Food and Agriculture Organization of the United Nations

Module 1
Introduction to Physical Sciences

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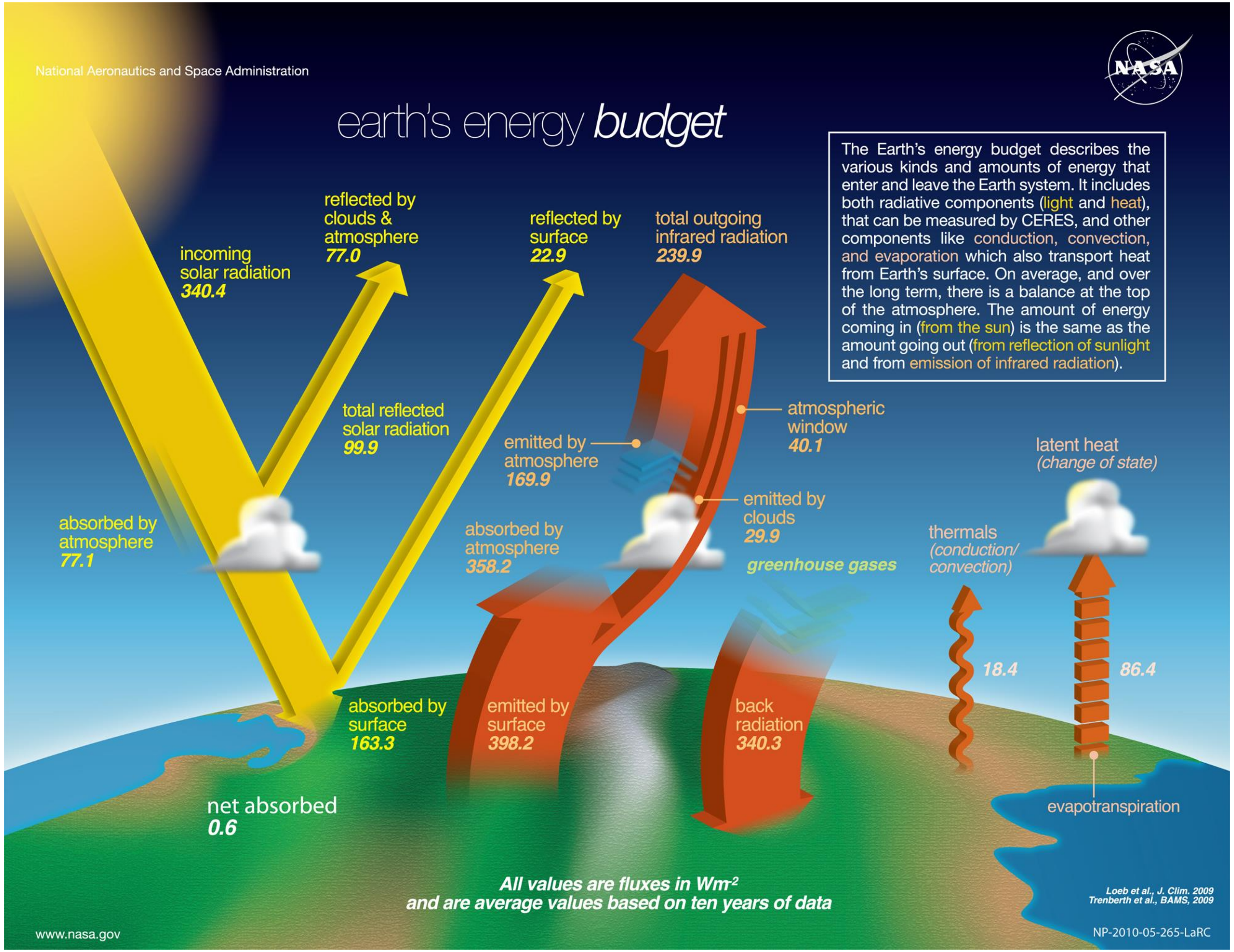
- Introduction to physical science
  a) Earth’s energy balance
  b) Astronomical, atmospheric, and geographical factors
  c) Moldova’s climate

- Introduction to climate models
  a) Earth System Models (ESMs) and General Circulation Models (GCMs). Why using more than one model?
  b) CMIP and CORDEX
  c) Representative Concentration Pathways (RCPs) and Shared Socioeconomic Pathways (SSPs)
  d) Global warming of 1.5 °C

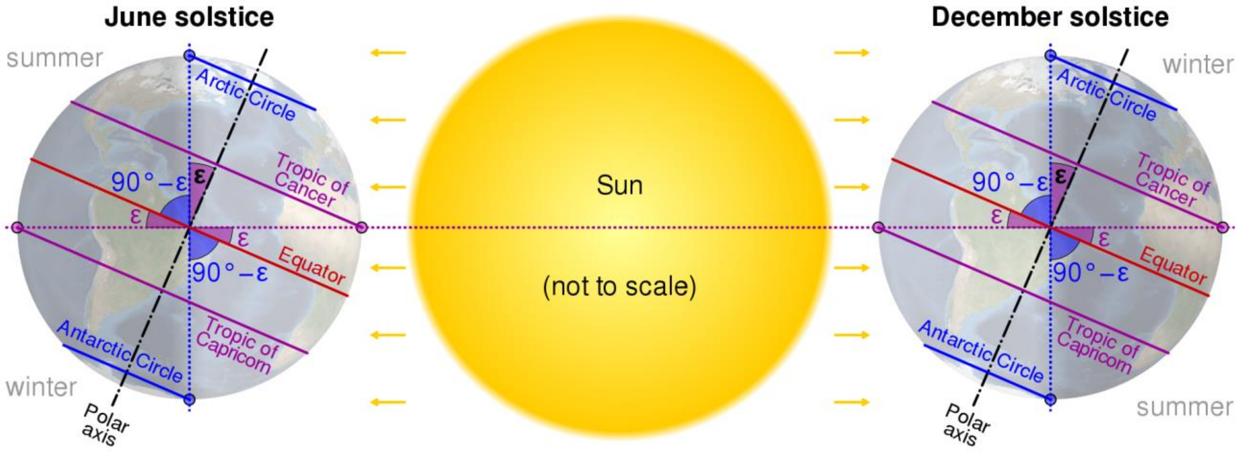
Earth's energy balance



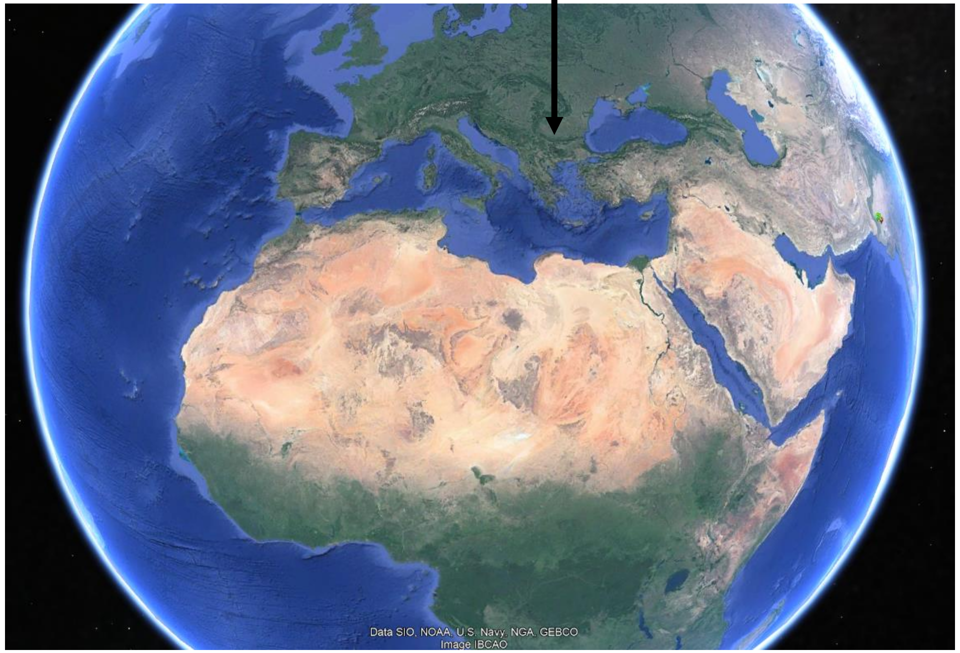
Astronomical, atmospheric, & geographical factors

