Climate Modelling and Data Analysis

Prof. Dr. Tobias Sauter

Date 02.05.2022

Important organisational details

Where do the classes take place?

- Mo. 9-13 h (ct), weekly until 18.07.22
- Alfred-Rühl-Haus **Room 1'206** Rudower Chaussee 16 and **Room 1'231**

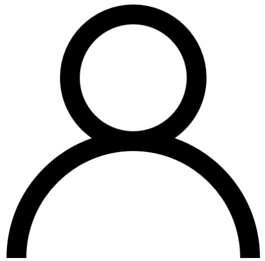
Moodle

- https://moodle.hu-berlin.de/course/view.php?id=110342
- Self-registration password: **modelling22**
- All further general correspondence happens via Moodle, and for matters regarding your talks, via your HU email address

What you need to successfully complete the course?

- You must attend the course regularly
- You should have worked on the exercises independently
- VL 2 SWS (4 LP), SE 2 SWS (4 LP)
- Exam 2 LP, scientific article (10 pages, 15.000-20.000 ZoL)

Important organisational details



The course is designed for those who ...

- are interested in models and want to understand how they work
- wants to learn more about the processes in the Earth system
- wants to design and develop their own simple models

Learning objectives

- The fundamentals of fluid dynamics and environmental processes
- The basics of climate models and parametrizations
- Numerical methods for solving differential equations
- Developing simple models
- Deeper understanding of selected atmospheric and environmental processes
- Understand how models are used in simulations
- How to share and communicate model results
- Learning by hands-on exercises on real-world problems

Important organisational details

What requirements do you need?

- You should know what the Python interpreter is and how to run Python programs.
- You should be familiar with the Jupyter Notebooks development environment.
- You should know the basics of Python (lists, loops, if-queries, functions)
- It would be advantageous if you have looked at the Numpy Library
- Fundamental of calculus

This course is not ...

- an introduction to Python
- a pure lecture on models and their application
- it is not a course on the impacts of climate change

Important organisational details

Literature

McGuffie K. & Henderson-Sellers A., 2014: **A Climate Modelling Primer**. Wiley & Sons.

Jacobson M., 2005: **Fundamentals of atmospheric modelling**. Cambridge University Press.

Kundu P.K., Cohen I.M., and Dowling D.R., 2016: **Fluid Mechanics**. Elsevier.

Von Storch H., Güss S. & Heimann M. (1999): **Das Klimasystem und seine Modellierung**. Springer Verlag, Heidelberg.

Rose, Brian E. J. (2020, November 9). *Insolation*, **The Climate Laboratory**, https://brian-rose.github.io/ClimateLaboratoryBook/courseware/insolation.html

Participants

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5:	569046	Wilbrand	Robert
6:	575931	Jaeppelt	Anne
7:	581860	Neumaier	Antonia
8:	583307	Deppermann	Lara-Heléne
9:	583557	Frankenfeld	Franziska
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12:	592624	Thiemann	Arne
13:	599591	Mahlau	Patrice Nicola
14:	609907	Nepomshina	Olga
15:	610570	Reckwitz	Anna
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20:	616868	Vergara Stuardo	Josefa Aletia
21:	616948	Buszydlo	Dominika
22:	617299	Leisenheimer	Leonie
23:	621029	Kelch	Ronja
24:	622445	Wolff	Sara

ÜWP students

Nr:	MtkNr:	Name:	Vorname:
1:	494341	Torosyan	Hasmik
2:	610257	Uebachs	Anna

Expectation and fulfilment?

Schedule

1. **What are models?**
   Exercise: Python Skills

2. **Energy budget of the Earth**
   Exercise: Simple Energy Balance Model

3. **Nonlinearity, Feedback, and Predictability**
   Exercise: Nonlinearity and Feedbacks
   Exercise: Revised Energy Balance Model

4. **Parametrization and Sensitivity**

5. **Radiative budget**
   Exercise: 1-layer greenhouse model
   Exercise: 2-layer greenhouse model

6. **Introduction to fluid dynamics**
   Exercise: Analytical katabatic flow model

7. **Finite difference method**
   Exercise: Advection-Diffusion Equation
   Exercise: Boundary layer Evolution
   Exercise: Numerical katabatic flow model
   Exercise: Heat Equation

8. **Implicit finite difference methods**
   Exercise: Boundary layer evolution

9. **Optimization problem**
   Exercise: Surface energy balance
   Exercise: Sublimation

10. **COSIPY snow model**
    Exercise: Simulations with COSIPY

11. **Introduction to PALM**
    Exercise: Simulations with PALM

12. **How to write an article**

What are models?

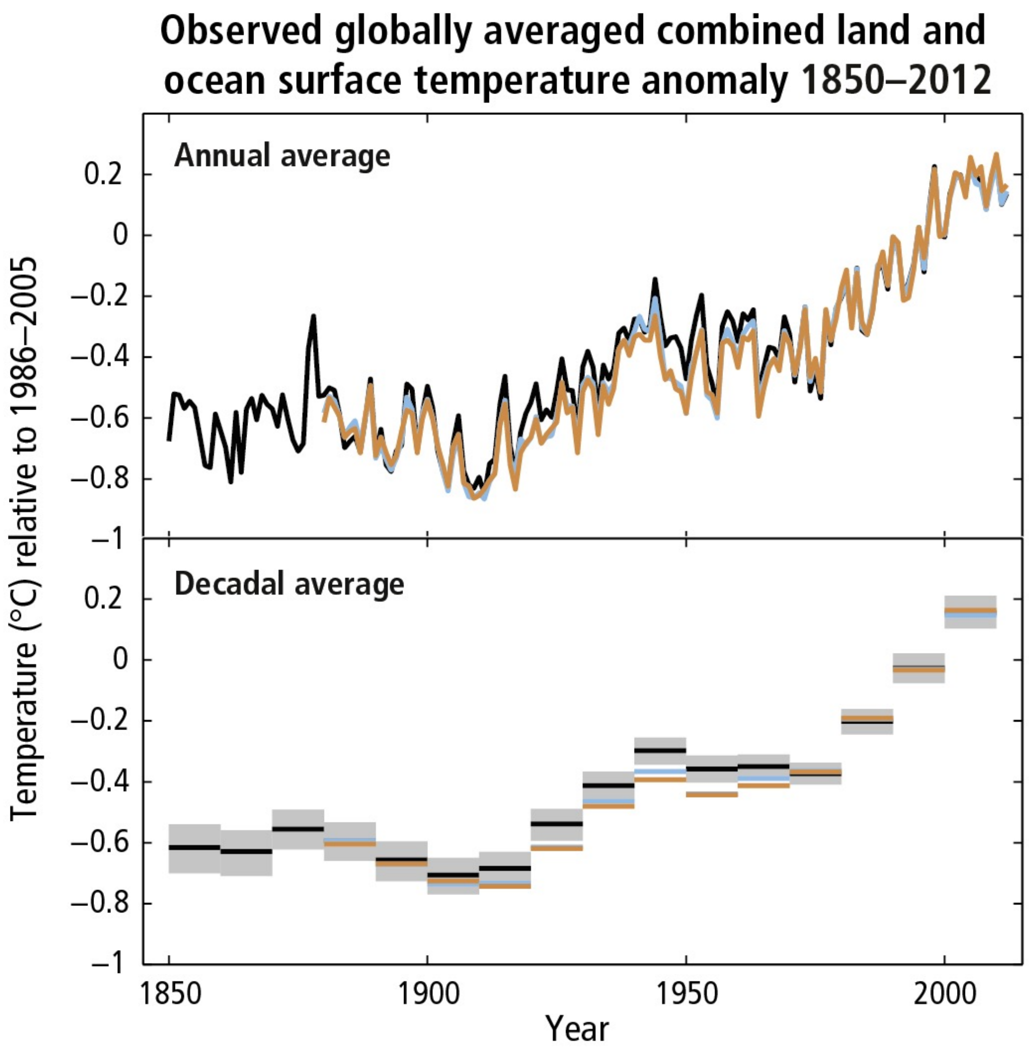
In the broadest sense, **models are for learning about the world** (in our case, the climate) and the learning takes place in the construction and the manipulation of the model, as anyone who has watched a child build idealised houses or spaceships with Lego, or built with it themselves, will know. Climate models are, likewise, **idealised representations of a complicated and complex reality** through which our understanding of the climate has significantly expanded. All models involve **some ignoring, distoring and approximating**, but gradually they allow us to build understanding of the system being modelled. A child's Lego construction typically contains the essential elements of the real objects, improves with **attention to detail**, helps them understand the real world, but is **never confused with the real thing**.

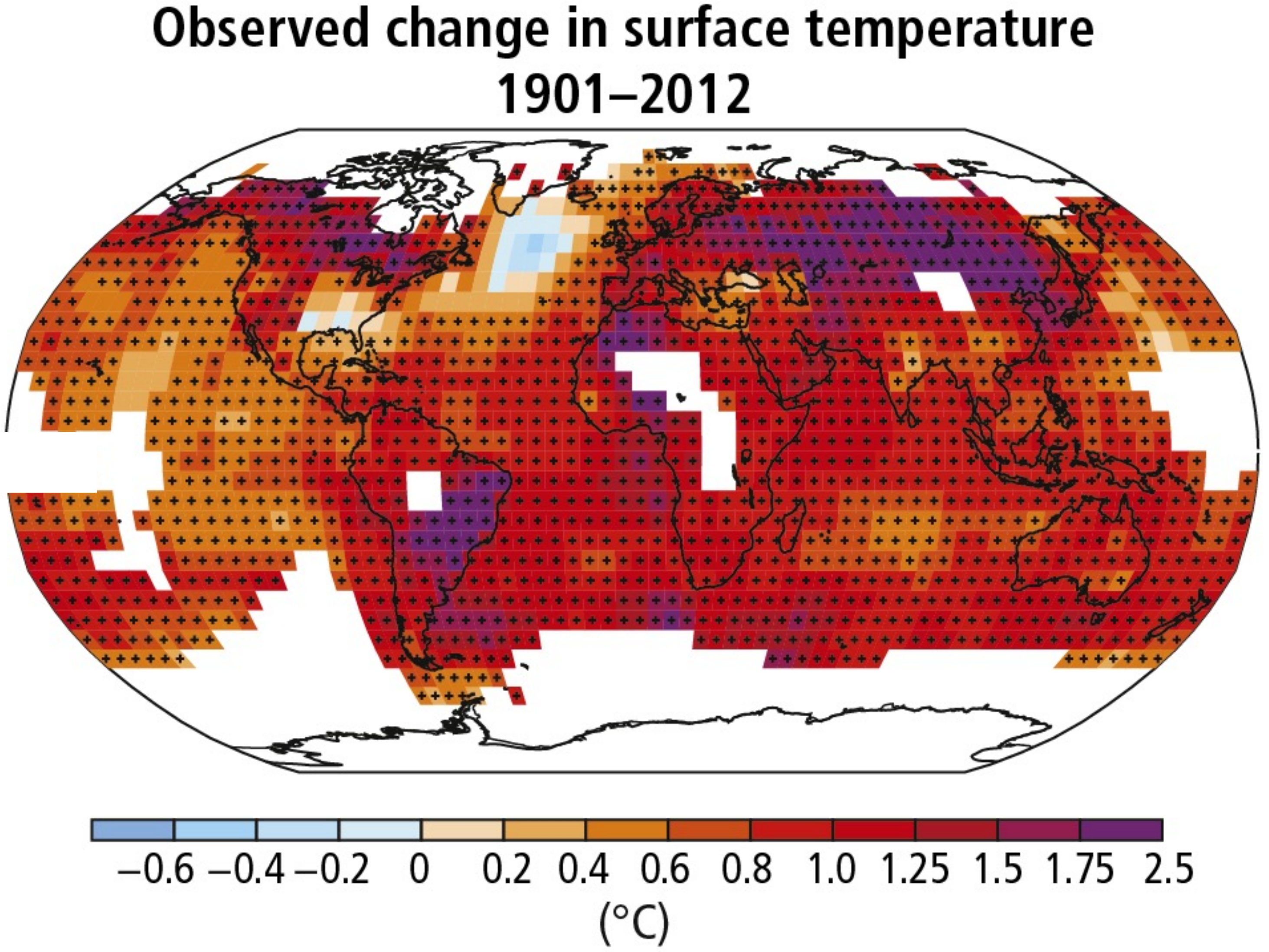
[Source: McGuffie and Henderson-Sellers, 2014]

Reasons for (climate) modelling

- To test the robustness of prevailing theories
- To illuminate features and core uncertainties
- Reduction of complexity
- Raise new questions and suggest analogies
- Models help to explain processes
- Help can be used as a plausibility check
- To communicate and educate public audience
- …

Observed Global Surface Temperature





IPCC AR5 WG1 ***SPM*** *(2013)*

Charney-Report (1979)

