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Inter-model variability in wheat yield responses to changes in climate in the IRS1 model experiment

S. Fronzek [1], N. Pirttioja[1], T. R. Carter[1], M. Bindi[2], H. Hoffmann[3], T. Palosuo[4],
M. Ruiz-Ramos[5], F. Tao[4], M. Trnka[6,7], M. Acutis[8], S. Asseng[9], P. Baranowski[10], B. Basso[11], P. Bodin[12], S. Buis[13], D. Cammarano[14], P. Deligios[15], M.-F. Destain[16], B. Dumont[16], F. Ewert[3], R. Ferrise[2], L. François[16], T. Gaiser[3], P. Hlavinka[6,7], I. Jacquemin[16], K. Christian Kersebaum[17], C. Kollas[17], J. Krzyszczak[10], I. J. Lorite[18], J. Minet[16], M. I. Minguez[5], M. Montesino[19], M. Moriondo[20], C. Müller[21], C. Nendel[17], I. Öztürk[22], A. Perego[8], A. Rodríguez[5], A. C. Ruane[23,24], F. Ruget[13], M. Sanna[8], M. Semenov[25], C. Slawinski[10], P. Stratonovitch[25], I. Supit[26], K. Waha[21], E. Wang[27], L. Wu[28], Z. Zhao[27,29], R. P. Rötter[4]

[1]Finnish Environment Institute (SYKE)

Session C4 “CropM Uncertainty and Risk analysis”
FACCE MACSUR Joint Workshops, Braunschweig, 29 October 2015

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Outline

- Introduction and aims
- Material and methods: sensitivity analysis with ensemble of wheat models
- Results I: Ensemble averages and ranges (published in Clim Res paper)
- Results II: Classification of response (preliminary results)
- Conclusions and outlook

Aims

- Crop modelling experiment in MACSUR/CropM/WP4

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 winter and spring wheat yield responses to changed climate across models
- By plotting results of the sensitivity analysis as impact response surfaces (IRSs)

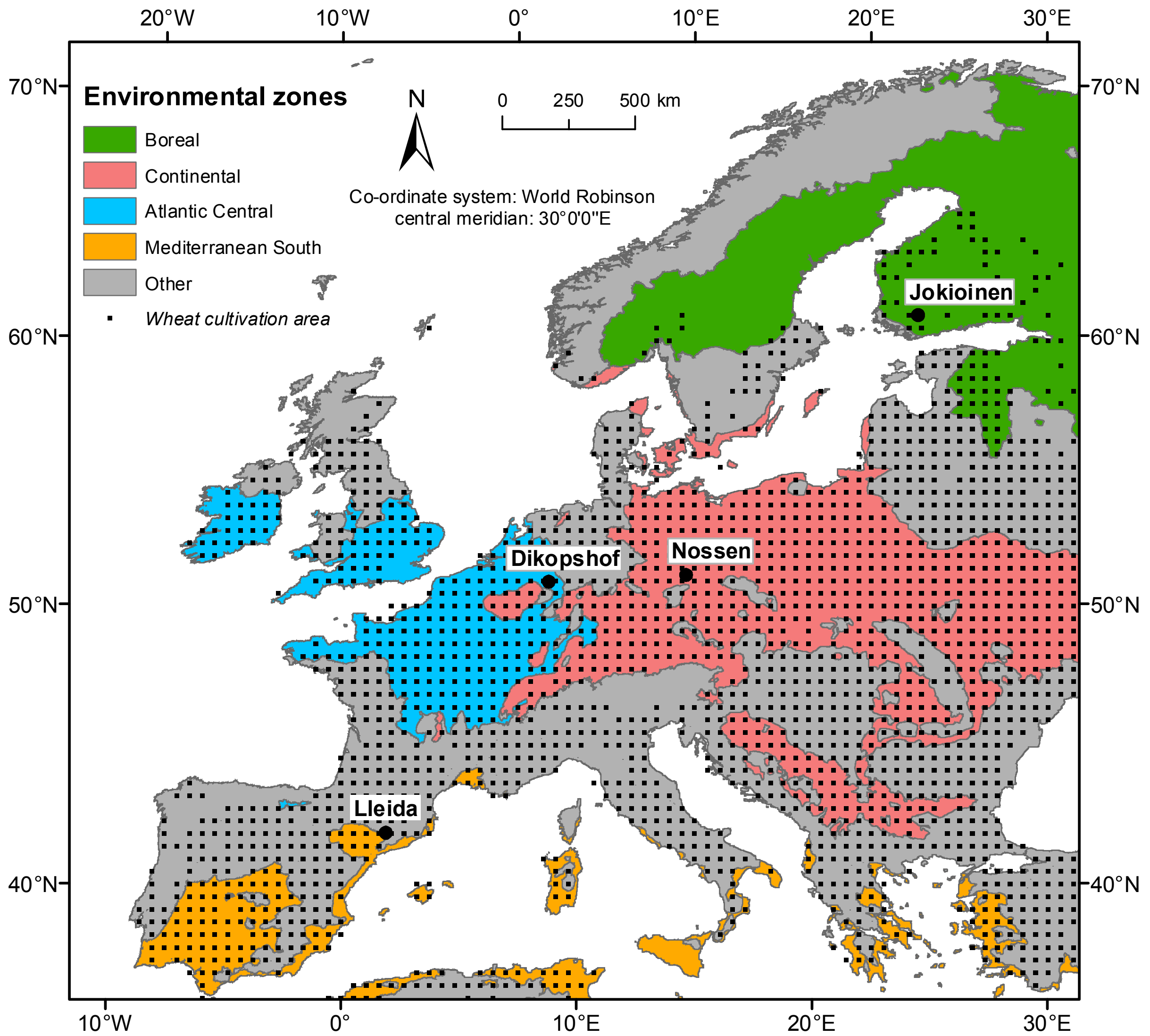
MATERIAL AND METHODS

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
LPJmI	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

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 precipitatio n limited

Simulation set-up (1/2)

- 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
- Several output variables: annual grain yield, biomass, phenology, cumulated water use, nitrogen content of yield

Simulation set-up (2/2)

Sites	***Country***	***Location***			***N***
	Finland	Jokioinen			
	Germany	Dikopshof (winter wheat), Nossen (spring wh.)			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**

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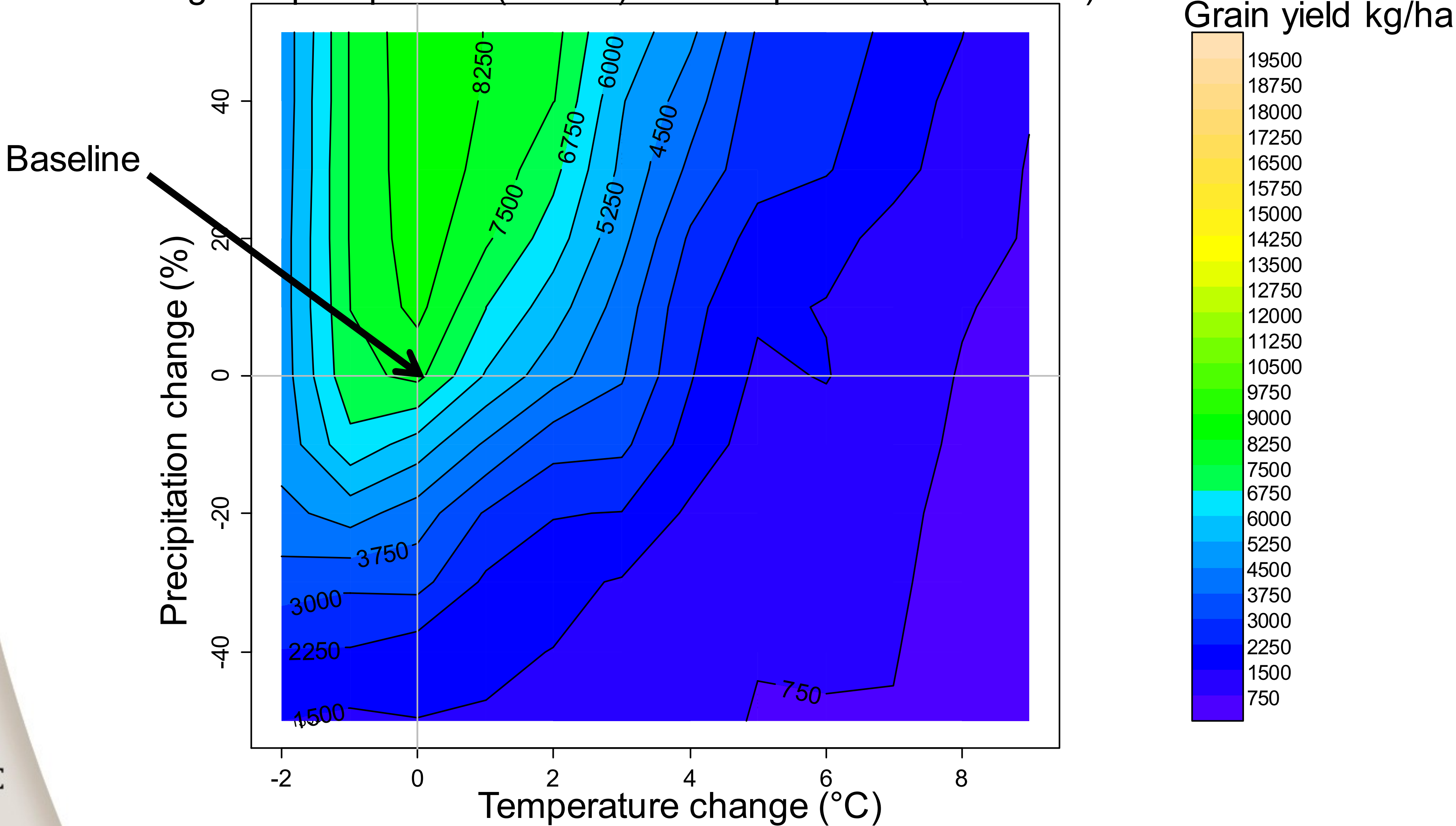
Impact response surface (IRS) of a single crop model for spring wheat yield, Germany, 2008

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



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CLIMATE RESEARCH
Clim Res

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Contribution to CR Special 31 'Modelling climate change impacts for food security'

FREE ACCESS

Temperature and precipitation effects on wheat yield across a European transect: a crop model ensemble analysis using impact response surfaces

N. Pirttioja[1,*], T. R. Carter[1], S. Fronzek[1], M. Bindi[2], H. Hoffmann[3], T. Palosuo[4], M. Ruiz-Ramos[5], F. Tao[4], M. Trnka[6,7], M. Acutis[8], S. Asseng[9], P. Baranowski[10], B. Basso[11], P. Bodin[12], S. Buis[13], D. Cammarano[14], P. Deligios[15], M.-F. Destain[16], B. Dumont[16], F. Ewert[3], R. Ferrise[2], L. François[16], T. Gaiser[3], P. Hlavinka[6,7], I. Jacquemin[16], K. C. Kersebaum[17], C. Kollas[17], J. Krzyszczak[10], I. J. Lorite[18], J. Minet[16], M. I. Minguez[5], M. Montesino[19], M. Moriondo[20], C. Müller[21], C. Nendel[17], I. Öztürk[22], A. Perego[8], A. Rodríguez[5], A. C. Ruane[23,24], F. Ruget[13], M. Sanna[8], M. A. Semenov[25], C. Slawinski[10], P. Stratonovitch[25], I. Supit[26], K. Waha[21,27], E. Wang[28], L. Wu[29], Z. Zhao[28,30], R. P. Rötter[4]

RESULTS I: FOCUS ON ENSEMBLE AVERAGES AND RANGES

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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