Astronomical (amount of heat): **axial tilt (23.5º)**, orbital eccentricity and precession

- Distance from the Equator (latitude north and south)



Moldova (45-48ºN)



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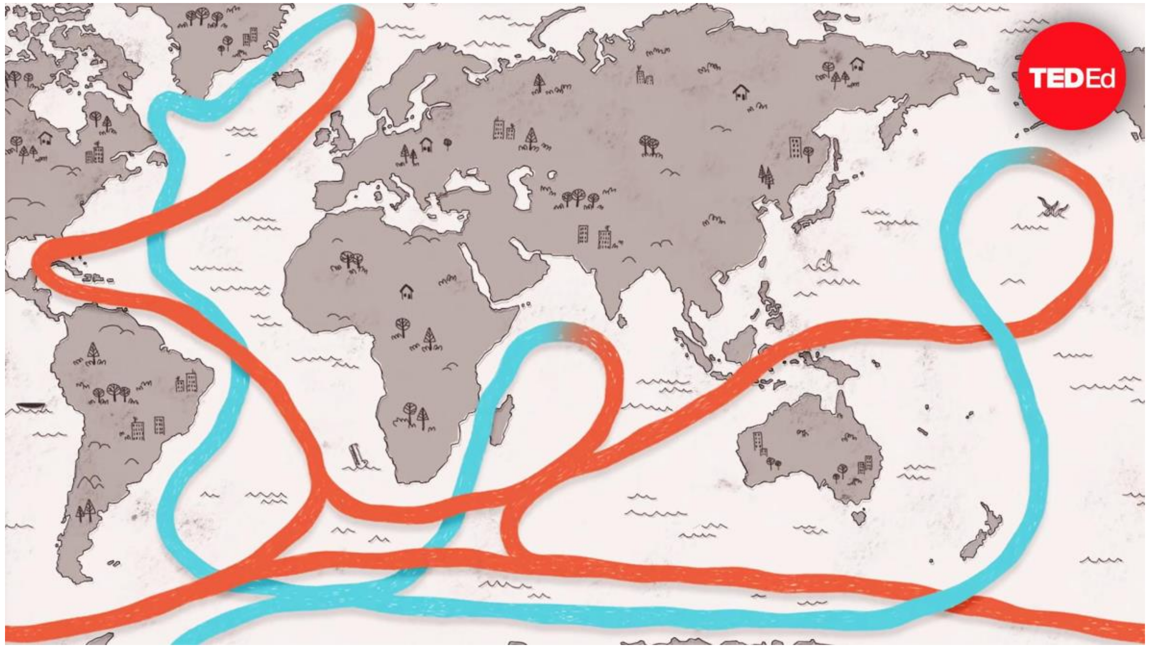
Astronomical, atmospheric, & geographical factors

<u>Ocean-atmospheric</u> (distribution of heat)

- Ocean currents (e.g., Gulf Stream)
- Large scale ocean-atmospheric ENSO and IOD
- Direction of prevailing winds



- Moldova's climate is governed by a complex interaction of meteorological and thermohaline factors over the Black Sea.

- The western and southern areas of the Black Sea are influenced by warm and humid Atlantic air, which enters the Black Sea through the Mediterranean Sea.

- In winter, severe cold and dry northeastern winds prevail over the northern parts.

Astronomical, atmospheric, & geographical factors

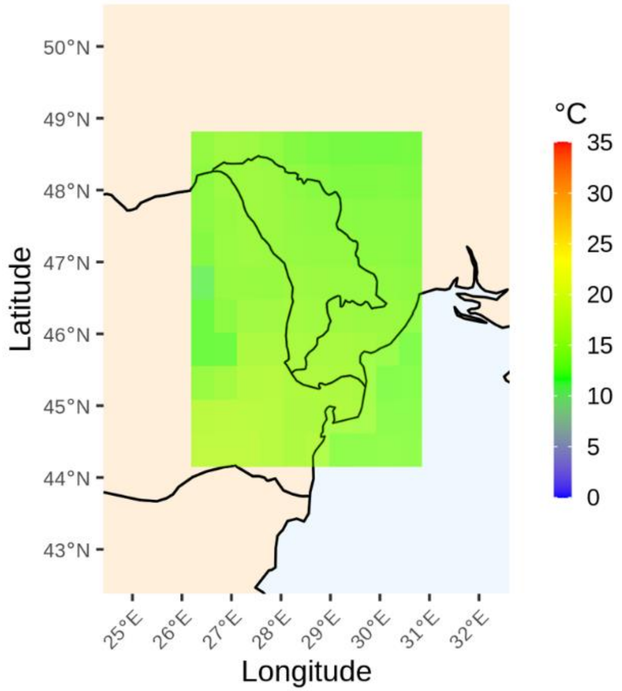
<u>Geographical</u> (physical barriers/characteristics for heat distribution)

- Distance from the sea.
- Mountains, land cover etc.

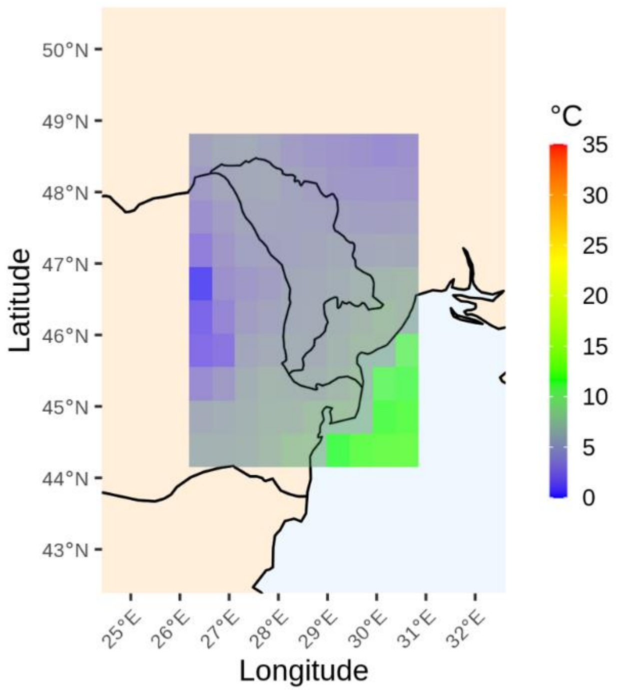
- Although not in direct contact with the Black Sea, Moldova's climate (particularly the south) is affected by the thermic-regulatory effect of the sea.

Moldova's climate: temperature

- Moldova has a temperate continental (Dfb) climate characterized by warm summers and average temperatures around 20ºC.
- Winters, instead, are mild to cold, with average temperatures dropping to -5ºC in January.
- On average, annual maximum temperatures are of 15-20ºC, while minimum temperatures are in the range of 5-10ºC.



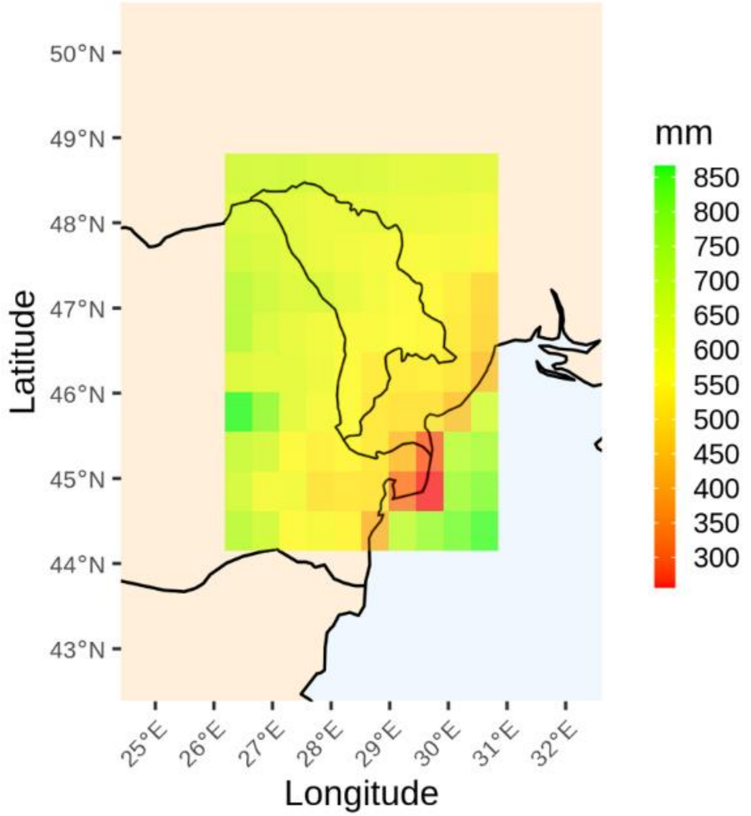
Mean Tmax
(1981-2005)