Carbon Dioxide and Climate: A Scientific Assessment

Report of an Ad Hoc Study Group on Carbon Dioxide and Climate

Woods Hole, Massachusetts

July 23–27, 1979

to the

Climate Research Board

Assembly of Mathematical and Physical Sciences

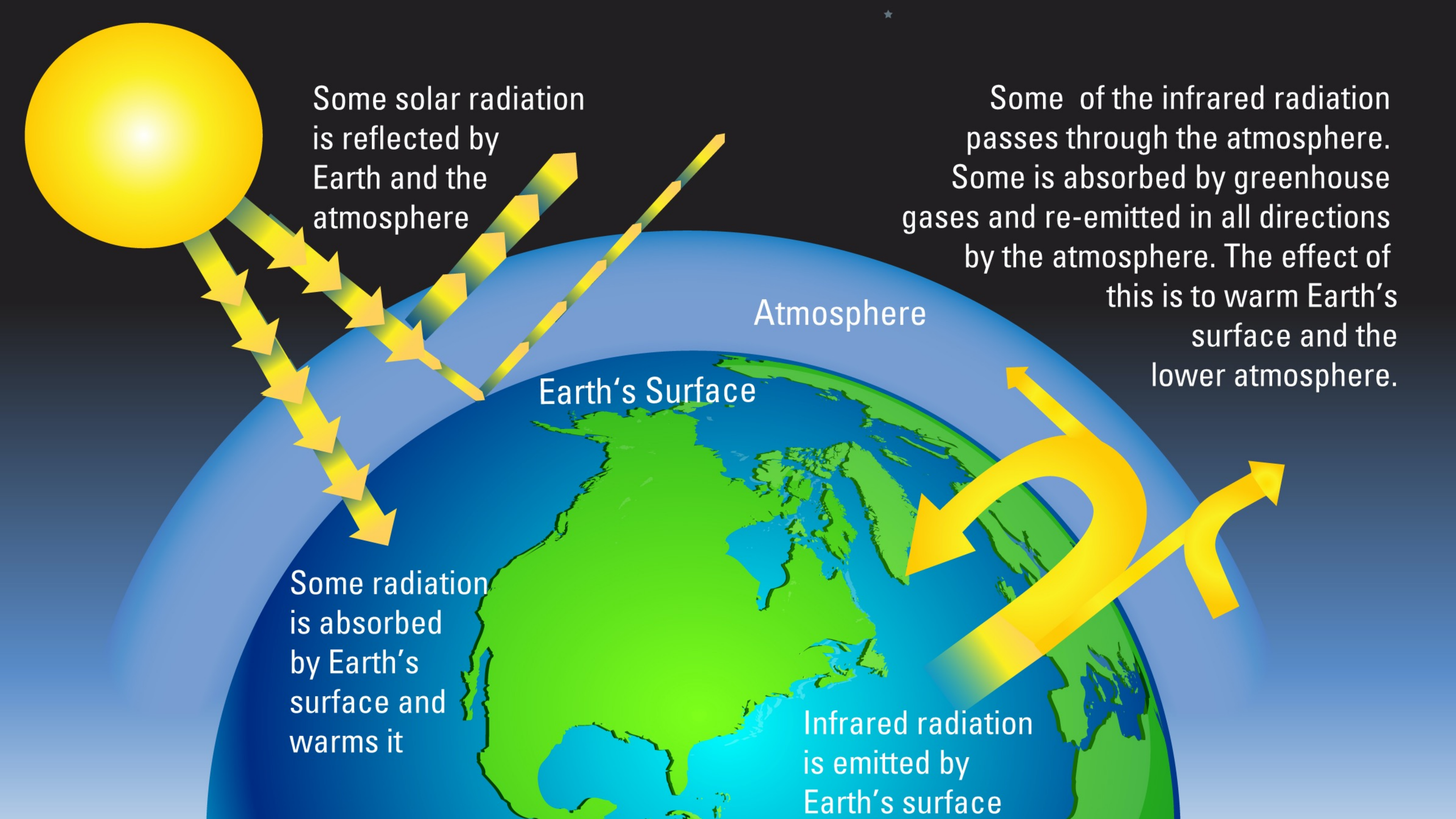
National Research Council

NATIONAL ACADEMY OF SCIENCES
Washington, D.C.
1979

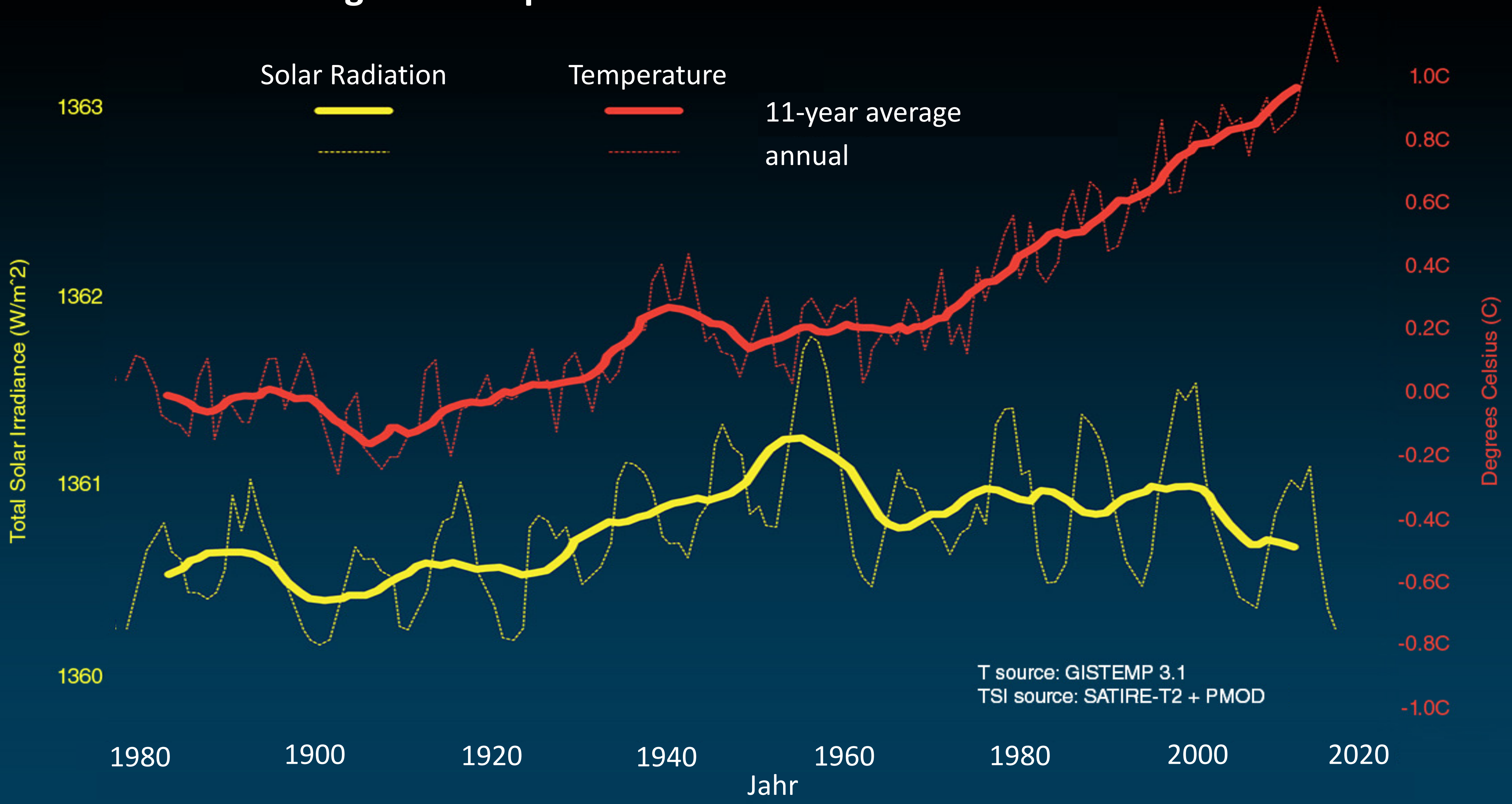
„When it is assumed that the **CO2** content of the atmosphere **is doubled** and statistical thermal equilibrium is achieved, the more realistic of the modeling efforts predict a **global surface warming of between 2°C and 3 °C**, with greater increases at high latitudes.“

Key messages:

- **Undeniable evidence** that human activities change the atmosphere
- A **wait and see strategy** means waiting until it is too late

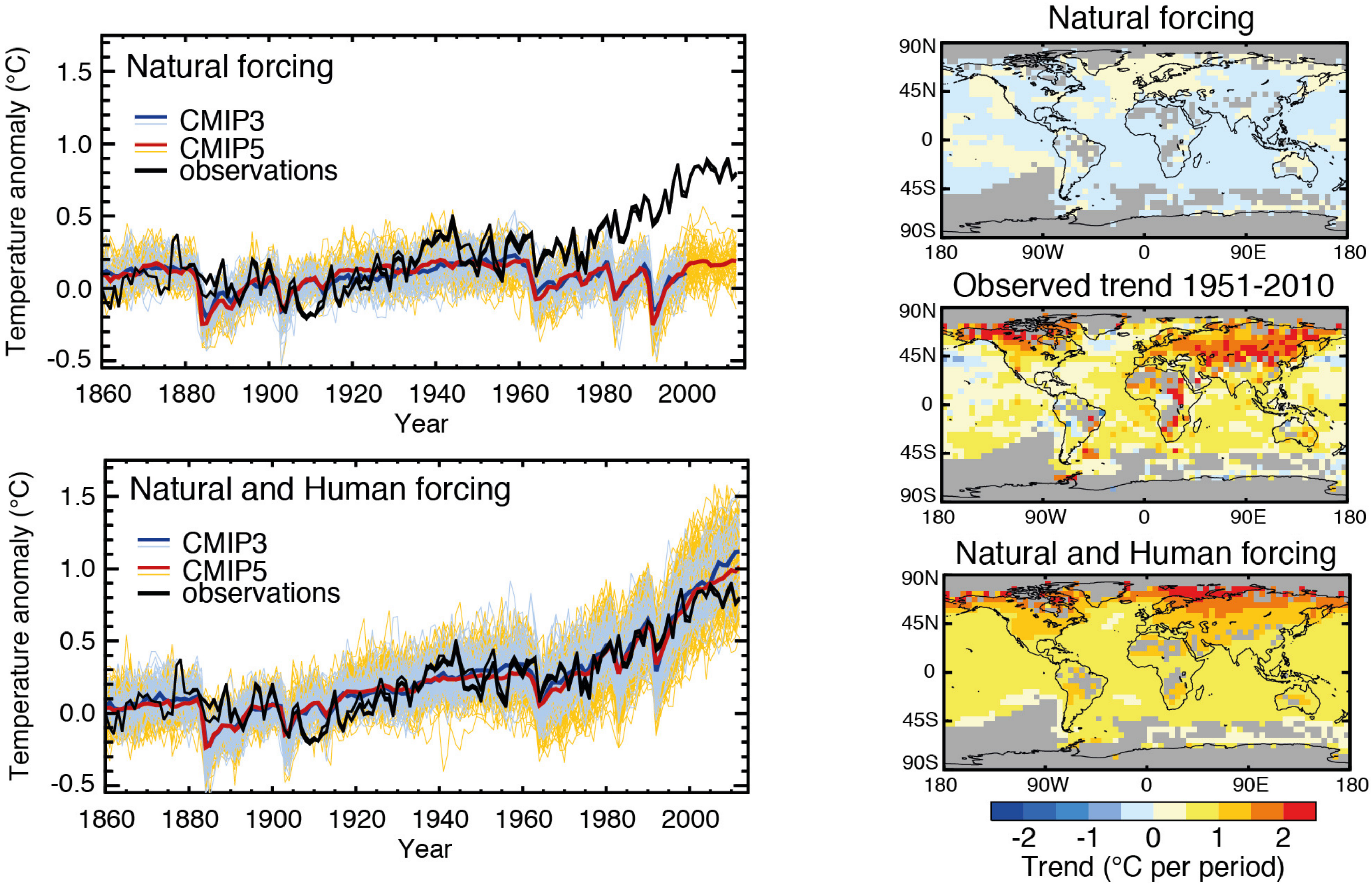

Some solar radiation is reflected by Earth and the atmosphere
Some of the infrared radiation passes through the atmosphere. Some is absorbed by greenhouse gases and re-emitted in all directions by the atmosphere. The effect of this is to warm Earth's surface and the lower atmosphere.
Atmosphere
Earth's Surface
Some radiation is absorbed by Earth's surface and warms it
Infrared radiation is emitted by Earth's surface

What causes the global temperature increase?

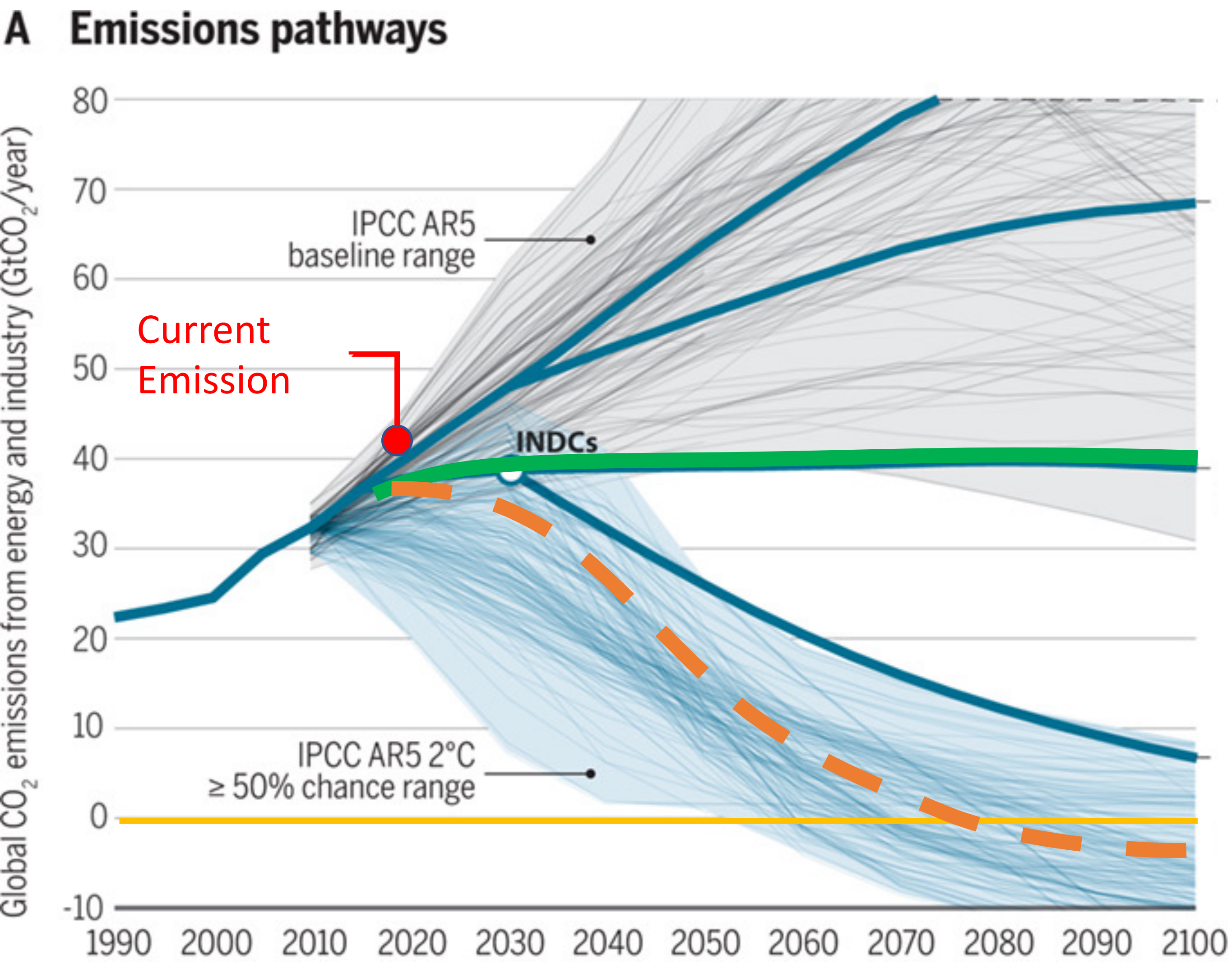


Quelle: https://climate.nasa.gov/.

