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CLIMATE DATA

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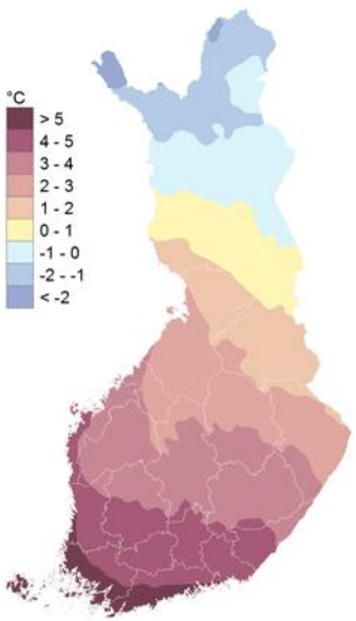
Finnish Meteorological Institute

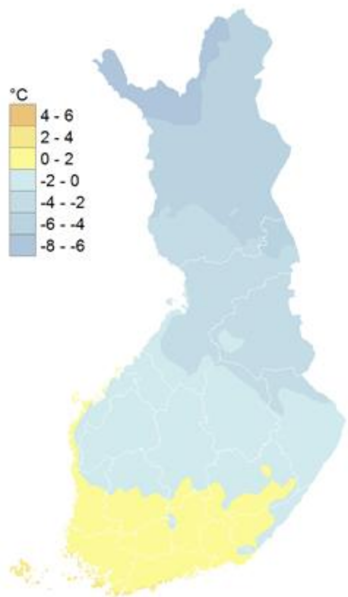
CLIMATE

What is climate?

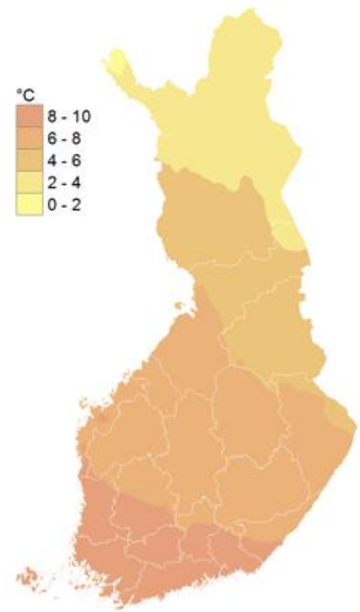
Short answer: It is the statistics of weather



Average temperature 1981-2010 (annual)



Minimum temperature 1981-2010 (annual)



Maximum temperature 1981-2010 (annual)

CLIMATE

Ususal convention is to use 30-year averages

- **Long enough to account reliably for variability of weather**
- **However, changing climate is a problem**

  => e.g. FMI updates the reference climate, or ”climate normal” every 10 years. Currently we use 1981-2010 as the baseline

- **Deviation from the climate normal is referred to as ”anomaly”**

  E.g. the january 2016 temperature anomaly in Helsinki was -4.9° C whereas the average is -3.9° C

CLIMATE DATA

In this presentation, I will consider

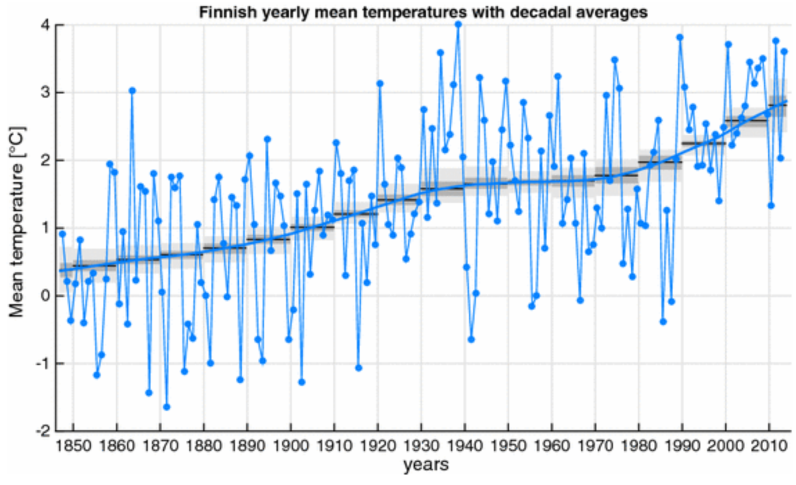
1. **Observational climate data (mostly temperature)**
2. **Climate model data**

So called reanalysis data – created by assimilating past observations to weather model simulation – is left to Achim Drebs.

Paleoclimate data – i.e, tree-ring, lake sediment etc. based climate reconstructions – is also outside the scope of my presentation.

OBSERVATIONAL CLIMATE DATA

- **Observational climate data equals in most cases yesterday's (and of course older) weather data.**
- **The longest temperature time is from Central England. Monthly data from 1659 and daily data from 1773 onward.**
- **In most places temperature measurements have been started some time in the 1800's.**



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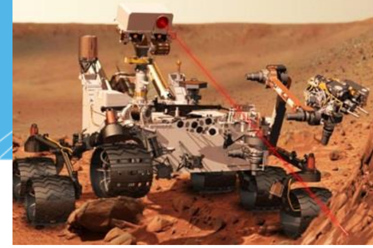
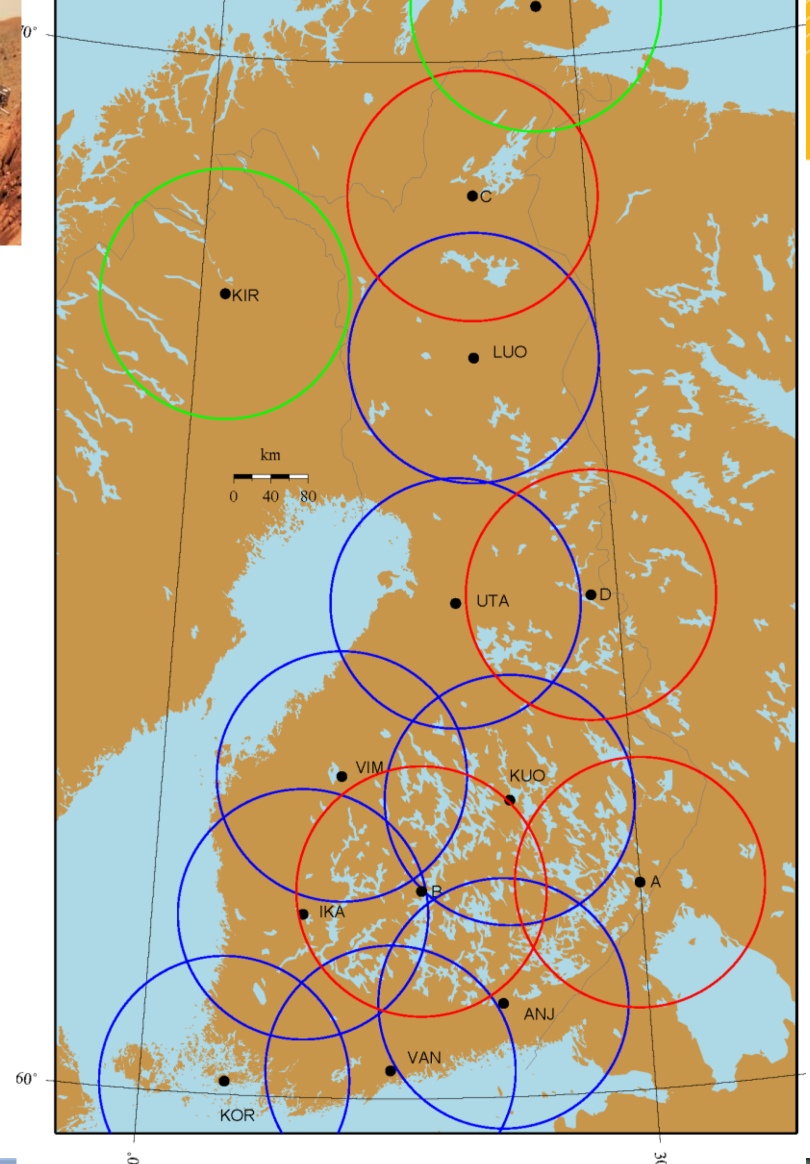


OBSERVATIONS

- **Operational stations** **400+**
- **AWS** **200**
- **Masts, aviation** **3**
- **Soundings** **3**
- **Dual polarimetric/doppler radars** **8**
- **Lightning detection** **8**
- **Air quality incl. radioactivity** **30**
- **Rain, manual** **100**
- **Sea level & waves** **17**
- **Scientific & special measurements** **50**
- **Lidars** **3**
- **Aviation stations (2012)** **25**

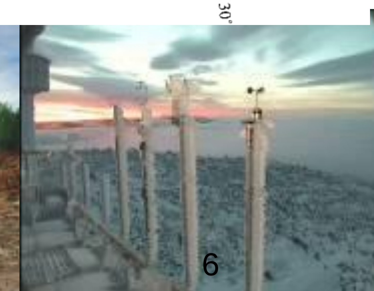
Automation rate > 97%











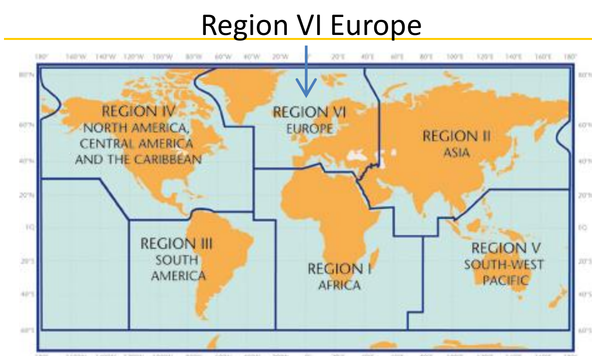
P. Taalas

Digitization – linked to ongoing work in WMO REGION VI

FMI’s CLIMATE SERVICE CENTER AND OBSERVATION UNIT HAVE CARRIED OUT DIGITIZATION WORK:

- 50 stations digitized 1900-1959 *
- Helsinki available in the open data archive from 1844 ->
- Sodankylä available in the open data archive 1891->
- **During 2015 aim is to have 5 more stations available in the open data archive**

ECA&D



European Climate Assessment & Dataset

* tday, tmin, tmax, snow, rrday, t_mon, rr_mon (manual quality control done)

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OBSERVATIONAL CLIMATE DATA

Past climate data is problematic because of several issues related to data quality. Examples:

- **Change of thermometer type**
- **Change of thermometer shelter design**
- **Change of observation site location (elevation)**
- **Change of daily observation time**
- **Change of bucket type for seawater T-measurement**
- **Change from measuring T of bucket water to measuring T of engine cooling water**
- **Missing data**

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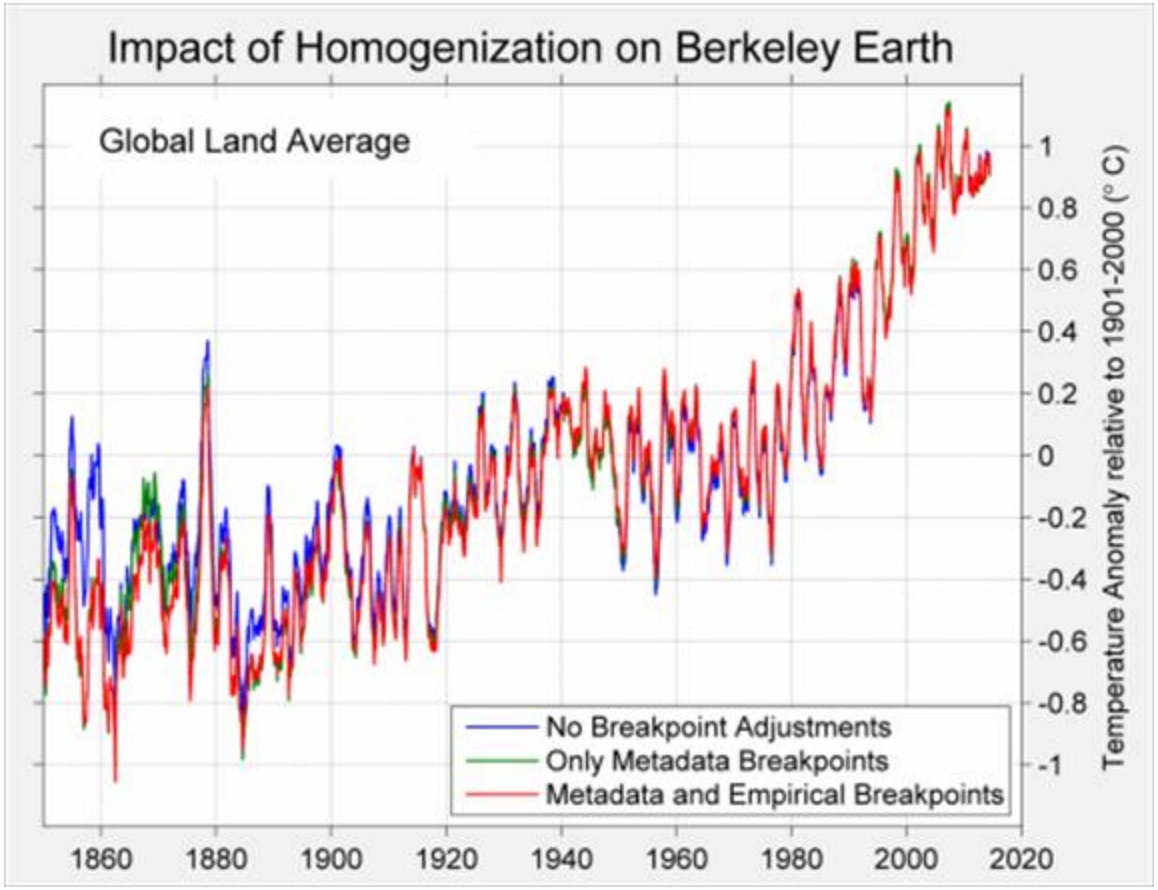
OBSERVATIONAL CLIMATE DATA

All long observational time series need to be ”homogenized”.

