Building Capacity to Use Earth Observations in Addressing Environmental Challenges in Bhutan

Day 1 – Overview of NASA Earth Exchange Global Daily Downscaled Projections for Coupled Model Intercomparison Project Phase 6 (NEX-GDDP-CMIP6)

Objectives:

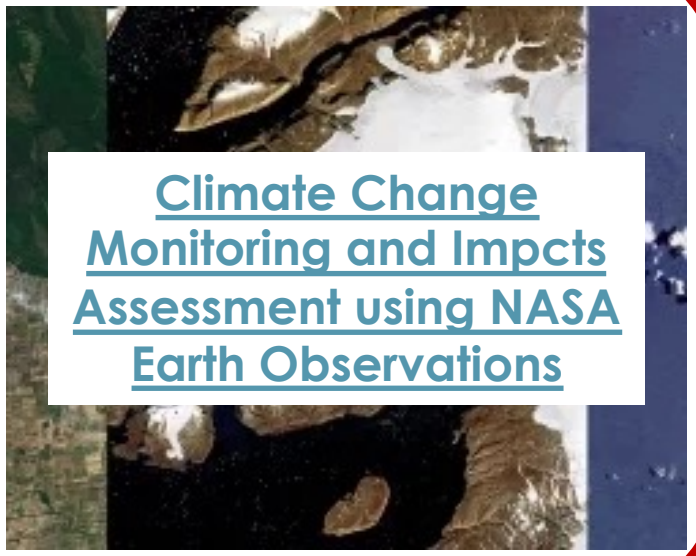
- By the end of this presentation, you will:
  - Become familiar about Coupled Model Intercomparison Project Phase 6 (CMIP6) and climate change projection scenarios
  - Recognize the procedure used in NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) to downscale CMIP6 data
  - Identify how to access and analyze NEX-GDDP climate projection data

Outline

- A brief background about climate variability and change, CMIP6, and climate change projections
- Description of NEX-GDDP-CMIP6 data
- Demonstration: NEX-GDDP-CMIP6 data access and analysis in Google Earth Engine

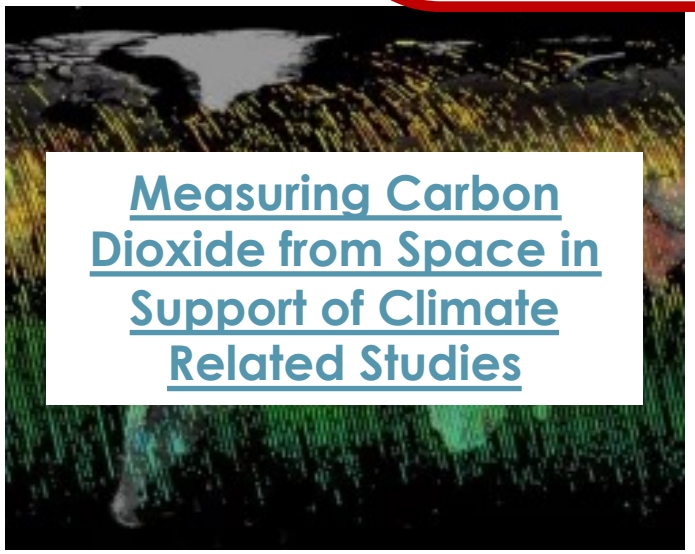
ARSET Trainings – Climate

Building Climate Risk Assessments from Vulnerability and Exposure



Climate Change Monitoring and Impcts Assessment using NASA Earth Observations

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



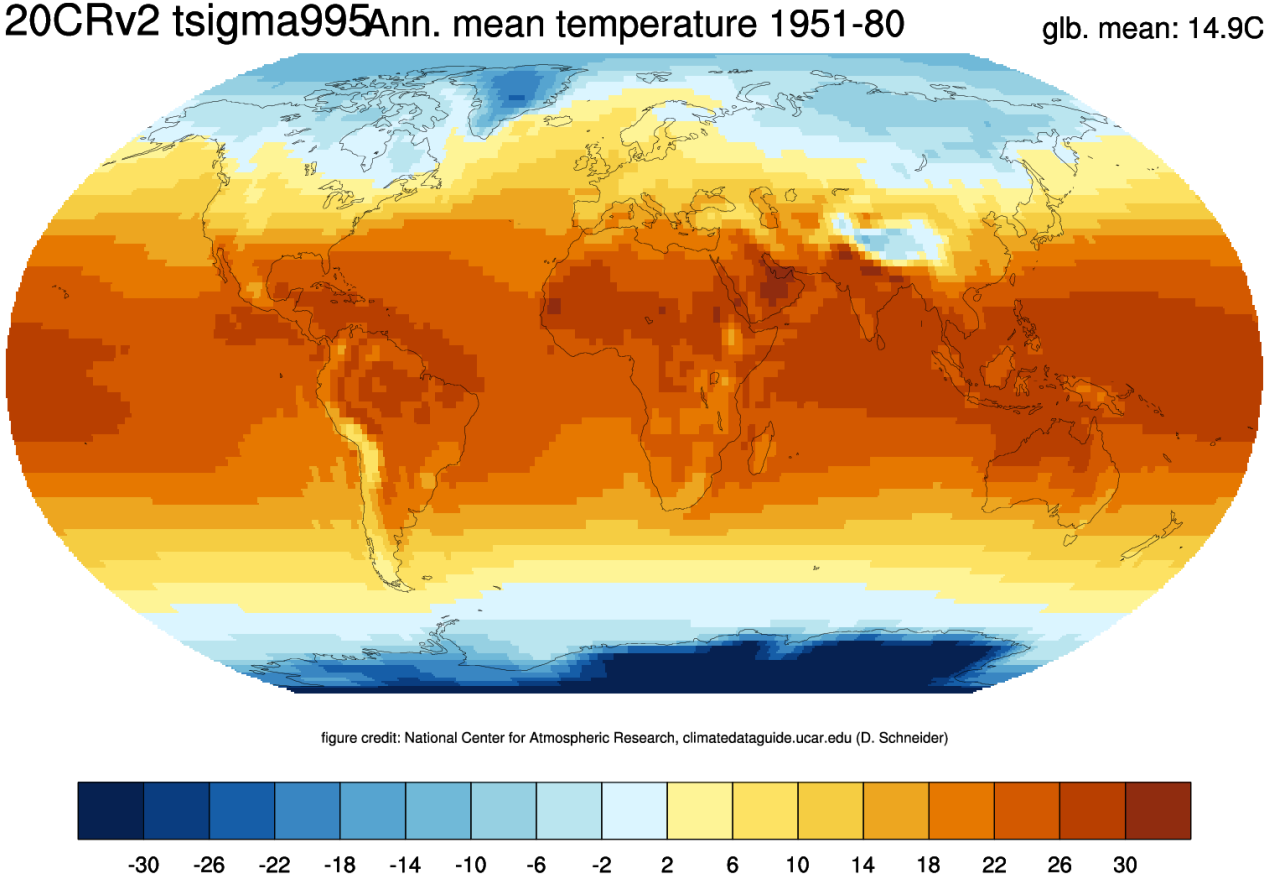
Measuring Carbon Dioxide from Space in Support of Climate Related Studies

