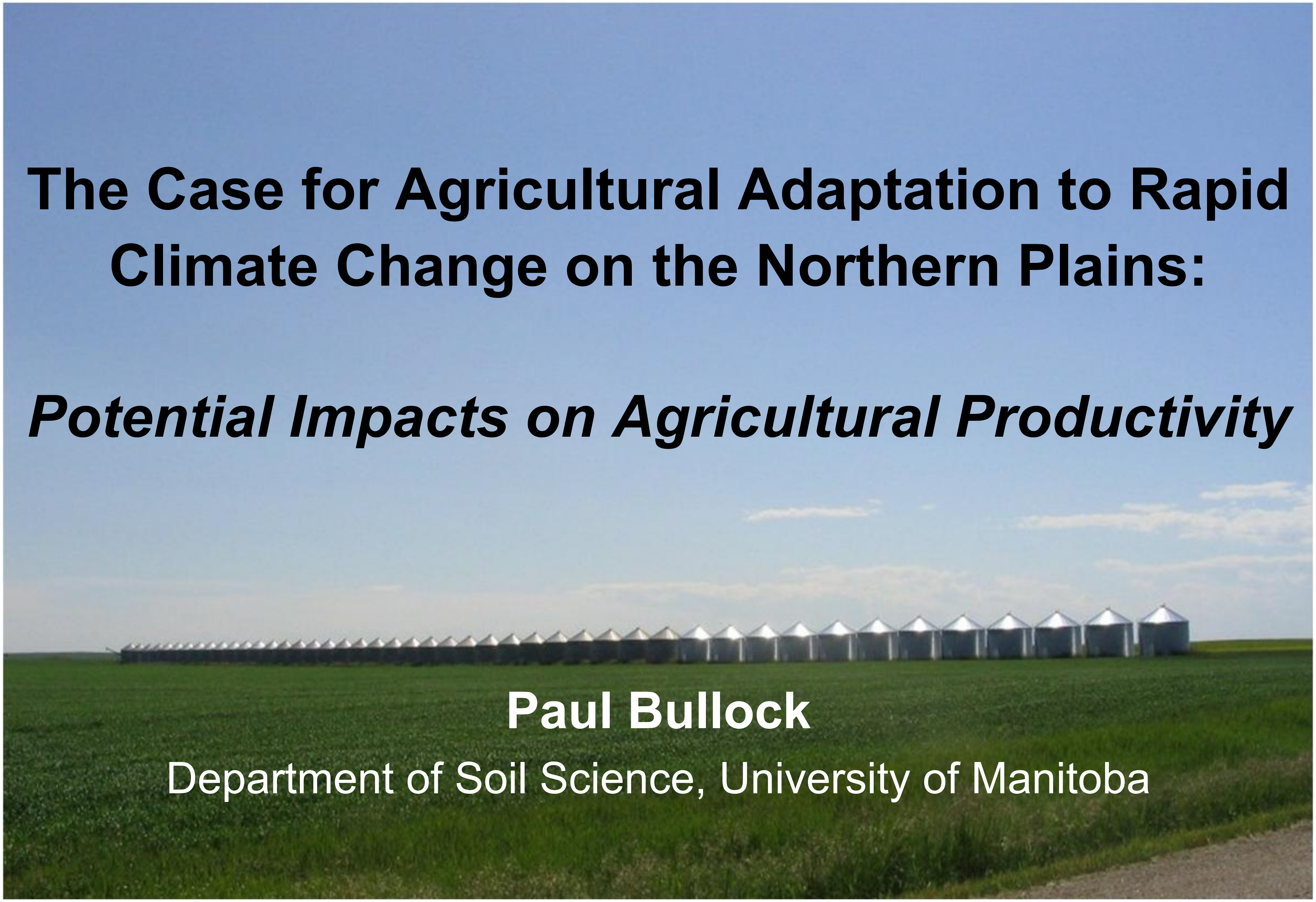
The Case for Agricultural Adaptation to Rapid Climate Change on the Northern Plains:

Potential Impacts on Agricultural Productivity



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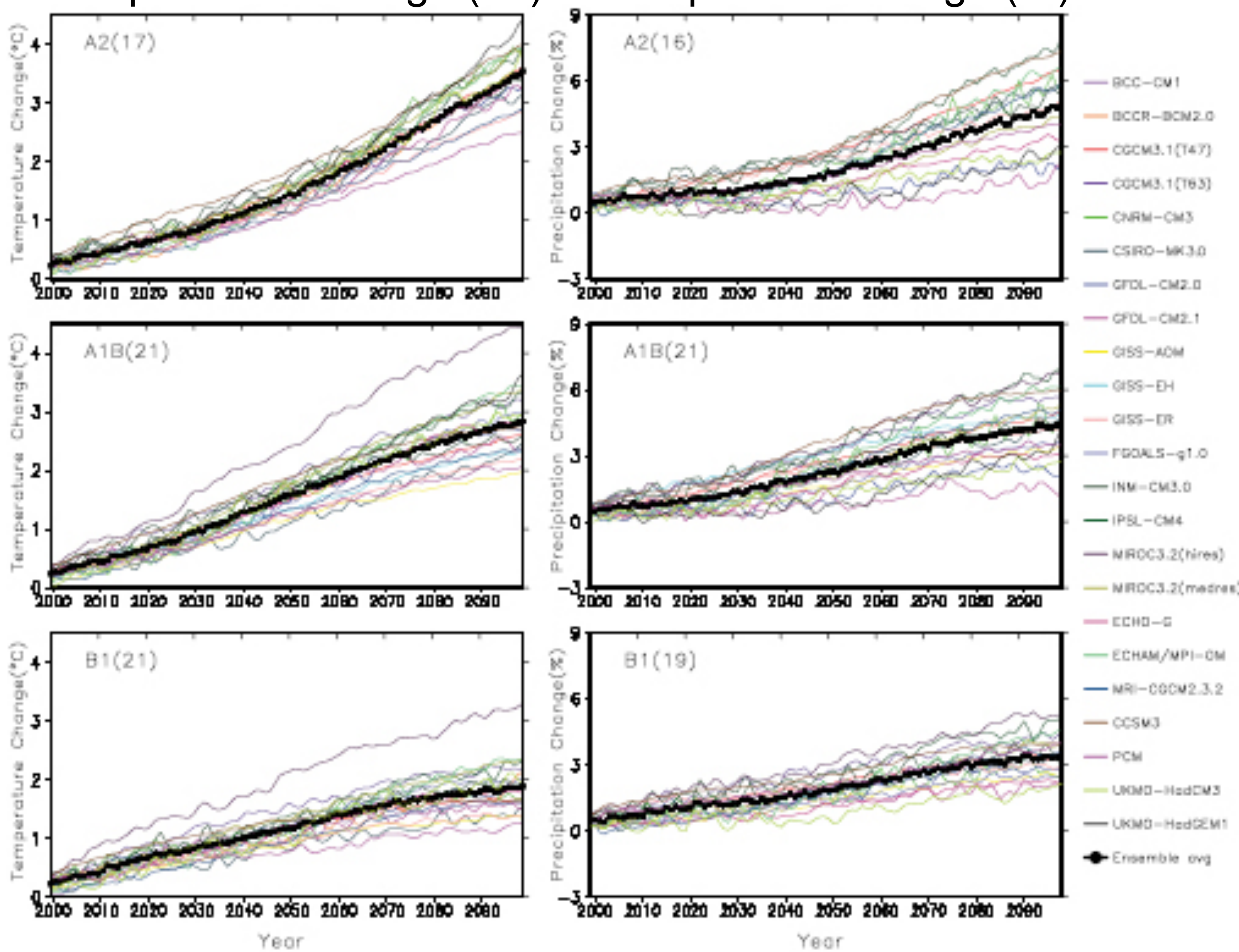
Outline

- Challenges
- Past Trends
- Predictions
- Potential impacts on agriculture

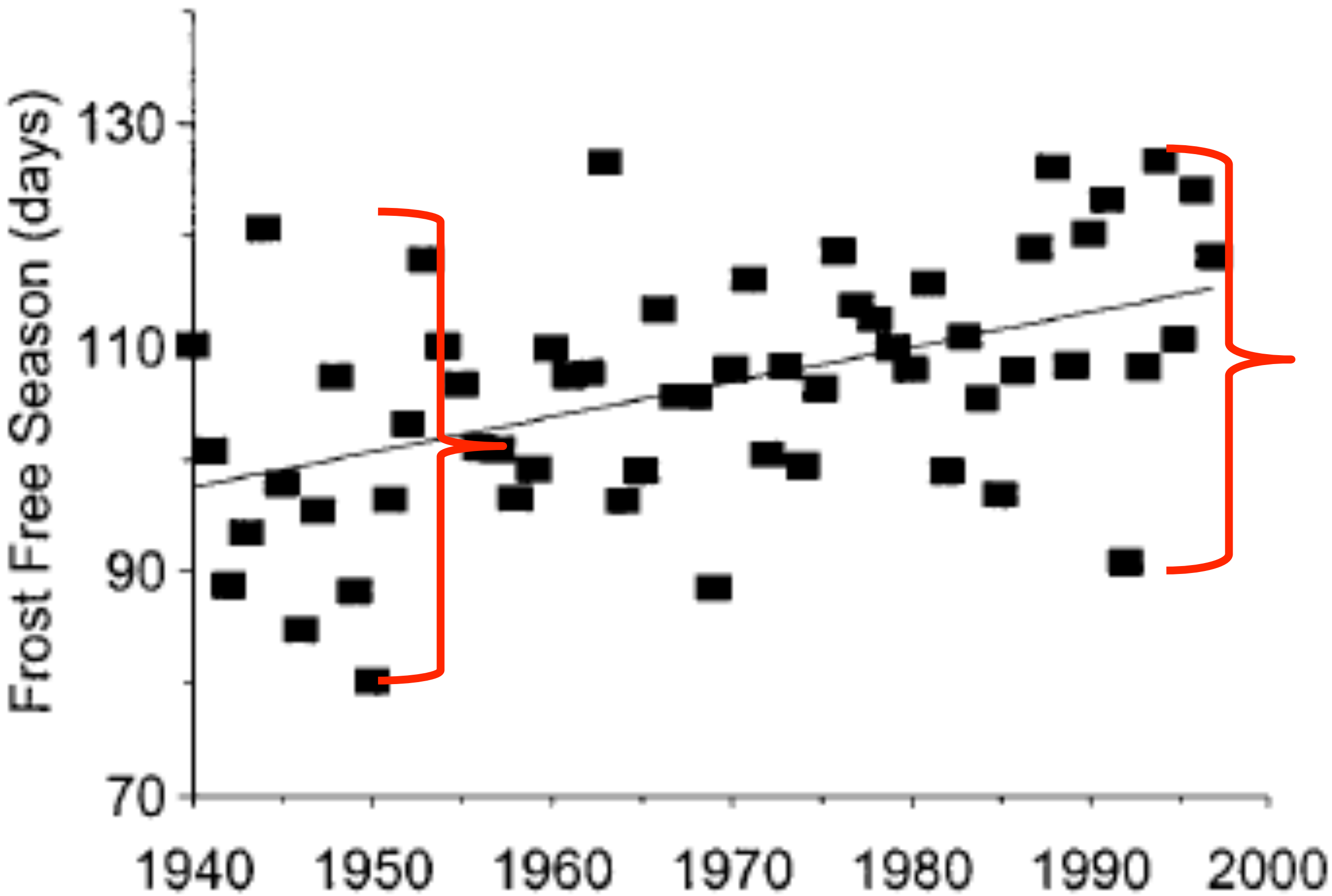
Future Climate Uncertainty

Forecast global (left) surface air temperature change, and (right) precipitation change from various global coupled models for three scenarios, relative to the 1980 to 1999 mean.
(IPCC, 2007: Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the IPCC [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104 pp.).

Temperature Change (°C) Precipitation Change (%)

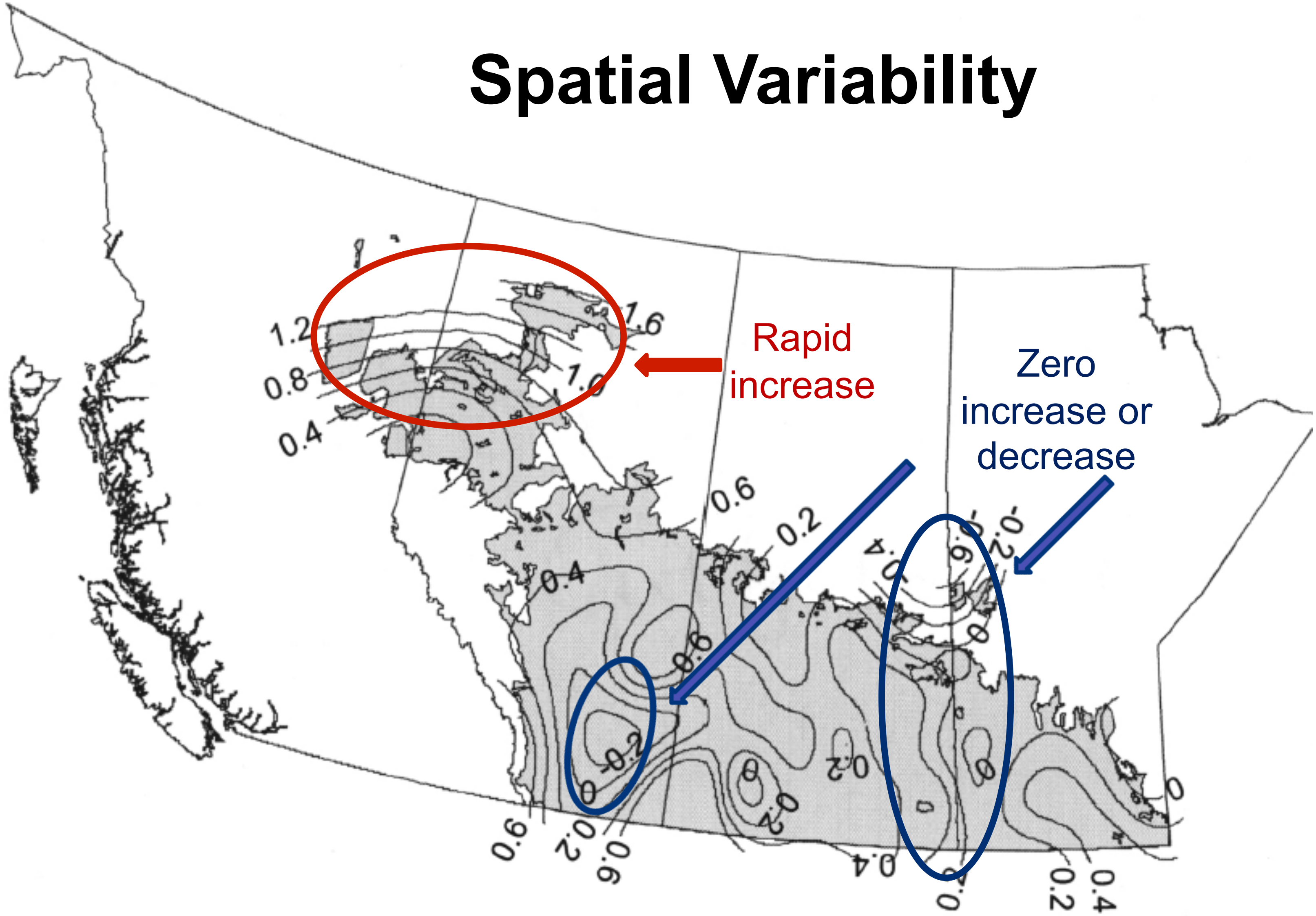


Inter-annual Variability



Annual frost-free period (using a 0°C benchmark) from 1940 to 1997 using average temperatures from 12 weather stations in western Canada (Cutforth et al. 2004, Can. J. Plant Sci. 84: 1085–1091).

