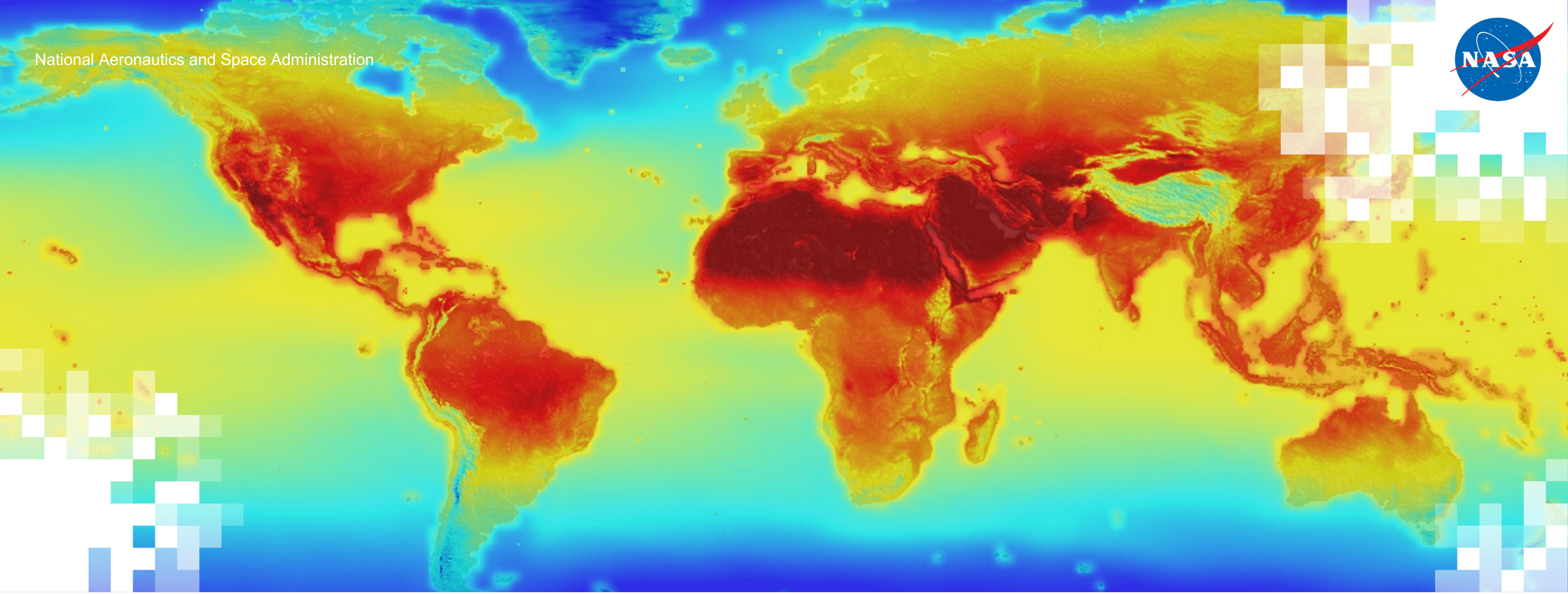
National Aeronautics and Space Administration



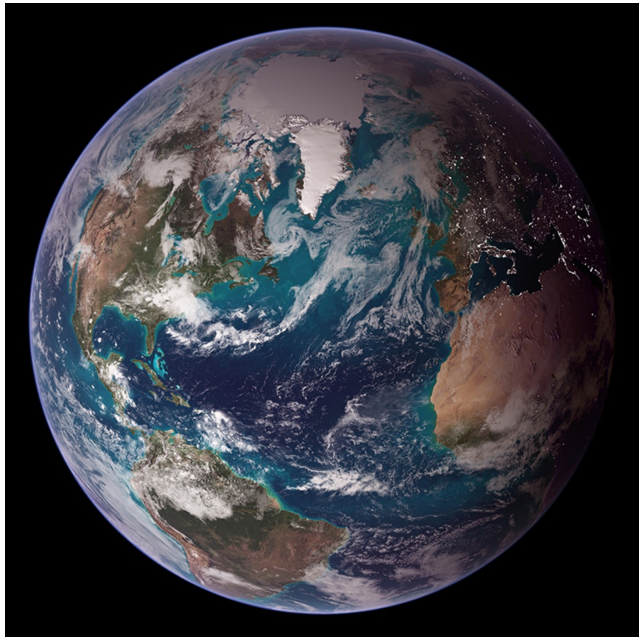
Climate Change Future Scenarios, Impact Forecasting, and Adaptation

Alex Ruane and Dan Bader, NASA Goddard Institute for Space Studies, New York

Oct 06, 2021

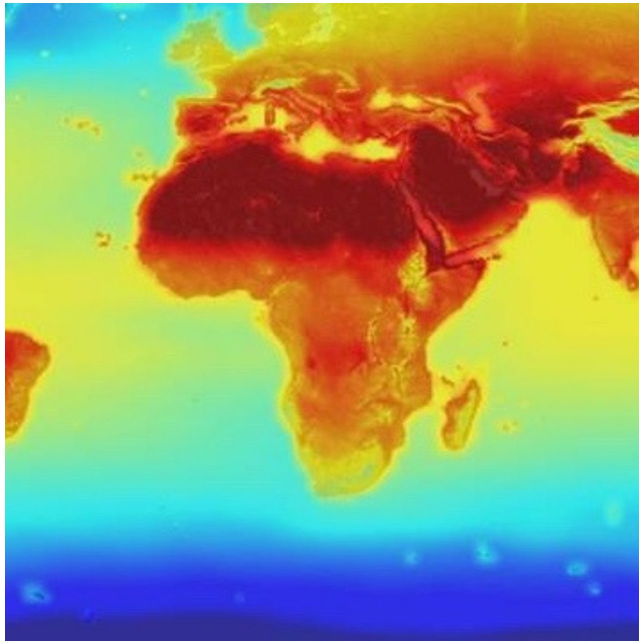
Training Outline

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

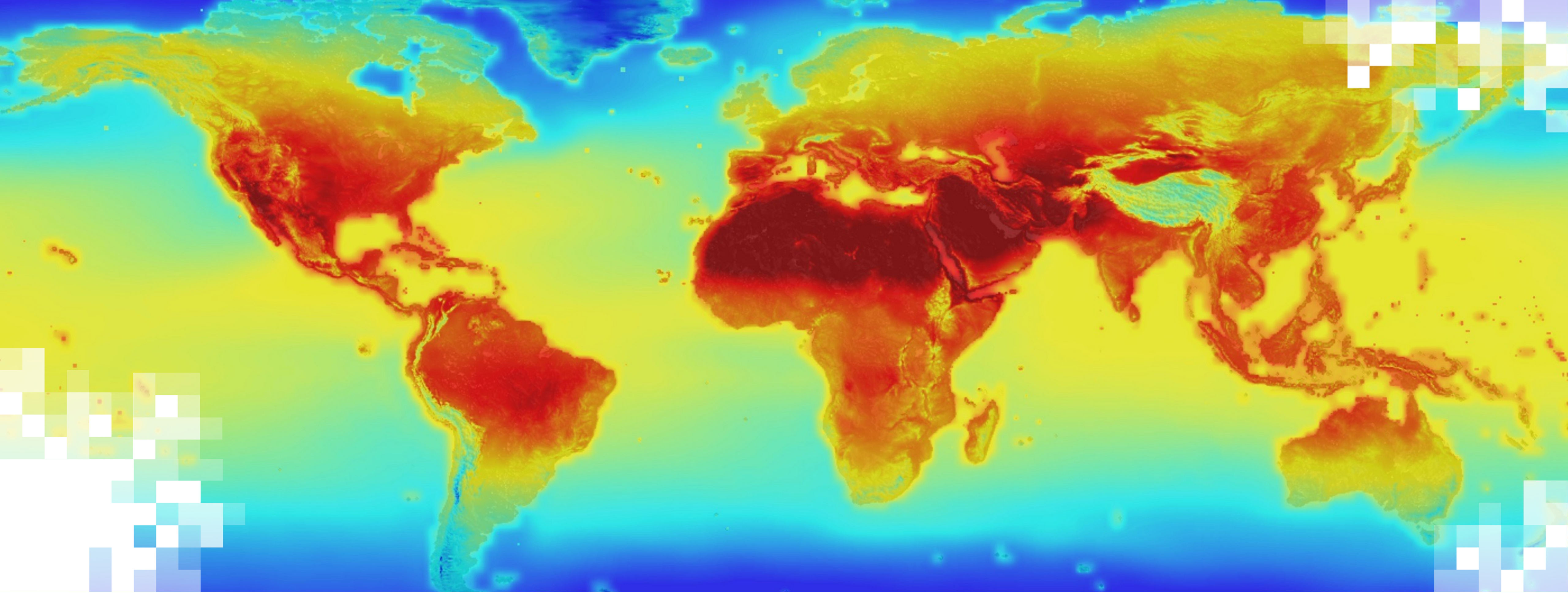
Homework and Certificate

- One homework assignment:
  - Answers must be submitted via Google Form, accessed from the ARSET website.
  - Homework will be made available on October 6, 2021.
  - Due date for homework: October 20, 2021.
- A certificate of completion will be awarded to those who:
  - Attend all live webinars
  - Complete the homework assignment by the deadline
  - You will receive a certificate approximately two months after the completion of the course from: marines.martins@ssaihq.com

Goals for this ARSET Session:

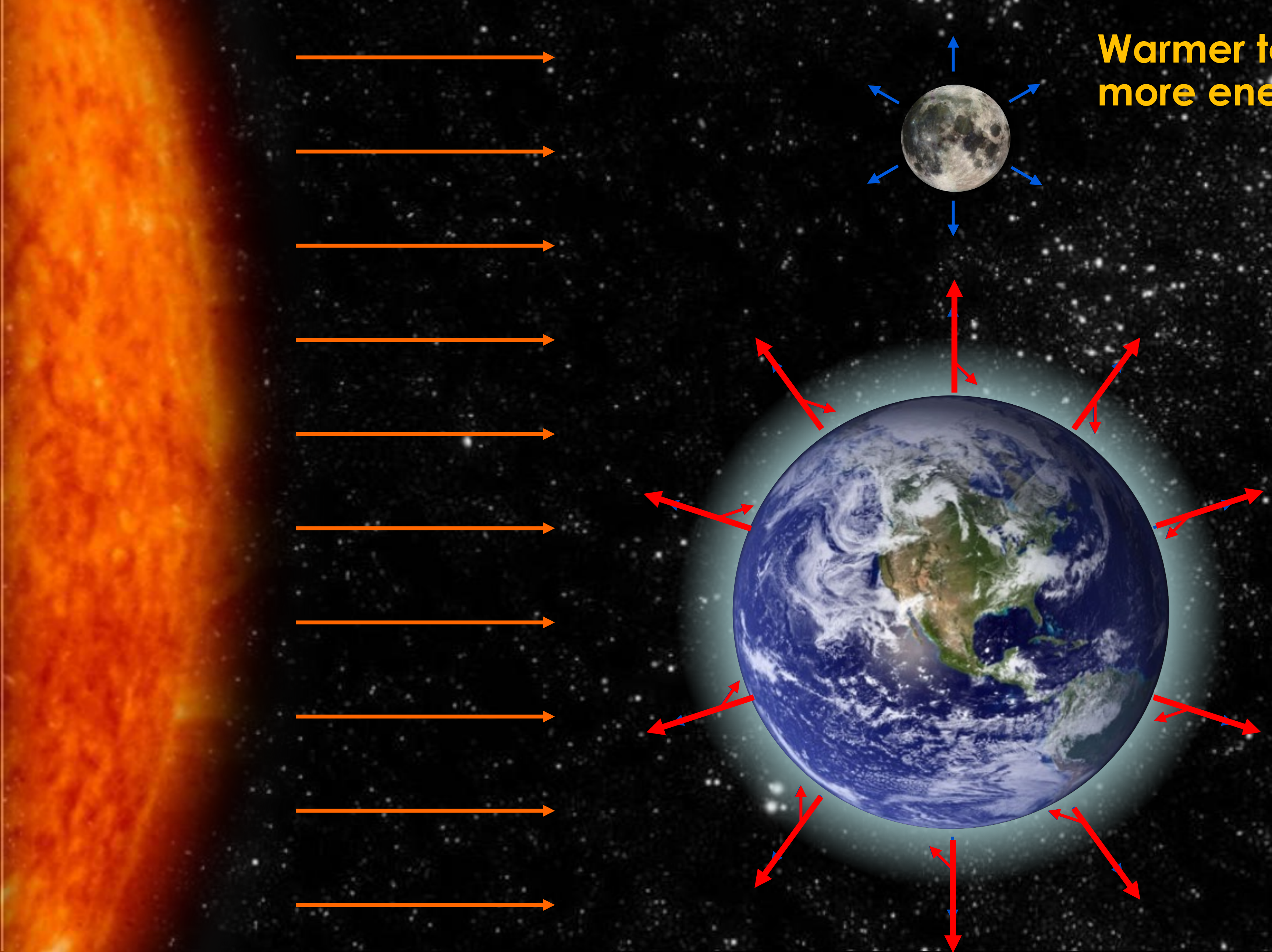
How can we make climate information useful?

- Basics of climate information
- Use of climate models
- Historical and future climate
- Approaches to assess climate impacts
- Designing climate adaptations



Climate Change Basics

Climate Change - Radiative Basis



Warmer temperature means more energy radiated away.

Moon (virtually no atmosphere)

Energy in = Energy Out

Earth

Energy In = Energy Out

Add Atmosphere
(or thicken with greenhouse gases)

- Same amount of sunlight in
- Some of outgoing energy trapped

Energy In > Energy Out

Warmer World

- Surface must warm to get back in balance

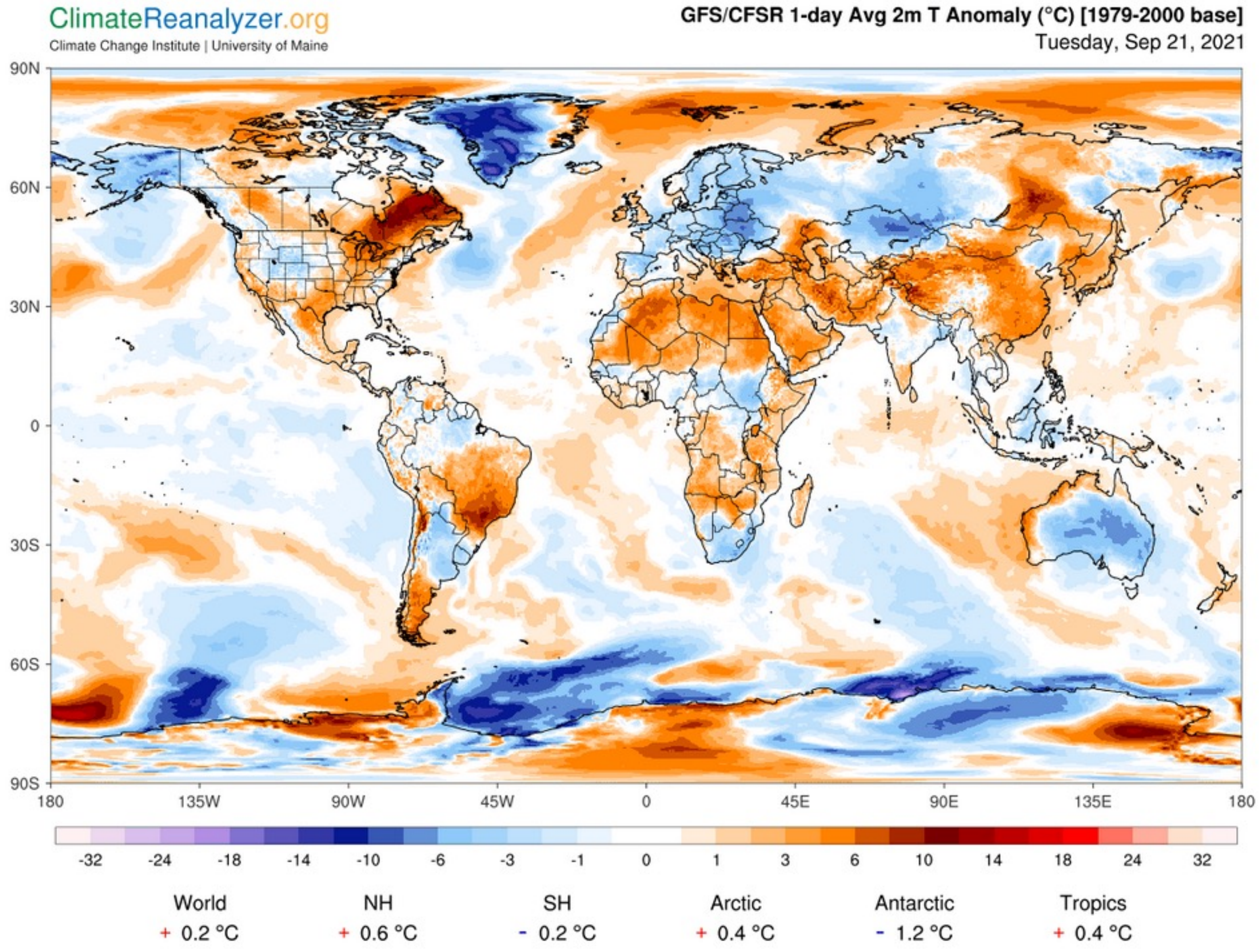
Energy In = Energy Out

Current Climate Research and Applications

- Energy must go somewhere.
  - Atmosphere (upper and lower)
  - Oceans (upper and lower)
  - Ice, land surface, vegetation
- That energy changes the way the climate behaves.
  - Changes in atmospheric patterns and rainfall
  - Extreme events and sea-level rise
  - Feedbacks
- A Changing climate affects nature and society.
  - Ecosystems and species
  - Agriculture, water resources, infrastructure, health, forests, fisheries, transportation
- How will our actions shape the future?
  - Emissions, adaptation, and risk management

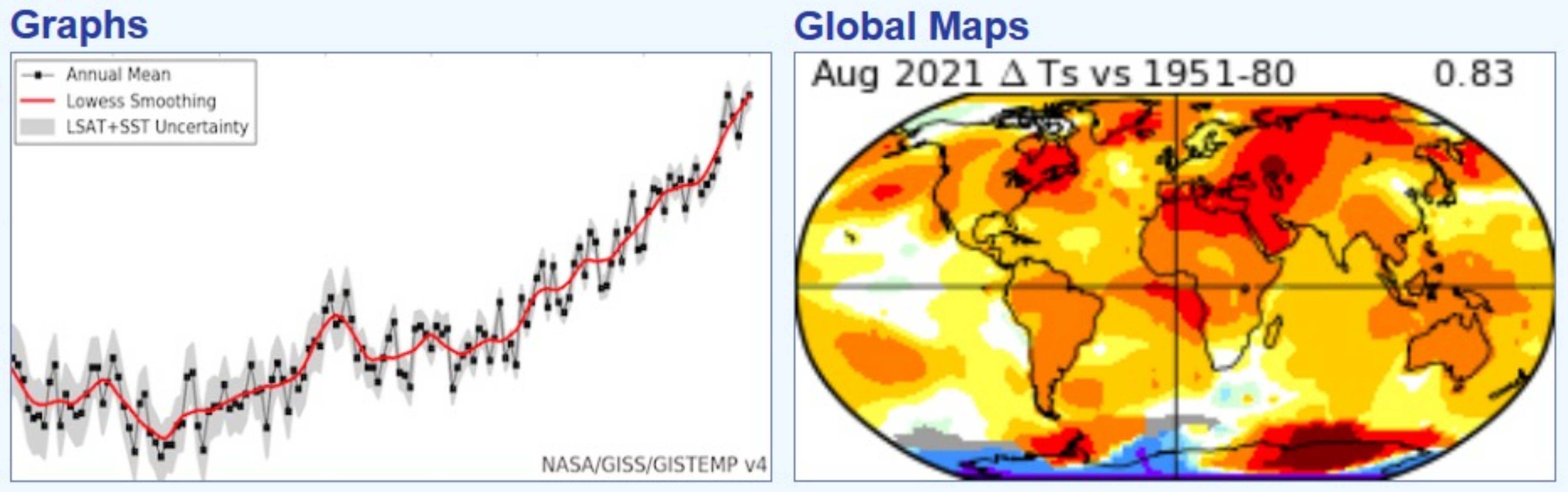
Models Fit for Purpose

Weather ≠ Climate



NASA GISS Surface Temperature Analysis

Weather ≠ Climate



https://data.giss.nasa.gov/gistemp/

- Built on networks of meteorological stations around world
- Covers 1880-present with updates around the middle of each month

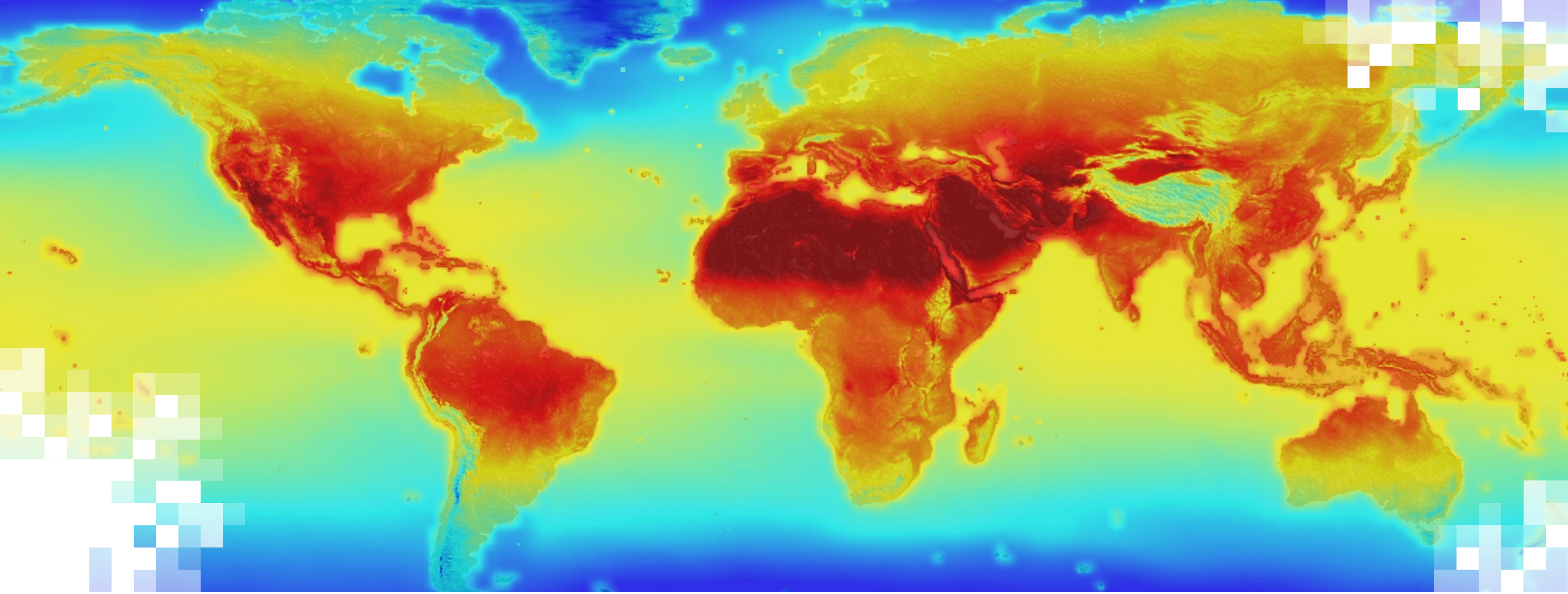
[Credit: Hong Nguyen | Unsplash]

> “Climate change is already affecting every region on Earth, in multiple ways.
>
> The changes we experience will increase with further warming.

ipcc
INTERGOVERNMENTAL PANEL ON climate change

WMO UNEP

Intergovernmental Panel on Climate Change Sixth Assessment Working Group I Report (August 2021)



Climate Simulation – Overview of Models

NASA has many products to monitor and simulate climate.

