CLIMATE-SMART Agriculture 2015

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# Wheat yield sensitivity to climate change across a European transect for a large ensemble of crop models

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[1]Finnish Environment Institute (SYKE), [2-29]see programme

Montpellier

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# Introduction

- Crop modelling experiment as part of FACCE-JPI, MACSUR


- To study crop model sensitivity to changes in precipitation and temperature using a large ensemble of crop models
- To quantify differences in average yield responses to changed climate across models
- To contrast multi-model responses of yield variability and reliability for each crop under baseline and changed climate across the transect.
- By plotting results of the sensitivity analysis as impact response surfaces

# MATERIAL AND METHODS

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# Ensemble of 26 wheat models

| Model | Modelling groups<br>Contact person(s) | Institute | Country |
|---|---|---|---|
| AFRCWHEAT2 | Manuel Montesino | University of Copenhagen | Denmark |
| APSIM-Nwheat | Senthold Asseng, Davide Cammarano | University of Florida | USA |
| APSIM | Enli Wang | CSIRO Land and Water | Australia |
| AquaCrop | Ignacio Lorite | IFAPA Junta de Andalucia | Spain |
| ARMOSA | Alessia Perego | University of Milan | Italy |
| CARAIB | Julien Minet | Université de Liège | Belgium |
| CERES-wheat DSSAT v.4.6 | Mirek Trnka, Petr Hlavinka | Mendel University in Brno | Czech Republic |
| CERES-wheat DSSAT v.4.5 | Margarita Ruiz-Ramos | Universidad Politecnica de Madrid | Spain |
| CERES-wheat DSSAT v.4.5 | Paola Deligios | University of Sassari | Italy |
| CropSyst | Marco Moriondo,<br>Roberto Ferrise, Marco Bindi | CNR-IBIMET<br>University of Florence | Italy<br>Italy |
| DNDC | Cezary Slawinski; Piotr Baranowski | Polish Academy of Sciences | Poland |
| EPIC | Luca Doro | University of Sassari | Italy |
| Fasset | Isk Öztürk | Aarhus University | Denmark |
| HERMES | Chris Kollas, Christian Kersebaum | Leibniz Centre for Agric. Landscape Research (ZALF) | Germany |
| Lintul2 | Holger Hoffmann, Thomas Gaiser, Frank Ewert | University of Bonn | Germany |
| Lintul4 | Iwan Supit | Wageningen University | Netherlands |
| LPJ-GUESS | Per Bodin | Lund University | Sweden |
| MCWLA | Fulu Tao | Luke Natural Resources Institute Finland | Finland |
| MONICA V1.2 | Claas Nendel | Leibniz Centre for Agric. Landscape Research (ZALF) | Germany |
| SALUS | Bruno Basso | Michigan State University | USA |
| Sirius 2010 | Mikhail Semenov, Pierre Stratonovitch | Rothamsted Research | UK |
| Sirius Quality | Roberto Ferrise, Marco Bindi | University of Florence | Italy |
| SPACSYS | Lianhai Wu | Rothamsted Research | UK |
| STICS | Benjamin Dumont, Françoise Ruget, Samuel Buis | Université de Liège & INRA EMMAH | Belgium & France |
| WOFOST 7.1 | Cezary Slawinski; Jaromir Krzyszczak | Polish Academy of Sciences | Poland |
| WOFOST 7.1 | Taru Palosuo, Reimund Rötter | Luke Natural Resources Institute Finland | Finland |

# Simulation set-up

| | | | | | |
|---|---|---|---|---|---|
| **Sites** | ***Country*** | ***Location*** | | | ***N*** |
| | Finland | Jokioinen | | | |
| | Germany | Dikopshof, Nossen | | | 3 |
| | Spain | Lleida | | | |
| **Crops** | ***Crop /Cultivar type*** | ***Cultivar*** | | | |
| | Spring wheat | Different cultivars for each location | | | 2 |
| | Winter wheat | Different cultivars for each location | | | |
| **Baseline** | ***Harvest years*** | 1981-2010 | | | 30 |
| **Perturbations** | ***Variable*** | ***Min*** | ***Max*** | ***Interval*** | |
| | Precipitation (%) | - 50 | + 50 | 10 | 11 |
| | Temperature (°C) | - 2 | + 9 | 1 | 12 |
| **$CO_2$ level** | 360 ppm (Year 1995) | | | | 1 |
| **Soils** | Clay loam | | | | 1 |
| **Management** | Fixed sowing date | Location specific (observed) | | | 1 |
| **Total number of simulations** | | Sites x crops x years x P-changes x T-changes | | | **23760** |

