Wednesday, Nov. 26

Syllabus, class notes, and homeworks are at:
www.as.utexas.edu → courses → AST 301, Lacy

Reading for this week: chapter 17

We won't have a help session this week.

Today: the greenhouse effect

Topics for this week

How can we use the concept of thermal equilibrium to calculate the temperature of the surface of a rock orbiting the Sun?

How does the result depend on the distance of the rock from the Sun?

How does the Earth's atmosphere affect the surface temperature of the Earth?

Why do Venus and Mars have such different surface temperatures?

How are we changing the Earth's atmosphere, and how do we think this will affect the surface temperature?

ABCD Quiz

The temperature of the surface of a planet is determined by an equilibrium between heating and cooling.

For the Earth, the heating of the surface is dominated by:

A. radioactive decay of Uranium inside of the Earth

B. absorption of visible light from the Sun

C. absorption of ultraviolet light from the Sun

D. infrared (blackbody) radiation

ABCD Quiz

The cooling of the surface of the Earth is dominated by:

A. emission of infrared radiation

B. reflection of sunlight by the surface

C. evaporation of water

D. conduction of heat into the air

(During the day, heat is conducted into the air, but at night the heat flows from the air into the ground.)

ABCD Quiz

The greenhouse effect causes an increase in the temperature of the surface of the Earth by:

A. preventing the radiation of infrared radiation by the ground

B. preventing the infrared radiation from the ground from getting out to space

C. preventing convection from removing heat from the ground

D. heating the atmosphere so it can emit infrared radiation which adds to the heating of the ground

I would accept answer B on a test, although D is better.

C is important in real greenhouses.

Calculating the rock's temperature

To calculate the temperature of the rock orbiting the Sun, we need to write down the formulas for the energy going into the rock and the energy going out each second.

Power going in is the flux of sunlight multiplied by the area of the side of the rock facing the Sun.

$P_{in} = F_{sunlight} \times A_{face} \times$ fraction absorbed

Power going out depends on the temperature of the rock and its total surface area.

$P_{out} = \sigma T^4 \times A_{surface}$

In equilibrium, the temperature is such that $P_{out} = P_{in}$.

Include only sunlight absorbed

Only the sunlight absorbed (not reflected) by the planet contributes to its heating.

Recalculating the temperatures including only the absorbed sunlight we get lower temperatures:

Planet	black rock	recalculated	actual surface T
Mercury	450 K	440 K	100-700 K
Venus	330 K	230 K	700 K
Earth	280 K	250 K	290 K
Mars	227 K	217 K	220 K
Jupiter	123 K	103 K	130 K

The greenhouse effect

By blocking some of the outgoing infrared radiation and returning it to the Earth, molecules in the Earth's atmosphere force the temperature of the surface of the Earth to rise until the outgoing flow of energy matches the incoming flow.

This is the greenhouse effect.

Because of the greenhouse effect, the surface of the Earth is warm enough for us to live here.

Only about on half of the radiation emitted by the surface of the Earth escapes to carry heat away from the Earth.

As a result, the average temperature of the surface of the Earth is warm enough for life.

Greenhouse gasses and Goldilocks

The molecules in the Earth's atmosphere which absorb the most infrared radiation are:

water vapor (H_2O)

carbon dioxide (CO_2)

methane (CH_4)

nitrous oxide (N_2O)

ozone (O_3)

Both Venus and Mars have atmospheres rich in CO_2, but Venus' atmosphere is about 100 times denser than ours, whereas Mars' atmosphere is about 100 times thinner.

Including the greenhouse effect we can explain why Venus is so hot and Mars so cold.

Differences between our atmospheres

Why do Venus, Earth, and Mars have such different atmospheres?

Our atmosphere probably once was rich in CO_2, but when CO_2 is dissolved in water it can react with metal ions to form limestone. Plankton and shellfish make this happen faster. Also, plants make cellulose from CO_2, releasing O_2.

Venus has always been too hot for water to be liquid, so it had no way to remove the CO_2 from its atmosphere. So it has a very strong greenhouse effect.

Mars probably once had oceans or lakes where limestone could form. It is also cold enough at its poles for CO_2 to freeze. And almost all of its water is frozen. So it has a very weak greenhouse effect.

Climate Change

If you've heard about the greenhouse effect, you've probably heard about how it is changing our climate.

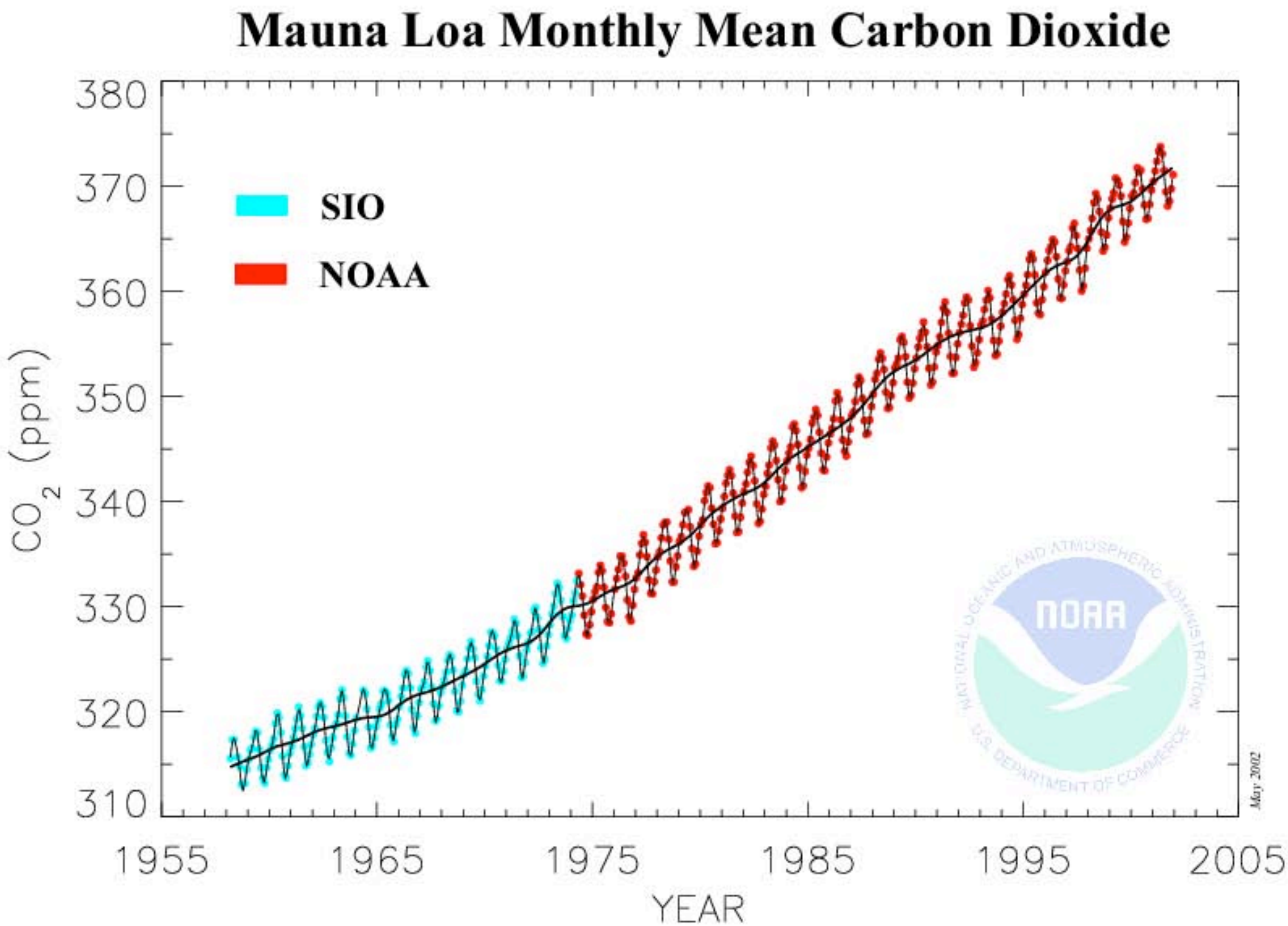
Although the greenhouse effect is desirable, and maybe necessary for life to exist on Earth, most life forms are slow to adapt to changes in the temperature.

