GCMs

Global Climate Models

Global Circulation Models

What is a GCM?

- A GCM is a three-dimensional global climate model
  - Models run for thousands of years
- Models are derived from **fundamental physical laws** which are modified to approximate the large-scale climate system.
  - 23 models were used in the AR4
  - Notable progress in recent years

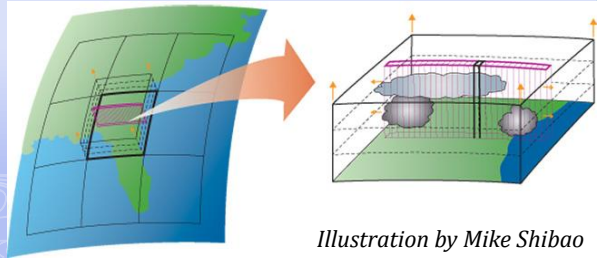


Illustration by Mike Shibao

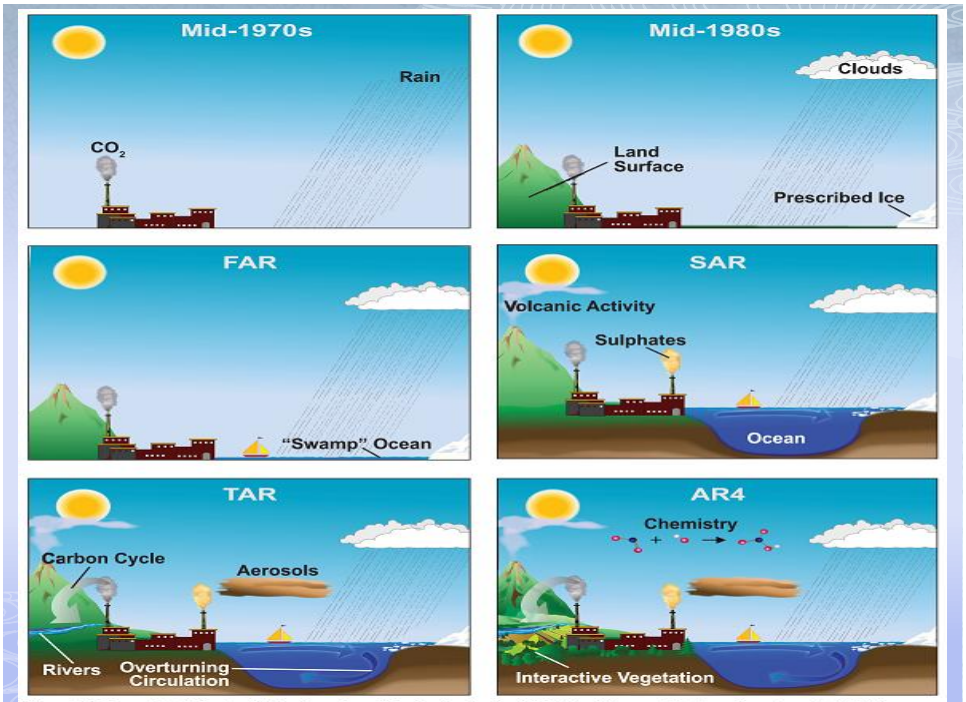
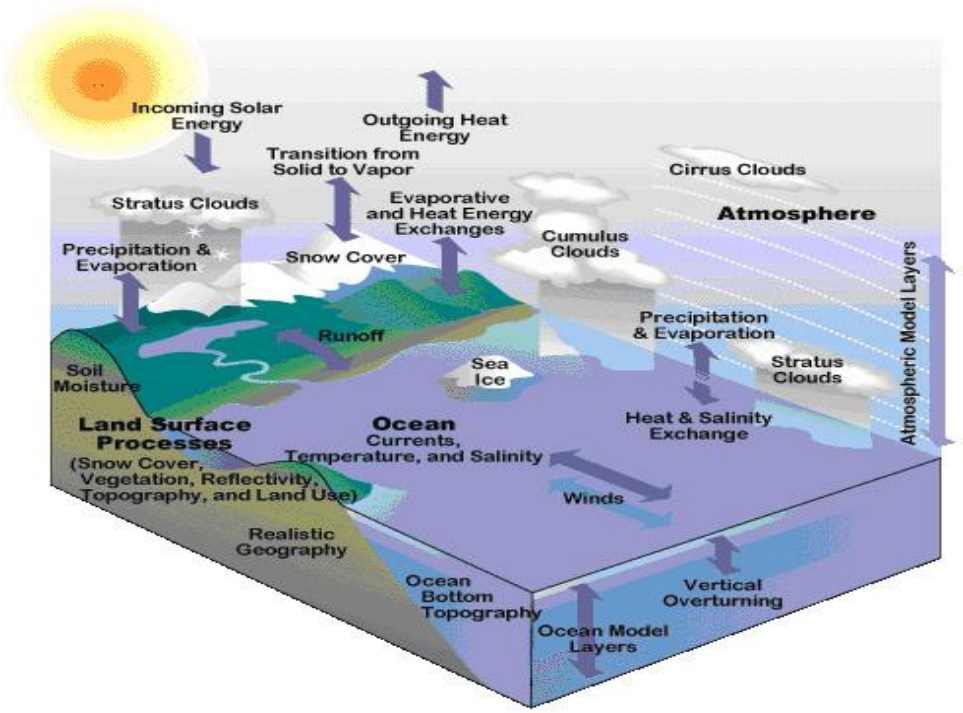
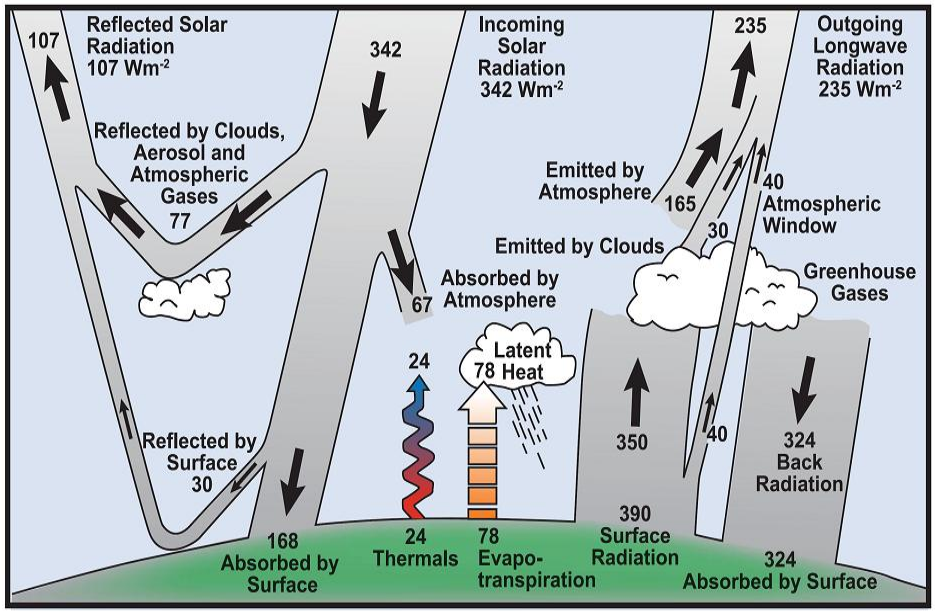
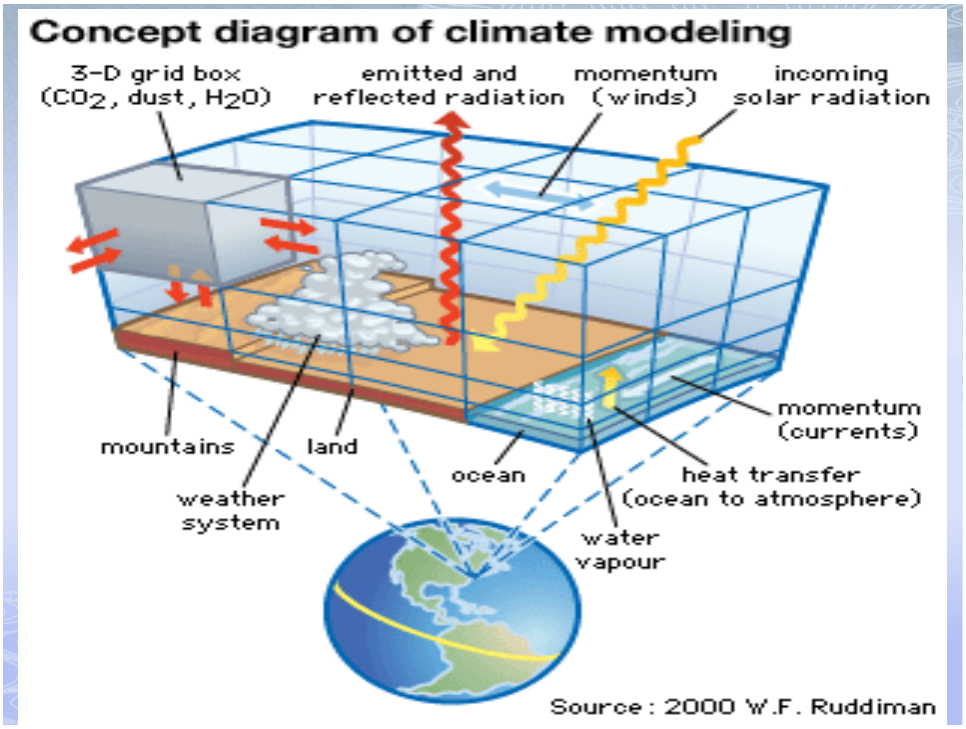


