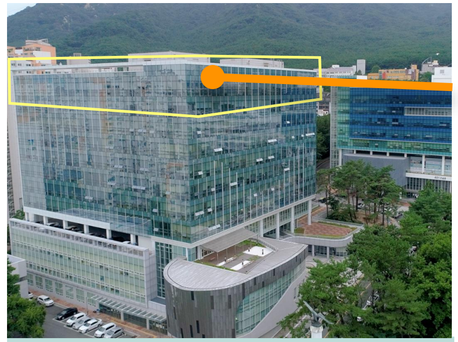
IBS Center
for Climate Physics

Next Generation Earth System Model Projections

Axel Timmermann

Founded: 2017



Here

Our home: PNU

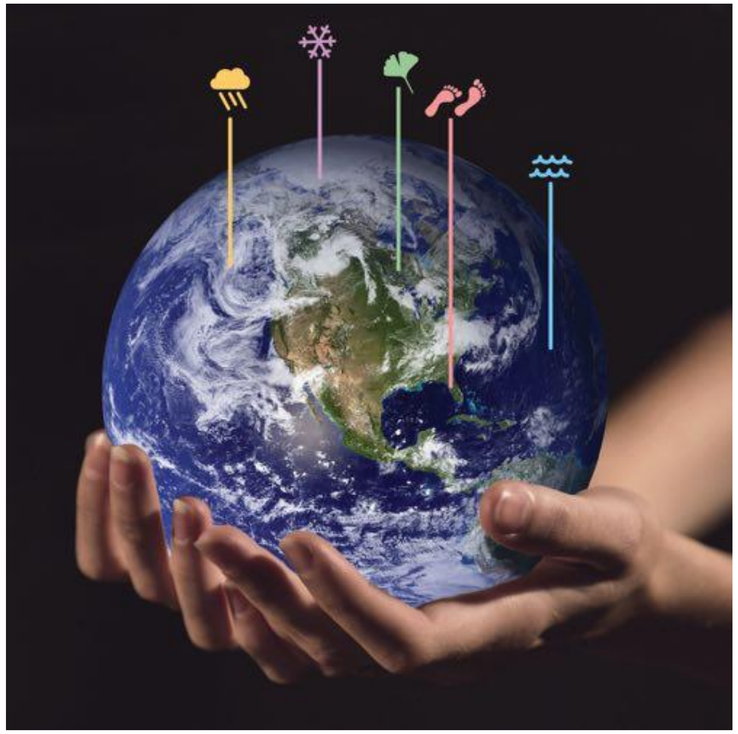
Aleph

Isotope lab

Over past 8 years: 100 members from 17 different countries,

Now: 61 members from 12 different countries, 6 professors

The IBS Center for Climate Physics

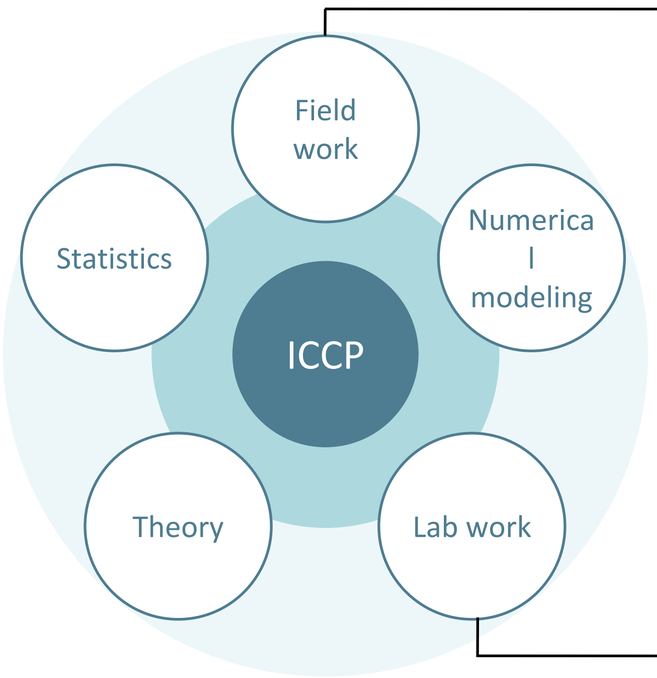


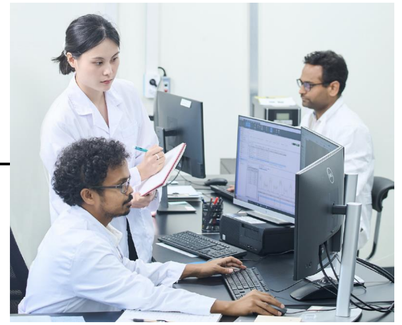
ICCP’s mission is to enhance the understanding of natural climate variability and anthropogenic climate change, and to improve the ability to simulate and predict climate impacts on ice-sheets, sea level, life, planetary health and regional processes.