Anthropogenic contribution to climate change

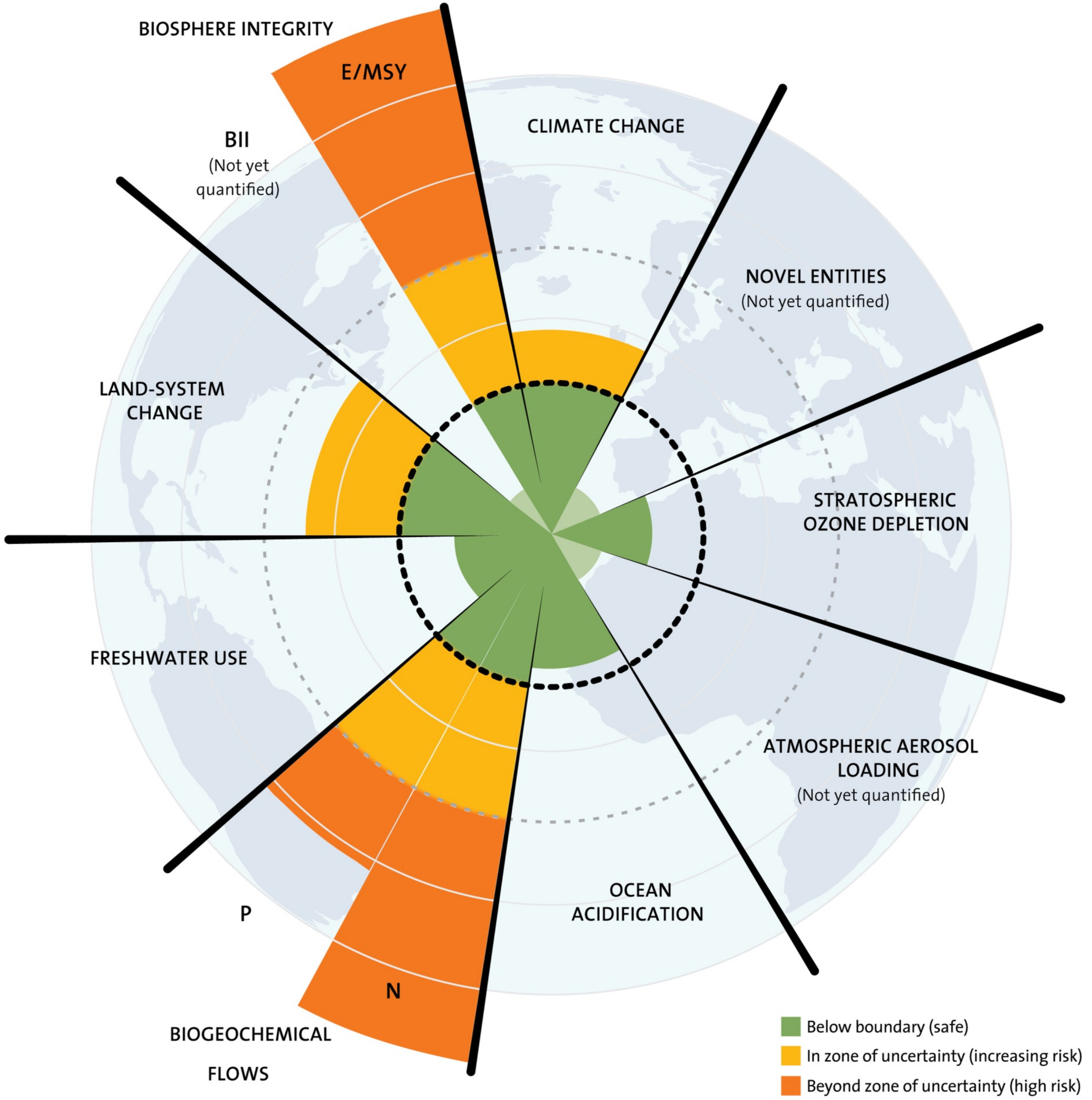


Probability to reach the 1.5ºC target



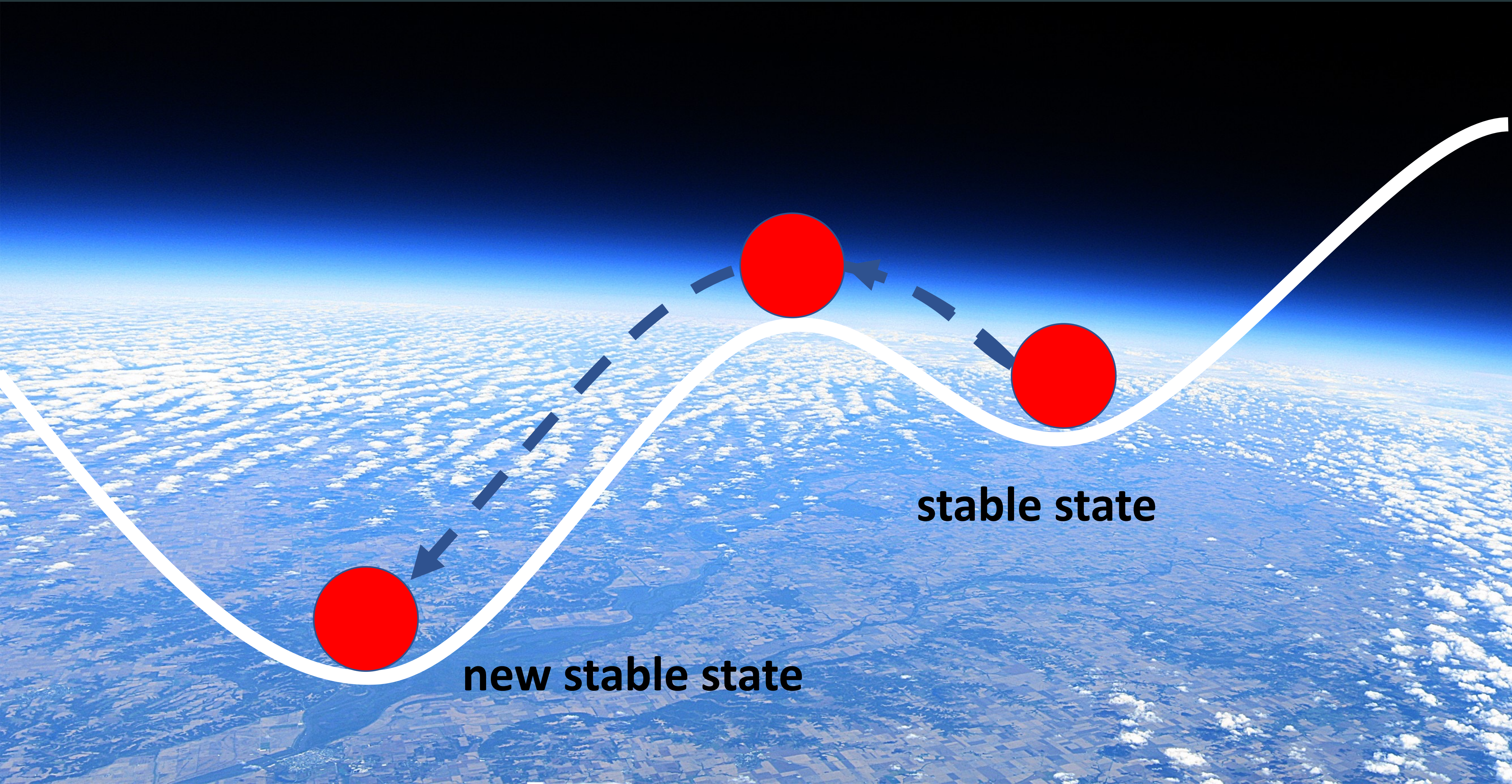
Allen A. Fawcett et al. **Science** 2015

