AST 301
Introduction to Astronomy

John Lacy
RLM 16.332
471-1469
lacy@astro.as.utexas.edu

Myoungwon Jeon
RLM 16.216
471-0445
myjeon@astro.as.utexas.edu

Bohua Li
RLM 16.212
471-8443
bohuali@astro.as.utexas.edu

web site: www.as.utexas.edu
Go to Department of Astronomy courses,
AST 301 (Lacy), course website

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?

Chapters on the test

The assigned reading for the test is Ch. 5,7,8,10 (and skim 12).

We haven't covered everything in those chapters.

Concentrate on the topics on the review sheet.

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.

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

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, $P_{out} = P_{in}$

Do the math

If $P_{out} = P_{in}$:

$$\sigma T^4 A_{surface} = F_{sunlight} A_{face}$$

$$T^4 = \frac{F_{sunlight}}{\sigma} \frac{A_{face}}{A_{surface}}$$

$$T = \sqrt[4]{\frac{F_{sunlight}}{\sigma} \frac{A_{face}}{A_{surface}}}$$

For a sphere, $A_{face} / A_{surface} = ¼$.

The answer comes out to 279 K, or 6^o C, or 42^o F.

Different temperatures

If the flux of sunlight is 1/16 as large 4 AU from the Sun, the temperature is multiplied by $\sqrt[4]{1/16} = 2$

We can calculate the temperature at the locations of the different planets:

Planet	distance	predicted T	actual surface T
Mercury	0.39 AU	450 K	100-700 K
Venus	0.72 AU	330 K	700 K
Earth	1.00 AU	280 K	290 K
Mars	1.52 AU	227 K	220 K
Jupiter	5.2 AU	123 K	130 K

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 effect of the atmosphere

We assumed that all of the infrared radiation emitted by the surface of the planet escaped to space, and so carried heat away from the planet.

This is not correct because the Earth's atmosphere is not transparent at all wavelengths.

Molecules in the Earth's atmosphere absorb many wavelengths of infrared radiation.

Molecules absorb infrared radiation when they rotate and vibrate.

The greenhouse effect

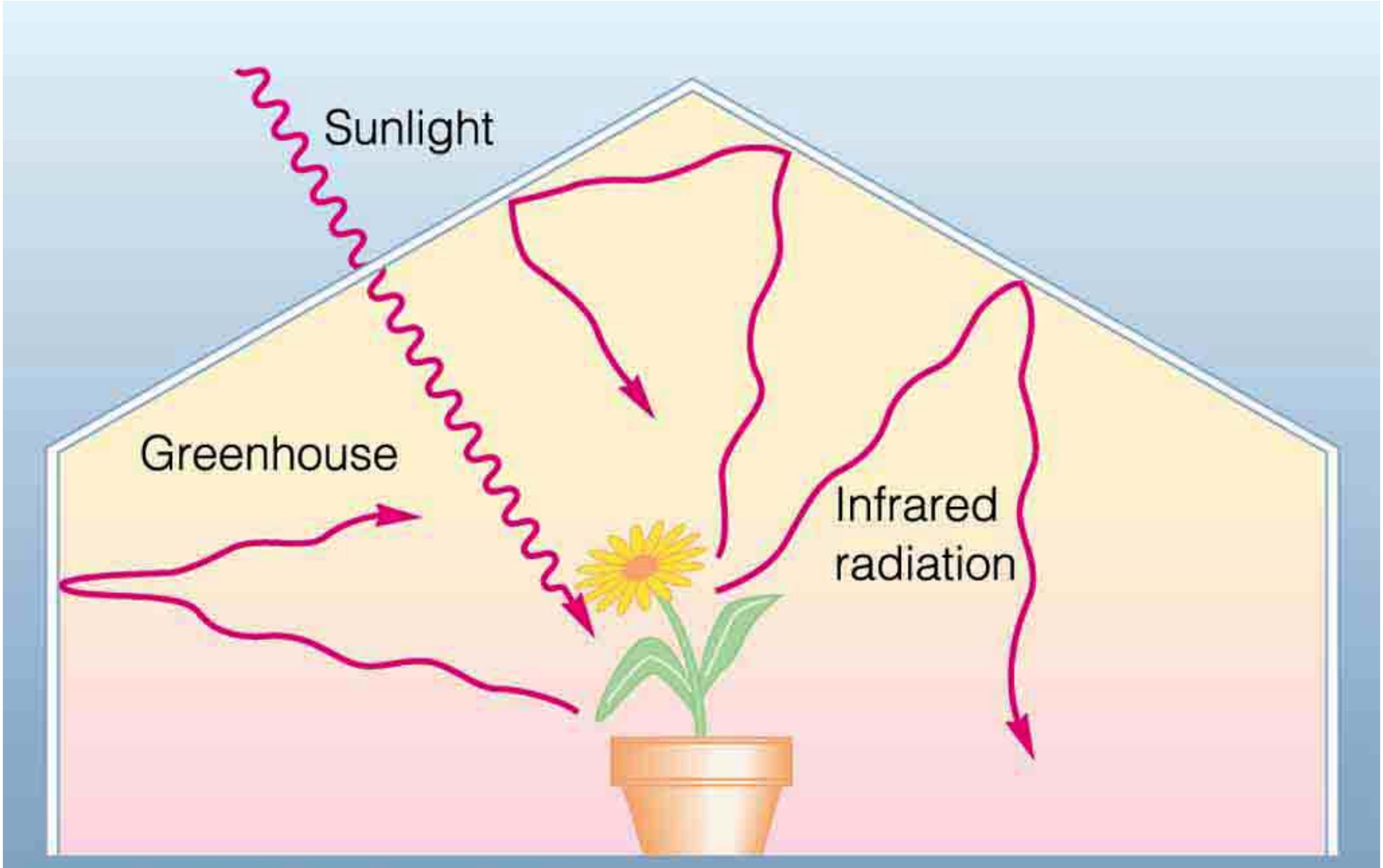
By blocking some of the outgoing infrared radiation, molecules in the Earth’s atmosphere force the temperature of the surface of the Earth to rise until the outgoing flow of energy matches the incoming flow.

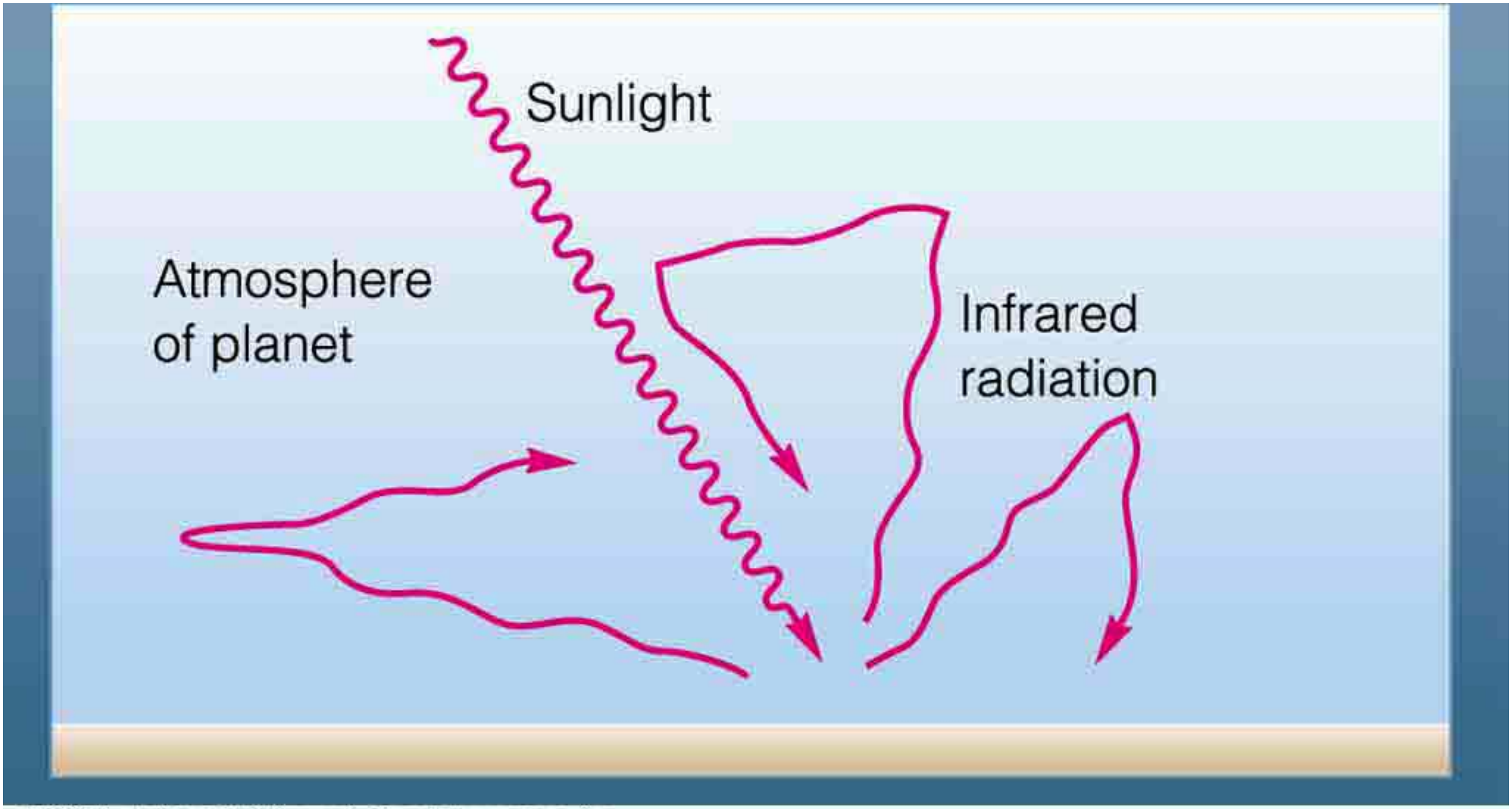
This is the greenhouse effect.

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.


Sunlight
Greenhouse
Infrared
radiation


Sunlight
Atmosphere
of planet
Infrared
radiation

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.

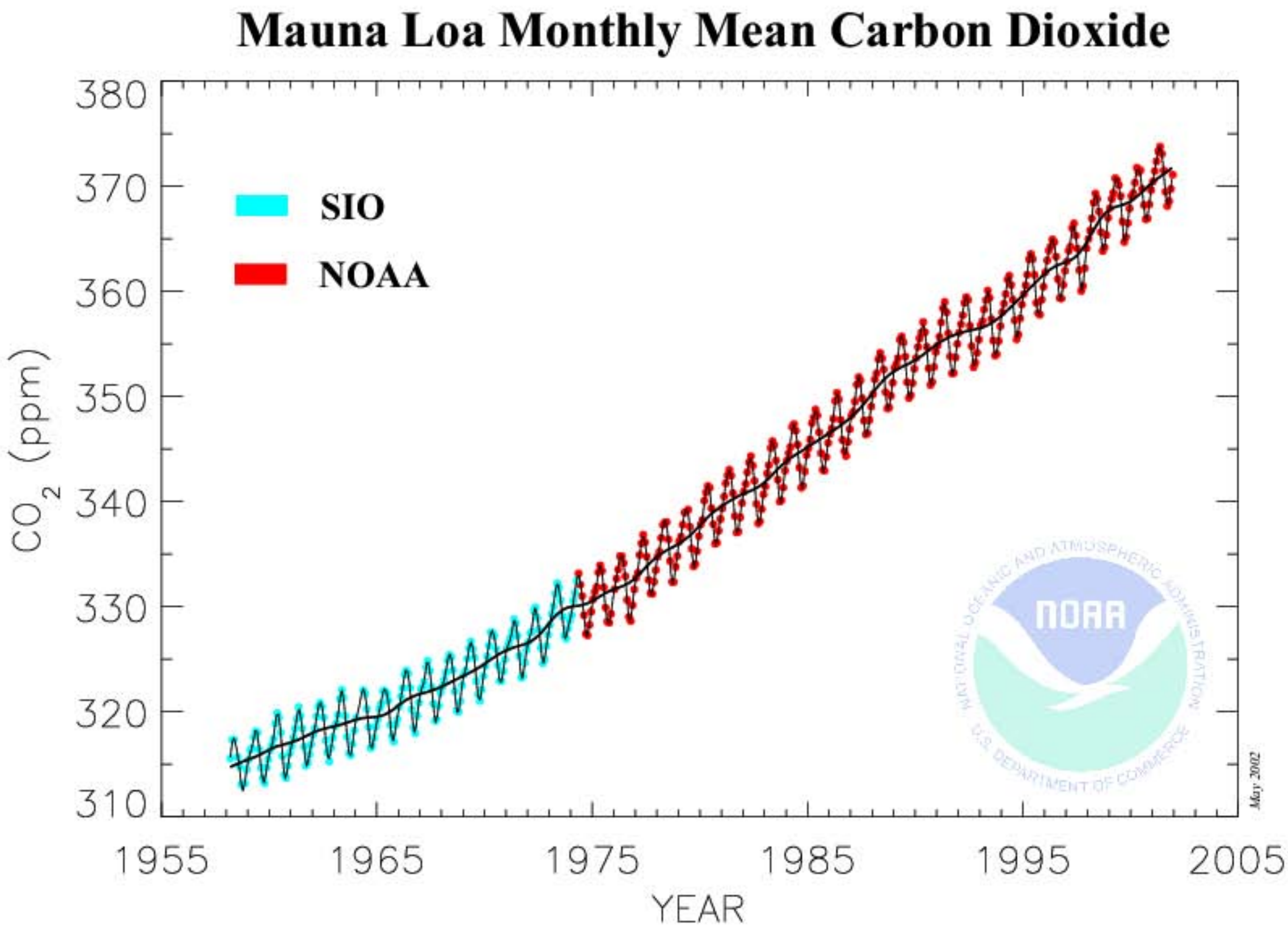
Although the greenhouse effect is desirable, and maybe necessary for life to exist on Earth, most life forms are slow to adapt to changes in the temperature.

A rapid change in the greenhouse effect can be harmful.

What are we doing that changes the greenhouse effect?

Anthropogenic increases in greenhouse gasses

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



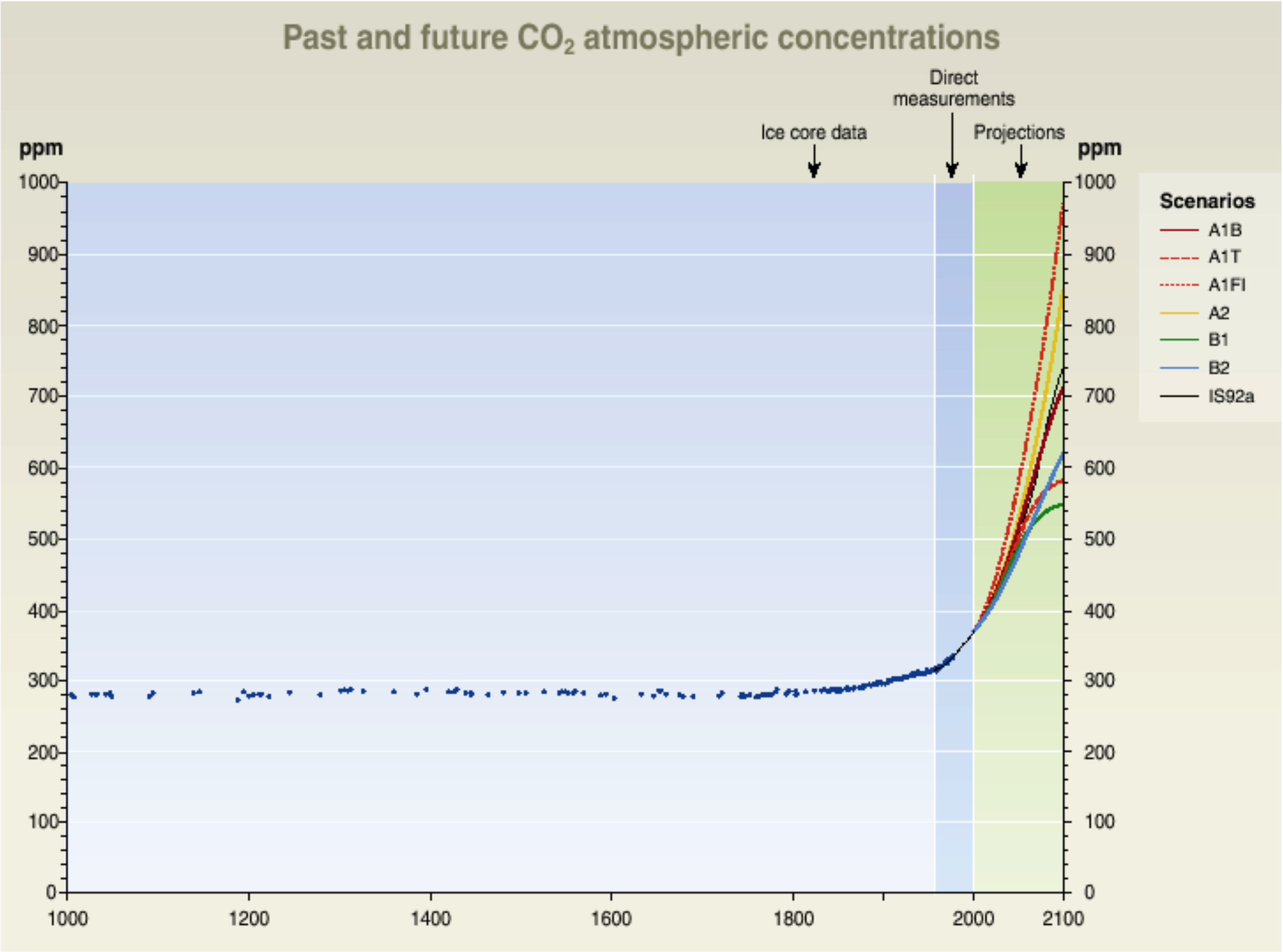


Figure SPM-10a: Atmospheric CO_2 concentration from year 1000 to year 2000 from ice core data and from direct atmospheric measurements over the past few decades. Projections of CO_2 concentrations for the period 2000 to 2100 are based on the six illustrative SRES scenarios and IS92a (for comparison with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

Q9 Figure 9-1a

Changes in Greenhouse Gases from Ice Core and Modern Data

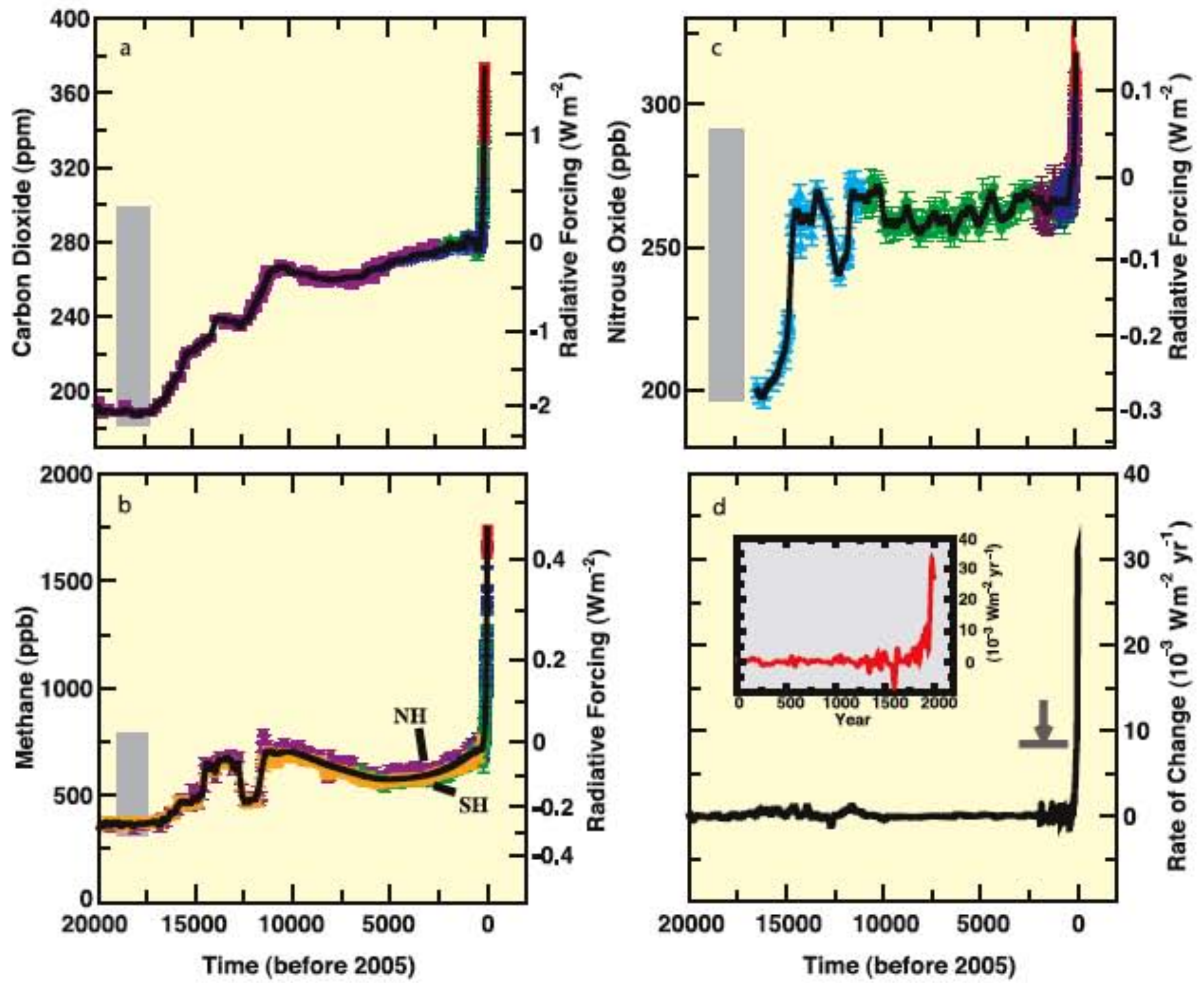


Figure TS.2. *The concentrations and radiative forcing by (a) carbon dioxide (CO_2), (b) methane (CH_4), (c) nitrous oxide (N_2O) and (d) the rate of change in their combined radiative forcing over the last 20,000 years reconstructed from antarctic and Greenland ice and firn data (symbols) and direct atmospheric measurements (panels a,b,c, red lines). The grey bars show the reconstructed ranges of natural variability for the past 650,000 years. The rate of change in radiative forcing (panel d, black line) has been computed from spline fits to the concentration data. The width of the age spread in the ice data varies from about 20 years for sites with a high accumulation of snow such as Law Dome, Antarctica, to about 200 years for low-accumulation sites such as Dome C, Antarctica. The arrow shows the peak in the rate of change in radiative forcing that would result if the anthropogenic signals of CO_2, CH_4, and N_2O had been smoothed corresponding to conditions at the low-accumulation Dome C site. The negative rate of change in forcing around 1600 shown in the higher-resolution inset in panel d results from a CO_2 decrease of about 10 ppm in the Law Dome record. {Figure 6.4}*

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.

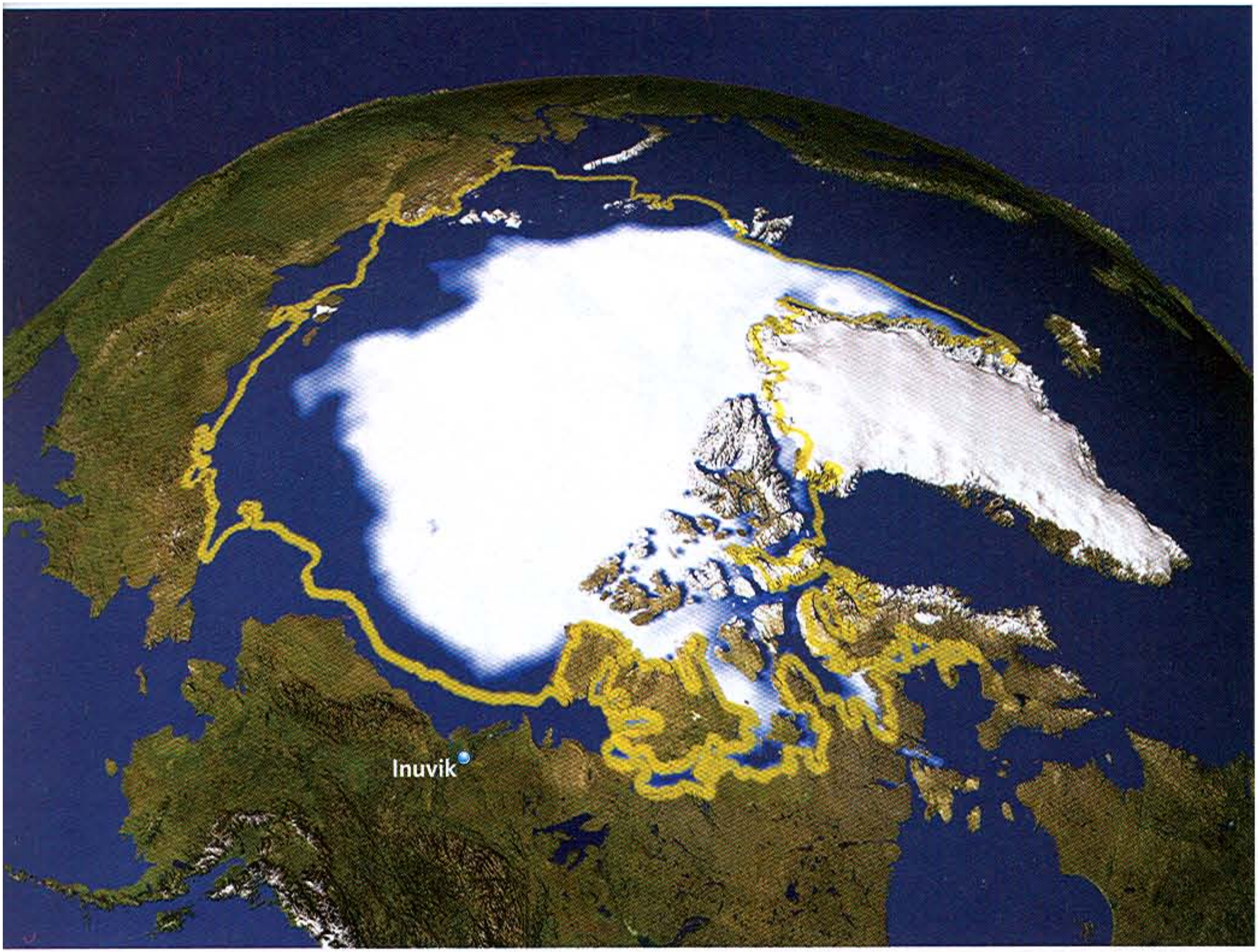
An increase in the temperature of the oceans will cause increased evaporation, increasing the amount of water vapor in the atmosphere.

This will magnify the effect.

But it will also get cloudier.

This will decrease the heating.

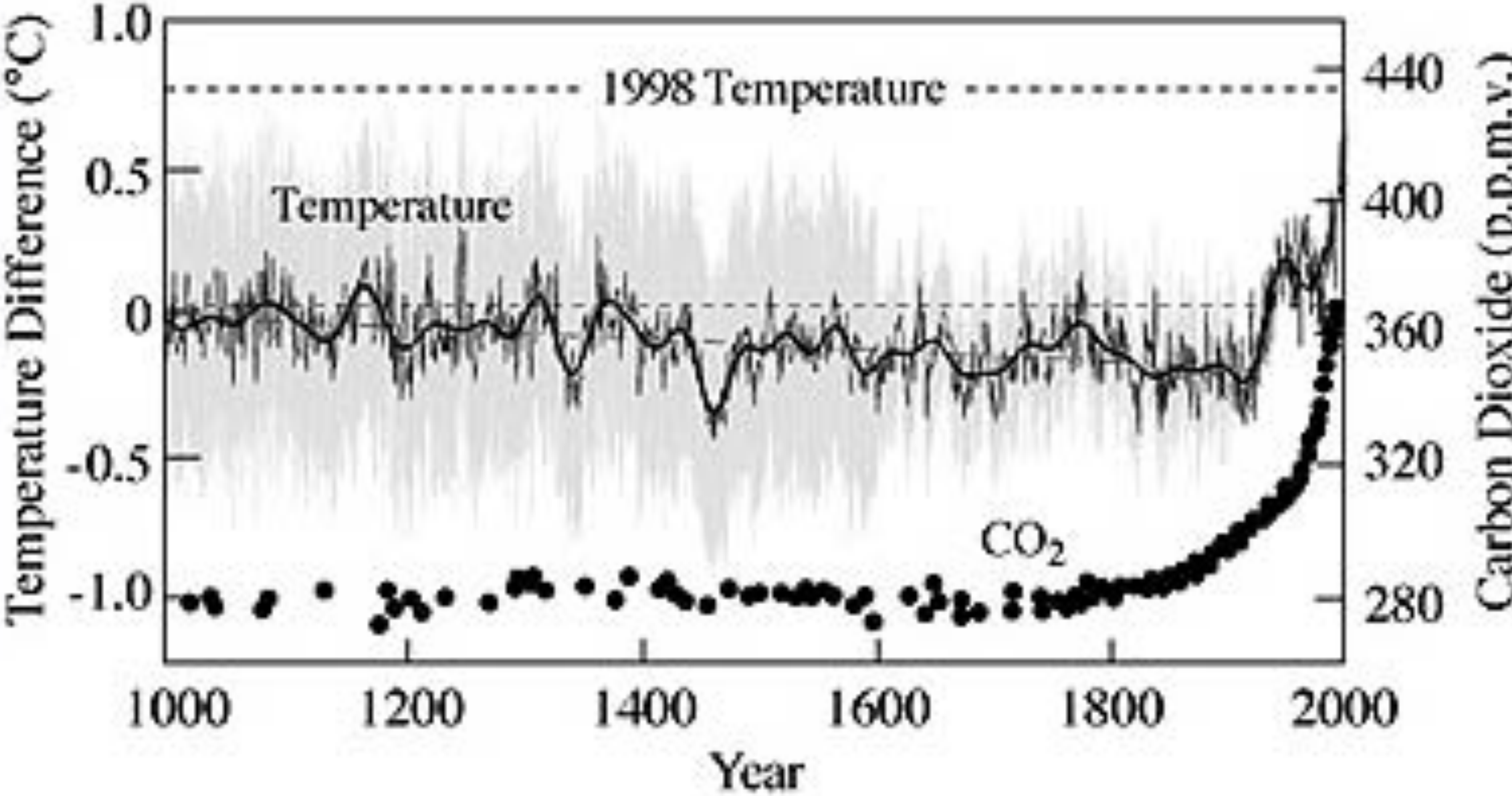
To include all of the relevant effects we run General Circulation models (GCMs).



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

Temperature is rising with the greenhouse gasses

Does this mean the CO_2 rise caused the temperature rise?

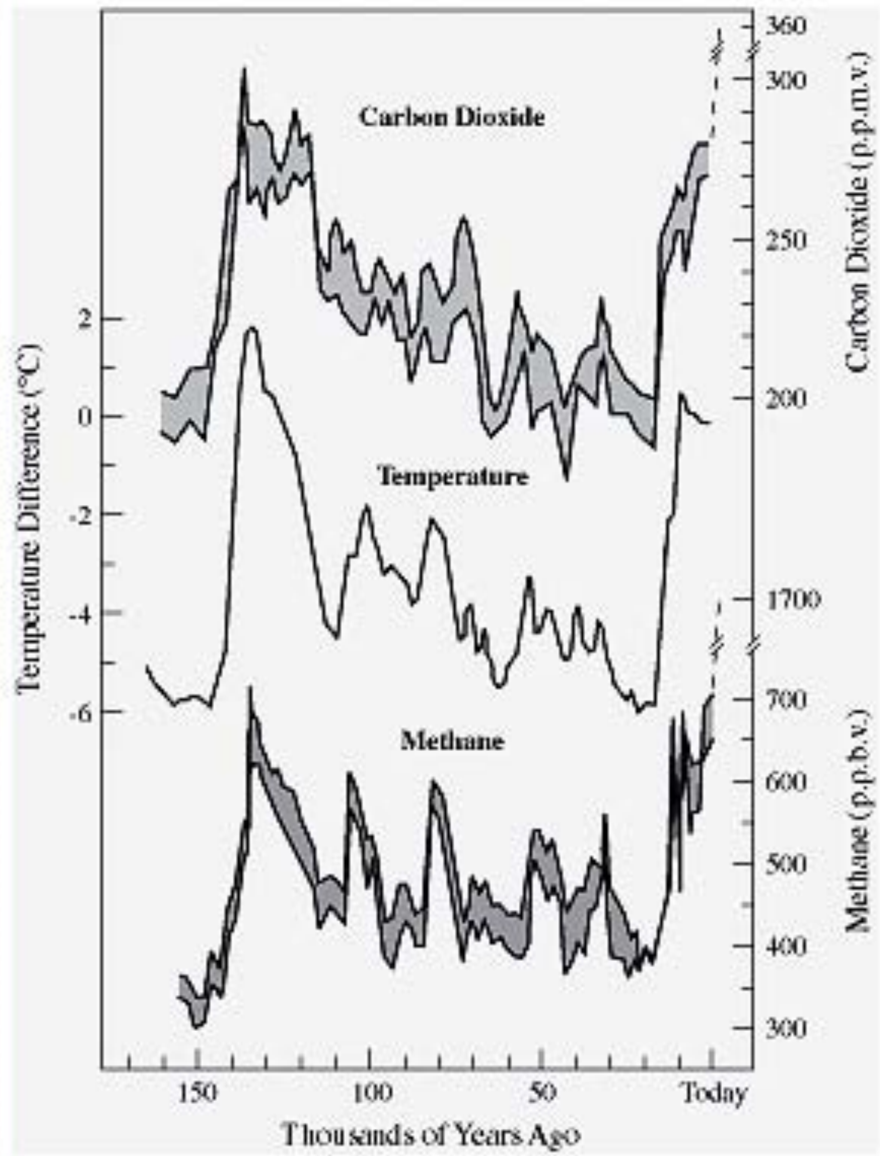


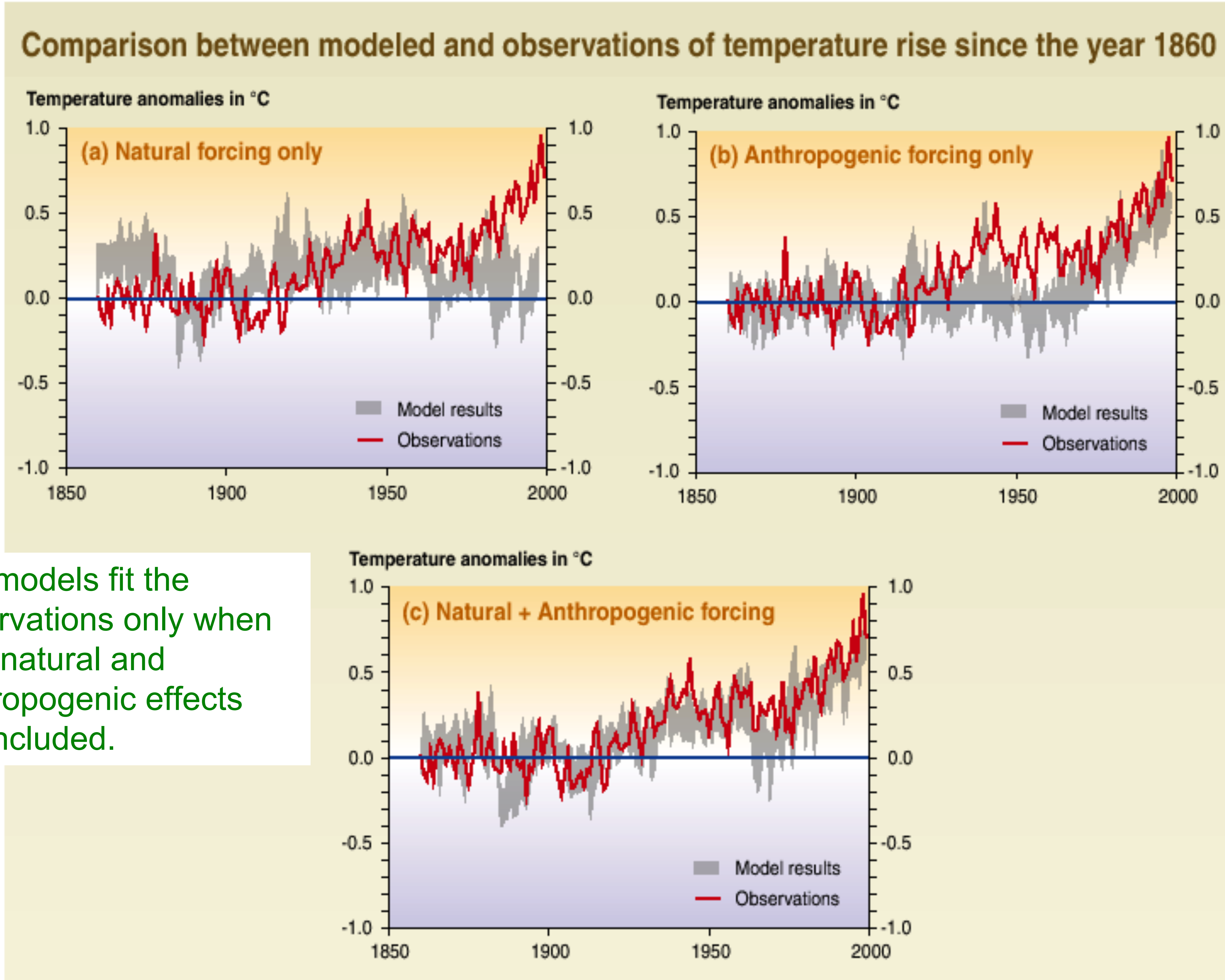
Can we avoid running (or trusting) GCMs?

From ice cores and various proxy records of temperature we know that CO_2 and T have varied together.

But does this prove that the CO_2 variations caused the T variations and that anthropogenic CO_2 variations will cause the same T variations?

Are the CH_4 variations cause or effect?





The models fit the observations only when both natural and anthropogenic effects are included.

Predictions of future temperature rise

What do the GCMs say about future temperatures, and how large are the uncertainties?

If the CO_2 concentration rises to twice the pre-industrial level of 280 ppm, the equilibrium temperature is predicted to rise by 3K +/-1K (1σ range).

The biggest uncertainty in what the temperature will be 50 or 100 years from now is in how much the CO_2 will rise, not in the models.

The CO_2 concentration is now at 380 ppm, and it is rising by 2 ppm/yr. If the rise continues linearly (not exponentially), CO_2 will reach 560 ppm by 2100.

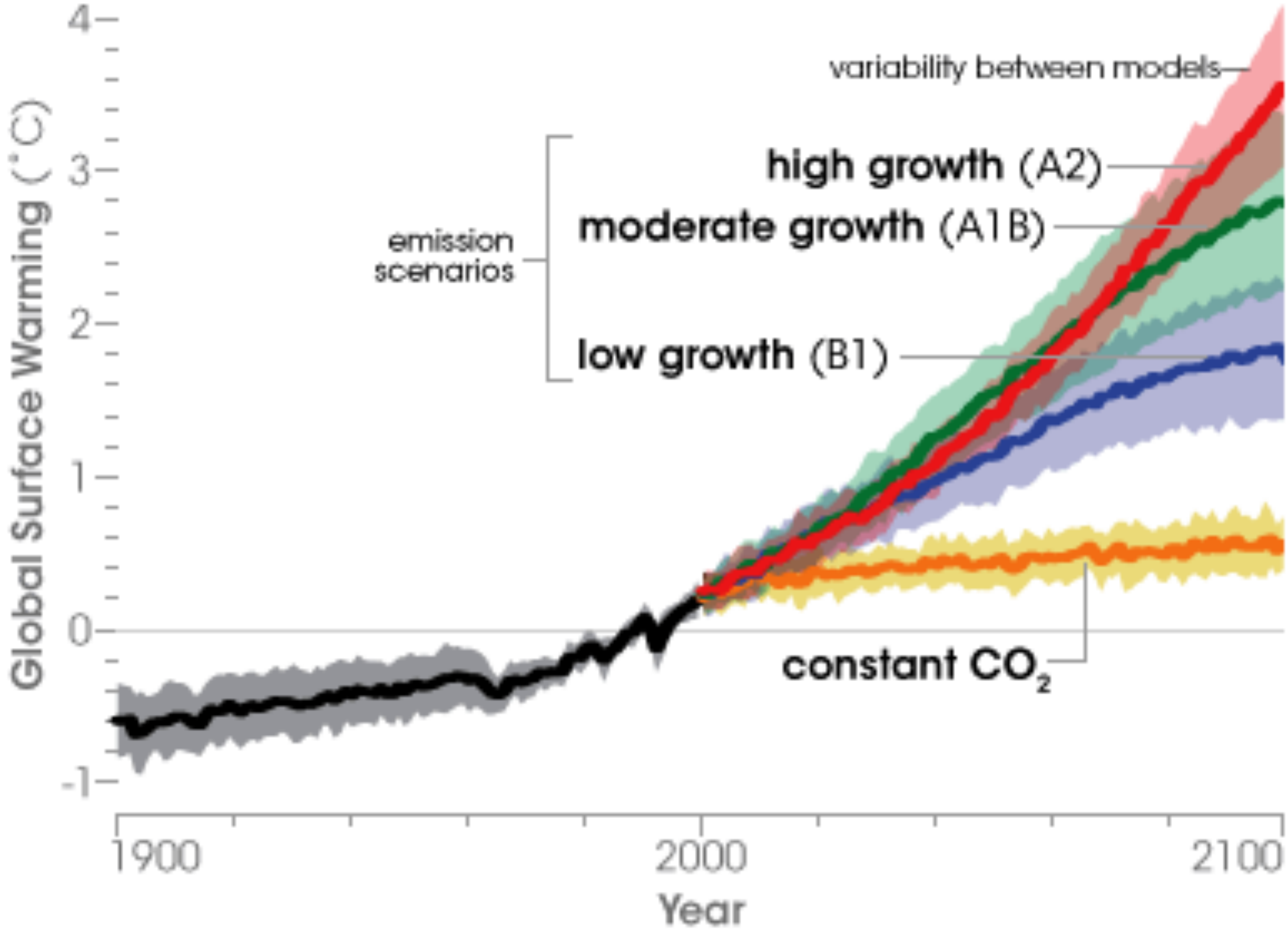


Figure 1: *Temperature projections to the year 2100, based on a range of emission scenarios and global climate models. Scenarios that assume the highest growth in greenhouse gas emissions provide the estimates in the top end of the temperature range. The orange line ("constant CO2") projects global temperatures with greenhouse gas concentrations stabilized at year 2000 levels. Source: NASA Earth Observatory, based on IPCC Fourth Assessment Report (2007)*

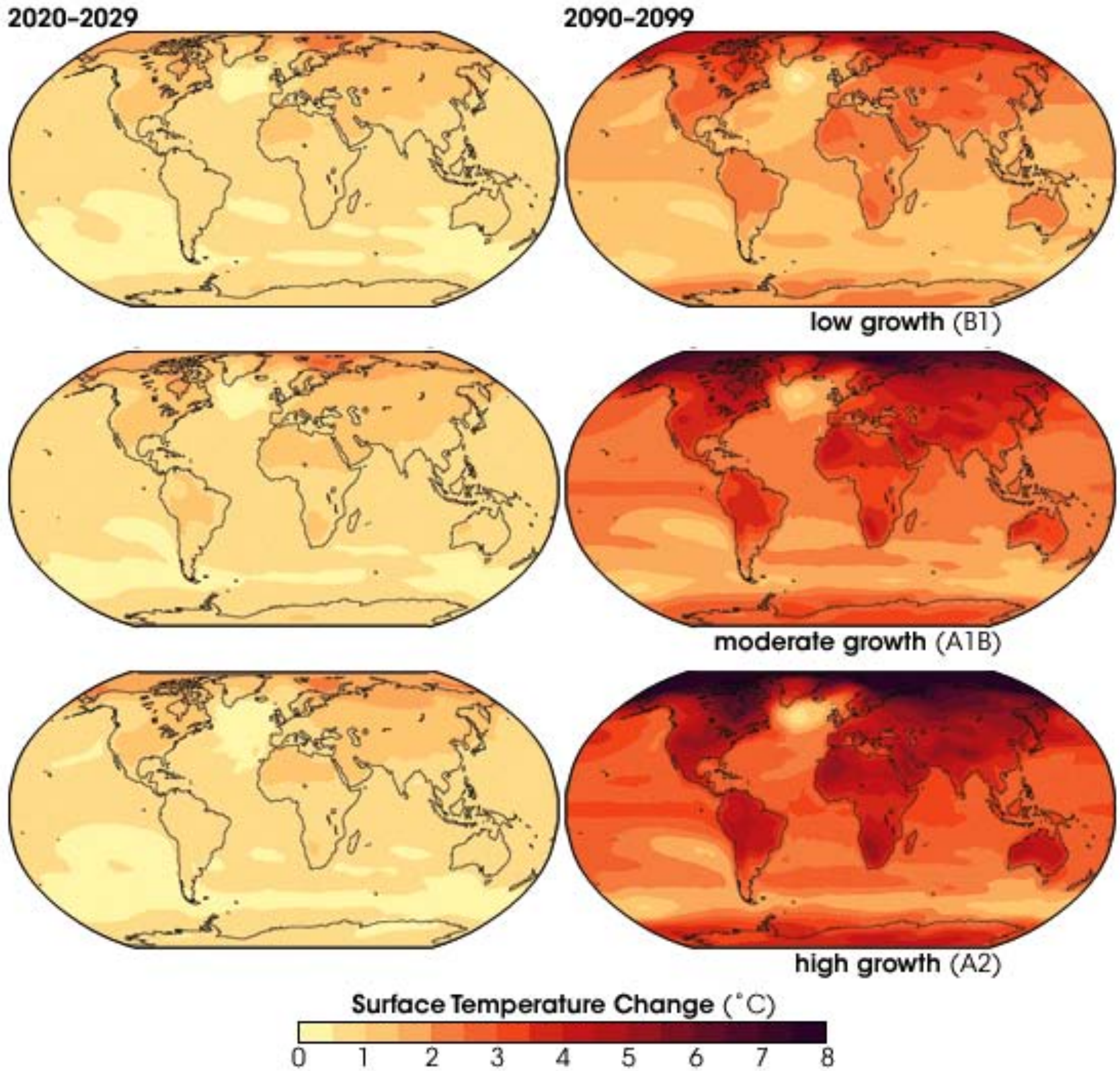


Figure 2: *Projected future regional patterns of warming based on three emissions scenarios (low, medium, and high growth). Source: NASA Earth Observatory, based on IPCC Fourth Assessment Report (2007)*

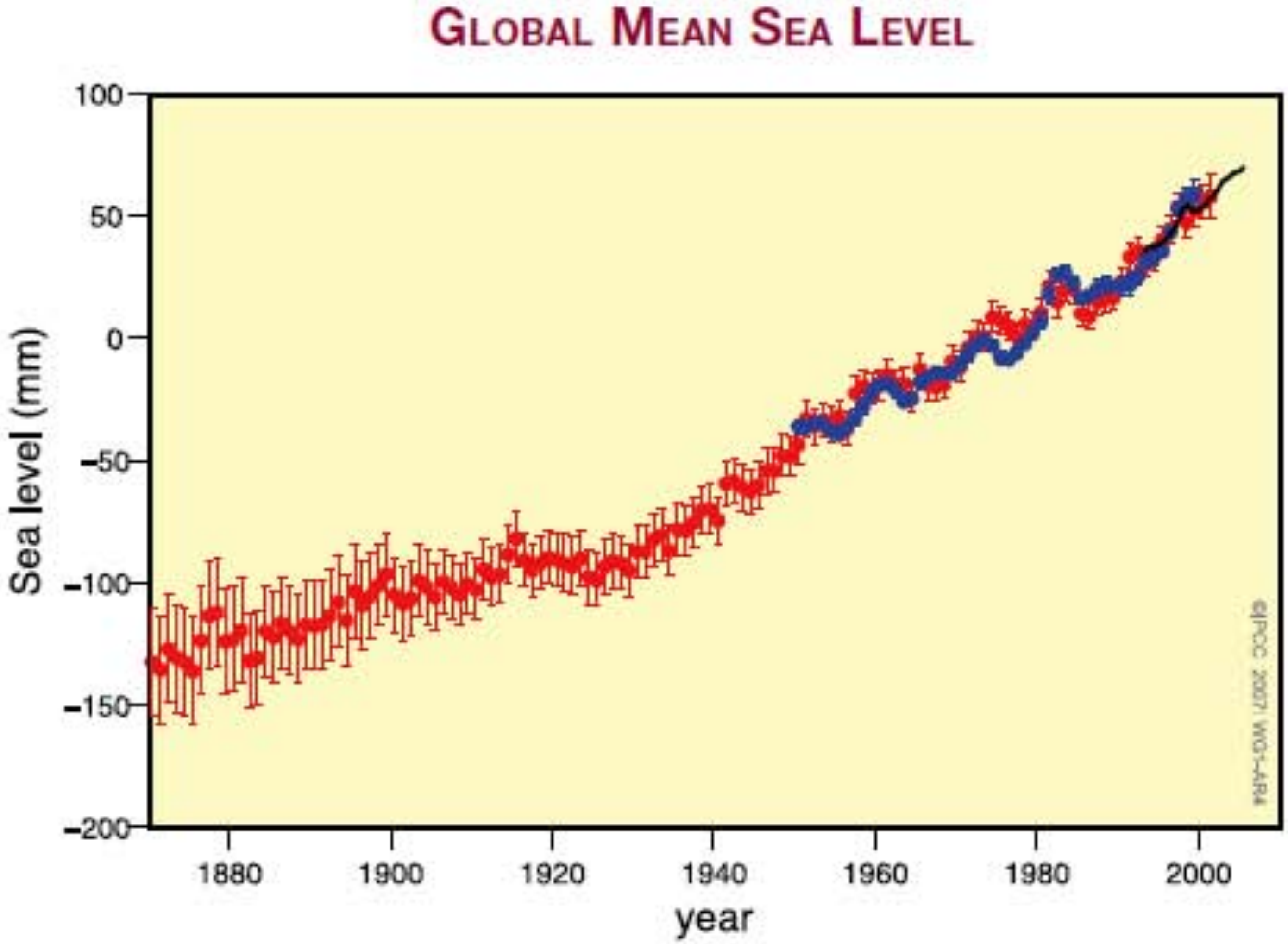


Figure TS.18. *Annual averages of the global mean sea level based on reconstructed sea level fields since 1870 (red), tide gauge measurements since 1950 (blue) and satellite altimetry since 1992 (black). Units are in mm relative to the average for 1961 to 1990. Error bars are 90% confidence intervals. {Figure 5.13}*

Is there a technological fix?

There had better be, because even if we cut our CO_2 production, the temperature will keep rising, just more slowly.

Hydrogen fuel and ethanol won’t help. They take as much energy to make as they 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.

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?

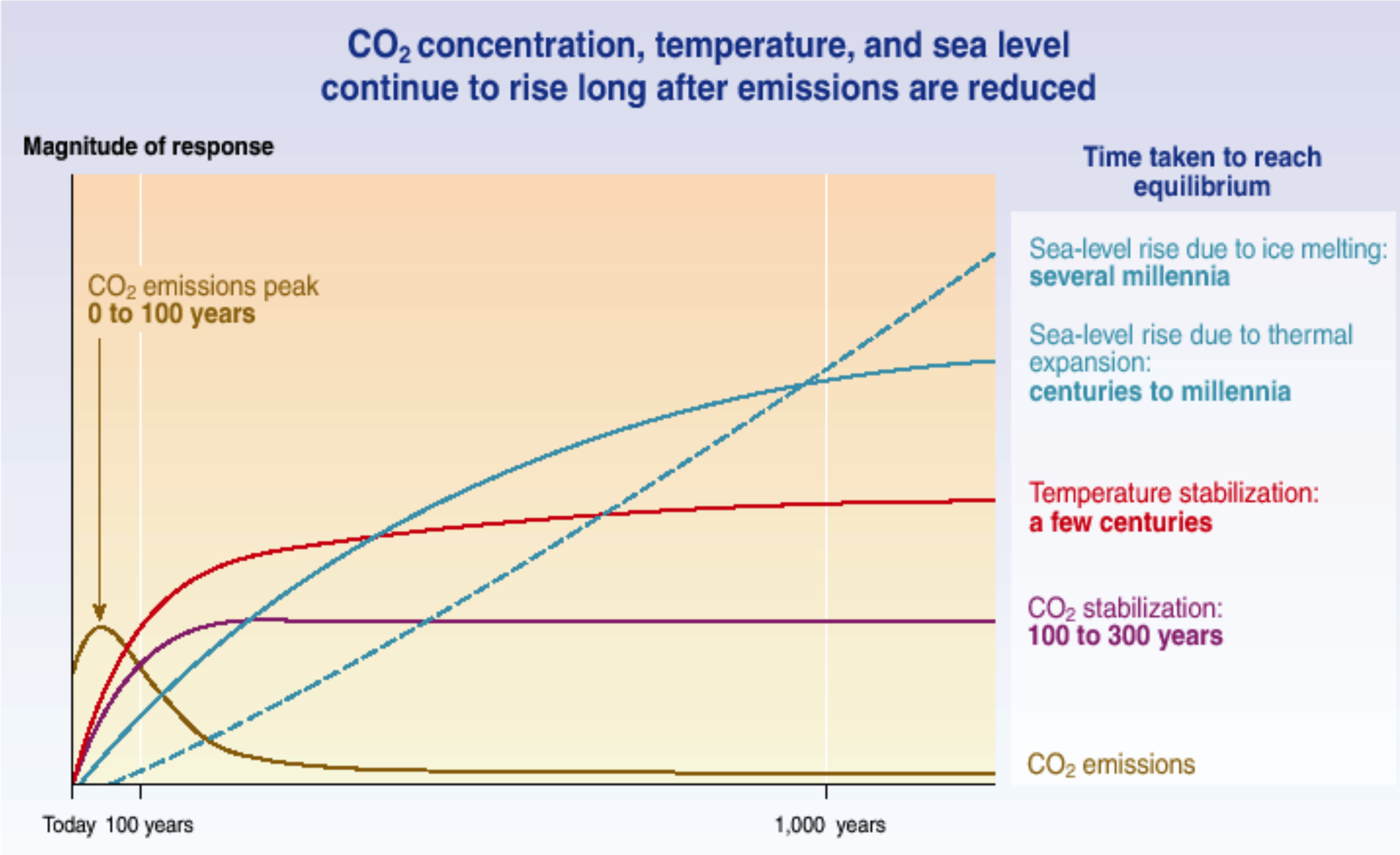
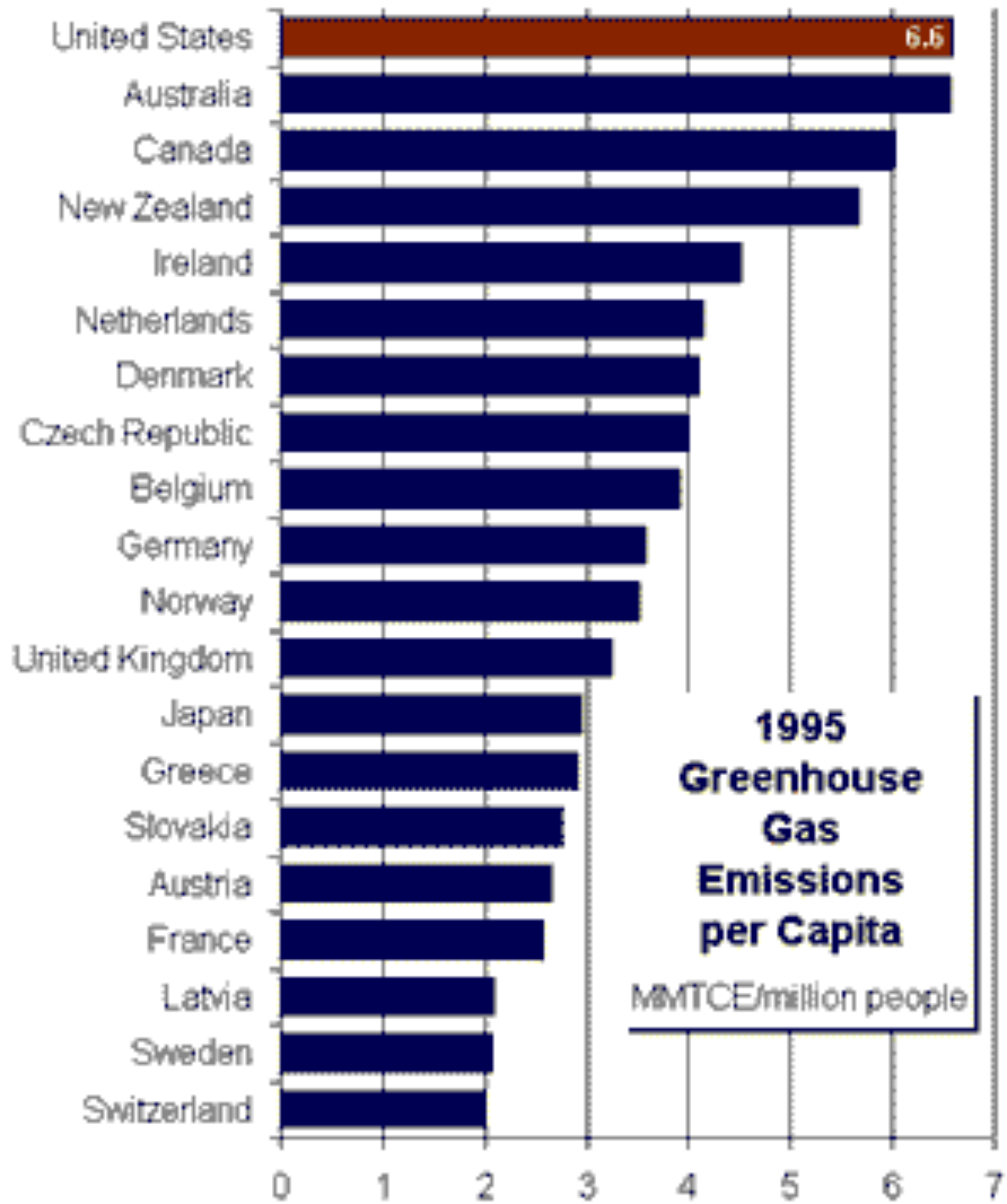