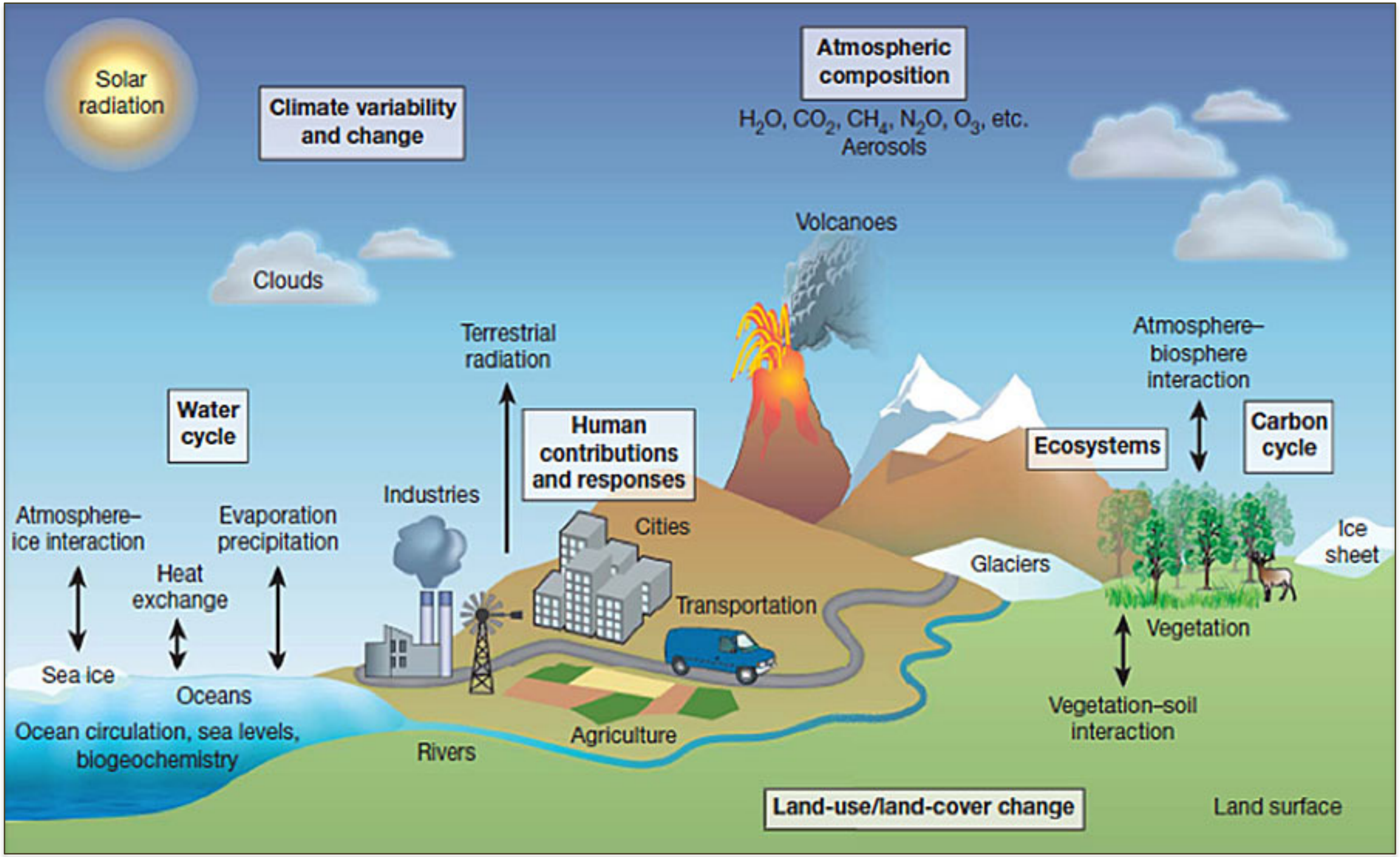
- See other ARSET trainings including Part 1 of this training
  - Climate Change Monitoring & Impacts Using Remote Sensing and Modeled Data

- 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)

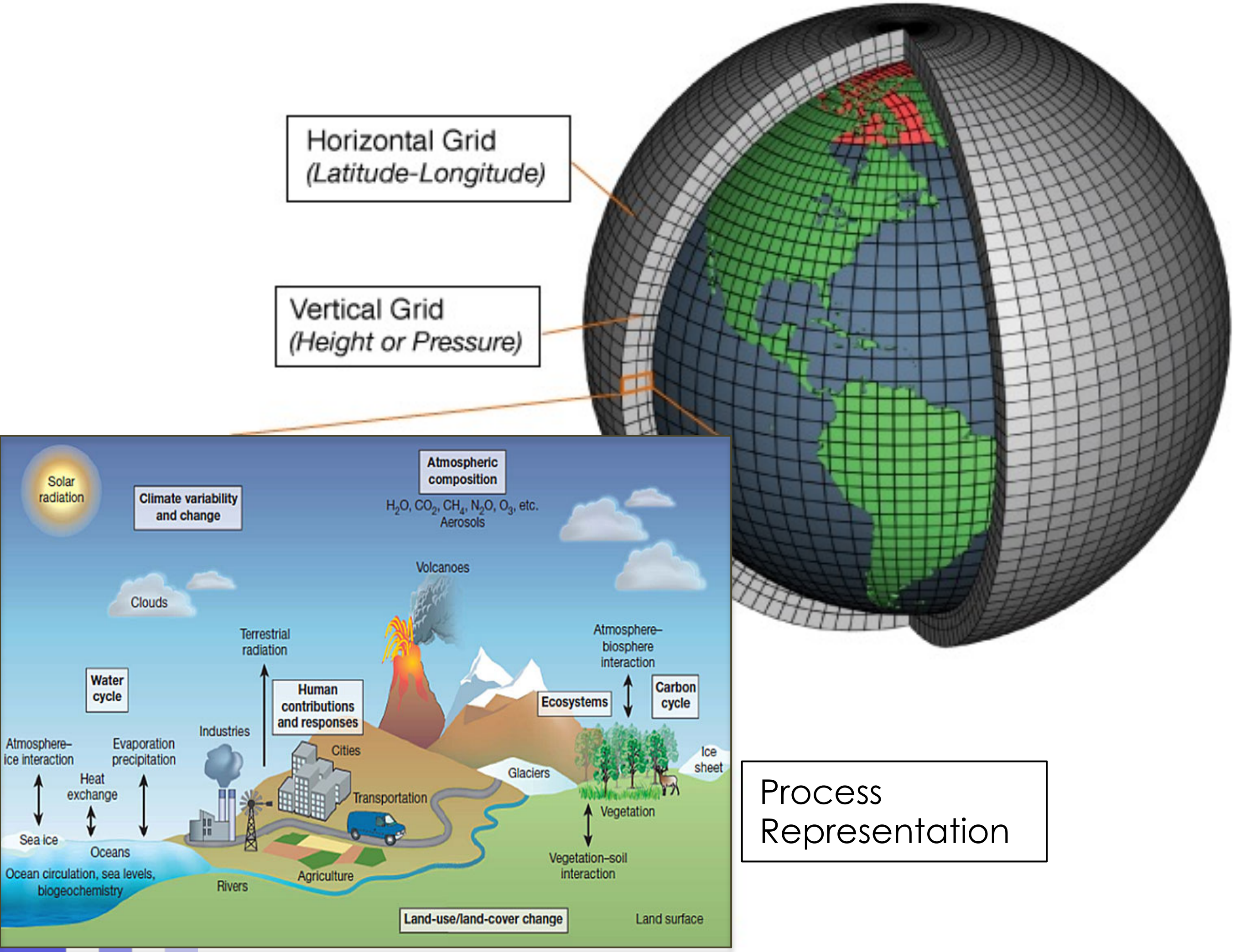
Components and Drivers of the Climate System



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

Climate Model Approaches

(e.g., NASA GISS Model-E)

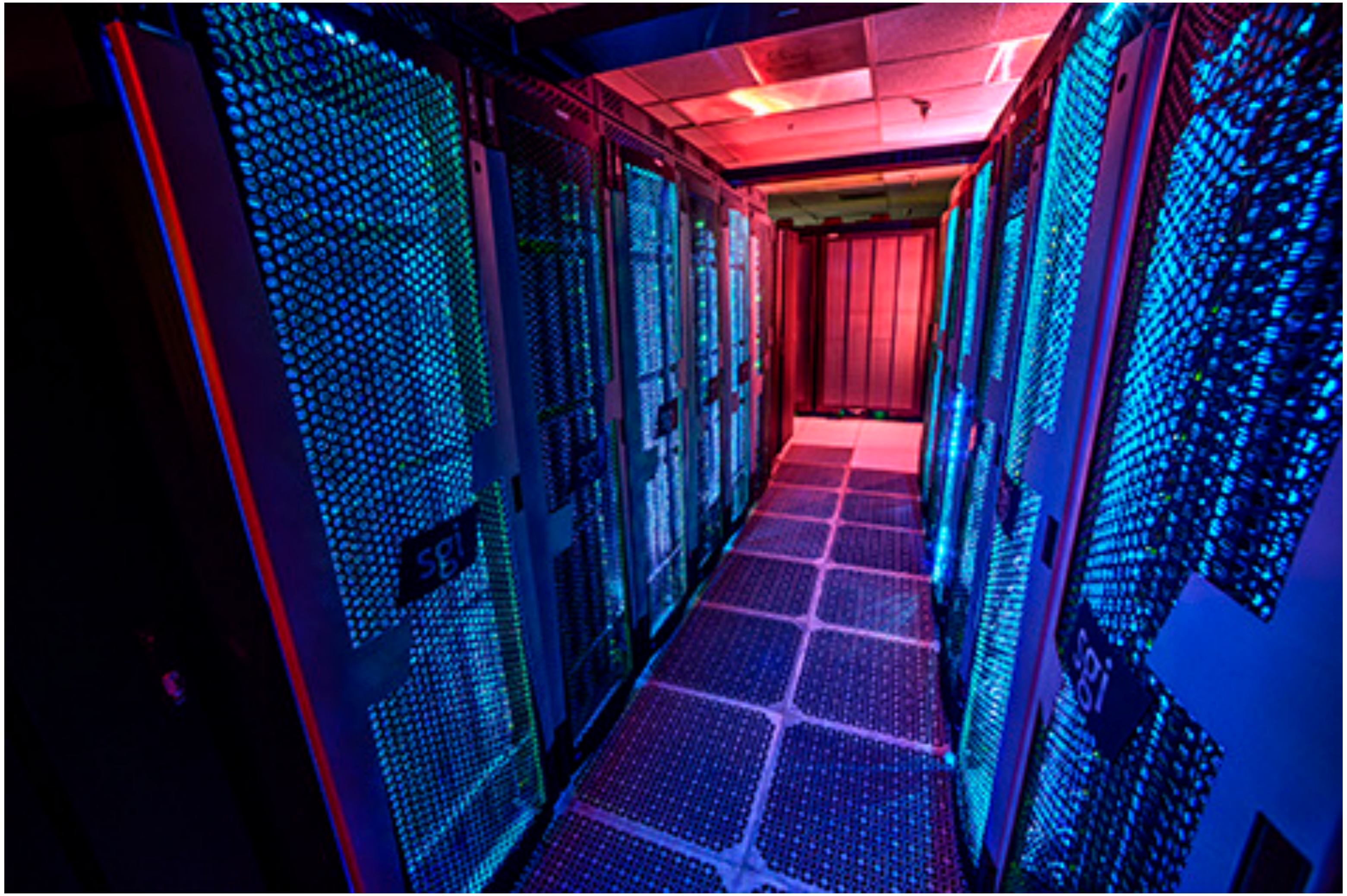


Process Representation

- Built on principles of physics and chemistry
- Balanced across water and energy budgets
- Dependent on initial conditions and boundary forcings *(e.g., sunlight, land use, greenhouse gas emissions)*
- Tuned using surface stations and remote sensing datasets with machine learning
- Independently validated against observed trends and variability
- Capable of extending beyond observed conditions
- Subject to limits in predictability given chaotic nature of climate system

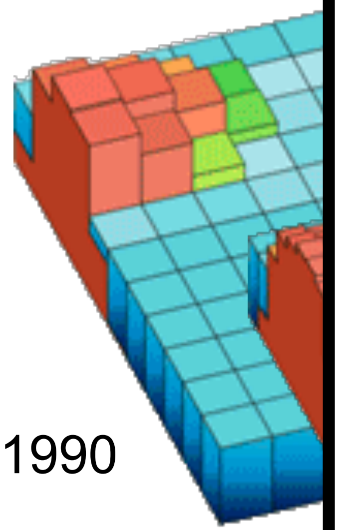
Adapted from NOAA: https://www.climate.gov/maps-data/primer/climate-models

High-performance computer systems enable GCM simulations.



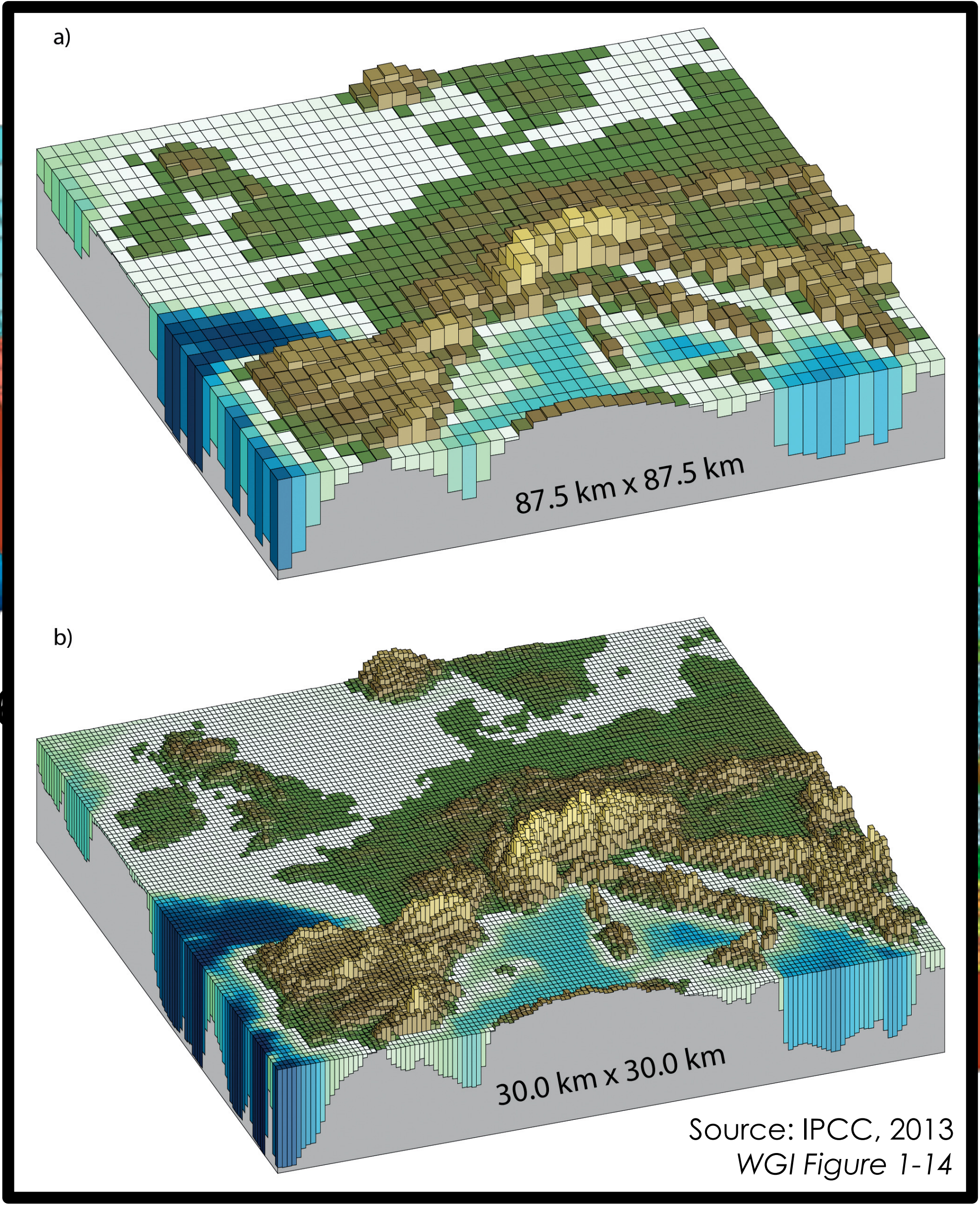
NASA Discover Supercomputer

Improved Resolution and Downscaling

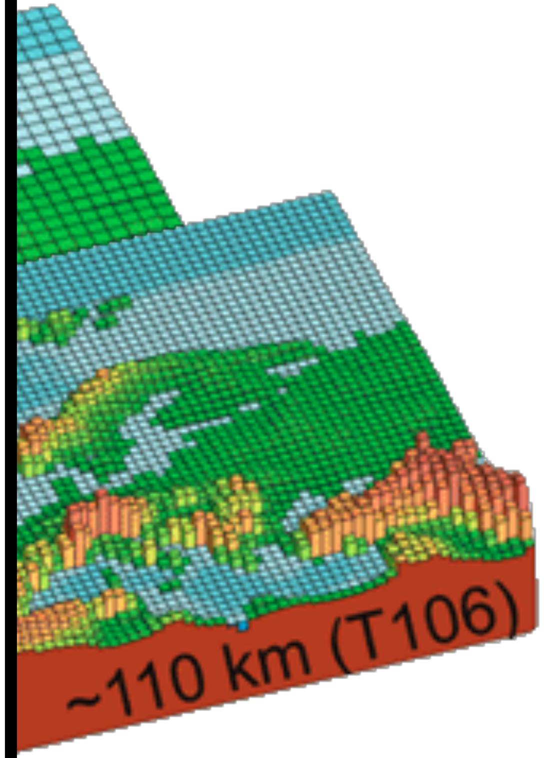


1990

199



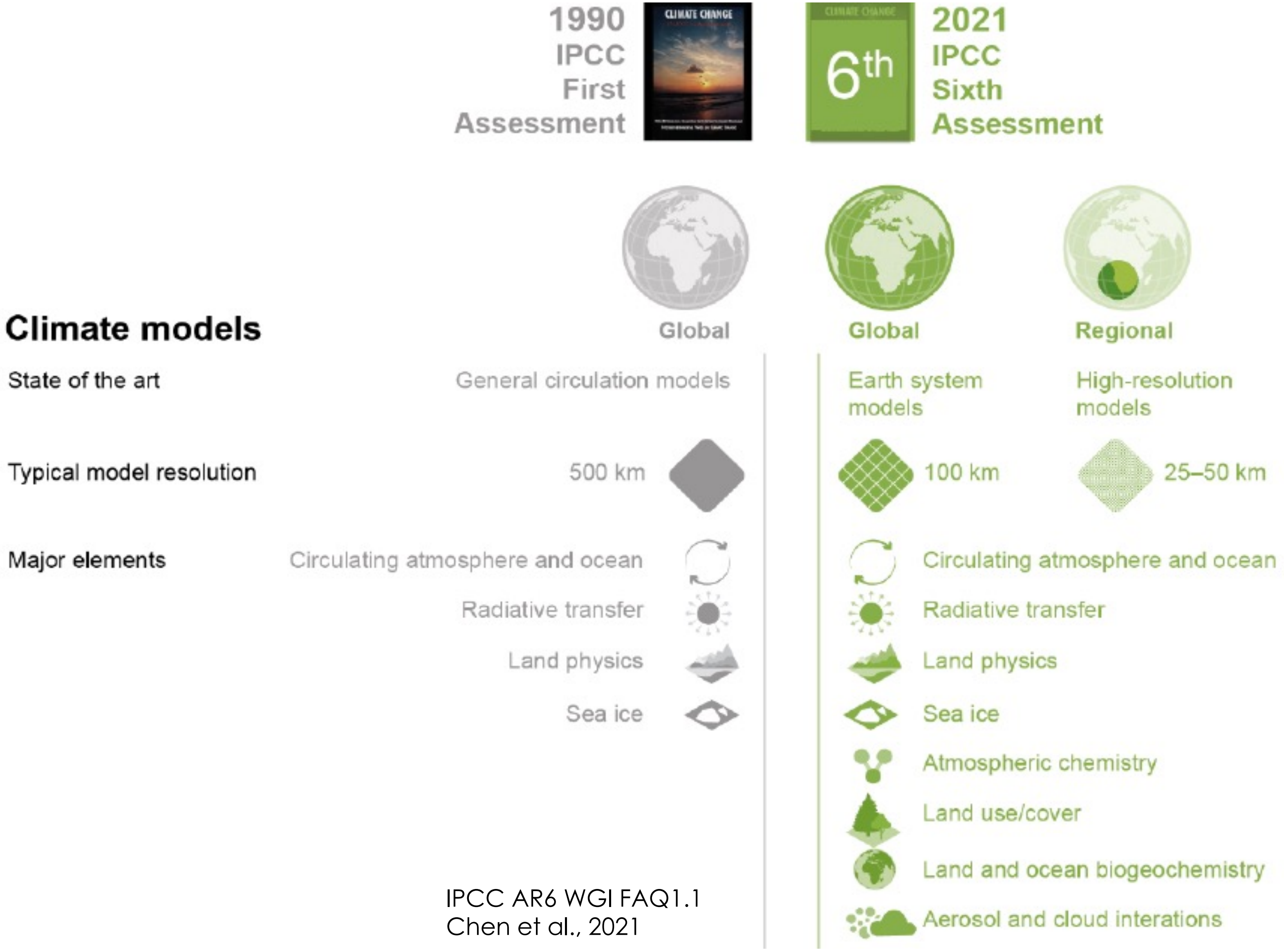
Source: IPCC, 2013
WGI Figure 1-14



Source: IPCC, 2007
Figure 1-4

- + Regional Climate Models
- + Empirical Models

Climate Model Advancements Since 1990



1990
IPCC
First
Assessment

2021
IPCC
Sixth
Assessment

Climate models	Global	Global	Regional
State of the art	General circulation models	Earth system models	High-resolution models
Typical model resolution	500 km	100 km	25–50 km
Major elements	Circulating atmosphere and ocean	Circulating atmosphere and ocean	
	Radiative transfer	Radiative transfer	
	Land physics	Land physics	
	Sea ice	Sea ice	
		Atmospheric chemistry	
		Land use/cover	
		Land and ocean biogeochemistry	
		Aerosol and cloud interations	

IPCC AR6 WGI FAQ1.1
Chen et al., 2021

What Are Climate Models Designed For?

Response to combined or individual driving factors or causes, e.g.:

- Methane as distinct from Carbon dioxide

Impacts of policy choices

Need for adaptation:

- In conjunction with local vulnerability assessment

Potential impact of “known unknowns”, e.g.:

- Effect of large volcanic eruptions

Adapted from Gavin Schmidt

What are climate models not particularly designed for?

