Environmental Factors
Carbon Dioxide

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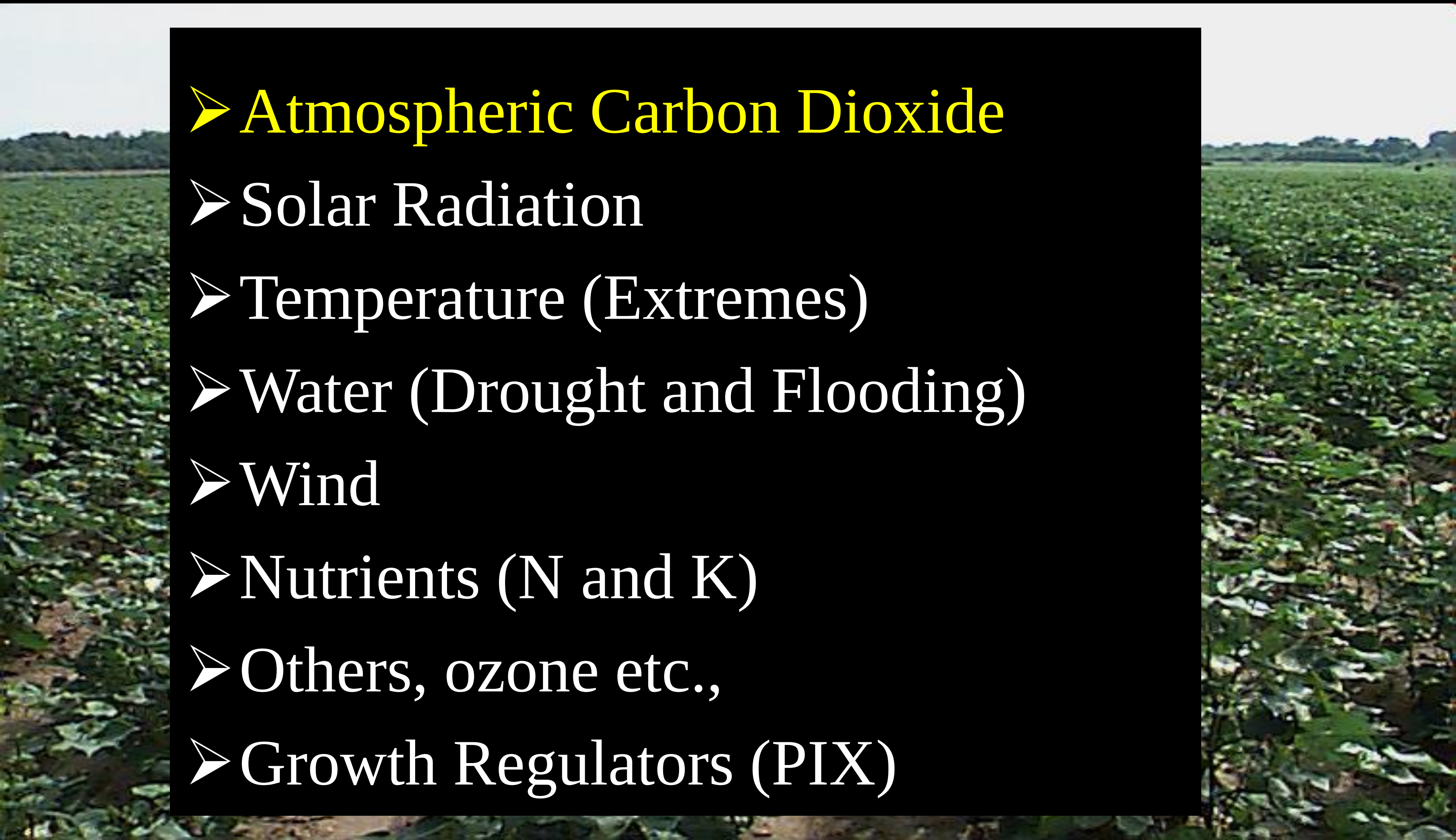
Environmental Plant Physiology
Objectives

- The objectives of this course are to learn plant responses to abiotic stresses, particularly plant growth and development, and to learn modeling methodologies on how to integrate those plant processes under multiple stress conditions.
- At the end, the students are expected to:
  - ✓ understand individual as well as interactive abiotic stress effects on photosynthesis, respiration, growth, development and finally yield.
  - ✓ understand on how to develop methodologies to integrate multiple stress factor effects on various plant/canopy processes.

Environmental and Cultural Factors Limiting Potential Yields



- Atmospheric Carbon Dioxide
- Solar Radiation
- Temperature (Extremes)
- Water (Drought and Flooding)
- Wind
- Nutrients (N and K)
- Others, ozone etc.,
- Growth Regulators (PIX)

Atmospheric Carbon Dioxide - Objectives

The objectives of this lecture are:

- To learn global, regional and local spatial and temporal trends in atmospheric CO_2.
- To learn diurnal trends in atmospheric CO_2.
- Contributing factors for fluxes/changes in global CO_2 concentration.
- The importance of atmospheric CO_2 and its role or effects on plants and ecosystems in general.

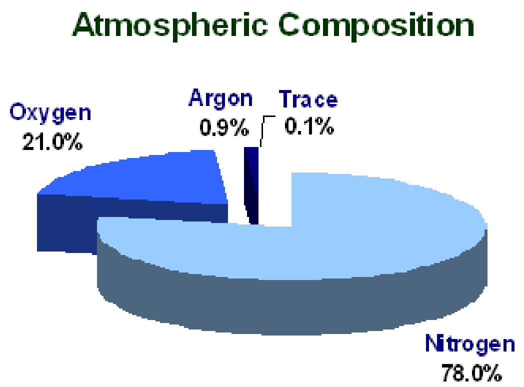
Why are we concerned with CO_2?

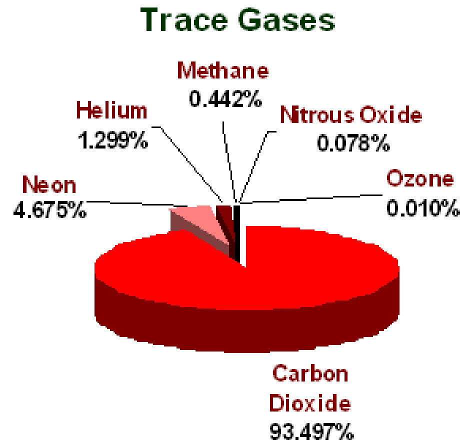
- Atmospheric CO_2 is essential for life on earth.
- Plants grow through photosynthesis, a process that uses the energy from sunlight to combine carbon dioxide (CO_2) from the air with water to make carbohydrates plus oxygen.

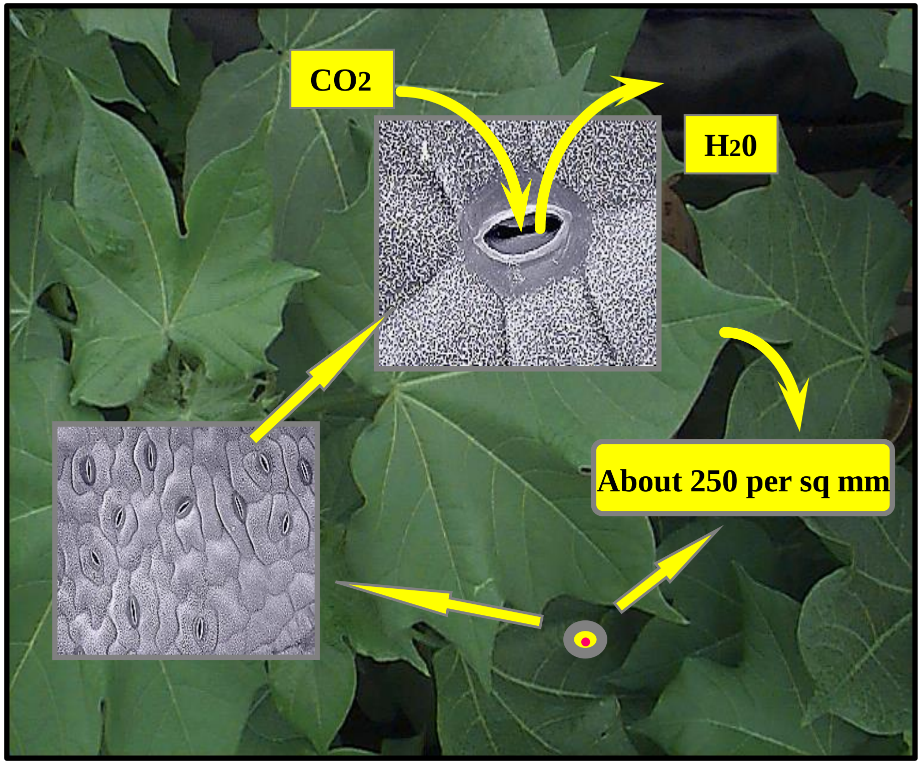
$$6\,CO_2 + 6\,H_2O \xrightarrow{\text{Light, Plant, Water, Nutrients}} C_6H_{12}O_6 + 6\,O_2$$

- The carbohydrates formed through photosynthesis feed not only the plants but also almost all other organisms on earth, including those that eat the plants and those that eat the animals that eat the plants.
- Now, as the atmospheric CO_2 is rising, we are seeing almost parallel decreases in atmospheric oxygen.
- The oxygen concentration is so much higher than that of CO_2 that the decrease in oxygen from fossil fuel combustion is not a problem, but it demonstrates the connection between these two critically important atmospheric constituents.

Plant Responses to Atmospheric Carbon Dioxide







Global Carbon Dioxide Concentrations

Temporal Trends in Global CO_2

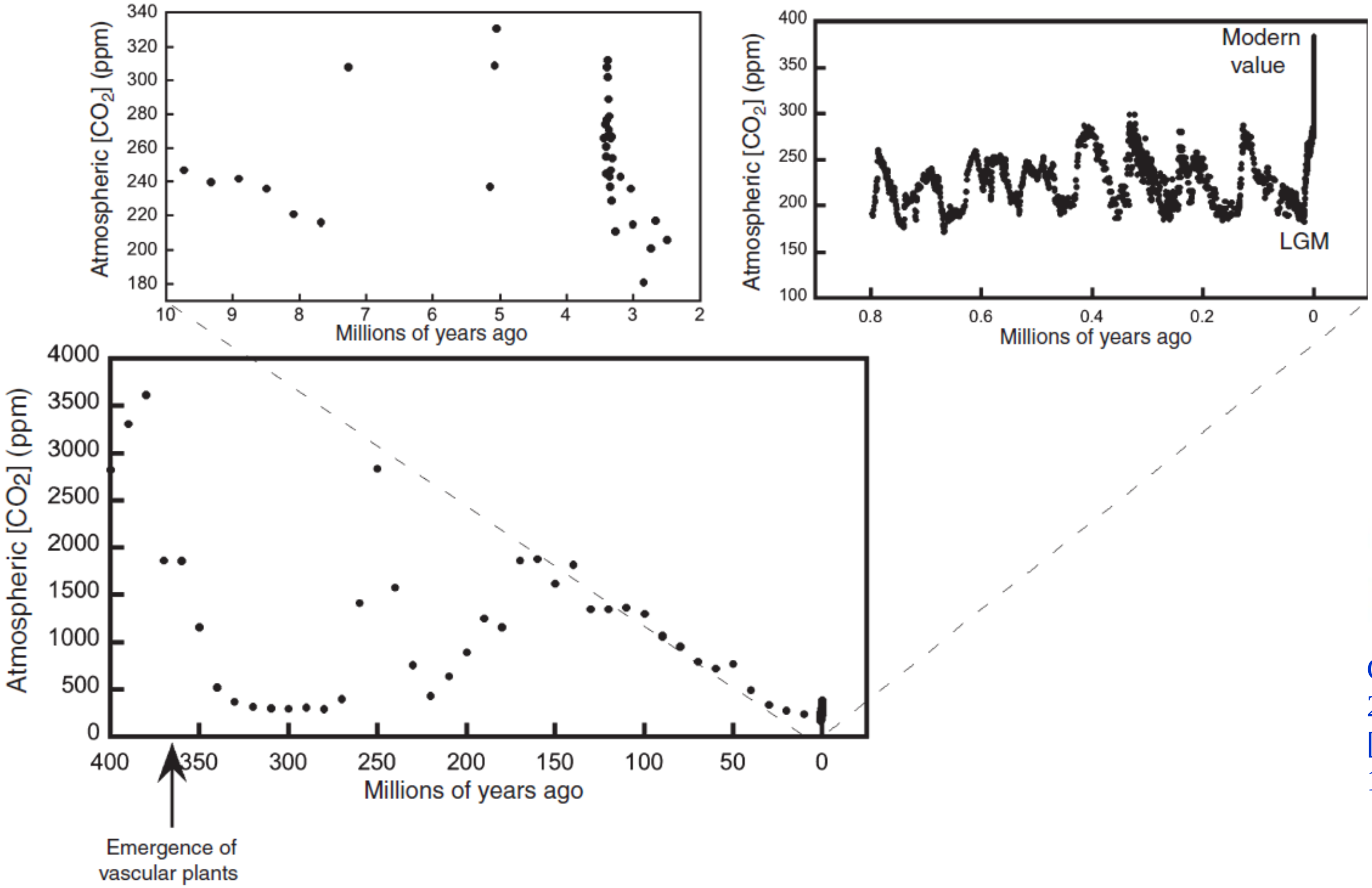


Fig. 1 Changes in atmospheric [CO_2] throughout the evolution of vascular land plants. The upper right insert shows the past million yr expanded in order to show low [CO_2] during glacial periods. The upper left insert is expanded to show low [CO_2] periods over the last 10 million yr (data are from Petit *et al.*, 1999; Monnin *et al.*, 2001; Siegenthaler *et al.*, 2005; Berner, 2006; Lüthi *et al.*, 2008; Keeling *et al.*, 2005; Tripati *et al.*, 2009).