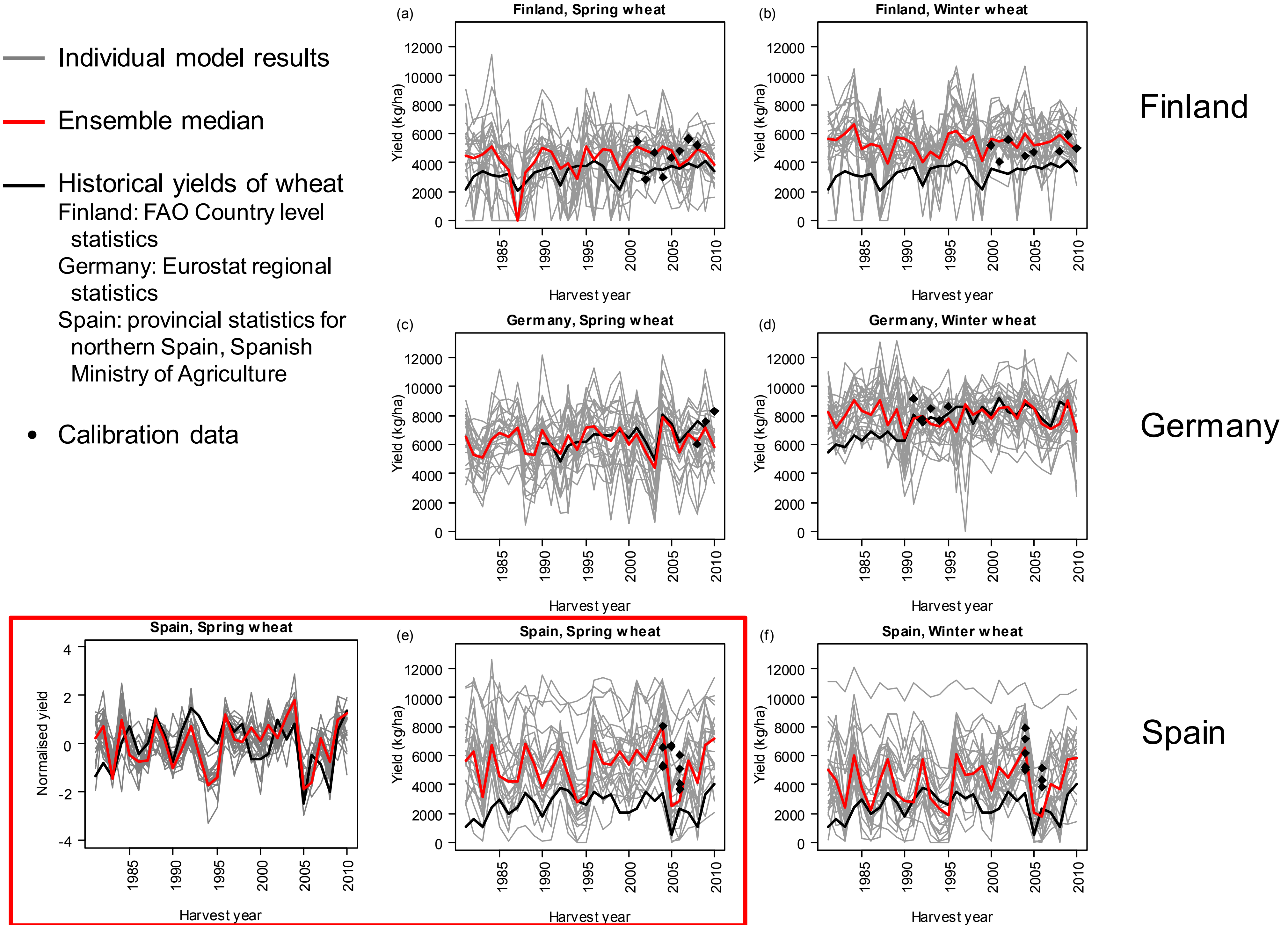
Sites – Finland (FI), Germany (DE) and Spain (ES)

Crops – spring (S) and winter (W) wheat

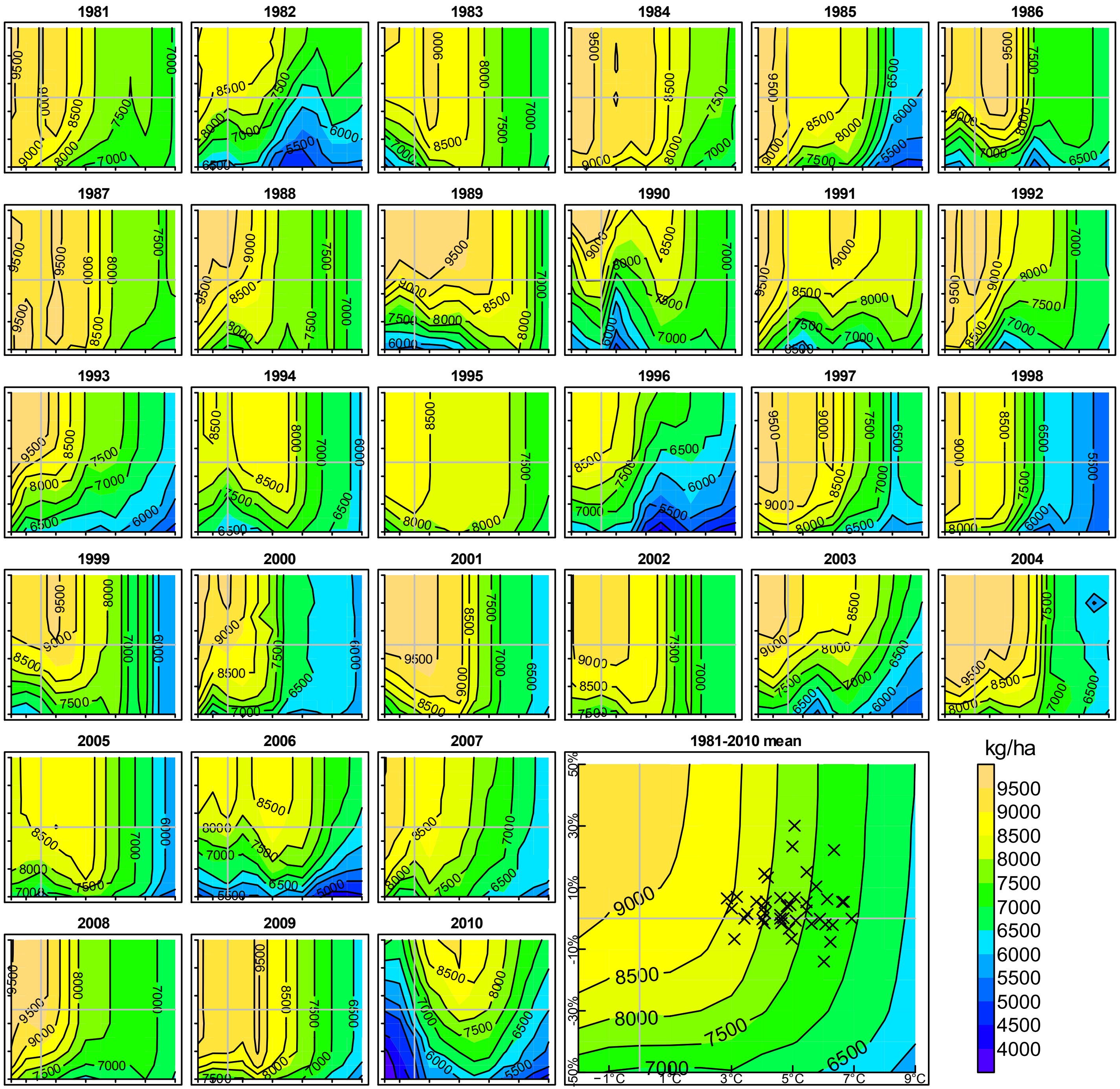
Values for Observations (O) indicate the number of years for which observed crop yield data were available

Models for which no results for a specific site or crop were provided are marked with N/A.

