National Aeronautics and Space Administration

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

Alex Ruane & Brock Blevins

Sep 20, 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

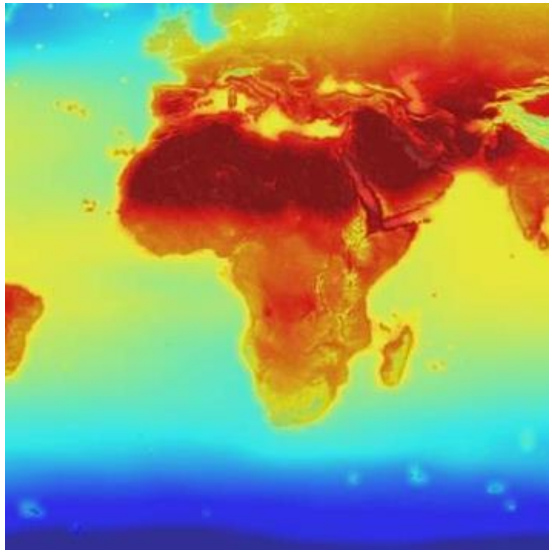
Prerequisites

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

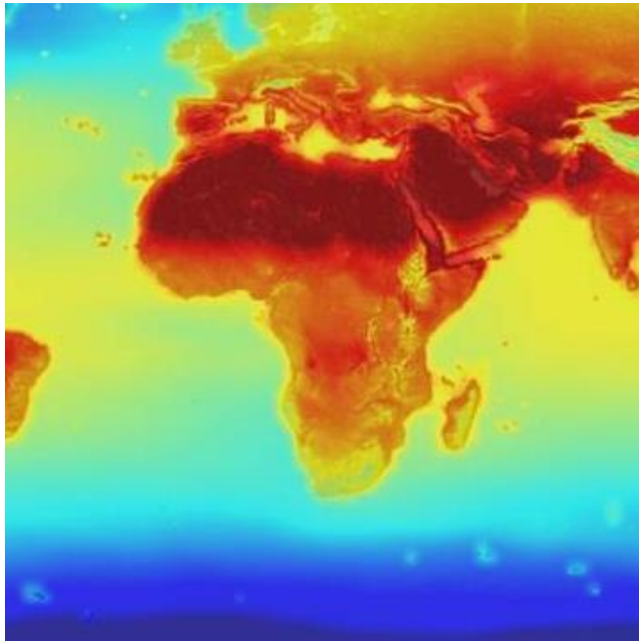


Training Outline

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*

National Aeronautics and Space Administration

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

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

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

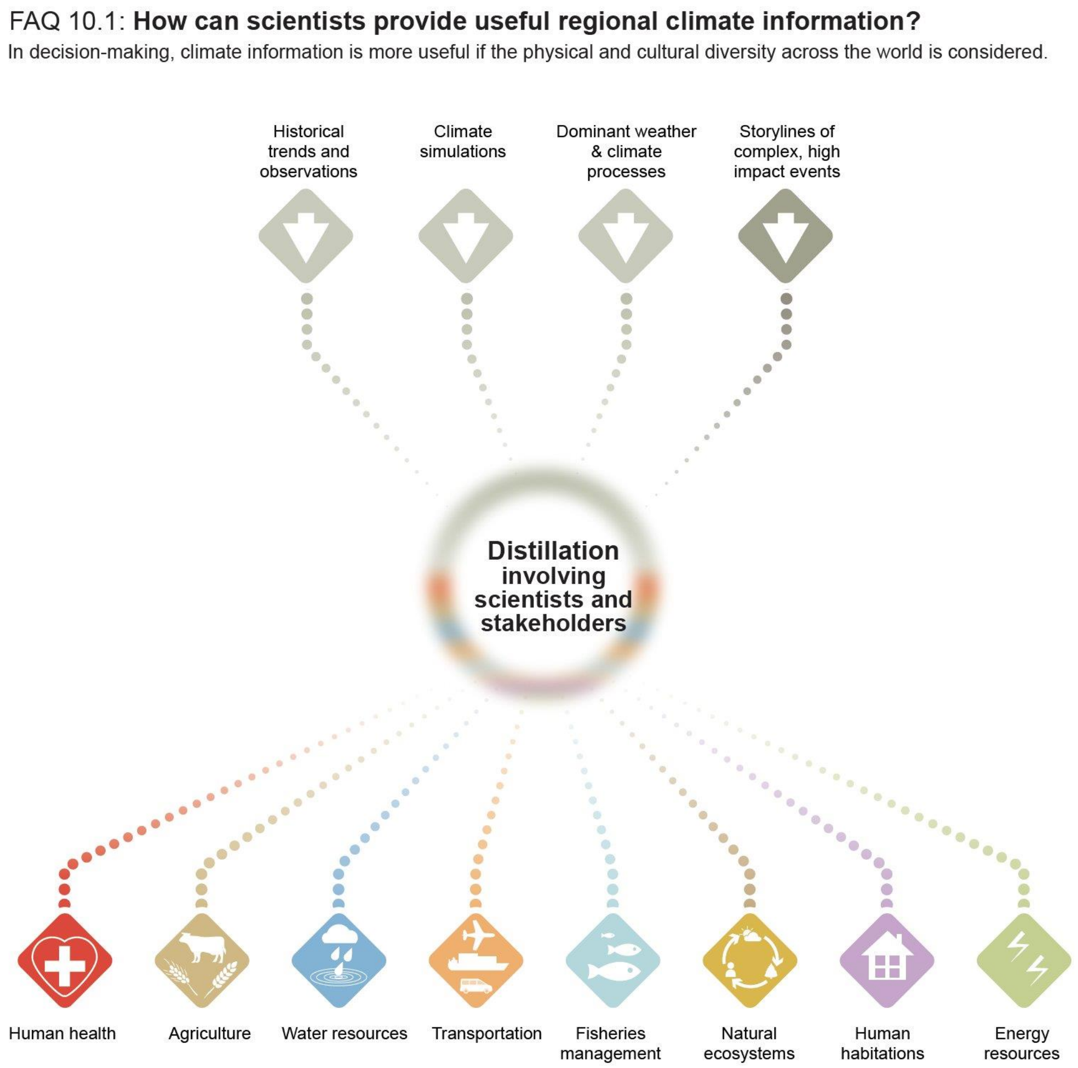
Recap of Part 1:

- **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.**

Matching Projection Set Characteristics to a Given Application's Needs

Co-Development Process Engaging with Stakeholders is Key

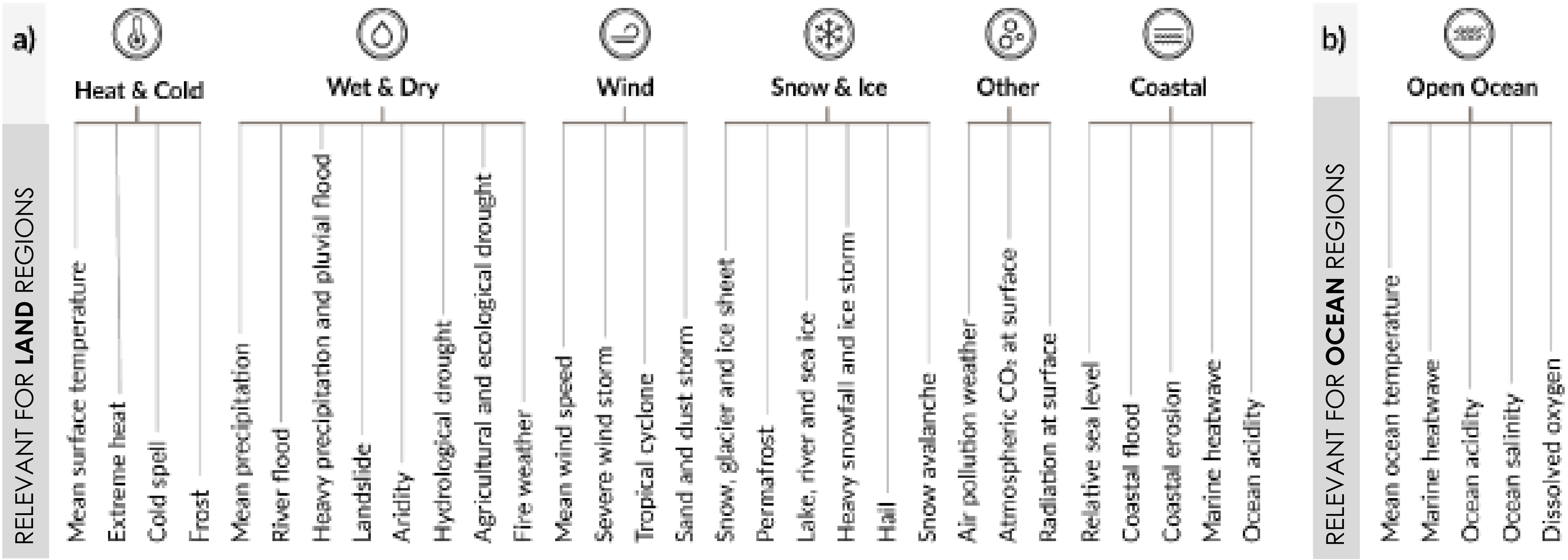
- Connect to system vulnerabilities and decision-making process
- Recognize values and motivations of all participants



Climate Information for Decision Makers
Doblas-Reyes et al., (2021)
IPCC AR6 WGI FAQ10.1

Targeting Useful Climate Information

A climatic impact-driver (CID) is a climate condition that directly affects elements of society or ecosystems. CIDs and their changes can lead to positive, negative or inconsequential outcomes (or a mixture).



