Food and Agriculture Organization of the United Nations

Module 1
Climate Data and Climate Science

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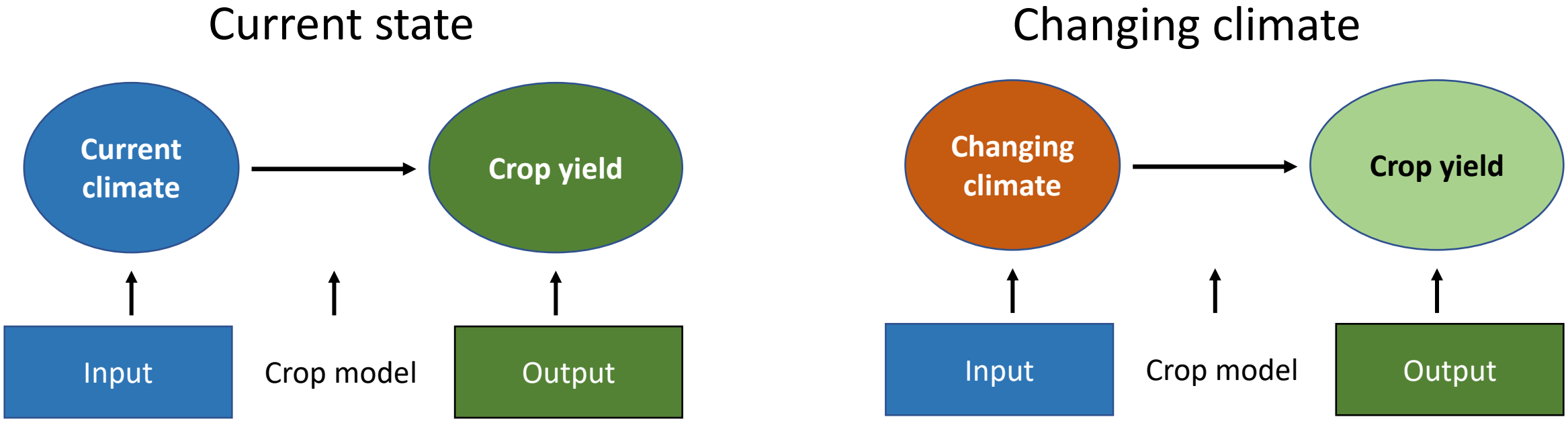
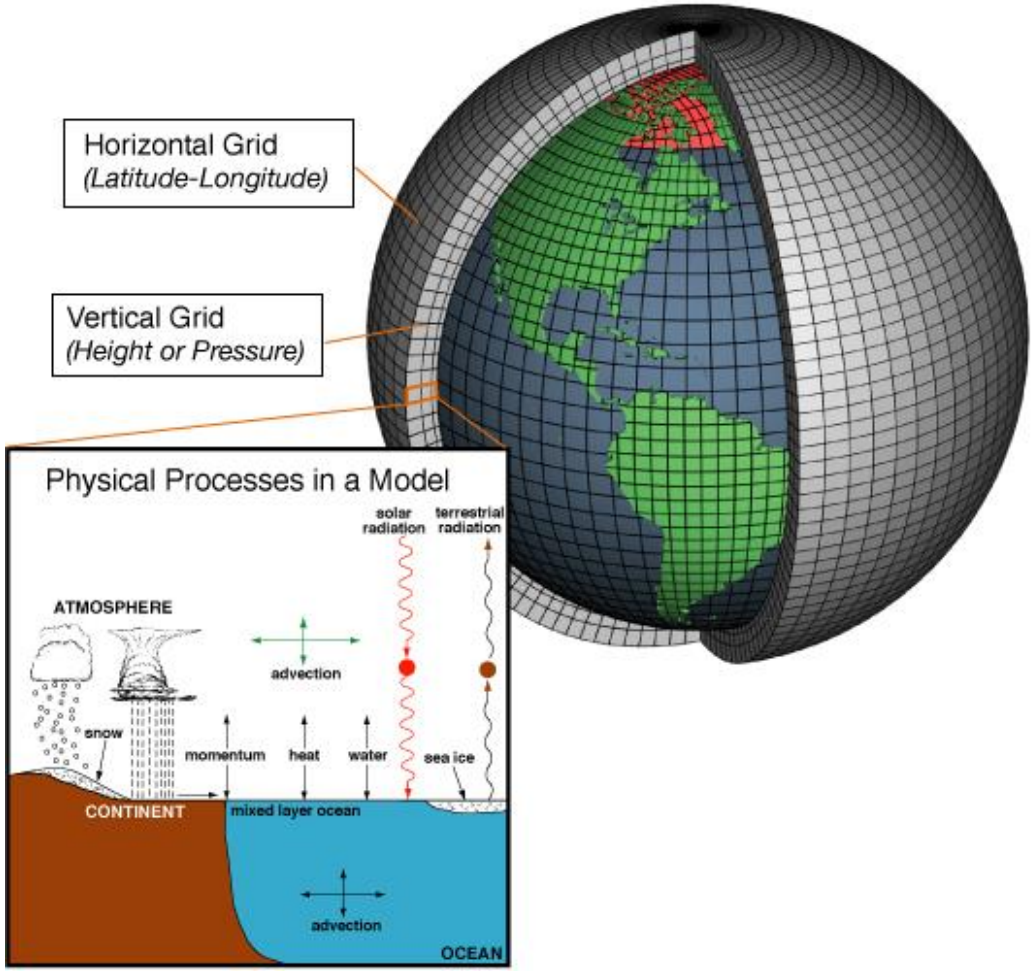
Why do we need climate models?

- They are the only reliable scientific tools for “predicting” future climate, including its impacts necessary for devising appropriate policies. Example:



What is a climate model?

