Impact of Climate Change on Crops

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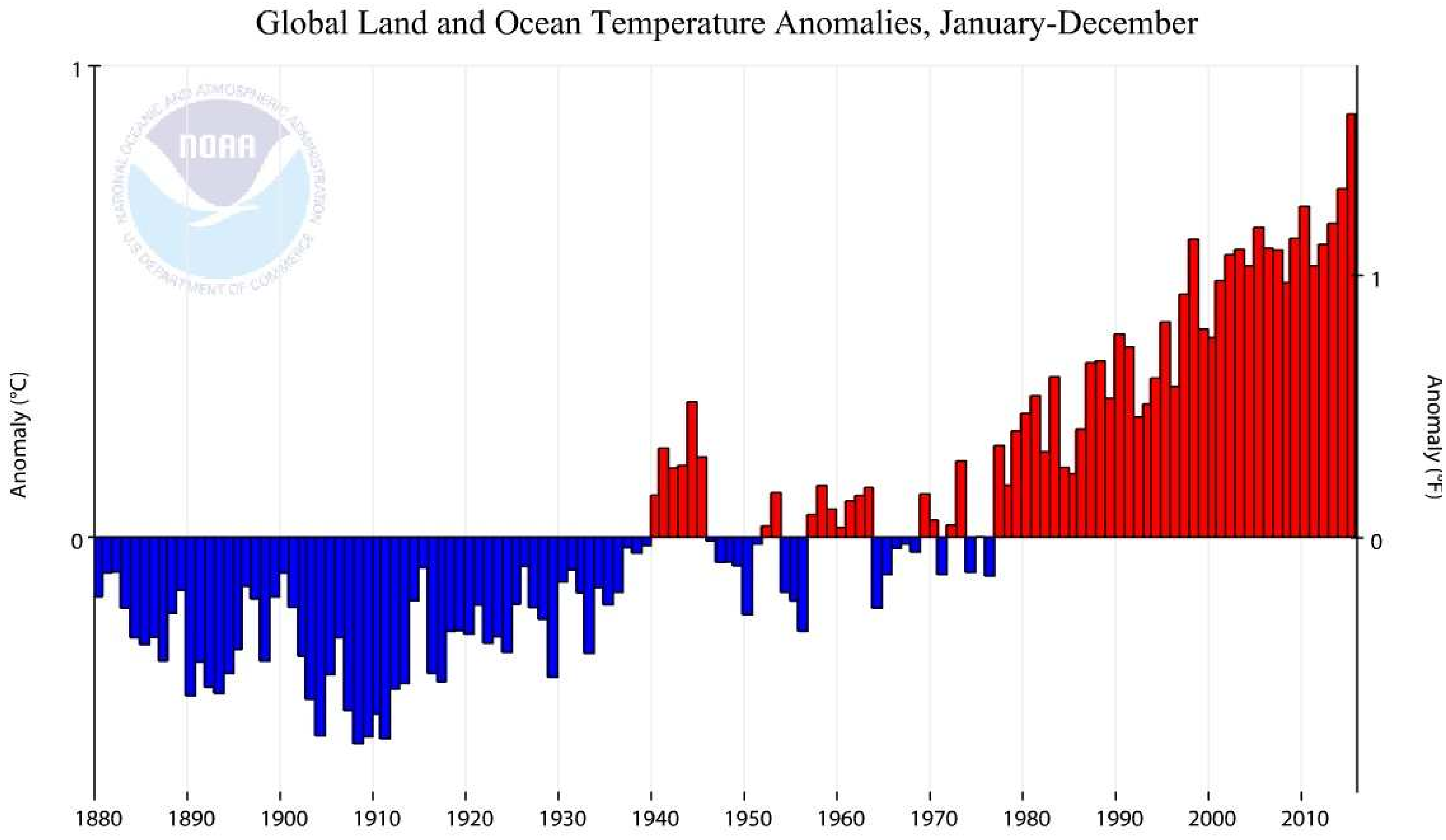
Julius Kühn-Institut (JKI)

- Julius Kühn (1825-1910) is one of the forefathers of agronomic research in Germany (phytomedicine)
- Federal Research Centre for Cultivated Plants
- 17 Institutes; >300 Scientists
- Ensure current and future food security
- Develop integrated concepts for plant cultivation

Impact of CC on crops

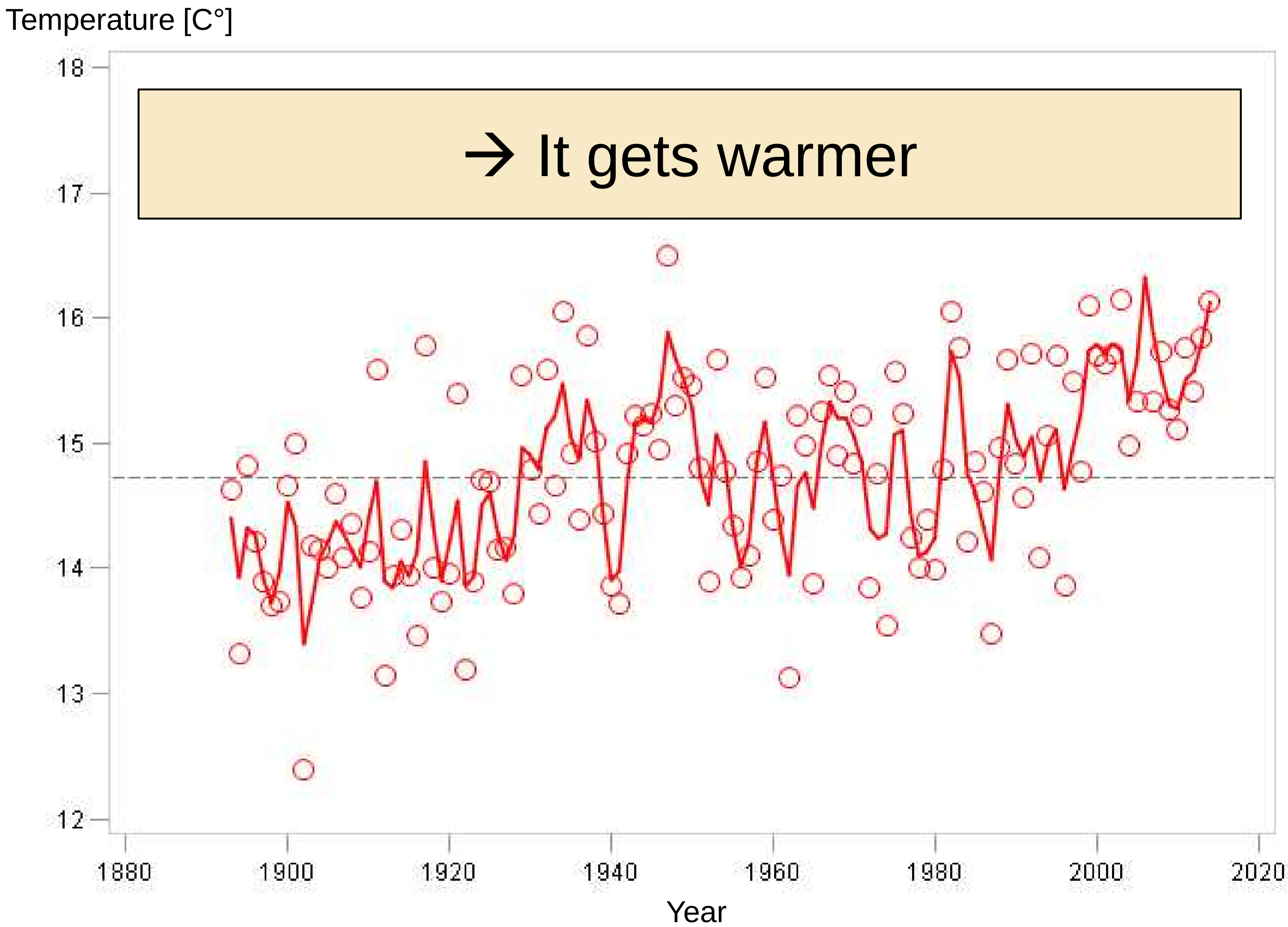
- There is no single answer
  - Variety of crops
  - Regional differences in CC
  - Interactions of different components of CC within the plant-soil-athmosphere continuum

Climate change is evident



NOAA, 2015

Climate change is evident



Reference line:
Average T 1961-90

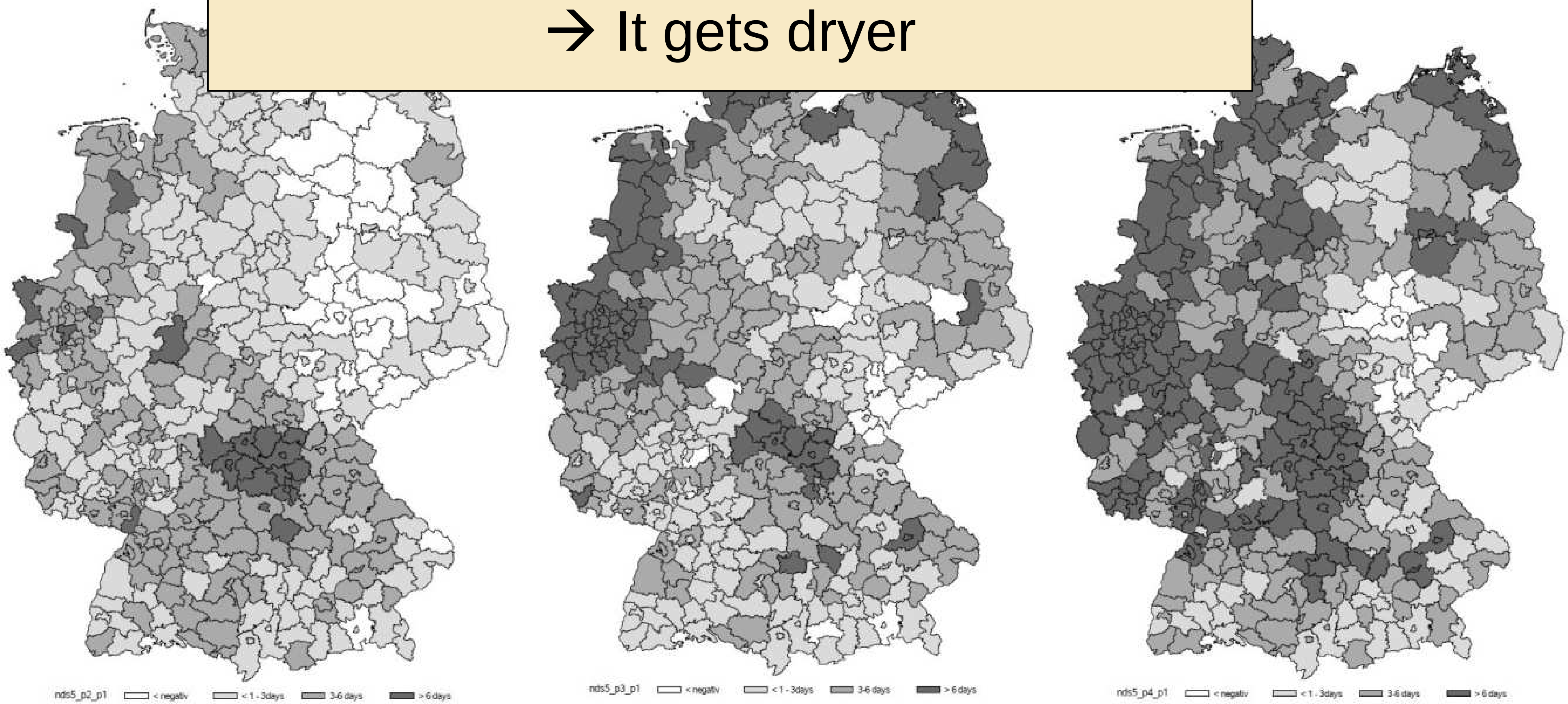
Average temperature during summer (April-October) in Potsdam, Germany during 1893-2014

Lüttger et al., 2015

Climate change is evident

1931-6 | | 010 vs. 1901-30

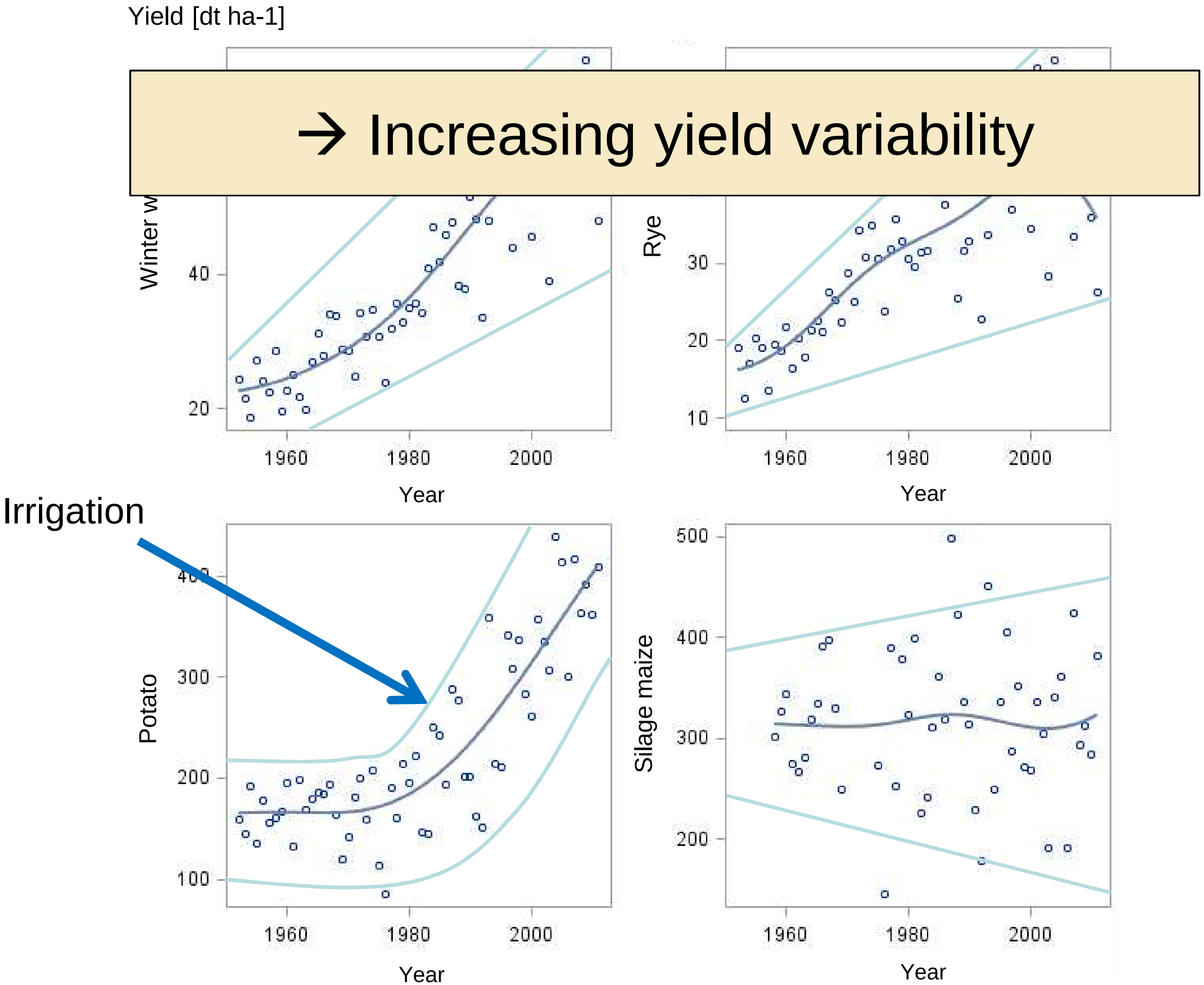
→ It gets dryer



Difference in the average number of precipitation free days longer than five days compared to the reference period 1901-1930

