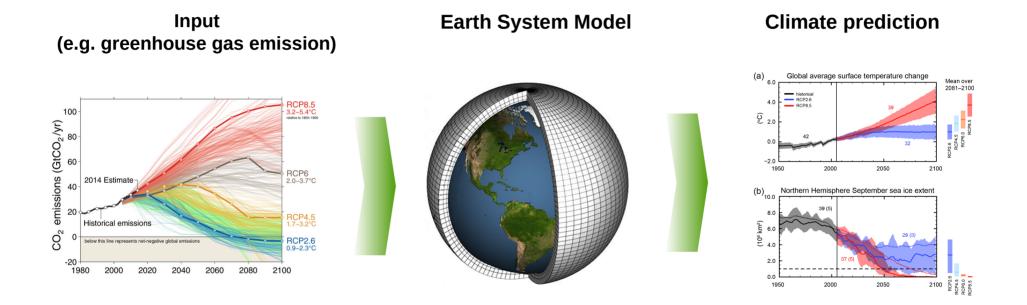
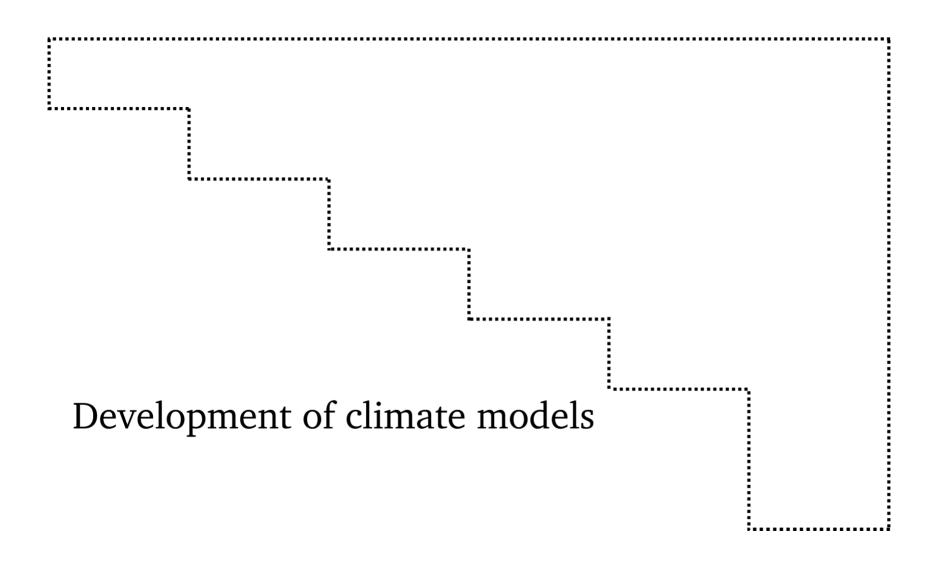
### Earth System Modeling