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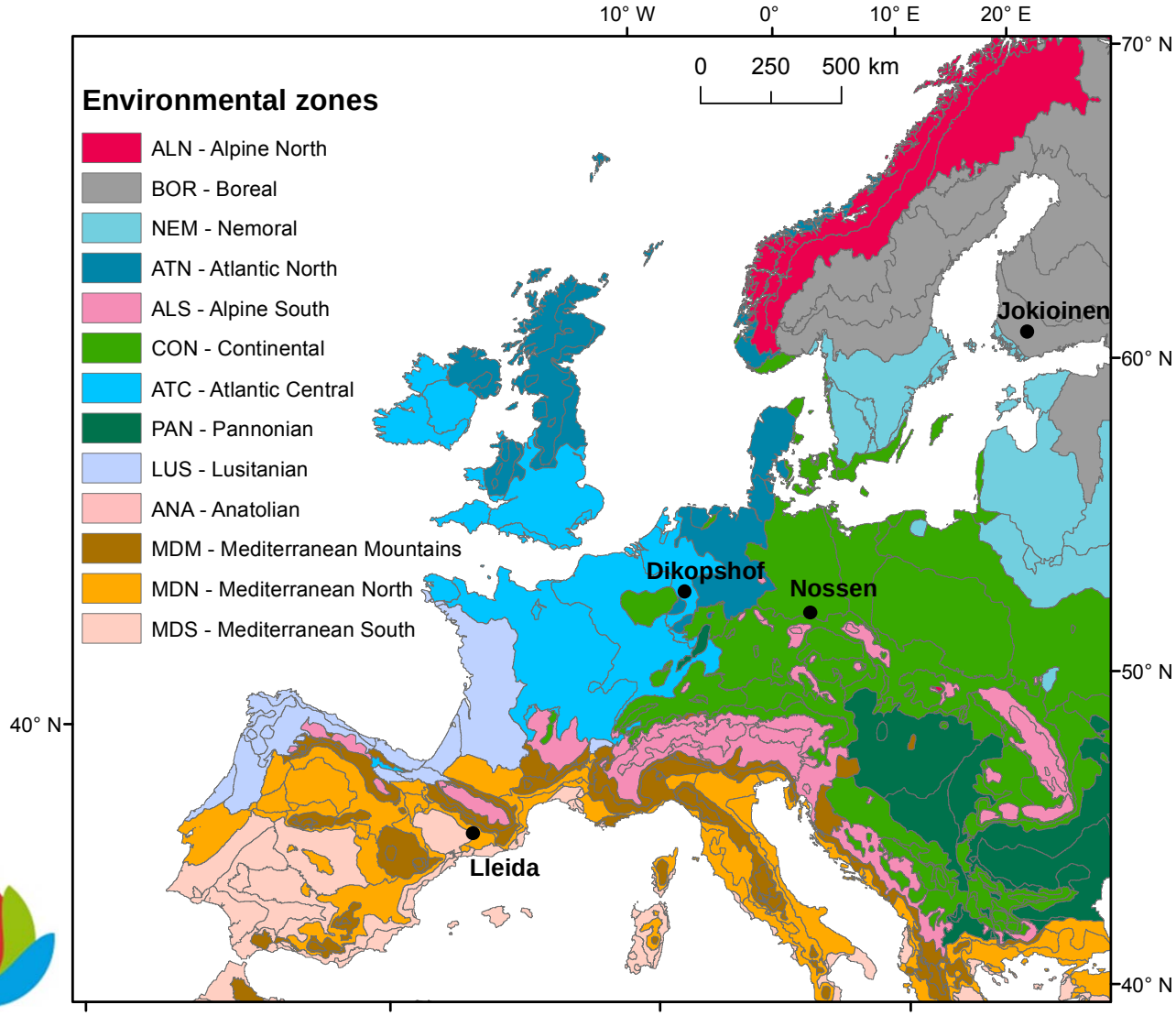
# Study sites across a European transect

Locations of weather stations used in this study and environmental zones of Metzger et al. (2005)




**Mainly temperature limited**

**High current suitability**

**Mainly precipitation limited**

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# Simulation set-up

- Each group calibrated their model independently
- Limited data for calibration was provided on:
  - crop phenology and yield
  - soil conditions
  - fertilization, tillage and irrigation (Spain) where available
- Model simulations were performed
  - on a daily time-step
  - for water-limited yields
  - assuming optimal nutrients
  - as a succession of independent years (no carry-over effects)
  - for modelled harvest dates up to a local "harvest cutoff”
- Error checking and model iteration

