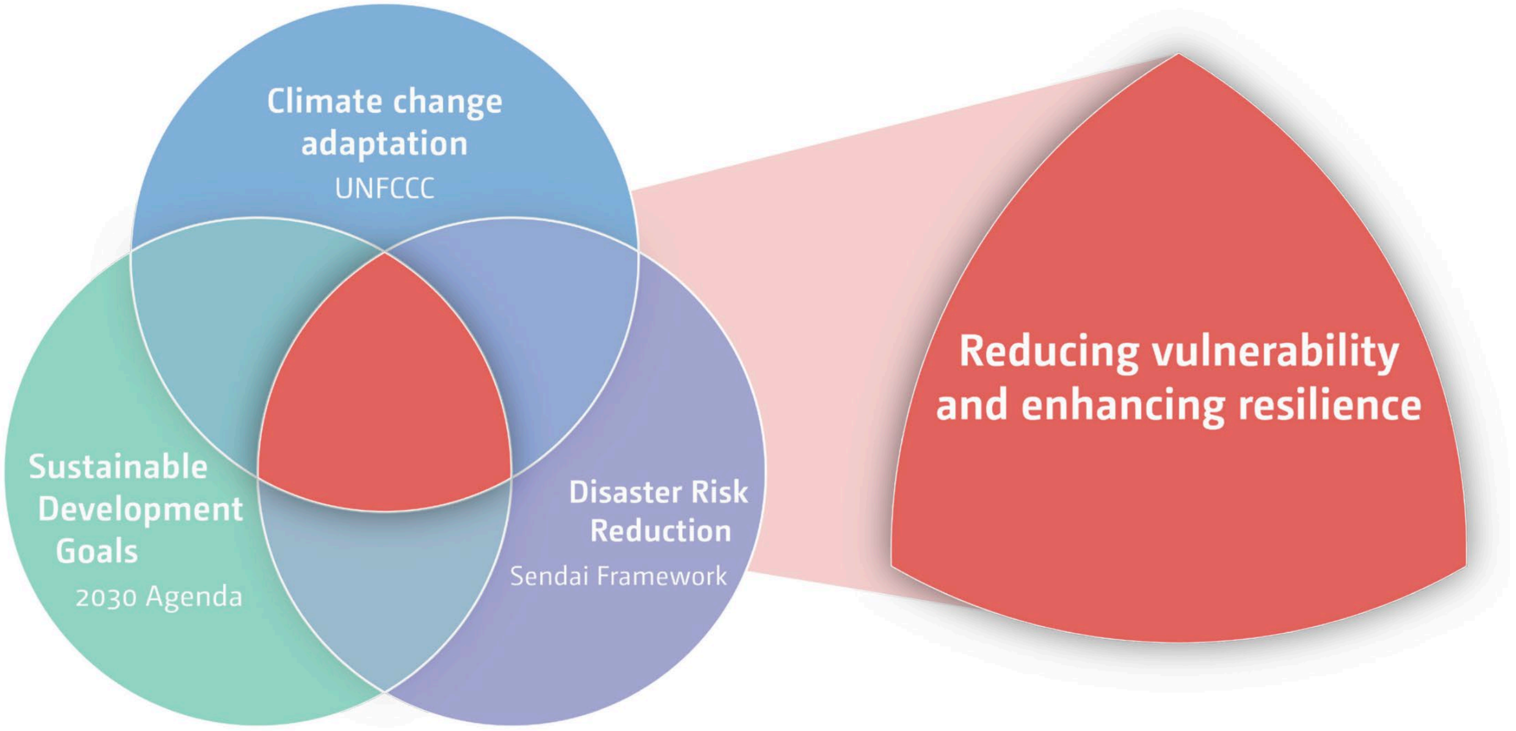
Components of Risk



Adapted from IPCC AR6 WGII Chapter 1 Figure 1.5c; Begum et al., 2022

Climate actions connect with disaster risk reduction and sustainable development.

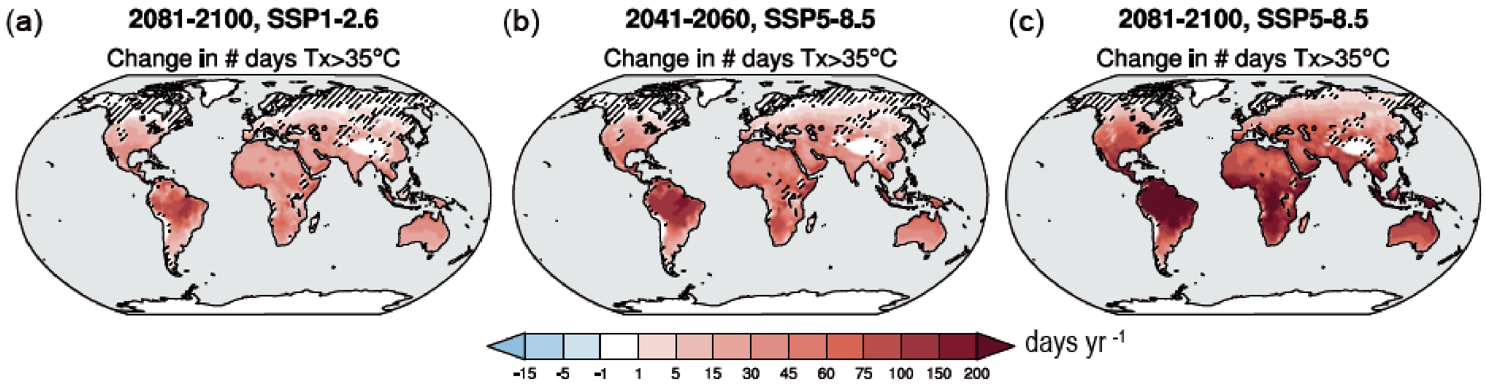
- Climate and disaster risk reduction are fundamental elements of sustainable development.
  - Easier to develop if risks are lowered
  - Easier to adapt if amount of climate change is lower
  - Easier to manage risk if adaptations are in place



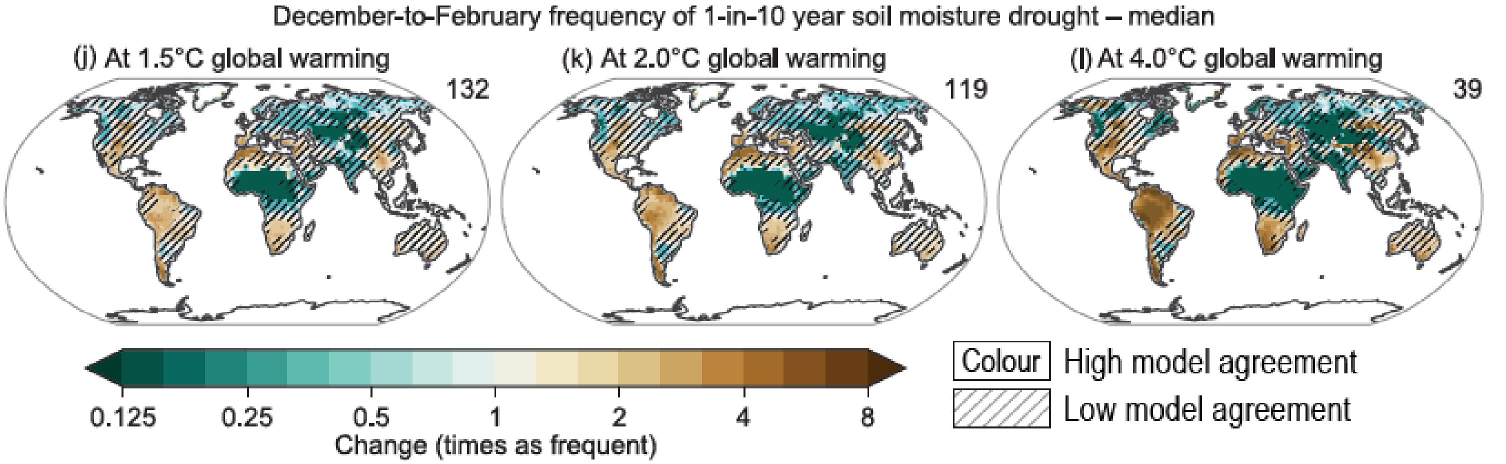
UNFCCC 2017: Opportunities and options for integrating climate change adaptation with the Sustainable Development Goals and the Sendai Framework for Disaster Risk Reduction 2015–2030

Mitigation Applications Approach

- Generally compares two different future conditions depending on societal emissions
- Can be based on climate conditions that evolve along a given scenario or pathway
- Can be based on emergent global warming levels that could be reached under a variety of societal actions



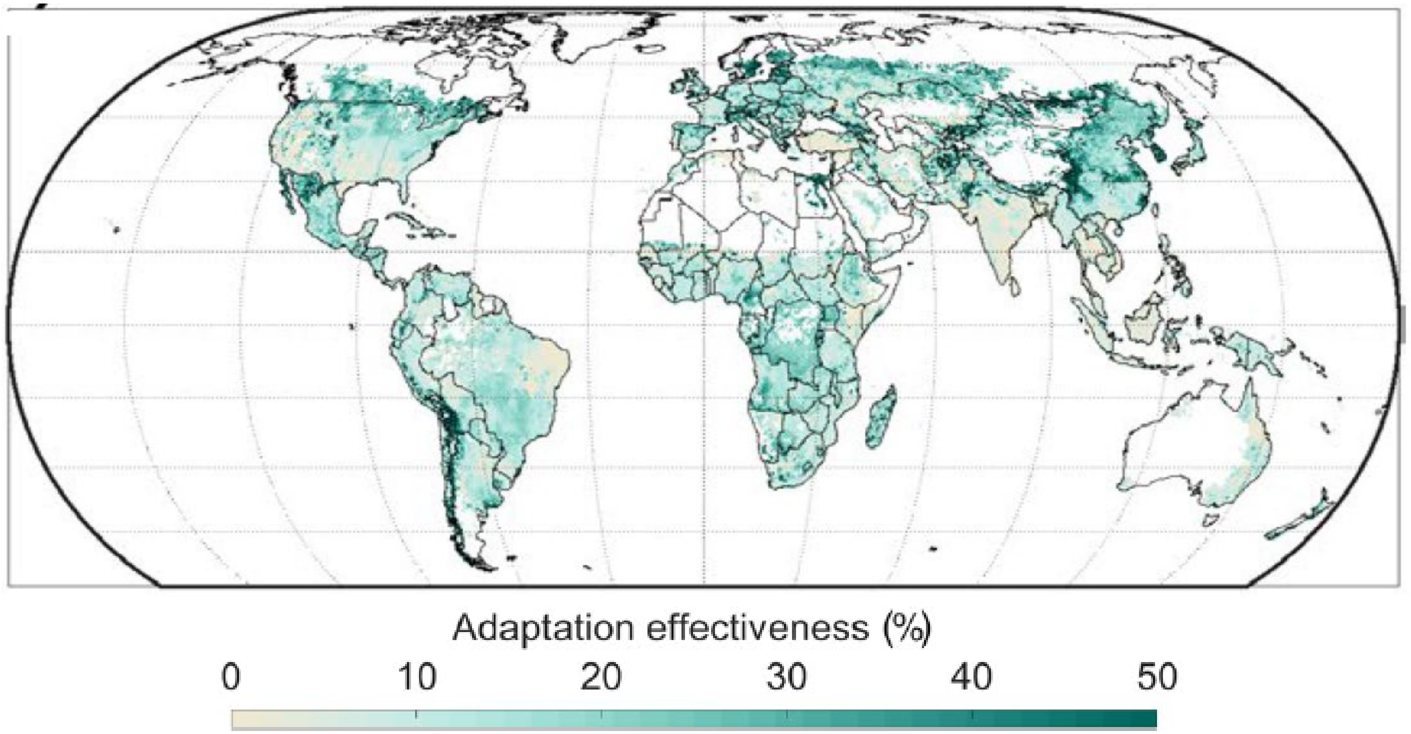
Ranasinghe et al., 2021 – IPCC AR6 CH12 Fig. 12.4