Mean Tmin
(1981-2005)

Moldova's climate: precipitation

- Total annual precipitation varies between 600-700mm in the northern areas to 500mm in the southern areas.
- Inter-annual precipitation variability is frequently characterized by the occurrence of long dry spells during summer, intercalated by heavy rainfall events in June and July.
- Most of the precipitation (>60%) is observed between April and September, while winter months (January-March) record low precipitation amounts (<150mm/season)



Mean annual precipitation
(1981-2005)

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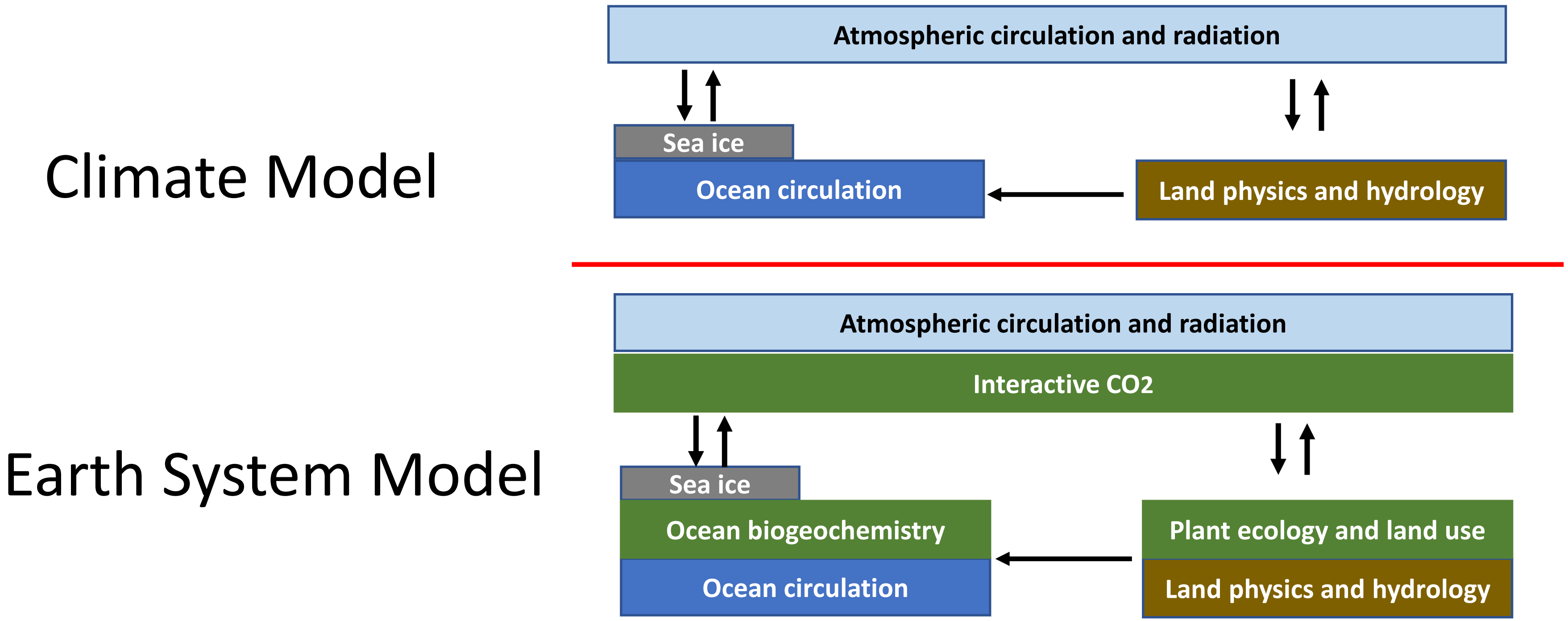
Module 1
Introduction to GCM and ESM

Riccardo Soldan

December 12, 2022

General Circulation Models and Earth System Models

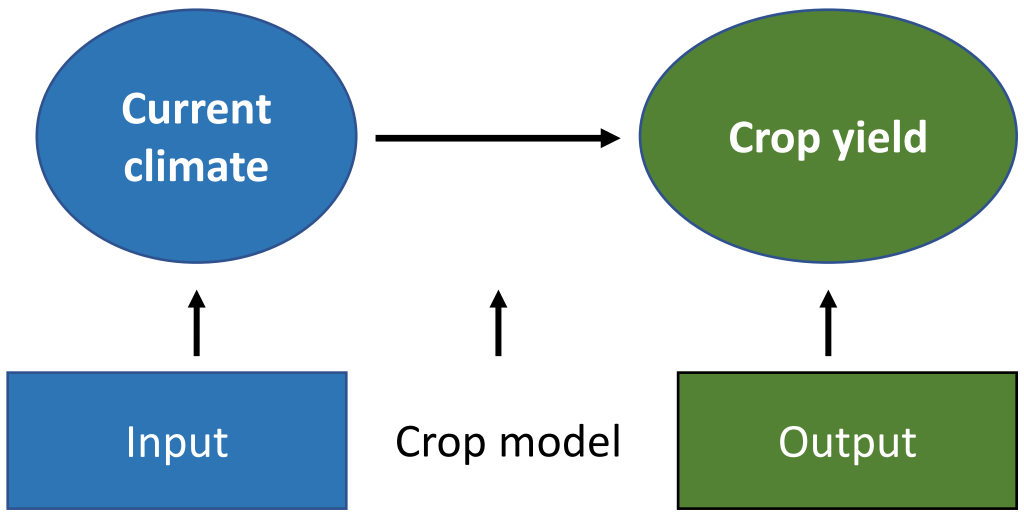
- GCM and ESM are the most advanced tools used to simulate the effect of increasing greenhouse gas concentrations on the global climate system
- ESMs differ from GCMs because GCMs do not account for carbon movement through the earth system



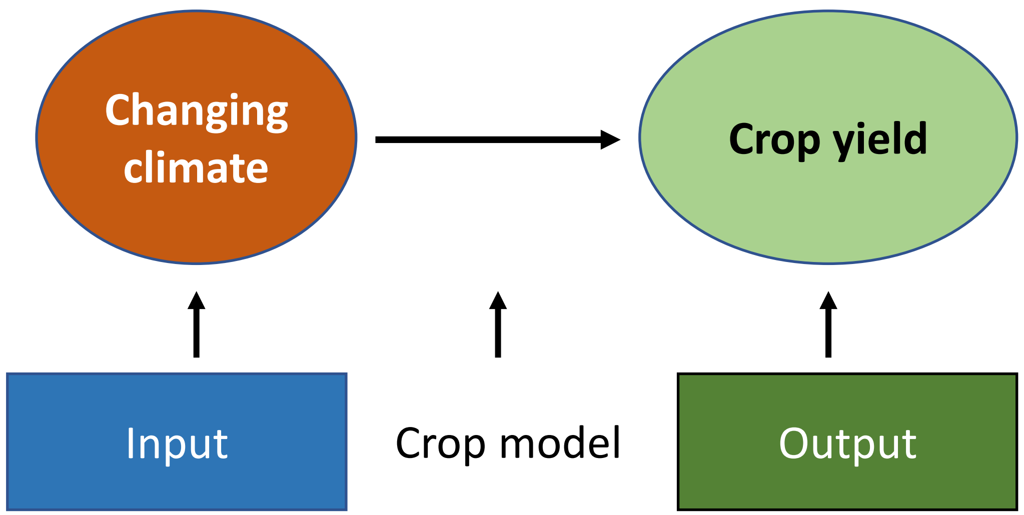
Why do we need climate models?