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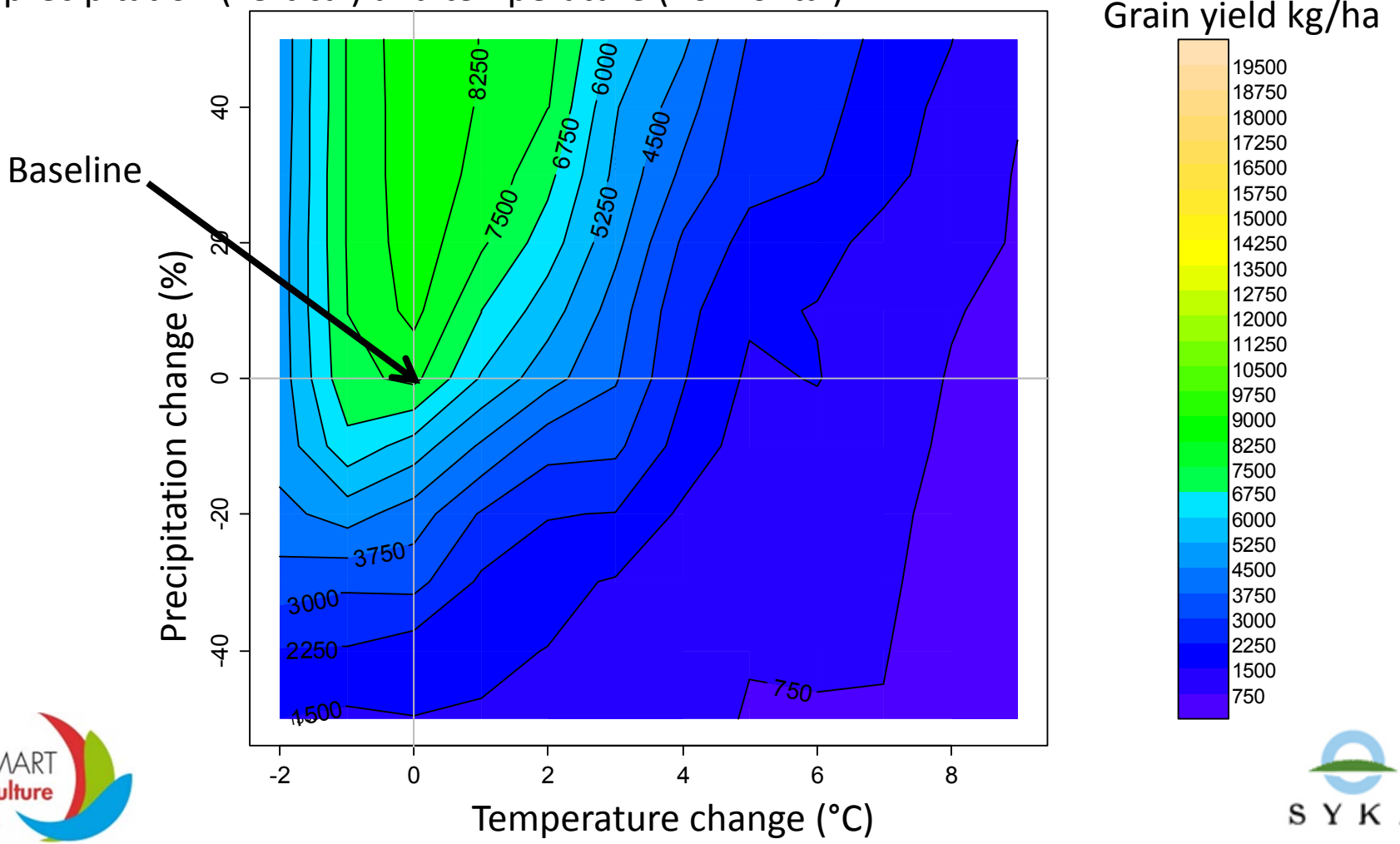
# Impact response surface (IRS) of a single crop model for spring wheat yield, Germany, 2008

- IRSs represent the sensitivity of modelled crop yield to incremental changes in precipitation (vertical) and temperature (horizontal)

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# RESULTS

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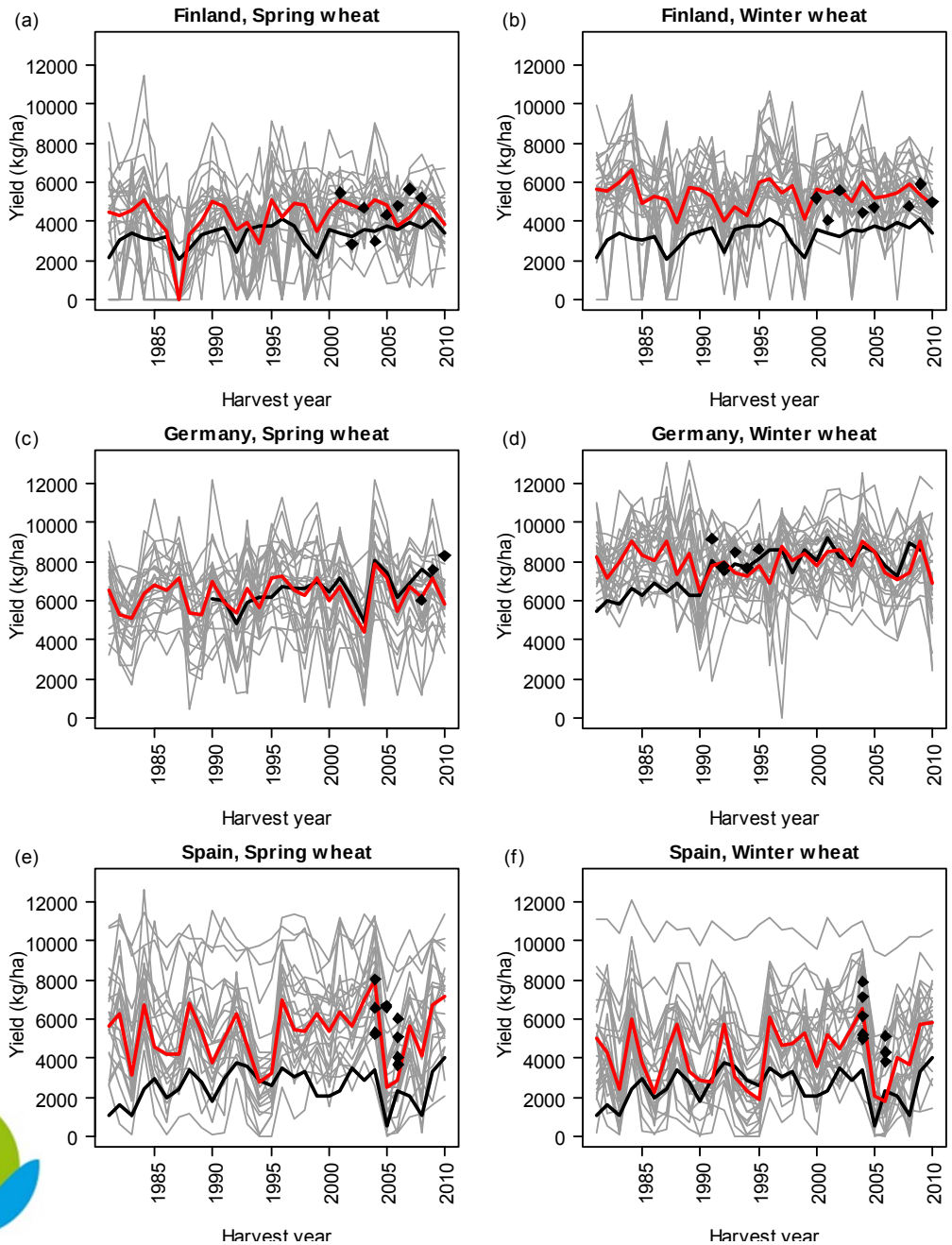
# Modelled yields for the baseline 1981-2010