The IBS Center for Climate Physics: Mission

Trans-disciplinary

Multi-tool



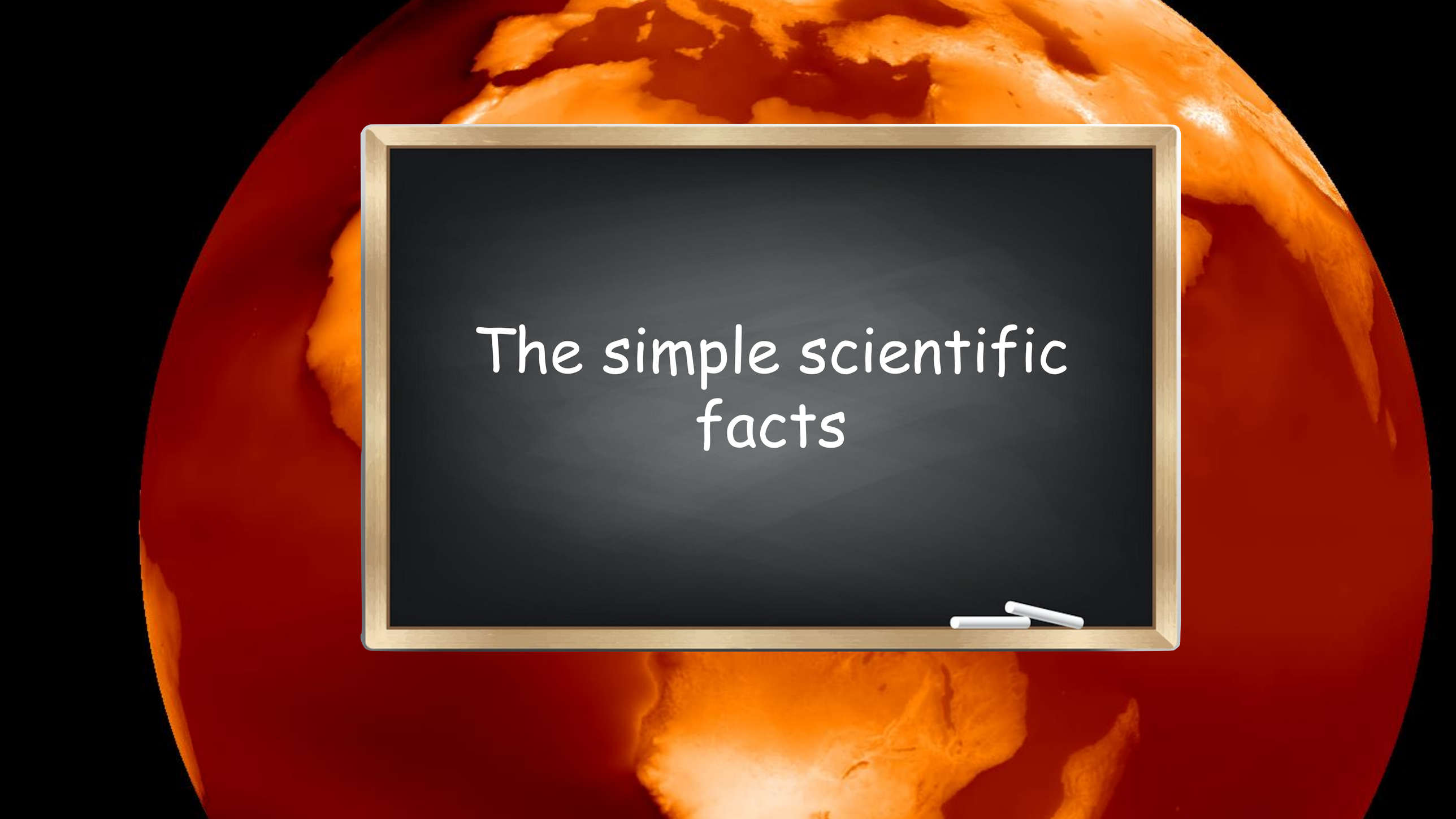


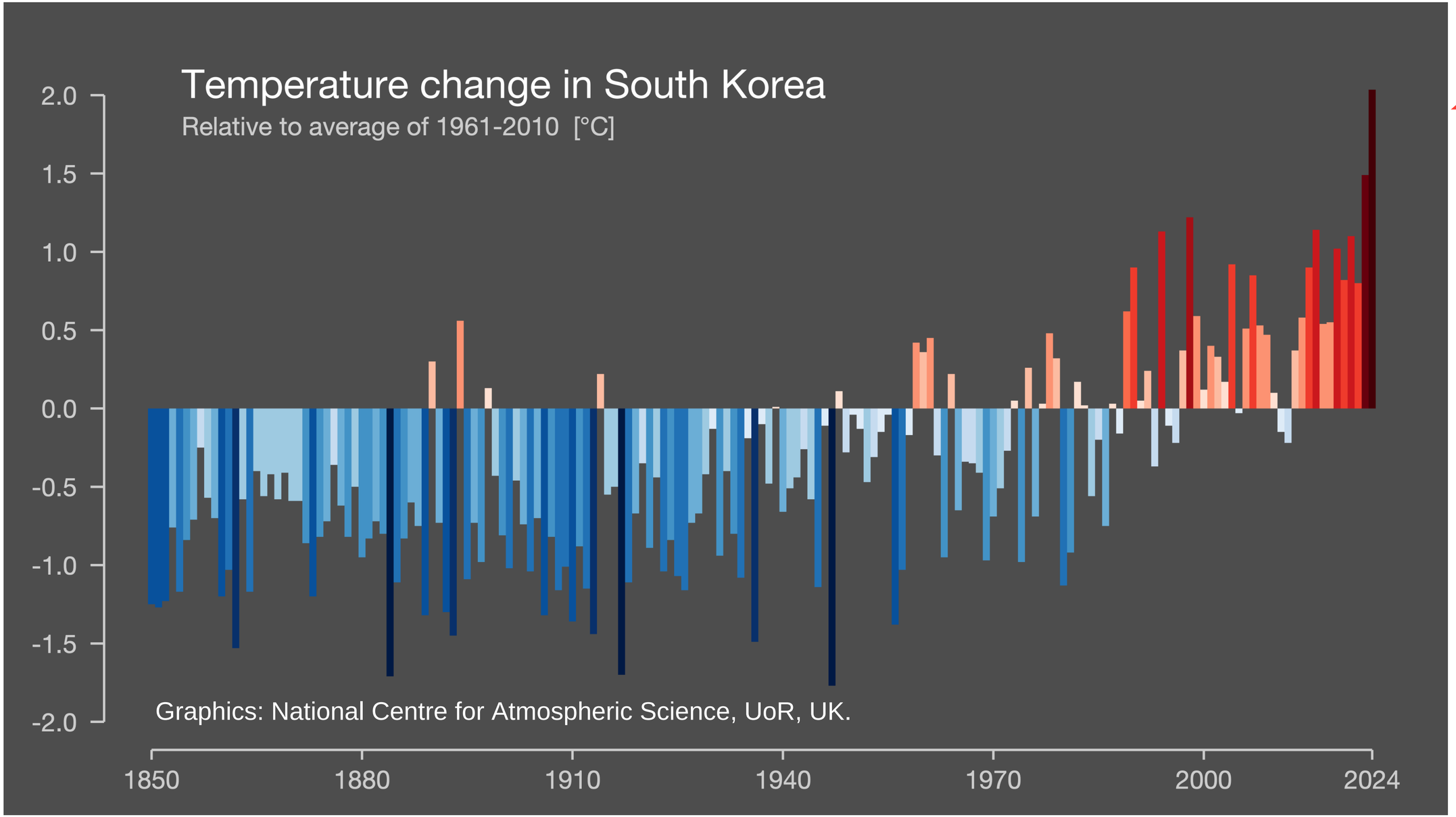
Past-to-Future

Transformative

End-to-End

The IBS Center for Climate Physics: Tools


The simple scientific facts

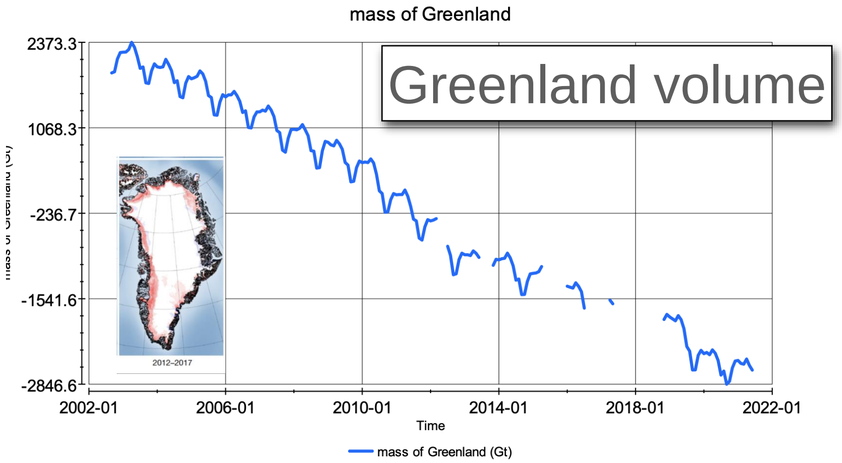


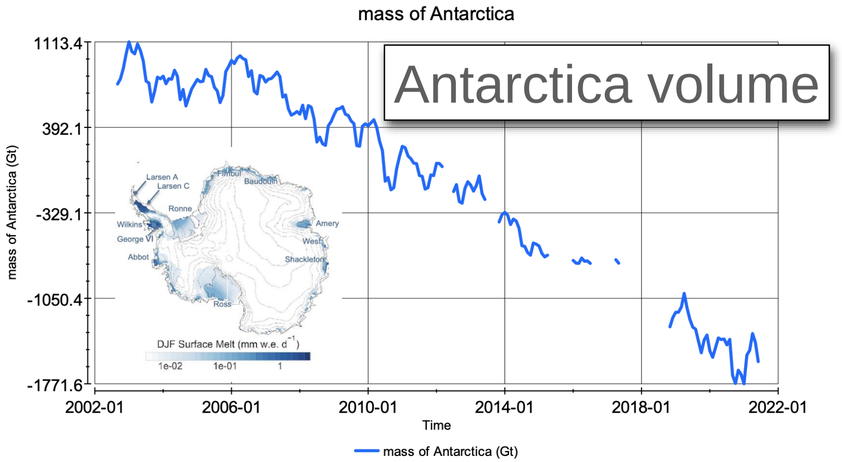
Increased risk of heat waves

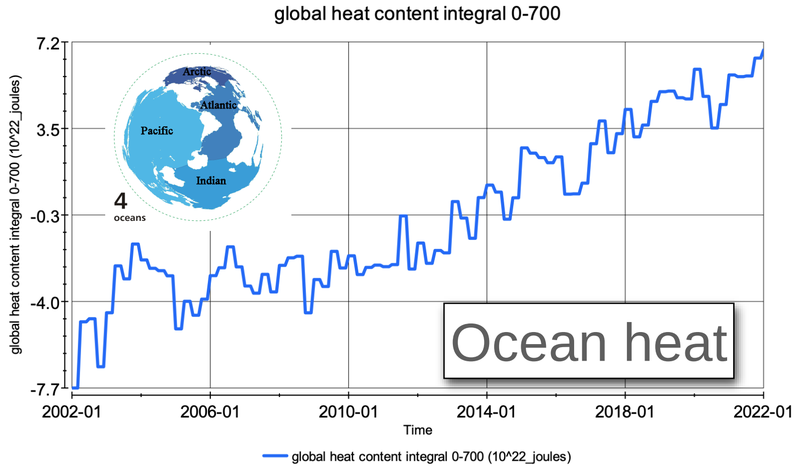
Increased risk of extreme rainfall

Our Planet is warming at unprecedented rates

Observed Trends

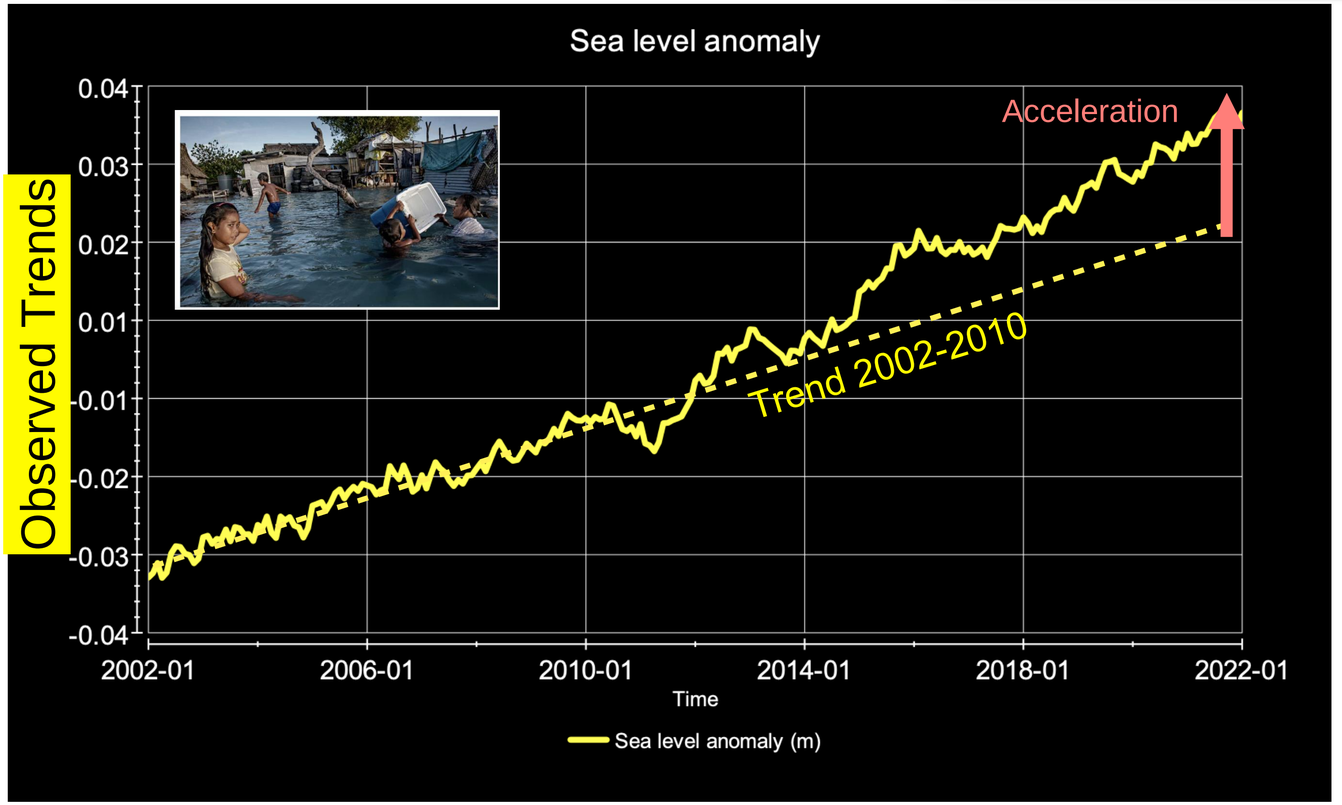






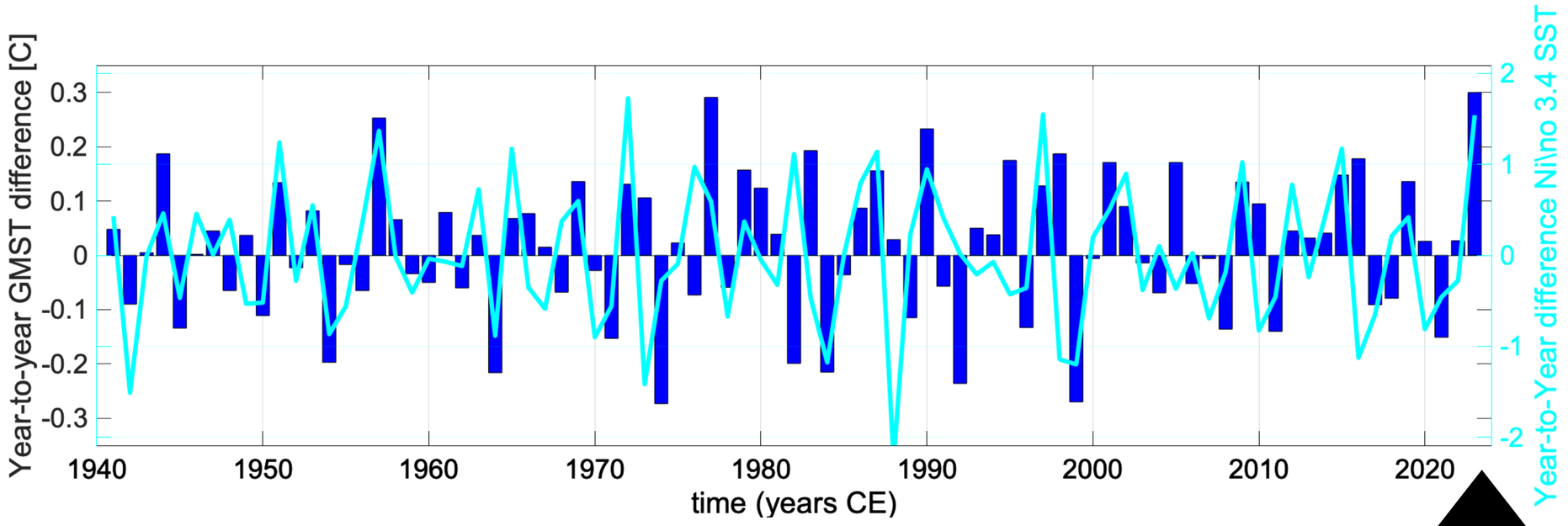
7 cm/23 years

Global Sea Level



Graphics: Axel Timmermann, IBS Center for Climate Physics, The Republic of Korea

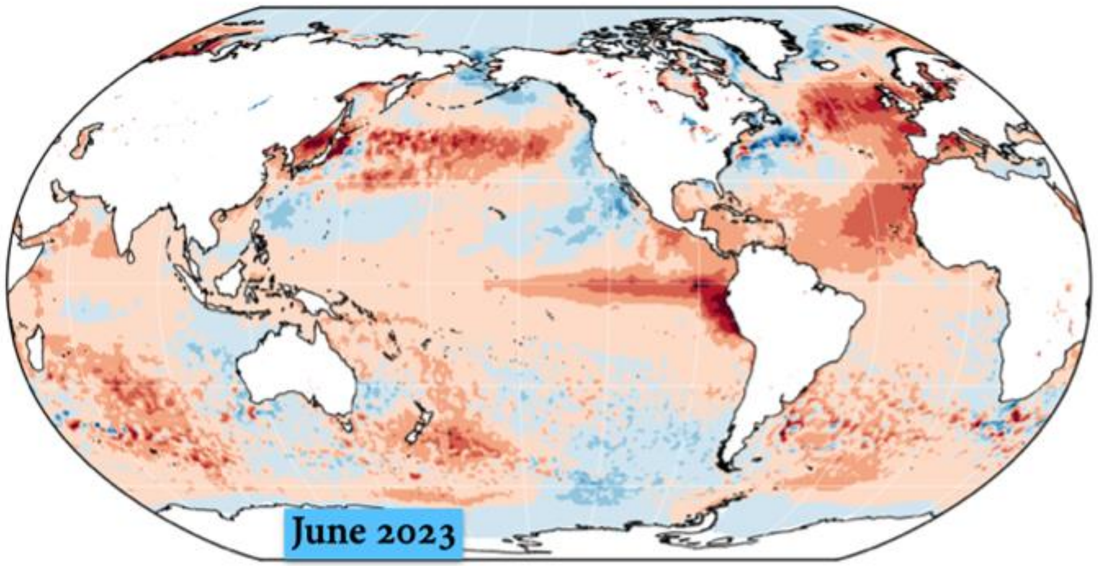
... causing sea level rise

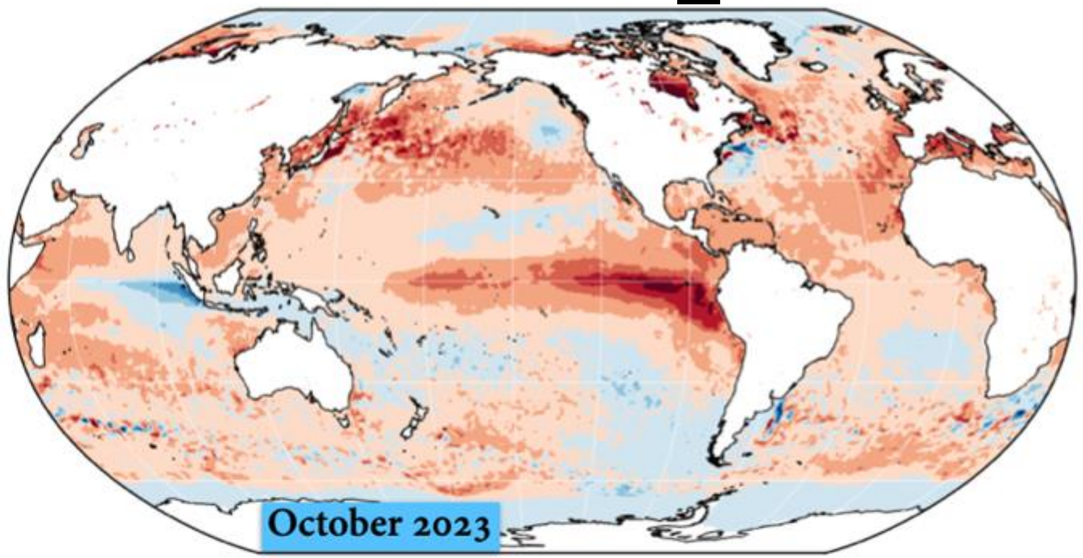


ENSO

Stratospheric water vapor

Reduced Aerosols





Graphics: Axel Timmermann, IBS Center for Climate Physics, The Republic of Korea

Some years faster than others...

AR3, 2001

"Most of the warming observed over the last 50 years **is likely** to have been due to the increase in greenhouse gas concentrations."

AR4, 2007

"Most of the observed increase in global average temperatures since the mid-20th century is **very likely** due to the observed increase in anthropogenic greenhouse gas concentrations."