Perfect short- or long-term predictions

- Chaotic nature of internal variability
- Model and data imperfections
- Uncertainty in economic drivers

Solving political issues or ethical quandaries

- Political/ethical calculations are not included in any subroutine

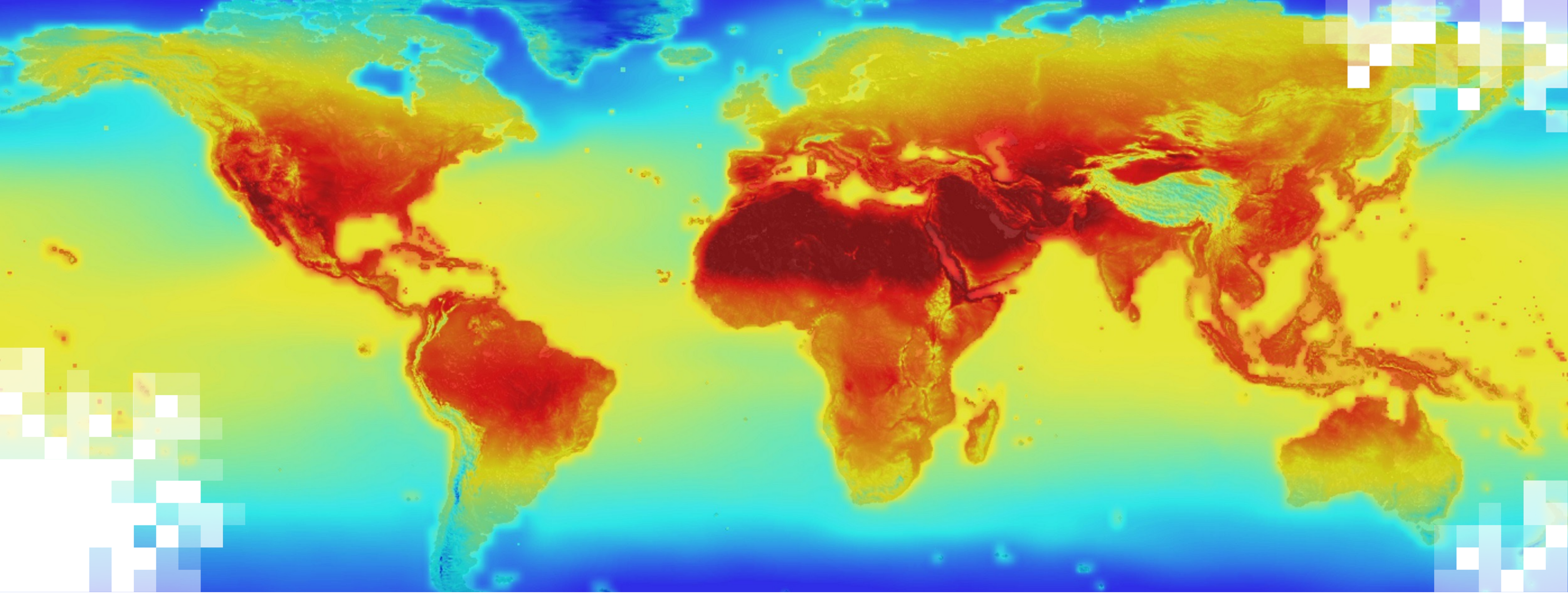
Truly local information

- Models evaluated primarily at larger scales
- Sub-100km information not likely to be reliable any time soon

Recognizing “unknown unknowns”, e.g.:

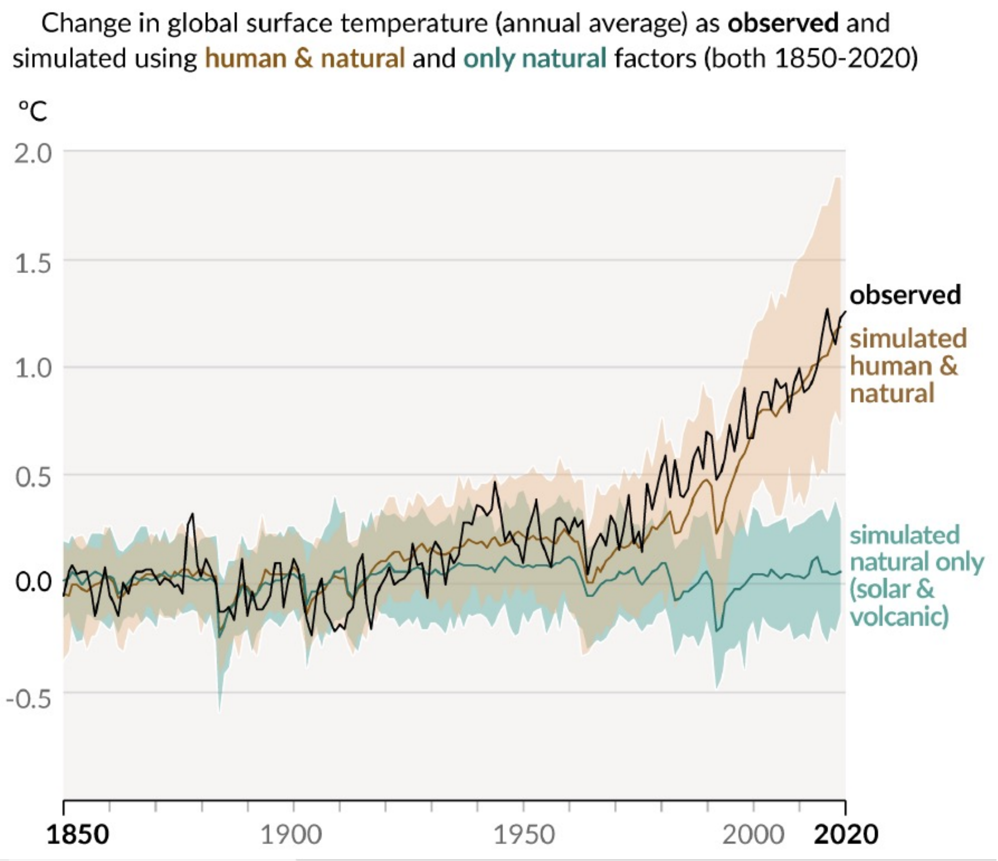
- Models in 1970 did not know about ozone hole

Adapted from Gavin Schmidt



Climate Simulation – Historical and Future Climate

How can we use climate models?
Determining Human Influence on Climate System

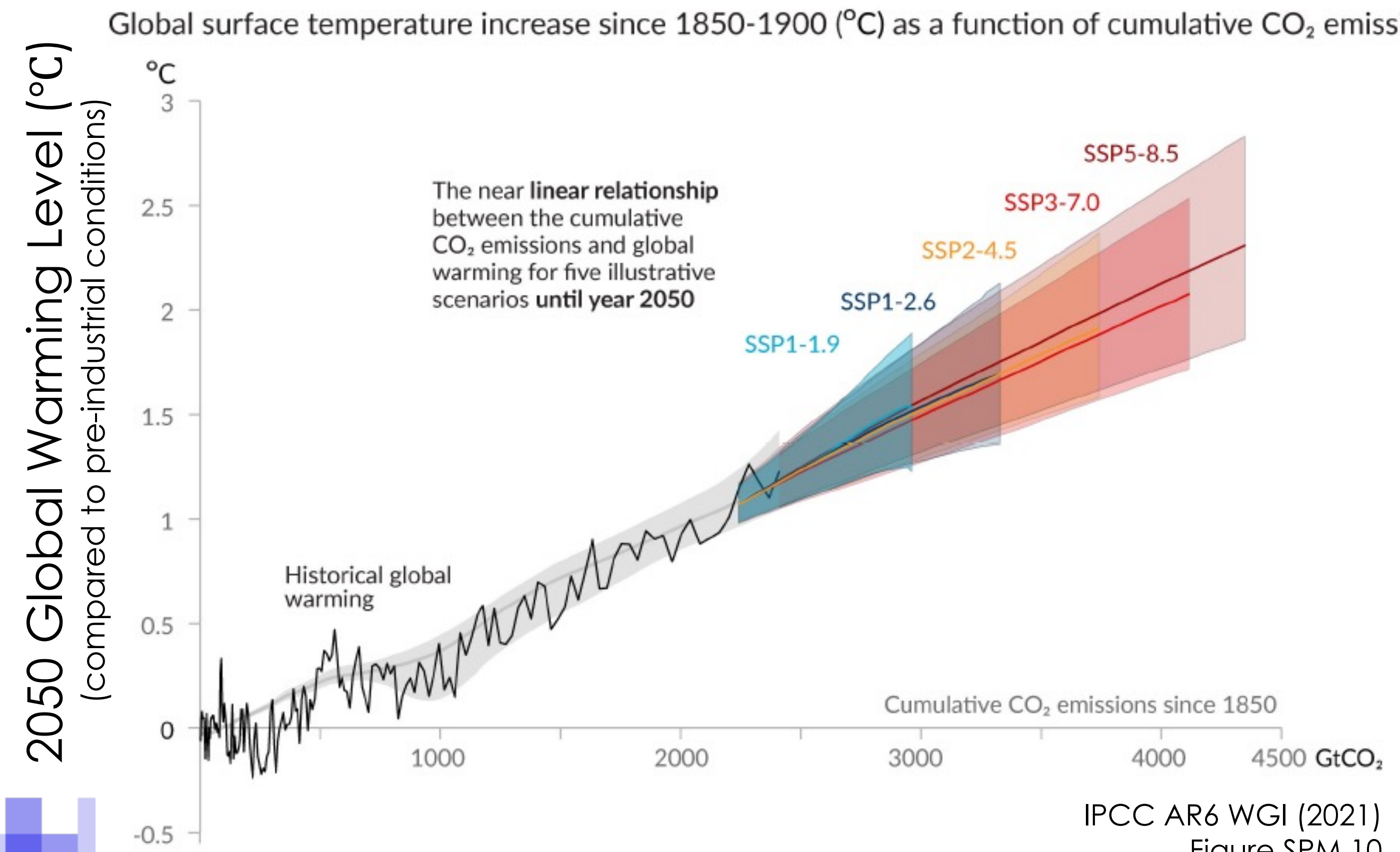


IPCC AR6 WGI (2021)
Figure SPM.3

- *Human influence attribution helps separate:*
  - **Natural Variability**
    - Volcanoes
    - Solar Cycles
    - Changes in Axis and Orbits
  - **Human Factors**
    - Greenhouse Gas Emissions
    - Aerosol Emissions
    - Land-Use Change

How can we use climate models?

- Greenhouse gas emissions policy and climate projections
- Modelers use illustrative scenarios (e.g., SSP1-1.9) to represent different pathways of development, technology, international cooperation, and greenhouse gas emissions.



Global surface temperature increase since 1850-1900 (°C) as a function of cumulative CO_2 emissions ($GtCO_2$)

IPCC AR6 WGI (2021)
Figure SPM.10

SSP-RCP Scenarios

SSP = Shared Socioeconomic Pathway
- *Income, technology, land use, governance*

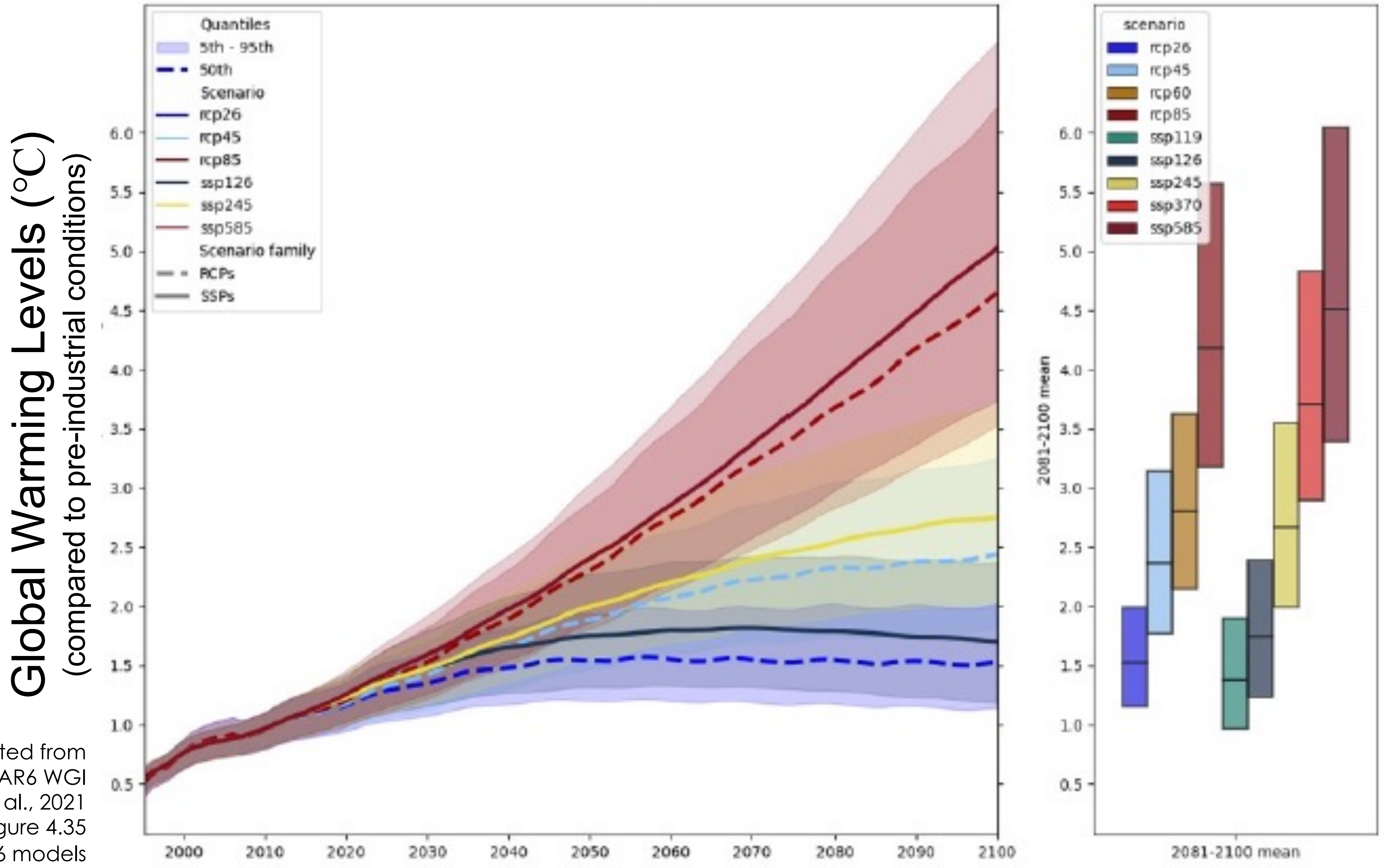
RCP = Representative Concentration Pathway
- *Greenhouse gases, aerosols, carbon fluxes*

Climate Projections

Organized primarily through the Coupled Model Intercomparison Project (**CMIP**)

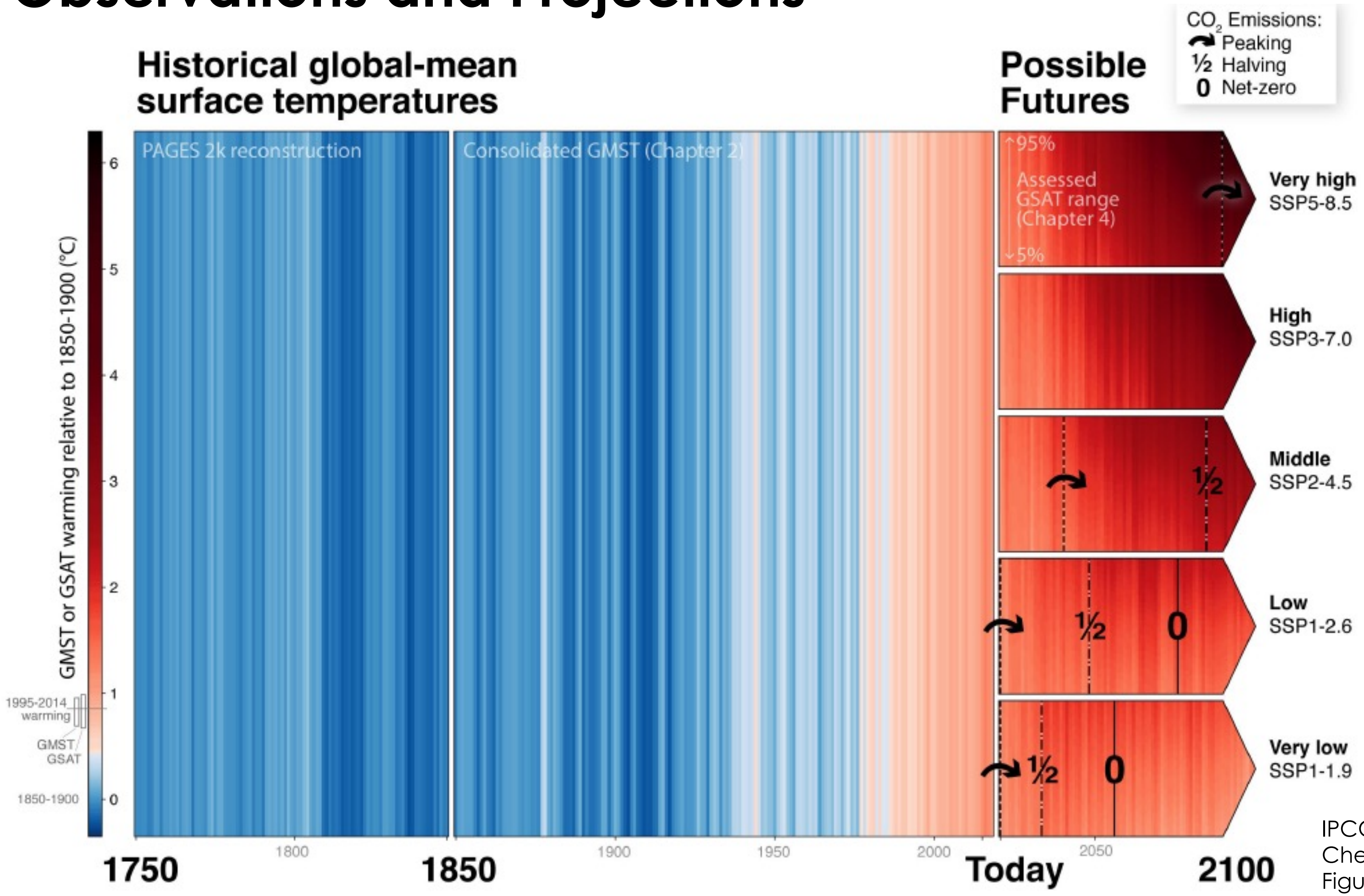
~50 Modeling Centers

~100 Distinct Models



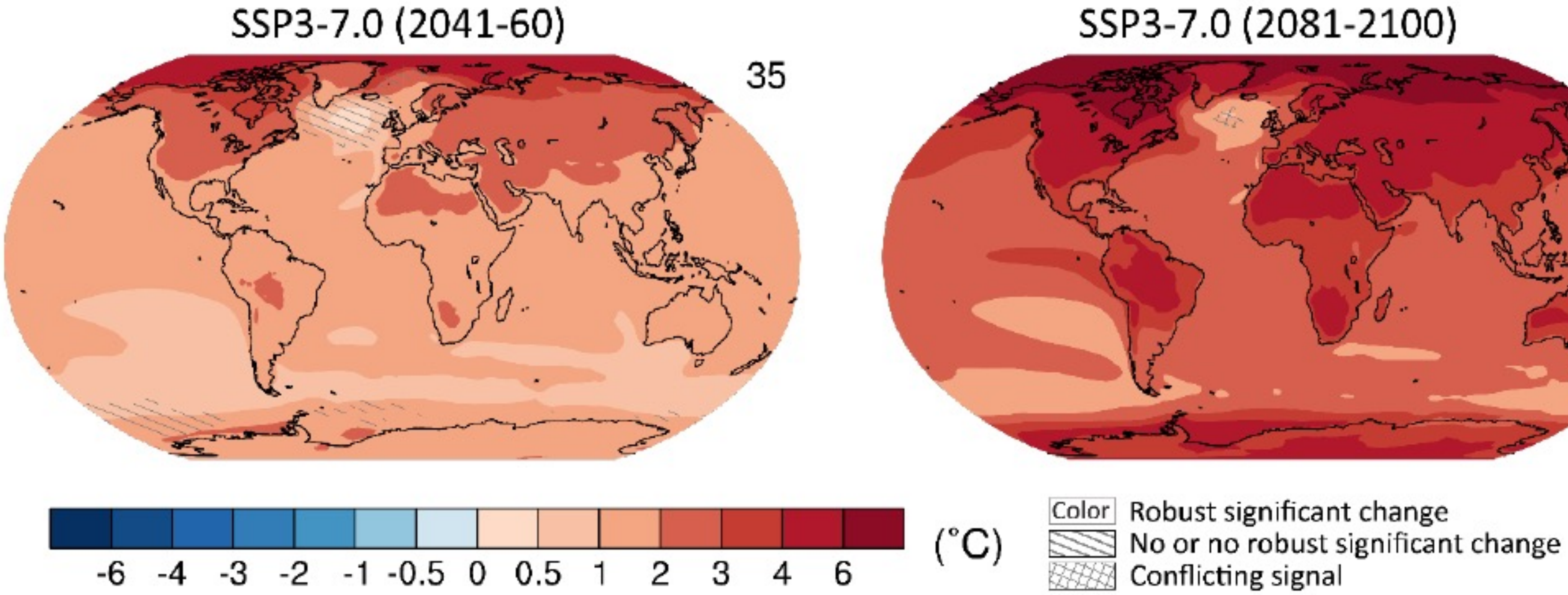
Adapted from
IPCC AR6 WGI
Lee et al., 2021
Figure 4.35
CMIP6 models

Climate Observations and Projections



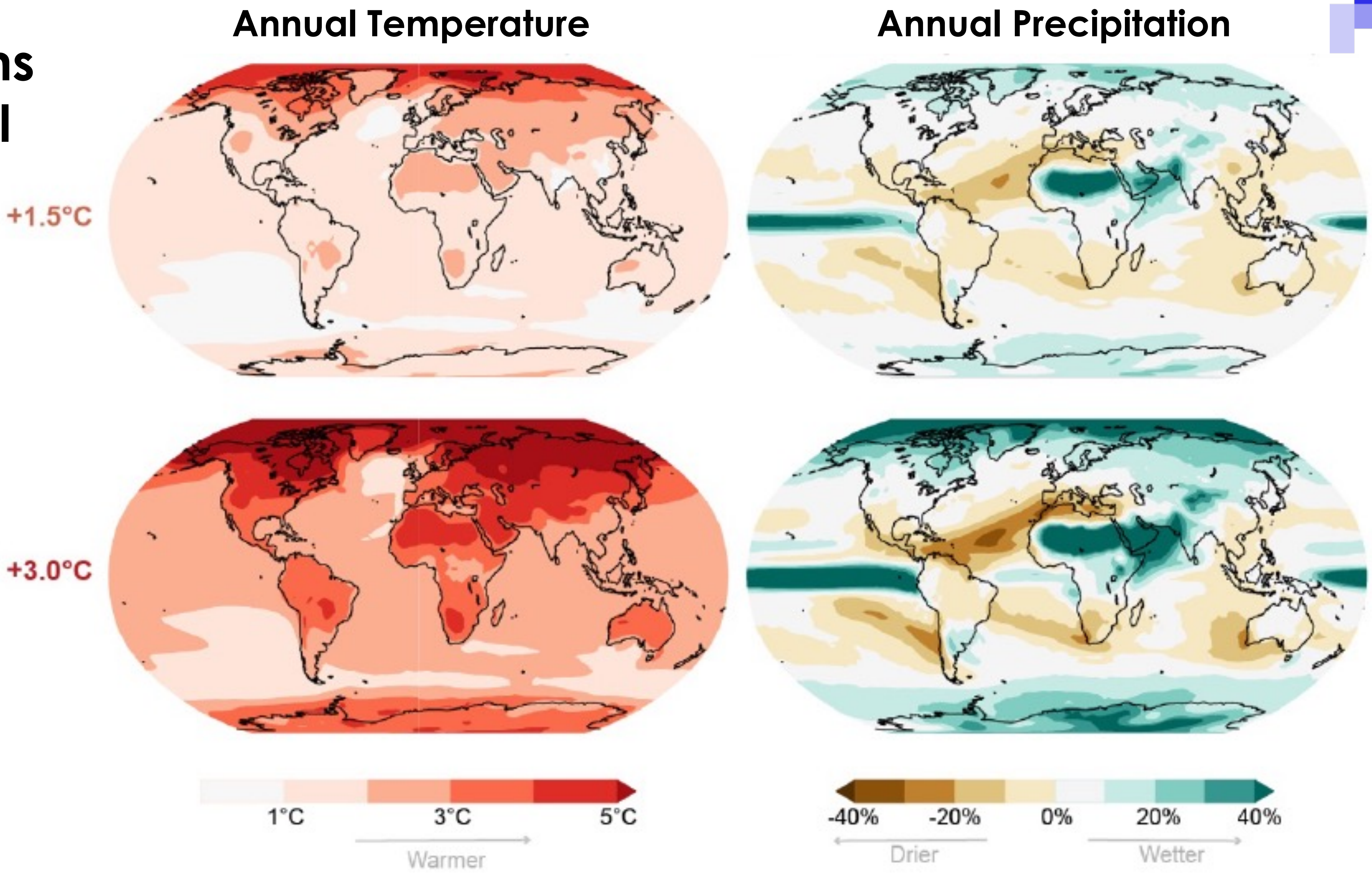
IPCC AR6 WGI
Chen et al., 2021
Figure 1.25