Simulated yields for the baseline 1981-2010



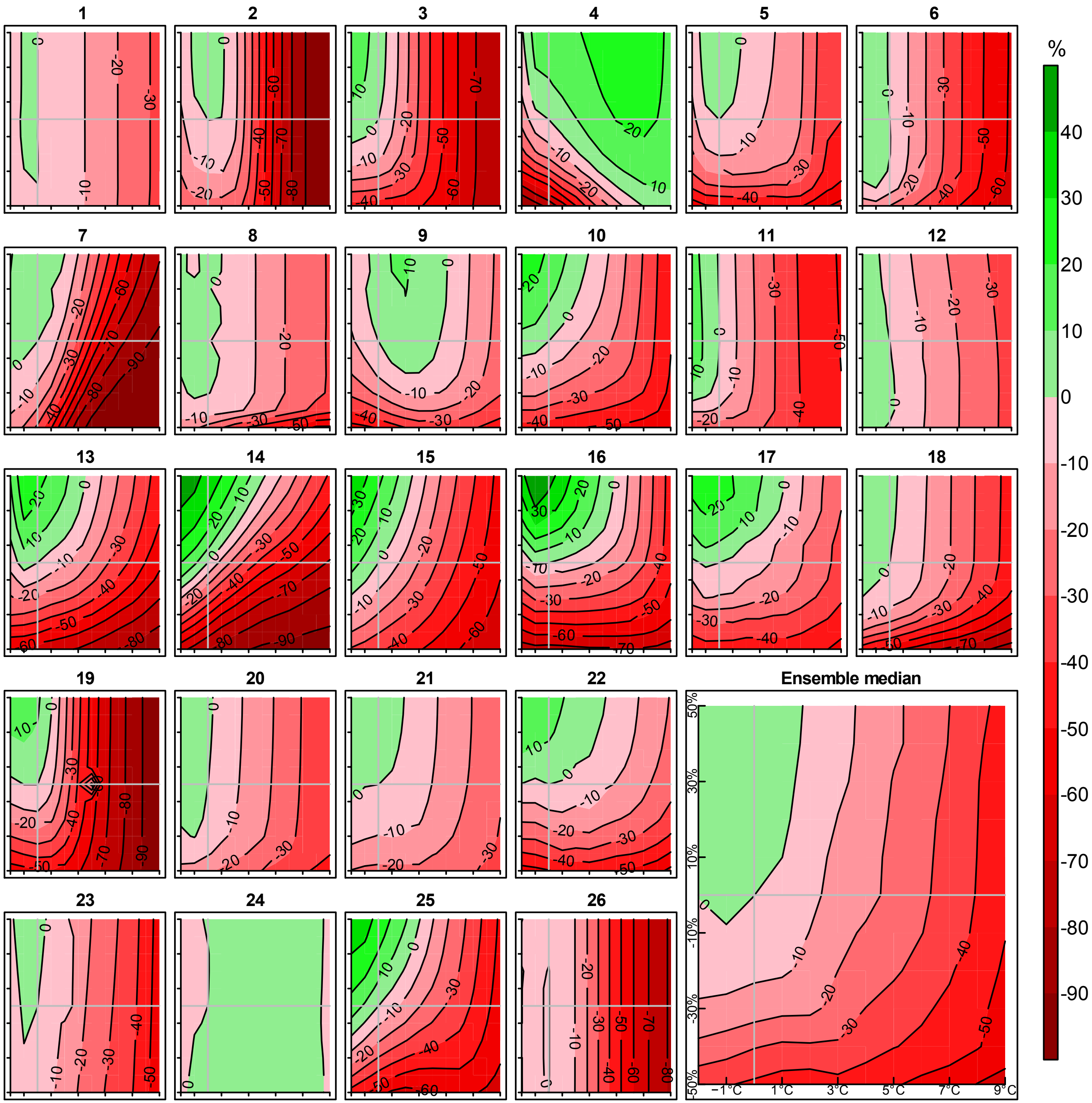
Winter wheat DM grain yields, Germany



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

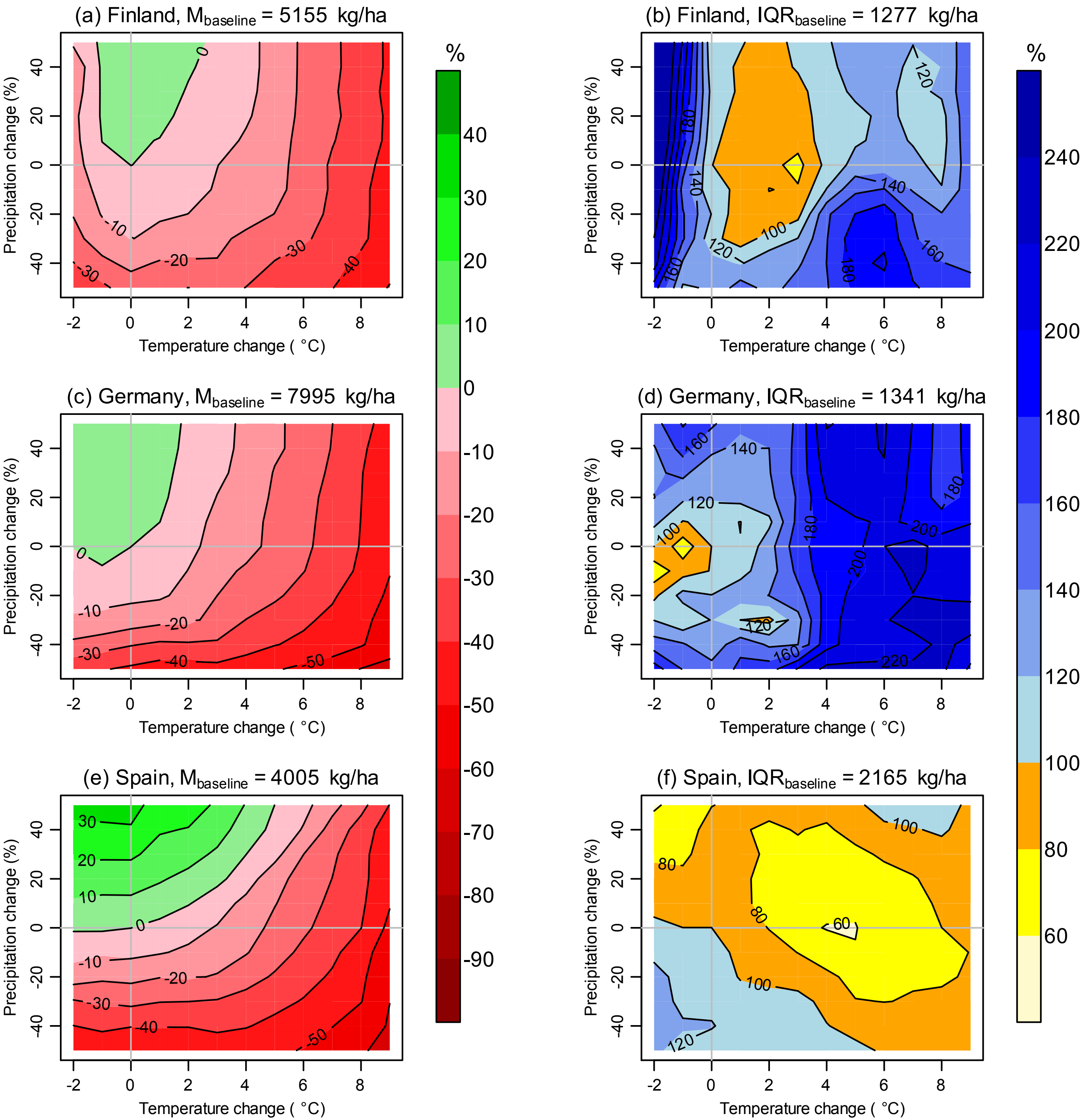


30-year average change in **winter wheat** DM yields relative to baseline climate (1981-2010) in **Germany**

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



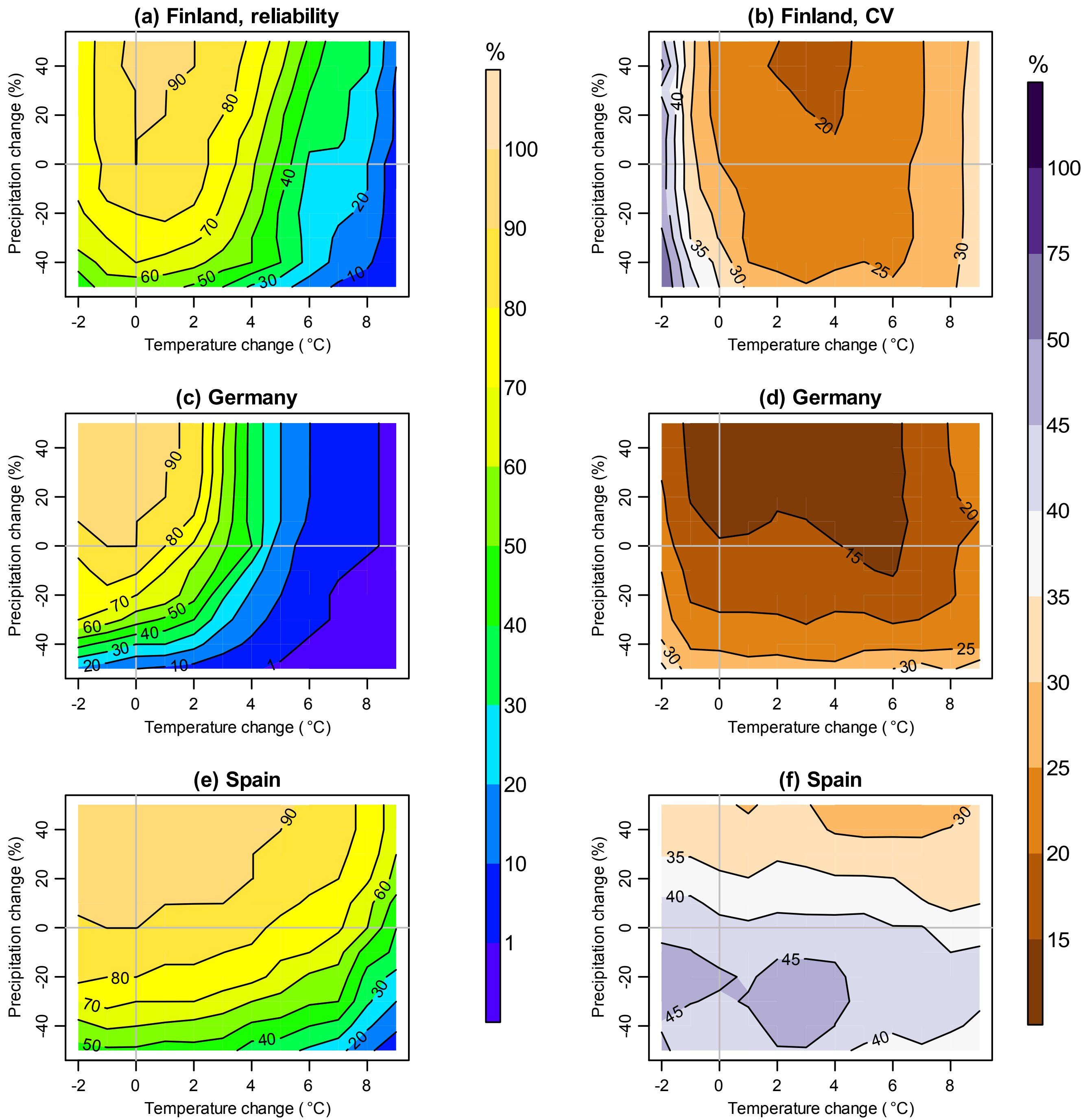
Winter wheat

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 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 26 crop models

RESULTS II: CLASSIFICATION OF MODEL RESPONSES

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Classification of responses

- Different models and different conditions show different behaviour

⇨ Can we group models according to their different sensitivities to climate change?

- Two approaches for grouping IRSs:
  - Clustering algorithm
  - Rules defined by expert judgment

⇨ Can we find explanations for different model responses?

Some preliminary results and ideas

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Clustering of IRSs based on correlation and Euclidian distance

- Distances between two IRSs are defined based on their pattern and magnitude:
  - Pearson correlation coefficient *r* *(-1) +1
  - Euclidian distance over all points of the IRS

  combined by taking the product of the two
- IRSs are clustered (per crop, for 3 locations) by hierarchical clustering that minimize the distances between members of each cluster:
  - *agnes* (agglomerative nesting) algorithm in R (Kaufman & Rousseeuw 1990), using the average method to determine clusters
  - The number of clusters was set to 7 (according to a rule of thumb = sqrt(n/2), but after removing ”outlying” IRSs that were in a separate cluster