Intensity, Frequency, Duration, Timing, Spatial Extent

Adopted from IPCC WGI (2021) Figure SPM.9; see also WGI Chapter 12

IPCC (2021); Ranasinghe et al. (2021)
Ruane et al. (in review)

Identifying Relevant Climatic Impact-drivers (CIDs)

Sector	Asset	Heat and Cold				Wet and Dry								Wind				Snow and Ice						Coastal			Open Ocean					Other		
		Mean air temperature	Extreme heat	Cold spell	Frost	Mean precipitation	River flood	Heavy precipitation and pluvial flood	Landslide	Aridity	Hydrological drought	Agricultural and ecological drought	Fire weather	Mean wind speed	Severe wind storm	Tropical cyclone	Sand and dust storm	Snow, glacier and ice sheet	Permafrost	Lake, river and sea ice	Heavy snowfall and ice storm	Hail	Snow avalanche	Relative sea level	Coastal flood	Coastal erosion	Mean ocean temperature	Marine heatwave	Ocean acidity	Ocean salinity	Dissolved oxygen	Air pollution weather	Atmospheric CO_2 at surface	Radiation at surface
Food, Fibre and Other Ecosystem Products (WGII Chapter 5)	Crop systems	Low/moderate	High	Low/moderate	High	High	High	High		High	High	High	Low/moderate	Low/moderate	Low/moderate	Low/moderate	Low/moderate	Low/moderate	Low/moderate		Low/moderate	High			Low/moderate							Low/moderate	High	Low/moderate
	Livestock and pasture systems	Low/moderate	High	High		Low/moderate	High	Low/moderate		High	Low/moderate	High	Low/moderate		Low/moderate		Low/moderate	Low/moderate			Low/moderate	Low/moderate			Low/moderate							Low/moderate	Low/moderate	Low/moderate
	Forestry systems	High	High	Low/moderate	Low/moderate	Low/moderate	Low/moderate			High		High	High	Low/moderate	Low/moderate			Low/moderate	Low/moderate		Low/moderate	Low/moderate			Low/moderate							Low/moderate	High	Low/moderate
	Fisheries and aquaculture systems	Low/moderate	Low/moderate				Low/moderate				Low/moderate			Low/moderate	Low/moderate	Low/moderate		Low/moderate		Low/moderate				Low/moderate	High		High	High	High	Low/moderate	Low/moderate			

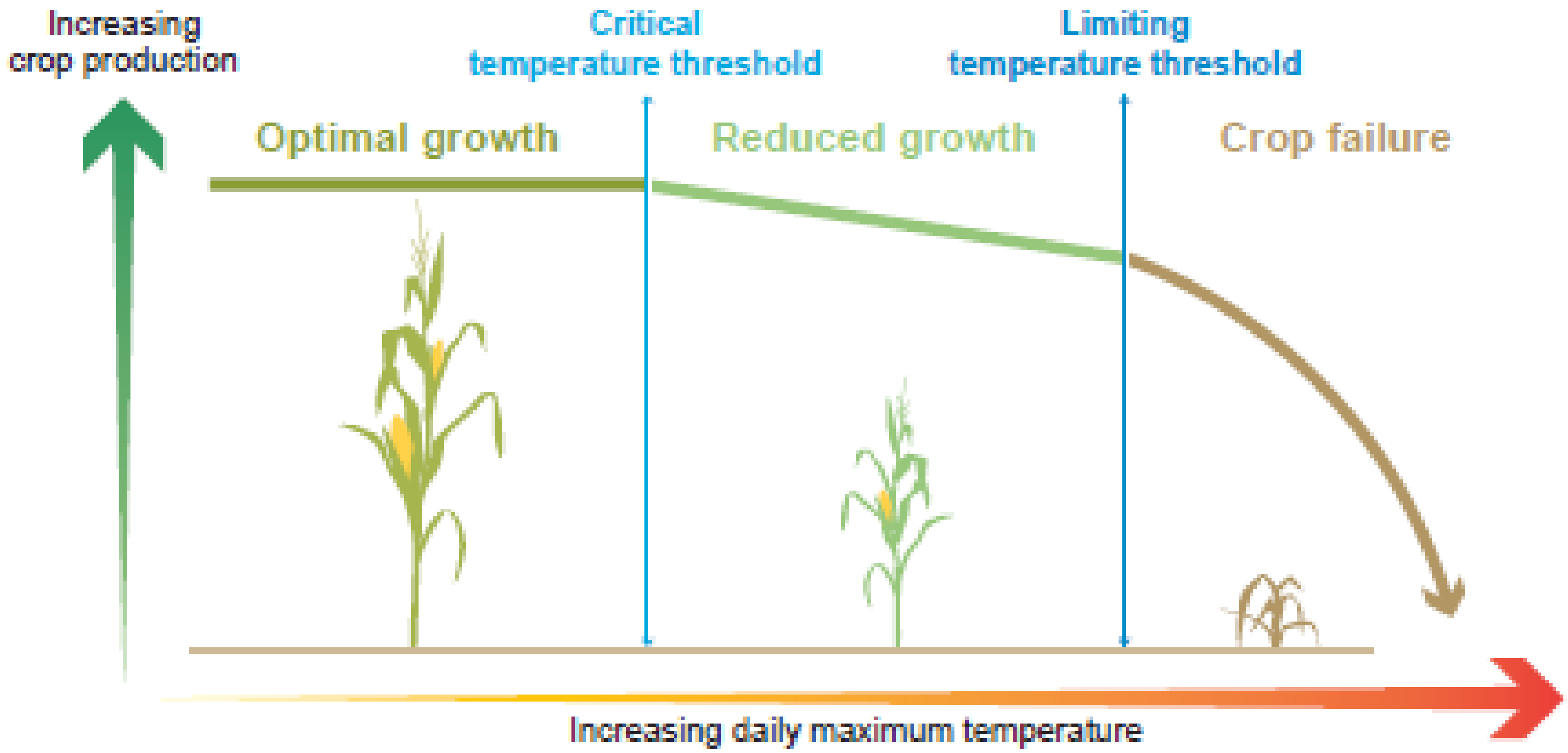
None/low confidence | Low/moderate | High

Impacts and risk relevance

Also important to note what is NOT included in a given projection set

IPCC AR6 WGI Chapter 12
Table 12.2
Ranasinghe et al. (2021)

Identifying Climatic Impact-Driver (CID) Indices

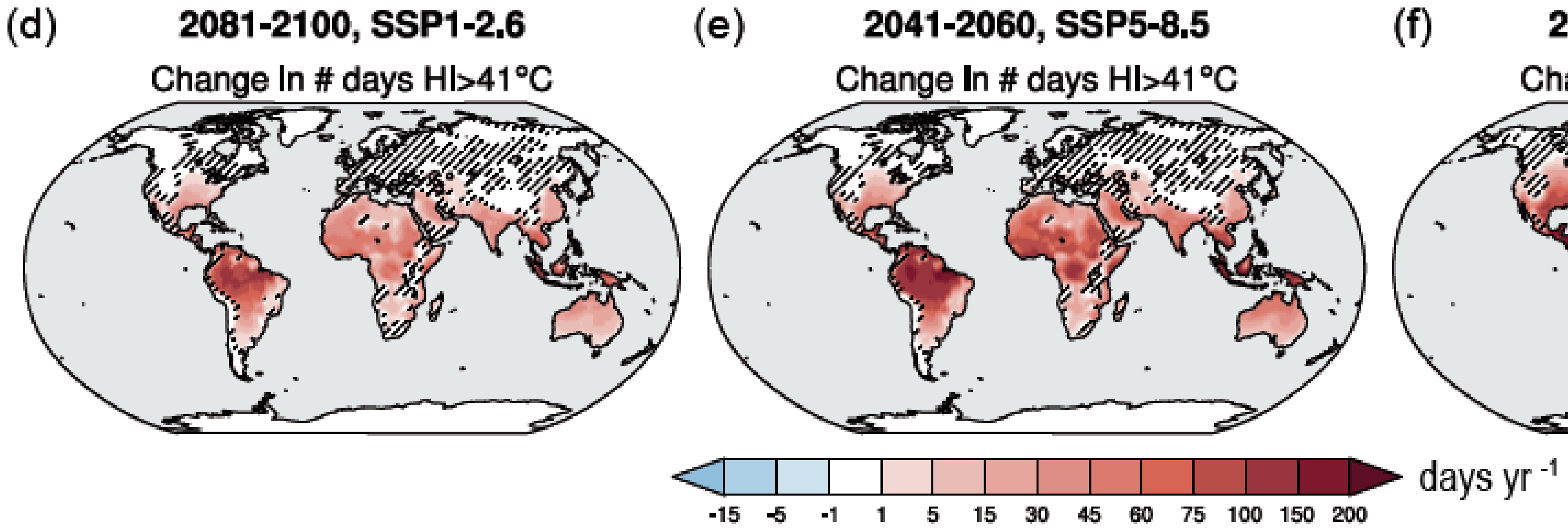


FAQ 12.2, Figure 1 | Crop response to maximum temperature thresholds. Crop growth rate responds to daily maximum temperature increases, leading to reduced growth and crop failure as temperatures exceed critical and limiting temperature thresholds, respectively. Note that changes in other environmental factors (such as carbon dioxide and water) may increase the tolerance of plants to increasing temperatures.

IPCC AR6 WGI Chapter 12
Ranasinghe et al. (2021)
FAQ12.2
See Also: Ruane et al. (in review)

Identifying Application Needs

- More specialized applications may require **tailored projection characteristics**.
- Availability of critical variables used to drive an impacts model.
  – Relationship to **sector-relevant tolerance thresholds** is particularly important.



Days above NOAA Heat Index > 41℃ , which is dangerous for outdoor exercise, construction, and agricultural labor.
Source: IPCC AR6 WGI CH12; Ranasinghe et al. (2021) Figure 12.4

Matching Scientific Information that will Enable Decisions

- **Scale of Analysis**:
  - Are projections needed at one point or across a broader domain?
    - Point-based analyses can allow more complex approaches given the reduction in spatial coverage.

- **Quality of Local Observations**:
  - Is application region relatively data sparse or data rich?
    - Bias-adjustment techniques work better where observations are strong.

- **Use of Further Impacts Models**:
  - Are projections designed to calculate single climatic impact-driver indices or to drive a more complex impact model?
    - Impact models require more coherence across space, time, and variables.

