

GCMs

**Global Climate Models
also known as
General Circulation Models
Fall 2013**

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**

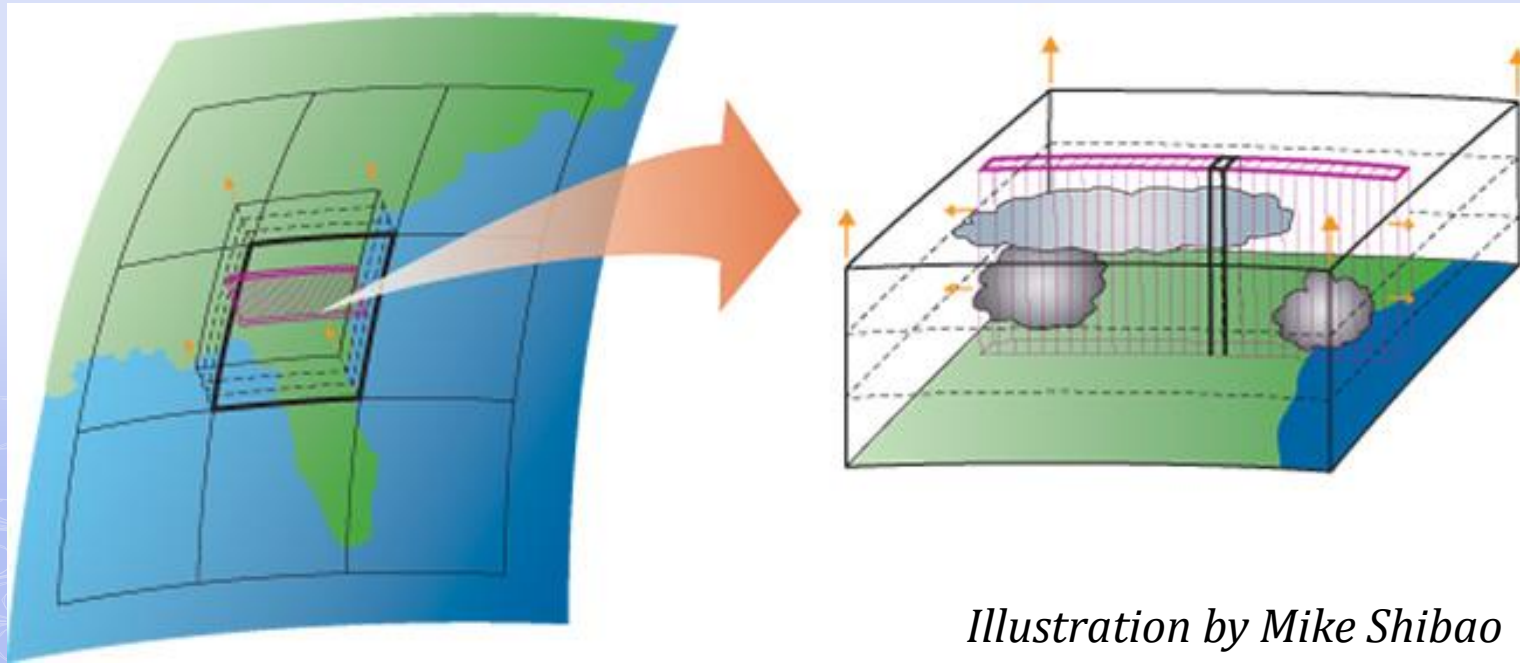


Illustration by Mike Shibao

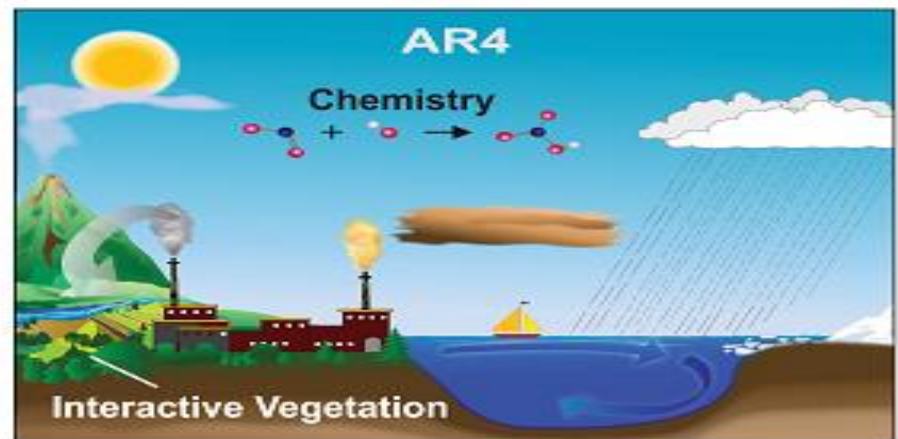
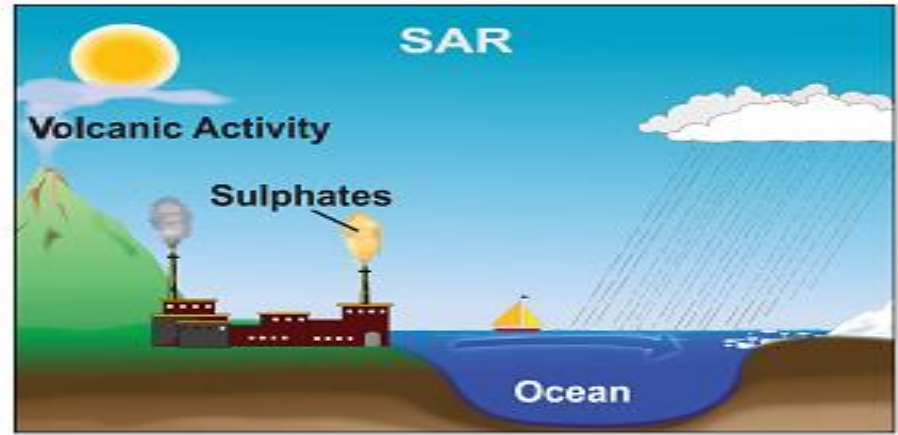
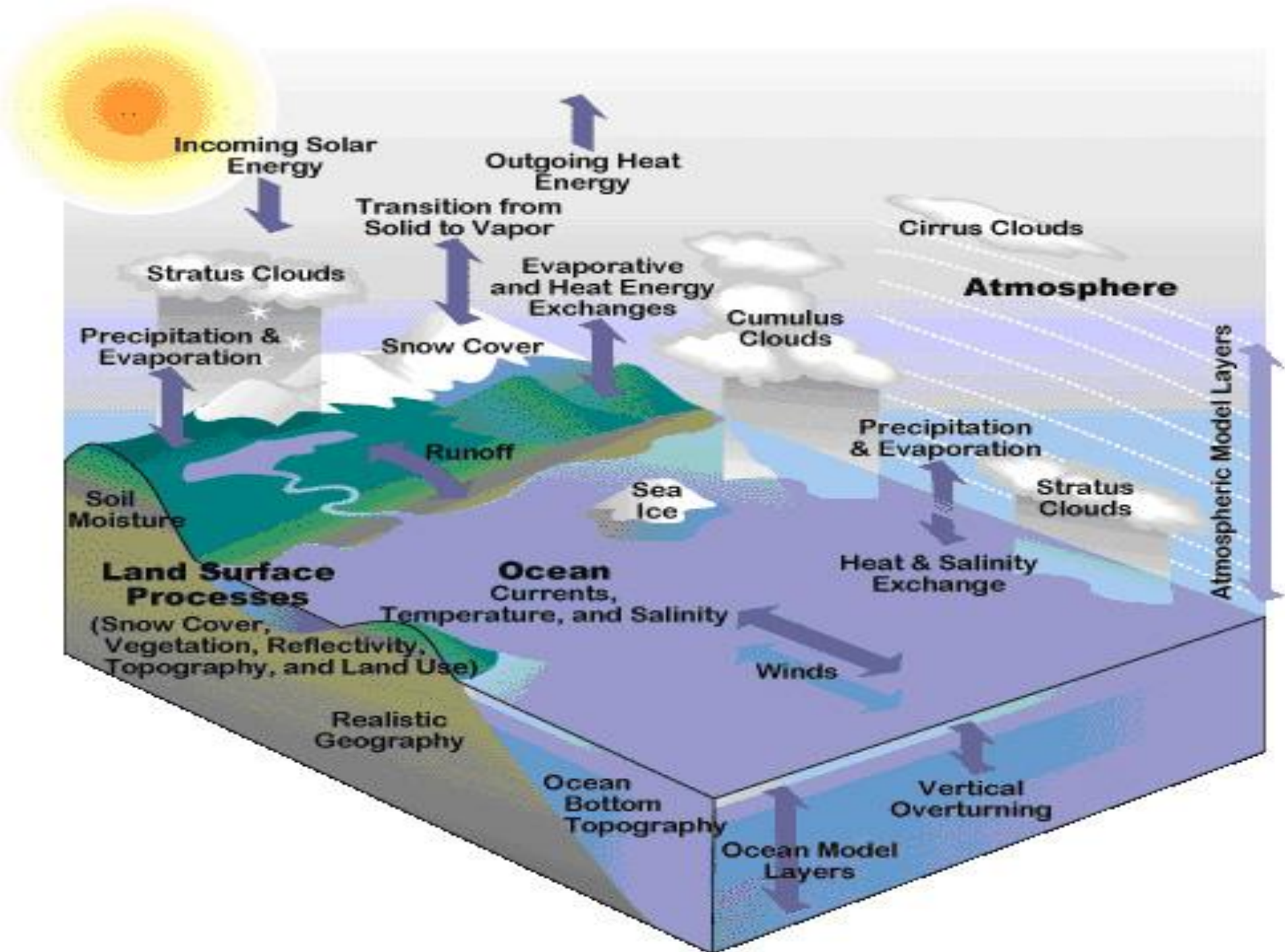
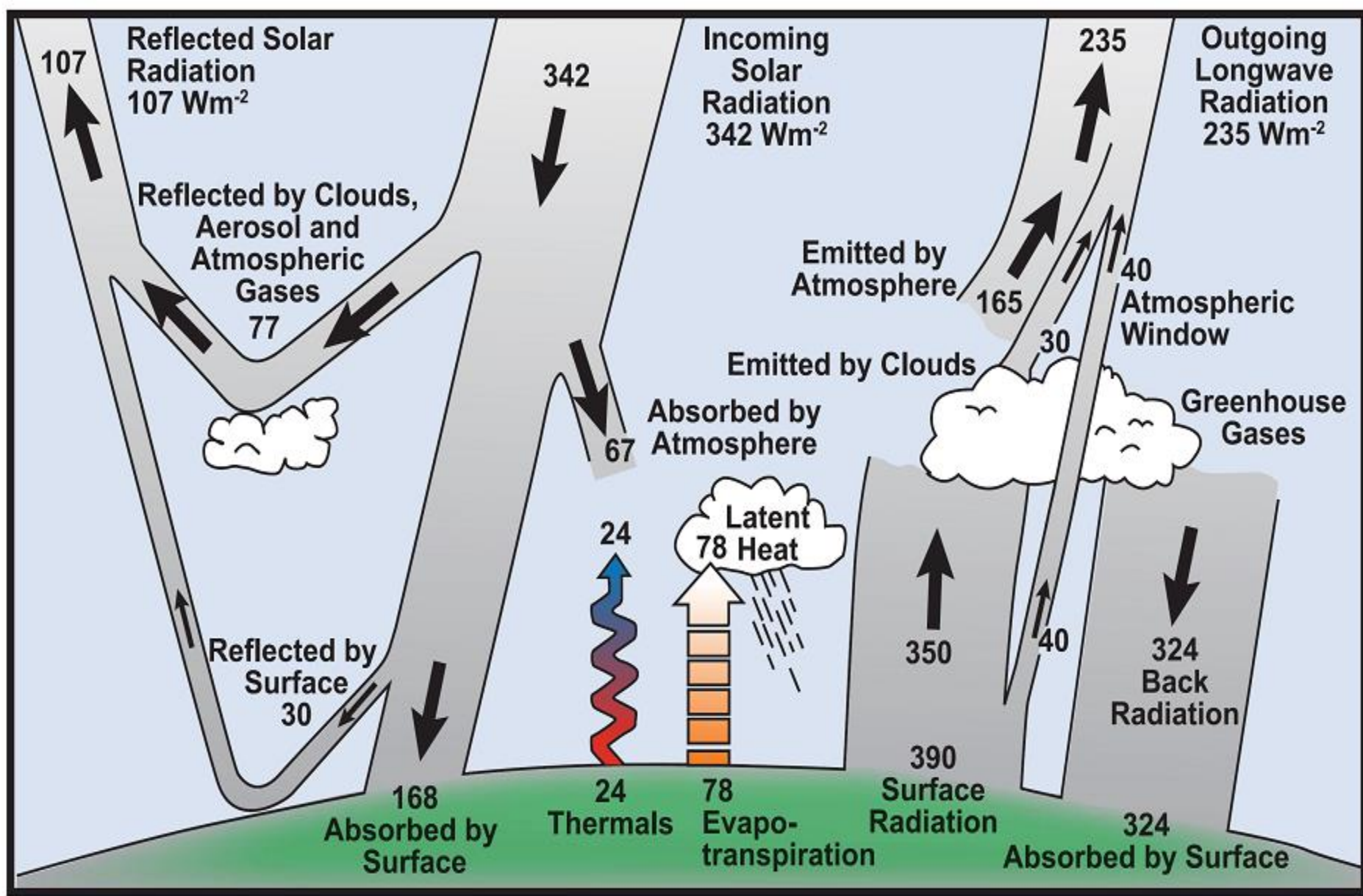


Figure 1.2. The complexity of climate models has increased over the last few decades. The additional physics incorporated in the models are shown pictorially by the different features of the modelled world.





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).

