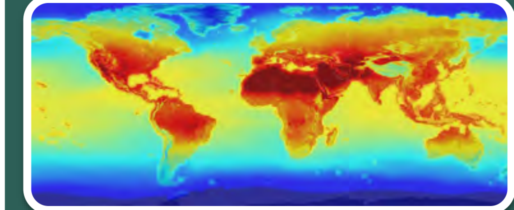
Workshop Agenda

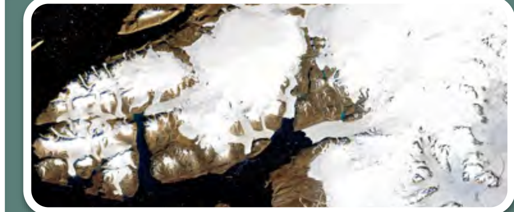


Session I: Introduction to Climate Change

- Overview of climate change
- Monitoring climate change drivers using NASA data

Session II: Earth observations for climate change impacts (Land & Atmosphere)

- Overview
- Focus area: Drought
- Focus area: Urban Heat Islands & Extreme Heat
- Focus area: Wildfires & Smoke



Session III: Earth observations for climate change impacts (Ocean & Ice)

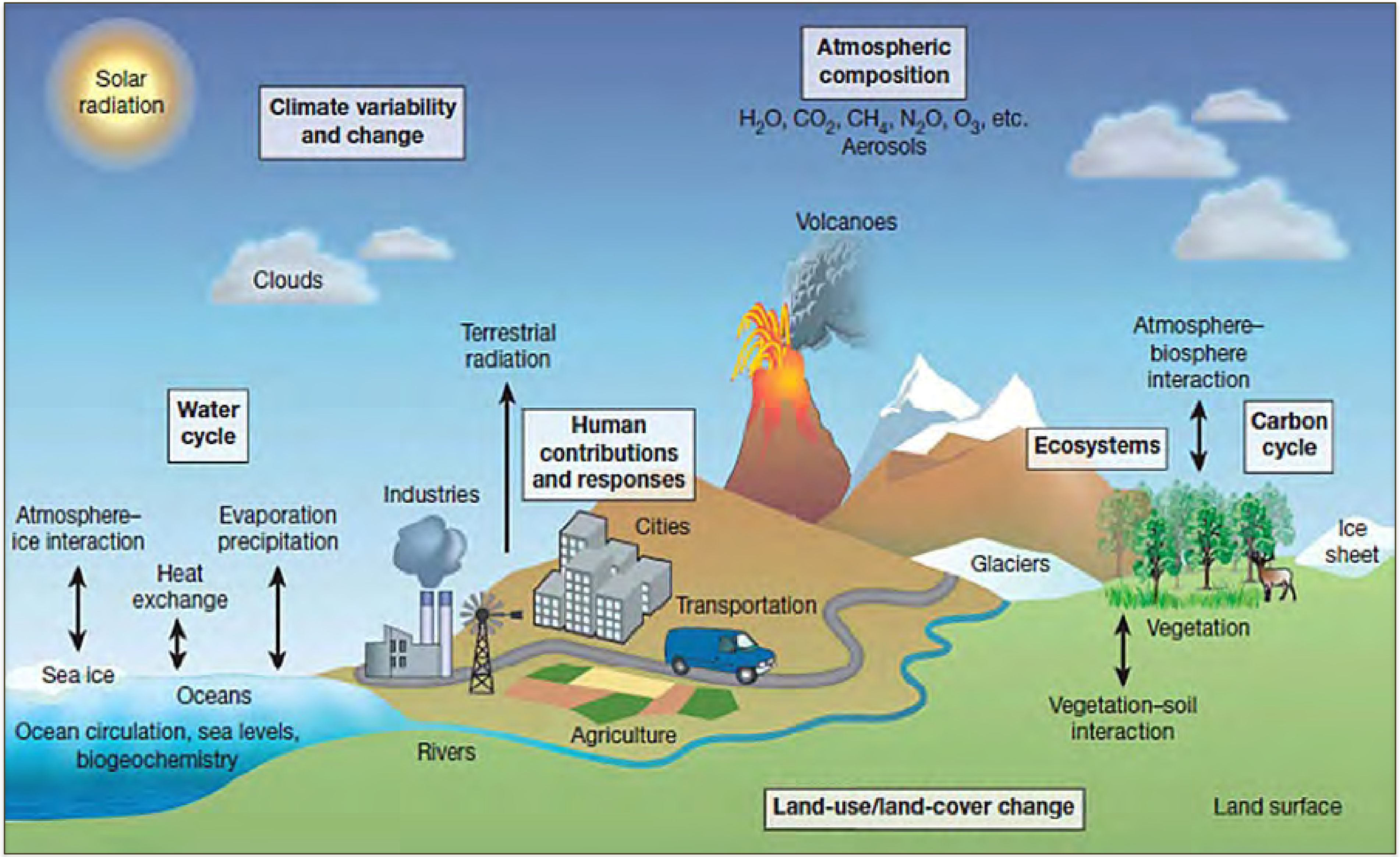
- Overview
- Focus Area: Sea Level Rise

Session IV: Climate Models, Policy & Decision making

- Climate Modeling
- NASA ESO

Climate Modeling

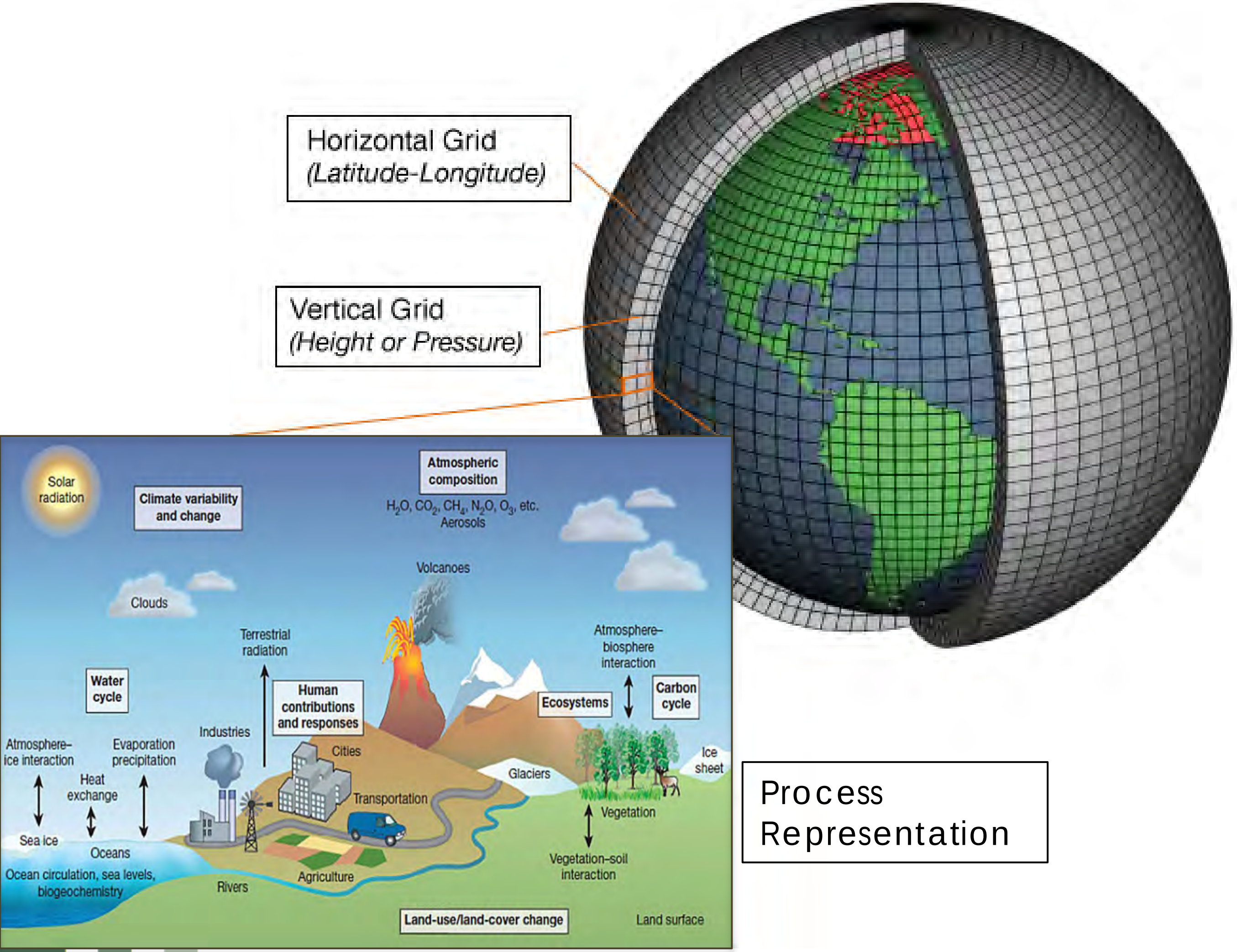
Components and Drivers of the Climate System



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

Climate Model Approaches

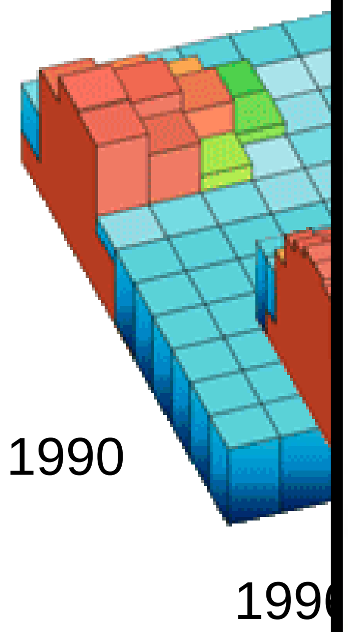
(e.g., NASA GISS Model-E)

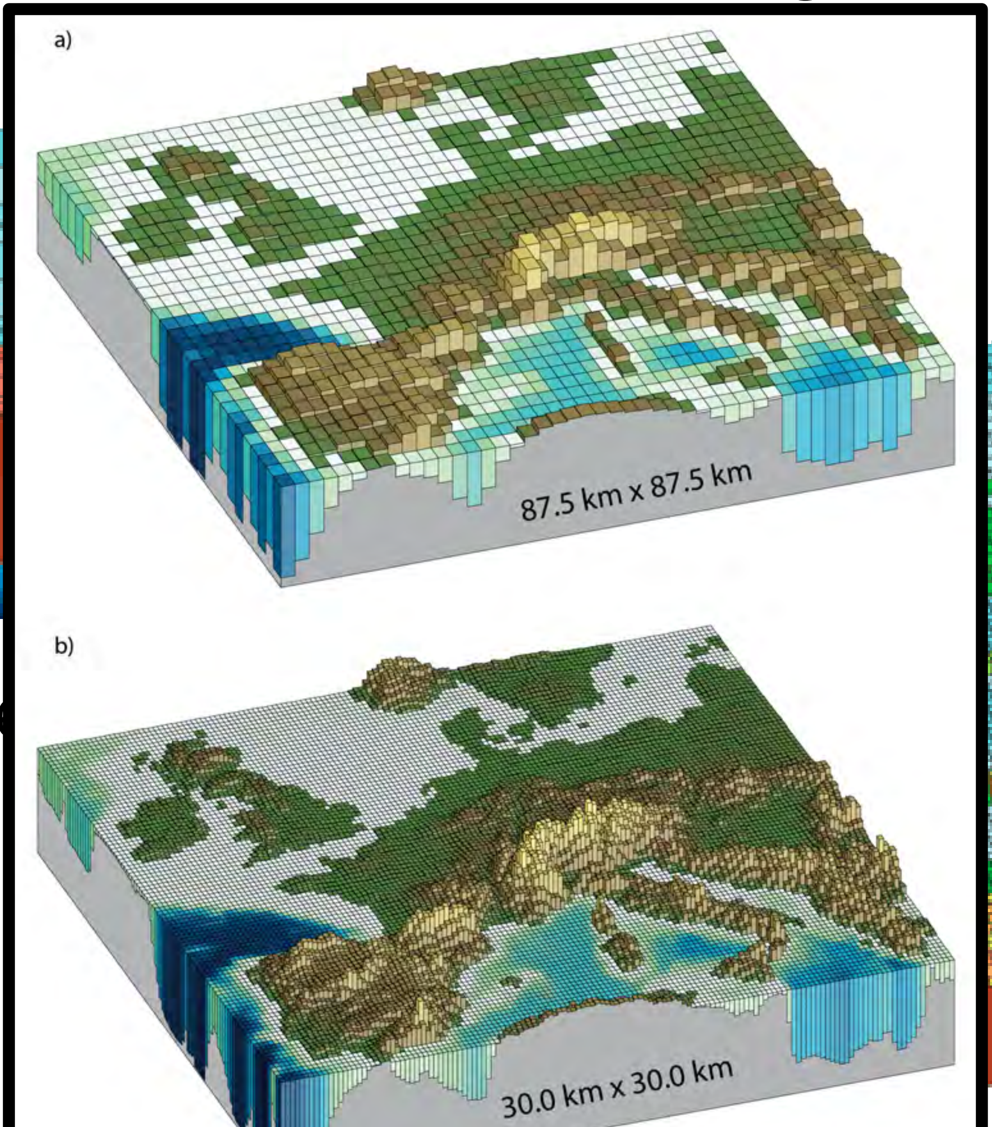


- Built on principles of physics and chemistry
- Balanced across water and energy budgets
- Dependent on initial conditions and boundary forcings *(e.g., sunlight, land use, greenhouse gas emissions)*
- Tuned using surface stations and remote sensing datasets with machine learning
- Independently validated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