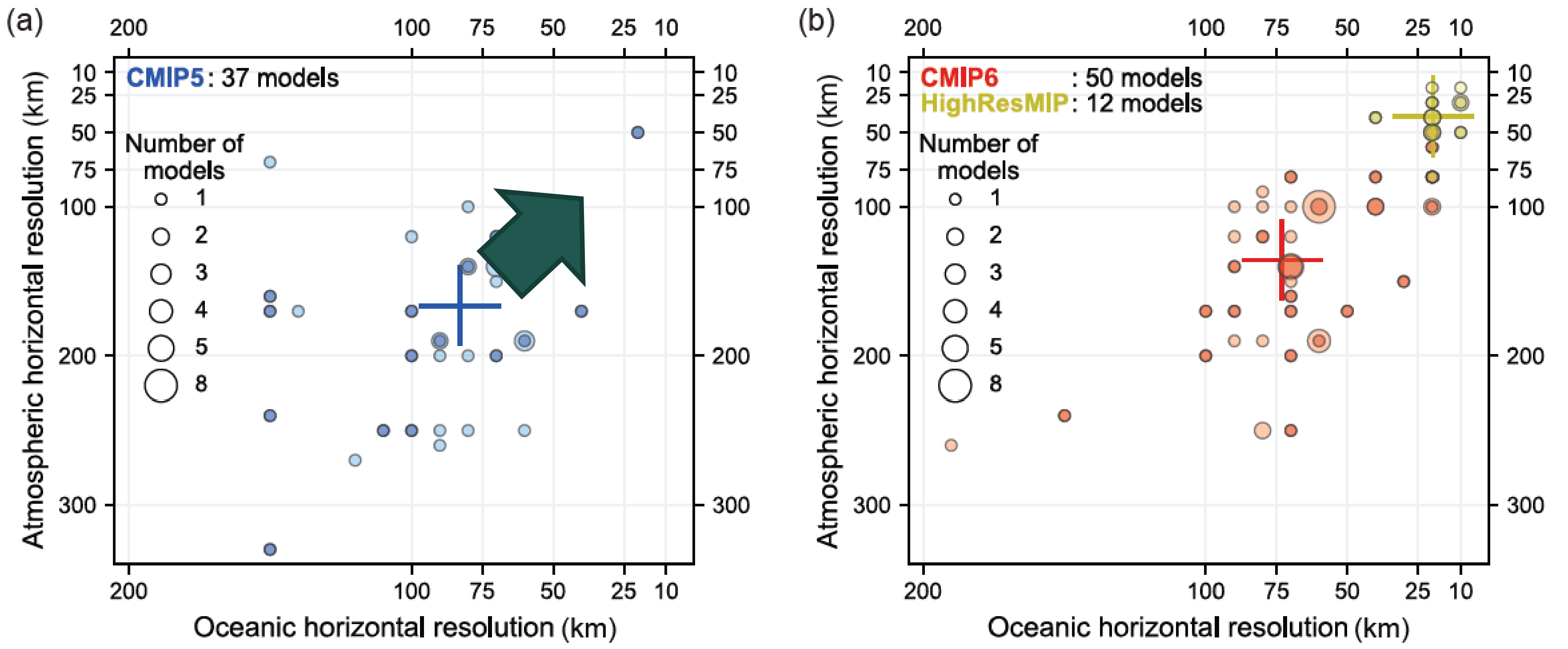
Advantage of Using Most Updated Versions

Benefits of Using Updated Versions

- **Substantial improvements over time in all aspects of climate projections:**
  1. Global Climate Models
  2. Scenarios and Storylines
  3. Downscaling
  4. Temporal Resolution
  5. Spatial Resolution
  6. Post-Processing
  7. ‘Applications-Ready’ Variables

Substantial Improvements in Climate Models

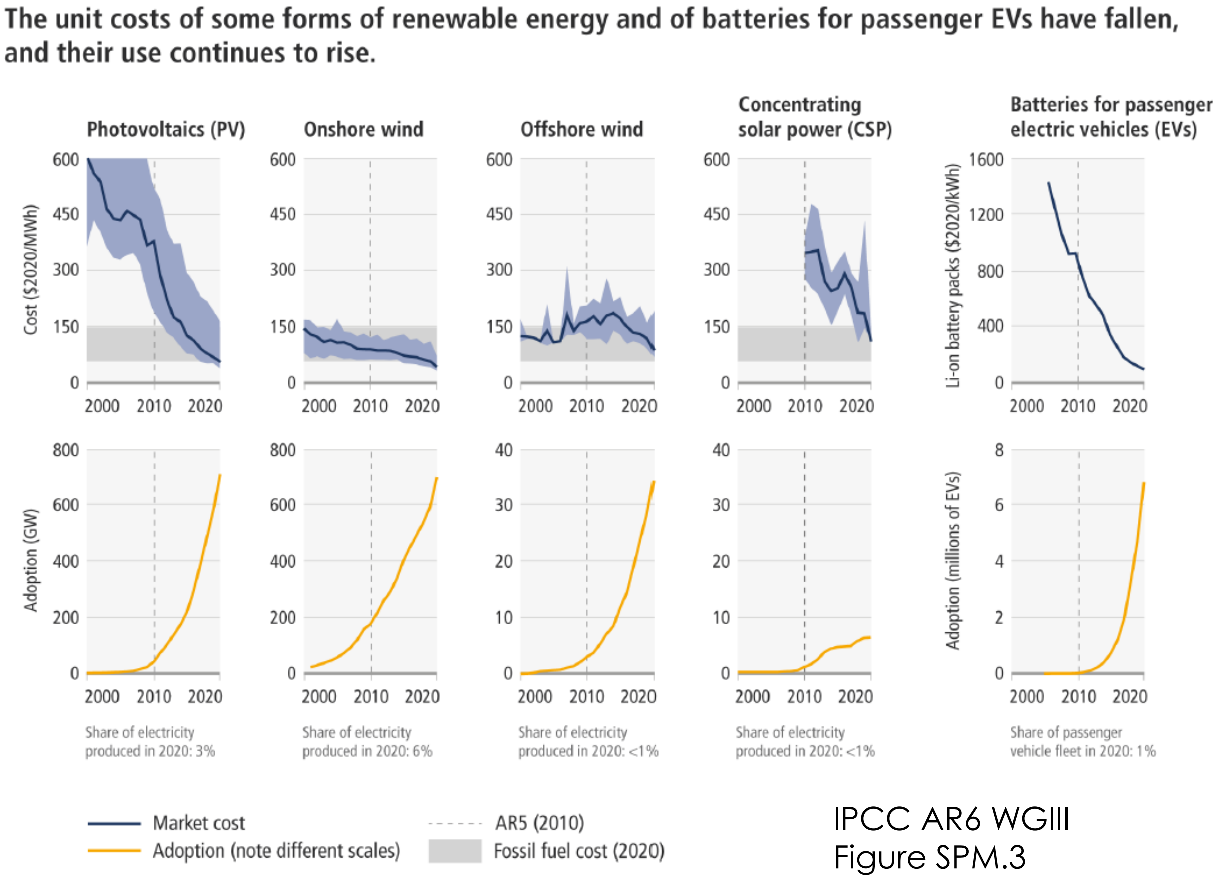
- **Aim for CMIP6 rather than CMIP5; avoid CMIP3 or older**
- Improved spatial resolution
- Improved physics and process representation
- Additional models with heightened diagnostic information



IPCC AR6 WGI CH1
Chen et al. (2021)
Figure 1.19

Substantial Improvements in Scenarios and Storylines

- **Aim for Global Warming Levels (GWLs) and SSP-RCPs, not RCPs or SRES**
- Scenarios community tracks many dynamically interacting aspects of society
- Huge changes in technology and socioeconomic growth in recent decades
- **Unforeseen Events**:
  - September 11th came after SRES scenarios
  - Paris Agreement (2015)
  - COVID-19
  - Conflict in Ukraine
  - Dramatic drop in green technology costs:
- **Renewed focus on GWLs**



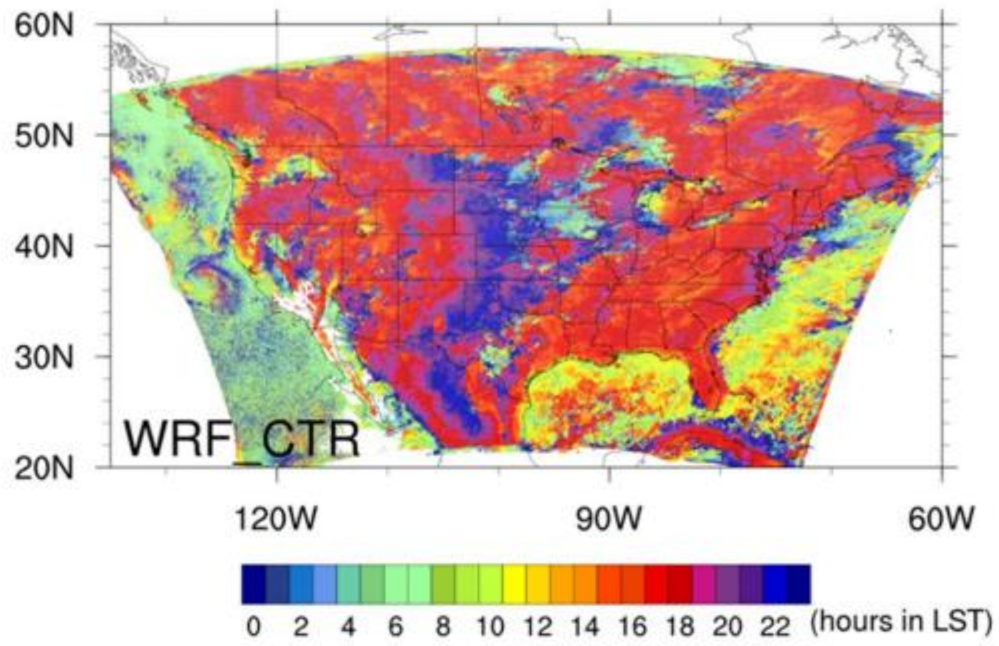
IPCC AR6 WGIII Figure SPM.3

Substantial Improvement in Downscaling

- **Look for models connected to strong benchmarking and intercomparison efforts.**

- The Coordinated Regional Downscaling Experiment (CORDEX) has facilitated multi-model ensemble approaches *[more on this in a later slide]*.