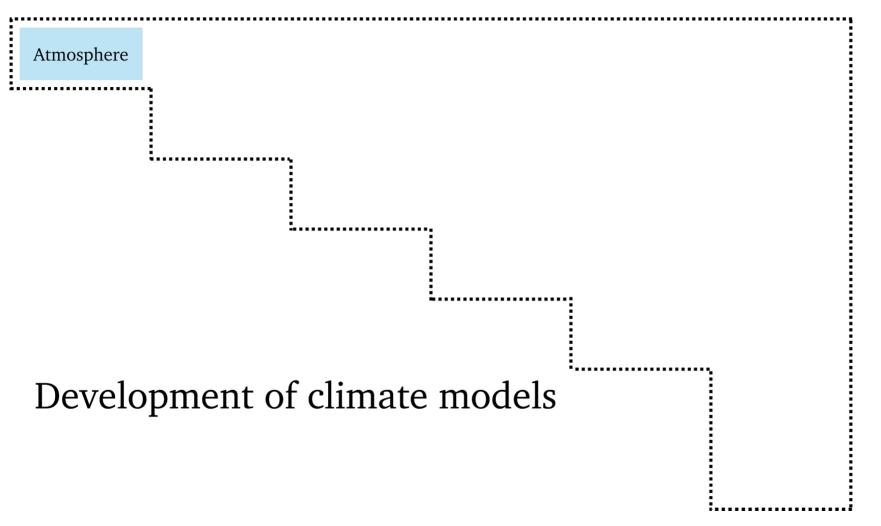
### **Risto Makkonen**

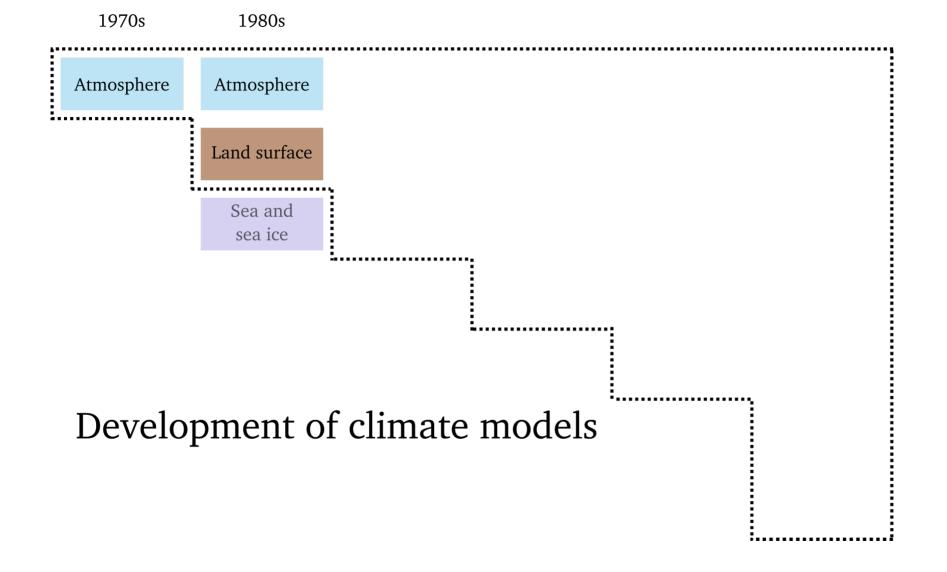
Finnish Meteorological Institute and University of Helsinki

