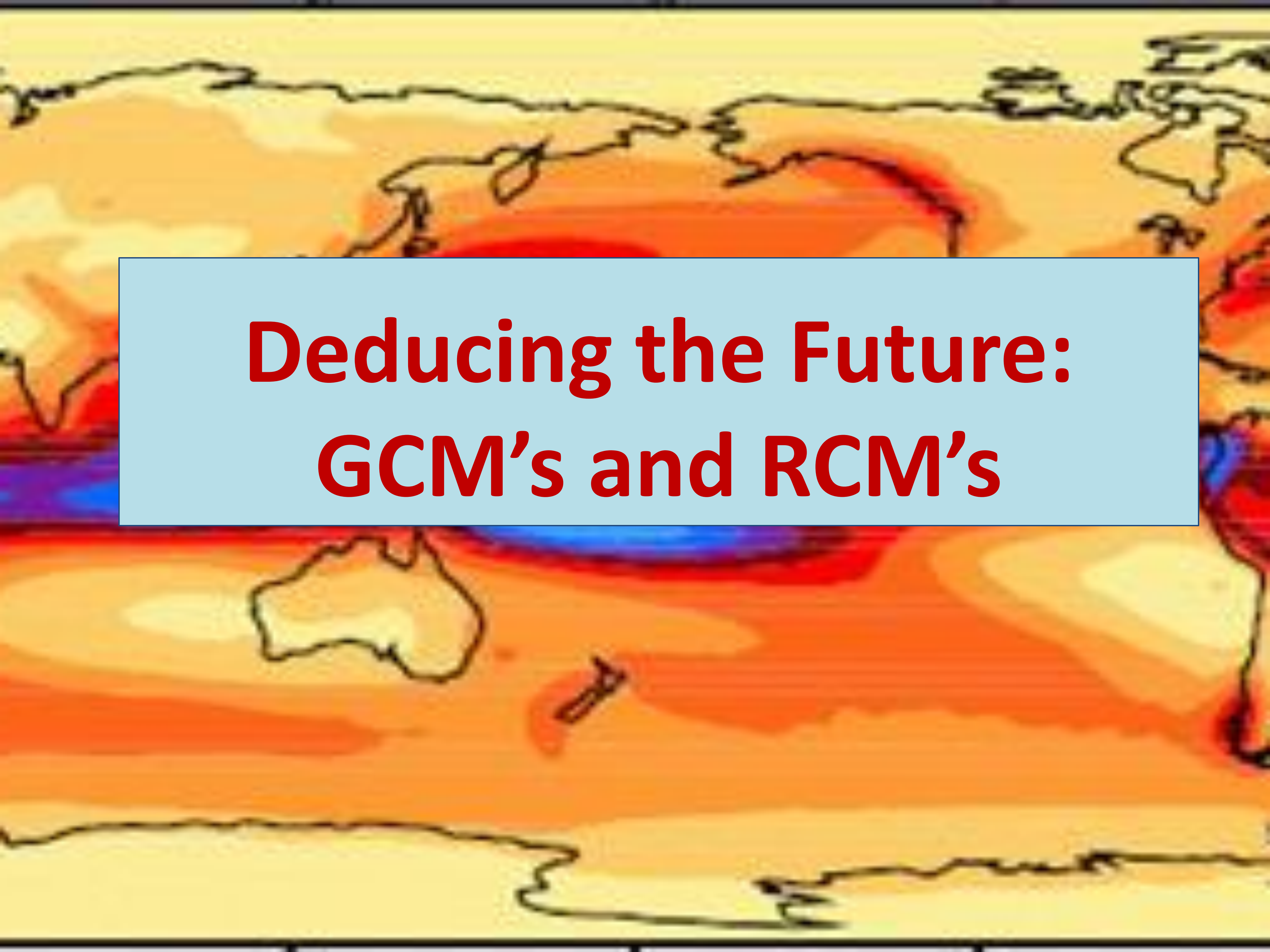
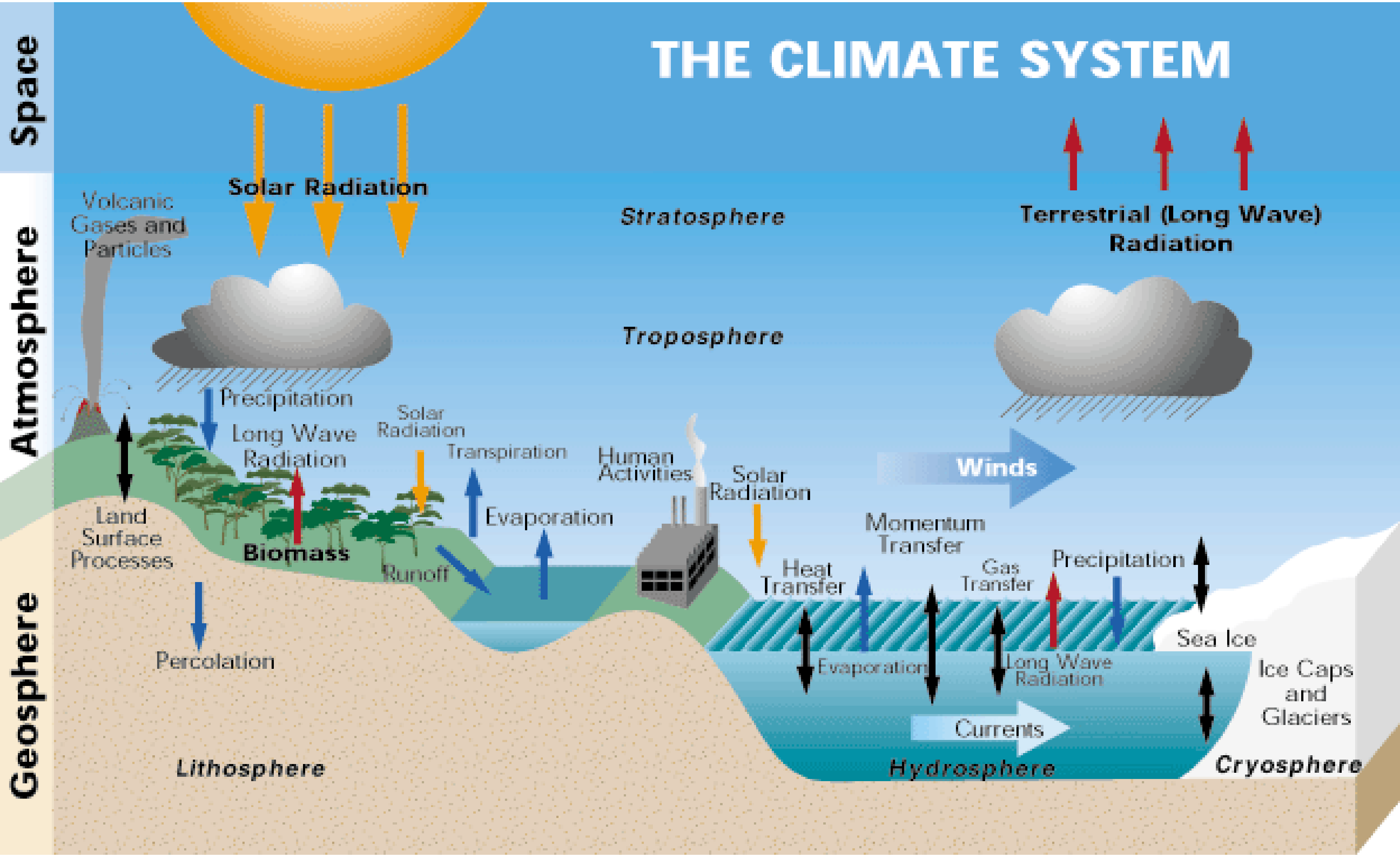
Deducing the Future: GCM's and RCM's




THE CLIMATE SYSTEM
Space
Atmosphere
Geosphere
Solar Radiation
Volcanic Gases and Particles
Stratosphere
Terrestrial (Long Wave) Radiation
Troposphere
Precipitation
Long Wave Radiation
Solar Radiation
Transpiration
Human Activities
Solar Radiation
Winds
Evaporation
Land Surface Processes
Biomass
Runoff
Momentum Transfer
Heat Transfer
Gas Transfer
Precipitation
Sea Ice
Evaporation
Long Wave Radiation
Ice Caps and Glaciers
Percolation
Currents
Lithosphere
Hydrosphere
Cryosphere

The origin of numerical weather forecasting

By the beginning of the XX Century, the English mathematician, Lewis Fry Richardson, set up the first numerical model of the weather. Using his slide-rule, he solved the appropriate equations and produced a six-hour forecast. It took him six months, and then it was not a very good result. But his basic methods, described in a book published in 1922, were correct. To apply his methods to real forecasts, Richardson imagined the possibility of a very large concert hall filled with people, each person carrying out part of the calculation.

Numerical weather forecasting. Early Milestones

- 1922. Lewis Fry Richardson
Basic equations and methodology for numerical weather prediction (NWP)
- 1950. Charney, Fjortoft and von Neumann
First NWF (1 level)
- 1956 Norman Phillips. First general circulation experiment (2 levels)
- 1960: Lorenz. Chaos theory and predictability limits.
- 1963 Smagorinsky, Manabe et al. (GFDL). 9 levels
- 1960-1970. Other NWP groups begin to work (UCLA, NCAR, Met Office (UK). Different global models appear.

Limits of predictability

NWF: Practical→ 5-10 days.
Theoretical: 20-30 days

What happens if the model goes on running?
It can’t predict the weather, but it is supposed to predict the climate!

→ Seasonal and long term predictions of statistical climate parameters.

General Circulation Models (GCM)

A general circulation model (GCM) is a mathematical model of the general circulation of a planetary atmosphere or ocean and based on the Navier–Stokes equations on a rotating sphere with thermodynamic terms for various energy sources.
These equations are the basis for complex computer programs commonly used for simulating the atmosphere or ocean of the Earth. Atmospheric and oceanic GCMs (AGCM and OGCM) are key components of global climate models along with sea ice and land-surface components.

AGCMs

Atmospheric GCMs (AGCMs) model the atmosphere (including a land-surface model) *and impose sea surface temperatures (SSTs).*

Equations of an AGCM

$$\frac{\partial \overline{V}}{\partial t} + \overline{V} \cdot \nabla \overline{V} = -\frac{\nabla p}{\rho} - 2\overline{\Omega} \times \overline{V} + \overline{g} + F_{\overline{V}}$$

Horizontal momentum equation.
(2^{nd} Newton's law)

$$C_p\left(\frac{\partial T}{\partial t} + \overline{V} \cdot \nabla T\right) = \frac{1}{\rho}\frac{dp}{dt} + Q + F_T$$

- **Thermodynamic equation.**
(Conservation of energy)

$$\frac{\partial \rho}{\partial t} + \overline{V} \cdot \nabla \rho = -\rho \nabla \cdot \overline{V}$$

- **Continuity equation.**
(Mass conservation)

$$\frac{\partial q}{\partial t} + \overline{V} \cdot \nabla q = \frac{S_q}{\rho} + F_q$$

Conservation of water
(similarly chemical tracers)

$$p = \rho R T$$

Equation of state.