Planetary Boundaries

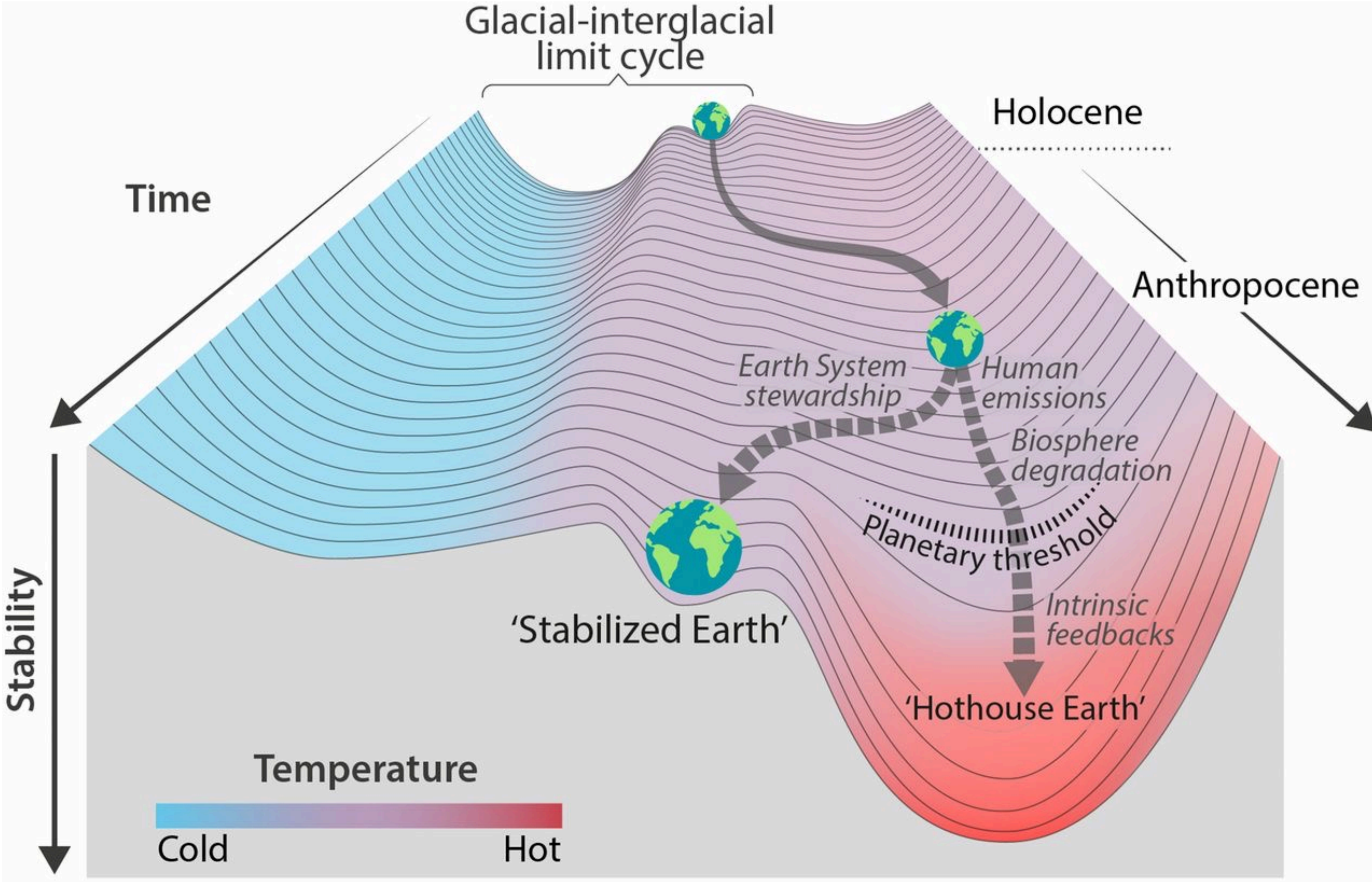


Source: Steffen et al., 2015

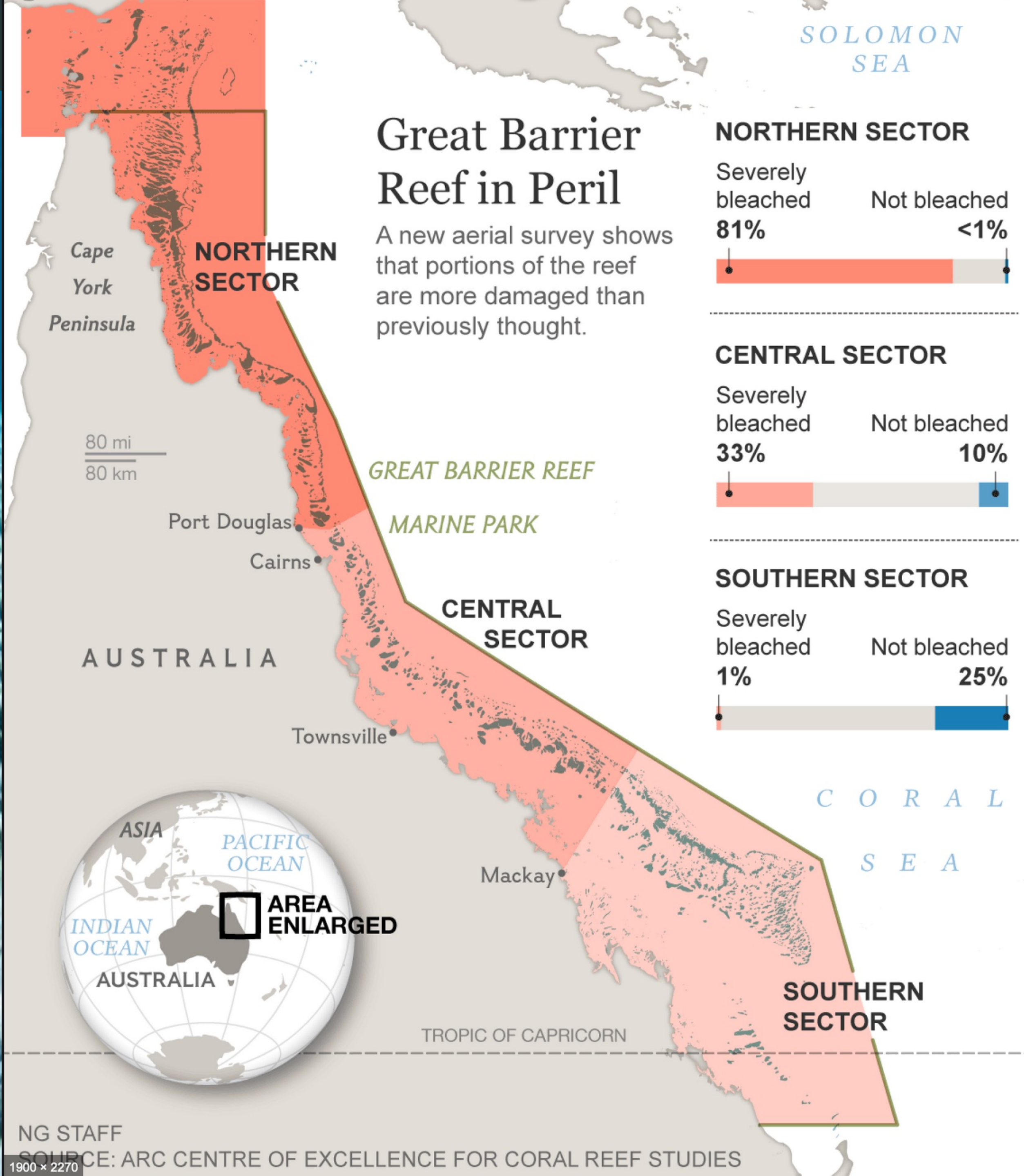
Tipping Points of the Earth System



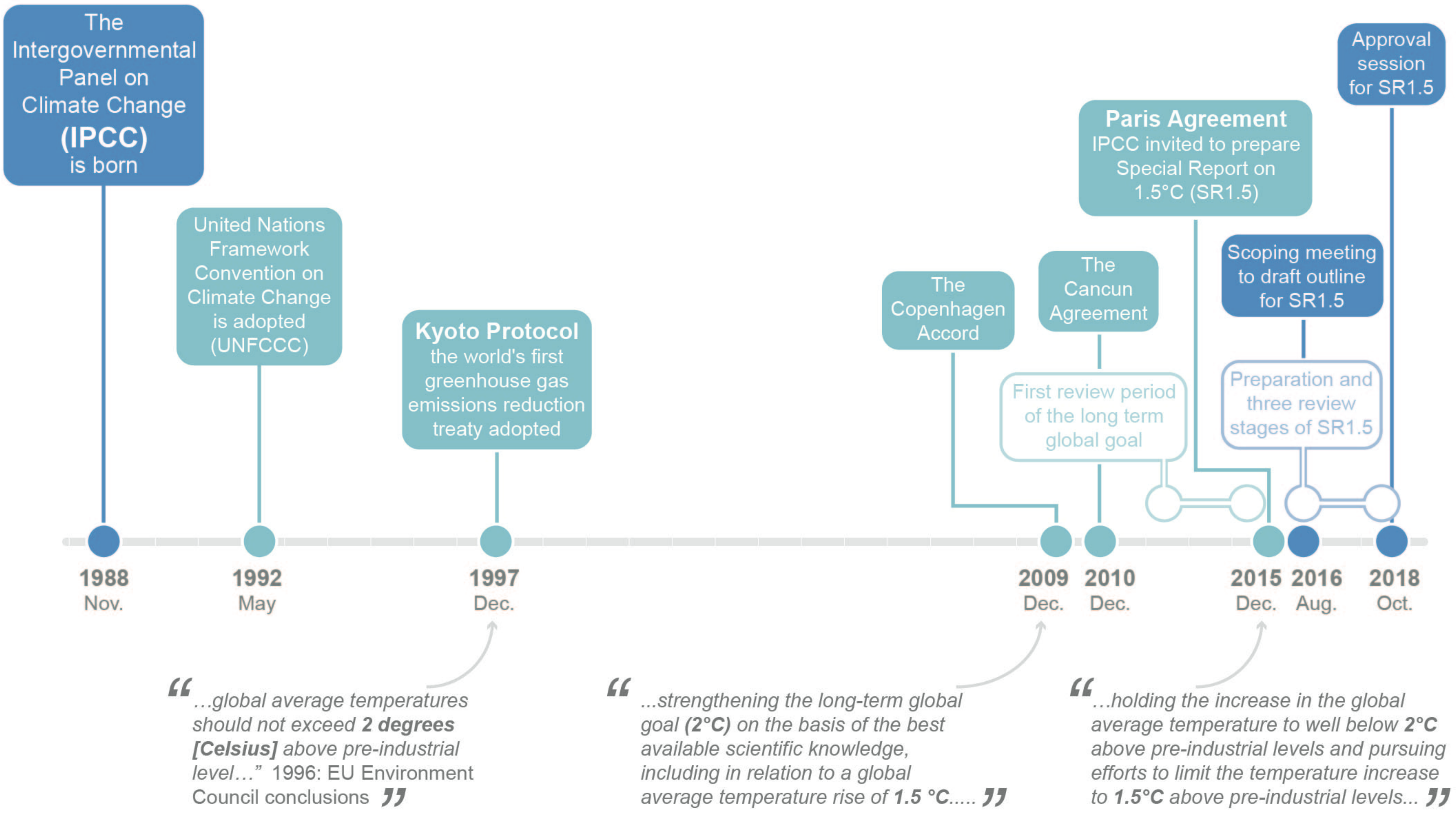
Tipping points of the Earth System



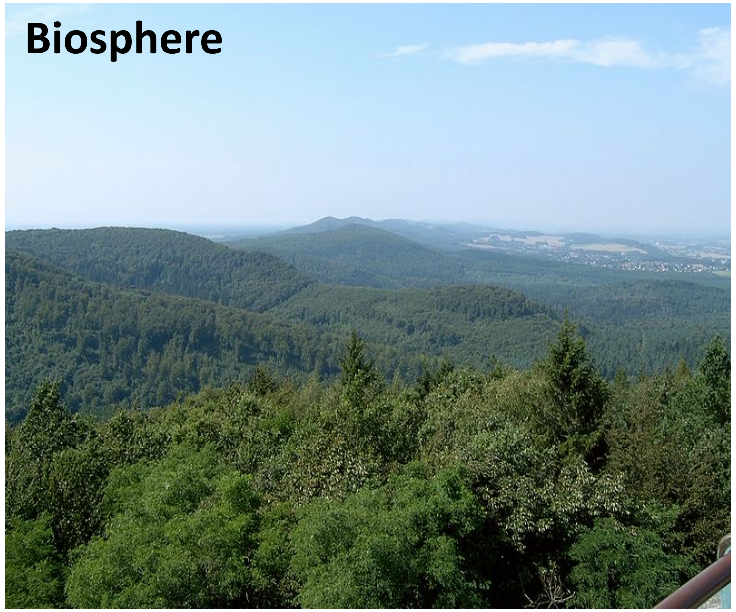
Example: Coral bleaching

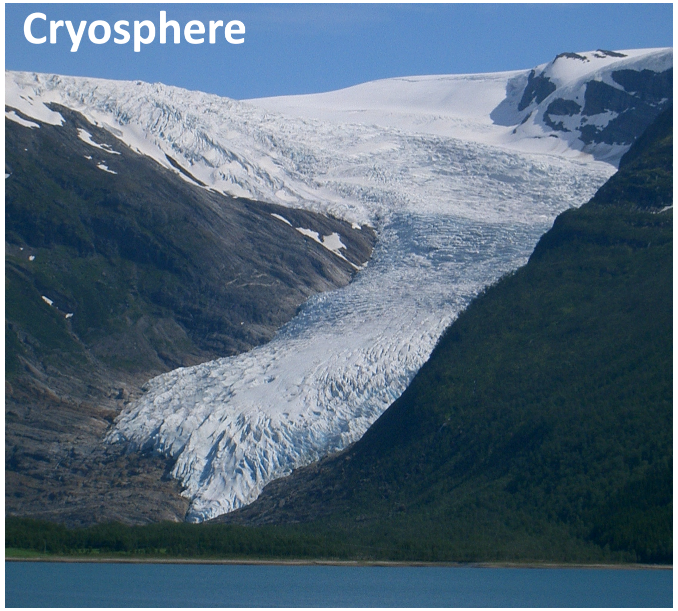


History of international climate negotiations

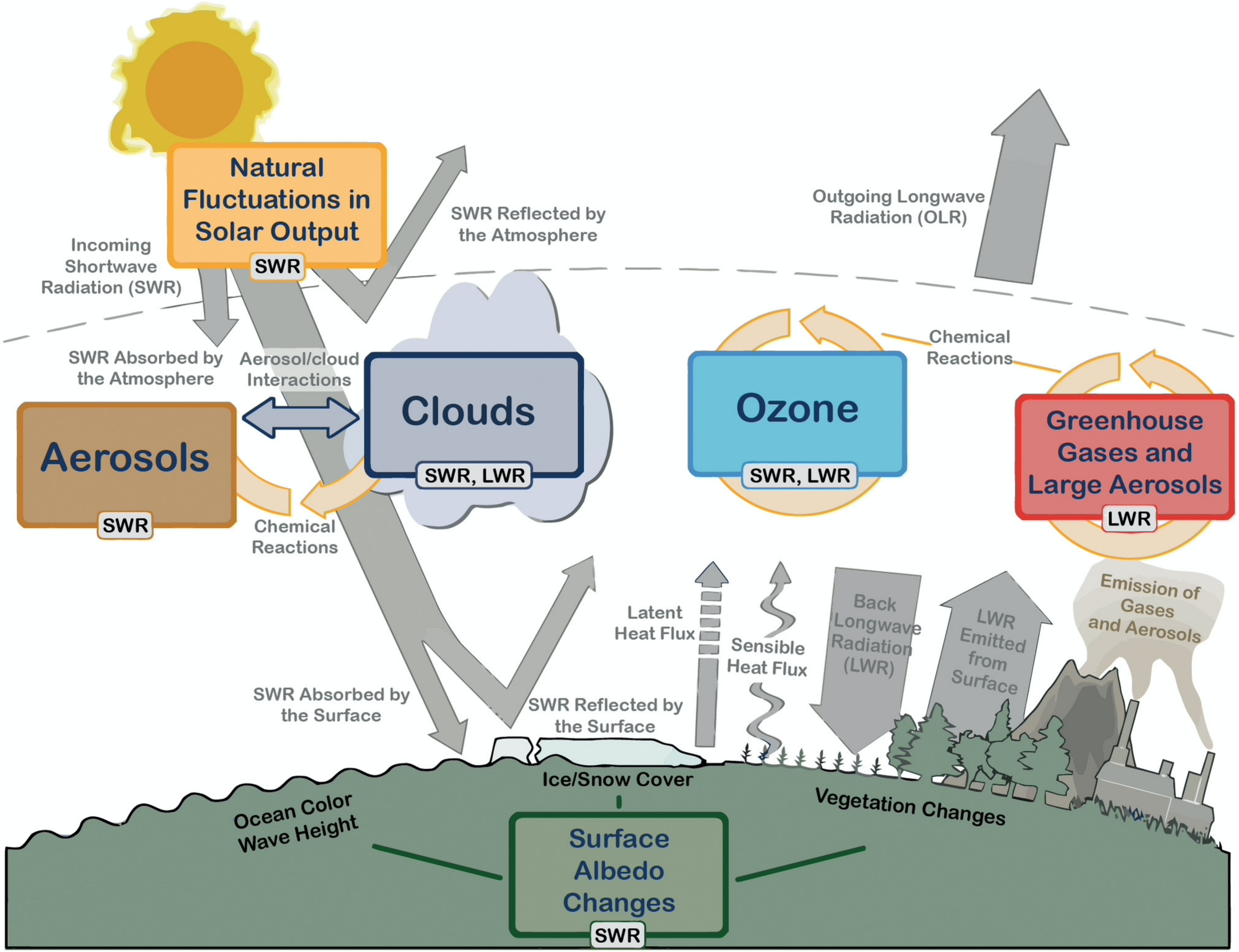


Climate system and its spheres

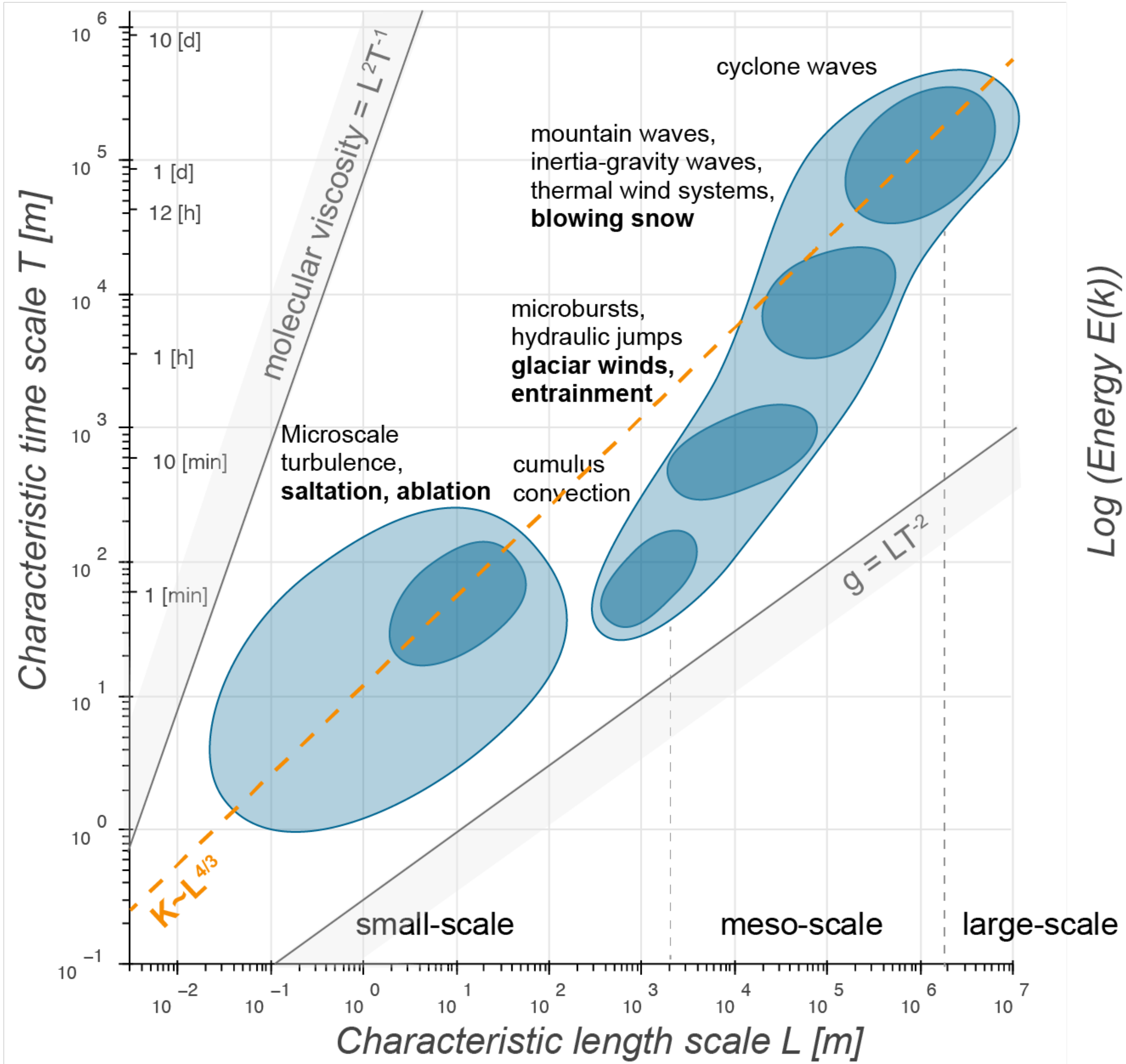




Main drivers of climate change



Scales in time and space



Equilibration Timescales

Climatic domain	Seconds	Equivalent
Atmosphere		
Free	10^6	10 days