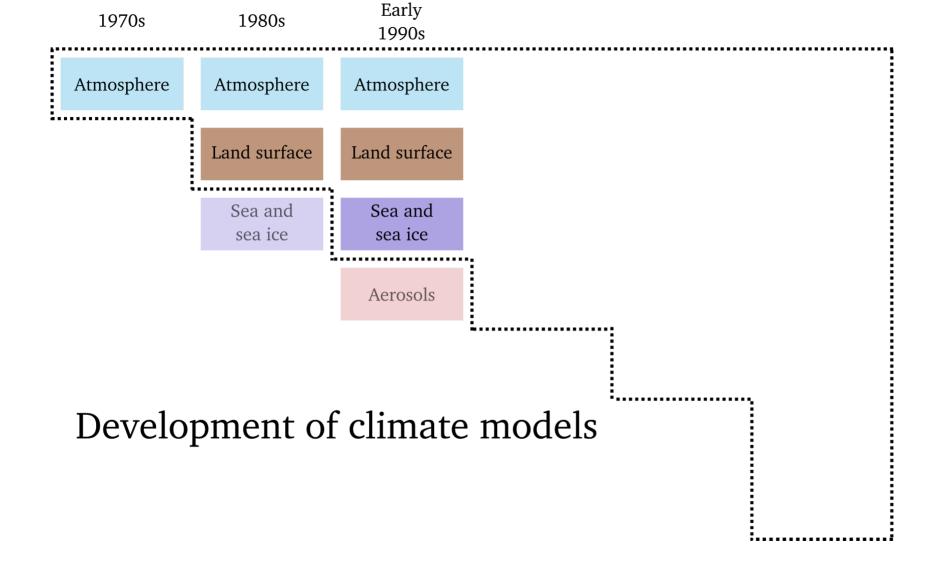


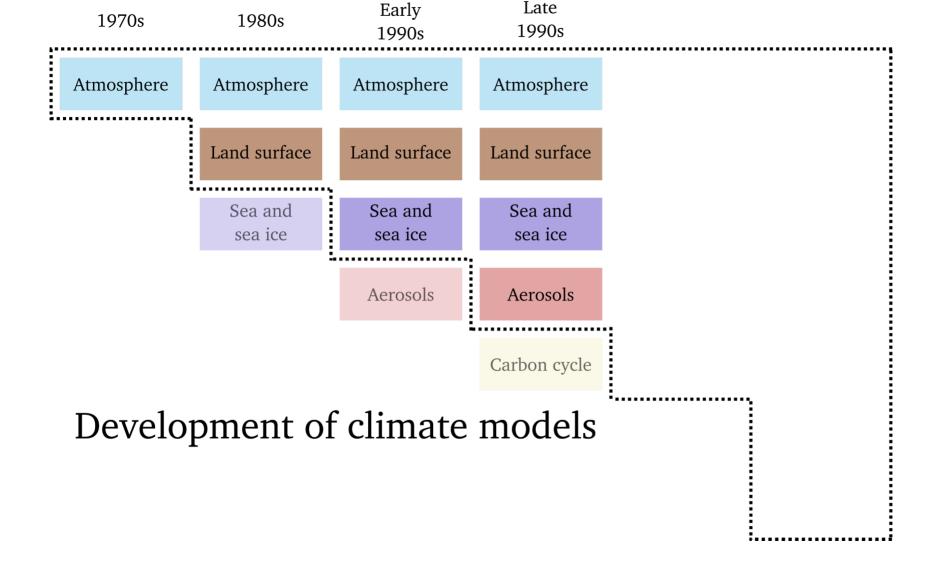


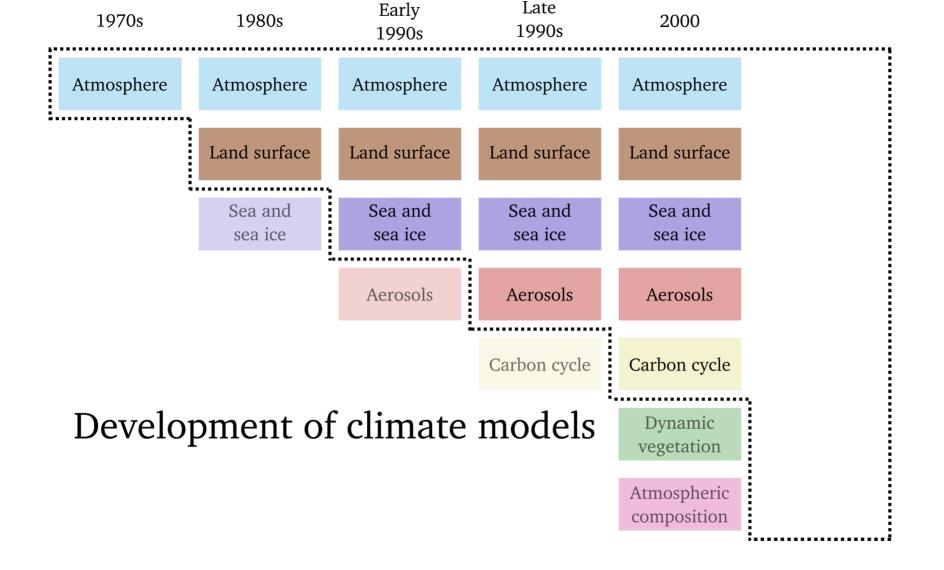


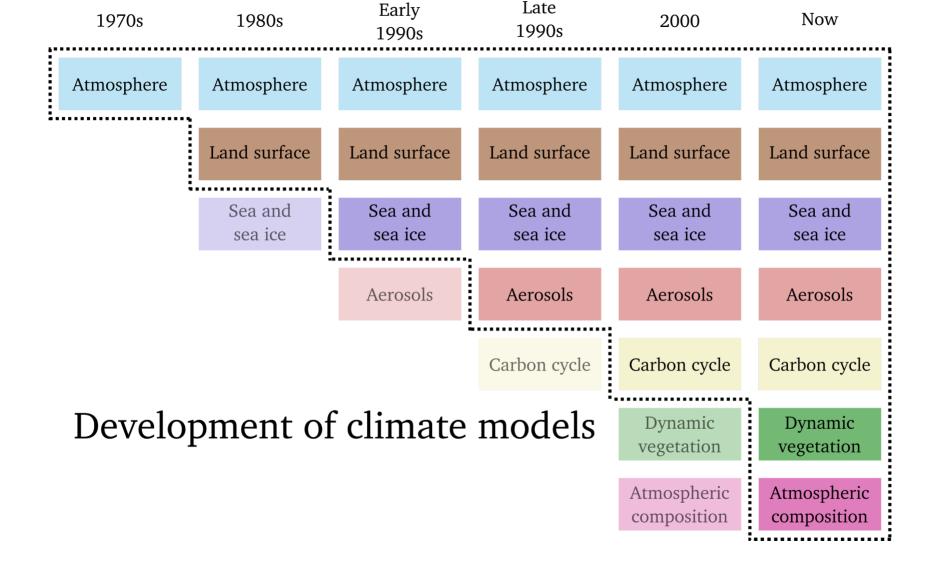


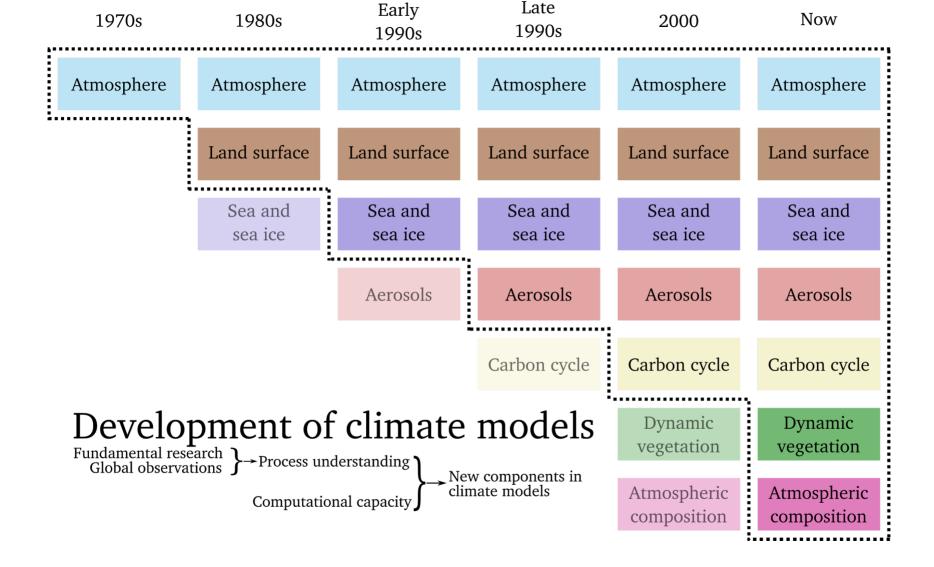


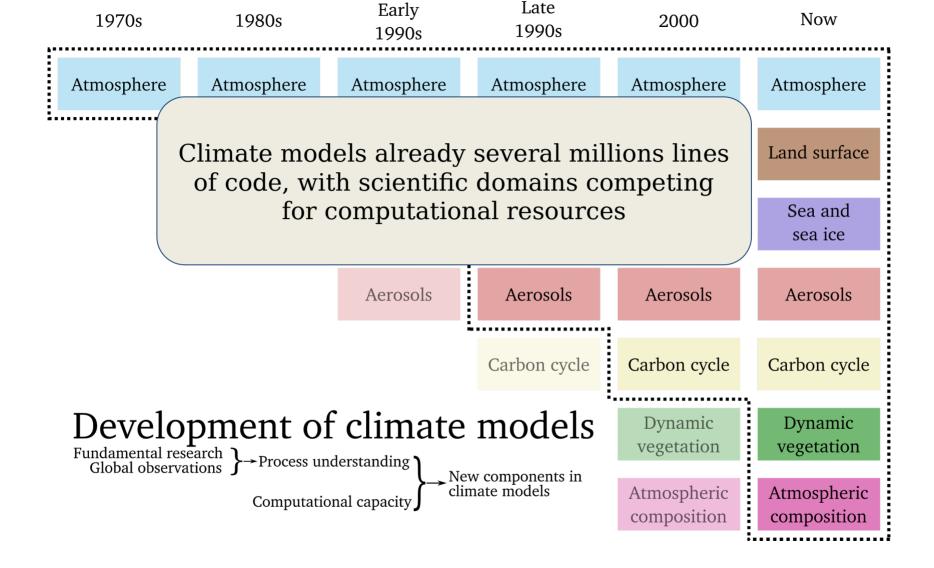






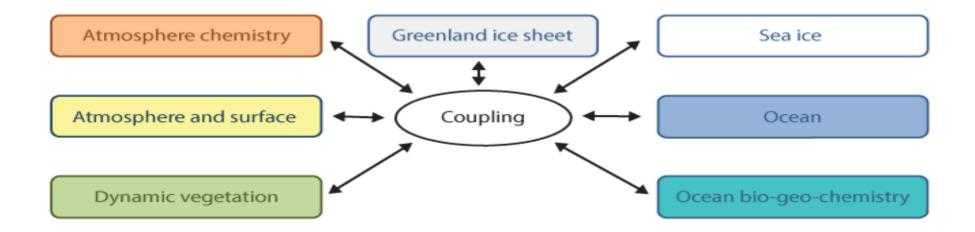






## **EC-Earth**

- 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