Spatial Variability



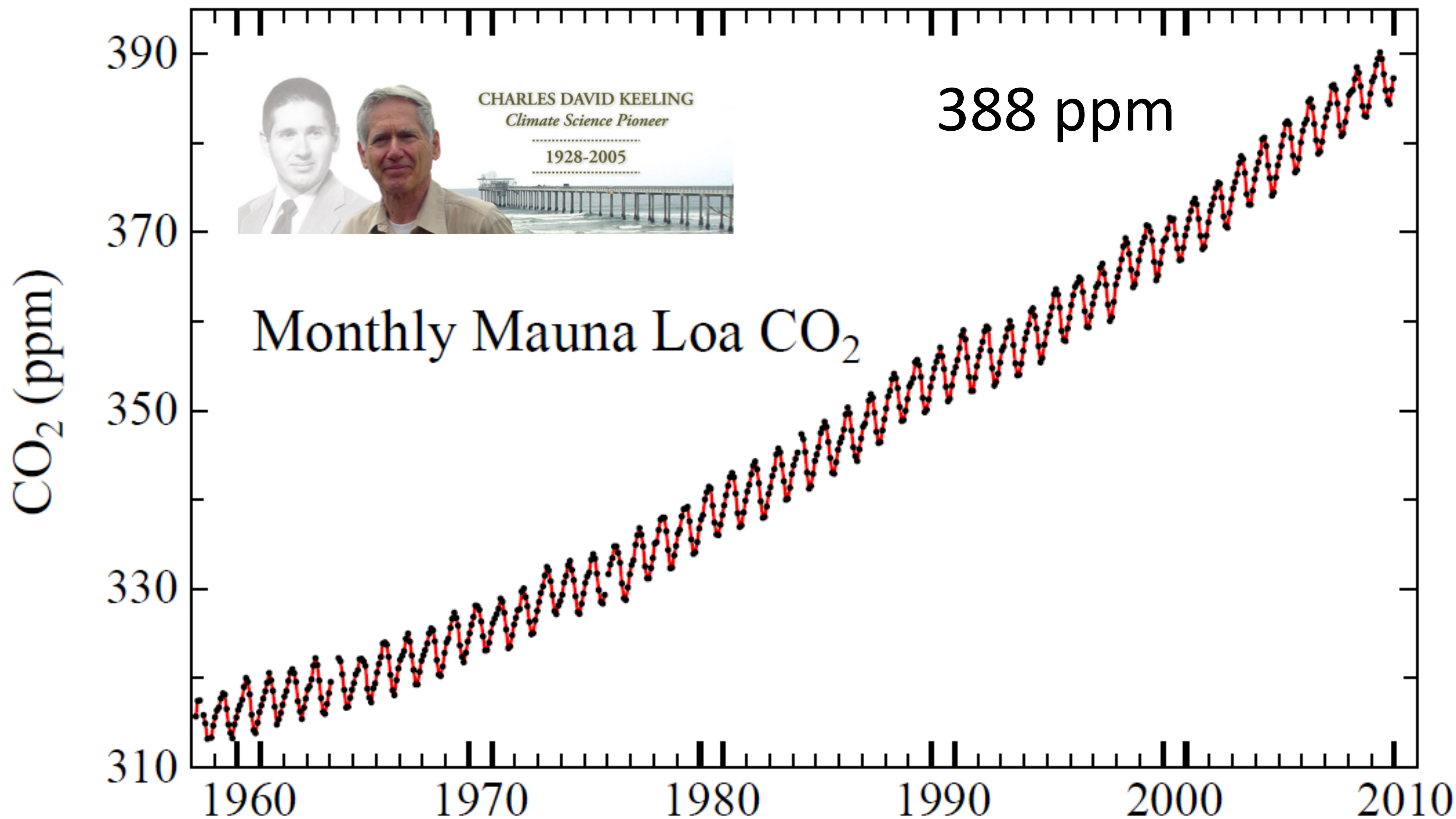
Rate of change (d y^{-1}) in the frost-free period (using a 0°C benchmark) from 1940 to 1997 (Cutforth et al. 2004, Can. J. Plant Sci. 84: 1085–1091).

Quantification of Weather Impacts

Quality variable	Cultivar	r^2	Equation
Thousand kernel weight	AC Barrie	0.66***	TKW = −0.53 × S_t24_Plant-Anth_Grp1 + 0.03 × Rain_Plant-Anth_Grp2 − 0.92 × Trange_avg_Anth-Mat_Grp1 + 47.96
	Superb	0.37***	TKW = 0.13 × HarWU_SD-Mat − 0.86 × S_t26_Plant-Anth_Grp1 + 36.53
Flour protein	AC Barrie	0.49***	Flour protein = −0.05 × S_t15_All − 0.03 × HarWU_Anth-Mat − 0.03 × S_t27_Plant-Anth_Grp1 + 21.81
	Superb	0.40**	Flour protein = −0.09 × S_t17_Plant-Anth + 0.48 × S_t30_Plant-Anth_Grp1 + 0.03 × BR3WUDef_Plant-Anth_Grp2 + 16.73
Soluble protein	AC Barrie	0.44***	Soluble protein = −0.17 × S_t27_Plant-Anth_Grp2−0.63 × S_t20_Anth-Mat_Grp2 + 0.38 × Trange_avg_Plant-Anth_Grp2 + 5.96
	Superb	0.33***	Soluble protein = −0.12 × S_t25_Anth-Mat_Grp1−0.04 × $\text{Pdays}_{3-16-30}$Plant-Anth_Grp1 + 18.38
Insoluble glutenin	AC Barrie	0.40***	Insoluble glutenin = −0.03 × S_t23_Anth-Mat + S_t30_Anth-Mat_Grp1 + 3.96
	Superb	0.46***	Insoluble glutenin = −0.03 × S_t17_Plant-Anth − 0.001 × Trange_sum_Anth-Mat − 0.009 × HarWU_Plant-Anth_Grp2 + 6.79
Mixograph PDR	AC Barrie	0.41***	PDR = −0.01 × $\text{Pdays}_{4-16-27}$All + HarWUDef_All + 56.78
	Superb	0.60***	PDR = −1.199 × S_t17_Plant-Anth + 0.278 × BR3WUDef_Plant-Anth_Grp2−0.146 × BR3WUDef_Anth-Mat_Grp1 + 117.53
Mixograph PBW	AC Barrie	0.47***	PBW = −0.303 × S_t15_All + 0.76 × S_t30_Plant-Anth + 0.072 × HarWUDef_Plant-Anth_Grp2 + 56.35
	Superb	0.51***	PBW = 0.14 × S_t21_All − 0.67 × S_t17_Plant-Anth − 0.63 × S_t26_Anth-Mat_Grp1 + 49.83
Farinograph absorption	AC Barrie		All variables were collinear (PDays_Plant-Anth_Grp1)
	Superb	0.52***	FarAbs = −0.056 × Days_All − 0.025 × Rain_Plant-Anth − 0.420 × S_t25_Plant-Anth_Grp1 + 73.17
Farinograph stability	AC Barrie	0.48***	FarStab = 0.18 × StressDeg_All − 0.98 × S_t16_Plant-Anth_Grp2 + 38.14
	Superb	0.59***	FarStab = −0.82 × S_t17_Plant-Anth + 0.47 × $\text{Pday}_{7-24-29}$Plant-Anth + 1.02 × BR3WUDef_Anth-Mat_Grp2−125.66

Best 3-variable regressions for wheat quality from producer field samples. (Jarvis et al. 2004, J. Sci. Food Agric. 88: 2357-2370).

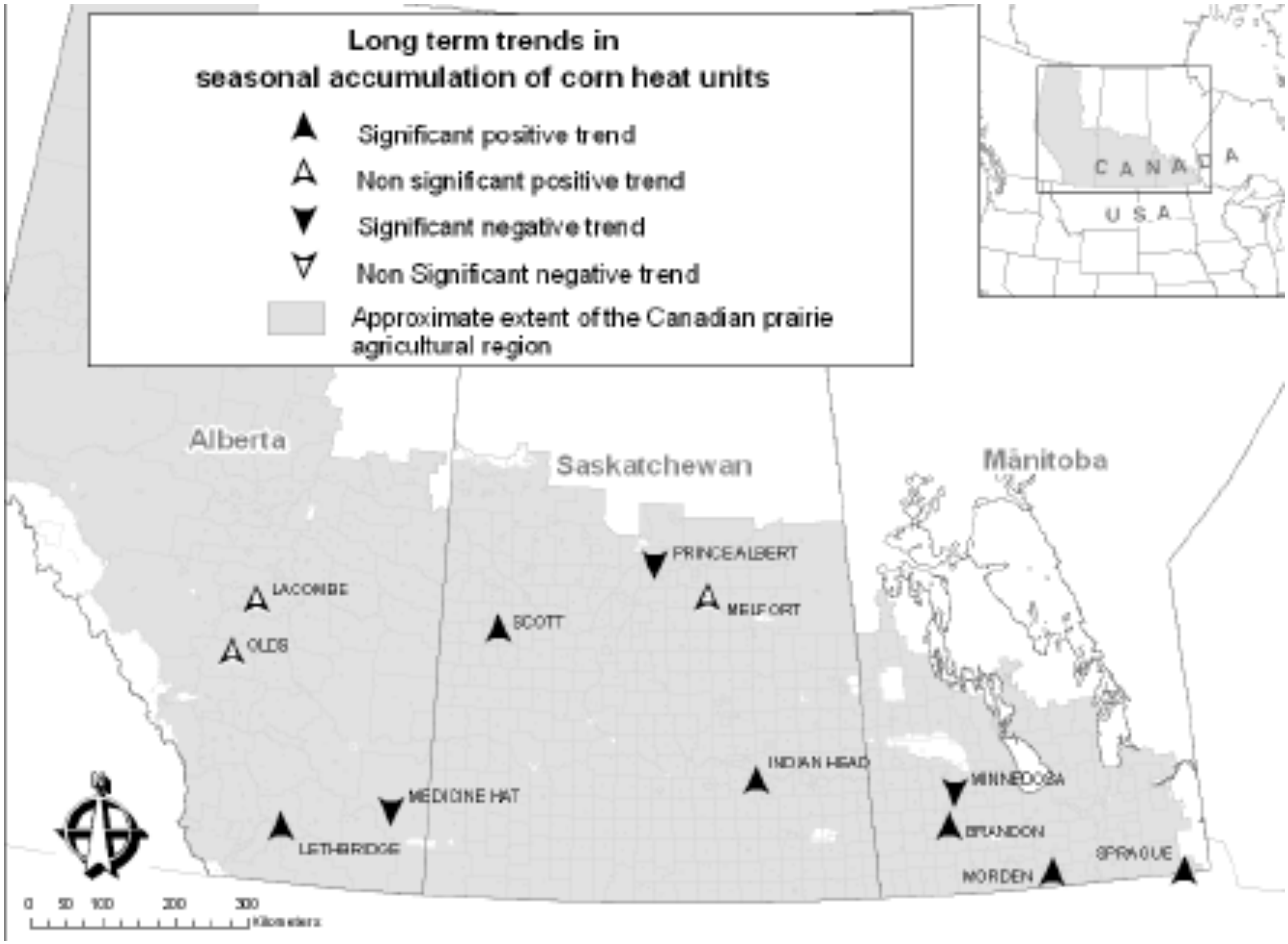
The “Keeling Curve”



http://www.columbia.edu/~mhs119/

Warmer Temperatures = Increased Thermal Time Units

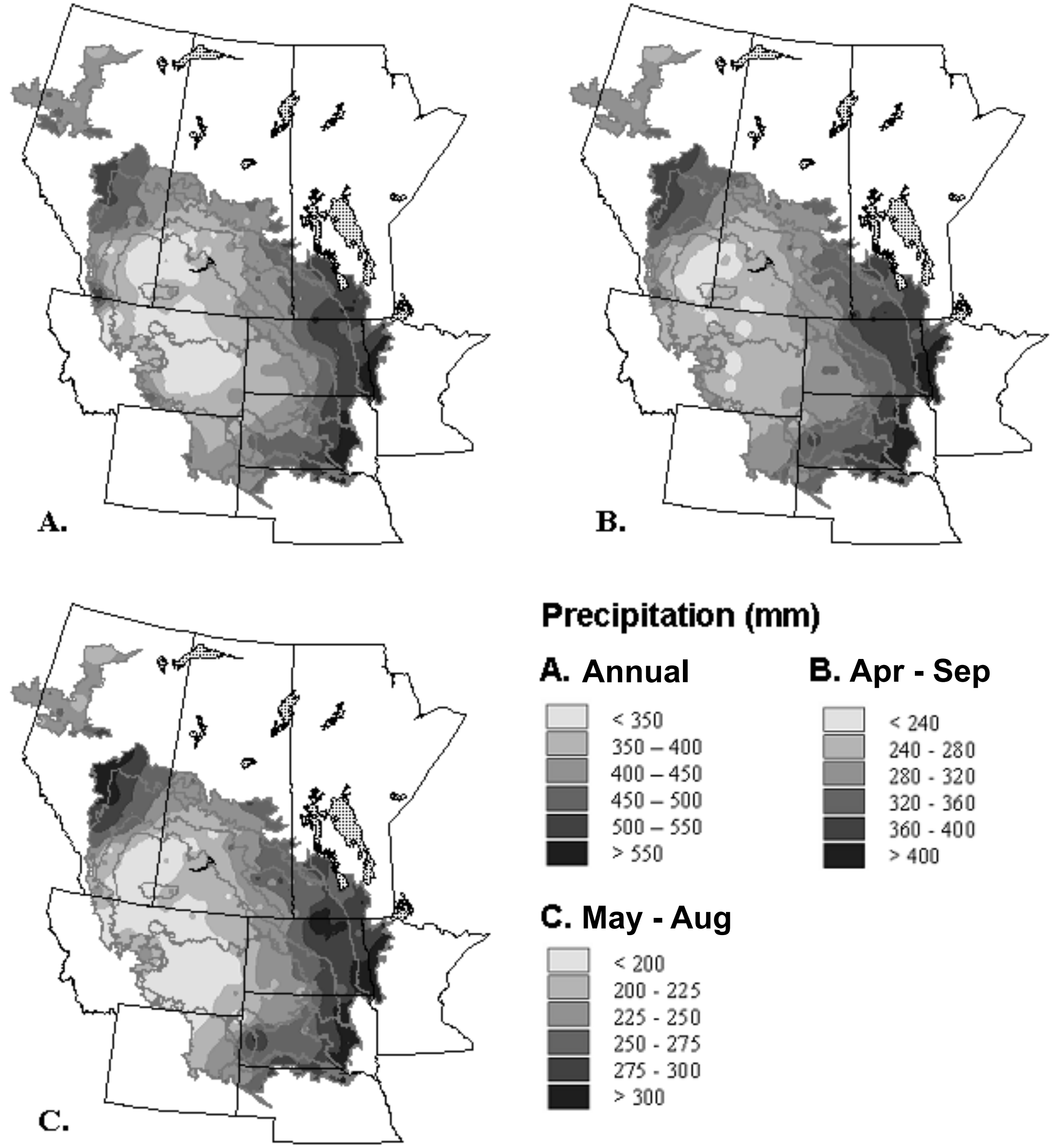
Change in area with average accumulated corn heat units (CHU) greater than 2000 in the province of Alberta over the 20th century.
(Shen et al. 2005, J. Appl. Meteorol. 44(7): 1090–1105).

