SMHI

OptimESM

Optimal high resolution **Earth System Models** for exploring future climate change

Optimal high resolution Earth System Models for exploring future climate change

Torben Koenigk and OptimESM consortium

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101081193.

Main goal of OptimESM

The **primary goal** of OptimESM is to develop the **next generation of ESMs, bringing together increased model resolution and process realism**, and to deliver **long-term climate projections** that better support policy and societal needs, providing guidance on **regional climate change at different levels of global warming**, the **risk of abrupt Earth system changes** at these warming levels and the **regional impacts** arising from such events.

The Consortium

OptimESM
Optimal high resolution **Earth System Models** for exploring future climate change

EARTH SYSTEM MODELS (ESMs)
- **EC-Earth** (SMHI, DMI, KNMI, BSC, ULUND, CNR, FMI)
- **UKESM** (METOFFICE, UNIVLEEDS, NOC, UoB, UREAD, UNEXE)
- **CNRM-ESM** (MF-CNRM, CERFACS)
- **IPSL-ESM** (CNRS)

REGIONAL CLIMATE MODEL
- **WRF** (THE CYPRUS INSTITUTE)

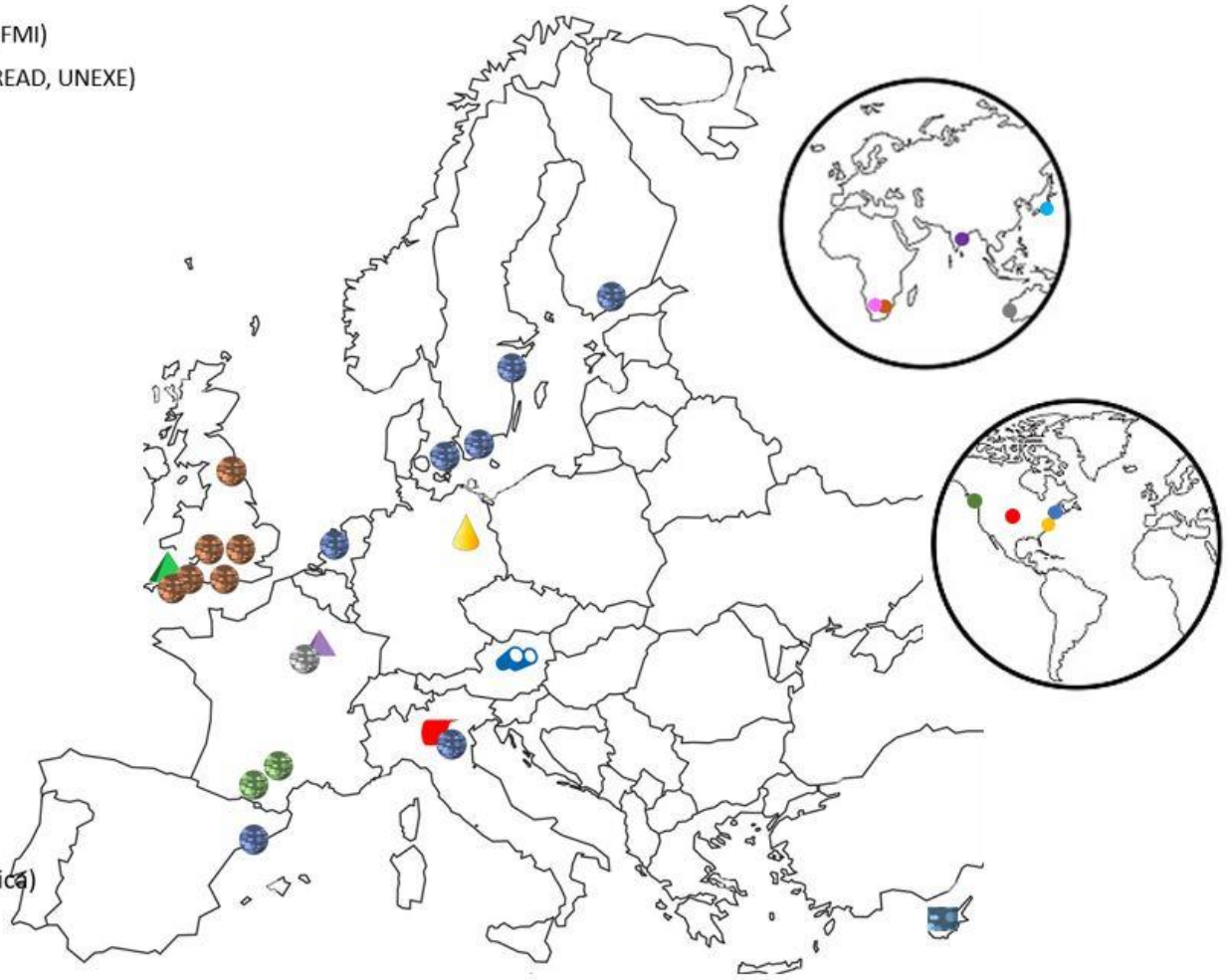
INTEGRATED ASSESSMENT MODELS (IAMs)
- **REMIND-MAgPIE** (PIK)

SIMPLE CLIMATE MODELS (SCMs)
- **ACC2** (CNRS)
- **FAIR** (METOFFICE)

OBSERVATIONS (B.GEOS)

DATA (CINECA)

INTERNATIONAL COLLABORATIONS
- NOAA-GFDL (USA)
- CCCma (Canada)
- LDEO Columbia University (USA)
- University of Pretoria (South Africa)
- University of the Witswatersrand (South Africa)
- IITM (India)
- University of Western Australia (Australia)
- JAMSTEC (Japan)



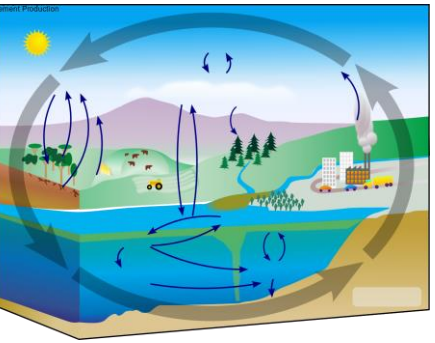
20 partners, 11 countries

9 international partners
USA, Canada, South Africa, India, Japan

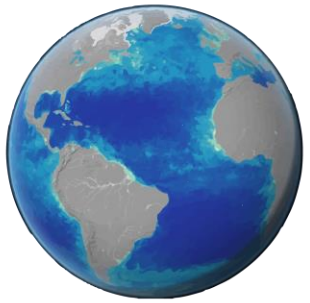
Project duration: 2023-2027

Concept – ESM development

OptimESM



OptimESM/CMIP7 models



Upgrade in process representation with repect to CMIP6
atmosphere
land
ocean
cryosphere

Post-CMIP6 models

Upgrade in process representation with repect to CMIF
atmosphere
land
ocean
cryosphere

hybrid-resolution approach

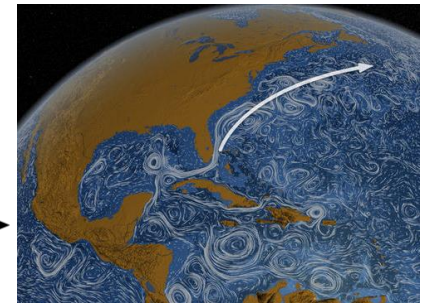
CMIP6 models

Upgrade in process representation with repect to CMIP6
atmosphere
land
ocean
cryosphere

Increased resolution
Improved process representation
Improved calibration and spin-up
Advanced numerical schemes
Machine learning-based algorithms

Model Complexity
high
low

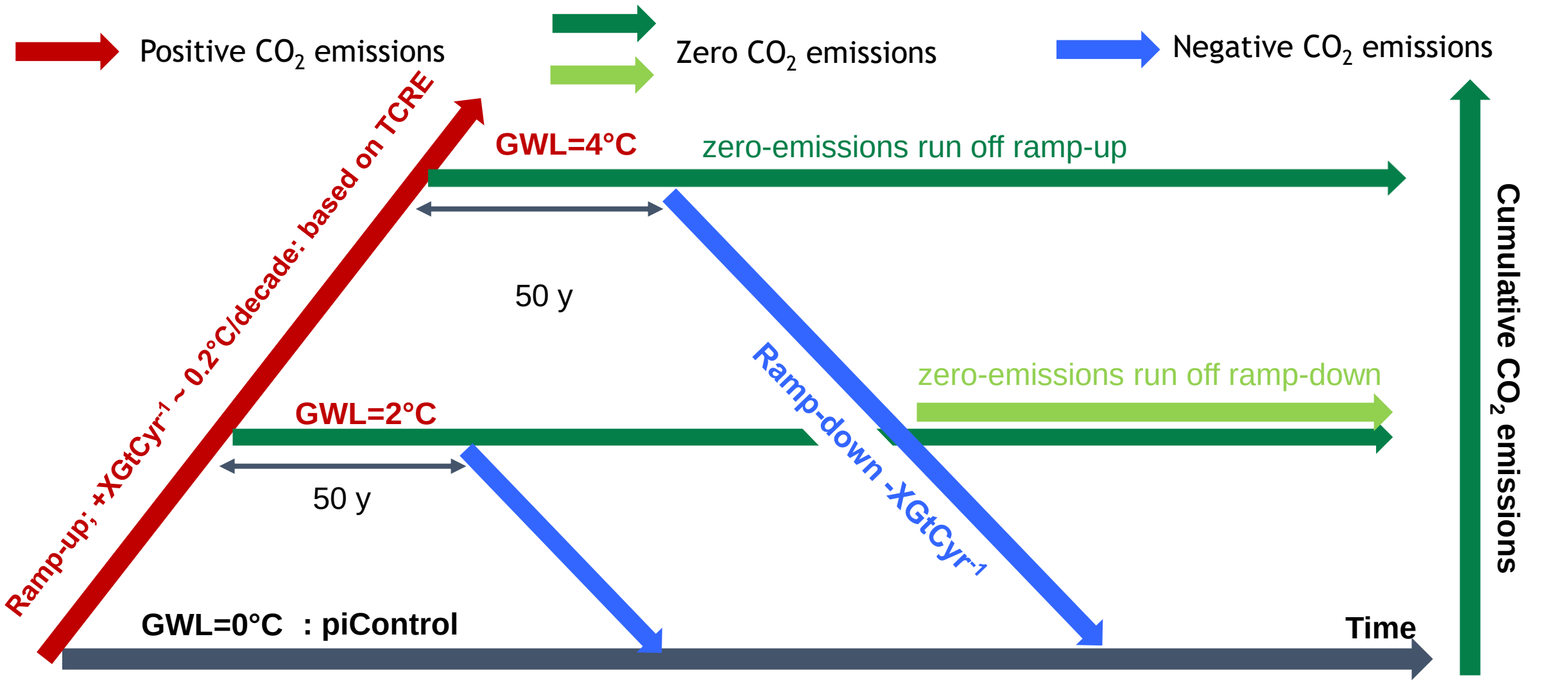
Coarse
Grid resolution
Fine



Idealised Warming and Overshoot Simulations

TIPMIP ESM Tier 1 experiment protocol:

Experiments run in CO_2-emission mode

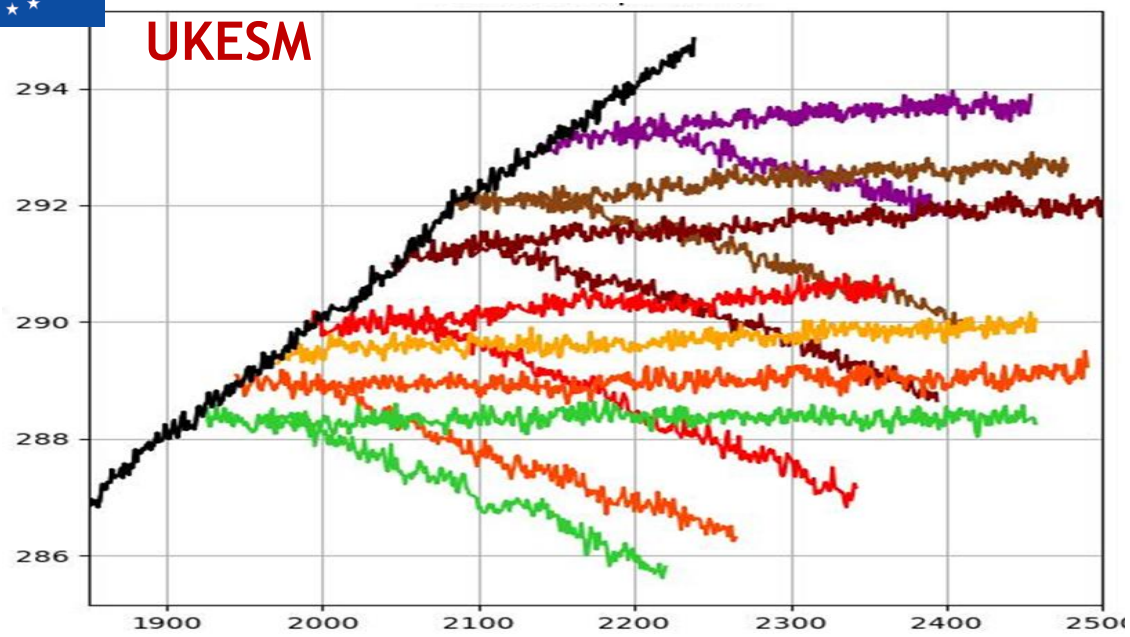


Global Mean Temperature

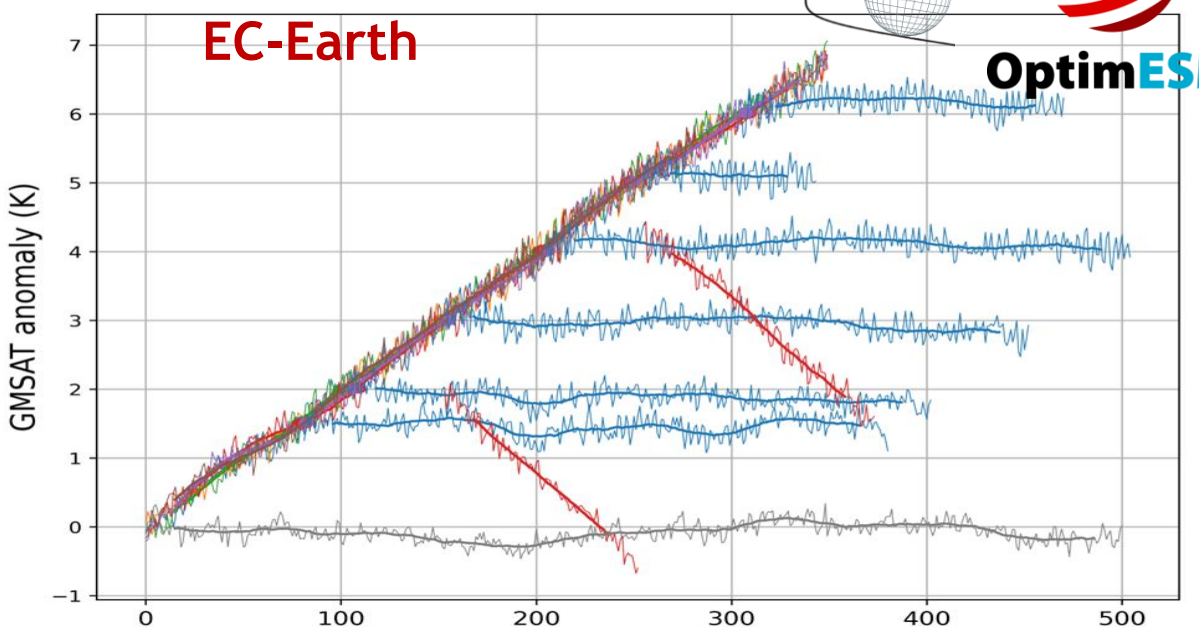
TipESM
Exploring Tipping Points and their Impacts Using Earth System Models