Figure SPM-5: After CO_2 emissions are reduced and atmospheric concentrations stabilize, surface air temperature continues to rise slowly for a century or more. Thermal expansion of the ocean continues long after CO_2 emissions have been reduced, and melting of ice sheets continues to contribute to sea-level 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

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^{o}F 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?

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?

I think the biggest (often unstated) misconception among people who understand the greenhouse effect is thinking that if we could level off our production of CO_2 the temperature would level off.

In fact, the temperature will only stop rising if we stop producing CO_2 entirely. It won't return to its previous level for over 1000 years.

Most of the sea level rise will occur long after we stop producing CO_2.


SOFIA
NASA
DLR
NASA

Overview of SOFIA

- SOFIA is 2.5 m telescope in a modified B747SP aircraft
  - Optical-mm performance
  - The obscured IR (30-300 μm) is most important
- Joint Program between the US (80%) and Germany (20%)
- First Science 2010 (NASA, DLR, USRA, DSI)
- Designed for 20 year lifetime
- Operating altitude
  - 39,000 to 45,000 feet (12 to 14 km)
  - Above > 99.9% of obscuring water vapor at sea level
- World Wide Deployments
- Ramp up to ~1000 science hours per year

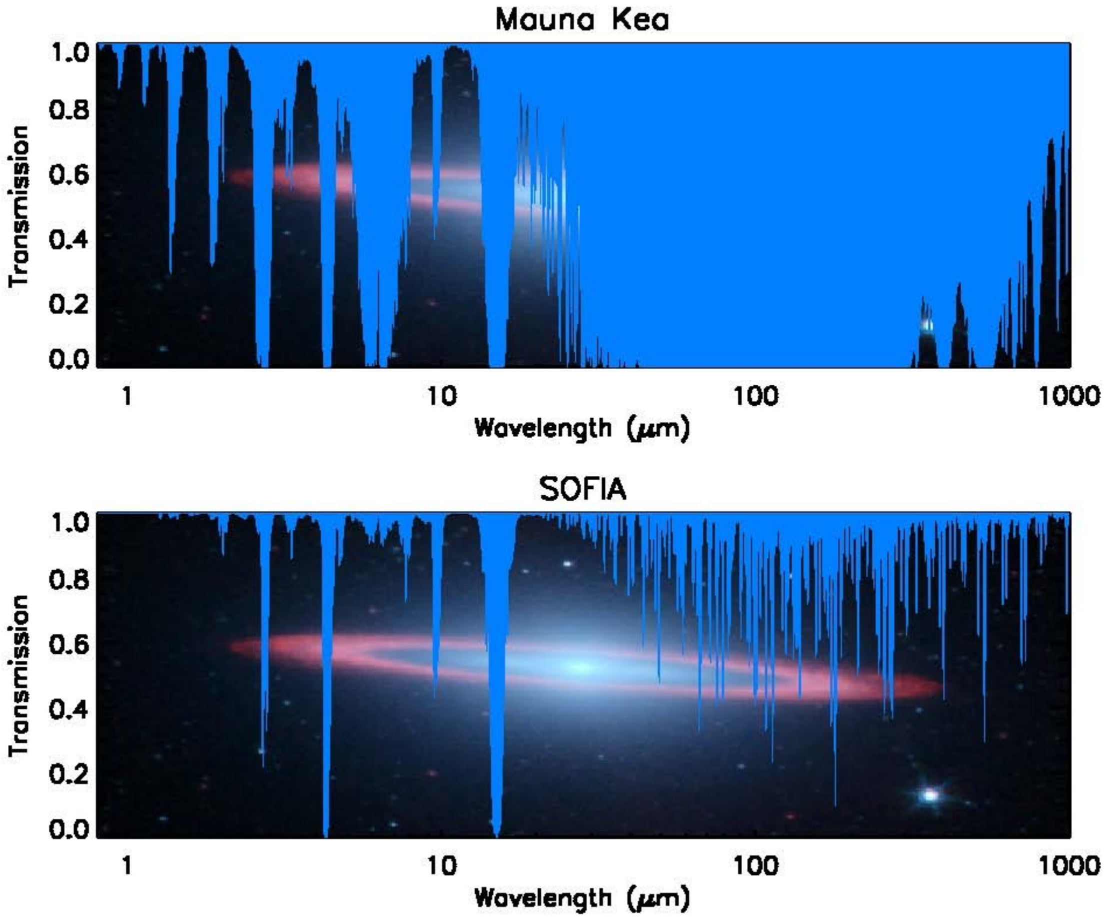
Why SOFIA?

Infrared transmission in the stratosphere very good: >80% from 1 to 1000 μm

Instrumentation:
wide complement,
rapidly interchangeable,
state of the art

Mobility: anywhere, anytime

Long lifetime



Should SOFIA fly?

We have been asking recently whether the likely scientific results from SOFIA are worth the cost.

About $600M have been spent so far on SOFIA.

It will take about $200M more to get to full operation.

And it will cost about $80M per year for the planned flight capability.

This will add up to about $2.4B over 20 years.

Is it worth it? I don't know.

There is no guarantee we would use it for something more worthwhile.

But since I care more about life on Earth than I do about money, I am more concerned about SOFIA's impact on the Earth.

How much oil will SOFIA use?

SOFIA will use about 30,000 gallons of aviation fuel for each flight.

That is about 15 times the per capita use of fossil fuels in the U.S. (not including any use of fuel in refining and transporting aviation fuel to SOFIA).

Even with 180 flights per year, that's a small fraction of what is used by all Americans.

But can I tell my students that it is worthwhile using compact fluorescent light bulbs, or buying small, low power cars, because every little bit helps, when any reduction in CO_2 that results from their conservation efforts will be undone by a single flight of SOFIA?

My conclusion

SOFIA will do some very interesting science.

But surely we can do astronomy without burning 30,000 gallons of aviation fuel for 6 hours of telescope time.

Astronomers have the training to understand the greenhouse effect and to understand the literature about the effects of increasing the greenhouse gasses.

We have an obligation to try to explain it to our students.

But we can’t argue that they should change their lifestyles to avoid a disaster if we choose to ignore the problem when we decide which astronomical projects to do.