Lüttger & Feike, 2016

Climate change impact



County level yield development in Teltow-Fläming, NE-Germany

Lüttger et al., 2015

Climate change is evident

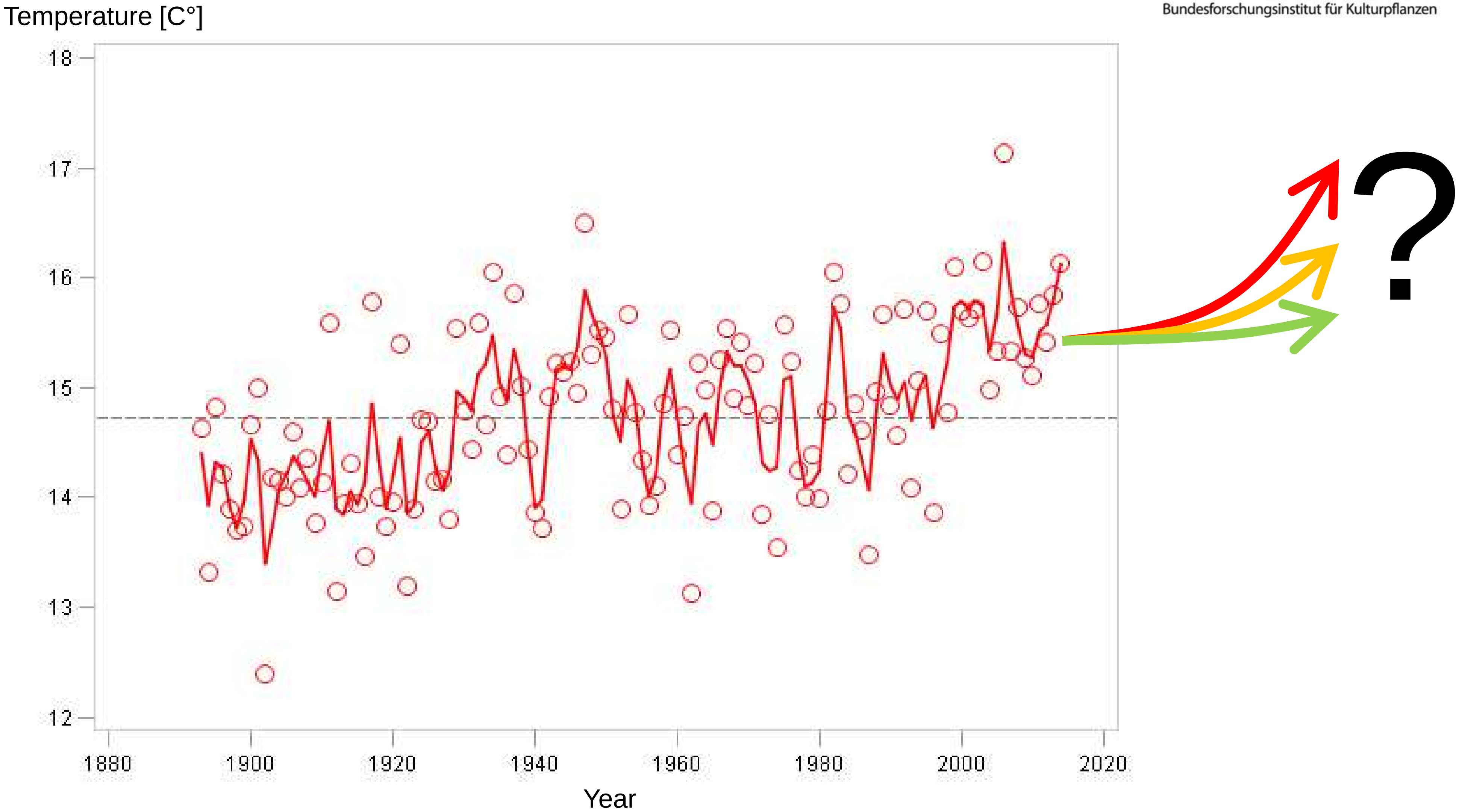
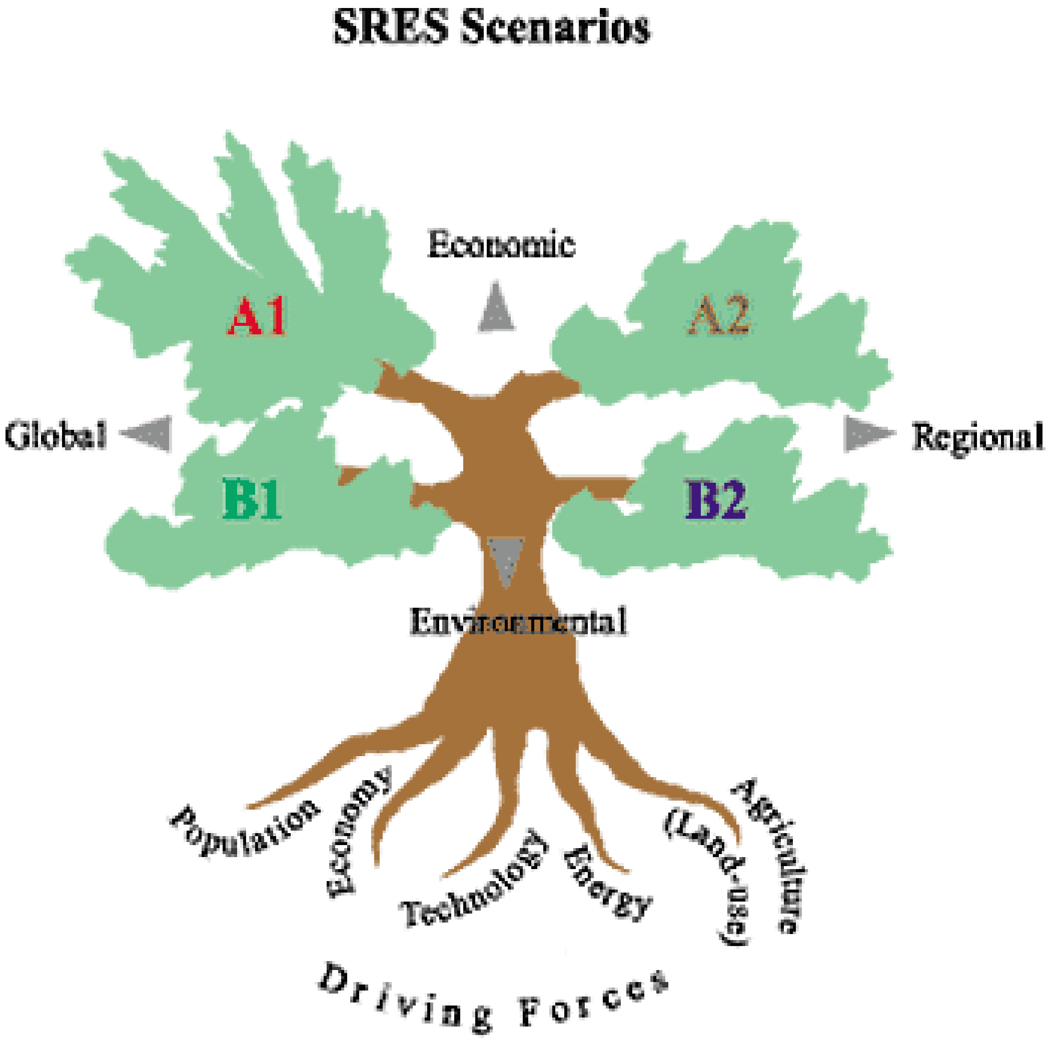


Fig. 1. Average temperature during summer (April-October) in Potsdam, Germany during 1893-2014

Lüttger et al., 2015

Future climate projections

➢ GHG emissions driven by future developments



IPCC, 2001

Future climate projections

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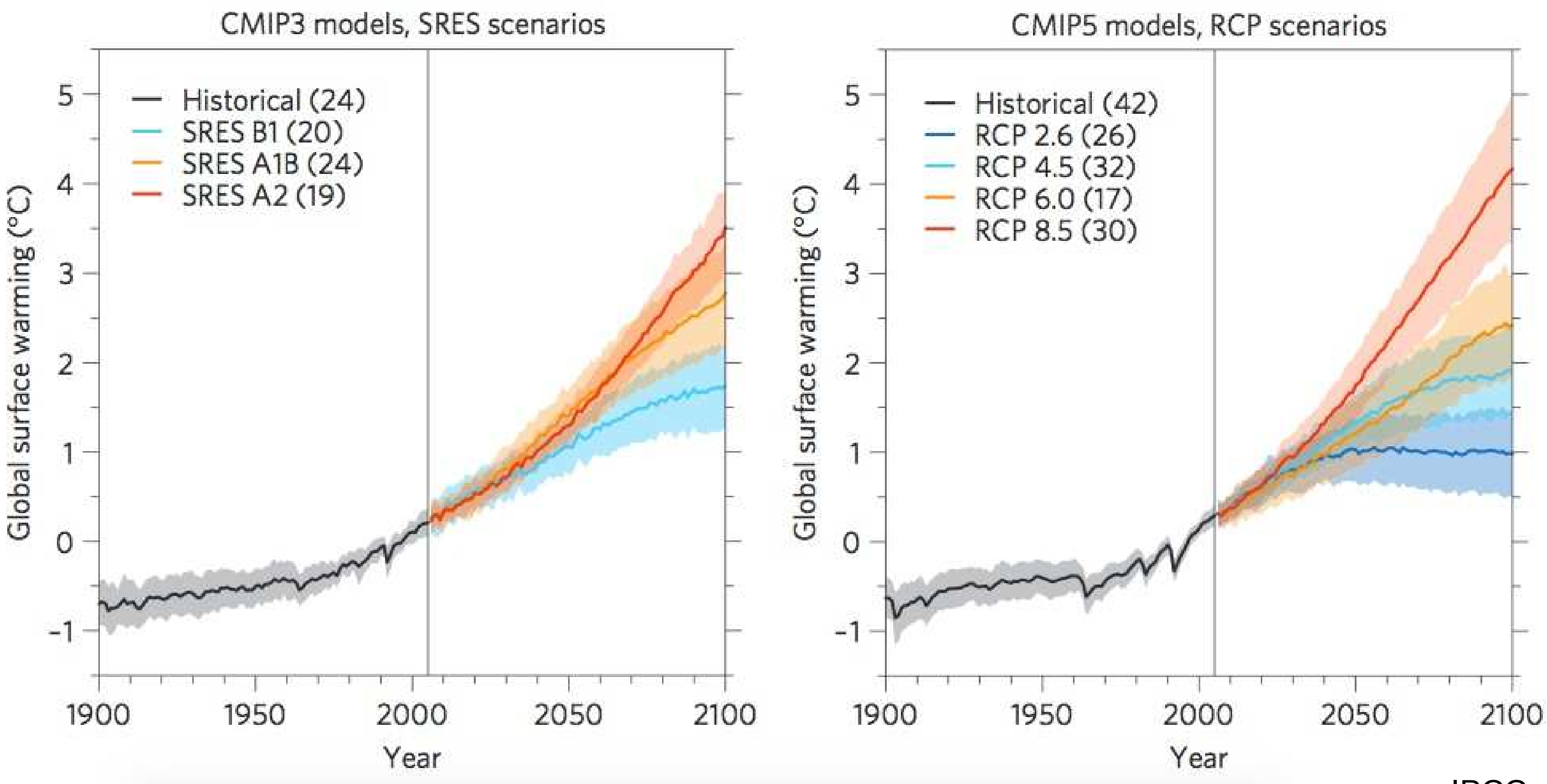
Bundesforschungsinstitut für Kulturpflanzen

Emissions Scenarios of the Special Report on Emissions Scenarios (SRES). Used in the IPCC 3rd Assessment Report (2001) and Assessment Report 4 (2007).		
A1. Rapid economic growth	**A1FI.** Emphasis on fossil fuels **A1B.** Balanced energy sources **A1T.** Emphasis non-fossil fuels	• Global population peaks in mid-century, then declines • Rapid introduction of new and more efficient technologies • Convergence among regions, capacity building and increased cultural and social interactions • Substantial reduction in regional differences in per capita income
A2. Heterogeneous world		• Self-reliance and preservation of local identities • Continuously increasing population • Per capita economic growth and technological change fragmented and slow
B1. Convergent world		• Same global population growth pattern as in the A1 storyline • Rapid change in economic structures toward a service and information economy • Reductions in material intensity • Introduction of clean and resource-efficient technologies • No additional climate initiatives
B2. Local solutions		• Continuously increasing global population, at a rate lower than A2 • Intermediate levels of economic development • Slower and more diverse technological change than A1 and B1 storylines.

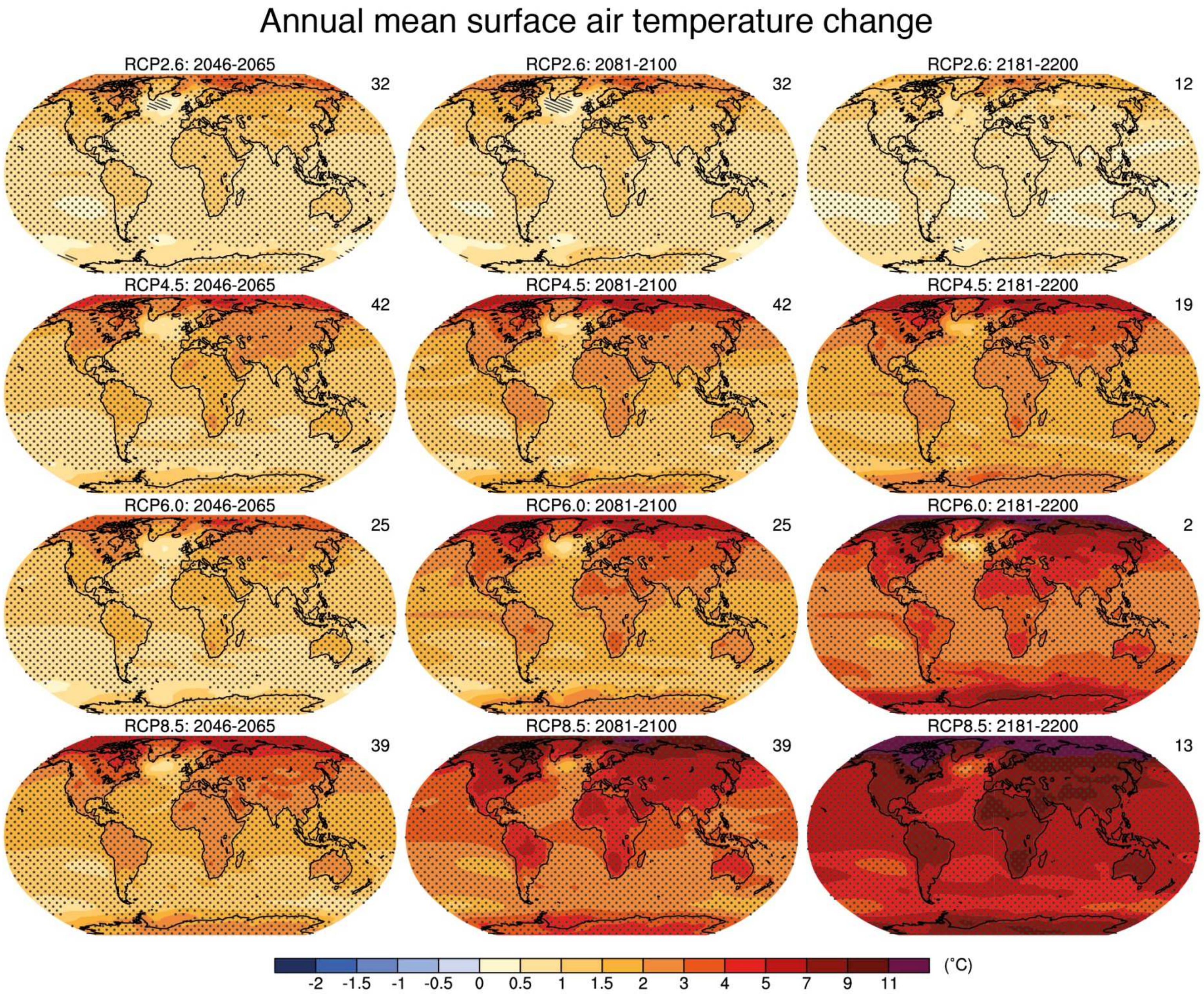
Future climate projections

IPCC Representative Concentration Pathways (RCPs). Used in IPCC Assessment Report 5 (2014).	
RCP 2.6	Global annual GHG emissions (measured in CO_2-equivalents) peak between 2010-2020, with emissions declining substantially thereafter
RCP 4.5	Emissions peak around 2040, then decline
RCP 6	Emissions peak around 2080, then decline
RCP 8.5	Emissions continue to rise throughout the 21st century