OptimESM

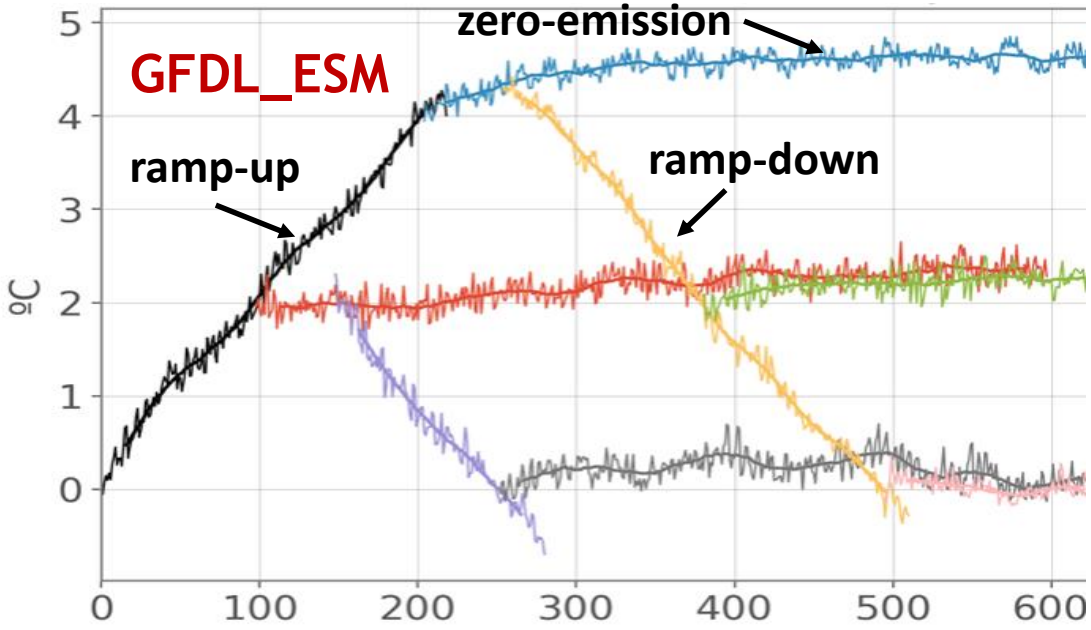
UKESM



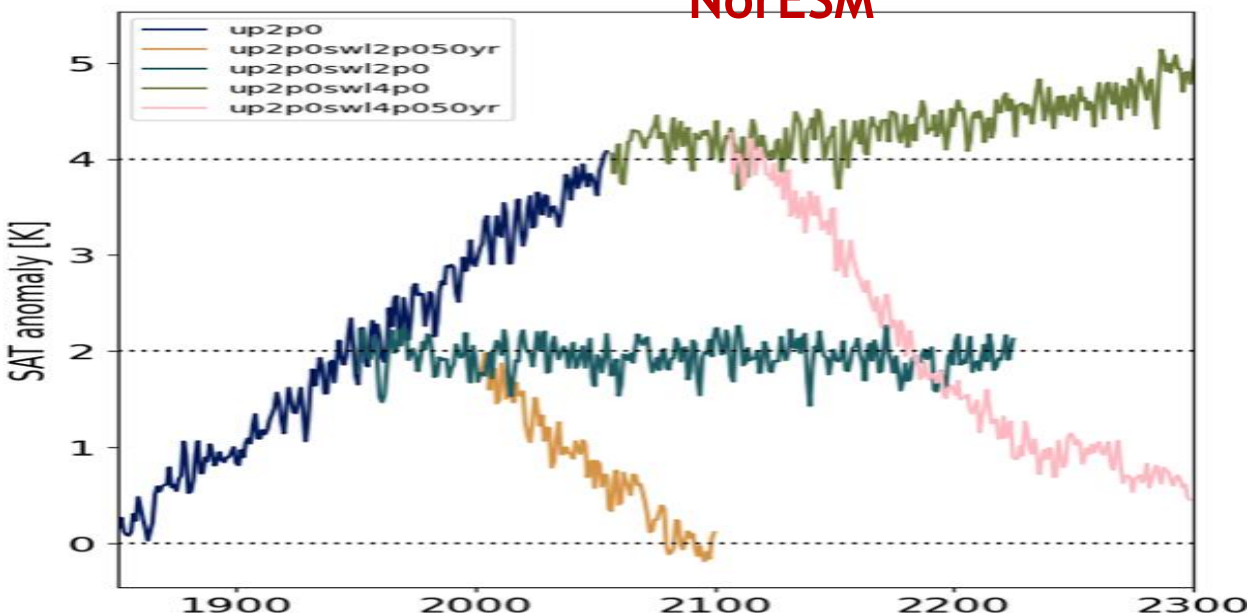
EC-Earth



GFDL_ESM



NorESM

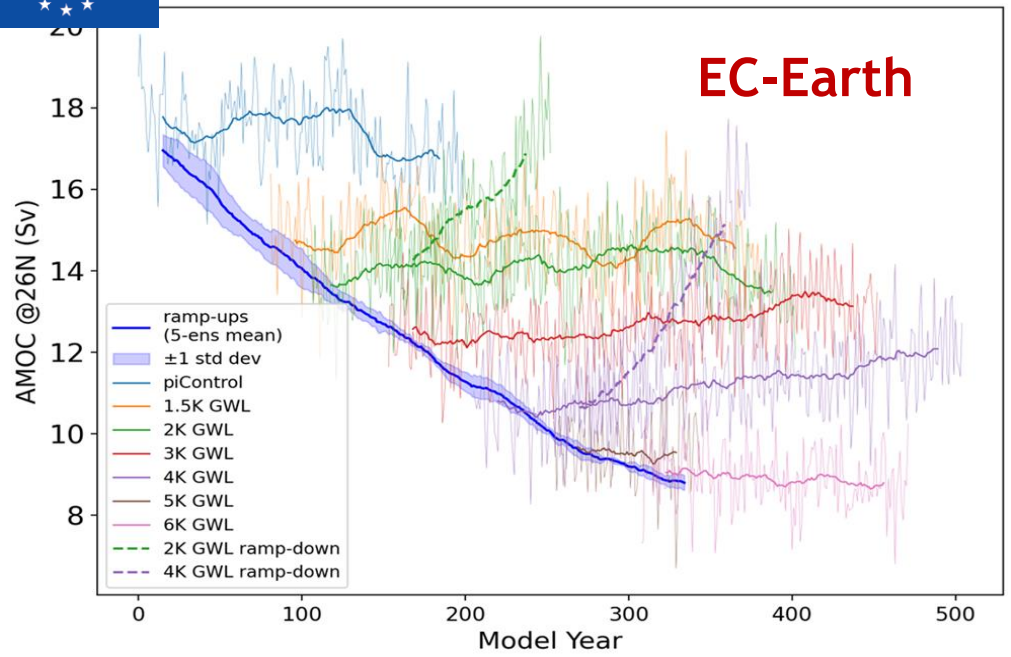


Atlantic Meridional Overturning Circulation

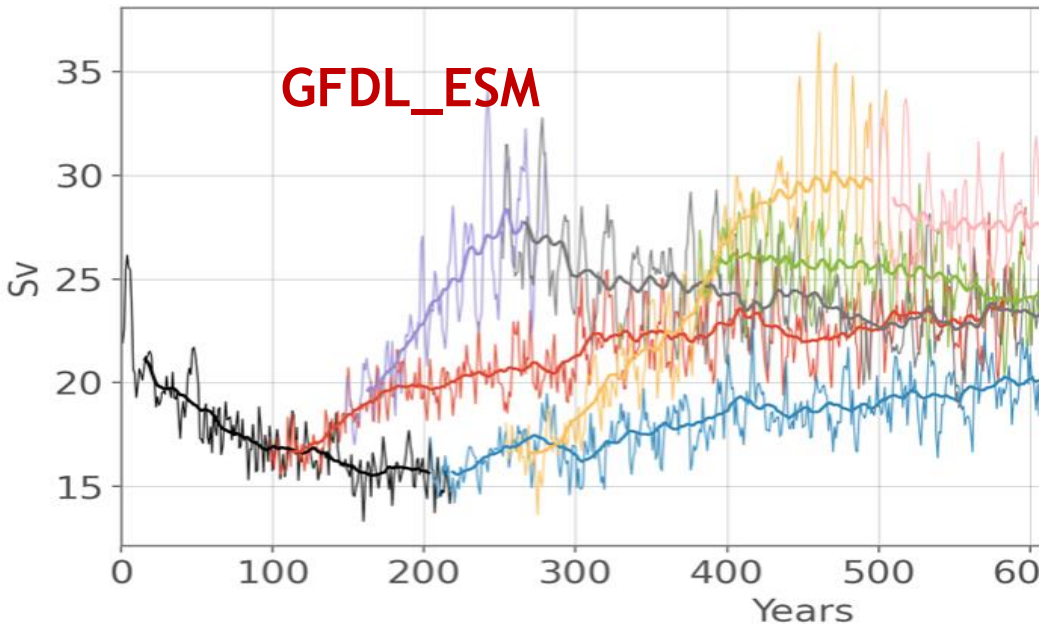
OptimESM

TipESM
Exploring Tipping Points and their Impacts Using Earth System Models