Climate Projections by Time and Scenario



IPCC AR6 WGI
Chen et al., 2021
Figure 4.19
CMIP6 Models

Climate Projections by Global Warming Level

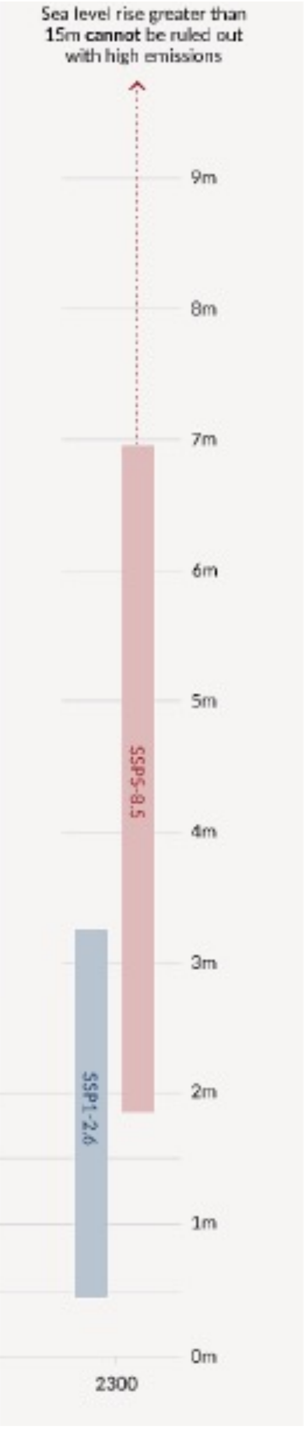


IPCC AR6 WGI
Chen et al., 2021
FAQ4,3 Figure 1
CMIP6 Models

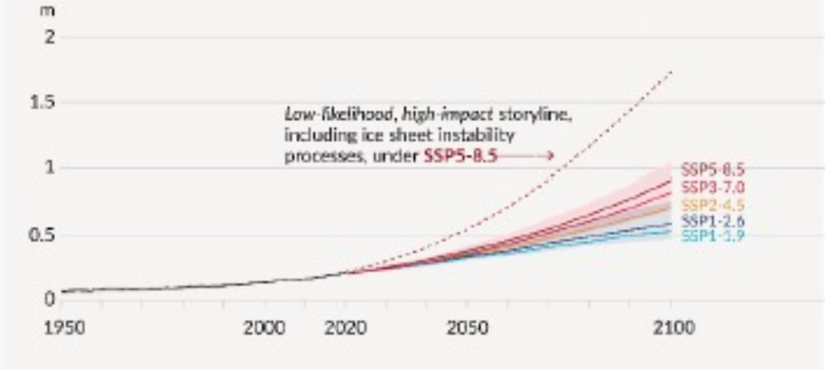
Climate change does not stop at 2100.

Some components of the earth system
(e.g., ice and deep oceans)
take a long time to respond to global warming.

Global Mean Sea Level Change in 2300 Compared to 1900

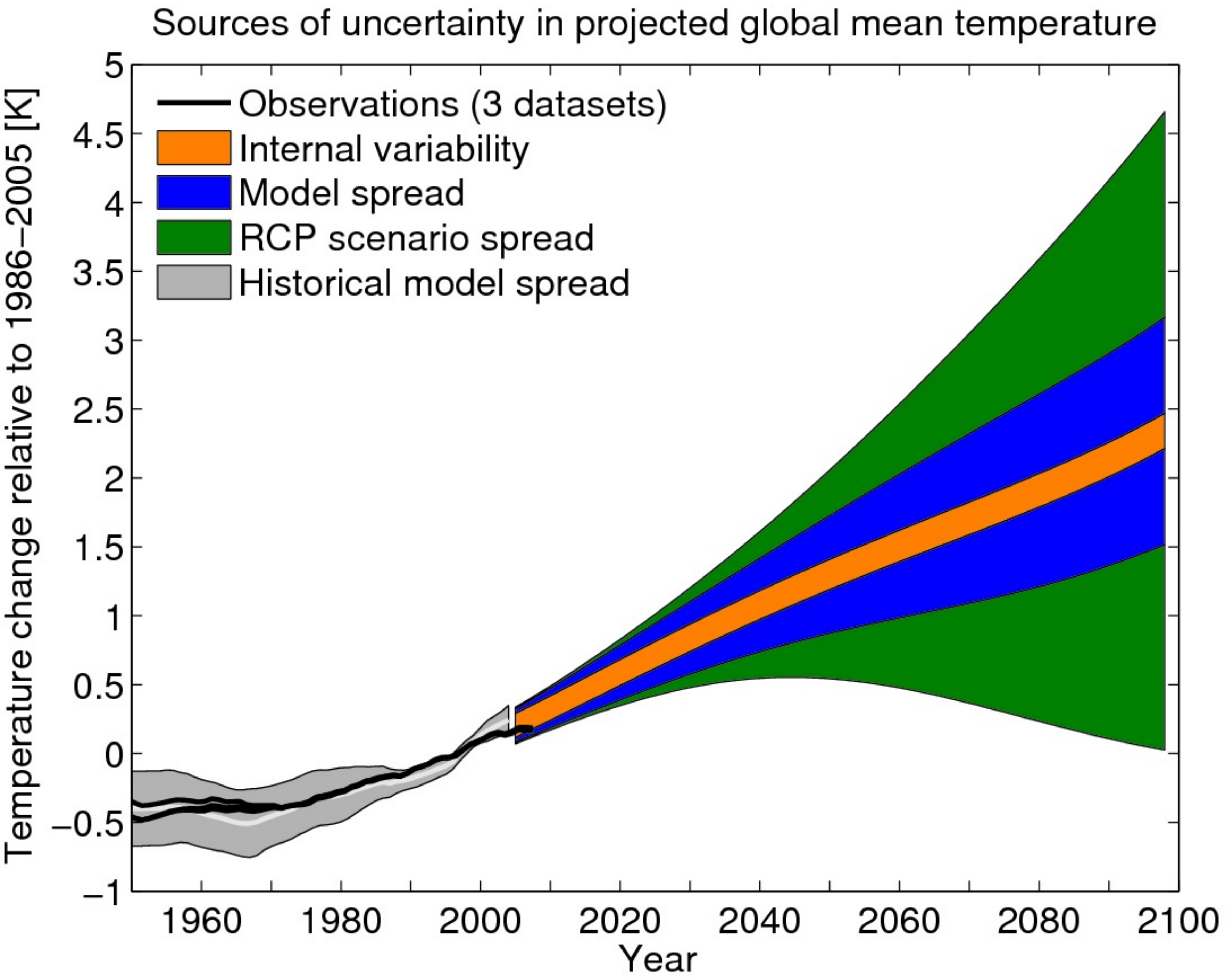


Global Mean Sea Level Change Relative to 1900



IPCC AR6 WGI SPM (2021)
Figure SPM.8
CMIP6 Models

Climate Projection Sources of Uncertainty

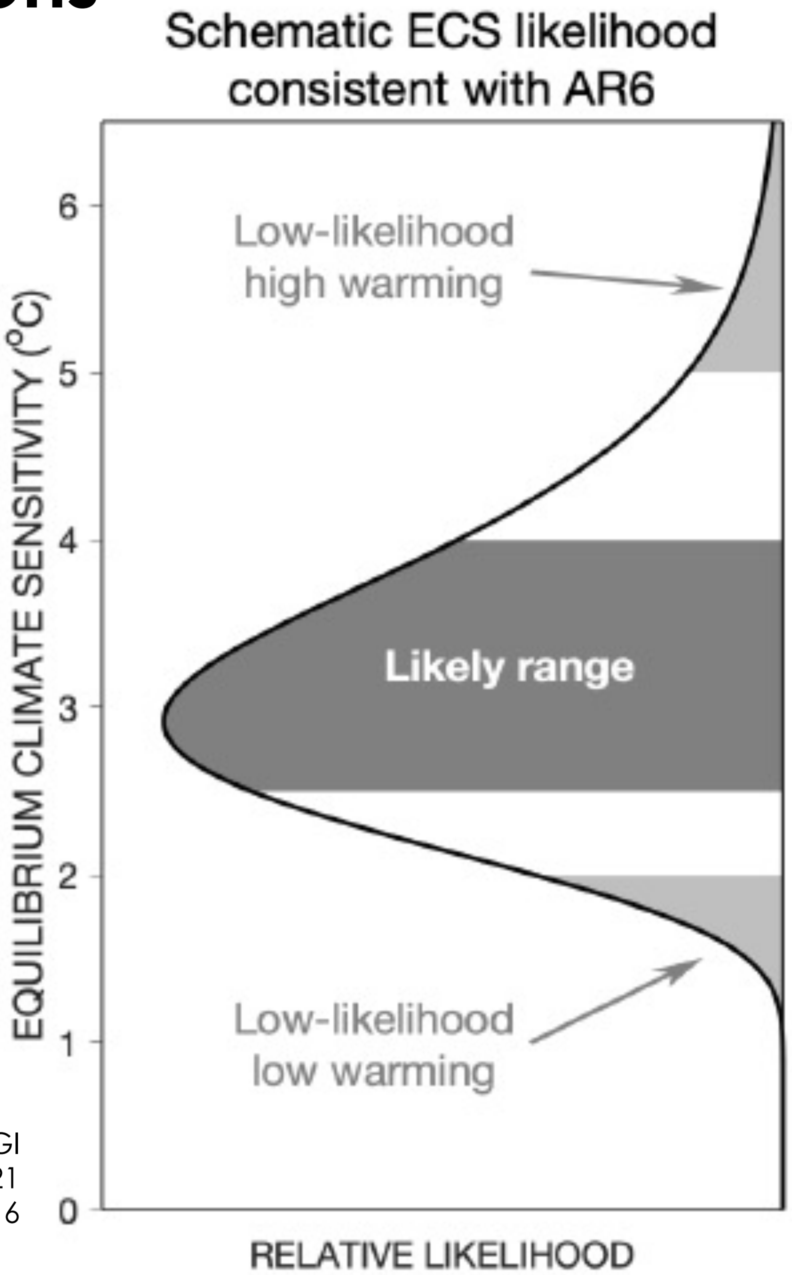


IPCC AR5 WGI
Kirtman et al., 2013
Figure 11.8
CMIP5 models

Uncertainty Across Models and Projections

- **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 AR6 Glossary, 2021)*

- **Parameter Uncertainty**
- **Internal Variability**
- **Scenario Uncertainty**



IPCC AR6 WGI
Chen et al., 2021
Figure 1.16

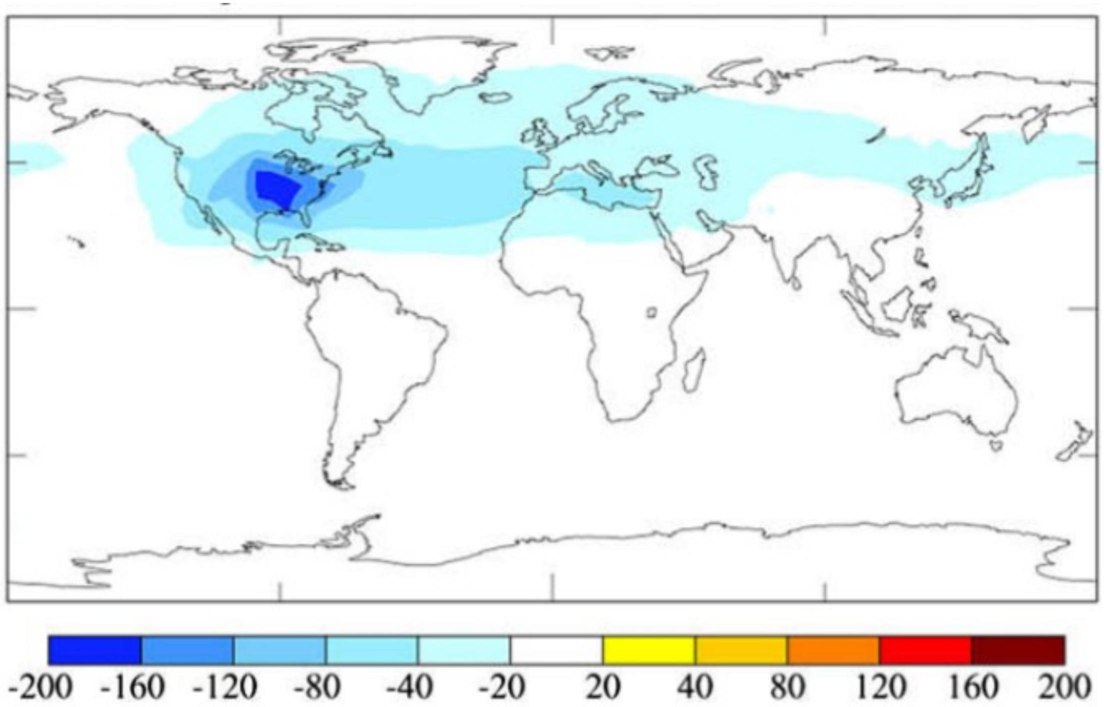
Additional Applications –

Models allow us to move beyond directly observed conditions.

- **Low-Likelihood High-Impact Events**
  - Effect of volcanos or shifts in major patterns of ocean circulation
- **Air Quality and Energy Policy** →
  - Different emissions have different effects on climate system

Hypothetical Electric Vehicle Policy Scenario:
Reduce on-road transportation emissions by 50%, replace with more power generation

Resulting Climate Forcing (mW/m²) from Non-CO_2 Factors
(e.g., sulfate aerosols):

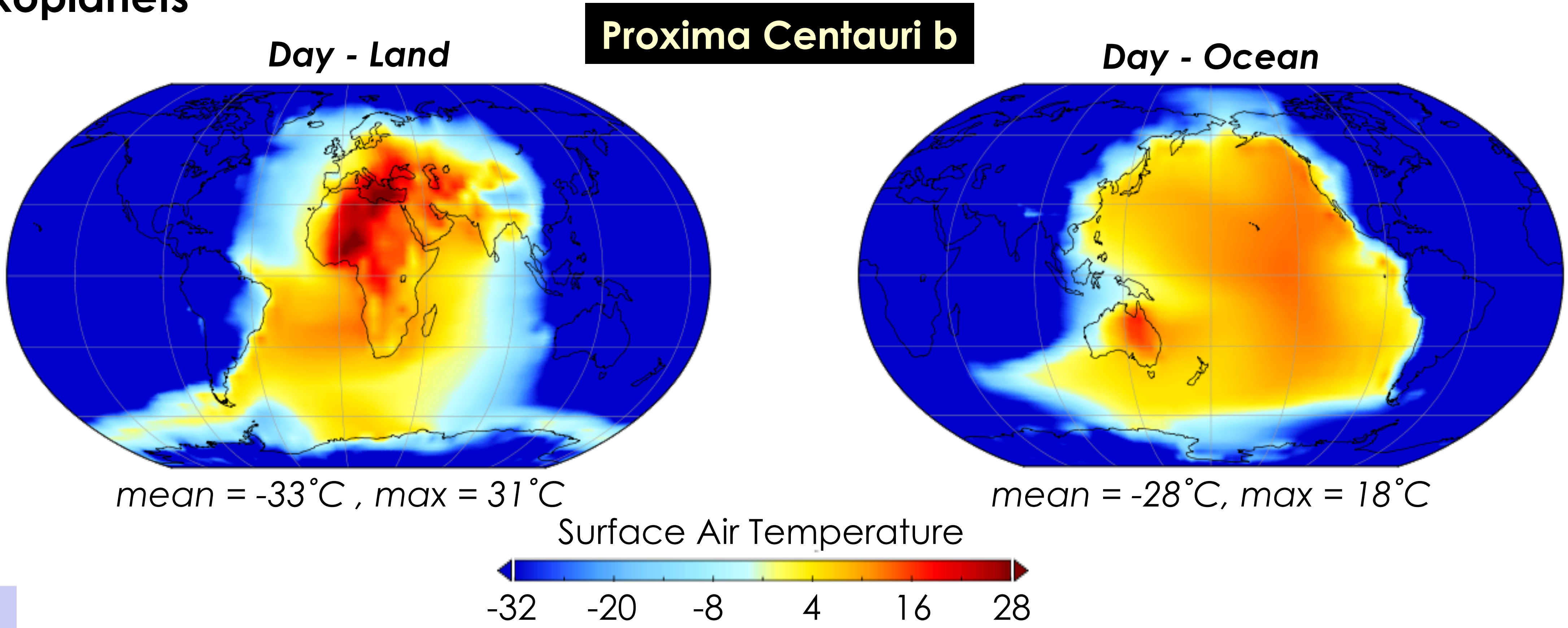


Unger et al., 2009; Atmospheric Environment

Additional Applications –

Models allow us to move beyond directly observed conditions.