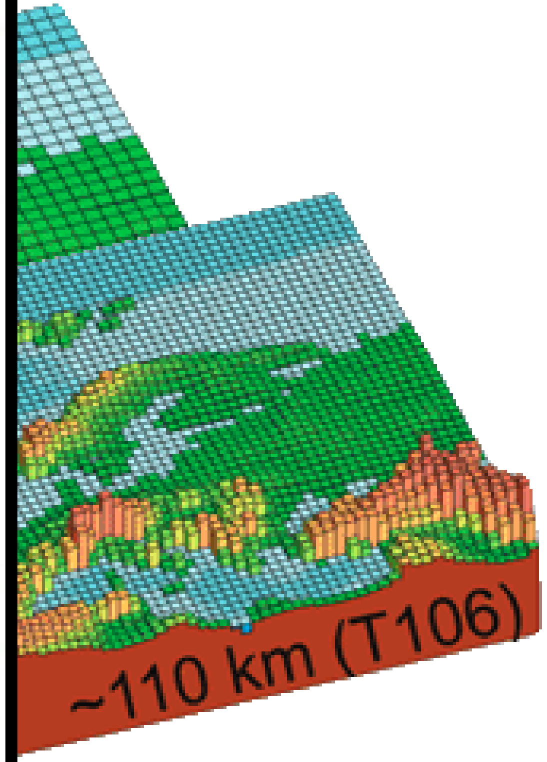
Adapted from NOAA: https://www.climate.gov/maps-data/primer/climate-models

Improved Resolution and Downscaling





Source: IPCC, 2013
WGI Figure 1-14



Source: IPCC, 2007
Figure 1-4

+ Regional Climate Models
+ Empirical Models

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

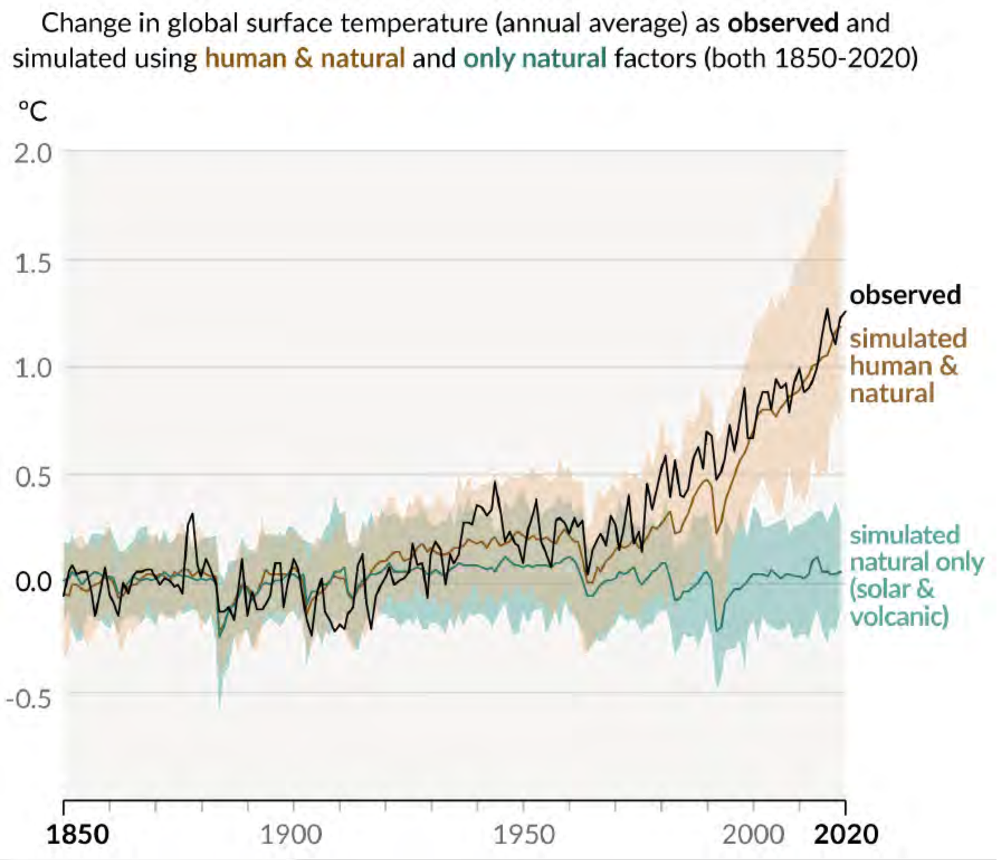
Recognizing “unknown unknowns”, e.g.:

- Models in 1970 did not know about ozone hole

Adapted from Gavin Schmidt

How can we use climate models?

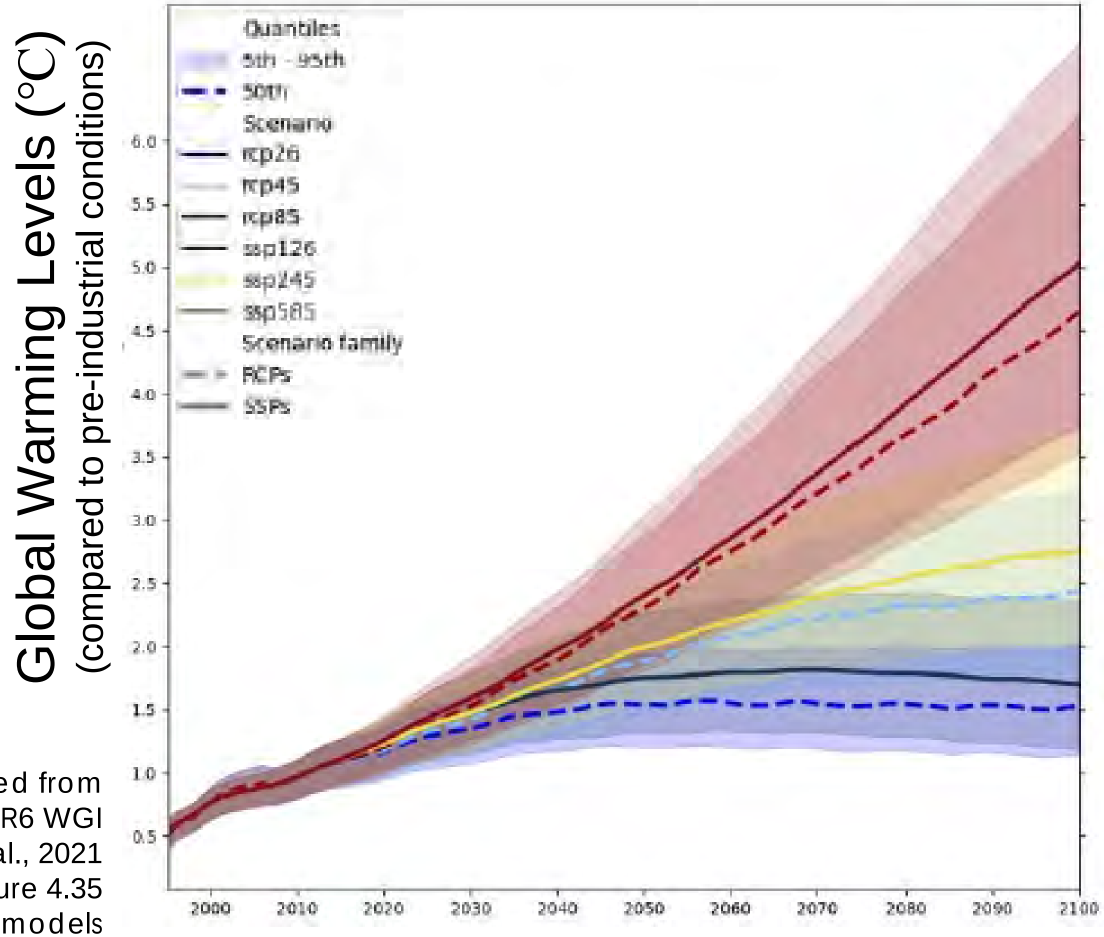
Determining Human Influence on Climate System



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?



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

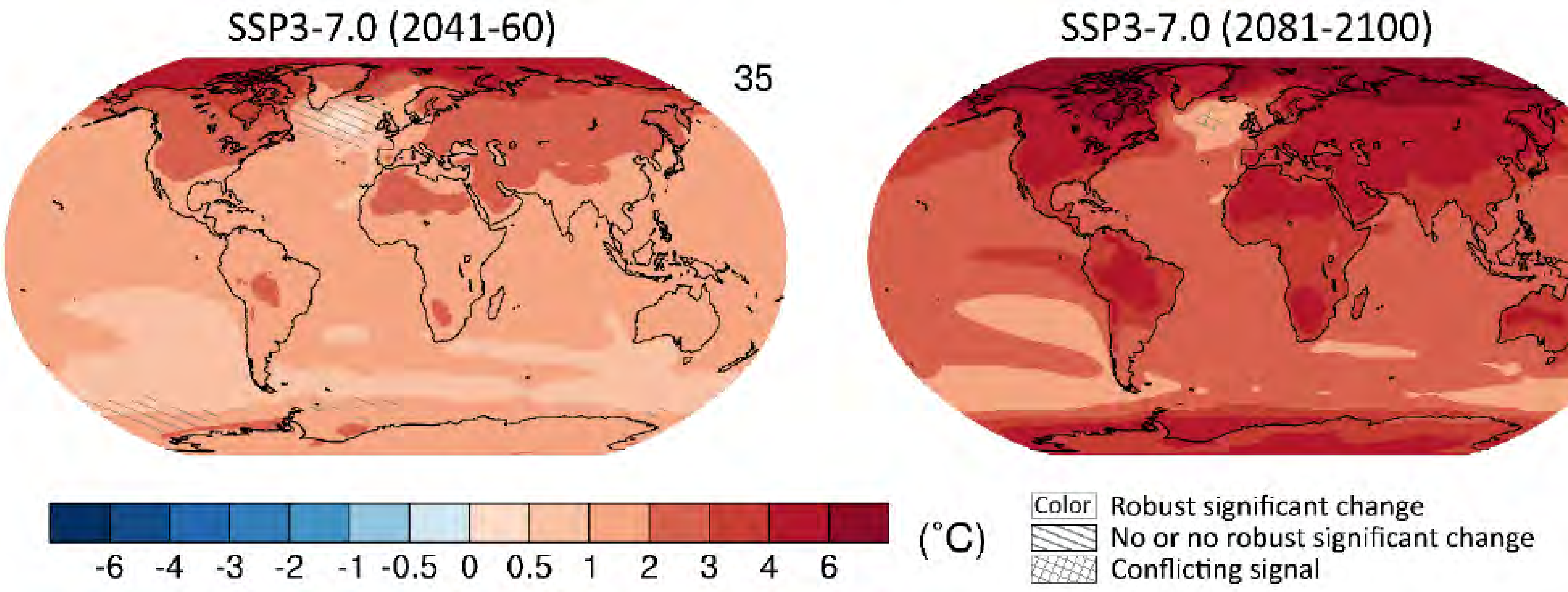
- *Greenhouse gas emissions policy and climate projections*
- Modelers use illustrative scenarios (e.g., SSP1-1.9) to represent different pathways of development, technology, international cooperation, and greenhouse gas emissions.

SSP-RCP Scenarios

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

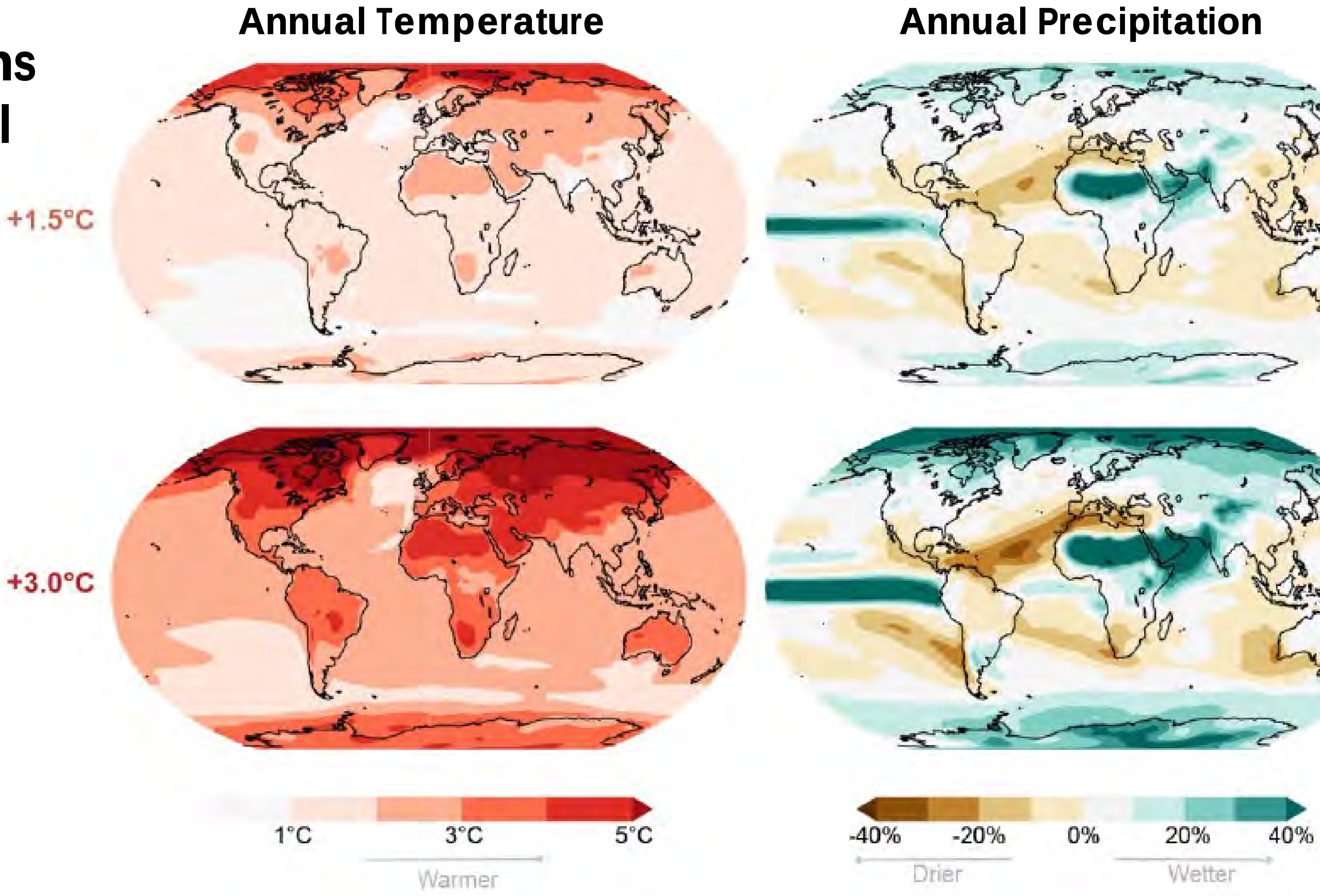
RCP = Representative Concentration Pathway
- *Greenhouse gases, aerosols, carbon fluxes*

