Some gaps in crop models that matter for adaptation studies

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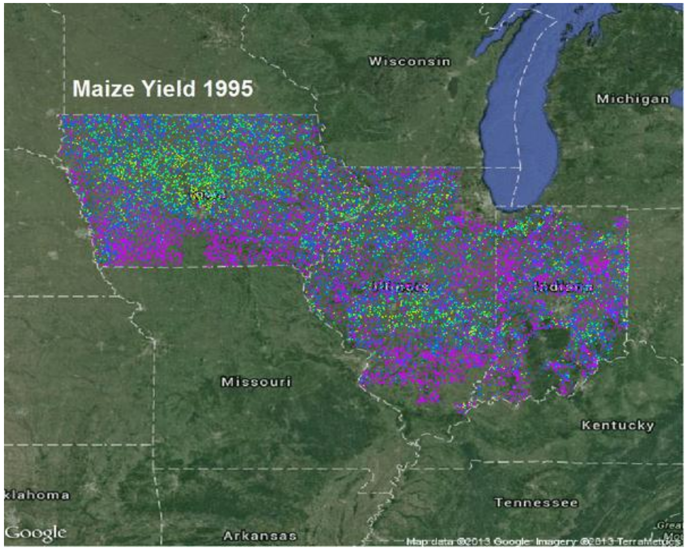
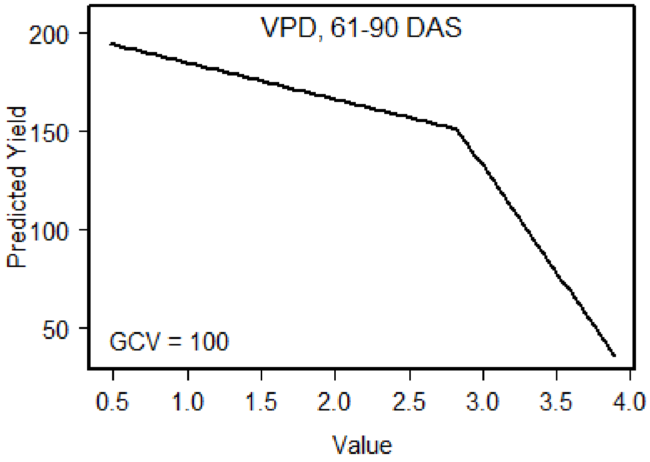
With inputs from: Scott Chapman, Graeme Hammer, Greg McLean, Vijaya Singh, Bangyou Zheng

My Perspective:

- Is mostly based on empirical studies, and occasionally testing how well process models can reproduce observed sensitivities





Lobell et al. 2014, *Science*

- But empirical models can't go very far (yet) in looking at adaptation potential of specific crop traits. That is the real strength of process models

My Perspective:

- But process models are only useful if their predictions are reasonably accurate for relevant conditions

- In general, model prediction error can be decomposed as:
    - Structural errors (missing or wrong equations)
    - Parameter errors (imperfect calibration)
    - Input errors (wrong inputs)

- Hard to decide what to prioritize, but it helps to have examples that demonstrate when a gap really matters

Three Brief Examples:

Gaps related to model structure/parameters

1. Effects of High Temperature on Grain Number and Size

2. Effects of High CO_2 on Canopy Temperatures

Gaps related to Inputs:

3. Effects of Humidity Changes on Drought Stress

Component	Modelling Needs	Urgency	Current
Phenology	Improved prediction of leaf number and sensitive growth stages	***	Good
	Variation associated with development (tillering etc)	*	Poor
Growth	Expansive growth (leaf, stem, root extension), inc. CO2	**	Mod
	Photo-system function (leaf and spike function)	**	Poor
	Night-time temperature (development + respiration)	****	Poor
Partitioning	Grain set and abortion	*****	Varies
	Grain expansion (grain size) and filling	****	Poor
	Changes in allocation and senescence of biomass	*	Poor
	Grain quality	**	Varies
Energy balance	Canopy + soil + irrigation/rainfall effects	***	Poor
	Temperatures of organs	***	Poor
	Diurnal dynamics	**	Mod
Water balance	Simulation of leaf+root transpirational cooling (& CO2?)	****	Poor
	Integration of heat and VPD effects on organ growth	****	Poor

