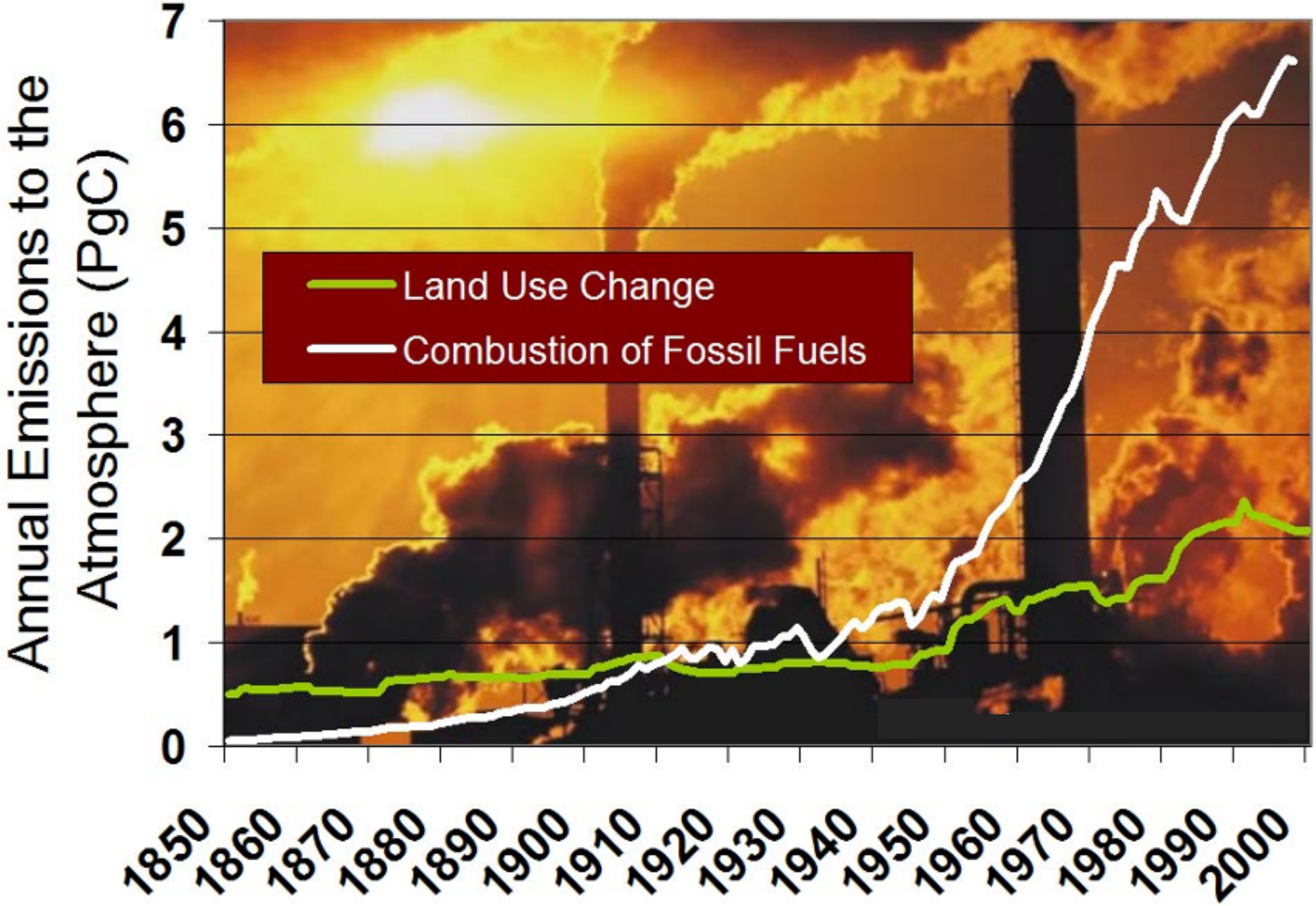
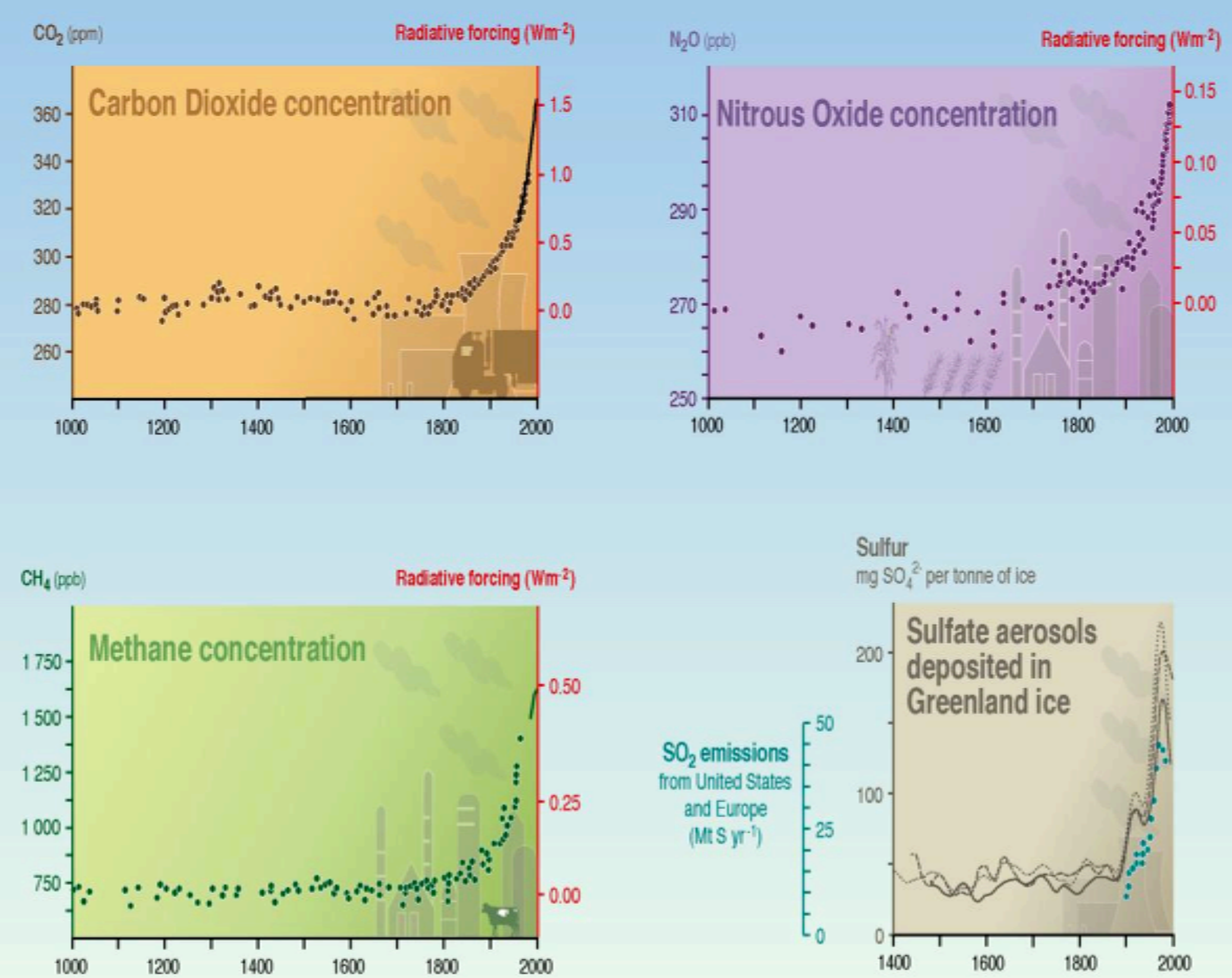
David Skole
Professor of Global Change Science
Michigan State University

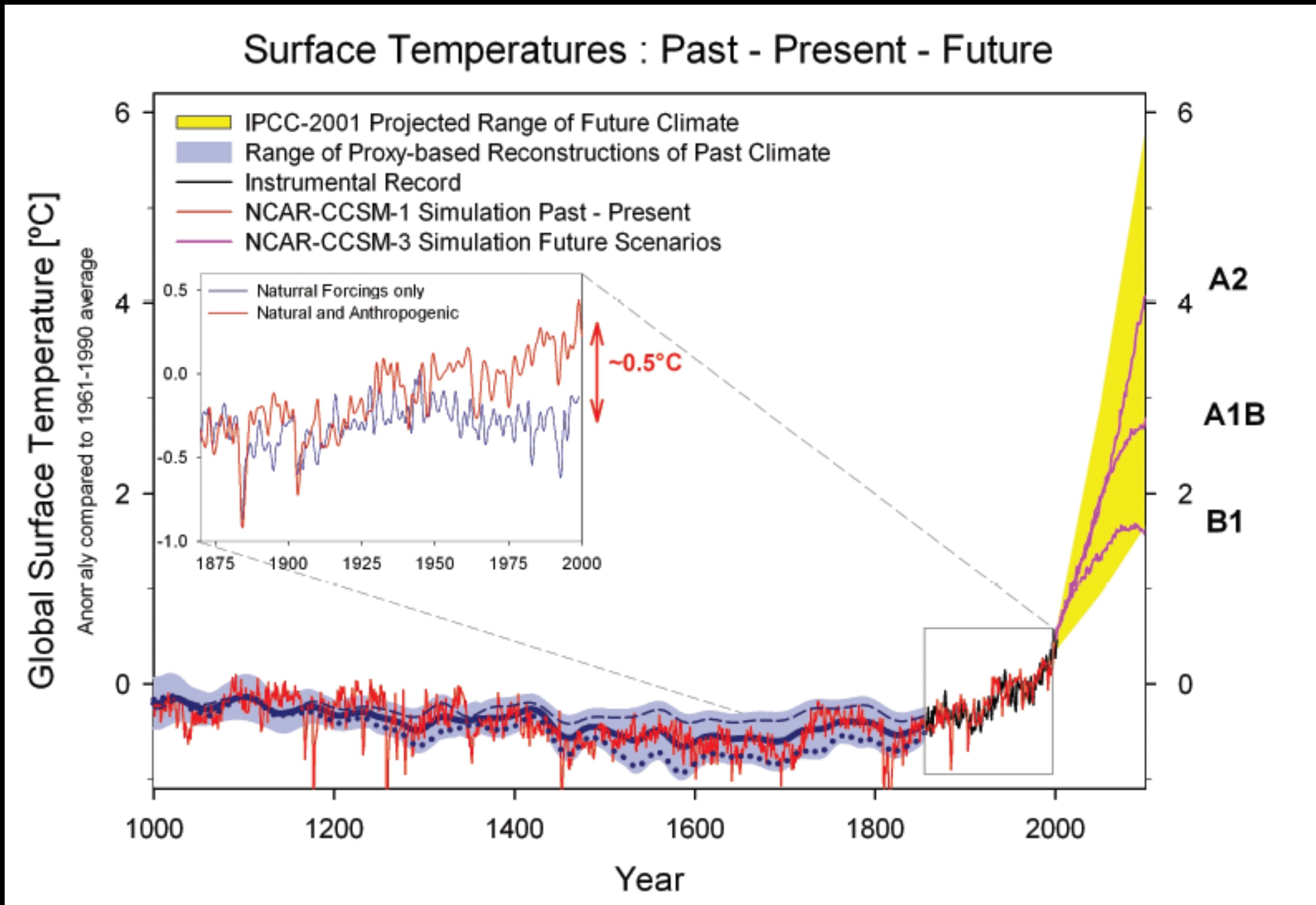
CLIMATE CHANGE CHALLENGE AND OPPORTUNITY