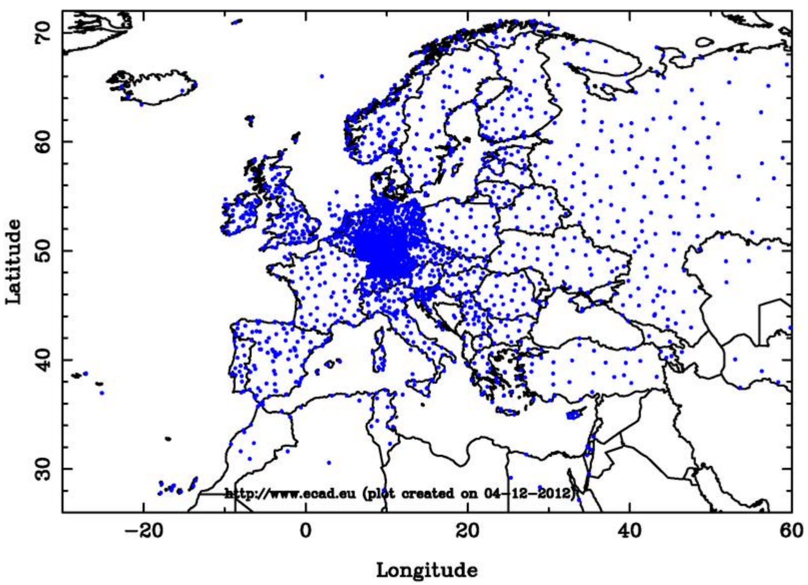
- **Metadata (about instruments, shelter types, measurement locations, observation times etc.) is very useful.**
- **Statistical methods can be used to detect shifts in the time series**
- **Temperatures are correlated to distances up to 1500 km => data from neighbouring weather stations can be used to detect shifts in a given time series, or to fill in for missing data.**

OBSERVATIONAL CLIMATE DATA

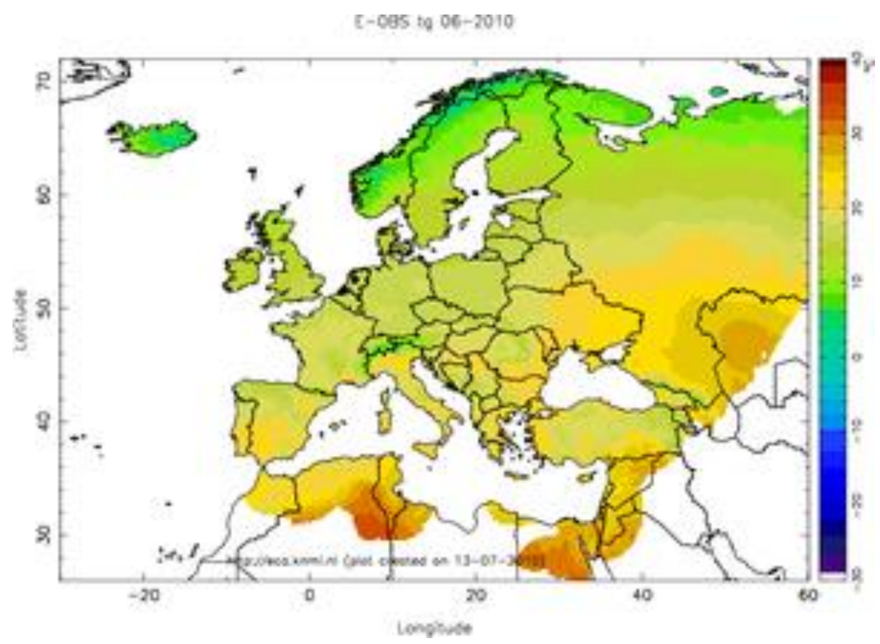


OBSERVATIONAL CLIMATE DATA

Gridded datasets: Observational data is interpolated into a regular grid. Sophisticated interpolation methods account e.g. for landscape elevation.



E–OBS measurement stations.



E–OBS mean temperature for June, 2010.

OBSERVATIONAL CLIMATE DATA

Precipitation and wind speed

- Precipitation from convective clouds difficult because it is local => a traditional rain cauge provides information only for that specific spot.
- Cloud radar data (from ~ 1990's onward) has good coverage, but it sees rain at altitude, precipitation at ground level may be different.
- The ground causes strong winds to be turbulent => large temporal variability of mean wind speed from seconds to minutes to hours to days

OBSERVATIONAL CLIMATE DATA

Global surface and ocean datasets

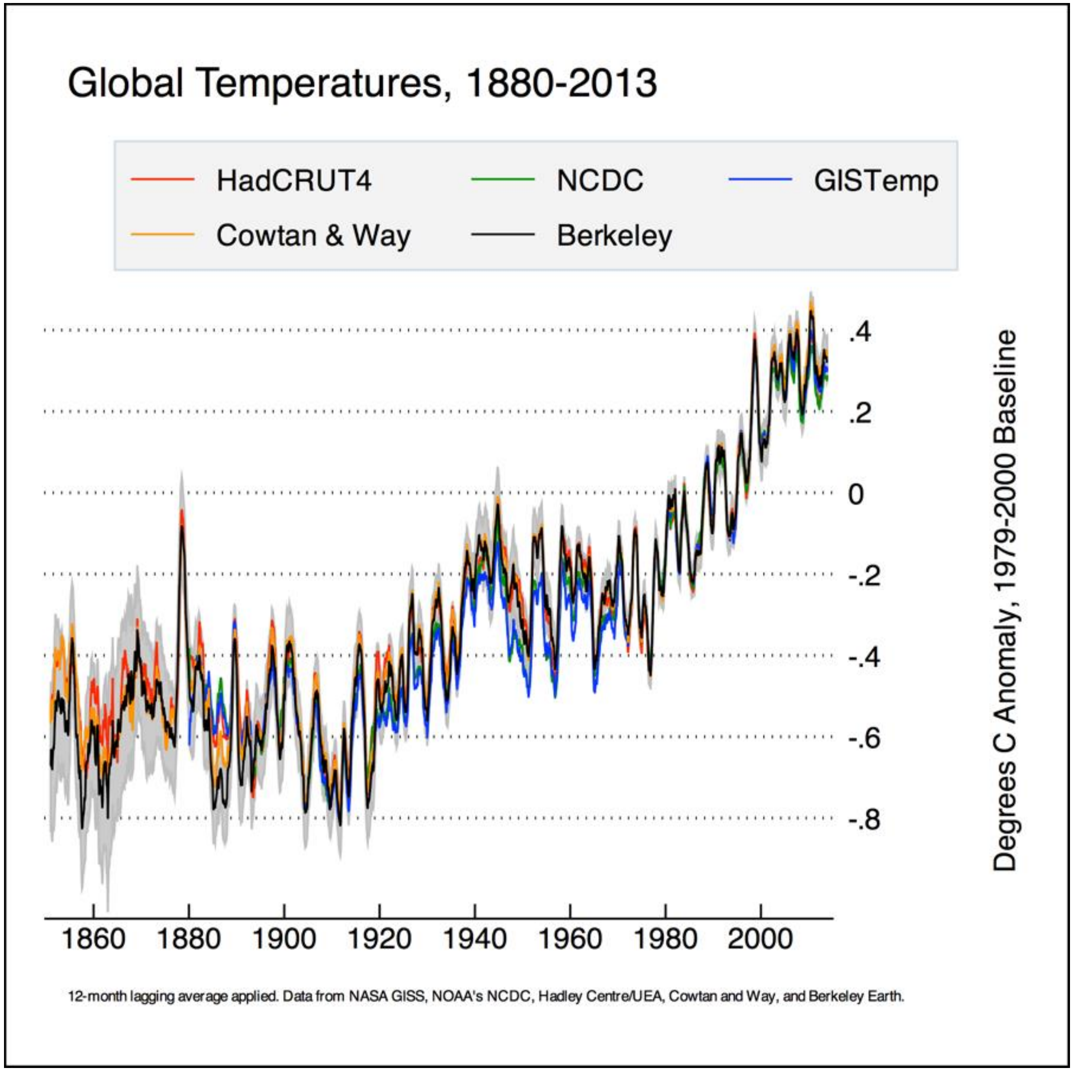
- NOAA's National Climatic Data Center maintains a global temperature data record since 1880
- NASA GISS temperature record is an independent analysis of NOAA's data, also since 1880
- HadCRUT is a collaboration between UK Met Office's Hadley Center and the climate research unit at University of East Anglia. Time series start in 1850
- Berkeley Earth is the latest addition (2012 ->) to the global analyses. Their land-only time series is from 1750 and land + ocean from 1850.

OBSERVATIONAL CLIMATE DATA

A few notes

- Land only temperatures represent air temperature at 2 meters' height.
- Ocean temperatures are sea surface temperatures.
- Especially land + ocean is a temperature *index* rather than actual average temperature
- The time series are usually represented as anomalies with respect to some baseline period. This is because the absolute average global temperature is, due to the imperfect coverage, a more uncertain quantity than the anomaly.
- Biggest variations between the different data sets originate from how large areas of missing data are handled. E.g. HadCRUT leaves the Arctic completely out of their temperature indices, whereas the others interpolate from the nearest measurement stations.

OBSERVATIONAL CLIMATE DATA



OBSERVATIONAL CLIMATE DATA

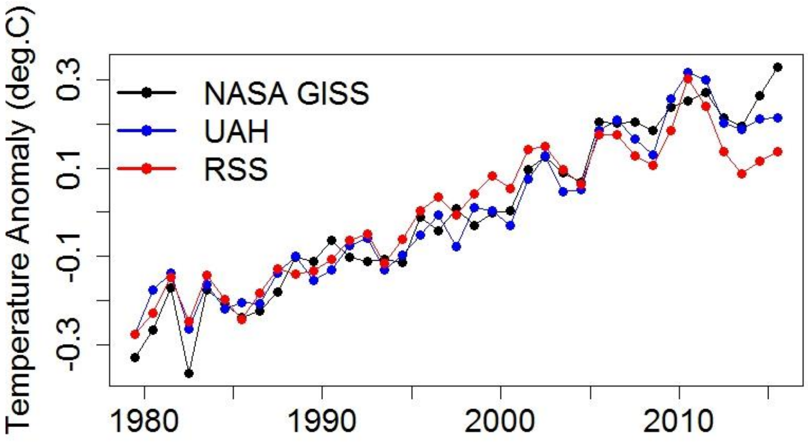
Upper air temperatures are available from balloon soundings with radiosondes (global coverage since about 1950's) and satellite measurements since 1978.

Satellites measure radiance in several microwave wavelength bands. Complex inversion of the measurements produces temperatures for the troposphere and the stratosphere (i.e. several km thick layers of air).

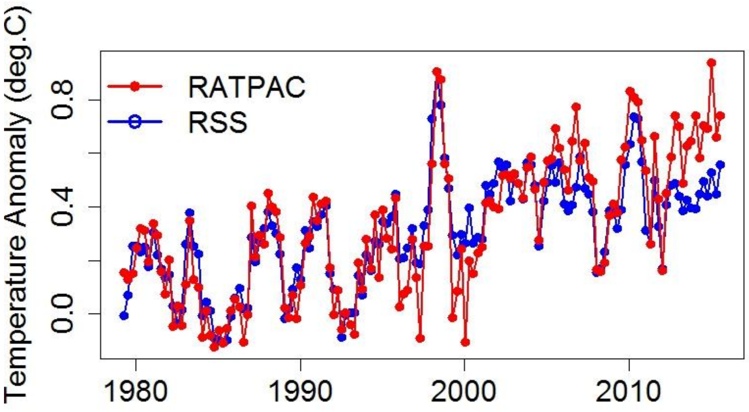
Additional problems: Satellites change often, sensors not identical, orbital drift and decay must be compensated for.