Grain Responses to High T in Sorghum

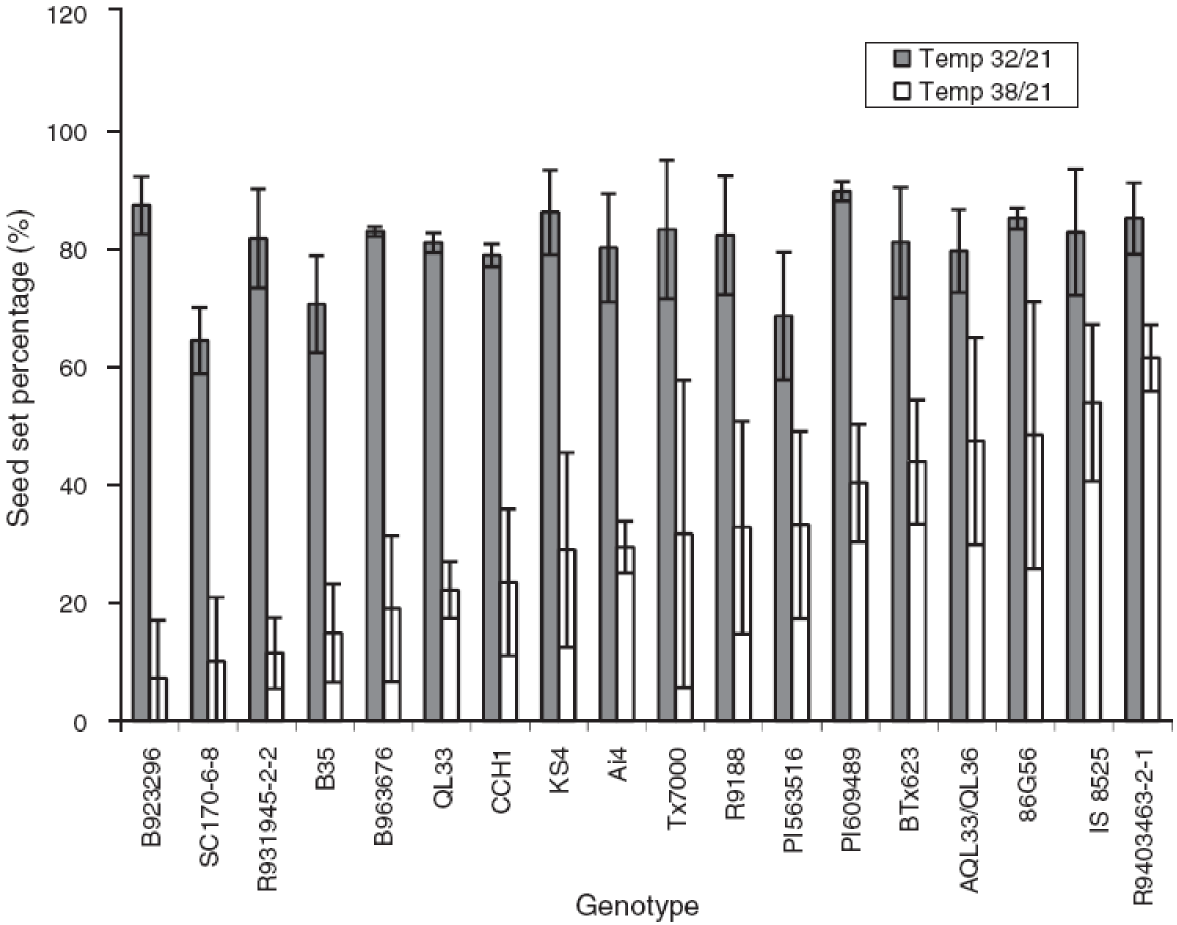
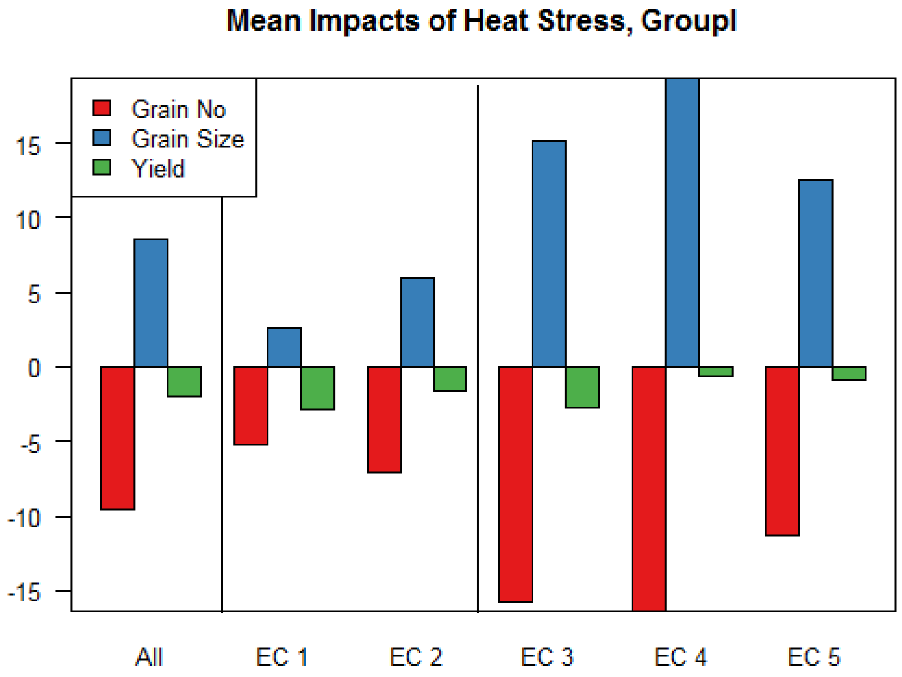


Fig. 6. Seed-set (%) for various genotypes, grown under optimum temperature (32 : 21°C, shaded bars) and high temperature (38 : 21°C, open bars) conditions. Vertical lines indicate the s.e. of the mean for each genotype × temperature combination.

Nguyen et al. 2013

Grain Responses to High T in Sorghum

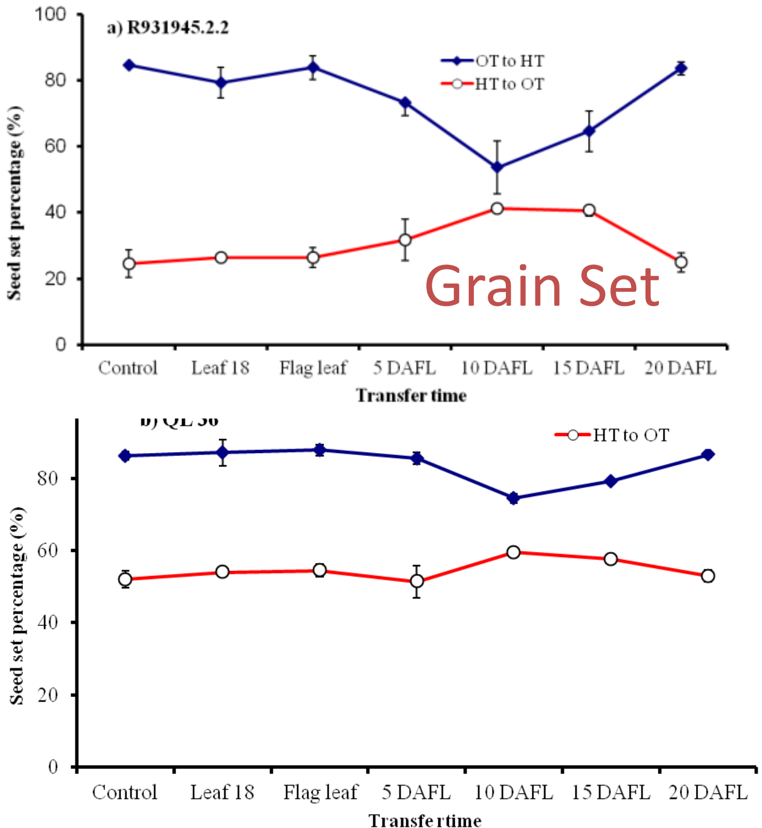
- Putting these effects into the APSIM model gives the expected effects on grain number.
- But unexpected amount of compensation on grain size