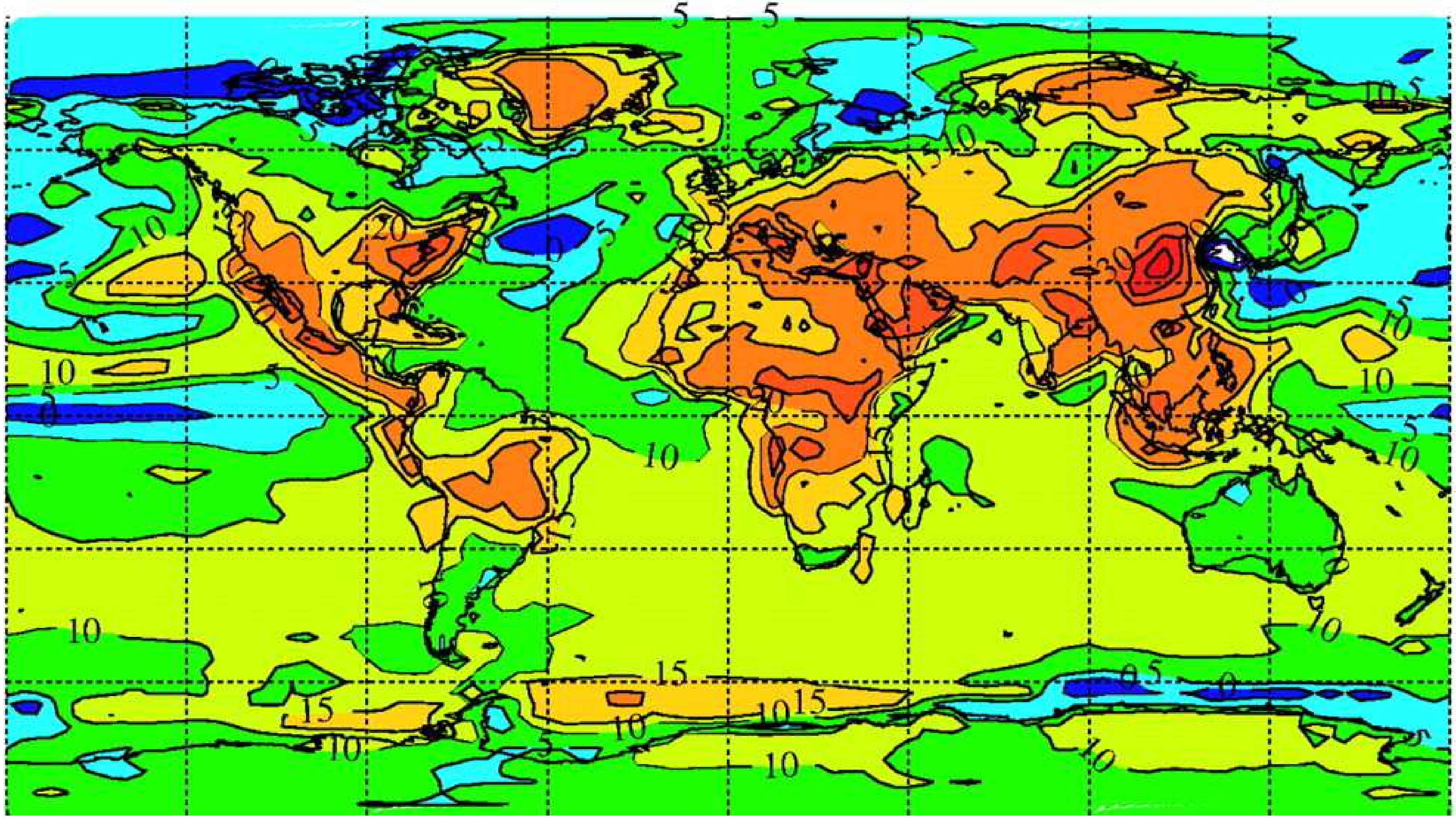
IPCC, 2007 & 2014

Temperature development



IPCC, 2014

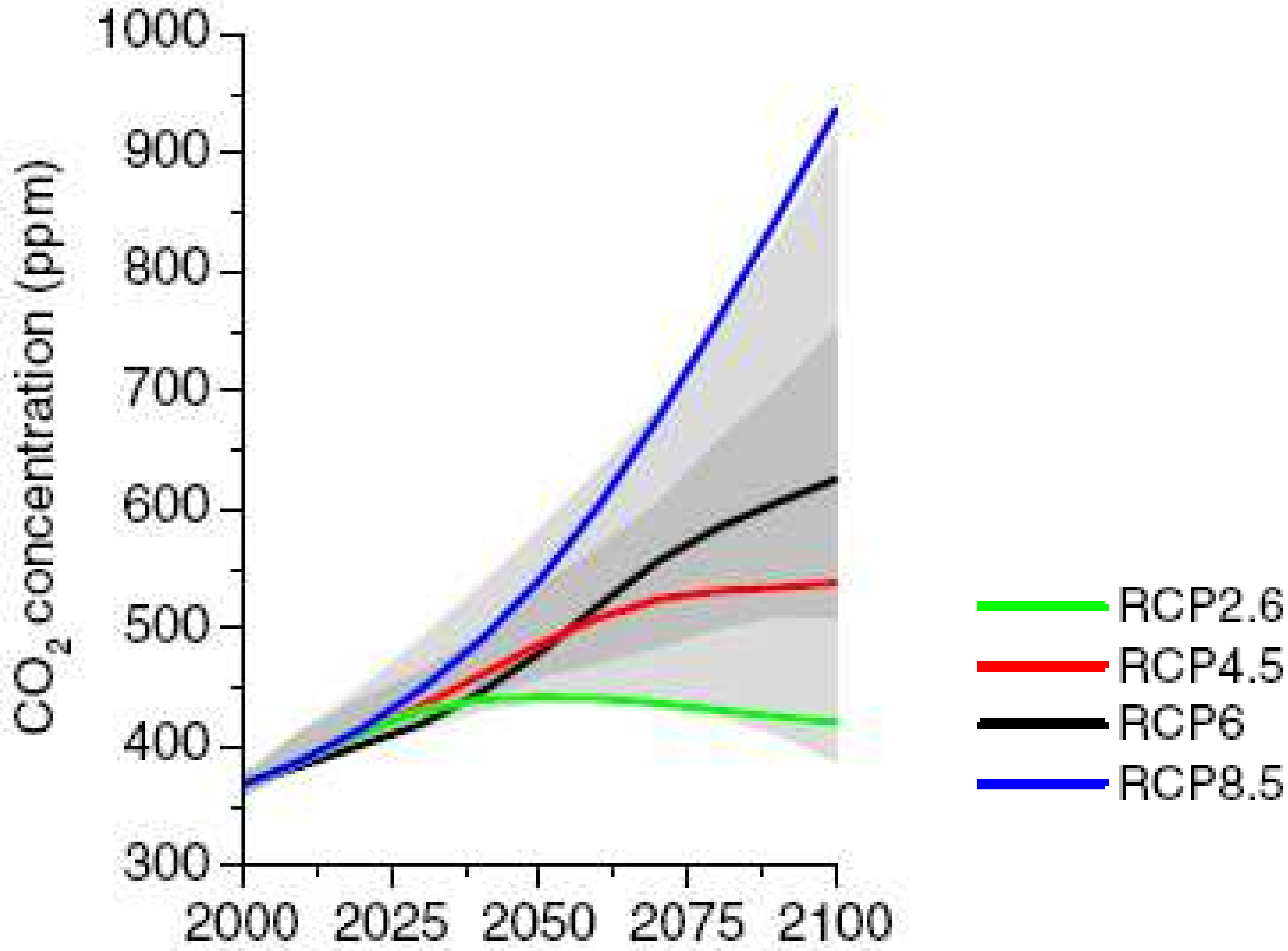
Surface-O_3 development



Projected difference in July mean surface ozone concentrations (ppbv) between 2000 and 2100

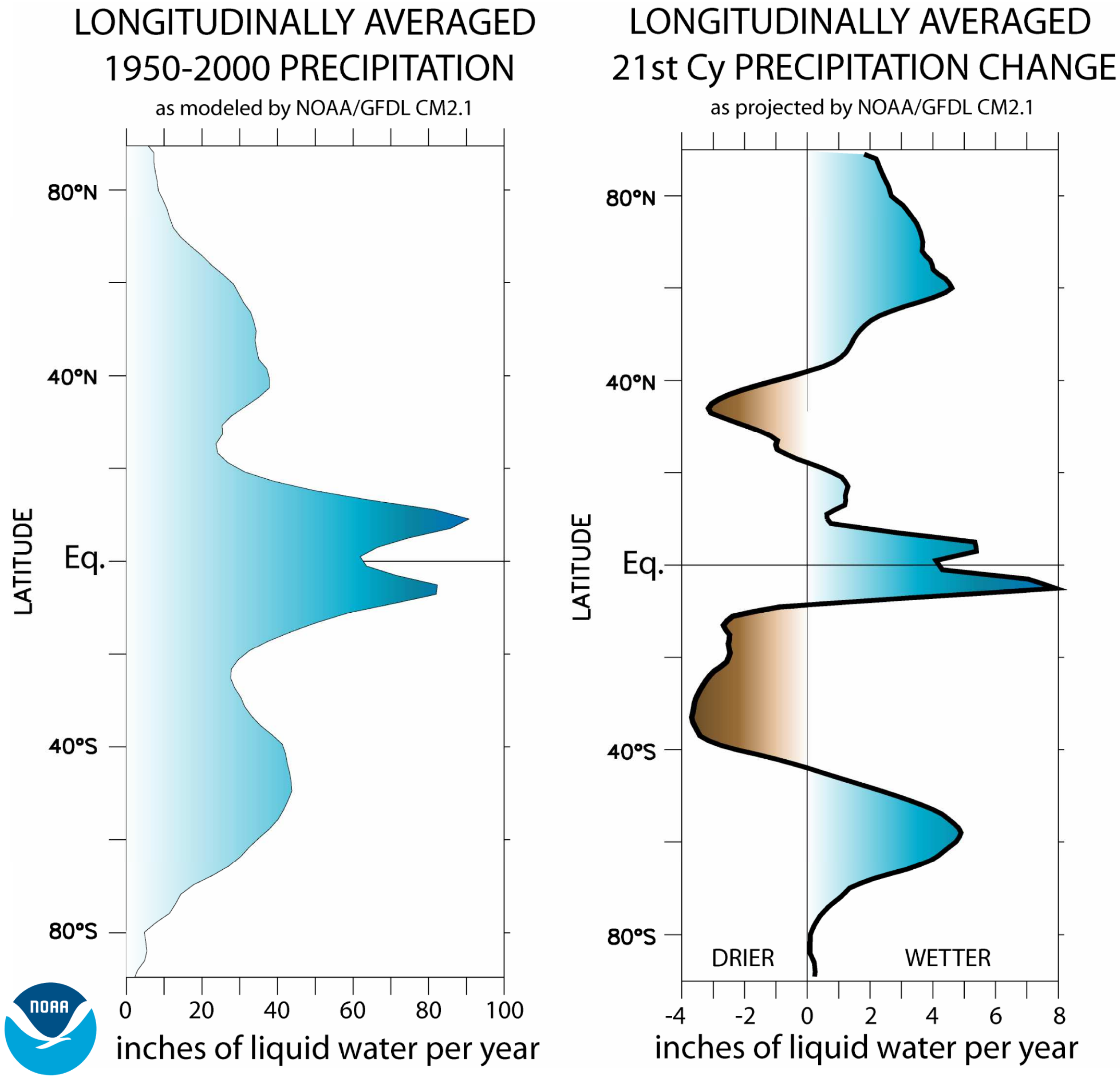
Pyle et al., 2007

CO_2-concentration development



IPCC, 2014

Precipitation development



NOAA, 2013

Climate change impact research

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Bundesforschungsinstitut für Kulturpflanzen

- Future climate projections
- Experimental approaches to understand/define crop reactions
- Historic data analysis + statistical models
- Process-based crop models

Climate change impact research

Temporal aspects of CC

- E.g. increase in average T by 2°C
- Daily: daytime (Max) and/or nighttime (Min)
- Seasonal: e.g. warmer winters and/or warmer summers
- Interannual: continuous increase vs. increased variability

→ Impact studies require long-term assessment

e.g. 20 years

CC impact on crop production

- Temperature increase (Mean & Max)
- Surface ozone increase
- CO_2-level increase
- Increasing variability and extreme events
    - Increasing maximum temperatures & heat stress
    - Precipitation – drought, floods, water logging, field inaccessibility

CC impact assessment

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- Experimental facilities:
  - Climate chambers
  - Climatrons, Terracosms, Ecotrons, etc

Images: Terracosm, OSU; Macrocosms: CNRS

CC impact assessment

- Experimental facilities:
  - Climate chambers
  - Climatrons, Terracosms, Ecotrons, etc
  - FACE – Free Air Carbon Dioxide Enrichment
  - + Rain-out shelters
  - + Infra-red heating

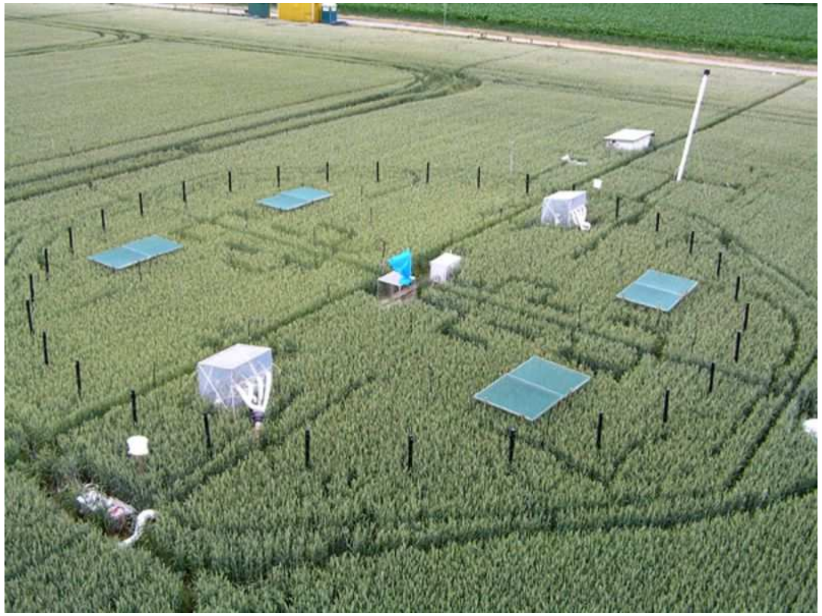
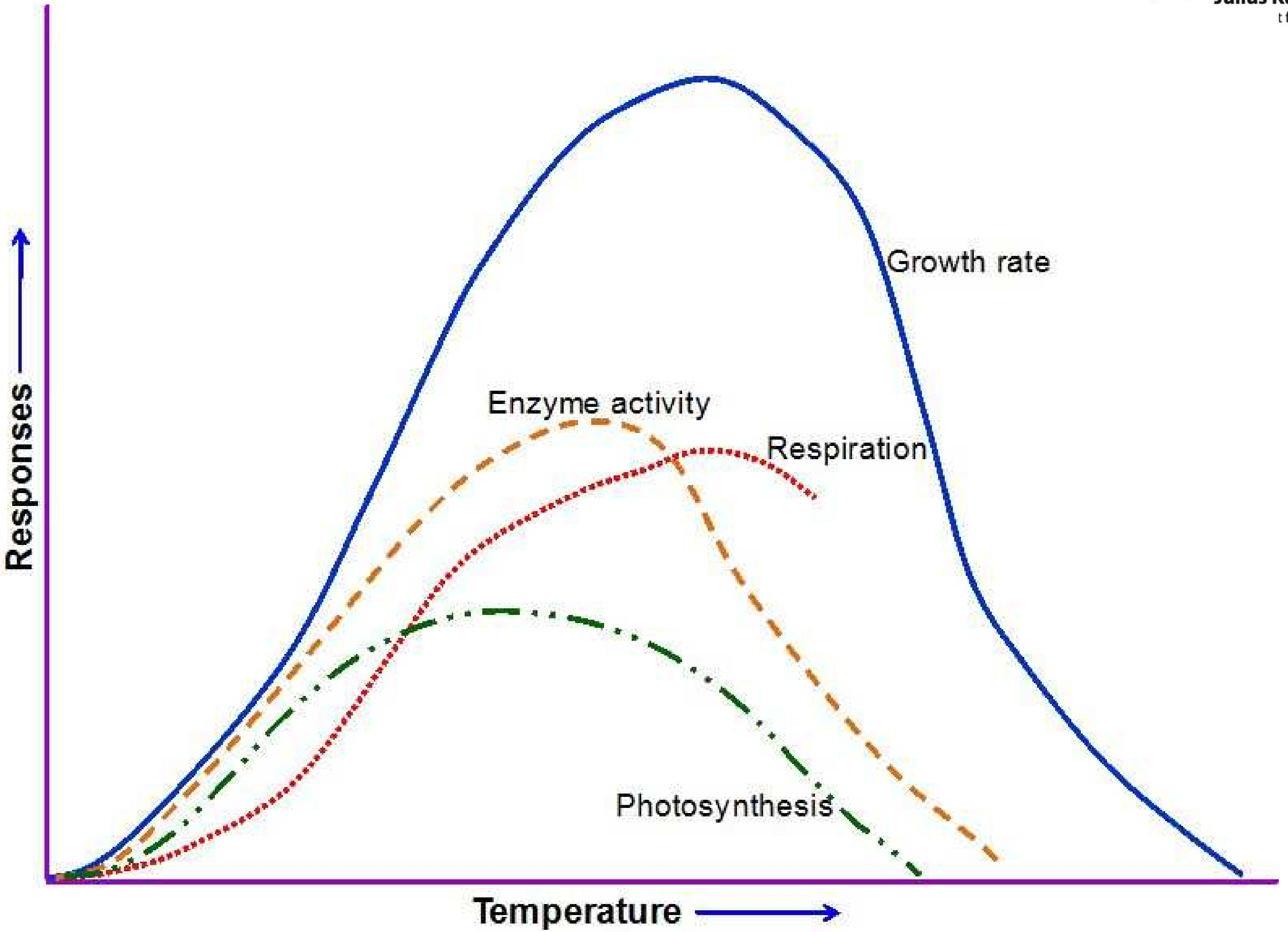


