



Towards food security in a warmer world: Understanding crop responses to climate

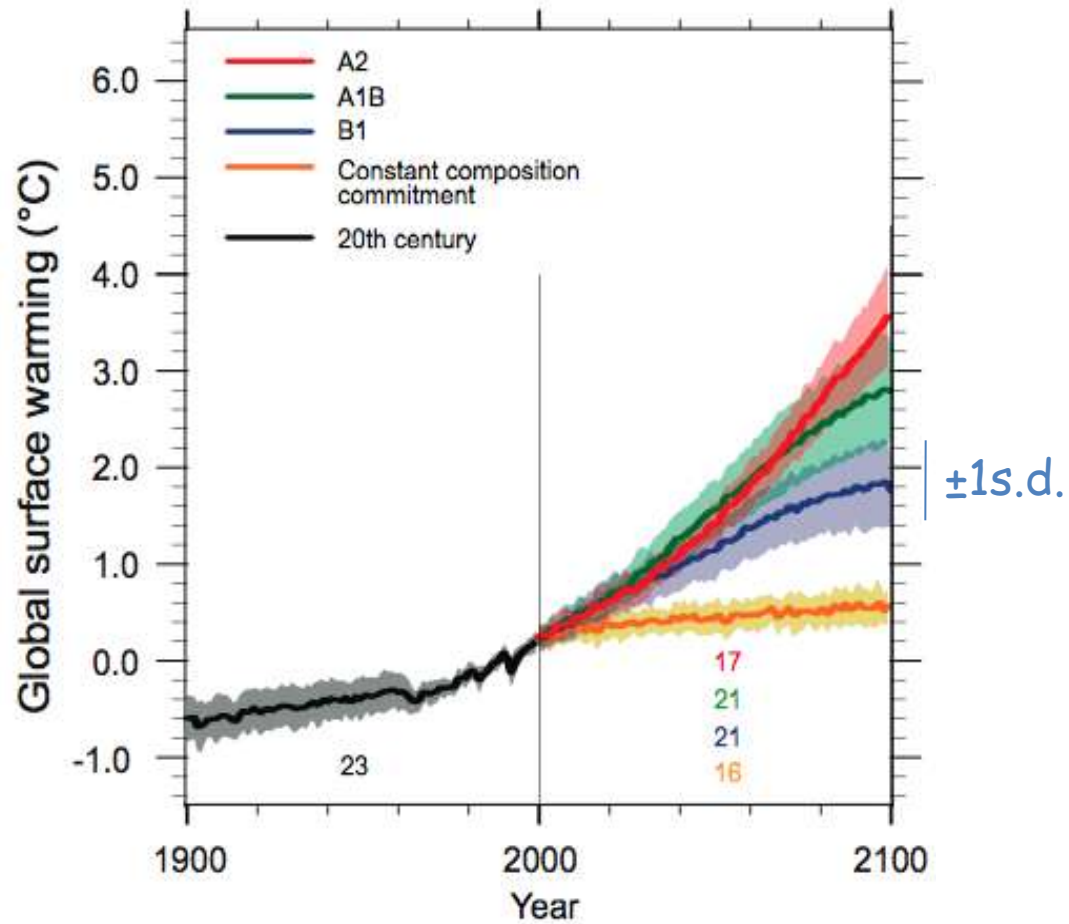
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Bren School, UC Santa Barbara, October 7, 2010

Motivating Facts

- Climate is changing

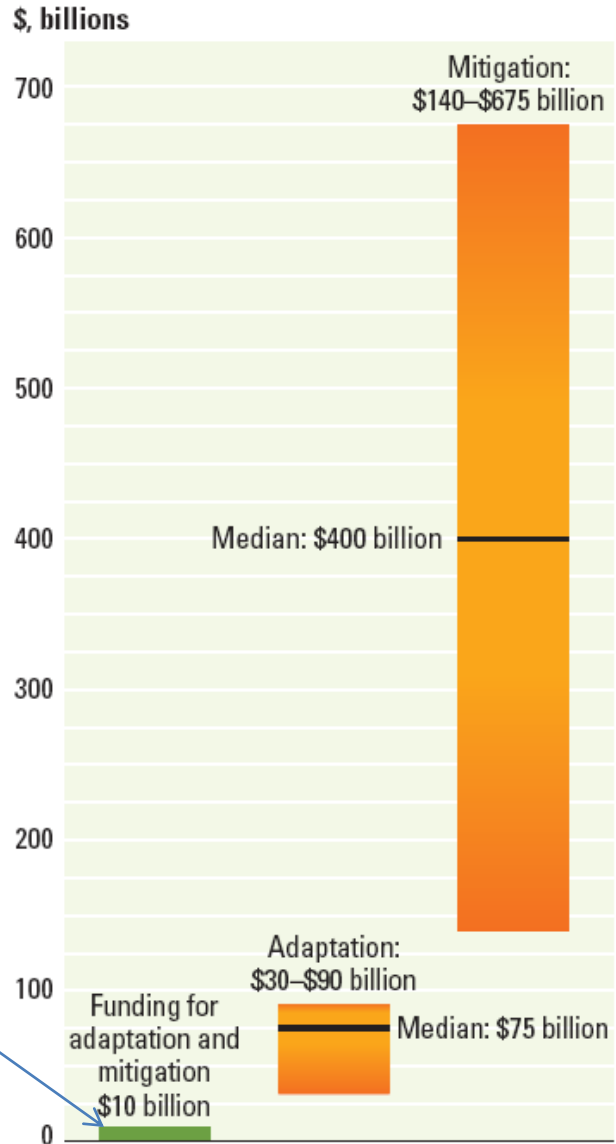


Motivating Facts

- Climate is changing
 - Crops are sensitive to climate (up to 10% per °C)
 - Food markets are increasingly tight
 - Chronic hunger affects 1 in 8 people today
 - Global land use & environment is sensitive to food prices
- How can we adapt our food system to a hotter world?

We Need to Adapt, but \$\$ is Short

Figure 10 The gap is large: Estimated annual climate funding required for a 2°C trajectory compared with current resources



For developing countries only

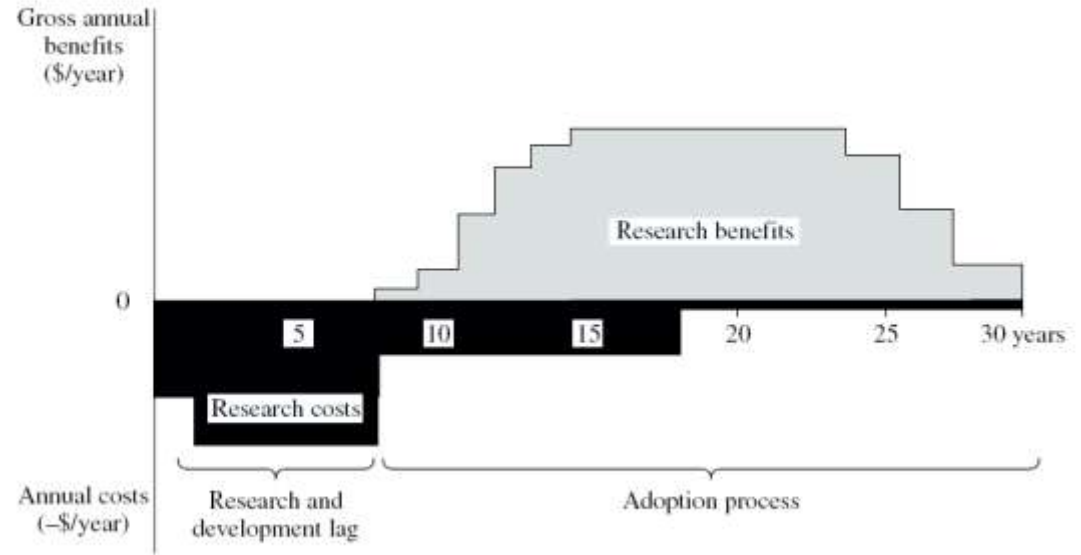
Adaptation < 1B

Current global development assistance

We Need to Adapt, but Time is Short



Figure 1—Flows of resources, benefits, and costs



Source: Alston, Norton, and Pardey 1995.

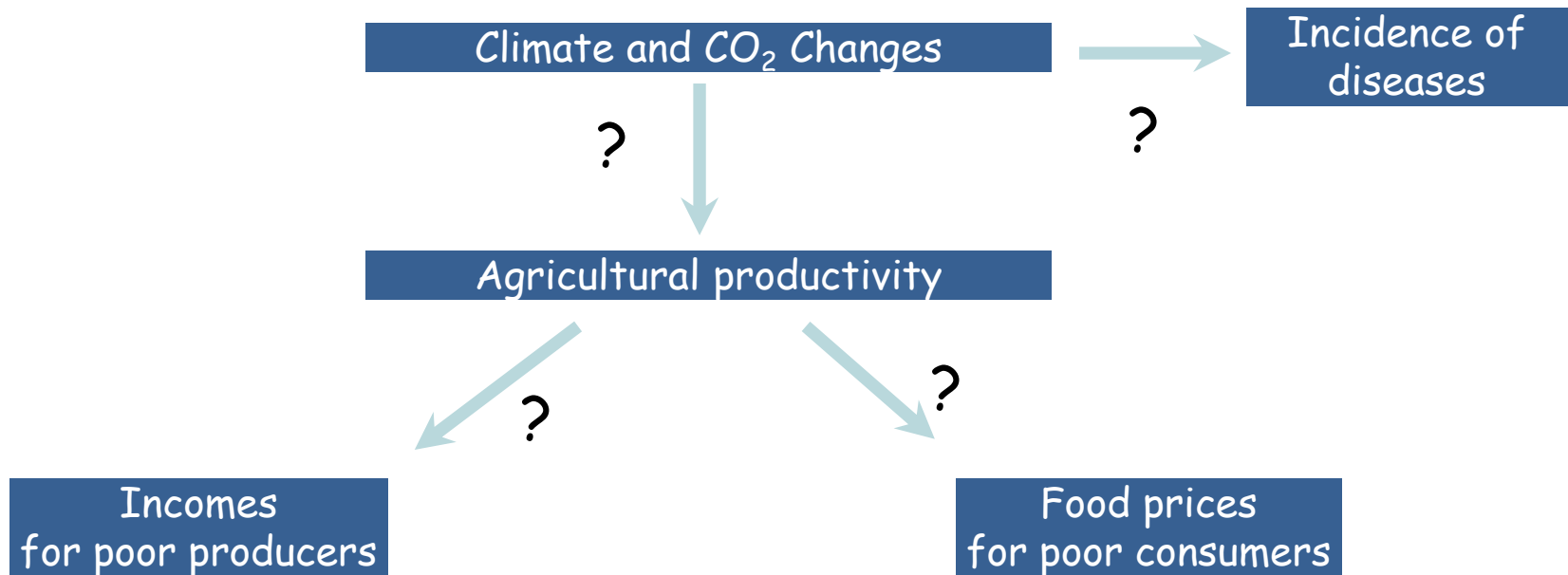
Adaptation

The Challenge:

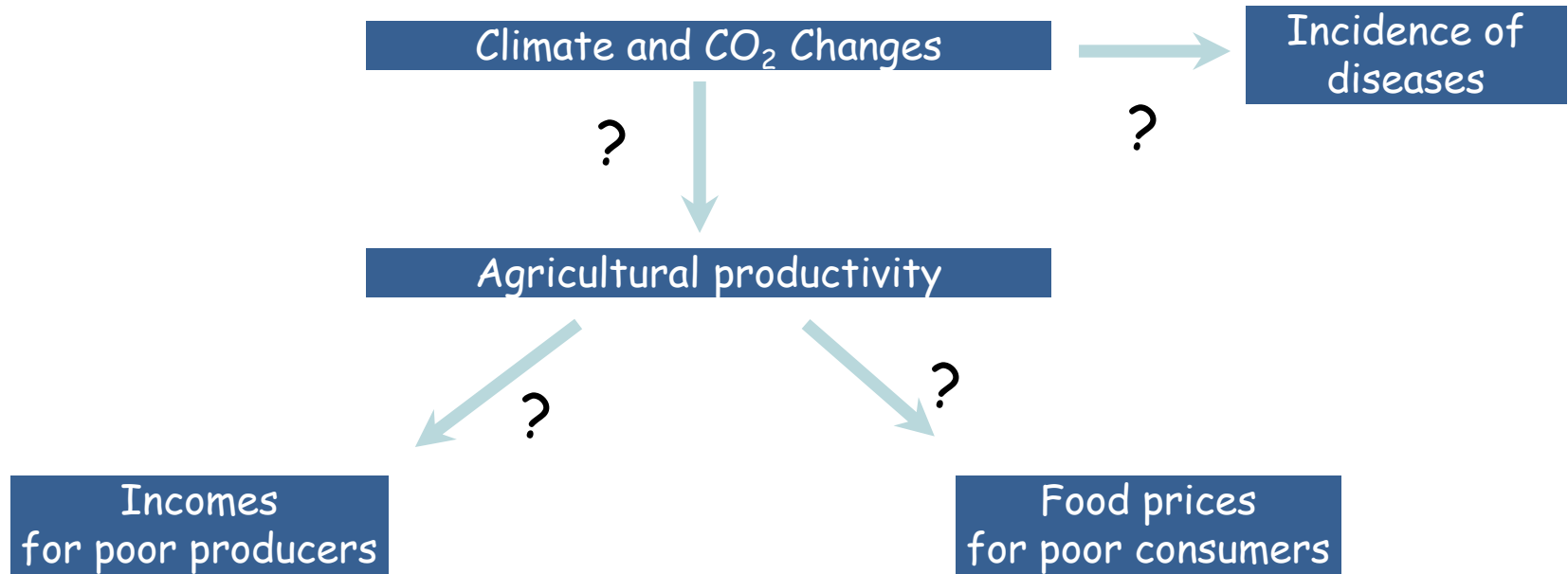
How do we intelligently allocate scarce resources to adaptation, given current uncertainties and objectives?

The elements of food security

1. Availability (The Pile of Grain)
2. Access (Ability to Grow or Buy Food)
3. Utilization (Ability to use nutrients in food)



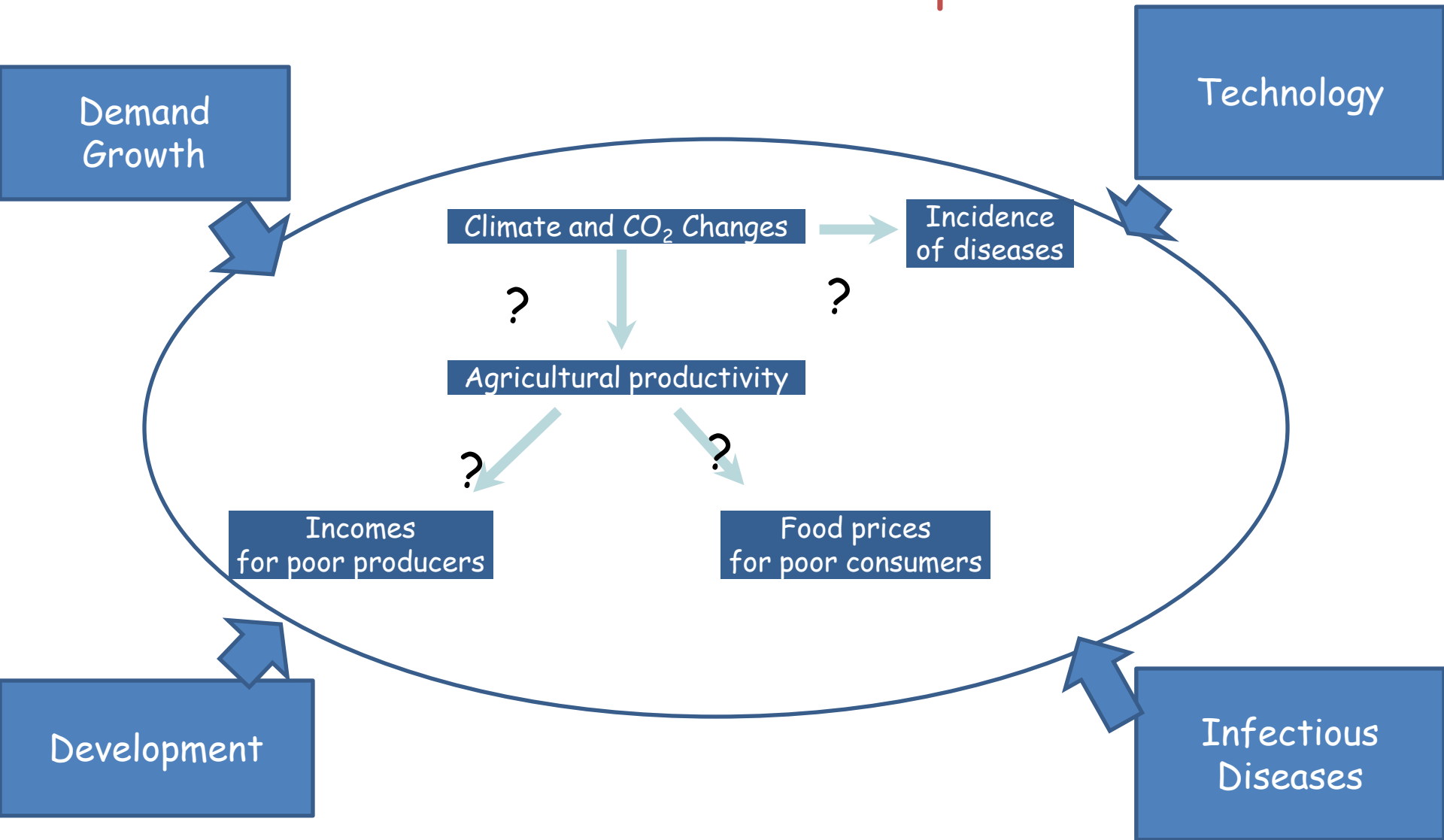
A modeler's view of the problem



For each of these links, we would like to understand the likely impacts of, and how to best adjust to, climate change

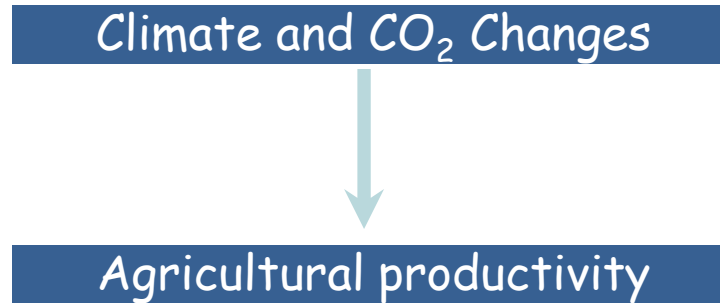
- 1) Choose an approach
- 2) Quantify impacts and uncertainties
- 3) Identify key sources of uncertainties
- 4) Find new data to reduce these uncertainties
- 5) Repeat 1-4

A modeler's view of the problem



Note: This is only part of a larger question about future food security

A modeler's view of the problem



For today, let's just consider this part of the part:

How will climate change affect crop productivity?

Past work is helpful, but has many limitations

- Time-scales are often too long
- Global studies have focused on major commodities, which miss many crops key to food security
- Incomplete understanding of uncertainties (only using 1-2 climate models, 1 crop model)
- For most regions and crops, spatial scale is often too small (model runs for 1-2 sites)

