Effects of climate change on global wheat production and food security

Senthold Asseng

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Outline

1. The agricultural challenge
2. Simulation models – AgMIP – multi-model approach
3. Temperature & CO_2 impact
4. Summary

The Agricultural Challenge

Increasing Food Demand

- **Population increase**

The Agricultural Challenge

Increasing Food Demand

- **Population increase**

People:

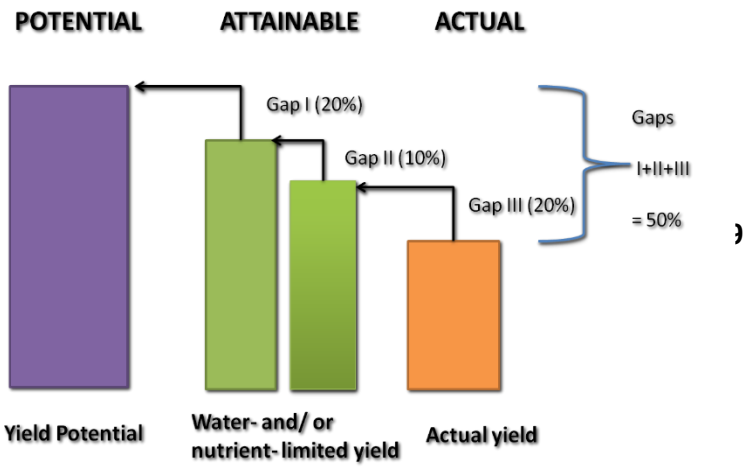
- **3 B in 1960**
- **7.3 B now**
- **>9 B in 2050**

- **800 M undernourished**

  (declined by 100 M in last 14 year)

- **BUT** (West et al. 2014 Science)…

Undernourished population

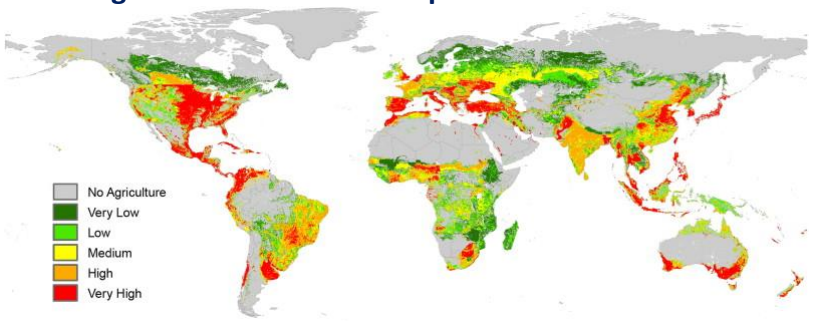


The Agricultural Challenge

Increasing Food Demand

- Population increase
- **Need 60% more food in 2050**
  (Alexandratos & Bruinsma 2012 FAO Report)
- **Increase nutritional value**
- **Reduce environmental impact**
  (Irrigation in agriculture = 70% of global water withdrawals with India, Pakistan, China, USA = 72% of all irrigation) (West et al. 2014 Science)

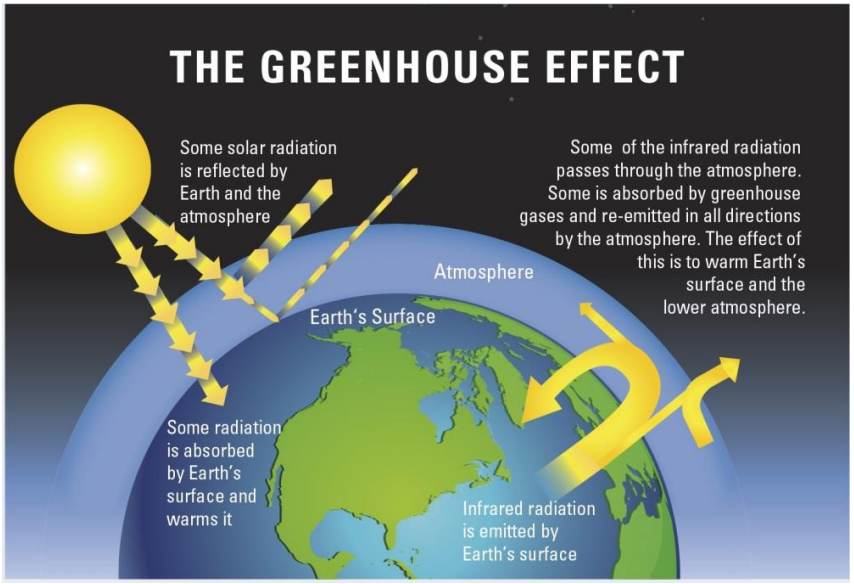
High risk of surface water pollution across the world