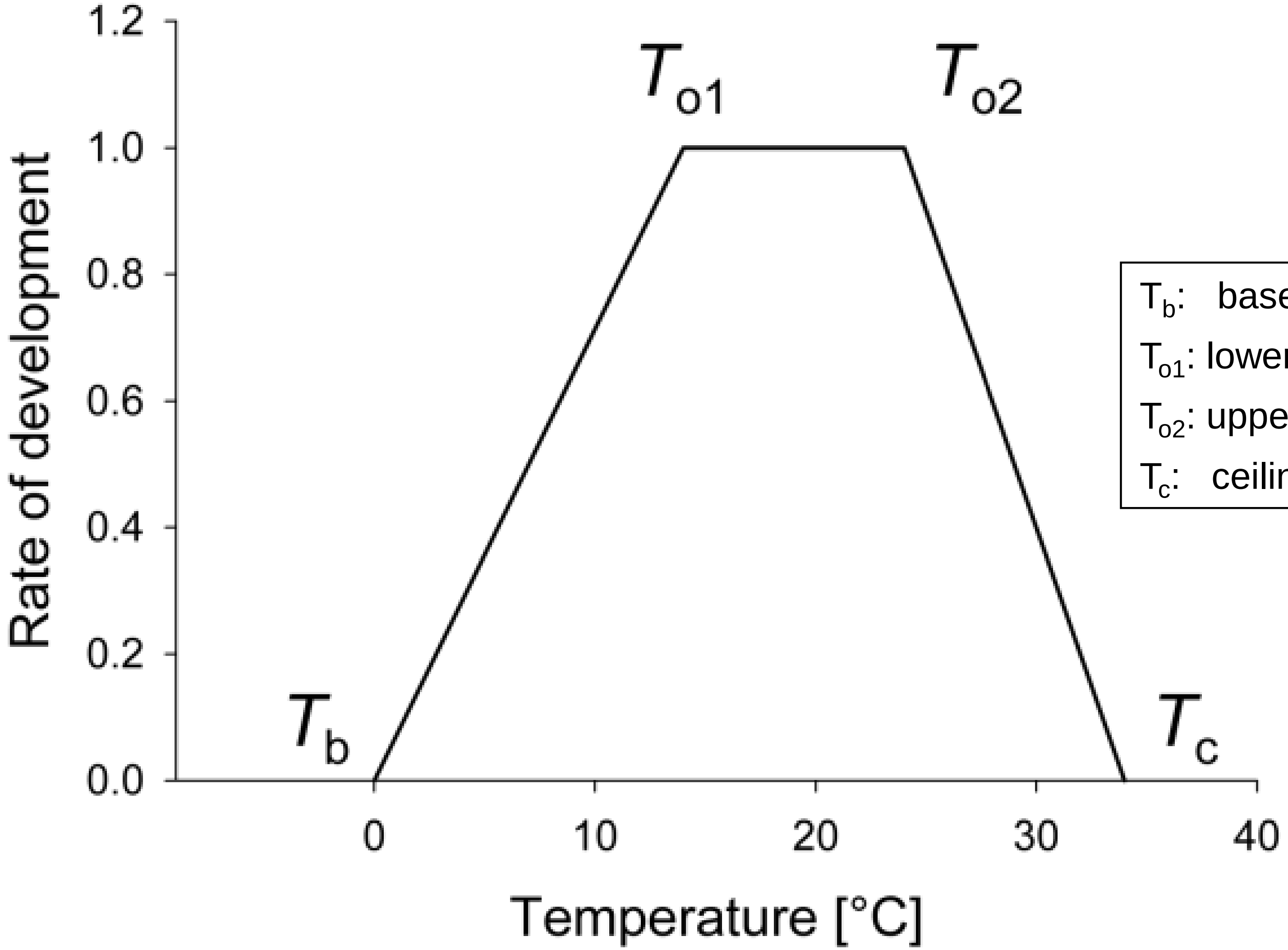
Image: Thünen Institut

Cardinal temperatures



Hasanuzzaman et al., 2011

Cardinal temperatures



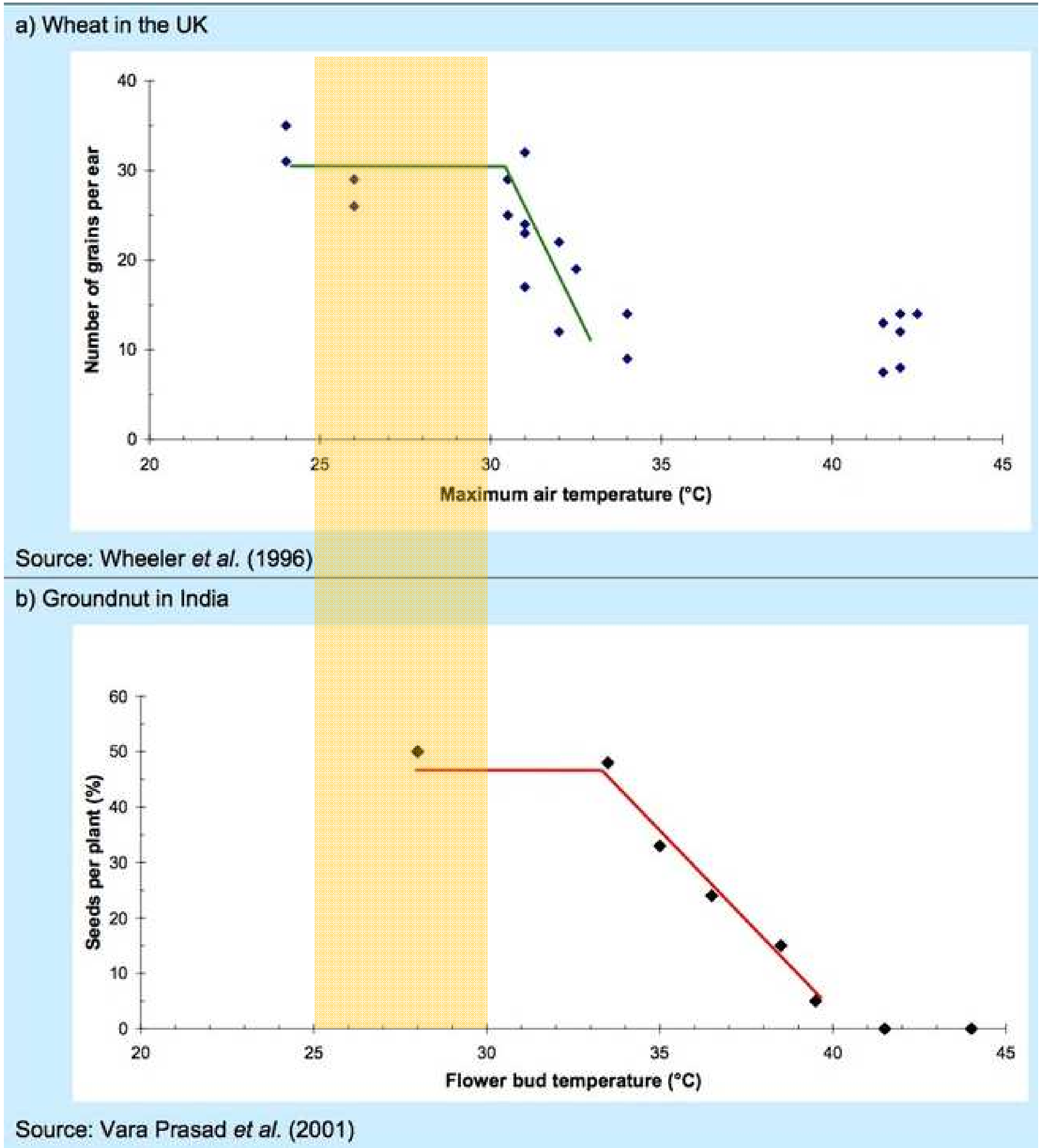
T_b: base temperature

T_{o1}: lower optimum temperature

T_{o2}: upper optimum temperature

T_c: ceiling temperature

Cardinal temperatures



Cardinal temperatures

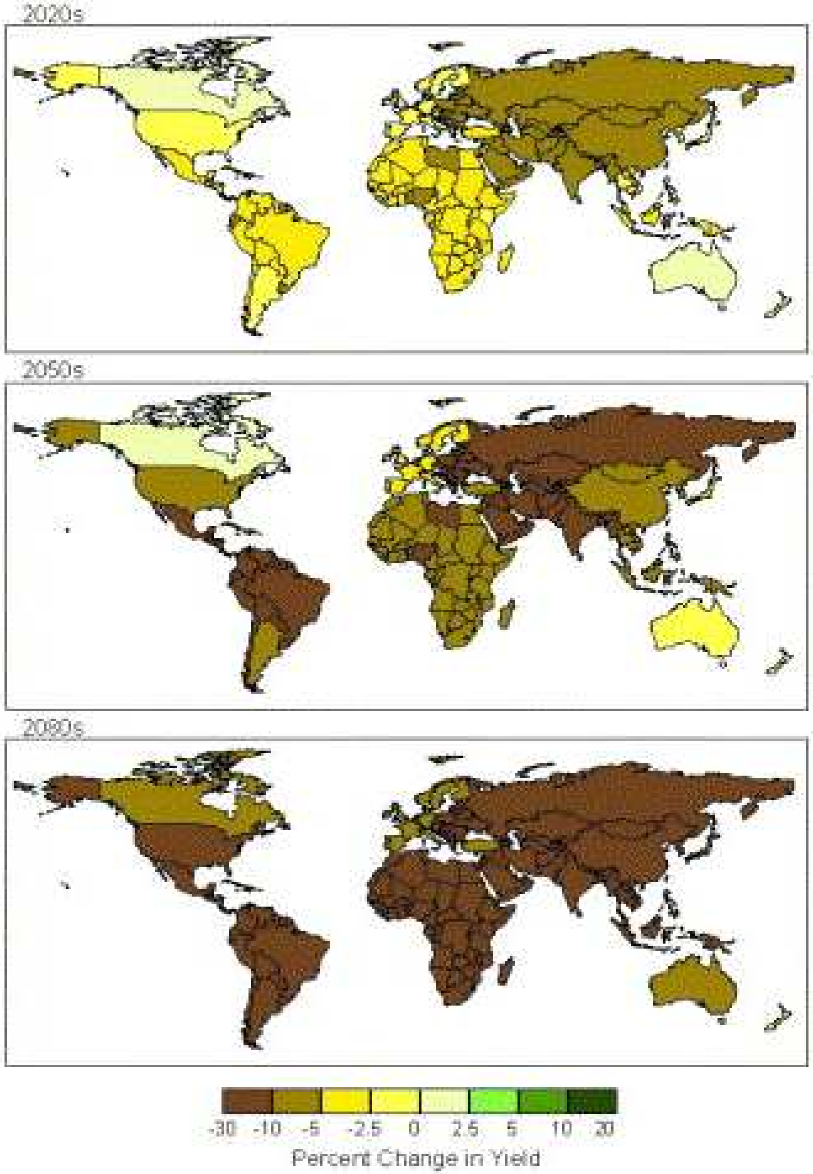
Table 2. Cardinal base and optimum temperatures (°C) for vegetative development and reproductive development, optimum temperature for vegetative biomass, optimum temperature for maximum grain yield, and failure (ceiling) temperature at which grain yield fails to zero yield, for economically important crops. The optimum temperatures for vegetative production, reproductive (grain) yield, and failure point temperatures represent mean temperatures 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†	34†	8†	34†		18-25‡	35§
Sorghum	8††††	34††††	8††††	31‡‡‡‡	26–34§§§§	25‡‡‡‡,¶¶¶¶	35‡‡‡‡
Bean					23#####	23–24#####,††††††	32#####
Cotton	14#####	37#####	14#####	28–30#####	34†††††	25–26‡‡‡‡‡	35§§§§§
Peanut	10¶¶¶¶¶						
Rice	8‡‡‡	36§§§	8‡‡‡	33‡‡‡	33¶¶¶	23–26§§§,####	35–36§§§
Soybean	7¶	30¶	6#	26#	25–37††	22–24††	39‡‡
Wheat	0§§	26§§	1§§	26§§	20–30¶¶	15##	34†††

† Kiniry and Bonhomme (1991), Badu-Apraku et al. (1983).
‡ Muchow et al. (1990).
§ Herrero and Johnson (1980).
¶ Hesketh et al. (1973).
# Boote et al. (1998).
†† Boote et al. (1997).
‡‡ Boote et al. (2005).
§§ Hodges and Ritchie (1991).
¶¶ Kobza and Edwards (1987).
Chowdhury and Wardlaw (1978).
††† Tashiro and Wardlaw (1990).
‡‡‡ Alocilja and Ritchie (1991).
§§§ Baker et al. (1995).
¶¶¶ Matsushima et al. (1964).
Horie et al. (2000).
†††† Alagarswamy and Ritchie (1991).
‡‡‡‡ Prasad et al. (2006a).
§§§§ Maiti (1996).
¶¶¶¶ Downs (1972).
K. R. Reddy et al. (1999, 2005).
††††† V. R. Reddy et al. (1995a).
‡‡‡‡‡ K. R. Reddy et al. (2005).
§§§§§ K. R. Reddy et al. (1992a, 1992b).
¶¶¶¶¶ Ong (1986).
Prasad et al. (2002).
†††††† Laing et al. (1984).

Hatfield et al., 2011

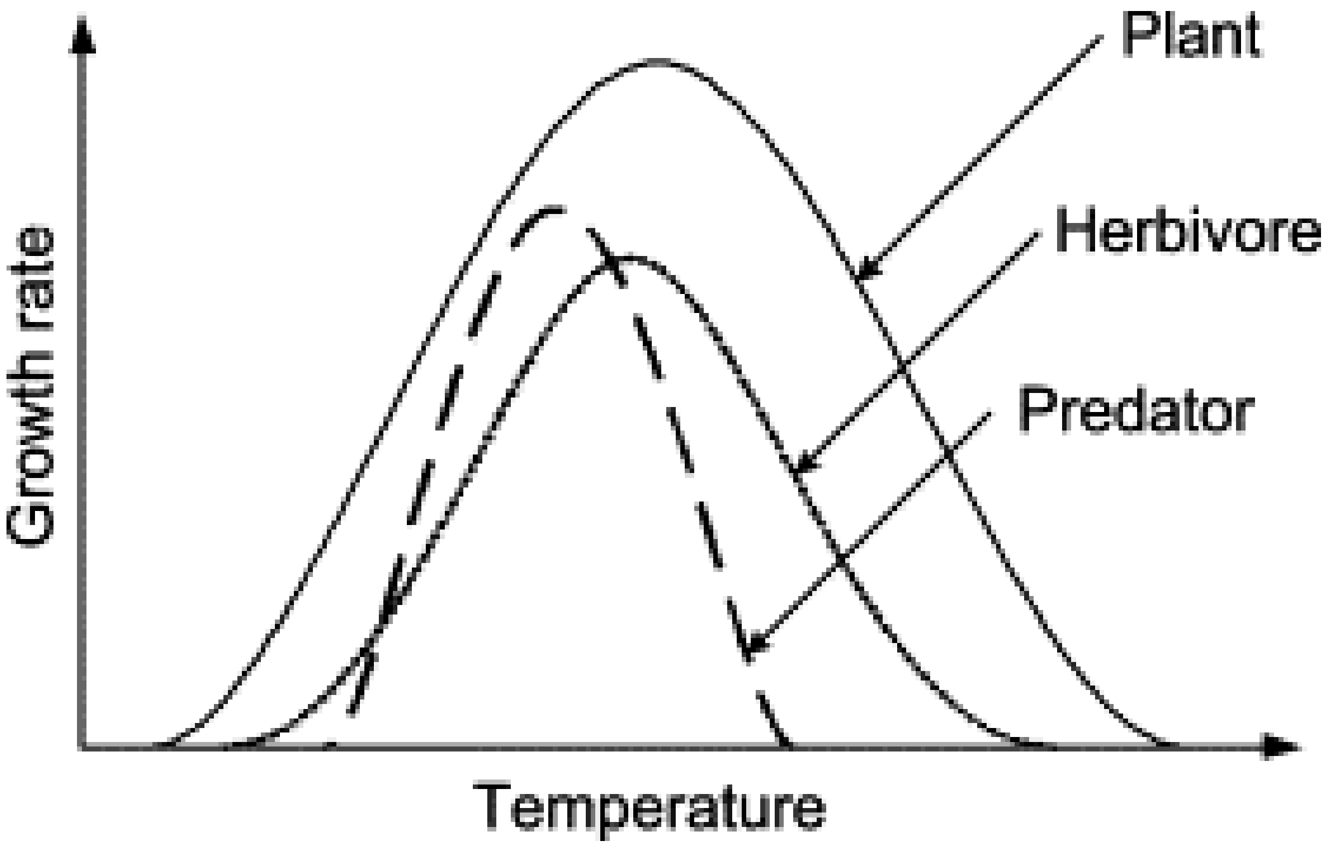
Impact of temperature increase



Potential changes (%) in national cereal yields for the 2020s, 2050s and 2080s (compared with 1990) under the HadCM3 SRES A2c scenario without CO2 effects

Parry et al., 2004

Tmean increase crops & pests



Hypothetical functions for growth rates of three species in a tritrophic system at constant resource across temperature (after Guiterrez, 2000).