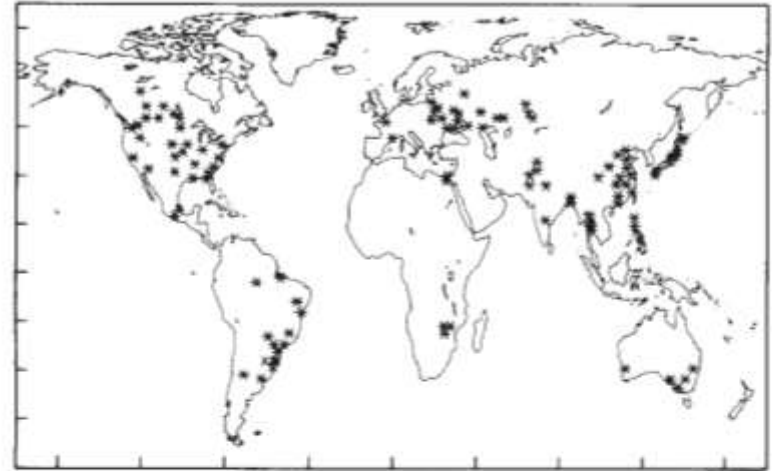
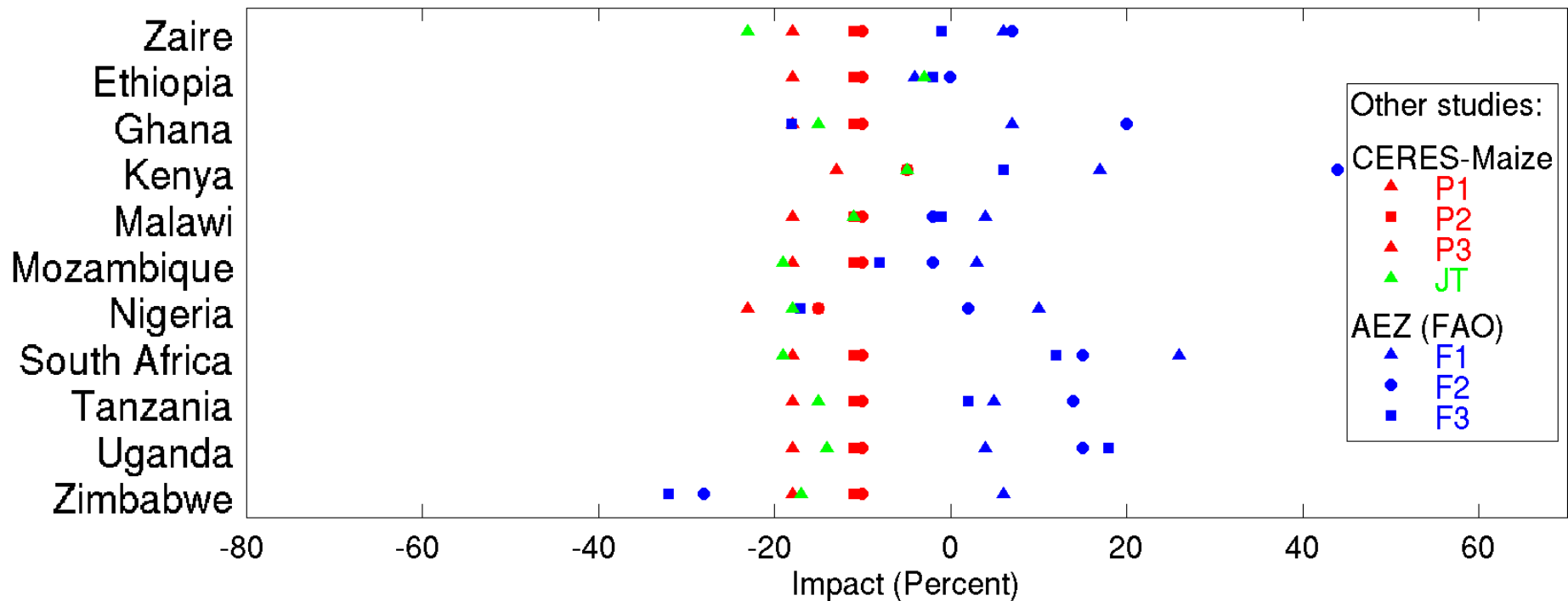


FIG. 1 Crop model sites⁶. Countries and participants were as follows: Argentina, O. E. Sala and J. M. Paruelo; Australia, B. D. Baer, W. S. Meyer and D. Erskine; Bangladesh, Z. Karim, M. Ahmed, S. G. Hussain and Kh. B. Rashid; Brazil, O. J. F. de Siqueira, J. R. B. Farias and L. M. A. Sans. Canada, M. Brklacich, R. Stewart, V. Kirkwood and R. Muma; China, Z. Jin, D. Ge, H. Chen, J. Fang and X. Zheng; Egypt, H. M. Eid; France, R. Delécolle, D. Ripoche, F. Ruget and G. Gosse; India, D. G. Rao; Japan, H. Seino; Mexico, D. Liverman, M. Dilley, K. O'Brien and L. Menchaca; Pakistan, A. Qureshi and A. Iglesias; Philippines, C. R. Escaño and L. Buendia; Thailand, M. L. C. Tongyai; Russia, G. Menzhulin, L. Koval and A. Badenko; USA, C. Rosenzweig, B. Curry, T.-Y. Chou, J. Ritchie, J. Jones and R. Peart; Uruguay, W. E. Baethgen; Zimbabwe, P. Muchena.

Past work is helpful, but has many limitations

Projected Impacts on Maize Yields by 2050 relative to 1960-2000(%)



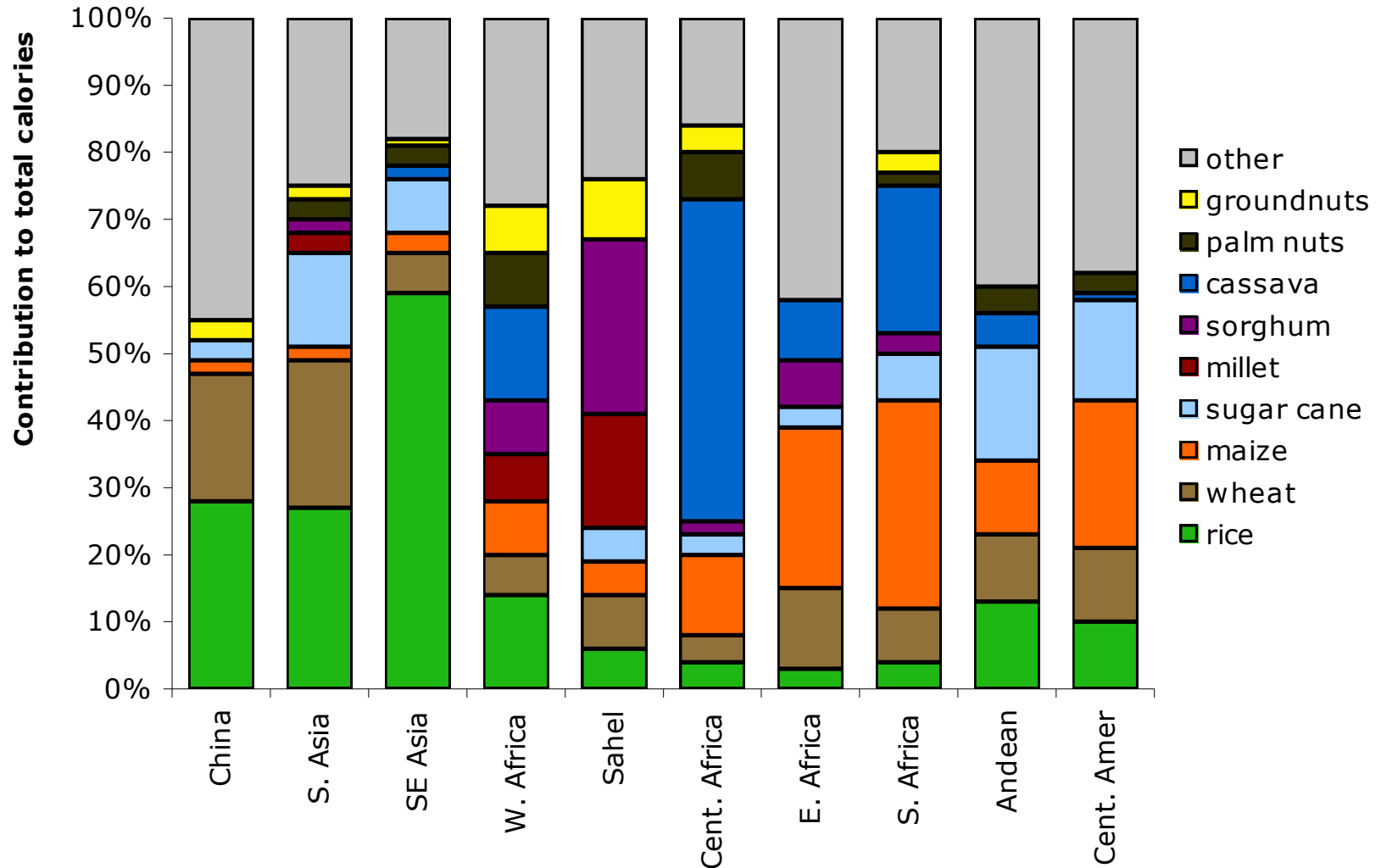
A modeler's view of the problem

An initial attempt (Lobell et al. 2008):

- a) Identify the most relevant crops/regions for food security
- b) Look at historical crop-climate relationships
- c) Combine these with climate model projections to assess near-term impacts if adaptation is ineffective

A couple of important features:

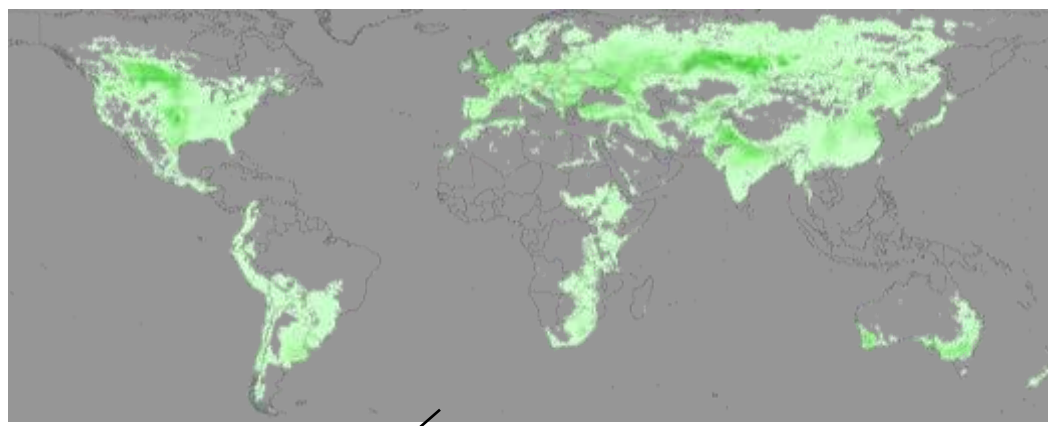
1) Include all major calorie sources, not just 1-2 crops



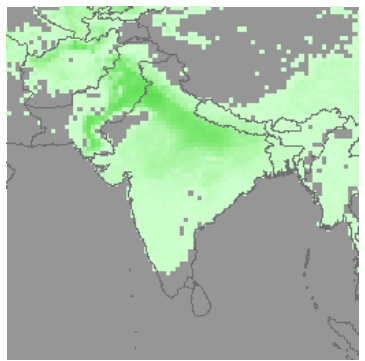
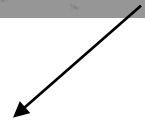
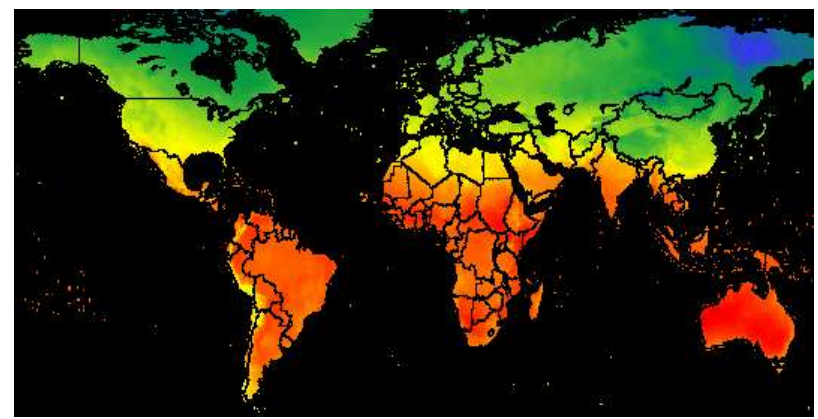
Regional diets, by contribution to total calories (2003, FAO)

A couple of important features: 2) Use climate information for where and when crop is growing

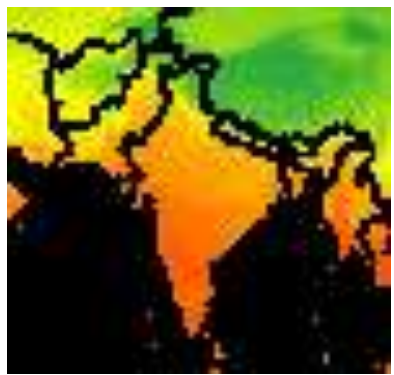
Global Wheat Area (Monfreda et al.)



