A crop model ensemble analysis of wheat yield sensitivity to changes in temperature and precipitation across a European transect

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Introduction

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

Aims:

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

MATERIAL AND METHODS

Ensemble of 26 wheat models

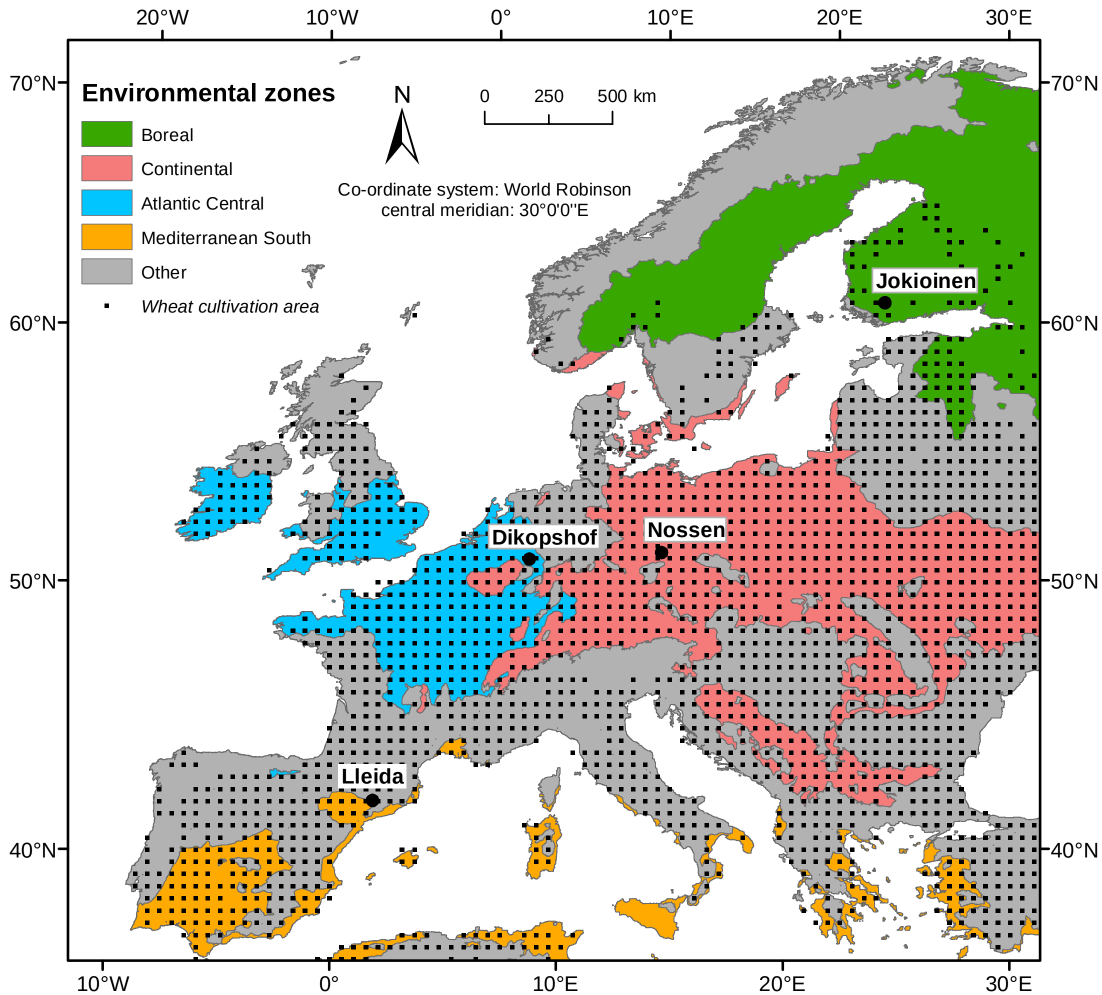
Model	Modelling groups Contact person(s)	Institute	Country
AFRCWHEAT2	Manuel Montesino	University of Copenhagen	Denmark
APSIM-Nwheat	Senthold Asseng, Davide Cammarano	University of Florida	USA
APSIM-Wheat	Enli Wang	CSIRO Land and Water	Australia
AquaCrop	Ignacio Lorite	IFAPA Junta de Andalucia	Spain
ARMOSA	Alessia Perego	University of Milan	Italy
CARAIB Crop	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, Roberto Ferrise, Marco Bindi	CNR-IBIMET University of Florence	Italy Italy
DNDC	Cezary Slawinski; Piotr Baranowski	Polish Academy of Sciences	Poland
Fasset	Isk Öztürk	Aarhus University	Denmark
HERMES	Chris Kollas, Christian Kersebaum	Leibniz Centre for Agric. Landscape Research (ZALF)	Germany
Lintul4	Iwan Supit	Wageningen University	Netherlands
LPJ-GUESS	Per Bodin	Lund University	Sweden
LPJml	Christoph Müller	Potsdam Institute for Climate Impact Research	Germany
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
SIMPLACE<Lintul2, Slim>	Holger Hoffmann, Thomas Gaiser, Frank Ewert	University of Bonn	Germany
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 cultivar for each location			2
	Winter wheat	Different cultivar 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

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

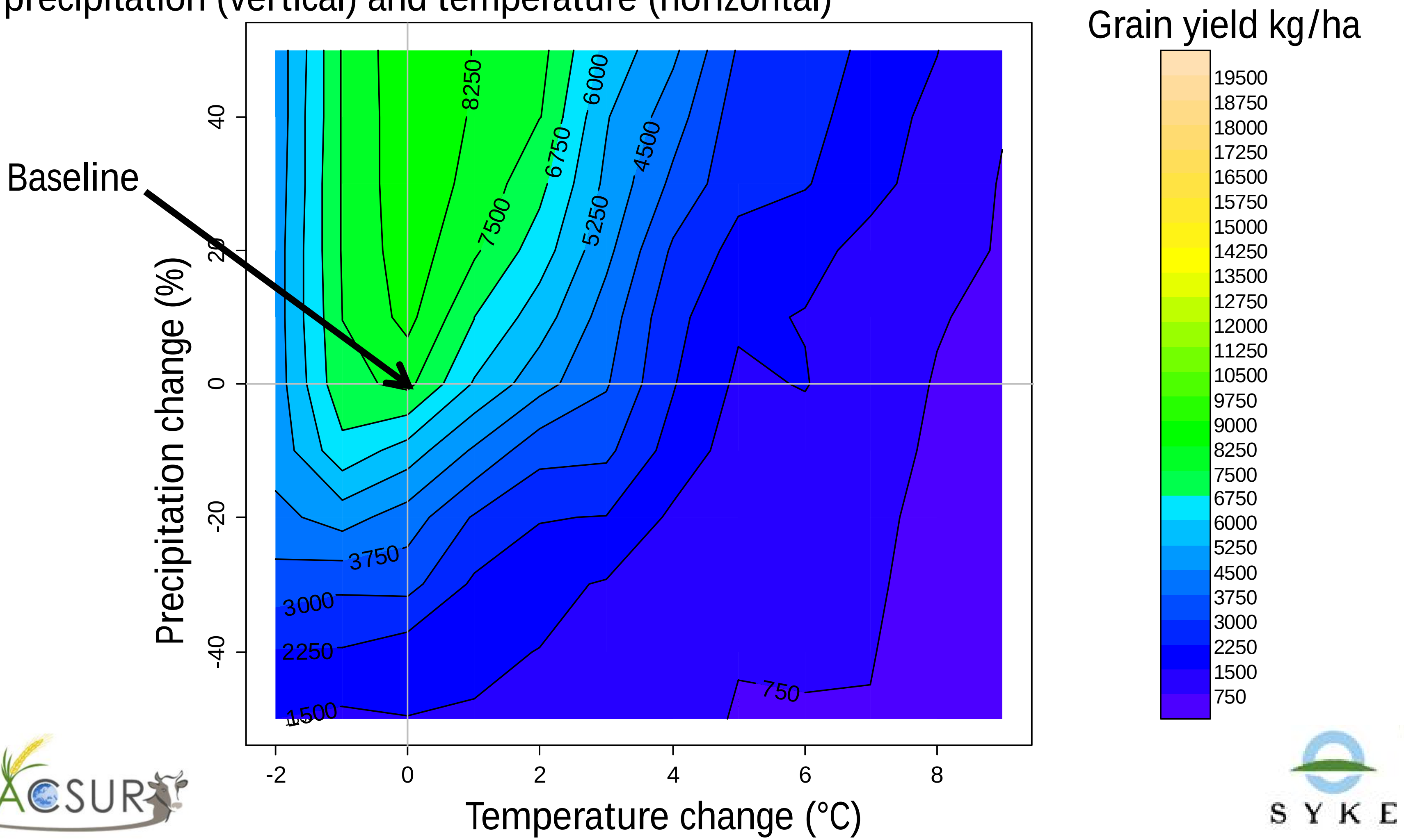
Mainly precipitation limited

Simulation set-up

- Each group calibrated their model independently
- Limited data for calibration was provided on:
  - crop phenology and yield
  - soil conditions
  - fertilisation, 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

