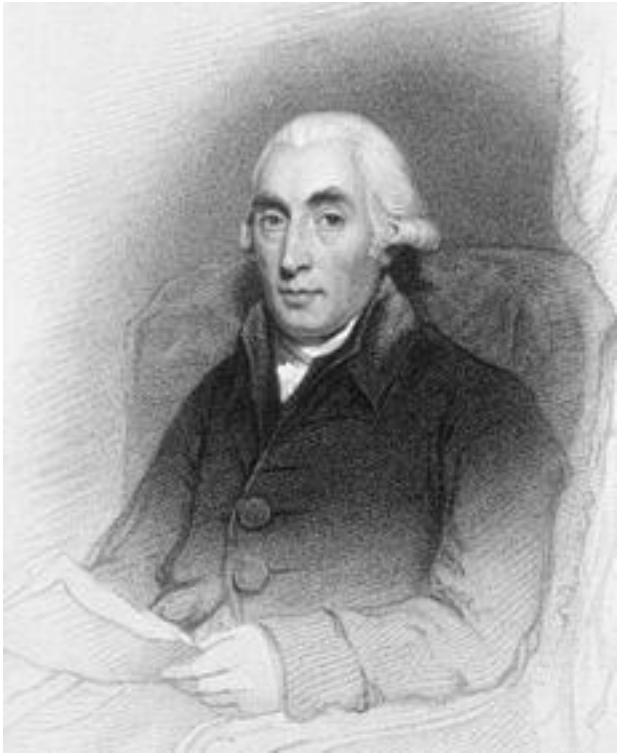
Carbon Dioxide: Reshaping our atmosphere, our plants & ourselves

Jesse Grist, Semipe Oni, & Niño Roco
CAPS 422

Outline

- History of CO_2
- Rising atmospheric carbon dioxide levels and global warming
- Effect of elevated CO_2 in plant physiology
- Effect of elevated CO_2 in human physiology

The Discovery of CO_2

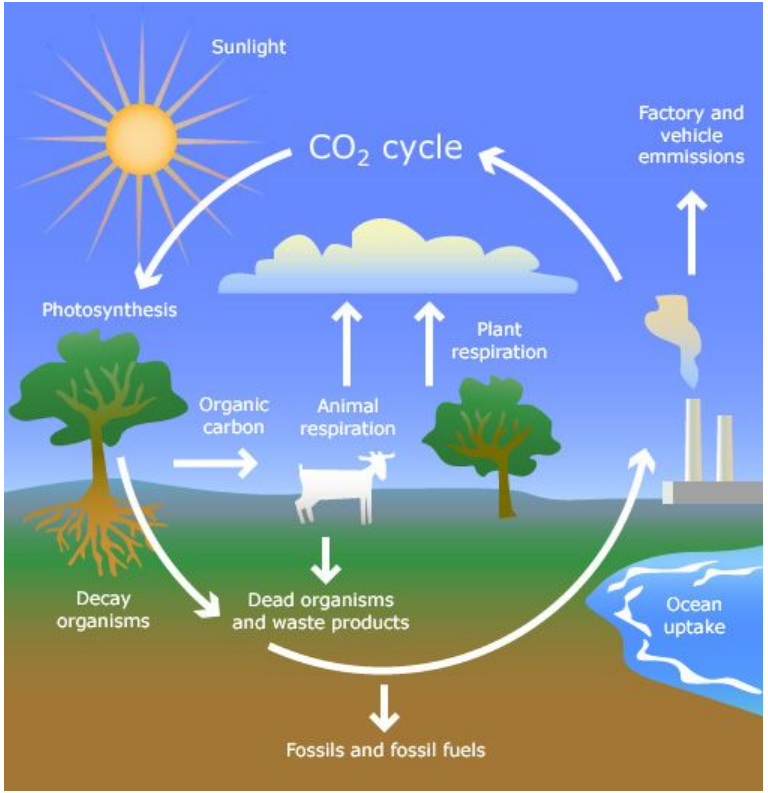


- Joseph Black: 1750s Scottish physician credited as the first to discover carbon dioxide
- Heated and treated magnesium carbonate with acid, producing a gas he termed “fixed air” (CO_2)
- Showed that this gas could extinguish a flame, could not support life, and was present in the gas exhaled from the lung
- This discovery marked a new era of research into respiratory gases