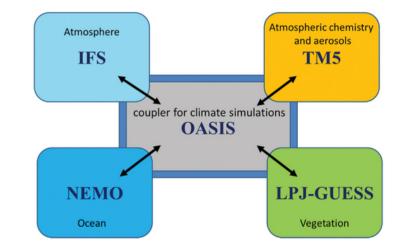
## EC-Earth as part of PEEX Modeling platform

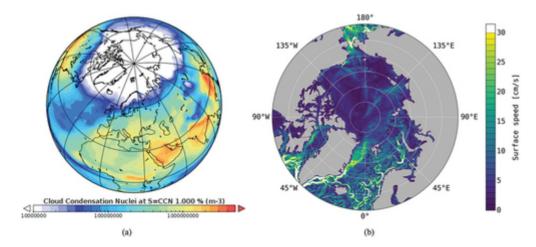
Original Research Article

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

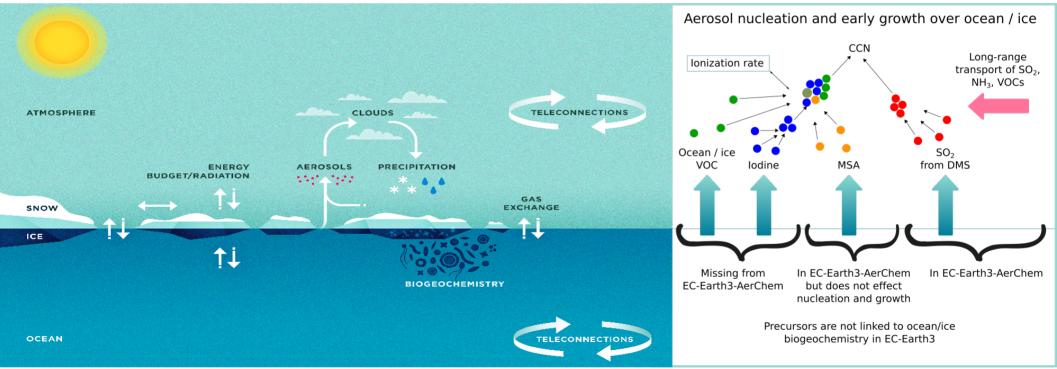
Pages 189-230 | Received 01 Sep 2023, Accepted 26 Feb 2024, Published online: 09 Apr 2024

