Uncertainties in modelling impacts of climatic change and variability on crop production.

Focus on European-led efforts (=> FACCE MACSUR)

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with contributions from WP Leaders CropM

Expert Consultation, Climate Change and Trade, FAO , Rome, 5-6 November 2013

8.11.2013

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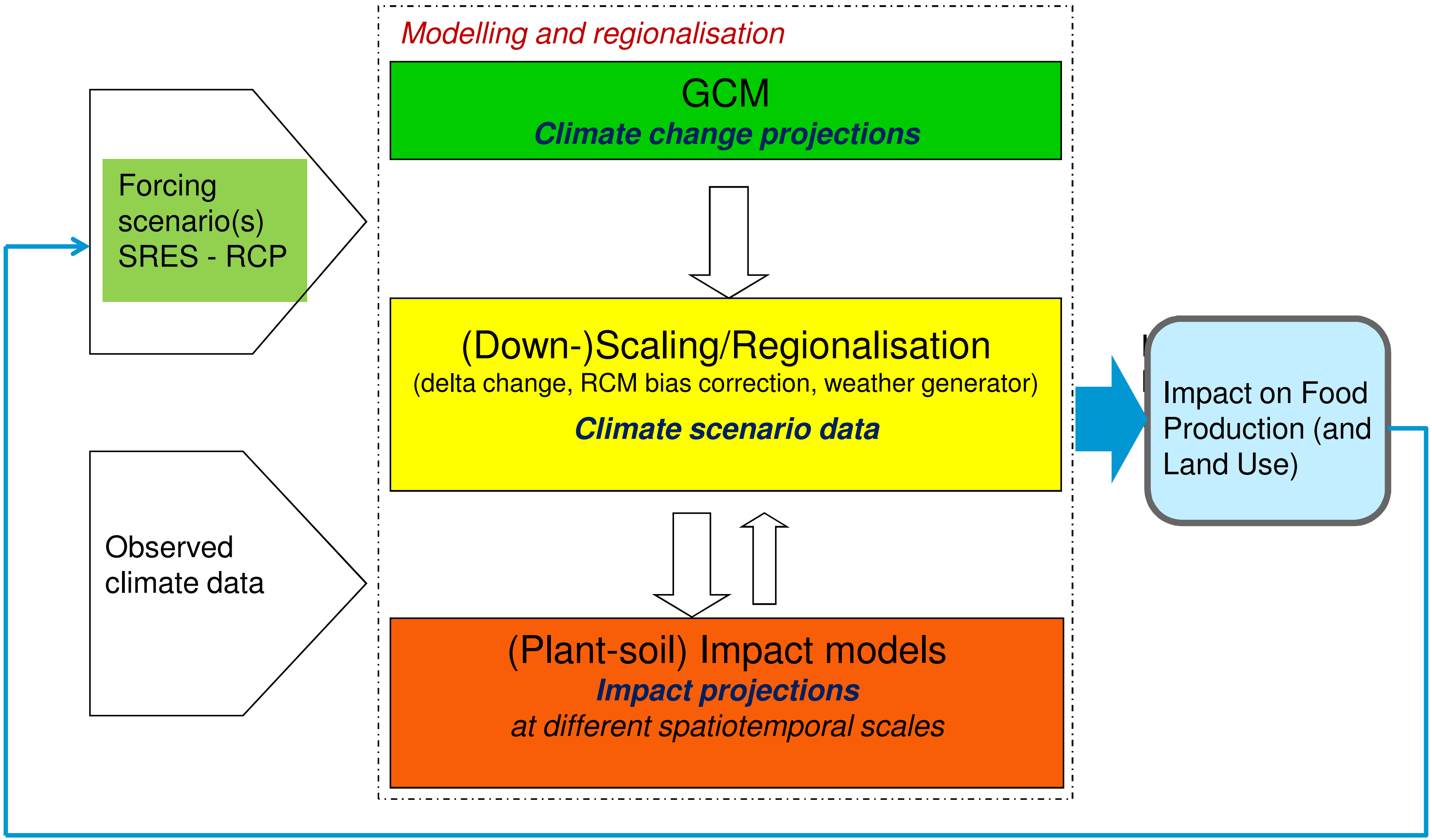
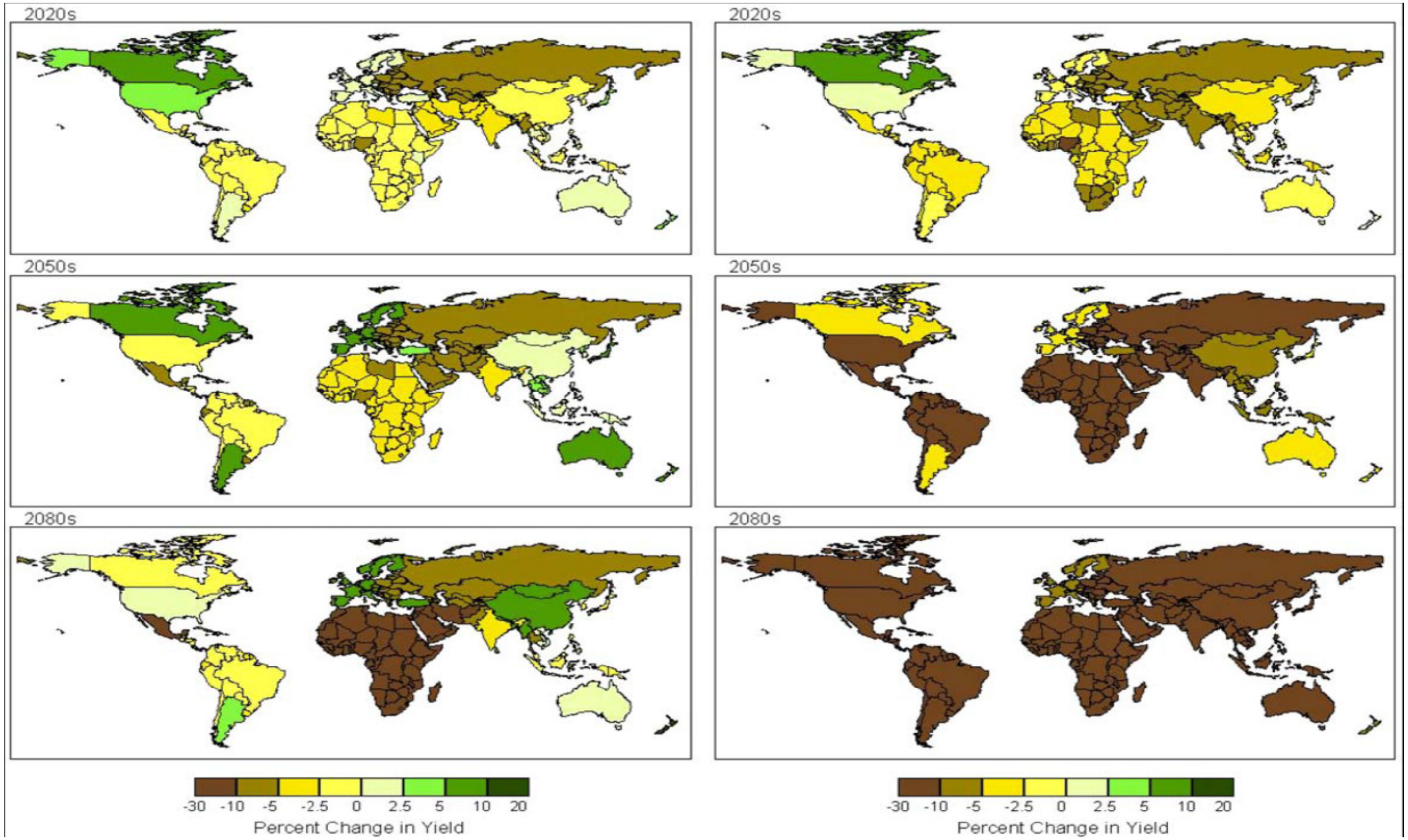
- **Introduction: Shortcomings of CC-IA methodologies, European efforts to improve (esp FACCE MACSUR);** *Challenges for CropM to simulate impacts of climate variability and extremes*
- **Crop model uncertainties and deficiencies – *examples – sources /causes and their relative importance***
- **Recent progress in model-based assessment methodologies**
- **Options for further improvement *(examples: e.g. extreme heat)* – and the need for international cooperation**

Uncertainty chain in CC impact assessment



(source: Rötter et al. 2012, Acta Agric Scand. Section A, 62(4), 166-180).

