

GCMs

**Global Climate Models
also known as
General Circulation Models
Fall 2010**

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

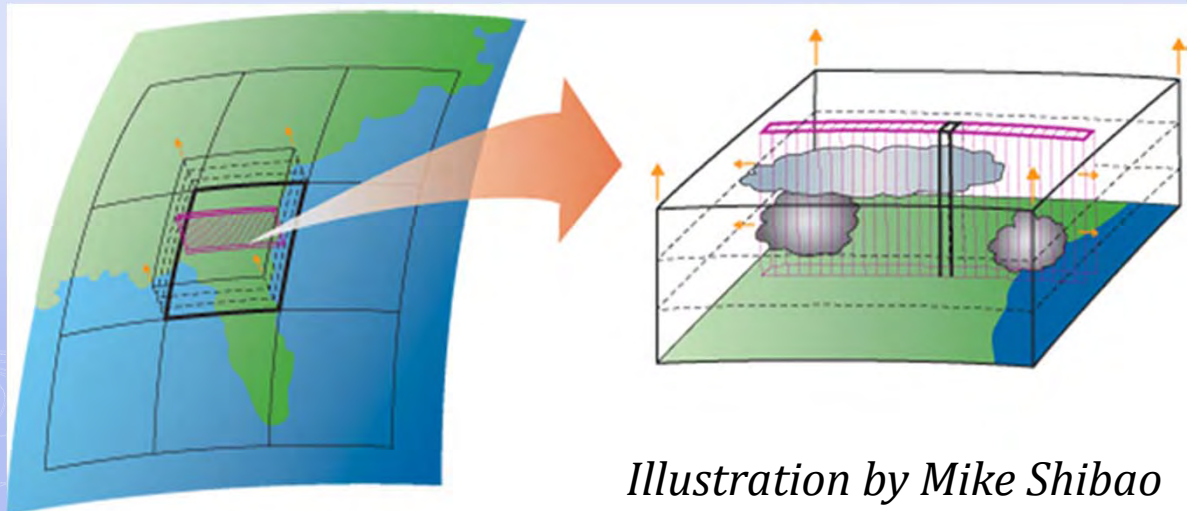


Illustration by Mike Shibao

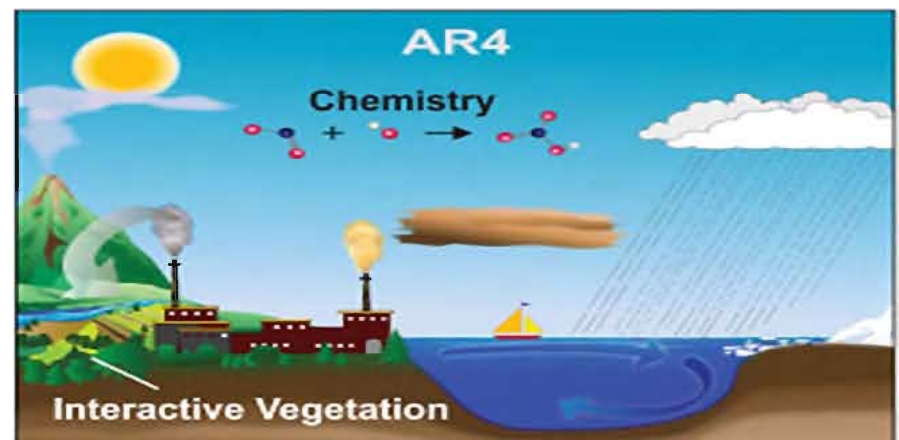
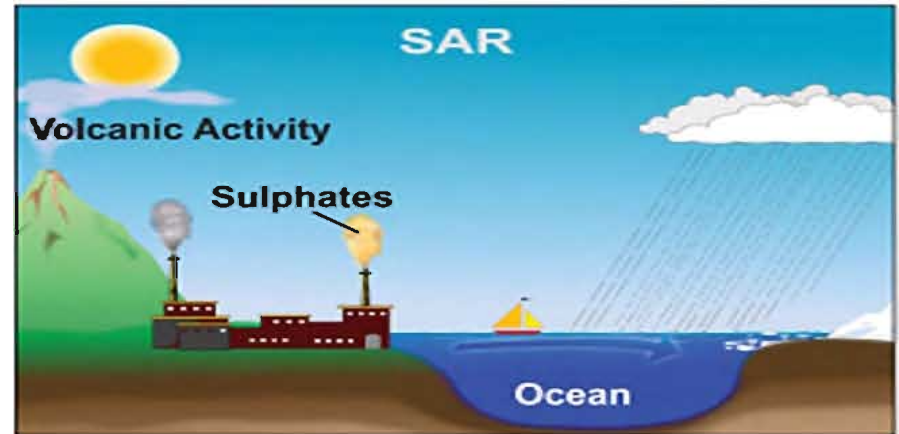
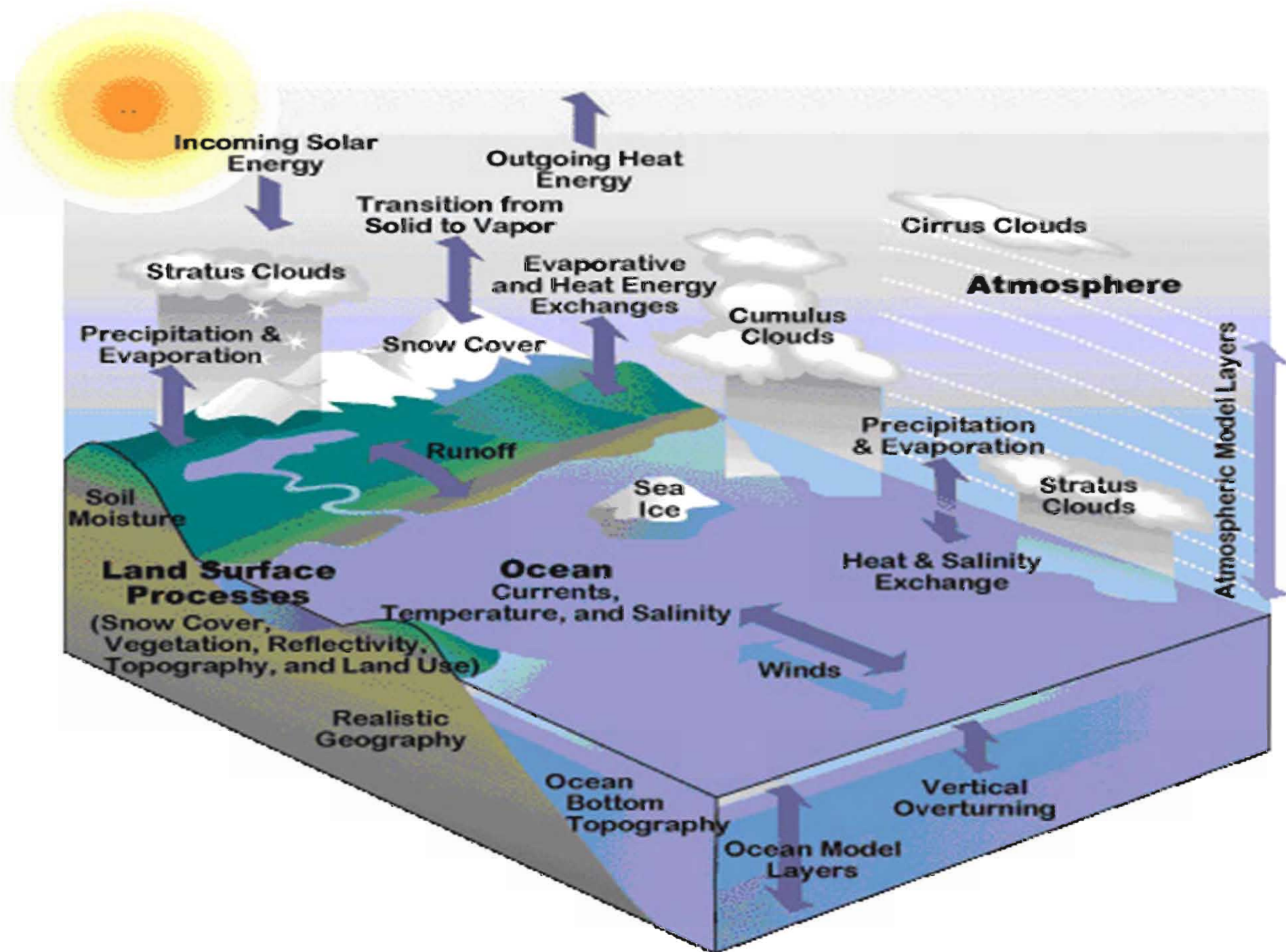
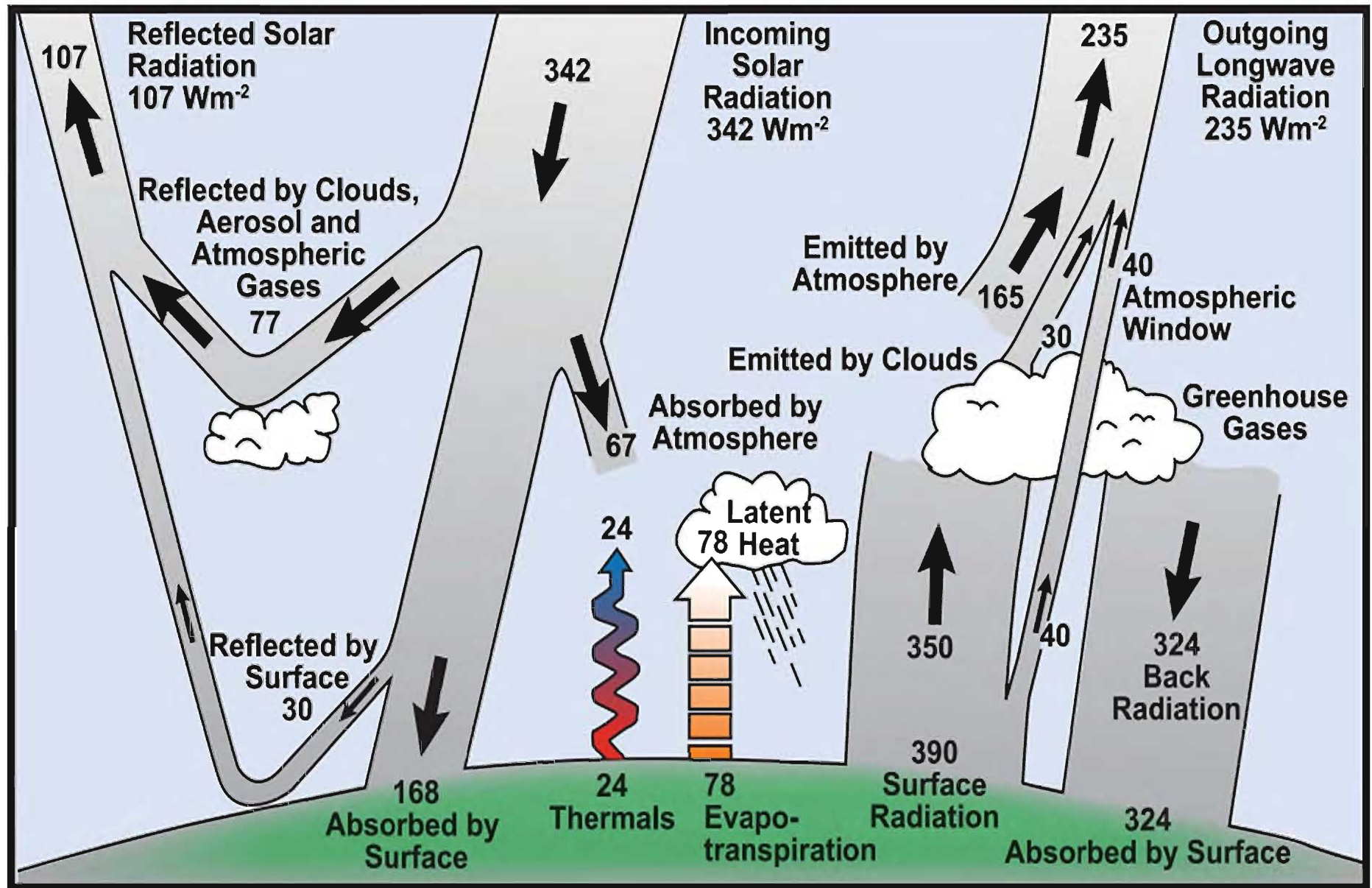


Figure 1.2. The complexity of climate models has increased over the last few decades. The additional physics incorporated in the models are shown pictorially by the different features of the modelled world.



