Heat tolerance is a key for high wheat yields in Europe under climate change

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Rothamsted Research

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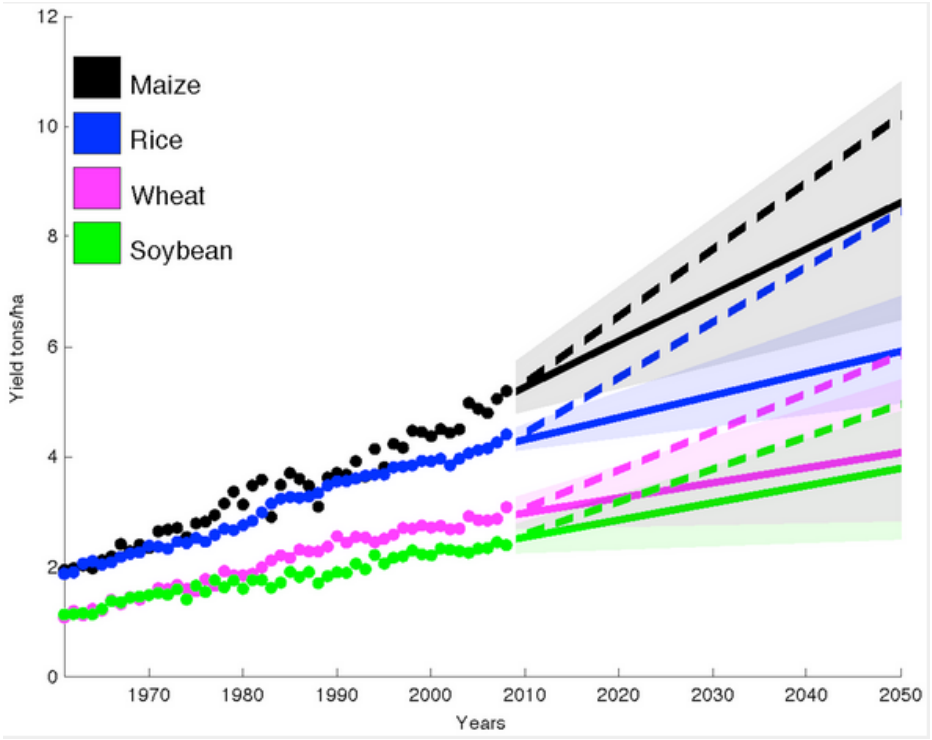
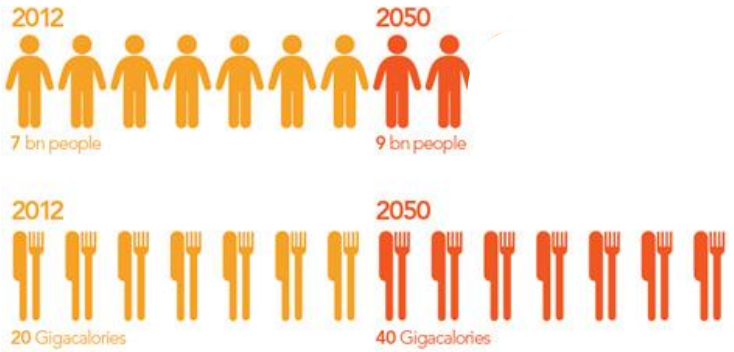
Food security: global food demand





(Ray et al, PLoS ONE, 2013)

2.4% yield increase per year required to double food production by 2050

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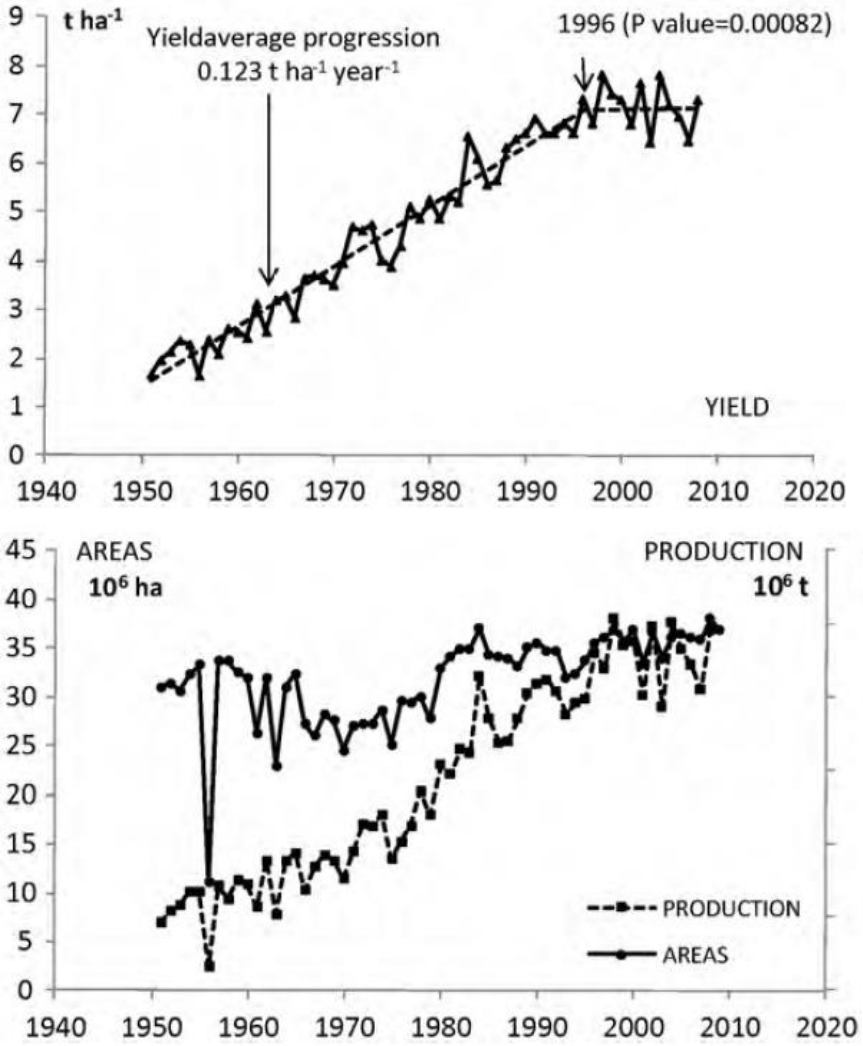
Wheat yield stagnation in Europe