Annual Emissions to the Atmosphere (PgC)
7
6
5
4
3
2
1
0
Land Use Change
Combustion of Fossil Fuels
1850
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000

Indicators of the human influence on the atmosphere during the Industrial era

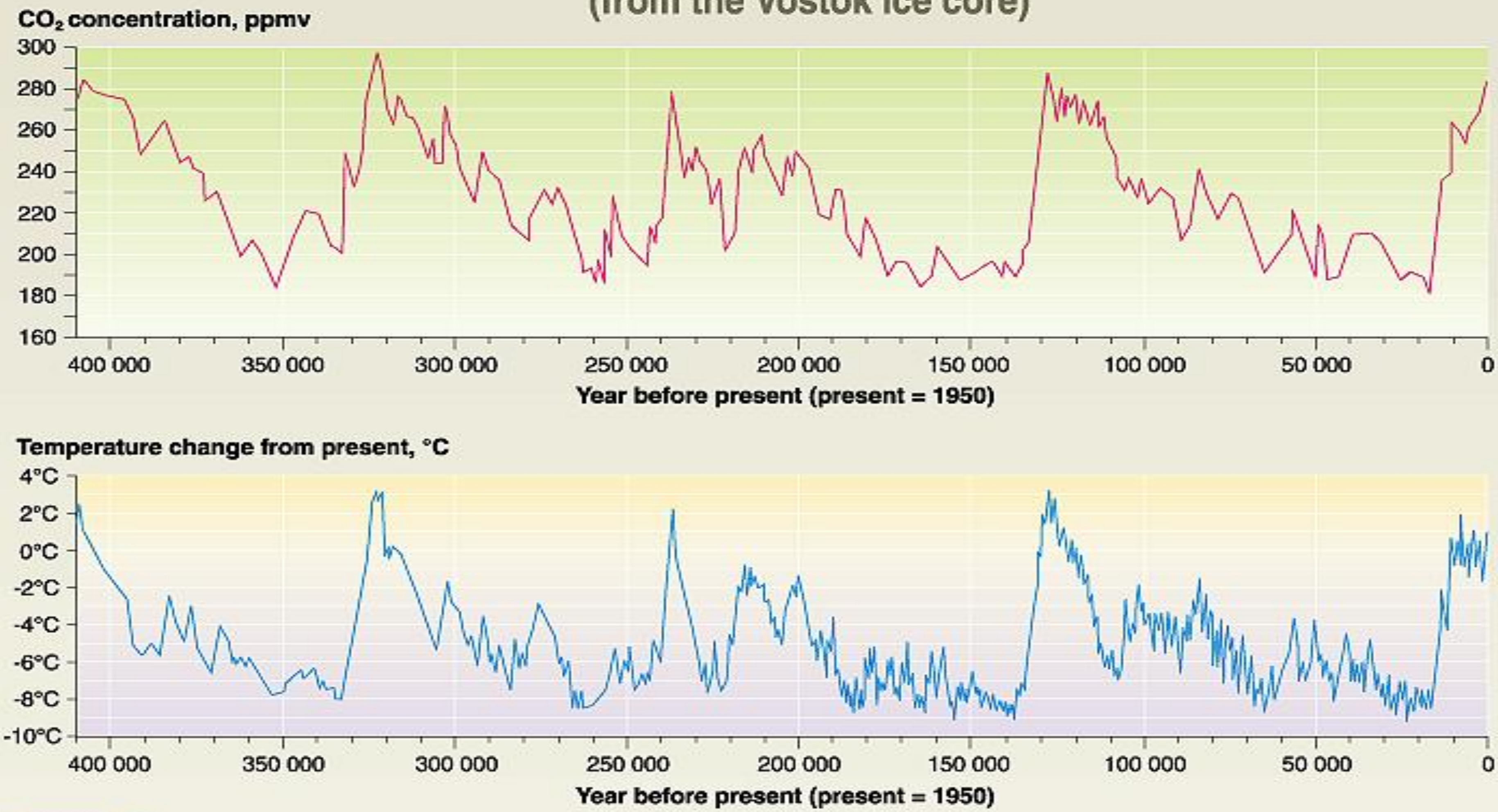


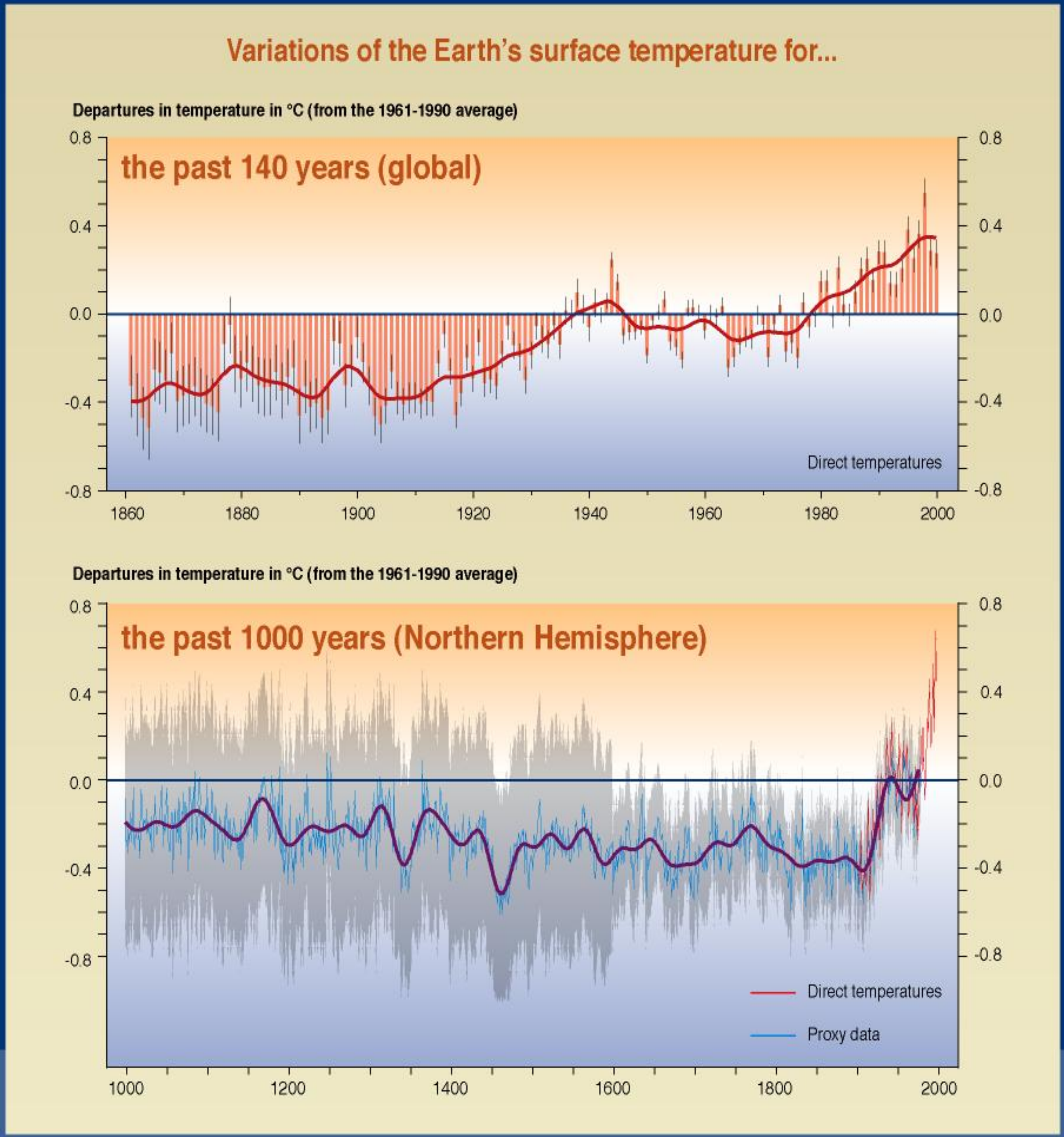
SYR - FIGURE 2-1
WG1 FIGURE SPM-2



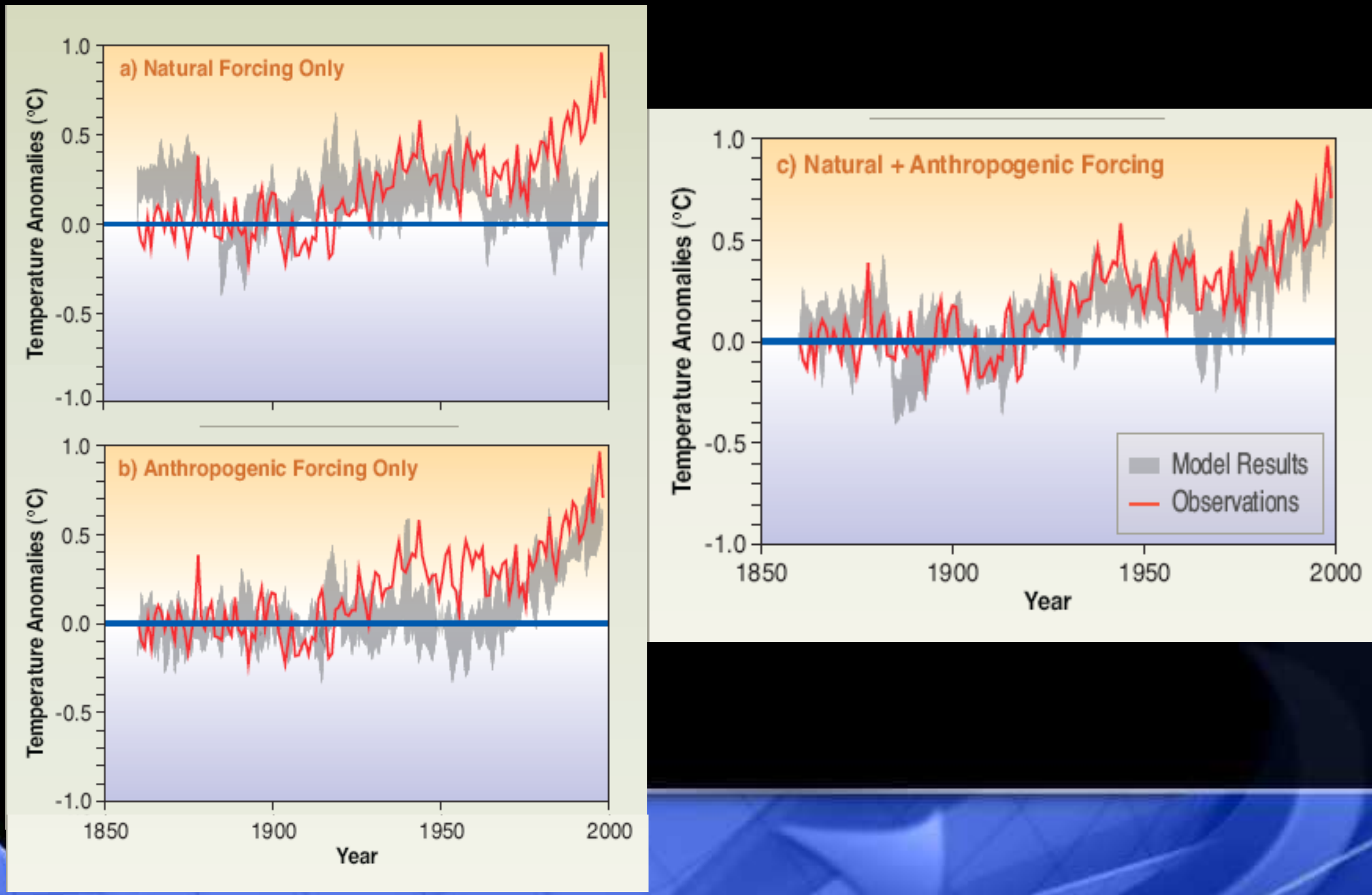
Surface Temperatures : Past - Present - Future
IPCC-2001 Projected Range of Future Climate
Range of Proxy-based Reconstructions of Past Climate
Instrumental Record
NCAR-CCSM-1 Simulation Past - Present
NCAR-CCSM-3 Simulation Future Scenarios
Naturral Forcings only
Natural and Anthropogenic
~0.5°C
A2
A1B
B1
Global Surface Temperature [°C]
Anomaly compared to 1961-1990 average
Year