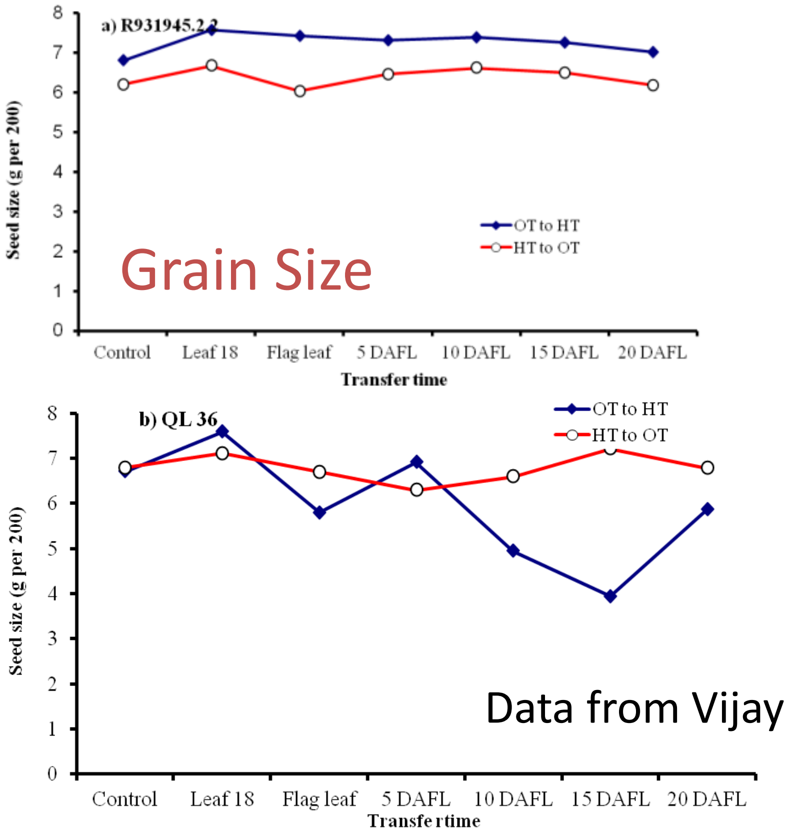
“Low Drought” “High Drought”

Grain Responses to High T in Sorghum

- The little experimental evidence that exists suggests, if anything, grain size is smaller in trials exposed to high T.
- So we have had to restrict grain size response in APSIM