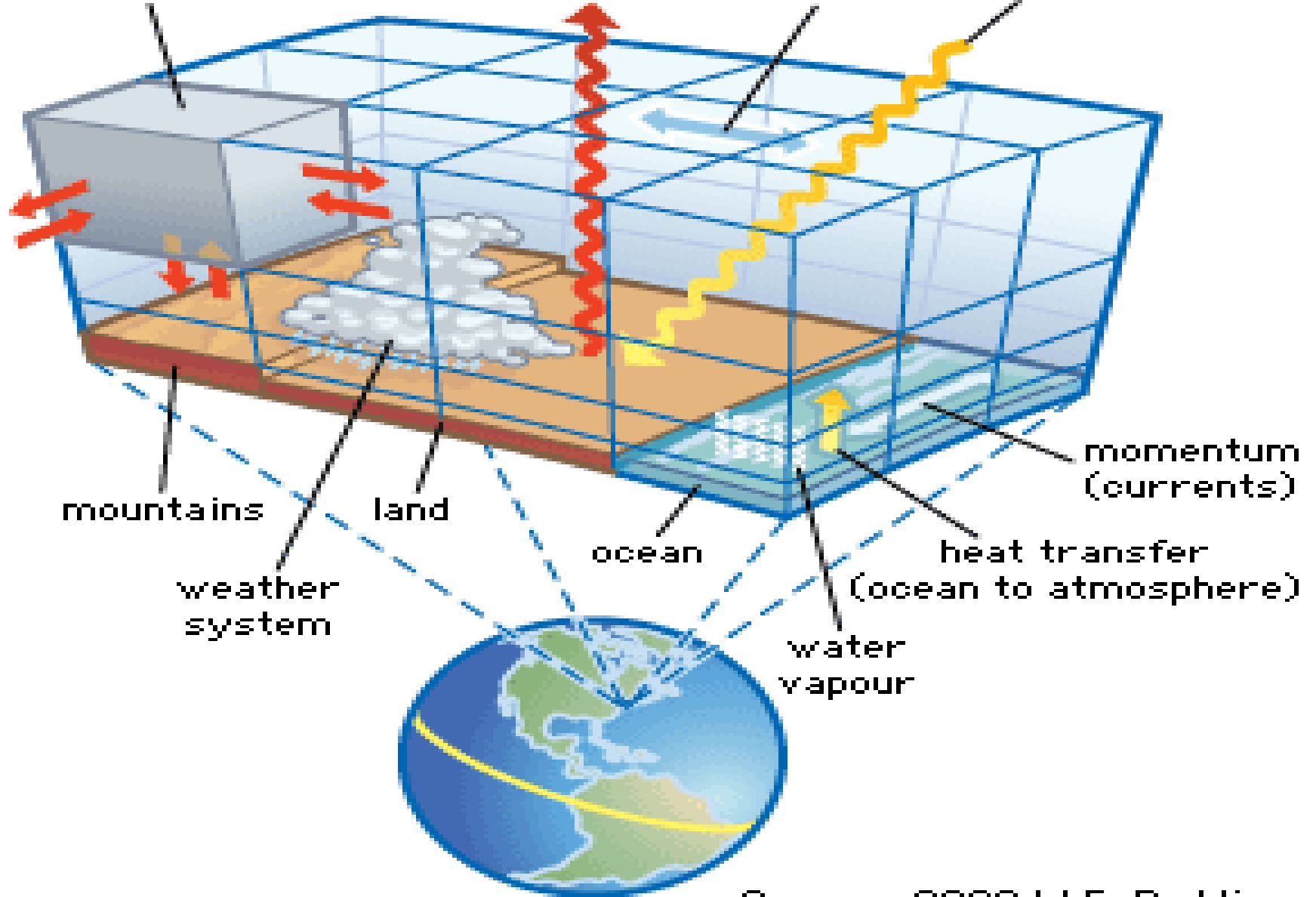
Concept diagram of climate modeling

3-D grid box
(CO₂, dust, H₂O)

emitted and
reflected radiation

momentum
(winds)

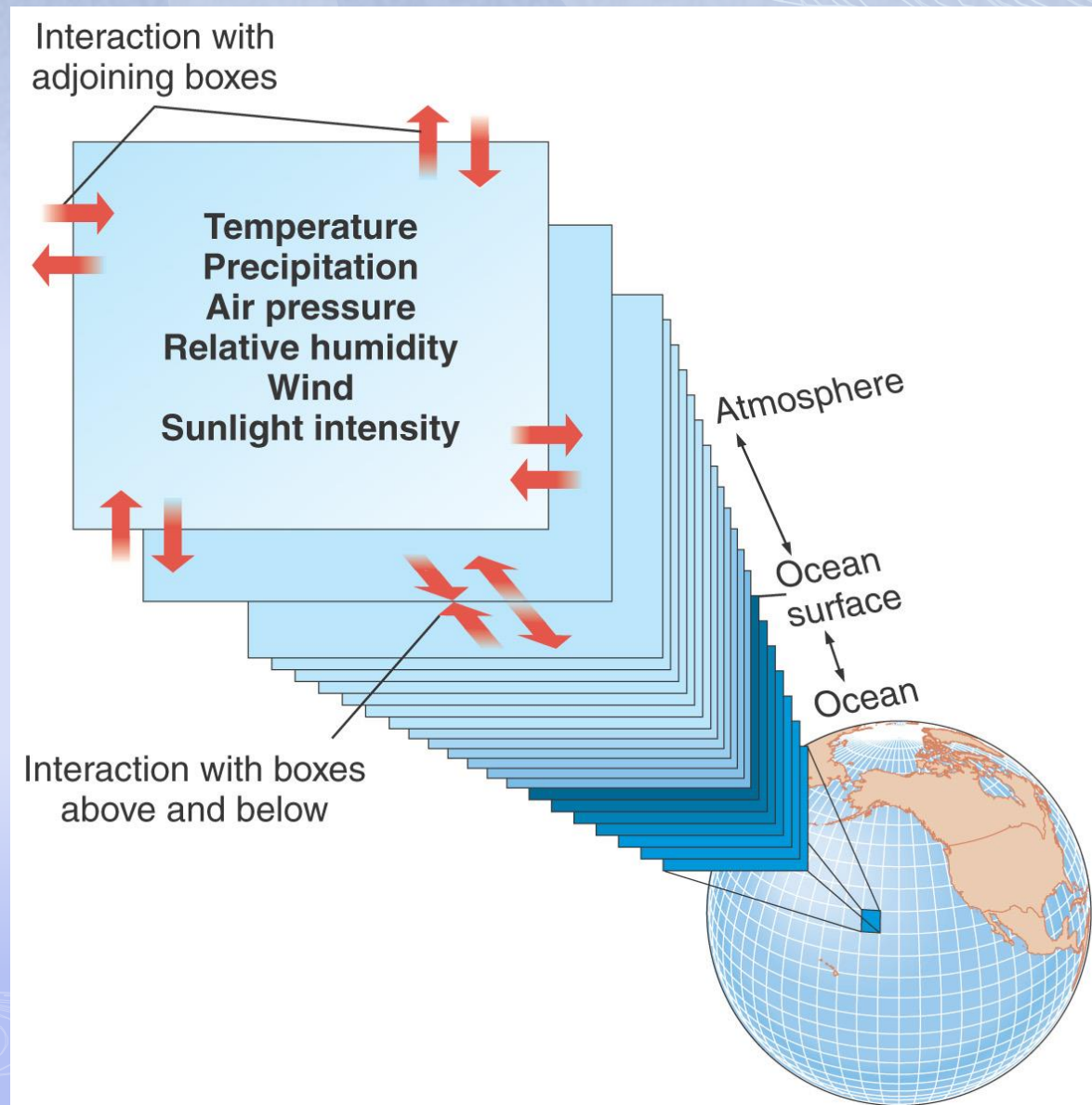
incoming
solar radiation



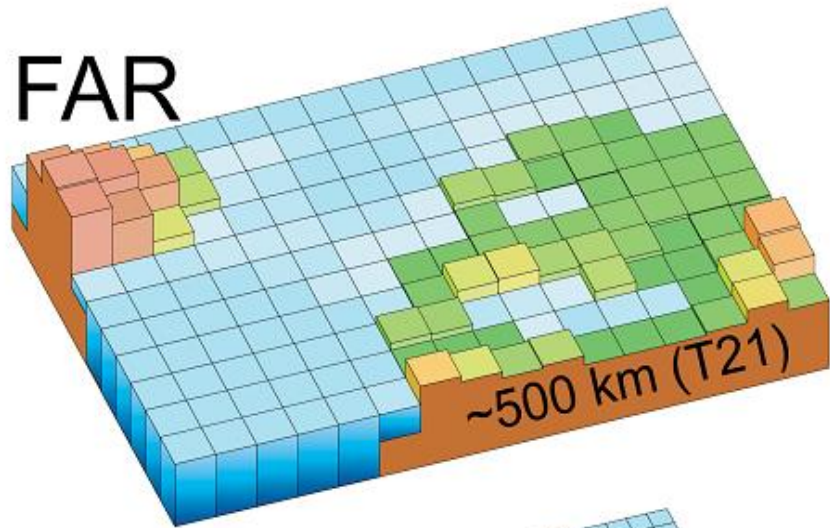
What about resolution?

□ **Computational constraints** limit the resolution that is possible in model equations. three-dimensional models

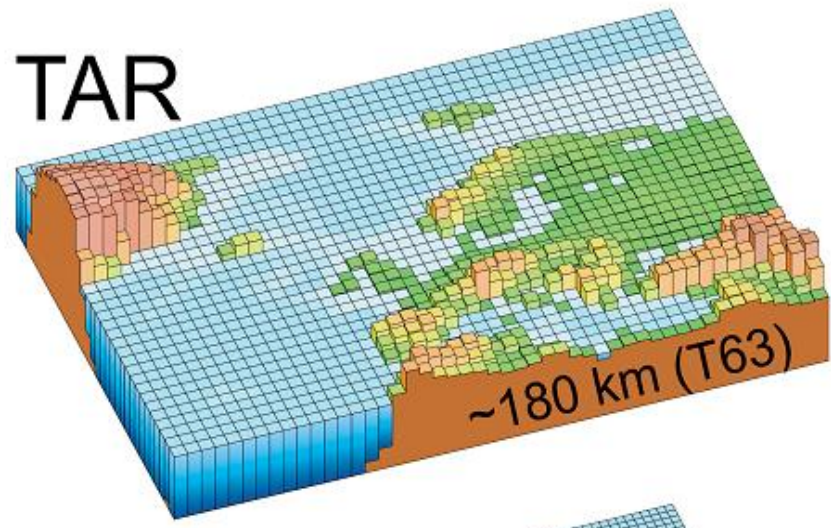
- Atmosphere:
 $2^{\circ} \times 2^{\circ}$, on average
- Ocean:
 $1.5^{\circ} \times 1.5^{\circ}$, on average



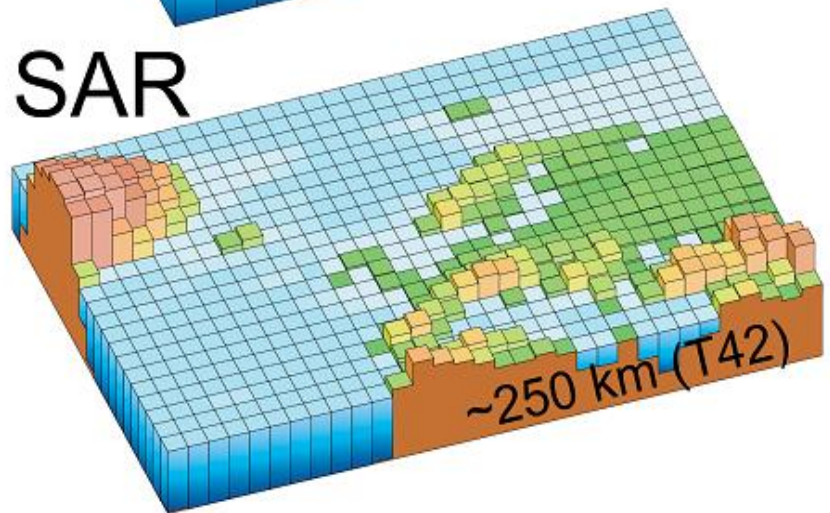
FAR



TAR



SAR



AR4

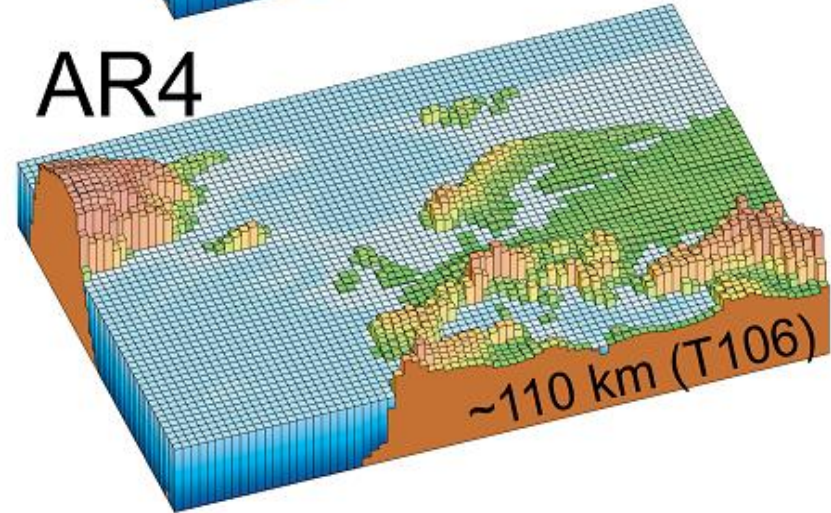
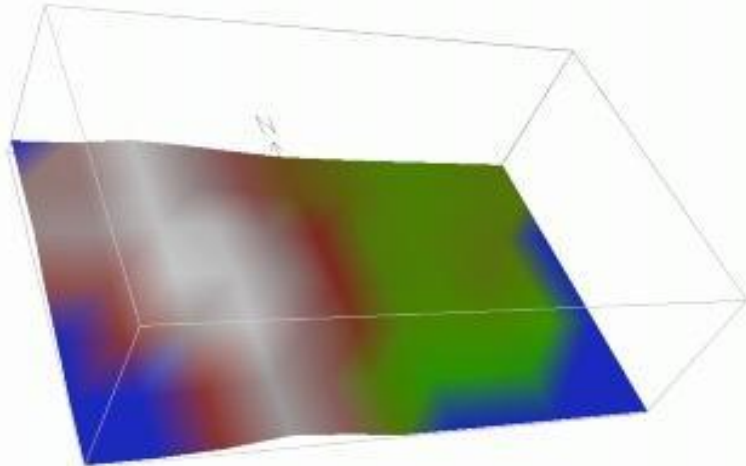


