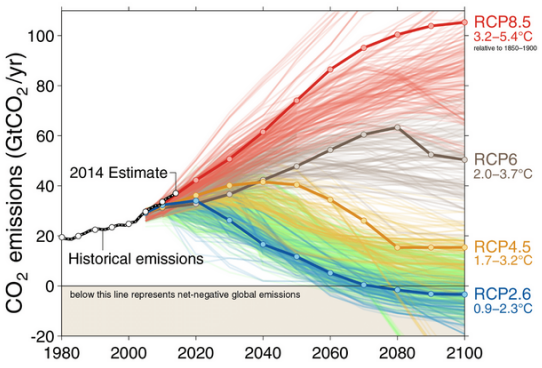
Earth System Modeling

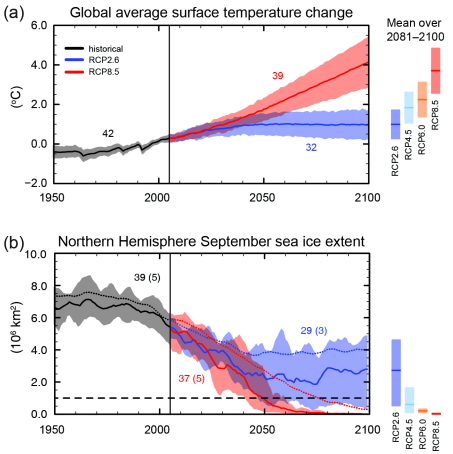
Risto Makkonen
Finnish Meteorological Institute
and University of Helsinki

Input
(e.g. greenhouse gas emission)