Seneviratne et al., 2021 – IPCC AR6 CH11 Fig 11.19

Adaptation Applications Approach

- Generally compares a future system with and without adaptation intervention
- Climate condition must also be defined
- Climate change adaptation is targeted toward a particular climate change factor



Production Benefit of Adapting Major Cereal Seed Varieties for Warmer Temperatures

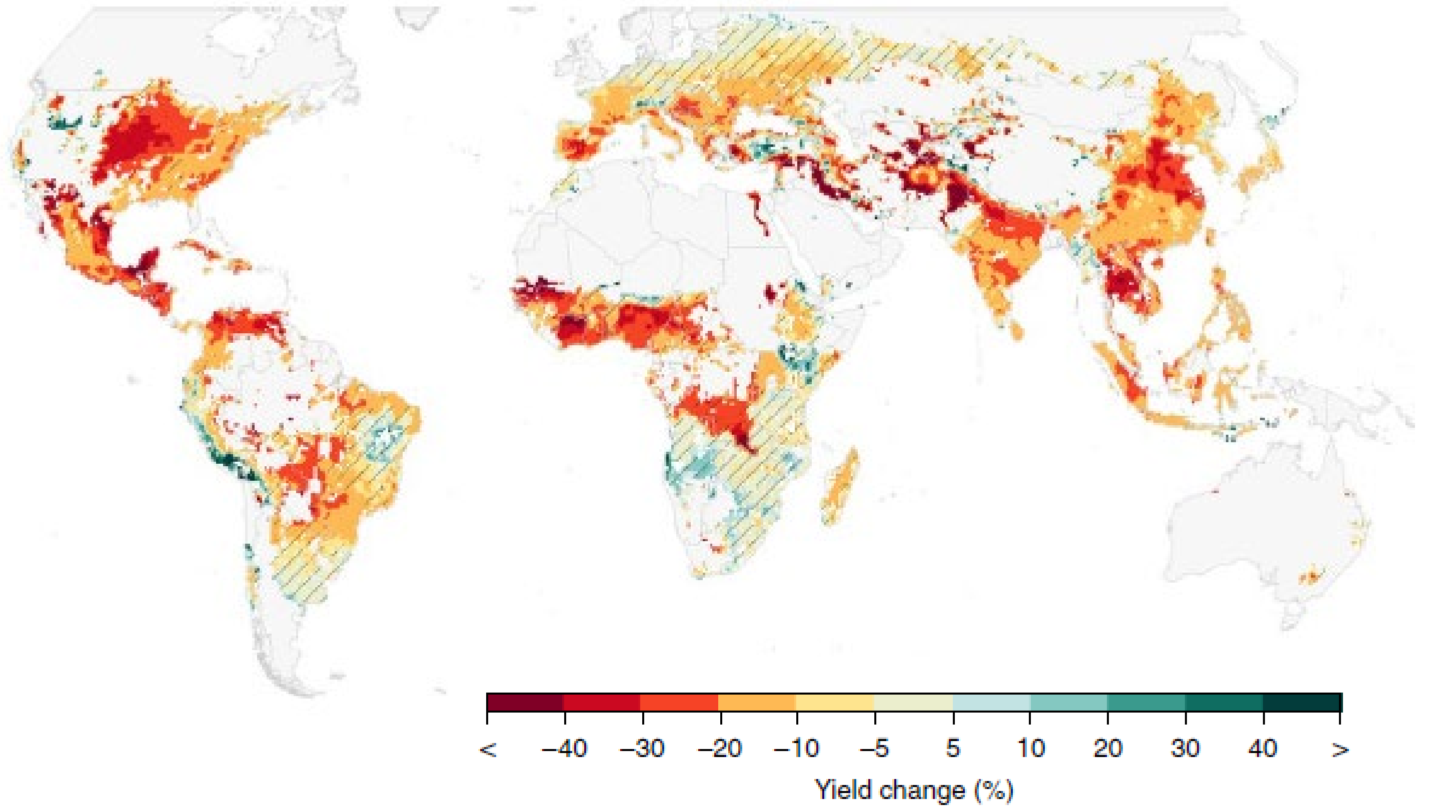
Moderate Emissions Scenario (SSP2-4.5) at End of Century (2070-2100)

From Zabel et al., 2021 (doi:10.1111/gcb.15649)

Risk Management Application Examples

- Generally compares the change in risk driven by shifting climate hazards, vulnerability, and exposure
- Reactive and proactive risk management require different lead time of planning
- Systems thinking is important to understanding how actions and risks interact with other parts of nature and society

Change in Maize Yield – End-of-Century SSP5-8.5



Jägermeyr et al., 2021
12 Crop models and 5 ISIMIP Climate Projections

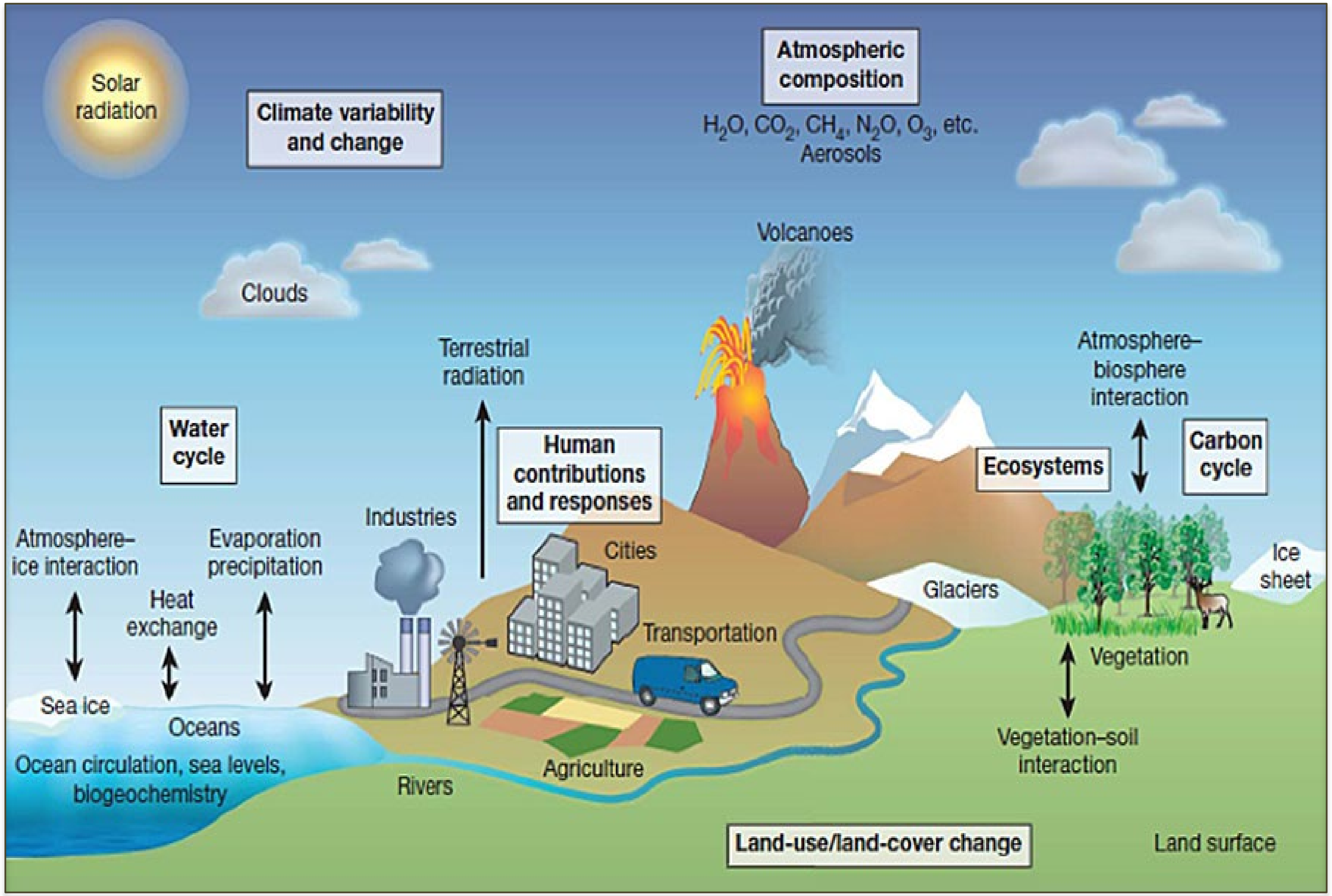
AgMIP The Agricultural Model Intercomparison and Improvement Project

Origin and Orientation of Climate Projection Sets

Projecting Human-Driven Climate Change

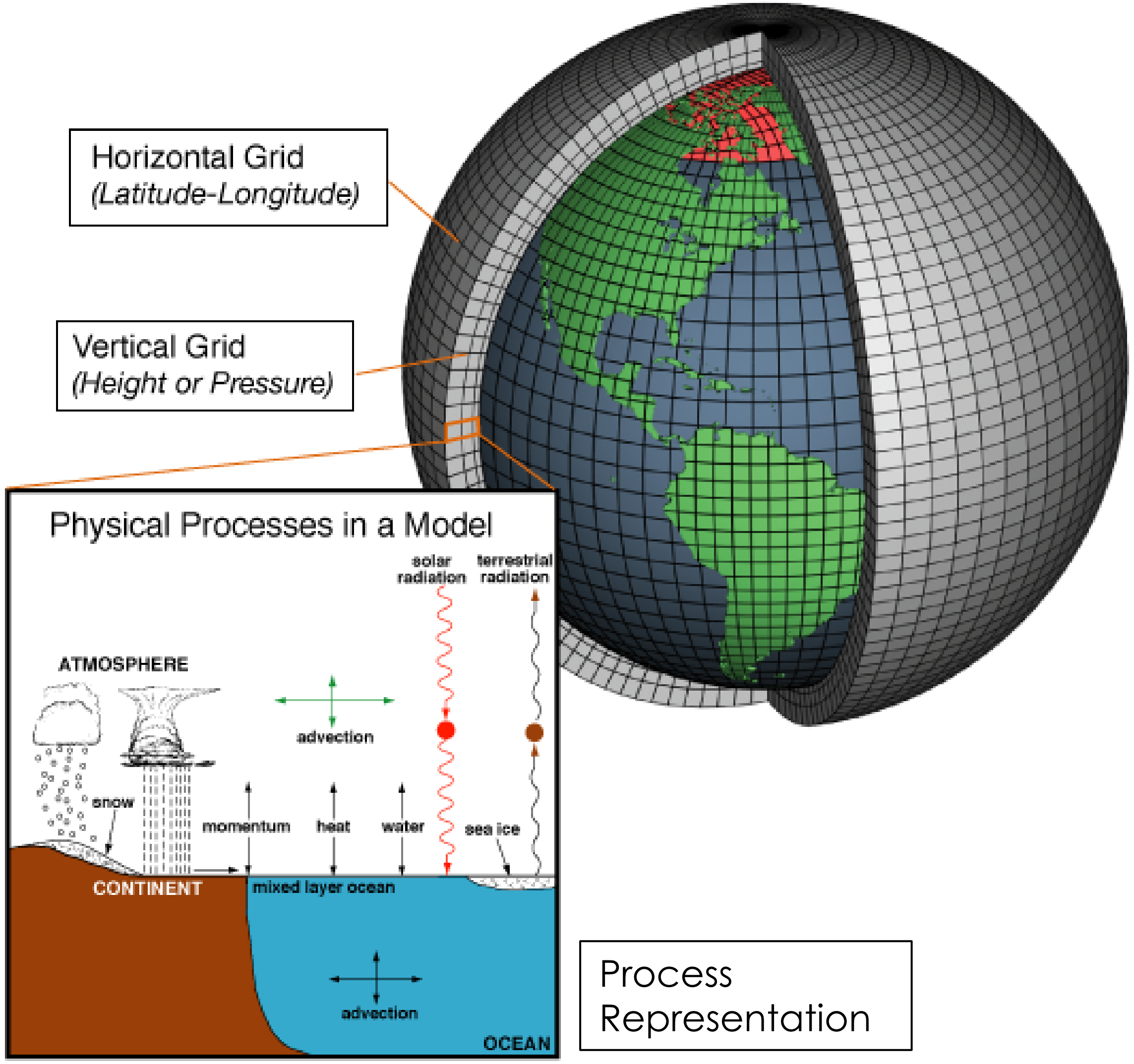
- The foundation of climate change projections comes from simulations that capture human influence on the climate system.