Gite this article Attps://doi.org/10.1080/20964471.2024.2325019





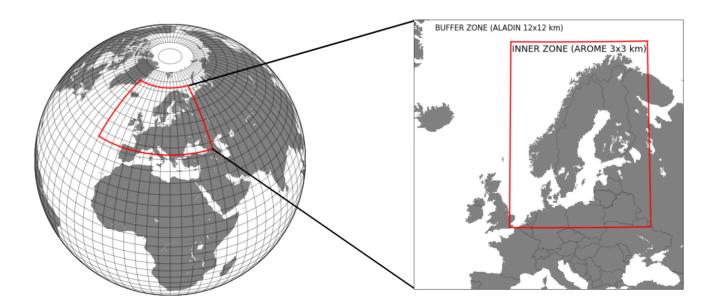
### New particle formation in polar regions: Current EC-Earth status and known gaps



### 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)



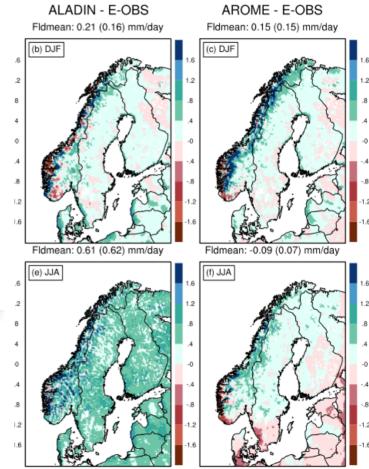
### HCLIM: Precipitation bias for different model resolutions

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

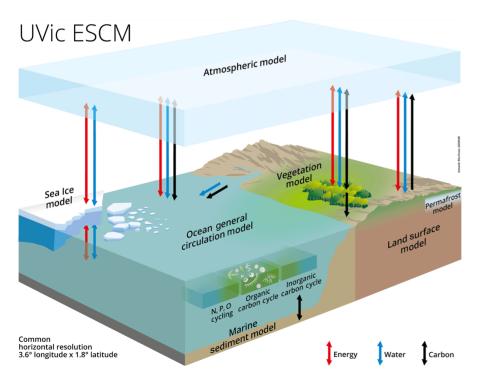
**Below**: Generated climate projections from reanalysis / parent ESMs at 3 km resolution (HCLIM-AROME)

#### Status of AROME simulations (convection permitting runs)

LBCs	Simulation period <sup>1</sup>	<b>Responsible Institute</b>	Start Date <sup>2</sup>	End Date <sup>3</sup>	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

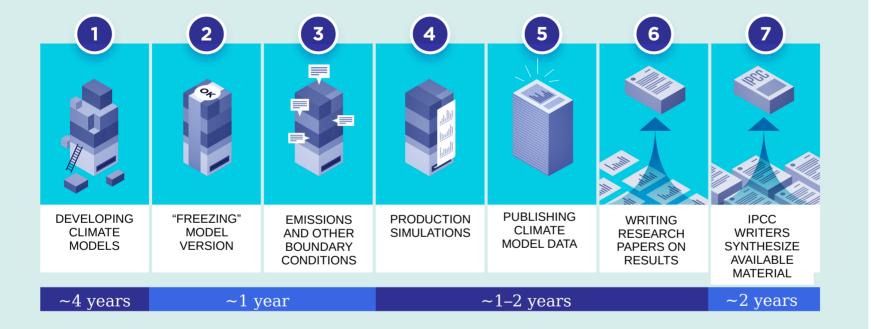


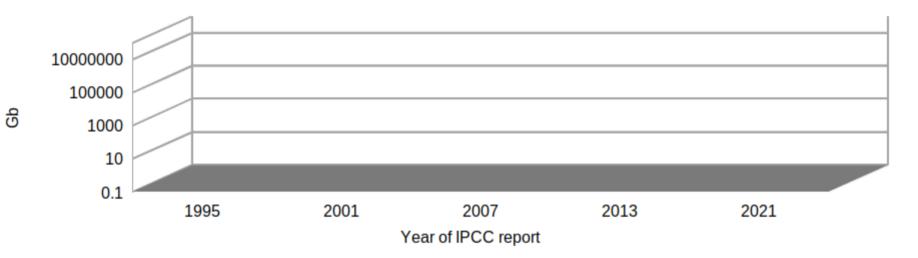
- Earth System Model of intermediate complexity
- Contains main components of the Earth system in a simpliefied way and with low resolution  $(1.8^\circ \times 3.6^\circ)$
- Can reproduce historical changes in global carbon cycle and temperature
- Due to low running cost, especially suitable for long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

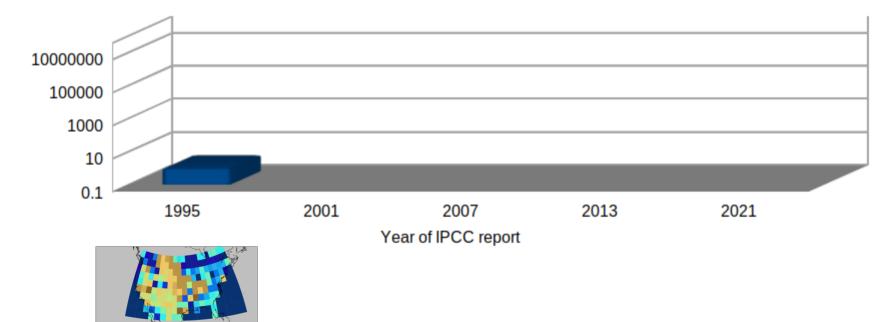
About 85,000 lines of Fortran Code (inclusing comments)