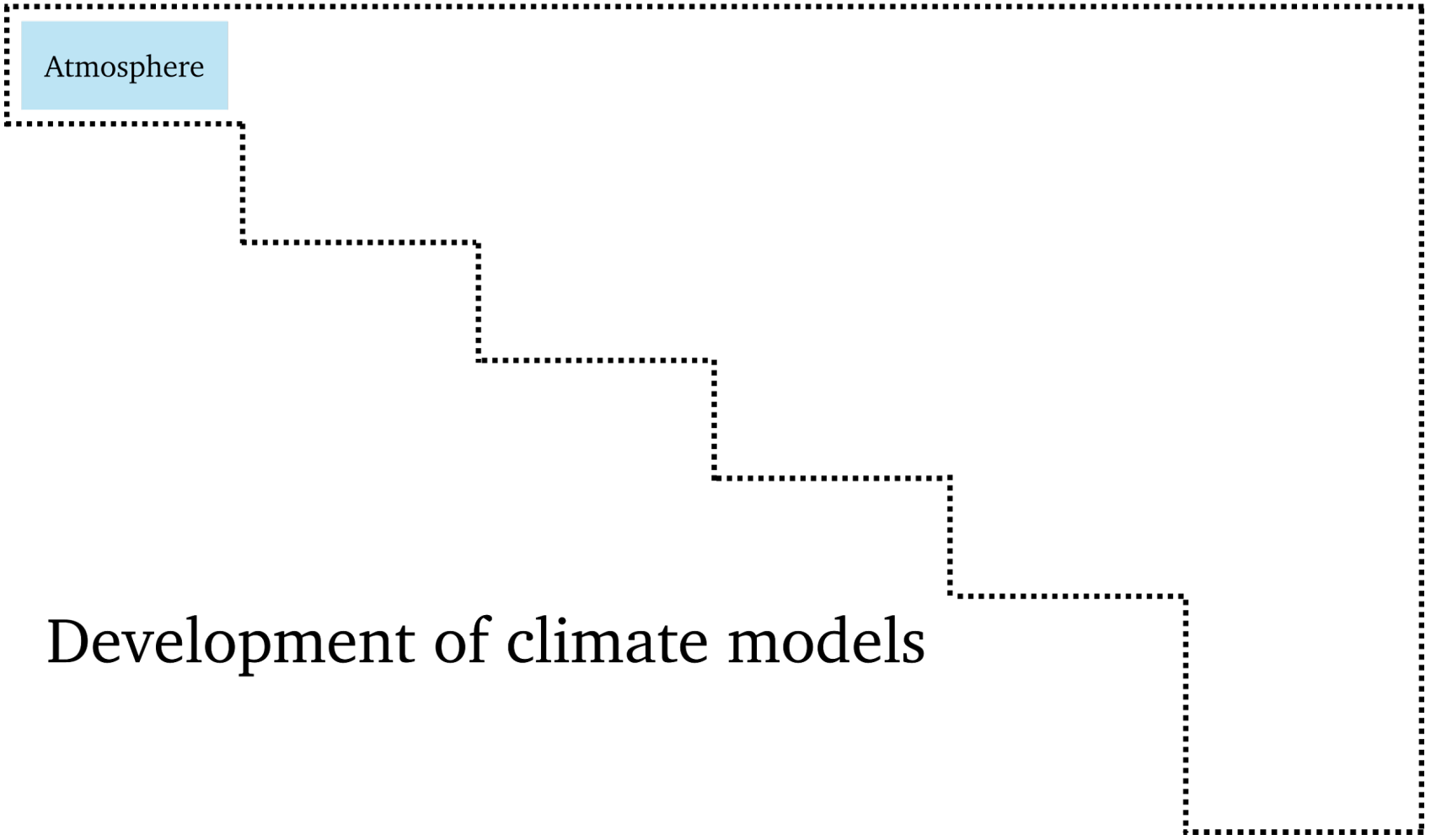
Earth System Model

Climate prediction

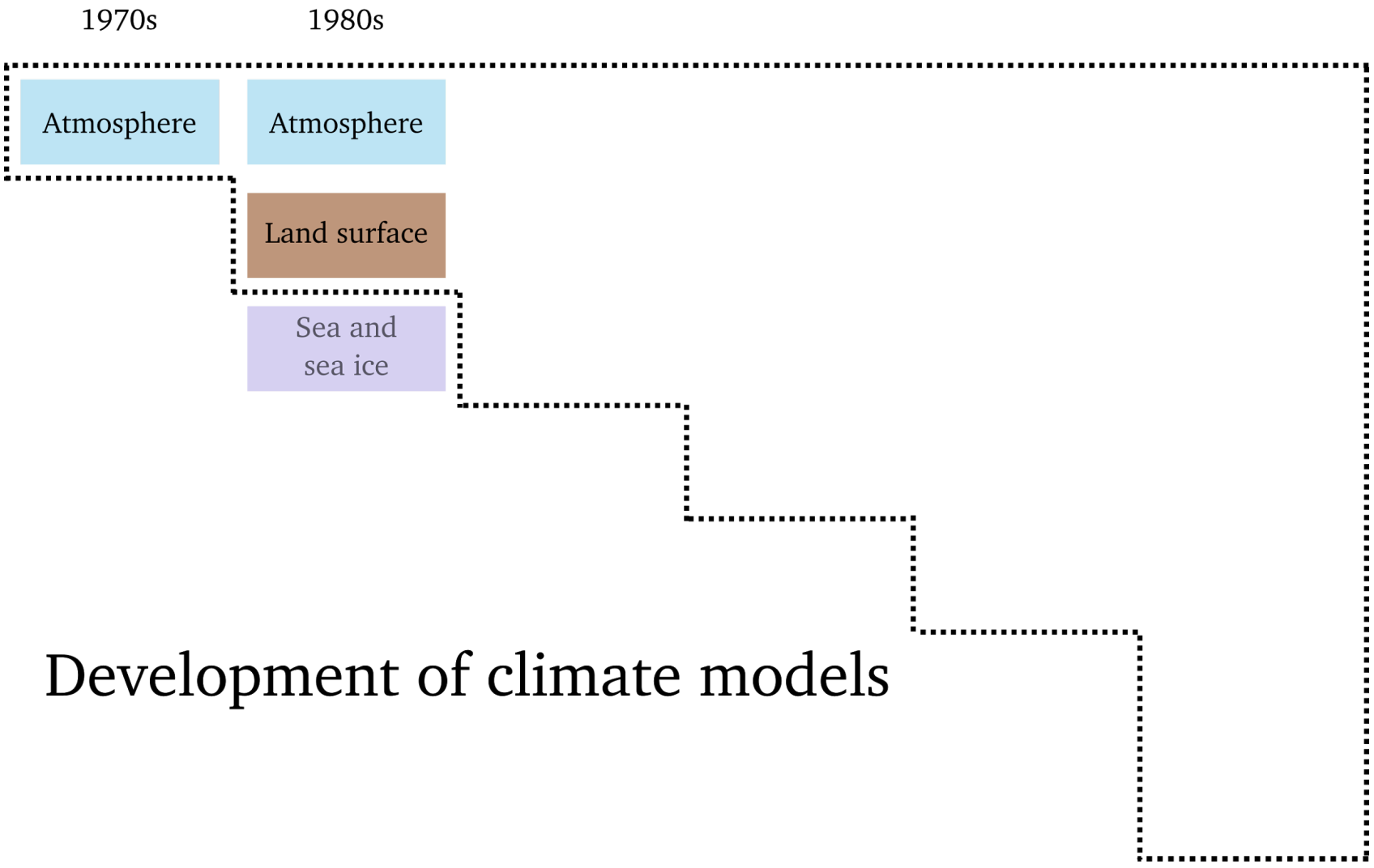


Development of climate models

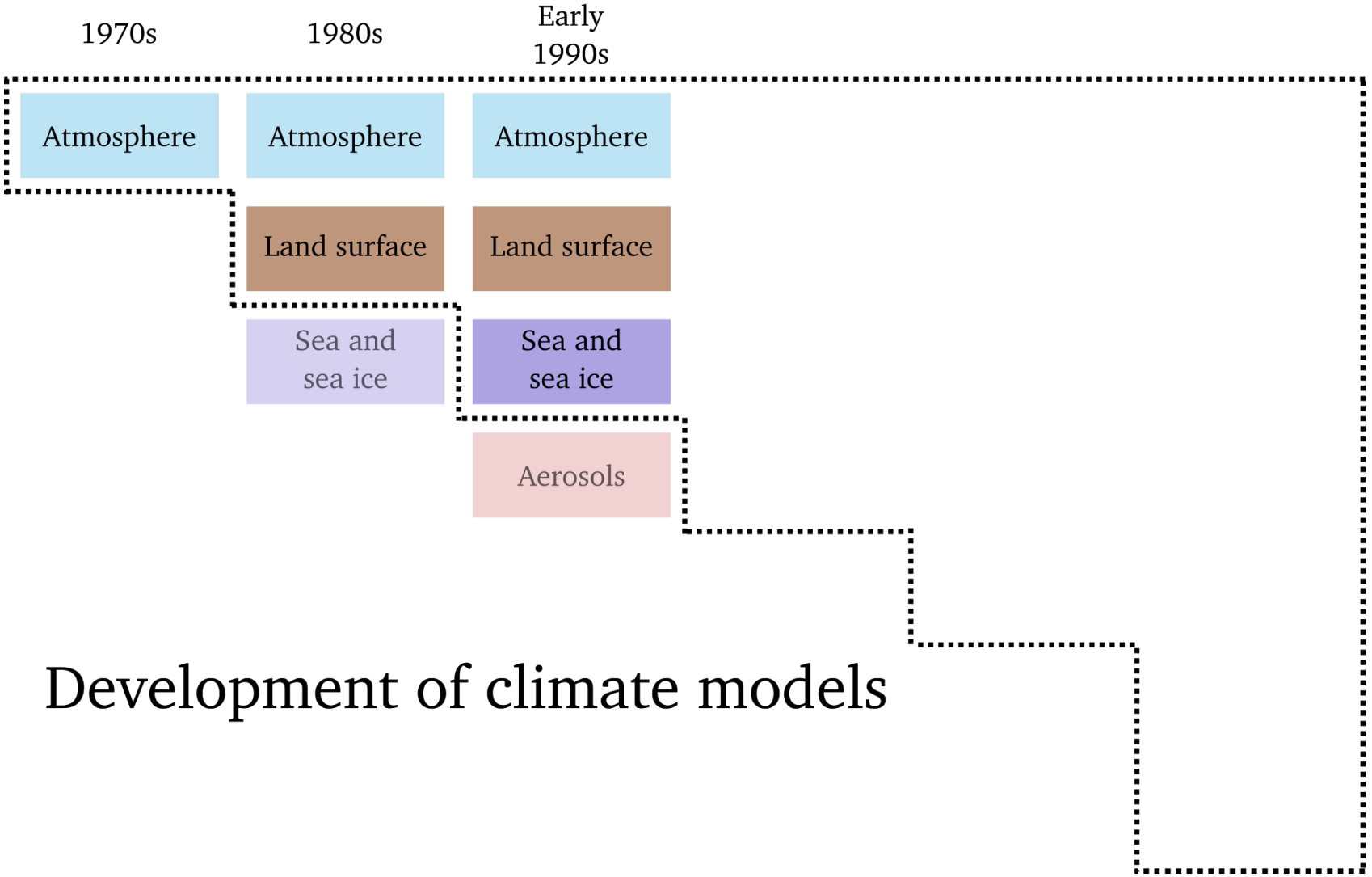
1970s



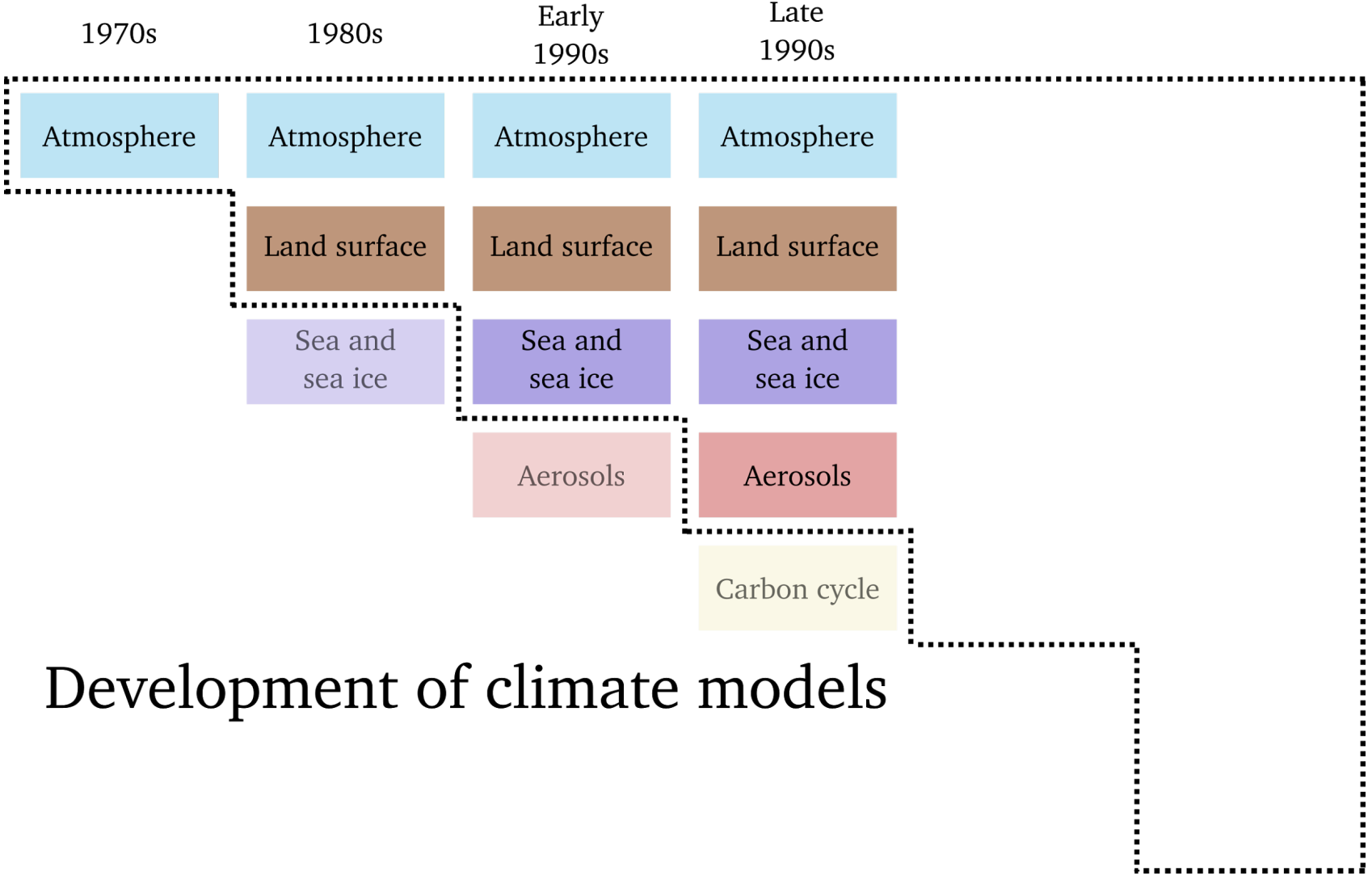
Development of climate models



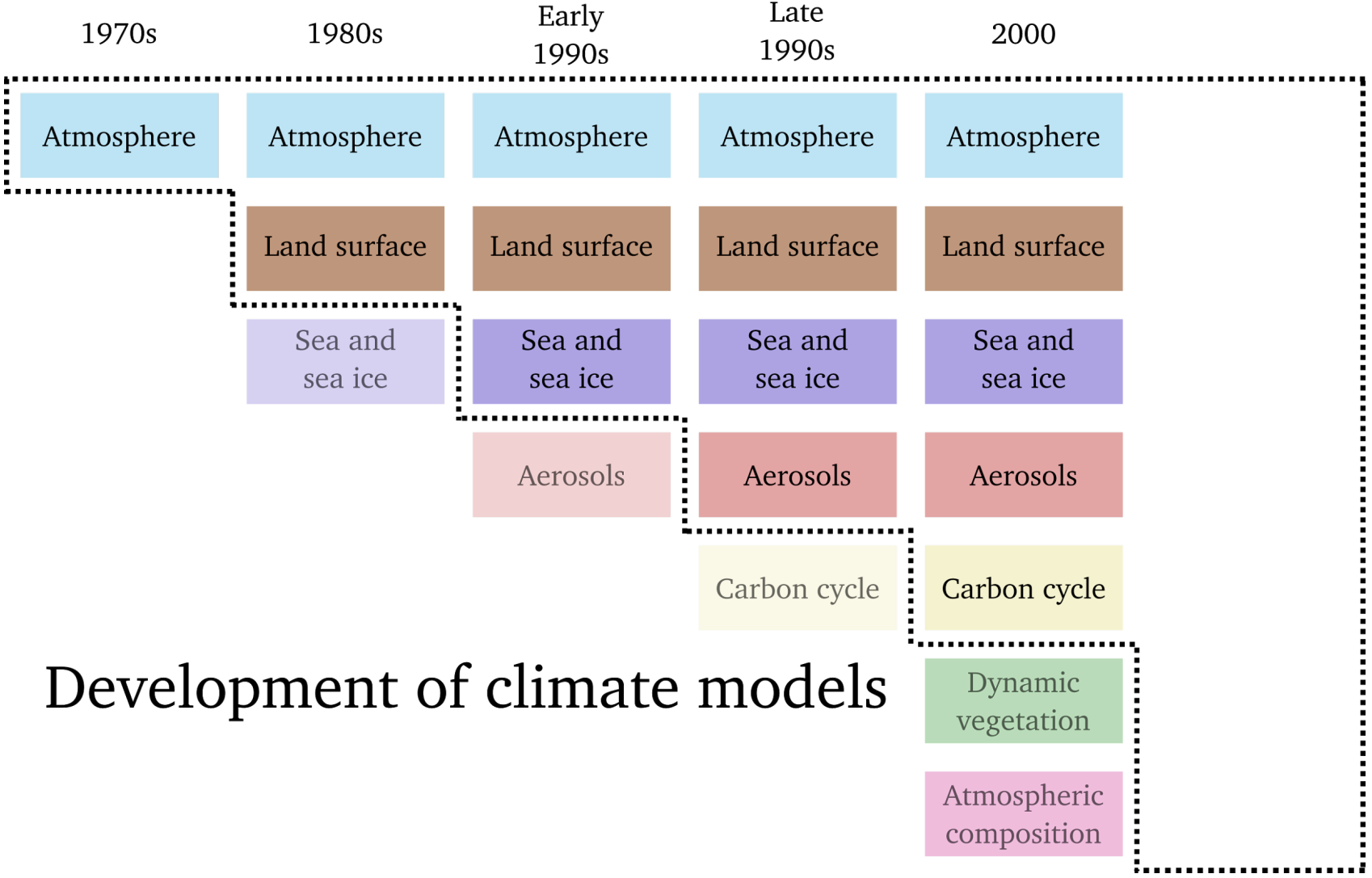
Development of climate models



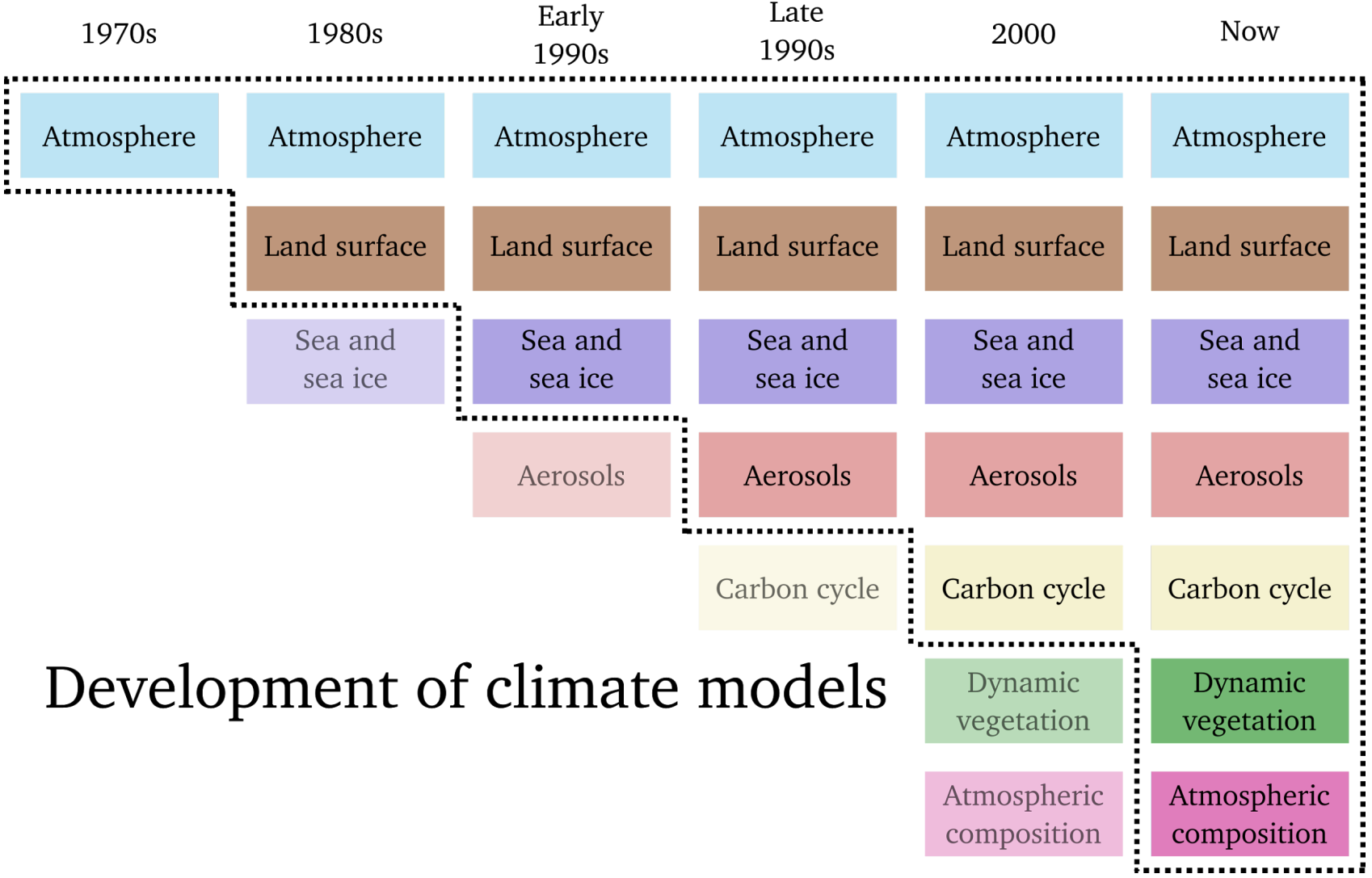
Development of climate models

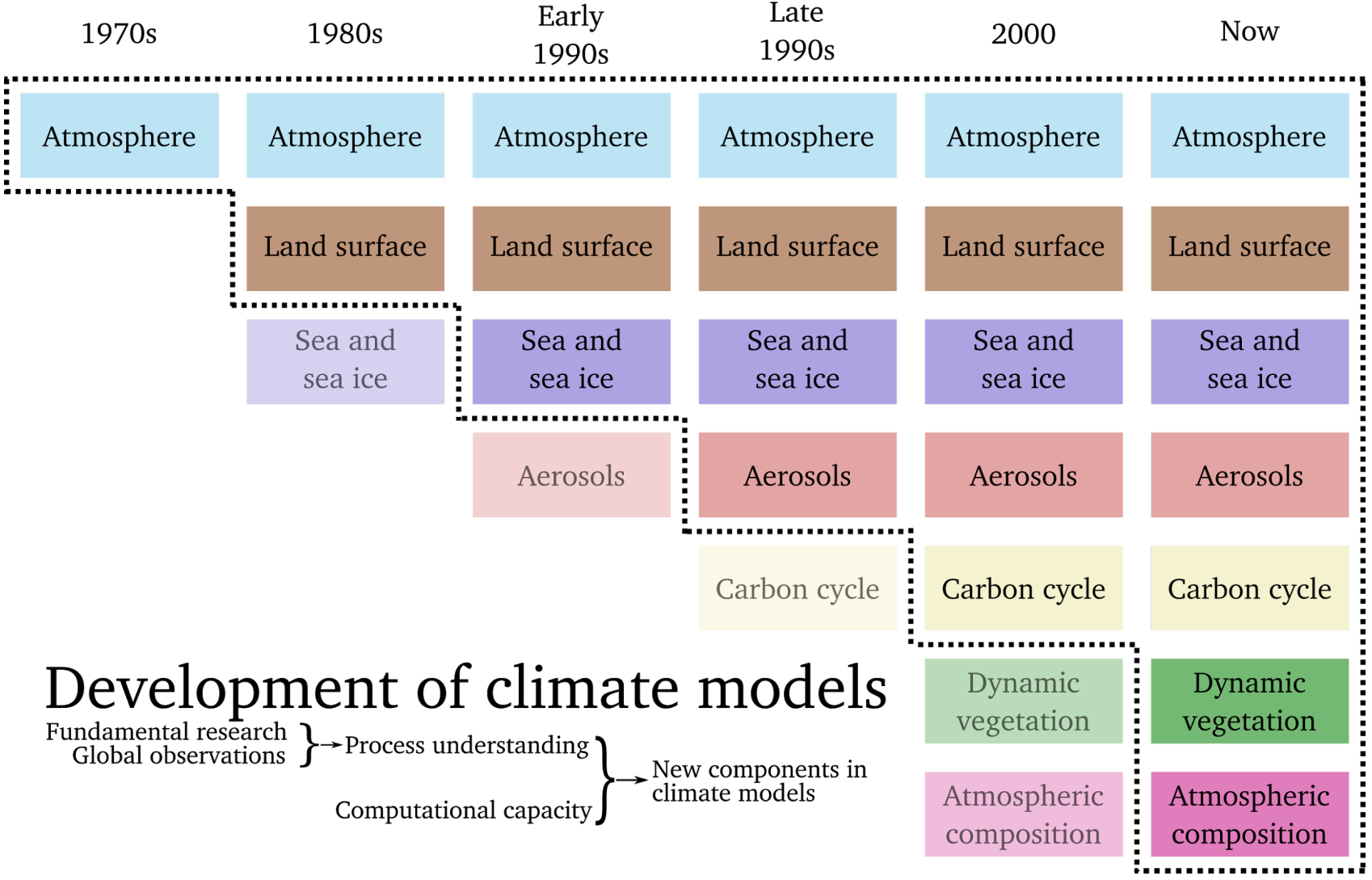


Development of climate models



Development of climate models


1970s
1980s
Early 1990s
Late 1990s
2000
Now
Atmosphere
Land surface
Sea and sea ice
Aerosols
Carbon cycle
Dynamic vegetation
Atmospheric composition
Development of climate models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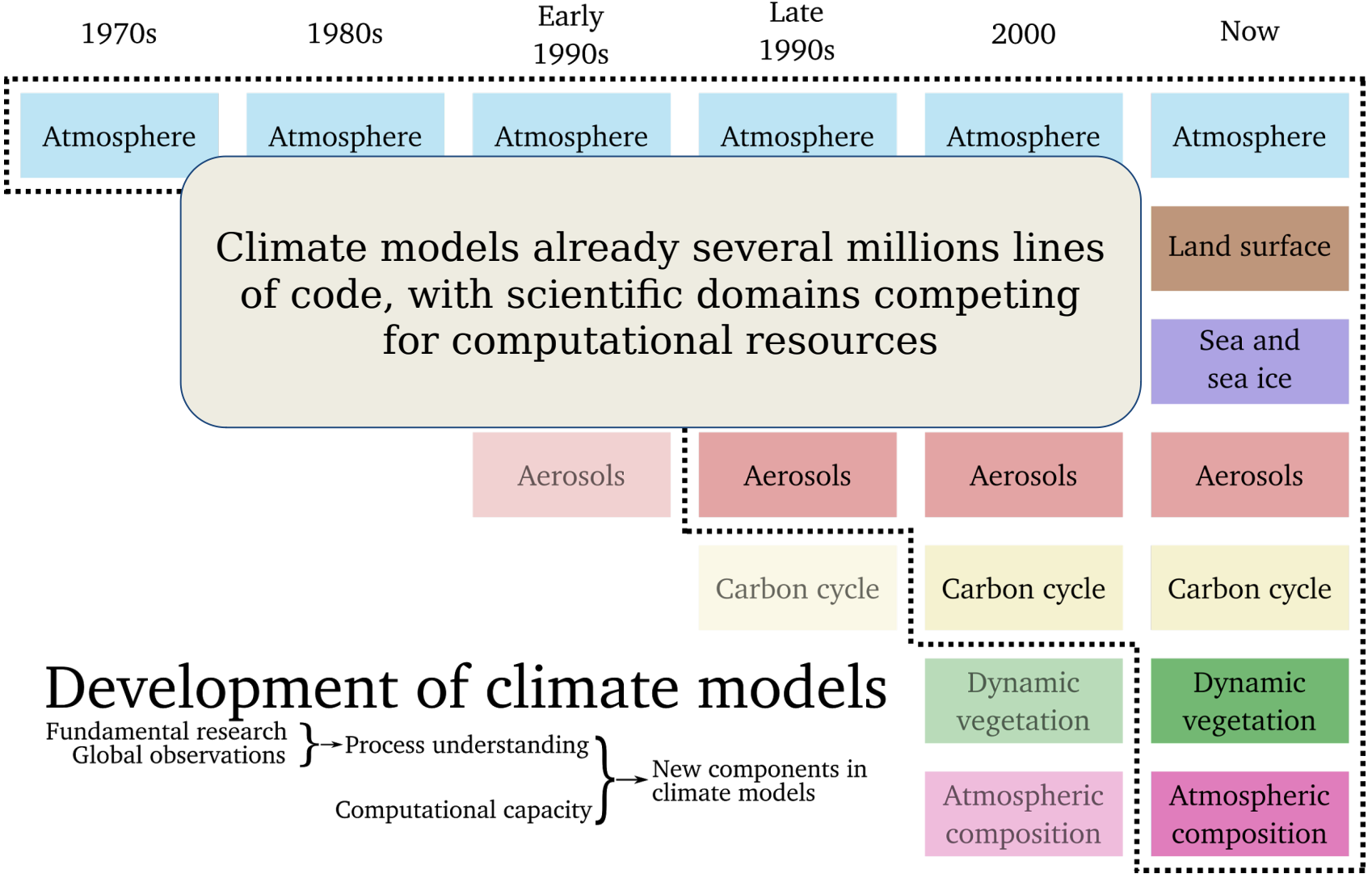
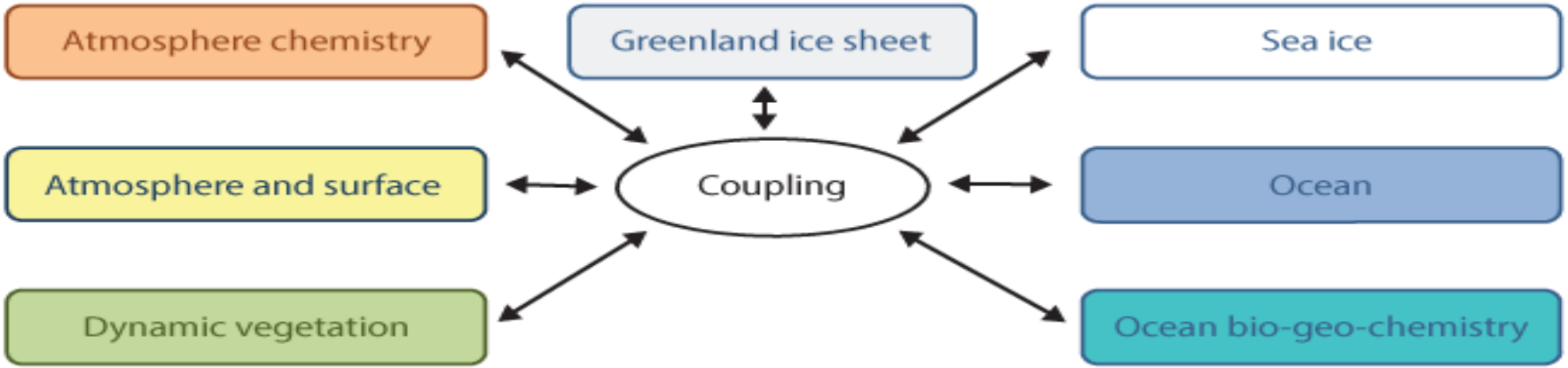
Development of climate models
Fundamental research
Global observations
Process understanding
Computational capacity
New components in climate models


1970s
1980s
Early 1990s
Late 1990s
2000
Now
Atmosphere
Atmosphere
Atmosphere
