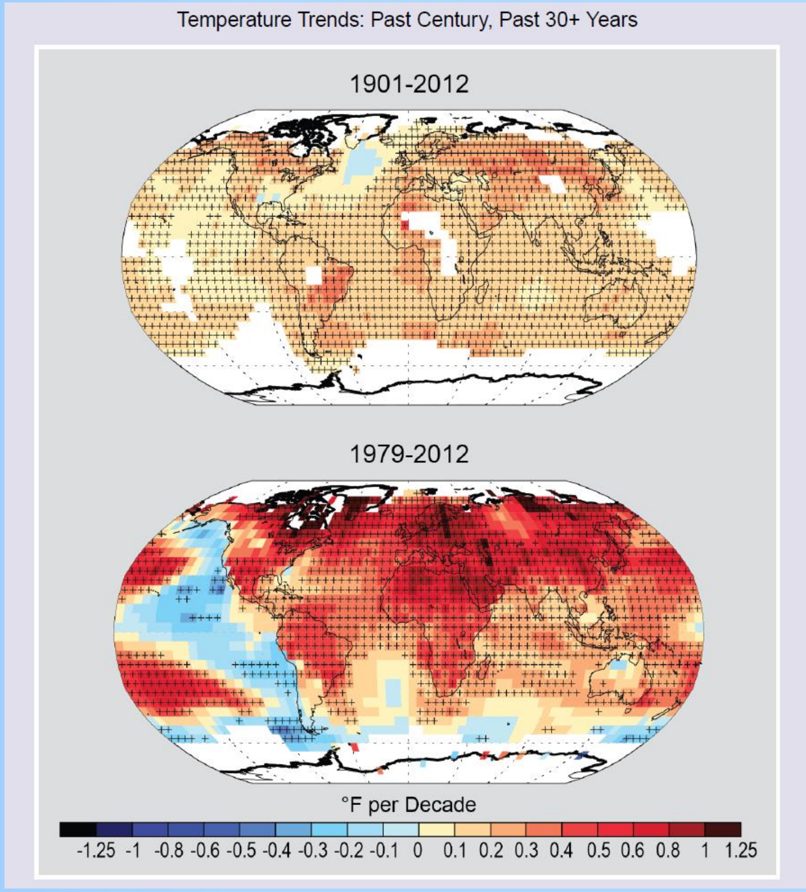
Climate Models
and
Climate Scenarios

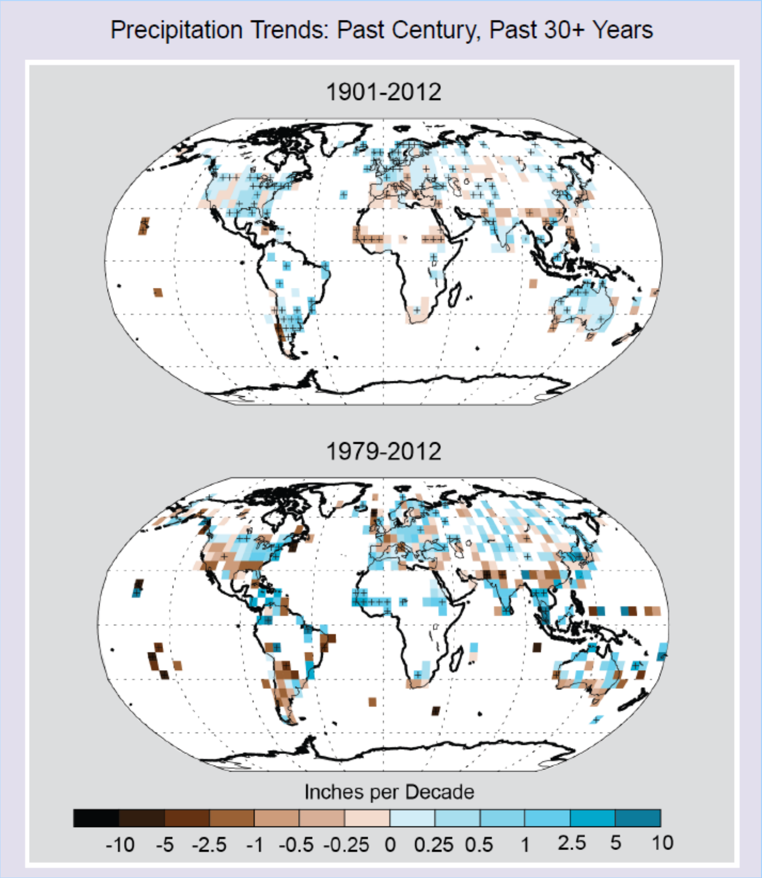
Prodromos Zanis
Professor
Department of Meteorology and Climatology, School of Geology

Kleareti Tourpali
Associate Professor
Laboratory of Atmospheric Physics, School of Physics

Aristotle University of Thessaloniki

Observed global temperature and precipitation trends





Current understanding for Climate Change and the Agriculture-Food chain

- Climate change threatens our ability to ensure global food security and achieve sustainable development.
- Climate change has both direct and indirect effects on agricultural productivity and food production
- Agriculture, farming and food production are significant sources of Greenhouse Gas (GHG) emissions from human activity and livestock.
- However, the Agricultural sector has a large mitigation potential.
- So it can be both part of the problem and part of the solution to Climate Change.

What are our scientific tools for:

- monitoring climate and climate change

- understanding and predicting future changes?

1. Observations of Climate

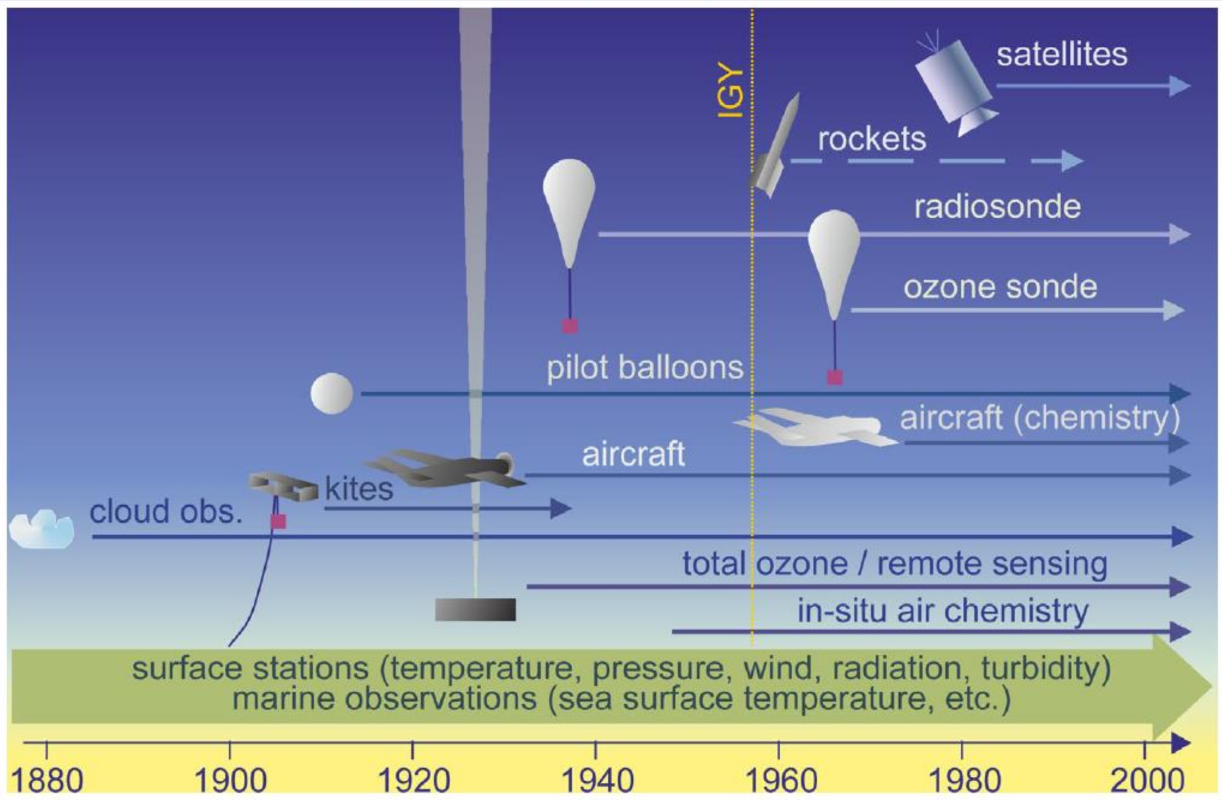
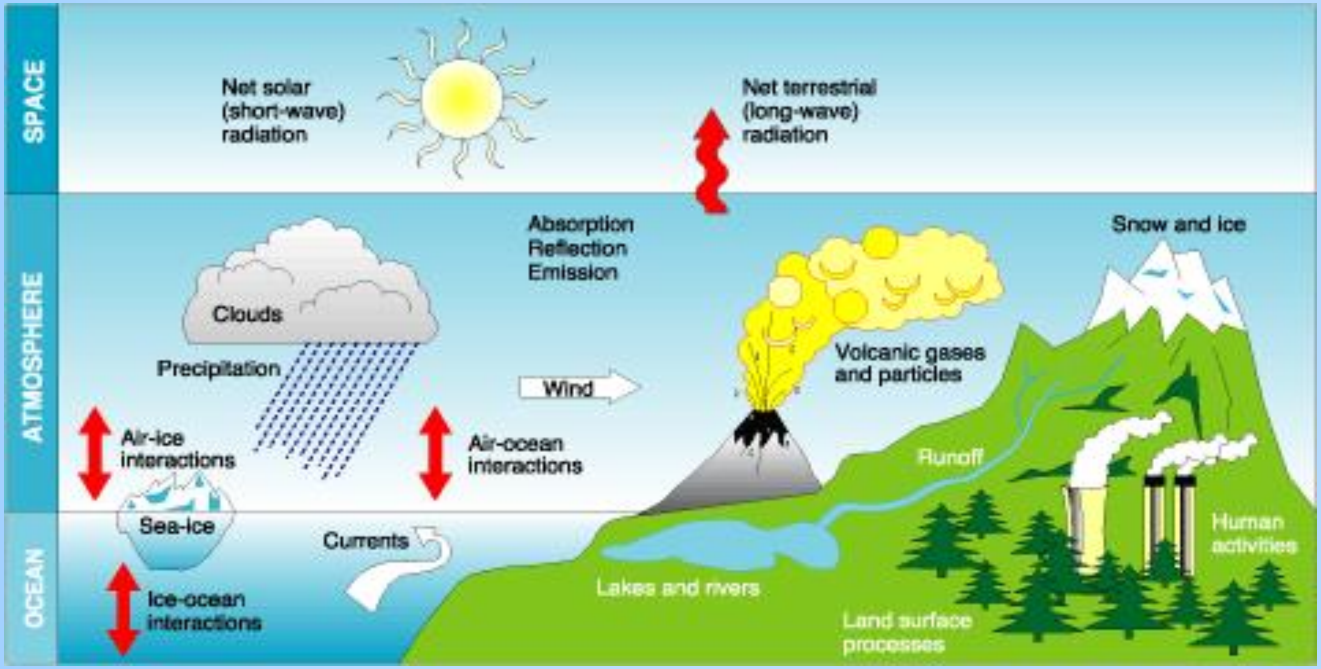


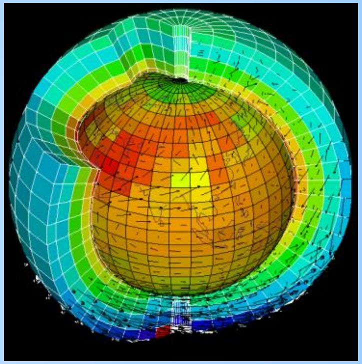
Figure 7. Changes in the mix and increasing diversity of technologies used to observe climate (IGY is the International Geophysical Year). (Figure source: adapted from Brönnimann et al. 2007[20]).

Essential for

i. describing variability of the current climate
ii. finding associations between different parts of the climate system
iii. evaluating climate model simulations.

2. Models


SPACE
ATMOSPHERE
OCEAN
Net solar (short-wave) radiation
Net terrestrial (long-wave) radiation
Absorption
Reflection
Emission
Snow and ice
Clouds
Precipitation
Wind
Volcanic gases and particles
Air-ice interactions
Air-ocean interactions
Runoff
Sea-ice
Currents
Human activities
Ice-ocean interactions
Lakes and rivers
Land surface processes



Why do climate modeling?

- We can't bring the entire atmosphere, ocean, land, and biosphere into the laboratory.
- We can't do experiments in the real world.

Models are tools to:

- Provide information where observations are missing:
  - in time (forecasts!), space and parameter space
- Test our understanding of processes and their interactions
  - forcings and feedbacks
- Make non-invasive experiments

So, models are **our laboratory**

Types of experiments

- simulations of present climate – first test of any model
- simulations of the past
  - ice ages
  - Maunder minimum
  - last 165 years (historical runs)
- sensitivity to different forcings
- sensitivity to different feedbacks
- predictions
- test different scenarios of future

Types of climate models

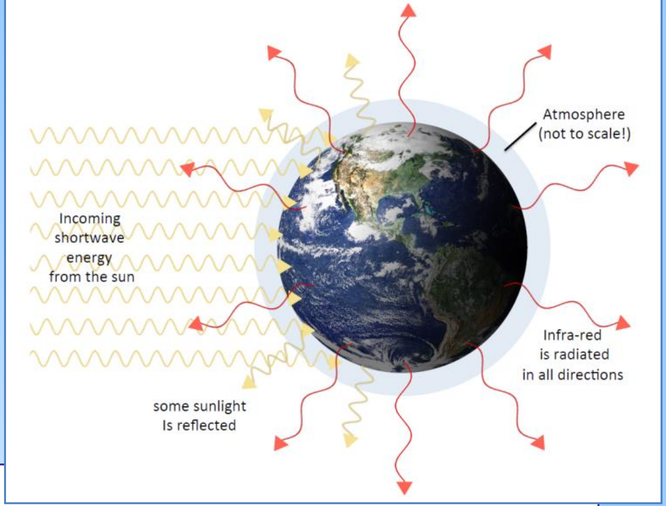
Determined by:

- spatial resolution and representation
- time step size, or steady-state
- portion of climate system that is included

Classification

- 0-dimensional ↔ 3-dimensional
- **atmosphere only** (with fixed sea surface temperatures), or
  with **mixed-layer ocean,** or
  with **complete dynamic ocean**
- inclusion of aerosols, chemistry, biosphere, stratosphere resolved in detail ...

A very simple climate model



Incoming solar radiation = outgoing blackbody radiation

$$(1-\alpha)S_0\pi r^2 = 4\pi r^2\varepsilon\sigma T^4$$

Albedo of the Earth

TSI, or Solar Constant

Radius of the Earth

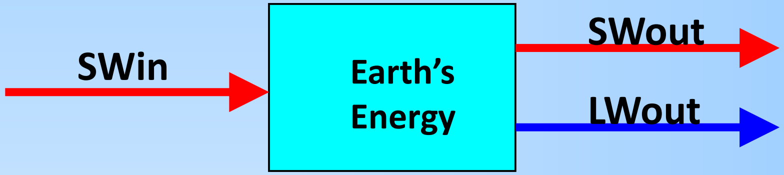
Emissivity of the Earth

Stefan-Boltzmann constant

Surface temperature of Earth

Types of climate models (1)

Energy-balance models



Zero-dimensional, steady-state:

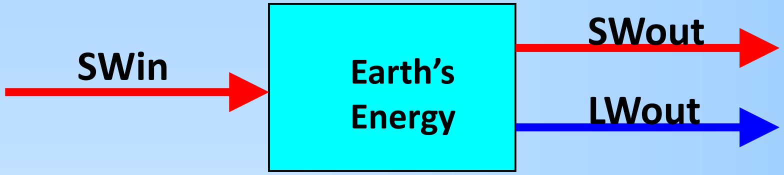
$$\frac{S_0}{4}(1-\alpha) = \varepsilon\sigma {T_e}^4$$

Zero-dimensional, time-dependent:

$$C\frac{\partial T_s}{\partial t} = \frac{S_0}{4}(1-\alpha) - \varepsilon\sigma {T_e}^4$$

Types of climate models (1)

Energy-balance models



Zero-dimensional, steady-state:

$$\frac{S_0}{4}(1-\alpha) = \varepsilon\sigma {T_e}^4$$

Zero-dimensional, time-dependent:

Radiative forcing

$$C\frac{\partial T_s}{\partial t} = \frac{S_0}{4}(1-\alpha) - \varepsilon\sigma {T_e}^4$$

Types of climate models (1)

Energy-balance models

$$C\frac{\partial T_s}{\partial t} = \frac{S_0}{4}(1-\alpha) - \sigma T_e{}^4$$

Disadvantages of this model:

- sensitivity and C cannot be evaluated here
- describes **only global average**

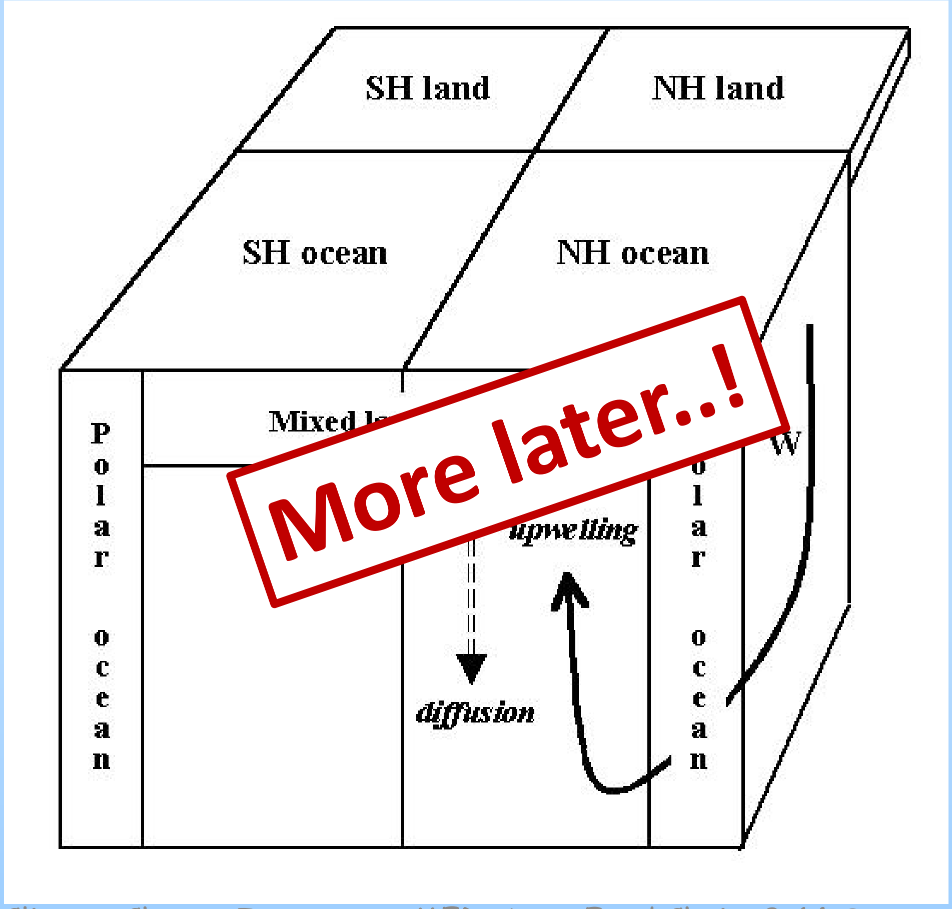
Advantages of this model:

- **easily understood**
- can be used to **interpret more complex models**

Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC)

an upwelling-diffusion energy-balance model

http://www.magicc.org/

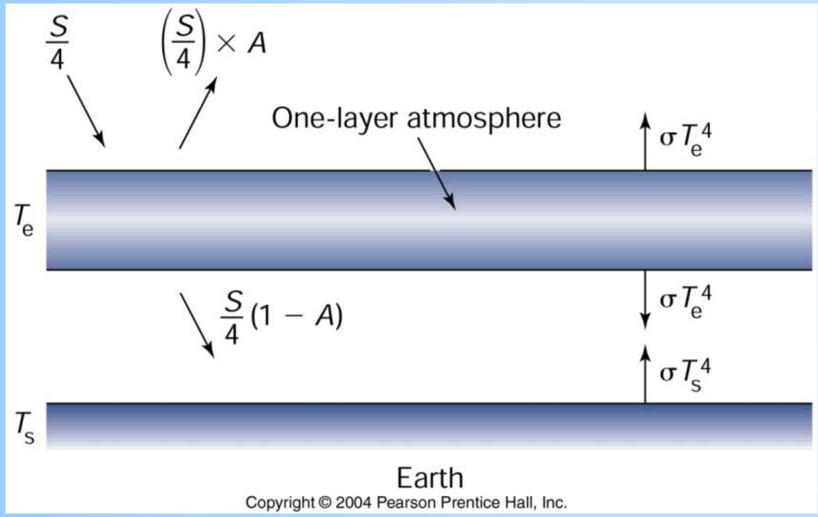


Types of climate models (2)

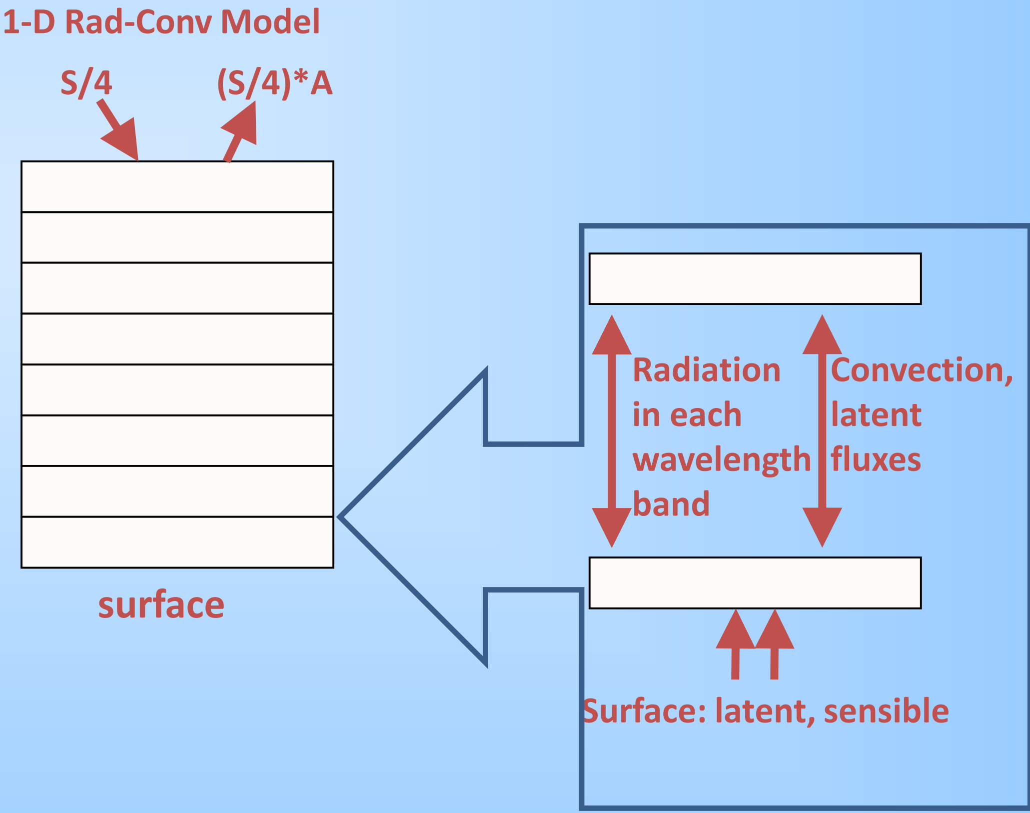
What is an RCM?

