ATMOS 1020 Climate Change

5. Greenhouse Gases

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Outline

- What are the main greenhouse gases?
- Which ones are changed by human activity?
- Natural vs. anthropogenic greenhouse effect

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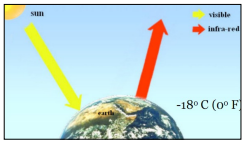
Primary Gases

- Our atmosphere is mostly N_2 (78%), O_2 (21%), and Ar (0.9%)
  - but these are **not greenhouse** gases
  - molecules with **1 atom** or **2 of the same atoms** aren't greenhouse gases
  - the primary gases in our atmosphere are **transparent to radiation**



If our atmosphere was only nitrogen, oxygen, and argon, this picture with no greenhouse effect would be accurate!

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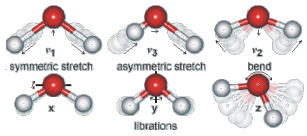
Major Greenhouse Gases

- Remember: greenhouse gases **block longwave radiation** from escaping directly to space; the extra downward longwave radiation from above warms the surface
- **Polyatomic (n ≥ 3) molecules** are greenhouse gases
  - water vapor (H_2O)
  - carbon dioxide (CO_2)
  - methane (CH_4)
  - nitrous oxide (N_2O)
  - ozone (O_3)
  - chlorofluorocarbons (CFCs)



Vibrational, stretching, and bending modes of **water vapor molecules** mean H_2O can absorb longwave radiation

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Greenhouse Gases

- Greenhouse gases are a tiny fraction of the atmosphere!
  - water vapor has the highest concentration: ~0.4%
  - carbon dioxide: 0.04% (~400 ppm)
  - methane: 0.0002%
- These "trace gases" have a **remarkable effect**
  - e.g., ozone is less than 0.00001% of the atmosphere, but it absorbs essentially all harmful UV radiation
- Let's discuss these gases …

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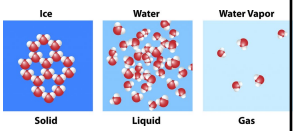
Water Vapor (H_2O)

- Gas form of water, invisible
  - AKA: humidity
  - not the same as steam, fog, or clouds: they are tiny water droplets or ice crystals suspended in air



- The **#1 greenhouse gas**!
  - powerful because there's a lot of it
- Not controlled by humans!
  - but observed to be increasing with global warming
  - this represents an indirect response, or a **feedback,** not a forcing (topic of a future lecture)

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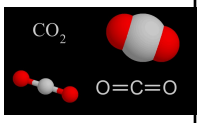
Carbon Dioxide (CO_2)

- It's what we breathe out (respiration) and plants breathe in (photosynthesis)
- Non-toxic, invisible
- The **primary contributor** to the anthropogenic (human-caused) greenhouse effect
  - **~60% of the anthropogenic greenhouse effect** so far
- Increases primarily due to
  - **fossil fuel burning** (80%)
  - deforestation, biomass burning, forest fires (20%)



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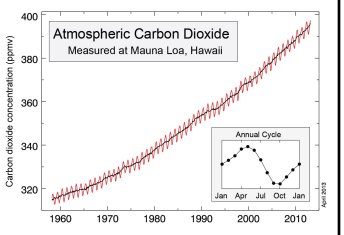
The "Keeling" Curve

- A graph showing the variation in atmospheric CO_2 since 1958
- Taken at the Mauna Loa Observatory (3,400 m) in Hawaii by Charles Keeling
- Preindustrial value (1860): **280 ppm** (parts per million, = 0.028%)
- Current value (Dec 2021): **417 ppm**
- The first evidence of rapidly increasing CO_2 levels
- Q: What causes the seasonal wiggles?