Atmosphere
Atmosphere
Atmosphere
Climate models already several millions lines of code, with scientific domains competing for computational resources
Land surface
Sea and sea ice
Aerosols
Aerosols
Aerosols
Aerosols
Carbon cycle
Carbon cycle
Carbon cycle
Dynamic vegetation
Dynamic vegetation
Atmospheric composition
Atmospheric composition
Development of climate models
Fundamental research
Global observations
Process understanding
Computational capacity
New components in climate models

EC-Earth

- Highly coupled global Earth System Model
- 30+ European partners
- INAR & FMI participated in CMIP6/IPCC AR6 with EC-Earth3
- INAR is in core of atmospheric aerosol+chemistry development



EC-Earth as part of PEEX Modeling platform

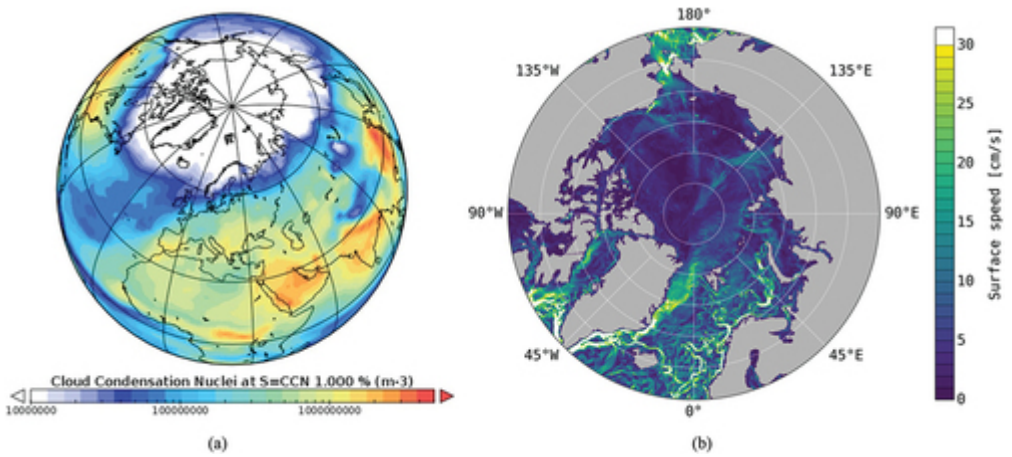
Original Research Article

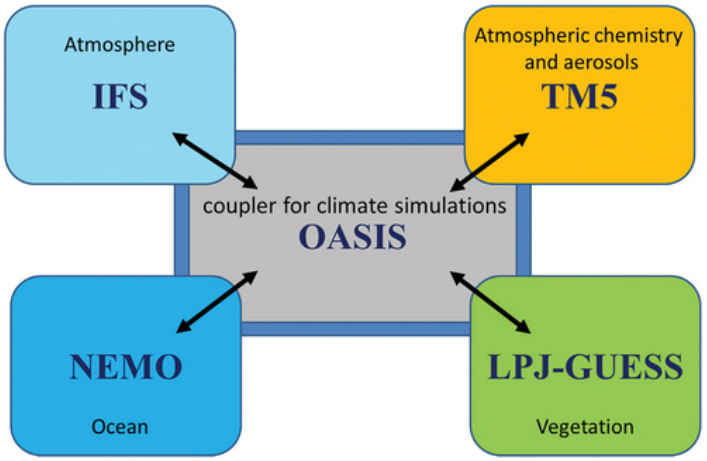
Towards seamless environmental prediction – development of Pan-Eurasian EXperiment (PEEX) modelling platform

Alexander Mahura, Alexander Baklanov, Risto Makkonen, Michael Boy, Tuukka Petäjä, Hanna K. Lappalainen, ...show all