AR5, 2013/14

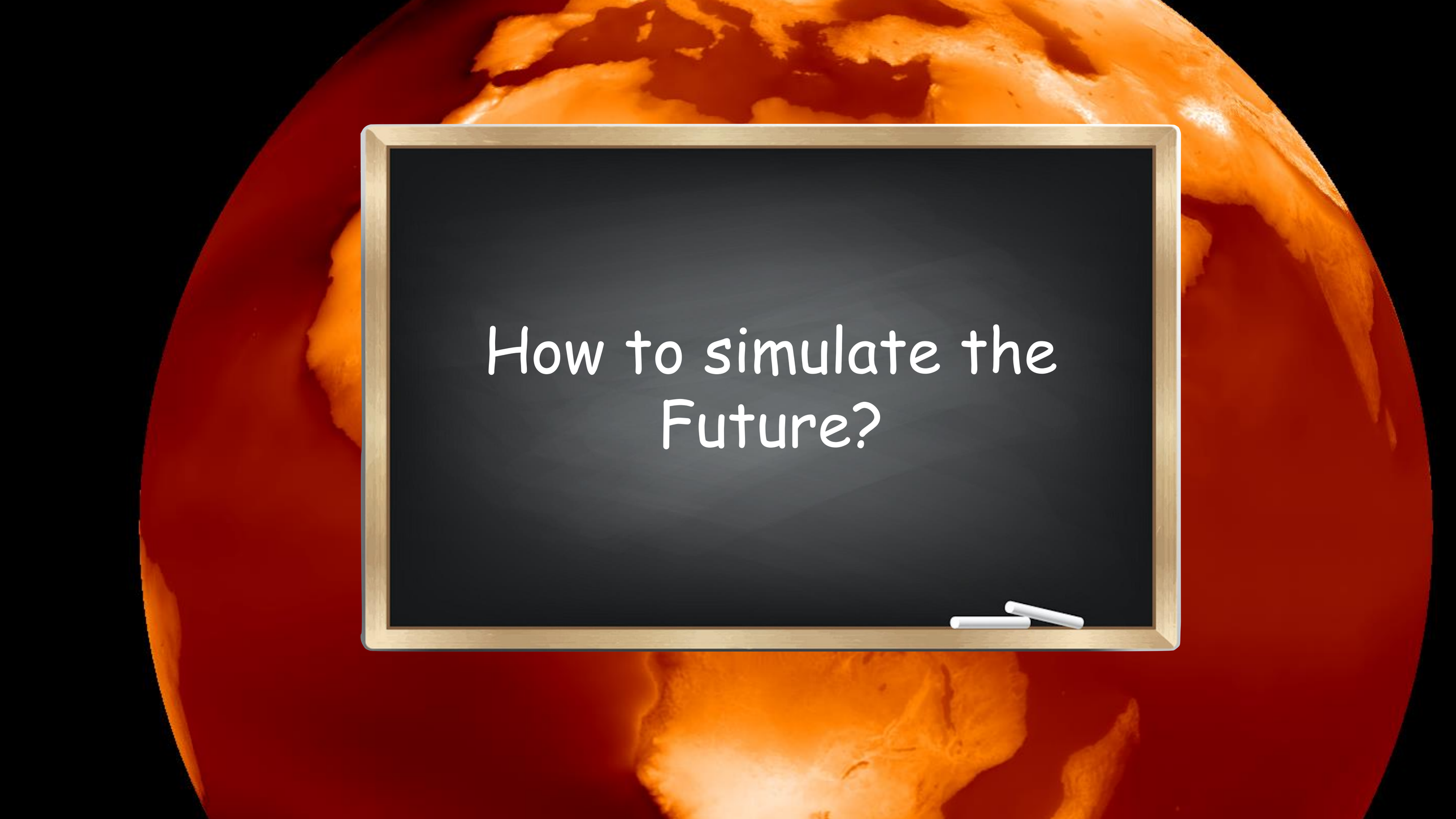
It is **extremely likely** that human influence has been the dominant cause of the observed warming since the mid-20th century

AR6, 2021/22

"It is **unequivocal** that human influence has warmed the atmosphere, ocean, and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere, and biosphere have occurred."

Summary for Policymaker Statements from Intergovernmental Panel On Climate Change

The cause: "Anthropogenic GHG emissions"


How to simulate the Future?

Physical equations

Electromagnetism

Quantum mechanics

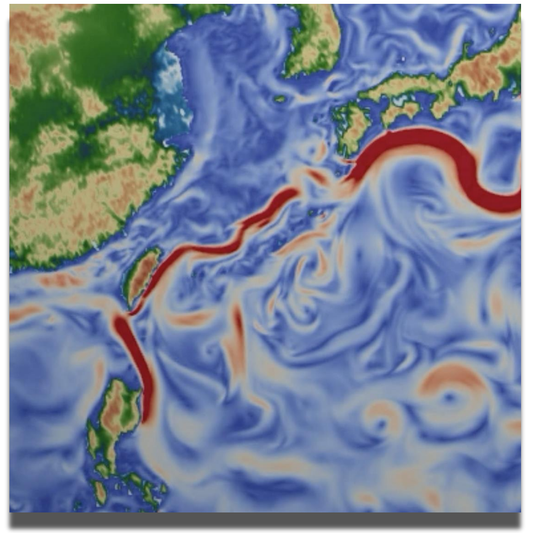
Fluid dynamics

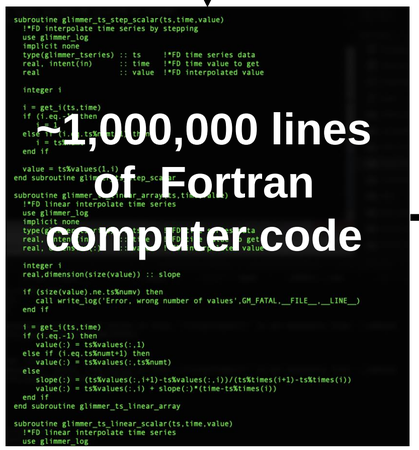
Thermodynamics

Empirical Parameterizations

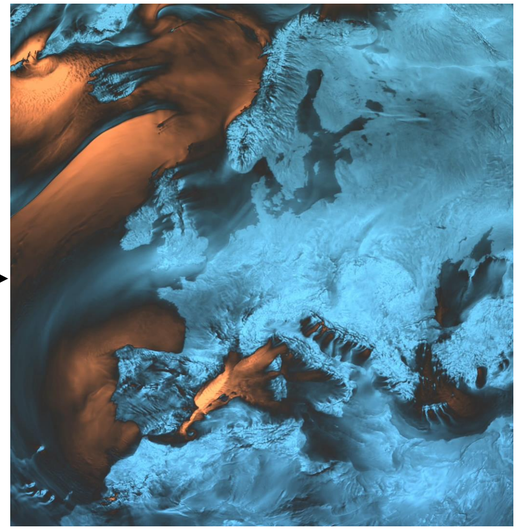
CLIMATE MODEL

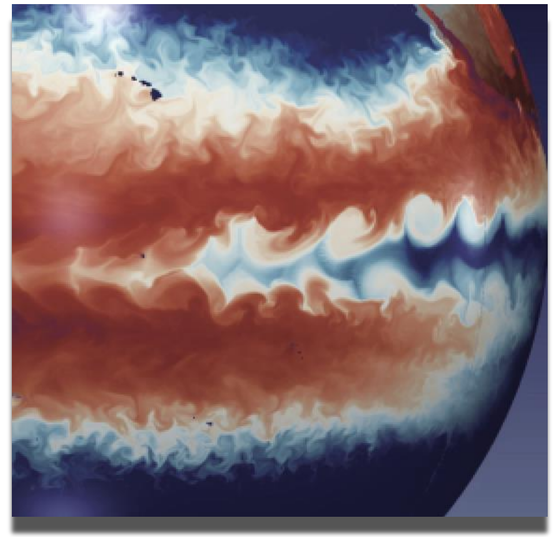
Forcings





~1,000,000 lines of Fortran computer code



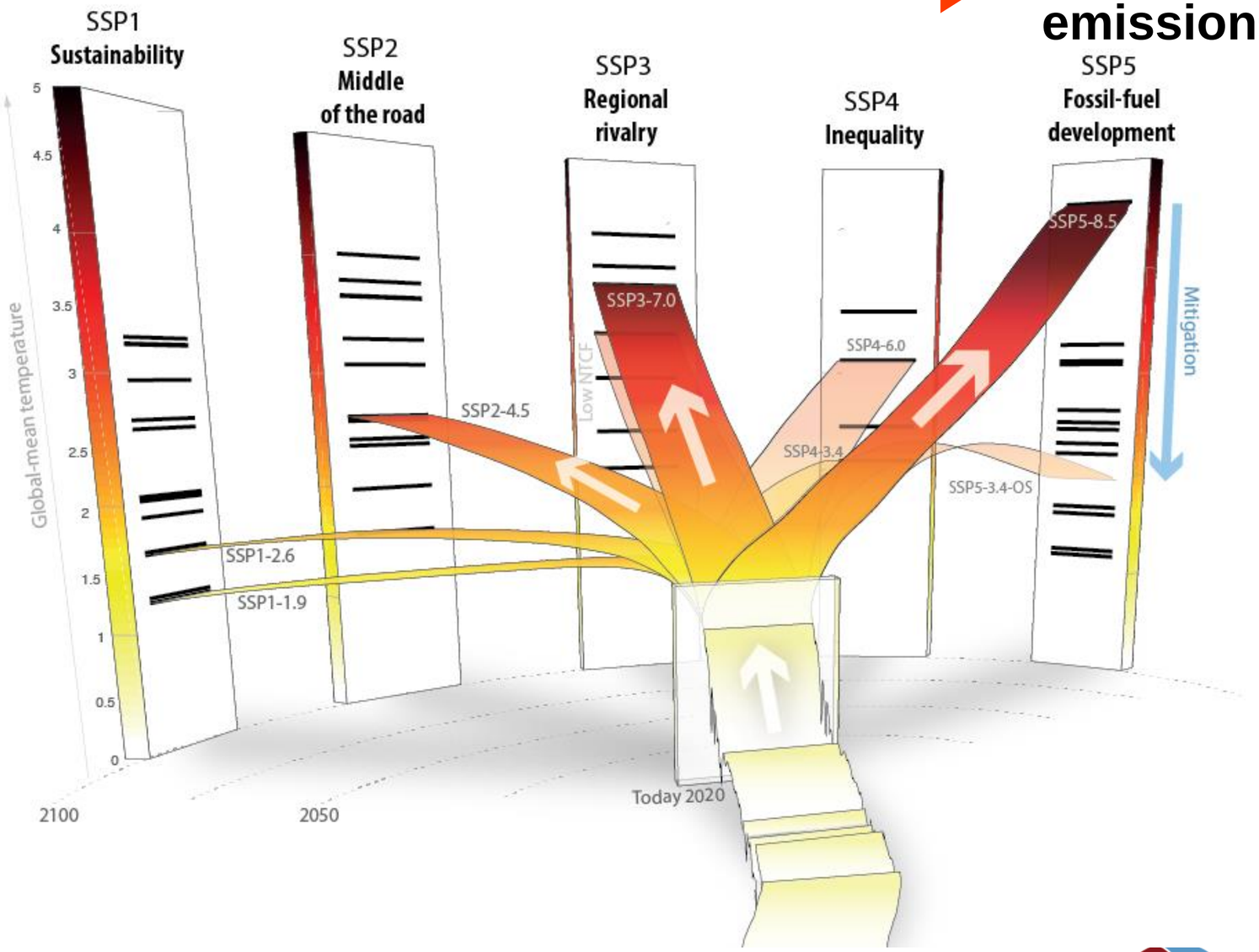


What is a Climate Model?

Low CO_2 emissions → **High CO_2 emissions**

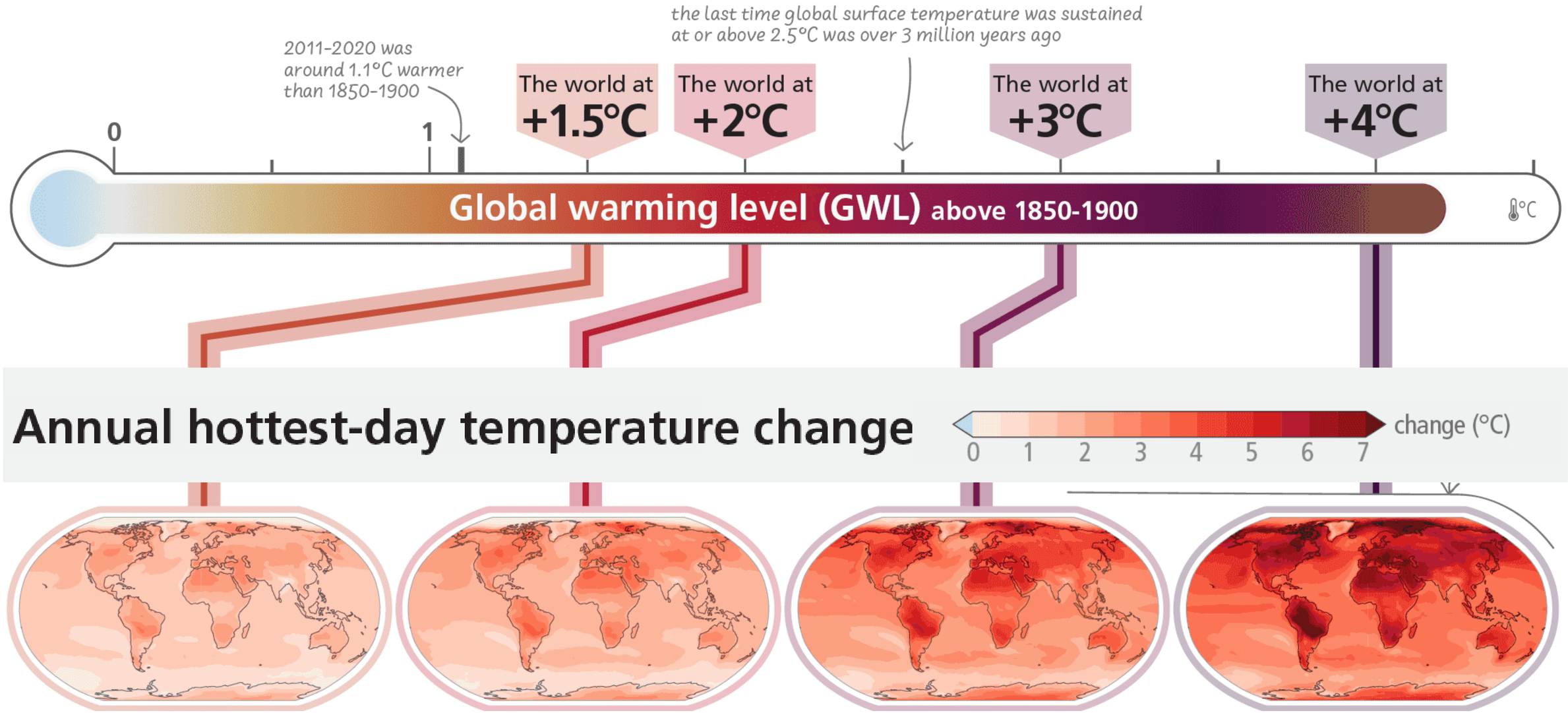
Shared Socioeconomic Pathways are future human development scenarios

- sustainable development (SSP1)
- middle-of-the-road development (SSP2),
- regional rivalry (SSP3),
- inequality (SSP4)
- fossil-fueled development (SSP5)