Finland

Germany

Spain




Individual model results

Ensemble median

Historical yields of wheat

Finland: FAO Country level statistics

Germany: Eurostat regional statistics

Spain: provincial statistics for northern Spain, Spanish Ministry of Agriculture

- Calibration data

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# Baseline 1981-2010 yield levels

O: regional statistics

1-26: individual models

E50: ensemble median

| Site | Crop | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | E50 | O |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FI | S | | | | | | | | | | | | N/A | | | | | | | | | | | N/A | | | | | 30 |
| FI | W | | | | | | | | | | | | | | | | | | | | | | | | | | | | 30 |
| DE | S | | | | | | | | | | | | N/A | | | | | | | | | | | | | | | | 20 |
| DE | W | | | | | | | | | | | | | | | | | | | | | | | | | | | | 29 |
| ES | S | | | | | | | | | | | | N/A | | | | | | | | | | | | | | | | 30 |
| ES | W | | | | | | | | | | | | | | | | | | | | | | | | | | | | 30 |

| *kg ha*$^{-1}$ | < 2000 | 2000-4000 | 4000-6000 | 6000-8000 | 8000-10000 | ≥10000 |
|---|---|---|---|---|---|---|

Sites – Finland (FI), Germany (DE) and Spain (ES)
Crops – spring (S) and winter (W) wheat
Values for Observations (O) indicate the number of years for which observed crop yield data were available
Models for which no results for a specific site or crop were provided are marked with N/A.