West, 2014

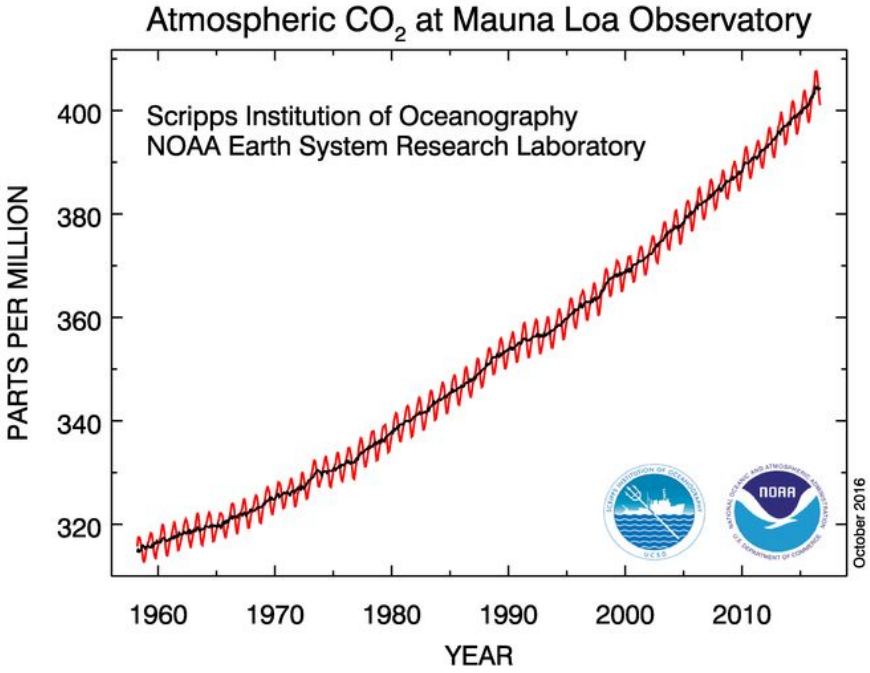
Carbon Dioxide and the Carbon Cycle

- CO_2 is **added** to the atmosphere through processes such as cellular respiration, combustion of organic matter, and volcanic activity
- CO_2 is **removed** from the atmosphere through photosynthesis and deposition of carbonates
- This cycle is **balanced** by various carbon sinks - forests, oceans - keeping atmospheric CO_2 levels relatively constant

