Uncertainty in the Assessment of Climate Change Impacts on the Agricultural Sector and Food Security

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NASA Goddard Institute for Space Studies, New York City

IMAGe Theme of the Year

August 7th, 2012

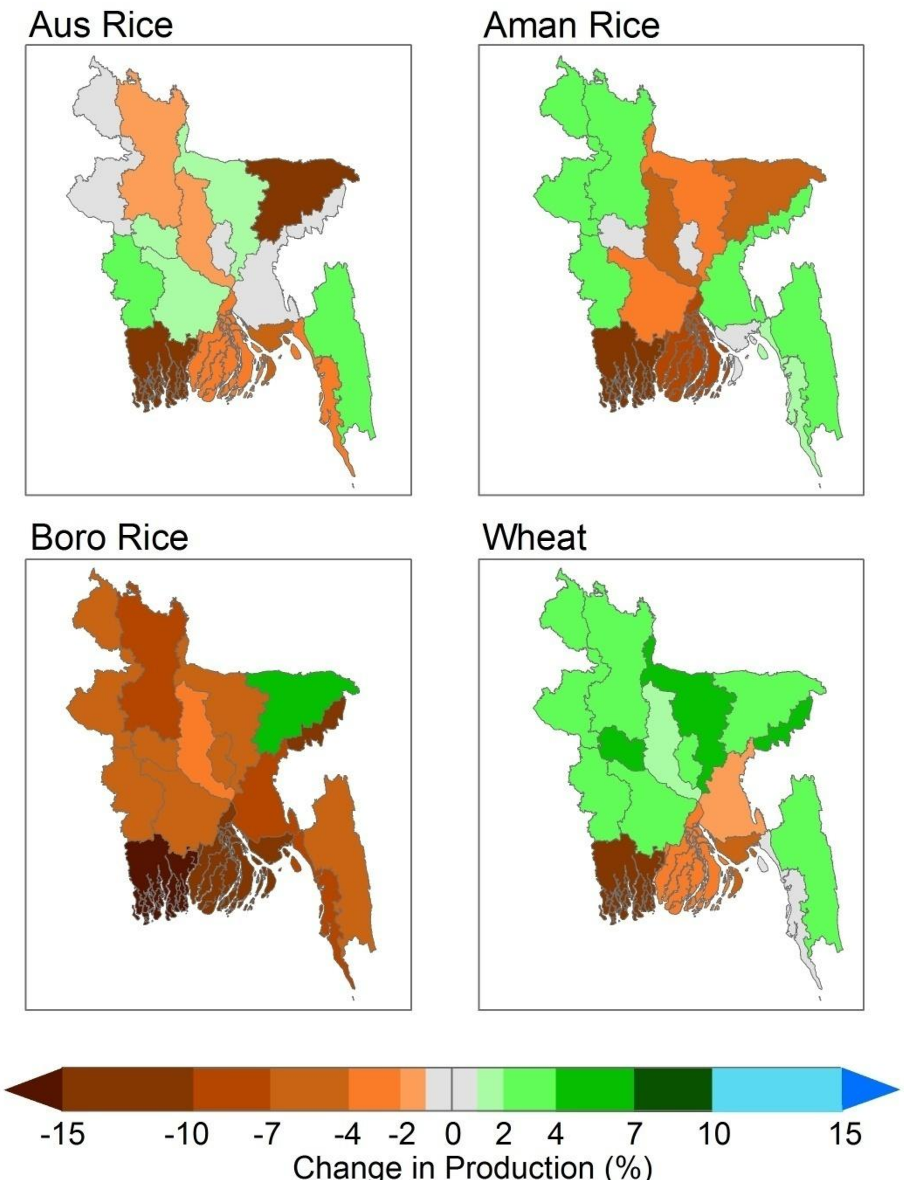
AgMIP The Agricultural Model Intercomparison and Improvement Project

CERES-Rice Crop Model Projections for Bangladesh (2050s)

World Bank project examined river floods, sea level rise, local rainfall, temperatures, and CO_2

(Yu et al., 2010; Ruane et al., 2012)

Projected Change in Production for combined 2050s
A2 and B1 Scenarios - Combined Effects



(2050s as compared to 1980s)
(median of 16 GCM-based scenarios displayed)

Outline

Agricultural impacts happening now

Plants grown on small scale
Agricultural products are traded in a world market
Production and prices affect rich and poor people differently