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

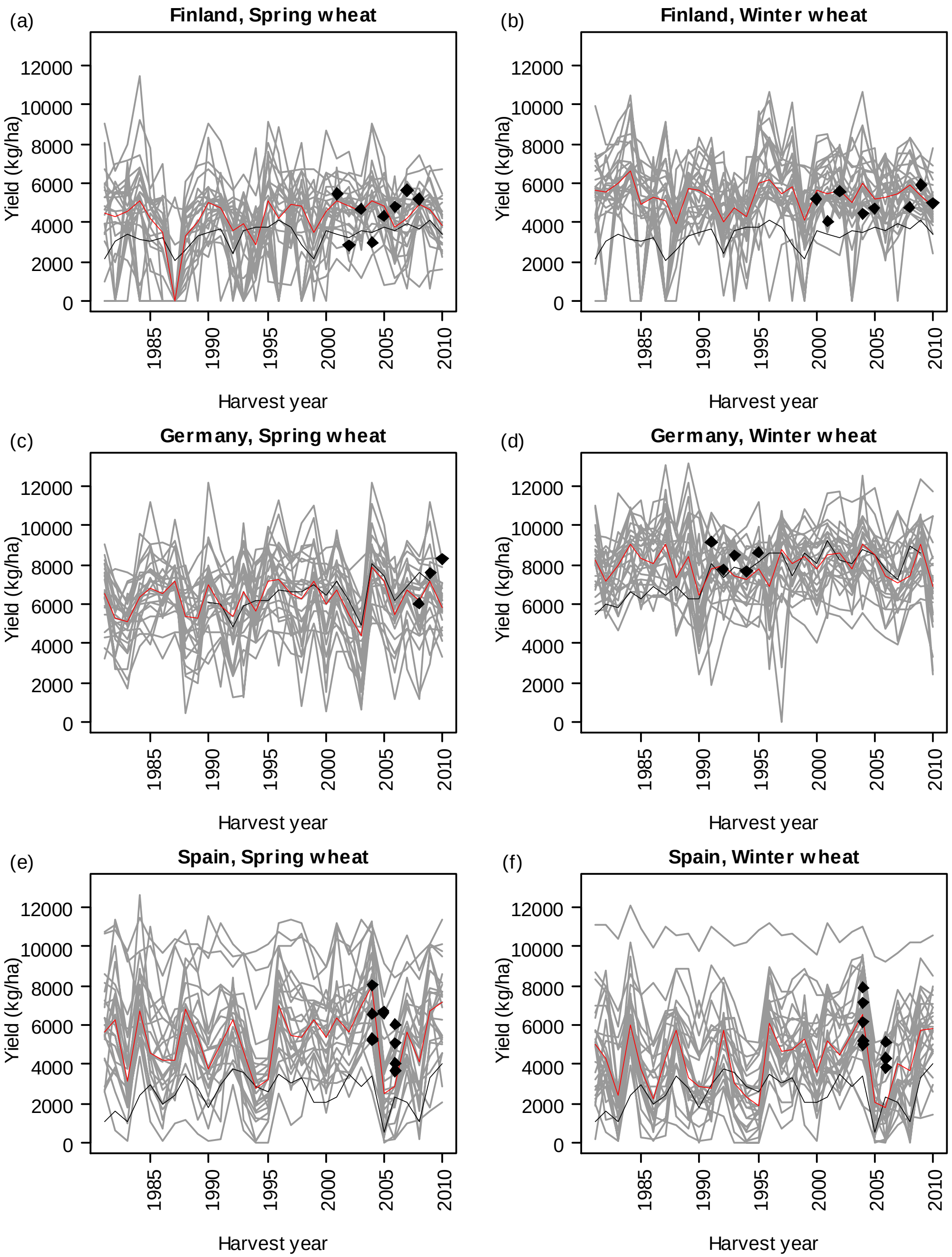
- IRSs represent the sensitivity of modelled crop yield to incremental changes in precipitation (vertical) and temperature (horizontal)