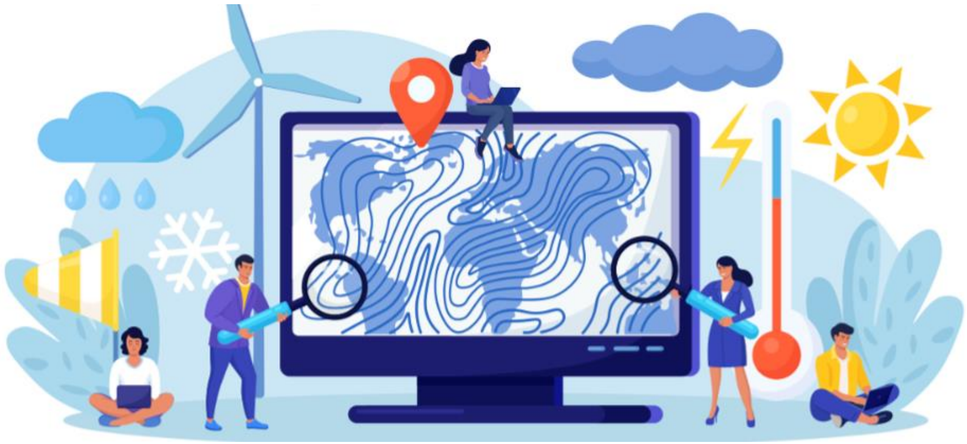
Graphics: Meinshausen et al. (2020)

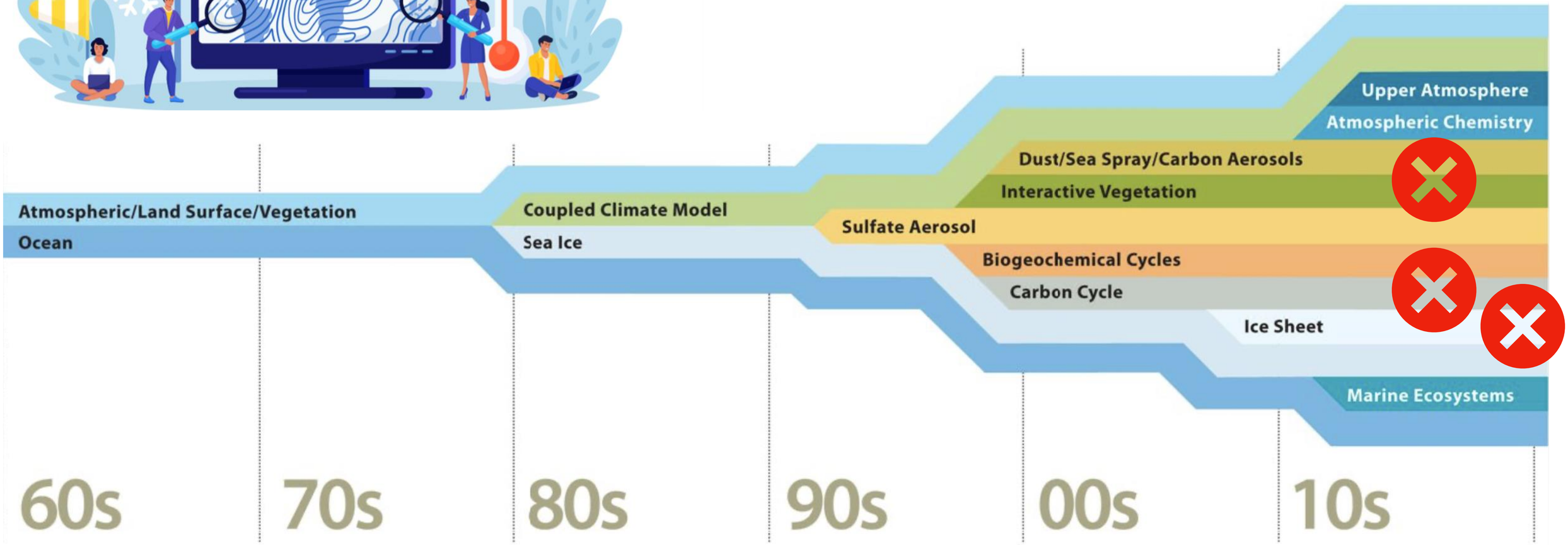
Emission Scenarios: the future is still in our hands



Graphics: Adapted from IPCC, AR6, Summary for Policymakers

Emission Scenarios: the future is still in our hands





Graphics: UCAR, Growth of Climate Modeling

Status of the Earth System Modeling

IBS Center
for Climate Physics

Abstract | Assets | Discussion | Metrics

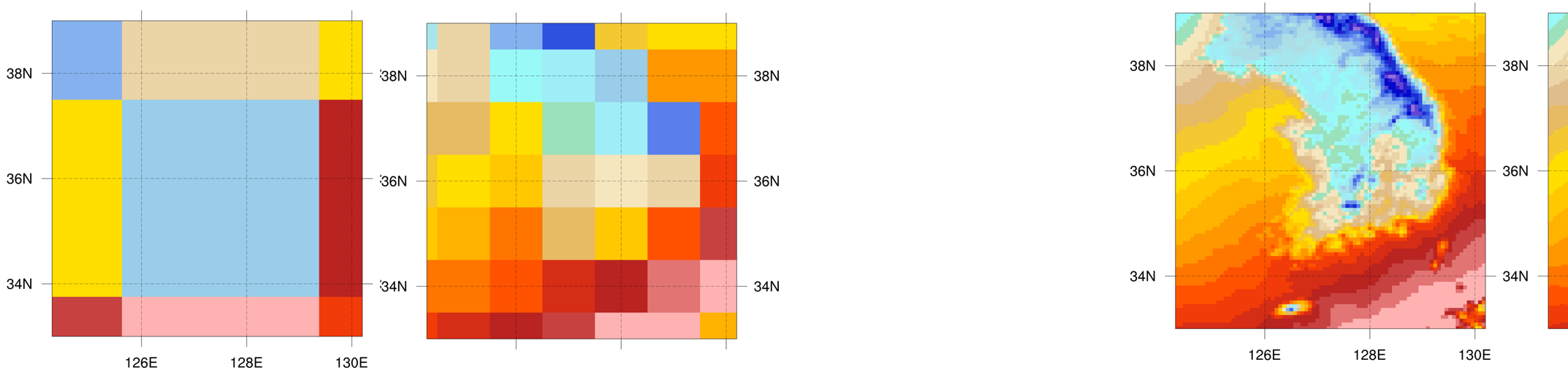
09 Aug 2024

90s | 00s | 10s

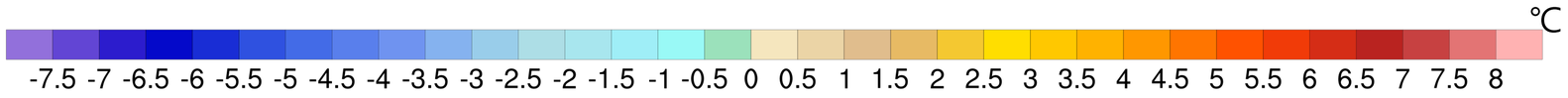
Earth's future climate and its variability simulated at 9 km global resolution

Ja-Yeon Moon, Jan Streffing, Sun-Seon Lee, Tido Semmler, Miguel Andrés-Martínez, Jiao Chen, Eun-Byeoul Cho, Jung-Eun Chu, Christian Franzke, Jan P. Gärtner, Rohit Ghosh, Jan Hegewald, Songyee Hong, Nikolay Koldunov, June-Yi Lee, Zihao Lin, Chao Liu, Svetlana Loza, Wonsun Park, Woncheol Roh, Dmitry V. Sein, Sahil Sharma, Dmitry Sidorenko, Jun-Hyeok Son, Malte F. Stuecker, Qiang Wang, Gyuseok Yi, Martina Zapponini, Thomas Jung, and Axel Timmermann

3.75º | 1º | 9 km | 4 km



Graphics: Sun-Seon Lee, IBS Center for Climate Physics



Climate Modelling: the issue of resolution


Climate Futures at 9 km global resolution

9 km

1950 control

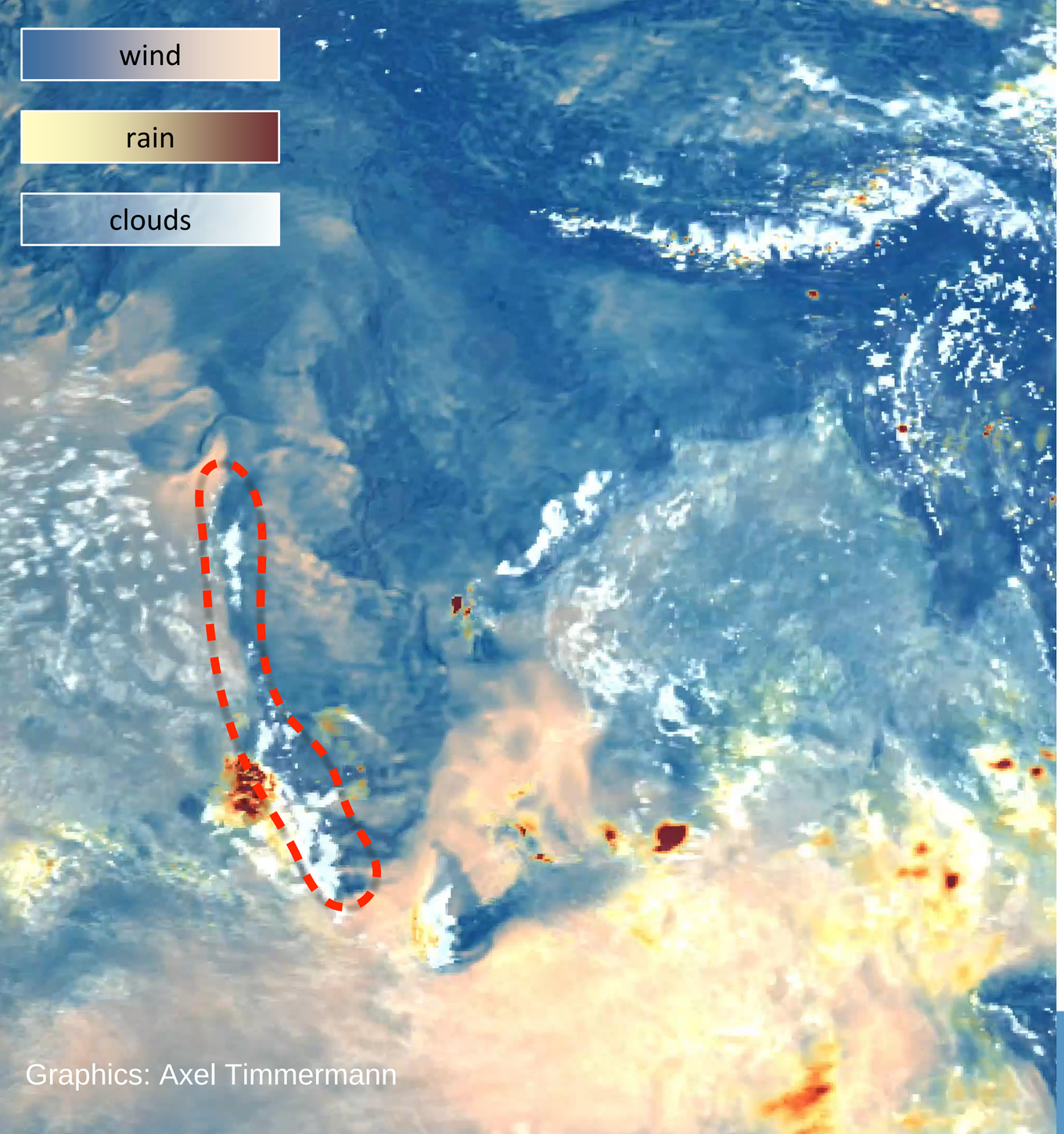
2000s

2030s

2060s

2090s

1950-2100 (31 km resolution)



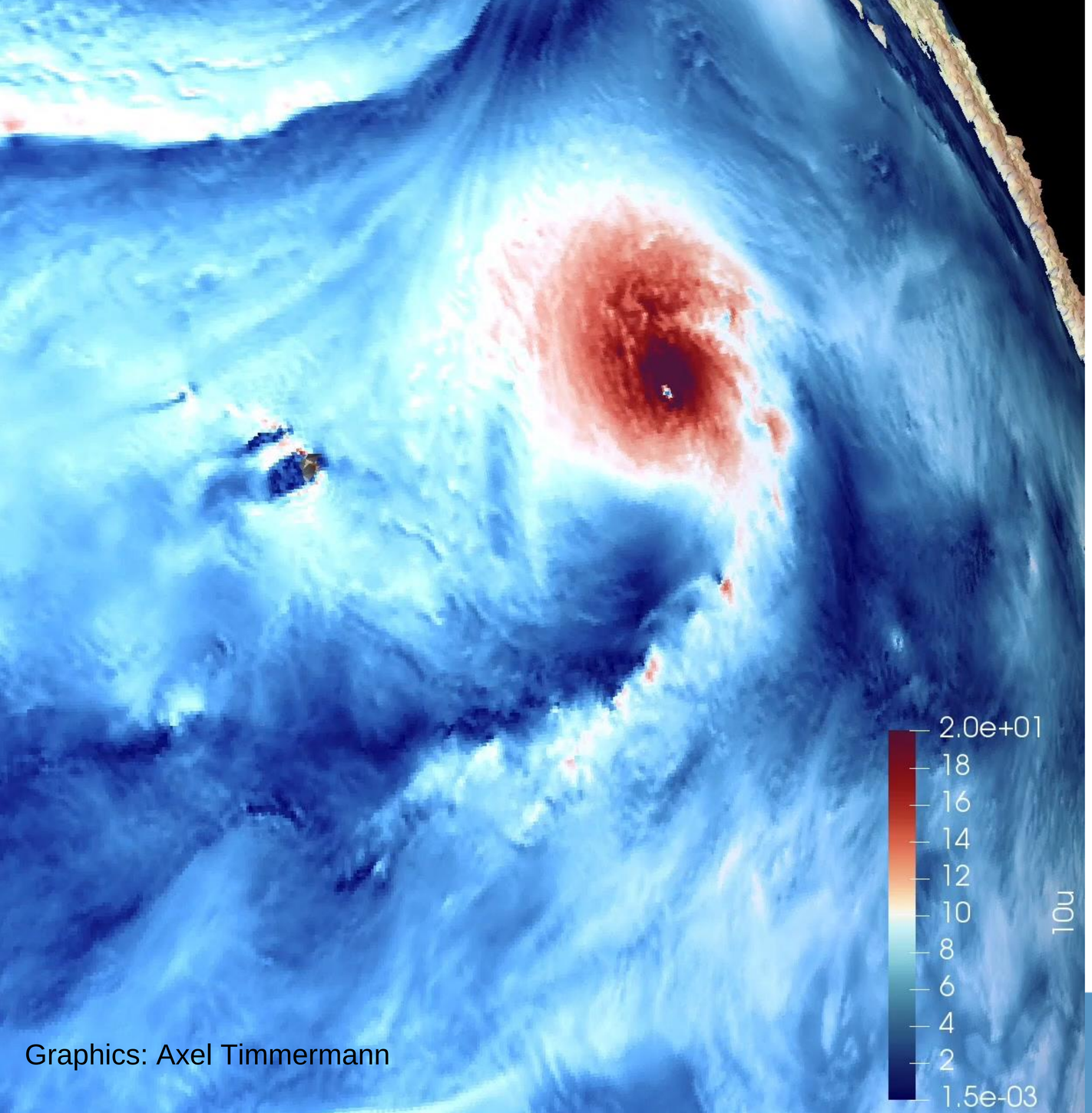
Graphics: Axel Timmermann

A high-resolution perspective on Monsoon systems

- Orographic features, such as the western Ghats play a key role in anchoring summer rainfall
- Mesoscale systems with small-scale filaments can also contribute to extreme rainfall across India
- These features are not well resolved in typical models used in the Coupled Model Intercomparison Project, phase 6

