Changes in Plant Metabolism Induced by Climate Change

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Outline

- How is the climate changing?

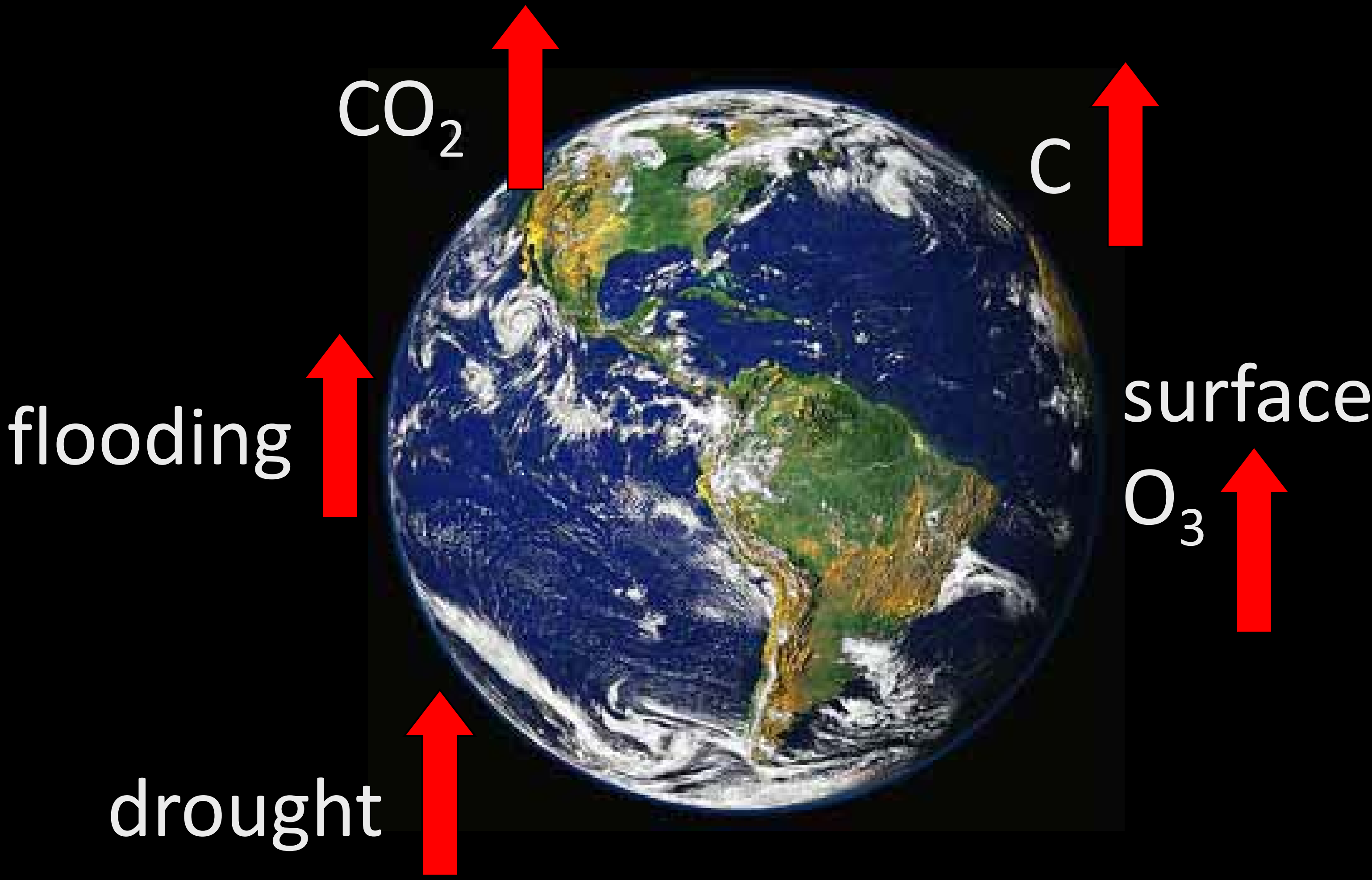
- How do we measure crop responses to climate change?

- How does rising [CO_2] affect crops?

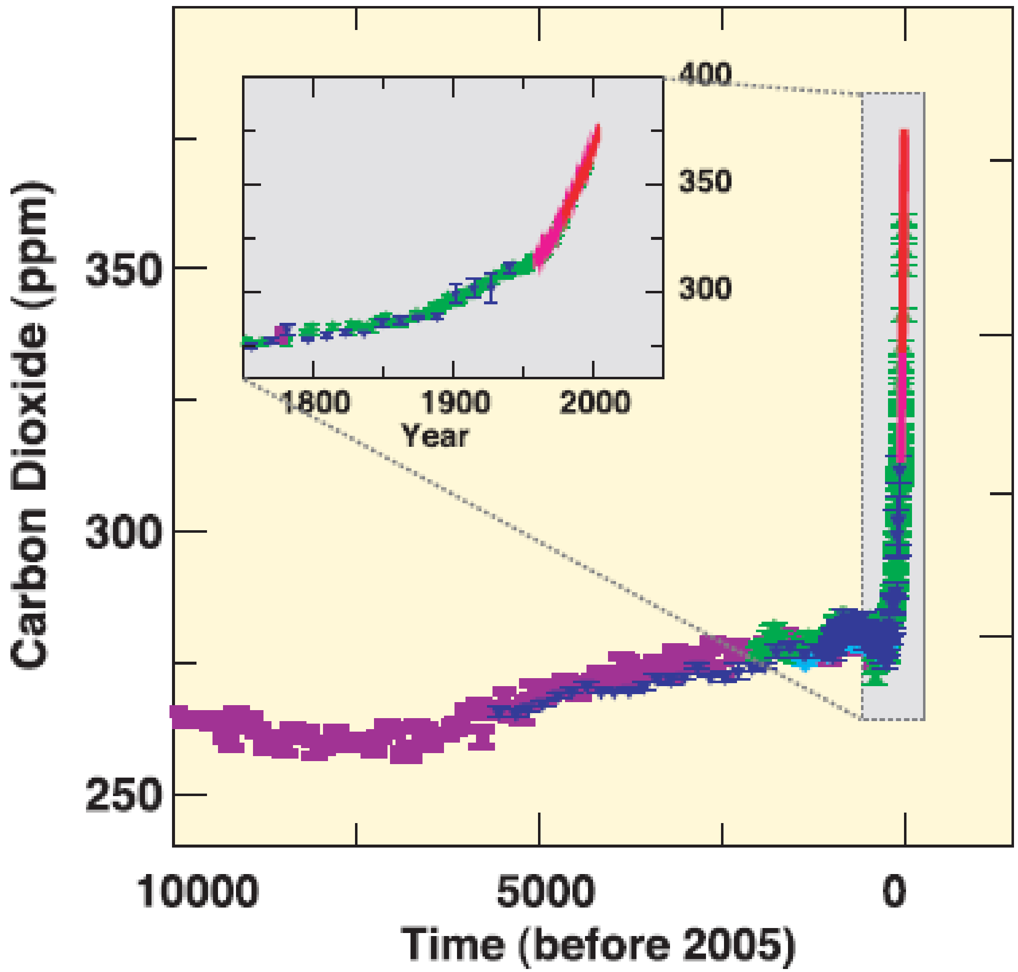
- How does rising [O_3] affect crops?

- How can we adapt crops to future climates and improve production?

Climate change is multifaceted

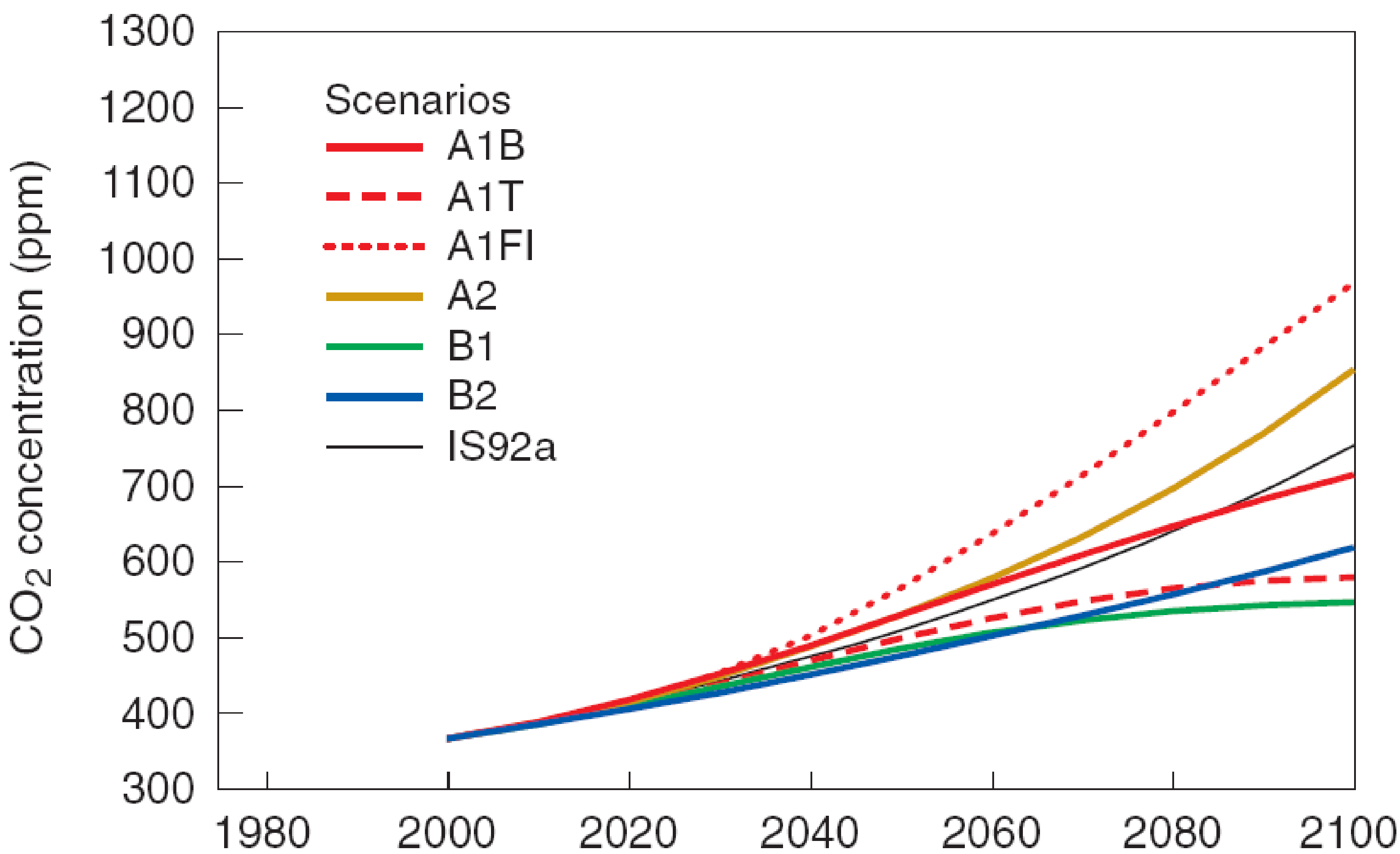


Atmospheric Carbon Dioxide Concentration



- Carbon dioxide is the most important anthropogenic greenhouse gas.
- The global atmospheric CO_2 concentration has increased from a pre-industrial value of ~280 parts per million (ppm) to 385 ppm in 2008.
- The atmospheric CO_2 concentration exceeds by far the natural range over the last 650,000 years (180 to 300 ppm).

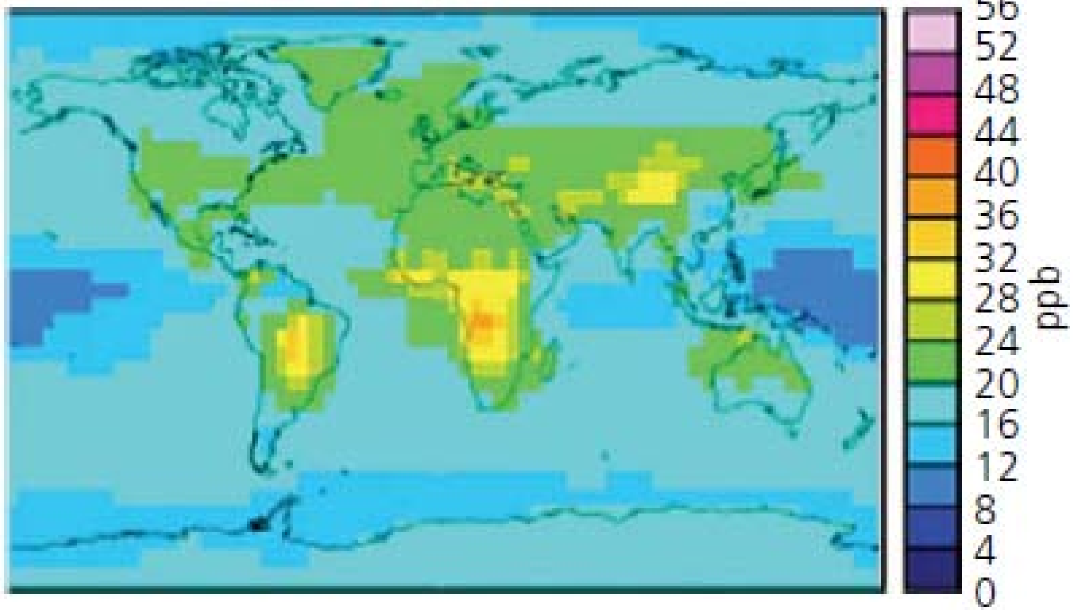
IPCC 2007



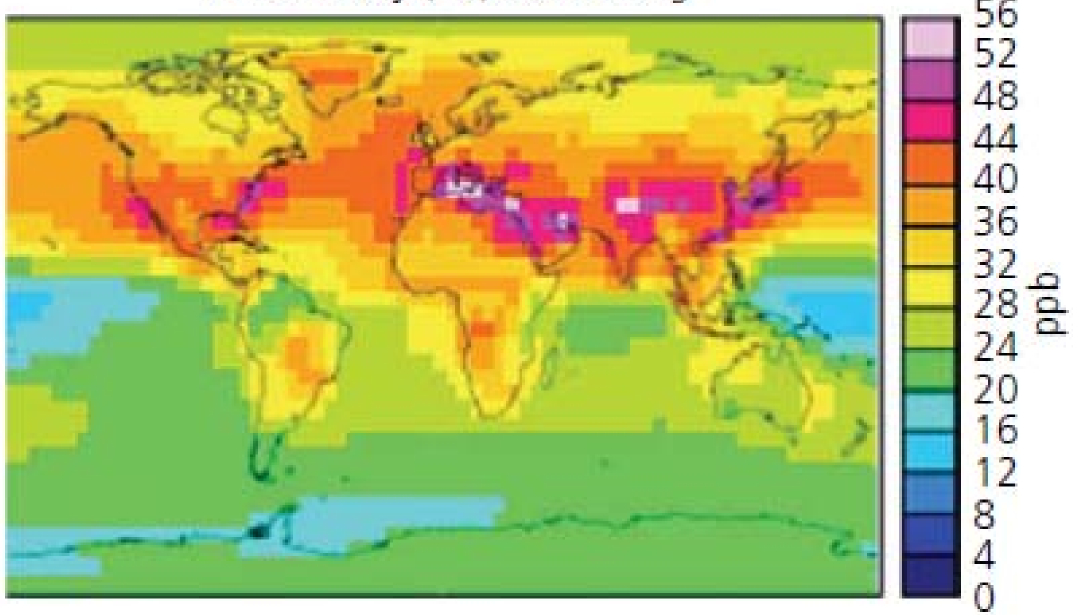
• Carbon dioxide concentration ([CO_2]) is projected to surpass 550 ppm by the middle of the century and top 700 ppm by 2100.

• Despite initial steps taken under the Kyoto Protocol, the world appears to be on a path that is likely to lead to a [CO_2] that exceeds the highest Intergovernmental Panel on Climate Change emissions scenario.

