The Greenhouse Effect and Global Warming

Lecture 9  February 11, 2020

FINANCIAL TIMES
Record Antarctic temperature met with the sound of cracking ice

High of 18.3°C this week underscores how rapidly climate change is affecting polar region

https://www.ft.com/content/7e34f062-49c6-11ea-aeb3-955839e06441?sharetype=blocked

Record Antarctic temperature met with the sound of cracking ice
High of 18.3°C this week underscores how rapidly climate change is affecting polar region
@ft.com

Antarctica logs hottest temperature on record with a reading of 18.3°C
theguardian.com Antarctica has logged its hottest temperature on record, with an Argentinian research station thermometer reading 18.3°C...
@paper.li
As 2019 draws to a close, it remains on track to be the second or third warmest year on record. The final ranking will be confirmed in January by the World Meteorological Organization, which consolidates leading international temperature datasets.

The FACT

Global Warming Debate Shifts Focus To 'Tipping Point' Experts Weigh Urgency of Need to Act Before Earth Changes Irreversibly
By Juliet Eilperin
Washington Post

Now that most scientists agree human activity is causing Earth to warm, the central debate has shifted to whether climate change is progressing so rapidly that, within decades, humans may be helpless to slow or reverse the trend.

This "tipping point" scenario has begun to consume many prominent researchers in the United States and abroad, because the answer could determine how drastically countries need to reduce their greenhouse gas emissions in the coming years. While scientists remain uncertain when such a point might occur, many say it is urgent that policymakers cut global carbon dioxide emissions in half over the next 50 years or risk the triggering of changes that would be irreversible.

Source: http://www.washingtonpost.com/wp-dyn/content/article/2006/01/28/AR2006012801021.html

Video ABC News

There are three specific events that we need to pay attention

• damage to the world's fisheries within three decades
• dramatic sea level rise by the end of the century that would take tens of thousands of years to reverse; and,
• a shutdown of the ocean current in 200 years that moderates temperatures in northern Europe.
http://climate.nasa.gov/

http://climate.nasa.gov/evidence/
Scientists can only predict the trend based on the current data.

Different models predict different rate of increase
The Green House Gas (GHG) : CO₂

Source
The gas that is released from tailpipes and smoke stacks during the burning of fossil fuels

(Each person in industrialized country is responsible for the production of 5 metric tons of CO₂. How many pounds of CO₂ is released when you burn a gallon of gasoline?)

Natural – forest fire

Uses
Dry Ice
Carbonation – Soda, Alka-Seltzer etc
Super critical CO₂ as solvent (caffeine extraction)

Video

More Videos at http://www.eepybird.com

Automobiles as a major source of CO₂ emission

Greenhouse gas emissions and fuel economy are directly related.
Carbon dioxide (CO₂), a greenhouse gas, contributing to greenhouse gas emissions, is emitted by the combustion of gasoline or diesel fuel in an engine.
For each gallon of gasoline fuel consumed, 9 kg CO₂ is released!

Each of the following activities add 1 kg of CO₂ to your personal carbon footprint:

- Travel by public transportation (train or bus) a distance of 10 to 12 km (6.5 to 7 miles)
- Drive with your car a distance of 6 km or 3.75 miles (assuming 7.3 litres gasoline per 100 km or 39 mpg)
- Fly with a plane a distance of 2.2 km or 1.375 miles.
- Operate your computer for 32 hours (60 Watt consumption assumed)
- Production of 5 plastic bags
- Production of 2 plastic bottles
- Production of 1/3 of an American cheeseburger emits 3.1 kg of CO₂!

Global warming over the past millennium

Very rapidly we have entered uncharted territory — what some call the *anthropocene* climate regime. Over the 20th century, human population quadrupled and energy consumption increased sixteenfold. Near the end of the last century, we crossed a critical threshold, and global warming from the fossil fuel greenhouse became a major, and increasingly dominant, factor in climate change. Global mean surface temperature is higher today than it’s been for at least a millennium.

…… Marty Hoffert NYU
Perennial, or year-round, sea ice in the Arctic is declining at a rate of nine percent per decade.

"Arctic sea ice has not only been shrinking in surface area in recent years, it's becoming younger and thinner as well.

[Image: Loss of Polar Ice Cap](https://youtu.be/2MhcPvX7enA)

http://svs.gsfc.nasa.gov/vis/a000000/a003200/a003266/index.html


This shift is hard to explain without attributing it in part to human-caused global warming

..... National Snow and Ice Data Center in Boulder, CO.
(NY Times, Sept 29, 2005 )
Alaska's glaciers are receding at twice the rate than previously thought.
“Once peripheral melting is under way around Greenland,” Vaughan says, “the ice sheet may enter a state where it can’t sustain itself.”