Introduction to NASA Resources for Climate Change Applications

Climate Variability and Change, CMIP6, and Climate Change Projections

What is Climate?

- Long-term (30+ years) average characteristics of geophysical quantities in temperature, precipitation, and humidity at a regional or global scale.



NOAA 20th Century Climate Reanalysis

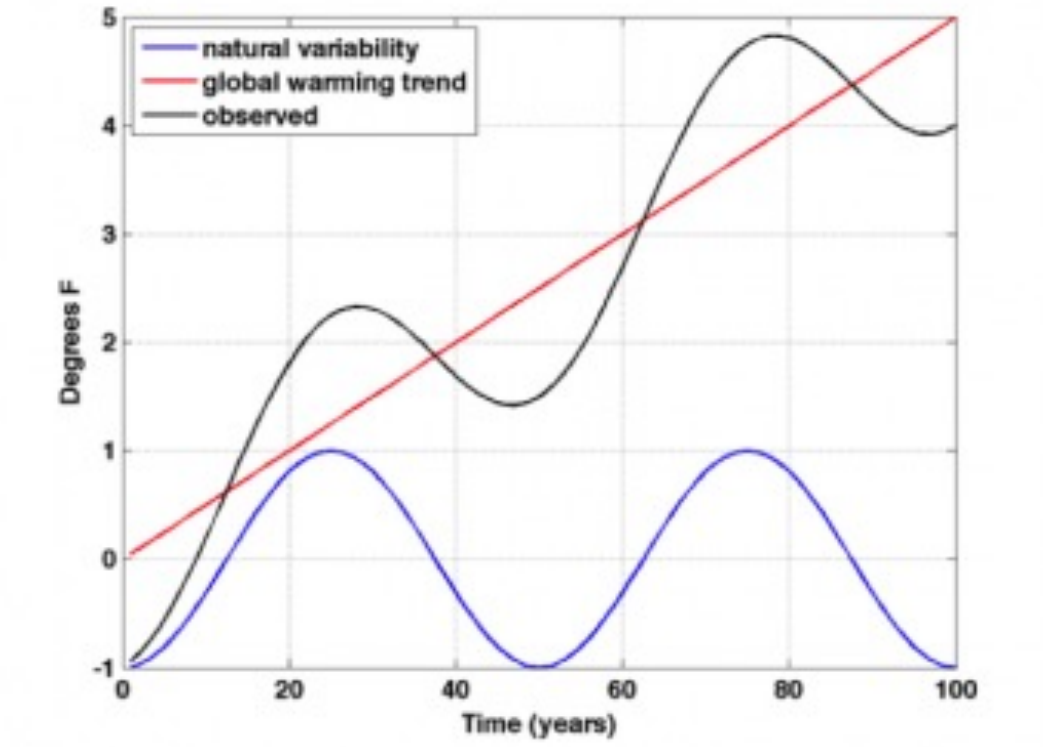
Climate Variability and Change

Natural Climate Variability and Change:

- Resulting from natural—not anthropogenic—causes such as:
  - Ocean-atmosphere-land interactions
  - Variability in incoming solar radiation
  - Volcanic activity
  - Earth's orbital variations.
- Examples: El Nino – Southern Oscillation
  Pacific Decadal Oscillation

Anthropogenic Climate Change:

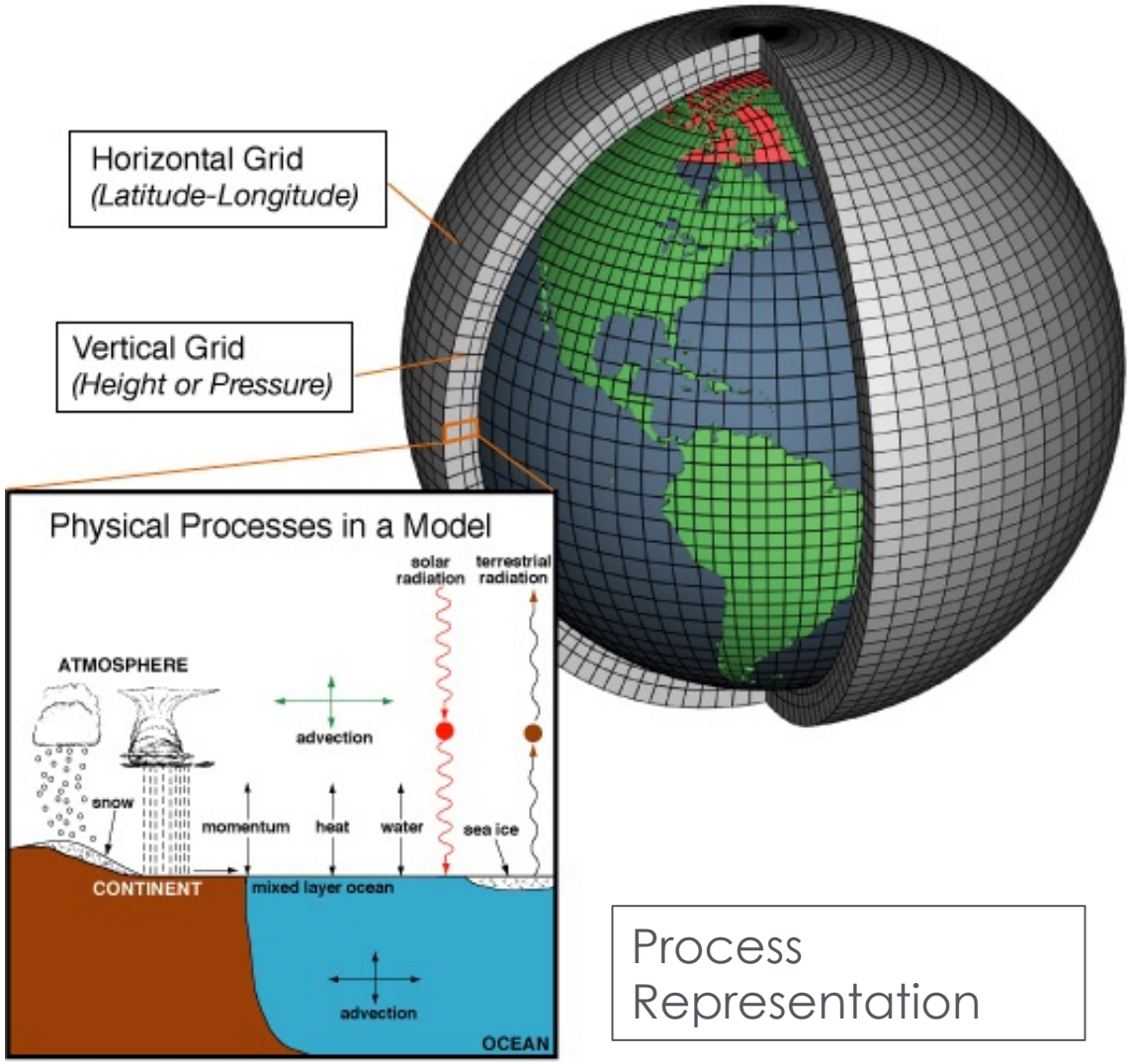
- Increasing greenhouse gases and aerosols in the atmosphere due to fossil fuel burning, industrial waste, deforestation



Climate Impact Group, University of Washington

Global Climate Models

- Climate models are often designed to capture global signals, with regional signals likely including biases.
- Observations are an important part of model development for initial and boundary conditions, and for validation and bias correction.
- Require super computers and big data management



Process Representation

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

Global Climate Models

- 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).
- 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.

Coupled Model Intercomparison Project Phase 6 (CMIP6)

https://wcrp-cmip.org/cmip6/ https://pcmdi.llnl.gov/CMIP6/

- The CMIP program is organized by the World Climate Research Program, currently on Phase 6, with the goal to understand past, current, and future climate change occurring in response to natural and anthropogenic causes using multi-model framework.
- The program has evolved since 1995 in which multiple models participate to 1.) assess model performance during a historical period (1850–2014) and 2.) produce future climate projections.
- Common experiments and forcing data are used by all models.
- A major goal is to quantify and understand the spread found among the model projections.