1. Radiative-Convective Model, *1-dimensional*

One-Layer



More Layers



Types of climate models (2)

What is an RCM?

1. Radiative-Convective Model*, or Single Column Model (SCM)*

Advantages: can look at

- radiation parameterizations
- cloud parameterizations and feedbacks
- water vapor feedbacks
- lapse rate feedbacks
- surface interactions and feedbacks
- effects of different atmospheric composition, including CO_2
- O_3 at different levels
- aerosols at different levels

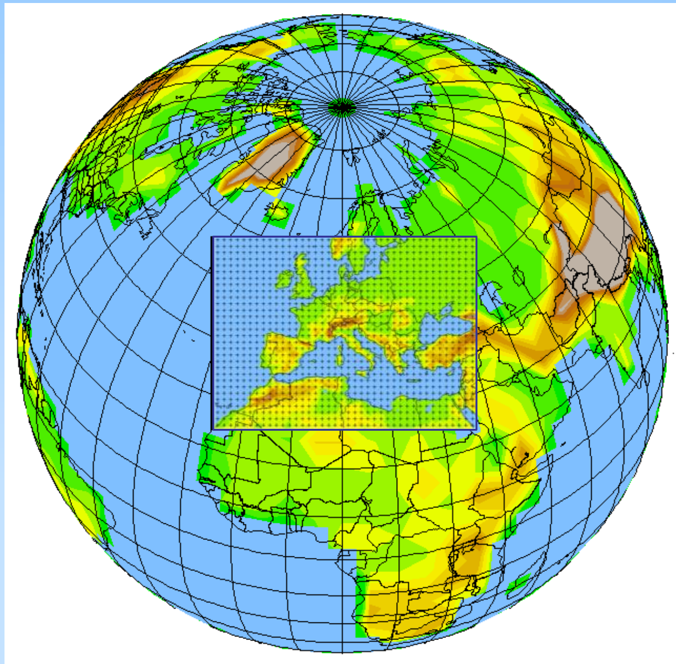
Disadvantages:

- no horizontal distributions, albedo feedbacks, dynamics

Types of climate models (2)

What is an RCM?

2. Regional Climate Model



Advantages:

- can look in detail at specific locations
- takes less computer time than a global simulation

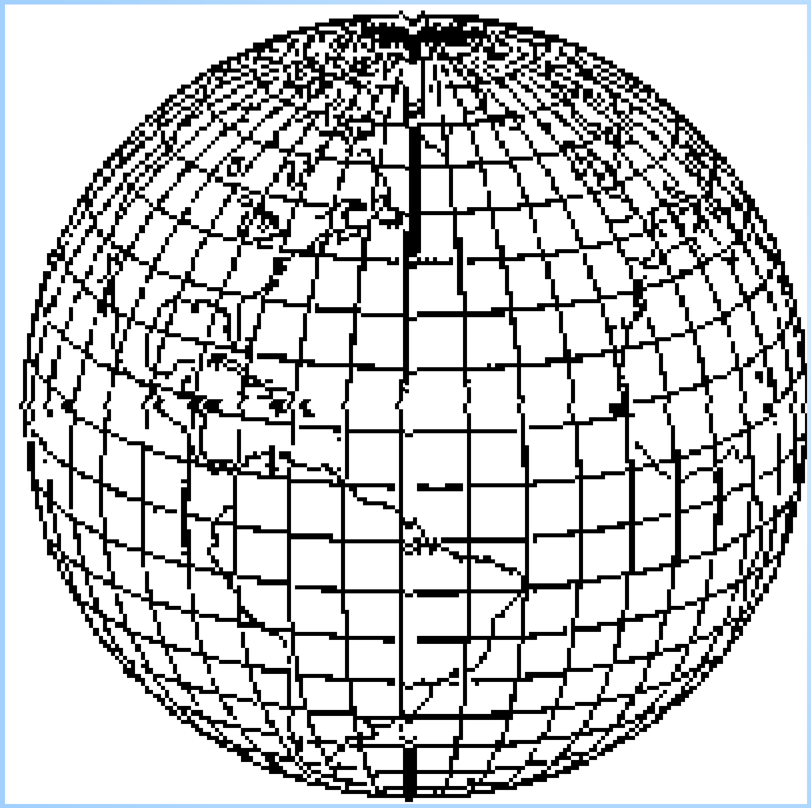
Disadvantages:

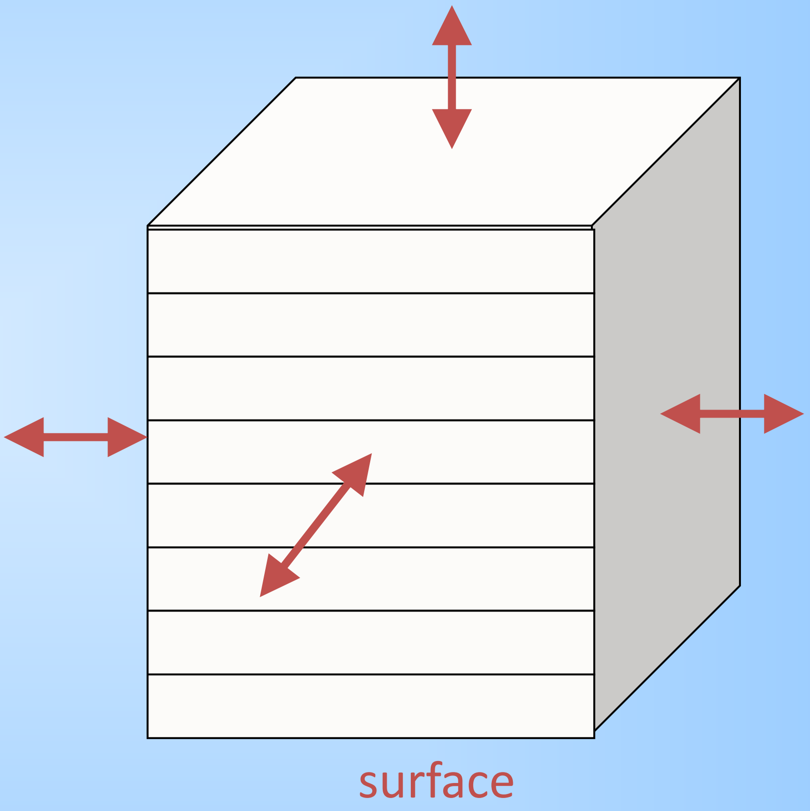
- complicated to connect to boundaries (spectral nudging helps)
- reproduces in detail the climate determined by the boundary conditions, but cannot change the basic climate.

More on this later…

Types of climate models (3)

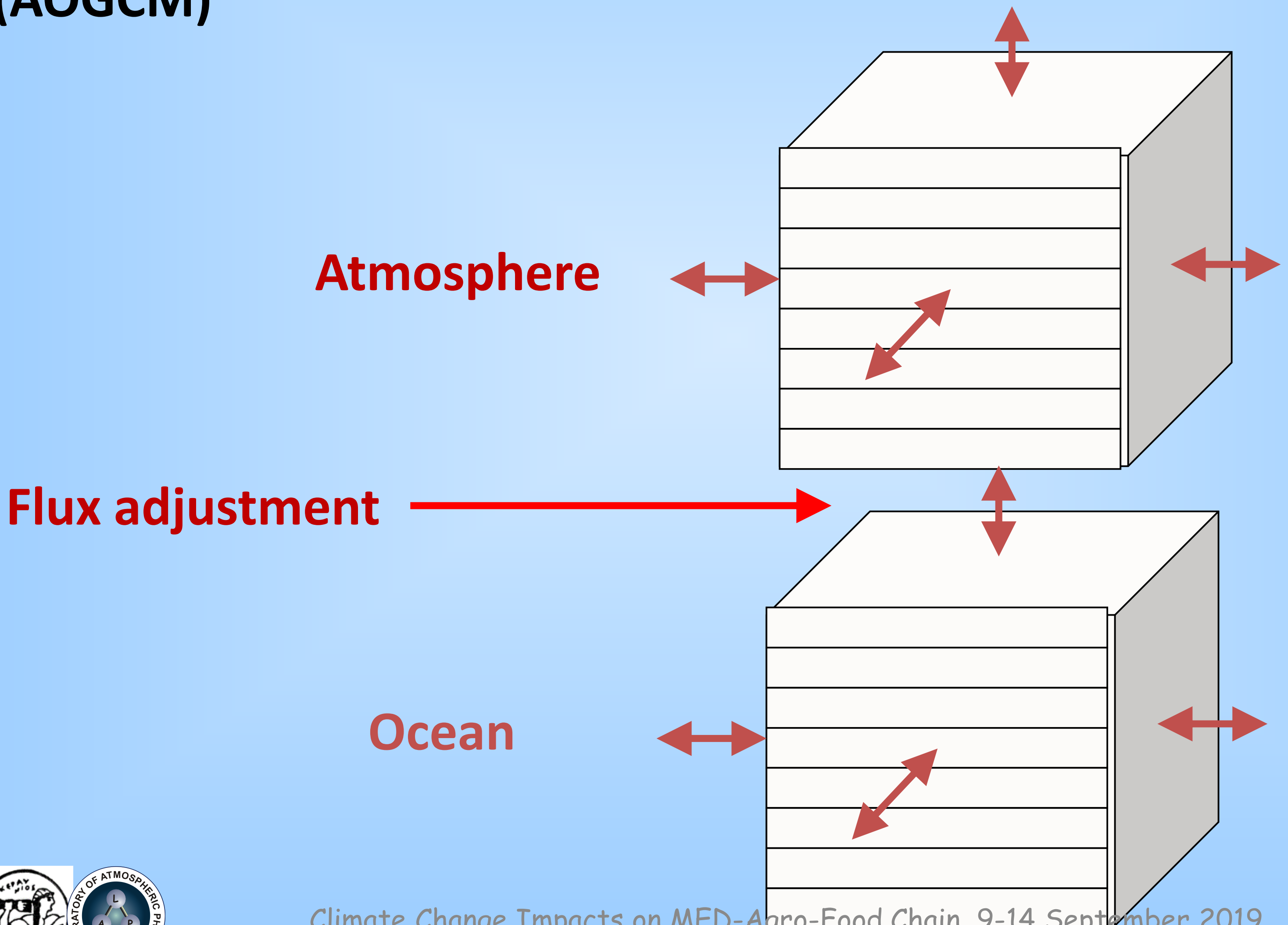
3-D Atmospheric General Circulation Model (AGCM)





Types of climate models (3)

3-D coupled atmosphere – ocean general circulation models (AOGCM)



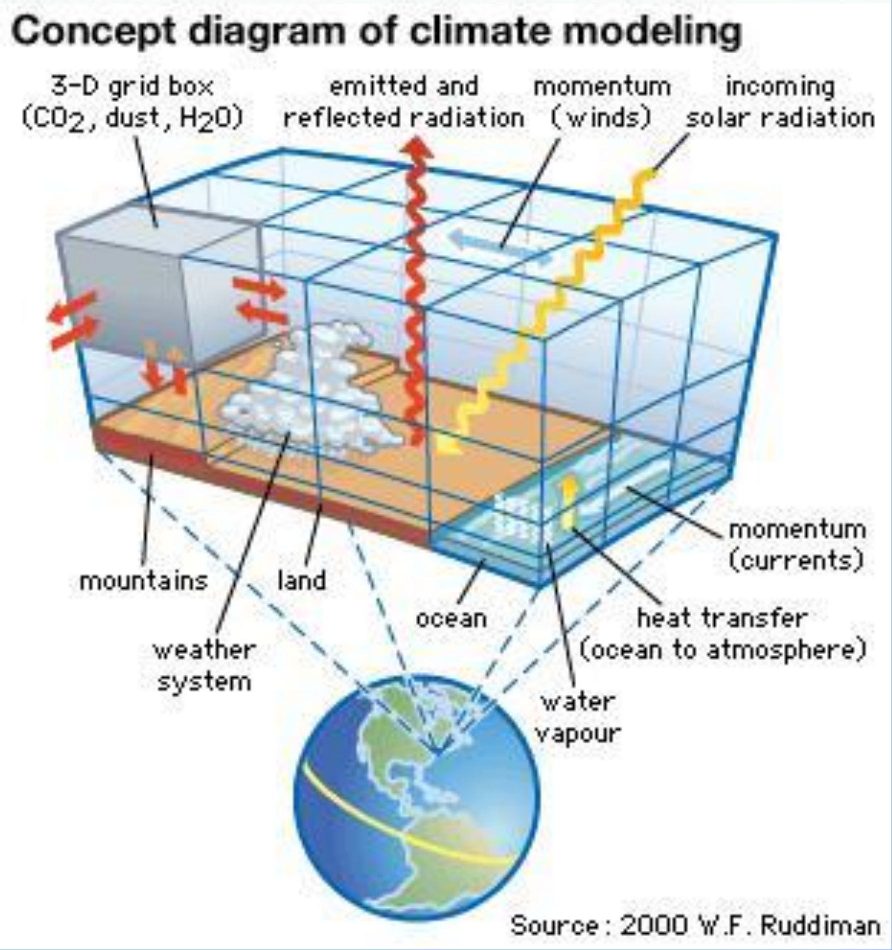
General Circulation Models (GCMs)

or Global Climate Models

1. Processes, physical laws, feedbacks, MIPs
2. Model resolution, subgrid-scale processes
3. Climate change experiments
   - equilibrium
   - transient
4. Uncertainty
5. Dependency on initial conditions
6. Results from different models

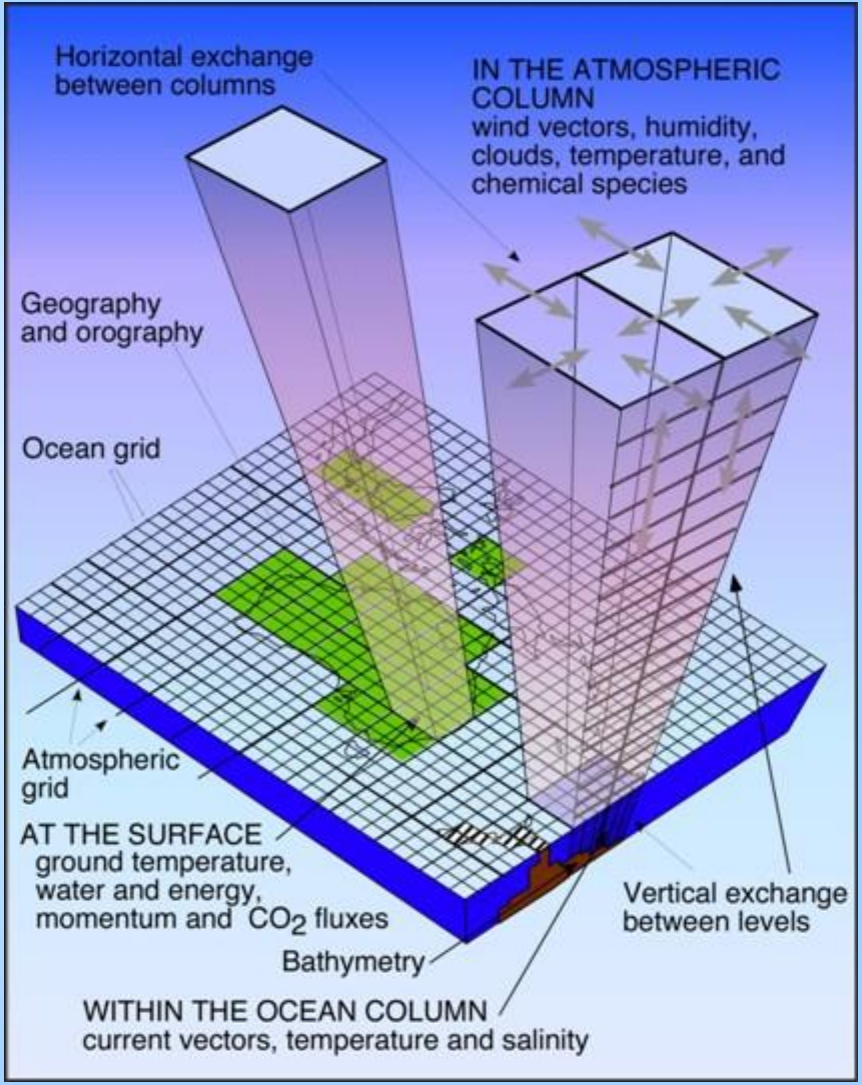
General Circulation Models (GCMs)

- The characteristics of the atmosphere are **determined by a set of physical laws** that can be expressed mathematically.
- A GCM is a **simulation system of the physical processes** that take place in the atmosphere.
- These **processes are approached using differential equations**. Solving these equations leads to **weather forecast and estimation of the future climate**



General Circulation Models (GCMs)

- GCMs divide atmosphere, oceans, and land into **a 3-D grid system.**
- Many calculations beyond the fundamental physics equations use **parameterizations**: formulas based on empirical evidence, on observations or on results of experiments.
- The physics equations and parameterizations are then **calculated for each cell** in the grid over and over again, representing the march forward in time, throughout the simulation.



Processes in GCMs

Three basic processes:

- **radiative** - the transfer of radiation through the climate system (*e.g*. absorption, reflection, scattering);
- **dynamic** - the horizontal and vertical transfer of energy (*e.g*. advection, convection, diffusion);
- **surface process** - processes involving land/ocean/ice, and albedo effects, emissivity and surface-atmosphere energy exchanges

Basic Physical Laws in GCMs

- **Conservation of energy *(First law of thermodynamics)***
- **Conservation of momentum *(Newton's second law of motion)***
- **Conservation of mass *(Continuity equation)***
- **Conservation of moisture**
- **Hydrostatic equilibrium**
- **Equation of state (Gas law)**

Basic Equations

Conservation of momentum:

$$\frac{\partial \vec{V}}{\partial t} = -(\vec{V} \bullet \nabla)\vec{V} - \frac{1}{\rho}\nabla p - \vec{g} - 2\vec{\Omega} \times \vec{V} + \nabla \bullet (k_m \nabla \vec{V}) - \vec{F}_d$$

Conservation of energy:

$$\rho c_p \frac{\partial T}{\partial t} = -\rho c_p(\vec{V} \bullet \nabla)T - \nabla \bullet \vec{R} + \nabla \bullet (k_T \nabla T) + C + S$$

Conservation of mass:

$$\frac{\partial \rho}{\partial t} = -(\vec{V} \bullet \nabla)\rho - \rho(\nabla \bullet \vec{V})$$

Conservation of H_2O (vapor, liquid, solid):

$$\frac{\partial q}{\partial t} = -(\vec{V} \bullet \nabla)q + \nabla \bullet (k_q \nabla q) + S_q + E$$

Equation of state:

$$p = \rho R_d T$$

V = velocity
T = temperature
p = pressure
ρ = density
q = specific humidity
g = gravity
Ω = rotation of earth
F_d = drag force of earth
R = radiation vector
C = conductive heating
c_p = heat capacity, const. p
E = evaporation
S = latent heating
S_q = phase-change source
k = diffusion coefficients
R_d = dry air gas constant

Physical Processes in GCMs

Wind
Radiation
Precipitation
Soil moisture
Ground water
Aerosols
Clouds, convective and large-scale
Air-sea exchanges of moisture, energy, and momentum
Air-land exchanges of moisture, energy, and momentum
Chemistry, particularly O_3, ODS, CO_2 and GHGs
Ocean temperature, salinity, and currents
Sea ice
Snow
Glaciers
Vegetation
Ocean biota

Evolution of processes included in state-of-the-art climate models

FAR: First IPCC Assessment Report (1990)

SAR: Second Report (1995)

TAR: Third Report (2001)

AR4: Fourth Report (2007)