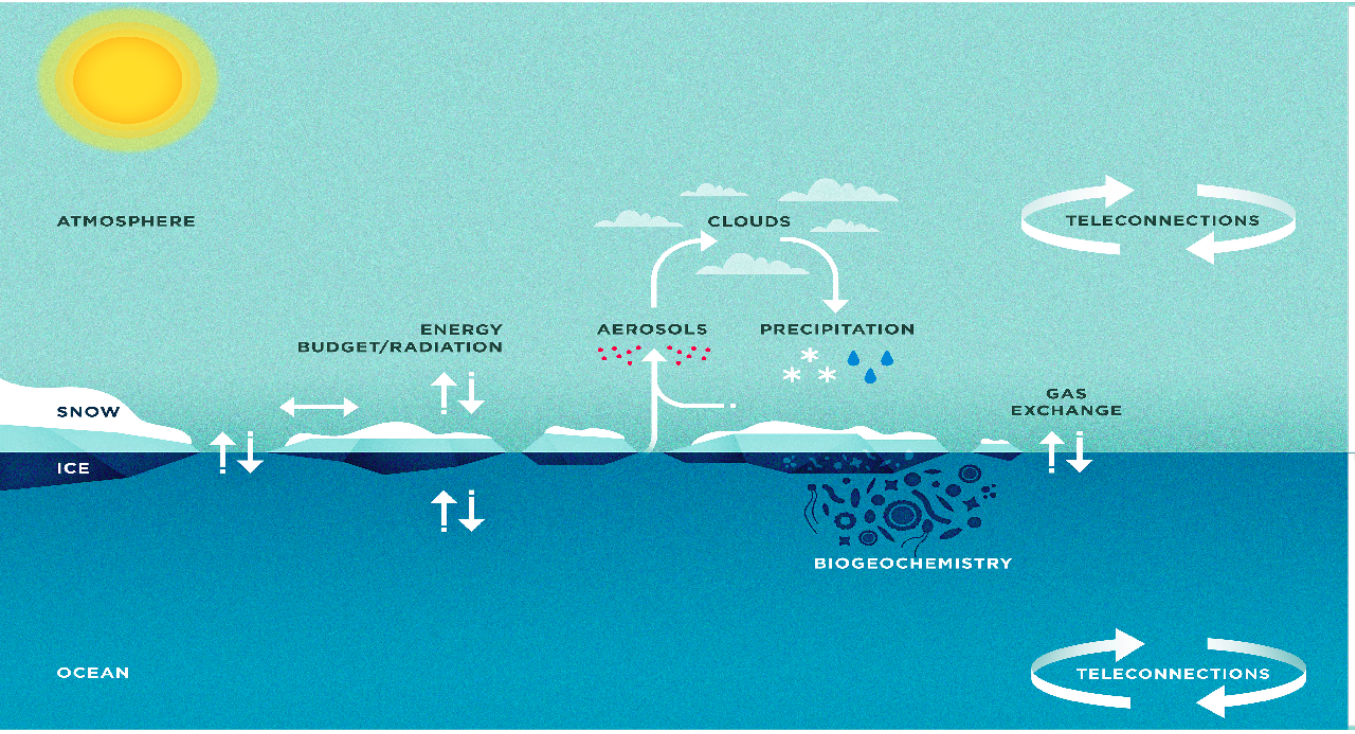
Pages 189-230 | Received 01 Sep 2023, Accepted 26 Feb 2024, Published online: 09 Apr 2024

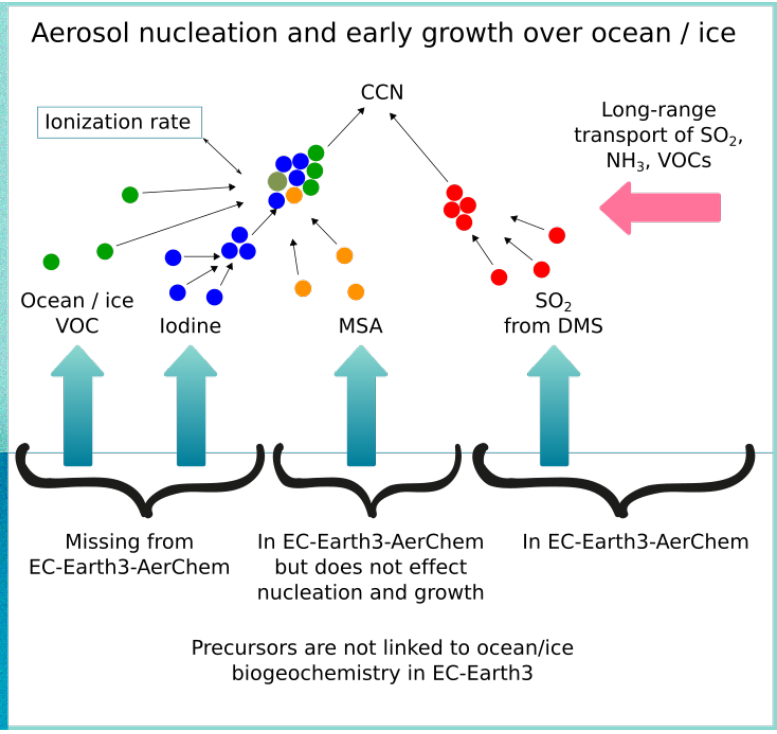
Cite this article https://doi.org/10.1080/20964471.2024.2325019 Check for updates





New particle formation in polar regions: Current EC-Earth status and known gaps



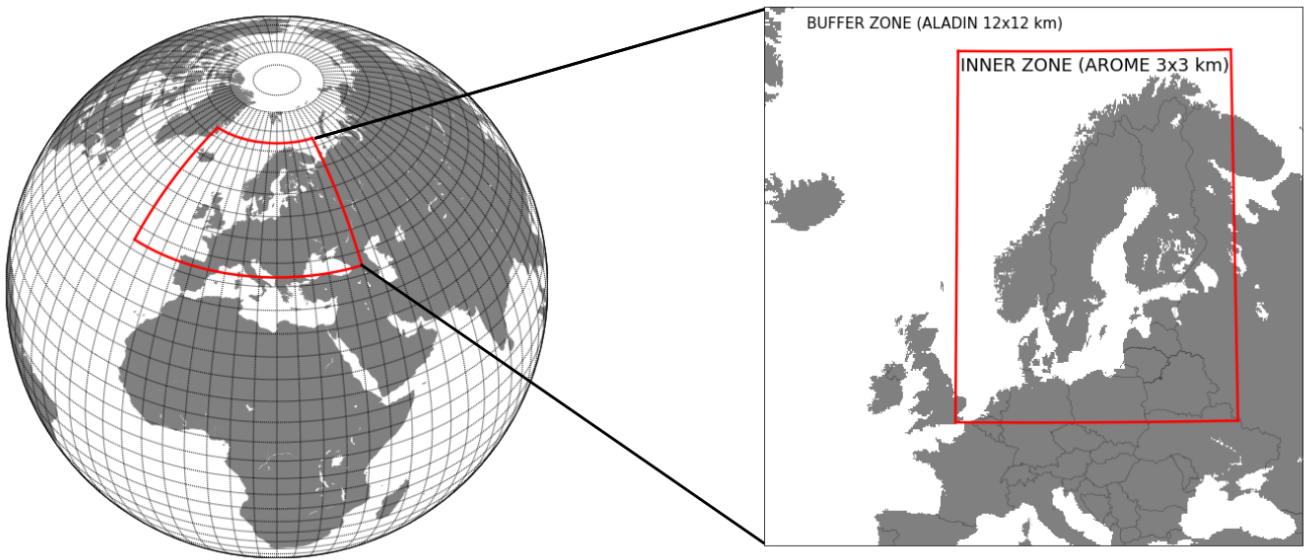


CRiceS

Regional climate model HARMONIE-CLIMATE (HCLIM)

We use *convection permitting* regional model HCLIM to generate detailed climate projections over the Nordic domain

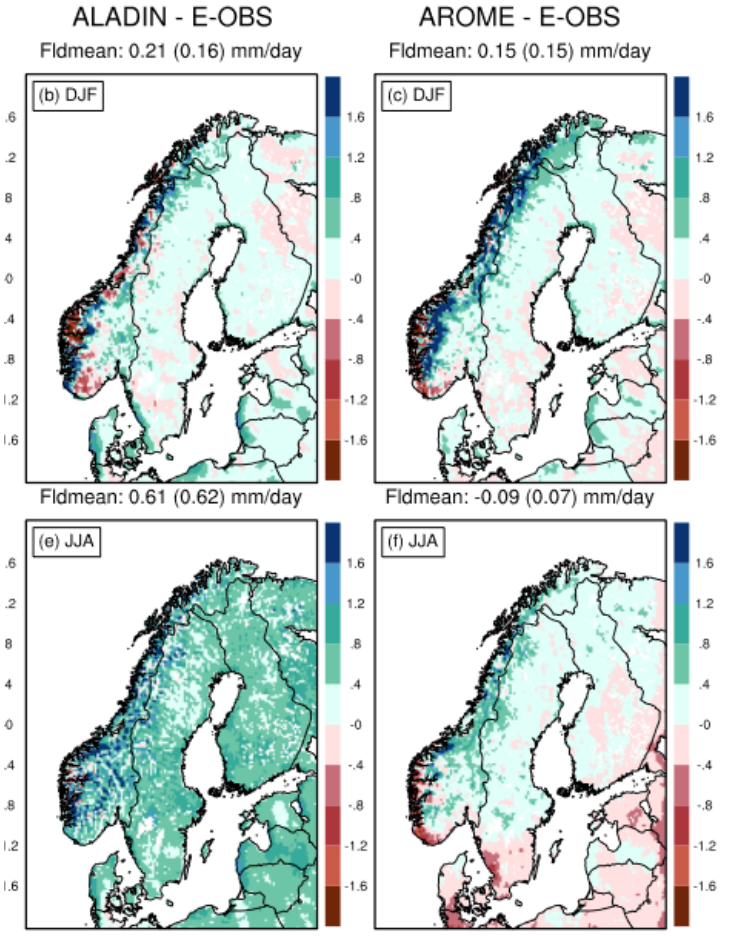
- Taking into account local conditions such as variable orography, land-sea, and land-inland water interactions, and other complex topography offers added value in the model's projections over the regional area.
- The nominal resolution of ~3km in HCLIM-AROME configuration allows convection to be explicitly modelled. This greatly enhances the modelling heavy precipitation events over the domain (Medus, 2022)



HCLIM: Precipitation bias for different model resolutions

On the right: Precipitation bias is reduced by increasing resolution particularly during summertime

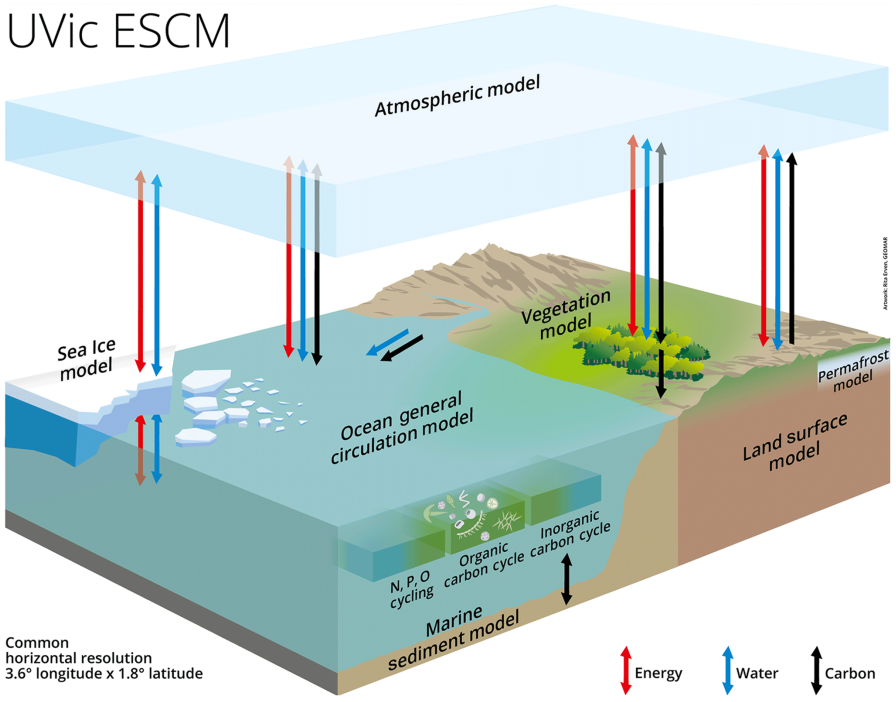
Below: Generated climate projections from reanalysis / parent ESMs at 3 km resolution (HCLIM-AROME)



Status of AROME simulations (convection permitting runs)

LBCs	Simulation period[1]	Responsible Institute	Start Date[2]	End Date[3]	HPC	Comments
ERA-Interim	1997 - 2018	SMHI	22 October 2018	5 March 2019	ECMWF	Finished
EC-Earth	1985 - 2005	FMI	13 November 2018	10 April 2019	ECMWF	Finished
EC-Earth	2040 - 2060	METNo	20 November 2018	11 June 2019	ECMWF	Finished
EC-Earth	2080 - 2100	DMI	19 December 2018	16 May 2019	ECMWF	Finished
GFDL	1985 - 2005	SMHI	19 December 2019	23 April 2020	ECMWF	Finished
GFDL	2040 - 2060	FMI	20 December 2019	9 June 2020	ECMWF	Finished
GFDL	2080 - 2100	METNo	19 December 2019	10 May 2020	ECMWF	Finished
EC-Earth RCP4.5	2080 - 2100	DMI	3 April 2020	24 August 2020	ECMWF	Finished
EC-Earth RCP4.5	2040 - 2060	FMI	28 October 2020	30 March 2021	ECMWF	Finished