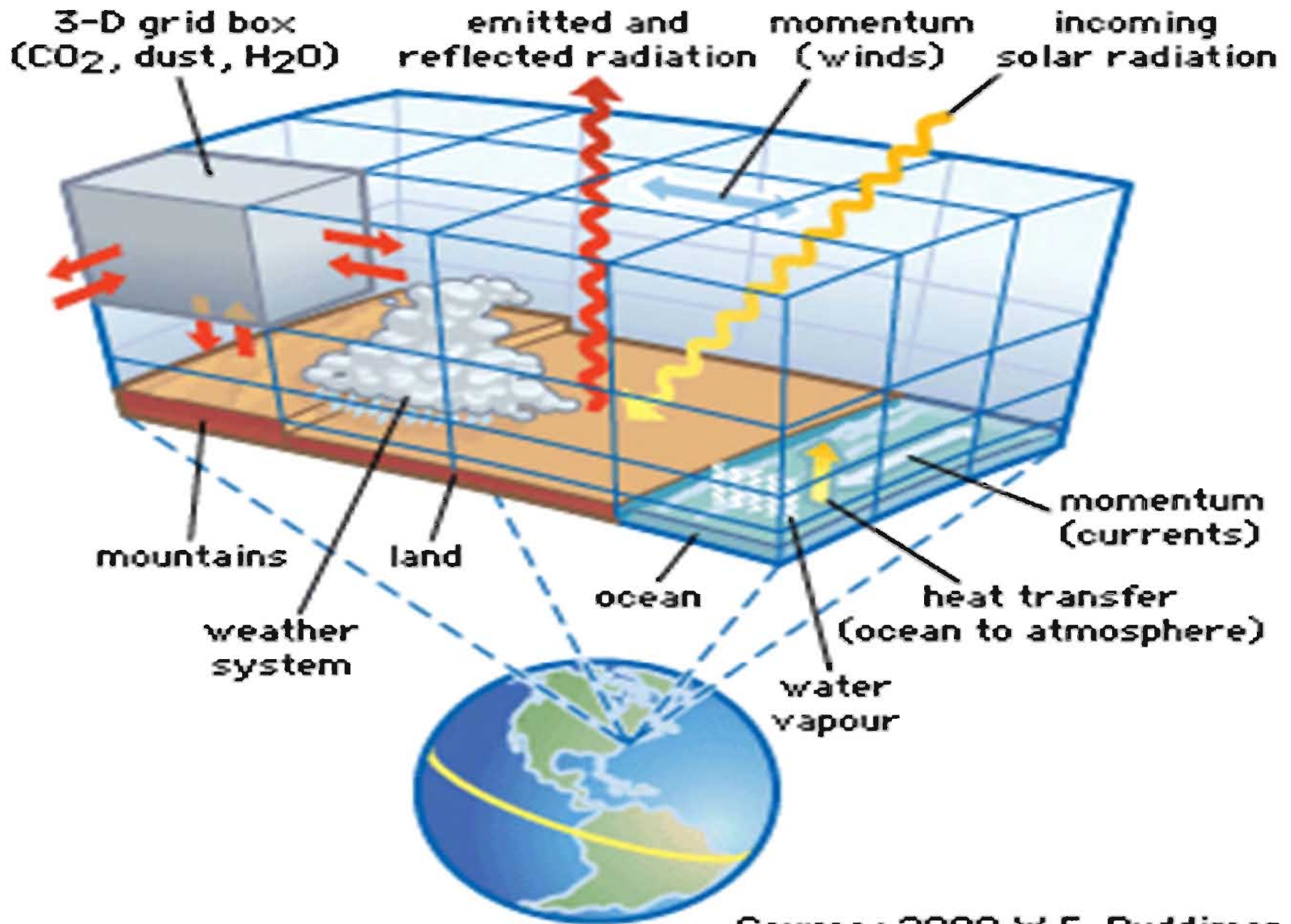


The Earth Simulator Center



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).

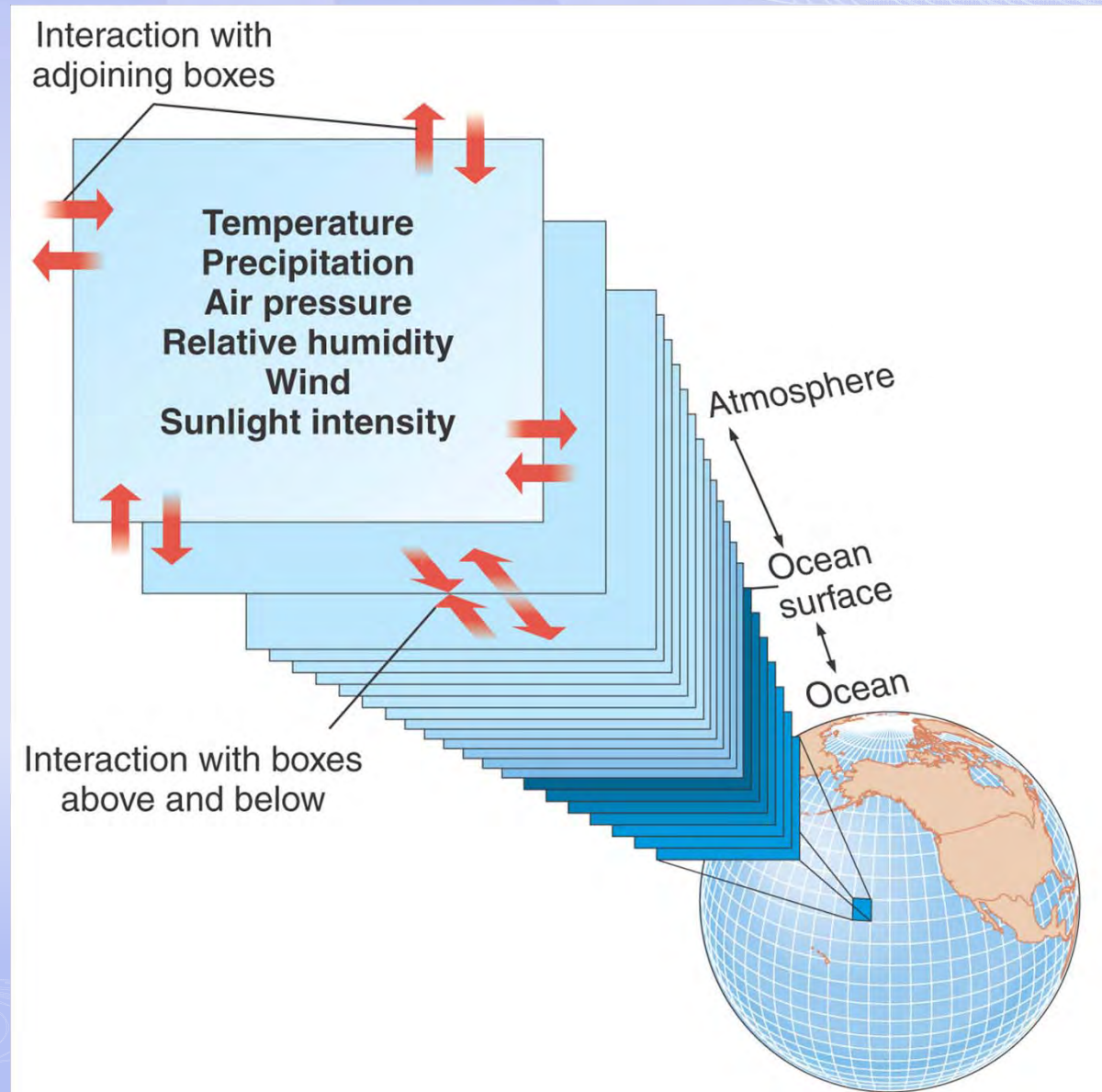
Concept diagram of climate modeling



Source : 2000 W.F. Ruddiman

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



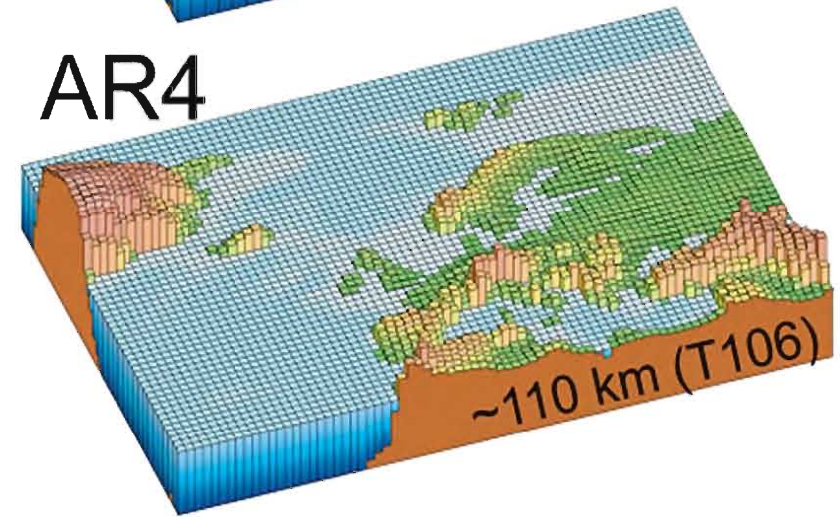
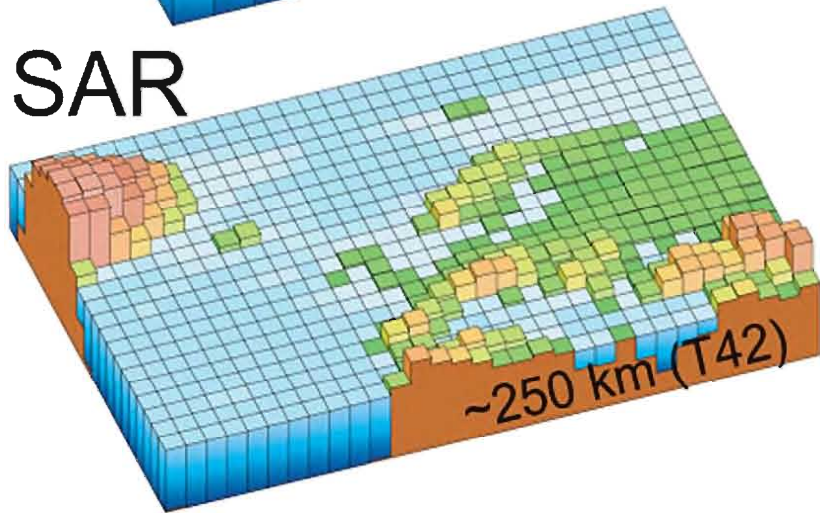
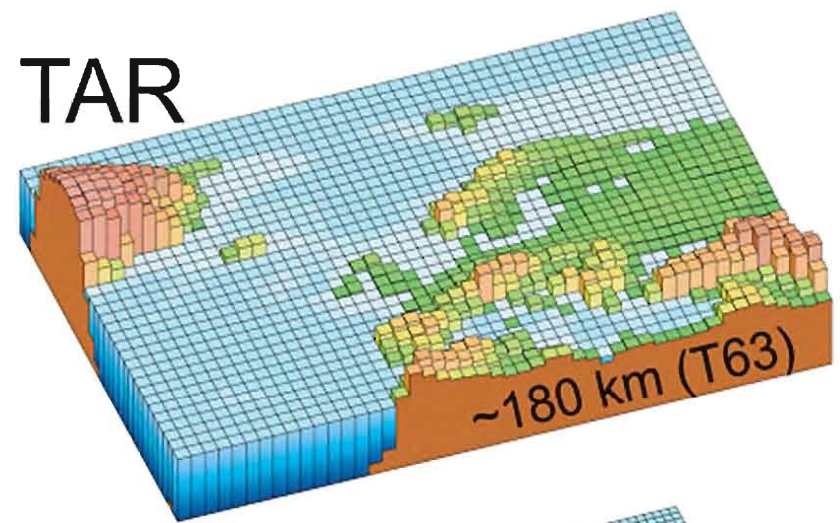
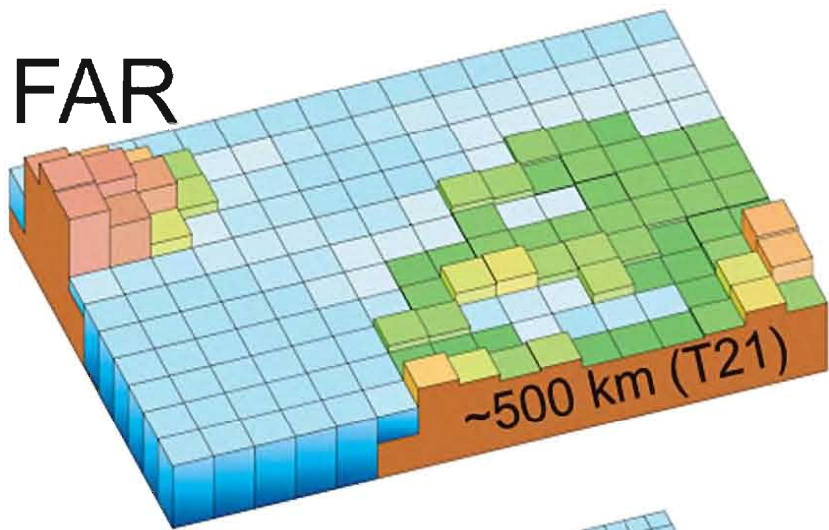
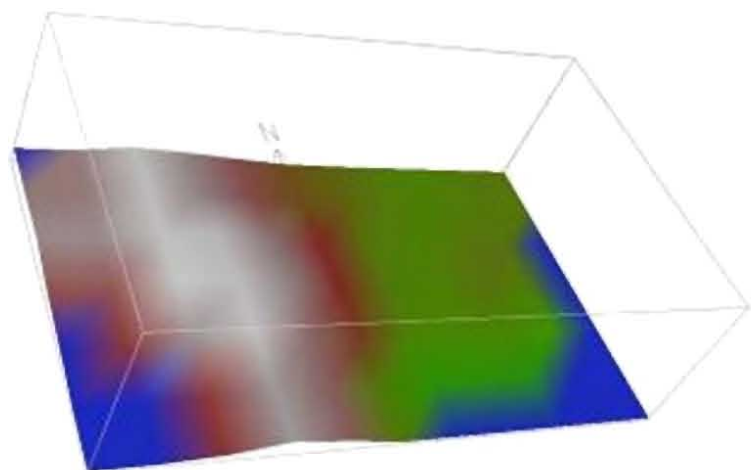


