GCMs

Global Climate Models

Global Circulation Models
Fall 2009

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

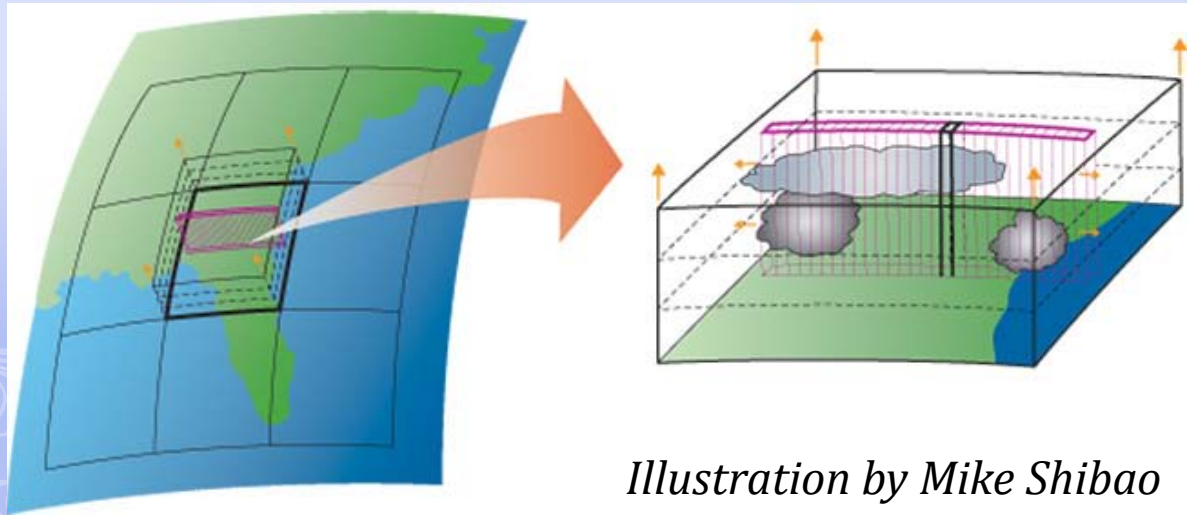


Illustration by Mike Shibao

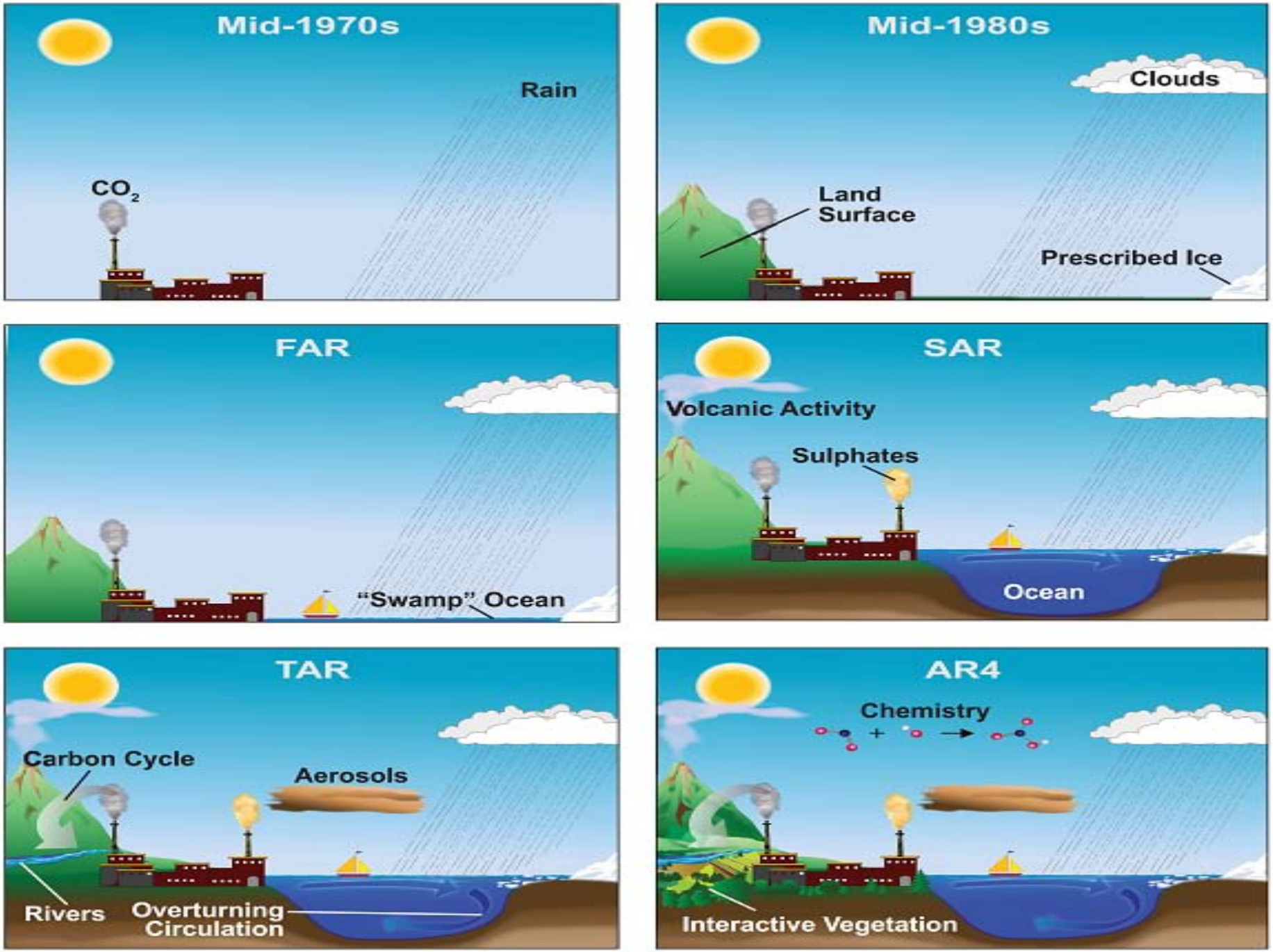
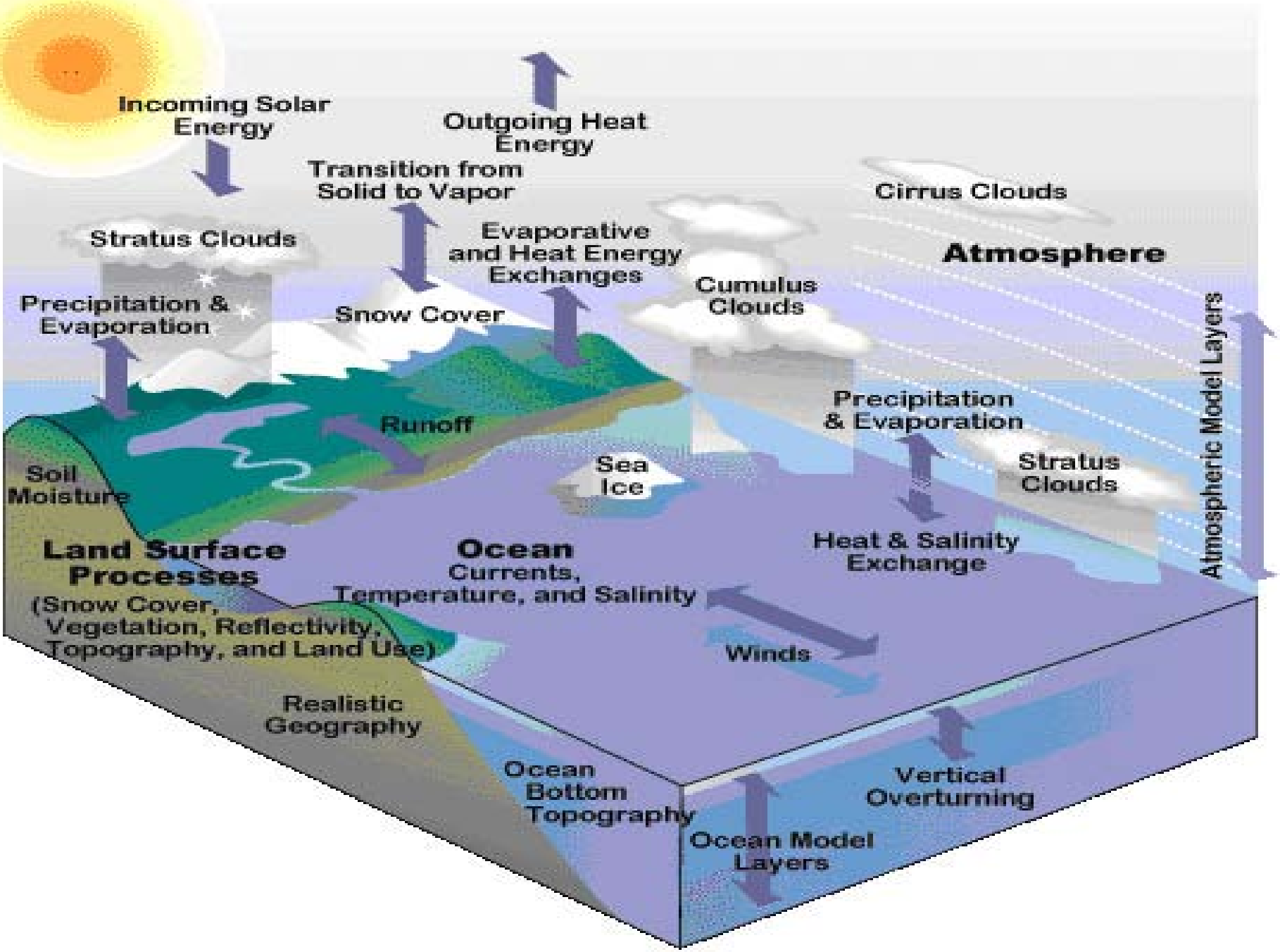
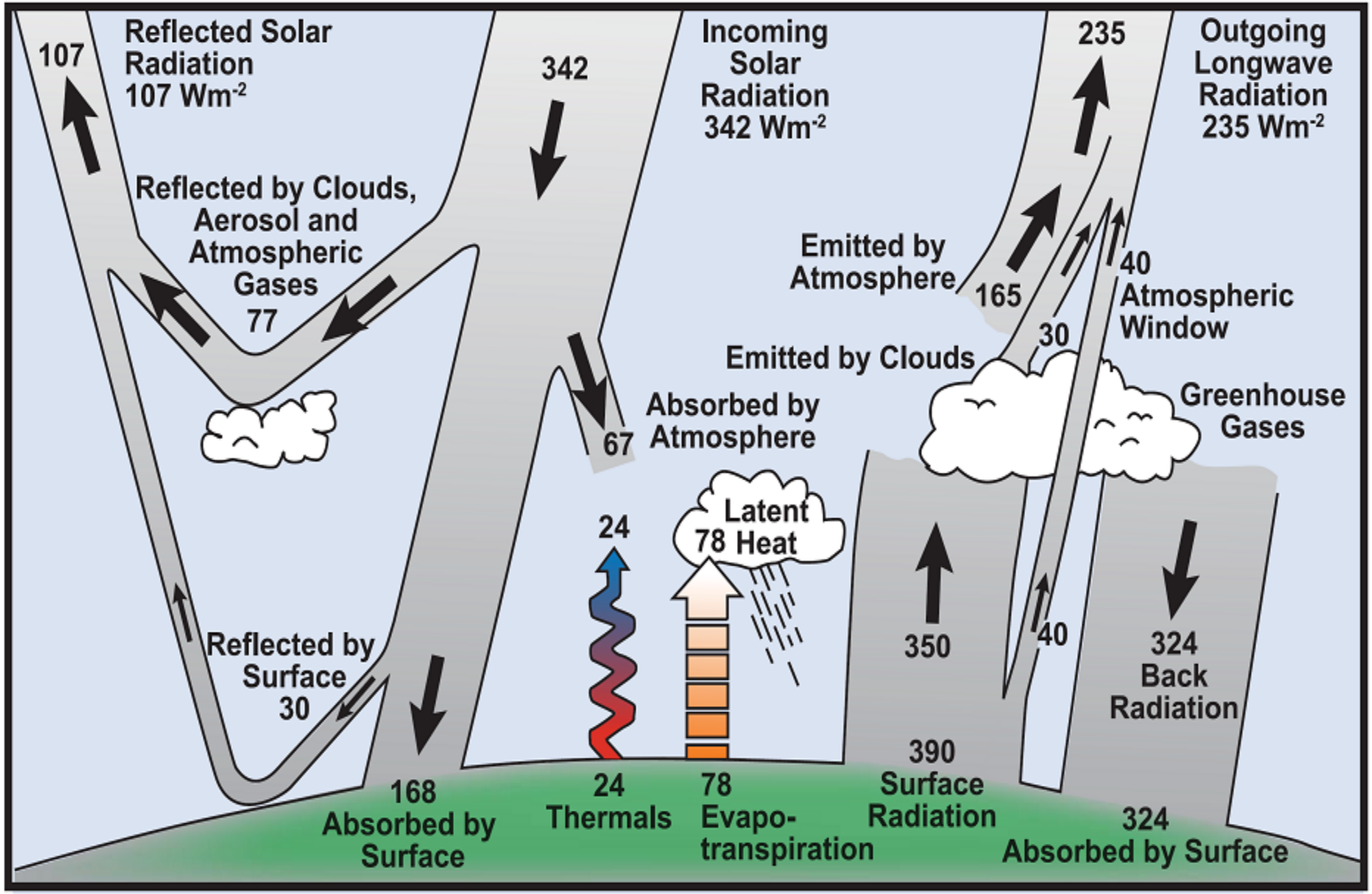


