Climate Modeling and Future Climate Change Projections

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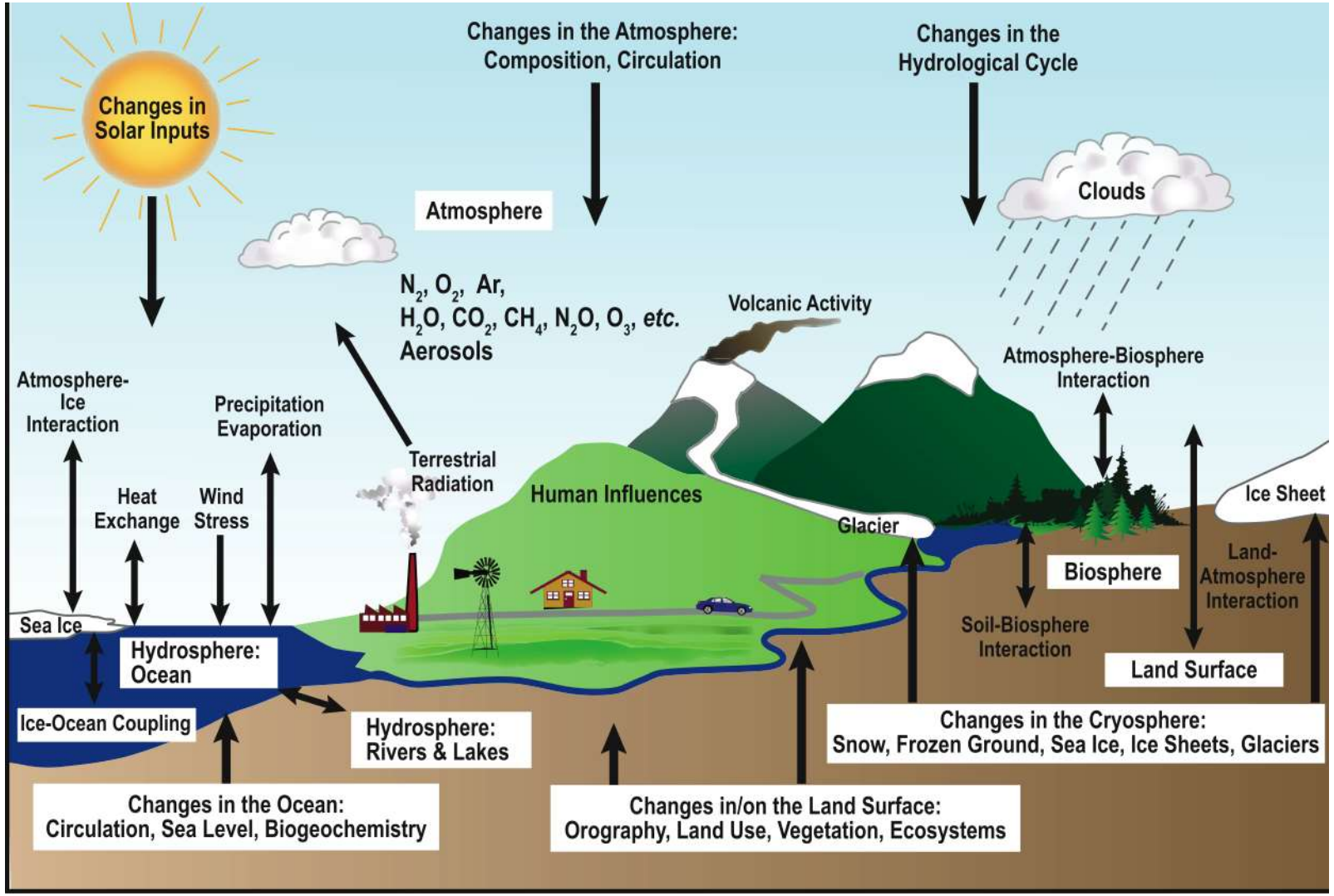
What is Climate Science?

(Common def.) Statistics about the weather. Climate is the average weather pattern over a longer period of time.

(Modern def.) Climate system is used to refer to the global, interlocking system of atmosphere, ocean, land surfaces, sea and land ice, and the parts of the biosphere and solid earth that are relevant for the problems of interest (NEELIN, 2011)

The Climate System



How do we simulate this?

What exactly is a model?

A model is only a "representation" of reality

Good modelers know the strong AND weak points of their models.