(Brisson et al, Field Crop Res 2010)

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World record wheat yields

- In 1981, the world record wheat yield of 13.99 t/ha at a field scale was achieved in Scotland
- In 2010, a NZ farmer had a new record of 15.64 t/ha (*cv.* Einstein)
- Average wheat yield in the UK is about 8 t/ha
- 20:20 Wheat ® aims to achieve yield potential of 20 t/ha in 20 years

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Adapting wheat for uncertain future

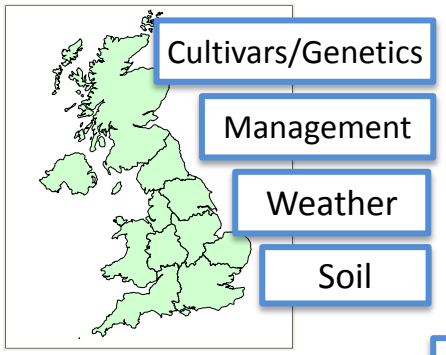
Challenges:

- Large uncertainty in predicting future environments and climates
- No clear targets for breeding: future threats to wheat production are unknown
- Candidate-cultivars can be only tested for the current, not future conditions

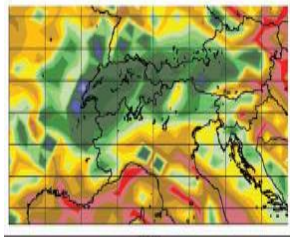
Key:

- **Modelling is a powerful tool to design wheat ideotypes for a changing climate and identify targets for crop improvement**