- Requires radiation physics, atmospheric dynamics, chemistry, oceans, biosphere, cryosphere, and human-driven shifts in emissions and land-use.

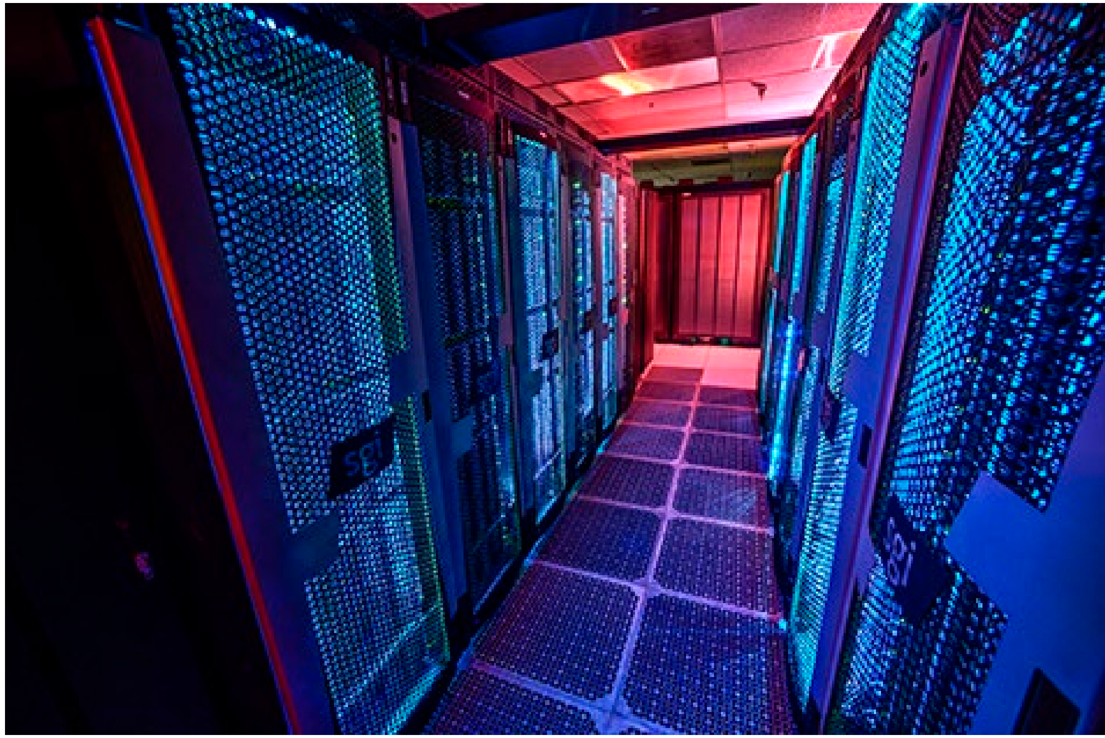


Moss et al., 2010 (https://doi.org/10.1038/nature08823)

Climate projections begin with global climate models.



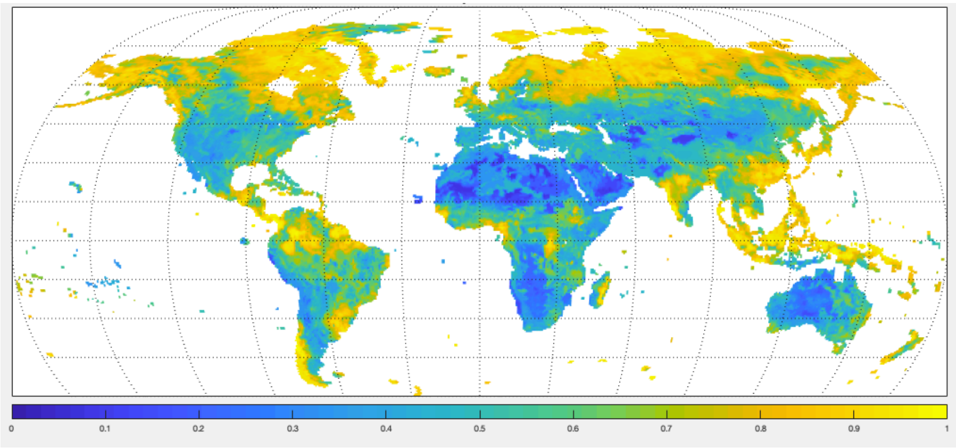
Adapted from NOAA: https://www.climate.gov/maps-data/primer/climate-models



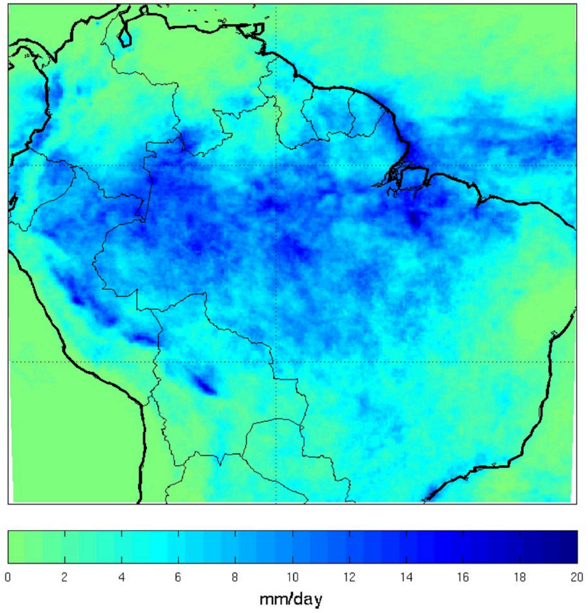
NASA Discover Supercomputer

Climate projection sets constrain model projections with observational data.

- Climate models are often designed to capture global signals, with regional signals likely including biases.
- Observations are an important part of model development and can also be used to reduce biases for applications.



Global Soil Moisture from MERRA-2 for July 2005 (fraction)



IMERG Mean Precipitation Rate in the Amazon December 2016 - March 2017

Climate projection sets are developed for use in applications.

- Land and Ocean Ecosystems, Agriculture, Water Resources, Cities and Infrastructure, Health, Energy, Social Systems, and more

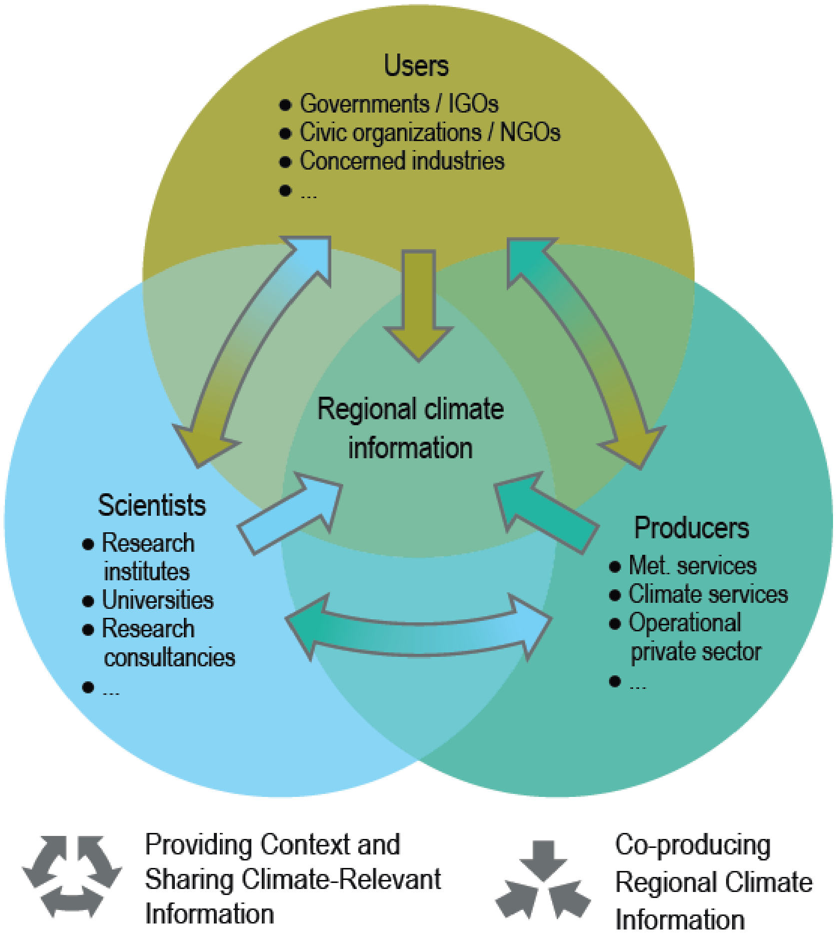
- Projection sets seek temporal and spatial scales aligned with decision context.

Climate projection sets are constructed according to a number of specific choices and shaped by resource constraints.

- Important to recognize the influence of values of scientists and stakeholders

- Applications often limited by resources
  - Time, money, computational, attention

- Projection sets intended to provide an ability to evaluate decisions conditional on future pathways of society and the climate system
  - Combination of foresight or forewarning and uncertainty



Effective Regional Climate Information Engagement
from Doblas-Reyes et al., 2021 (IPCC AR6 WGI Chapter 10)

Key Distinguishing Features Between Climate Projection Sets

Information You Should Understand about the Climate Projection Set You Select

1. Global Climate Model Output Used

- There are 100+ **Earth System Models** (ESMs) from 50+ modeling institutions.
- Leading modeling groups have coordinated simulations of climate change scenarios within the auspices of the **Coupled Model Intercomparison Project** (CMIP; Phase 6 now available).
  - **CMIP3**: Data from the Coupled Model Intercomparison Project 3 **(~2007)**
  - **CMIP5**: Data from the Coupled Model Intercomparison Project 5 **(~2013)**
  - **CMIP6**: Data from the Coupled Model Intercomparison Project 6 **(~2020)**
- Modeling institutions are **constantly improving** their models.
  - Higher resolution, improved physics and chemistry, more processes
- CMIP provides important **diagnostic and evaluation information** for each ESM.

1. Global Climate Model Output Used

Additional Sources of Global Climate Projections:

- **Direct access** to outputs from a modeling group (outside of CMIP)
- **Large Ensembles** use many initial conditions to better understand internal variability
- **Climate Model Emulator**: Statistical representations of the climate system
  - Often created to reproduce CMIP outputs with low computational cost
  - Commonly utilized in integrated assessment models
  - Important to consider which elements were included in statistical approach:
    - Global vs. Regional Detail
    - Variables and their Coherence
    - Average vs. Extreme Conditions

2. Scenarios and Storylines

- **Scenarios** describe a future world through a plausible and internally consistent set of assumptions, potentially including greenhouse gas and aerosol emissions, land use change, socioeconomic development, and technological change.
- The IPCC notes that scenarios are neither predictions nor forecasts, but are used to provide a view of the implications of developments and actions.