Temperature and CO_2 concentration in the atmosphere over the past 400 000 years (from the Vostok ice core)





SYR - FIGURE 2-3


a) Natural Forcing Only
b) Anthropogenic Forcing Only
c) Natural + Anthropogenic Forcing
Temperature Anomalies (°C)
1.0
0.5
0.0
-0.5
-1.0
1850
1900
1950
2000
Year
Model Results
Observations

Climate change not global warming

- Clearly average continental and global temperature rise is an important feature
- The other feature is CO_2 concentration in the atmosphere
  - Unambiguous
  - Important to agriculture
- CO2 in seawater – ocean acidification

Climate change dynamics

- Even global average temperature change by itself is less interesting than dynamics:
  - E.g. winter night time lows
  - E.g. no overwinter pest kills
- Frost free growing season length
- Consider feedback effects
  - E.g. global temperature rises, triggers more cloud formation, stabilizes temp. rise
  - But more clouds less PAR

From dynamics to variability

- A more energized hydrologic cycle and energy budget (even without temp rise)
- Un-seasonable events, variability, extremes

Current concerns

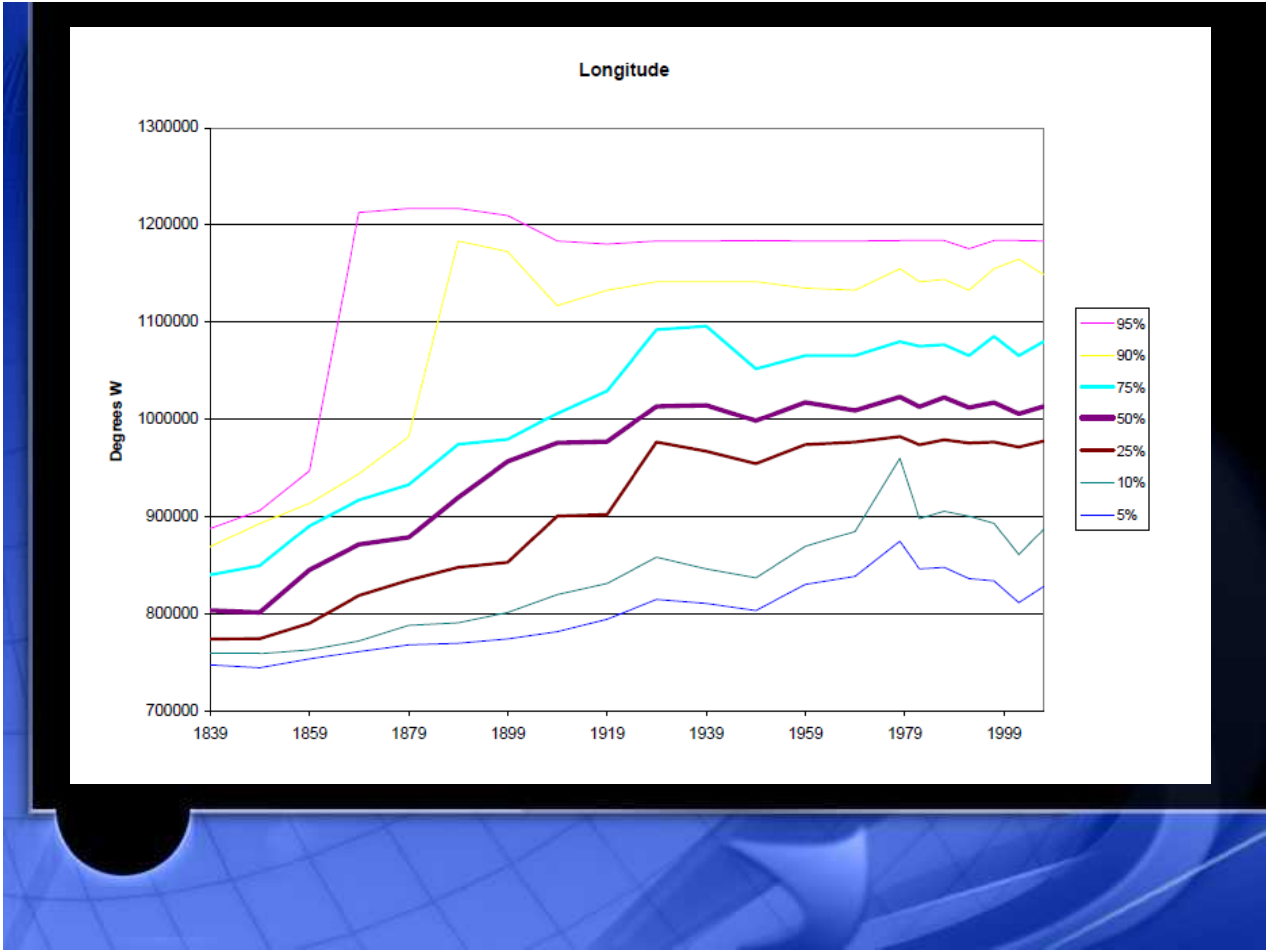
- U.N. Intergovernmental Panel on Climate Change, the earth's temperature rising by 0.13 degrees C every decade for the past fifty years.
- Many climate models project that in this century temperatures in North America will be 2-3 degrees higher at its coasts 5 degrees C higher mid continent

Implications for wheat

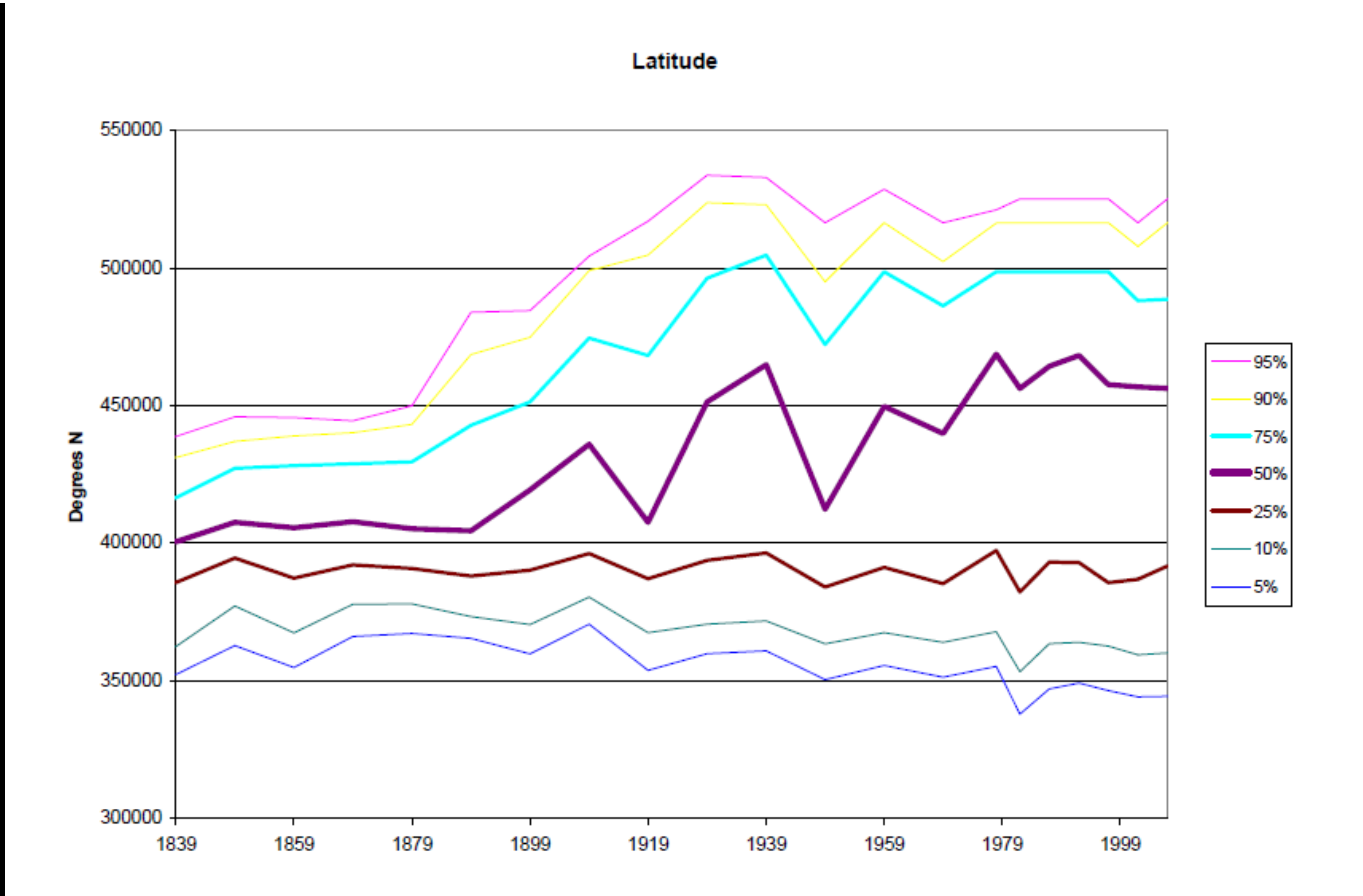
- International Maize and Wheat Improvement Center:
  - North America wheat farmers will have to cease production at the southern end of the grain belt
  - but may be able extend cultivation up another 600-700 miles from the current northern limit of production