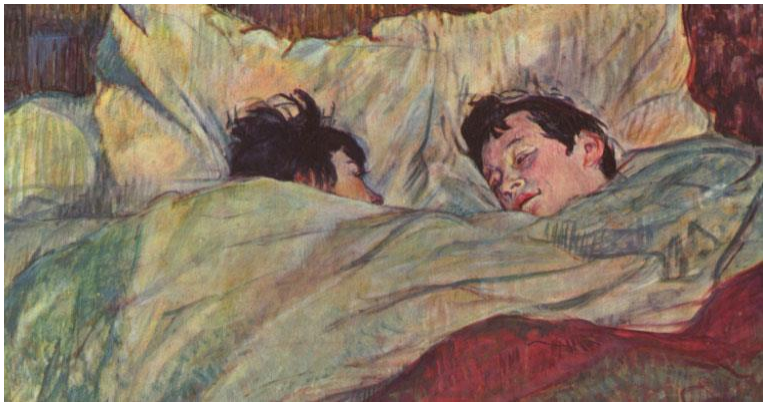


Ippolito et al. 2015 Environmental Pollution

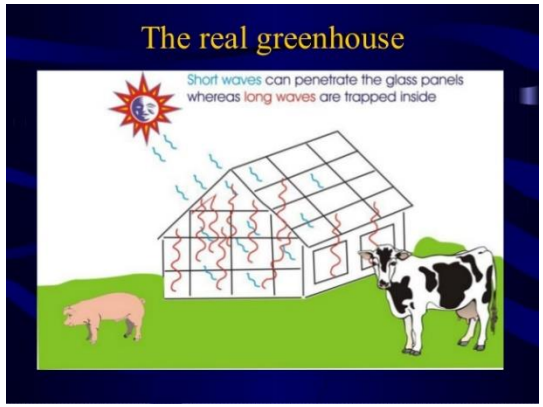
Climate Change

Climate change & green house effect

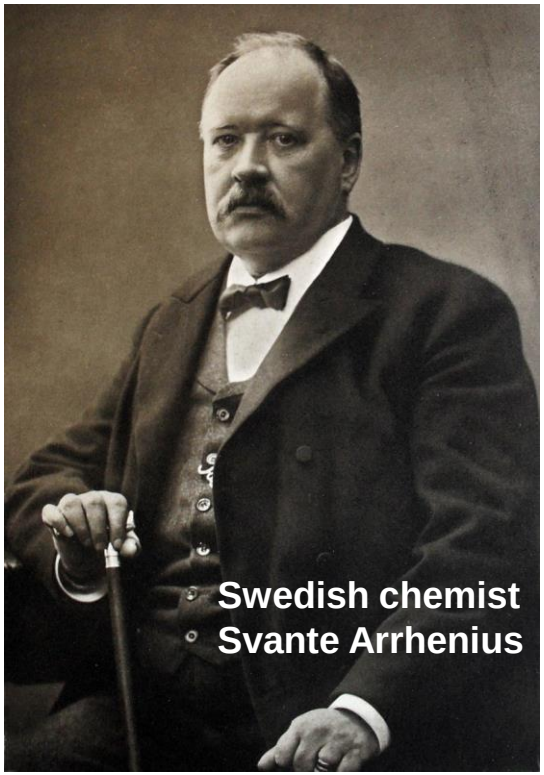




<u>Carbon dioxide</u> acts like a blanket, absorbing IR radiation & preventing it from escaping into outer space. -→ net effect heating of Earth



Since when do we know about climate change?

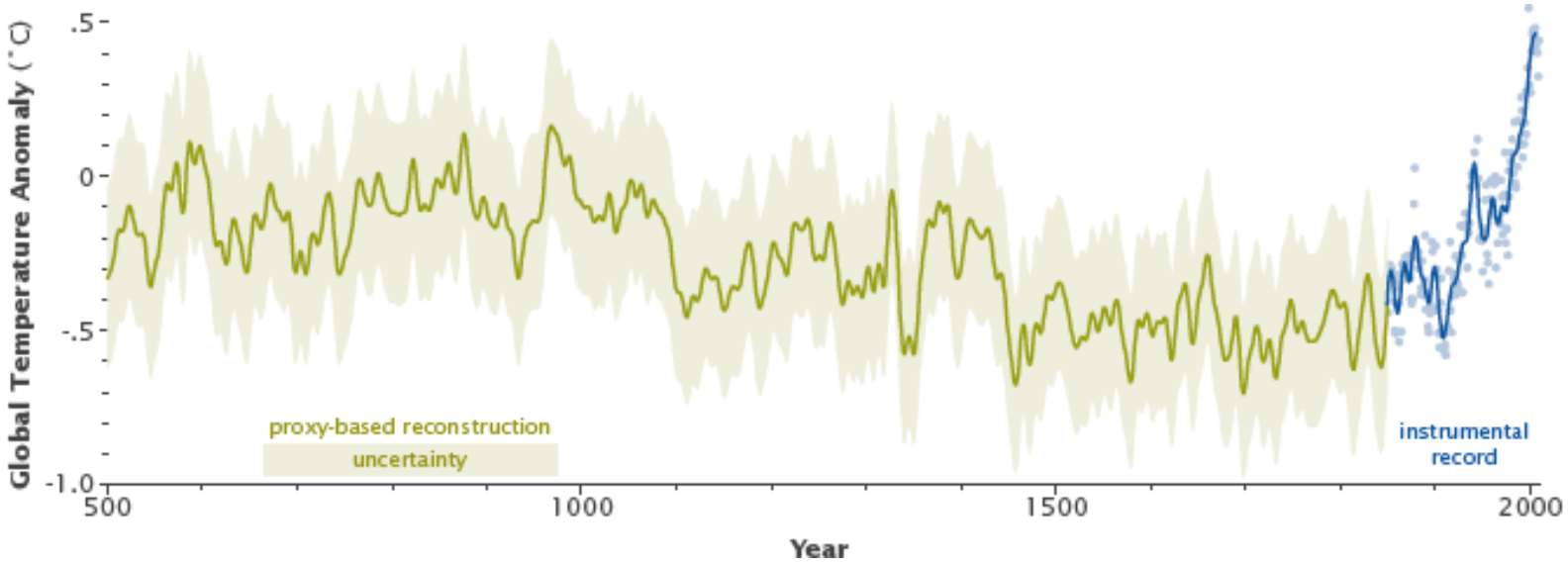


Arrhenius 1896 ***Philosophical Magazine and Journal of Science***

- doubling of atmospheric CO_2 could cause an increase in Earth's surface temperature of 11°F to 14.5°F

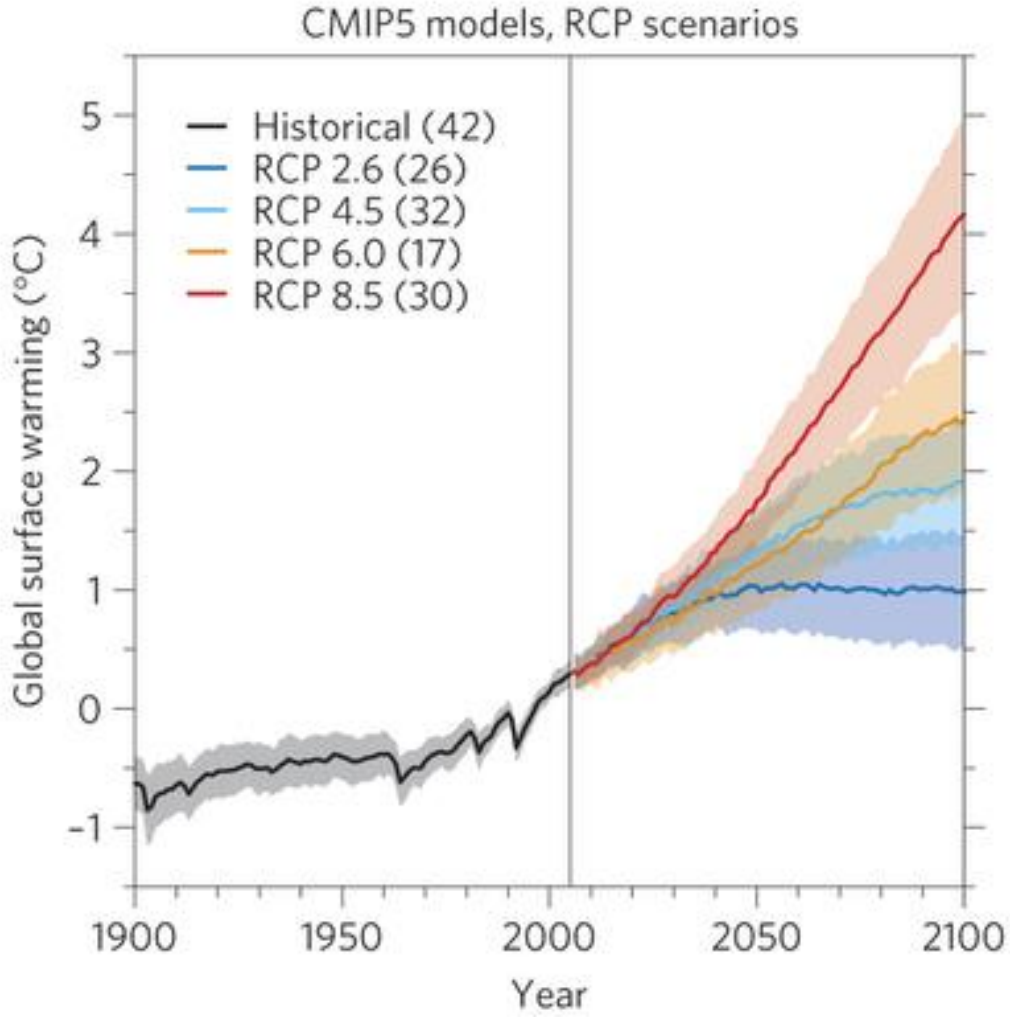
(5.5°F to 9°F suggest by GCMs)