IPCC AR4, Chapter 1

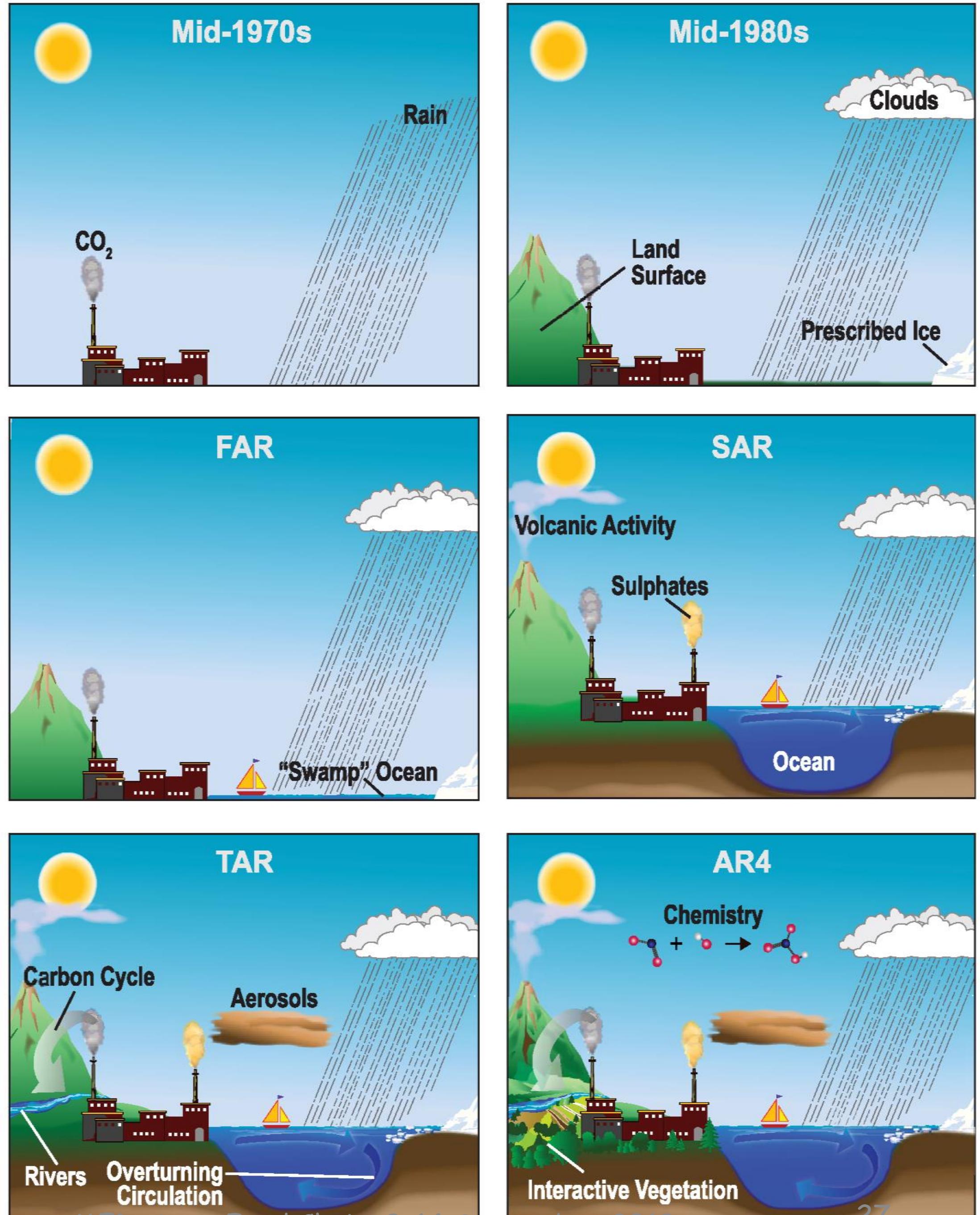
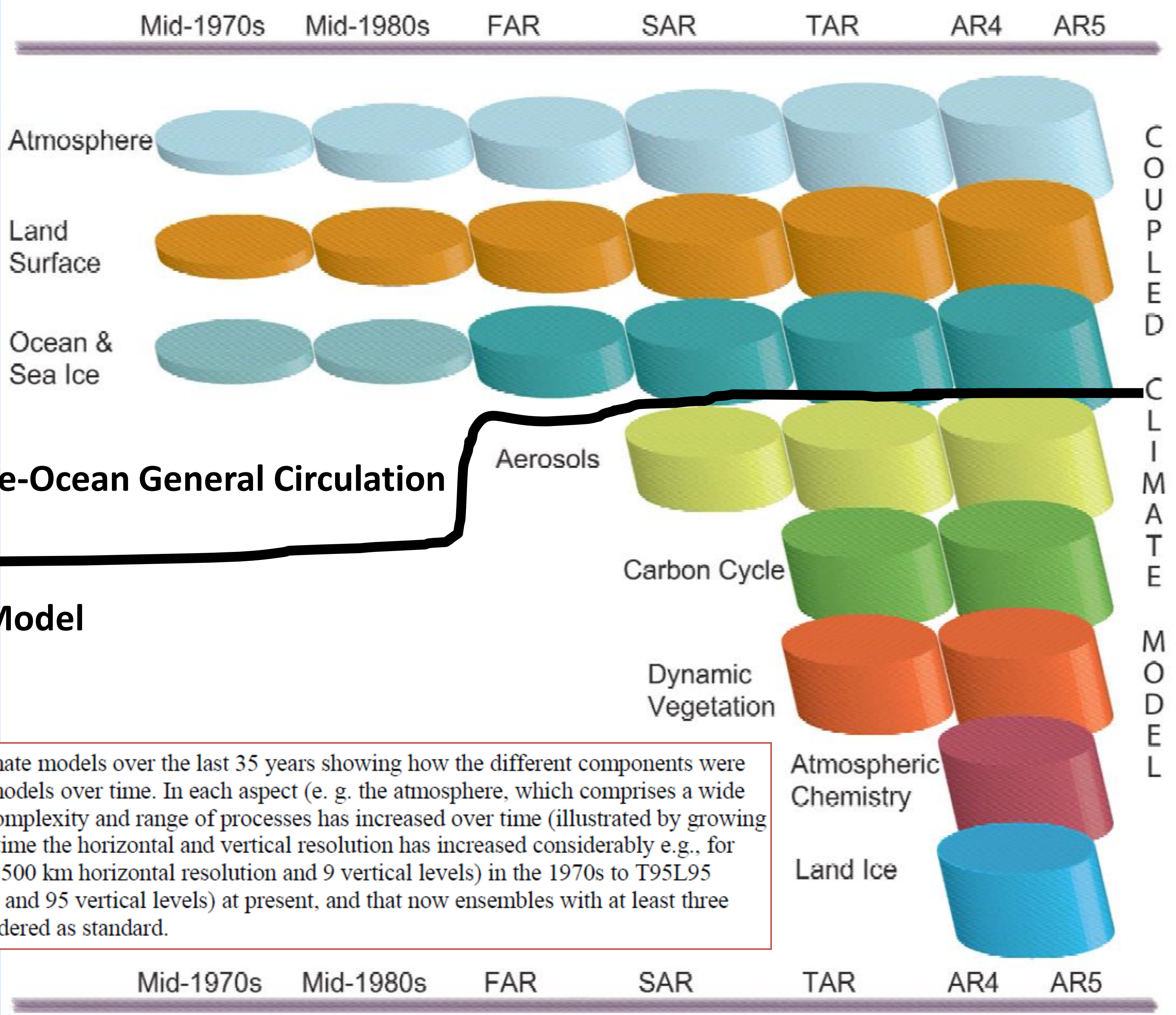


Figure 1.2. *The complexity of climate models has increased over the last few decades. The additional physics incorporated in the models are shown pictorially by the different features of the modelled world.*

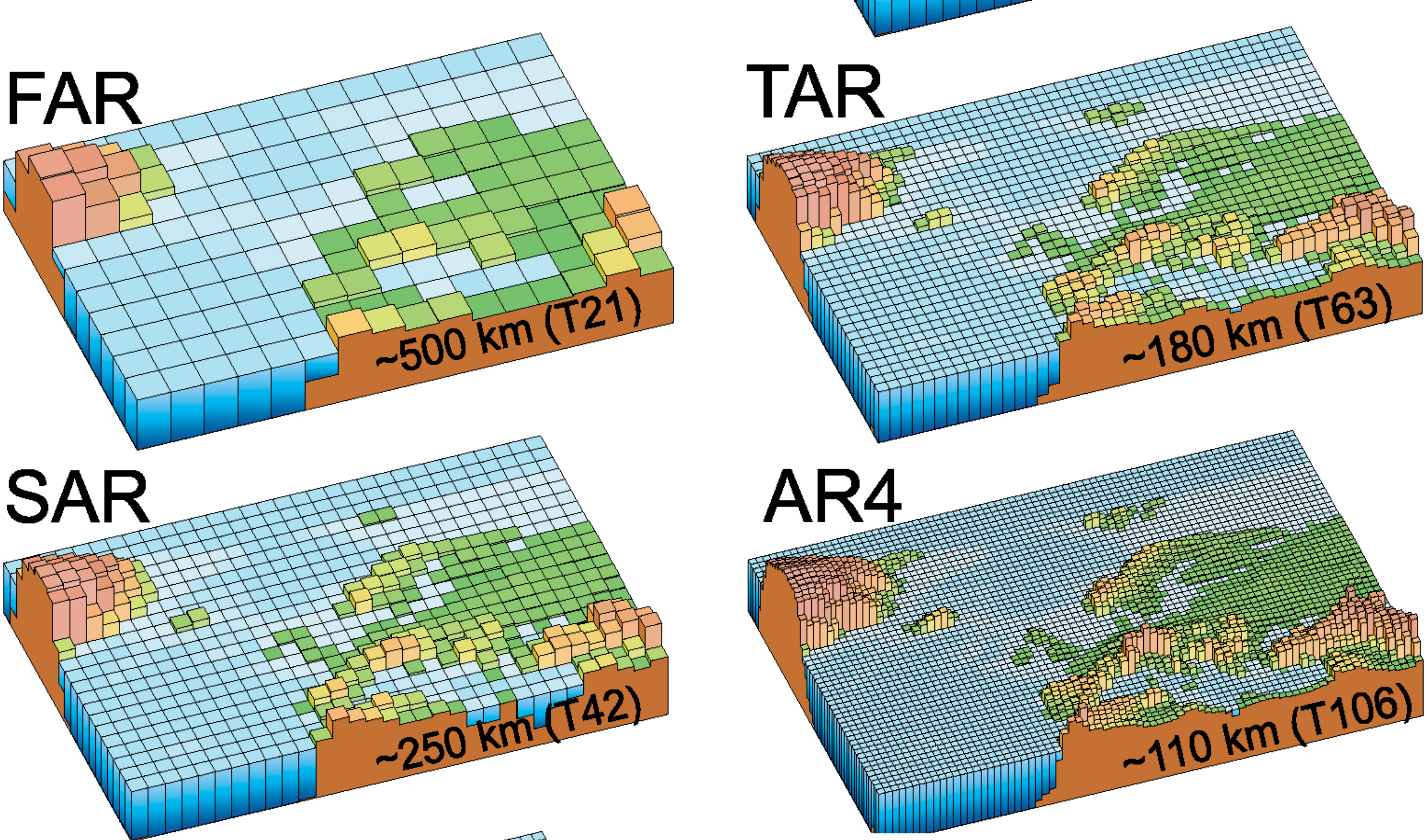
Final Draft (7 June 2013) Chapter 1 IPCC WGI Fifth Assessment Report



AOGCM = Atmosphere-Ocean General Circulation Model.

ESM = Earth System Model

Figure 1.13: The development of climate models over the last 35 years showing how the different components were coupled into comprehensive climate models over time. In each aspect (e. g. the atmosphere, which comprises a wide range of atmospheric processes) the complexity and range of processes has increased over time (illustrated by growing cylinders). Note that during the same time the horizontal and vertical resolution has increased considerably e.g., for spectral models from T21L9 (roughly 500 km horizontal resolution and 9 vertical levels) in the 1970s to T95L95 (roughly 100 km horizontal resolution and 95 vertical levels) at present, and that now ensembles with at least three independent experiments can be considered as standard.



IPCC AR4, Chapter 1

Figure 1.4. *Geographic resolution characteristic of the generations of climate models used in the IPCC Assessment Reports: FAR (IPCC, 1990), SAR (IPCC, 1996), TAR (IPCC, 2001a), and AR4 (2007). The figures above show how successive generations of these global models increasingly resolved northern Europe. These illustrations are representative of the most detailed horizontal resolution used for short-term climate simulations. The century-long simulations cited in IPCC Assessment Reports after the FAR were typically run with the previous generation's resolution. Vertical resolution in both atmosphere and ocean models is not shown, but it has increased comparably with the horizontal resolution, beginning typically with a single-layer slab ocean and ten atmospheric layers in the FAR and progressing to about thirty levels in both atmosphere and ocean.*

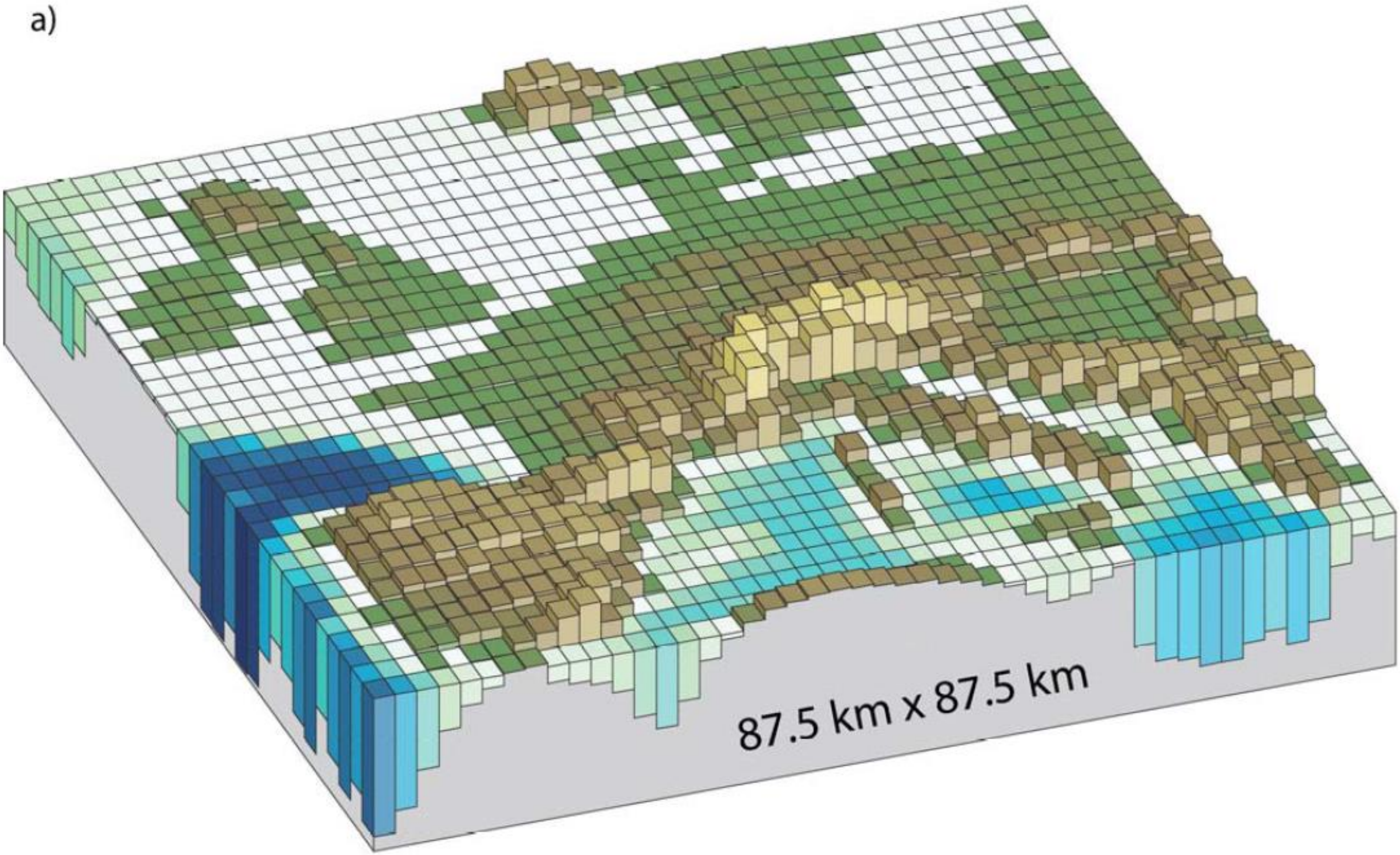
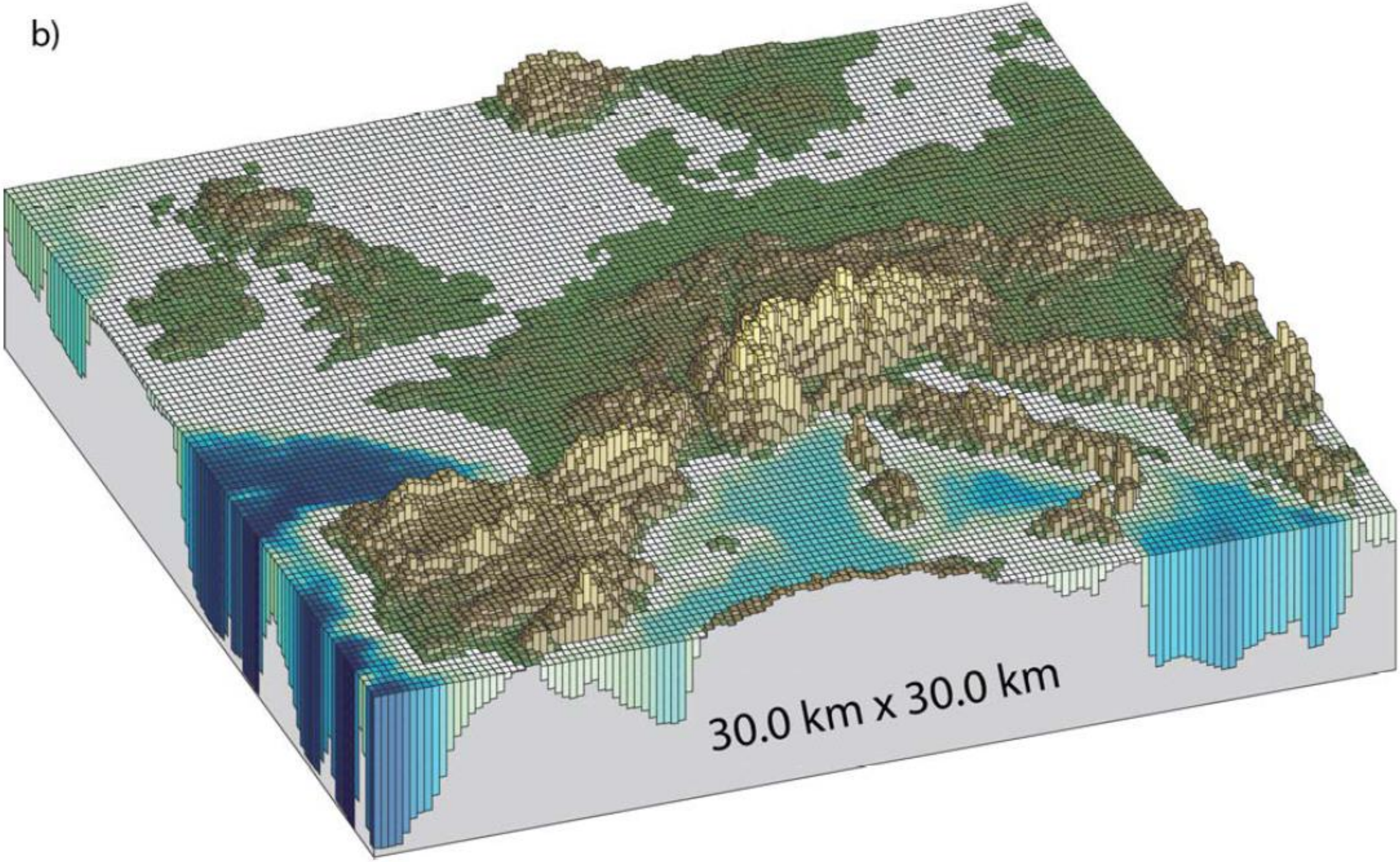


Figure 1.14: Horizontal resolutions considered in today's higher resolution models and in the very high resolution models now being tested: a) Illustration of the European topography at a resolution of 87.5 x 87.5 km; b) same as a) but for a resolution of 30.0 x 30.0 km.



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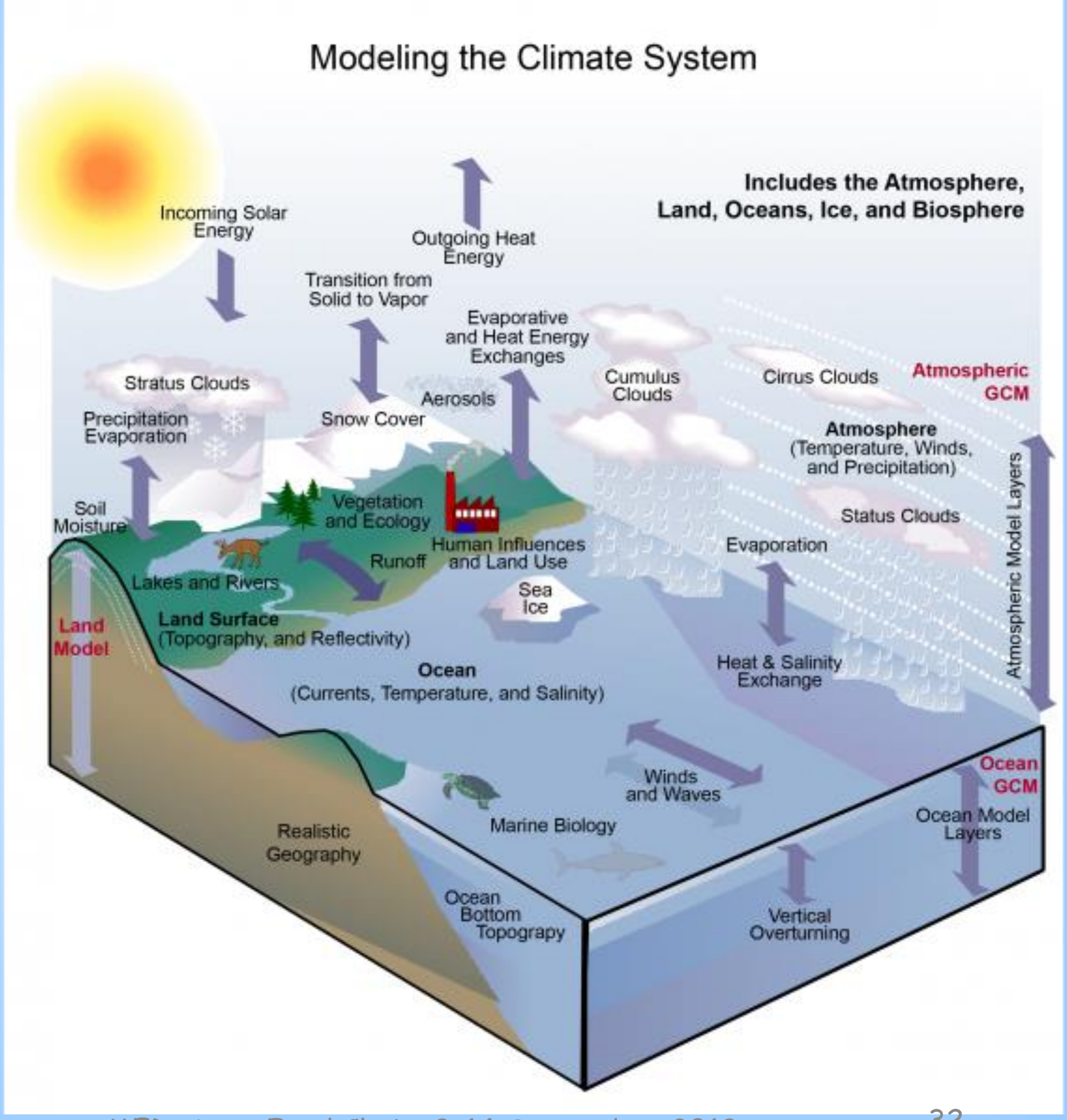
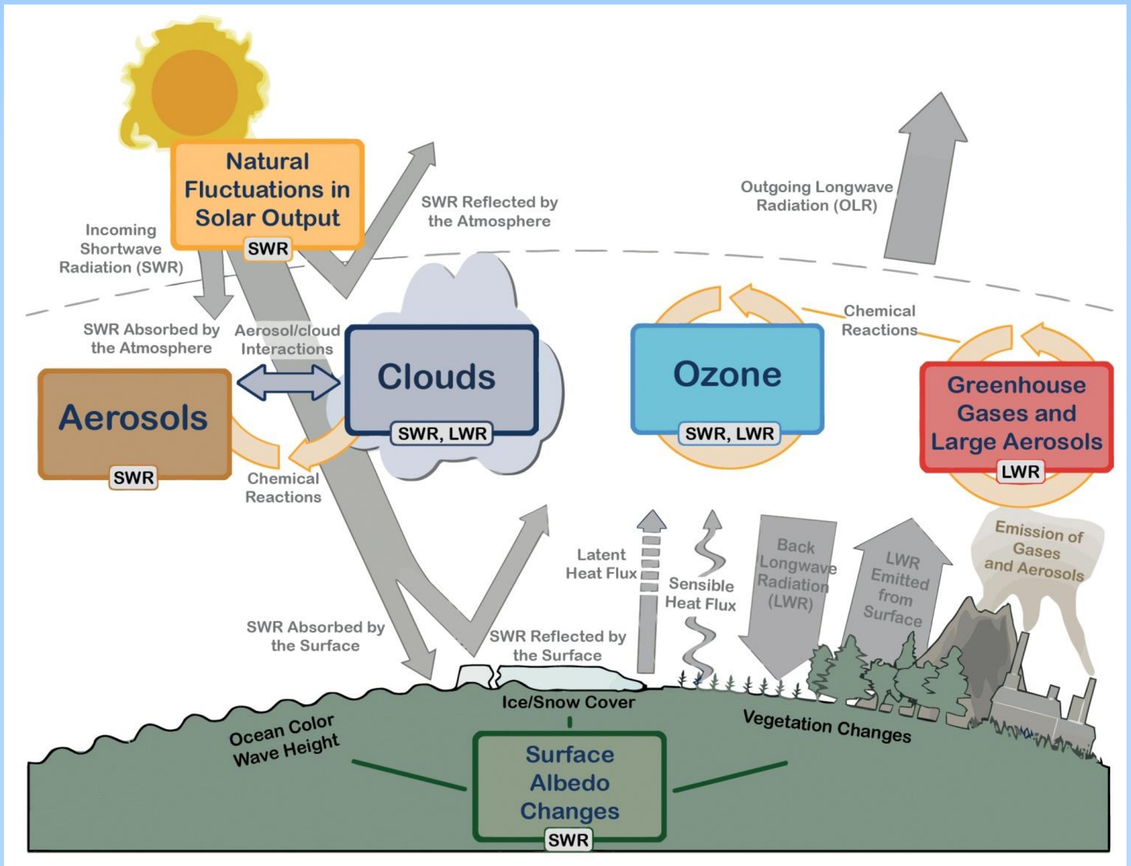
Global Climate Models (GCMs): many processes…