Conv. CC IA meth. /Winners /Loosers; mean changes; Here: Potential changes in cereal yields, A2 (*Parry et al., 2004*)



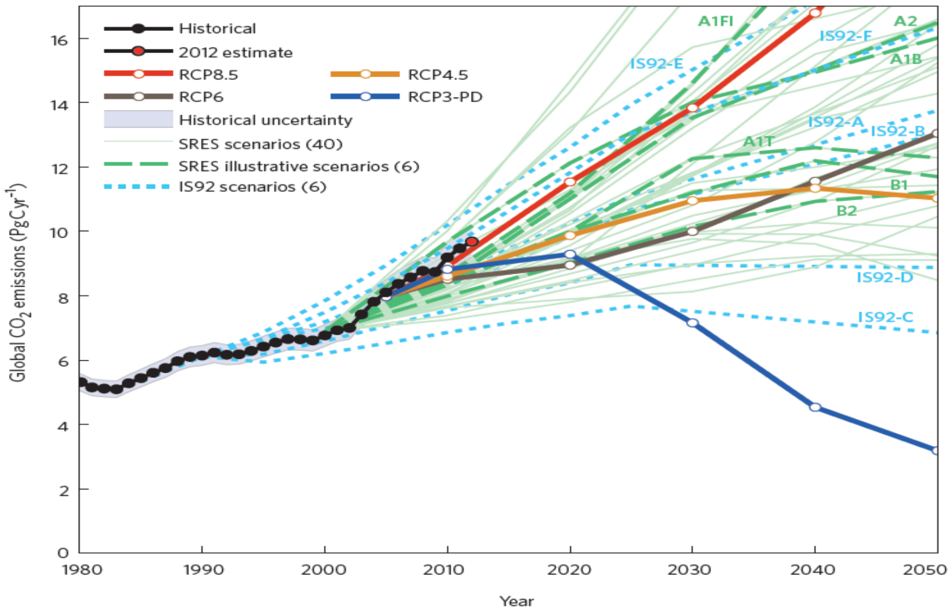
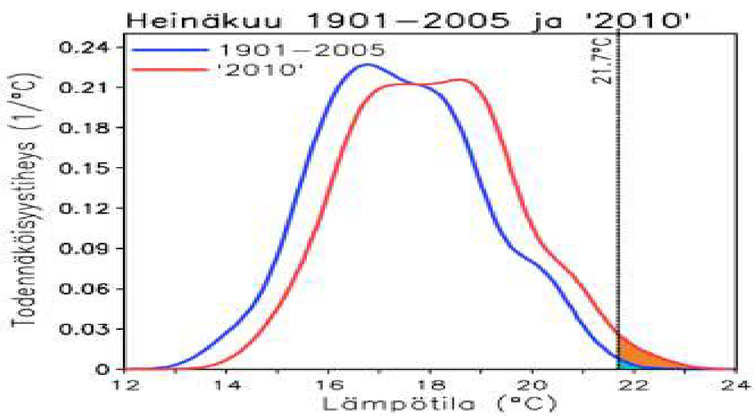


Figure 1 | Estimated CO_2 emissions over the past three decades compared with the IS92, SRES and the RCPs. The SA90 data are not shown, but the most relevant (SA90-A) is similar to IS92-A and IS92-F. The uncertainty in historical emissions is ±5% (one standard deviation). Scenario data is generally reported at decadal intervals and we use linear interpolation for intermediate years.

(*Source: Peters, 2013; Nat Clim Change*)



Shift in PDF of July temperatures
S Finland (*Source:* Räisänen 2010)

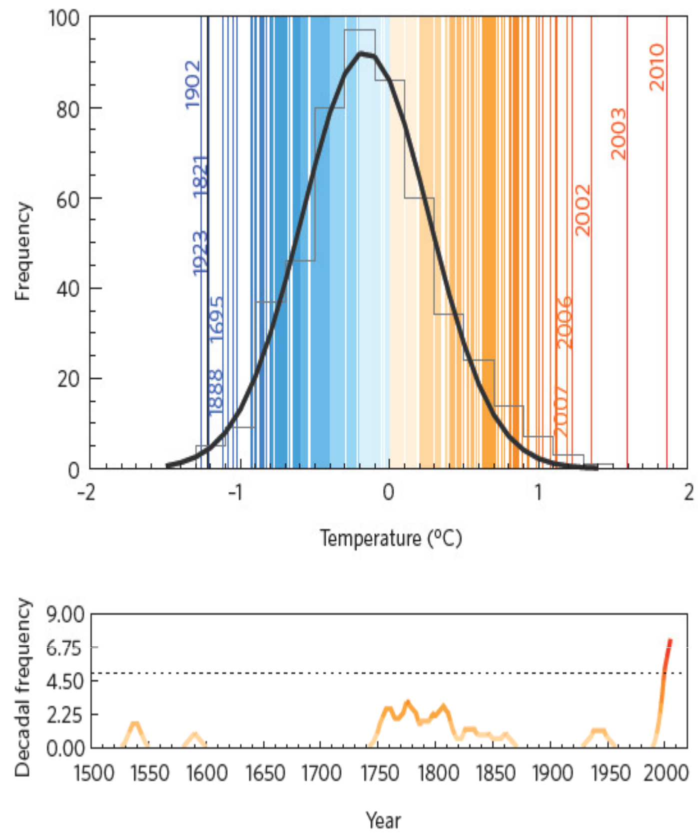


Figure 4 | European summer temperatures for 1500-2010. The upper panel shows the statistical frequency distribution of European (35° N, 70° N; 25° W, 40° E) summer land-temperature anomalies (relative to the 1970-1999 period) for the 1500-2010 period (vertical lines). The five warmest and coldest summers are highlighted. Grey bars represent the distribution for the 1500-2002 period with a Gaussian fit shown in black. The lower panel shows the running decadal frequency of extreme summers, defined as those with a temperature above the ninety-fifth percentile of the 1500-2002 distribution. A ten-year smoothing is applied. Reproduced with permission from ref. 69, © 2011 AAAS.

Source: Coumou & Rahmsdorf, 2012

Impact assessments by process-based crop models
REVIEW *(summer 2011)*: CSMs need an overhaul...


nature climate change

JULY 2011 VOL 1 NO 4
www.nature.com/natureclimatechange

Tell-tale signs of climate tipping

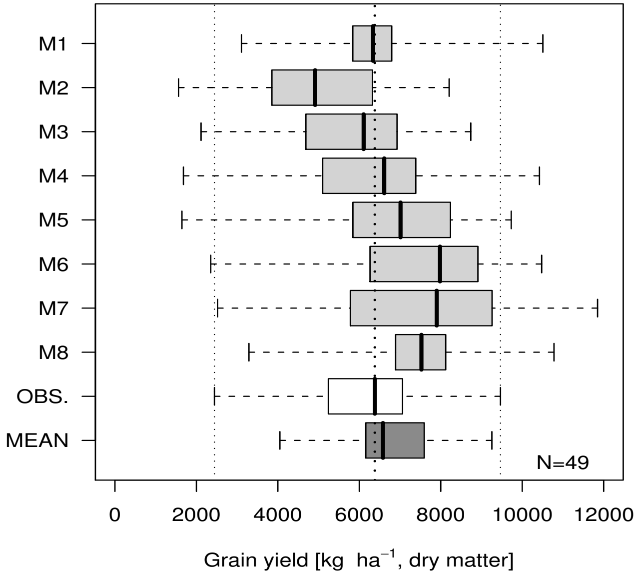
in this issue

Towards competent crop models
To meet the world's growing demand for food, it may be necessary to boost agricultural productivity by as much as 70% by 2050. The extent to which large yield gains can be achieved in a changing climate remain unknown, but estimates depend heavily on crop models. Reimund Rötter and colleagues argue that current crop modelling tools are out of date and not fit for purpose. They argue strongly that researchers need to switch to more rigorous multi-model approaches to better quantify inherent uncertainties. Only then will model estimates of crop yields under climate change provide a firm basis for delivering robust and usable information, for everyone from farmers to policymakers.
[Commentary p175]

ATER'S CARBON FOOTPRINT
A thirsty business

CROP-CLIMATE MODELS
Food for thought

ARCTIC CARBON BALANCE
Push from pathogens



Source: Palosuo et al. 2011, EJA

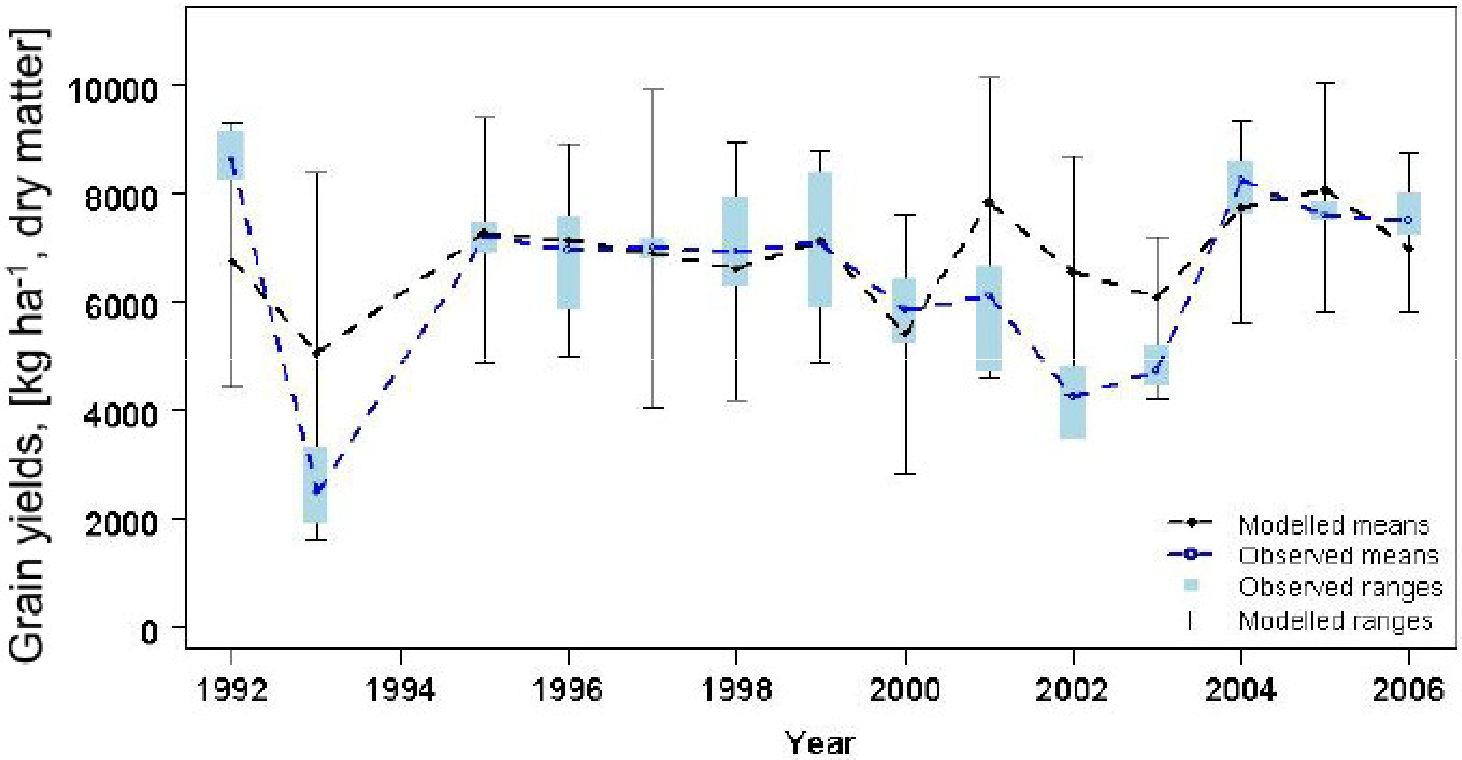
1) **Based on Palosuo et al. (2011) and results of three companion studies within COST 734, during 2008-2011 => use multi-model ensemble approach mean/median as predictor – *first test in Rötter et al. 2012, FCR; extended /confirmed by Asseng et al. 2013 & work in progr (AgMIP Wheat)***
2) ***Need for better reporting uncertainties in IA***
3) ***Reduce model deficiencies to better capture climatic variability and extremes***