OpenIFS-FESOM, 9 km atmosphere Moon et al. ESD (2025)

A high-resolution perspective on Tropical Cyclones

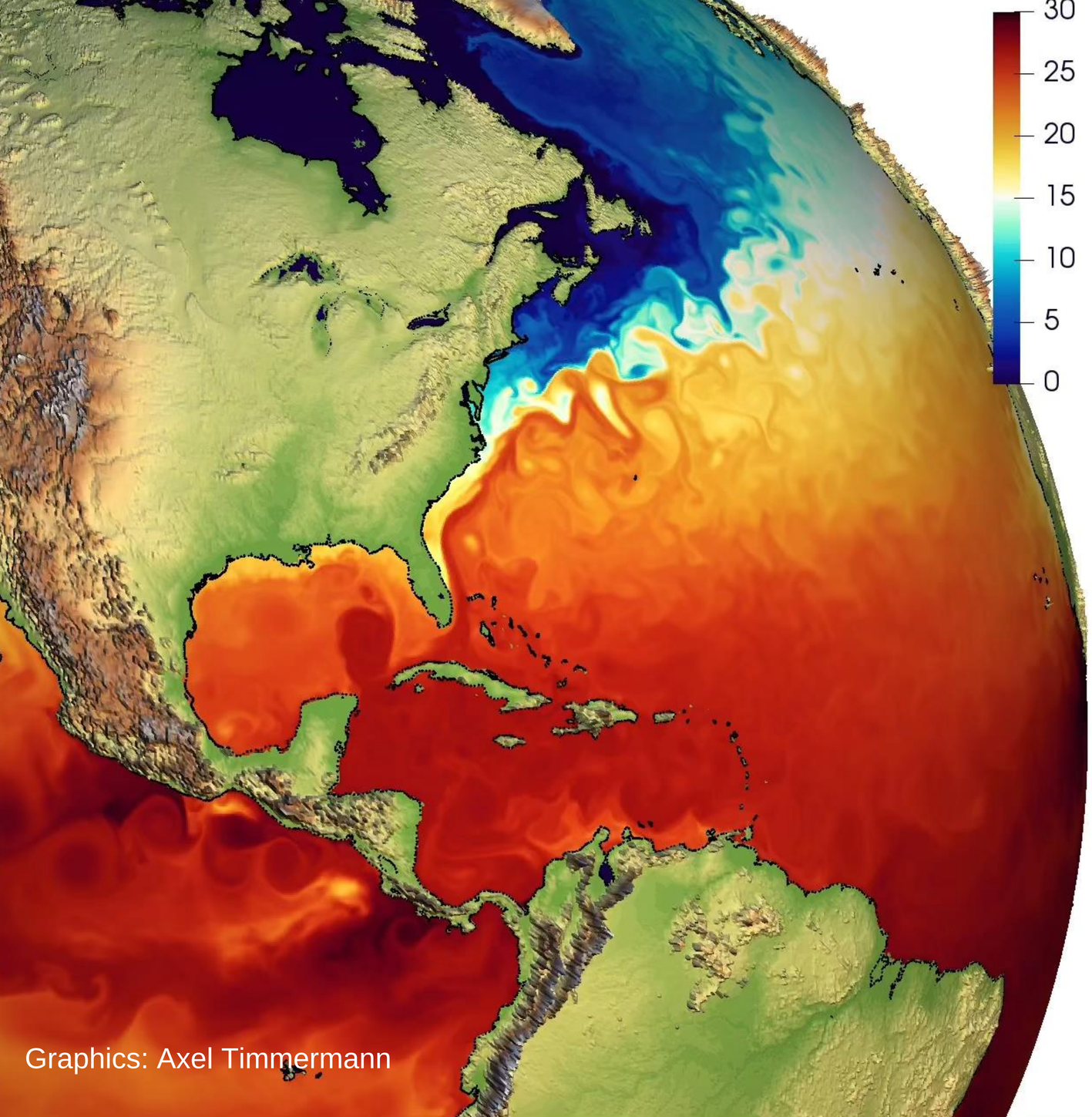


Graphics: Axel Timmermann

- Convective-scale processes can be resolved in high resolution models
- Eye-wall structures and rainfall extremes realistic
- Better resolution of coastal and topographic interactions
- These features are not well resolved in typical models used in the Coupled Model Intercomparison Project, phase 6

OpenIFS-FESOM, 9 km atmosphere Moon et al. ESD (2025)

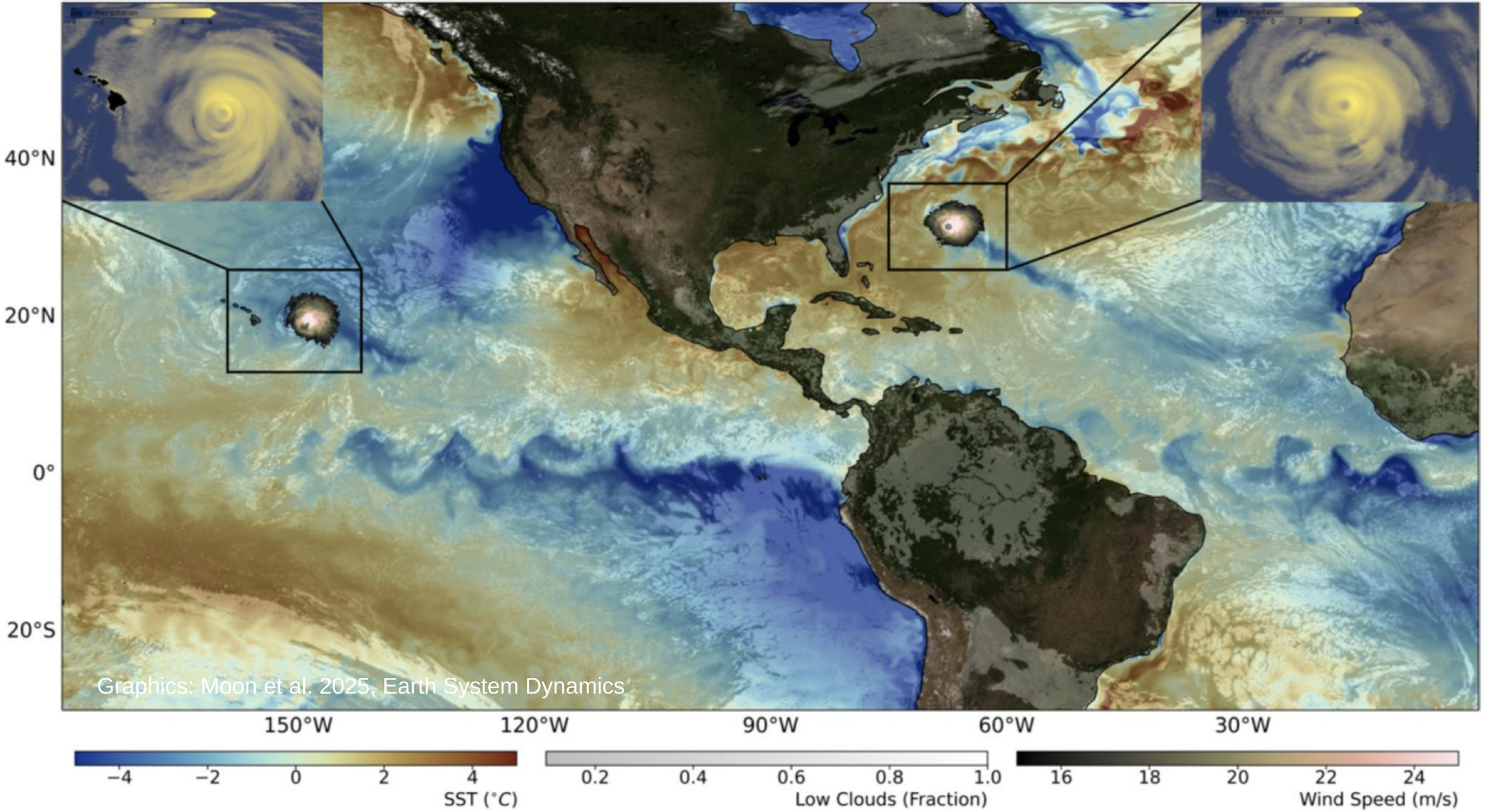
A high-resolution perspective on Ocean Circulation

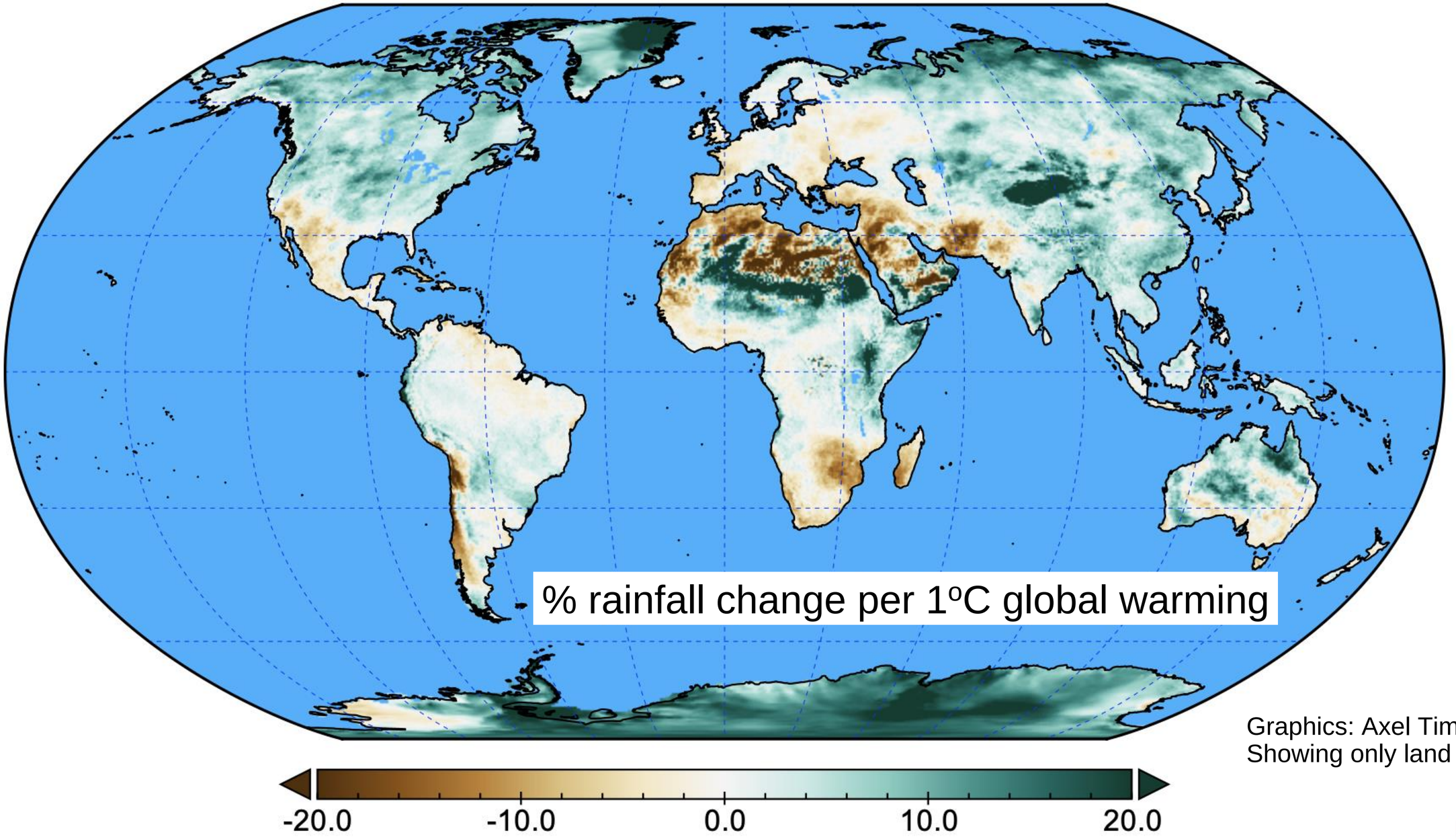


- Small-scale ocean currents and eddies better resolved
- Coastal features well captured
- Tropical cyclone wake effects on ocean temperatures represented
- These features are not well resolved in typical models used in the Coupled Model Intercomparison Project, phase 6