Past temperature trend



NASA

Future temperature trend



Knutti and Sedlacek 2013 Nature CC

The Agricultural Challenge

Increasing Food Demand

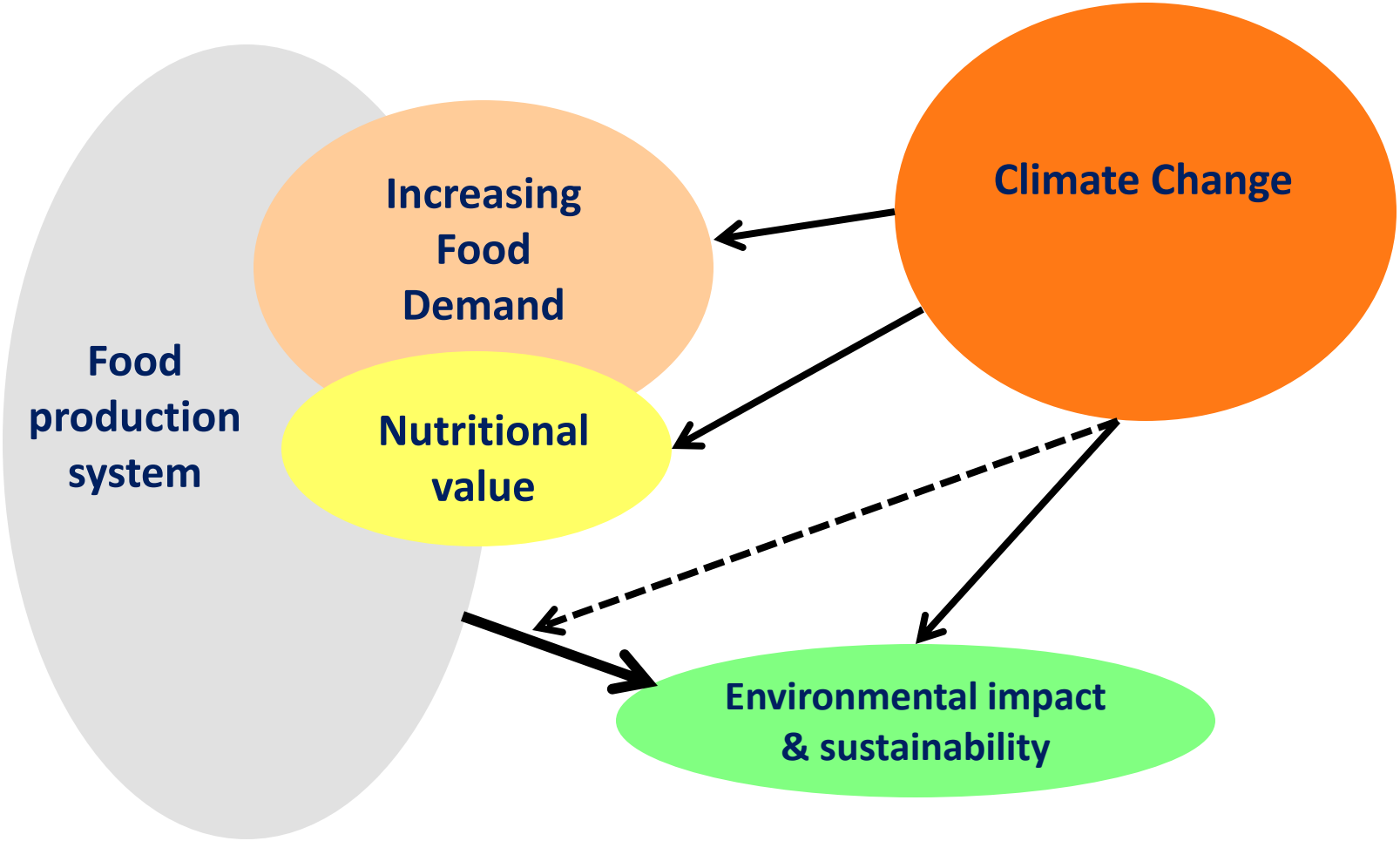
- Population increase
- Need 60% more food in 2050
- Increase nutritional value
- Reduce environmental impact

Climate Change

- **Temperature increased by 1.0 ^{o}C**
- **By 2050: Atmospheric CO_2 >500ppm**
- **By 2100:**
  - **Temperature +2 to 4 ^{o}C**
  - **More extremes (heat, droughts, rainfall).**

(IPCC 2015)

