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A discussion on the paper "Uncertainty in simulating wheat yields under climate change"

Nature Climate Change
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Outline

- Introduction
- Materials and Methods
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- Discussion

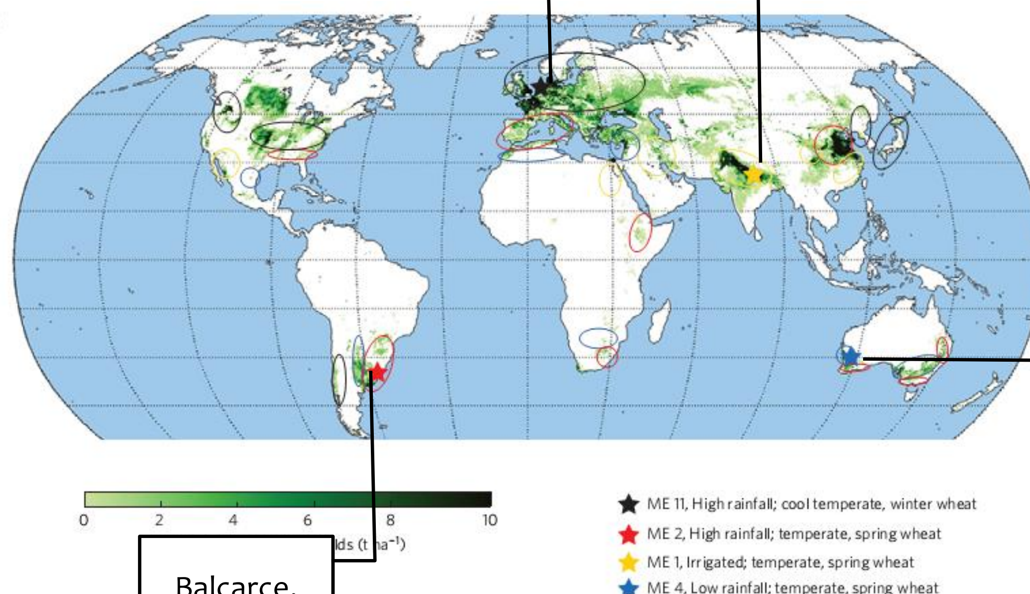
Introduction

- Multi-model uncertainty analysis of crop responses to climate change is rare because systematic and objective comparisons among process-based crop simulation models are difficult.
- Simulated climate change impacts vary across models owing to differences in model structures and parameter values.
- Uncertainties in simulated impacts increased with CO_2 concentrations and associated warming.

Materials and Methods

	Experiment			
	A[a]	B[b]	C[c]	D[d]
Location	Wageningen	Balcarce	New Delhi	Wongan Hills
Country	The Netherlands	Argentina	India	Australia
Latitude	51.97	-37.5	28.38	-30.89
Longitude	5.63	-58.3	77.12	116.72
Environment	high-yielding long-season	high/medium-yielding medium-season	irrigated short-season	low-yielding rain-fed short-season
Average growing season	November-July	June-December	November-April	May-December
Soils				
Soil type	Silty clay loam	Clay loam	Sandy loam	Loamy sand
Maximum Root depth (cm)	200	130	160	210
PAWC[†] (mm to maximum rooting depth)	354	205	121	125
Crop management				
Cultivar	Arminda	Oasis	HD 2009	Gamenya
Sowing date (DOY[‡])	294	223	328	164
Total applied N fertilizer (kg N/ha)	160	120	120	50
Total irrigation (mm)	0	0	383	0
Phenology				
Anthesis (DOY)	178	328	49	275
Maturity (DOY)	213	363	93	321
Experimental year	1982/83	1992	1984/85	1984
Mean growing season temperature	8.8 °C	13.7 °C	17.3 °C	14.0 °C
Mean growing season precipitation	595 mm	336 mm	383 mm[*]	164 mm
Baseline				
Mean growing season temperature	8.5 °C	12.0 °C	18.9 °C	16.2 °C
Mean growing season precipitation	716 mm	395 mm	467 mm*	246 mm
Climate change scenario[**]				
GCM scenario examined	ukmo_hadcm3	ncar_ccsm3.0	mpi_echam5	csiro_mk3.0
Mean growing season temperature	11.4 °C	14.2 °C	23.6 °C	18.7 °C
Mean growing season precipitation	690 mm	432 mm	583 mm*	164 mm