Boundary conditions
(exogenous variables)

vs

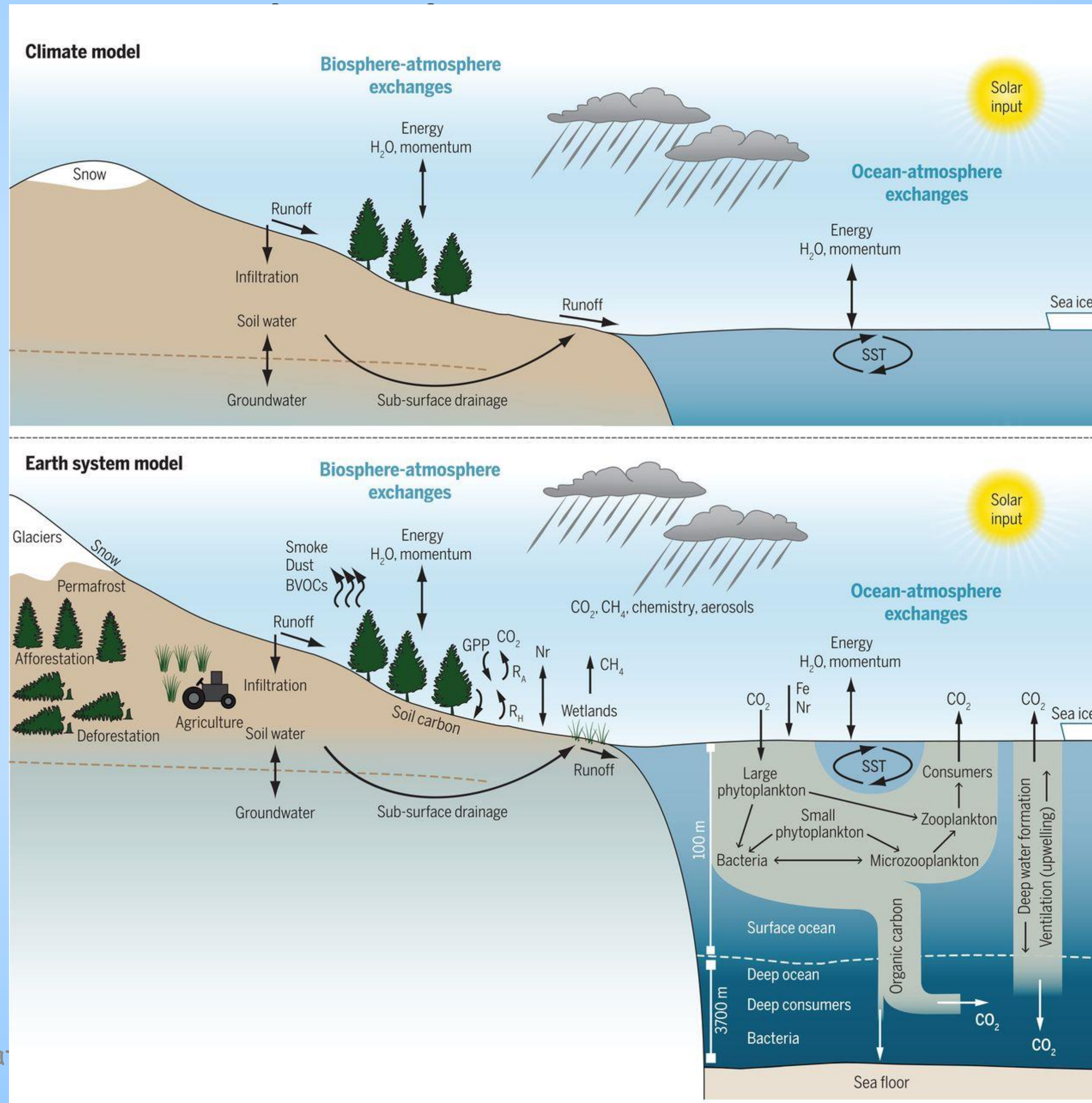
modeled processes
(endogenous variables)



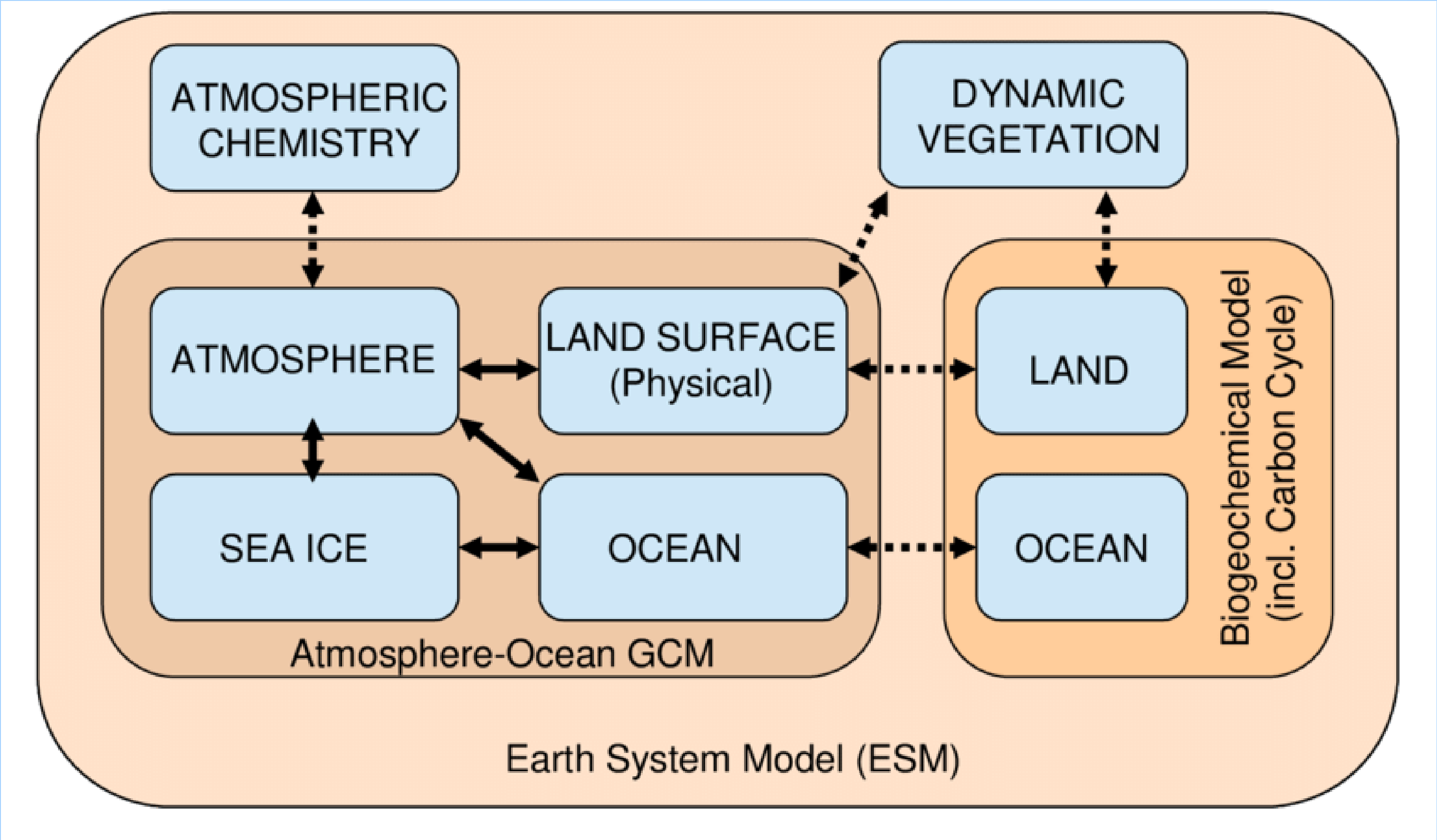


Main drivers of climate change. The radiative balance between incoming solar shortwave radiation (SWR) and outgoing longwave radiation (OLR) is influenced by global climate 'drivers'.
Natural fluctuations in solar output (solar cycles) can cause changes in the energy balance (through fluctuations of incoming SWR)
Human activity changes the emissions of gases and aerosols, which are involved in atmospheric chemical reactions, resulting in modified O3 and aerosol amounts. O3 and aerosol particles absorb, scatter and reflect SWR, changing the energy balance. Some aerosols act as cloud condensation nuclei modifying the properties of cloud droplets and possibly affecting precipitation (Section 7.4). Because cloud interactions with SWR and LWR are large, small changes in the properties of clouds have important implications for the radiative budget (Section 7.4). Anthropogenic changes in GHGs (e.g., CO2, CH4, N2O, O3, CFCs) and large aerosols (>2.5 µm in size) modify the amount of outgoing LWR by absorbing outgoing LWR and re-emitting less energy at a lower temperature (Section 2.2). Surface albedo is changed by changes in vegetation or land surface properties, snow or ice cover and ocean colour (Section 2.3). These changes are driven by natural seasonal and diurnal changes (e.g., snow cover), as well as human influence (e.g., changes in vegetation types) (Forster et al., 2007).

Representation of the biosphere in Earth system models



Earth Systems. Within the boundary of the Earth, the five interdependent "spheres"
the **atmosphere,**
the **cryosphere**
the **hydrosphere**,
the **lithosphere**,
the **biosphere**,



AOGCMs represent the climate system's physical components. An Earth System Model (ESM) closes the carbon cycle.

Feedbacks

There are many important feedbacks in the climate system that can either amplify (positive feedback) or dampen (negative feedback) forcings

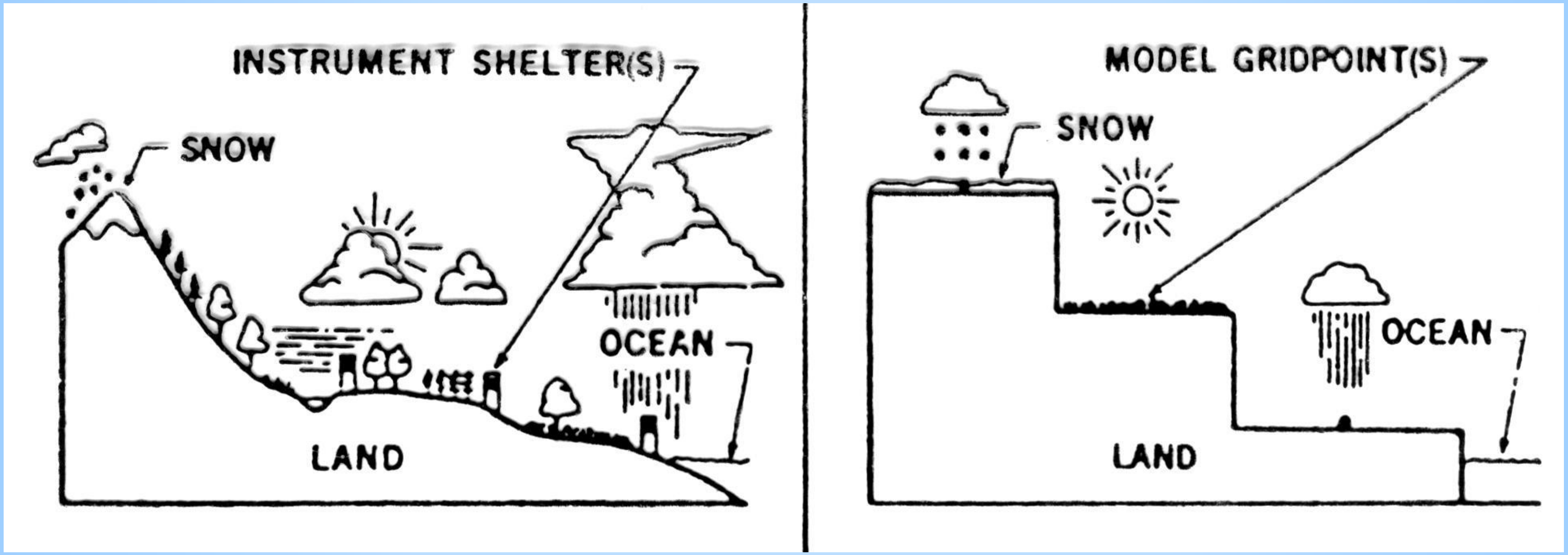
e.g. **Initial perturbation = temperature increases**

- **+ Water vapour** – a warmer atmosphere holds more water, which is a greenhouse gas
- **+ Ice albedo** – a warmer atmosphere has less ice cover, and reduces albedo
- **+/- Clouds** – a more cloudy atmosphere tends to be warmer at night, but cooler during the day. Cloud height is also important

Uncertainties in feedbacks lead to uncertainties in future predictions – currently one of the main sources of uncertainty

what we see what the model sees

Real World vs. Model World



Model Intercomparison Projects (MIPs)

AMIP: The first Atmospheric Model Intercomparison Project, using specified sea surface temperatures, and running from 1979 through 1988.

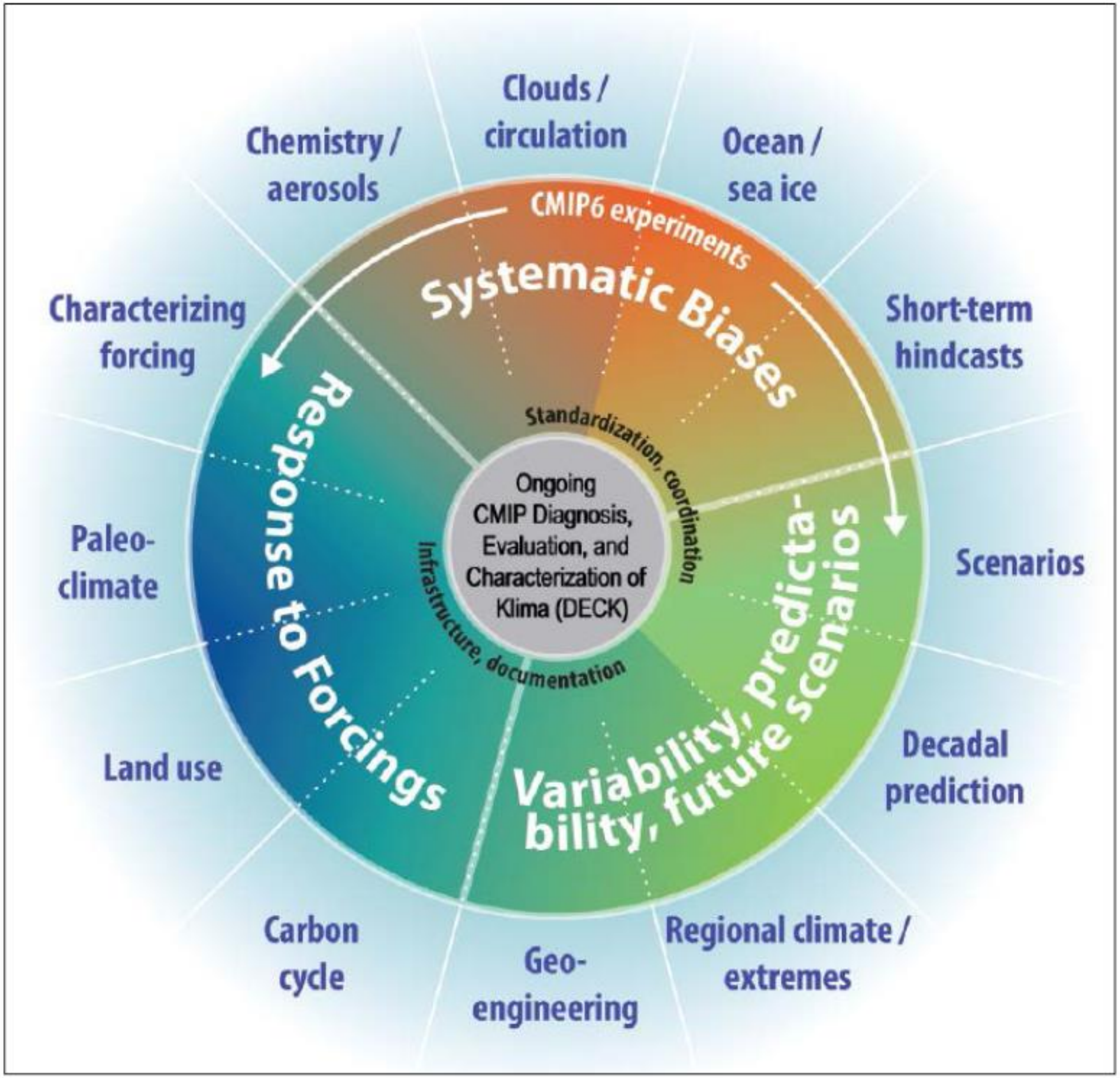
CMIP (Coupled Model Intercomparison Project)

CMIP3 used for **IPCC AR4** and **CMIP5** used for **AR5**.

CMIP6 is now used for **AR6**.

There are also MIPs for just parts of the climate system
https://www.wcrp-climate.org/wgcm-cmip

Climate Model Intercomparison Project 6 (CMIP6) design



Meehl, G. A., R. Moss, K. E. Taylor, V. Eyring, R. J. Stouffer, S. Bony and B. Stevens, 2014: Climate model intercomparisons: Preparing for the next phase, *Eos*, **95**, 77-78, doi:10.1002/2014EO090001.

Model Intercomparison Projects (MIPs)

All find that models are different from each other and different from observations, so why perform intercomparisons?

- models are tested in a controlled regime, and modelers find errors in models when comparing to observations
- estimation of range of confidence or uncertainty in models
- identification of outliers
- development and dissemination of data sets that can be useful to all

Results show that:

- no one model is best at everything
- no one test evaluates all aspects of models
- after excluding outliers with serious errors, the model consensus outperforms any individual model

But what do models need to perform simulations?
How do they actually work?

Modeling Climate Response

Ultimate purpose of a model

To identify the response of the climate system to changes in the parameters and processes that control the state of the system

Climate response occurs in order to **restore equilibrium** within the climate system

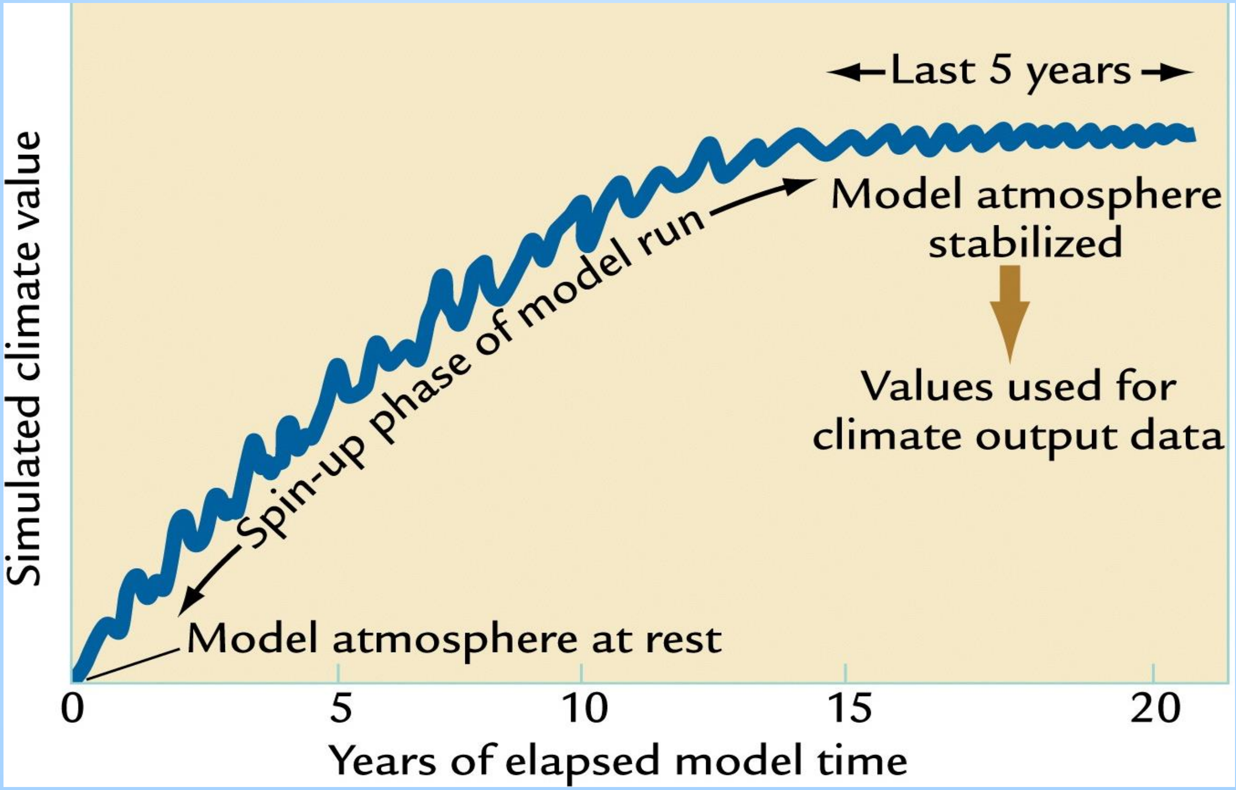
If radiative forcing associated with an increase in atmospheric CO_2 perturbs the climate system, then…

The model will assess how the climate system responds to this perturbation to restore equilibrium

Model Equilibrium

Models may require many years of simulations to reach equilibrium

– Final years of simulation averaged



GCM Experiments-some useful terms

Typically, experiments are performed using GCMs to estimate the effect of changing boundary conditions (e.g. increasing GHGs, or other forcing agents) on climate.

