- These slides contain animations, when the PowerPoint file is played
- The content gradually appears with clicks
- Questions appear before their answers

Green Chemistry and Living in the Desert

Sun

- What we do and don't want from it
- Energy from the sun (fossil fuels vs renewables)
- Light/matter interactions
- Infrared, heat, greenhouse effect
- Ultraviolet, sunburn, sunscreen, oxygen, ozone layer

Green Chemistry and Living in the Desert

Sun

What do we want from the sun?

Light to see
Light for plants to grow
Energy to power things
Warmth (in winter)

What don't we want from it?

Sun damage
Sun burn
Too much heat (summer)
Sun in eyes while driving?

These processes result from the different ways that sunlight interacts with matter

Green Chemistry and Living in the Desert

Sun

Did you know?/have you noticed:

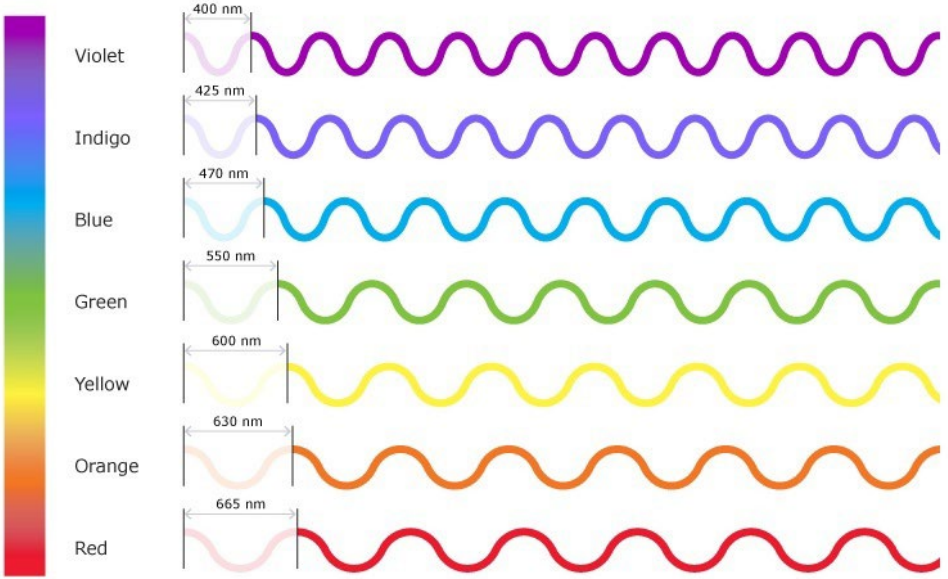
You can sit in the sun behind a window and feel just as hot as if the window was not there, yet not get sunburned

On a somewhat cloudy day you can feel relief from the heat of the sun, yet you can still easily be sunburned

What is going on in those situations?

Light Matter Interactions

Considering light as a wave, we can classify light by its wavelength:

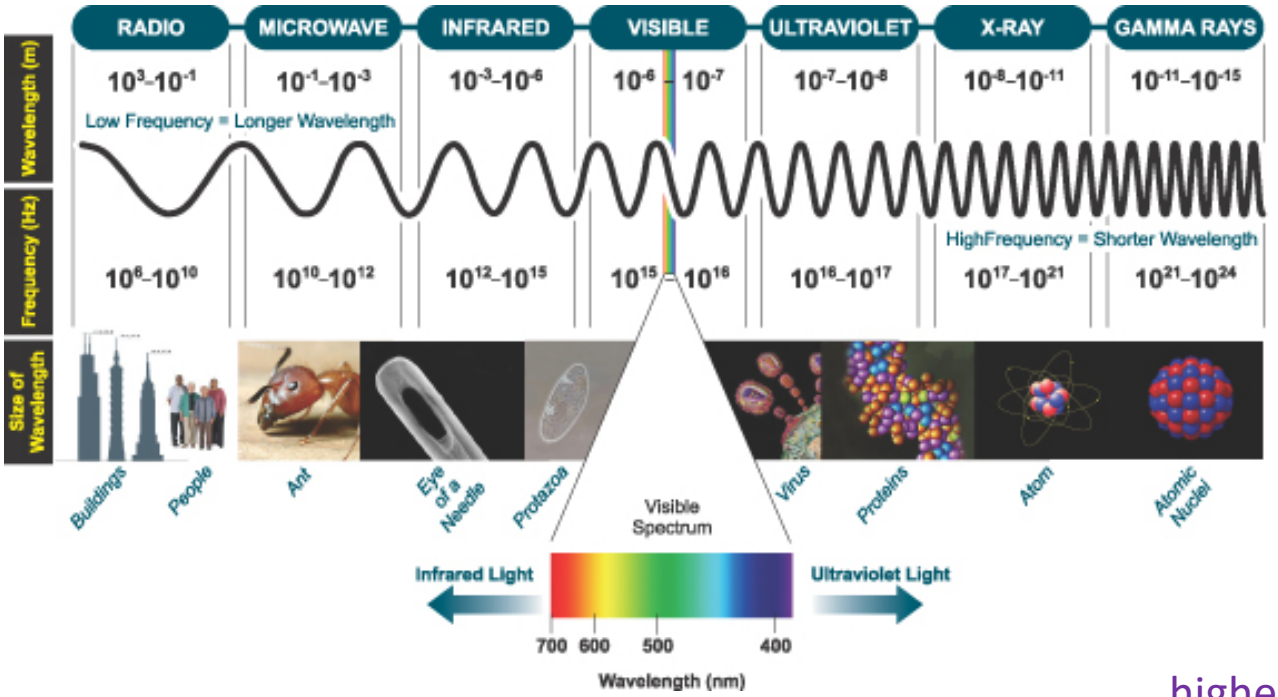


higher energy

But this is just what we can see!

Light Matter Interactions

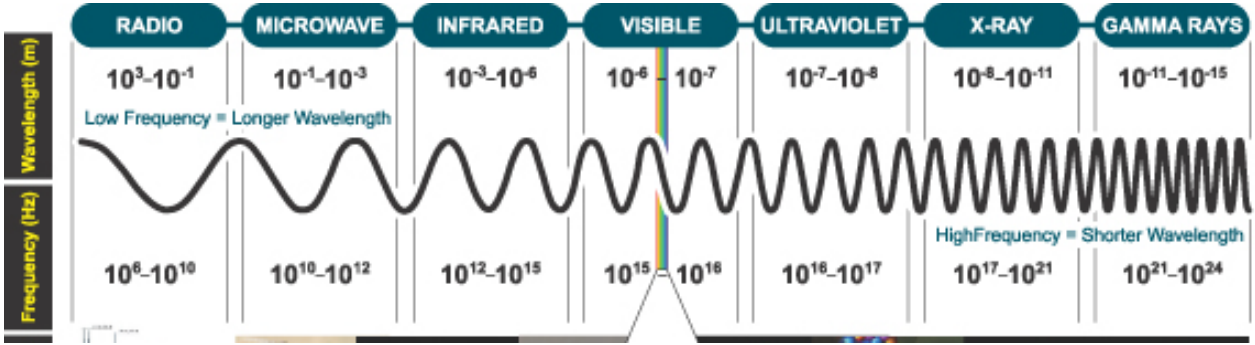
There is a whole range light types at both higher and lower wavelengths:



higher energy

http://www.astro.virginia.edu/~rsl4v/PSC/light.html

Light Matter Interactions



What effects does each type (wavelength) of light have on matter?:

a) X-rays
b) Ultraviolet radiation
c) Visible light
d) Infra red light
e) Microwaves
f) Radiowaves

http://www.astro.virginia.edu/~rsl4v/PSC/light.html

Light Matter Interactions

a) X-rays	Promotion of electrons from low-lying atomic orbitals
b) Ultraviolet radiation	Promotion of electrons from molecular orbitals to higher energy molecular orbitals
c) Visible light	Same as UV
d) Infrared light	Excites bond vibrations in molecules
e) Microwaves	Excite rotations in molecules
f) Radiowaves	Excite nuclear spins in atoms