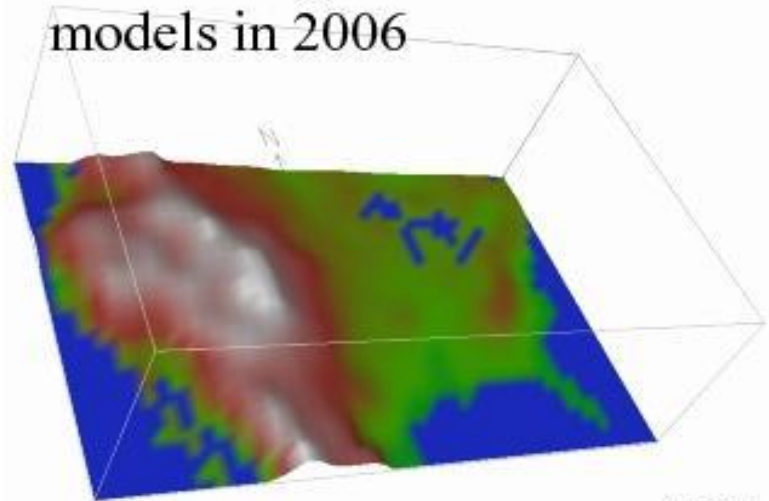
Figure 1.4. Geographic resolution characteristic of the generations of climate models used in the IPCC Assessment Reports: FAR (IPCC, 1990), SAR (IPCC, 1996), TAR (IPCC, 2001a), and AR4 (2007). The figures above show how successive generations of these global models increasingly resolved northern Europe.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



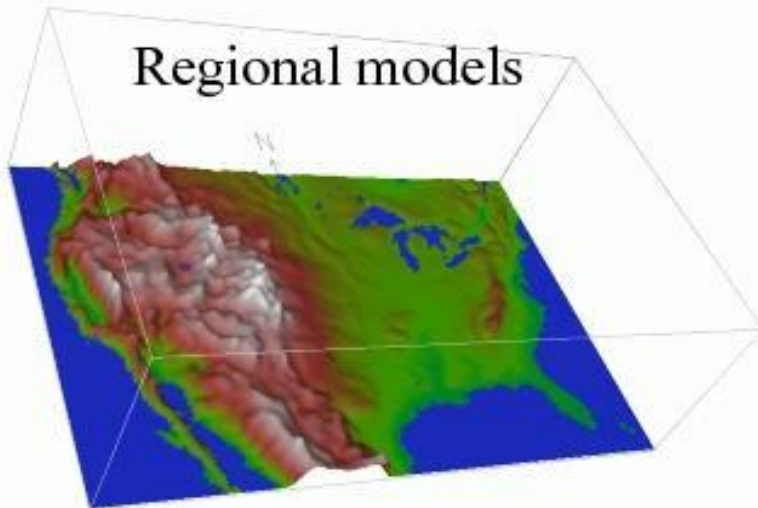
400 km

Global coupled climate models in 2006



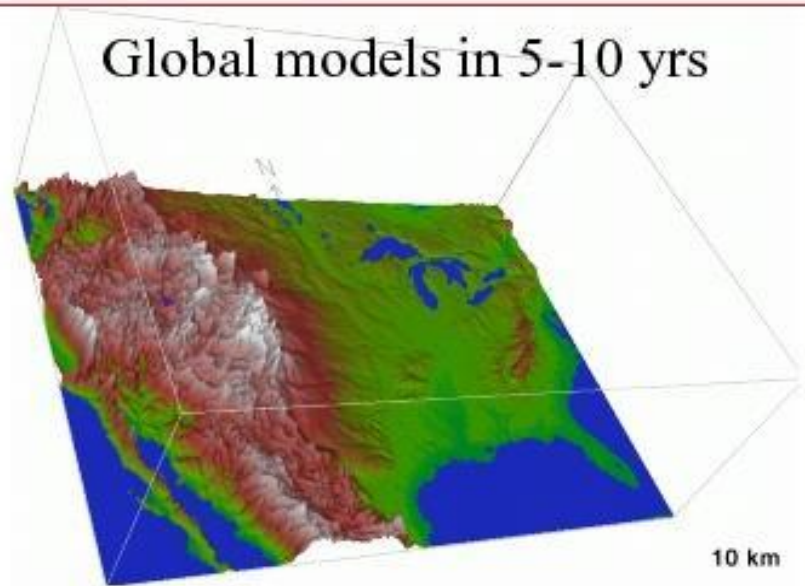
100 km

Regional models



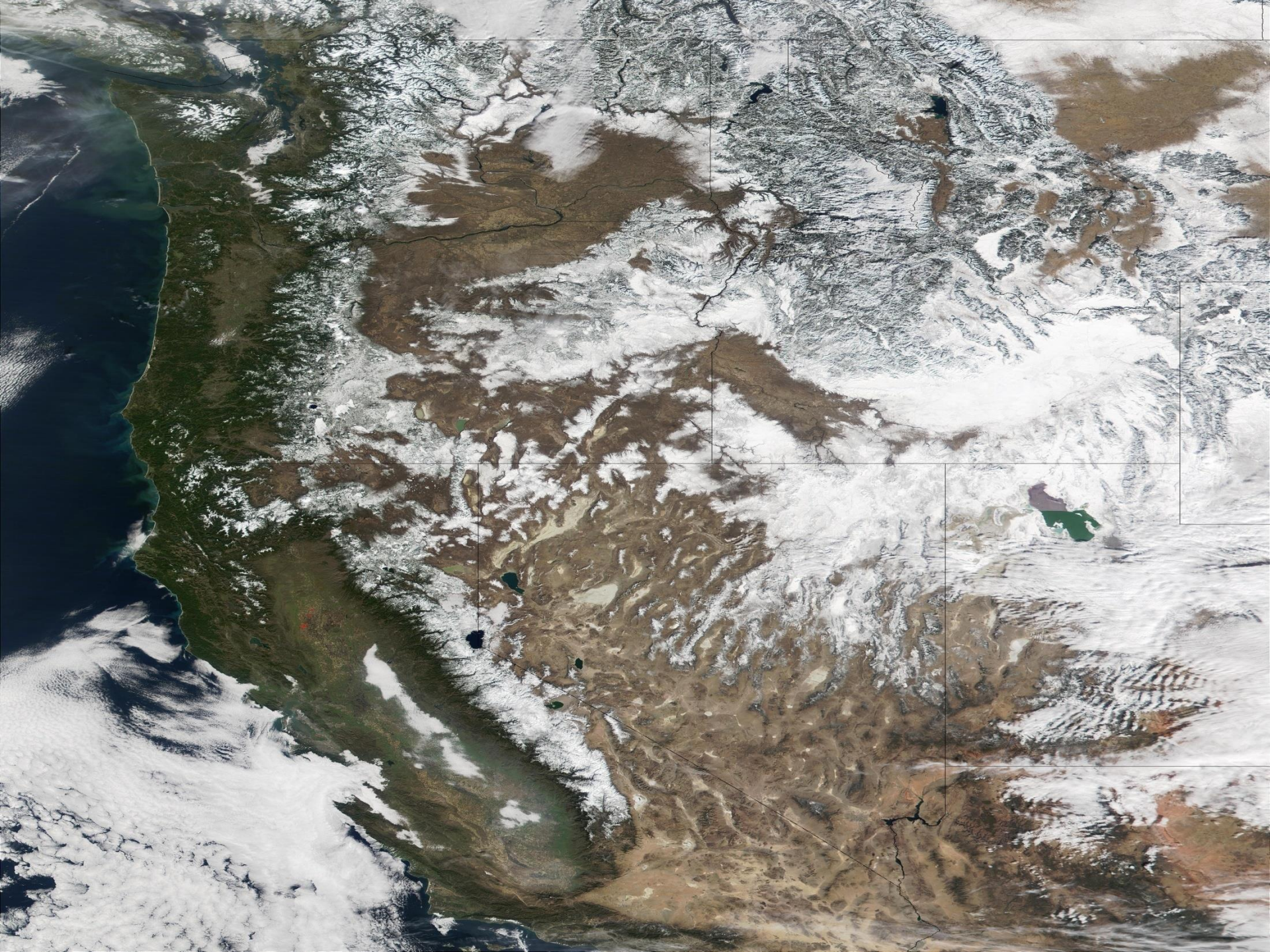
25 km

Global models in 5-10 yrs

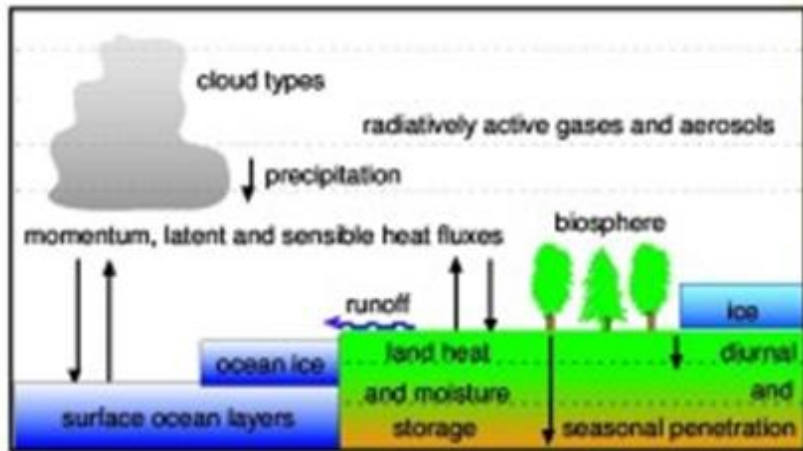


10 km

Optimistic view on model-development



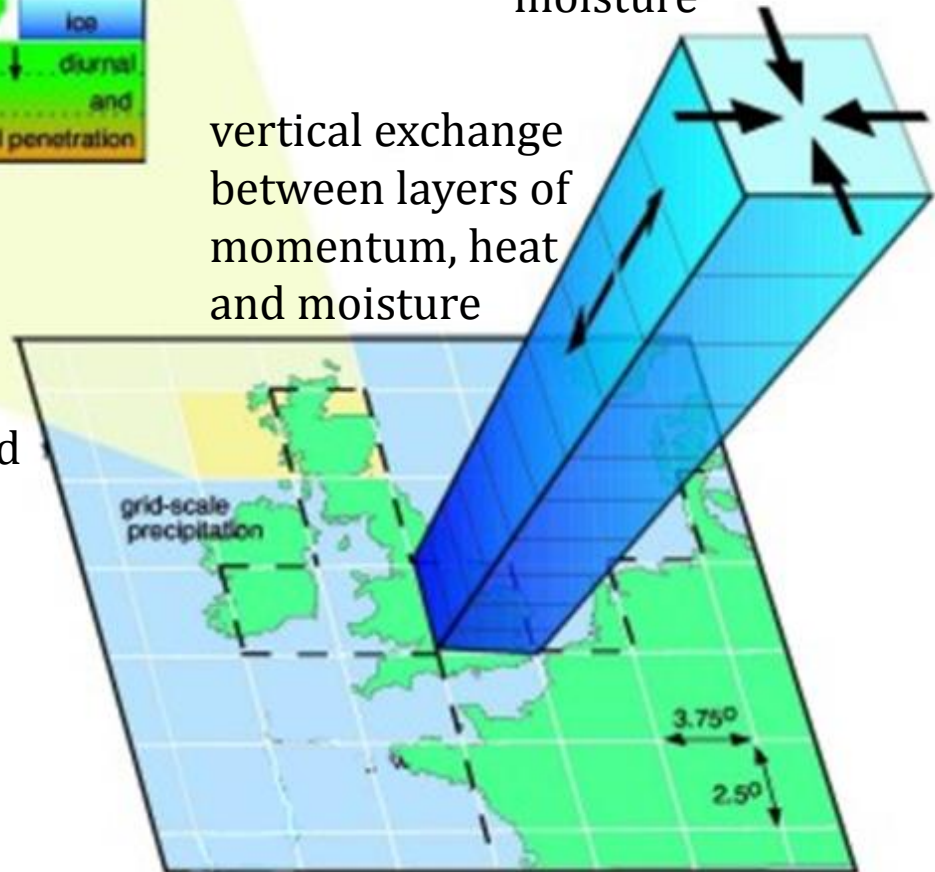
Atmospheric GCMs (AGCM)