- Emergence of convection-resolving models



Time of Day for Diurnal Peak Precipitation (Historical period – June)
4km Weather Research and Forecasting (WRF) Model Simulation
from Scaff et al., 2020 (doi:10.1007/s00382-019-04754-9)

Advantages in Temporal and Spatial Resolution

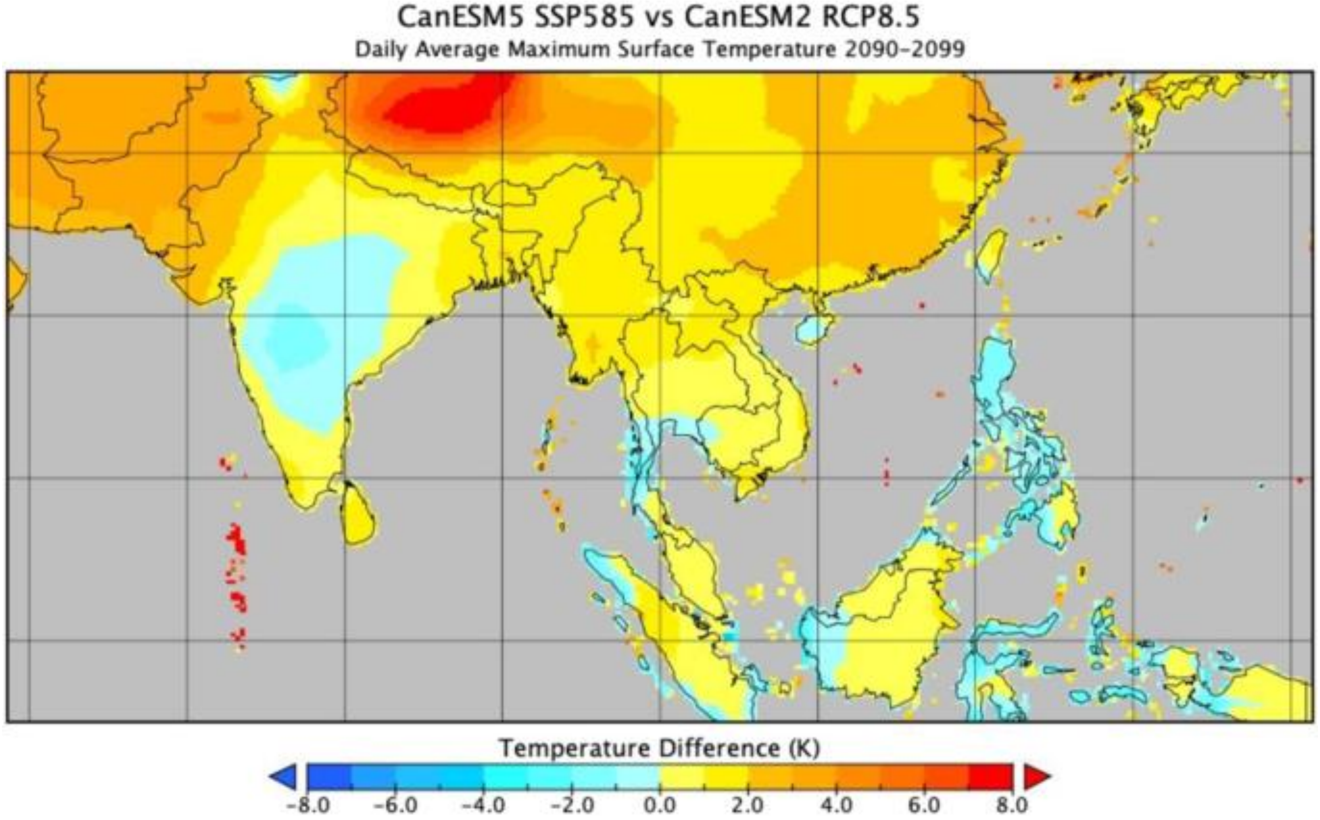
Newer projection sets are more likely to have high-resolution information.

- More models and ensemble members have provided daily and hourly outputs.
- Spatial resolutions are also increasing for models, downscaling, and bias-adjustment approaches.

Advantages in Post-Processing and Bias-Adjustment

Bias-adjustment techniques are improving with better methods, datasets, and computational power.

- New approaches to maintain coherence between complex variables
- New methods to maintain trends in bias-adjustment
- Improvement in underlying observational datasets



End-of-Century Maximum Daily Temperature Difference between NEX-GDDP-CMIP5 vs. NEX-GDDP-CMIP6 (CanESM)
from Thrasher et al., 2022 (doi:10.1038/s41597-022-01393-4)

Advances in Applications-Ready Variables

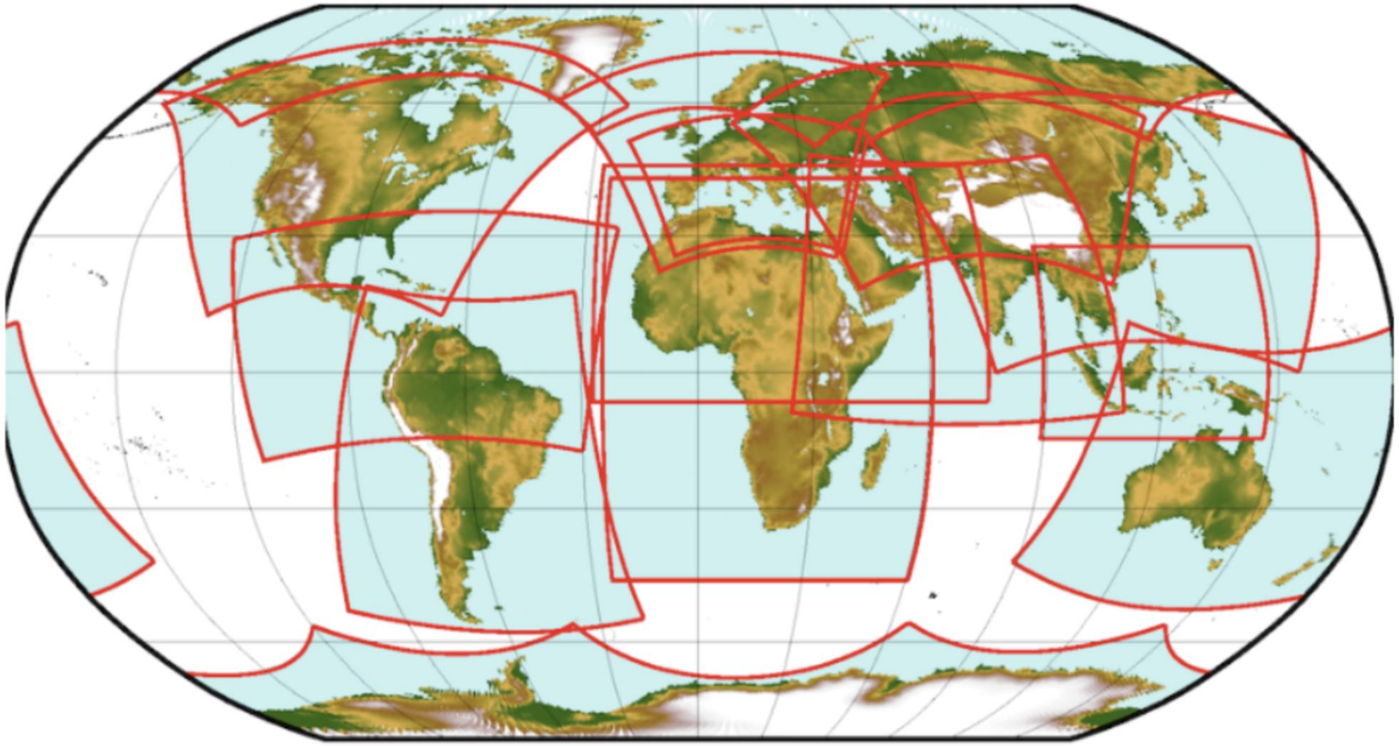
More modeling groups and project sets have made more variables available.

- More projection sets include information beyond temperature and precipitation.
- Sectoral impact groups have developed variable packages for specific applications.
  - The Vulnerability, Impacts, Adaptation, and Climate Services (VIACS) Advisory Board at CMIP6
  - The Inter-Sectoral Impacts Model Intercomparison Project (ISIMIP)
    - *[More on this in a later slide]*
  - The Agricultural Model Intercomparison and Improvement Project (AgMIP)
  - Plus, more community efforts around forestry, fisheries, and ecosystems (e.g., Bioclim variables appropriate for ecosystem suitability mapping)

Examples of Common Projection Sets

Coordinated Regional Climate Downscaling Experiment (CORDEX)