Pre-industrial (PI) surface O_3



Present-day (PD) surface O_3



The Royal Society, 2008

Future Surface Ozone Levels

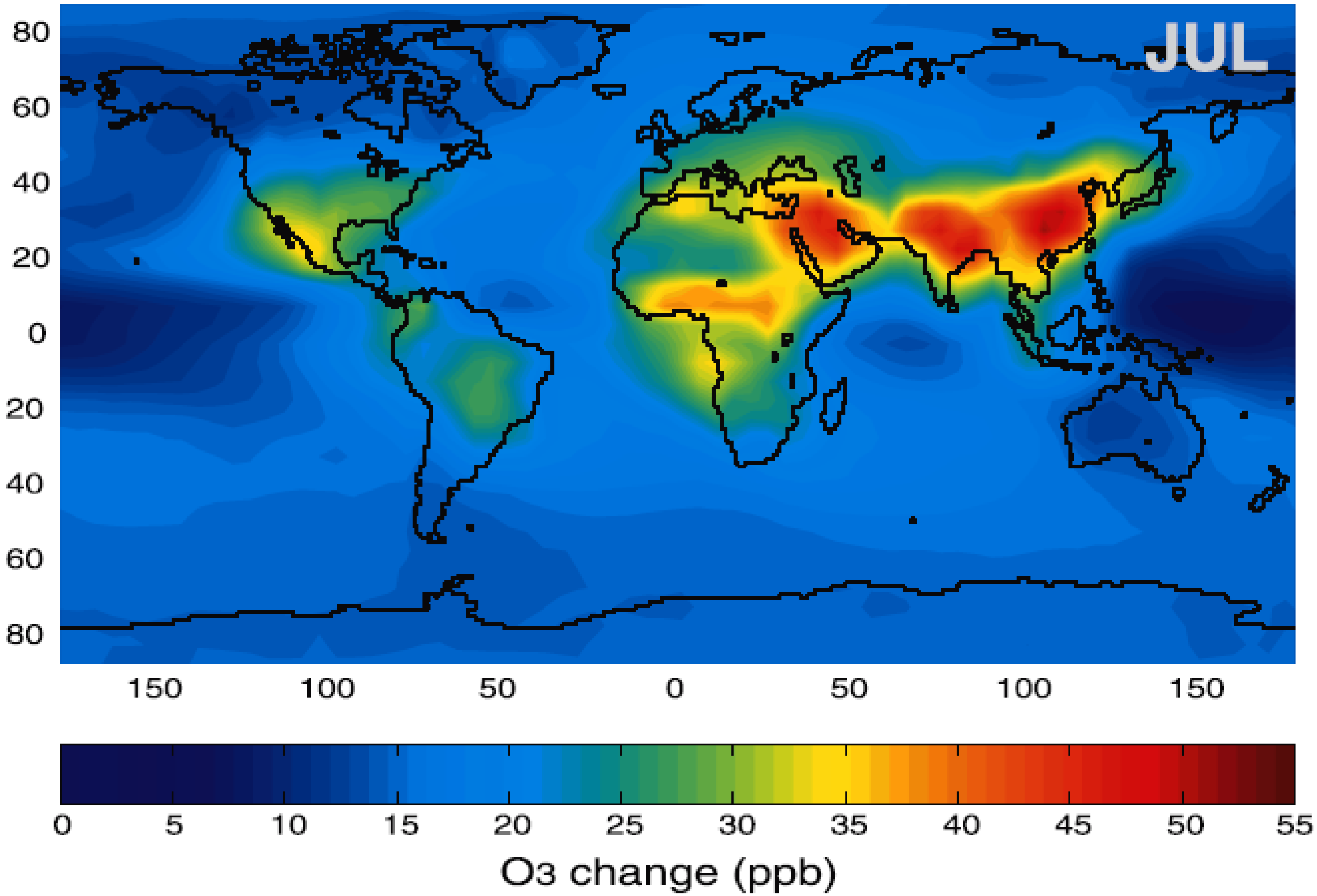
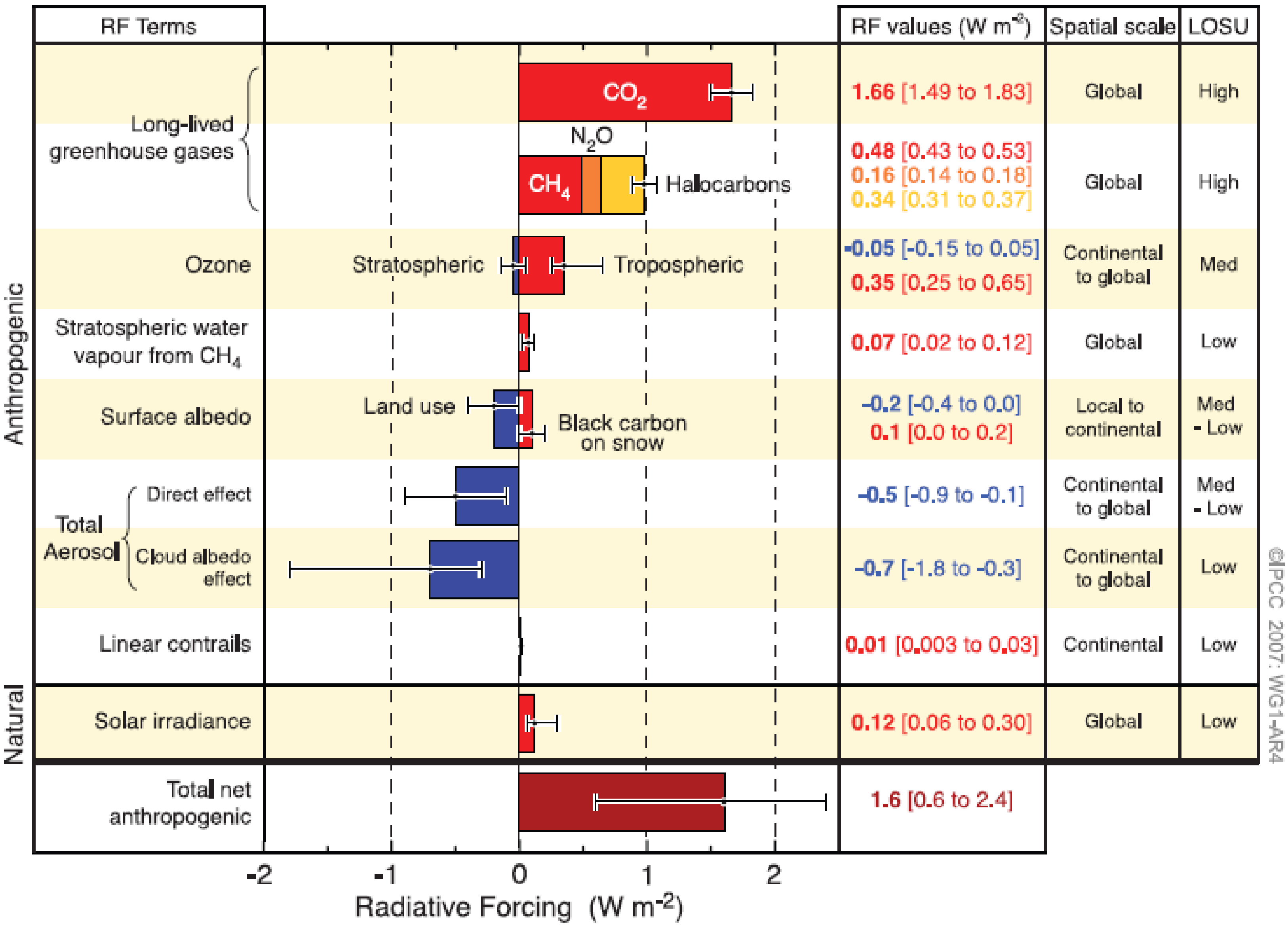
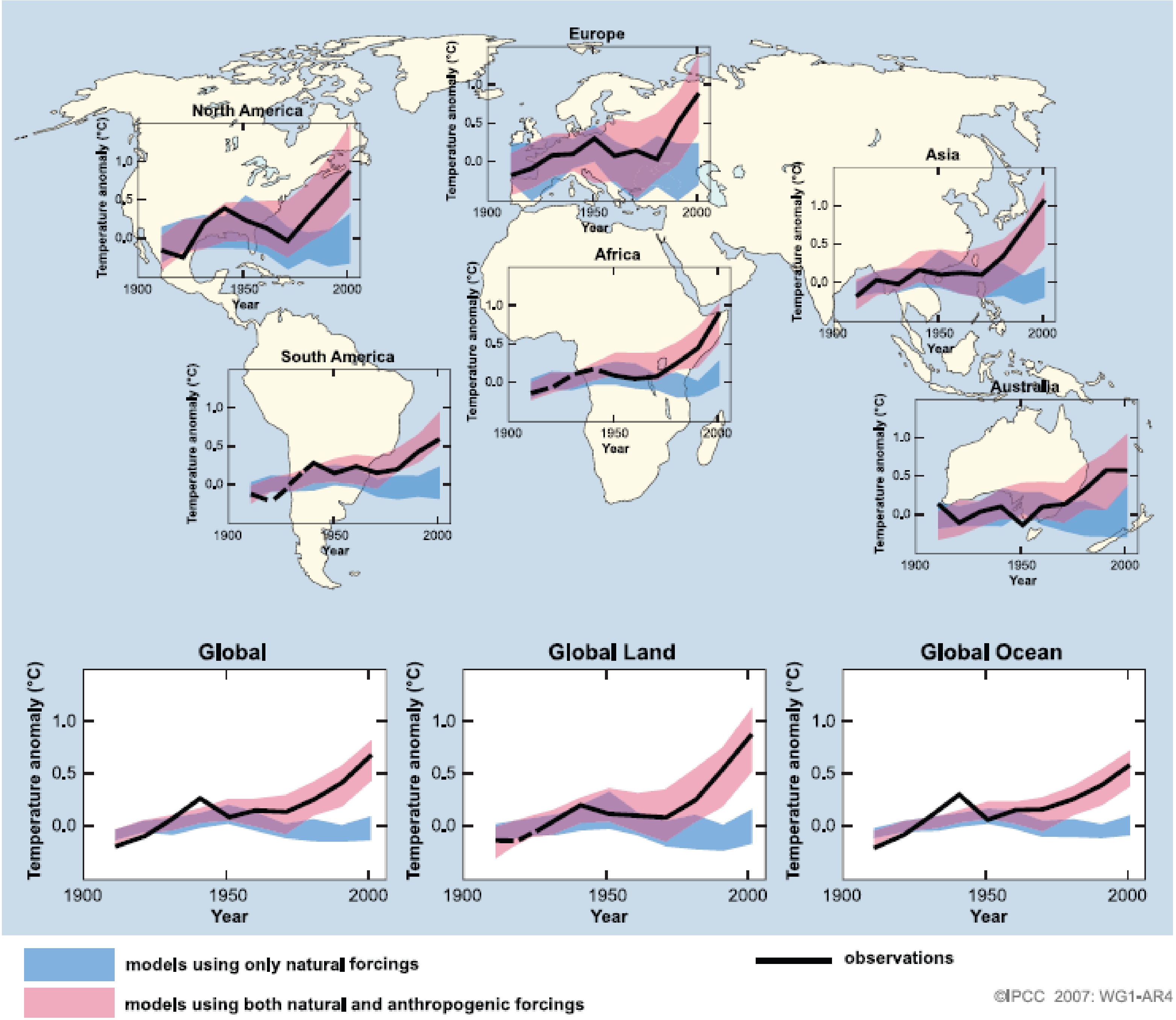


Figure 1. Monthly mean surface O_3 increase (ppb) for Jan and Jul from Y2000 to Y2100 following scenario A2x. Results are the average of 10 models [*Prather and Ehhalt*, 2001]: HGIS, IASB, KNMI, MOZ1, MOZ2, UCAM, UCI, UIO1, UKMO, ULAQ.

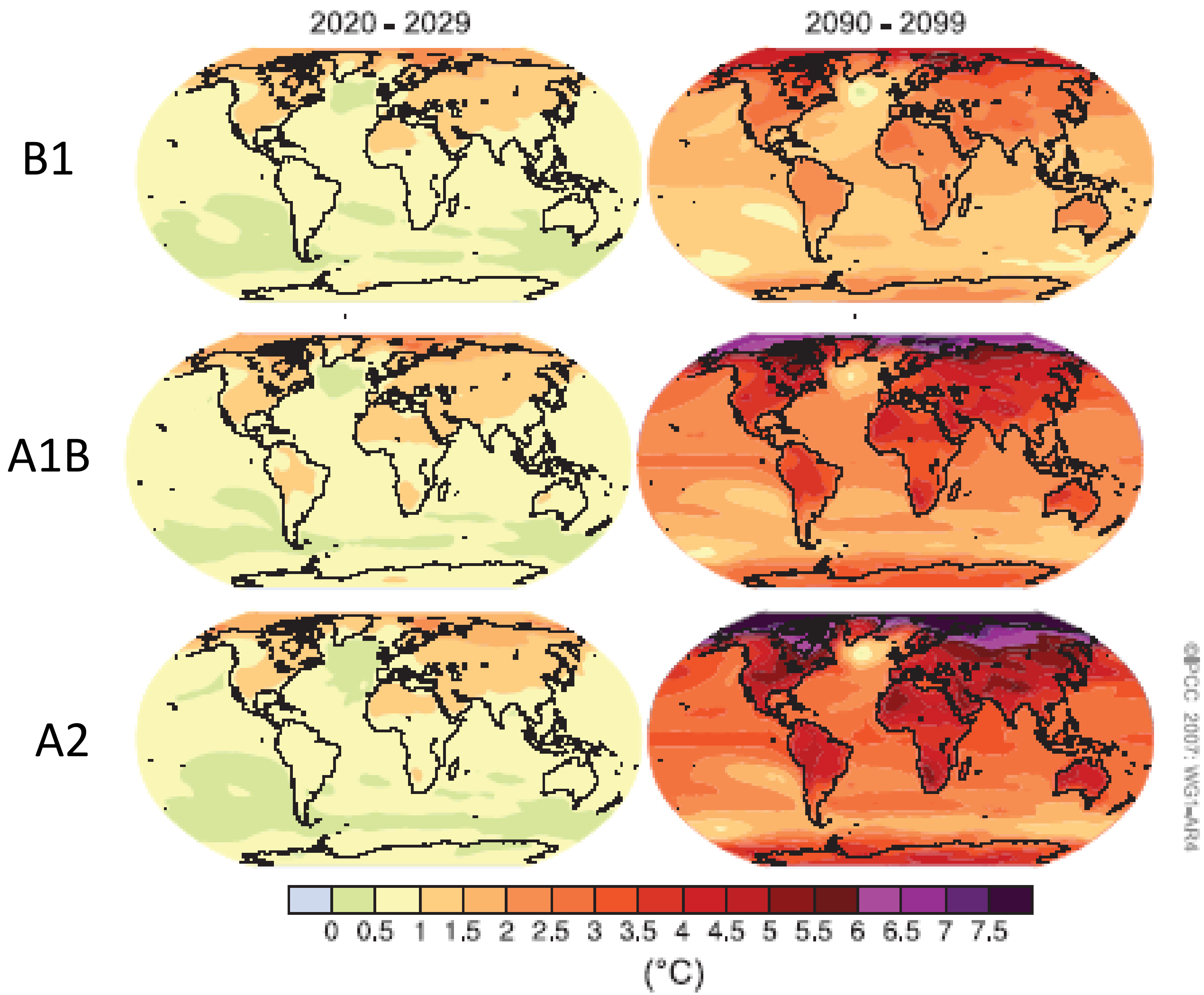
GEOPHYSICAL RESEARCH LETTERS, VOL. 30, NO. 2, 1100, doi:10.1029/2002GL016285, 2003