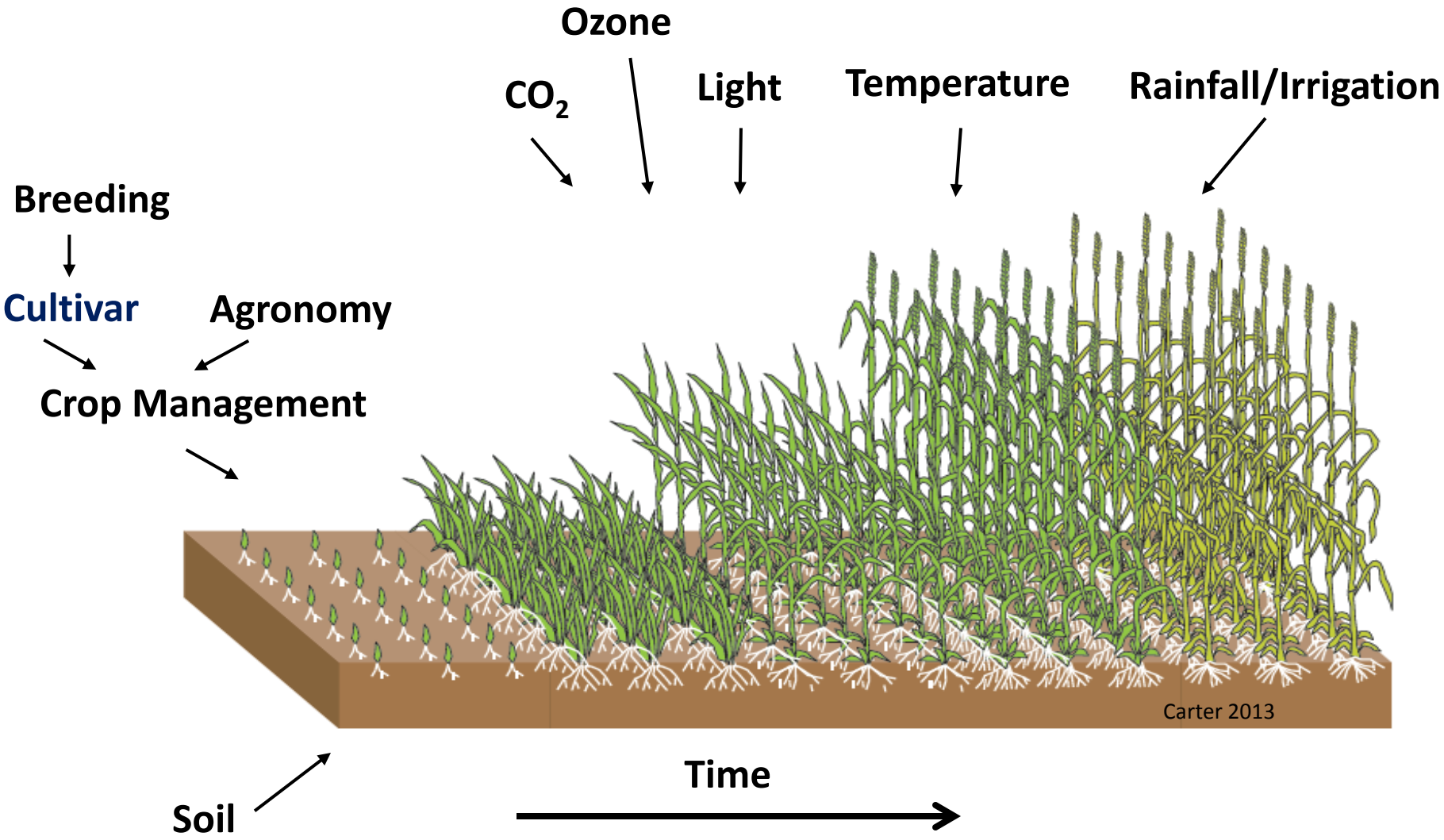
Complexity


Food production system
Increasing Food Demand
Nutritional value
Climate Change
Environmental impact & sustainability

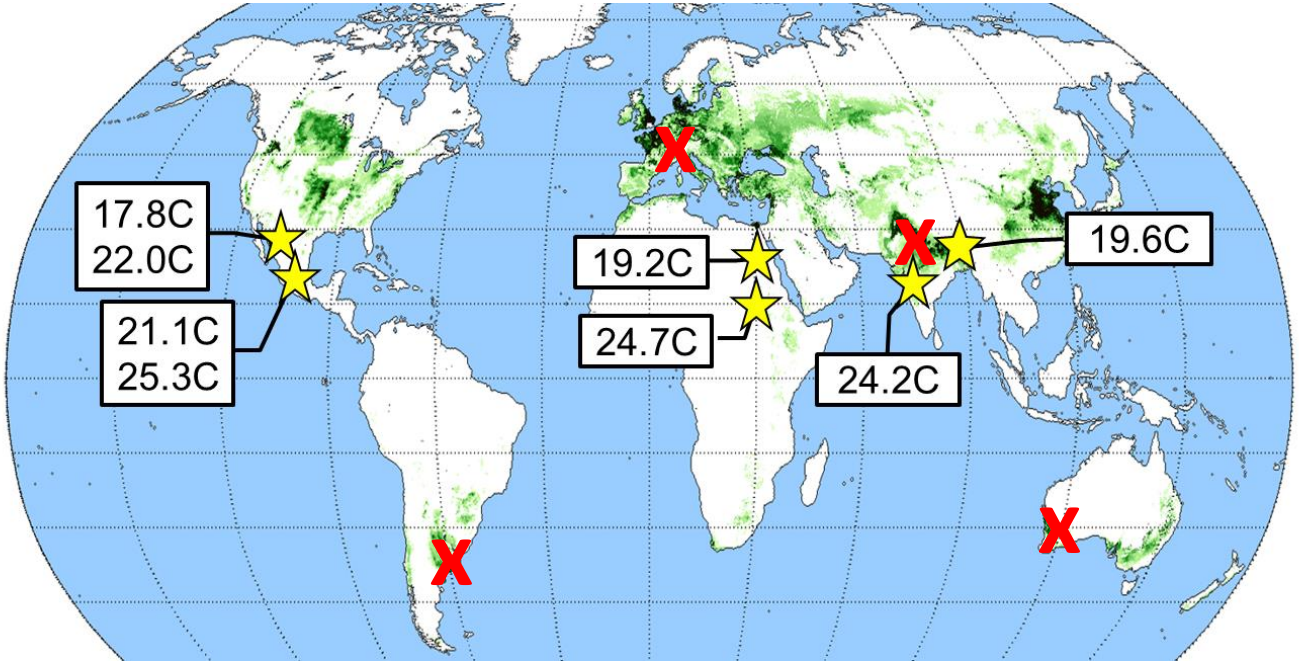
Potential climate change impacts

Change	Positive Impact	Negative Impact
1. Temperature increase	• Less frost damage • Improved winter growth • Earlier planting	• Faster phenology • Reduced chill hours • Increased heat stress • Increased water use • Increased pest/disease
2. Increased CO_2	• Growth stimulus (if nutrients not limiting) • Increased water use efficiency	• Reduced nutrition • Warmer canopies (increased heat stress) • Increased weeds
3. More intense rainfall (Florida)	• Reduced diseases? (longer dry periods)	• More runoff • More chemical leaching • More irrigation