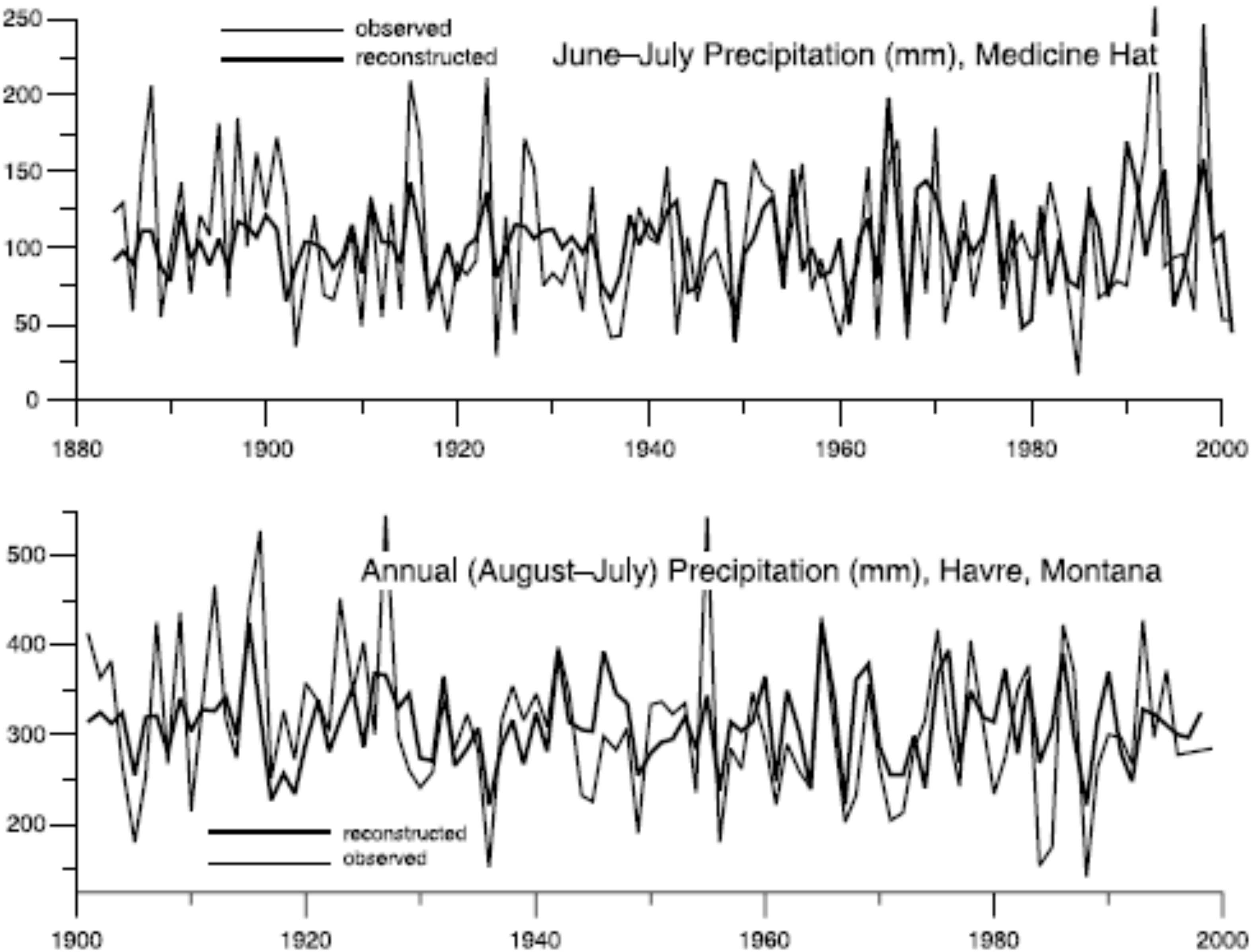


Long-term trends (1920's to 2000) in growing season accumulation of corn heat units at 12 locations across the Canadian Prairies (Nadler and Bullock, 2010, Clim. Change, accepted).

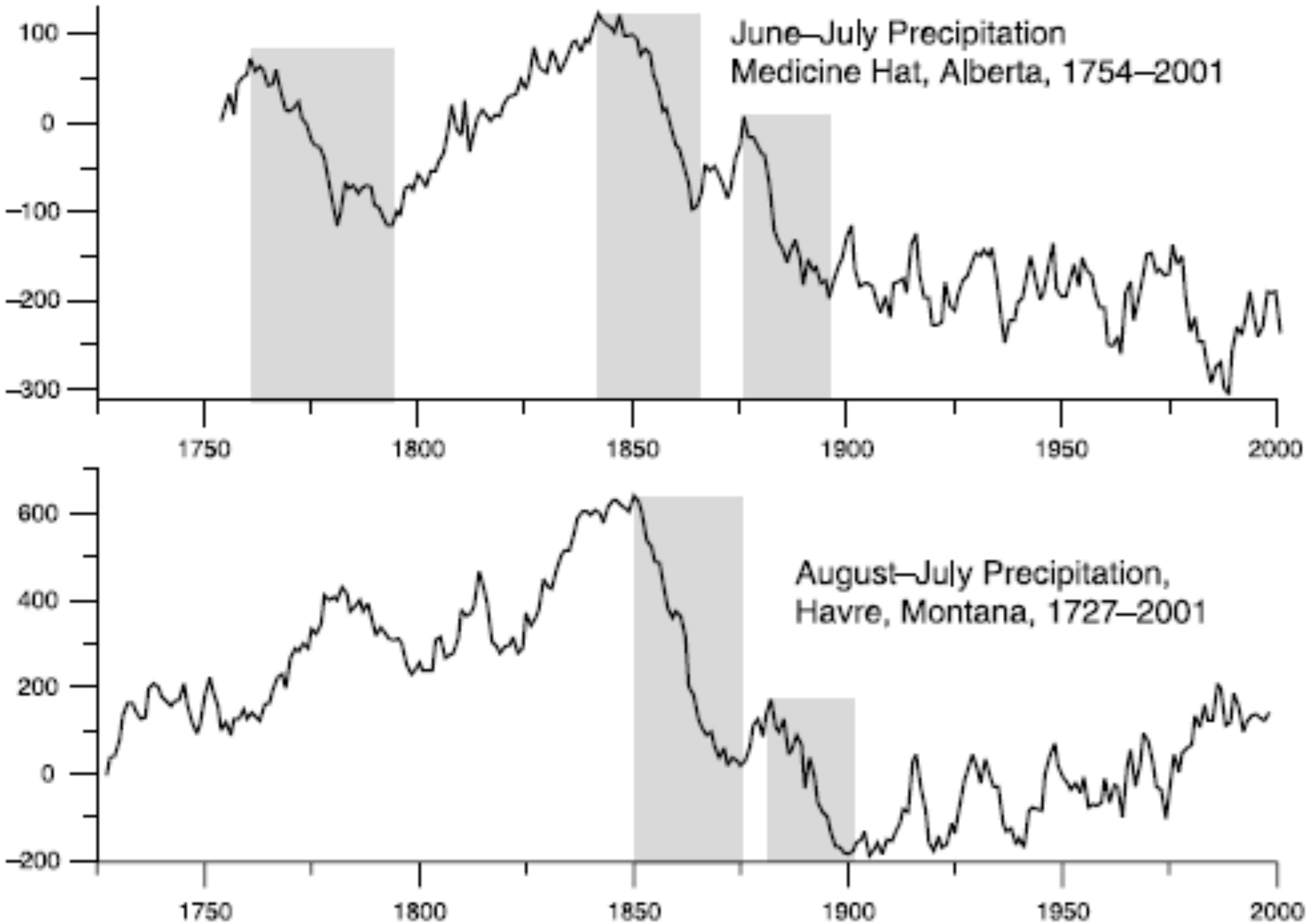
Precipitation on the northern Great Plains based on weather station data for 1971 to 2006.

Bullock et al, 2010, In <u>Recent Trends in Soil Science and Agronomy Research in the Northern Great Plains of North America</u> (Malhi, et al., eds.), Research Signpost, Kerala, India.

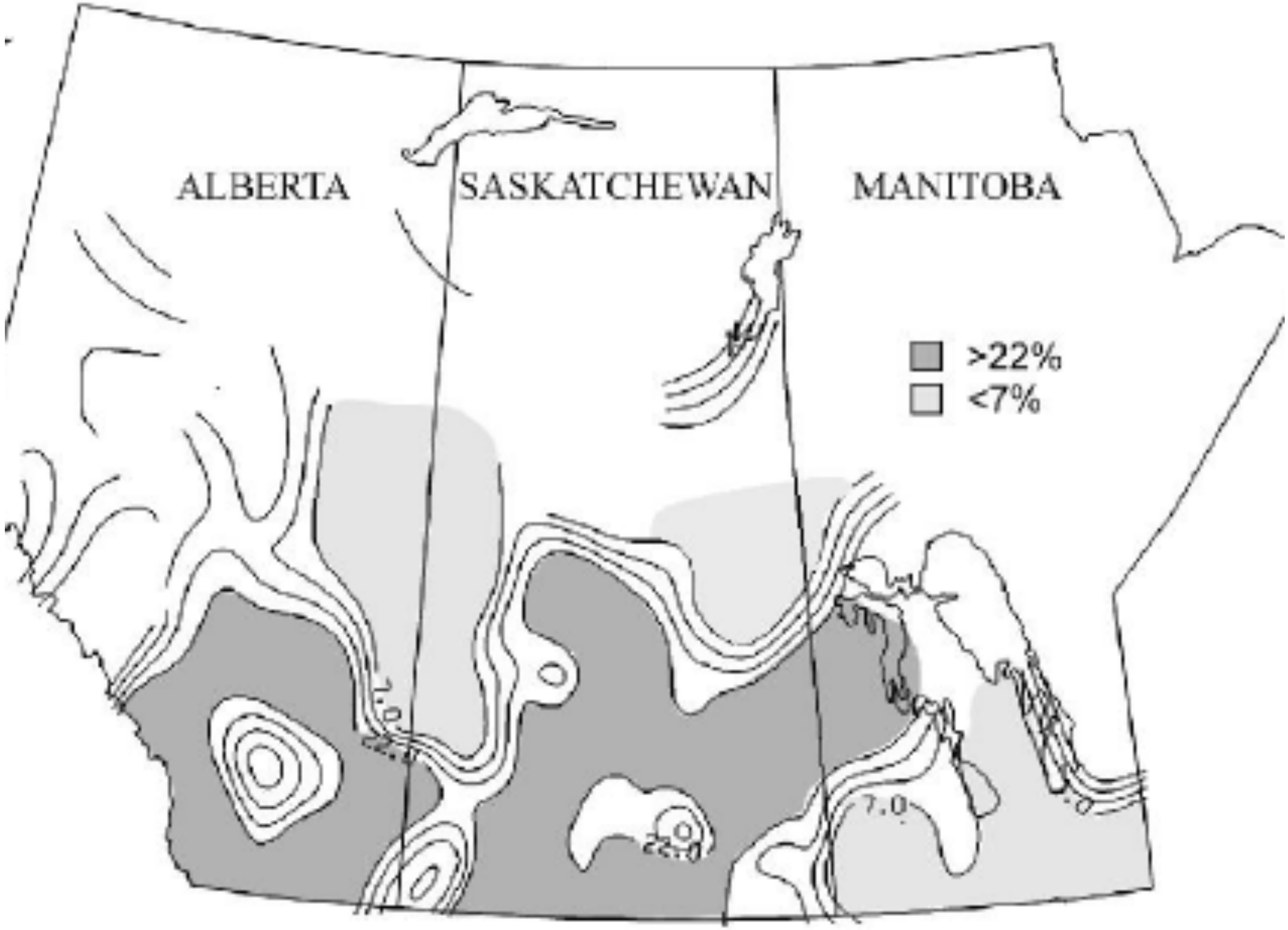




Observed precipitation versus precipitation reconstructed from tree rings (Sauchyn et al, 2001, Geog. J. 169: 158-167).



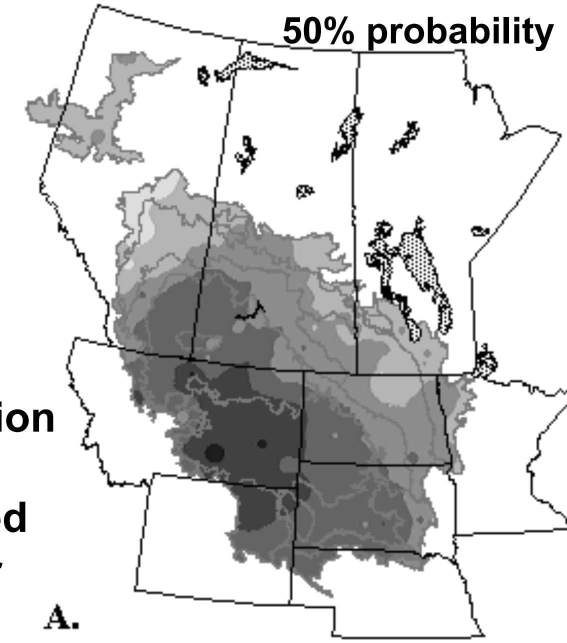
Cumulative departure from median precipitation. Long periods of consistent drying (grey highlights) preceded the 20th century and most of the instrumental weather records (Sauchyn et al, 2001, Geog. J. 169: 158-167).

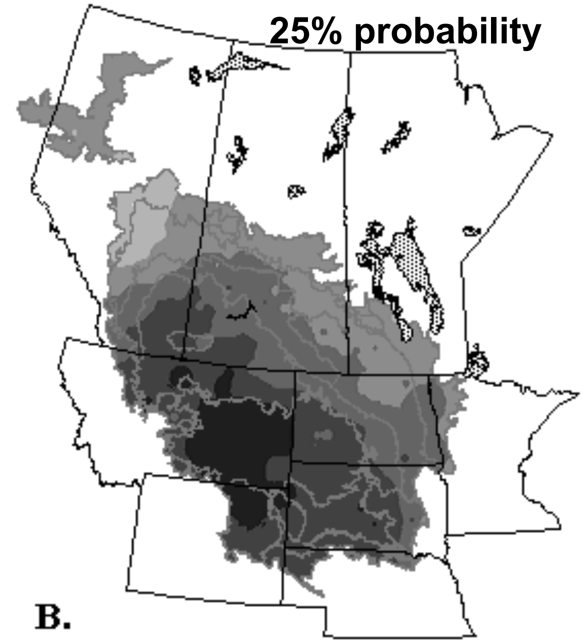


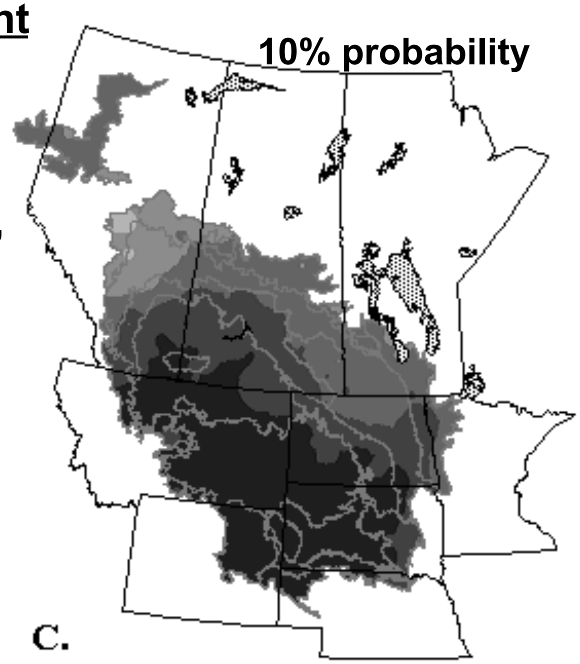
Linear trend in annual rainfall amount (% of the 40-year mean) from 1956 to 1995 across the Canadian Prairies (Akinremi et al, 2001, J. Clim. 14: 2177–2182).

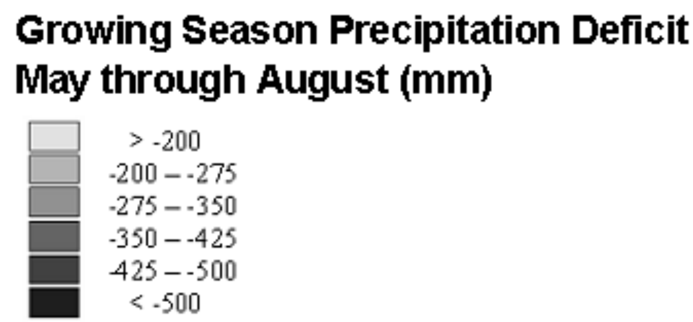
Growing season precipitation deficit (P – ETo)on the northern Great Plains based on weather station data for 1971 to 2006.