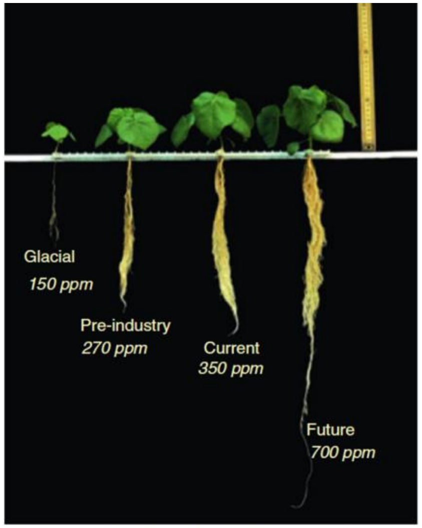
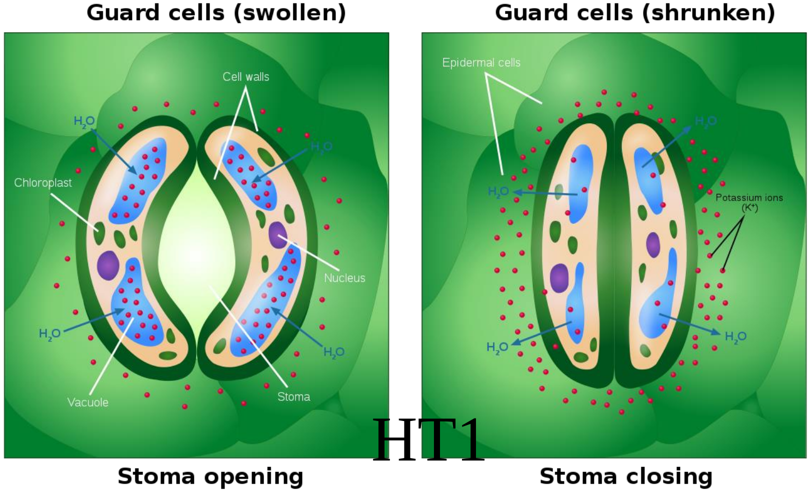


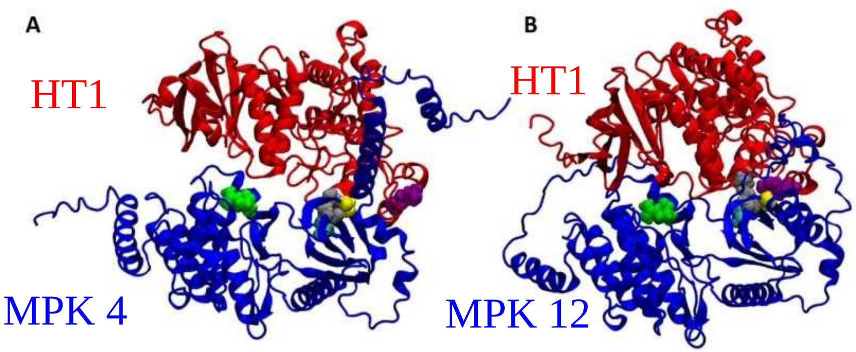
Fig. 2 Representative plants of *Abutilon theophrasti* (C_3) grown at glacial through future [CO_2]. All plants were 14 d of age and were grown under similar water, light, and nutrient conditions. These plants were photographed during a study by Dippery *et al.* (1995). (Photograph is courtesy of Anne Hartley, Florida Gulf Coast University.)

Gerhart, L.M. and J.K. Ward. 2010. Plant responses to low [CO_2] of the past. New Phytol. 188: 674–695

Global Carbon Dioxide Concentrations

CO2-Sensing Mechanism – How do plants control their mouths





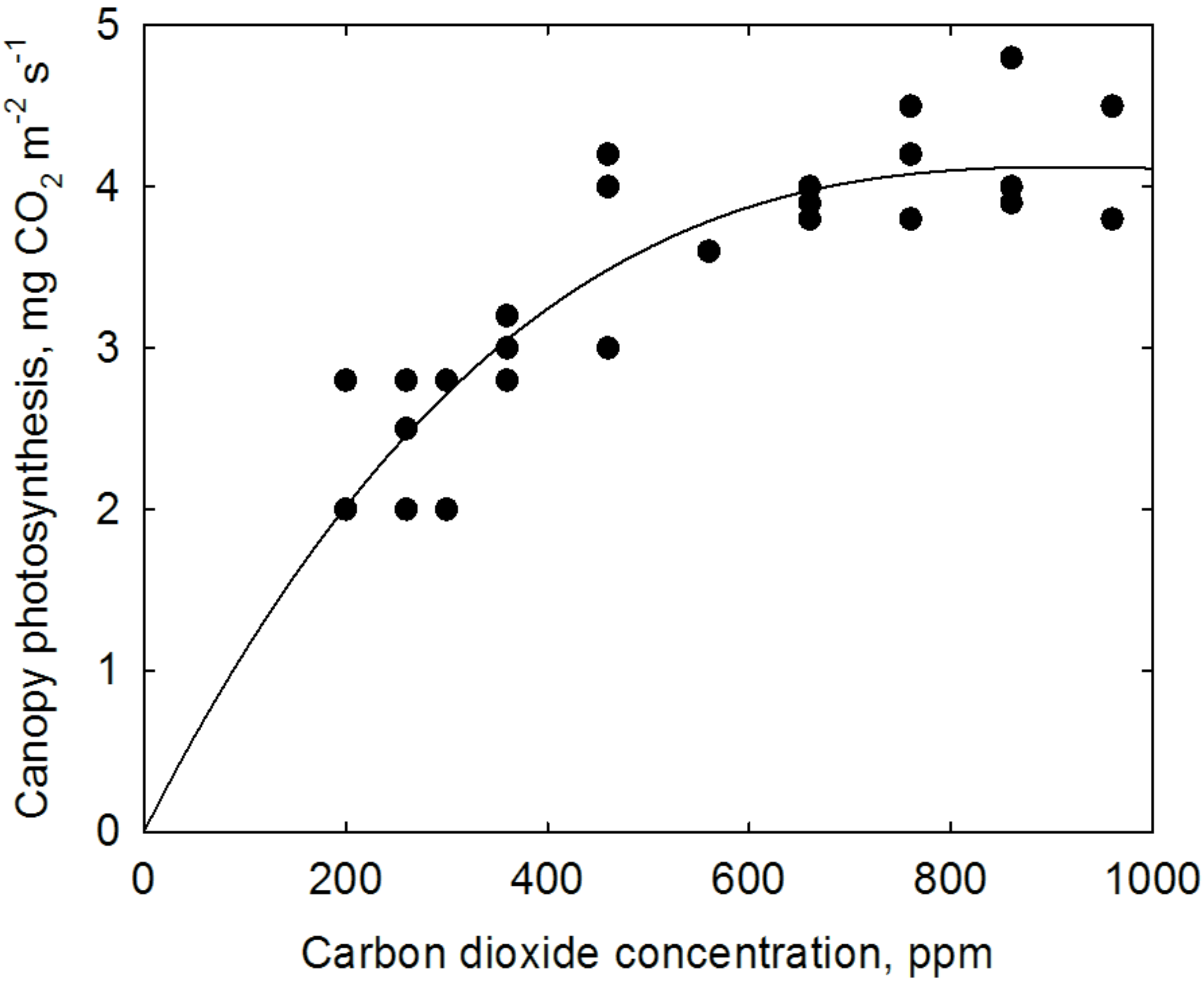
The CO_2 sensors were identified as 1) a "high leaf temperature1" protein kinase known as HT1 and 2) specific members of a mitogen-activated protein kinase family, or "MAP" kinase enzyme, known as MPK4 and MPK12.

When stomata are open, a typical plant loses about 200-500 molecules of water through evaporation for each molecule of CO_2 taken.

Science Advances, 2022, https://www.science.org/doi/epdf/10.1126/sciadv.abq6161

Photosynthesis and Management

Response to Carbon Dioxide – Cotton, a C3 Plant



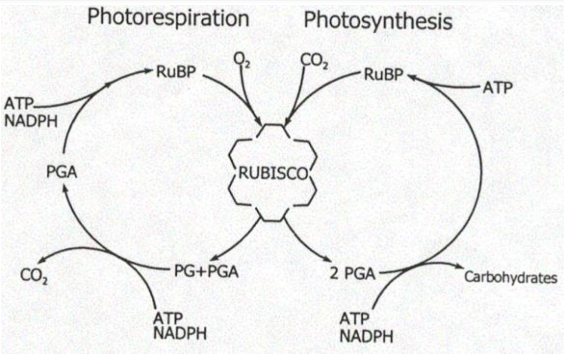
Low ⟷ High

Photosynthesis

Light, Plant

$$6\ CO_2 + 6\ H_2O \longrightarrow C_6H_{12}O_6 + 6\ O_2$$

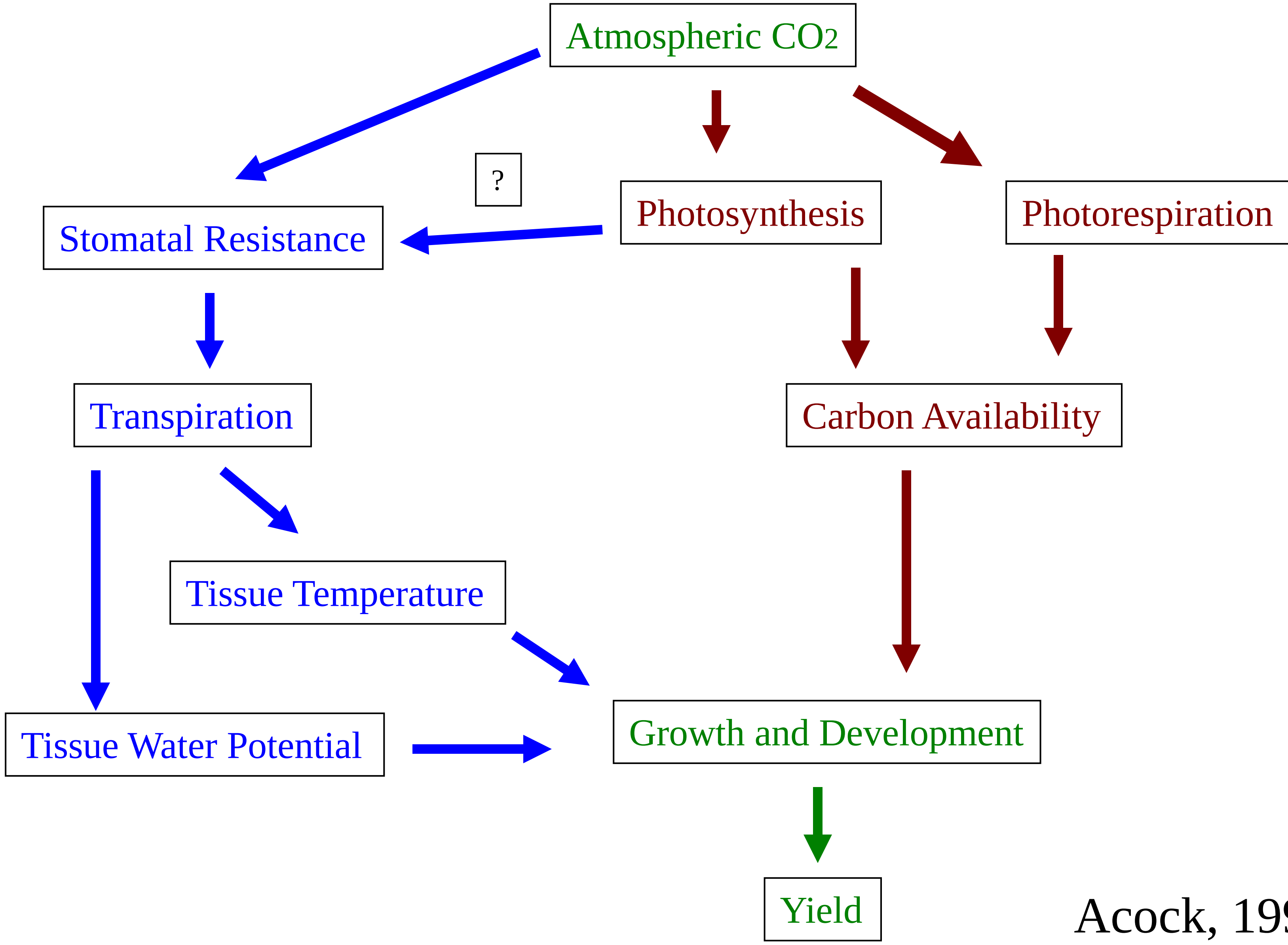
Water, Nutrients



Preindustrial – 286 ppm
1958 – 315 ppm + 29 ppm
2013 – 400 ppm + 114 ppm
2017 – 406 ppm + 120 ppm

16% increase in PHS
Between
1958 and 2013

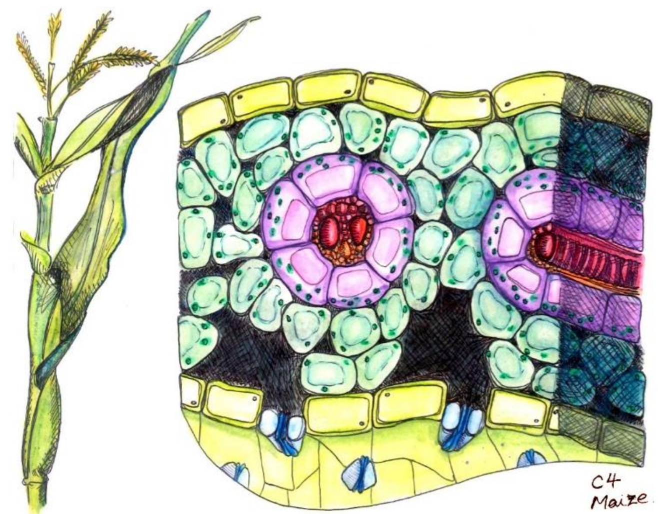
A Hierarchy of Plant Responses to CO_2 – C_3 Plants