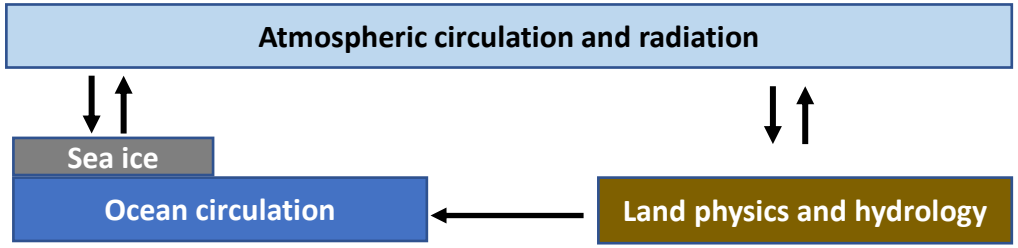


Set of mathematical equations used to simulate the transfer of energy and materials through the climate system. These equations need to be solved for each grid box and for each time step.

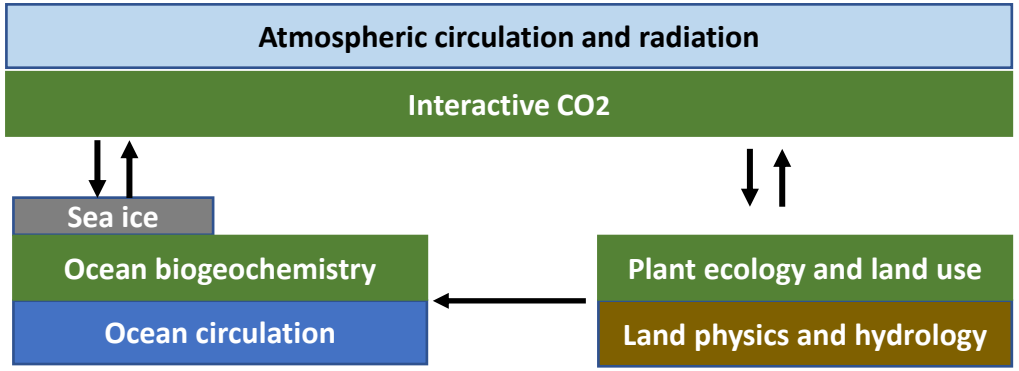
General Circulation Models and Earth System Models

- GCMs and ESMs are the most advanced tools used to simulate the effect of increasing greenhouse gas concentrations on the global climate system
- ESMs differ from GCMs because GCMs do not account for carbon movement through the earth system

Climate Model



Earth System Model



Is there only one climate model?

There is not a best climate model because:

- Diversity of equally plausible approaches to modelling climate systems
- Difficult to establish the exact relationship between doubling greenhouse gasses concentration and global warming (climate sensitivity)

Thus:

- The selection of climate models for impact studies is important

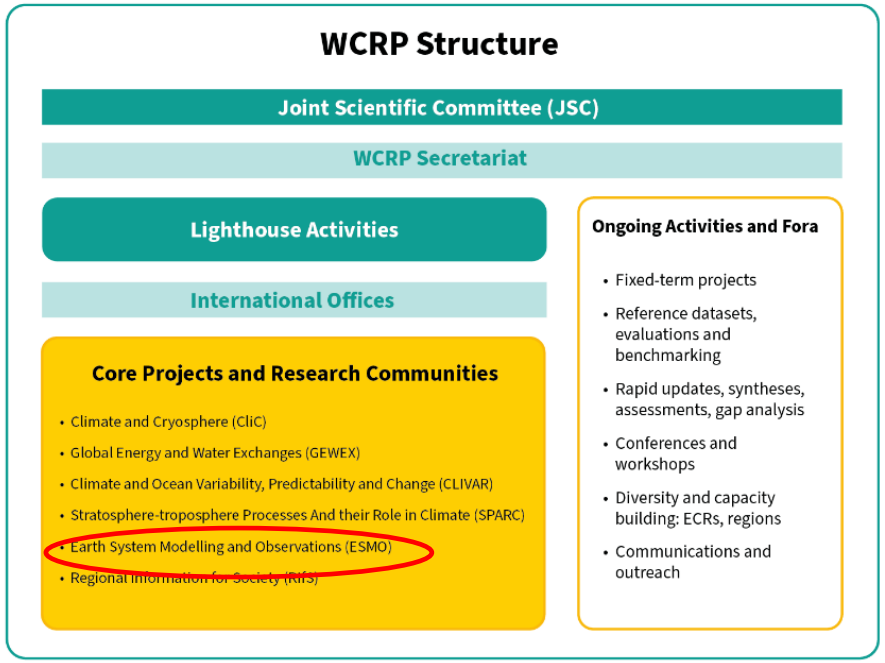
Questions:

When do you think ESMs instead of GCMs would be needed?

How many GCMs do we need?

