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

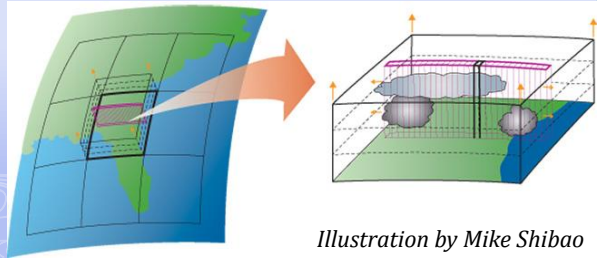


Illustration by Mike Shibao

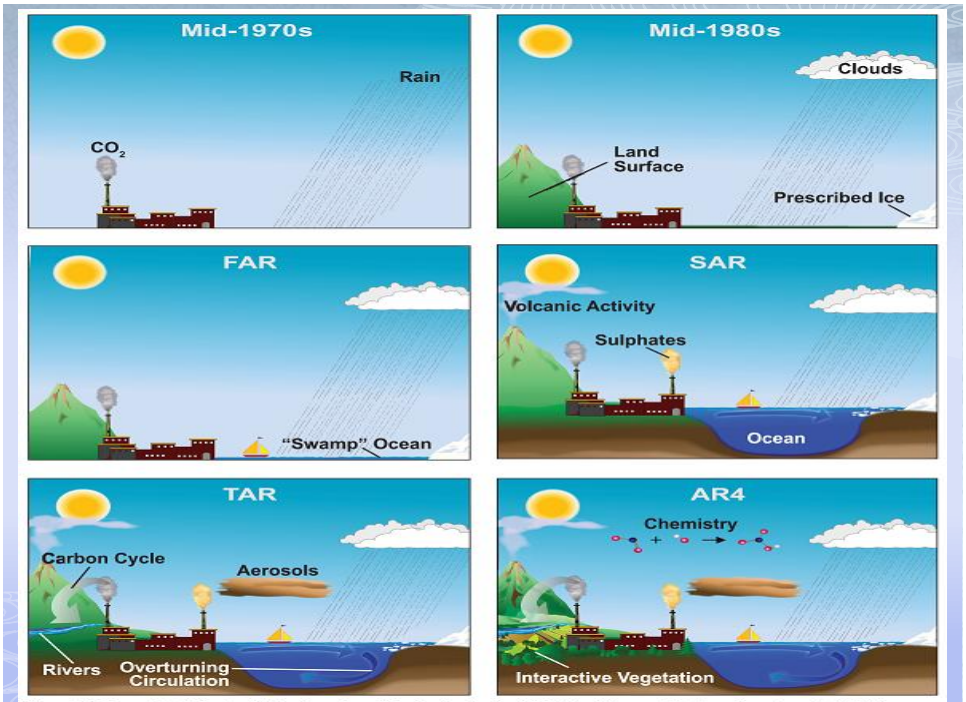
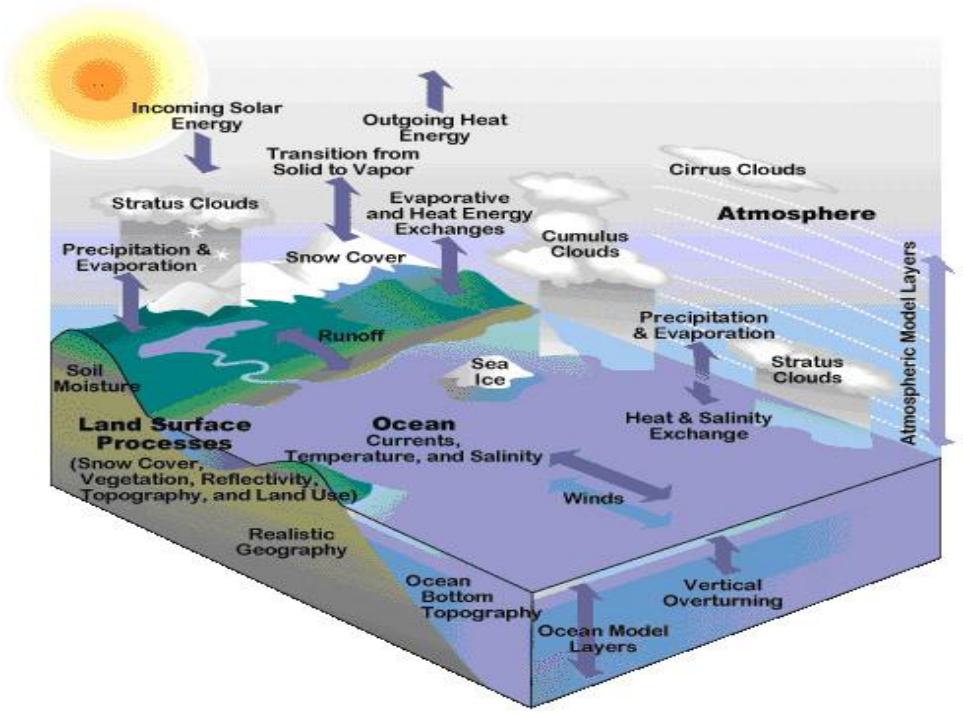
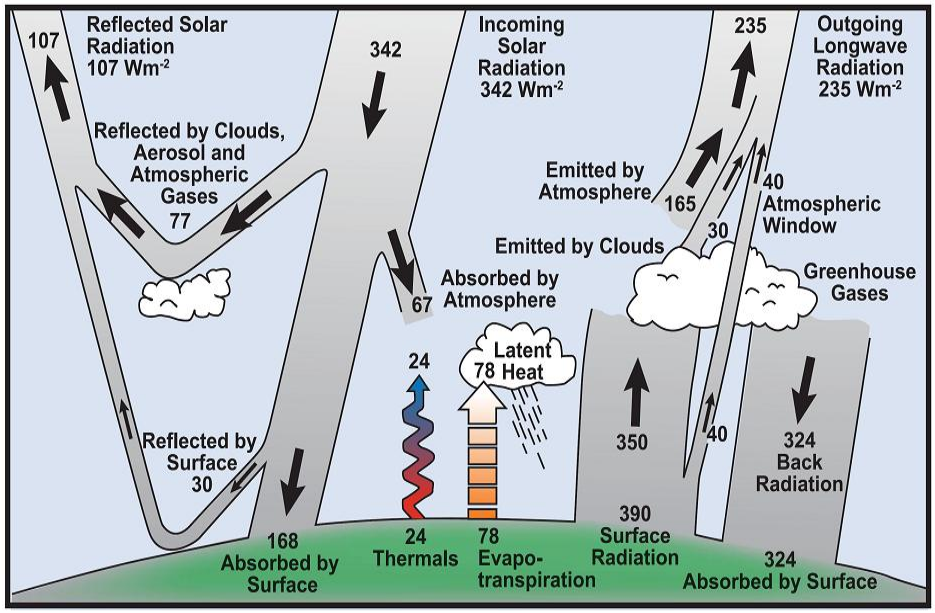
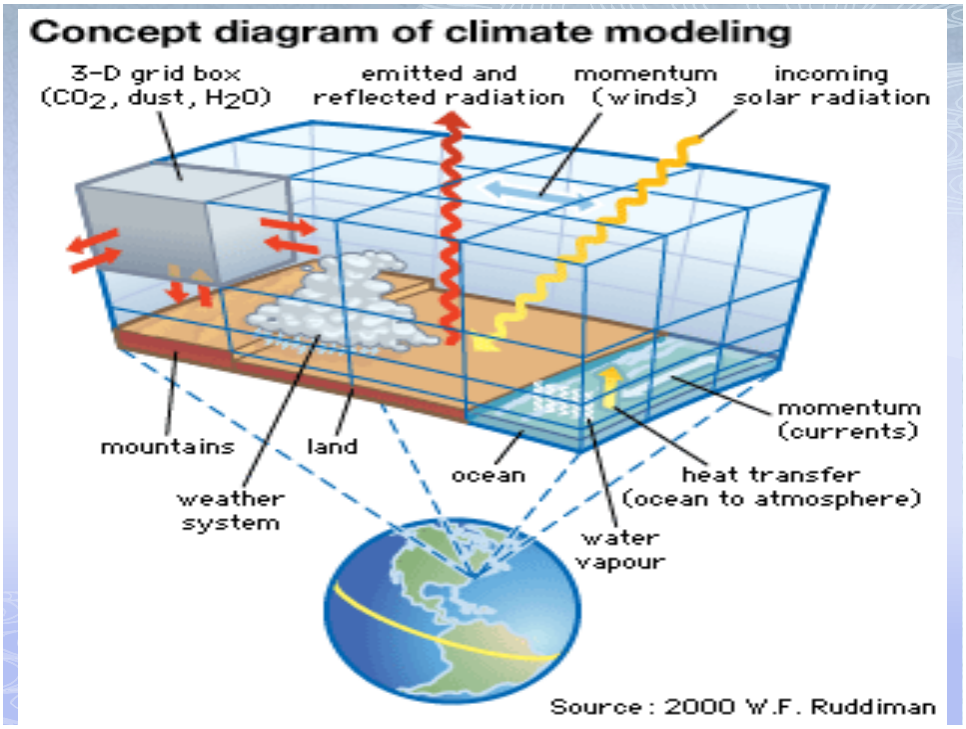