Fuhrer, 2003

Impact of heat stress increase

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- Sensitive growth phases
  - Esp. Anthesis (Hatfield et al., 2011):

    >27-31°C in wheat

    >35°C maize

    >39-47°C in soybean

    >33-40°C in rice
  - Pollen viability and fertilization impeded

Impact of heat stress increase

Effect of heat stress during flowering in Kansas

Sterile spikelets of rice

Images: oklahomafarmreport.com (left); Hasanuzzaman et al. (2011)

Impact of Ozone increase

- Increased aound 6-fold in US (Ashmore, 2005)

- Toxic at acute and chronic levels → decrease photosynthesis, DM & yield

- Estimated yield losses due to O_3 increase → 10% in wheat and soybean; 3-5% in maize (van Dingenen et al., 2009)

Impact of CO_2-level increase

- CO_2-fertilization effect:
  - Increased photosynthesis:

$$6CO_2 + 6H_2O + \text{(solar) energy} \rightarrow C_6H_{12}O_6 + 6O_2$$

  - Increased dry matter production
  - Negative effects on quality

→ Protein & microelements↓

→ Carbohydrates ↑

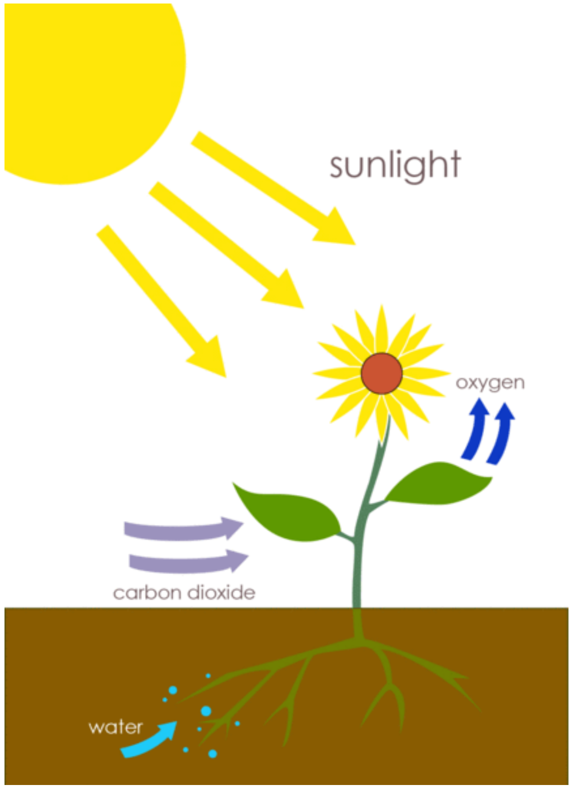
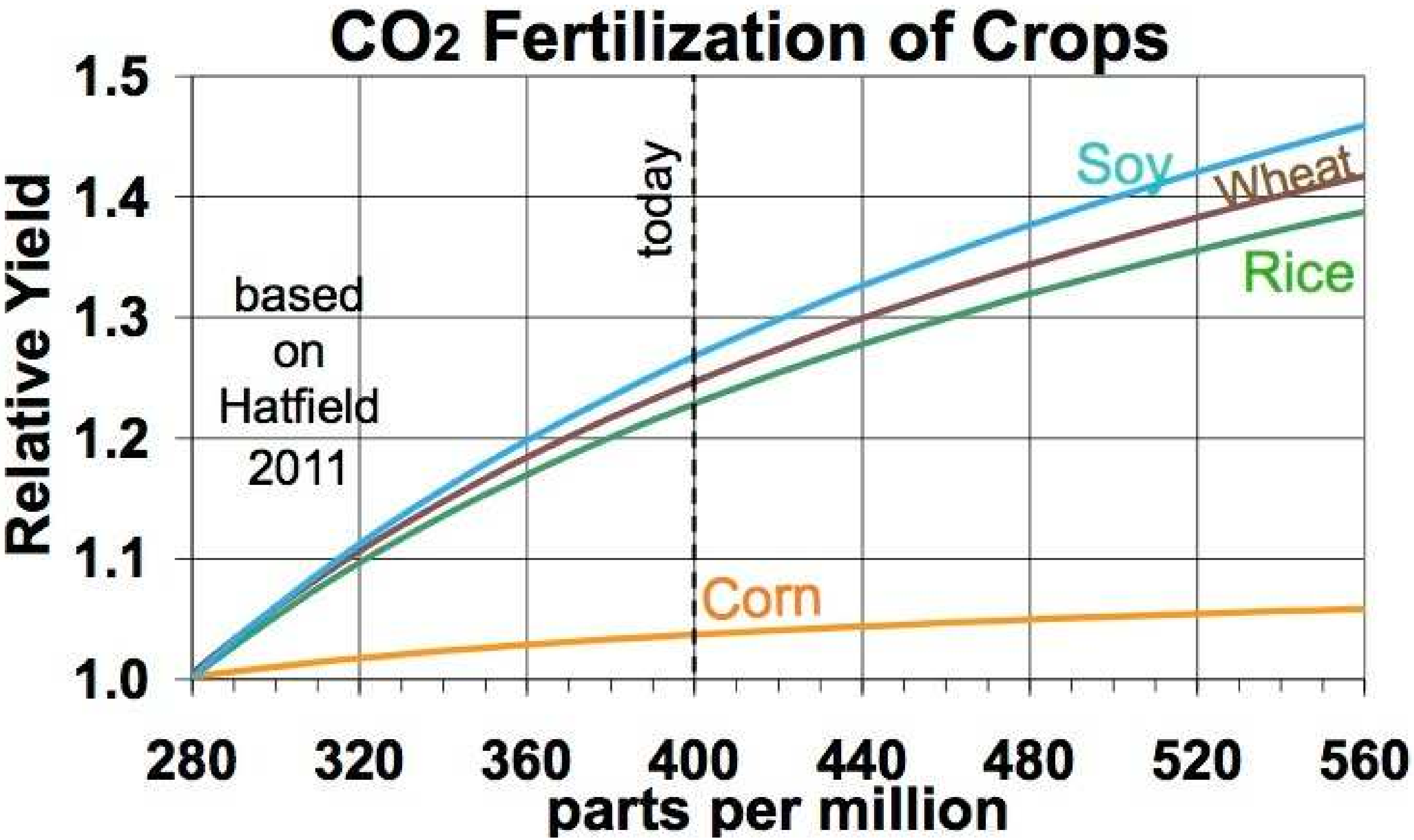
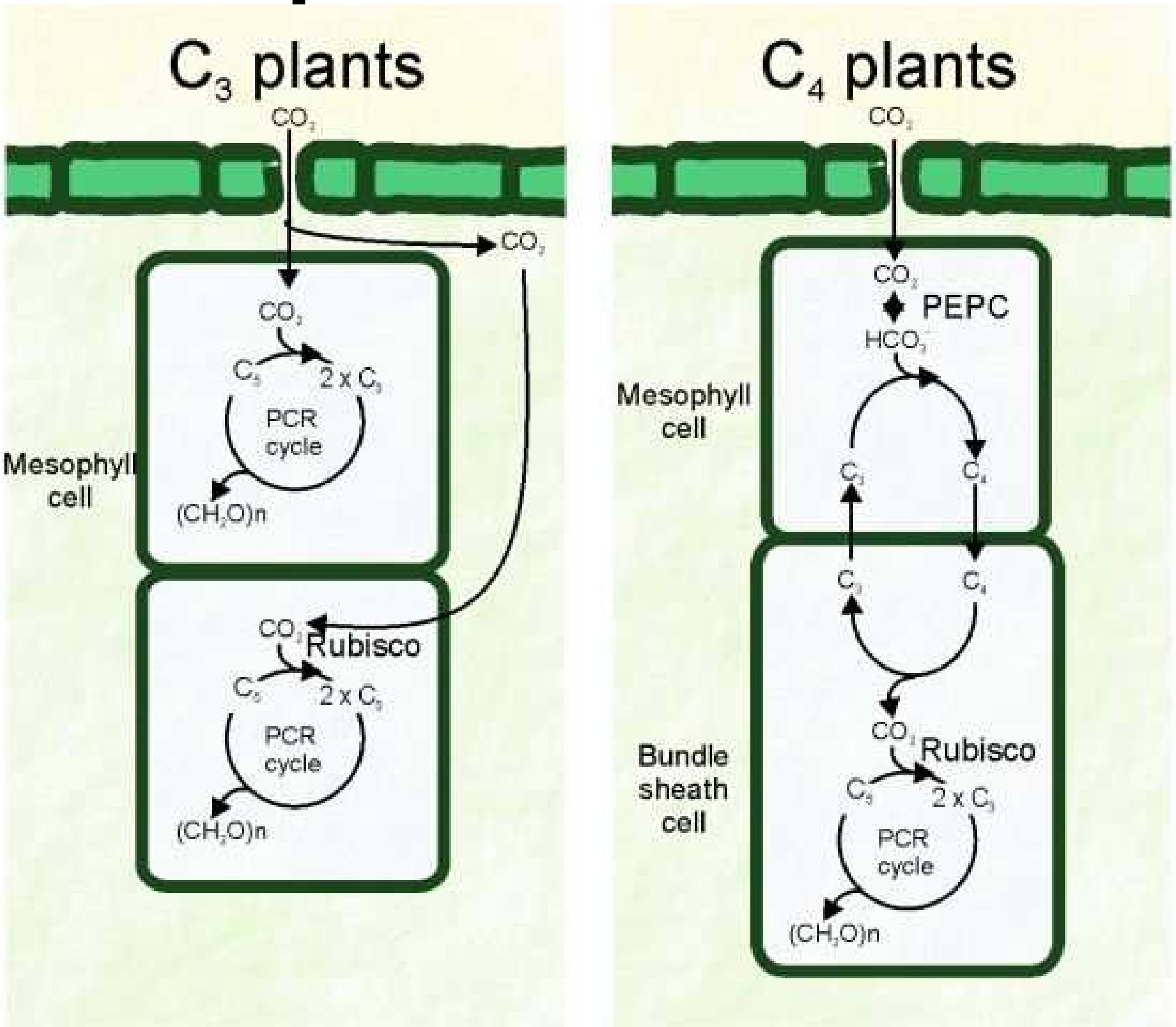


Image: Wikipedia

Impact of CO_2-level increase



C3 vs C4-crops

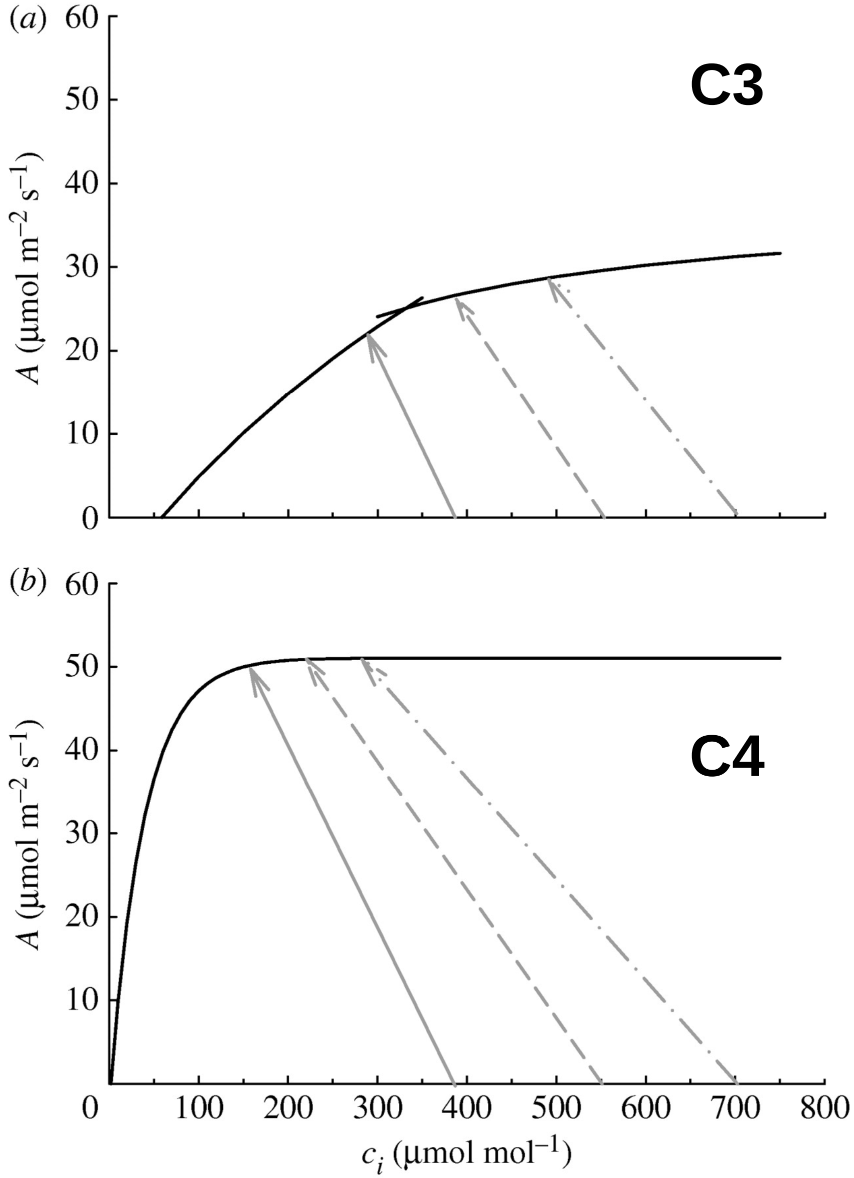


Simplified scheme of carbon fixation pathways operating in C3 and C4 plants.

Abbreviations: C3, three-carbon organic acids; C4, four-carbon organic acids; C5, ribulose-1,5-bisphosphate; PCR, Photosynthetic Carbon Reduction Cycle; PEPC, phosphoenolpyruvate carboxylase; Rubisco, Ribulose-1,5-bisphosphate carboxylase/oxygenase.