***Models are our laboratory**. We use them to*

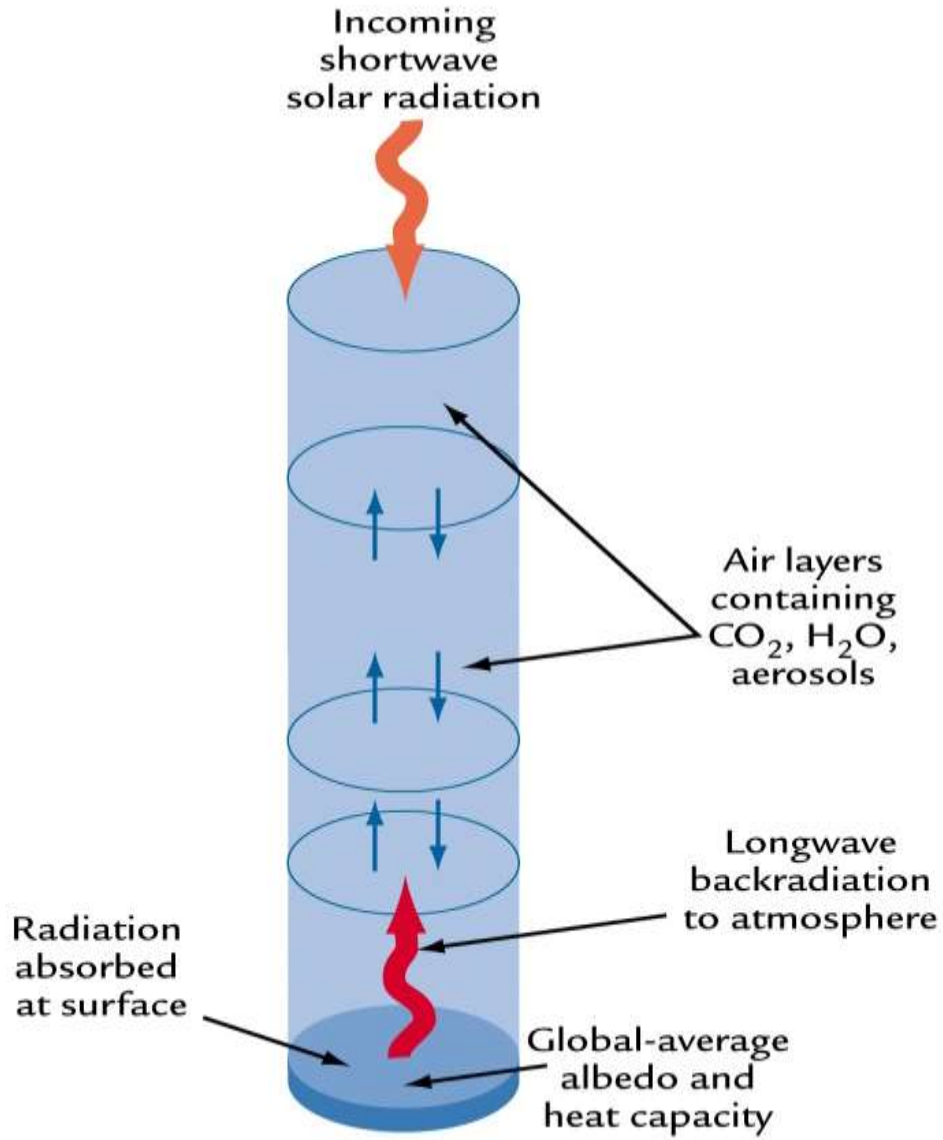
(i) investigate predictability

(ii) to explore forcing and feedbacks in the climate system

(iii) to test hypotheses

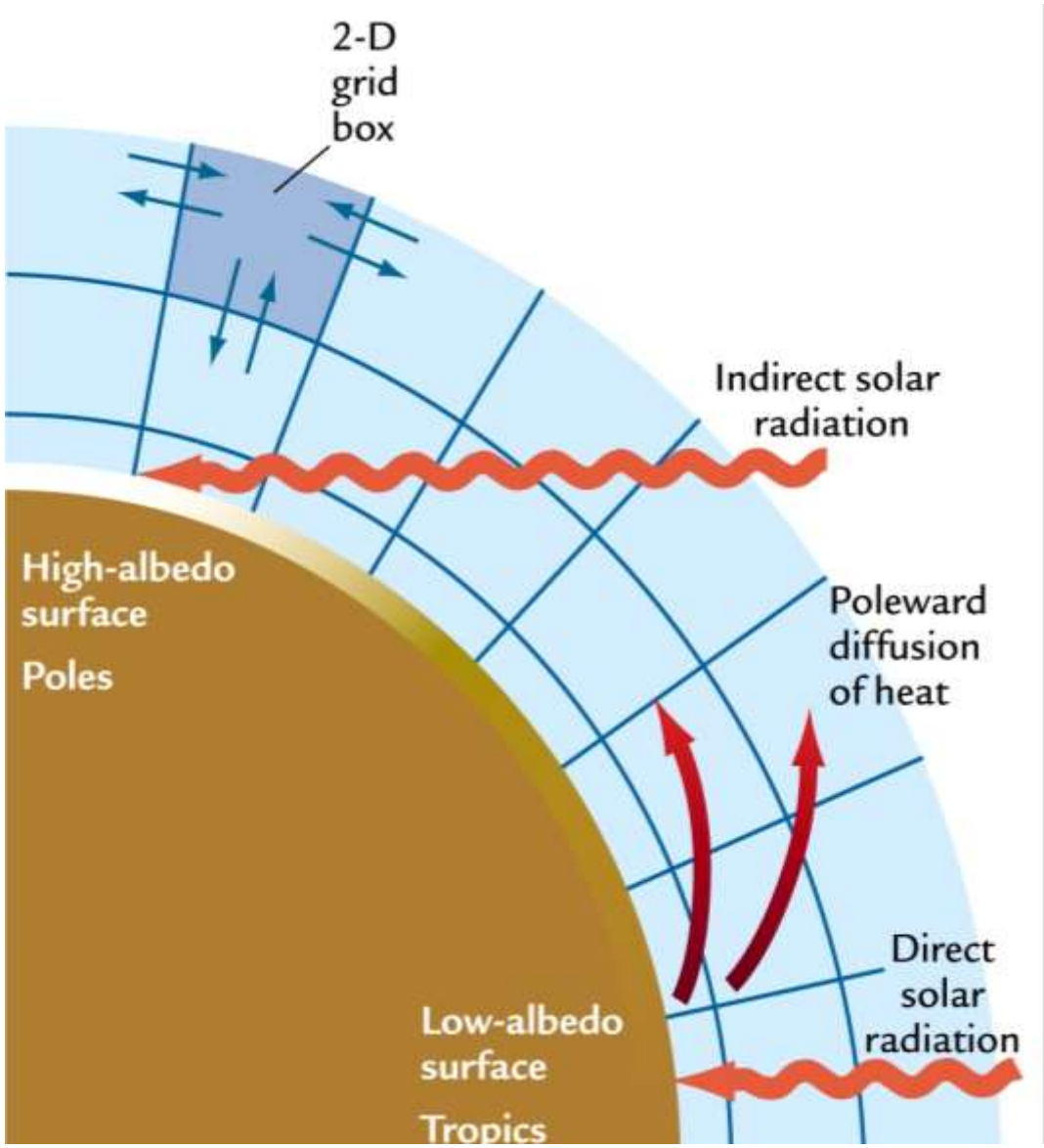
One-Dimensional Climate Models

- Simplified representation of entire planet
  - Model driven by global mean incoming solar radiation and albedo
- Single vertical column of air divided into layers