UVic ESCM 2.1



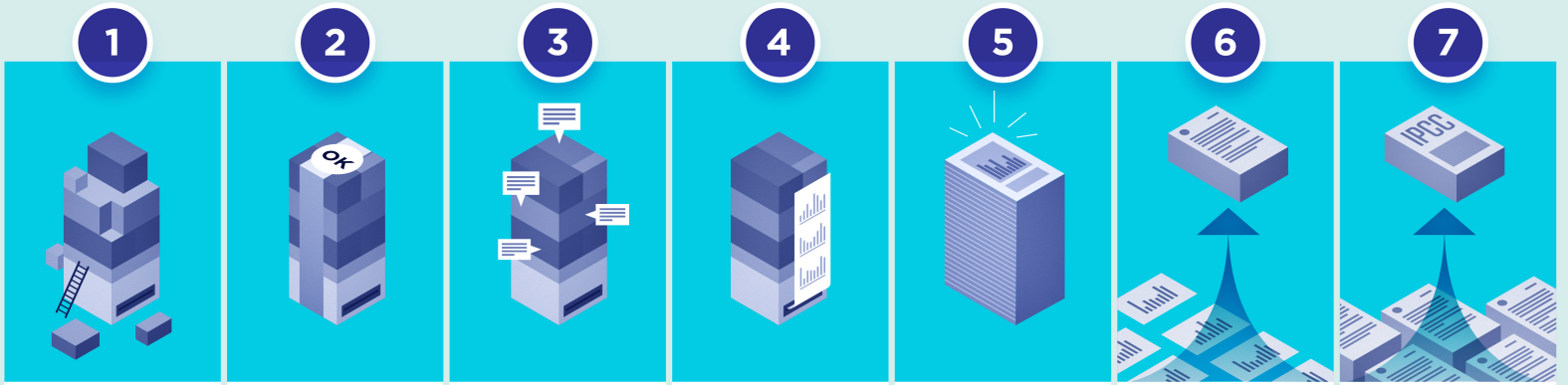
- Earth System Model of intermediate complexity
- Contains main components of the Earth system in a simpliefied way and with low resolution (1.8° × 3.6°)
- Can reproduce historical changes in global carbon cycle and temperature
- Due to low running cost, especially suitable for long century to millennial time scales or uncertainty analysis spanning thoudands of simulations

Mengis et al. (2020), https://gmd.copernicus.org/articles/13/4183/2020/

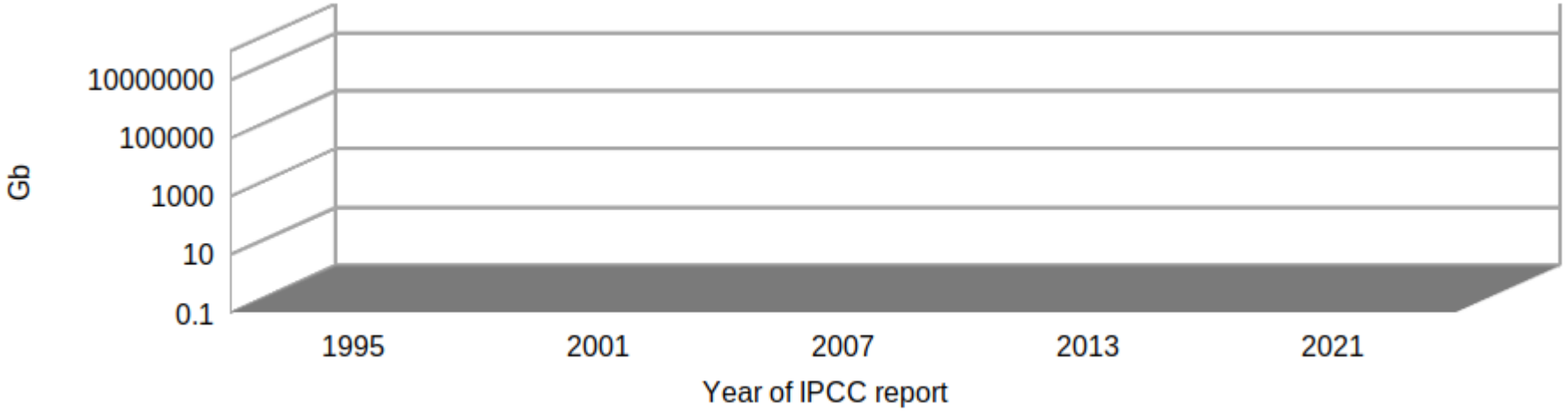
About 85,000 lines of Fortran Code (inclusing comments)

From climate simulations to IPCC reports

Coupled Model Intercomparison Project (CMIP)



Amount of data produced in Coupled Model Intercomparison Project (CMIP)



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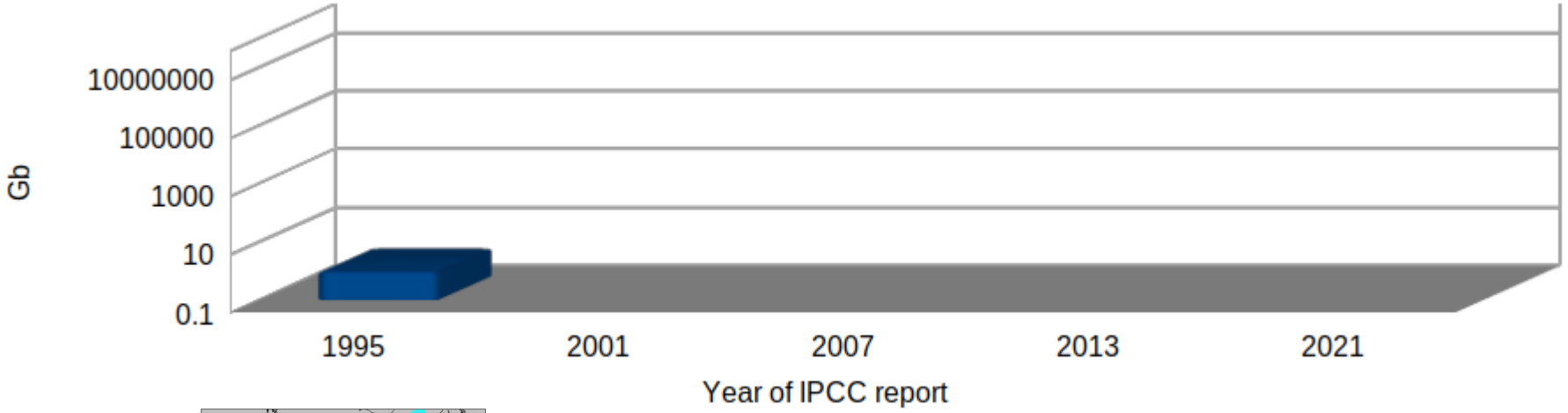

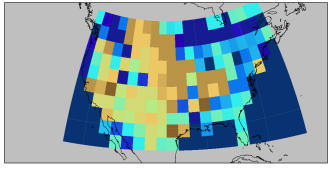

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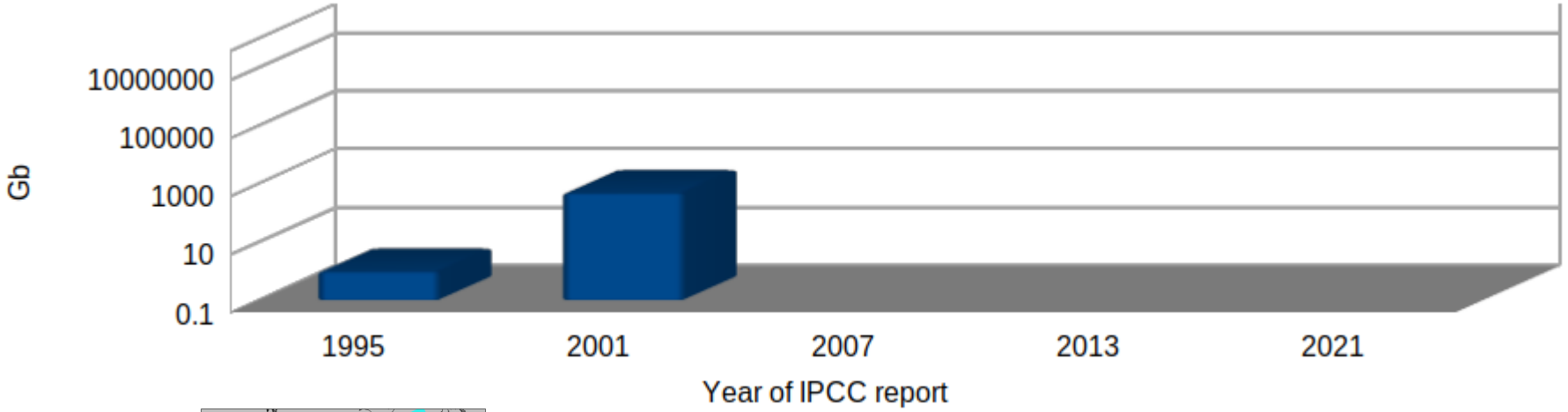

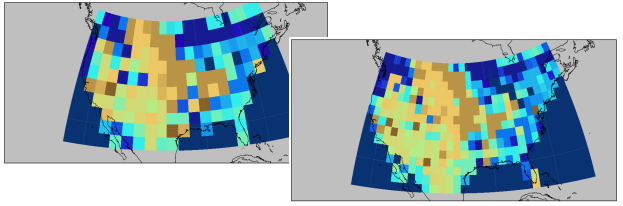

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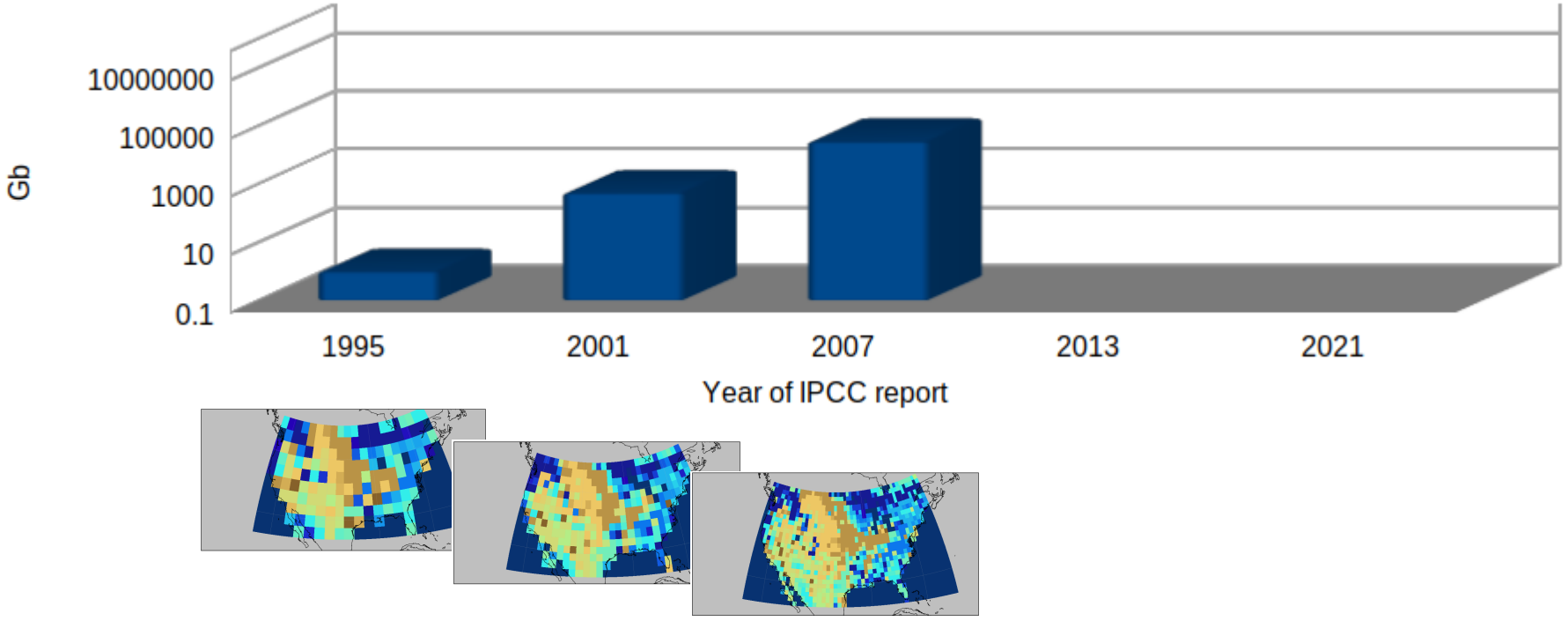