Figure 1.2. *The complexity of climate models has increased over the last few decades. The additional physics incorporated in the models are shown pictorially by the different features of the modelled world.*

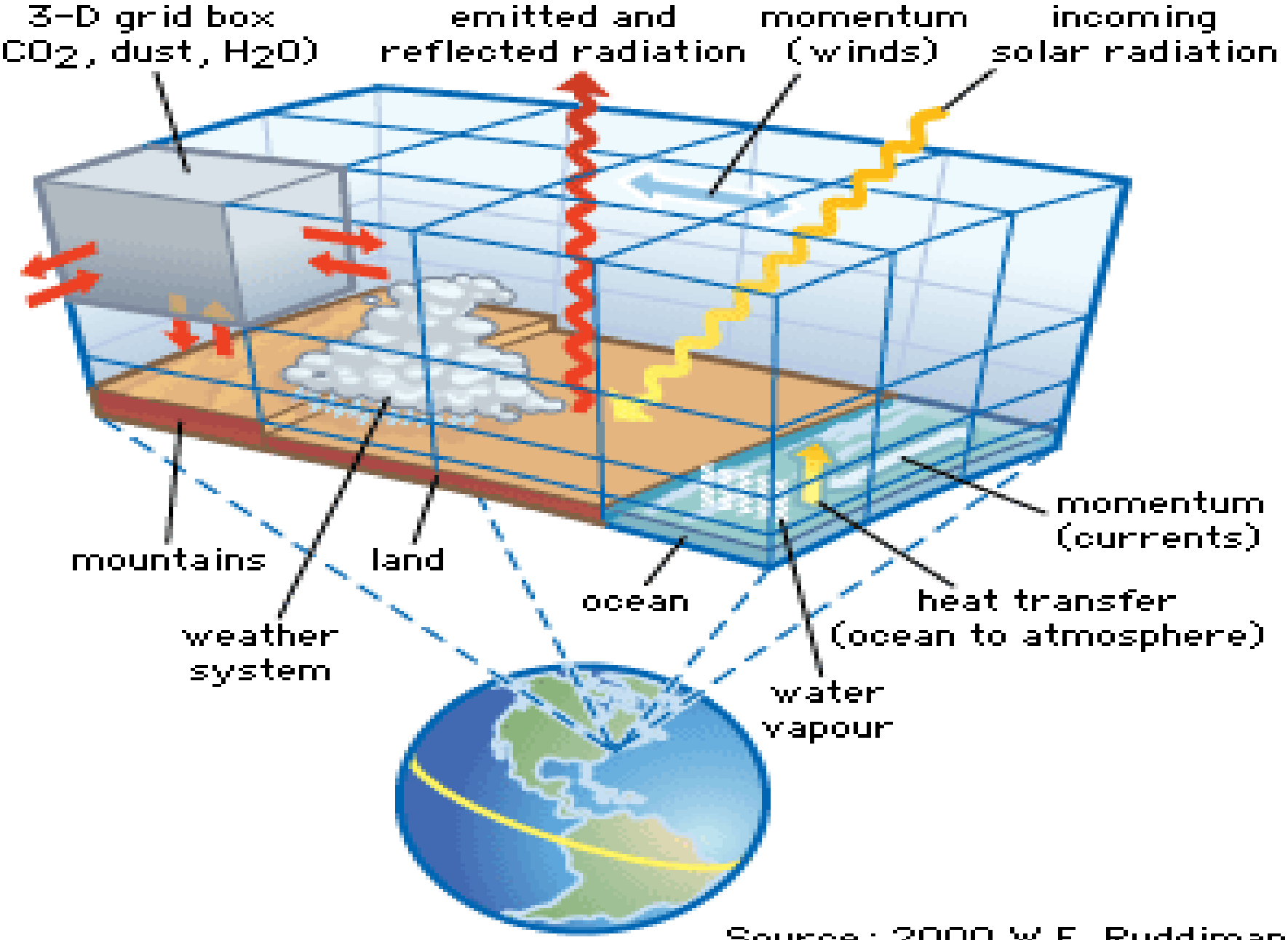

Incoming Solar Energy
Outgoing Heat Energy
Transition from Solid to Vapor
Cirrus Clouds
Stratus Clouds
Evaporative and Heat Energy Exchanges
Atmosphere
Precipitation & Evaporation
Snow Cover
Cumulus Clouds
Runoff
Precipitation & Evaporation
Atmospheric Model Layers
Soil Moisture
Sea Ice
Stratus Clouds
Land Surface Processes
(Snow Cover, Vegetation, Reflectivity, Topography, and Land Use)
Ocean
Currents, Temperature, and Salinity
Heat & Salinity Exchange
Winds
Realistic Geography
Ocean Bottom Topography
Vertical Overturning
Ocean Model Layers


The Earth Simulator Center



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).*

Concept diagram of climate modeling



Source : 2000 W.F. Ruddiman

What about resolution?

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

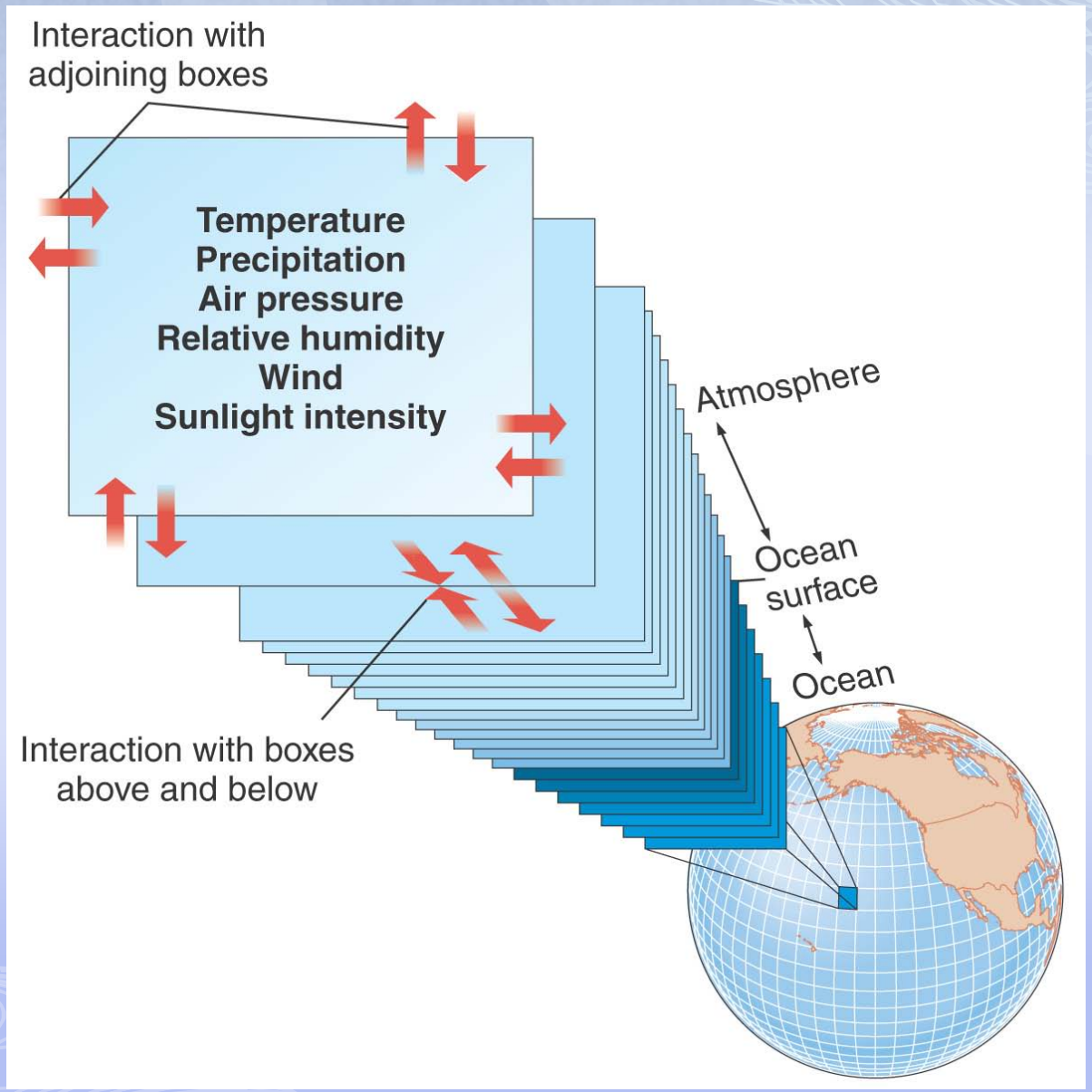
  three-dimensional models

  - Atmosphere:

    2° x 2°, on average

  - Ocean:

    1.5° x 1.5°, on average



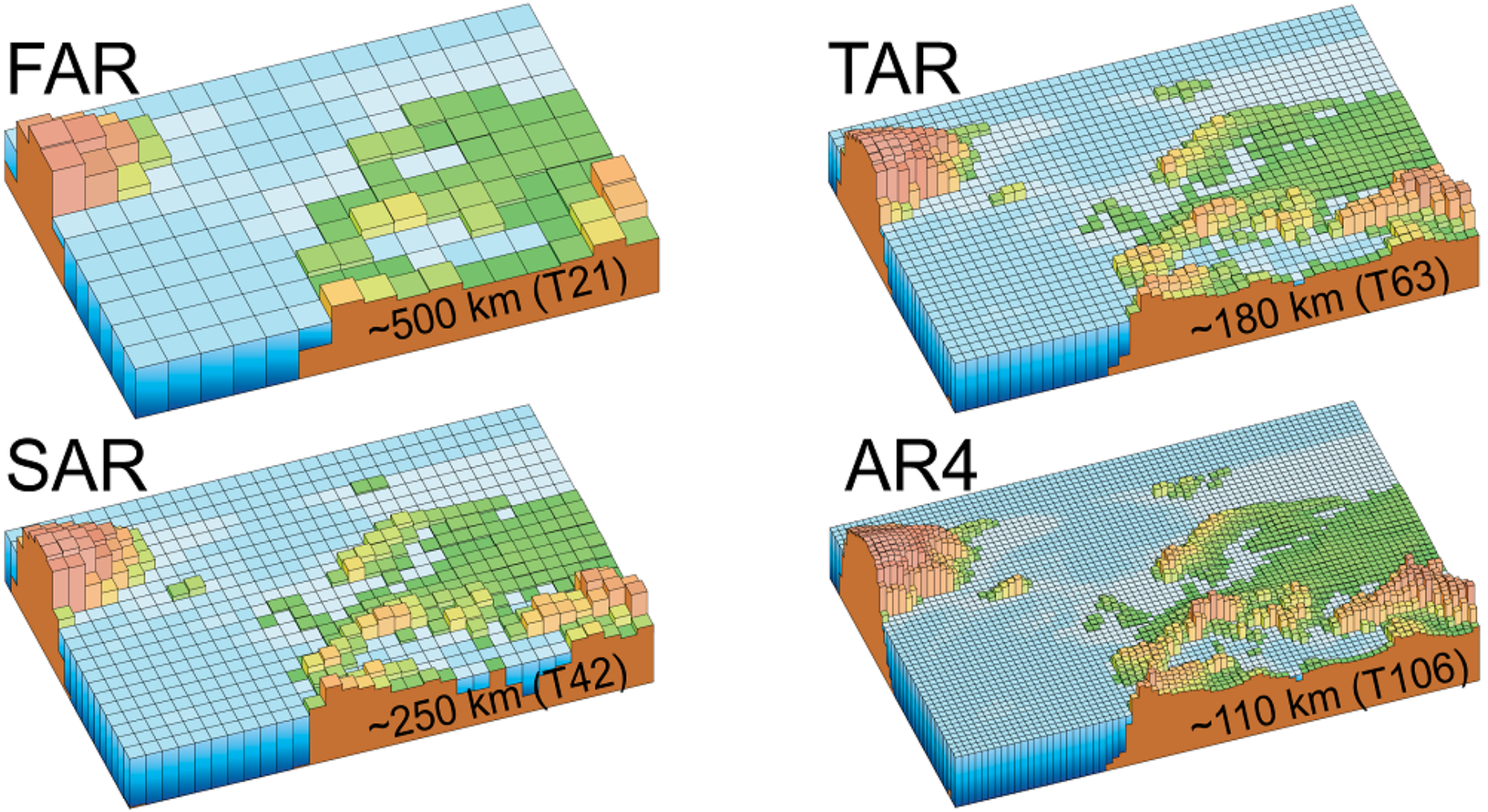
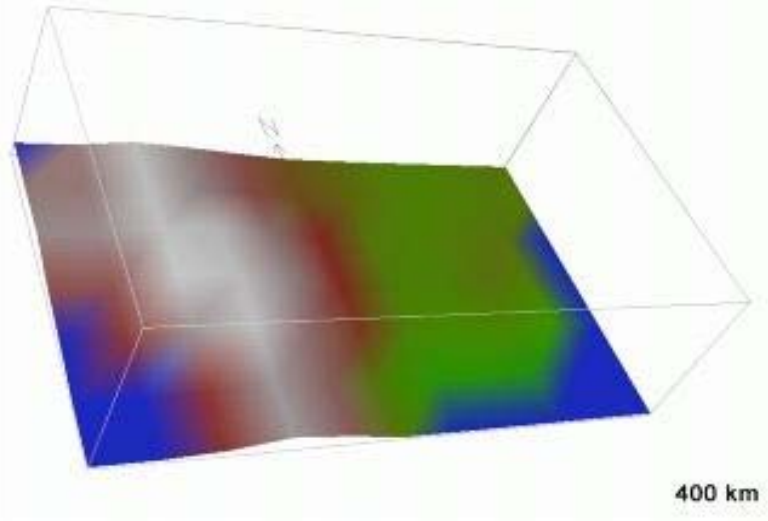
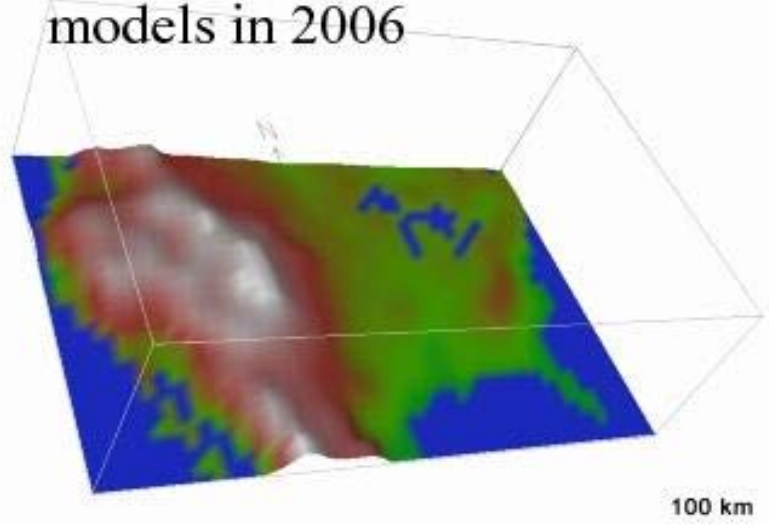


Figure 1.4. *Geographic resolution characteristic of the generations of climate models used in the IPCC Assessment Reports: FAR (IPCC, 1990), SAR (IPCC, 1996), TAR (IPCC, 2001a), and AR4 (2007). The figures above show how successive generations of these global models increasingly resolved northern Europe.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