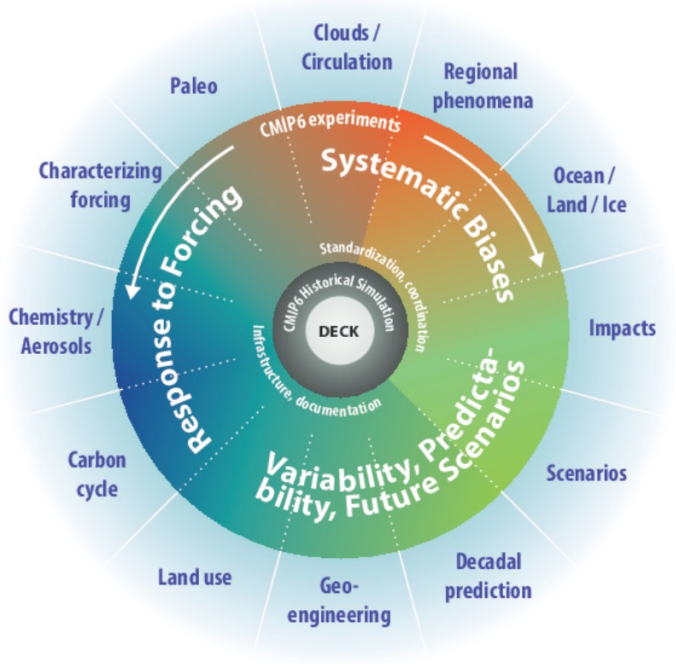


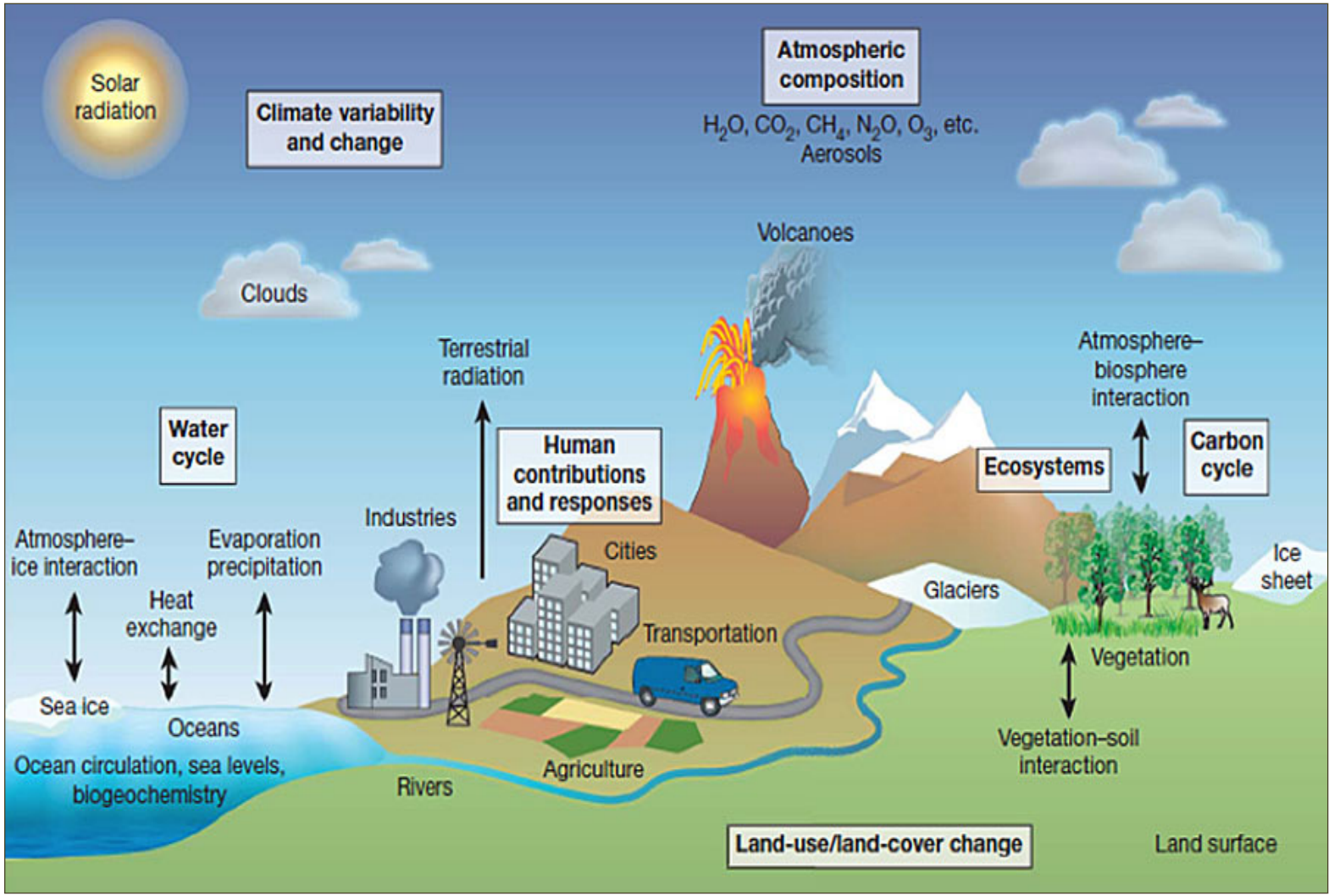
Figure 2. Schematic of the CMIP/CMIP6 experiment design. The inner ring and surrounding white text involve standardized functions of all CMIP DECK experiments and the CMIP6 historical simulation. The middle ring shows science topics related specifically to CMIP6 that are addressed by the CMIP6-Endorsed MIPs, with MIP topics shown in the outer ring. This framework is superimposed on the scientific backdrop for CMIP6 which are the seven WCRP Grand Science Challenges.