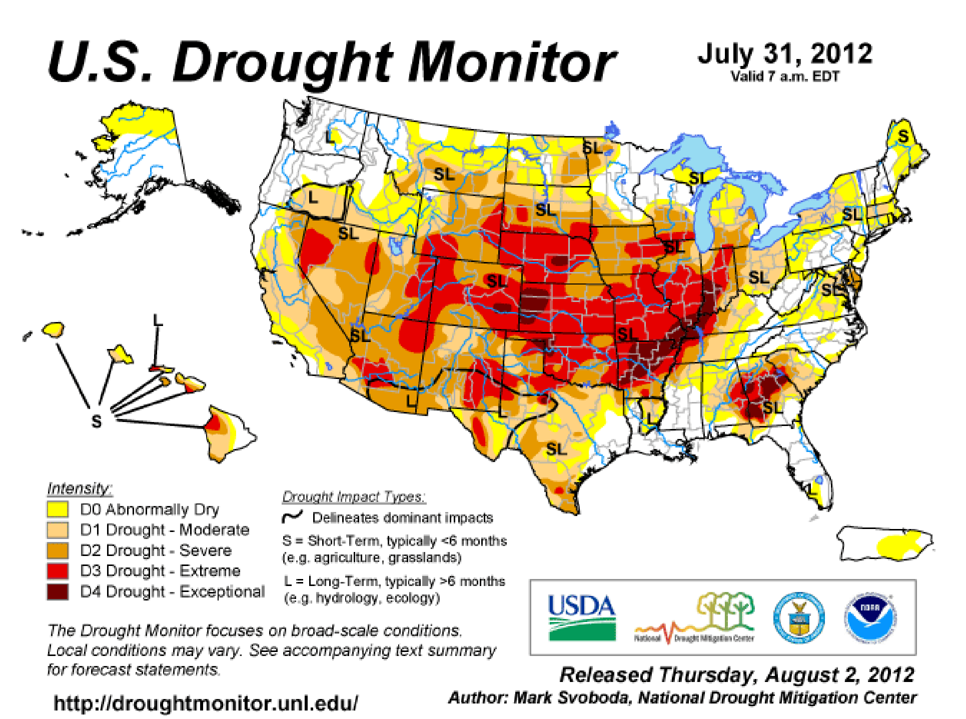
Motivation and organization of the Agricultural Model Intercomparison and Improvement Project (AgMIP)

Agricultural impacts depend on a variety of uncertain development factors before we even get to modeling

Agricultural Impacts assessments have multiple sources of uncertainty

Continuing Uncertainty Challenges

Agricultural Impacts are Happening now…



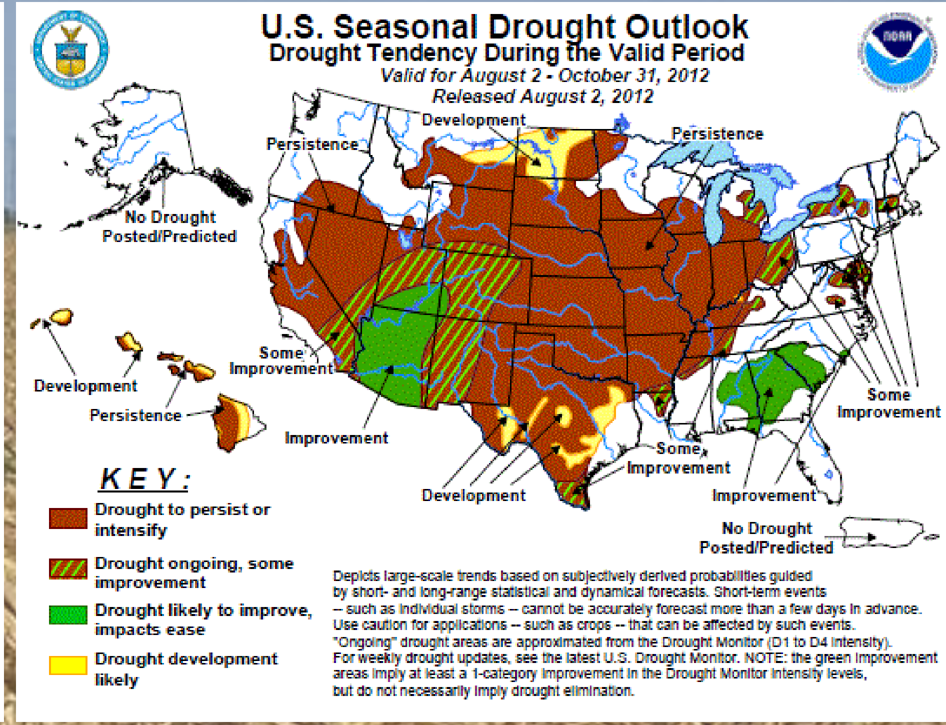


Photo: Billy Hathorn, Wikimedia Commons

Half of US counties now considered disaster areas

AP By JIM SUHR | Associated Press – 11 hrs ago

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Corn plants struggle to survive in drought-stricken farm fields in Jasper, Indi