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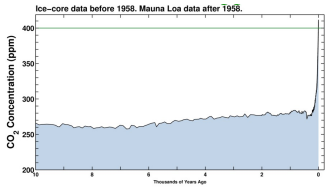
Past 10,000 years

- Since 1860, CO_2 has risen from 280 ppm to now 417 ppm
- A 50% increase
- Entirely caused by humans
- Has a heating effect of 2 Wm^{-2}
- Increases global temperatures by 1°C



https://scripps.ucsd.edu/programs/keelingcurve/wp-content/plugins/sio-bluemoon/graphs/co2_10k.png

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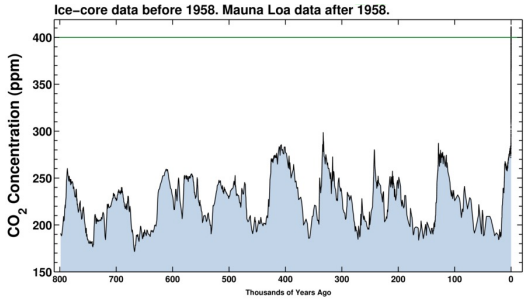
Past 800 Thousand Years



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The "Cyanide Cocktail"

- Some claim that 0.0137% CO_2 (that's the 137 ppm increase from humans) can't be bad because the number is small
- Similar claim: A man offers you a cocktail with cyanide. The man assures it is safe, since the amount of cyanide in your body after this drink would be only 0.001%!

- **The effect is what counts**!
- CO_2 in the air could also be expressed in kg
  - it is 3200 billion tons or 3,200,000,000,000,000 kg
  - humans are responsible for almost 1000 billion tons, that's the 0.0137% increase

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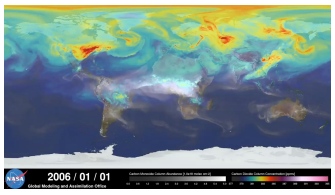
Carbon Dioxide In The Air

- CO_2 has a long life time and is fairly well mixed
- But there are tiny regional variations (here: 377 - 395 ppm) in CO_2 that can be detected from space or simulated by models
- The circulation transports CO_2 away from its source regions



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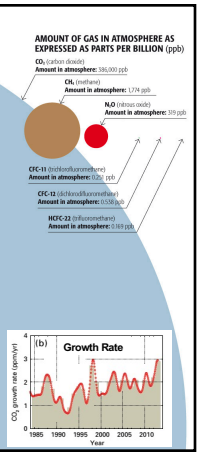
Carbon Dioxide (CO_2)

- CO_2 will be our main problem in the future
  - it's **extremely long-lived** in the atmosphere
  - **55%** of what we emit quickly gets **taken up** by the ocean and land; we'll discuss this more later
  - most of the rest sticks around for **over 100 years**
  - some of what we emit will still be in the atmosphere over **1000 years** from now!
- Growth rate: **~2-3 ppm/yr** or 0.7%



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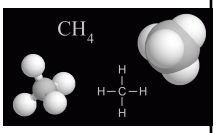
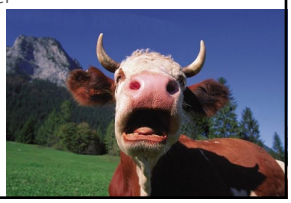
Methane (CH_4)

- Natural gas like in stoves/heating systems
- Methane is a **much stronger greenhouse gas** on a per molecule basis than CO_2
- Only 1.8 ppm though – much smaller concentration than CO_2
- Natural sources
  - marshes (swamp gas) and other wetlands
- Increases anthropogenically
  - farm animals (cow burps)
  - rice farming
  - landfills
  - natural gas leakage





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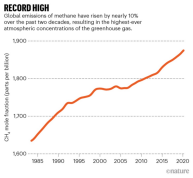
Methane (CH_4)

- Lifetime of methane is "only" **8 years**
- This is significantly shorter than that of carbon dioxide
- CH_4 breaks down in the atmosphere by chemical reactions
- Concentrations have been leveling off in the early 2000s (possibly because of droughts) but increasing again since 2007



https://www.nature.com/articles/d41586-020-02116-8

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Global Warming Potential (GWP)