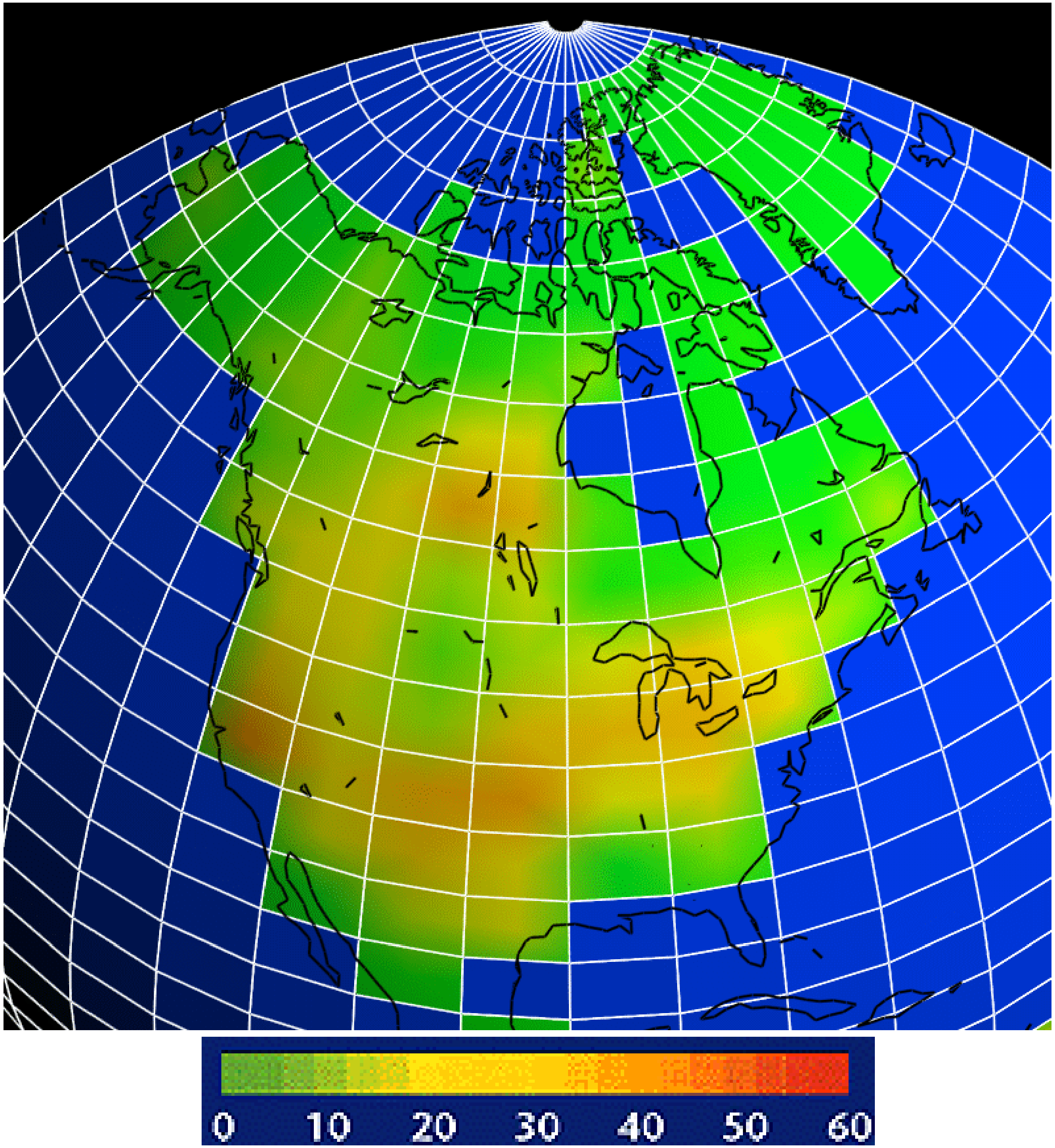
RADIATIVE FORCING COMPONENTS



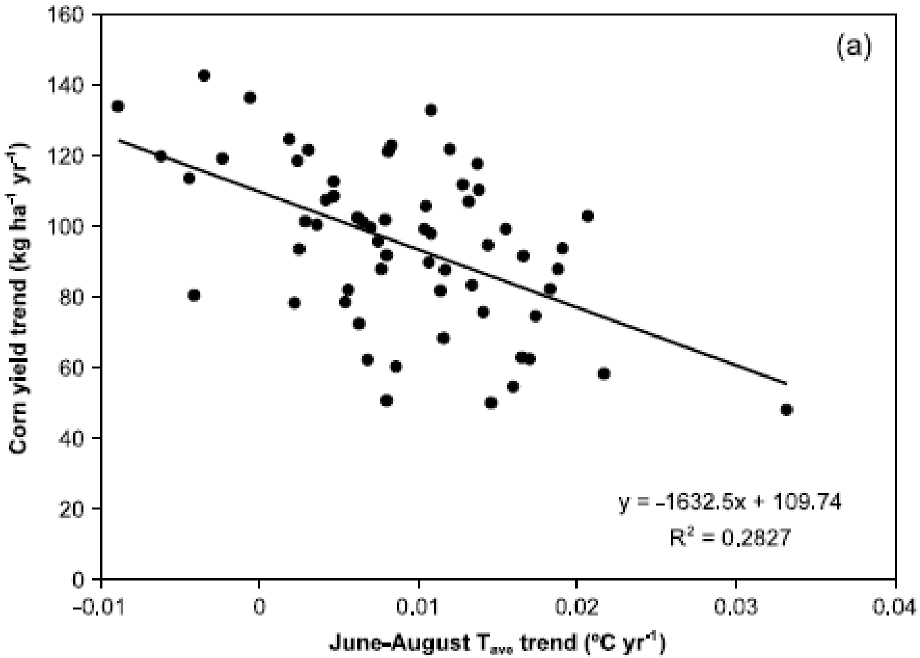

Europe
North America
Asia
Africa
South America
Australia
Temperature anomaly (°C)
Year
Global
Global Land
Global Ocean
1.0
0.5
0.0
1900
1950
2000
models using only natural forcings
models using both natural and anthropogenic forcings
observations

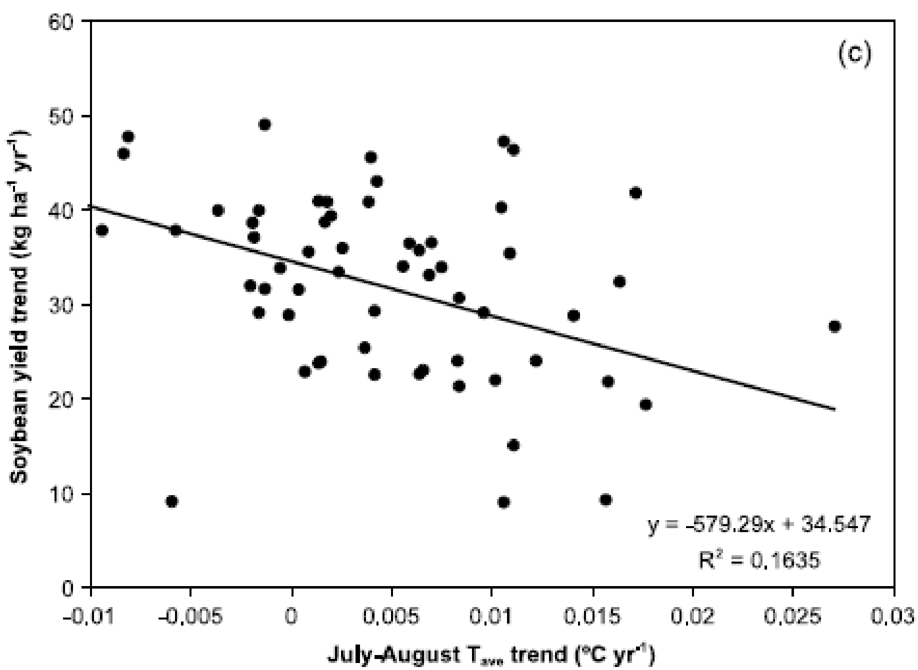
IPCC Projections of Surface Temperatures





% decrease in summer soil moisture at 2x CO_2





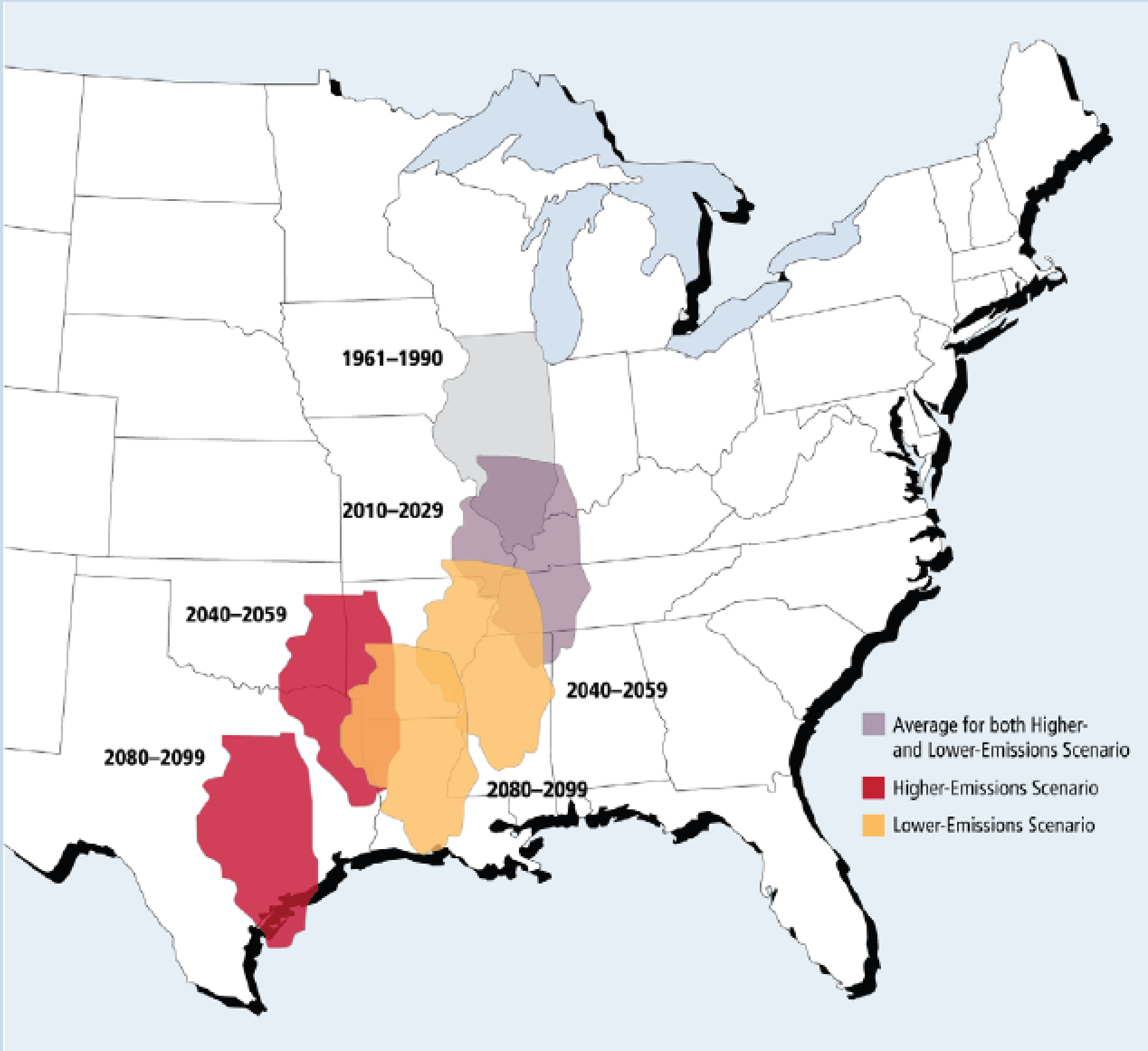
- Analysis of 61 counties in Wisconsin analyzed from 1976–2006.

- There is a negative correlation between temperature and corn and soybean yields.

- Each additional degree (◦C) of future warming during summer months could potentially decrease corn and soybean yields by 13% and 16%, respectively.

ENVIRONMENTAL RESEARCH LETTERS 3 (2008) 034003 (10pp)