  - Each layer contains important constituents (dust, greenhouse gases, etc)
  - Layers exchange only vertically



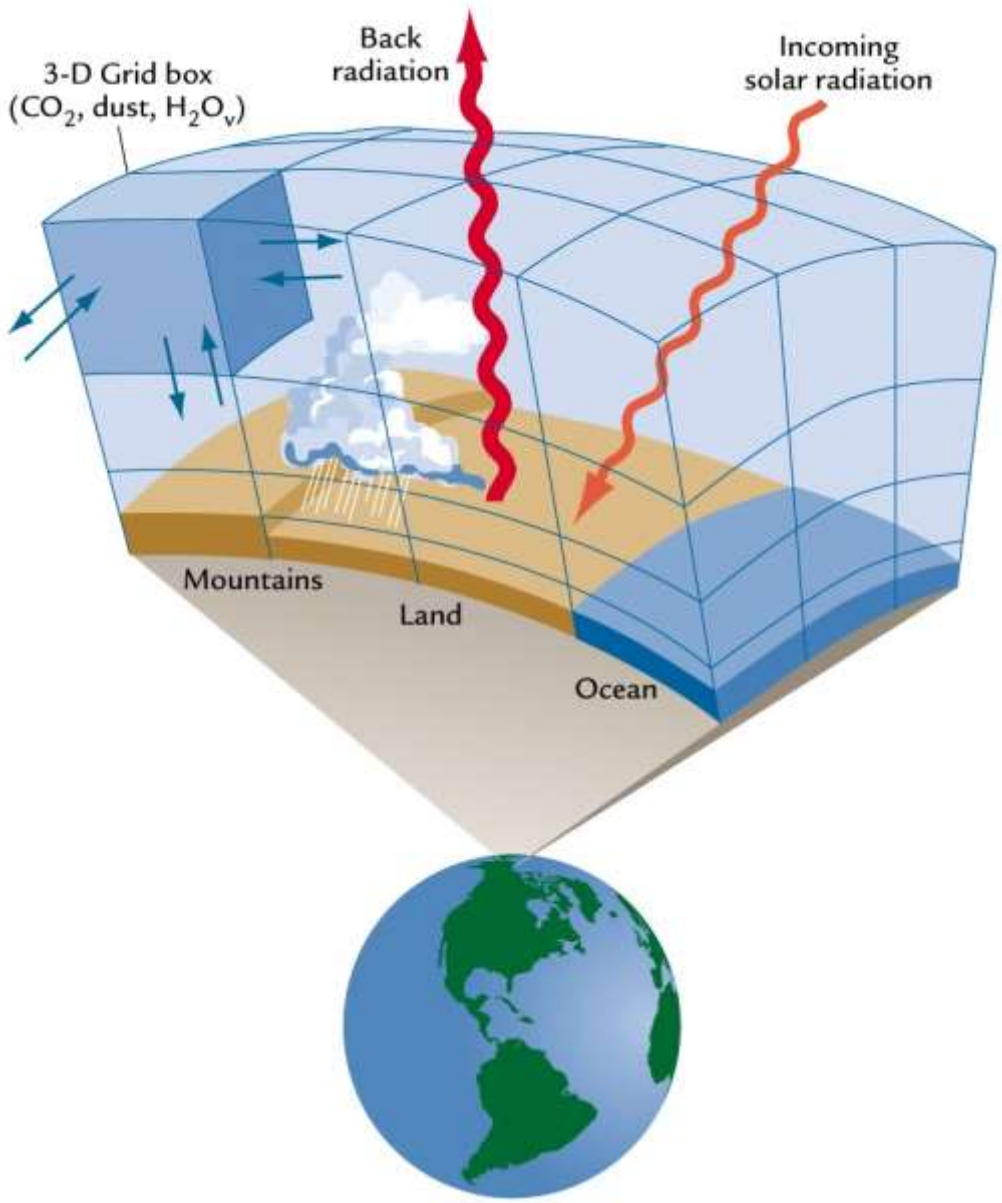
Two-Dimensional Climate Models

- Multi-layered atmosphere coupled with Earth's physical properties averaged by latitude
- Allows simulations of climatic processes that vary with latitude
  - Angle of incoming solar radiation
  - Albedo of Earth's surface
  - Heat capacity changes