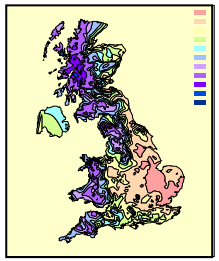
Modelling framework: wheat ideotypes



CMIP5 climate projections



LARS-WG
weather generator



Local-scale
weather

Sirius
crop model

Ideotypes optimised
for future climates

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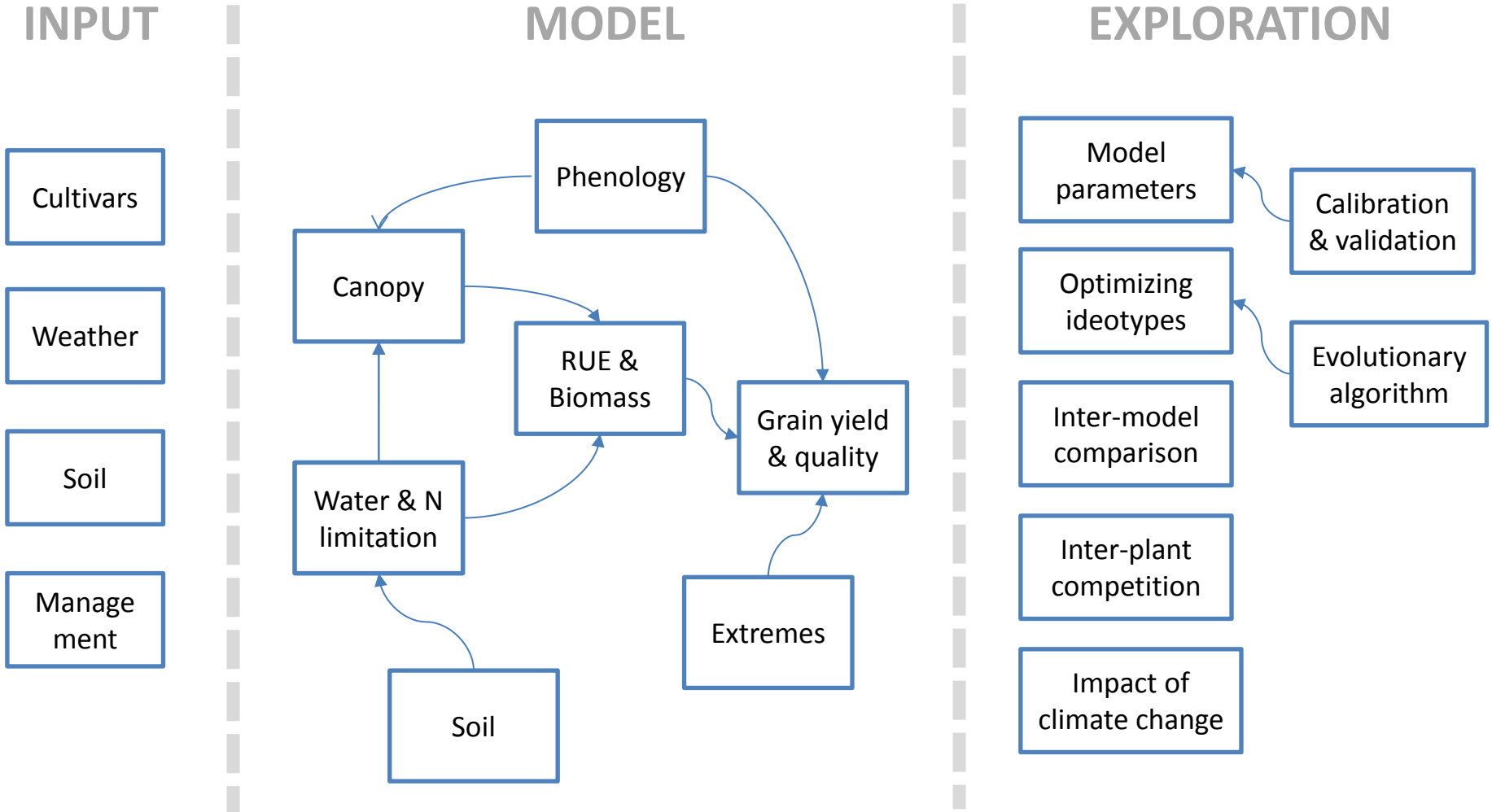
Sirius: crop simulation model



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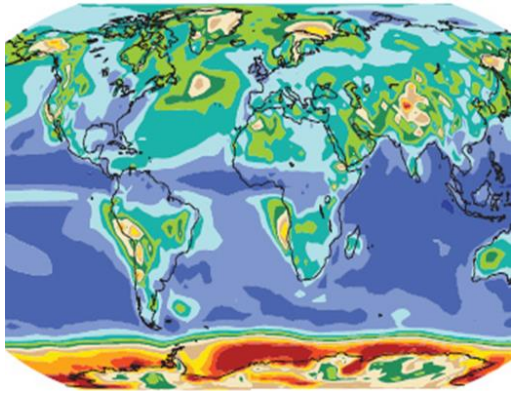
LARS-WG: downscaling climate projections

CMIP5 ensemble
of Global Climate Models



Local-scale parameters derived
from observed weather

LARS-WG

Local-scale climate scenarios