Climate Projection for Illinois



Donald Wuebbles

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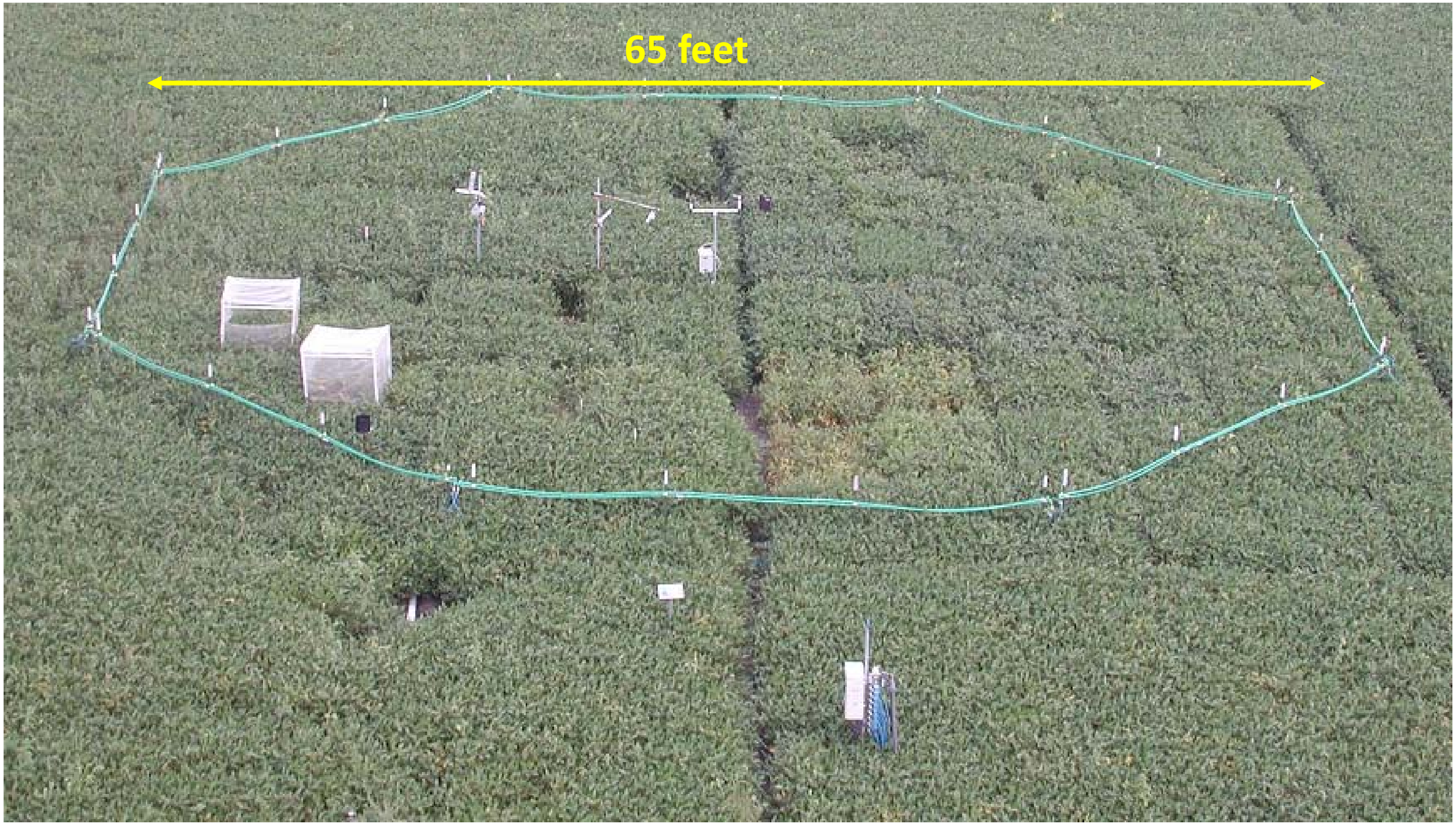
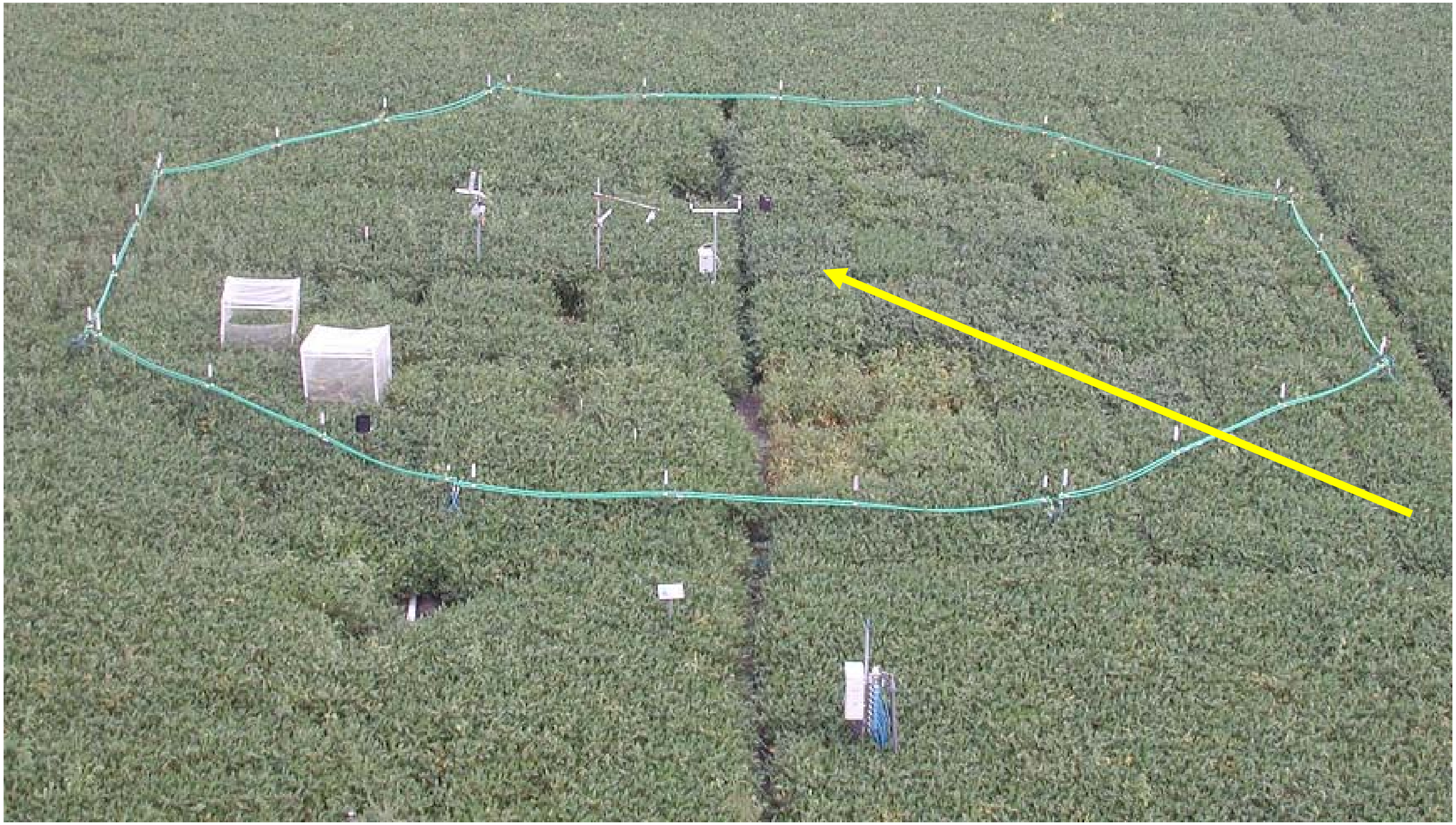
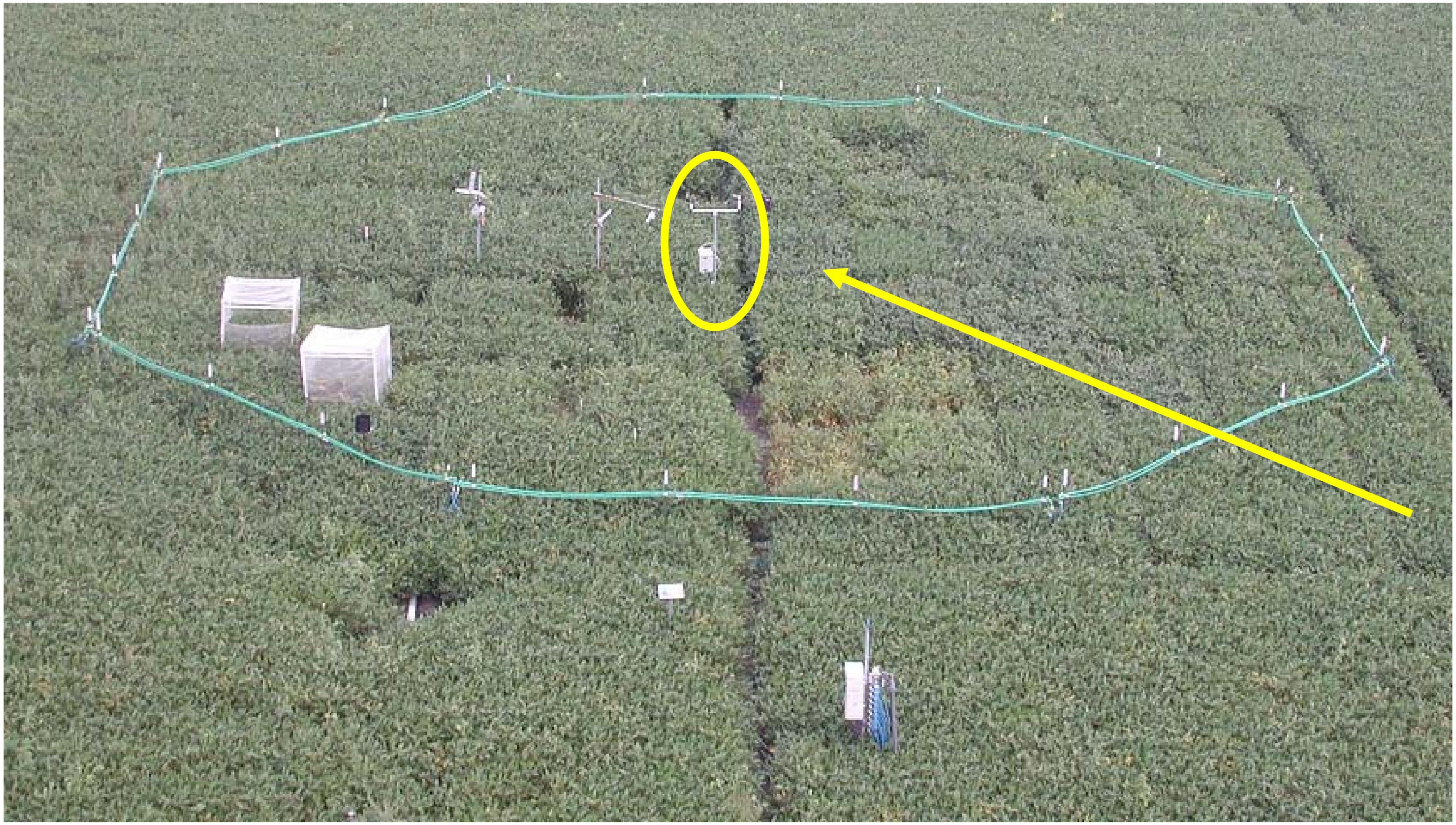
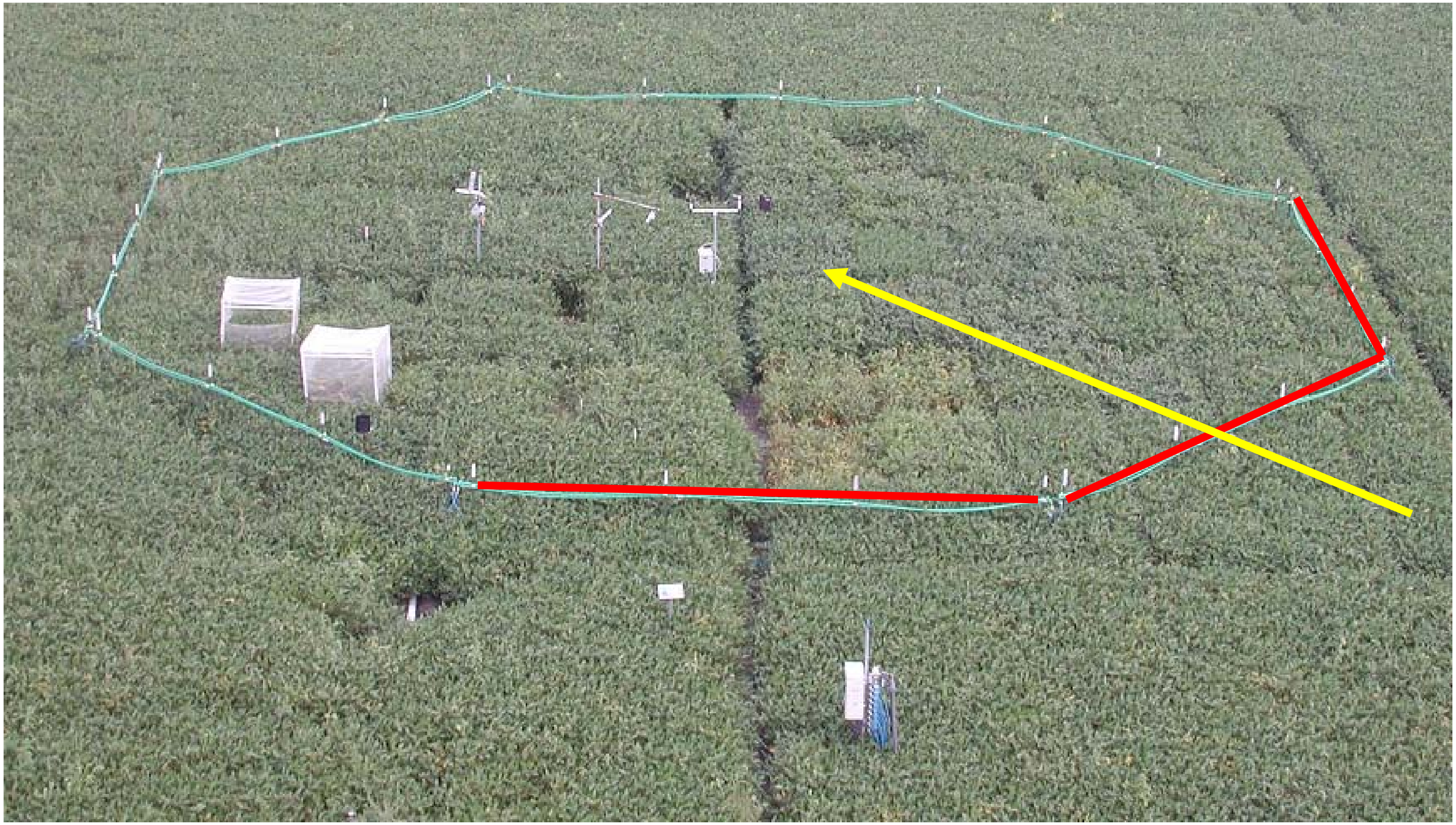
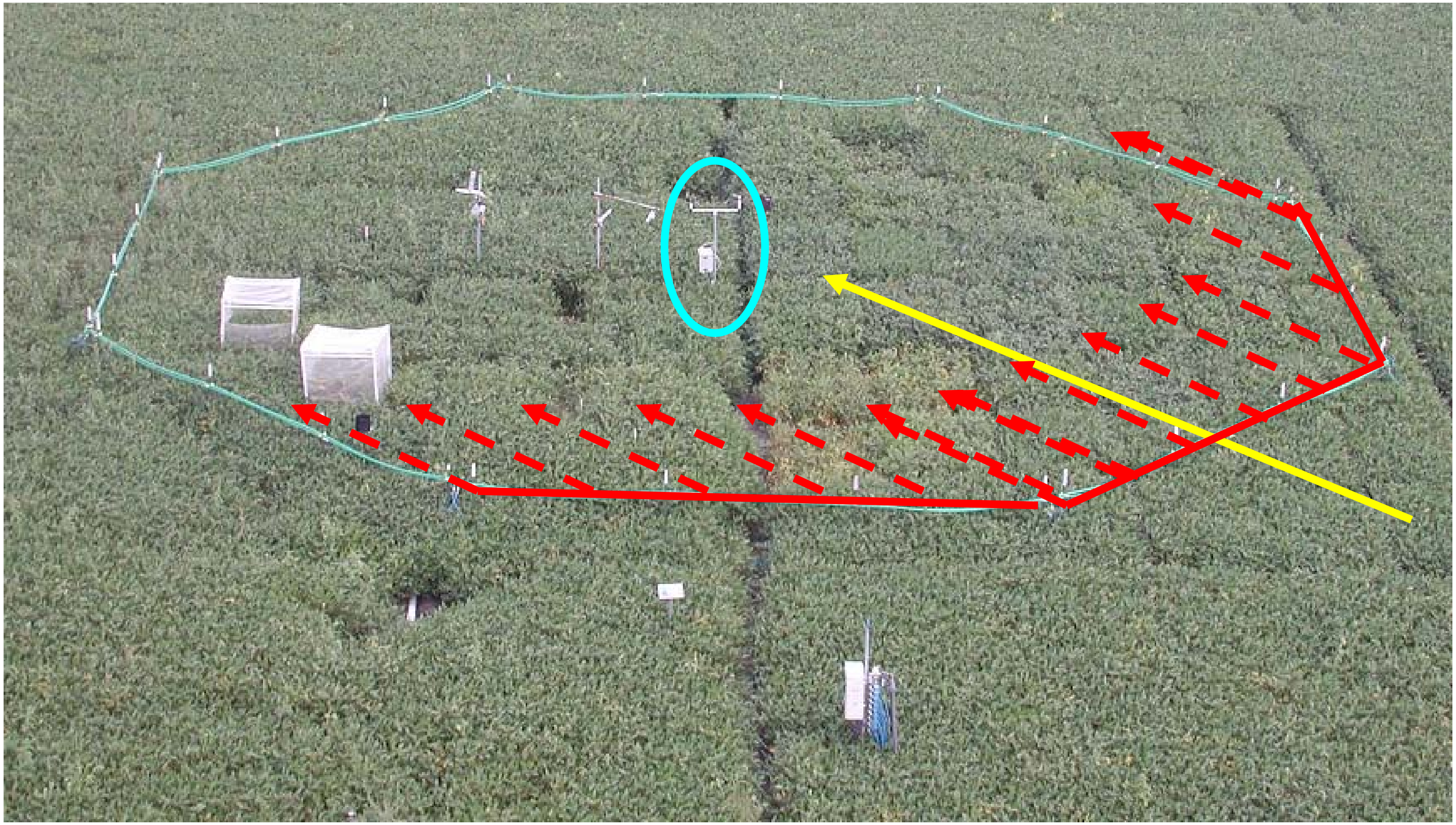
Free Air Concentration Enrichment (FACE)