GLOBAL WARMING
Climate Change Demands Action, Says U.K. Report

CAMBRIDGE, U.K.—As climate change climbs up the political agenda, researchers have pooled much of the most recent research into what many believe is a compelling case for the immediacy of global warming.

This week’s report*, based on a meeting convened last year at the request of U.K. Prime Minister Tony Blair, warns of catastrophic consequences if steps are not taken now. It says a range of measures, from emissions trading to nuclear power, are needed to both minimize future impacts and cope with those that cannot be avoided. “It is clear from the work presented that the risks of climate change may well be greater than we thought,” says Blair in a foreword to the report. “The U.K. government is taking this issue very seriously.”

* Acting Director, Climate Change, www.defra. gov.uk/environment/climatechange/internat/ dmpretec.htm

glaciologist David Vaughan of the British Antarctic Survey, “and it’s nice to see the government consulting scientific opinion.” During 2005, Blair was both chair of the G8 leaders of industrial powers and president of the European Union and pledged to use his twin roles to combat global poverty and climate change. To advance the climate initiative, 200 researchers from across the globe met at the Hadley Centre for Climate Prediction and Research in Exeter last February. The meeting came 4 years after the last assessment report from the Intergovernmental Panel on Climate Change (IPCC)—the benchmark for global warming—and the scientists chewed over new results. “It was a good time to take stock,” says meeting committee chair Dennis Tipping, head of the climate change unit at the Organisation for Economic Co-operation and Development in Paris. According to the meeting report, “compared to the [IPCC’s 2001] assessment, there is greater clarity and reduced uncertainty about the impacts of climate change.” The report contains models showing how the acidity of the oceans will increase as a result of more carbon dioxide in the atmosphere. It also forecasts a 100-year rise in sea levels as a result of thermal expansion of the oceans and melting of the Greenland and Antarctic ice sheets, even if greenhouse gas emissions are stabilized. “Once peripheral melting is under way around Greenland,” Vaughan says, “the ice sheet may enter a state where it can’t sustain itself.”

Tipping says politicians need to realize that time is running out and that the next generation may live on a planet that has no ice caps in the summer months. “It will be a profoundly different world, and we cannot imagine what that will mean,” he says. “Do you want to risk the consequences?”

—SAMUEL CLEARY
The ACE index reflects the collective intensity and duration of tropical storms and hurricanes during a given hurricane season. Values are given as percentage of the median from 1951 to 2000; the white band indicates normal conditions, the blue is below normal, and the pink is above normal, according to NOAA.

Kevin Trenberth. Science 38, 1753 (17 Jun 2005)

Annual mean SST anomalies relative to 1961 to 1990 (23) for 1870 to 2004, averaged over the tropical Atlantic (10°N to 20°N, excluding the Caribbean west of 80°W) (top) and the extratropical North Atlantic (30°N to 65°N) (bottom). Heavy lines are 10-year running means.

Environmental Impact of Rise in Global Temperature
The answer lies in the difference between local weather and climate. Climate refers to how the atmosphere acts over a long period of time, while weather describes what’s happening on a much shorter time scale. The climate can be thought of, in a way, as the sum of long periods of weather.

Or, to use an analogy Mr. Trump might appreciate, weather is how much money you have in your pocket today, whereas climate is your net worth. A billionaire who has forgotten his wallet one day is not poor, anymore than a poor person who lands a windfall of several hundred dollars is suddenly rich. What matters is what happens over the long term.


Why are gases (CO₂, CH₄, CFC) called Green House gases?
What makes these gases absorb infrared light?
How do these green house gases keep us warm?
The Earth’s climate system constantly tries to maintain a balance between the energy from the Sun that is absorbed by the Earth, and the energy that goes from Earth back out to space. We refer to this process as Earth’s "radiation budget."

This radiation budget allows the Earth to maintain the moderate temperature range essential for life as we know it.

The components of the Earth system that are important to the radiation budget are the planet’s surface, atmosphere, and clouds.

### Radiation Balance

- **Radiation Balance (Image)**

### Albedo (a)

- The fraction of solar energy that is reflected back to space is called the *albedo*.
- Different parts of the Earth (surface and cloud cover) have different *albedo*.
- Over the whole Earth, about 30 percent of incoming solar energy is reflected back to space.
- Clouds account for two-thirds (67%) of the global albedo
- Backscattering from gaseous molecules and particles in the air: 20%
- Earth’s surface: 13%