Figure 1.2. *The complexity of climate models has increased over the last few decades. The additional physics incorporated in the models are shown pictorially by the different features of the modelled world.*





FAQ 1.1, Figure 1. *Estimate of the Earth's annual and global mean energy balance. Over the long term, the amount of incoming solar radiation absorbed by the Earth and atmosphere is balanced by the Earth and atmosphere releasing the same amount of outgoing longwave radiation. About half of the incoming solar radiation is absorbed by the Earth's surface. This energy is transferred to the atmosphere by warming the air in contact with the surface (thermals), by evapotranspiration and by longwave radiation that is absorbed by clouds and greenhouse gases. The atmosphere in turn radiates longwave energy back to Earth as well as out to space. Source: Kiehl and Trenberth (1997).*



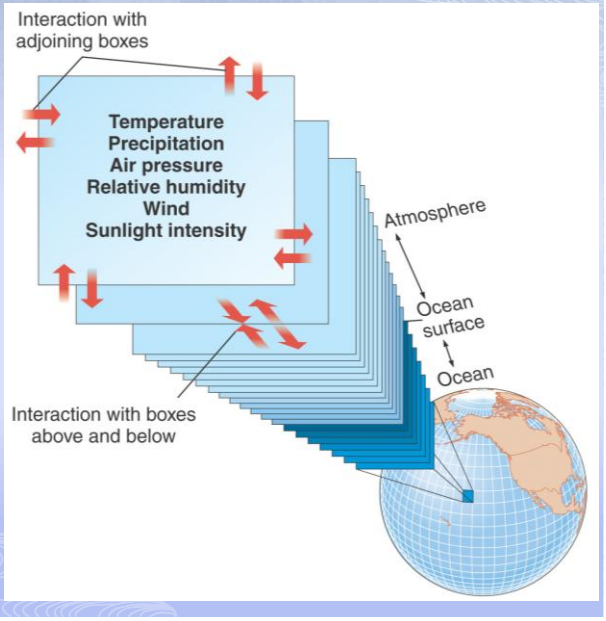
Basic Equations of a GCM (Hansen et al., 1983)

- Conservation of momentum
  $\frac{\partial \vec{V}}{\partial t} = -(\vec{V} \cdot \nabla)\vec{V} - \frac{1}{\rho}\nabla p - \vec{g} - 2\vec{\Omega} \times \vec{V} + \nabla \cdot (k_m \nabla \vec{V}) - \vec{F}_d$
- Conservation of energy
  $\rho c_{\vec{V}} \frac{\partial T}{\partial t} = -\rho c_{\vec{V}} (\vec{V} \cdot \nabla) T - \nabla \cdot \vec{R} + \nabla \cdot (k_T \nabla T) + C + S$
- Conservation of mass
  $\frac{\partial \rho}{\partial t} = -(\vec{V} \cdot \nabla)\rho - \rho(\nabla \cdot \vec{V})$
- Conservation of H_2O (vapor, liquid, solid)
  $\frac{\partial q}{\partial t} = -(\vec{V} \cdot \nabla) q + \nabla \cdot (k_q \nabla q) + S_q + E$
- Equation of state
  $p = \rho R_d T$

What about resolution?

- **Computational constraints** limit the resolution that is possible in model equations.

  three-dimensional models
  - Atmosphere:
    2° x 2°, on average
  - Ocean:
    1.5° x 1.5°, on average