RESULTS

Modelled yields for the baseline 1981-2010

- 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

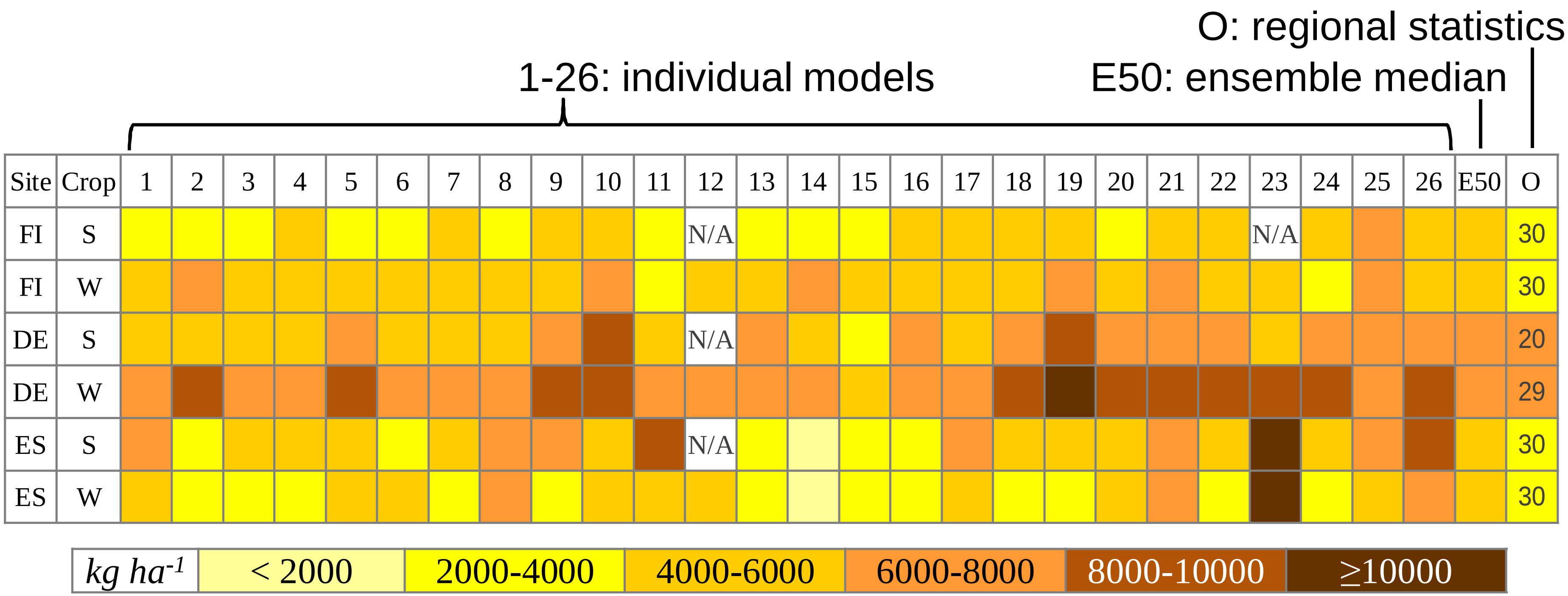


Finland

Germany

Spain

Baseline 1981-2010 yield levels



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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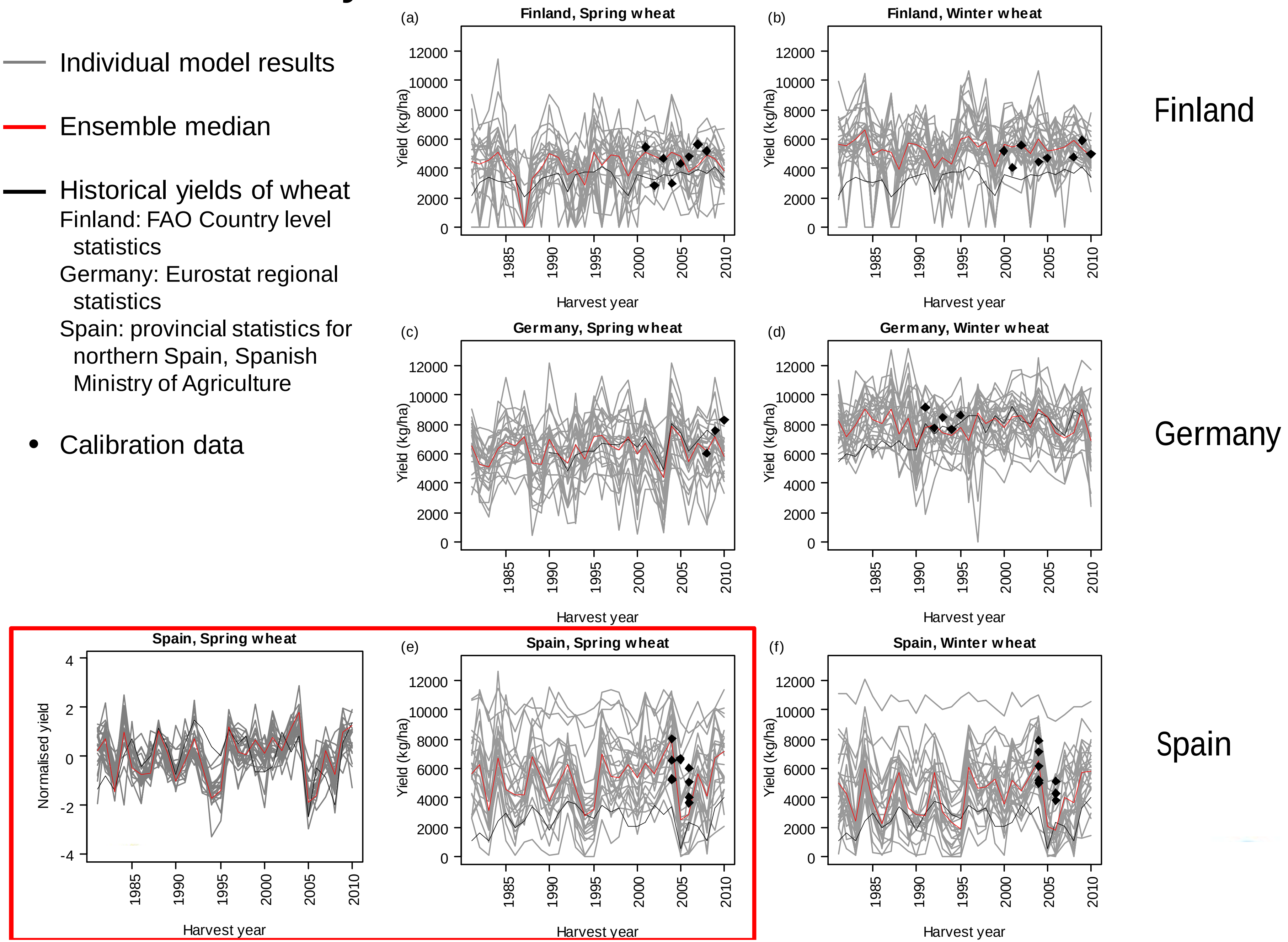

Modelled yields for the baseline 1981-2010

Ensemble median

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Finland: FAO Country level statistics

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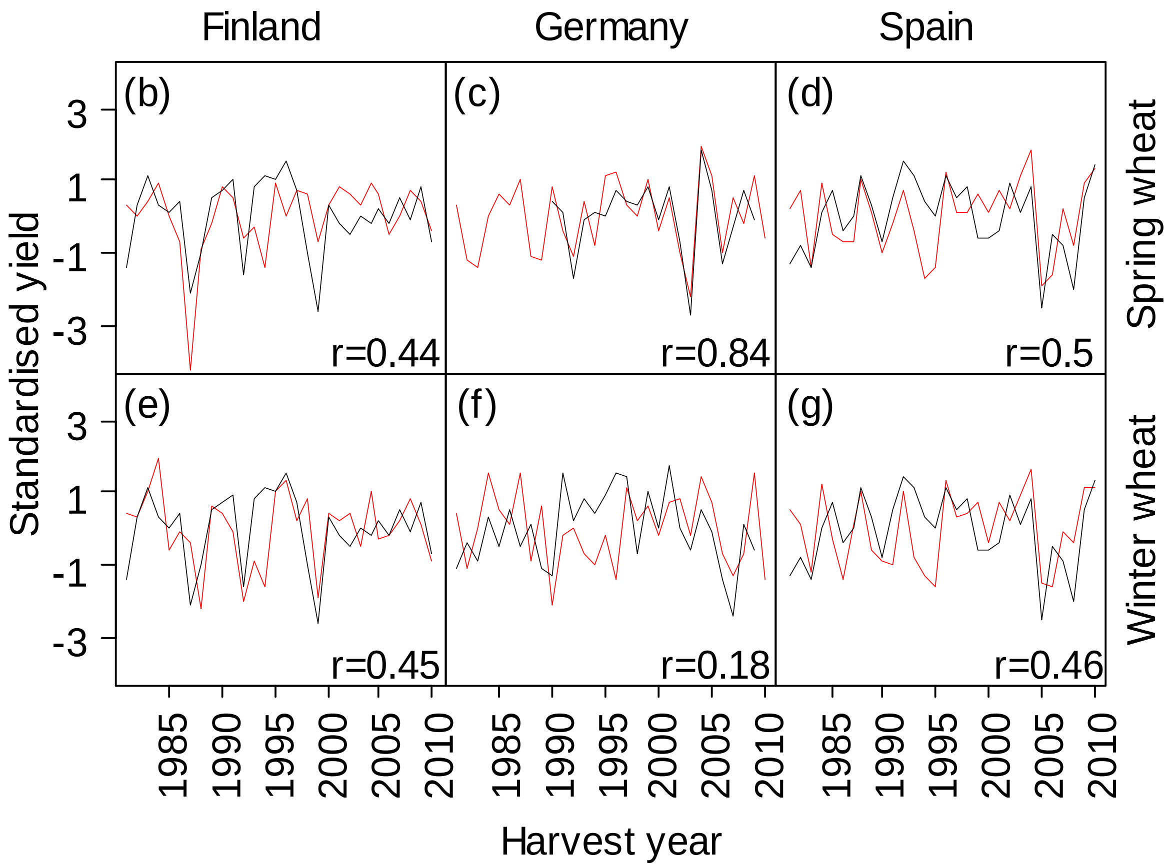