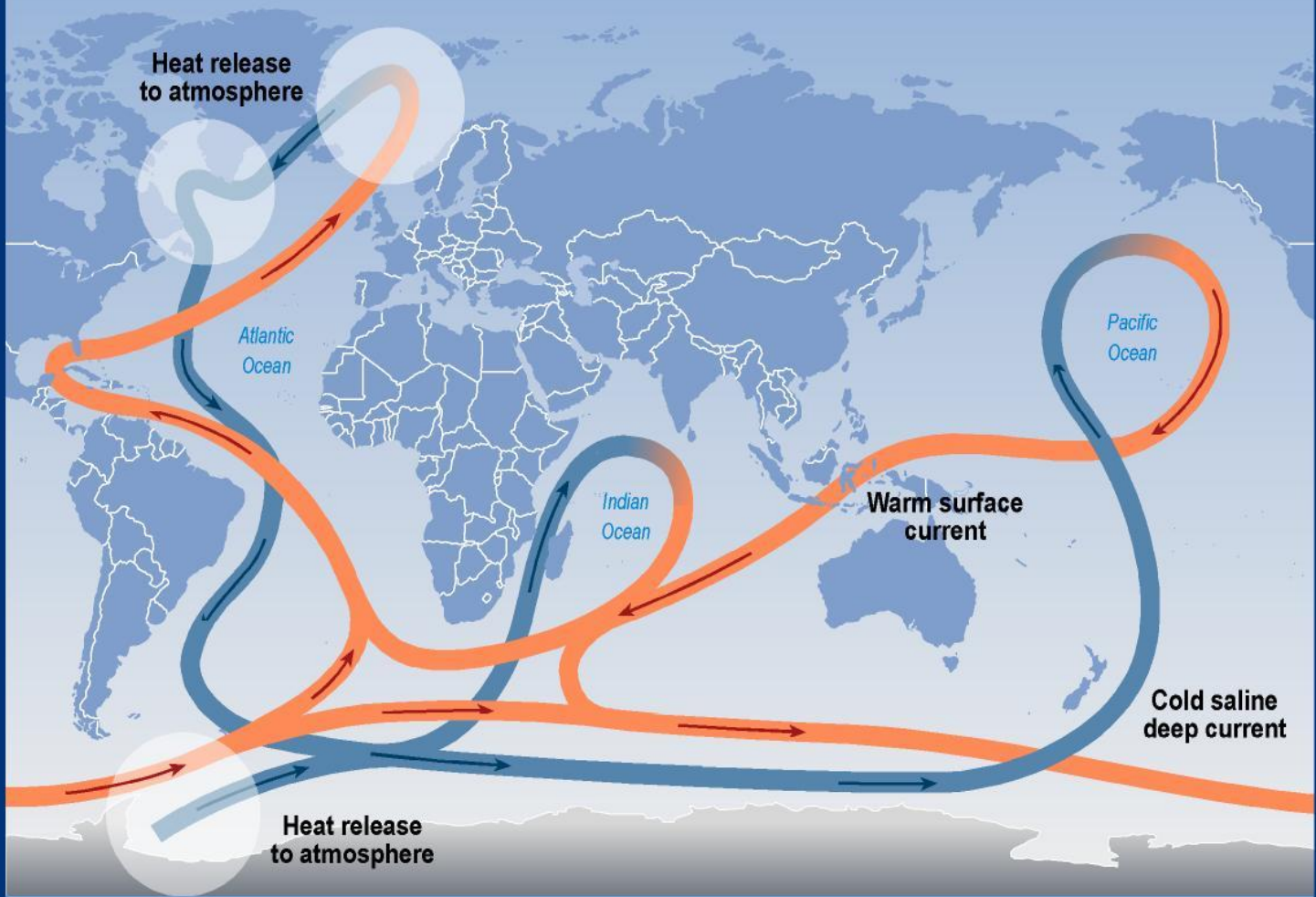
Horizontal exchange between columns of momentum, heat and moisture

vertical exchange between layers of momentum, heat and moisture

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

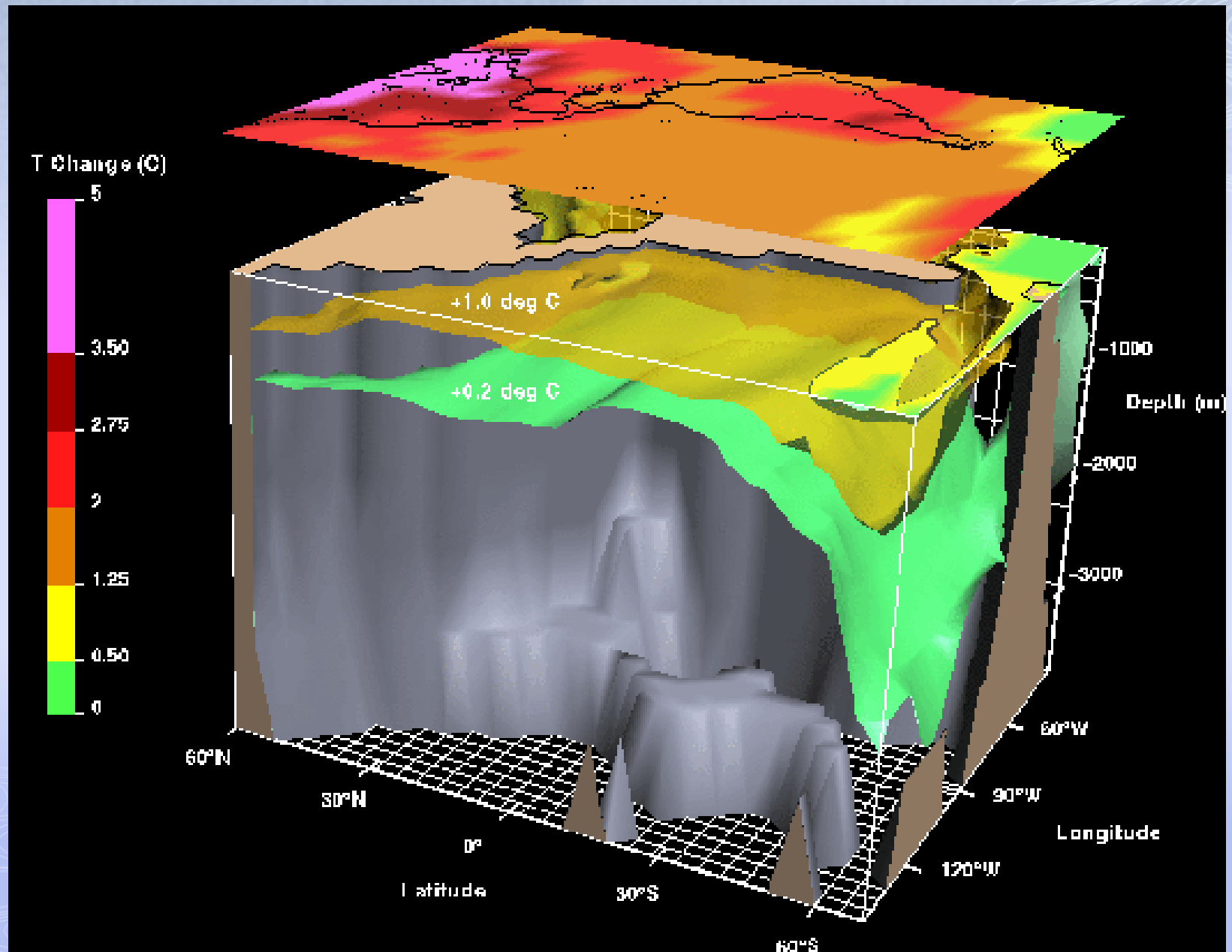


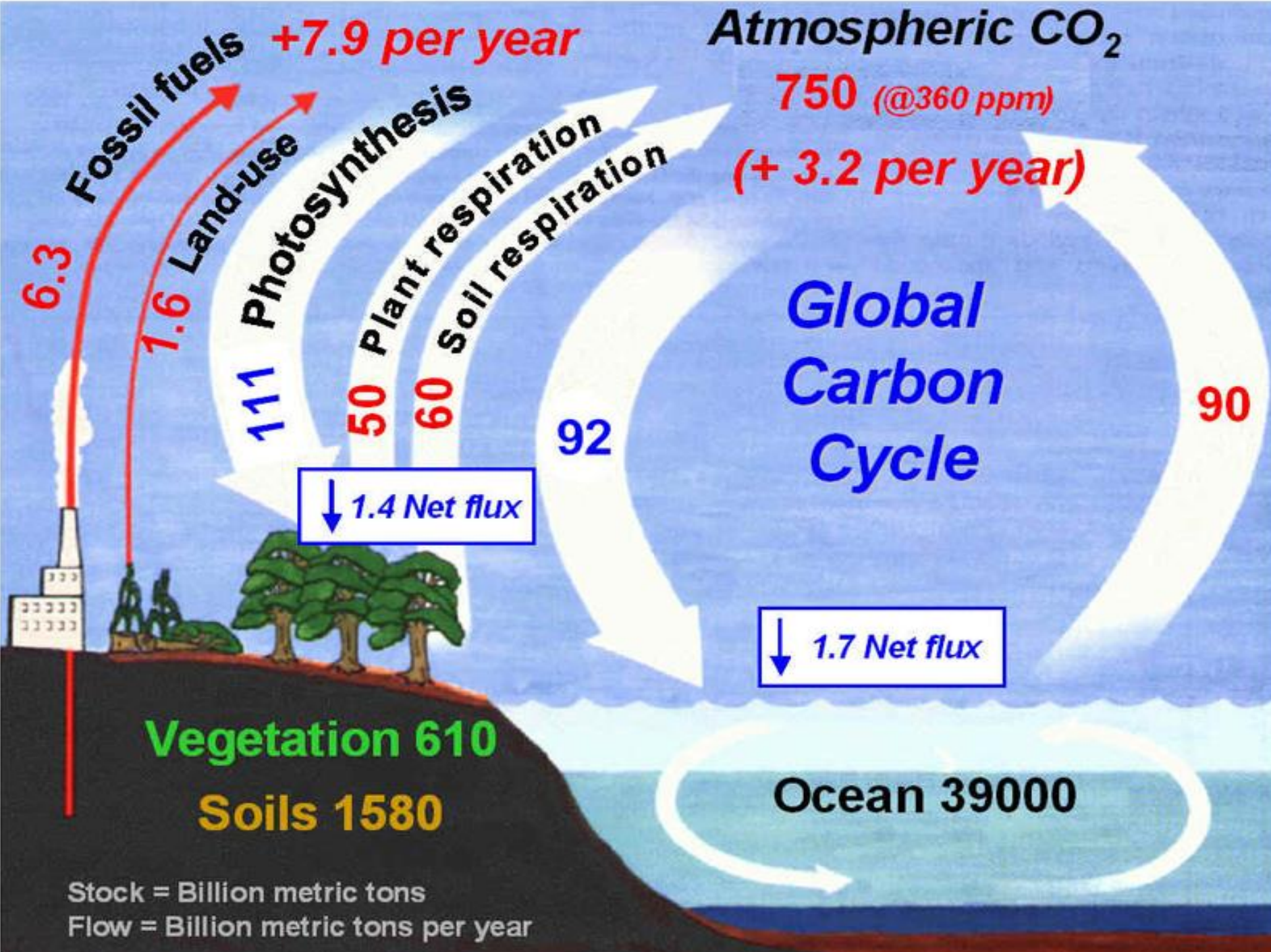
Great ocean conveyor belt



SYR - FIGURE 4-2

Combined GCMs (AOGCM)





Atmospheric CO₂

750 (@360 ppm)

(+ 3.2 per year)

**Global
Carbon
Cycle**

90

92

↓ 1.4 Net flux

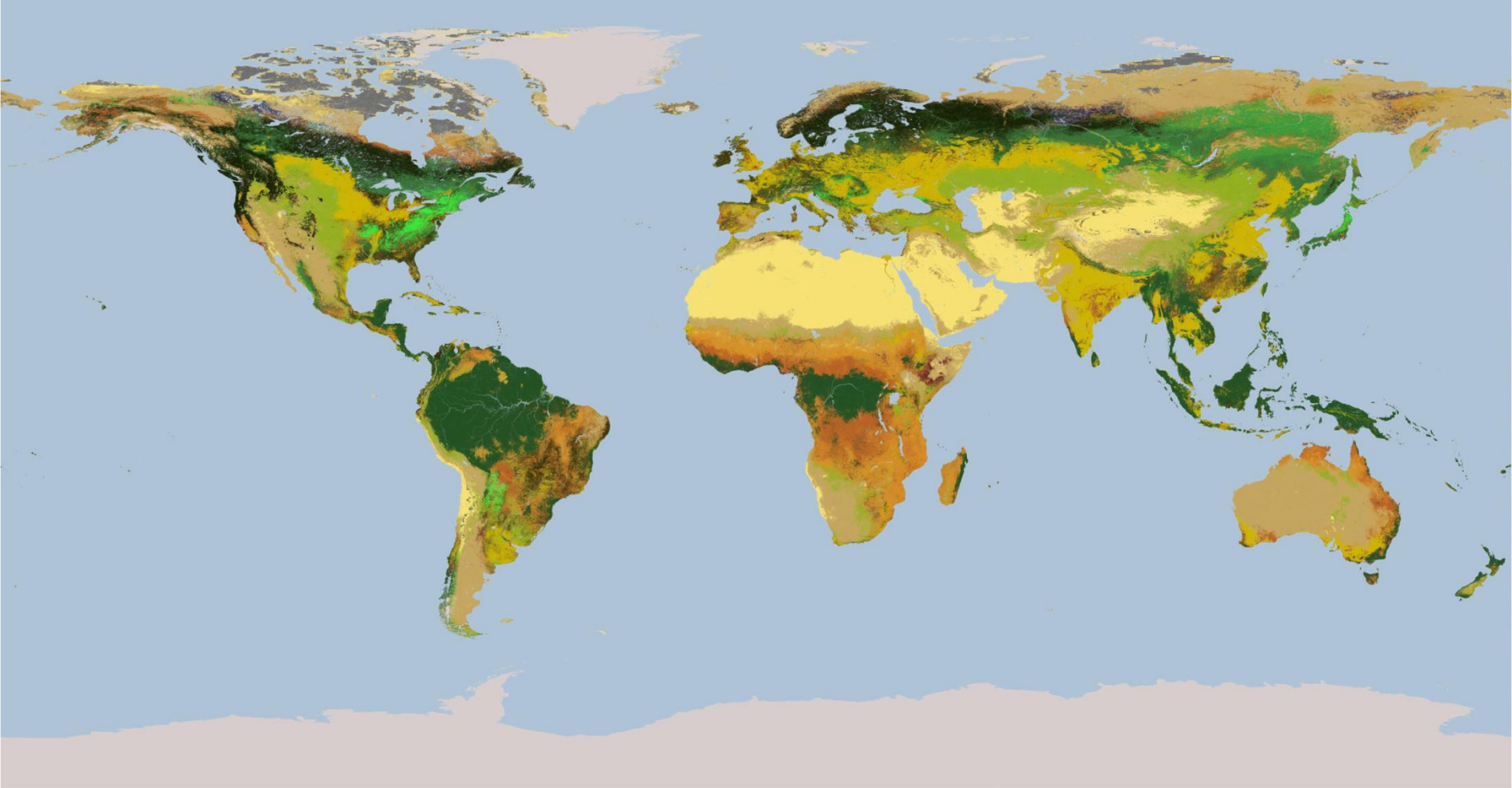
↓ 1.7 Net flux










Vegetation 610

Soils 1580

Ocean 39000

Stock = Billion metric tons
Flow = Billion metric tons per year



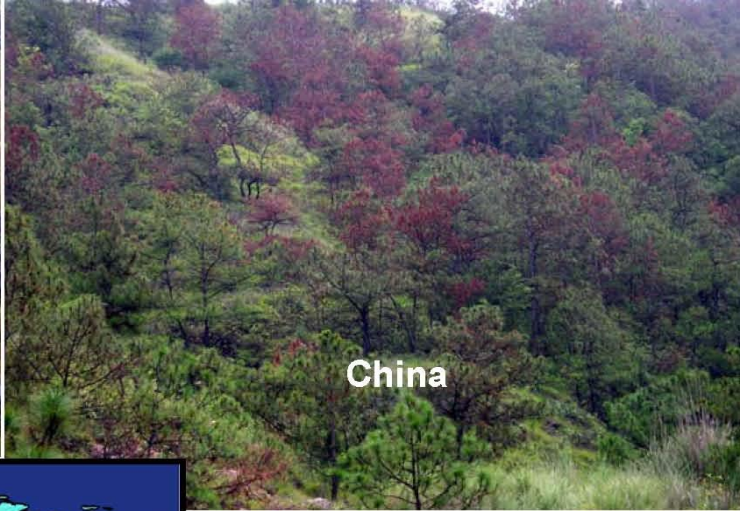
- | | | |
|---|---|---|
|  0 Water |  6 Closed Shrublands |  12 Croplands |
|  1 Evergreen Needleleaf Forest |  7 Open Shrublands |  13 Urban and Built-Up |
|  2 Evergreen Broadleaf Forest |  8 Woody Savannas |  14 Cropland/Natural Veg. Mosaic |
|  3 Deciduous Needleleaf Forest |  9 Savannas |  15 Snow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