- **Paleoclimate**
  - Ice ages and megadroughts
- **Exoplanets**

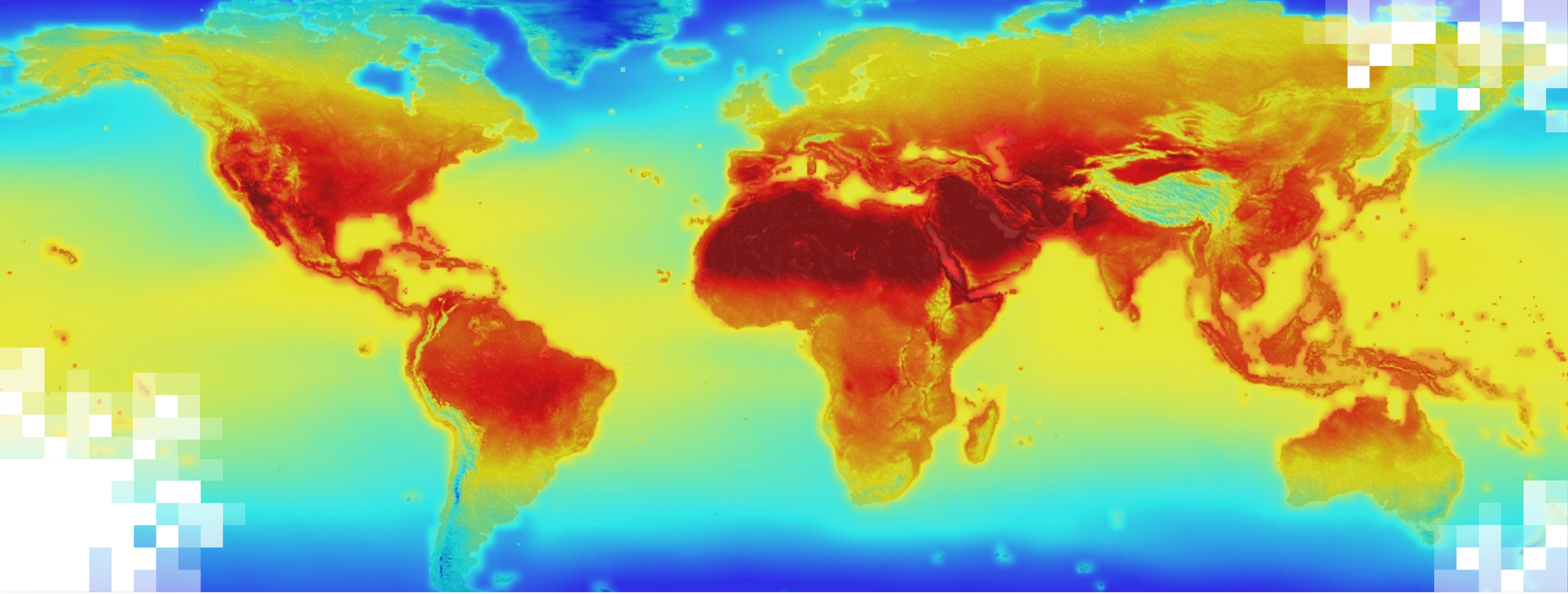


Proxima Centauri b

mean = -33˚C , max = 31˚C

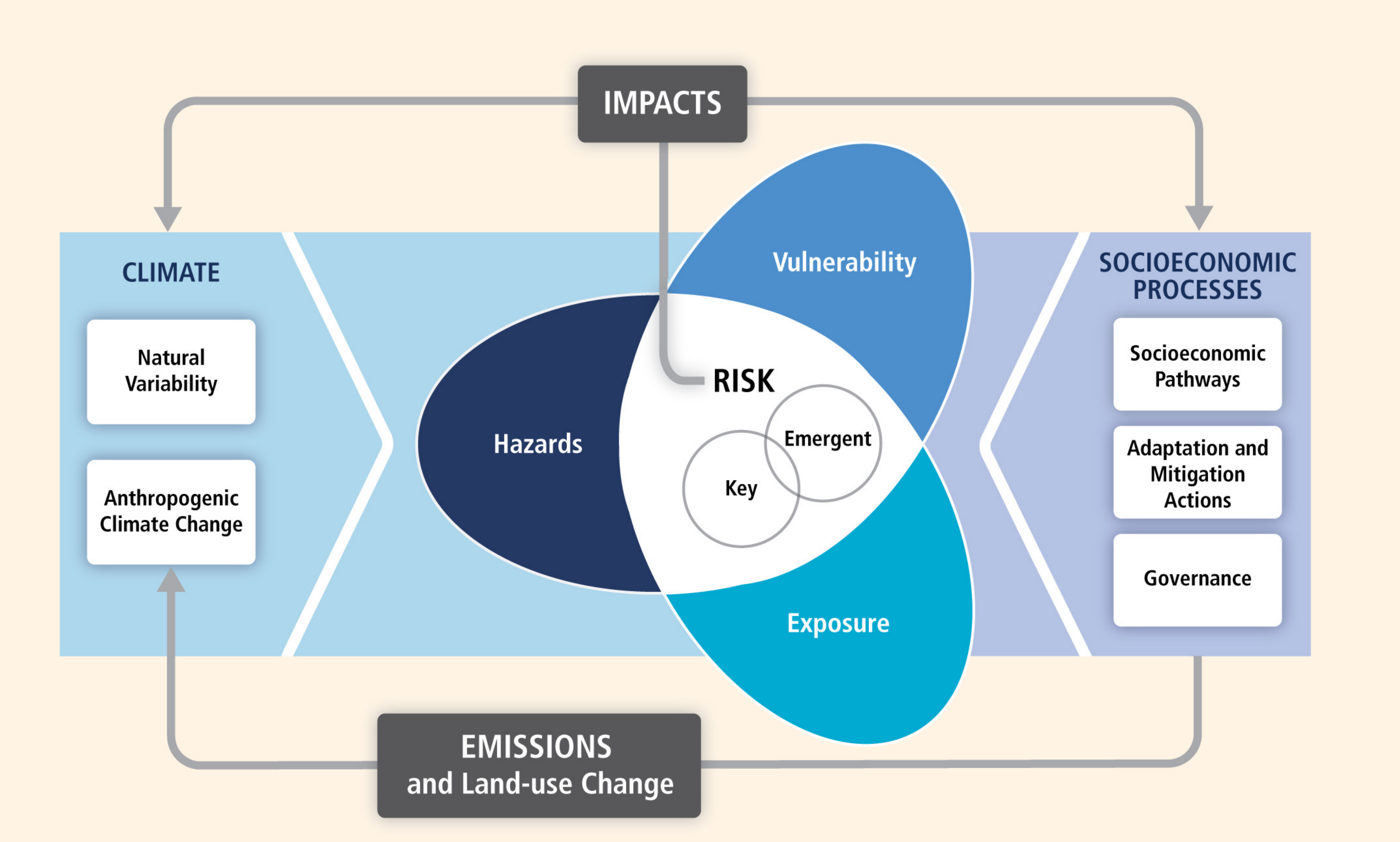
mean = -28˚C, max = 18˚C

Del Genio et al., 2018



Climate Impact and Risk Sectors

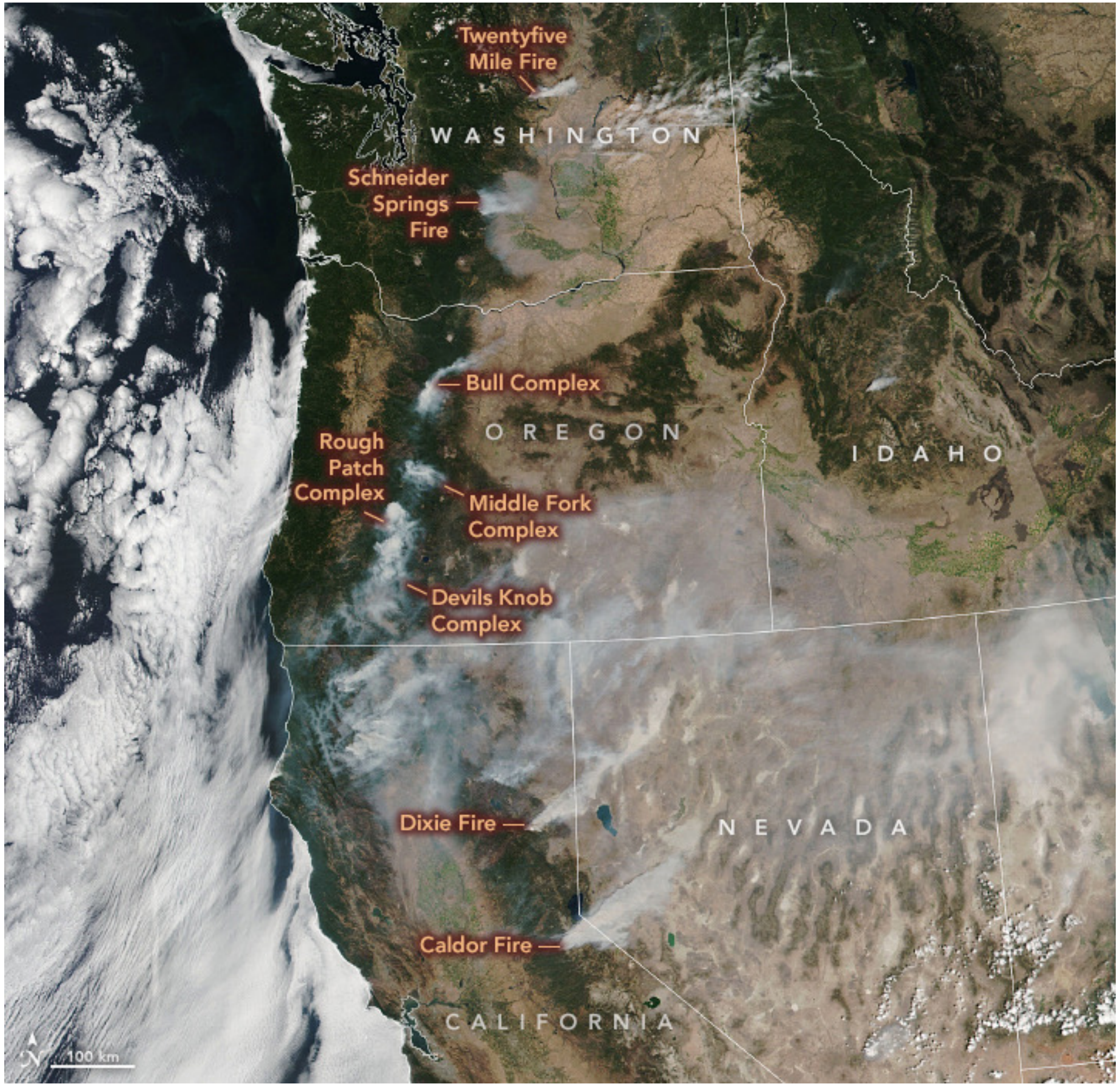
Assessing Climate Impacts and Risks for Things We Care About



Adaptation and mitigation responses can also affect risk.

IPCC AR5 WGII Chapter 19
Oppenheimer et al., 2014
Figure 19.1

Terrestrial Ecosystems



Wildfires Burning in the Western United States, August 2021

Source: NASA

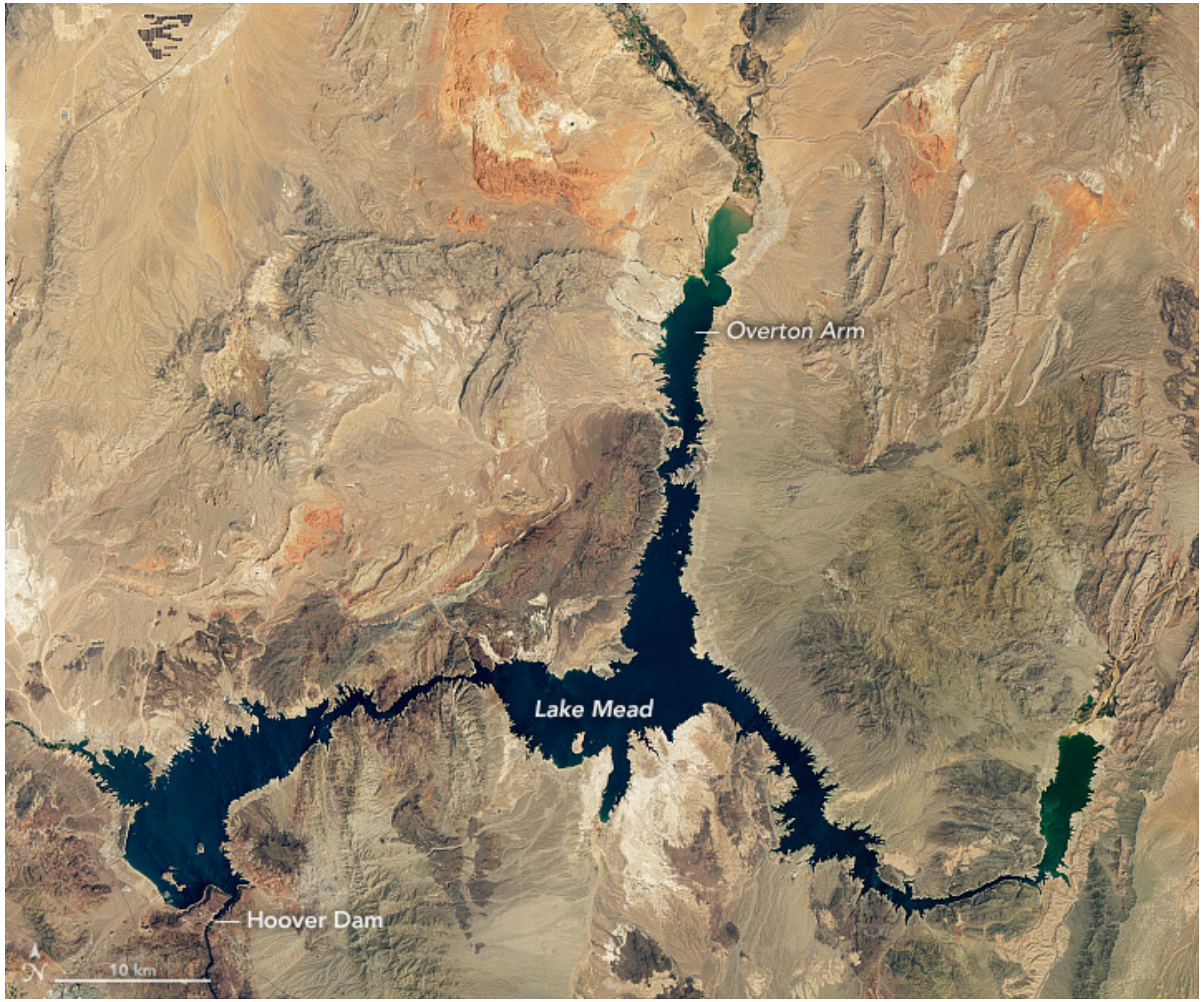
Marine Ecosystems

Mangroves in Belize

Photos: Manishka De Mel

Water Resources

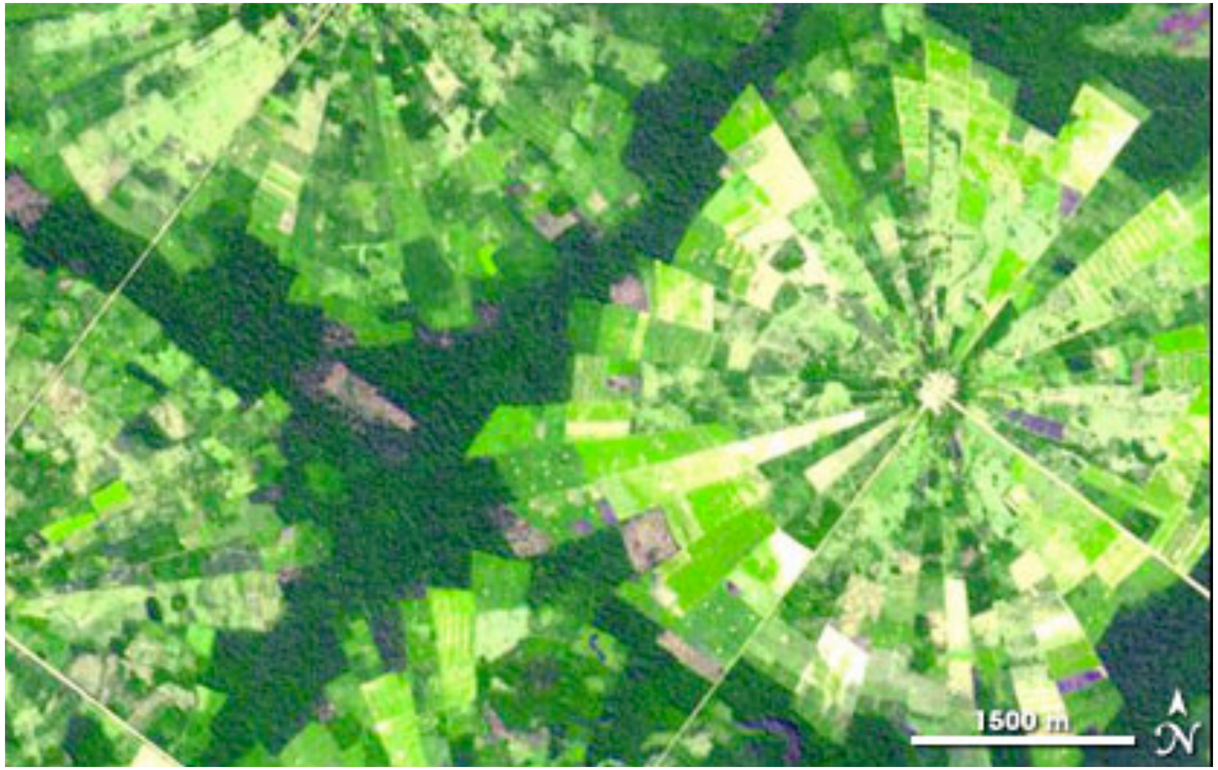
Lake Mead, August 2000



Lake Mead, August 2021

NASA Earth Observatory
https://earthobservatory.nasa.gov/images/148758/lake-mead-drops-to-a-record-low

Food Systems



Agriculture Encroaching on Tropical Forests in Bolivia
Image: NASA/GSFC/METI/JAPAN SPACE SYSTEMS,
and U.S./JAPAN ASTER SCIENCE TEAM

Photos: Alex Ruane

Urban Areas

New York City
Subway System After
Hurricane Sandy, 2012

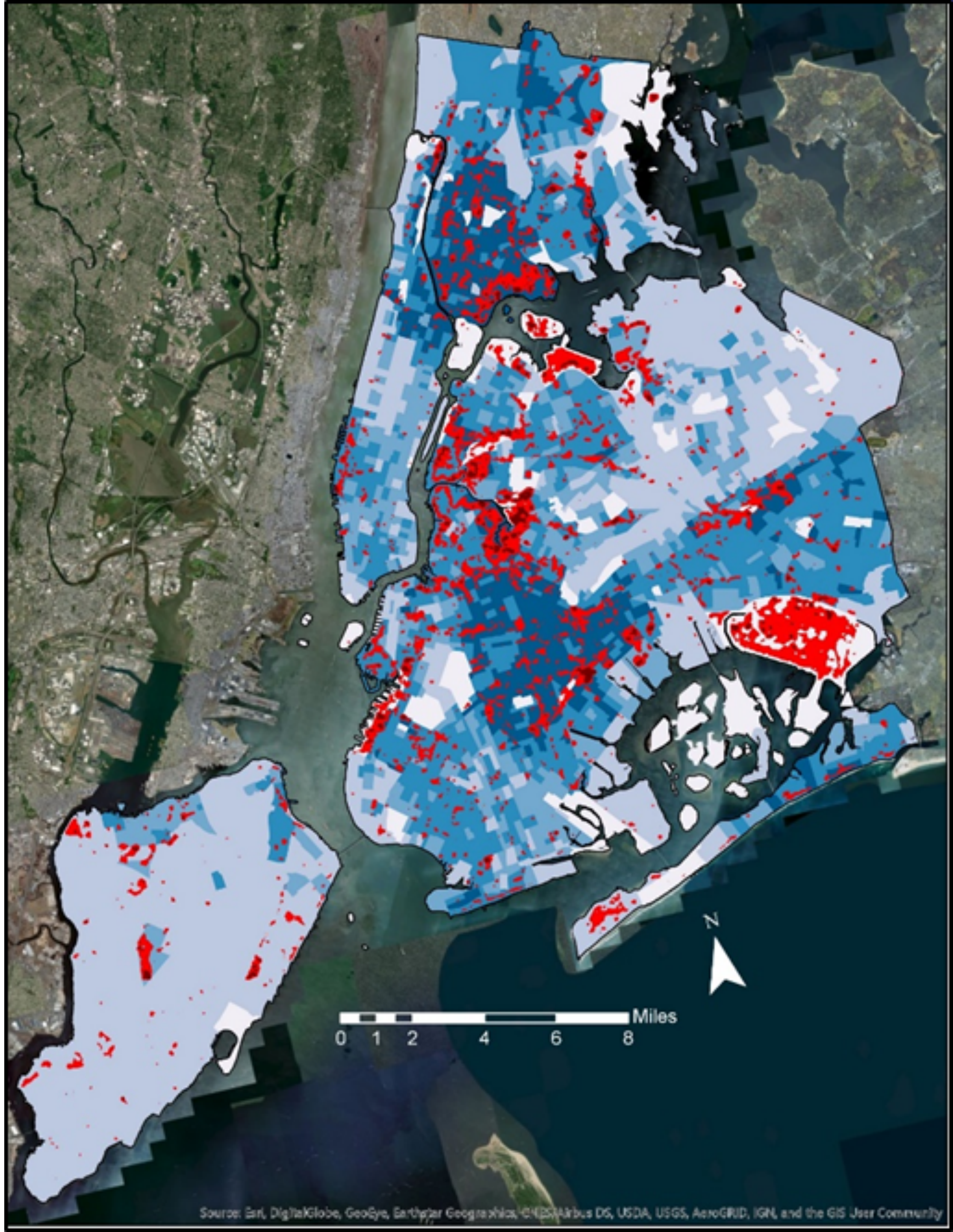
Photo: Daniel Bader

Human Health

Average Thermal Hotspot Location (1990-2019) in New York City Compared to Location of Heat-Vulnerable Neighborhoods

Red represents areas with elevated surface temperature (Landsat ARD 1990-2019), while **darker blue** areas represent neighborhoods with increased heat vulnerability.

(Heat Vulnerability Index; NYCDOHM, 2015; NASA DEVELOP)

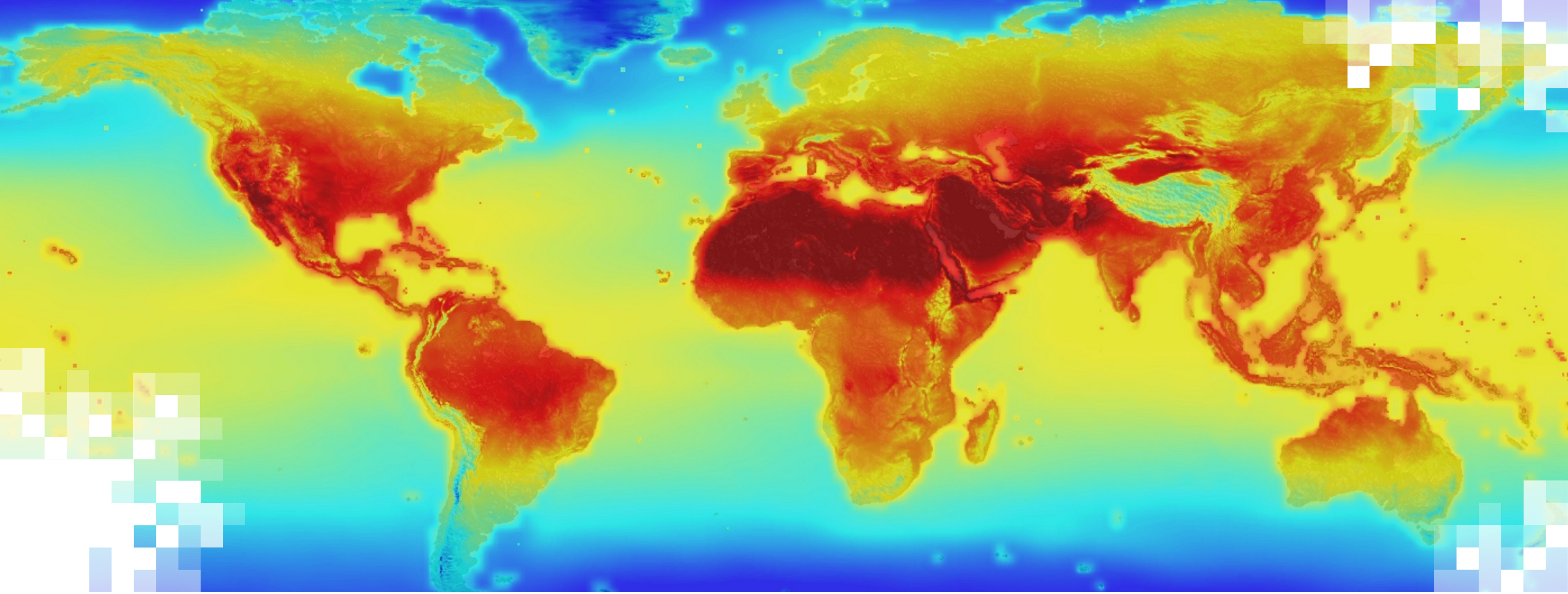


Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Livelihood/Development

Dhaka, Bangladesh

Photo: Alex Ruane



Climate Impact and Risk Projection

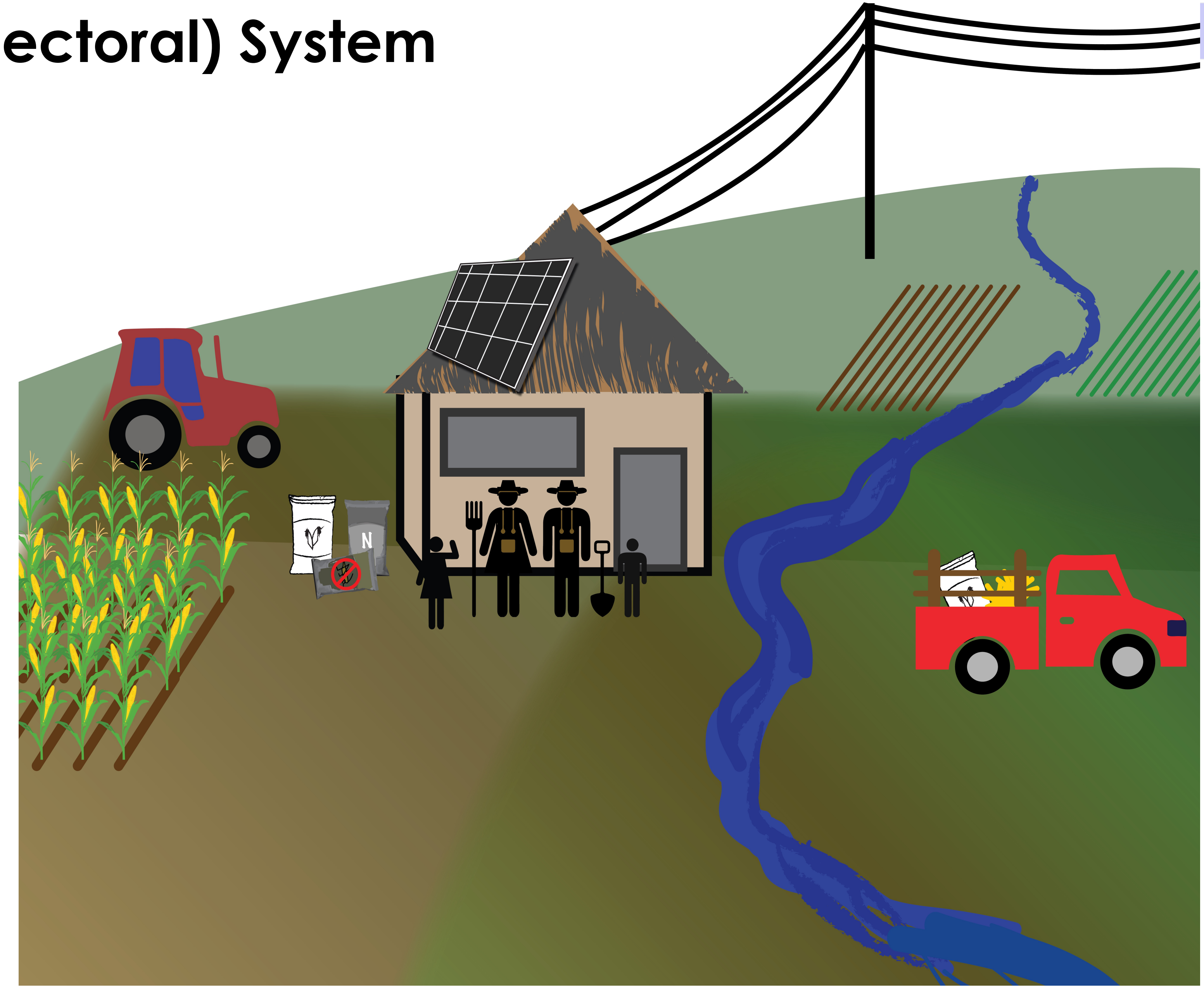
Framework to Assess Future Impacts for Applications