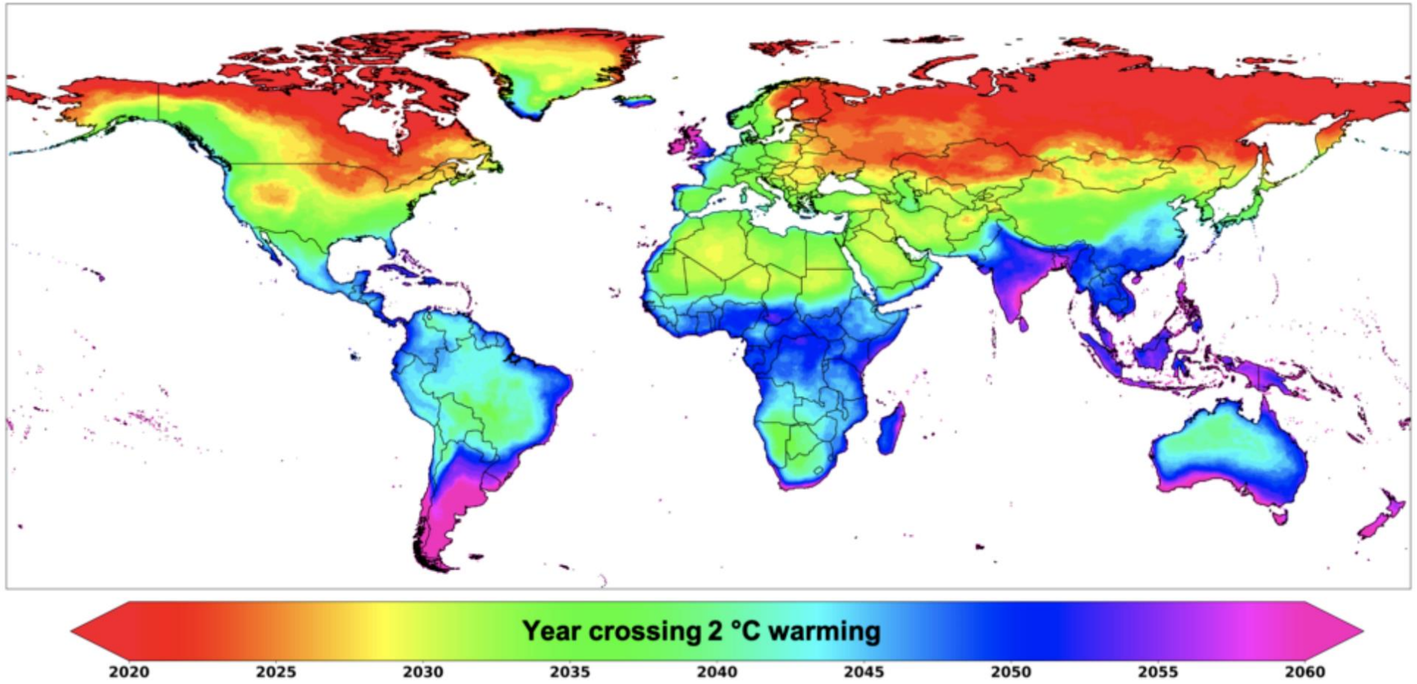
- Coordination between global and regional models to produce regional climate projections for a set of domains
- Standardized domains, formats, variable units, and experiments (scenarios) with diverse GCM-RCM combinations
- CORDEX CMIP5:
  - 14 domains across the globe with varying GCM-RCM combinations
  - 2-3 RCP scenarios
  - Spatial resolution between 0.22-degrees and 0.44-degrees
  - Up to sub-daily outputs
  - Many climate variables available
  - May need additional bias-adjustment
  - Availability of latest climate model outputs tends to lag behind statistical downscaling approaches



Overview of CORDEX Domains with Topography
Source: WCRP CORDEX

NASA Earth Exchange (NEX)

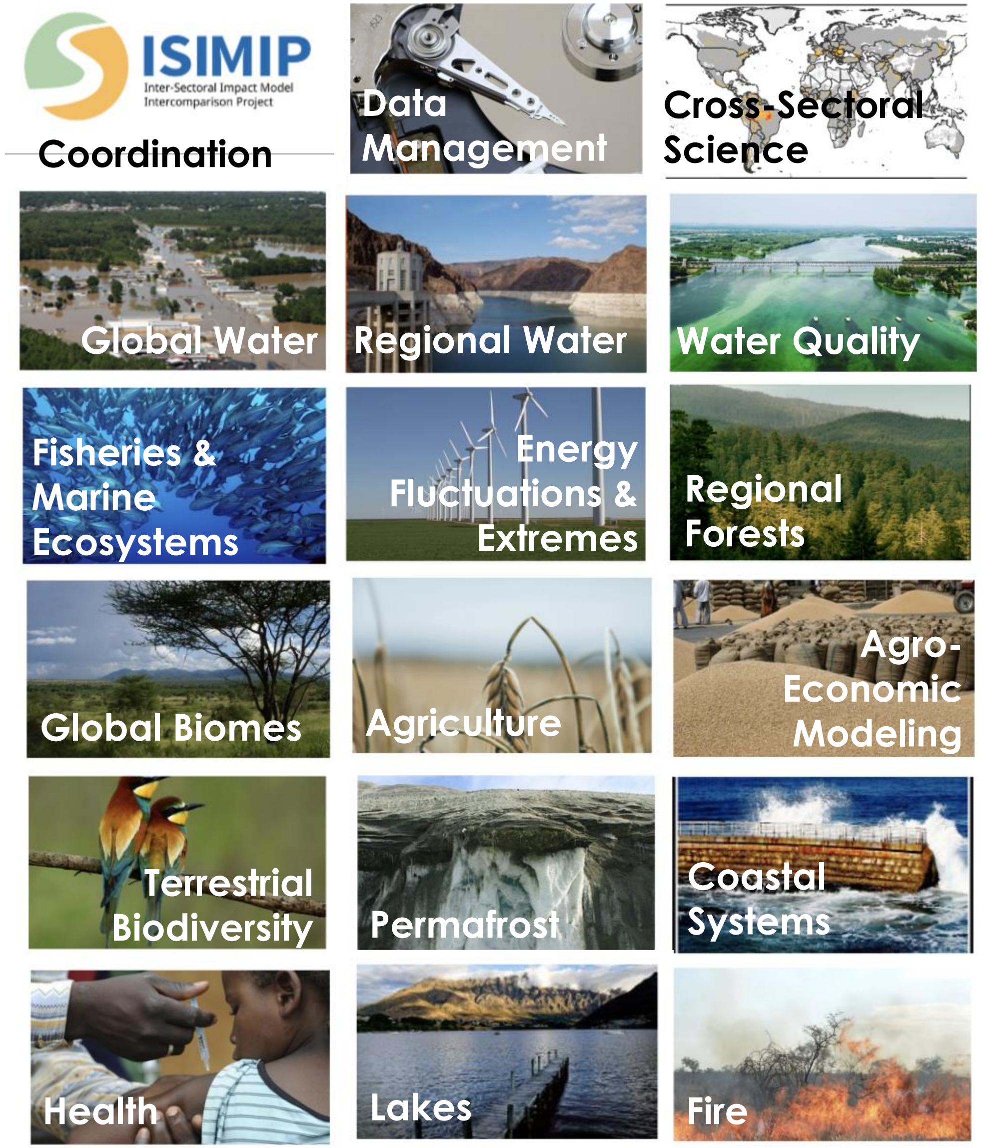
- Standardized formats with multiple methods (GDDP, LOCA, etc.)
- NEX-GDDP
  - 35 CMIP6 GCMs
  - Four SSP-RCP scenarios for most GCMs
  - Global 0.25-degree domain
  - Bias-adjusted using global meteorological forcing dataset
  - 9 climate variables for most GCMs
  - Daily outputs
- NEX-LOCA
  - ~1 km resolution over US
  - Monthly outputs



Year of Crossing 2C Warming Relative to 1950-1979 under SSP5-8.5 Scenario
Source: NASA NEX-GDDP
https://www.nasa.gov/nex/gddp

Inter-Sectoral Impacts Model Intercomparison Project (ISIMIP)

- Consistent, downscaled, bias-adjusted climate projections serve as drivers across multiple impacts, sectors, and scales.
- International network of impacts modeling groups
- Overview of Outputs:
  - Five CMIP6 GCMs available early
    - Additional models still coming online
  - Three SSP-RCP scenarios
  - Global 0.5-degree domain
  - Bias-adjusted using WFDE5 and ERA5 historical climate forcing datasets
  - Daily outputs
  - 11 climate variables selected to enable impacts model simulations