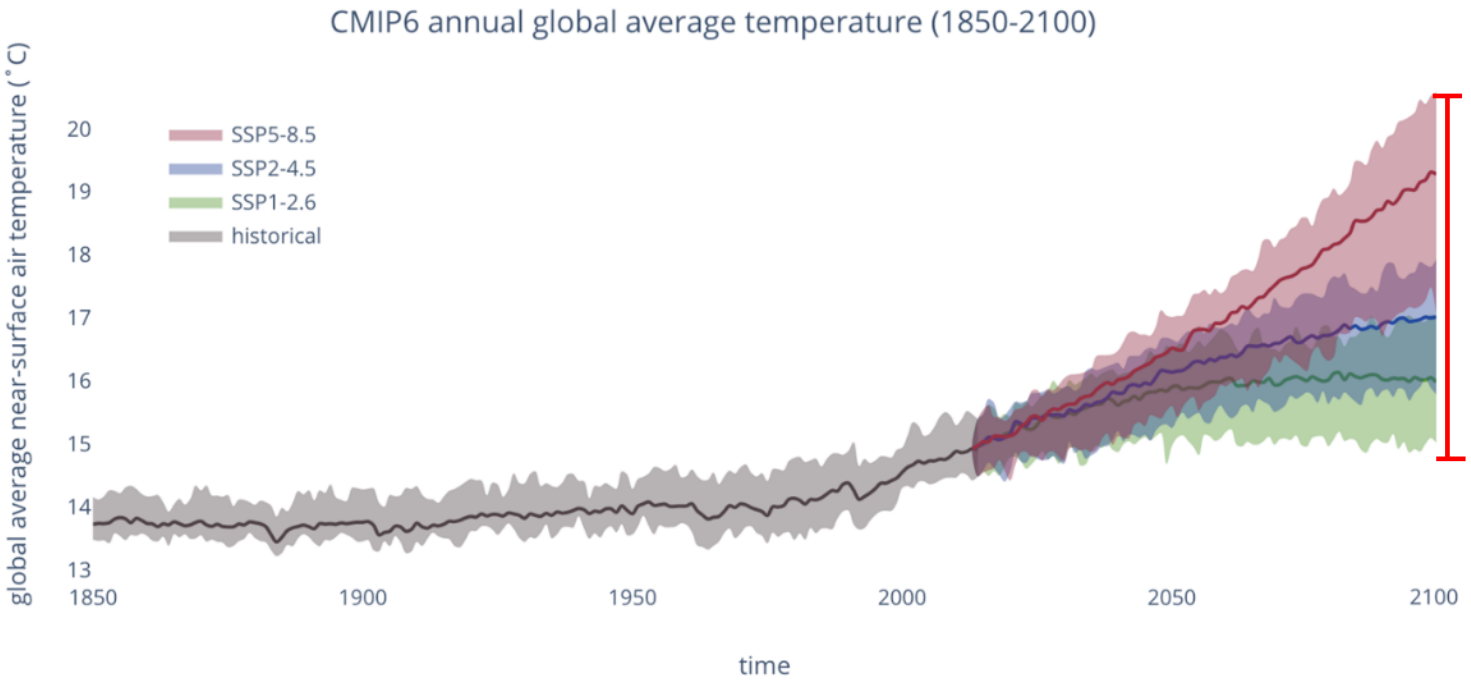
CMIP

- The Coupled Model Intercomparison Project (CMIP) is a project of the World Climate Research Programme (WCRP)'s Working Group of Coupled Modelling (WGCM).
- **CMIP objectives are to lead to a better understanding of past, present, and future climate change and variability in a multi-model and coordinated framework.**
- Started in 1995, CMIP is now in its 6th phase. CMIP6 is used for the IPCC report (AR6).

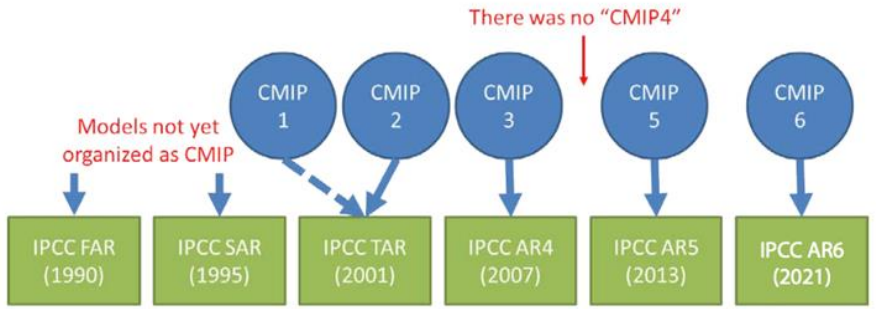


CMIP in numbers

- CMIP5 (40 models, 1.5 PB). 1 PB is 1,000,000 GB
- CMIP6 100+ models from 50 modeling centers around the world



Global mean temperature between 1850 and 2100 for selected CMIP6 models. The grey-shaded area shows the range of historical simulations and the coloured areas show potential future temperature change based on different greenhouse gas emission scenarios (red is pessimistic, blue is realistic and green is optimistic). Credit: Copernicus Climate Change Service, ECMWF.



Relation between CMIP and IPCC reports

Representative Concentration Pathways (RCPs)

- CMIP5 models considered different radiative forcings (due to changes in CO2, methane, and aerosol) spanning from 2.6 to 8.5 W/m^2
- In other words, what would happen to the global climate with a certain concentration of greenhouse gasses in the atmosphere

RCP	Relative radiative forcing	CO_2 ppm	Global warming	CO_2 emission pathway
1.9	1.9 W/m^2	450 ppm	1.5 °C	Zero by 2050
2.6	2.6 W/m^2	490 ppm	2 °C	Zero by 2075
4.5	4.5 W/m^2	650 ppm	3 °C	Falling after 2050
8.5	8.5 W/m^2	1370 ppm	5 °C	Keep rising

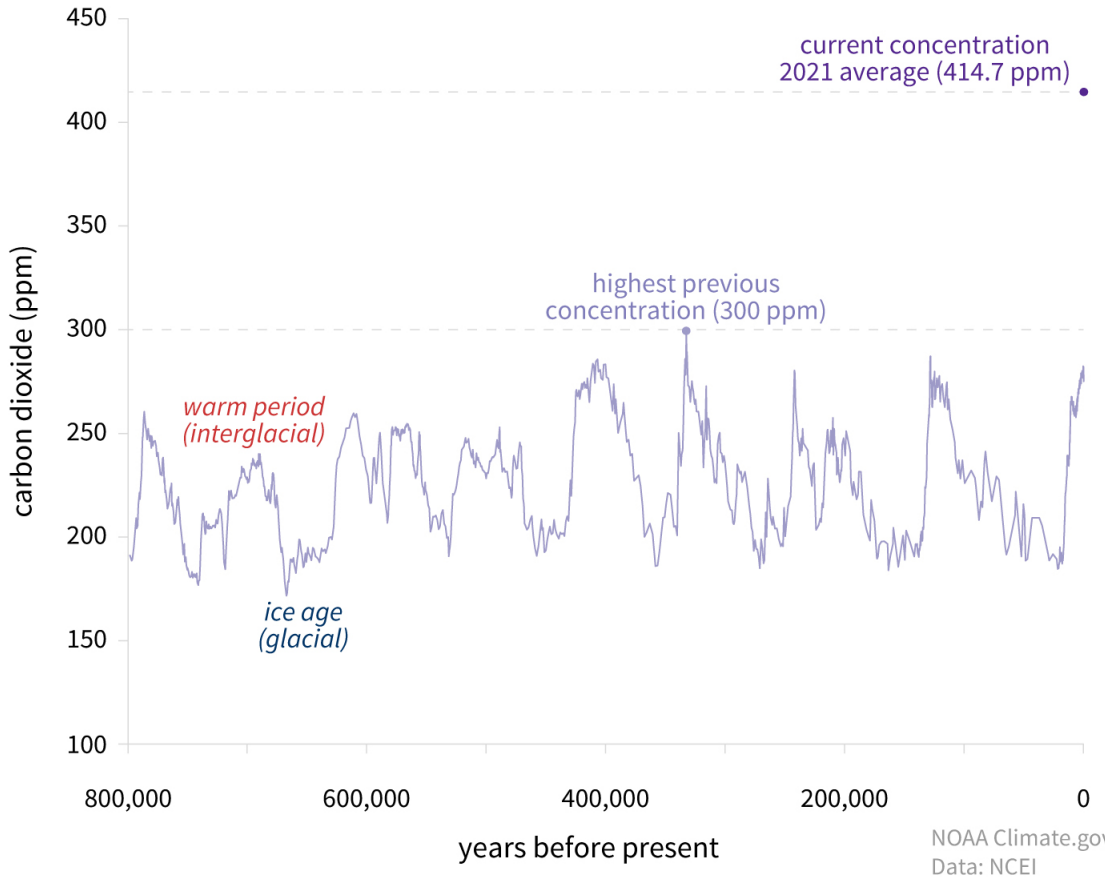
Resources:

https://link.springer.com/article/10.1007/s10584-011-0148-z (RCPs)

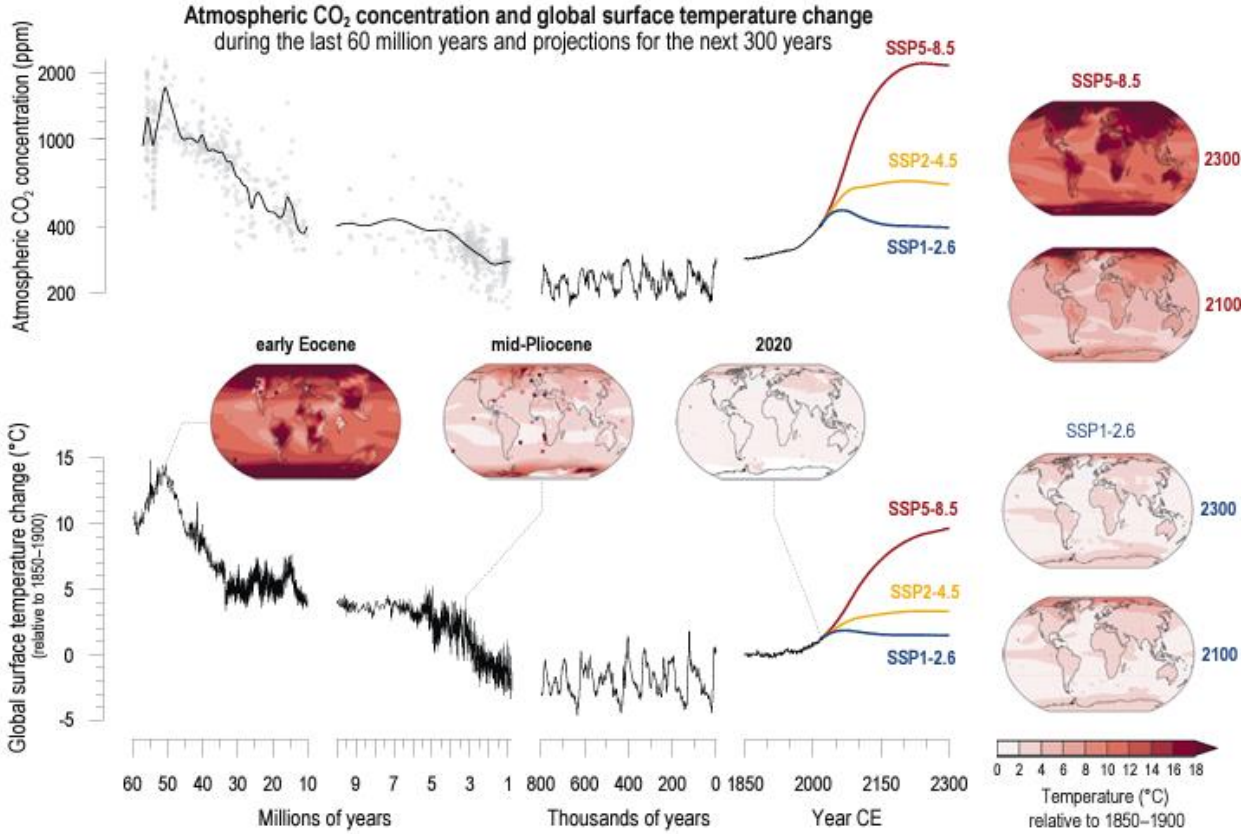
https://link.springer.com/article/10.1007/s10584-013-0904-3 (SSPs)

CO_2 concentration in the last 800,000 years

CARBON DIOXIDE OVER 800,000 YEARS



NOAA Climate.gov
Data: NCEI



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Shared Socioeconomic Pathways (SSPs)