- Carbon dioxide lifetime > 100 years
- Methane lifetime = 8 years
- But per molecule, methane is a much stronger greenhouse gas
- How to put these on similar terms?
- Global warming potential (or GWP)
  - how much greenhouse effect emissions of a given gas cause over a fixed amount of time (usually 100 years)
  - measured relative to CO_2 (= 1)

Table ES-1: Global Warming Potentials (100-Year Time Horizon) Used in the Inventory Report

Gas	GWP
CO_2	1
CH_4*	21
N_2O	310
HFC-23	11,700
HFC-32	650
HFC-125	2,800
HFC-134a	1,300
HFC-143a	3,800
HFC-152a	140
HFC-227ea	2,900
HFC-236fa	6,300
HFC-4310mee	1,300
CF_4	6,500
C_2F_6	9,200
C_4F_{10}	7,000
C_6F_{14}	7,400
SF_6	23,900

Source: IPCC (1996)
* The CH_4 GWP includes the direct effects and those indirect effects due to the production of tropospheric ozone and stratospheric water vapor. The indirect effect due to the production of CO_2 is not included.

- Methane's global warming potential is **21**
  - measured over 100 years, one CH_4 molecule released into the atmosphere is 21 times more potent than CO_2 even though CH_4 stays around for only 8 years

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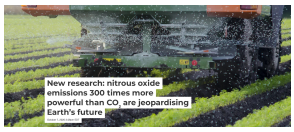
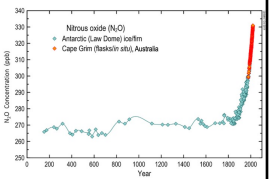
Nitrous Oxide (N_2O)

- Laughing gas (dentists use it)
- Also more potent on a per molecule basis than CO_2
- Global warming potential: **310**





- Sources
  - agriculture (fertilizer)
  - chemical industry
  - deforestation
- Small concentrations of only 0.33 ppm

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Summary So Far

- CO_2, CH_4 and N_2O all strongly increased since the industrial revolution (ca. 1750)
- Even the rate of increase is increasing!

	CO_2	CH_4	N_2O
Global abundance in 2013[4]	396.0±0.1 ppm	1824±2 ppb	325.9±0.1 ppb
2013 abundance relative to year 1750[a]	142%	253%	121%

Source: WMO greenhouse gas bulletin 2014

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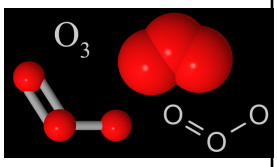
Ozone (O_3)

Occurs in two places:



- **Stratospheric ozone**
  - good
  - natural UV protection
- **Tropospheric ozone**
  - bad
  - near the Earth's surface by air pollution (photo smog)
  - is a greenhouse gas
  - much more potent on a per molecule basis than CO_2
  - very short-lived
- Global warming potential for ozone is not usually calculated – rather it's wrapped into the GWPs of the other gases that lead to its chemical creation

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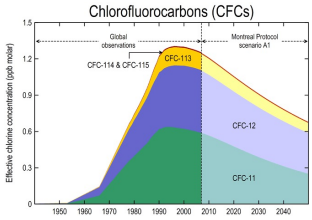
Chlorofluorocarbons (CFCs)

- CFCs not only destroy stratospheric ozone, they are also **very strong** greenhouse gases
- Global warming potentials of up to 11,000!
- Their reduction likely saved significant global warming in addition to the ozone layer!