Climate Projections by Time and Scenario



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

Climate Projections by Global Warming Level

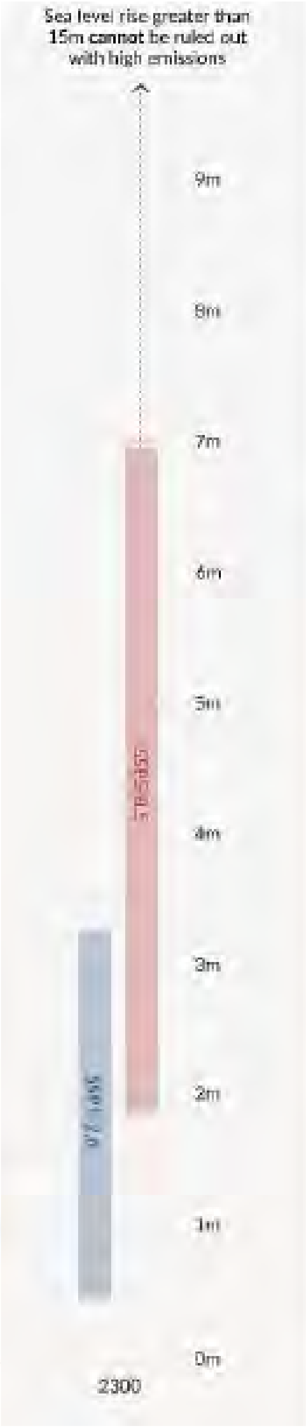


IPCC AR6 WGI
Chen et al., 2021
FAQ4,3 Figure 1
CMIP6 Models

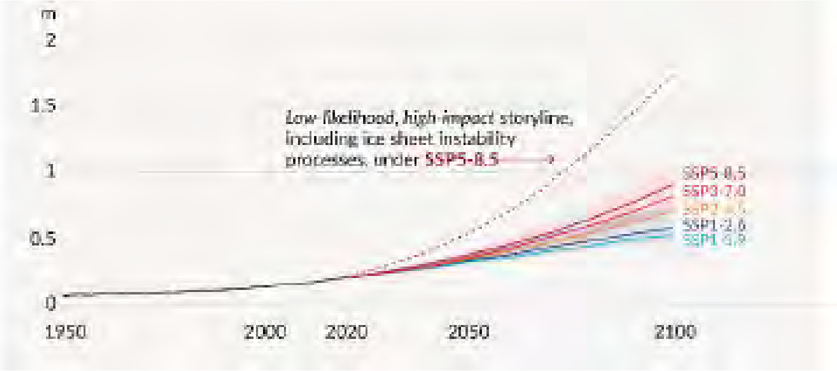
Climate change does not stop at 2100.

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

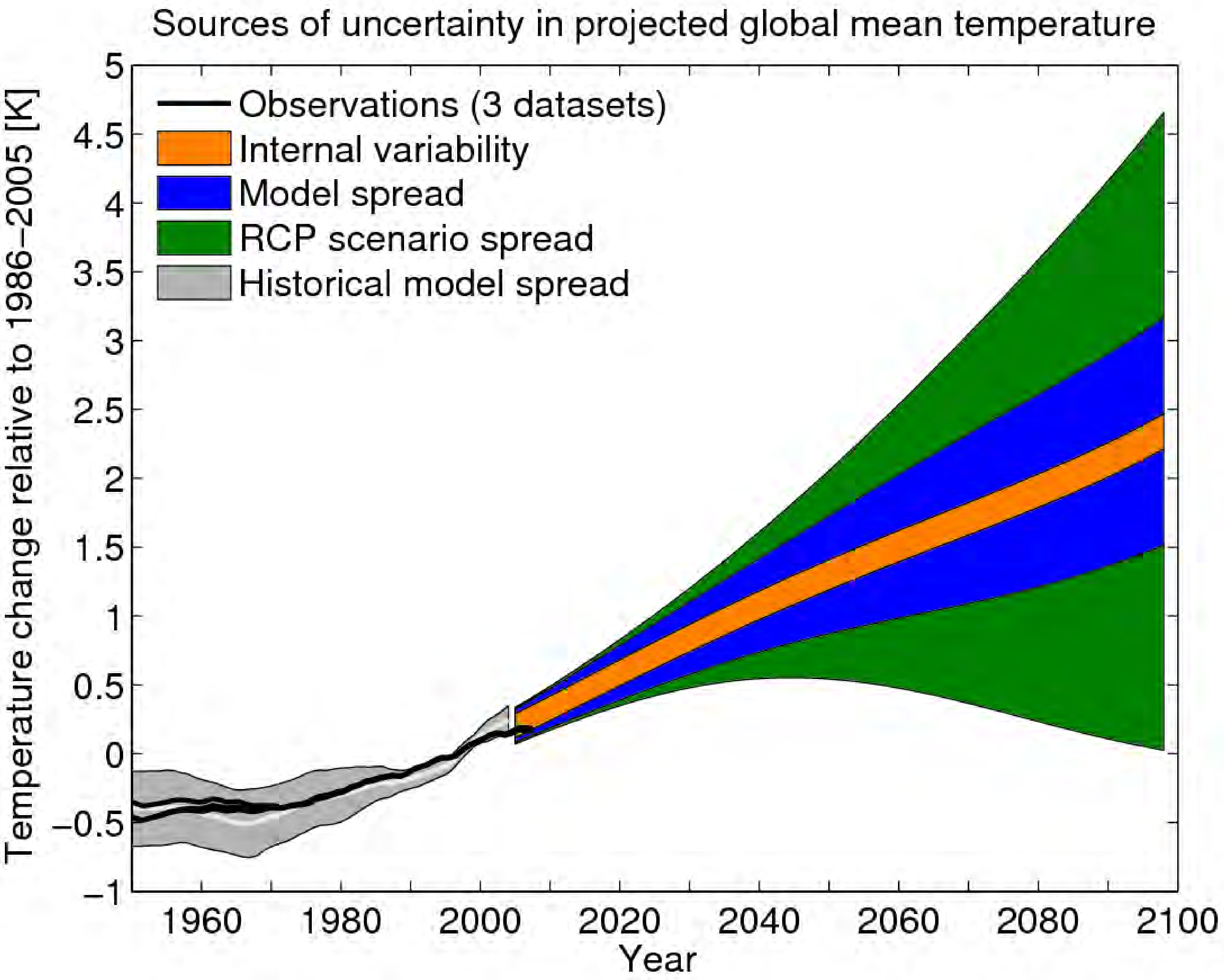


Global Mean Sea Level Change Relative to 1900



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

Climate Projection Sources of Uncertainty

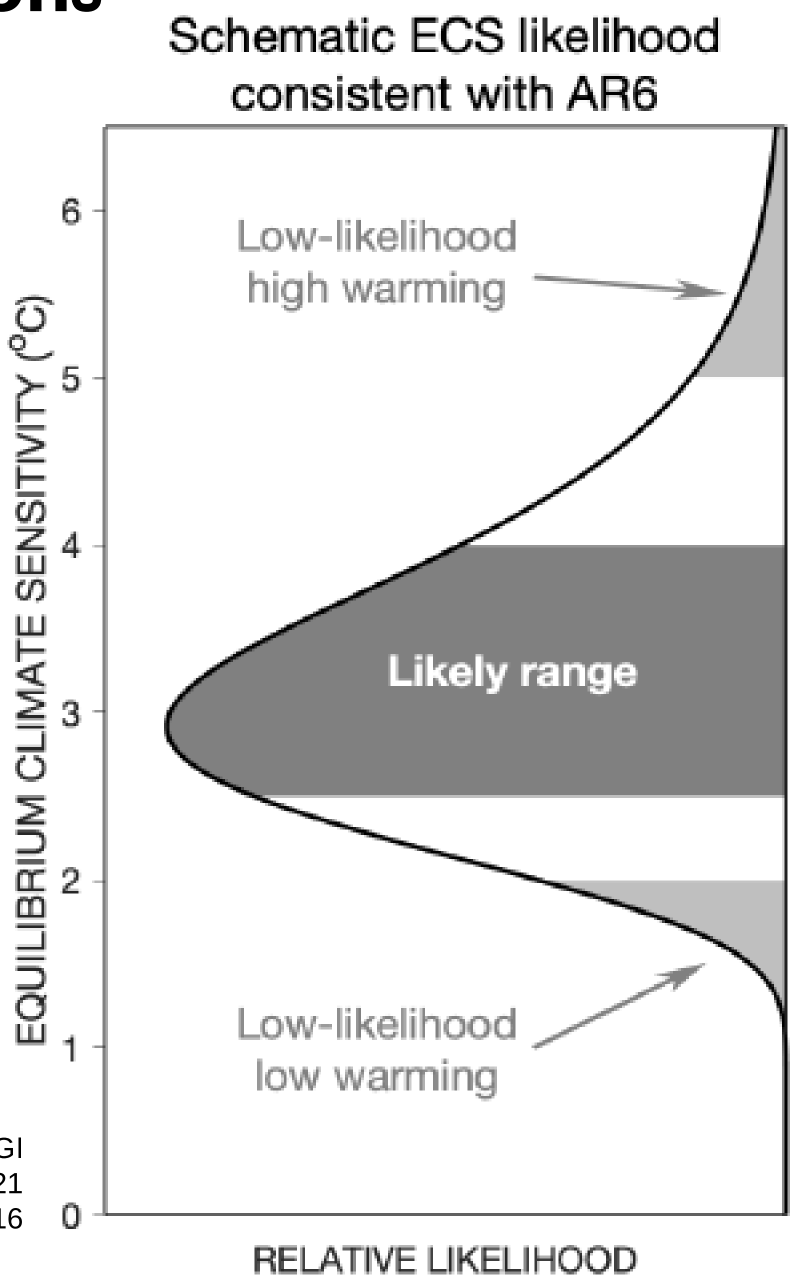


IPCC AR5 WGI
Kirtman et al., 2013
Figure 11.8
CMIP5 models

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)*

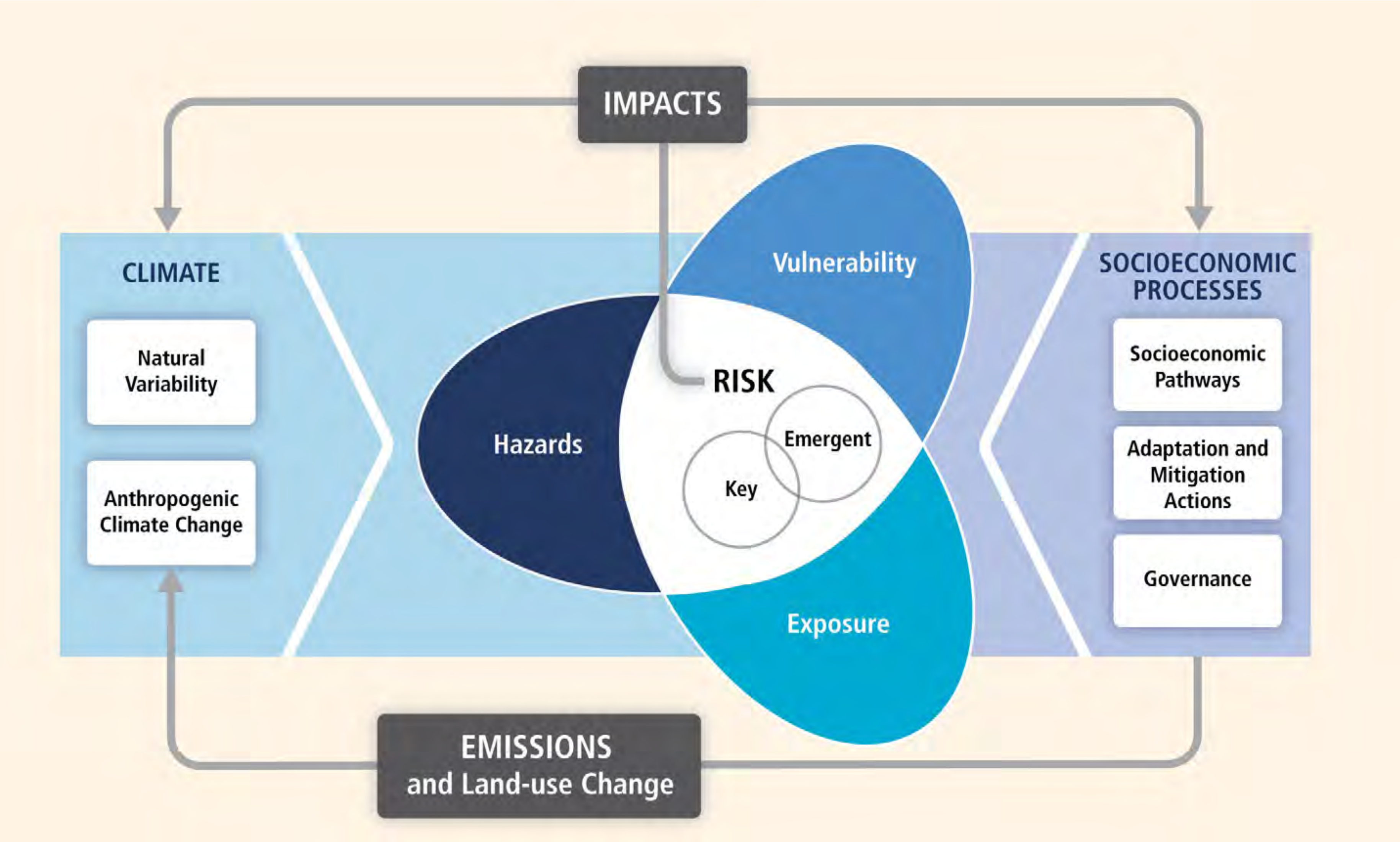
- **Parameter Uncertainty**
- **Internal Variability**
- **Scenario Uncertainty**