http://www.astro.virginia.edu/~rsl4v/PSC/light.html

Light Matter Interactions

- When we heat matter the atoms and molecules vibrate faster
- IR light absorption causes atoms to vibrate within molecules
- As a consequence, absorbing IR light causes heating
- When we feel heat from the sun's rays, we are feeling the IR radiation
- Importantly, it is the ultraviolet radiation that causes skin damage and sunburn, not the heat from the sun (IR)

Light Matter Interactions

- Feeling hot from the sun and getting sunburned have different causes
- The earlier examples highlight this:

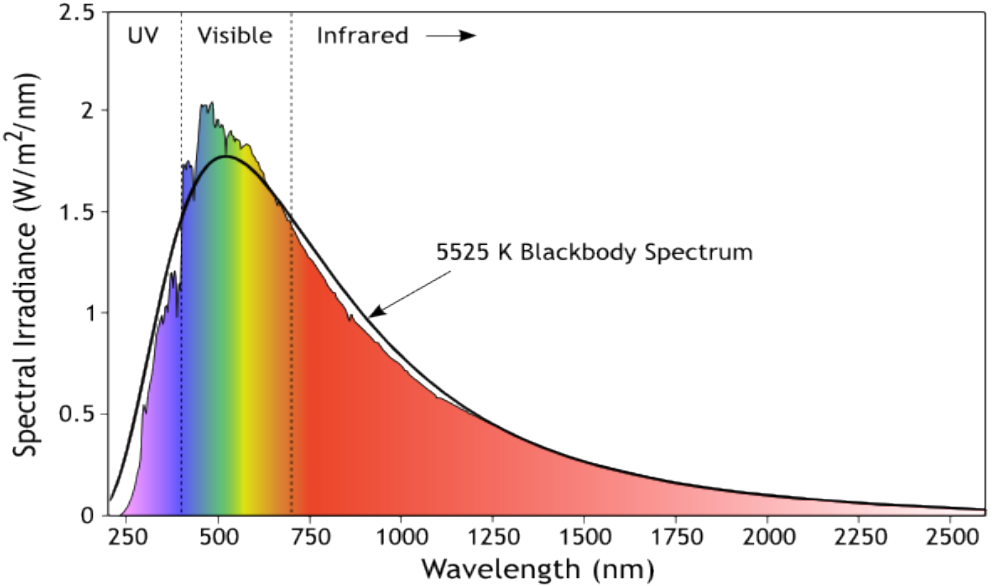
You can sit in the sun behind a window and feel just as hot as if the window was not there, yet not get sunburned

Glass absorbs the UV radiation that causes sunburn yet allows longer wavelengths (visible and some IR wavelengths) to pass. So, we still feel plenty hot due to the IR radiation.

On a somewhat cloudy day you can feel relief from the heat of the sun, yet you can still easily be sunburned

Clouds (water) absorb and scatter IR radiation more effectively than they do UV. So, we may feel cooler because less IR is striking us, however the penetrating UV can still easily cause sunburn.

Light from the Sun



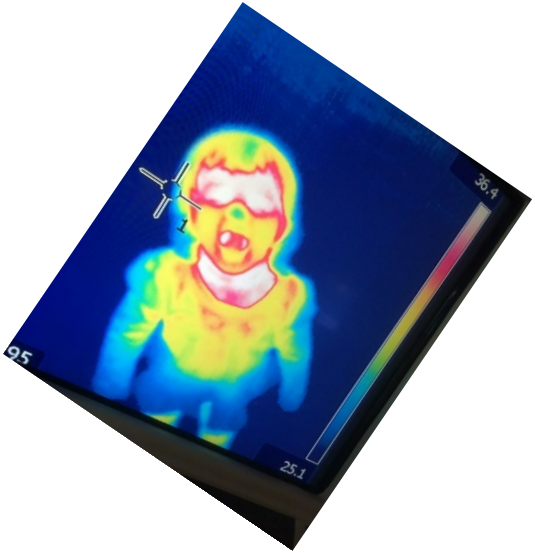
Sunlight energy reaching the earth's surface:

3-5%	Ultraviolet
42-43%	Visible
52-55%	Infrared

Wikipedia – "Sunlight"

Light Matter Interactions

- You have probably heard of IR imaging:



- Absorbing IR light causes heating
- Similarly, in the reverse process warm objects emit IR radiation
- Hotter objects emit more IR energy than colder ones

Light Matter Interactions

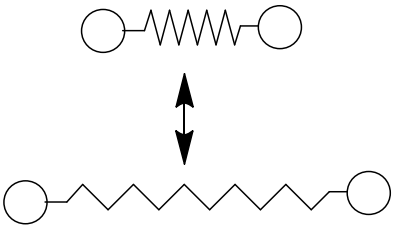
a) X-rays	Promotion of electrons from low-lying atomic orbitals
b) Ultraviolet radiation	Promotion of electrons from molecular orbitals to higher energy molecular orbitals
c) Visible light	Same as UV
d) Infrared light	Excites bond vibrations in molecules
e) Microwaves	Excites bond rotations in molecules
f) Radiowaves	Excites nuclear spins in atoms

IR Absorption

The energy of the IR light absorbed corresponds to the stretching and bending of chemical bonds

Stretching

- Just as if the bond between the atoms acts like a spring:

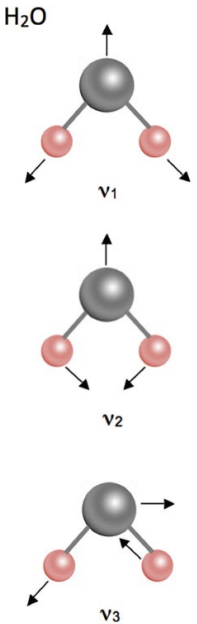


- The frequency of IR radiation is in the same range as the rate of oscillation of the “spring”
- It’s a little more complicated for molecules with more than 2 atoms

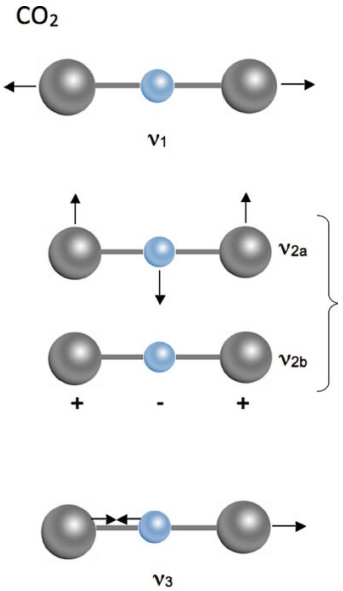
Light Matter Interactions

- Water and carbon dioxide molecules provide good examples for what happens when IR light is absorbed

Water



Carbon Dioxide



Why are these particular compound's interactions with IR radiation very important? The Greenhouse Effect