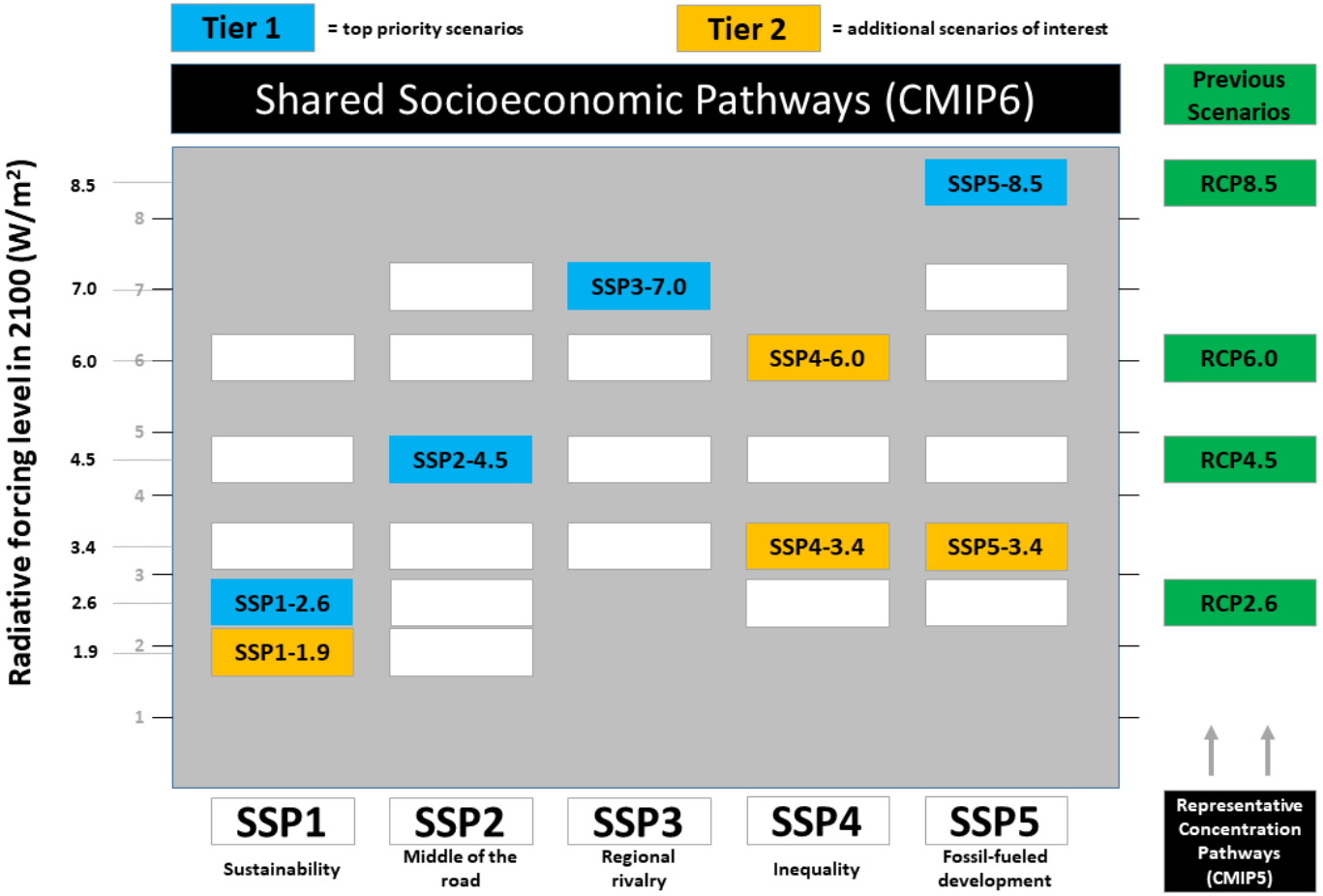
- RCPs do not tell us anything regarding socioeconomic development. RCPs are just climatic pathways
- Shared Socio-economic pathways (SSPs) are scenarios of projected socioeconomic global changes (land cover, population, GDP, urbanization, etc.)
- Integrating RCPs with SSPs allows us to look at future pathways by integrating both socioeconomic and climate pathways

1. **SSP1** (Sustainability)
2. **SSP2** (Middle of the road)
3. **SSP3** (Regional rivalry)
4. **SSP4** (Inequality)
5. **SSP5** (Fossil fuel development)

Questions:

How can we combine SSP5 with RCP2.6?

More about SSPs



SSP and RCP combination. Figure reproduced from O'Neil et al (2016)

RCP (AR5)	SSP (AR6)
	SSP1-1.9 (≈ 1.4°C)
RCP2.6 (≈ 1.6°C)	SSP1-2.6 (≈ 1.8°C)
RCP4.5 (≈ 2.4°C)	SSP2-4.5 (≈ 2.7°C)
RCP6.0 (≈ 2.8°C)	SSP3-7.0 (≈ 3.6°C)
RCP8.5 (≈ 4.3°C)	SSP5-8.5 (≈ 4.4°C)

Global warming levels (end of the century compared to 1800-1850) in different RCPs and SSPs/RCPs combinations

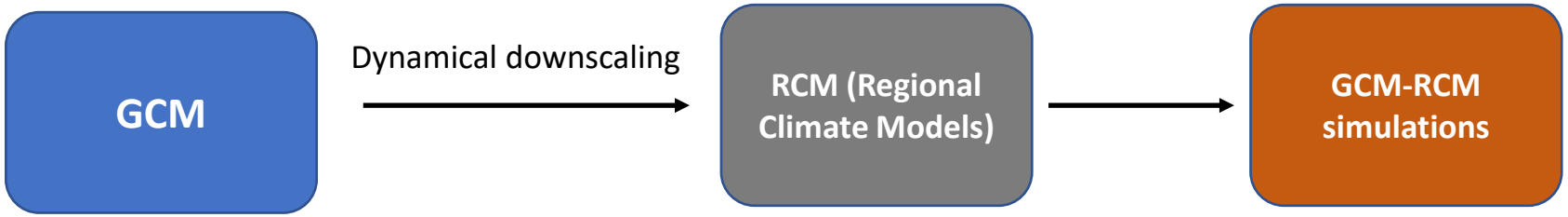
Downscaling

- Most GCMs have a spatial resolution of 100 km or more
- They do not capture well regional dynamics and are often unsuitable for country-level assessments

- GCMs can be downscaled using two main different techniques:
  - Statistical downscaling: creating the linkages between large-scale atmospheric variables and observed data. These statistical relationships are then applied to future projections to tailor climate data to a specific point of interest (stational level information but computationally efficient)
  - Dynamical downscaling: a regional model (RCM) uses boundary conditions driven by the GCM. Computationally intensive (gridded product but need supercomputers)