a



Materials and Methods

Model	Leaf area / light interception [a]	Light utilization [b]	Yield formation [c]	Phenology [d]	Root distribution over depth [e]	Environmental constraints involved [f]	Type of water stress [g]	Type of heat stress [h]	Water dynamics [i]	Evapotranspiration [j]	Soil CN-model [k]	Process modified by elevated CO_2 [l]	No. cultivar parameters	Climate input variables [m]	Model relative [n]	Model type [o]
APSIM-Nwheat	S	RUE	Prt	T/DL/V	EXP	W/N/A	S	V	C	PT	CN/P(3)/B	RUE/TE	7	R/Tx/Tn/Rd	C	P
APSIM-wheat	S	RUE	Prt/Gn/B	T/DL/V/O	O	W/N/A	E	-	C/R	**PT**/PM	CN/P(3)/B	RUE/TE/CLN	7	R/Tx/Tn/Rd/e/W	C	P
AquaCrop	S	TE	HI/B	T/DL/V/O	EXP	W/N/H	E/S	V/R	C	PM	none	TE	2	R/Tx/ETo	none	P
CropSyst	S	TE/RUE	HI/B	T/DL/V	EXP	W/N/H	E	R	C/R	PM	N/P(4)	TE/RUE	16	R/Tx/Tn/Rd/RH/W	none	P
DSSAT-CERES	S	RUE	B/Gn	T/DL/V	EXP	W/N	E/S	-	C	PT	CN/P(4)/B	RUE/TE	7	R/Tx/Tn/Rd/RH/W	C	P
DSSAT-CROPSIM	S	RUE	Prt	T/DL/V	LIN	W/N	E/S	V	C	PT	CN/P(4)/B	RUE/TE	21	R/Tx/Tn/Rd/	none	p
Ecosys	D	P-R	Gn-Prt	T/DL/V/O	Call	W/N/A/H	E/S	V/R	R	EB	P30/B5	F	2	R/Tx/Tn/Td/Rd/W	none	P
EPIC wheat	S	RUE	HI	T/V	EXP	W/N/H	E	V	C	P/**PM**/P T/HAR	N/P(5)/B	RUE/TE/GY	16	R/Tx/Tn/Rd/RH/W	E	P/G
Expert-N – CERES	S	RUE	B/Gn	T/DL/V	EXP	W/N	E/S	-	R	PM	CN/P(3)/B	RUE	7	R/Tx/Tn/Rd/RH/W	C	P
Expert-N – GECROS	D	P-R/TE	Gn/Prt	T/DL/V	EXP	W/N	E/S	-	R	PM	CN/P(3)/B	RUE/TE	10	R/Tx/Tn/Rd/RH/W	S	P
Expert-N – SPASS	D	P-R	Gn/Prt	T/DL/V	EXP	W/N	E/S	-	R	PM	CN/P(3)/B	RUE	5	R/Tx/Tn/Rd/RH/W	C/S	P