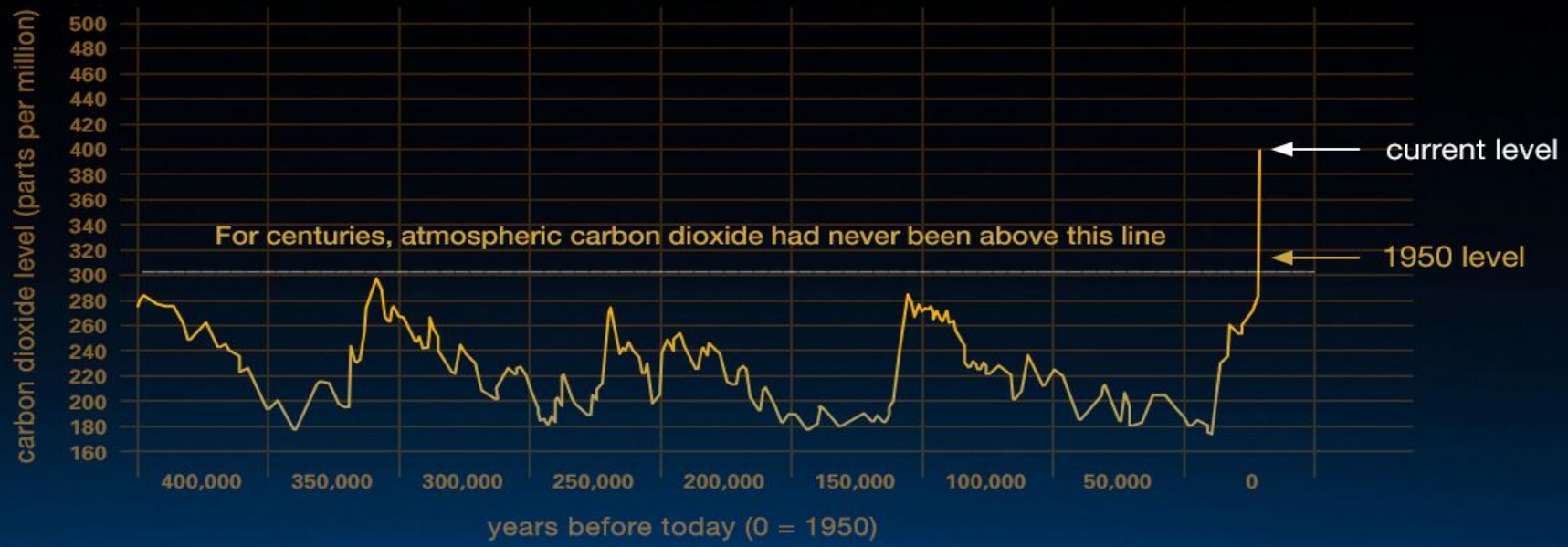


The Recent History of Atmospheric Carbon Dioxide

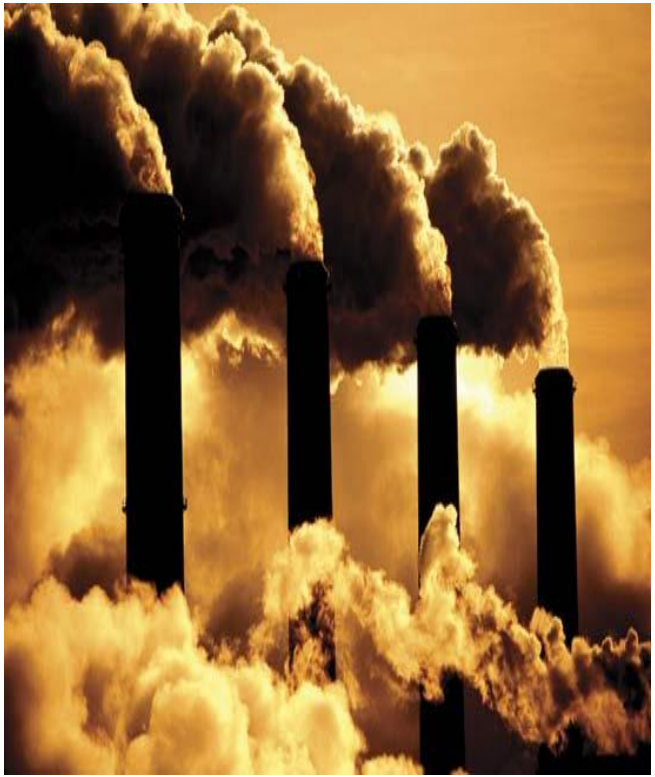
- The Earth's atmosphere tends to keep carbon dioxide levels between 180ppm (glacial) and 300ppm (interglacial)
- Pre-industrial revolution: **280ppm** atmospheric CO_2 (10000 years)
- Currently: **400ppm** atmospheric CO_2
- Atmospheric CO_2 is continuing to rise at 2ppm/year
- The highest it's been in 800,000 years