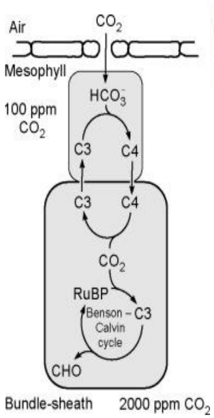
Acock, 1990

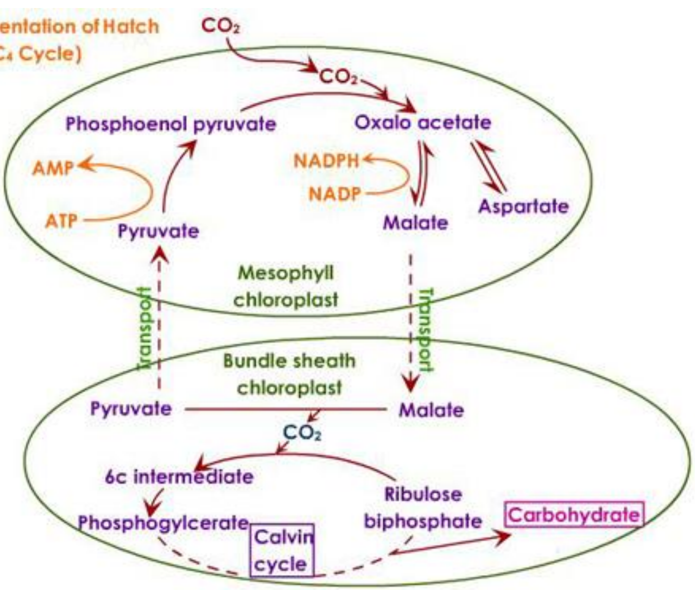
Crop Responses to Atmospheric Carbon Dioxide

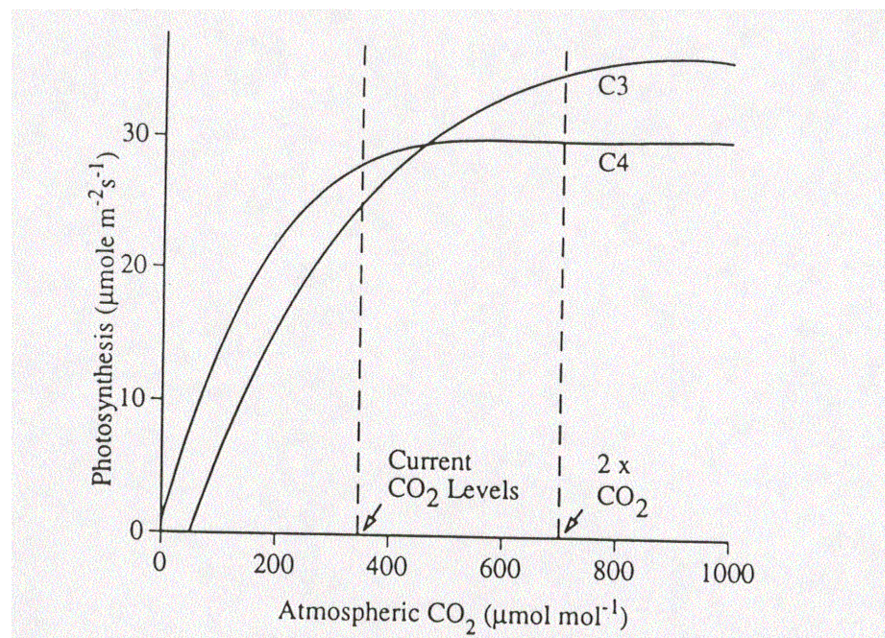
Photosynthesis response to CO_2 _ Species variability



- 25-32 million years ago – Convergent evolution.
- 6-7 million years ago – Became ecologically significant.
- Currently about 3.2% of higher plants contribute to about 30% of global carbon fixation & 25% of land plant biomass.







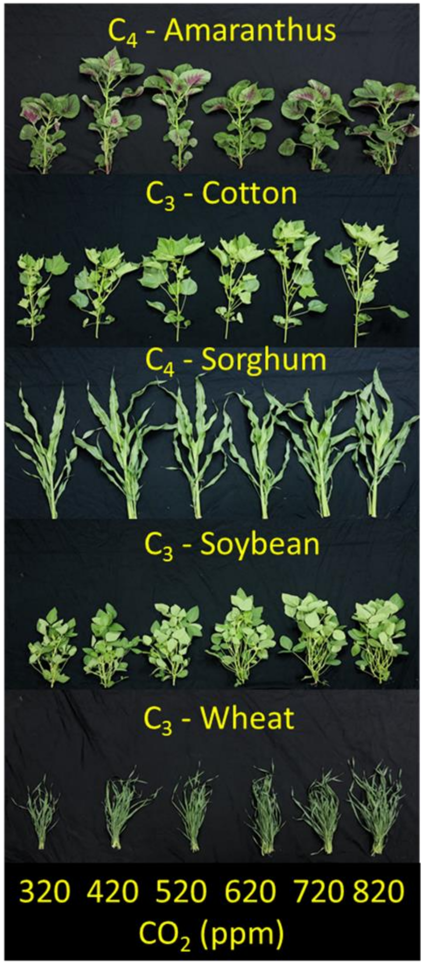
Plant Adaptations to Atmospheric Carbon Dioxide

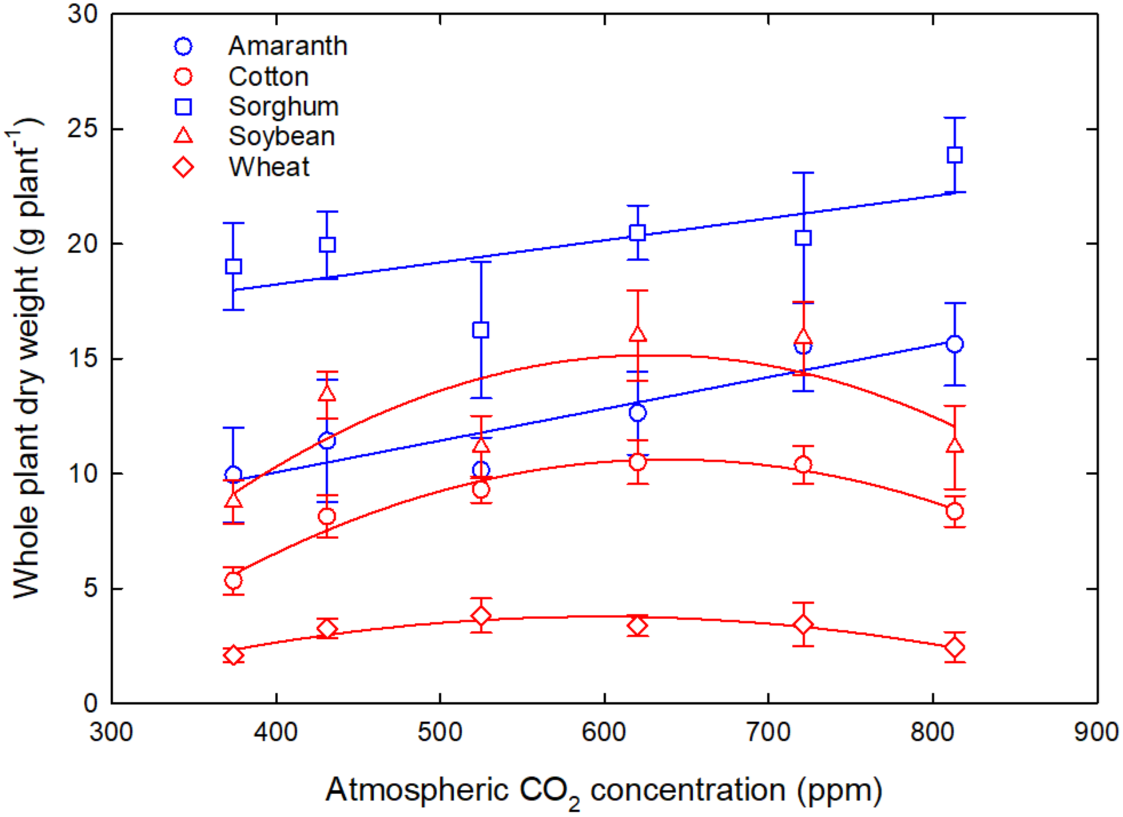
The direct effect of increased CO_2 on crop photosynthesis might lead to higher global food production

- ✓ Weeds: Plants are NOT unique and UNIFORM in the stimulation of their photosynthesis by elevated CO_2.
- ✓ Losses to Pests: Several recent studies show that insects eat more high-CO2-grown material because of decreased protein levels.
- ✓ Climate: The connection between CO_2 and climate is increasingly well understood, with the vast majority of evidence indicating that the continued build-up of these radiative gases causes gradual warming and other changes in climate.

Climate Change and Crop Species Variation

Photosynthesis – Carbon Dioxide Concentration





There are about 380,000 known species of plants on the planet and 35,687 are utilized for various purposes, spanning 10 use categories.

Of the 250,000 higher plant species that produce seed:

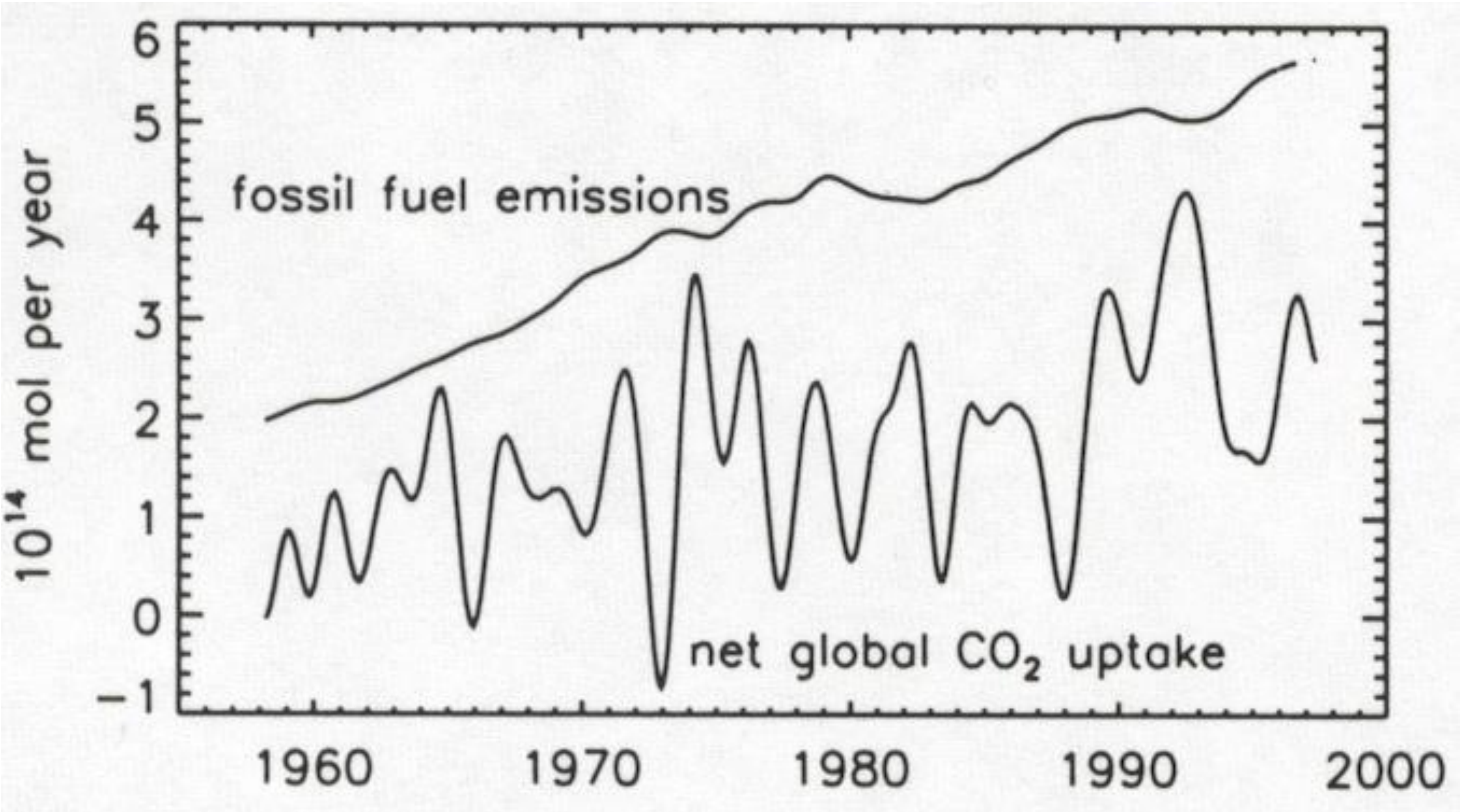
C3 photosynthetic model = 222,000 (89%)

C4 photosynthetic model = 8,100 (3.2%)

Crassulacean Acid Metabolic (CAM) photosynthetic model = 20,000 (8%)

