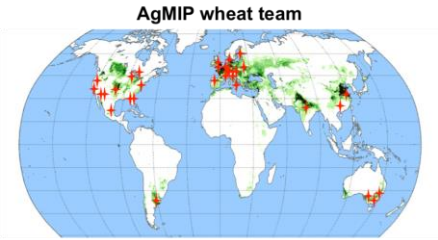


AgMIP The Agricultural Model Intercomparison and Improvement Project

Reducing uncertainty in prediction of wheat performance under climate change

Pierre Martre, Senthold Asseng, Frank Ewert

P.R. Rötter, D.B. Lobell, D. Cammarano, A. Maiorano, B.A. Kimball, M.J. Ottman, G.W. Wall, J.W. White, M.P. Reynolds, P.D. Alderman, P.V.V. Prasad, P.K. Aggarwal, J. Anothai, B. Basso, C. Biernath, A.J. Challinor, G. De Sanctis, J. Doltra, E. Fereres, M. Garcia-Vila, S. Gayler, G. Hoogenboom, L.A. Hunt, R.C. Izaurralde, M. Jabloun, C. Jones, C. Kersebaum, A.-K. Koehler, C. Müller, N.K. Soora, C. Nendel, G.J. O'Leary, J.E. Olesen, T. Palosuo, E. Priesack, E. Eyshi Rezaei, A.C. Ruane, M.A. Semenov, I. Shcherbak, C. Stöckle, P. Stratonovitch, T. Streck, I. Supit, F. Tao, P. Thorburn, K. Waha, E. Wang, D. Wallach, J. Wolf, Z. Zhao, Y. Zhu

_01

Evolution des modèles de culture

Les grandes étapes des modèles de culture

1965 - 1980

- Développement de concepts et formalismes
- Modèles de croissance potentiel (heuristiques)

1981 - 1990

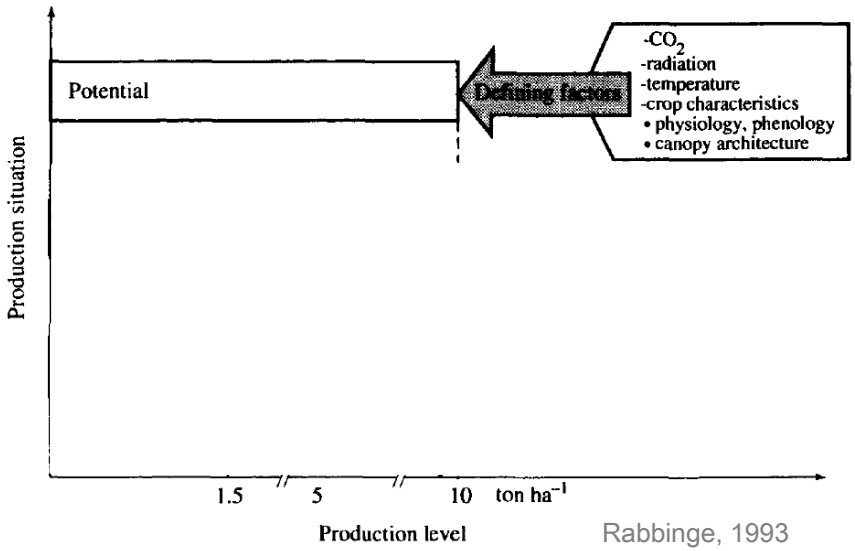
- Modèles de croissance atteignable
- Vers l'applicatif: simplification, diffusion

1991 - 2000

- Modèles de croissance réelle
- Développement d'outils de simulation (plateformes)
- Diffusion dans la communauté
- Développement de modèles de rotation et à sorties environnementales
- Emergence des (F)SPM

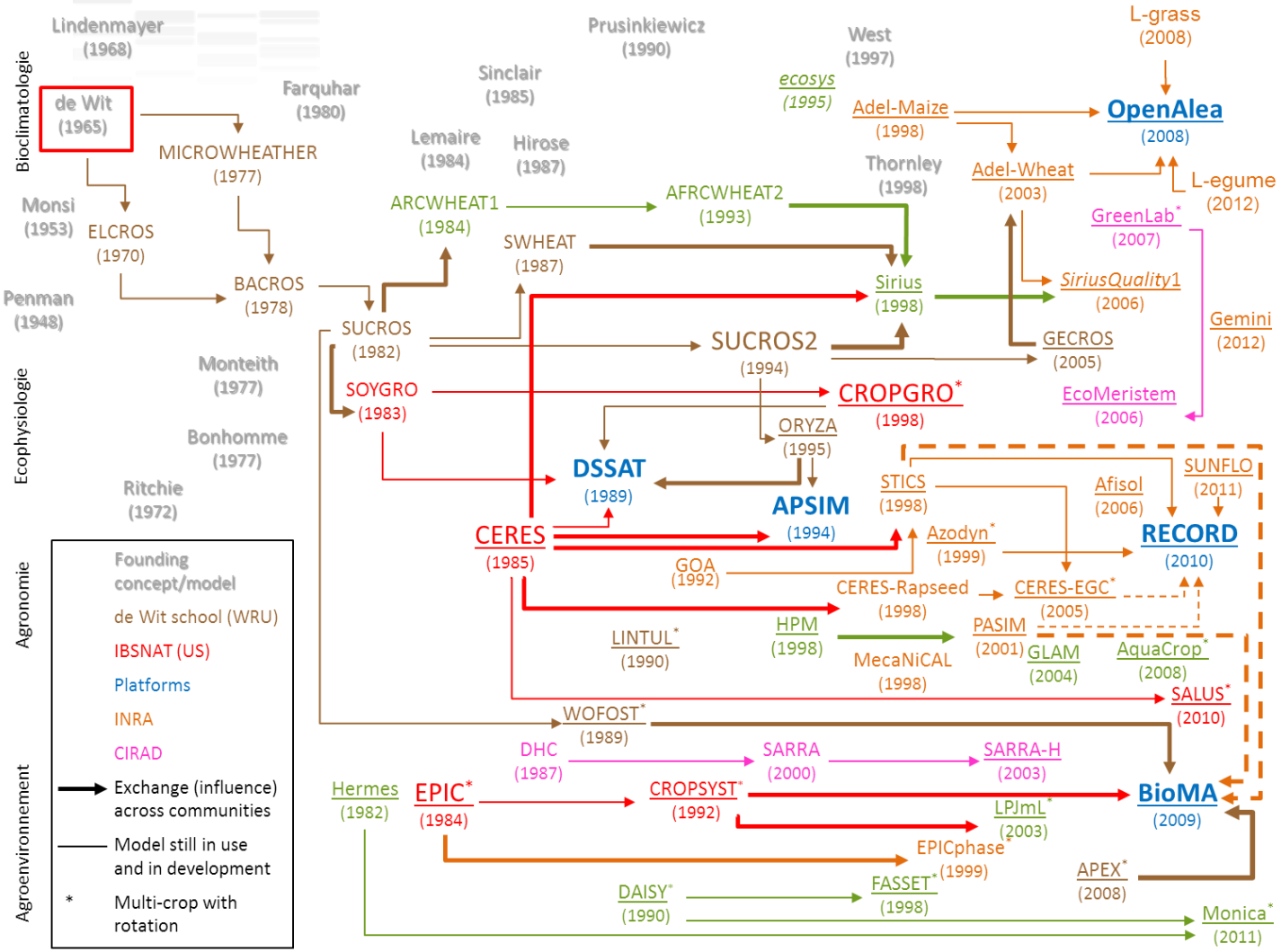
2001 – 2010

- Utilisation hors de la communauté, couplage avec modèles économiques, climatiques, etc.
- Développement de plateformes de simulation de systèmes de culture (DSSAT ⇨ DSSAT–CSM)
- Modélisation de la variabilité génétique, phénotypage
- Modularisation (FP6 Seamless)



Rabbinge, 1993

Une grande diversité de modèles



Une pratique mature, mais qui doit être renouvelée

- Les modèles de culture sont une représentation simplifiée du système sol-plante-atmosphère avec un cadre conceptuel robuste (mis à l'épreuve depuis +30 ans)
- Multiplication des modèles (env. 40 pour le blé) a une valeur heuristique (pour un groupe qui développe son propre modèle)
- Manque de transparence lié à l'utilisation et à la diffusion de modèles « boites noires »
- Peu amène aux changements (pression des utilisateurs, « plat de spaghettis »)
- Très peu d'échanges entre les modèles/plateformes (PF = ensemble de modèles monolithiques)
- Beaucoup sont des outils pour les études d'impacts ou de scénarios, plus que des outils analytiques du fonctionnement des peuplements cultivés
- Faible diffusion des connaissances acquises en écophysiologie

Des évolutions majeures ces dernières années

- De nouveaux questionnements
  - **Modélisation de la variabilité génétique et aide à la sélection**
  - **Phénotypage** (inversion de modèles)
  - Intégration de données
  - **Changement climatique – Impact, Mitigation, Adaptation** (événements climatiques extrêmes, interactions entre facteurs climatiques)

Des évolutions majeures ces dernières années

- Coordination internationale (MACSUR, AgMIP, ISI-MIP, CCAFS, IFPRI,…)
  - **Intercomparaison des modèles** selon des protocoles standardisés
  - Nouvelle stratégie de modélisation basée sur des **ensembles de modèles**
  - Questionnement des formalismes
  - **Coordination de l'amélioration des modèles** (Projet AgMaize coordonné par Monsanto)

AgMIP: The Agricultural Model Intercomparison and Improvement Project

AgMIP The Agricultural Model Intercomparison and Improvement Project

Led by Cynthia Rosenzweig, James W. Jones, Jerry Hatfield & John Antle

<u>Goals</u>

- To improve the characterization of world food security due to climate change,
- To enhance adaptation capacity in both developing and developed countries.

www.agmip.org

02

Crop model intercomparison: the AgMIP crop pilot studies

Objectifs des projets pilotes par espèce

- Constituer une communauté scientifique internationale pour confronter les approches.
- Comparer les résultats.
  - Avec un objectif commun: réponse à l'eau, CO_2, température, et azote.
  - Dans le cadre de protocoles de simulation identiques avec le plus grand nombre de modèles possibles.
- Explorer les incertitudes : d'où viennent les différences ?
  - Ordre de grandeur.
  - Dépendance des lieux, des cultures.
  - Rôle des types de modèles.
  - Entrées ? Equations ? Paramètres ? Données ?
- Constituer des outils faits d'ensembles de modèles.
  - Combien ?
  - Comment les utiliser ? (moyennes ? Méta-modèles ?)
- Améliorer les modèles.
  - Nouvelles équations (ex: réponses à la T).
  - Informatique pour les relier entre eux (format des entrées sorties).
  - Mieux identifier les paramètres et conditions initiales.