- Climate projections may also be associated with a given storyline:

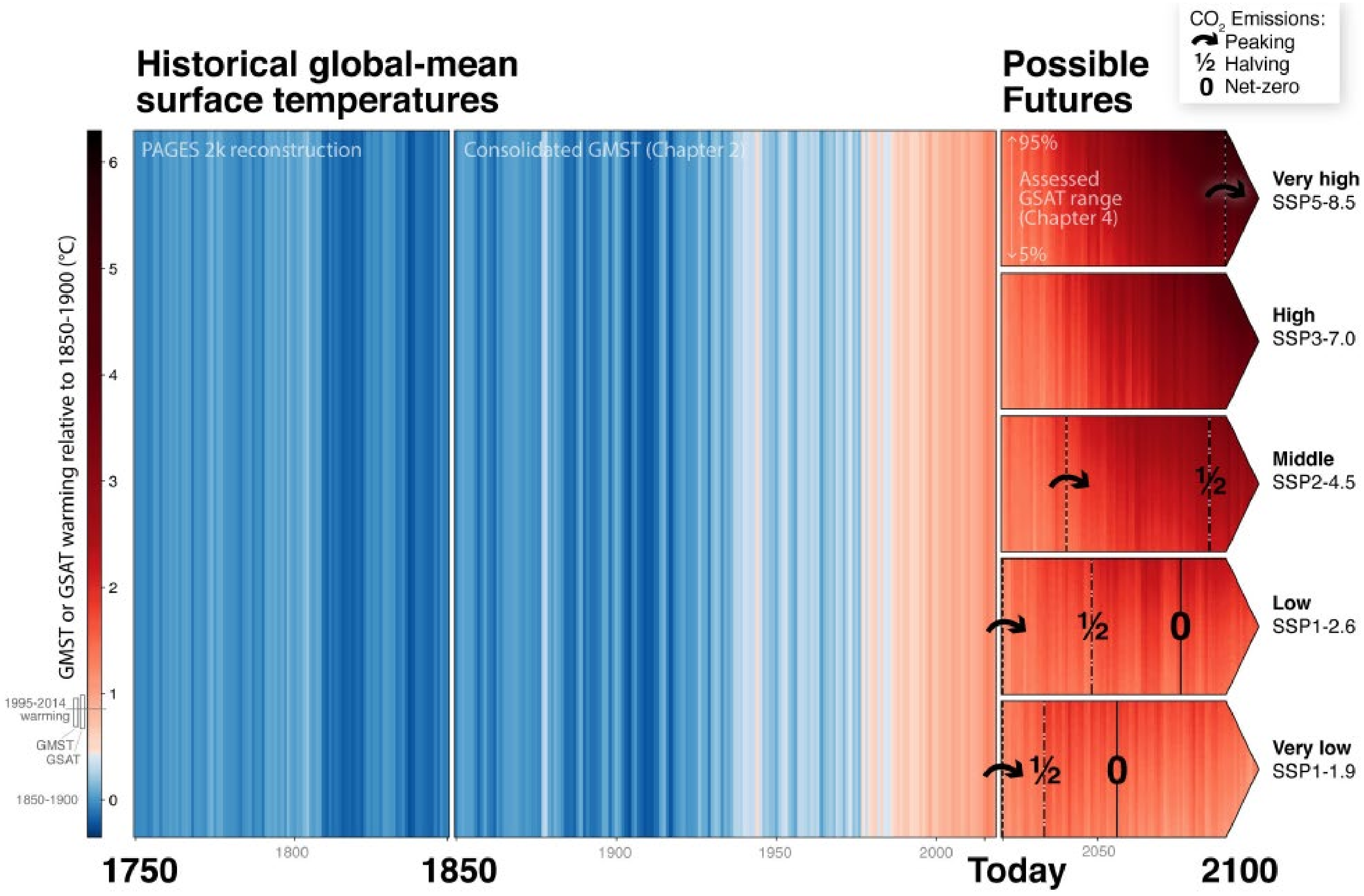
IPCC AR6 WGI defined a **Storyline** as: A way of making sense of a situation or a series of events through the construction of a set of explanatory elements. Usually, it is built on logical or causal reasoning.

- Storylines can have societal and physical elements, e.g.:
  - A major drought in the 2080s
  - The physical implications of a given amount of global warming
  - A set of conditions stemming from the discovery of a new technology
  - The ramifications of a given policy or new financing being implemented

See IPCC AR6 WGI Glossary for more information

2. Scenarios and Storylines

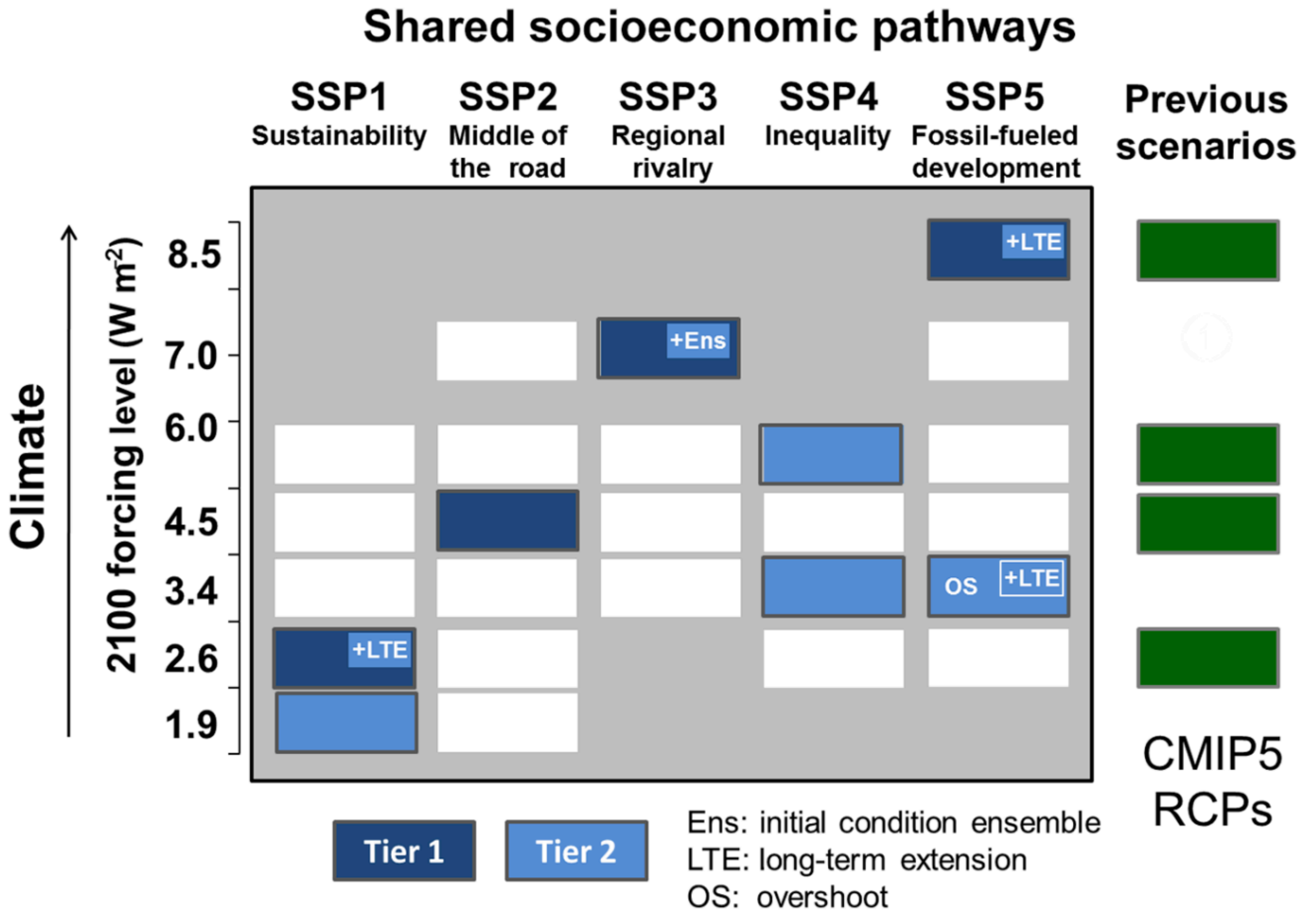
- Examples:
  - **SRES**: Special Report on Emissions Scenarios developed for IPCC TAR (2000) – [A2, B1, A1B]
  - **RCP/SSP-RCP**: Representative Concentration Pathways or Shared Socioeconomic Pathways (or combined)
    - SSP3-7.0 and SSP1-2.6 often used as plausible high- and low-end scenarios
  - **GWLs**: Global Warming Levels
  - **NDCs**: Nationally-Determined Contributions



IPCC AR6 WGI
Chen et al., 2021 Figure 1.25

2. Scenarios and Storylines

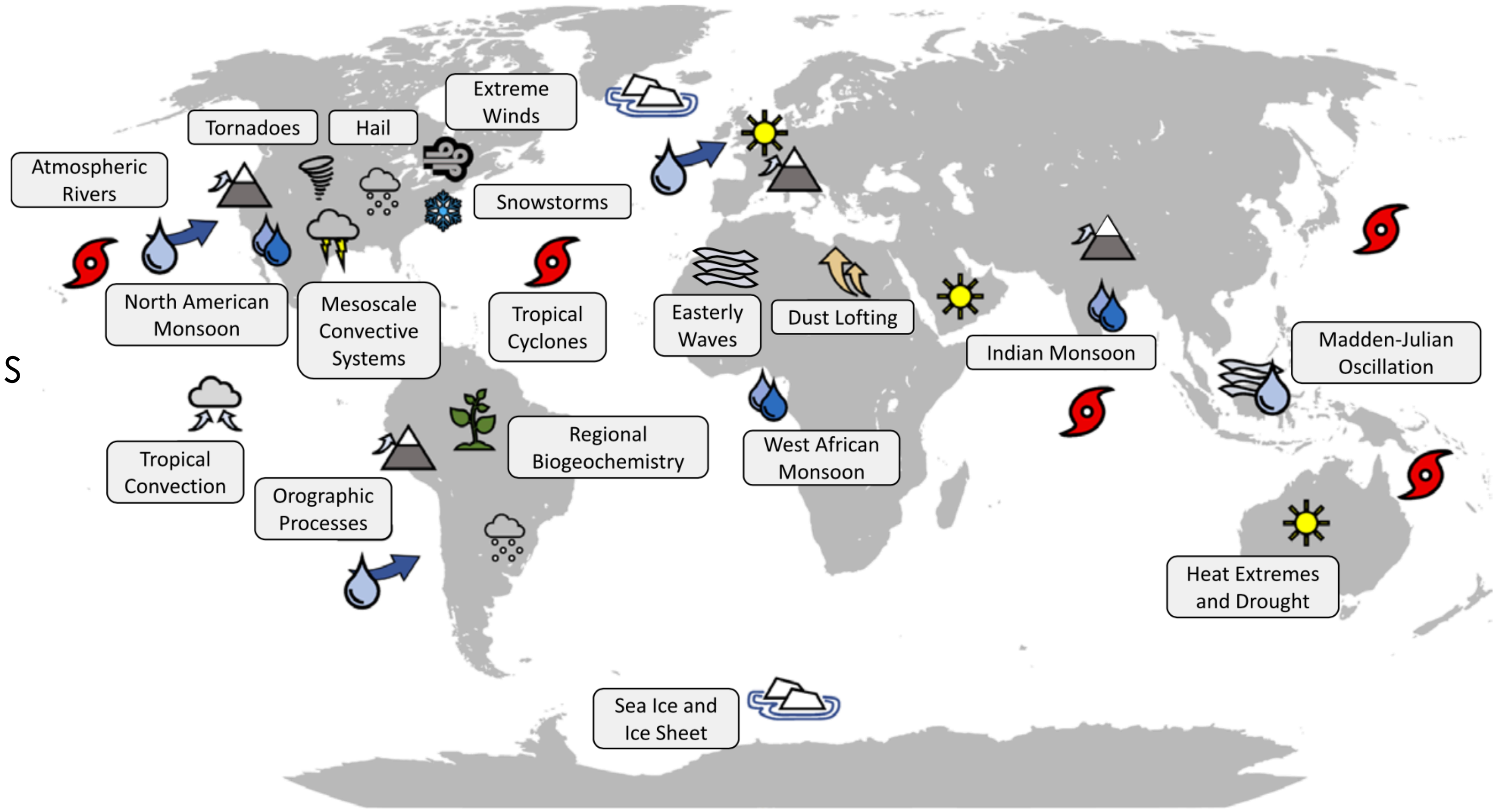
- SSPs describe socioeconomic development.
- RCPs describe greenhouse gas concentrations.
- These can be related, and mitigation can create unique combinations.
- Each SSP leads to a given RCP without mitigation, but mitigation can lower RCPs.