- Represent Current System of Interest
- Represent Current Climate
- Represent Future System Changes
- Project Future Climate
- Project Future Climate Impacts
- Identify and test adaptation and risk management strategies

Represent Current (Sectoral) System

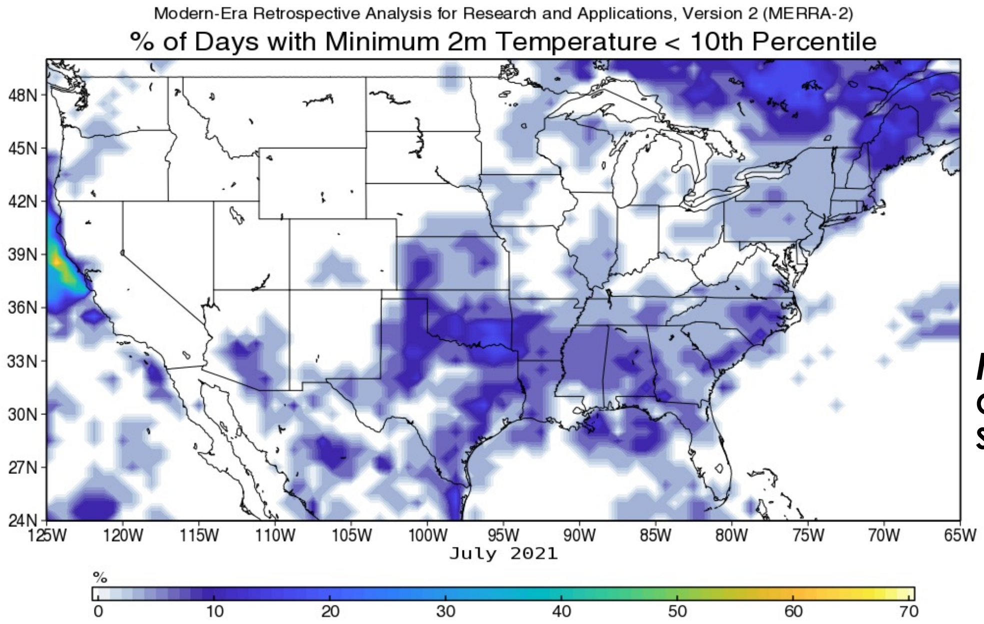
Example of a Farm System

- System elements
- Element conditions and lifetimes
- Actor management and motivations
- System boundaries and pressures



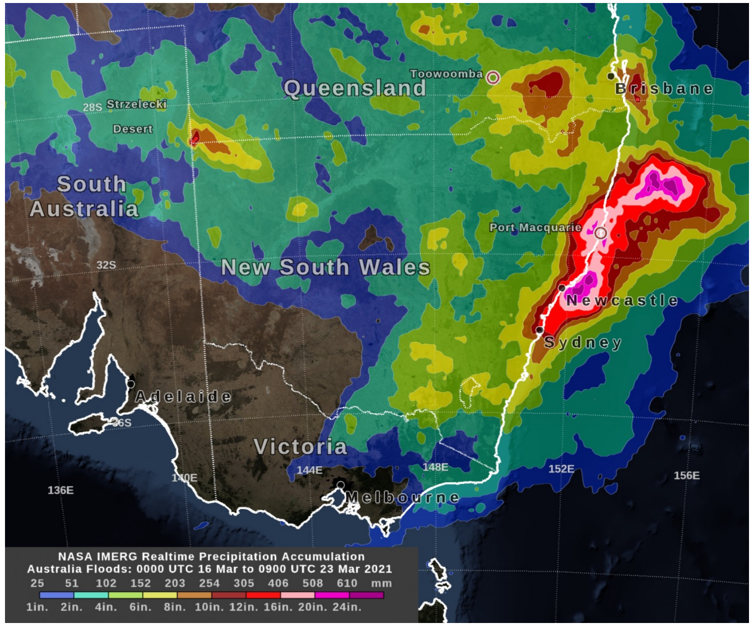
Represent Current Climate

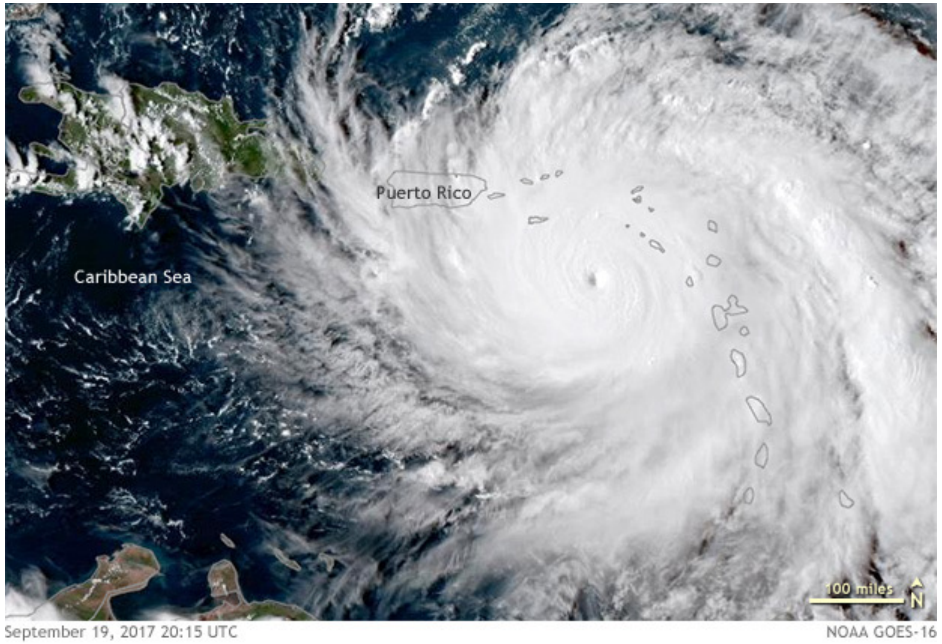
NASA models and missions help capture extreme events and characterize current climate conditions.



MERRA-2
Cold Spell in Southern US

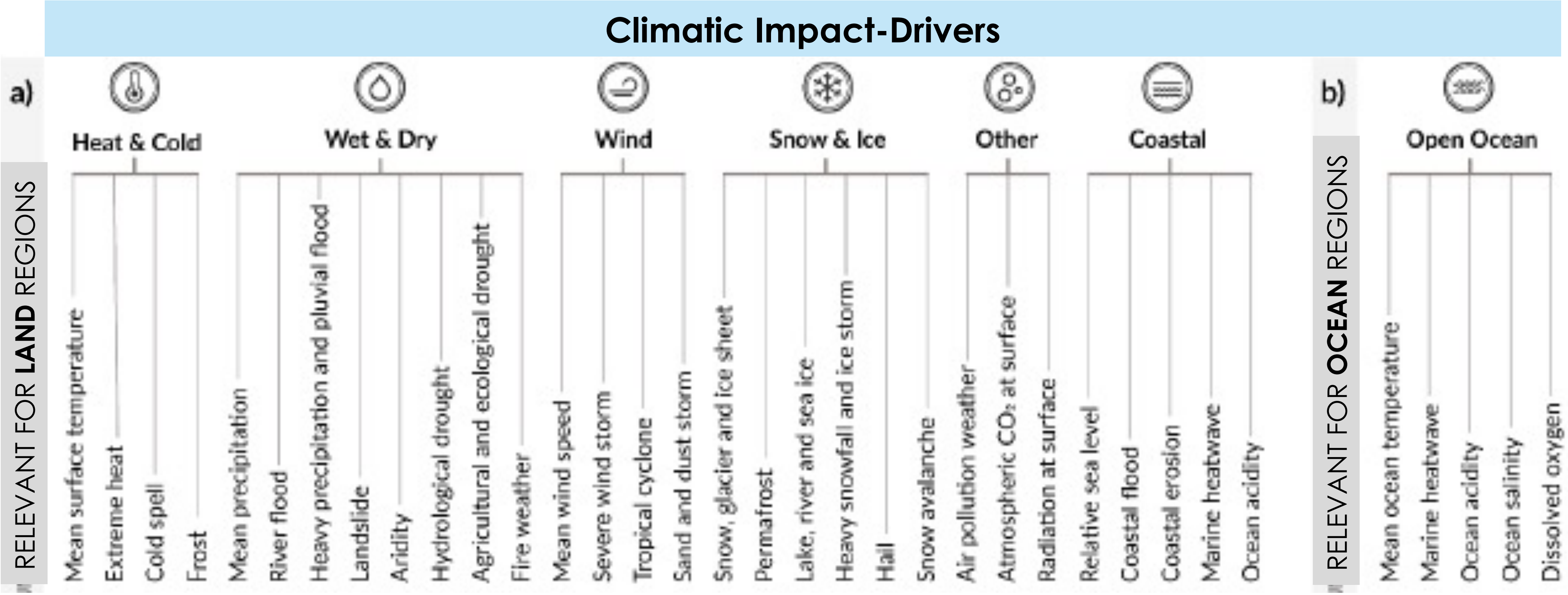
IMERG
Heavy Rains in SE Australia





GOES-16
Hurricane Maria Approaching Puerto Rico (2017)

Look for Relevant Responses Across Many Climate Factors

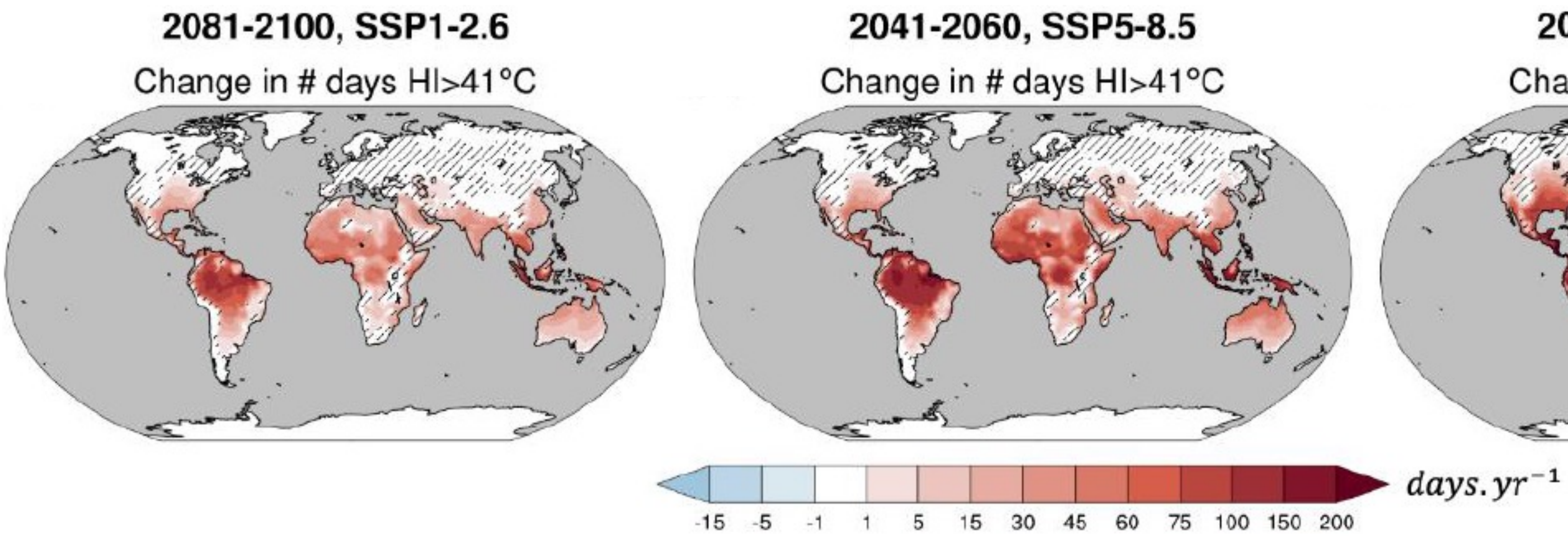


A climatic impact-driver (CID) is a climate condition that directly affects elements of society or ecosystems. Climatic impact-drivers and their changes can lead to positive, negative, or inconsequential outcomes (or a mixture).

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

Project Future Climate

- Relationship to **sector-relevant thresholds** is particularly important

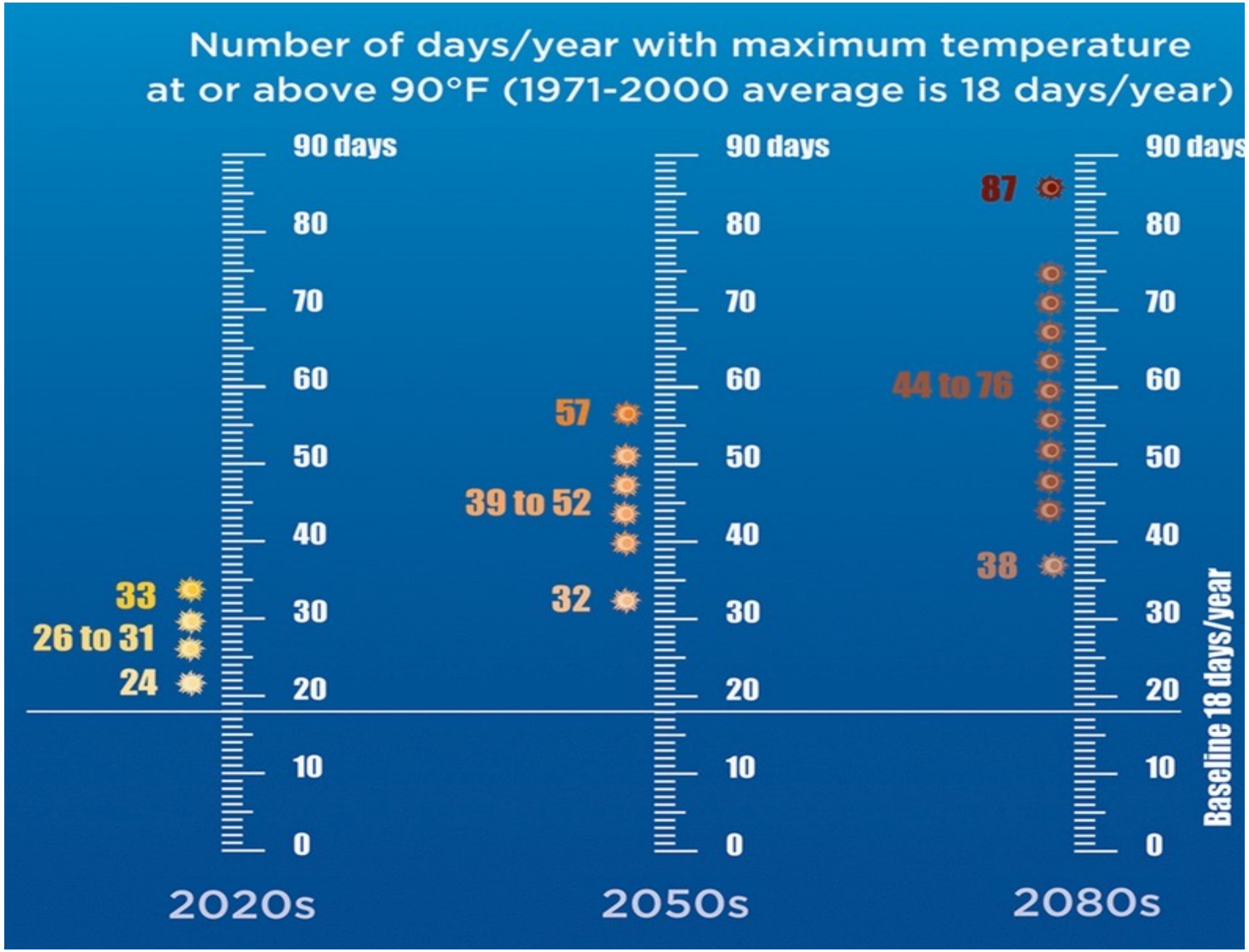


NOAA Heat Index > 41 ℃ is considered "Dangerous."
Heat and humidity make conditions difficult for outdoor exercise, construction, and agricultural labor.

From IPCC AR6 WGI Chapter 12 (Ranasinghe et al., 2021) Figure 12.4

Project Future Climate

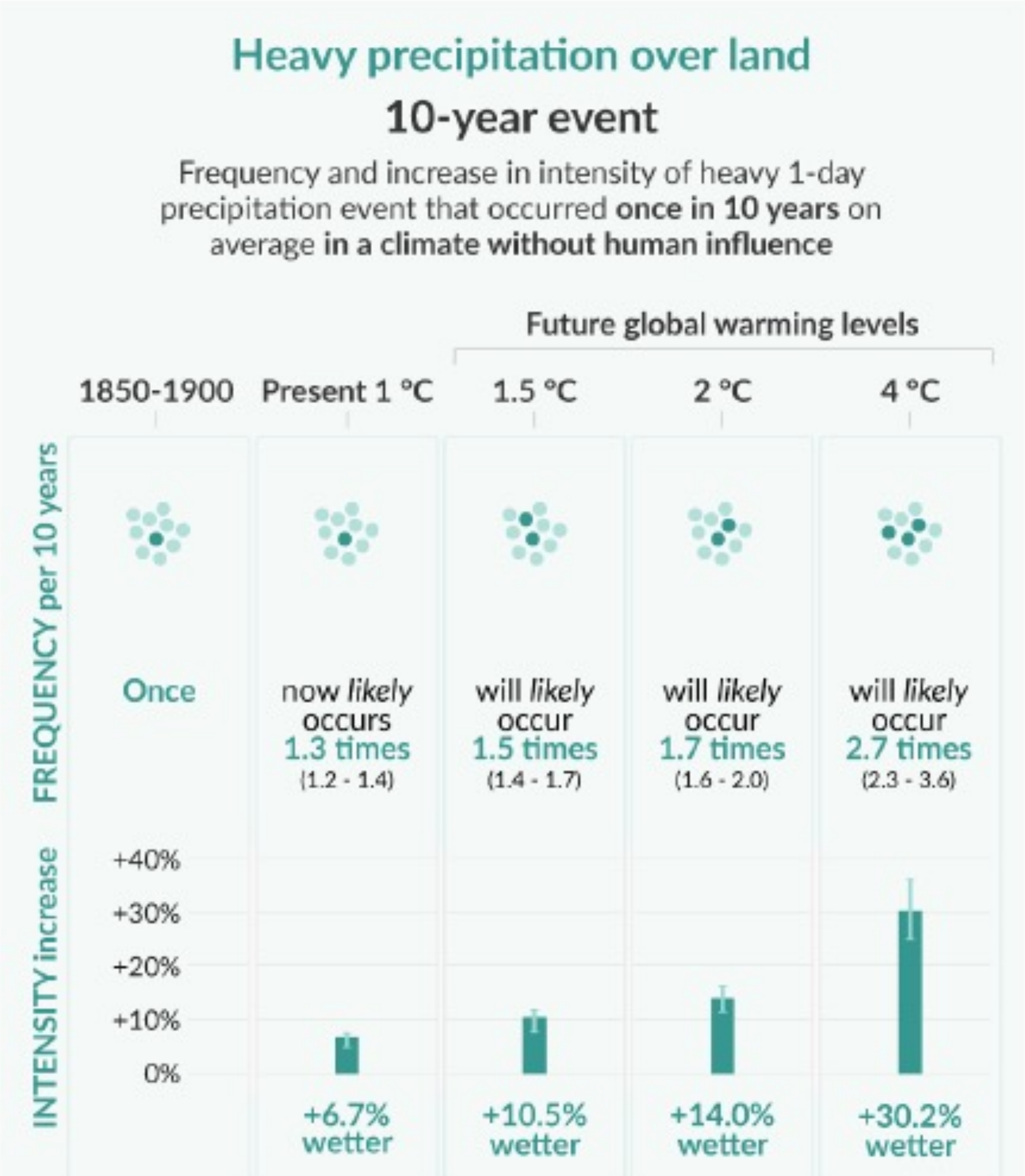
- **Intensity**, frequency, duration, seasonal timing, and spatial extent
- Relationship to **tolerance thresholds** is particularly important



Projected Hot Days (Tmax > 90°F) in New York City

From Rosenzweig and Solecki, 2015 (doi:10.1111/nyas.12715)

Changes in Climate Extreme Frequency and Intensity

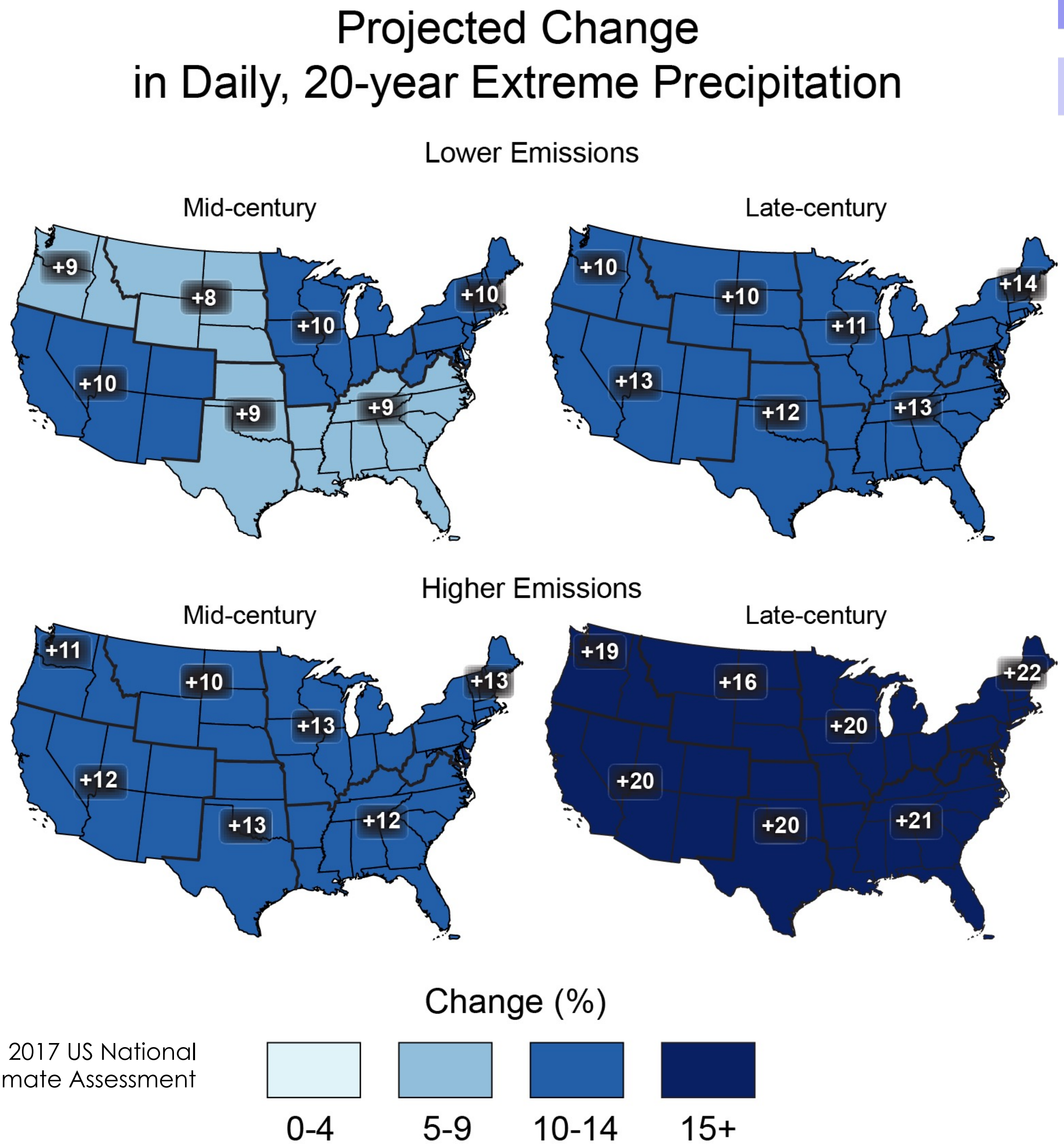

Heavy precipitation over land

10-year event

Frequency and increase in intensity of heavy 1-day precipitation event that occurred **once in 10 years** on average **in a climate without human influence**