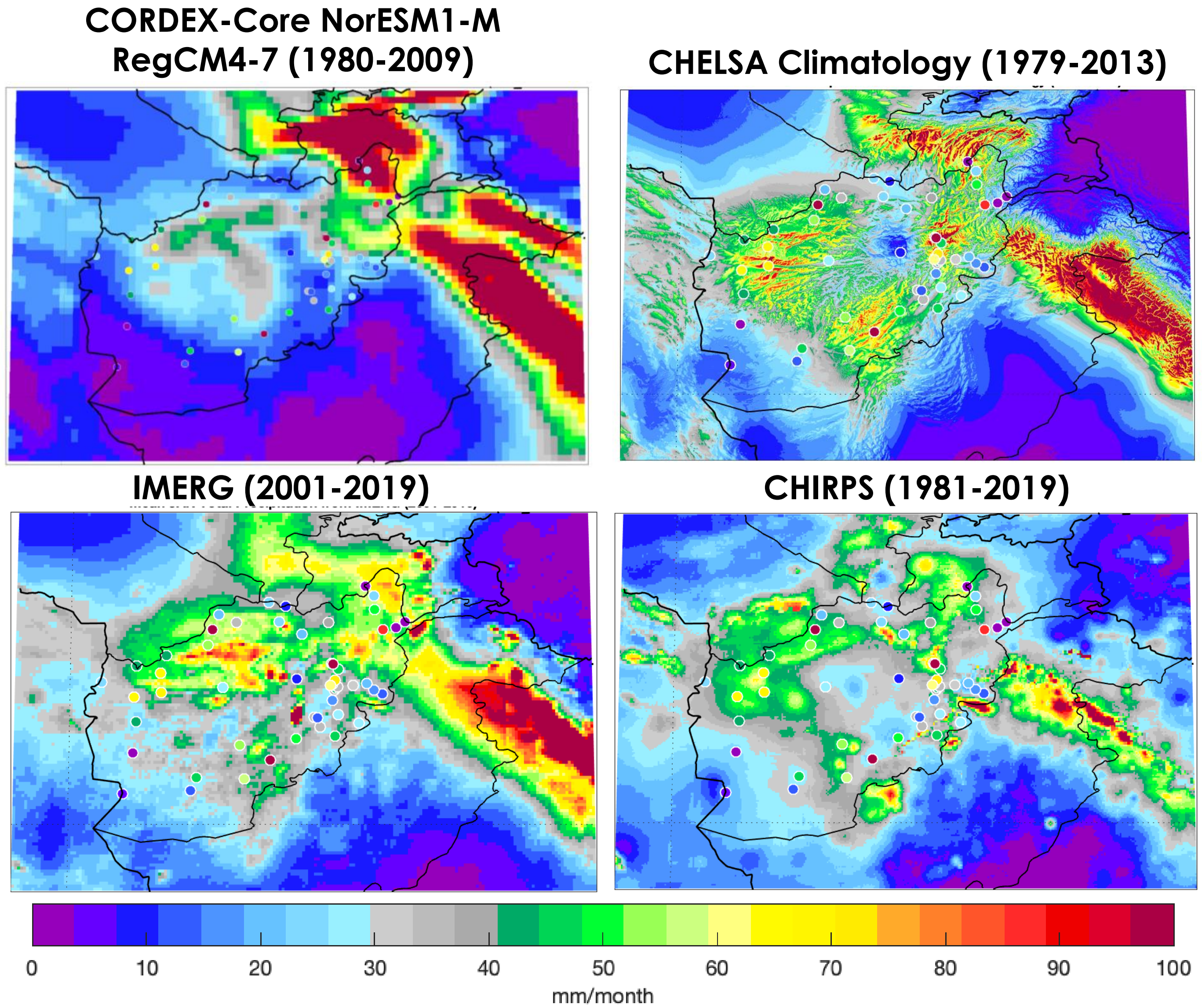


ISIMIP: Overview of Sectors
Source: ISIMIP

Tradeoffs in Using More Complex Climate Projection Sets

Tradeoffs in Using More Complex Climate Projection Sets

- Existence of data at higher resolution does not necessarily indicate higher quality.
- Potential illusion of false levels of detail.
- Data-sparse regions are difficult to benchmark (what's correct?).
- Observational datasets used in bias correction may have higher fidelity at lower resolutions.
- Higher resolution requires more computational space and processing time.



Afghanistan Baseline Total January Precipitation

Ruane et al., in prep for Wildlife Conservation Society

Tradeoffs in Using More Complex Climate Projection Sets

Temporal Resolution

Hours x **Days** x **Months** x **Years** x **Scenarios** x **ESMs** x **Ensemble Members** **x** **Variables**

24 x 30 x 12 x 120 x ~4 x ~20 x ~5 x ~4

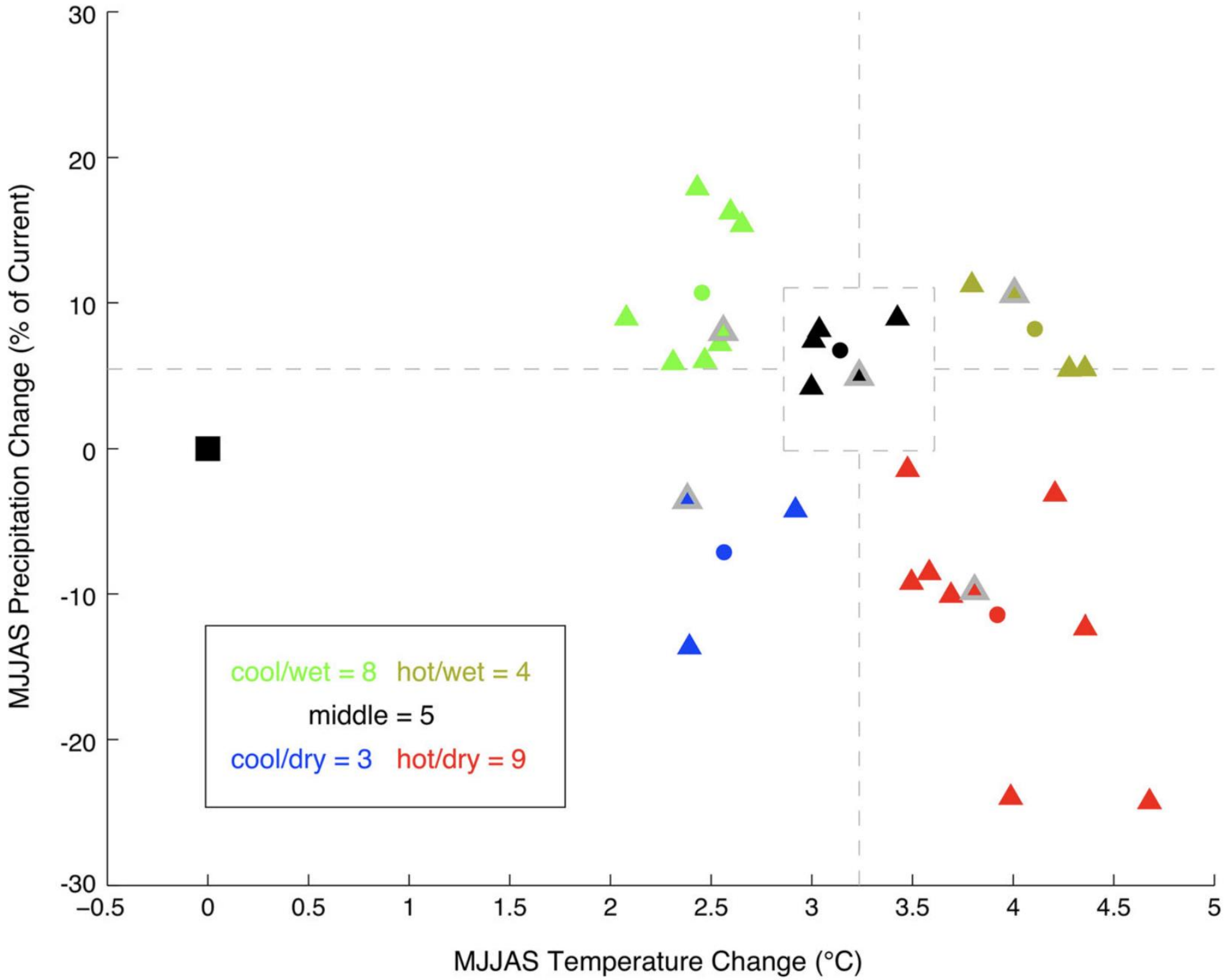
= 1.6+ billion data points (for one location)

- Monthly outputs alone reduce this number by 720x
- Fewer ESMs have posted outputs at higher temporal resolution

Model Subsets Due to Resource Constraints

- **Model Democracy** was common through CMIP5
  – One model = one vote? (*no subsets whenever possible*)

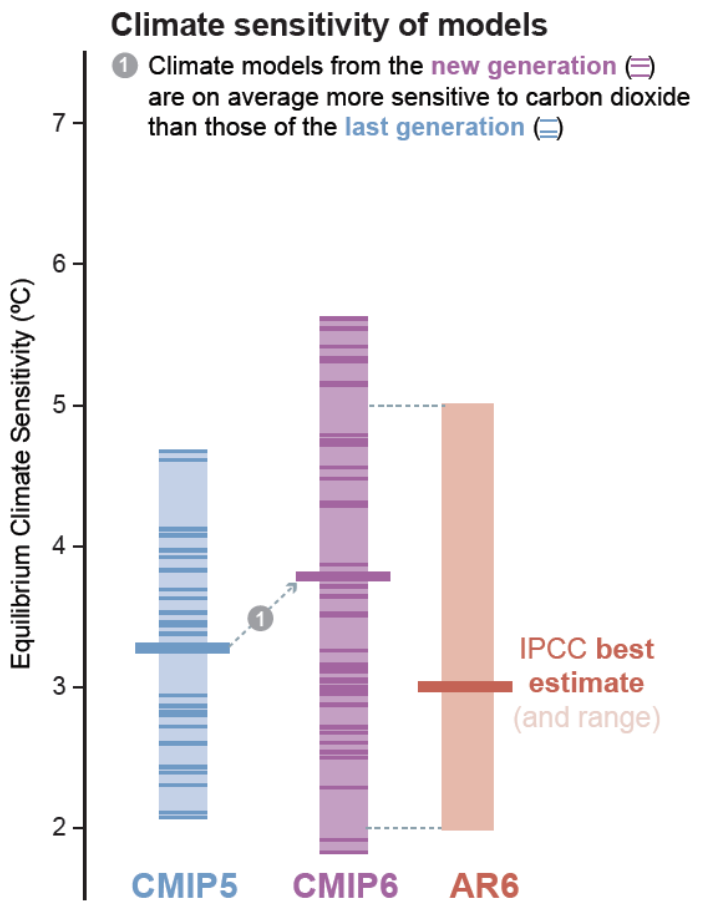
- **Resource Constraints** – Choose models that convey storylines



Representative Subset of GCMs for Ames, Iowa
by temperature and precipitation change
From Ruane and McDermid, 2017 (doi:10.1186/s40322-017-0036-4)

Model Subsets Due to Physical Constraints

- **"Hot Models"** (See IPCC AR6 Glossary plus WGI CH7: Forster et al., 2021; Hausfather et al., 2022)
  - Equilibrium Climate Sensitivity (**ECS**) = The equilibrium (steady state) change in the surface temperature following a doubling of the atmospheric carbon dioxide (CO_2) concentration from pre-industrial conditions.
    - IPCC Assessed very likely range for ECS: 2.0-5.0℃
  - Transient Climate Response (**TCR**) = The surface temperature response for the hypothetical scenario in which atmospheric carbon dioxide (CO_2) increases at 1% yr^{-1} from pre-industrial to the time of a doubling of atmospheric CO2 concentration (year 70).
    - IPCC Assessed very likely range for TCR: 1.2-2.4℃
  - Beware of models with ECS or TCR beyond assessed range, 'hot models' may be overly sensitive to greenhouse gas emissions and aerosol changes.