Three-Dimensional Climate Model (GCM)

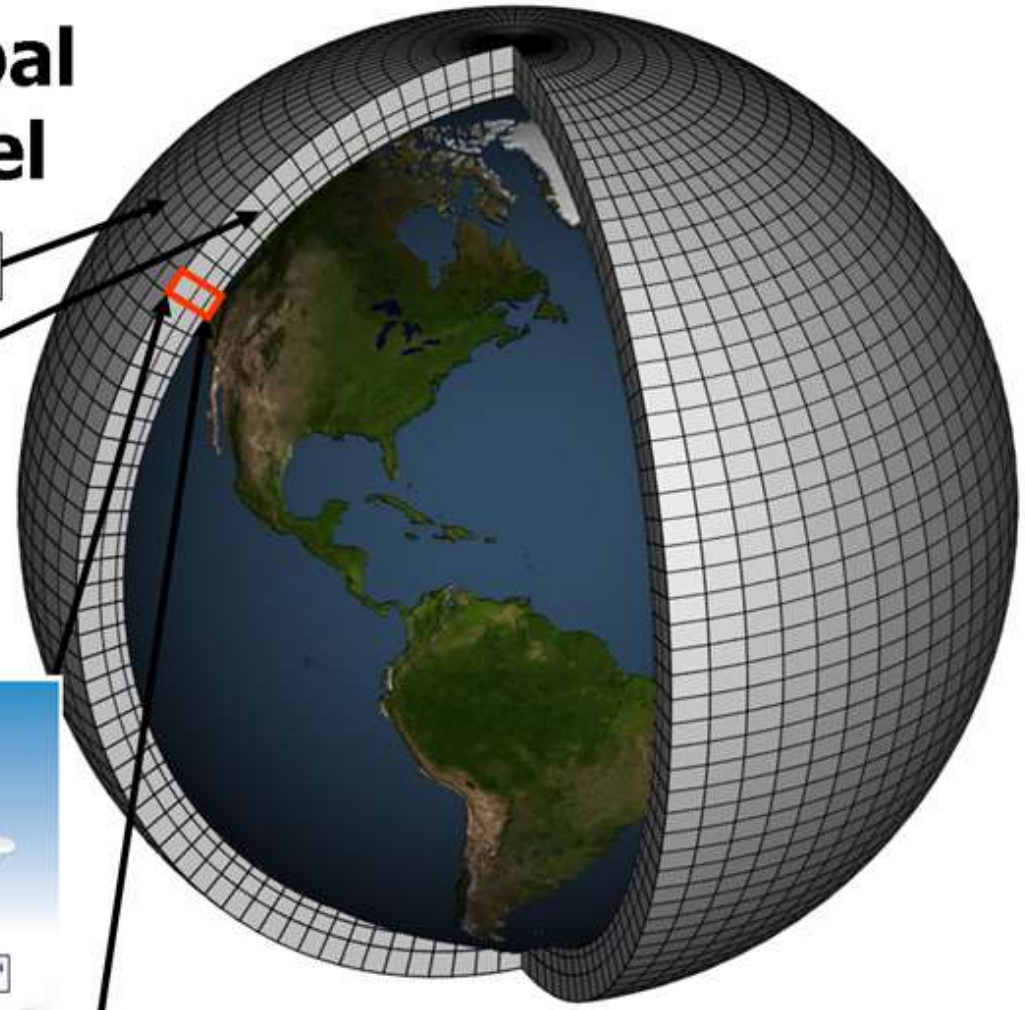
- 3-D representation of Earth's surface and atmosphere
- Most sophisticated attempt to simulate the climate system
- 3-D model based on fundamental laws of physics:
  - Conservation of energy
  - Conservation of momentum
  - Conservation of mass
  - Ideal Gas Law