Figure 1.2. *The complexity of climate models has increased over the last few decades. The additional physics incorporated in the models are shown pictorially by the different features of the modelled world.*





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).*



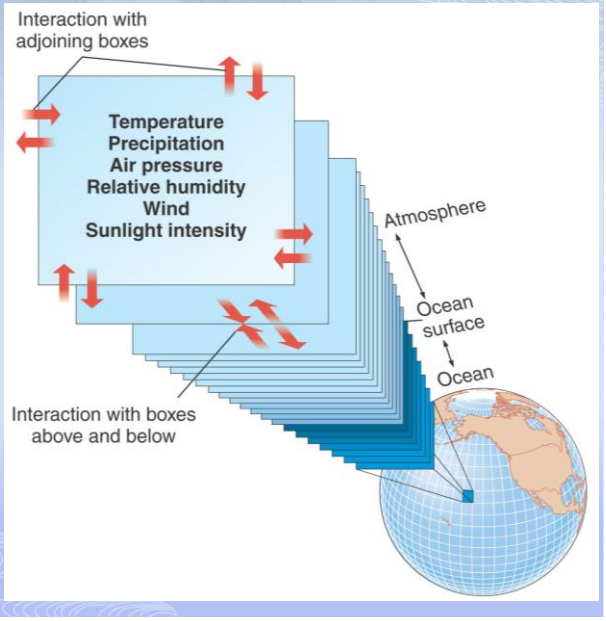
Basic Equations of a GCM (Hansen et al., 1983)

- 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



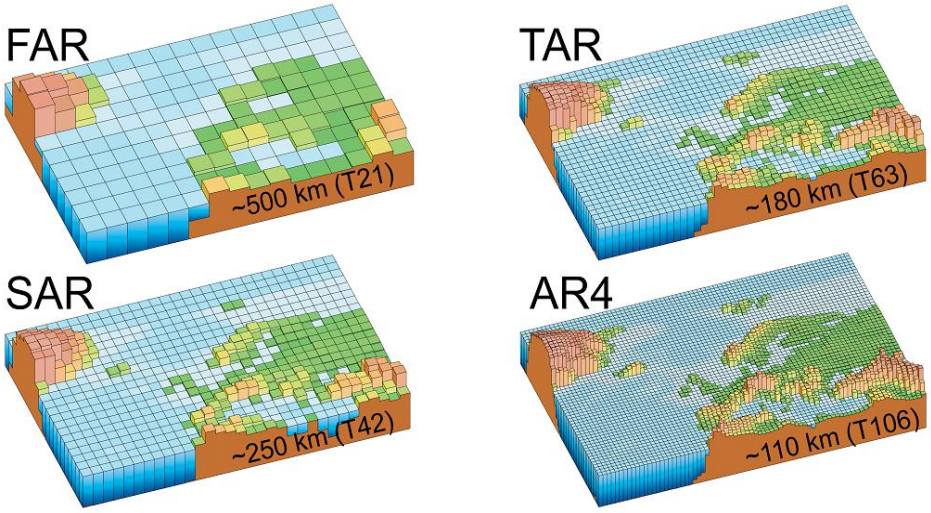
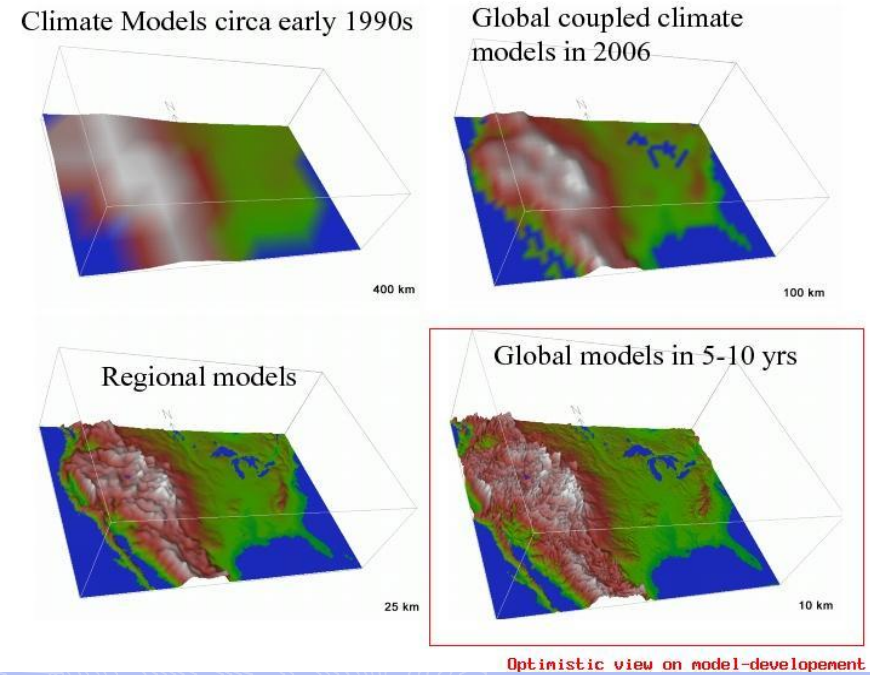
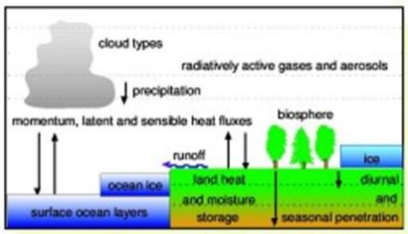