The AgMIP cereal multimodel ensembles

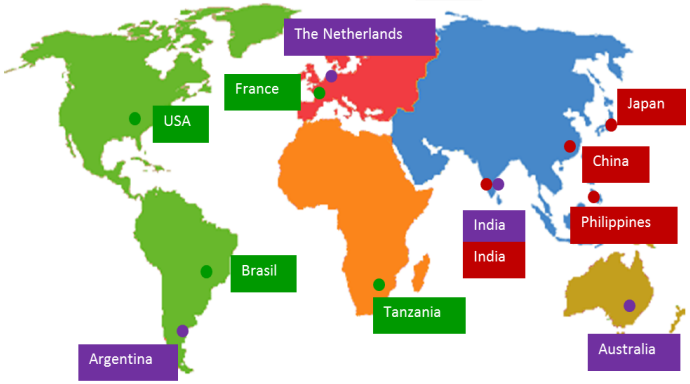
	Wheat (n = 27)	Maize (n = 26)	Rice (n = 15)
Common models	APSIM	APSIM-Maize	APSIM-Oryza
	APSIM-Nwheat		
	AquaCrop	AquaCrop	
	CropSyst	CropSyst	
	DSSAT-CERES	DSSAT-CERES	DSSAT-CERES
	EPIC wheat	EPIC Maize	EPIC
	Expert-N-CERES	Expert-N-CERES-Wheat	
	Expert-N–GECROS	Expert-N–GECROS	GECROS
	Expert-N–SPASS	Expert-N–SPASS	
	Expert-N- SUCROS	Expert-N- SUCROS	
	HERMES	HERMES	
	InfoCrop	InfoCrop	
	LPJmL	LPJmL	
	MCWLA-Wheat	MCWLA-Maize	MCWLA-Rice
	MONICA	MONICA	
	SALUS	SALUS	
	STICS	STICS	STICS
	WOFOST	WOFOST	
Specific models	LINTUL –FAST	HYBRID-Maize	DNDC-Rice
	DSSAT-CROPSIM	IXIM	NIRAES
	Ecosys	LINPAC	ORYZA2000
	FASSET	Missi	RiceGrow
	GLAM-wheat	MSB	SAMARA
	LINTUL	PlantSys	SIMRIW
	O'Leary-model	PEGASUS	WARM
	Sirius	SARRAH	
	SiriusQuality		

AgMIP The Agricultural Model Intercomparison and Improvement Project

Crop model intercomparison pilot studies

- Wheat (27 models), Maize (18), and Rice (14) Pilots underway
- Pilots under development for sugarcane, millet/sorghum, soybean, groundnut, and potato

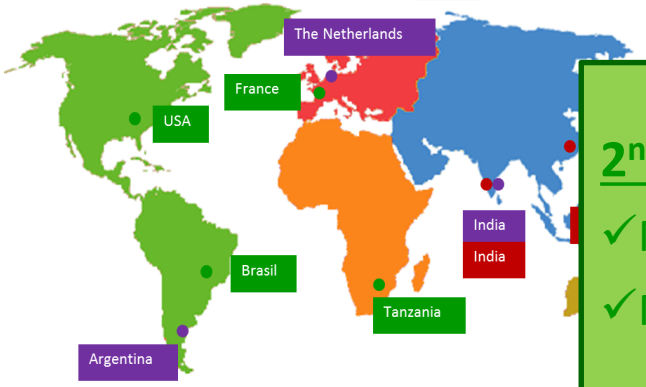
A shared protocol



1st run: "low information"

- ✓ Daily weather data
- ✓ Soil texture
- ✓ Soil water and N initial conditions
- ✓ Crop management (sowing date, water and N)
- ✓ Cultivar (qualitative phenology information)
- ✓ Observed phenology (anthesis and maturity)

A shared protocol



1st run: "low information"

2nd run: "ful information"

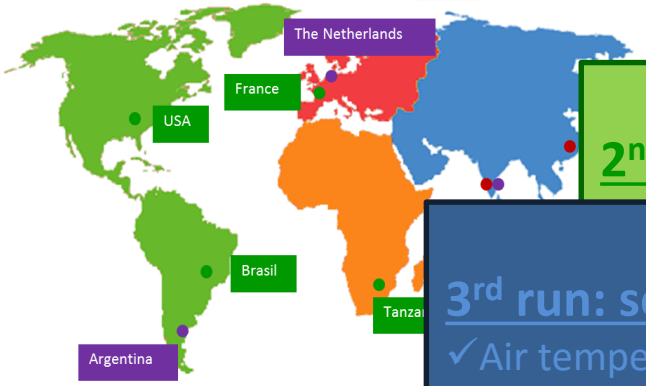
✓Measured in-season crop responses (biomass, LAI, N, …)

✓Measured in-season soil soil water N contents

CALIBRATION PHASE OF THE MODEL

RECOMMANDATION TO LIMIT CALIBRATION TO CULTIVAR PARAMETERS

A shared protocol



1st run: "low information"

2nd run: "ful information"

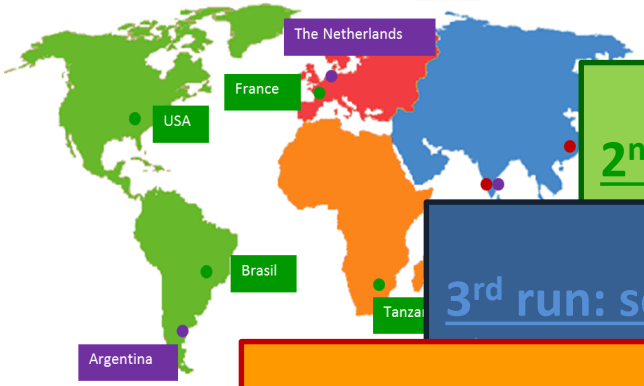
LAI, N, …)

3rd run: sensitivity analysis

- ✓ Air temperature: -3°C, 0°C, +3°C, +6°C, and + 9°C
- ✓ *Atmospheric [CO_2] : 360, 540, 720 ppm*
- ✓ +/- 50 % of N Fertilizer
- ✓ +/- 20 % of available soil water
- ✓ +/- 10 days of sowing date

Simulation for 30 years of current climate and A2 scenario for mid-century

A shared protocol



1st run: "low information"

2nd run: "ful information"

LAI, N, …)

3rd run: sensitivity analysis

o for

4th run: sensitivity to various CGMs cenarios

A2 scenario for mid-century downscaled from 16 CGMs

04

Multimodel uncertainty under climate change

Objectives and strategy

1. To quantify the uncertainty of wheat multi-model ensembles and to create simulation capacity to assist the assessment of impacts of climate change.

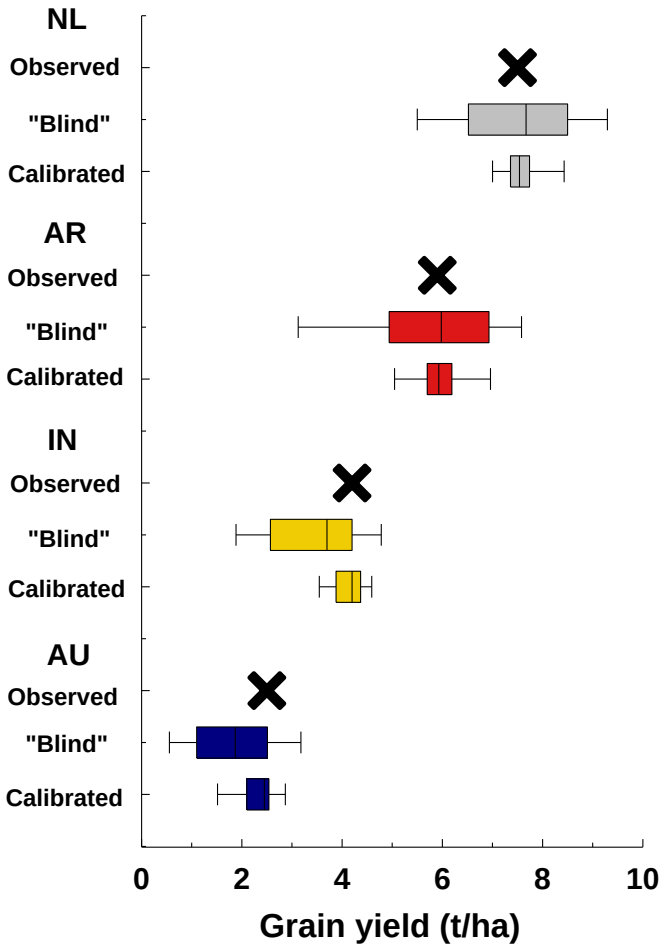
2. To improve identification of climate change hotspots, and promising regional-specific wheat breeding traits and crop management

3. To improve quantification of adaptation options across the globe.

Step-wise strategy to improve model accuracy through addressing physiological crop growth processes in increasing order of complexity.