Eyring et al., 2016: https://doi.org/10.5194/gmd-9-1937-2016

Modeling and 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 Change Scenarios and Storylines

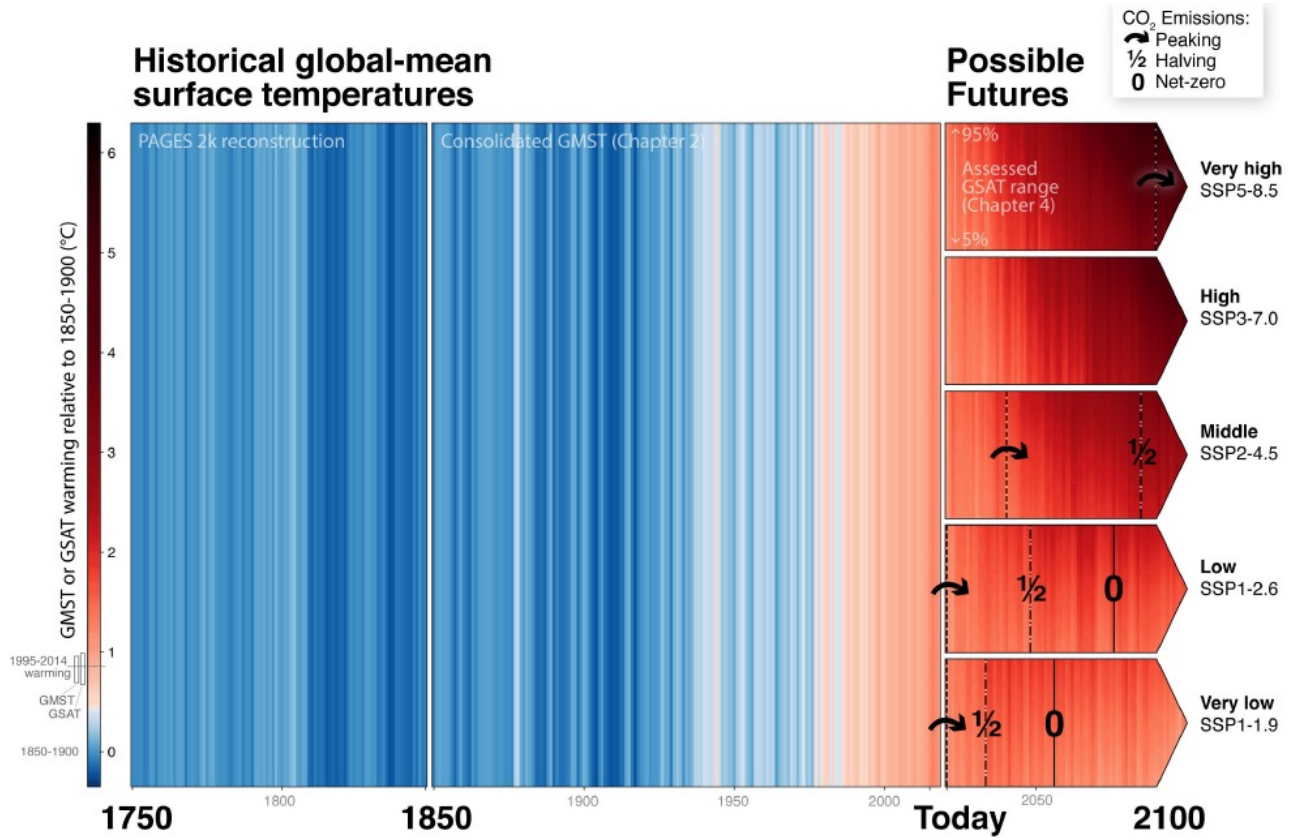
- **Scenarios:** Describe a future world through a plausible and internally consistent set of assumptions, potentially including greenhouse gas and aerosol emissions, land use change, socioeconomic development, and technological change.
- **The IPCC notes that scenarios are neither predictions nor forecasts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

- **Storyline**: 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.:
  - The physical implications of a given amount of global warming
  - Potential impact of increasing population
  - The ramifications of a given policy or new financing being implemented

See IPCC AR6 WGI Glossary for more information.

Scenarios and Storylines

- **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)
- **GWLs**: Global Warming Levels
- **NDCs**: Nationally-Determined Contributions