Expert-N – SUCROS	D	P-R	Prt	T	EXP	W/N	E/S	-	R	PM	CN/P(3)/B	RUE	2	R/Tx/Tn/Rd/RH/W	S	P
FASSET	D	RUE	HI/B	T/DL	EXP	W/N	E/S	-	C	MAK	CN/P(6)/B	RUE	14	R/Tx/Tn/Rd	none	P
GLAM-Wheat	S	RUE/TE	B/HI	T/DL/V	LIN	W/H	E	R	C	PT	none	RUE/TE	22	R/Tx/Tn/Td/Ta/e	none	G
HERMES	D	P-R	Prt	T/DL/V/O	EXP	W/N/A	E/S	-	C	**PM**/TW/ PT	N/P(2)	RUE/F	6	R/Tx/Tn/Rd/e/RH/W	S/C	P
InfoCrop	D	RUE	Prt/Gn	T/DL	EXP	W/N/H	E	V/R	C	**PM**/PT	CN/P(2)/B	RUE/TE	10	R/Tx/Tn/Rd/W/e	S	P
LINTUL-4	D	RUE	Prt/B	T/DL	LIN	W/N/A	E	-	C	P	N/P(0)*	RUE/TE	4	R/Tx/Tn/Rd/e/W	L	P
LINTUL-FAST	D	RUE	Prt	T/DL/V	EXP	W	E	-	C	PM	CN/P(3)	RUE/TE	4	R/Tx/Tn/Rd/RH	L	P
LPJmL	S	P-R	HI_mws/B	T/V	EXP	W	E	-	C	PT	none	F	3	R/Ta/Rd/Cl	E	G
MCWLA-Wheat	S	P-R	HI/B	T/DL/V	EXP	W/H	E	V/ R	R	PM	none	F	7	R/Tx/Tn/Rd/e/W	none	G
MONICA	S	RUE	Prt	T/DL/V/O	EXP	W/N/A/H	E	V	C	PM	CN/P(6)/B	F	15	R/Tx/Tn/Rd/RH/W	H	P
O'Leary-model	S	TE	Gn/Prt	T/DL	SIG	W/N/H	E/S	V	C	P	N/P(3)/B	TE	18	R/Tx/Tn/Rd/RH/W	none	P
SALUS	S	RUE	Prt/HI	T/DL/V	EXP	W/N/H	E	V	C	PT	CN/P(3)/B(2)	RUE	18	R/Tx/Tn/Rd	C	P
Sirius	D	RUE	B/Prt	T/DL/V	EXP	W/N	E	-	C	P/**PT**	N/P(2)	RUE	14	R/Tx/Tn/Rd/e/W	none	P
SiriusQuality	D	RUE	B/Prt	T/DL/V	EXP	W/N	S	-	C	**P**/PT	N/P(2)	RUE	14	R/Tx/Tn/Rd/e/W	I	P
STICS	D	RUE	Gn/B	T/DL/V/O	SIG	W/N/H	E/S	V/R	C	P/PT/ **SW**	N/P(3)/B	RUE/TE	15	R/Tx/Tn/Rd/e/W	C	P
WOFOST	D	P-R	Prt/B	T/DL	LIN	W/N*	E/S	-	C	P	P(1)	RUE/TE	3	R/Tx/Tn/Rd/e/W	S	G