CRU TS2.1, Average Temperature, January 1981

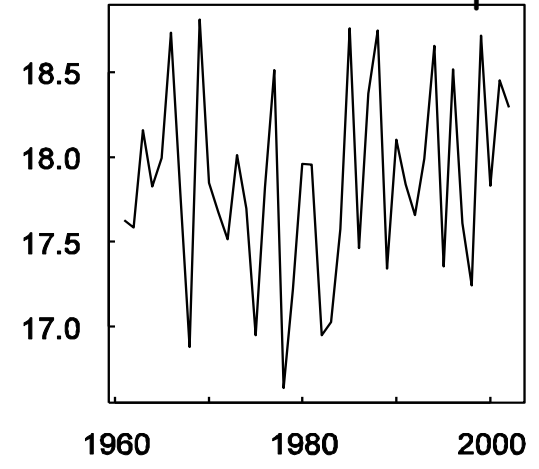


X



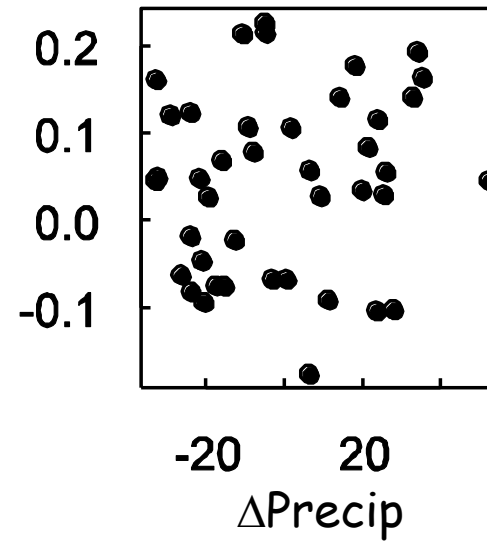
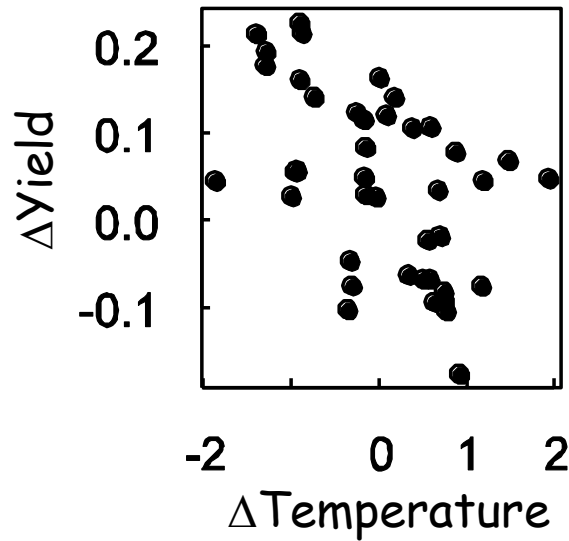
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Grow.Seas.Temp.



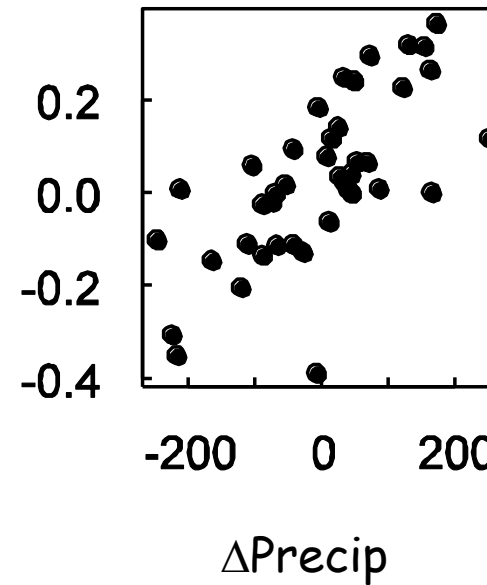
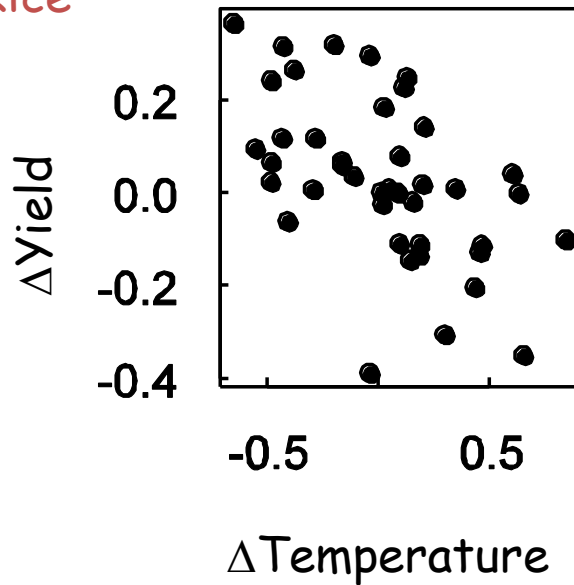
Some examples