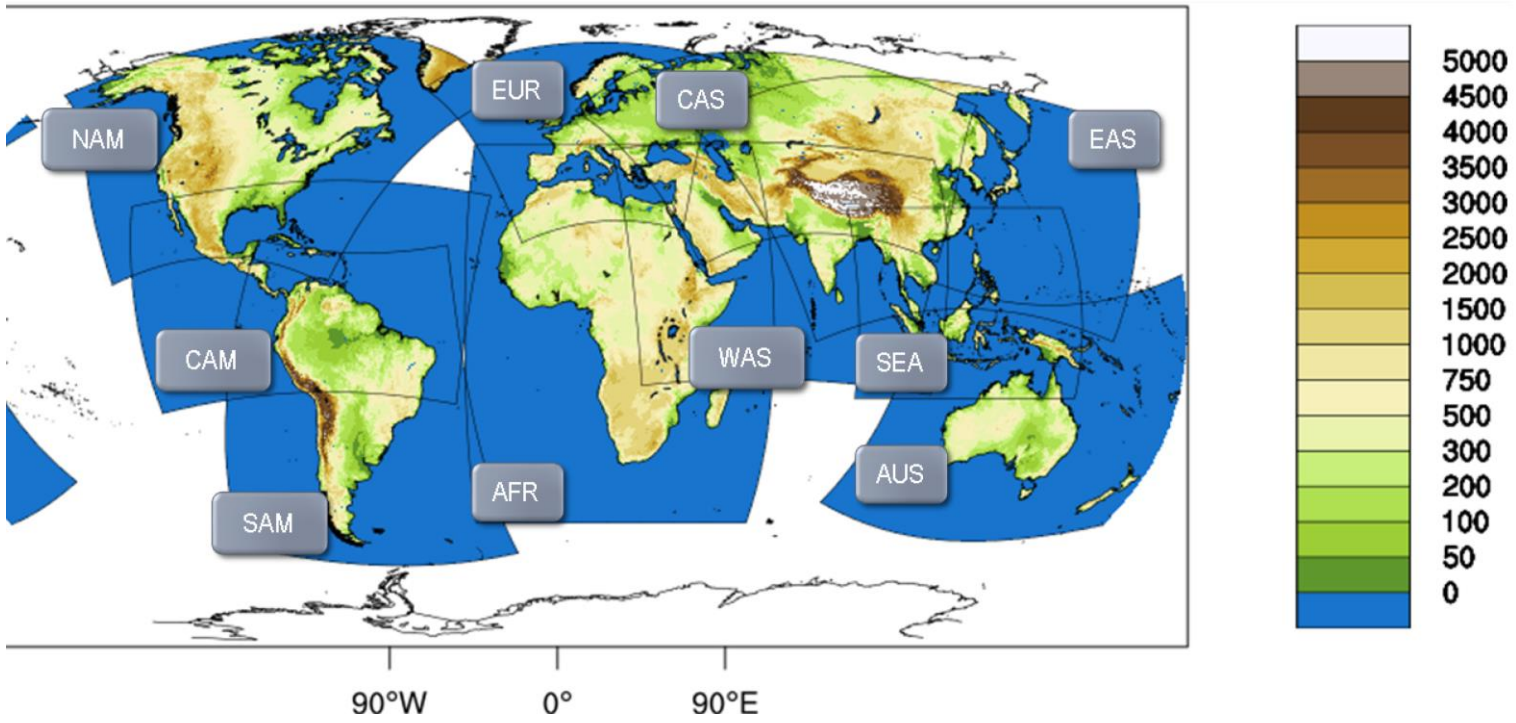
CORDEX

- CMIP models cover the entire world (GCM) at different spatial resolutions (CMIP5 models were at 1-2°, which corresponds to 100-200Km)
- Not ideal for representing regional climate and supporting adaptation assessment and planning
- The Coordinated Regional Climate Downscaling Experiment (**CORDEX**) provides projections with much greater detail and more accurate representation of localized extreme events (50 km resolution)



CORDEX

- Since GCM are dynamically downscaled through RCM, these are region specific
- Several RCMs exist. In CORDEX, no specific requirements for the number of GCM-RCM combinations available in each domain



CORDEX-CORE

- CORDEX-CORE harmonizes the selection of GCM and RCM across different domains.
- 6 simulations per domain available (3 GCM downscaled with 2 RCM).
- The selection of GCM was based on climate sensitivity (from low to high).
- 25 km^2 spatial resolution.
- CORDEX and CORDEX-CORE are currently only available for CMIP5 models.
- CORDEX CMIP6 will already provide data at 25 Km^2 resolution and CORDEX-CORE will cease to exist