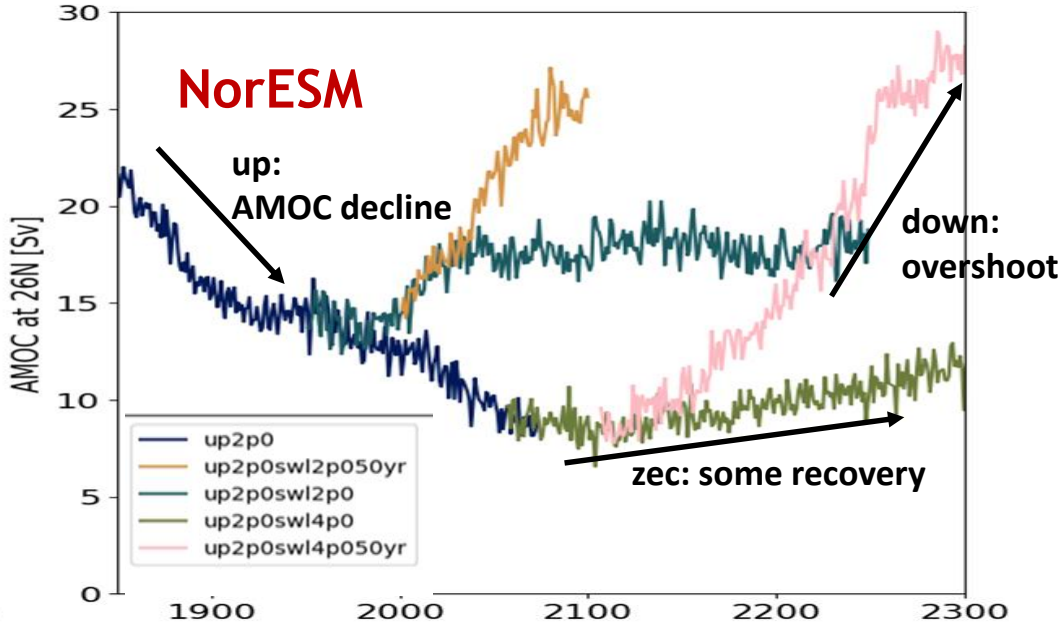
EC-Earth



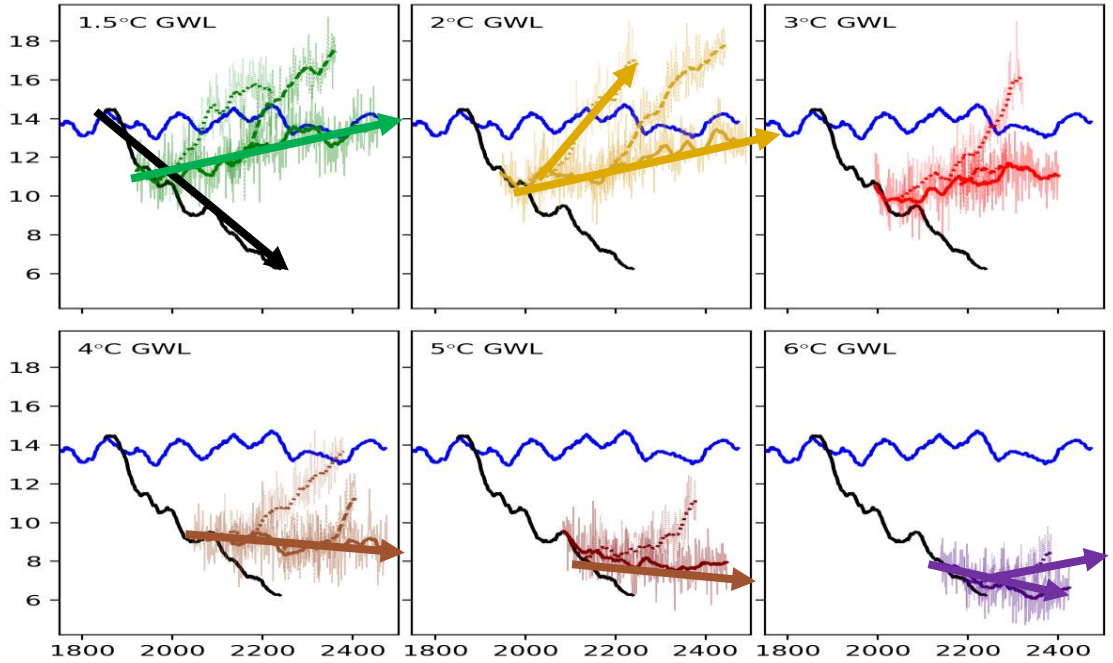
GFDL_ESM



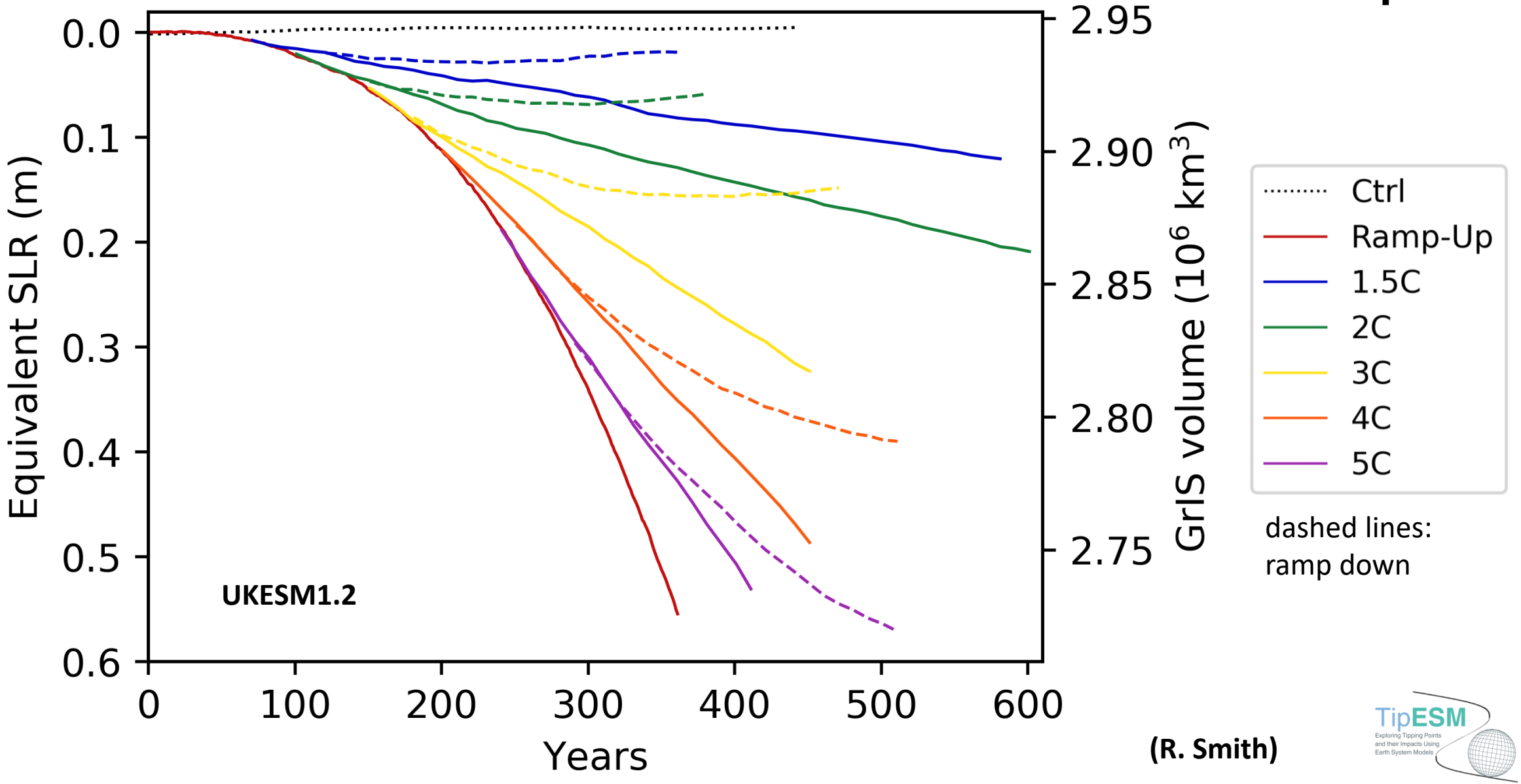
NorESM



UKESM



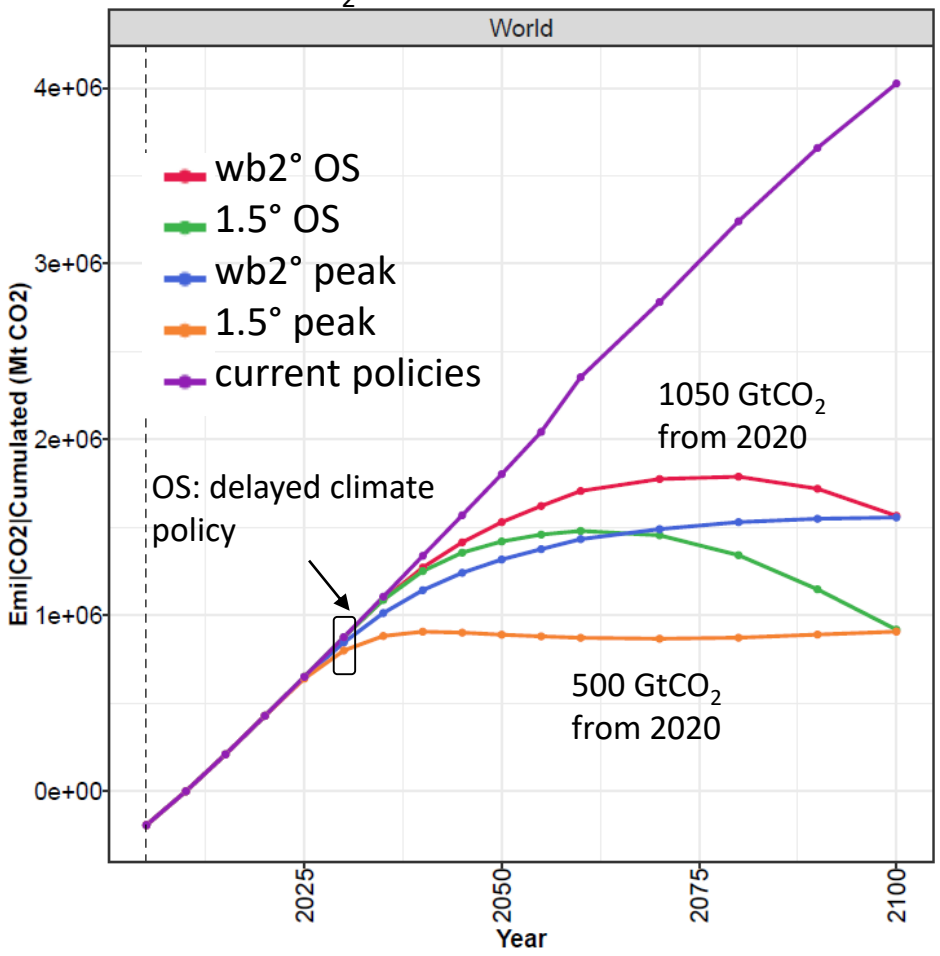
Greenland Ice Sheet Response

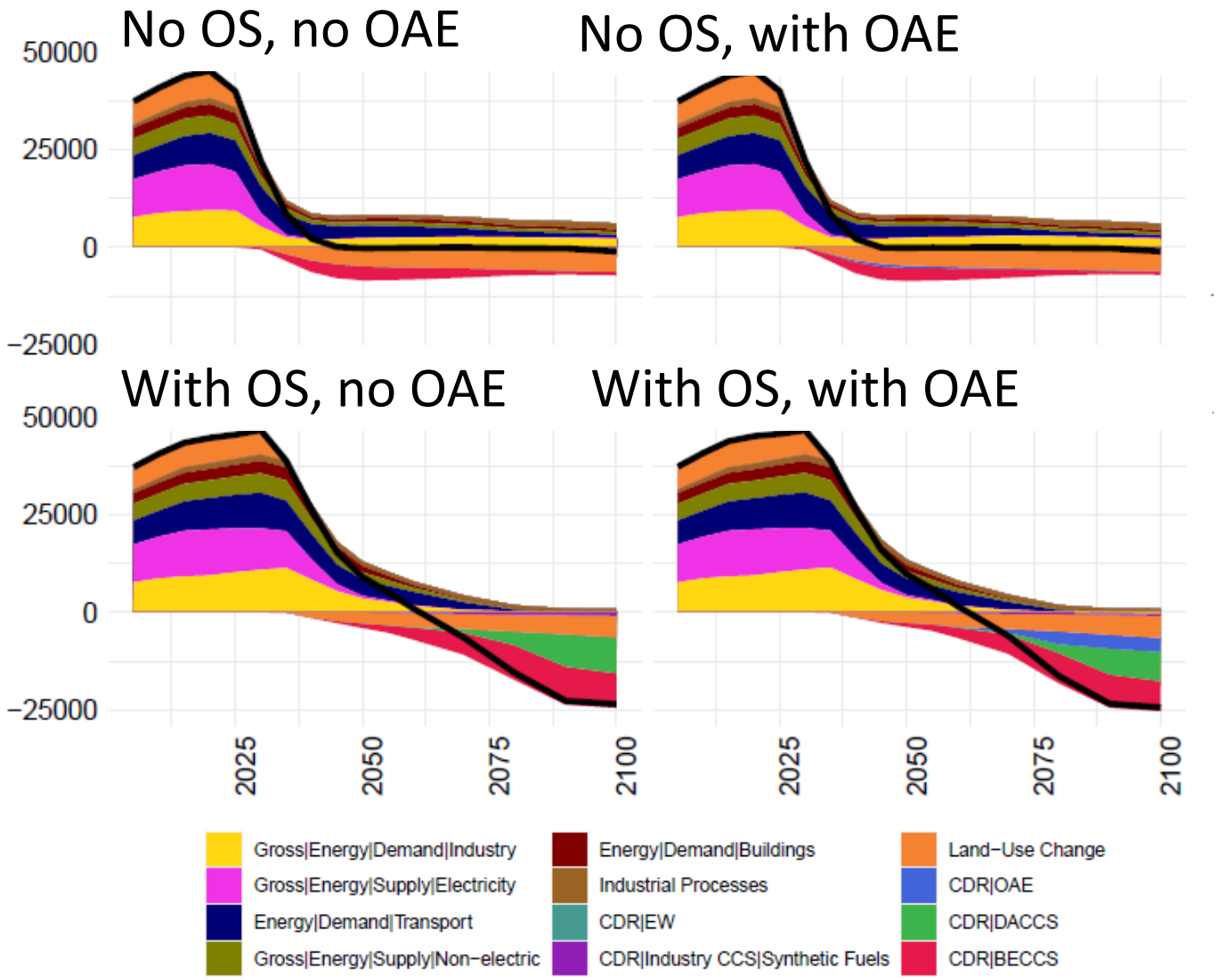


(R. Smith)