S. Asia Wheat



$R^2 = 0.27$

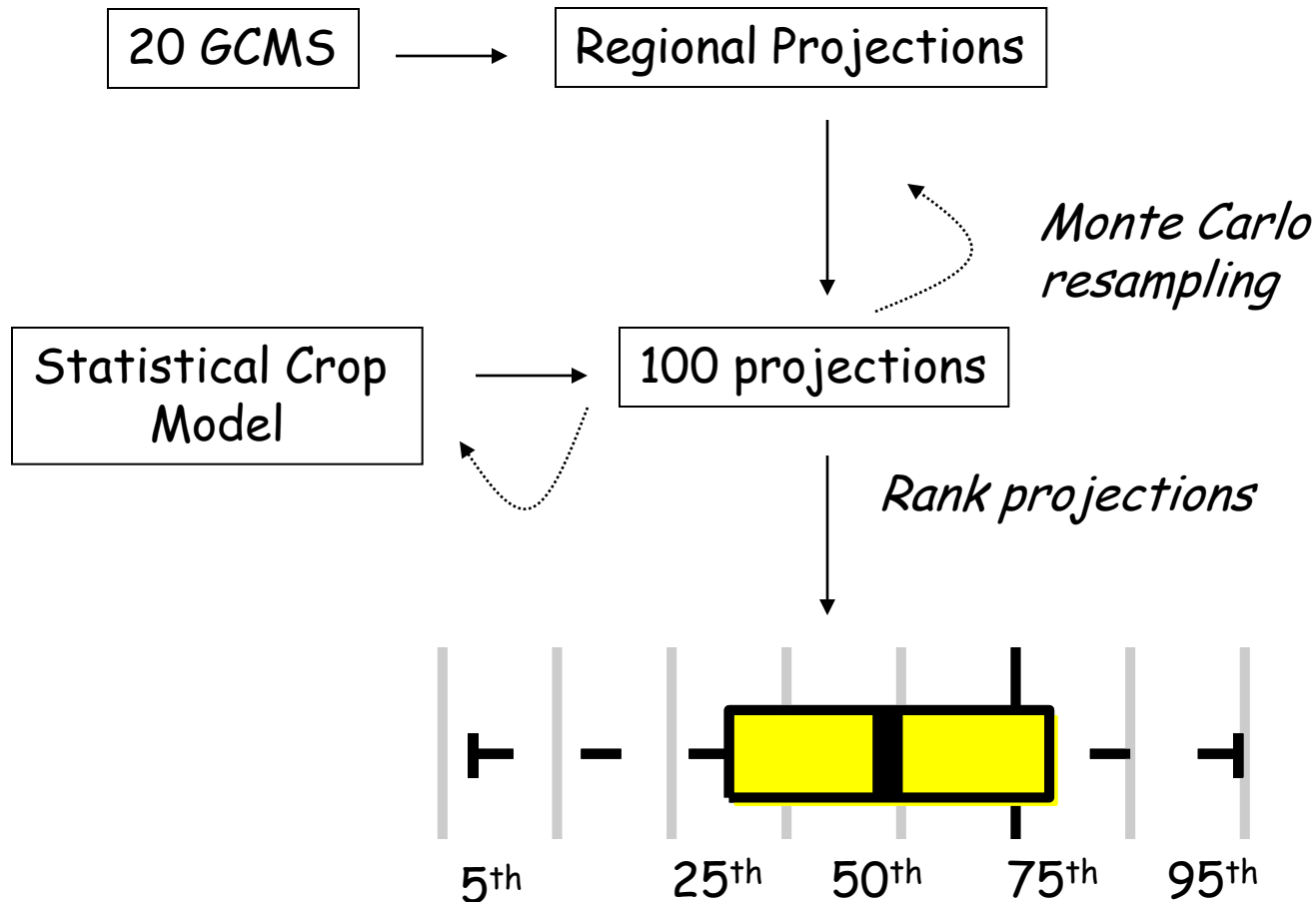
S. Asia Rice



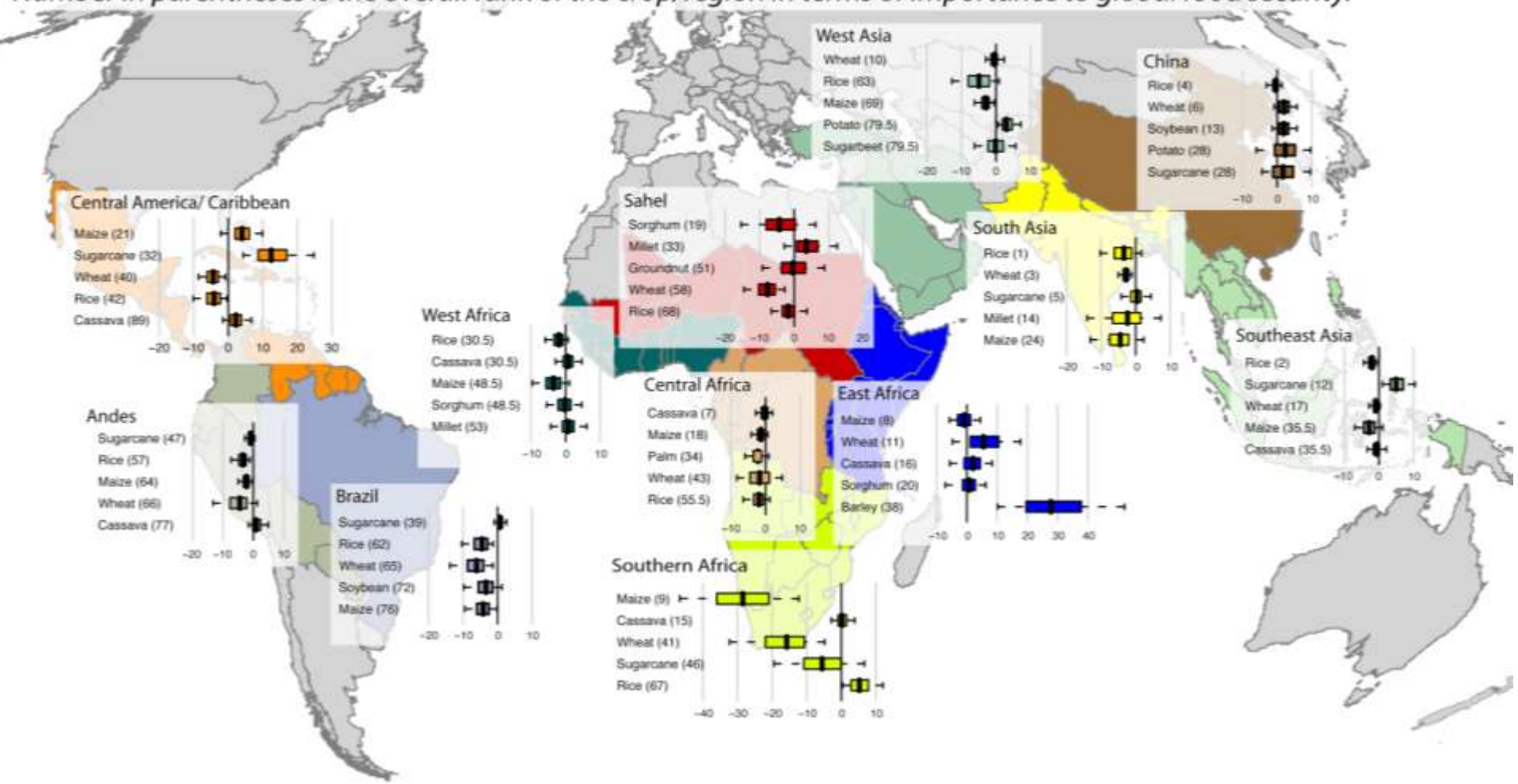
$R^2 = 0.63$

$$\Delta Y = \beta_T \Delta T + \beta_P \Delta P$$

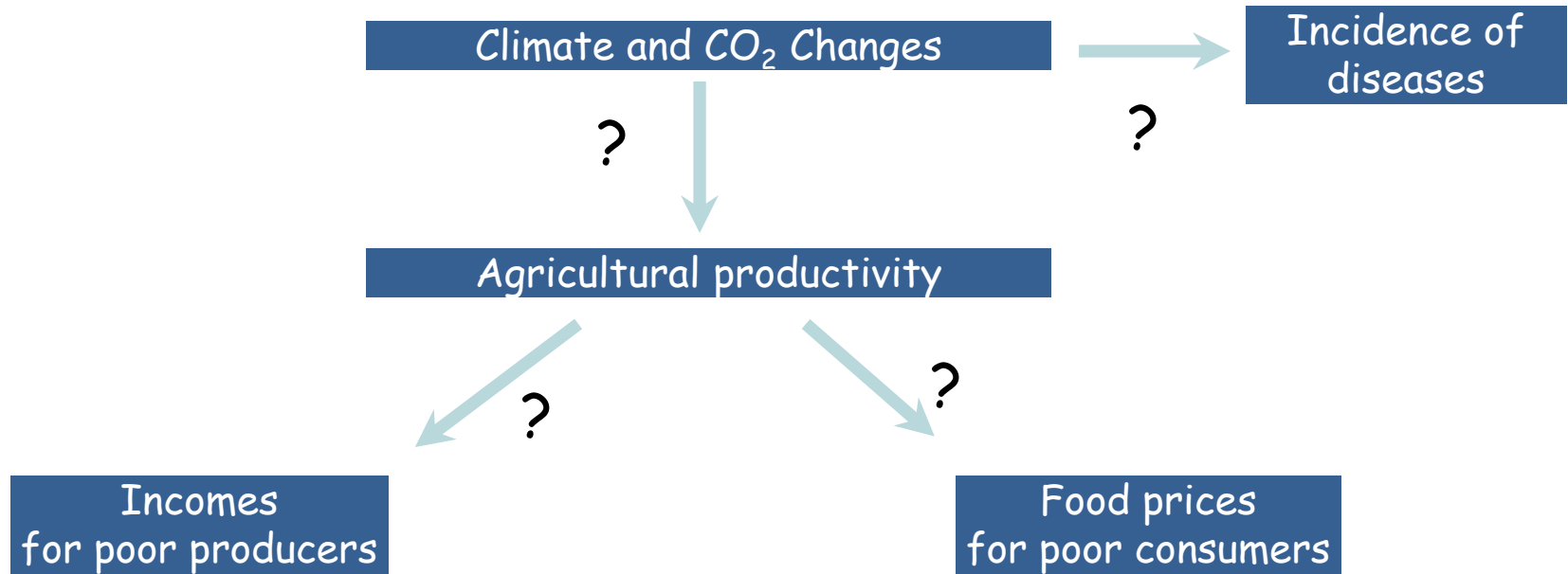
from climate models
from crop models



Projected impacts of climate change by 2030, for top 5 most important crops in each region
 Boxes represent 25th-75th percentile of model projections, whiskers 5th-95th, and dark line the median projection.
 Number in parentheses is the overall rank of the crop/region in terms of importance to global food security.



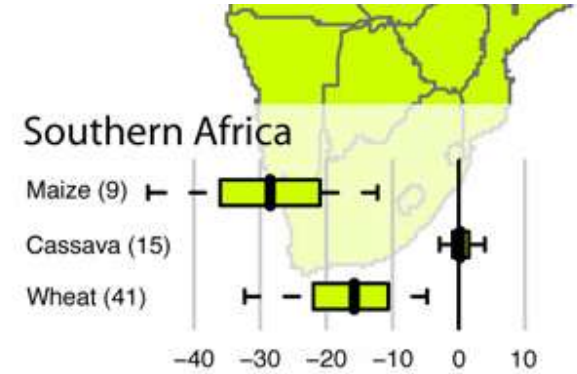
A modeler's view of the problem



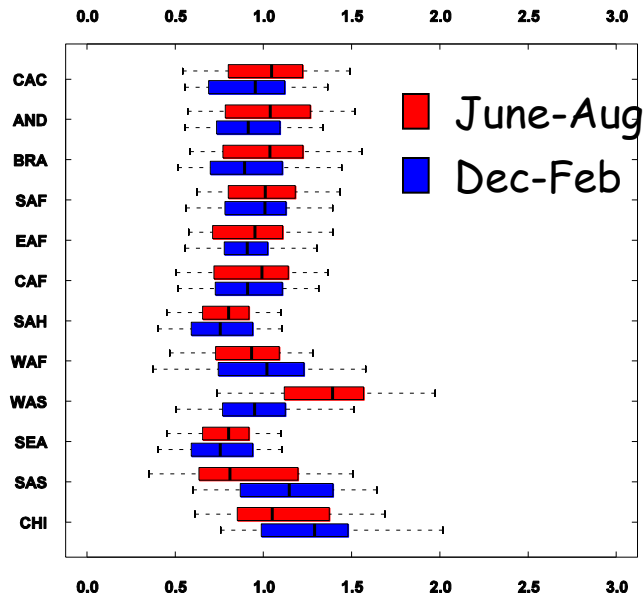
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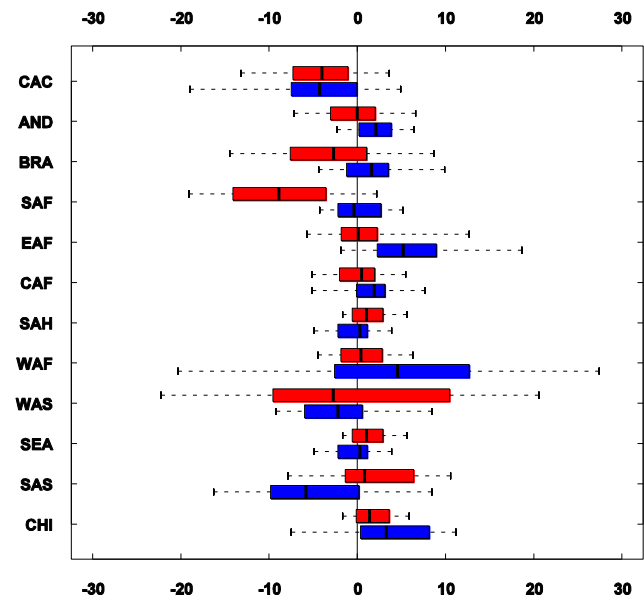
Why are uncertainties so large?