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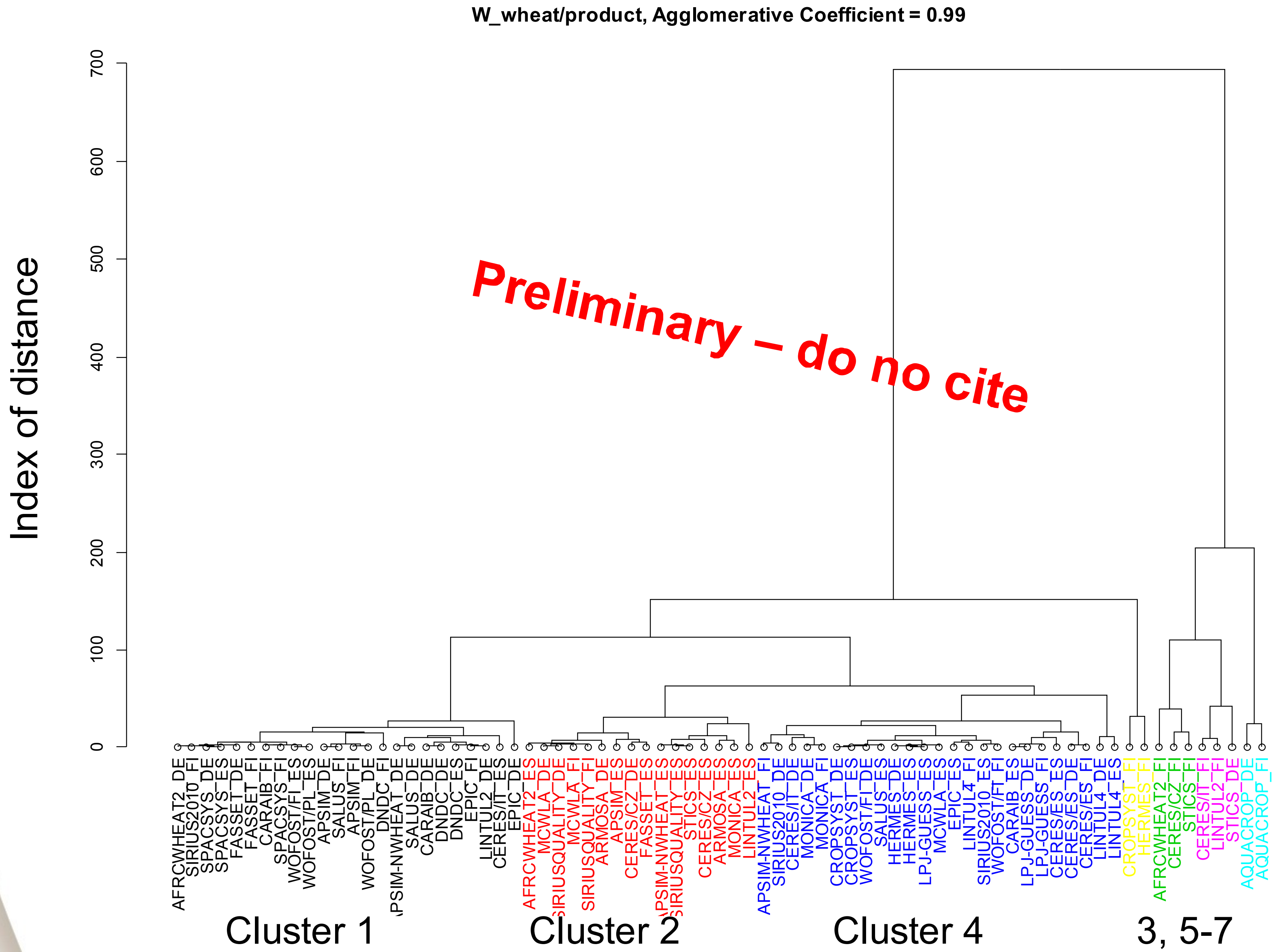
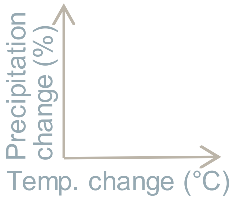
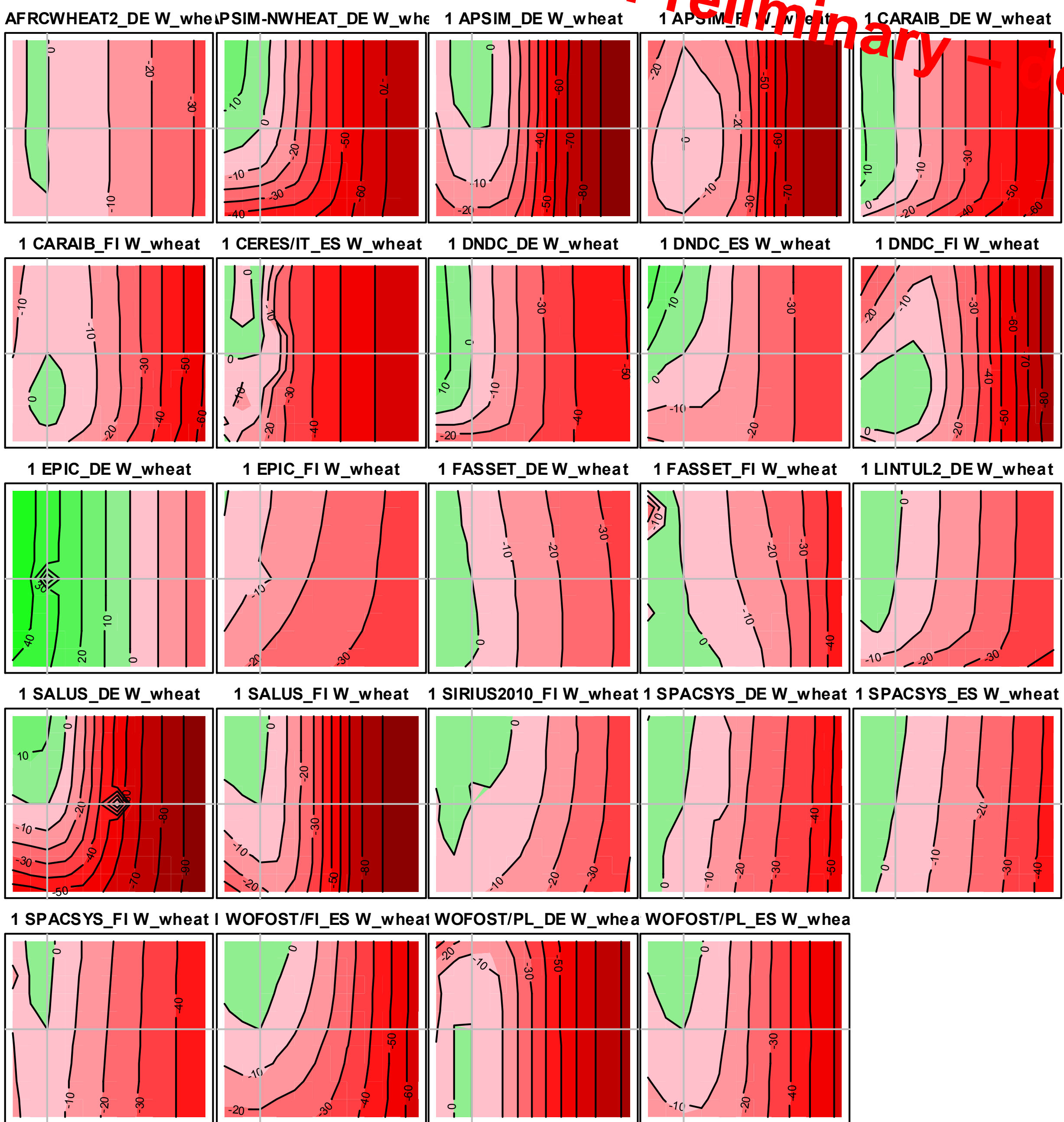
Winter wheat
30-yr mean change in yield IRSs



S Y K E

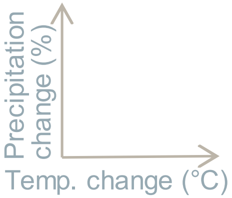
Cluster 1: strong temperature-sensitivity, yield decreases with warming, no precip-sens for high warming

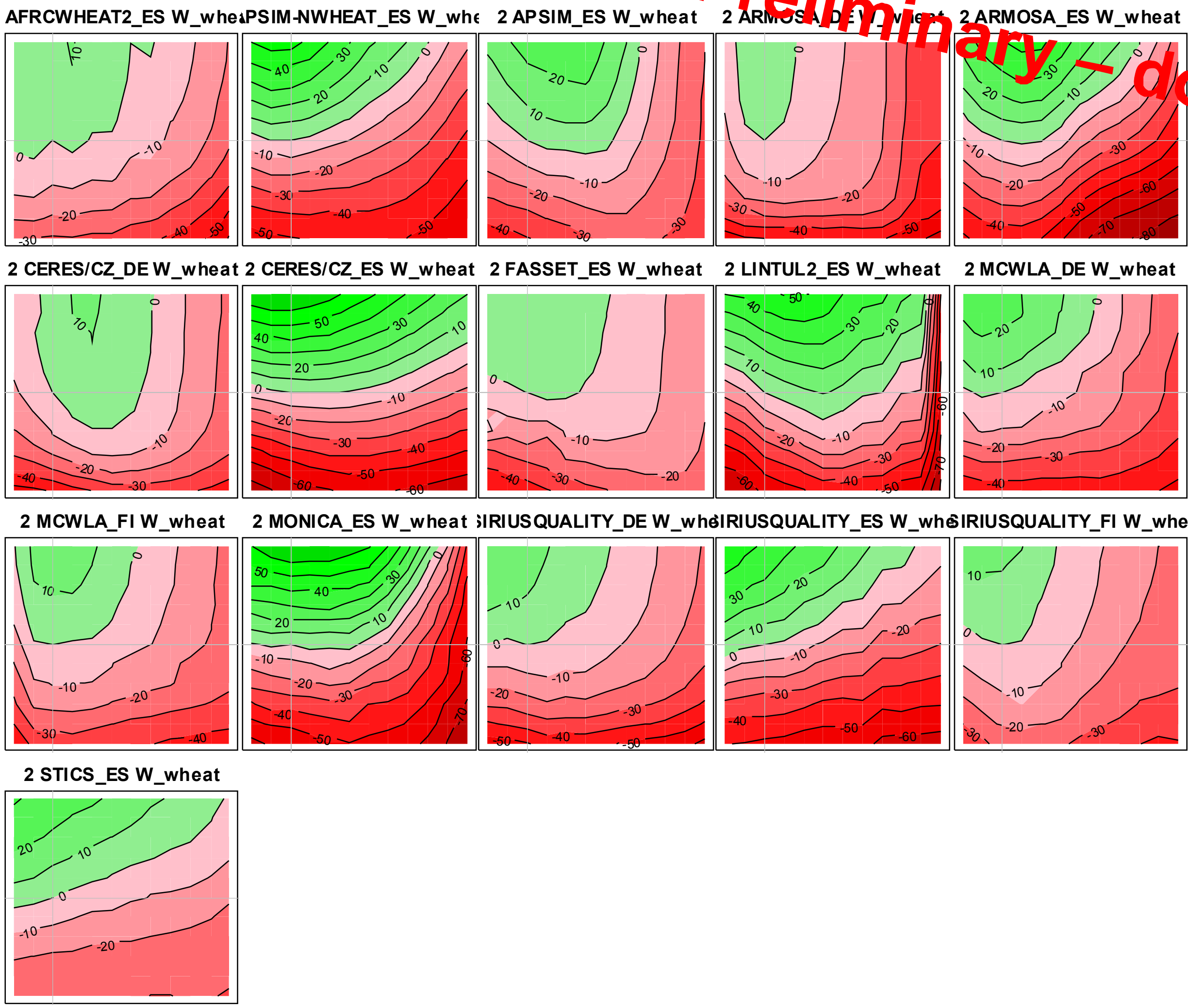




Cluster 2: strong precip-sensitivity, except for large warming

Preliminary – do no cite





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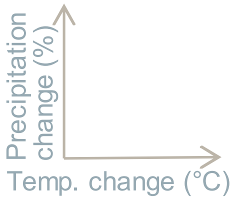
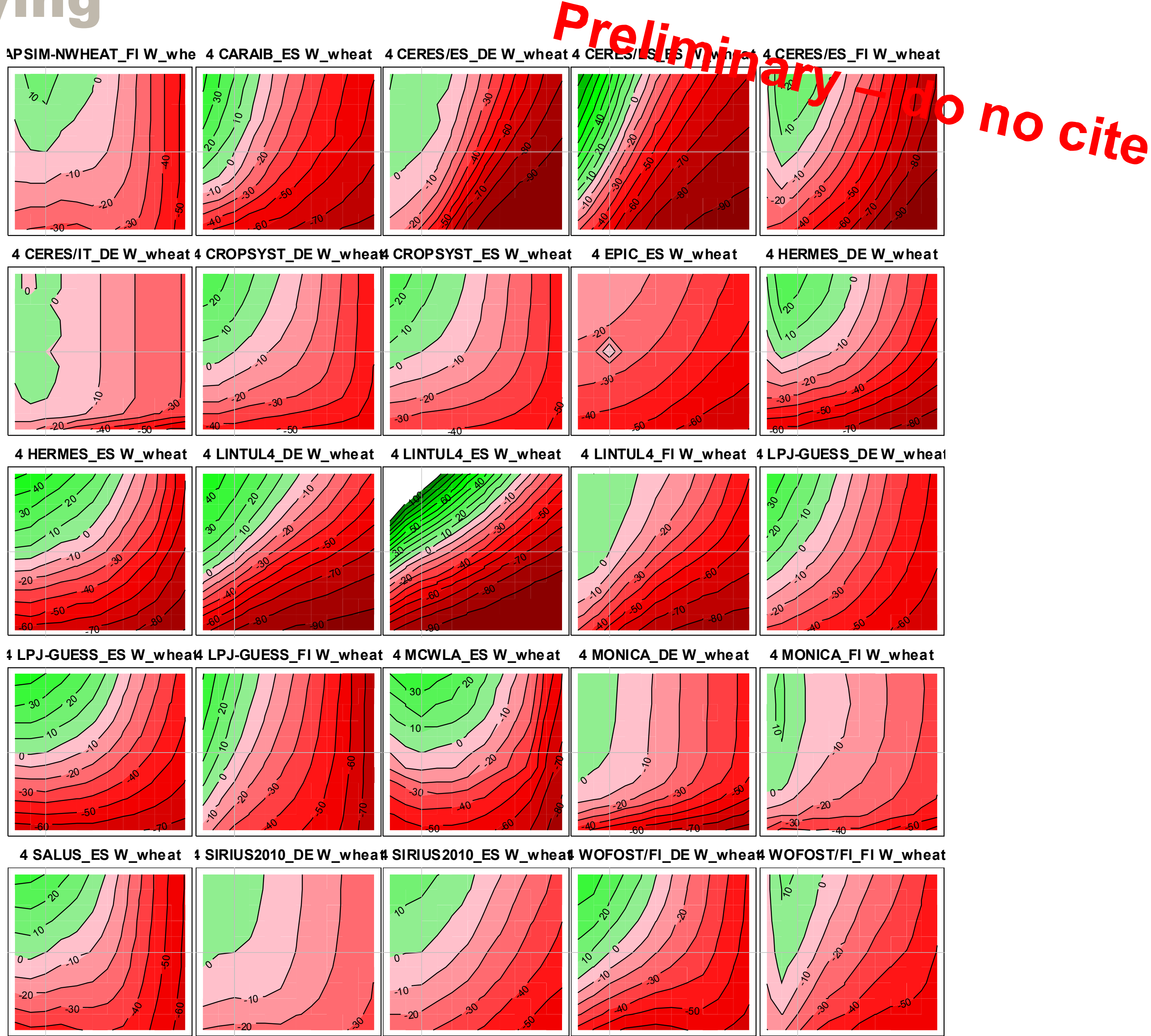
Cluster 4: yield decrease with warming and drying