IPCC AR6 WGI
Chen et al., 2021
Figure 1.16

Climate Impact and Risk Projection

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

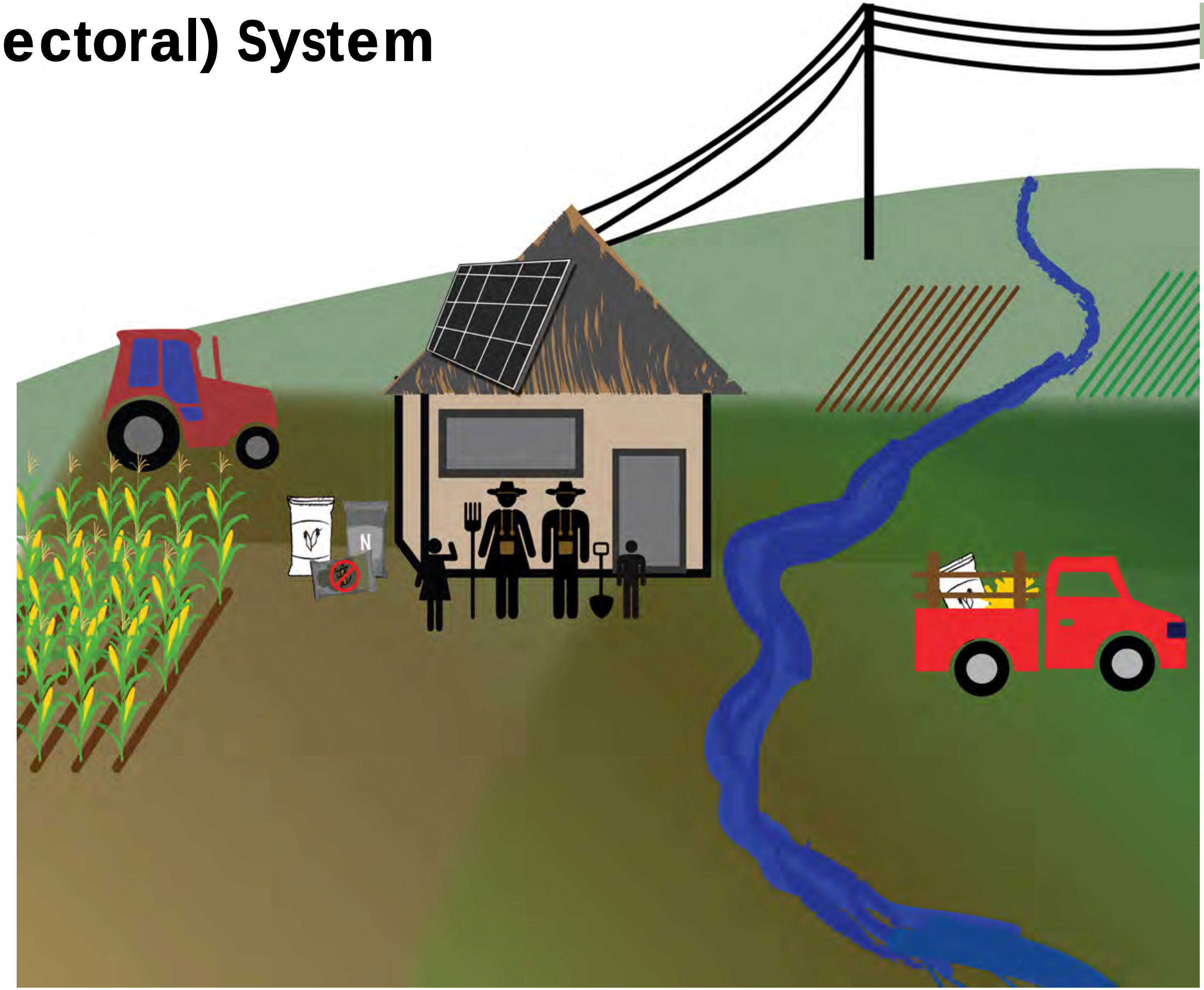
Framework to Assess Future Impacts for Applications

- 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

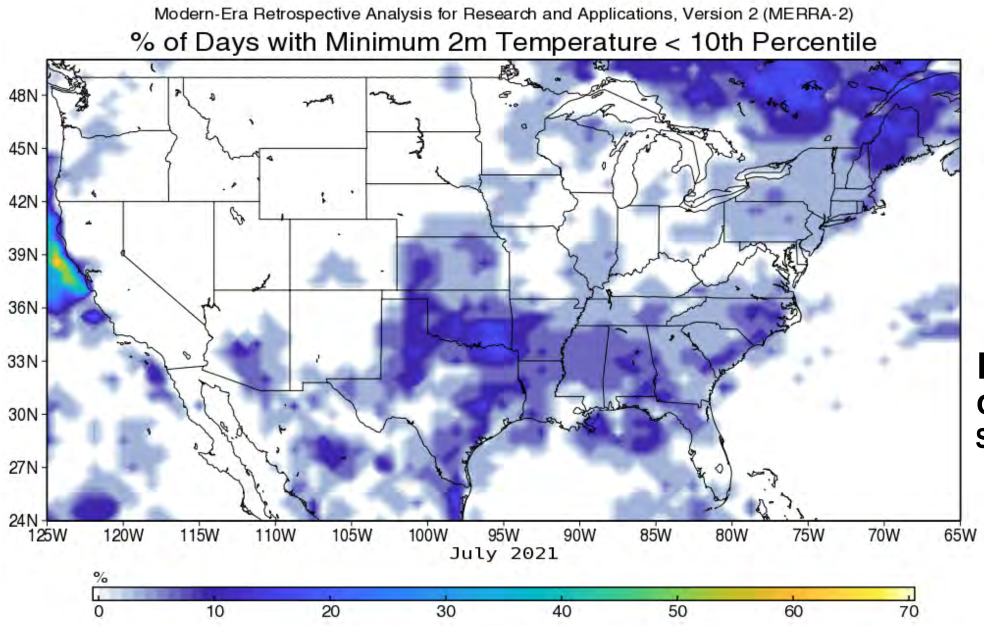
Example of a Farm System

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

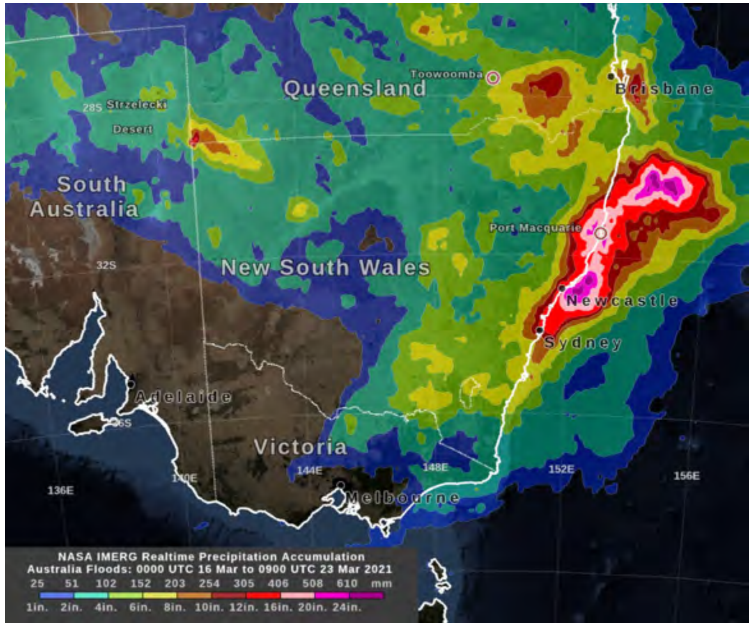


Represent Current Climate

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



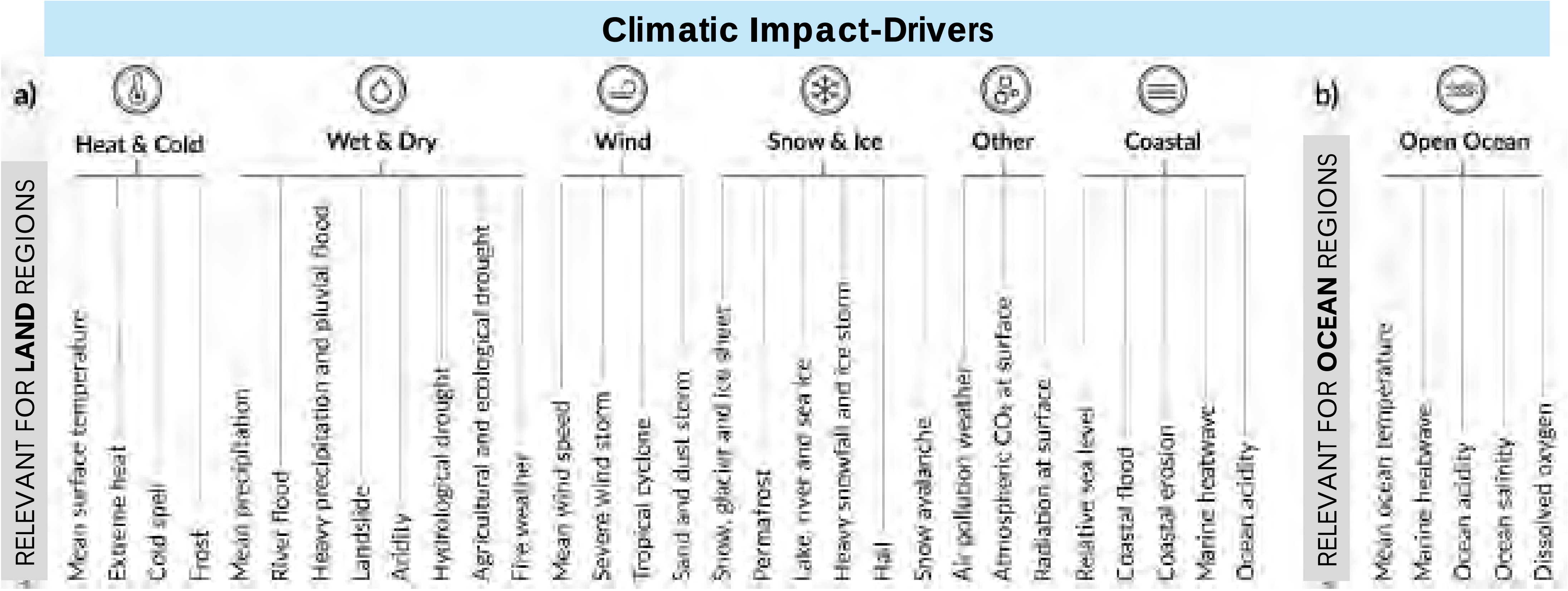
MERRA-2
Cold Spell in Southern US



IMERG
Heavy Rains in SE Australia

GOES-16
Hurricane Maria Approaching Puerto Rico (2017)

Look for Relevant Responses Across Many Climate Factors

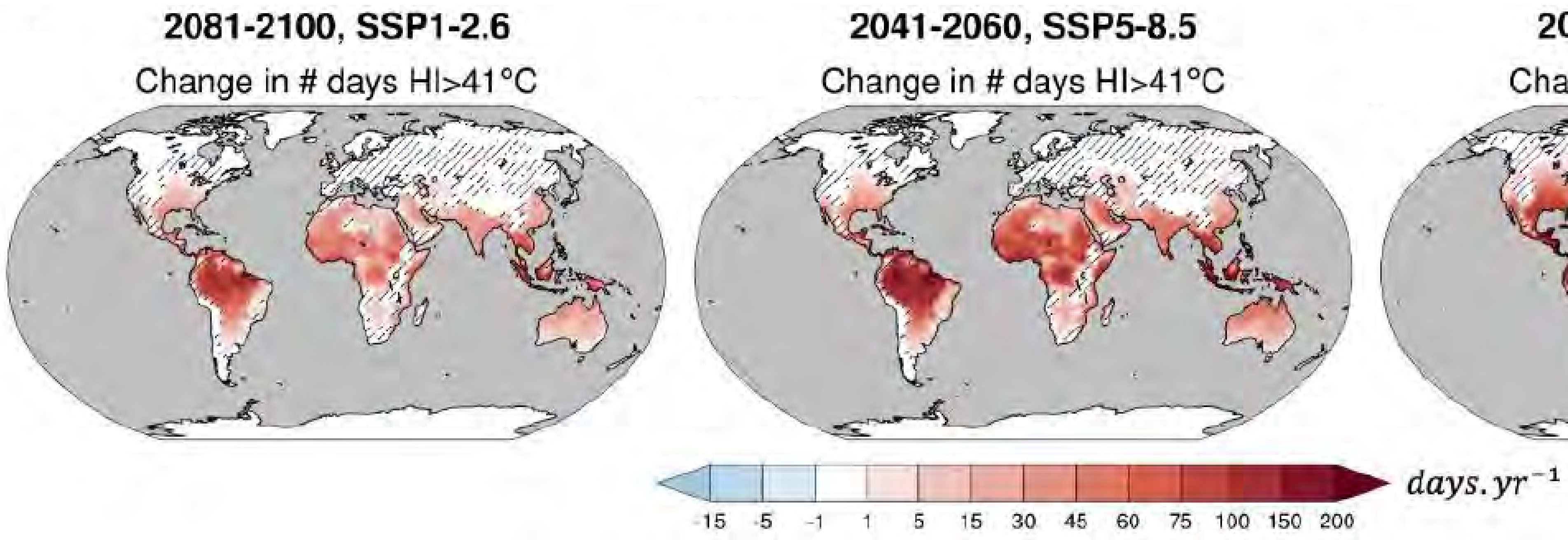


A climatic impact-driver (CID) is a climate condition that directly affects elements of society or ecosystems. Climatic impact-drivers and their changes can lead to positive, negative, or inconsequential outcomes (or a mixture).