Dynamics

$$\frac{\partial \overline{V}}{\partial t} + \overline{V} \cdot \nabla \overline{V} = -\frac{\nabla p}{\rho} - 2\overline{\Omega} \times \overline{V} + \overline{g} + F_{\overline{V}}$$

Gravity

Coriolis Force

Pressure gradient force

$$C_p\left(\frac{\partial T}{\partial t} + \overline{V} \cdot \nabla T\right) = \frac{1}{\rho}\frac{dp}{dt} + Q + F_T$$

Adiabatic heating

$$\frac{\partial \rho}{\partial t} + \overline{V} \cdot \nabla \rho = -\rho \nabla \cdot \overline{V}$$

Compressibility

$$\frac{\partial q}{\partial t} + \overline{V} \cdot \nabla q = \frac{S_q}{\rho} + F_q$$

$$p = \rho R T$$

“Physics”

$$\frac{\partial \overline{V}}{\partial t} + \overline{V} \cdot \nabla \overline{V} = -\frac{\nabla p}{\rho} - 2\overline{\Omega} \times \overline{V} + \overline{g} + \overline{F}_{\overline{V}}$$

Friction and turbulence

$$C_p\left(\frac{\partial T}{\partial t} + \overline{V} \cdot \nabla T\right) = \frac{1}{\rho}\frac{dp}{dt} + Q + F_T$$

Diabatic and friction heating

$$\frac{\partial \rho}{\partial t} + \overline{V} \cdot \nabla \rho = -\rho \nabla \cdot \overline{V}$$

$$\frac{\partial q}{\partial t} + \overline{V} \cdot \nabla q = \frac{S_q}{\rho} + F_q$$

Sources and sinks of water

$$p = \rho R T$$

Numerical predictions using AGCMs

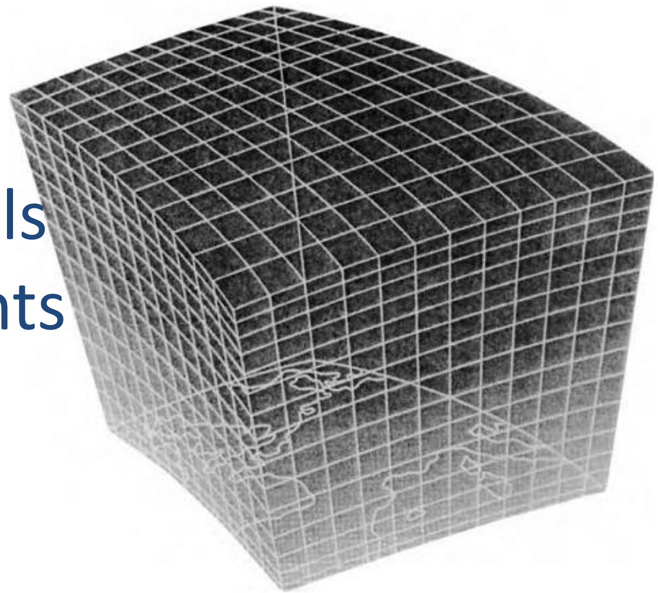
Most of the equations in the model are differential equations, which describe the way in which quantities such as pressure and wind velocity change with time and with location. If the rate of change of a quantity such as wind velocity and its value at a given time are known, then its value at a later time can be calculated. Constant repetition of this procedure is called **integration, and provides *the model's predictive powers*.**

Numerical predictions using AGCMs

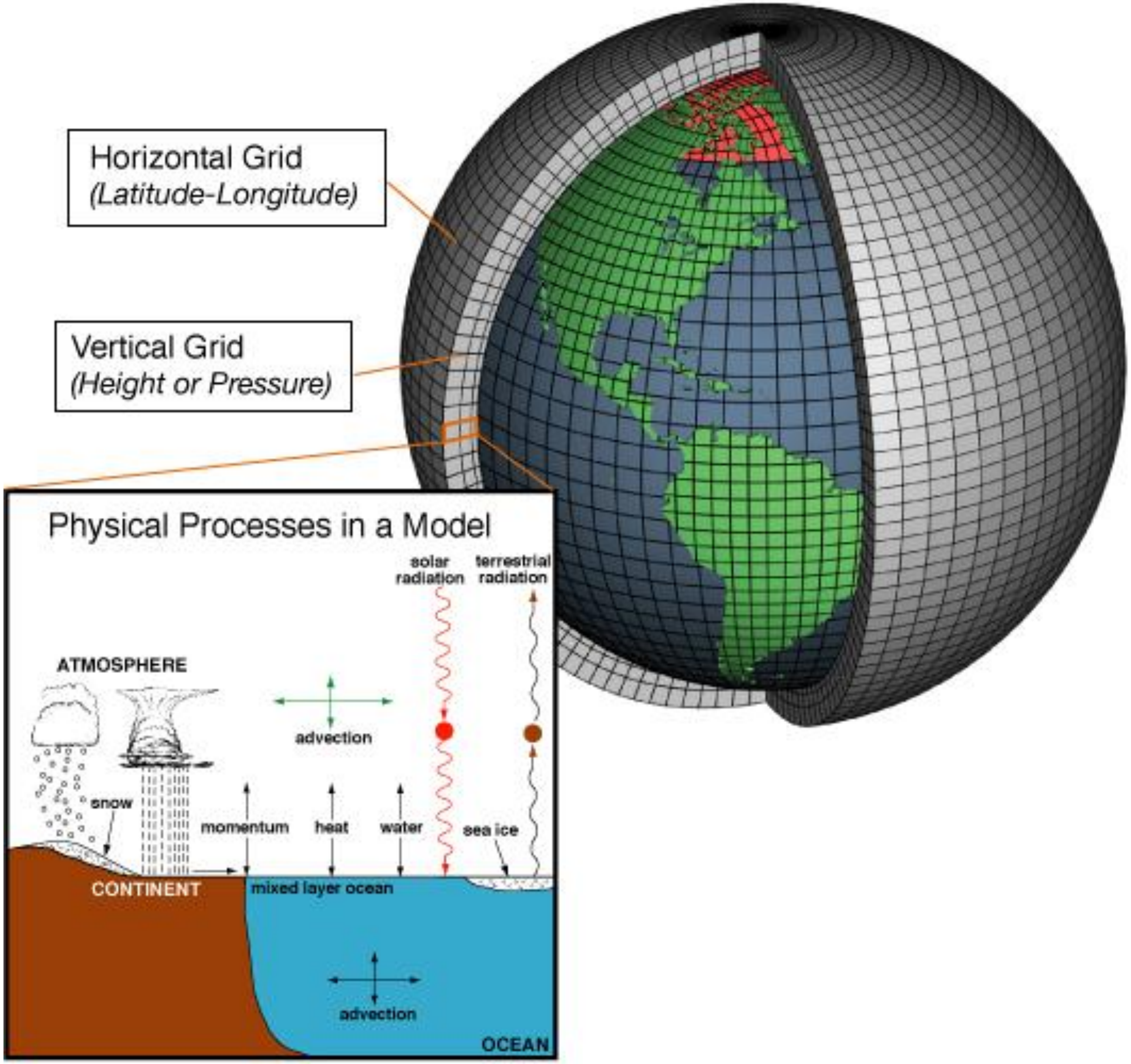
AGCMs contain a number of **prognostic equations** that are stepped forward in time (typically winds, temperature, moisture, and surface pressure). At every time step, additional variables are calculated or **diagnosed.**

AGCM Model grids

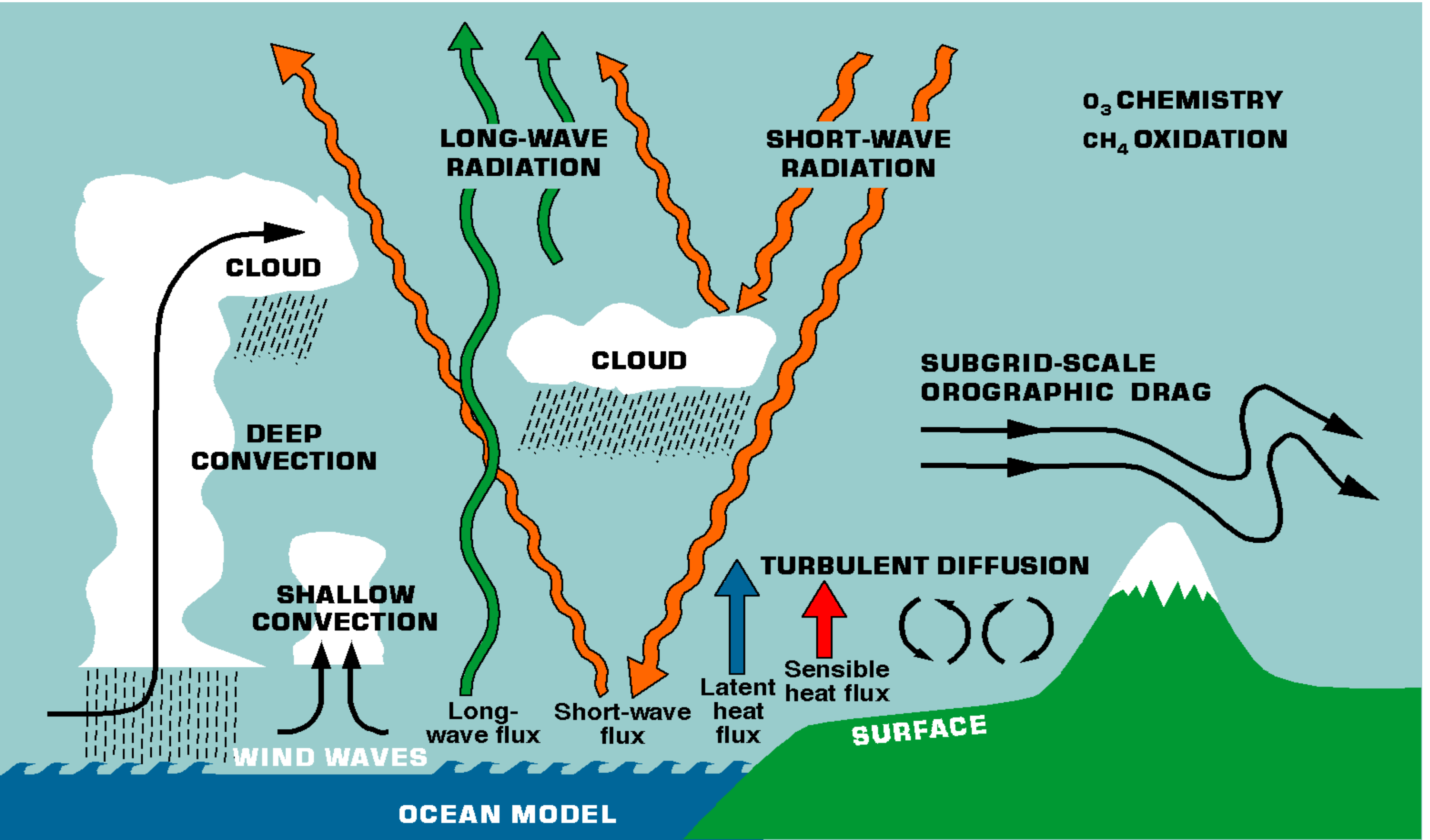
•Horizontal Resolution: 1-5 degrees
•Vertical resolution: 10-30 levels
HadAM3 :
3.75° in long. x 2.5° in lat. and 19 levels in the vertical →96 x 73 x 19 grid points
•4 variables: u,v, T, Q
→ ≈ 500,000 "basic" variables
HadGEM1. Res. 1.875° long.x1.25° lat
HiGEM, Res. 1.25° x 0.83°
Ocean model resolutions tend to be higher.