ScenarioMIP Shared Socioeconomic Pathways
from O'Neill et al., 2016 (doi:10.5194/gmd-9-3461-2016)

3. Downscaling

- Analyses designed to bring global model information to finer resolution, potentially including:
  - Representation of finer-scale features such as land use, mountains, and coastlines
  - Physical processes associated with finer resolution dynamics

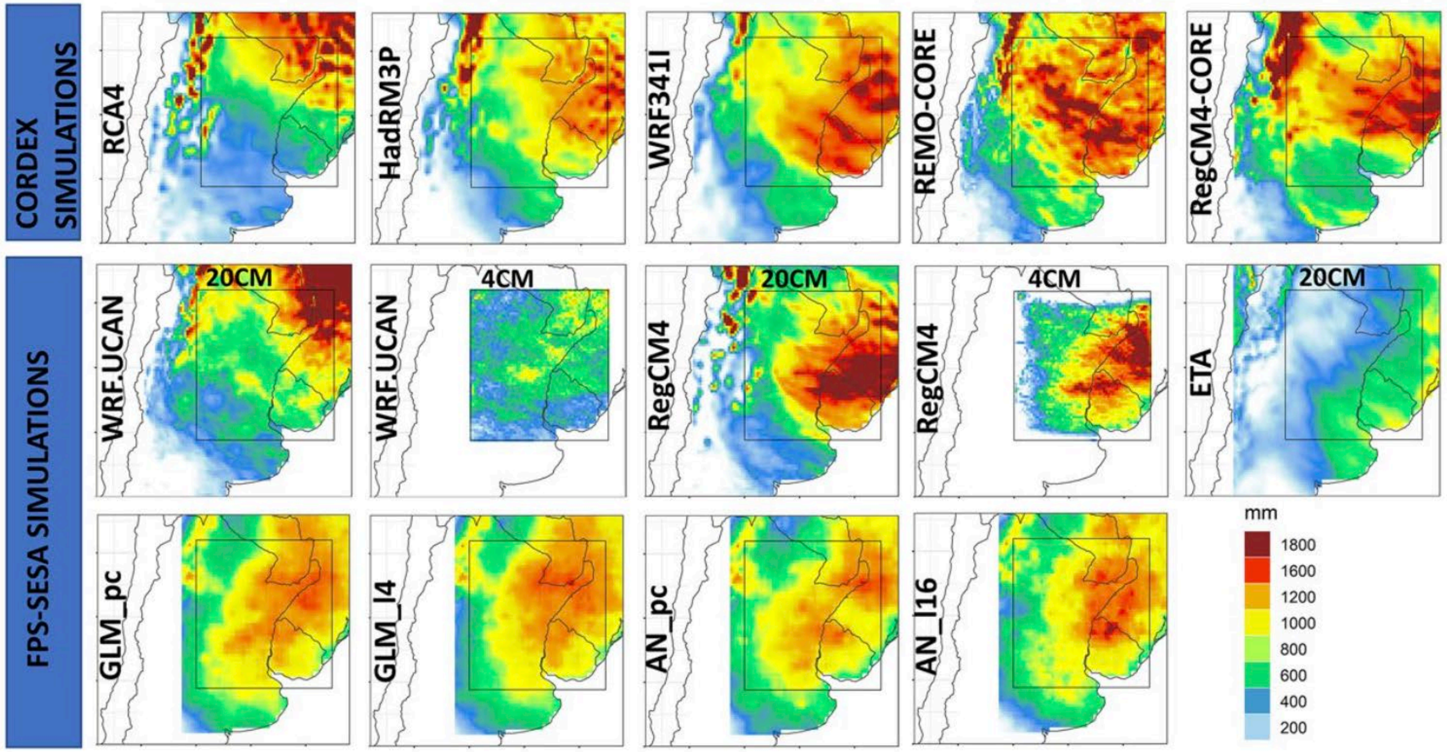


Features of Climate System that Might Benefit from More Fine-Scale Regional Modeling

From Gutowski et al., 2020, Figure 1 (doi:10.1175/BAMS-D-19-0113.1)

3. Downscaling

- Possibilities:
  - **Dynamical:** Fine resolution model driven by GCM boundary conditions
  - **Statistical**: Empirical approaches predict fine-scale features from large-scale conditions
  - **Climate Analogues**: Use weather types and historical conditions to construct local conditions

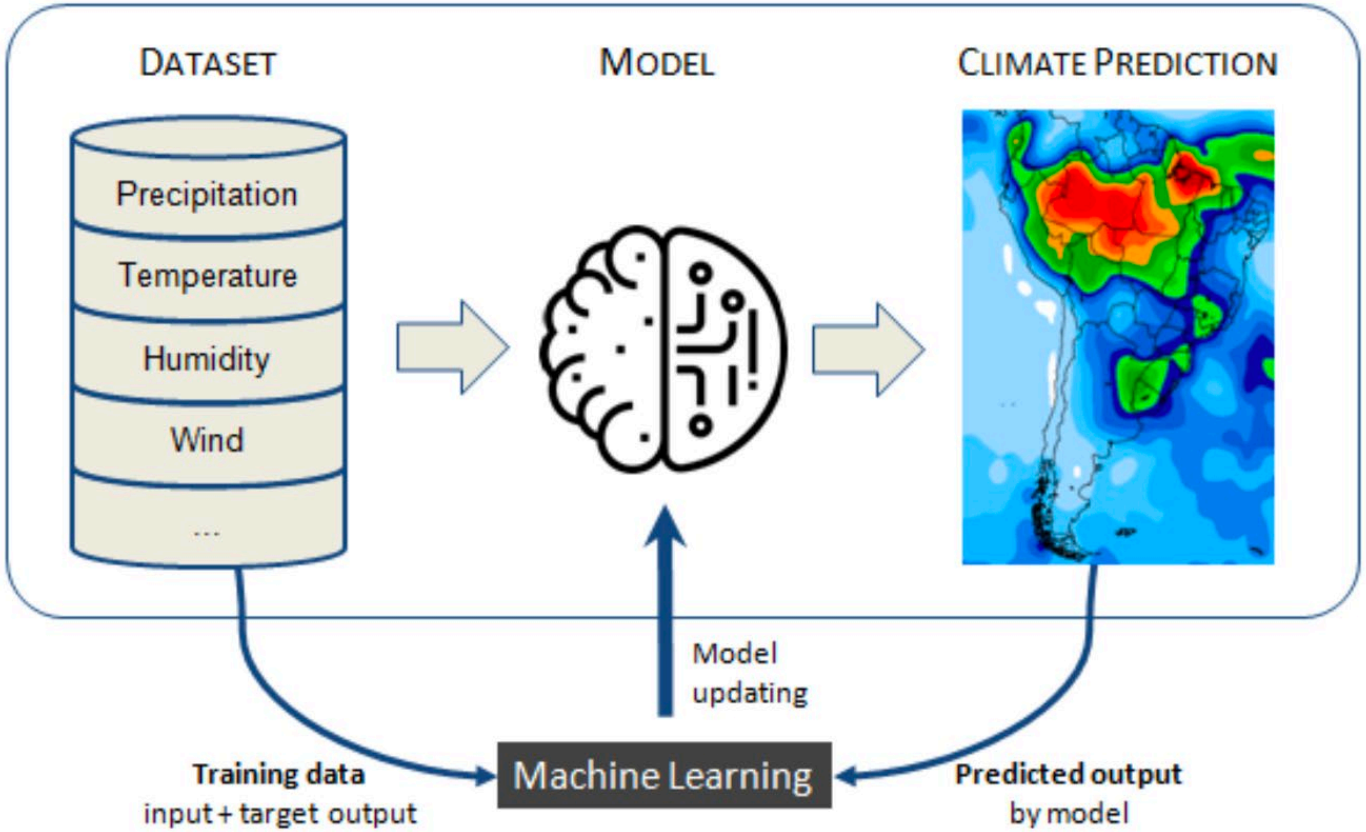


Total Precipitation Amount during the 2009-2010 Warm Season from CORDEX-RCMs (top row) and FPS-SESA Dynamical Downscaled (middle row) and Empirical-Statistically Downscaled (bottom two rows)

From Bettolli et al., 2021 (doi:10.1007/s00382-020-05549-z)

3. Downscaling
Machine Learning in Climate Projection Sets

- Machine learning (ML) algorithms, unlike traditional regression, automate the process of model improvement.
- Allows for more accurate predictions over time as the model "learns" and dynamically changes from each iteration.



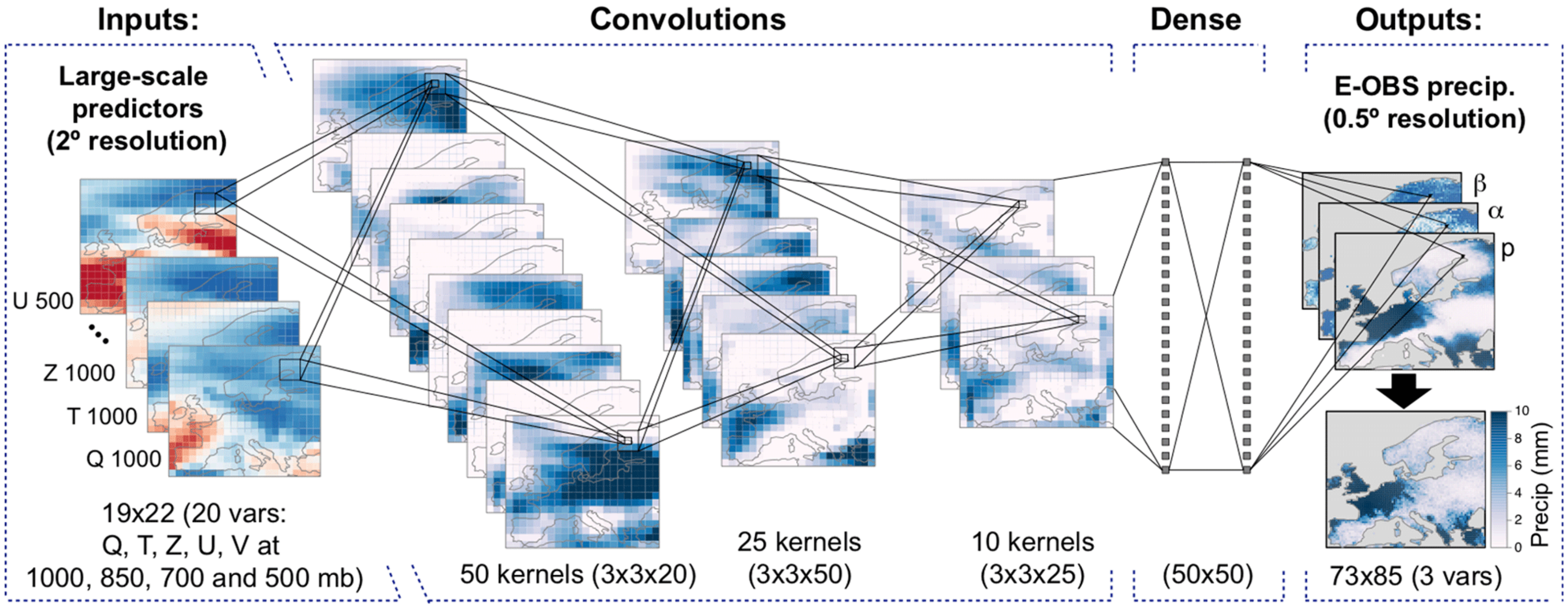
Example of a Scheme for Predicting Future Climate using Observational Data, Climate Model(s), and Machine Learning Algorithms
From Anochi et al., 2021, Figure 2 (doi:10.3390/rs13132468)

3. Downscaling

Machine Learning (ML) Methods

Inputs (predictors): Five variables at four pressure levels

Convolutions (hidden layers): 50, 25 or 10 neurons (kernels) at 3x3 grid



Additional "dense" (fully connected) layers

Outputs: Network estimates probability of rain based on shape (α) and scale (β) of gamma distribution