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

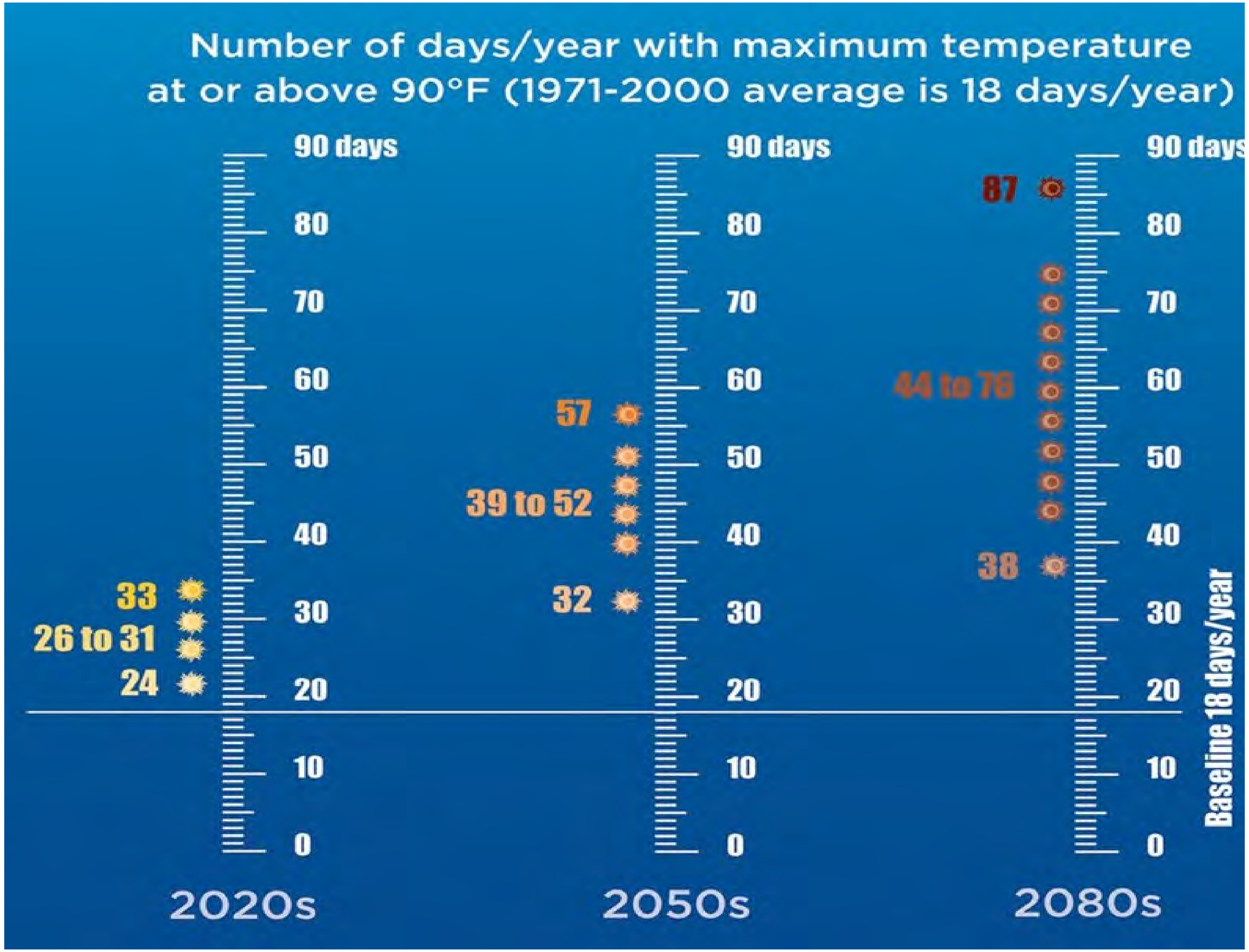


NOAA Heat Index > 41 ℃ is considered "Dangerous."
Heat and humidity make conditions difficult for outdoor exercise, construction, and agricultural labor.

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

Project Future Climate

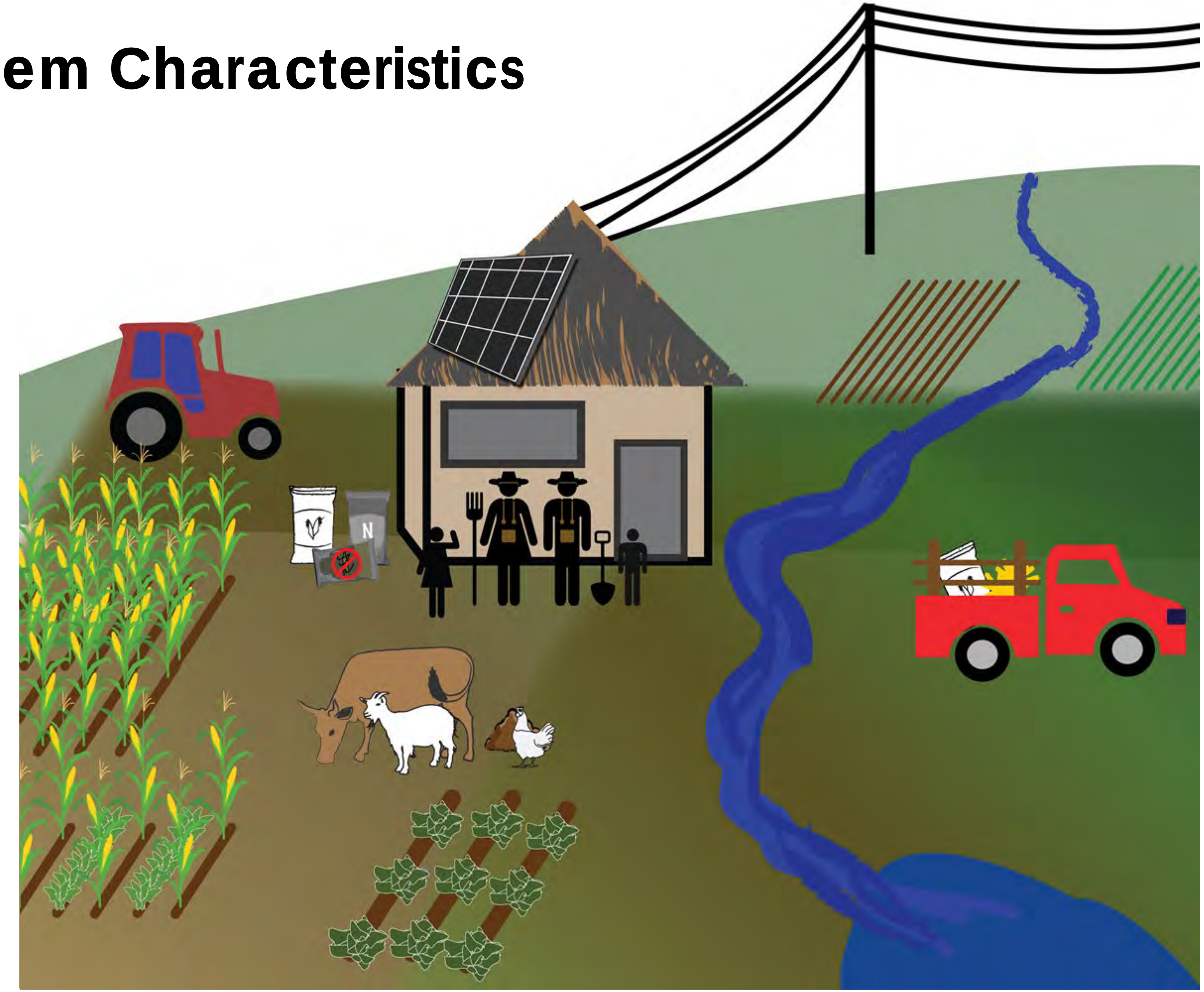
- **Intensity**, **frequency**, **duration**, **seasonal timing**, and **spatial extent**
- Relationship to **tolerance thresholds** is particularly important



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

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

Project Future System Characteristics



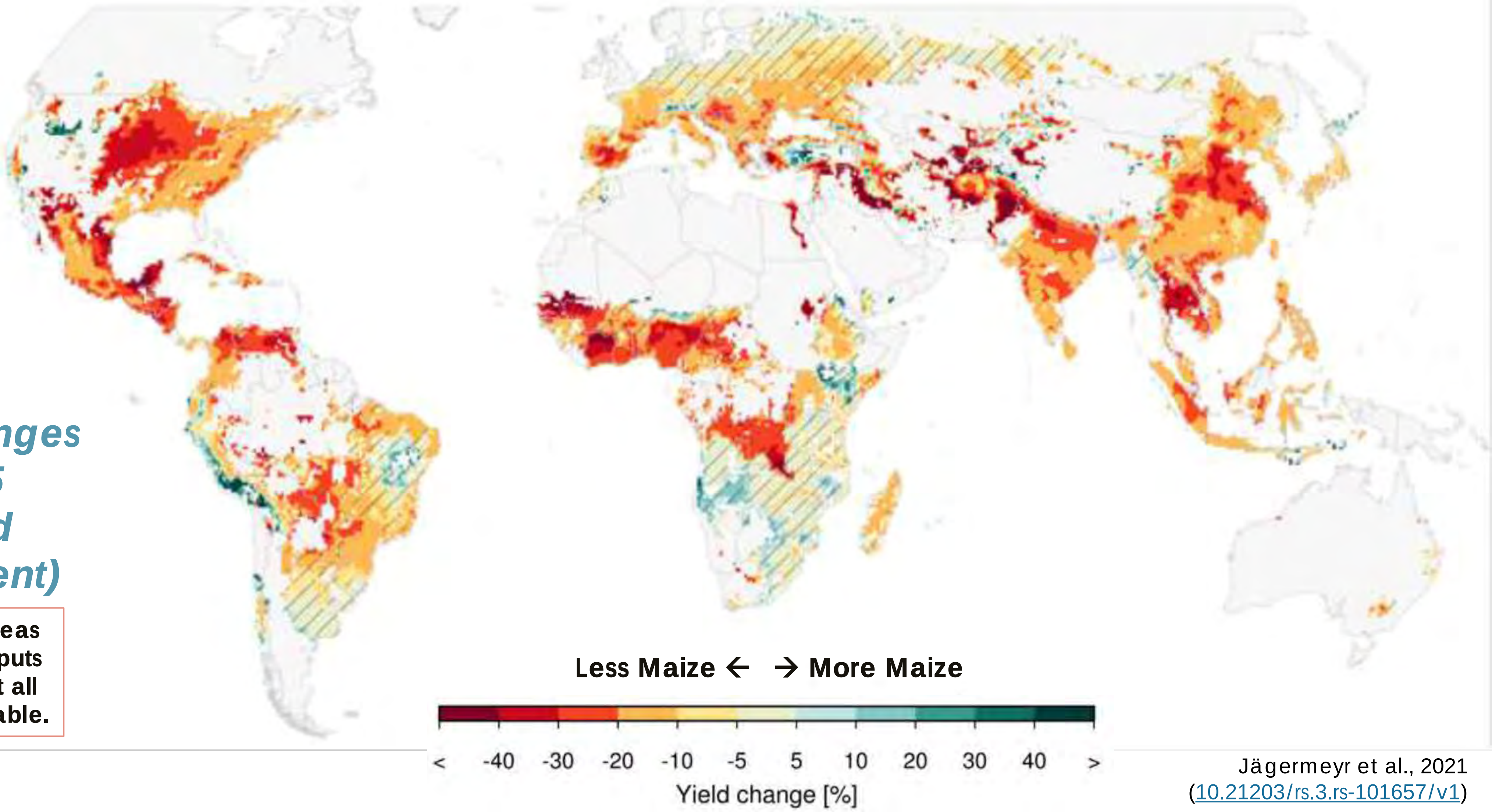
Future Farms

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., 2021 (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