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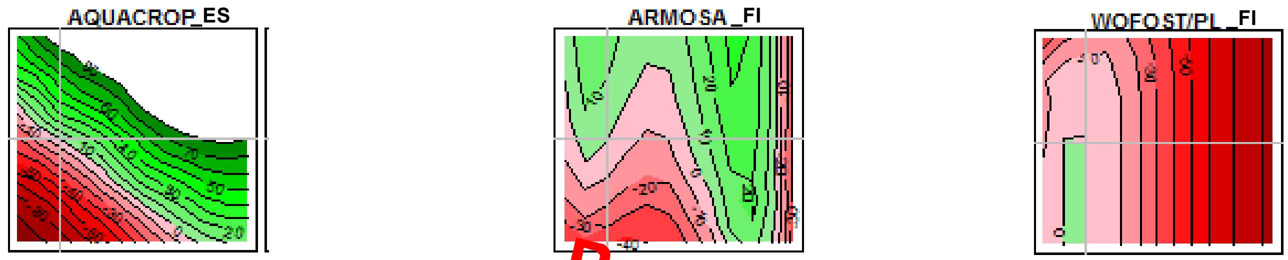
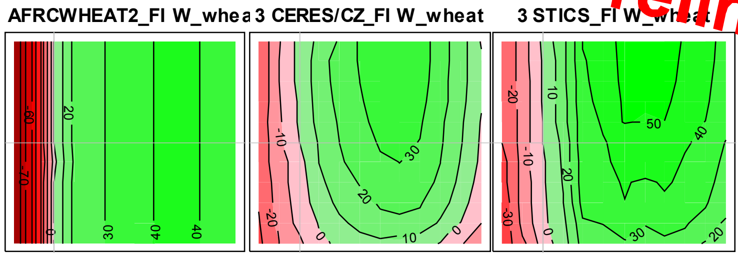
Separate clusters

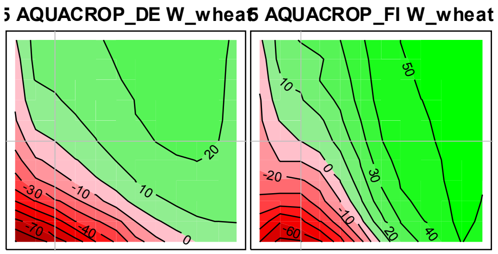


Preliminary – do no cite

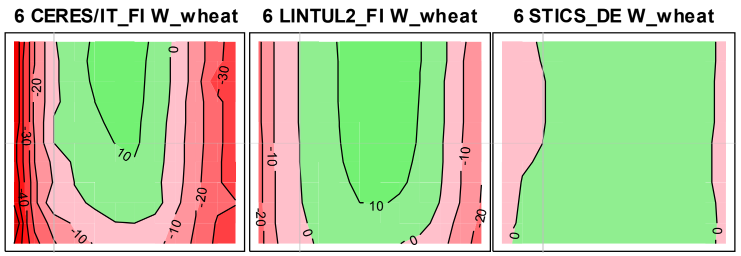
Cluster 3: strong temp-sensitivity, exept for large warming



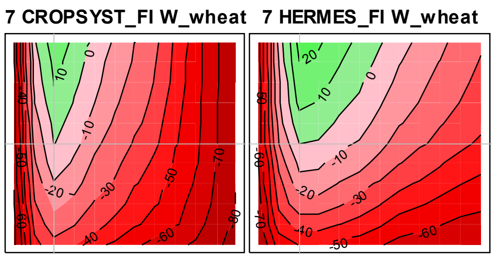
Cluster 5: yield increases with warming and precip increases

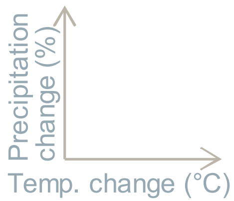


Cluster 6: yield increases with warming and precip increases, but decreases for high warming



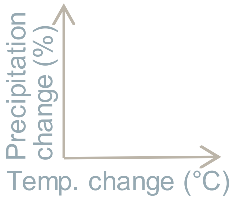
Cluster 7: V-shape with centred around 0-change



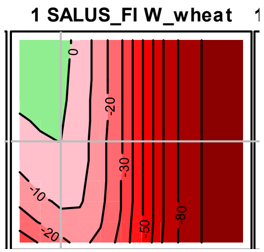


Central examples from each cluster

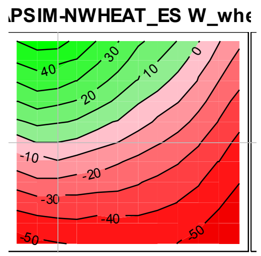
Preliminary – do no cite



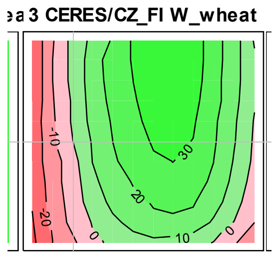
Cluster 1: n=24



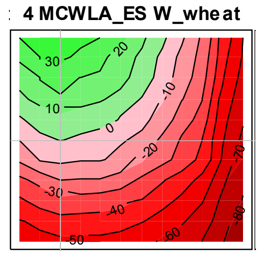
Cluster 2: n=16



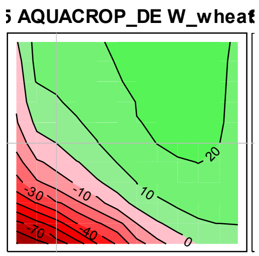
Cluster 3: n=3



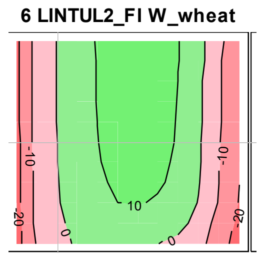
Cluster 4: n=25



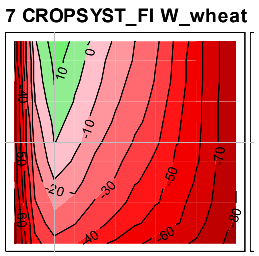
Cluster 5: n=2



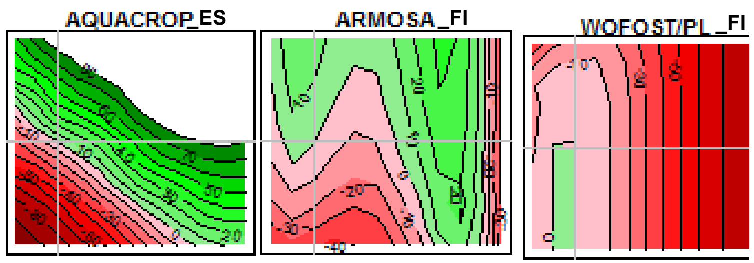
Cluster 6: n=3



Cluster 7: n=2



Separate: n=1



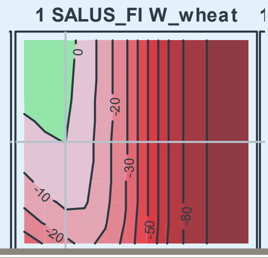
Labels and cluster groups: winter wheat

Yield decrease (Y-) with temperature increase (T+)

Preliminary – do no cite

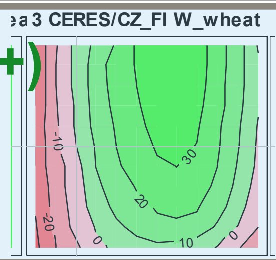
T-dominant (Y-: T+)

Cluster 1: n=24



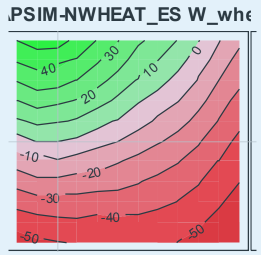
T-dominant (Y+: T+)

Cluster 3: n=3

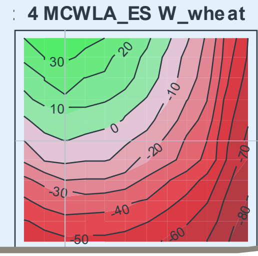


P-dominant (Y+: P+)

Cluster 2: n=16

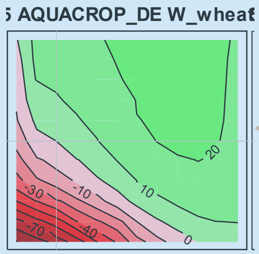


Cluster 4: n=25



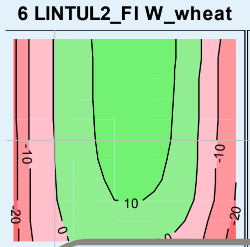
Y+: T+ & P+

Cluster 5: n=2



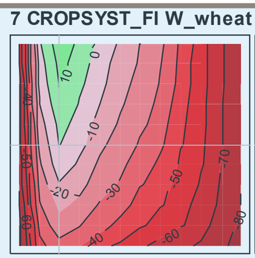
Y+: T+, Y-: T++

Cluster 6: n=3

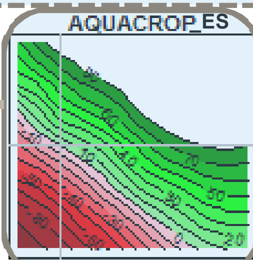


V-shape

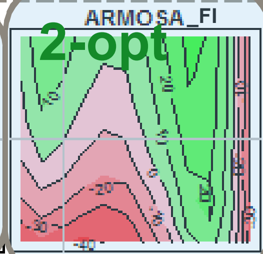
Cluster 7: n=2

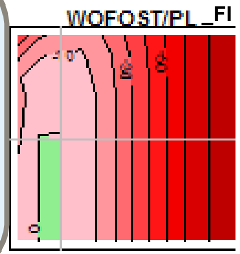


Separate: n=1



2-opt





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Clustering of IRS for 30-year-mean change in winter wheat yields

Preliminary – do no cite

T-dominant (Y-: T+)	1
P-dominant (Y+: P+)	2
T-dominant (Y+: T+)	3
Y+: T+ & P+	4
Y+: T+, Y-: T++	5
V-shape	6
2-opt	7

	FI		ES		DE		# of different clusters
AFRCWHEAT2	Y+:T+	3	Y+:P+	2	Y-:T+	1	3
APSIM	Y-:T+	1	Y+:P+	2	Y-:T+	1	2
APSIM-NWHEAT	Y+:P+	4	Y+:P+	2	Y-:T+	1	3
AQUACROP	Y+:T+,P+	5	Y+:T+,P+	5	Y+:T+,P+	5	1
ARMOSA	2-T-opt	8	Y+:P+	2	Y+:P+	2	2
CARAIB	Y-:T+	1	Y+:P+	4	Y-:T+	1	2
CERES/CZ	Y+:T+	3	Y+:P+	2	Y+:P+	2	2
CERES/ES	Y+:P+	4	Y+:P+	4	Y+:P+	4	1
CERES/IT	Y+:T+,Y-:T++	6	Y-:T+	1	Y+:P+	4	3
CROPSYST	V-shape	7	Y+:P+	4	Y+:P+	4	2
DNDC	Y-:T+	1	Y-:T+	1	Y-:T+	1	1
EPIC	Y-:T+	1	Y+:P+	4	Y-:T+	1	2
FASSET	Y-:T+	1	Y+:P+	2	Y-:T+	1	2
HERMES	V-shape	7	Y+:P+	4	Y+:P+	4	2
LINTUL2	Y+:T+,Y-:T++	6	Y+:P+	2	Y-:T+	1	3
LINTUL4	Y+:P+	4	Y+:P+	4	Y+:P+	4	1
LPJ-GUESS	Y+:P+	4	Y+:P+	4	Y+:P+	4	1
MCWLA	Y+:P+	2	Y+:P+	4	Y+:P+	2	2
MONICA	Y+:P+	4	Y+:P+	2	Y+:P+	4	2
SALUS	Y-:T+	1	Y+:P+	4	Y-:T+	1	2
SIRIUS2010	Y-:T+	1	Y+:P+	4	Y+:P+	4	2
SIRIUSQUALITY	Y+:P+	2	Y+:P+	2	Y+:P+	2	1
SPACSYS	Y-:T+	1	Y-:T+	1	Y-:T+	1	1
STICS	Y+:T+	3	Y+:P+	2	Y+:T+,Y-:T++	6	3
WOFOST/FI	Y+:P+	4	Y-:T+	1	Y+:P+	4	2
WOFOST/PL	?		Y-:T+	1	Y-:T+	1	1