for impact assessments

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Coding wheat ideotypes: cultivar parameters

Phenology

- phyllochron **Ph**: 70 - 140
- daylength response **PP**: 0.05 – 0.7
- duration of grain filling **Gf**: 500 - 900

Canopy

- max leaf size **A**: 0.003 – 0.01
- "stay green" **S**: 1-2

Tolerance to drought

- response of photosynthesis to water stress **Wsa**: 0.1 – 0.21
- leaf senescence **Wss**: 0.12 – 0.19

Roots efficiency

- water uptake **Ru**: 1 - 7

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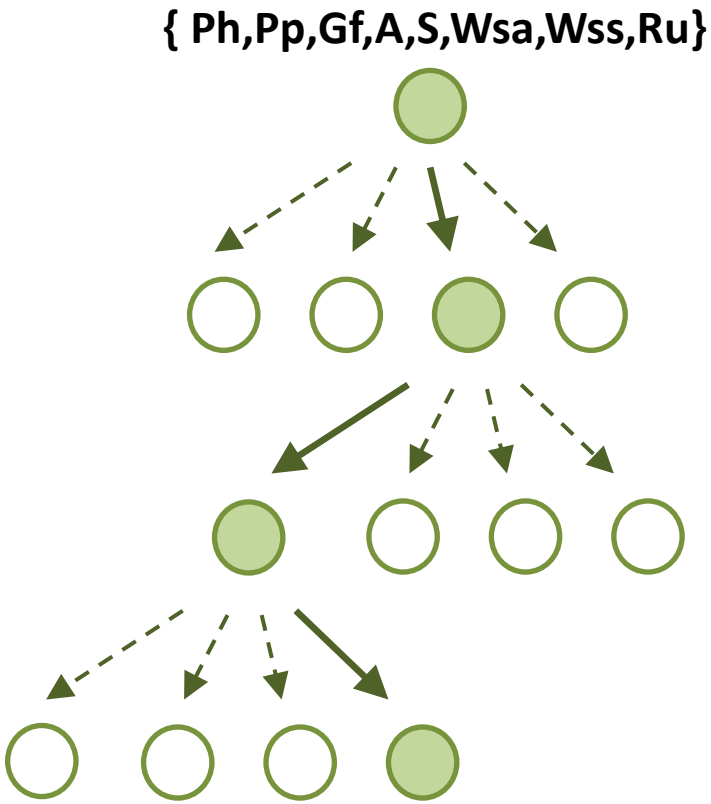
Optimisation: evolutionary algorithm