Best-known datasets: UAH (Univ. Of Alabama, Huntsville) and RSS (Remote Sensing Systems, a private company)

OBSERVATIONAL CLIMATE DATA

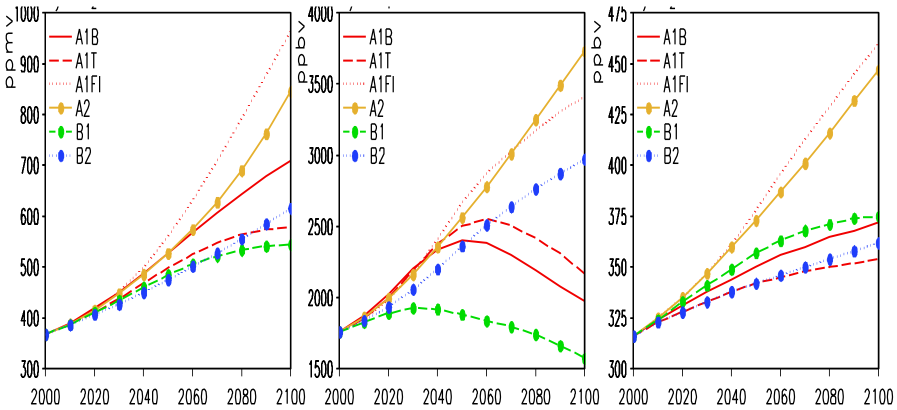


Satellites vs. surface temperature

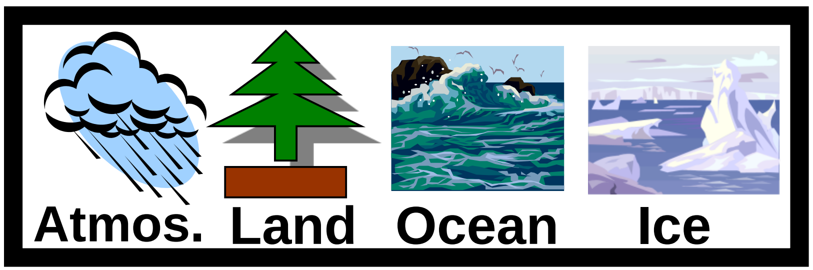


Satellite (RSS) vs. soundings

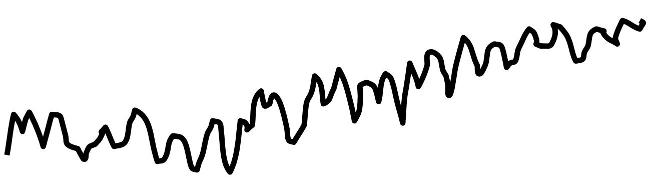
Modeling of future climate



External factors affecting climate (e.g., greenhouse gas concentrations) as a function of time



Climate model: laws of nature as a computer program, as well as the current knowledge allows

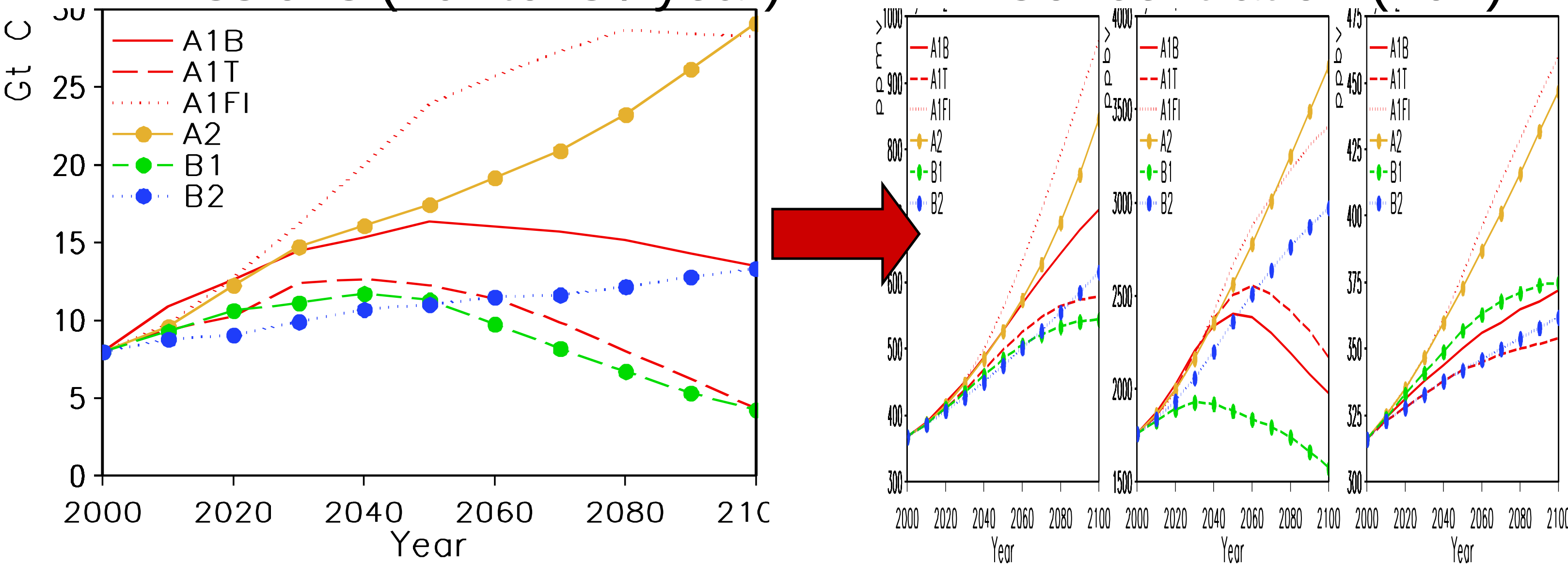


"Long weather forecast"

Climate = statistical properties of weather

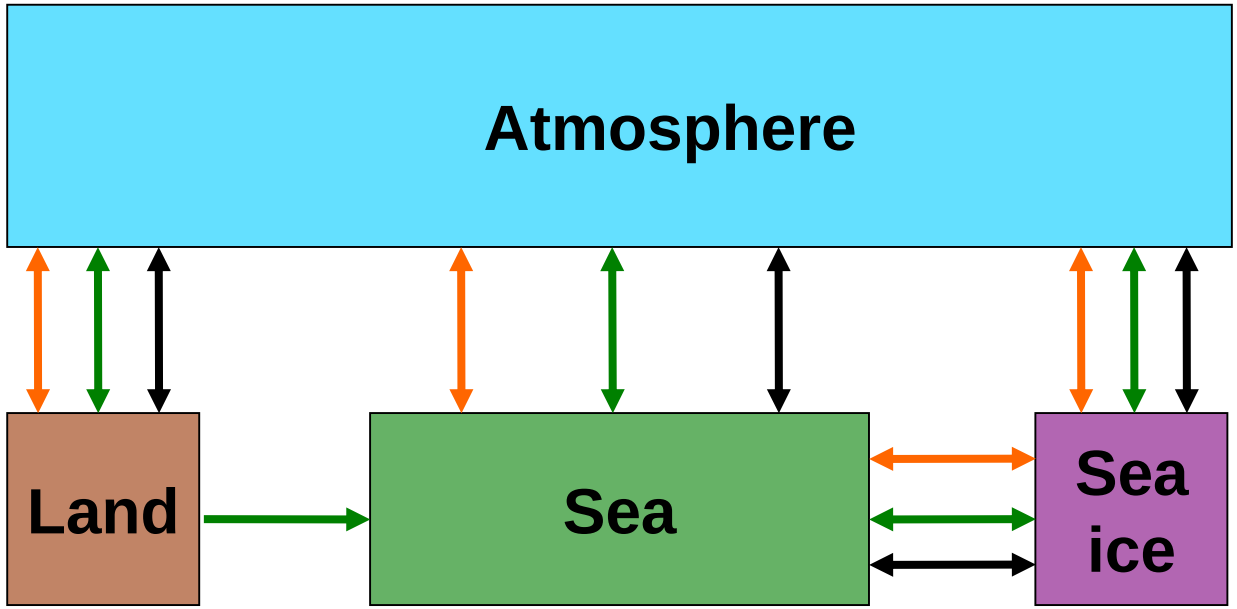
Scenarios: CO_2-emissions and concentrations

Emissions (10^9 tons / year) Concentration (10^{-6})



- Population and economical growth increase emissions in the short term; in the long range large spread depending on assumptions
- CO_2 stays long in the atmosphere → concentration continues to increase even in those scenarios with stabilized / reduced emissions
- Unlike CO_2, aerosol particles are short-lived.
  Cleaner technology → stabilized / reduced aerosol concentrations
  → Reduced cooling impact in the future?

Components of a climate model



The arrows indicate the exchange of heat ( ), water ( ) and momentum ( ) between the the different components

Each component (submodel) has a lot of internal structure!

Structure of an atmospheric model

- Global 3-dimensional grid

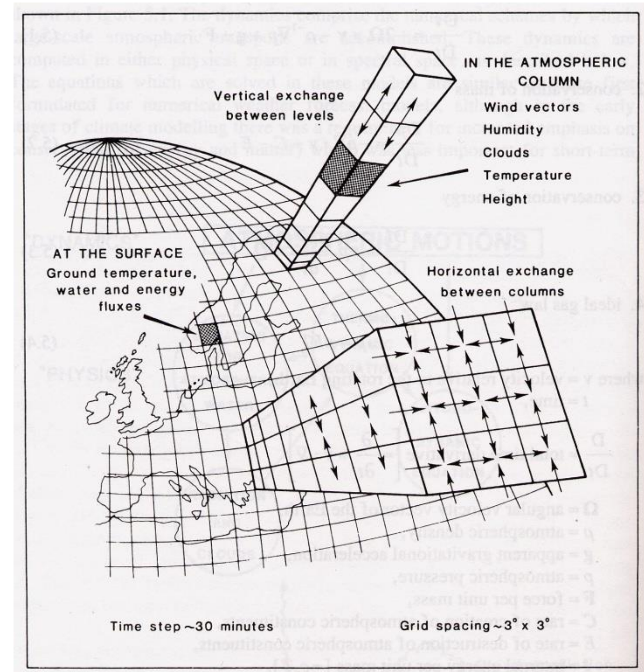
  ($\Delta\lambda \sim \Delta\varphi \sim 2^\circ$ ~ 200 km; ~20-30 levels)

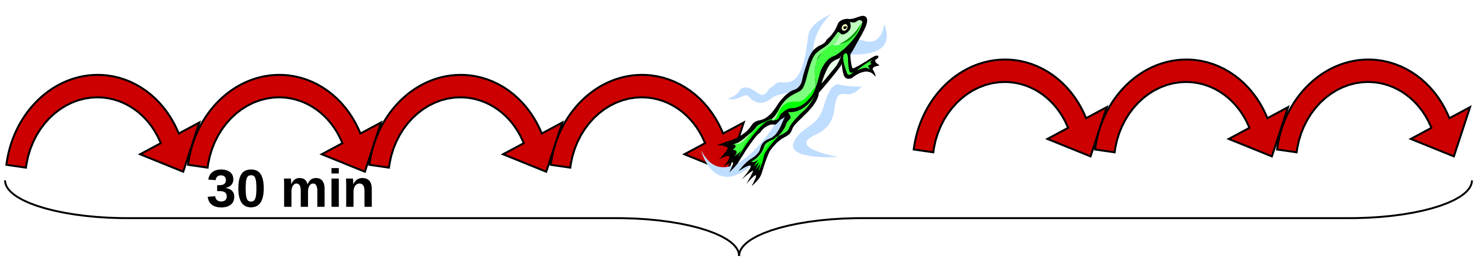
- Primitive equations

  → <u>instantaneous rates of change</u> for temperature, wind, water vapour content, pressure etc. at each grid point

- Time integration

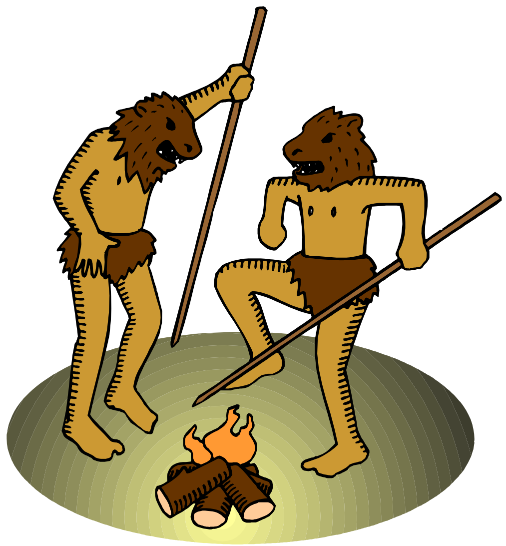
  (E.g. 30 min time-step, for ~100-300 years. New rates of change computed every time step.)