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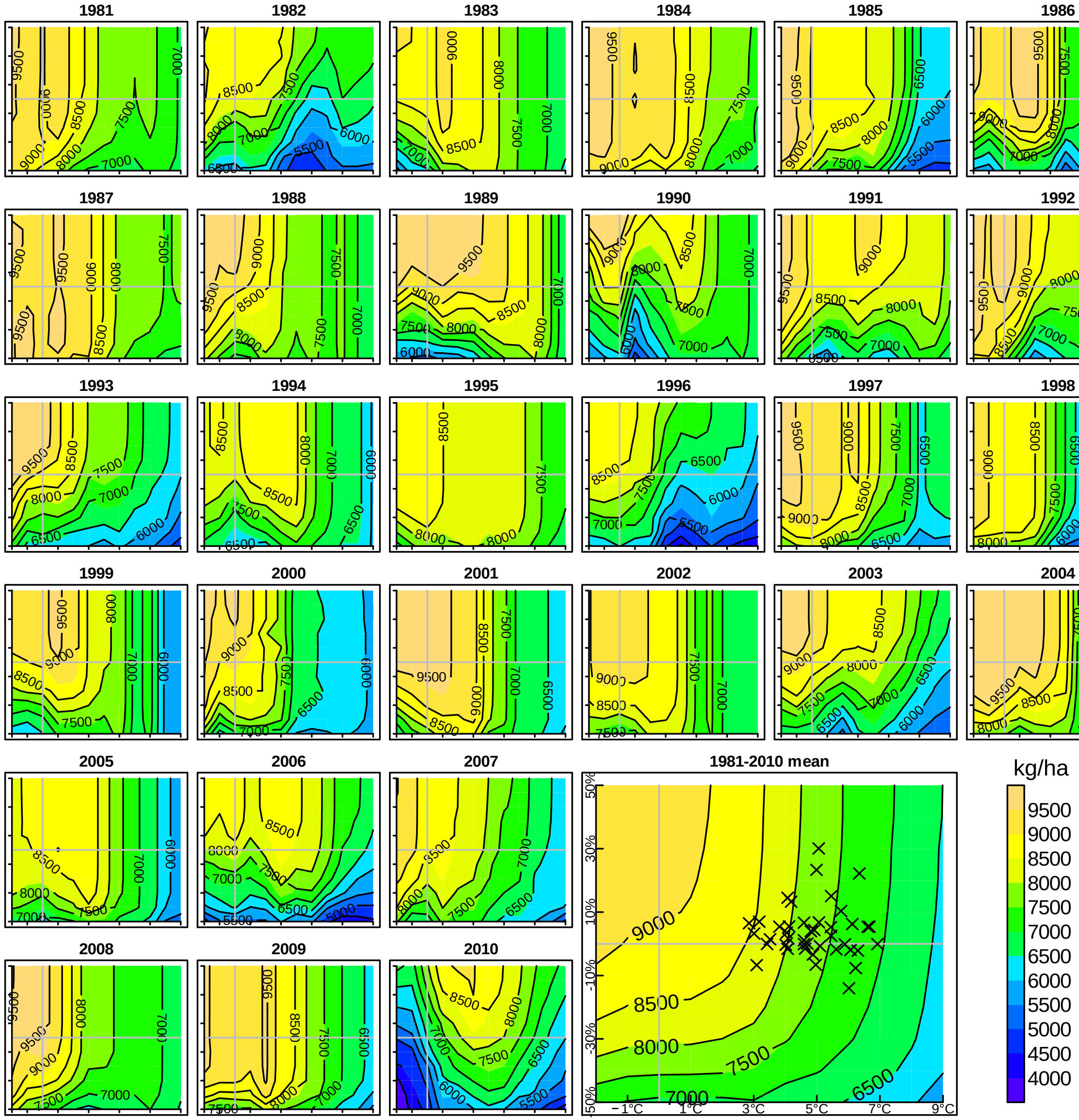
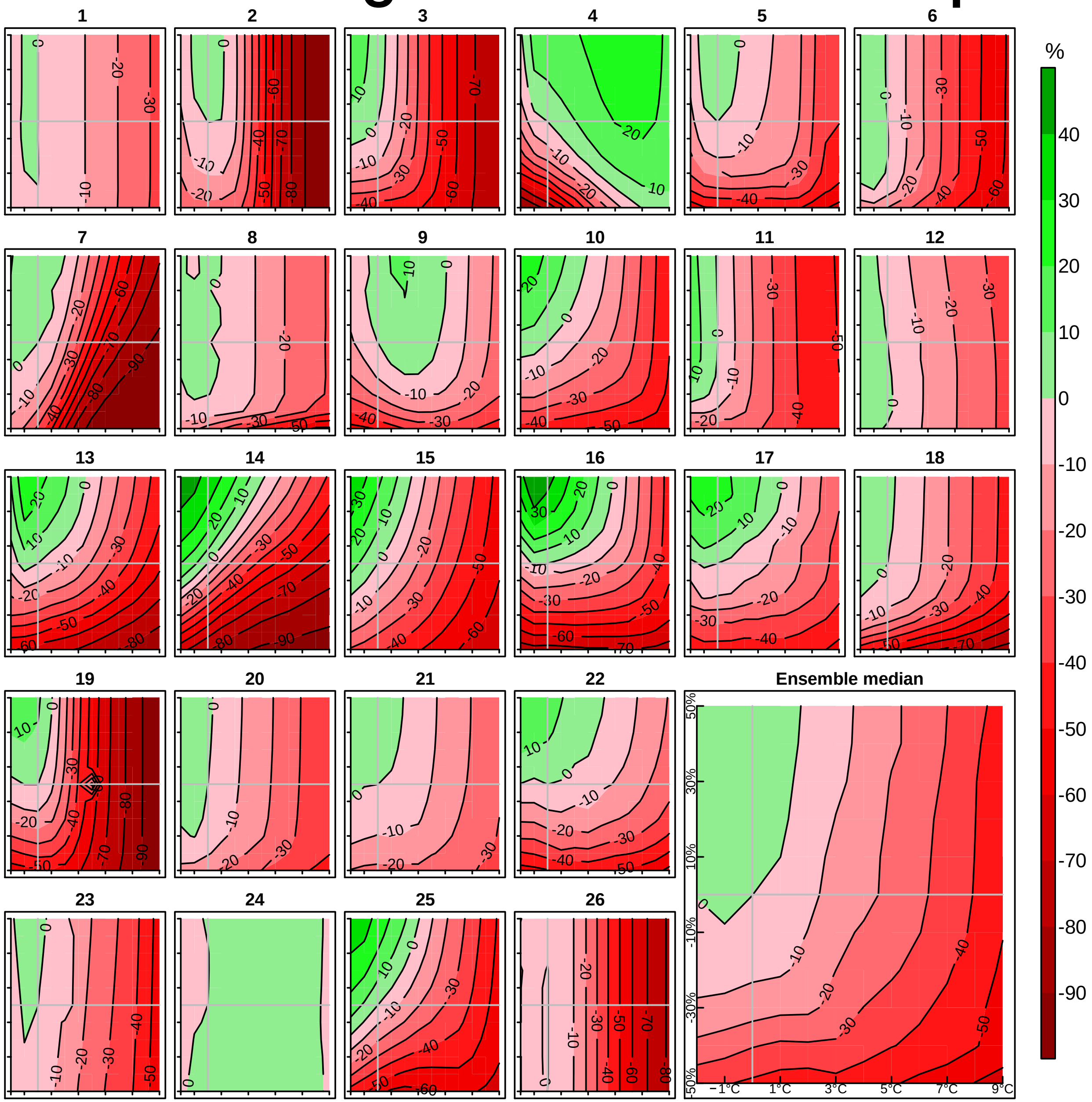
Winter wheat DM grain yields, Germany



