Anthropogenic climate change

Astronomy 101
Syracuse University, Fall 2019
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November 19, 2019


Earth

Accommodations for events on campus: final exam

The final exam will now consist of two distinct parts:

- A standard-length exam on Unit 4, graded as a standard exam
    - This can be dropped like any other exam if it is your lowest grade

- About a dozen questions on each of the previous units
- Each of these segments will now be an opportunity to improve your grade on the previous exam
    - If you do better on one of these than you did on a previous exam, it will raise your grade on that exam
    - If you do worse, then it won't affect anything

- They are all optional; if you want to devote your time to other things, you don't have to take them

The exams in the course will, in total, still comprise the same portion of your final grade.

Accommodations for events on campus: project

- If you do not do a final project, its weight will be reallocated among all other components of the course ("dropped")
- This will likely on average be slightly detrimental to your grade, since final project grades tend to run slightly above other things.
- If you do complete a final project, it will likely help you (and, if you do something excellent, possibly help you a great deal).
- These projects are often very rewarding for students, and if you have something rewarding you want to do, do it and enjoy, and this will help your grade!
- But if you are viewing it as "another paper you have to write", you may skip it and we'll calculate your grade from the rest of your work.

Accommodations for events on campus: recording

Class today will be audiorecorded to accommodate students who are not here.

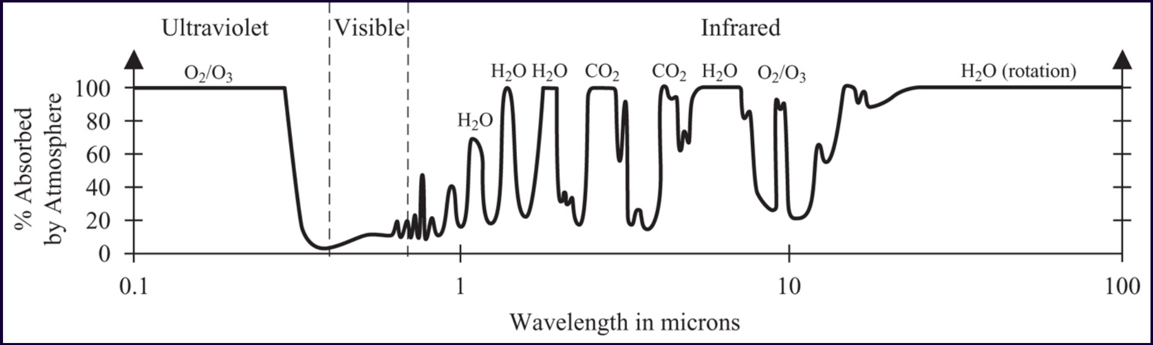
Summary

- Review: the greenhouse effect
- History
  - What is the history of the Earth's climate?
  - What processes caused it to vary?
  - How do they affect each other?
- The Anthropocene: the era of human influence on geology
  - In an eyeblink, a drastic jump in atmospheric CO_2:
  - Evidence that this is already causing warming
  - Evidence that this has the potential to cause far more warming

Summary, II

- Consequences
  - Exaggerated effect in the Arctic
  - Sea level rise
  - Disruption to society
  - Ecological shocks and extinctions
- What do we do about this?
  - What are the sources of CO_2 emissions?
  - *Who* are the sources of CO_2 emissions (spoiler: us)
  - Electricity generation
  - Transportation
  - Obstacles, legitimate and otherwise
  - Positive signs

The greenhouse effect



The greenhouse effect

Venus has a *tremendously thick* atmosphere and a powerful greenhouse effect.

- Its atmosphere contains a great deal of CO_2, which reflects IR strongly
- The thermal radiation that would carry heat away from Venus can't get out
- It is over 400 K hotter than was predicted by the calculation you did last week

Earth has a *thinner* atmosphere.

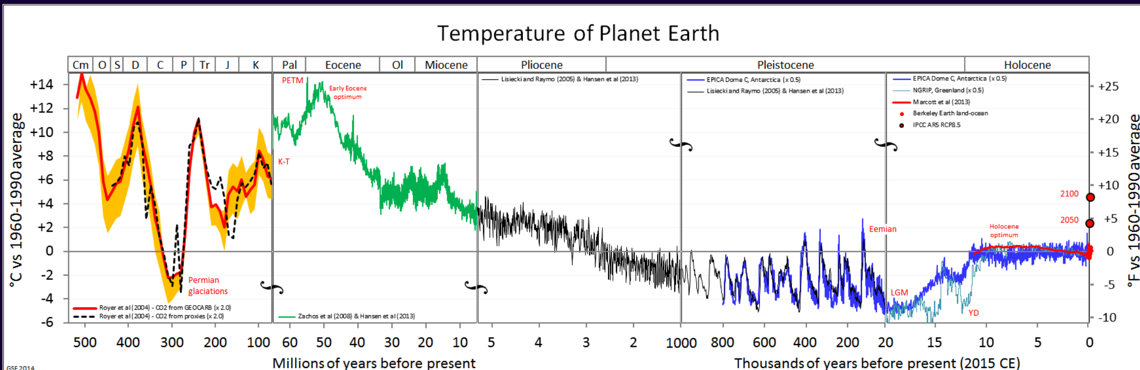
- Nitrogen doesn't absorb strongly at any relevant wavelengths
- H_2O and CO_2 are strong greenhouse gases, but they are only a bit of the atmosphere
- We are about 20 K warmer than predicted by that crude math (more precise math: 30 K)
- These gases are very important for determining Earth's temperature!

The greenhouse effect

The upshot:

- The Sun is around 5500 K, and emits visible/short-wavelength IR; this goes through Earth's atmosphere and warms it
- The Earth is around 300K K, and emits longer-wavelength IR
- Some of that energy is absorbed by gases (water, carbon dioxide, methane) in the atmosphere
- When the atmosphere reradiates it, much of it falls back to Earth
- If the short-wavelength sunlight has an easier time getting in than the long-wavelength Earthlight has getting out, Earth's temperature will go up
- This is called the greenhouse effect.

Variation of Earth's climate



Earth has seen quite a lot in its lifetime...

The past state of Earth can help us study what the future may hold.

The climate spectrum

Temperature differences compared to 20th century average:

- -33C: complete lack of greenhouse effect
- -10C: "snowball Earth"; glaciers cover entire planet except for a small band at Equator
- -5C: ice age; Syracuse covered in glaciers
- 0C: our familiar climate
- +5C: ??? (but maybe our future)
- +10C: Like the time of the dinosaurs; inland seas common; much of America underwater

What process is most driving these fluctuations in climate?

A: Changes in the Sun's brightness affect the amount of energy reaching Earth

B: Changes in the rate that volcanoes discharge greenhouse gases into the atmosphere affect the strength of the greenhouse effect

C: Changes in the Earth's orbit affect the axial tilt and the distance from the Sun

D: All of the above

E: An increase in CO_2 in the atmosphere due to the burning of fossil fuels has increased the strength of the greenhouse effect

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- Look at the time axis – the industrial revolution is just the last eyeblink of history

Positive and negative feedback

The Earth is quite complex. If the Earth warms, then...

- ... certain effects will cause even more warming: *positive feedback*
- ... other effects will slow that warming down: *negative feedback*

Positive feedback: snow

White snow absorbs less heat than dark soil
This is why snow piles take so long to melt!

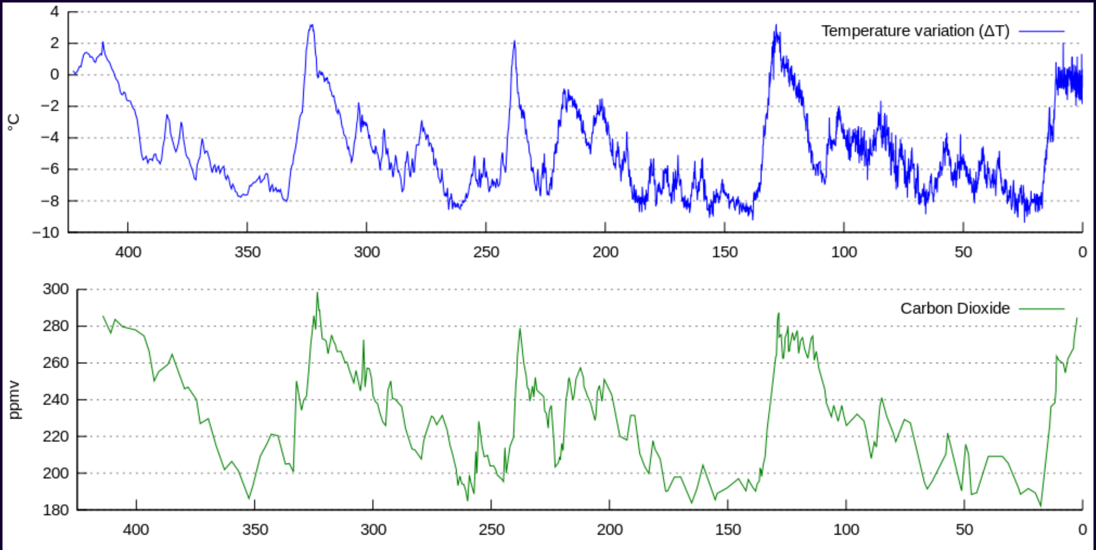
This feedback loop is *fast* – it doesn't take that long to melt snow (years)

Negative feedback: oceans

More CO_2 in the air → oceans absorb faster
This brings the CO_2 levels back down.

This feedback loop is *slow* – it takes a long time for CO_2 to be absorbed (hundreds/thousands of years)

In the short term, the positive feedback mechanisms win out.
This means that *small changes to the climate are amplified.*



CO_2 is strongly correlated with temperature (positive feedback).

- More CO_2 in the atmosphere strengthens the greenhouse effect, raising the temperature
- Higher temperatures speed up chemical processes that release carbon stored in rocks
- Lower temperatures speed up chemical processes by which rocks *absorb* carbon

What if we change CO_2 on our own?

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A: The climate will be altered for a few centuries

B: The climate will be altered for a few tens of thousands of years

C: The climate will be altered for a few million years

D: The climate will be altered forever

How high must atmospheric CO_2 levels get for the climate to be seriously changed compared to the past few hundred thousand years?

A: 275 ppm (parts per million – see plot)

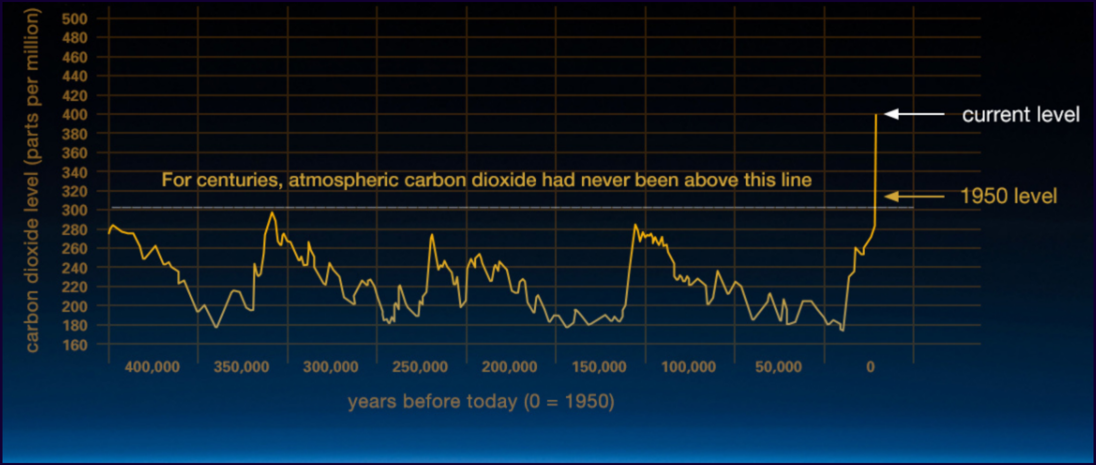
B: 300 ppm

C: 325 ppm

D: 350 ppm

The current state

The 2017 average CO_2 level was 405 ppm.
The Industrial Revolution took us there in a geological blink of an eye.



(NASA)

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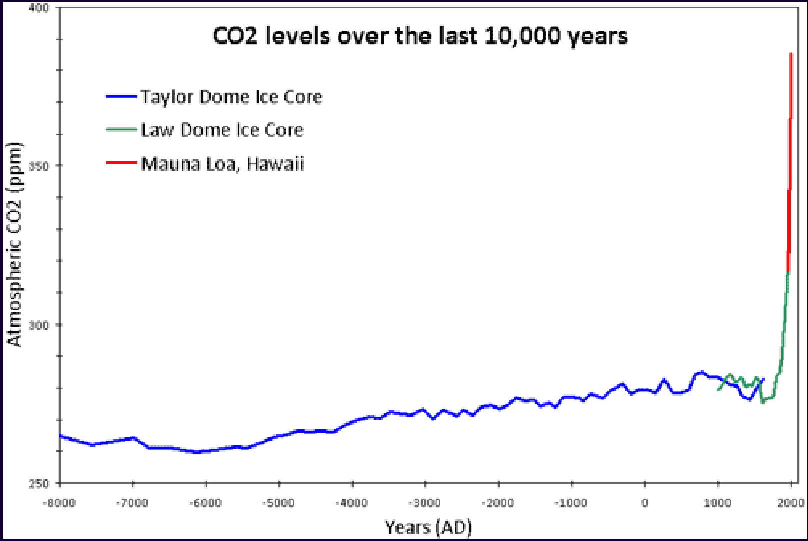


What will this do to Earth?

Geophysics is enormously complicated.

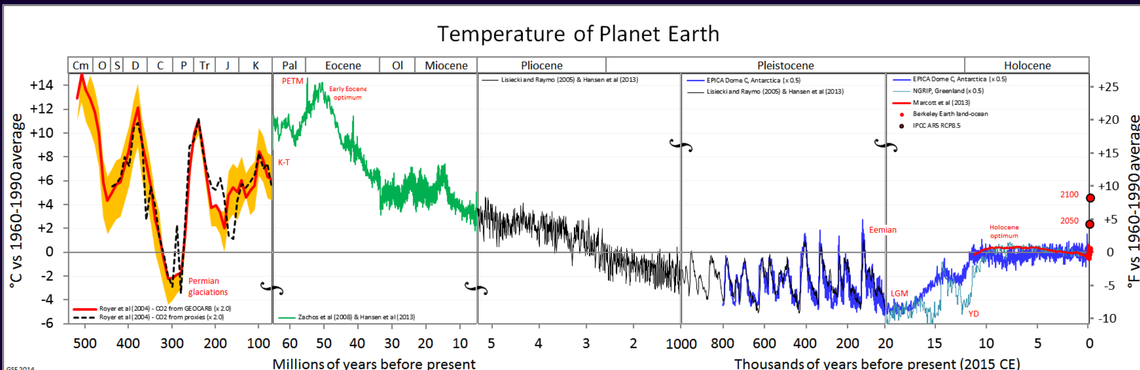
Models (from simple ones to enormous supercomputer simulations) tell us unequivocally: the CO_2 produced by humans will warm the planet.

But for how much, and for how long, and to what effect?

We'll talk about those models in a bit, but in the meantime, let's look at history to get an answer.

This happened once before...

The “Paleocene-Eocene Thermal Maximum” was a sudden release of carbon dioxide 56 Myr ago. (We’re not sure from where, but we know it happened, by looking at isotope ratios in fossils.)



- Something caused a rapid release of CO_2 over two thousand years, at a peak rate of up to 6 billion tons/year.
- This caused a temperature spike of 5-8 C that lasted many thousands of years
- The oceans absorbed much of this carbon as carbonic acid, bleaching corals
- There was a mass extinction of deep-ocean life and large changes to surface life

Positive feedback

Positive feedback effects dominate in the short term:

- Melting of ice, darkening the surface so it absorbs more sunlight
- Increased amounts of water vapor in the air
- Melting of permafrost in Siberia, which has a great deal of trapped methane
- (Water vapor and methane are also greenhouse gases)
- $\rightarrow$ Earth processes will magnify any effects from human CO_2 emissions
- Even a little nudge from humans can have large effects

A candid word on scientific rigor

As we've discussed, a crucial part of scientific integrity is honesty about the limitations of your knowledge.

In preparing for this class, I've used as source material:

- The UN Intergovernmental Panel on Climate Change Fifth Assessment Report (2015)
- The US Fourth National Climate Assessment (2017-018)

These documents are *meticulous* about this. They make sure to describe:

- uncertainties in measurements and estimates
- how confident they are in conclusions
- when important things are still unknown

These climate assessments are exemplary in their integrity and honesty in this regard.

What climate change is and is not

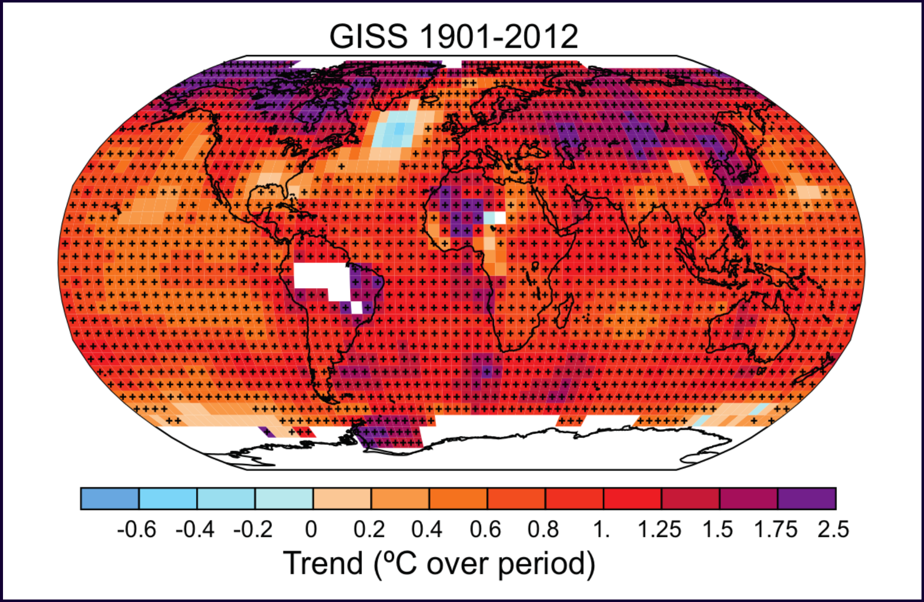
Climate change is a moderate, overall warming of the planet by a few degrees.

It does not mean an end to cold weather – and cold weather does not mean that climate change is not happening.

Most of the world will have more hot extremes and fewer cold ones, but there is a difference between weather and climate.

Effects on the Arctic

Computer models and observations show that the effects of current and future warming are magnified in the Arctic, because of the albedo effect from melting snow.



Sea level rise

All that water must go somewhere; heat also causes the oceans to expand. The Marshall Islands may simply cease to exist.

Miami, Manhattan, New Orleans, etc. are also threatened...

It's definitely happening, and we did it

Global climate is changing rapidly compared to the pace of natural variations in climate that have occurred throughout Earth's history. Global average temperature has increased by about $1.8°$ *F from 1901 to 2016, and observational evidence does not support any credible natural explanations for this amount of warming; instead, the evidence consistently points to human activities, especially emissions of greenhouse or heat-trapping gases, as the dominant cause.*

–The Fourth National Climate Assessment (US Government), 2018

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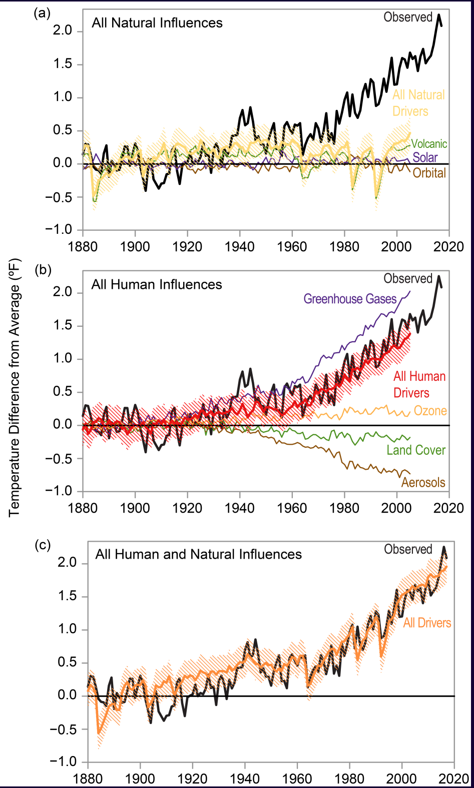

We've gone from the simple calculations of Arrhenius to massive supercomputer simulations of the Earth's climate.

If we're going to trust them to predict details about the future, they ought to accurately capture the past.

The observed climate trends *are not* consistent with simulations of natural influences on the climate, but are *very* consistent with simulations including human effects.

Climate simulations are accurate for broad trends like global temperature.

Effects on humans

Our societies are adapted for certain weather patterns and coastlines.
If the earth warms:

- People may have to abandon coastal cities like Manhattan and Miami

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- Seasonal rainfall patterns that equatorial farmers rely on may change
- Extreme weather events may become more likely, including wildfires and storms

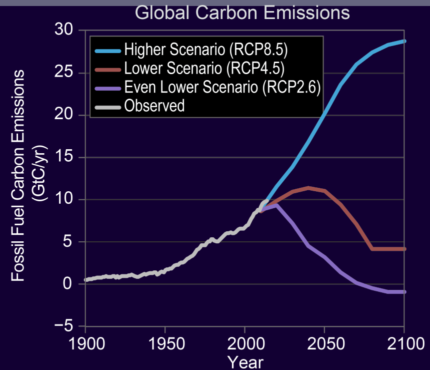
In wealthy nations like the US this will cause massive economic losses, as people are forced to adapt.

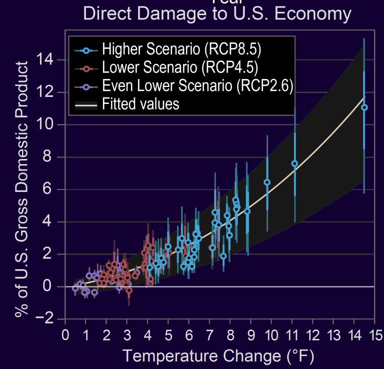
In poorer nations people may not have the resources to adapt...

Climate change mitigation

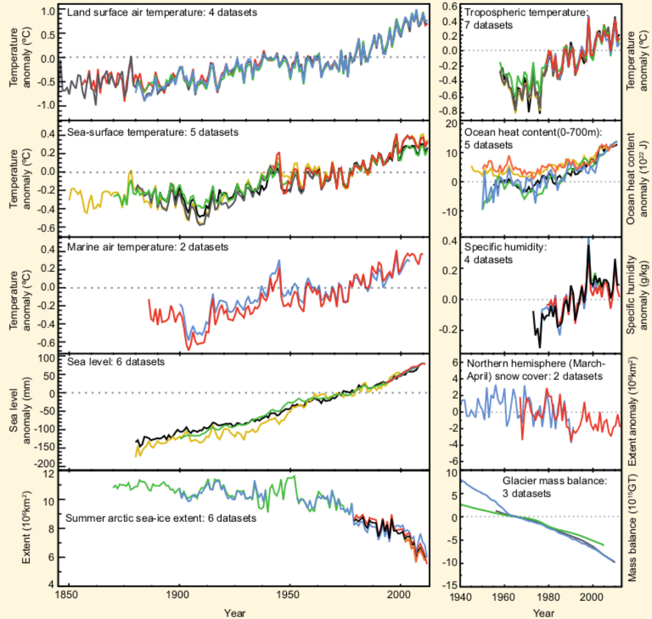
The effect on global temperature – and on human society – will depend a great deal on how quickly and deeply we cut CO_2 emissions.

- Warming to date: 1° C (2° F)
- Depending on our choices: from 2 – 7° C (4 – 12° F likely.
- The next decade or two are crucial for what happens later





What's going on now?



FAQ 2.1, Figure 2 | Multiple independent indicators of a changing global climate. Each line represents an independently derived estimate of change in the climate element. In each panel all data sets have been normalized to a common period of record. A full detailing of which source data sets go into which panel is given in the Supplementary Material 2.SM.5.

(IPCC FAR)

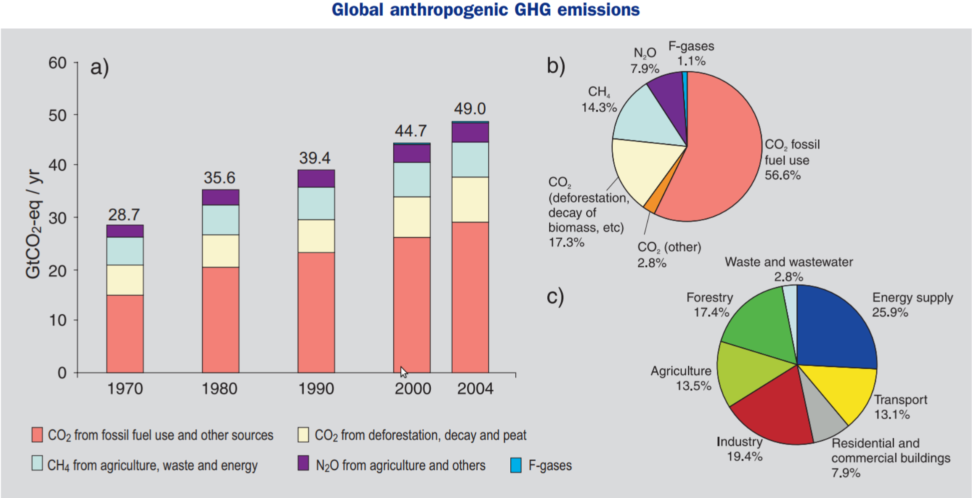


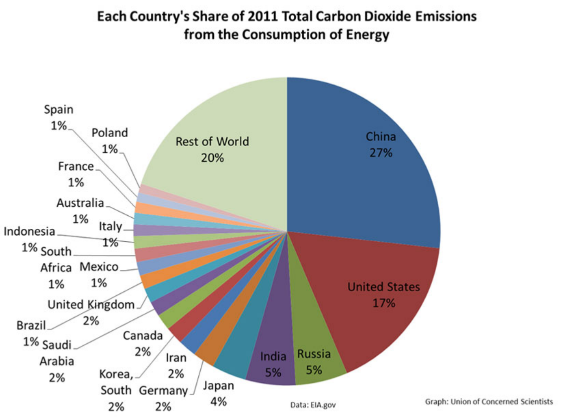
Figure SPM.3. *(a) Global annual emissions of anthropogenic GHGs from 1970 to 2004.[5] (b) Share of different anthropogenic GHGs in total emissions in 2004 in terms of carbon dioxide equivalents (CO_2-eq). (c) Share of different sectors in total anthropogenic GHG emissions in 2004 in terms of CO_2-eq. (Forestry includes deforestation.) {Figure 2.1}*

Most of our greenhouse gases come from burning fossil fuels.

These are mostly used to generate electricity, power vehicles, and in industry.

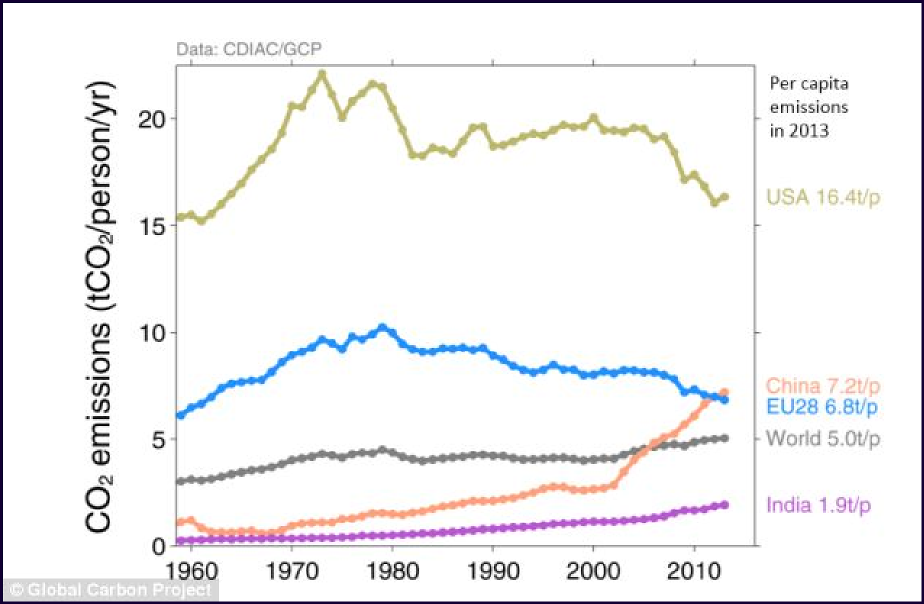
Who's doing most of this?

Us – the global wealthy.



(from the Union of Concerned Scientists)

Top CO_2 sources



What do you conclude from these data?

Pointing fingers

Globalization means that countries now specialize in different things:

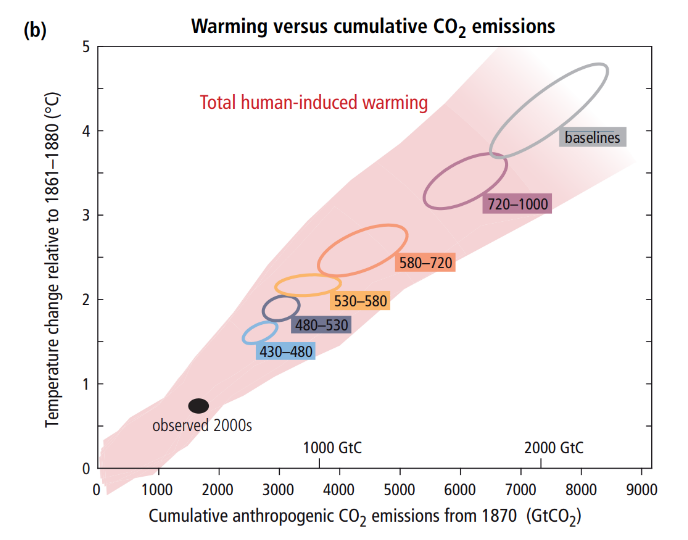
- Many wealthy countries (USA, France) are moving away from industrial economies ("Rust Belt")
- Middle-income countries are industrializing, with many of their products exported

Pointing fingers

Globalization means that countries now specialize in different things:

- Many wealthy countries (USA, France) are moving away from industrial economies ("Rust Belt")
- Middle-income countries are industrializing, with many of their products exported
- It is wrong to only blame industrial countries like China for CO_2 emissions – this misses a big part of the story
- My laptop: designed by Americans, CPU by Americans and Israelis, software from a South African company, built in China with Chinese aluminum
- ... but used by an American!
- In a global economy, this is a global problem!

A crossroads



Warming is inevitable (it's already happened). How much more depends on our choices.

Electricity generation

Electrical power is the largest source of CO_2 emissions.