Materials and Methods

- In addition to simulations of the single-year experiments, simulations were carried out with long-term measured daily climate data (solar radiation, maximum and minimum temperature, precipitation, surface wind, dew point temperature, relative humidity, and vapor pressure) using measured soil characteristics, measured initial soil water and soil N contents, crop management, measured anthesis and maturity dates from the single-year-experiments.
- Each of the 27 wheat models was used to simulate the field experiments in two separate steps, 1) with limited in-season information from the experiments being made available to the modelers (partial calibration or 'blind' simulations), and 2) all available information being made available to the modelers (full calibration).

Materials and Methods

- Data analysis

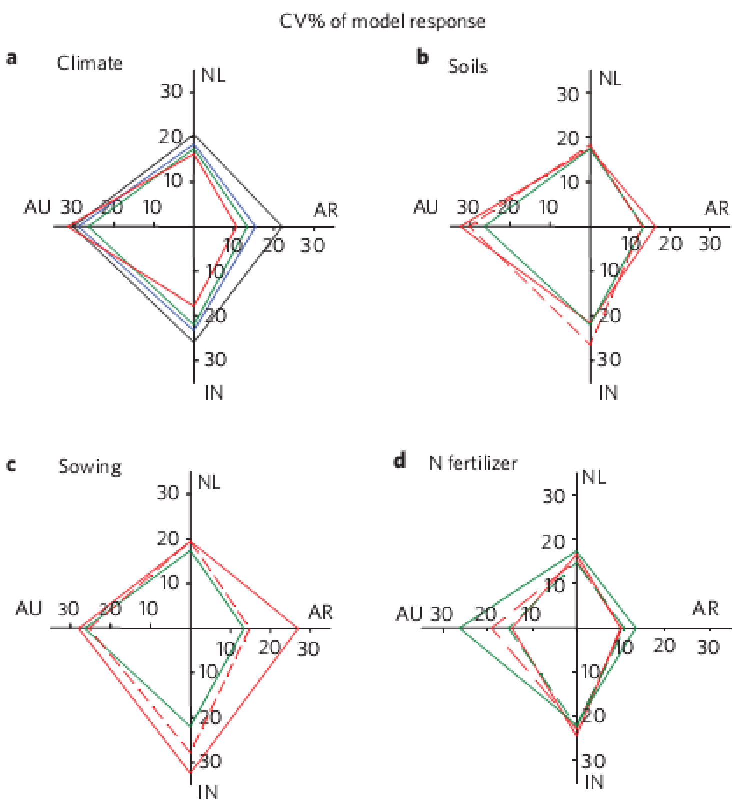
$$\text{RMSE} = \sqrt{\frac{1}{n}\Sigma_{i=1}(y_i - \hat{y}_i)^2}$$

$$x_k = \bar{y}_{future,k} - \bar{y}_{baseline,k}$$

$$CV\% = \frac{\sigma}{\bar{x}} * 100$$

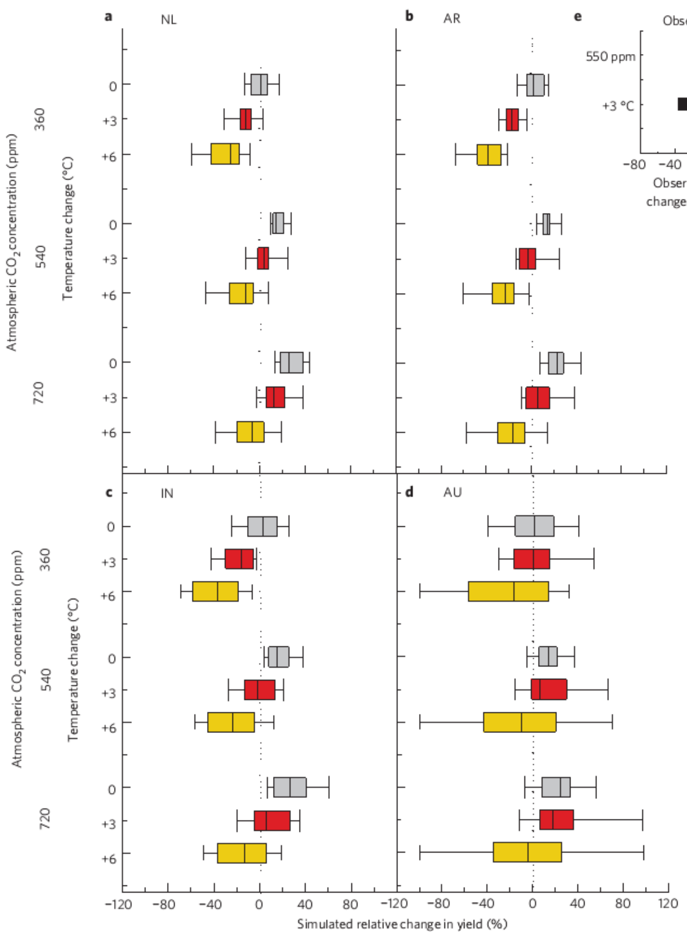
$$r_k = \frac{\bar{y}_{future,k} - \bar{y}_{baseline,k}}{\bar{y}_{baseline,k}} * 100$$