A rapid change in the greenhouse effect can be harmful.

What are we doing that changes the greenhouse effect?

Changing the atmosphere

We are increasing the CO_2, CH_4, and O_3 in our atmosphere.



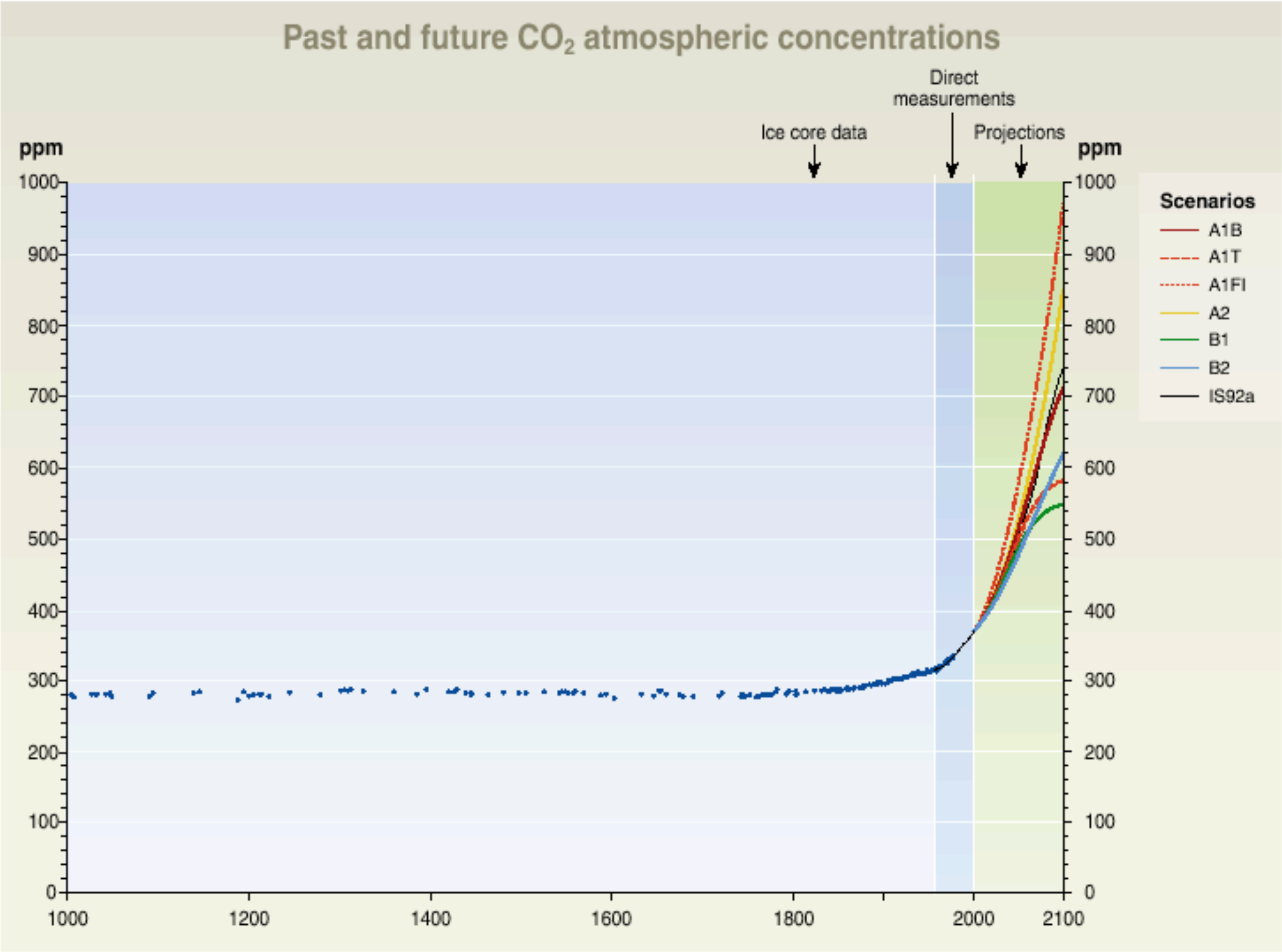


Figure SPM-10a: Atmospheric CO_2 concentration from year 1000 to year 2000 from ice core data and from direct atmospheric measurements over the past few decades. Projections of CO_2 concentrations for the period 2000 to 2100 are based on the six illustrative SRES scenarios and IS92a (for comparison with the SAR).

Q9 Figure 9-1a

Will the temperature rise?

The direct effect of the CO_2 and other gasses we are putting into the atmosphere on the temperature of the surface of the Earth is relatively small.

If nothing else changed the temperature would rise less than 1^o C in the next century.

But other things will change.

An increase in the temperature of the oceans will cause increased evaporation, increasing the amount of water vapor in the atmosphere.

This will magnify the effect.

But it will also get cloudier.

This will decrease the heating.

EPA : Global Warming : About The Site - Netscape

U.S. Environmental Protection Agency

Global Warming

Recent Additions | Contact Us | Print Version Search Area: GO

EPA Home > Global Warming > About The Site

Climate

Emissions

Impacts

Actions

News and Events

Resource Center

Where You Live

Visitor Center

Global Warming For Kids!

About The Site

The EPA Global Warming Site is provided as a public service by the U.S. Environmental Protection Agency. EPA's climate change programs and activities are an integral part of the Agency's mission and purpose. With the Global Warming Site, we strive to present accurate information on the very broad issue of climate change and global warming in a way that is accessible and meaningful to all parts of society – communities, individuals, business, public officials and governments.

The United States has based its climate change policies on the conclusions of the Intergovernmental Panel on Climate Change (IPCC), which has provided an authoritative international consensus on the science of climate change. Content presented on the Global Warming Site relies heavily on the IPCC literature, as well – particularly the reports listed below.

The United States, the International Community, and the Global Warming Site also rely on the work of the U.S. Global Change Research Program (USGCRP). In fact, the USGCRP provides a major contribution to the research base on which the IPCC assessments rely. In addition, the Site uses reports related to climate change that have been produced by or for the Agency over the years; many of these reports are available within the Site's Publications section.

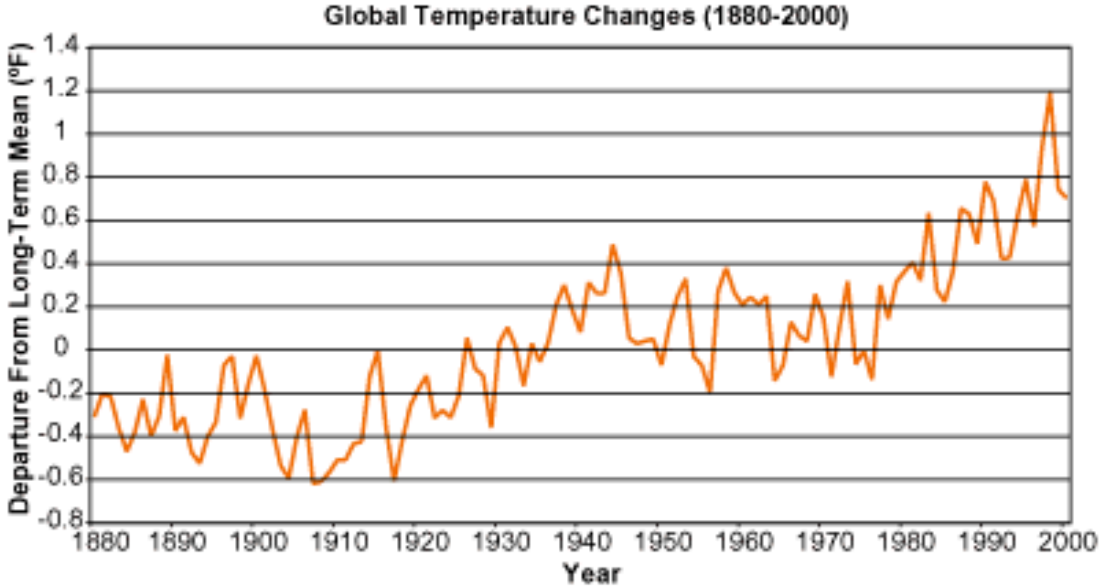
Enjoy this award-winning Site and we will continue to present or direct you to the most accurate and timely social, scientific, and logistic information available on the global warming issue.