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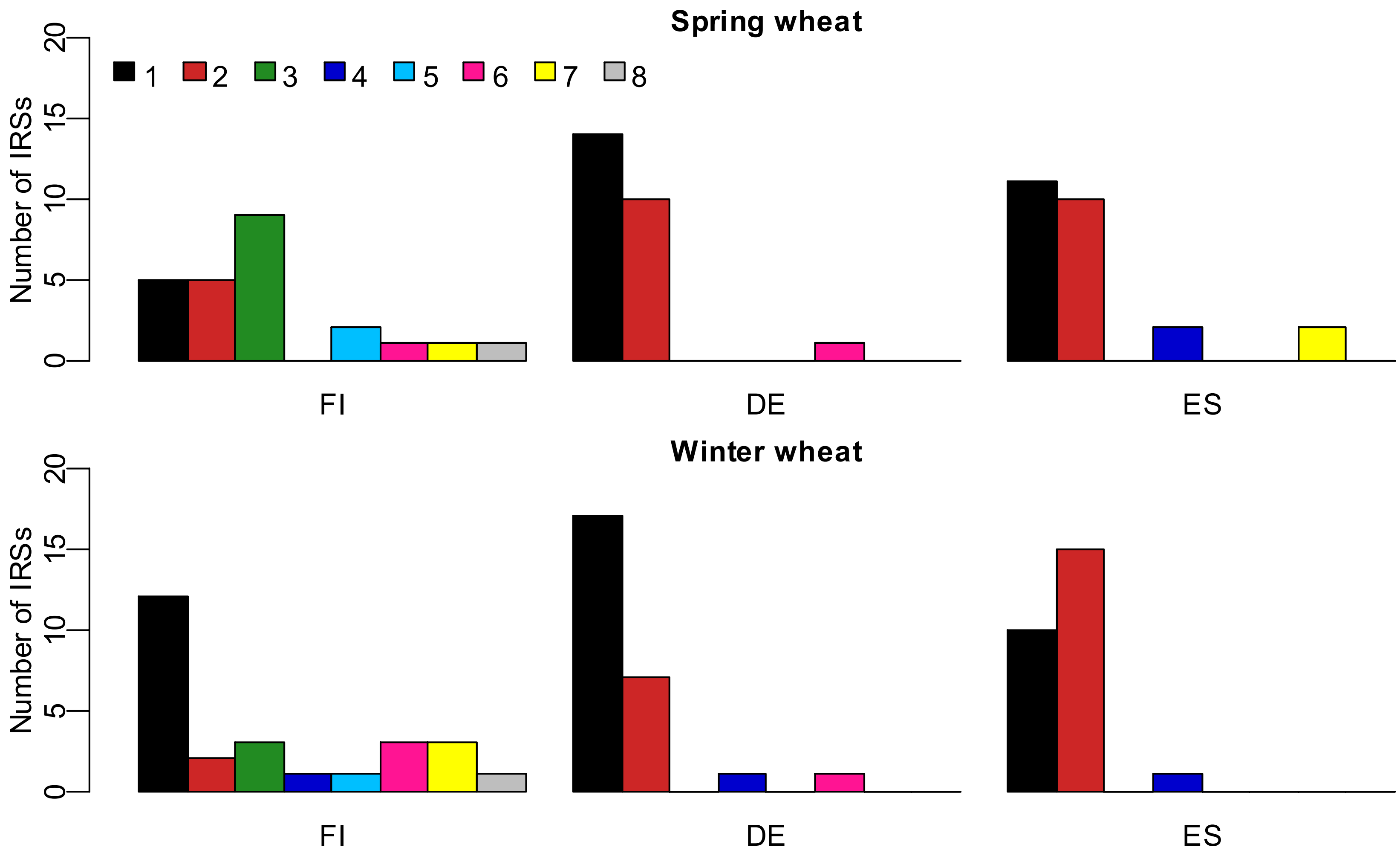
Number of IRSs per cluster for spring and winter wheat at the Finnish (FI), German (DE) and Spanish (ES) sites

Preliminary – do no cite



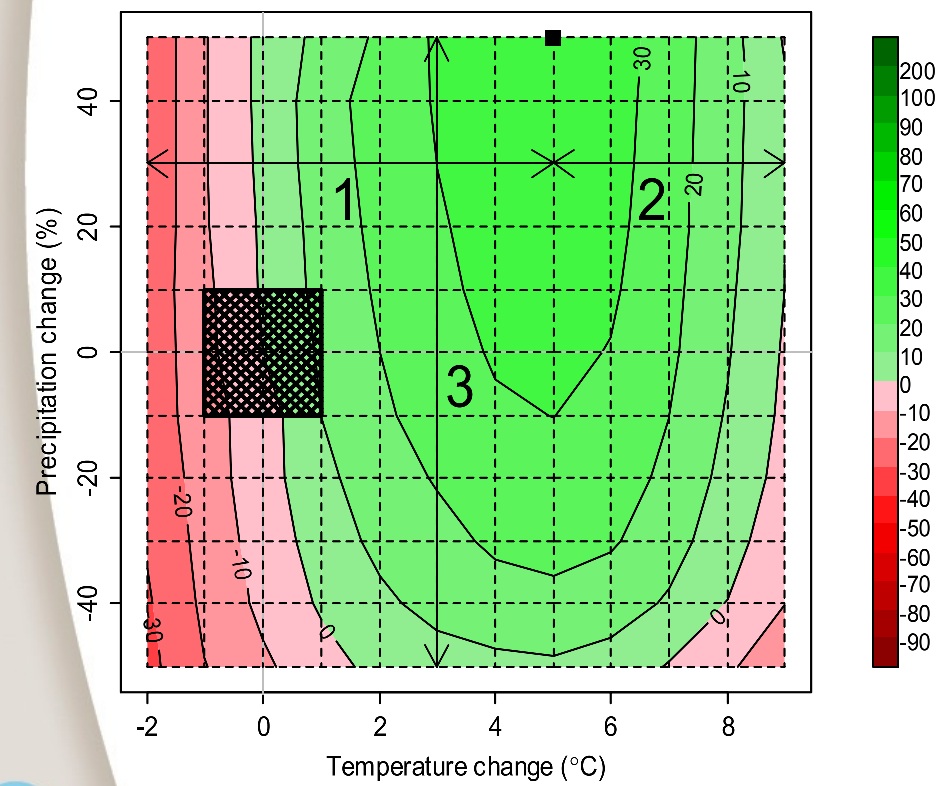
CLIMATE CHANGE PROGRAMME

Grouping of IRSs with expert judgement

$\underline{T}_{B+}P_D$

T-dominant response; optimal yield at baseline T; strong decline with rising T; baseline P-deficit

Preliminary – do no cite



Symbol	Variants
T	Temperature response dominates
P	Precipitation response dominates
B	Optimum yield close to baseline climate
C	Optimum yield cooler than baseline T
W	Optimum yield warmer than baseline T
D	Precipitation deficit limits baseline yield
+	Strong response with large increase relative to baseline
-	Strong response with large decrease relative to baseline
±	Strong response with large increase and large decrease relative to baseline

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Results – Clustering of IRSs

”Subjective” method applies expert judgement to describe the climatic conditions relative to the baseline and the relative influence of temperature and precipitation on yields away from the baseline

Yield response behaviour

1 T-dominates; Insensitive to P
2 T-dominates; P has less effect
3 T and P have comparable effect
4 P-dominates; T has less effect
5 P-dominates; Insensitive to T
6 Unclassified

Winter wheat

Preliminary – do no cite

Model	FI	ES	DE
AFRCWHEAT2	1	4	1
APSIM-Nwheat	3	4	2
APSIM	2	4	2
AquaCrop	2	4	4
ARMOSA	6	4	4
CARAIB	2	2	2
CERES-wheat DSSAT v.4.6/CZ	2	5	4
CERES-wheat DSSAT v.4.5/ES	2	2	2
CERES-wheat DSSAT v.4.5/IT	2	2	2
CropSyst	2	2	3
DNDC	2	2	2
EPIC	6	6	6
Fasset	1	4	1
HERMES	3	3	4
Lintul2	2	4	2
Lintul4	2	4	4
LPJ-GUESS	2	3	2
MCWLA	4	3	4
MONICA V1.2	2	4	3
SALUS	2	3	2
Sirius 2010	2	2	2
Sirius Quality	4	4	4
SPACSYS	2	1	1
STICS	2	4	1
WOFOST 7.1/FI	2	2	2
WOFOST 7.1/PL	2	2	2

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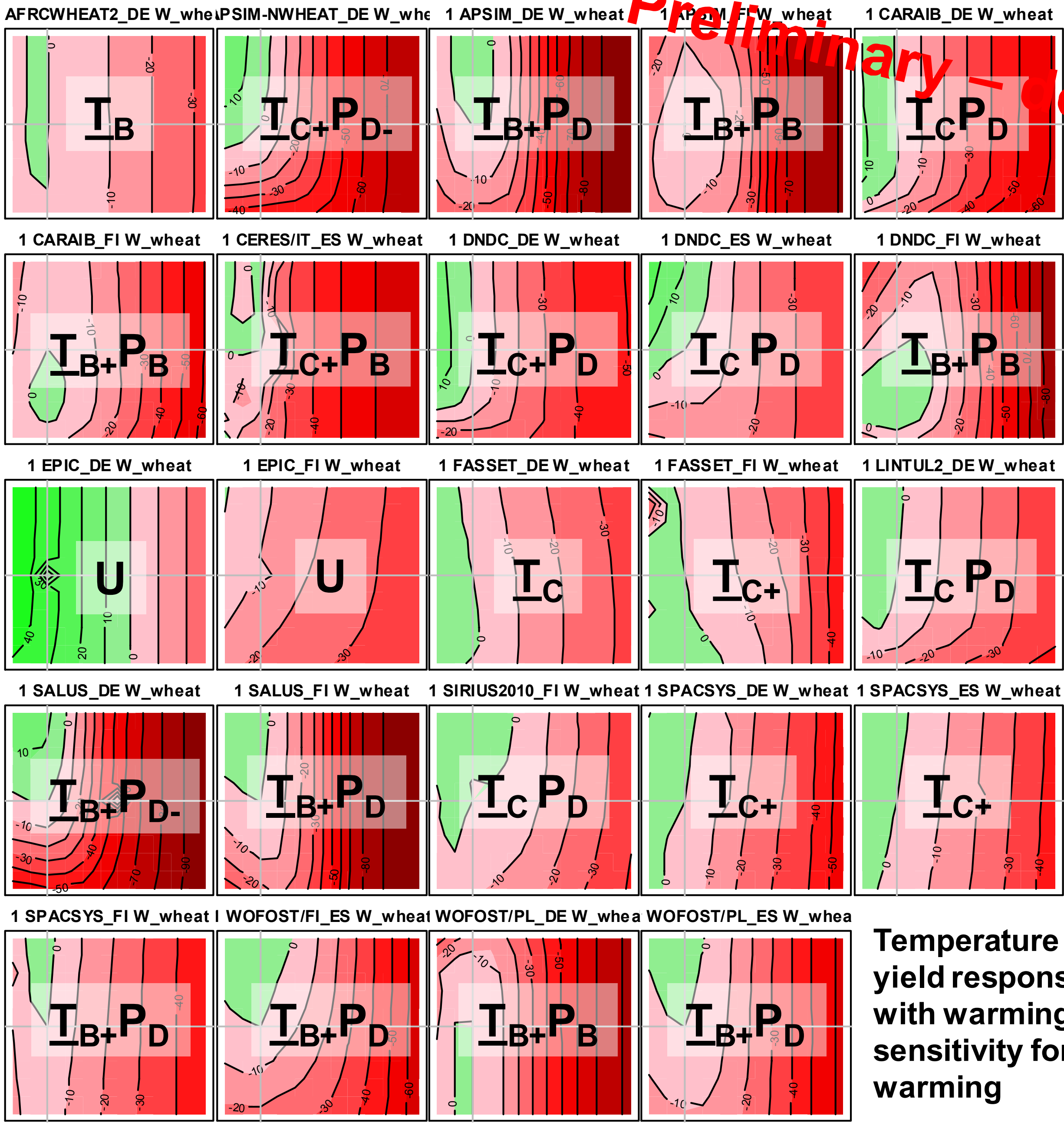
Results – Clustering of IRSs