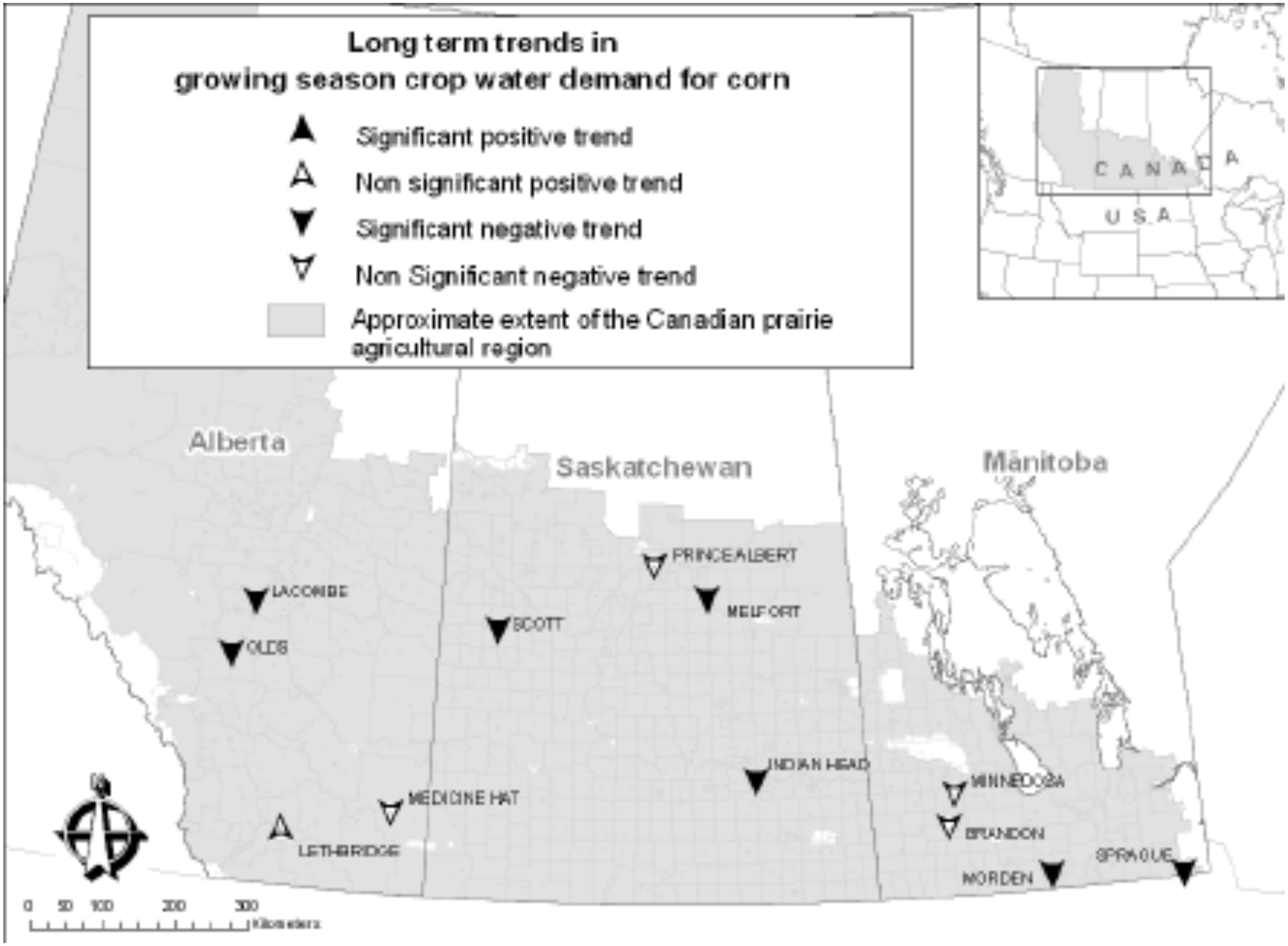
Bullock et al, 2010, In Recent Trends in Soil Science and Agronomy Research in the Northern Great Plains of North America (Malhi, et al., eds.), Research Signpost, Kerala, India.



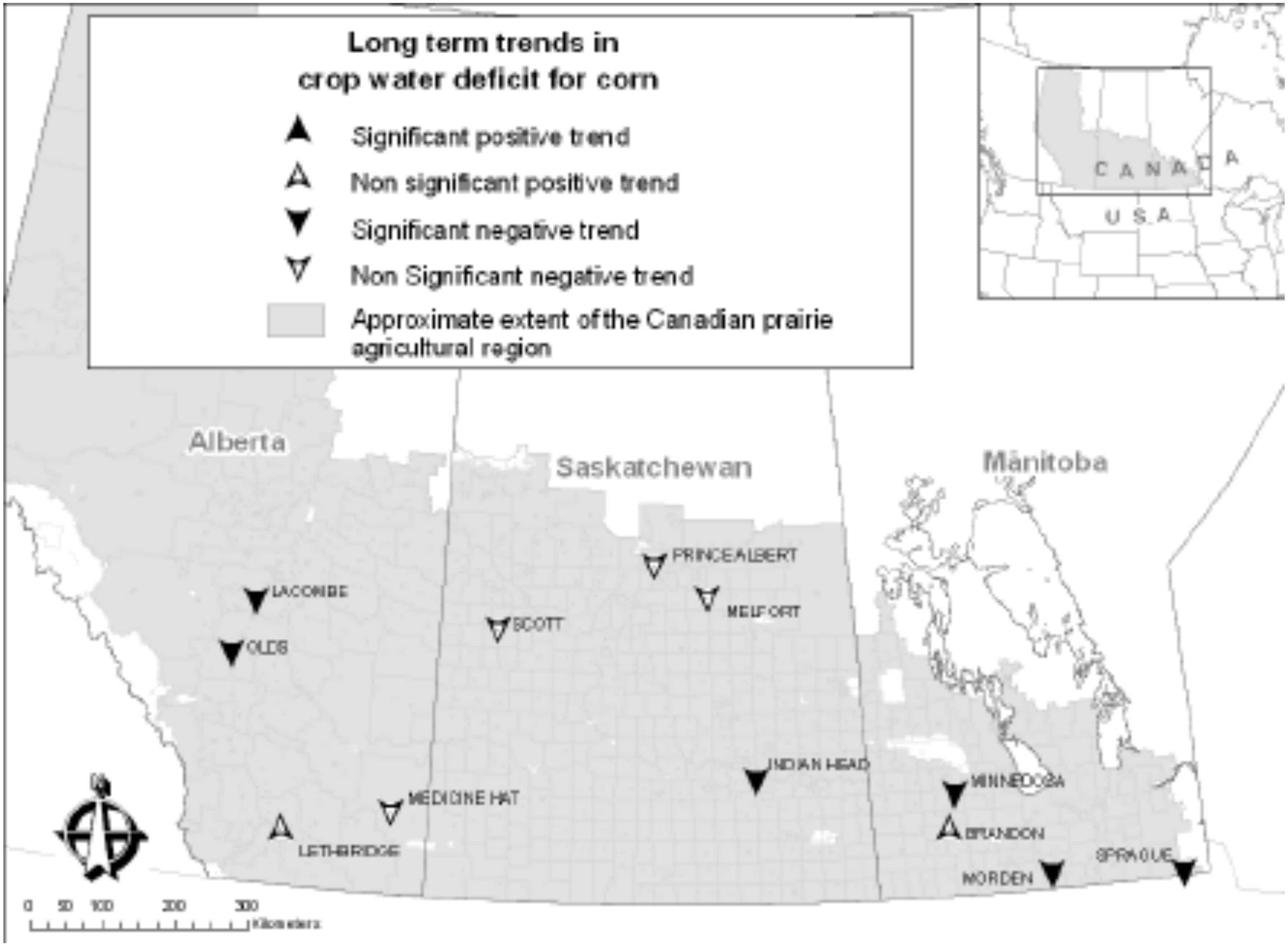








Long-term trends (1920's to 2000) in growing season crop water demand for corn at 12 locations across the Canadian Prairies (Nadler and Bullock, 2010, Clim. Change, accepted).

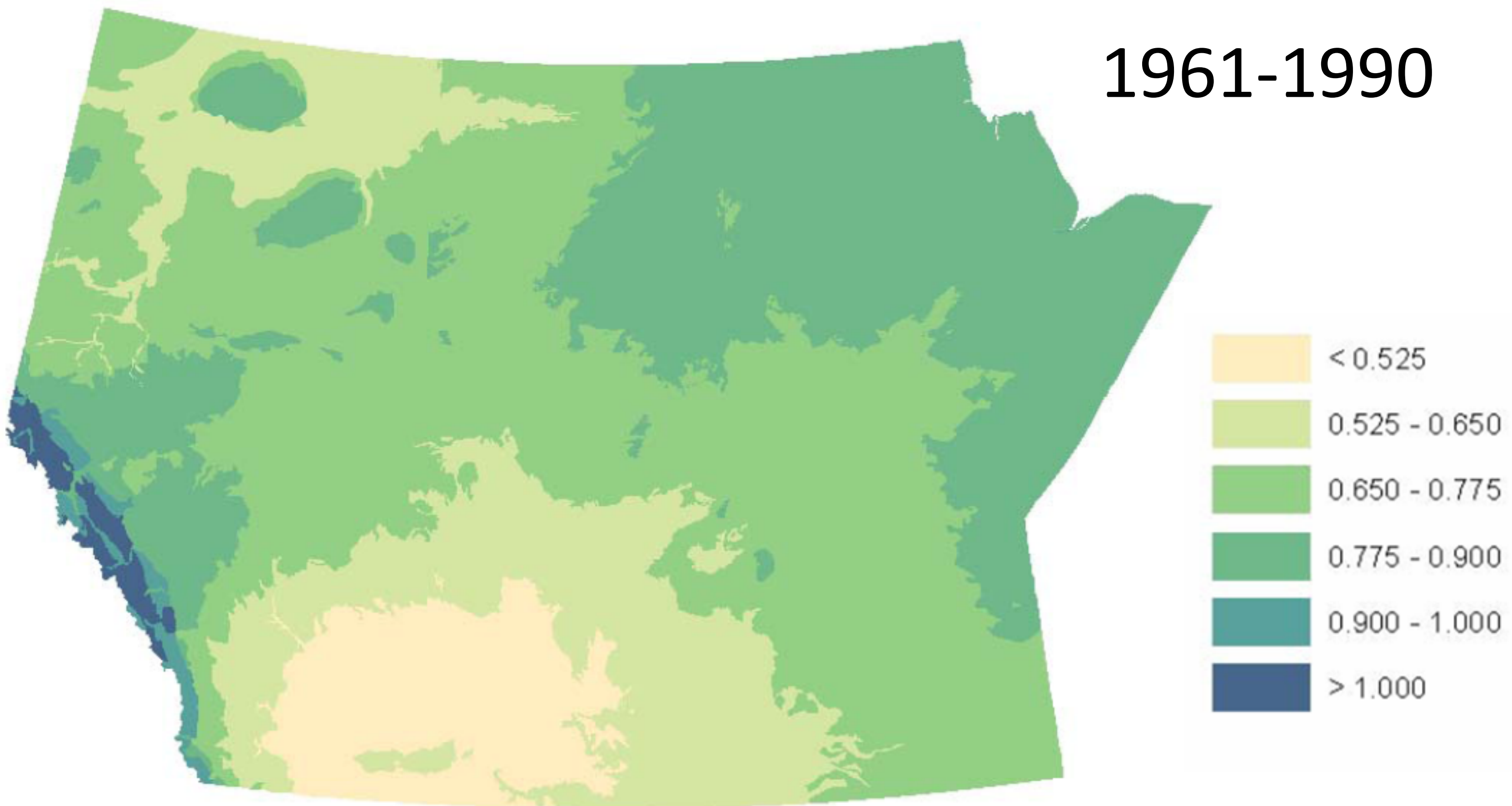


Long-term trends (1920's to 2000) in growing season crop water deficit at 12 locations across the Canadian Prairies (Nadler and Bullock, 2010, Clim. Change, accepted).

Aridity Index (P/PET)

Annual aridity index for five drought years for the agricultural zone of the prairie provinces (Sauchyn et al. 2002, Géographie physique et Quaternaire 56: 247-259).

Aridity Index (P/PET)

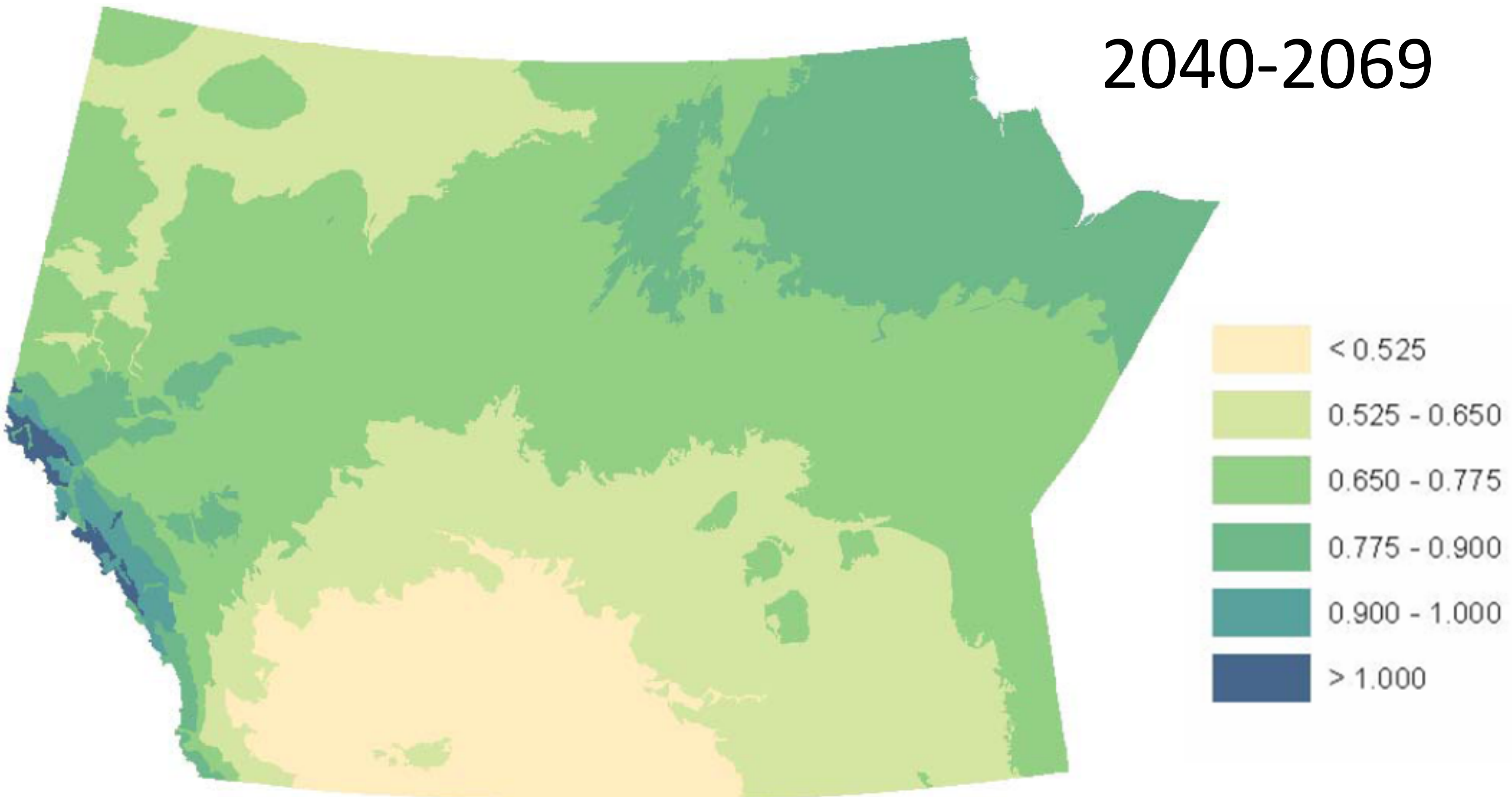


PARC

David Sauchyn

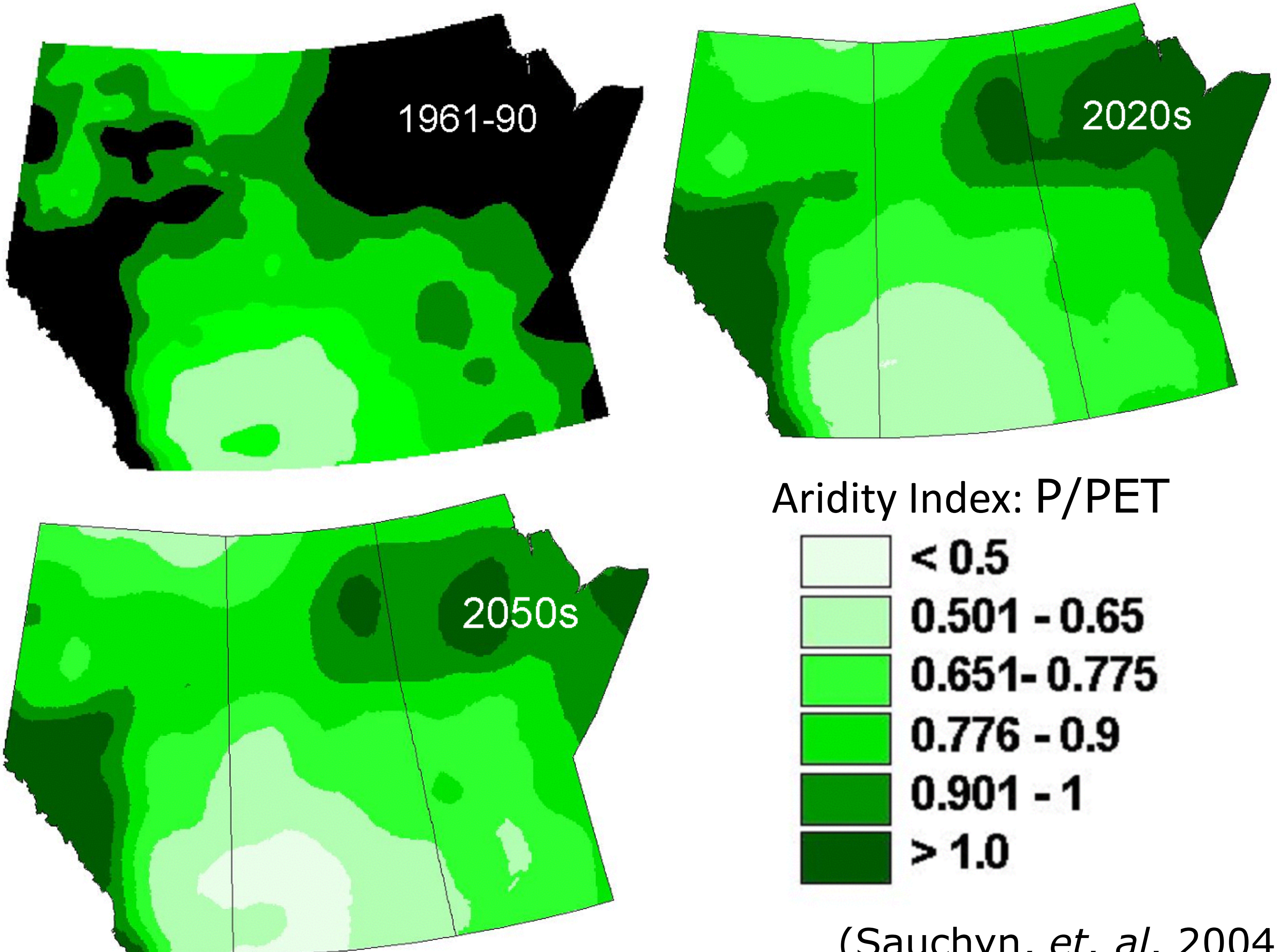
Aridity Index (P/PET)