Graphics: Axel Timmermann

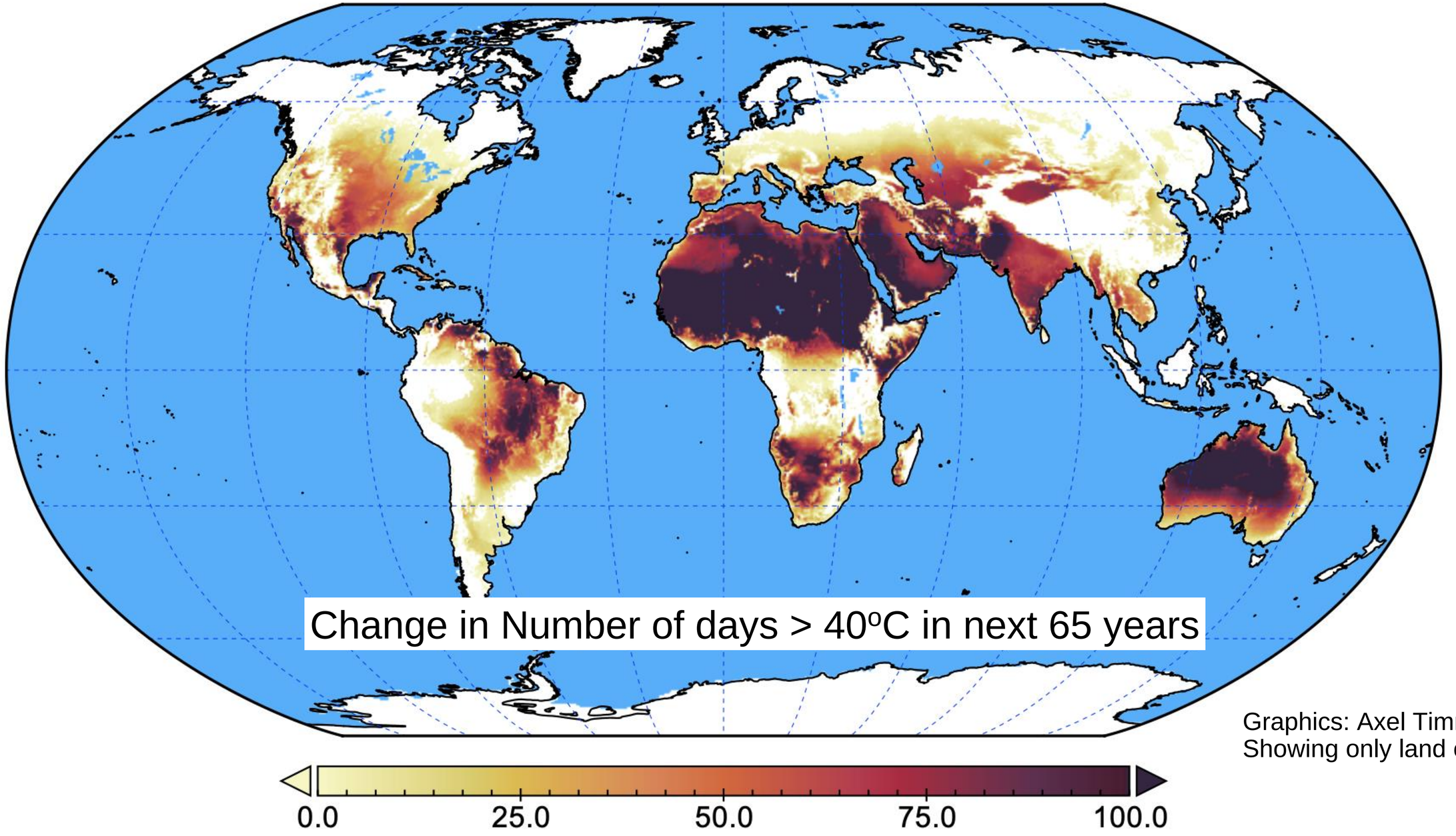
OpenIFS-FESOM, 9 km atmosphere Moon et al. ESD (2025)


40°N
20°N
0°
20°S
150°W
120°W
90°W
60°W
30°W
Graphics: Moon et al. 2025, Earth System Dynamics
−4
−2
0
2
4
SST (°C)
0.2
0.4
0.6
0.8
1.0
Low Clouds (Fraction)
16
18
20
22
24
Wind Speed (m/s)



Graphics: Axel Timmermann,
Showing only land changes

9 km global warming projections



Graphics: Axel Timmermann,
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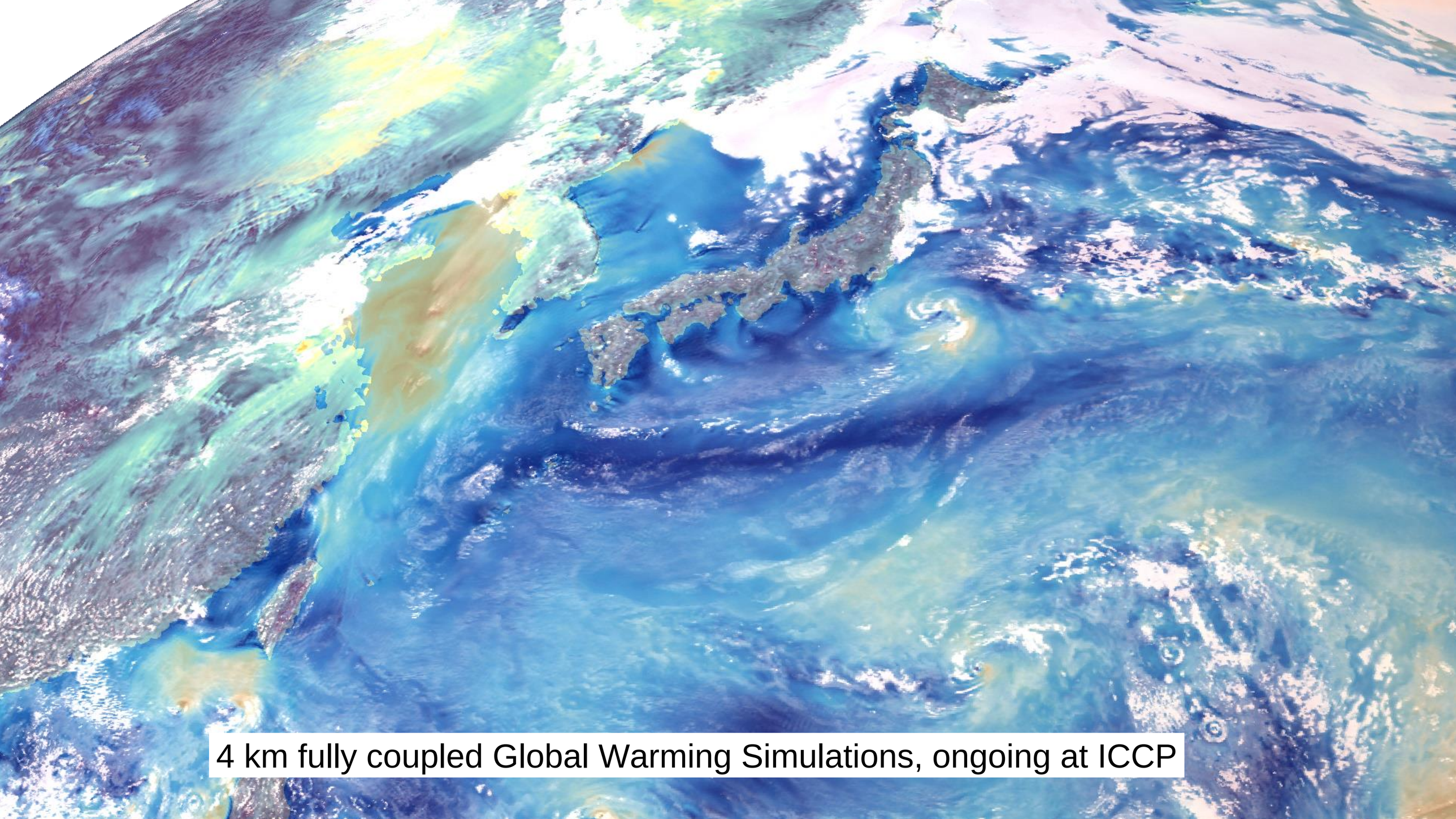
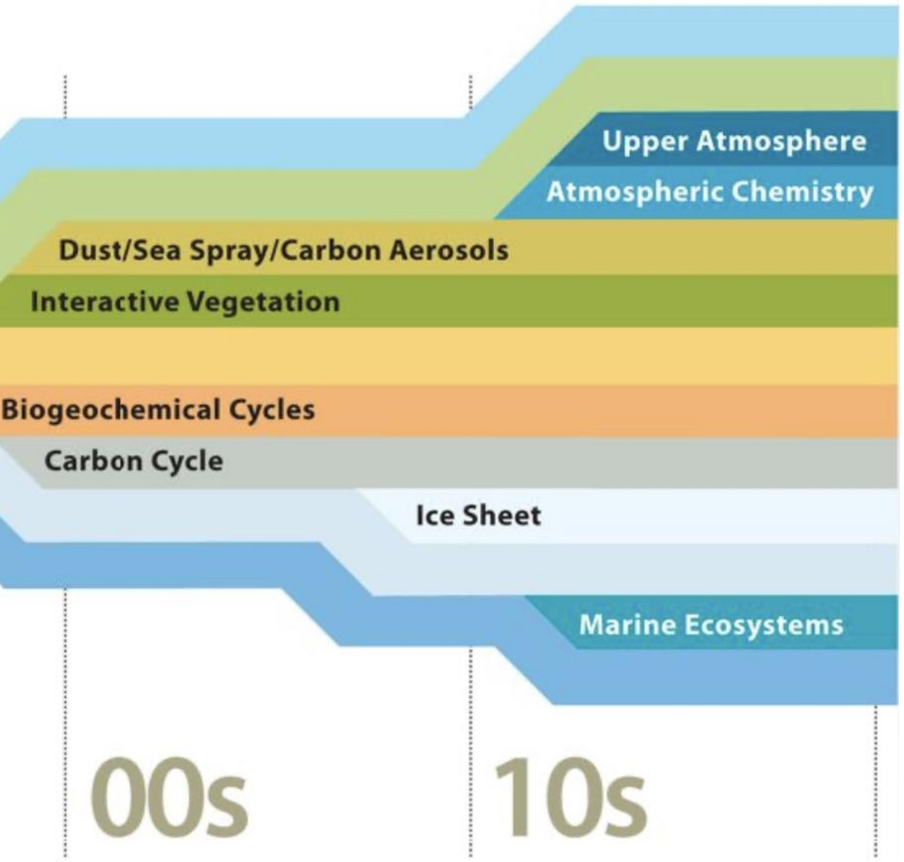

4 km fully coupled Global Warming Simulations, ongoing at ICCP


The next Frontier in
Earth System Modeling



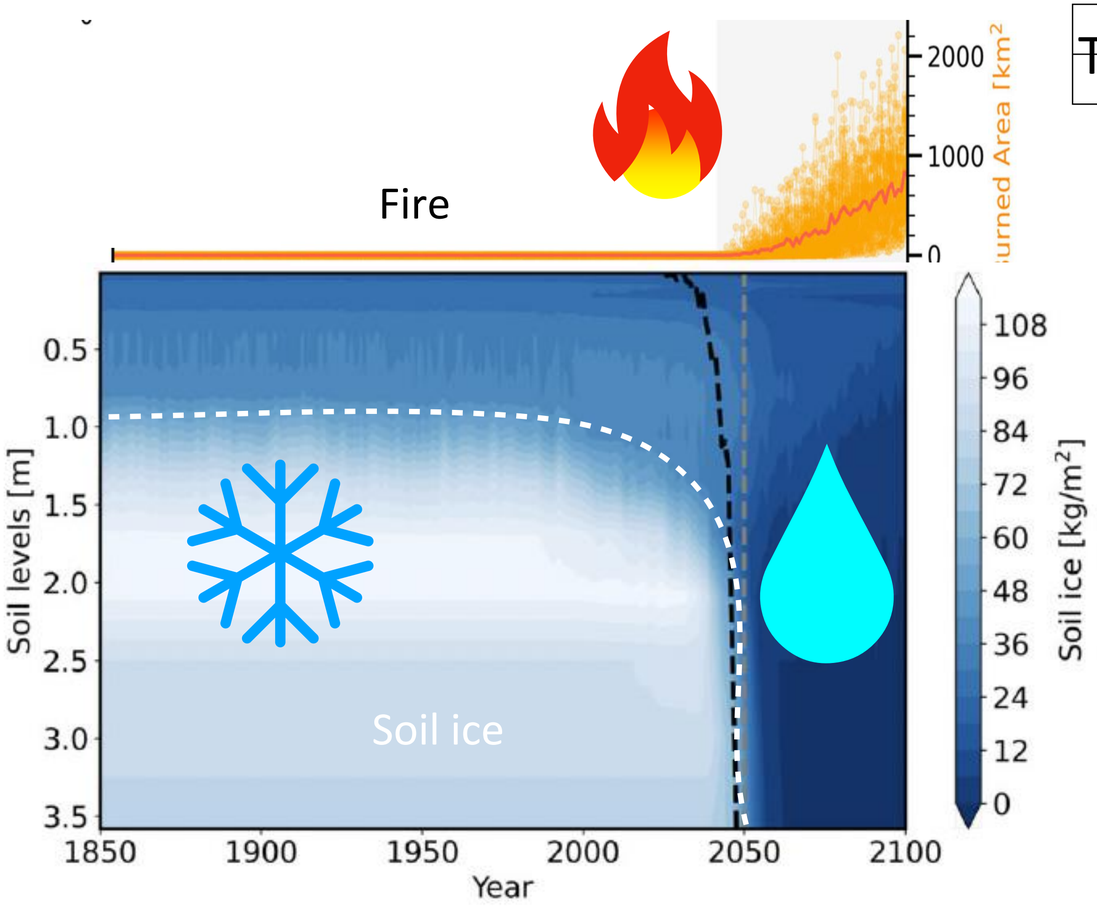
Graphics: UCAR, Growth of Climate Modeling

Vegetation, Permafrost	Lightning Fire/aerosol coupling Dispersal
Carbon Cycle	Permafrost carbon Glacial carbon sequestration Carbonate dissolution
Ice Sheets	Glacial ice sheet dynamics Coupling with Ocean/Atm.
Marine and Terrestrial Ecosystems	Adaptability Habitats Plasticity

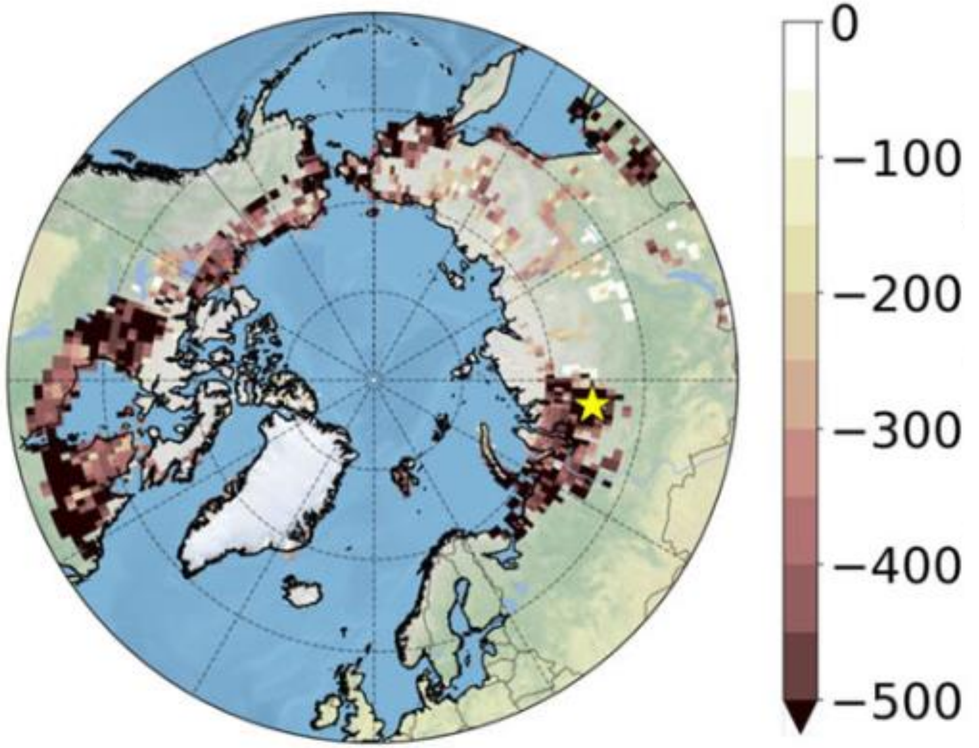
Improving Earth System Components

Vegetation, Permafrost

Lightning
Fire/aerosol coupling
Dispersal



Timing of abrupt wildfire and permafrost change



Abrupt increase in wildfires in subarctic regions between 2030-2090.