Results



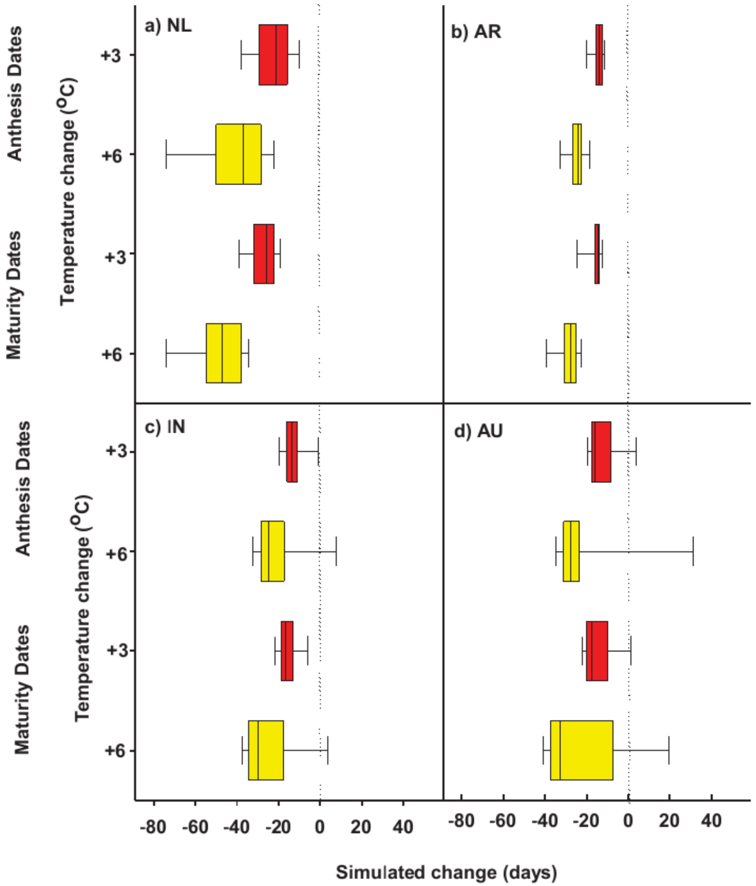
- Uncertainty in simulated climate change impacts differed across the environments.
- In addition, uncertainty in simulated impacts varied with soil and crop management.
- Selecting a subset of models that perform best in present environments does not reduce uncertainty in simulated climate change impacts.

Results



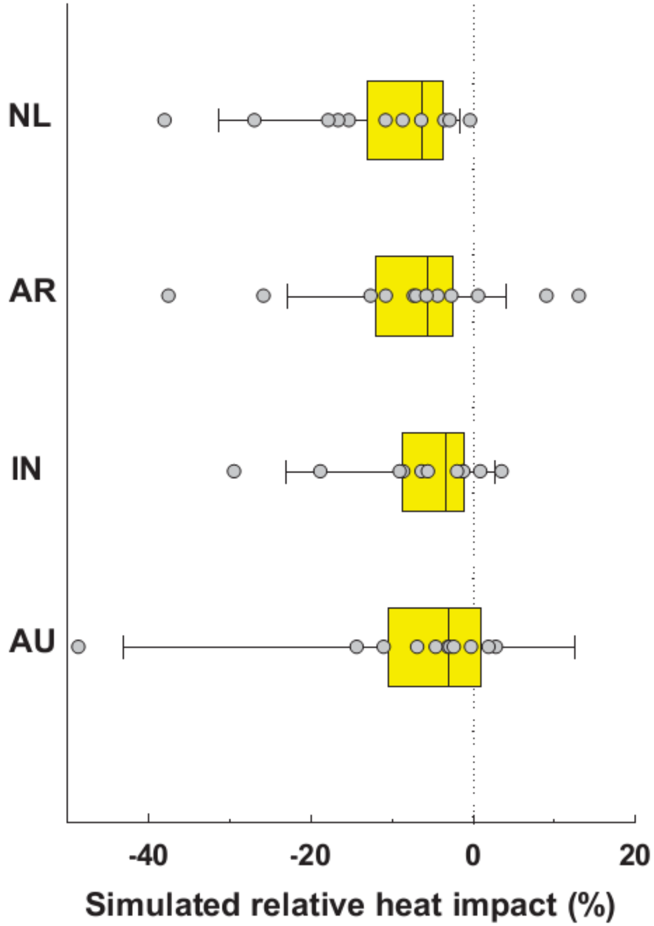
- Simulated impacts of elevated CO_2 on yields varied relatively little across models, but the variation across 80% of the crop models increased under elevated CO_2 concentration mostly in the low-yielding environment of Australia.
- Most simulated yield responses to a 180ppm CO_2 increase at present temperatures were within the range of measured responses, ranging from 8% to 26% with elevated atmospheric CO_2 concentrations across experiments conducted in the USA, Germany and China.