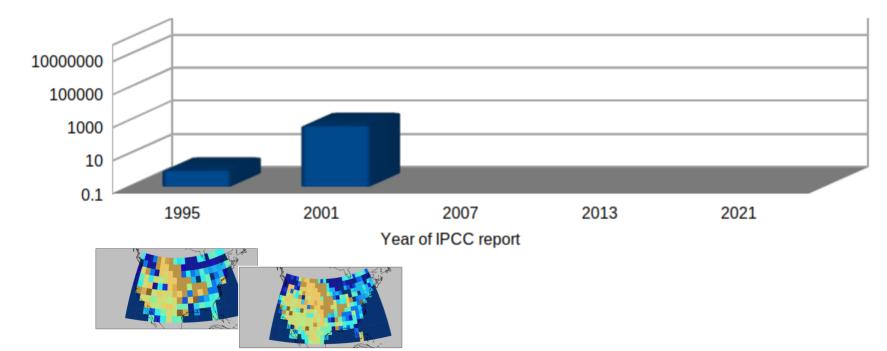
Mengis et al. (2020), https://gmd.copernicus.org/articles/13/4183/2020/

### **From climate simulations to IPCC reports** Coupled Model Intercomparison Project (CMIP)

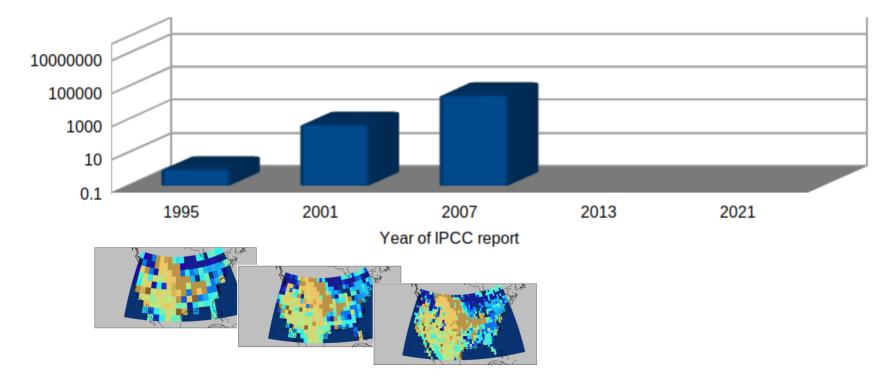




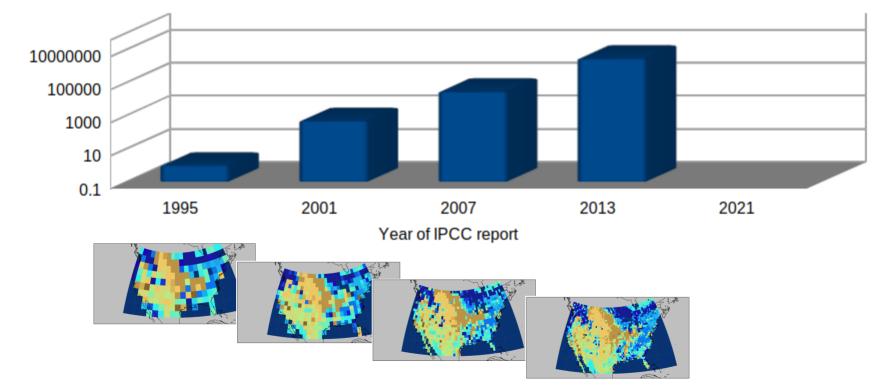




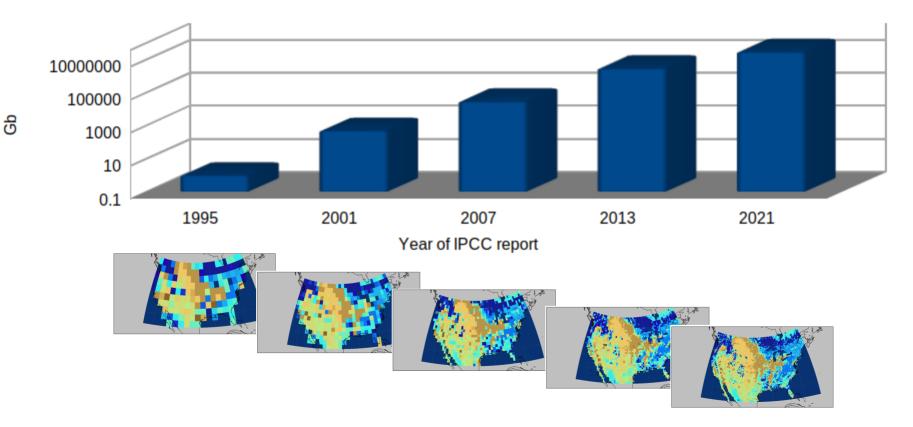
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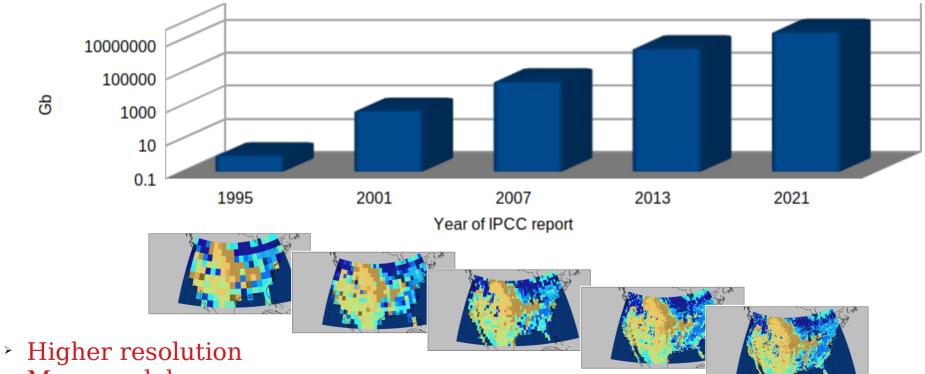


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- More models
- More components
- More experiments

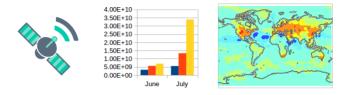
### **Open Climate Data**

Various data portals and websites to visualize and download climate data

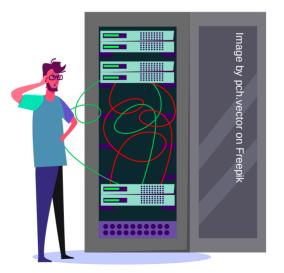


Most of weather and climate data is **open and free to use!** 

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

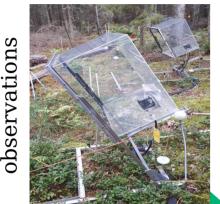


### Petabytes of data available!



## Climate and weather data

Land



.ong-term

Ocean

Atmosphere



Remote sensing



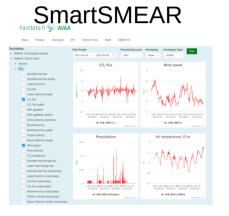
Connecting observations with models to create global datasets

## **Technical considerations**

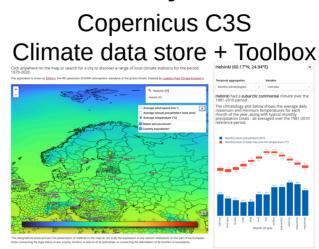
- The data can be in various formats, including
  - CSV (Comma separated values), which can easily be opened in spreadsheet programs