Convolutional Neural Network used to Downscale European Precipitation in ERA-Interim using Observational Dataset E-OBS v14

From Baño-Medina et al., 2020, Figure 3 (doi:10.5194/gmd-13-2109-2020)

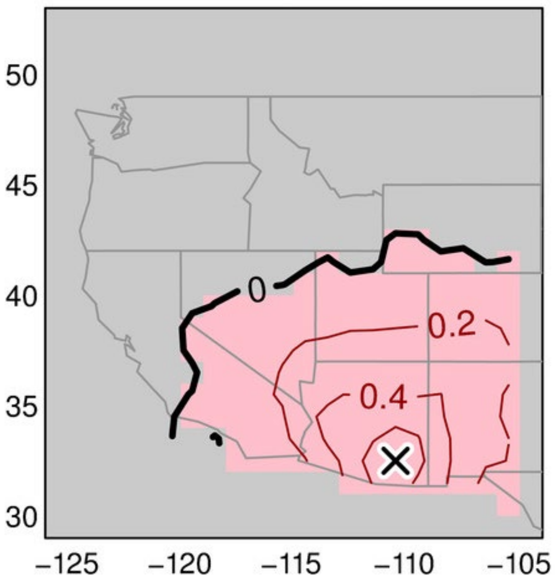
3. Downscaling

Analog Approaches (e.g., Localized Constructed Analog - LOCA)

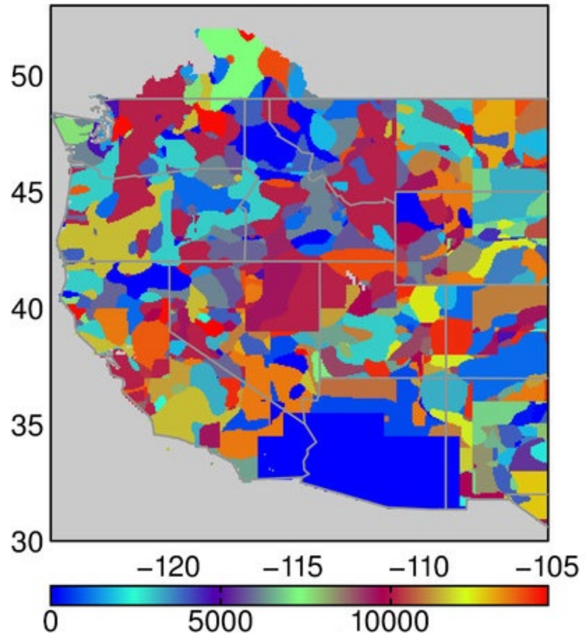
Step 1: For each point, find 30 days in observational data that best match model in wider region around the point being downscaled

Step 2: Identify the single day of those 30 that best matches the model day in the immediate region of the point being downscaled

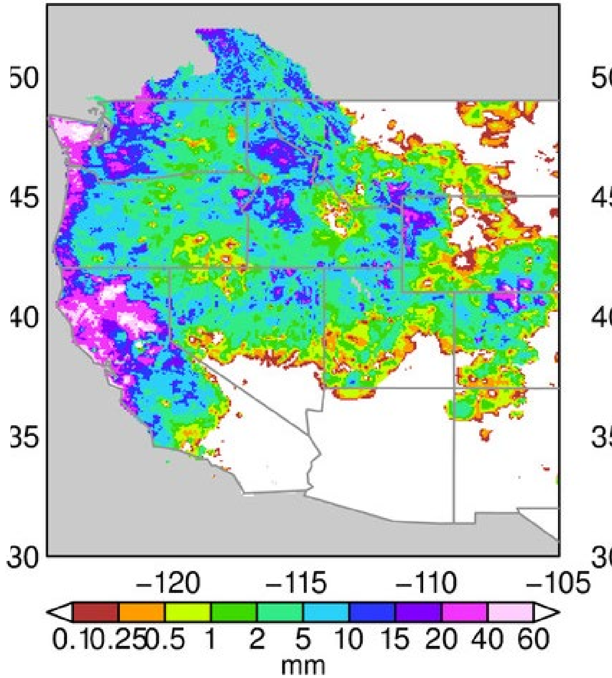
Step 3: Find the best of the 30 analog days in the immediate region by minimizing RMSE with model



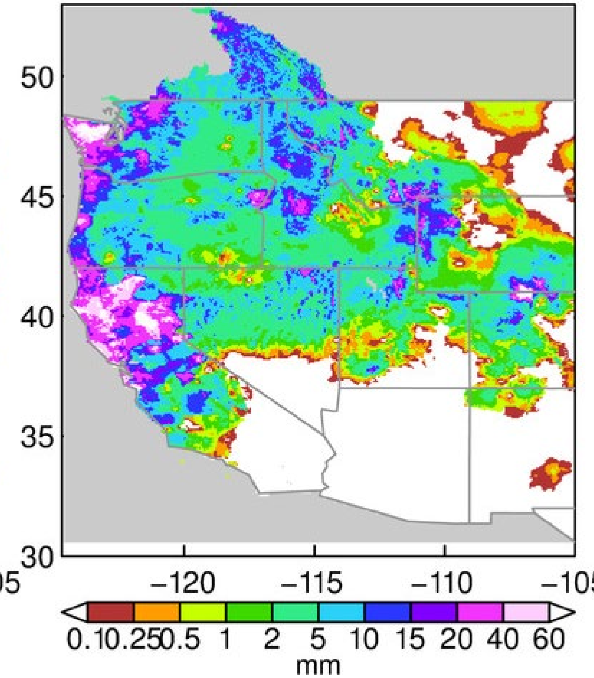
Sample mask for point X for JJA season precipitation in Western U.S.A.



Analog day number as integer date starting 1 Jan 1970 and ending 31 Dec 2010



Downscaled Precipitation for January 1, 1940 in Western U.S.A.



Observed Precipitation for January 1, 1940 (Livneh product)

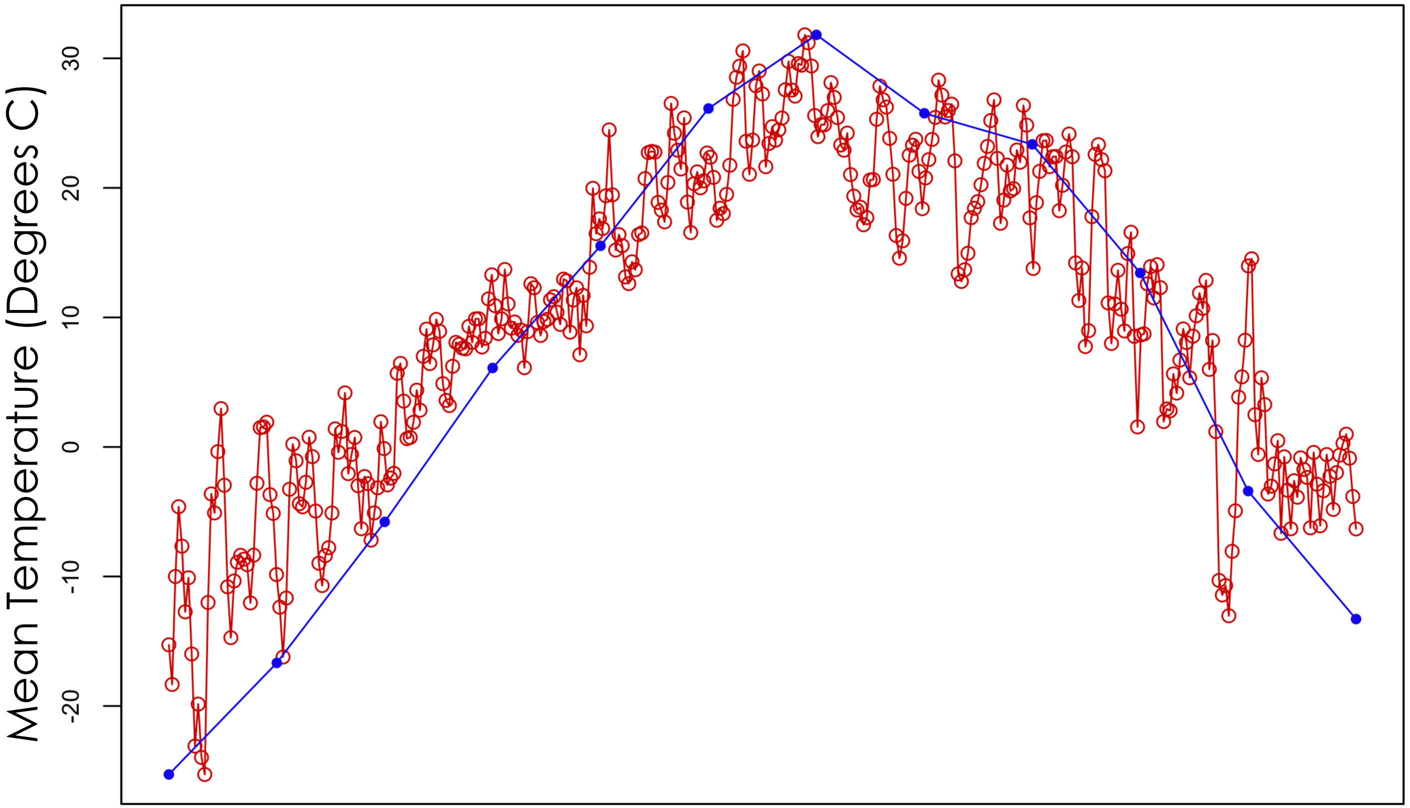
From Pierce et al., 2014 (doi:10.1175/JHM-D-14-0082.1)

4. Temporal Resolution

- Temporal resolution of finest comprehensive output available

- Examples:
  - **Decadal**
  - **Annual**
  - **Monthly**
  - **Daily**
  - **Sub-Daily**

- Temporal resolution helps determine what types of extremes you might evaluate.



NEX-GDDPv6 GISS E2.1-G
Mean Temperature in Ames, IA for 2014 (historical)
Daily vs. Monthly Time Step

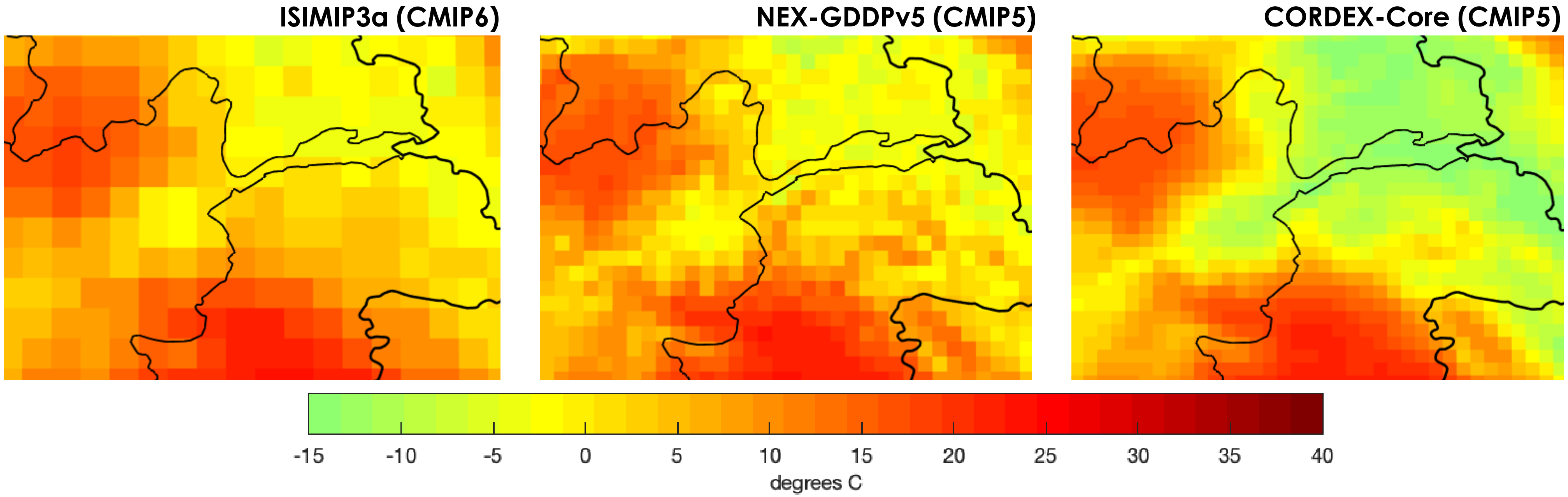
5. Spatial Resolution

- Typical spatial resolution (e.g., width of a grid cell) of finest comprehensive output available
- Note that finer resolution does not necessarily correspond to higher quality information