Modeling (Wheat) Cropping Systems



AgMIP-Wheat



25 models consistent across 2 data sets:

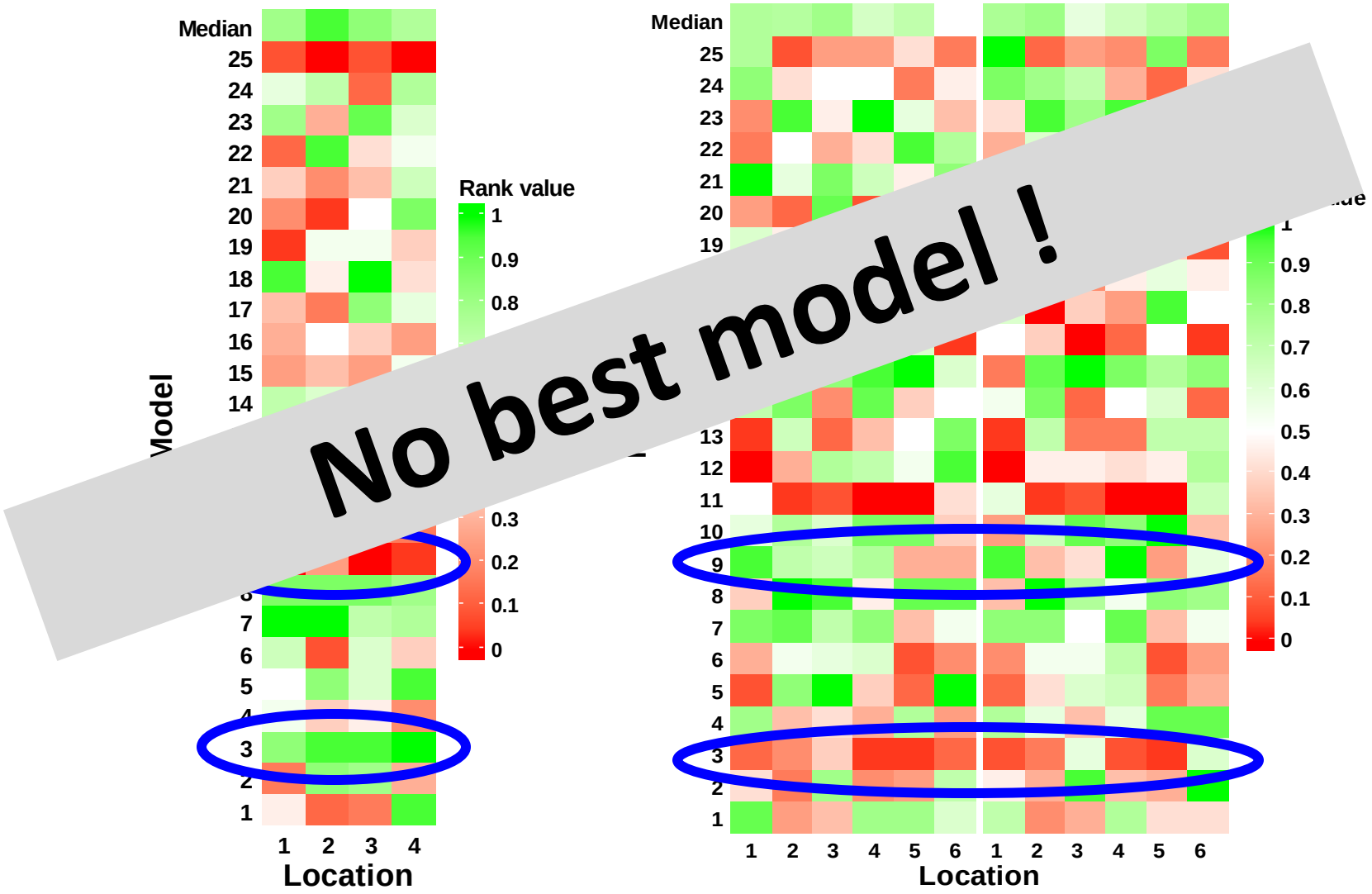
a) **4 pilot locations – contrasting conditions**

b) **6 CIMMYT hot locations (2 cultivars)**

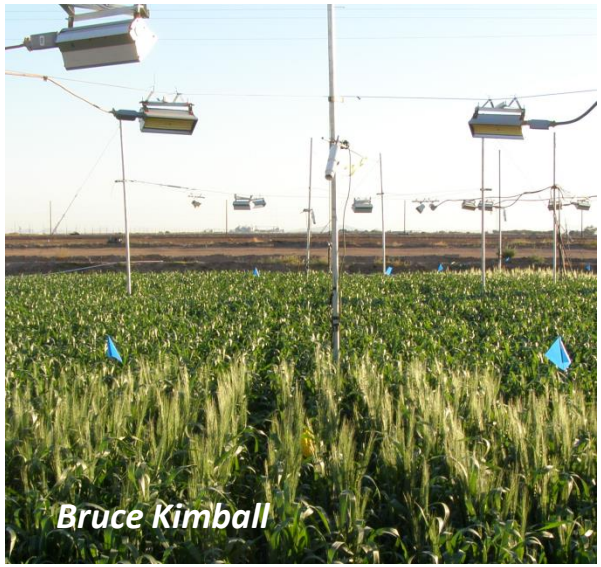
Model ranking (to observation)