Importance of impacts of climate variability

- The challenge:
- **"Until we can confidently ascribe fluctuations in the yield of crops we have already grown to specific features of the weather they were exposed to, we have little hope of predicting how our food supplies might be affected by the changes of temperature and rainfall which climatologists now observe when they increase the amount of CO2 in their models".** (*Monteith, J. L. Q. J. R. Meteorol. Soc.* ***107, 749–774 (1981).***

- ***Why is it so difficult*** to simulate effects of climate variability on crop yields with process-based crop models ?
- ***Current status:*** Has substantial progress been made regarding model-based estimates of yield variability at different scales (field, region, supra-national) ? *Examples*
- ***Outlook:*** What further efforts need/can be made to reduce uncertainties in model-based estimates of yield variability in response to climate ?

COST 734 model intercomparisons 2008-11

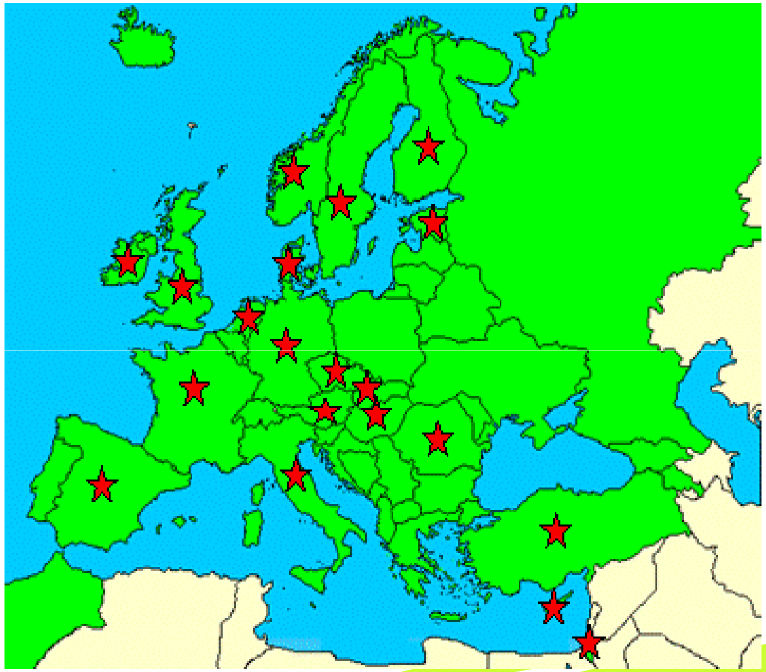


Source: Palosuo et al., 2011; crop: winter wheat; location: Lednice, CZ Republic;

Means and ranges of model-based estimated and observed (blue line and rectangles) yields for 14 growing seasons studied

FACCE MACSUR: A detailed climate change risk assessment for European Agriculture. – Partners: 16+1 very (inter-)active country teams (70 groups)

- (Austria)
- Belgium
- Czech Republic
- Cyprus
- Denmark
- (Estonia)
- Finland
- France
- Germany
- Hungary
- Ireland
- Israel
- Italy
- Netherlands
- Norway
- Poland
- (Romania)
- Slovakia
- Spain
- Sweden
- Turkey
- UK



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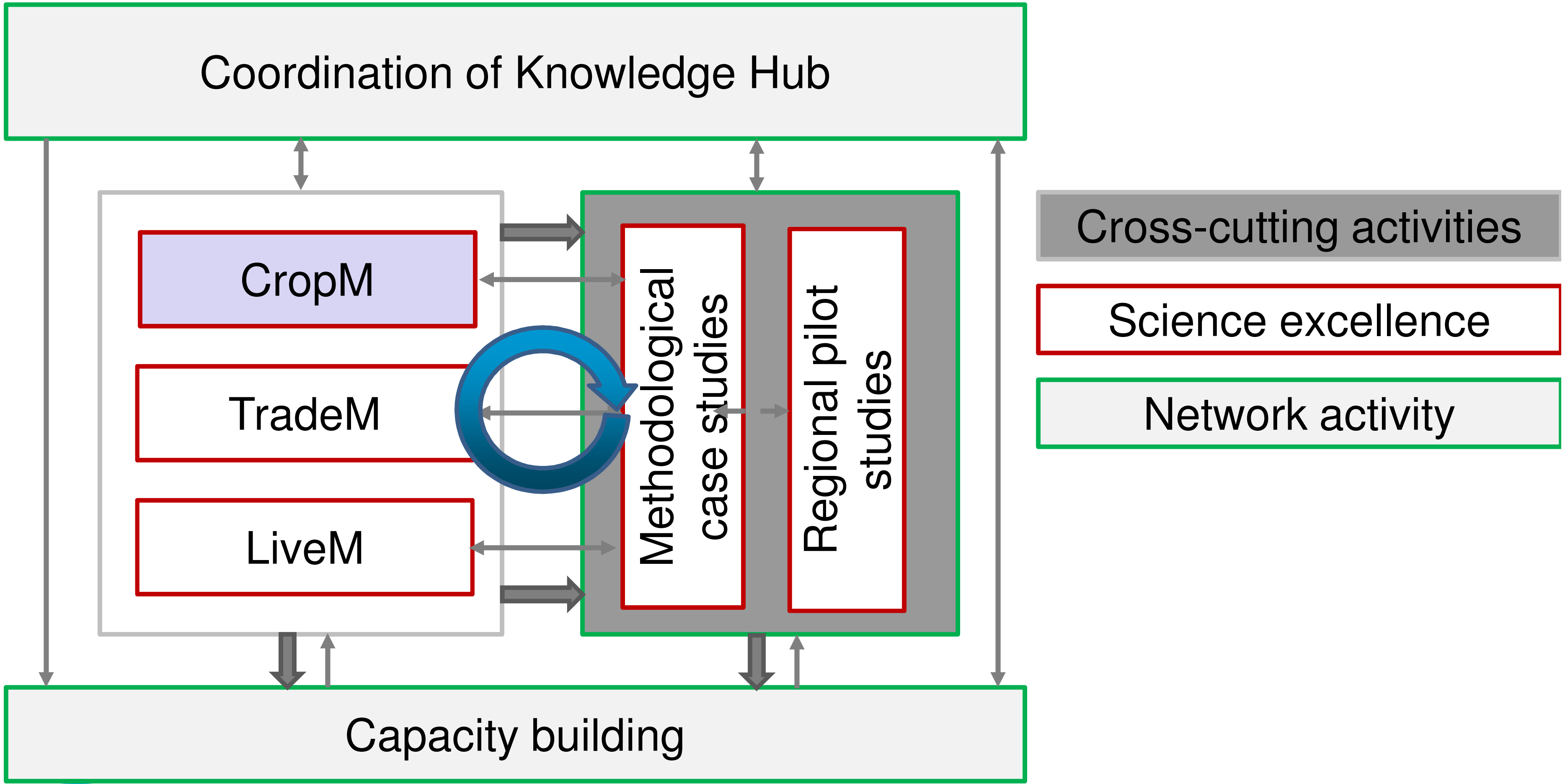
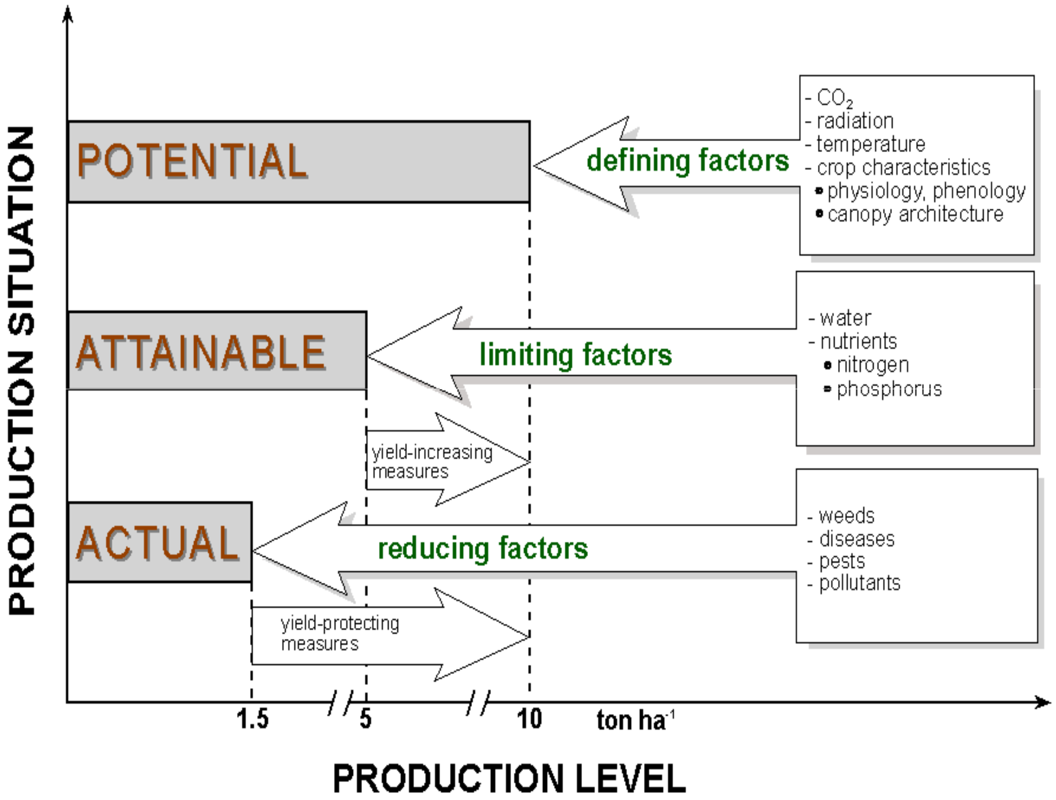
FACCE MACSUR structure