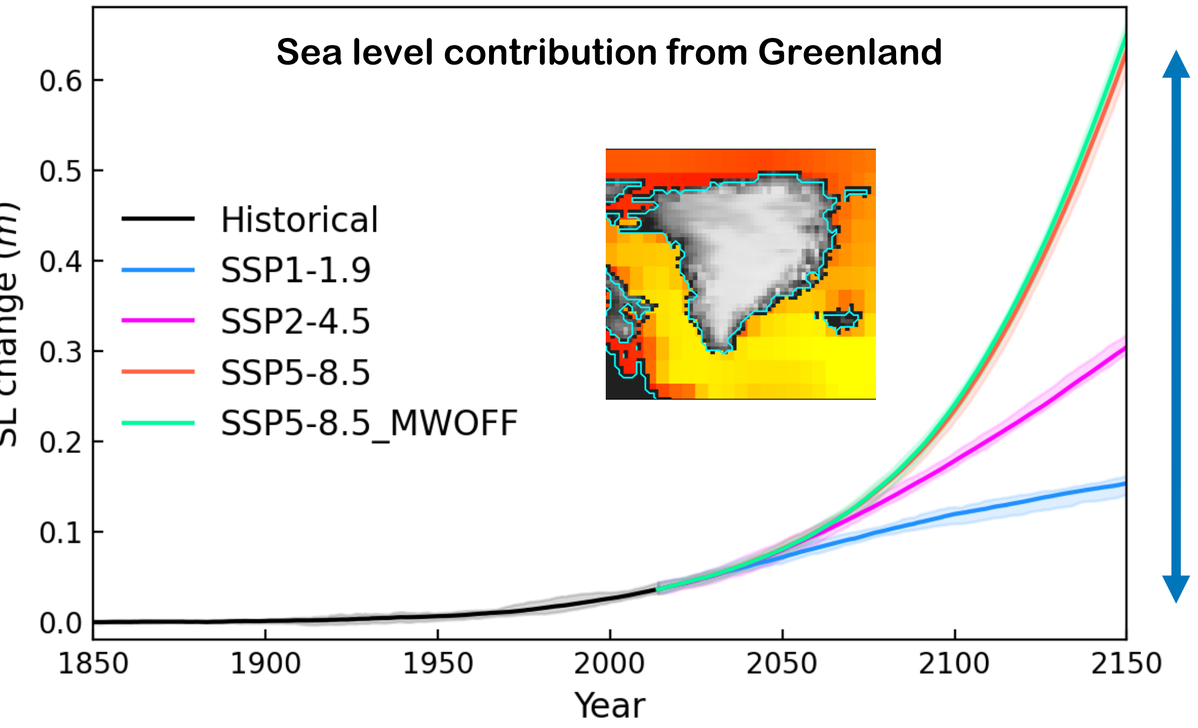
Graphics: In Won Kim, ICCP, Nature Communications 2024

Fire, permafrost, climate interactions

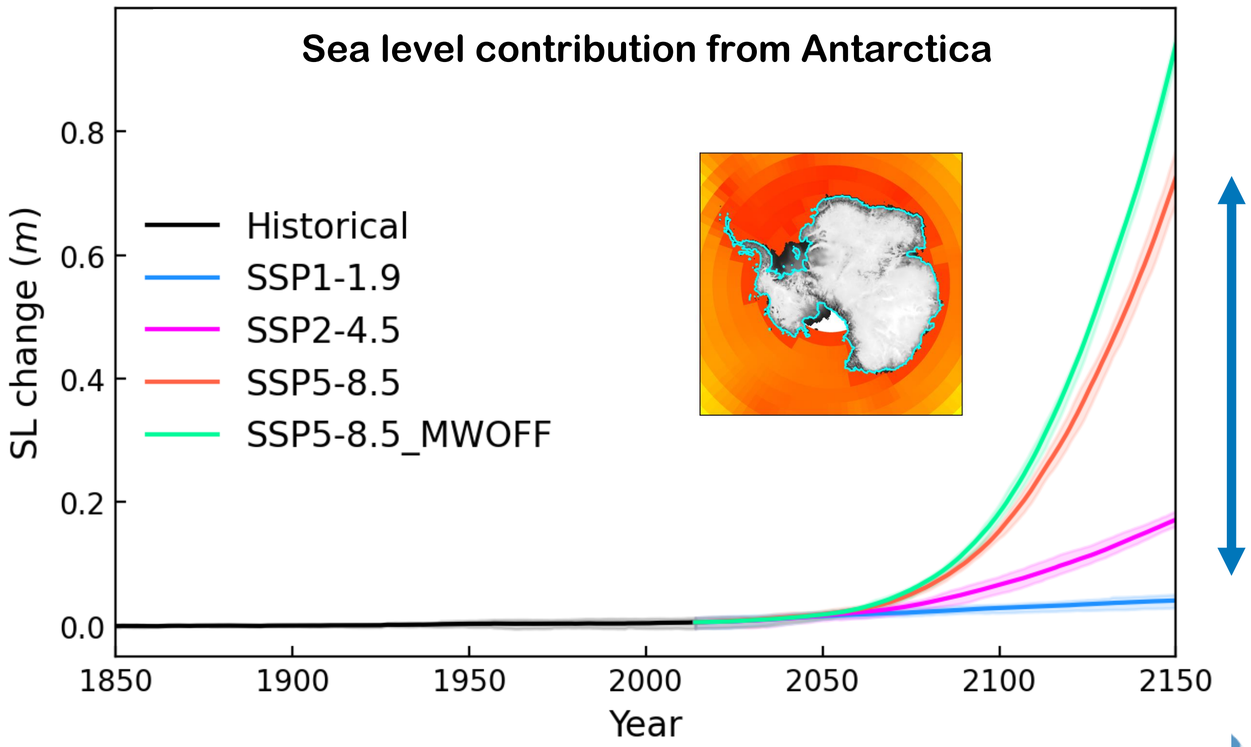
Ice Sheets

Glacial ice sheet dynamics
Coupling with Ocean/Atm.

0.6 m

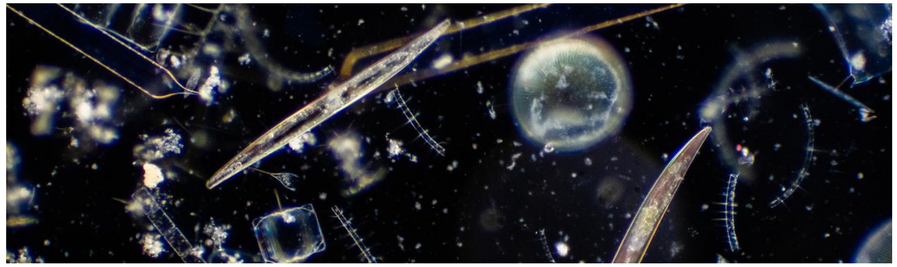


0.75 m



Graphics: Jun-Young Park, ICCP, Nature Communications 2024

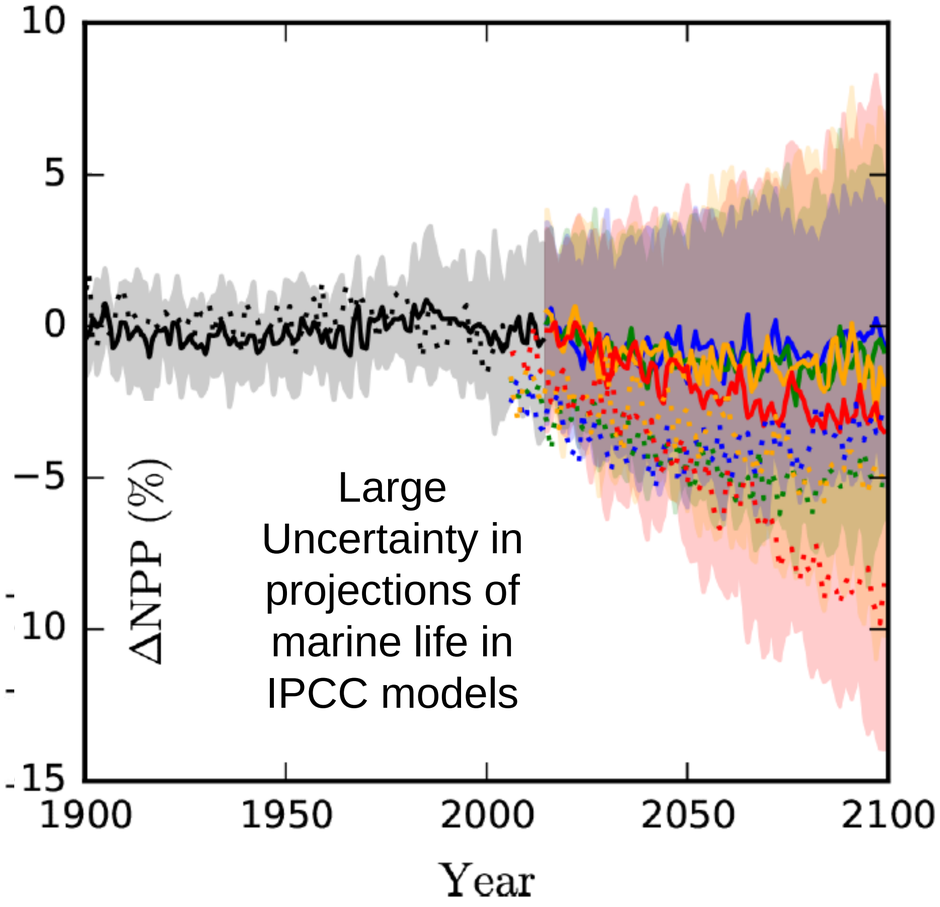
Total sea level rise by 2150: 1.4 m + thermal expansion & other contributions