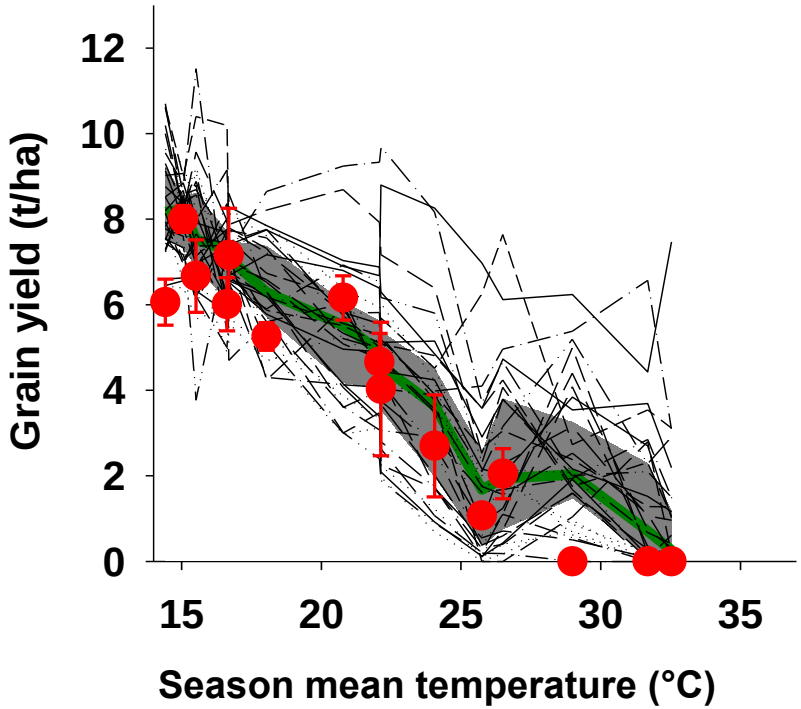
4-pilot locations – contrasting conditions

6-CIMMYT hot locations (2 cultivars)



Multi-model ensembles





Asseng et al. 2015 Nature CC

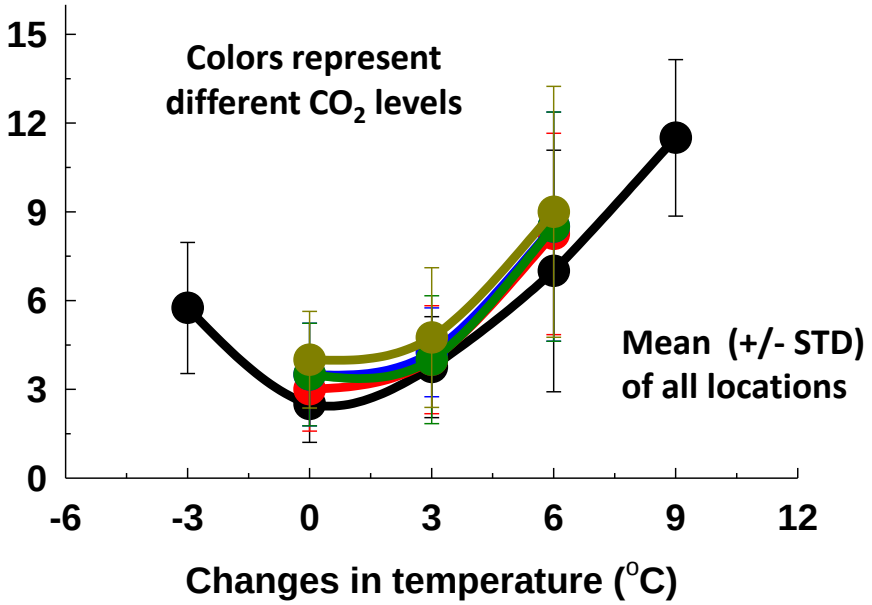
Multi-model ensembles

➢ **Multi-model ensemble median is a better predictor than any single model !**

- **Wheat yields --- *Asseng et al. 2013 Nature CC***
- **Wheat yields (heat stress) --- *Asseng et al. 2015 Nature CC***
- **Wheat variables --- *Martre et al. 2014 GCB***
- **Maize yields --- *Bassu et al. 2014 GCB***
- **Rice yields --- *Li et al. 2014 GCB***
- **Potato yields --- *Fleisher et al. 2016 GCB***

Multi-model ensembles to reduce uncertainty

Required number of crop models to achieve <13.5% simulated impact variability (-)



Asseng et al. 2013 Nature CC

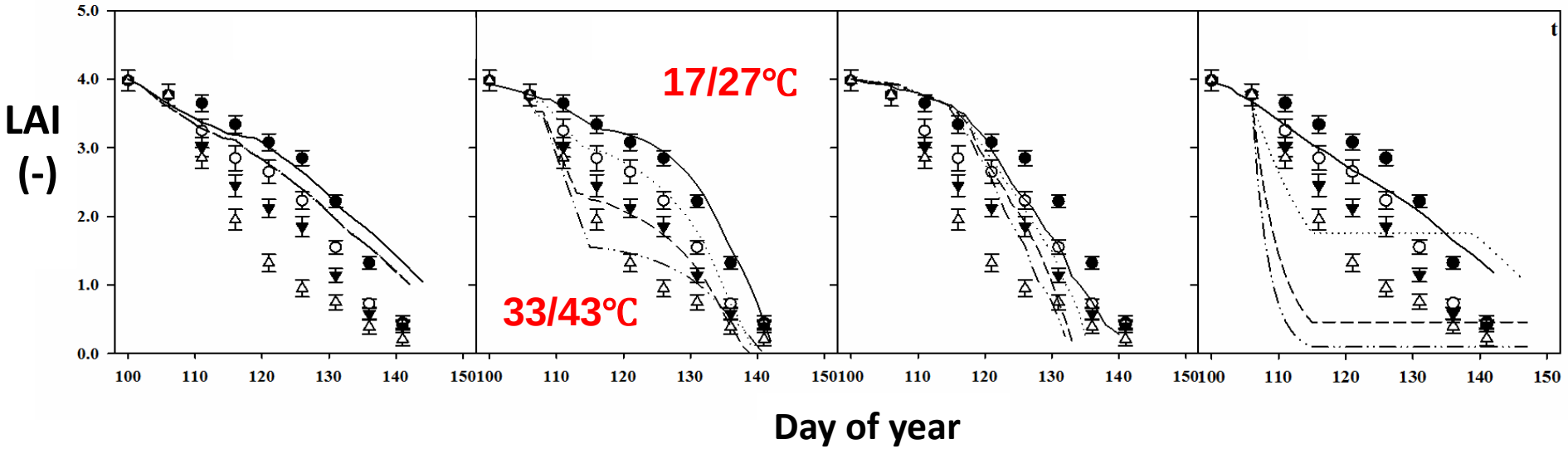
(13.5% = Mean exp CV% (Taylor et al. 1999))