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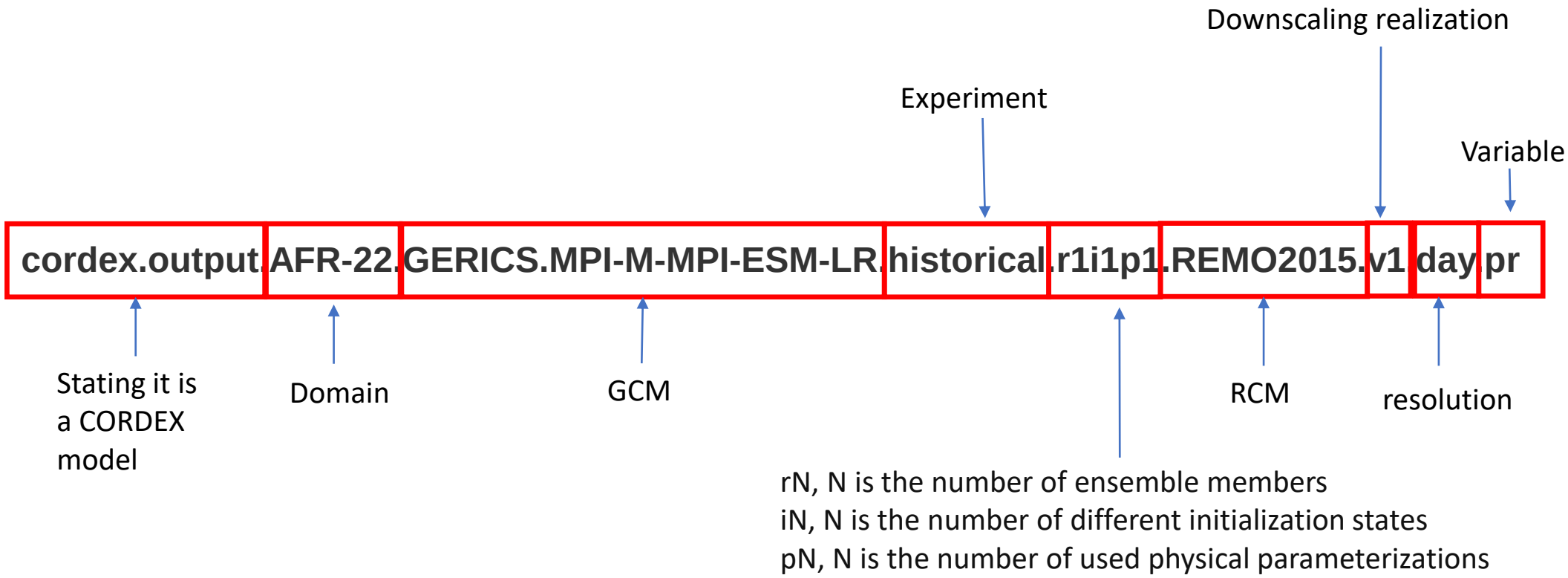
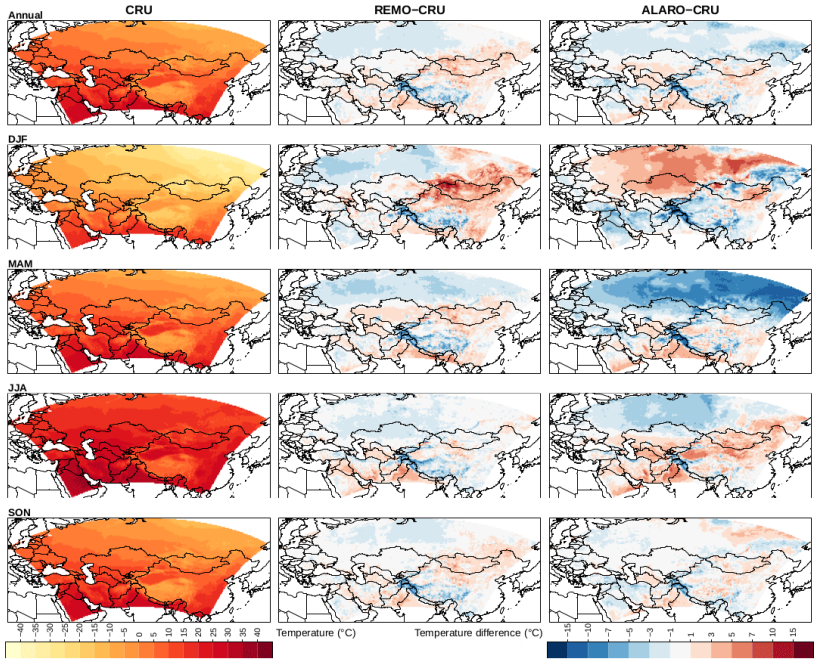
Example of CORDEX model name



Bias correction

- Usually climate models are not perfect representation of the reality
- Often, needs bias adjustment. Bias correction is performed by learning the difference between the historical simulation run of the models and observational dataset. The “difference” is applied to the projections to correct the model.



Left column: mean air temperature (°C) at 2 m height over the CAS-CORDEX domain based on the observational CRU dataset for the 1980–2017 period on an annual level and for winter (DJF), spring (MAM), summer (JJA), and autumn (SON). Middle columns: difference in mean temperature between models and CRU. Top et al., 2021

How many models?

- Debated topic, many different ways for selecting climate models.
- When using CORDEX-CORE, we are limited to the number of models available (6 simulations but three GCMs)
- If we are conducting an impact assessment on a large scale (continental level), we can follow the envelope approach.

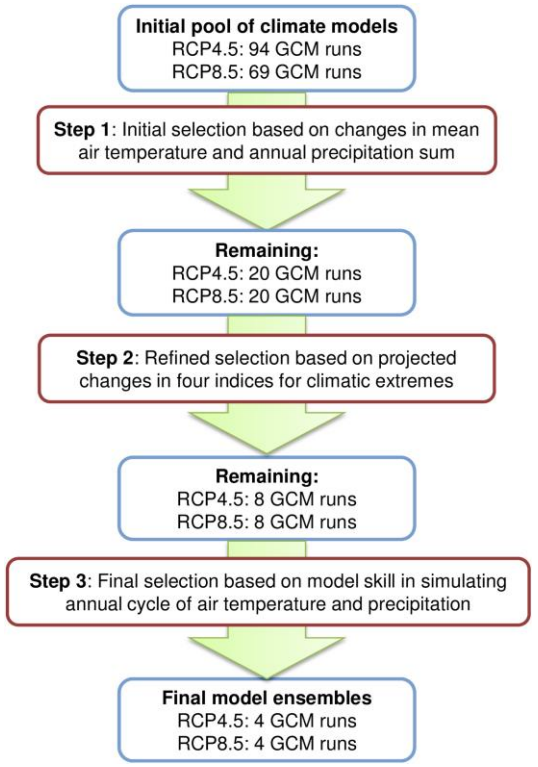
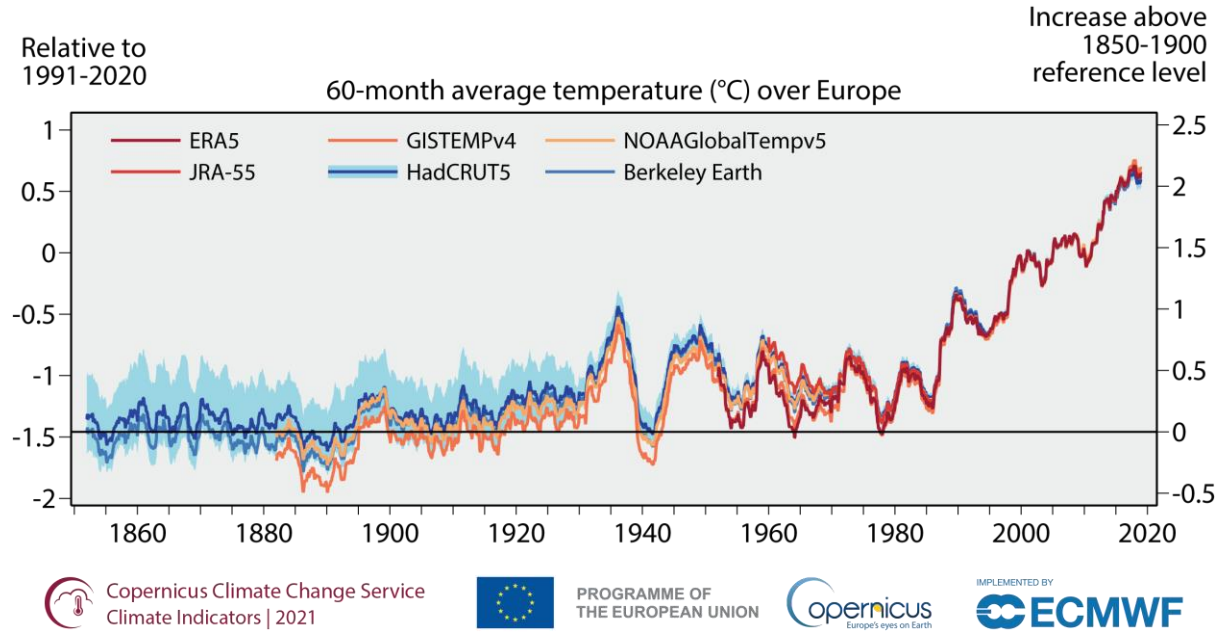