2040-2069



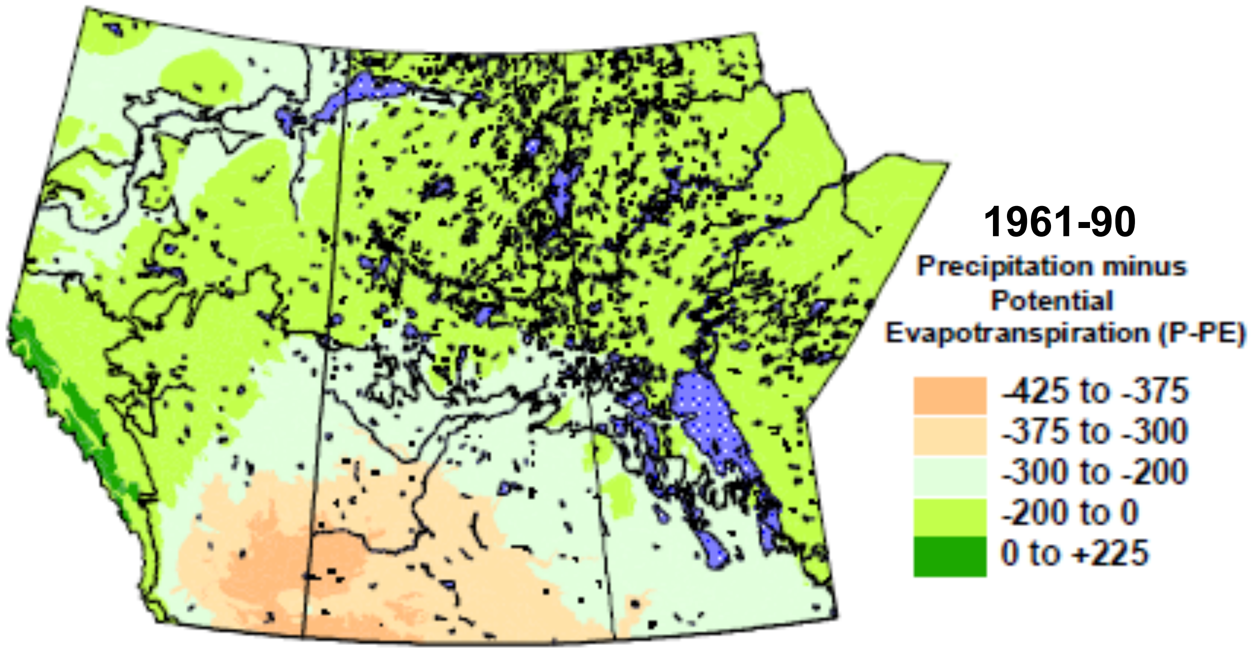
PARC

David Sauchyn

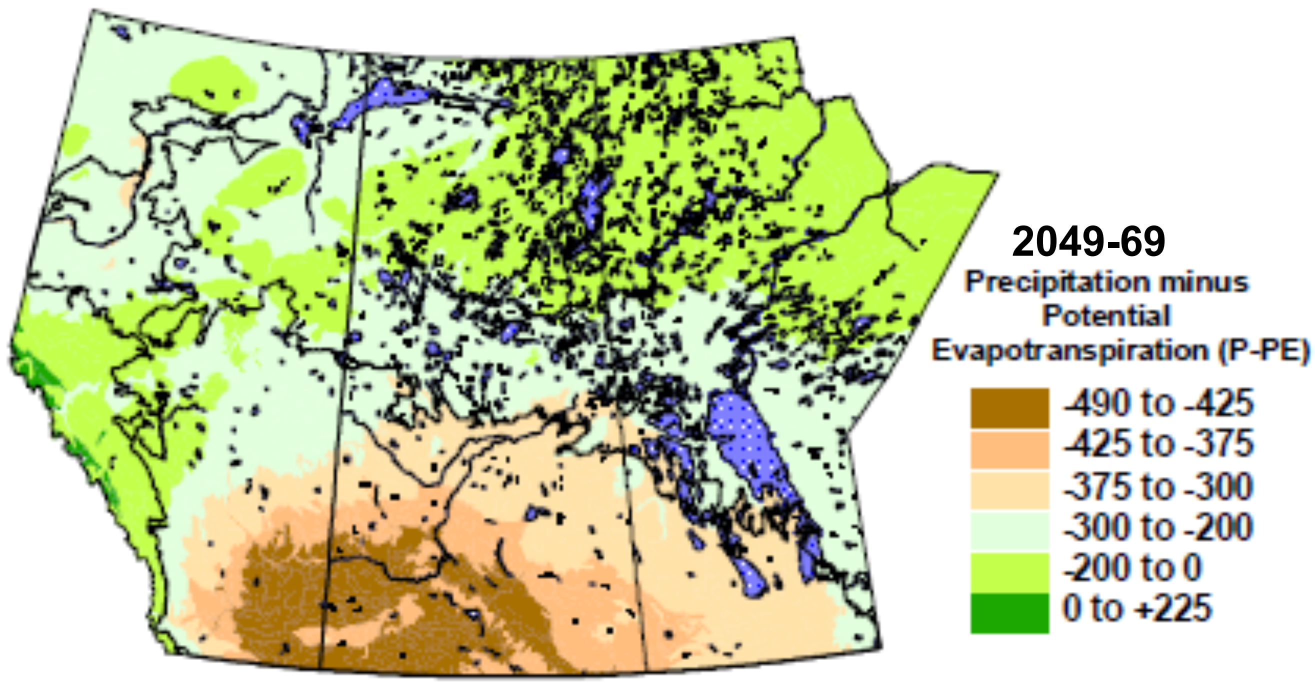


(Sauchyn, *et. al*. 2004)

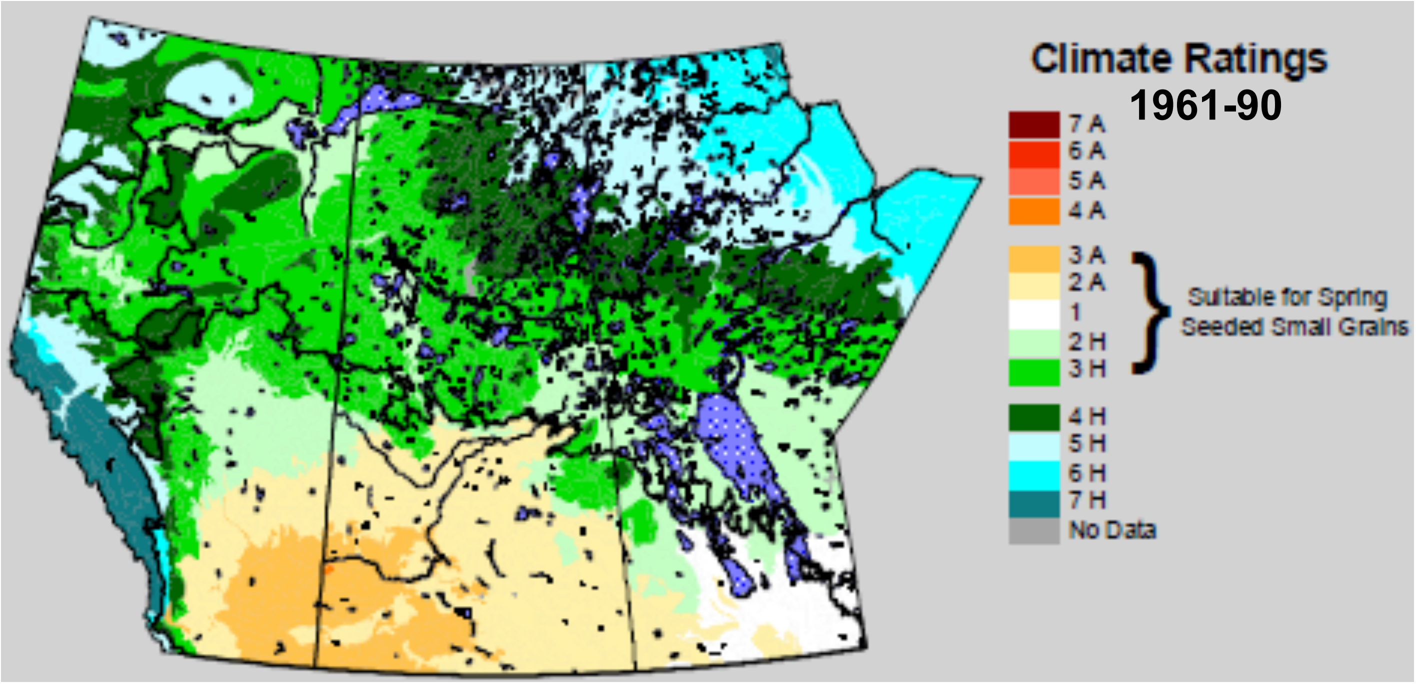
Increased precipitation deficits are forecast

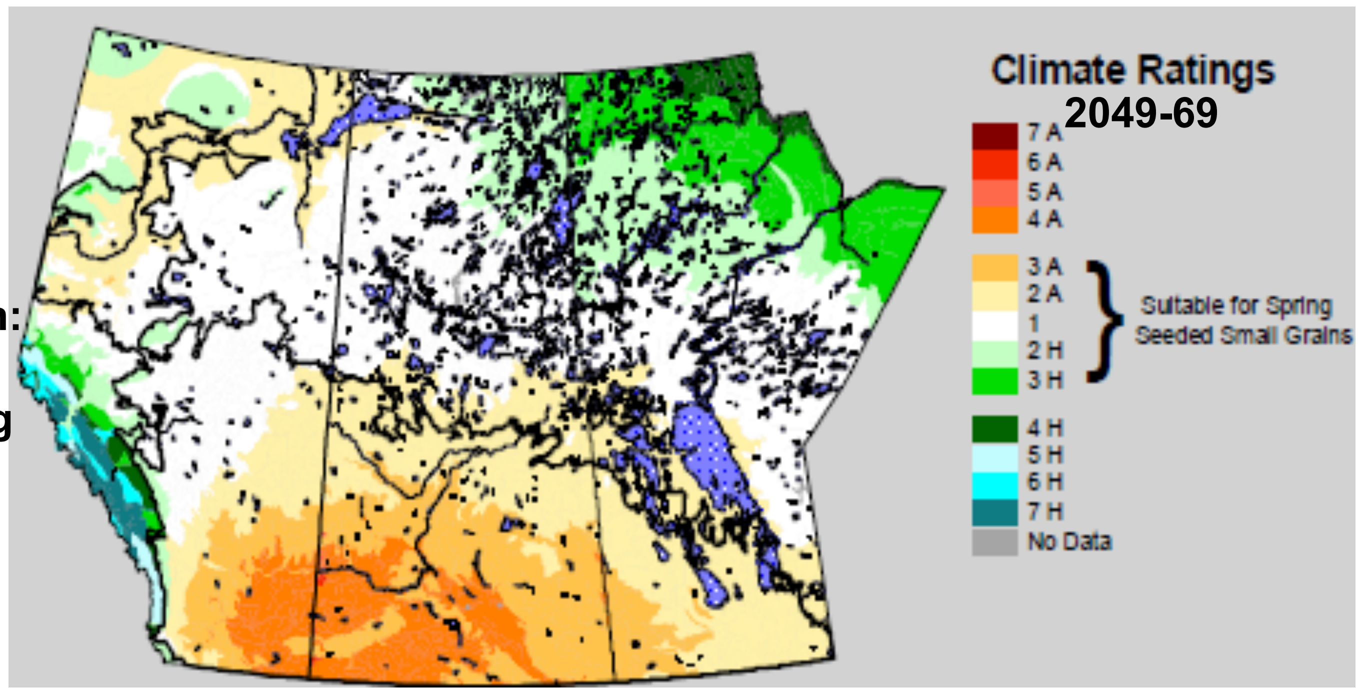


Change in precipitation deficit (P – PE) based on projected changes in temperature and precipitation from the CGCM1.
Nyirfa and Harron, 2001, In: PARC QS-3 Determination of sustainability of farming practices on the Prairies with predicted climate change scenarios. Agriculture and Agri-Food Canada, Regina.