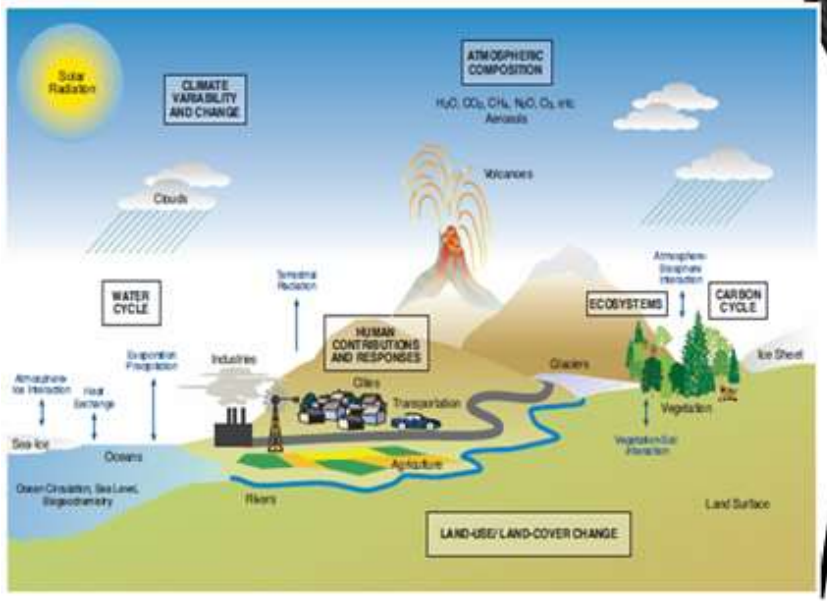


Schematic for Global Atmospheric Model

Horizontal Grid (Latitude-Longitude)

Vertical Grid (Height or Pressure)





Climate Models

- A climate model is a mathematical representation of the physical processes that control climate
- Equations are complicated: Computers are used to solve them
- The most sophisticated climate models are called **General Circulation Models (GCMs)**
- These models attempt to simulate all processes in the atmosphere and ocean relevant to climate

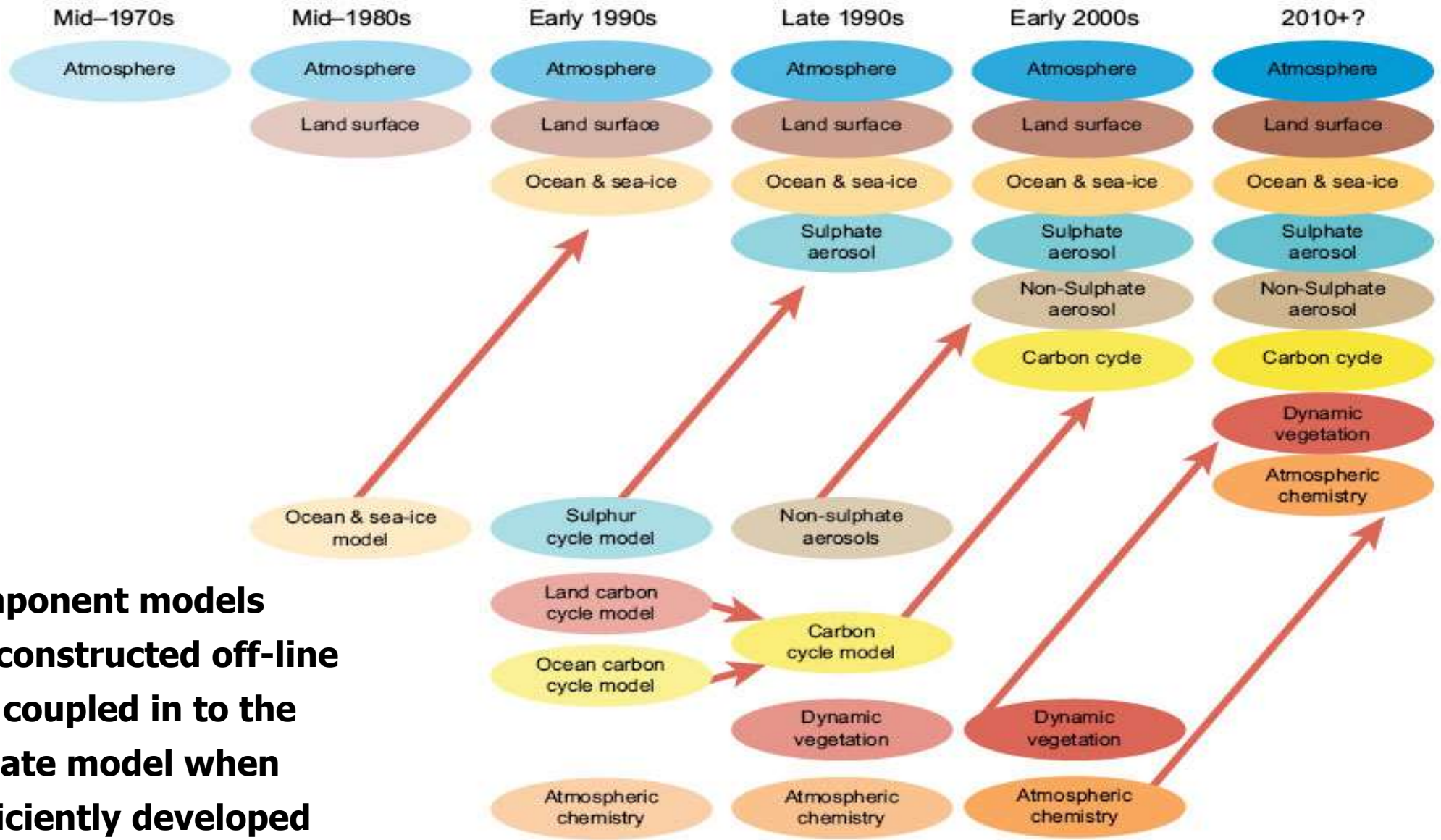
Ultimate purpose of a climate model

- Identify response of the climate system
- Change in the parameters and processes that control the state of the system
- Climate response occurs to restore equilibrium within the climate system
- If radiative forcing associated with an increase in atmospheric CO_2 perturbs the climate system
- Model will assess how the climate system responds to this perturbation to restore equilibrium

What is in a climate model?