  - NetCDF (Network Common Data form = Selfdescribing, Portable, Scalable, Appendable, Sharable, Archivable), which requires special software or libraries
  - Others: HDF,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

Examples of climate data portals for research, training and education

## Climate data platforms Reviewing data portal usability in education







### Copernicus C3S Seasonal forecasts

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### 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"

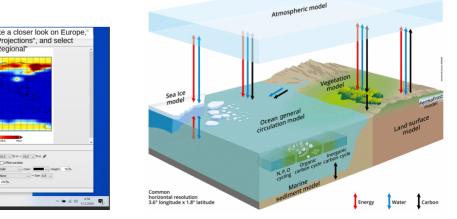
- Works directly in browser
- Based on comprehensive calculations (e.g. IPCC data)
- Easy to visualize existing trajectories

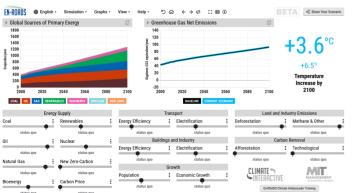
#### **Education climate models**

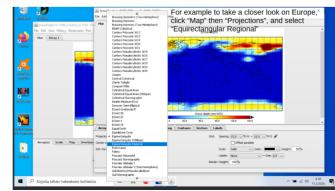
- Interface designed for first-time users
- Can be run on laptop/PC
- Limited capabilities in teaching processes and e.g. mitigation

#### **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 atmospheri flux, soil, tree physiologi and water quality measurements from SME stations
- Preview S from high sch ٠ on.
- Download/API research and ٠ higher education projects
- CC BY licence

	About	Preview	Download	API	Terms Of Use	INAR SMEAR IV		
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nool		Update			CO <sub>2</sub> flux	Quality class flag for carbon dioxide flux, tower at	Metek USA-1 anemometer/thermometer &	LI- <u>-</u>