CIMMYT Study

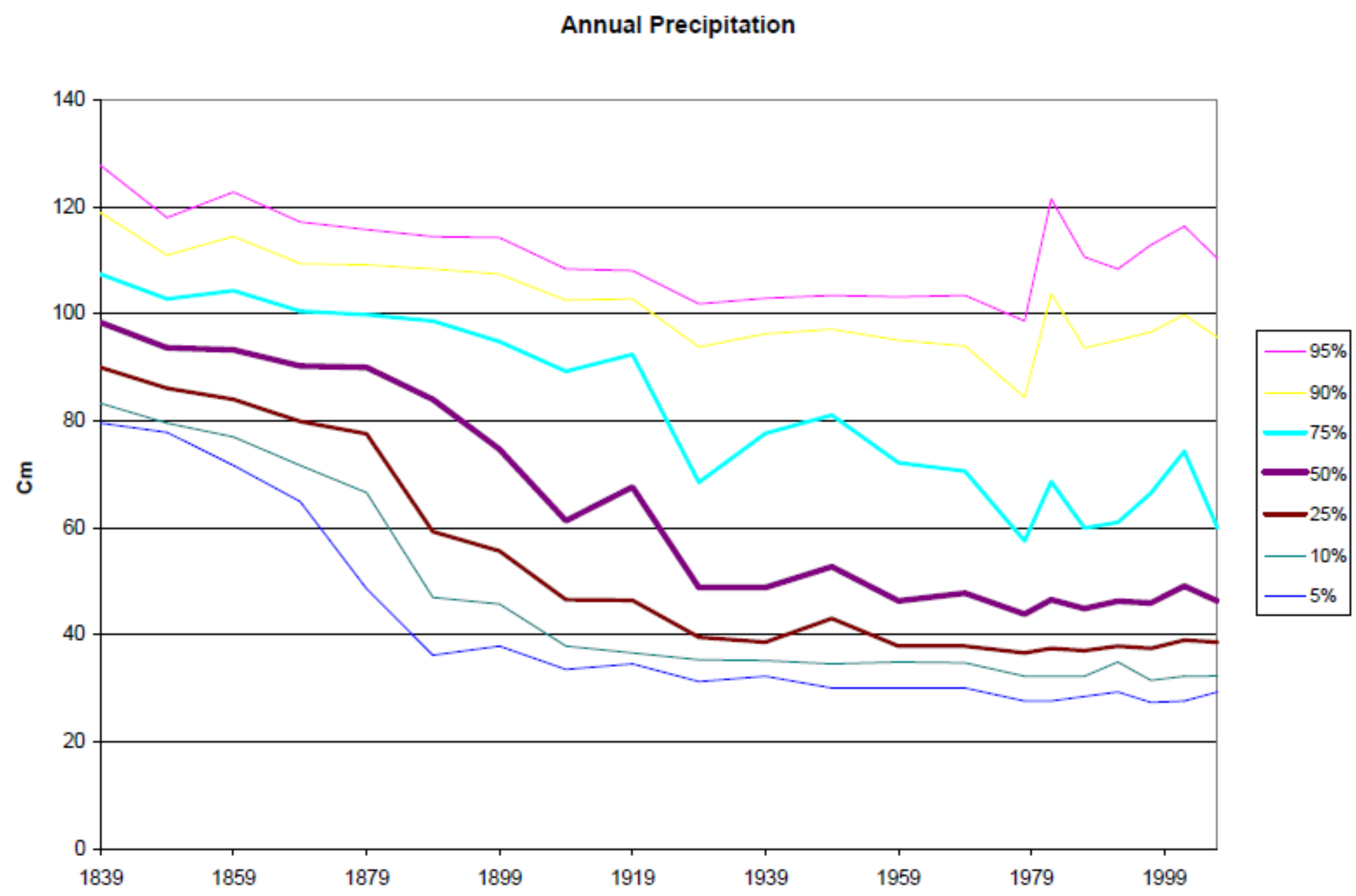
Some historical context 1858

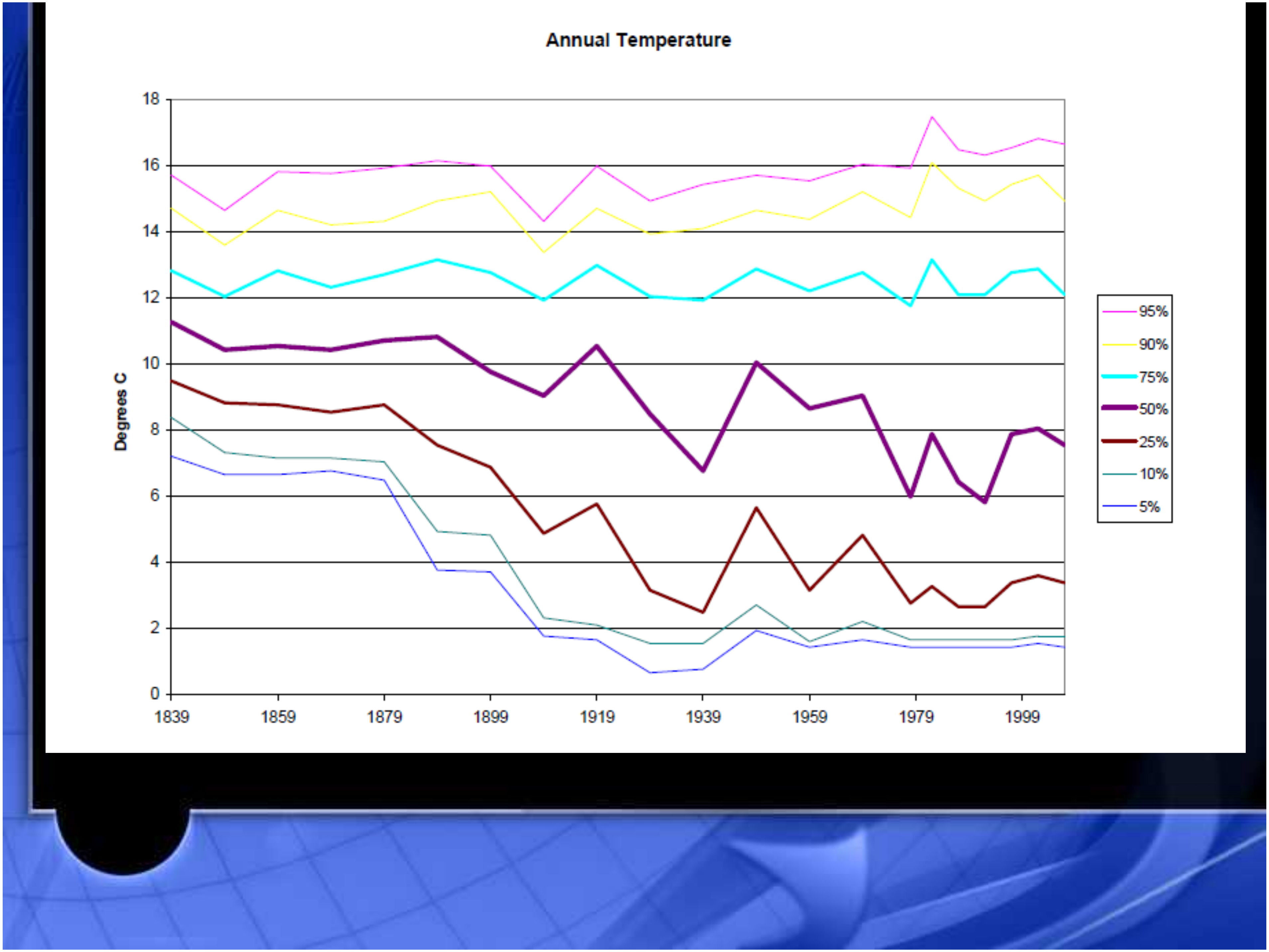


Longitude
1300000
1200000
1100000
1000000
900000
800000
700000
Degrees W
1839
1859
1879
1899
1919
1939
1959
1979
1999
95%
90%
75%
50%
25%
10%
5%



Latitude
Degrees N
550000
500000
450000
400000
350000
300000
1839
1859
1879
1899
1919
1939
1959
1979
1999
95%
90%
75%
50%
25%
10%
5%


Annual Precipitation
Cm
140
120
100
80
60
40
20
0
1839
1859
1879
1899
1919
1939
1959
1979
1999
95%
90%
75%
50%
25%
10%
5%


Annual Temperature
Degrees C
18
16
14
12
10
8
6
4
2
0
1839
1859
1879
1899
1919
1939
1959
1979
1999
95%
90%
75%
50%
25%
10%
5%