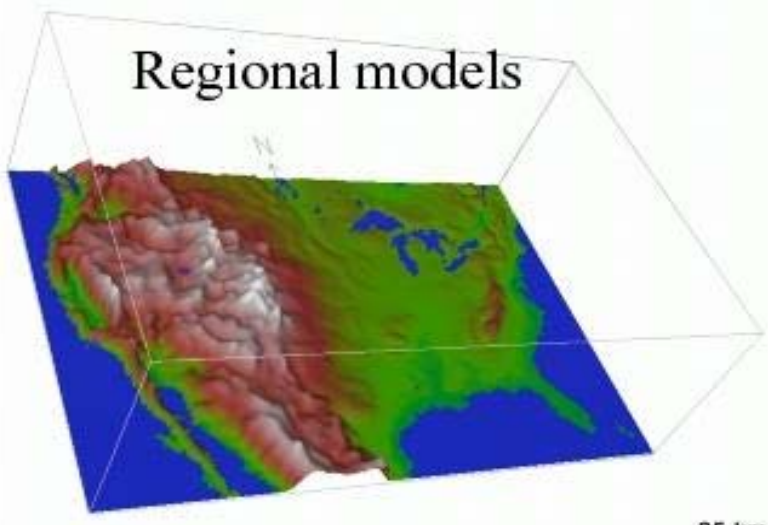
Climate Models circa early 1990s



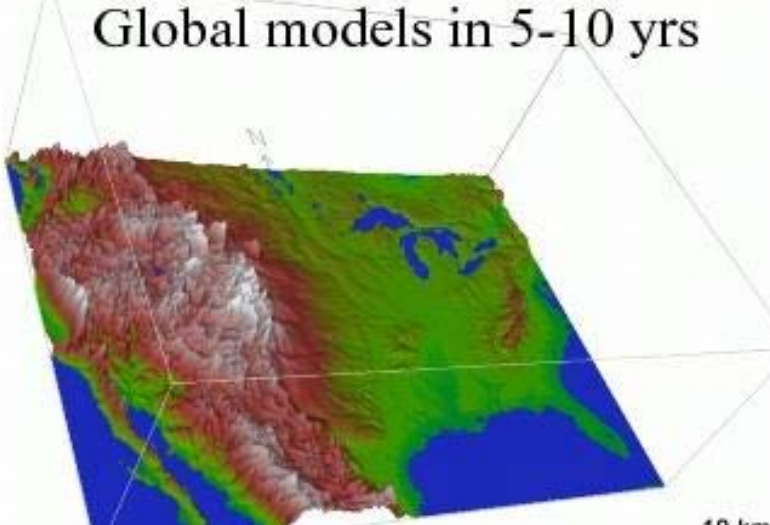
Global coupled climate models in 2006



Regional models

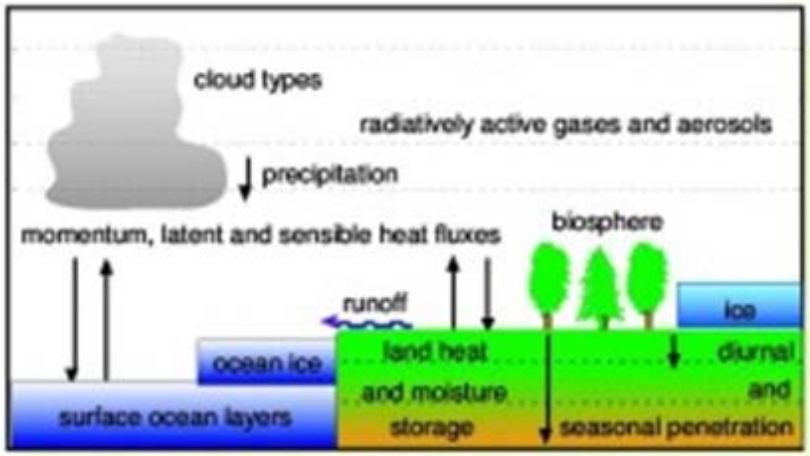


Global models in 5-10 yrs



Optimistic view on model-developement

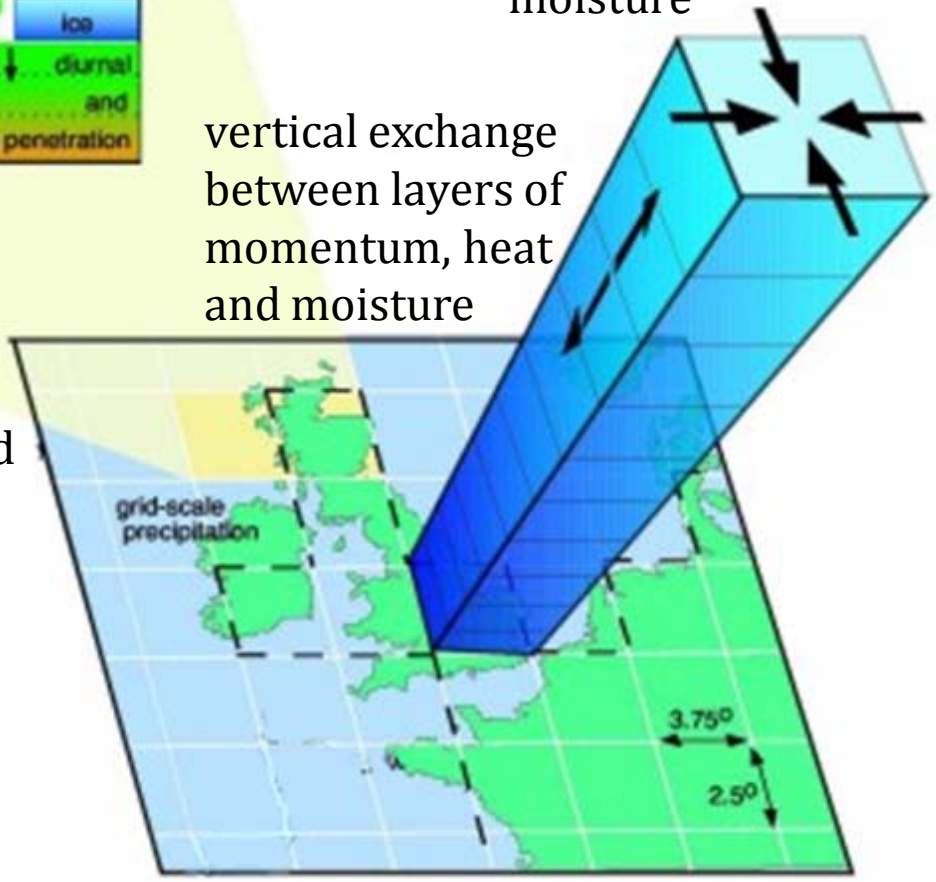