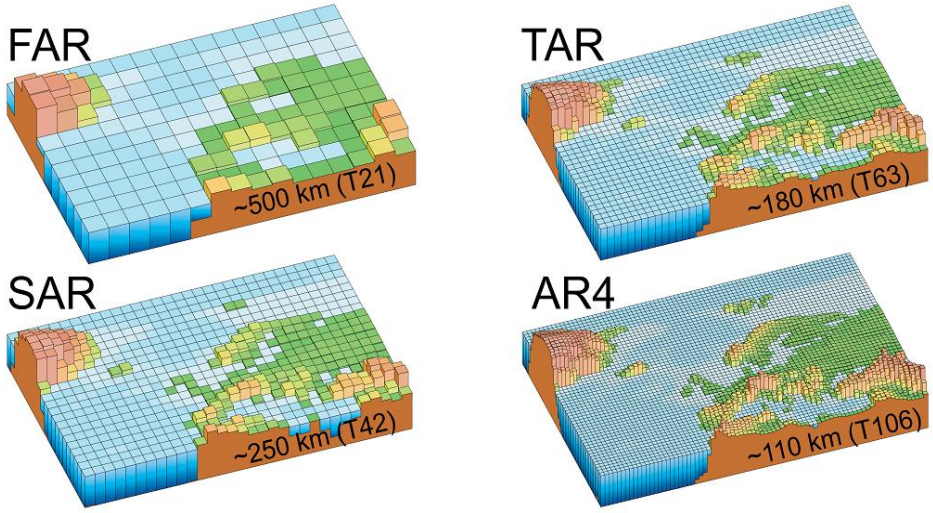
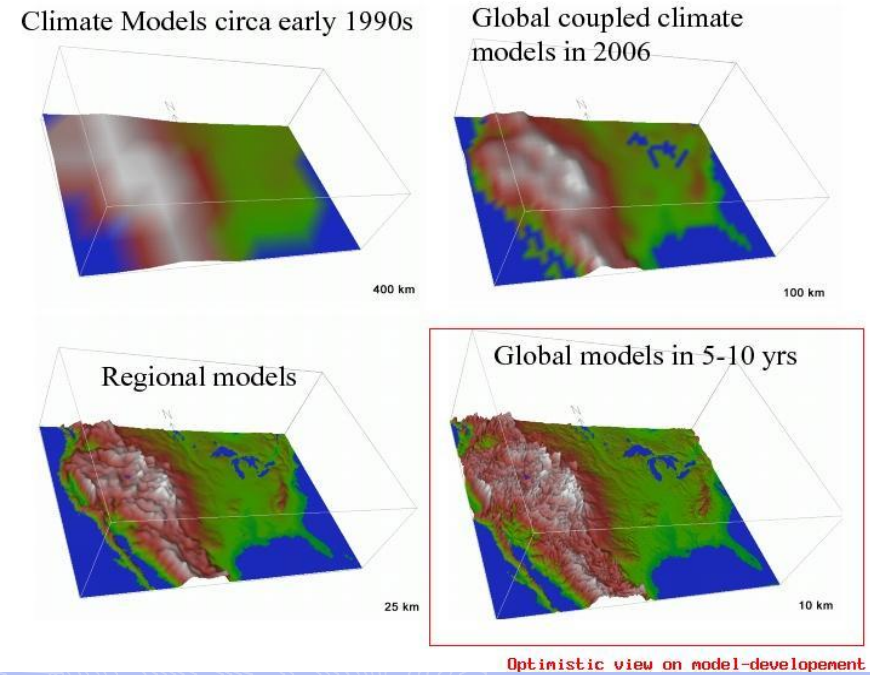
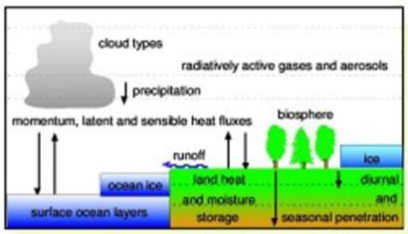


Figure 1.4. *Geographic resolution characteristic of the generations of climate models used in the IPCC Assessment Reports: FAR (IPCC, 1990), SAR (IPCC, 1996), TAR (IPCC, 2001a), and AR4 (2007). The figures above show how successive generations of these global models increasingly resolved northern Europe. 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.*



Optimistic view on model-developement

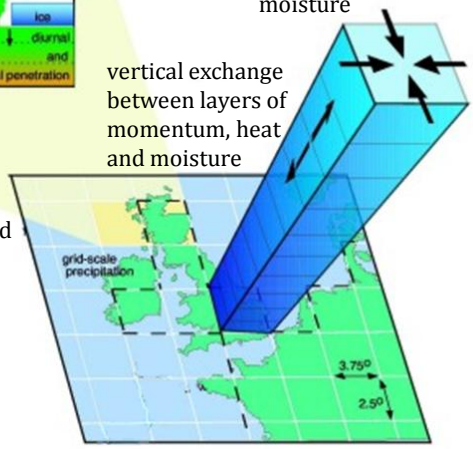
Atmospheric GCMs (AGCM)



Horizontal exchange between columns of momentum, heat and moisture

vertical exchange between layers of momentum, heat and moisture

orography, vegetation and surface characteristics included at surface on each grid box



Dr. David Vinter, 1998, 2002

Combined GCMs (AOGCM)