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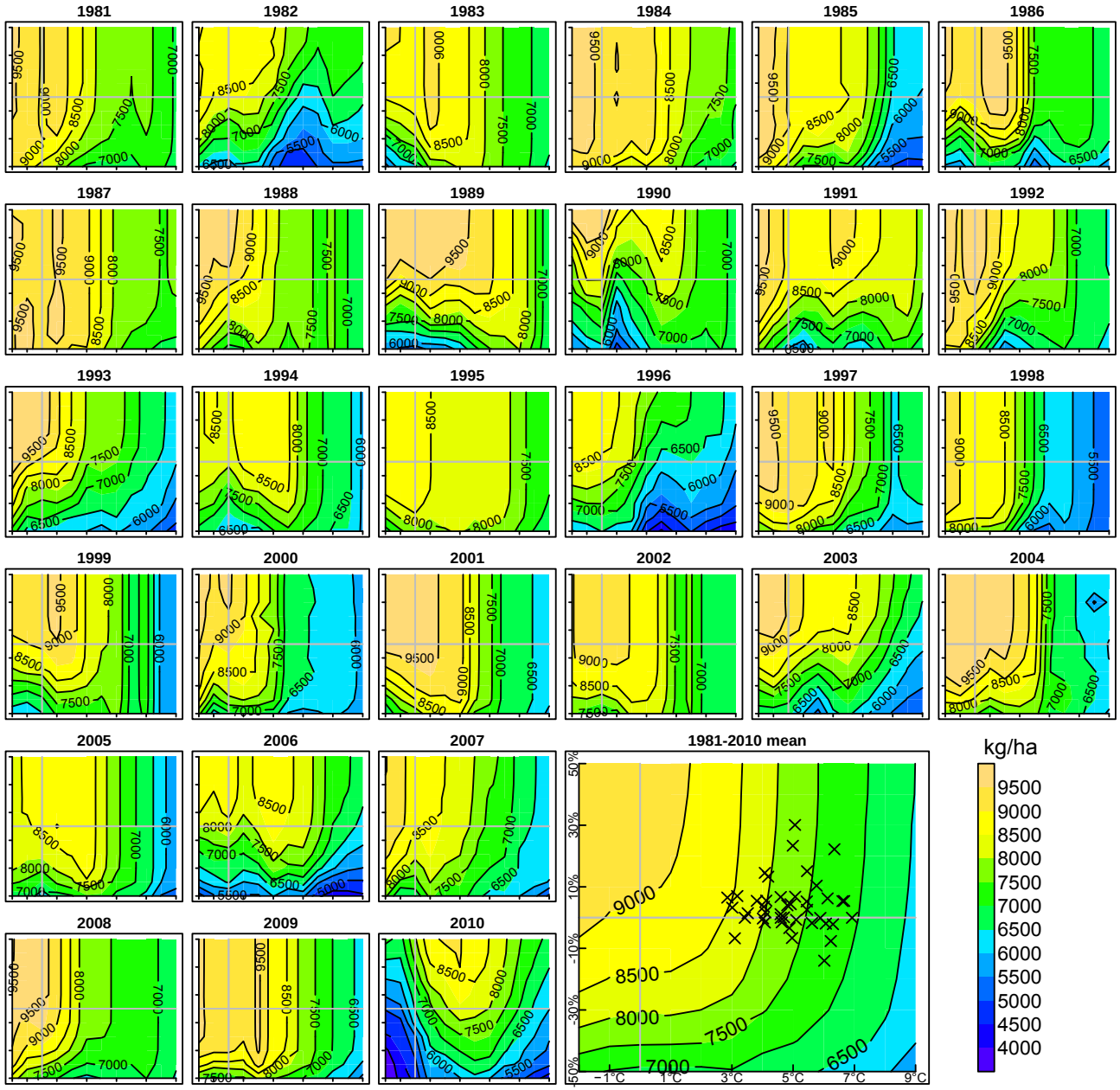
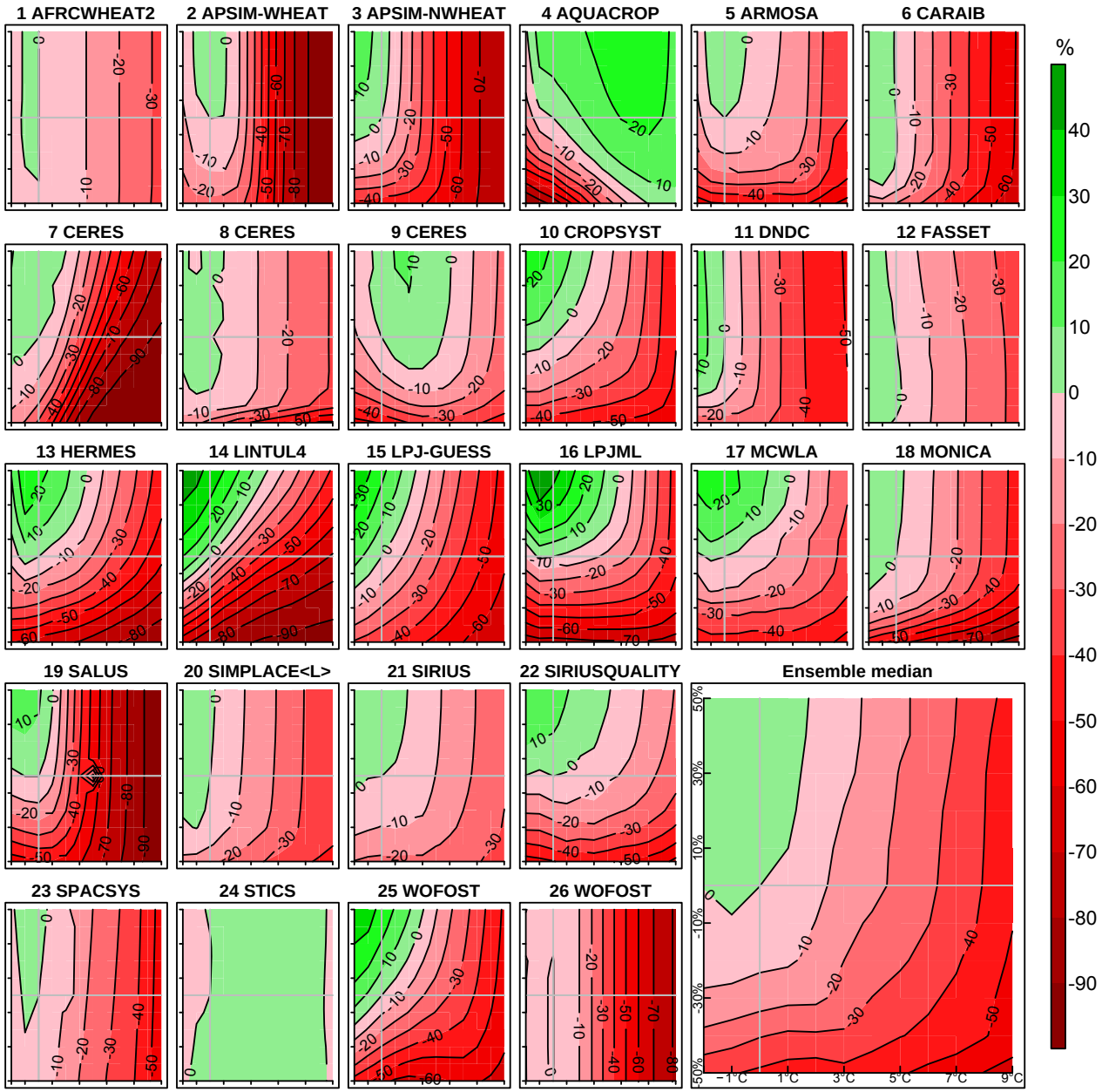
# Winter wheat DM grain yields, Germany