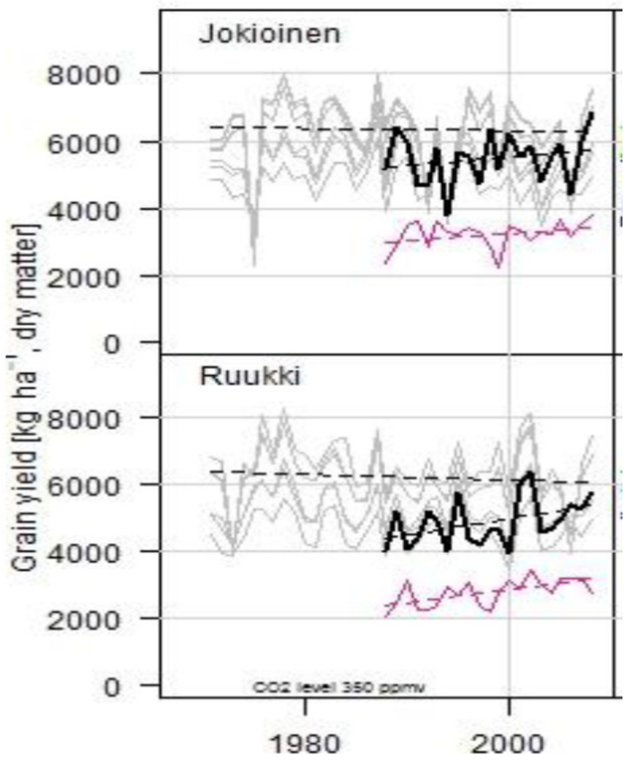
CropM Work Packages

NO.	WORK PACKAGE TITLE	COORDINATION
WP1	Model intercomparison (develop protocols; extend sites, crops)	Christian Kersebaum (GER) Marco Bindi (IT)
WP2	Model improvements through generating and compiling data	Jorgen Olesen (DK) Mirek Trnka (CZ)
WP3	Scaling methods and model linking	Frank Ewert (GER), Sander Janssen (NL) Martin van Ittersum (NL)
WP4	Scenario development and impact uncertainty analysis	Reimund Rötter (FI), Daniel Wallach (FR), M Semenov (UK), Mike Rivington (UK)
WP5	Capacity building	John R Porter (DK)
WP6	Case studies on impact assessment (cross cutting theme package and linkage to decision-making)	Jan Verhagen (NL) Derek Stewart (UK) Pier Paolo Roggero (IT)

2. Crop model uncertainties / deficiencies
Model situations /yield gaps analysis



(Source: Van Ittersum & Rabbinge, 1997)



Palosuo et al. 2013. modelling historical adaptation/cultivar choice Proceed Impacts World 2013

2. Crop model uncertainties ?

What kind of <u>extremes and impacts</u> are we talking about ?

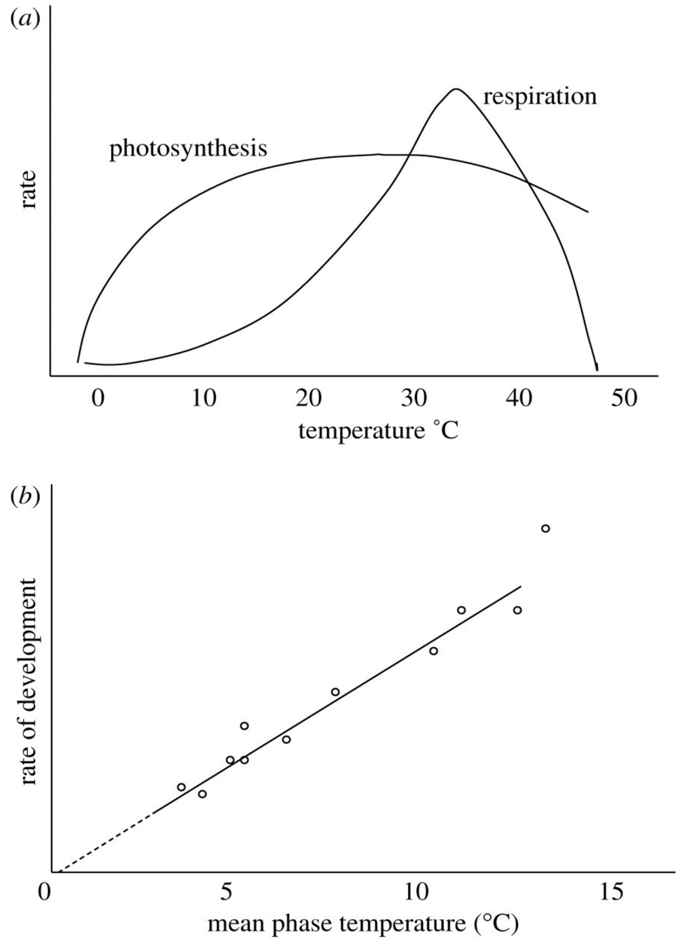
(1) Heat shocks (high Tmax) => floret mortality, heat waves => leaf senescence, shortened grain-filling period

(2) Dry spells/water deficits => stomatal closure, photosynthesis reduced, leaf senescence.......

(3) Heavy rain => water logging, oxygen stress; post.-maturity delayed harvest; wetness increasing occurrence of pests/ diseases

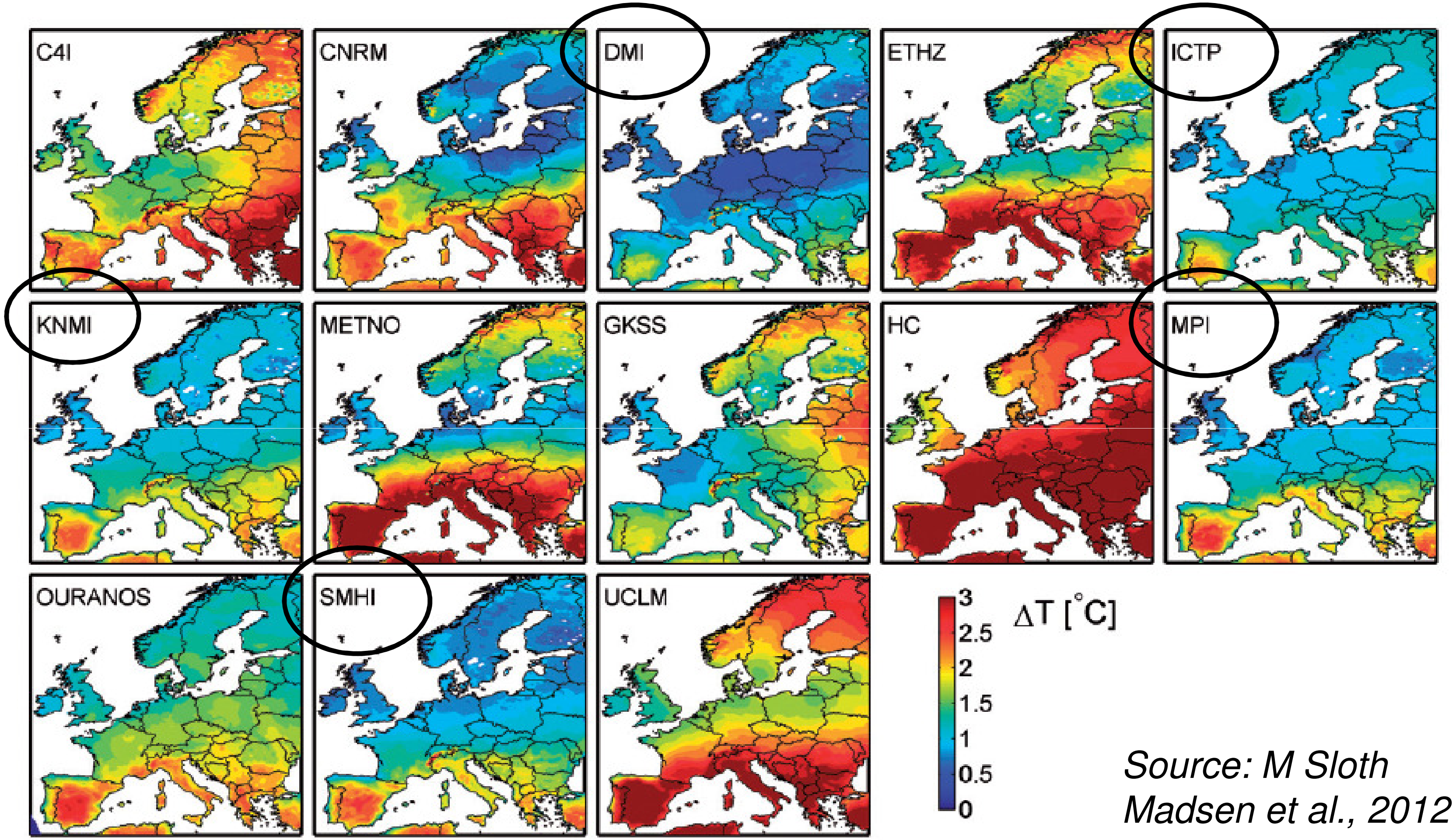
(4) Heavy rain/warm winters – indirect via soil Processes (e.g. nitrogen losses by leaching)