<table>
<thead>
<tr>
<th>Surface</th>
<th>Albedo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clouds (average over all types)</td>
<td>0.35-0.40</td>
</tr>
<tr>
<td>Snow</td>
<td>0.60-0.80</td>
</tr>
<tr>
<td>Ocean</td>
<td>0.06-0.20</td>
</tr>
<tr>
<td>Deserts</td>
<td>0.25-0.40</td>
</tr>
<tr>
<td>Agricultural land</td>
<td>0.10-0.20</td>
</tr>
<tr>
<td>Forest</td>
<td>0.10-0.20</td>
</tr>
</tbody>
</table>
The incoming solar energy per unit area at the earth’s surface

- Solar energy strikes earth at 1370 watts/m² to a disk area \( \pi r^2 \) (\( r \): earth radius).
- Earth distributes to its entire surface, which is \( 4 \pi r^2 \).
- The energy Earth receives at the top of the atmosphere is therefore: \( S_0/4 \).
- A fraction \( (a) \) of solar energy is reflected back to the space.

The incoming solar energy per unit area at the Earth’s surface:

\[
S = (1 - a) \frac{S_0}{4} = (1 - a)340watts / m^2
\]

How does the outgoing energy of the earth relate with the Earth’s temperature?

Blackbody radiation: At a given temperature, there is a maximum amount of energy that can be emitted per unit time per unit area of a body.

The maximum amount of radiation for a certain temperature is called blackbody radiation.

\[
E = kT_e^4
\]

- \( E \): radiated energy per unit time per unit area
- \( T_e \): Effective Blackbody temperature

Stefan-Boltzmann law

\[
k = 5.67 \times 10^{-8} w/ m^2 K^{-4}
\] : Stefan – Boltzman constant
## Spectral distribution of solar and terrestrial radiation and blackbody temperature

**Wein’s Law**

\[
\lambda_{\text{peak}} (\text{nm}) = \frac{2.9 \times 10^6}{T}
\]

<table>
<thead>
<tr>
<th>(\lambda_{\text{max}})</th>
<th>(T_e) (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun 483nm</td>
<td>6,000 K</td>
</tr>
<tr>
<td>Earth 10,000nm</td>
<td>255 K</td>
</tr>
</tbody>
</table>

## Balancing incoming and outgoing energy for the Earth-Atmosphere system

**Incoming = outgoing**

\[
\frac{S_\alpha (1-a)}{4} = kT_e^4
\]

\[
T_e = \left[ \frac{S_\alpha (1-a)}{4k} \right]^{1/4}
\]

<table>
<thead>
<tr>
<th>(a)</th>
<th>(T_e) (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>279</td>
</tr>
<tr>
<td>0.15</td>
<td>268</td>
</tr>
<tr>
<td>0.3</td>
<td>255</td>
</tr>
</tbody>
</table>

Temperature of the Earth-Air system determined from the solar emission.
**Why the blackbody temperature of the earth-atmosphere system seen from the space is 33 K colder than the average temperature at the earth surface?**

- Earth-Atmosphere temperature determined from radiation: 255k
- Earth surface average temperature: 288k
- **Answer:** *Greenhouse effect.*

The atmosphere traps much of the heat emanating from Earth’s surface and radiates it back, raising the surface temperature.

*Note: This greenhouse effect is part of a natural carbon cycle.*

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**Can the human energy consumption affect the energy balance?**

$$S = kT^4$$

How much energy input we need to increase the temperature by 1K?

For such a small change we can differentiate above equation

$$dS/S = 4dT/T$$

*The fractional increase in the energy budget is four times the fractional increase in temperature*

*For 1 K rise from 255 K* $dT/T = 1/255 = 0.00392$ *and*

$$dS/S = 4 \times 0.00392 = 0.0157$$

Thus energy consumption equal to 1.57% of the solar input is necessary to see 1K rise in temperature

- currently at 0.01%, expected to increase to ~2% in 20-50 years, if we maintain current growth of fossil fuel consumption
CO₂ Concentration vs. Earth’s temperature

- IR emitted from the earth’s surface and atmosphere escapes directly into space.
- Shortly after its absorption by GHG molecules (CO₂) this infrared light is reemitted in all directions. Some of this thermal IR is redirected back towards earth surface.
- This effect will increase with more CO₂ molecules in the atmosphere (enhanced greenhouse effect).

Amplification of Greenhouse Effect: Global Warming:

*What we know*
1. CO₂ contributes to an elevated global temperature.
2. The concentration of CO₂ in the atmosphere has been increasing over the past century.
3. The increase of atmospheric CO₂ is a consequence of human activity.
4. Average global temperature has increased over the past century.

*What might be true:*
1. CO₂ and other gases generated by human activity are responsible for the temperature increase.
2. The average global temperature will continue to rise as emissions of anthropogenic greenhouse gases increase.
Absorption of Infrared light by GHG molecules

The absorption at 15 μm represents the bending motion of CO₂. It corresponds to 2x10^{13} cycles/s (hertz).

