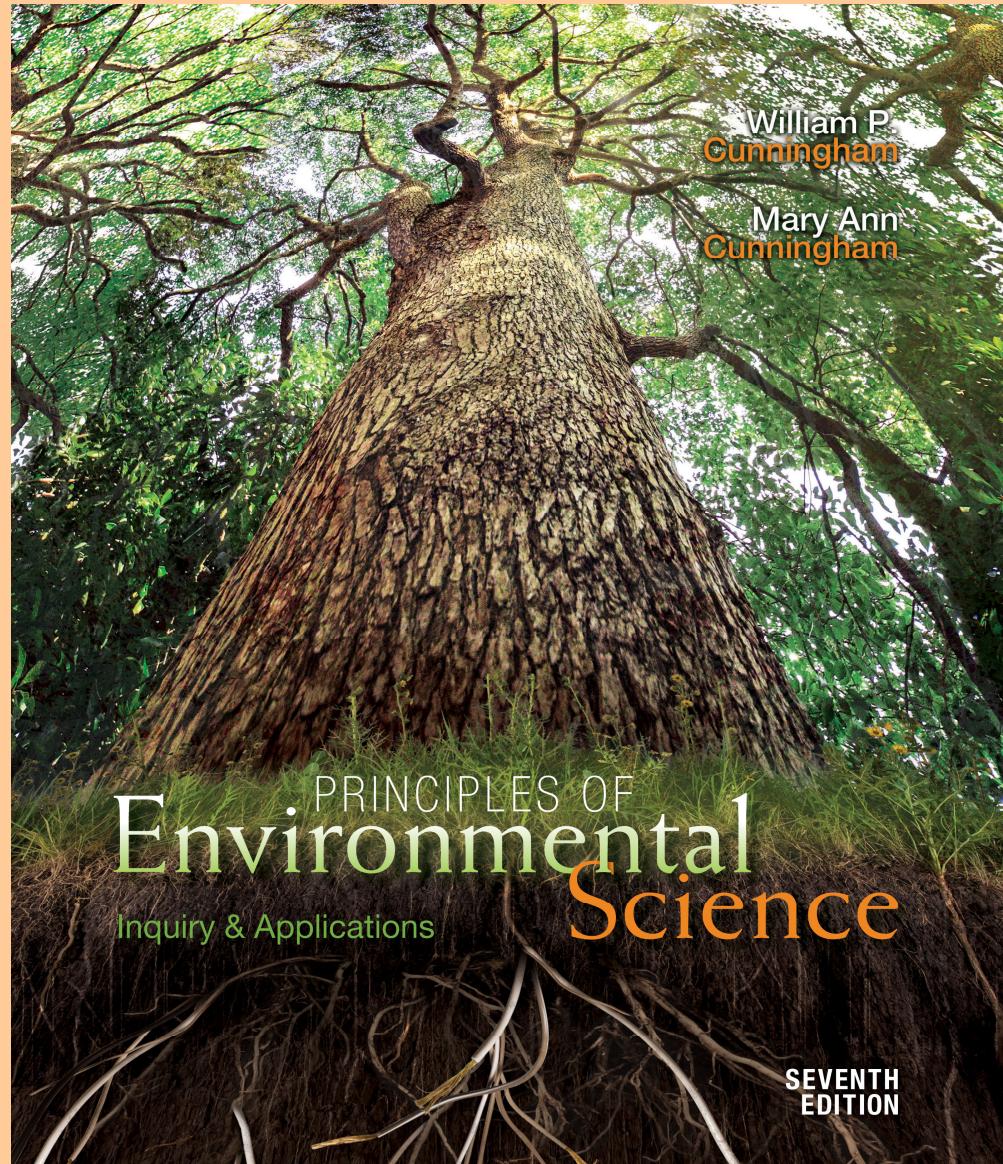




Chapter 9

Lecture Outline



Learning Outcomes

After studying this chapter, you should be able to answer the following questions:

- How do the troposphere and stratosphere differ?
- What are some factors in natural climate variability?
- Explain the greenhouse effect and how it is changing our climate.
- How do we know the nature and cause of recent climate change?
- List some effects of climate change.
- What are some strategies for minimizing global climate change?

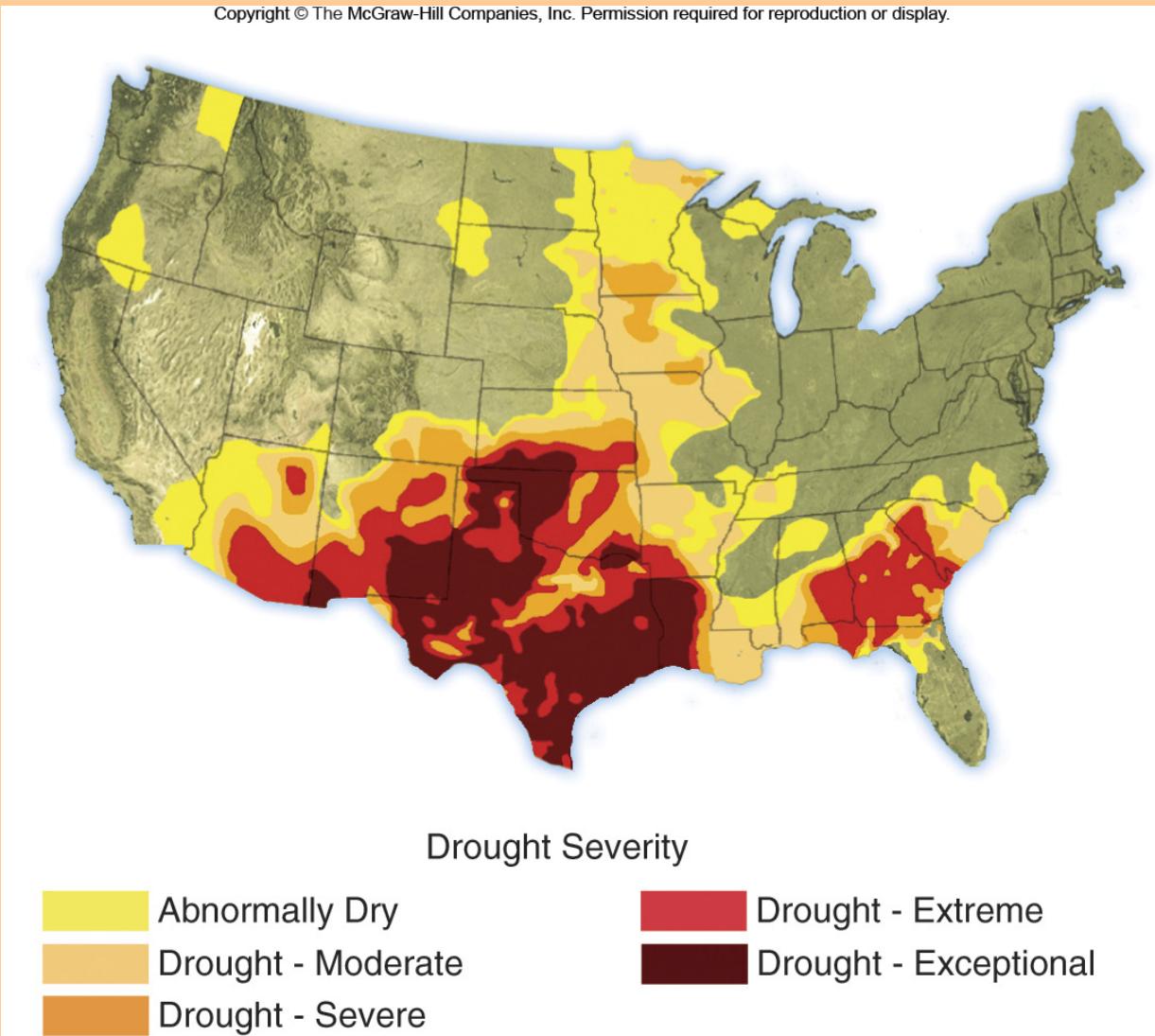
“The next decade is critical. If emissions do not peak by around 2020, . . . the needed 50% reduction by 2050 will become much more costly. In fact, the opportunity may be lost completely.”

—International Energy Agency, 2010

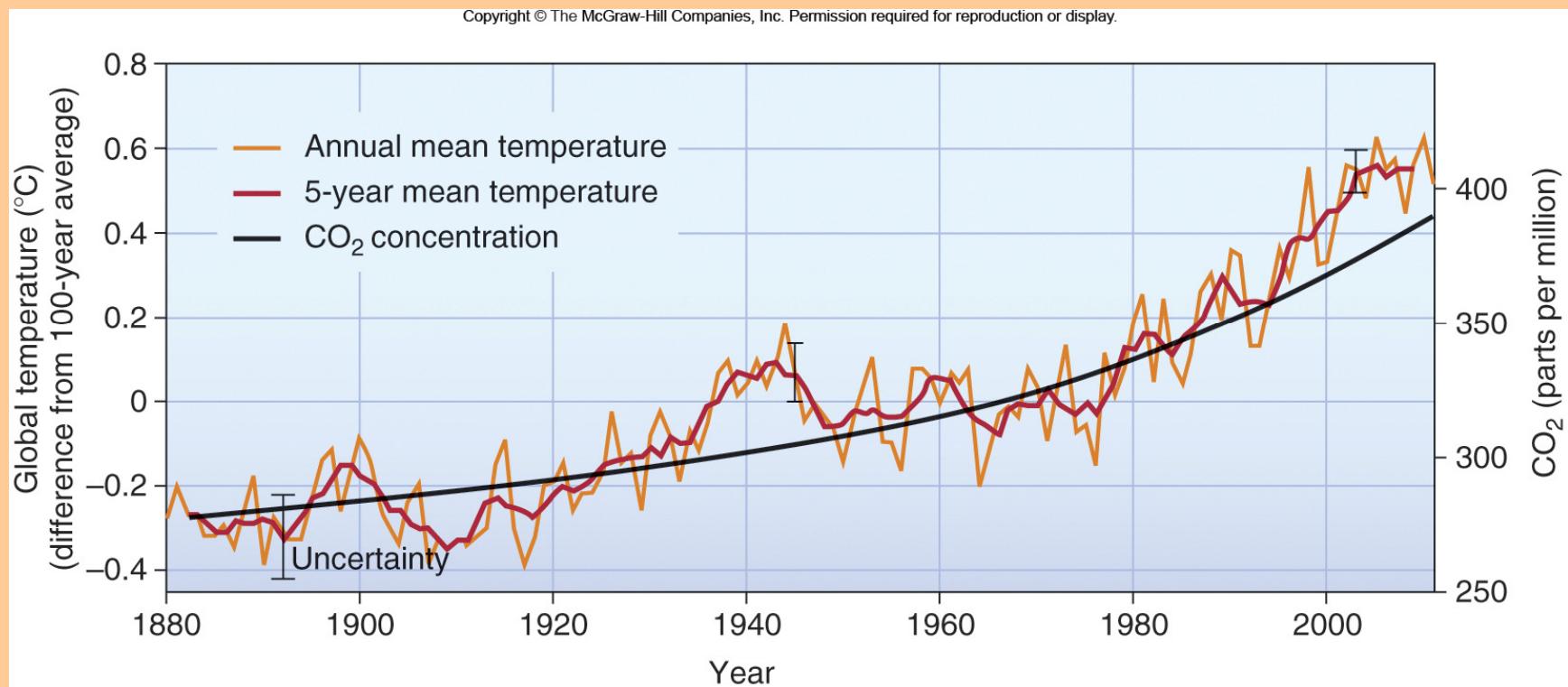
CASE STUDY:

Is Weird Weather the New Normal?

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Global Average Temperatures Have Increased

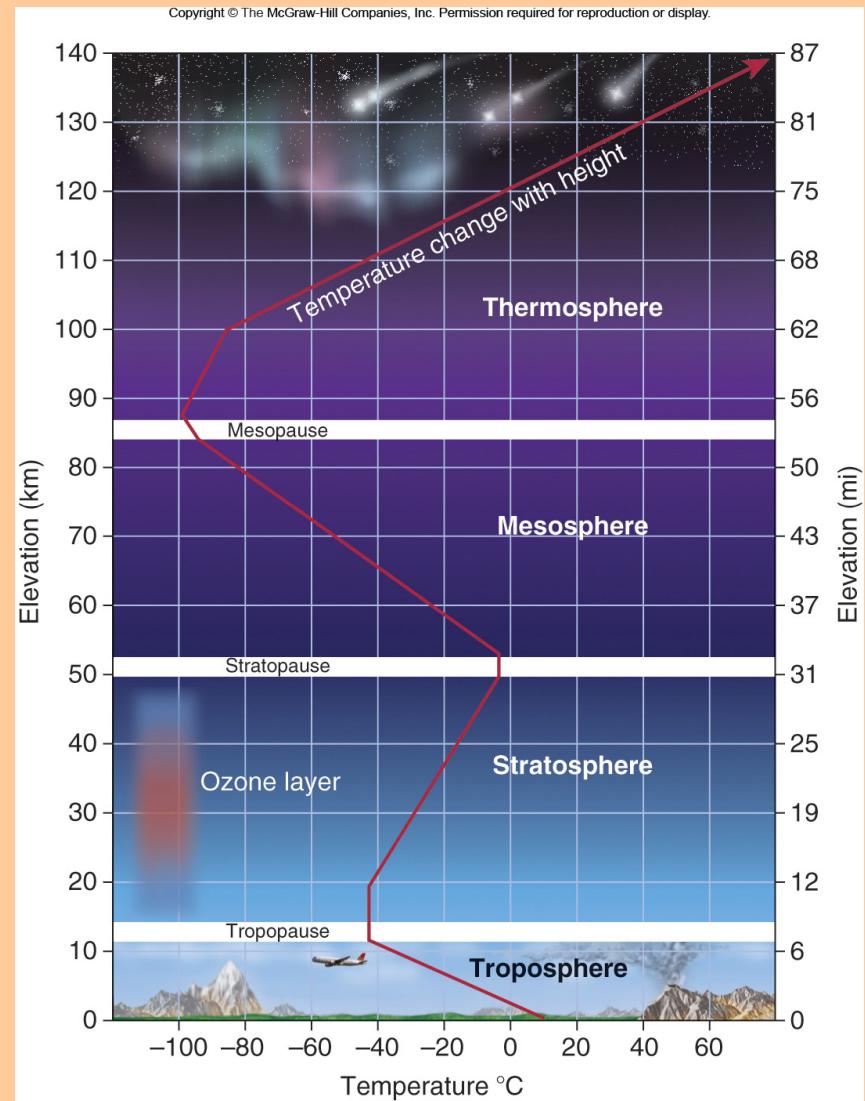


9.1 What is the Atmosphere?

- Earth's atmosphere consists of gas molecules, mostly nitrogen and oxygen and a variety of other trace gases, relatively densely packed near the surface and thinning gradually to about 500 km (300 mi) above the earth's surface.
- Minute particles and liquid droplets—collectively called **aerosols**—also are suspended in the air.
- The atmosphere has four distinct zones of contrasting temperature due to differences in absorption of solar energy.
- The layer closest to the earth's surface, the **troposphere**, experiences daily temperatures changes, wind, and precipitation that we collectively call **weather**.

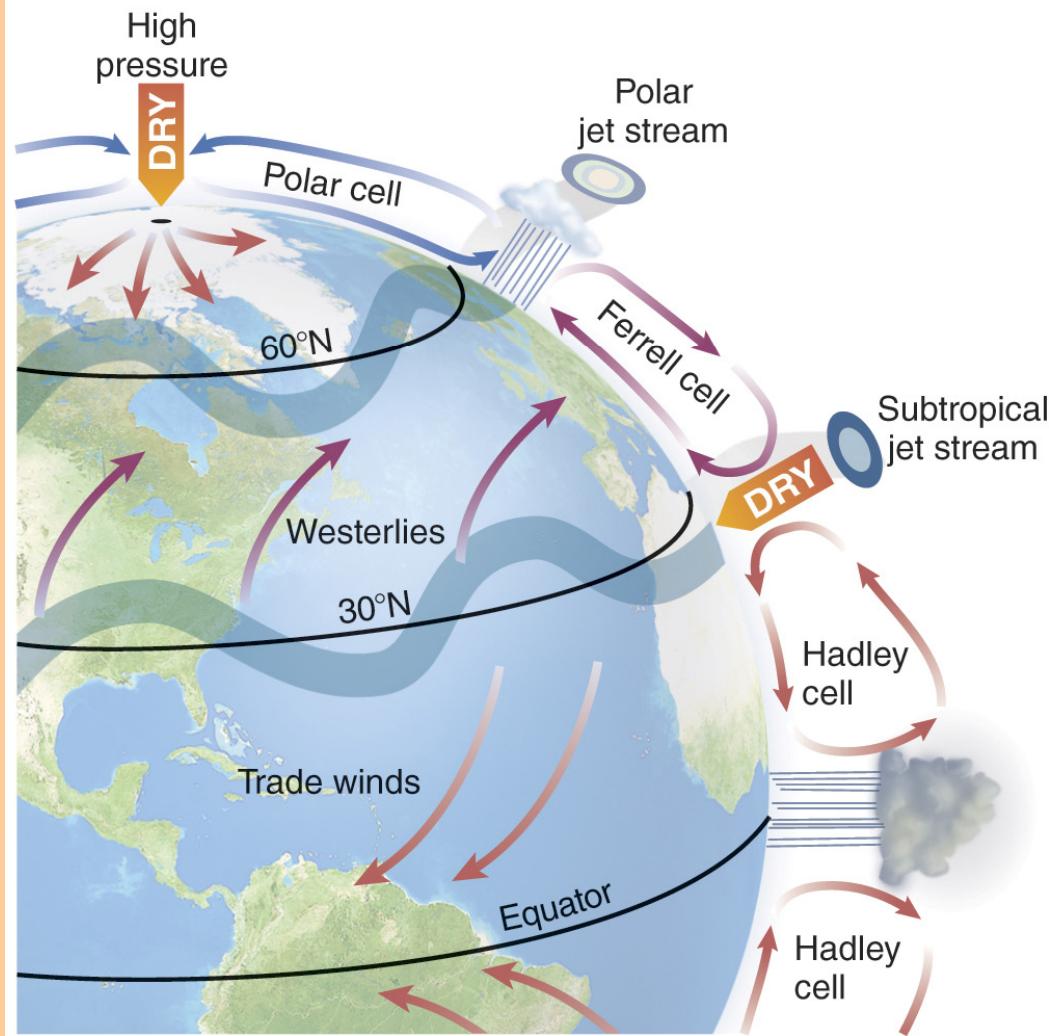
4 Distinct Zones of the Atmosphere

- Within the **troposphere**, air circulates in great vertical and horizontal **convection currents**.
- The **stratosphere** has almost no water vapor and nearly 1,000 times more **ozone (O_3)**.



Convection Cells Circulate Air, Water Vapor and Heat

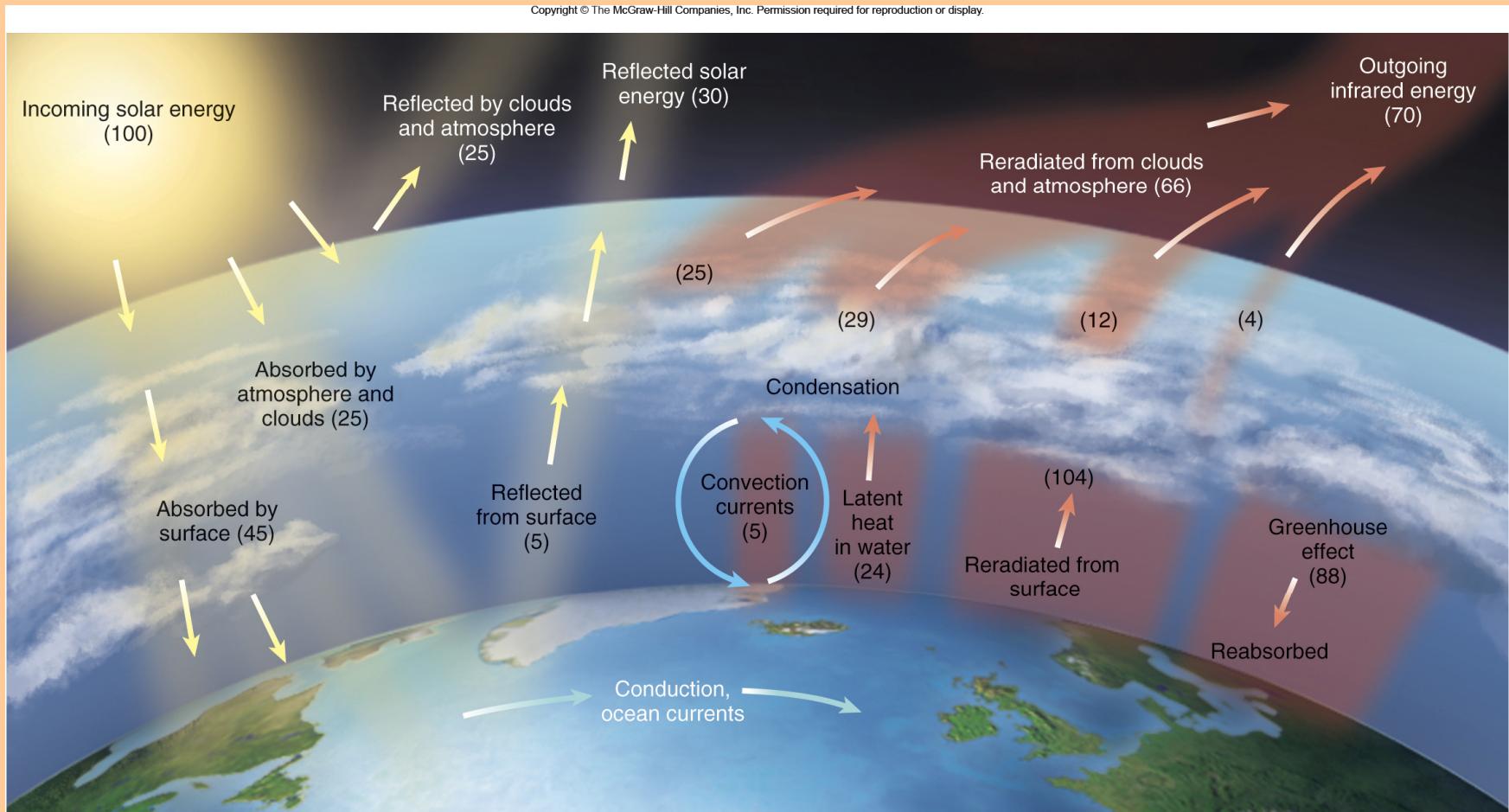
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The Atmosphere Captures Energy–Selectively

- The sun supplies the Earth with abundant energy, especially near the equator.
- Of the solar energy that reaches the outer atmosphere:
 - $\frac{1}{4}$ is reflected by clouds and atmospheric gases.
 - $\frac{1}{4}$ is absorbed by carbon dioxide, water vapor, ozone, methane, and a few other gases.
 - $\frac{1}{2}$ of incoming solar radiation (**insolation**) reaches the Earth's surface.

The Sun Warms Our World



Albedo (reflectivity) of Earth Surfaces

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TABLE 9.1 | Albedo (reflectivity) of Earth Surfaces

SURFACE	ALBEDO (%)
Fresh snow	80–85
Dense clouds	70–90
Water (low sun)	50–80
Sand	20–30
Forest	5–10
Water (sun overhead)	5
Dark soil	3

The Greenhouse Effect

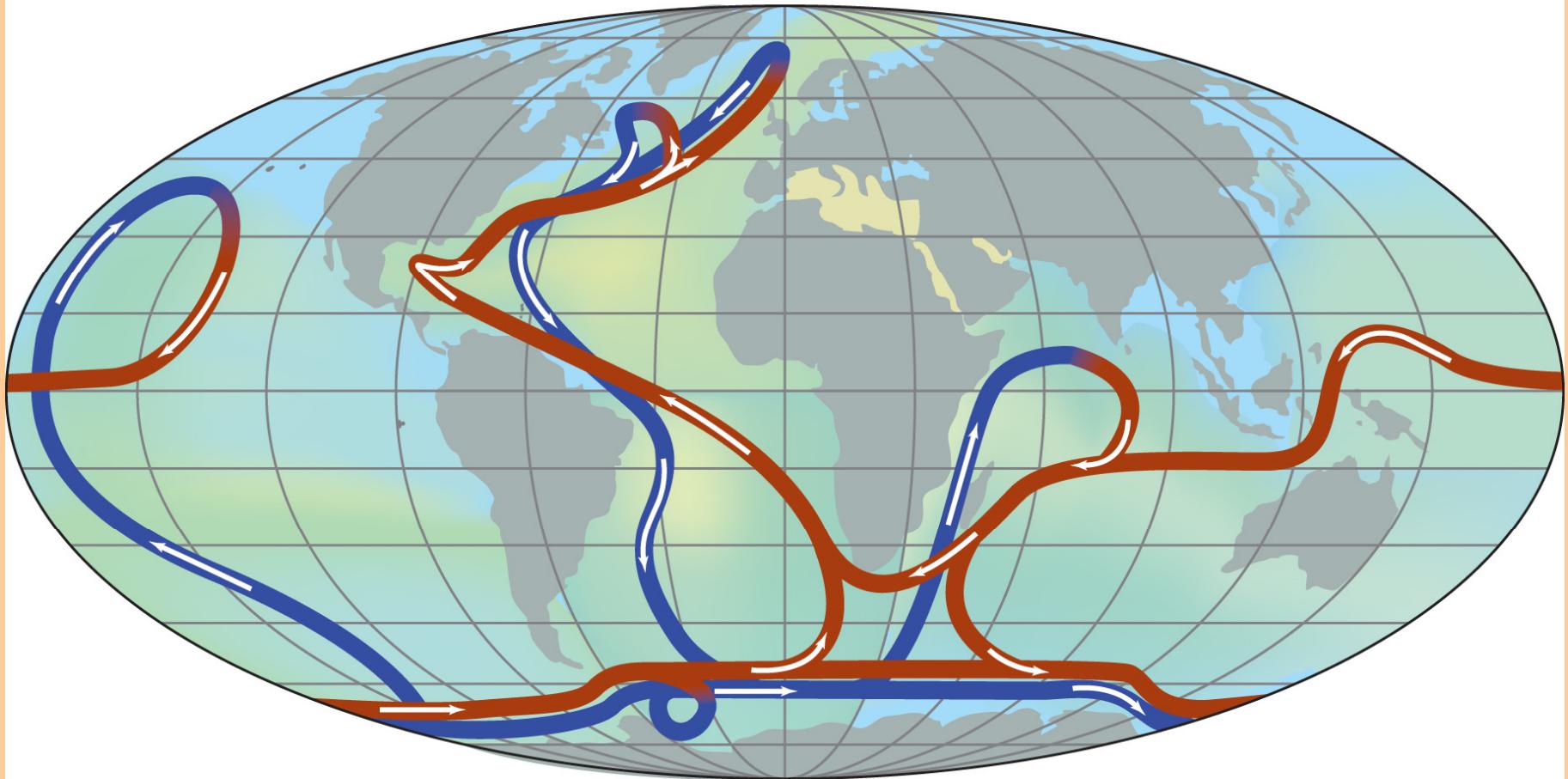
- If our atmosphere didn't capture this reemitted energy, the earth's average surface temperature would be about -6° C (21° F), rather than the current 14° C (57° F) average.
- Thus, energy capture is necessary for liquid water on earth and for life as we know it.
- The **greenhouse effect** is a common term to describe the capture of energy by gases in the atmosphere.

Evaporated Water Stores and Redisributes Heat

- Much of the incoming solar energy is used to evaporate water.
- Every gram of evaporating water absorbs 580 calories of energy as it transforms from liquid to gas.
- Globally, water vapor contains a huge amount of stored energy, known as **latent heat**.
- When water vapor condenses, returning from a gas to a liquid form, the 580 calories of heat energy are released.

Ocean Currents Also Modify Our Climate

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9.2 Climate Changes Over Time

- How stable is climate? That depends upon the time frame you consider. Over centuries and millennia, we know that climate shifts somewhat, but usually we expect little change on the scale of a human lifetime.
- The question now is whether that is a reasonable expectation.
- If climate does shift, how fast might it change, and what will those changes mean for the environmental systems we depend on?

Ice Cores Tell Us About Climate History

- In Greenland and Antarctica and other places where cold is persistent, yearly snows slowly accumulate over the centuries. New layers compress lower layers into ice, but still tiny air bubbles remain.
- Each bubble is a tiny sample of the atmosphere at the time that snow fell.
- Climatologists have discovered that by drilling deep into an ice sheet, they can extract ice cores samples that show how the atmosphere has changed over time.

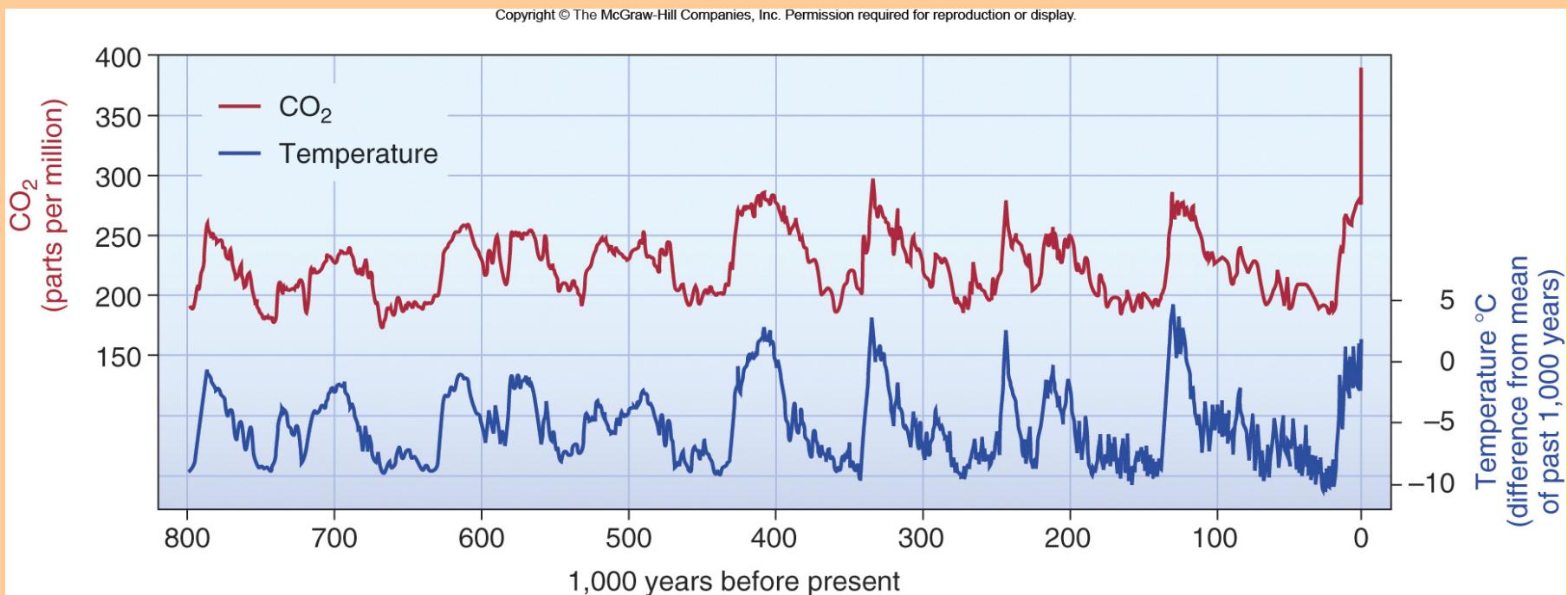
Scientists Study Ice Cores to Understand Past Climate Changes

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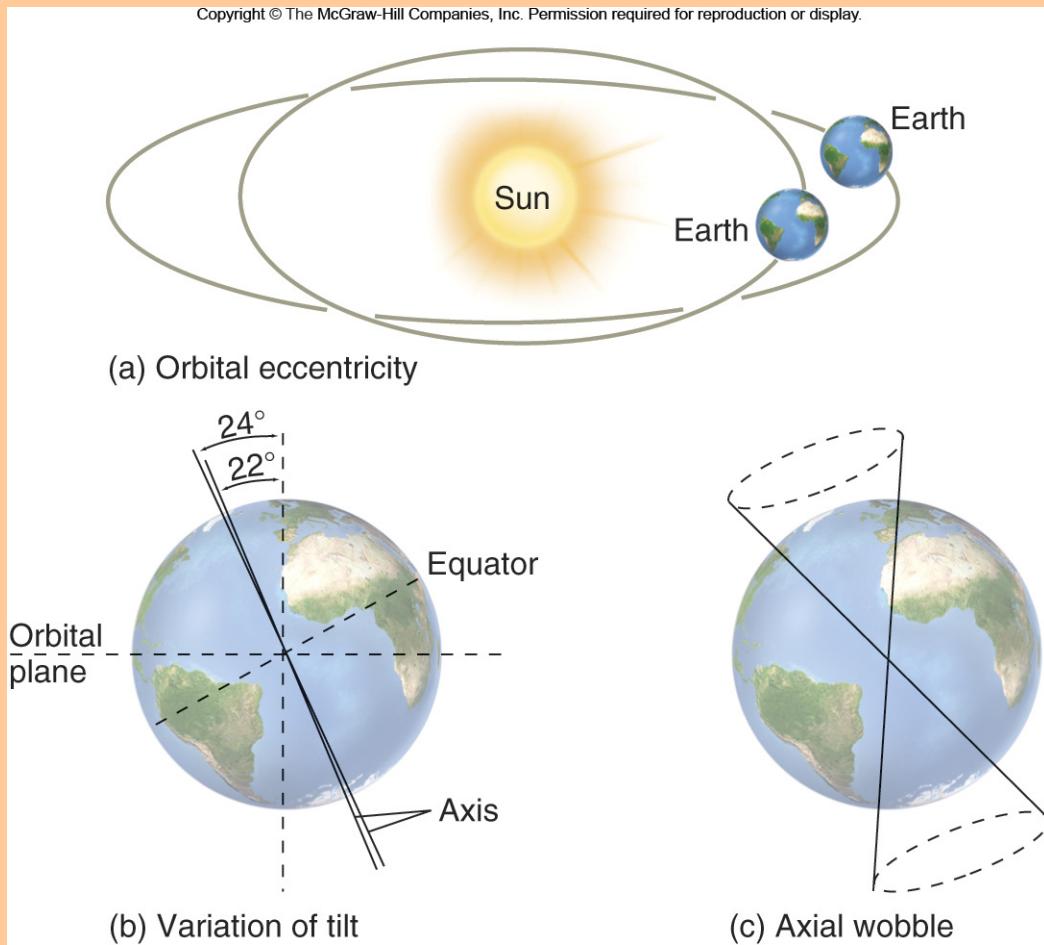


Courtesy Candice Kohl, University of California, San Diego

The Correlation Between Historic CO₂ Levels and Historic Temperatures



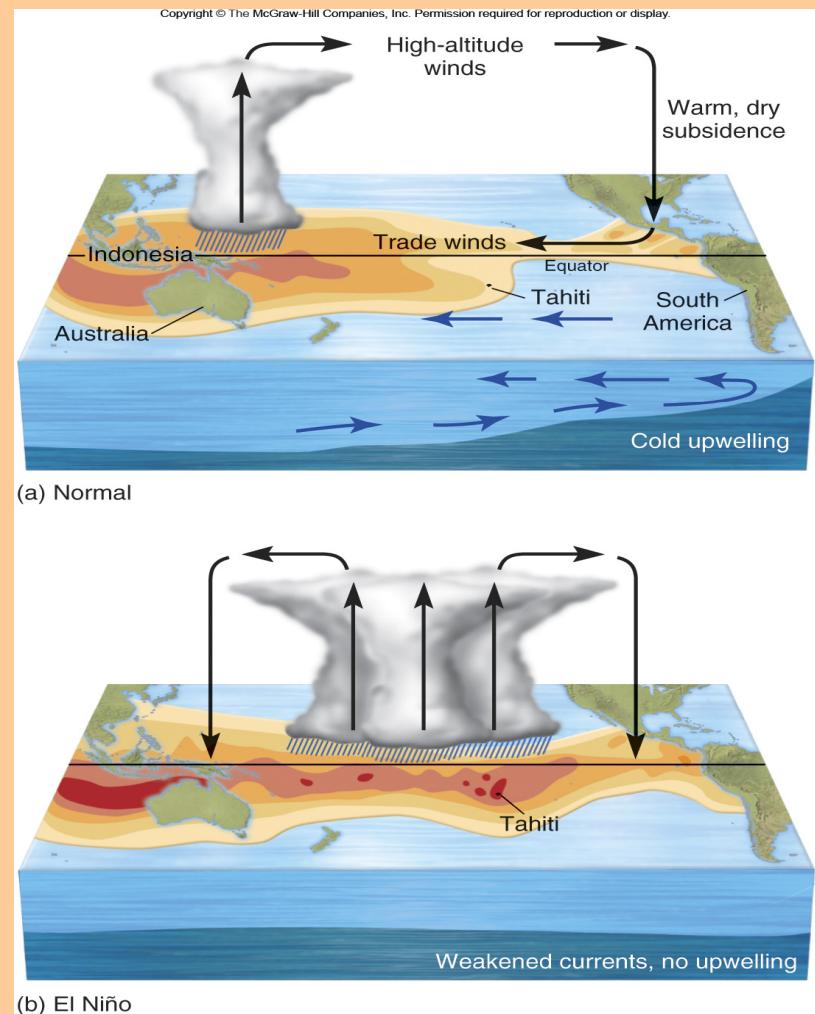
What Causes Natural Climatic Swings?



- Modest climate changes correspond to an 11-year cycle in the Sun's intensity.
- More dramatic shifts called **Milankovitch cycles** are due to changes in the Earth's orbit and tilt and wobble on its axis.

The El Niño/Southern Oscillation Can Have Far-reaching Effects

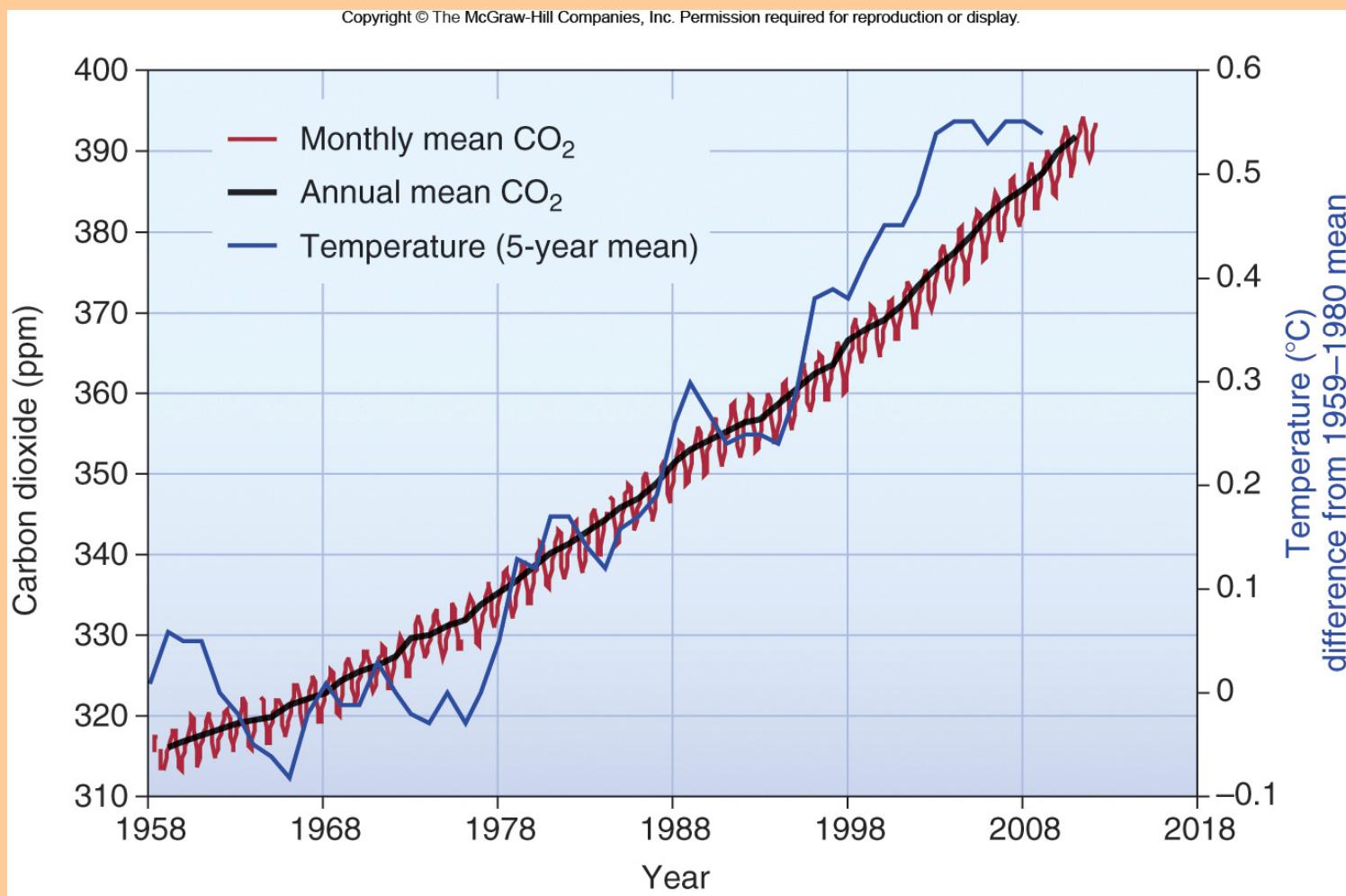
- The climate also changes according to oscillations in the ocean and atmosphere.
- **El Niño/ Southern Oscillation (ENSO) is the best known.**
- ENSO affects weather throughout the Pacific, causing heavy monsoons or serious droughts.



How Do We Know the Climate is Changing Faster than Usual?

- Many scientists consider anthropogenic (human-caused) global climate change to be the most important environmental issue of our times.
- Pivotal evidence that human activities are increasing atmospheric CO₂ came from an observatory on Mauna Loa volcano in Hawaii.
- Measurements show CO₂ levels increasing about 0.5% per year since 1958. This “Keeling curve” shows that CO₂ concentrations have risen from 315 ppm in 1958 to 393 ppm in 2012.

CO₂ and Temperature Readings from Mauna Loa Volcano in Hawaii



Scientific Consensus is Clear

- Because the climate is so complex, climate scientists worldwide have collaborated in collecting and sharing data and in programming models to describe how the climate system works.
- Evidence shows minor differences among models but no disagreement about the direction of change.
- The evidence shows unequivocally, that climate is changing, and the global average is a warming because of increased retention of energy in the lower atmosphere.

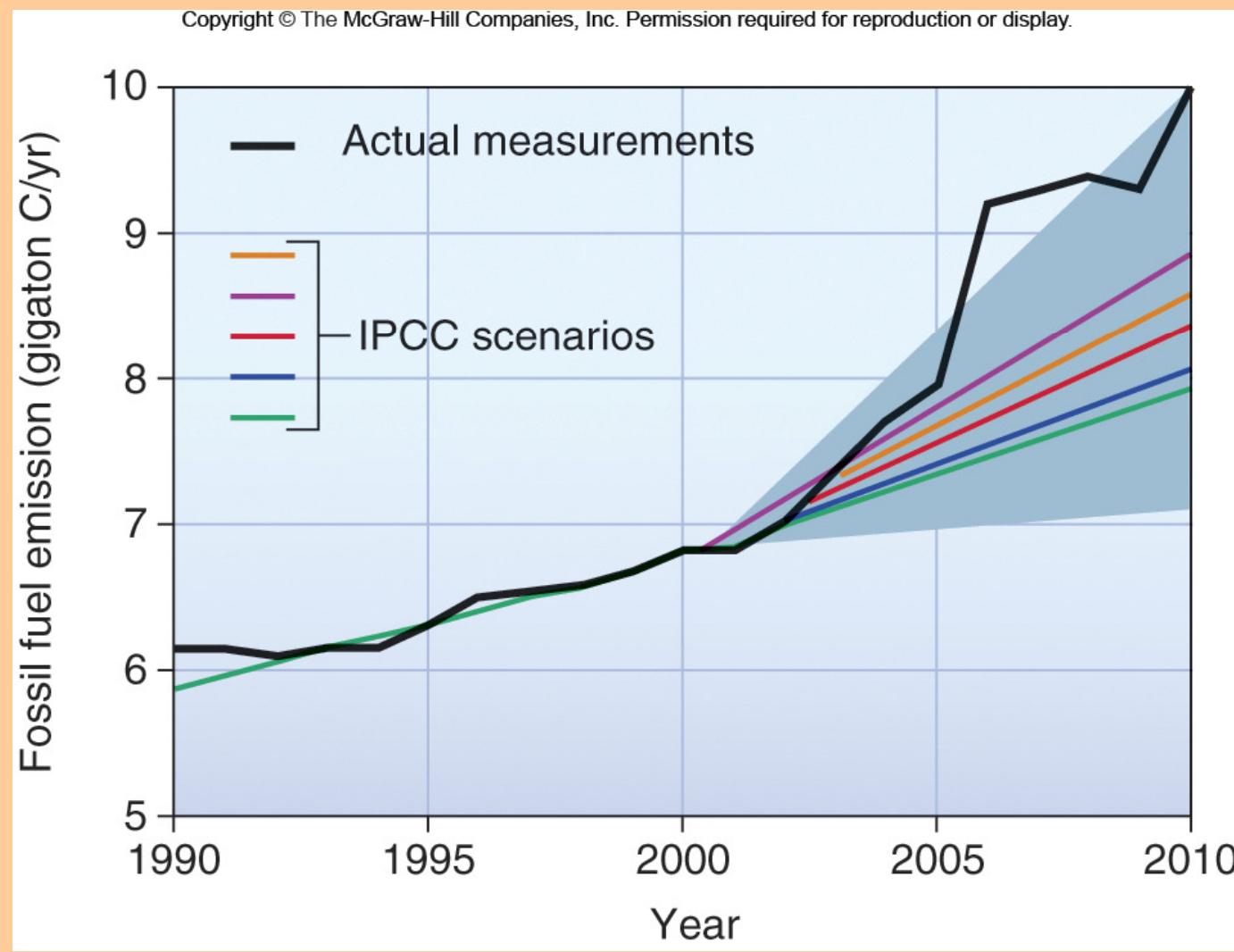
What is the IPCC?

- The most comprehensive effort to describe the state of climate knowledge is that of the **Intergovernmental Panel on Climate Change (IPCC)**.
- The IPCC brings together scientists and government representatives from 130 countries with the aim to review scientific evidence on the causes and likely effects of human-caused climate change.
- In 2007, the IPCC issued its 4th Assessment Report. The conclusion is a 90% certainty that observed climate change is caused by human activity.
 - Subsequent reports raised that certainty to 99%.

Changes in Heat Waves, Sea Level, and Storms are Expected

- The 4th IPCC Report presents a variety of climate scenarios for predicted emissions of greenhouse gases. For each scenario, the IPCC modeled future emissions, starting in 2000.
- Observations since 2007 show that all the IPCC scenarios were too conservative – Greenhouse gas emissions, temperature rises, sea level, and energy use have accelerated faster than IPCC projections.
- Droughts, floods, crop failure, and waves of refugees may result.

Comparison of Emissions Projections and Actual Emissions



Impact of a 1 m Rise in Sea Level

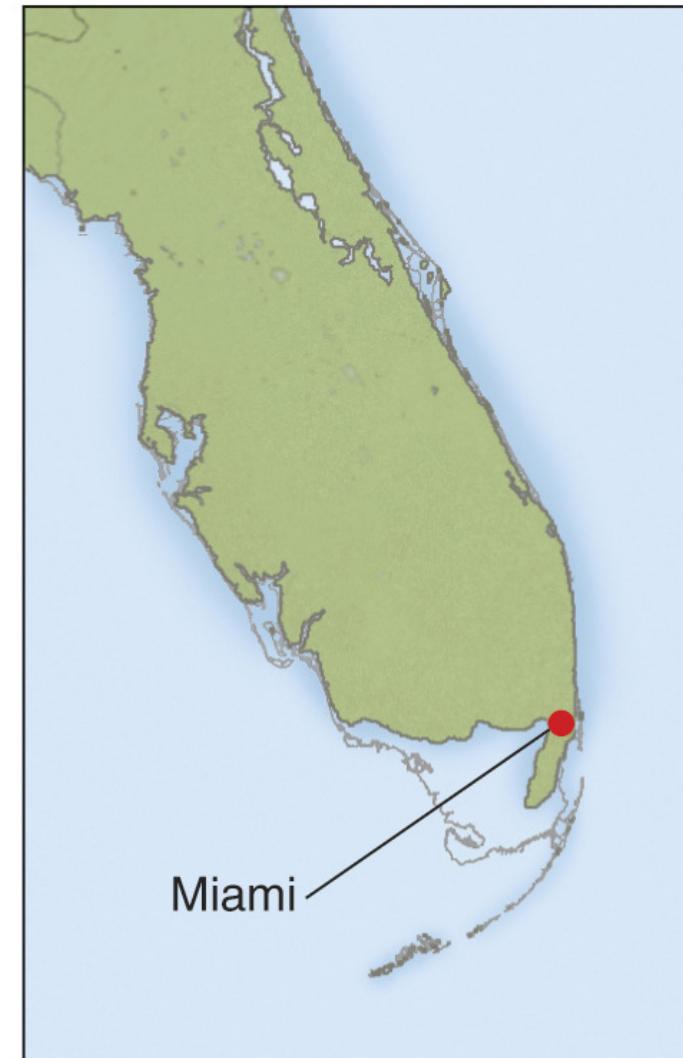
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Remaining land
 Current shoreline

0 100 Km

0 50 Miles



Policy Makers Have Made Little Progress in Finding Solutions

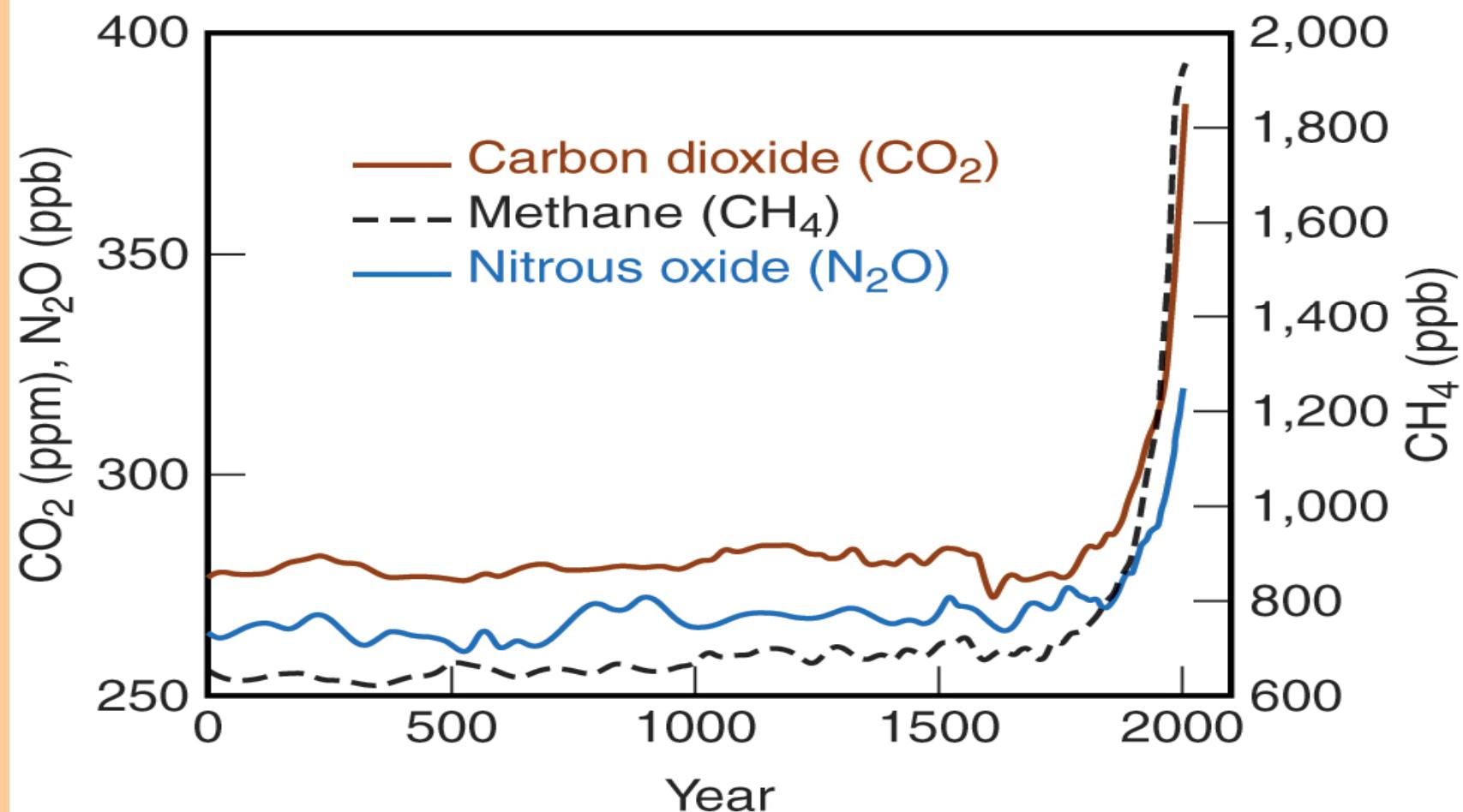
- Climate control is a classic free-rider problem, in which nobody wants to take action for fear that someone else might benefit from their sacrifices.
- The question is whether the sacrifices need necessarily be as big as some policy makers suggest.
- Climate scientists point out that shifting our energy strategy from coal to wind, solar, and greater efficiency, could produce millions of new jobs and save billions in health care costs associated with coal burning.

The Main Greenhouse Gases are CO_2 , CH_4 , and N_2O

- Since pre-industrial times, atmospheric concentrations of CO_2 , methane (CH_4), and nitrous oxide (N_2O) have climbed by over 31%, 151 %, and 17 % respectively.
- Carbon dioxide is by far the most important of these because of its abundance and because it lasts for decades or centuries in the atmosphere.
- If current trends continue, CO_2 concentrations could reach about 500 ppm (approaching 2X the pre-industrial level of 280 ppm) by the end of the 21st century.

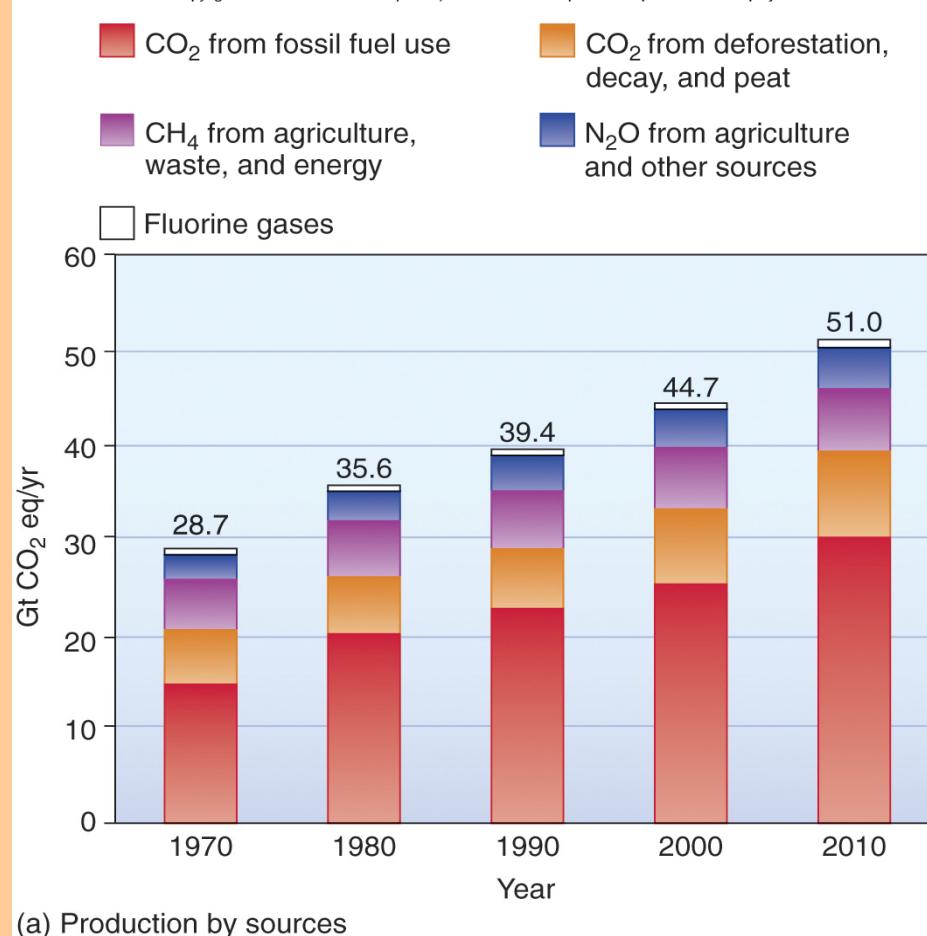
Increases in Greenhouse Gases Since Industrialization

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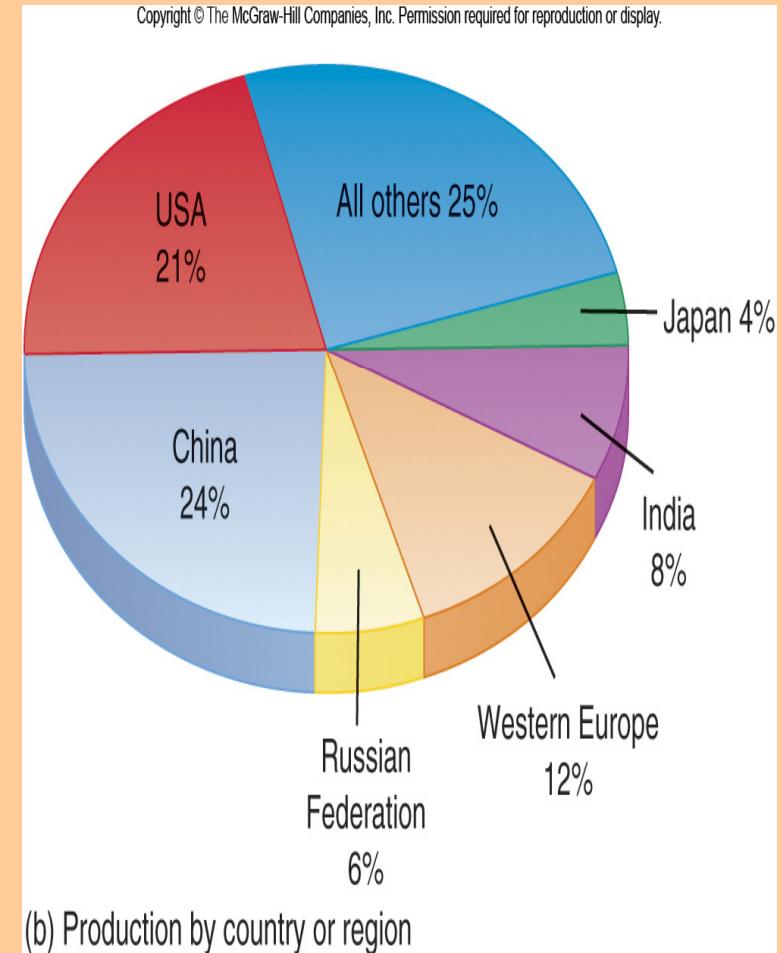
Contributions to Global Warming from Different Gases

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(a) Production by sources

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(b) Production by country or region

What Consequences Do We See?

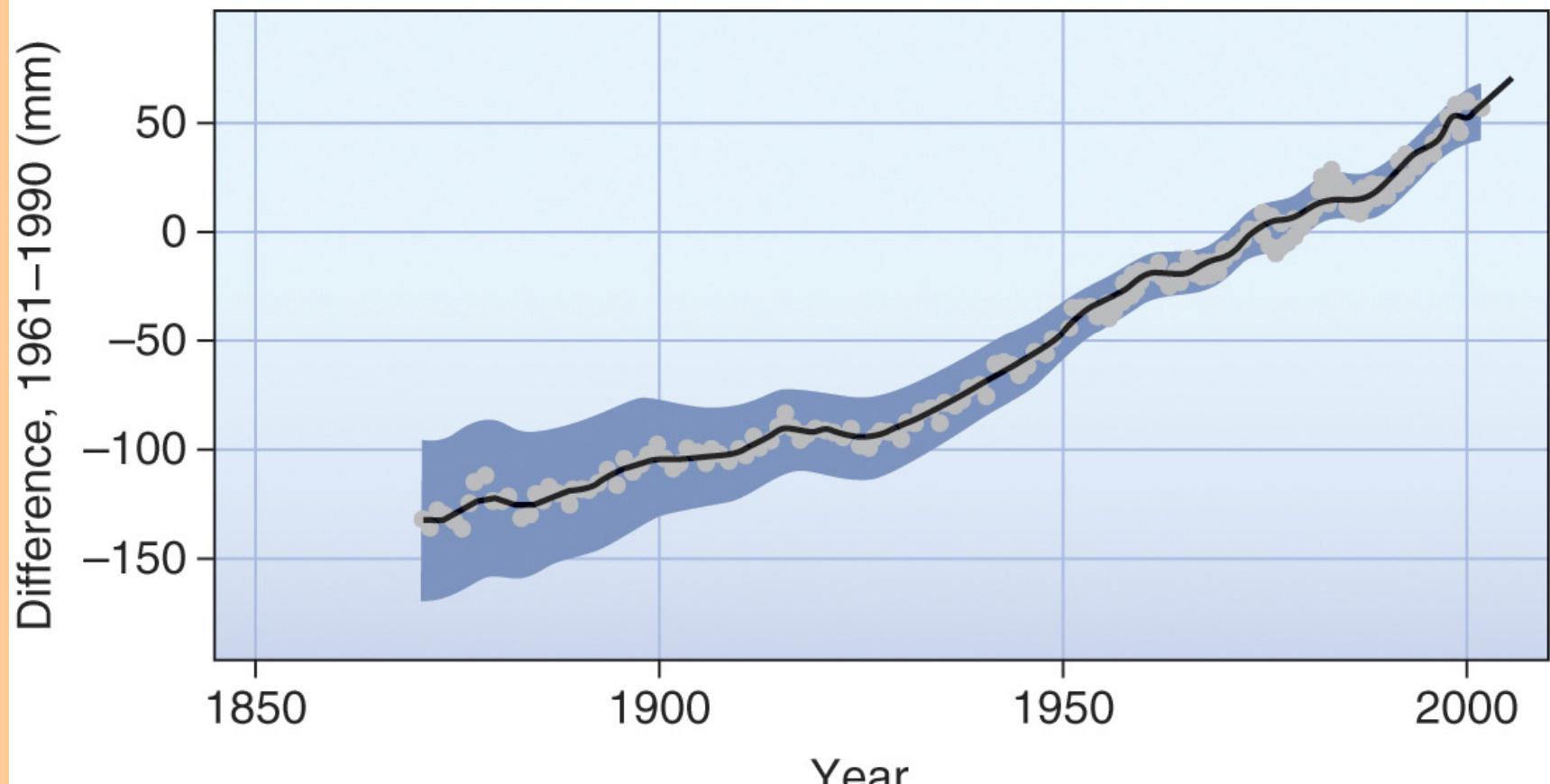
- It is now warmer than it has been in the last two thousand years.
- Over the last century, the average global temperature has climbed about 0.6 degree C (1 degree F).
- Global sea level has risen approximately 20 cm (8 in.) in the past century.
- Permafrost is melting; houses, roads, pipelines, sewage systems, and transmission lines are being damaged as the ground sinks beneath them.
- Arctic sea ice is only half as thick now as it was 30 years ago and Antarctic ice shelves are breaking up.

Evidence (continued)

- Nearly all mountain glaciers are retreating rapidly and many have disappeared entirely.
- Satellite images and surface measurements show that growing seasons are now as much as three weeks longer in a band across northern Eurasia and North America than they were 30 years ago.
- Droughts are becoming more frequent and widespread.
- Plants and animals are breeding earlier or extending their range into new territory.
- Coral reefs worldwide are “bleaching,” losing key algae.

Evidence of Climate Change

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(a) Global average sea level

Evidence of Climate Change: Ice Dependent Penguins Declining

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(b)

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Evidence of Climate Change: Alpine Glaciers Retreating

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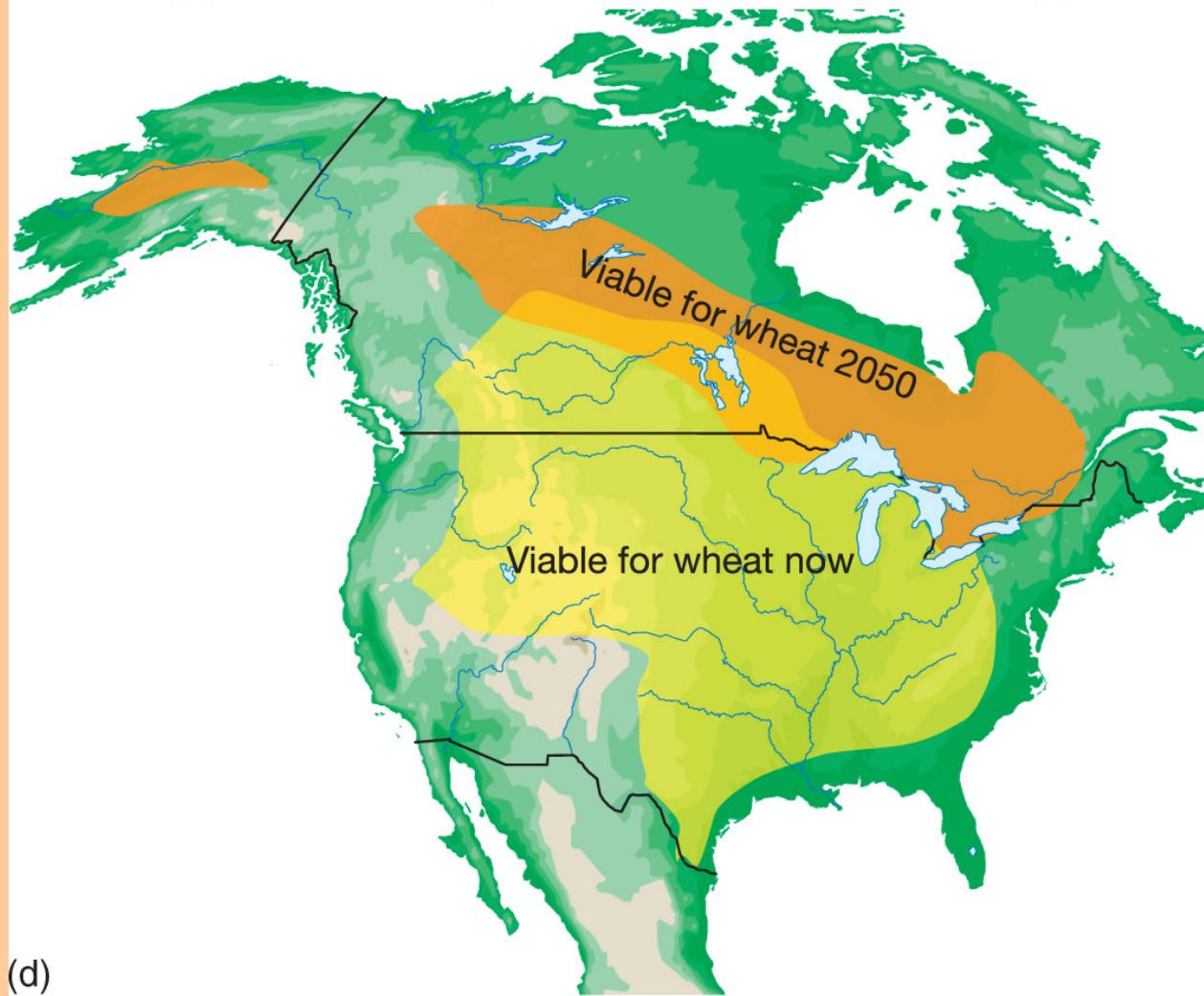
(c)

Photographer Lisa McKeon, courtesy of Glacier National Park Archives



Evidence of Climate Change: Changing Climactic Range for Growing Wheat

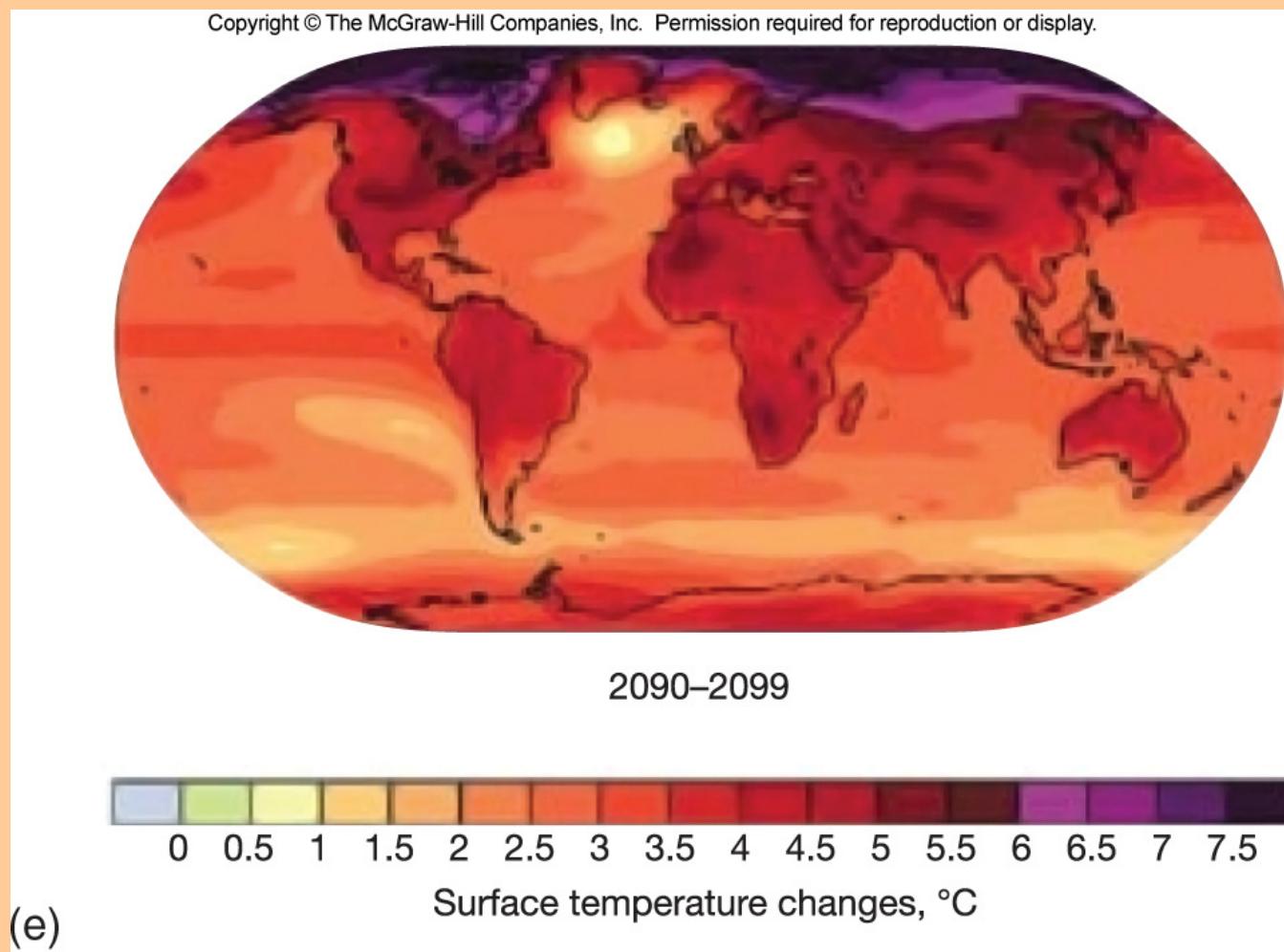
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(d)

9-37

Evidence of Climate Change: IPCC Surface Temperature Projections



Controlling Emissions is Cheaper than the Cost of Climate Change

- A 2010 study by the Pew Trust estimates the cost of lost ecological services by 2100. Costs included factors such as lost agricultural productivity from drought, damage to infrastructure from flooding and storms, lost biological productivity, health costs from heat stress, and lost water supplies.
- The Pew report found that climate change is likely to cost between \$5 trillion and \$90 trillion by 2100.
- The Stern report estimates a cost of only about 1% of global GDP to avoid the worst impacts of climate change.

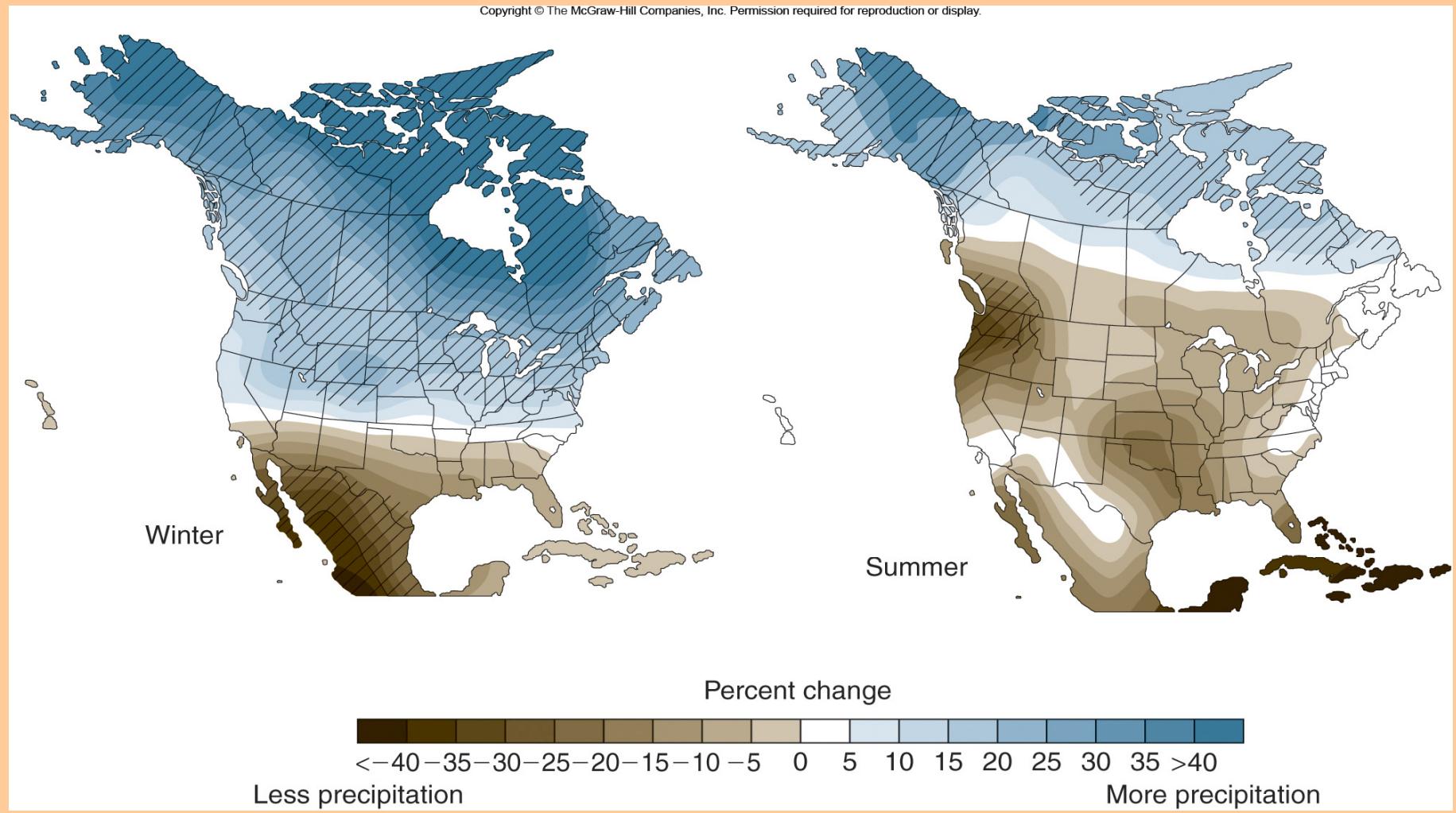
Why are there Disputes Over Climate Evidence?

- Climate scientists offer the following responses to some of the claims in the popular media:
 - *Reducing climate change requires abandoning our current way of life* (no, but it does require that we use different energy sources).
 - *There is no alternative to current energy systems* (Europe and China are showing this to be false).
 - *A comfortable lifestyle requires high CO₂ output* (data show this is false).
 - *Natural changes such as solar variation can explain observed warming* (changes are slight and do not coincide with the climate changes).

Responses to Disputes Over Climate Change

- *The climate has changed before, so this is nothing new* (Today's CO₂ level exceeds anything the Earth has seen for nearly a million years).
- *Temperature changes are leveling off* (True on short time frames sometimes, but over decades the trends in surface air temperatures and in sea level continue to rise).
- *We had cool temperatures and snowstorms last year, not heat and drought* (Regional differences in temperature and precipitation trends are predicted by climate models).
- *Climate scientists don't know everything, and they have made errors and misstatements* (fraud in data collection is almost unheard of in science).

Climate Change Will Cause Changes in Precipitation



9.4 Envisioning Solutions

- Former president Bill Clinton has argued that combating climate change doesn't have to mean economic hardship.
- It could be the biggest development stimulus since World War II, creating millions of jobs and saving trillions of dollars in foreign fuel imports.
- What are some of the strategies we have available?

There are Many Ways We Can Control Greenhouse Emissions

- We can reduce dependence on coal, which produces more CO₂ per energy unit than any other fuel.
- We could institute fees for selling fossil fuels—these would help fossil fuel prices represent their many hidden costs.
- We can invest in new technologies and energy efficiency.
- We can institute emissions trading by instituting a legal cap on emissions then allowing companies to buy and sell shares of that total cap.