Global Carbon Fluxes

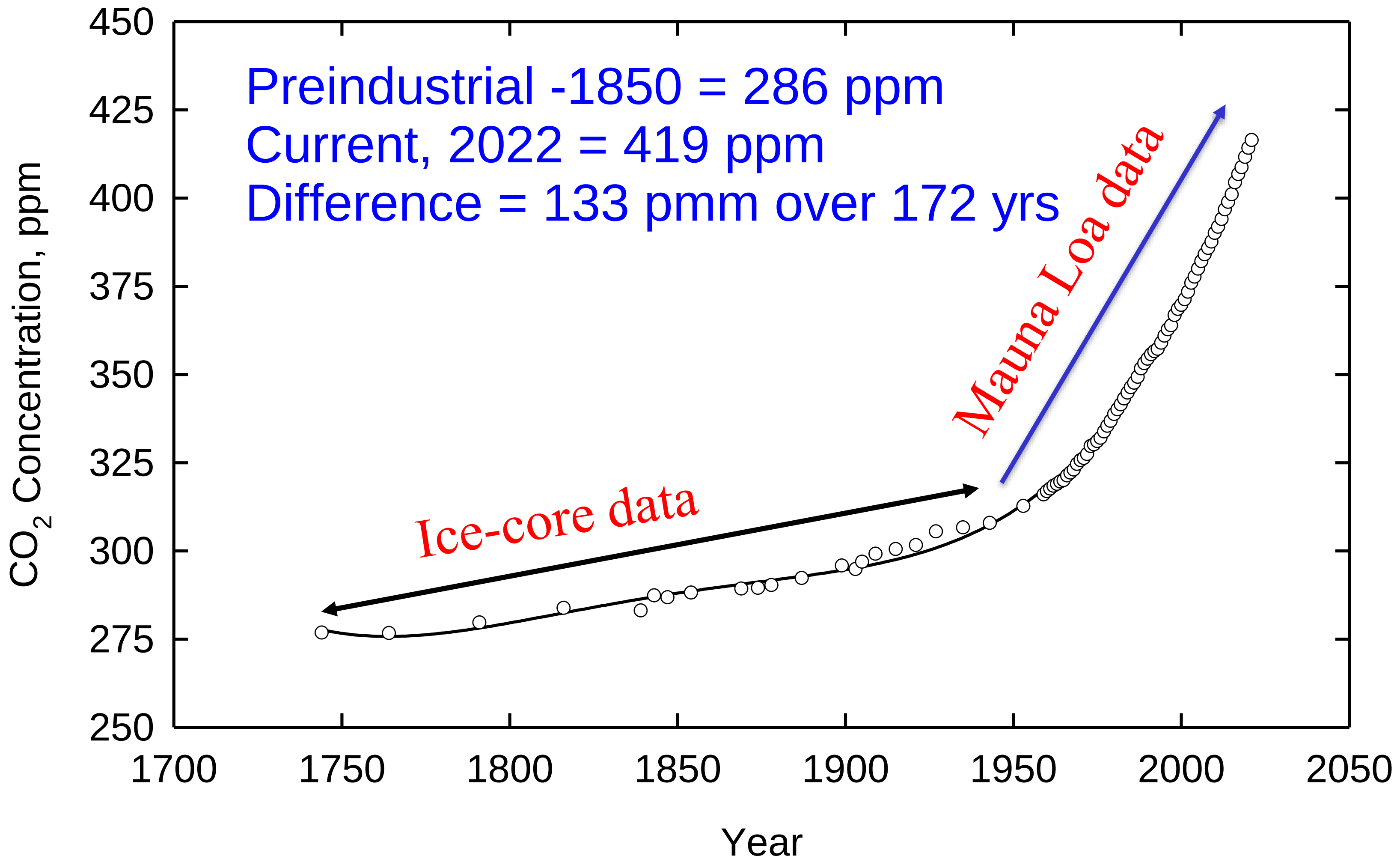
Global carbon emissions and Carbon fixation



Global Carbon Dioxide Concentrations

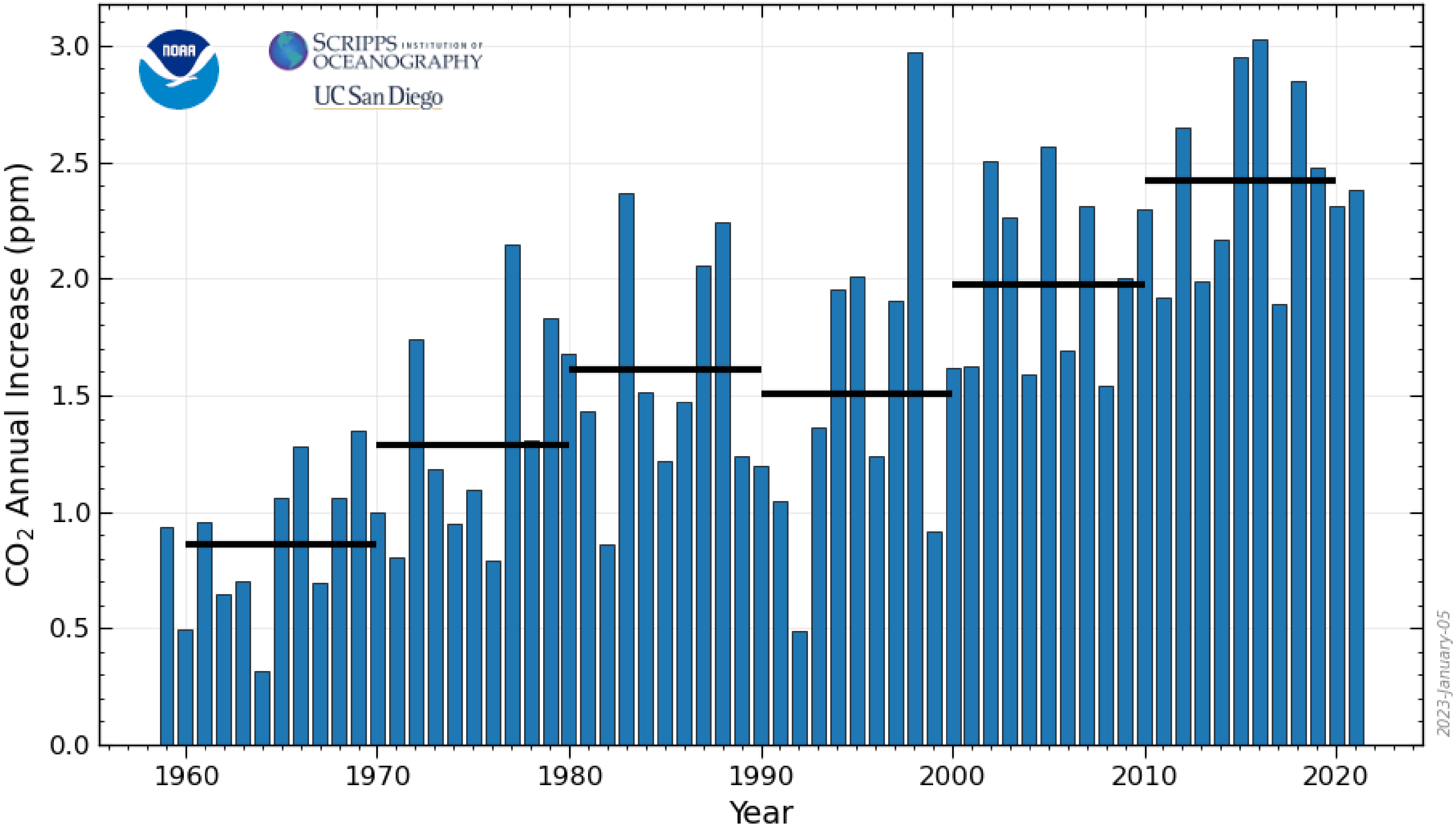
Temporal trends in CO_2 from 1750 to 2022

Ice-core data and Mauna Loa (HI) measurements



Atmospheric Carbon Dioxide Concentration

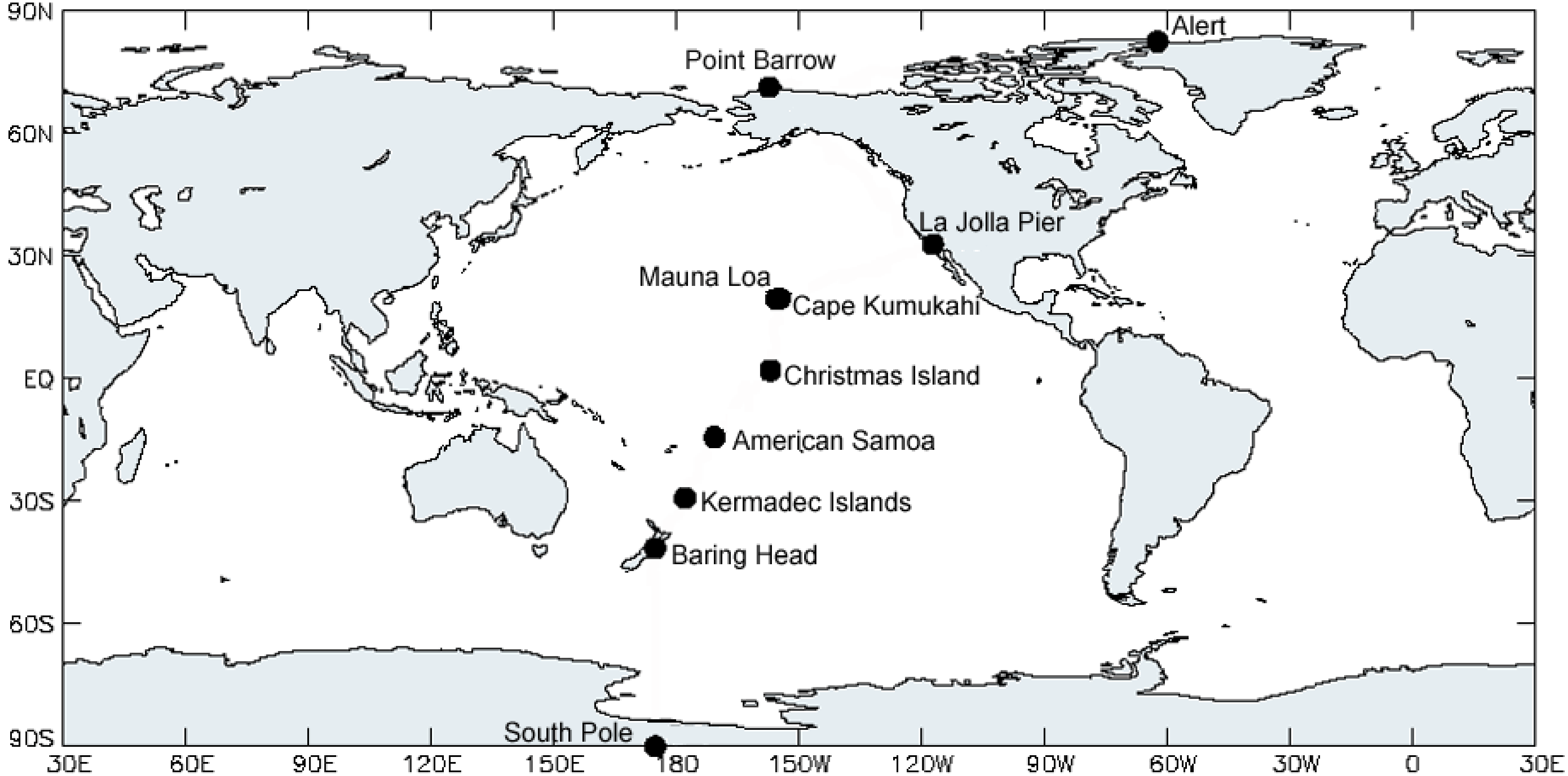
The annual rate of increase in CO_2 concentration (ppm)



https://gml.noaa.gov/ccgg/trends/gr.html

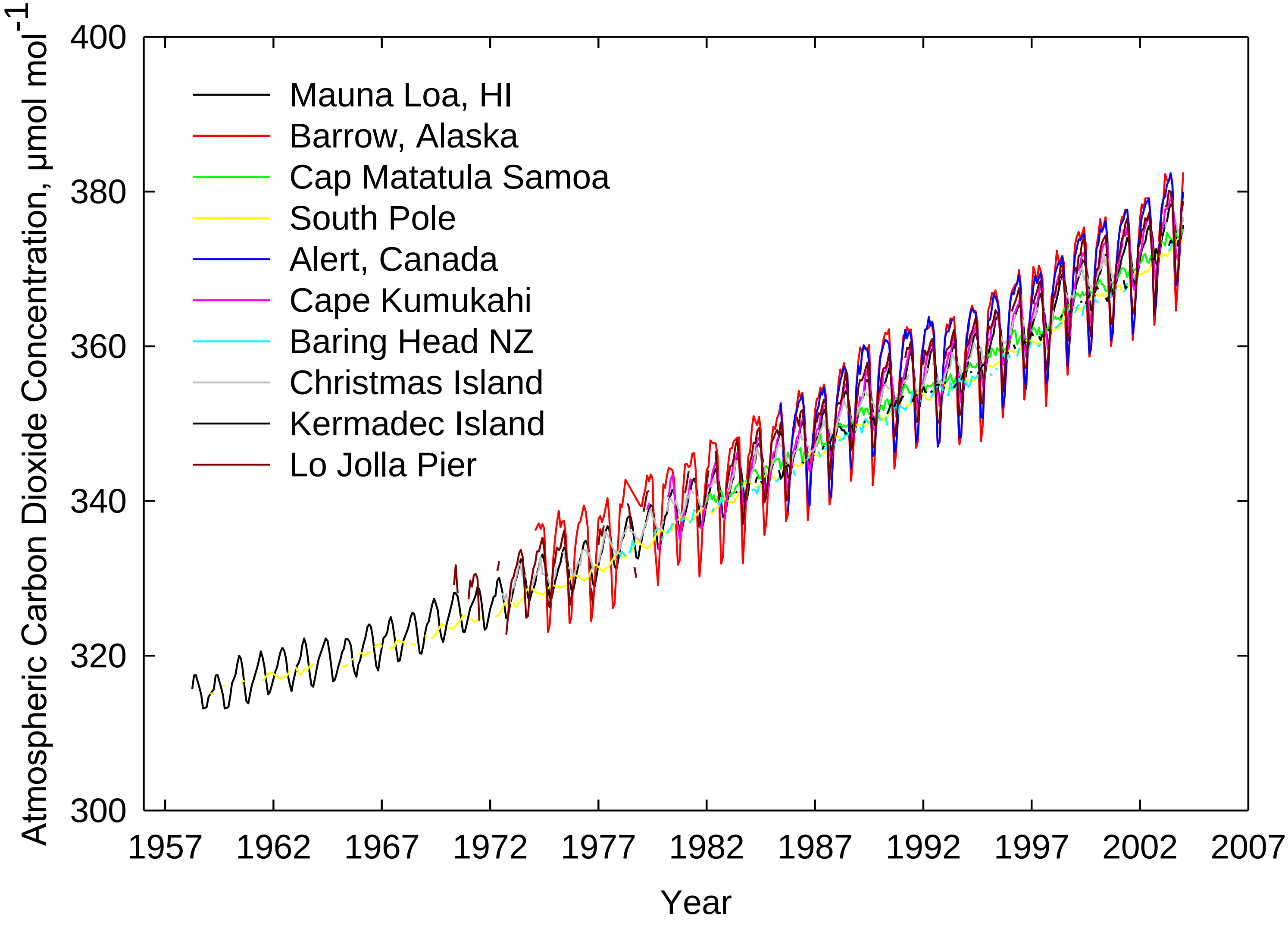
Atmospheric Carbon Dioxide Concentration