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

Current state



Changing climate



Why do we need more than 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?

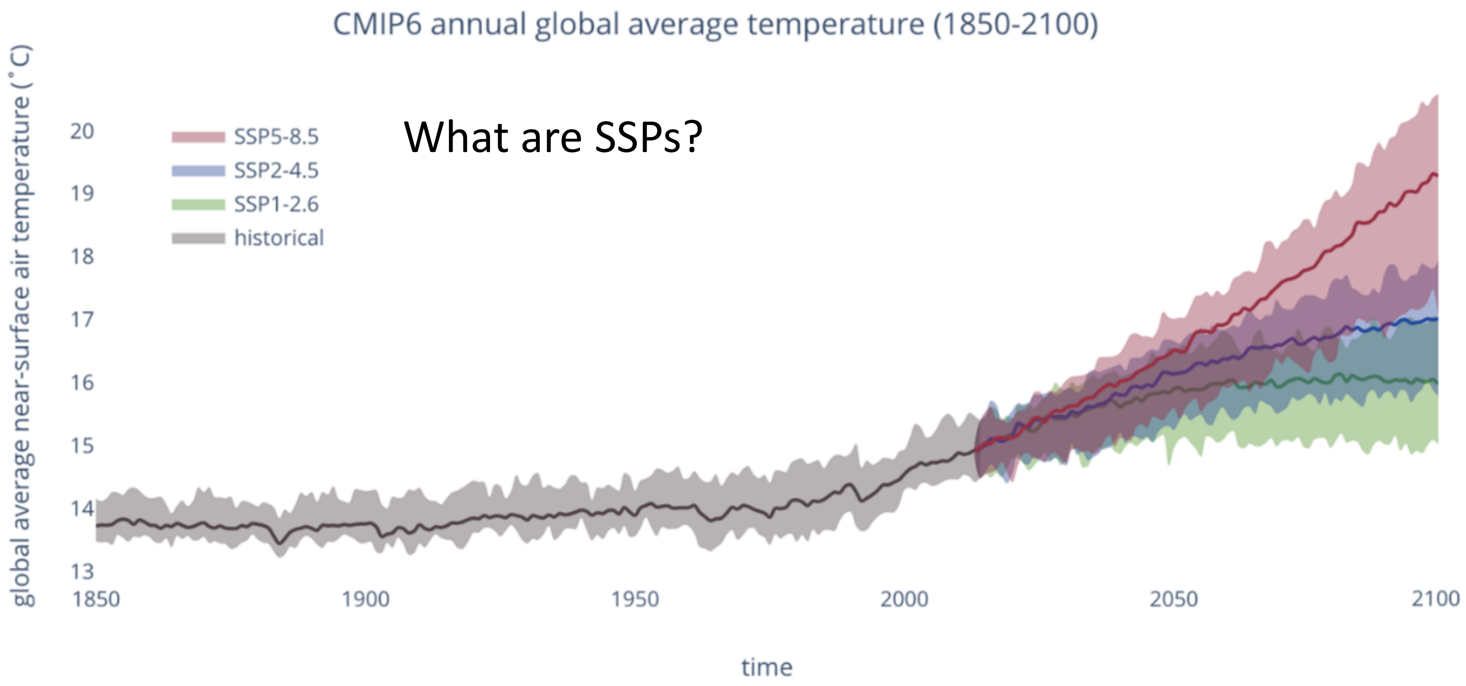
How many GCMs do we need?

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.
- CMIP defines common experiment protocols, forcings, and outputs.
- Started in 1995, CMIP is now in its 6^{th} phase. CMIP6 is used for the IPCC report (AR6).

CMIP in numbers

- CMIP5 (40 models, 1.5 PB). 1 PB is 1000000 GB
- CMIP6 100+ models from 50 modelling 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.

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)

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Shared Socioeconomic Pathways (SSPs)

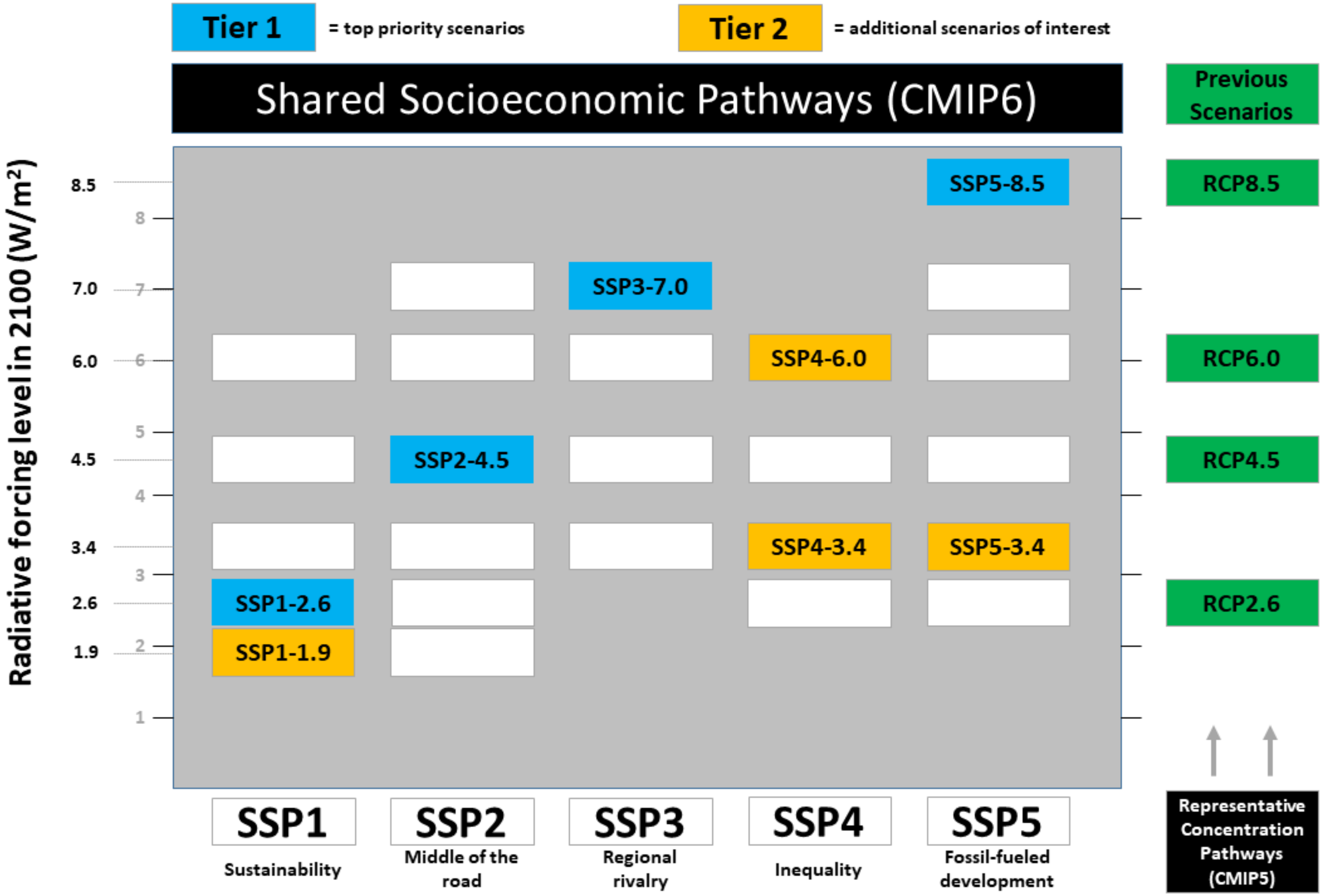
- RCPs do not tell us anything regarding socioeconomic development. They are climatic pathways
- Shared Socio-economic pathways (SSPs) are scenarios of projected socioeconomic global changes (land cover, population, GDP, urbanization, etc.)
- Integrating RCPs with SSPs allows us to look at future pathways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