Development of new IAM scenarios

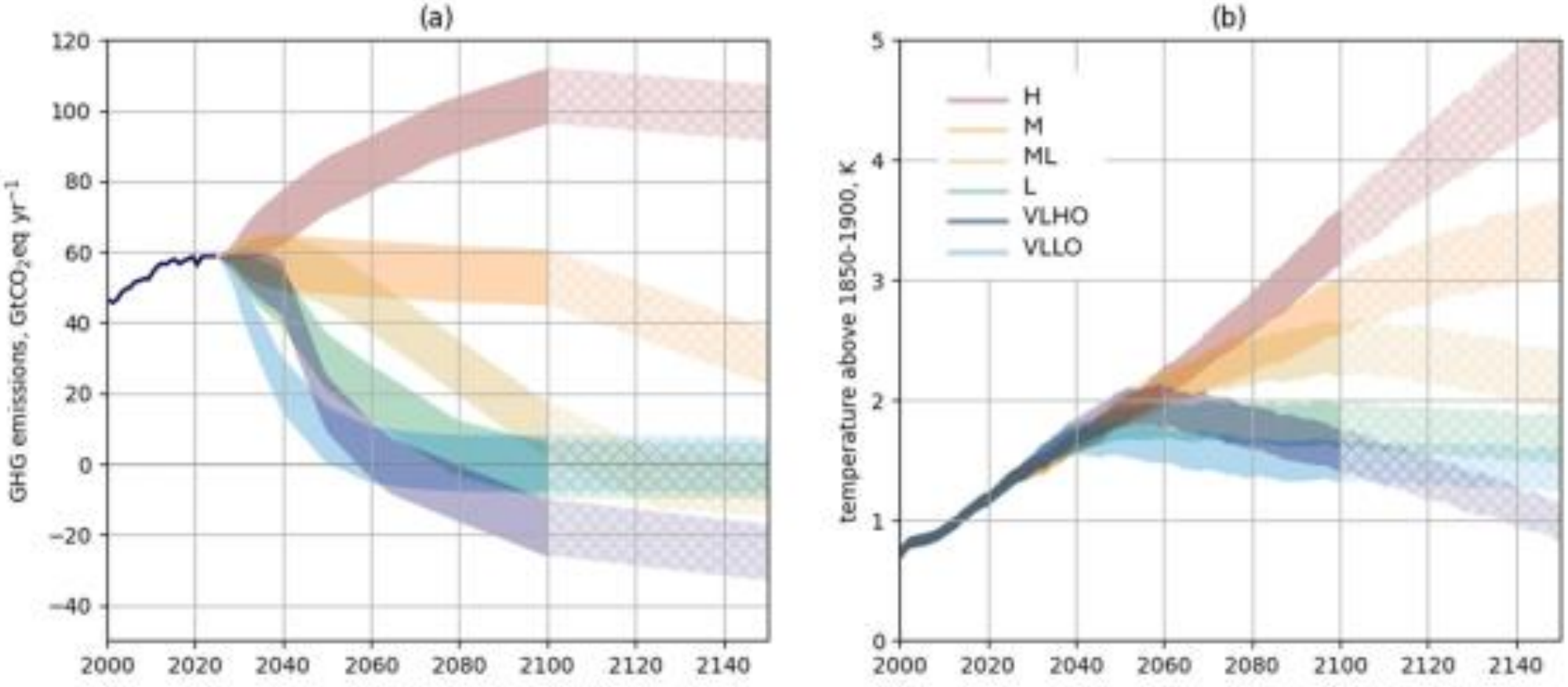
Cumulative CO_2 emissions





together with EU-project RESCUE

…but AR7 Fast Track is starting soon



Van Vuuren et al. 2025, Figure 1: Draft scenarios for CMIP7 ScenarioMIP, showing (a) GHG emissions pathways (b) the expected global average temperature outcomes.

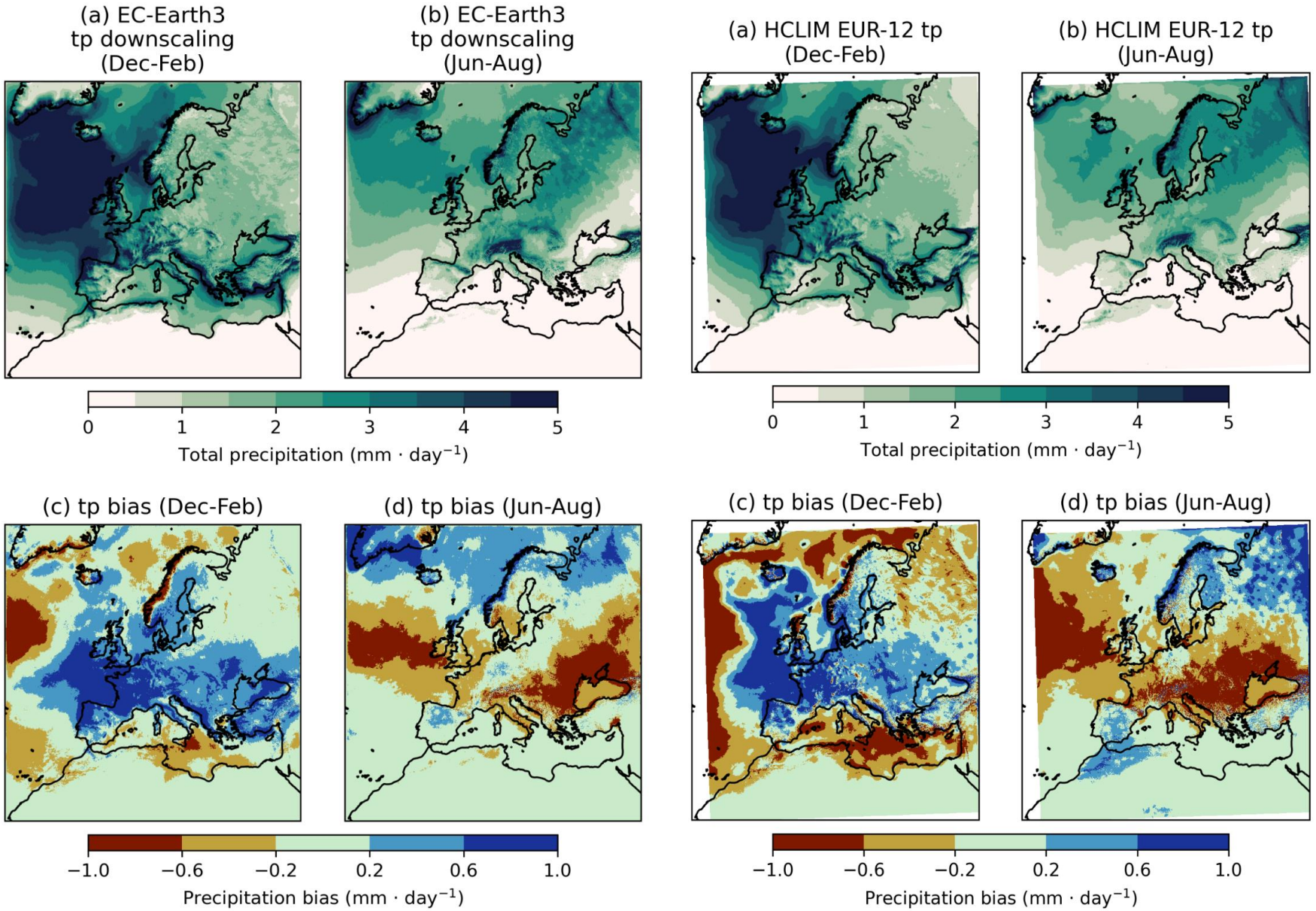
OptimESM would run those scenarios first that are relevant for ISIMIP to ensure an as quick as possible delivery of input data.