Boundary layer	10^5	24 hours
Ocean		
Mixed layer	10^6–10^7	Months–years
Deep	10^{10}	300 years
Sea-ice	10^6–10^{10}	Days–100s of years
Continents		
Snow and surface ice layer	10^5	24 hours
Lakes and rivers	10^6	10 days
Soil/vegetation	10^6–10^{10}	Days–100s of years
Mountain glaciers	10^{10}	300 years
Ice sheets	10^{11}	3000 years
Earth's mantle	10^{15}	30 million years

Types of climate models

Energy balance models (EBM)

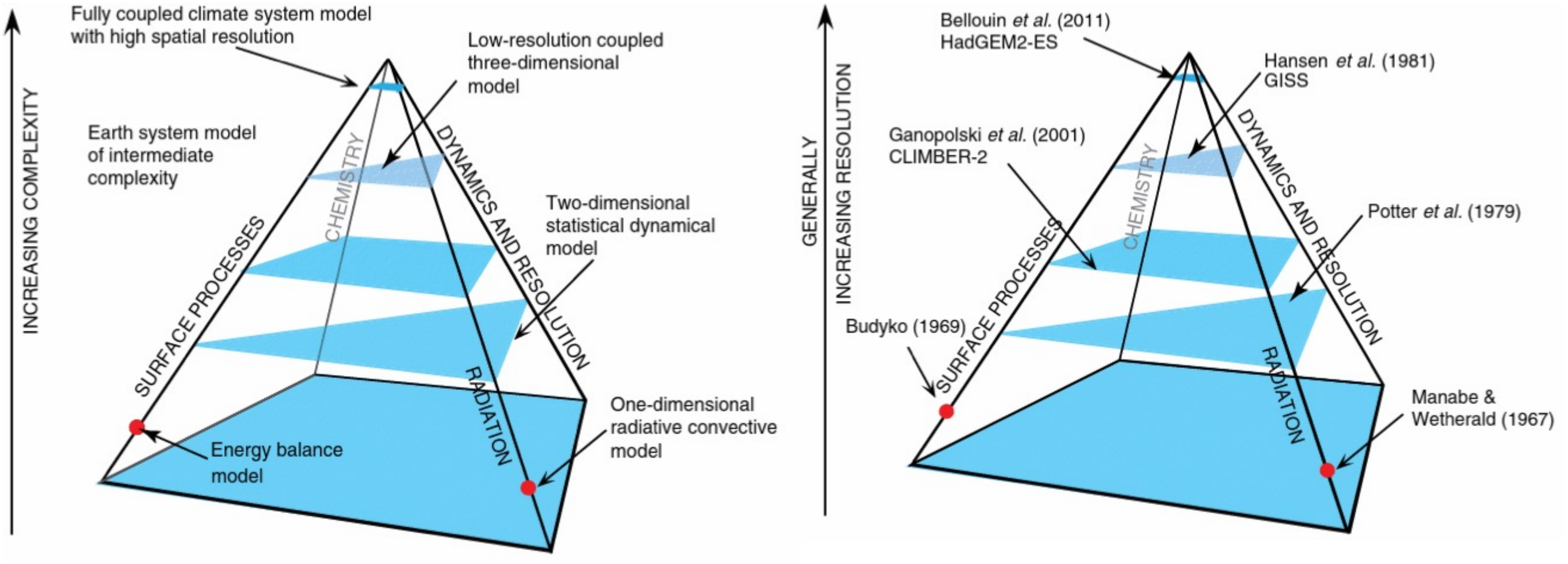
Radiative-convective (RC) models or single-column models (SCM)

Dimensionally constrained models

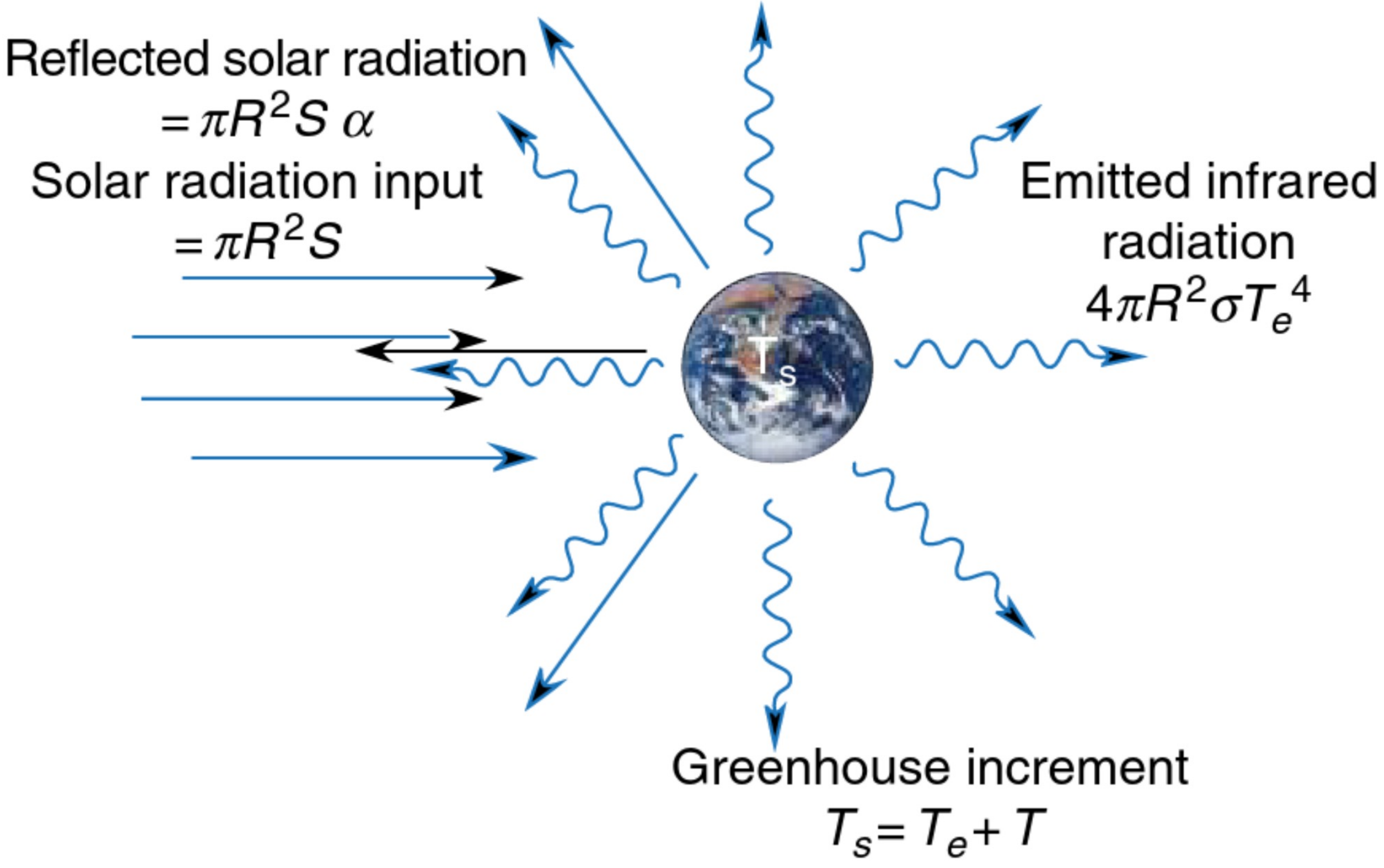
Global Circulation Models (GCM)

Earth System Models (ESM)