"Subjective" method

	Basic class
1	T_B
	T_C
	T_W
2	$T_B P_B$
	$T_B P_D$
	$T_C P_B$
	$T_C P_D$
	$T_W P_D$
3	$T_B P_D$
	$T_C P_D$
4	$T_B P_D$
	$T_C P_D$
	$T_W P_D$
5	P_D
6	U

"Objective" method, Cluster 1

Preliminary – do no cite



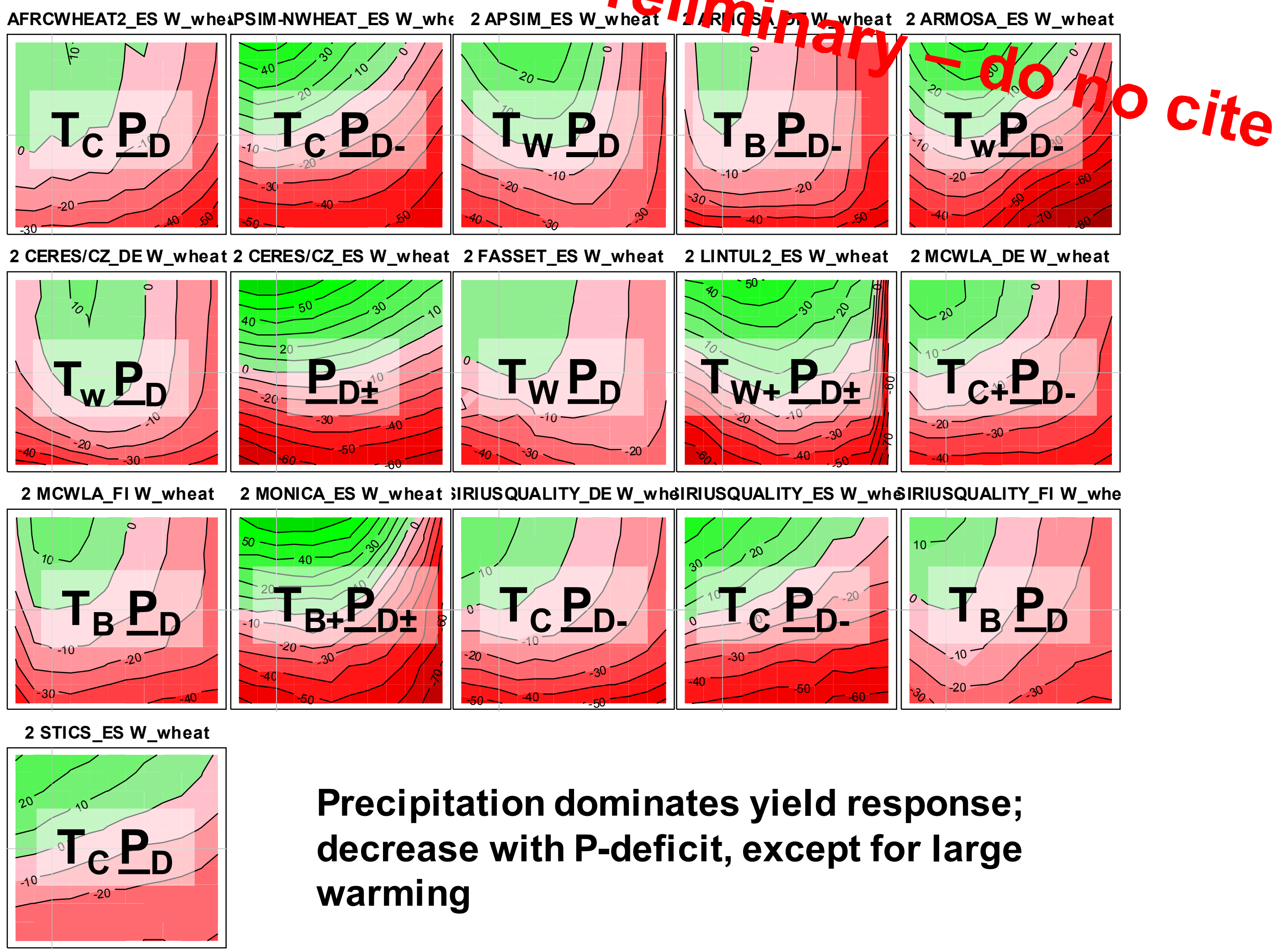
Temperature dominates yield response; decrease with warming; low P-sensitivity for strong warming

Results – Clustering of IRSs

”Subjective” method

	Basic class
1	$\underline{T}_B$
	$\underline{T}_C$
	$\underline{T}_W$
2	$\underline{T}_B P_B$
	$\underline{T}_B P_D$
	$\underline{T}_C P_B$
	$\underline{T}_C P_D$
	$\underline{T}_W P_D$
3	$\underline{T}_B \underline{P}_D$
	$\underline{T}_C \underline{P}_D$
4	$T_B \underline{P}_D$
	$T_C \underline{P}_D$
	$T_W \underline{P}_D$
5	$\underline{P}_D$
6	U

”Objective” method, Cluster 2



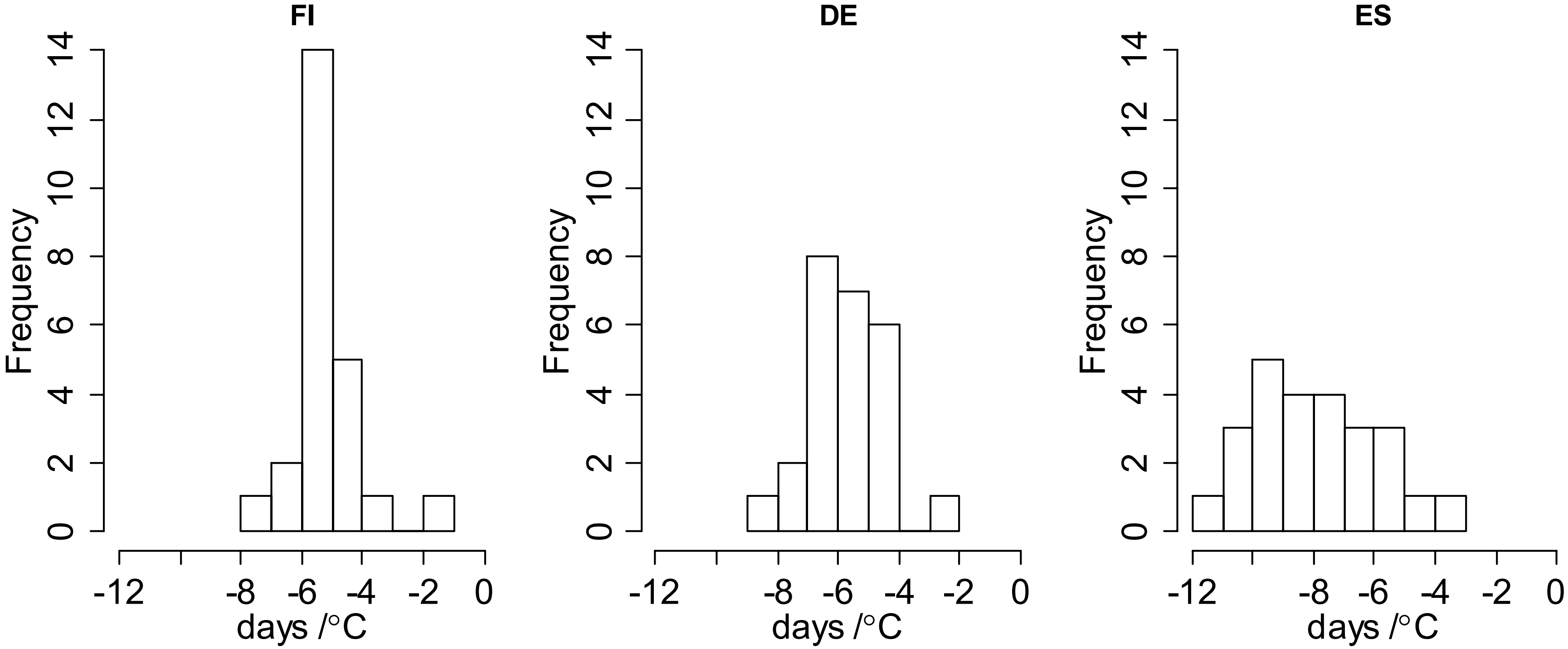
Precipitation dominates yield response; decrease with P-deficit, except for large warming

Ideas for attempting to explain model response

- Comparing clusters of yields responses to
  - Simulated harvest index and length of growing period
  - model characteristics

Ensemble distribution of simulated 30-year averaged responses in the rate of change of growing period length for spring wheat (sowing to maturity)

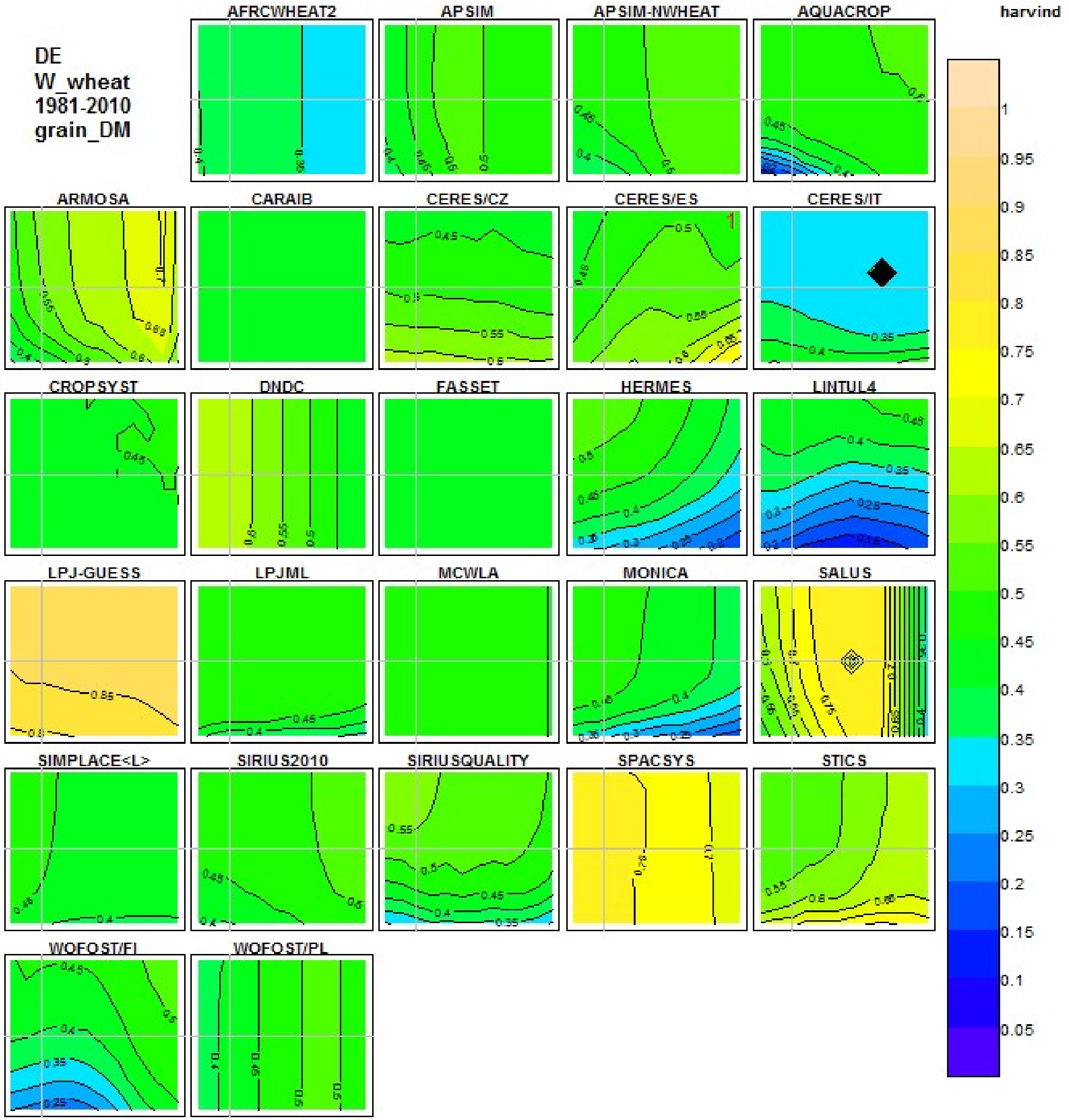
Preliminary – do no cite



Harvest index for winter wheat in Germany

Preliminary – do no cite

Ratio of grain to above-ground dry matter at harvest



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Harvest index for winter wheat in Germany