ML-based downscaling of an ESM, EC-Earth

1985-2014
0.11 °

Using convolutional neural network

Precipitation



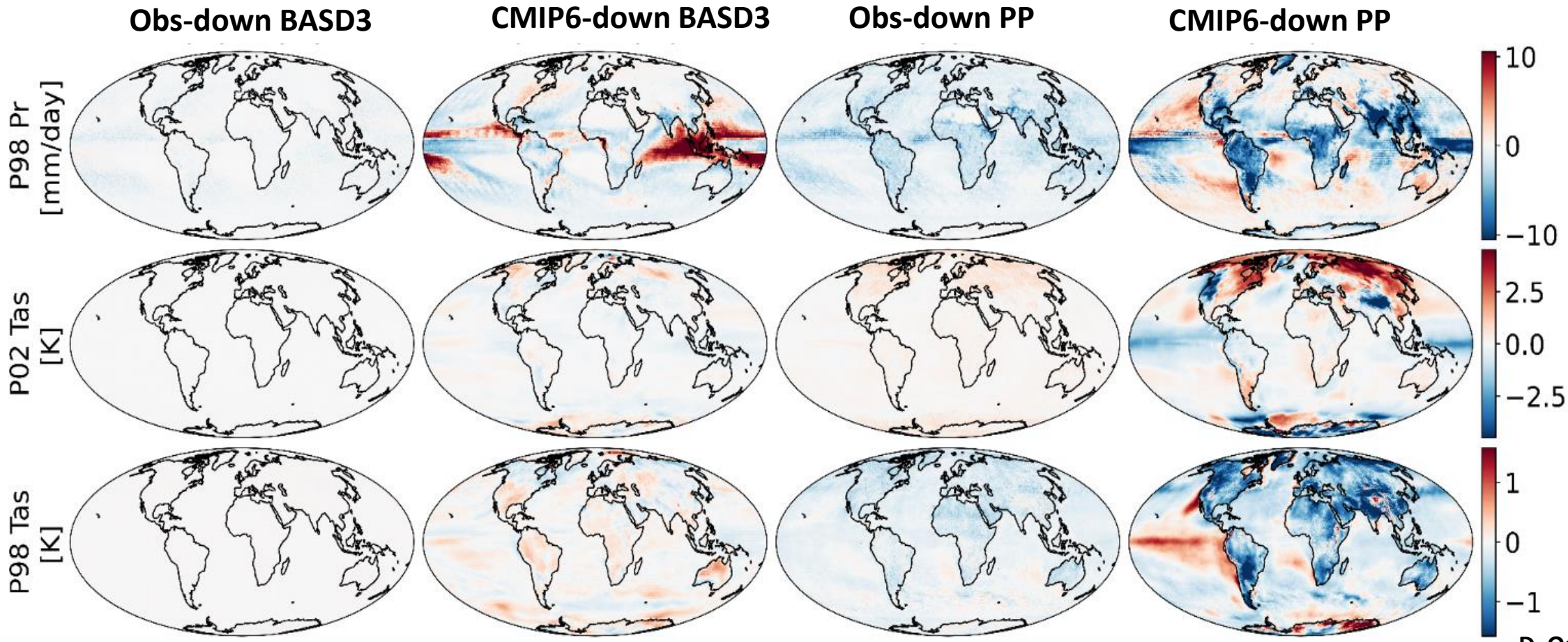
Comparable to dynamical downscaling with the regional model HCLIM

M. Ivanov,
R Fuentes Franco

Global downscaling and bias-correction

Perfect Prognostic Approach (PP-under development) –
First comparison to ISIMIP3BASD- Global application from 2° to 0.5

Biases of downscaled P and T2m extremes



D. Quesada

Conclusions

- Updated ESMs after CMIP6 ready and running
- PI and historical runs (CMIP6-based) and idealized overshoot simulations performed
- Start first Fast Track scenario simulations as quickly as forcing data will be available (for AR7)
- OptimESM works on ML-based downscaling methodologies
- First results:
  - warming might continue after zeroing emissions
  - GIS continues melting after ZEC
  - AMOC declines but no collapse, might overshoot after cooling

→ Climate after a temperature overshoot differs from before.

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OptimESM

OptimESM will develop a novel generation of Earth system models to deliver cutting-edge and policy-relevant knowledge around the consequences of global warming, including the risk of rapid change in key Earth system phenomena and regional impacts.

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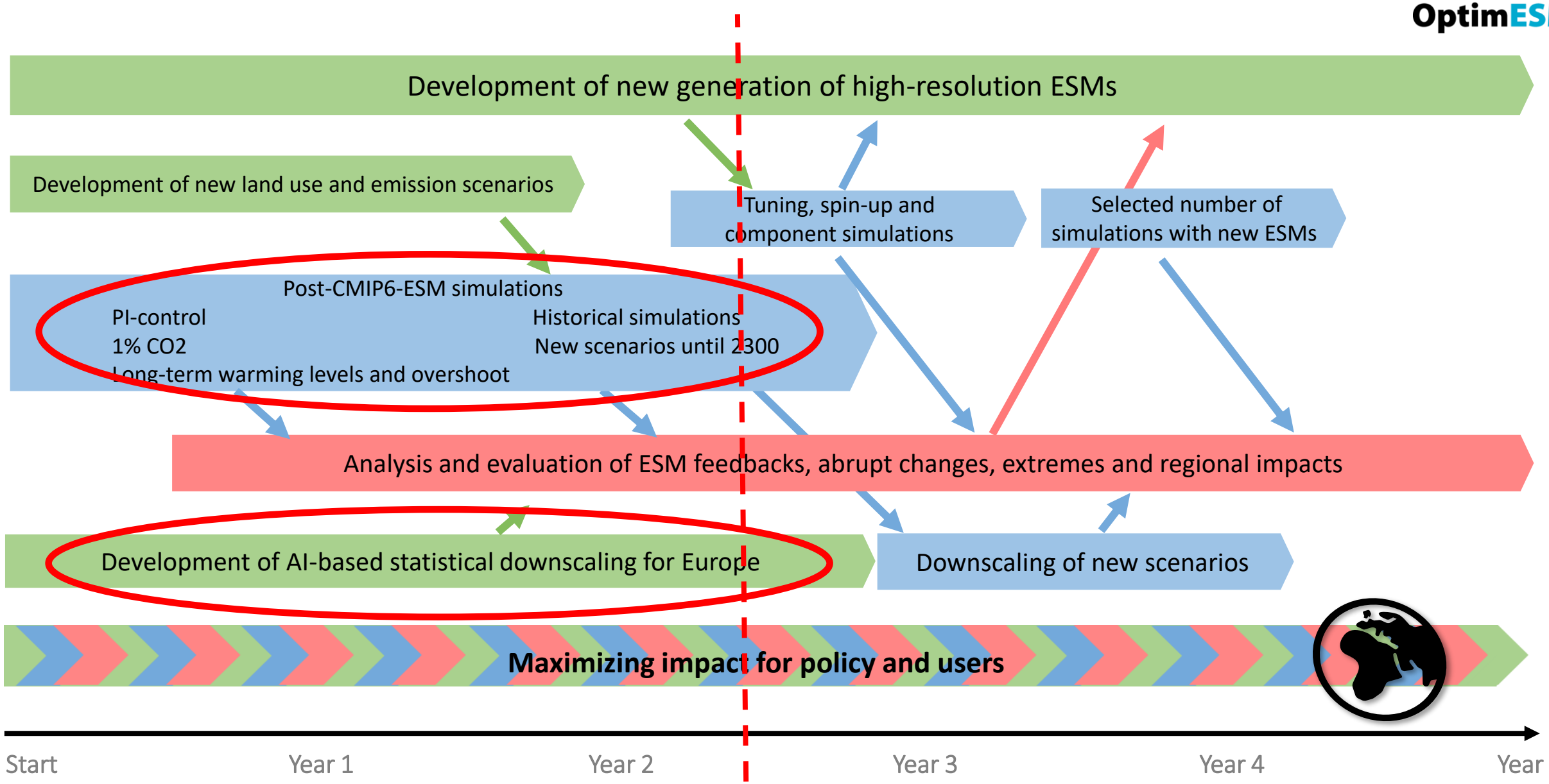
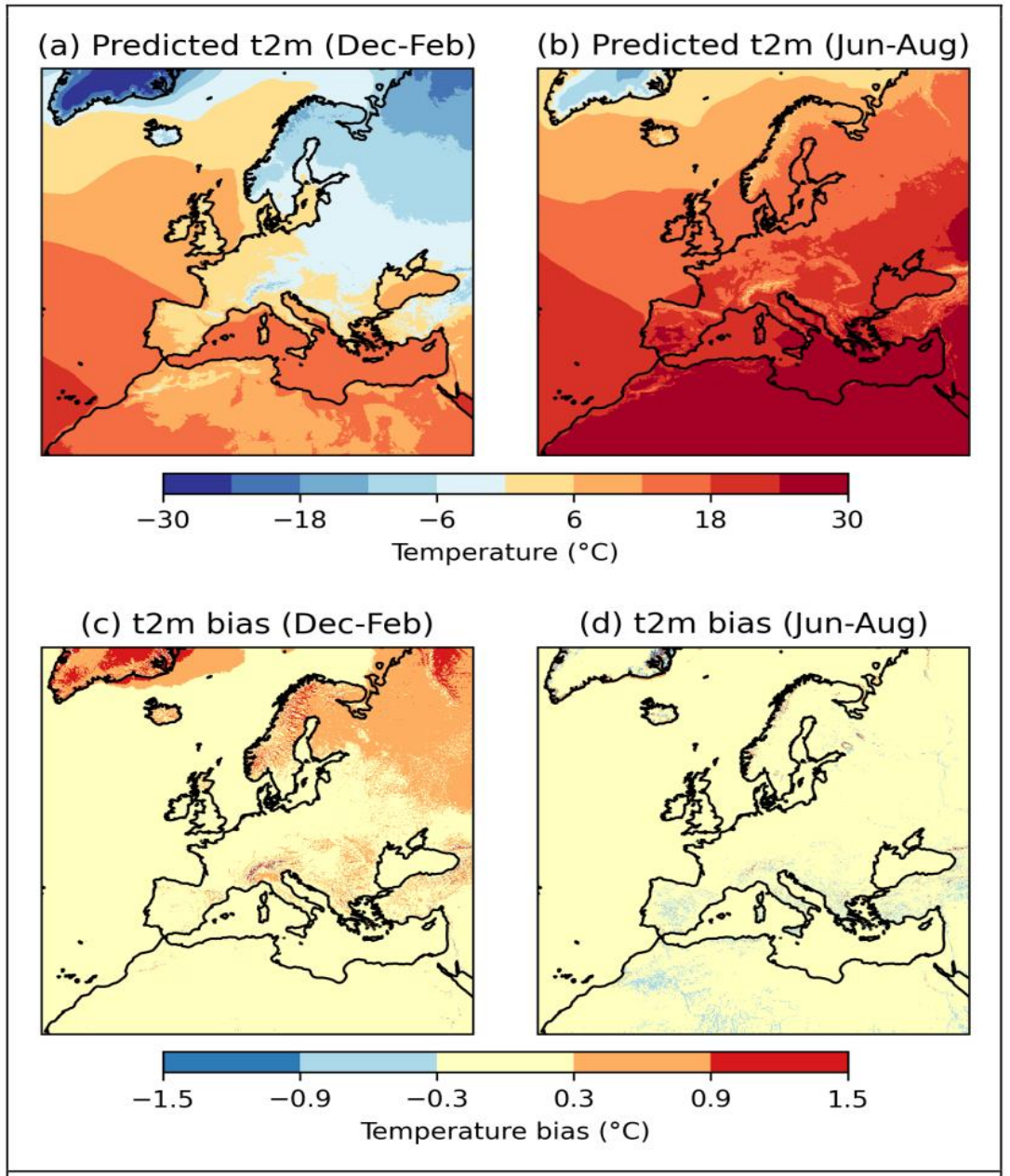
Activities and Workflow