Changes in the rate of (a) C3 photosynthesis and respiration and (b) rate of crop development as a function of temperature.



Porter J R , and Semenov M A Phil. Trans. R. Soc. B 2005;360:2021-2035

3. Recent Progress: Considering uncertainties in climate model projections (RCMs)



Source: M Sloth Madsen et al., 2012

Figure 2. (Colour online). Projected changes in mean summer (June–August) temperature for the scenario period 2031–2050 as compared with the reference period 1975–1994. Note that similar patterns are seen for the five models using the ECHAM5 GCM.

Effects of spatial aggregation of model input (examples SW Finland)

C. Angulo et al. / Europ. J. Agronomy 49 (2013) 104–114

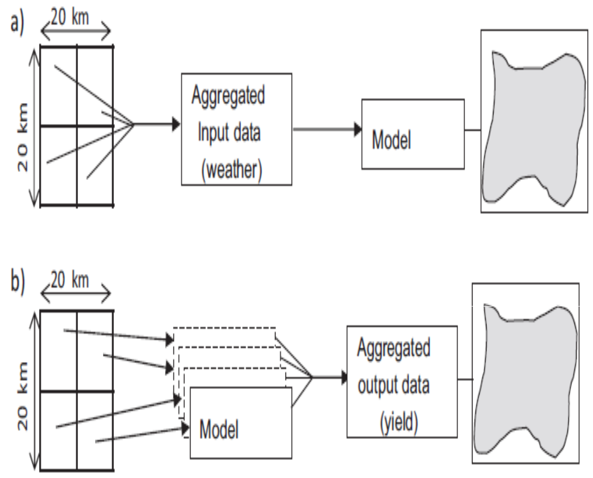
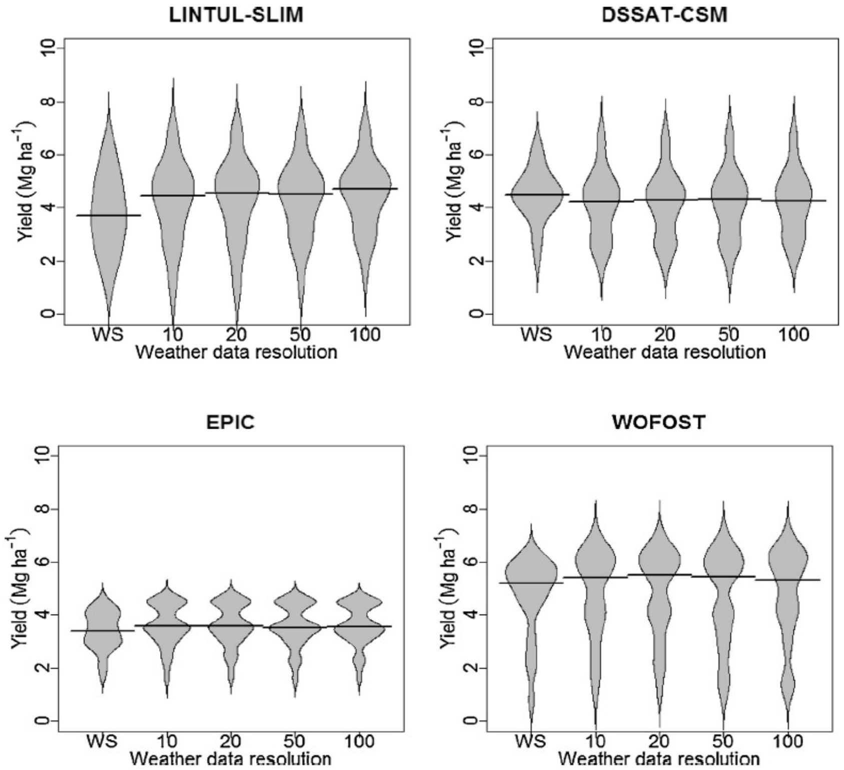


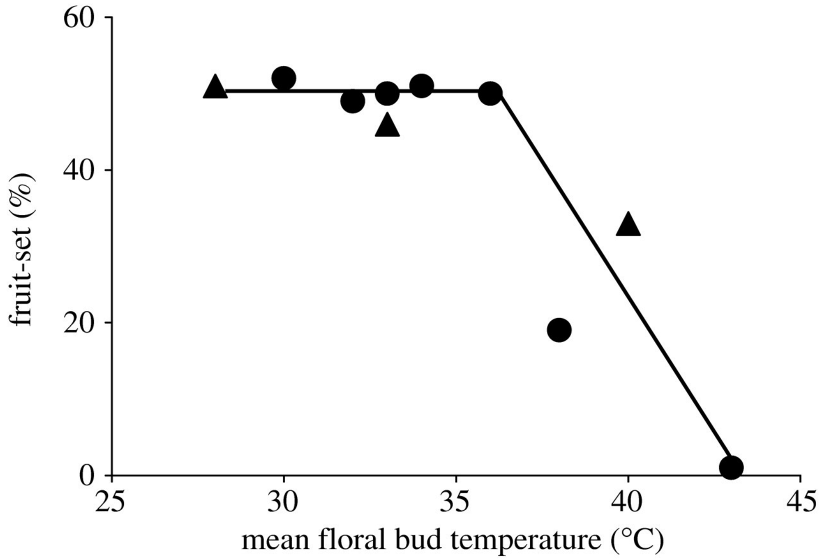
Fig. 2. Schematic representation of scaling methods compared in this study, referring to: (a) aggregation of weather input data and (b) aggregation of outputs



ig. 3. Comparison of frequency distributions of simulated yields of four crop growth models using 5 weather data resolutions (WS: weather station, 10 = 10 km × 10 km rid cell, 20 = 20 km × 20 km grid cell, 50 = 50 km × 50 km grid cell, 100 = 100 km × 100 km grid cell, horizontal black lines in the bean plot represent the median value of the requency distribution).

Angulo, C., Rötter, R., Trnka, M., Pirttioja, N., et al. 2013. Characteristic 'fingerprints' of crop model responses to weather input data at different spatial resolutions. European Journal of Agronomy 49: 104-114.

Relationship between percentage fruit set (angular transformed data) and mean floral temperature, from 08:00 to 14:00h, 9 days after flowering in groundnut (Vara Prasad et al. 2000).



Porter J R , and Semenov M A Phil. Trans. R. Soc. B 2005;360:2021-2035

Algorithm: reducing factor for

$$HI = dHI/dt \times GF$$

Challinor et al., 2005; GLAM-HTS

EXREME HEAT :
FLORET MORTALITY, SPIKELT INFERTILITY

Examples of implementation: Rice (ORYZA1, Kropff et al., 1993; SimwRice, Horie et al., 1991); recently: wheat, barley (MONICA, Nendel et al., 2011); ......