Interactions and processes in AGCMs



Parameterizations of sub-grid processes in a GCM



OGCMs

Oceanic GCMs (OGCMs) model the ocean *(with fluxes from the atmosphere imposed)* and may or may not contain a sea ice model.

HadOM3. Res. 1.25^{o}

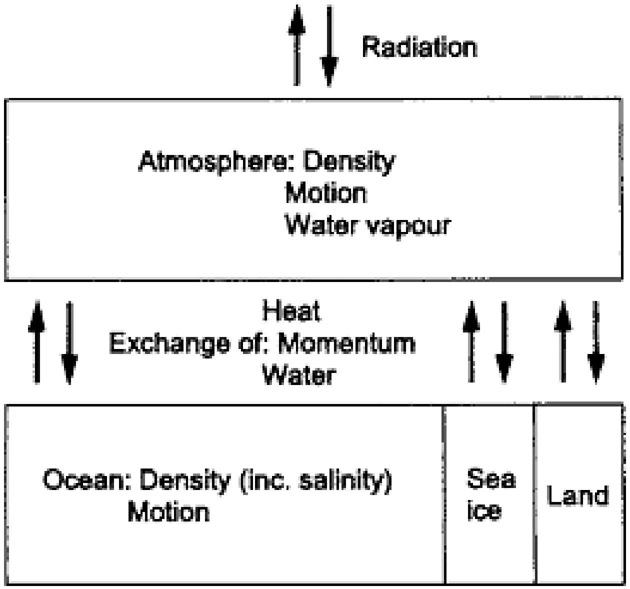
20 vertical levels, →1,500,000 variables.

AOGCMs

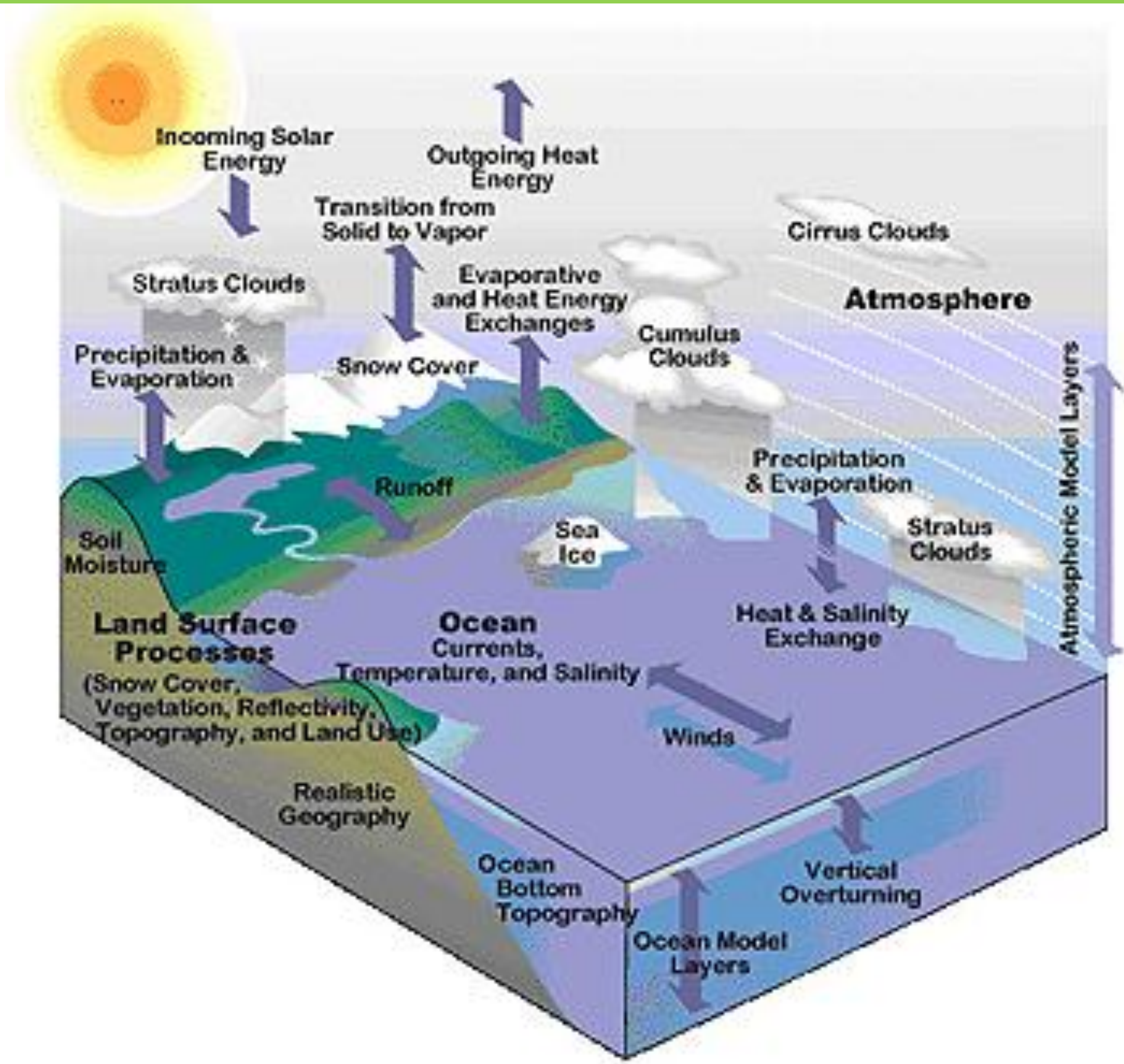
Coupled atmosphere–ocean GCMs (AOGCMs) (e.g. HadCM3, GFDL CM2.X) combine the two models. They thus have the advantage of removing the need to specify fluxes across the interface of the ocean surface.

These models are the basis for sophisticated model predictions of future climate, such as are discussed by the IPCC.

AOGCMs are the most complex and complete climate models.



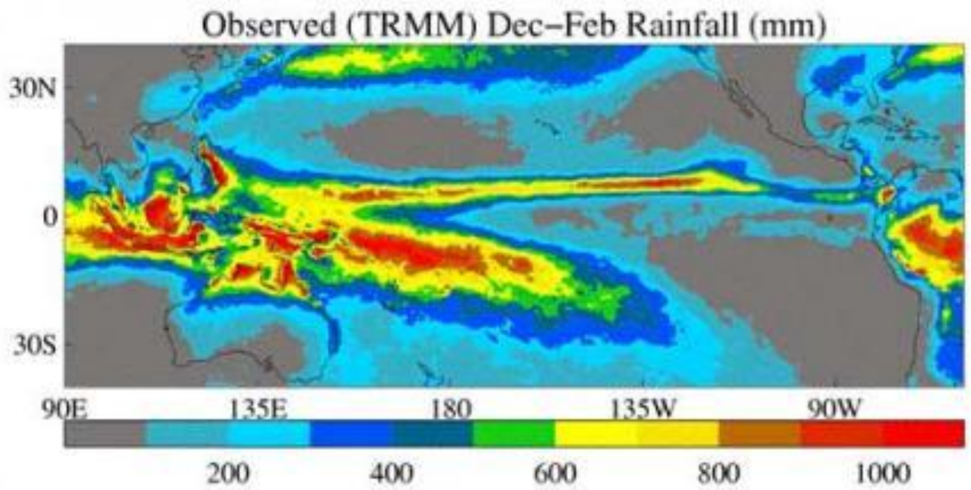
Interactions and processes in AOGCMs

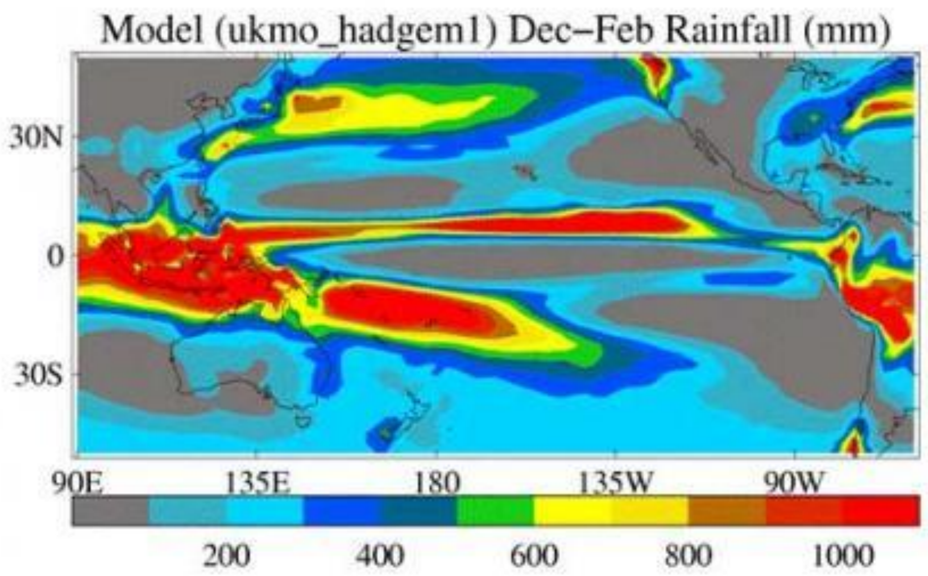


Output variables

Most models include software to diagnose a wide range of variables for comparison with observations or study of atmospheric processes. (1.5-m temperature, 10 m wind components, Mean sea level pressure, etc) This variables are not directly predicted from the model but are deduced from the surface and lowest-model-layer variables . Other software is used for creating plots and animations.