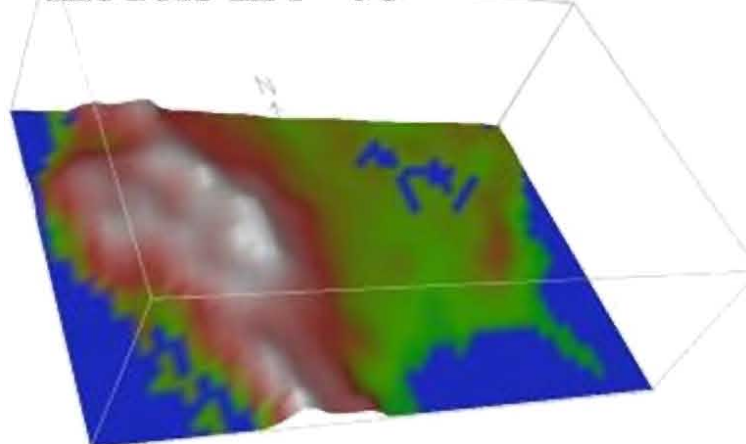
Figure 1.4. Geographic resolution characteristic of the generations of climate models used in the IPCC Assessment Reports: FAR (IPCC, 1990), SAR (IPCC, 1996), TAR (IPCC, 2001a), and AR4 (2007). The figures above show how successive generations of these global models increasingly resolved northern Europe.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



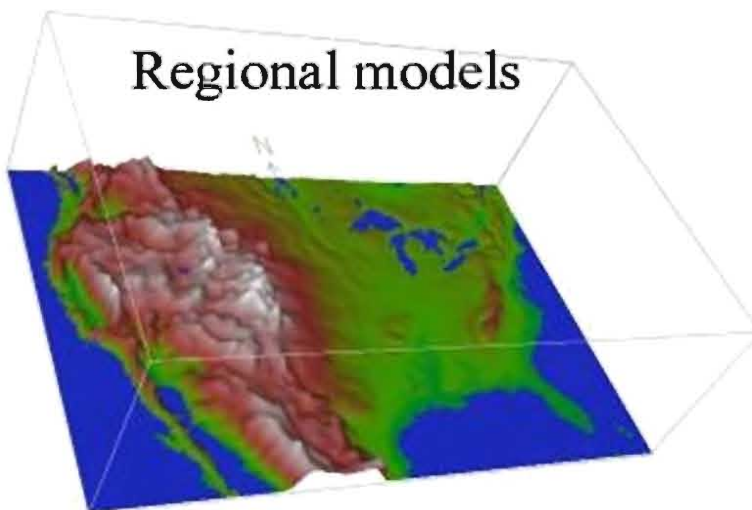
400 km

Global coupled climate models in 2006



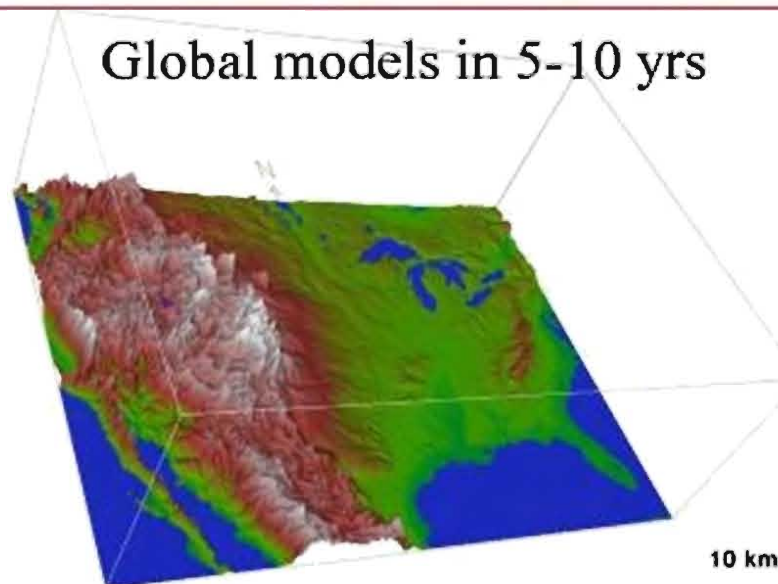
100 km

Regional models



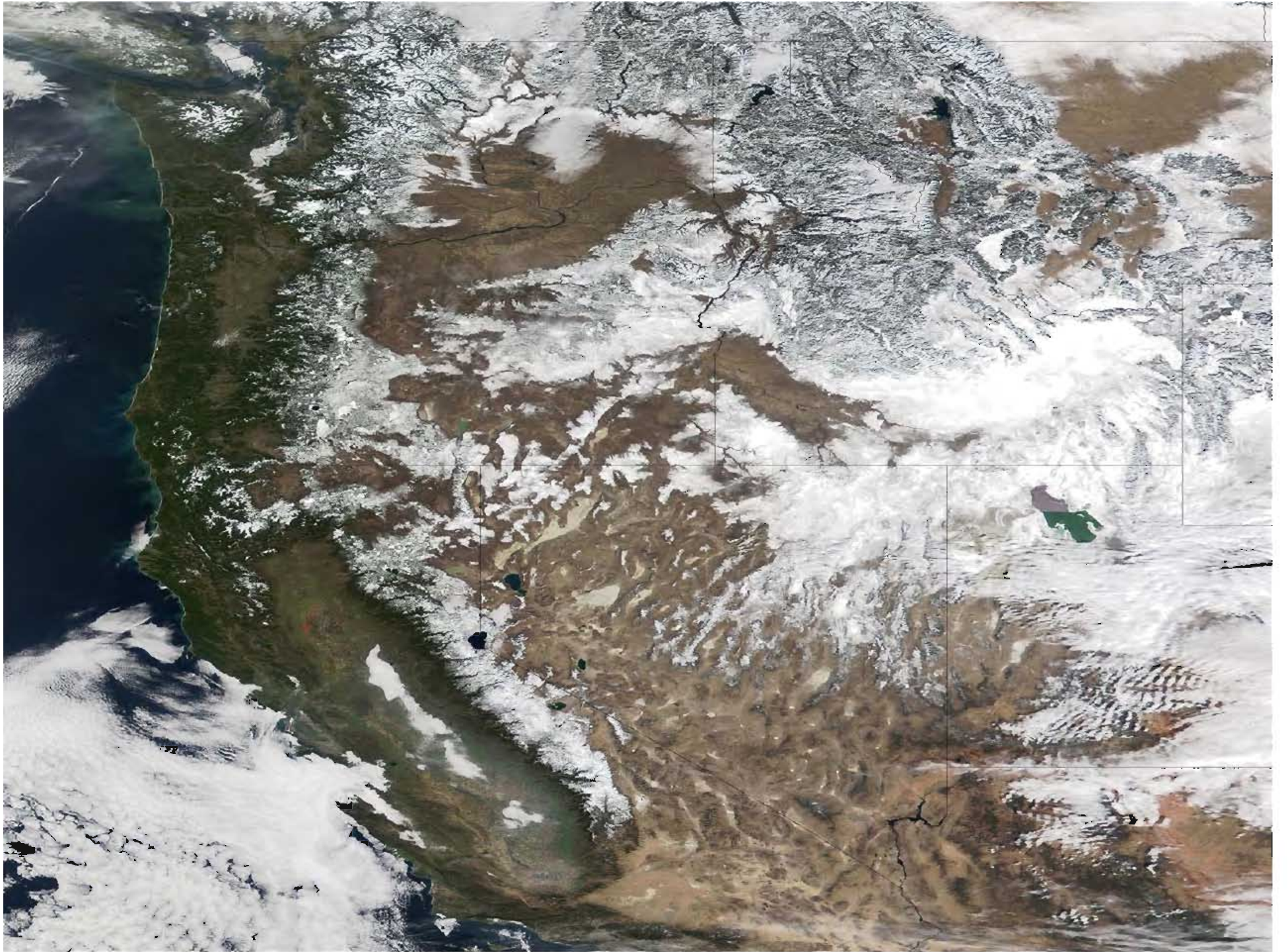
25 km

Global models in 5-10 yrs

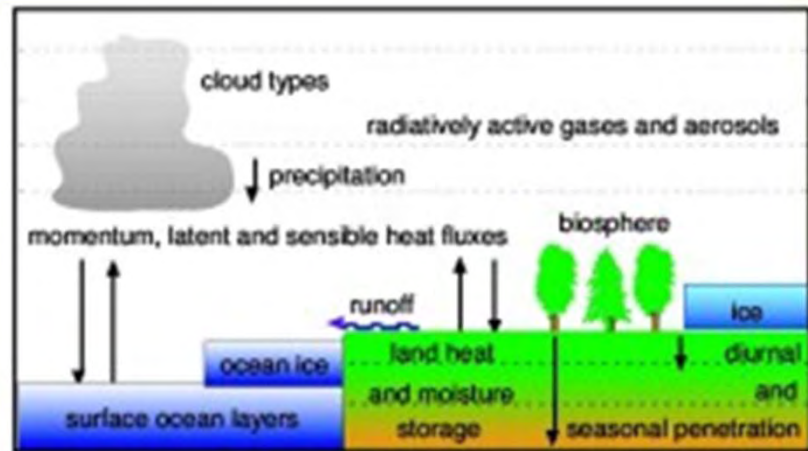


10 km

Optimistic view on model-development



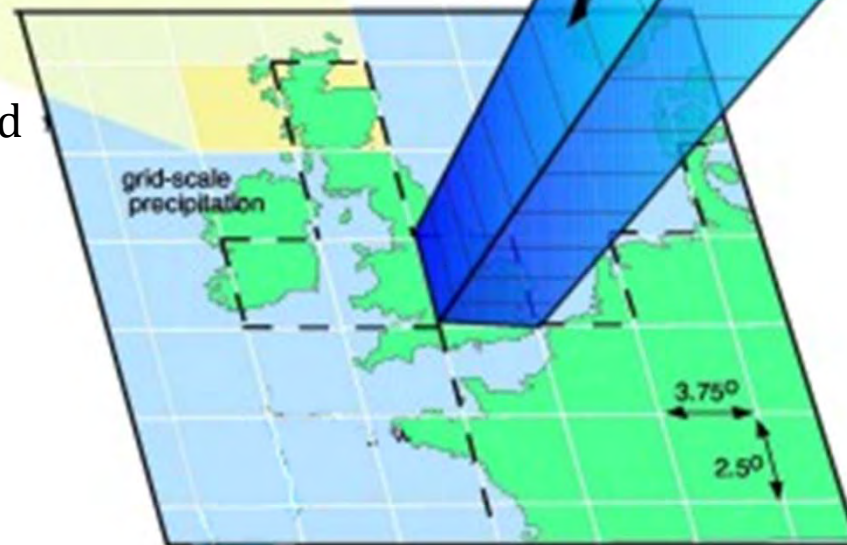
Atmospheric GCMs (AGCM)