Afghanistan Panj-Amu River Basin Baseline Mean Annual Temperature

from ensemble mean across GCMs in three climate projection sets

Ruane et al., in prep for Wildlife Conservation Society

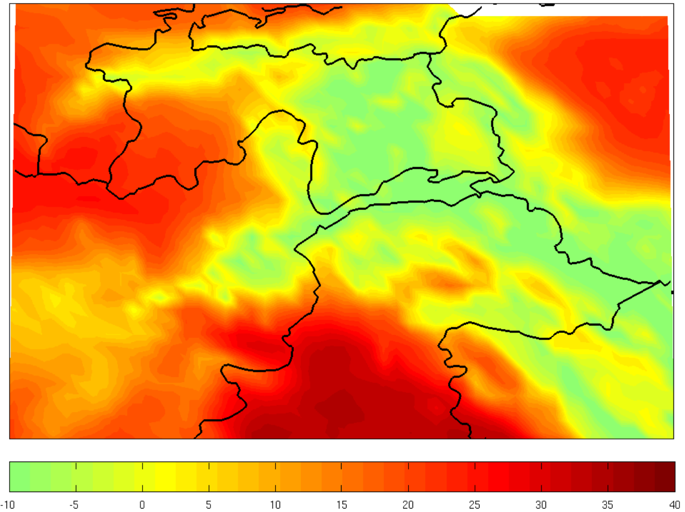


6. Post-Processing

- Describes methods applied to connect simulations with observed conditions
- Examples:
  - **Bias Adjustment**: Outputs adjusted to match statistics of observed conditions in historical period
    - Rooted in high-quality observational datasets
    - Variety of statistical and machine learning approaches

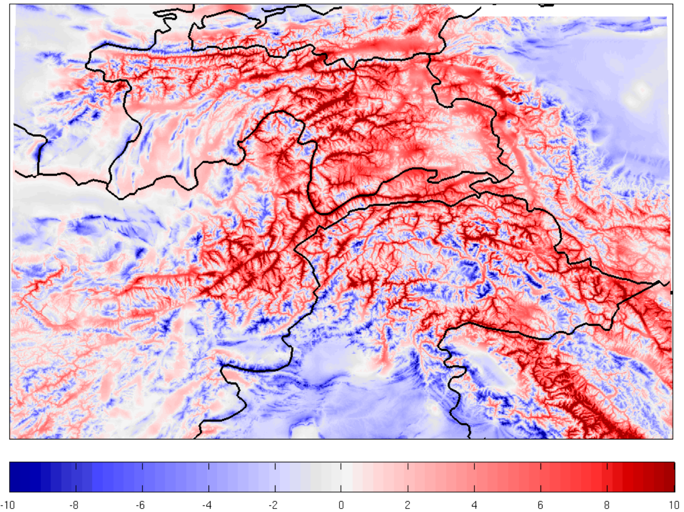
Afghanistan Panj-Amu River Basin CORDEX-Core May Temperature Bias Adjustment

Ruane et al., in prep for Wildlife Conservation Society



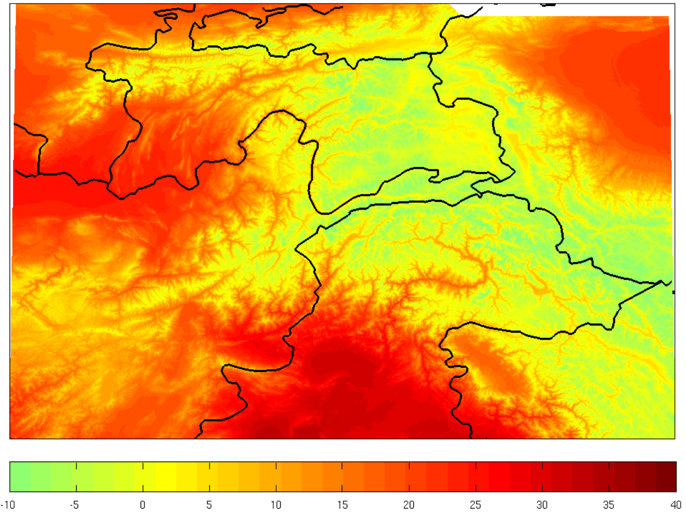
CORDEX-Core MPI-ESM-LR REMO2015 2010 May Temperature (C)

+



CHELSA May Temperature – CORDEX-Core MPI-ESM-LR REMO2015 May Temperature (1979-2013) Difference

=



Bias-Adjusted CORDEX-Core MPI-ESM-LR REMO2015 2010 May Temperature (C)

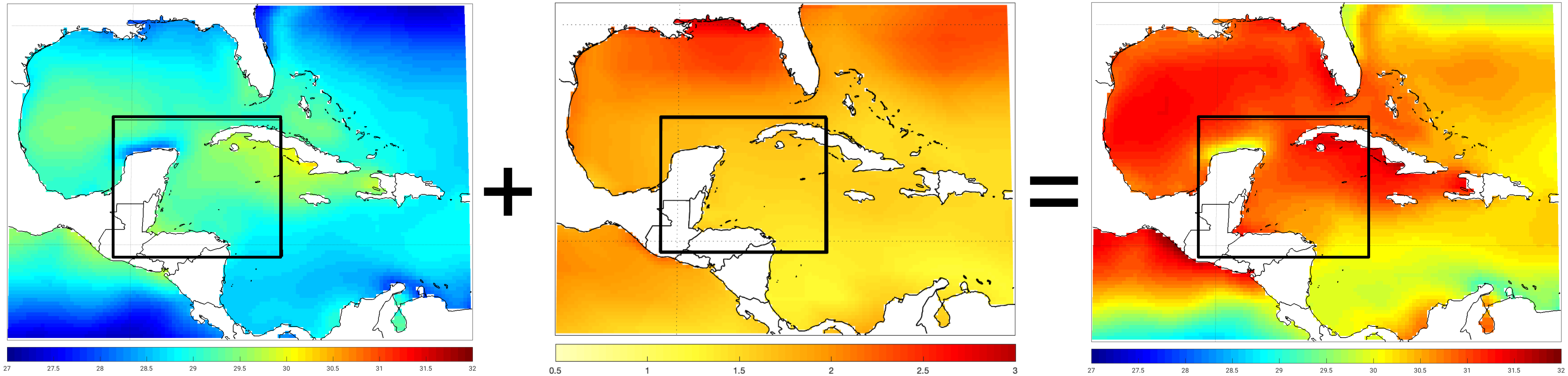
6. Post-Processing
Distribution Stretching

Rather than adjusting model output to look more like observations, some projections are made by adjusting observations to look more like climate change:

- **Delta Method**: Combines projected changes in climate means with observed data
- **Advanced Scaling**: Combines projected changes in climate distribution parameters (e.g., mean, standard deviation, *gamma* factor) with observed data

Delta Method of Adjusting GISS E2.1-G SSTs in the Mesoamerican Reef

Phillips et al., in prep

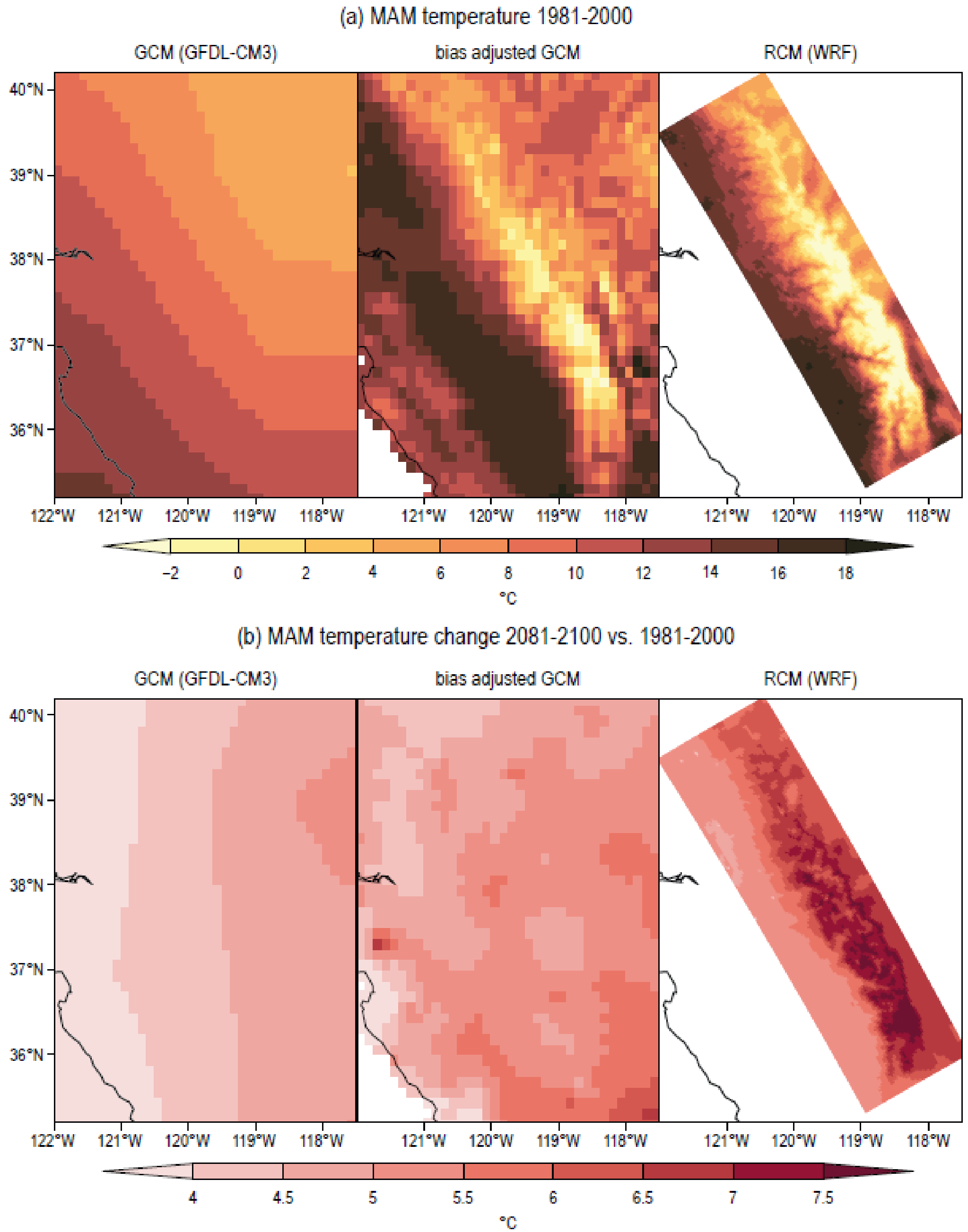


MERRA-2 Mean September SSTs 1980-2009 (degrees C) | *GISS E2.1-G Increase in September SSTs SSP5-8.5 2050-2059* | *GISS E2.1-G Mean September SSTs 2050-2059 Under SSP5-8.5 (degrees C)*

See also Ruane et al., 2015 (doi:10.1142/9781783265640_0003) for AgMIP crop modeling approaches

Bias-Adjustment vs. Downscaling

- Bias-adjustment can impose observed features, but does not necessarily capture the interaction of those features with climate change.



Daily Mean Temperature in the Sierra Nevada Region in California

IPCC AR6 WGI Chapter 10: Box 10.2

6. Post-Processing

Emerging Pipelines Involving Multiple Approaches to Reach Target

- IPCC AR6 WGI Chapter 10 noted several approaches that can combine many methods into local projections *(still rare)*.