What is the IPCC?

Recognizing the problem of potential global climate change the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) established the Intergovernmental Panel on Climate Change EXIT disclaimer in 1988. It is open to all members of the UNEP and WMO.

Changing Climate

Global mean surface temperatures have increased 0.5-1.0°F since the late 19th century. The 20th century's 10 warmest years all occurred in the last 15 years of the century. Of these, 1998 was the warmest year on record. The snow cover in the Northern Hemisphere and floating ice in the Arctic Ocean have decreased. Globally, sea level has risen 4-8 inches over the past century. Worldwide precipitation over land has increased by about one percent. The frequency of extreme rainfall events has increased throughout much of the United States.



Source: U.S. National Climatic Data Center, 2001

Increasing concentrations of greenhouse gases are likely to accelerate the rate of climate change. Scientists expect that the average global surface temperature could rise 1-4.5°F (0.6-2.5°C) in the next fifty years, and 2.2-10°F (1.4-5.8°C) in the next century, with significant regional variation. Evaporation will increase as the climate warms, which will increase average global precipitation. Soil moisture is likely to decline in many regions, and intense rainstorms are likely to become more frequent. Sea level is likely to rise two feet along most of the U.S. coast.

Calculations of climate change for specific areas are much less reliable than global ones, and it is unclear whether regional climate will become more variable.

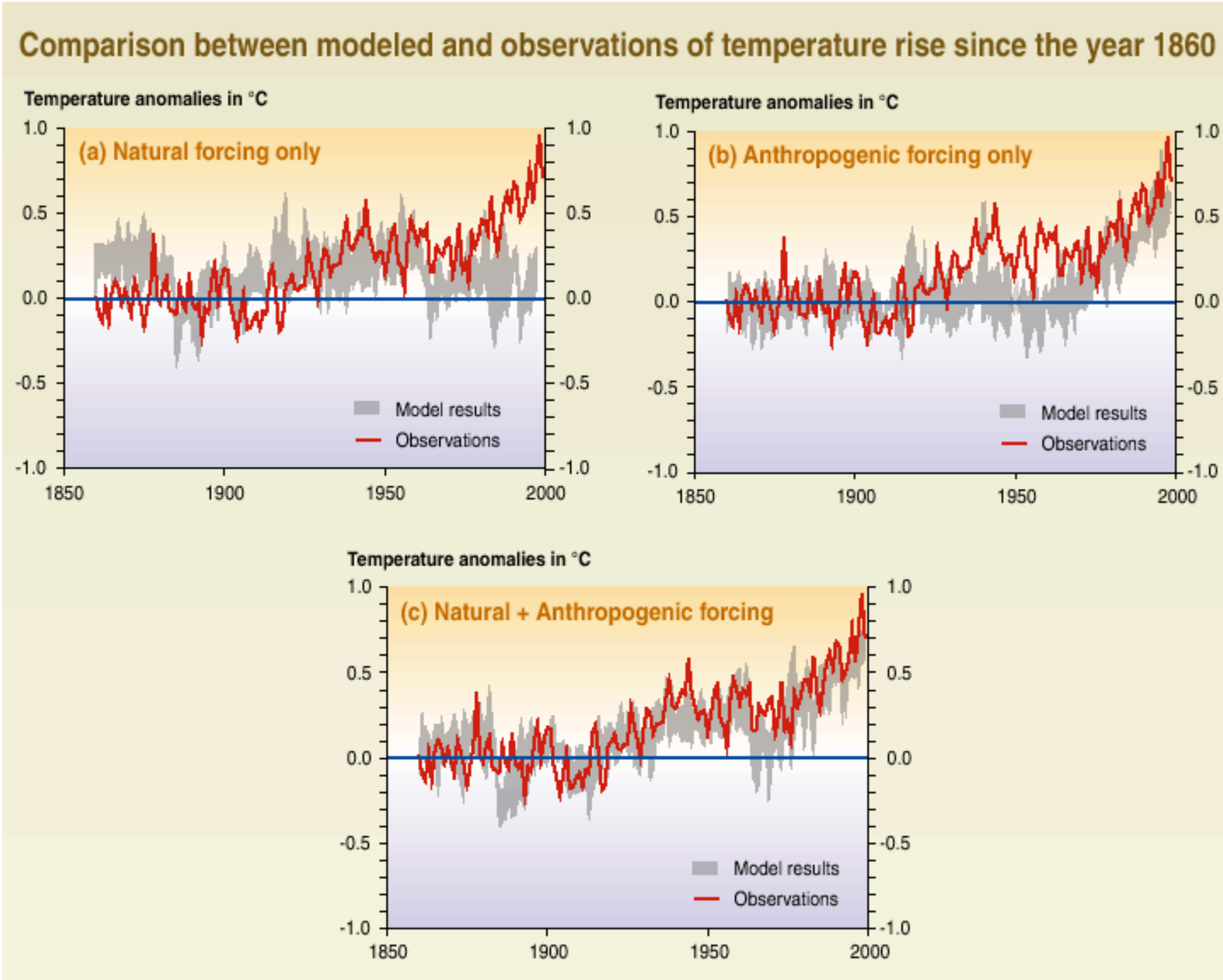


Figure SPM-2: Simulating the Earth's temperature variations (°C) and comparing the results to the measured changes can provide insight to the underlying causes of the major changes. A climate model can be used to simulate the temperature changes that occur from both natural and anthropogenic causes. The simulations represented by the band in (a) were done with only natural forcings: solar variation and volcanic activity. Those encompassed by the band in (b) were done with anthropogenic forcings: greenhouse gases and an estimate of sulfate aerosols. And those encompassed by the band in (c) were done with both natural and anthropogenic forcings included. From (b), it can be seen that the inclusion of anthropogenic forcings provides a plausible explanation for a substantial part of the observed temperature changes over the past