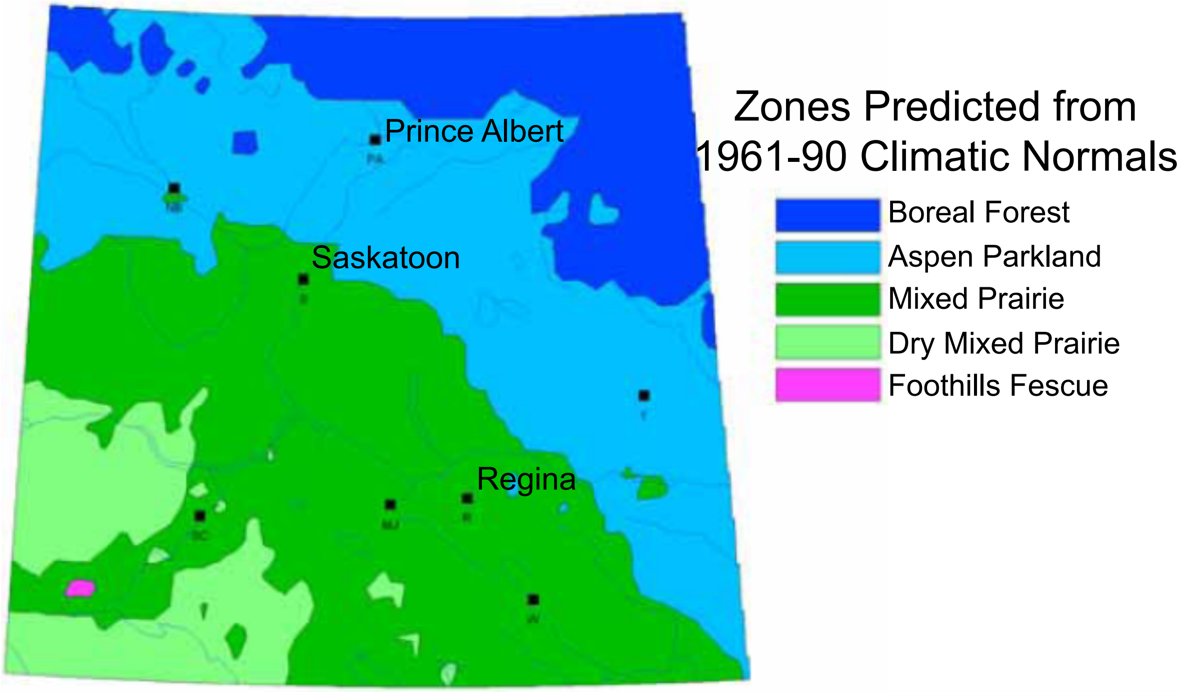
Climate suitability forecast to shift from too cool to too dry

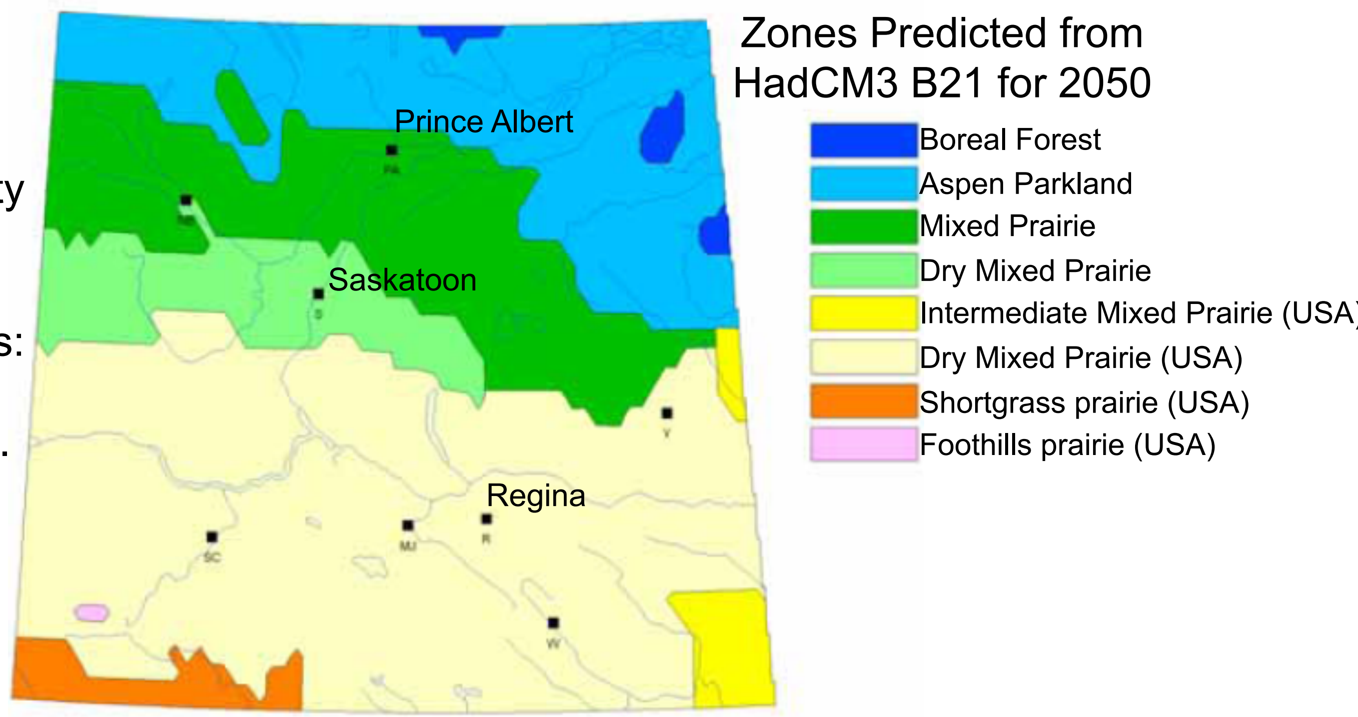




Land suitability climate classification based on projected changes in temperature and precipitation from the CGCM1. Nyirfa and Harron, 2001, In: PARC QS-3 Determination of sustainability of farming practices on the Prairies with predicted climate change scenarios. Agriculture and Agri-Food Canada, Regina.

Ecozones predicted to shift northward



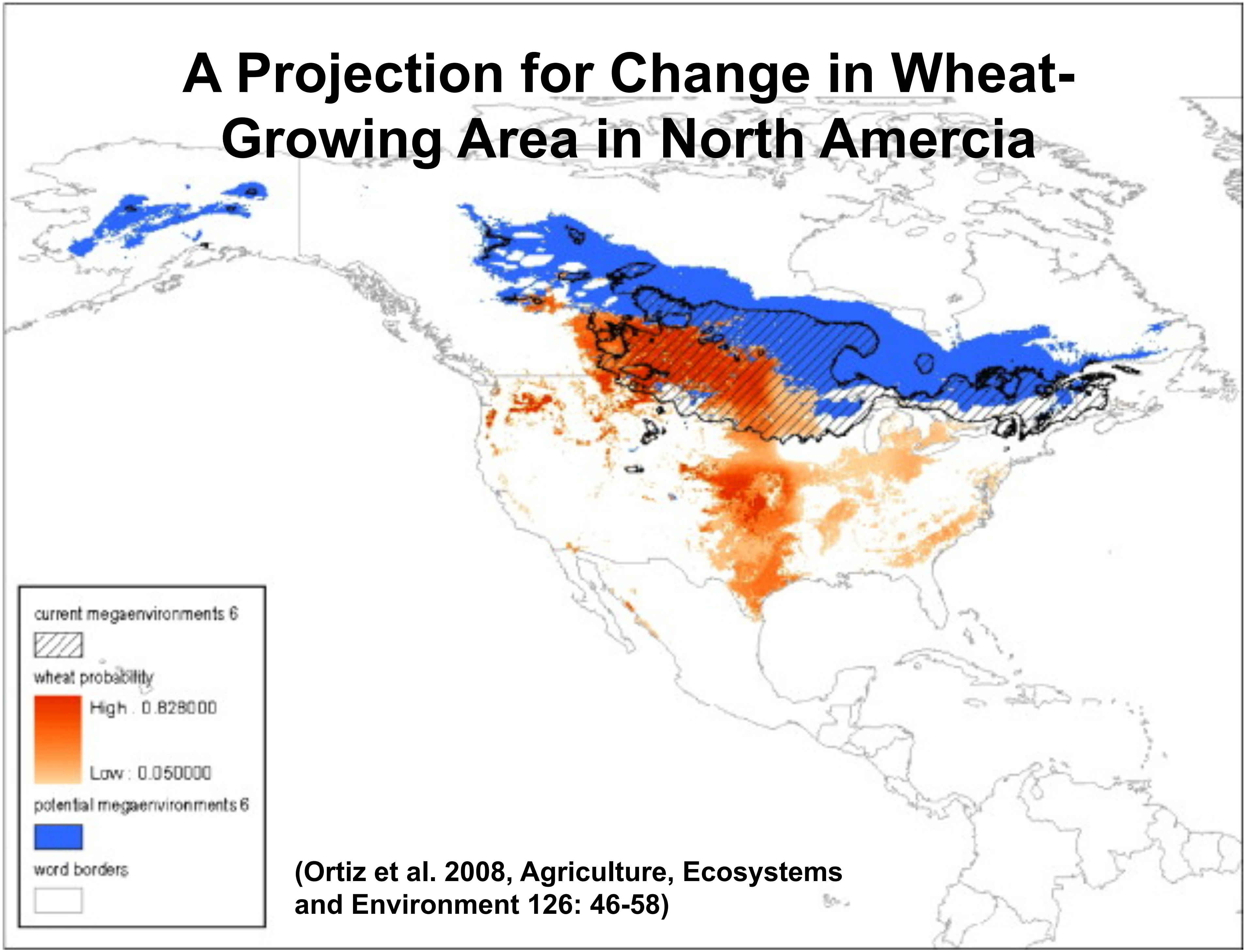


Vandall et al. 2006. Suitability and adaptability of current protected area policies under different climate change scenarios: the case of the Prairie Ecozone, Saskatchewan. Sask. Res. Coun. Publ. No. 11755-1E06

Increased Temperature Effects

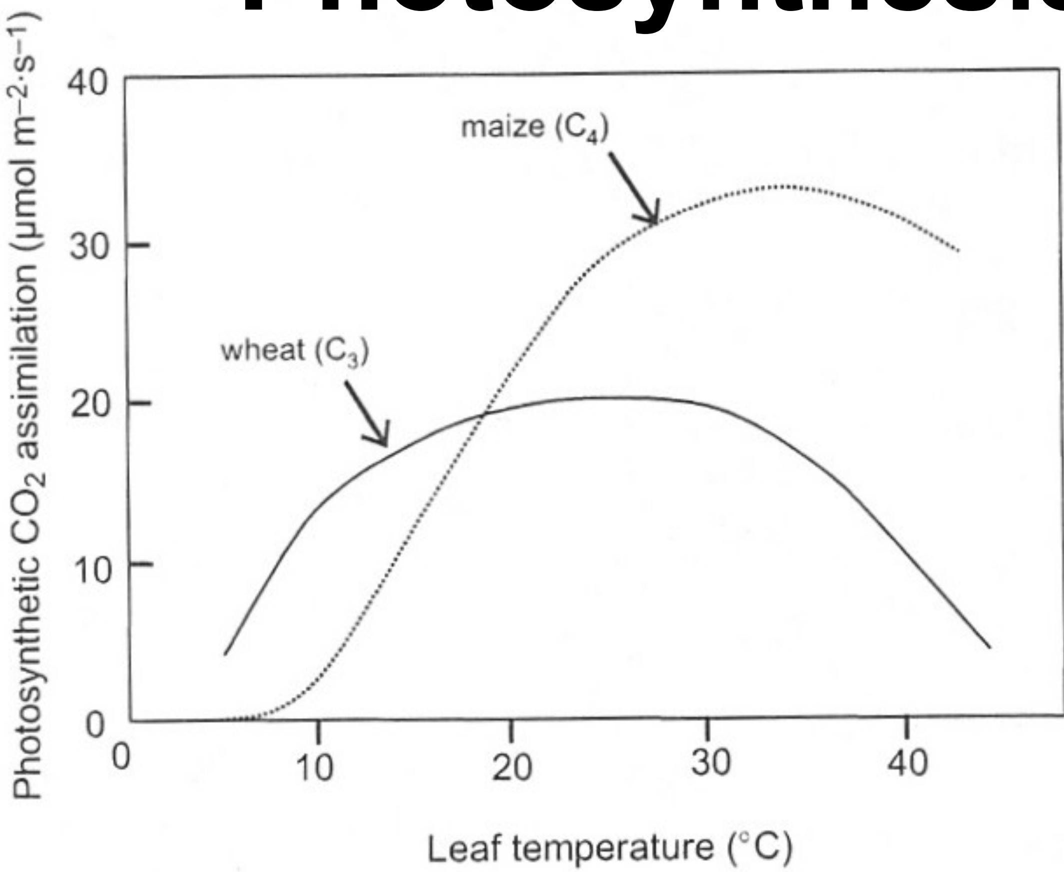
- Shift in area of favorable climate for crops
- Closer to optimum for C4 photosynthesis
- Decreased root:shoot biomass ratio
- Increased root growth → increased water and nutrient uptake
- Increased pest pressure
- Decreased time from flowering to maturity (reduced filling period → lower grain yield)

A Projection for Change in Wheat-Growing Area in North Amercia

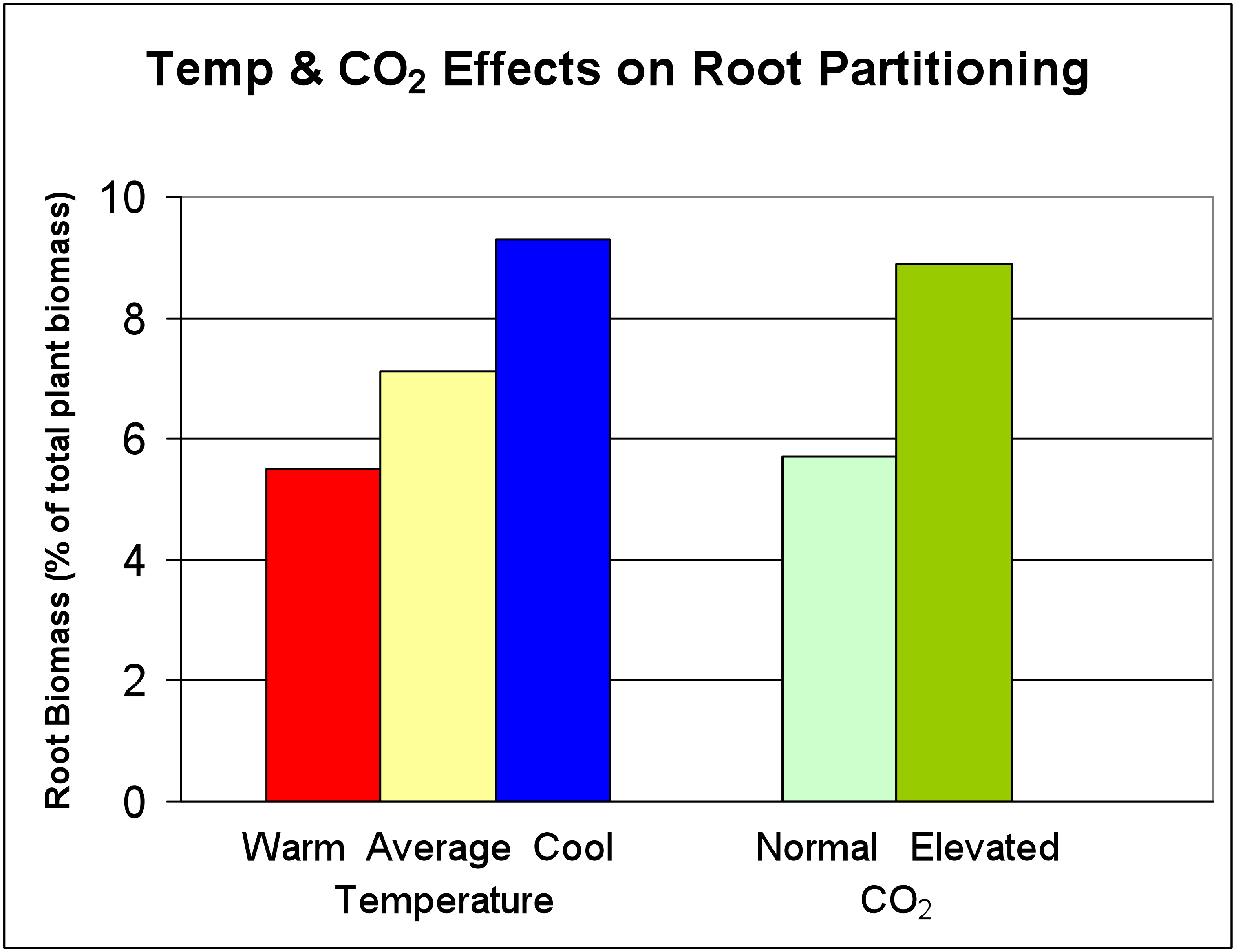


(Ortiz et al. 2008, Agriculture, Ecosystems and Environment 126: 46-58)