Site specific model calibration

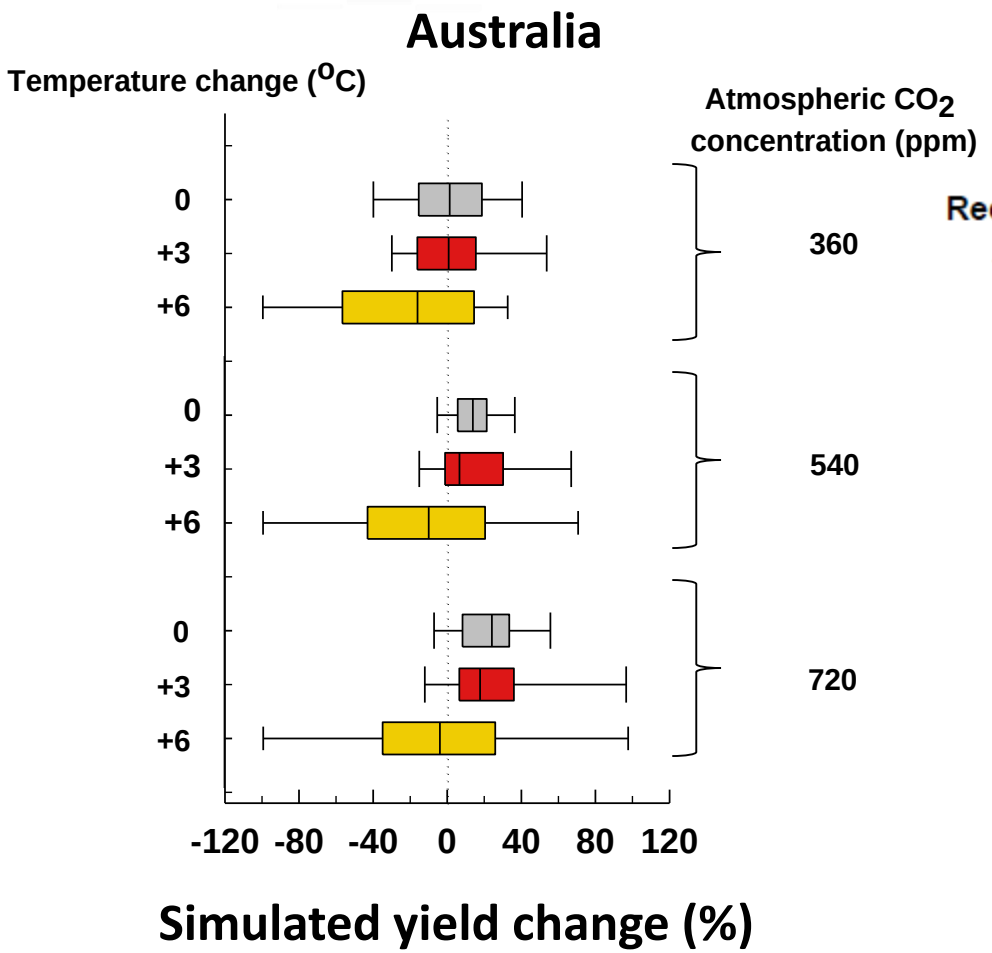
NCC 2013, 3:827-832.

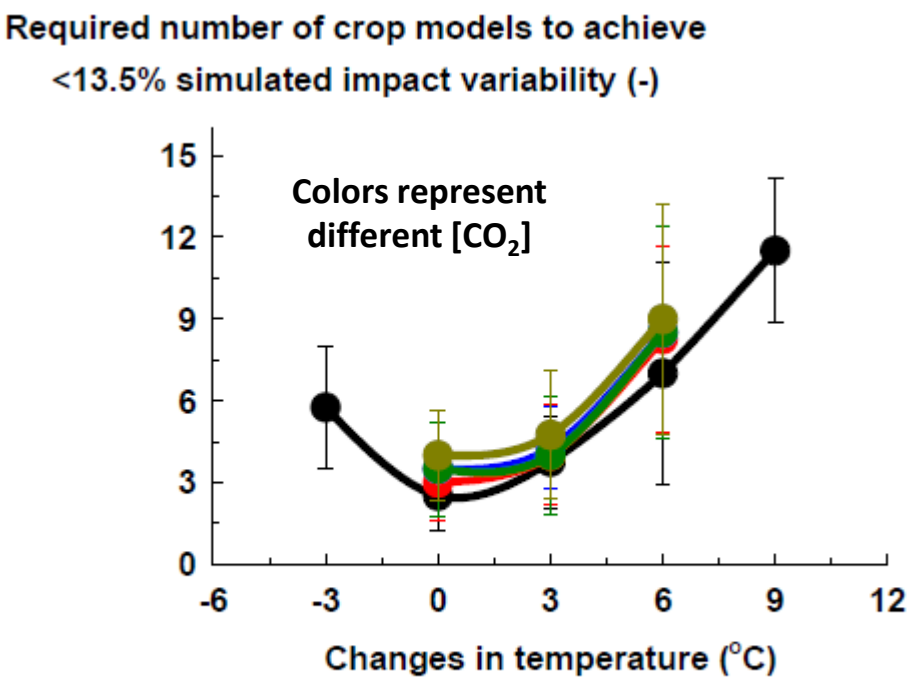


Line = median
Box = 50%
Bars = 80%

Multi-model yield response to CO_2 and temperature changes

NCC 2013, 3:827-832.



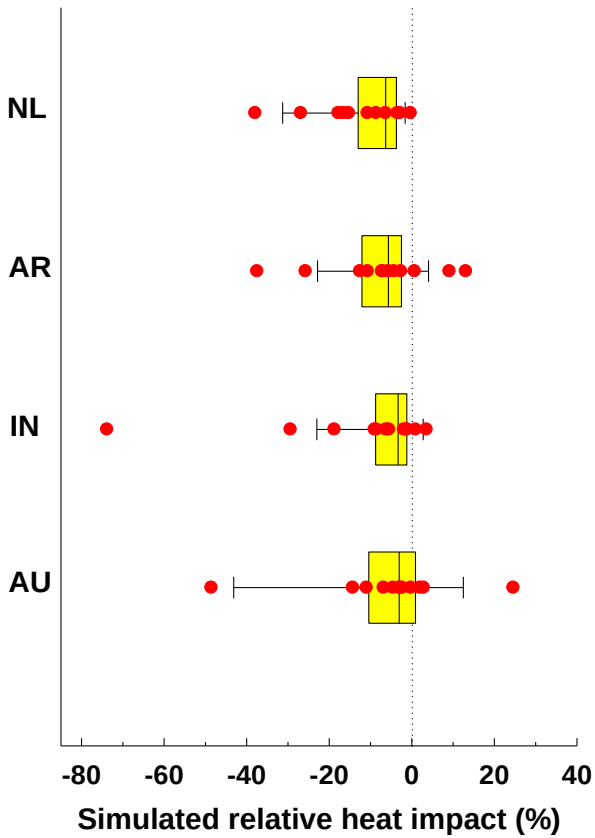


(13.5% = Mean exp error (Taylor et al. 1999))

Multimodel yield response to short spells of heat

NCC 2013, 3:827-832.