Q2 Figure 2-4

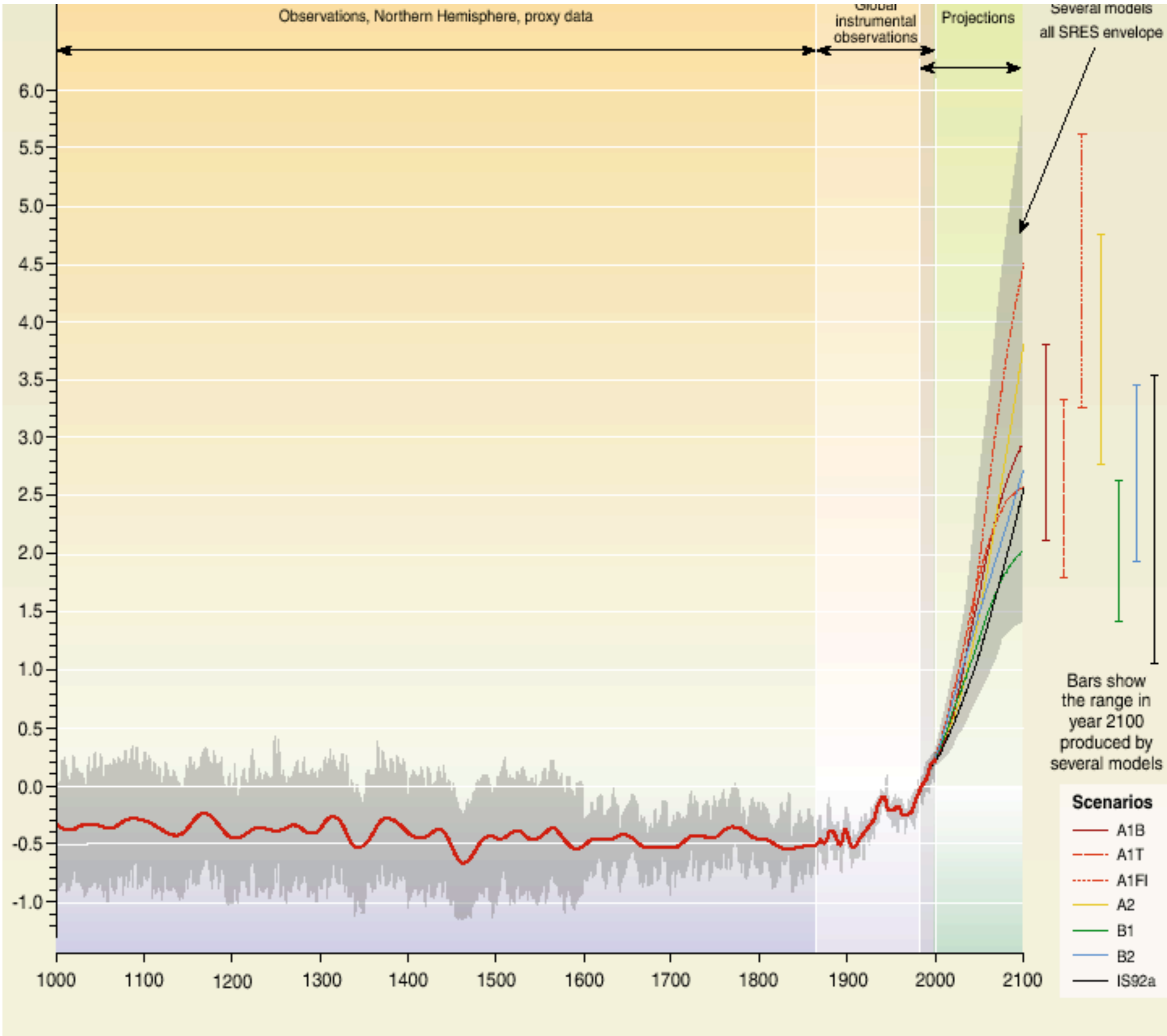
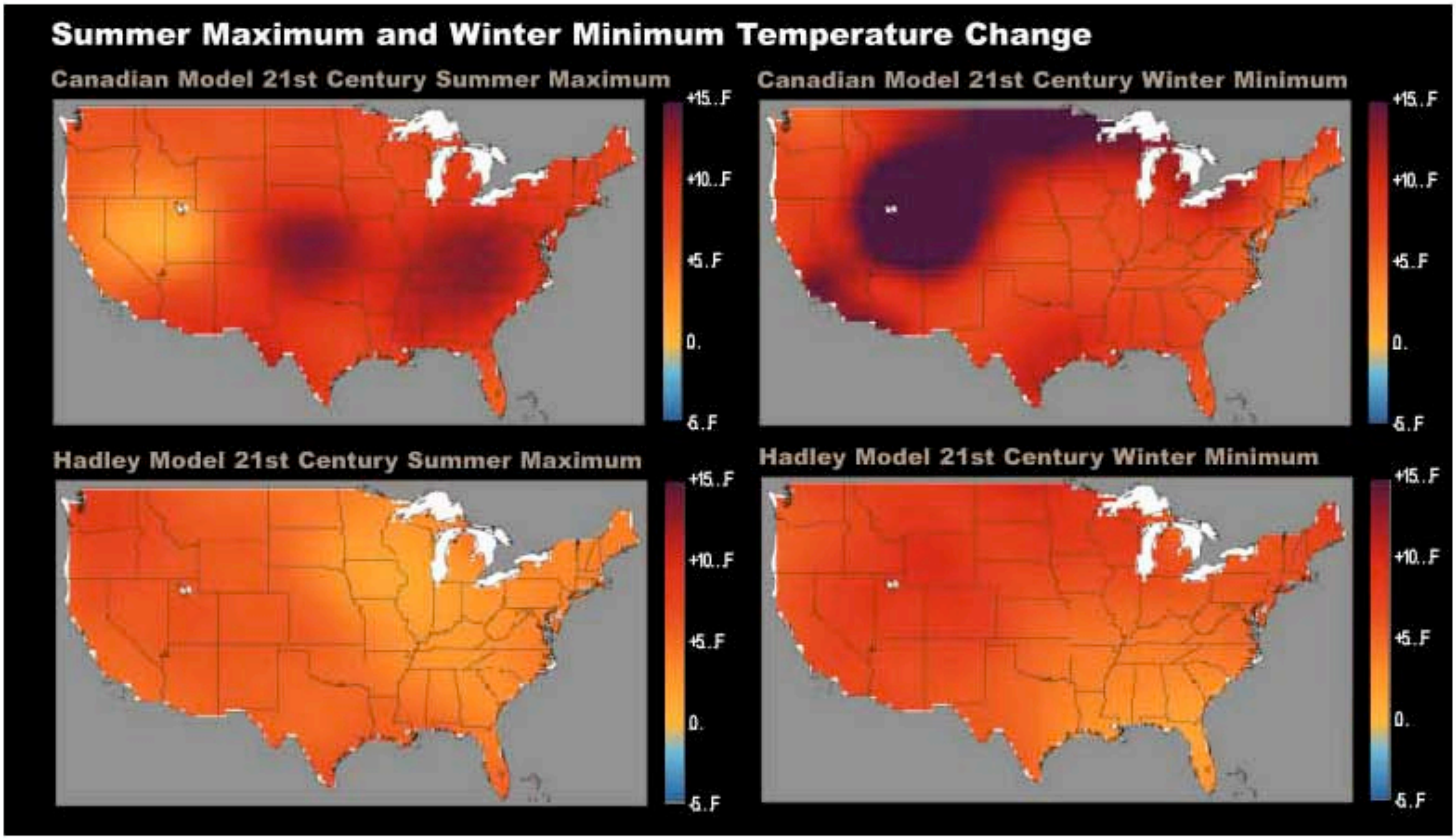


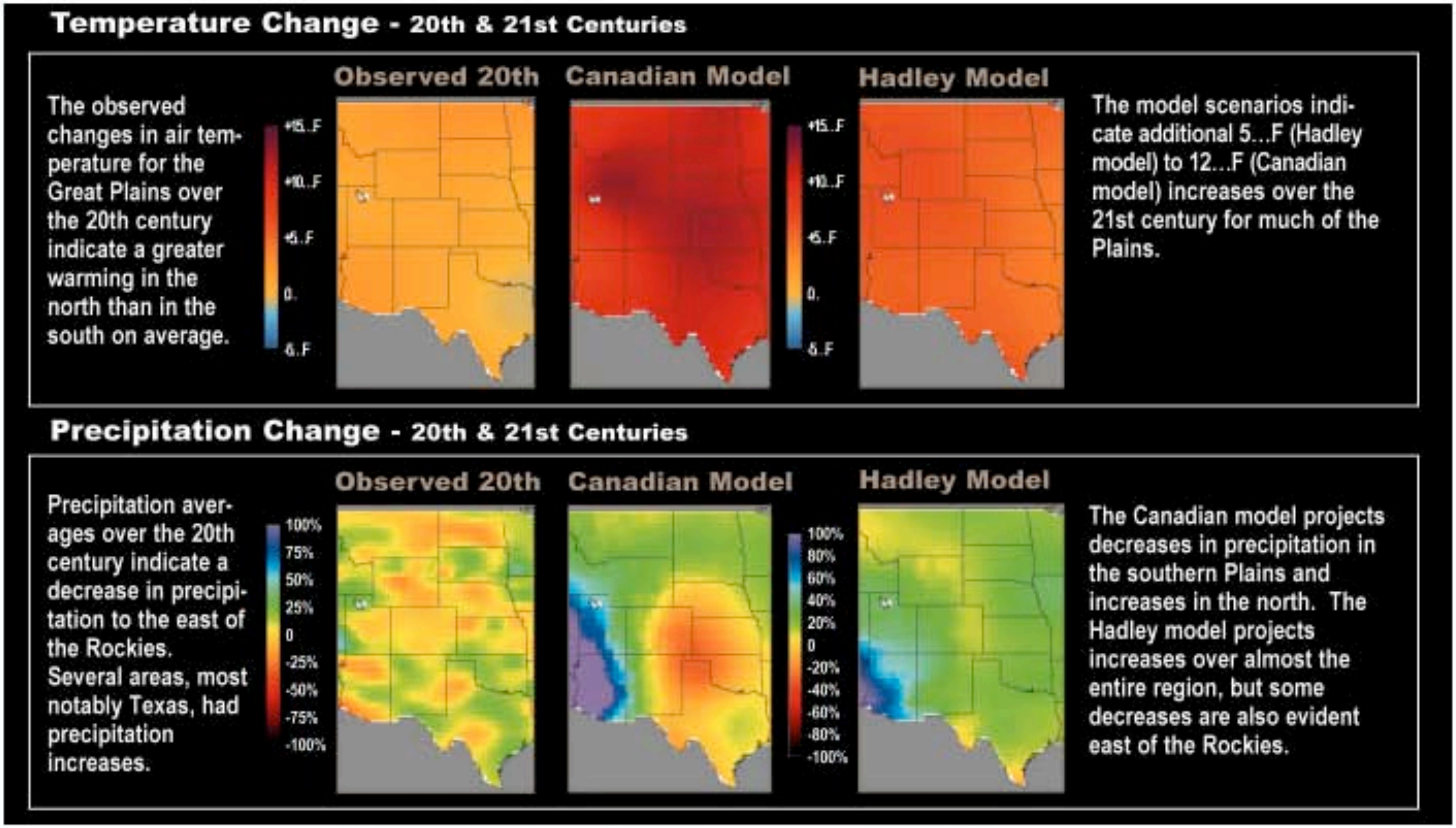
Figure SPM-10b: Variations of the Earth's surface temperature: years 1000 to 2100. From year 1000 to year 1860 variations in average surface temperature of the Northern Hemisphere are shown (corresponding data from the Southern Hemisphere not available) reconstructed from proxy data (tree rings, corals, ice cores,

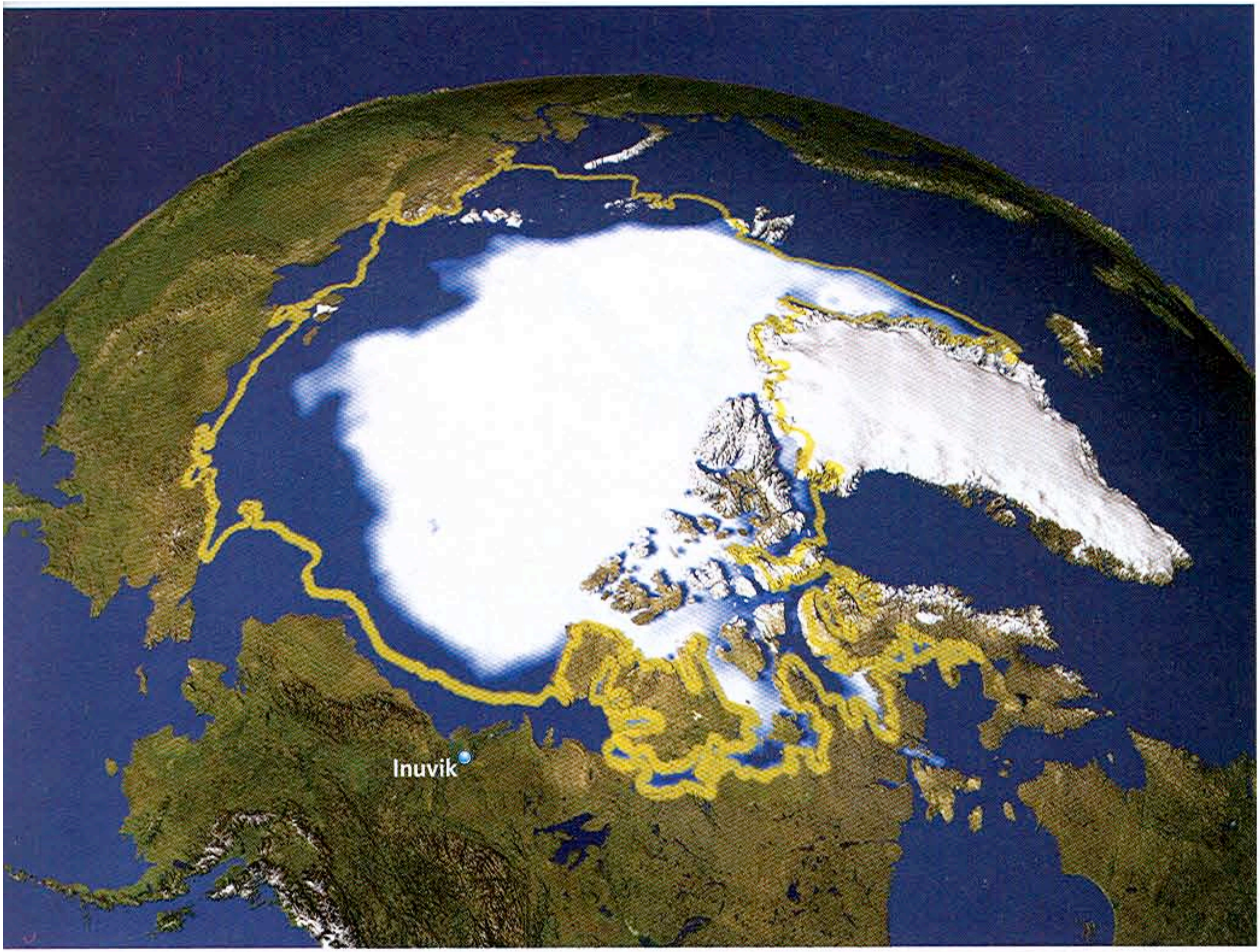
Q9 Figure 9-1b

Who will be affected?



All politics is local





By 2005, summer ice coverage was only about three-quarters of the Artic's long-term average (outline).

The new face of the Arctic

Every summer the Arctic Ocean loses more ice — and it could all be gone within decades. Quirin Schiermeier looks at how the vanishing summer ice affects those living in the north.

N. DUBREUIL / LOOKATSCIENCES

It was on Christmas day that Duane Smith first noticed that something weird was happening. When he and his family went to church, they did so in the rain.

That was in 1983. "We'd never ever seen anything like it," remembers Smith — then a little boy in Inuvik, a town of 3,500 people just north of the Arctic Circle, and now president for the Inuit Circumpolar Council (Canada), an indigenous people's organization. "Around Christmas it was supposed to be some 30 degrees below zero. None of our elders had any memory of such mild weather in winter."

It could just have been weird weather. In fact, it was a harbinger of things to come. Nowhere else on the planet is the current warming trend more pronounced than in the Arctic, and nowhere else does it seem to leave a deeper mark. The Arctic was a favoured site for early-warning systems during the cold war. Today, it is the early-warming system for climate change.

In recent years, researchers have started to pin down the details of what might happen to the Arctic as the planet warms. Although many of the specifics remain speculative (see 'How the Arctic might change', overleaf), everyone is certain that change is coming — and fast. "The Arctic is changing extremely abruptly on a geological time scale," says David Barber, a climatologist and sea-ice specialist at the University of Manitoba in Winnipeg, Canada. "There is no good historical analogue that could tell us what might happen."

Blame it on the sea ice. Unlike Antarctica — a continent surrounded by oceans — the Arctic is for the most part an ice-covered ocean, making it particularly vulnerable to climate change. Within several decades, the entire Arctic Ocean, including Hudson Bay and the countless channels between Canada's Arctic islands, could be free of ice during the summer months[1]. Palaeoclimatic evidence suggests that this has not been the case for at least the past 1 million years.

Less ice during the Arctic summer might not necessarily be all bad. New shipping channels and oil and gas regions could open up, for instance, and local hunters could get around by boat more easily (see 'Life in a warming world', overleaf). But the rate and magnitude of the changes are unprecedented, and the consequences are difficult to predict[2].

The amount of sea ice in the Arctic usually reaches its maximum — more than 14 million square kilometres in recent years — around the end of March. The slowly moving pack ice is separated from the immobile ice attached to the coastlines by the perennial 'circumpolar flaw lead' — a narrow corridor of open water that is rich in biological productivity and crucial for the heat exchange between the ocean and the atmosphere. This lead will be the focus of a multinational expedition led by Canada during this International Polar Year.

During the summer, ice melts and thins, reaching its minimum in September. The minimum extent of sea ice in the Arctic has decreased from a long-term average of more than 7 million square kilometres since 1979, to less than 6 million square kilometres in 2002 (ref. 3). Every year since, it has continued to drop or stay at near-record low levels. In

By 2005, summer ice coverage was only about three-quarters of the Artic's long-term average (outline).

NASA/GODDARD SPACE FLIGHT CENTER

September 2005, the Arctic was covered by just 5.32 million square kilometres of ice — the lowest yet.

As more and more ice disappears, a vicious cycle sets in. Ice reflects away a large fraction of incoming sunlight, whereas the darker open ocean absorbs more radiation. This 'albedo' effect is the main reason why the influence of warming is significantly more pronounced at high northern latitudes than in temperate or tropical regions. A reduced albedo in the Arctic affects the entire planet's energy balance, causing yet more energy to be absorbed in the darker waters.

A sizeable problem

The ice is not only shrinking in its area, but also in its depth, as recorded by submarines[4] and radar images from satellites. And it seems to be declining even in the winter[5]. If the ice continues to disappear at its current rate of nearly 9% per decade, the Arctic Ocean will be ice-free in September by 2060. But if, as some scientists suspect, the shrinking were to accelerate, this date will come forward by 20 years to 2040.

This dire scenario is just one of seven computer simulations published in December by a team led by Marika Holland of the National Center for Atmospheric Research in Boulder, Colorado[1]. That particular simulation suggests that the summer Arctic sea ice will decrease from 6 million square kilometres to 2 million square kilometres in the course of a decade. The ice that remains would be tucked along the coasts of Canada and Greenland, leaving the central Arctic basically free of ice by the end of the melting season, although the region would refreeze during the winter.

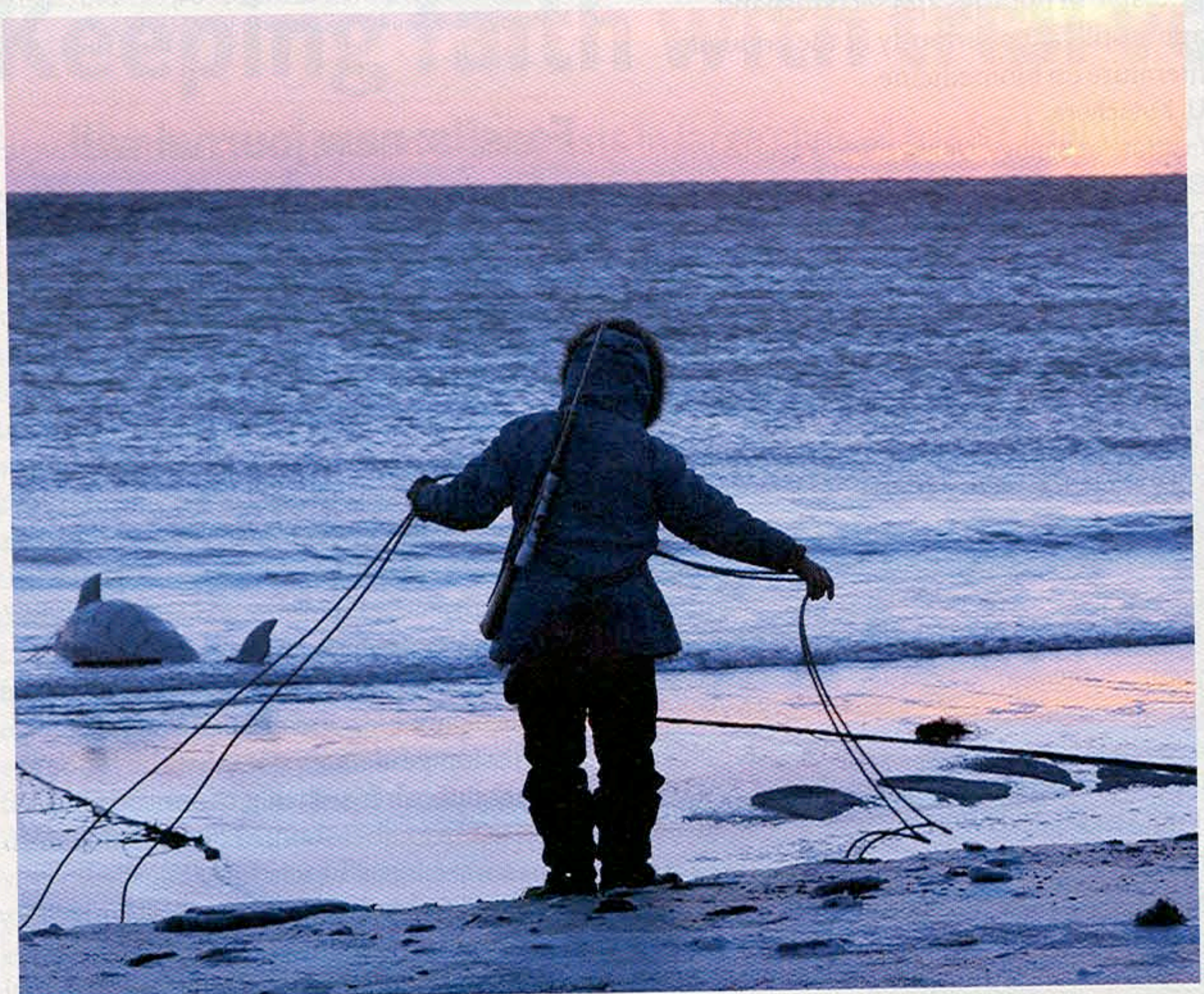
The receding ice cover could also affect large-scale patterns of ocean circulation. Ice, for instance, seems to be moving at an increasing rate out of the Arctic Ocean through the Fram Strait to the east of Greenland and through the Canadian Arctic archipelago to Greenland's west. On average, the amount of ice moving out is around 10%, but during the winter of 2005 to 2006, a strong counterclockwise rotation pattern in the Arctic Ocean pushed about 40% of the pack ice into the warmer Atlantic waters. The events over the past two years, says Barber, are the first sign that the rates of ice export can change dramatically. If more storms start to enter the Arctic, as expected with the rising temperatures around the world, the pack ice will be broken up and potentially carried away more often.

Flow-on effects

Reduced sea-ice cover might also increase the influx of warm Pacific waters through the Bering Strait between Russia and Alaska.

HOW THE ARCTIC MIGHT CHANGE

5 years from now	10 years from now	20 years from now
The polar bear is listed as a threatened species.	The amount of multi-year pack ice decreases catastrophically.	The Arctic Ocean remains ice-free in September.
The UN Convention on the Law of the Sea adopts a protocol for the new polar ocean.	A new UN environmental regime for the Arctic comes into effect.	All known Russian offshore hydrocarbon deposits (oil, gas and gas condensate) are exploited commercially.
Development of hydrocarbon deposits starts in the eastern Kara Sea off Siberia.	Russia auctions offshore exploration licences for up to 20 billion tonnes of natural gas and petroleum.	Offshore oil and gas resources, unknown today, are being extensively developed.
The Galileo satellite system is used to combat illegal fisheries in Arctic waters.	Vector-borne diseases become more widespread among the Inuit as mosquitoes migrate to the Arctic.	Oil tankers and container ships sail the Northeast passage.
Norwegian oil companies commit themselves to being carbon neutral.	The Arctic cod is displaced by temperate fishes.	The United States and Russia undertake military manoeuvres in the polar sea.
All-season Canadian icebreakers patrol the eastern and western Arctic.	Canada installs high-frequency radar at the entrance to the Northwest passage to bolster its sovereignty.	



Subsistence farmers in Alaska adapt their practices to cope with the ever-changing climate.