Vostok Ice Core Data/J.R. Petit et al. 1997; NOAA Mauna Loa CO2 record

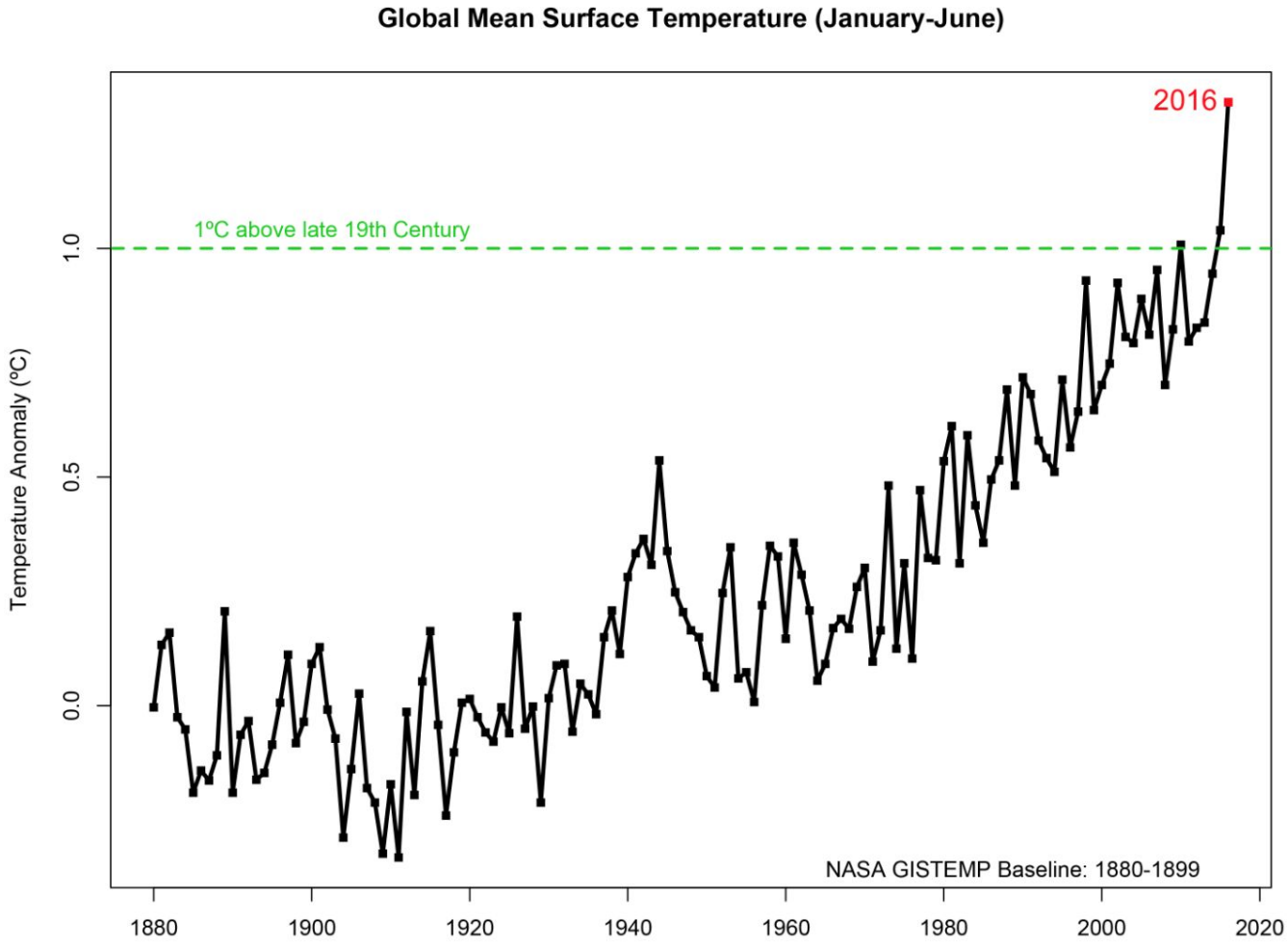

carbon dioxide level (parts per million)
500
480
460
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
For centuries, atmospheric carbon dioxide had never been above this line
current level
1950 level
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
years before today (0 = 1950)

Anthropogenic Causes & The Greenhouse Effect



- The increase in atmospheric CO_2 has been attributed to various human sources: fossil fuel combustion, deforestation
- Additional load of human activity surpasses the balancing effect of carbon sinks
- This leads to the gradual increase of CO_2 in the atmosphere
- More atmospheric CO_2 = More solar radiation trapped in atmosphere
- The increase in CO_2 levels is estimated to be responsible for a 70% change in the Earth's radiative force

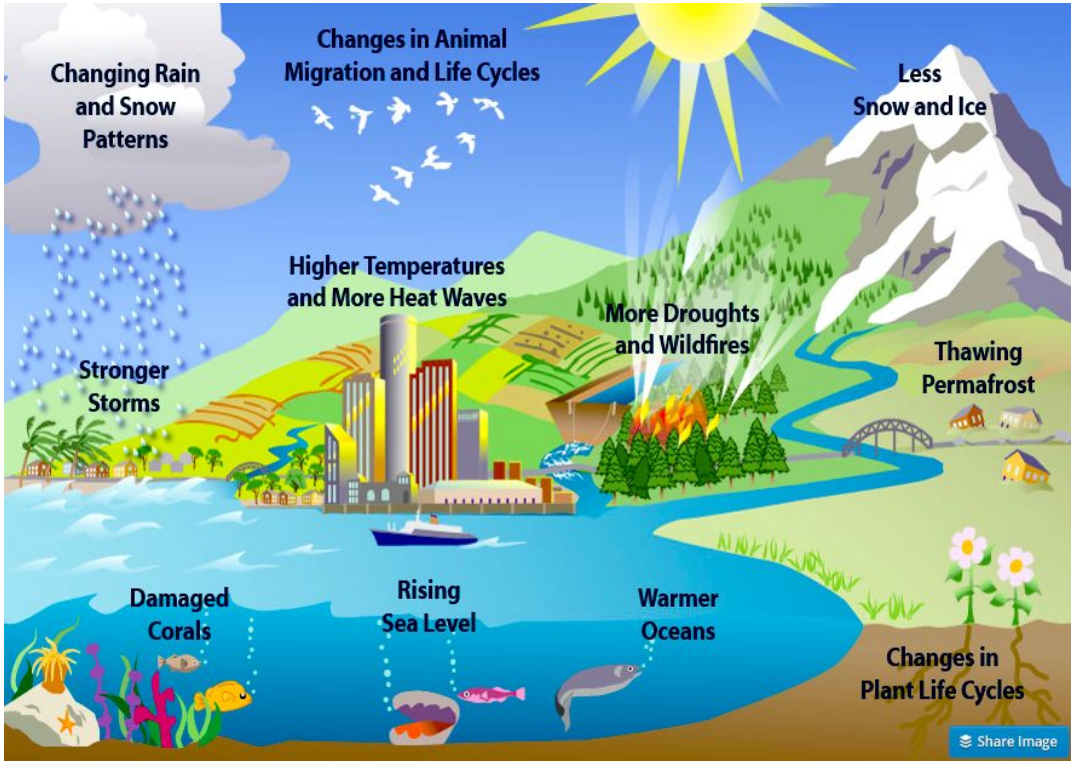
Intergovernmental Panel on Climate Change's Fifth Assessment Report, 2014