Fig.Crop model CROPSYST calibrated for wheat and sunflower (Moriondo et al., 2011)

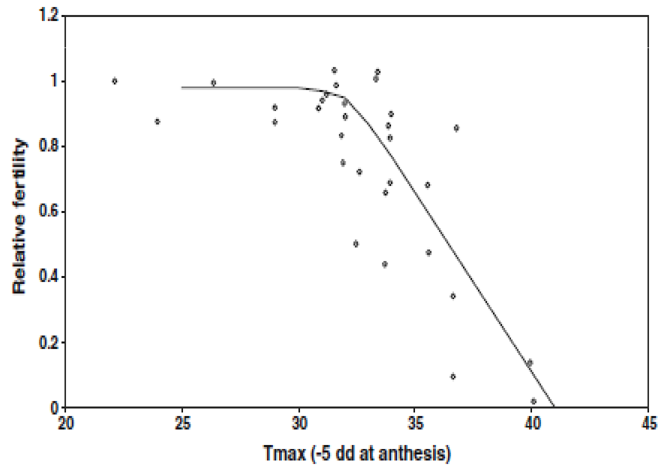
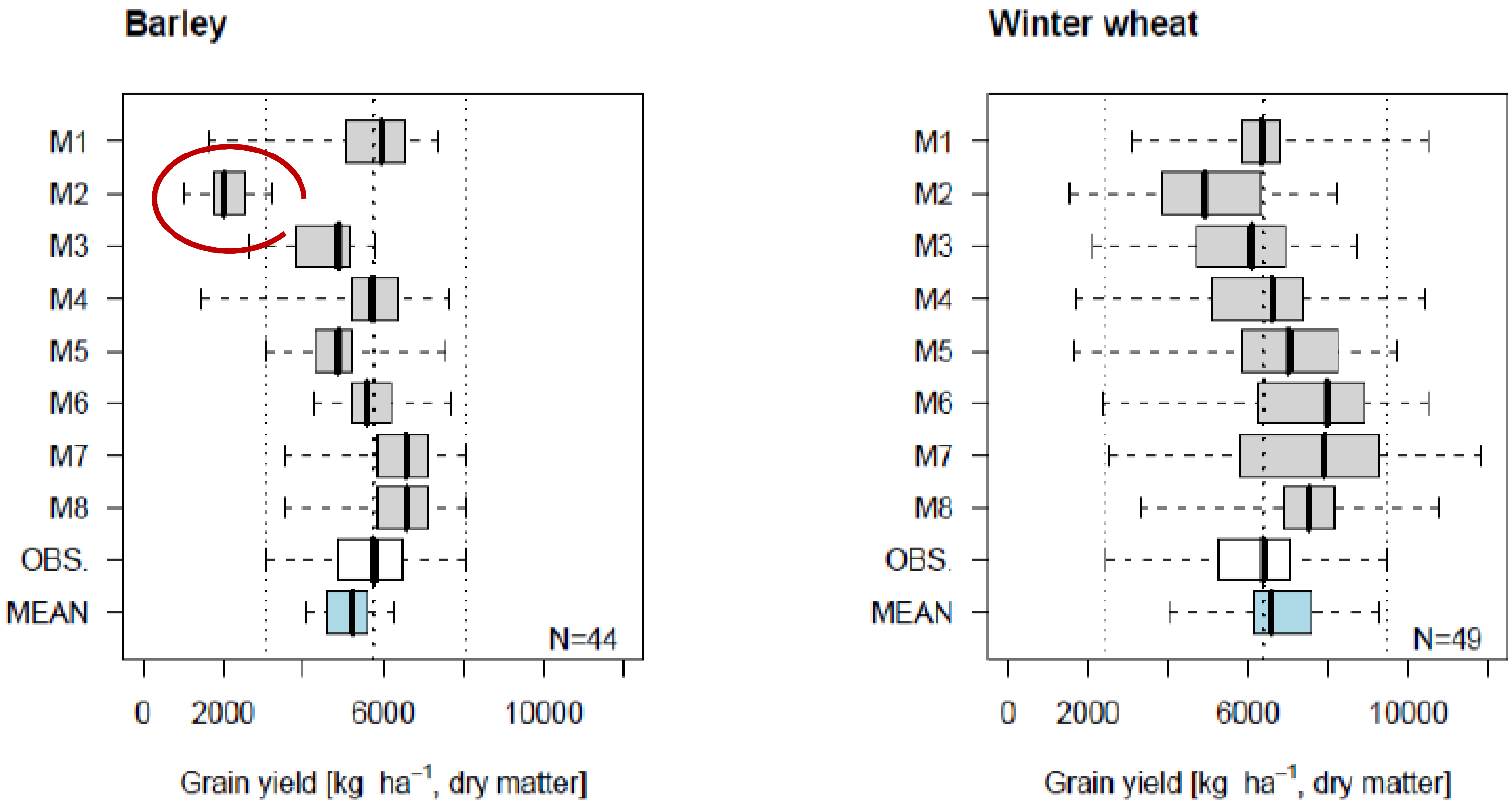


Fig. 2 Wheat ear fertility versus the effect of increasing temperatures in the 5-day period ending at anthesis (Wheeler et al. 2000) simulated by the model proposed by Challinor et al. (2005) after the calibration process (35 grains per ear were considered as fertility = 1)

Source: Climatic change (2011) 104, p. 687

4. OUTLOOK: Need for further improvements
Study ensemble modelling – ? MMM/MME – observed (COST734 mod. intercomp with restr. calibration - example barley)



Sources: Rötter et al. FCR (2012); Palosuo et al., EJA (2011);

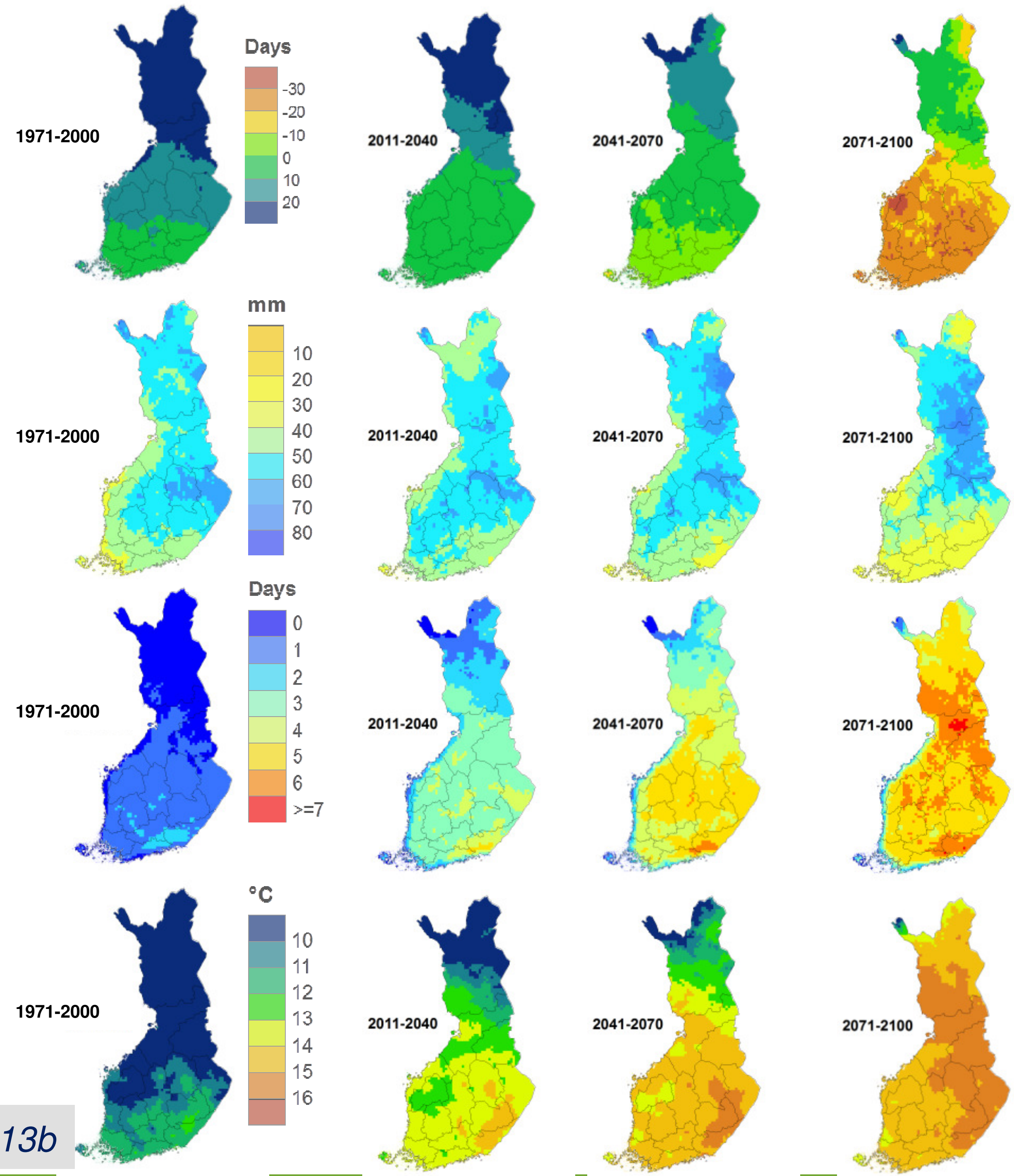
MIROC 3_2
Medres A1B

Sowing date deviation (relative to May 1st)

Rain 3-7 weeks after sowing (early drought stress)

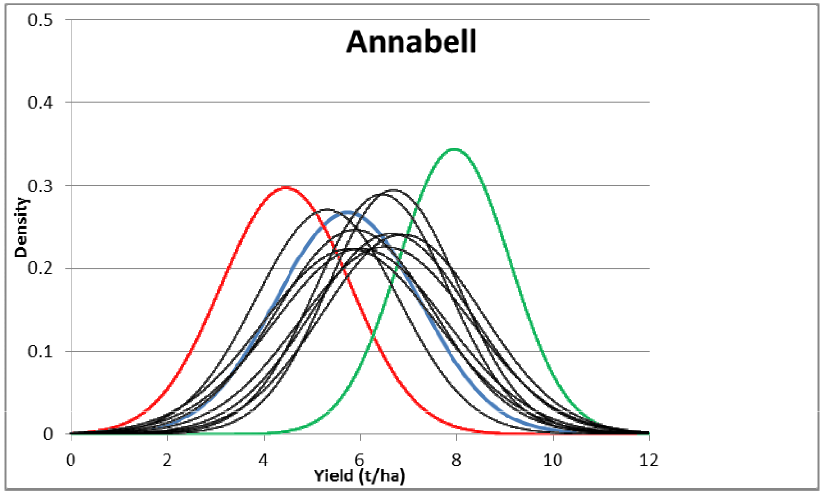
No. of days with Tmax >=28°C around heading (specific heat stress)