Supporting Materials that Make a Climate Projection Set More Appealing

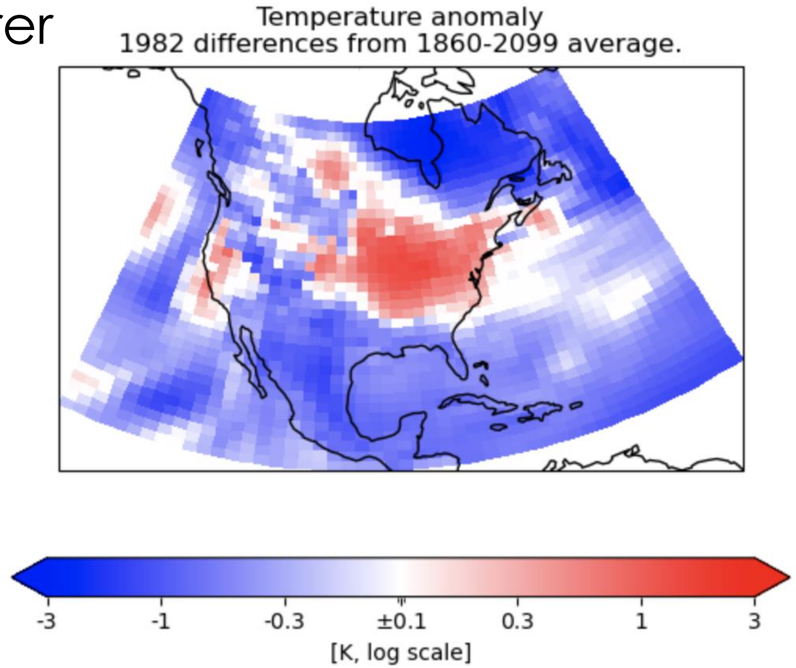
Other Important Aspects of an Appealing Projection Set

- **Clear Guidance Material**: Documentation indicates suggested use, caveats, and potential pitfalls of projection set application.
- **Reformatting Pipelines**: Results may be repackaged to formats common for applications (e.g., crop model input files from AgMIP).
- **Cloud Access**: Datasets are available via cloud services (rather than requiring a full download of all materials).
- **Visualization**: Graphical display of key projection set features.

Online Visualization and Processing Tools

Many online databases facilitate process of visualizing projections, including:

- SciTools - scitools.org.uk
- Climate Analytics Climate Impact Explorer
  climate-impact-explorer.climateanalytics.org/
- KNMI Climate Explorer
- IPCC WGI Interactive Atlas *[more in next slide]*



Coloring Anomaly Data with Logarithmic Scaling
Source: IRIS tool gallery from scitools.org.uk

Select an annual time series

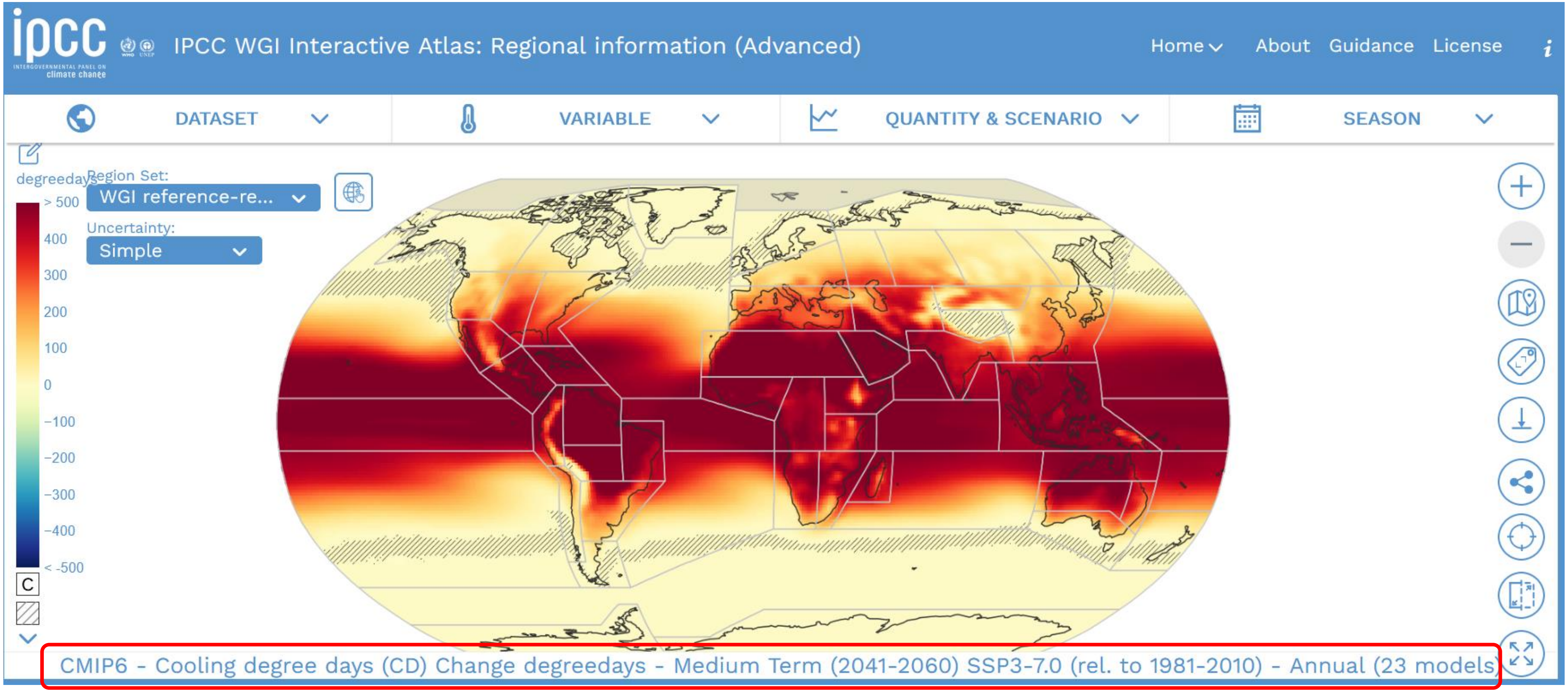
Annual climate reconstructions

Please note that many of these time series have been derived from (very) indirect data and have large uncertainties. The Climate Explorer cannot currently represent the uncertainty margins, please consult the documentation of the time series to obtain these. You are encouraged to compare a few reconstructions of the same quantity and compare with instrumental data on the overlap period.

Select a time series by clicking on the name		
ENSO	1,100 Year El Niño/Southern Oscillation (ENSO) Index Reconstruction (900-2002, Li et al 2011)	i
	Niño3 Reconstruction (500-2006, Mann et al 2009)	i
NAO	Multidecadal winter NAO reconstruction (1049-1995, Trouet 2009)	i
PDO	Pacific Decadal Oscillation Reconstruction for the Past Millennium (993-1996, MacDonald&Case 2005)	i
	PDO Reconstruction (500-2006, Mann et al 2009)	i
AMO	AMO Reconstruction (500-2006, Mann et al 2009)	i
Temperature	Moberg Northern Hemisphere temperature (1-1979, Moberg 2005)	i
	NH Temperature Reconstruction (500-2006, Mann et al 2009)	i
	Global SST Reconstruction (500-2006, Mann et al 2009)	i
	Winter, summer and annual mean temperature in the Netherlands (753-2000, v. Engelen, Buisman, IJnsen)	i
Sea level	Global sea level (error) (1700-2002, PSMSL)	i
Radiation	CO_2 concentration 1000-now, logarithm	i
Sun	Reconstructed solar constant (1610-2008, FUB)	i
	Reconstructed open solar flux (1675-2010, Lockwood)	i
Drought	Western US Drought Index (800-2003, Cook et al, 2004)	i

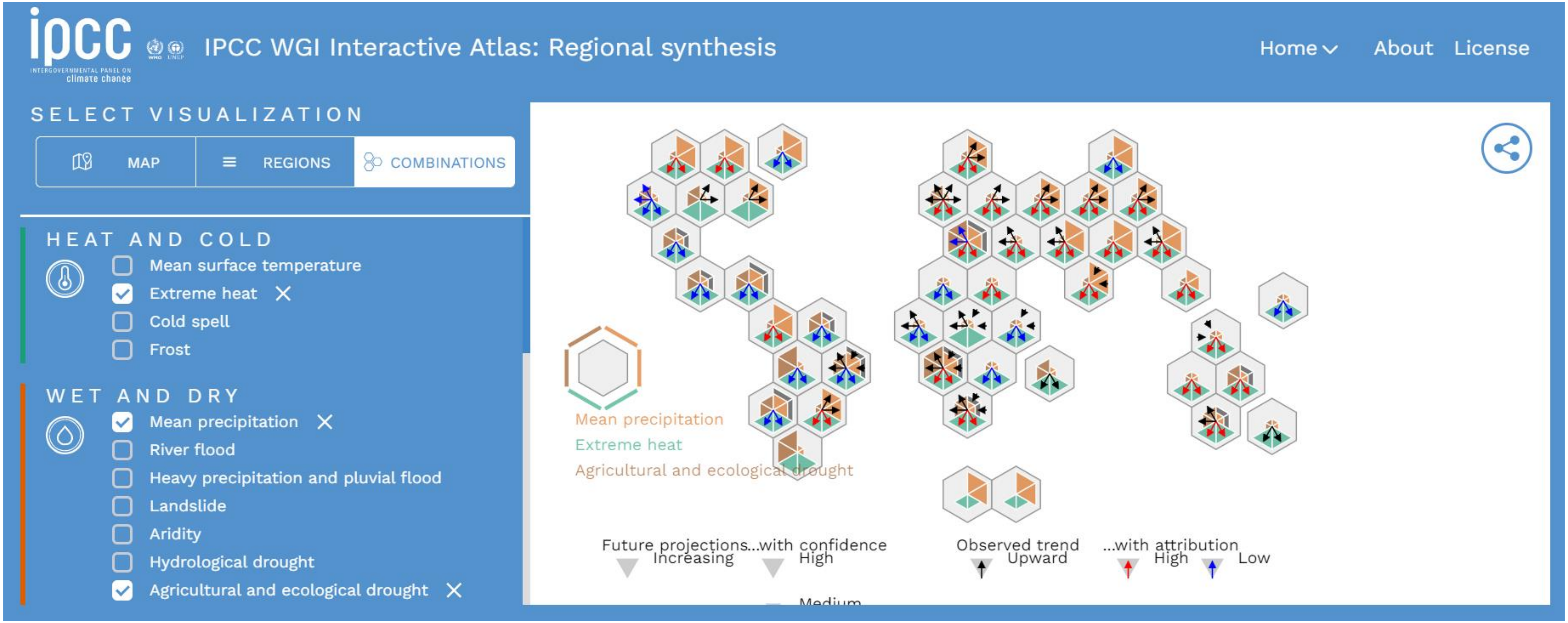
KNMI Climate Explorer
Source: https://climexp.knmi.nl/start.cgi