Marine Ecosystems

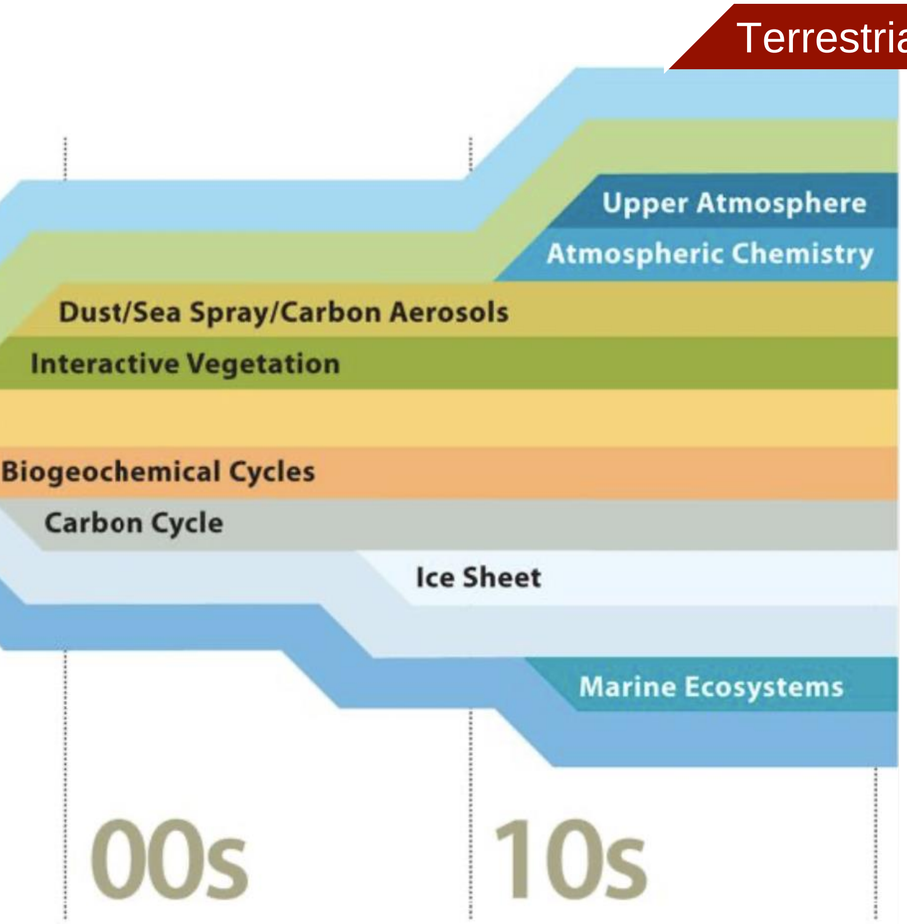
Adaptability
Habitats
Plasticity

Graphics: Eun Young Kwon, ICCP, Science Advances 2023



Nutrient deficiency in surface ocean was believed to reduce phytoplankton

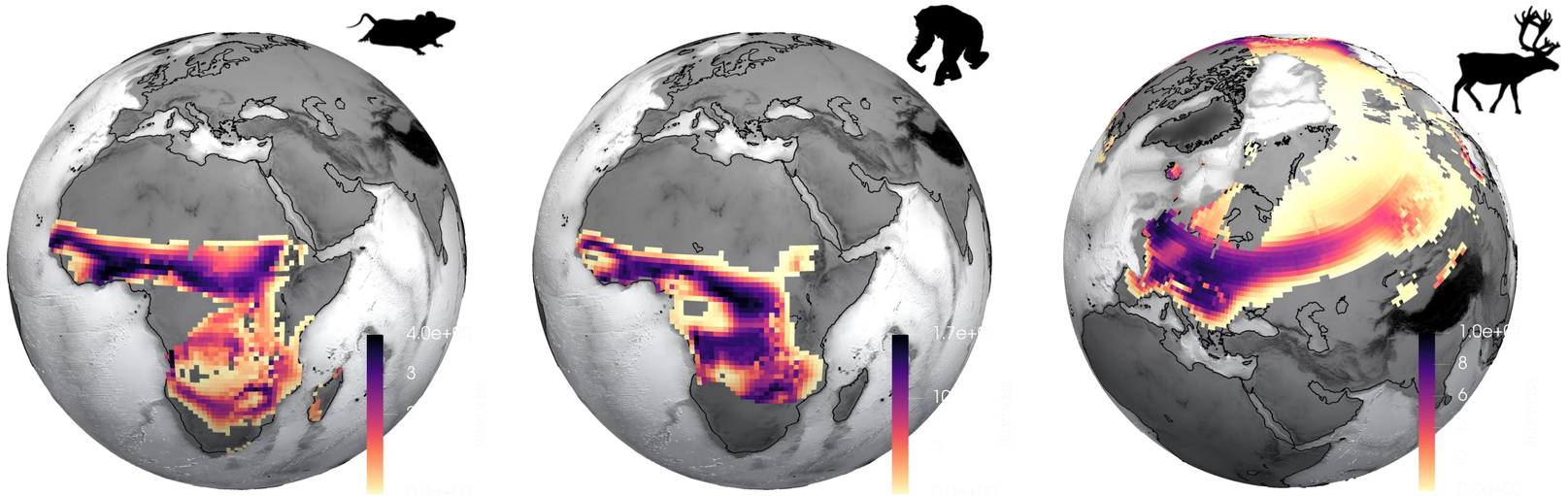
The plasticity of life in a changing climate



Graphics: UCAR

Terrestrial Life

Mammals
Humans
Insects, etc.

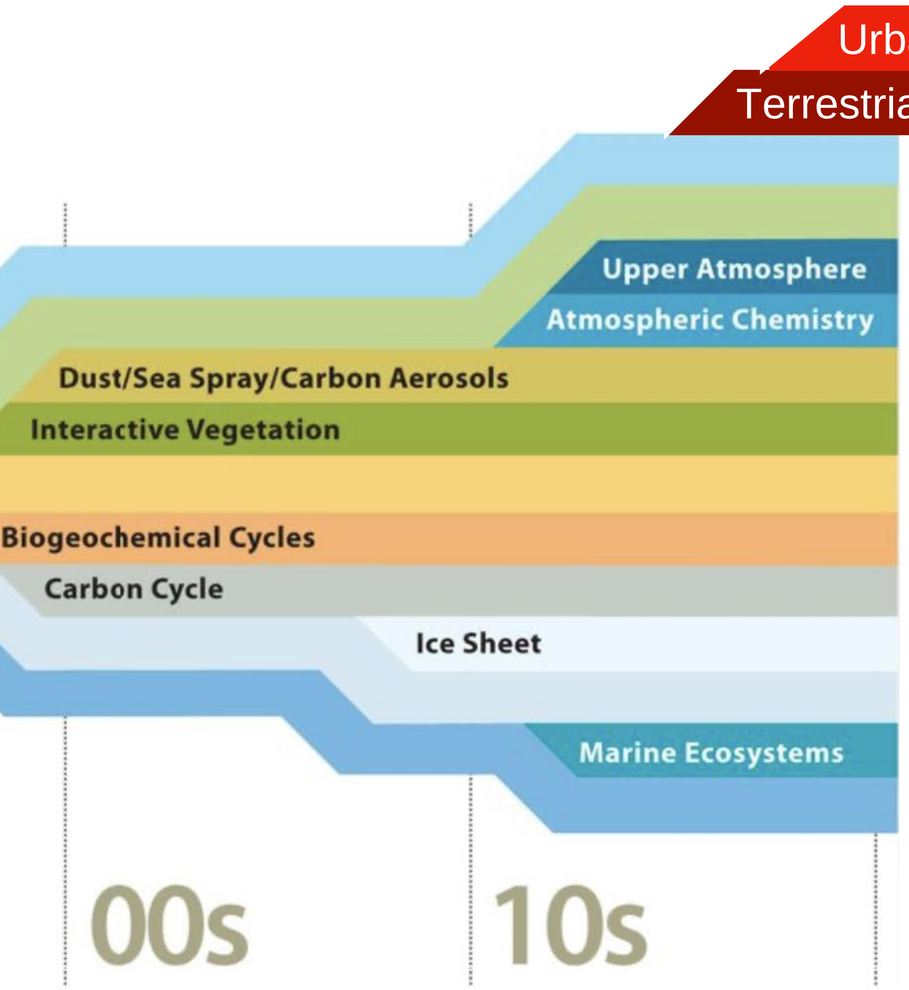


Planetary Health

Vegetation

Graphics: Axel Timmermann, ICCP, 2025

Simulating the future of terrestrial mammals



Graphics: UCAR

Shortwave and longwave radiation in a city is complicated

Strong sensible heat fluxes, small latent heat flux

Extra heat sources from AC, heating, exhausts

Graphics: Firefly Adobe

We live in cities, many climate models don't know cities


Climate Change Service Centers

Climate Model

High Resolution

Large Ensemble

Climate Product

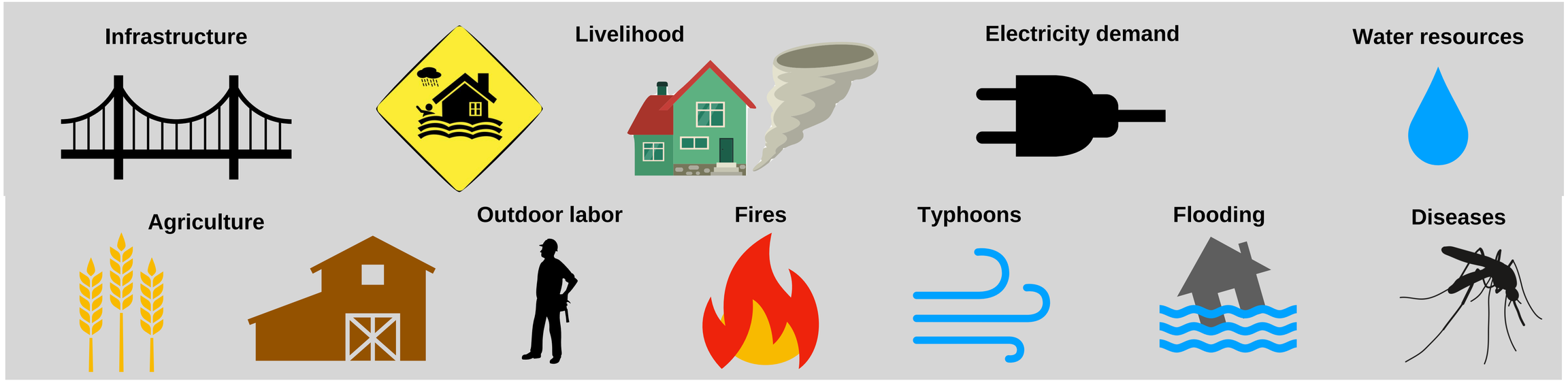
Tailored products

Impact assessments

Stakeholder

Government institutions

Companies, NGOs, citizens

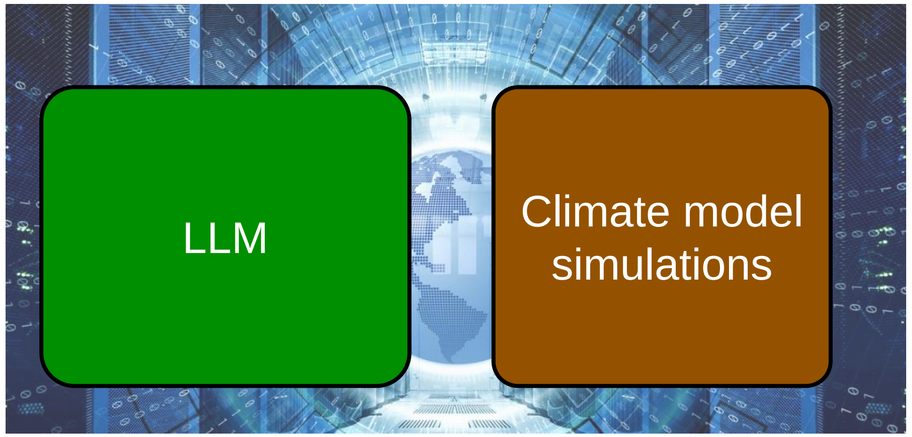


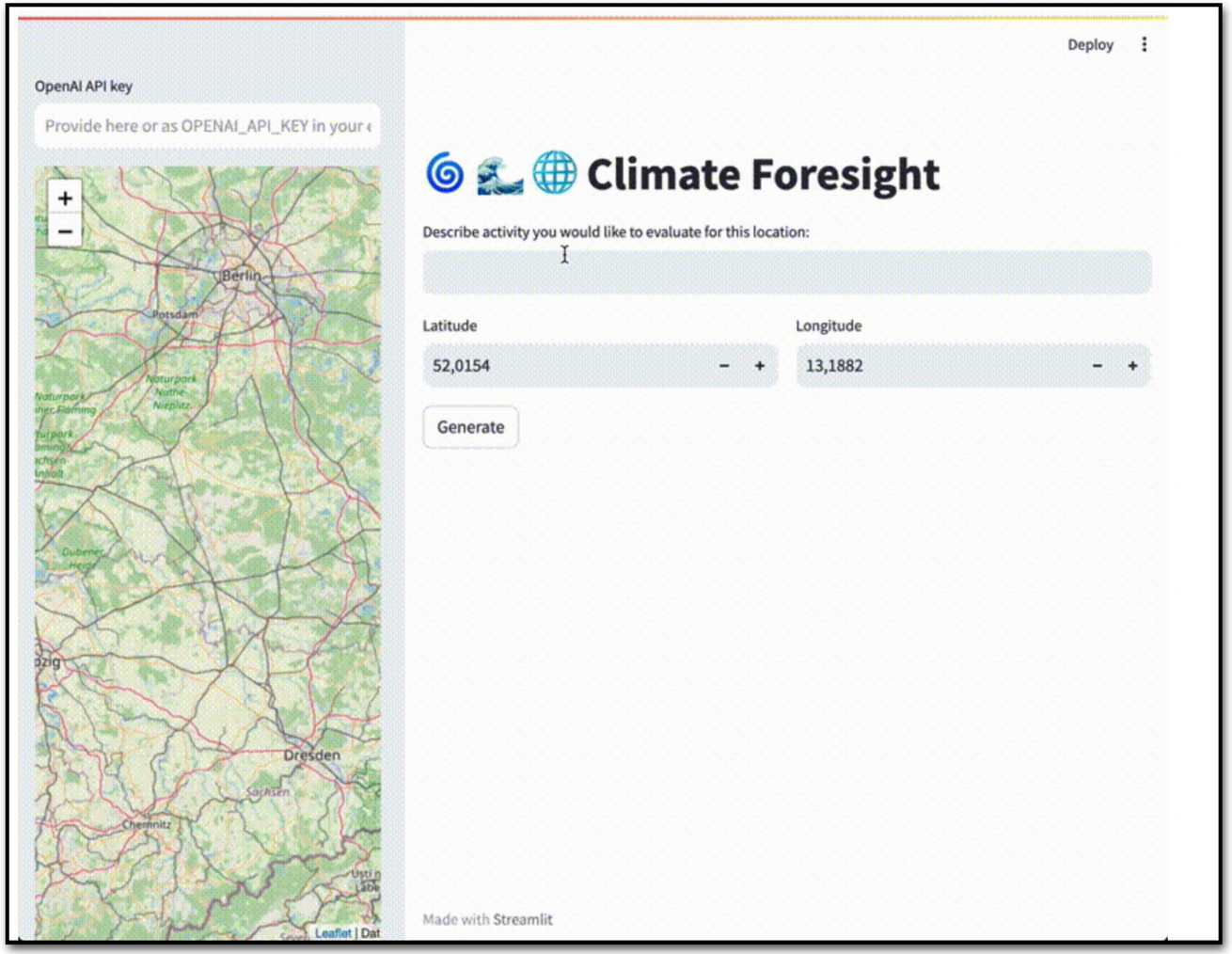
Graphics: Axel Timmermann, ICCP, 2024

Climate Change Service Centers

Local climate services for all, courtesy of large language models

Nikolay Koldunov & Thomas Jung





Movie: from Koldunov and Jung, Communications, Earth and Environment, 2024

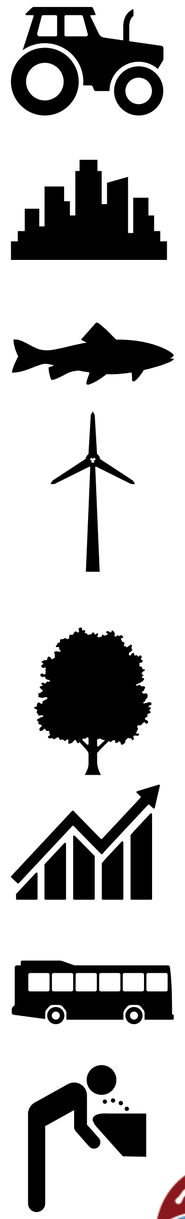
ICCP

ICCP

APCC

Busan Climate Change Service Center (BCS)

- Agriculture
- Cities
- Ecosystems
- Energy
- Forestry management
- Supply Chains
- Transportation
- Water management




Thank you for
your attention