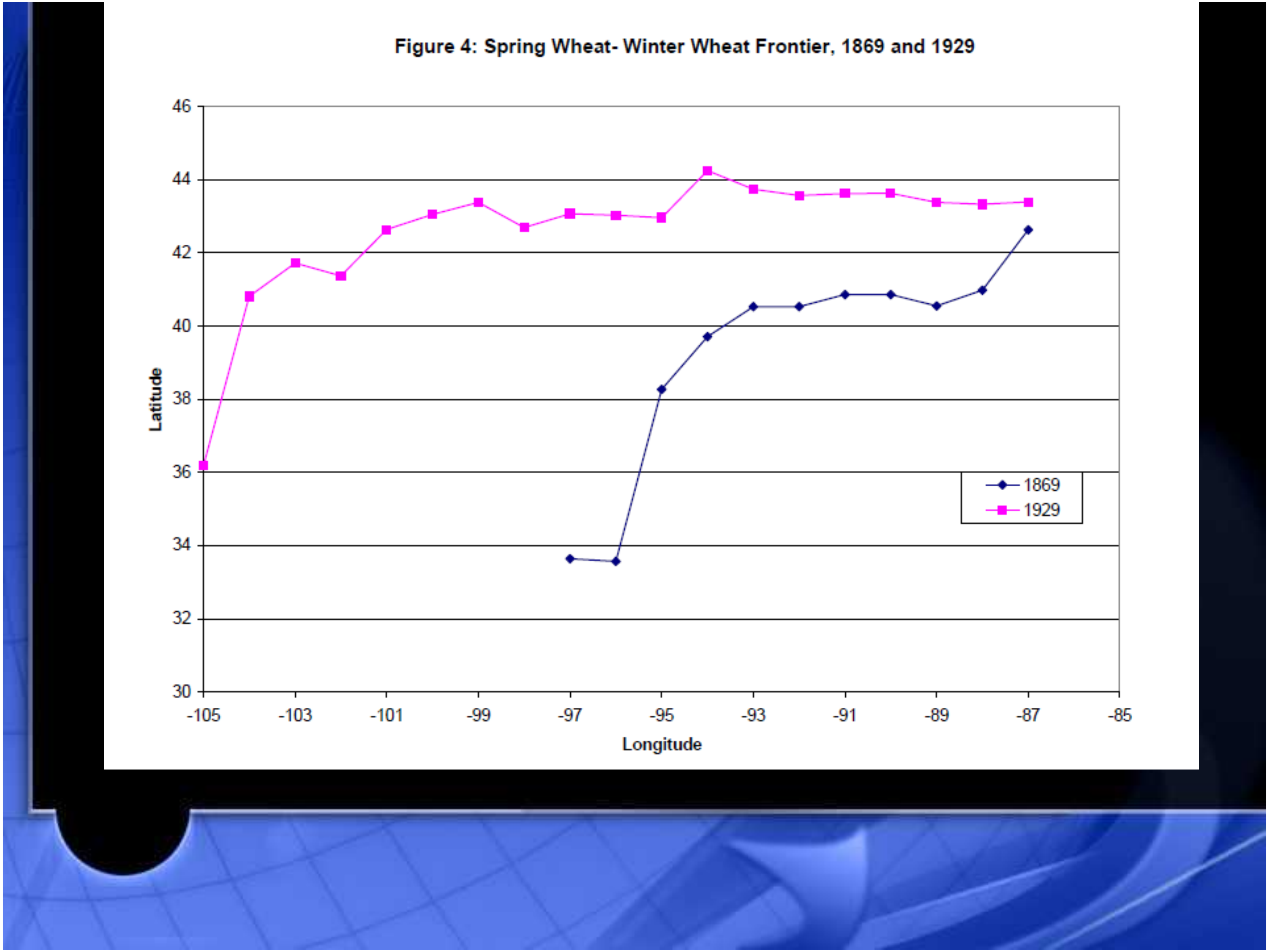
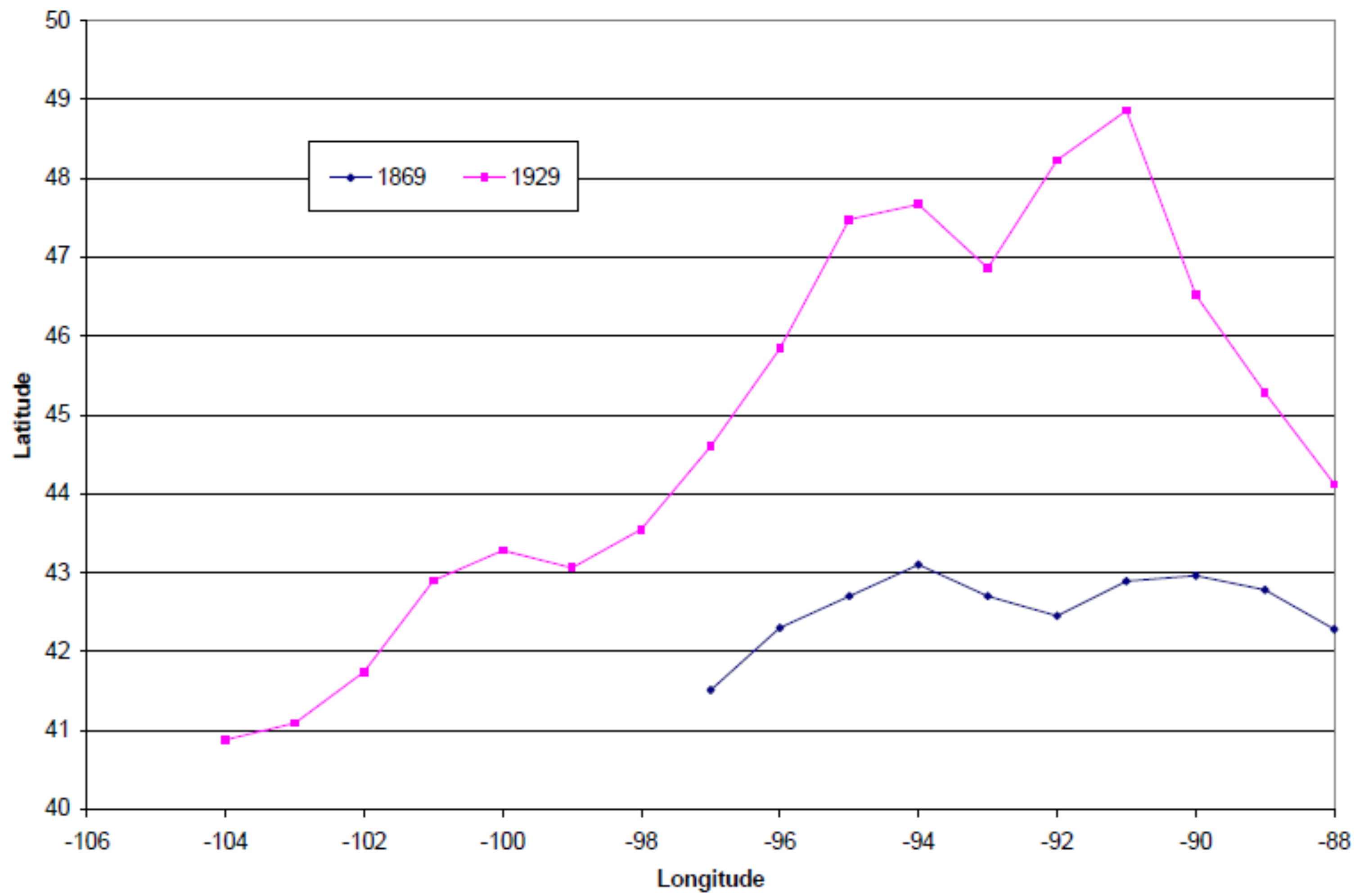


Figure 4: Spring Wheat- Winter Wheat Frontier, 1869 and 1929
Latitude
46
44
42
40
38
36
34
32
30
-105
-103
-101
-99
-97
-95
-93
-91
-89
-87
-85
Longitude
1869
1929

Figure 7: Corn-Wheat Frontier, 1869 and 1929



Prospects in our time (Easterling)

- There is evidence for the following long-term trends:
  - a) an earlier start (~11 days) of the frost-free season and occurrence of fewer extreme cold days in the northeastern U. S.
  - b) an increase in one-day heavy precipitation (>1”) events nationally (by approximately 2-12% across the Corn Belt)
  - c) a pronounced increase in minimum daily temperatures nationally (but no trend in maximum temperatures)
  - d) an increase in the area of the U. S. experiencing extreme wetness (but no change in dryness).

Continued…

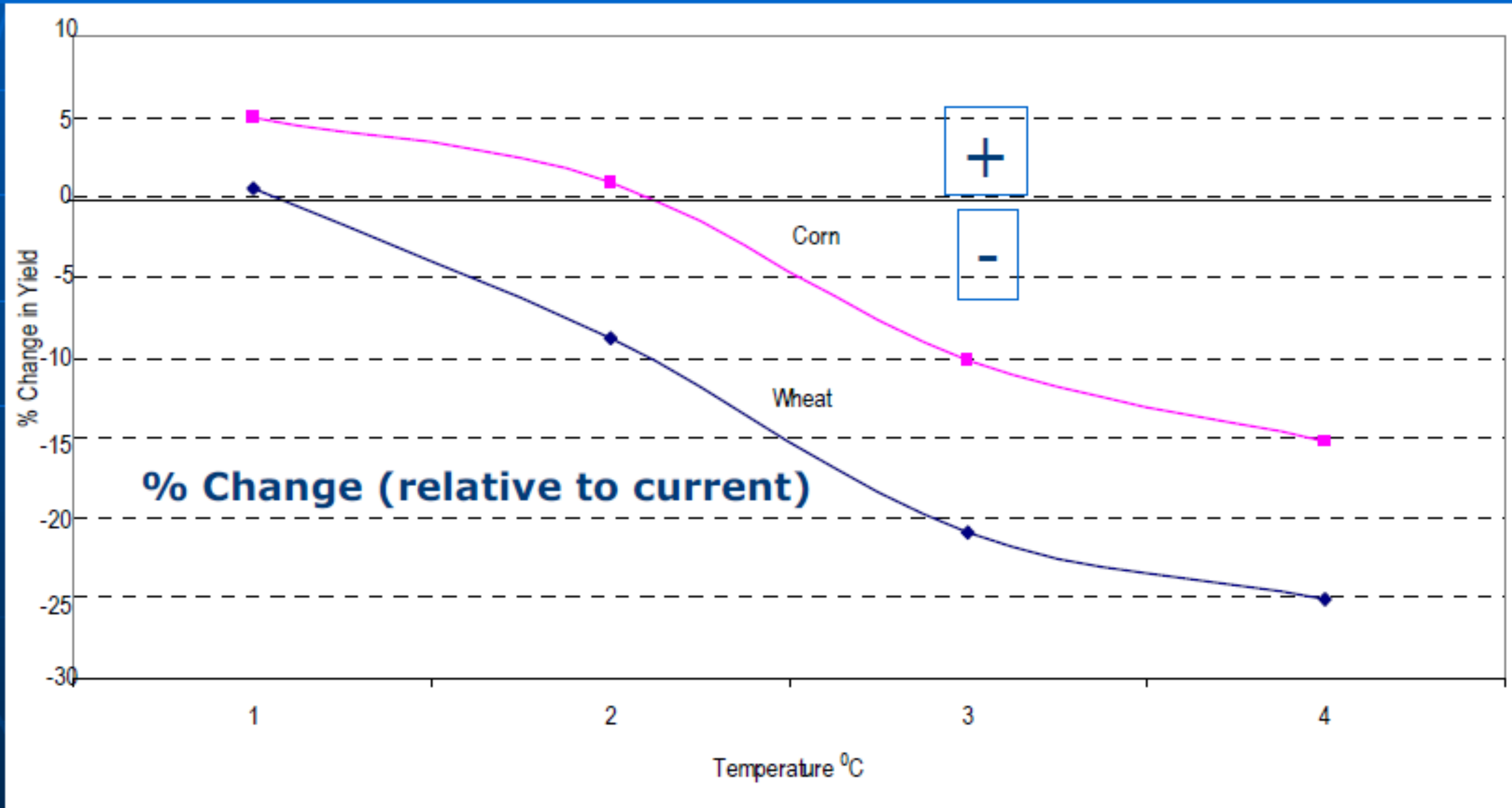
- Climate model simulations indicate that most mid-continental locations in the Northern Hemisphere will warm more than the global average and will receive more precipitation than current.
- The trend toward more high-intensity rainfall events is expected to continue.
- However, droughts are likely to become more frequent in these regions, in spite of more rainfall, due to higher ET; soils will eventually dry.
- Growing seasons likely will be extended, but the probability of destructive heat waves will rise.

Continued…CO_2 effects

- Experiments demonstrate the positive effects of rising atmospheric CO2 concentrations on photosynthesis of certain major crops such as soybeans and wheat and on the drought-tolerance of all crops.
- It appears that the CO2 effect is slightly higher under moisture stress than under adequate moisture
- However, experiments are showing that the beneficial effects of CO2 may decline as temperatures rise above crop photosynthetic optima.
- Moreover, these effects are not likely to fully offset stresses of warmer temperatures and drier soils,