7 days around anthesis with T_{max} = 35°C

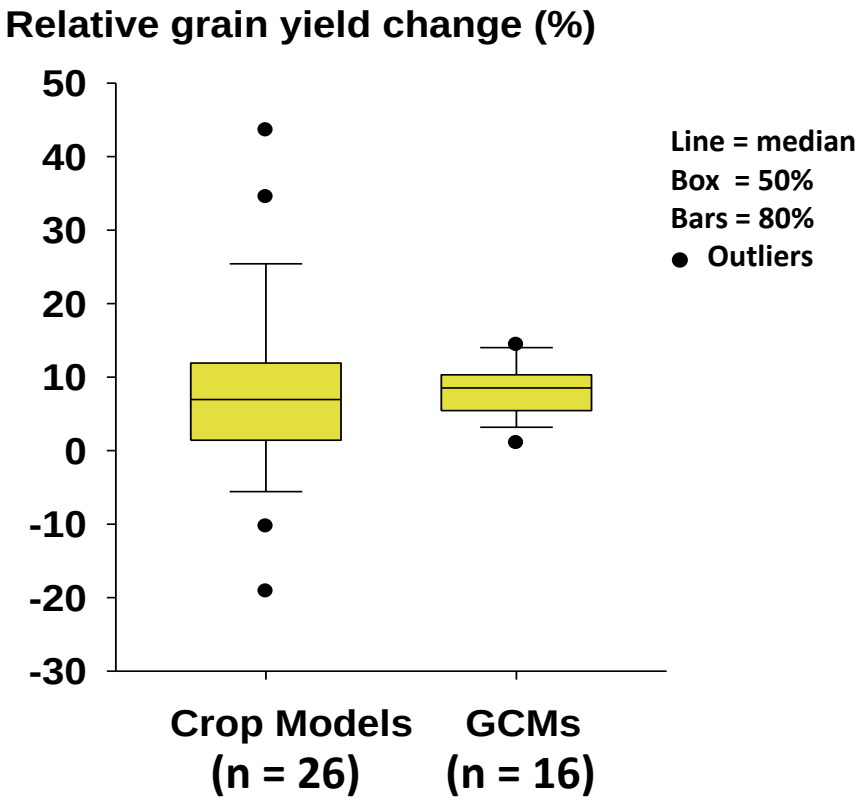


Line = median
Box = 50%
Bars = 80%
● Models with heat stress routine

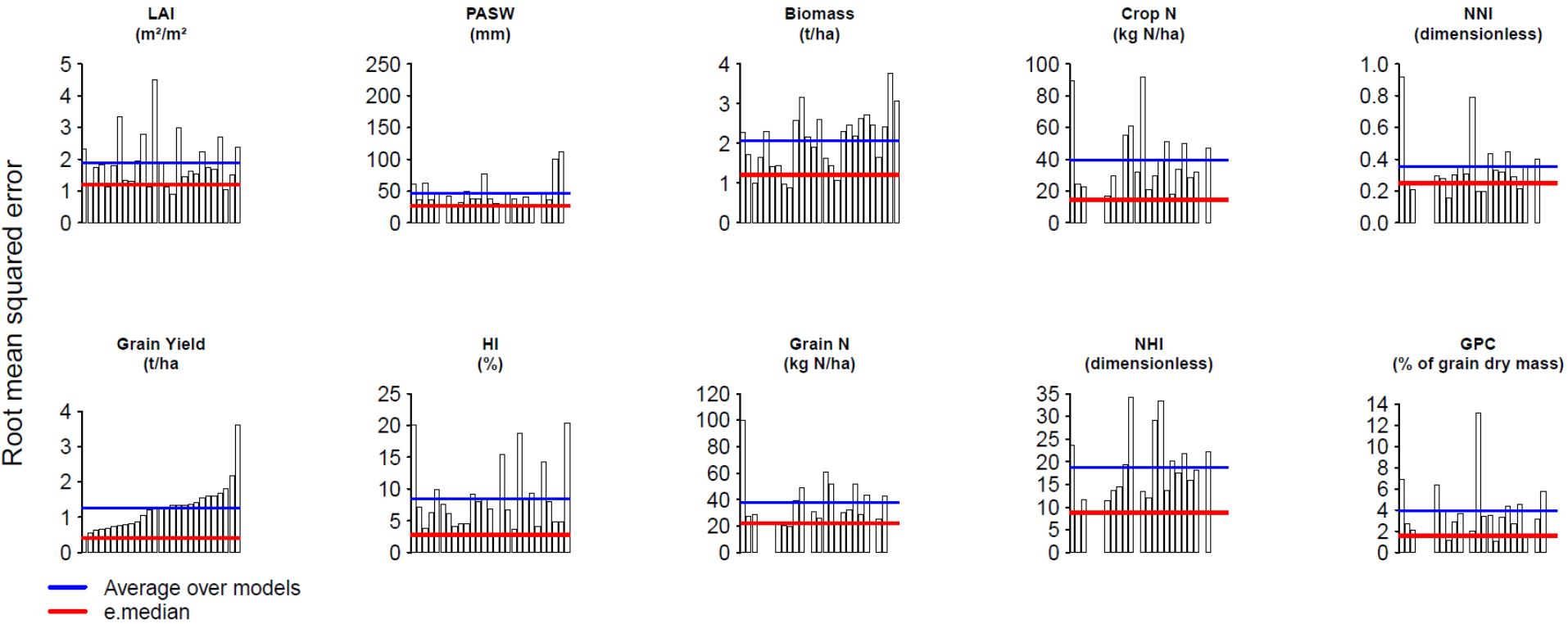
Comparison of crop model and downscaled GCMs uncertainty

NCC 2013, 3:827-832.

A2 scenario for mid-Century

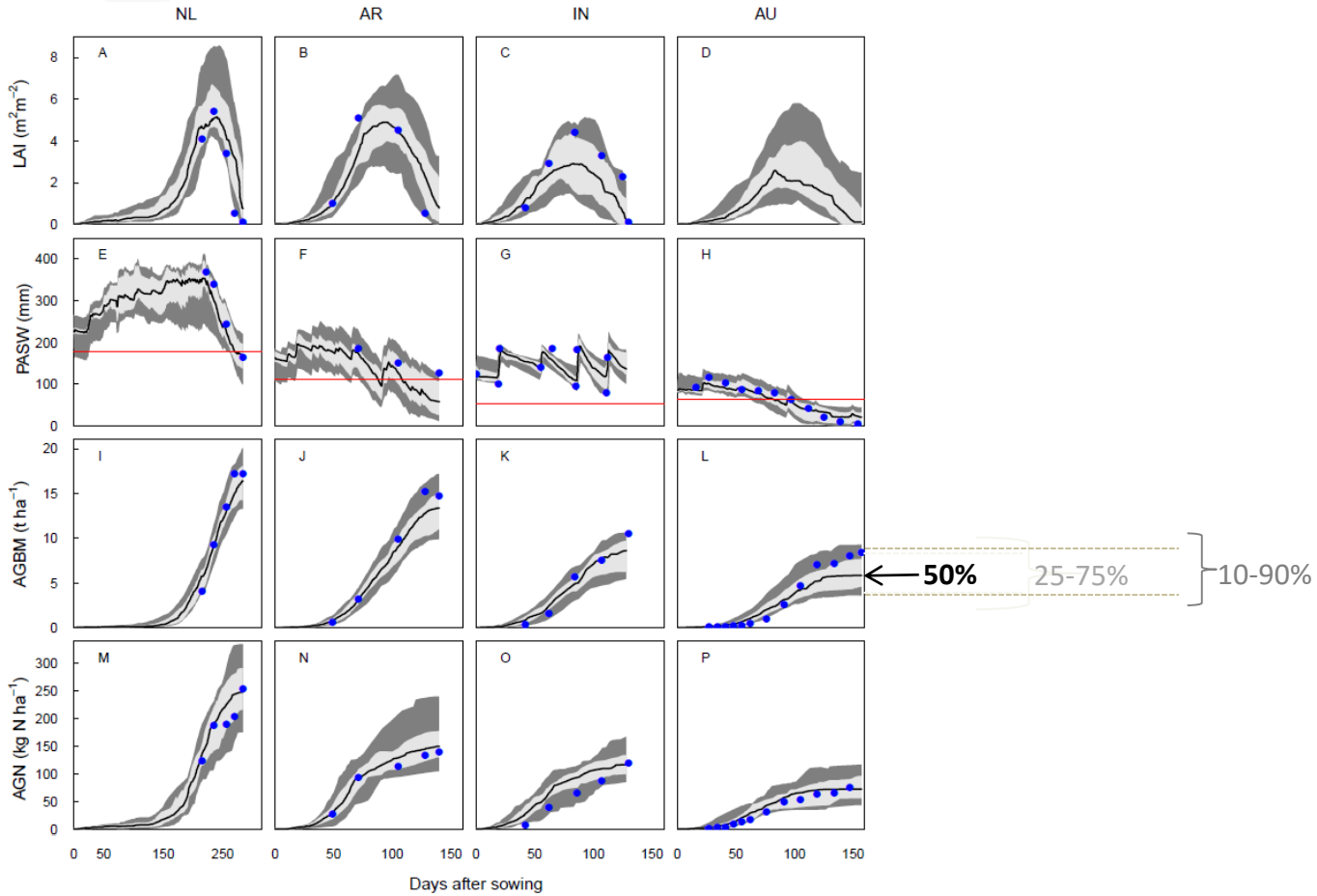


The median of the models is a better predictor than any of the models



GCB 2015, 21: 911-925.

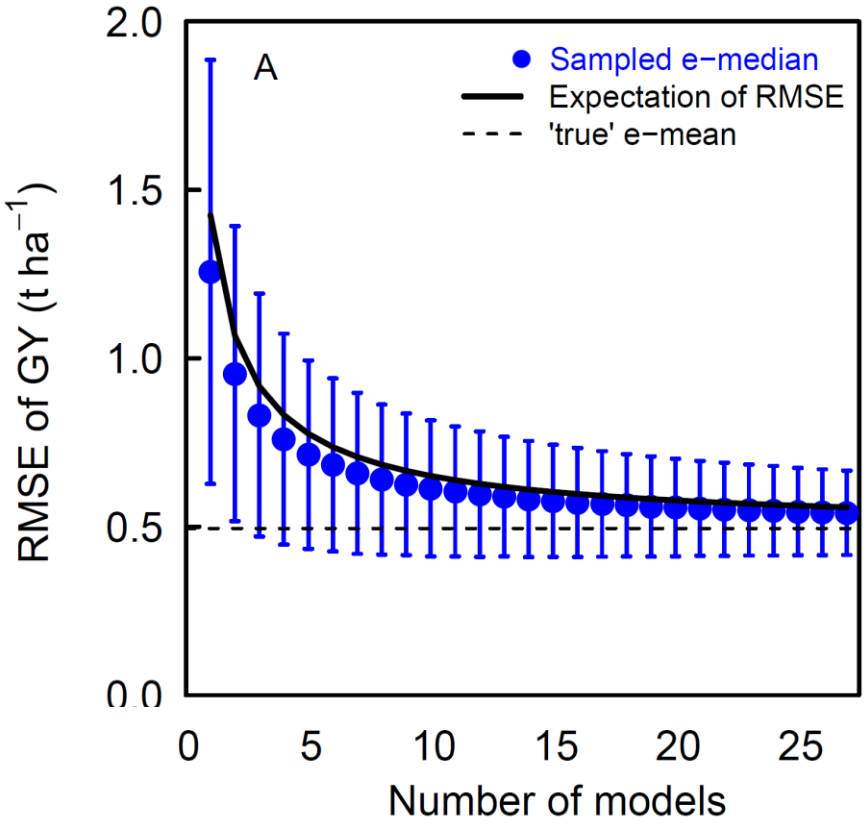
Probabilistic simulations



GCB 2015, 21: 911-925.