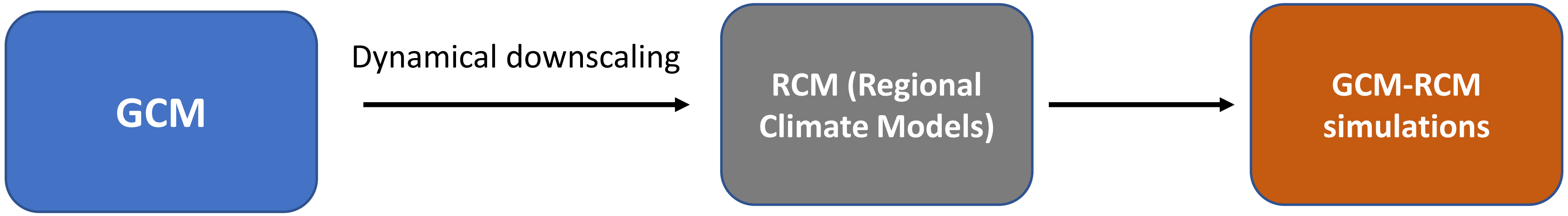
More about SSPs



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

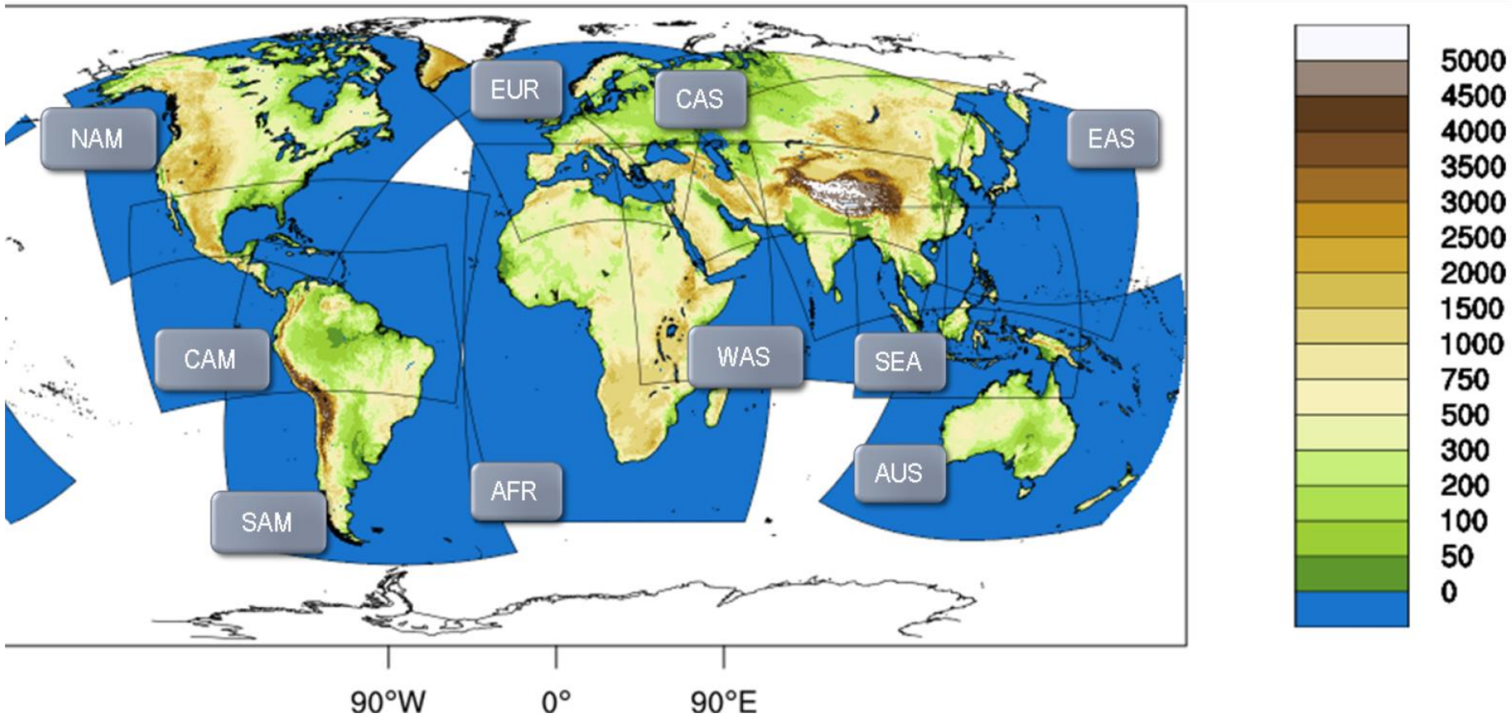
CORDEX

- CMIP models cover the entire world (GCM) at different spatial resolutions (CMIP5 models were at 1-2°, which corresponds to 100-200Km)
- <u>Not ideal for representing regional climate and supporting adaptation assessment and planning</u>
- 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



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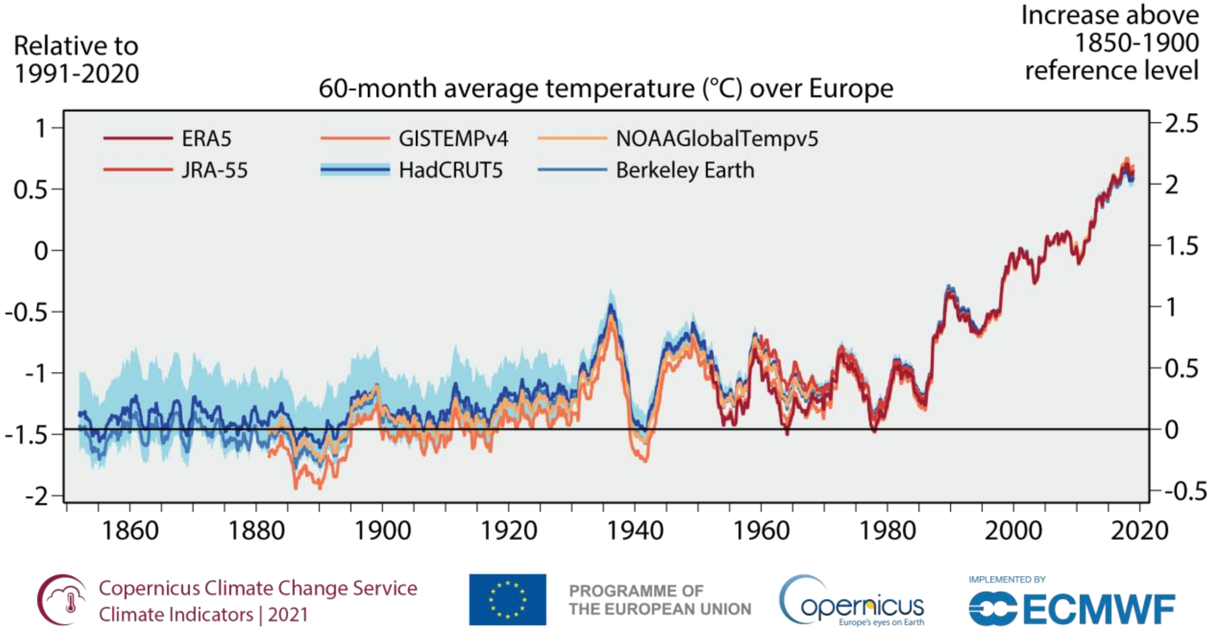
CORDEX-CORE

- 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 spatial resolution.
- CORDEX and CORDEX-CORE are currently only available for CMIP5 models.
- CORDEX CMIP6 will already provide data at 0.25 Km resolution and CORDEX-CORE will cease to exist