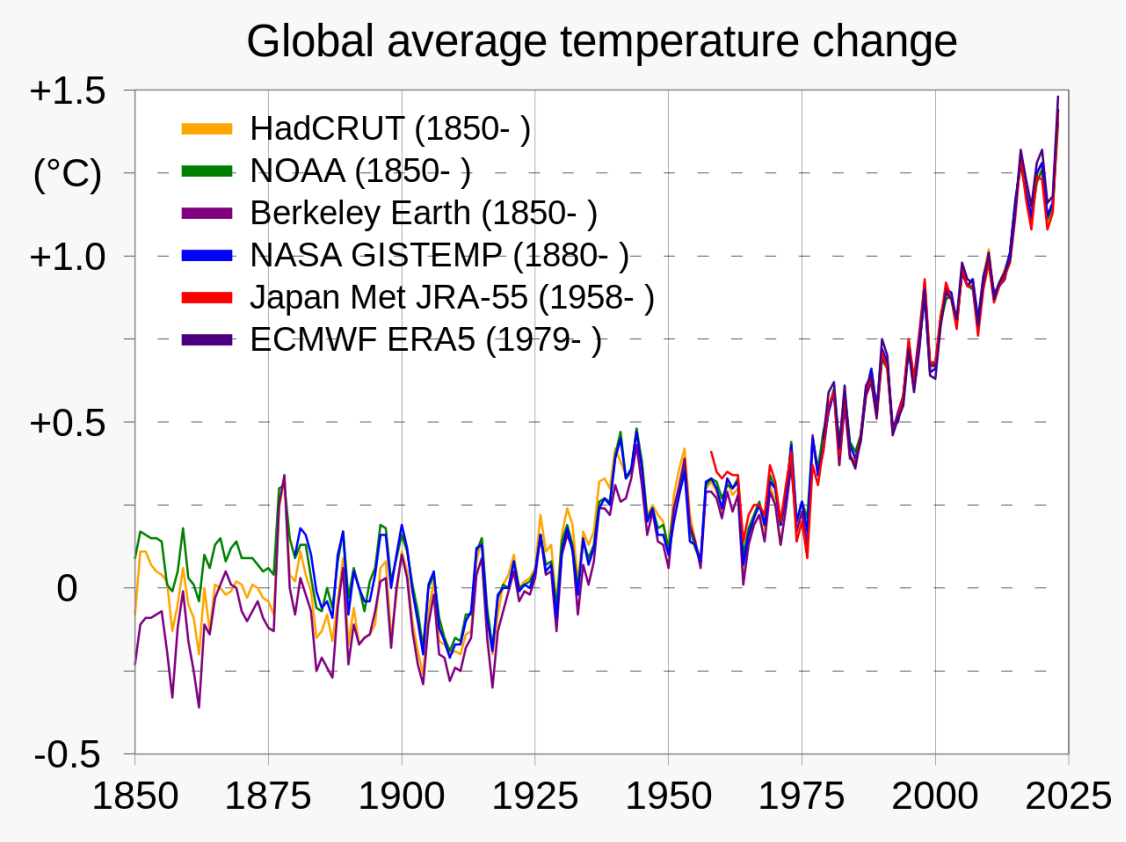
https://link.springer.com/chapter/10.1007/978-3-031-08834-6_4

Global Warming

How are the ideas of the greenhouse effect, global warming, and climate change related?

Related to pollution, what do we usually hear about as being the "cause" of this problem?

Global Warming



Wikipedia – “Scientific consensus on climate change”

Global Warming

- Everybody knows!

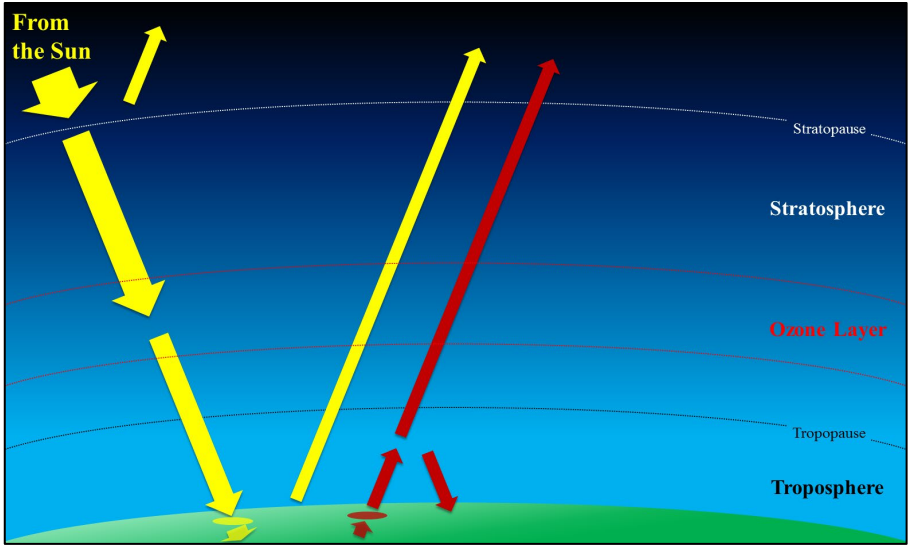
- In 1917 Alexander Graham Bell wrote "[The unchecked burning of fossil fuels] would have a sort of greenhouse effect", and "The net result is the greenhouse becomes a sort of hot-house."[

- Wikipedia

Green House Effect

What is it?