Temperature sum accumulation rate per day at grain filling (yield potential reduction risk)



Source: Rötter et al., 2013b

Probability density functions of spring barley yields during 1971-2000 and 2071-2100 under selected climate change scenarios at Utti



Baseline (1971-2000)

IPSL CM 4 A2

GISS MODEL_E_R B1

cccma_cgcm3_1 A1B

miroc3_2_medres A1B

csiro_mk3_5 B1

inmcm3_0 A1B

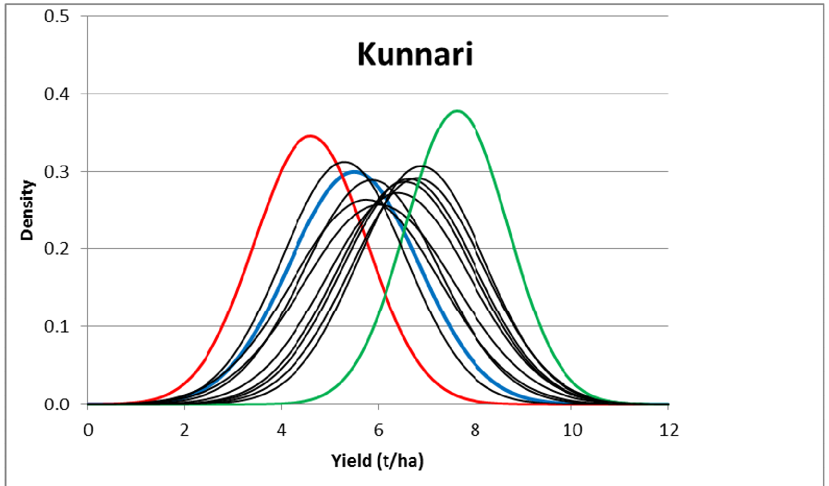
cnrm_cm3 B1

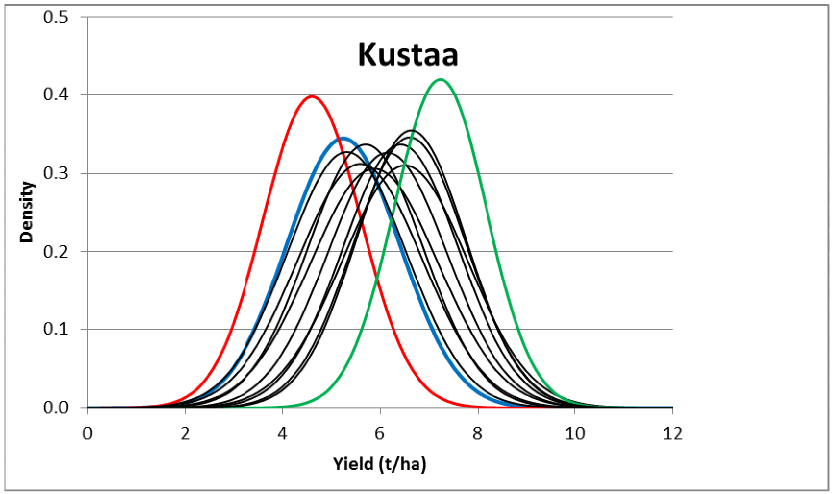
bccr_bcm2_0 A2

cnrm_cm3 A2

cccma_cgcm3_1_t63 A1B

csiro_mk3_5 A1B





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Rötter, Höhn, Trnka, Fronzek, et al. 2013, Acta Agric Scand.

Impact Response Surface Analysis /Probabilistic assessment of CC impacts on crop production

Examples from SW Finland: Pirttioja et al. (2012 ff)

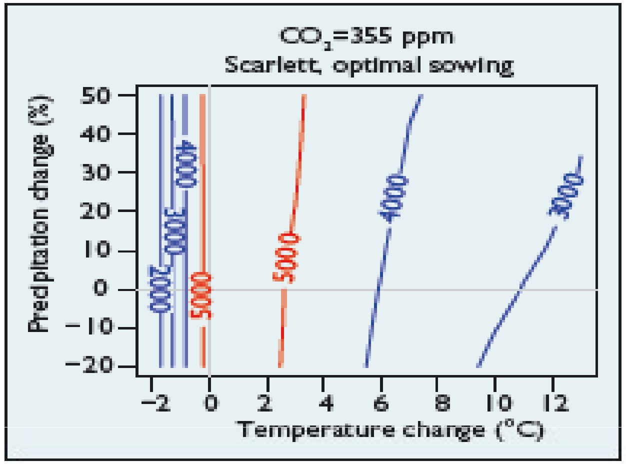


Fig. 2. Impact response surfaces of modelled barley yield with respect to mean annual temperature (°C) and precipitation (%) change relative to 1971-2000 for 355 ppm [CO_2] – 1990 value – and optimal sowing. The bold red isoline indicates the mean yield in 1971-2000 (5000 kg/ha) for 10 May sowing used as a threshold.

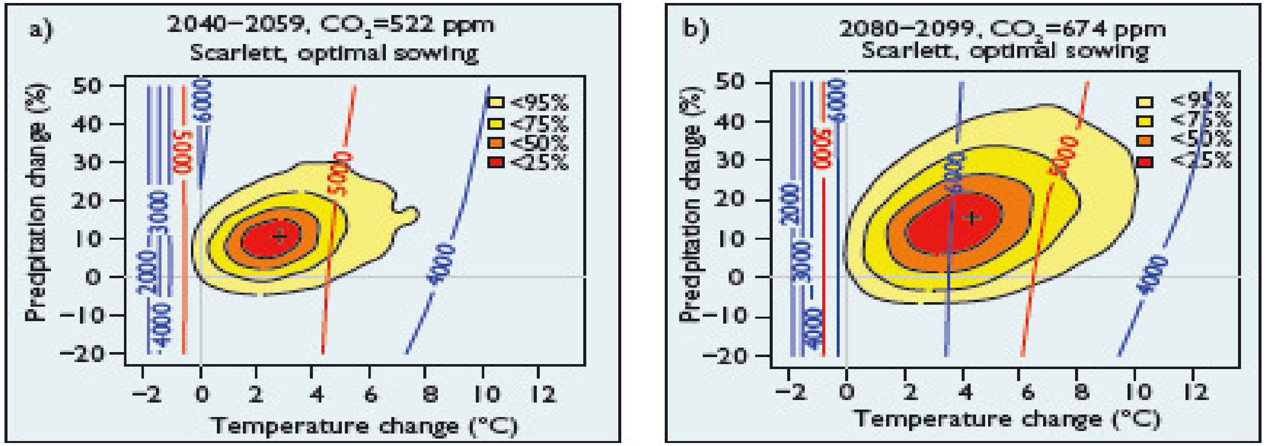
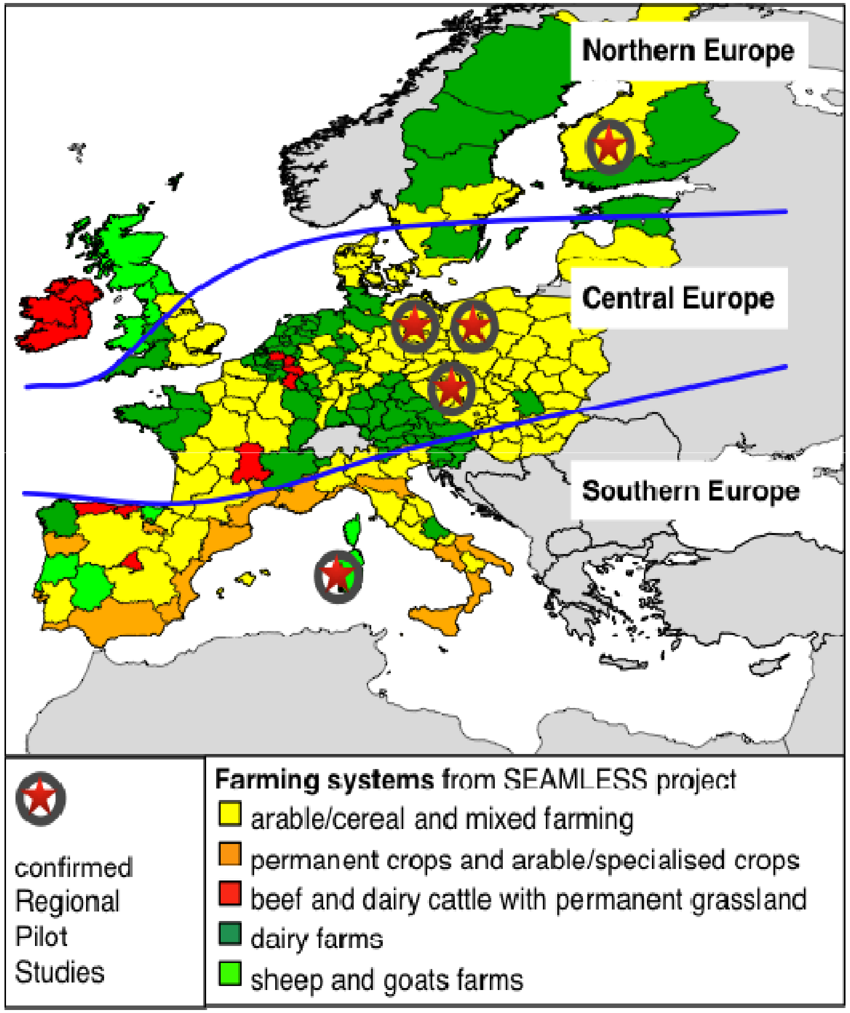
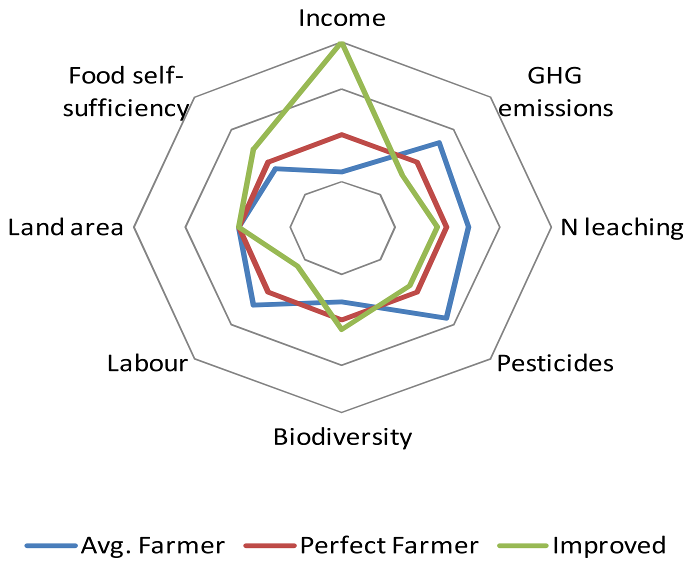