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

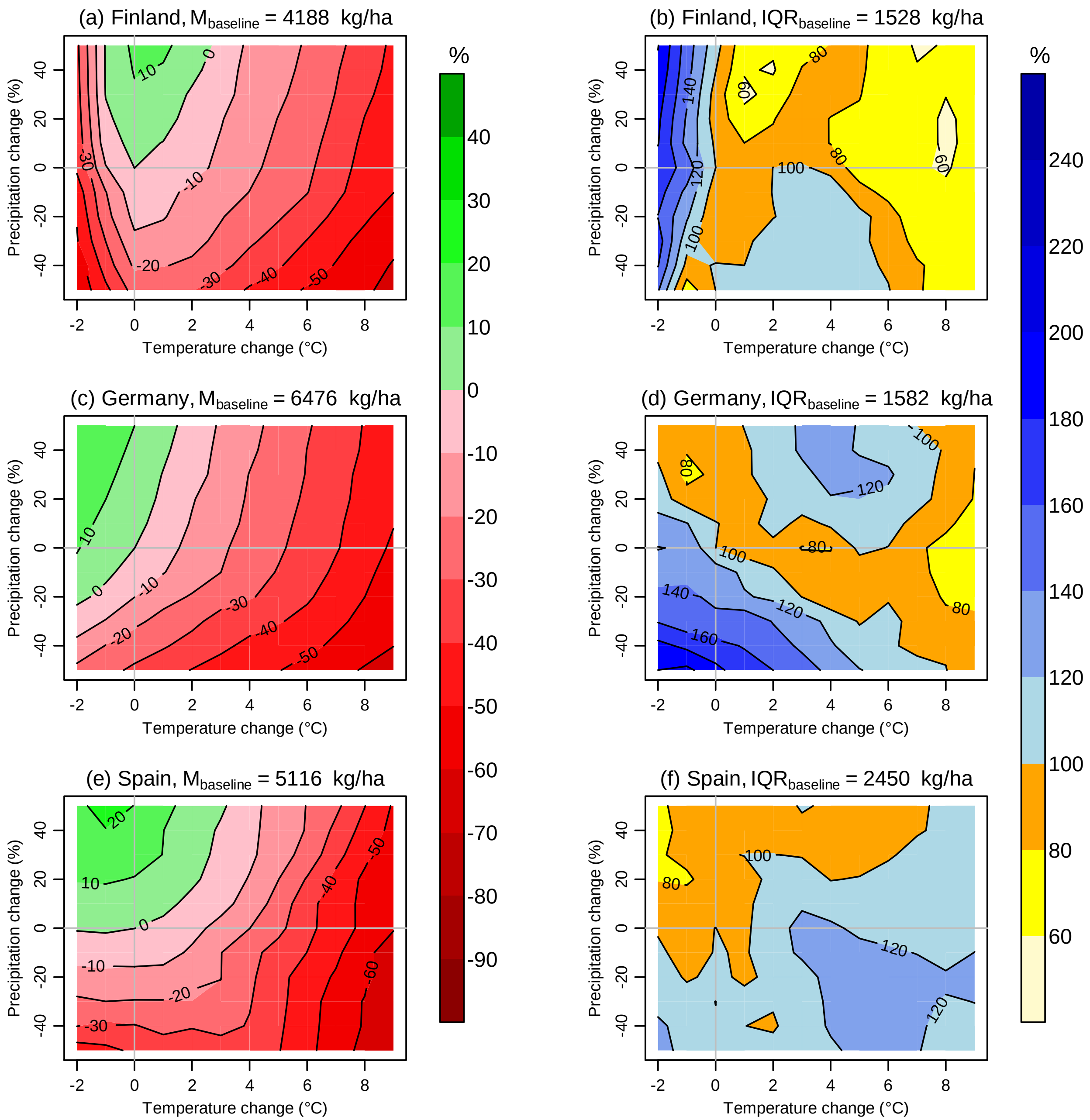


30-year average change in winter wheat DM yields relative to baseline climate (1981-2010) in Germany

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 of yield changes and model IQR



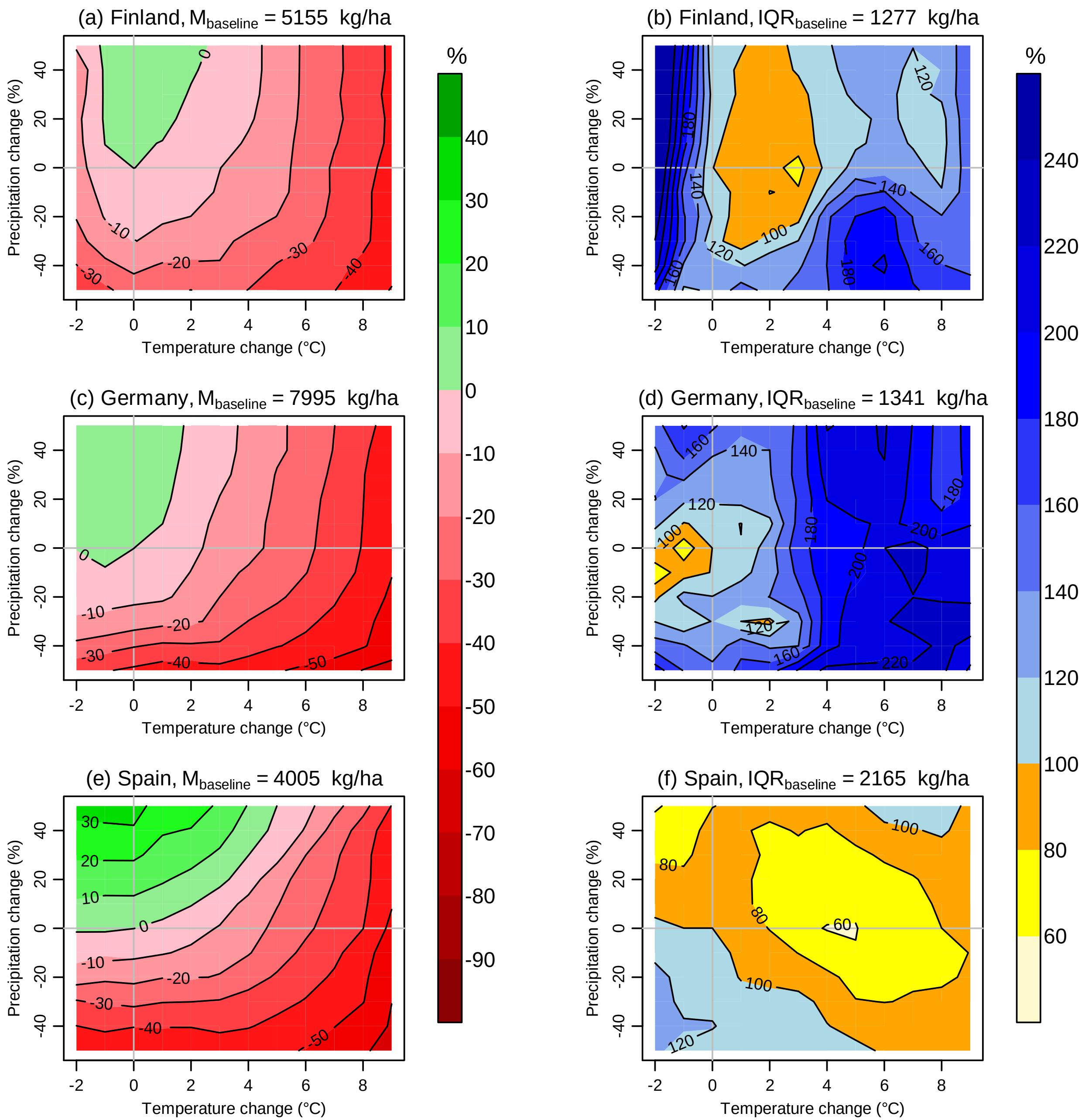
Spring wheat

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.