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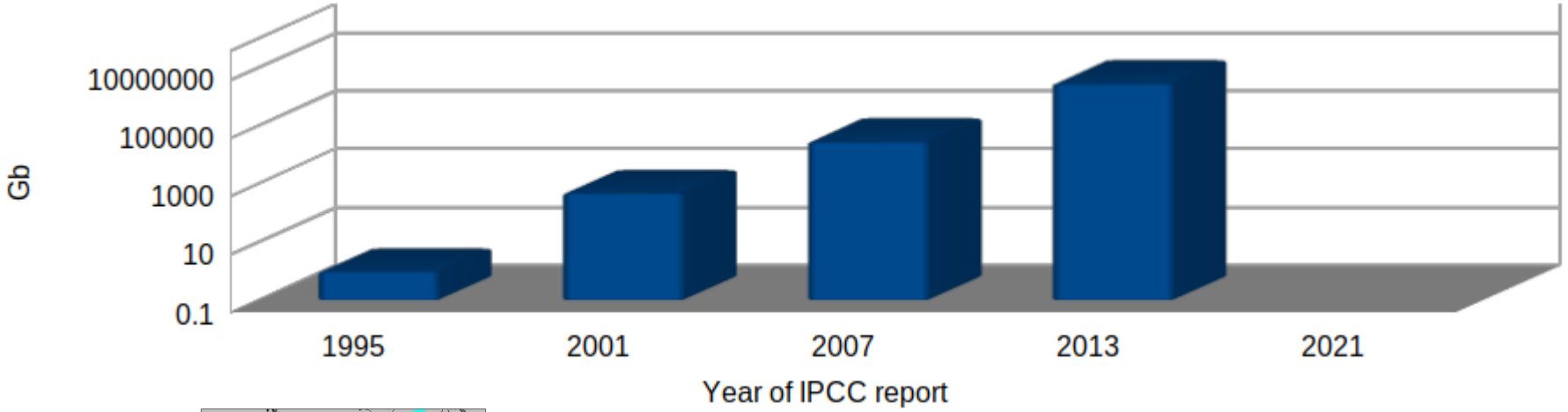

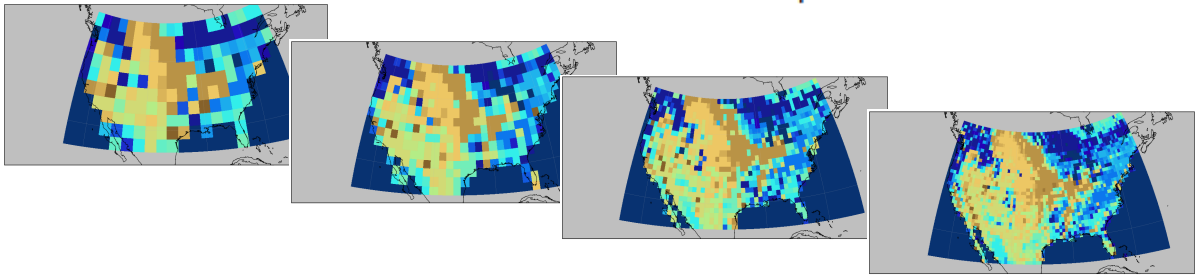

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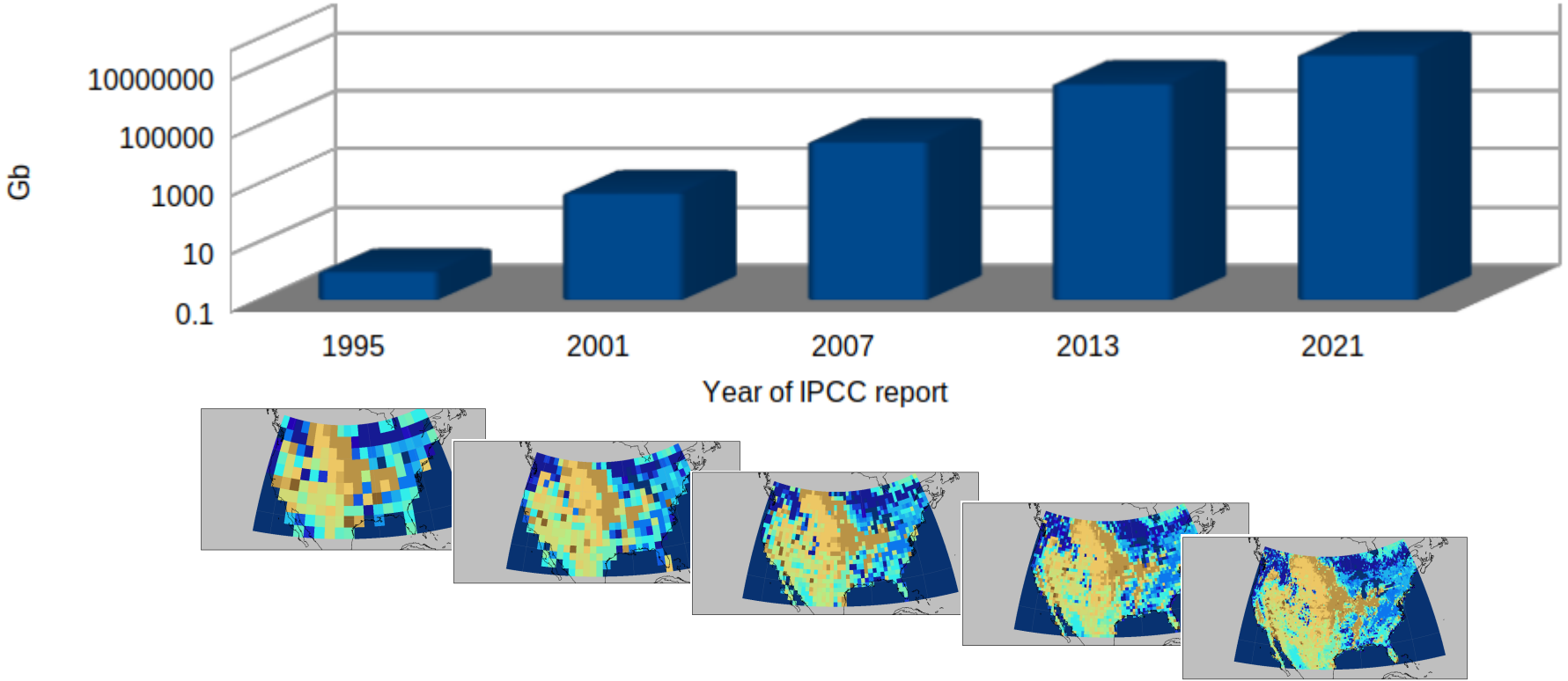

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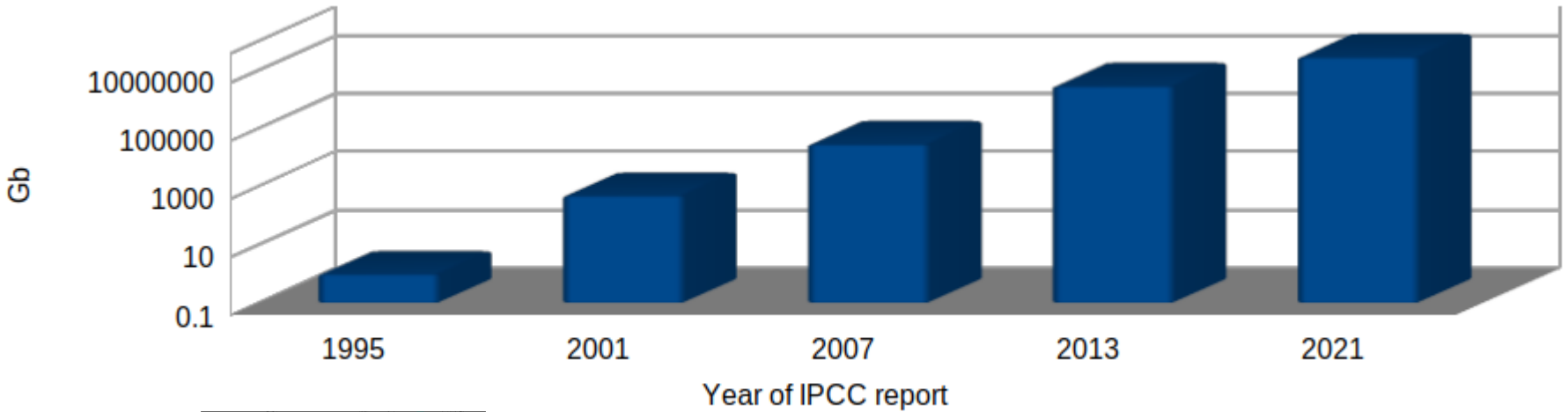
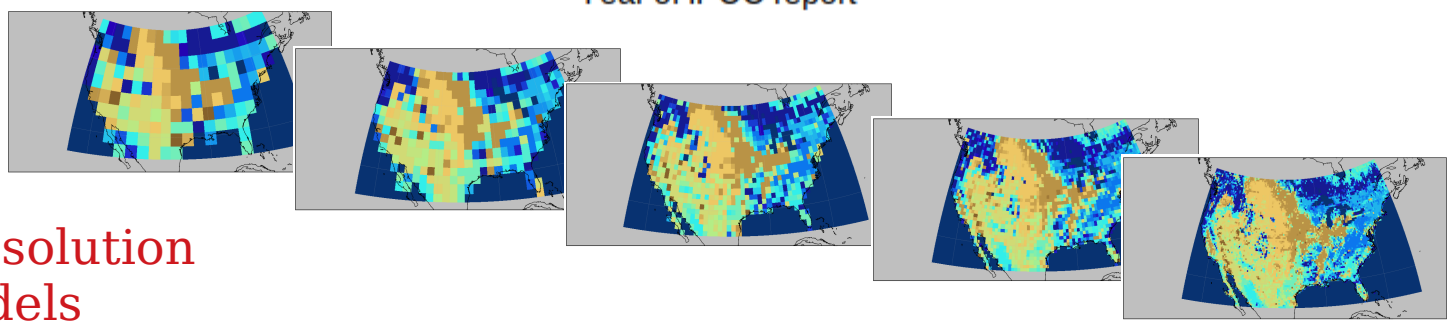
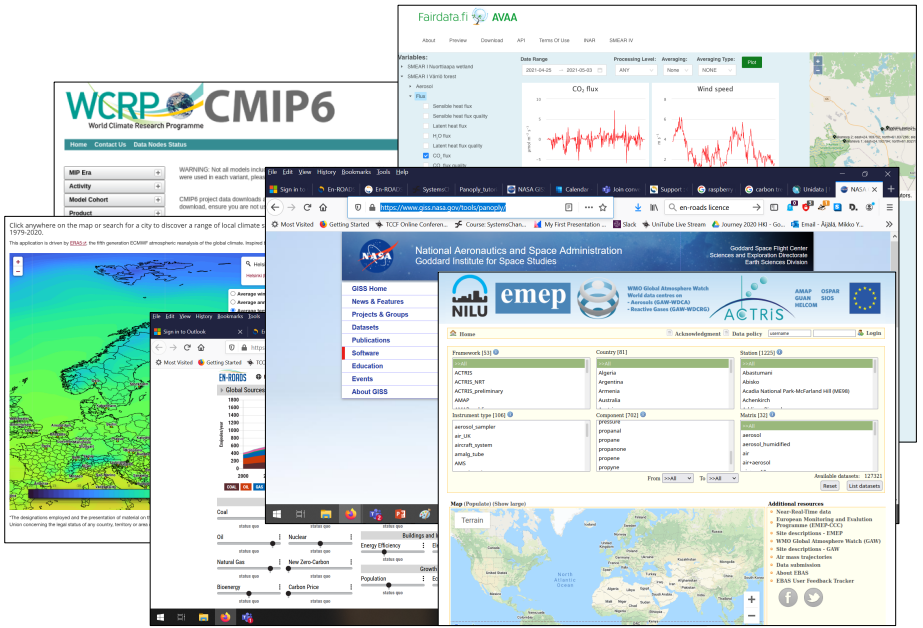




- Higher resolution
- More models
- More components
- More experiments

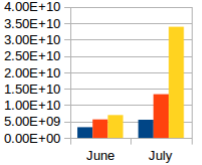
Open Climate Data

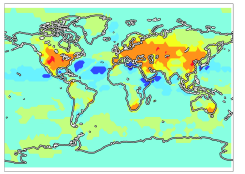
Various data portals and websites to visualize and download climate data



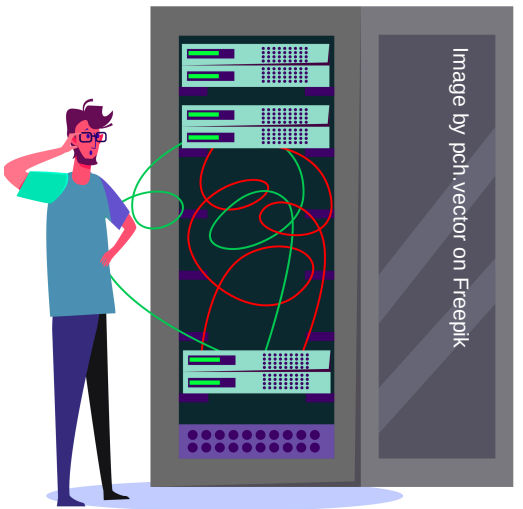
Most of weather and climate data is **open and free to use!**

Data from climate and weather models, weather and greenhouse gas observations, satellites





Petabytes of data available!