Lara and Andreo (2011)

C3 vs C4-crops

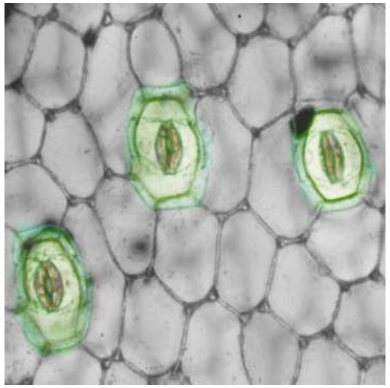


Photosynthesis (A) response to intercellular CO2 concentration (ci) under light saturation

Leakey, 2009

Impact of CO_2-level increase

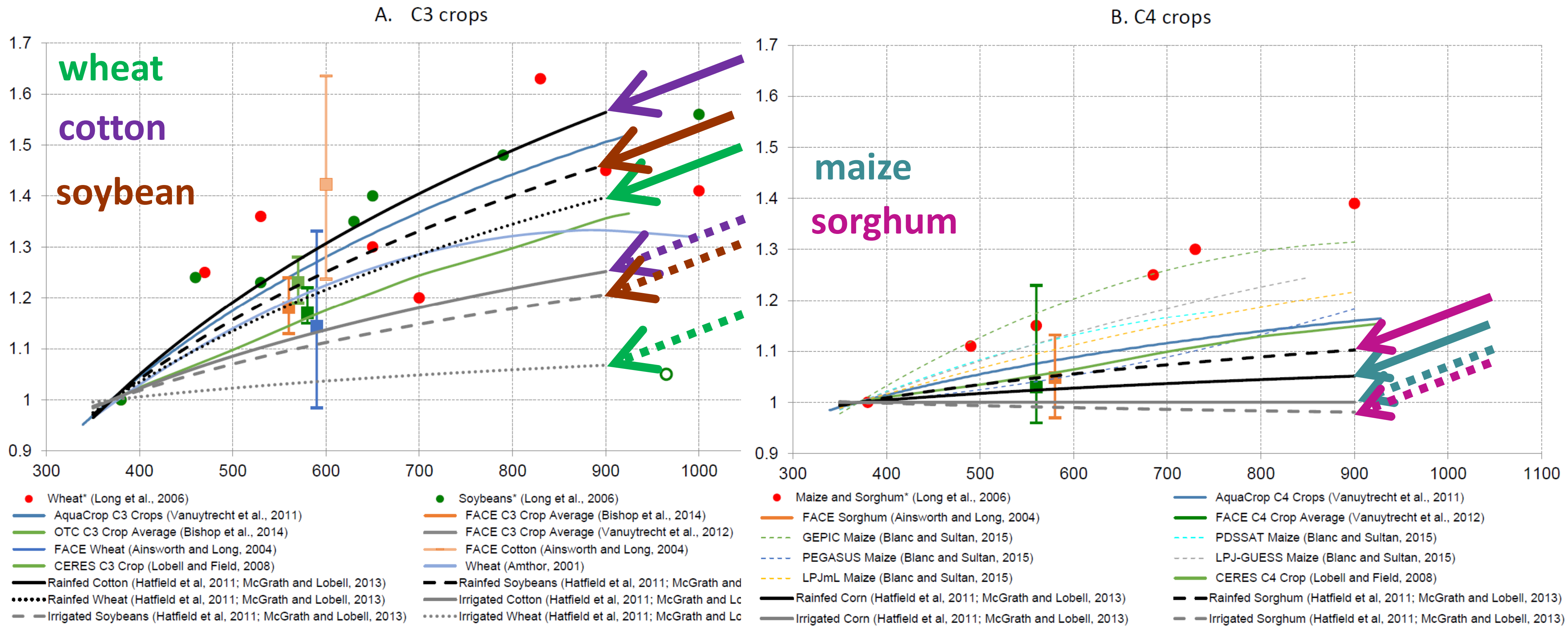
- CO_2-fertilization effect:
  - Decreased stomatal conductance
  - Increased water use efficiency



Images: Flickr.com

Impact CO_2-level increase

- C3-crops vs. C4-crops + rainfed vs. irrigated



Wing et al., 2015

C3 vs C4-crops

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Table 1. Response of plant physiological variables to a doubling of CO_2 concentrations from research studies.

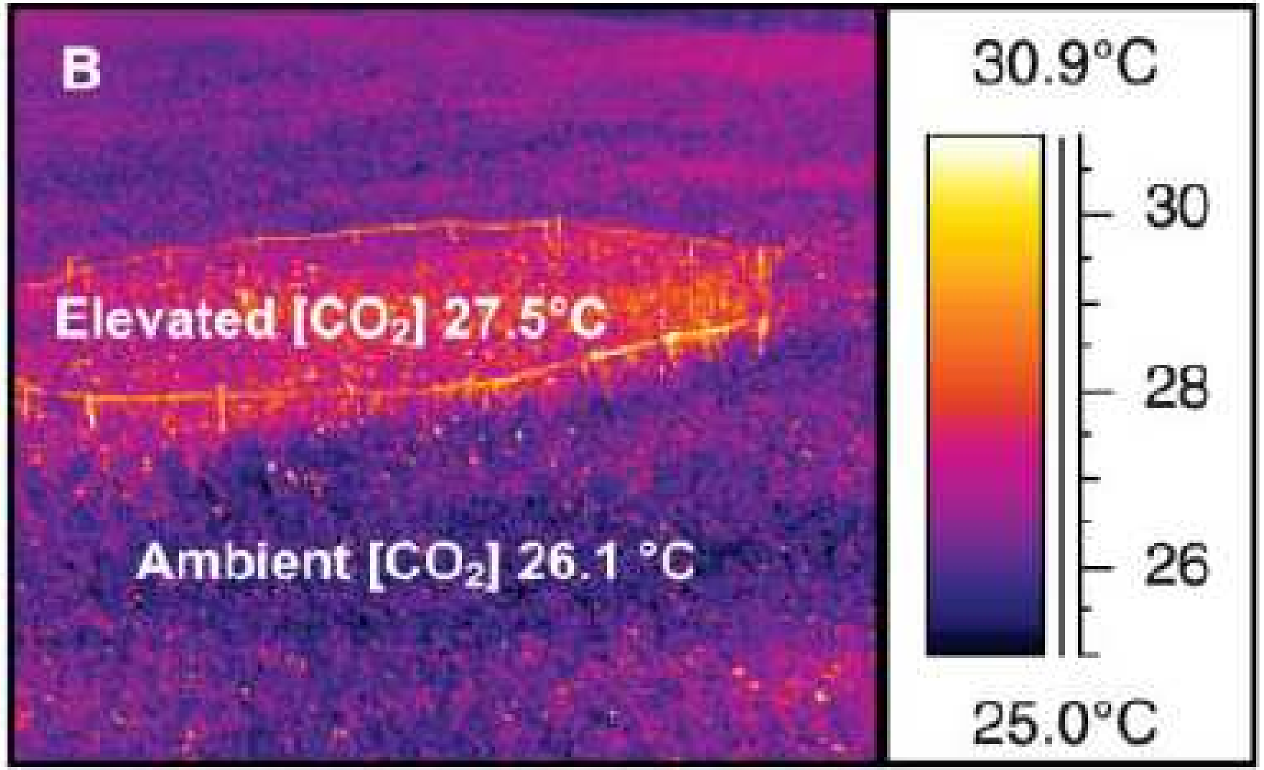
Crop	Leaf photosynthesis	Total biomass	Grain yield	Leaf stomatal conductance	Canopy evapotranspiration
	% change				
Maize	3[†]	4[†,‡,§,¶]	4[†,‡]	−34[†]	
Sorghum	9[#,††]	3[‡‡]	0,8[#]	−37[††]	−13[§§]
Bean	50[¶¶]	30[¶¶]	27[¶¶]		
Cotton	33[##,†††]	36[##,†††]	44[##,†††]	−36[##,†††]	0[§§§§§§], −8[‡‡‡]
Peanut	27[¶¶]	36[¶¶]	30[¶¶]		
Rice	36[§§§]	30[§§§]	30[§§§,¶¶¶]		−10[####,††††]
Soybean	35[‡‡‡‡]	37[‡‡‡‡]	34[§§§§]–38[‡‡‡‡]	−40[‡‡‡‡]	−9[¶¶¶¶], −12[#####,†††††]
Wheat	35[‡‡‡‡‡]	15–27[§§§§§]	31[¶¶¶¶¶]	−33 to −43[######]	−8[††††††,‡‡‡‡‡‡,¶¶¶¶¶¶]

† Leakey et al. (2006).
‡ King and Greer (1986).
§ Ziska and Bunce (1997).
¶ Maroco et al. (1999).
# Prasad et al. (2006a).
†† Wall et al. (2001).
‡‡Ottman et al. (2001).
§§ Triggs et al. (2004).
¶¶ Prasad et al. (2003).
Reddy et al. (1995a).
††† Reddy et al. (1997).
‡‡‡ Reddy et al. (2000).
§§§ Horie et al. (2000).
¶¶¶ Baker and Allen (1993a).
Baker et al. (1989).
†††† Yoshimoto et al. (2005).
‡‡‡‡ Ainsworth et al. (2002).
§§§§ Allen and Boote (2000).
¶¶¶¶ Allen et al. (2003).
Jones et al. (1985).
††††† Bernacchi et al. (2007).
‡‡‡‡‡ Long (1991).
§§§§§ Lawlor and Mitchell (2000).
¶¶¶¶¶ Amthor (2001).
Wall et al. (2006).
†††††† Andre and duCloux (1993).
‡‡‡‡‡‡ Kimball et al. (1999).
§§§§§§ Hunsaker et al. (1994).
¶¶¶¶¶¶ Hunsaker et al. (1996, 2000).

Hatfield et al., 2011

Impact CO_2-level increase

- CO_2-fertilized crops → lower ET → higher T compared to ambient conditions



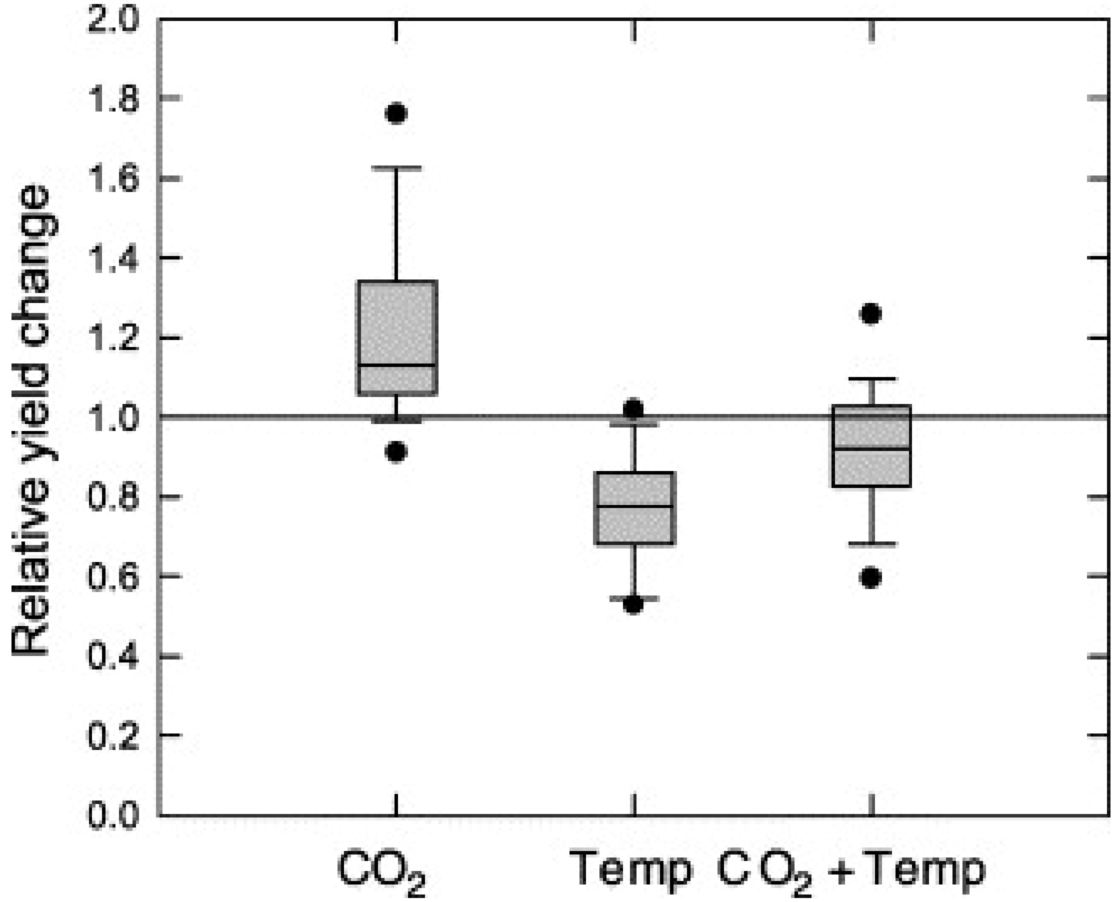
Leakey, 2009

CO_2 and drought increase

- CO_2 ↑ → ET↓ → WUE & ASM↑
- Beneficial under moderate water scarcity
- But not effective under severe drought

Images: commons.wikimedia (left; Texas, US, 2011), flickr / D. Kelleher (right; Victoria, AU, 2006)