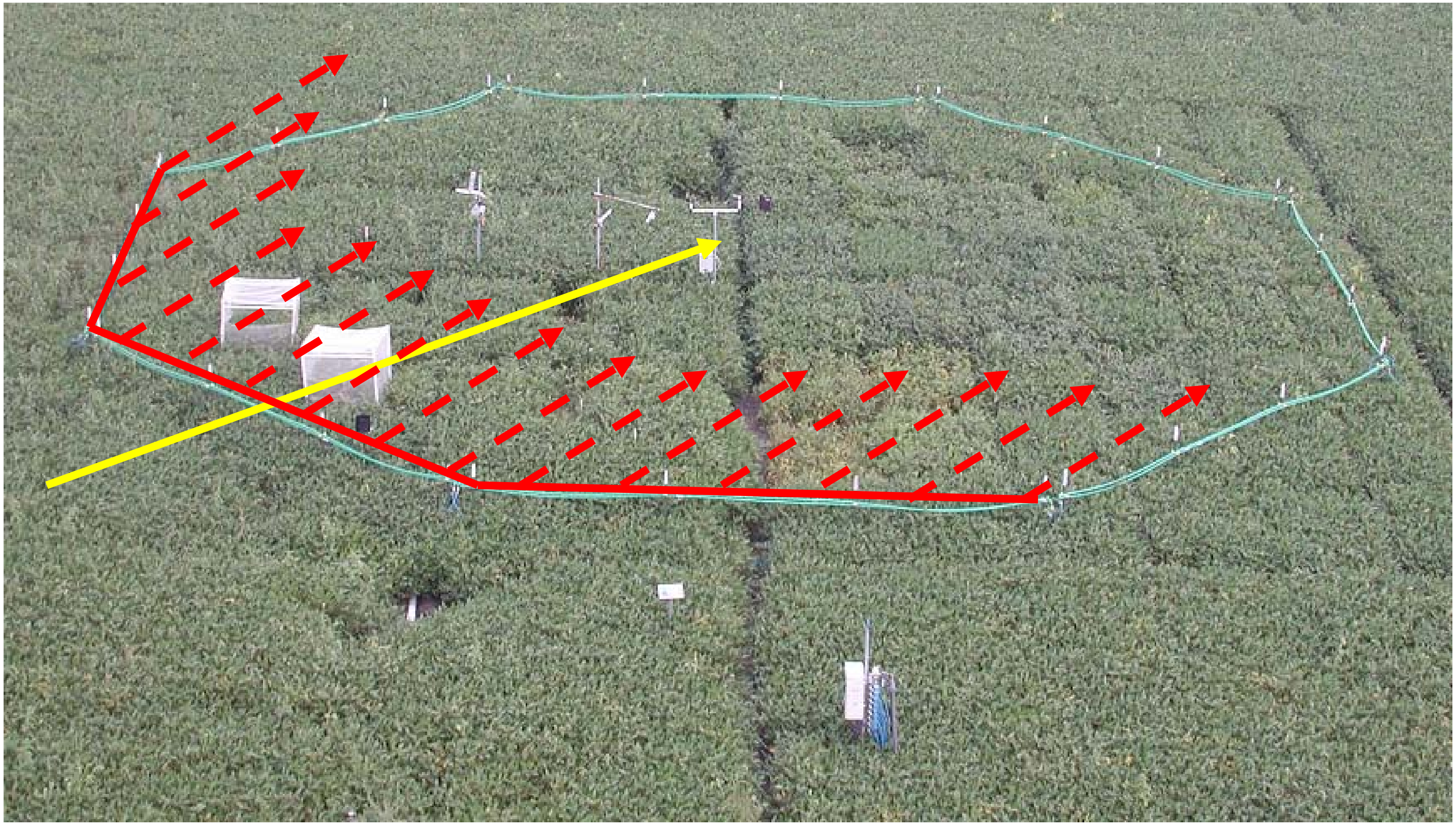

65 feet



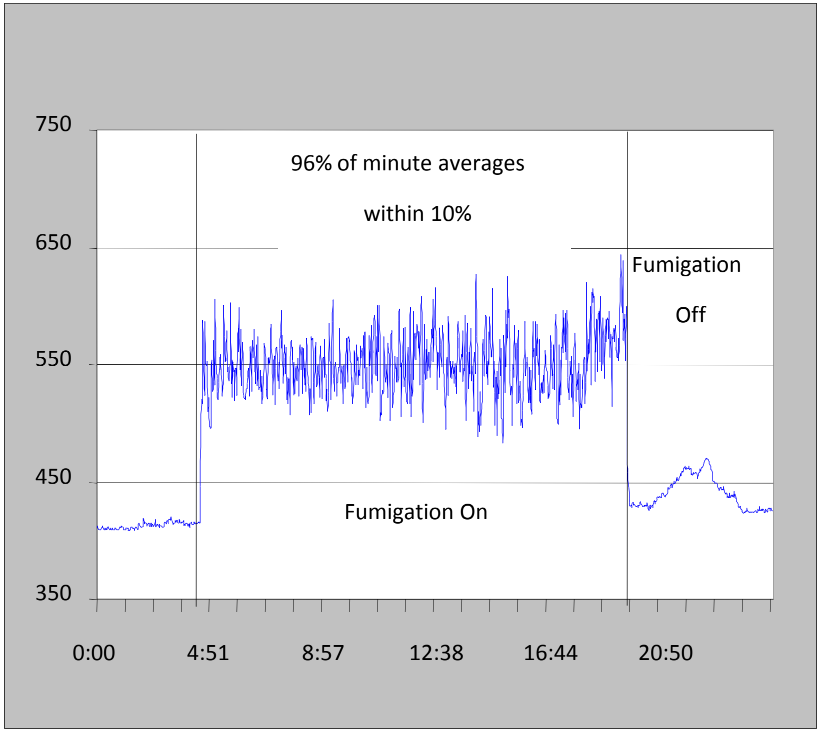


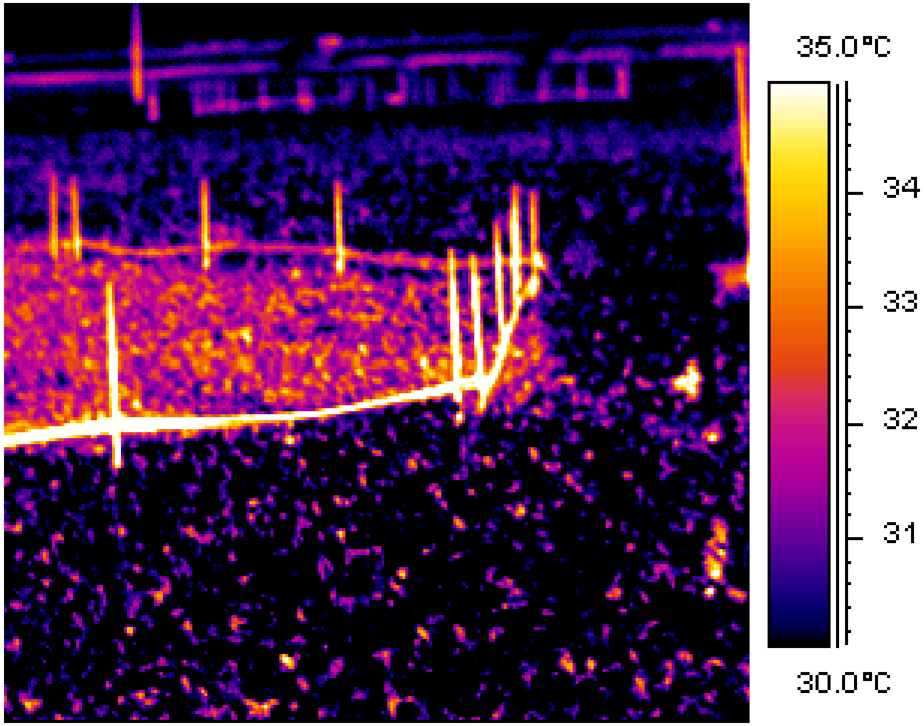






FACE: Accurate and homogenous fumigation





Tim Mies

Andrew Leakey

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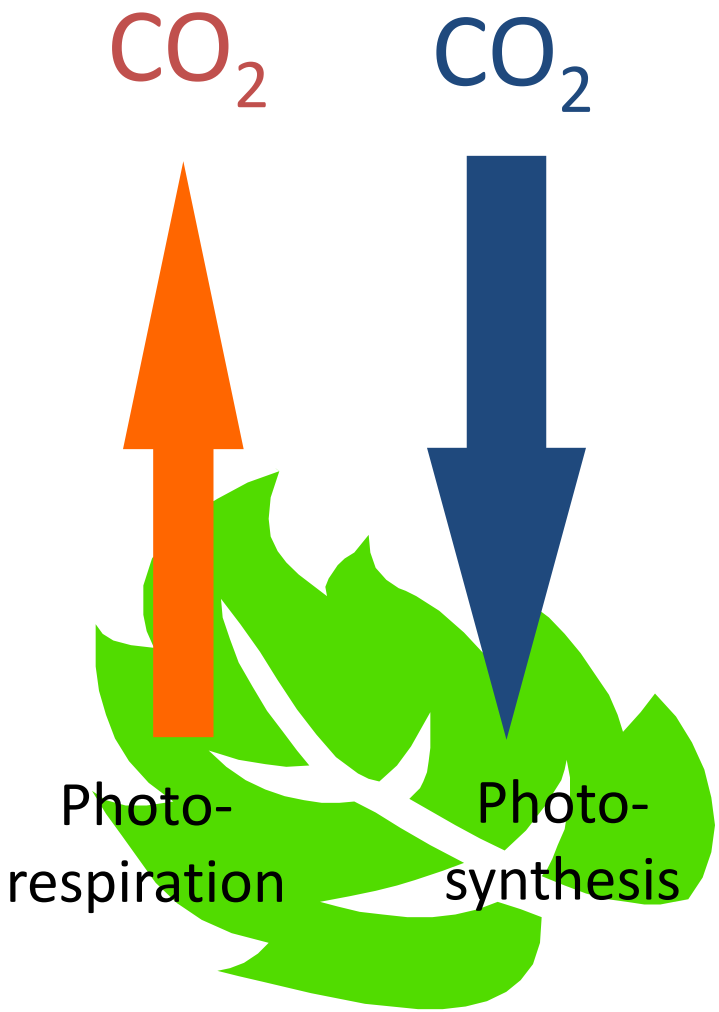
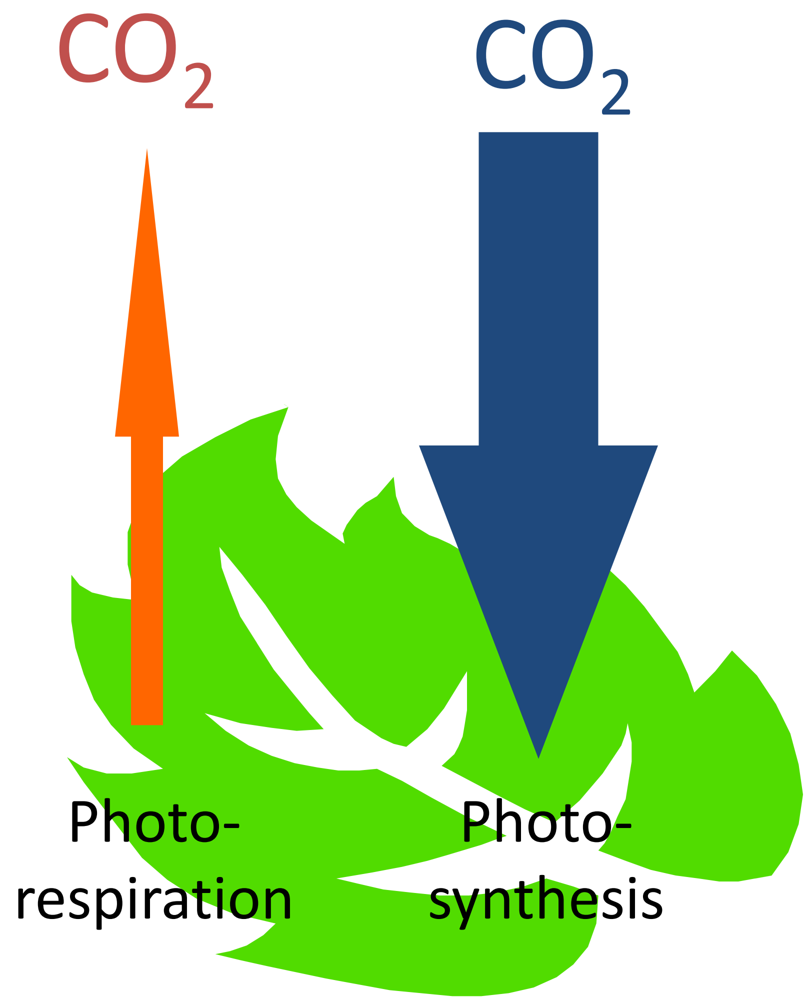
What are the direct effects of CO_2 on C_3 crops?

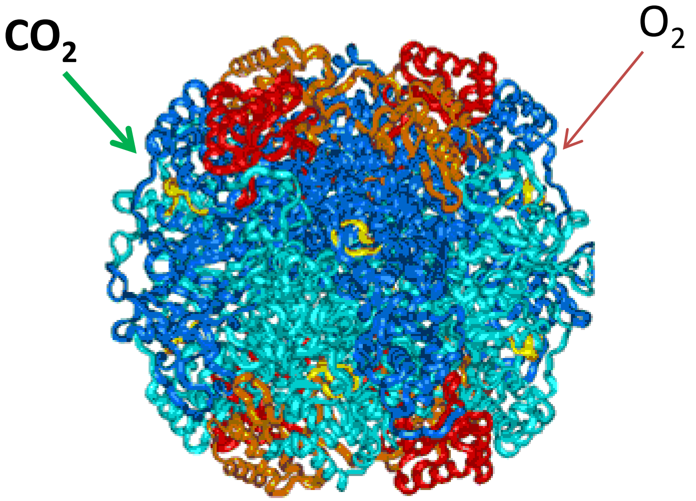
Current CO_2 Concentration



CO_2 Concentration in 2050



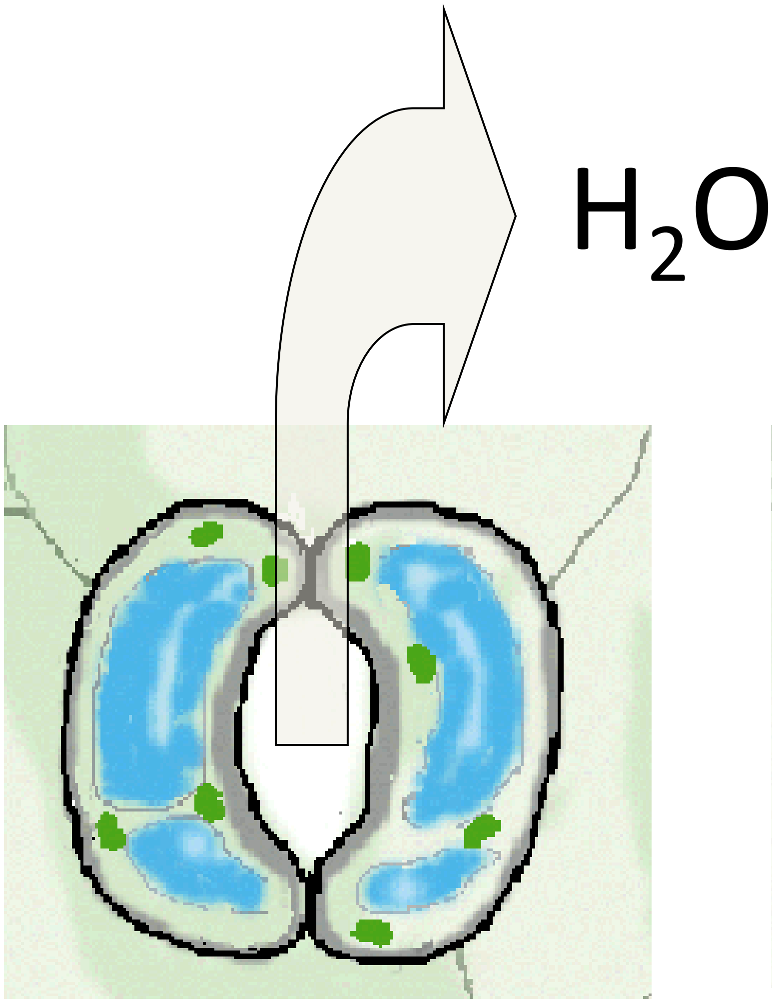
Elevated CO_2 Stimulates Photosynthesis



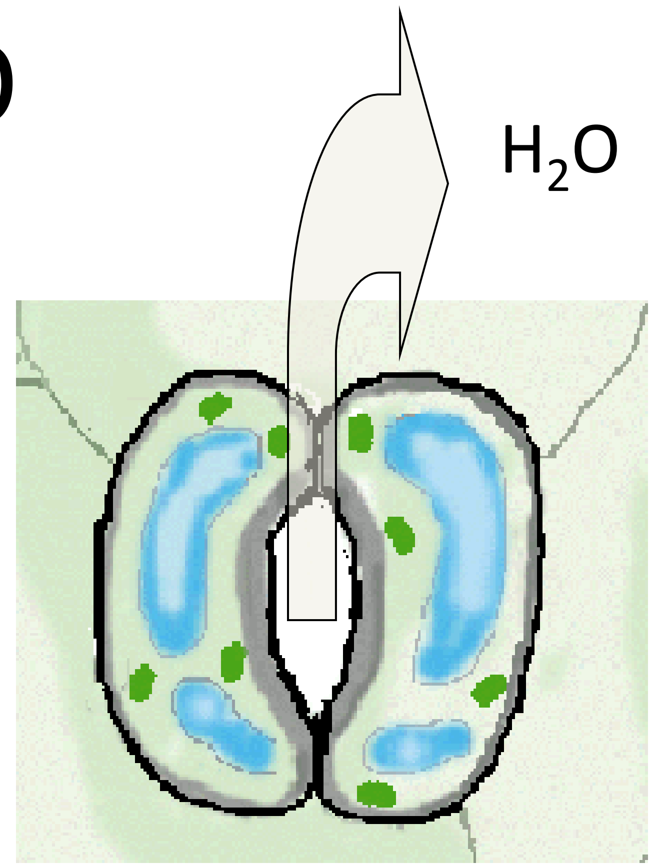
Ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco)

Increased carbon gain from increased rates of carboxylation and decreased rates of oxygenation and subsequent photorespiration

Elevated CO_2 Decreases Stomatal Conductance

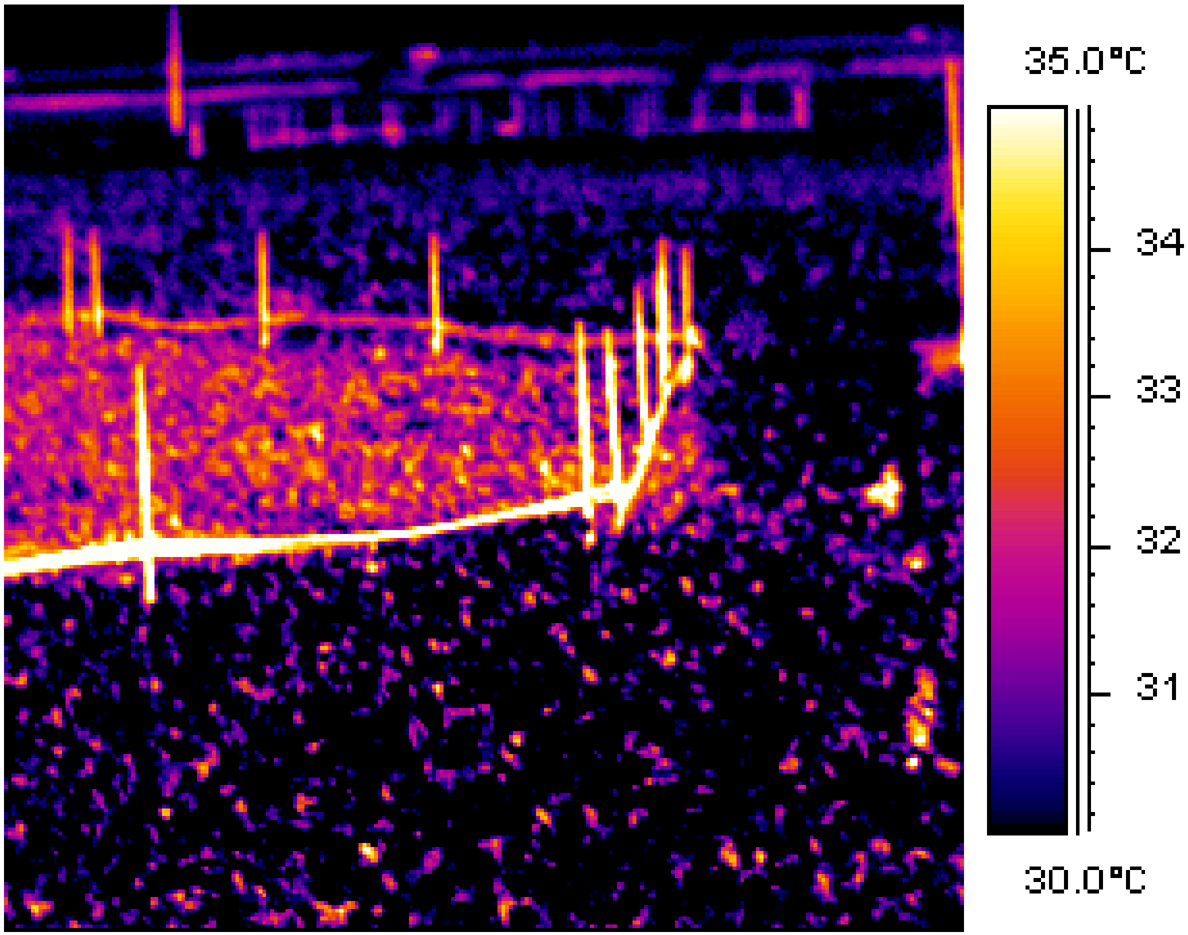


Ambient 385 ppm
[CO_2]