  Dynamical:
  - Global Models
  - Regional Models
  - Further Nested Models

  Statistical:
  - Bias-Adjustment
  - Perfect Prognosis *(Establish relationship between large-scale conditions and observations)*
  - Weather Generators *(Create high number of artificial weather sequence iterations)*

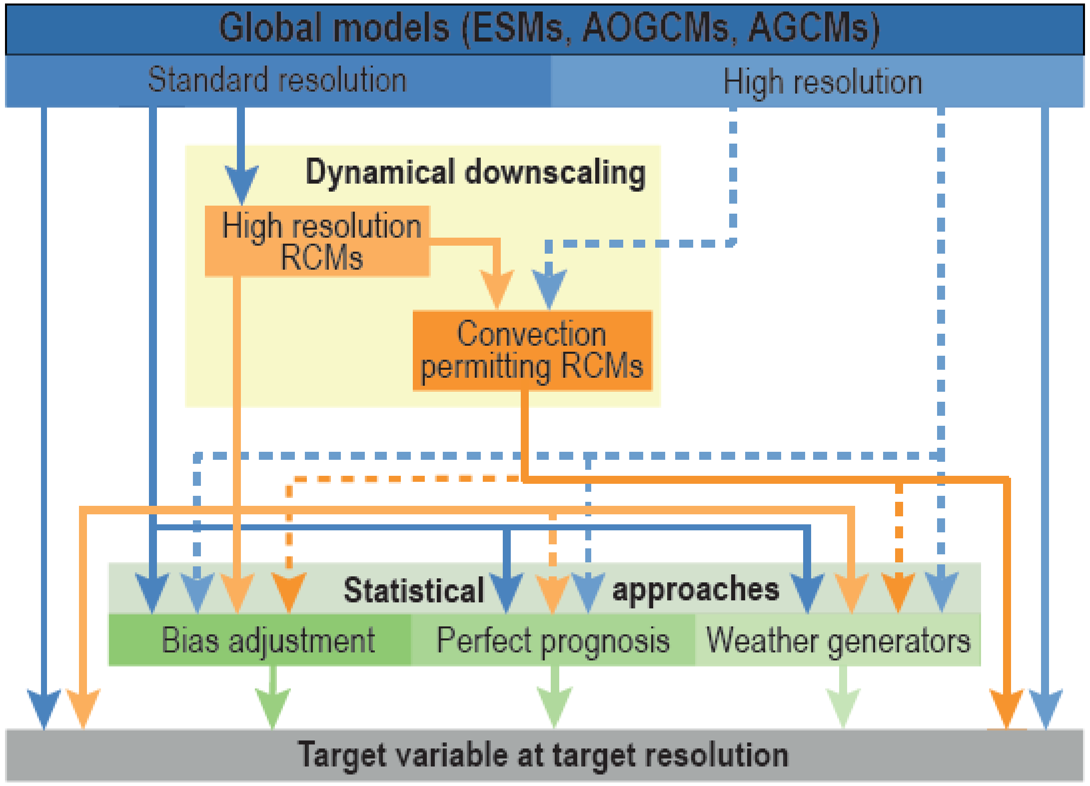
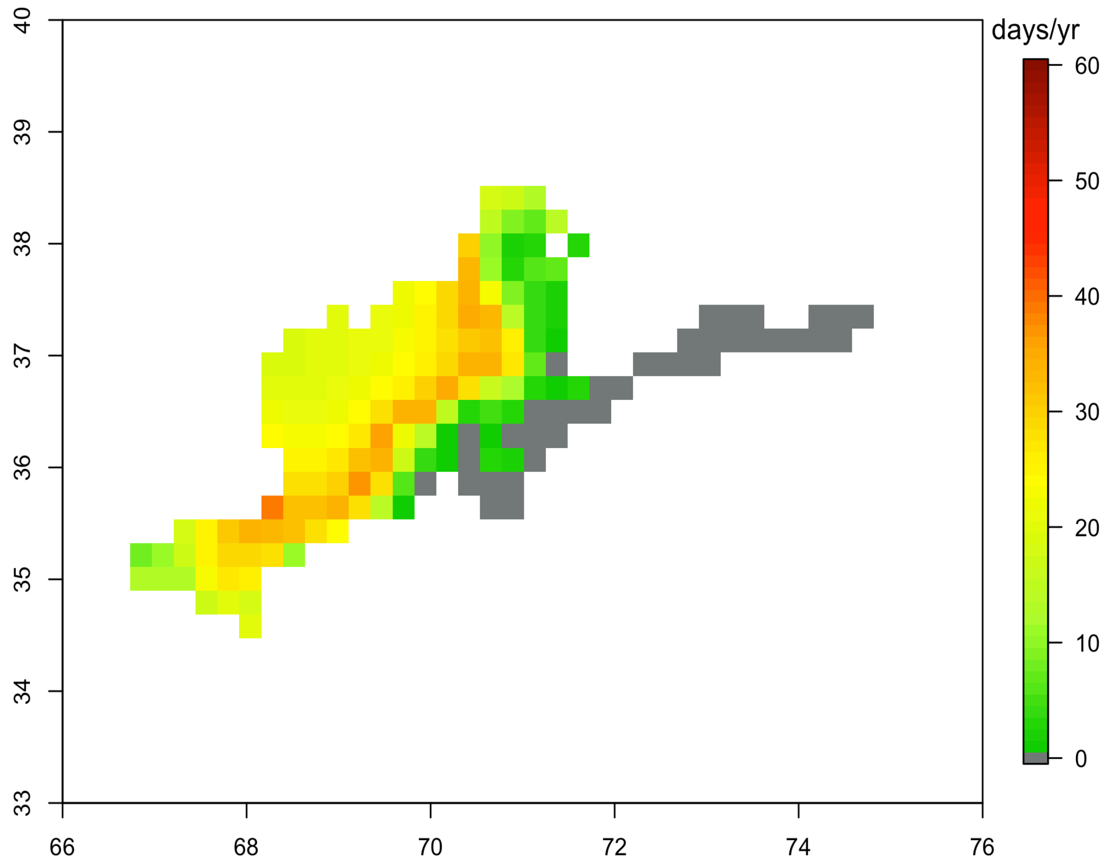


Figure 10.5 | Typical model types and chains used in modelling regional climate. The dashed lines indicate model chains that might prove useful but have not or only rarely been used. Hybrid approaches combining the model types shown have been developed.

IPCC AR6 WGI CH10; Doblas-Reyes et al., 2021

7. 'Application-Ready' Variables Available

- Describes the variables available for applications (out of the 100s available from ESM outputs)
- Examples of Common Sets:
  - **Temperature and Precipitation**: Most common minimum dataset for climate change applications.
  - **Climate Extremes:** Enhanced information about extreme climate events, potentially including extreme heat or cold, droughts, floods, and severe storms.
  - **Energy:** Information about surface short-wave and long-wave radiation budgets.

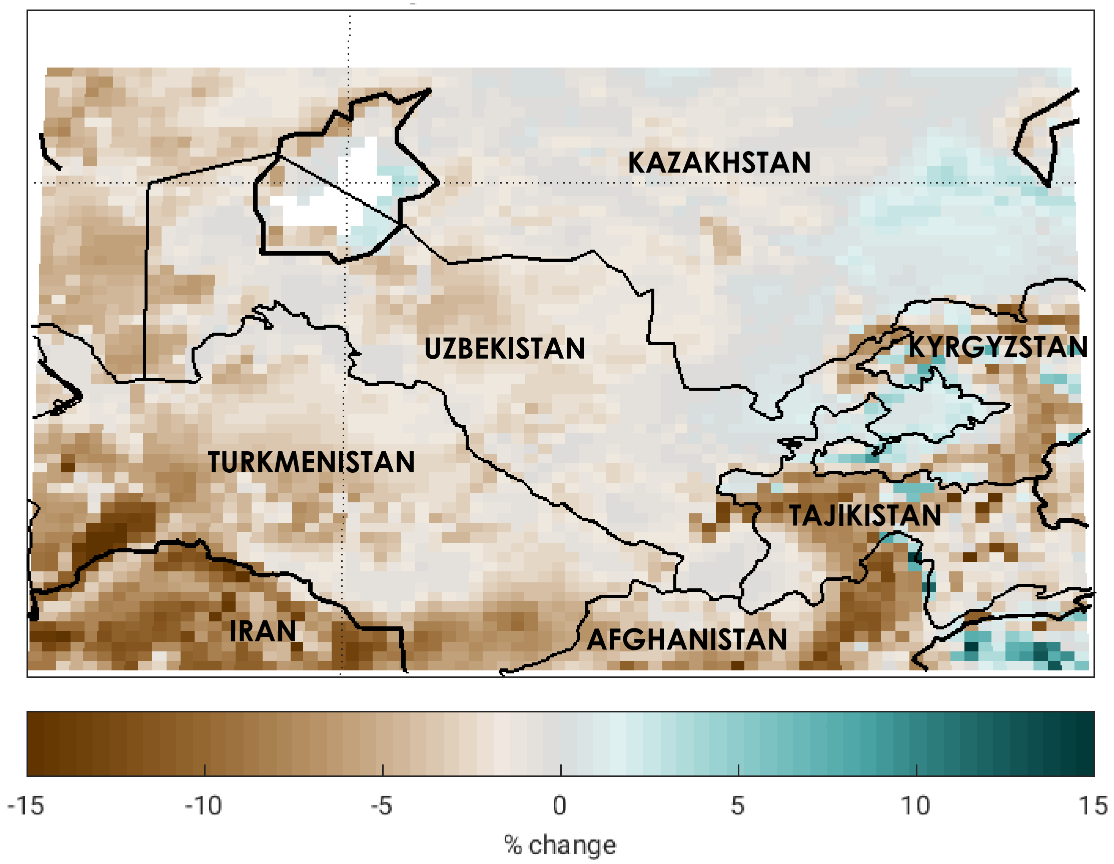


CORDEX-Core Change in High Heat Days (>25C) Per Year in Afghanistan Panj-Amu River Basin Mid-Century Period (2040-2069) Under RCP8.5

Ruane et al., in prep for Wildlife Conservation Society

7. ‘Application-Ready’ Variables

- Examples:
  - **Hydrology and Soils:** Enhanced information about the water cycle, potentially including enhanced information about soil moisture, runoff, river flows, and evapotranspiration.
  - **Snow and Ice**: Including cryospheric conditions such as snowpack, glaciers, permafrost, and freshwater or sea ice.
  - **Marine Hazards**: Including ocean variables such as ocean temperature and structure, marine heatwaves, and ocean chemistry (salinity, oxygen, or acidification).



CORDEX-Core Change in Mean Soil Moisture for Rainfed Cotton Season in Uzbekistan for End-of-Century (2070-2099 -- RCP8.5)
De Mel et al., in prep for United Nations Development Programme

Summary of Part 1:

- **Mitigation, adaptation, and risk applications areas have unique contexts.**
- **Climate projection sets come from climate models and are oriented toward decision-making.**
- **Key characteristics of a climate projection set:**
  1. Global Climate Models
  2. Scenarios and Storylines
  3. Downscaling
  4. Temporal Resolution
  5. Spatial Resolution
  6. Post-Processing
  7. ‘Applications-Ready’ Variables
- **Part 2 will describe considerations in choosing a projection set for a given application.**

Questions

- Please enter your questions in the Q&A box. We will answer them in the order they were received.
- We will post the Q&A to the training website following the conclusion of the webinar.

Contacts

Follow us on Twitter
@NASAARSET

- Trainers:
  - Brock Blevins: sean.mccartney@nasa.gov
  - Alex Ruane: alexander.c.ruane@nasa.gov
- Training Webpage:
  - https://appliedsciences.nasa.gov/join-mission/training/english/arset-selecting-climate-change-projection-sets-mitigation-adaptation
- ARSET Website:
  - https://appliedsciences.nasa.gov/what-we-do/capacity-building/arset

Check out our sister programs: