Global Warming

What is global warming?

Dec 11, 2018

So, this course has considered GW for maybe 30 years.

GW simply means average global temperature (air and oceans) are increasing.

Whether there is GW is a **different question** from what is causing it.

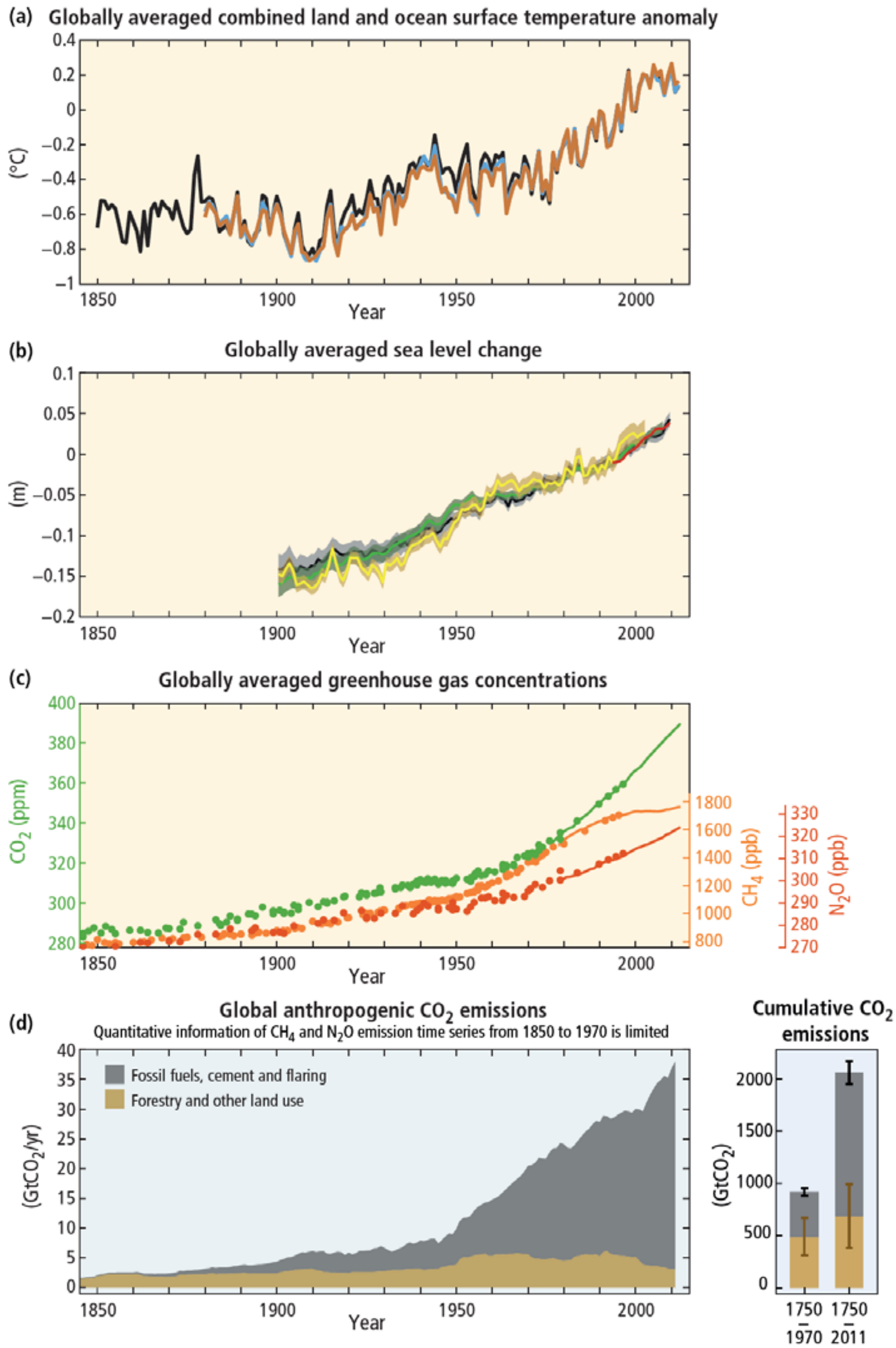
The current best estimate is that mean global temperature has increased 1 C since pre-industrial levels.

The first set of graphs are from *Climate Change 2014: Synthesis Report* at

http://www.ipcc.ch/report/ar5/syr/

This report, part of a series, was produced by IPCC (the intergovernmental panel on climate change)

The first two graphs show **deviations** from the long-term average (the average over the whole period. If temperatures are rising the deviations should start negative and then go positive.



gure SPM.1 | The complex relationship between the observations (panels a, b, c, yellow background) and the emissions (panel d, ght blue background) is addressed in Section 1.2 and Topic 1. Observations and other indicators of a changing global climate system. Observa- ons: **(a)** Annually and globally averaged combined land and ocean surface temperature anomalies relative to the average over the period 1986 to 2005. olours indicate different data sets. **(b)** Annually and globally averaged sea level change relative to the average over the period 1986 to 2005 in the ngest-running dataset. Colours indicate different data sets. All datasets are aligned to have the same value in 1993, the first year of satellite altimetry ata (red). Where assessed, uncertainties are indicated by coloured shading. **(c)** Atmospheric concentrations of the greenhouse gases carbon dioxide O_2, green), methane (CH_4, orange) and nitrous oxide (N_2O, red) determined from ice core data (dots) and from direct atmospheric measurements (lines). dicators: **(d)** Global anthropogenic CO_2 emissions from forestry and other land use as well as from burning of fossil fuel, cement production and flaring. umulative emissions of CO_2 from these sources and their uncertainties are shown as bars and whiskers, respectively, on the right hand side. The global fects of the accumulation of CH_4 and N_2O emissions are shown in panel c. Greenhouse gas emission data from 1970 to 2010 are shown in Figure SPM.2. *igures 1.1, 1.3, 1.5}*

Other factoids from this report

Ocean warming dominates the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated between 1971 and 2010 (*high confidence*), with only about 1% stored in the atmosphere. On a global scale, the ocean warming is largest near the surface, and the upper 75 m warmed by 0.11 [0.09 to 0.13] °C per decade over the period 1971 to 2010. It is *virtually certain* that the upper ocean (0–700 m) warmed from 1971 to 2010, and it *likely* warmed between the 1870s and 1971. *{1.1.2, Figure 1.2}*

Since the beginning of the industrial era, oceanic uptake of CO_2 has resulted in acidification of the ocean; the pH of ocean surface water has decreased by 0.1 (*high confidence*), corresponding to a 26% increase in acidity, measured as hydrogen ion concentration. *{1.1.2}*

Over the period 1992 to 2011, the Greenland and Antarctic ice sheets have been losing mass (*high confidence*), *likely* at a larger rate over 2002 to 2011. Glaciers have continued to shrink almost worldwide (*high confidence*). Northern Hemisphere spring snow cover has continued to decrease in extent (*high confidence*). There is *high confidence* that permafrost temperatures have increased in most regions since the early 1980s in response to increased surface temperature and changing snow cover. *{1.1.3}*

The annual mean Arctic sea-ice extent decreased over the period 1979 to 2012, with a rate that was *very likely* in the range 3.5 to 4.1% per decade. Arctic sea-ice extent has decreased in every season and in every successive decade since 1979, with the most rapid decrease in decadal mean extent in summer (*high confidence*). It is *very likely* that the annual mean Antarctic sea-ice extent increased in the range of 1.2 to 1.8% per decade between 1979 and 2012. However, there is *high confidence* that there are strong regional differences in Antarctica, with extent increasing in some regions and decreasing in others. *{1.1.3, Figure 1.1}*

Over the period 1901 to 2010, global mean sea level rose by 0.19 [0.17 to 0.21] m (Figure SPM.1b). The rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia (*high confidence*). *{1.1.4, Figure 1.1}*

So, what do we have to here?

GW is occurring, and the rate of GW is increasing.

CO2 emission have greatly increased in the in the last 100 years

And CO2 concentrations in the atmosphere are increasing.

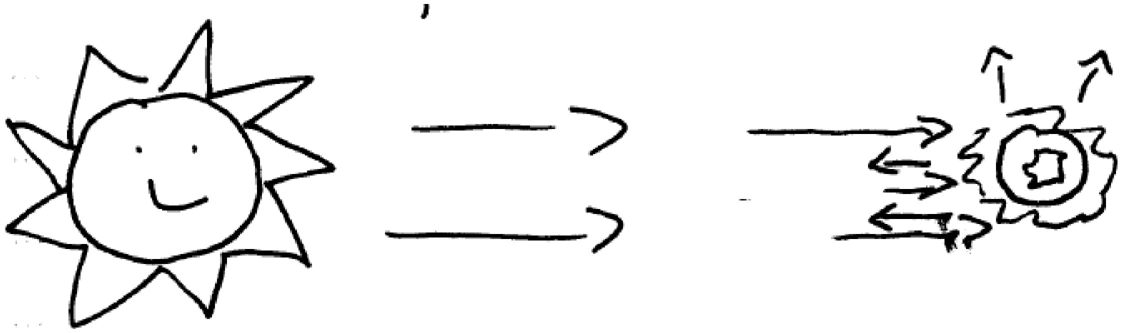
Note that these facts do not prove that CO2 emissions cause GW.

Why isn't it always freezing outside?

The gases in the atmosphere keep us warm.

Without the gases in our atmosphere earth would be very cold.

Energy from the sun hits the earth and some of this energy is held as heat by the gases in the atmosphere, some as the heat of water and earth, and some of the heat escapes.



In equilibrium, the average temperature remains constant and the amount of heat received from the sun = the amount lost to space.

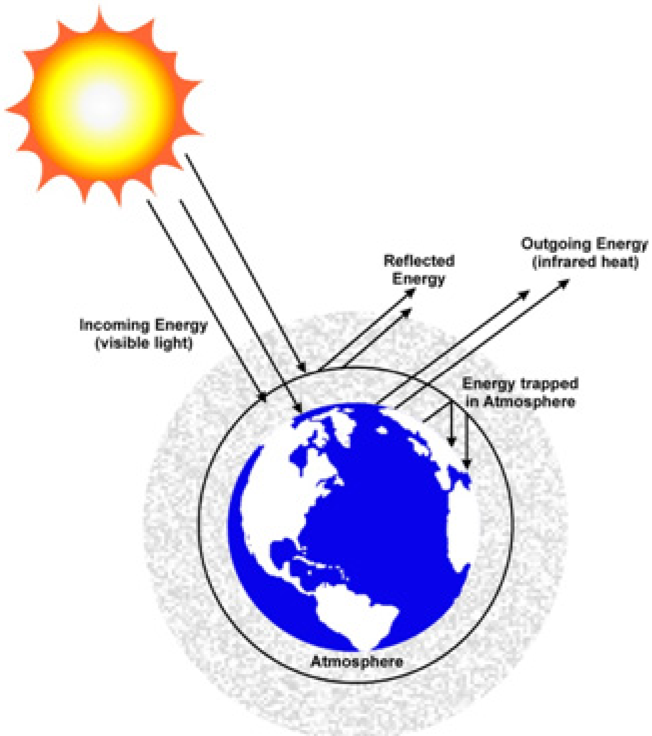
From the NETL: the energy lab at
http://www.netl.doe.gov/technologies/carbon_seq/FAQs/carbondioxide4.html
This is part of the DOE

Carbon Storage
FAQ Information Portal: Carbon Dioxide 101

What is the greenhouse effect?

Greenhouse Effect

The greenhouse effect is used to describe the phenomenon whereby the Earth's atmosphere traps solar radiation, caused by the presence of gases, such as carbon dioxide (CO_2), methane (CH_4), and water vapor (H_2O), in the atmosphere that allow incoming sunlight to pass through but absorb heat radiated back from the Earth's surface, resulting in higher temperatures. The greenhouse effect gets its name from what actually happens in a greenhouse. In a greenhouse, short wavelength visible sunlight shines through the glass panes and warms the air and the plants inside. The radiation emitted from the heated objects is of longer wavelength and is unable to pass through the glass barrier, maintaining a warm temperature similar to a car's warming interior when parked in sunlight.

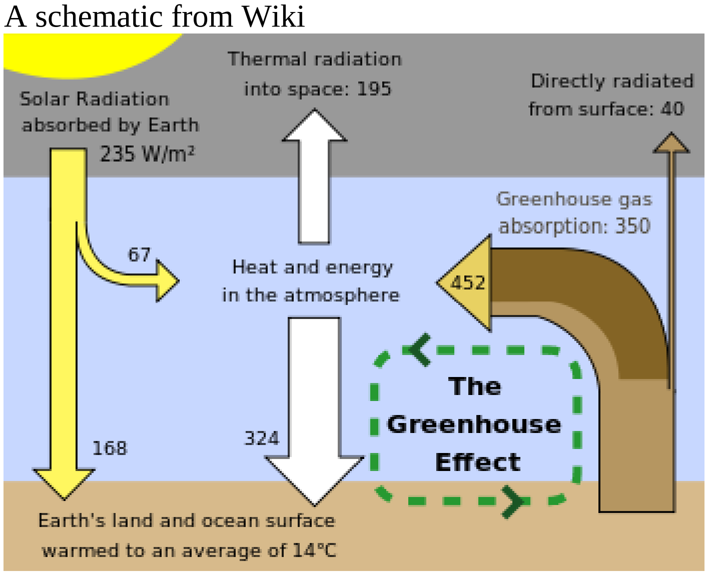


Schematic of the Greenhouse Effect.

The Earth's natural greenhouse effect is similar. Sunlight that enters the atmosphere is either reflected, absorbed, or simply passes through. The sunlight that passes through the atmosphere is either absorbed by the Earth's surface or reflected back into space. The Earth's surface heats up after absorbing this sunlight and emits long wavelength radiation back into the atmosphere. Some of this radiation passes through the atmosphere and into space, but the rest of it is either reflected back to the surface or absorbed by greenhouse gases (GHGs) that re-radiate longer wavelength radiation back to Earth's surface. These GHGs trap the sun's energy within the atmosphere to warm the planet.

GHGs, such as CO_2, CH_4, H_2O, and nitrous oxide (N_2O), can be compared to the glass panes in the greenhouse example, as they trap indirect heat from the sun. GHGs do not have a negative effect when present in natural amounts; in fact, the Earth would be 0°F (-18°C) without them.

A schematic from Wiki



Greenhouse effect schematic showing energy flows between space, the atmosphere, and Earth's surface. Energy exchanges are expressed in watts per square meter (W/m^2).

Note that in the schematic, the amount of energy entering the system (235 watts per meter squared) is equal to the amount of energy leaving the system, so in the schematic there is no GW.

So, in equilibrium (energy in equals energy out), if I understand correctly, light energy from the sun hits the ground and oceans, where it converts to heat. Some of this heat is retained by the ground and water, but some is radiated back up into the atmosphere. Some of this radiated energy goes straight back into space. But some of it is captured by the greenhouse gases (they heat up). Some of this heat in the GH gases, radiates back to heat up the planet. And, on and on.

As the amount of heat absorbing gases in the atmosphere ↑ equilibrium temp ↑.

It is important to us that the equilibrium amount of these gases is conducive to our health and prosperity

Too little—we freeze,
Too much –we cook.

Most of the gases in the atmosphere have no ability to hold heat.

The two most abundant gases, nitrogen and oxygen, have no heat-trapping ability.

99% of the atmosphere has no ability to retain heat.

A few trace gases are responsible for holding most of the heat

Water vapor
CO_2 carbon dioxide
Methane
Nitrous Oxide
Ozone

This was determined in the 1850s.

According to Wiki:
The major greenhouse gases are water vapor, which causes about 36–70 percent of the greenhouse effect; carbon dioxide (CO_2), which causes 9–26 percent; methane (CH_4), which causes 4–9 percent; and ozone (O_3), which causes 3–7 percent.[34][35][36]

While greenhouse gases are important, we would not instantly freeze without them, the oceans and the land also retain heat.

Man is causing significant ↑ in the atmospheric concentrations of CO_2, O_3, and CH_4. These are called anthropogenic effects (man-causes)

And this increased concentrations contribute significantly to the currently observed GW.

It is correct to say that almost every climate scientist who does not appear on Fox News believes this.

That is, science on this is simple, old, and accepted, at least by physicists, chemists and atmospheric scientists.[1]

Man doesn't have a significant direct effect on the amount of water vapor.

CO_2 is the big man-made player.
The concentrations of CO_2 and methane have increased by 36% and 148% respectively since 1750.[37] **These levels are much higher than at any time during the last 650,000 years**, the period for which reliable data has been extracted from ice cores.[38][39][40]

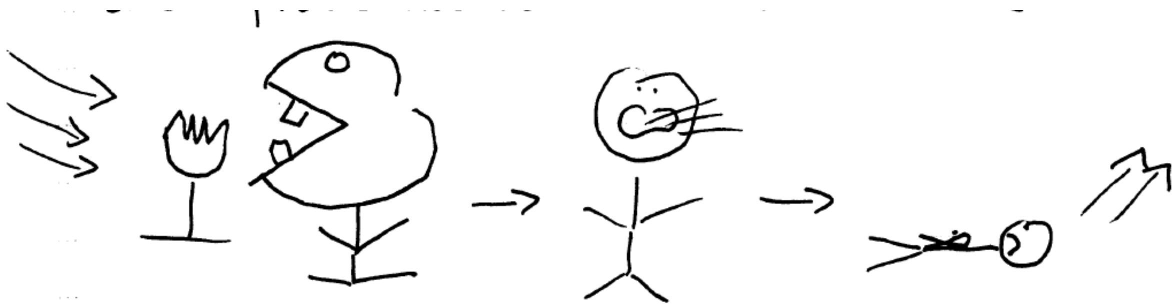
Using the six IPCC SRES "marker" scenarios, models suggest that by the year 2100, the atmospheric concentration of CO_2 could range between 541 and 970 ppm.[49] This is an increase of 90-250% above the concentration in the year 1750. Fossil fuel reserves are sufficient to reach these levels and continue emissions past 2100 if coal, tar sands and methane clathrates are extensively exploited.[50]

[11] Note that most people believe many things that are inconsistent with scientist knowledge.

Why are we ↑ the atmospheric concentration of CO_2?

To understand the process, we need to understand the carbon cycle.

Carbon is stored in plants (their prime ingredient). Animals eat plants and absorb carbon (one of their main ingredients). You are a lot carbon. When we exhale, we exhale CO_2. When animals die and decay: their carbon is either stored in the ground or it combines with oxygen to form CO_2, which plants absorb and convert to carbon body mass.

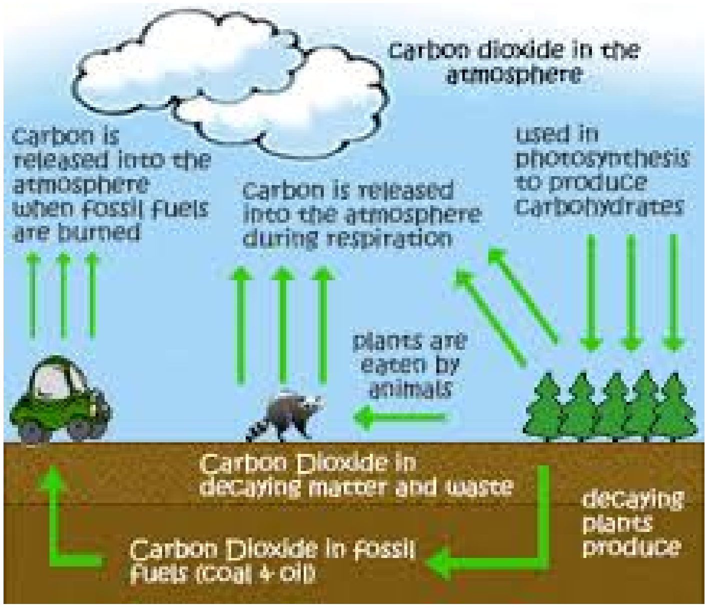


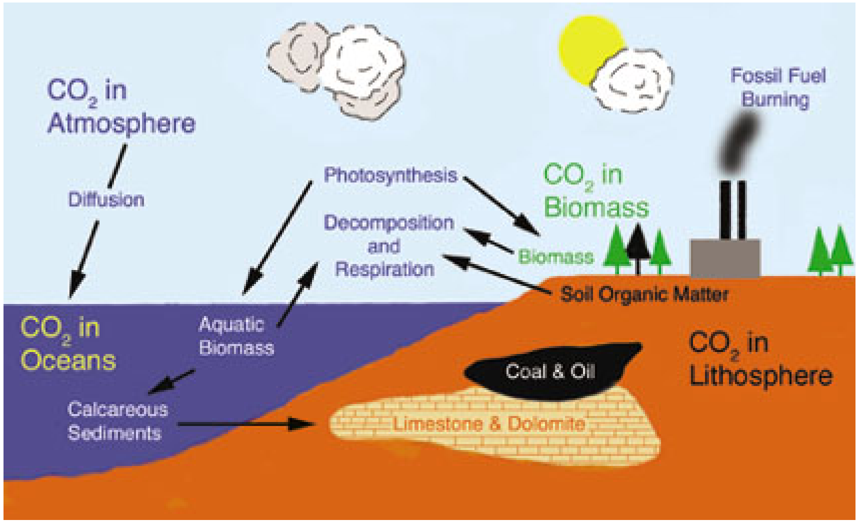
Note that fossil fuels (oil, gas, coal, etc.) are made from dead plants and animals, which are mostly carbon, so are stored carbon.[2]

When we burn fossil fuels, we release stored carbon which combines with oxygen to form CO_2 in the atmosphere.[3]

Some schematics of the carbon cycle for kids:

[2] If you choose to be cremated, or have your body burned on a funeral pyre, your carbon will be quickly converted to CO2, as compared to being left in the woods to rot and be eaten by critters. All the dead trees (standing and down) on my property north of Steamboat are stored carbon.
[3] Note that oxygen is required for carbon to burn.





In the last couple of hundred years we have been burning a lot of fossil fuels.

By the 1890s scientists had figured out that the great blossoming of combustion in the Industrial Revolution had the potential to change the atmosphere's load of carbon dioxide.

> In **1896** the Swedish chemist **Savante Arrhenius** said, "We are evaporating our coal mines into the air." Interestingly, Savante thought GW would be a good thing—he thought it would prevent a new ice age. Note that GW is probably good for Sweden, ignoring, of course, Nordic skiers.[45]

[4] Quoting Arrhenius "Since, now, warm ages have alternated with glacial periods, even after man appeared on the earth, we have to ask ourselves: Is it probable that we shall in the coming geological ages be visited by a new ice period that will drive us from our temperate countries into the hotter climates of Africa? There does not appear to be

CO_2 gases in the atmosphere are currently ↑ at approx. 1.6%/year.

---

much ground for such an apprehension. The enormous combustion of coal by our industrial establishments suffices to increase the percentage of carbon dioxide in the air to a perceptible degree." (p61)
"We often hear lamentations that the coal stored up in the earth is wasted by the present generation without any thought of the future, and we are terrified by the awful destruction of life and property which has followed the volcanic eruptions of our days. We may find a kind of consolation in the consideration that here, as in every other case, there is good mixed with the evil. By the influence of the increasing percentage of carbonic acid in the atmosphere, we may hope to enjoy ages with more equable and better climates, especially as regards the colder regions of the earth, ages when the earth will bring forth much more abundant crops than at present, for the benefit of rapidly propagating mankind." (p63). Arrhenius (translated H. Born) *Worlds in the Making* (1908).

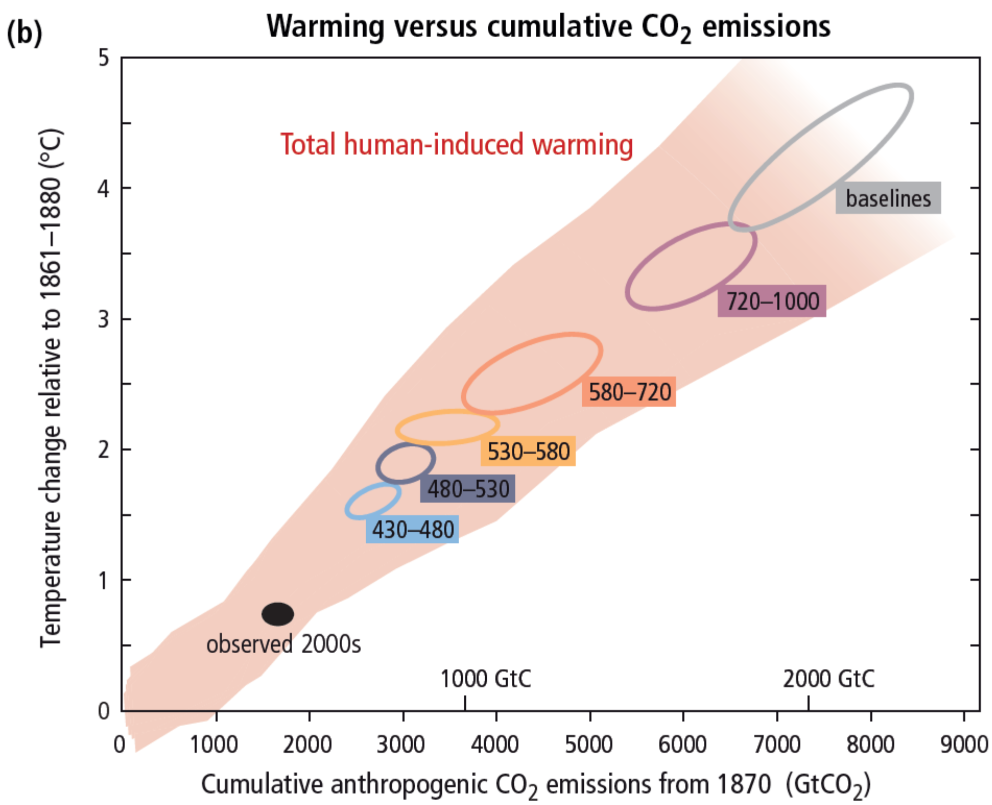
Some additional interesting quotes: "To a certain extent the temperature of the earth's surface, as we shall presently see, is conditioned by the properties of the atmosphere surrounding it, and particularly by the permeability of the latter for the rays of heat." (p46)
"That the atmospheric envelopes limit the heat losses from the planets had been suggested about 1800 by the great French physicist Fourier. His ideas were further developed afterwards by Pouillet and Tyndall. Their theory has been styled the hot-house theory, because they thought that the atmosphere acted after the manner of the glass panes of hot-houses." (p51)
"If the quantity of carbonic acid in the air should sink to one-half its present percentage, the temperature would fall by about 4°; a diminution to one-quarter would reduce the temperature by 8°. On the other hand, any doubling of the percentage of carbon dioxide in the air would raise the temperature of the earth's surface by 4°; and if the carbon dioxide were increased fourfold, the temperature would rise by 8°." (p53)
"Although the sea, by absorbing carbonic acid, acts as a regulator of huge capacity, which takes up about five-sixths of the produced carbonic acid, we yet recognize that the slight percentage of carbonic acid in the atmosphere may by the advances of industry be changed to a noticeable degree in the course of a few centuries." (p54)

[5] There is a famous, old, Nobel laureate, physicist, Freeman Dyson, who also thinks that global warming might be a good thing. See Nicolas Davidoff, The Civil Heretic, NYT March 28, 2009

Predictions
What is going to happen depends on what we do, or don't do.

GW warming predictions differ from scenario to scenario. For example, GH gas emissions increasing at their current rate is one possible scenario—a likely scenario.

In the next graph from the 2014 report, baseline is the current trend, the other circles represent different degree of reductions in GH gas emissions.



The current situation is the black dot (1000 Gt of CO2 in the atmosphere and average temp. about 1-degree C about preindustrial levels)

Note that an increase of 5 degrees C is an increase of about10 degrees F: WOW.
And this is all in the 21^{st} Century.
Note that the horizontal axis is in terms of cumulative emissions, not per-year emissions.[6]
The pink reflects confidence intervals on the estimates.

[6] A gigaton is a thousand million tons. "GtCO2" is an abbreviation for "gigatons of equivalent carbon dioxide". It is a simplified way to put emissions of various GHGs on a common footing by expressing them in terms of the amount of carbon dioxide that would have the same global warming effect.

Surface temperature is projected to rise over the 21st century under all assessed emission scenarios. It is *very likely* that heat waves will occur more often and last longer, and that extreme precipitation events will become more intense and frequent in many regions. The ocean will continue to warm and acidify, and global mean sea level to rise. *{2.2}*

Make sure you understand the confidence intervals. The estimates are a function of CO2 concentrations in the atmosphere, so for a given level of concentration the variance in the estimated temperature is due to modeling differences and the fact that the inputs into those models are variables measured with uncertainty.

The graph does not predict how much CO2 will end up in the atmosphere.

The newest IPCC report Oct (2018) is at.

http://www.ipcc.ch/report/sr15/
This is the web page for the IPCC (intergovernmental panel on climate change) report on GW of 1.5. C, published Oct 2018

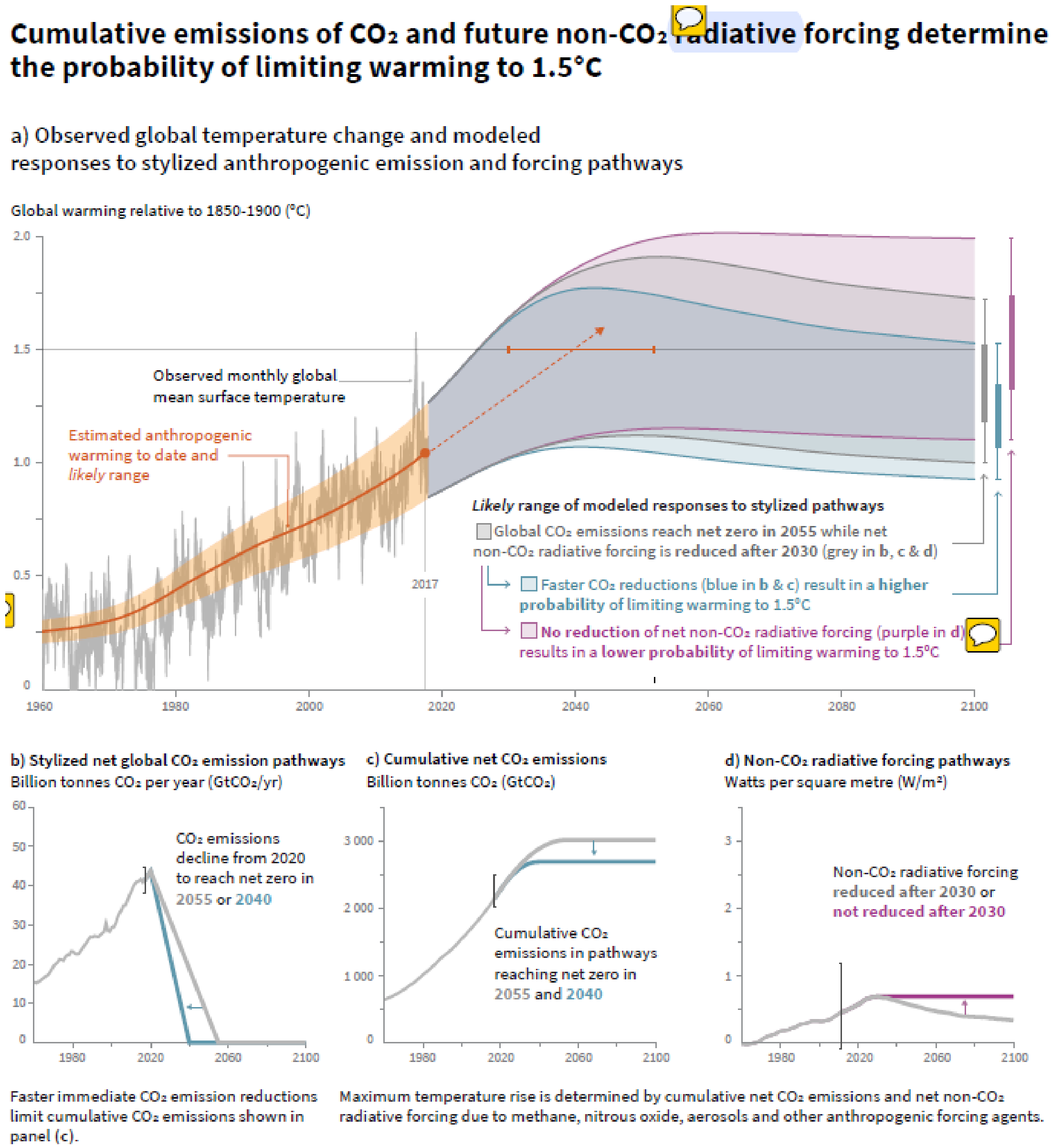
Go to the "Summary for Policy Makers and skim.
an IPCC special report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty

This current report is mostly **not** about what will happen if we do nothing, it is more about whether we can keep the rise about pre-industrial levels to 1.5 C or less.

A1. Human activities are estimated to have caused approximately 1.0°C of global warming5 above pre-industrial levels, with a *likely* range of 0.8°C to 1.2°C. Global warming is *likely* to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate. (*high confidence*) {1.2, Figure SPM.1}

Note that many of the paths in the next graph, are predictions based on scenarios where CO2 emission drop to zero in the next 30 or so years.

Note that the graph does not say that temperature increase will max out at a 2 degree increase about pre-industrial levels. (project the arrow line out).



Snow cover in North America has declined in last 25 years and growing seasons are ↑ in length.

↑ Temperatures causes the atmosphere to suck up more water from the oceans, which makes more water available for rain-making and storms.

Make sure you recognize the distinction between GW and what causes GW. (Professor Phil Graves, for example, believes, that there is GW, but is not convinced man has played a big role)

Effects of global warming are not uniform.

Some areas will get colder
wetter
dryer
More variation in weather

Is GW good or bad? That is, is global warming good or bad?

Besides Savante, only an economist would ask this question?

The answer depends on:

1. How fast temp ↑?
2. Time preference
3. Where you live?

1. The slower the temp ↑ the more time we (and nature) will have to adjust (mitigate some or all of the negative effects).

The costs of a rapid ↑ are much greater than the costs of a gradual ↑.

If temp ↑ slowly enough (and not too much in total, or does not hit a threshold), most of us won't notice much. We will gradually adapt, and while bad things will happen, they will happen very slowly.[7] But, we are noticing, so the rate of increase is not that slow.

However, a rapid ↑ could be very costly.
Or, a threshold temperature that causes a discrete, and large jump, in injuries.

2. How much we want to spend now to improve the future depends on our rate of time preference

How we choose to discount the future.

More on this soon.

3. The B & C of global warming will not be uniformly distributed.

Some gainers; some losers.

What we should do depends on how we count these different groups (who do we include in society).

Some models predict that the U.S. will, on net, benefit slightly from global warming but that many poor developing countries will suffer greatly. "America First"

---

[7] I am aware of GW. When I grew up in Chicago there typically was snow on the ground for most of the winter. I remember this because I still have my memory; it will fade soon with old age. But Chicagoans born in the last twenty-five years have a different history of Chicago weather, a much warmer status quo than mine.

Some other important "Stylized" facts.

1. ≈ 7 billion tons of CO_2 and other heat-trapping gases are added to the air each year.

U.S. was, until recently, the leading source (≈ 25%), but now it is China

And, most of the emissions come from the developed countries (but some developing countries are rapidly ↑ the output—China, India, Brazil[8]).

2. The affect of these gases on global warming is **independent of where the emissions occur**.

   It is a global pollutant – efficiency requires that is controlled globally.

3. Greenhouse gases are **stock pollutants**: the stock builds up year to year, rather than quickly dissipating.[9]

The amount we emit now will affect CO_2 concentrations in the atmosphere for 100s of years. Even if we immediately go to zero CO2 emission, GW will continue, just at a slower rate. The polar bears [10]and the Eskimo culture are probably history no matter what we do now.

The current CO_2 concentrations are a function of our total emissions from the time of the Industrial Revolution.

4. The first Bush administration (Republican) signed a global treaty negotiated in Rio de Janeiro in 1992.[11]

   The treaty required that we ↓ emissions of GH gases to 1990 levels.

5. In 1998 the Clinton administration (Democrat) signed the Kyoto Protocol.

   The Clinton Administration agreed to ↓ emissions of GH gases to 93% of 1990 levels in the next 10 to 15 years.

   This treaty has never been ratified by the U.S. Senate. It has not even been submitted for consideration and won't be anytime soon.[12]

---

[8] The next President of Brazil, like Trump, does not believe in man-induced GW.
[9] As compared to flow pollutants that the environment absorbs and breaks down.
[10] There is some debate about whether polar bears and grizzles are separate species. They do interbred and their rate of interbreeding is increasing, as their populations shift locations.
[11] Many republican politicians used to believe in GW, and man being a contributing factor.
[12] 67 Senate votes are needed to ratify a treaty (that is 2/3 of the 100). This makes ratification very difficult.

For the rest of the world, the Kyoto Protocol went into "effect"—whatever that means—but the U.S. was not a party to the treaty. It was signed and ratified by almost 200 countries. It is supposedly "binding" on those countries until 2012 (which is now the past)

6. Our last President Bush (Republican), and the corresponding Congress, had no interest in the Treaty.

7. Obama had interest when he became President, but he and the last Democratic Congress (Democrats controlled congress when Obama first became President) failed in doing anything about it. All U.S. treaties need to be ratified by the Senate and it takes 60 votes to overcome a filibuster. In the current Senate, there is no chance the Treaty, or any GW treaty, will be ratified.

8. In 2009, several major countries, including the U.S. "produced" the Copenhagen Accord.[104] Parties agreeing with the Accord aim to limit the future increase in global mean temperature to below 2 °C.[105]. Many countries agreed: they "agreed to take note of" the Accord." Obama went to the meeting and made a last-minute closed-door deal. The Copenhagen Accord has no teeth. There have been target reductions submitted by a number of countries, but these targets are not binding. The Copenhagen meetings are considered a failure.

9. The coal, gas and oil industries in the U.S. have lobbied, and continue to lobby, very hard, and very successfully, to not reduce the use of their outputs. Note the Koch brothers.

10. Representatives and Senators from big carbon-energy producing states (Penn. Ohio, W Virginia, Wyoming, etc.) are not likely to vote on measures that would reduce the use of carbon-based fuels. In Colorado this is an issue, but a lesser issue.

11. Many members of the current Congress do not believe in GW, but now a majority of Americans believe that the planet is warming, and that man is influencing the rate.

12. A big change: On 12/07/2009 The EPA stated (http://yosemite.epa.gov/opa/admpress.nsf/7ebdf4d0b217978b852573590040443a/08d11a451131bca585257685005bf252!OpenDocument)

    After a thorough examination of the scientific evidence and careful consideration of public comments, the U.S. Environmental Protection Agency (EPA) announced today that greenhouse gases (GHGs) threaten the public health and welfare of the American people. EPA also finds that GHG emissions from on-road vehicles contribute to that threat…

    EPA's final findings respond to the **2007 U.S. Supreme Court decision** that GHGs fit within the Clean Air Act definition of air pollutants. The findings do not in and of themselves impose any emission reduction requirements but rather allow EPA to finalize the GHG standards proposed earlier this year for new light-duty vehicles as part of the joint rulemaking with the Department of Transportation….

    President Obama and his EPA Administrator Jackson have publicly stated that they support a legislative solution to the problem of climate change and Congress' efforts to pass comprehensive climate legislation.

However, climate change is threatening public health and welfare, and it is critical that EPA fulfill its obligation to respond to the 2007 U.S. Supreme Court ruling that determined that greenhouse gases fit within the Clean Air Act definition of air pollutants.

EPA issued the proposed findings in April 2009 and held a 60-day public comment period. The agency received more than 380,000 comments, which were carefully reviewed and considered during the development of the final findings.

Information on EPA's findings: http://www.epa.gov/climatechange/endangerment.html

Arguably, EPA now has the legal right and obligation to regulate green-house gas emissions, even if Congress does nothing.

But the EPA has not done a lot to reduce CO2 emission, and the current EPA wants to reverse those minor actions.

13. In Nov. 2014 President Obama and the Chinese government agreed to each reduce their future emissions. It is not clear exactly how this will happen, and the current Congress does not like it. It cannot pass as a formal treaty. That said, it was a big deal.

14. (wiki) The **Paris Agreement** (French: *Accord de Paris*), **Paris climate accord** or **Paris climate agreement** is an agreement within the United Nations Framework Convention on Climate Change (UNFCCC) dealing with greenhouse gas emissions mitigation, adaptation and finance starting in the year 2020. The language of the agreement was negotiated by representatives of 196 parties at the 21st Conference of the Parties of the UNFCCC in Paris and adopted by consensus on 12 December 2015.[3][4] As of November 2017, 195 UNFCCC members have signed the agreement, and 170 have become party to it.[1] The Agreement aims to respond to the global climate change threat by keeping a global temperature rise this century well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius.[5]

    In the Paris Agreement, each country determines, plans and regularly reports its own contribution it should make in order to mitigate global warming.[6] There is no mechanism to force[7] a country to set a specific target by a specific date,[8] but each target should go beyond previously set targets.

    In June 2017, U.S. President Donald Trump announced his intention to withdraw the United States from the agreement, causing widespread condemnation both internationally and domestically. Under the agreement, the earliest effective date of withdrawal for the U.S. is November 2020. The U.S. has now withdrawn.

15. **The uncertainties with respect to the benefits and costs of global warming** are much greater than the uncertainties with respect to the magnitude of global warming. Difficult to estimate B & Costs. Make sure you distinguish between injuries and damages.

16. Particulate pollution, ceteris paribus, probably ↓ temperatures, so partially offsets the impact of ↑ CO_2 concentrations.

So, ceteris paribus, ↓ particulate pollution might increase the rate of global warming.

17. Global warming is a global problem and requires a global solution.

18. There are many game-theoretic aspects of negotiating and enforcing a global treaty.

Should the U.S. agree to unilaterally ↓ emissions while emissions from developing countries are rapidly ↑? The impact of my reductions on global warming is a function of what you do and vice versa.

Is it "fair" to ask developing countries to ↓ or not ↑ emissions when the problem to date has been caused by the developed countries?

Note the U.S. China agreement.

19. Humans did not evolve in a word where world-wide accords were required, situations where we must cooperate with people outside of our tribe, or group. On the contrary, we tend to be suspicious towards and competitive with other groups. In ages past, problems were local problems.

20. Humans did not necessarily evolve to be logical or scientific. Science is a relatively new invention—only a couple of thousand-years old.

21. Members of a group will reject the idea that GW is occurring and is man-made if the idea is coming from people who are not part of their group, particularly if there are hostilities between the groups.

22. The Oct 2018 Un Report on the effects of a 1.5 C temperature increase are sobering.

Consider some "policy" to reduce or ↓ the rate of ↑ in global warming.

For example, achieving the Kyoto Protocol for the U.S. by ↓ the emissions of greenhouse gases to 93% of 1990 levels, or the new U.S. Chinese goals, or the new Paris goals.

Such a policy will generate a stream of benefits and costs.

Let
B_t = *benefits (in $) at time t*
t = 0, 1, 2, 3, ….. ⌡
where
t = 0 is the current year.

C_t = costs (in $) at time *t*.

What is the present value of this project?

$$PV = (B_0 - C_0) + \frac{B_1 - C_1}{D(1)} + \frac{(B_2 - C_2)}{D(2)} + \frac{B_3 - C_3}{D(3} + \cdots +$$

$$= \sum_{t=0}^{\infty} \frac{(B_t - C_t)}{D(t)} \quad \text{where } D(0) = 1$$

D(t) is a function D of t, such that $D(t+1) \geq D(t)$

That is, net benefits of X is period t+1 have less value in the present (present value than do net benefits of X in period t.

Distinguish between how the market discounts the future (determine by lending and borrowing_
The rare at which you as an individual discounts the future
The rate a which society wants to discount the future (the social rate of discount)

So, we might distinguish between $D_m(t)$, $D_p(t)$, and $D_s(t)$

Experiments and observed behavior indicate that most people have a positive personal rate of discount; that is, they discount the future.

The market place uses *exponential discounting*.[13] That is, it is assumed that

$D(t)=(1+r)^t$

[13] Probably a historical accident?

Where r is the constant rate of discount: is an interest rate

If society is using exponential discount, r_s is the *social rate of discount.*

Let's play a bit with exponential discounting.[14]

If $r = 0$
PV= $\sum_{t=0}^{\infty}(B_t - C_t)$

In this case, the present value of a net benefit to society in period *t* does not depend on *t*.

If society's $r = 0$, society is indifferent between a net benefit of $1000 today and a benefit of $1000 *t* years from today.

If $r > 0$, society discounts the future.

A net benefit of $*x* *t* years from today is worth less today than a net benefit of $*x* today.

Having a positive discount rate means we prefer present benefits to future benefits; that is, we put less weight (discount) benefits received in the future

And,
a net benefit of $*x* (*t*+1) years from today is worth less today than a net benefit of $*x* *t* years from today.

What if r was infinity?

You have some personal rate of discount, the rate at which you personally discount the future benefits and costs that you will experience. You might or might not discount exponentially.

A high r_s is another way of saying society heavily discounts future benefits and costs. r_s=0 says means society discounts the future not at all. An r of infinity says we completely discount the future.

For any given positive *r*, and exponential discounting, the more distant the future net benefit, the more we discount it.

E.g.

[14] For practice consider a two-period world, where you start with I dollars of income. C0 is your consumption this period and C1 is your consumption next period. Income you do not spend this period can be invested and earn $(1+r_m)$ on each dollar invested. Let r_p denote your personal rate of discount. Graph you budget line and some of your indifference curves. Identify the relationships between r_p and the slope of your indifference curves, and identify the relationship between r_m and the slope of your budget line.

(years in future)/(discount rate)	0	1	5	10	50	100
0	$1	$1	$1	$1	$1	$1
.01	$1	99¢	95¢	91¢	37¢	37¢
.05	$1	95¢	78¢	61¢	9¢	1¢
.10	$1	91¢	62¢	39¢	1¢	0¢
.20	$1	83¢	40¢	16¢	0¢	0¢

Note that the present value of anything a hundred years from now is ≈ 0 if r = .05 or greater.

Just to be clear: society, supposedly, has some rate of time preference and if this rate of time preference can be expressed in terms of a constant interest rate, r.

If r = .10 the present value of any net benefit that occurs 50 or more years from now is effectively 0.

If r = .20 the present value of any net benefit that occurs __ or more years from now is effectively 0.

If we have a proposed project/policy with SR costs but benefits that would not occur for at least 100 years, it would have a negative PV if society's r ≥ .05.

If we have a project/policy with SR costs but benefits that do not occur for at least 50 years, it would have a negative PV if society's r ≥ .10.

In summary, for a lot of discount rates, projects that don't produce benefits for a long time fail the B/C test because they have a negative present value.

For example:
If r = .10
If all the cost is incurred in the current year and that c = 100
and if all the benefits incur in year 100 and B_{100} = 10,000

$$PV = -100 + \frac{10{,}000}{(1+.10)^{100}} = -100 + 72¢$$

= -$99.28

And the policy would fail the B/C test – it is not a PPP, it is not efficiency increasing.

Read the class reading on discounting and present value.

At this point, you should be thinking the following:

If exponential discounting is the way society wants to discount the future
And if $r_s > 0$

Any project with large upfront costs, and benefits that only occur after 20 or 30 years, will not be efficiency increasing.

So, policies to decrease the rate of GW are likely to be efficiency decreasing; that is fail a benefit-cost test.

But who says society (or you) must discount the future using exponential discounting.

There are other functions D(t) with the property that $D(t+1) \geq D(t)$

There are many mathematical functions that can be used to down weight the future and down weight the farther future more than the nearer future: the exponential formula presented above with a constant r is just one way of mathematically down-weighting future benefits and costs. For example, one might imagine using a declining (or increasing) r as one move farther into the future. God has not told us that exponential discounting is best. For a discussion of what some noted economists thought, in 1999, about discounting, see Portney (1999). **Read this article.**

Hyperbolic discount: an alternative form of D(t)

Many studies find when choosing between a current benefit and a larger future benefit
People become more impulsive the shorter the wait.

Quoting from an article by the Joseph Redden: Hyperbolic Discounting - behaviorlab.org

"When offered a larger reward in exchange for waiting a set amount of time between possible future rewards, people act less impulsively (more often choose to wait) as the two possible rewards happen further in the future.

Put another way, people avoid waiting more as the wait nears the present time…. To illustrate, many people prefer $100 now to $110 in a day, but very few people prefer $100 in 30 days to $110 in 31 days.

This behavior is not consistent with exponential discounting.

This type of intertemporal choice is consistent with something called hyperbolic discounting, which is the formula

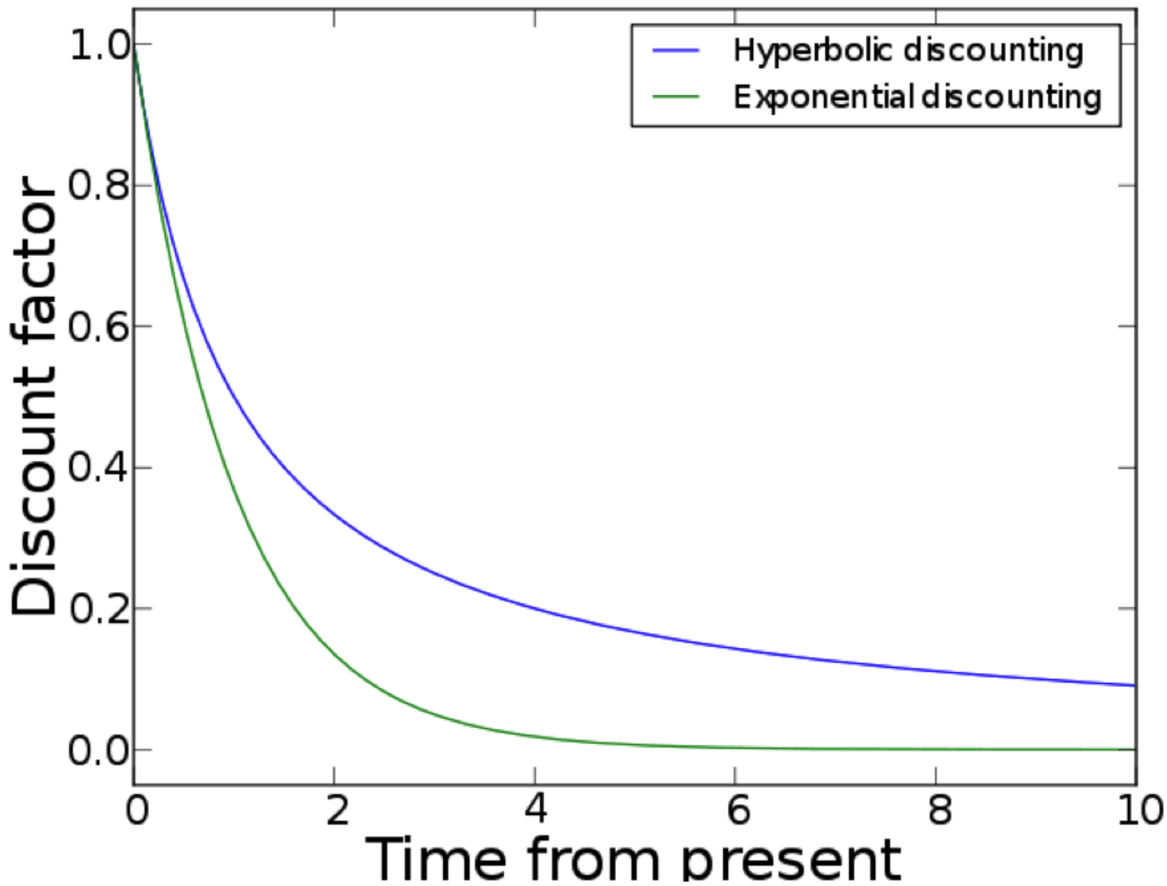
$$\sum_{t=0}^{\infty} \frac{(B_t - C_t)}{(1+kt)^{a/b}}$$

where *a*, *b* and *k* are positive constants.[15] With hyperbolic discounting, the rate of discount declines the farther the delay is in the future; that is, now and a year from now is discounted more than ten years from now vs. eleven years from now.

See also: https://en.wikipedia.org/wiki/Hyperbolic_discounting

---

[15] A simple special case is a=b.


Hyperbolic discounting
Exponential discounting
Discount factor
Time from present
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
10

At what rate, and how, “should” society discount the future?

This is an ethical question.

Whether to use exponential or hyperbolic, or some other from of D(t) is an ethical question.

And, then if exponential is chosen, what r is an ethical question.

Or, if hyperbolic, what values for a and b.

How society should discount the future, is critical to what are, and what are not, efficiency increasing environmental policies.

If society want to discount the future, it does not have to be exponential discounting?

Most economists believe economists have no expertise in determining D(t): what rate to use is more a question for philosophers and religious leaders than for economists. At least that is what an economist would say.

There are different opinions.

Possibilities:

D(t)=1 for all t (in terms of exponential r = 0 that is, no discounting)[16]

D(t) mimics the long-run rate of technical progress (in terms of exponential, r = long-run rate of technical progress)

D(t) mimics the long-run risk-free market rate of interest (In terms of exponential, r = real rate of interest on long-term risk-free bonds (LT U.S. government bonds)).

The long-term rate of technical progress is a few percent.

The real rate of interest on long-term U.S. government bonds is determined by current demand and supply for these bonds, which is determined by the time preferences of people currently alive, future generations get no direct vote.

If you wanted to treat all generations equally and you believed that technical progress will continue at its historical rate, ….

---

[16] Most economists advocate discounting the future, but they disagree as to how much. See the article by Portney.

set *r* = long-term rate of technical progress > 0.

Ceteris paribus, technical progress will make the future better, so to “even the playing field” we would discount the future by the rate of technical progress.

If you wanted to treat all generations equally but were not willing to assume that technical progress will continue (assuming no technical progress is extreme),

set *r* = 0 or at least a rate less than the historical technical rate of progress.

If you feel the market correctly weights the preferences of the future (why?),

set *r* = real rate of interest on long-term risk-free bonds.

If we choose a positive *r*, we won’t want to do much today to reduce global warming 50 or more years from now if you assume r is a constant (the discounting described above assumes r is a constant.), even if the GW in 50 years is a disaster.

If we discount the future with a constant r of more than a few percent society does not want to start projects that cost now but only pay off in more than 50 years.

Raises question about how much we should or should not worry about the condition of nuclear waste a 1000 years from now. (Any positive discount rate means the PV of a cost or benefit that happens a thousand zeros in the future is zero)

An important aside: Assuming that discounting should be done with the formula $\sum_{t=0}^{\infty} \frac{(B_t - C_t)}{(1+r)^t}$ pretty much guarantees that if r>0 the future will count for little. This functional form imposes it: it says that a future net benefit is discounted by the same fixed percentage for each additional year of waiting. This is called *exponential discounting* and the method used in financial discounting.

If, in fact, current people have substantial caring for the future, but in the shorter run they care more for the present than the near present, this is probably not the formula to use.

As noted above, many studies show that most of us do not discount our future benefits and costs using exponential discounting.

And most people make social policy decision that are exponential discounting. For example, people care whether the methods used to store nuclear waste will still be protective in a 1000 years. But that is only consistent with exponential discounting if r=0.

Let’s proceed assuming hyperbolic discounting, but not at too high of a rate

In which case, to proceed with the analysis, we need to estimate:

> The costs and benefits, at each point in the future, of policies to ↓ global warming,
>
> The way to ↓ global warming is to ↓ the burning of fossil fuels (gas, oil, coal, etc.).[17]

First consider the benefits and costs of global warming.

Note that a benefit from global warming is a cost of ↓ global warming.[18]

And

A cost of global warming is a benefit of ↓ global warming.

So, to keep things straight let’s use costs to represent only the **costs of reducing** or storing GH gas emissions. So, **benefits would cover all of the effec**ts (positive and negative) associated with less GW.

There numerous ways this could be analyzed/graphed: in terms of rates of GW (increasing left to right on the horizontal axis), or in terms of rates of GW (decreasing left to right on the horizontal axis), or emissions of GH gases on the horizontal axis (increasing left to right or decreasing left to right).

Other options might be in terms of total CO2 in the atmosphere (concentrations)

That is, there are lot of ways to describe the problem.

Analysis is simplified by the fact that (without capture) there is a one-to-one between amount of carbon in a unit of fuel and the amount of CO2 that will be produced by burning it.

For fun, graph a couple of different ways.

What are some of the costs of global warming?

What are some of the benefits?

---

[17] Or possibly plant a lot of trees, or store CO2 in underground caverns. Note that world-wide the stock of living wood is on the decline. See, for example, Gillis (2011).

[18] That is, if there is a benefit from GW and one reduces GW that benefit will be lost.

What are some of the costs of global warming?

↑ Storm damage
Flooding from storms (temporary)
↑ Cooling costs (air conditioning and refrigeration)
Some crops will no longer be viable in their current locations
↑ Sea level rise will eliminate land and cause damages to buildings
↑ Heat-related disease and fatalities
Loss of some cultural resources
↓ Tourism in some areas
Loss of some species, particularly species that currently live in very cold areas, and species where migration north is difficult (e.g. animals in Yellowstone).

What are some of the benefits of global warming?

↓ Cost of heating
↑ Growing season
Some areas that are not currently agriculturally viable will become viable
↓ Cold related disease and fatalities (guys freezing after passing out in the snow on the way home from the bar)
↑ Tourism in some areas

The economic models make many assumptions and the predictions have wide confidence intervals (highly sensitive to assumptions made).[19]

What do these models suggest? Economic impact of global warming on temperate zones will smaller in temperate zones.

↑ In agricultural productivity,
↑ In storm damage and coastal flooding.

East coast of the U.S. will suffer more than the NW in terms of sea rise and temperature rise (it is cold and rainy is Seattle and the land rises quickly from the ocean.
Canada and Russia are predicted to suffer less losses than a lot of other places.[20]

Big negative impact on poor, agricultural tropics vulnerable to flooding, drought and epidemics: places like northern Africa, Bangladesh.

This will motivate mass migrations north. We are starting to see this.

[19] There is more uncertainty about the effects of an x% temperature increase than whether temperature will increase x% if CO_2 concentrations increase by y%.
[20] That said, pond hockey is on the decline in Canada because they don't freeze over like they used to.

Continuing to assume *low rate of discounting*

If we are only concerned with ourselves (we define society as the U.S. now and in the future) we probably should do little (do I really believe this, or am I just trying to rile up the students?).

I don’t really believe this. But I would say that we should do less if we do not care about foreigners

Alternatively, if we expand the definition of society to include all humans, including future generations,

We should take steps, maybe modest, maybe humongous, to **either** reduce global warming or to mitigate the effects of global warming.

If are only goal was to help the poor of developing countries (ignore our WB), which of the following should we do

1. ↓ our emissions of greenhouse gases at a cost to us in terms of our current consumption?

2. Allocate current resources to those countries that will be most effected, requiring that they invest in capital that will help them mitigate the effects of global warming? Stuff like dikes, irrigation systems, better and more heat-resistant agricultural methods.

3. Allocate current resources to those countries that will be most effected to ↓ or mitigate the effects of pollution that is currently affecting them (smog, water pollution, sewage, water treatments plants, etc.)?

4. Allocate current resources to those countries that will be most effected to ↑ their standard of living now (↓ poverty).

How would <u>you</u> allocate the resources? Let’s vote.

Fifteen years ago, Thomas Schelling, an outstanding economist (he won the Nobel Prize), suggests that it makes most sense to divert the sums needed to curb global warming into investments that mitigate poverty in the developing world.

> "They have more immediate environmental problems ... sanitation, congestion, disease ... that demand prior attention."

> Read his two papers on the class web page:

What Makes Greenhouse Sense: Time to Rethink the Kyoto Protocol, Thomas Schelling, Foreign Affairs, June, 2002

The Cost of Combating Global Warming, Thomas Schelling, Foreign Affairs, Nov-Dec 1997

What are some of the important assumptions behind the Schelling conclusion? A primary one is that GW will **not** have a large negative effect on us? And a dollar spent on other environmental issues in impacted poor countries will reap benefit immediately whereas a dollar spent now on reducing green-house gas emission will not reap benefits for many years. And, we are capable of improving environmental conditions in these countries through investments in those countries (the funds will not be wasted on corruption, etc.).

Think about where one would get more PV bang for the buck, a dollar spent on reducing green-house gas emissions, or a dollar spent on improving the standard of living in poor countries. If there is more PV bang for the buck from reducing emissions, efficiency would dictate that we do that.

If we DO want to reduce greenhouse emissions how should we do it?

How to efficiently ↓ emissions of greenhouse gases?

If we take the Kyoto Protocol (or some other target) as given

> That is, take as given that we need to ↓ the emissions of greenhouse gases to below 1990 levels
>
> > And not ask whether this is the appropriate ↓.

Then, efficiency dictates that we achieve this reduction in emissions at minimum cost. (This is a critical point)

See my econ 2010 notes on this (I am serious. Read these notes) :
Achieving Environmental goals at minimum cost

I will ask questions from these notes on the **fina**l

Note that current levels are significantly higher than in 1990.

How best to achieve the reduction?

Economists recommend:
Either
A carbon tax
or
Permits for emissions (emissions trading)

but NOT
Command and Control.

Other factoids and estimates

1. The total cost of ↓ the concentrations of greenhouse gases by some specific amount is a rapidly ↑ function of the speed of with which we do it. So, might want to approach the target level gradually, but not too gradually.

2. The marginal cost of ↓ the emissions of greenhouse gases is likely much lower in developing countries than it is here or in the other developed countries.

> William Nordhaus, an economist at Yale, estimates that bribing or bullying the developing world to switch to energy-saving, carbon-sparing technologies – things like insulating buildings and generating electricity with natural gas rather

than coal – would get the job done for one-ninth the cost of squeezing comparable emissions out of the developed economies.

3. Coal is one of the most carbon-intensive fuels.

What is a carbon tax?

It is a tax on fuels in proportion to their carbon content.

If the goal for the U.S. was to reduce their emissions of greenhouse gases to "Kyoto levels," we (the U.S.) could do it efficiently (a minimum cost) with such a tax.

Achieving the goal with such a tax would minimize the cost of achieving the goal.

A carbon tax in the U.S. would be quite easy to administer and monitor: the tax would be applied on oil, natural gas and coal as a function of their carbon content. This would happen at the production level or when it is imported.

How do we determine the tax rate that will reduce U.S. CO2 emissions to their 1990 levels?

The slower the tax is increased to the necessary level, the more time people will have to adjust and the lower the total cost of adjustment.

Would the U.S. want to give credit (reduce your carbon taxes) for carbon reductions in other countries?[21]

Would a carbon tax be technically feasible for developing countries? Yes, most oil, gas and coal come from a limited number of sources.

The chances of Republicans voting for a carbon tax are slim. Chances of a Senator or House Member from a coal or oil state voting for it are slim.

[21] Firms in Russia were recently accused of selling fake credits.

Permits for the emissions of greenhouse gases:

Read the following two articles. The second one describes the trading scheme for CO_2 permits that is being phased in in the European Union.

The Tradable Permits Approach to Protecting the Commons: What have we learned? -Tom Tietenberg

Designing Emissions Trading in Practice: General Considerations and Experiences from the EU Emissions Trading Scheme (EU ETS), Peter Heindl and Andreas Löschel, Discussion paper 2011

Would a trading system need different types of permits for different greenhouse gases? Or could a permit be denoted in terms of carbon-release equivalents (e.g. one unit of methane requires X carbon credits. This is easy)

A country or region (like the EU) could agree to reduce their CO_2 emissions by a certain amount and then choose how they want to achieve the goal (tax, permits, C and C).

Since the effect of greenhouse gases is independent of where they are emitted - a ton emitted here is equivalent to emitting a ton there - a permit system or carbon tax would not cause distributional pollution impacts, even if were only regional.

One could consider a permit system as a way for a country to achieve its reduction goal. Or, in theory, one could imagine a world-wide system.

If there were a world-wide permit system, as long as the marginal cost of ↓ emissions is lower in the developing countries, the developed countries would purchase their permits and the reductions would occur in the developing countries.

Enforcement is always an issue. How difficult enforcement would be depends on a what point in the process one needs a permit. For example, if the domestic producer of oil needed the permits to sell the oil then enforcement would not be a gigantic deal, even is a less-developed country. Of course, corruption is always a problem.

Some number of permits could be issued, possibly greater than the target amount, and then the U.S. or some international organization (as examples) could buy some up over time gradually ↓ the number of permits to their target level.

How should international permits be initially distributed?

To countries as a proportion of their current level of emissions?

On a per-capita basis?

How best to get international approval?

How best to get domestic approval?

What can you do if you want to both reduce global warming and reduce its impact on your heirs?

You might have one less kid, or one kid whichever is the larger number.

This, of course, is not necessarily the minimum cost/efficient way of achieving a reduction in the rate of global warming (either for you, or for society). But it has the interesting feature that it reduces, in theory, the number of people that will be negatively impacted by GW.[22]

How would fewer kids affect things?

Why would a restriction on births not necessarily be a cost-effective way of achieving a reduction in the rate of GW?

> Maybe you would prefer reducing your emissions footprint in another way. For example, maybe I would prefer to live in the woods with my six kids and no car.

If the effect if GW turns out to be terrible, this might cause people to have fewer kids, as in "I am not bringing any kids into this world."

[22] There is the possibility that if we have fewer kids, other people might respond by having more kids.

Edward's opinion, an informed opinion.

GW is happening. I have seen changes in my lifetime. CO2 emissions by man is a major player. If we drastically reduce emissions in the next 20 to 30 years, we can affect the rate of increase in GW in your lifetimes (probably not in my lifetime)

I would advocate for a significant reduction U.S. CO2 emissions (and other GHGs). The obvious and efficient way to do this is with a carbon tax.

To make it more palatable (politically acceptable) I would make it revenue neutral.

I would not call it a tax, I might call it a "royalty payment"

The rate could be phased in over a number of years (e.g. tax increases x per year, until the target rate is achieved). This would make the adjustment easier.

I independent government entity would be created to collect and distribute the payments: set up so the other branches of government could not grab the money.

I would pitch it as an energy independent program, arguing that we need to be less dependent on foreign oil, and one way to do this is to burn less of it.

The royalty rate on imported Carbon fuels might be set higher than the royalty rate on domestically extracted carbon fuels.

Possibly some percentage of the total funds collected (maybe 10%) could be put in a separate fund to help people who loss their jobs because of the program.

One could argue that the U.S. should not do anything until China, India, etc. agree. I would not argue this. I would argue that the U.S. is one of the richest countries in the world, CO2 emissions have played a significant role in making us rich, and we are still the second biggest emitter,

So, we have a moral responsibility to lead the show.

An important empirical question is how what the royalty rate would need to be to drive CO2 emissions to near zero in 30 years.

Probably, not super high: maybe something that would translate into $2 or $3 a gallon of gas.

Make sure you can explain why a carbon tax is an efficient method for reducing CO2 emissions.

I recently added the following GB readings:

U.S. and China reach climate accord after months of talks, NYT Mark Landler, Nov 11, 2014.

NASA CO2 Animation Recalls 1859 Account of the Global Flow of this Gas, By Andrew C. Revkin NYT Nov. 19, 2014.

A carbon tax could bolster green energy, Eduardo Porter, NYT Nov 18, 2014.

The end of snow, Porter Fox, NYT, Feb 7, 2014

Climate Realities, Robert Stavens, NYT, Sept 21, 2014 Rob is a well-known environmental economist at Harvard.

Climate change study finds that the U.S. is already widely affected, Justin Gills, NYT May 6, 2014

Growing clamor about inequities of climate crisis, Steven Myers and Nicholas Kulish, NYT, November 16, 2013

Considering a U.S. carbon tax: frequently asked questions, Resources for the Future, Dec. 2012.

Q. and A.: Ann E. Carlson and Alex Wang on the U.S.-China Climate Accord, Edward Wong, NYT Nov 2014. (A legal and political take on the accord)

Climate Trades (The Financial Page), James Surowieki, The New Yorker Oct. 13 2014 (about GW, the Coase Theorem and "payments for eco-system services")

Note that for GW you should also do the readings on discounting at

Some Readings on Discounting and Present Value (in addition see Tietenberg -check the index for the appropriate pages)

Check out discounting, present value and interest rates in you math econ text

Counting the cost of fixing the future, Eduardo Porter, NYT, September 10, 2013

Time and Money: Discounting's Problematic Allure by Paul Portney, Resources, Summer 1999.

Guatemalan Squatters Torching Park Forests, NYT, May 20, 2000 (what does this article have to do with discount rates?)

Make sure you are up to speed on all of the global warming questions at http://www.edwardmorey.org/4545/global/4545set4.pdf