One crop model, individual years 1981-2010 (small sub-plots) and 30-year mean (larger sub-plot)

Crosses in the 30-year mean plot: changes in annual temperature and precipitation projected by the CMIP5 ensemble of 36 global climate models for RCP8.5 over central Europe by 2070-2099 relative to 1981-2010.

# Yield changes relative to unperturbed baseline

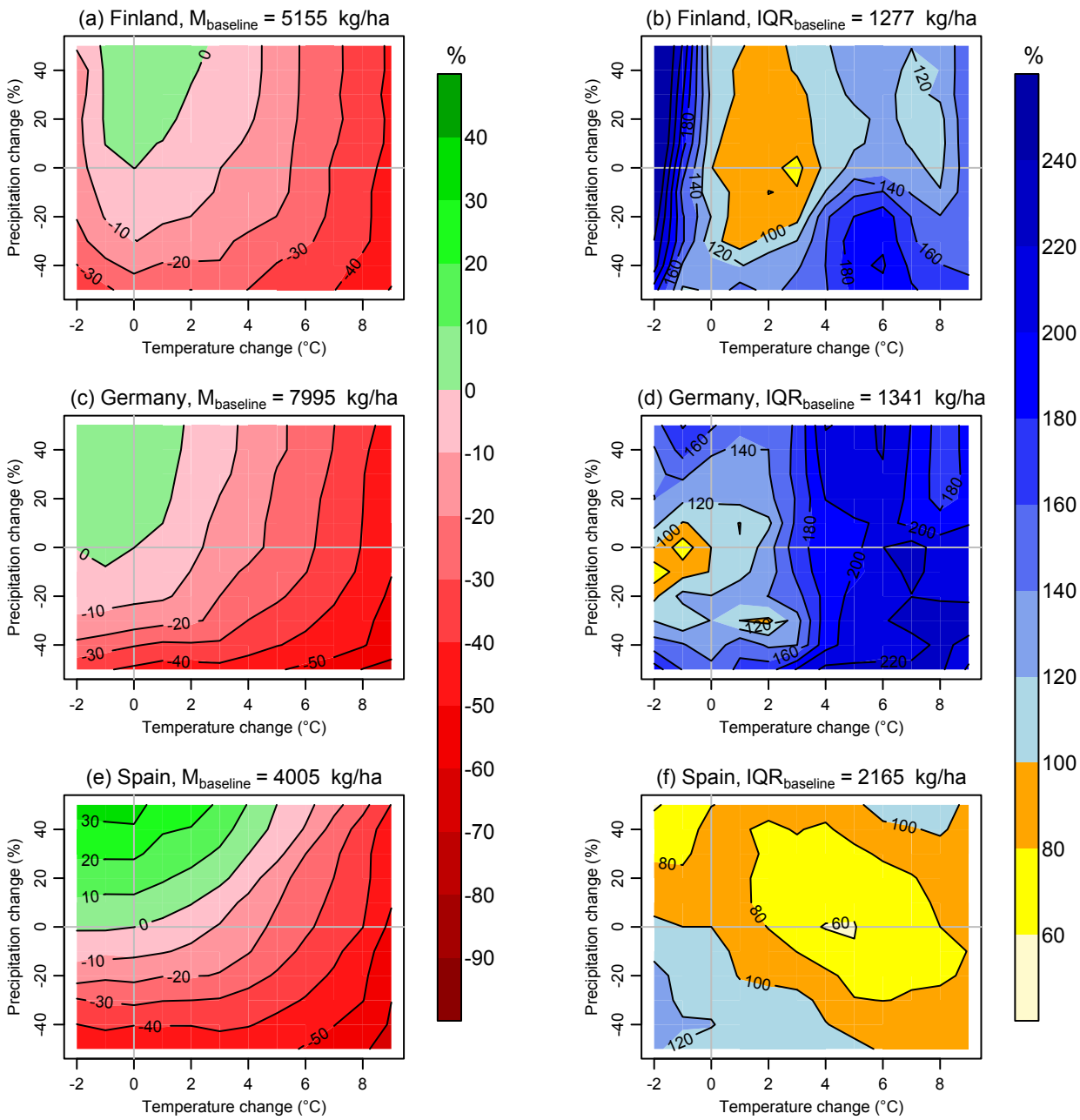



30-year average change in winter wheat DM yields relative to baseline climate (1981-2010) in Germany

26 models (small sub-plots) and ensemble median (larger sub-plot)

By definition, the yield change is 0% for the baseline climate at the intersection of the grey lines.