Temperate Crop Yields with Warming and CO_2 Effects

Synthesized From Existing Modeling Studies



USDA free air experiments

- Increased soil C (slightly)
- Decreased flour protein

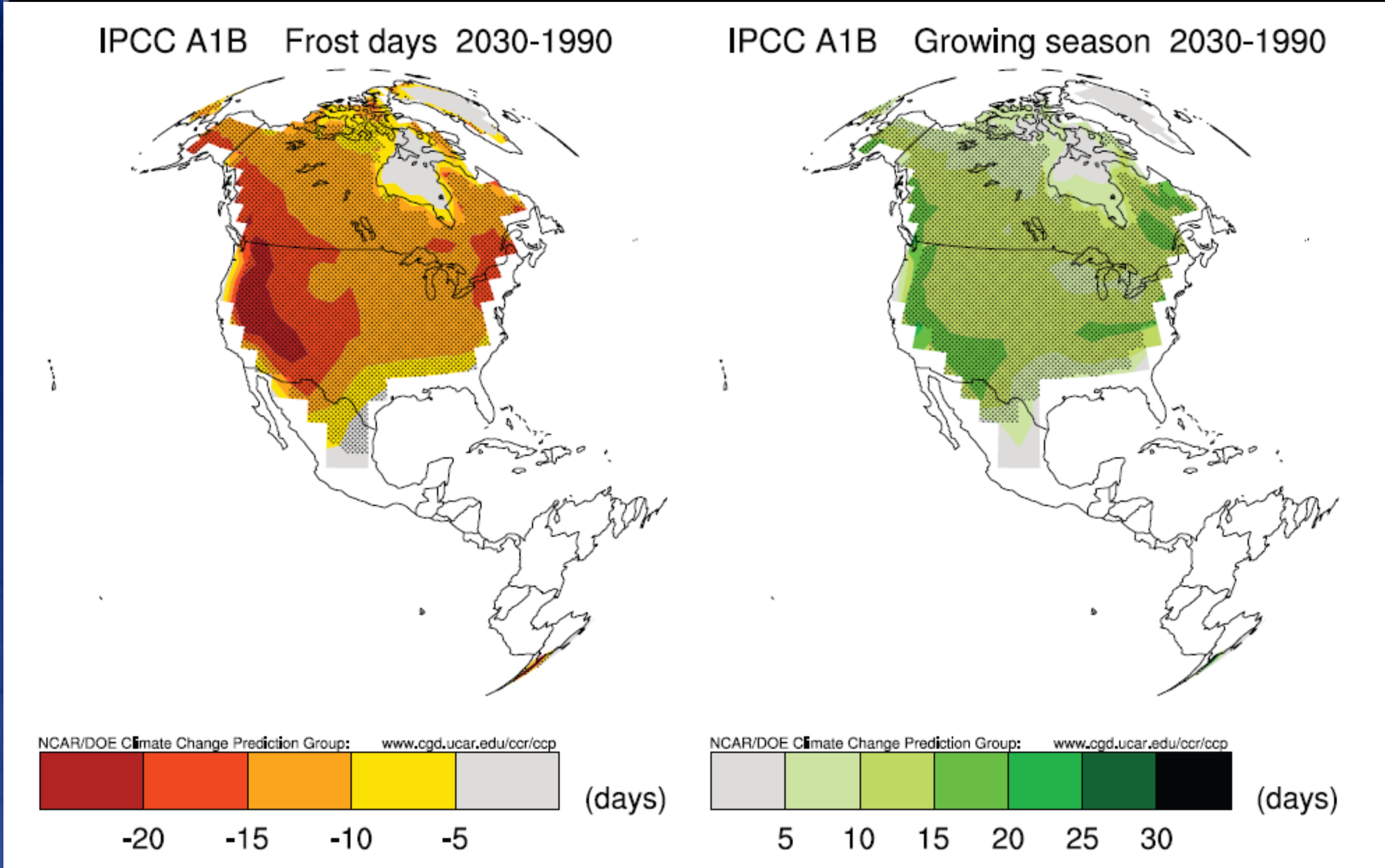
Table 2.7 Percent response of leaf photosynthesis, total biomass, grain yield, stomatal conductance, and canopy temperature or evapotranspiration, to a doubling in CO_2 concentration (usually 350 to 700 ppm, but sometimes 330 to 660 ppm). *Responses to increase from ambient to 550 or 570 ppm (FACE) are separately noted.

Crop	Leaf Photosynthesis	Total Biomass	Grain Yield	Stomatal Conductance	Canopy T, ET
	% change				
Corn	3[1*]	4[1,2,3,4]	4[1,2]	-34[5]	
Soybean	39[6]	37[6]	38[6], 34[7]	-40[6]	-9[8], -12[9,10*]
Wheat	35[11]	15-27[12]	31[13]	-33 to -43[14*]	-8[15,16*]
Rice	36[17]	30[17]	30[17,18]		-10[19,27]
Sorghum	9[20,21*]	3[22*]	8[20], 0[22*]	-37[21*]	-13[23*]
Cotton	33[24]	36[24]	44[24]	-36[24]	-8[25]
Peanut	27[26]	36[26]	30[26]		
Bean	50[26]	30[26]	27[26]		

References: [1]Leakey et al. (2006)*; [2]King and Greer (1986); [3]Ziska and Bunce (1997); [4]Maroco et al. (1999); [5]Leakey et al. (2006)*; [6]Ainsworth et al. (2002); [7]Allen and Boote (2000); [8]Allen et al. (2003); [9]Jones et al. (1985); [10]Bernacchi et al. (2007)*; [11]Long (1991); [12]Lawlor and Mitchell (2000); [13]Amthor (2001); [14]Wall et al. (2006)*; [15]Andre and duCloux (1993); [16]Kimball et al. (1999)*; [17]Horie et al. (2000); [18]Baker and Allen (1993a); [19]Baker et al. (1997a); [20]Prasad et al. (2006a); [21]Wall et al. (2001); [22]Ottman et al. (2001)*; [23]Triggs et al. (2004)*; [24]K.R. Reddy et al. (1995,1997); [25]Reddy et al. (2000); [26]Prasad et al. (2003); [27]Yoshimoto et al. (2005).

Table 2.6 Percent grain yield and evapotranspiration responses to increased temperature (1.2°C), increased CO_2 (380 to 440 ppm), and the net effects of temperature plus increased CO_2 assuming additivity. Current mean air temperature during reproductive growth is shown in parentheses for each crop/region to give starting references, although yield of all the cereal crops declines with a temperature slope that originates below current mean air temperatures during grain filling.

	Grain Yield			Evapotranspiration	
Crop	Temperature (1.2°C) [1]	CO_2 (380 to 440 ppm) [2]	Temp/CO_2 Combined Irrigated	Temp (1.2°C) [3]	CO_2 (380 to 440 ppm) [4]
	% change				
Corn – Midwest (22.5°C)	-4.0	+1.0	-3.0	+1.8	
Corn – South (26.7°C)	-4.0	+1.0	-3.0	+1.8	
Soybean – Midwest (22.5°C)	+2.5	+7.4	+9.9	+1.8	-2.1
Soybean – South (26.7°C)	-3.5	+7.4	+3.9	+1.8	-2.1
Wheat – Plains (19.5°C)	-6.7	+6.8	+0.1	+1.8	-1.4
Rice – South (26.7°C)	-12.0	+6.4	-5.6	+1.8	-1.7
Sorghum (full range)	-9.4	+1.0	-8.4	+1.8	-3.9
Cotton – South (26.7°C)	-5.7	+9.2	+3.5	+1.8	-1.4
Peanut – South (26.7°C)	-5.4	+6.7	+1.3	+1.8	
Bean – relative to 23°C	-8.6	+6.1	-2.5	+1.8	


IPCC A1B Frost days 2030-1990
IPCC A1B Growing season 2030-1990
NCAR/DOE Climate Change Prediction Group: www.cgd.ucar.edu/ccr/ccp
-20 -15 -10 -5
(days)
NCAR/DOE Climate Change Prediction Group: www.cgd.ucar.edu/ccr/ccp
5 10 15 20 25 30
(days)

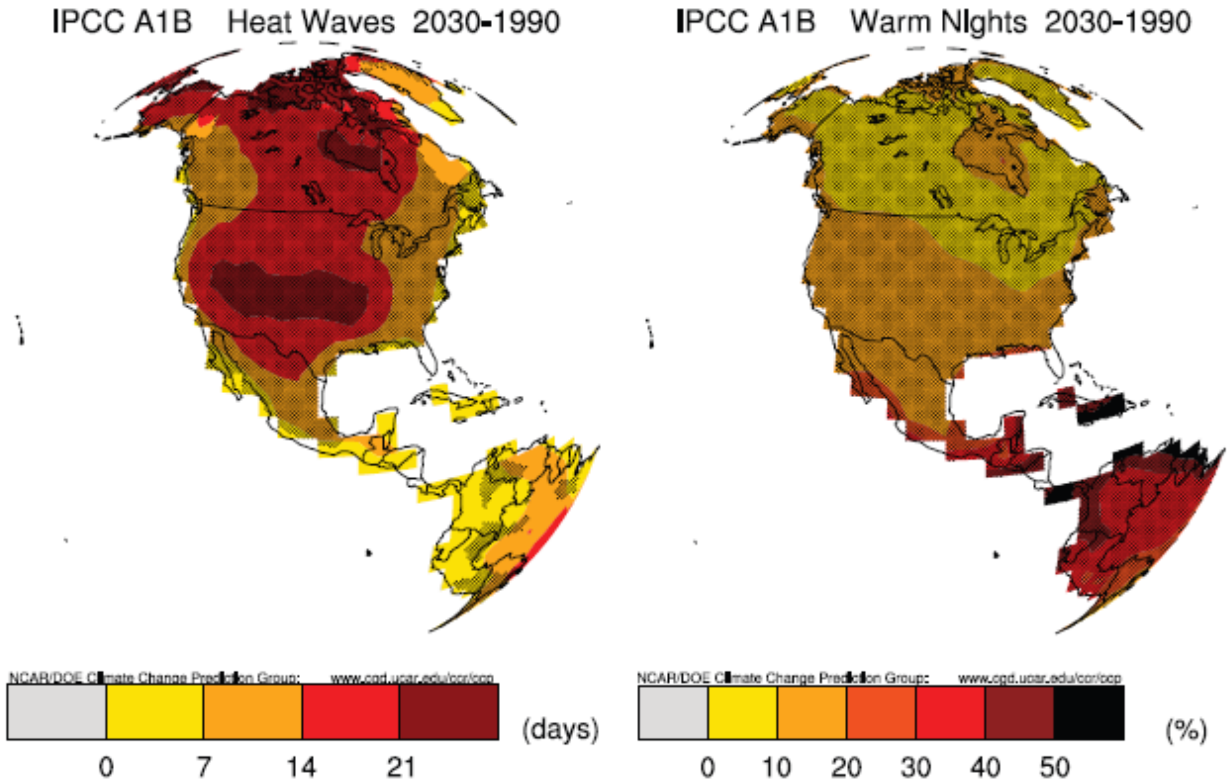


Figure 1.6 Simulated U.S. Heat Wave Days and Warm Nights in 2030. The left panel shows the projected change in number of heat wave days (days with maximum temperature higher by at least 5°C (with respect to the climatological norm)). The right panel shows changes in warm nights (percent of times when minimum temperature is above the 90th percentile of the climatological distribution for that day). Both panels show results for IPCC emissions scenario A1B, which would increase the atmospheric concentration of greenhouse gases to about 700 parts per million by 2100 (this is roughly double the pre-industrial level). The changes are shown as the difference between two 20-year averages (2020-2040 minus 1980-1999). Shading indicates areas of high inter-model agreement. These results are based on simulations from nine different climate models from the IPCC AR4 multi-model ensemble. The simulations were created on supercomputers at research centers in France, Japan, Russia, and the United States. Adapted by Lawrence Buja and Julie Arblaster from Tebaldi et al. 2006: *Climatic Change*, Going to the extremes; An intercomparison of model-simulated historical and future changes in extreme events, *Climatic Change*, 79:185-211.