Grain Set

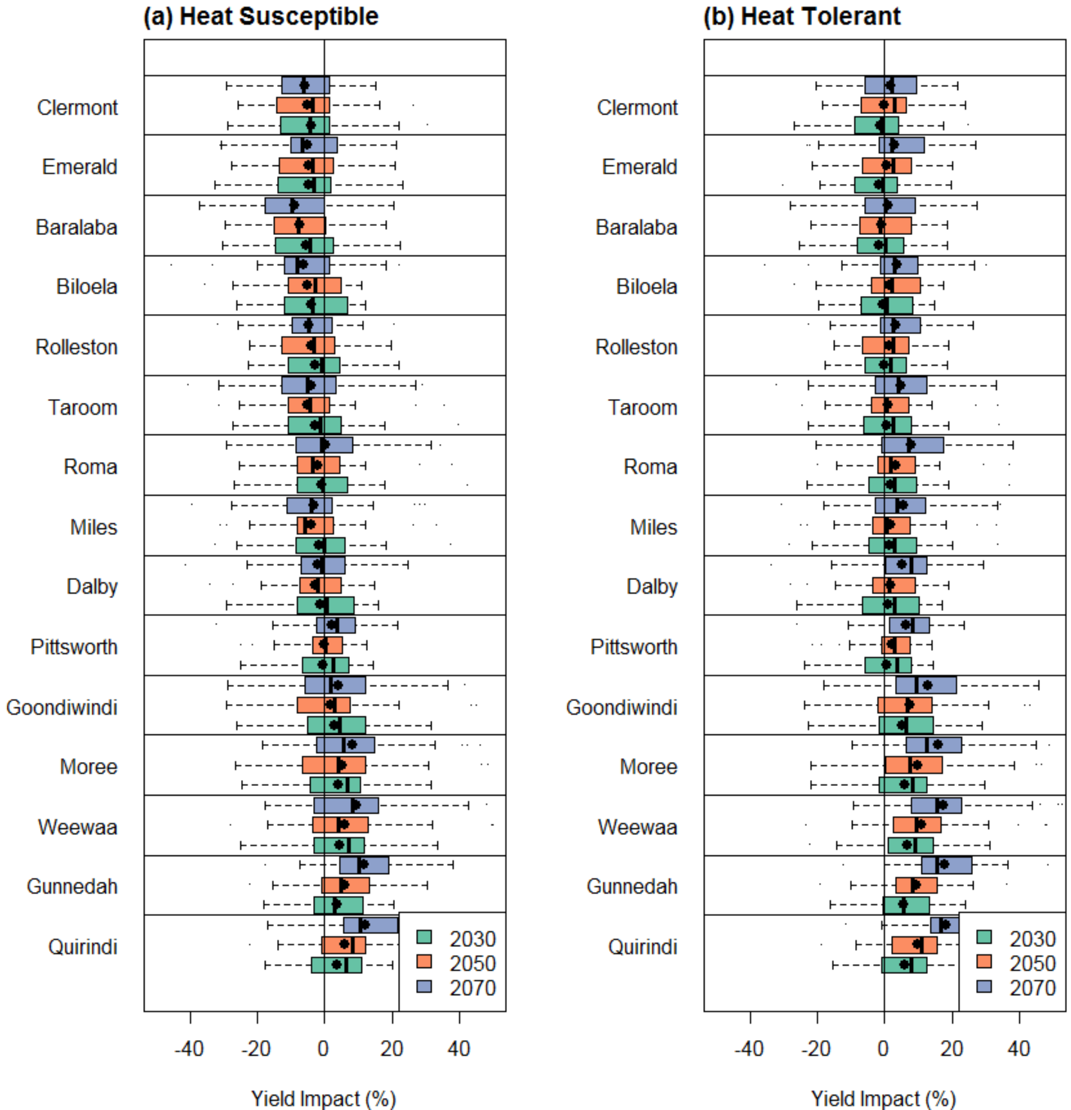


Grain Size

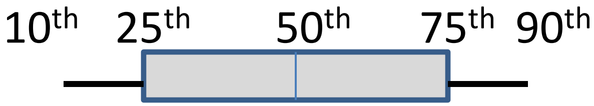
Data from Vijaya Singh

Grain Responses to High T in Sorghum

- Grain set effects clearly matter for assessing impacts/adaptations



Distribution of Projected Sorghum Impacts by Site



High CO$_2$ Effects on Canopy T

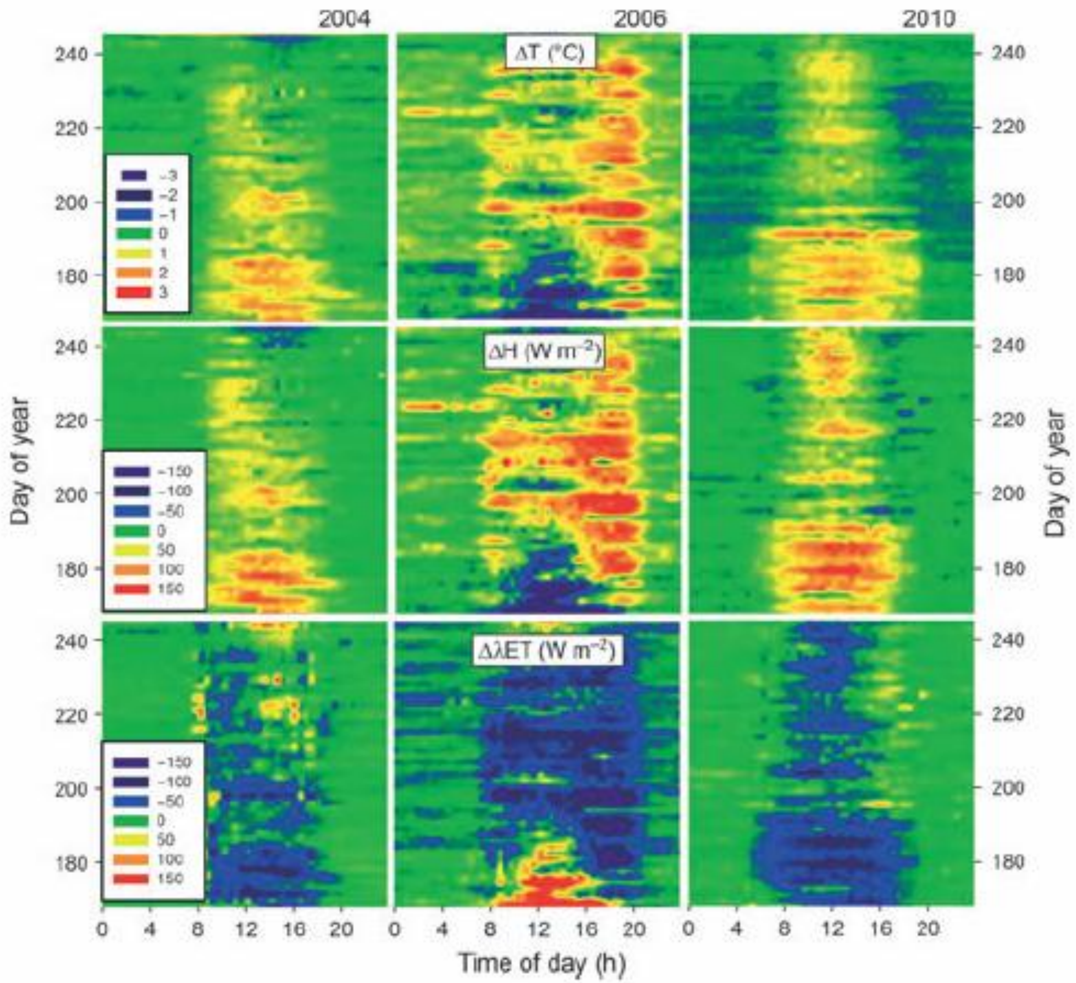


Fig. 4 The difference (elevated [CO$_2$] – control) in canopy temperature (ΔT_c; top row), sensible heat flux (ΔH; middle row), and latent heat flux ($\Delta\lambda$ET; bottom row), over the diel time course (*X*-axes) and throughout the growing season (*Y*-axes) for 3 years. Standard errors are not graphed here, but range from 0.09 °C to 0.04 °C, 2.58–5.20 W m^{-2}, 3.52–5.43 W m^{-2} for T_c, H, and λET, respectively depending on the year.