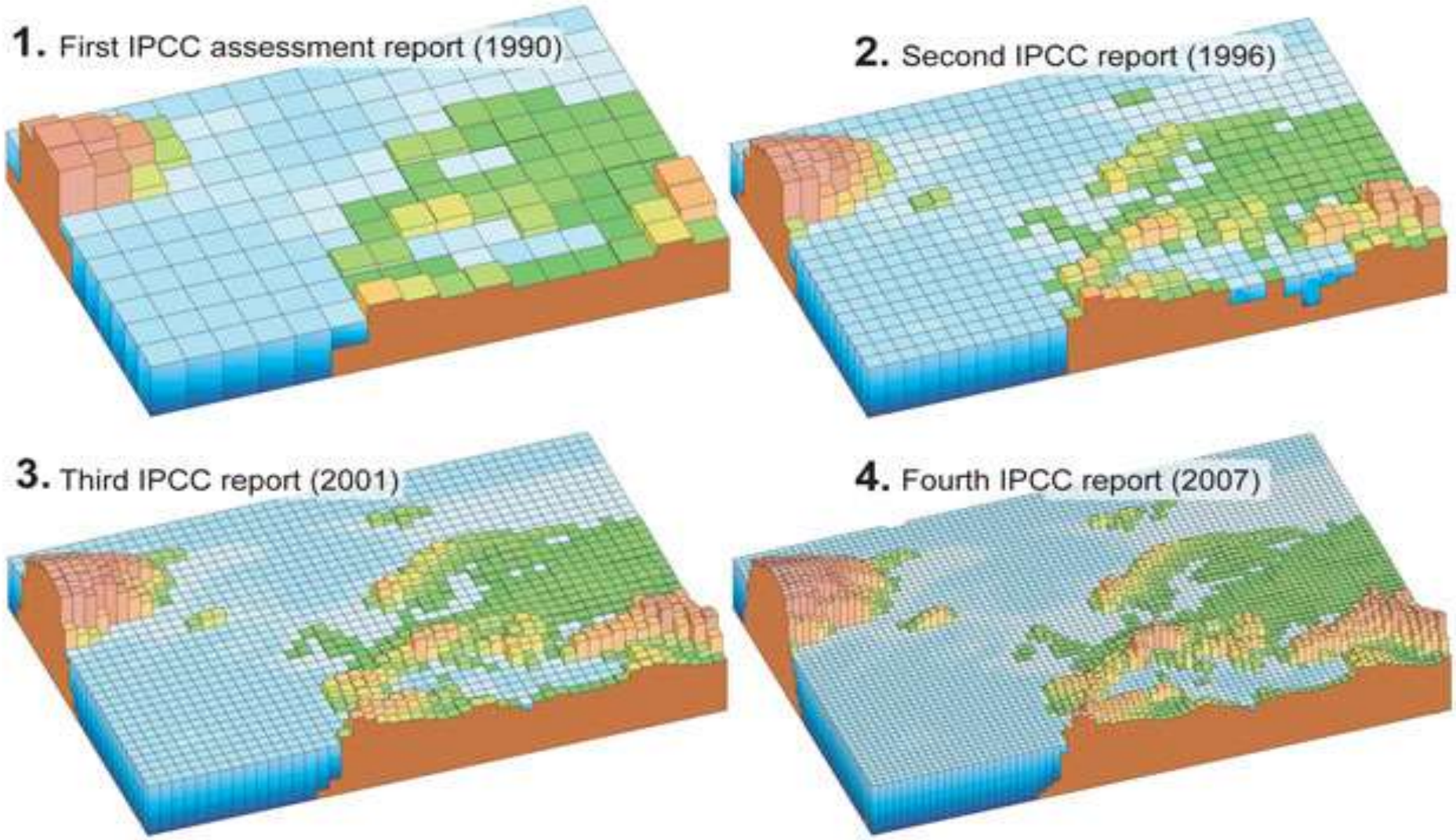
- Atmospheric general circulation model
  - Dynamics
  - Sub-grid scale parameterized physics processes
    - Turbulence, solar/infrared radiation transport, clouds.
- Oceanic general circulation model
  - Dynamics (mostly)
- Sea ice model
  - Viscous elastic plastic dynamics
  - Thermodynamics
- Land Model
  - Energy and moisture budgets
  - Biology
- Chemistry
  - Tracer advection, possibly stiff rate equations.

The Development of Climate Models: Past, Present and Future



Component models are constructed off-line and coupled in to the climate model when sufficiently developed

The resolution of global climate models has improved



Why are climate models so computationally intensive?

- Lots of stuff to calculate!
  - This is why successful climate modeling efforts are collaborations among a diverse set of scientists.
    - Big science.