- Some replacements for CFCs (called HFCs) are strong greenhouse gases too

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The Natural Greenhouse Effect

- The greenhouse effect is a **natural phenomenon**
- We need it to keep our planet warm **($0^oF \rightarrow 60^oF$)**
- Contributions to the natural greenhouse effect:
  - **H_2O** (water vapor): **60%**
  - **CO_2** (natural carbon dioxide only): **26%**
  - all others: 14%

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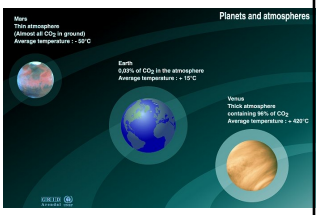
Planets and Atmospheres

- A planet's climate is decided by its
  - **mass** to create gravity and to keep its atmosphere
  - **sun distance** for heat energy
  - atmospheric **composition** for greenhouse effect
- **Mars**
  - small mass
  - thin atmosphere (CO_2)
  - away from sun
  - **-50°C**
- **Earth**
  - some greenhouse gases: CO_2 (0.04%), H_2O (0-4%)
  - **+15°C**



- **Venus**
  - similar mass as Earth
  - thick atmosphere (96% CO_2)
  - close to sun
  - **+420°C**

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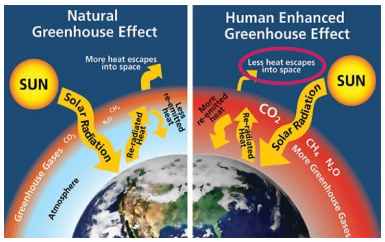
Anthropogenic Greenhouse Effect

- Human activity has increased the concentration of certain greenhouse gases above their natural levels
- This makes it even harder for outgoing radiation to escape to space



- This **enhances the natural greenhouse effect**
- **Less longwave radiation to space, less cooling**
- The **planet must warm** in order to increase its outgoing longwave radiation until new energy balance is reached

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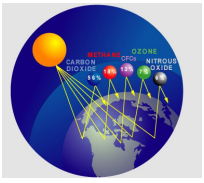
Anthropogenic Greenhouse Effect

- Global warming is due to an anthropogenic enhancement of the natural greenhouse effect
- Contributors to the anthropogenic greenhouse effect:
  - carbon dioxide: 60%
  - methane: 18%
  - CFCs, HFCs: 13%
  - tropospheric ozone: 7%
  - nitrous oxide: 6%



http://www3.epa.gov/climatechange/ghgemissions/global.html

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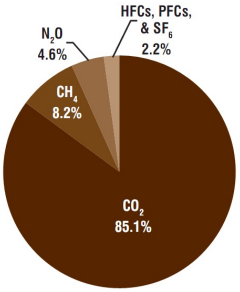
US Greenhouse Effect

- US contributors to the "anthropogenic" greenhouse effect based on 2008 emissions
- CO_2 is the big problem in the US (85% vs. 60%)
- Note how much lower the CFCs are than on the previous slide (2% vs. 13%)
  - this is b/c we basically don't emit CFCs anymore



From US EPA 2010 report: http://www.epa.gov/climatechange/emissions/downloads10/US-GHG-Inventory-2010_ExecutiveSummary.pdf

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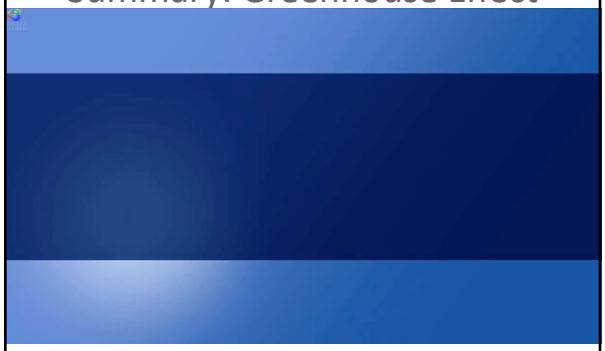
Summary: Greenhouse Effect



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Summary

- Natural greenhouse gases:
  - #1 is water vapor (60%)
  - #2 is carbon dioxide (26%)
- The greenhouse effect is a natural phenomenon, but it is enhanced by human activity on Earth
- Global warming potential: total warming caused over a fixed period of time
- Anthropogenic greenhouse effect (global warming):
  - #1 is carbon dioxide (60%)
  - methane, nitrous oxide, tropospheric ozone, CFCs are also of concern

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