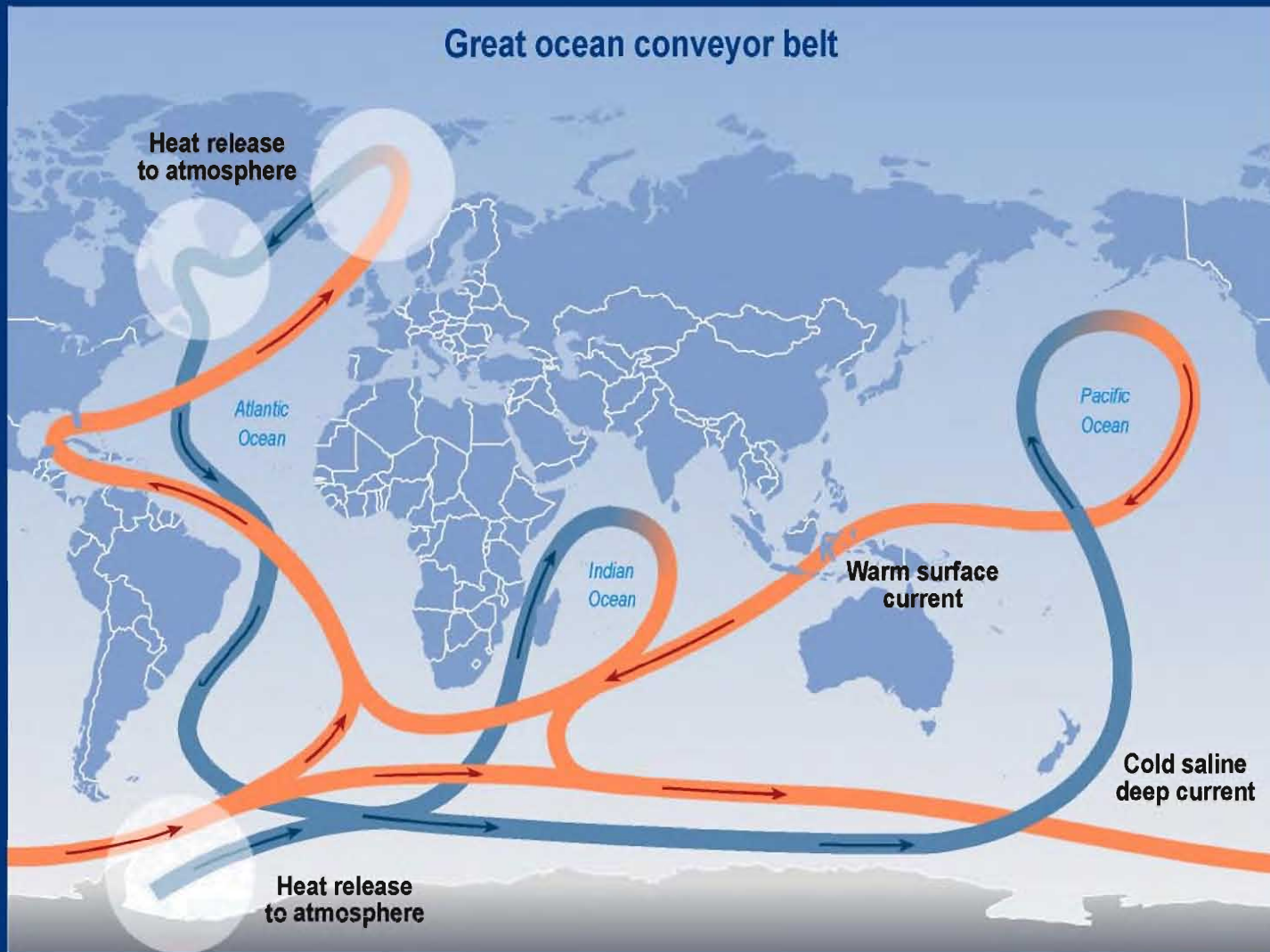


Horizontal exchange between columns of momentum, heat and moisture

vertical exchange between layers of momentum, heat and moisture

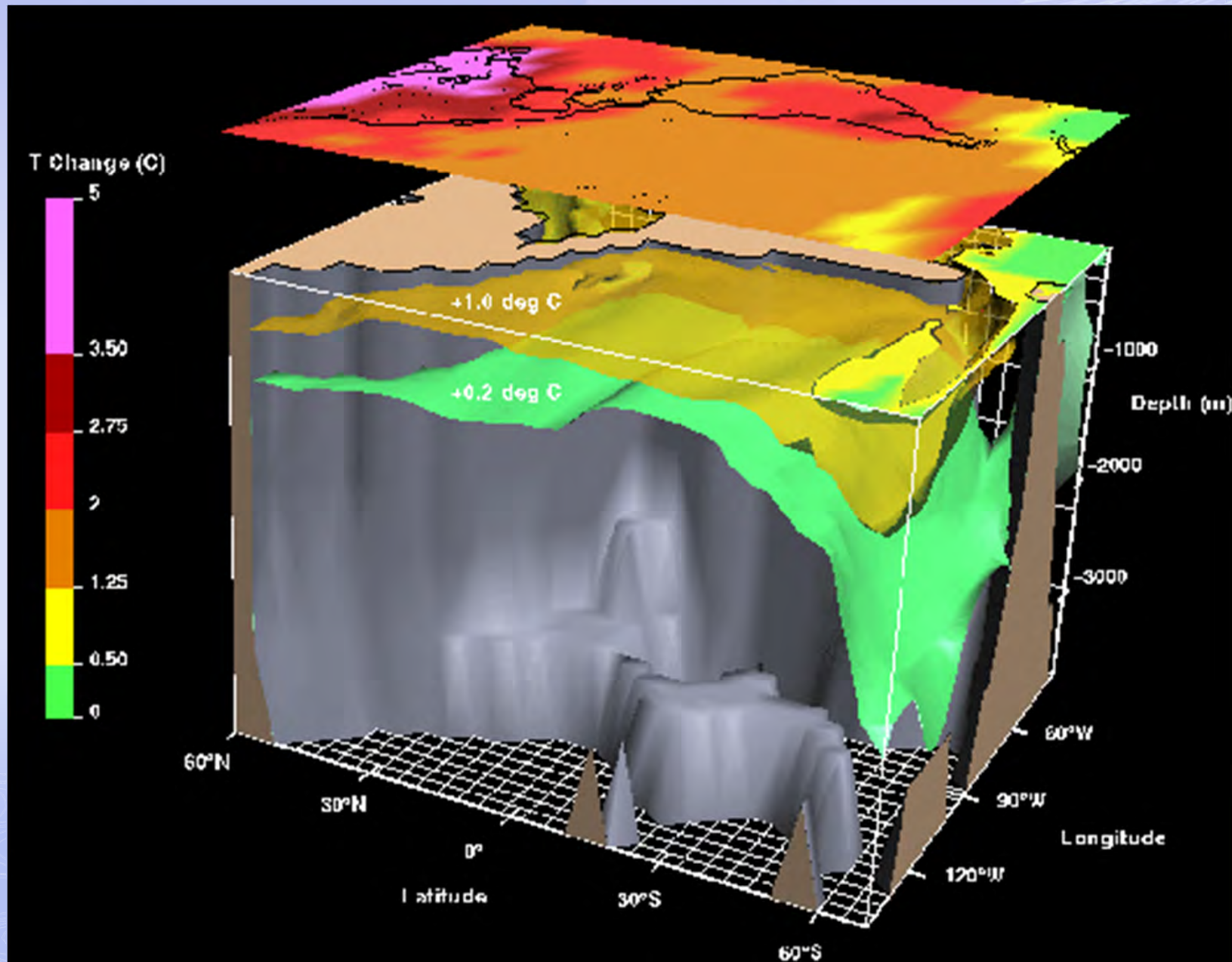
orography, vegetation and surface characteristics included at surface on each grid box





SYR - FIGURE 4-2

Combined GCMs (AOGCM)

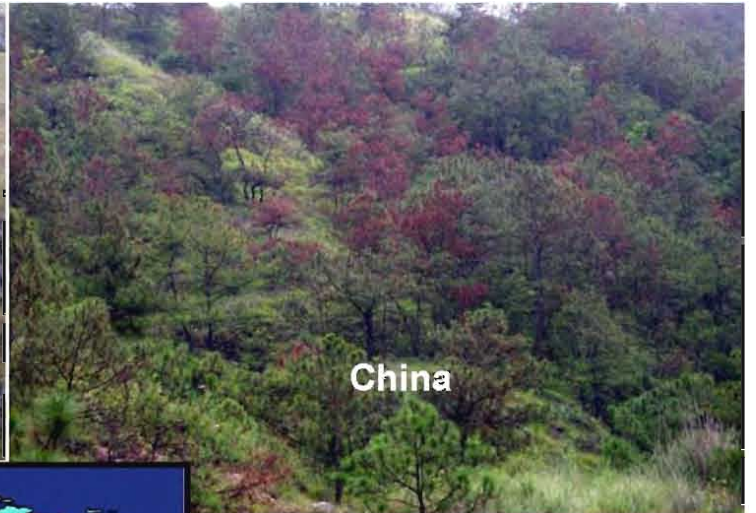




New Mexico



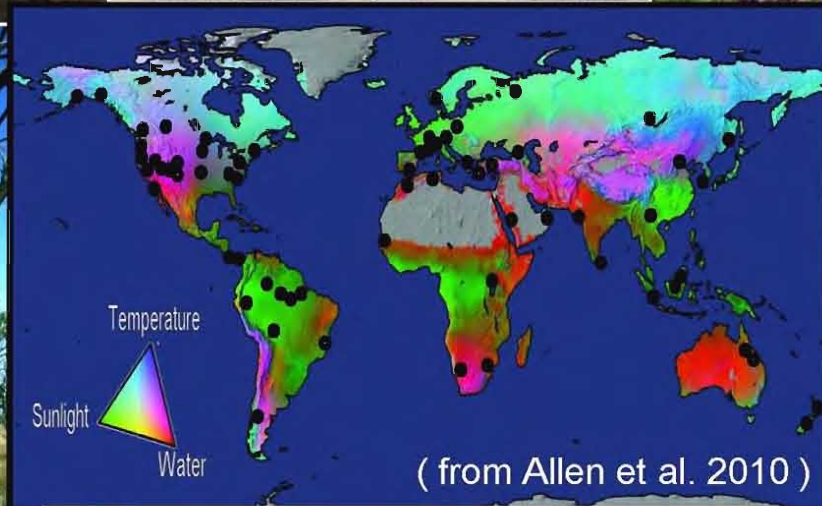
Alberta



China



Australia



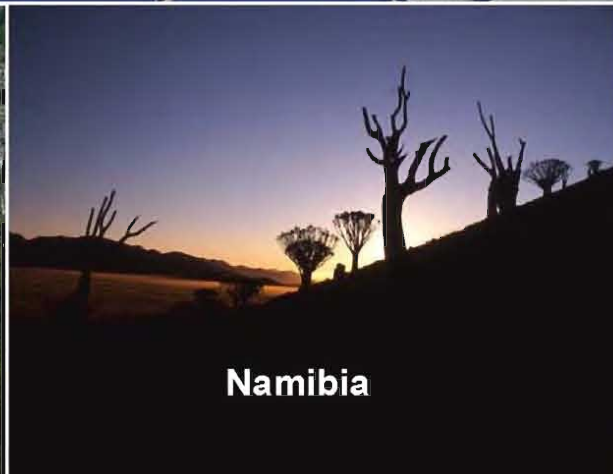
(from Allen et al. 2010)