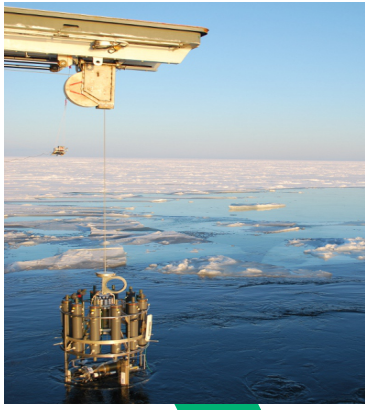


Climate and weather data

Long-term observations

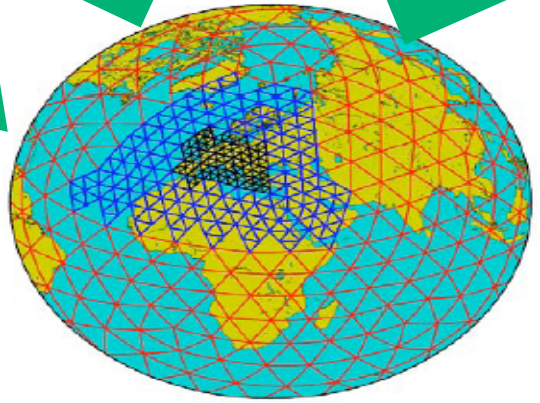
Land

Ocean



Atmosphere

Remote sensing



Connecting observations with models to create global datasets

Technical considerations

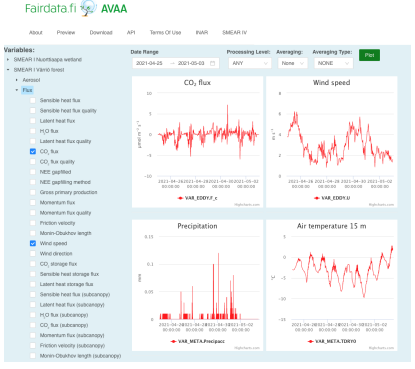
- The data can be in various formats, including
  - CSV (Comma separated values), which can easily be opened in spreadsheet programs
  - NetCDF (Network Common Data form = Self-describing, Portable, Scalable, Appendable, Sharable, Archivable), which requires special software or libraries
  - Others: HDF, GRIB, NASA AMES, XLSX, ...

Examples of climate data portals for research, training and education

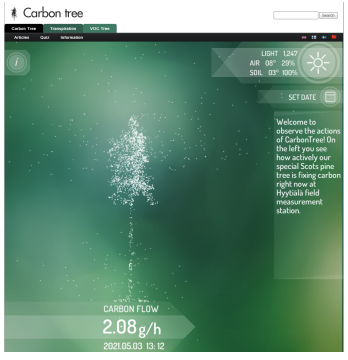
Climate data platforms

Reviewing data portal usability in education

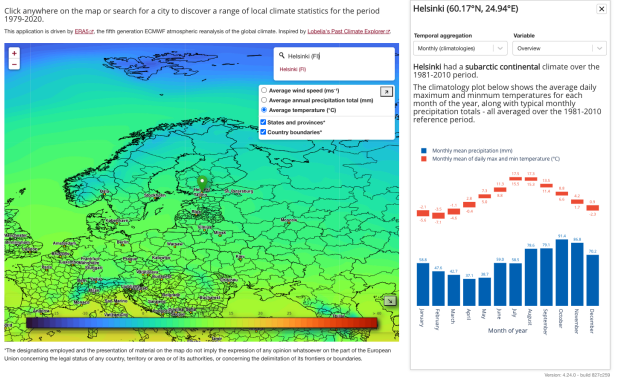
SmartSMEAR



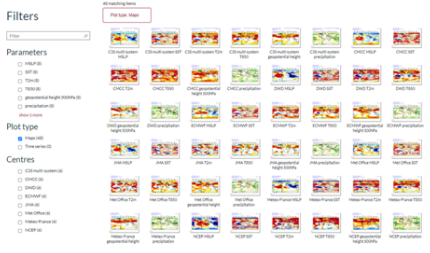
CarbonTree



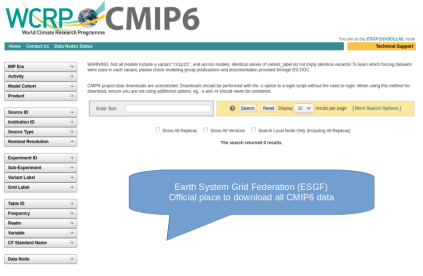
Copernicus C3S
Climate data store + Toolbox



Copernicus C3S
Seasonal forecasts



Official climate data portal for IPCC



And many more, including
FMI Open Data (weather and climate),
ICOS portal (greenhouse gases),
ESA Earth Online (Earth Observation data)

Using climate models in education

- Significant learning outcome potential on Earth System understanding, climate change trajectories and mitigation pathways
  - Students could create climate scenarios using their own assumptions, or e.g. study upscaling a certain mitigation technology
- Climate models and their subcomponents are already used in University courses on climate, meteorology, oceanography
- Major technical difficulties remain
  - Typically some level of coding and/or scripting needed
  - Time needed to learn the model, how to run simulations and how to analyze results
  - Computational demand: is laptop enough or is a supercomputer needed
- Climate models currently in educational use as well as other promising options
  - Selection of model system will depend on selected case studies, level of education and resource constraints for the training

Using climate models in education

Several levels of complexity for different purposes

Online data “models”

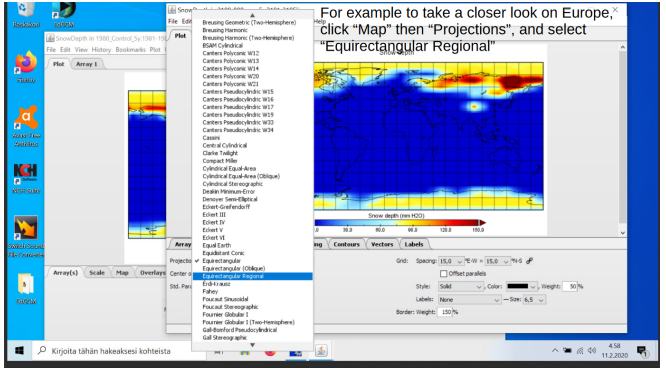
- Works directly in browser
- Based on comprehensive calculations (e.g. IPCC data)
- Easy to visualize existing trajectories

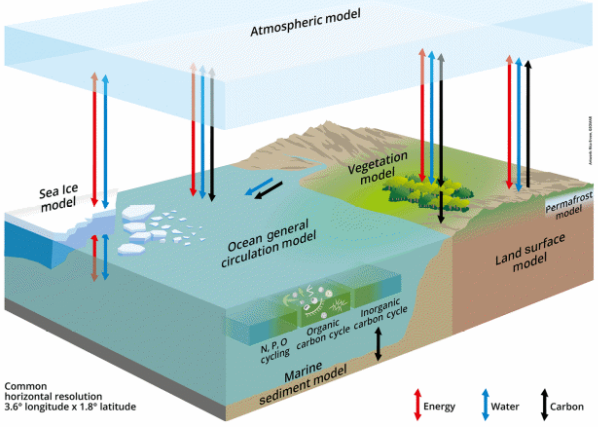
Education climate models

- Interface designed for first-time users
- Can be run on laptop/PC
- Limited capabilities in teaching processes and e.g. mitigation

Full Earth System Models

- Computationally heavy
- Interface designed for researchers, not Plug&Play
- More flexible to design learning projects around mitigation

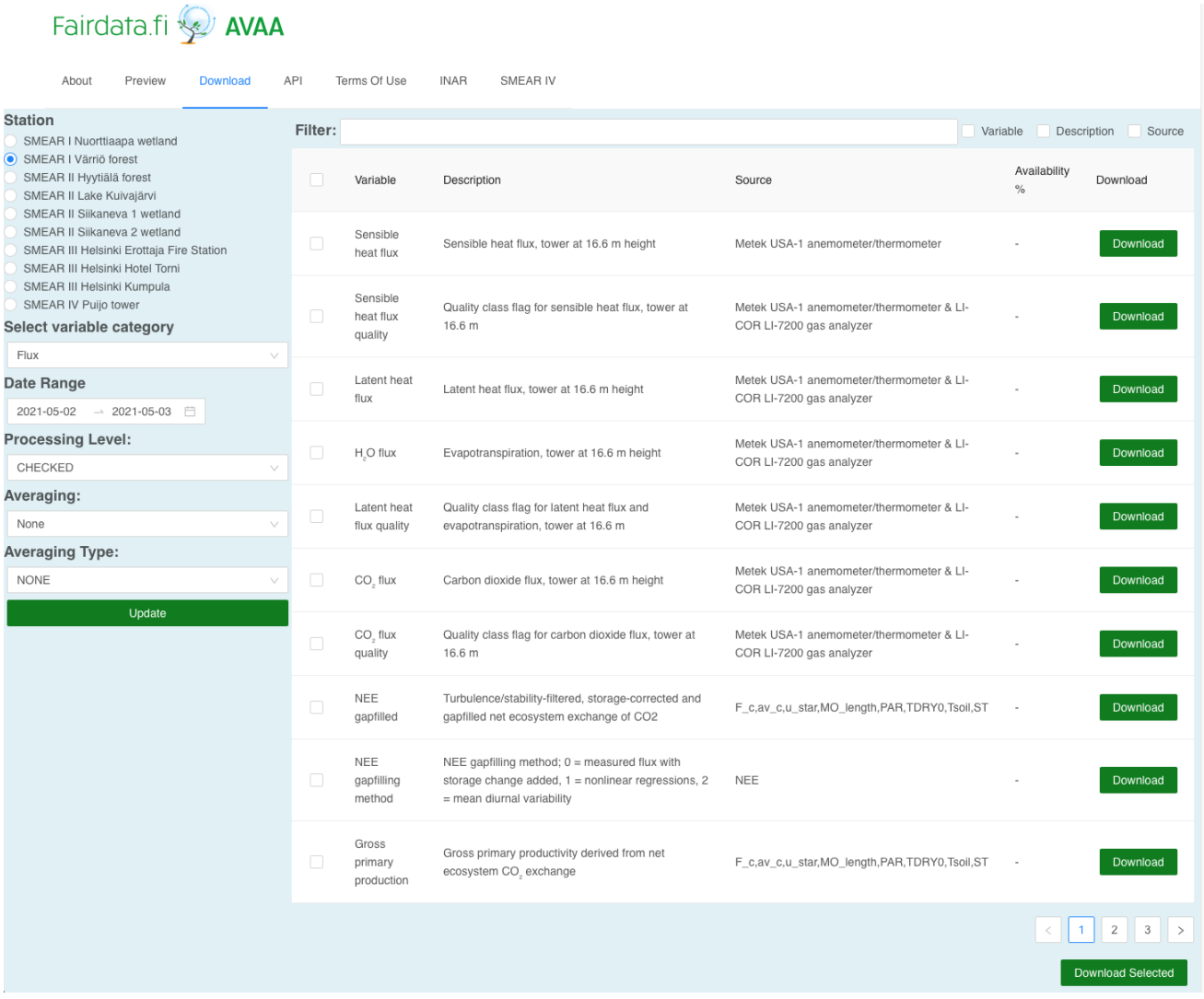




SmartSMEAR

https://smear.avaa.csc.fi

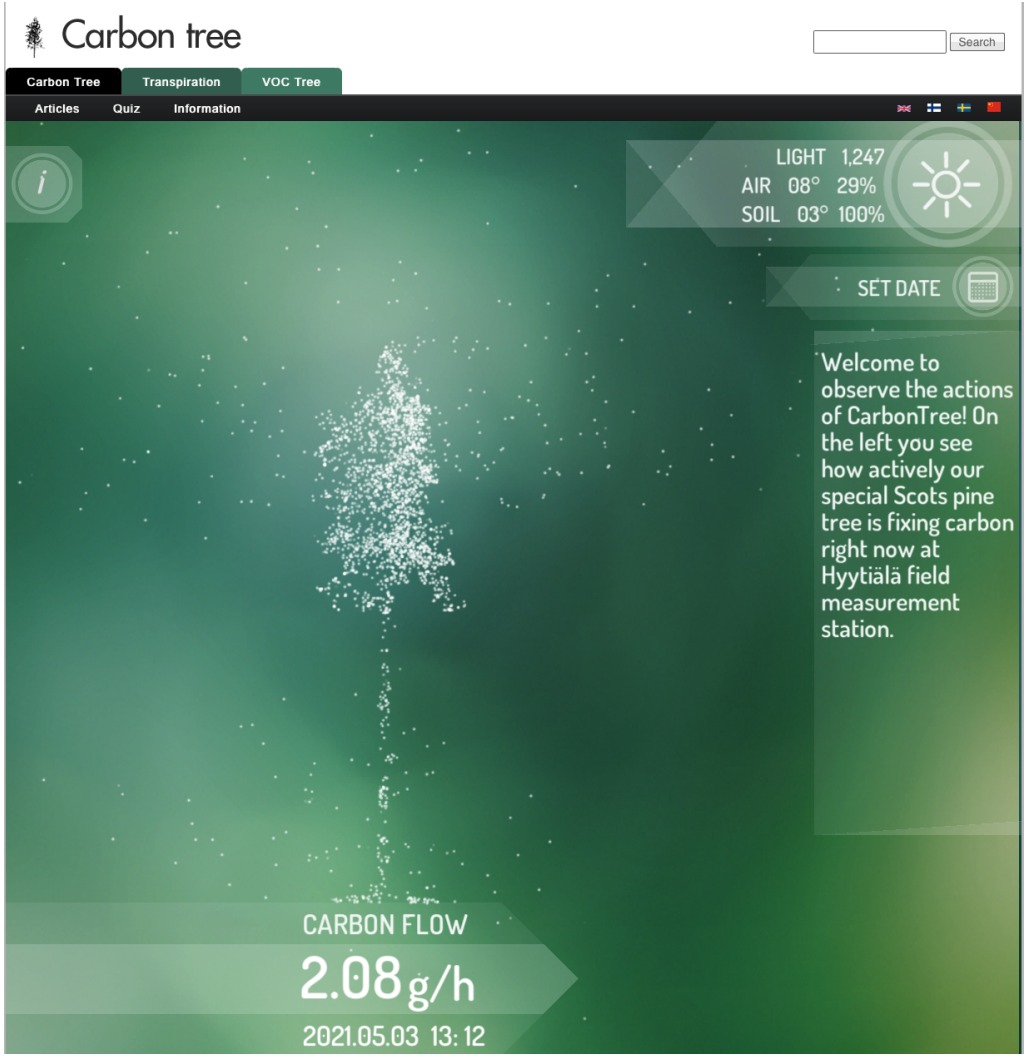
- For visualizing and downloading atmospheric, flux, soil, tree physiological and water quality measurements from SMEAR stations
- Preview ✉ from high school on,
- Download/API ✉ research and higher education projects
- CC BY licence