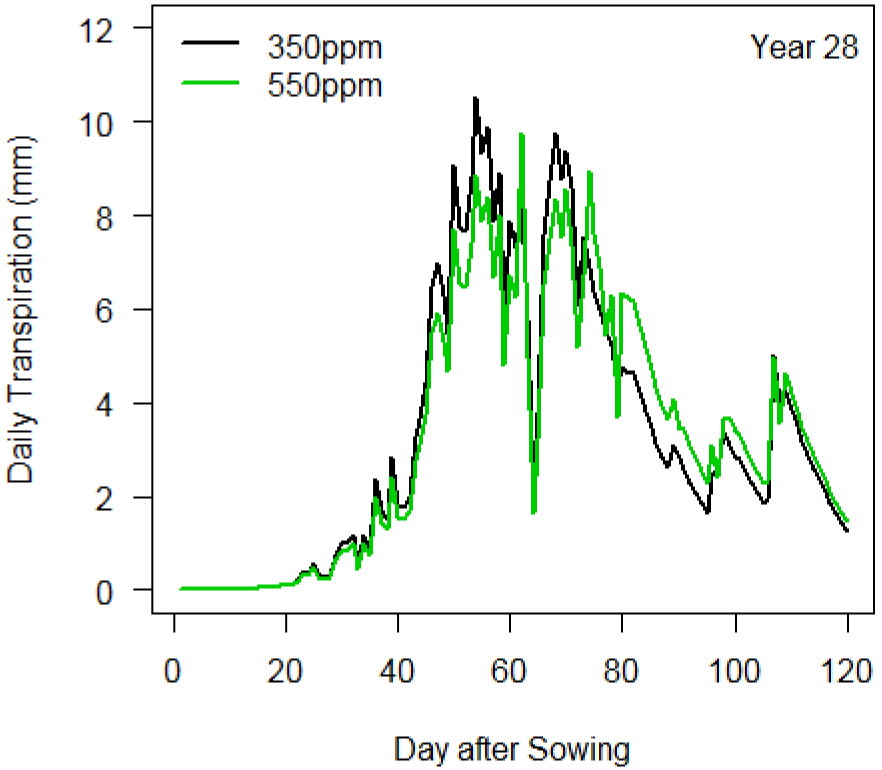
Hussain et al., GCB, 2013

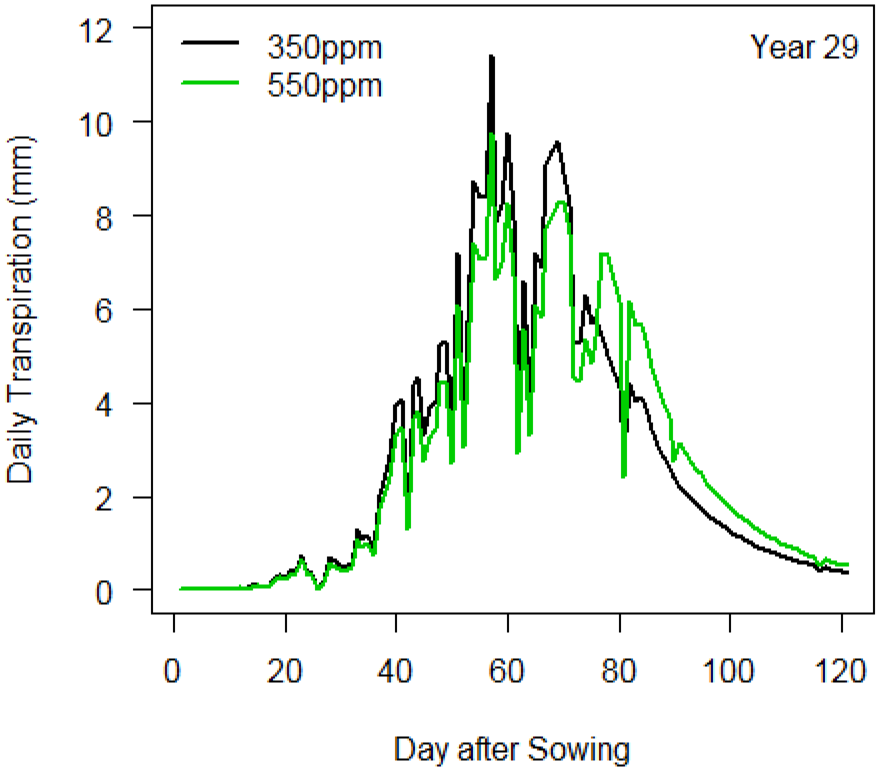
High CO_2 Effects on Canopy T

- For APSIM-maize simulations, we added grain set effects of heat
- Then perform APSIM “experiments” with elevated CO_2 and T in central Iowa
- Are feedbacks of CO_2 on canopy T big enough to affect grain set?