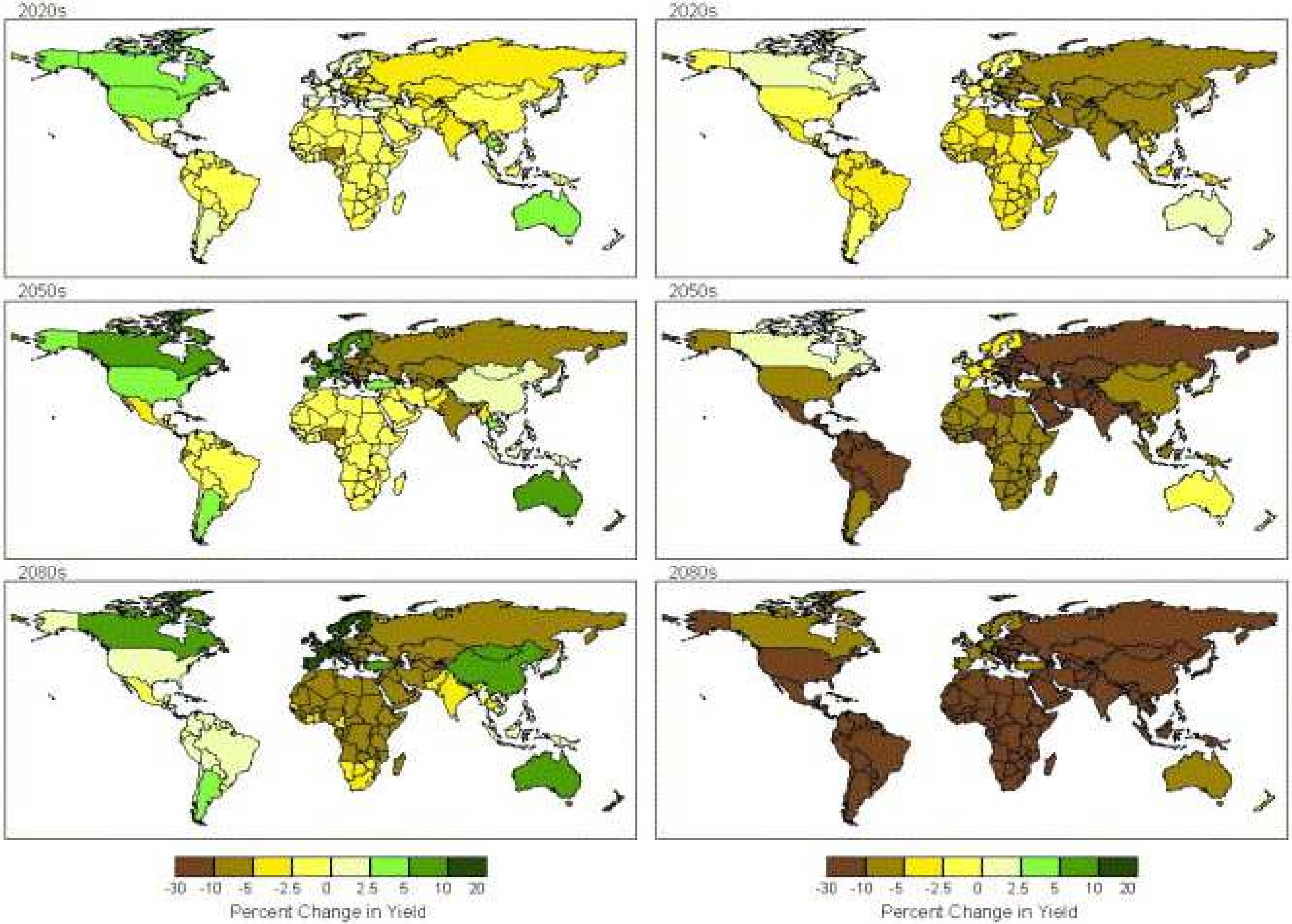
CO_2 and temperature increase



Impact of elevated CO_2 and temperature on wheat yields

Fuhrer, 2003

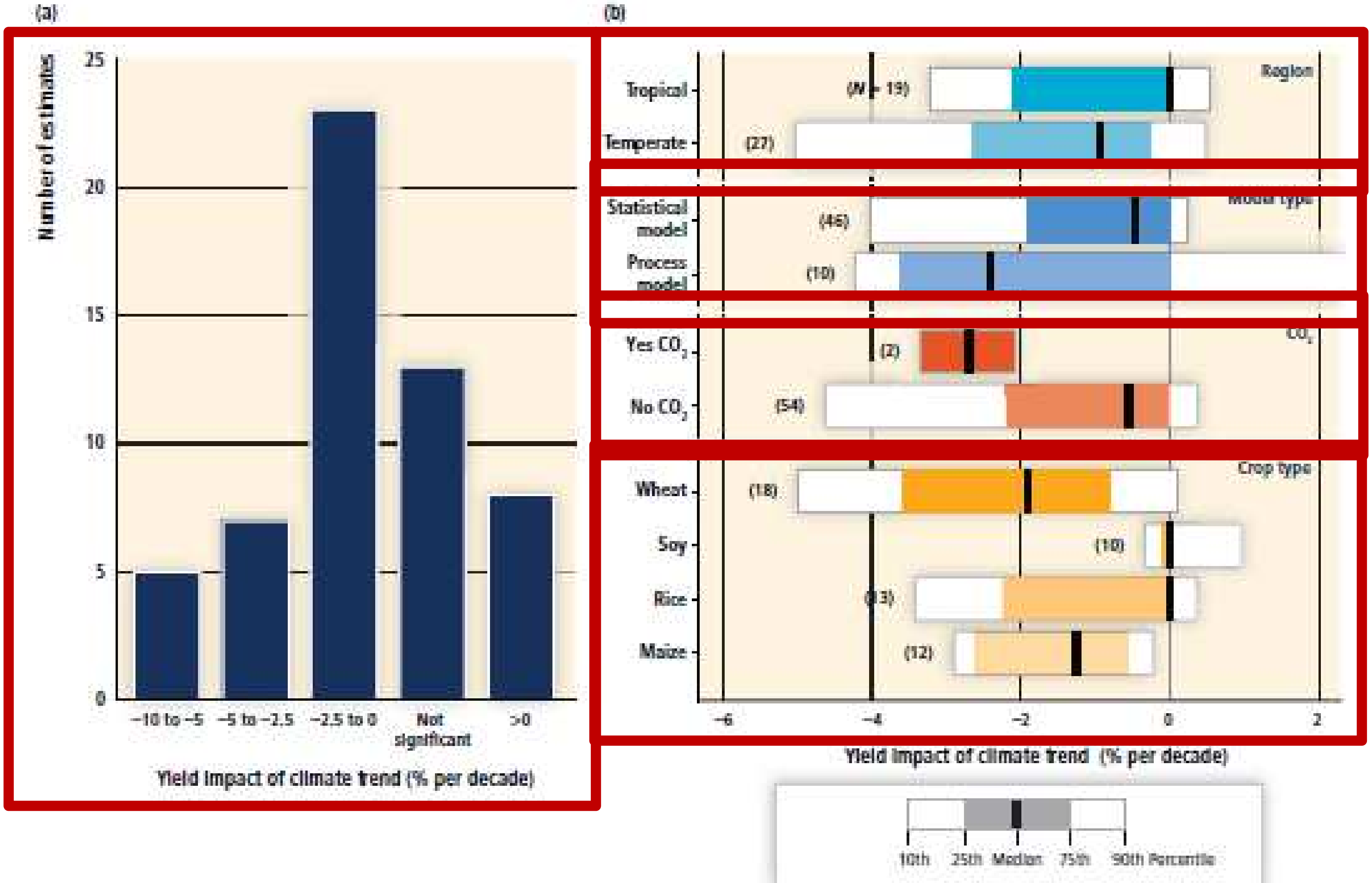
Impact of temperature + CO_2



Potential changes (%) in national cereal yields for the 2020s, 2050s and 2080s (compared with 1990) under the HadCM3 SRES A2c scenario with and without CO2 effects

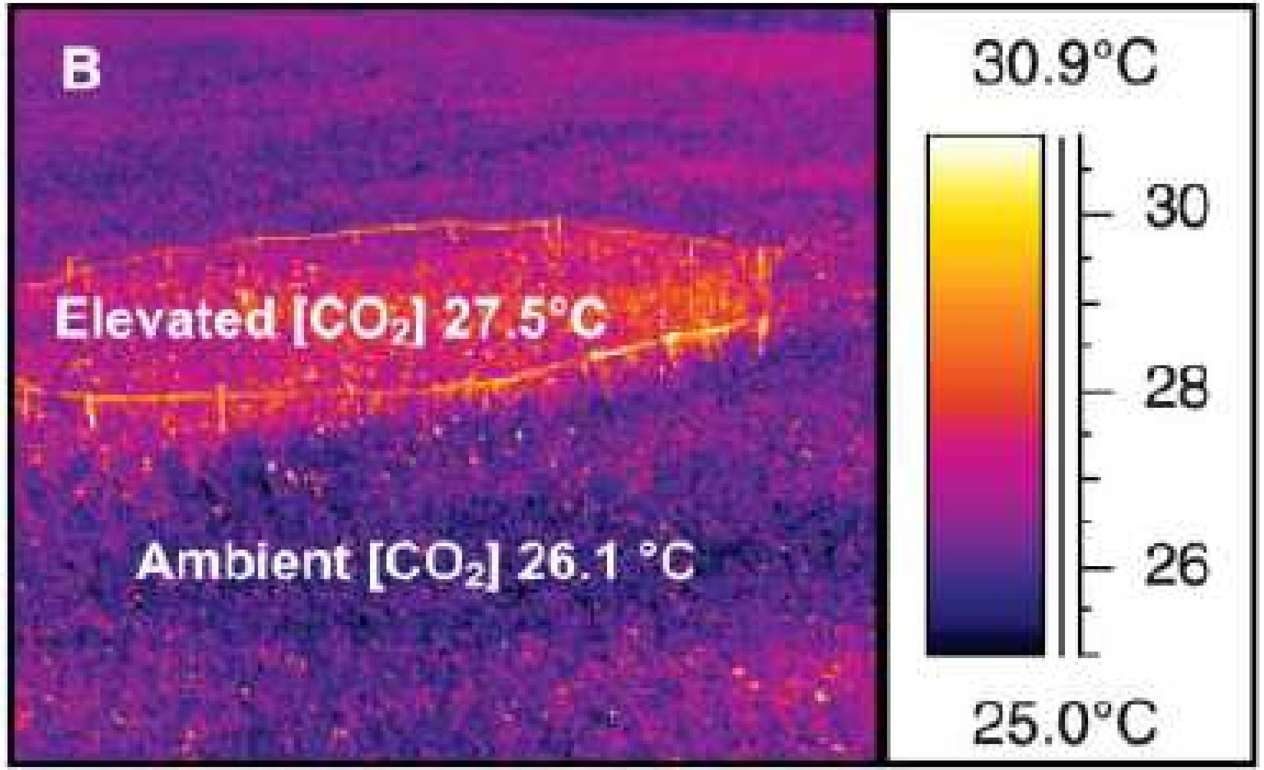
Parry et al., 2004

IPPC – AR5 CC impact summary



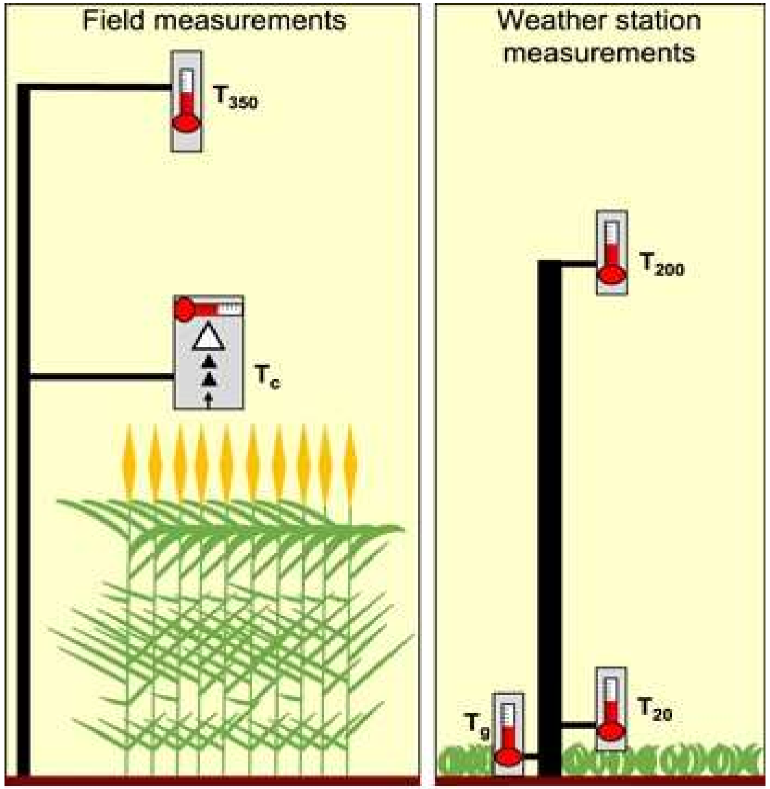
IPCC, 2014

Interactions CO_2-Temp-ET



Leakey, 2009

Interactions CO_2-Temp-ET



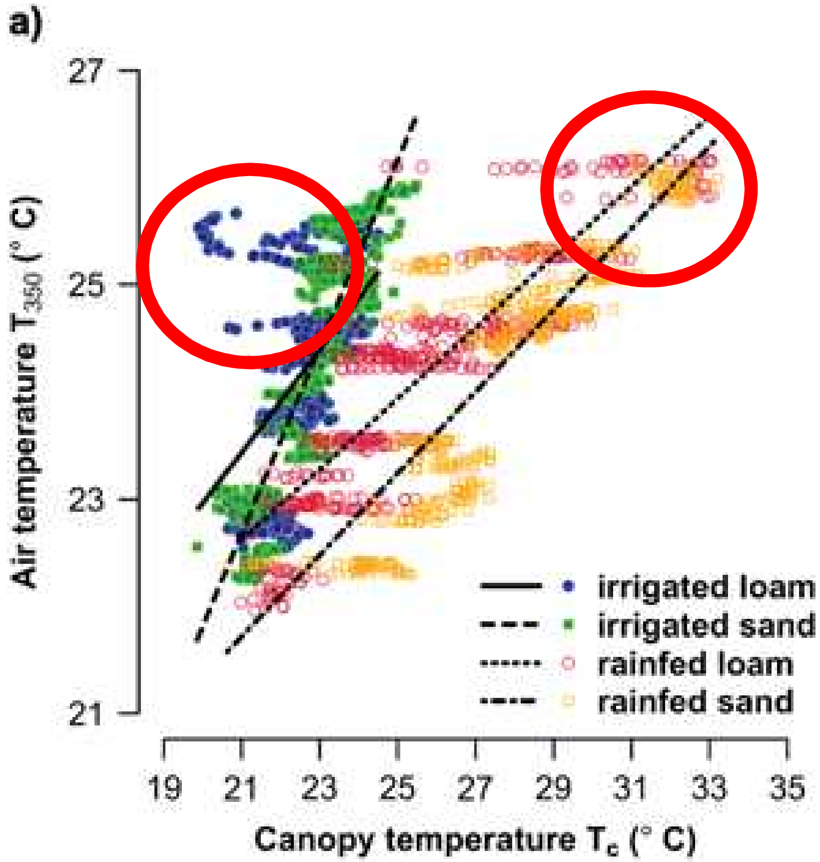


Figure 1 from Impact of heat stress on crop yield—on the importance of considering canopy temperature
Stefan Siebert et al 2014 Environ. Res. Lett. 9 044012 doi:10.1088/1748-9326/9/4/044012

Siebert et al., 2014

Adaptation - passiv

- Wheat in Germany 1951-2009
  - Increasing Tmean accelerates phenological development
  - 14 days earlier day of heading
  - Avoid (increased) heat stress during anthesis

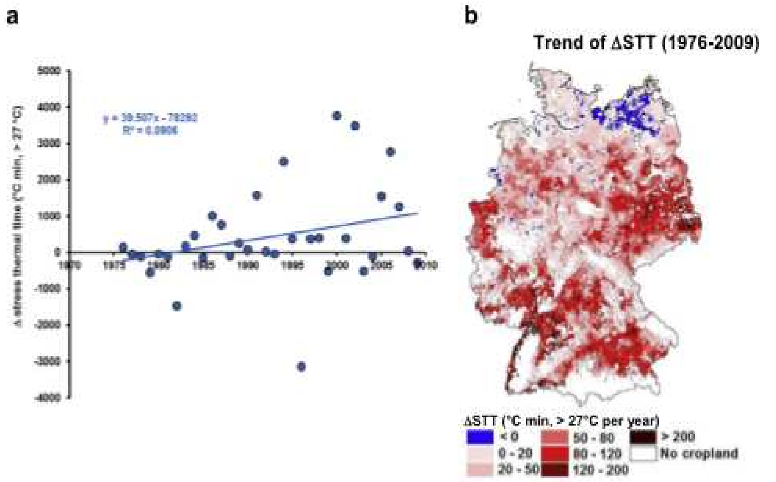


Figure 4. Heat stress avoided due to earlier heading of winter wheat. ΔSTT (stress thermal time calculated with de-trended day of heading—stress thermal time calculated with observed day of heading) shown as mean across cropland in Germany (a) and as map showing the trend in ΔSTT (b) for period 1976–2009.

Rezaei et al. (2015)

Adaptation - activ

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- Adjust cultivation period
- Cultivar choice + breeding
- Crop choice
- Supplemental irrigation
- Crop diversification
- …

Summary

- Impact of CC on crops is evident
- Neg. more common, pos. only for high lat.
- Rising T (Tmax) and O_3 adverse
- Precipitation on coutry scale important but uncertain predictions
- CO_2-fertilization positive (C3 vs C4; C3 weeds)
- Interactive effect of CO_2↑+O_3↑ +temp↑+pp↓ challenging
- Adaptation options exist; need to be tailored

→ Consideration of canopy temperatures

→ Consideration of phenological shifts

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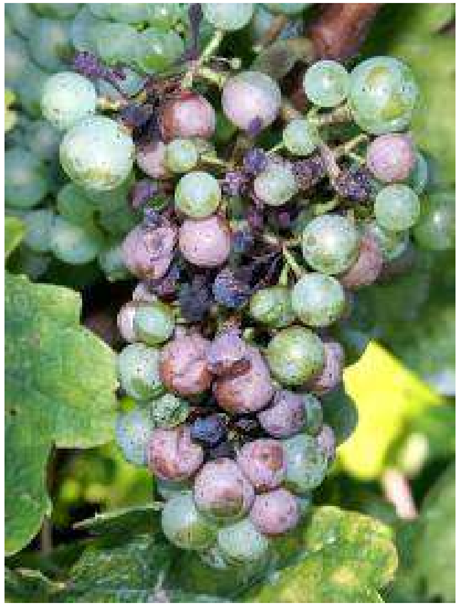
Thank you
for your attention