Validation (Comparison with data)

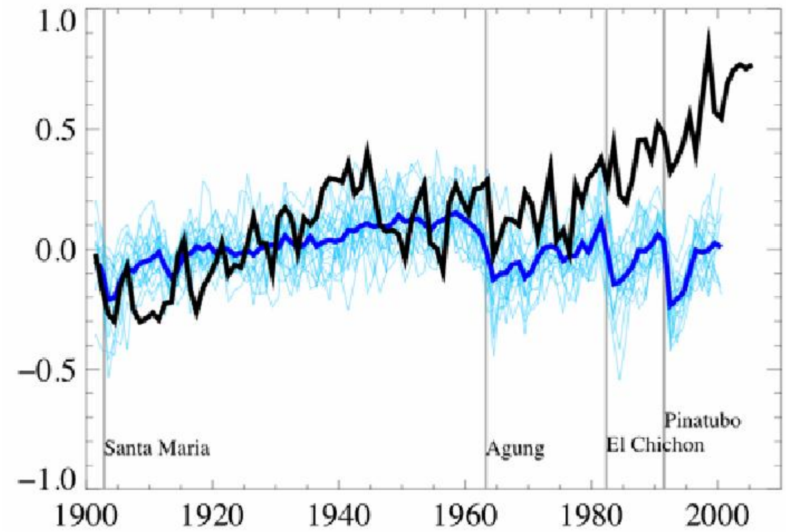




The December to February mean rainfall across the surface of the earth:

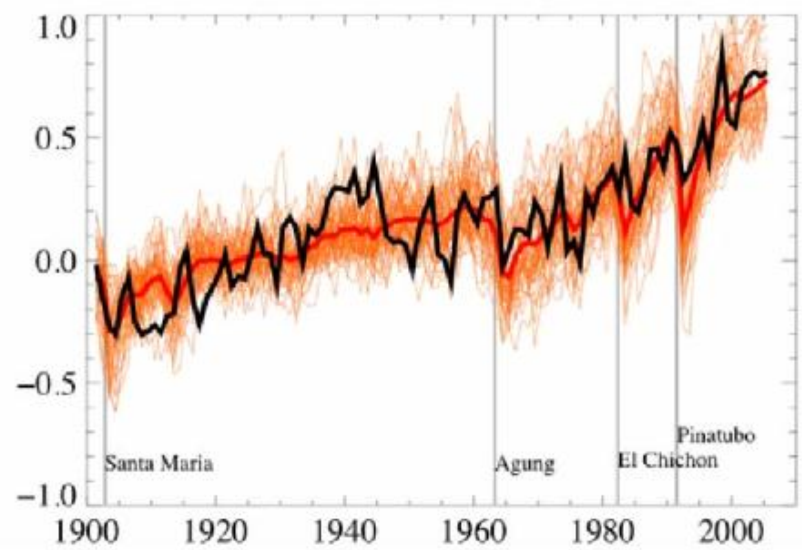
Simulations with AOGCM using natural and anthropogenic forcings. (IPCC, 2007)

Simulations with natural forcings

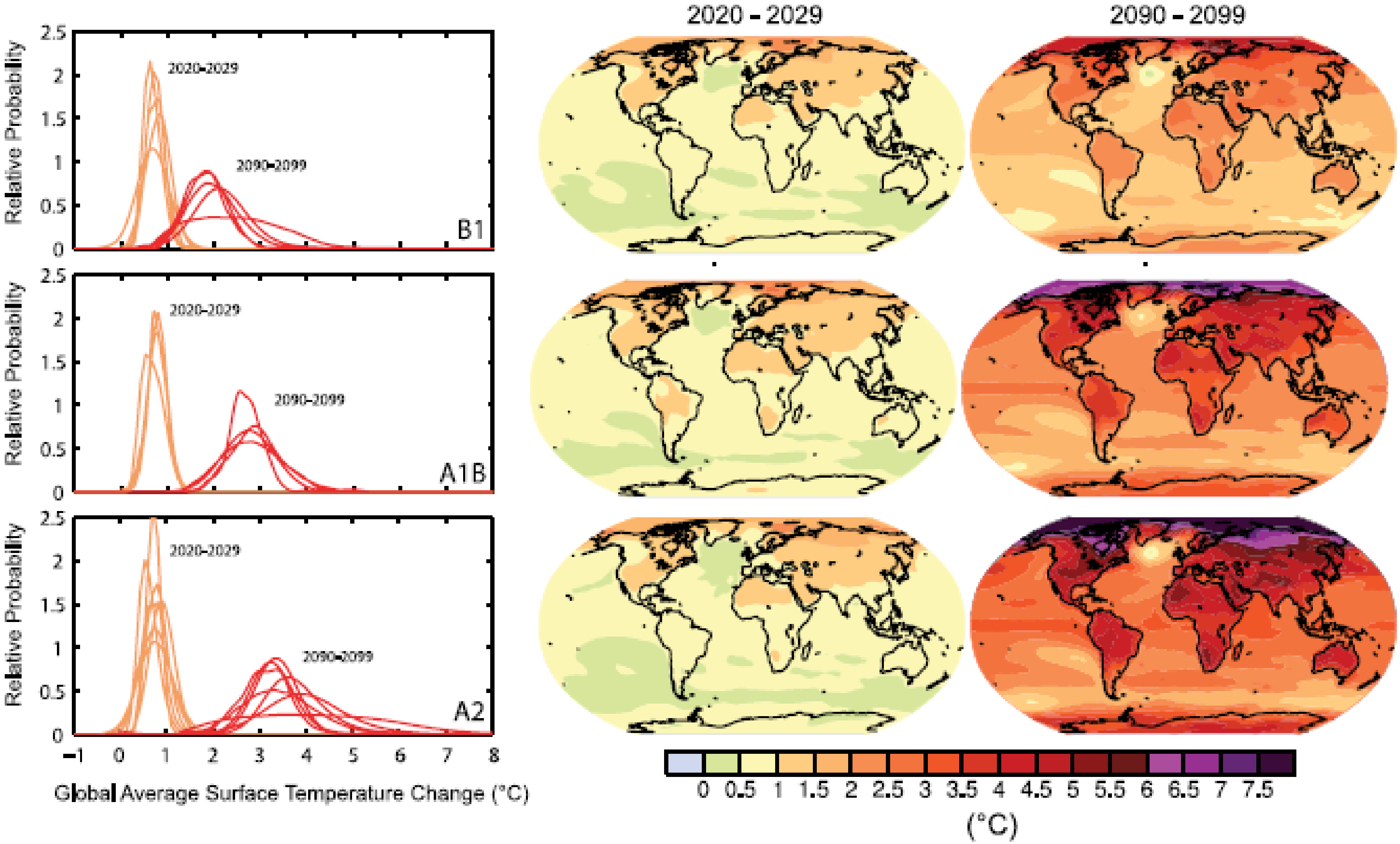


Simulated and observed annual global mean surface temperatures

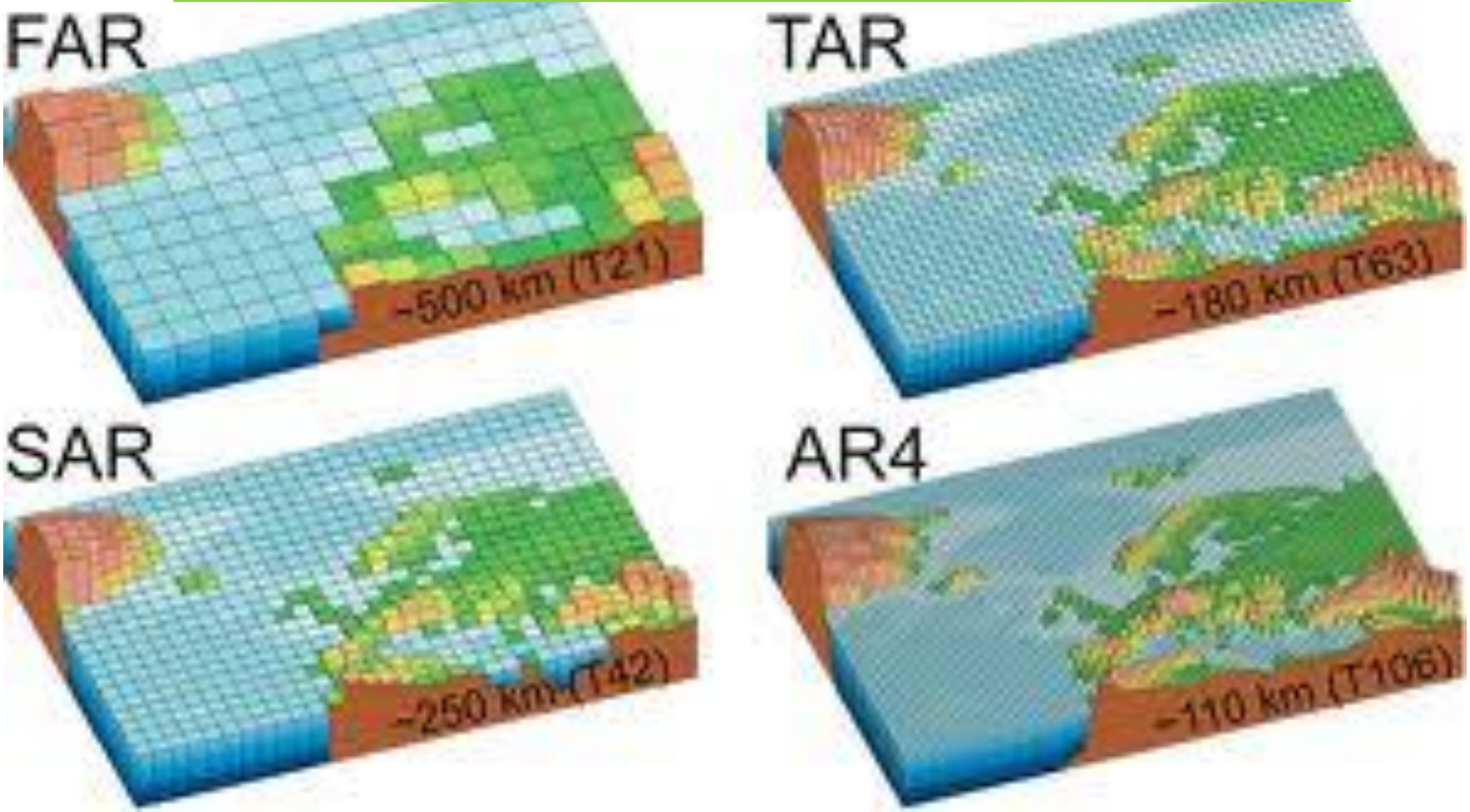
Simulations with anthropogenic forcings



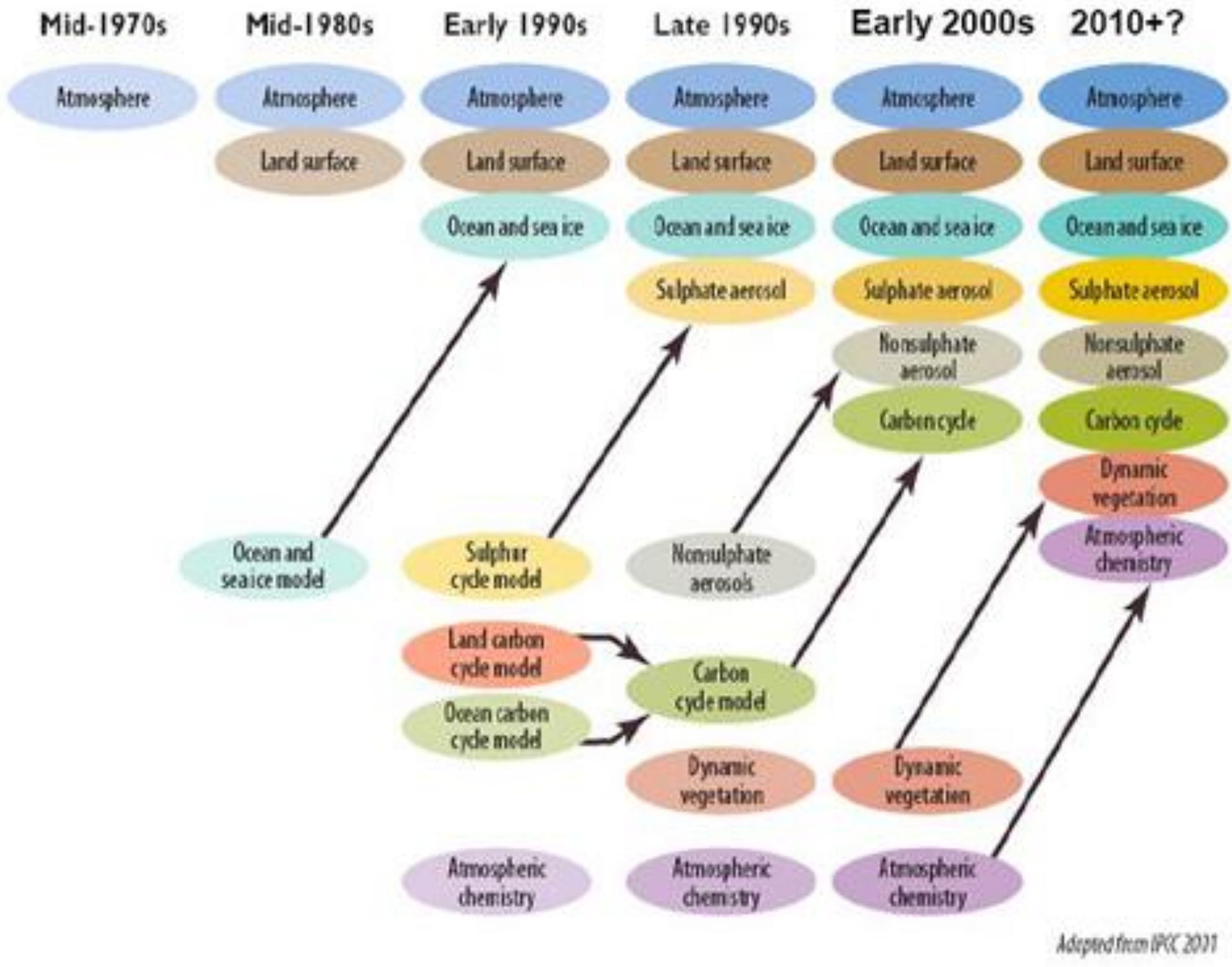
AOGCM Projected mean surface temperature (IPCC, 2007)