How many models do we need?

- **RMSE expectation of multimodel ensemble:** $E\left(\mathrm{MSE}_{M'}\right)=\frac{1}{N}\sum_{i=1}^{N}\left[\left(y_i-\mu^*_i\right)^2+\frac{\mathrm{var}\left(\hat{y}_i\right)}{M}\right]$
- **Bootstrap sampling of ensembles of size 1 to 27**

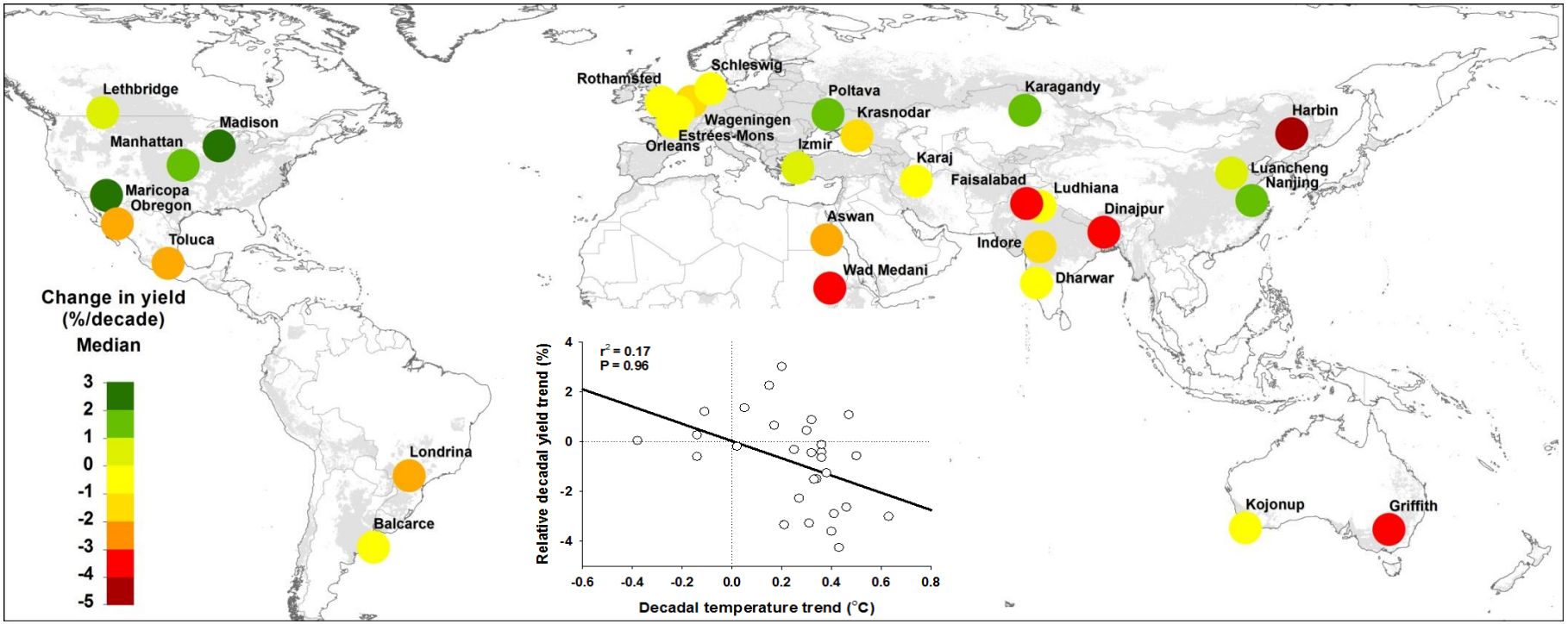


GCB 2015, 21: 911-925.

Past yield trends (1981-2010)

NCC 2015, 5:143-147.

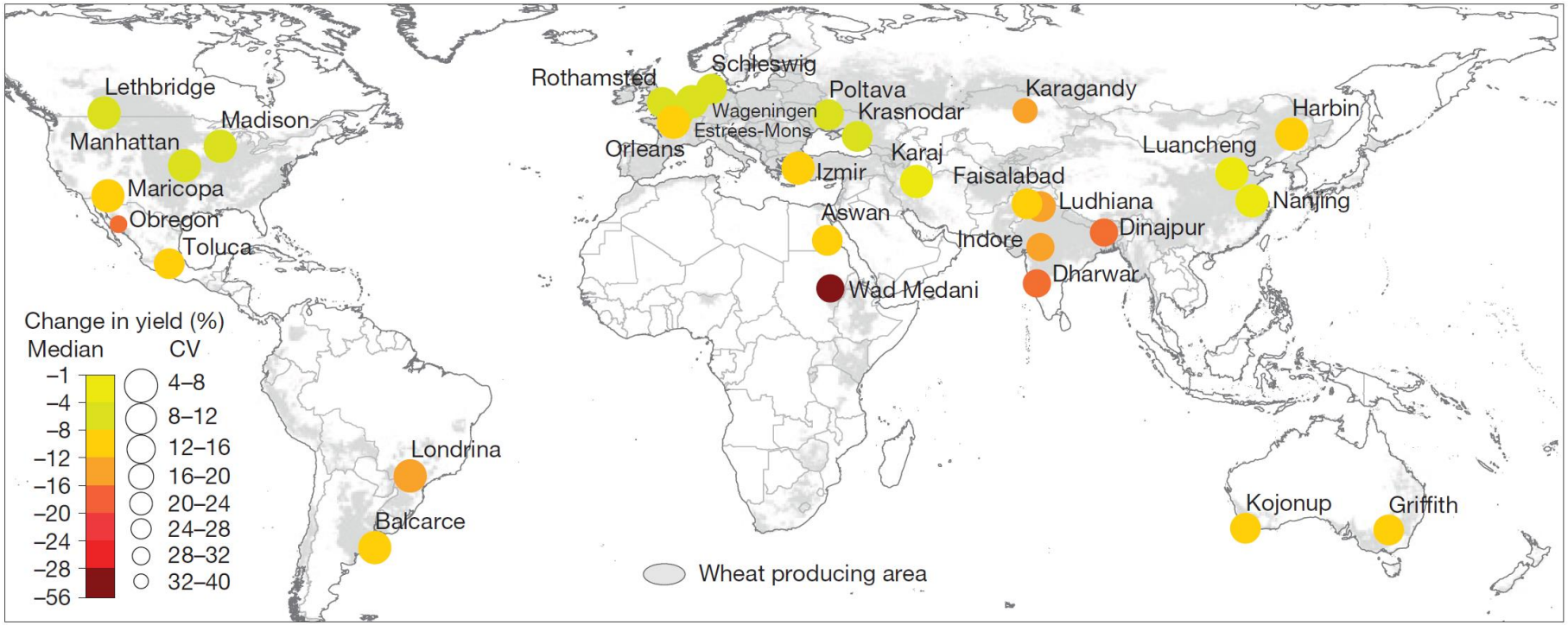
30 model ensemble median



Assessment of the global impact of temperature increase

NCC 2015, 5:143-147.

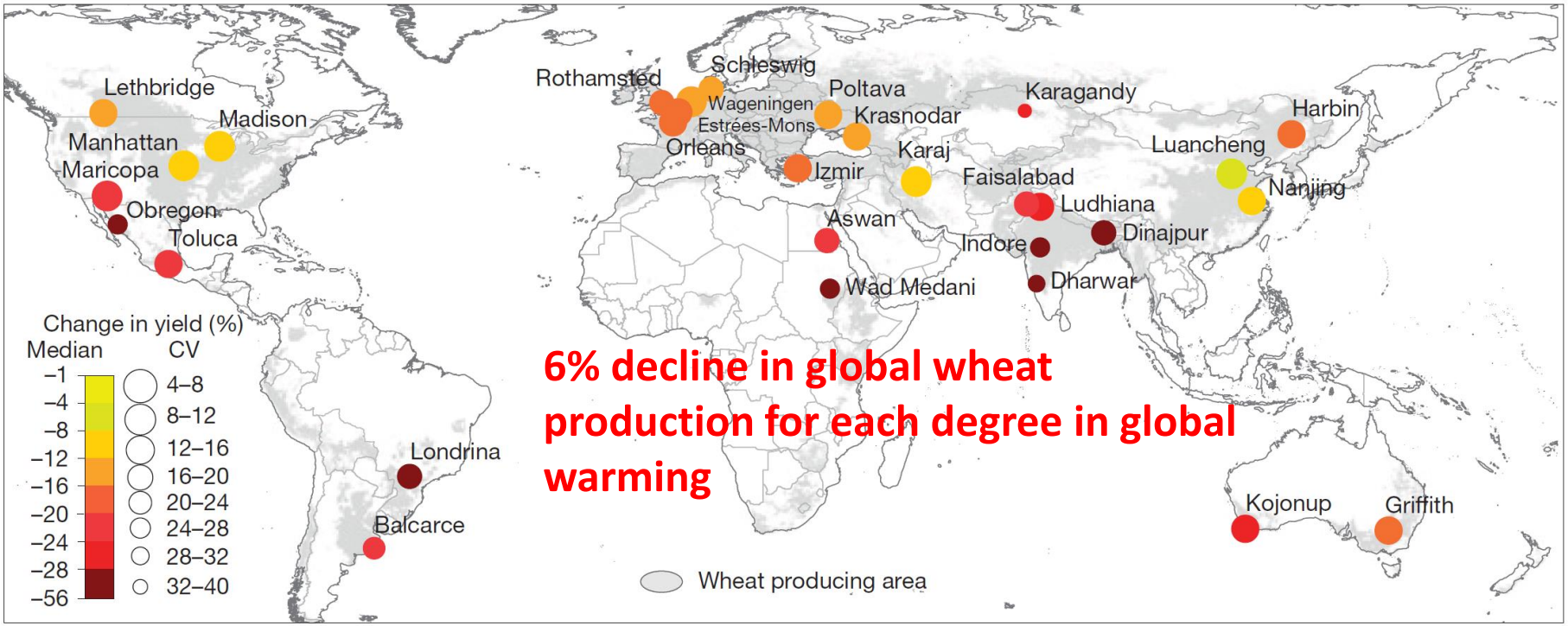
+2 °C temperature increase imposed on the 1981-2010 period



Assessment of the global impact of temperature increase

NCC 2015, 5:143-147.