New Mexico



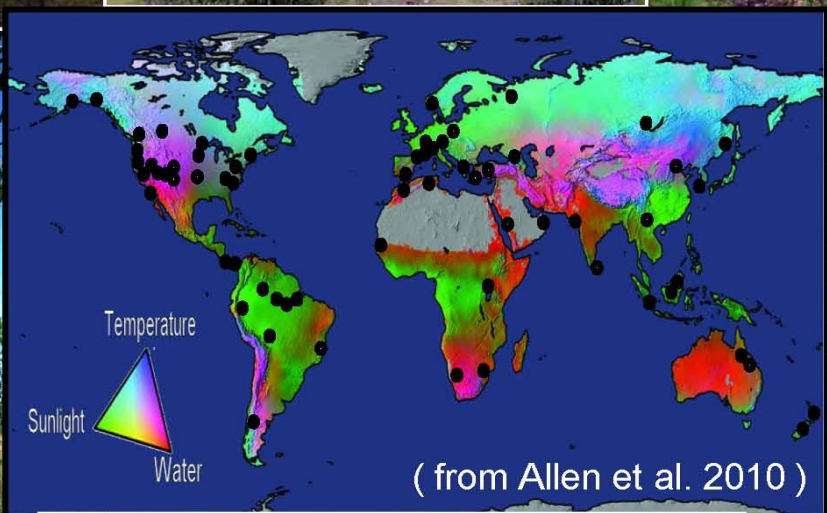
Alberta



China



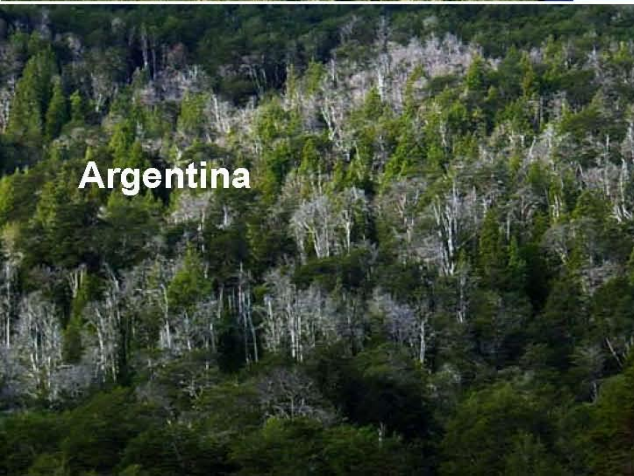
Australia



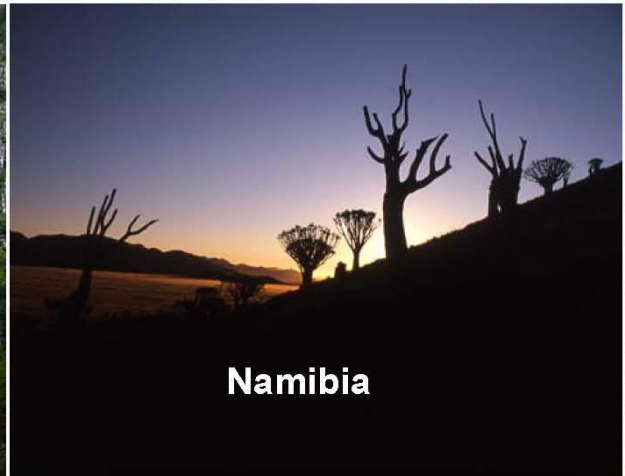
(from Allen et al. 2010)