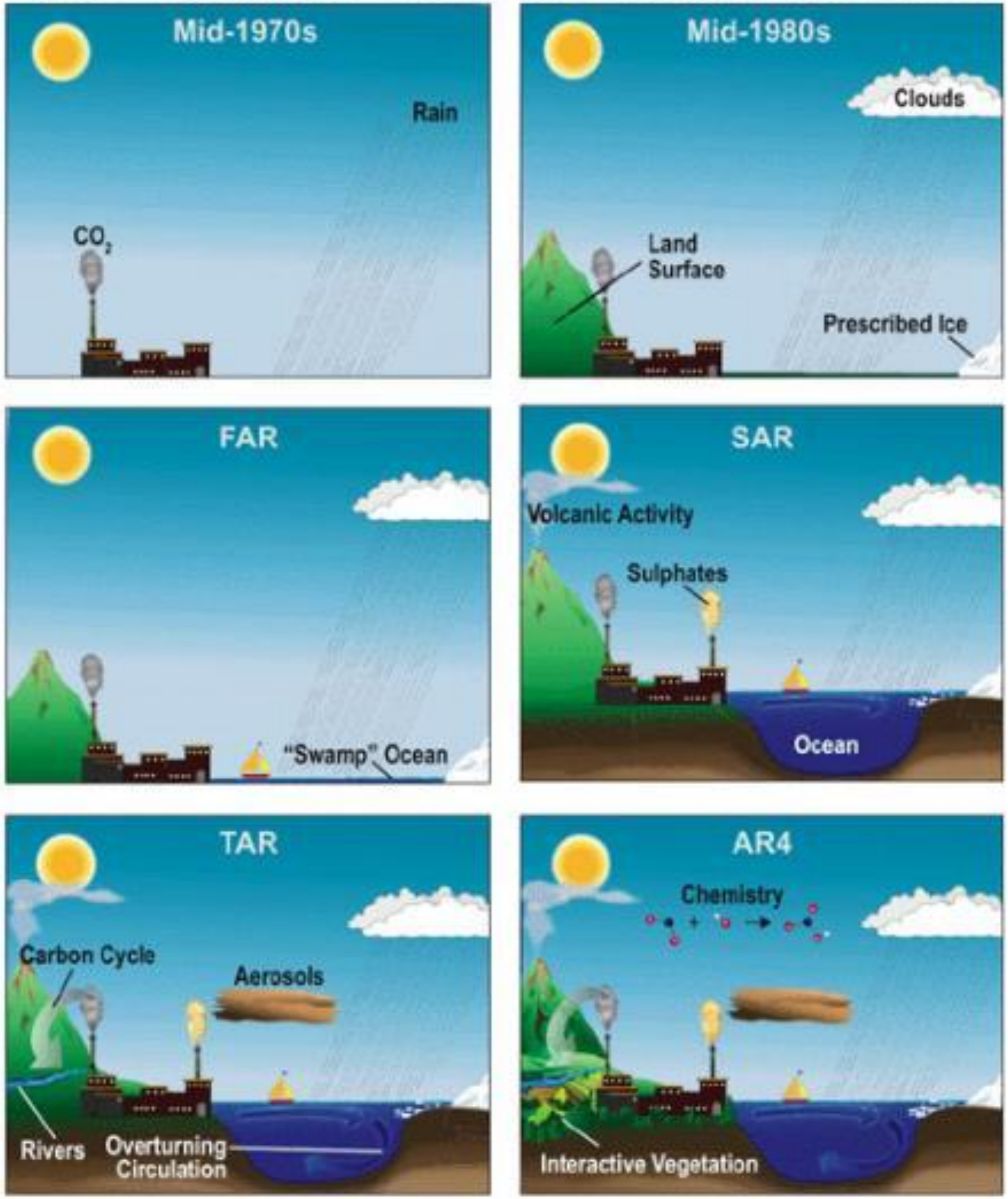
Development of GCMs. Improvement in Resolution



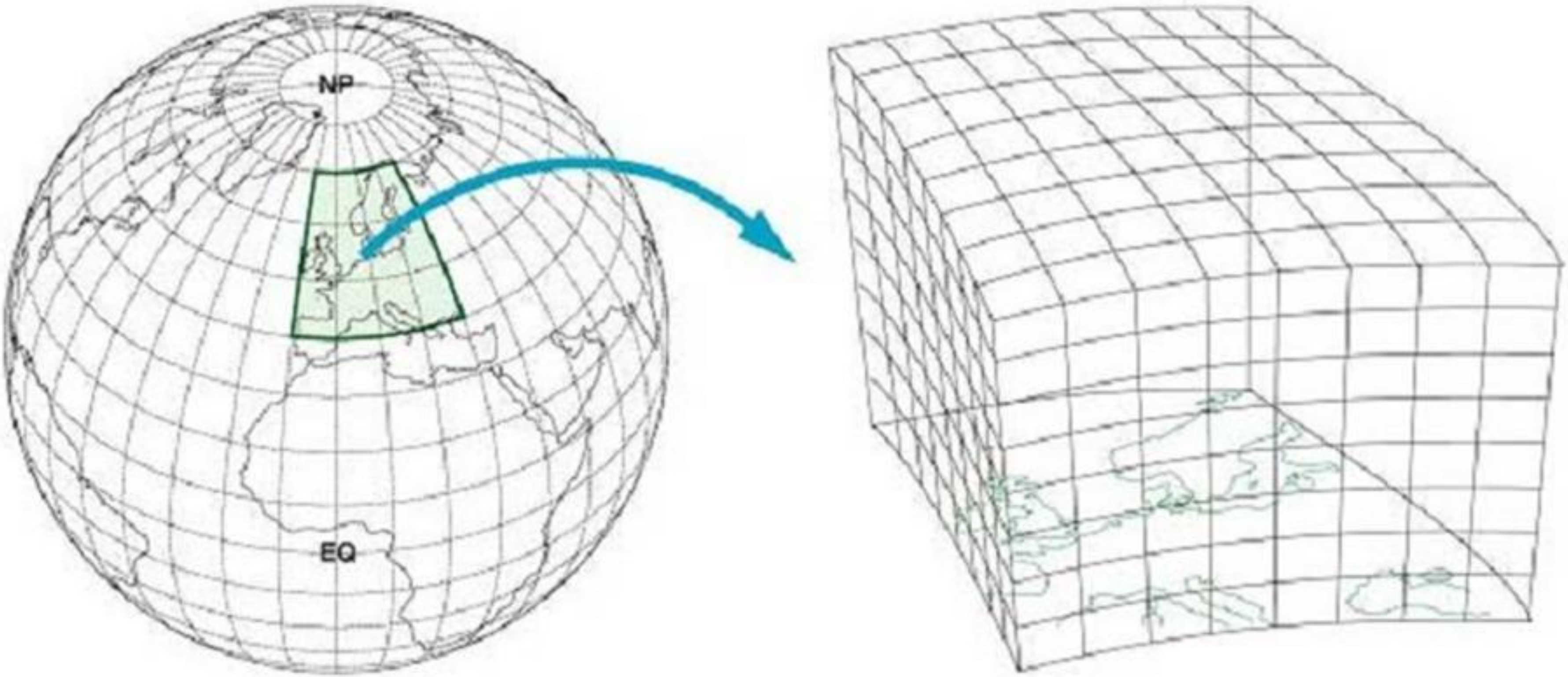
Development of Climate Models: Past, Present, and Future