Nasa/Goddard Institute of Space Studies, 2016

Effects of Global Warming

- Rising sea levels & melting polar ice caps
- Rising global temperature
- Warming oceans
- Increase in extreme meteorological events
- Ocean acidification
- Plant and human physiological consequences?

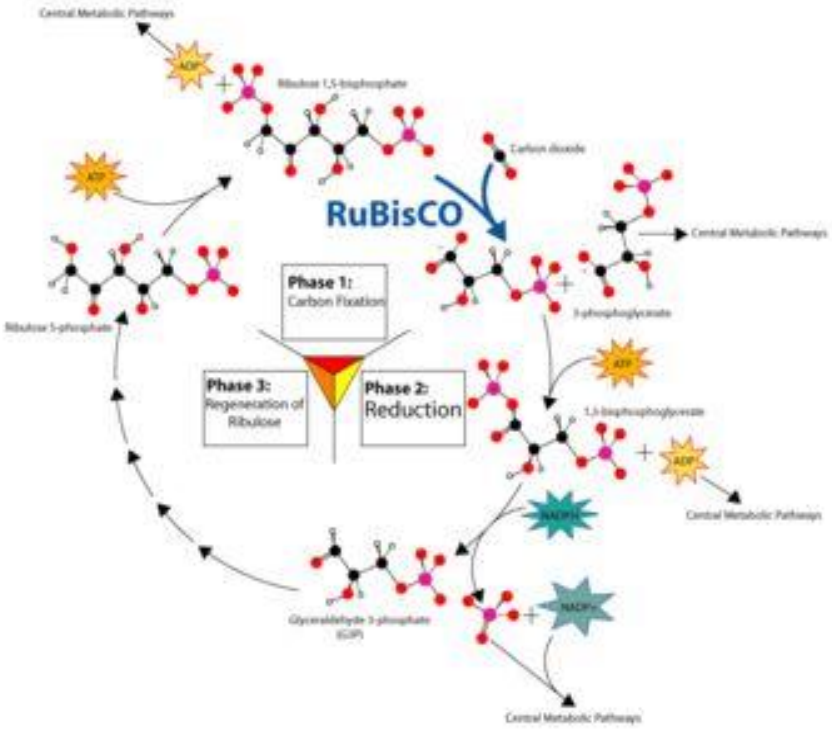


Importance of CO_2 to plants

Photosynthesis: a biochemical process in which plants are able to convert atmospheric CO_2 into energy-rich organic molecules such as glucose.

Two major roles of CO_2 in photosynthesis:

1. An activator and substrate for ribulose-1,5- bisphosphate carboxylase/oxygenase (rubisco).
2. Regulation of stomatal closure.



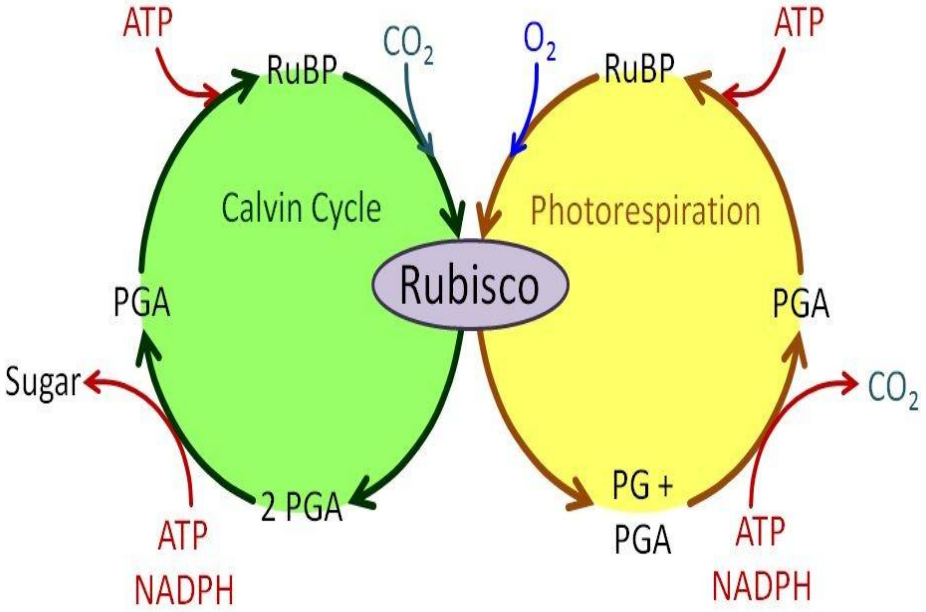
Free Air Carbon Enrichment (FACE)