16.6 m

Turbulence/stability-filtered, storage-corrected and

gapfilled net ecosystem exchange of CO2

= mean diurnal variability

ecosystem CO, exchange

NEE gapfilling method; 0 = measured flux with

Gross primary productivity derived from net

storage change added, 1 = nonlinear regressions, 2

quality

NEE

NEE

gapfilling

method

Gross

primary

production

gapfilled



1 2 3 >

COR LI-7200 gas analyzer

NEE

F c.av c.u star.MO length.PAR.TDRY0.Tsoil.ST

F\_c,av\_c,u\_star,MO\_length,PAR,TDRY0,Tsoil,ST

Description Source

Download

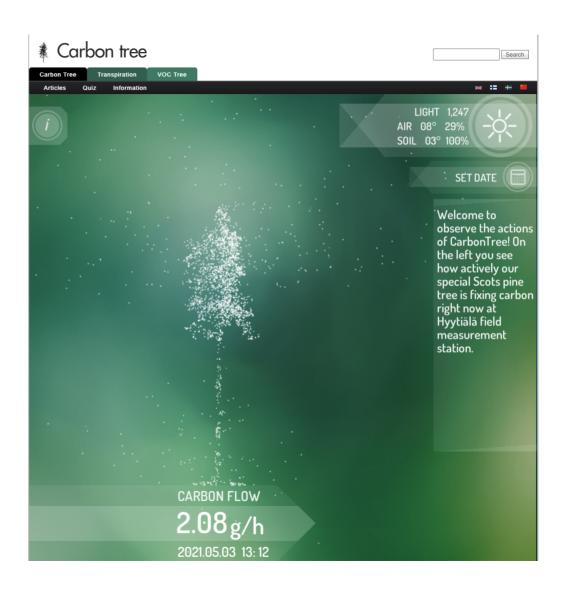
Download Selected

Availability

## Carbon Tree

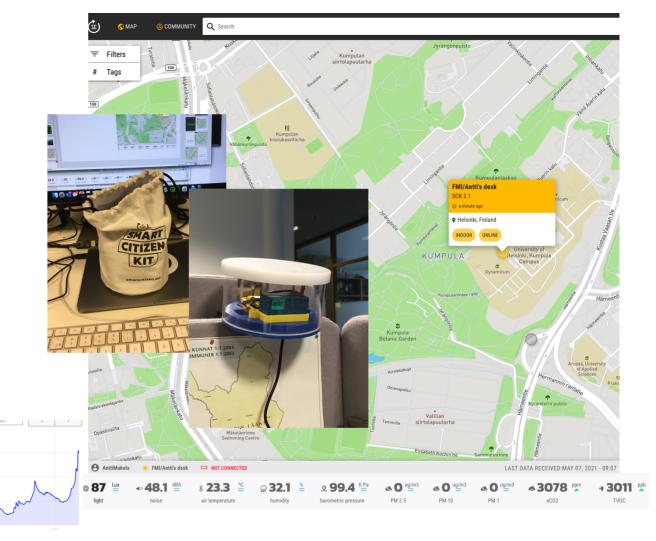
### http://www.carbontree.fi

- 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 SDcard)
- One sensor at Antti's FMI desk:
- <u>https://smartcitizen.me/kits/11043</u>
- To whom: from elementary school to university students

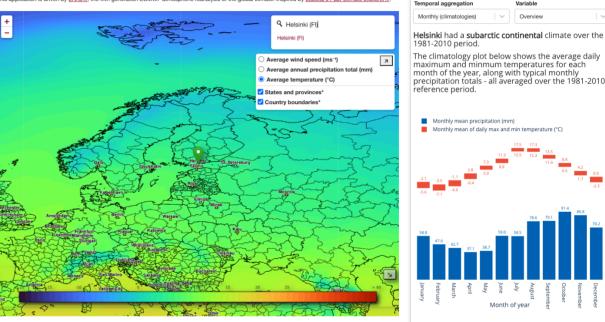


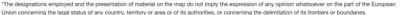
### C3S Climate Data Store & its Toolbox

- 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 ٠
- 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 knowhow to use the CDS?)
  - Could CLIMCOMP support C3S in educating in the use of CDS?

Click anywhere on the map or search for a city to discover a range of local climate statistics for the period 1979-2020

This application is driven by ERA5 & the fifth generation ECMWF atmospheric reanalysis of the global climate. Inspired by Lobelia's Past Climate Explorer &





Monthly mean of daily max and min temperature (°C) Month of year

Variable

Overview

Helsinki (60.17°N, 24.94°E)

Version: 4.24.0 - build 827c25

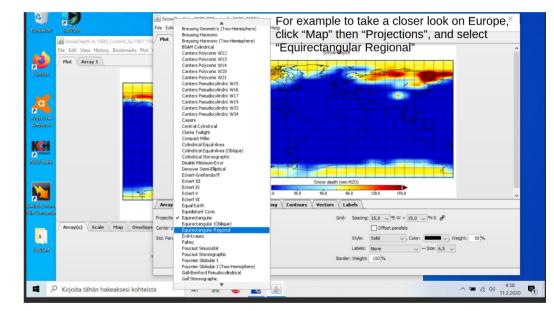
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Example application made with the CDS Toolbox editor:

https://cds.climate.copernicus.eu/cdsapp#!/software/ app-era5-explorer?tab=app

## edGCM

- <u>http://edgcm.columbia.edu/</u>
- 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

- <u>https://en-roads.climateinteractive.org/scenario.html?v=2.7.39</u>
- 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