The antisymmetric stretching motion results in the absorption at 4.26 μm, corresponding to the frequency of 7x10^{13} cycles/s.

How molecules interact with light

- shorter wavelength
- Ultraviolet
- molecule dissociates

- Visible
- molecule vibrates

- Infrared
- Microwave
- molecule rotates
Molecular Vibrations

(a) Bond-stretching vibration

\[ X \rightarrow Y \quad X \equiv Y \quad X \rightarrow Y \quad X \equiv Y \quad X \rightarrow Y \]

X-Y distance (R) varies by symmetric or antisymmetric stretch

(b) Angle-bending vibration

\[ X \quad \phi \quad Z \quad Y \quad Z \quad X \quad \phi \quad Z \quad Y \quad Z \quad X \quad \phi \quad Z \quad Y \quad Z \quad X \quad \phi \quad Z \quad Y \quad Z \]

Angle-bending vibration in a triatomic molecule
Change in the magnitude of dipole moment at some stage of vibration

Which of the molecules will absorb IR?

\[ \text{H}_2, \text{CO}, \text{Cl}_2, \text{O}_3, \text{CCl}_4, \text{NO}, \text{Ar} \]

The two groups of electrons will be 180° from each other: the CO\(_2\) molecule is linear.

Stretching

2349 cm\(^{-1}\) (4.26 μm)

Bending

667 cm\(^{-1}\) (15.00 μm).

https://en.wikipedia.org/wiki/Molecular_vibration
The infrared spectrum for CO₂

As IR radiation is absorbed, the amount of radiation that makes it through the sample is reduced.

1. Wavenumber (cm⁻¹) = \(10,000\) wavelength (µm)
2. 2349 cm⁻¹ or 4.6 µm or 4600 nm
3. 667 cm⁻¹ or 15 µm or 15000 nm

(b) stretching
(e) and (d) bending
The carbon cycle and fate of excess CO₂

Atmospheric CO₂ level is on the rise

http://www.esrl.noaa.gov/gmd/ccgg/trends/
Historic temperature trends

Increase of 0.5 °C in last 25 years reflects overall rate of 2°C/year

What about fluctuations in the Sun’s total output or solar winds? ……This could only account for global temperature change of 0.1°C

https://www.esrl.noaa.gov/gmd/ccgg/about/co2_measurements.html
https://scripps.ucsd.edu/programs/keelingcurve/2018/04/12/video/
Fate of CO₂

Photosynthesis extracts huge quantities of CO₂ each Spring and summer

\[ n\text{CO}_2 + n\text{H}_2\text{O} + \text{sunlight} \rightarrow \text{O}_2 + (\text{CH}_2\text{O})_n \]

The seasonal fluctuations account for only ~10 ppm

Fate of Carbon Emission

- The anthropogenic releases of CO₂ is only about 4% of the amounts produced in nature.
- Deep Ocean is eventual sink for CO₂.
- It takes 50-200 years to adjust to its new equilibrium.
- Only about half of the CO₂ emissions are removed over short or medium term. Hence the gas continues to accumulate.
The Paris Agreement’s central aim is to strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below 2 degrees Celsius above pre-industrial levels.

131 Parties have ratified the Paris Agreement as of 4 November 2016, the first session of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement (CMA 1) took place in Marrakech, Morocco from 15-18 November 2016. For more information, please see: http://unfccc.int/paris_agreement/items/9485.php
Leading scientific journals have taken strong editorial positions on the side of global warming, which, I argue, they have no business doing. Under the circumstances, any scientist who has doubts understands clearly that they will be wise to mute their expression. One proof of this suppression is the fact that so many of the outspoken critics of global warming are retired professors. ….

“The Day After Tommorrow’ is about a time not in the too distant future where a climate shift happens. This is where the ice caps melt dumping a load of salt water into the sea, causing a rapid change in current temperatures.”

“The Fiction

Michael Crichton

http://www.foxhome.com/dayaftertomorrow/
Thursday, November 17, 2005
Top Ten Signs There's Global Warming presented by Tom Hanks

10."I just bought ocean front property in Topeka, Kansas"
9."Glaciers are receding faster than Letterman's hairline"
8."'Cool Ranch' Doritos really 'Lukewarm Ranch' Doritos"
7."No matter what you teach them, parrots only say, I'm sweating my
nuts off"
6."Ed Sullivan Theater is now a balmy 48 degrees"
5."Paris Hilton saying, 'That's hot' even about stuff that is so not"
4."No shirt, no shoes? You still get service"
3."Average temperatures have risen one degree over the last one hundred
years - -One degree! That's what this is all about!!"
2."Ted Williams' head just woke up asking for iced tea"
1."I'm so disoriented from the heat, I agreed to do a lame Top Ten List"

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