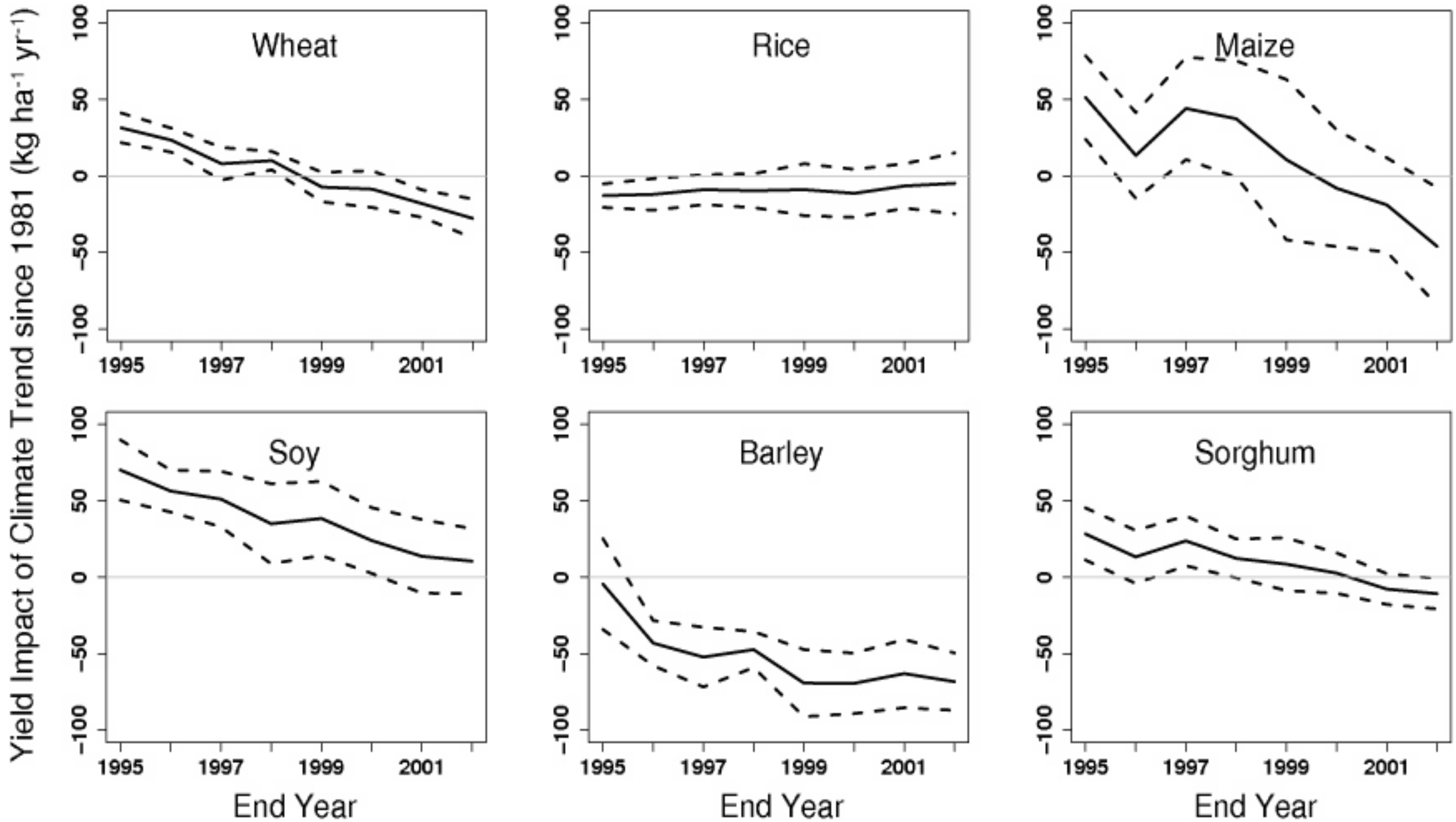
Table 2.3. For several economically significant crops, information is provided regarding cardinal, base, and optimum temperatures (°C) for vegetative development and reproductive development, optimum temperature for vegetative biomass, optimum temperature for maximum grain yield, and failure (ceiling) temperature at which grain yield fails to zero yield. The optimum temperatures for vegetative production, reproductive (grain) yield, and failure point temperatures represent means from studies where diurnal temperature range was up to 10°C.

Crop	Base Temp Veg	Opt Temp Veg	Base Temp Repro	Opt Temp Repro	Opt Temp Range Veg Prod	Opt Temp Range Reprod Yield	Failure Temp Reprod Yield
Maize	8[1]	34[1]	8[1]	34[1]		18-22[2]	35[3]
Soybean	7[4]	30[4]	6[5]	26[5]	25-37[6]	22-24[6]	39[7]
Wheat	0[8]	26[8]	1[8]	26[8]	20-30[9]	15[10]	34[11]
Rice	8[12]	36[13]	8[12]	33[12]	33[14]	23-26[13,15]	35-36[13]
Sorghum	8[16]	34[16]	8[16]	31[17]	26-34[18]	25[17,19]	35[17]
Cotton	14[20]	37[20]	14[20]	28-30[20]	34[21]	25-26[22]	35[23]
Peanut	10[24]	>30[24]	11[24]	29-33[25]	31-35[26]	20-26[26,27]	39[26]
Bean					23[28]	23-24[28,29]	32[28]
Tomato	7[30]	22[30]	7[30]	22[30]		22-25[30]	30[31]

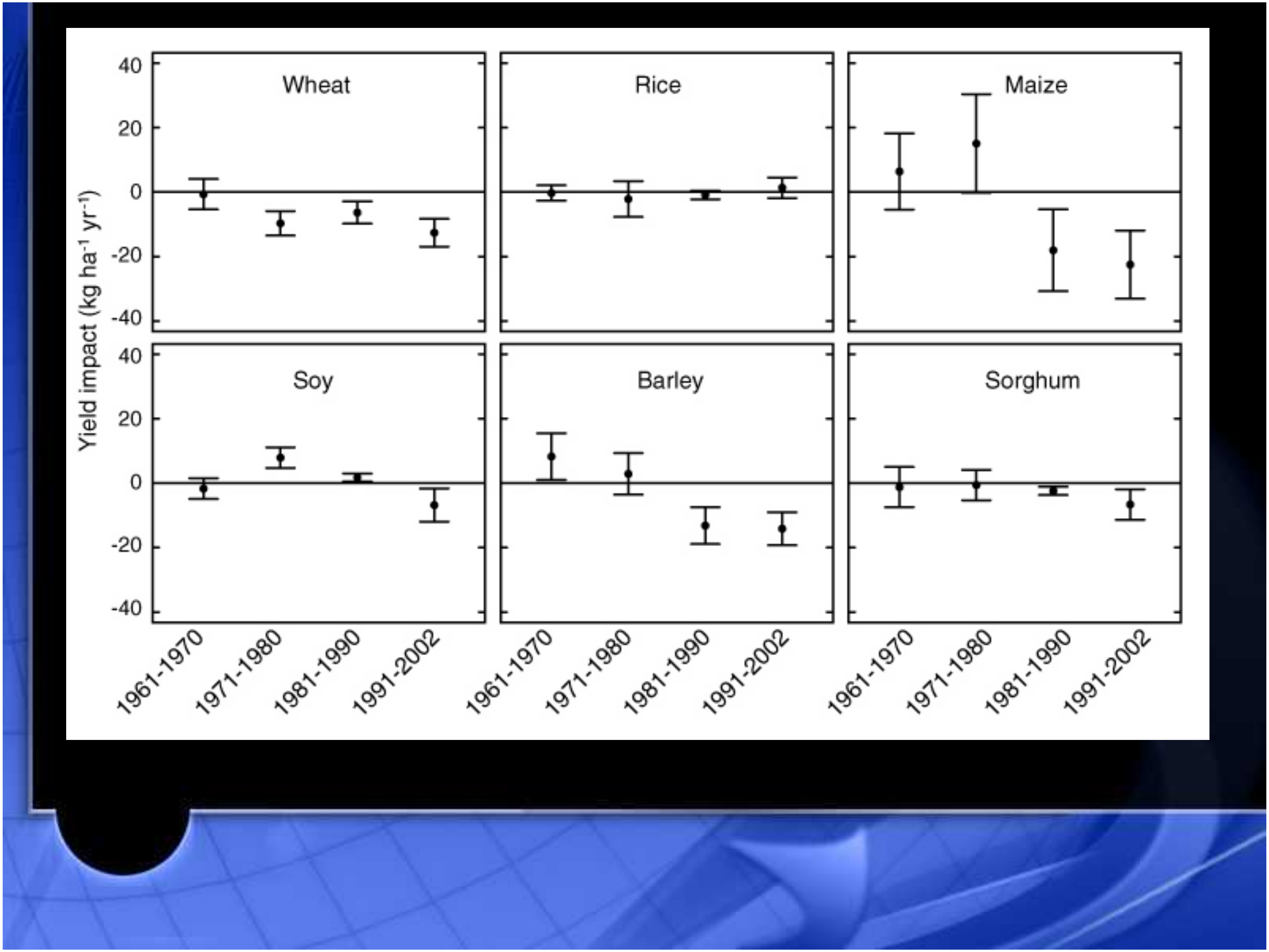
[1]Kiniry and Bonhomme (1991):, [2]Muchow et al. (1990); [3]Herrero and Johnson (1980); [4]Hesketh et al. (1973); [5]Boote et al. (1998); [6]Boote et al. (1997); [7]Boote et al. (2005); [8]Hodges and Ritchie (1991); [9]Kobza and Edwards (1987); [10]Chowdury and Wardlaw (1978); [11]Tashiro and Wardlaw (1990); [12]Alocilja and Ritchie (1991); [13]Baker et al. (1995); [14]Matsushima et al. (1964); [15]Horie et al. (2000); [16]Alagarswamy and Ritchie 1991); [17]Prasad et al. (2006a); [18]Maiti (1996); [19]Downs (1972); [20]K.R. Reddy et al. (1999, 2005); [21]V.R. Reddy et al. (1995); [22]K.R. Reddy et al. (2005); [23]K.R. Reddy et al. (1992a, 1992b); [24]Ong (1986); [25]Bolhuis and deGroot (1959); [26]Prasad et al. (2003); [27]Williams et al. (1975); [28]Prasad et al. (2002); [29]Laing et al. (1984); [30]Adams et al. (2001); [31]Peat et al. (1998).

Agriculture: Impacts of Climate Change

- New studies show an increase in temperature by 1^{o} C will decrease yields for rice (Asia, Africa) maize and soybeans (North America, Latin America) by 11-17%
- These data are empirical: this is happening now, and will continue into the future
- A decade of agricultural research wiped out



Yield Impact of Climate Trend since 1981 (kg ha-1 yr-1)
Wheat
Rice
Maize
Soy
Barley
Sorghum
100
50
0
-50
-100
1995
1997
1999
2001
End Year