Results



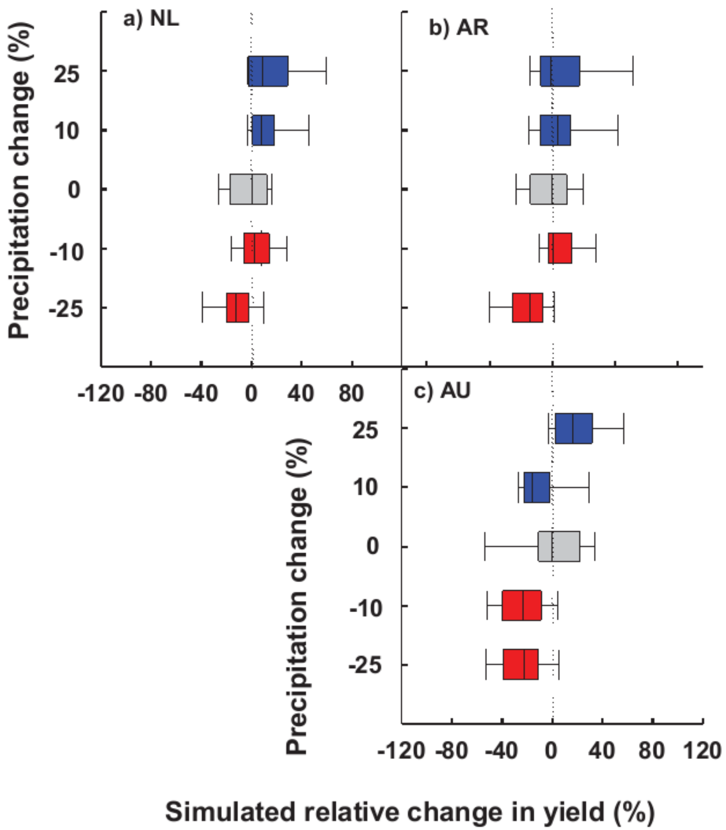
- An increased model uncertainty with increasing temperature is partly related to simulated phenology.
- For example, phenology is often enhanced with increasing temperature resulting in less time for light interception and photosynthesis and consequently less biomass and yield.

Results



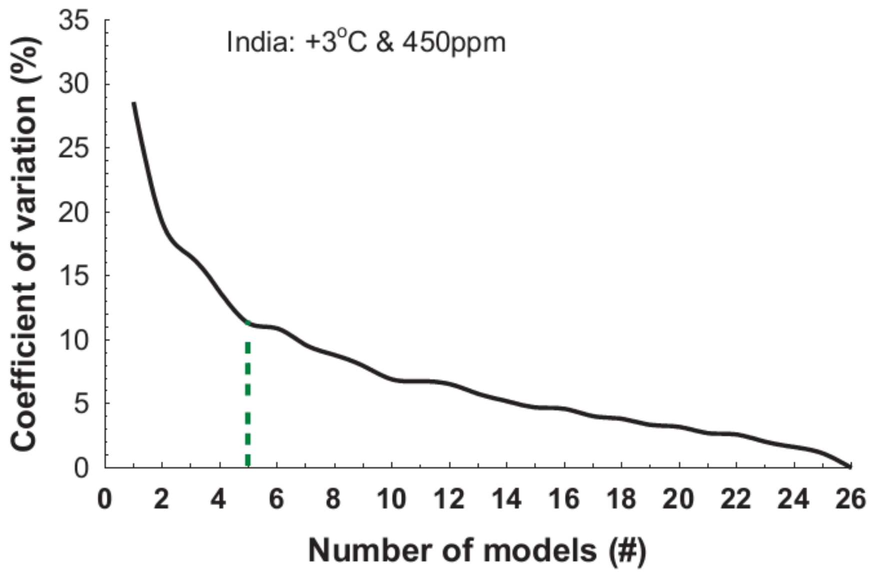
- The increased model uncertainty is also partly due to an increased frequency of high-temperature events and its simulated impact on crop growth.

