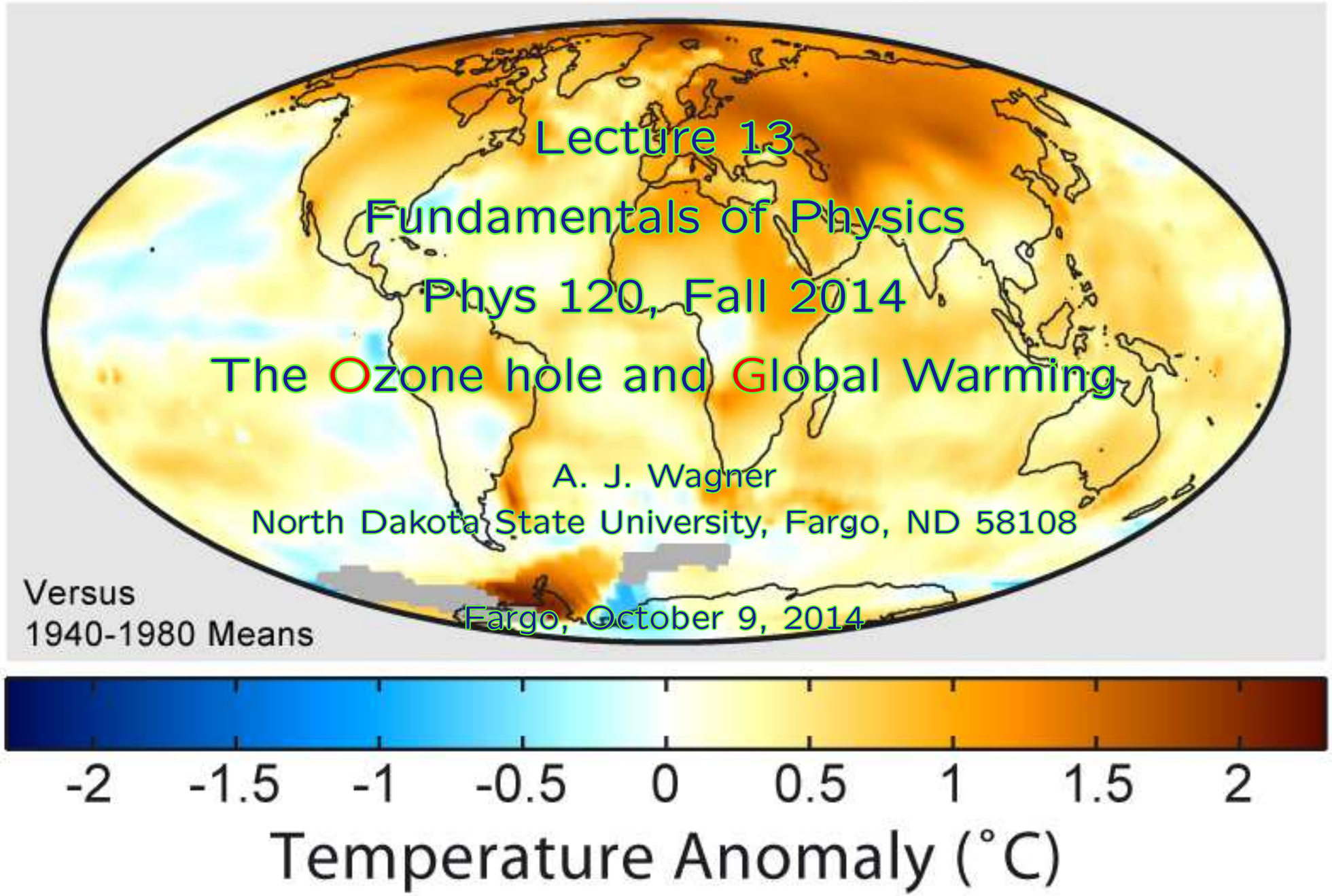


Lecture 13

Fundamentals of Physics

Phys 120, Fall 2014

The Ozone hole and Global Warming

A. J. Wagner

North Dakota State University, Fargo, ND 58108

Fargo, October 9, 2014

Overview

- Paris climate conference
- Global warming
- The Ozone hole

The Paris meeting

Yesterday a new climate meeting began in Paris. Leaders meet till Dec. 11.

What is this meeting about?

Climate Change

You will have heard the predictions that the global climate is warming. They key reason for the warming trend lies in the release of greenhouse gases.

This leads us to a number of questions:
What determines the temperature on a planet?
How does the composition of the atmosphere influence the temperature?

The temperature of a planet

Different planets have different temperatures at their surface. What is the key determinant for their temperature?

It is the distance from the sun!

But how does this work?

The energy reaching a planet

You can think of the sun as a black body at a temperature of 5777K.

Some amount of the black body radiation is received here at the earth. If we start with a very cold earth then this radiation will continue to heat the earth.

But would this heating continue or would it reach some equilibrium temperature?

The energy balance

In order to have an energy balance the earth has to give up heat as well. The simplest way it can do that is again as a black body. Once the earth has reached a temperature that radiates the same amount of enery into space that we receive from the sun, then we have reached an equilibrium state.

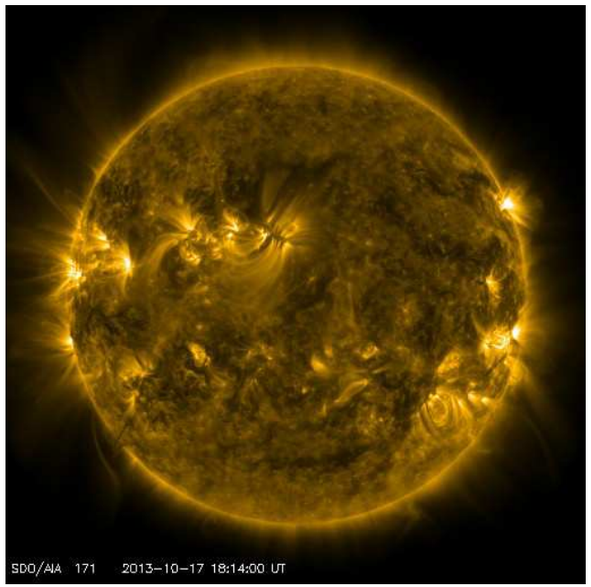
The effect of the atmosphere

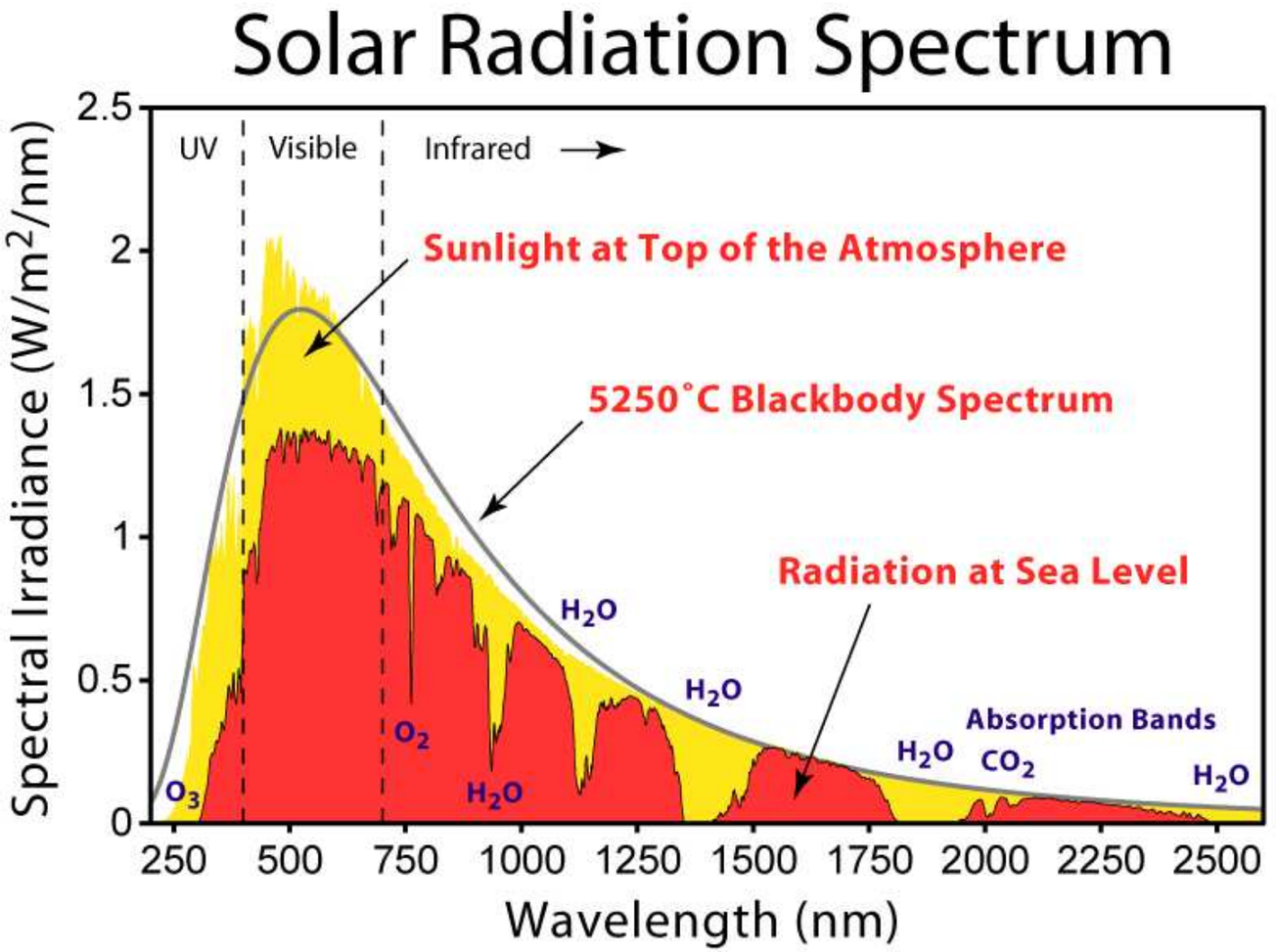
Our climate is determined primarily by the energy transferred to earth from the sun and then re-emitted from the earth.

But the details of this process depend on the structure of our atmosphere.

Earth's Atmosphere	Percentage	GHG?
Nitrogen	78.08%	No
Oxygen	20.95%	No
Water	**0 to 4%**	**Yes**
Argon	0.93%	No
Carbon Dioxide	**0.039%**	**Yes**
Neon	0.0018%	No
Helium	0.0005%	No
Methane	**0.00017%**	**Yes**
Hydrogen	0.00005%	No
Nitrous Oxide	**0.00003%**	**Yes**
Ozone	**0.000004%**	**Yes**

Solar radiation





In the US an average of 200 watts (J/s) strikes every square mater of ground.

Making estimates

Photovoltaic cells are devices that transrom solar energy into electric current. If such devices were 100% efficient, about how much area would need to be covered by such cells on order to provide the average 1.3 kilowatts of electric power that a typical family home uses?

Actual photovoltaic cells are only about 15% (or approx. 1/7) efficient. At this efficiency, how much area must be covered? Could you put this on your roof?

Solutions

$$1.3kW = 200\frac{W}{m^2} * A \tag{1}$$

$$A = \frac{1300}{200}m^2 = 6.5m^2 \tag{2}$$

If the efficency is only 1/7 then the area required will be seven times as big:

$$6.5 * 7m^2 = 45.5m^2$$

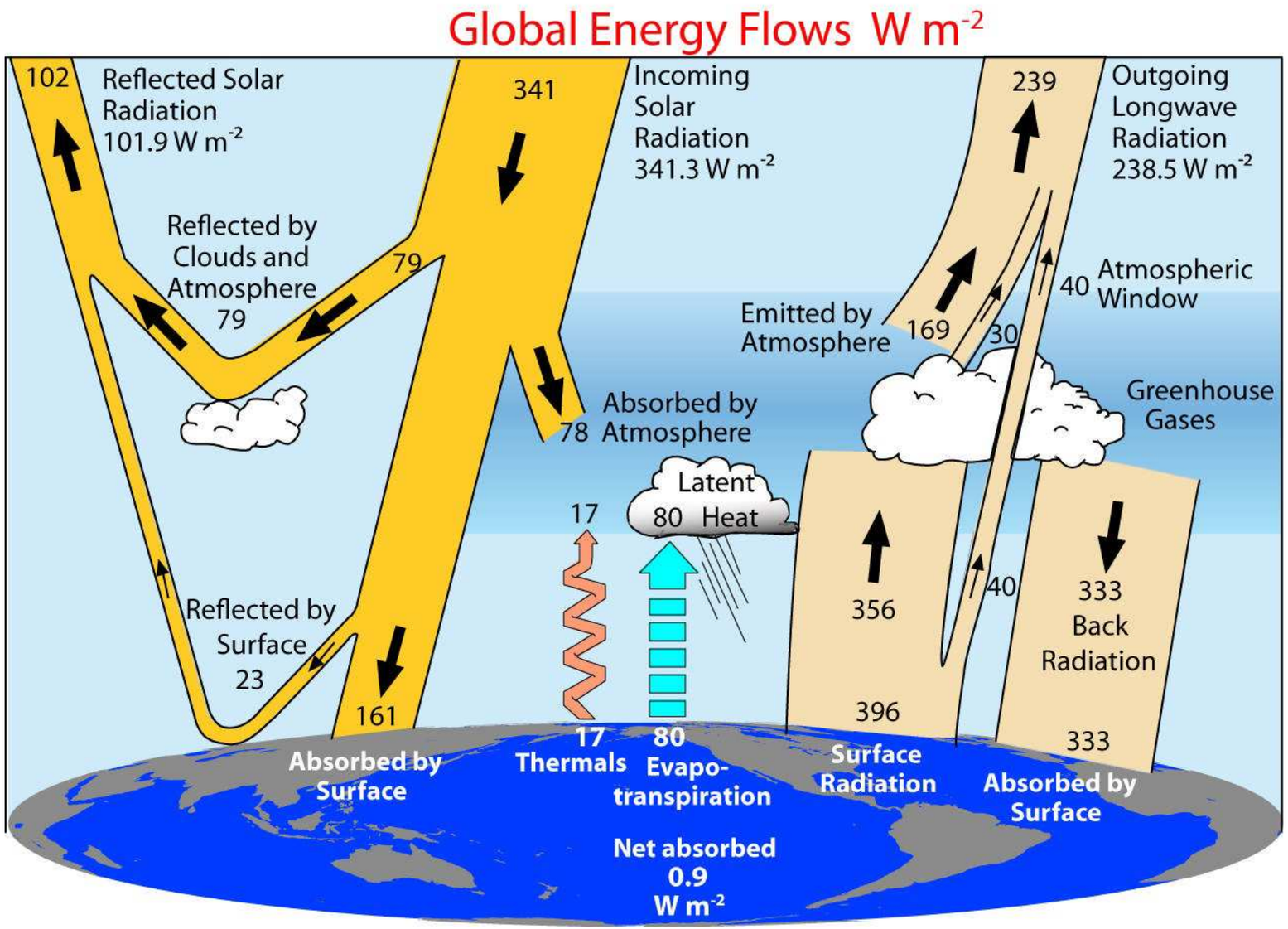
The greenhouse effect

The sun transports energy to the planets in the form of sunlight. This causes a warming of the planets until they radiate the same amount of energy (on average) as they receive from the sun.

From space the temperature of earth appears to be $-19^{\circ}C = -2^{\circ}F$, but on the surface it is $+14^{\circ}C$. This difference is due to the greenhouse effect leading to a warming of 33 degrees! (more later)

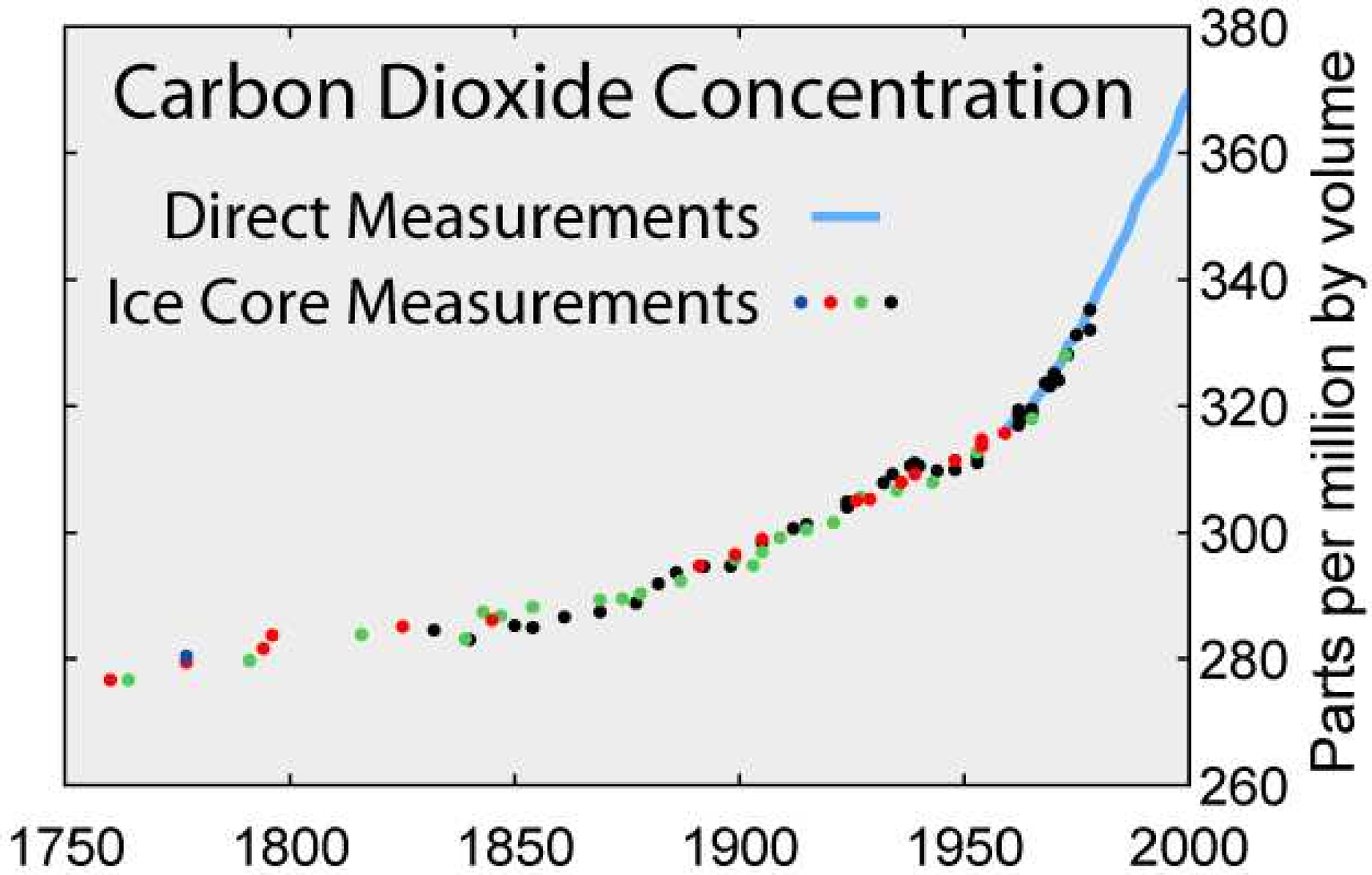
Mars has no atmosphere and no greenhouse effect.

Venus has a CO_2 rich atmosphere with an amazing $503^{\circ}C$ of greenhouse effect warming!


Global Energy Flows W m-2
102
Reflected Solar Radiation 101.9 W m-2
341
Incoming Solar Radiation 341.3 W m-2
239
Outgoing Longwave Radiation 238.5 W m-2
Reflected by Clouds and Atmosphere 79
79
40 Atmospheric Window
Emitted by Atmosphere
169
30
Greenhouse Gases
Absorbed by 78 Atmosphere
Latent 80 Heat
17
356
40
333 Back Radiation
Reflected by Surface 23
161
396
333
17 Thermals
80 Evapo-transpiration
Surface Radiation
Absorbed by Surface
Absorbed by Surface
Net absorbed 0.9 W m-2

greenhouse gases	produced by	lifespan	natural effect on GW	human-made effect on GW
Carbon Dioxide (CO_2)	• defrostation • animal respiration • burning biomass • burning fossil fuels	100 yrs.	25%	70%
Methane (CH_4)	• wetlands agriculture livestock	12 yrs.	little	24%
Nitrous Oxide (N_2O)	• fertilizer use • chemical industry	115 yrs.	little	6%
Ozone (O_3)	• industry • natural processes in upper atmosphere	short	8%	O_3 levels are dropping due to CFCs
Chloroflorocarbons (CFC)	• man-made • used in consumer goods	1000 yrs.	none	potentially high, but destroys O_3
Water (H_2O)	• evaporation at the rate linked to temperature	constant circulation	60%	unclear - see text

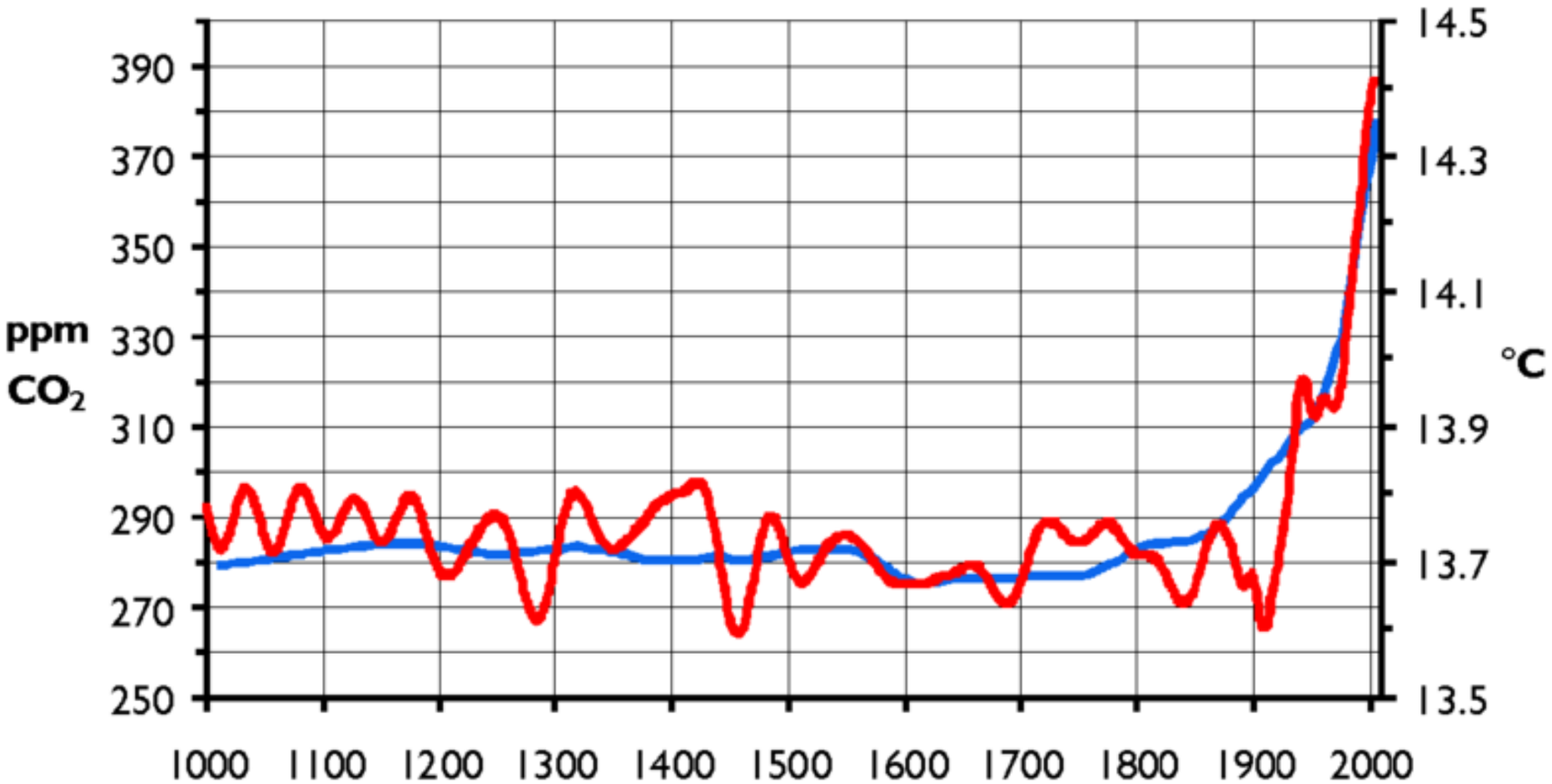
Co_2 concentration in atmosphere



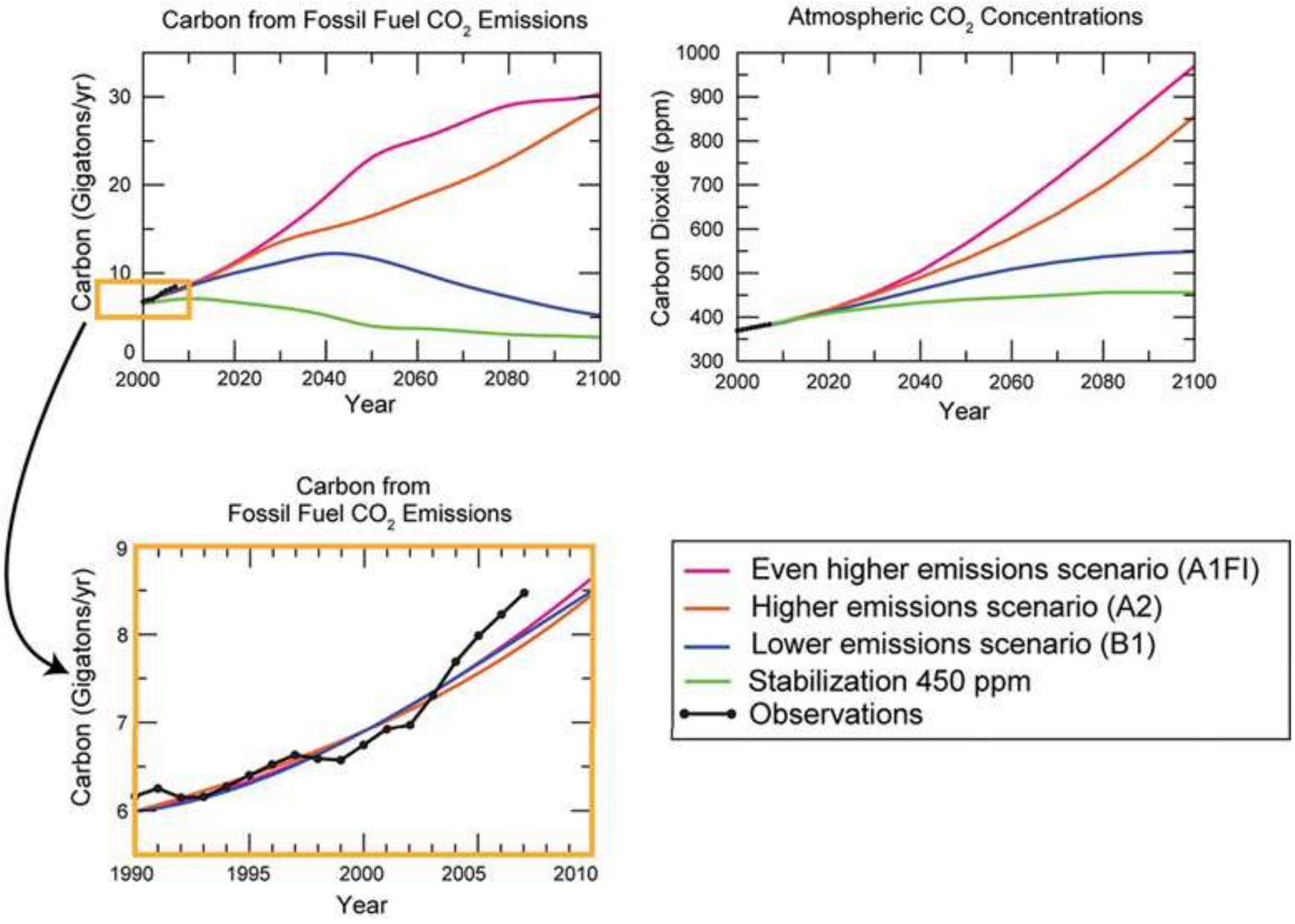
How do we know rise in CO_2 since 1750 is manmade?

1) Rise agrees well with historical CO_2 emission.
2) Radioactive C^{14} is continually created in high-energy atmospheric events. But the ratio of C^{14} to C^{12} decreases with time. This is the basis of Carbon dating.

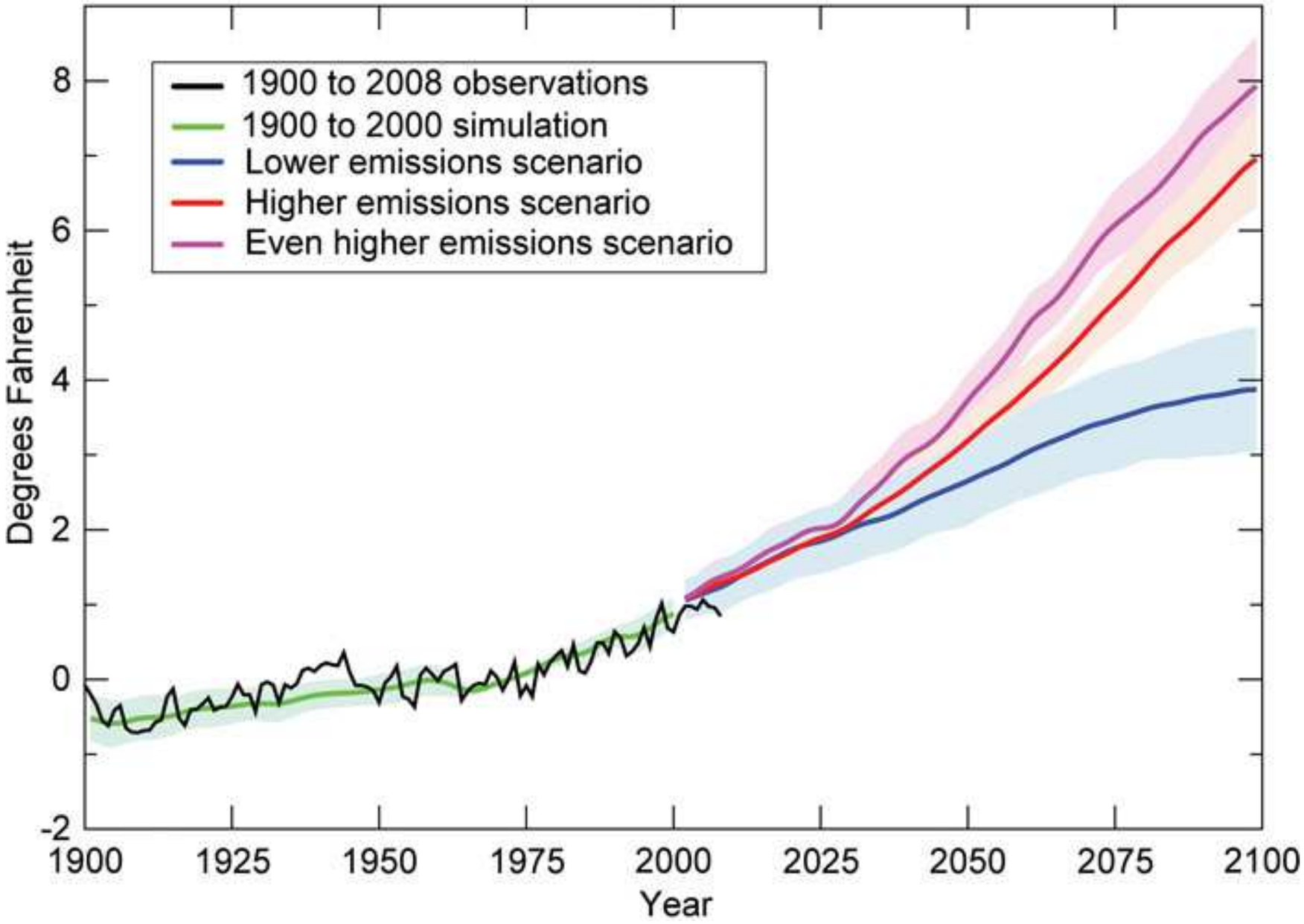
Global temperatures and CO_2



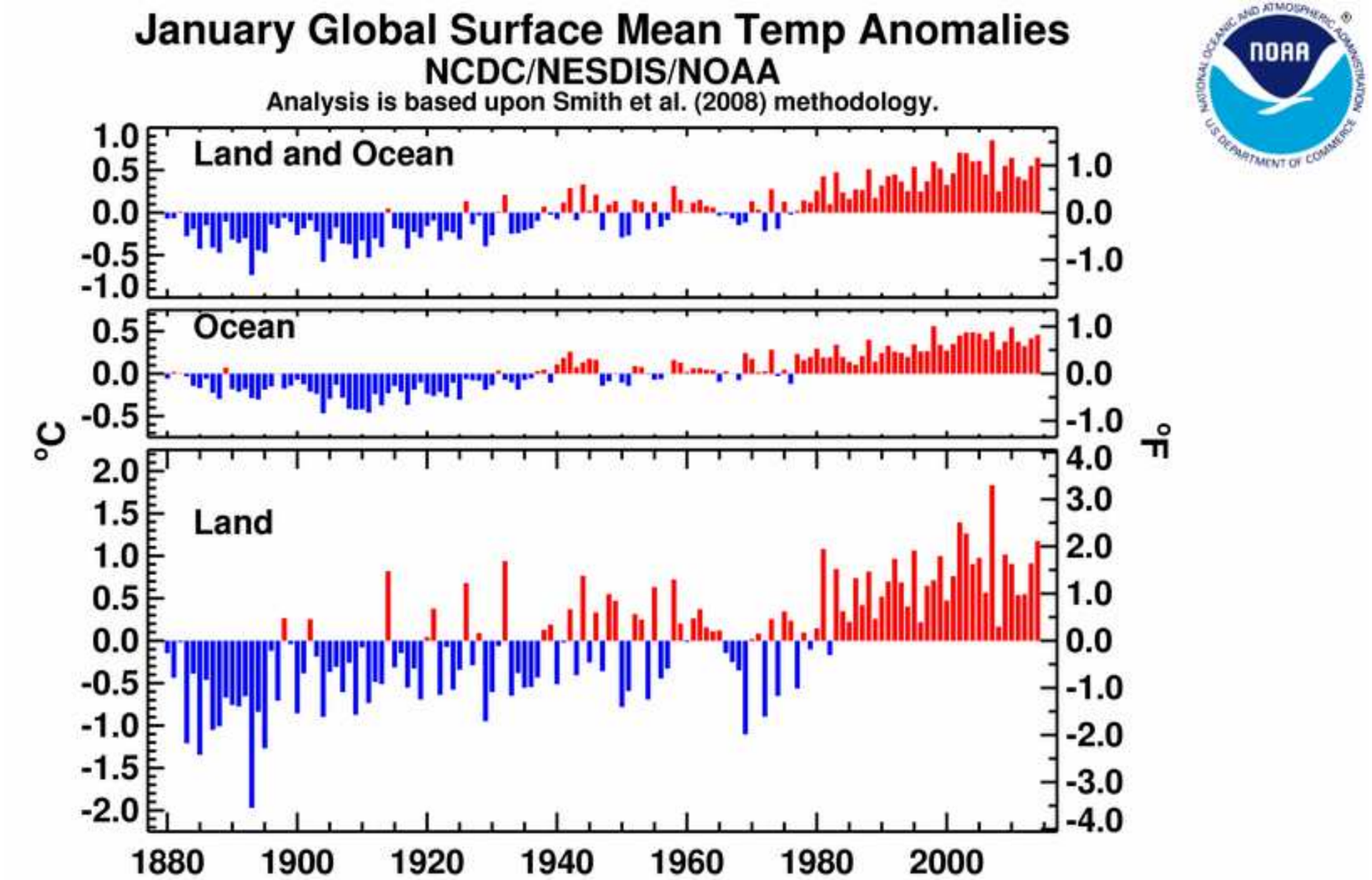
The Future


Carbon from Fossil Fuel CO_2 Emissions
Carbon (Gigatons/yr)
0
10
20
30
2000
2020
2040
2060
2080
2100
Year
Atmospheric CO_2 Concentrations
Carbon Dioxide (ppm)
300
400
500
600
700
800
900
1000
2000
2020
2040
2060
2080
2100
Year
Carbon from
Fossil Fuel CO_2 Emissions
Carbon (Gigatons/yr)
6
7
8
9
1990
1995
2000
2005
2010
Year
Even higher emissions scenario (A1FI)
Higher emissions scenario (A2)
Lower emissions scenario (B1)
Stabilization 450 ppm
Observations

The Future


1900 to 2008 observations
1900 to 2000 simulation
Lower emissions scenario
Higher emissions scenario
Even higher emissions scenario
Degrees Fahrenheit
8
6
4
2
0
-2
1900
1925
1950
1975
2000
2025
2050
2075
2100
Year

Some more recent data



Meltwater

Feedback

There is negative feedback (like higher temperatures causing more cloud cover, reducing the temperature)
and positive feedback (like more H_2O in the atmosphere can lead to more global warming).
Positive feedback can lead to a "run away" effect.

Potential for positive feedback: melting of sea ice inducing heating of ocean.

Energy production

In fact energy production from fossile fules is expanding unabated in the US. To learn more about this, please watch: this video on the effect of shale gas production on human health as homework.

There is grave resistance to the idea of reducing fossile fule production. Why is this?

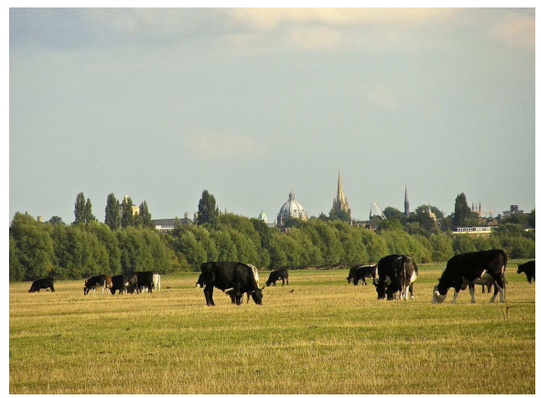
Tragedy of the commons

If we know that producing more fossile fuel is bad for us, why do we keep doing it?

There is an interesting idea based on the idea of common lands (the original article 1968 is added as supplemental material to your LON-CAPA course). It goes back to an observation from Oxford.

Port Meadow, Oxford





This meadow is a beautiful place at the themse. In return for helping to defend the kingdom against the marauding Danes, the Freemen of Oxford were given the 300 acres (120 ha) of pasture next to the River Thames by Alfred the Great who founded the city in the 10th century. The Freemen's collective right to graze their animals free of charge is recorded in the Domesday Book of 1086 and has been exercised ever since.

The tragedy of the commons is the simple effect that these meadows suffered from overgrasing since every commoner had an advantage of adding an animal for himself, whereas his share of the overgrazing damage caused by this one animal was shared with all the other commoners. So his personal incentive (as well as that of all commoners) is against the common good. This is known as the tragedy of the commons.

Ozone problems

In the 1970 a reduction in Ozone (O_3) in the upper atmosphere was discovered, and scientists related it to the human release of chloroflurocarbons (CFCs) used as coolants for refrigerators and in spray cans.

These CFC compounds were originally considered ideal for these applications since they are nearly inert, and do not react with other substances under normal conditions. This makes them non-toxic and apparently ideal for consumer applications.

Fixing the Ozone hole

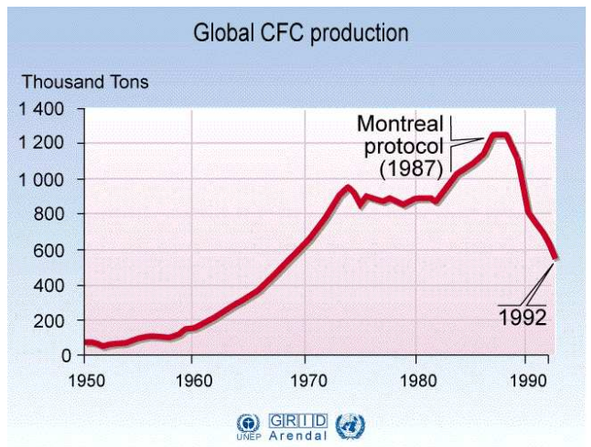
In 1974 most people considered it absurd to think that coolants and spray cans could cause a catastrophe, because it violated the intuitive notion that human activities were far too puny to alter the global environment. But some were alarmed. A debate, of now familiar type, ensued. The chemical industry argued that theory was speculative and that there should be no economically damaging CFC restrictions until there was more evidence.

Pro-environment consumer pressures played a crucial role when a consumer boycott reduced the U.S. market for CFC-powered sprays by two-thirds, pressuring manufacturers to support CFC restrictions.

Ozone depletion: a vulnerable planet

A thin layer of Ozone 10-50 km above the earth's surface is responsible for absorbing a large fraction of the sun's UV radiation (see Solar spectrum). This layer would be only 2mm thick at normal atmospheric pressures!

In 1928 the General Motors Company invented **chlorflourocrbons** (CFCs), a cooling liquid for refrigerators that is **chemically inert.** They were incredible successful and began spreading exponentially.



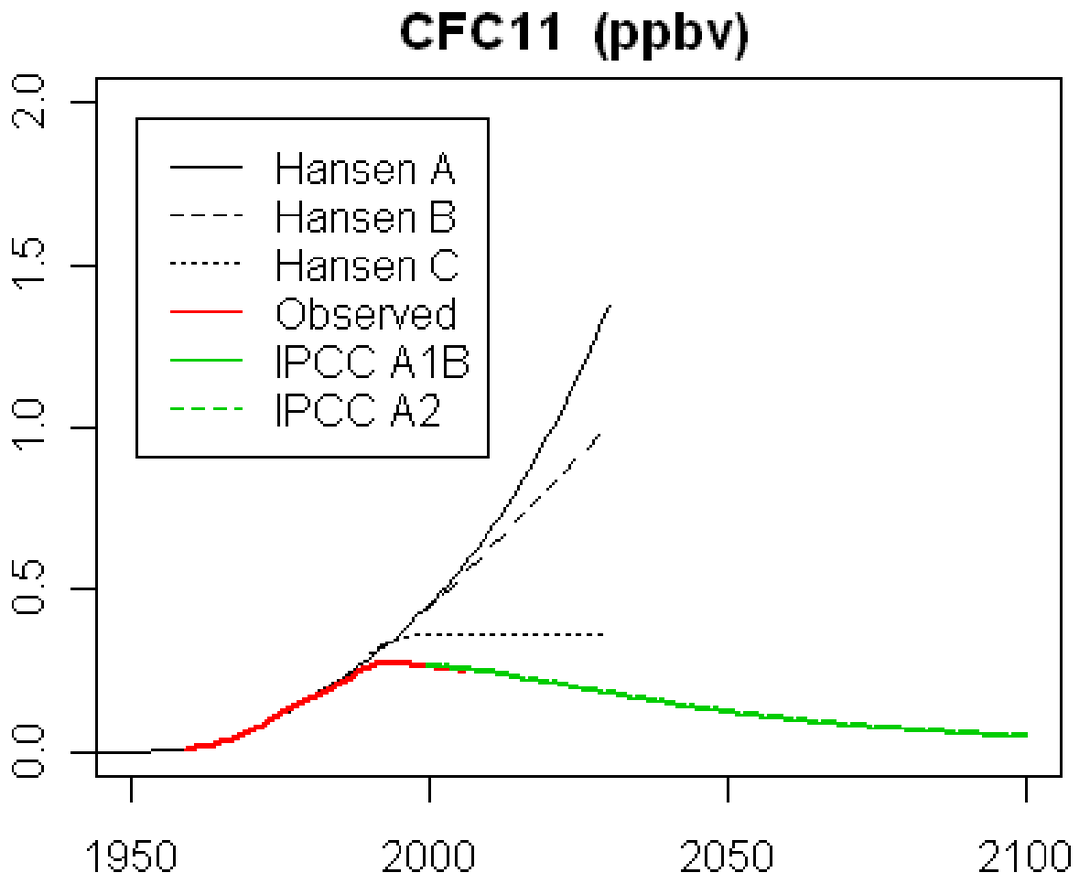
In 1974 scientists (M. Molina, S. Rowland) began to wonder where all the CFCs were ending up. They suggested the alarming prospect that they may end up in the Stratosphere where UV radiation would split them releasing chlorine that could be detrimental to the ozone.

$$Cl + O_3 \rightarrow ClO + O_2$$

$$ClO + ClO + UV \rightarrow Cl + Cl + O_2$$

a cyclic process where 1 Cl atom may destroy 100,000 ozone molecules.

Effect of treaty on CFC concentrations - success!



It was important that the world acted **before** the scientific evidence became overwhelming.

How did we escape the tragedy of the commons with CFCs?

The problem of CFCs was restricted to a few companies that produced these chemicals, it was technologically quite straight forward to replace them and there was essentially no cost to the public. Additionally there was a large public involvement in demanding action.

In the end it became more profitable for these companies to switch to non-ozone destroying chemicals and in doing so placated their customers.

Can we escape the tragedy of the commons with fossile fuels?

Here the situation is much more difficult. Here are some issues:

- Consumer pressure is hard to apply. Cars are ubiquitous and hard to replace. Electricity comes from your provide and you can't switch.

- Companies duty is to their shareholders and the paramount game is the next quartely earnings report.

- Regulatory units controlled by politicians who want to be re-elected on at most a 4 Year basis. Bringing back manufacturing jobs to the US next year with cheap natural gas is more important than avoiding flooding of New York in 20 years time.

- How many politicians are there that would risk a fight with an important industry over an issue that few Americans care about?

Summary

The temperature of a planet.

Moderating effects of an atmosphere: the greenhouse effect.

Changing the composition of the atmosphere: releasing CO_2 from fossile fuels.

The tragedy of the commons.

CFC regulation and hope for the future

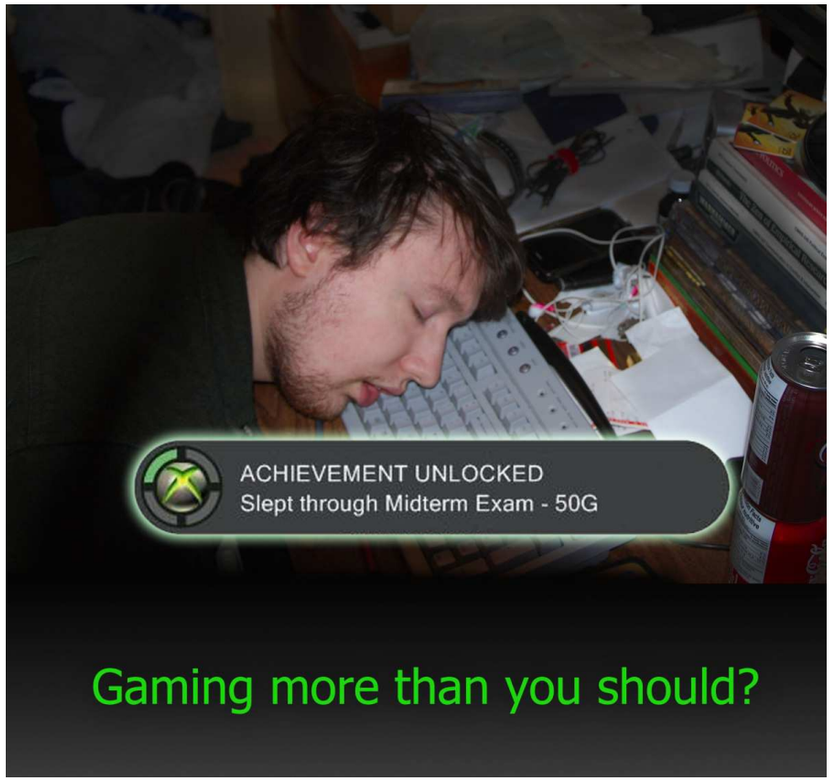
Limiting population growth

All the issues we talk about today can fundamentally be traced back to the increasing size of the human population.

We talked about this in a previous lecture. There are a few trends that tend to (eventually) cause a reduction in birth rates.

I observed some of these in my youth, when Germany was still split into East and West Germany. The birthrate in East Germany was significantly larger than in West Germany, and there were two reasons: a) there was a feeling of boredom in East Germany and a feeling that there was little else one could do. b) The cost of having children was small as there was a lot of support, even for single parents that could easily hold downs a job and receive free child care.

West Germany



In West Germany there are lots of other fun things to do. And being a working parent is hard, and if you are not yet financially secure, it is not all that much fun. And having more than two kids (which still leads to a shrinking population) is rare.

However, these effects will not reduce the population growth in the short term, which is what we focus on in this lecture.