Fig. 3. Impact response surfaces of modelled barley yield with respect to annual temperature and precipitation change for [CO_2] levels representing two future periods (isolines) and relative frequency of annual temperature and precipitation changes for the same periods relative to 1971–2000 (coloured shading, %) – projected under the SRES A1B scenario for: (a) 2040–2059, and (b) 2080–2099. The bold red isoline is the threshold yield level.

MACSUR : Regional Pilot Studies

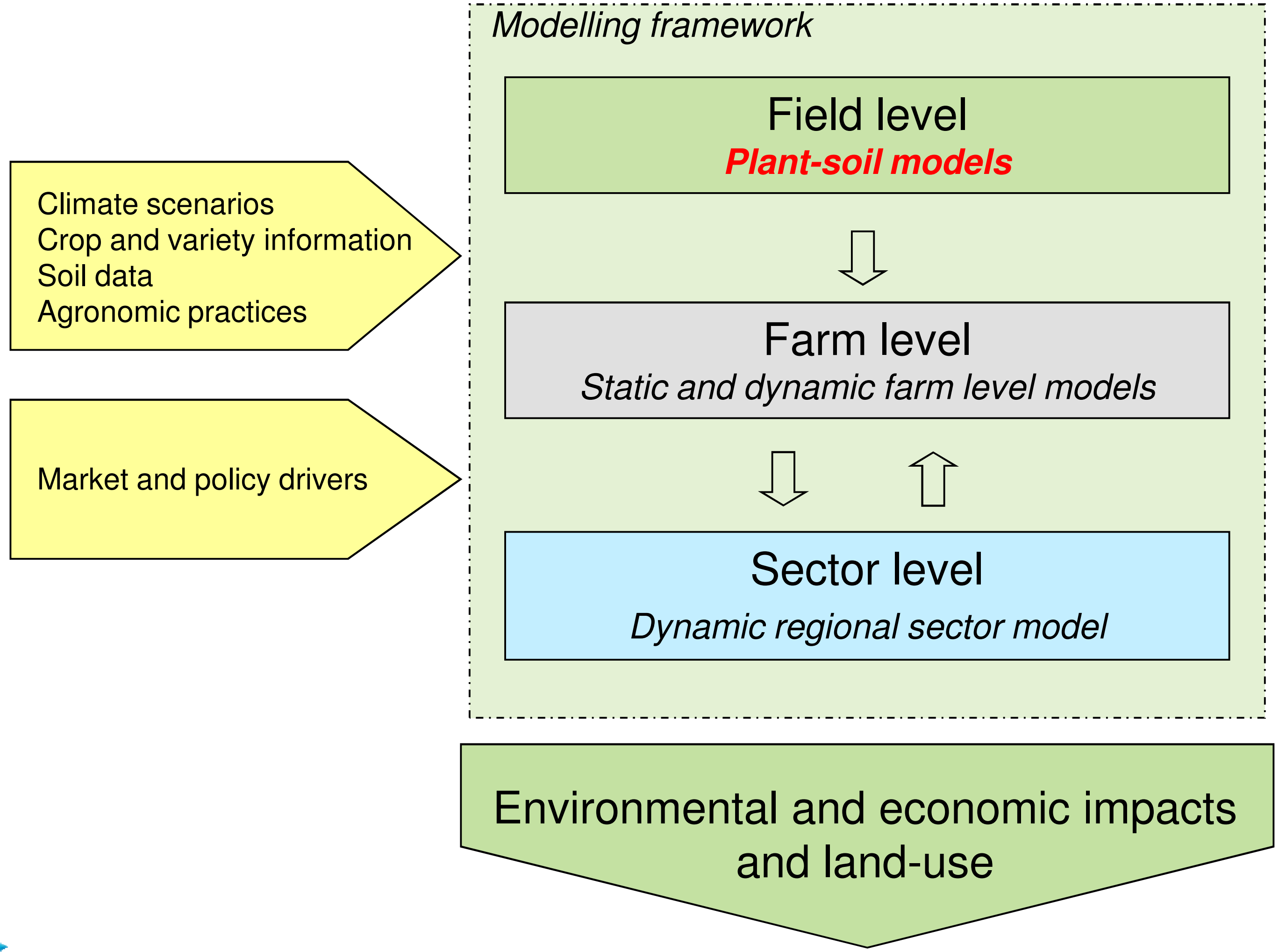


Multitude of appoaches – one direction is upscaling from ***farrm level*** (for typical farm types) of mitigative adaptation options via region/national to supra-national scales – also takingInto account other Sustainable DevGoals – e.g. NORFASYS *Rötter et al., 2013b*)

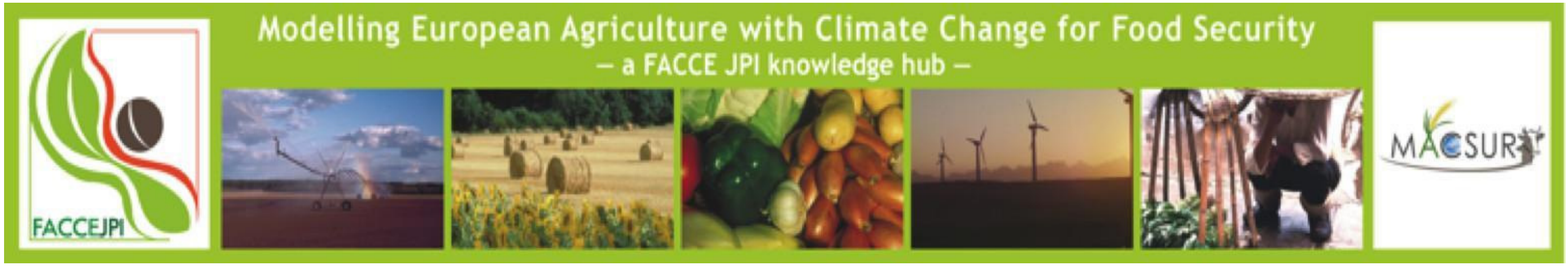


Qualitative illustration goal achievement under alternative management

Agro-ecosystem models as part of IA modelling systems (e.g. NORFASYS)



Lehtonen et al. 2010. JAS



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CropM International Symposium and Workshop: Modelling climate change impacts on crop production for food security

The international crop modelling community meets between **10-12 February 2014 at Oslo, Norway**, to assess the state-of-the-art in crop modelling for climate change risk assessment, and develop a joint vision and research agenda for the future. The event is organized by CropM of MACSUR.

Confirmed keynote speakers at the symposium:
John R Porter (Denmark): State-of-the-art of crop modelling ...
Gerald C Nelson (USA): Critical Challenges for Integrated Modelling of CC ....

THANKS!

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Selection for Further Reading

Overview articles – climate variations, weather and crop yields; uncertainties in modelling climate impacts on crops/plants

- Angulo et al., 2013, Europ. J. Agronomy 49, 104-113.
- Asseng et al. 2013, Nat Clim. Chang., 3, 827-832.
- Boote et al., 2013, Plant ,Cell and Environment. Doi: 10.1111/pce.12119 (in press)
- Monteith, 1981. Q. J. R. Meteorol. Soc. 107, 749–774.
- Palosuo et al., 2011. Europ J. Agronomy 35, 103-114.
- Porter & Semenov, 2005. Phil. Tran. R. Soc. B., 360, 2021-2035
- Reyer et al., 2013. Glob. Change Biol., 97, doi: 10.1111/gcb.12023
- Rötter et al., 2011, Nat Clim. Chang., 1, 175-177.
- Rötter et al., 2012, Field Crops Res. 133, 23-36.
- Rötter et al., 2013a, Ecology and Evolution 3, 4197-4213.
- Rötter et al., 2013b. http://www.climate-impacts-2013.org/files/wism_roetter_1.pdf Proceed Impacts World 2013
- Rosenzweig, & Parry 1994, Nature 367, 133-138.
- Rosenzweig et al., 2013. Agricultural and Forest Meteorology 170, 166-182.
- Wallach et al., in prep. AgMIP White paper on Characterizing and Quantifying Uncertainty
- Wheeler & von Braun, 2013, Science. 341, 508-513.