- An experimental method used to study the effects of elevated CO_2 on plants grown under natural conditions.
- Better way of estimating how plant growth will change in the future as CO_2 concentrations rise in the atmosphere.

Effects of elevated atmospheric CO_2 levels on plant physiology: Short-term increase in Photosynthetic Rates

Short-term increases in CO_2 levels leads to an increase in photosynthetic rates:

- The fixation of CO_2 into photosynthetic metabolism is catalyzed by rubisco.
- O_2 also acts as a substrate for this enzyme in the photorespiratory pathway.
- Whether rubisco uses CO_2 or O_2 as a substrate depends on the ratio of the partial pressures of these gases.
- Elevating CO_2 levels in air stimulates carboxylation and suppress the oxygenation → Increase photosynthesis

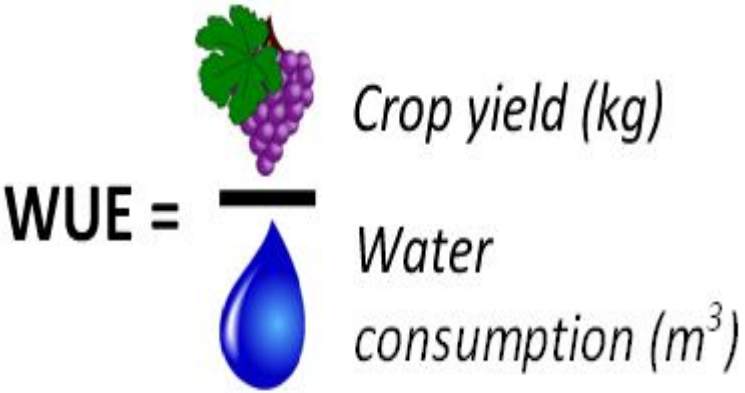


(Makino and Mae., 1999)

Effects of elevated atmospheric CO_2 levels on plant physiology: Increased Water Use Efficiency (WUE)

Water use efficiency: refers to the ratio of water used in plant metabolism to water lost by the plant through transpiration.

- An increase in CO_2 levels leads to increased stomatal closure.
- Decrease in stomatal conductance leads to a reduction in leaf transpiration.
- This leads to an improvement in plant water use efficiency by reducing water loss.



(Drake and Gonzàlez-Meler, 1997)

Effects of elevated atmospheric CO_2 levels on plant physiology: Increased Nitrogen Use Efficiency (NUE)

Nitrogen use efficiency: Rate of carbon assimilation per unit leaf nitrogen

- Long-term exposure to CO_2 leads to photosynthetic acclimation in plants.
- This is often accompanied by a reduction in the amounts of rubisco & other photosynthetic proteins.
- As a result, nitrogen concentrations decrease and is mobilized out of leaves to be reallocated to other photosynthetic or non-photosynthetic processes.
- This increase in NUE is advantageous because it demonstrates that elevated CO_2 can stimulate photosynthesis under severely limited nutrient supply.

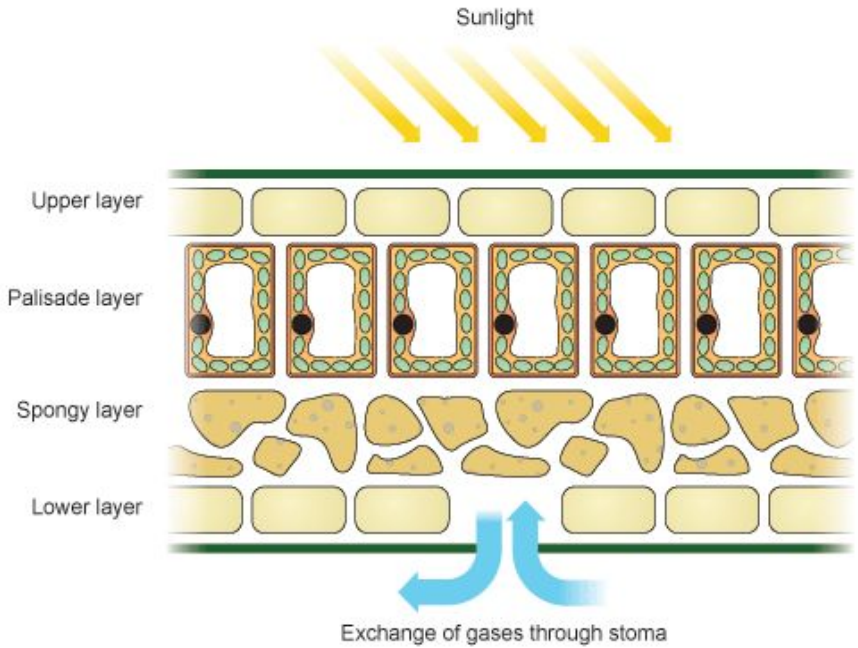
(Davey et al., 1999)