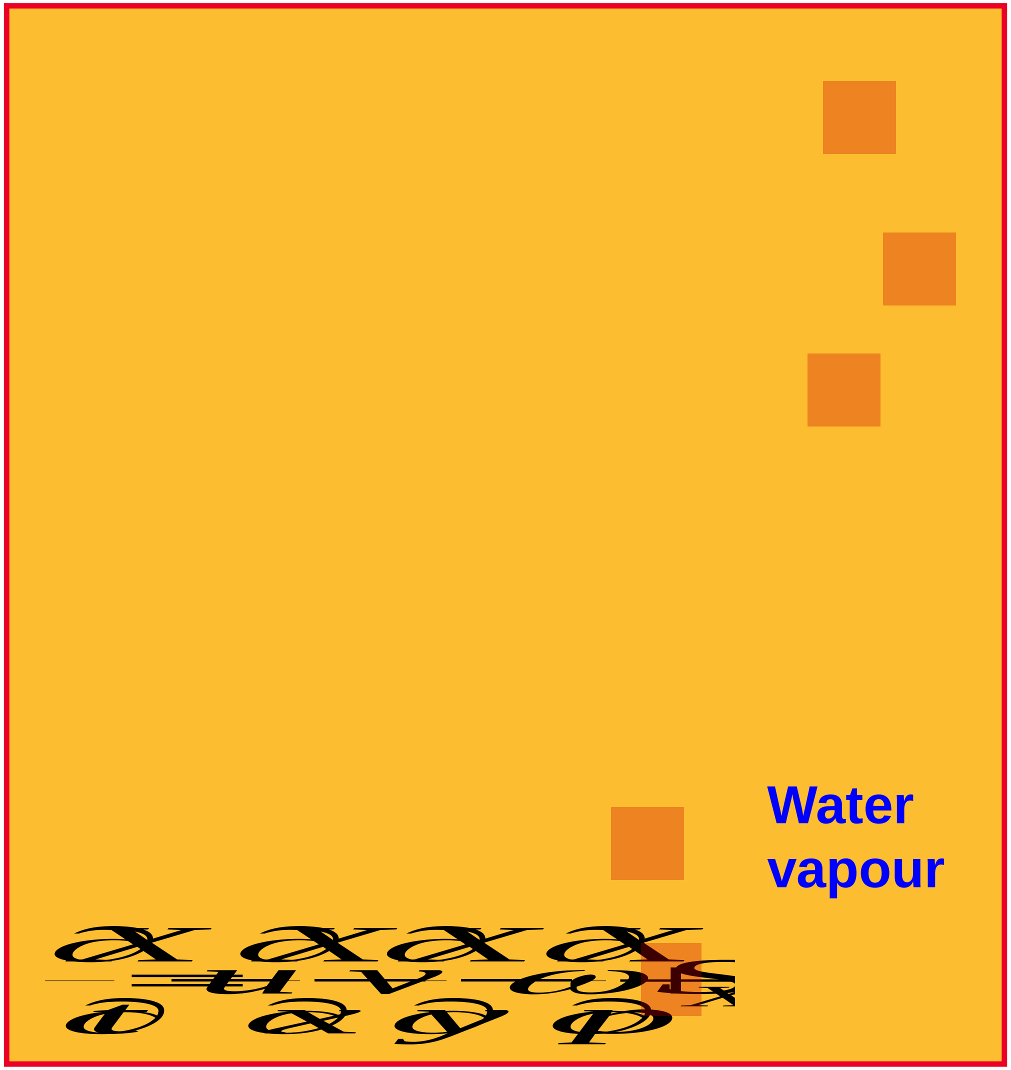




100-300 years

Primitive equations





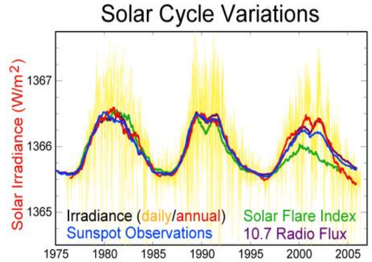
Same group of equations as in weather prediction models

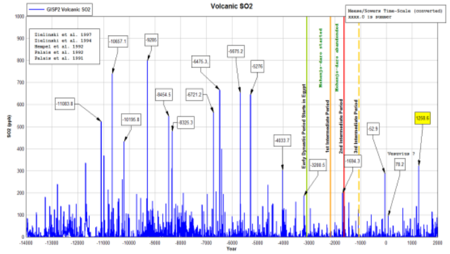
In principle, an accurate description of atmospheric physics

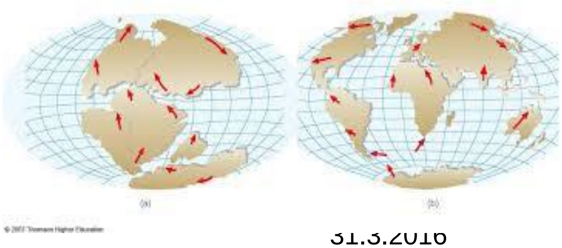
However, some terms (F_x, F_y, Q, S_q …) cannot be computed precisely: they depend on phenomena too small to be resolved by the model → the major uncertainty in climate models

The model simulations are constrained by external climate forcings

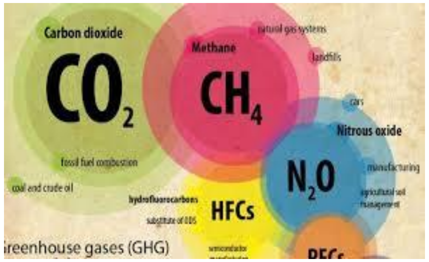
Natural forcings



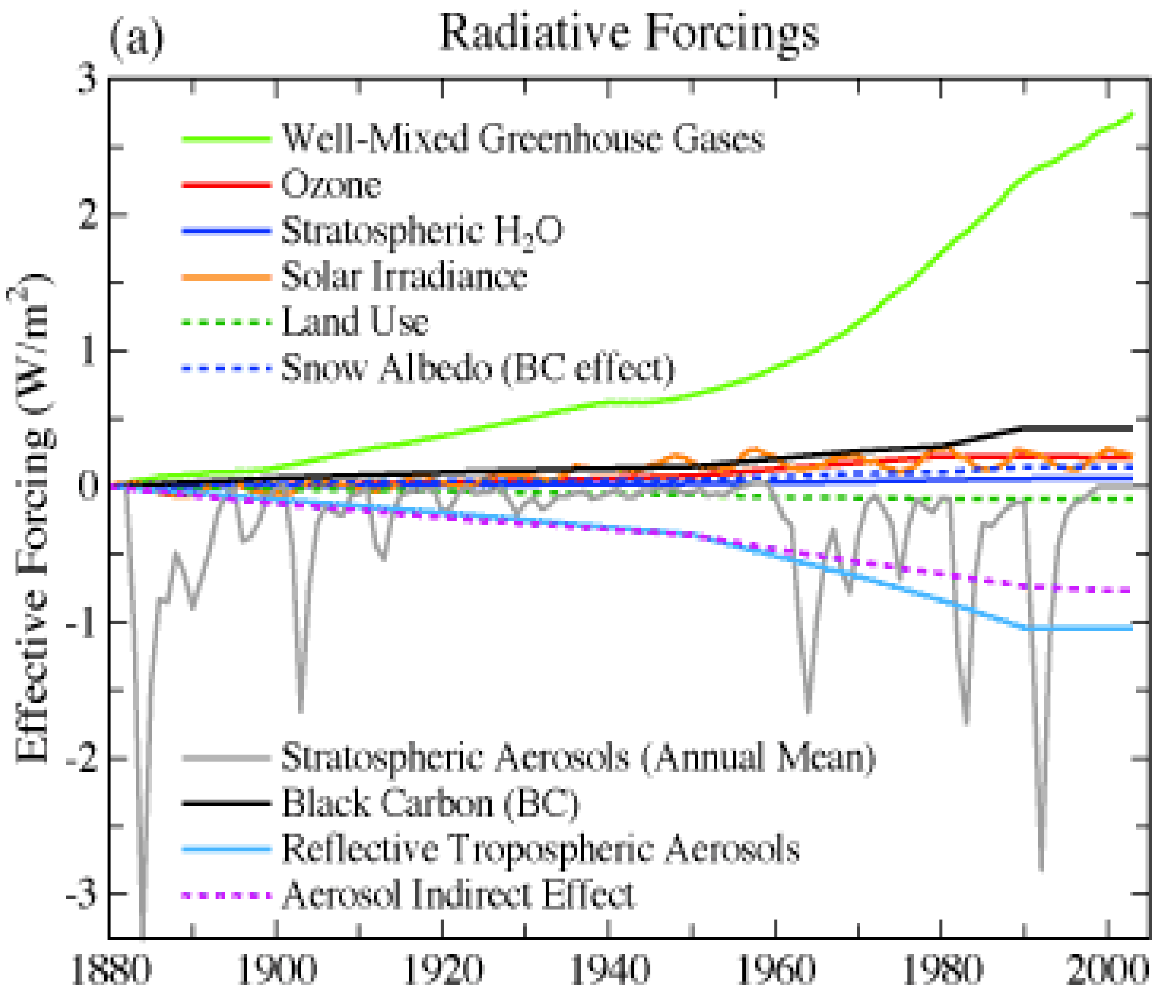




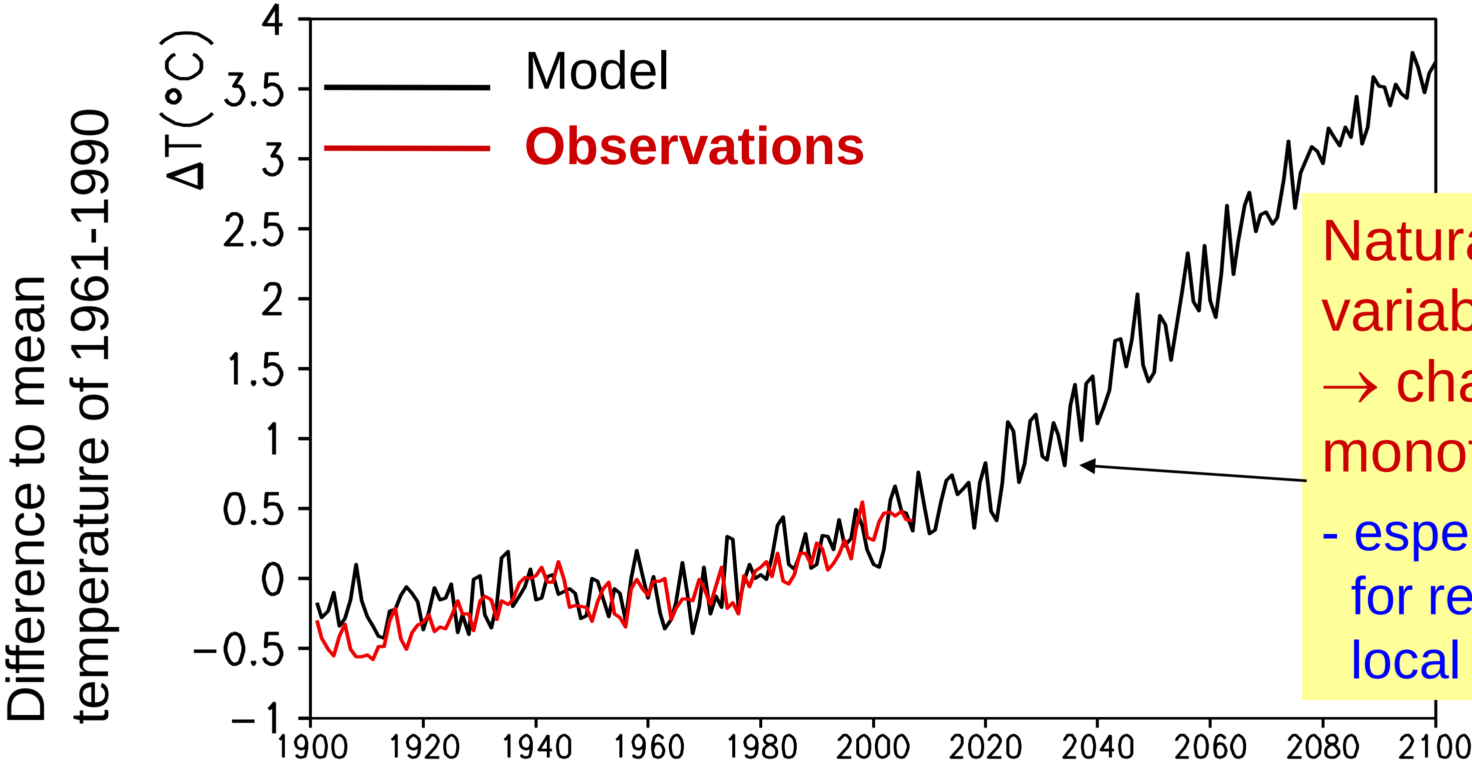
Anthropogenic forcings



Past forcings are relatively well-known



Example: global-mean temperature change in a single model experiment



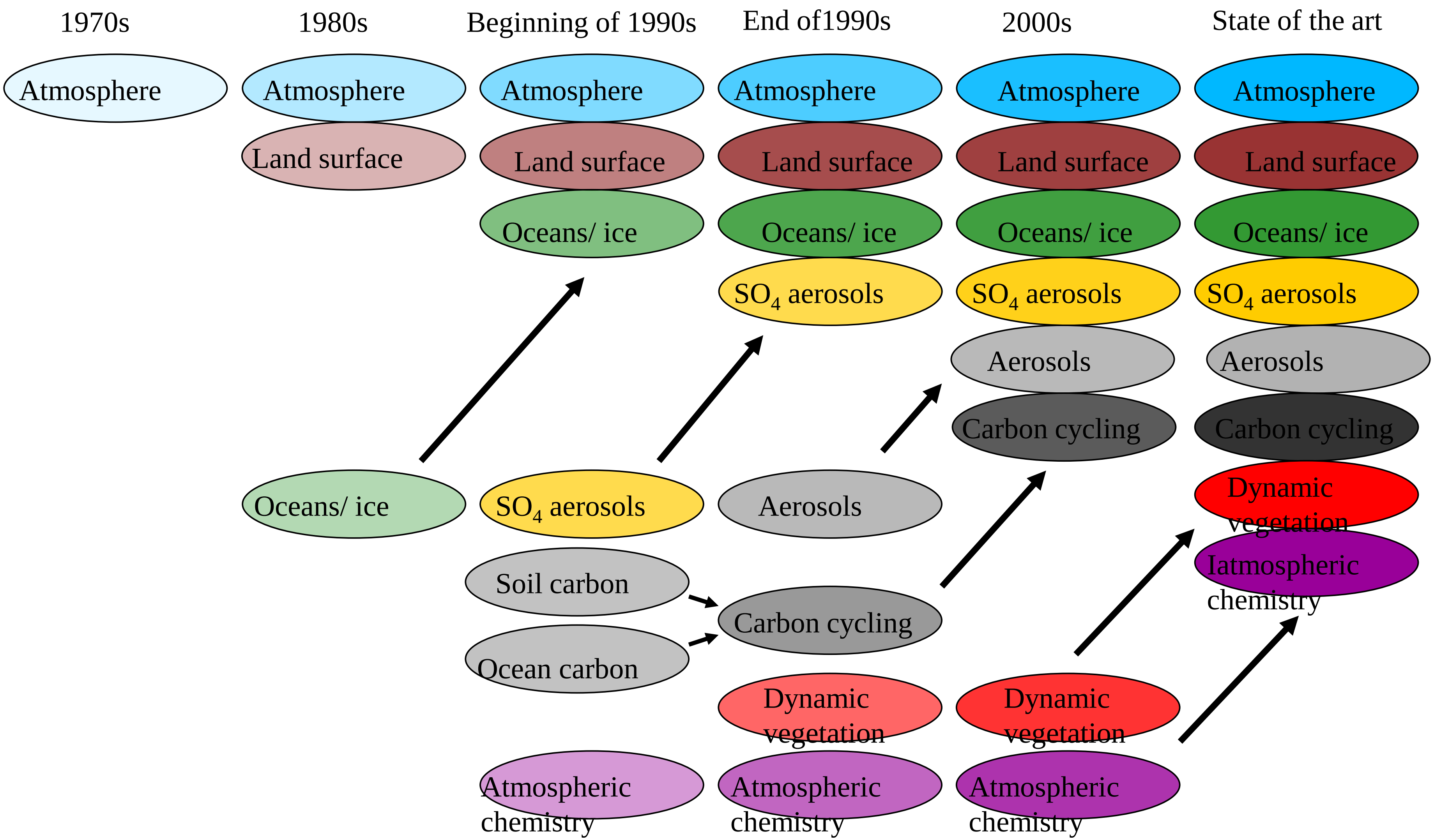
Natural climate variability → change not monotonic