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

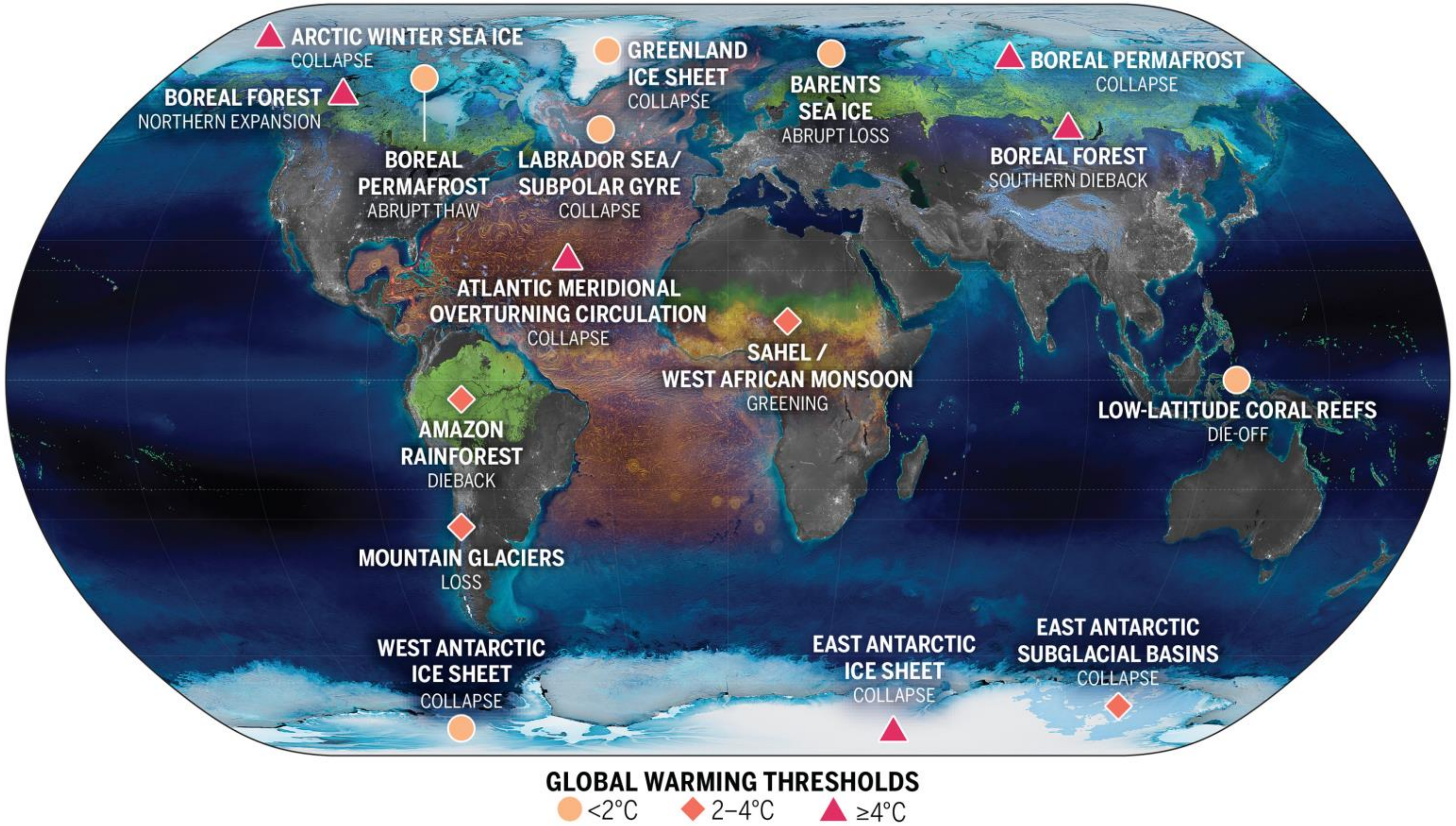
= 23.1

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

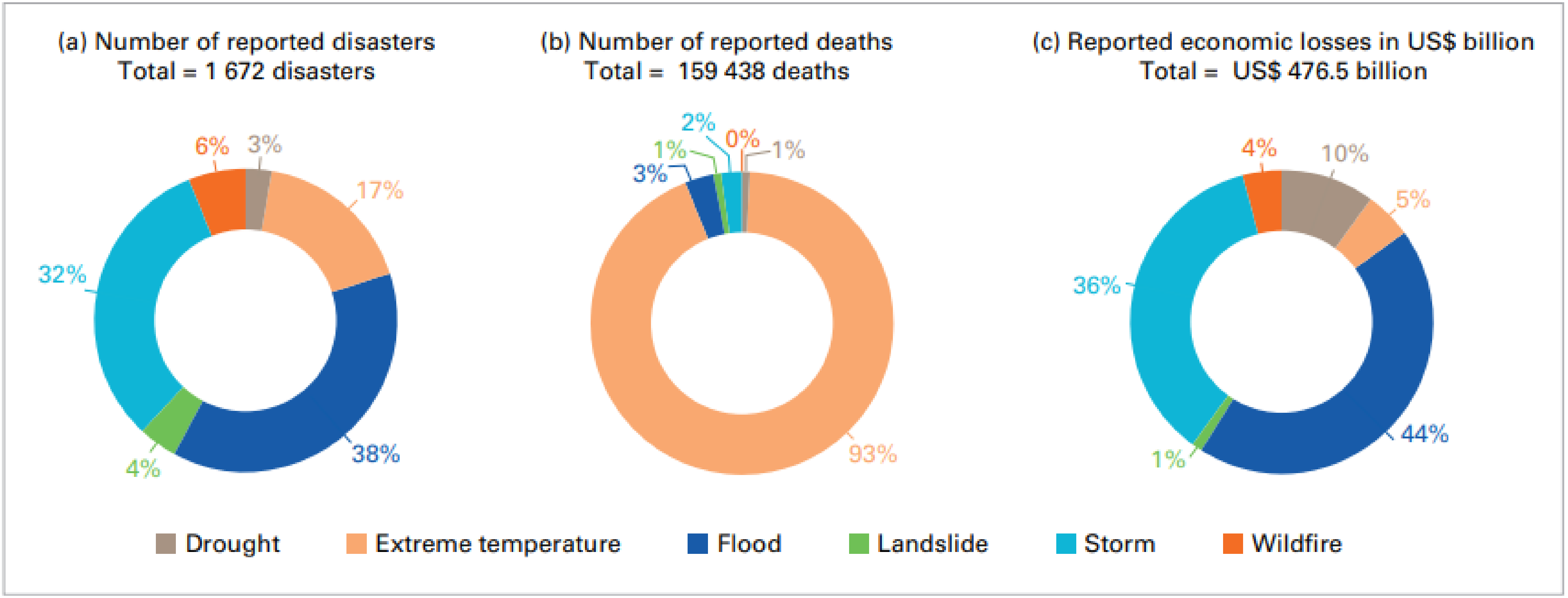
= 24.6

2ºC global warming-tipping points



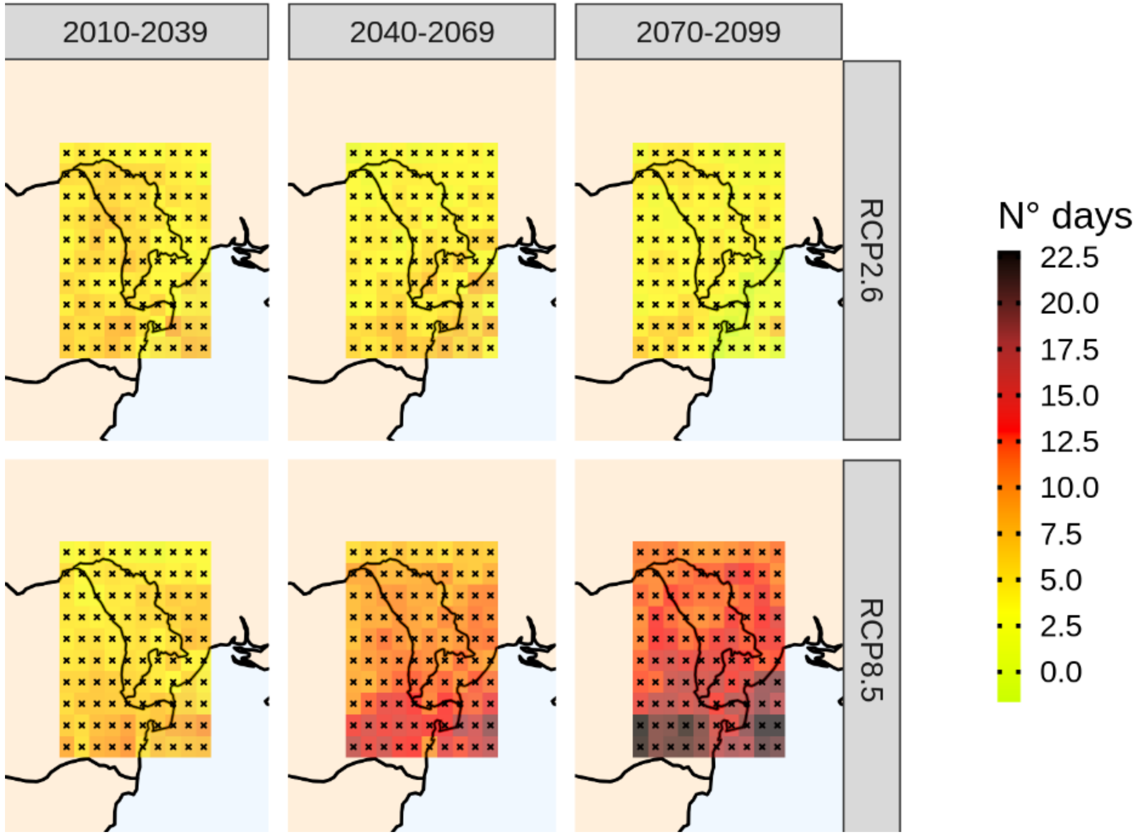
[Reproduced from Mckay et. al 2022]