Objective:

maximise 100yr mean yield for ideotypes with yield CV < 15% and HI95 < 0.63

Stopping rule:

search stops when Y95 exceeds a target, or no further improvement is possible

Optimization for a single site requires evaluation of ~50,000 ideotypes. However, the algorithm may converge to a local, not global, optimum. Therefore, we start with 20 “parents” randomly scattered in the parameter space.

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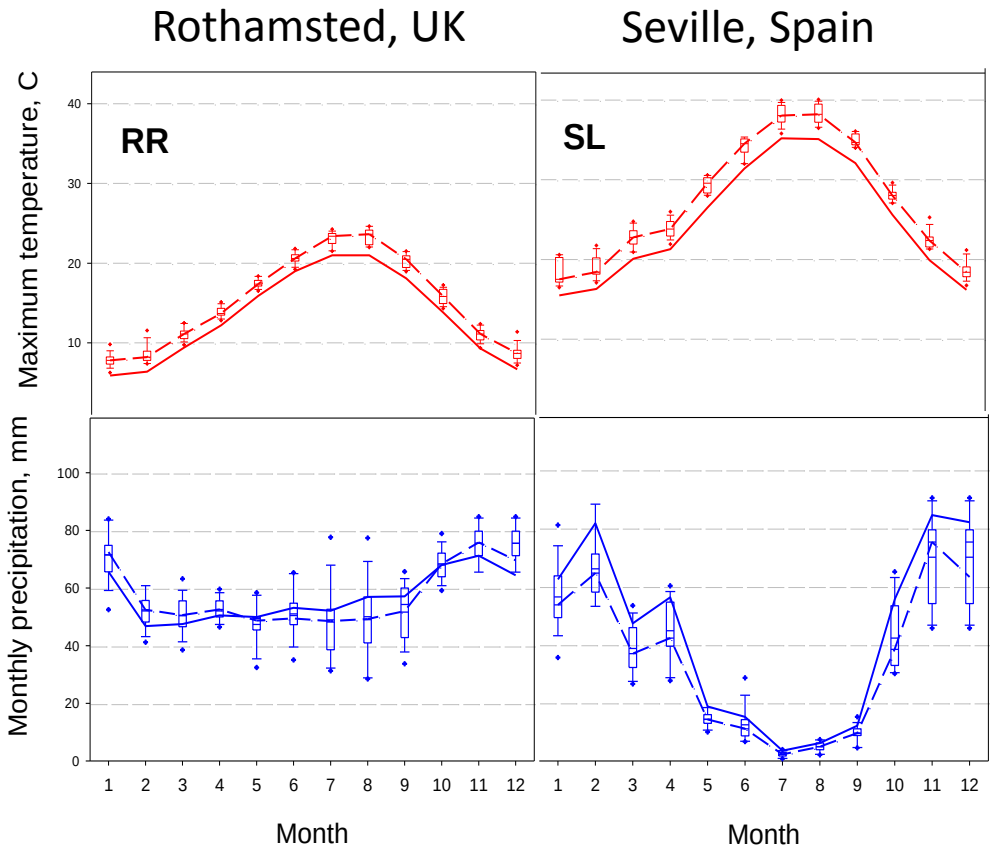
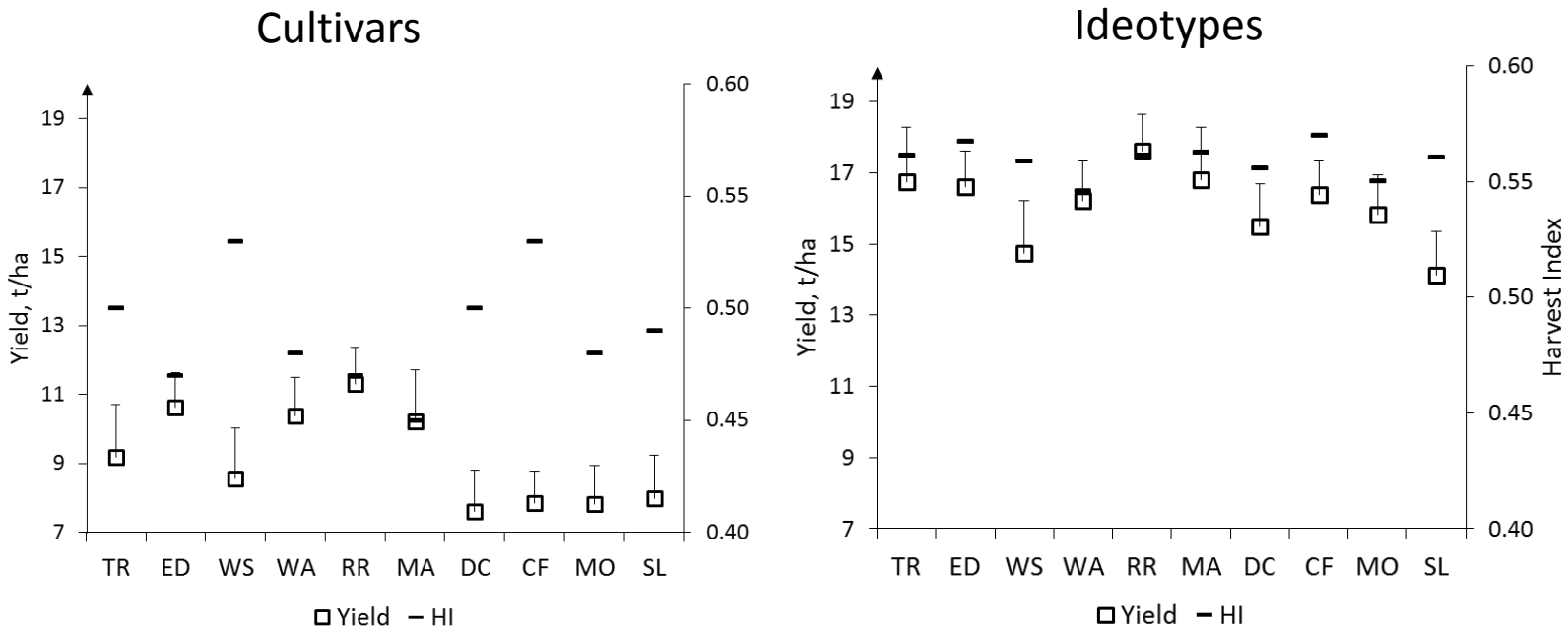
Target environments: Europe, CMIP5, 2050