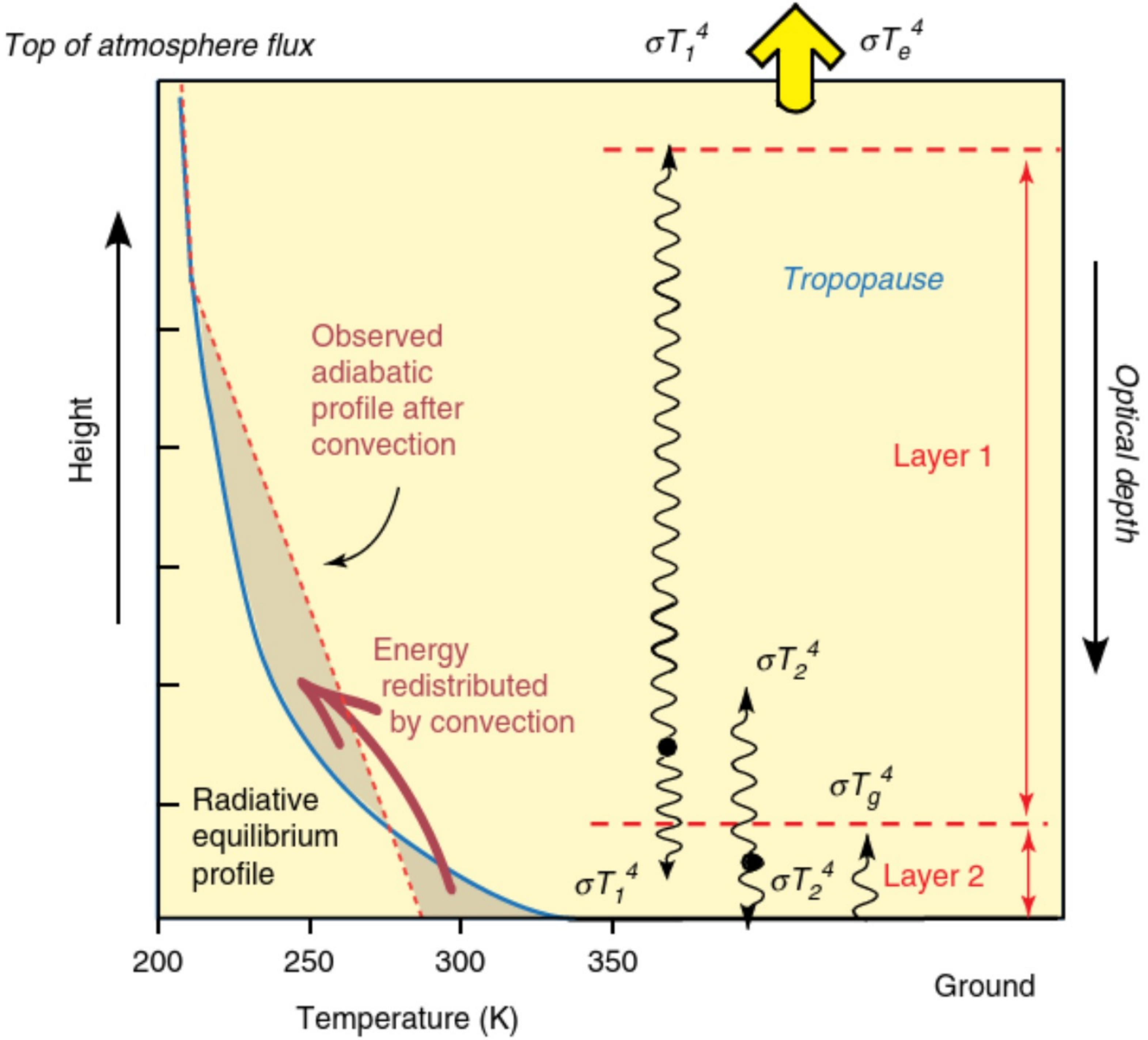
Model complexity



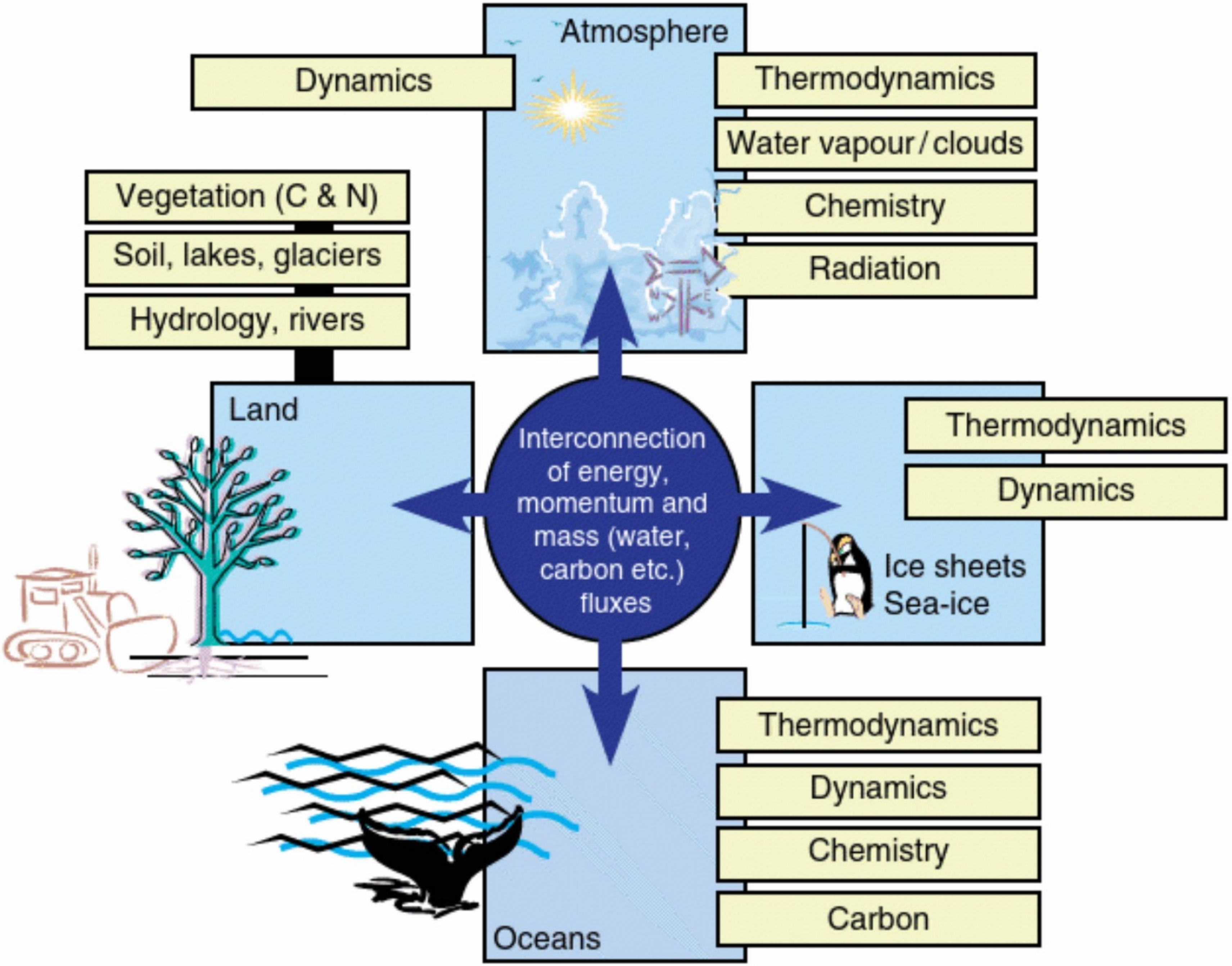
Energy Balance Models



Radiative-convective models



Global Circulation Models



Components of climate models

Radiation - short- and longwave radiation fluxes

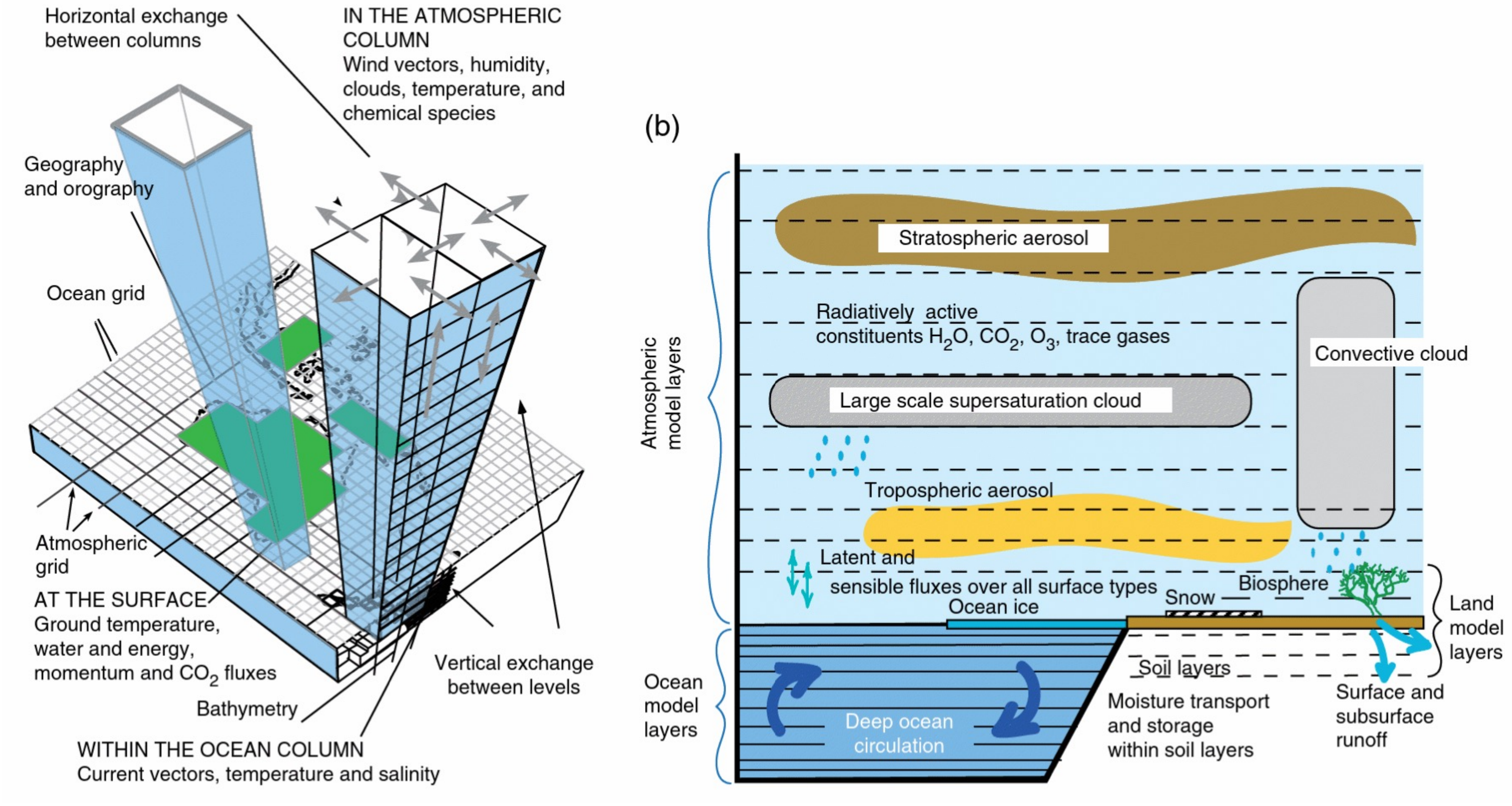
Dynamics – energy and mass fluxes

Surface processes – effects of sea and land ice, snow, vegetation

Chemistry – chemical composition fo the atmosphere and interactions

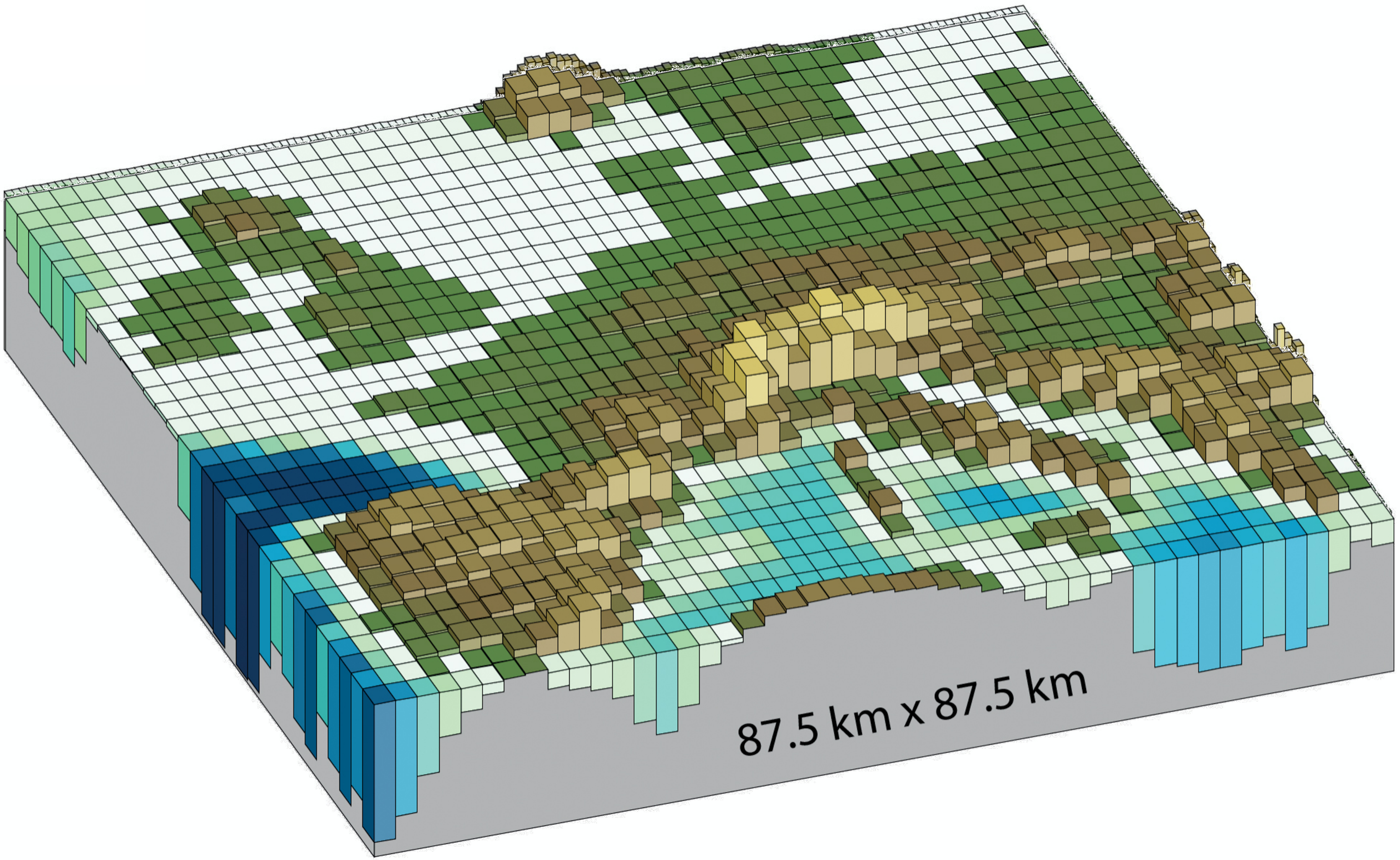
Resolution in time and space – the timestep of the model and the horizontal and vertical scales resolved