Global warming: impacts in Europe



Overview of weather-, water- and climate-related disasters, deaths and US$ economic losses reported in Europe (1970–2019). Source: Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes (1970–2019) (WMO-No. 1267)

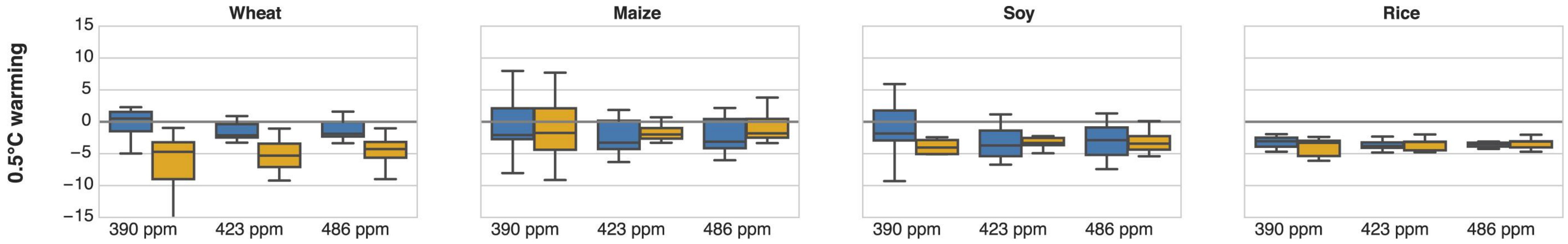
Every fraction of a degree matters



Climate change signal in the maximum duration of dry spells (maximum number of consecutive days with pr ≤1mm) over the 21st century. The black cross indicates whether at least 60% of the models agree on the sign of the climate change signal (positive or negative). A multi-model ensemble-mean of 3 GCMs downscaled with RCM REMO2005 is used. Figure produced with the CAVA Analytics

Difference between 1.5 and 2 °C of global warming-**agricultural impacts**

- [10% further reduction in maize crop yield]
- [More frequent unlikely low crop yields]
- [Reduced uncertainty regarding negative effects]



Projected changes in global (blue) and tropical (yellow) crop productivity relative to the 2006–2015 period for ~0.5 °C GMT increases at different levels of CO_2 concentrations. Adapted from Schleussner at el, 2018.

Questions:

What about the positive impacts of increasing CO_2 ?

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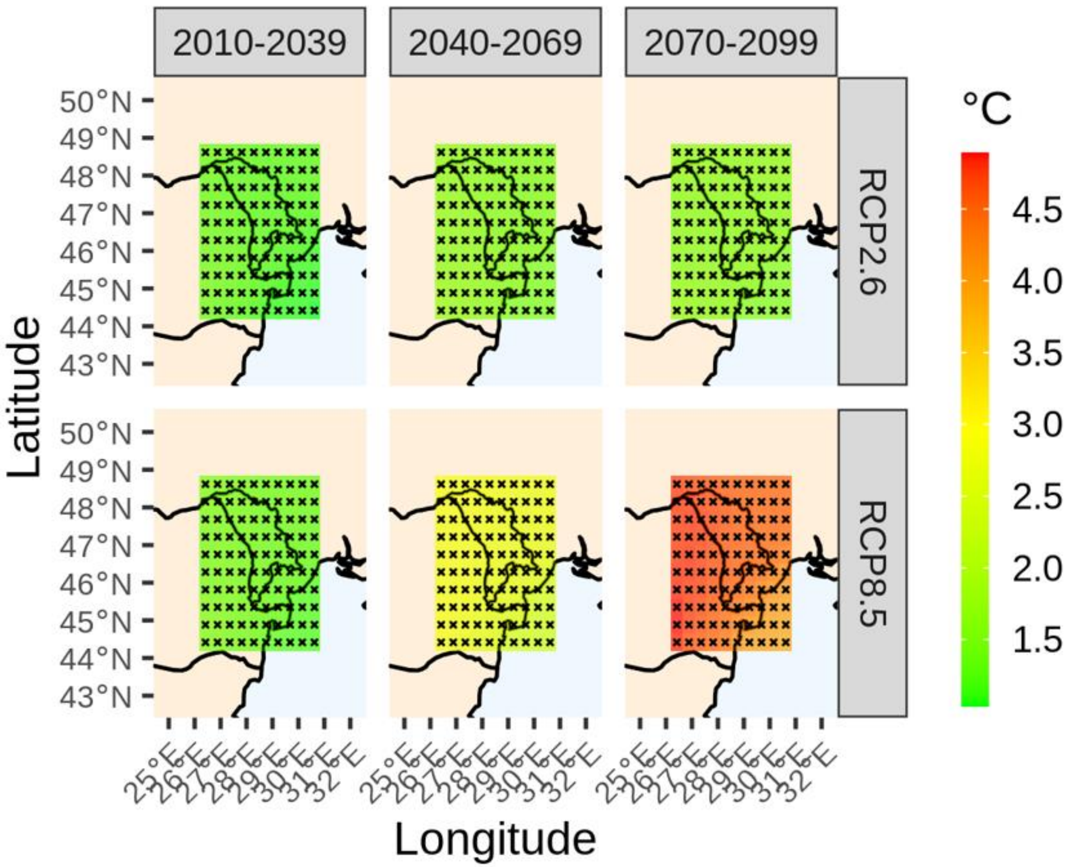
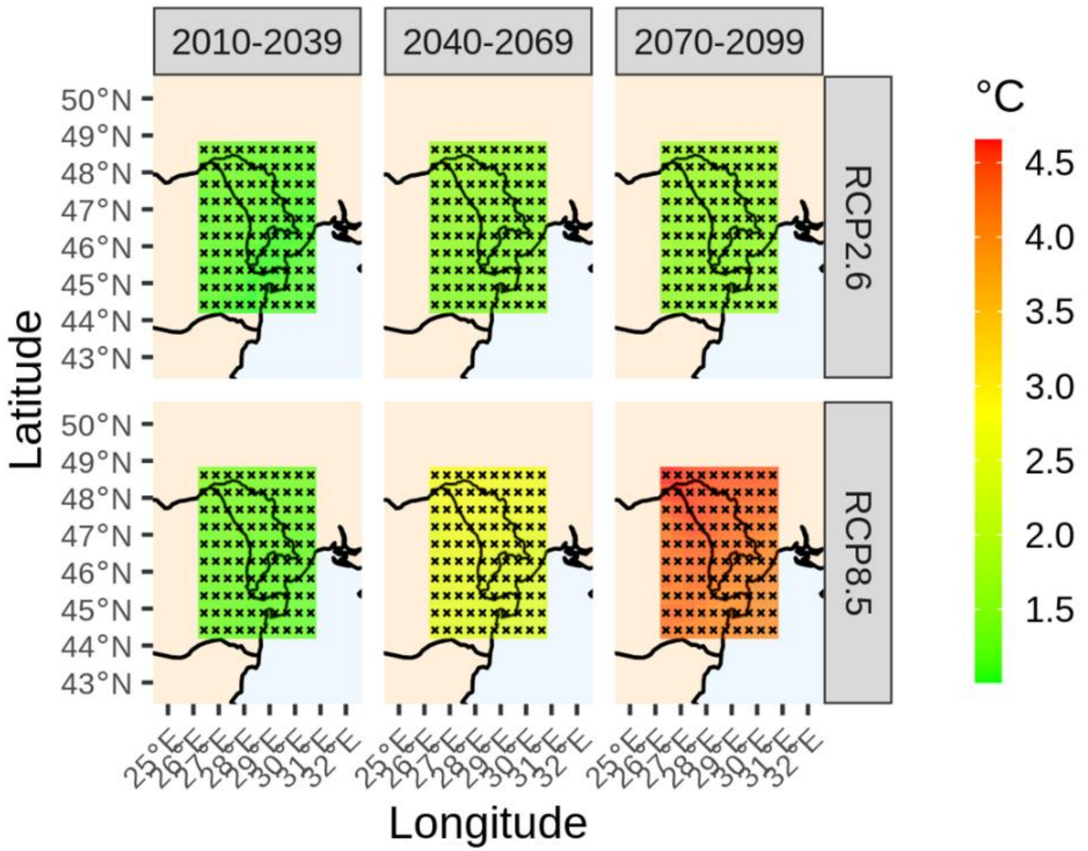
Future climate projections: temperature (changes)