Pole to pole measurement sites



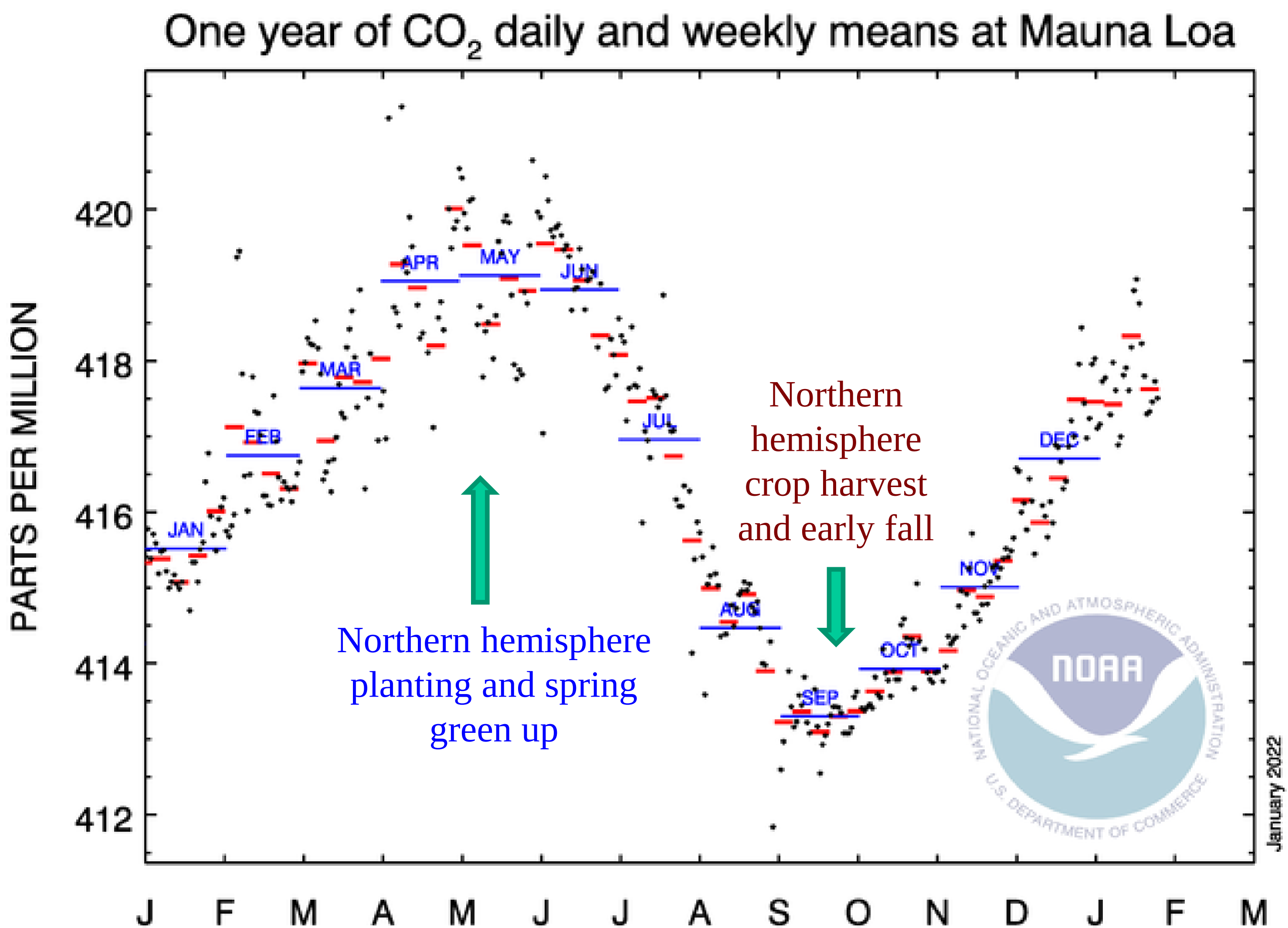
Atmospheric Carbon Dioxide Concentration

Temporal trends in CO_2 concentration from pole to pole



Global Carbon Dioxide Concentrations

Trends – Atmospheric Carbon Dioxide – 2022 Year



https://gml.noaa.gov/webdata/ccgg/trends/co2_weekly_mlo.png

Global Circulation Models

Predictive capabilities – Data requirements

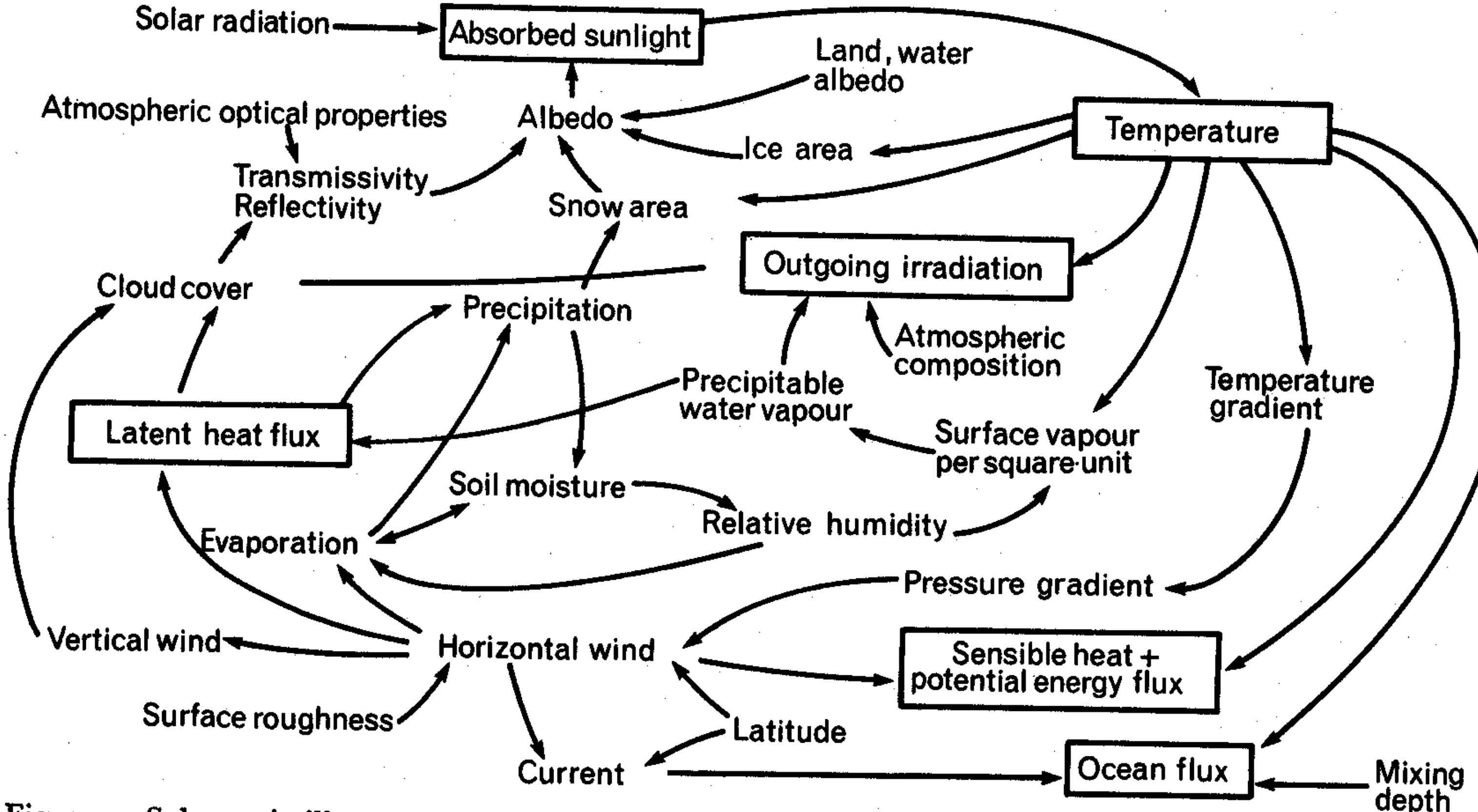
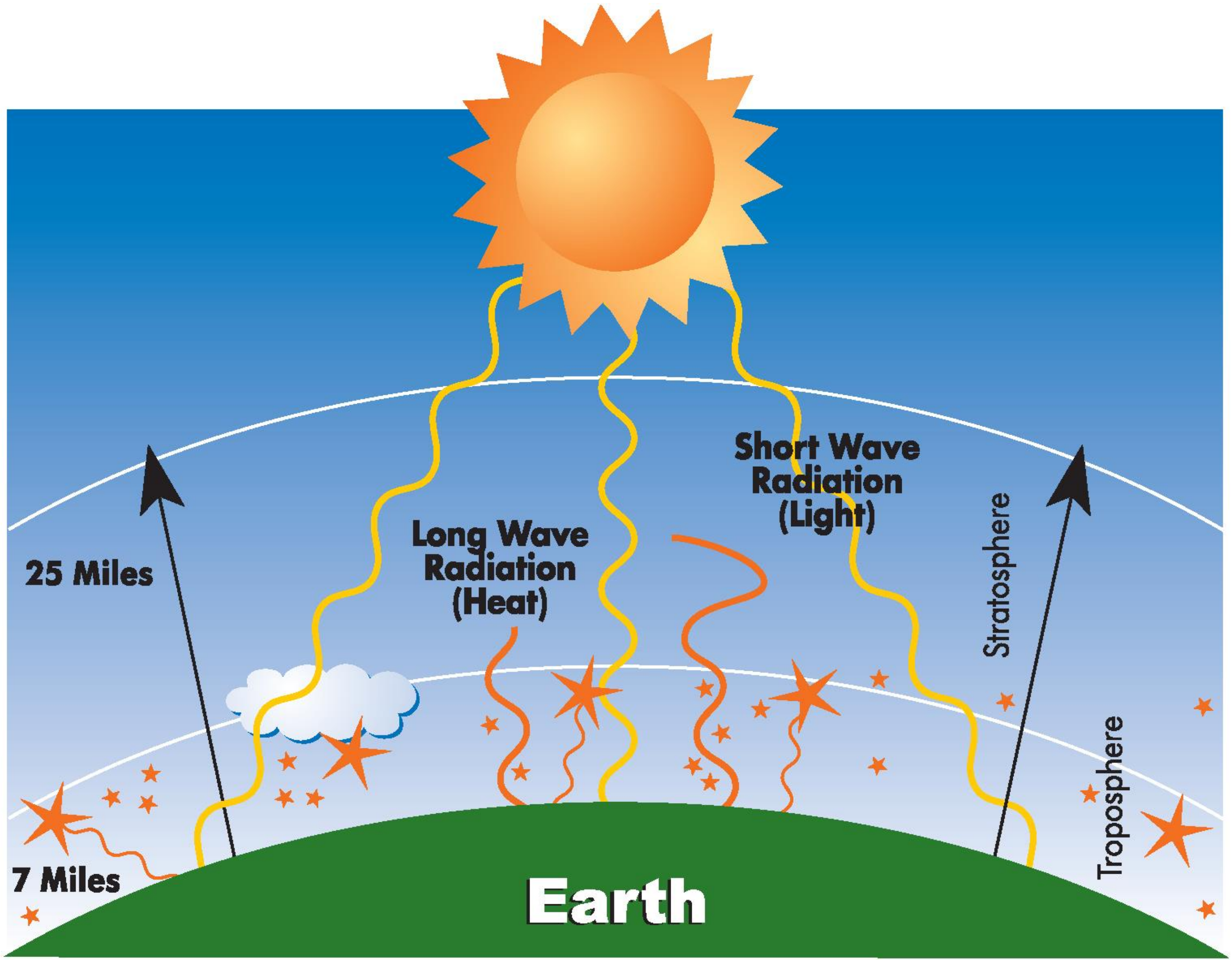