Diagram of the advanced envelope-based approach. Lutz et al., 2016

Thinking about 1.5 degrees of global warming

- Calculated globally (spatial average)
- Warming is compared to the 1850-1900 time period, with a 30 years-time window
- Global temperature is rising by 0.2 °C (0.1 SD) per decade
- 1.5 °C will be reached between 2035 and 2040
- Europe is warming at a higher pace compared to the global average (already reached 2 °C of warming)



Interactive tool

1.5 degrees of global warming

- 1.5 °C of global warming does not mean that you can simply consider the temperature of today and add 1.5 °C

Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
22	21	19	22	23	24	25	23	25	27

= 23.1

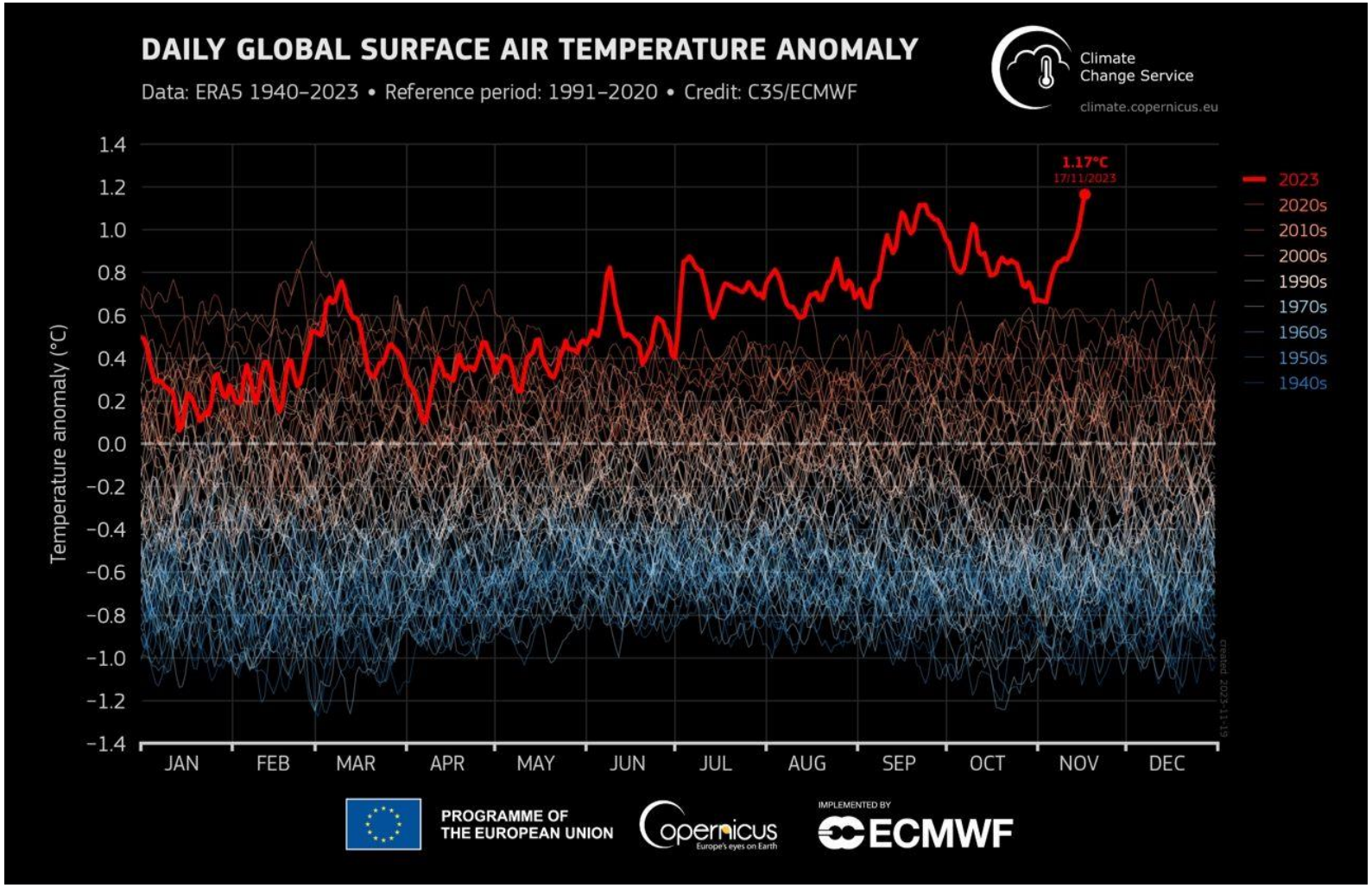
1.5 °C

Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
40	25	35	21	20	19	20	23	24	19

= 24.6

1.5 degrees of global warming

Why is 2023 so warm?



Take-away home messages

- Difference between RCP and SSP
- Differences between downscaling and bias correction
- Considerations regarding climate model choices

Thank you!

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