# Ensemble medians and IQR of yield changes



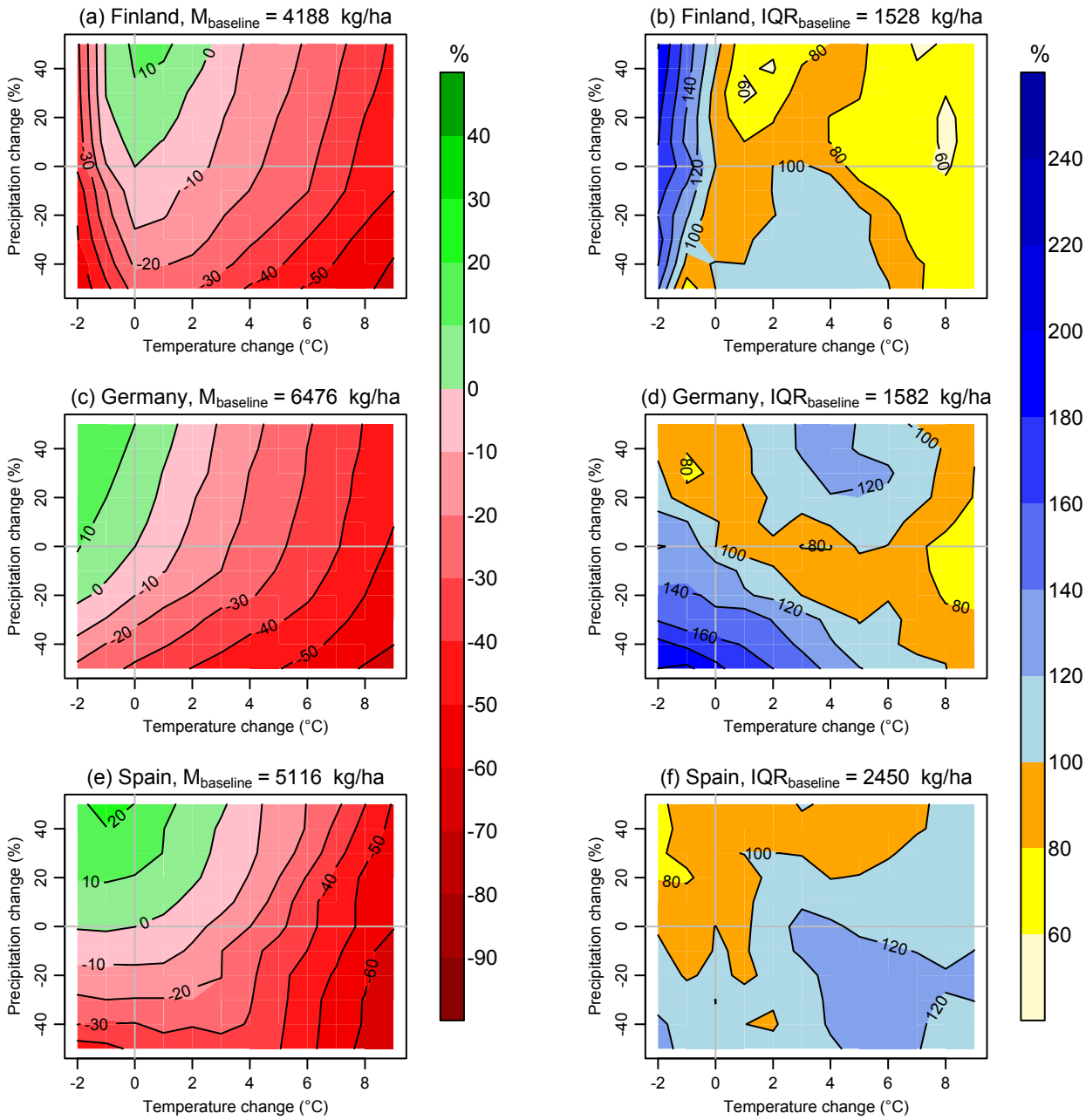

## Winter wheat

Left: Median of yield changes by 26 crop models

Right: Inter-quartile range (IQR) of relative responses scaled to 100% at baseline

The ensemble median ($M_{baseline}$) and ensemble inter-quartile range ($IRQ_{baseline}$) of absolute yields for the baseline are listed above each plot.