Average Tmax

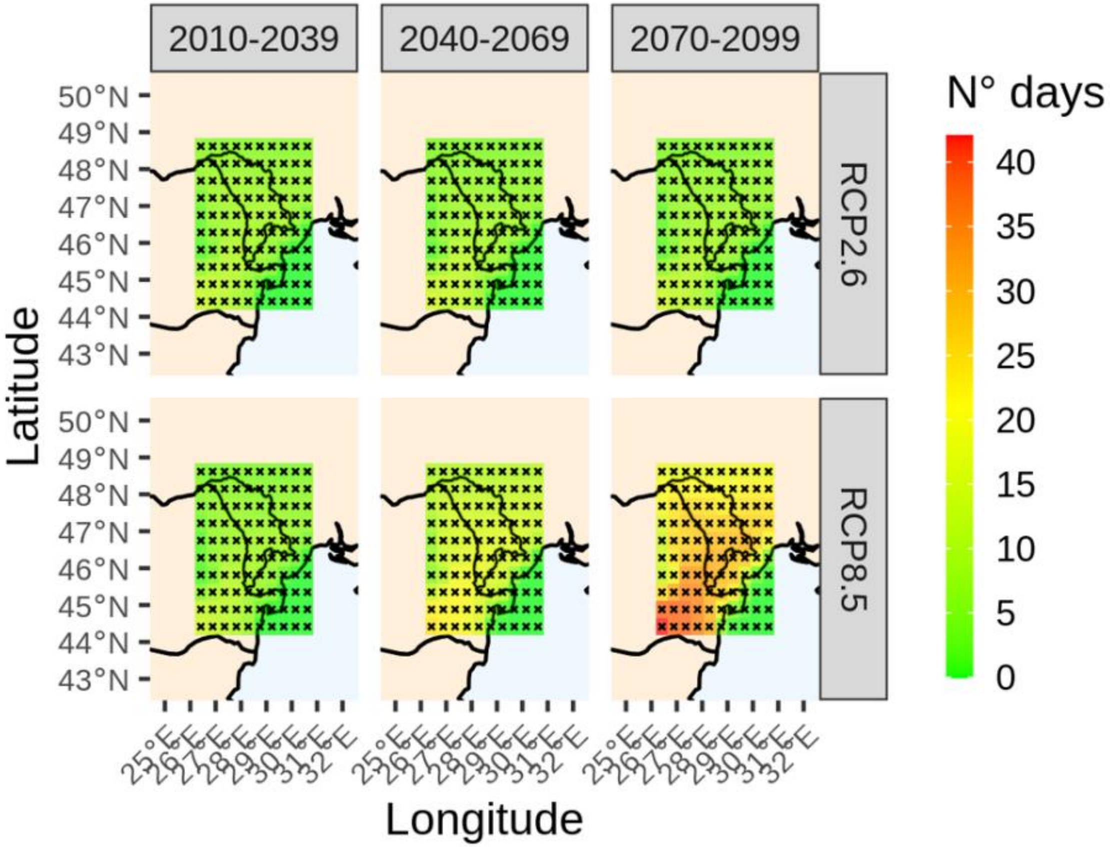


Average Tmin



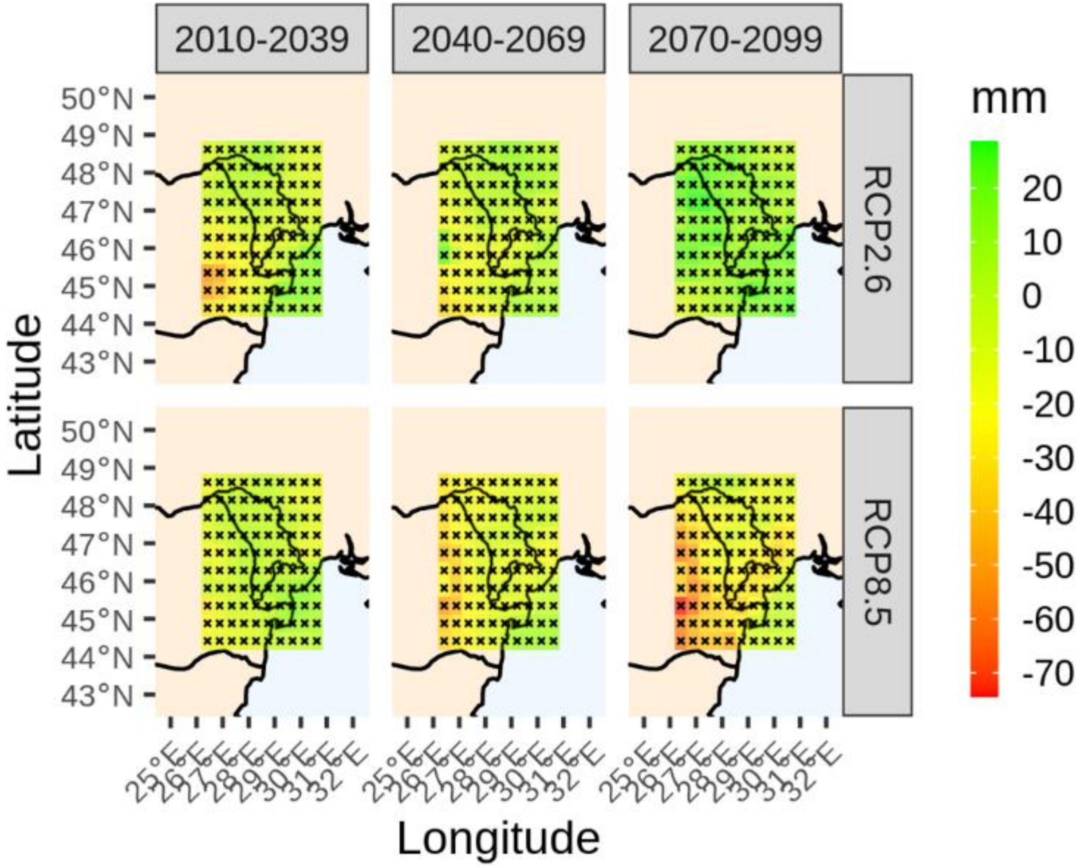
Climate change signal in **average Tmax (left)** and **average Tmin (right)** over the 21st century (reference period 1981-2005). The black dot indicates whether at least 60% of the models agree in the sign of the climate change signal (positive or negative). A multi-model ensemble-mean of 3 GCMs is used. Figure produced with CAVA Analytics, developed by FAO Risk team (OCB division)

Future climate projections: temperature (extremes)



Climate change signal in the **average number of days per year with maximum temperatures above 30ºC** (reference period 1981-2005). The black dot indicates whether at least 60% of the models agree in the sign of the climate change signal (positive or negative). A multi-model ensemble-mean of 3 GCMs is used. Figure produced with CAVA Analytics, developed by FAO Risk team (OCB division)

Future climate projections: precipitation (changes)



Climate change signal in changes in **total annual precipitation** (reference period 1981-2005). The black dot indicates whether at least 60% of the models agree in the sign of the climate change signal (positive or negative). A multi-model ensemble-mean of 3 GCMs is used. Figure produced with [CAVA Analytics](), developed by FAO Risk team (OCB division)

Thank you!

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