High CO_2 Effects on Canopy T

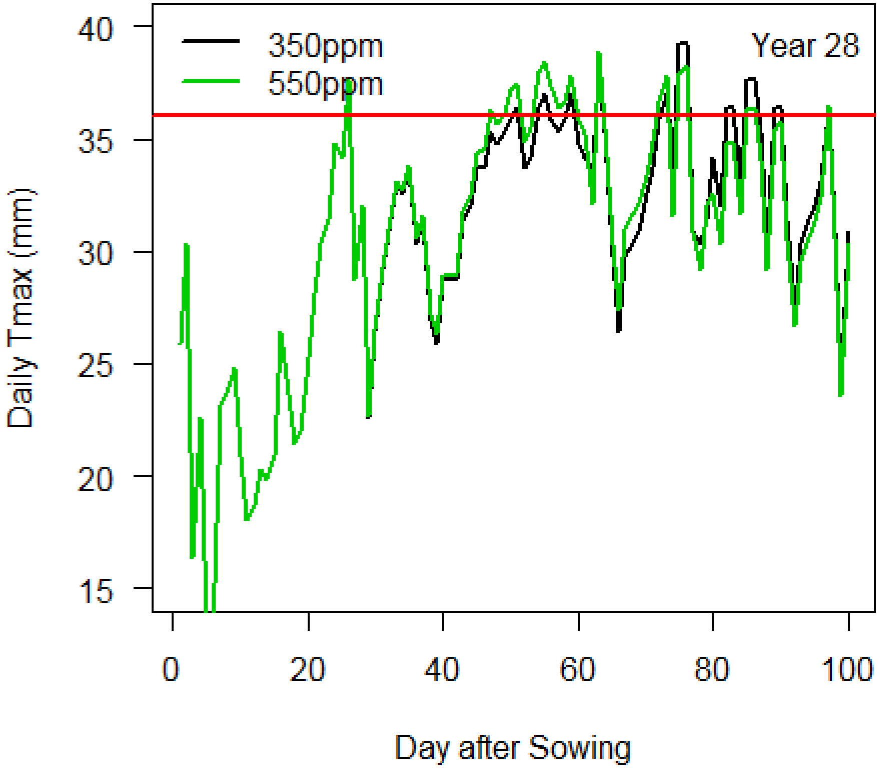
CO_2 lowers transpiration mid-season

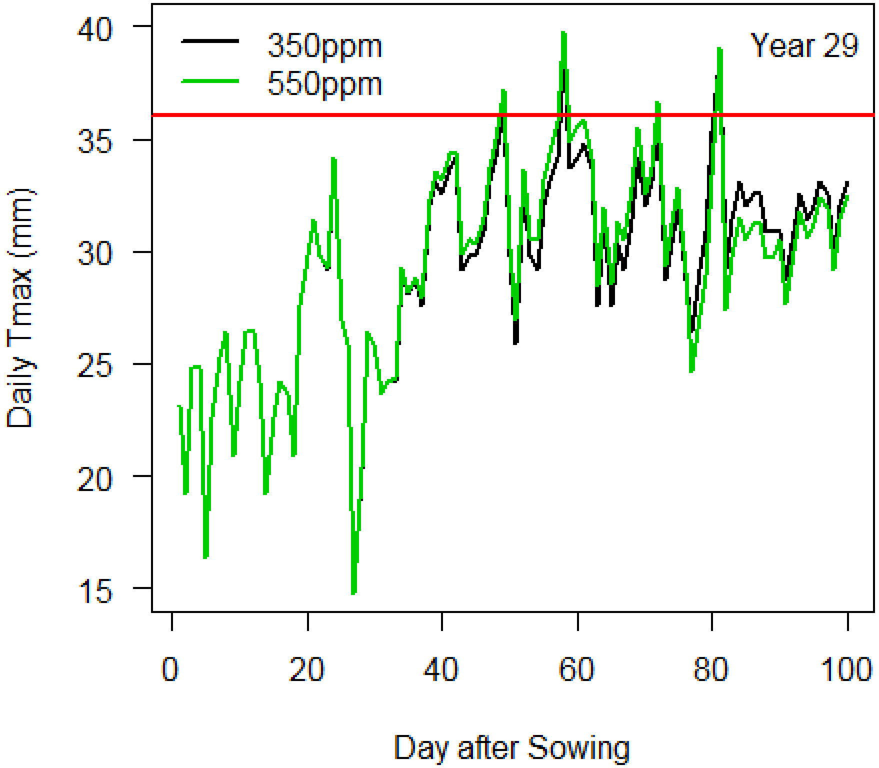




High CO_2 Effects on Canopy T

These transpiration changes were then used to adjust Tmax





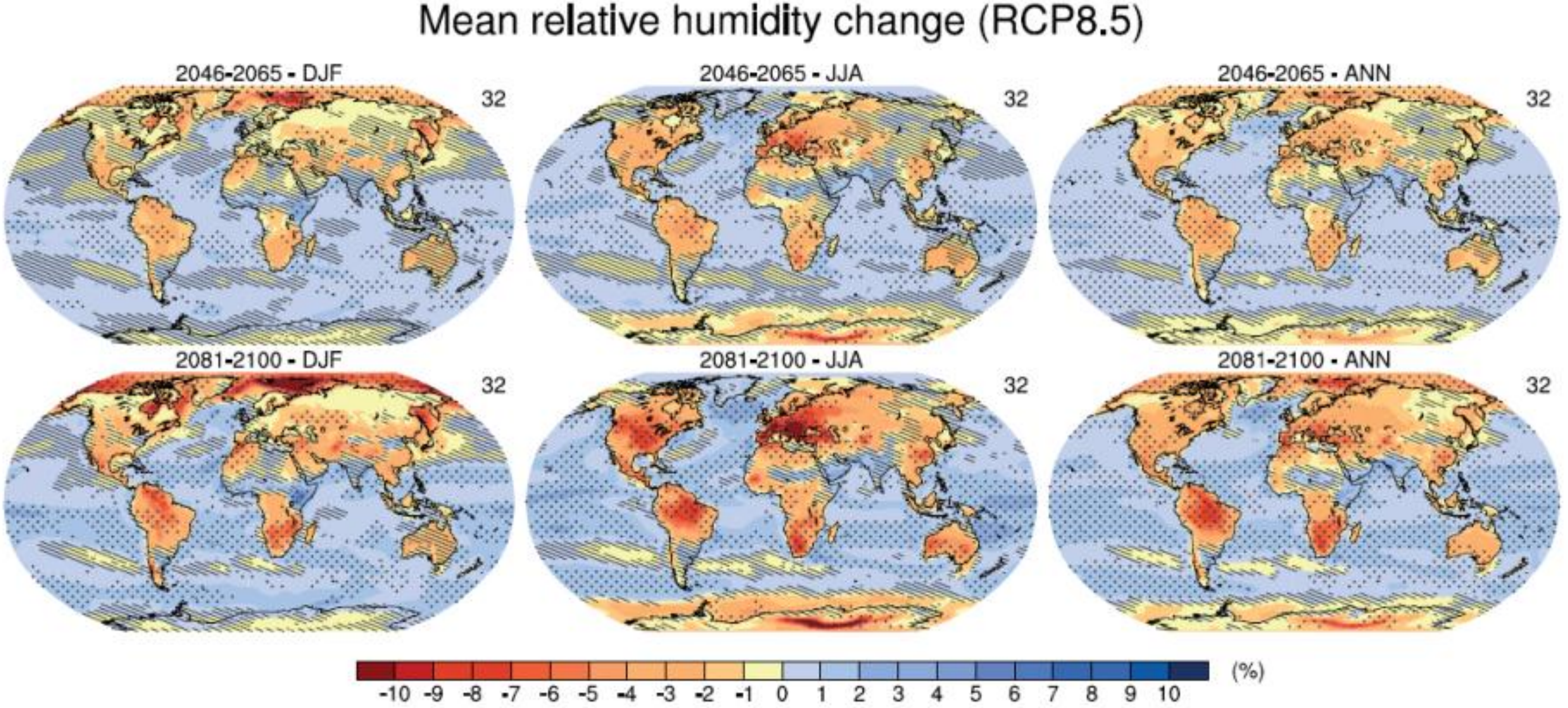
High CO_2 Effects on Canopy T

Mean simulated yield changes in Johnston, IA for 3 scenarios

	High cultivar sensitivity to heat	**Medium cultivar sensitivity to heat**	**Low cultivar sensitivity to heat**
+2 °C only	-13%	**-5.7%**	-4.3%
+2 °C, + 200ppm, no T feedbacks	-11%	**-1.7%**	-0.4%
+2 °C, + 200ppm, with T feedbacks	-17%	**-3.6%**	-0.6%