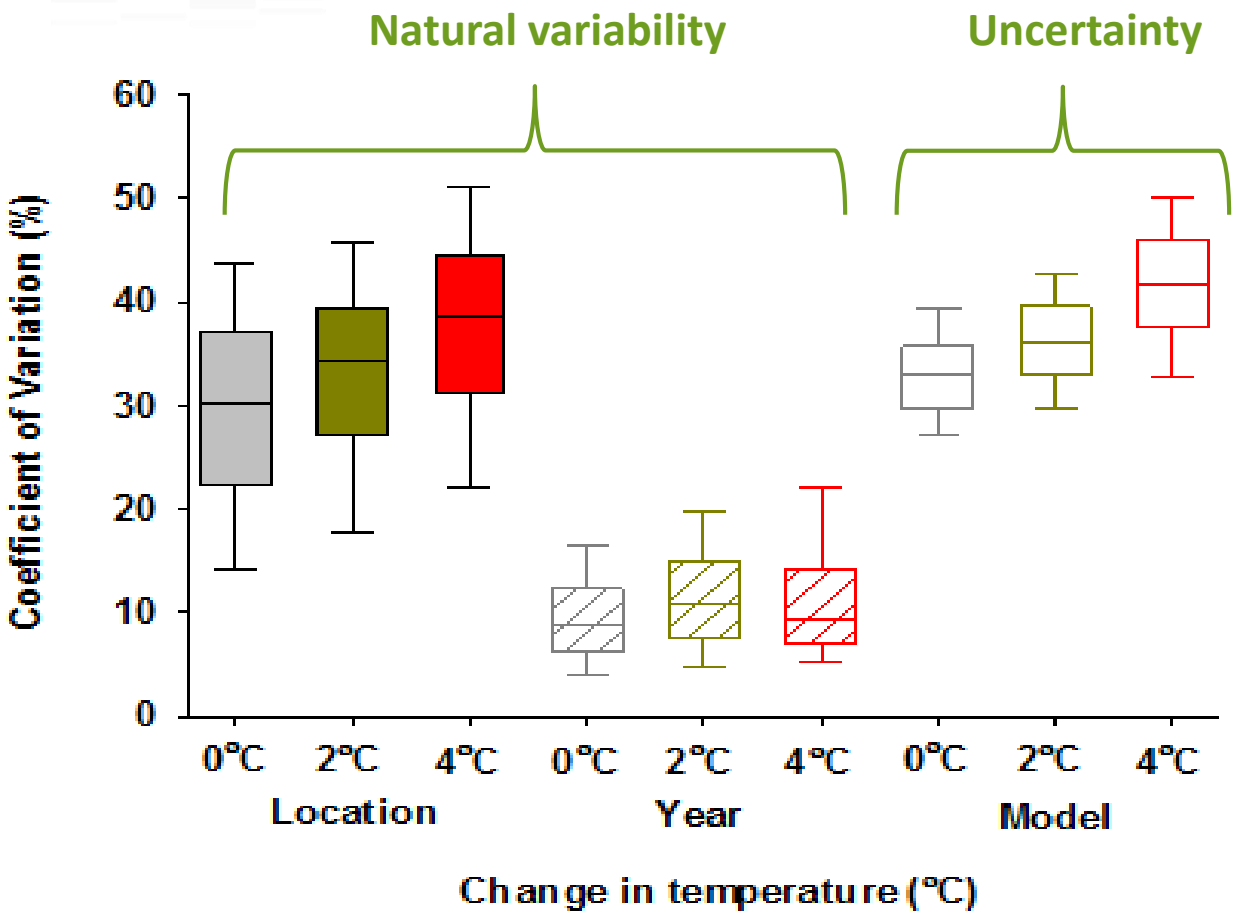
+4 °C temperature increase imposed on the 1981-2010 period



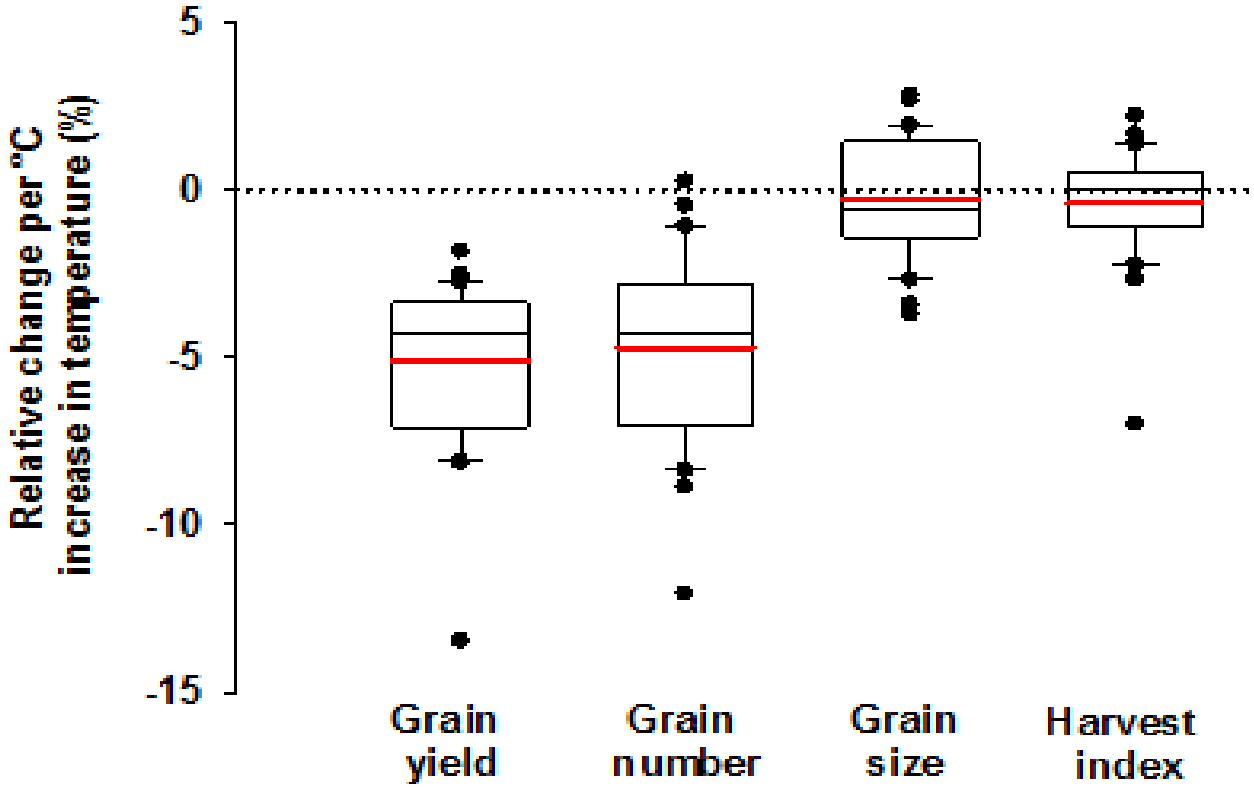
6% decline in global wheat production for each degree in global warming

Natural variability vs. uncertainty

NCC 2015, 5:143-147.