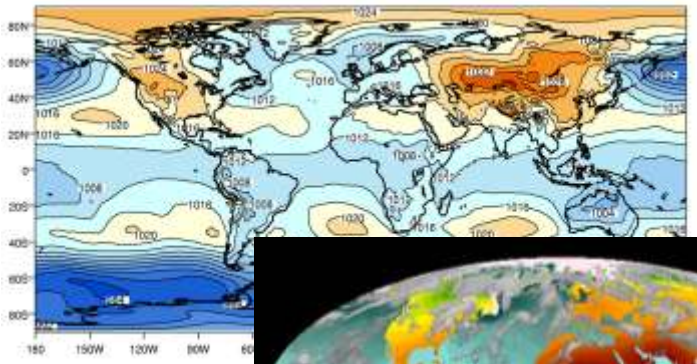
- But this computational burden has other causes.
  - Fundamental cause is that interesting climate change simulations are century scale. Time steps are limited by stability criterion to minute scale.
    - A lot of minutes in a century.

How the climate models performance is evaluated?

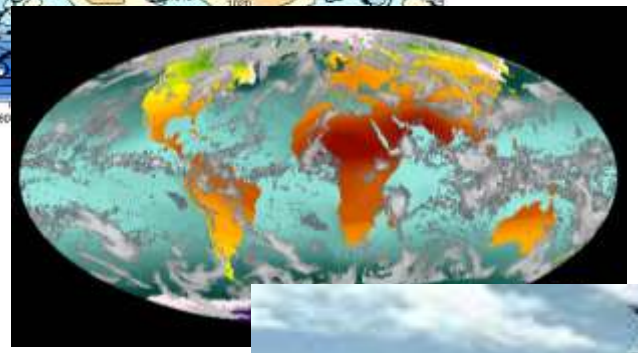
- Does historical climate—and its variability and change— well-simulated?
- How big are differences between model-calculated versions of various climate quantities and corresponding observational estimates?
- Which models perform better than others for certain climate variables?
- Are the definition of scores, the way they compute, the observations that used (which are themselves uncertain to some extent), and the manner in which various scores are combined accurate?
- How the climate projections spanning a century or more regularly verified, particularly as anthropogenic forcing is driving the climate system toward conditions not previously observed in the instrumental record?

To address these questions modellers use:

Observations of the climate:



Re-analyses of the global circulation



Satellite Observations

In situ Measurements

Paleoclimatic reconstructions
(e.g., tree rings, marine sediment cores, ice cores)

Language Problem: Forecast

A **"forecast"** implies that we know (or think we know) all the factors that determine the future

even though we may know them only imperfectly.

Some important factors we do *not* know for the future:

What will humans do about GHG emissions, aerosol generation and land use?

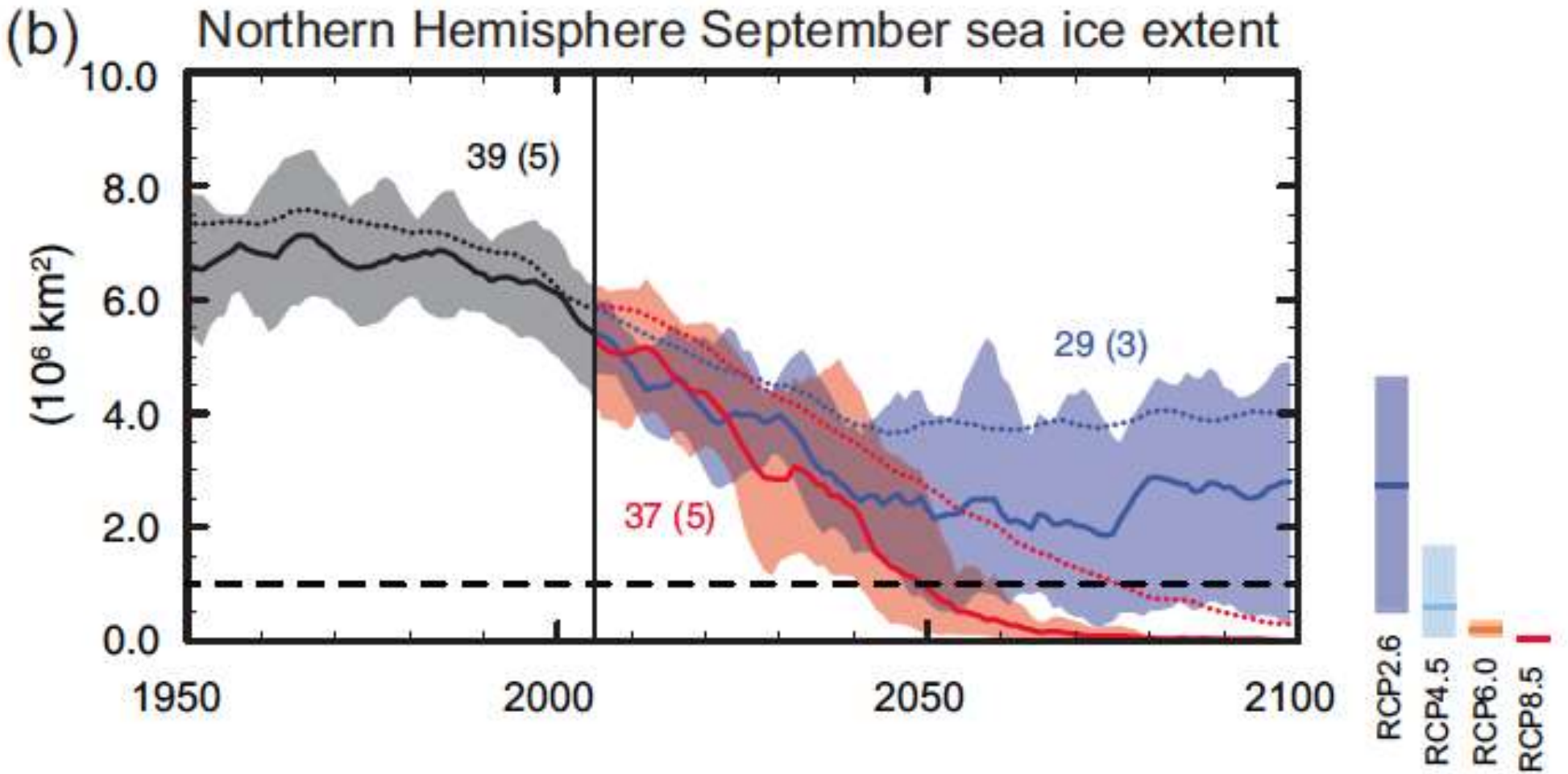
When and where will volcanoes erupt, and how strongly?