- **Control Run:** Model experiment simulating present climate conditions using *present GHG concentrations-forcings* (e.g. CO_2)
- **Equilibrium experiments:** Model experiment simulating the climate *under changed conditions* by changing the concentrations of GHGs (or forcings) to values predicted for the future (e.g. $2xCO_2$)
- **Transient Experiments:** Model experiment simulating *the gradual change from present to future* over the years(e.g. increase in CO_2 by 1% per year)
- **Timeslice experiments:** simulation of two separate slices of time, e.g. one for the present and one for the future, or one for solar maximum and one for solar minimum conditions; time between is skipped

GCM Experiments - Resolution & subgrid scale processes

- **Resolution:** The larger the grids, the less realistic the model; typically ~1^0x1^0 (lat x lon)

  Big grid boxes = **low** resolution

  Small grid boxes = **high** resolution

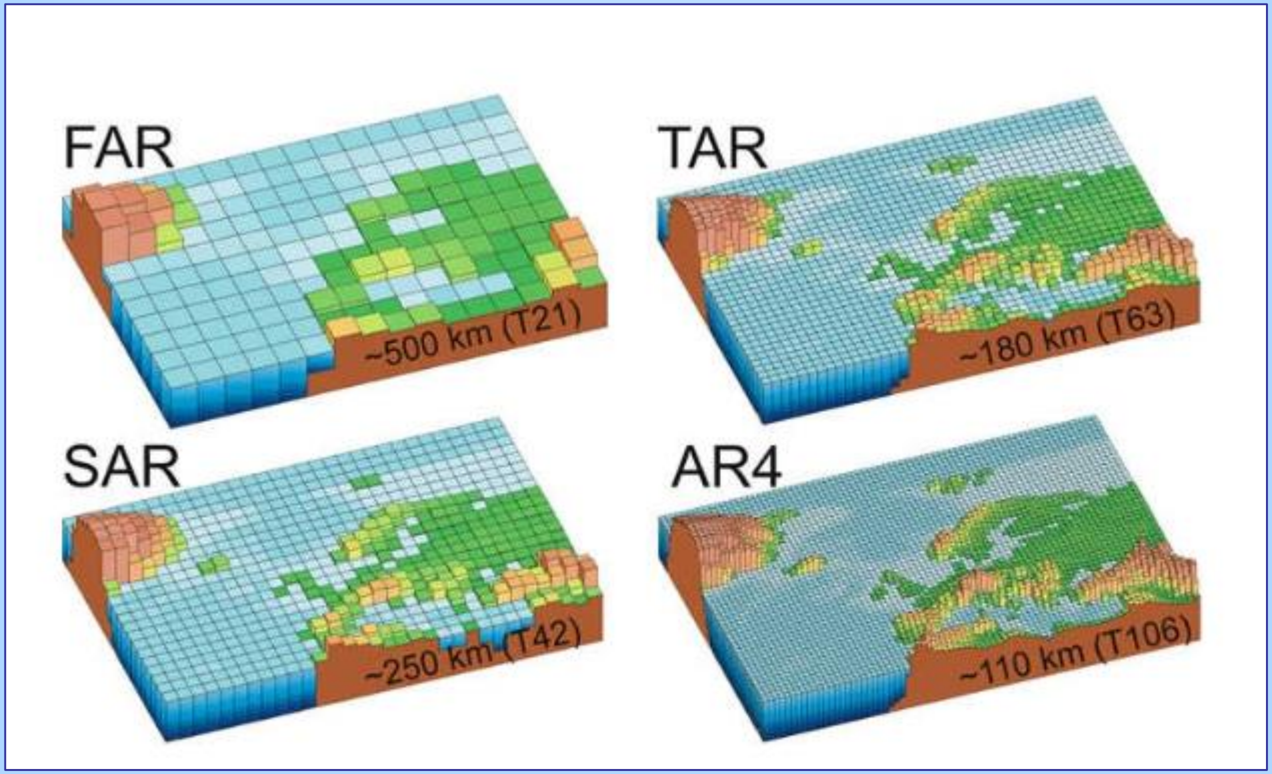
- **Subgrid-scale processes:** important physical processes may occur on very small spatial scales (e.g. cloud formation). Since the model resolution is much larger, these processes can not be physically modeled, so we use
- **Parameterization:** is a simple method, usually a statistical model, to account for subgrid-scale processes for which the physically-based equations can not be included.

GCM Experiments - Resolution & subgrid scale processes

- One of the most important and difficult climate elements to parameterize is **cloudiness**. Clouds have a *much smaller spatial and temporal scale* than a typical GCM grid box.
- Usually, we consider separately 2 types of clouds:
  - **layer clouds**
  - **convective clouds.**
- There is no fundamental prognostic equation for clouds (no conservation of clouds principle); rather *they form when condensation takes place and dissipate due to precipitation and evaporation*

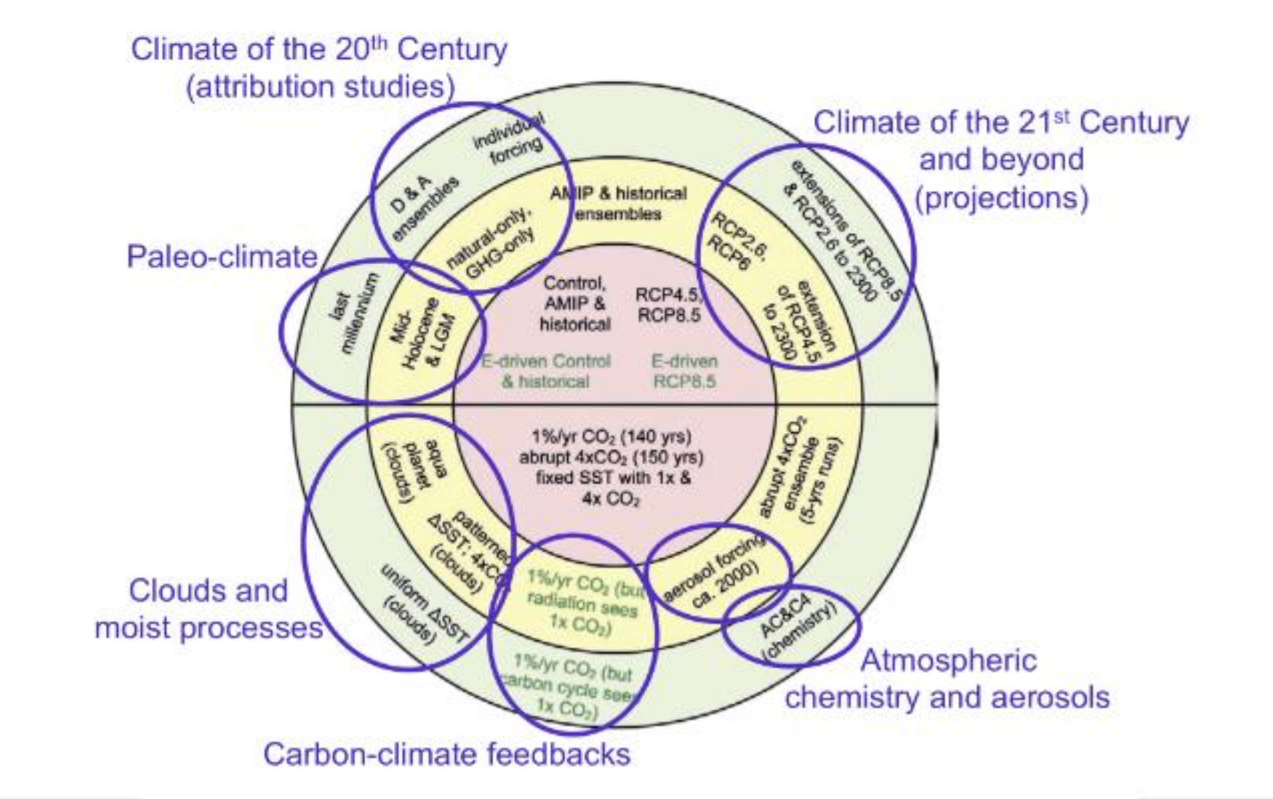
Steps to perform an experiment

1. Configure the model



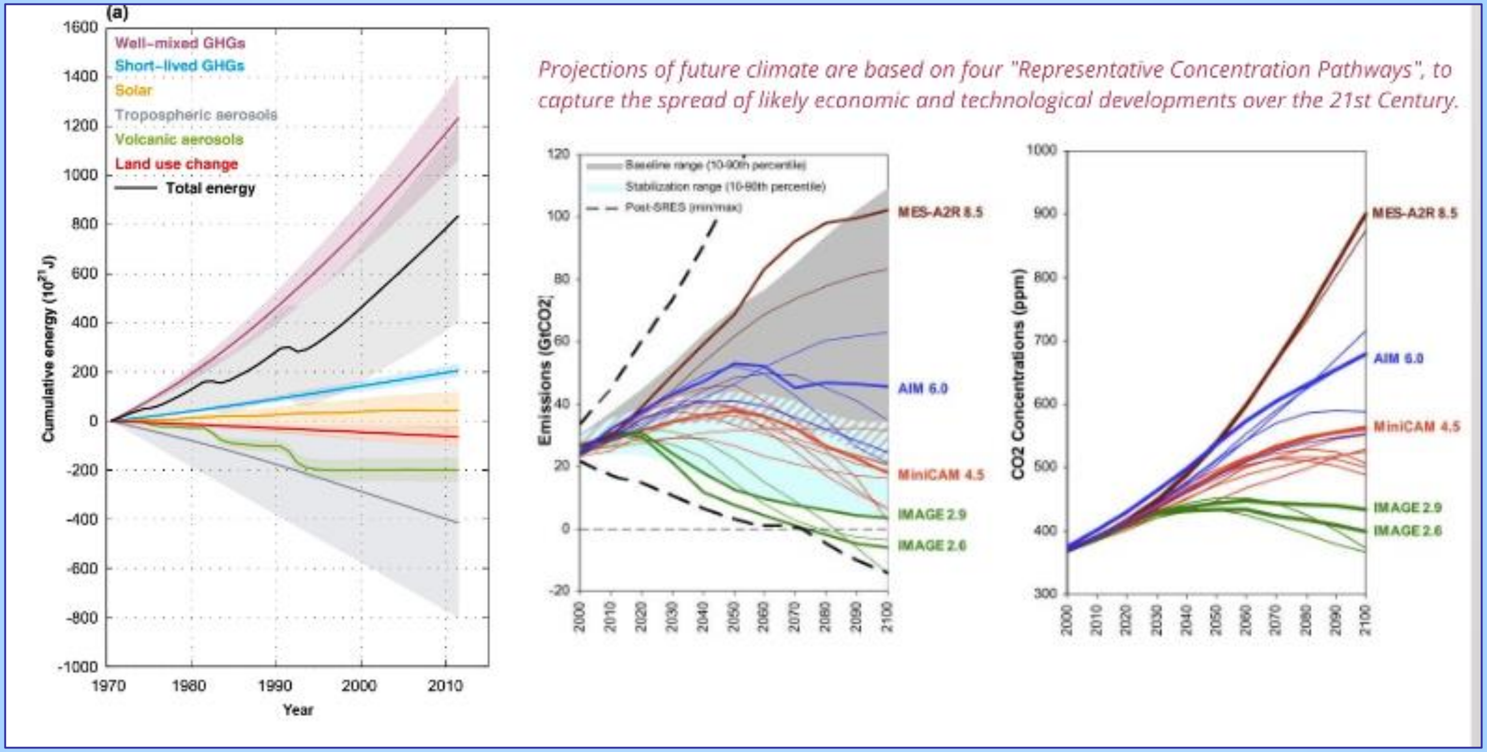
Steps to perform an experiment

2. Choose your experiment



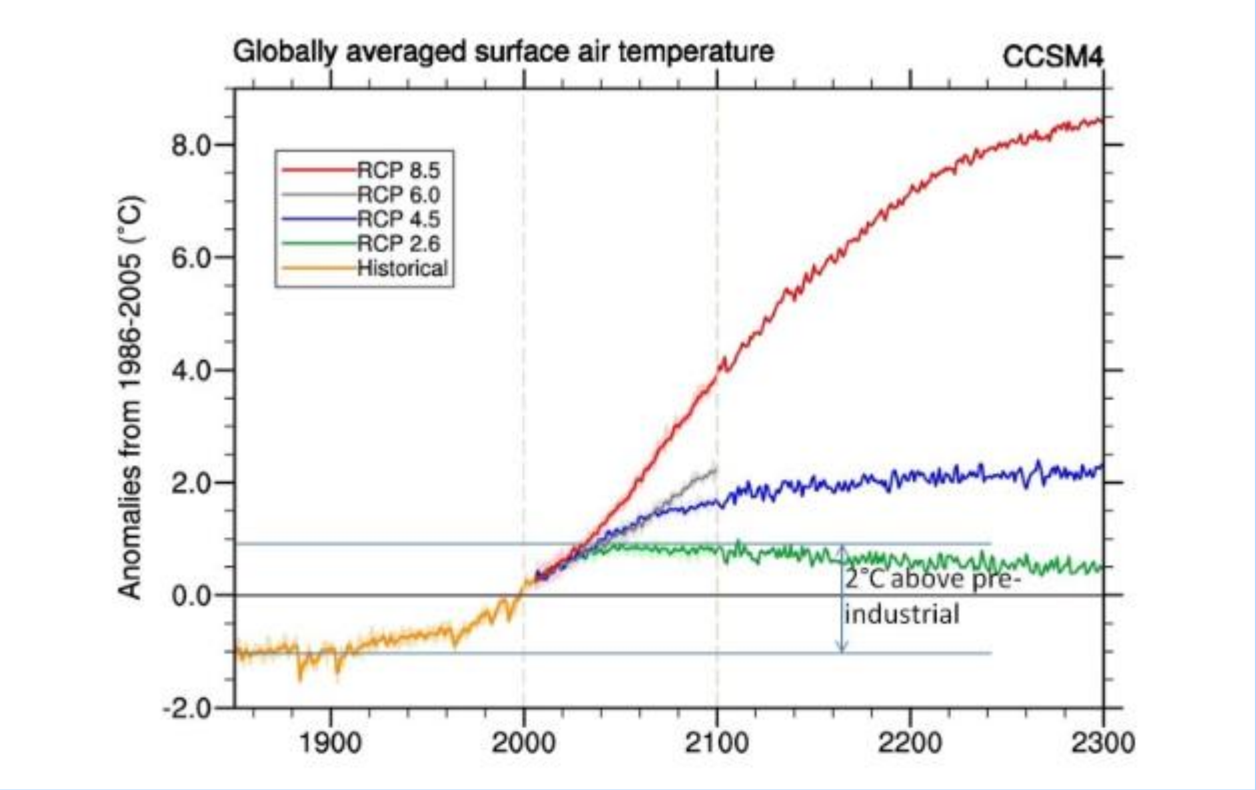
Steps to perform an experiment

3. Set the forcings



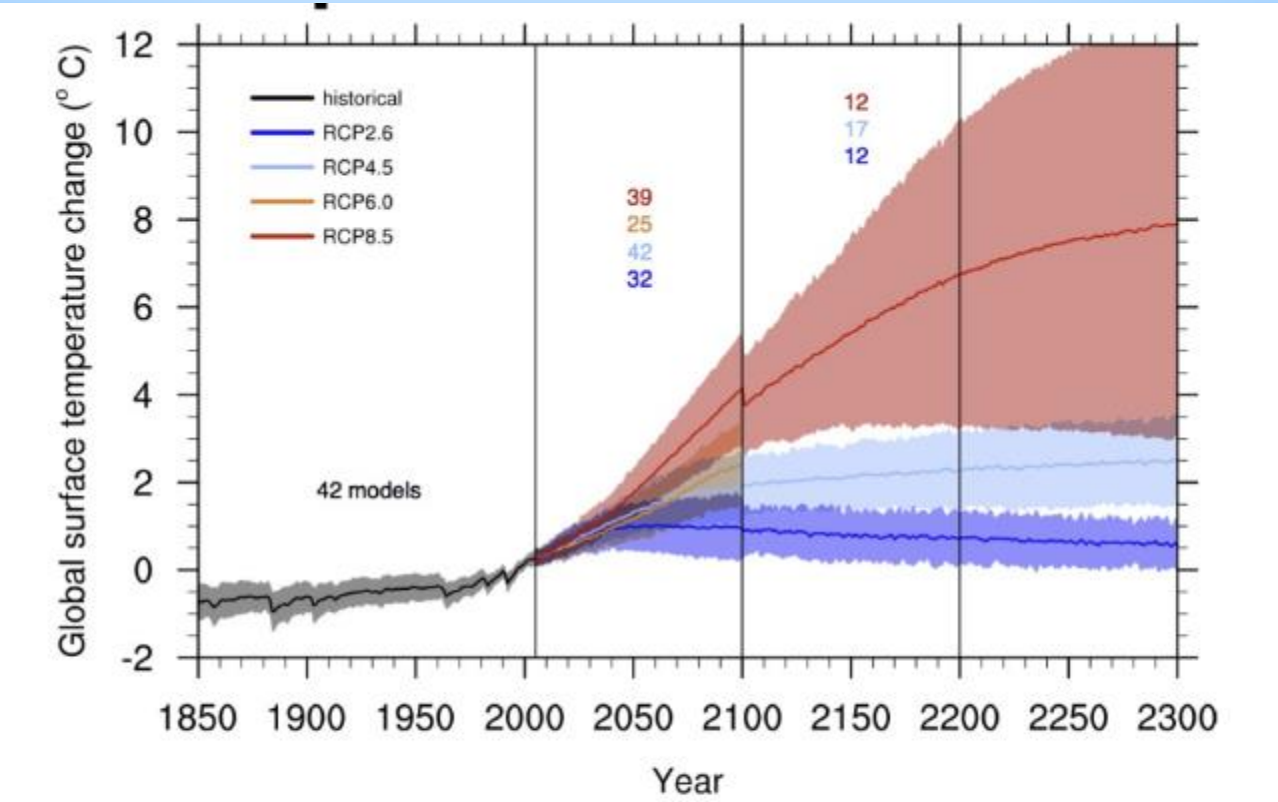
Steps to perform an experiment

4. Analyze the results



Steps to perform an experiment

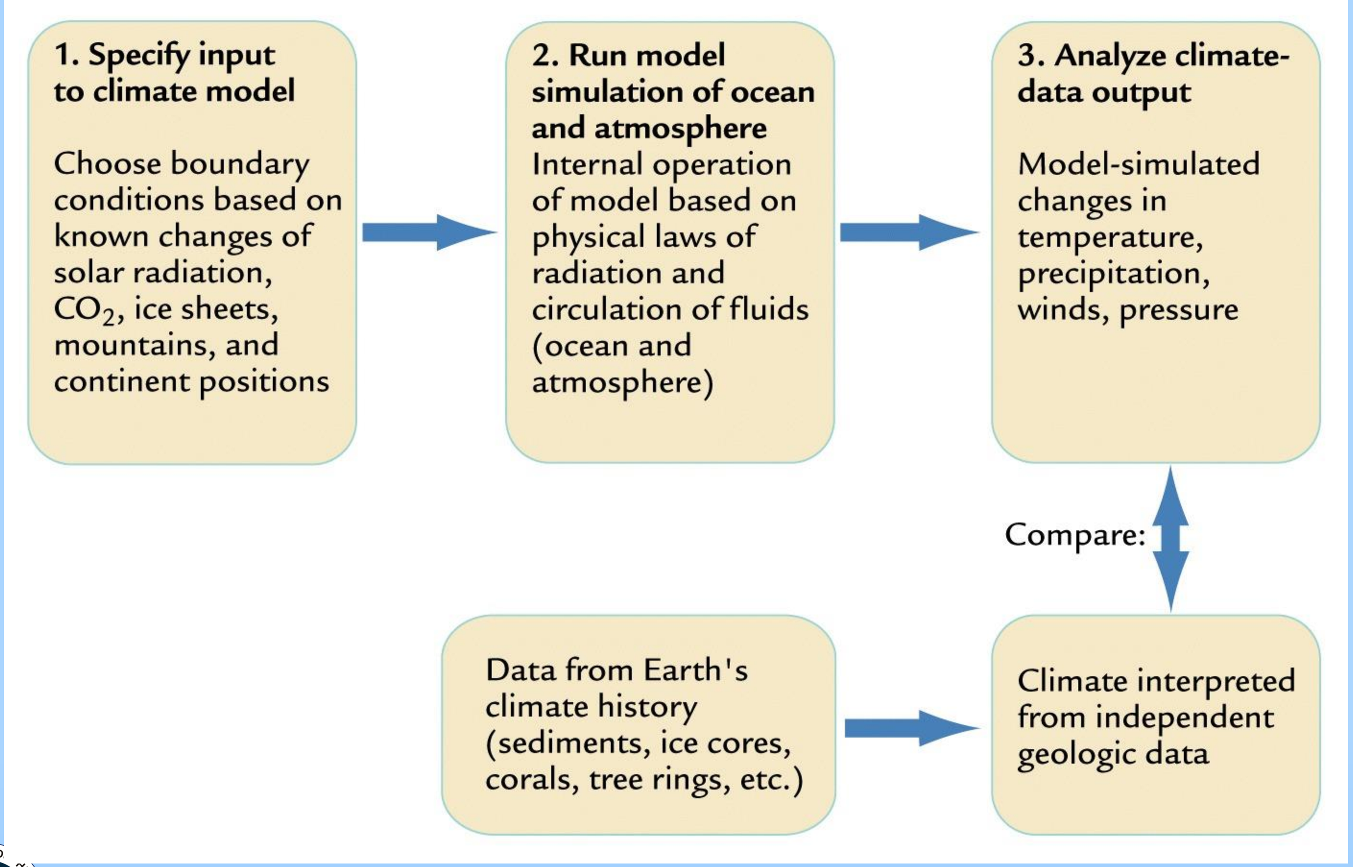
5. Compare with other models



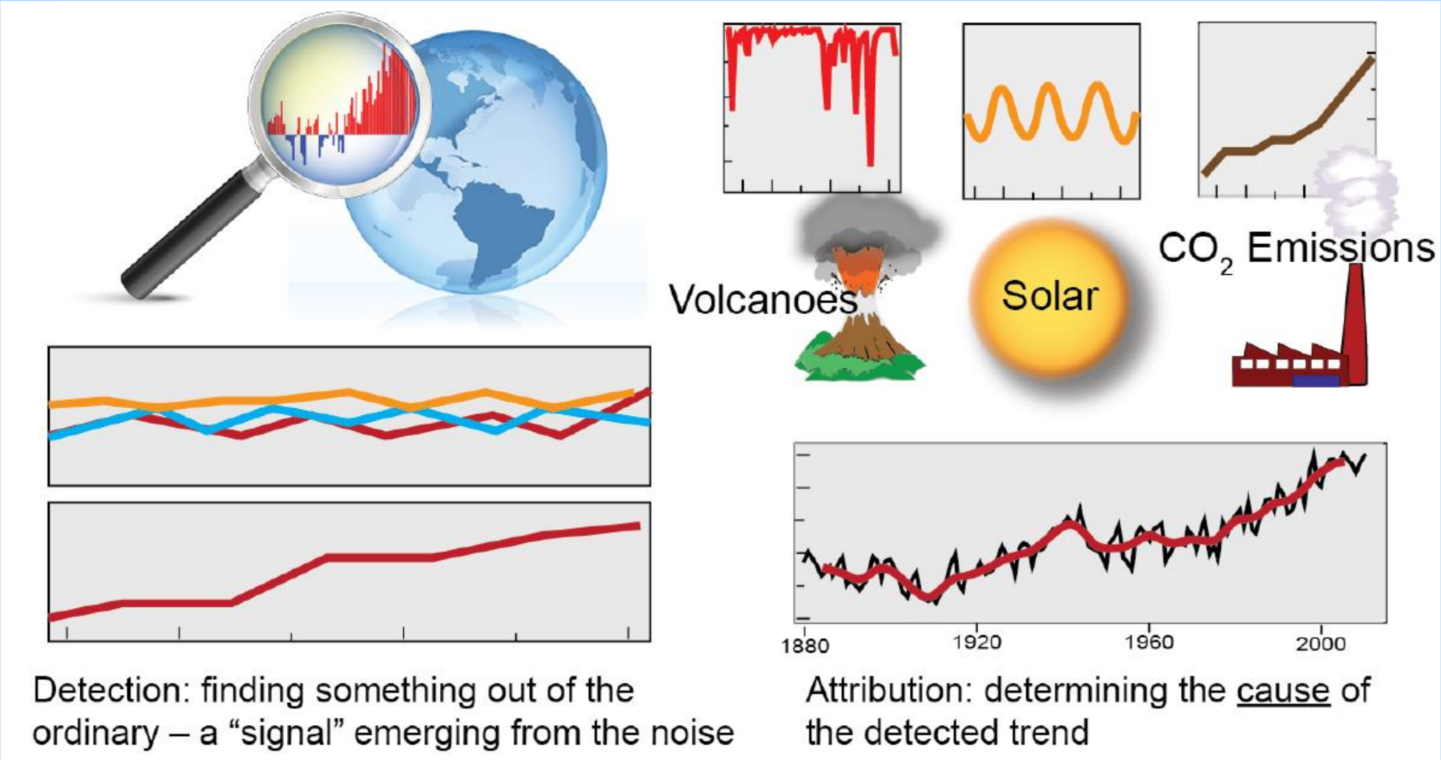
Data-Model Comparisons (historical, modern)