Simulating heat stress

Senescence acceleration routine with heat

✓

Model A **Model B** **Model C** **Model D**

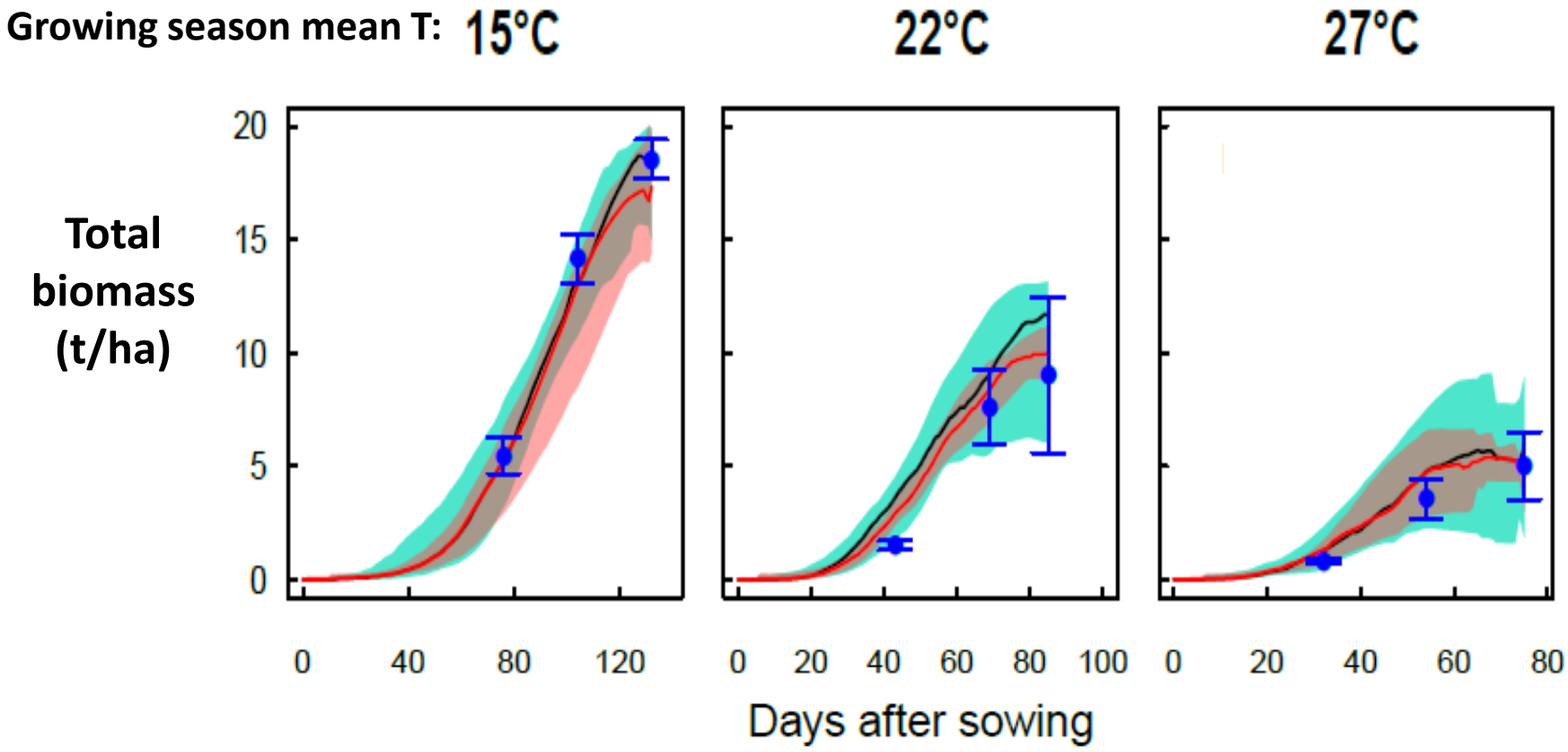


Heat = 9 days around anthesis

Liu et al. 2016 GCB

Observed = symbols **Simulation = lines**

Improved simulation of heat stress



Maiorano et al. 2016 FCR

Observed = symbols

Multi-model simulation = shades (red shade = improved models)

Multi-model simulation medians = lines

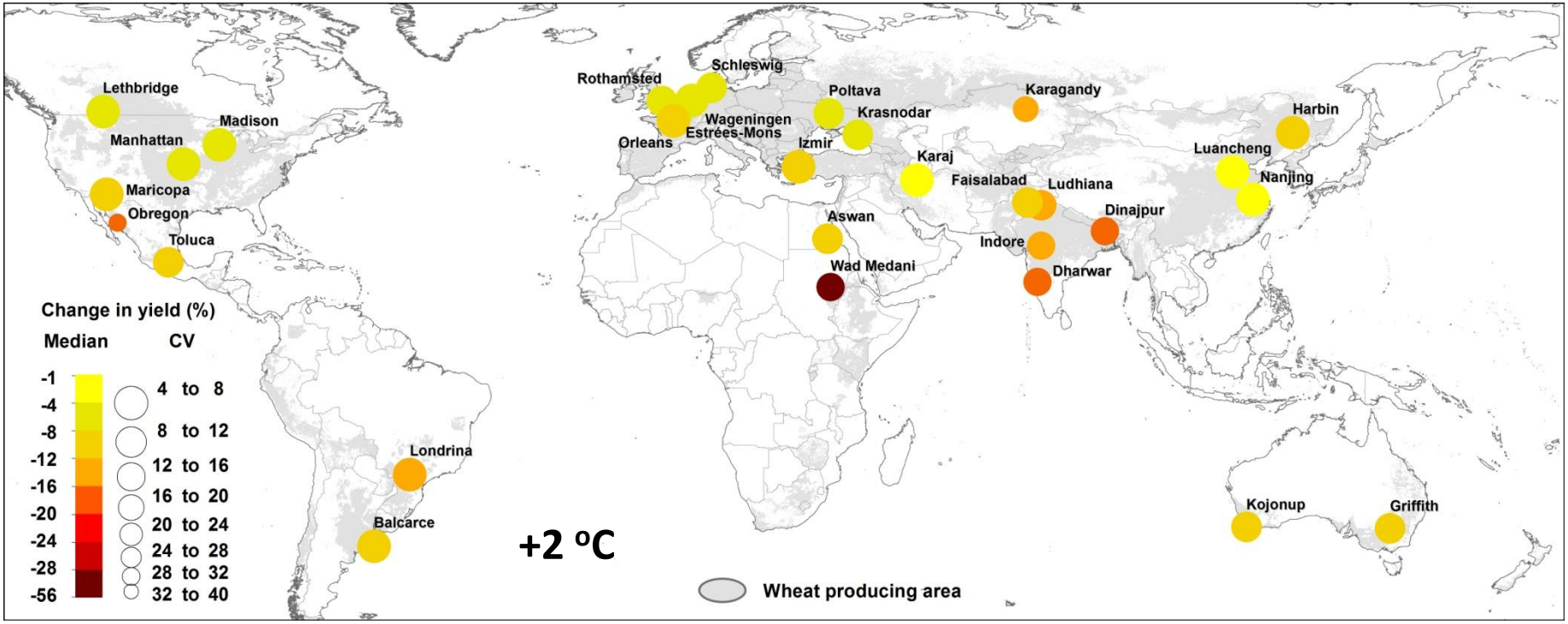
Multi-model ensembles to reduce uncertainty