Life in a warming world

Some 100,000 Inuit live in regions north of the Arctic Circle on land that their ancestors have hunted and fished for generations. They know, both from their own observations and from what scientists tell them, that their environment is a hot spot for global warming.

"We don't get much cold any more, spring is coming earlier, and ice conditions are getting unpredictable to the point of people falling through the ice and drowning," says Duane Smith, an Inuit leader from Inuvik, Canada. Yet many reject the notion that climate change is all bad.

"I feel that governments are panicking a bit," says Frank Pokiak, a native of Tuktoyaktuk, Alaska, who chairs the Inuvialuit Game Council. "People need to understand that we've been living with changes all our lives. Climate change is just another thing we need to adapt to. We may need to harvest other species, perhaps grizzly bear, perhaps caribou, but we won't quit existing."

A warming Arctic has some advantages. The early breaking up of ice, for example, gives hunters a longer time to harvest beluga whales. Less ice would also facilitate hunting and travelling by boat.

On the other hand, regional hubs such as Inuvik depend on roads across the ice for food and other supplies. Hunting, transport and road safety will all be affected if the tundra turns into bogs earlier and freezes later. Increased dependence on helicopters has already notably increased the Inuits' cost of living, says Smith.

Many Inuit are working with scientists to help investigate the changes in the Arctic. Hunters and trappers, for instance, are being taught how to handle meteorological instruments. The Inuit have plenty to teach the scientists as well; at one point, researchers were about to conclude that Arctic cod (*Arctogadus glacialis*) had all gone because stocks were nowhere to be found, but Inuit fishermen showed them where on Canada's Mackenzie shelf the fish had hidden.

But some things are more difficult for indigenous people to understand. Explaining to Inuit that they and their food could be contaminated with chemicals produced far in the south is challenging, says Louis Fortier from University Laval in Quebec. Their native language knows nothing of 'molecules' or 'chemistry'.

So, working with Inuit elders, linguists from ArcticNet, an interdisciplinary network of Canadian researchers, have produced a bilingual glossary for terms that relate to climate change. In it, for instance, the word for 'carbon' — a key term in the future of the Inuit — is illustrated as 'the soot of fire'. **Q.S.**

Should we wait and see?

Since we aren't sure whether the temperature rise will be a problem, should we wait until we know before changing our production of greenhouse gasses?

Should we wait and see?

Since we aren't sure whether the temperature rise will be a problem, should we wait until we know before changing our production of greenhouse gasses?

The problem is that the temperature will continue to rise long after we stop producing CO_2.

The longer we wait to decide the greater the likely effects.

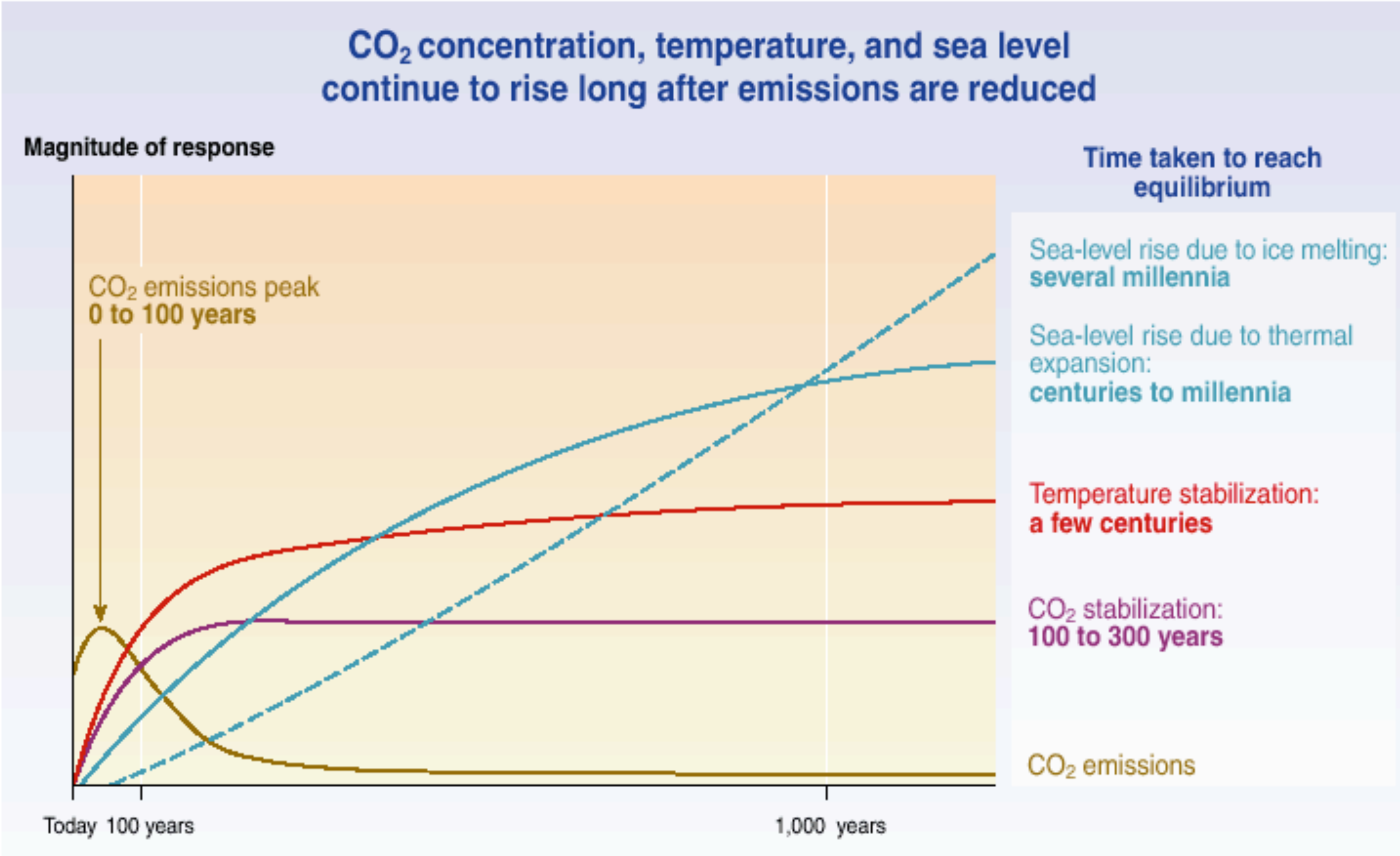


Figure SPM-5: After CO_2 emissions are reduced and atmospheric concentrations stabilize, surface air temperature continues to rise slowly for a century or more. Thermal expansion of the ocean continues long after CO_2 emissions have been reduced, and melting of ice sheets continues to contribute to sea-level rise for many centuries. This figure is a generic illustration for stabilization at any level between 450 and 1,000 ppm, and therefore has no units on the response axis. Responses to stabilization trajectories in this range show broadly similar time courses, but the impacts become progressively larger at higher concentrations of CO_2.

Q5 Figure 5-2

Is there a technological fix?

I hope so, because even if we cut our CO_2 production by a factor of 3, the temperature will keep rising, just more slowly.

Hydrogen fuel (and maybe ethanol) won't help. It takes as much energy to make as it provides.

Coal is even worse than oil.

Nuclear power is expensive and dangerous, and we don't know how to get rid of the wastes.

It will be very difficult to get enough solar power and wind power to provide our current usage of electricity.

One promising idea is to pump CO_2 from power plants into the ground. But we don't know if it will stay there and what effects it might have. I wish we could make it into limestone, but I don't think we can.

Will conservation help?

To stop the temperature rise we must stop all use of fossil fuels.

But we don’t yet have the technology to replace all fossil fuels with other energy sources.

I hope we will by the end of this century.