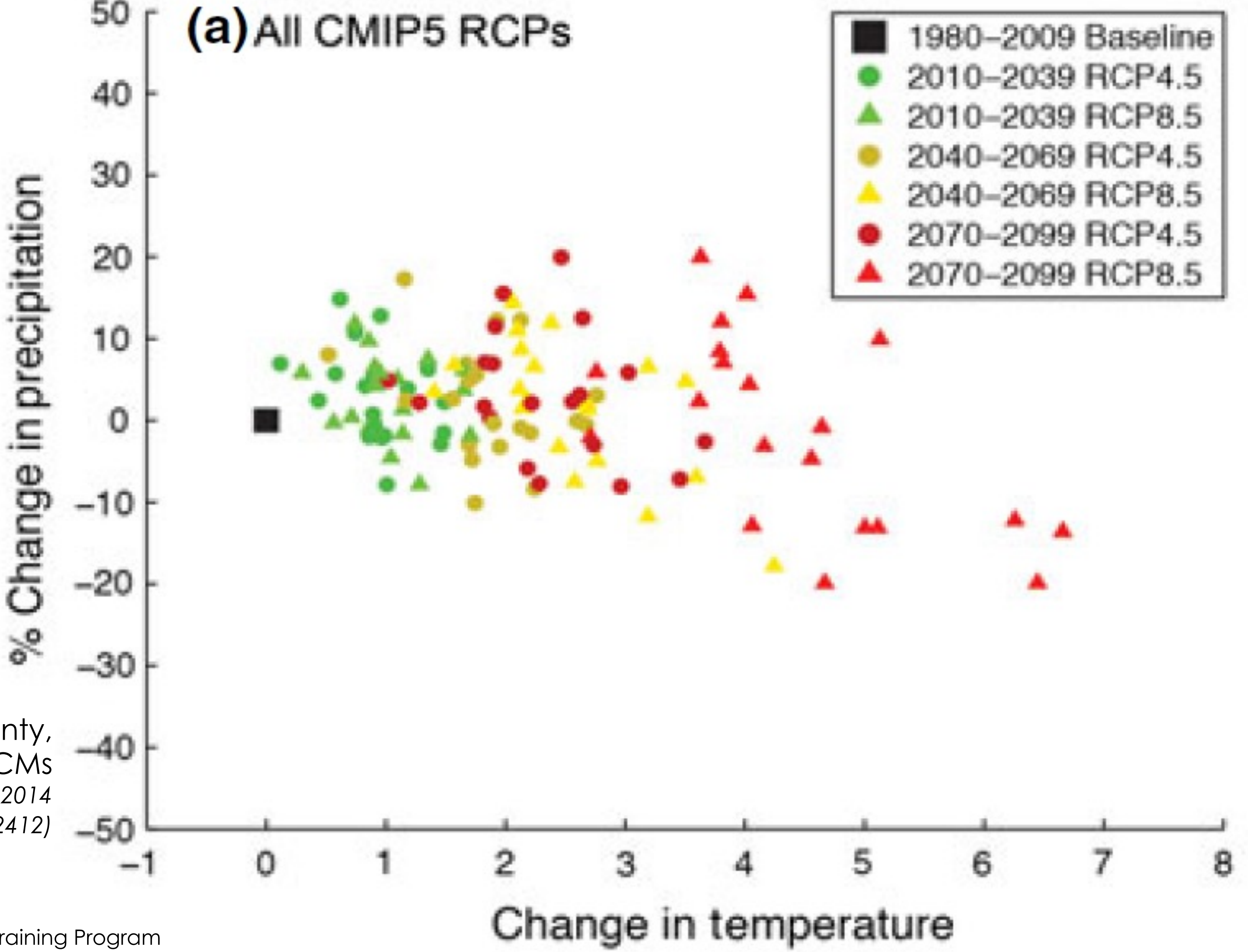
Project Future Climate – Scale Matters

Statistics may be more robust over broader regions, but actions are often taken locally.



2017 US National Climate Assessment

Project Future Climate – Spread of Local Projections



Climate Change in Henry County, Alabama Across 20 CMIP5 GCMs

From Ruane et al., 2014 (doi:10.1111/gcb.12412)

Bridging the Current Climate to Future Climate Scenarios

Fidelity of future scenario depends on quality of present observations

Bias-Adjusted Climate Projections

1. Determine climate model biases by comparing against historical observations
   - E.g., Intensity, frequency, distribution, and finer spatial patterns
2. Adjust climate model projections to counteract these biases

Benefits:

- Reduces many biases that are important to sector responses

Drawbacks:

- Assumes historical biases are same in future
- Limited in areas with poor observational coverage
- Only focus statistics are affected
- Adjustments can lead to temporal, spatial, or internal inconsistencies in adjusted dataset

NASA NEX High-Resolution Climate Projections from CMIP5

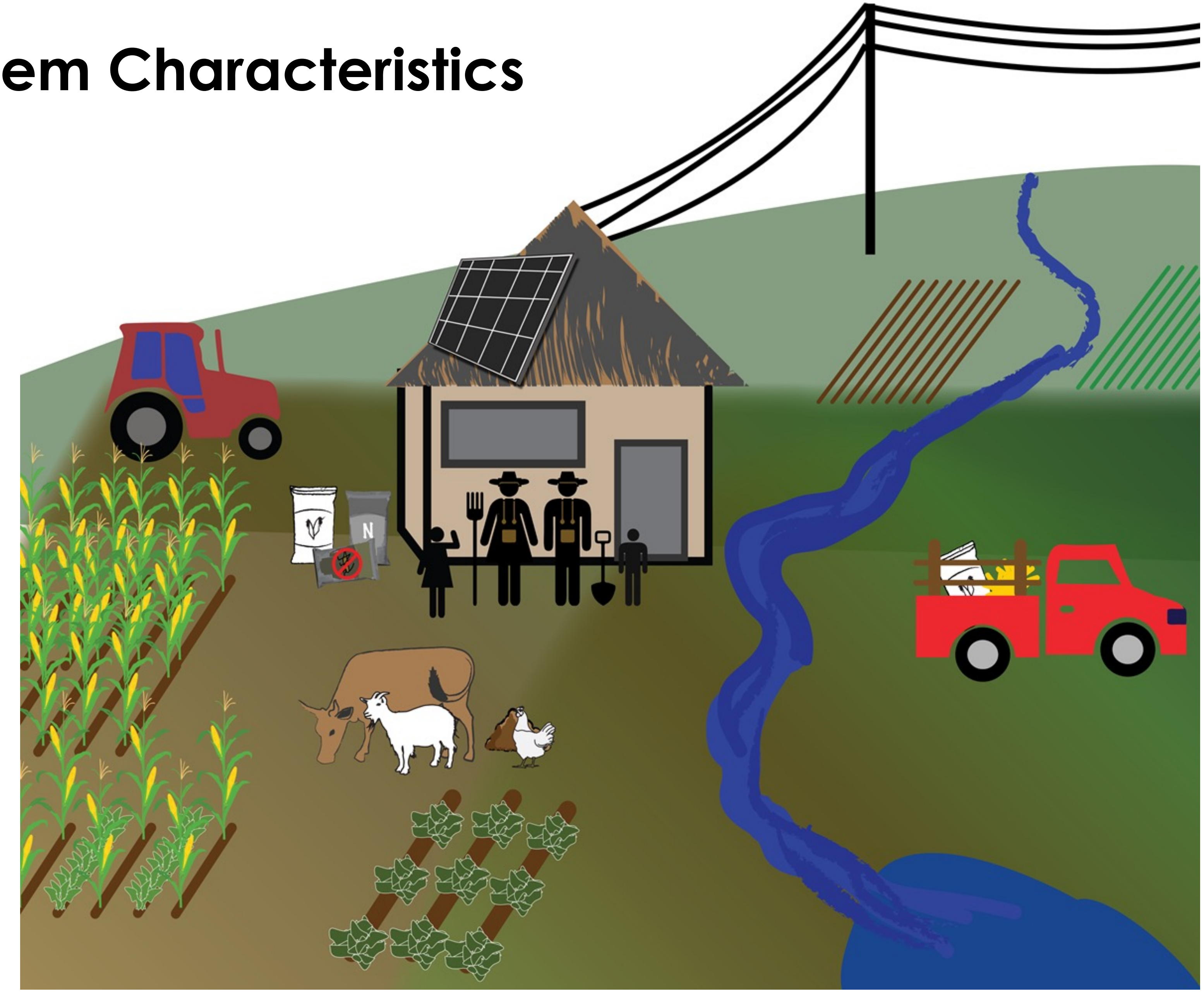
- Temperature, Precipitation
- 4 methodological approaches
- 30+ models; major scenarios
- Global coverage
  at ~25 km resolution (daily)
- Continental US coverage up to ~800 m resolution (monthly) and ~ 6 km resolution (daily)

NEX CMIP6 Projections Coming Soon with more models and variable fields!

Project Future System Characteristics

Future Farms

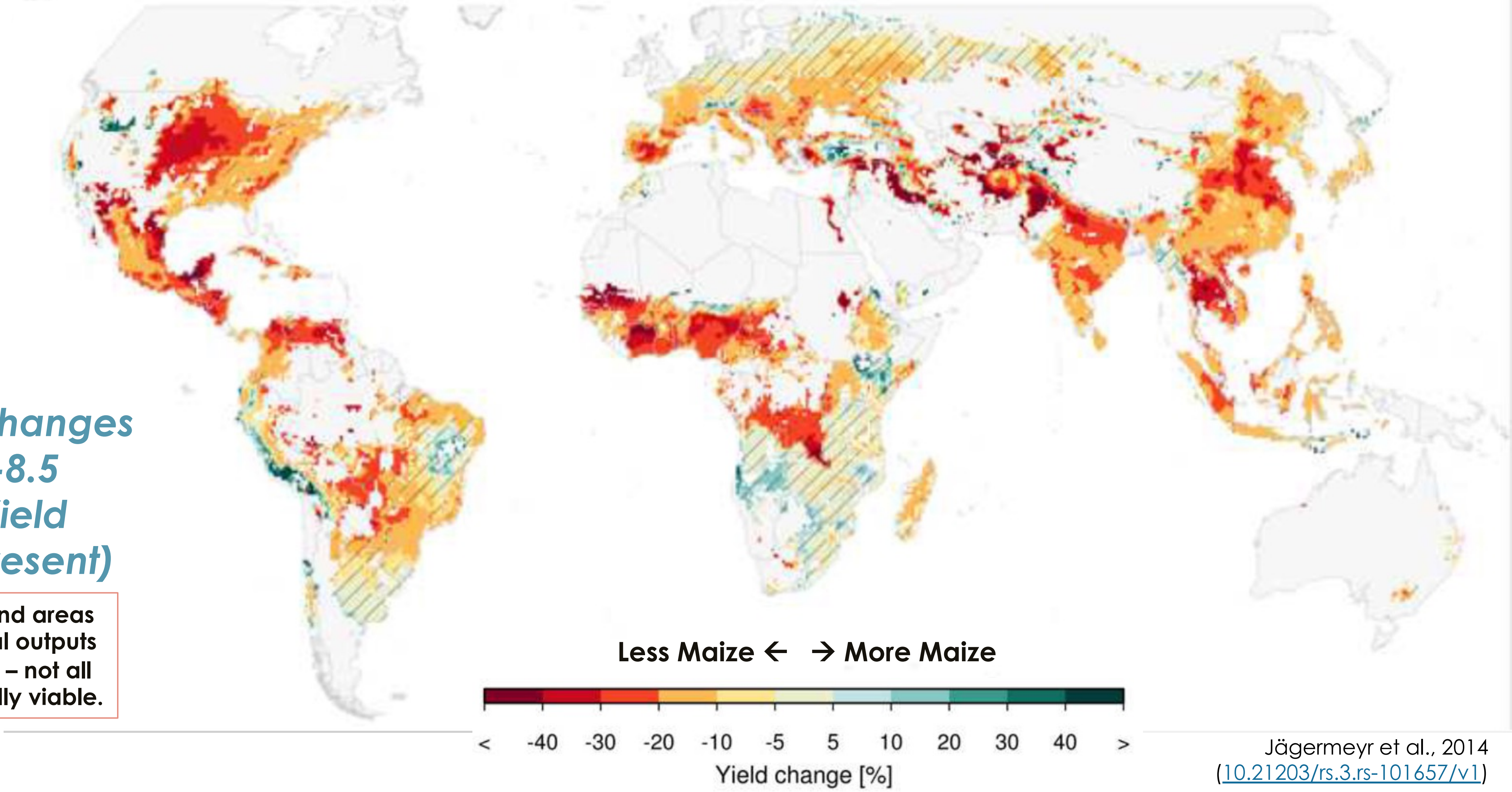
Additional or updated elements can change system responses.



Project Climate Impacts

Modeled Changes in SSP5-8.5 Maize Yield (2080s – Present)

Note that all land areas with agricultural outputs were modeled – not all are economically viable.



Jägermeyr et al., 2014 ([10.21203/rs.3.rs-101657/v1](https://doi.org/10.21203/rs.3.rs-101657/v1))

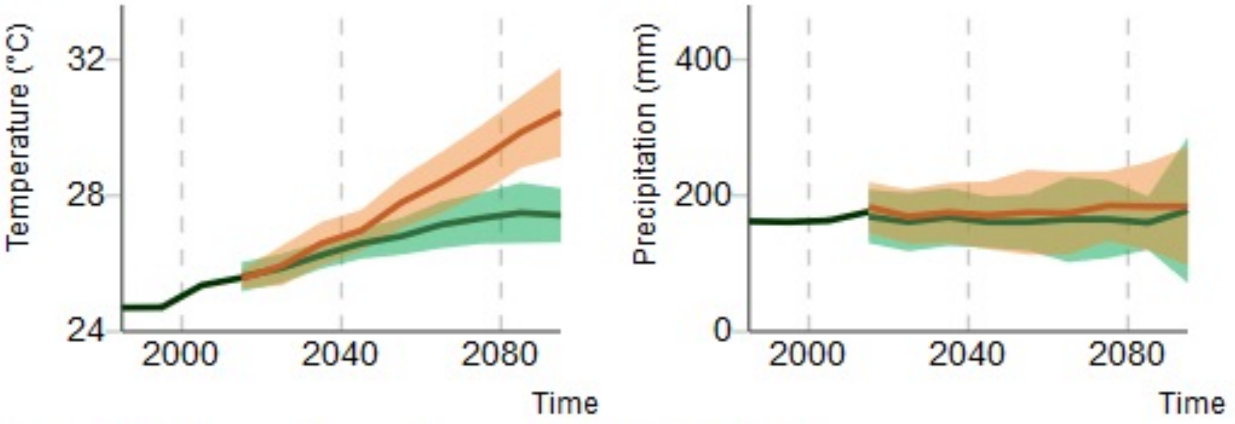
5 Bias-Adjusted Climate Models, 12 Global Gridded Crop Models; Hatched Areas = <70% agreement in sign of change

Simulations organized by AgMIP and ISIMIP

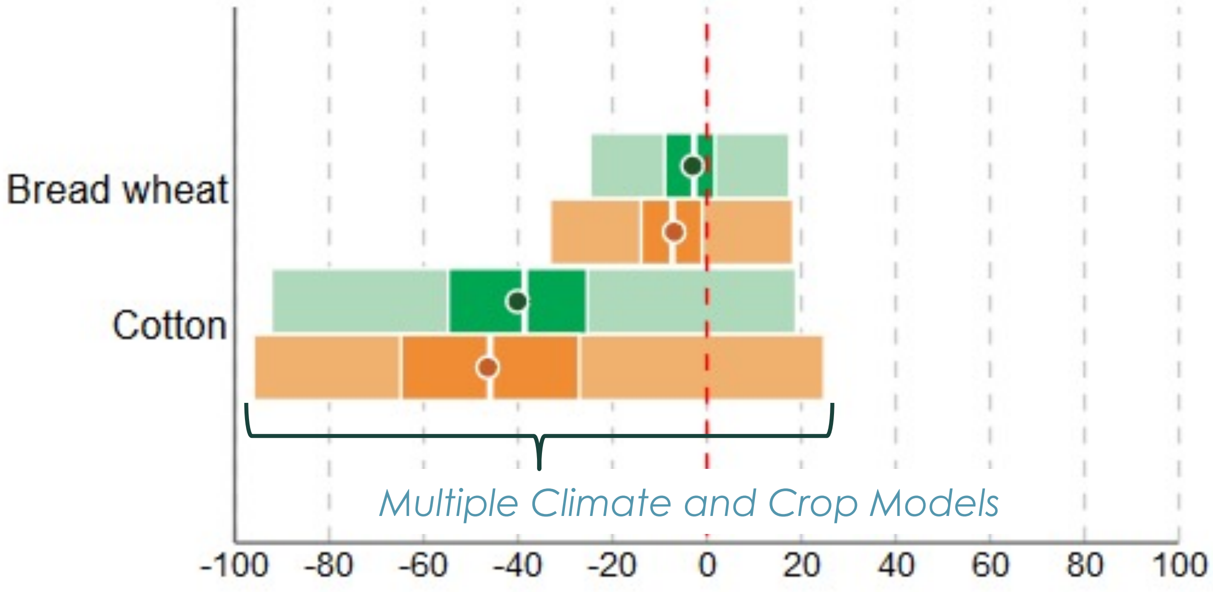
Representing Climate Uncertainty in Impacts Process

- Climate model, impacts model, and scenario can all contribute to uncertainty.

Climate Change Projections *(1985-2095)*

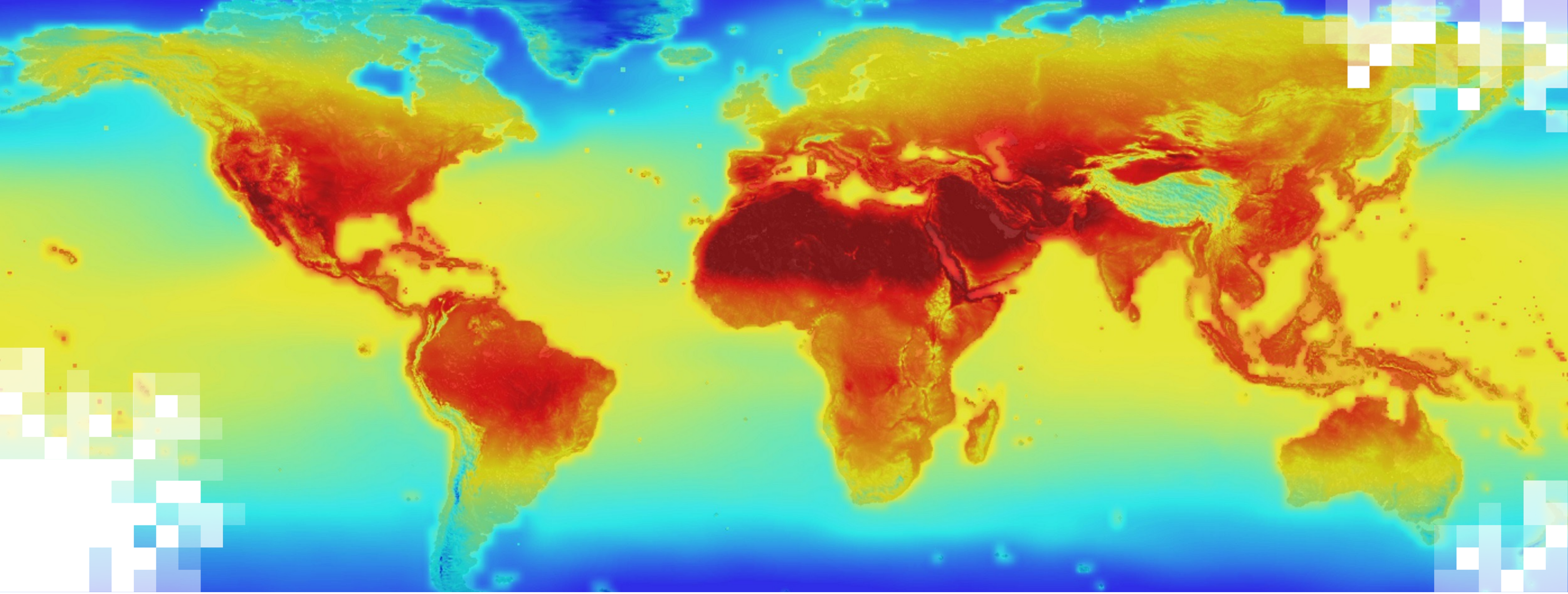


Climate Change Impact on Yields (2050s)



Projections of wheat and cotton yields in Pakistan under different climate models and scenarios. Green is a moderate emissions scenario (RCP4.5), Orange is a high emissions scenario (RCP8.5).

From Ahmad et al., 2015 (doi:10.1142/9781786348814_0006)



Climate Change Adaptation

Use of Climate Information for Adaptation

Climate adaptation must be **targeted** to climate hazards and **tailored** to the affected system.