Figure 1.4. *Geographic resolution characteristic of the generations of climate models used in the IPCC Assessment Reports: FAR (IPCC, 1990), SAR (IPCC, 1996), TAR (IPCC, 2001a), and AR4 (2007). The figures above show how successive generations of these global models increasingly resolved northern Europe.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

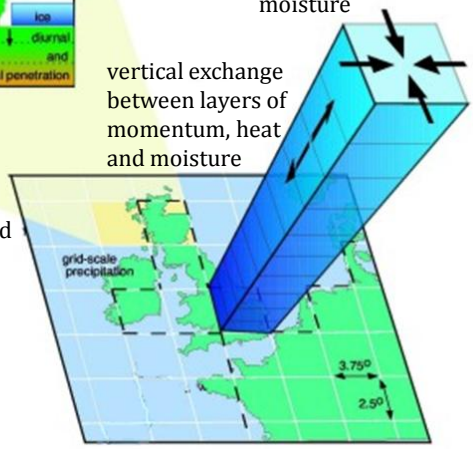
Atmospheric GCMs (AGCM)



Horizontal exchange between columns of momentum, heat and moisture

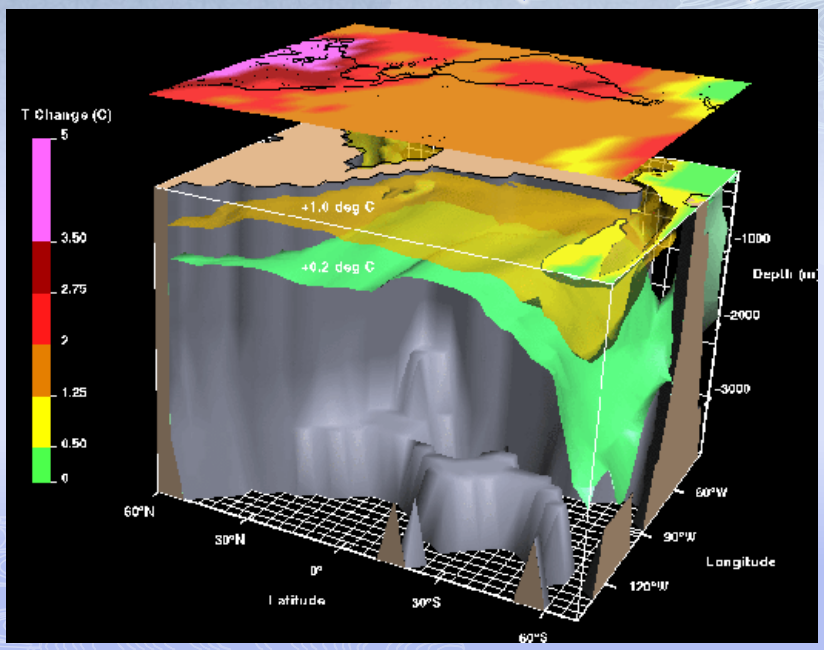
vertical exchange between layers of momentum, heat and moisture