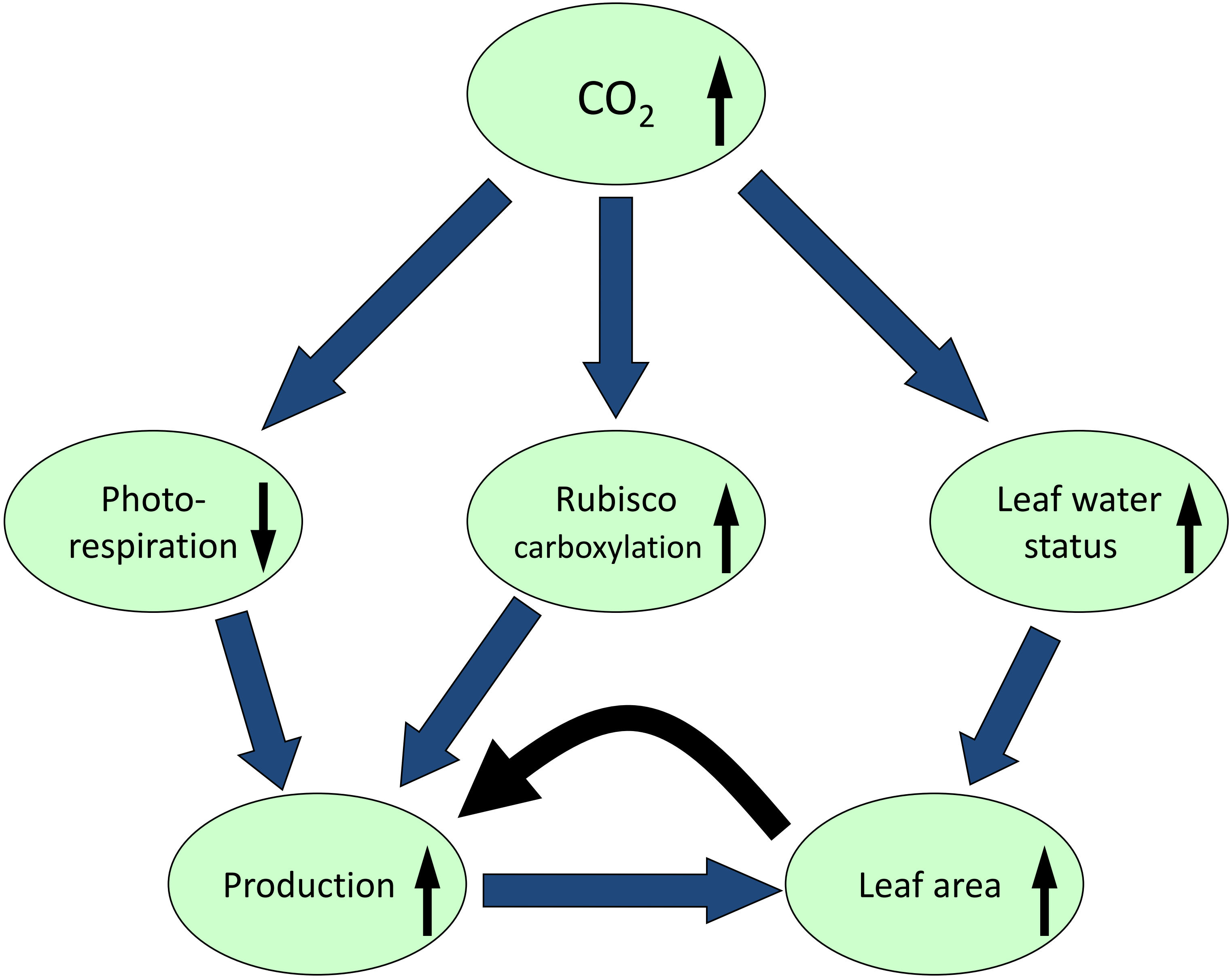


Elevated 550 ppm
[CO_2]

Lower stomatal conductance at elevated [CO_2] reduces evaporative cooling and warms the crop canopy



Andrew Leakey



Annu. Rev. Plant Biol. 2004. 55:591–628

Crop Yield Responses to FACE

Table 7.1 Average percent change in economic yield, final above-ground biomass, individual seed or grain weight, and harvest index of crops grown at elevated [CO_2] (~550 ppm) in FACE experiments. Bold numbers represent statistically significant changes ($p<0.10$) reported in primary literature sources

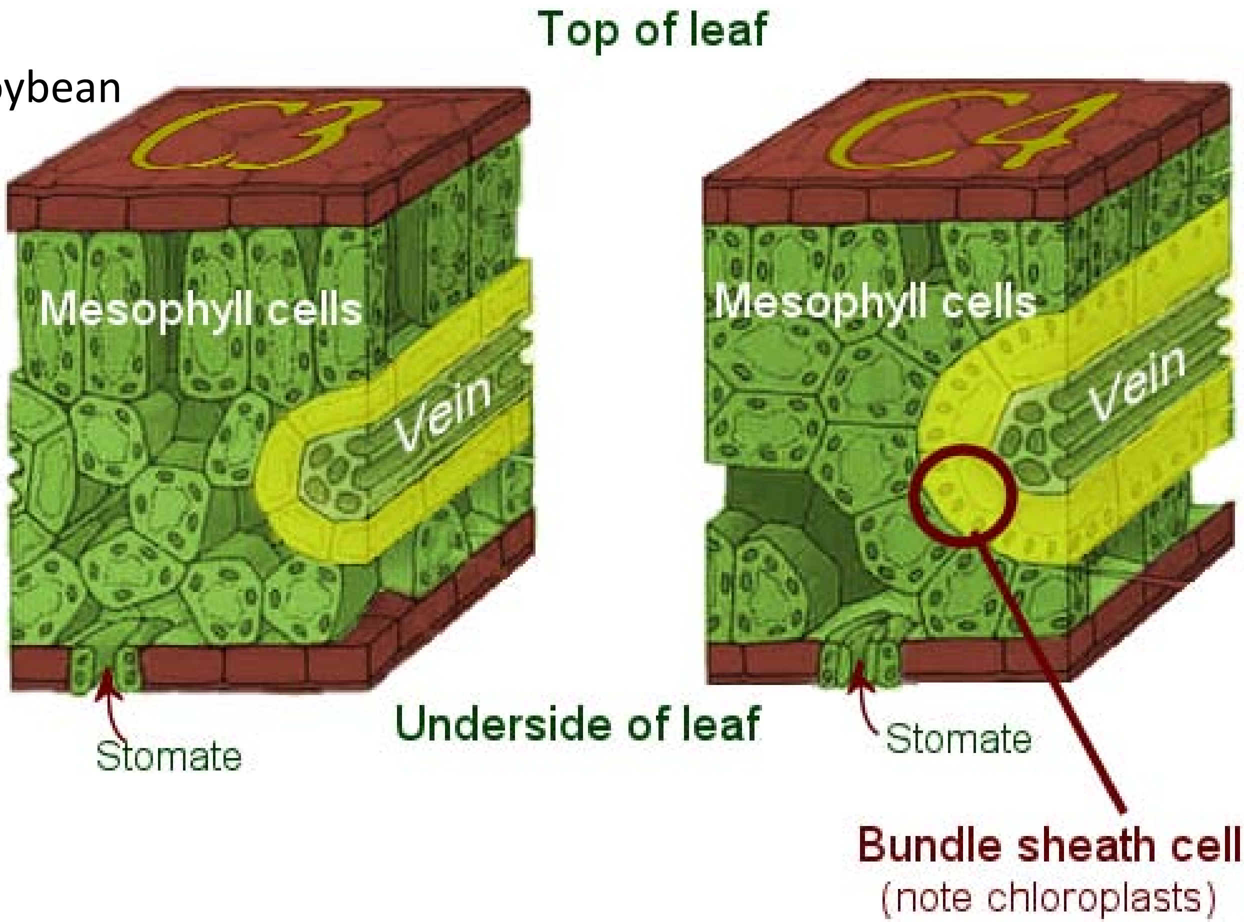
Crop	Economic yield (%)	Above-ground biomass (%)	Individual seed or grain weight (%)	Harvest index (%)
Soybean[a]	**+14**	**+16**	0	**−2**
Wheat[b]	**+13**	**+10**	–	–
Rice[c]	**+13**	**+27**	+1	−2

D. Lobell and M. Burke (eds.), *Climate Change and Food Security*, Advances in Global Change Research 37, DOI 10.1007/978-90-481-2953-9_7,

Photosynthesis is not directly stimulated by elevated CO_2 in C4 crops including corn.

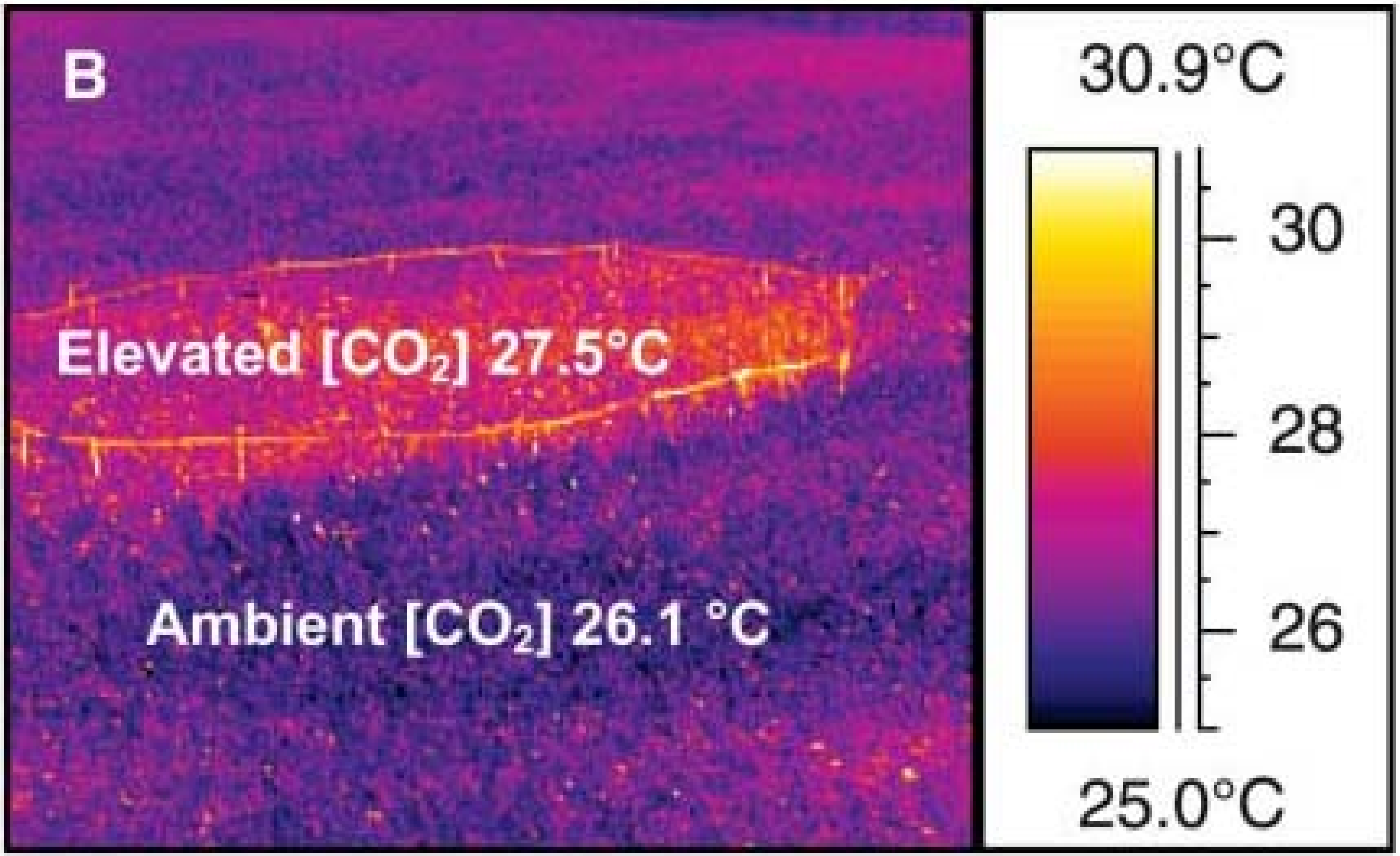
soybean

corn



$[CO_2]$ in the bundle sheath cells is ~1000 ppm

Stomatal conductance is lower in C_4 crops (corn), which increases canopy temperature.



Despite higher canopy temperature, total canopy evapotranspiration is lower at elevated [CO_2], and soil moisture is improved.

Leakey et al. Plant Physiology 140: 779–790.

Crop Yield Responses to Elevated CO_2

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Rice[c]	**+13**	**+27**	+1	−2
Maize[f]	0	−2	−1	−2
Sorghum[g]	+4	**+9**	−1	−2

D. Lobell and M. Burke (eds.), *Climate Change and Food Security*, Advances in Global Change Research 37, DOI 10.1007/978-90-481-2953-9_7,