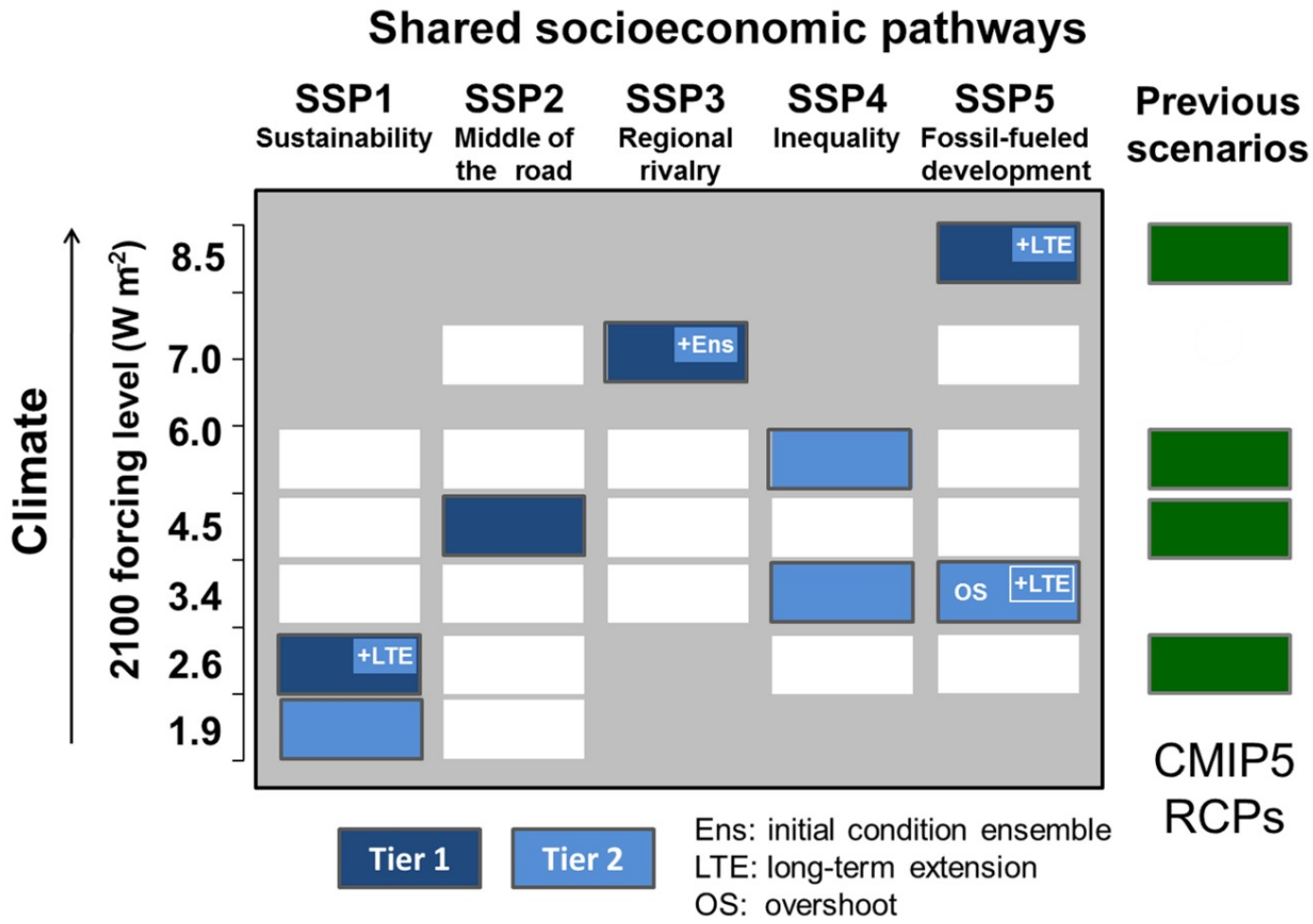


IPCC AR6 WGI

Chen et al., 2021 Figure 1.25

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.



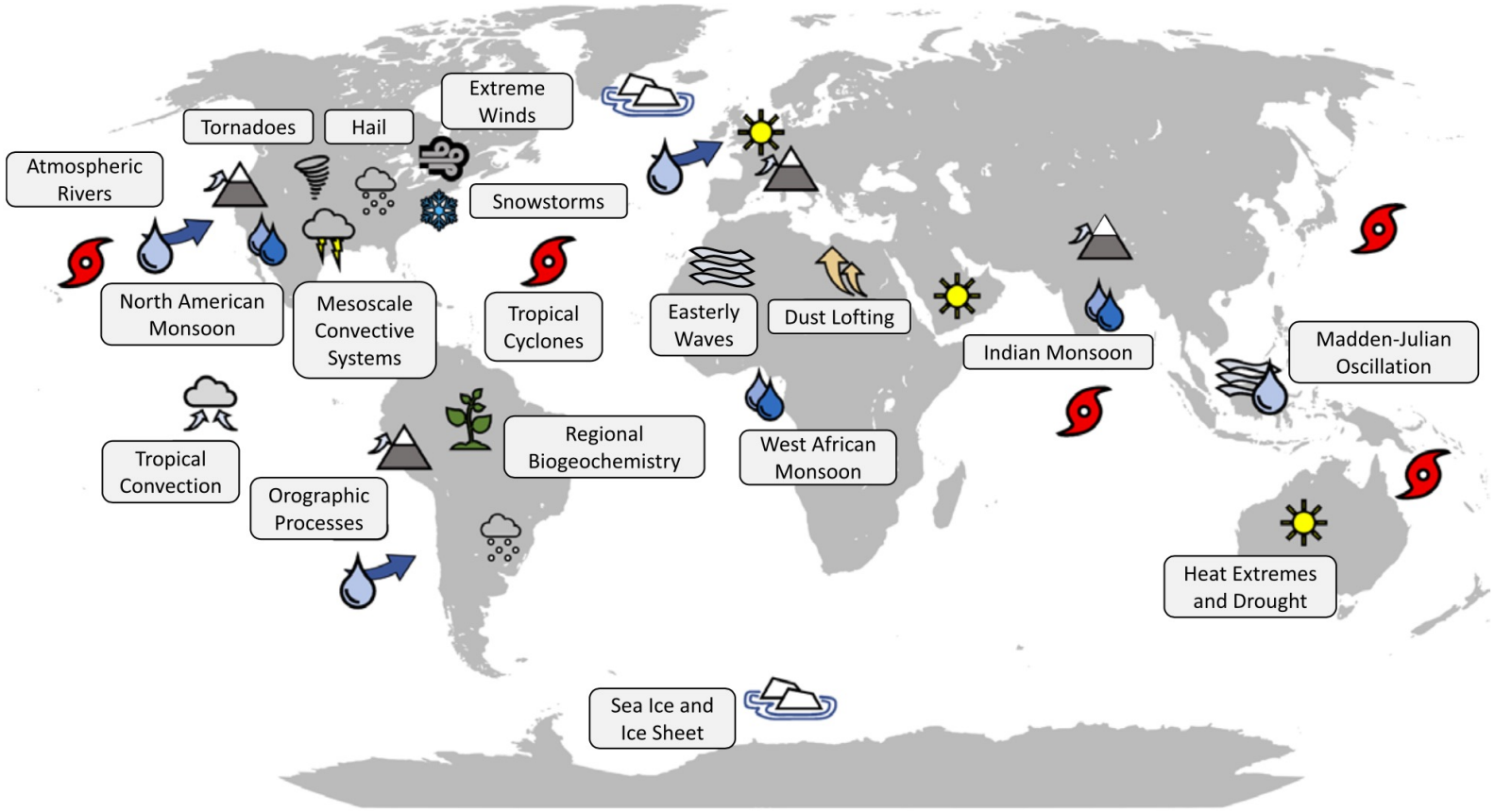
ScenarioMIP Shared Socioeconomic Pathways