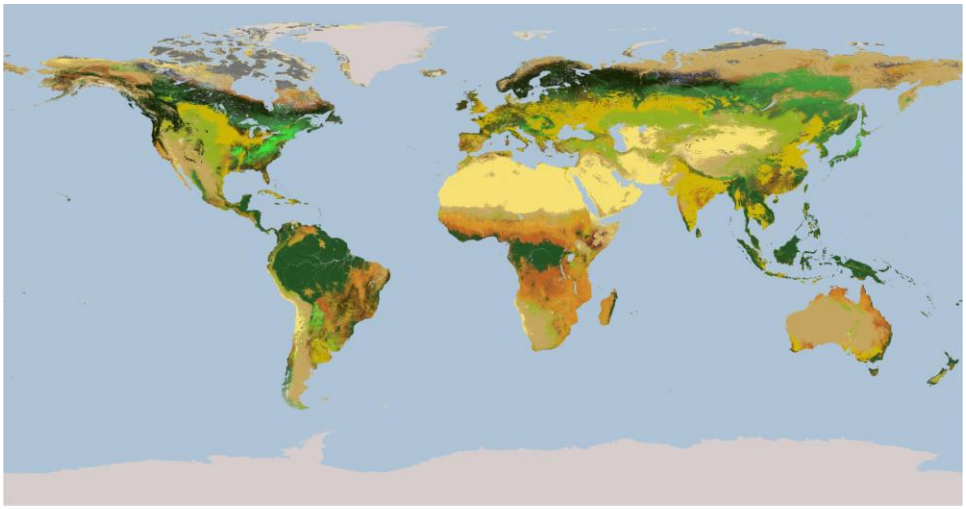
orography, vegetation and surface characteristics included at surface on each grid box



Dr. David Vinter, 1998, 2002

Combined GCMs (AOGCM)





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

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

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

Special Report on Emissions Scenarios (SRES): Why storylines?

- To help the writing team to think more coherently about the complex interplay among scenario driving forces within each and across alternative scenarios;
- To make it easier to explain the scenarios to the various user communities by providing a narrative description of alternative futures that goes beyond quantitative scenario features;
- To make the scenarios more useful, in particular to analysts who contribute to IPCC WGII and WGIII;
  - The social, political, and technological context described in the scenario storylines is all-important in analyzing the effects of policies either to adapt to climate change or to reduce GHG emissions; and
- To provide a guide for additional assumptions to be made in detailed climate impact and mitigation analyses
  - At present no single model or scenario can possibly respond to the wide variety of informational and data needs of the different user communities of long-term emissions scenarios.

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 on-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

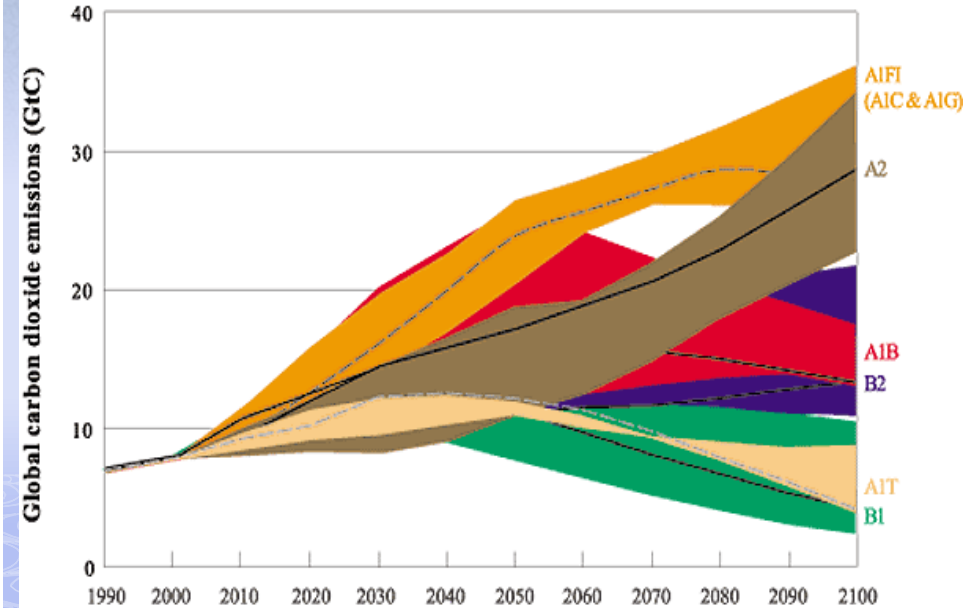
SRES: B1 Storyline – A more integrated, more ecologically friendly world