- especially true for regional and local climate

- simulated changes consistent with observations

- the warming accelerates during this century (increased greenhouse gas emissions + stabilized / reduced aerosol emissions)

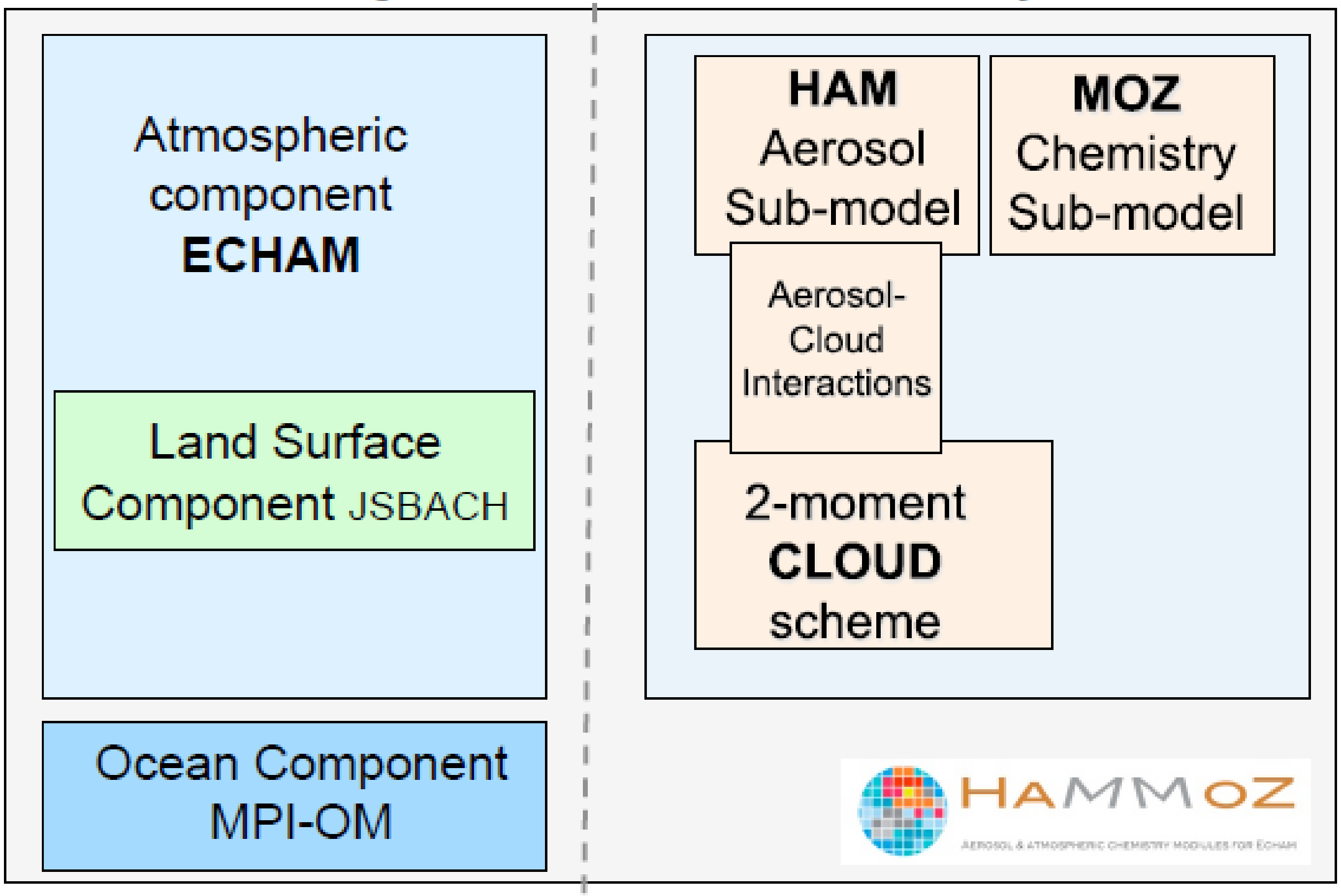
The development of earth system models

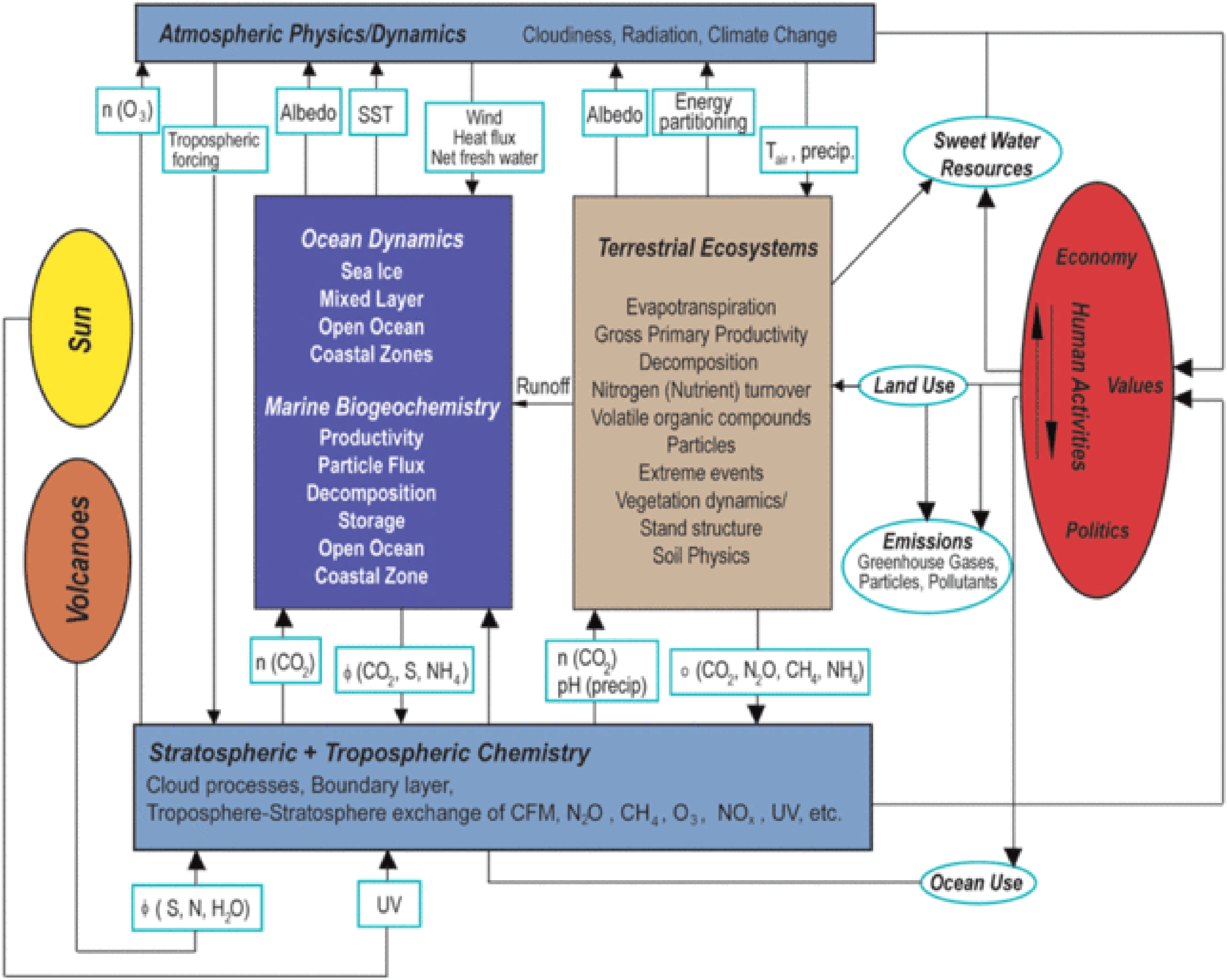


The ECHAM-HAMMOZ model

Developed, maintained & distributed by MPI-Met, Hamburg

Since 2009: developed by the international HAMMOZ consortium, maintained & distributed by C2SM/ETH





Atmospheric Physics/Dynamics
Cloudiness, Radiation, Climate Change
n (O_3)
Tropospheric forcing
Albedo
SST
Wind
Heat flux
Net fresh water
Albedo
Energy partitioning
T_{air}, precip.
Sweet Water Resources
Sun
Volcanoes
Ocean Dynamics
Sea Ice
Mixed Layer
Open Ocean
Coastal Zones
Marine Biogeochemistry
Productivity
Particle Flux
Decomposition
Storage
Open Ocean
Coastal Zone
Runoff
Terrestrial Ecosystems
Evapotranspiration
Gross Primary Productivity
Decomposition
Nitrogen (Nutrient) turnover
Volatile organic compounds
Particles
Extreme events
Vegetation dynamics/
Stand structure
Soil Physics
Land Use
Economy
Human Activities
Values
Politics
Emissions
Greenhouse Gases,
Particles, Pollutants
n (CO_2)
ϕ (CO_2, S, NH_4)
n (CO_2)
pH (precip)
ϕ (CO_2, N_2O, CH_4, NH_4)
Stratospheric + Tropospheric Chemistry
Cloud processes, Boundary layer,
Troposphere-Stratosphere exchange of CFM, N_2O, CH_4, O_3, NO_x, UV, etc.
Ocean Use
ϕ (S, N, H_2O)
UV

CLIMATE MODEL ENSEMBLES

- **Climate models contain 5-10 adjustable parameters**
- **Adjusting is done in a tuning procedure before the model version is released**
- **Nevertheless, the adjustable parameters create uncertainty**
- **Models also have structural uncertainty related to model resolution, missing components, coupling between different submodules.**
- **In addition, there is initial condition uncertainty and boundary uncertainty (CO_2 scenarios)**

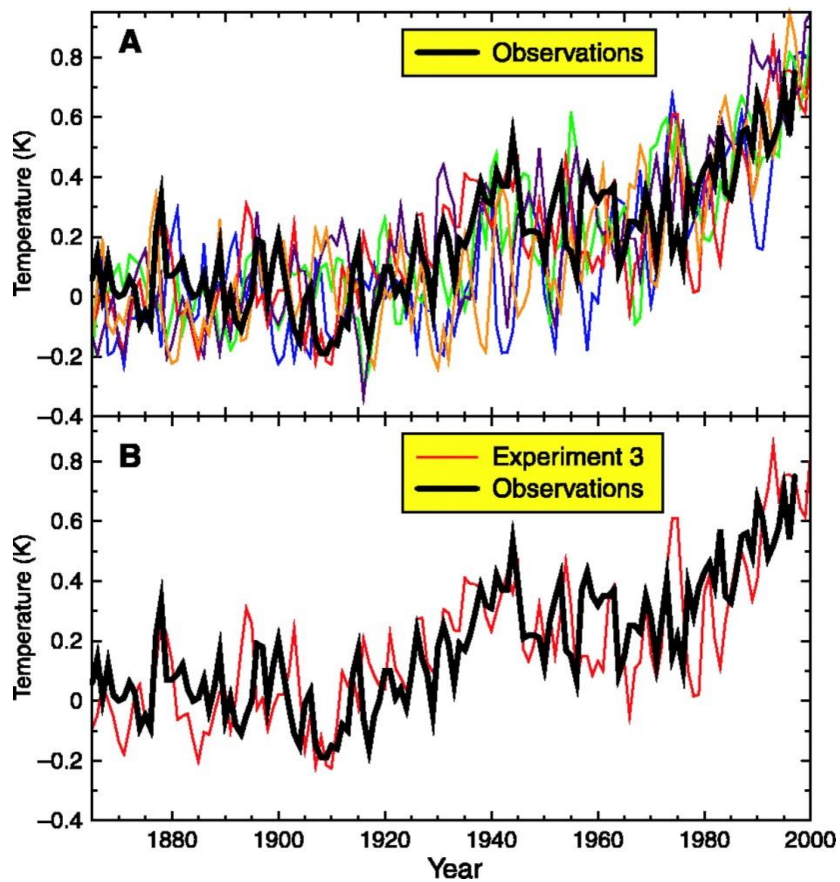
Uncertainties are dealt with using different types of model ensembles

CLIMATE MODEL ENSEMBLES

- **Initial condition uncertainty => Make an ensembele by running your model several times with slightly different initial conditions**
- **Parameter uncertainty => Perturbed physics ensemble**
- **Boundary uncertainty => Different scenarios for the future (IPCC)**
- **Structural uncertainty => Multi-model ensembles (IPCC)**

Figure 1 (A) Time series of global mean surface temperature from the observations (heavy black line) and the five model experiments (various colored lines).