Atmospheric GCMs (AGCM)



Horizontal exchange between columns of momentum, heat and moisture

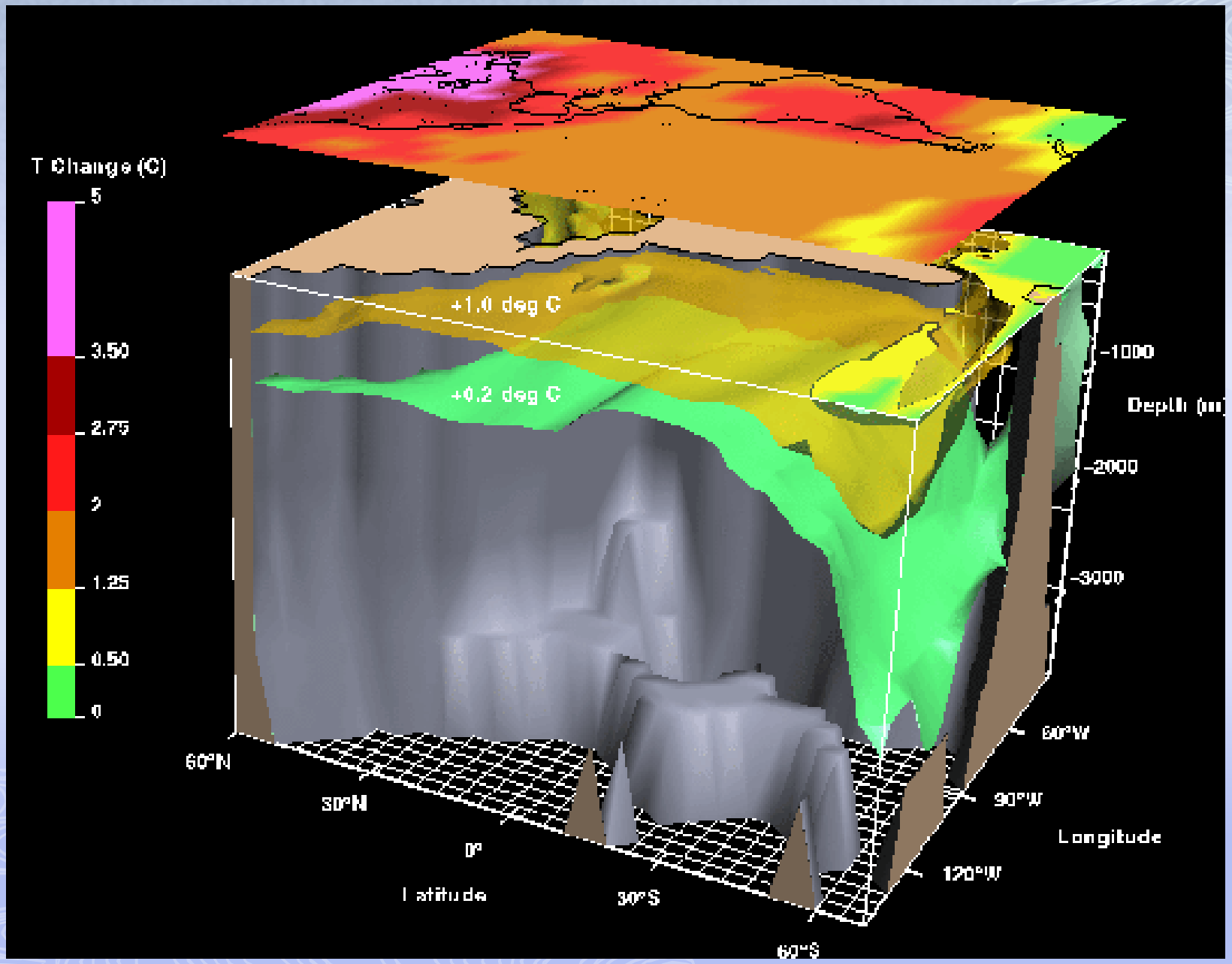
vertical exchange between layers of momentum, heat and moisture

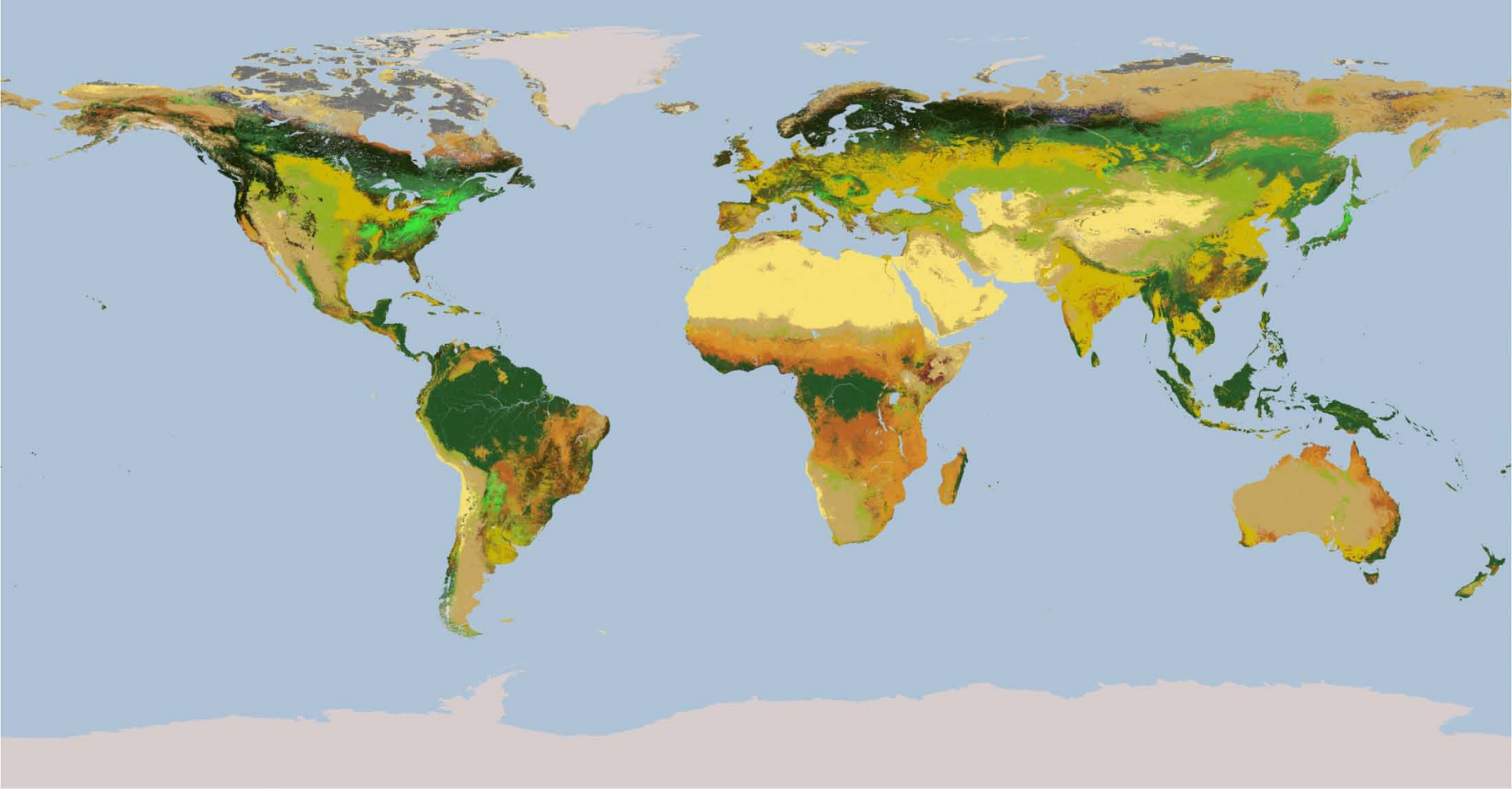
orography, vegetation and surface characteristics included at surface on each grid box