Model validation (evaluation)

- Models constructed to simulate Modern circulation
  - Changes based on Earth History inserted in model
  - Climate output compared with observations



Detection and Attribution as Forensics

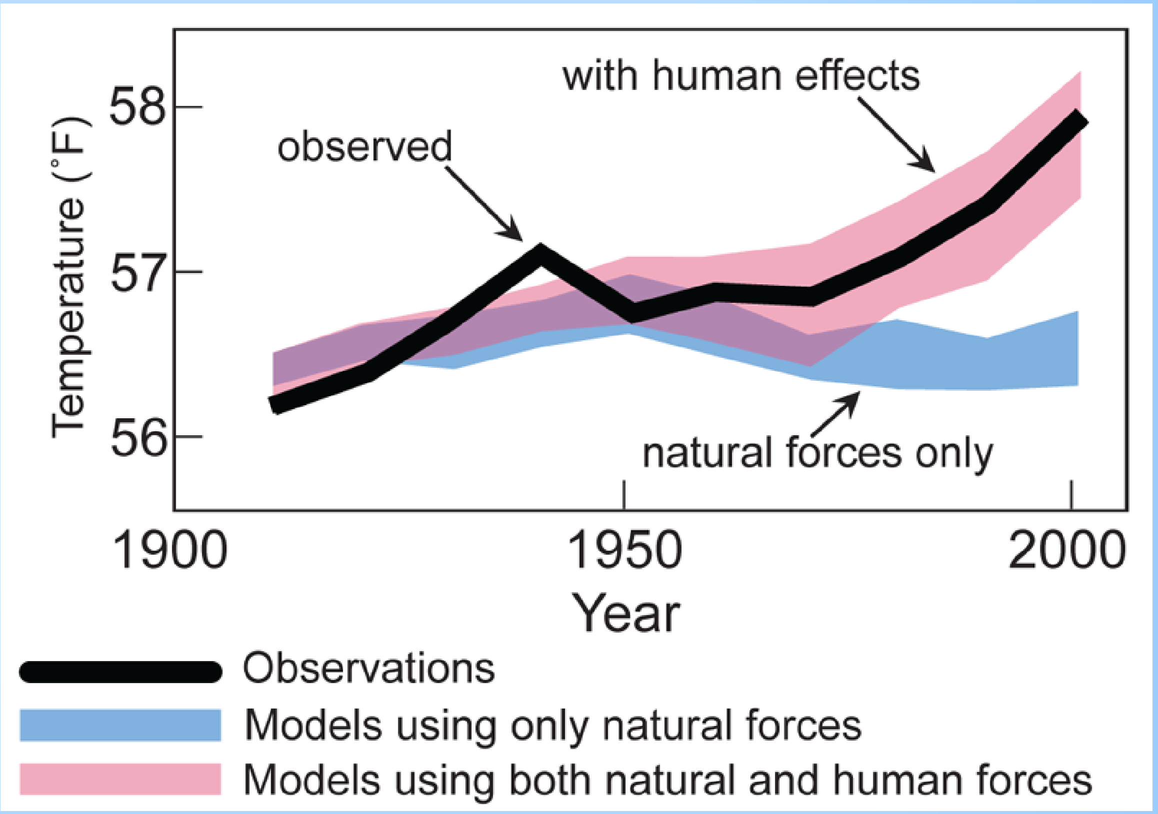


Simplified image of the methodology that goes into detection and attribution of climate changes. The natural factors considered usually include changes in the sun's output and volcanic eruptions, as well as natural modes of variability such as El Niño and La Niña. Human factors include the emissions of heat-trapping gases and particles as well as clearing of forests and other land-use changes. *(Figure source: NOAA NCDC / CICS-NC).*

Understanding and Attributing Climate Change

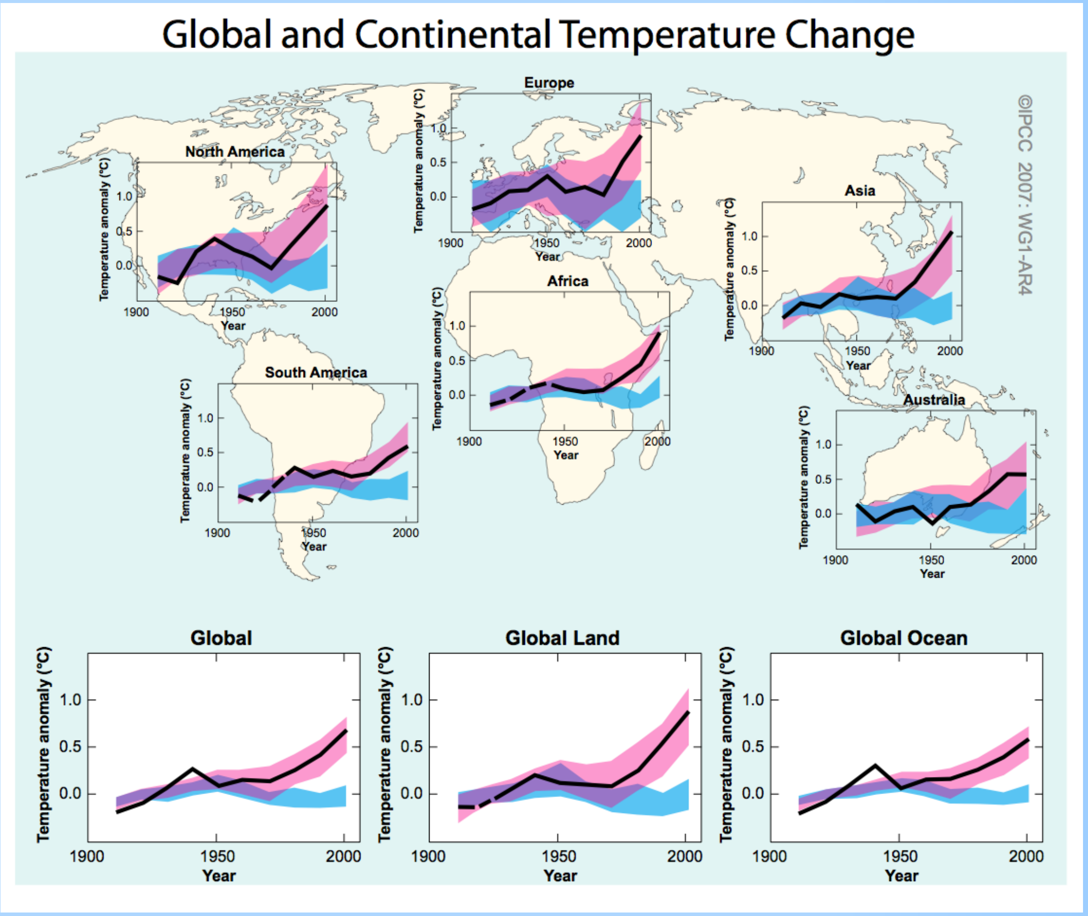
observed changes are:

- **consistent with expected responses** to forcings
- **inconsistent with alternative** explanations



Understanding and Attributing Climate Change

Continental warming *likely* shows a significant anthropogenic contribution over the past 50 years



What About Uncertainty?

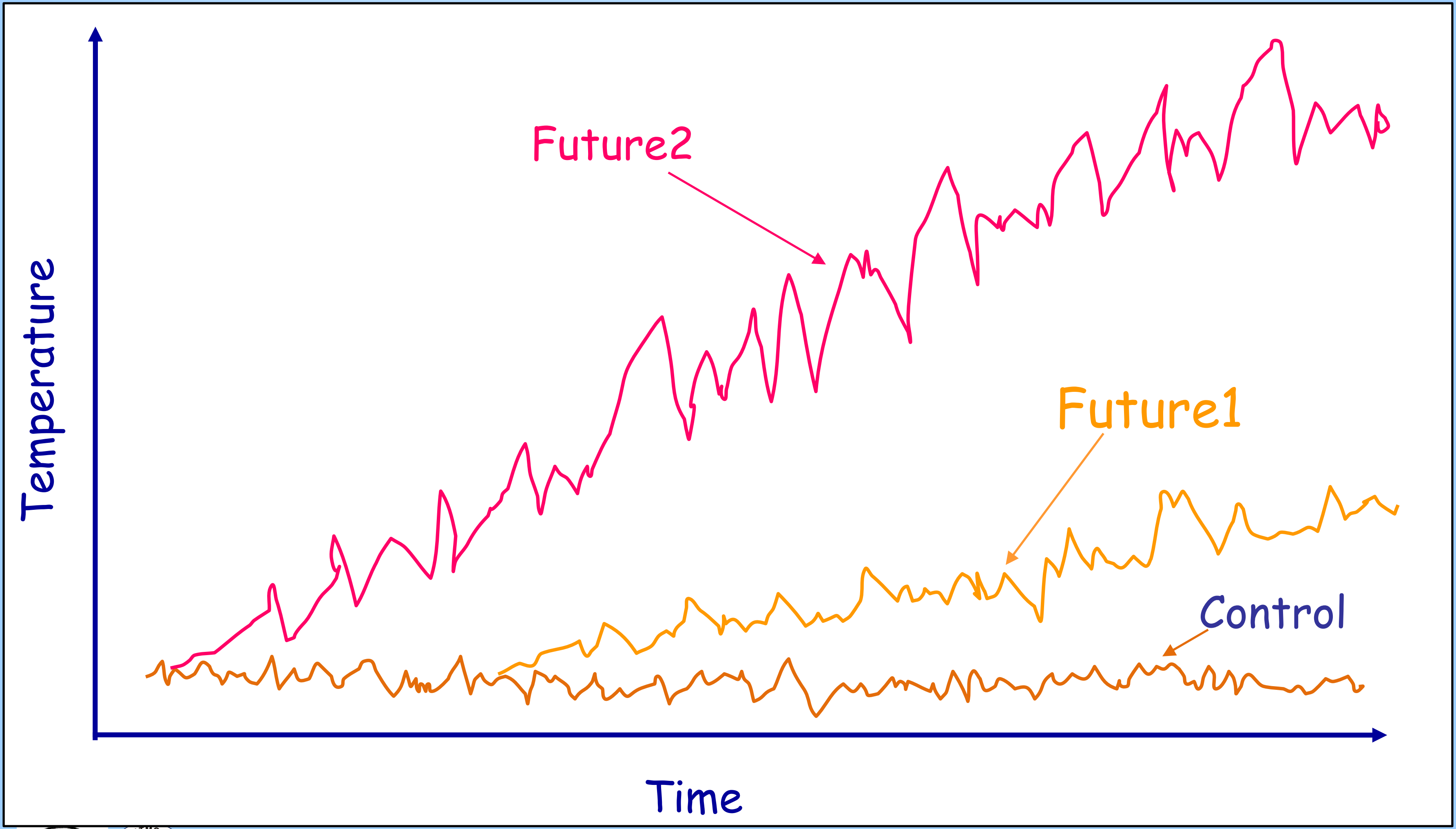
Uncertainties in climate projections arise from our lack of knowledge about future boundary conditions

- Lack of knowledge about physical factors
  - Volcanic activity
  - Solar activity
- Limited knowledge of anthopogenic factors (e.g. emission of greenhouse gases and aerosols, changes in land use)
  - Social and economical development
  - Technological progress
- Limited knowledge of feedbacks and system response
- Construction of future scenarios instead of forecasting the external factors affecting future climate

Dependency on Initial Conditions

- **Initial conditions:** the values of all "state variables" (e.g. temperature, pressure, etc) at each grid point must be specified in the beginning of a model experiment.
- The transient response of GCMs *can change when initial conditions are changed even slightly*. This is because the climate is ***a chaotic system.***
- **Ensemble experiments:** the same model experiment is performed a number of times with slightly different initial conditions; the results of the ensemble members are averaged to get the "ensemble mean"

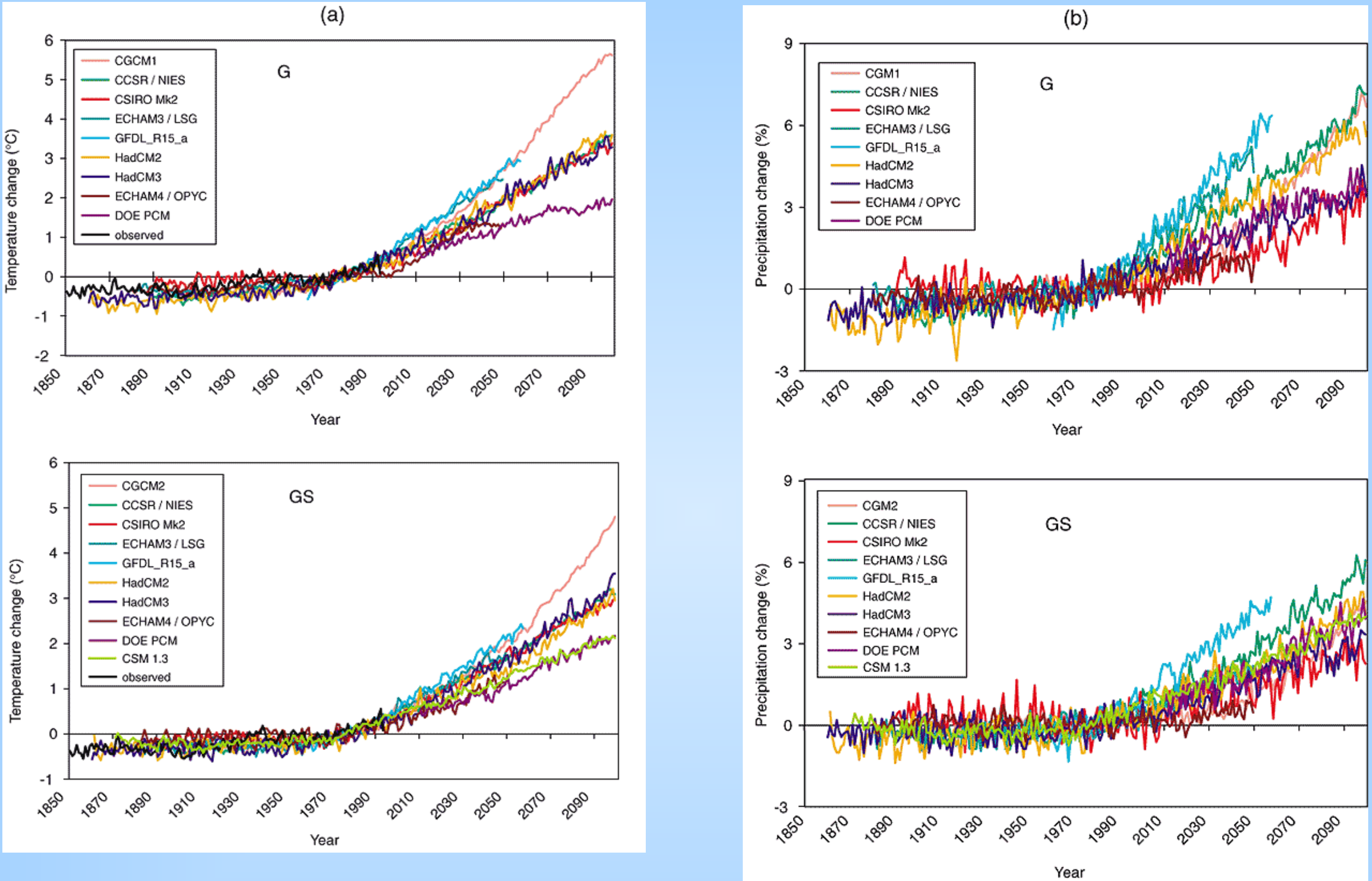
The climate can evolve differently, depending on the initial conditions



Why are the results from different models not identical?

- **Most GCMs** outputs have many similarities, so they give similar results
- **Differences between GCMs are mainly due to parameterization of processes:** somewhat different results.
- E.g. GCMs agree much **more closely on temperature than on precipitation:** **Temperature** changes are more dependent on **large scale processes**, which are modeled similarly in most models. **Precipitation** depends on **subgrid-scale** processes, which are parameterized differently by the different modeling groups.

Results from different models



Left: globally averaged *temperature change* relative to the years (1961 to 1990)
G: greenhouse gas only (top), GS: greenhouse gas and sulphate aerosols (bottom).
Right: *Precipitation changes* for the same set of models/experiments

Predicting future climate…

Due to **the internal variability** and to the **non-linearity** of the climatic system, along with the lack of knowledge of the **external factors affecting the future climate**, a numerical prediction of climate change is an estimation of certain probability among many other probable estimations about the future climate.

The purpose of performing future climatic simulations is **not the accurate prediction of the climate**, but rather

- **the sensitivity analysis of the climate for certain scenarios of development**
- **the reduction of uncertainties,** and
- the construction of a probability density function about future climate.

Summary (i) Modelling the Earth's Climate

We discussed **modeling of the Earth's Atmosphere-Ocean System** with physically based climate models of different complexities

We discussed some of the more common types, which have different levels of complexity:

Zero-dimensional radiation balance models

1-dimensional radiative-convective models

3-D Atmospheric General Circulation Models (AGCM)

3-D coupled atmosphere – ocean models (AOGCM)

We had a flavour of Earth System Models (ESMs)

Focusing on 3-D models, we discussed their governing physical laws and processes, resolution characteristics, their forcings and uncertainties of results.

Summary (ii) Modelling the Earth's Climate

Climate models are important tools to advance our understanding of current and past climate. They provide qualitative and quantitative information about potential future climate.