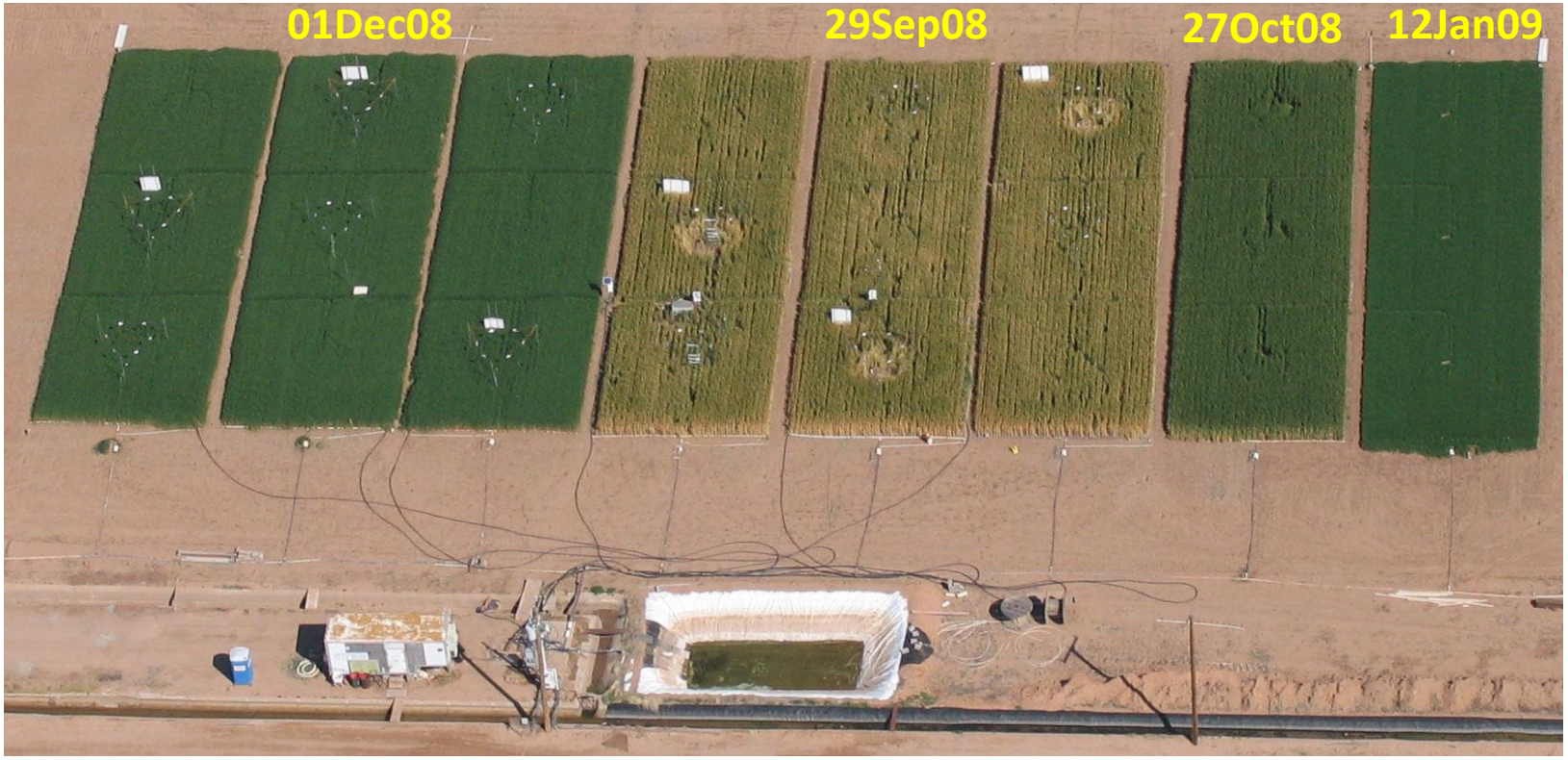
Components of yield change with increasing temperature



Asseng et al. 2014 Nature Climate Change

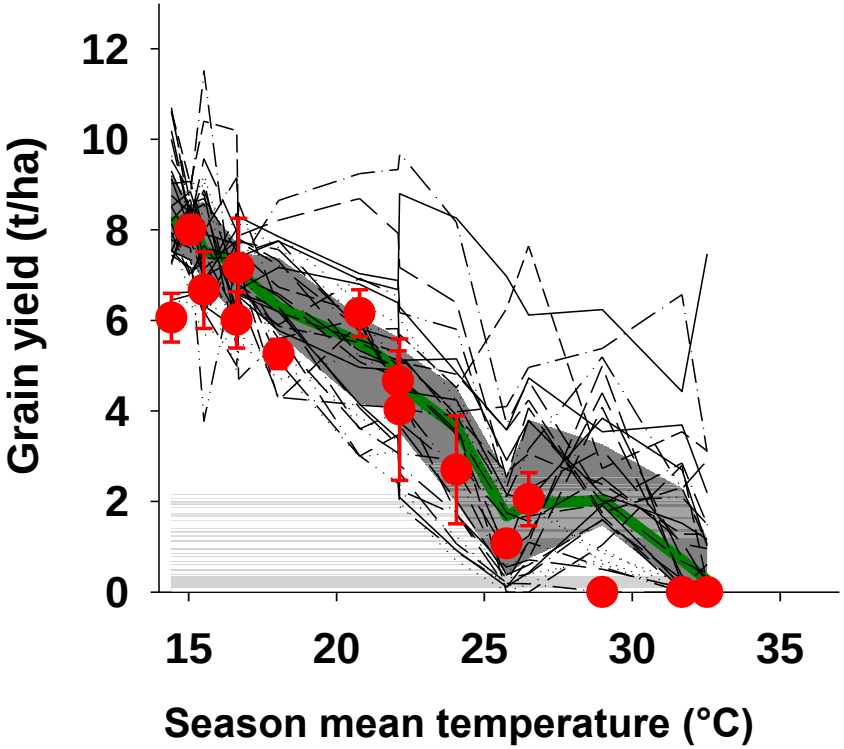
Hot Serial Cereal Experiment, Maricopa, AZ, USA

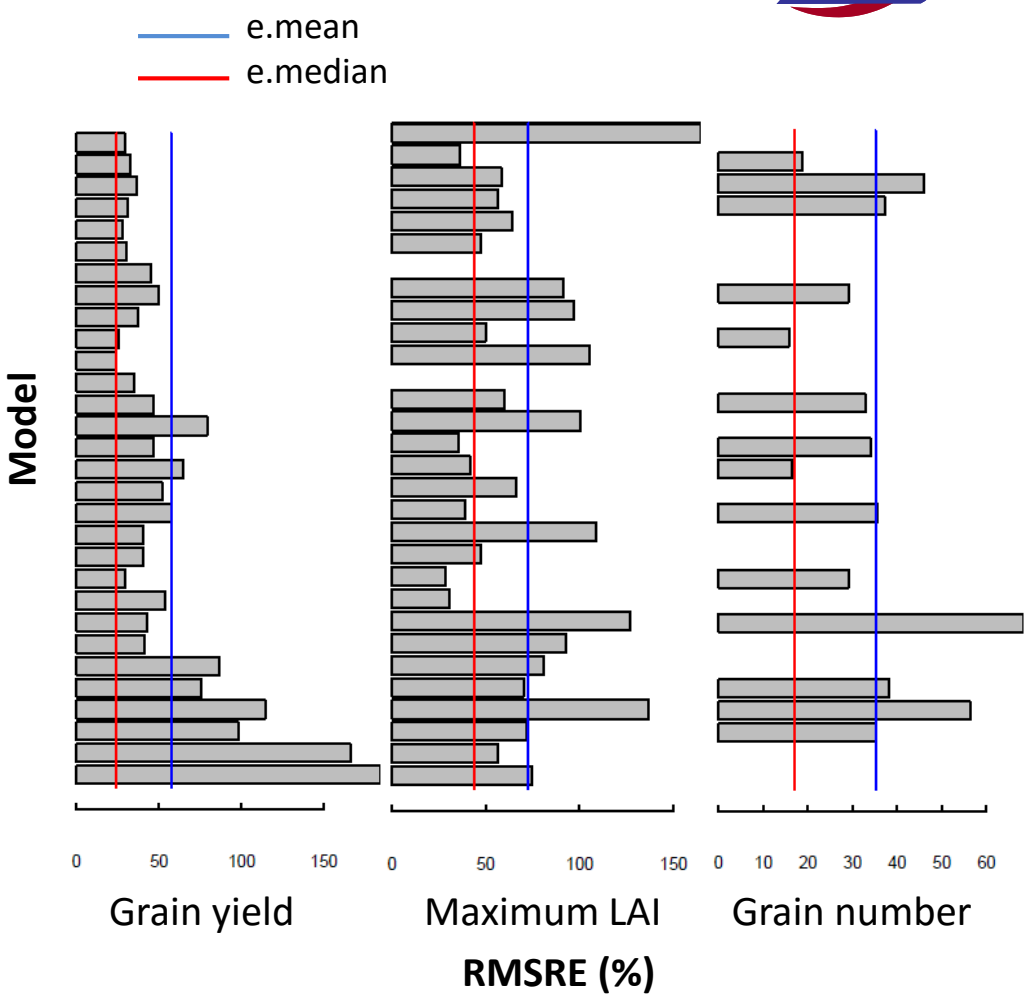
"Cereal" because it's on wheat, "Serial" because the wheat is being planted serially every 6 wks for 2 y, "Hot" because IR heaters are deployed on some of the planting dates.



Grant R.F. et al., 2011; Kimball B.A. et al., 2012; Ottman M.J. et al., 2012, 2013; Wall G.W. et al., 2011; White J.W. et al., 2011, 2012

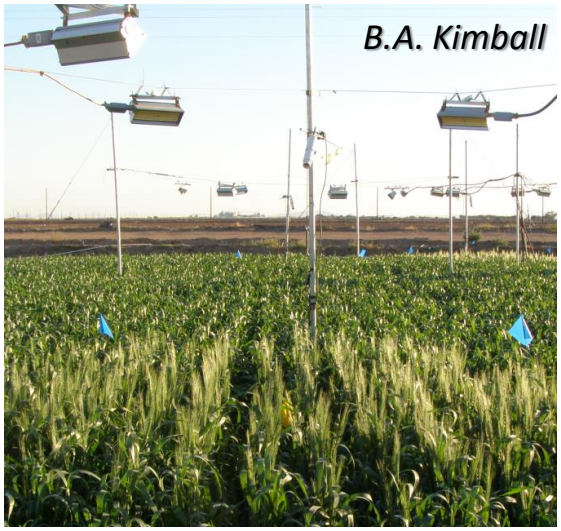
Simulation of wheat response to temperature in the HSC experiment