Substantial increase in yield by 2050



Modelling predicts yield increase of **56-109** % for ideotypes optimized for future climates compared with current wheat cultivars.

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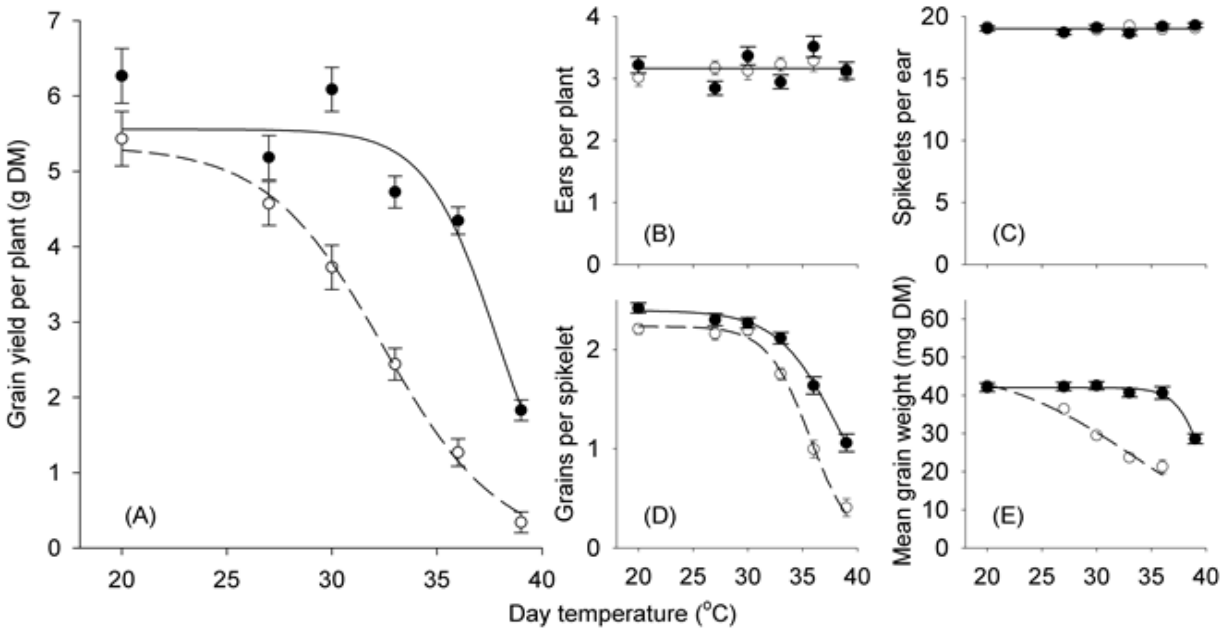
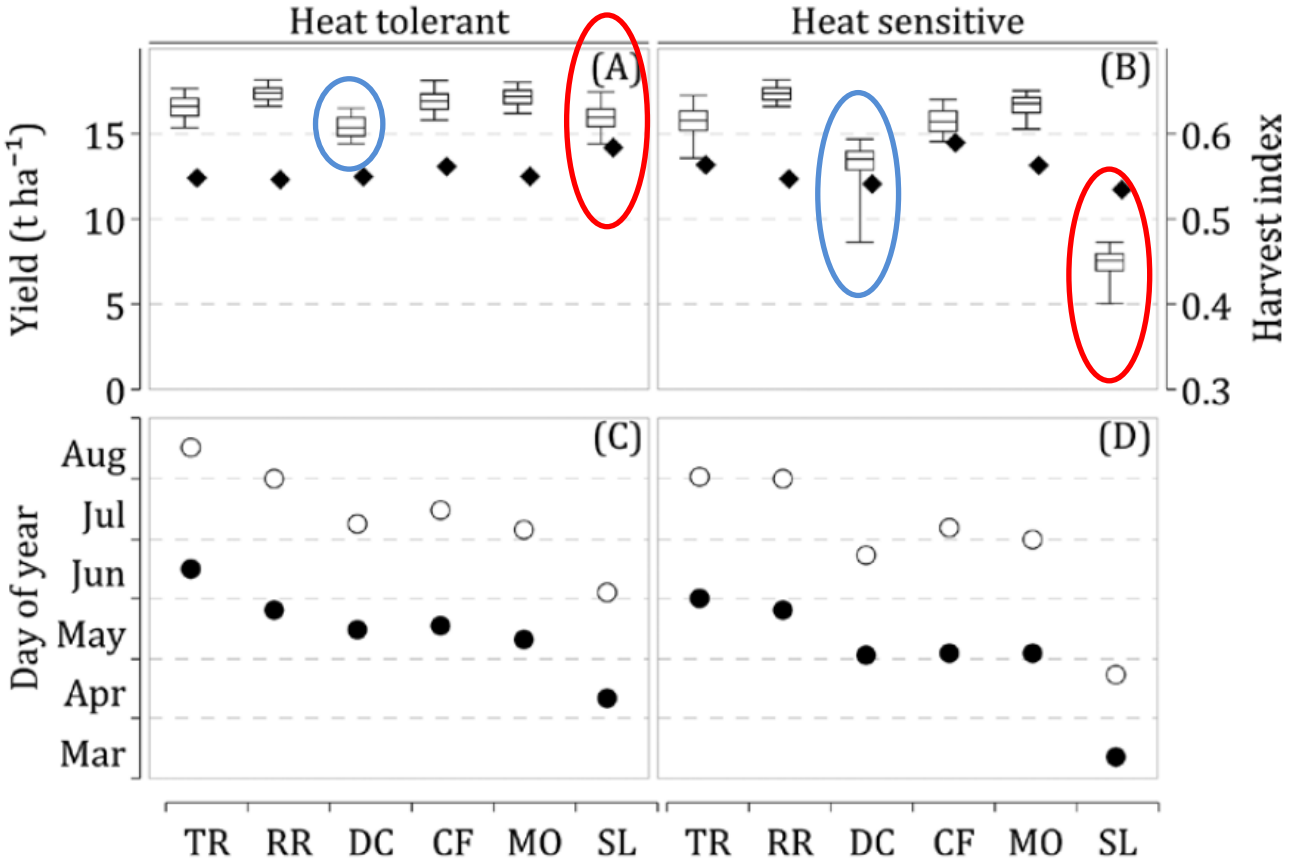
Effect of heat stress and drought around flowering on grain yield



(Alghabari *et al*., J Agr Crop Sci 2013)

High temperature and water stress during booting reduce grain number and grain weight in winter wheat

Heat tolerance is a key trait in S.Europe



(Stratonovitch & Semenov, JxB 2015)

In Seville, HT ideotypes can achieve 111% higher yield potential compared with HS, in Debrecen yield CV increased by 265% for HS ideotypes