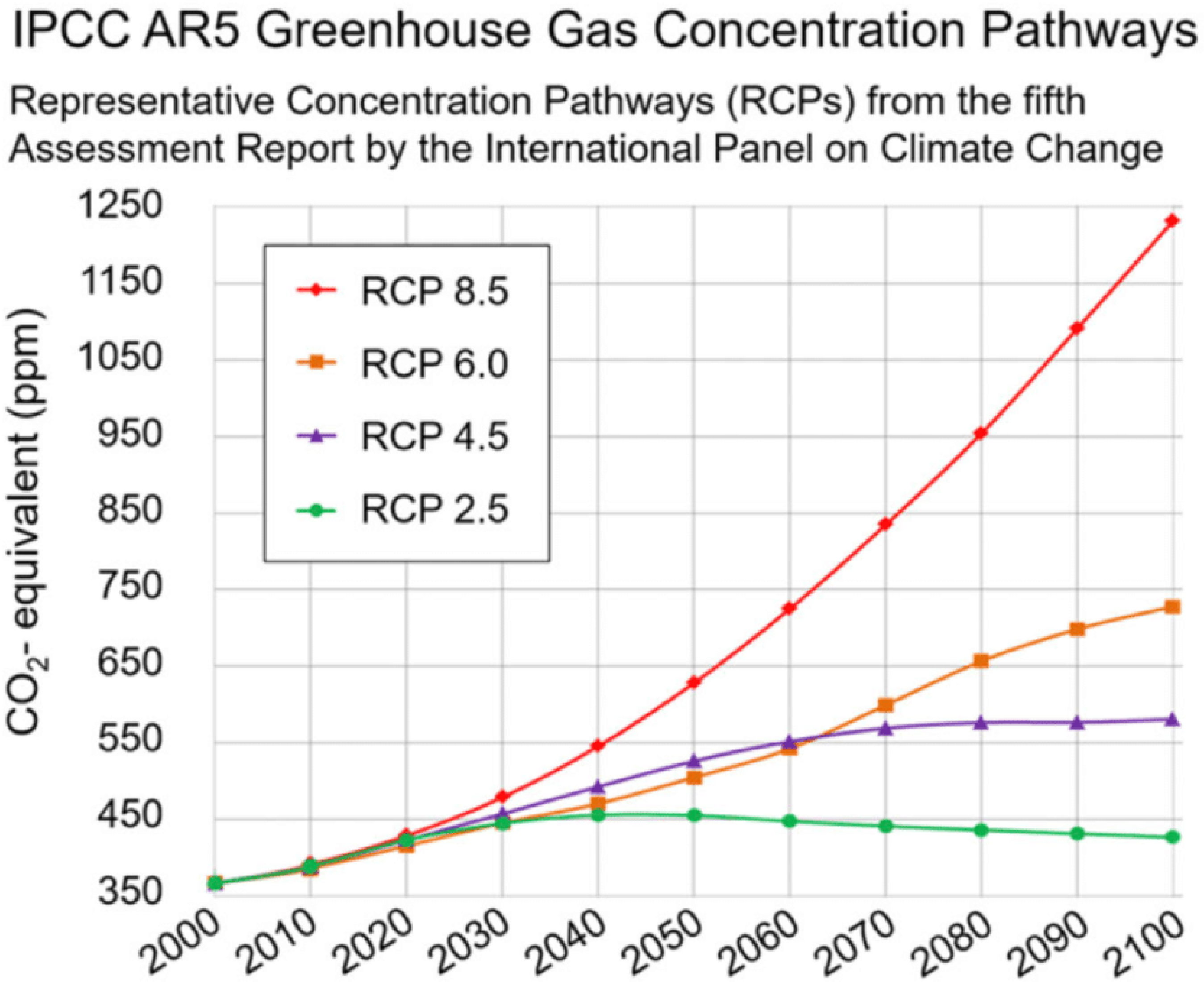
Fig. 14.5. Schematic illustration of many of the potential climatic feedback interactions that need to be considered in a climatic model.[27]

Greenhouse Gases and Climate Change

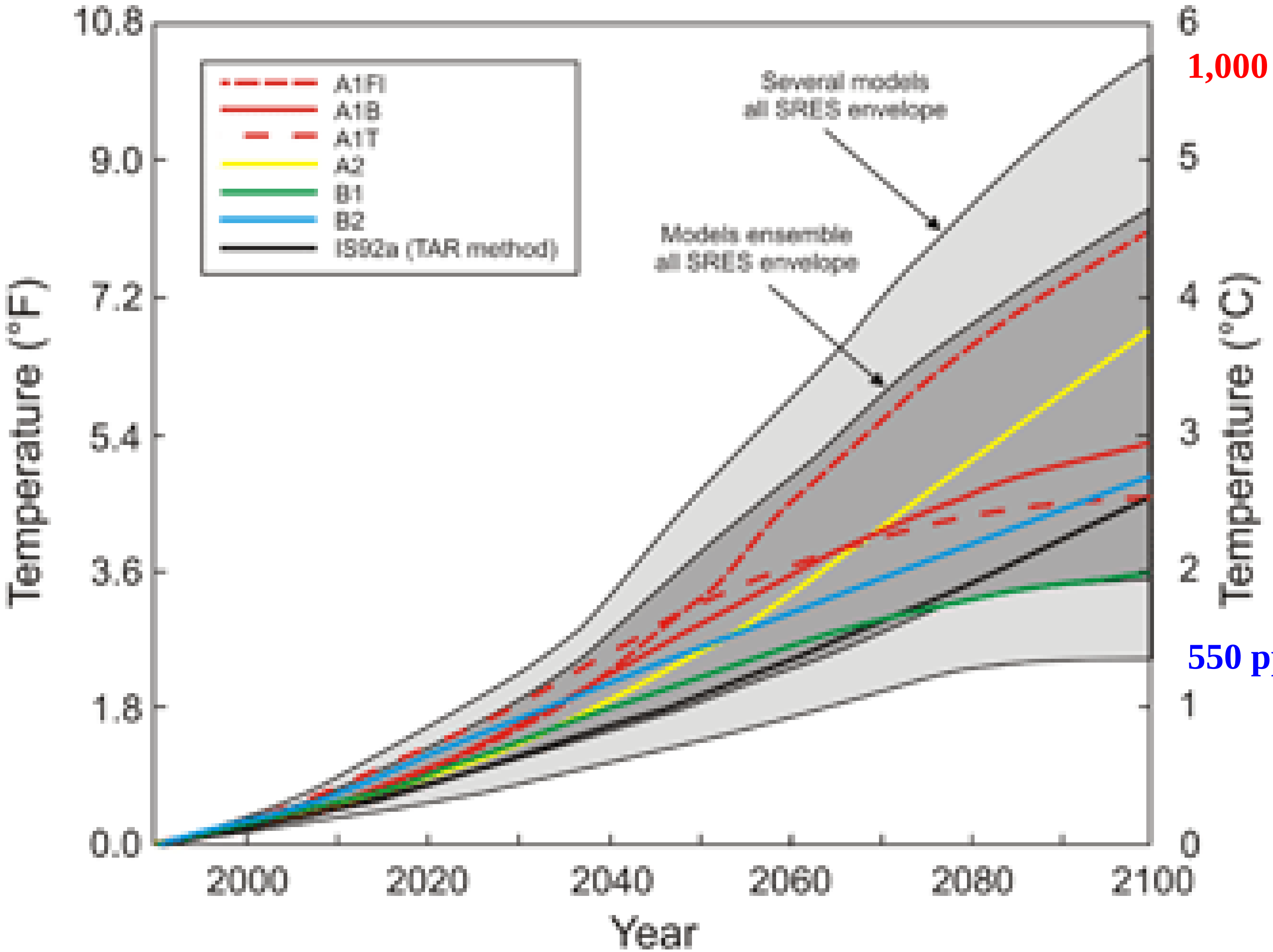


Global Carbon Dioxide Concentrations

Projected trends



Future Trends in Global Surface Air Temperatures



1,000 ppm CO_2

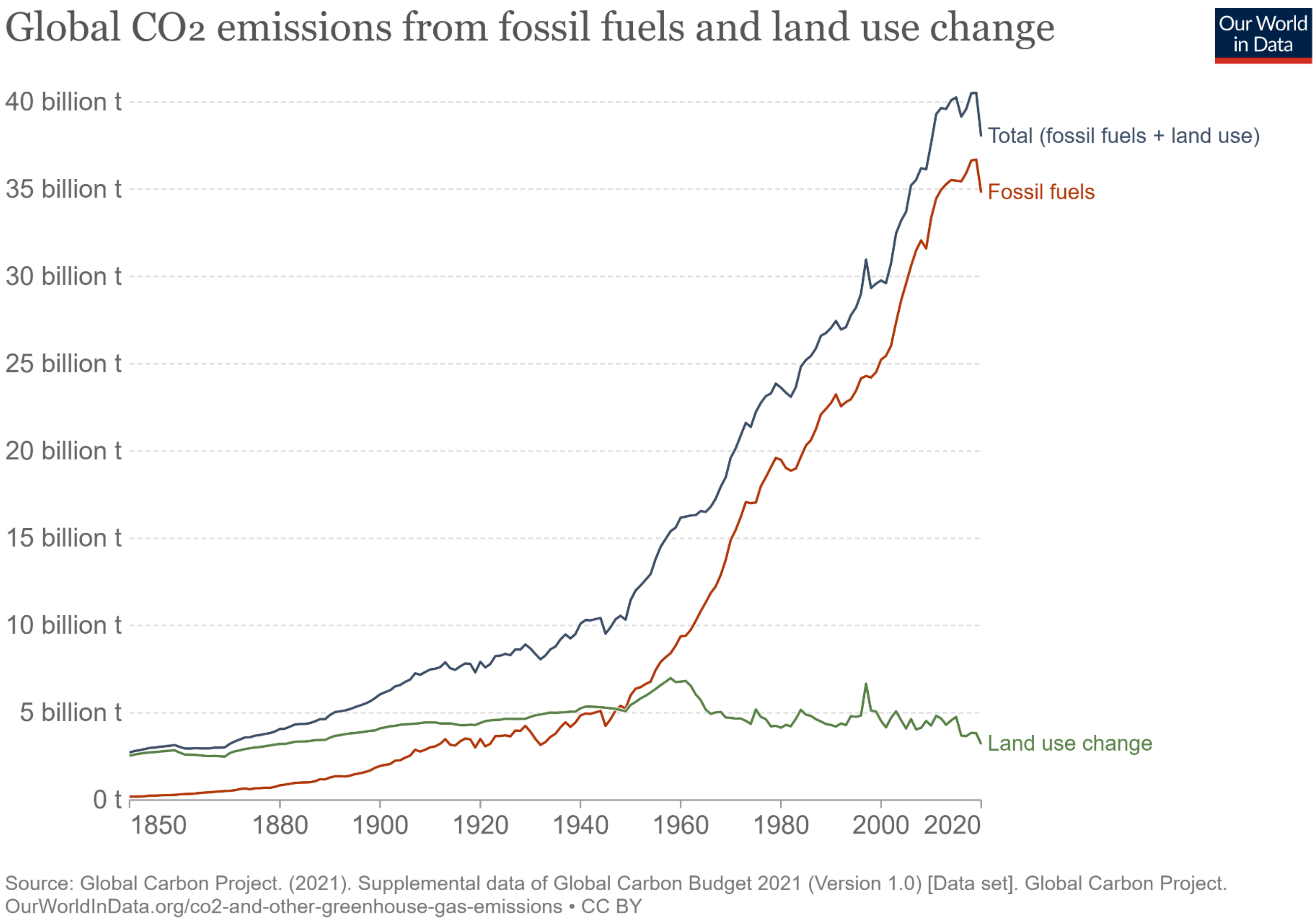
550 ppm CO_2

This shows temperatures associated with seven different carbon dioxide (CO_2) emissions scenarios. The low end of the IPCC range suggests that in the year 2100 the concentration of CO_2 in the atmosphere would be approximately 550 parts per million (ppm), or approximately double the pre-industrial value, while an alternate scenario suggests that the concentration could be close to 1,000 ppm. The other five scenarios fall somewhere in between. http://ccir.ciesin.columbia.edu/nyc/ccir-ny_q1e.html

Our biosphere is changing

Atmospheric Carbon Dioxide Concentration

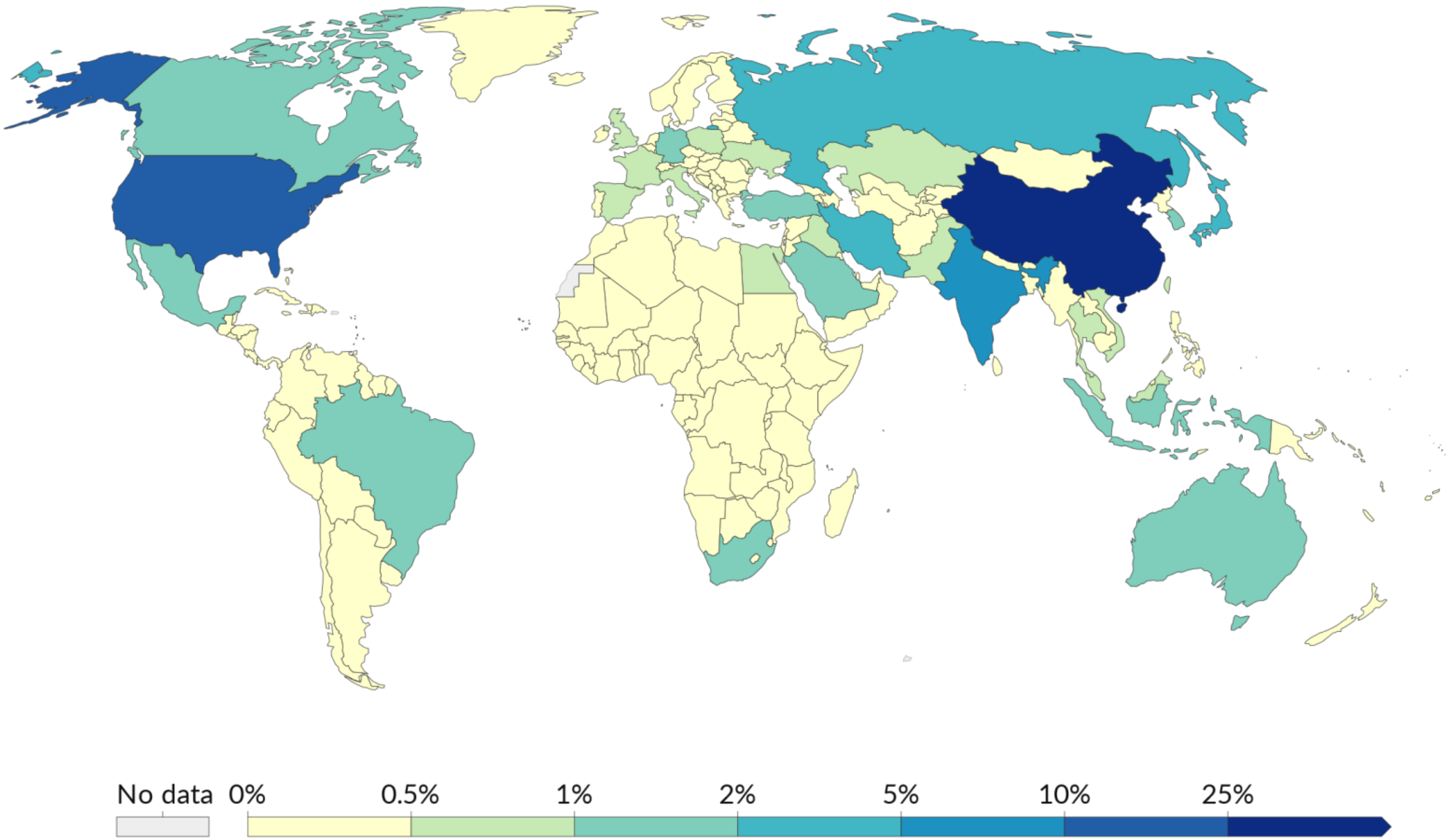
Sources - Cause of recent increases in Atmospheric CO_2 concentration



Global Carbon Emissions

Annual share of global CO_2 emissions, 2020

Each country's share of global carbon dioxide (CO_2) emissions. This is measured as each country's emissions divided by the sum of all countries' emissions in a given year plus international aviation and shipping (known as 'bunkers') and 'statistical differences' in carbon accounts.