# Ensemble medians and IQR of yield changes



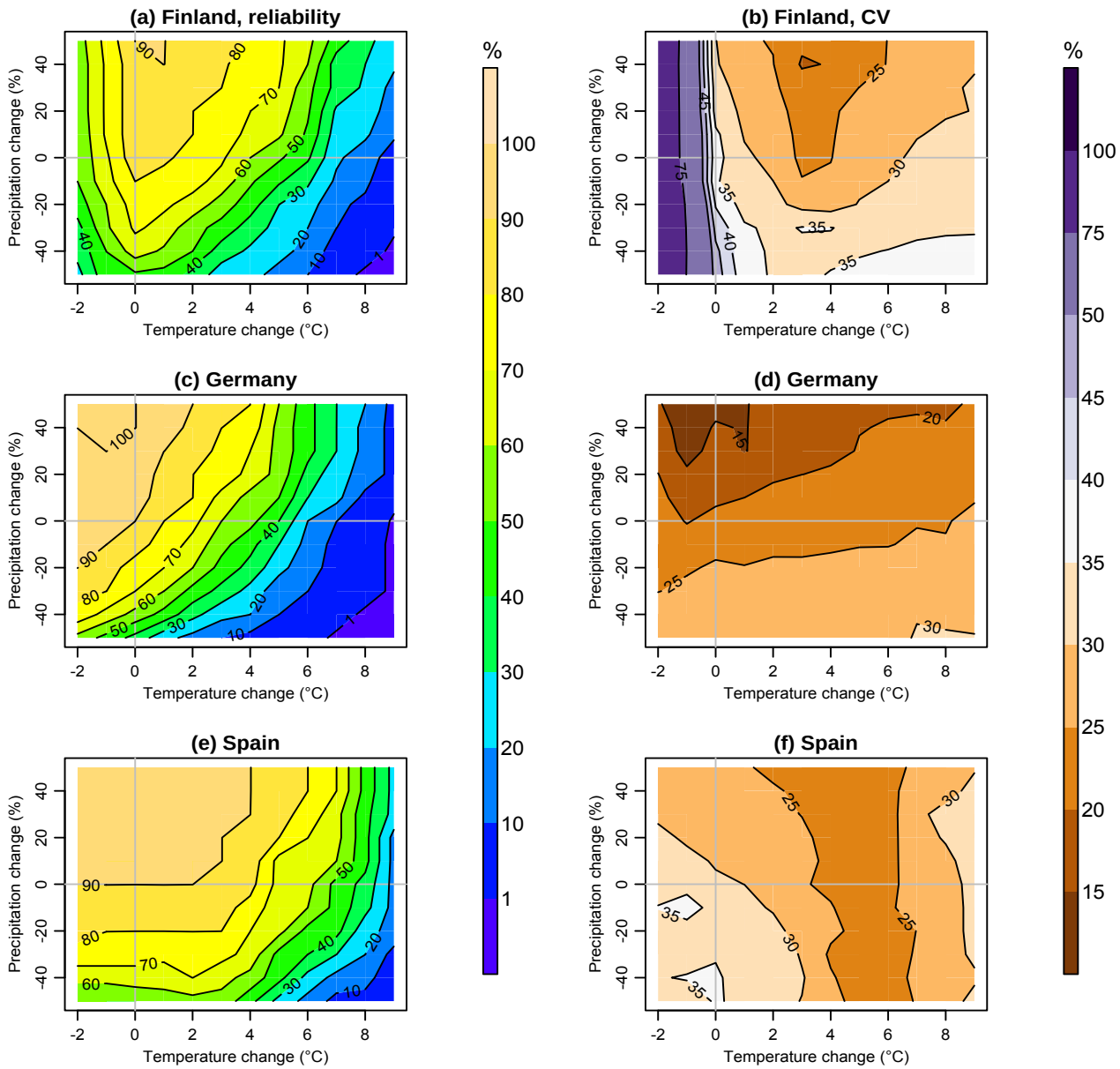

## Spring wheat

Left: Median of yield changes by 24 (Finland) or 25 (Germany, Spain) crop models

Right: Inter-quartile range (IQR) of relative responses scaled to 100% at baseline

The ensemble median ($M_{baseline}$) and ensemble inter-quartile range ($IRQ_{baseline}$) of absolute yields for the baseline are listed above each plot.

# Interannual variability of ensemble medians




Spring wheat

Left:
Yield reliability = % of years when yield is above the 10th %-tile of the baseline yield

Right:
Coefficient of variation (CV) of annual yields

Ensemble medians of 24 (Finland) or 25 (Germany, Spain) crop models

# CONCLUSIONS

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# Conclusions 1/2

- Demonstration of a new method that uses Impact Response Surfaces (IRSs) for a systematic intercomparison of crop model behaviour under conditions of changing climate
- Ensemble average yields decline with higher temperatures (3–7% per 1°C) and decreased precipitation (3–9% per 10% decrease), but benefit from increased precipitation (0-8% per 10% increase)
- Yields are more sensitive to temperature than precipitation changes at the Finnish site compared to the German and Spanish sites

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# Conclusions 2/2

- Inter-model variability is highest for baseline climate at the Spanish site, but relatively insensitive to changed climate; modelled responses diverge most at the Finnish and German sites for winter wheat under temperature change
- Optimal temperatures for present-day cultivars are close to the baseline under Finnish conditions but below the baseline at the German and Spanish sites
- Future work will use IRSs
  1. to classify response patterns of different models
  2. to investigate uncertainties in modelled yield response to $CO_2$ concentration
  3. to evaluate future changes in crop yield reliability, by superimposing probabilistic climate projections

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