ML-based downscaling for Europe

ERA-5 (input)	CERRA (ground truth)
Low-res (0.25°)	High-res (5.5 km)

- Using convolutional neural network
- Temperature and Precipitation



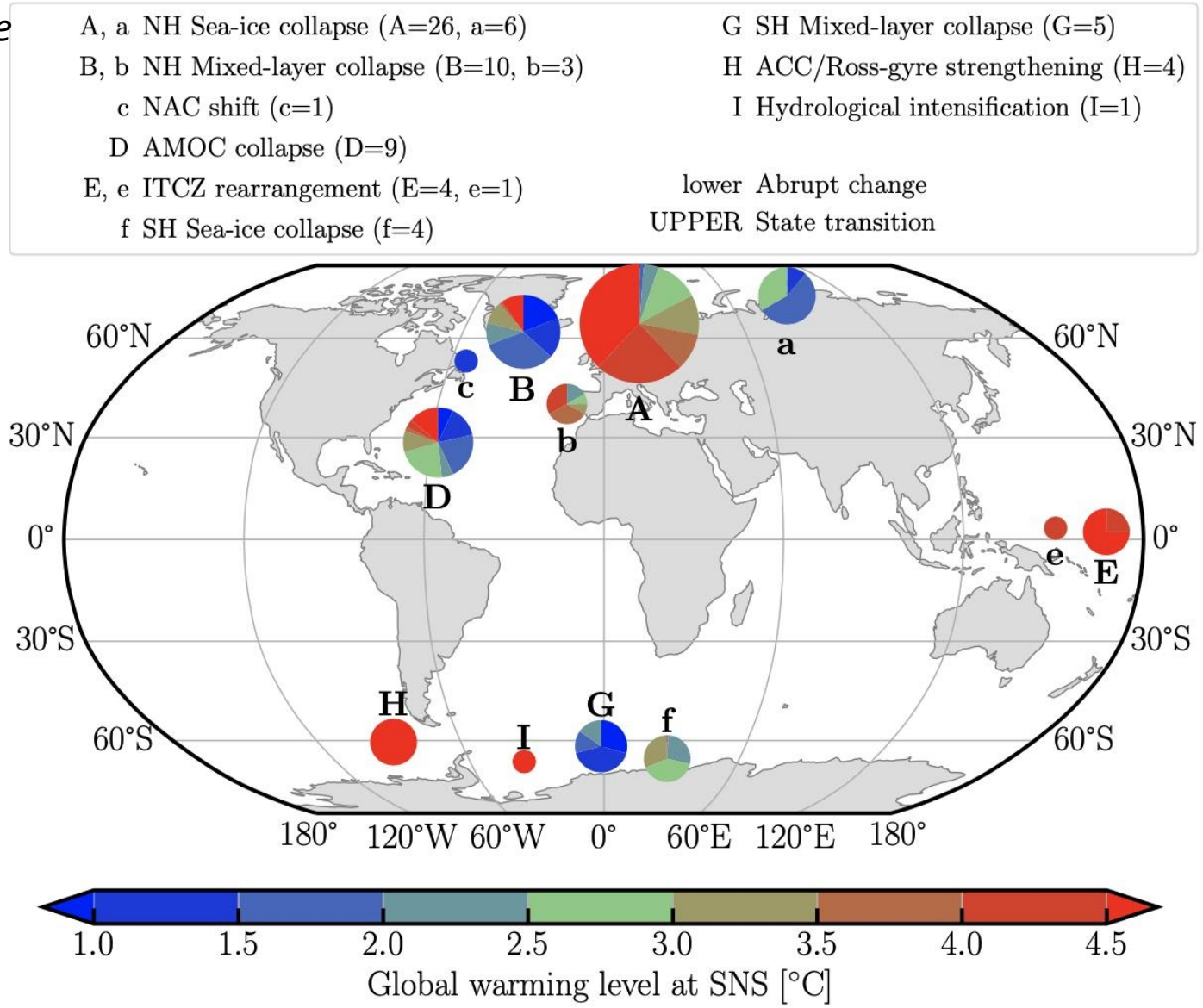
Seasonal means and biases compared to CERRA

Fuentes Franco et al., submitted

Task 2.1 Search, find and identify TPs in the physical and biogeochemical system of ESM simulations.