Spain



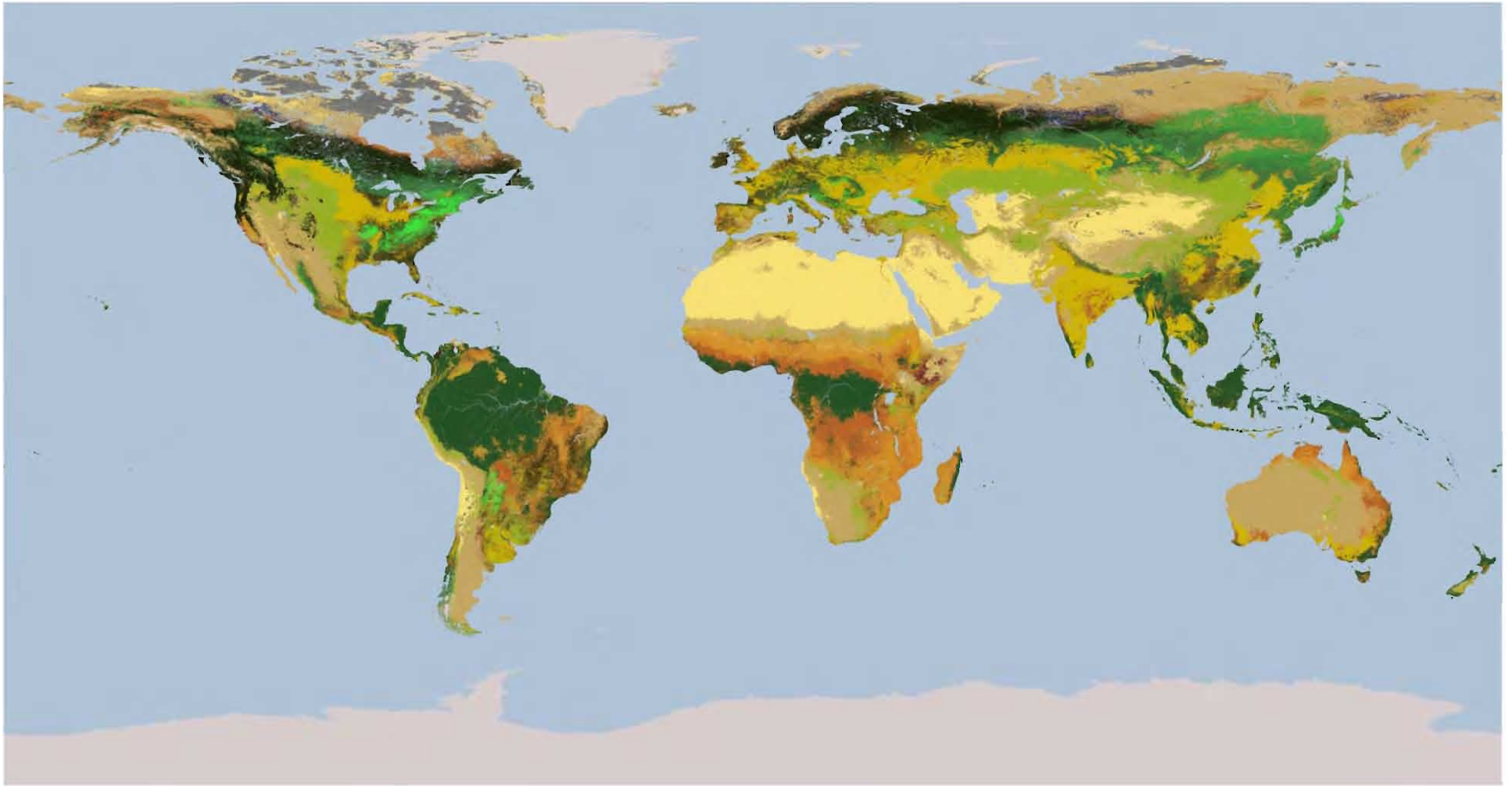
Argentina



Namibia



Algeria



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

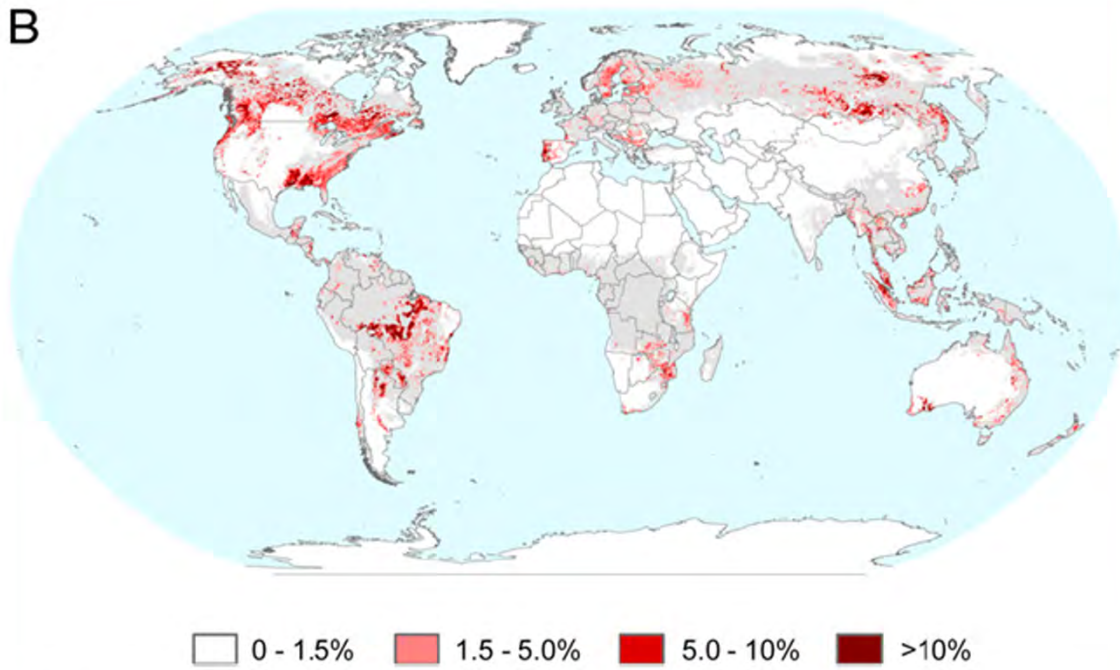
14 Cropland/Natural Veg. Mosaic

15 Snow and Ice

16 Barren or Sparsely Vegetated

17 Tundra

B



**% FOREST COVER LOSS
2000-2005**

From Hansen et al PNAS,
2010

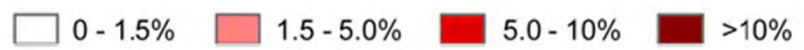
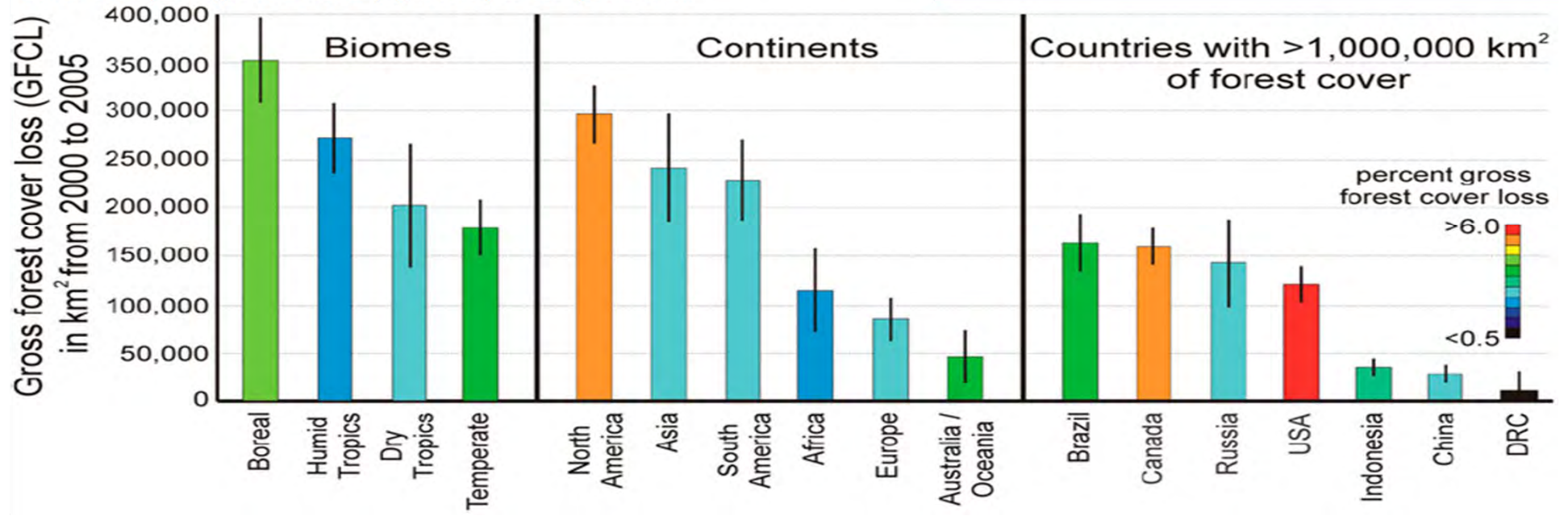
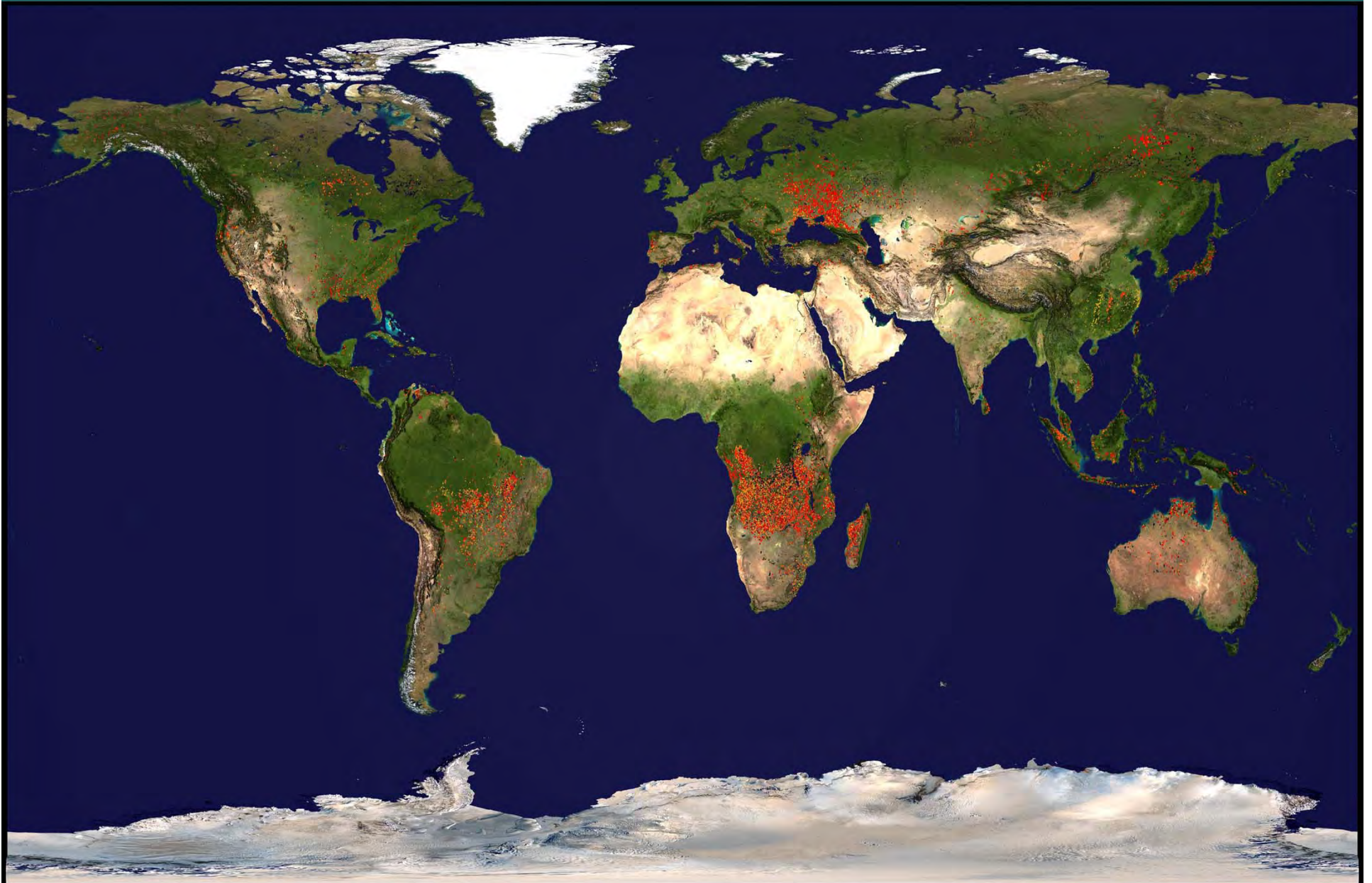


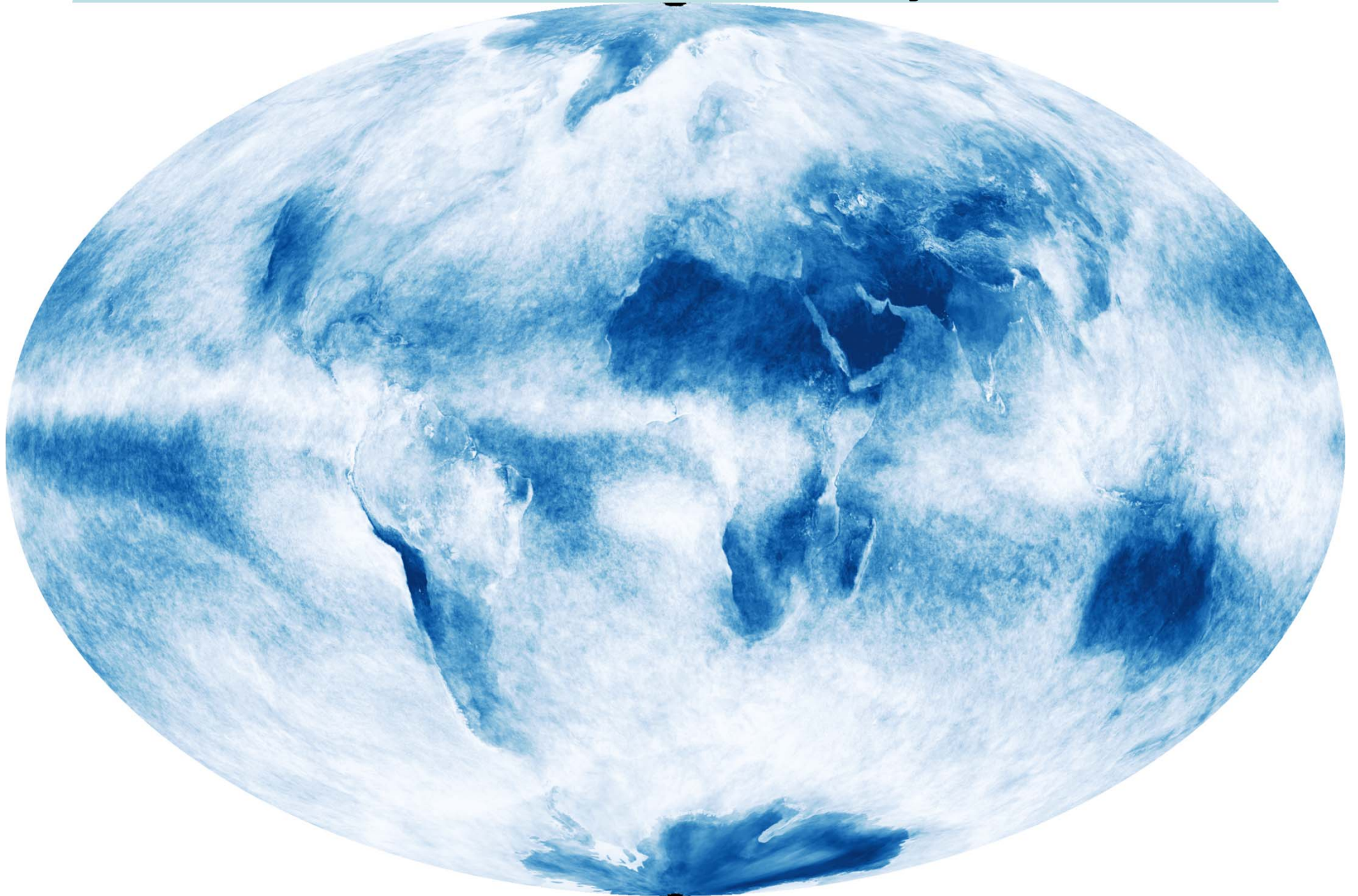
Fig. 1. Estimated percent forest cover, 2000 (A) and percent gross forest cover loss (GFCL), 2000–2005 (B), both per sample block.