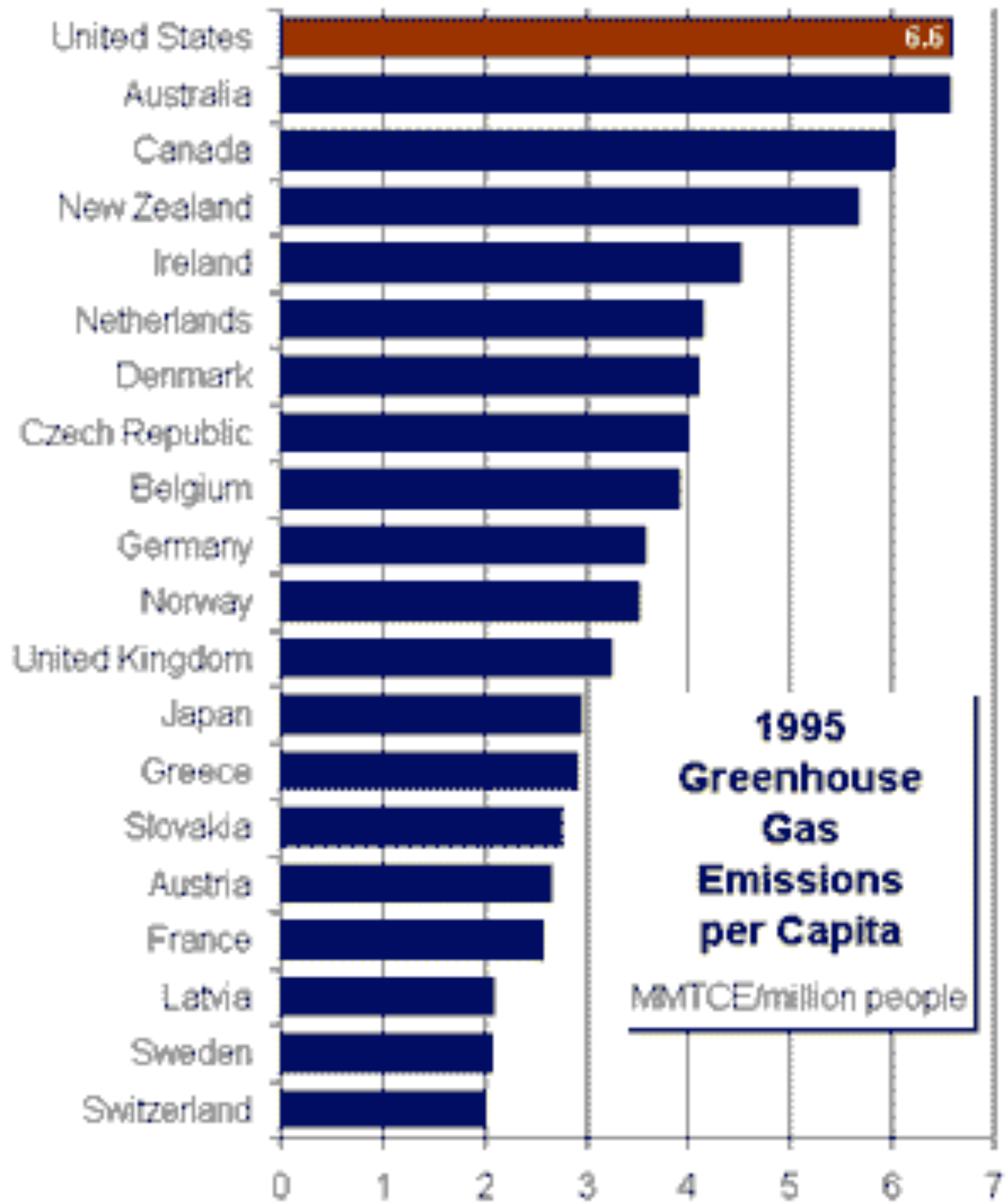
Since the greenhouse gasses we put into the atmosphere will stay there for over 1000 years, the amount of fossil fuel we use until technology improves will affect the temperature for a long time.

If we can limit the amount of fossil fuel we use in this century we will minimize the effect we have on future generations.

Can we cut our use of fossil fuels without destroying our economy?

Emissions vary based on the country in which you live (*see International Emissions*). The U.S. presently emits more greenhouse gases per person than any other country.

Emissions also vary based on the state you live in. Several factors can affect the emissions per person in a state, for example, the types of fuel used to generate electricity, population and vehicle miles traveled (people tend to drive longer distances in sparsely populated areas), and whether fossil fuels are extracted or processed within the state. You will find additional information concerning emissions in your state in the State Emissions section.



Could you lower your production of CO_2?

To produce as little CO_2 as each person in Switzerland does, we would each have to produce less than 1/3 of what we do now.

Would you be willing to drive 1/3 as much as you do now?

Or could you buy a car that uses only 1/3 as much gas?

Could you live without air conditioning in the summer?

Could you survive in a house at 60^oF in the winter?

Would you be willing to eat only canned and dried food in the winter instead of eating fruit flown here from Chile?

Does UT need to light up the tower and the intramural field every night?

At least you can switch to compact fluorescent lights!

Should I fly on an airborne observatory?

The Stratospheric Observatory for Infrared Astronomy

Program making progress!

- Aircraft structural modifications complete
- Telescope installed, several instruments tested on ground observatories
- Completed first flight and ferry flight to NASA Dryden
- Full envelope flight testing (closed door) has started.
- Several subsystems will be installed spring/summer 08 (Door motor drive, coated primary mirror)
- First science in ’09

SOFIA will be one of the primary facilities for far-IR and sub-millimeter astronomy for many years

Will gasohol help?

Studies say biofuels increase greenhouse gases 'substantially'

By Elisabeth Rosenthal
THE NEW YORK TIMES

Almost all biofuels used today cause more greenhouse gas emissions than conventional fuels if the full emissions costs of producing "green" fuels are taken into account, two studies published Thursday say.

The benefits of biofuels have come under increasing attack in recent months, as scientists took a closer look at the global environmental cost of their production.

The latest studies, published in the journal Science, are likely to add to the controversy. The studies for the first time take a detailed, comprehensive look at the emissions effects of the huge amount of natural land that is being converted to cropland globally to support biofuels development.

The destruction of natural ecosystems — whether rain forest in the tropics or grasslands in South America — not only releases greenhouse gases into the atmosphere when they are burned and plowed, but also deprives the planet of natural sponges to absorb carbon emissions.

Cropland also absorbs far less carbon than the rain forests or even scrubland that it replaces.

Together the two studies offer sweeping conclusions: It does not matter if it is rain forest or scrubland that is cleared, the greenhouse gas contribution is significant. More important, they discovered that, globally, the production of almost all biofuels resulted, directly or indirectly, intentionally or not, in new lands being cleared for food or fuel.

"When you take this into account, most of the biofuel that people are using or planning to use would probably increase greenhouse gases substantially," said Timothy Searchinger, lead author of one of the studies and a researcher in environment and economics at Princeton University.

Industry groups, like the

Will gasohol help?

Studies say biofuels increase greenhouse gases 'substantially'

does not matter if it is rain forest or scrubland that is cleared, the greenhouse gas contribution is significant. More important, they discovered that, globally, the production of almost all biofuels resulted, directly or indirectly, intentionally or not, in new lands being cleared for food or fuel.

"When you take this into account, most of the biofuel that people are using or planning to use would probably increase greenhouse gases substantially," said Timothy Searchinger, lead author of one of the studies and a researcher in environment and economics at Princeton University.

Industry groups, like the Renewable Fuels Association, attacked the new studies as "simplistic."

"Biofuels like ethanol are the only tool readily available that can begin to address the challenges of energy security and environmental protection," Bob Dineen, the group's director, said in a statement.

Plant-based fuels were originally billed as better than fossil fuels because the carbon released when they were burned was balanced by the carbon absorbed when the plants grew. But that equation proved overly simplistic because the process of turning plants into fuels causes its own emissions — for refining and transport, one of the studies says.

The clearing of grassland releases 93 times the amount of greenhouse gas that would be saved by the fuel made annually on that land, said Joseph Fargione, lead author of the second paper, and a scientist at the Nature Conservancy.

Searchinger said the only possible exception he could see for now was sugar cane grown in Brazil, which take relatively little energy to grow and is readily refined into fuel. He added that governments should focus their attention on developing biofuels that did not require cropping, such as those from agricultural waste products.