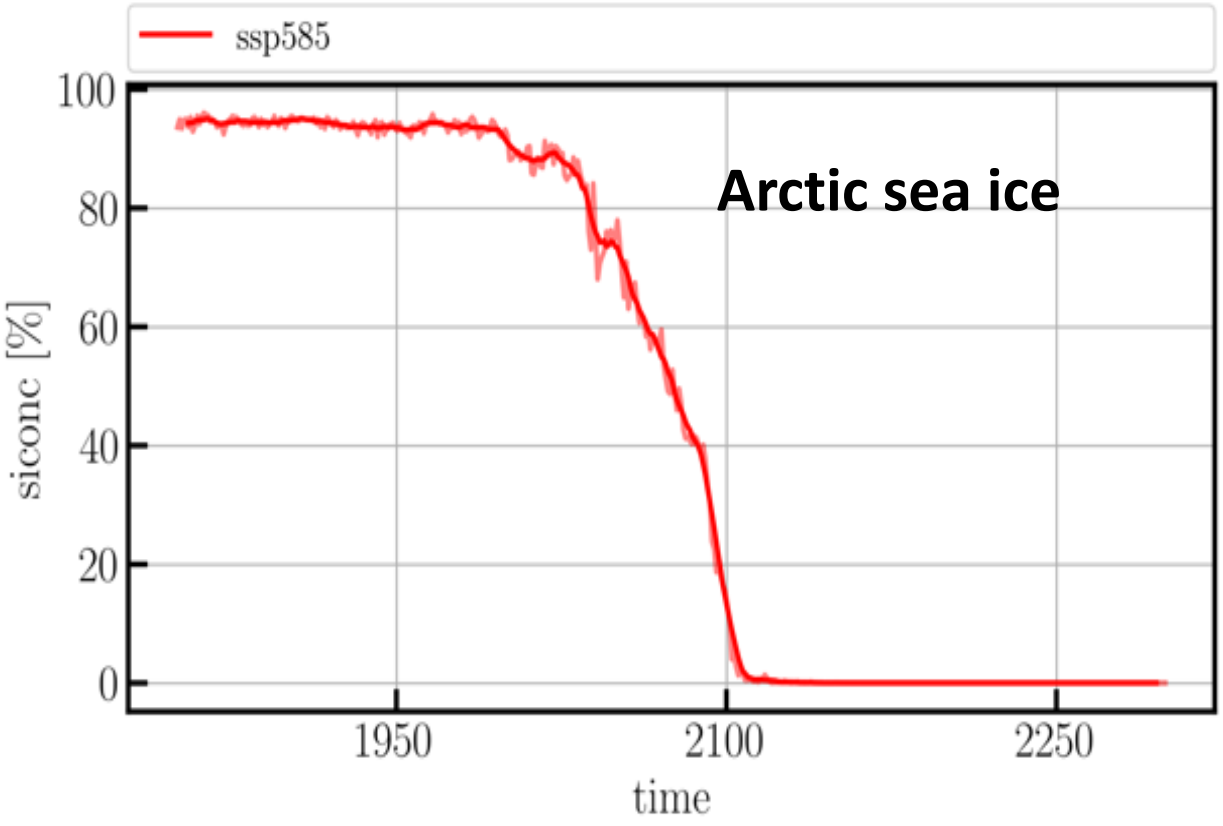
Sybren Drijfhout and Joran Angevaare

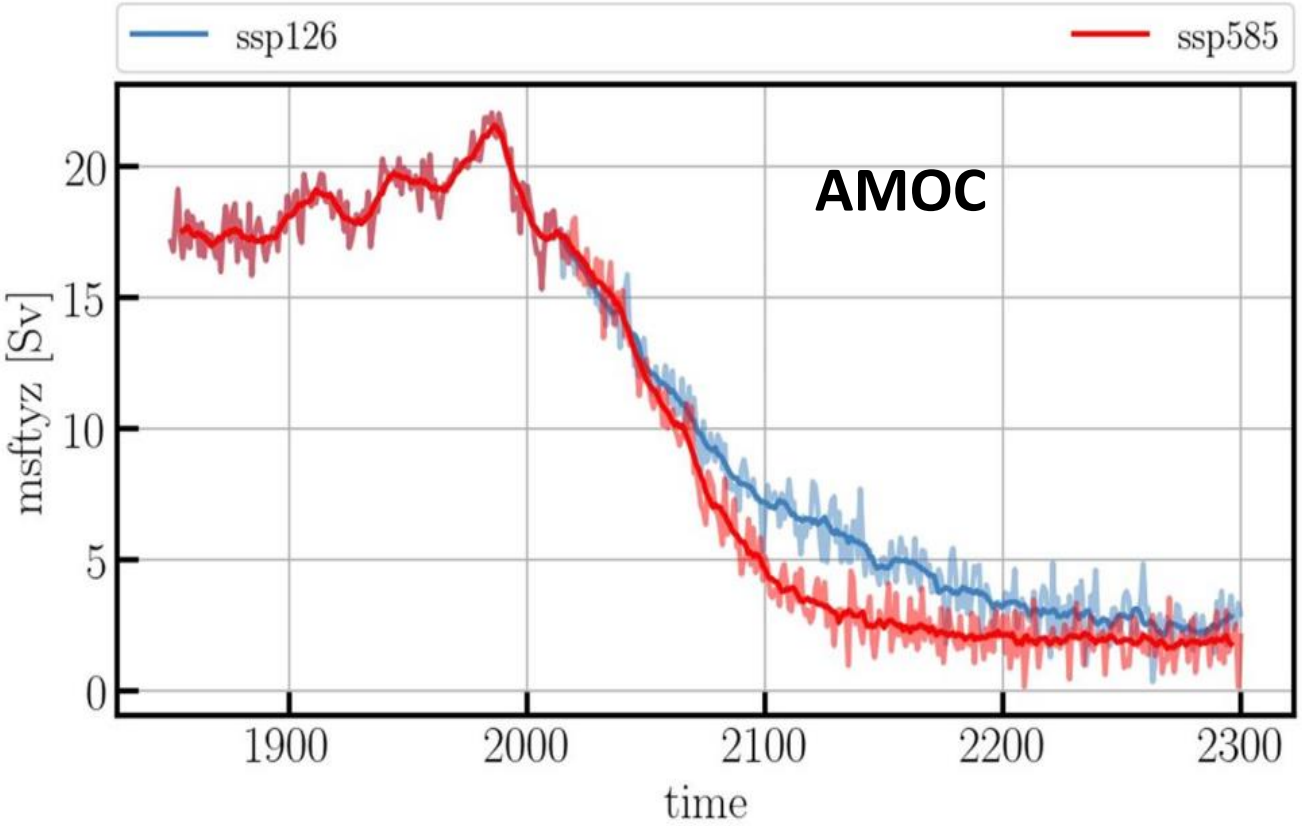
CMIP6



Abrupt changes in the Earth system

Examples for rapid transitions in CMIP6 models

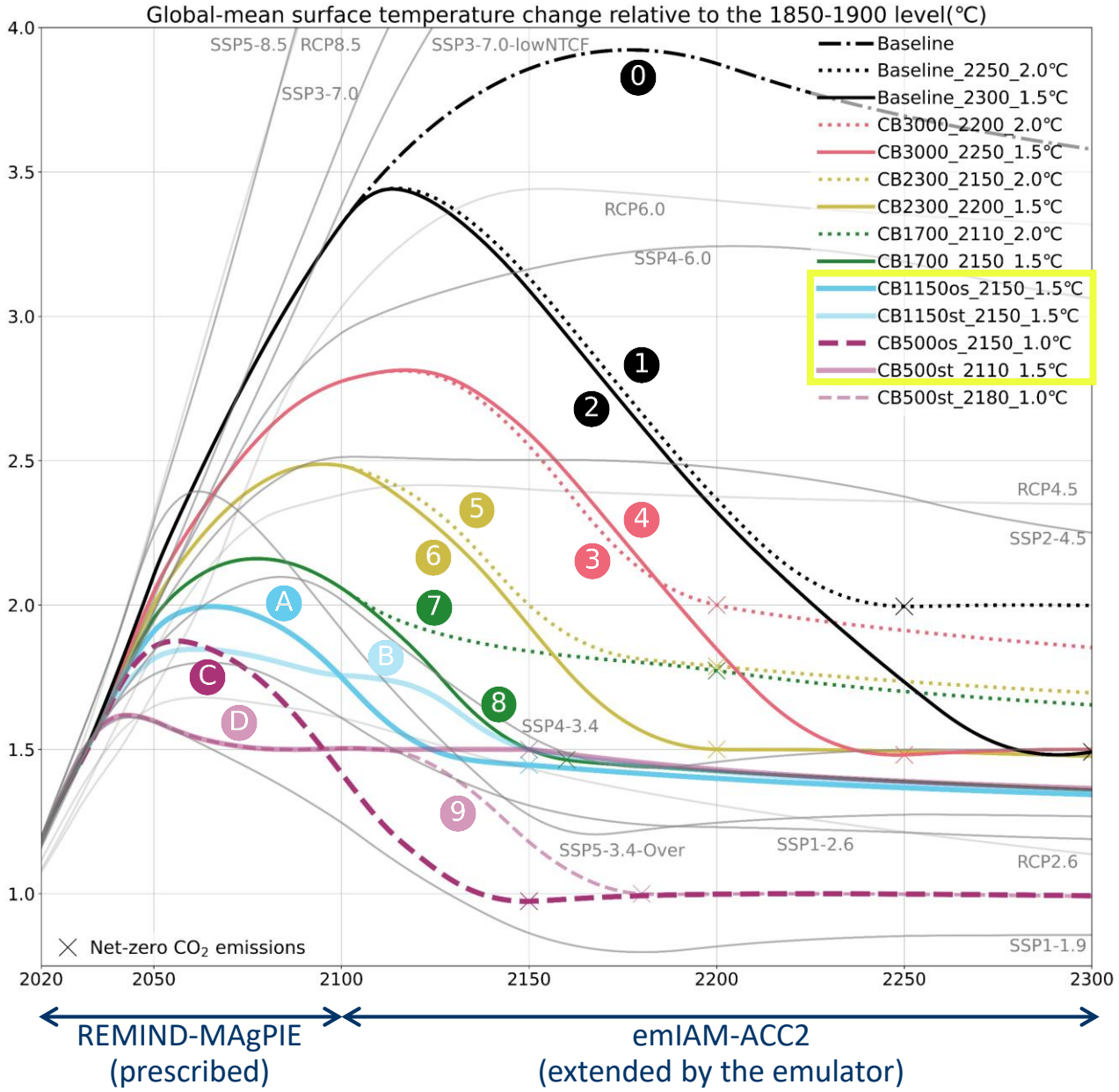


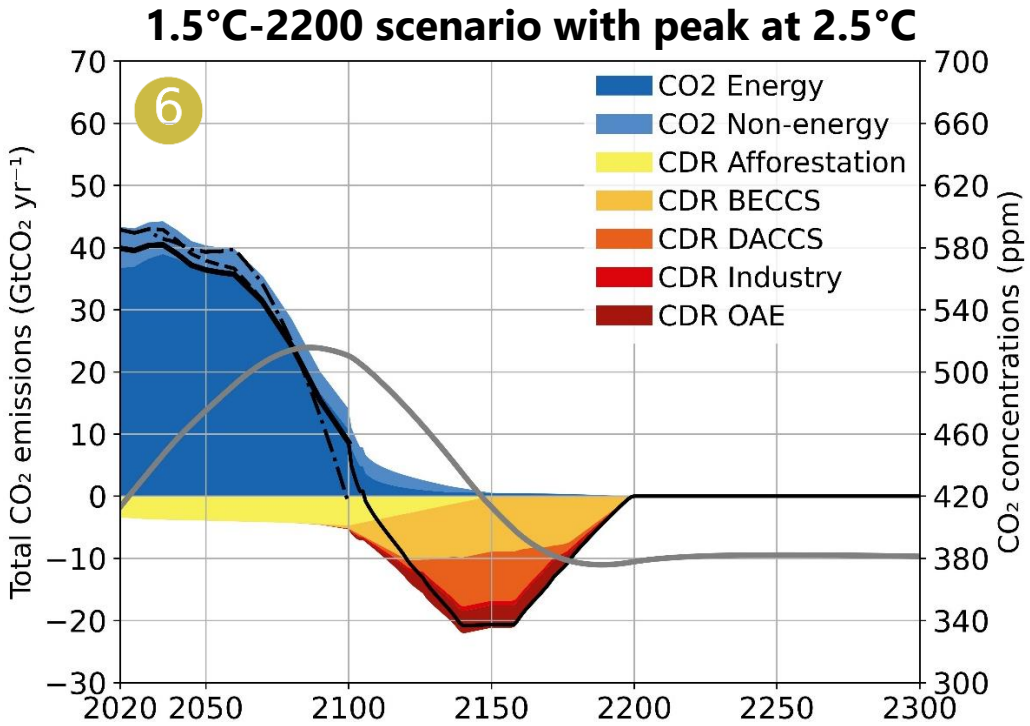


(J. Angevaare, S. Drijfhout)

Left: *annual mean sea ice cover in the Arctic in the CESM2-WACCM model in SSP5-8.5.*
Right: *AMOC at 26.5 N in MRI-ESM2.0*

Overview of extended scenarios





Proposed for ESM simulation A B C D

- Cost-effective scenarios for 1.5 or 1 °C stabilization in 2150 (with overshoots internally calculated by cost minimization)
- Net-zero CO_2 emissions beginning in 2150
- Actual temperature profiles will be model-dependent (i.e., ECS, ZEC, TCRE+ (lump-up), and TCRE— (lump-down)).

Optional for ESM simulations 0 9

- Covering higher temperature space, beyond those above