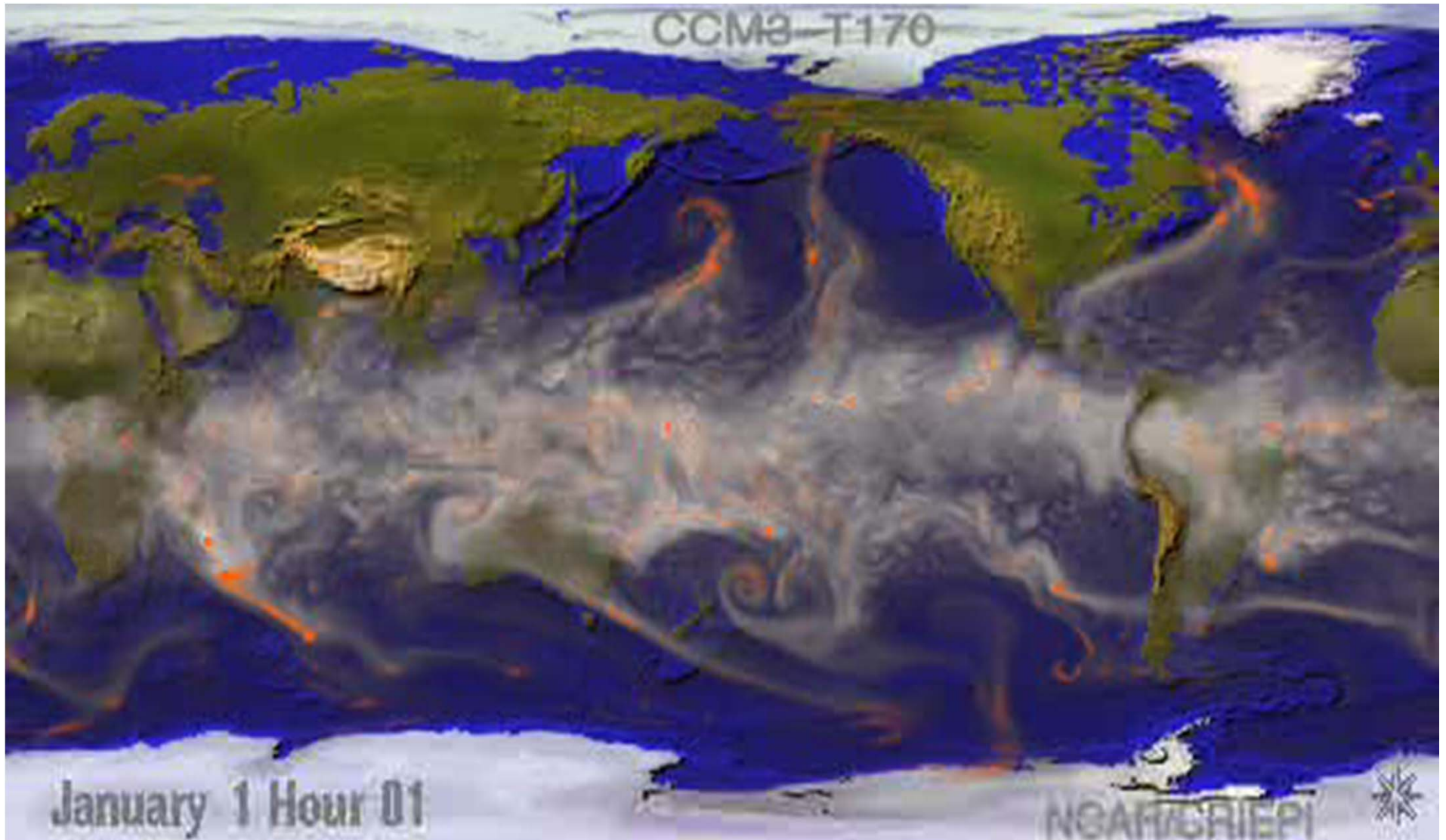
Global Fires for 10 Days

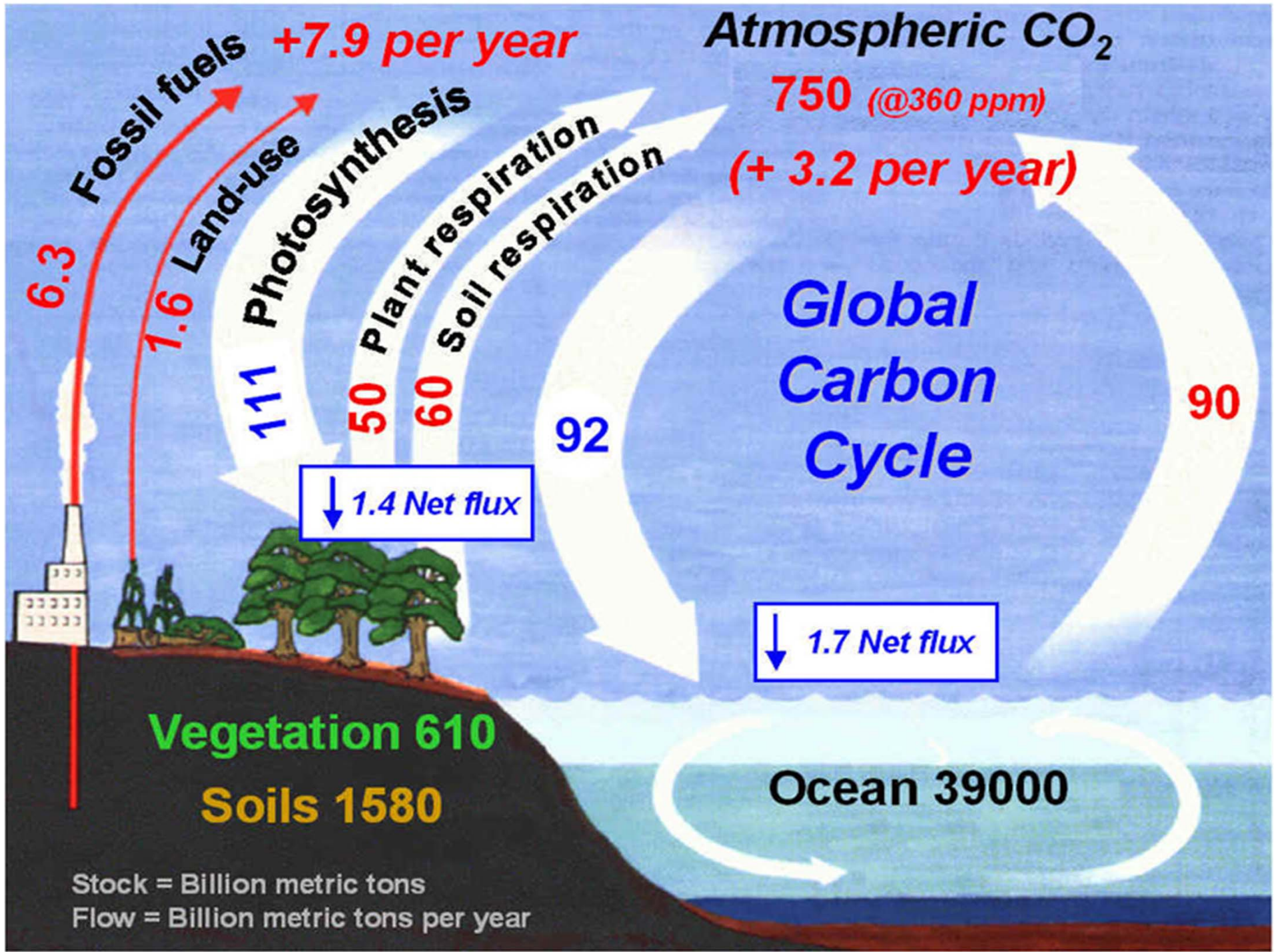


EARTH is 60-70% Cloudy



A GCM IN ACTION





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 ($\sim 3\%$ /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

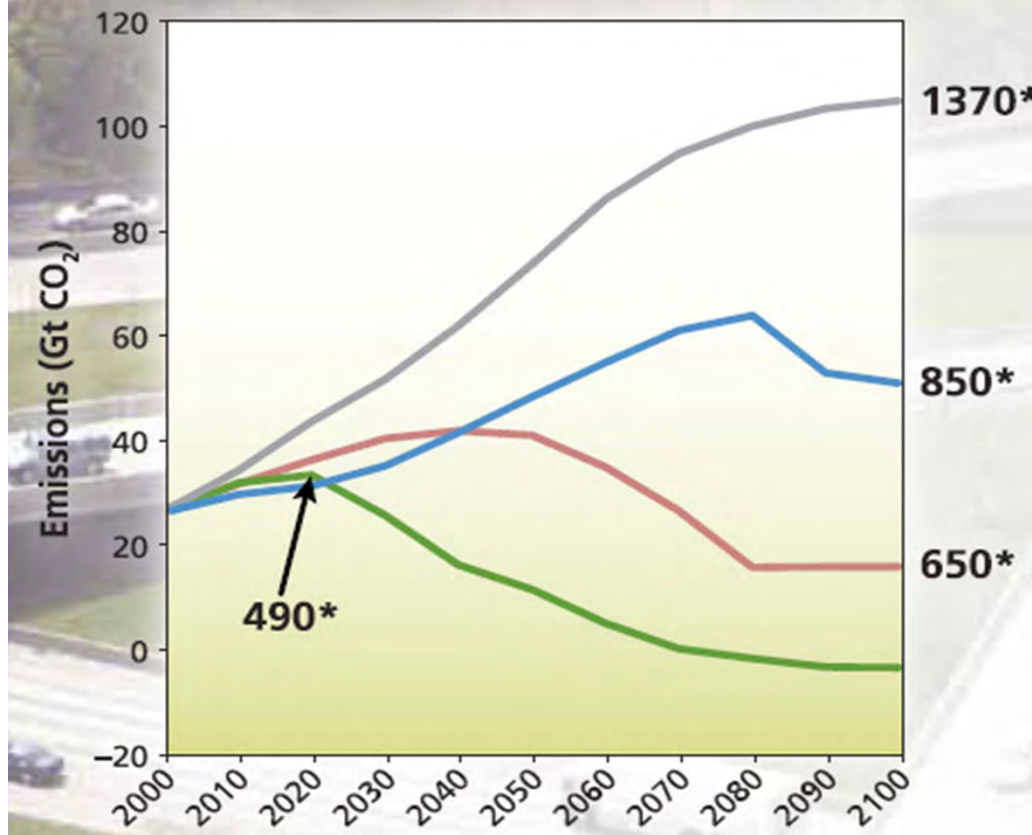
SRES: B1 Storyline – A more integrated, more ecologically friendly world

- 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 emissions pathways

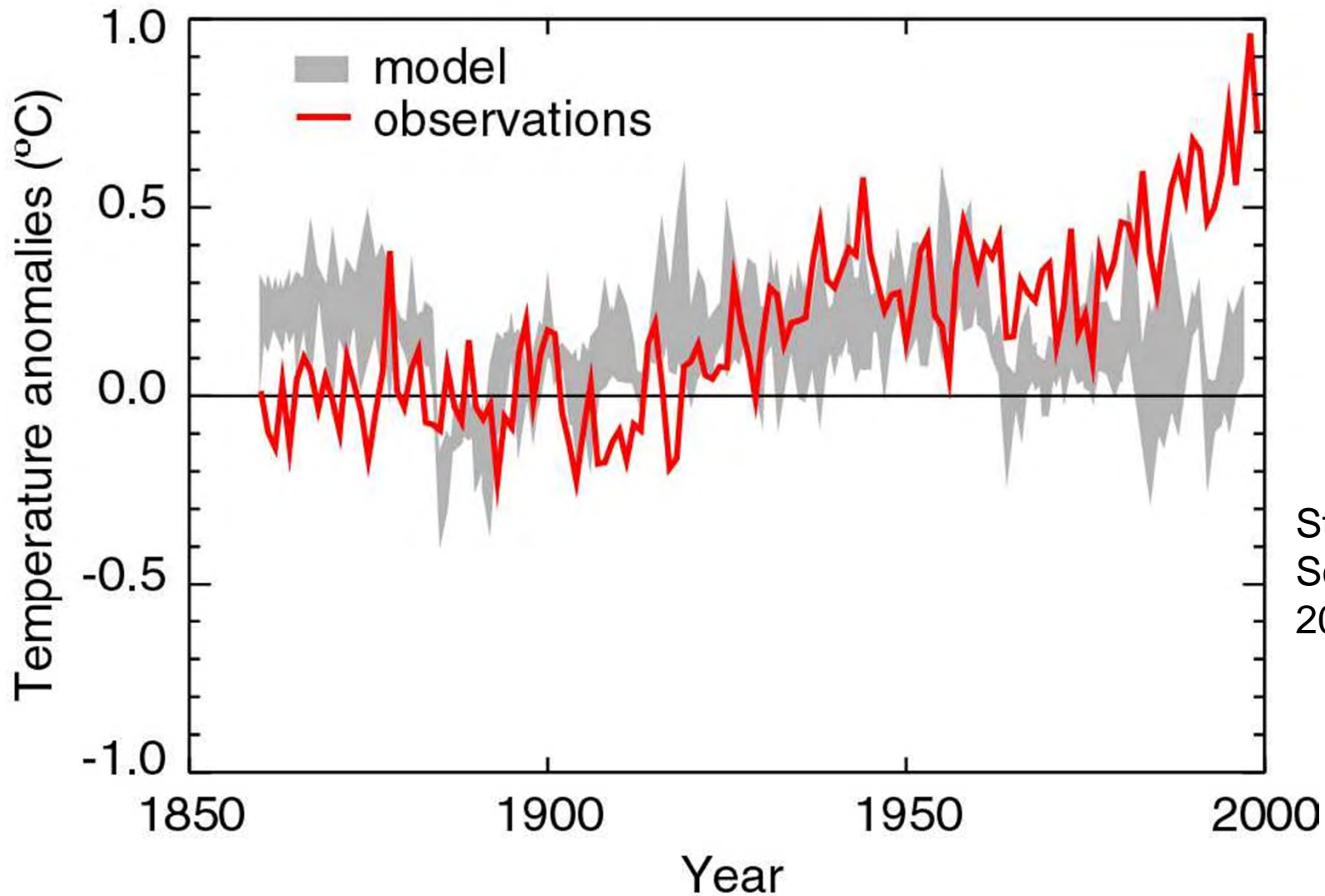


IPCC- 5th Assessment Emissions Scenarios

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

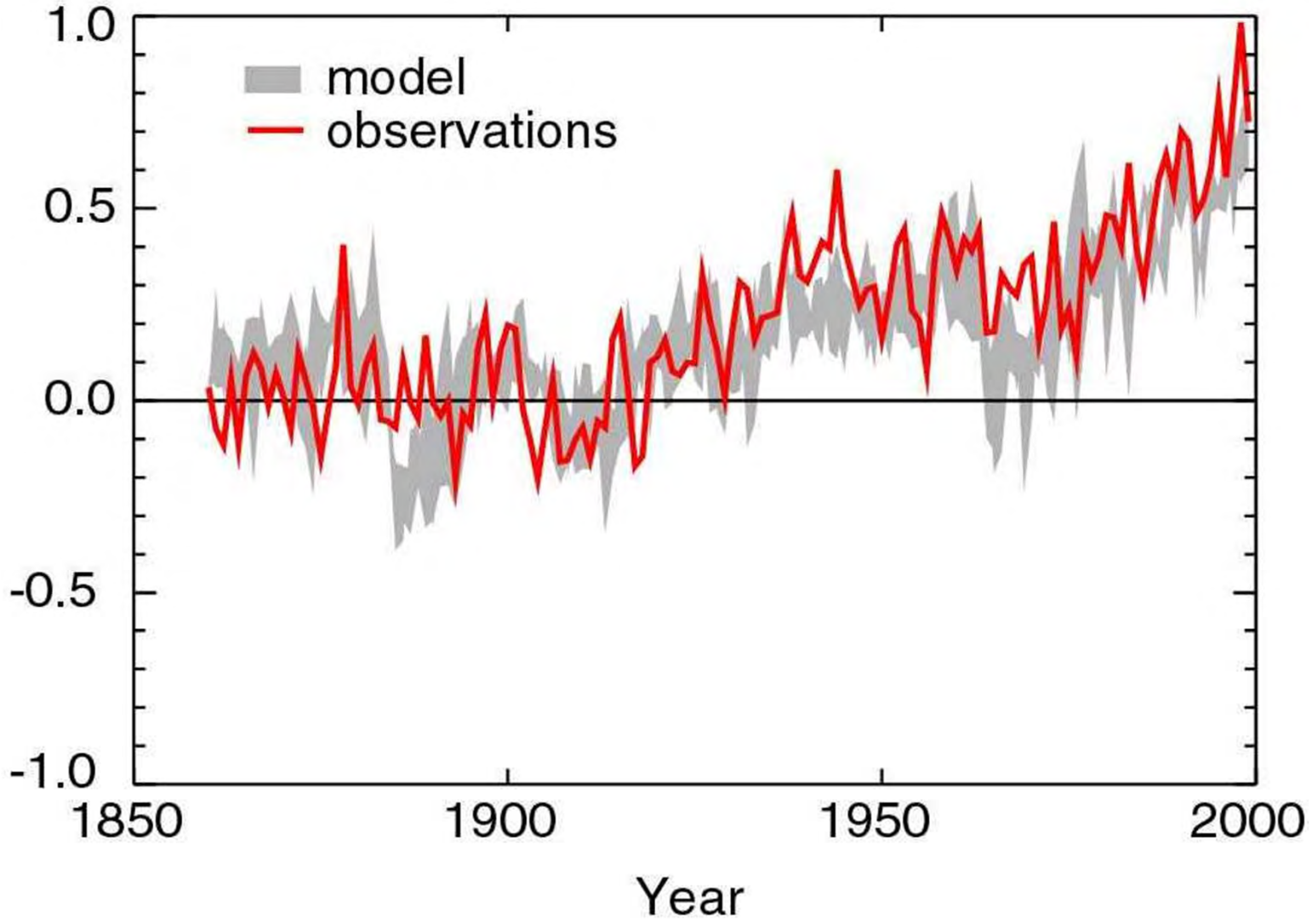
**“Simulations of the response to natural forcings alone
... do not explain the warming in the second half of the
century”** **SPM**