Use of Climate Information for Adaptation

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

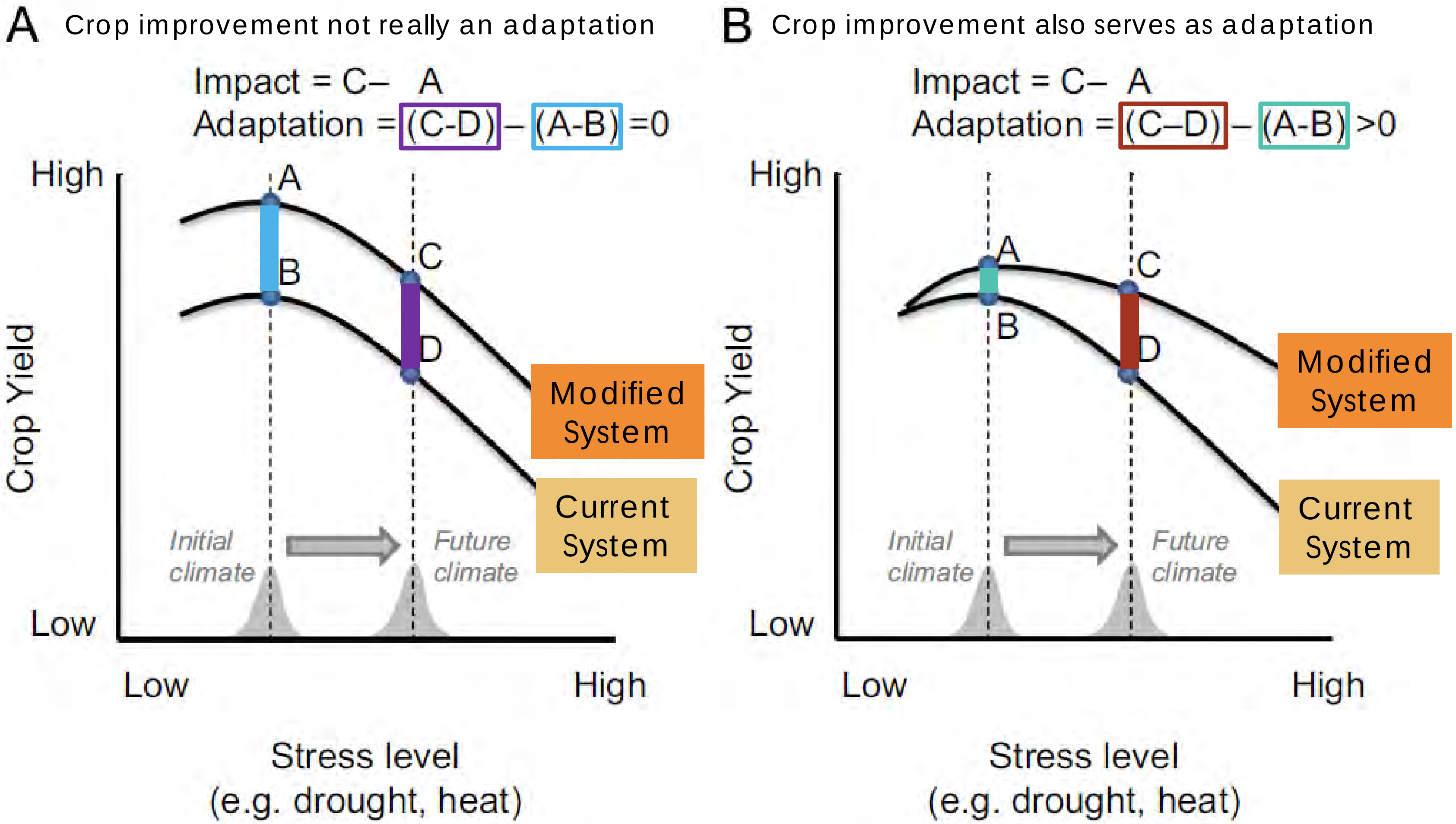
Adaptation Time Scales

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

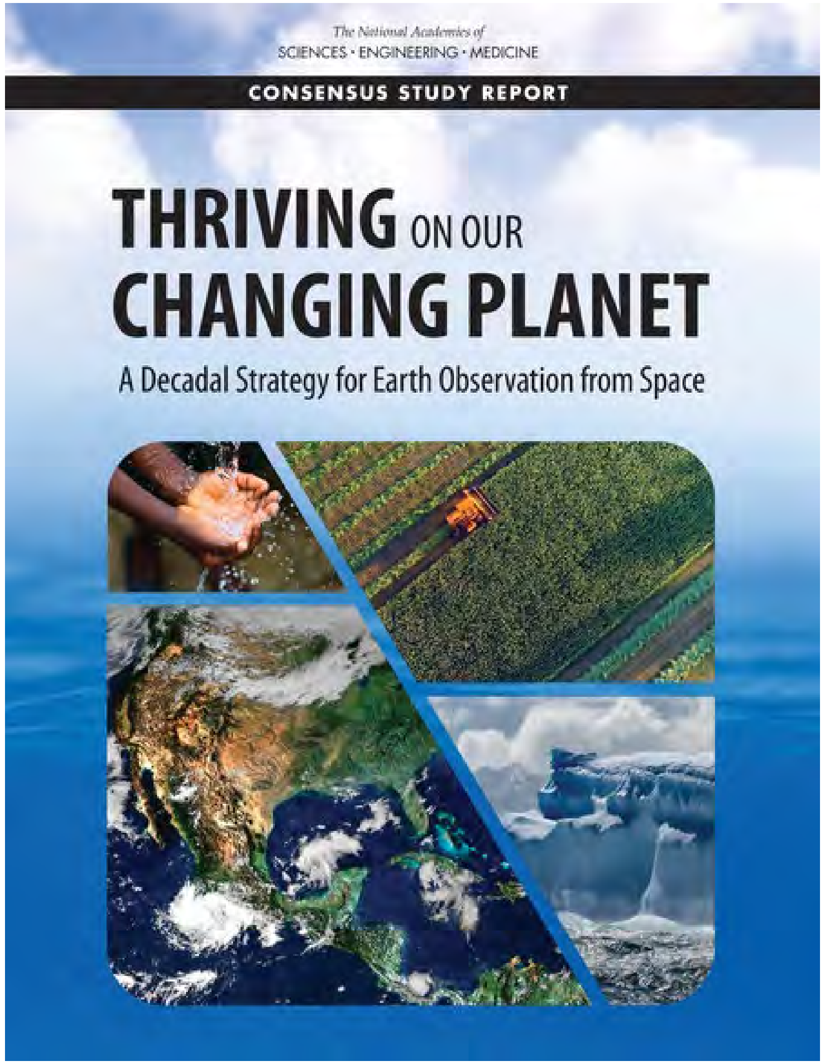
Summary

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

Earth System Observatory (ESO)

2017 Decadal Survey



https://www.nationalacademies.org/our-work/decadal-survey-for-earth-science-and-applications-from-space

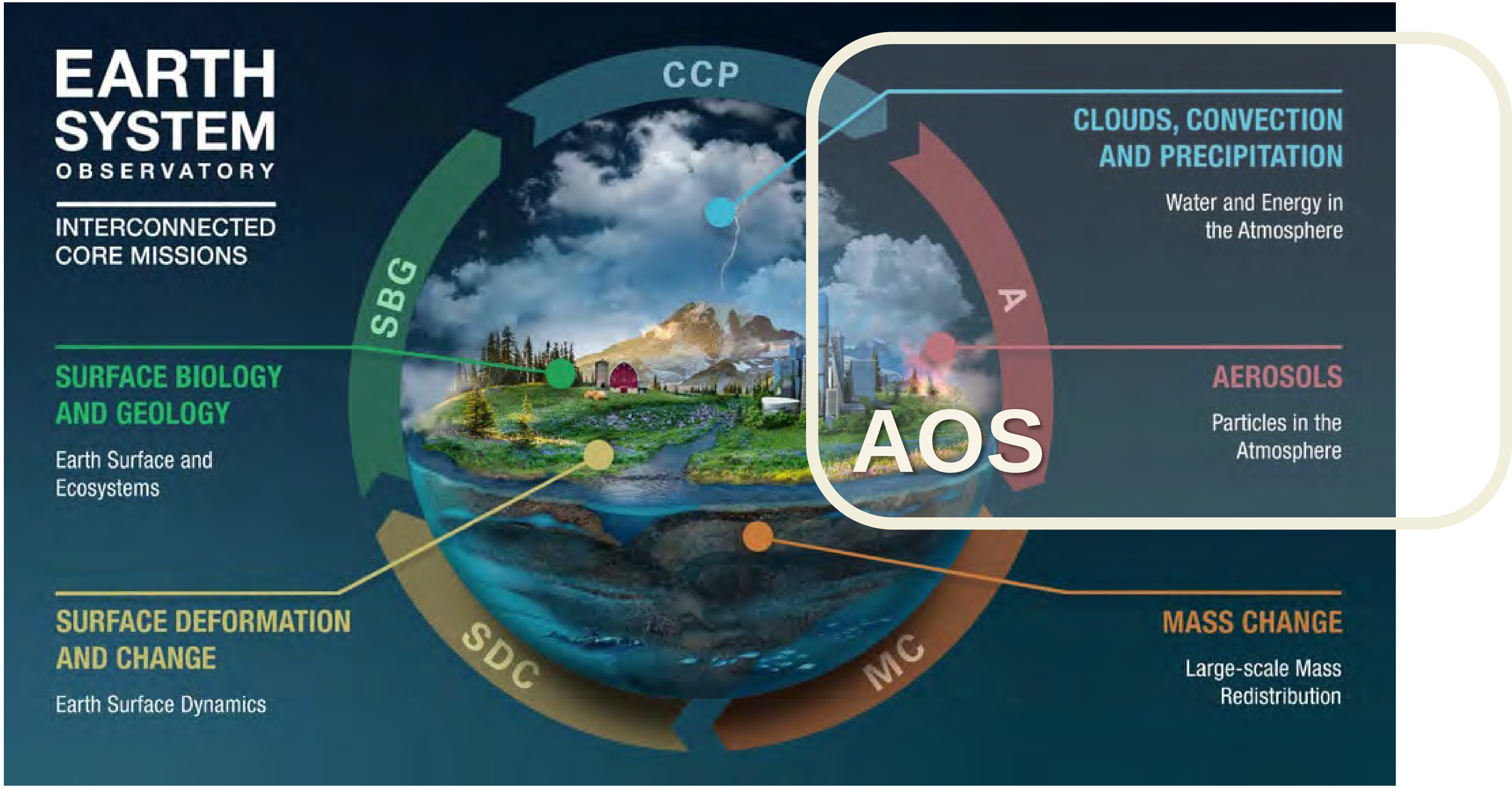
Recommended three classes of missions:

- 5 **Designated**
  - Essential to overall program
- 6 **Explorer**
  - Science and application objectives deemed ‘Most Important”
- 3 **Incubation**
  - Investment in innovation for the future

NASA ESO

https://svs.gsfc.nasa.gov/4920

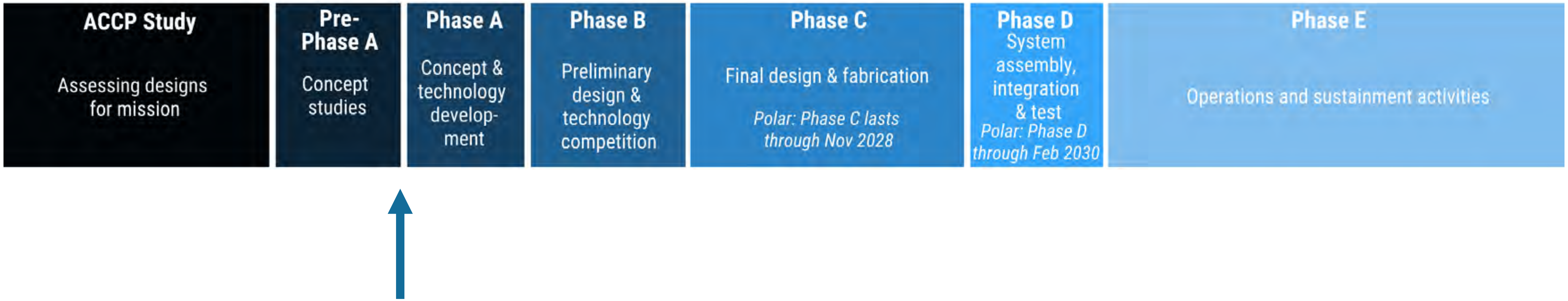
NASA ESO



https://svs.gsfc.nasa.gov/4920

Architecture Studies and Mission Phases

- Architecture studies began in ~2018
  - Investigate observing system architectures, consider synergies with other missions, identify potential applications and partnerships



SBG, AOS, and MC are about here

Atmosphere Observing System

Decadal Survey Candidate Measurement Approaches

Targeted Observable	***Science/Applications Summary***	***Candidate Measurement Approach***
Aerosols	Aerosol properties, vertical profiles, and cloud properties to understand their effects on climate and air quality	Backscatter lidar and multi-channel, multi-angle/polarization imaging radiometer
Clouds, Convection and Precipitation	Coupled cloud and precipitation state and dynamics for monitoring the global hydrological cycle and understanding contributing processing, including cloud feedback	Dual-frequency radar (Doppler capability) with multi-frequency passive microwave and sub-mm radiometer

https://nap.nationalacademies.org/catalog/24938/thriving-on-our-changing-planet-a-decadal-strategy-for-earth

AOS – Traceability to the Decadal Survey

DS Science Questions

Climate Feedback and Sensitivity
C-2agh, C-5cd, C-9a

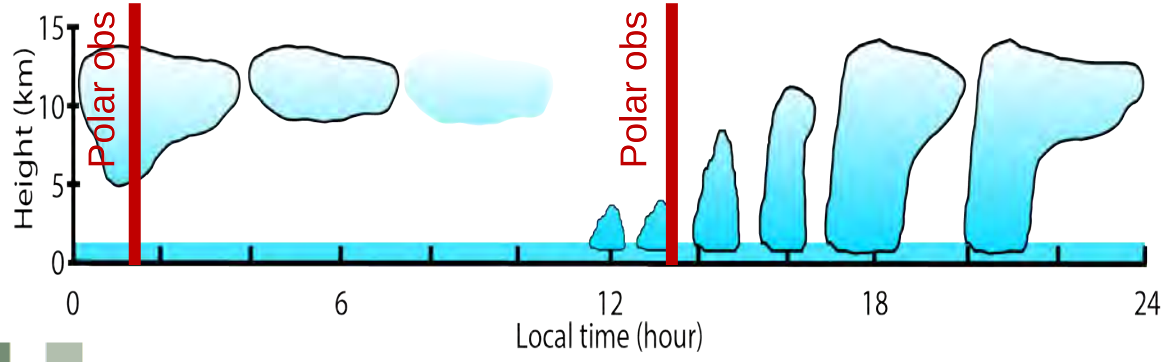
Convective Storm Formation Processes
W-4, W-2a, C-2g, C-9a