GCMs

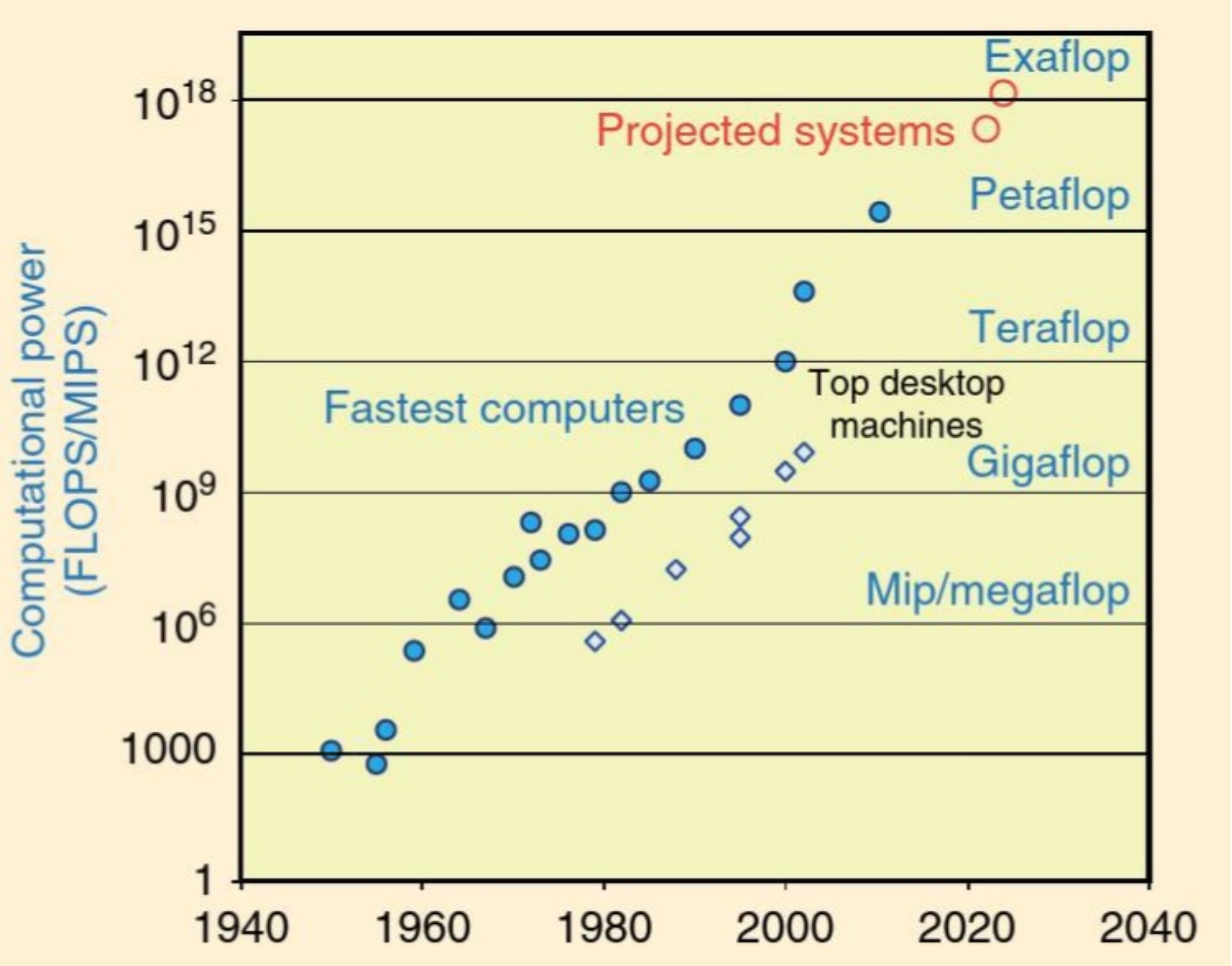


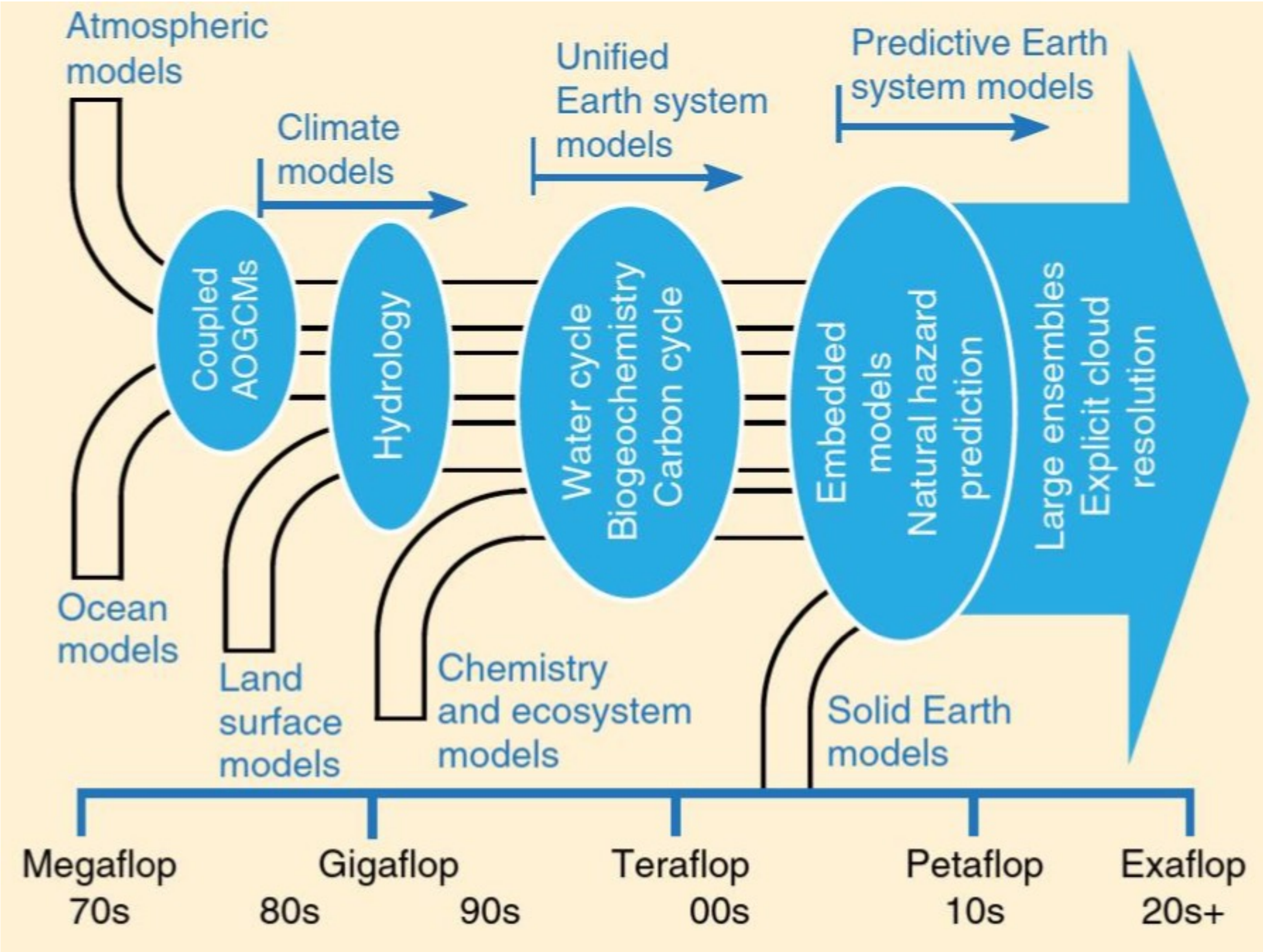
Horizontal exchange between columns
IN THE ATMOSPHERIC COLUMN
Wind vectors, humidity, clouds, temperature, and chemical species
Geography and orography
Ocean grid
Atmospheric grid
AT THE SURFACE
Ground temperature, water and energy, momentum and CO_2 fluxes
Bathymetry
Vertical exchange between levels
WITHIN THE OCEAN COLUMN
Current vectors, temperature and salinity
(b)
Atmospheric model layers
Stratospheric aerosol
Radiatively active constituents H_2O, CO_2, O_3, trace gases
Convective cloud
Large scale supersaturation cloud
Tropospheric aerosol
Latent and sensible fluxes over all surface types
Biosphere
Snow
Ocean ice
Land model layers
Soil layers
Ocean model layers
Deep ocean circulation
Moisture transport and storage within soil layers
Surface and subsurface runoff