Spain



Argentina

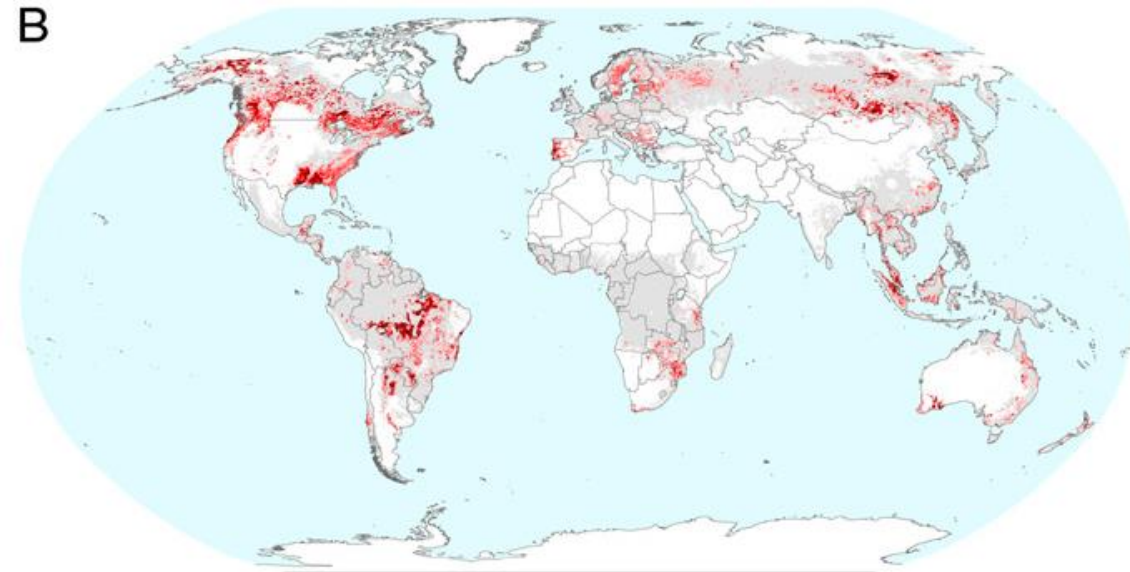


Namibia



Algeria

B

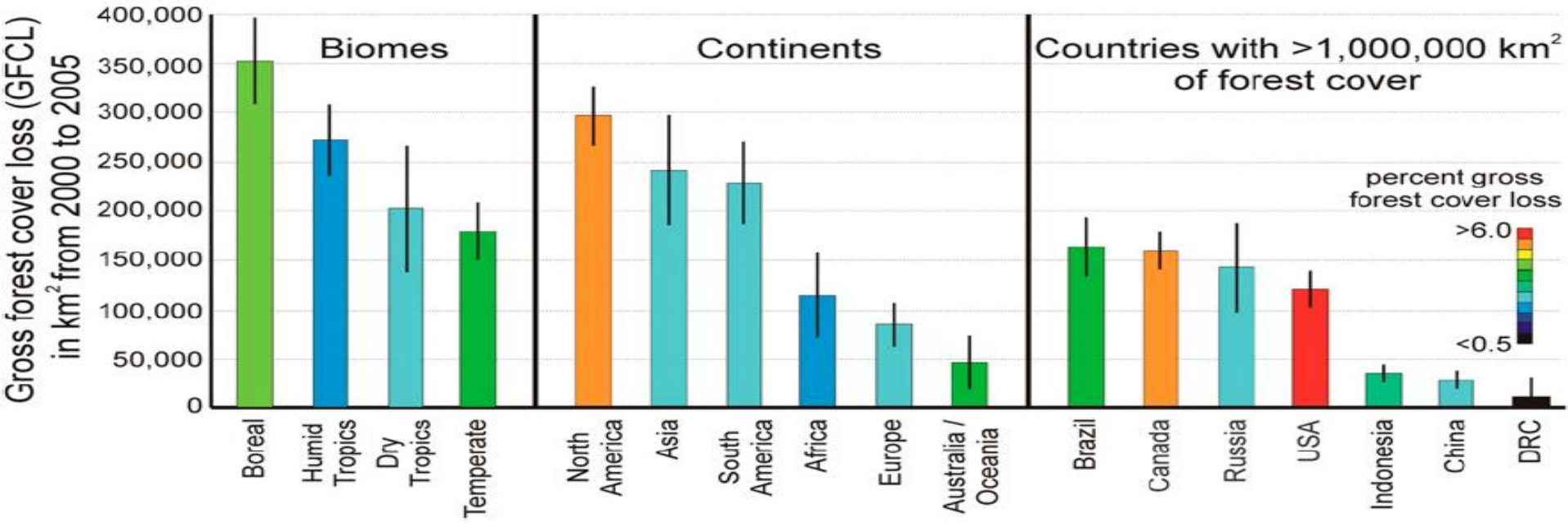


0 - 1.5%
 1.5 - 5.0%
 5.0 - 10%
 >10%

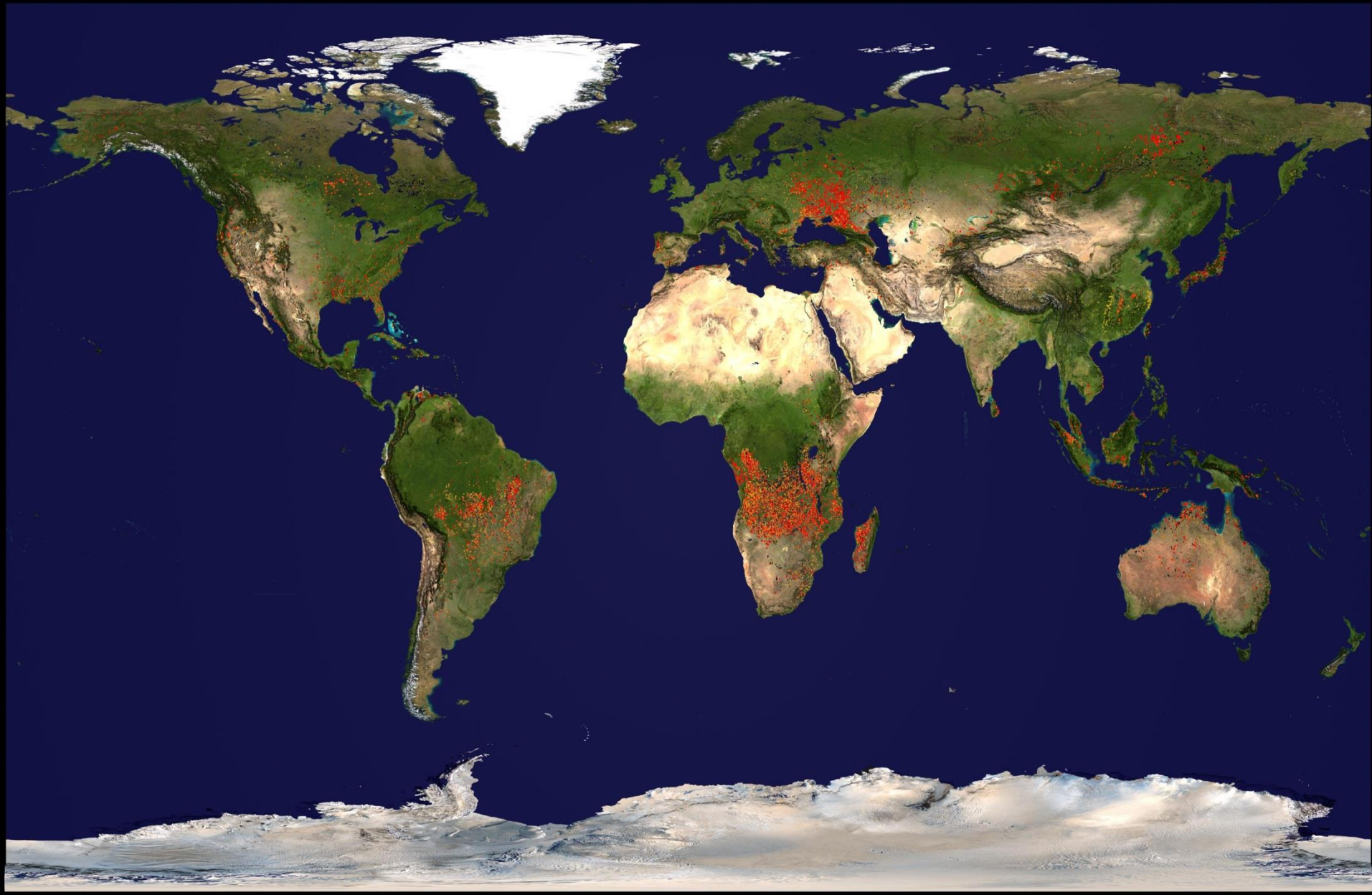
**% FOREST COVER LOSS
2000-2005**

**From Hansen et al PNAS,
2010**

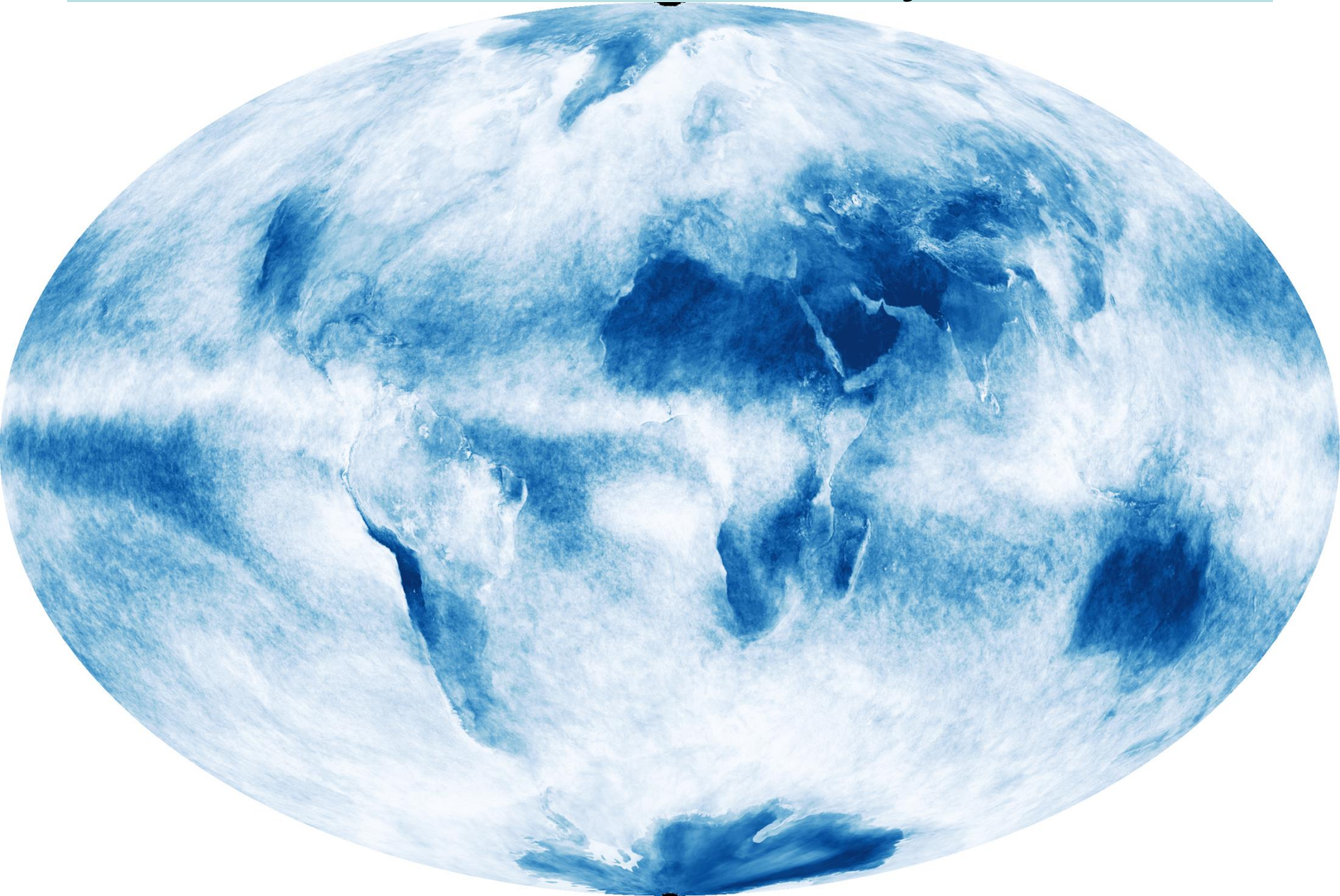
Fig. 1. Estimated percent forest cover, 2000 (A) and percent gross forest cover loss (GFCL), 2000–2005 (B), both per sample block.



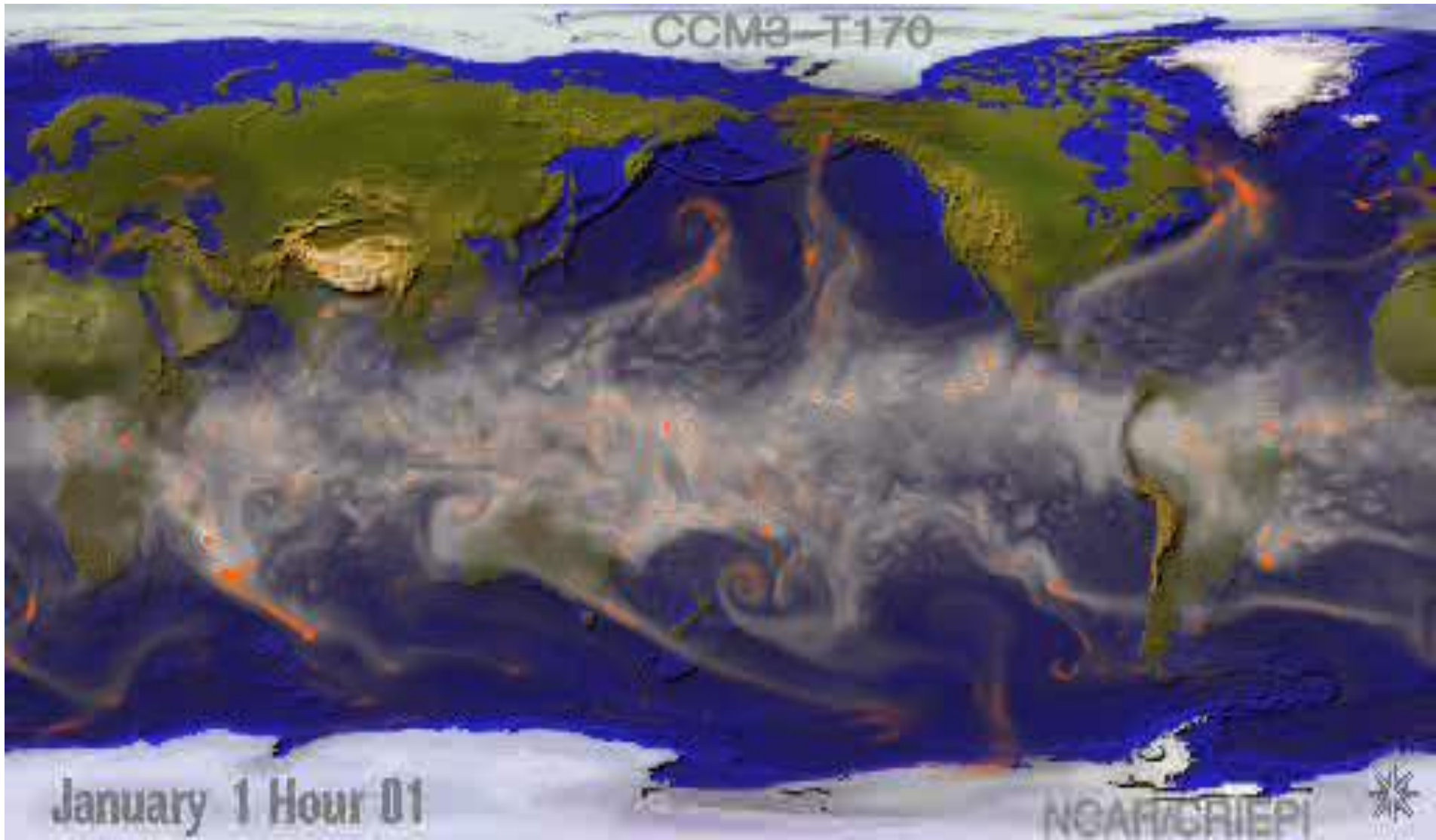
Global Fires for 10 Days



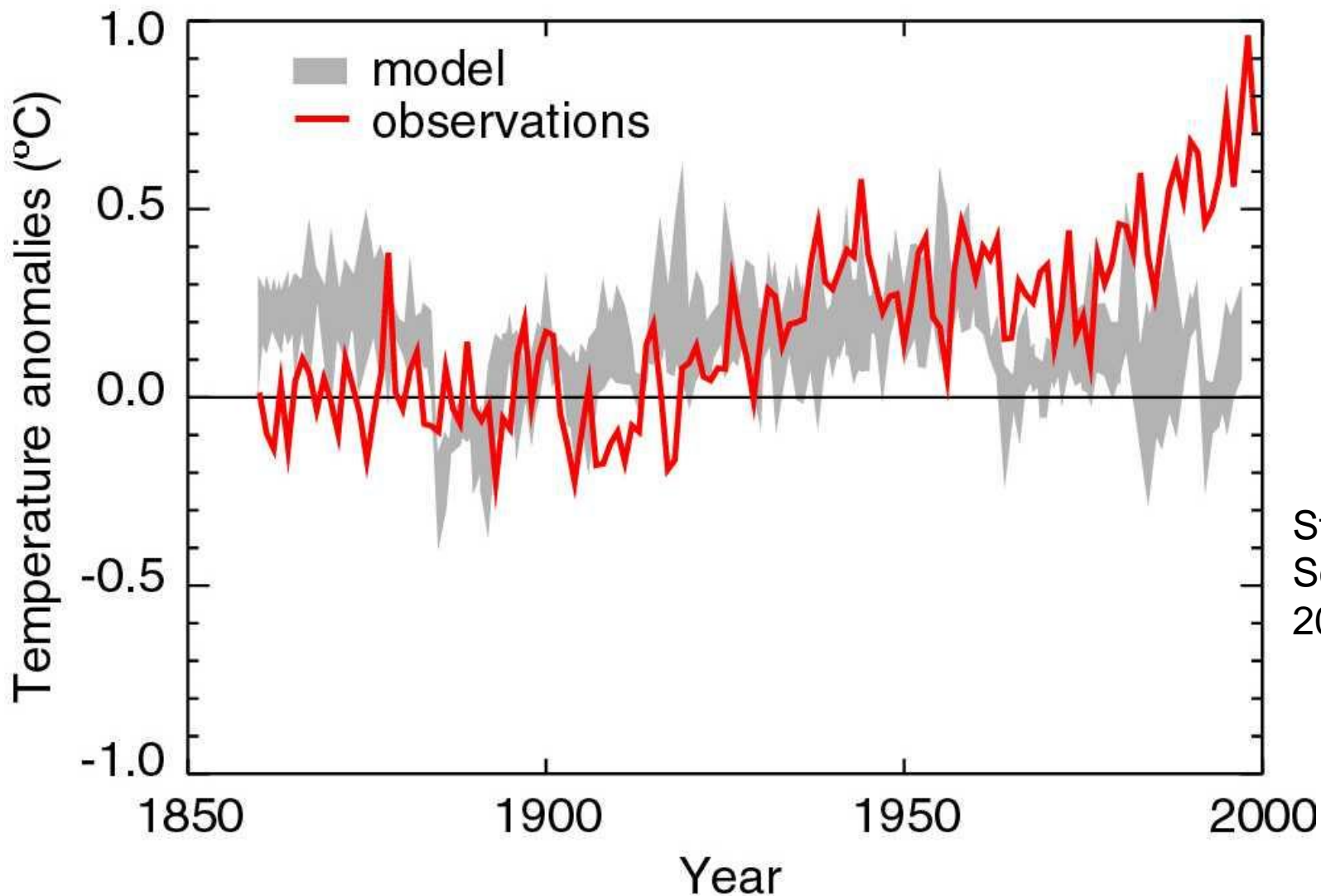
EARTH is 60-70% Cloudy



A GCM IN ACTION



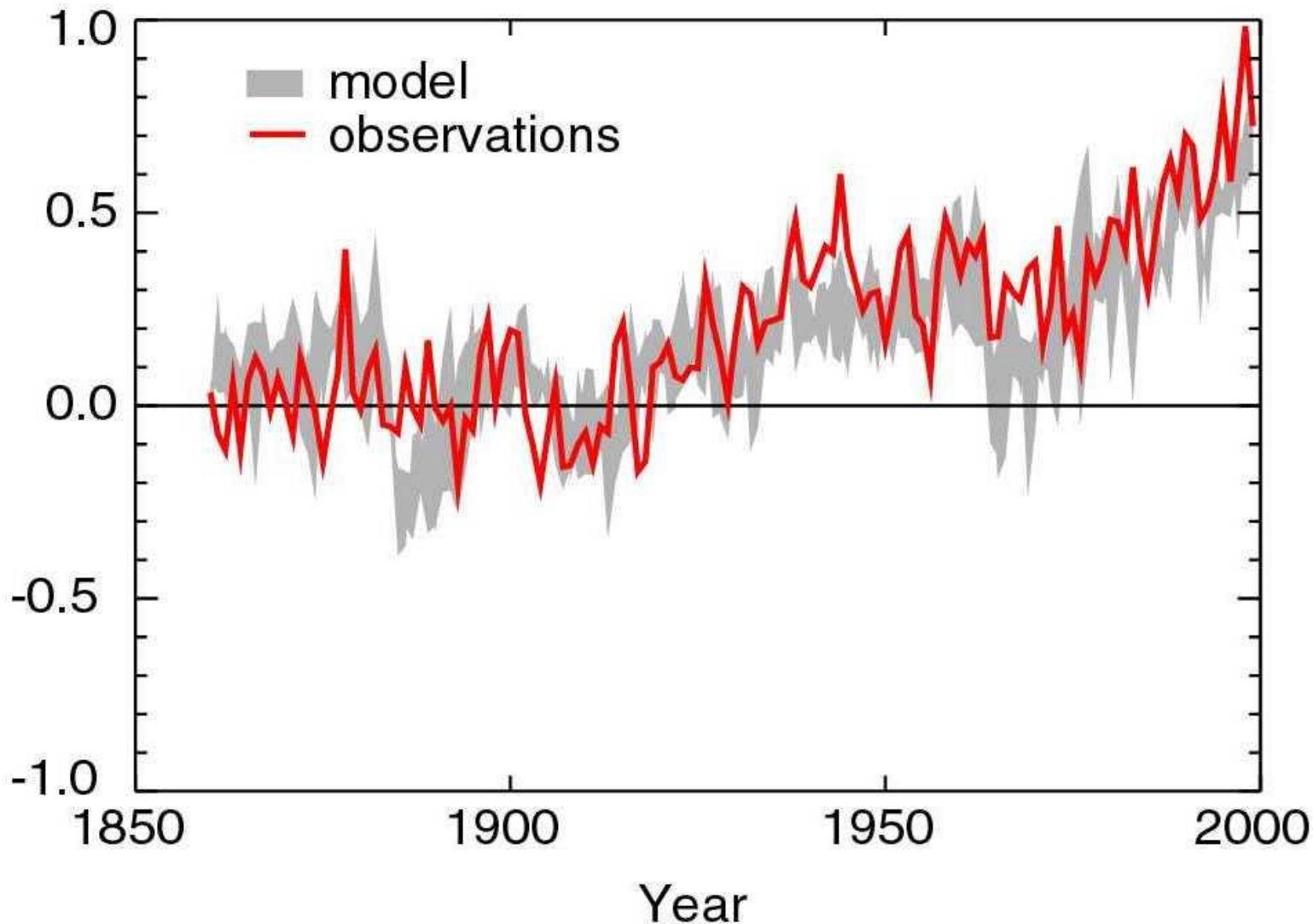
**“Simulations of the response to natural forcings alone
... do not explain the warming in the second half of the
century”** **SPM**