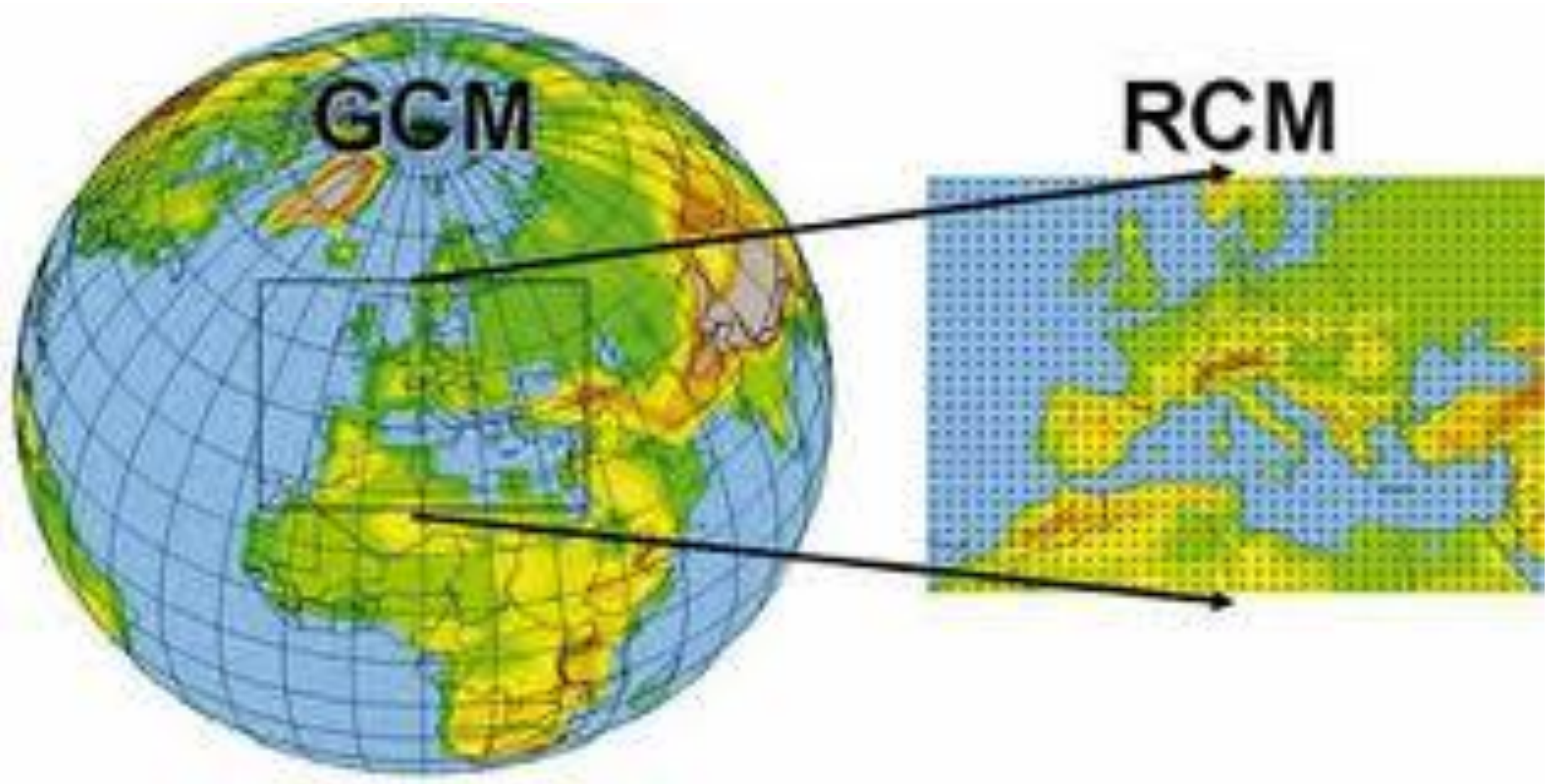
The World in Global Climate Models



Regional Climate Models



Regional atmospheric modelling: nesting into a global state


GCM
RCM

Regional Climate Models

The main goal of regional climate models (RCMs) is to reproduce the main climatic features in complex terrain, where mesoscale forcing becomes important and coarse-resolution global climate models (GCMs) are not sufficient for assessing local climate variability. Very high resolution GCMs are an extremely costly alternative solution.

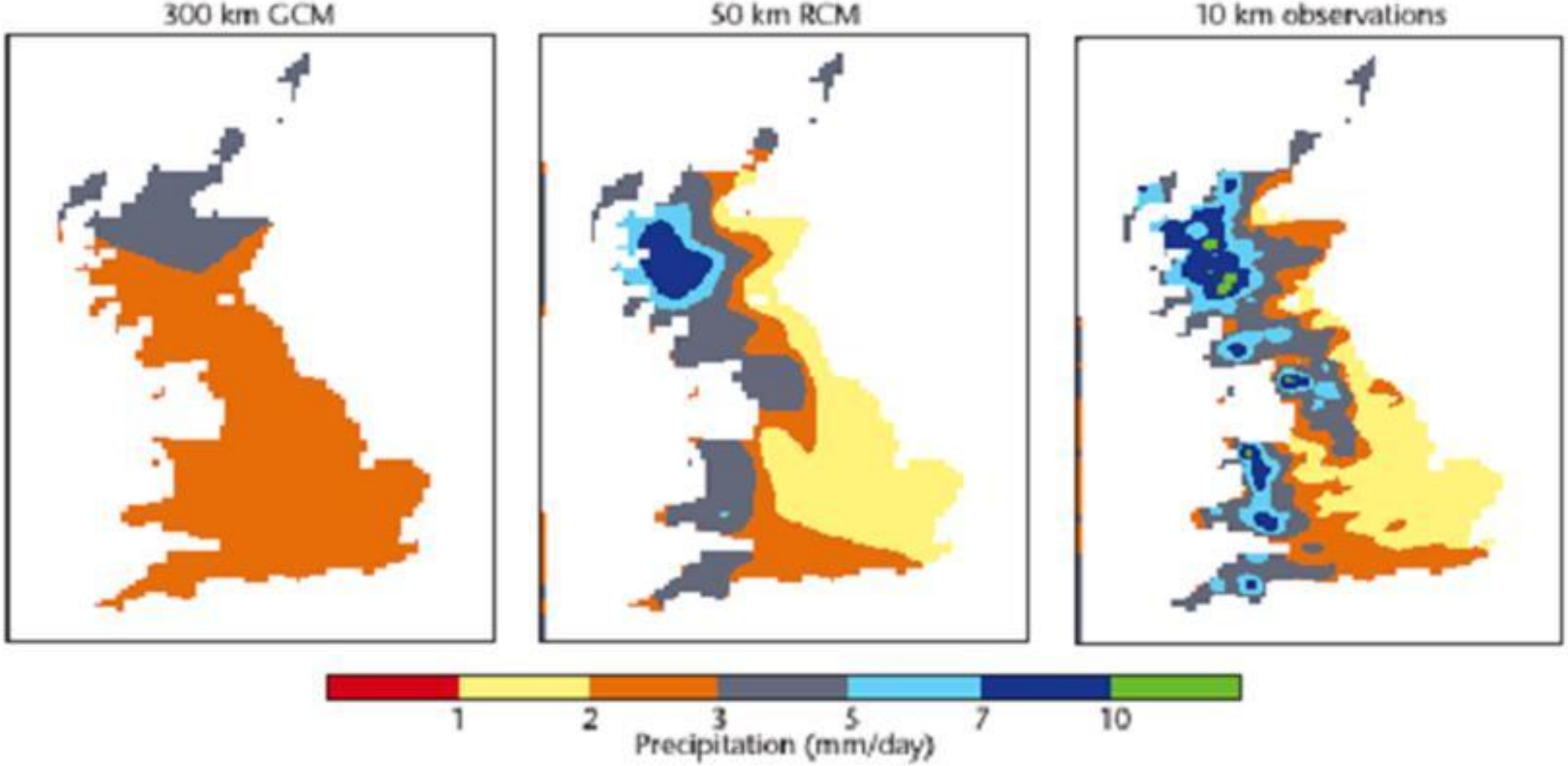
The Caribbean islands and adjacent territories are an example of the usefulness of RCM.

Regional climate modeling technique

The nested regional climate modeling technique consists of defining a limited region (e.g., Europe, South America, the Caribbean Region) and run a high resolution model only for that region, using the output of a GCM as boundary conditions.

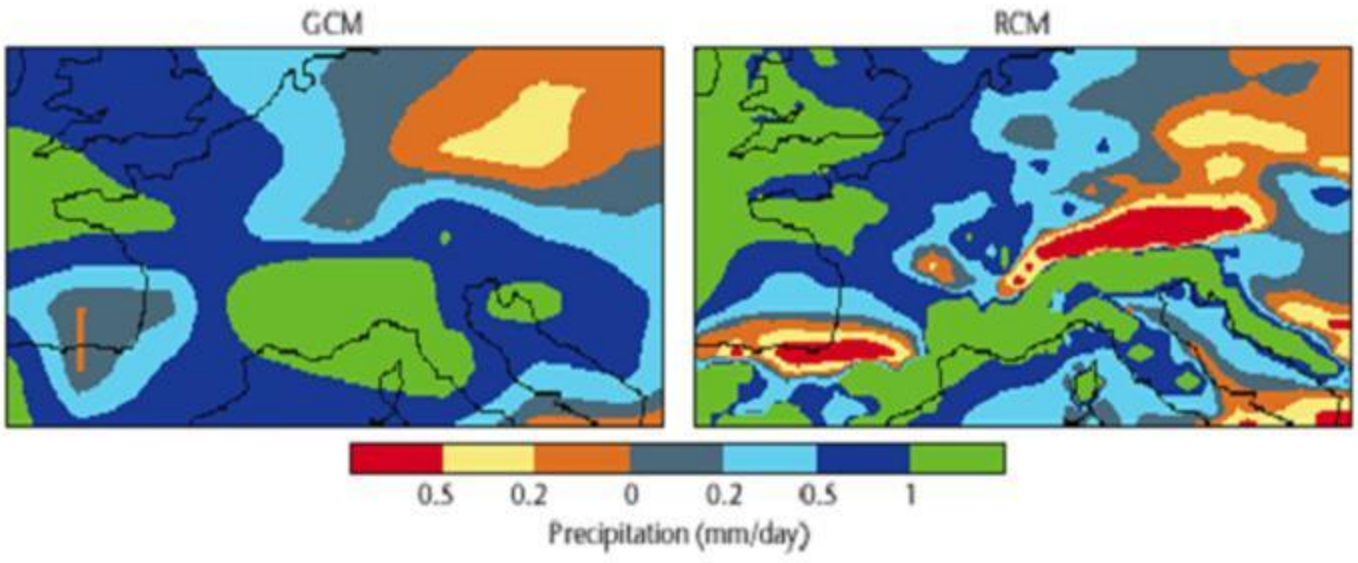
This technique has been mostly used only in one-way mode, i.e. with no feedback from the RCM simulation to the driving GCM. The basic strategy is thus to use the global model to simulate the response of the global circulation to large scale forcings (synoptic scale systems) and the RCM to account for sub-GCM grid scale forcings (e.g. local circulations, complex topographical features and land cover inhomogeneity).

RCMs simulate current climate more realistically



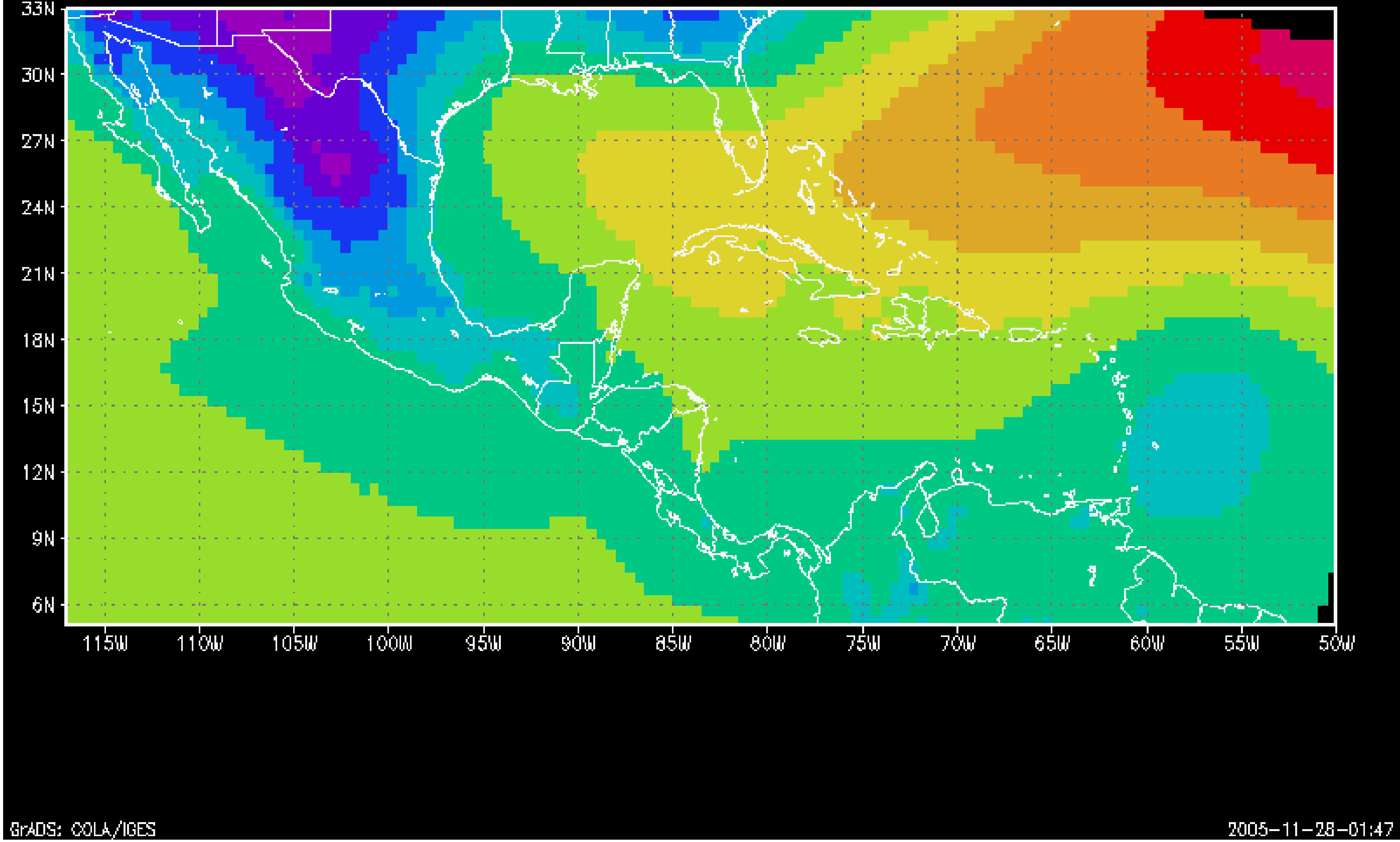
Patterns of present-day winter precipitation over Great Britain