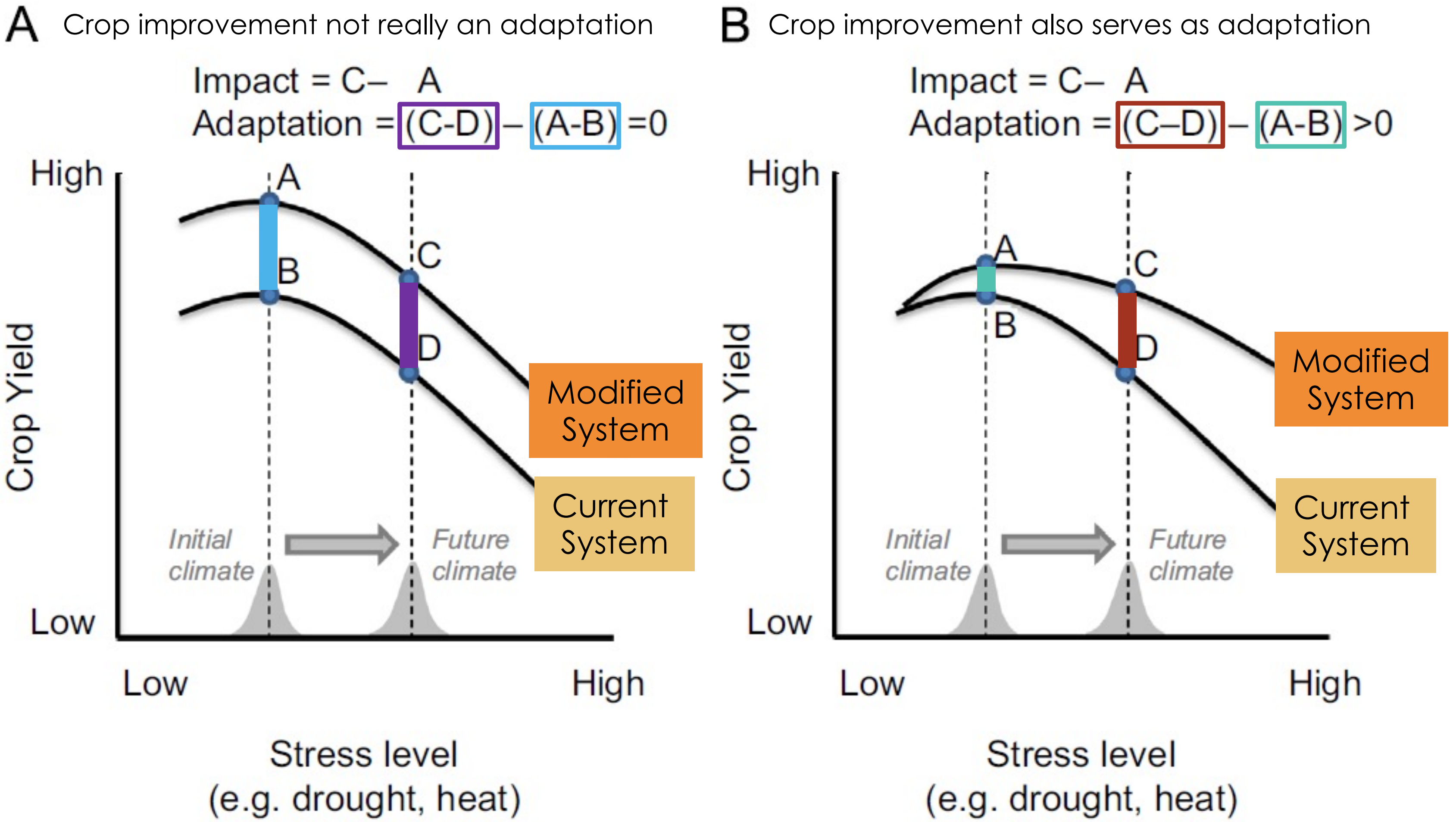
Adaptation Time Scales

Reactive adaptations and **proactive** adaptations both have benefits and drawbacks.

Adaptations in Context

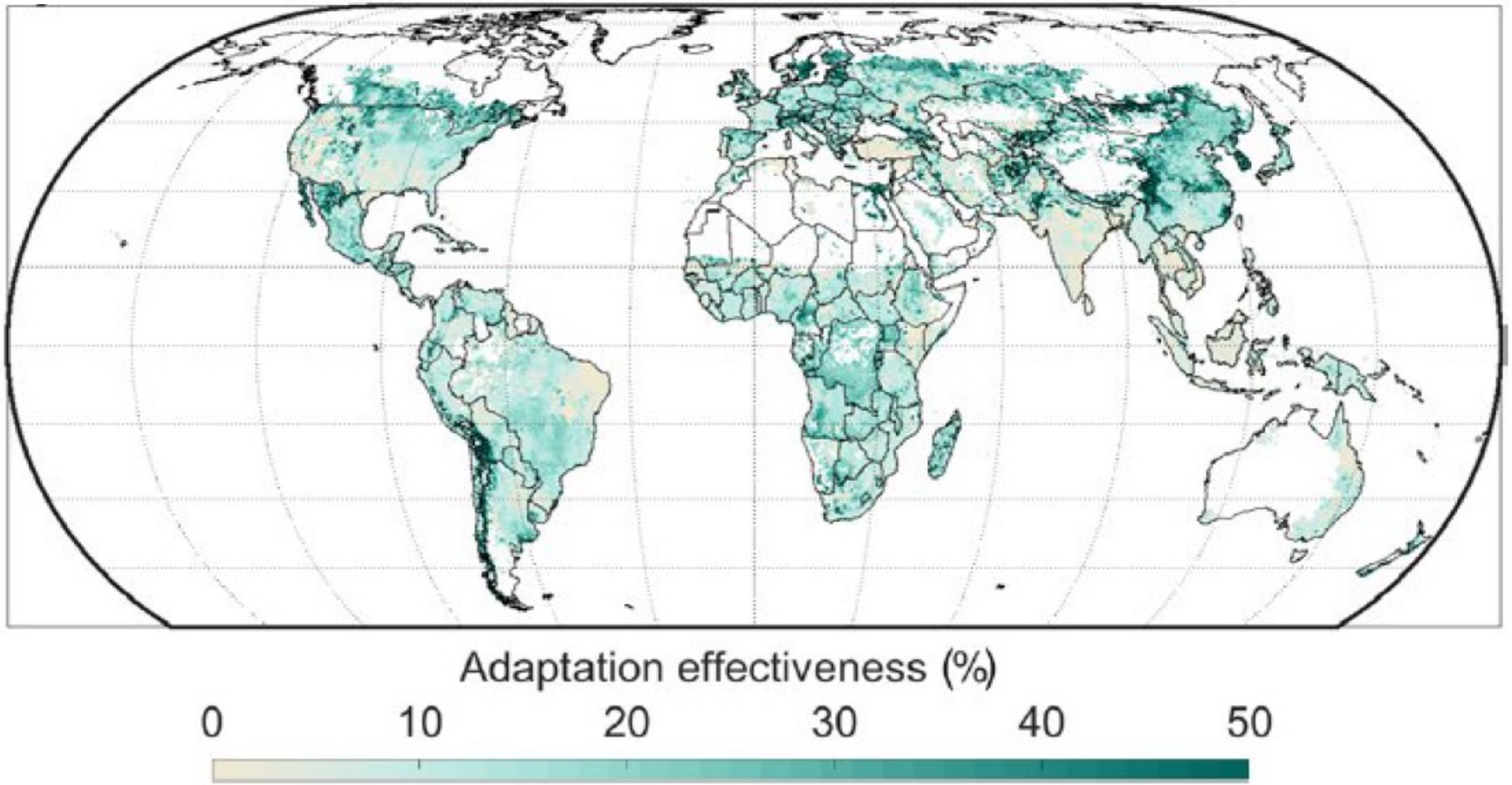
- Account for existing infrastructure, investments, and connections to other systems
- Recognize that decision makers often have multiple, sometimes competing motivations
- Benefit from integration into natural cycles of investment, updates, and maintenance
- Adaptation is a continuing process bolstered by solid scientific information

Identify Adaptations that Respond to Changing Risks



Adapted from Lobell, 2014
doi:10.1016/j.gfs.2014.05.002

Test Responses to Climate Scenarios



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)

Creating the Space for Adaptation Actions

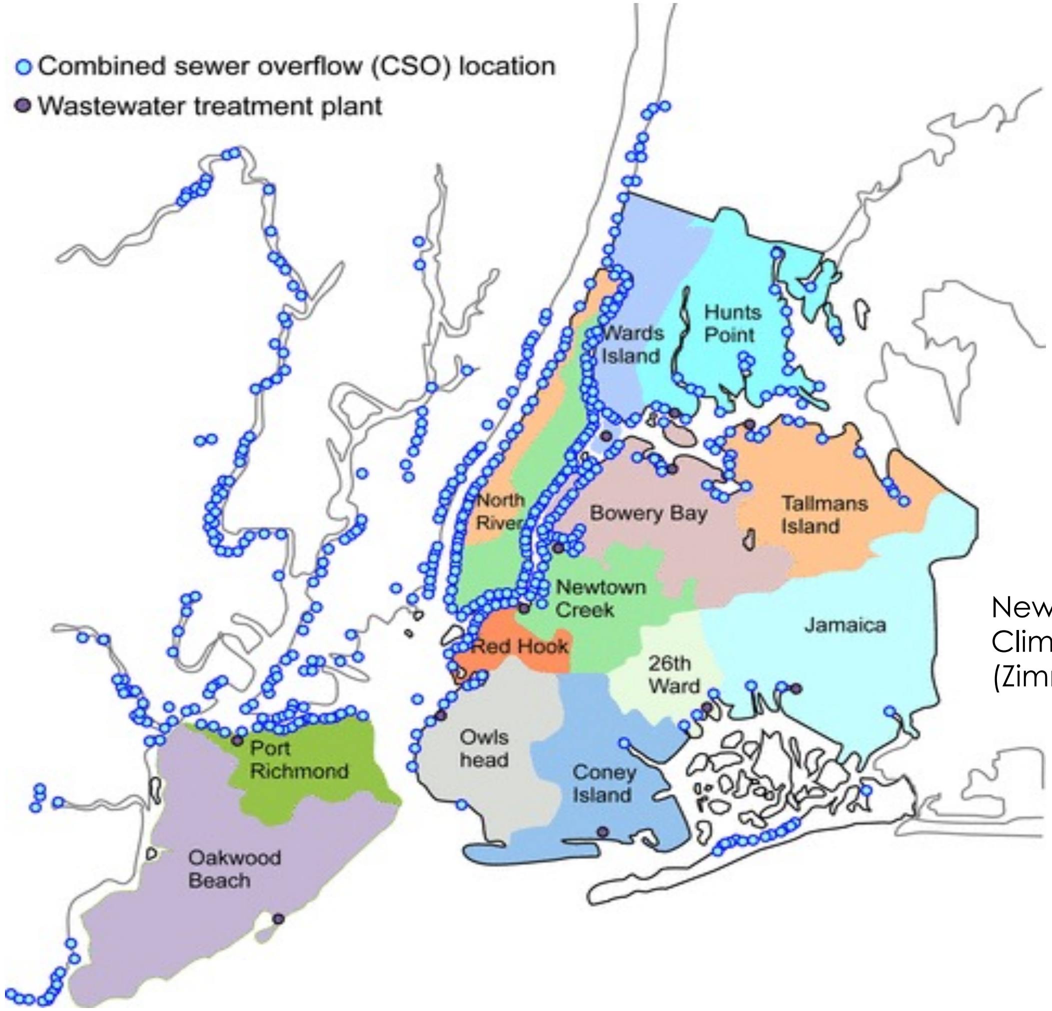
Case Study: The New York Panel on Climate Change

NASA scientists facilitated a consortium of New York City agencies and private corporations and academic leaders to prepare the city for climate impacts.

NASA Scientist Cynthia Rosenzweig with New York Mayor Michael Bloomberg (February 2009).
Photo: Christina Santucci/qns.com

Creating the Space for Adaptation Actions

Case Study: The New York Panel on Climate Change



New York City Panel on Climate Change (Zimmerman et al., 2010)

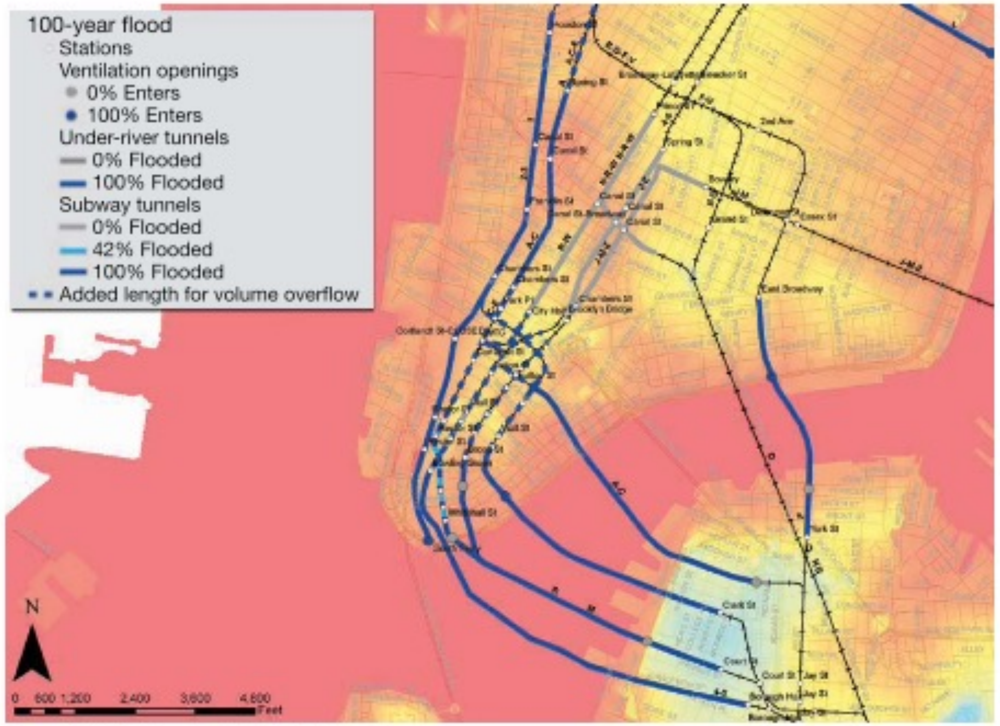
2001 - Water Treatment Tanks Overflow at Hunt's Point, Bronx

From Major et al., 2009
(New York Panel on Climate Change)
Photo: Christina Santucci

City lifted coastal wastewater treatment plants in anticipation of coastal surges exacerbated by climate change (2009)

Creating the Space for Adaptation Actions

Case Study: The New York Panel on Climate Change



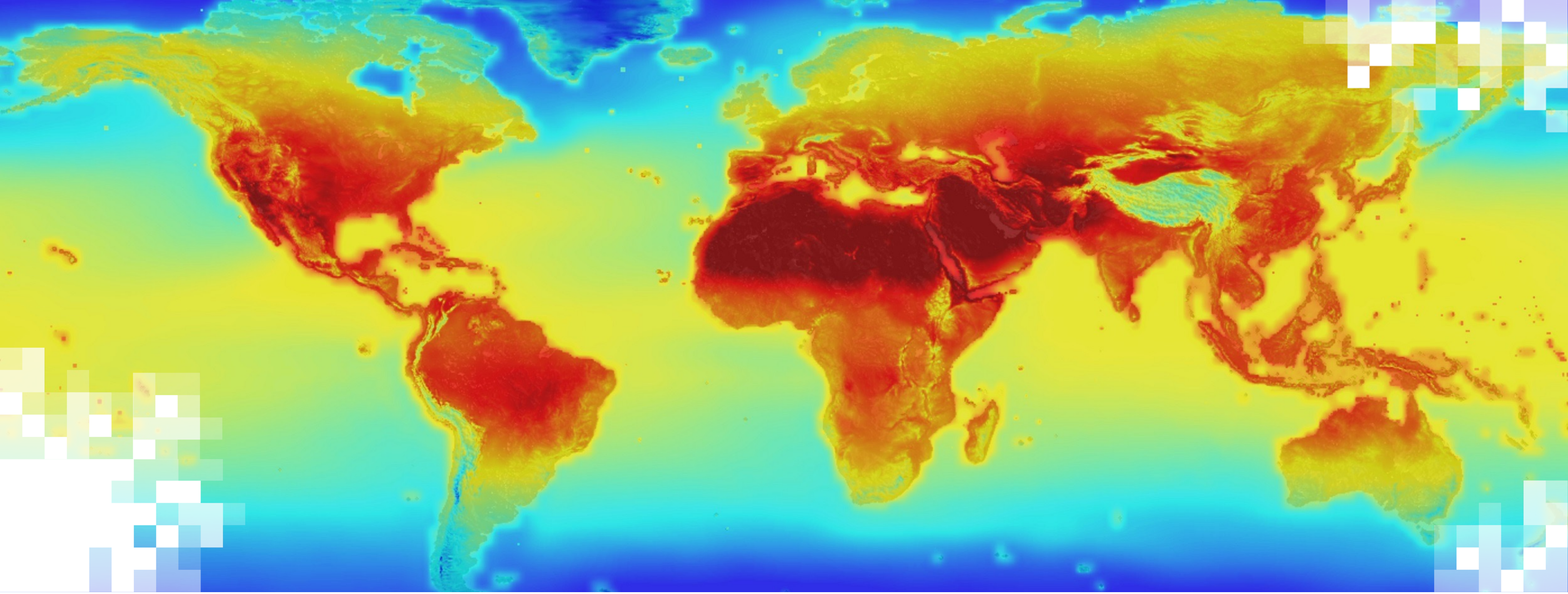
Source: LDEO/Civil Engineering, Columbia University

Figure 9.11A 100-year flooding without sea level rise of Lower Manhattan subways and adjacent East River tunnels crossing to Brooklyn; the heavy blue lines indicate fully flooded tunnels, and broken lines show overflow into tunnels located in areas that are not flooded above-ground; background colors show topographic surface elevations (yellow≥30ft)

New York City Transportation System and the subway tunnels that would be inundated with 100-year Flood levels. From: Jacob et al., 2011

Hurricane Sandy,
Hoboken, NJ
2012

Climate Information:
Sea Level Rise
Tropical Cyclones
Coastal Flooding



Summary

Summary

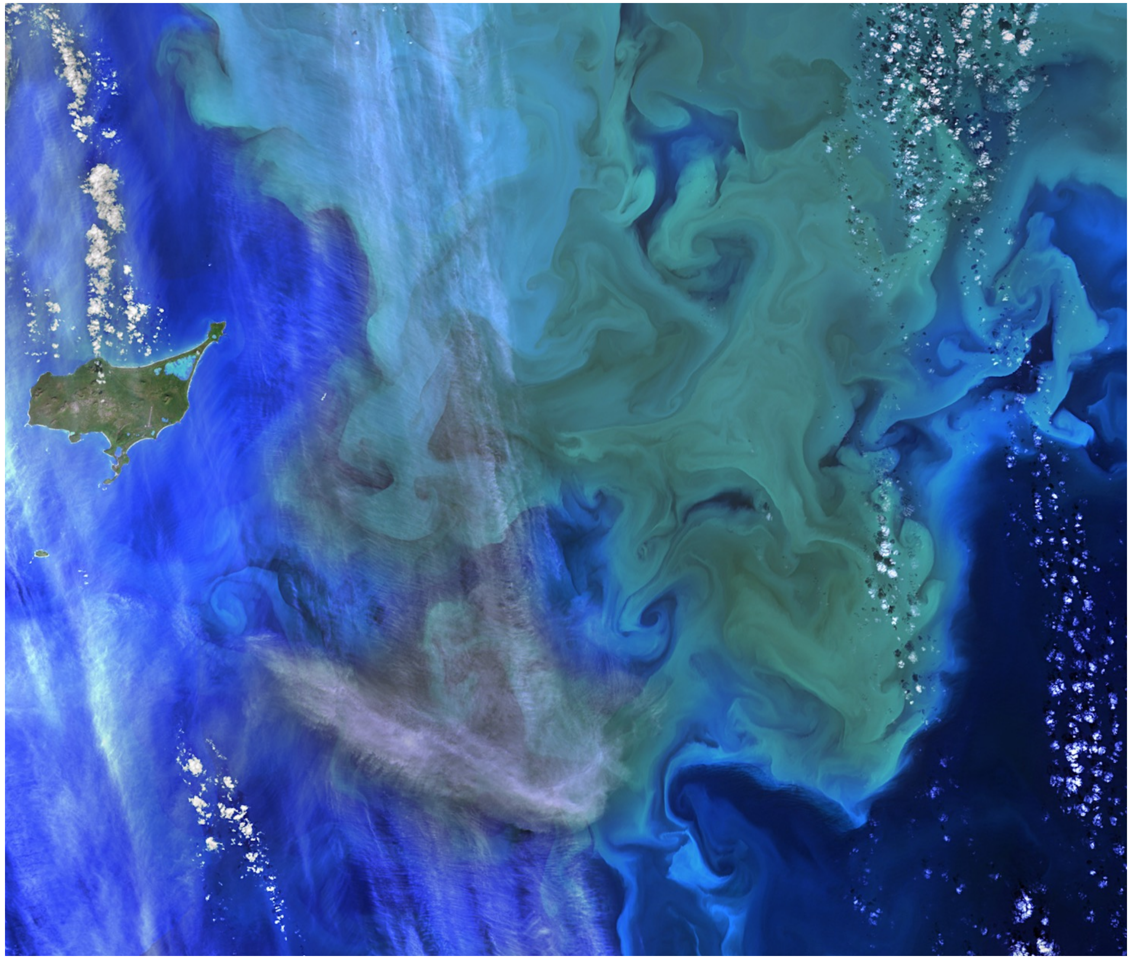
Climate information products can support mitigation, adaptation, and risk planning within strong scientific frameworks.

- NASA products support improved understanding of climate system
- Climate applications require selection of fit-for-purpose model and datasets
- Climate impacts and risk affect many aspects of nature and society
- Historical and future climate and sectoral conditions drive planning
- Climate decisions are facilitated by tailored climate information

Thanks also to NASA Climate Adaptation Science Investigator Work Group (CASI) preparing climate adaptation and risk plans for NASA facilities.

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.



Credit: USGS

Contacts

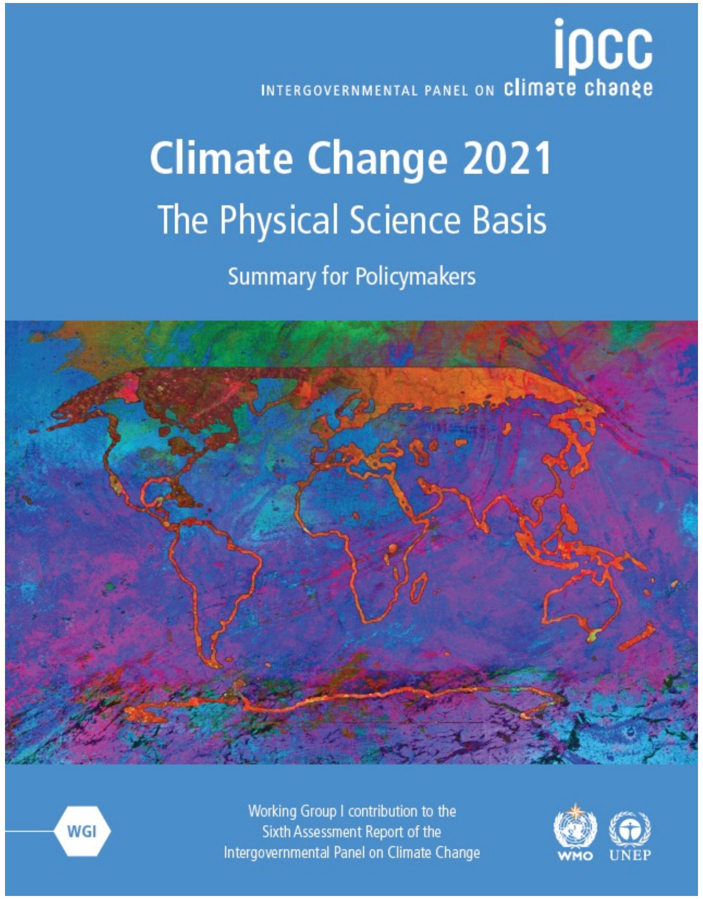
- Trainers:
  - Alex Ruane: alexander.c.ruane@nasa.gov
  - Dan Bader: dab2145@columbia.edu
- Training Webpage:
  - https://appliedsciences.nasa.gov/join-mission/training/english/arset-introduction-nasa-resources-climate-change-applications
- ARSET Website:
  - https://appliedsciences.nasa.gov/what-we-do/capacity-building/arset


APPLIED REMOTE SENSING TRAINING PROGRAM
TRAIN - EMPOWER - ADVANCE

Thank You!

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