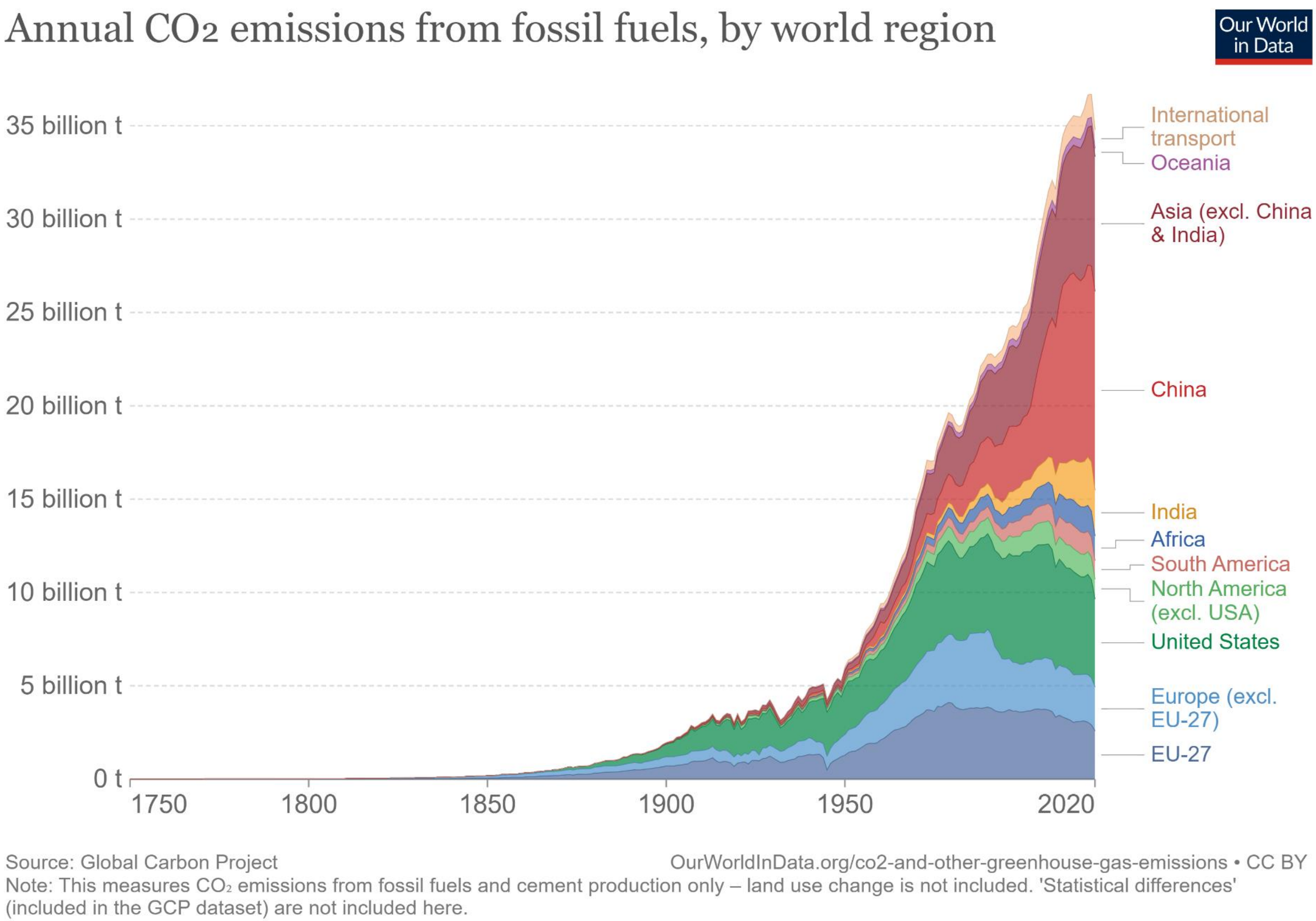


Source: Our World in Data based on the Global Carbon Project

OurWorldInData.org/co2-and-other-greenhouse-gas-emissions •

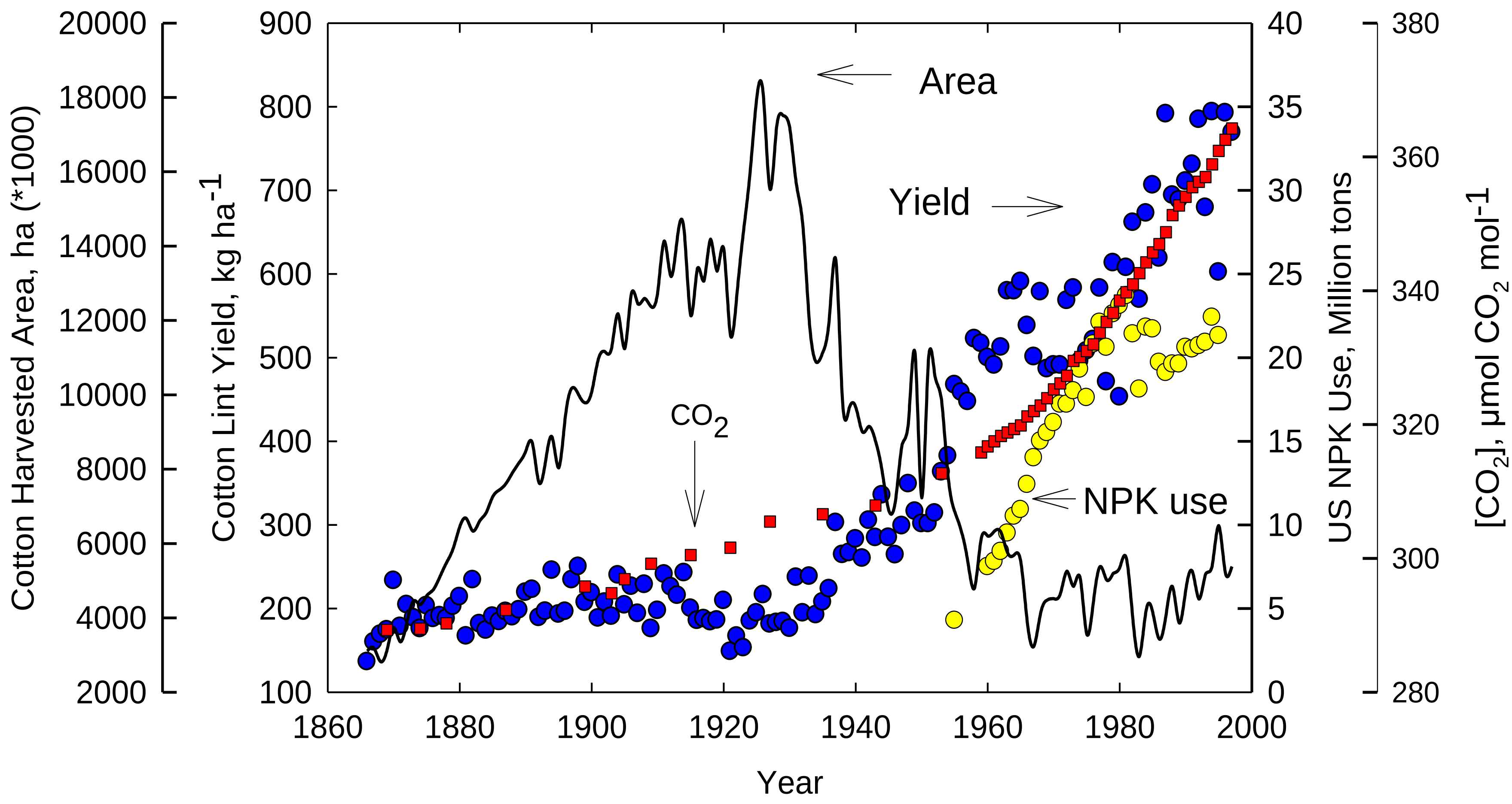
Global Carbon Emissions

Top 20 Countries



Climate Change and Crop Production

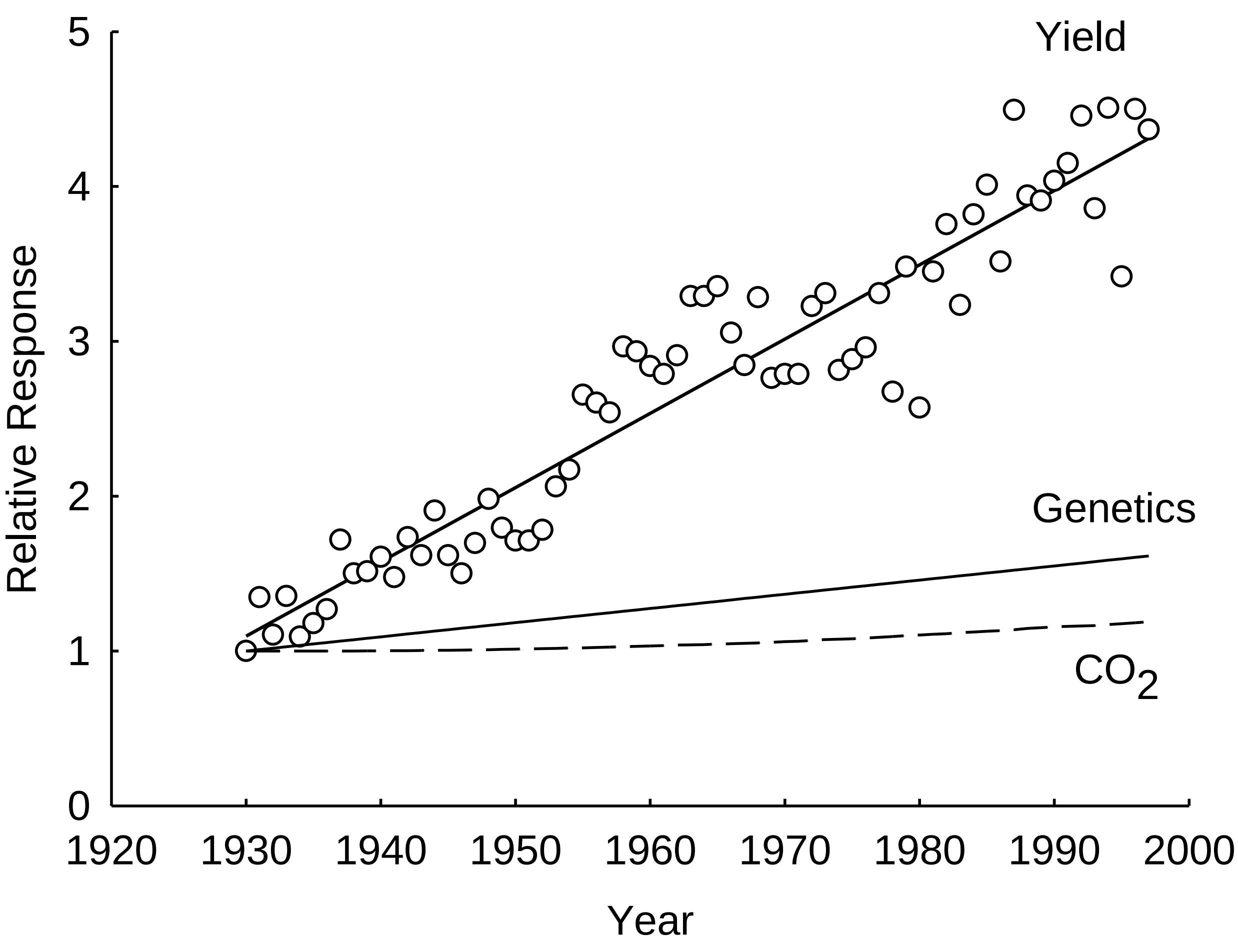
CO2, NPK Use, Cotton Acreage and Yields



Cotton Yield Trends

Best management practices, genetics, CO_2

Relative contributions

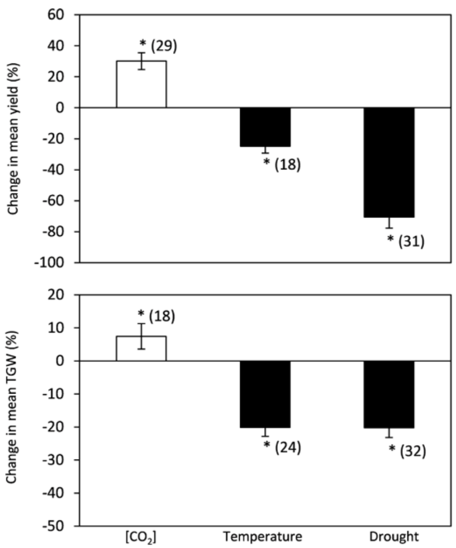


- 1940 (306) to 1997 (364) = 58 ppm CO_2 could increase yield by about 19%.
- Genetics to about 50%.
- N use efficiency about 10%.
- Best management practices (BMP's) about 270%.