Ensemble medians of yield changes and model IQR



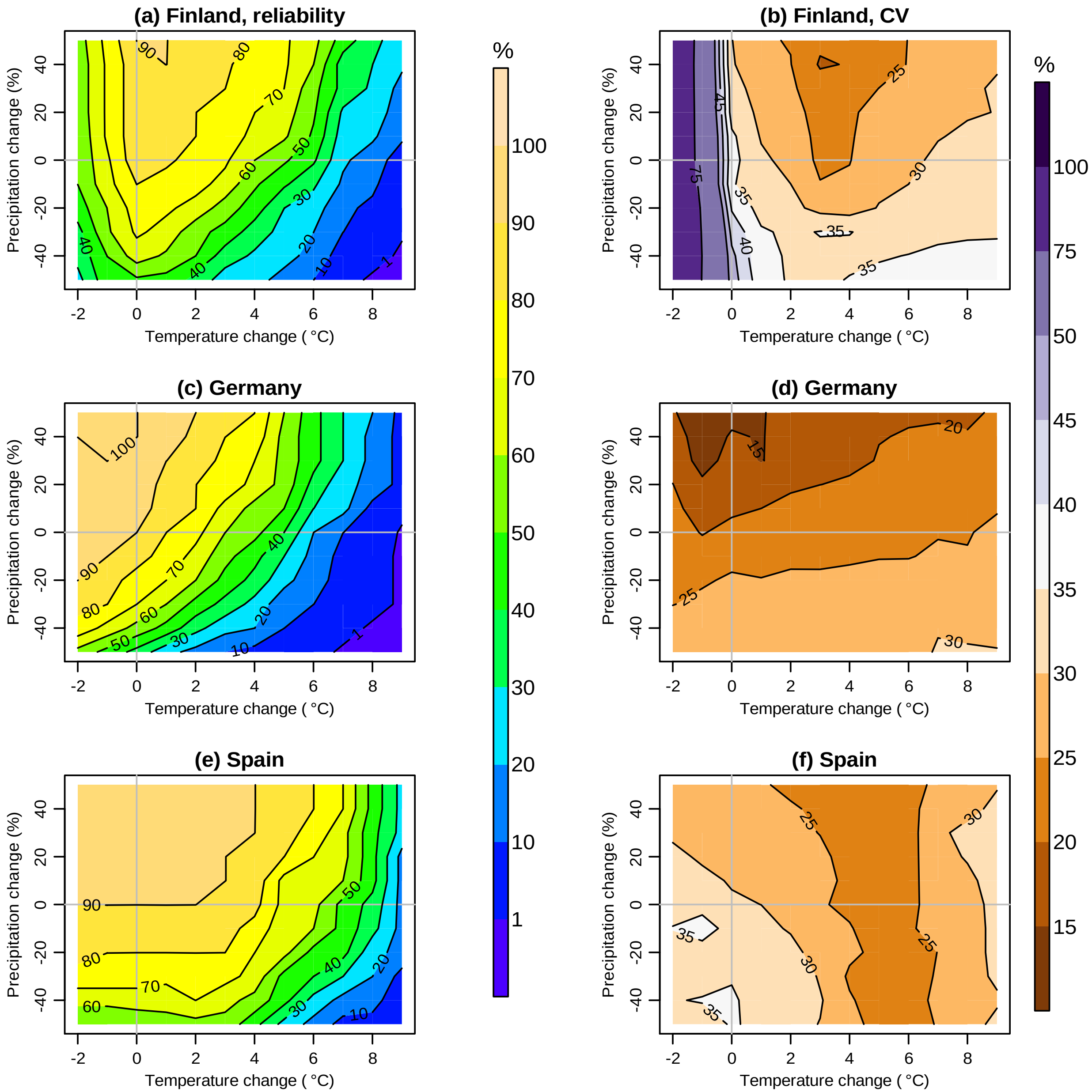
Winter wheat

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 of inter-annual variability



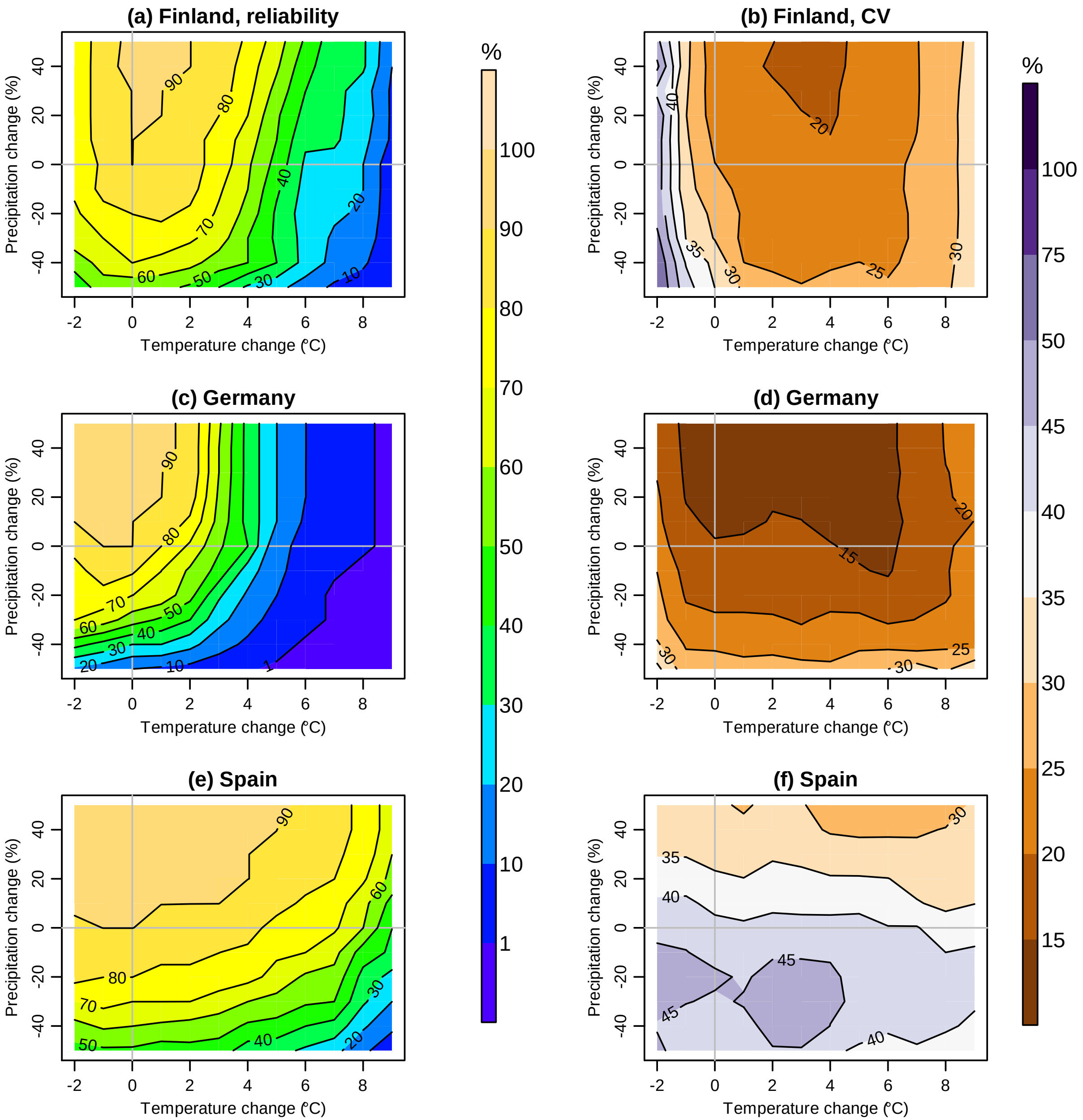
Spring wheat

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

Ensemble medians of inter-annual variability



Winter 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

Conclusions 1/2

- Demonstration of using 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 while sensitivities are mixed at the German and Spanish sites
- 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