Results



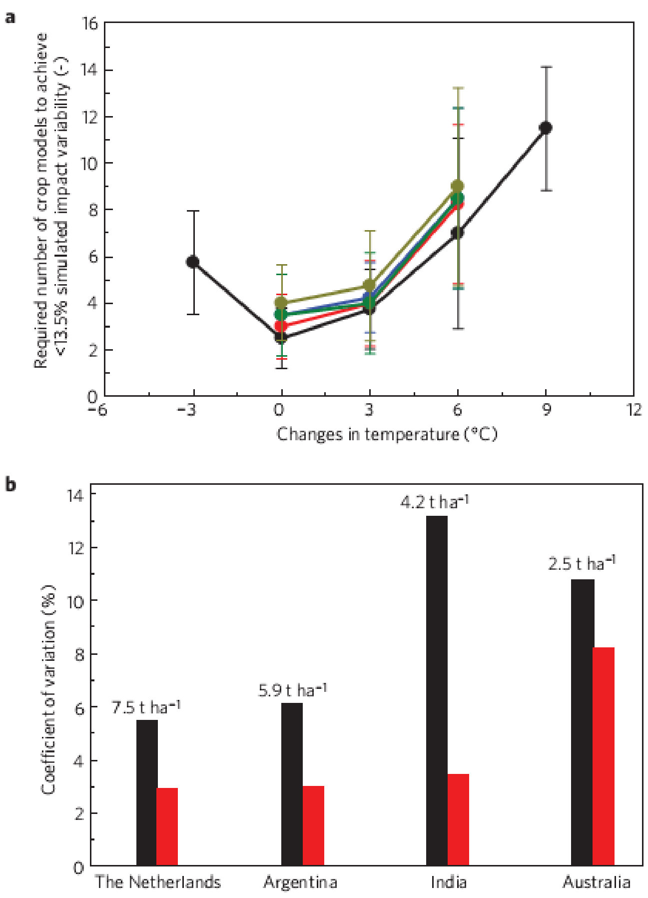
- Precipitation affected simulated yields, but precipitation change had little impact on the range of simulated responses.

Results



* If averaging multi-model simulations is superior to a single crop or climate model simulation because the ratio of signal (mean change) to noise (variation) increases with the number of models and errors tend to cancel each other out, we should be able, with caution, to estimate how many models would be required for robust projections.

Results



- The number of models required for robust assessments of climate change varied depending on the magnitude of temperature change and interactions with the change in atmospheric CO_2 .
- When simulating impacts assuming amid-century A2 emissions scenario (556ppm of CO_2) for climate projections from 16 downscaled GCMs using 26 wheat models, a greater proportion of the uncertainty in yields was due to variations among crop models than to variations among the downscaled GCMs.

Discussion

- We conclude that projections from individual crop models fail to represent the significant uncertainties known to exist in crop responses to climate change.
- On the other hand, model ensembles have the potential to quantify the significant, and hitherto uncharacterized, crop component of uncertainty.
- Crop models need to be improved to more accurately reflect how heat stress and high-temperature-by-CO_2 interactions affect plant growth and yield formation.

Thank you for your attention