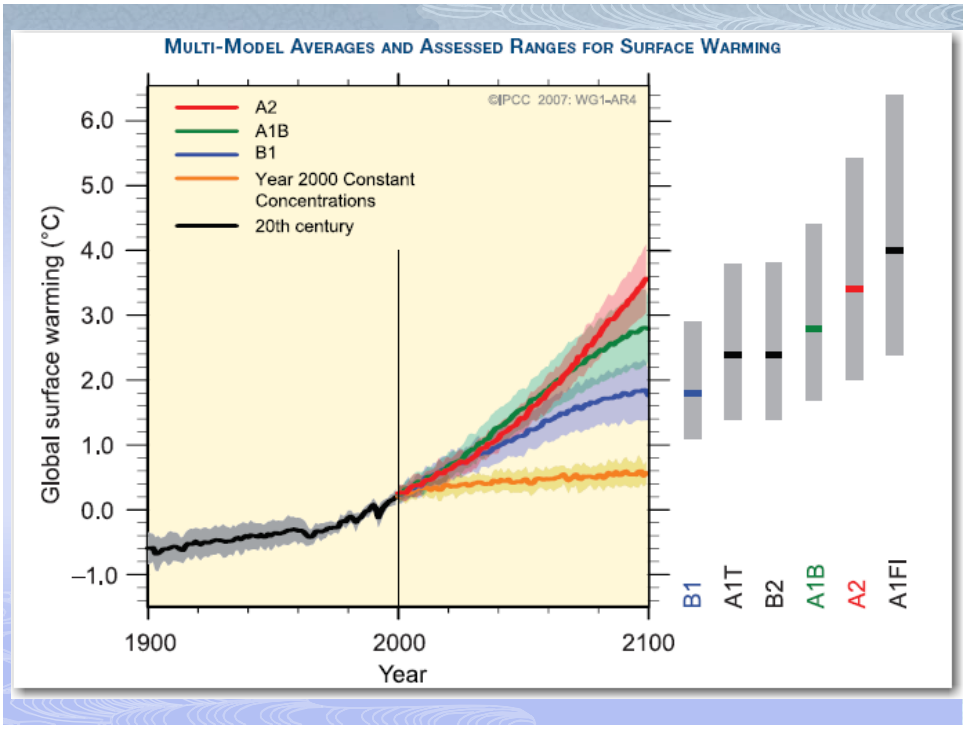
- High level of environmental and social consciousness; globally coherent approach to more sustainable development
- Rapid economic growth as in A1, but with rapid changes towards a service and information economy
- Global population reaches 9 billion in 2050 and gradually declines as in A1
- Reductions 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)





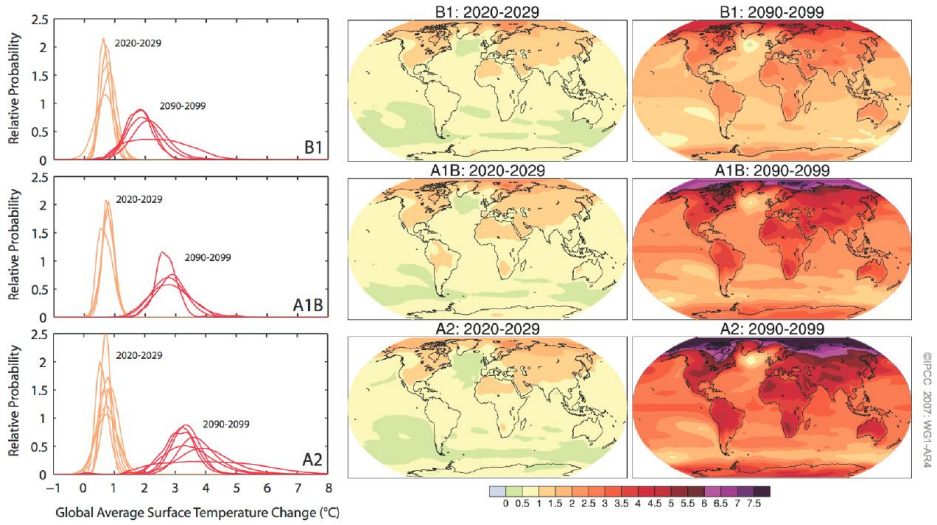
Projected Globally Averaged Surface Warming and Sea-Level Rise at the End of the 21st Century

	Temperature Change (°F at 2090–2099 relative to 1980–1999)		Sea-Level Rise (inches at 2090–2099 relative to 1980–1999)
Case	Best estimate	Likely range	Model-based range excluding future rapid dynamical changes in ice flow
Constant Year 2000 concentrations	1.1	0.5 – 1.6	NA
B1 scenario	3.2	2.0 – 5.2	7.1 – 15.0
A1T scenario	4.3	2.5 – 6.8	7.9 – 17.7
B2 scenario	4.3	2.5 – 6.8	7.9 – 16.9
A1B scenario	5.0	3.1 – 7.9	8.3 – 18.9
A2 scenario	6.1	3.6 – 9.7	9.1 – 20.1
A1FI scenario	7.2	4.3 – 11.5	10.2 – 23.2