Missing inputs: the importance of humidity

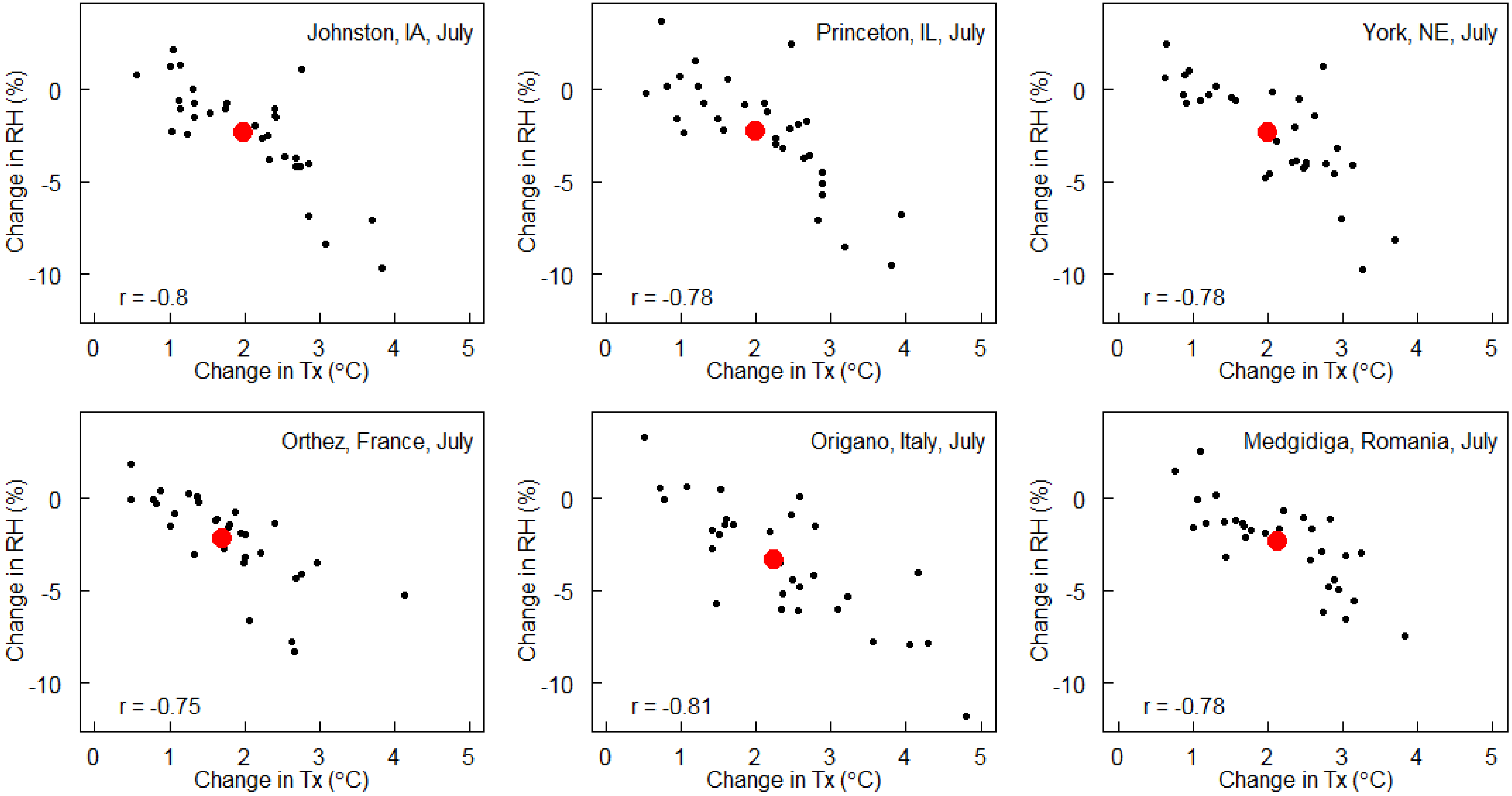
- Relative humidity is expected to decline in many cropped areas



IPCC (2013), WG1, CH12

Missing inputs: the importance of humidity

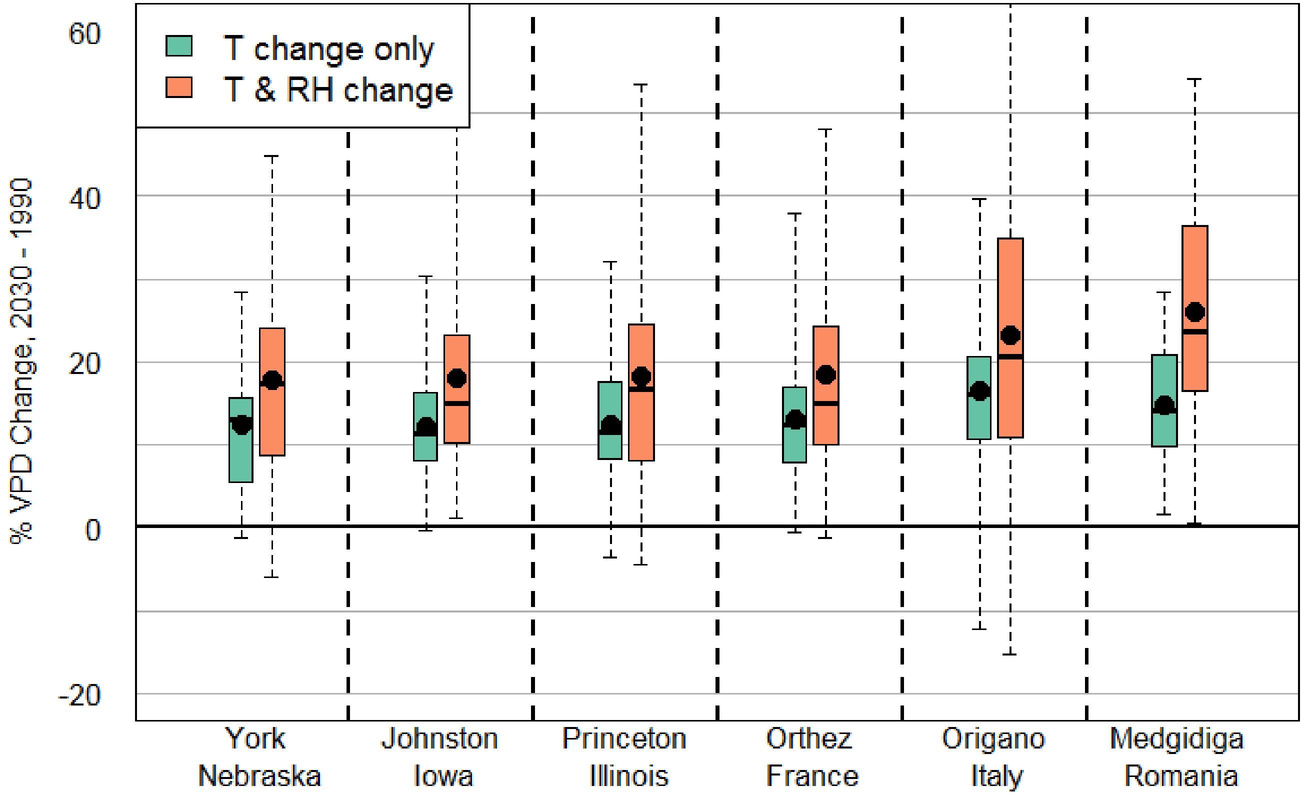
- And there tends to be a strong negative correlation between projected Tmax and humidity (shown for 6 sites in US and EU)



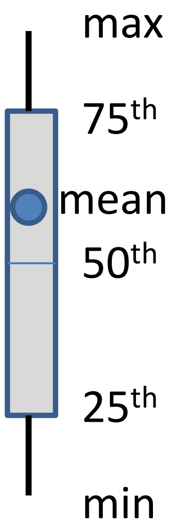
Lobell et al., unpub.