Initial condition ensemble



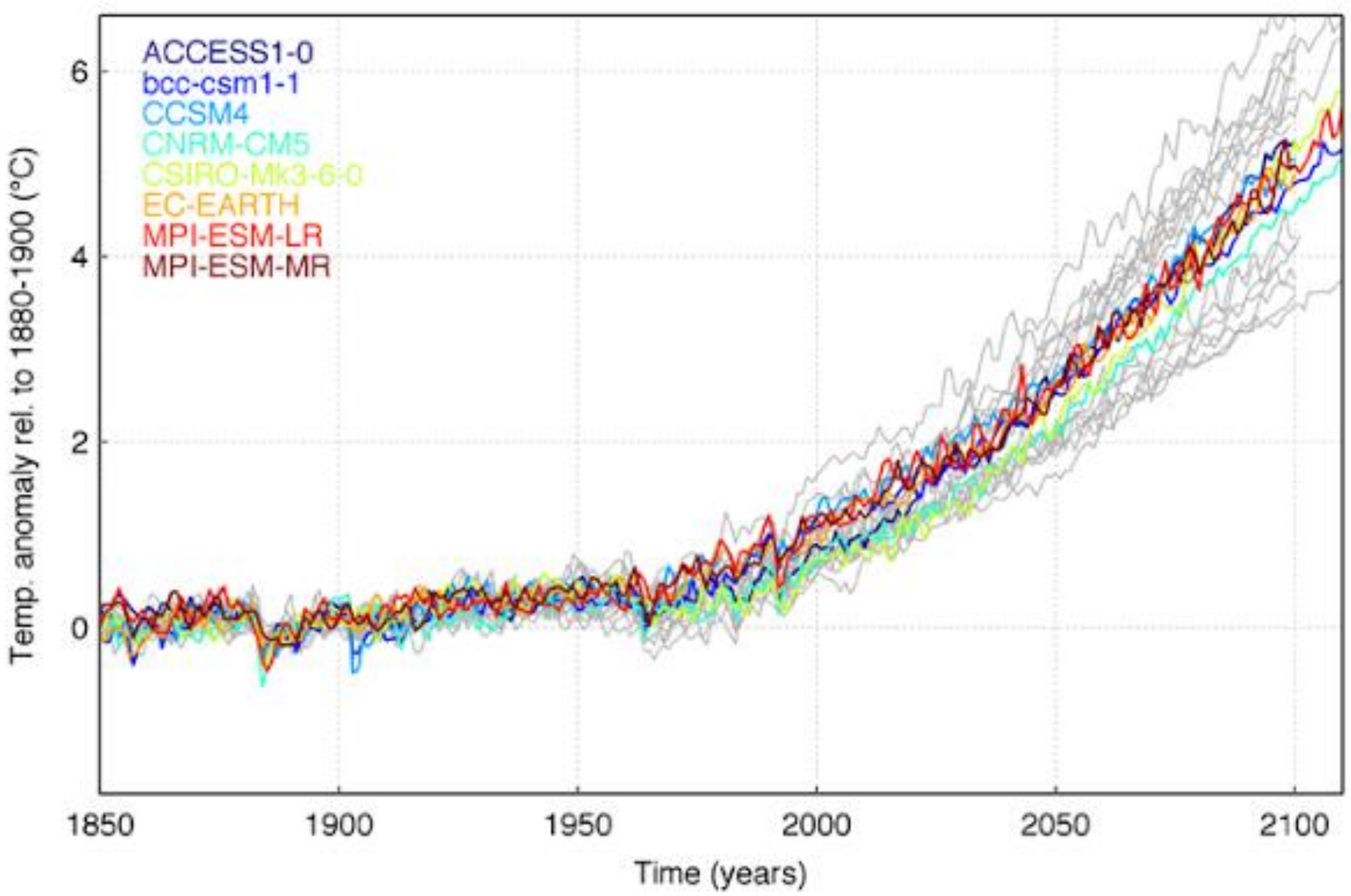
T L Delworth, T R Knutson Science 2000;287:2246-2250

Note: Wiggles of the model are of same magnitude as observations

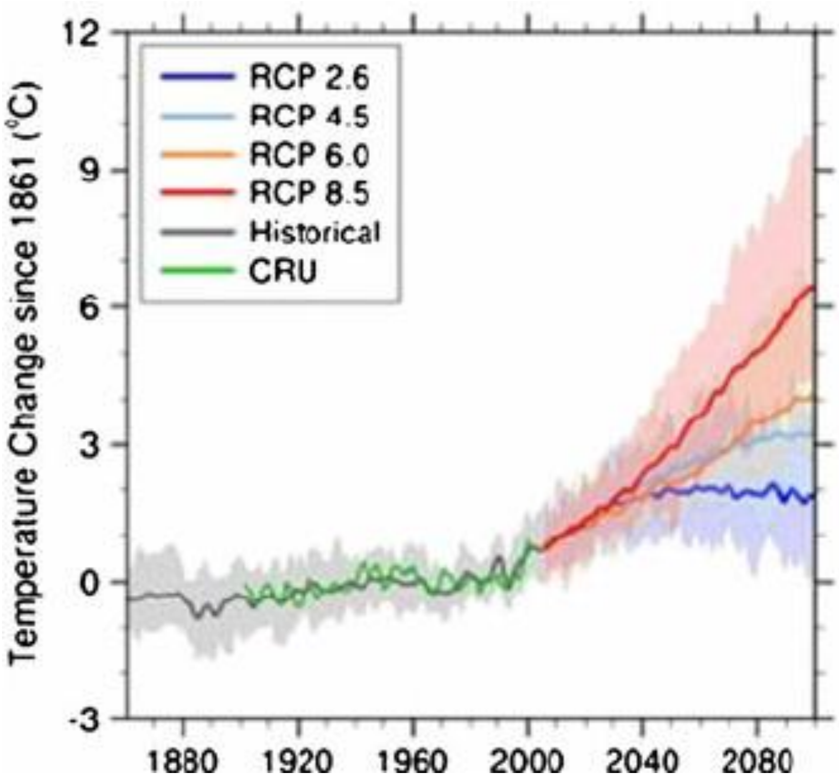
Science AAAS

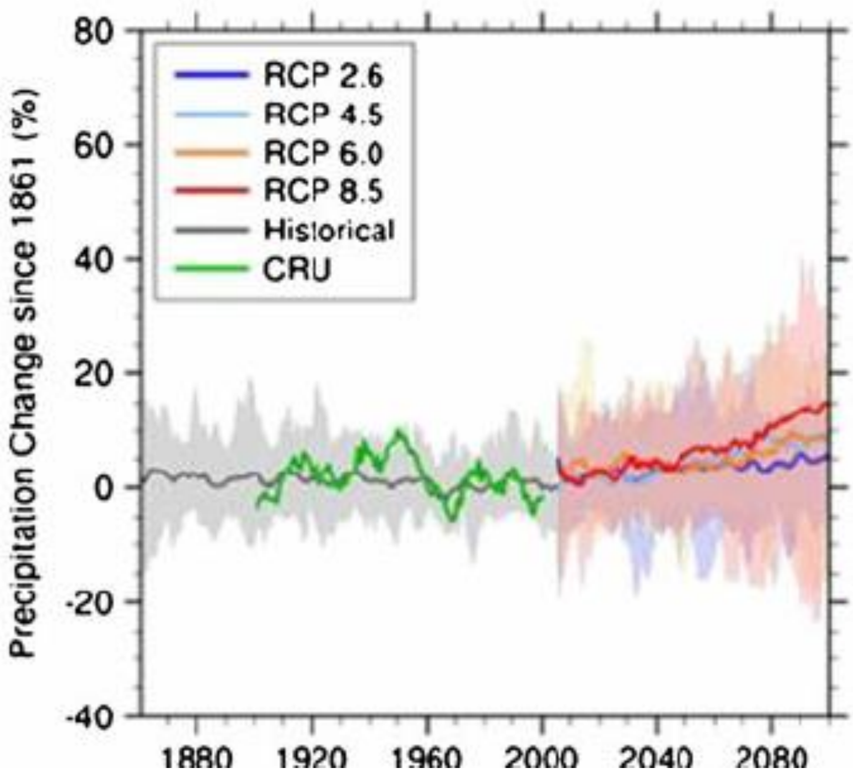
Published by AAAS

Multi-model ensemble, 24 models, one scenario



Multi-model ensemble, four future scenarios



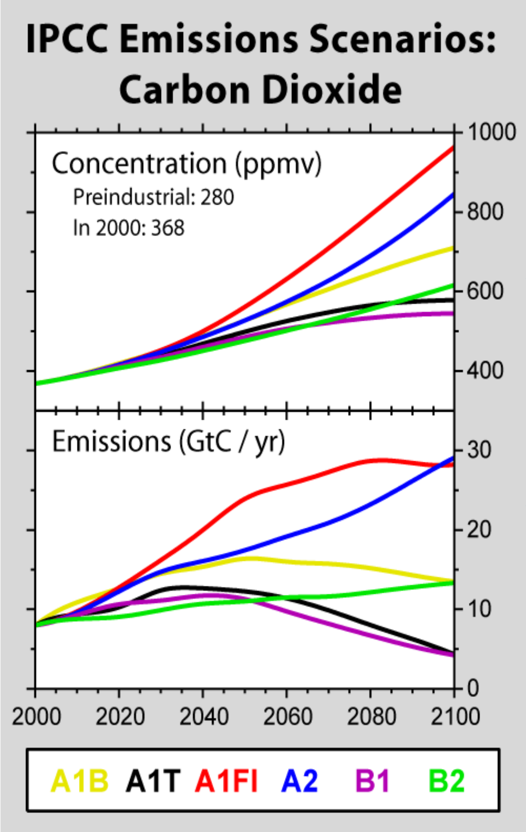


Coupled Model Intercomparison Project (CMIP)

- **CMIP phases 1, 2, 3 and 5 have produced multi-model ensembles used for making the climate projections for IPCC's 2nd, 3rd, 4th and 5th assessment reports, respectively.**
- **Around 15-20 different models were involved in CMIP1-3, and 35 models in CMIP5.**
- **All data are publicly available for registered users**

Emission scenarios

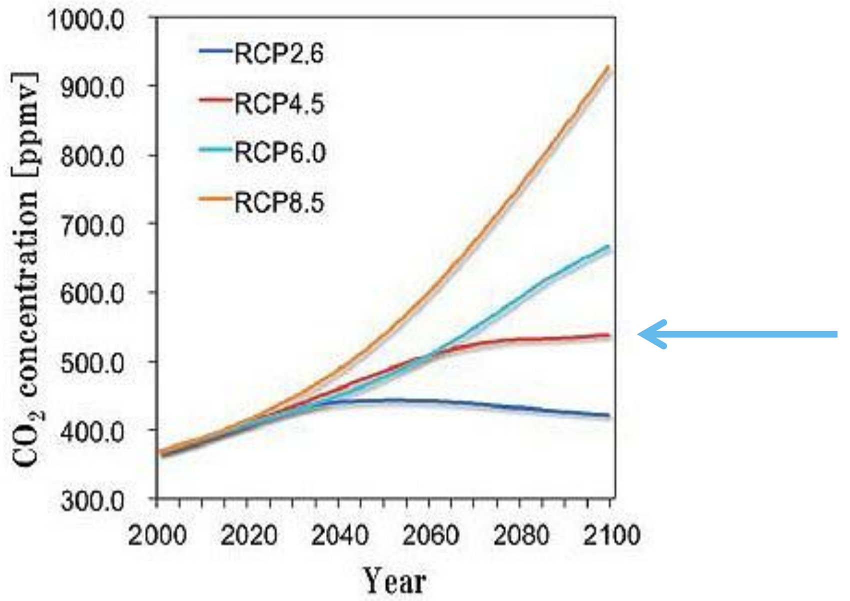
Until the 4th assessment report (2007), IPCC's climate projections were based on greenhouse gas emission scenarios (SRES).