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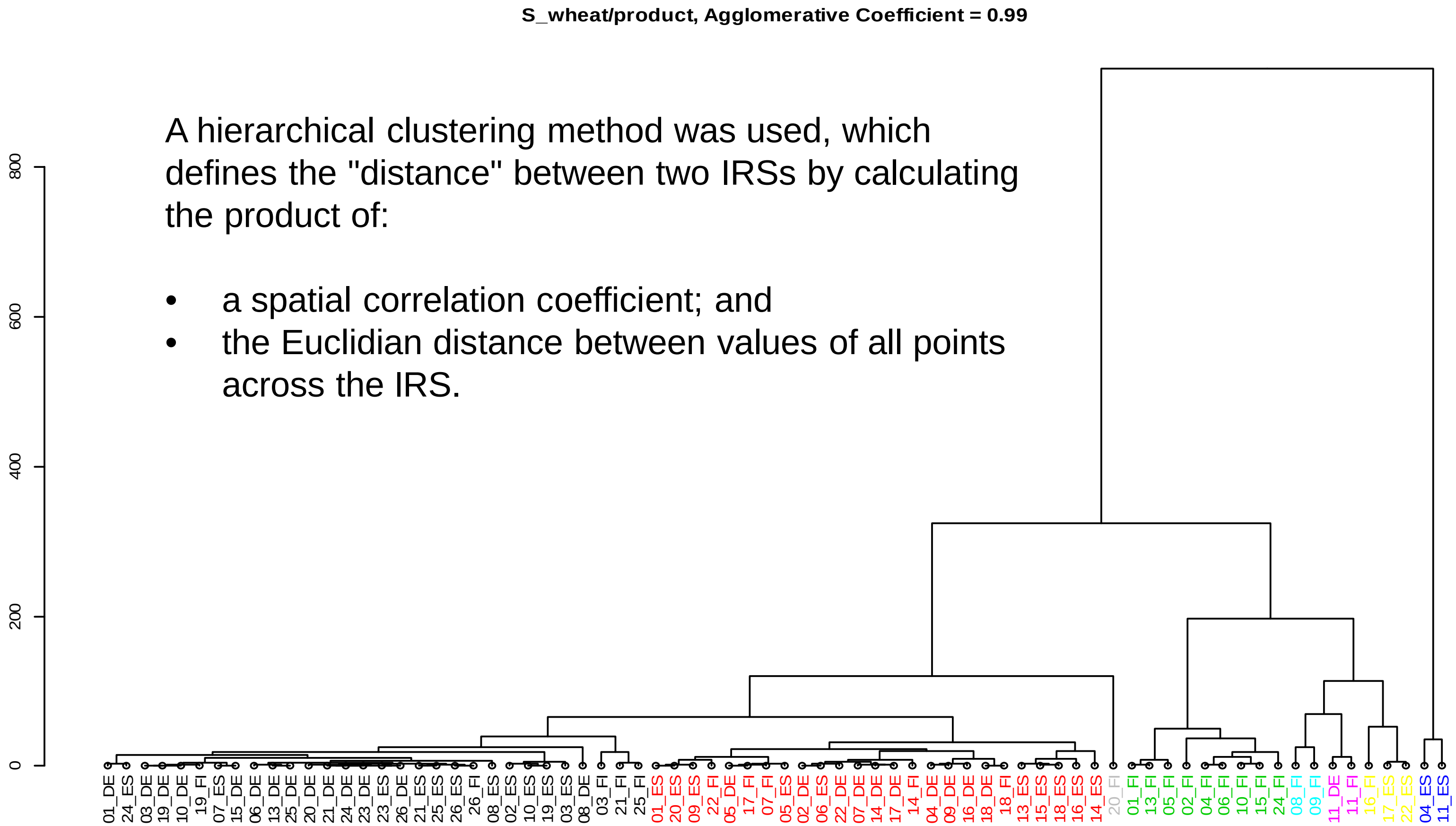
Conclusions 2/2

- Shortcomings of the IRS approach:
  - IRSs depict responses for temperature and precipitation changes alone
  - all other variables, including CO_2, are assumed to remain fixed at baseline values
- Utility of the IRS approach:
  - rapid evaluation of model sensitivities, including identification of notable discontinuities and model behaviour under changed climatic conditions
  - analysis and comparison of multiple model simulations of yield responses to changes in climate across a wide range of plausible future conditions, not specific to individual projections from climate models
- Future work will use IRSs
  1. to classify response patterns of different models
  2. to assess effectiveness of adaptation options after introducing more realism to model simulations (e.g. CO_2, seasonality)
  3. to evaluate future changes in crop yield reliability, by superimposing probabilistic climate projections on the IRSs

Future work - Classifying response patterns



A hierarchical clustering method was used, which defines the "distance" between two IRSs by calculating the product of:

- a spatial correlation coefficient; and
- the Euclidian distance between values of all points across the IRS.

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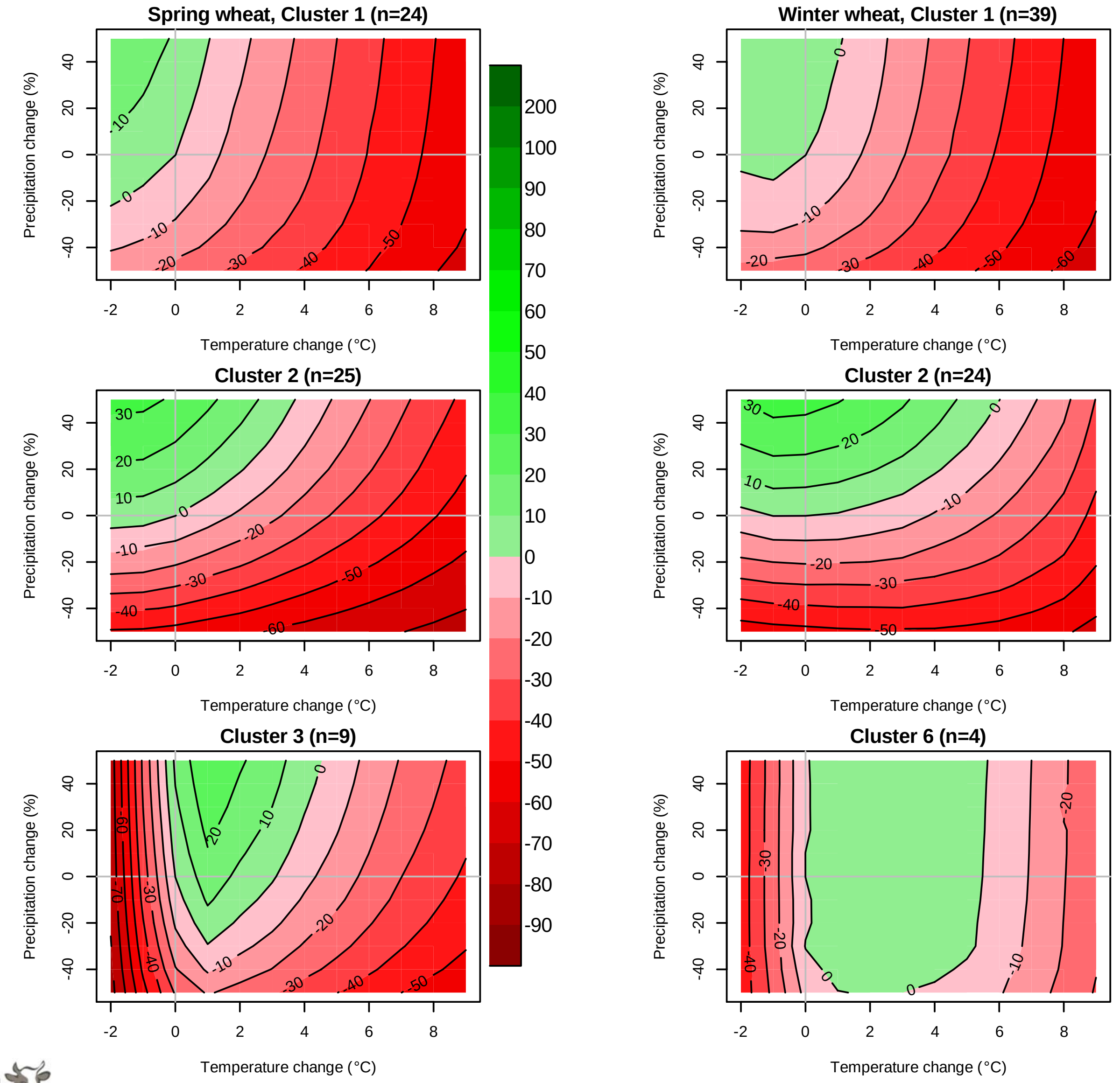
Future work - Classifying response patterns