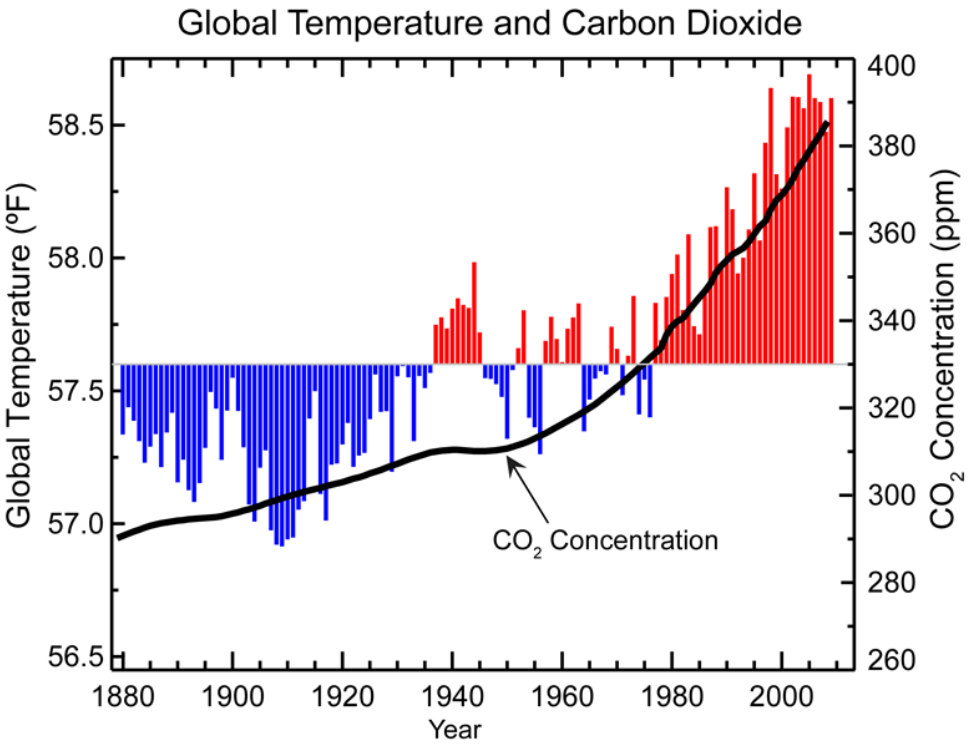
When heat energy is radiated from the earth's surface, molecules in the atmosphere absorb some of that radiation, effectively leading to a retention of the heat



Green House Effect

A real greenhouse works because the air that is heated inside is trapped by the structure.

Carbon Dioxide



What does this graph tell us?

- Pretty compelling that with more CO_2 the temperature is higher!

Atmosphere Composition

We know that CO_2 is the gas that everyone talks about when discussing global warming. But how much of it is there in the air?