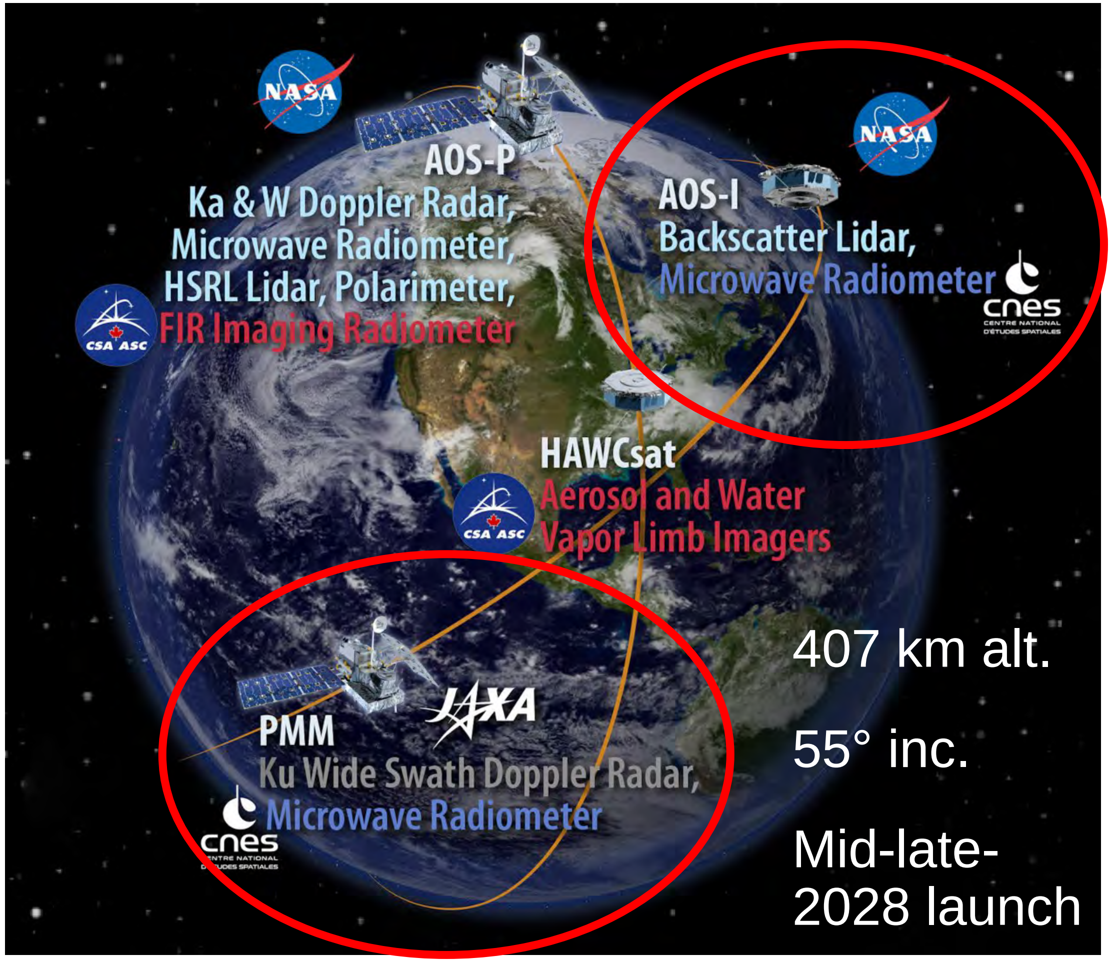
Air Pollution Processes and Distribution.
W-5a, W-6a, C-5a, S-1a

AOS Science Objectives		Key Science Focuses
O1	**Low Clouds**	Sensitivity of low clouds to environmental factors; solar radiative climate feedbacks
O2	**High Clouds**	Relationship of high cloud properties to deep convection, environment; radiative climate feedbacks
O3	**Convective Storms**	Relationship between storm vertical motions and microphysics
O4	**Cold Clouds and Precipitation**	Processes that govern phase partitioning and precipitation formation in cold clouds; key drivers of climate feedbacks at high latitudes
O5	**Air Quality and Aerosol Attribution**	Identifying major sources of aerosols and their type; factors that relate aerosol microphysical/optical properties to near-surface air quality
O6	**Aerosol Redistribution & Processing**	Wet removal and processing of aerosol by clouds and precipitation; impacts of vertical and long-range transport of aerosol
O7	**Aerosol Direct Effects**	Role of aerosols in the Earth's energy budget; impact of absorbing aerosols on climate
O8	**Aerosol Indirect Effects**	Aerosol impacts on clouds and precipitation systems; modulation of climate forcing due to changes in cloud radiative properties

The AOS Architecture (Pending HQ Reviews, Decisions)

- Inclined orbit required for developing understanding of **diurnal variability of deep convection, high clouds**
- Adds time-varying aerosol, PBL profiles, follow-on to CATS
- First ever time-difference microwave TBs for inferring dynamics, microphysics

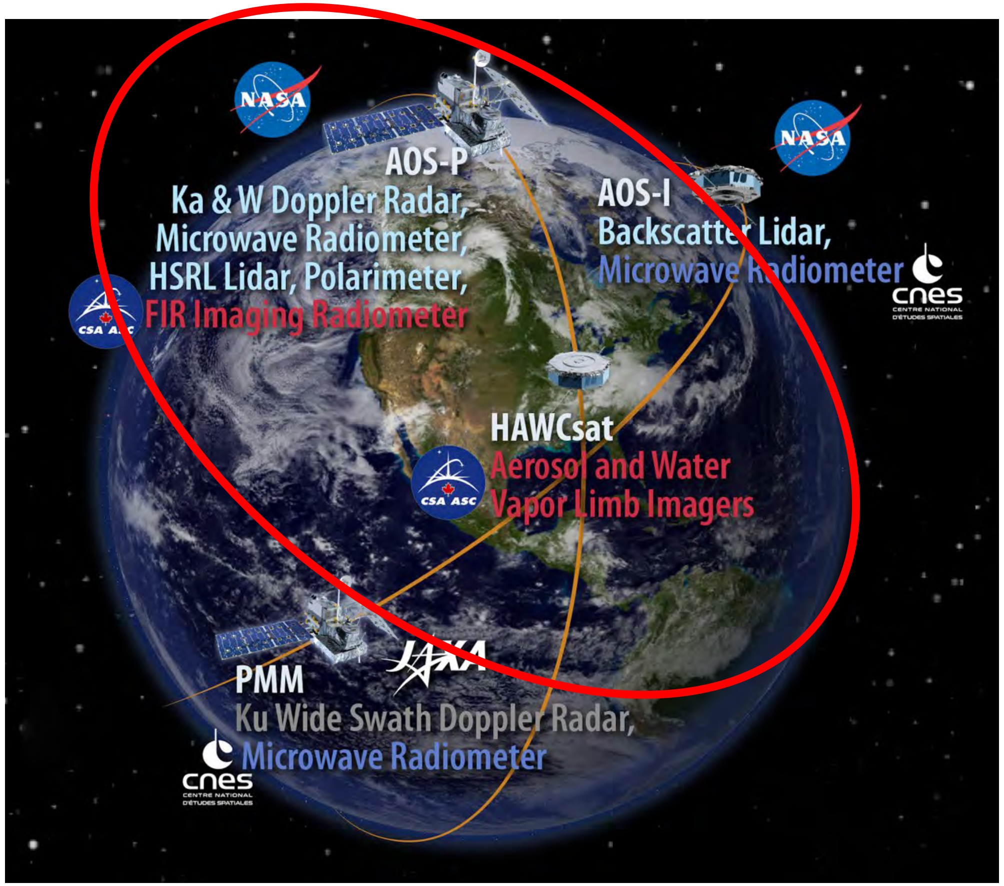




Pre-Decisional – AOS is in Pre-Phase A and NASA makes no commitments on the final design of the mission or instruments

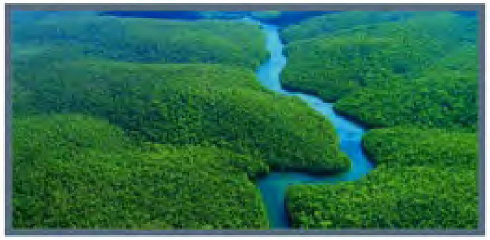
The AOS Architecture (Pending HQ Reviews, Decisions)

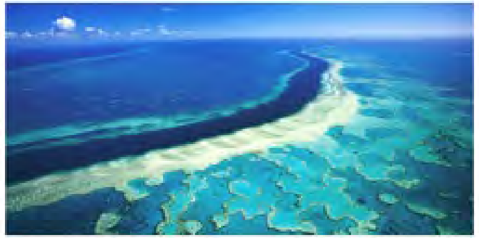
- Global perspective required for developing understanding of **climate sensitivity, feedbacks, and aerosol forcing of the climate**
  - o **Low latitude** clouds and interaction with aerosol are fundamental to climate feedbacks
  - o **Midlatitude** cloud-precipitation processes are important to water resources and energy transport
  - o **Polar regions** are important for capturing aerosol transport, critical to Earth's energy budget, and highly sensitive to climate change
- Global observations key to understanding linkages between energy and water cycles of the Earth system
- **AOS-P builds on the heritage of the A-Train**



Pre-Decisional – AOS is in Pre-Phase A and NASA makes no commitments on the final design of the mission or instruments

SBG is Responsive to the Decadal Survey





SBG is key to understanding in five research and applications (R&A) focus areas:

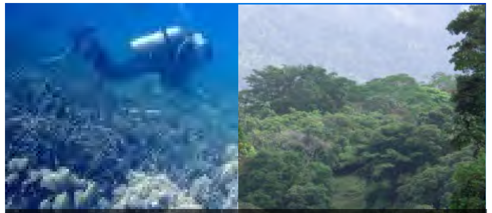
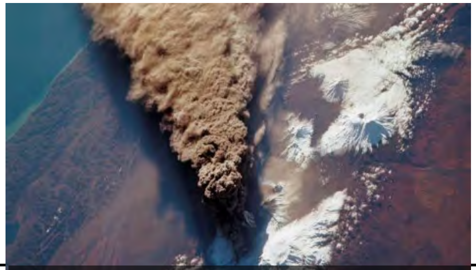
- Terrestrial and aquatic ecosystems
- Hydrology
- Weather
- Climate
- Solid Earth

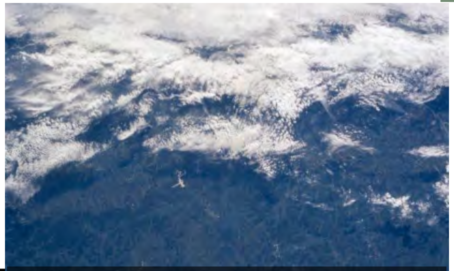
The Decadal Survey (DS) defines the implementation as two sensors *"Hyperspectral imagery in the visible and shortwave infrared; multi- or hyperspectral imagery in the thermal IR*":

1. "….a moderate spatial resolution (30-45 m GSD), hyperspectral resolution (10 nm; 400-2500 nm), high fidelity (SNR = 400:1 VNIR/250:1 SWIR) imaging spectrometer is needed for characterizing land, inland aquatic, coastal zone, and shallow coral reef ecosystems"
2. "….30-60 m TIR observations in the 10.5-11.5 μm and 11.5-12.5 μm spectral regions are needed with a 2-4 day revisit frequency"

https://sbg.jpl.nasa.gov/doc_links/2022-05-17-sbg-community-webinar-8/2022-05-17-8th-sbg-community-webinar/view