1. **Social scientists developed various "storylines" for the future society**
2. **These gave input to so called Integrated Assessment Models, that outputted emission scenarios**
3. **Emission scenarios were translated into concentration scenarios using carbon cycle models**
4. **Concentration scenarios were used to constrain CMIP climate model simulations**

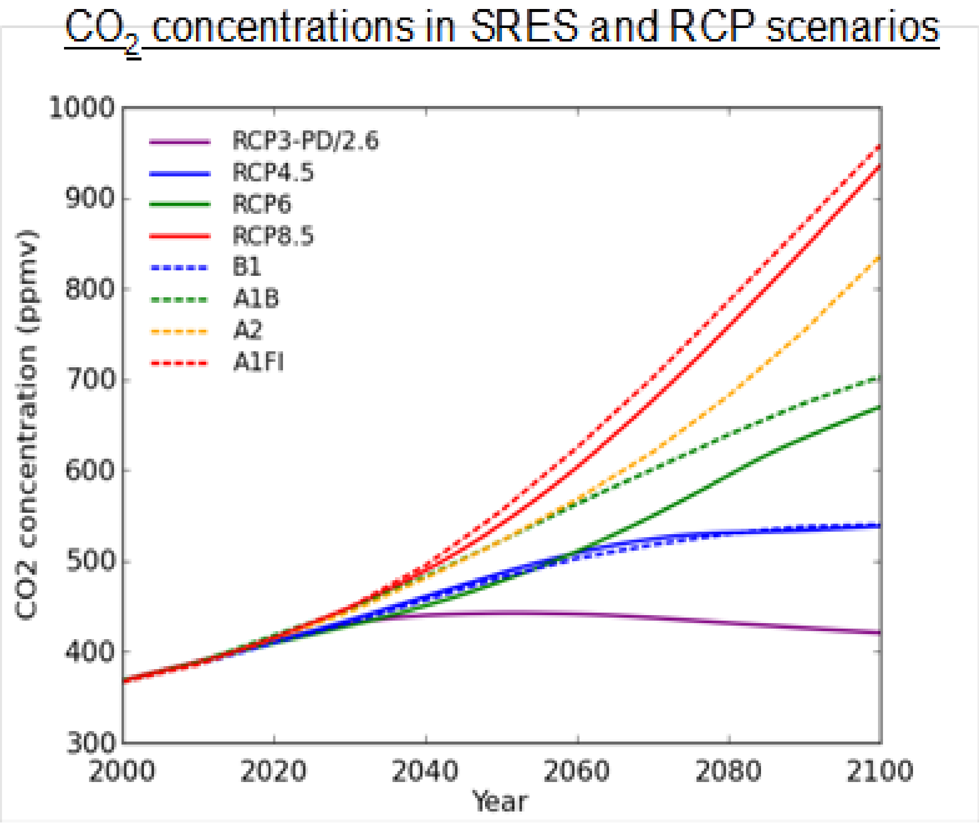
New concentration scenarios

The procedure for creating the scenarios was very heavy and slow.
For the 5th assessment report the procedure was renewed to directly produce so called REPRESENTATIVE CONCENTRATION PATHWAYS (RCP)



2x(pre-industrial CO2)

- **Storyline ”range” was taken from the literature, and the IAM’s produced the concentration pathways directly**
- **The numbers in RCP2.6, RCP4.5, RCP6.0 ja RCP8.5 represent the radiative forcings in 2100 (W/m2)**



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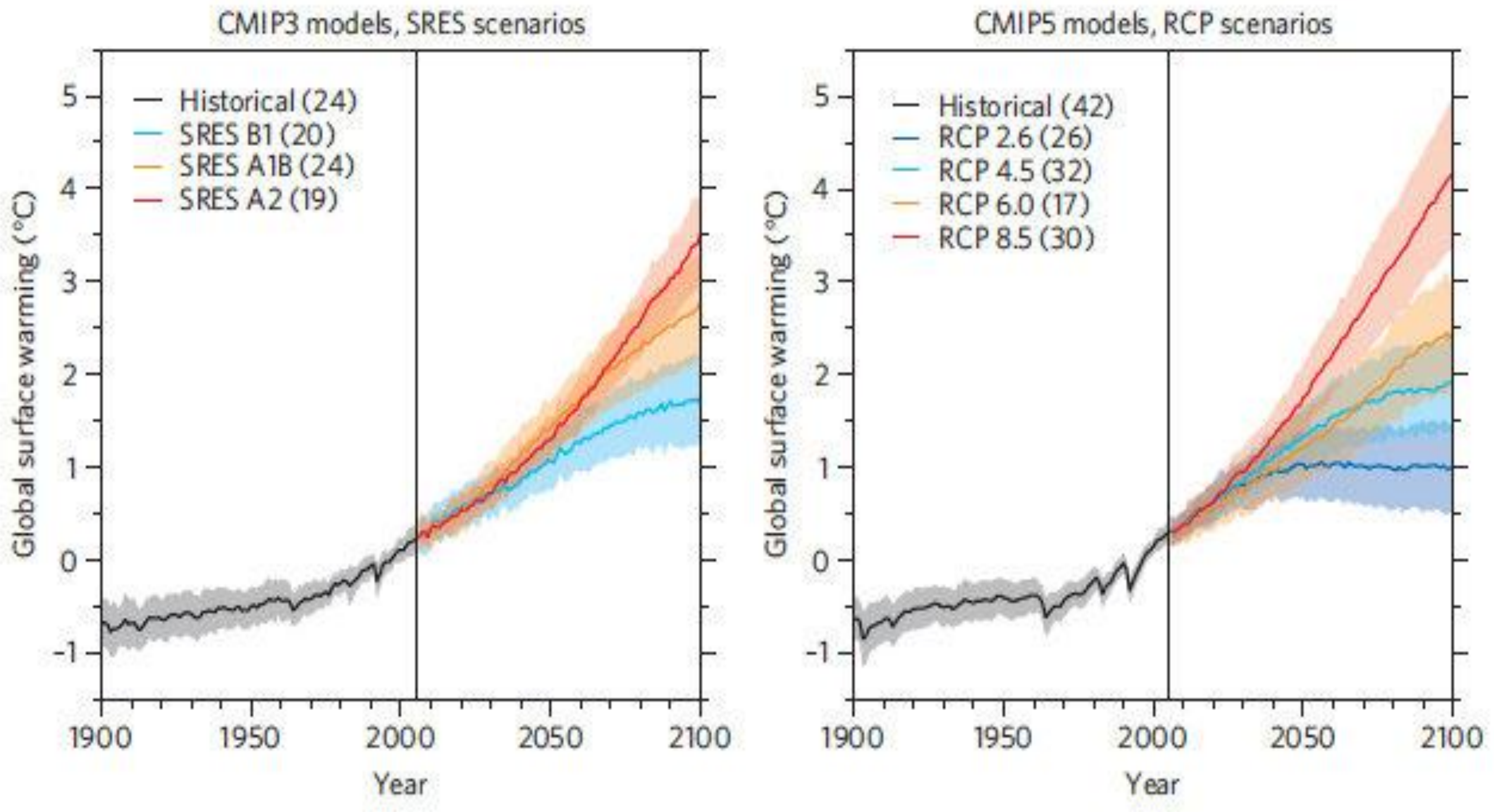
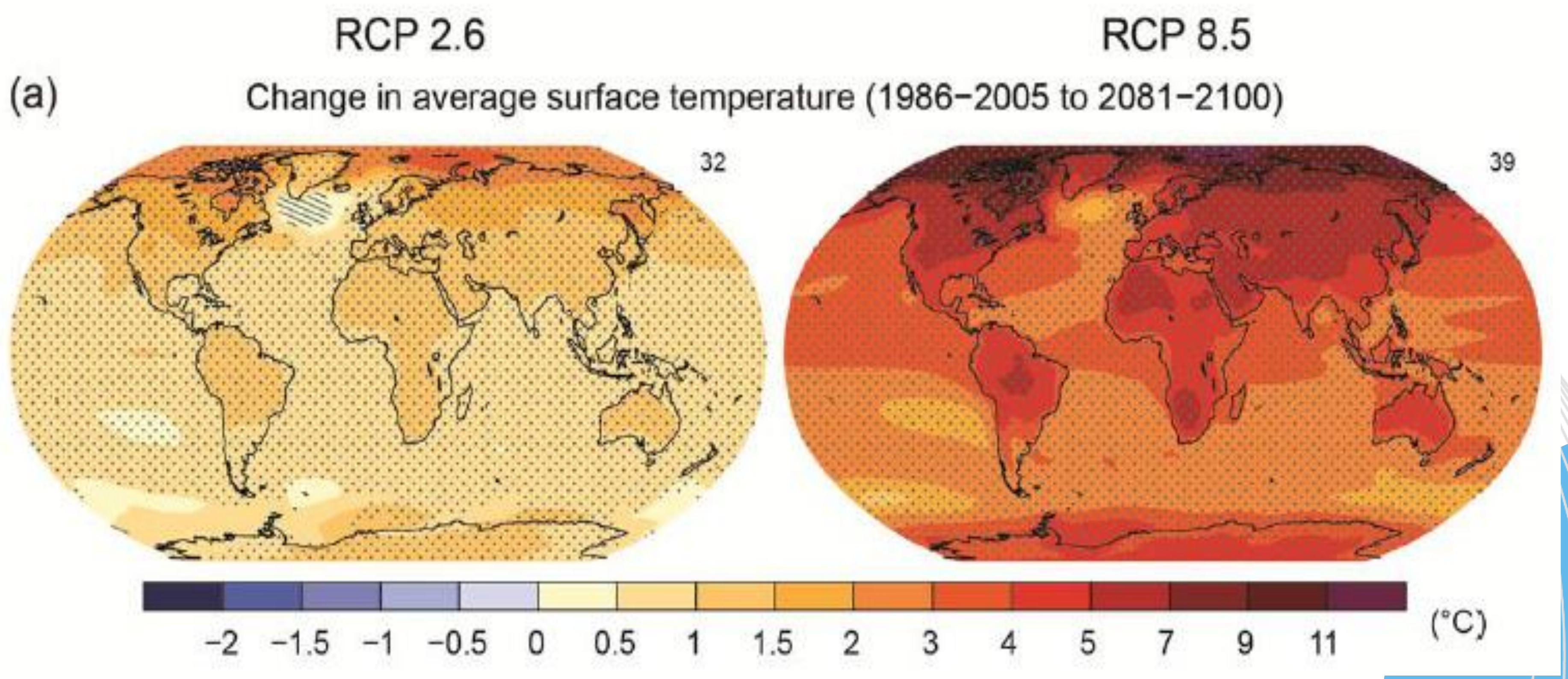
Climate projections from SRES and RCP scenarios



Climate projections from RCP scenarios



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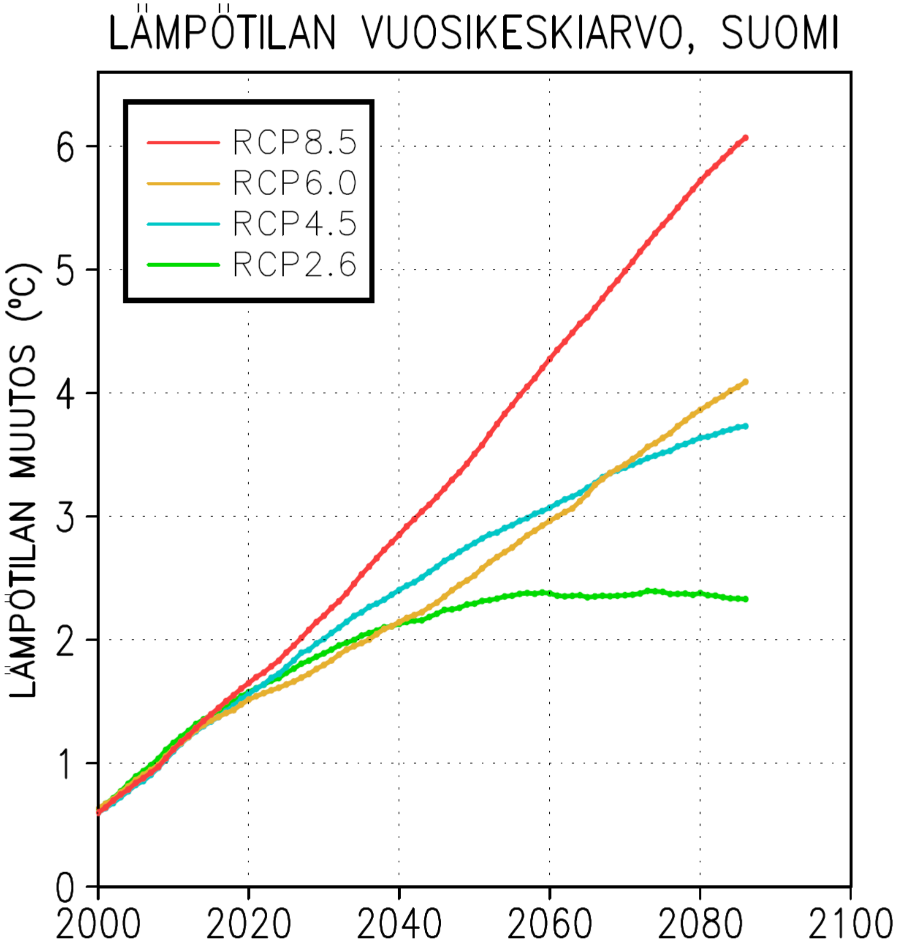
Climate projections from RCP scenarios