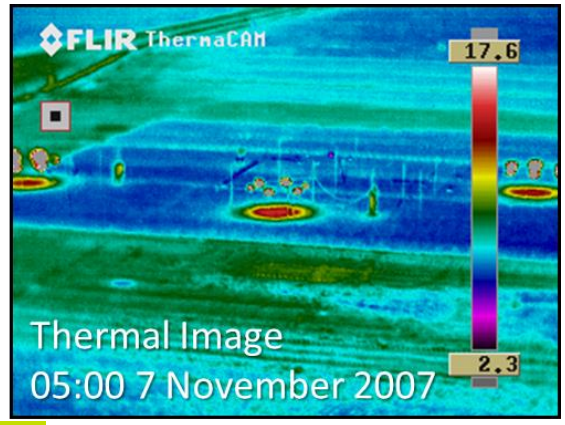




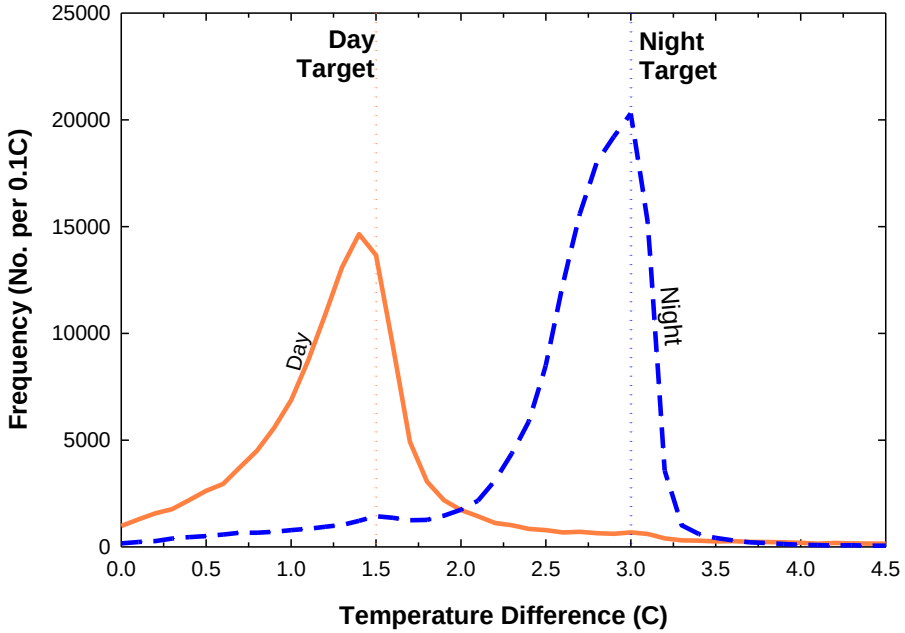
NCC 2015, 5:143-147.

Hot Serial Cereal Experiment, Maricopa, AZ, USA

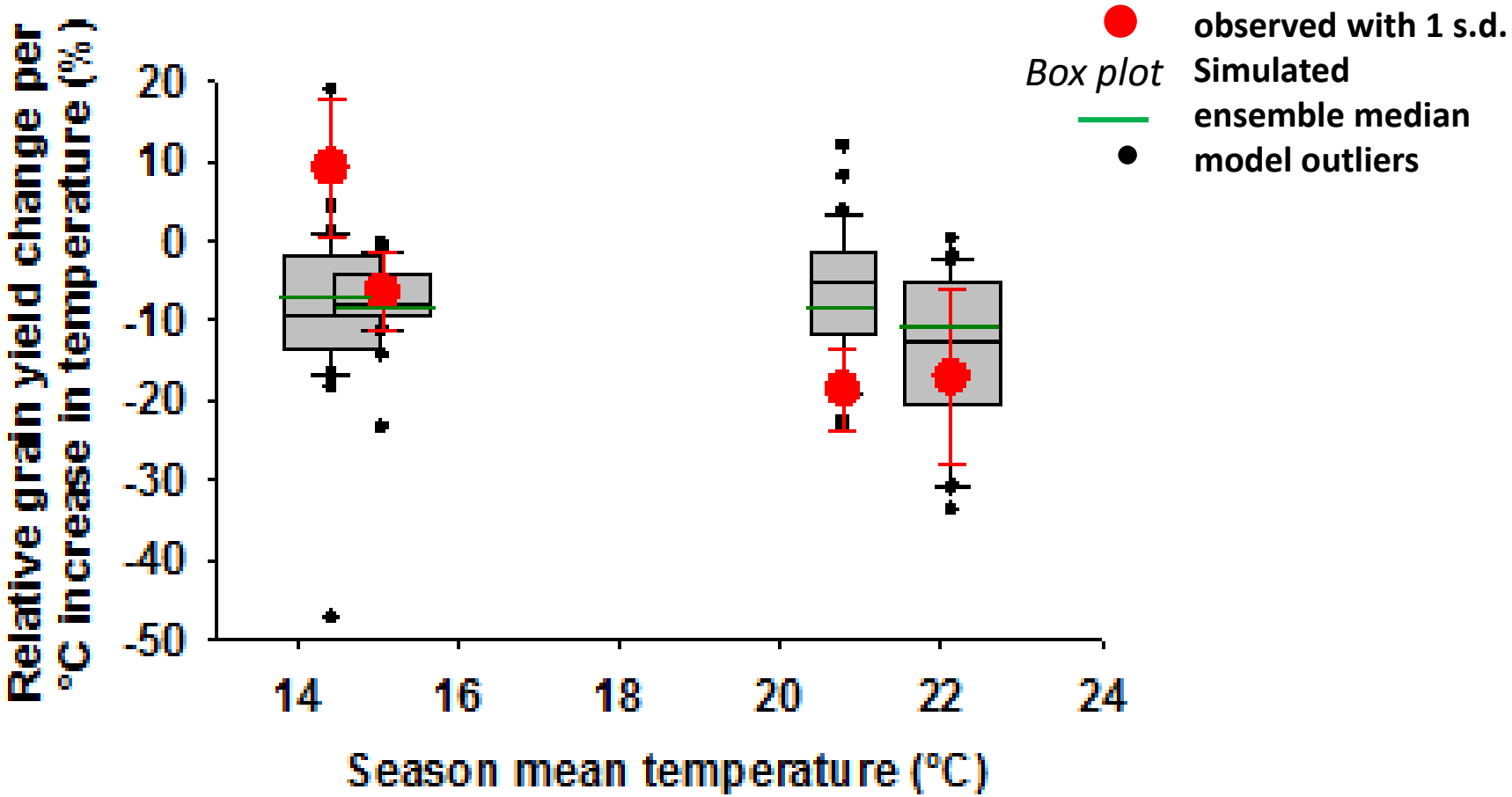




Frequency distribution of 10-min. average wheat canopy temperature differences from day- and nighttime setpoints.



Yield response to artificial temperature increase



NCC 2015, 5:143-147.

Summary

1. Many of the crop models can reproduce observed temperature response,
2. Yet the median of multi-model ensembles is consistently more accurate in simulating wheat temperature response than any single model.
3. Uncertainty in simulated grain yield shows a strong dependency on temperature.
4. Extrapolating the model ensemble temperature response (at current atmospheric [CO_2]) indicates that warming is already slowing yield gains at a majority of wheat-growing locations.
5. Global wheat production is estimated to fall by 6% for each °C of further temperature increase and to become more variable over space and time (at current atmospheric [CO_2]).

Publications

nature climate change LETTERS
PUBLISHED ONLINE: 9 JUNE 2013 | DOI: 10.1038/NCLIMATE1916
doi:10.1038/nclimate1916

Uncertainty in simulating wheat yields under climate change

S. Asseng, F. Ewert, C. Rosenzweig, J. W. Jones, J. L. Hatfield, A. C. Ruane, K. J. Boote, P. J. Thorburn, R. P. Rötter, D. Cammarano, N. Brisson, B. Basso, P. Martre, P. K. Aggarwal, C. Angulo, P. Bertuzzi, C. Biernath, A. J. Challinor, J. Doltra, S. Gayler, R. Goldberg, R. Grant, L. Heng, J. Hooker, L. A. Hunt, J. Ingwersen, R. C. Izaurralde, K. C. Kersebaum, C. Müller, S. Naresh Kumar, C. Nendel, G. O'Leary, J. E. Olesen, T. M. Osborne, T. Palosuo, E. Priesack, D. Ripoche, M. A. Semenov, I. Shcherbak, P. Steduto, C. Stöckle, P. Stratonovitch, T. Streck, I. Supit, F. Tao, M. Travasso, K. Waha, D. Wallach, J. W. White, J.

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A statistical analysis of three ensembles of crop model responses to temperature and CO_2 concentration

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COMMENTARY: Making the most of climate impacts ensembles

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Rising temperatures reduce global wheat production

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Canopy temperature for simulation of heat stress in irrigated wheat in a semi-arid environment: A multi-model comparison

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Global Change Biology (2014), doi:10.1111/gcb.12768

Multimodel ensembles of wheat growth: many models are better than one

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Response of wheat growth, grain yield and water use to elevated CO_2 under a Free Air CO_2 Enrichment (FACE) experiment and modelling in a semi-arid environment

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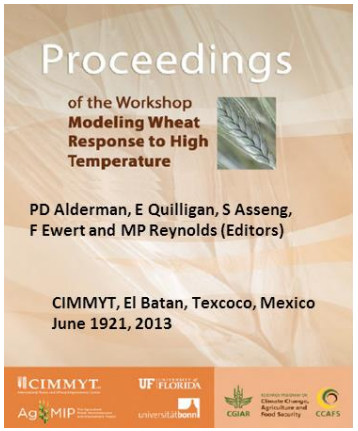

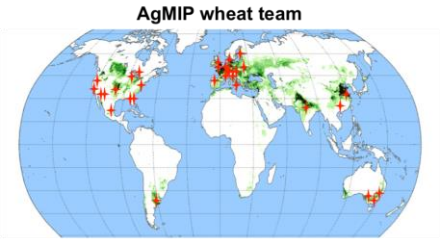

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