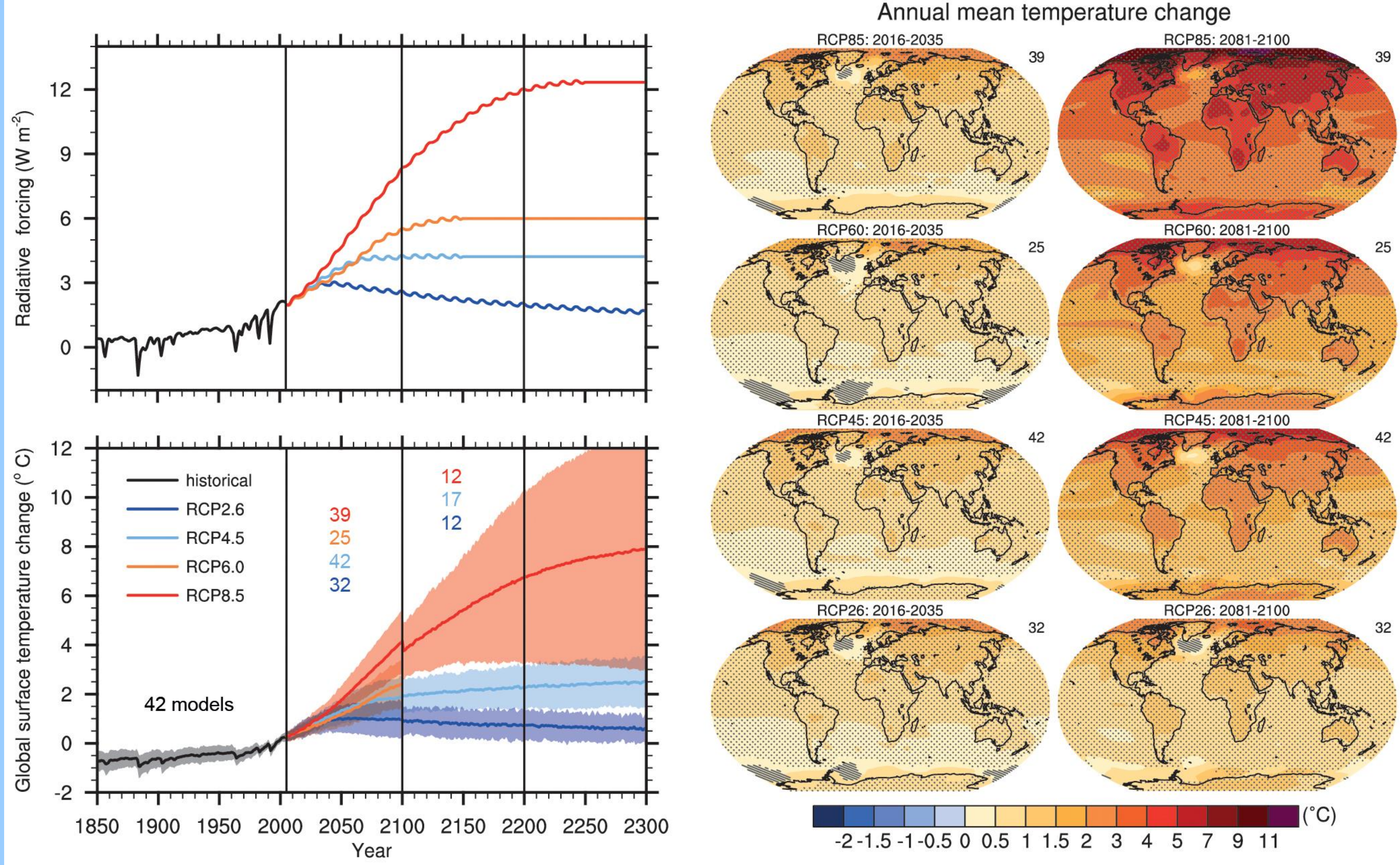
Climate models represent the main components of the climate system, with their interactions and feedbacks

Climate models have skills at simulating present-day climate, and also the trend over the 20th century

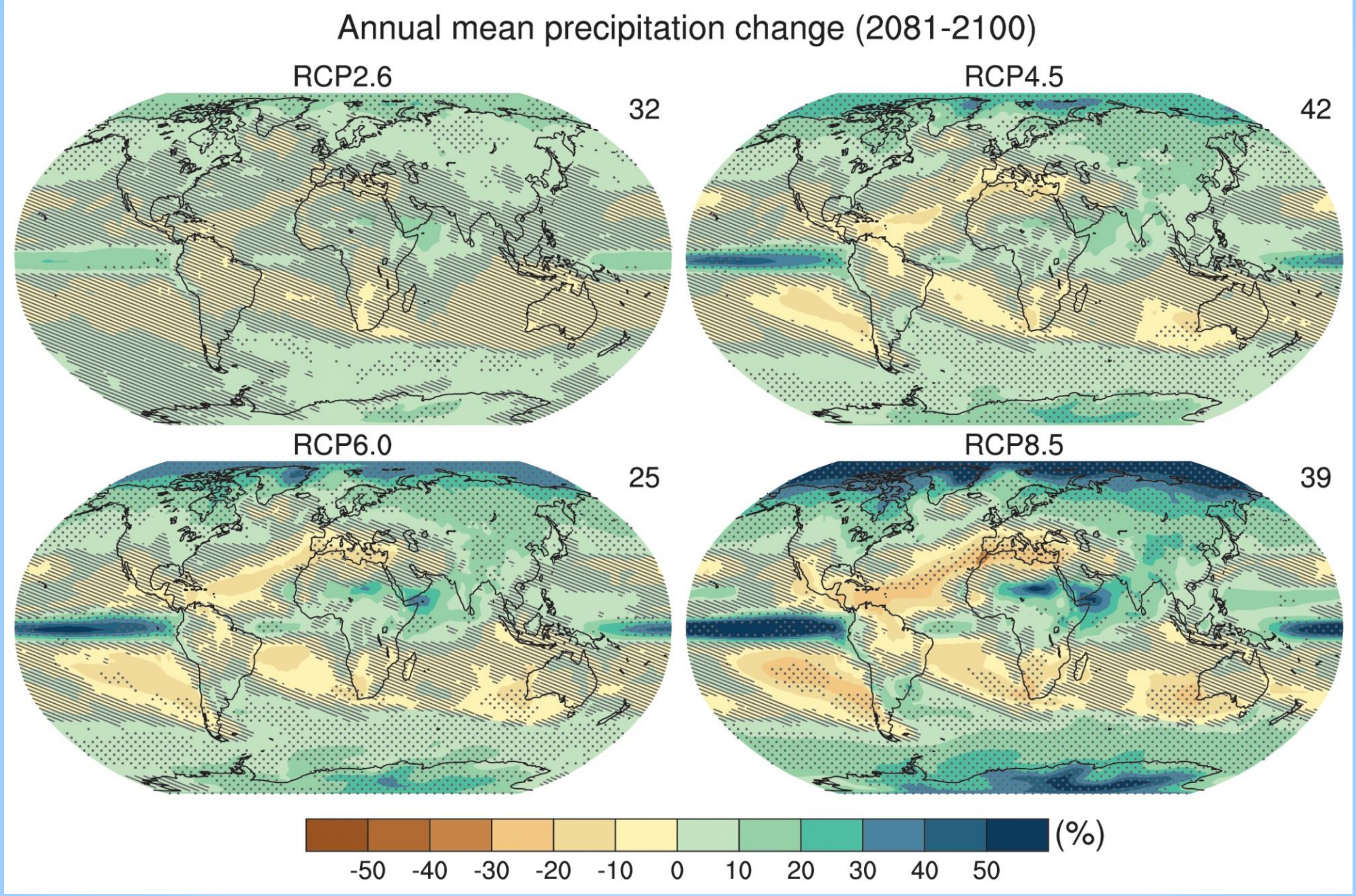
This gives us some confidence that they can predict the future.

Still, climate simulations for the future **do not aim at the accurate prediction of future climate**, but rather **to assess climate sensitivity and uncertainties** for certain scenarios of development and to **estimate the most probable evolution**

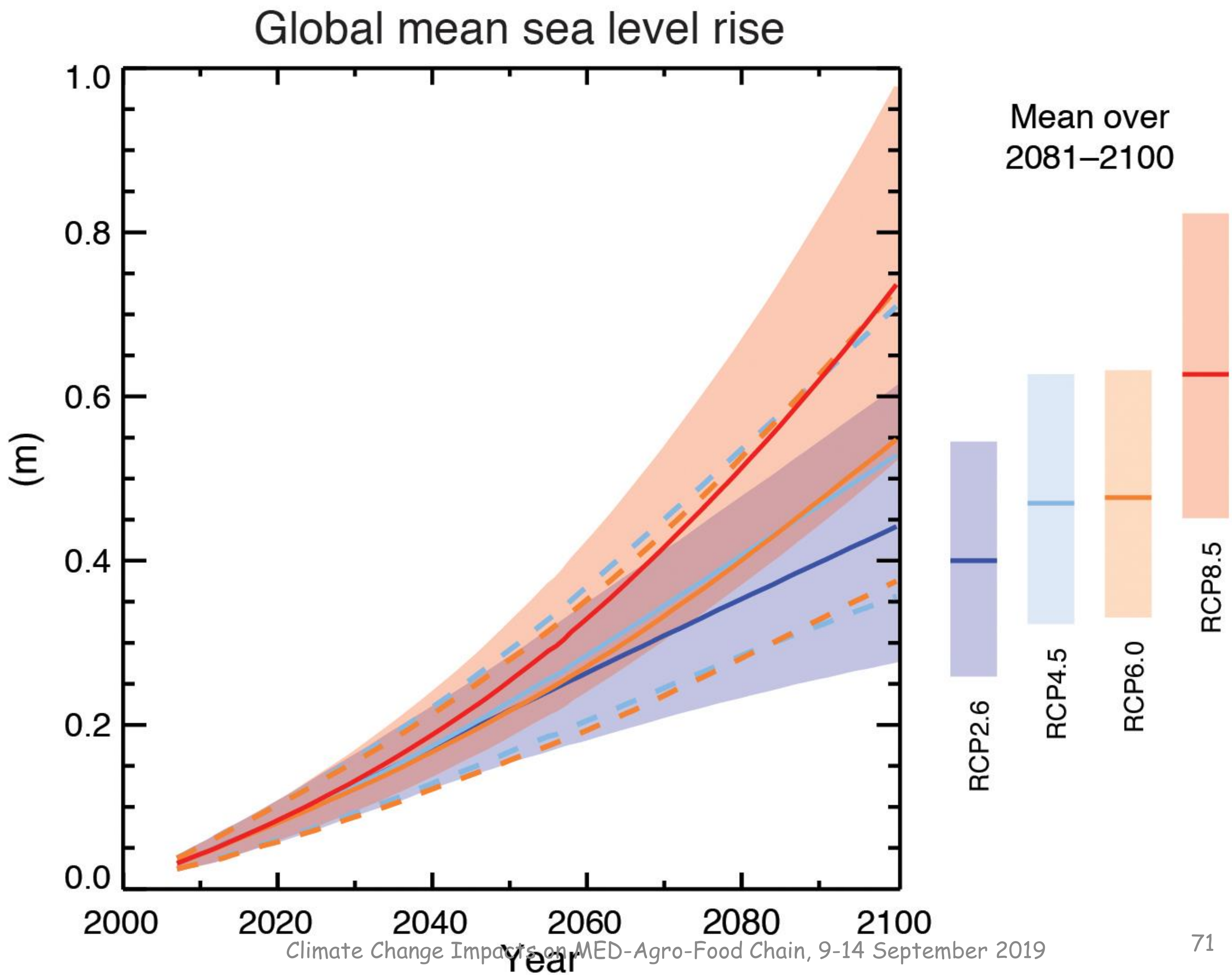
How about their output?



Top left: Global RF for 4 RCP scenarios according to the MAGICC model.
Bottom left: Estimates of global surface temperature change for 4 RCP scenarios from various AOGCMs. The shading indicates the range ± 1.64 X standard deviation (5-95%) of the distribution of the simulations from the individual models.
Right: Change in the surface temperature for early and late 21st century compared to 1986-2005.

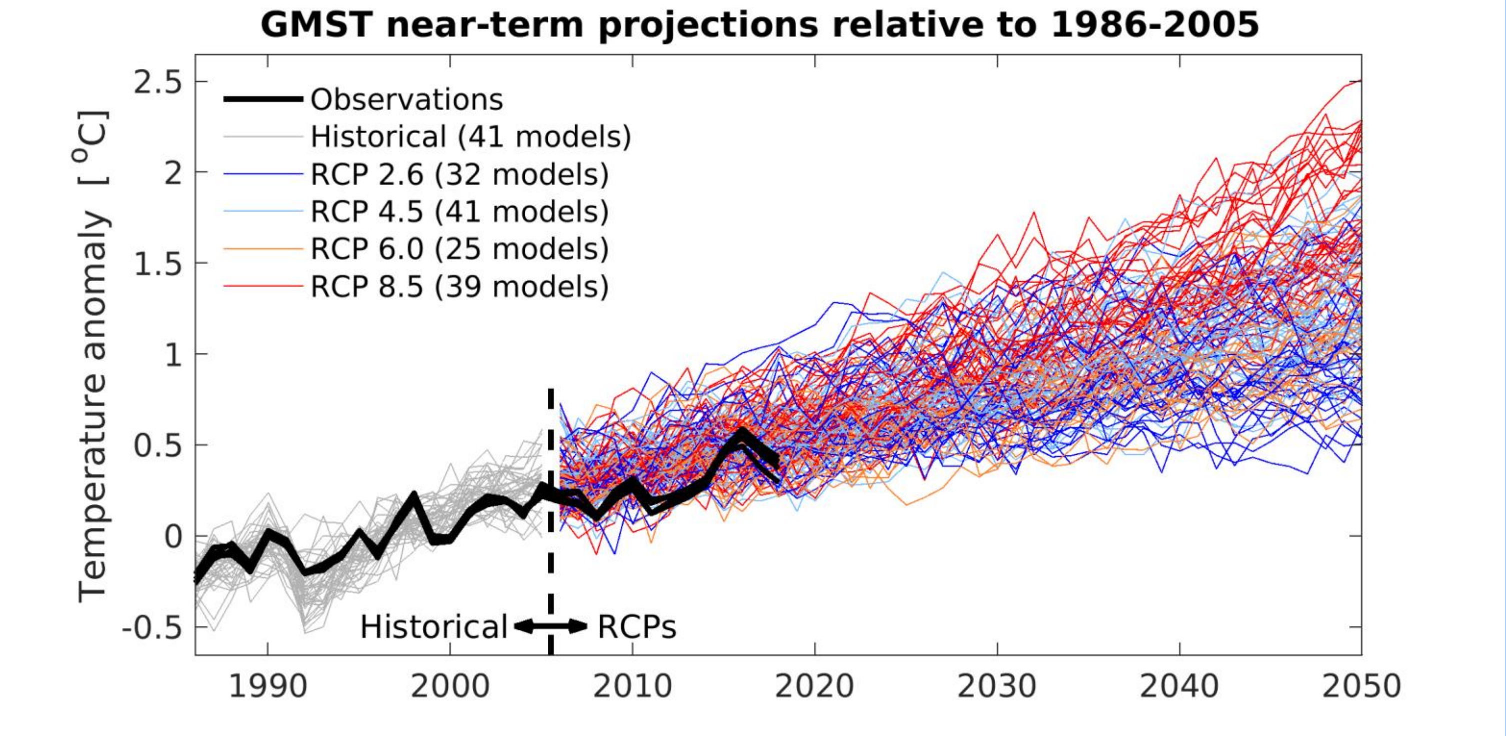


Relevant changes in rainfall (in percentage) for the period 2081-2100, for the period 1986-2005. Values are averages from several AOGCMs based on 4 RCP scenarios. The number of climatic CMIP5 used for each scenario is written in the top right corner of each figure. Shading indicates areas where the average of models is less than a standard deviation of internal variability. Punctuation indicates areas where the average of models is greater than two standard deviations of internal variability, and where 90% of models agree to the signal of change (IPCC 2013).



Global mean sea level rise
(m)
1.0
0.8
0.6
0.4
0.2
0.0
2000
2020
2040
2060
2080
2100
Year
Mean over
2081–2100
RCP2.6
RCP4.5
RCP6.0
RCP8.5

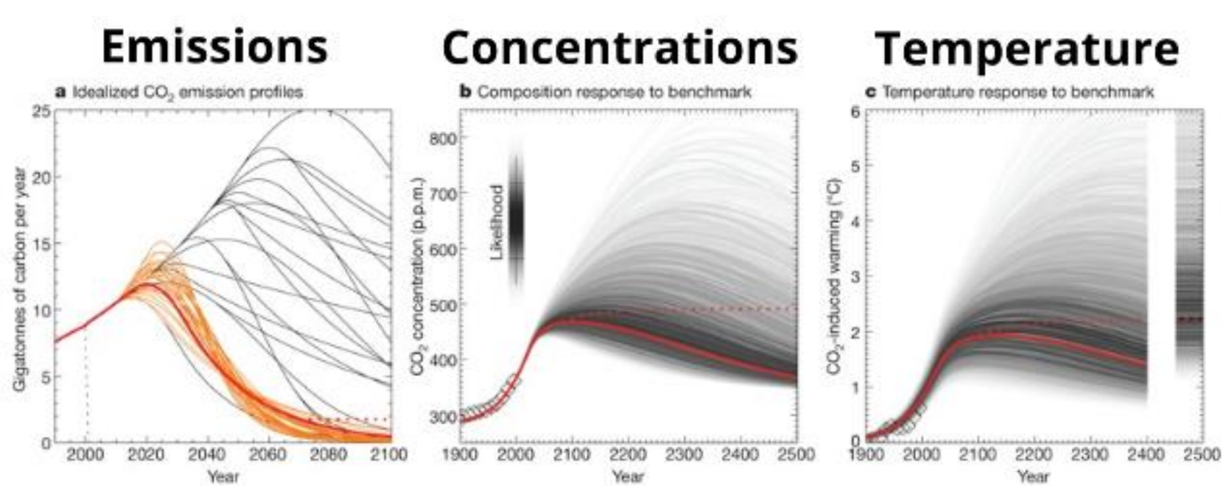
How about their output?



Updated version of IPCC AR5 Figure 11.25a, showing observations and the CMIP5 model projections relative to 1986-2005. The black lines represent observational datasets (HadCRUT4.6, Cowtan & Way, NASA GISTEMP, NOAA GlobalTemp, BEST)
Source: www.climate-Lab-book.ac.uk

To properly set the forcings, we need Scenarios

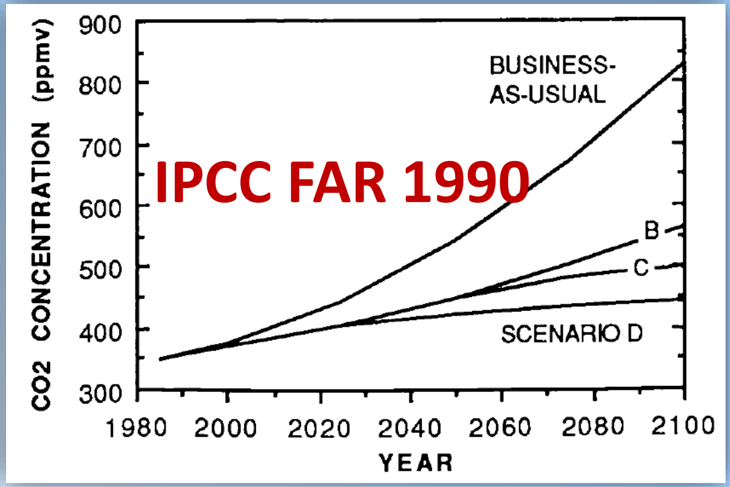
- The impacts of climate change on the environment and society will depend not only on the response of the Earth system but also on how humankind responds through changes in technology, economy, lifestyle and policy. These responses are uncertain, so future **scenarios** are used to explore the consequences of different options.
- A **scenario** is an image of a potential future based on **historical knowledge** and **assumptions of future change**.
- **IPCC scenarios** follow this route.

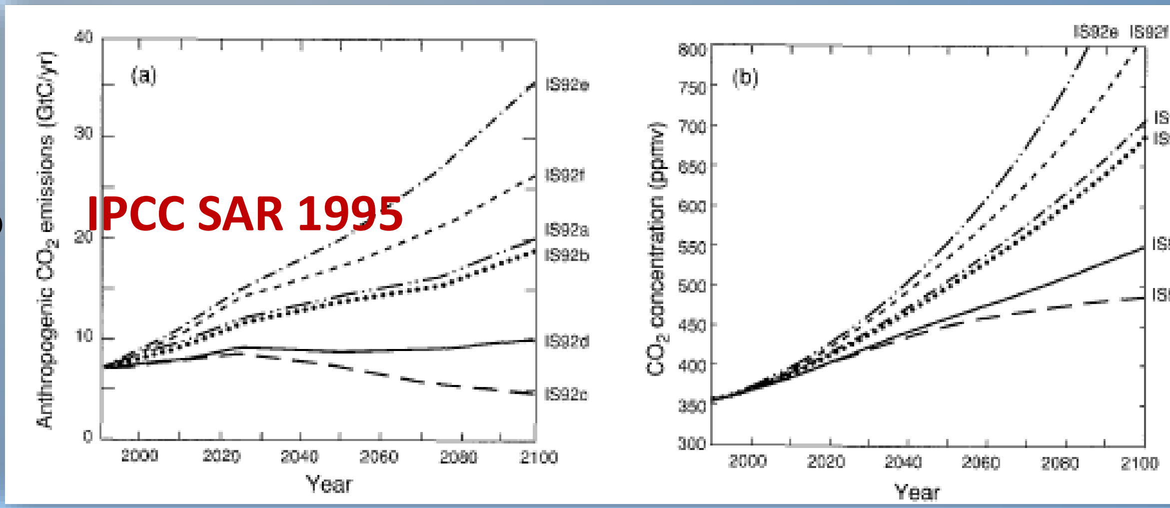


MR Allen et al. Nature 458, 1163-1166 (2009)

Scenario History – SA90 & IS92

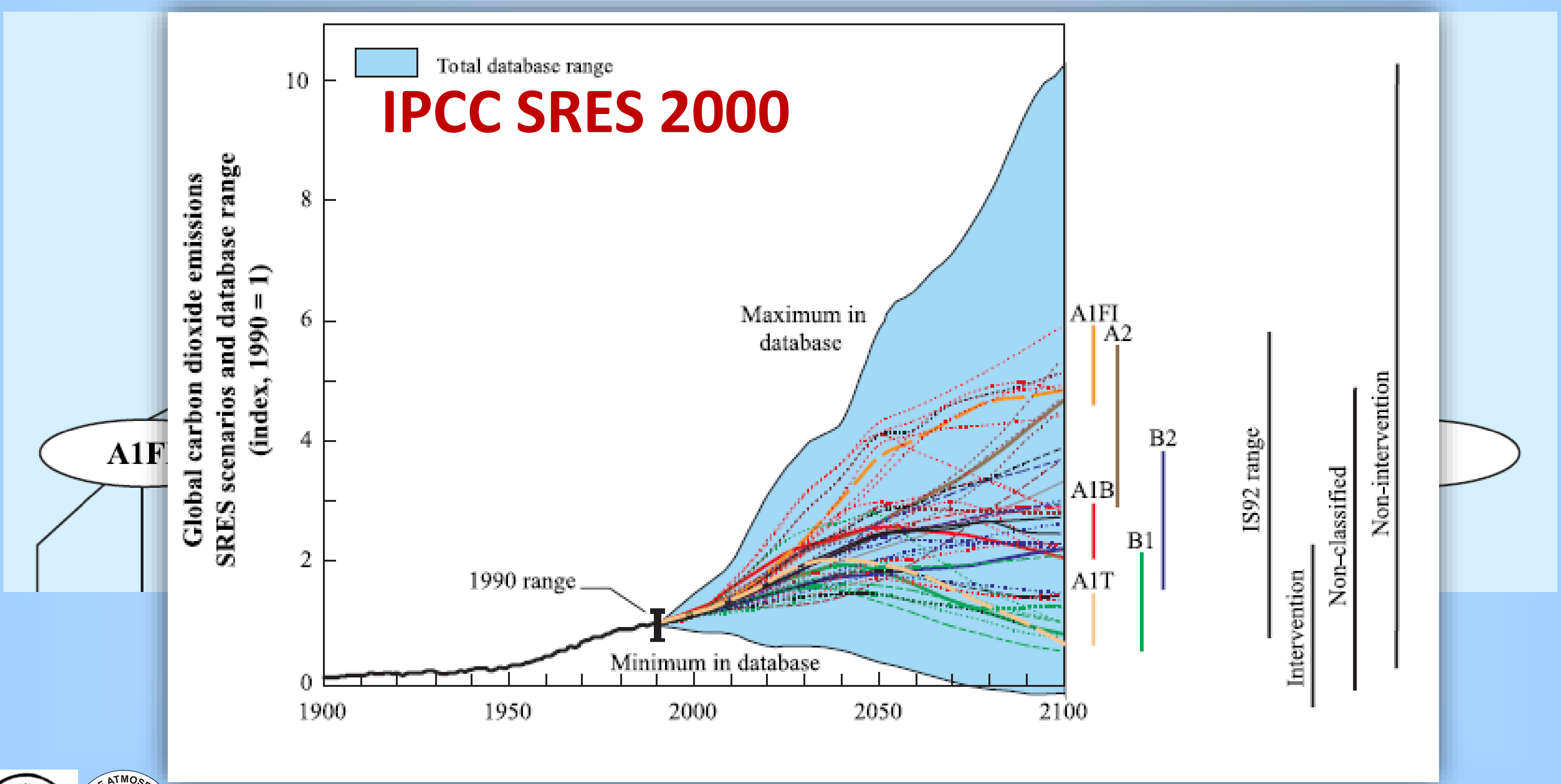
- A wide range of scenario families have informed the IPCC assessment reports over last decades:
- **IPCC First Assessment Report (FAR):** *four SA90 scenarios* (Business-As-Usual, B, C, D) until 2100, same assumptions for economy and population, only varying future energy mix, one non-intervention scenario.
- **IPCC Second Assessment Report (SAR):** *six IS92 scenarios* (IS92a to f) until 2100, varying population, income growth and fossil fuel resource assumptions, five non-intervention scenarios.