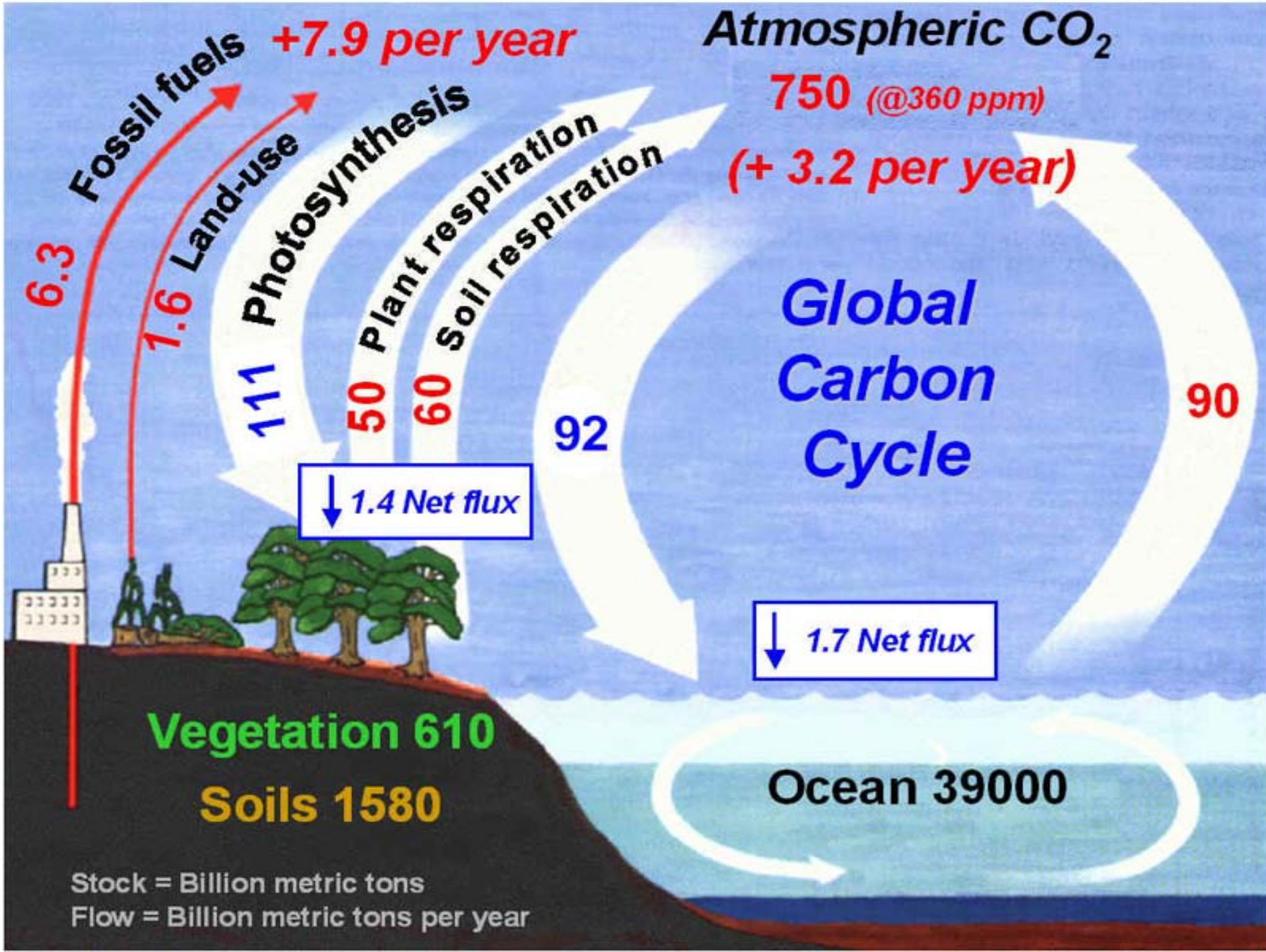


Dr. David Vinter, 1998, 2002

Combined GCMs (AOGCM)




0 Water
1 Evergreen Needleleaf Forest
2 Evergreen Broadleaf Forest
3 Deciduous Needleleaf Forest
4 Deciduous Broadleaf Forest
5 Mixed Forests
6 Closed Shrublands
7 Open Shrublands
8 Woody Savannas
9 Savannas
10 Grasslands
11 Permanent Wetlands
12 Croplands
13 Urban and Built-Up
14 Cropland/Natural Veg. Mosaic
15 Snow and Ice
16 Barren or Sparsely Vegetated
17 Tundra


Fossil fuels
+7.9 per year
Atmospheric CO_2
750 (@360 ppm)
(+ 3.2 per year)
6.3
Land-use
1.6
Photosynthesis
111
Plant respiration
50
Soil respiration
60
92
Global Carbon Cycle
90
1.4 Net flux
1.7 Net flux
Vegetation 610
Soils 1580
Ocean 39000
Stock = Billion metric tons
Flow = Billion metric tons per year

Special Report on Emissions Scenarios (SRES)

- Available at http://www.grida.no/climate/ipcc/emission/
- 4 storylines
  - Consider future greenhouse gas pollution, land-use change, and other driving forces
  - Peak Oil is *not* discussed
  - *Do not* include additional climate initiatives (e.g., UNFCCC or Kyoto Protocol emissions targets
- 40 different scenarios, grouped by family into the storylines
  - These are not predictions or forecasts!
  - There is NO "best guess" scenario
  - Scenarios are NOT policy recommendations
- 6 scenario groups are considered equally sound and span a wide range of uncertainty

SRES: A1 Storyline – A more integrated world

- Rapid economic growth (~3%/year to 2100)
  - Strong commitment to market-based solutions
- Global population reaches 9 billion in 2050 and gradually declines
- Quick spread of new and efficient technologies
  - High rates of investment and innovation at national & international level
- Convergent world
  - Income and way of life converge between regions
  - Extensive social and cultural interactions worldwide

SRES: A1 Storyline Subsets

- A1F1
  - Emphasis on fossil fuels
- A1B
  - Balanced emphasis on all energy sources
- A1T
  - Emphasis on non-fossil energy sources

SRES: A2 Storyline – A more divided world

- World of independently operating, self-reliant nations (lower trade flow, less international cooperation)
- Continuously increasing population (15 billion by 2100)
- Regionally oriented economic development
  - Self-reliance and preservation of local identities
- Slower and more fragmented technological changes and improvements to per capita income
  - Primary changes in agricultural productivity to feed the 15 billion