Carbon Tree

http://www.carbontree.fi

- Real-time animation of exchange of carbon dioxide based on measurements in Hyytiälä
- Articles and material about forests vs climate
- Visual online tool > easy to use > from high school on?
- No data download



SmartCitizen.me

- "Citizen sensor" => cheap, easy to use
- Quality?
- Realtime observations of some weather and air quality parameters
- If sensor is connected to internet, it sends observations in realtime to the SmartCitizen-platform (otherwise on SD-card)
- One sensor at Antti's FMI desk:
- https://smartcitizen.me/kits/11043
- To whom: from elementary school to university students
-
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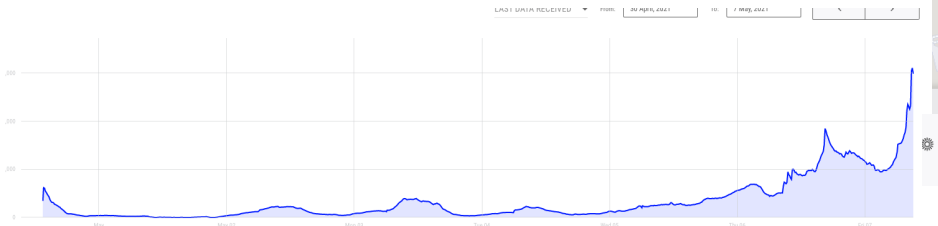
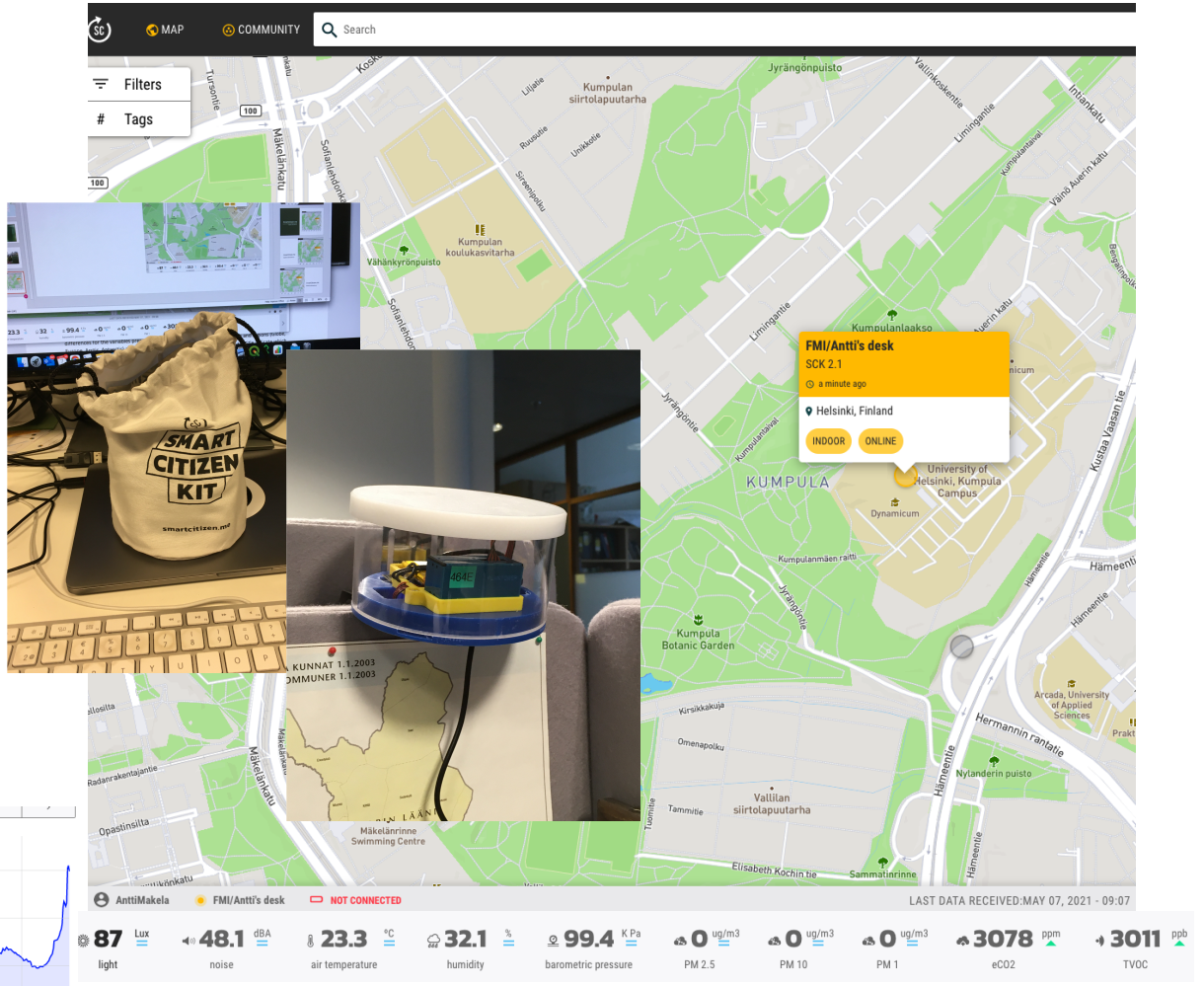
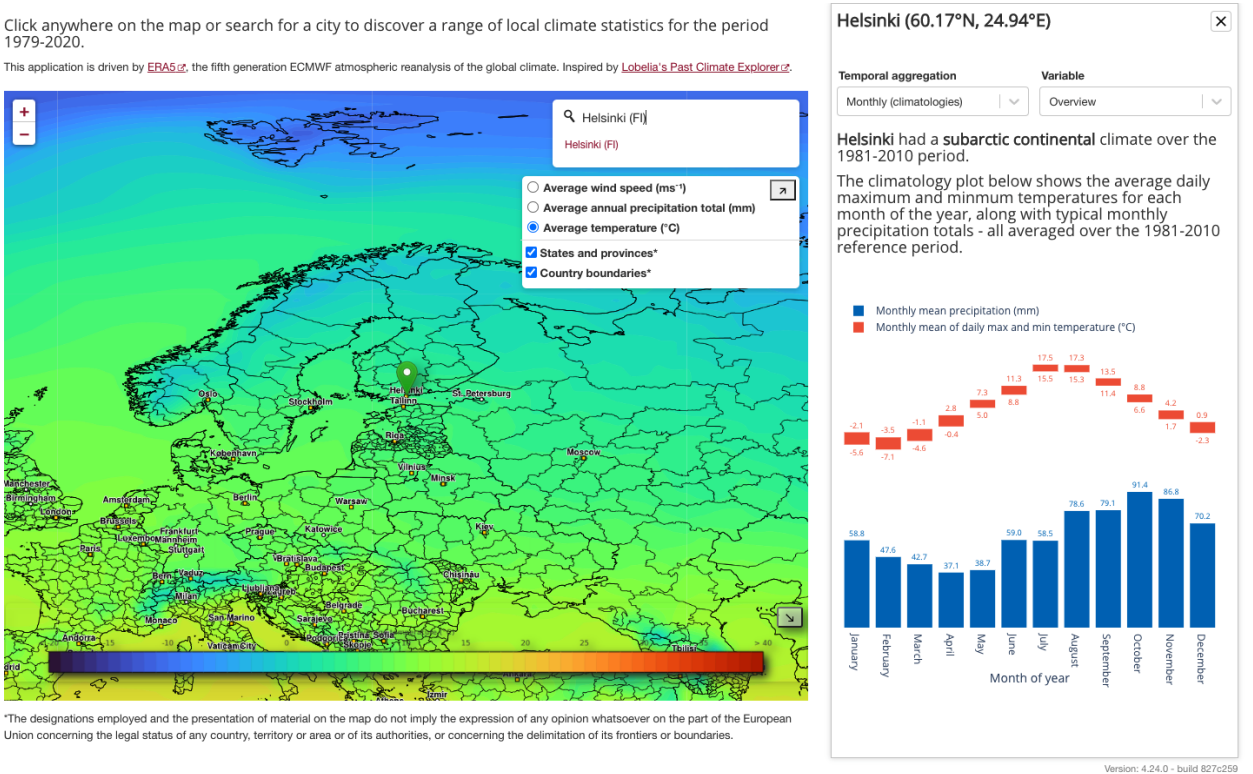




C3S Climate Data Store & its Toolbox

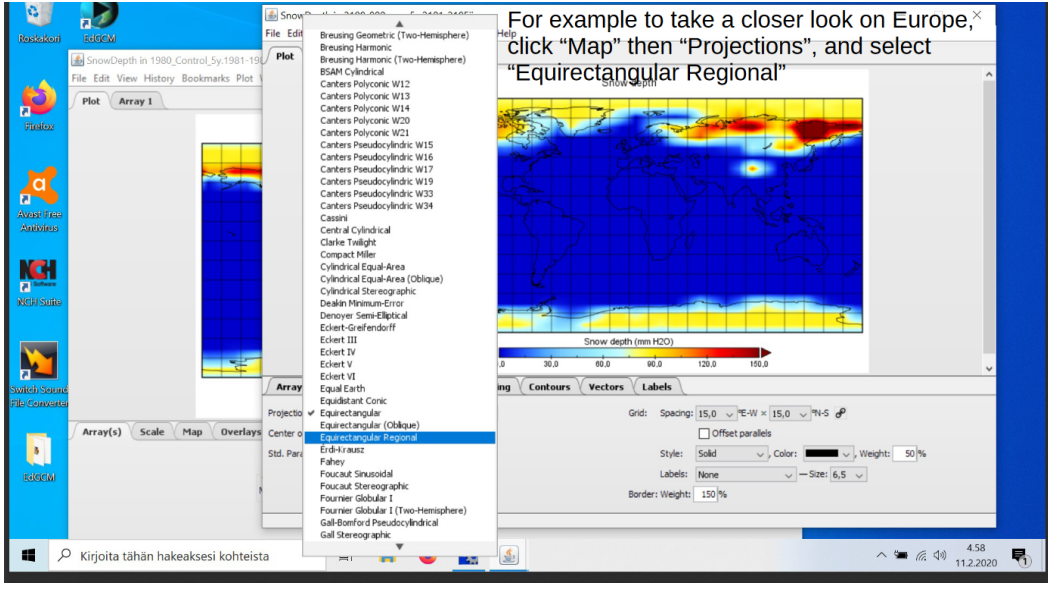
- Huuuuuuge amount of climate data
  - In-situ, satellite, reanalysis, seasonal forecasts, climate projections, …
- Free to use by anyone (must register though)
- Manual downloading, but also API
- Toolbox:
  - Python coding console for retrieving, analysing CDS data and making your own workflows and applications
- Data in .grib and .netcdf
  - CDO, QGIS etc can be used for analysing, visualising etc
- To whom: university (but the lecturer/teacher should have the know-how to use the CDS?)
  - Could CLIMCOMP support C3S in educating in the use of CDS?



Example application made with the CDS Toolbox editor: https://cds.climate.copernicus.eu/cdsapp#!/software/app-era5-explorer?tab=app

edGCM

- http://edgcm.columbia.edu/
- GISS II based, educational climate model
- Possibility to design & run own climate scenarios!
- Good functionalities for educational modeling use, provide "real" climate model outputs
- Severe technical problems on installation and running, limited versions in macOS, no Linux version, requires admin rights in windows etc.
- Licenced software



En-ROADS interactive (educational) model

- https://en-roads.climateinteractive.org/scenario.html?v=2.7.39
- Very easy to use, browser based, does not require any installations.
- Societal model more so than natural scientific
- More depth "under the hood", good simulation of interventions
- Does not provide spatial output or use many physics / met variables