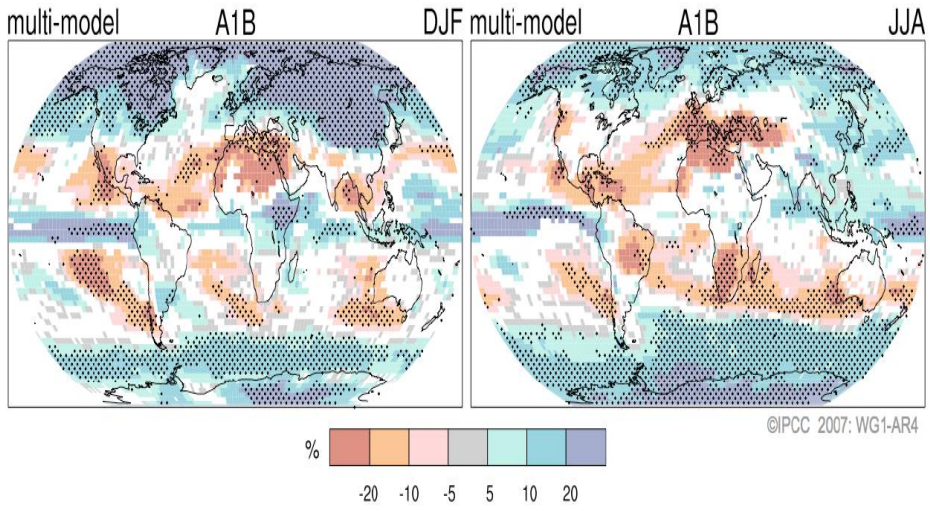
Source: Climate Change 2007: The Physical Science Basis—Summary for Policymakers.

Relative temperature change in °C is equal to °F / 1.8. 1" = 2.54 cm.
For example, the B2 Scenario has the best estimate of temperature change of 2.4 °C and a sea level rise of 20-43 cm by 2090-2099.

AOGCM Projections of Surface Temperatures



Projected Patterns of Precipitation Changes

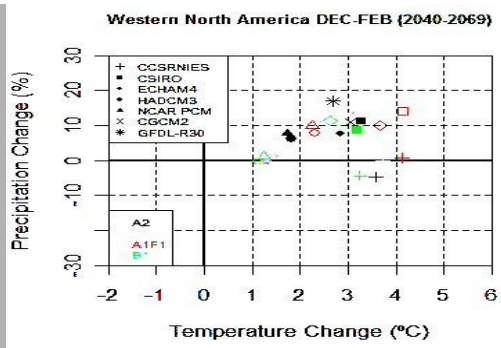


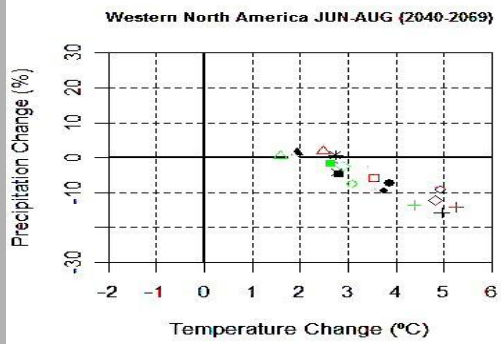
IPCC 4th Assessment GCMs

All Year
3°C (5.4°F) warmer

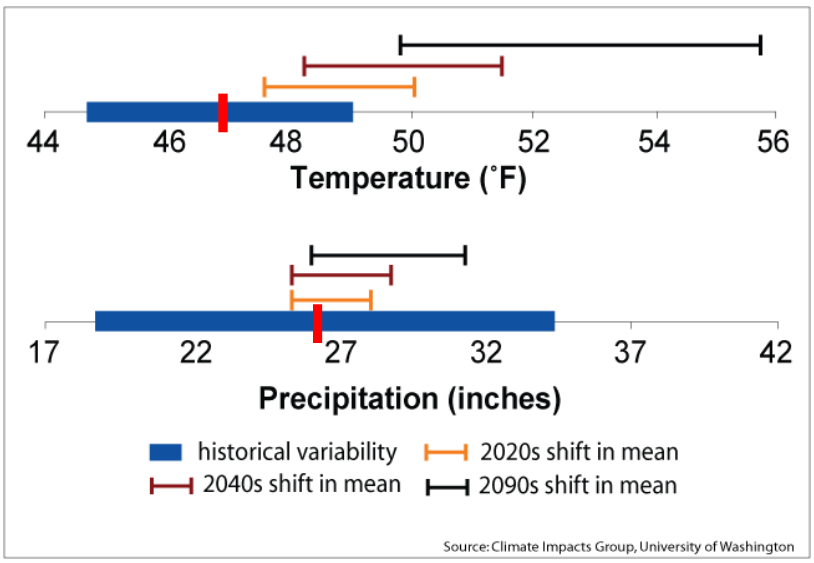
BUT
Winter – wetter

Summer – drier





Comparing Projected Change in Mean with 20th Century Variability



Rising Temperatures

- Full range of projected temperature increase is 1.1-6.4°C (2-11.5°F)
- Best estimate range is 1.8-4.0 °C (1.8-4.0°F)
- Warming is expected to be greatest over land and at most high northern latitudes
  - Least over Southern Ocean and parts of North Atlantic Ocean

Source: IPCC *Climate Change 2007: The Physical Science Basis*—Summary for Policymakers.