Stott et al,
Science
2000

“..model estimates that take into account both greenhouse gases and sulphate aerosols are consistent with observations over this period”

SPM

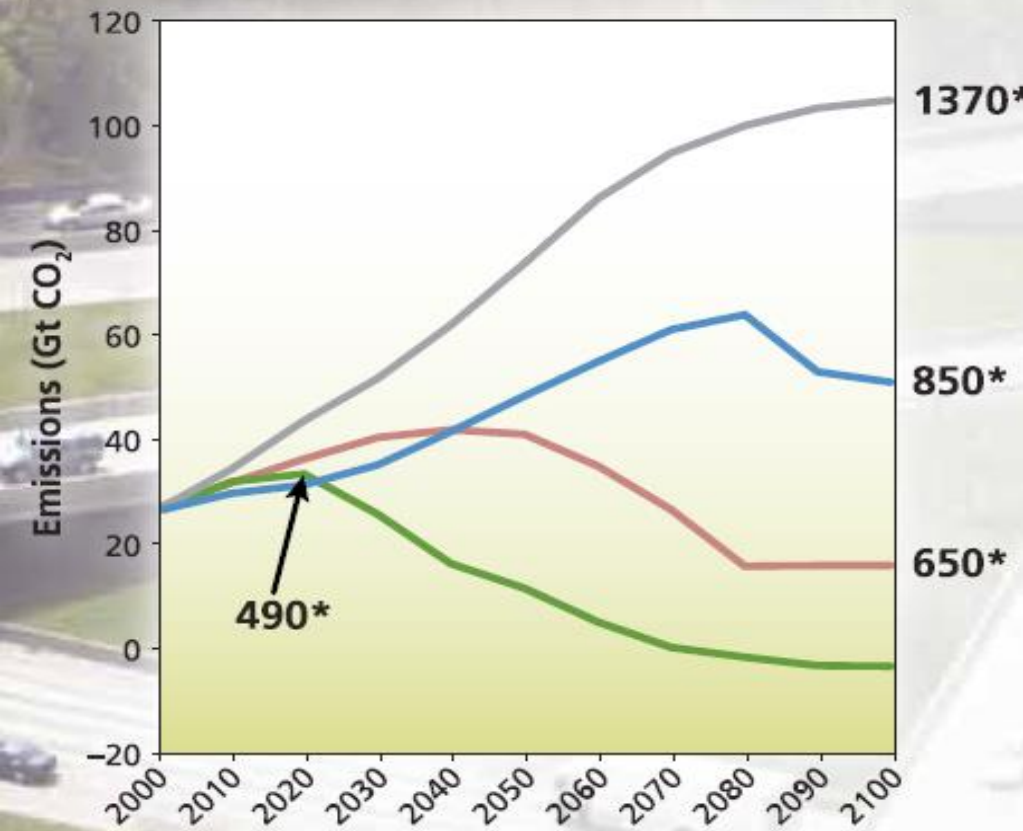


Stott et al,
Science
2000

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

Global emissions pathways



IPCC- 5th Assessment Emissions Scenarios

The four pathways

Radiative forcing	*Atmospheric CO ₂ equivalent (parts per million)	When
8.5	>1370	By 2100, but rising
6	850	Stabilisation after 2100
4.5	650	Stabilisation after 2100
2.6	490	Peak before 2100 then decline

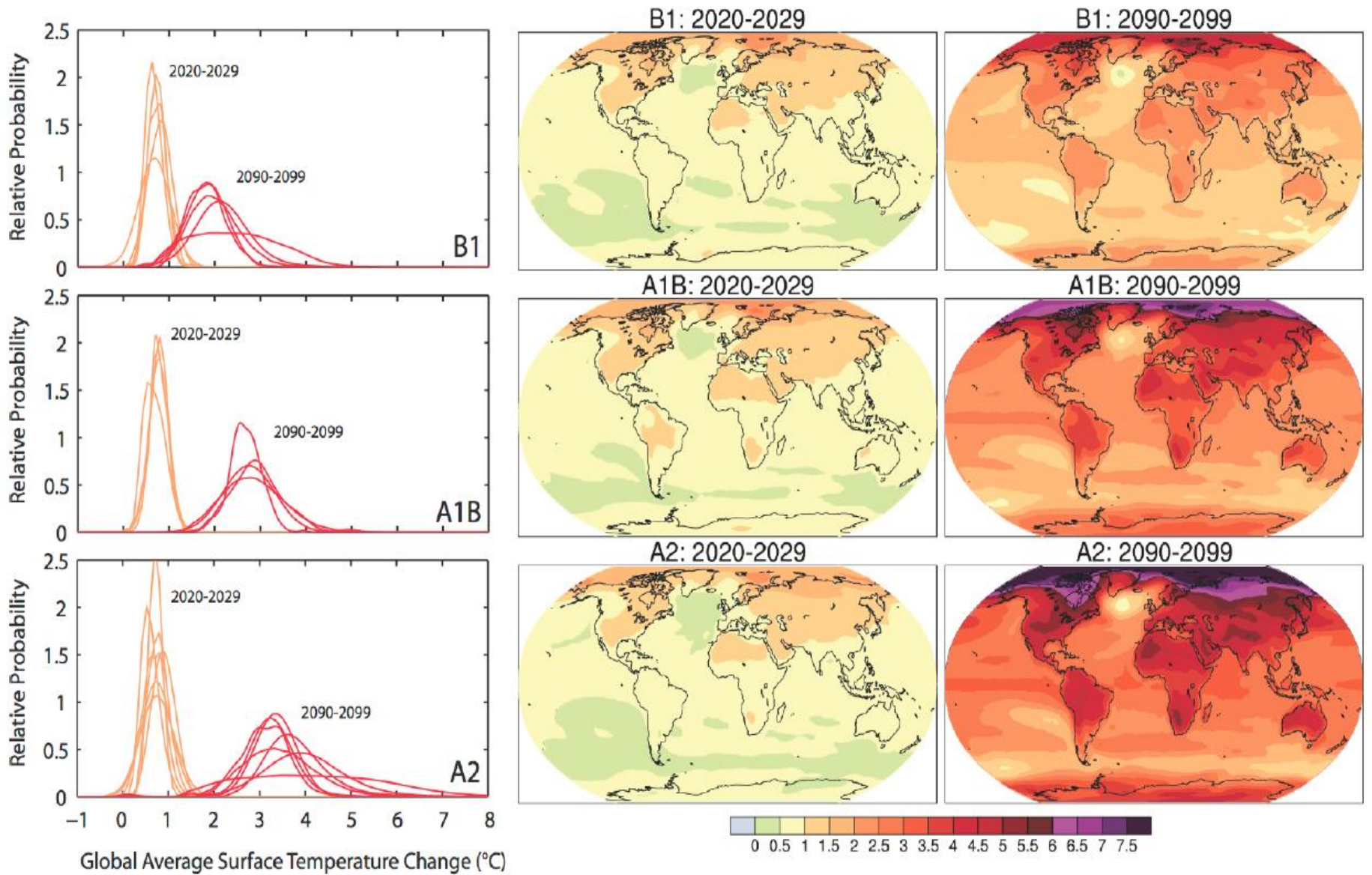
IPCC AR5 Strategy

- **More emphasis on extreme events**
- **Shorter term, now to 2050**
- **Regional impacts**
- **Policy options and consequences**

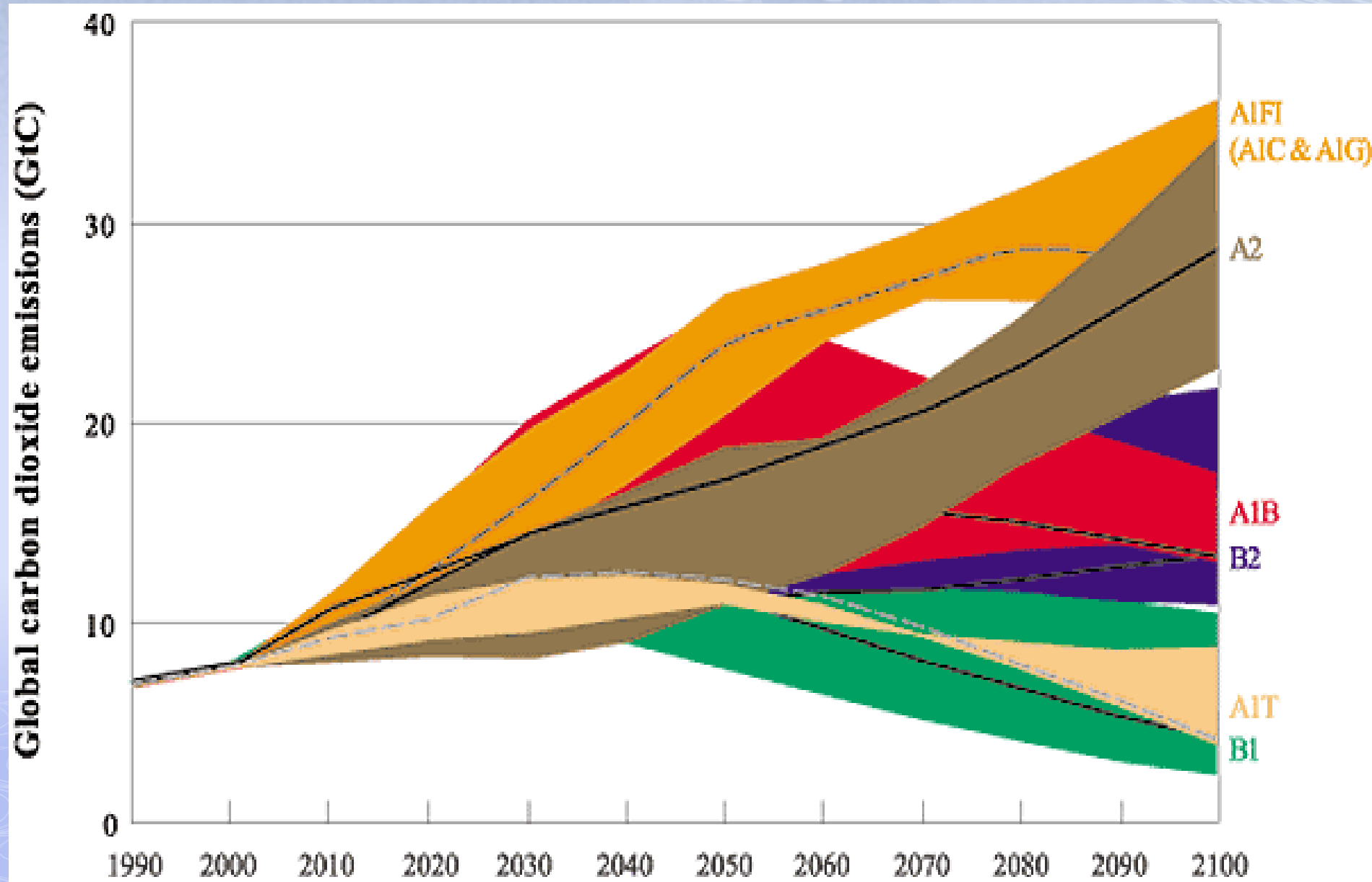
IPCC AR5 SCHEDULE

- **WG I: The Physical Science Basis**
mid September 2013
- **WG II: Impacts, Adaptation and Vulnerability**
mid March 2014
- **WG III: Mitigation of Climate Change**
early April 2014
- **AR5 Synthesis Report (SYR)**
October 2014

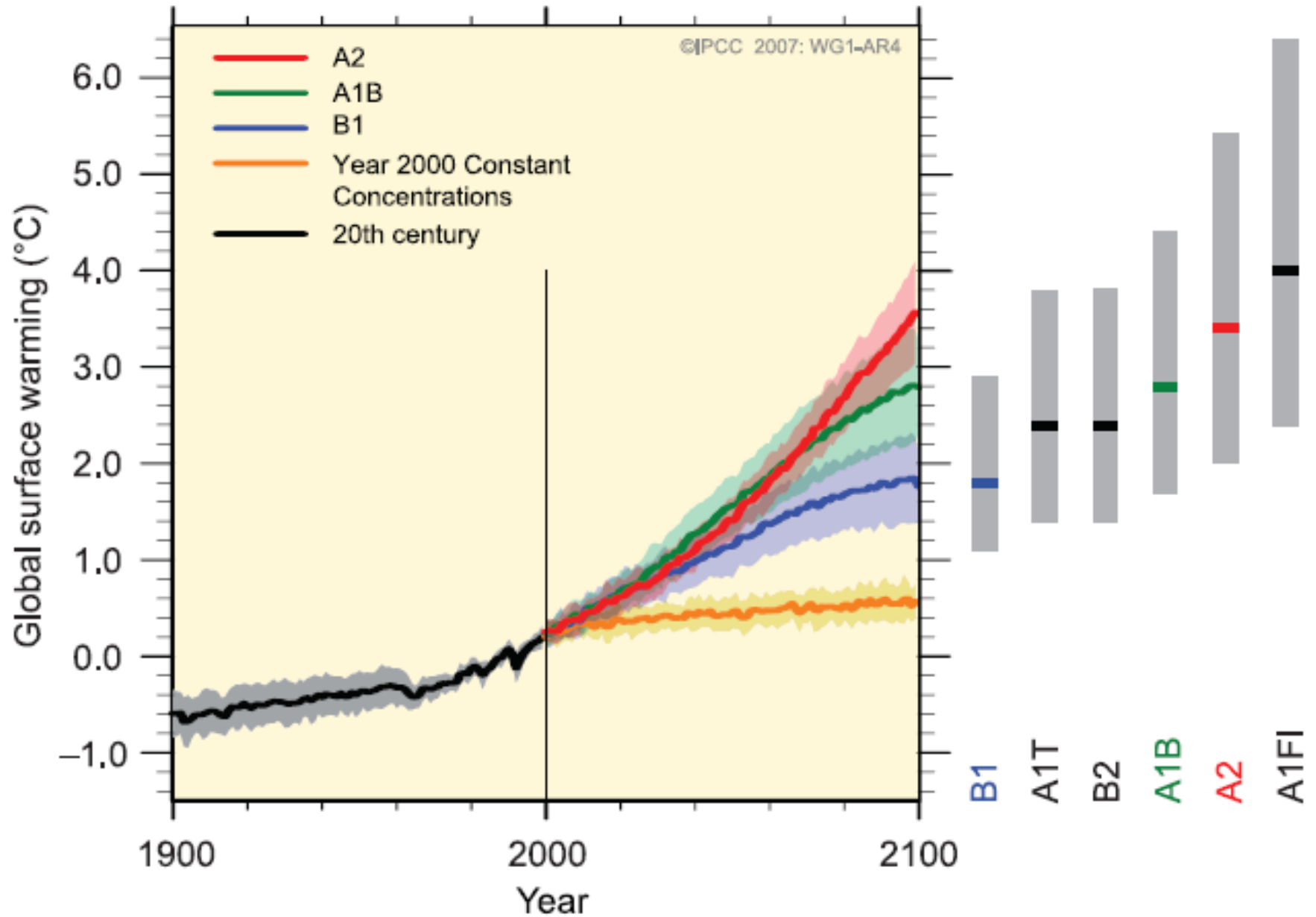
AOGCM Projections of Surface Temperatures