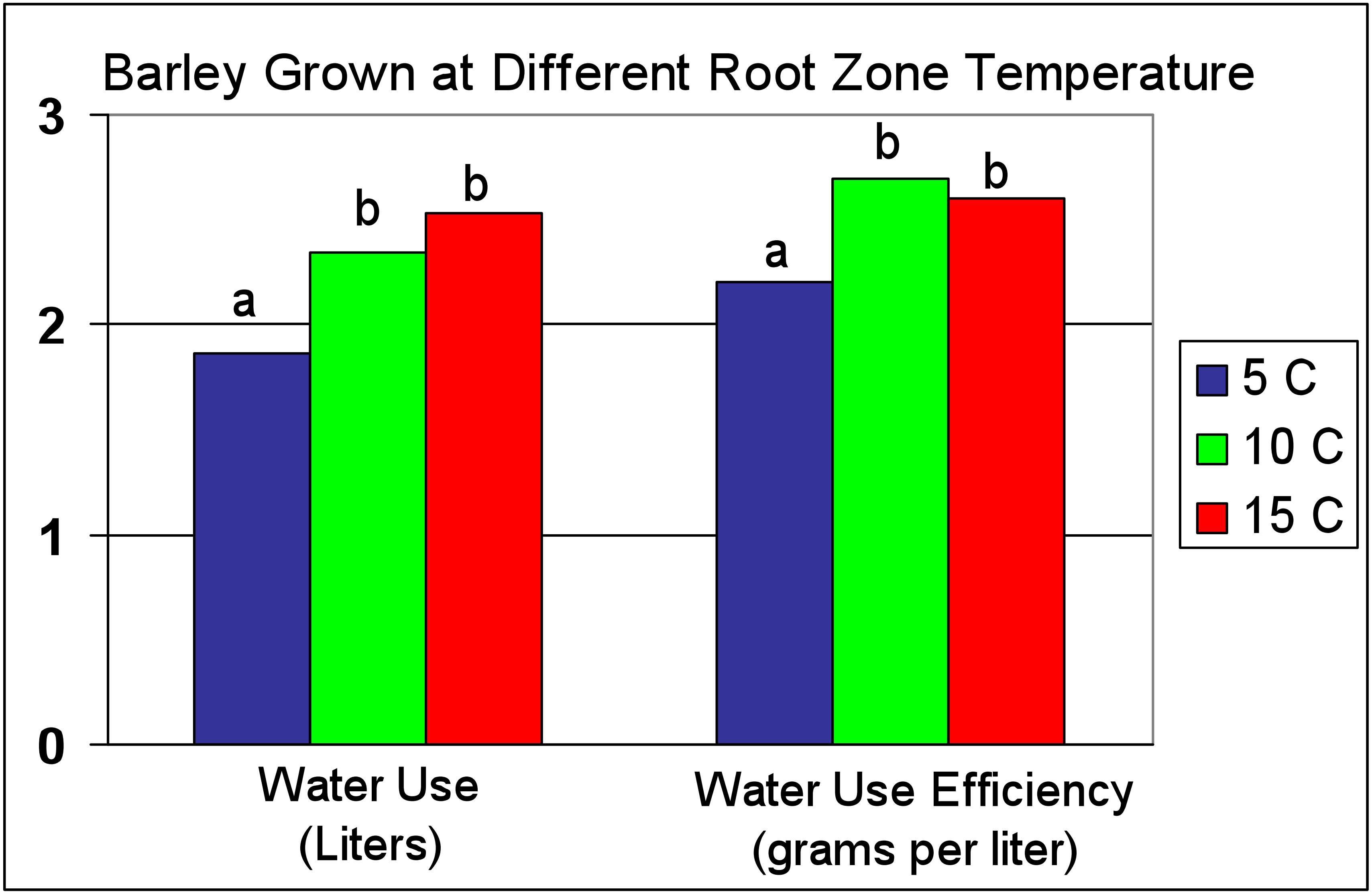
C_3 versus C_4 Photosynthesis



(Adapted from Stone, 2001, as reported in Pritchard and Amthor 2005 Crops and environmental change. Food Products Press)



Root biomass as a % of total plant biomass.
(Data from Batts et al, 1998. J. Agr. Sci. 130:17-27)



Root growth response to soil temperature within the range found in western Canada as measured by barley water use (Data from Sharratt, 1991, Agron. J. 83:237-239).

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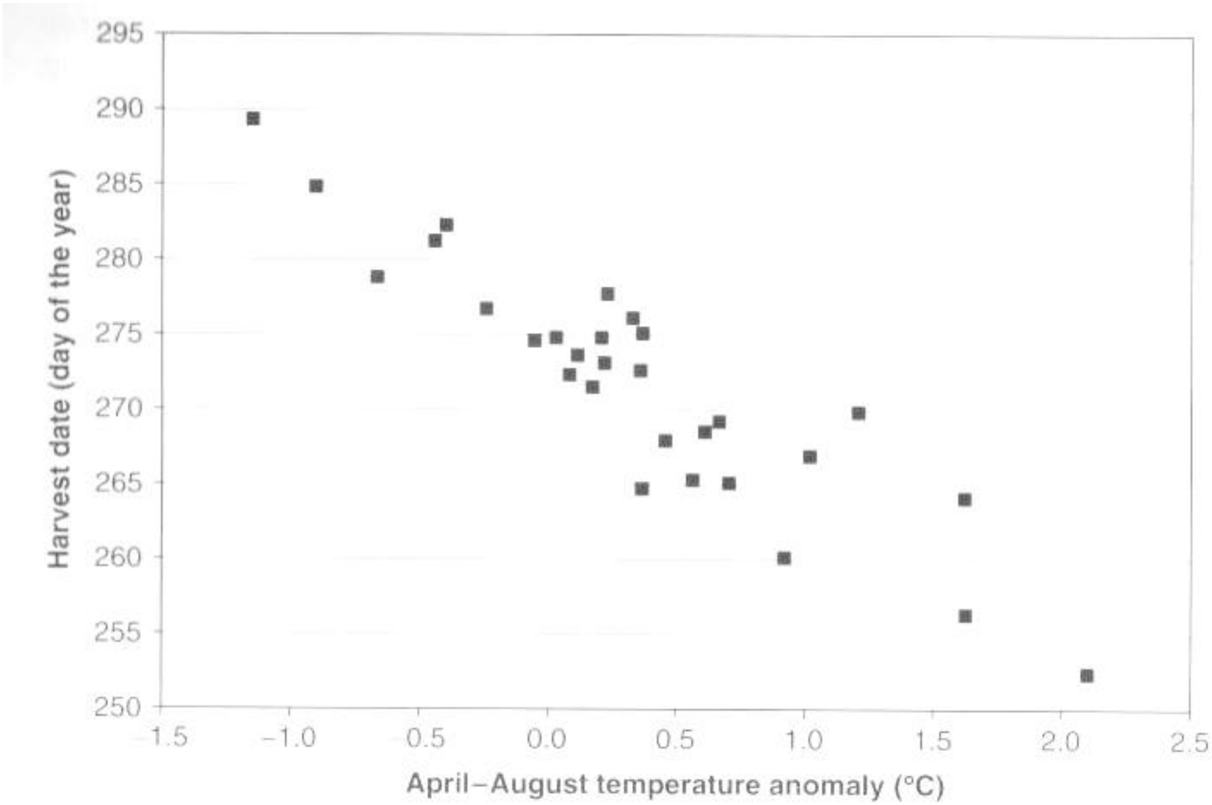
From ‘Agriculture and Climate Change’, November 2005, National Farmers Union

http://www.nfuonline.com

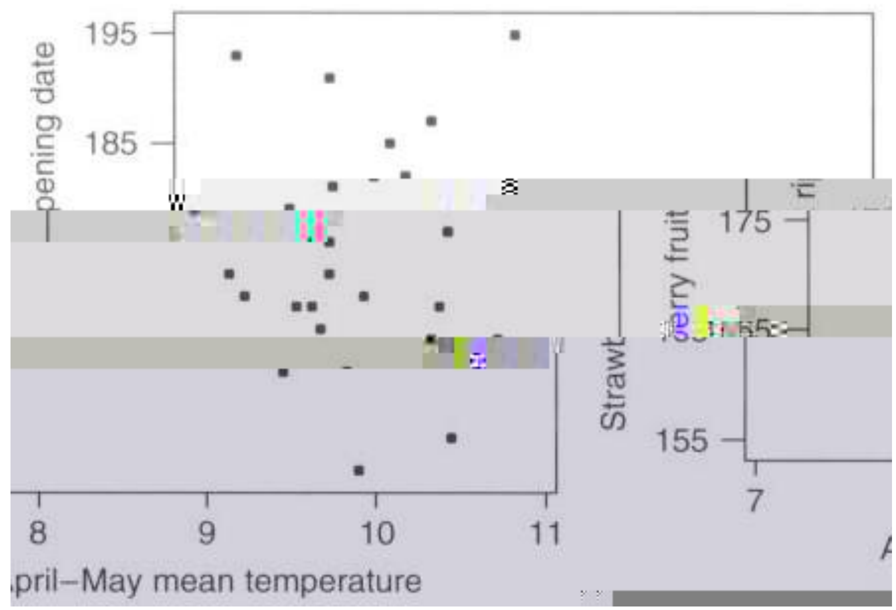


Grapevine harvest date in France, Switzerland and SW Germany in relation to April-August temperature.

(Menzel and Sparks, 2006, Chapter 4 in Plant Growth and Climate Change (Morison and Morecroft, eds.), Blackwell Publishing, Oxford).

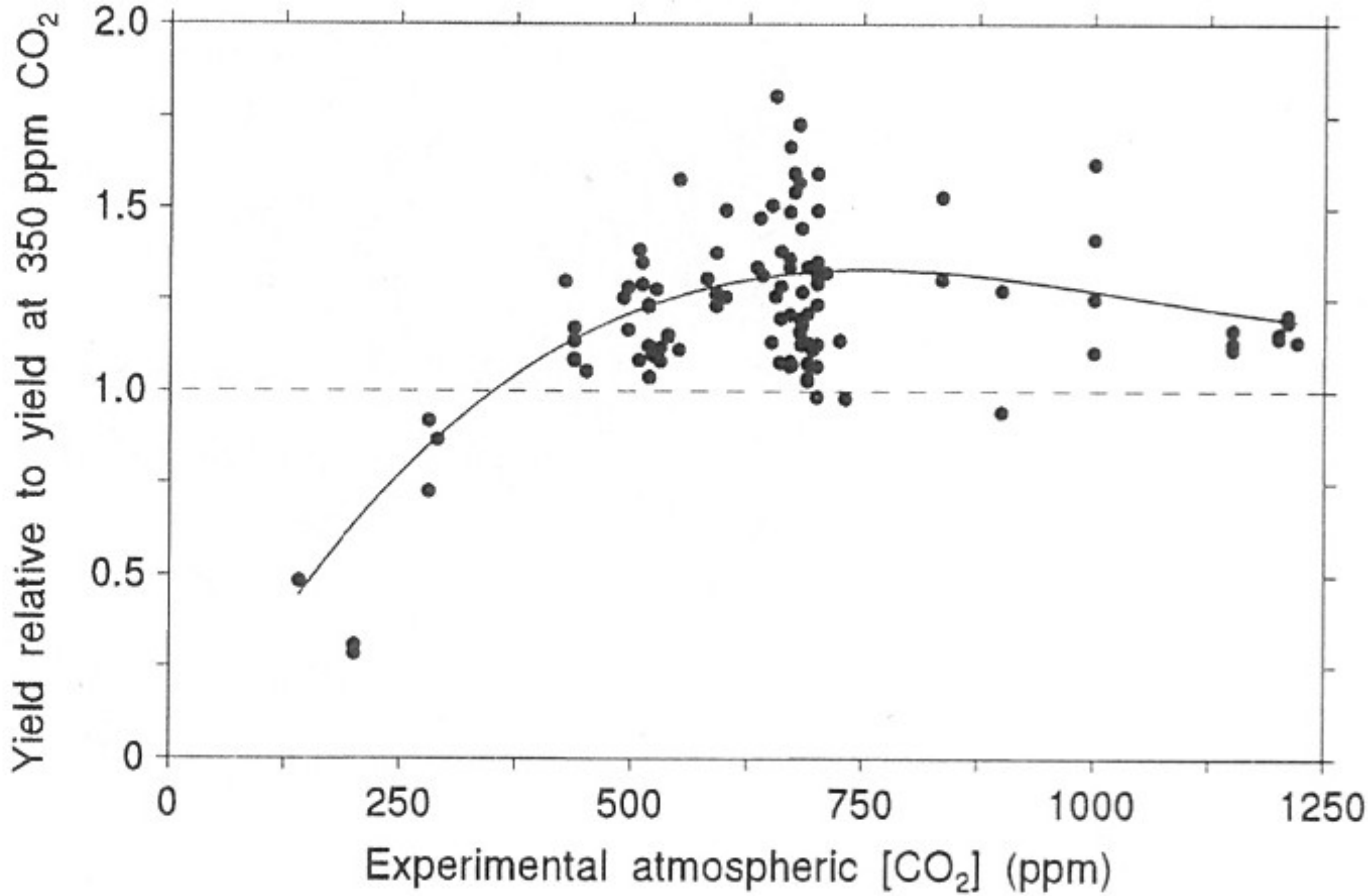
Fruit ripening dates of strawberry (1874-1902) in central England in relation to April-May temperature.

(Menzel and Sparks, 2006, Chapter 4 in Plant Growth and Climate Change (Morison and Morecroft, eds.), Blackwell Publishing, Oxford).



Increased CO_2 Effects

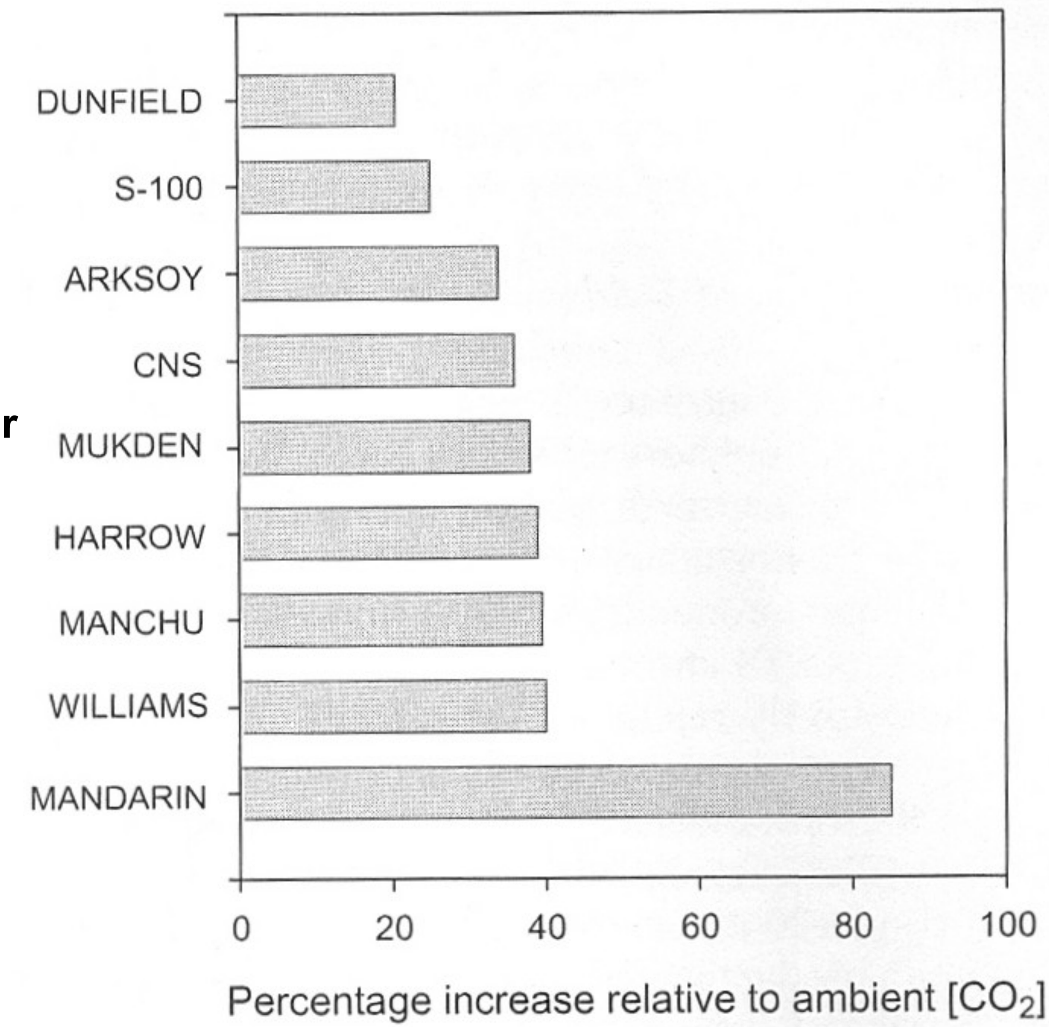
- Plant biomass production increases, especially in C3 plants
- Tends to improve water use efficiency
- Increases root:shoot biomass ratio
- Decreases mineral content in the biomass
- Increases weed growth