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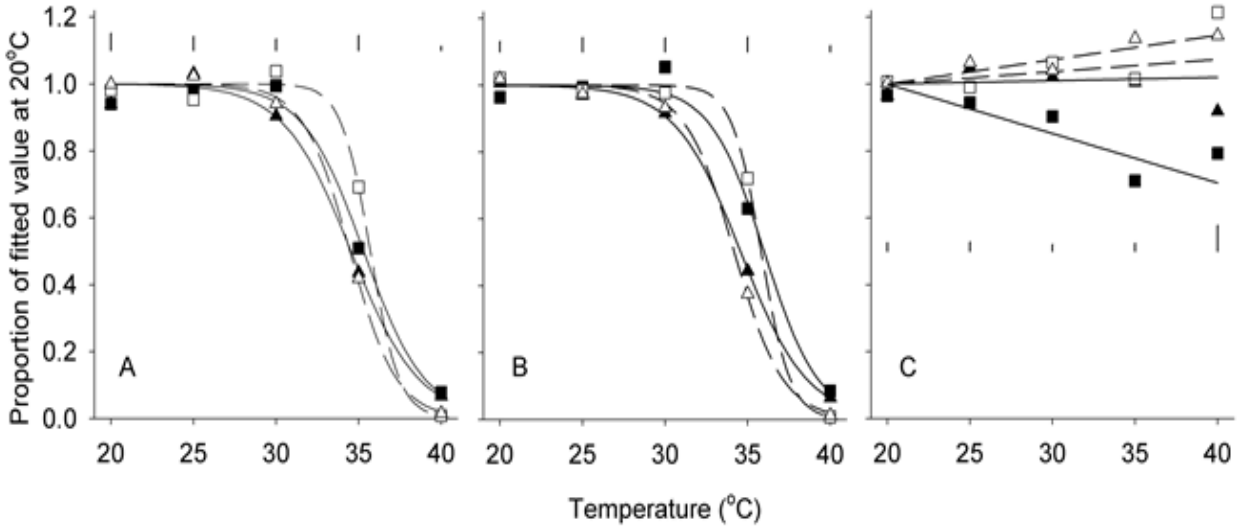
Lack of tolerance to heat stress in European wheats



(Semenov *et al*., J Cer Sci 2014)

Effect of temperature during 3-day transfers to controlled environment cabinets during anthesis on (A) grain yield and (B) grains per spikelet (C) grain weight of S.European (**MV Emese, Renesansa**) and UK wheat cultivars (**Mercia, Savannah**)

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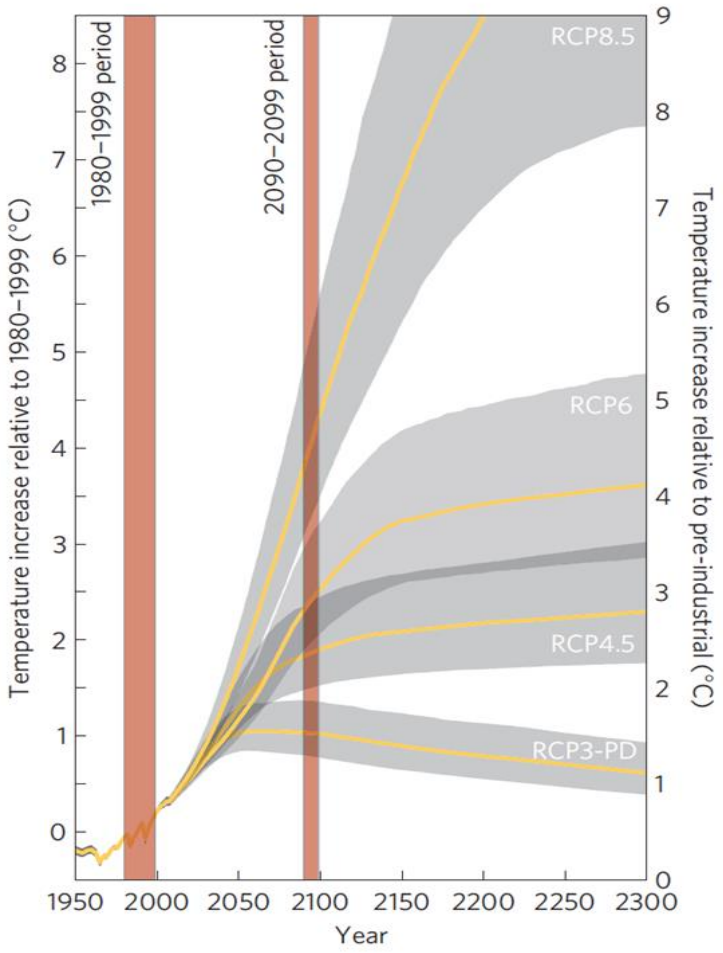
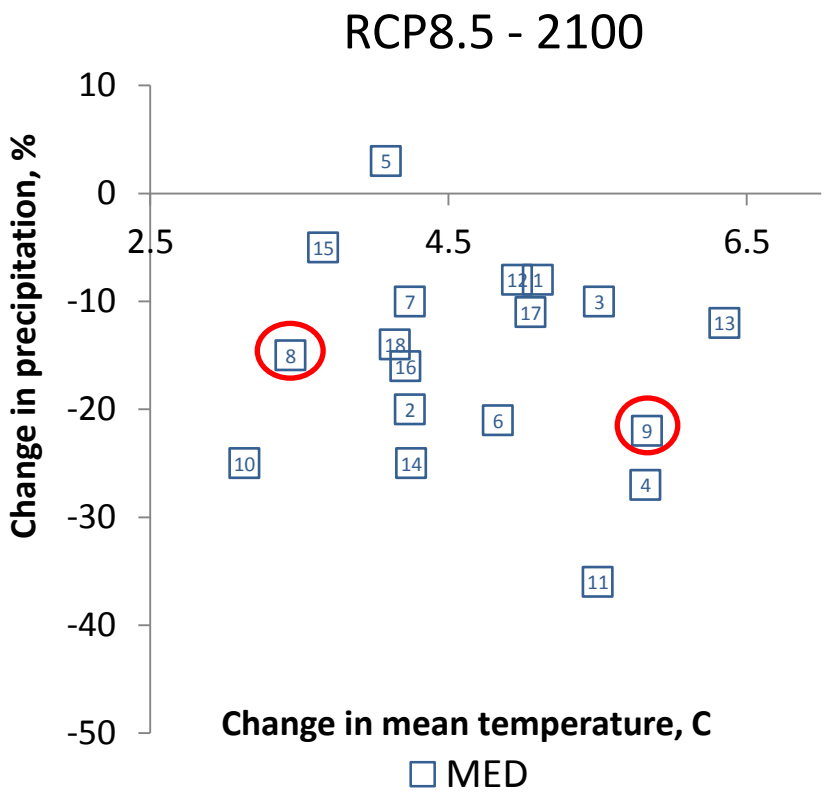
CMIP5: uncertainty in climate projections