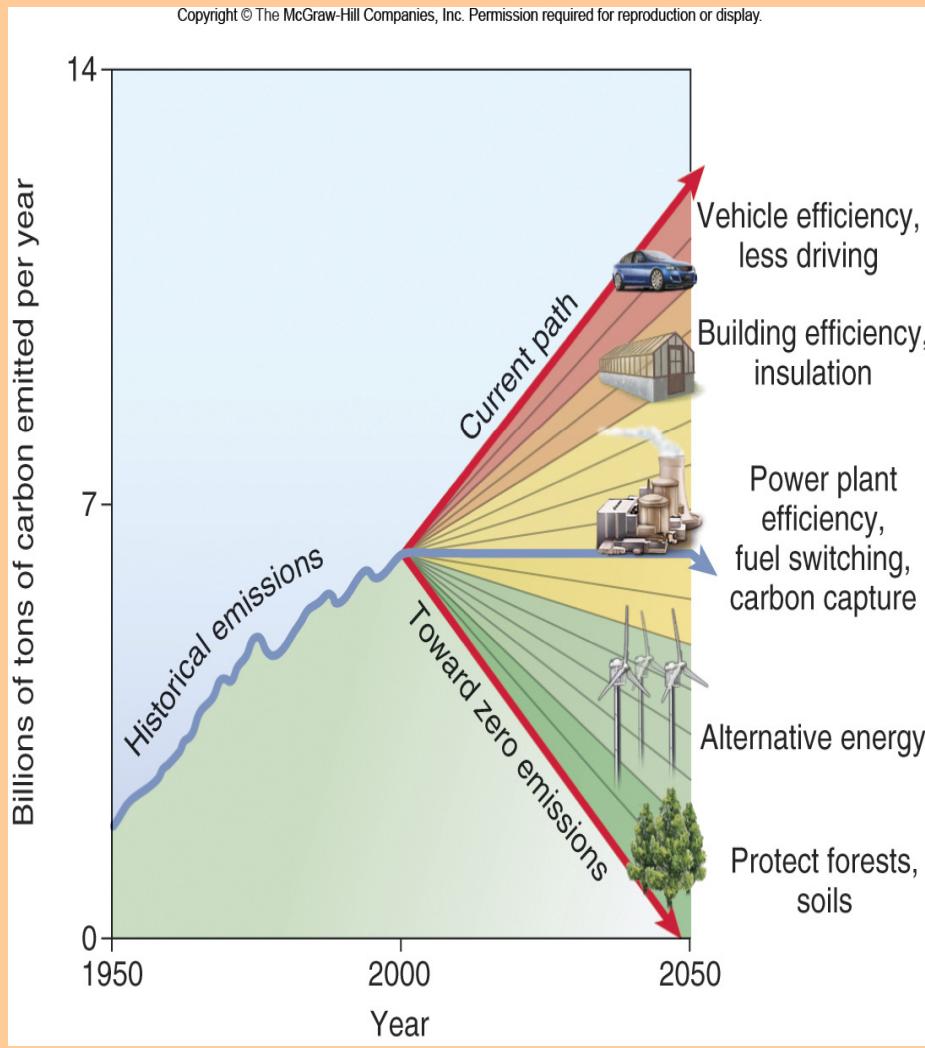
International Protocols Have Tried to Establish Common Rules

- In 1992 The United Nations Earth Summit meeting in Rio de Janeiro set an objective of stabilizing greenhouse gas emissions.
- In Kyoto, Japan, in 1997, 160 nations agreed to roll back CO₂, methane, and nitrous oxide emissions about 5 percent below 1990 levels by 2012, but China and India were exempted from the agreement and the U.S. never ratified this agreement.

A Wedge Approach Could Fix the Problem

- An alternative approach is wedge analysis, breaking down a large problem into smaller, bite-size pieces.
- Each one might start small now, but their impacts will grow over time, producing a larger wedge-like impact in 50 years.
- Pacala and Socolow's paper described 14 "wedges", each represents 1 GT (1 billion tons) of carbon emissions avoided in 2058.

Wedge Analysis



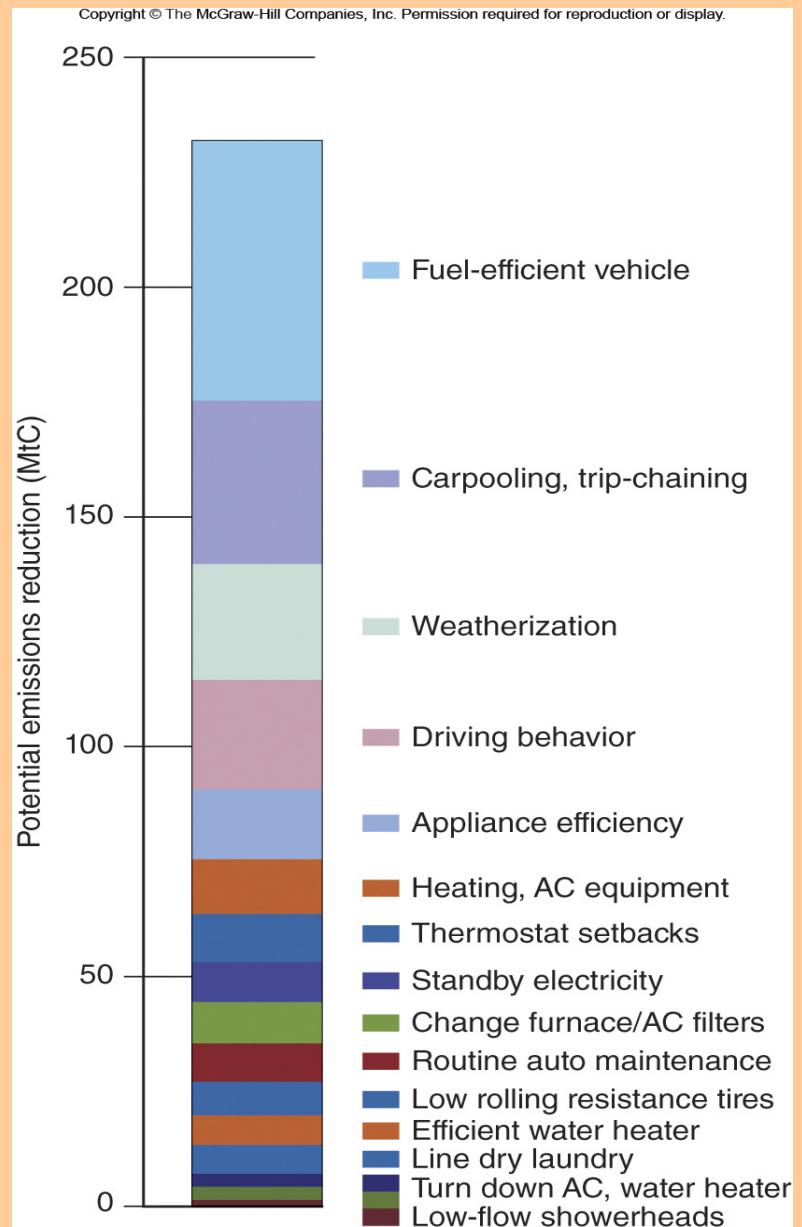
- Accomplishing just half of these wedges could level off our emissions.
- Accomplishing all of them could return to levels well below those envisioned in the Kyoto protocol.

Local Initiatives are Everywhere

- Britain has already started to substitute natural gas for coal, promote energy efficiency in homes and industry, and raise its already high gasoline tax.
- New Zealand Prime Minister Helen Clark pledged that her country will be the first to be “carbon neutral”.
- Germany has reduced its CO₂ emissions at least 10 percent by switching from coal to gas and by encouraging energy efficiency throughout society.
- Denmark now gets 20% of its electricity from windmills.

Reducing Individual CO₂ Emissions

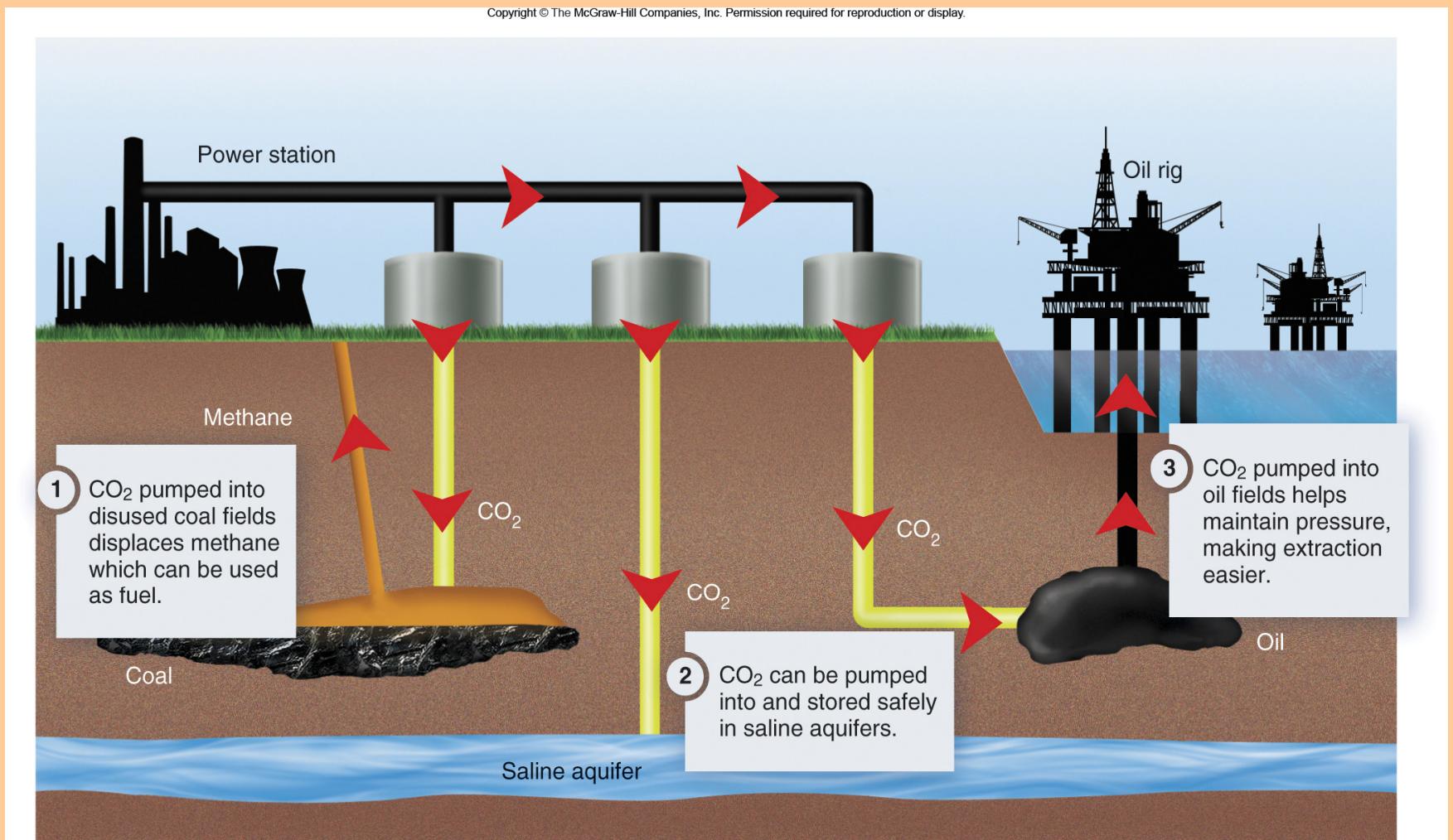
- Individual actions can have tremendous impacts on climate change because our actions are multiplied by millions of others who make similar decisions.
- This graph shows a summary of which individual steps would make the most impact.



Carbon Capture Stores CO₂ but is Expensive

- It is possible, though expensive, to store CO₂ by injecting it deep into geologic formations.
- Since 1996, Norway's Statoil has been pumping more than 1 million metric tons of CO₂ per year into an aquifer 1,000 m below the seafloor in the North Sea.
- The pressurized CO₂ enhances oil recovery and saves on carbon taxes in Norway.
- Around the world, deep, briny aquifers could store a century's worth of CO₂ output at current fossil fuel consumption rates.

Carbon Capture Technology



Conclusion

- Temperatures are now higher than they have been in thousands of years, and climate scientists say that if we don't reduce greenhouse gas emissions soon, drought, flooding of cities may be inevitable.
- Exhaustive modeling and data analysis by climate scientists show that these changes can only be explained by human activity.
- The “stabilization wedge” proposal is a list of immediate steps that could be taken to accomplish needed reductions in greenhouse gases.