Resolution of GCMs

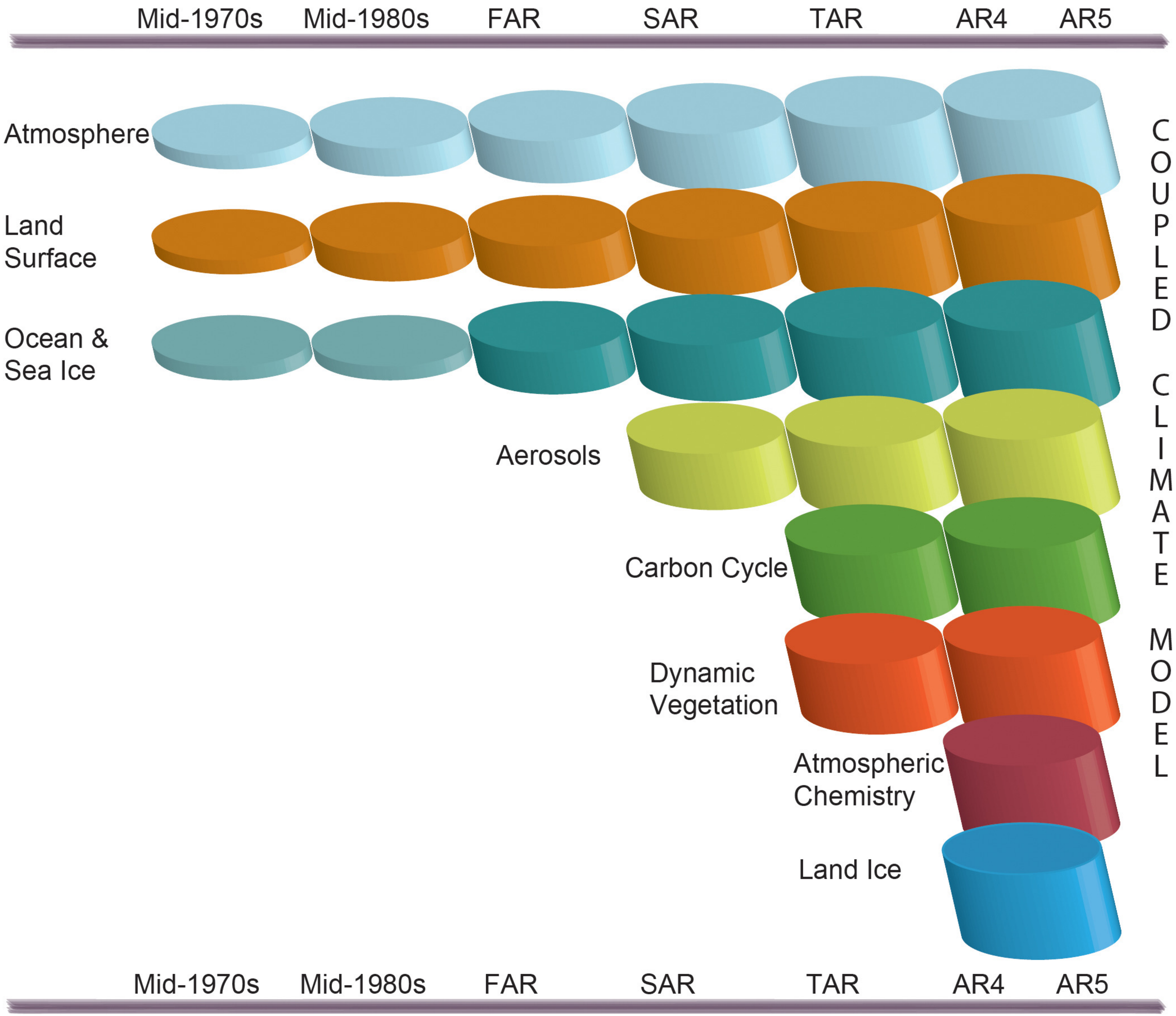


Computational needs

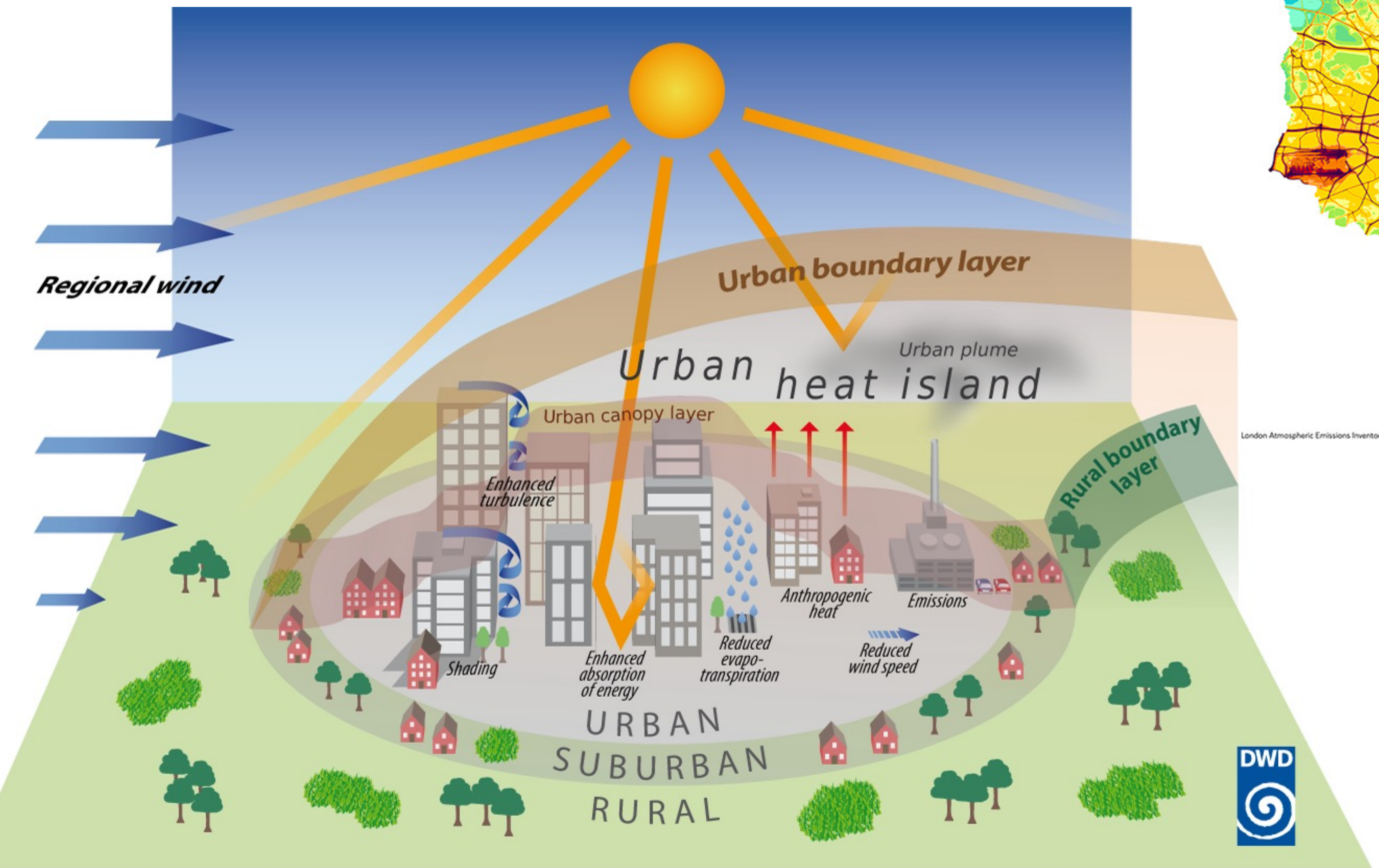




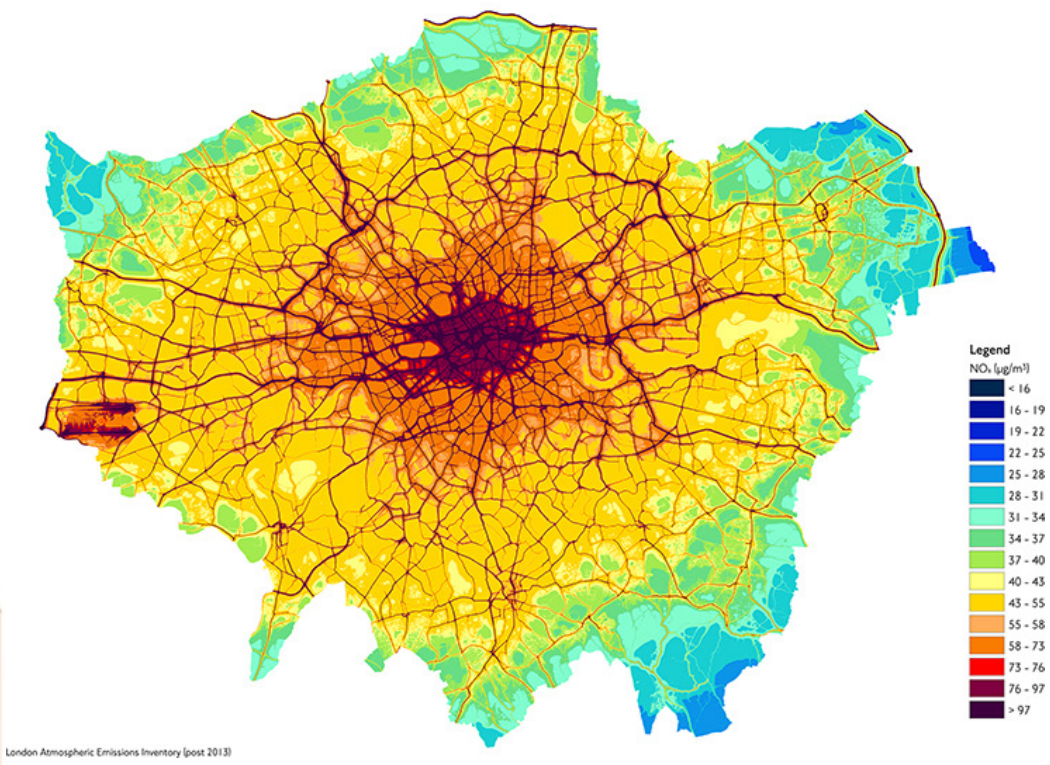
Evolution of GCMs



Urban Climate



Greater London - Annual Mean NO_x concentrations 2013



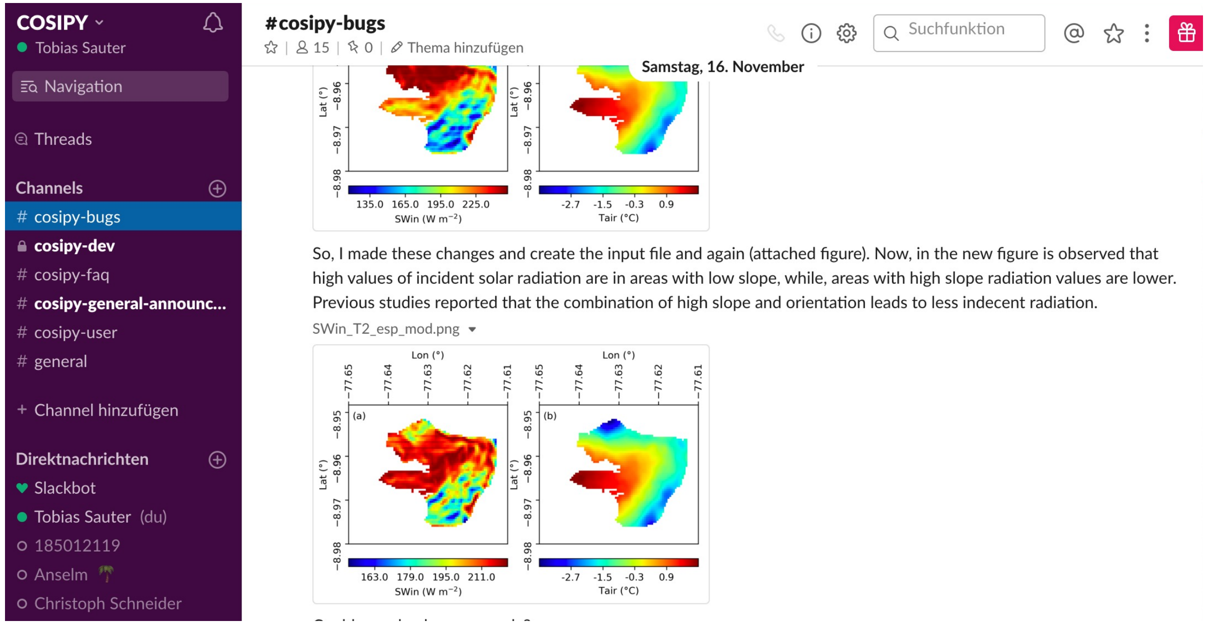
Source: Gunawardena and Kershaw, 2017

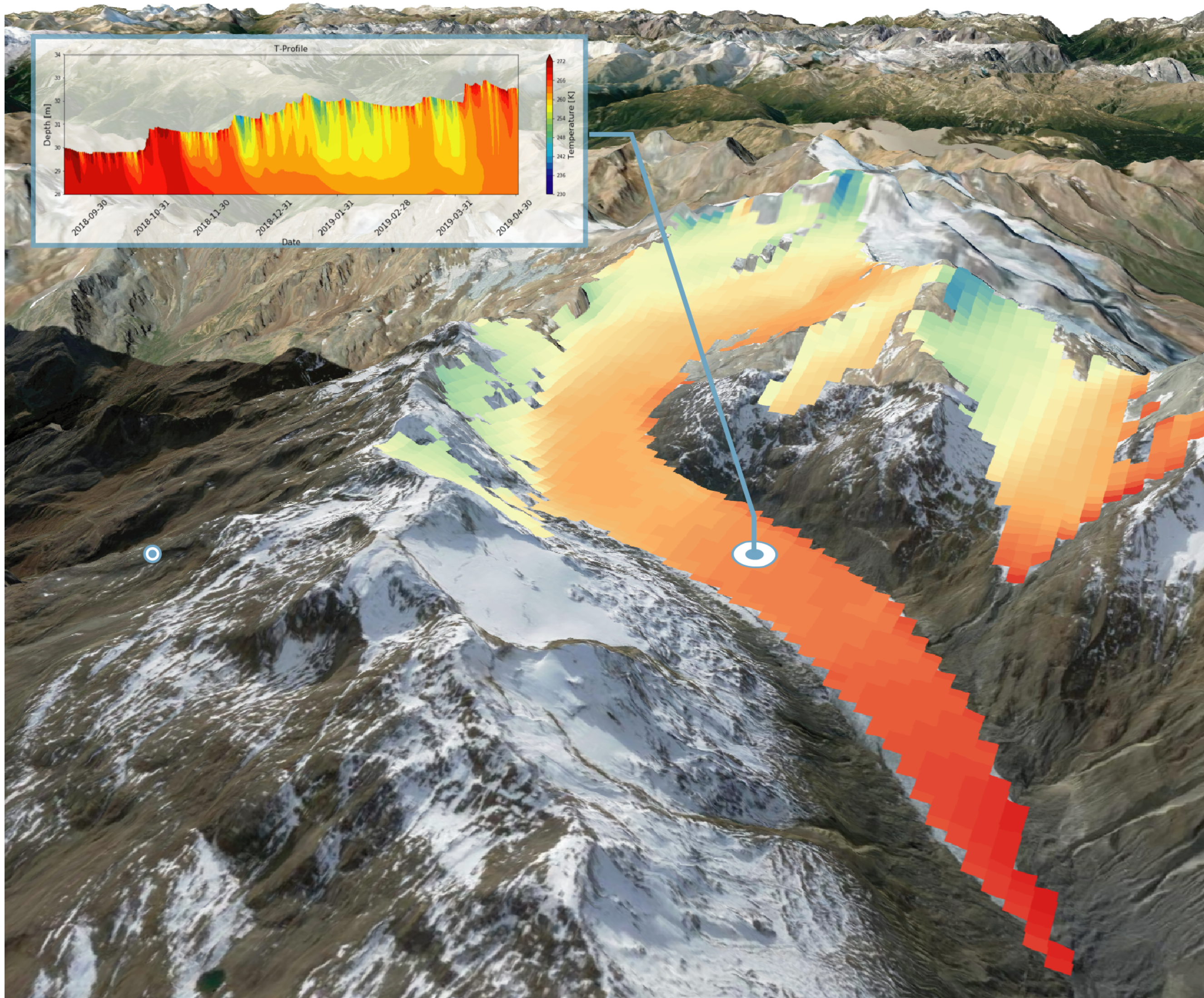
COSIPY

Coupled snowpack and ice surface energy and mass balance model

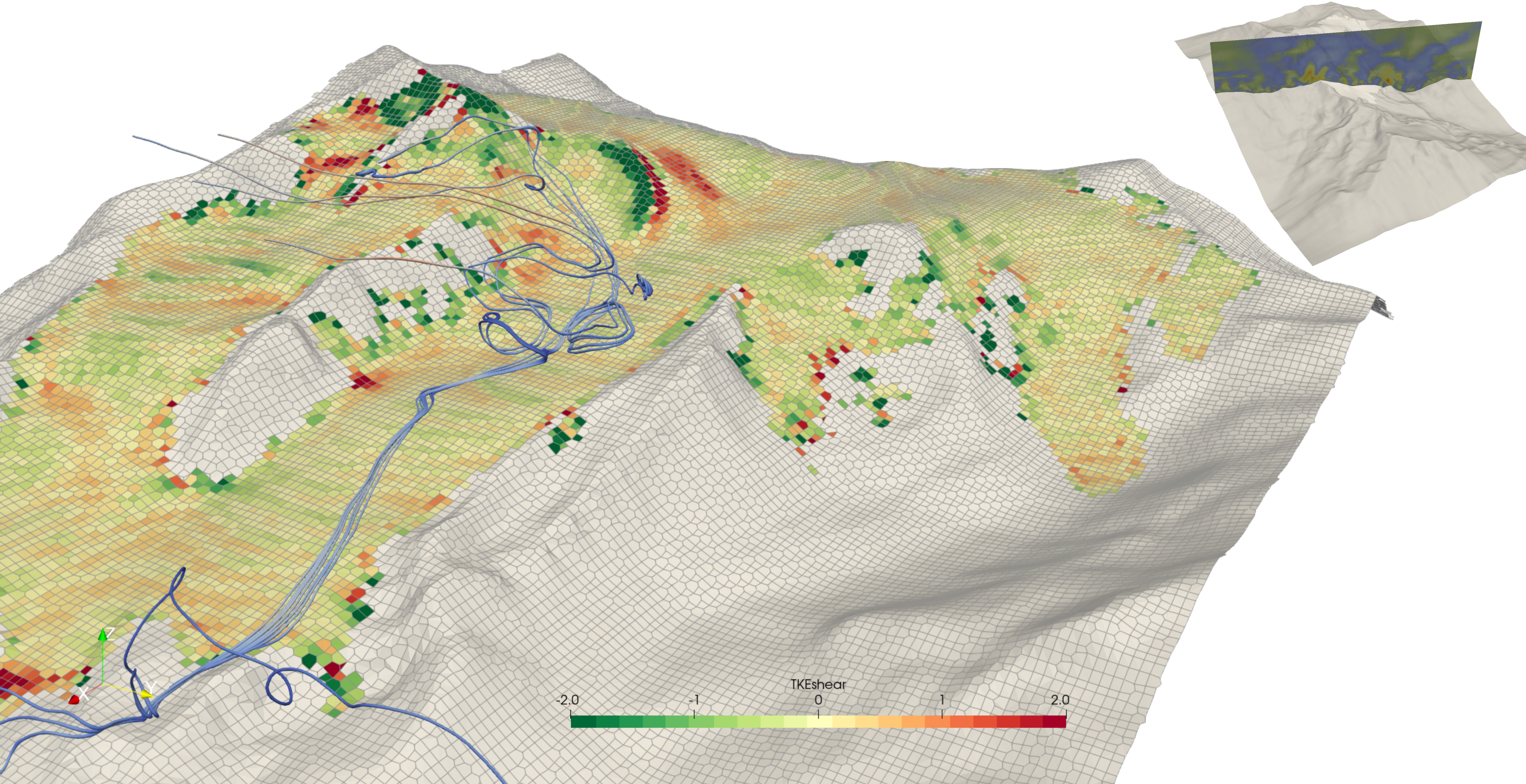
https://github.com/cryotools/cosipy

- Lean, flexible, and user-friendly open source code
- Testbed for new theories, parametrization and methods
- Reproducible results by other research groups
- Community platform to exchange ideas and problems





Large-Eddy Simulations



PALM-LES

Exercises

Access to the workstations

- A virtual Ubuntu server has been set up and is available to all participants
- You can log in via the Windows RDP using the IP **141.20.141.167**
- The password must be set at the first login

Exercises

- https://sauterto.github.io/climate_modelling/welcome.html
- Every week new exercises will be added
- The exercises are Jupyter notebooks that can be run locally on the computer as well as on Binder and Colab.
- Python is available on the virtual enviroment and the corresponding modules can be loaded with "**source /home/public/venv/bin/activate**".
- Buddy-System: Every week, two people form a team which is randomly selected