Decadal Survey R&A Questions and Targeted Observables Span Five Focus Areas

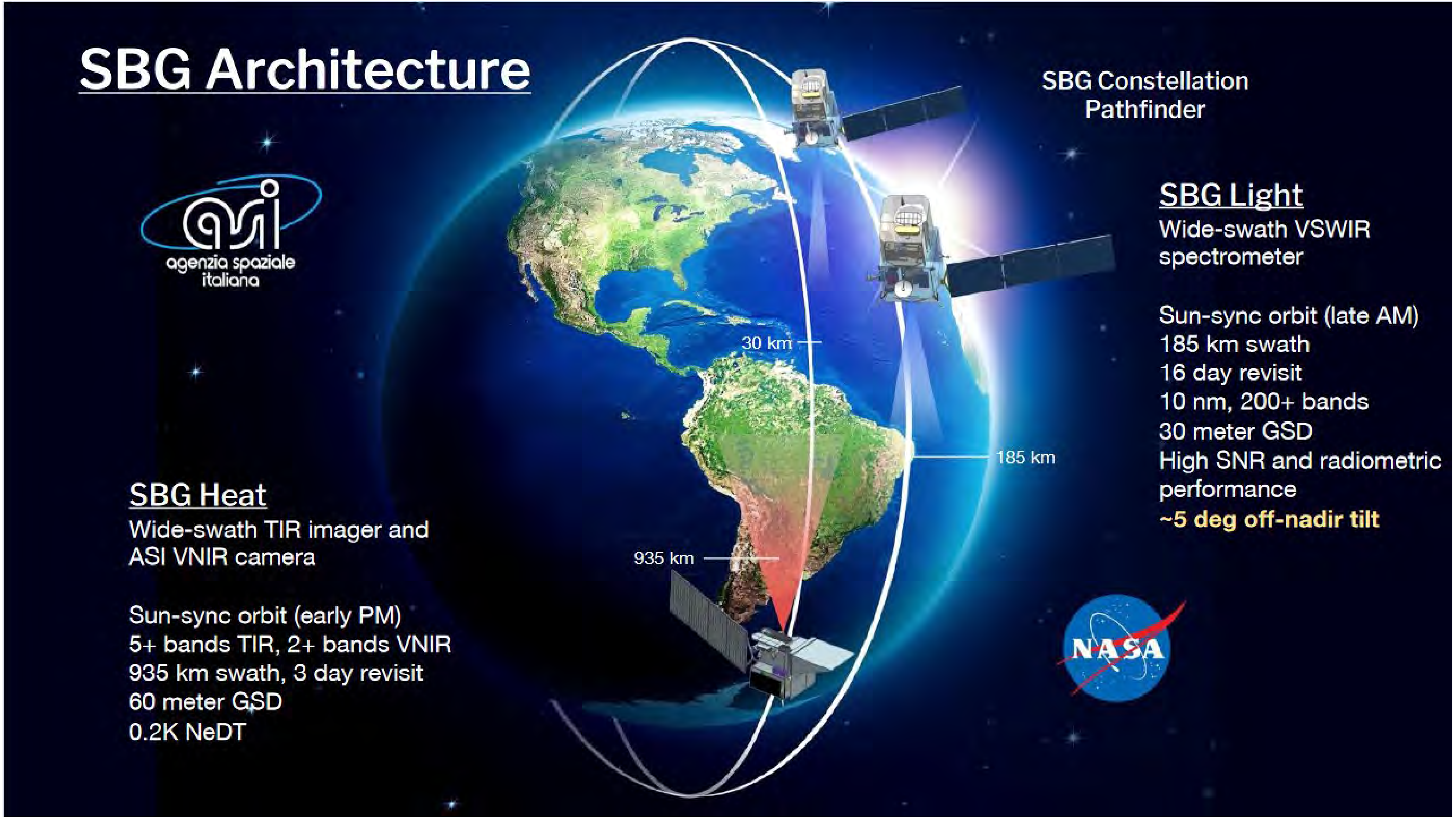


Hydrology	Ecosystems & Natural Resources	Solid Earth	Climate	Weather
H-1. **How is the water cycle changing? (3 observables)***	E-1. **What are the structure, function, and biodiversity of Earth's ecosystems? (7 observables)**	S-1. **How can large-scale geological hazards be accurately forecast? (5 observables)**	C-3. **How large are the variations in the global carbon cycle? (1 observable)**	W-3. **How do spatial variations in surface characteristics modify transfer between domains? (1 observable)**
H-2. **How do anthropogenic changes in climate, land use, water use, and water storage, interact and modify the water and energy cycles? (4 observables)**	E-2. **What are the fluxes between ecosystems and the atmosphere, the ocean, and the solid Earth, and how and why are they changing? (1 observable)**	S-2. **How do geological disasters directly impact the earth system? (3 observables)**		
H-4. **How does the water cycle interact with other Earth system processes to change the predictability and impacts of hazardous events and hazard chains (1 observable)**	E-3. **What are the fluxes (of carbon, water, nutrients, and energy) within ecosystems? (2 observables)**			

Eight of 10 DS R&A questions need both VSWIR and TIR observables

Slide from B. Poulter (NASA)

SBG Architecture (Pending HQ Reviews, Decisions)



https://sbg.jpl.nasa.gov/doc_links/2022-05-17-sbg-community-webinar-8/2022-05-17-8th-sbg-community-webinar/view

Mass Change

https://science.nasa.gov/earth-science/decadal-mc

Targeted Observable	*Science/Applications Summary*	*Candidate Measurement Approach*
Mass Change	Large-scale Earth dynamics measured by the changing mass distribution within and between the Earth's atmosphere, oceans, ground water, and ice sheets	Spacecraft ranging measurement of gravity anomaly

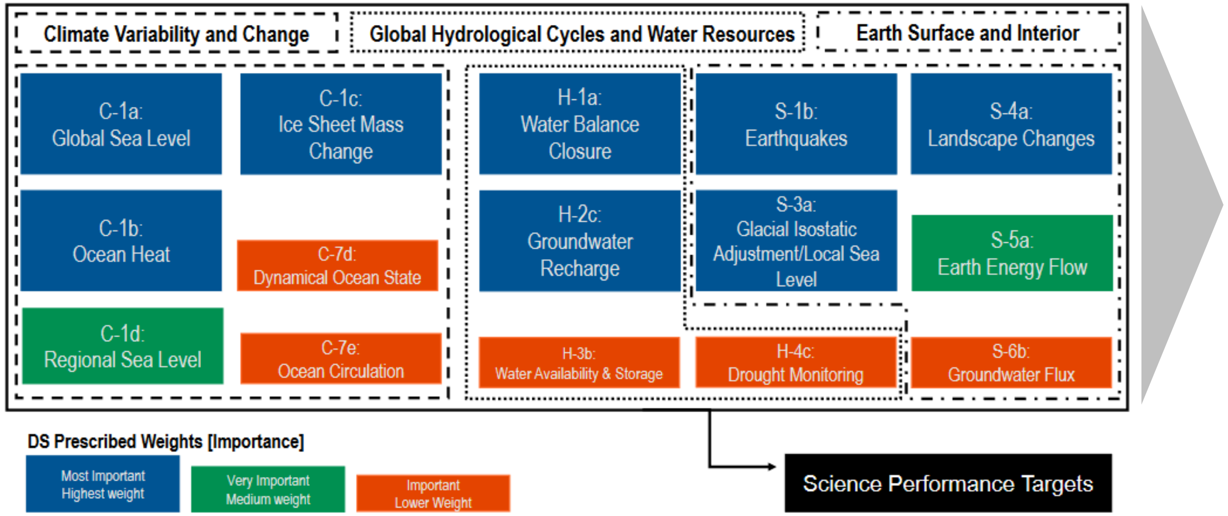
Focus Area	Most Important (MI)	Very Important (VI)	Important
Hydrology	1a, 2c		3b, 4c
Climate	1a, 1b, 1c	1d	7d, 7e
Earth Surface and Interior	1b, 3a, 4a	5a	6b

Mass change is determined by measuring **gravitational changes** over set time periods.

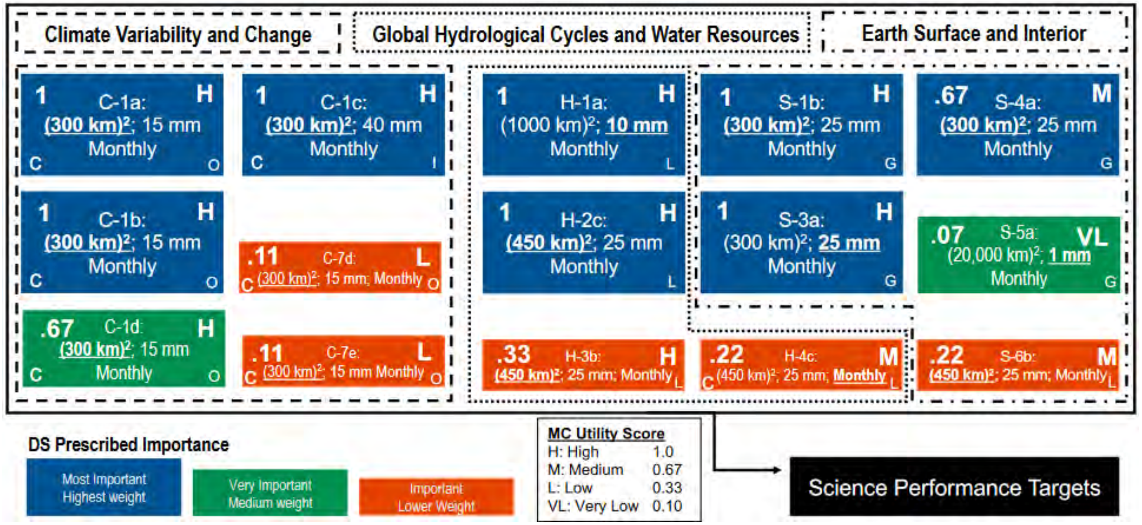
"MC provides an integrated view of the entire physical Earth system that allows the relating of changes in one system component to changes in another."

https://science.nasa.gov/science-pink/s3fs-public/atoms/files/Mass%20Change%20Town%20Hall%20Presentation_191212.pdf

Science Objectives to Measurement Parameters



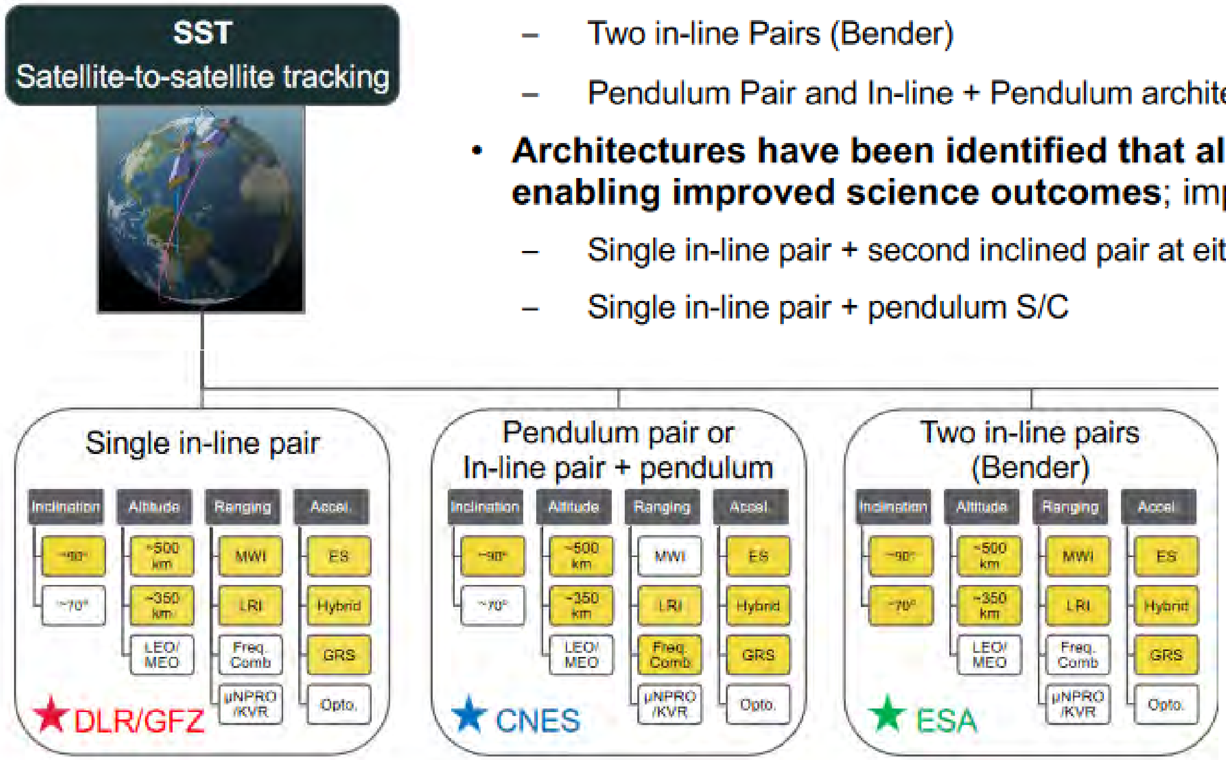
https://science.nasa.gov/science-pink/s3fs-public/atoms/files/Mass%20Change%20Town%20Hall%20Presentation_191212.pdf



https://science.nasa.gov/science-pink/s3fs-public/atoms/files/MC_EGU_fullpresentation.pdf

MC Architectures

- **Satellite-Satellite-Tracking (SST) is the recommended architecture** for implementation as the MC observing system. Promising variants include
  - Single in-line Pair
  - Two in-line Pairs (Bender)
  - Pendulum Pair and In-line + Pendulum architectures
- **Architectures have been identified that allow for highest likelihood of continuity with GRACE-FO while also enabling improved science outcomes**; implementation of the full observing system can be synchronous or staggered
  - Single in-line pair + second inclined pair at either high altitude or low altitude
  - Single in-line pair + pendulum S/C



https://science.nasa.gov/science-pink/s3fs-public/atoms/files/MC_EGU_fullpresentation.pdf

SDC

Targeted Observable	*Science/Applications Summary*	*Candidate Measurement Approach*
Surface Deformation & Change	Earth surface dynamics from earthquakes and landslides to ice sheets and permafrost	Interferometric Synthetic Aperture Radar (InSAR) with ionospheric correction

- NISAR is a trailblazer for SDC
- SDC formulation team has gone through a similar process as the other mission, but is waiting on 'lessons learned' from NISAR

NASA-ISRO SAR (NISAR) Mission

https://nisar.jpl.nasa.gov/

Science themes addressed by SDC

Global Hydrological Cycles & Water Resources (H)
(Also referred to as Hydrology)

Weather & Air Quality (W)
(Also referred to as Weather)

Marine & Terrestrial Ecosystems & Natural Resource Management (E
(Also referred to as Ecosystems)

Climate Variability & Change – Seasonal to Centennial (C)
(Also referred to as Cryosphere)

Earth Surface & Interior – Dynamics (S)
(Also referred to as Solid Earth)

https://science.nasa.gov/science-pink/s3fs-public/atoms/files/SDC_SATM_Phase1_Final_0.pdf

Thank You!