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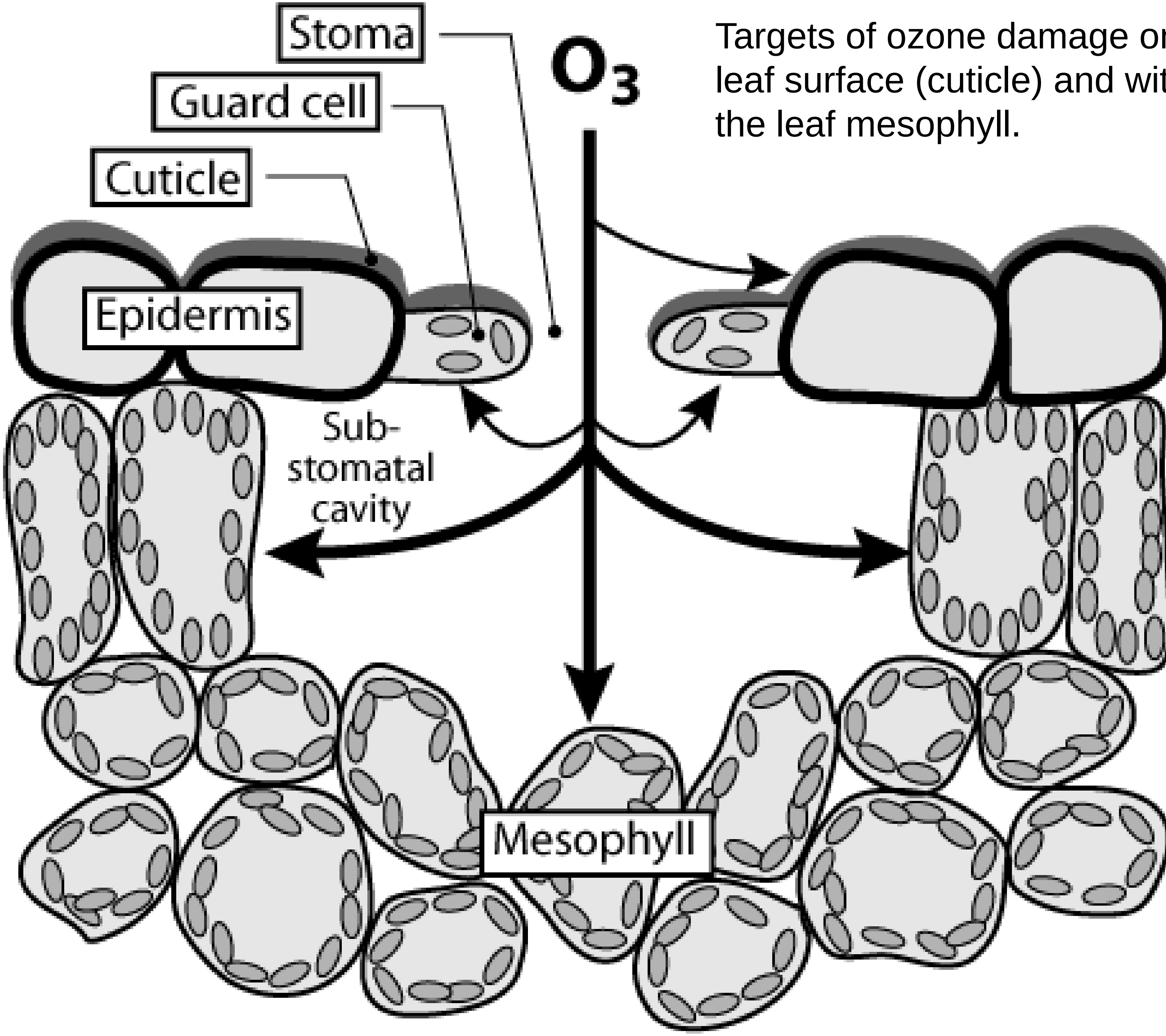
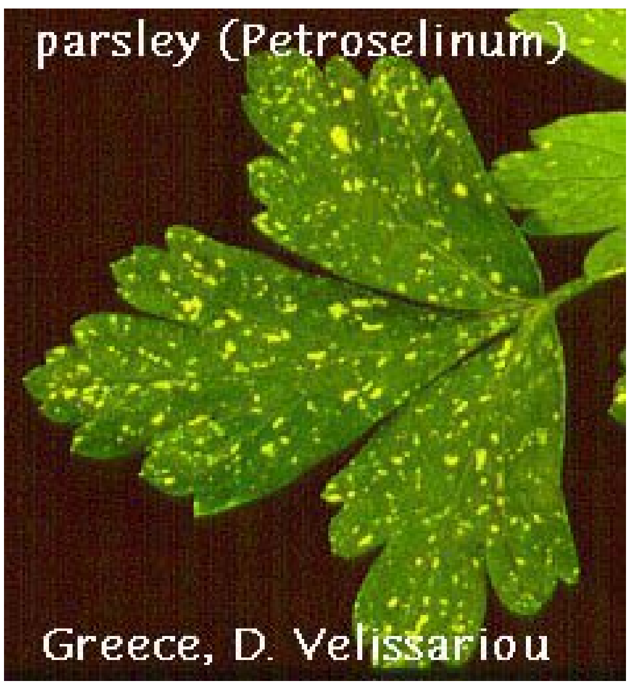
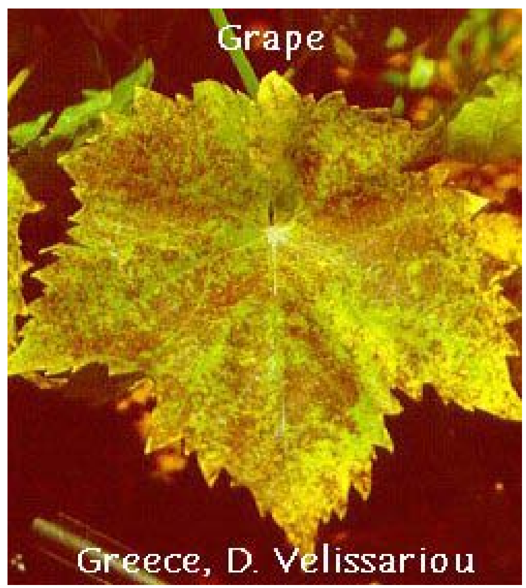
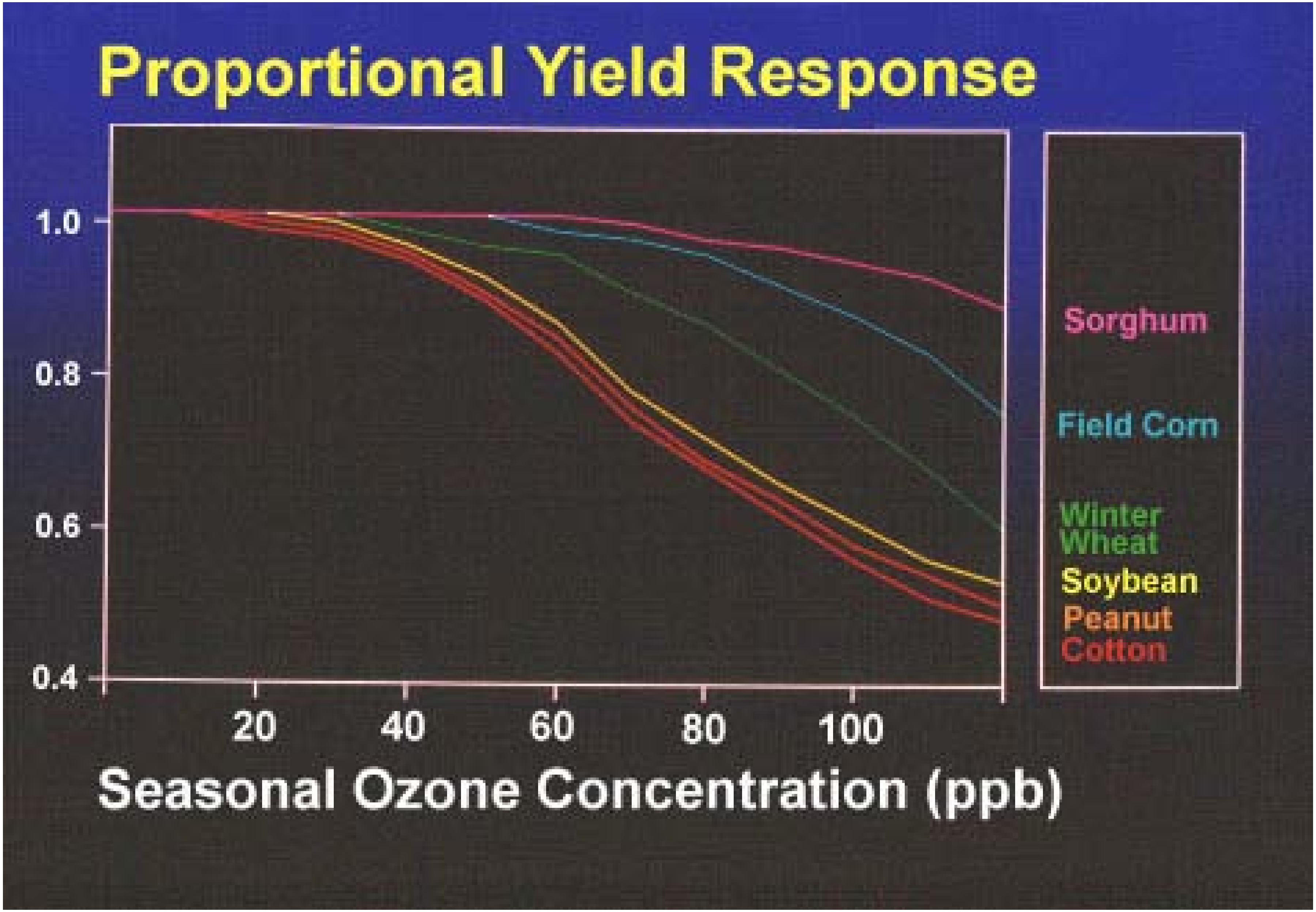
Targets of ozone damage on the leaf surface (cuticle) and within the leaf mesophyll.




wheat (Triticum aestivum)
Greece, D. Velissariou

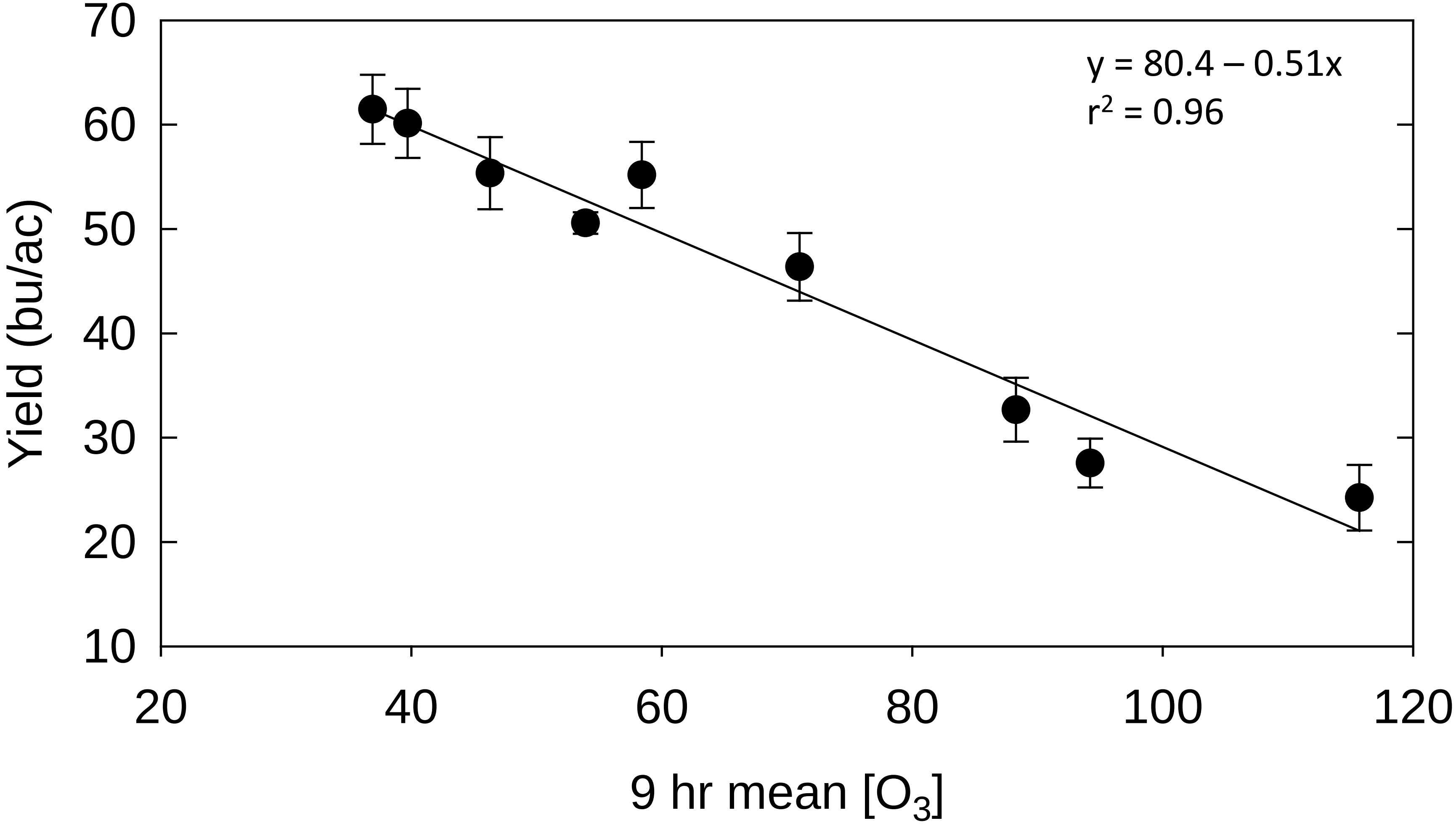

parsley (Petroselinum)
Greece, D. Velissariou


Grape
Greece, D. Velissariou



USDA NCLAN study

Soybean seed yield response to ozone concentration



What is the cost of ozone pollution?

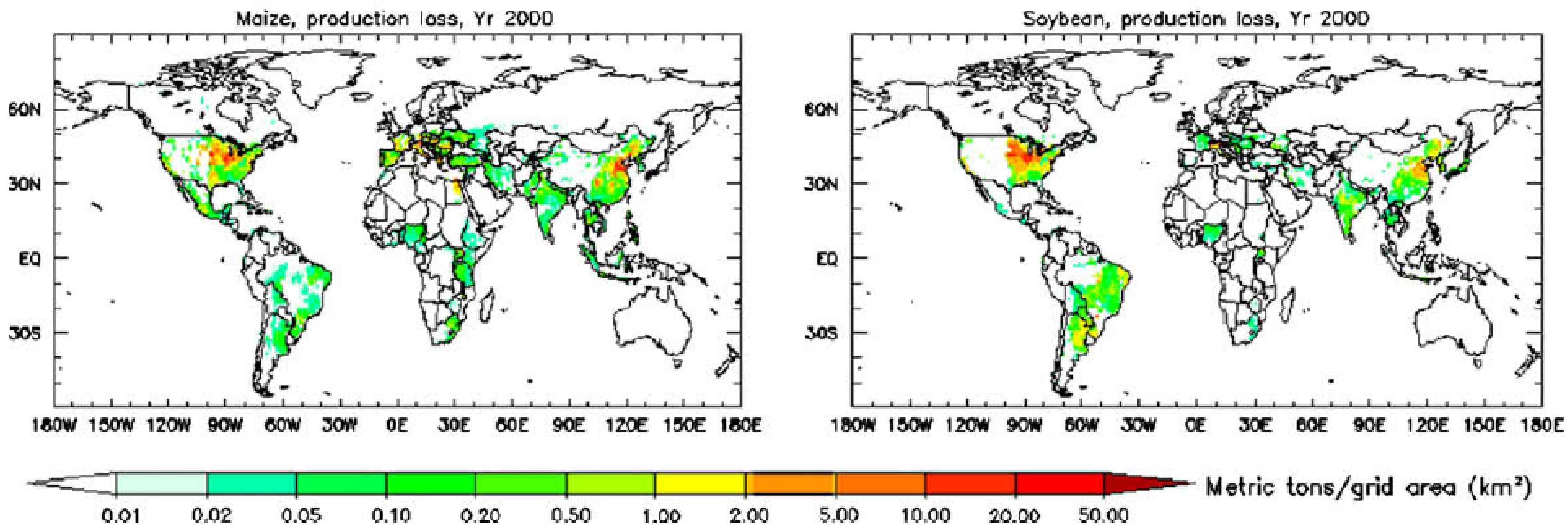


Fig. 10. Average crop production loss from 2 metrics for the 4 crops, year 2000. The production loss numbers are normalized to the grid cell area.

In the Midwest U.S., current ozone concentrations are costing 1-5 metric tons/km^2 of potential corn yields and 5-20 metric tons/km^2 of potential soybean yields.

Atmospheric Environment 43 (2009) 604–618

What is the economic cost of ozone pollution?

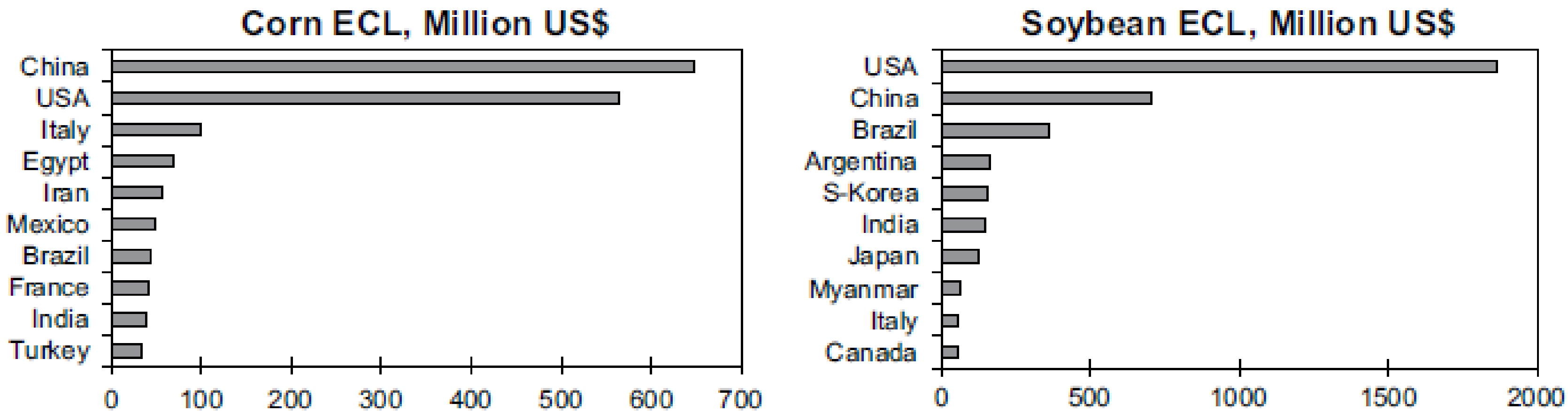
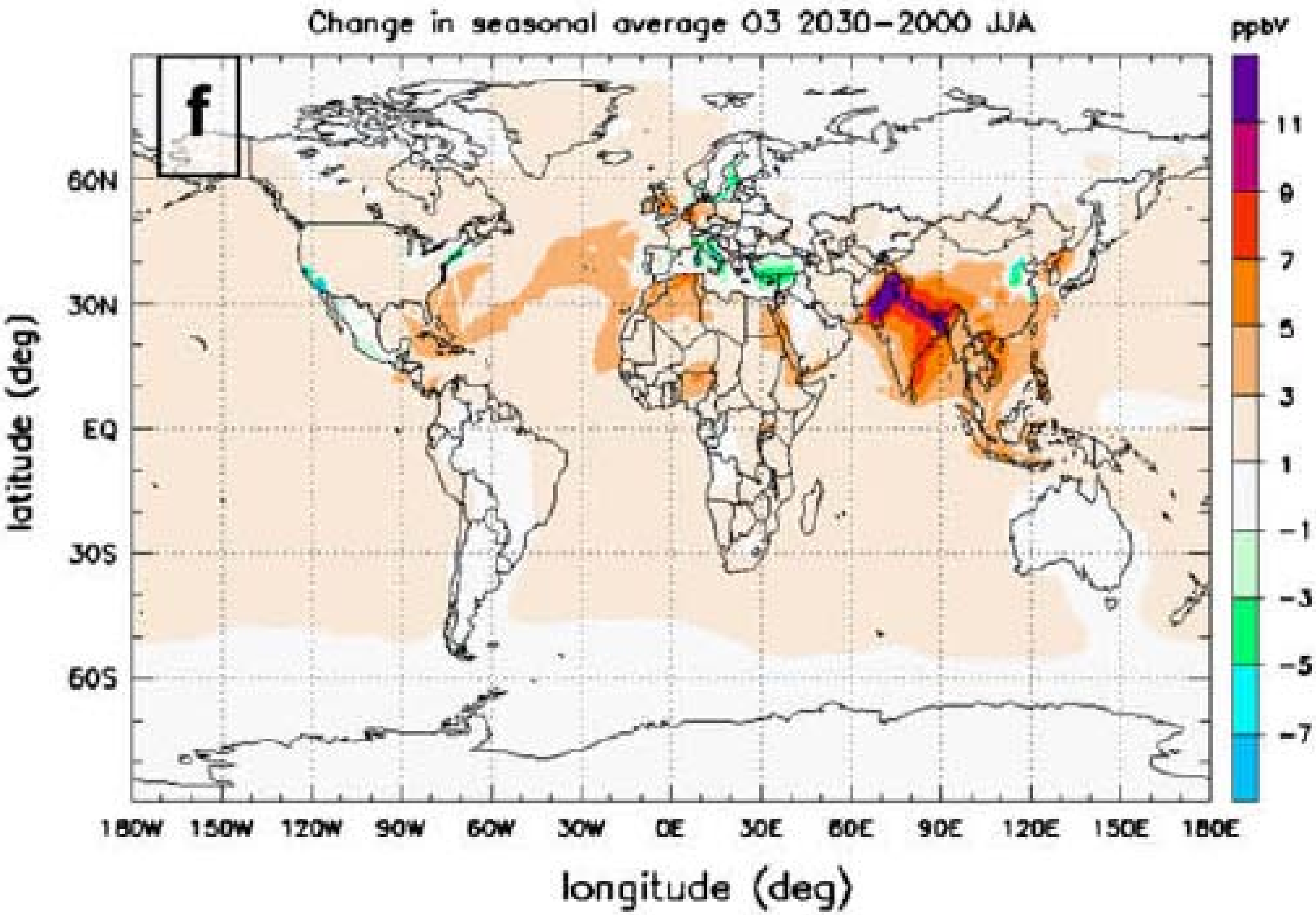


Fig. 11. Estimated economic losses of 10 highest ranked countries for the year 2000.