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

Description of NEX-GDDP-CMIP6

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
- Necessary for assessing climate impacts on local/regional scale



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)

NEX-GDDP-CMIP6

- **NEX-GDDP:**
  - Initiated in 2015 with CMIP5 project to downscale GCMs
  - Updated with CMIP6 with newer climate projections
  - 35 CMIP6 global models are included in the downscaling
  - A number of geophysical parameters are downscaled from most models

List of GCMS and Parameters

Model	Variant	hurs	huss	pr	rlds	rsds	sfcWind	tas	tasmax	tasmin
ACCESS-CM2	r1i1p1f1									
ACCESS-ESM1-5	r1i1p1f1									
BCC-CSM2-MR	r1i1p1f1									
CanESM5	r1i1p1f1									
CESM2	r4i1p1f1									
CESM2-WACCM	r3i1p1f1									
CMCC-CM2-SR5	r1i1p1f1									
CMCC-ESM2	r1i1p1f1									
CNRM-CM6-1	r1i1p1f2									
CNRM-ESM2-1	r1i1p1f2									
EC-Earth3	r1i1p1f1									
EC-Earth3-Veg-LR	r1i1p1f1									
FGOALS-g3	r3i1p1f1									
GFDL-CM4 (gr1)	r1i1p1f1									
GFDL-CM4 (gr2)	r1i1p1f1									
GFDL-ESM4	r1i1p1f1									
GISS-E2-1-G	r1i1p1f2									
HadGEM3-GC31-LL	r1i1p1f3									
HadGEM3-GC31-MM	r1i1p1f3									
IITM-ESM	r1i1p1f1									
INM-CM4-8	r1i1p1f1									
INM-CM5-0	r1i1p1f1									
IPSL-CM6A-LR	r1i1p1f1									
KACE-1-0-G	r1i1p1f1									
KIOST-ESM	r1i1p1f1	*								
MIROC-ES2L	r1i1p1f2									
MIROC6	r1i1p1f1									
MPI-ESM1-2-HR	r1i1p1f1									
MPI-ESM1-2-LR	r1i1p1f1									
MRI-ESM2-0	r1i1p1f1									
NESM3	r1i1p1f1									
NorESM2-LM	r1i1p1f1									
NorESM2-MM	r1i1p1f1									
TaiESM1	r1i1p1f1									
UKESM1-0-LL	r1i1p1f2									

Table 2. CMIP6 models included in downscaled archive . Key: Green = all experiments available; yellow = historical & some SSP(s) available; red = no data available. *Original GCM output for hurs SSP245 missing year 2058

Thrasher, B., Wang, W., Michaelis, A. *et al.* NASA Global Daily Downscaled Projections, CMIP6. *Sci Data* **9**, 262 (2022). https://doi.org/10.1038/s41597-022-01393-4

NEX-GDDP-CMIP6 Downscaling Methodology

- Statistical downscaling method used a daily variant of the monthly bias correction/spatial disaggregation (BCSD) method.
- Observational data and reanalysis data at 0.25° scale are used for bias correction.
- After the bias correction, spatial disaggregation merges observed historical climatology at each time step with changes from GCM simulations to produce final downscaled products.

BCSD code used to generate the downscaled outputs is available here: https://github.com/bthrasher/daily_BCSD

Wood, et al. (2002): J. of Geophysical Research-Atmospheres 107. Wood, et al. (2004)" Climatic Change 62, 189–216.

NEX-GDDP-CMIP6 Data

- The GDDP data are available for the following climate projection scenarios: **Historical, SSP126, SSP245, SSP370, and SSP585**
- Quality-checked data are available at **daily** time scale with **0.25 x 0.25-degree** spatial resolution
- **Data Access:** NASA Center for Climate Simulation (NCCS) from Amazon Web Service

THE SHARED SOCIO-ECONOMIC PATHWAYS (SSPs)