Stott et al,
Science
2000

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

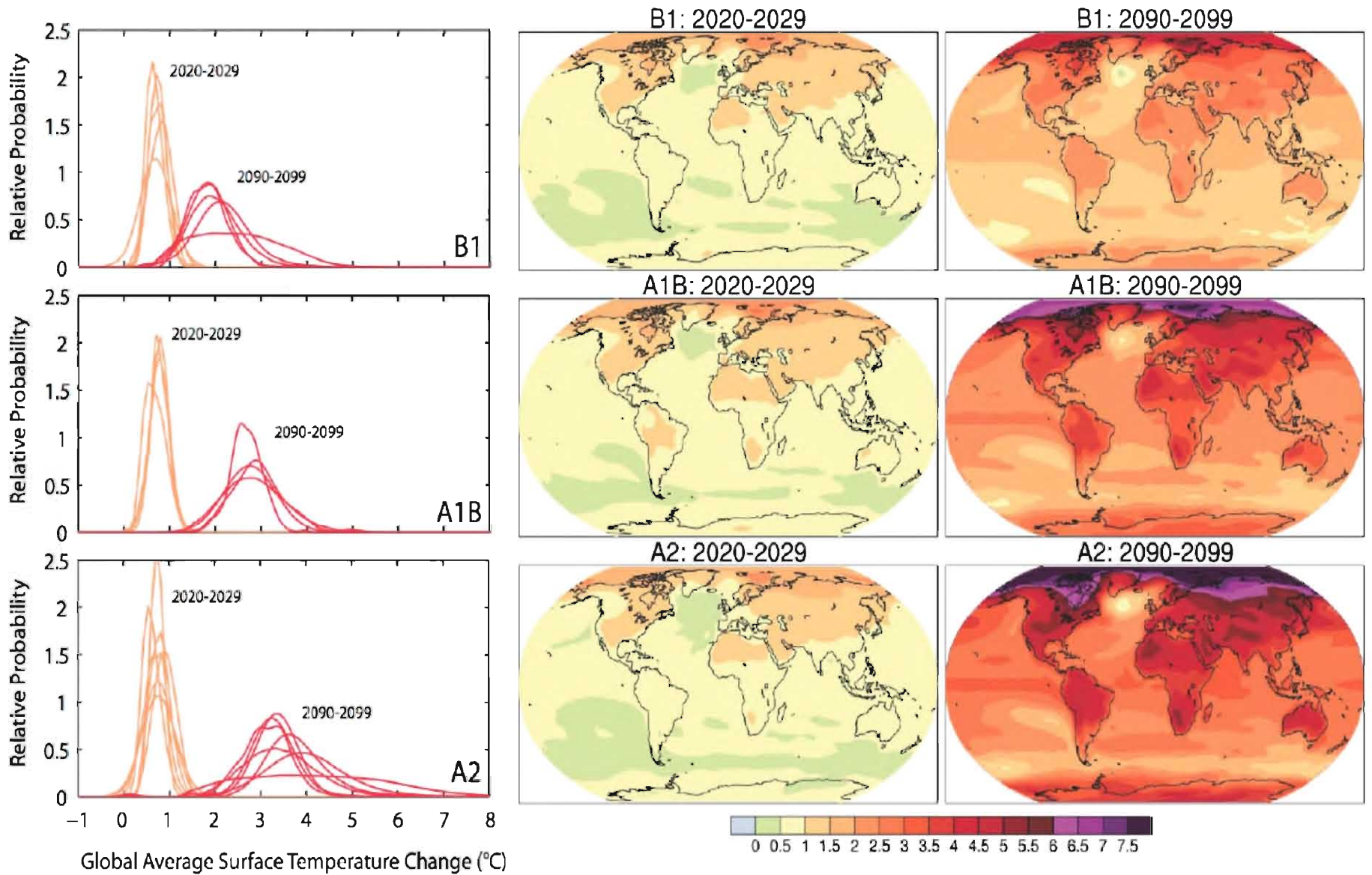
SPM



Stott et al,
Science
2000

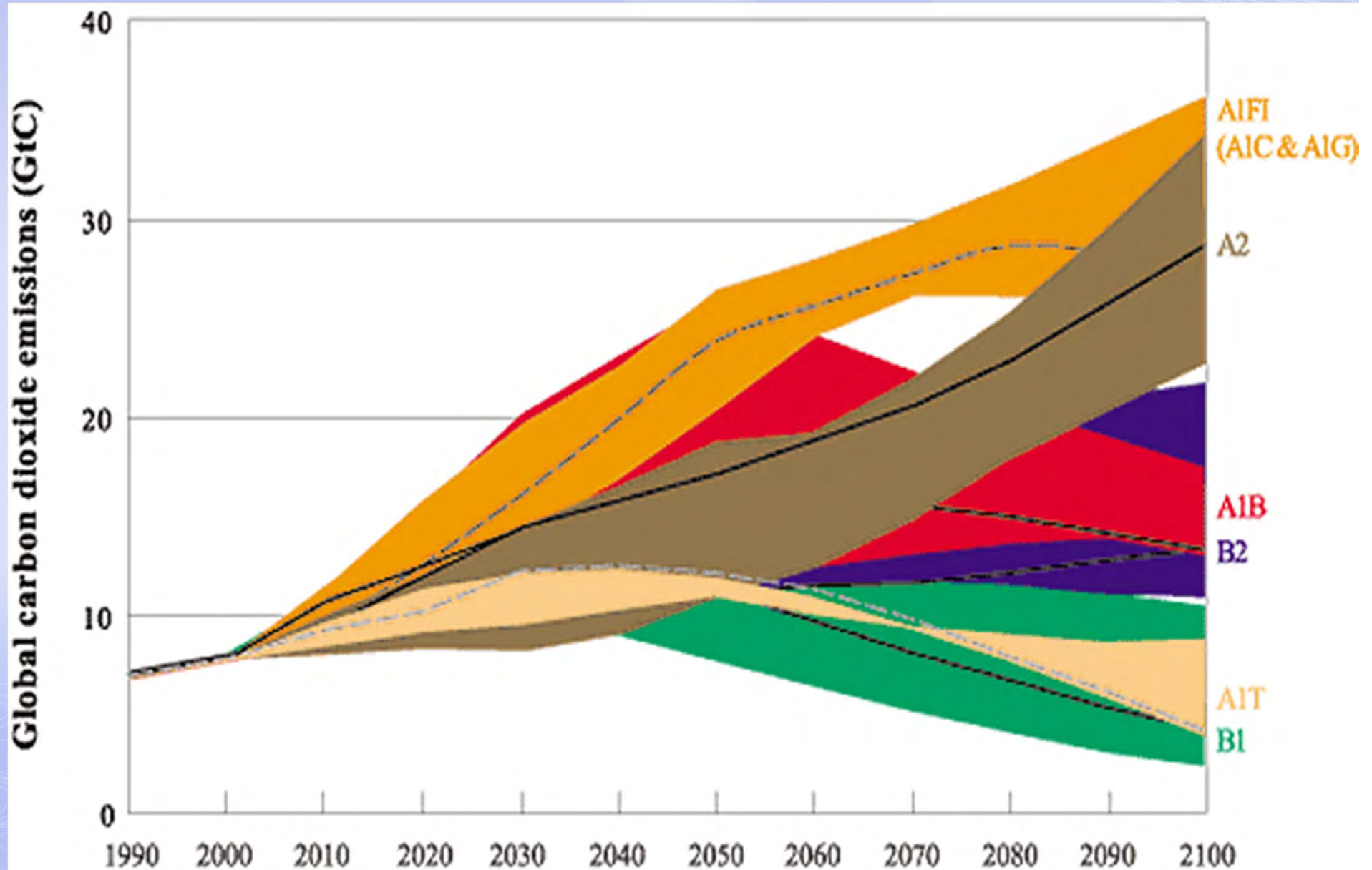


AOGCM Projections of Surface Temperatures

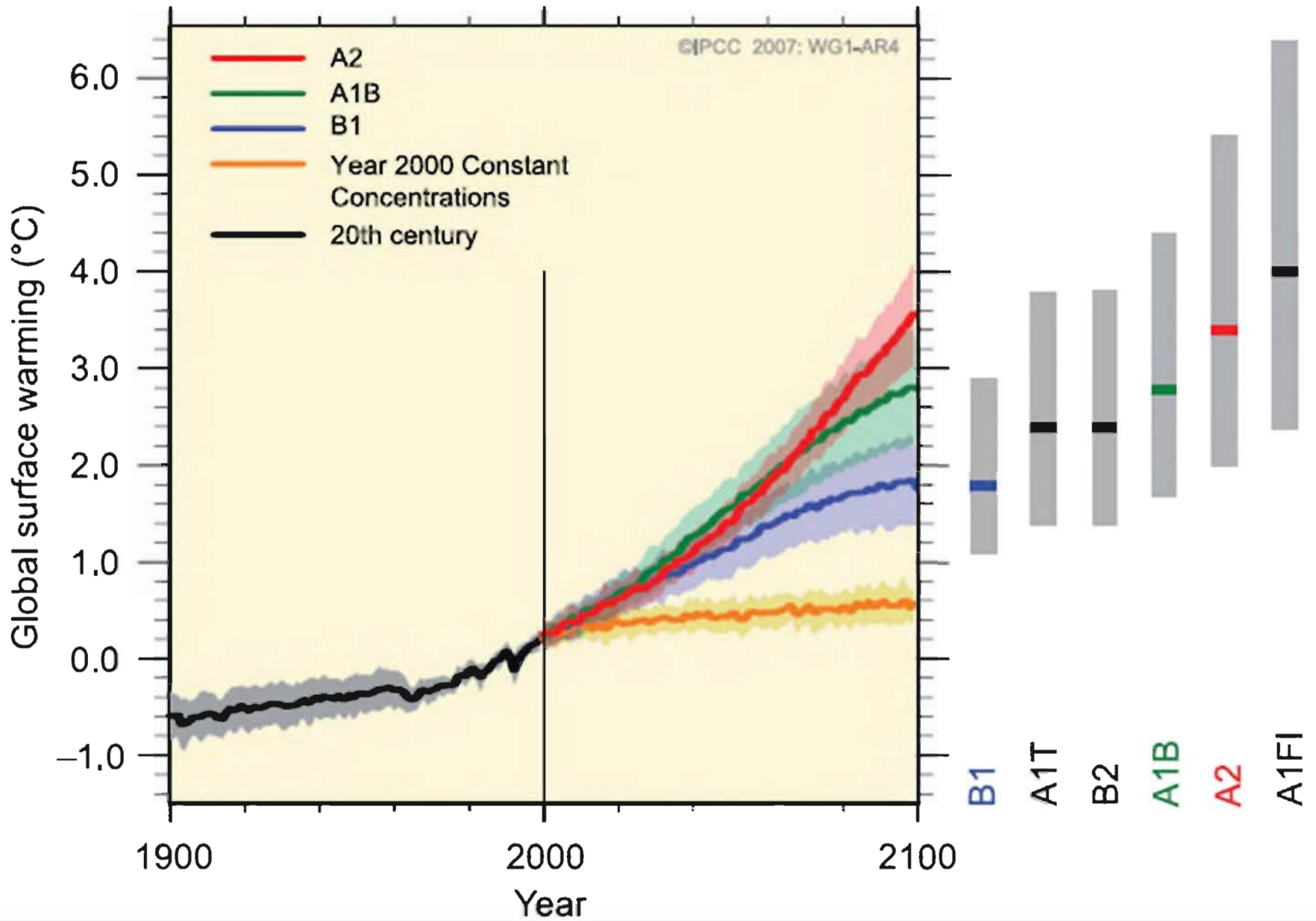


©IPCC 2007: WG1-AR4

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 the EdGCM website in a Mozilla Firefox browser window. The browser's address bar displays <http://edgcm.columbia.edu/>. The website's main header features the text "EdGCM Educational Global Climate Modeling" over a world map background. A search bar is located in the top left corner of the page content.