SRES: B1 Storyline – A more integrated, more ecologically friendly world

- High level of environmental and social consciousness; globally coherent approach to more sustainable development

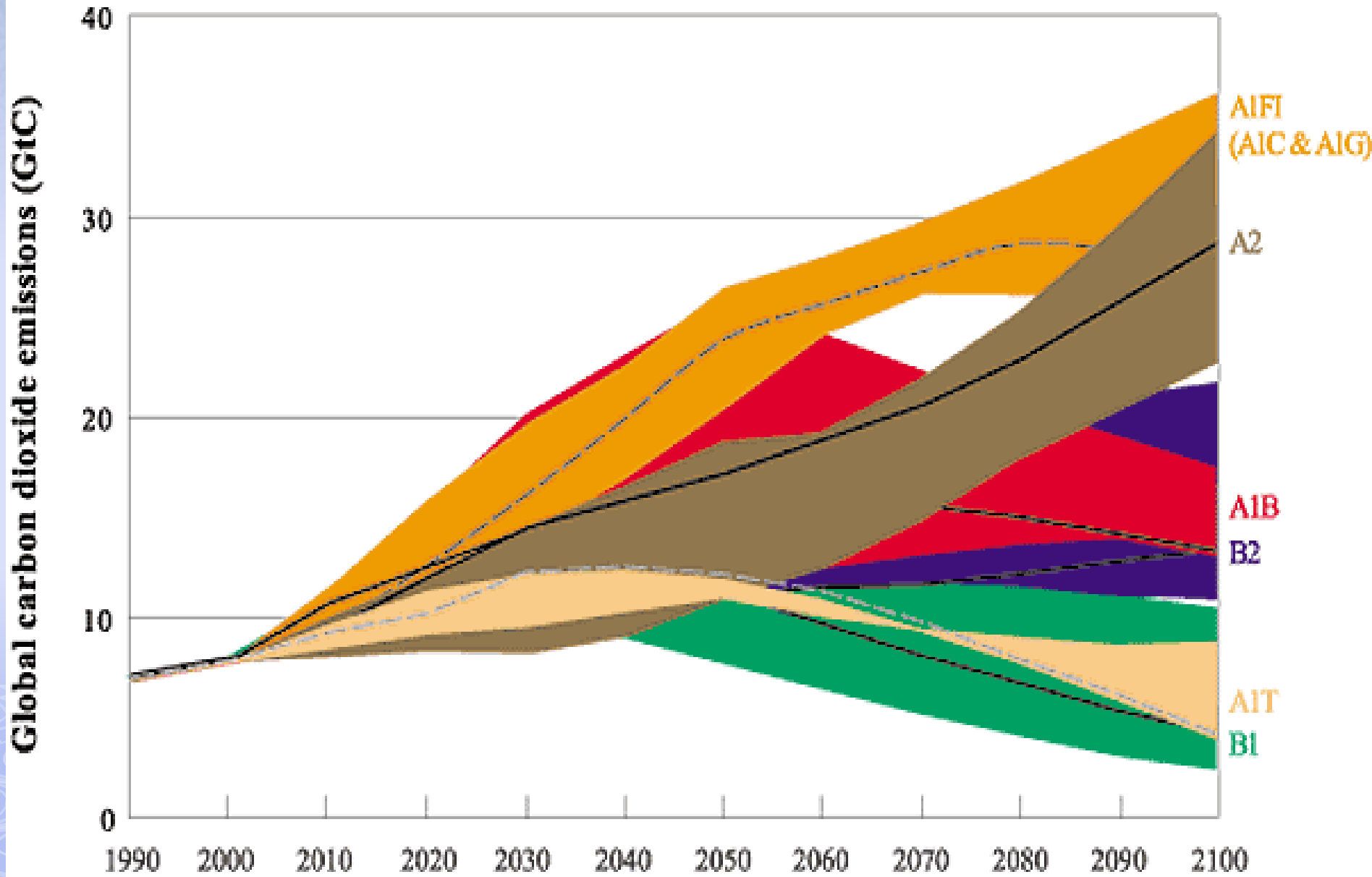
- Rapid economic growth as in A1, but with rapid changes towards a service and information economy
- Global population reaches 9 billion in 2050 and gradually declines as in A1
- Reductions in material intensity and the introduction of clean and resource efficient technologies
  - Smooth transition to alternative energy systems as conventional oil and gas resources decline
- Emphasis on global solutions to economic, social and environmental stability

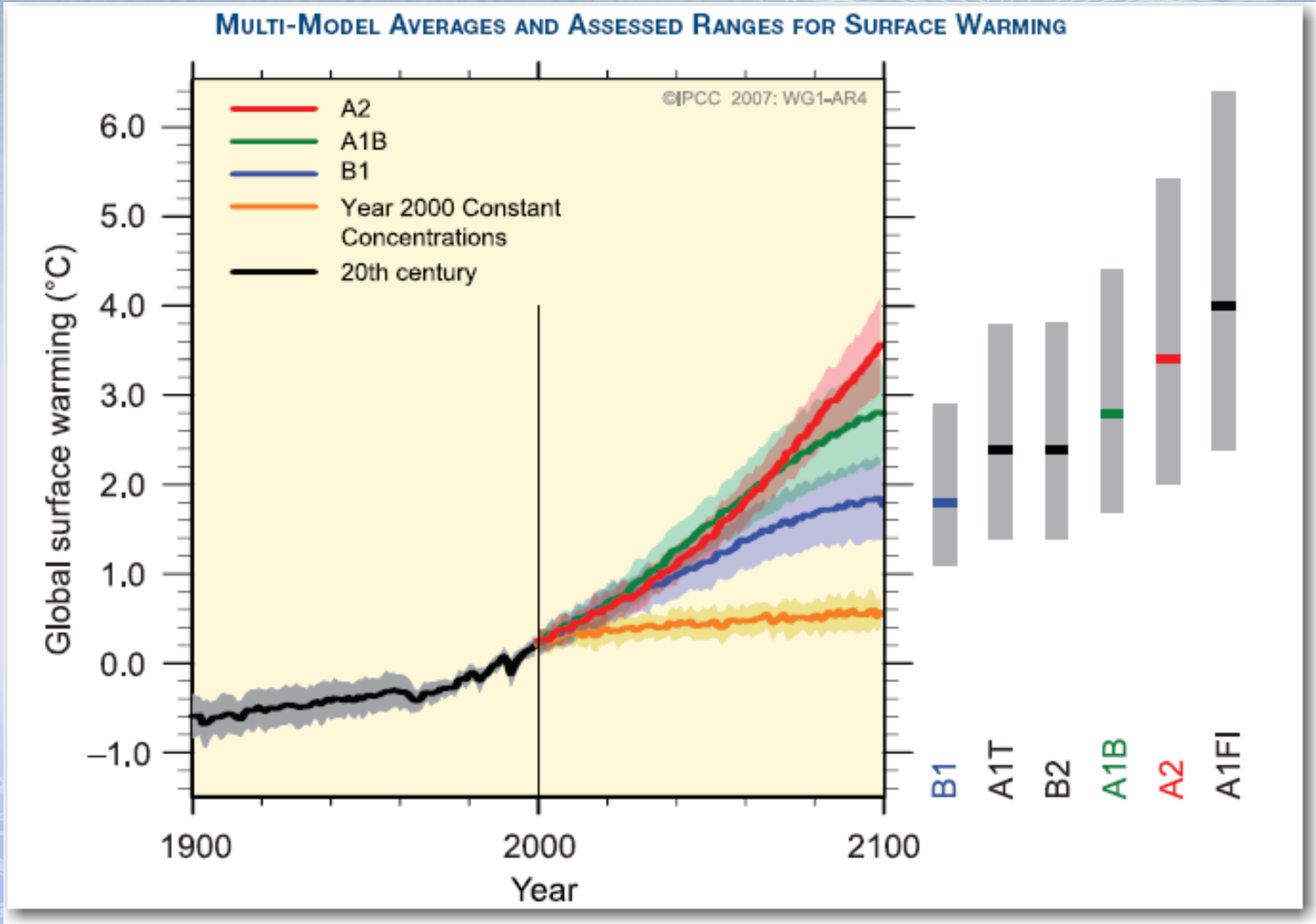
SRES: B2 Storyline – A more divided, but more ecologically friendly world

- Increased concern for environmental and social sustainability compared to A2, with shift to local and regional decisions

- Continuously increasing population, but at a slower rate than in A2
- Emphasis on local, rather than global, solutions to economic, social and environmental stability
- Intermediate levels of economic development
- Less rapid and more fragmented technological change than in B1 & A1.