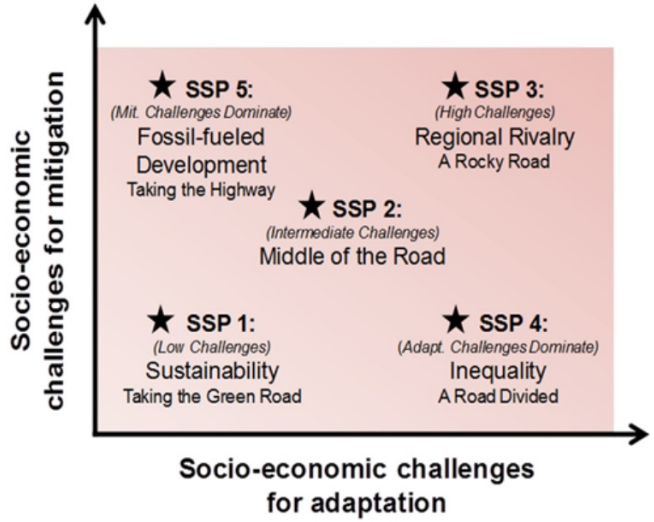


***Fig. 1** Overview of SSPs*
(Narratives in O'Neill et al., 2016, Glob Env Change, online first)
SSP1: low challenges for mitigation (resource efficiency) and adaptation (rapid development)
SSP3: high challenges for mitigation (regionalized energy / land policies) and adaptation (slow development)
SSP4: low challenges for mitigation (global high tech economy), high for adapt. (regional low tech economies)
SSP5: high challenges for mitigation (resource / fossil fuel intensive) and low for adapt. (rapid development)

UNCCC SSP Overview

NEX-GDDP data also available from: Google Earth Engine.

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

https://appliedsciences.nasa.gov/get-involved/training/english/arset-selecting-climate-change-projection-sets-mitigation-adaptation

- 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

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.

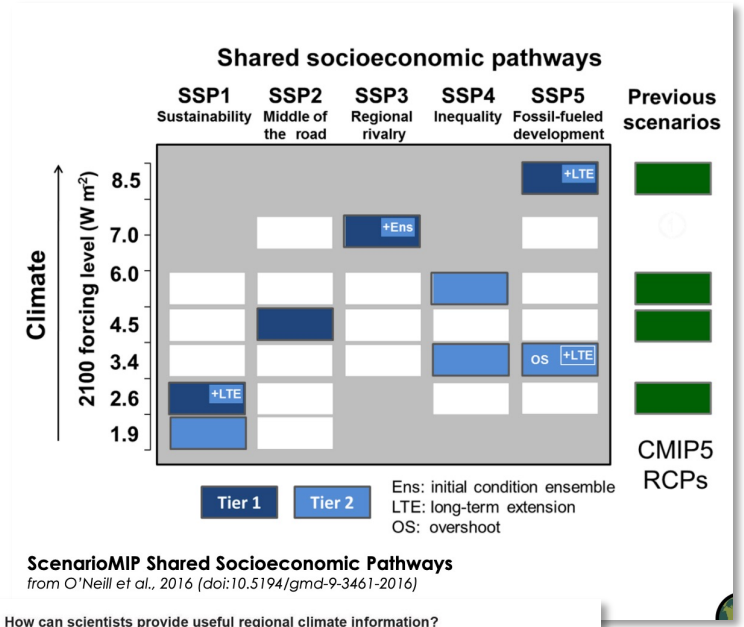
Note that we will not be giving you one recommendation, but aim to empower you in your selection process.

Photo from US Navy, Available on Wikimedia Commons

Note: ARSET does not recommend any particular model or scenario for climate change but provides general steps to access and analyze GCM data to facilitate your efforts in selecting appropriate GCM data for your region.

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

- Overview of application areas (mitigation, adaptation, risk)
- Where climate projection sets come from
- Key distinguishing features between climate projection sets
- Tradeoffs in using more complex climate projection sets
- **Selecting an appropriate climate projection set given application needs**
- Downscaling, Spatial & Temporal Resolutions
- Post-Processing and Bias Correction
- Application-Ready Parameters (*Temperature, Precipitation, Soil Moisture, Evapotranspiration, Runoff, Snow & Ice, Climate Indices)*



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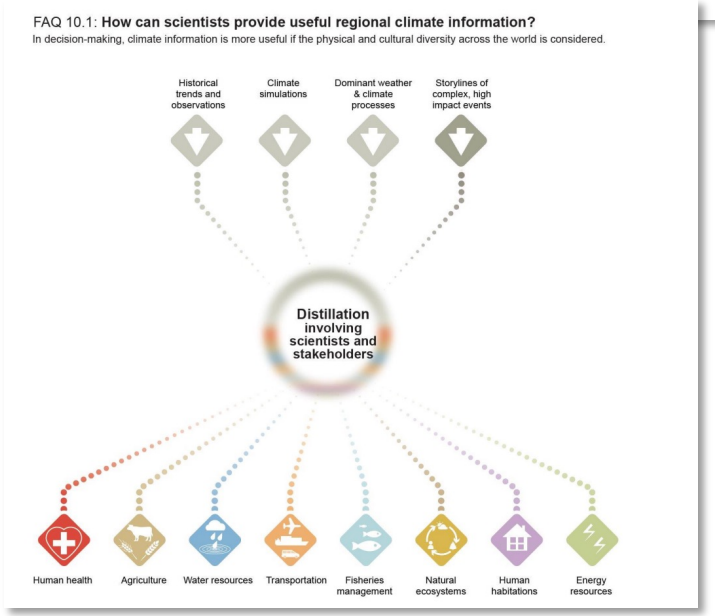

Demonstration:
NEX-GDDP-CMIP6 Data Access and Analysis in Google Earth Engine