Those yield losses translate to ~$600,000,000 in lost profit for corn and $1.7B in lost profit for soybean.

Atmospheric Environment 43 (2009) 604–618

Cost of ozone pollution will only increase in the future without efforts to breed for ozone tolerance.



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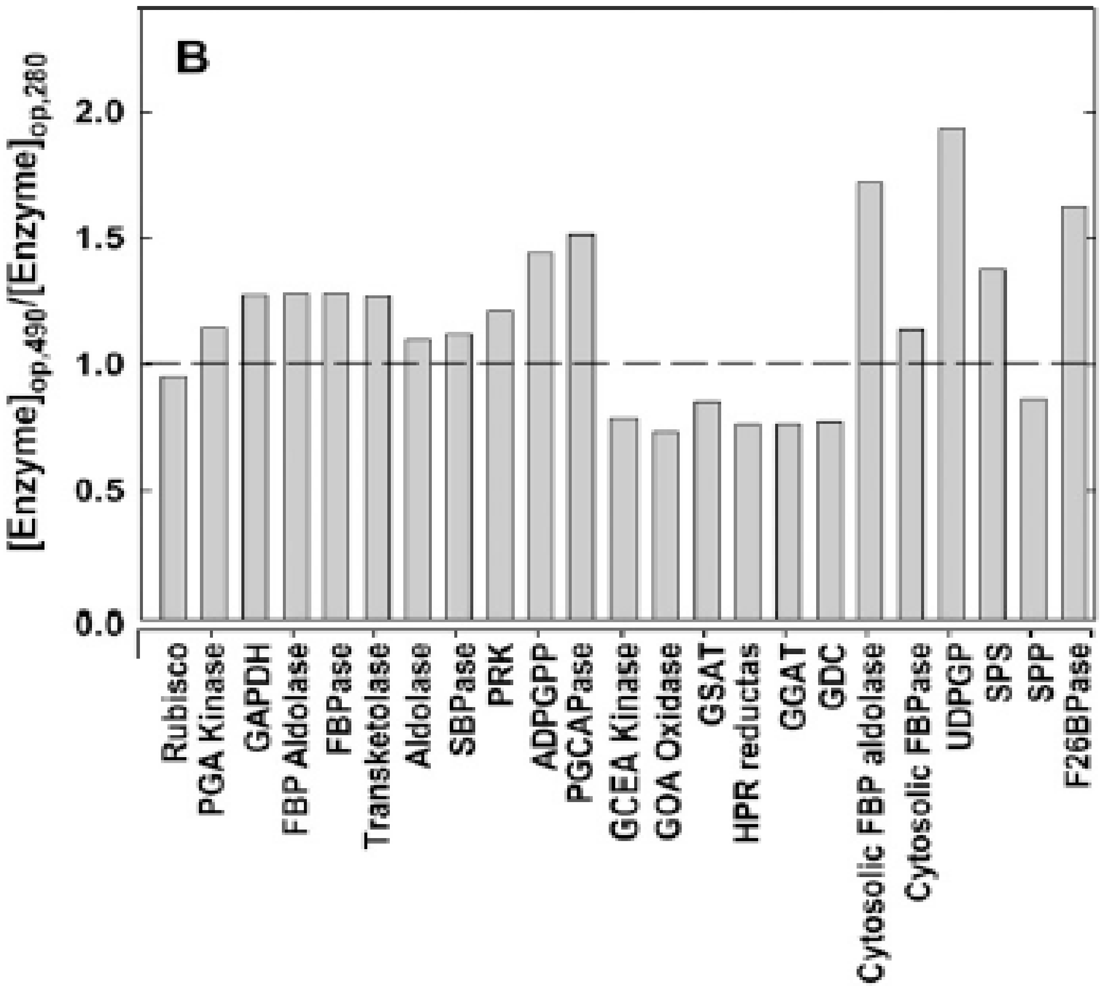
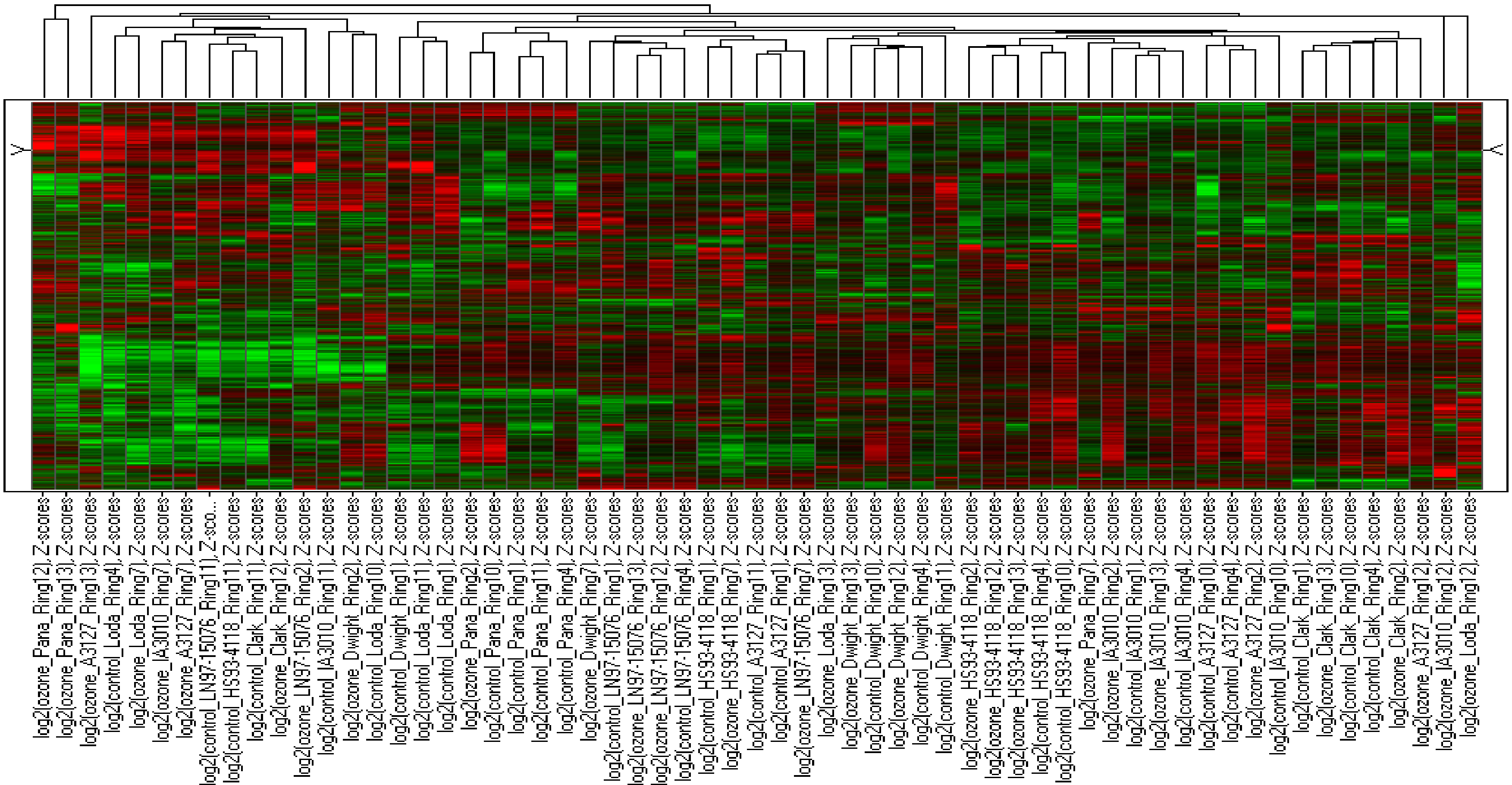
Alter the distribution of resources among photosynthetic enzymes to improve the efficiency of photosynthesis.



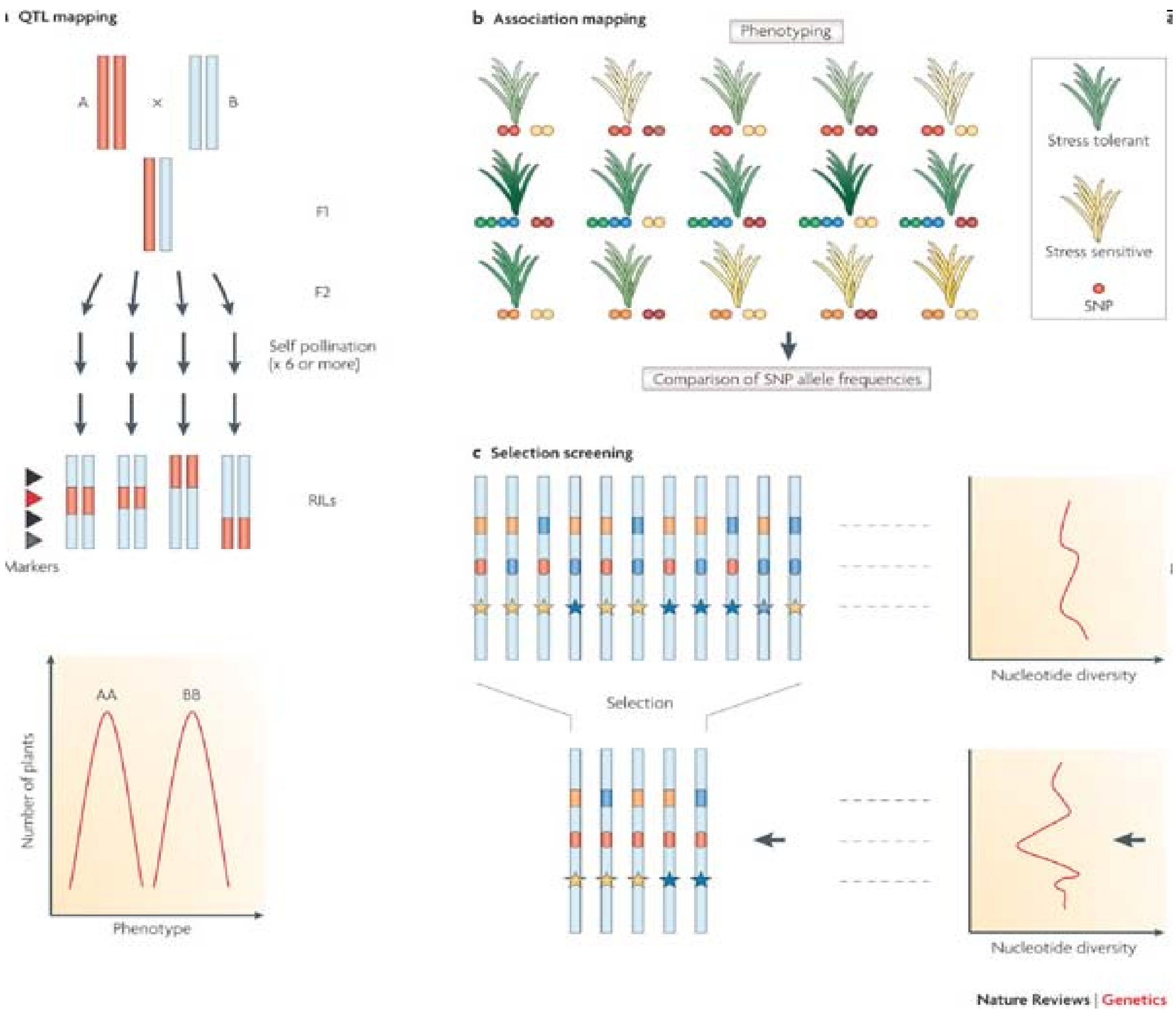
Plant Physiology, October 2007, Vol. 145, pp. 513–526, Identify cultivars with strong sink capacity.

Test Cultivar	Akitakomachi	Wixiangjing 14	Shanyou 63
Genotype	Japonica	Japonica	Hybrid indica
% Increase in Yield	+12.8%	+12.8%	+34.1%

Identify molecular signals of CO_2 responsiveness or O_3 tolerance

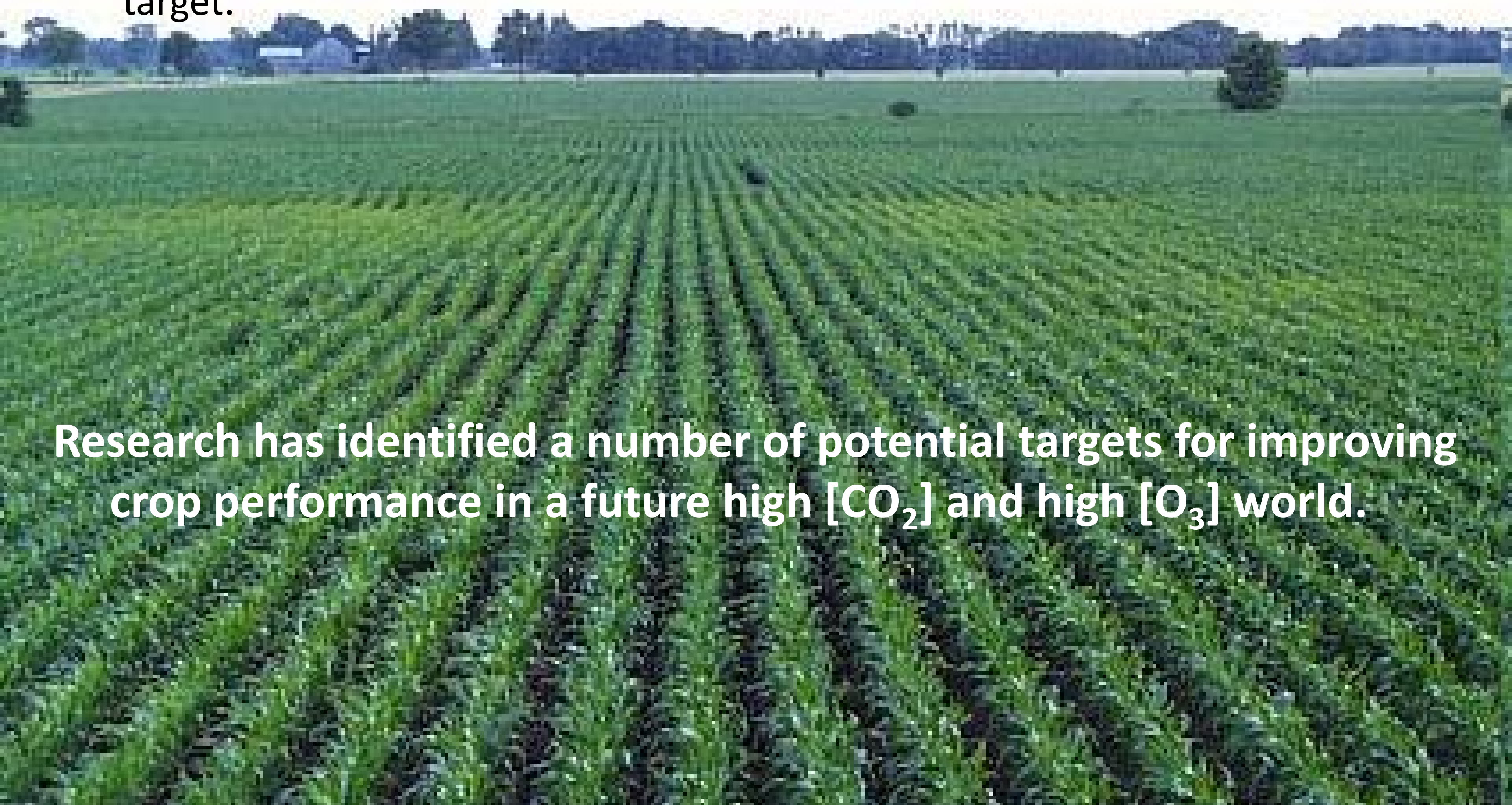


Genetic dissection of CO_2 responsiveness and O_3 tolerance



Global climate change will add at least three new dimensions to agriculture:

(1) the production environment will be more variable and more stressful
(2) climatic variation will be greater between years and locations of field trials
(3) the environment for which crops are being designed will be a rapidly moving target.



Research has identified a number of potential targets for improving crop performance in a future high [CO_2] and high [O_3] world.