Global annual CO₂ emissions – all sources (6 scenario groups)



MULTI-MODEL AVERAGES AND ASSESSED RANGES FOR SURFACE WARMING



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

The screenshot shows a Mozilla Firefox browser window displaying the EdGCM website. The browser's address bar shows the URL <http://edgcm.columbia.edu/>. The website's header features the EdGCM logo and the text "Educational Global Climate Modeling" over a world map background. A search bar is located on the left side of the page. The main content area is divided into several sections:

- EdGCM: The Project**: A section with a globe icon and text describing the project's goal to develop a research-quality global climate model (GCM) with a user-friendly interface. It lists various scientific processes involved, such as designing experiments, running simulations, and creating manuscripts. A "Read more..." link is provided.
- "Anthropocene" Greenhouse Gas Effects**: A section titled "Outreach - Student Projects" written by Dominique Alhambra and Christine Kwitek on Wednesday, 09 May 2007. It discusses the early anthropogenic hypothesis by William Ruddiman and includes a photograph of a forest. A "Read more..." link is provided.
- Snowball Earth: Effect of Obliquity**: A section titled "Outreach - Student Projects" written by John Swain and Jeremiah Marsicek on Wednesday, 09 May 2007. It discusses geologic evidence from the Sturtian period (~750Ma) and includes a small map of the Earth showing the location of the Sturtian period. A "Read more..." link is provided.
- Examining the Effects of Global Warming on Greenland**: A section titled "Outreach - Exercises" written by Mark Chandler on Sunday, 11 December 2005. It discusses tracking changes in temperature and snowfall over Greenland and includes a small globe icon. A "Read more..." link is provided.

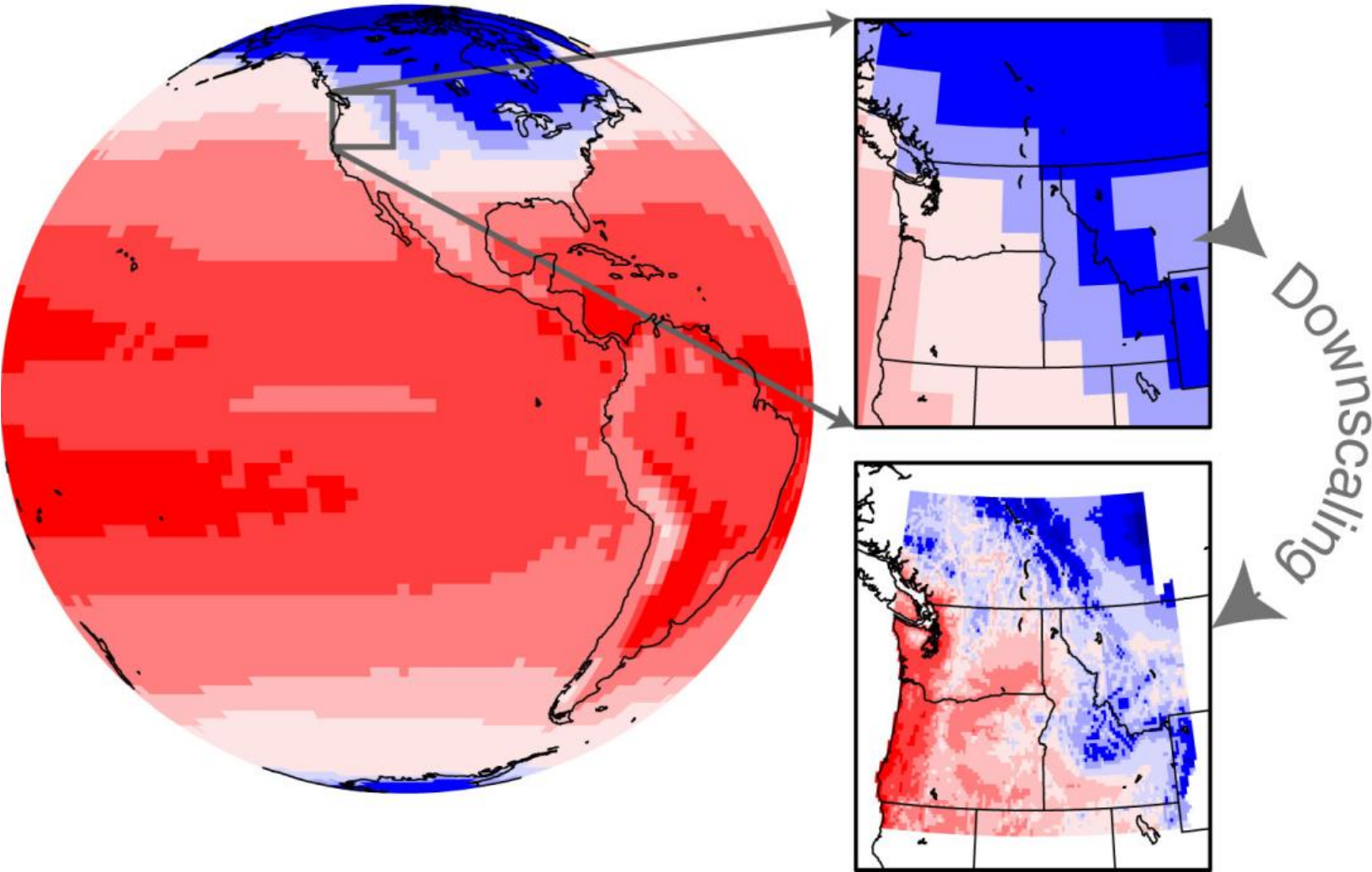
On the right side of the page, there are three additional sections:

- EdGCM in Antarctica**: A section with a list of links including "More Blogging but Elsewhere", "ANDRILL in Google Earth", "Off the Ice", "Departure", "12 Hours at the South Pole", "Head, meet foot", and "South Pole (Yes?)".
- EdGCM Forum Posts**: A section with a list of links including "Google Earth", "Ocean albedo calculations", "source code for Modern File VBX10.vag", "Terrain and initial conditions", and "4d tools?".
- Visitor Locations**: A section with a map titled "Visitor locations" showing various locations marked with red dots. A "Click to see" link is provided.

The browser's status bar at the bottom shows the system tray with icons for network, volume, and power, along with the current date and time: "Now: Fair and 57°F", "Today: 73°F", and "Fri: 78°F".

Downscaling global models for regional studies

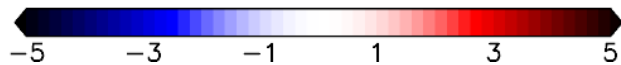
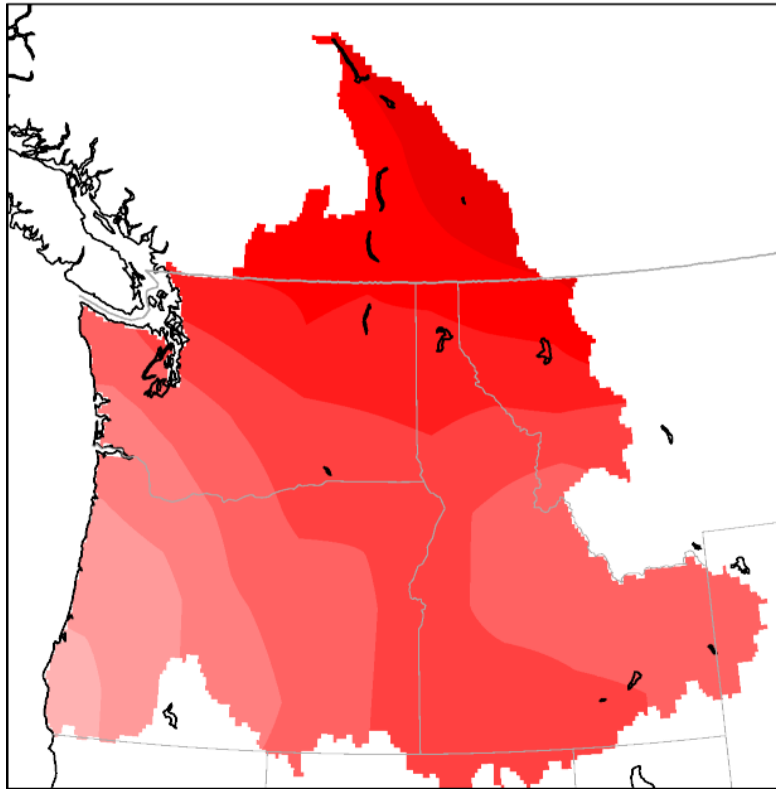
Global Climate Model Air Temperature



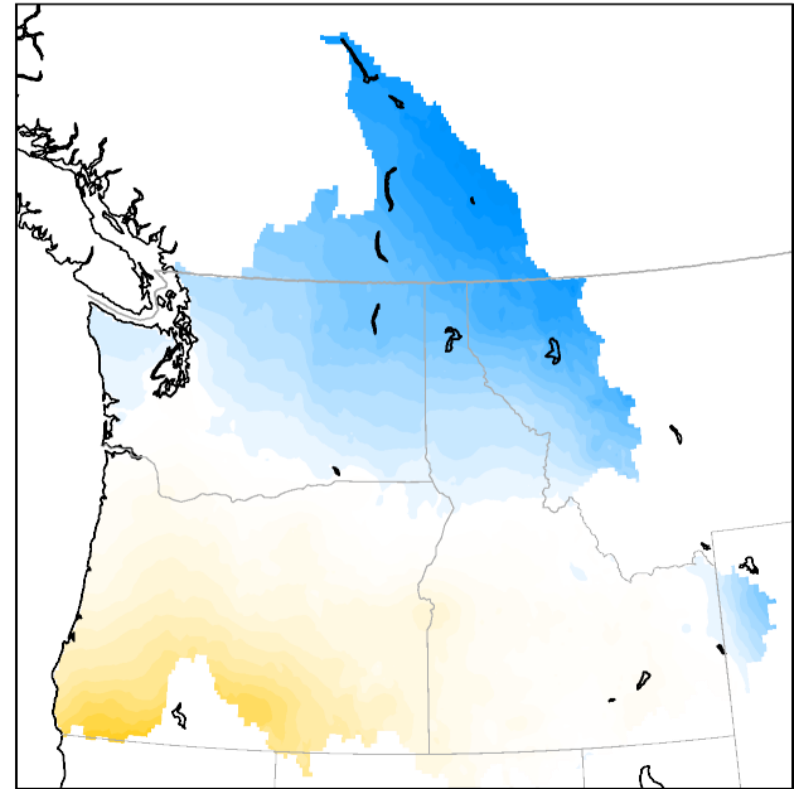
Downscaling -- Winter

DJF Difference to 2040 CCSM3

Temp (C)



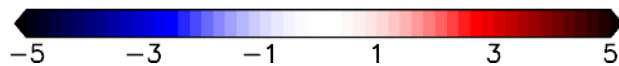
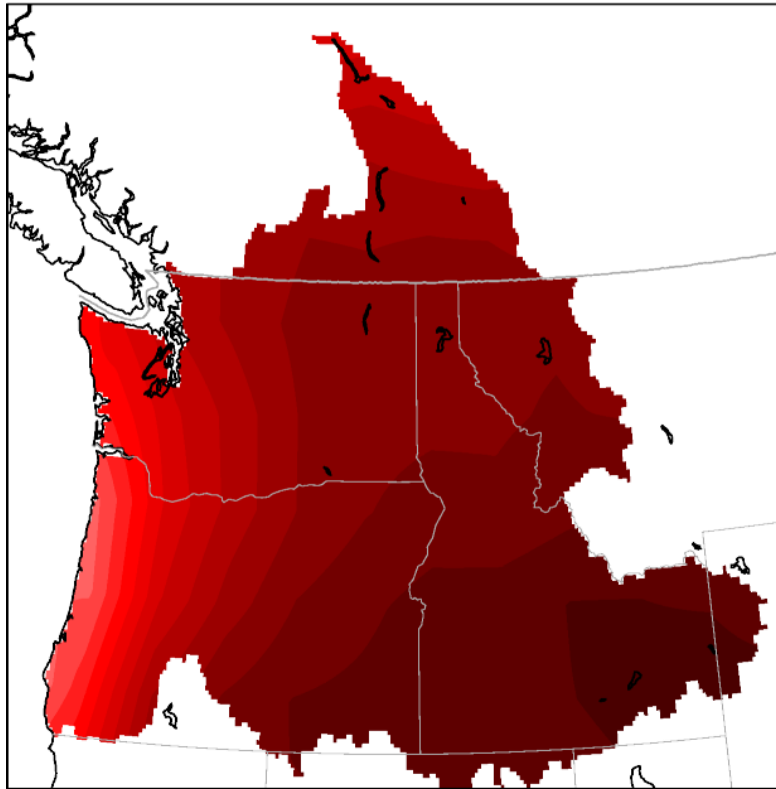
Precip (%)



Downscaling -- Summer

JJA Difference to 2040 CCSM3

Temp (C)



Precip (%)