Our hypothesis: Most of the uncertainty is due to uncertain rainfall changes



Temperature Change (°C)



Precipitation Change (%)

Why are uncertainties so large?

$$\Delta Y = \beta_T \Delta T + \beta_P \Delta P$$

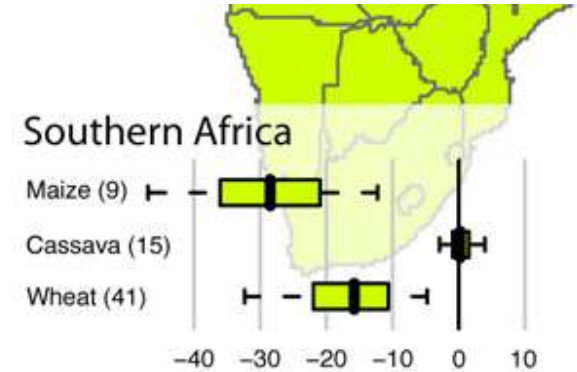
-We don't know perfectly:

How much temperature will change (ΔT)

How much (and in what direction) rainfall will change (ΔP)

How crops respond to temperature (β_T)

How crops respond to rainfall (β_P)



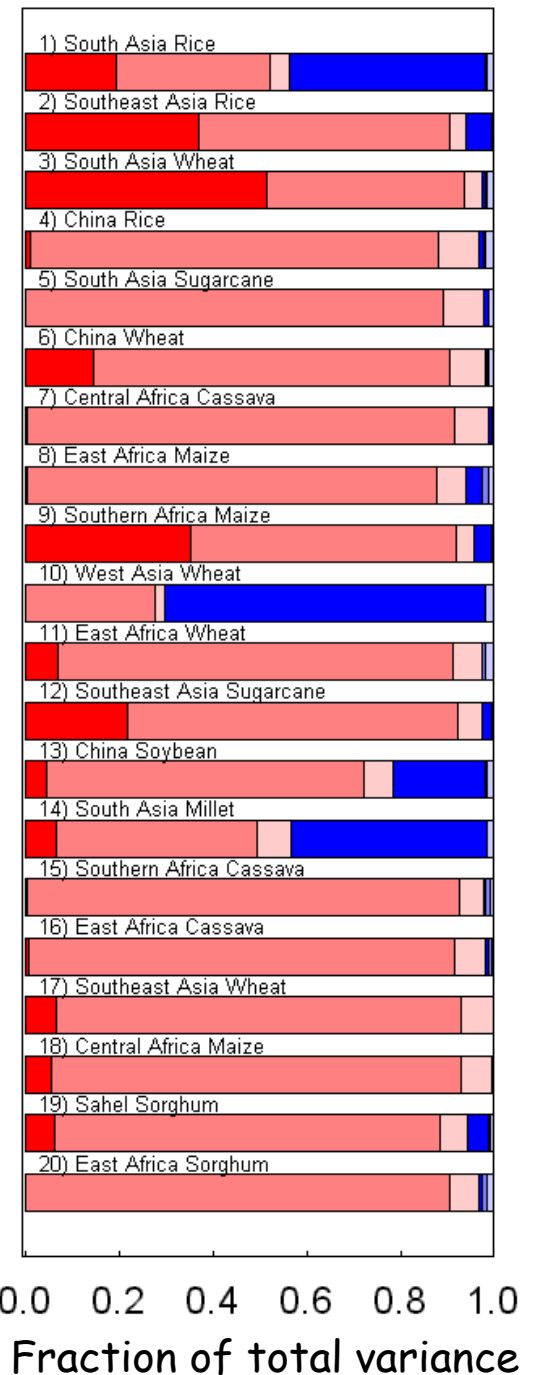
$$\Delta Y = \beta_T \Delta T + \beta_P \Delta P$$

$$\text{Var}(\Delta Y) = \text{Var}(\beta_T \Delta T + \beta_P \Delta P) = E[\beta_T]^2 \text{Var}(\Delta T) + E[\Delta T]^2 \text{Var}(\beta_T) + \text{Var}(\beta_T) \text{Var}(\Delta T) + E[\beta_P]^2 \text{Var}(\Delta P) + E[\Delta P]^2 \text{Var}(\beta_P) + \text{Var}(\beta_P) \text{Var}(\Delta P)$$

Why are uncertainties so large?

$$\text{Var}(\Delta Y) = E[\beta_T]^2 \text{Var}(\Delta T) + E[\Delta T]^2 \text{Var}(\beta_T) + \text{Var}(\beta_T) \text{Var}(\Delta T) + E[\beta_P]^2 \text{Var}(\Delta P) + E[\Delta P]^2 \text{Var}(\beta_P) + \text{Var}(\beta_P) \text{Var}(\Delta P)$$

Our hypothesis is not even close!

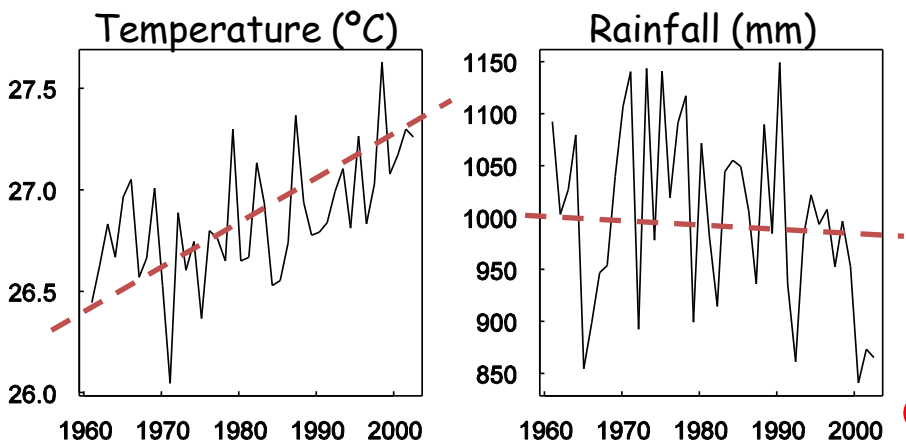


0.0 0.2 0.4 0.6 0.8 1.0
Fraction of total variance

Why are uncertainties so large?

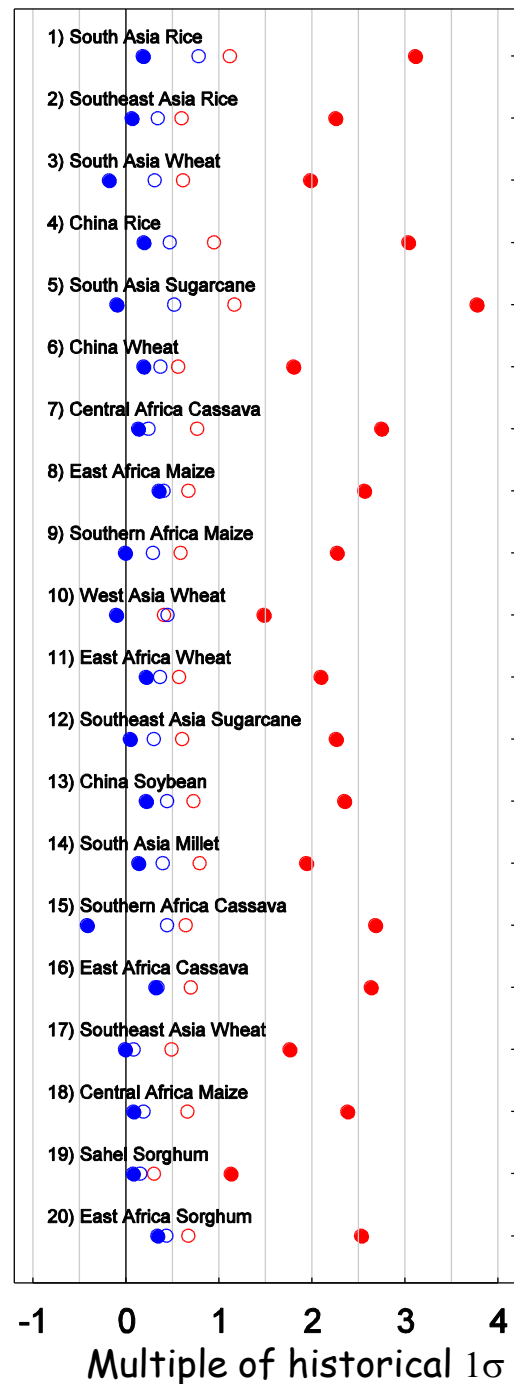
Why does temperature dominate uncertainty?

Because both the trend and the uncertainty in temperature are so large relative to historical variability. S. Asia Rice



- Mean(T trend)
- SD(T trend)
- Mean(P trend)
- SD(P Trend)

$$\text{Var}(\Delta Y) = E[\beta_T]^2 \text{Var}(\Delta T) + E[\Delta T]^2 \text{Var}(\beta_T) + \text{Var}(\beta_T) \text{Var}(\Delta T) + E[\beta_P]^2 \text{Var}(\Delta P) + E[\Delta P]^2 \text{Var}(\beta_P) + \text{Var}(\beta_P) \text{Var}(\Delta P)$$



So, what have we learned?

Temperature sensitivity of crops is very important for

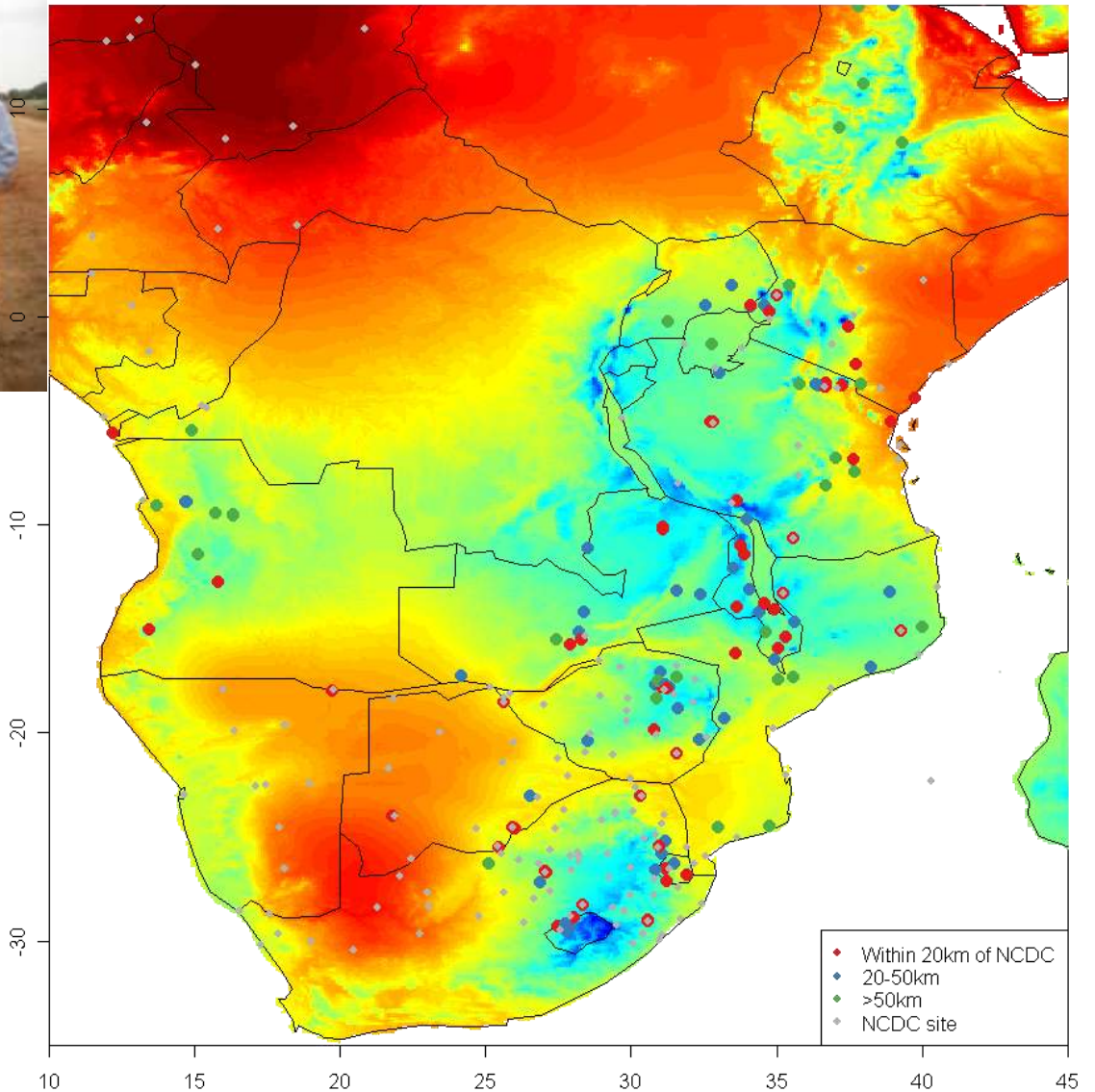
1) Projecting likely impacts without adaptation.