Increasingly Severe Weather

Tropical cyclones (hurricanes and typhoons) are likely to become more intense, with higher peak wind speeds and heavier precipitation associated with warmer tropical seas.

Source: IPCC *Climate Change 2007: The Physical Science Basis*—Summary for Policymakers.

Increasingly Severe Weather

Associated Press

en.wikipedia.org/wiki/North_American_blizzard_of_2005

Increases in the amount of high latitude precipitation are very likely.

Source: IPCC *Climate Change 2007: The Physical Science Basis*—Summary for Policymakers.

Drought

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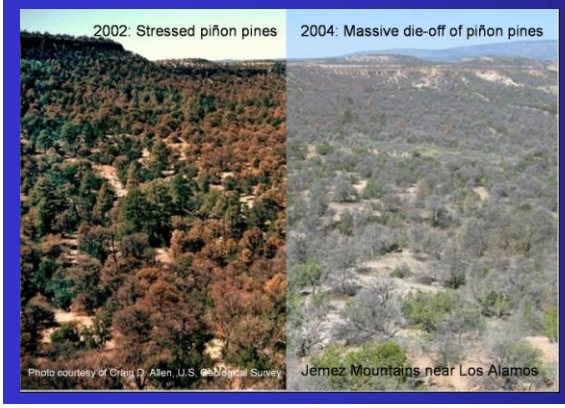
National Park Service

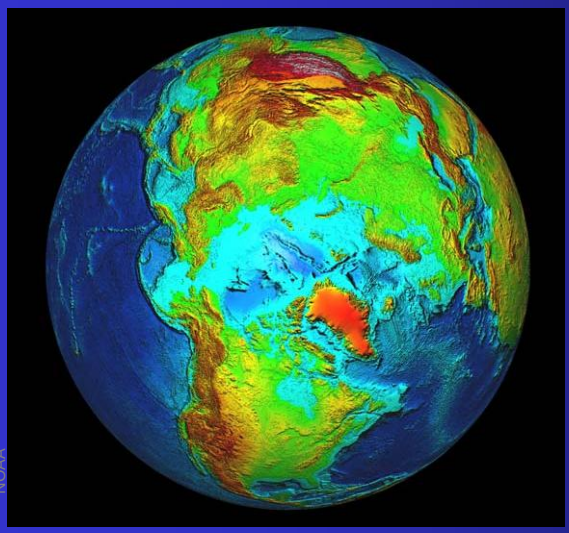
Decreases in precipitation are likely in most subtropical land regions



AP / Mustafa Quraishi

Source: IPCC *Climate Change 2007: The Physical Science Basis*—Summary for Policymakers.

Melting Ice



NOAA

- Sea ice is projected to shrink in both the Arctic and Antarctic under all model simulations.
- Some projections show that by the latter part of the century, late-summer Arctic sea ice will disappear almost entirely.

Source: IPCC *Climate Change 2007: The Physical Science Basis*—Summary for Policymakers.

Sea-level Rise Projections Include:

- ocean expansion resulting from increased water temperatures;

National Park Service

- meltwater runoff from mountain glaciers around the world; and

NASA

- a contribution due to increased ice flow from Greenland and Antarctica **at the rates observed for 1993-2003**.

Source: IPCC *Climate Change 2007: The Physical Science Basis*—Summary for Policymakers.

Sea-level Rise Projections DO NOT Include:

Photo Roger Braithwaite

iStockphoto.com

- Ice sheet instability
- Carbon dioxide uptake changes

IPCC: "Larger values cannot be excluded, but understanding of these effects is too limited to assess their likelihood or provide a best estimate or an upper bound for sea-level rise."

Source: IPCC *Climate Change 2007: The Physical Science Basis*—Summary for Policymakers.

Threshold risks:

Weiss and Overpeck U. Arizona

Some models do suggest that sustained warming between 2-7°F above today's global average temperature would initiate irreversible melting of the Greenland ice sheet—which could ultimately contribute about ***23 feet*** to sea-level rise.

Source: IPCC *Climate Change 2007: The Physical Science Basis*—Summary for Policymakers.