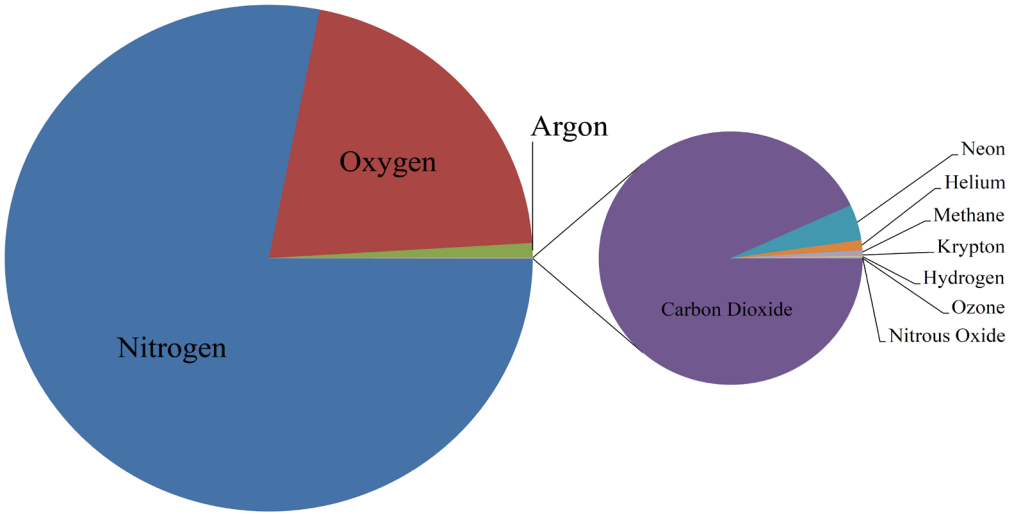
What is the air made of?

N_2	78%
O_2	21%
Ar	1%
H_2O	~1% (varies)

So, where's the CO_2?

Atmosphere Composition

- There's not much CO_2 in the air (about 0.04%), but that amount has a large effect



- Importantly, the atmosphere's two major gases N_2 and O_2 <u>do not</u> absorb IR radiation.

Green House Effect

The earth's average surface temperature is about 14 °C (57 °F)
What would you expect the earth's surface temperature to be under the following circumstances?:

a) No atmosphere
b) 100% oxygen atmosphere
c) Air with 5% CO_2 atmosphere
d) 100% CO_2 atmosphere

Green House Gases

- The major contributor to the green house effect on earth is actually water

- Percentage contribution (the major contributors) to the greenhouse effect:

  - Water vapor 36-70% ~ 1.000000%
  - Carbon dioxide 9-26% ~ 0.042000%
  - Methane 4-9% ~ 0.000170%
  - Ozone 3-7% ~ 0.000007%

But what are the percentages of these in the air?

Green House Gases

Contribution to greenhouse effect	Percentage of the atmosphere
• Water vapor 36-70%	~ 1.000000%
• Carbon dioxide 9-26%	~ 0.037000%
• Methane 4-9%	~ 0.000170%
• Ozone 3-7%	~ 0.000007%

- Clearly, the gases do not influence the greenhouse effect with the same efficiency
- Another factor that must be considered is how long the gases persist in the atmosphere
- “Global Warming Potential” is a number that factors all of these into consideration.

Some Other Greenhouse Gases

Atmospheric lifetime and GWP relative to CO_2 at different time horizon for various greenhouse gases.

Gas name	Chemical formula	Lifetime (years)	Global warming potential (GWP) for given time horizon		
			20-yr	100-yr	500-yr
Carbon dioxide	CO_2	30–95	1	1	1
Methane	CH_4	12	72	25	7.6
Nitrous oxide	N_2O	114	289	298	153
CFC-12	CCl_2F_2	100	11 000	10 900	5 200
HCFC-22	$CHClF_2$	12	5 160	1 810	549
Tetrafluoromethane	CF_4	50 000	5 210	7 390	11 200
Hexafluoroethane	C_2F_6	10 000	8 630	12 200	18 200
Sulfur hexafluoride	SF_6	3 200	16 300	22 800	32 600
Nitrogen trifluoride	NF_3	740	12 300	17 200	20 700

https://en.wikipedia.org/wiki/Greenhouse_gas

Carbon Dioxide

Where is all this CO_2 coming from?

The combustion of hydrocarbon fuels:

$$C_xH_y + O_2 \rightarrow x\ CO_2 + 2y\ H_2O + \text{Energy}$$

Where are those from?

Mostly from:

Natural Gas
Petroleum
Coal

The “fossil fuels”