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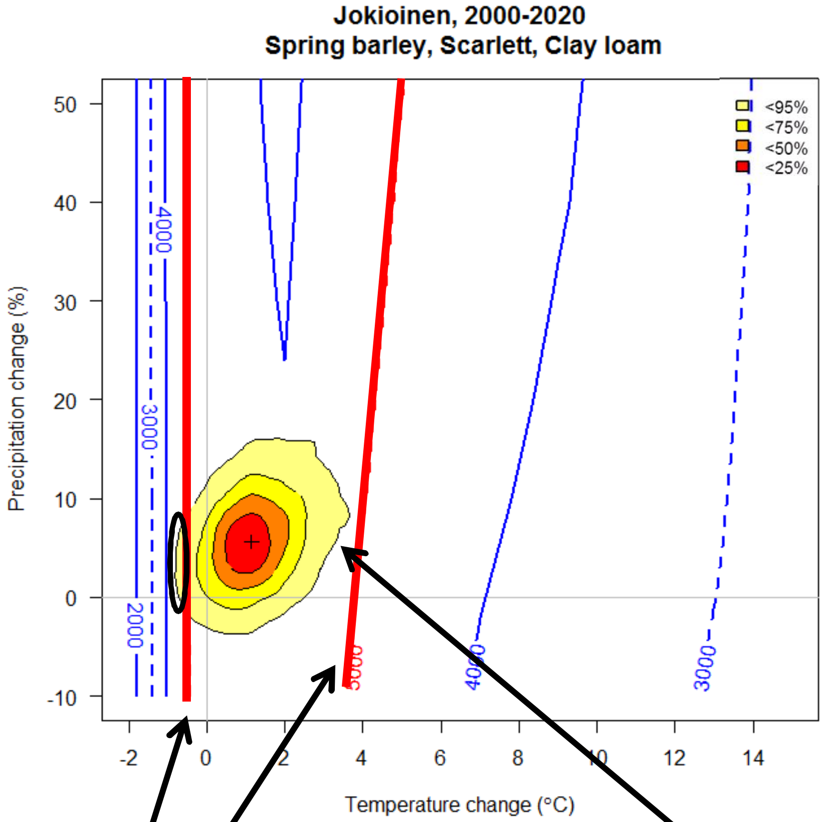
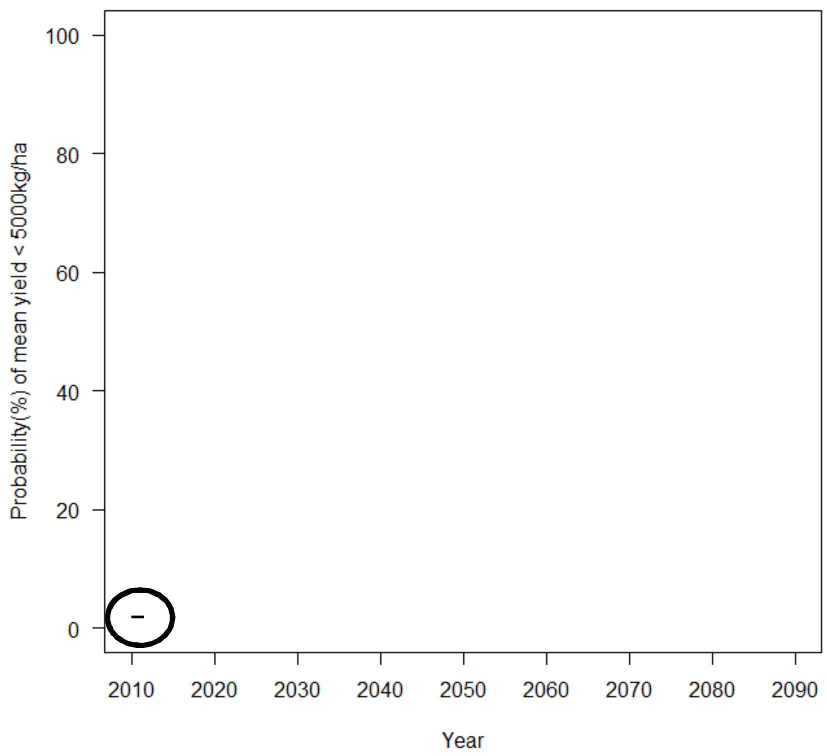
Future work - Likelihood of impacts

Crop yield kg/ha



Likelihood of yield shortfall



Impact threshold

Probabilistic projection of temp and precip change

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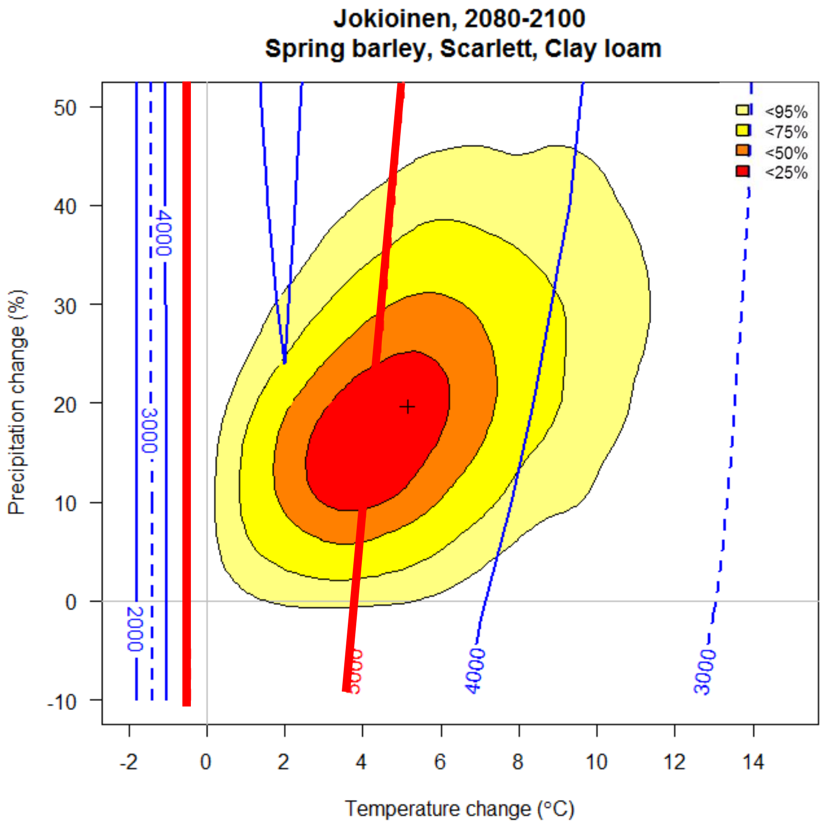
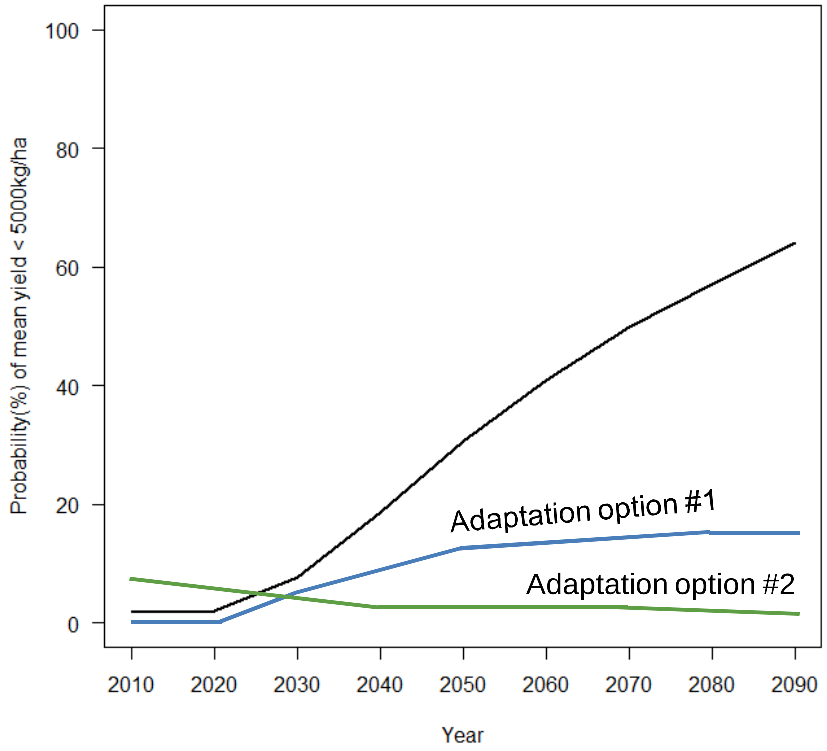
Future work - Likelihood of impacts

Crop yield kg/ha



Likelihood of yield shortfall



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