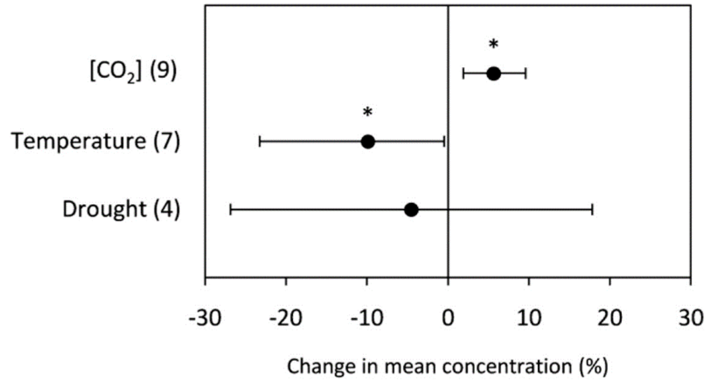
Ref: Reddy et al. 2000. Crop ecosystem responses to Climatic change: Cotton. *In:* Climate Change and Global Crop Productivity, Ed. KR Reddy and HF Hodges, CABI, UK, page 161-187.

Atmospheric [CO_2] Grain & Yield Quality

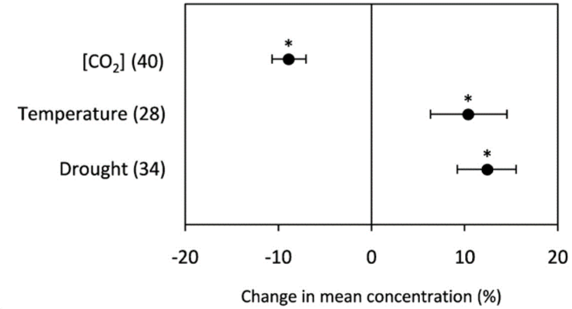
Yield and 1000 Grain wt.



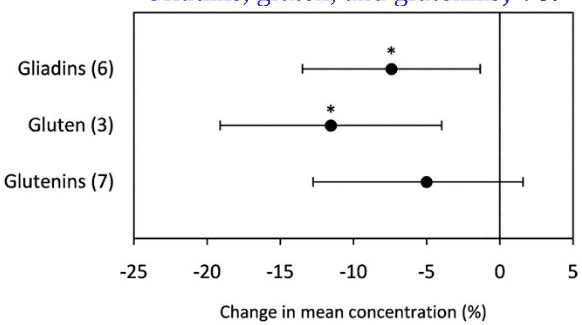
Starch, %.



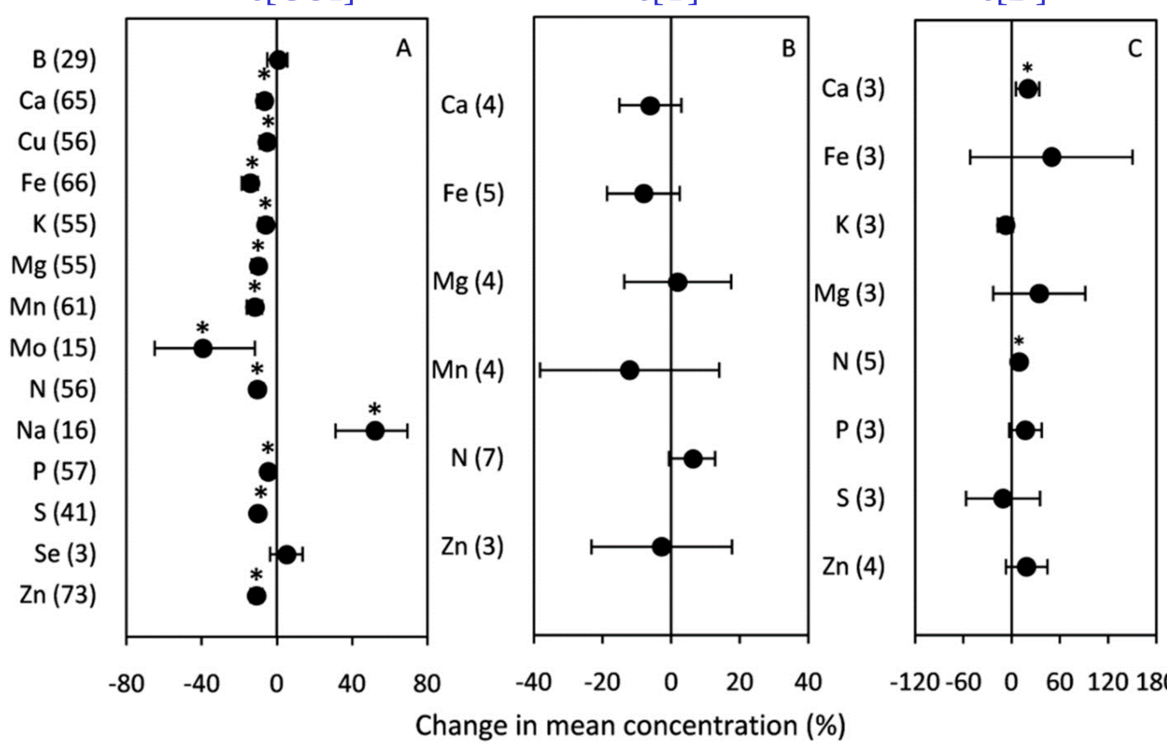
Protein, %.



Gliadins, gluten, and glutenins, %.



Minerals, %.



Citation: Ben Mariem, S.; Soba, D.; Zhou, B.; Loladze, I.; Morales, F.; Aranjuelo, I. Climate Change, Crop Yields, and Grain Quality of C3 Cereals: A Meta-Analysis of [CO2], Temperature, and Drought Effects. Plants 2021, 10, 1052. https://doi.org/10.3390/plants10061052

What will be the short-term (<100 years) and the long-term (>millions of years) effects of projected changes in climate and, particularly, CO2?

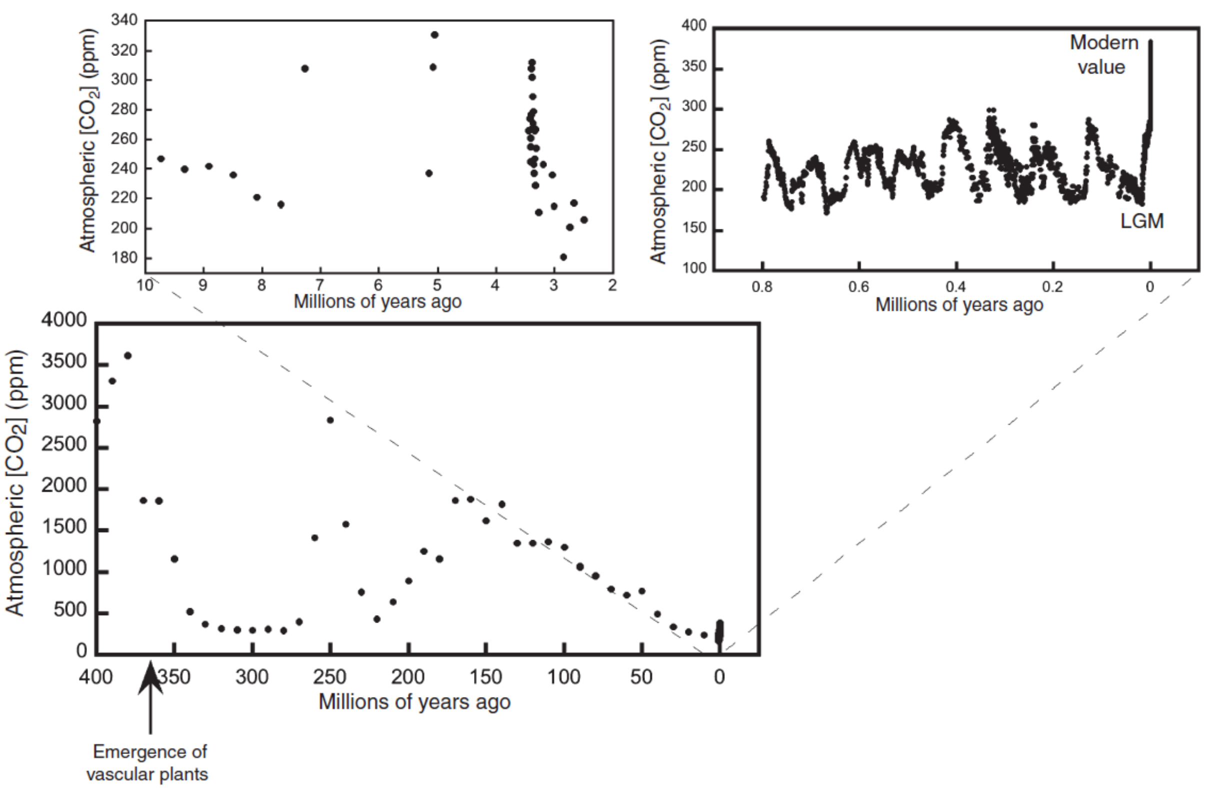
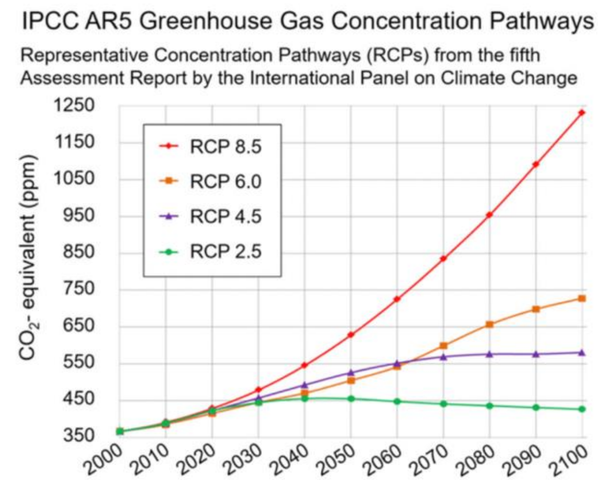
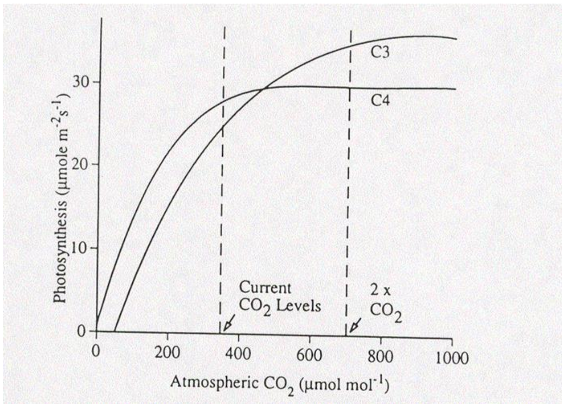


Fig. 1 Changes in atmospheric [CO_2] throughout the evolution of vascular land plants. The upper right insert shows the past million yr expanded in order to show low [CO_2] during glacial periods. The upper left insert is expanded to show low [CO_2] periods over the last 10 million yr (data are from Petit *et al.*, 1999; Monnin *et al.*, 2001; Siegenthaler *et al.*, 2005; Berner, 2006; Lüthi *et al.*, 2008; Keeling *et al.*, 2005; Tripati *et al.*, 2009).





Summary

- ✓ Atmospheric CO_2 is a critical component of the atmosphere.
- ✓ Increases in CO_2 will have both positive and negative impacts on agriculture and natural ecosystems.
- ✓ The negative impacts expressed through climate change and global warming affect not only agriculture but also other sectors.
- ✓ Overall, increasing CO_2 is likely to have serious consequences.

Summary

- ✓ It is extremely unlikely that terrestrial uptake of CO_2 will be sufficient to prevent these climate problems.
- ✓ A major adaptive response for agriculture ecosystems will be breeding or designing new cultivars: heat-and-cold and drought-resistant crop varieties that may be better adapted to a new climate (short-term fixes).
- ✓ Plants in the natural ecosystems will have to cope with changes in climate and adapt accordingly.

- ✓ Additional steps to limit CO_2 emissions by world nations are another possibility (long-term strategies).

Suggested Reading Material:

1. Climate Change and the Global Harvest. C. Rosenzweig and D. Hillel. 1998. Oxford University Press, pages 1-69.
2. Climate change and variability by L. O. Mearns. In: Climate Change and Global Crop Productivity, edited by K. R. Reddy and H. F. Hodges. 2000. Pages 7-35. https://www.cabi.org/cabebooks/ebook/20073012550
3. Agricultural contribution to Greenhouse gas emissions by D. C. Reicosky, J. L. Hatfield and R. L. Sass. In: Climate Change and Global Crop Productivity, edited by K. R. Reddy and H. F. Hodges. 2000. Pages 37-55. https://www.cabi.org/cabebooks/ebook/20073012551
4. David B. Lobell and Sharon M. Gourdji. 2012. The Influence of Climate Change on Global Crop Productivity. Plant Physiology. 160: 1686-1697. https://doi.org/10.1104/pp.112.208298

Suggested Reading Material:

https://www.npr.org/sections/thesalt/2018/06/19/616098095/as-carbon-dioxide-levels-rise-major-crops-are-losing-nutrients

https://www.nature.com/scitable/knowledge/library/effects-of-rising-atmospheric-concentrations-of-carbon-13254108/

https://www.vox.com/2018/5/24/17384110/rice-vitamin-nutrition-food-security-co2

https://www.politico.com/agenda/story/2017/09/13/food-nutrients-carbon-dioxide-000511/

https://www.sciencedaily.com/releases/2019/07/190718085308.htm

https://www.nytimes.com/2018/05/23/climate/rice-global-warming.html