Predict climate change with more detail



Projected changes in winter precipitation between now and 2080s.

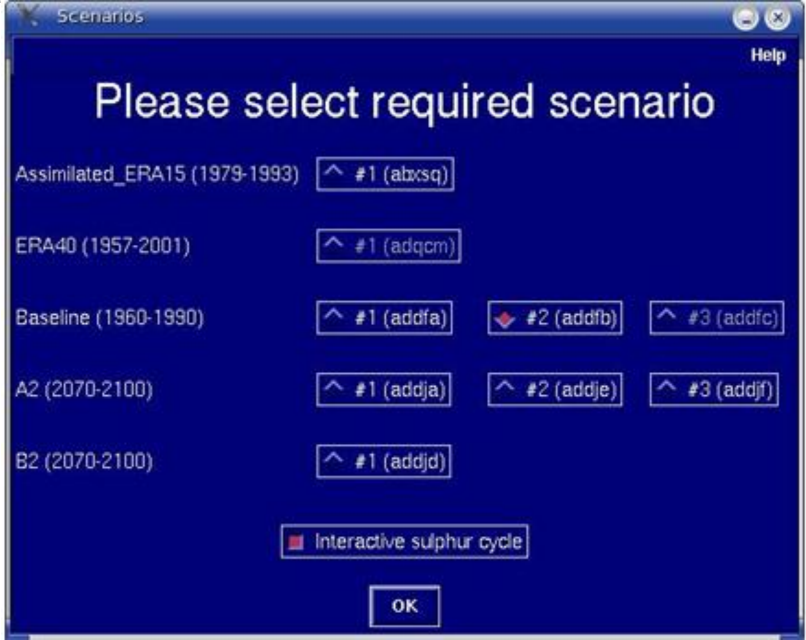
Represent Tropical cyclones



PRECIS

(Providing REgional Climates for Impact Studies)

- PRECIS (Providing REgional Climates for Impacts Studies) is a PC-based regional climate model developed by the Hadley Centre of the Meteorological Office of the United Kingdom for use by non-Annex I Parties to the United Nations Framework Convention on Climate Change.



The PRECIS Regional Climate Model (RCM)

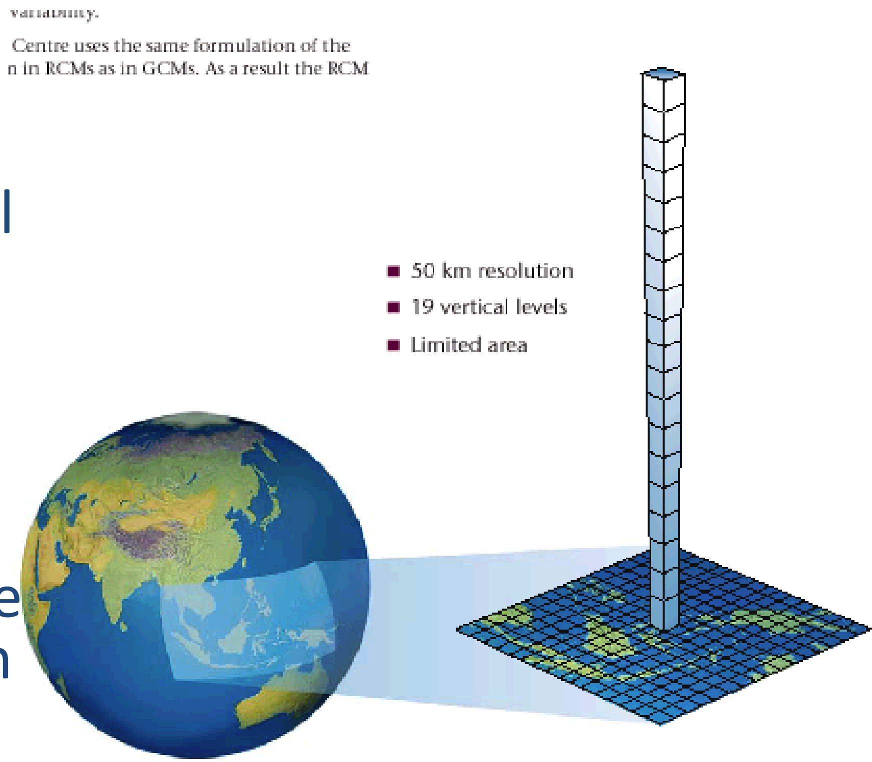
- An atmospheric and land surface model of limited area and high resolution locatable over any part of the globe.
- The Hadley Centre’s most up to date model: HadRM3P
- Hadley Center’s driving model HadAMP3 using emission scenarios.

Boundary conditions

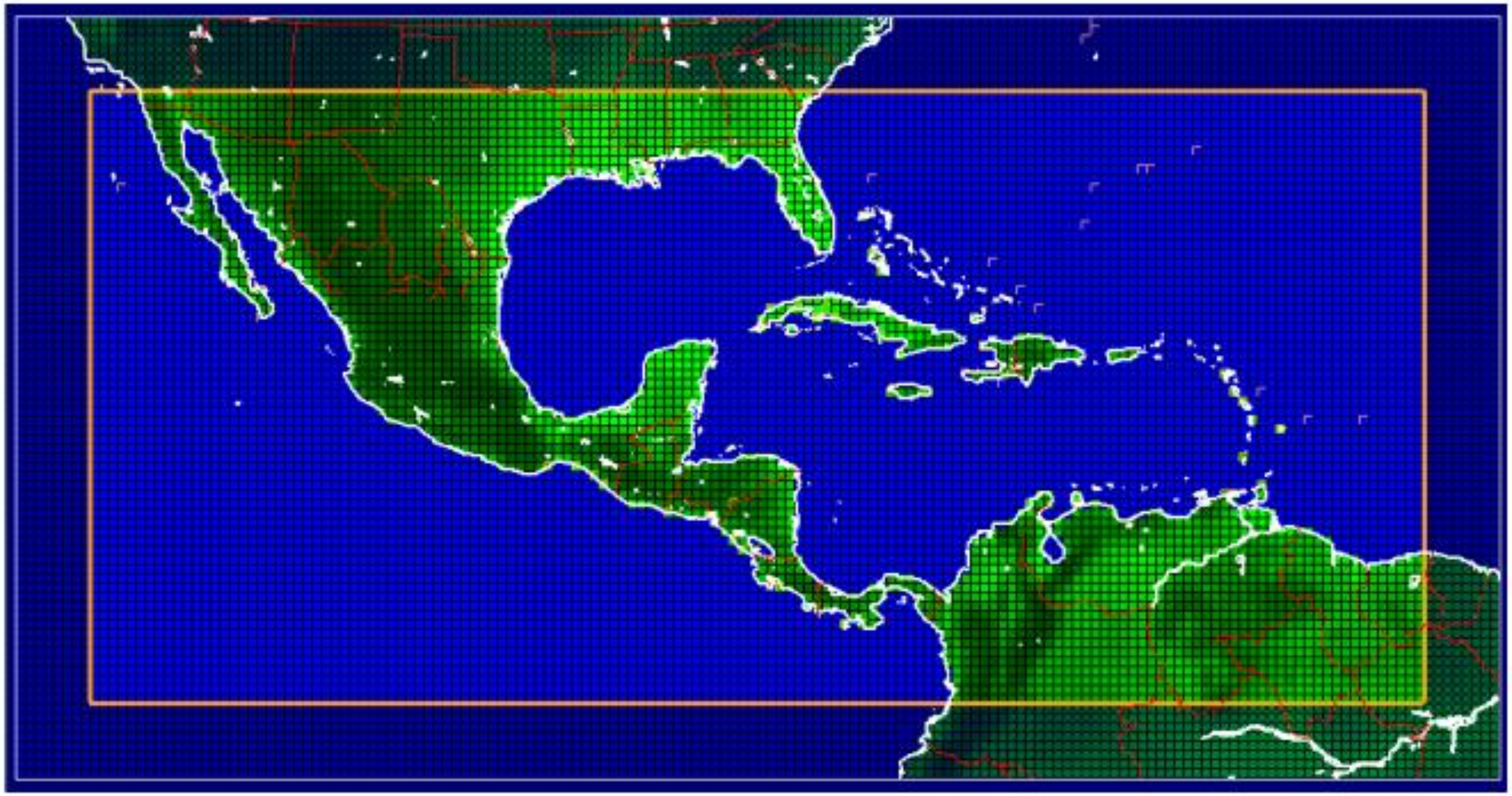
- The model requires prescribed surface and lateral boundary conditions (P,U,V,T,RH). Surface boundary conditions are only required over water, where the model needs time series of surface temperatures and ice extents.
- These lateral boundary conditions are updated every six hours; surface boundary conditions are updated every day.