IPCC Interactive Atlas



https://interactive-atlas.ipcc.ch/

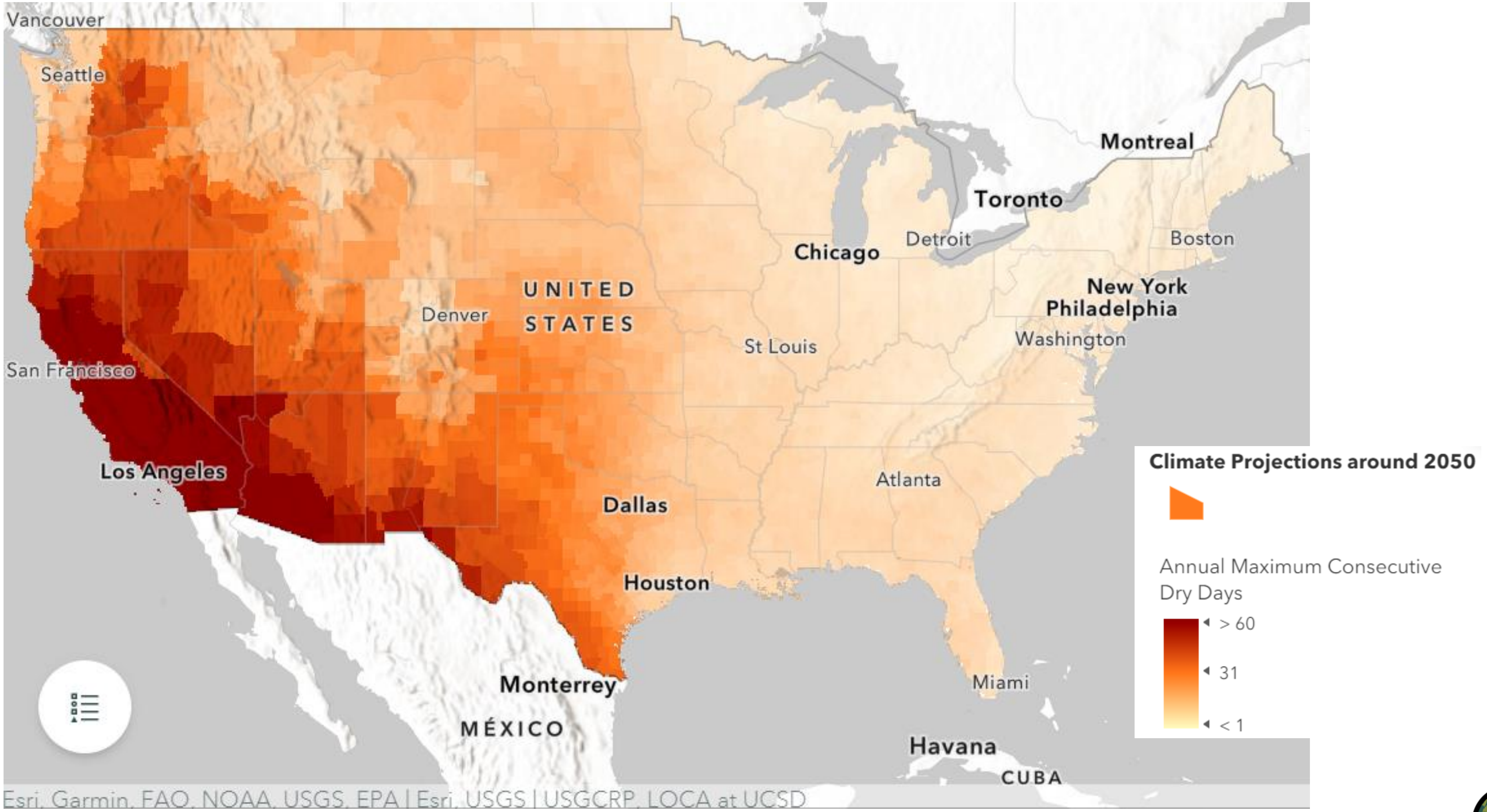
IPCC Interactive Atlas



https://interactive-atlas.ipcc.ch/

Climate Mapping for Resilience and Adaptation (CMRA)

White House Initiative in Partnership with ESRI



Data License

- Some projection sets are public goods created to encourage application.
- Other projection sets are commercial products (could be expensive).

- Clarify data license to describe legal parameters for authorized use conditions:
  - **Not Determined**: No license, or not declared
  - **Proprietary**: Not for public use.
  - **Limited**: Available for use if conditions determined by the projection set creator are satisfied.
  - **Open, Non-Commercial**: Open use for non-commercial applications.
  - **Open, Commercial**: Open use, including for commercial applications.

Related Products

Projection sets may be appealing because a new application will instantly connect to many existing applications.

- **Example: US National Climate Assessment used CMIP5 LOCA Projections**
  - Any new assessment can instantly be compared to published assessment
  - Results from new assessments can be combined with existing results
    - E.g., water resources results become important inputs for agricultural models

- Particularly useful when linking into economy-wide and systems models such as Integrated Assessment Models (IAMs)

Important Information to Note

- **Funding and Links:**
  - **Funding and Use**: Acknowledge funding support and motivating use of the dataset (e.g., for use in a particular sector, project, or assessment).
  - **International Links**: Connection to international programs (e.g., scenario set may have been created for multiple regional domains as part of same global effort).
  - **Detailed Documentation**: Web location of detailed documentation of the scenario set, including a citation for use.
- **Access:**
  - Data website/server
  - Primary person of contact

Summary

Summary of Part 2:

- Projection set selection depends strongly on given application needs.
- Close engagement with stakeholders is important for the decision process.
- Steady improvements in all characteristics of climate projection set generation underscore the appeal of using cutting-edge projection sets.

- More complex projection sets are not necessarily better.
  - Resource constraints
  - Illusion of high levels of detail

- Online tools, support, and documentation make projection sets more appealing.

- It may be important to connect with applications beyond your immediate focus.

Goals for this ARSET Session

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

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- Where climate projection sets come from
- Key distinguishing features

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

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APPLIED REMOTE SENSING TRAINING PROGRAM

TRAIN - EMPOWER - ADVANCE

Thank You!

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
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- 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:

Extra Slides

NASA has many products to monitor and simulate climate.

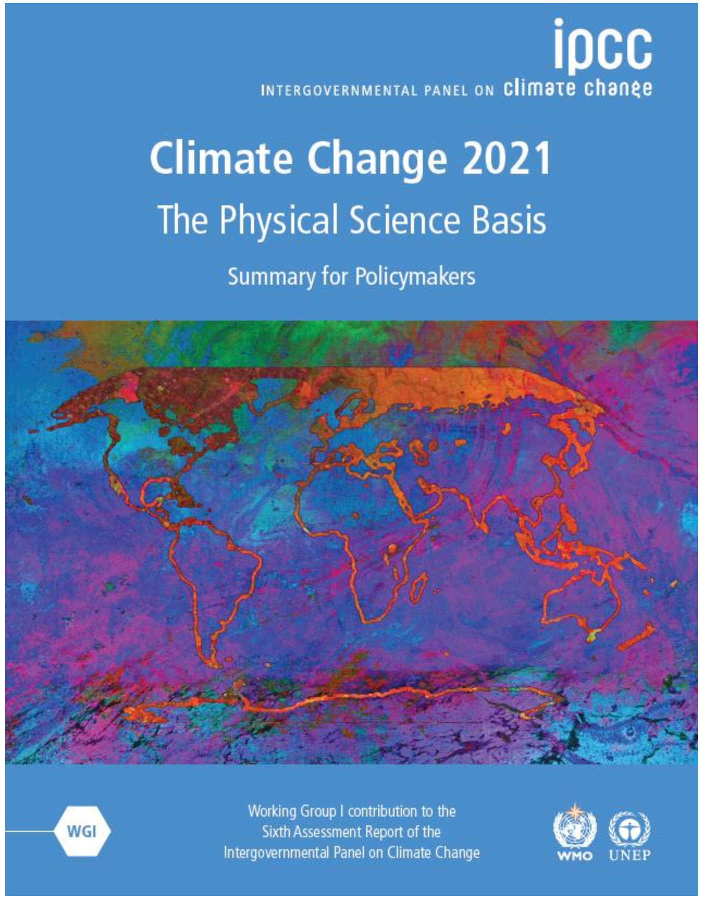
- **See Other ARSET Trainings:**
  - Climate Change Monitoring & Impacts Using Remote Sensing and Modeled Data
  - Climate Change Future Scenarios, Impact Forecasting, and Adaptation

- **Examples of Key Observational Products:**
  - The Integrated Multi-satellitE Retrievals for GPM (IMERG) - Precipitation
  - Moderate Resolution Imaging Spectroradiometer (MODIS) - Temperature - Vegetation
  - Soil Moisture Active-Passive (SMAP) - Soil Moisture
  - Orbiting Carbon Observatory (OCO-2) - Carbon
  - National Snow and Ice Data Center (NSIDC) - Sea Ice

- **Examples of Key Simulation Products:**
  - The Modern-Era Retrospective analysis for Research and Applications (MERRA-2)
  - NASA GISS Model-E
  - NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP)

Additional Recommended Materials

- Other NASA ARSET Trainings: https://appliedsciences.nasa.gov/join-mission/training
- Intergovernmental Panel on Climate Change: https://ipcc.ch
- NASA GISS Surface Temperature Analysis: https://data.giss.nasa.gov/gistemp/
- NASA Global Climate Vital Signs: https://climate.nasa.gov/
- Agricultural Model Intercomparison and Improvement Project: www.agmip.org



IPCC AR6 WGI Summary for Policymakers released August 9th, 2021