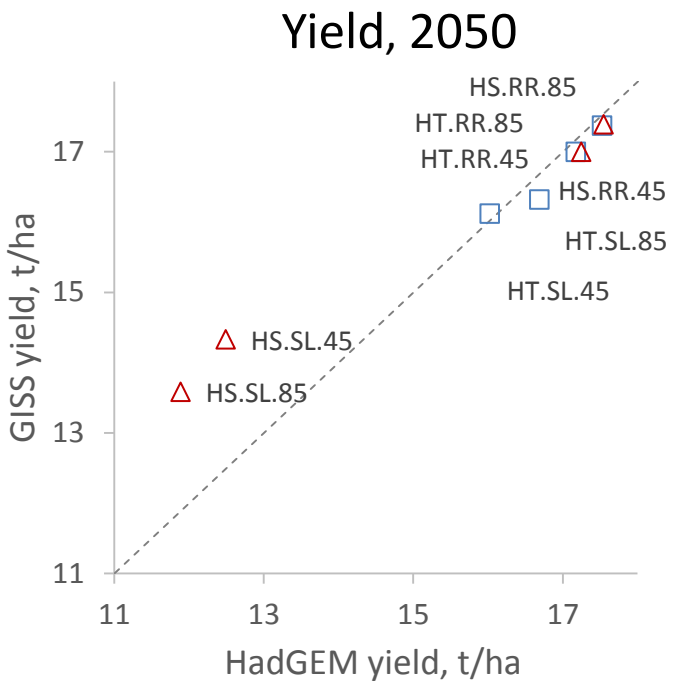


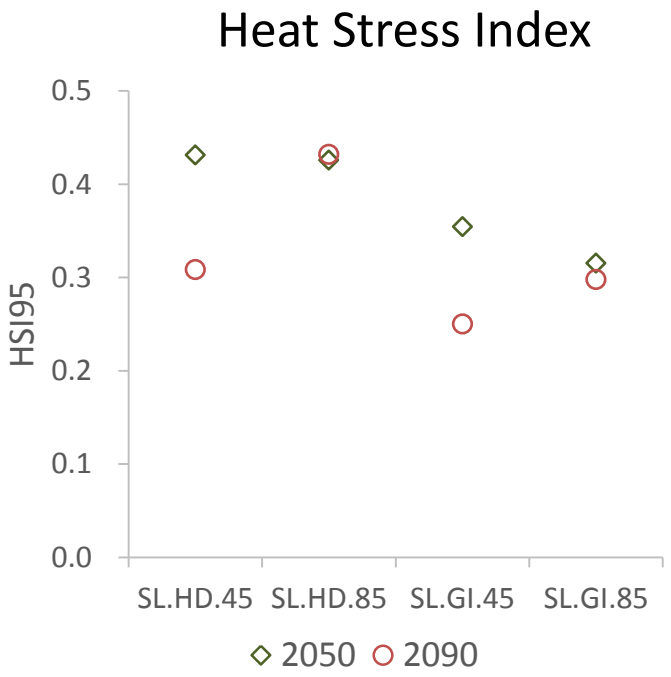
(IPCC AR5 WG1)



RCP4.5 – RCP85; GISS - HadGM

Quantifying uncertainty in predictions





(Semenov & Stratonovitch, Clim Res 2015)

Sensitivity to heat stress around flowering and grain filling will seriously limit wheat yield potential in S.Europe

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Key messages

- Wheat yield potential can be substantially increased in Europe by 2050.
- Increase in light use efficiency, extended duration of grain filling and optimal phenology are key factors. In water-limited environments, increased drought tolerance will be needed.
- To achieve the high yield potential in S.Europe, tolerance to heat stress is required. Sensitivity to heat stress not only reduces mean yield, but increases its variability.
- Identified key traits for wheat improvement are robust and unaffected by the uncertainty in CMIP5 climate projections

Acknowledgements

Pete Jamieson, NZ (sailing around the World)

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