- Coal: cheap and easy, but emits lots of CO_2
- Natural gas: Rapidly becoming cheap (fracking), and emits roughly half the CO_2

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Should we invest in natural gas power plants?

A: Yes; they emit less CO_2 for the energy we get

B: No; we should only build zero-emissions power plants

C: Yes; American energy independence is important and we have lots of gas

D: No; once built the gas industry will politicize their continued use

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Zero-emissions power sources:

- Hydropower: Cheap, but not always available, and disrupts rivers
- Nuclear: Large startup cost, more expensive than coal/gas, but reliable and clean
- Geothermal: Cheap where you've got it; clean
- Wind: More expensive and fickle
- Solar: *Rapidly* decreasing in cost

Projected LCOE in the U.S. by 2020 (as of 2015) $/MWh

Power generating technology		Minimum	Average	Maximum
Geothermal		43.8	**47.8**	52.1
Wind	Onshore	65.6	**73.6**	81.6
	Offshore	169.5	**196.9**	269.8
Natural Gas-fired	Conventional Combined Cycle	70.4	**75.2**	85.5
	Advanced Combined Cycle	68.6	**72.6**	81.7
	Advanced CC with CCS	93.3	**100.2**	110.8
	Conventional Combustion Turbine	107.3	**141.5**	156.4
	Advanced Combustion Turbine	94.6	**113.5**	126.8
Hydro		69.3	**83.5**	107.2
Coal	Conventional Coal	87.1	**95.1**	119.0
	IGCC (Integrated Coal-Gasification Combined Cycle)	106.1	**115.7**	136.1
	IGCC with CCS	132.9	**144.4**	160.4
Advanced Nuclear		91.8	**95.2**	101.0
Biomass		90.0	**100.5**	117.4
Solar	Photovoltaic	97.8	**125.3**	193.3
	Concentrated Solar Power	174.4	**239.7**	382.5

(Wikipedia / US Energy Information Administration)

Costs vary greatly based on location and other factors!

Transportation

- Cars – prices dropping, charging infrastructure growing rapidly
- Buses – great in cities (see "bus rapid transit")
- Trains – great if you have the transport density
- Bicycles – the most efficient transport in existence
- Airplanes – long-distance fast travel is very hard

Steps forward:

- Continual gains in efficiency: smaller/better cars, hybrid cars/buses
- Electrification of everything we can: electric trains, electric cars/lorries
- Improve mass transit access and desirability
- Bike lanes in cities
- Rail/air balance for long-haul travel is hard

The "tragedy of the commons"

The problem:

- Carbon emissions consume a *shared resource* – the ability of Earth to absorb them
- Our economic markets are based on *price signals*:
  - If a resource is precious, limited, or labor-intensive, its owner will charge more for it
  - People will buy less of it since it costs more
- ... the atmosphere is shared by everyone, but it's hard to assert "ownership" of
- There is currently no charge at *all* for using that resource!

On politics (warning: personal opinion!)

Climate action in the USA is often framed as a partisan issue.

But it doesn't need to be a *politically divisive* issue!

There are liberal, conservative, socialist, and libertarian framings of both the problem of climate change and its solutions.

Avenues for climate change mitigation

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Avenues for climate change mitigation

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- “Cap and trade”: need a permit to burn fossil fuels. Society decides to what extent to limit CO_2 and auctions that many permits; market forces determine how best to use them
- Carbon fee: Similar idea, where market incentives raise the cost and thus decrease the use of fossil fuels
- Government subsidies for lower-emission alternatives
- Decarbonization of the public sector

Balance between rich and poor countries

India and China have built a lot of coal power plants.

Some arguments:

- "It's not fair for developed countries to have burned their coal already, but developing countries can't benefit in the same way, just because they were a little later"
- "Things are different now that we know what CO_2 does, so developing countries are going to have to leave their coal in the ground"

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- We're all in this together – global problems demand global action

Obstacles

- “Regulatory capture” of government by fossil fuel industry
- Organized campaign of misinformation (compare to smoking/cancer link)
- Manufactured controversy:
  - The overwhelming scientific consensus stands behind what I’ve presented
  - ... but well-funded “skeptics” can speak with a loud voice
- Distraction:
  - Eyes have lately been (rightfully) drawn to other issues in politics
  - This is a hard time to think about decades-long issues...
- International nature of the problem:
  - Addressing climate change requires cooperation between nations
  - Our species has never really done this before
  - Historical asymmetry between nations

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  - Altered rainfall patterns
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- Solutions are technically well-understood
- ... the problem is just the cooperation needed to implement them