-We need better models of temperature response than we have, especially if we want to get down to impacts at fine scales. The other main options (1) process-based models, and (2) statistical models trained on more data.

2) Adapting crops to climate change

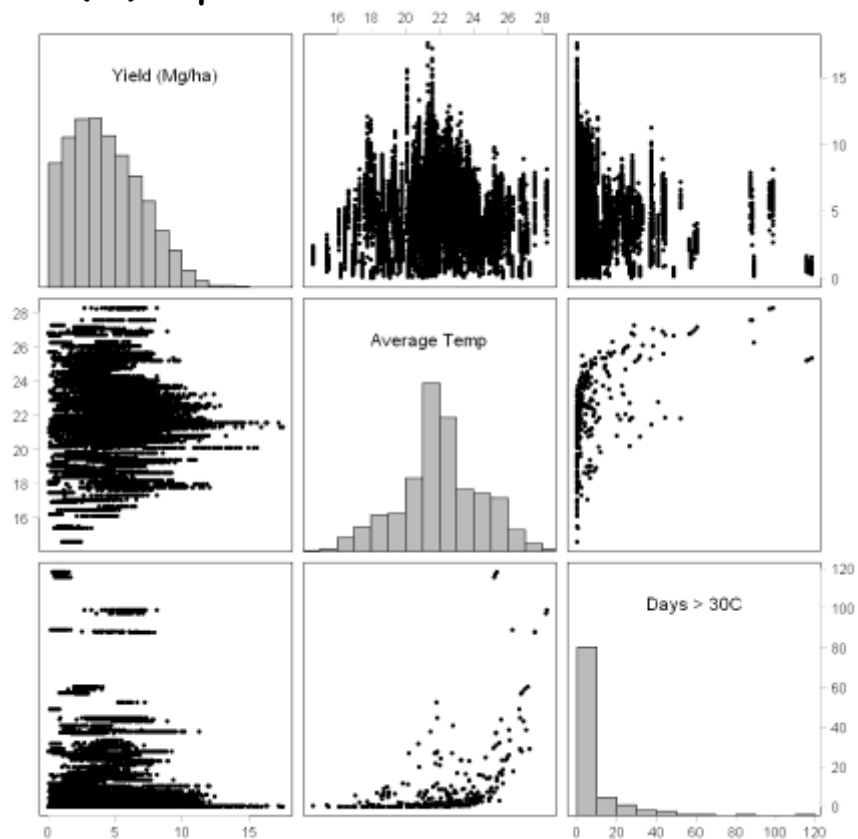
-working with crop development community to evaluate strategies for reducing temperature sensitivity.