Effects of elevated atmospheric CO_2 levels on plant physiology: Long-term decrease in Photosynthetic Rates

Long-term CO_2 enrichment reduces initial stimulation of photosynthesis and frequently suppresses photosynthesis:

- Accumulation of carbohydrates has been observed in many studies on plant growth under CO_2 enrichment.
- Negative feedback inhibition: High carbohydrate level leads to inhibition of further carbohydrate synthesis.
- Starch accumulation may hinder CO_2 diffusion into chloroplast → reduced photosynthetic rates.

(Makino and Mae., 1999)



Effects of elevated CO_2 on human physiology:

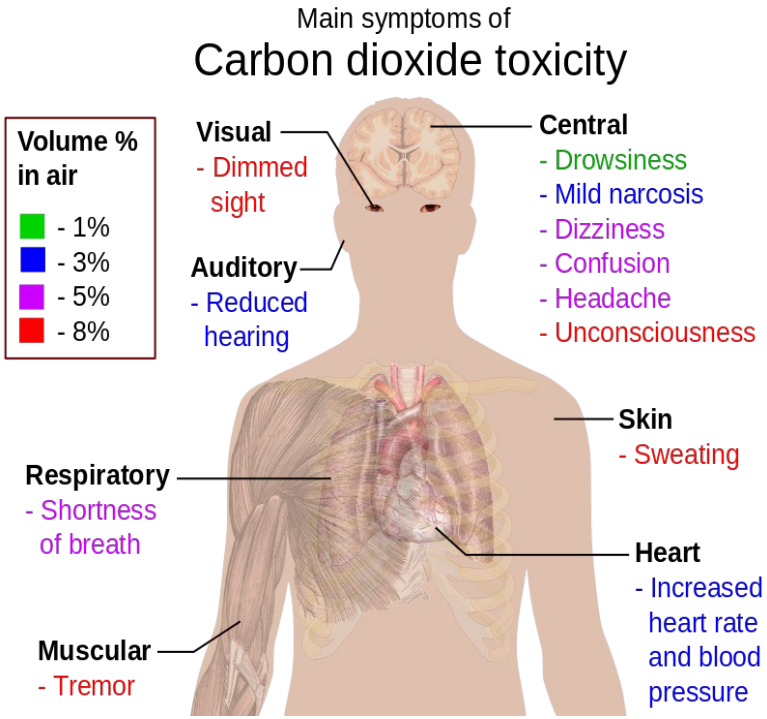
Hypercapnia (a.k.a. Hypercarbia)

- Increased CO_2 in the bloodstream
- Causes blood pH levels to decrease: Acidemia
  - Prolonged Acidemia: **Acidosis**

CO_2 can induce:

- Visual disturbances, Headache, Reduced reasoning, Dyspnea, etc.

Asphyxiation - CO_2 as an asphyxiant displaces breathable O_2 and impairs pulmonary gas exchange. Suffocation due to selective O_2 depletion.



(Guais et al. 2011; www.cdc.gov, 2009)

CO_2 Exposure : Symptoms / Health Effects

Exposure Limits (% in Air)	Symptoms / Health Effects
2-3	Unnoticed at *Rest.* Possible shortness of breath during *Exertion*.
3	Breathing noticeably deeper and more frequent at *Rest.*
3-5	Breathing rhythm increases. Repeated exposure may provoke headaches.
7.5	Rapid breathing, Increased heart rate, Headaches, Sweating, Dizziness, Shortness of breath, Muscular Weakness, Impairment of mental abilities, Drowsiness, Impaired hearing.
8-15	Headache, Vertigo, Vomiting, Loss of consciousness. Possibility of Death.
10	Respiratory distress develops rapidly with loss of consciousness in 10-15 minutes
15	Lethal concentration, exposure to higher levels are intolerable
>25	Convulsions and rapid loss of consciousness after a few breaths. Death imminent if maintained.