- ***Model improvements reduce required number of models in multi-model ensembles***

Maiorano et al. 2016 FCR

Wheat Yield decline with increasing temperature

30 model ensemble median (& mean of 30 years)



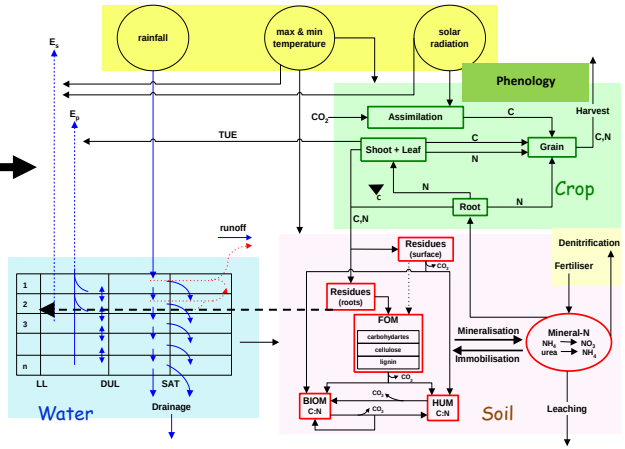
➢ 6% decline in global wheat production for each degree in global warming

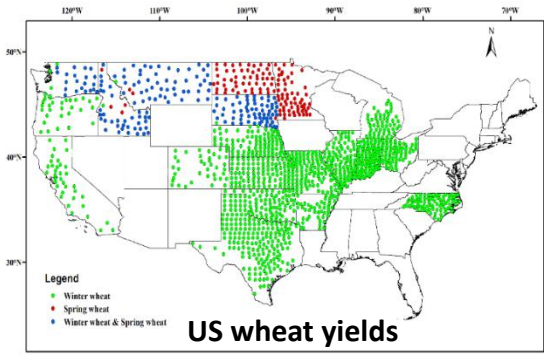
Asseng et al. 2015 Nature CC

Experiments

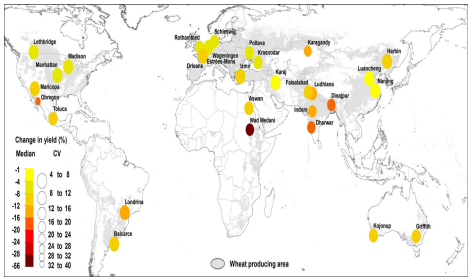
Crop models

Statistical models

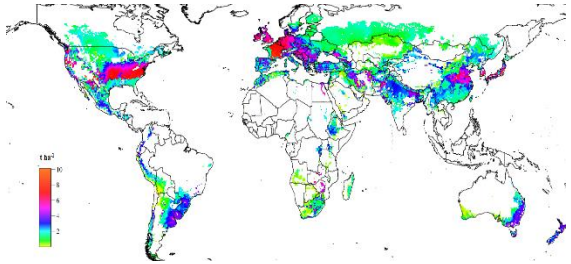




Multi-model points

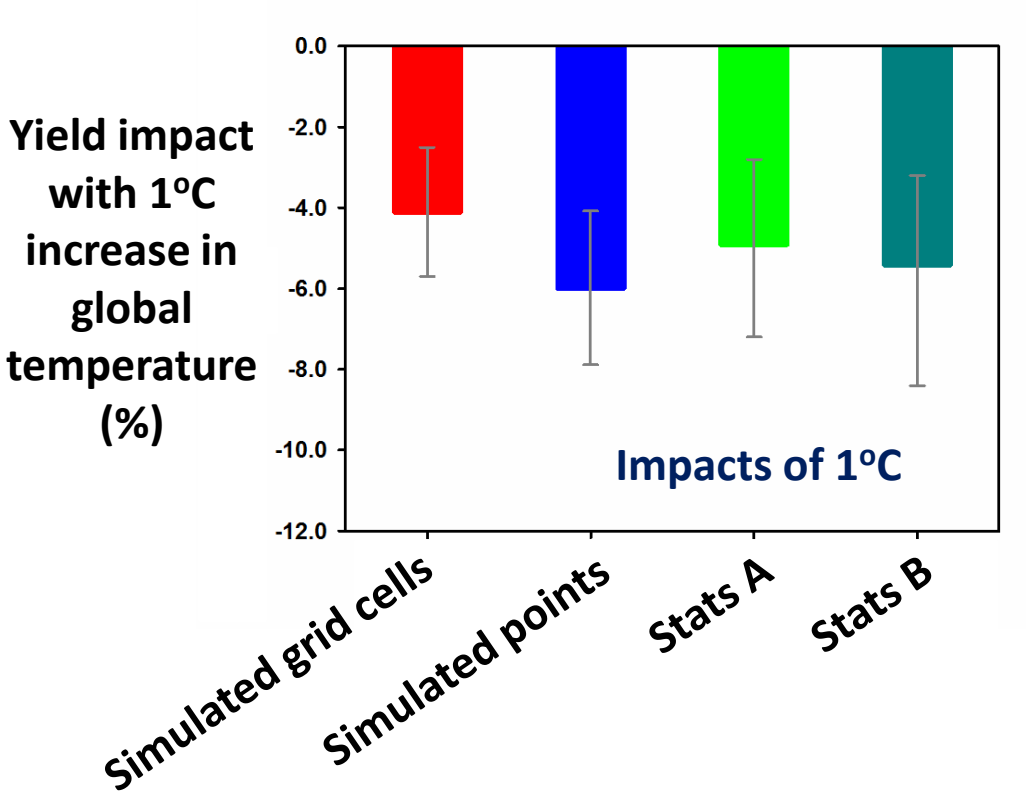


Global-gridded



Impact

Impacts of global temperature increase on global wheat yield estimated by different assessment methods



Liu et al. 2016 Nature CC

- **Consistent with observations**

(Fischer, Beyerlee and Edmeades 2015 Book: Crop Yields and Global Food Security)

Summary

1. Agricultural challenge is huge and complex; increasing yields is part of it,

2. Multi-model ensemble = best predictor across environments,

3. Ensemble of 2-5 models sufficient to reduce uncertainty to experimental error; model improvements ---> less models required,

4. 6% decline in global wheat for each degree in global warming,
   - similar across methods,

5. Loss of CO_2 growth stimulus with increasing temperature.

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