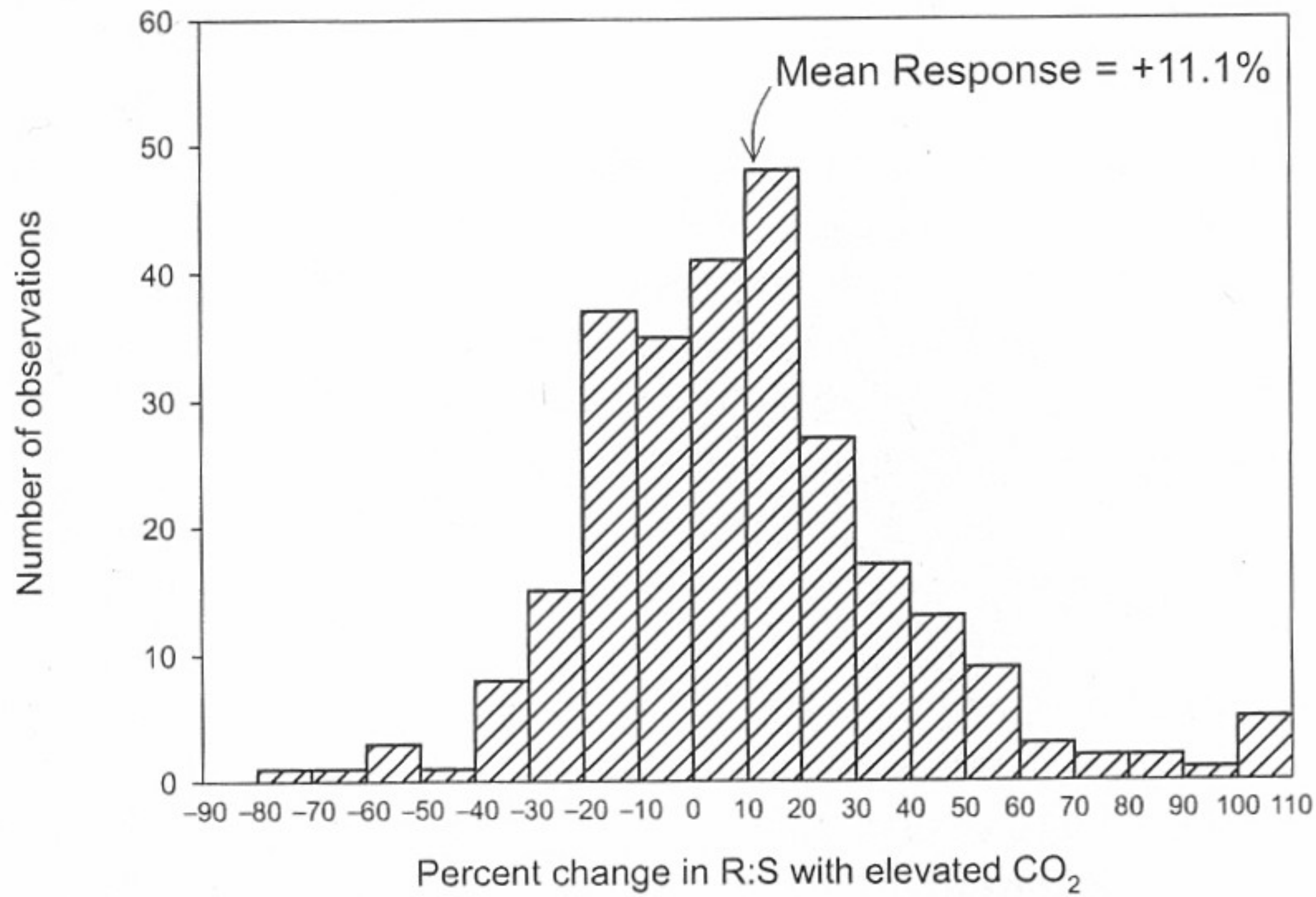


Wheat yield versus atmospheric CO_2. (Amthor, 2001, as reported in Pritchard and Amthor 2005 Crops and environmental change. Food Products Press)

% increase in yield of 9 soybean varieties grown in CO_2-enriched air compared to ambient air.

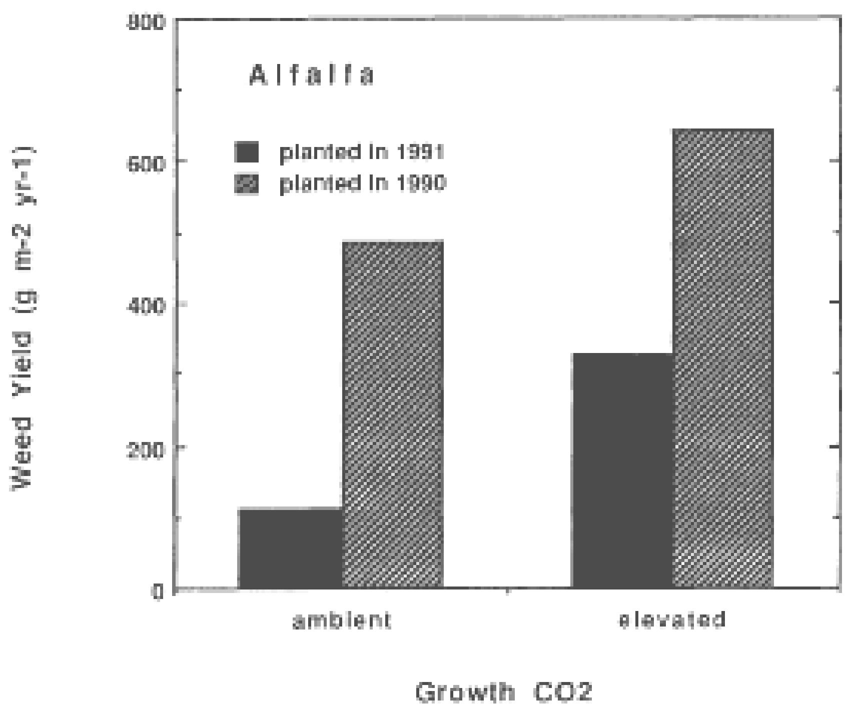
(Ziska et al, 2001, as reported in Pritchard and Amthor 2005 Crops and environmental change. Food Products Press)

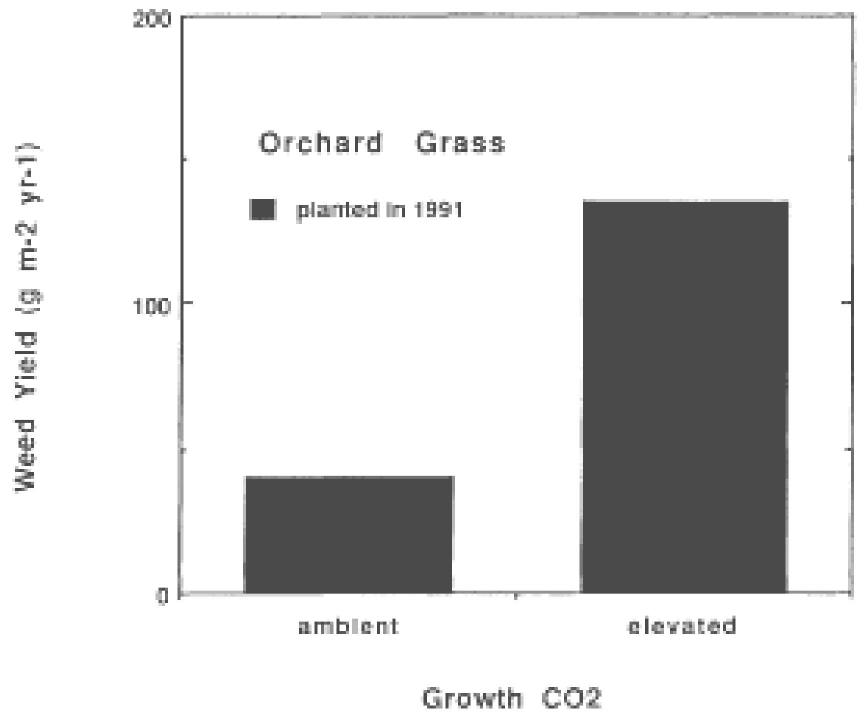




% change in root/shoot ratio for crops in CO_2-enriched atmosphere (264 observations). (Data from Rogers et al, 1996 as reported in Pritchard and Amthor 2005 Crops and environmental change. Food Products Press)

Elevated CO_2 and Weeds





Weed yield was 2 to 4 times higher in both alfalfa and orchard grass with elevated CO_2 (Bunce, 1995. J Biogeog. 22: 341).

Elevated CO_2 and Weeds

A. C_4 Crops / C_4 Weeds
  - Elevated CO_2 favors **WEED**

B. C_4 Crops / C_3 Weeds
  - Elevated CO_2 favors **WEED**
  -

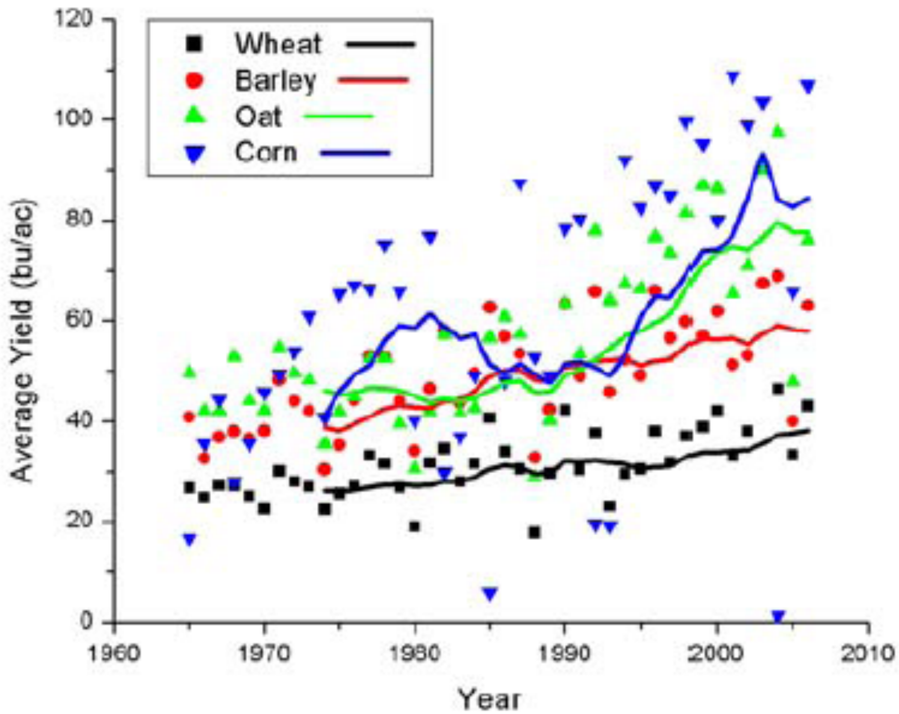
C. C_3 Crops / C_3 Weeds
  - Elevated CO_2 favors **WEED**

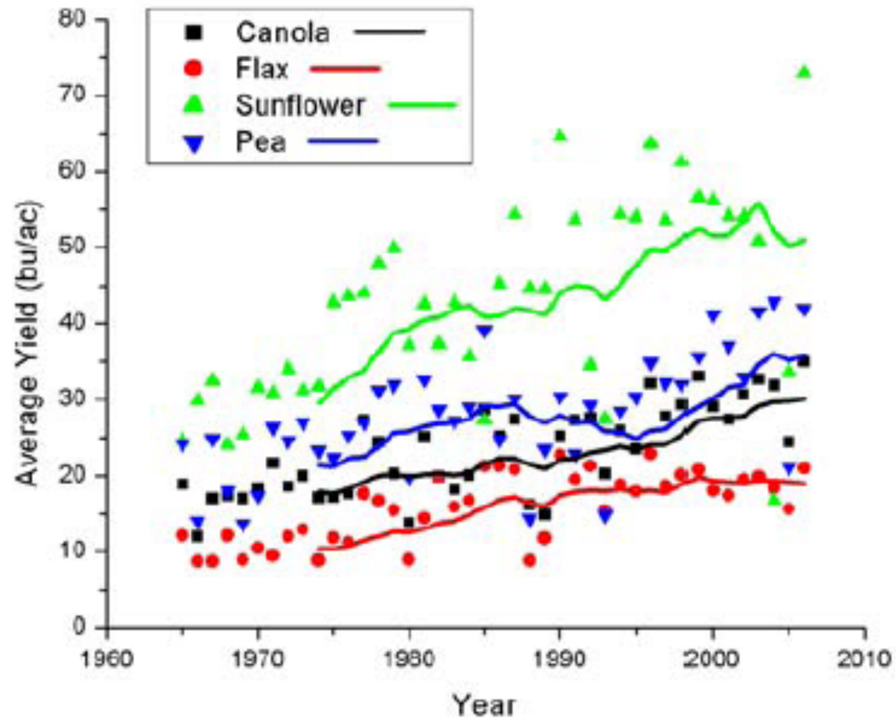
D. C_3 Crops / C_4 Weeds
  - Elevated CO_2 favors **CROP**

Ziska and Bunce, 2006. Chapter 2, in Plant Growth and Climate Change (Morison and Morecroft, eds.), Blackwell Publishing, Oxford

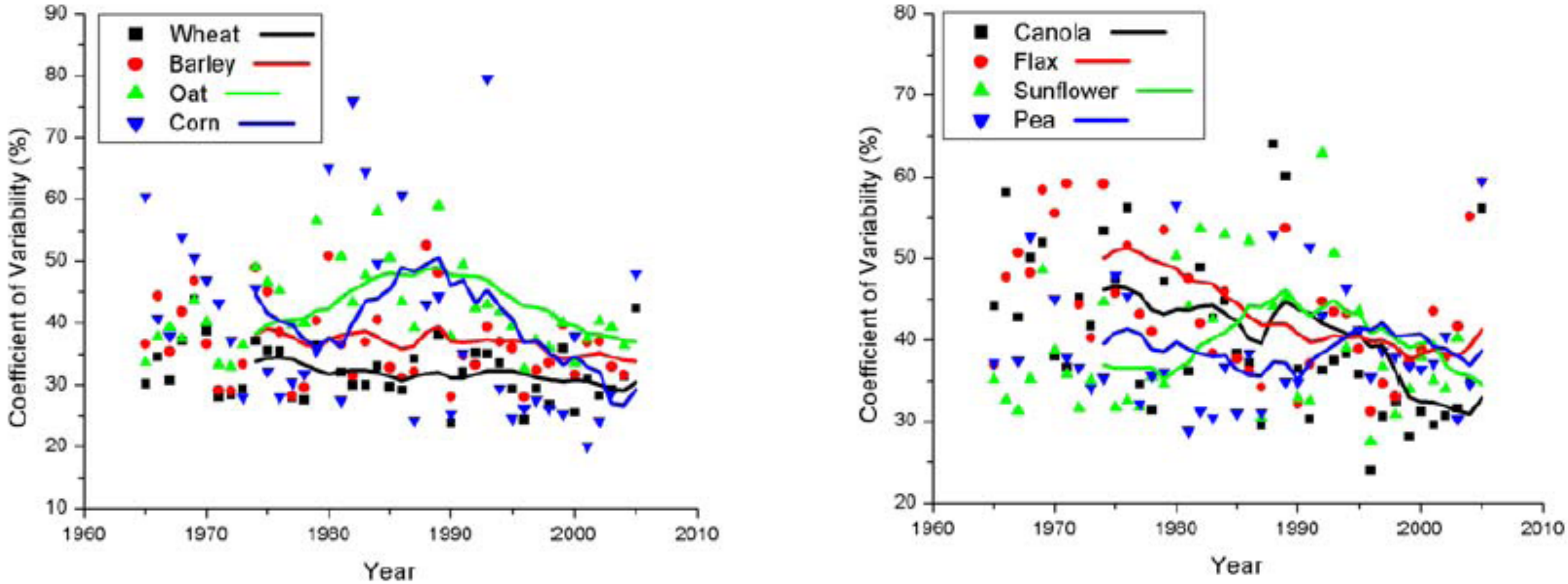
Indirect Climate Change Effects on Agricultural Productivity

- Increased aridity → increased wind erosion (Wolfe and Nickling 1997), higher risk of desertification (Sauchyn et al 2005)
- More frequent "extreme" weather events → greater losses to hail, flood, etc. → higher insurance costs
- Warmer and wetter spring weather → increased soil microbial activity → faster organic matter decomposition, increased soil nutrient availability (Anderson 1992)





Yield and yield trends (Manitoba Crop Insurance data) for several crops grown in Manitoba from 1966 to 2006.
(Wilcox, 2006, Proceedings of the Manitoba Agronomist Conference, University of Manitoba, Winnipeg, www.umanitoba.ca/afs/agronomists_conf).



Coefficient of variation for yield of several crops grown in Manitoba from 1966 to 2006.
(Wilcox, 2006, Proceedings of the Manitoba Agronomist Conference, University of Manitoba, Winnipeg, www.umanitoba.ca/afs/agronomists_conf).

Summary

Potential Positive Impacts

- Longer season, more heat units allowing cultivation of higher-yielding crops
- Improved water use efficiency (higher CO_2)
- Warmer soils creating deeper roots and increased water uptake
- Higher soil nutrient availability

Potential Negative Impacts

- More aridity causing more frequent and severe moisture stress (drought)
- More pests (insects, disease, weeds)
- More crop losses to extreme weather
- More rapid crop maturation and lower yields