Finland

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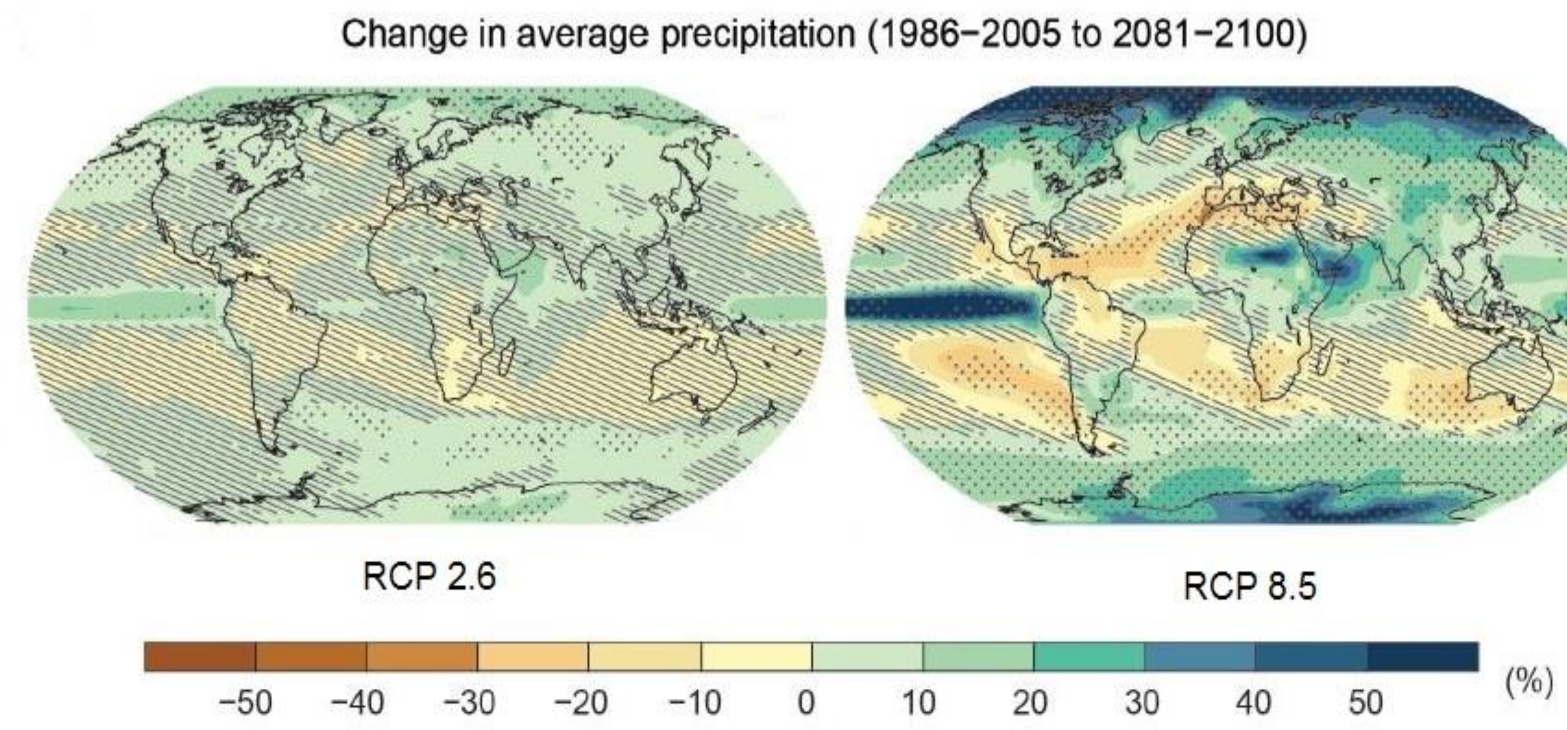
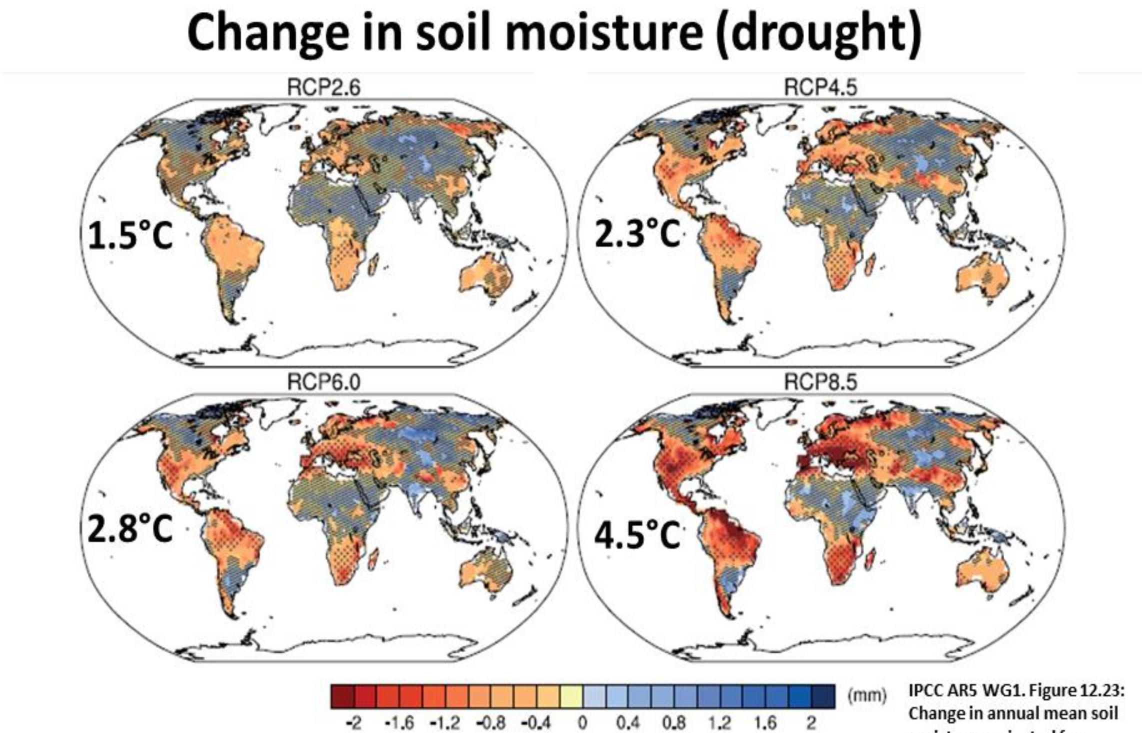
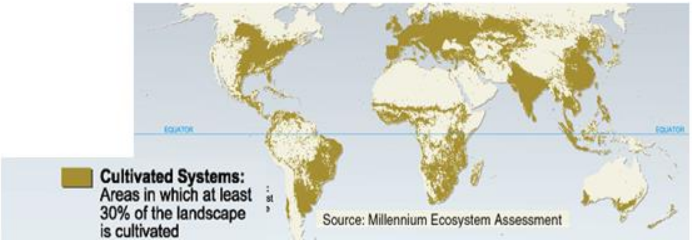
Climate projections from RCP scenarios



Climate projections from RCP scenarios



IPCC AR5 WG1. Figure 12.23: Change in annual mean soil moisture projected for 2081–2100 .



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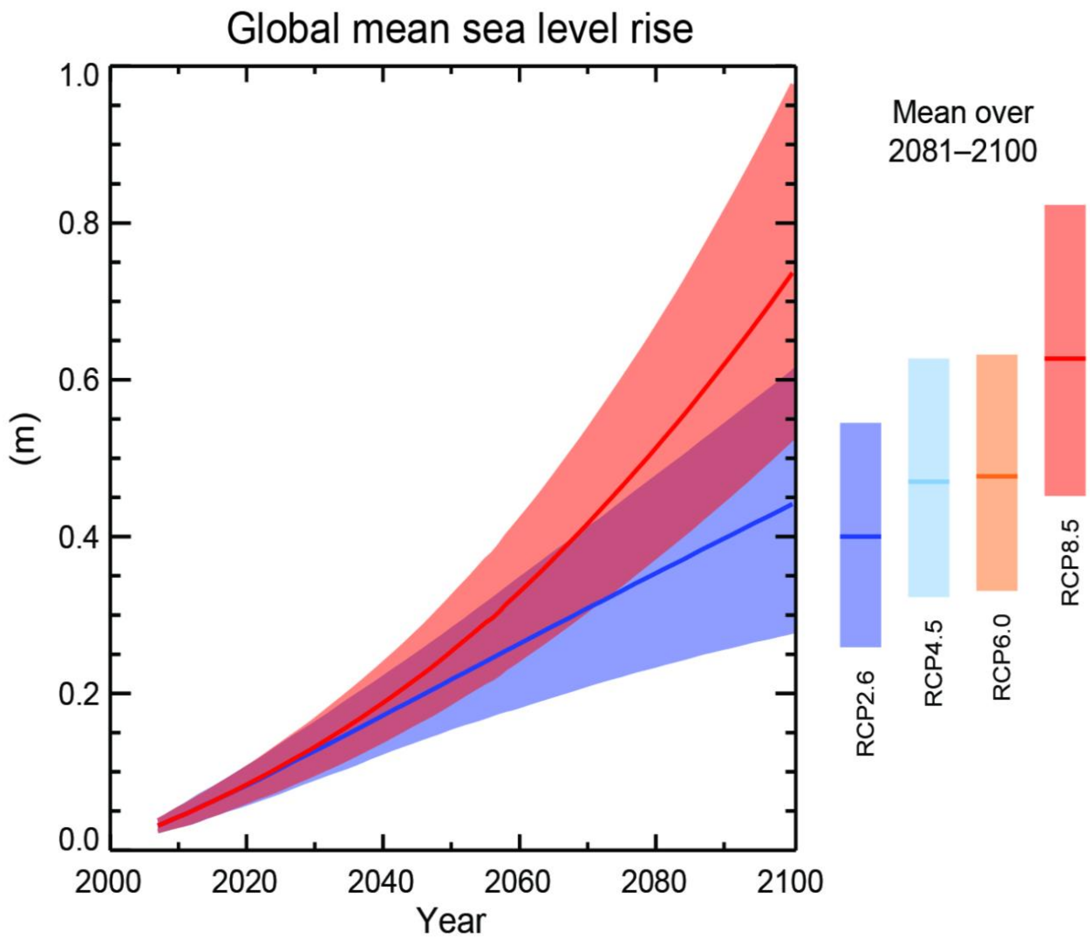
Climate projections from RCP scenarios



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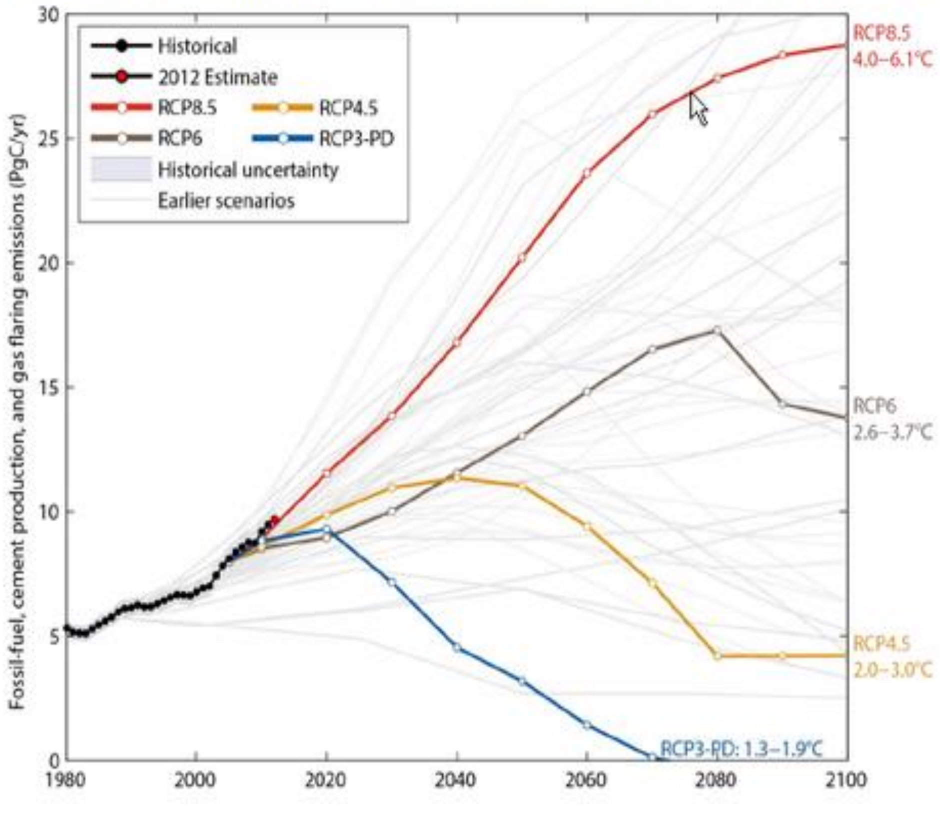
What about CO2 emissions?

Emissions are heading to a 4.0-6.1°C "likely" increase in temperature
Large and sustained mitigation is required to keep below 2°C



Linear interpolation is used between individual datapoints

Source: Peters et al. 2012a; Global Carbon Project 2012;

Summa summarum

- **RCP2.6 – and the ”2 degree target” – are extremely hard to reach. And 1.5 degrees…**
- **Even to reach RCP4.5, emission increase has to be rapidly stopped.**
- **We have lost 6 years after the Copenhagen meeting. If we stay another 6 years on or above the RCP8.5-path, it is surely bye-bye for the 2-degree target.**

Want to play with climate data, past or future?

I recommend the KNMI Climate Explorer:

*https://climexp.**knmi**.nl/*


That's All
Folks!