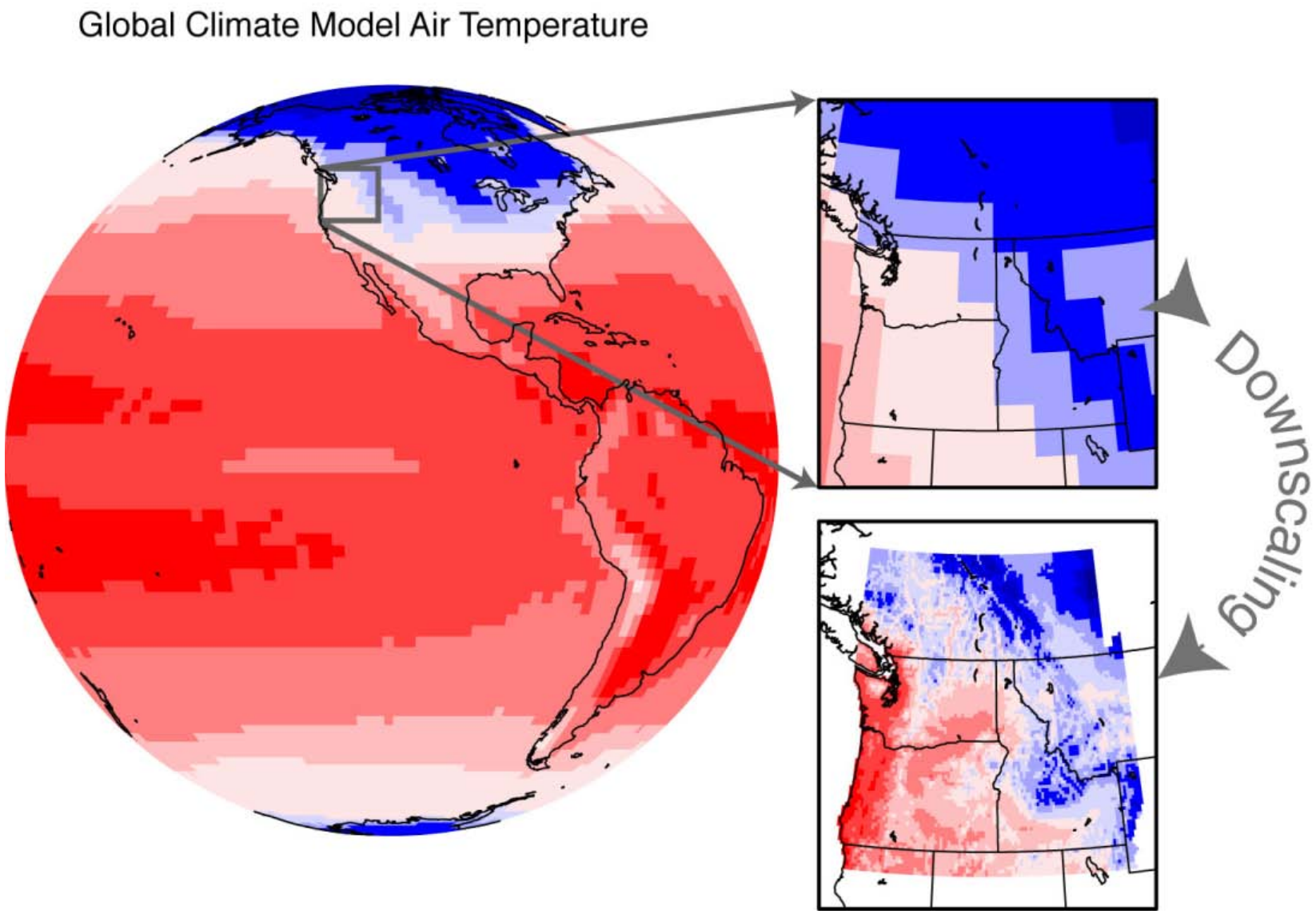
Global annual CO_2 emissions – all sources (6 scenario groups)



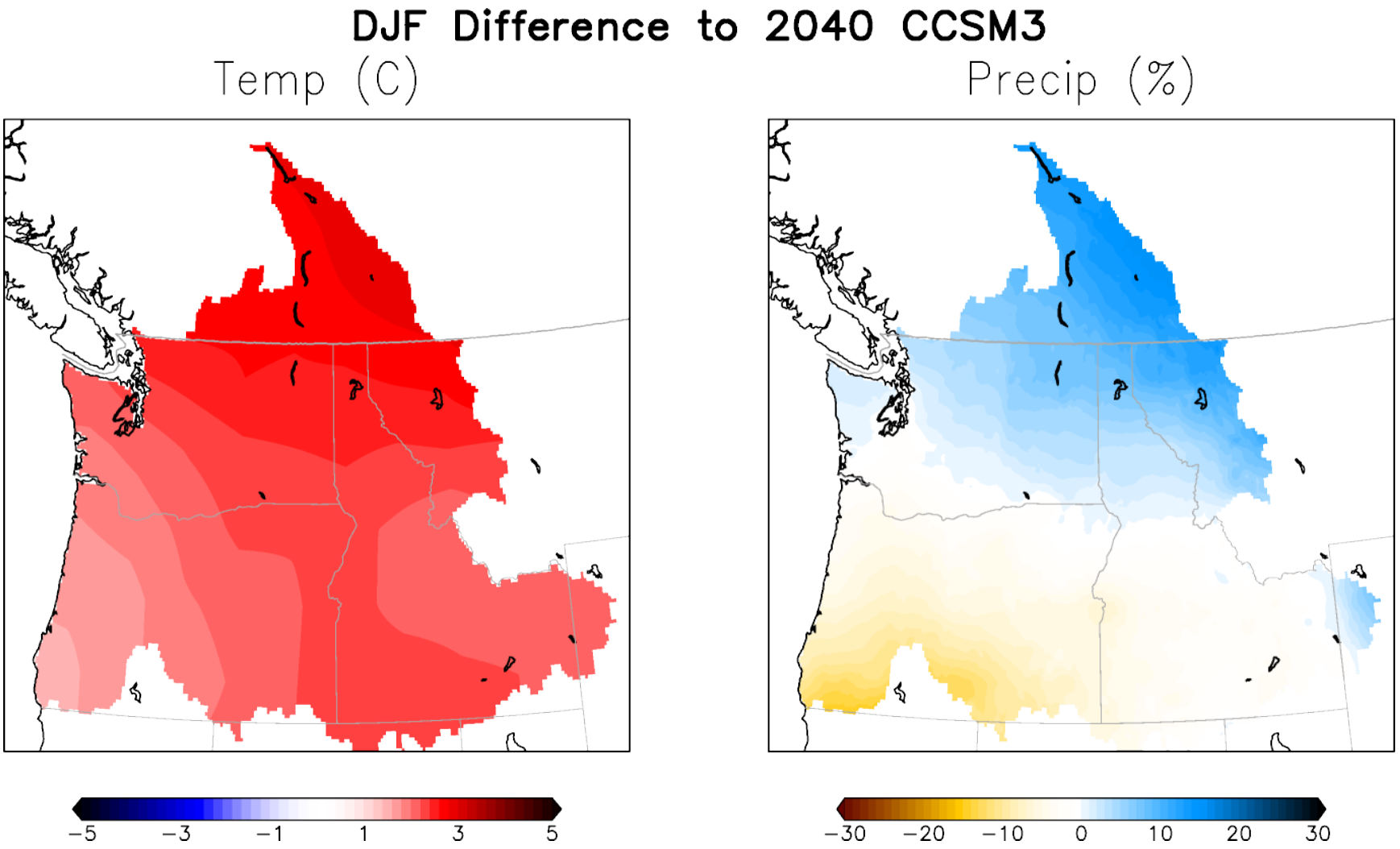

Multi-Model Averages and Assessed Ranges for Surface Warming
©IPCC 2007: WG1-AR4
A2
A1B
B1
Year 2000 Constant Concentrations
20th century
Global surface warming (°C)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
–1.0
1900
2000
2100
Year
B1
A1T
B2
A1B
A2
A1FI

You can try it out for yourself with EdGCM!
http://edgcm.columbia.edu

Downscaling global models for regional studies



Downscaling -- Winter



Downscaling -- Summer