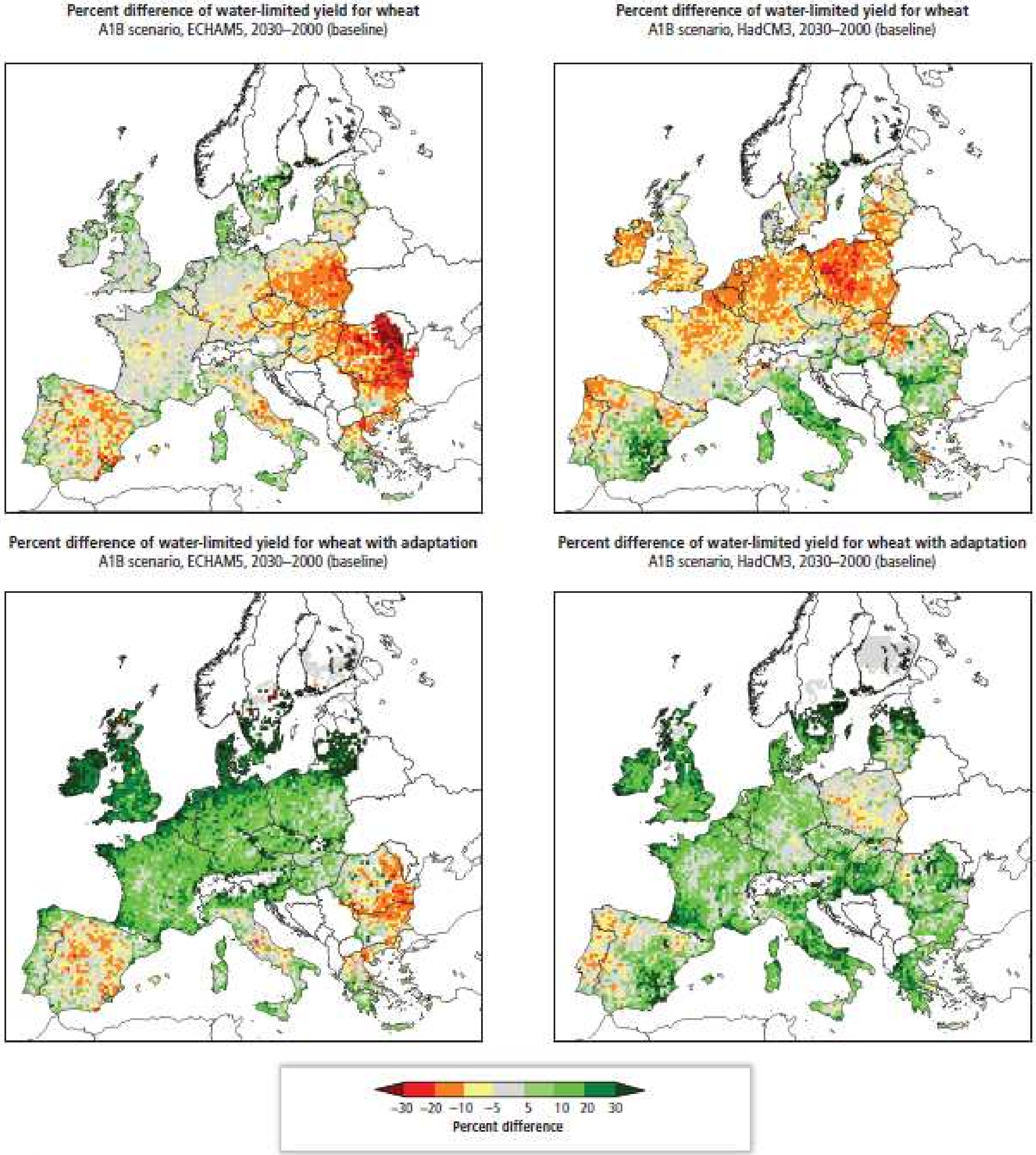
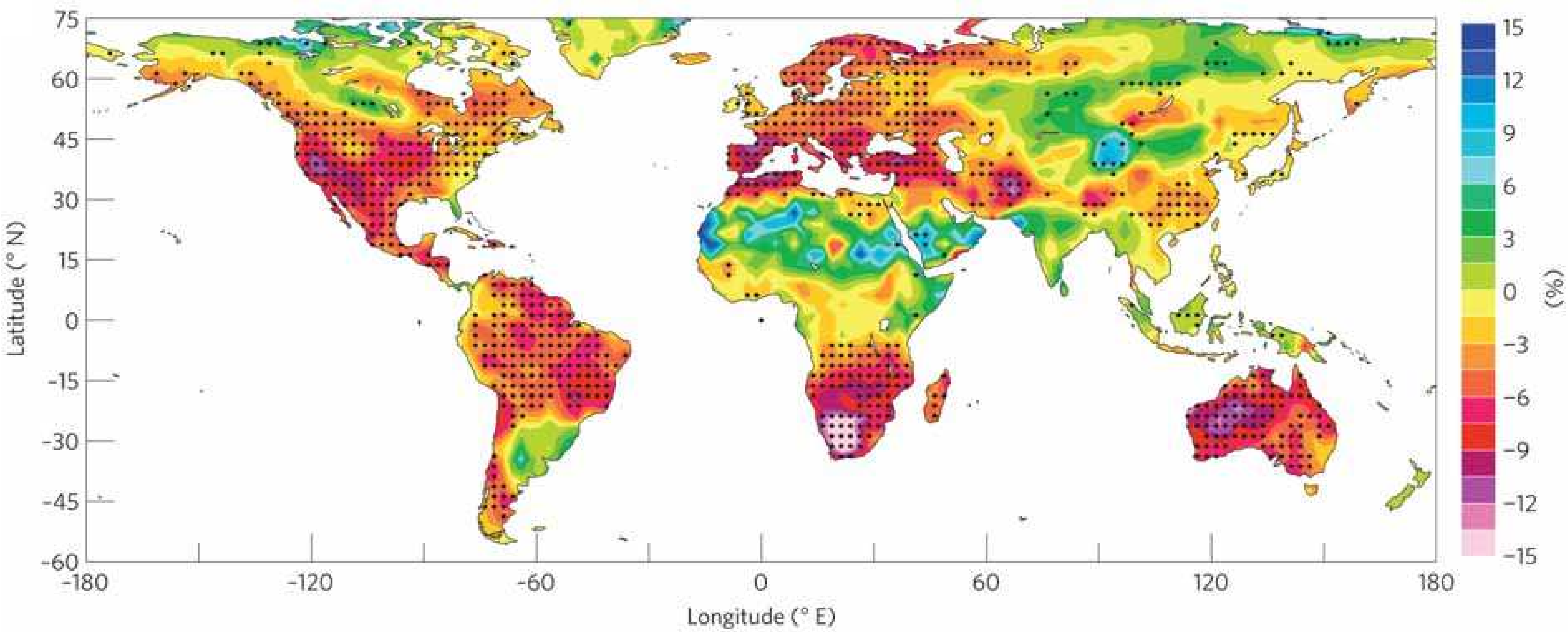



Figure 23-4 | Percentage change in simulated water-limited yield for winter wheat in 2030 with respect to the 2000 baseline for the A1B scenario using European Centre for Medium Range Weather Forecasts and Hamburg 5 (ECHAM5; left column) and Hadley Centre Coupled Model version 3 (HadCM3; right) General Circulation Models (GCMs). Upper maps do not take adaptation into account. Bottom maps include adaptation. Analysis developed at the Joint Research Centre of the European Commission. Source: Donatelli et al., 2012.

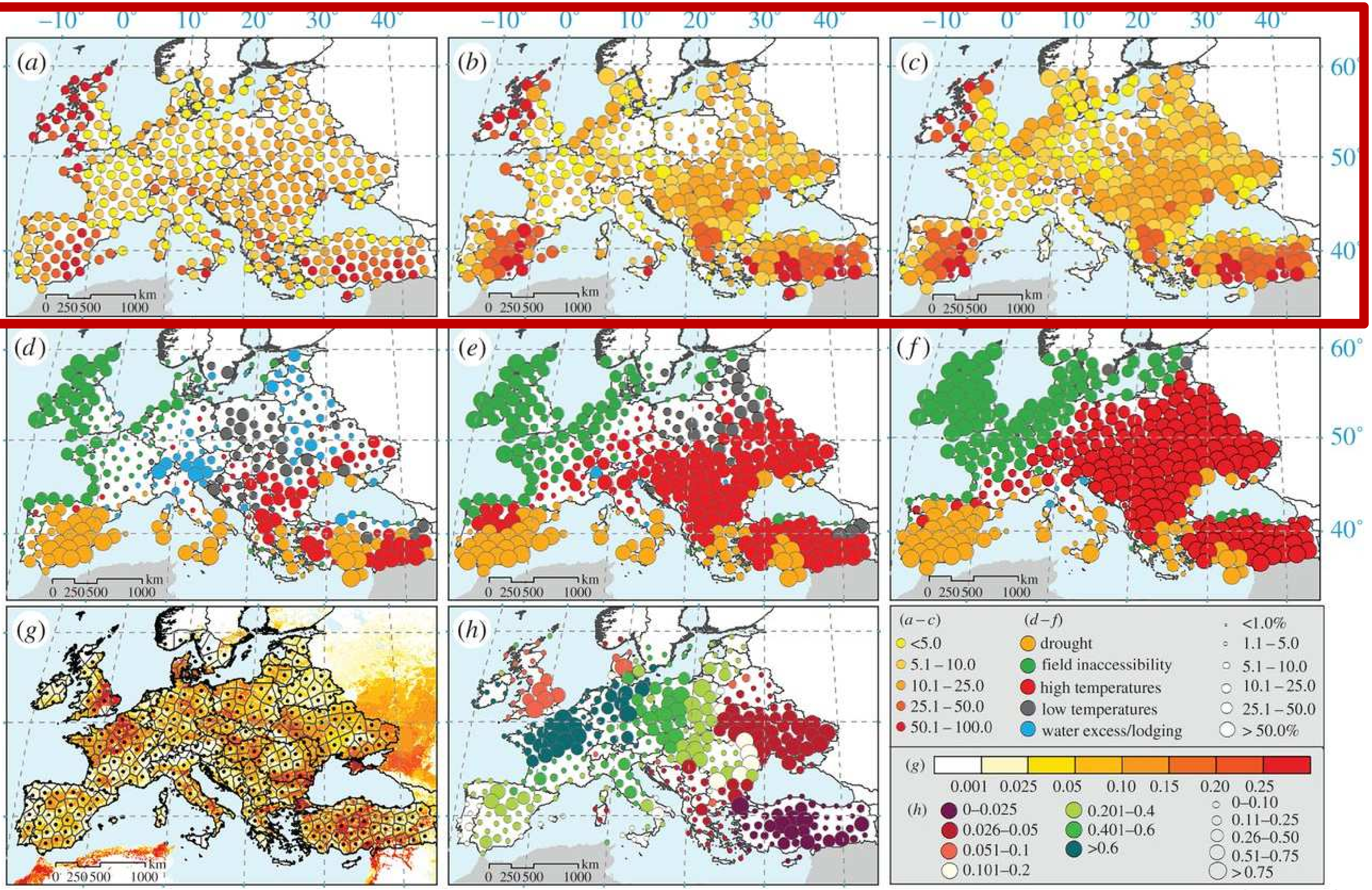
Soil moisture development



Percentage changes from 1980–1999 to 2080–2099 in multimodel ensemble mean soil-moisture content in the top 10 cm layer (broadly similar for the whole soil layer) simulated by 11 CMIP5 models under the RCP4.5 emissions scenario. Stippling indicates at least 82% (9 out of 11) of the models agree on the sign of change.

Dai, 2013

Additive negative CC effects



Trnka et al. (2016)

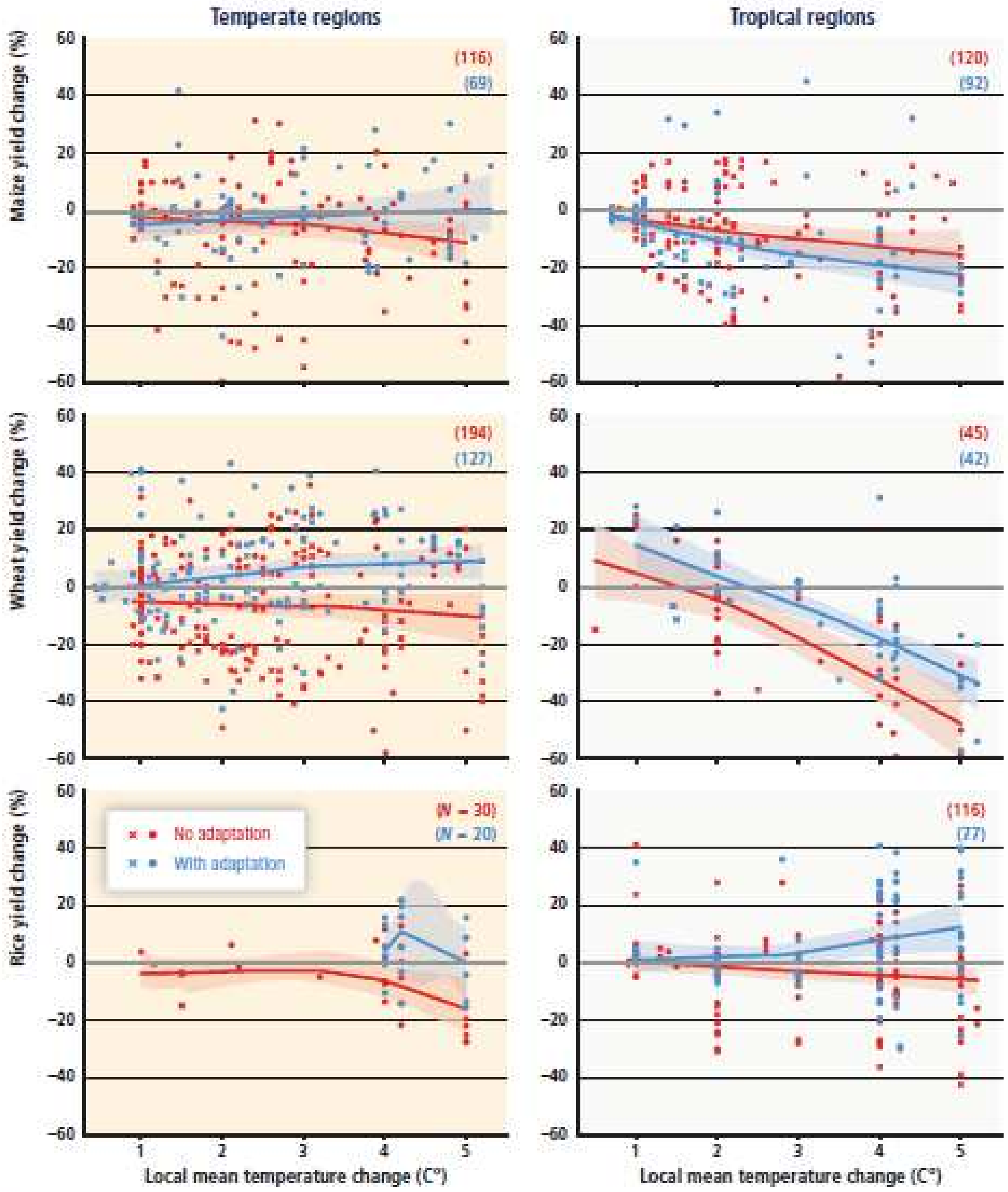


Figure 7-4 | Percentage simulated yield change as a function of local temperature change for the three major crops and for temperate and tropical regions. Dots indicate where a known change in atmospheric CO_2 was used in the study; remaining data are indicated by x. Note that differences in yield value between these symbols do not measure the CO_2 fertilization effect, as changes in other factors such as precipitation may be different between studies. Non-parametric regressions (LOESS, span = 1 and degree = 1) of subsets of these data were made 500 times. These bootstrap samples are indicated by shaded bands at the 95% confidence interval. Regressions are separated according to the presence (blue) or absence (red) of simple agronomic adaptation (Table 7-2). In the case of tropical maize, the central regression for absence of adaptation is slightly higher than that with adaptation. This is due to asymmetry in the data—not all studies compare adapted and non-adapted crops. Figure 7-8 presents a pairwise adaptation comparison. Note that four of the 1048 data points across all six panels are outside the yield change range shown. These were omitted for clarity. Some of the studies have associated temporal baselines, with center points typically between 1970 and 2005. Note that local warming in cropping regions generally exceeds global mean warming (Figure 21-4). Data are taken from a review of literature: Rosenzweig and Parry, 1994; Karim et al., 1996; El-Shaher et al., 1997; Kapetanaki and Rosenzweig, 1997; Lal et al., 1998; Moya et al., 1998; Winters et al., 1998; Yates and Strzepek, 1998; Alexandrov, 1999; Kaiser, 1999; Reyenga et al., 1999; Alexandrov and Hoogenboom, 2000; Southworth et al., 2000; Tubiello et al., 2000; DeJong et al., 2001; Izaurralde et al., 2001; Aggarwal and Mall, 2002; Abou-Hadid, 2006; Alexandrov et al., 2002; Corobov, 2002; Chipanshi et al., 2003; Easterling et al., 2003; Jones and Thornton, 2003; Luo et al., 2003; Matthews and Wassmann, 2003; Droogers, 2004; Howden and Jones, 2004; Butt et al., 2005; Erda et al., 2005; Ewert et al., 2005; Gbetibouo and Hassan, 2005; Izaurralde et al., 2005; Porter and Semenov, 2005; Sands and Edmonds, 2005; Thomson et al., 2005; Xiao et al., 2005; Zhang and Liu, 2005; Zhao et al., 2005; Abraha and Savage, 2006; Brassard and Singh, 2007, 2008; Krishnan et al., 2007; Lobell and Ortiz-Monasterio, 2007; Xiong et al., 2007; Tingem et al., 2008; Walker and Schulze, 2008; El Maayar et al., 2009; Schlenker and Roberts, 2009; Thornton et al., 2009a, 2010, 2011; Tingem and Rivington, 2009; Byjesh et al., 2010; Chhetri et al., 2010; Liu et al., 2010; Piao et al., 2010; Tan et al., 2010; Tao and Zhang, 2010, 2011a,b; Arndt et al., 2011; Deryng et al., 2011; Iqbal et al., 2011; Lal, 2011; Li et al., 2011; Rowhani et al., 2011; Shuang-He et al., 2011; Osborne et al., 2013.

Climate impact