Main Menu

- Home
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- Support Forums
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- Events Calendar

Outreach

- Community Showcase
- Simulation Exchange
- eJournal Exchange

Education

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- Classroom Exercises
- Education Standards
- Student Projects
- Workshops / Training

Polls

What Interests You?

- Global Warming
- Paleoclimate
- Little Ice Age
- Catastrophic Events
- Climate Prediction
- Intl. Protocol
- Climate Modelling

EdGCM: The Project

The EdGCM Project develops and distributes a research-quality global climate model (GCM) with a [user-friendly interface](#) that runs on desktop computers. Anyone can explore the subject of climate change using the same methods and tools that scientists employ. The software allows users to experience the full scientific process including: designing experiments, setting up and running computer simulations, post-processing output, using [scientific visualization](#) to display results, and creating [scientific manuscripts](#) ready for publishing to the web.

[Read more...](#)

"Anthropocene" Greenhouse Gas Effects

[Outreach - Student Projects](#)
Written by Dominique Alhambra and Christine Kwitck
Wednesday, 09 May 2007
Submitted in partial fulfillment of: Course No. AOS 331, Prof. Jack Williams, Dept of Geography, Univ. of Wisconsin - Madison, Fall 2006

The early anthropogenic hypothesis by William Ruddiman posits that human influence on climate may have actually begun thousands, not hundreds, of years ago. Increased greenhouse gas levels were not solely caused by greenhouse gas emissions from fossil fuel burning after the start of the Industrial Revolution, but also caused by our ancestors' first agricultural developments. The resultant rise in temperature then delayed the glacial onset that should have occurred naturally. Through climate simulations with the EdGCM model, we compared pre- and post-industrial levels to estimated natural levels for five greenhouse gases: carbon dioxide, methane, nitrous oxide, and two chlorofluorocarbons (CFCs). Our results put our model at, or very close to, an incipient glacial state, supporting the hypothesis of an overdue glaciation.



[Read more...](#)

Snowball Earth: Effect of Obliquity

[Outreach - Student Projects](#)
Written by John Swain and Jeremiah Marsicek
Wednesday, 09 May 2007



Geologic evidence suggests that during the Sturtian period (~750Ma) of the Neoproterozoic Era the Earth was blanketed by snow and ice. Glacial deposits are found on all continents, including regions that were at low latitudes.

Examining the Effects of Global Warming on Greenland

[Outreach - Exercises](#)
Written by Mark Chandler
Sunday, 11 December 2005



Tracking the changes in temperature and snowfall over Greenland is of great interest to scientists because of the concern that global warming could lead to a melting of the Greenland ice sheet and add to rising sea levels.

EdGCM in Antarctica

- [More Blogging but Elsewhere](#)
- [ANDRILL in Google Earth](#)
- [Off the Ice](#)
- [Departure](#)
- [12 Hours at the South Pole](#)
- [Head, meet foot.](#)
- [South Pole \(Yes?\)](#)

EdGCM Forum Posts

- [Google Earth](#)
- [Ocean albedo calculations](#)
- [source code for Modern File VBX10.vagt](#)
- [Terrain and initial conditions](#)
- [4d tools?](#)

Visitor Locations



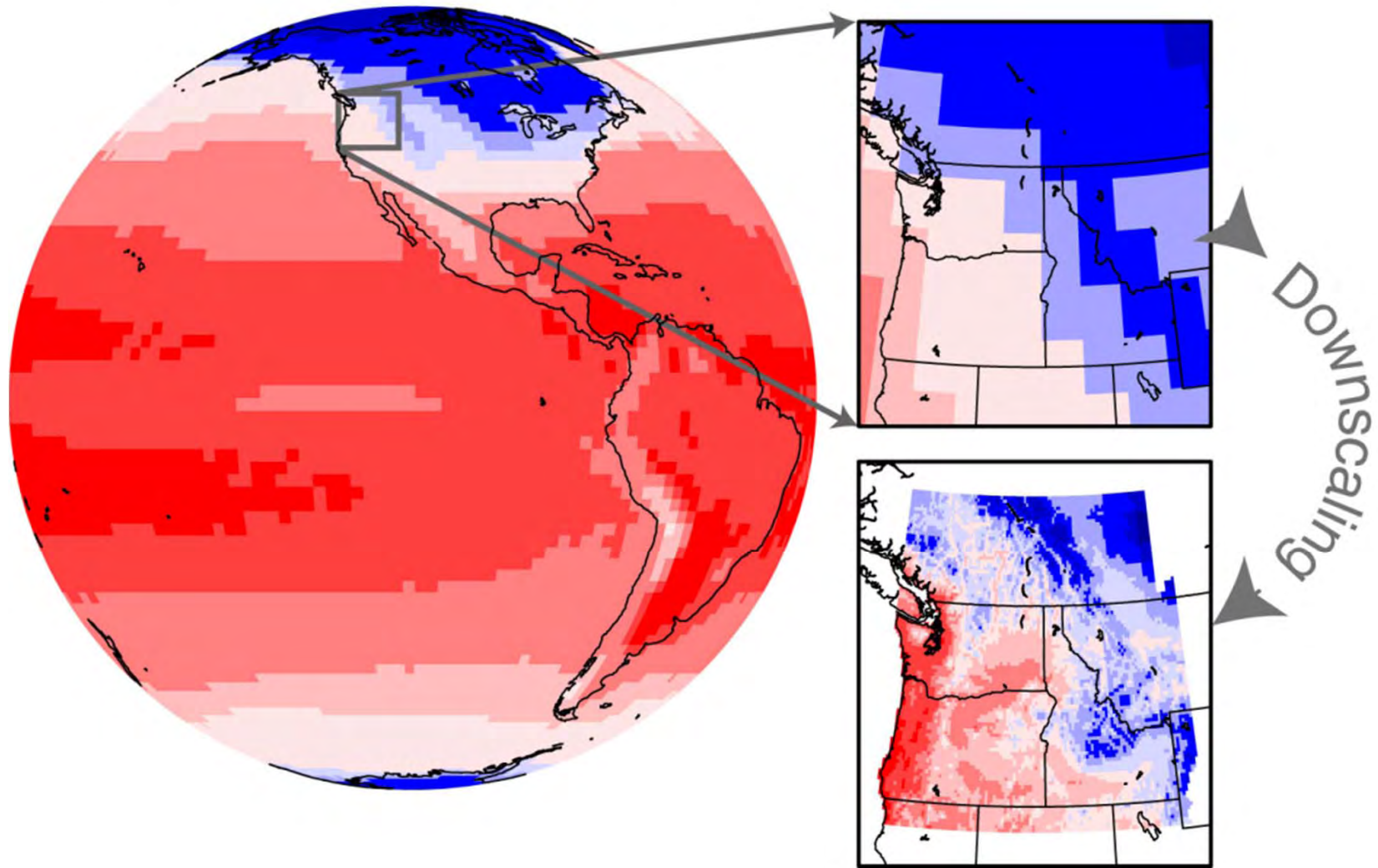
Click to see

Done

Now: Fair and 57°F Today: 73°F Fri: 78°F

Downscaling global models for regional studies

Global Climate Model Air Temperature

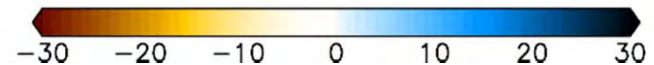
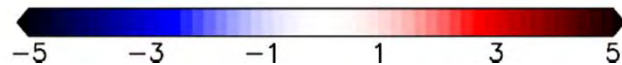
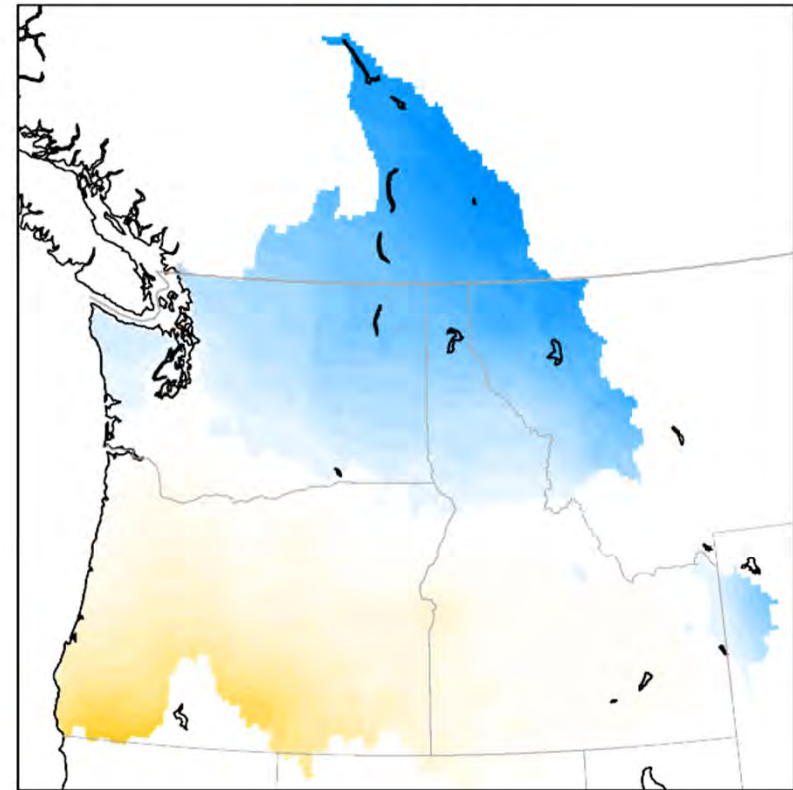
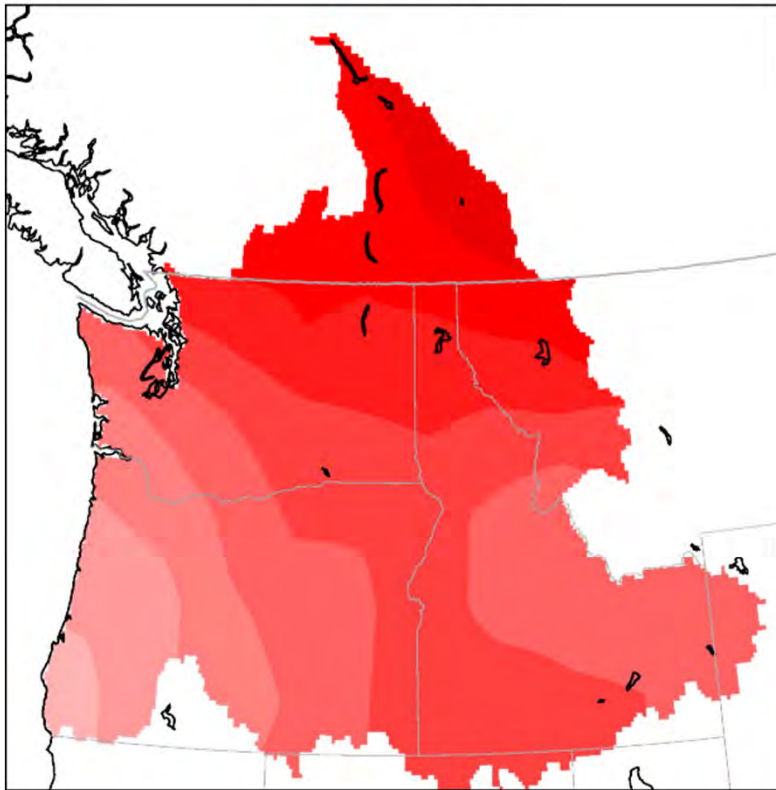


Downscaling -- Winter

DJF Difference to 2040 CCSM3

Temp (C)

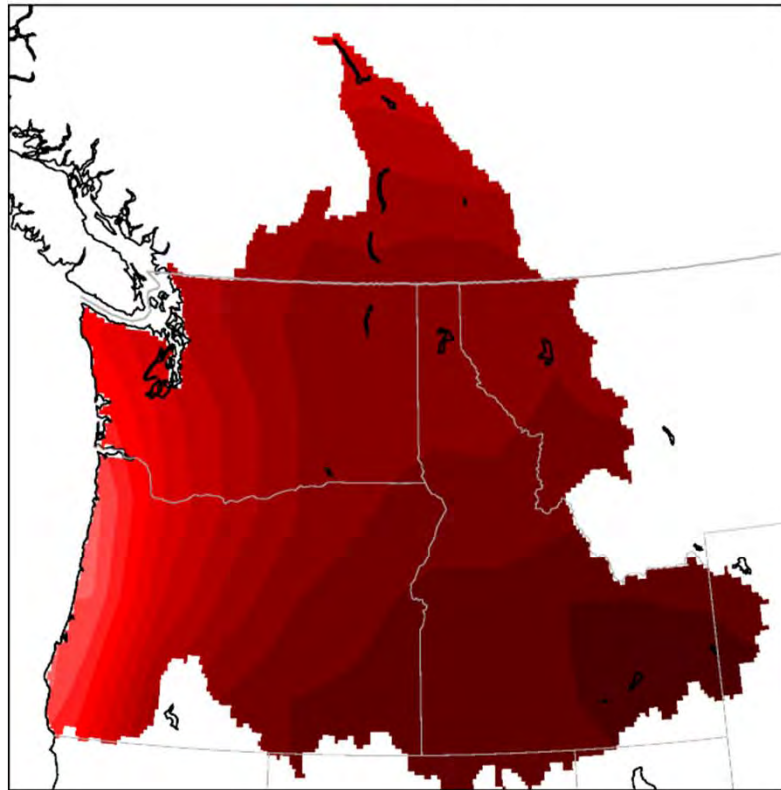
Precip (%)



Downscaling -- Summer

JJA Difference to 2040 CCSM3

Temp (C)



Precip (%)