Missing inputs: the importance of humidity

- This drives greater increases in VPD



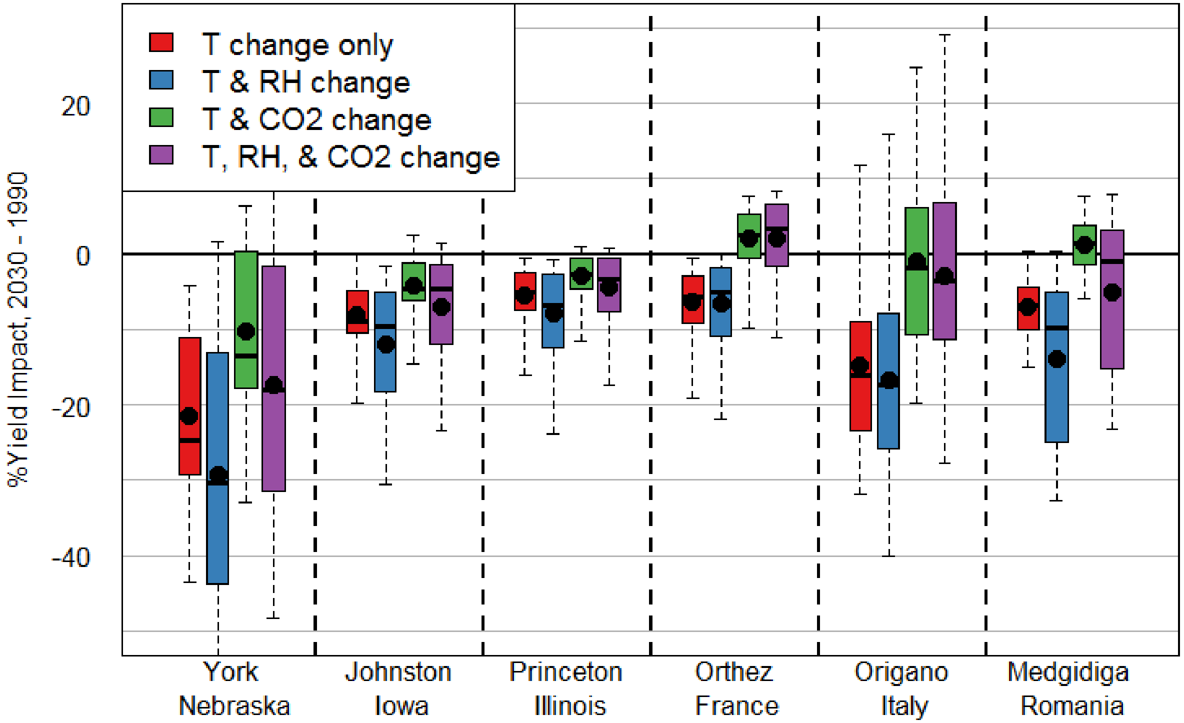
Distribution across GCMs



Lobell et al., unpub.

Missing inputs: the importance of humidity

- Accounting for these RH changes are important for simulated maize impacts, arguably as important as CO_2 for some places



Lobell et al., unpub.

Conclusions:

- The good news is a lot of room left for progress
- Experiments will remain indispensible, but models will improve much faster if also using the growing piles of observations for testing, especially for high temperatures (and possibly for CO_2)

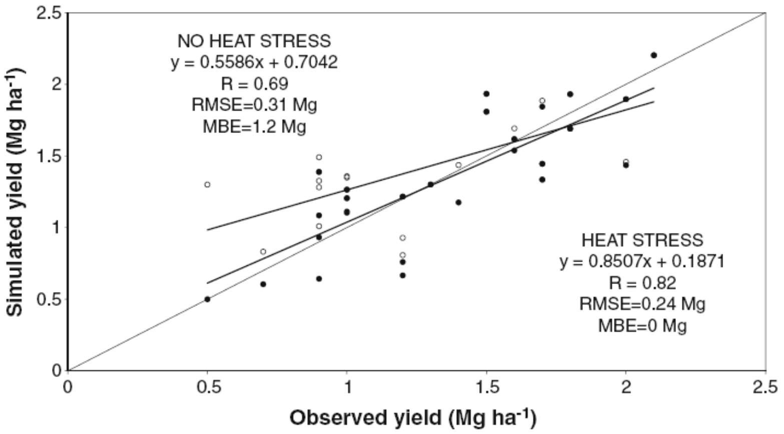
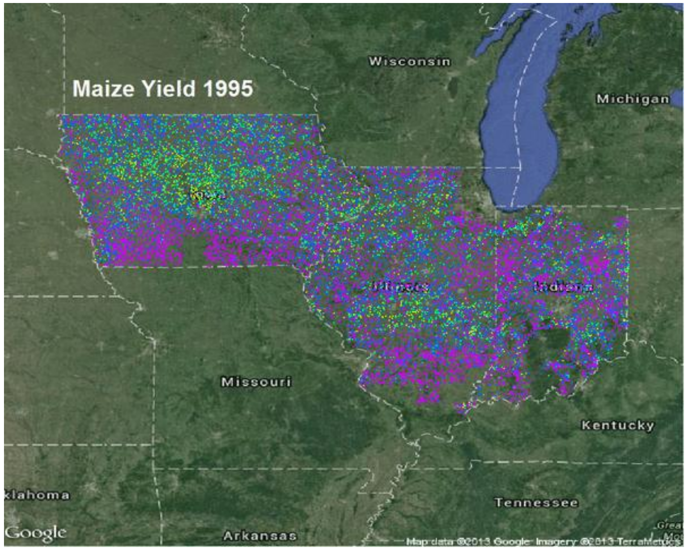


Fig. 4 Observed versus simulated sunflower yield in 2003, including (*filled circle*) and not including (*open circle*) the impact of heat stress at anthesis. Data represent the average yield on the regional scale for Italy, Southern France, Greece and Spain



Moriondo et al. Climatic Change, 2010

Lobell et al. 2014, *Science*