Leveraging unused datasets

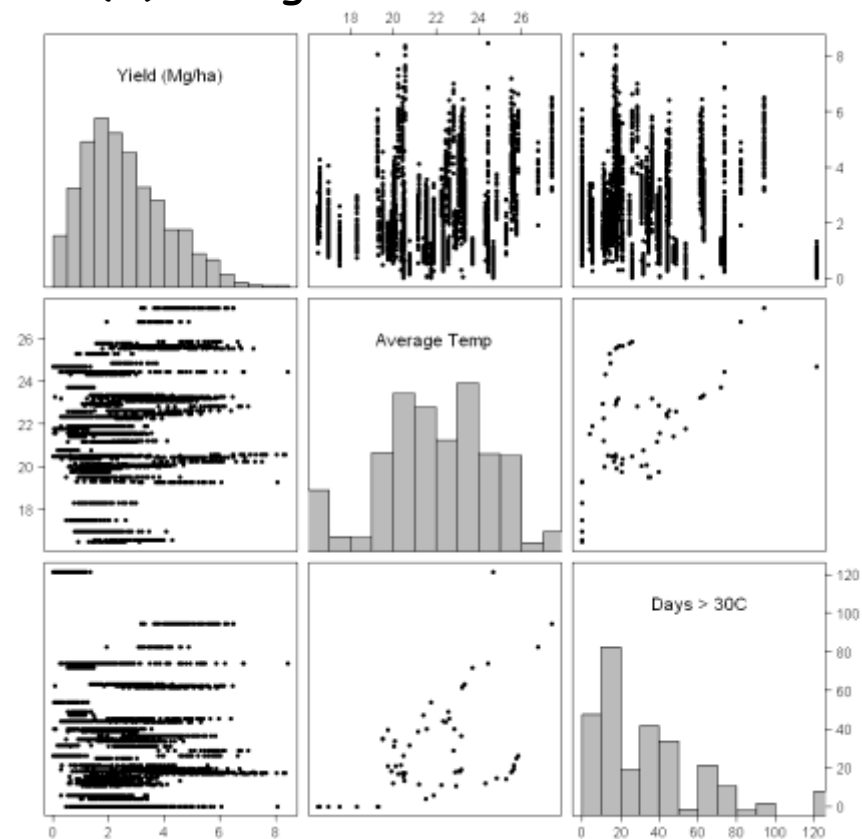


Thousands of trials, under both optimal rainfed and drought management

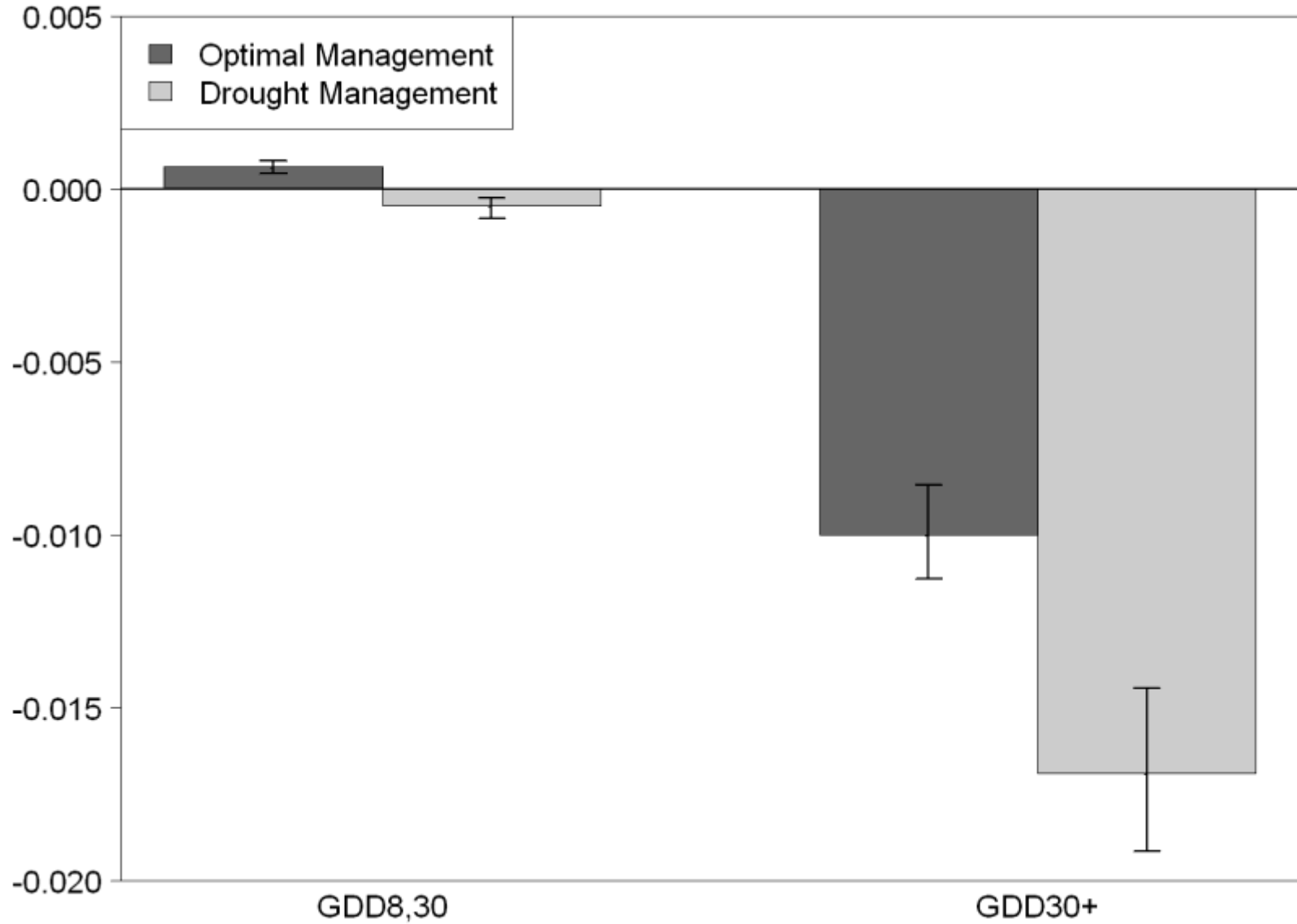
(A) Optimal



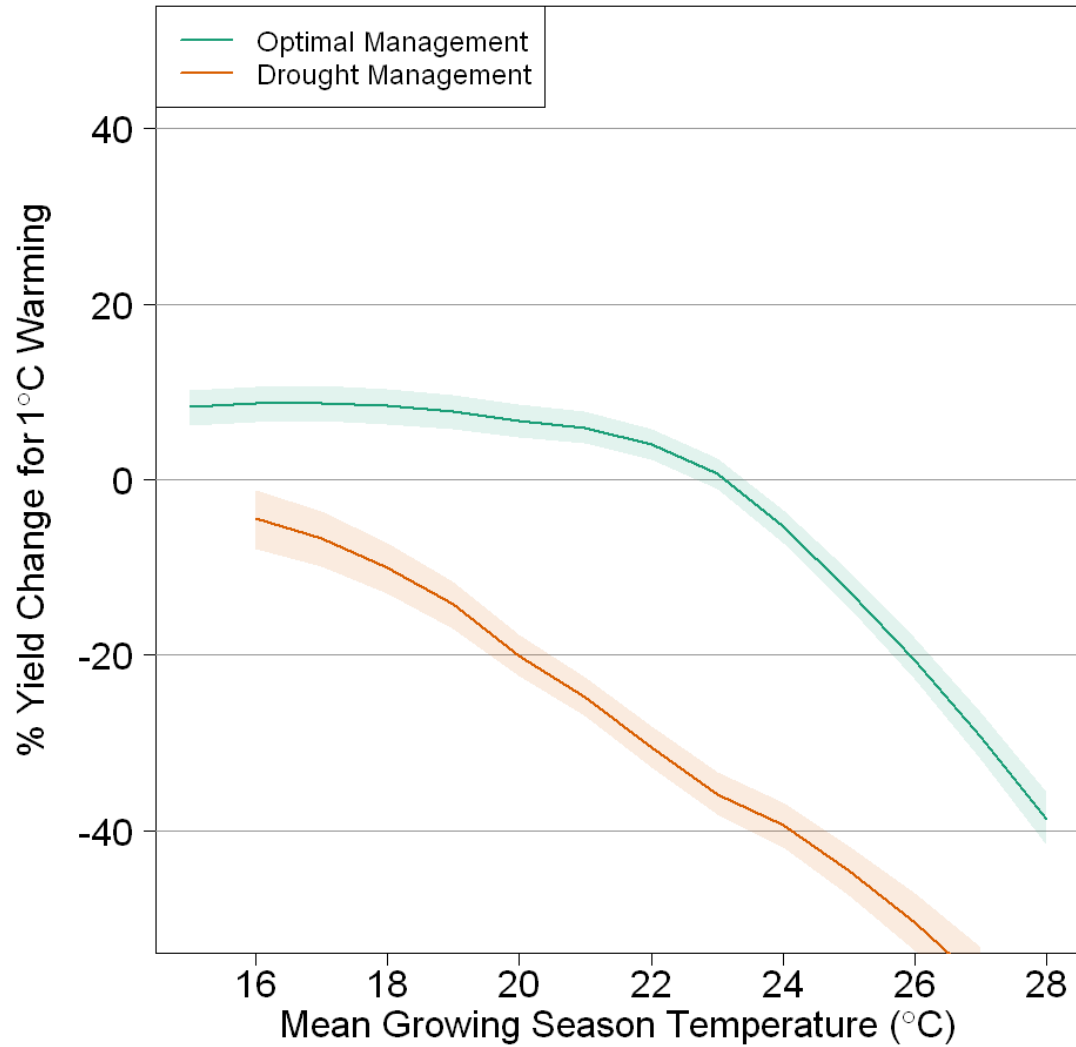
(B) Drought



A clear effect of temperature on tropical maize yields

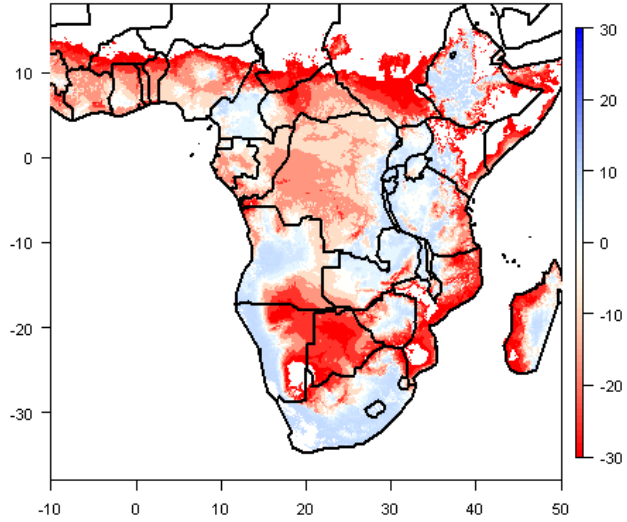


Sensitivity to warming by 1 °C for trials at different base temperatures

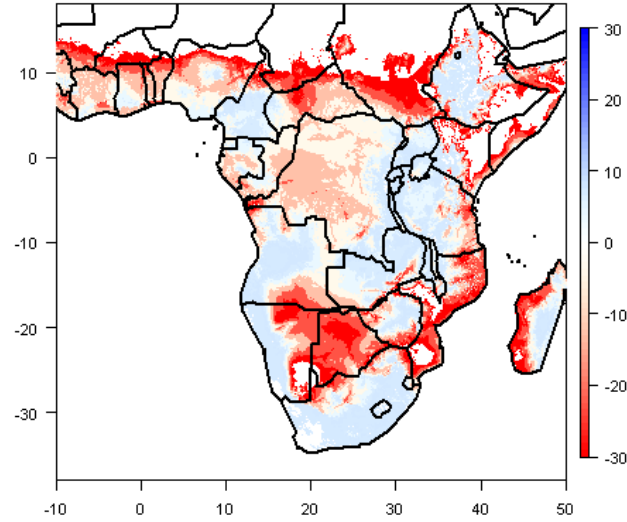


Sensitivity to warming by 1 °C, mean and (5th,95th percentile) estimates

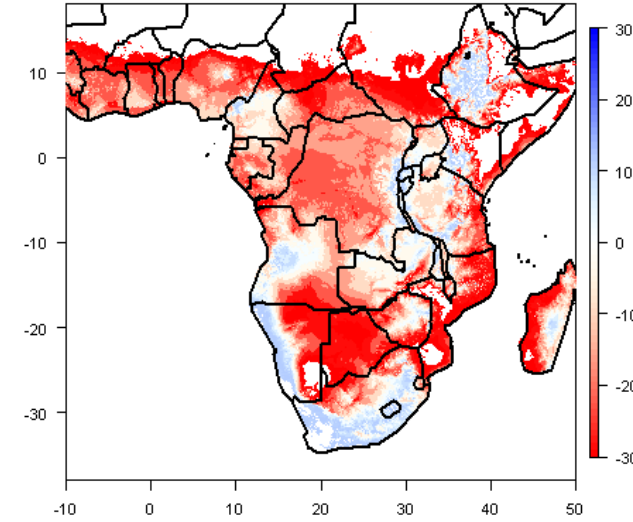
Optimal Management, Mean Estimate



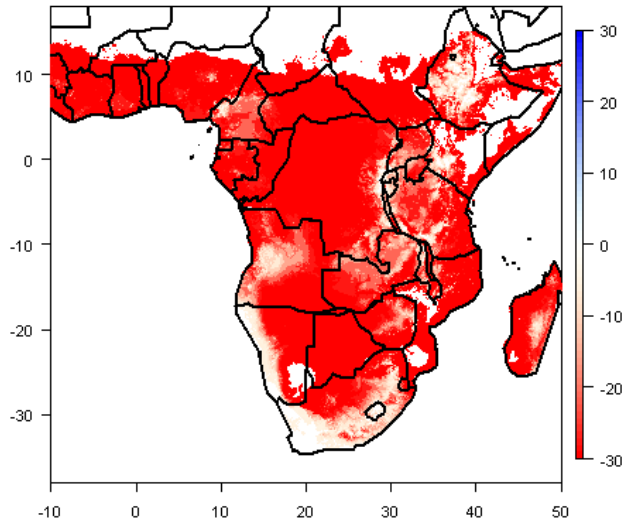
Optimal Management, 5th Percentile



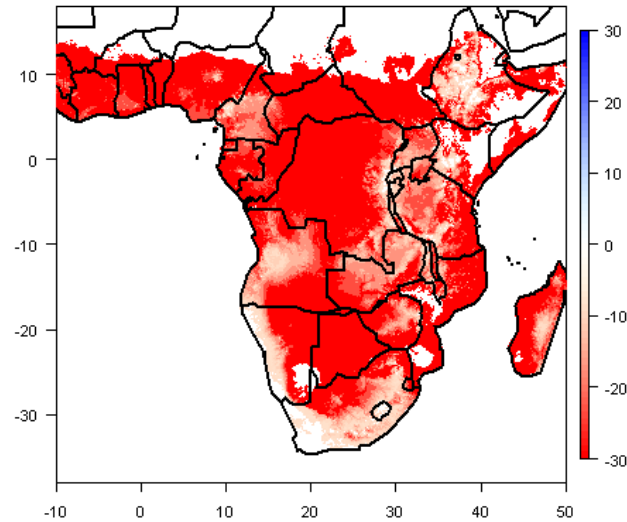
Optimal Management, 95th Percentile



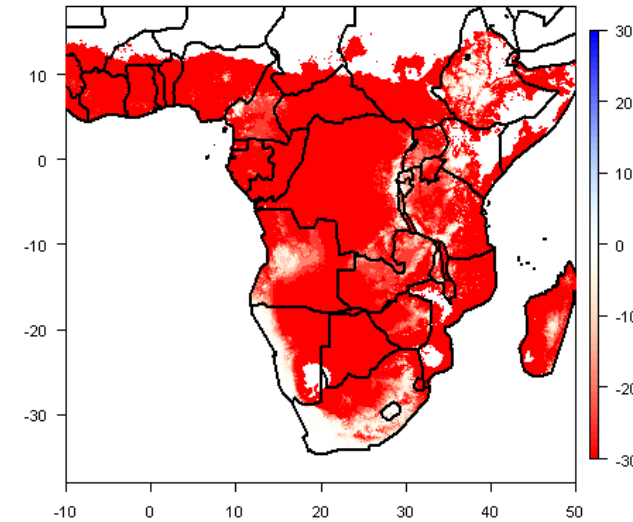
Drought Management, Mean Estimate



Drought Management, 5th Percentile



Drought Management, 95th Percentile



Summary

- 1) For crop impacts, temperature trends and crop sensitivity to heat are more important than most people think
- 2) New datasets can help to improve our understanding of future impacts, if we focus them on the key sources of uncertainty