Scenario History - SRES

- **IPCC TAR (2001) and AR4 (2007):** In 2000, the Special Report on Emission Scenarios (SRES) provided 40 new pathways and six illustrative scenarios (all non-intervention) until 2100, covering four main narratives.

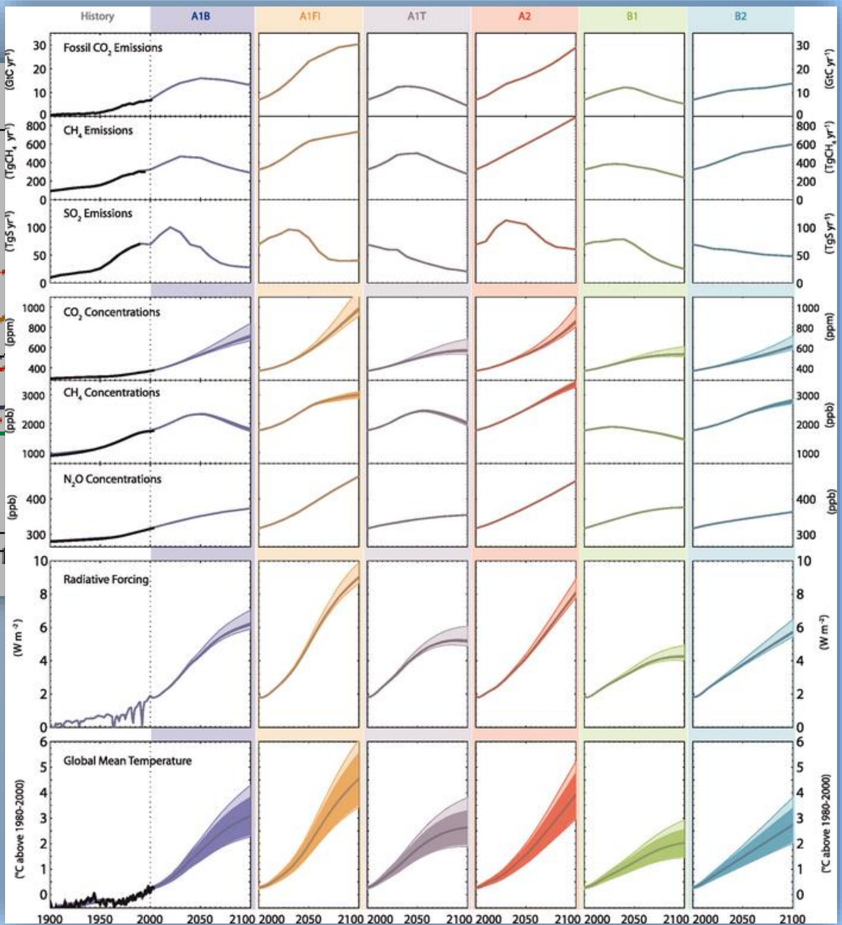


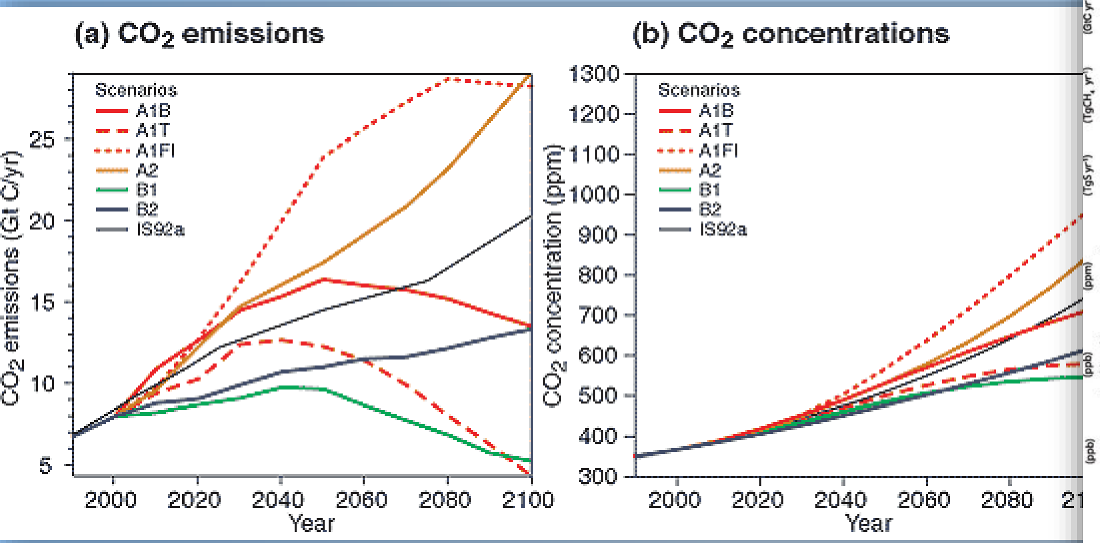
Scenario History - SRES

- **A1:** *rapid economic growth*, global population peaking mid-century, rapid introduction of efficient technology (fossil intensive A1FI, non-fossil A1T, balanced A1B)
- **A2:** *heterogeneous world*, self-reliance, increasing population, fragmented economic growth and technological change
- **B1:** *convergent world*, A1 population, more rapid changes towards information and service based economy, clean technologies
- **B2:** *local solutions* to economic, social, and environmental sustainability, lower continuous population growth than A2, less rapid, more diverse technological change than A1/B1

Scenario History - SRES

IPCC AR4 2007





IPCC TAR 2001

Scenarios - RCPs

IPCC Fifth Assessment Report (AR5): Four Representative Concentration Pathways (RCPs) developed

Prescribed pathways for greenhouse gas and aerosol concentrations, together with land use change (consistent with a set of broad climate outcomes used by the climate modelling community).

RCPs include one mitigation scenario leading to a very low forcing level (RCP2.6), two medium stabilization scenarios (RCP4.5 and RCP6) and one very high baseline emission scenario (RCP8.5)

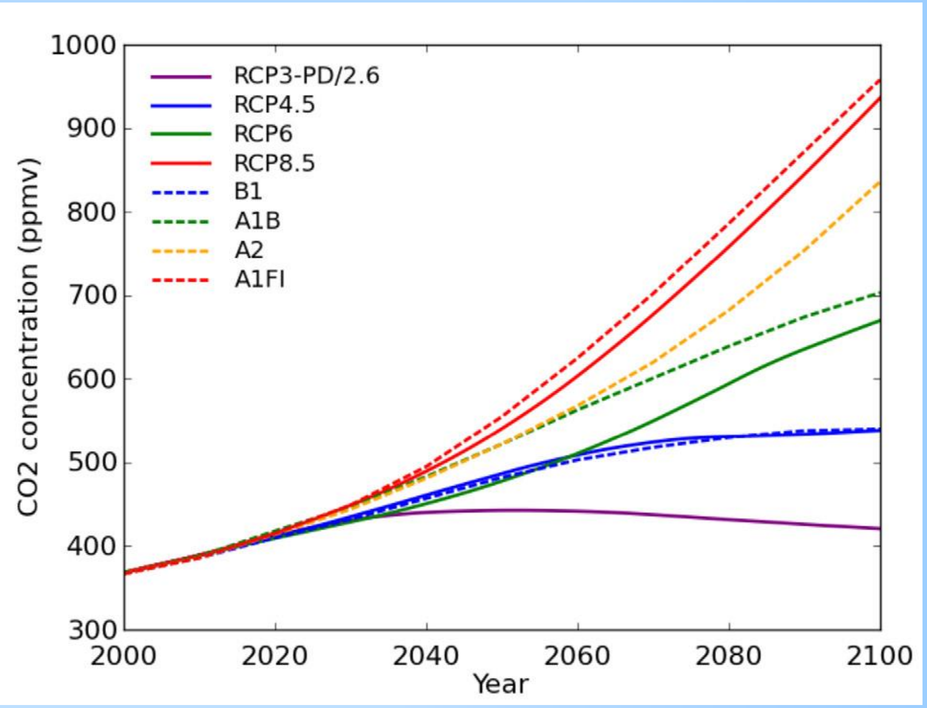
- 2100 radiative forcing levels of 8.5, 6.0, 4.5 and 2.6 Wm^{-2} identified to cover broad range of climate outcomes.
- RCP extensions (ECPs) have been introduced until 2300 to allow for analysis of longer term climate responses.

Scenarios-RCPs

- The **8.5** RCP arises from: little effort to reduce emissions and represents a failure to curb warming by 2100.
- **RCP6.0** pathway stabilizes total radiative forcing shortly after 2100 by the application of a range of technologies and strategies for reducing greenhouse gas emissions
- **RCP4.5** is similar to the lowest-emission scenario (B1) assessed in the IPCC AR4.
- **RCP2.6** is the most ambitious pathway. Consistent with keeping warming below 2°C relative to pre-industrial with a likely chance. Emissions peak early, then fall due to active removal of atmospheric carbon dioxide. It needs **early participation from all the main emitters, including those in developing countries.** is consistent with keeping warming below 2°C relative to pre-industrial with a likely chance.

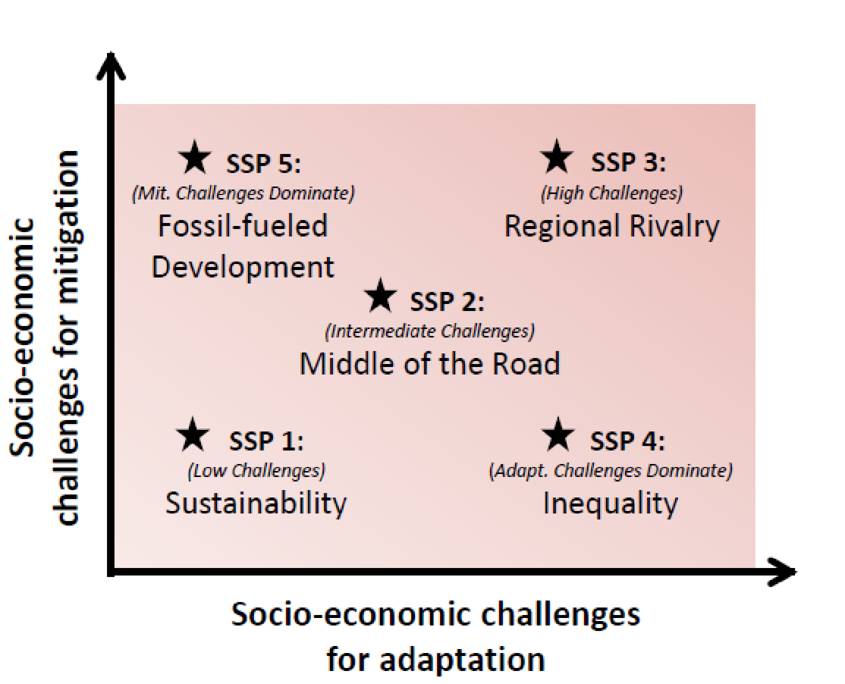
Differences to SRES
(Special Report on Emission Scenarios-previous set)

- RCPs span a wider range of possibilities
- RCPs start with atmospheric concentrations of greenhouse gases rather than socioeconomic processes – so uncertainties are reduced
- In contrast to SRES, some of the RCPs also include mitigation and adaptation policies.



Shared Socio-Economic Pathways (SSPs)
New Scenarios for CMIP6

- The Shared Socioeconomic Pathways (SSPs) <u>complement</u> the RCPs with new global emissions pathways under different socioeconomic scenarios: harmonized emissions trajectories through the end of the century
- 5 baseline SSPs concerning socioeconomic development, energy systems, land use, greenhouse gas (GHG) emissions, ***including air pollution***.



SSP1: *sustainable development*
marker IAM: IMAGE

SSP2: *'middle of the road'*
marker IAM: MESSAGE-GLOBIOM

SSP3: *regional rivalry*
marker IAM: AIM/CGE

SSP4: *inequality*
marker IAM: GCAM

SSP5: *high energy demand, fossil- fuel development*
marker IAM: REMIND-MAGPIE

Source: Gidden, M. J., et al., Geosci. Model Dev., 2019; B. O'Neill, 2017

Shared Socio-Economic Pathways (SSPs)
New Scenarios for CMIP6

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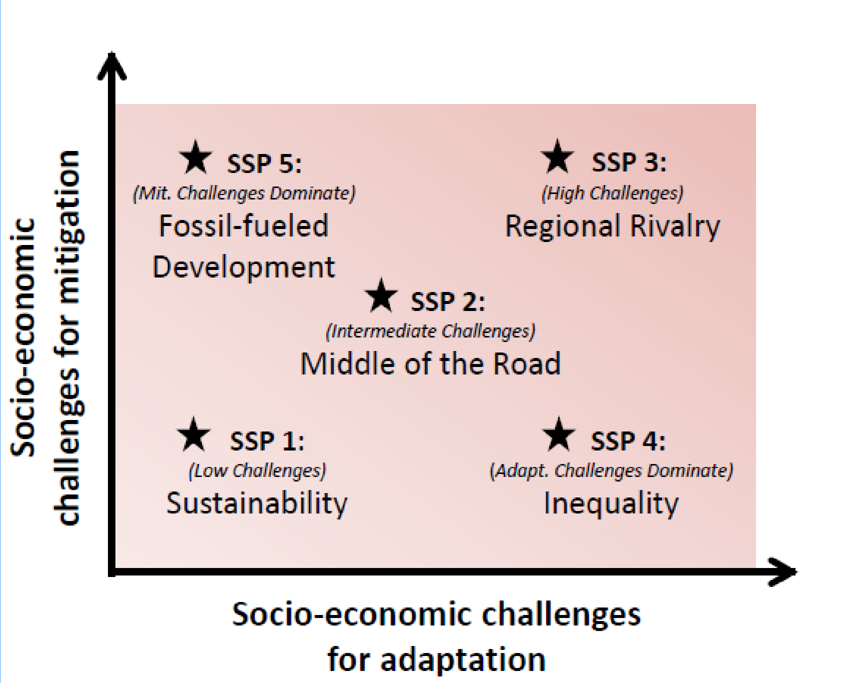
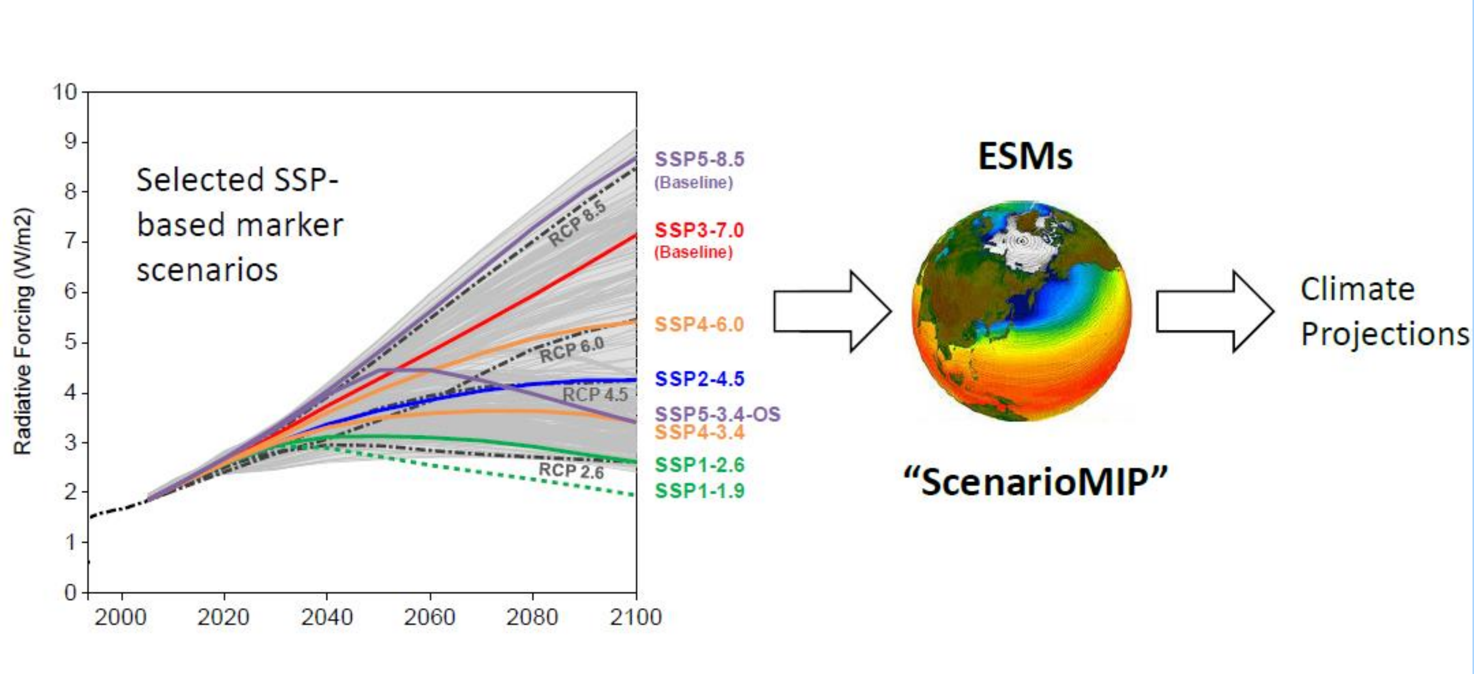


•**SSP1** and **SSP5** describe worlds with strong economic growth via sustainable and fossil fuel pathways.
•**SSP2:** moderate population growth and slower convergence of income levels across countries. Food consumption expected to increase and energy generation continues to *rely on fossil fuels* at approximately the same rates as today, resulting in continued growth of GHG emissions.
•**SSP3** and **SSP4** depict futures with high inequality between countries and within countries

Source: Gidden, M. J., et al., Geosci. Model Dev., 2019; B. O'Neill, 2017

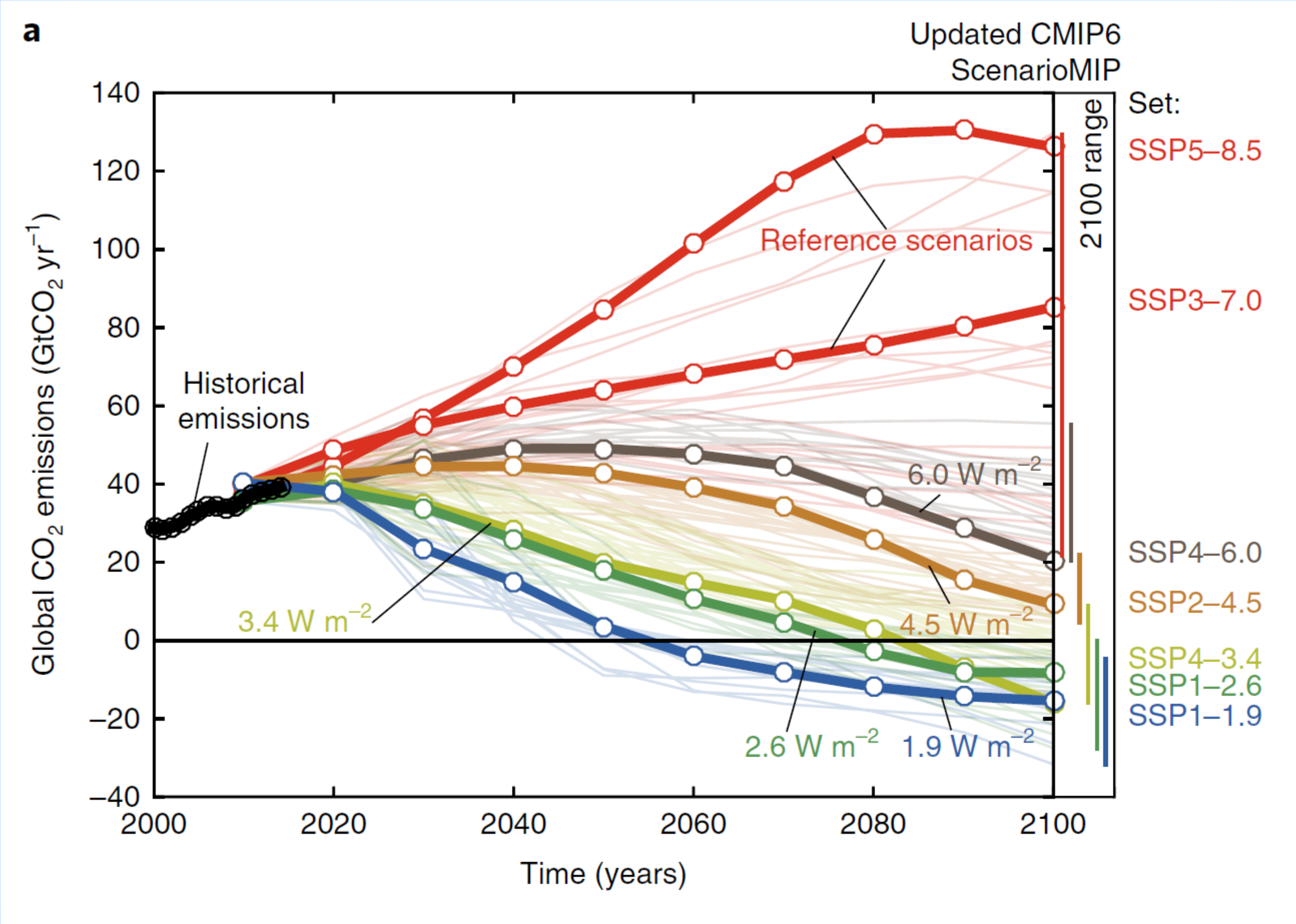
Shared Socio-Economic Pathways (SSPs)
New Scenarios for CMIP6

- Application of Scenarios



Source: Gidden, M. J., et al., Geosci. Model Dev., 2019; B. O'Neill, 2017

Shared Socio-Economic Pathways (SSPs)
New Scenarios for CMIP6



Shared Socio-Economic Pathways (SSPs)
Applications to other projects

Source: B. O'Neill, 2017

		SSP-related Information		
Project		**Narratives**	**Quant. Elements**	**IAM scenarios**
AgMIP	Agricultural Model Inter-comparison & Improvement Project	X	X	
ISIMIP	Inter-Sectoral Impact Model Intercomparison Project	X	X	X
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services	X	X	X
TWI2050	The World in 2050	X	X	X
CD-LINKS	Linking Climate and Development Policies		X	X
IMPRESSIONS	EU project: Impacts and Risks from High-End Scenarios	X	X	
Shock Waves	World Bank Report: Climate & Poverty	X	X	
BRACE	NCAR project: Benefits of Reduced Anthropogenic Climate changE	X	X	X

End of part 1- Thanks!