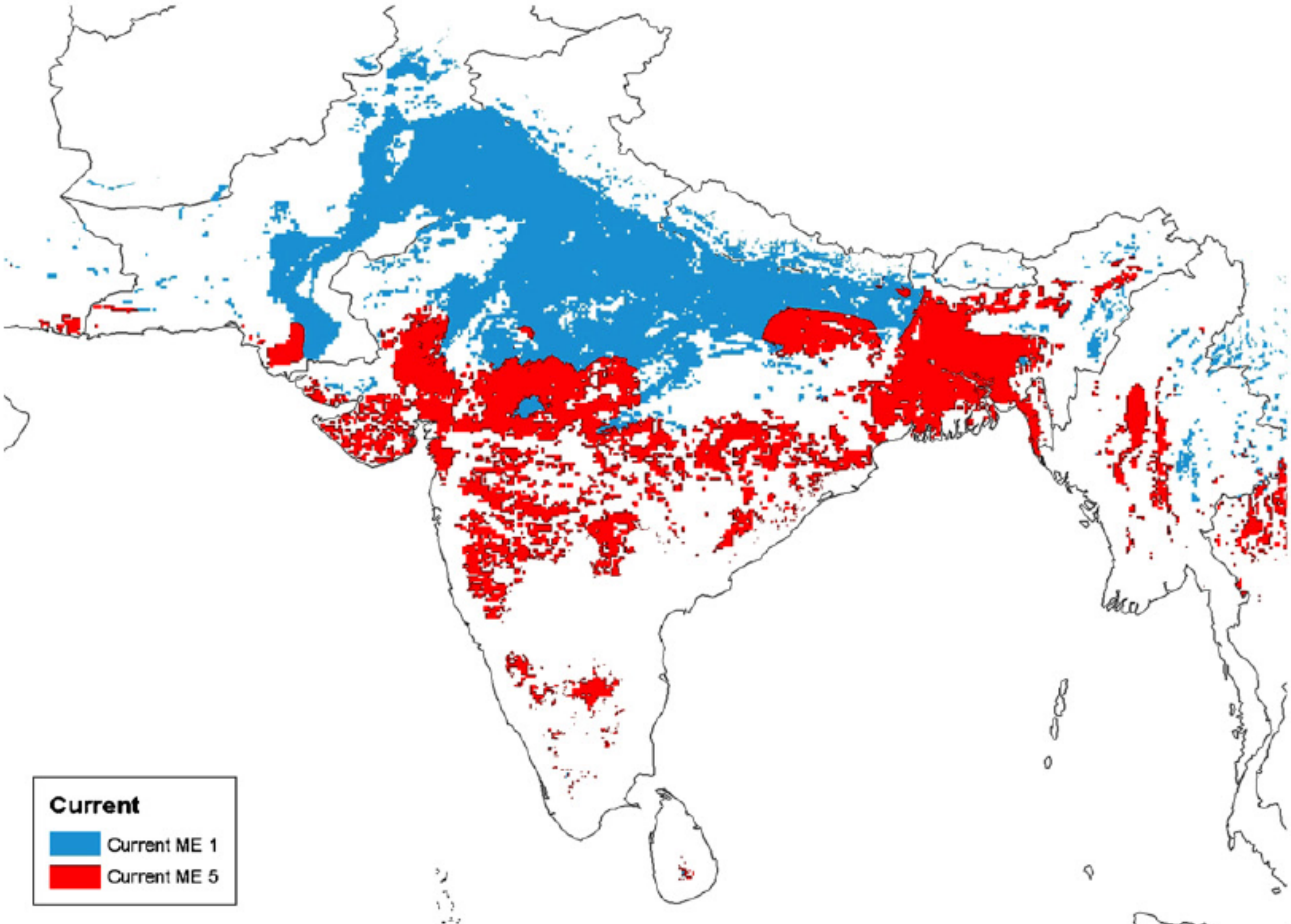


Wheat
Rice
Maize
Soy
Barley
Sorghum
Yield impact (kg ha⁻¹ yr⁻¹)
40
20
0
-20
-40
1961-1970
1971-1980
1981-1990
1991-2002

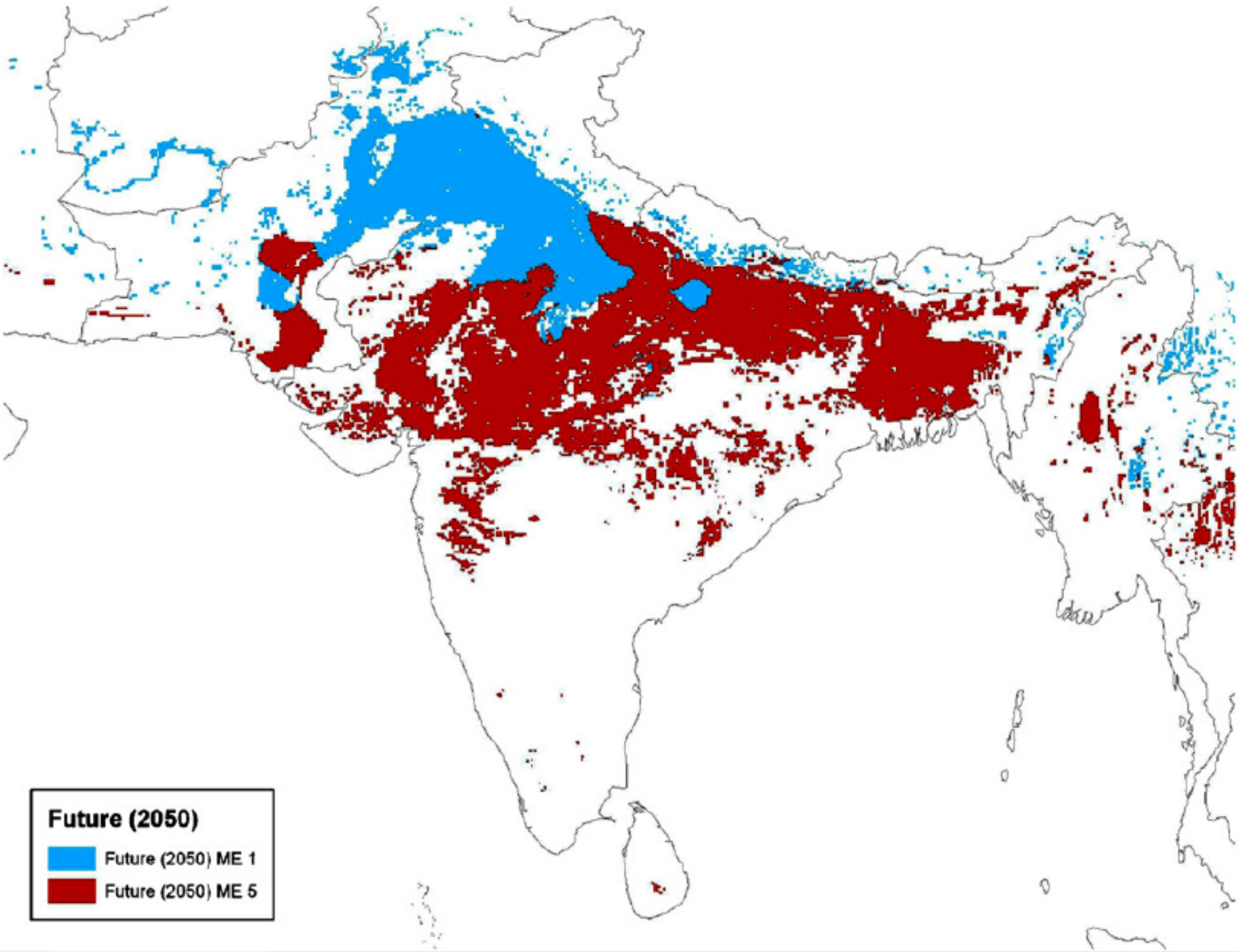
Table 2. Global area, production and yield changes for six major crops.

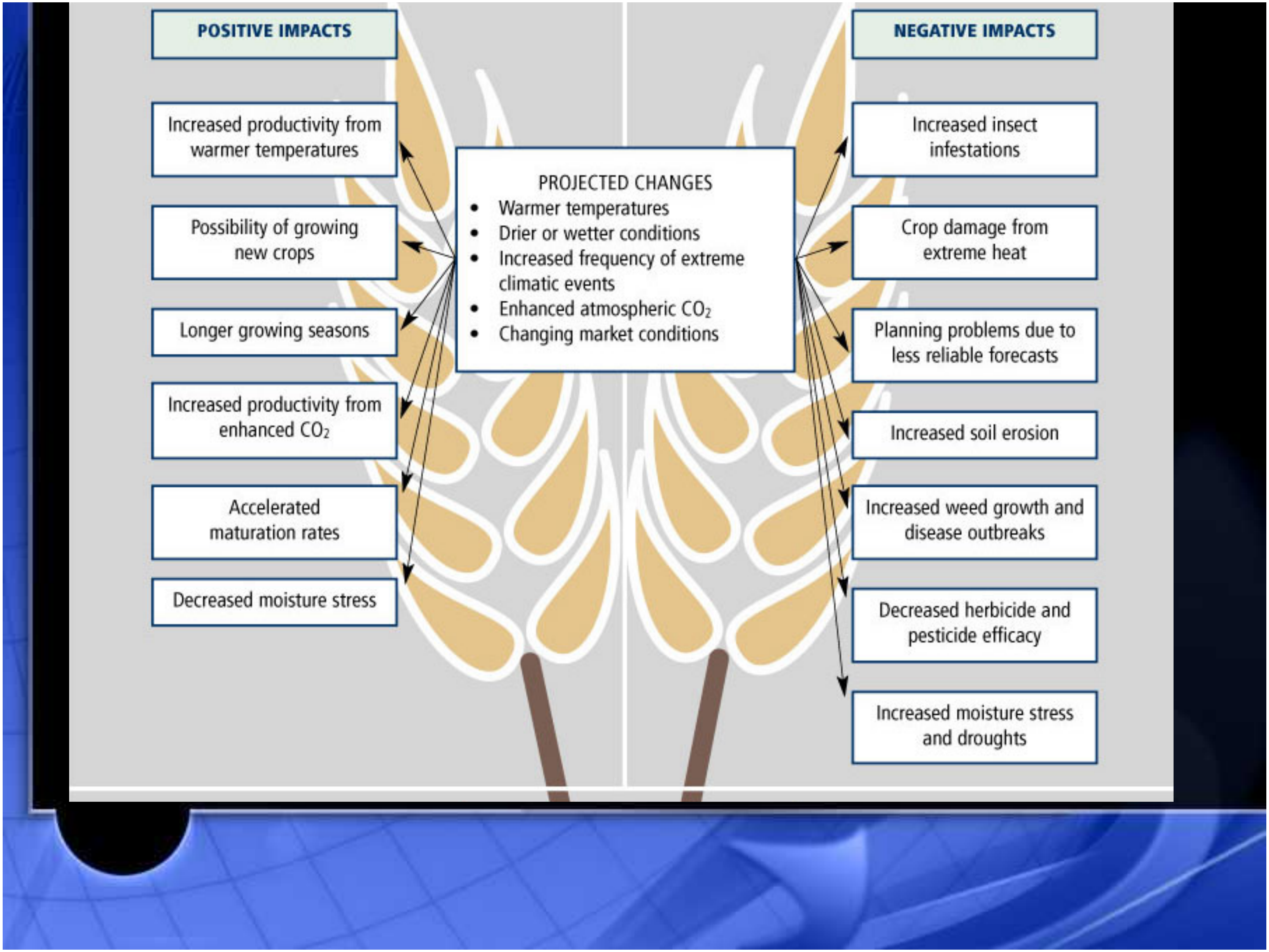
	Wheat	Rice	Maize	Soybean	Barley	Sorghum
2002 Area (Mha)	214	148	139	79	55	42
2002 Production (Mt yr^{-1})	574	578	602	181	137	54
Yield change, 1981–2002 (kg ha^{-1})	846	1109	1178	632	473	−80
Climate-driven yield change, 1981–2002 (kg ha^{-1})	−88.2	−10.5	−90.3	23.1	−144.9	−19.5
Climate-driven production change, 1981–2002 (Mt yr^{-1})	−18.9	−1.6	−12.5	1.8	−8.0	−0.8

(a) Current



(b) Future




POSITIVE IMPACTS
Increased productivity from warmer temperatures
Possibility of growing new crops
Longer growing seasons
Increased productivity from enhanced CO_2
Accelerated maturation rates
Decreased moisture stress
PROJECTED CHANGES
• Warmer temperatures
• Drier or wetter conditions
• Increased frequency of extreme climatic events
• Enhanced atmospheric CO_2
• Changing market conditions
NEGATIVE IMPACTS
Increased insect infestations
Crop damage from extreme heat
Planning problems due to less reliable forecasts
Increased soil erosion
Increased weed growth and disease outbreaks
Decreased herbicide and pesticide efficacy
Increased moisture stress and droughts