Preliminary – do no cite

Number of models in four range classes of the harvest index (HI; ratio of grain to above-ground dry matter at harvest) for spring and winter wheat in Finland, Germany and Spain for the baseline climate, for a large warming (T+9; temperature change = +9°C, precipitation at baseline) and large drying (P-50; temperature at baseline, precipitation change = -50%). Thresholds for the HI ranges are based on experimental data presented by Hay (1995) and Foulkes et al. (2011). The colours indicate if the number of models remains the same as for the baseline (grey), decreases (blue) or increases (red).

	Finland			Germany			Spain		
HI class (range)	**Baseline**	**T+9**	**P-50**	**Baseline**	**T+9**	**P-50**	**Baseline**	**T+9**	**P-50**
Spring wheat									
Low (<0.31)	2	3	2	1	2	3	2	3	7
Normal (0.31-0.50)	11	13	14	19	17	17	18	13	11
High (0.51 - 0.64)	9	5	7	3	4	3	3	7	6
Implausibly high (>0.64)	2	3	1	2	2	2	2	2	1
Winter wheat									
Low (<0.43)	10	13	12	6	9	15	16	17	15
Normal (0.43-0.53)	12	9	10	15	13	4	8	6	9
High (0.54-0.64)	2	1	2	2	2	4	0	0	1
Implausibly high (>0.64)	2	3	2	3	2	3	2	3	1

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Comparison of clusters to model characteristics

Source: Pirttioja et al. 2015

Table S1. Characteristics of the models applied in the study (based on Asseng et al. 2013; modified). Key references of the models are listed below the table.

ID	Model	Leaf area / light interception (a)	Light utilization (b)	Yield formation (c)	Phenology (d)	Root distribution over depth (e)	Type of water stress (f)	Type of heat stress (g)	Water dynamics (h)	Evapo-transpiration (i)	Process modified by elevated CO2 (j)	Climate input variables (k)	Model relative (l)	Model type (m)
1	AFRCWHEAT2	D	P-R	Prt/Gn/B	T/DL/V	EXP	E/S	P/R	C	PM	RUE	R/Tx/Tn/Ta/Td/Rd/e/W	I	P
2	APSIM-Nwheat	S	RUE	Prt	T/DL/V	EXP	S	V	C	PT	RUE/TE	R/Tx/Tn/Rd	C	P
3	APSIM-Wheat	S	RUE	Prt/Gn/B	T/DL/V/O	O	E	V	C/R	PT	RUE/TE/CLN	R/Tx/Tn/Rd	C	P
4	AquaCrop	S	TE	HI_mw/B	T	O	E/S	R	C	PM	TE	R/Tx/Tn,Ta,Rd,RH,W	none	P
5	ARMOSA	D	P-R	Prt/B	T/DL/V	O	E/S	V/P	C	PT	RUE/TE	R/Tx/Tn/Rd	S	P/G
6	CARAIB	D	P-R	HI/B	T	O	S	-	C/R	P	F	Cl/R/Tx/Tn/RH/W	none	G
7&8	CERES-wheat DSSAT	S	RUE	B/Gn	T/DL/V	EXP	E/S	-	C	PT	RUE/TE	R/Tx/Tn/Rd/RH/W	C	P
9	CERES-wheat DSSAT	S	RUE	B/Gn/Prt/HImw	T/DL/V	EXP	E/S	-	C	PT	RUE/TE	R/Tx/Tn/Rd	C	P
10	CropSyst	S	TE/RUE	HI/B	T/DL/V	EXP	E	R	C/R	PM	TE/RUE	R/Tx/Tn/Rd/RH/W	none	P
11	DNDC	S	RUE	HI/B	T/DL	EXP	E/S	P	C	P	RUE	R/Tx/Tn/Rd/RH/W	none	P/G
12	FASSET	D	RUE	HI/B	T/DL	EXP	E/S	-	C	MAK	RUE	R/Tx/Tn/Rd	none	P
13	HERMES	D	P-R	Prt	T/DL/V/O	EXP	E/S	-	C	PM	TE/F	R/Tx/Tn/Ta/Rd/RH/W	S/C	P
14	LINTUL-4	D	RUE	Prt/B	T/DL	LIN	E	-	C	P	RUE/TE	R/Tx/Tn/Rd/e/W	L	P
15	LPJ-GUESS	S	P-R	HI_mw/B	T/DL/V	LIN	E/S	P	C	PT	F	R/Ta/Rd	E	G
16	LPJmL	S	P-R	HI_mw/B	T/DL/V	EXP	E	-	C	PT	F	R/Ta/Rd	E	G
17	MCWLA-Wheat	S	P-R	HI/B	T/DL/V	EXP	E	V/ R	R	PM	F	R/Tx/Tn/Rd/e/W	none	G
18	MONICA	S	P-R	Prt	T/DL/V/O	EXP	E	V	C	PM	F	R/Tx/Tn/Rd/RH/W	H	P
19	SALUS	S	RUE	Prt/HI	T/DL/V	EXP	E	V	C	PT	RUE	R/Tx/Tn/Rd	C	P
20	SIMPLACE <Lintul2, Slim>	S	RUE	Prt/B	T/DL/V	LIN	E	P	C	P	not considered	R/Tx/Tn/Rd/W	L	P
21	Sirius	D	RUE	B/Prt	T/DL/V	LIN	E	-	C	PT	RUE	R/Tx/Tn/Rd/e/W	none	P
22	SiriusQuality	D	RUE	B/Prt	T/DL/V	EXP	S	-	C	P	RUE	R/Tx/Tn/Rd/e/W	I	P
23	SPACSYS	S	P-R	Prt	T/DL/V	EXP/Call	E	-	R	PM	RUE/TE	R/Tx/Tn/Rd/RH/W	none	P
24	STICS	S	RUE	HI/Gn	T/DL/V/O	O	E/S	R/V/P	C	SW	RUE/Tr	R/Tx/Tn/Rd/e/W	none	P
25&26	WOFOST	D	P-R	Prt/B	T/DL	LIN	E/S	-	C	P	RUE/TE	R/Tx/Tn/Rd/e/W	S	G

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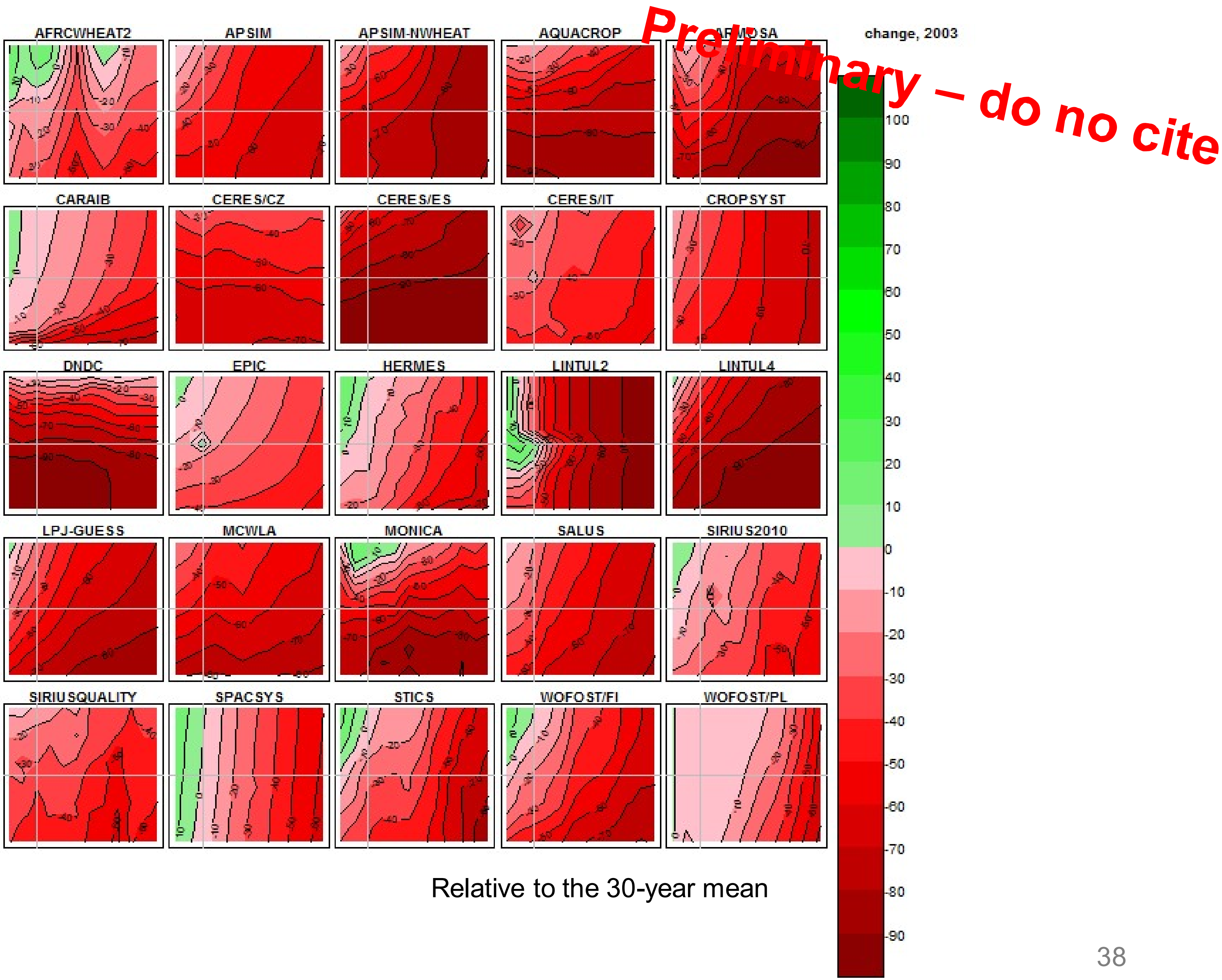
Results – analysis of extreme years

Example of a particularly dry year at Nossen (DE) (spring wheat), year 2003



Relative to the 30-year mean

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CONCLUSIONS

CLIMATE CHANGE PROGRAMME

Conclusions 1/2

From Climate Research paper (1st part of this presentation):

- 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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CLIMATE CHANGE PROGRAMME

Conclusions 2/2

- We have shown that clustering methods can be used to analyse patterns of IRSs for
- Next step is to start diagnosing the reasons for the different behaviours, the approach for this was outlined using information about the harvest index and phenology of simulations
- Clustering will also be tested for extreme years

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