Model description

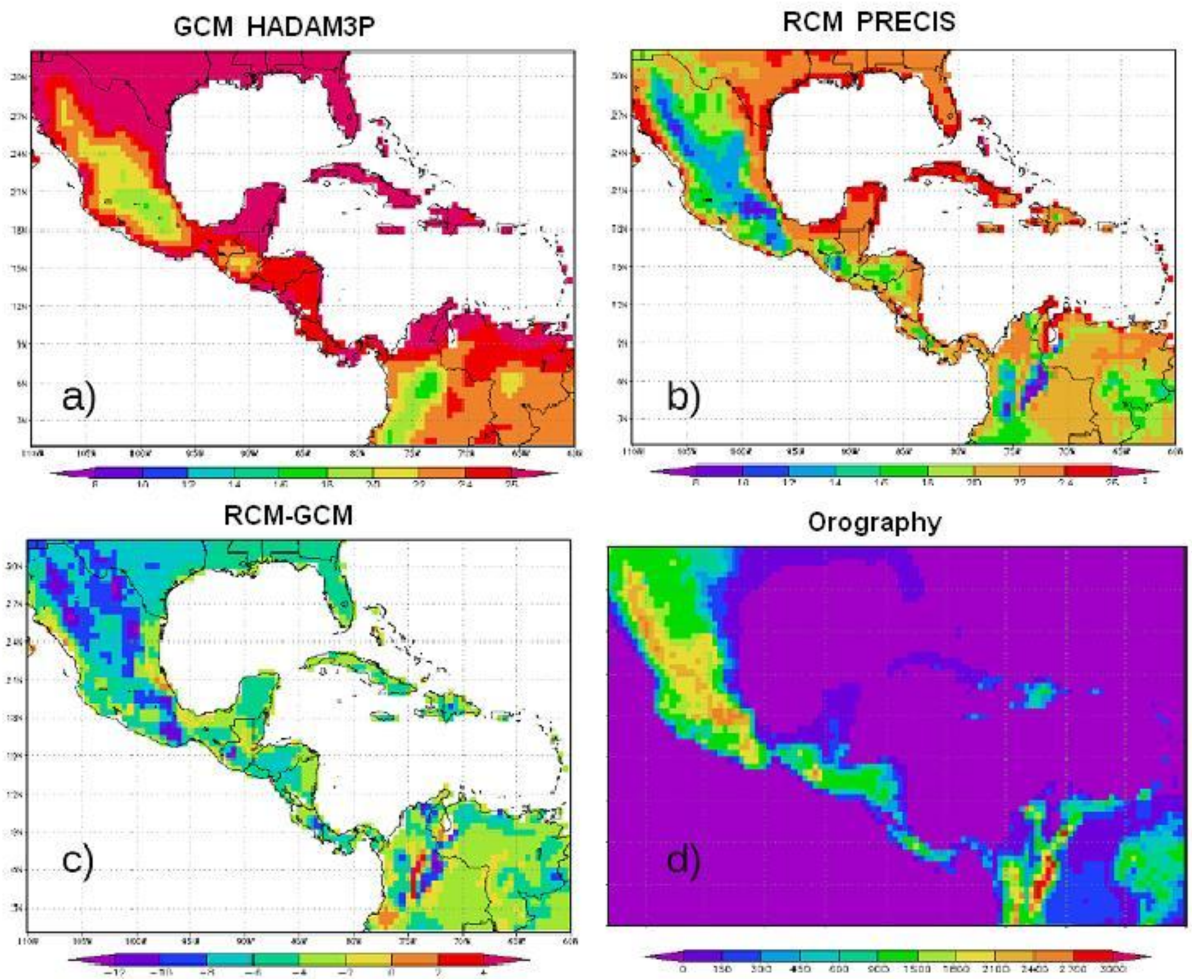
- Hydrostatic
- Complete Coriolis force
- Regular latitude-longitude grid in the horizontal and a hybrid vertical coordinate.
- 19 vertical levels, the lowest at ~50m and the highest at 0.5 hPa with terrain-following -coordinate used for the bottom four levels, purely pressure coordinates for the top three levels and a combination in between



PRECIS Caribbean Domain

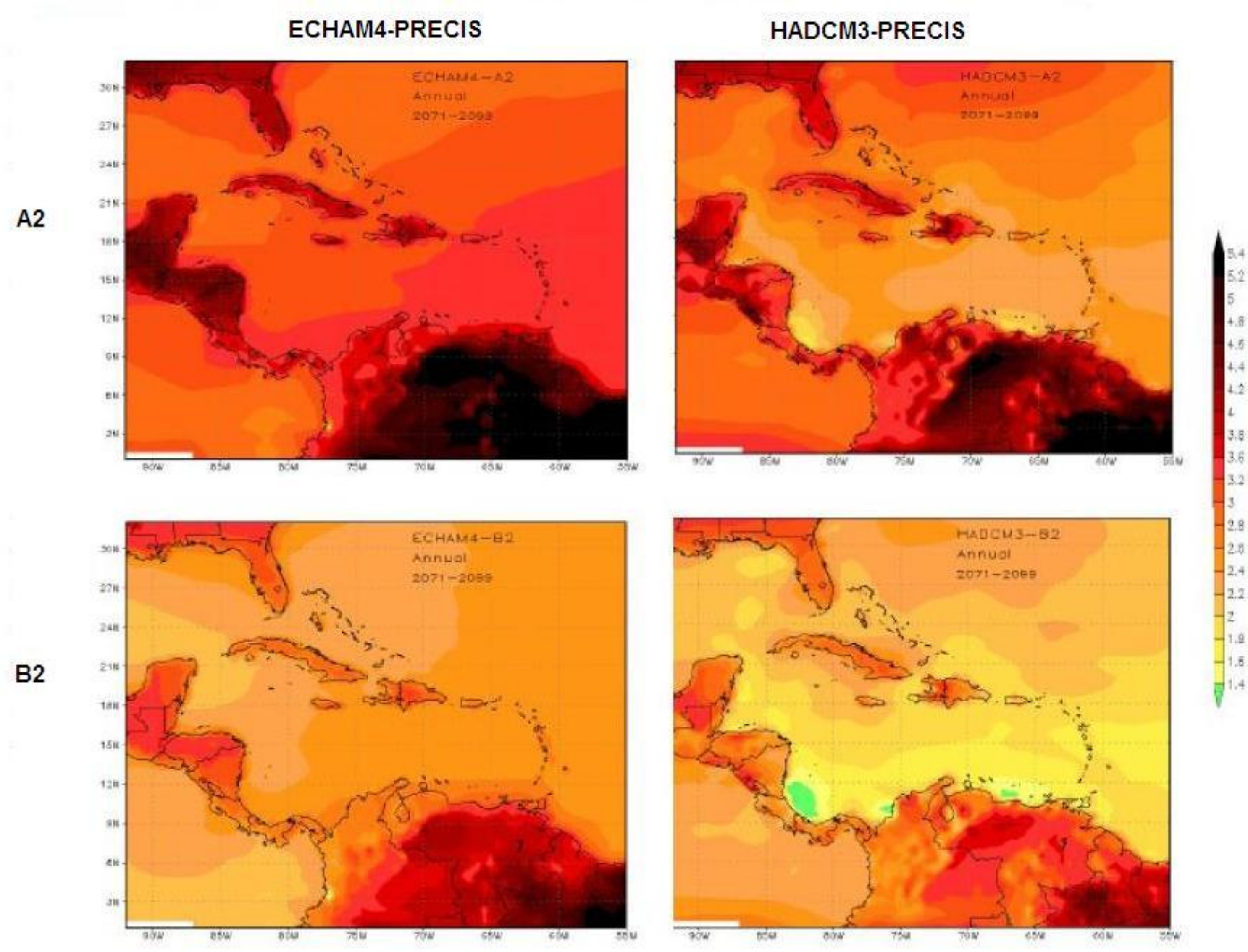


GCM-RCM simulations in the Caribbean

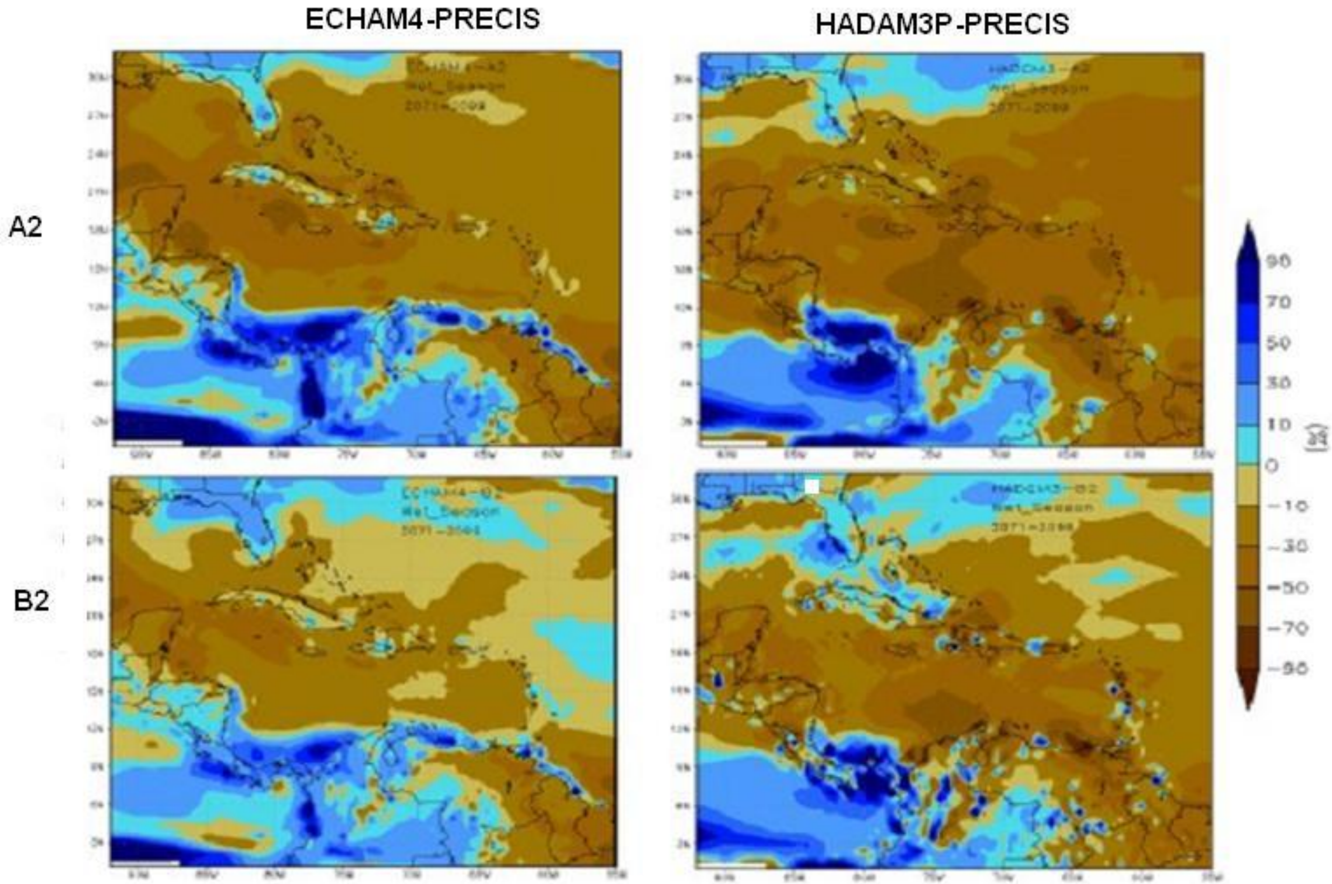


Mean surface air temperature simulations for JJA for the period 1961-1989. a. GCM HADAMP3 b. RCM PRECIS HCT c. Differences d. Orography

GCM-RCM Climate Projections in the Caribbean. Difference in yearly mean air temperature. 2071-2000



GCM-RCM Climate Projections in the Caribbean. Difference in yearly rainfall. 2071-2000



PRECIS projections of the change in yearly rainfall, driven by ECHAM4 and HADAM3P boundary conditions

Thank you!