(http://www.ivhhn.org/index.php?option=com_content&view=article&id=84)

Summary of CO_2 Exposure / Activity Levels

	At Rest (65 Wm^2)		Very high work rate (400 Wm^2)	
Average $\%CO_2$	Potential Effects and/or Limitations	Exposure Limit (time)	Potential Effects and/or Limitations	Exposure Limit (time)
1.5	No restrictions	Indefinite	Increased ventilation	Unknown
2.5	Increased ventilation	Unknown	Increased ventilation	2 hours
3.0	Increased ventilation No restrictions within exposure limit	15 hours	Increased ventilation	30 minutes
5.0	Increased ventilation No restrictions within exposure limit	8 hours	Increased ventilation Collapse / Unconsciousness	5 minutes
7.0	Increased ventilation Severe limitations on activity	< 30 minutes	Collapse / Unconsciousness	n/a
10.0	Increased heart rate Collapse / Unconsciousness	< 2 minutes	Collapse / Unconsciousness	n/a

(http://www.cdc.gov/niosh/npptl/resources/certpgmspt/meetings/09172009/pdfs/9CO202PresentWJW.pdf)

Effects of elevated CO2 on human physiology: Projected Atmospheric CO2

Projected atmospheric CO_2 concentration:

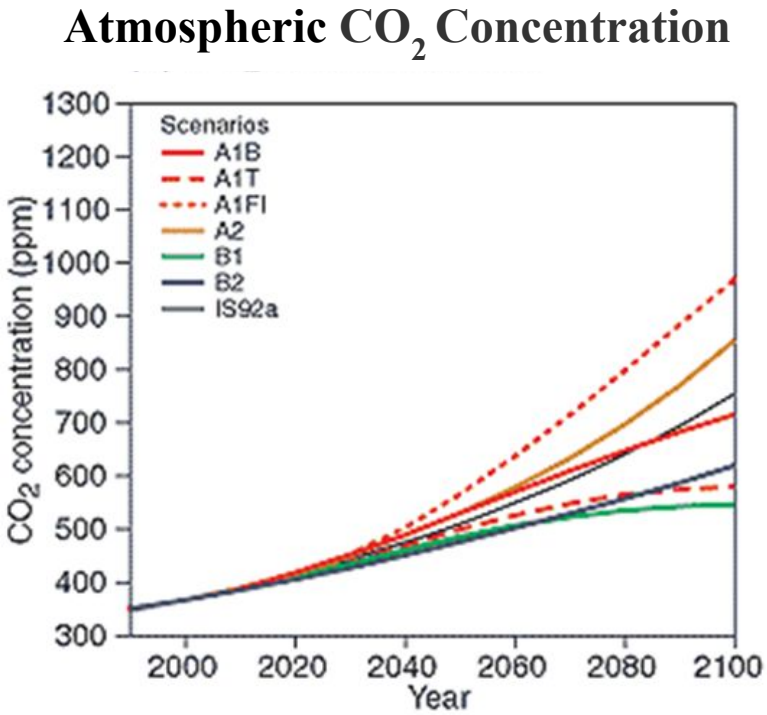
2050 Baseline (A1FI) Projection:

~600 ppm CO_2 → ~0.06 % in Air

2100 Baseline (A1FI) Projection:

~1000 ppm CO_2 → ~0.10 % in Air

Estimated toxic level of Atmospheric CO_2 under lifetime exposure is **426 ppm**.



(Robertson, 2001 2006; http://www.ipcc-data.org/observ/ddc_co2.html)

Summary

- Carbon dioxide levels have been increasing in the atmosphere due to human activity, such as the burning of fossil fuels and deforestation.
- Increased atmospheric carbon dioxide has caused an increased global mean temperature and a wide range of environmental effects, including impacts on both plant and human physiology.
- Benefits of increased CO2 in plant physiology include: short-term increase in photosynthetic rates and increase in nitrogen and water use efficiency.
- However, in the long-term, increased CO2 levels can also lead to a decrease in photosynthetic rates.
- CO_2 exposure effects:
  - < 3% CO_2: Could induce deeper and more frequent breaths, and headaches.
  - 3 - 10% CO_2: Results in impaired mental ability, respiratory distress and unconsciousness.
  - > 15% CO_2: Lethal concentration.
- Baseline CO_2 Projections predict that by 2050, the average atmospheric CO_2 concentration would surpass ~600 ppm. Potential long-term health effects.

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Questions?