Terminology: Projection

To recognize this uncertainty, many climate scientists describe a simulation of possible future climate as a *projection.*

IPCC:
"A *projection* is a potential future evolution of a quantity or set of quantities, often computed with the aid of a model."

How good are climate models?



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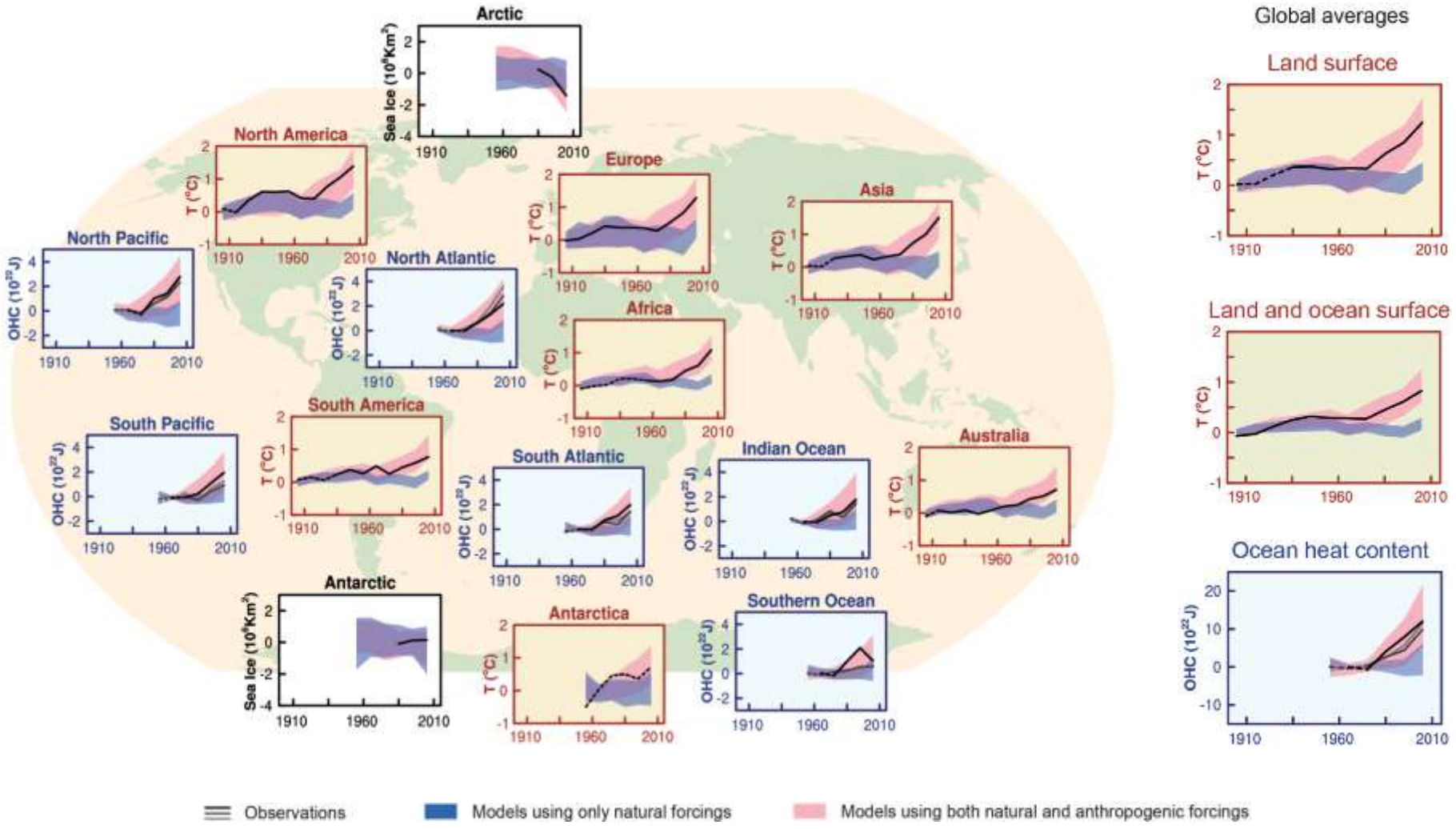

Summary

- Basics of the climate system
- Definition of climate model
- Climate model components
- Climate model development
- Climate change projections