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ST. LOUIS (AP) — Nearly
states were added Wedne
natural disaster areas as t
help for frustrated, cash-s

GRAINS-Corn and soybeans hit record highs, stir food crisis fear

Reuters; July 19, 2012

* Soybeans set record high

* Corn front-month hits record top, off peak

* Wheat nears four-year high

* U.S. govt forecasts hot, dry weather to continue (Adds analyst quotes, updates market action at the close)

By K.T. Arasu

CHICAGO, July 19 (Reuters) - Corn and soybeans soared to record highs on Thursday as the worsening drought in the U.S. farm belt stirred fears of a food crisis, with prices coming off peaks after investors cashed out of the

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India's Drought Highlights Challenges of Climate Change Adaptation

The current drought brings into focus India's vulnerabilities to the changes wrought by global warming

By Robert S. Eshelman and ClimateWire | August 3, 2012 | 6

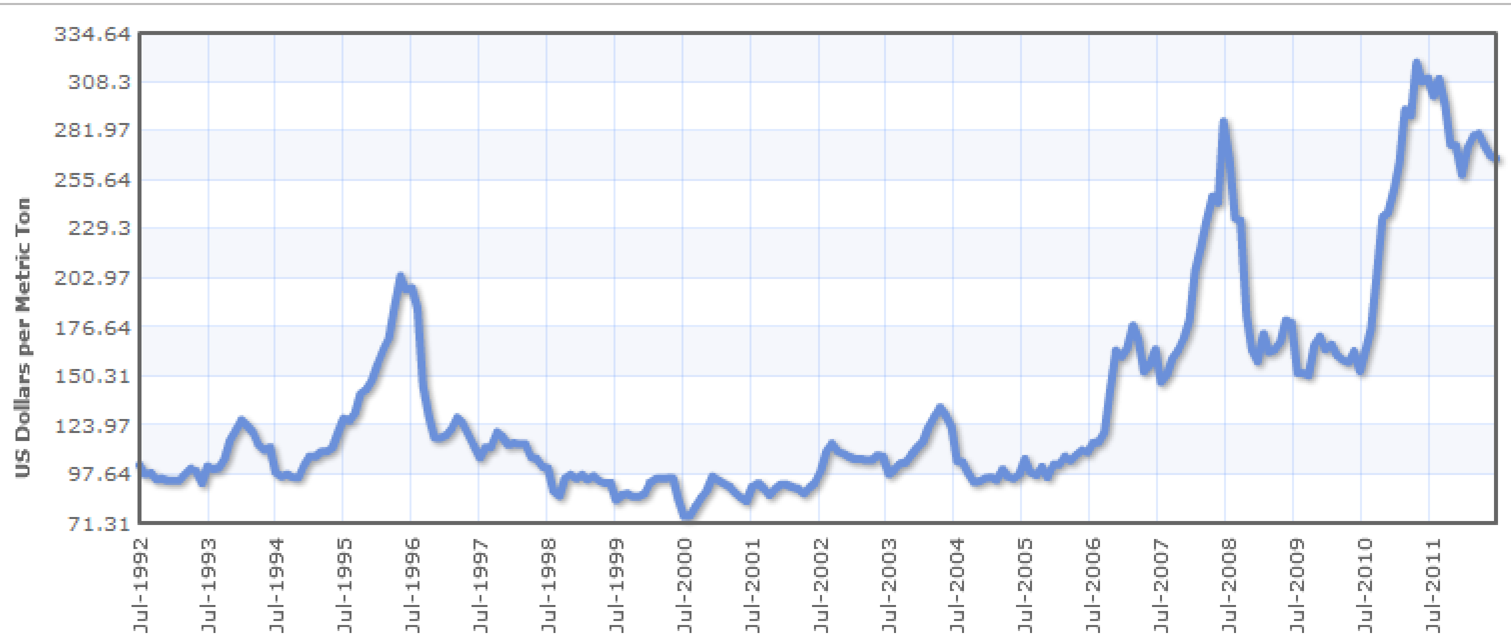
Maize (corn) Daily Price

339.37

Maize (corn), U.S. No. 2 Yellow, FOB Gulf of Mexico, U.S. price, US$ per metric ton
Price in US$ per bushel: 8.62
As of: Friday, August 03, 2012
Source: USDA Market News

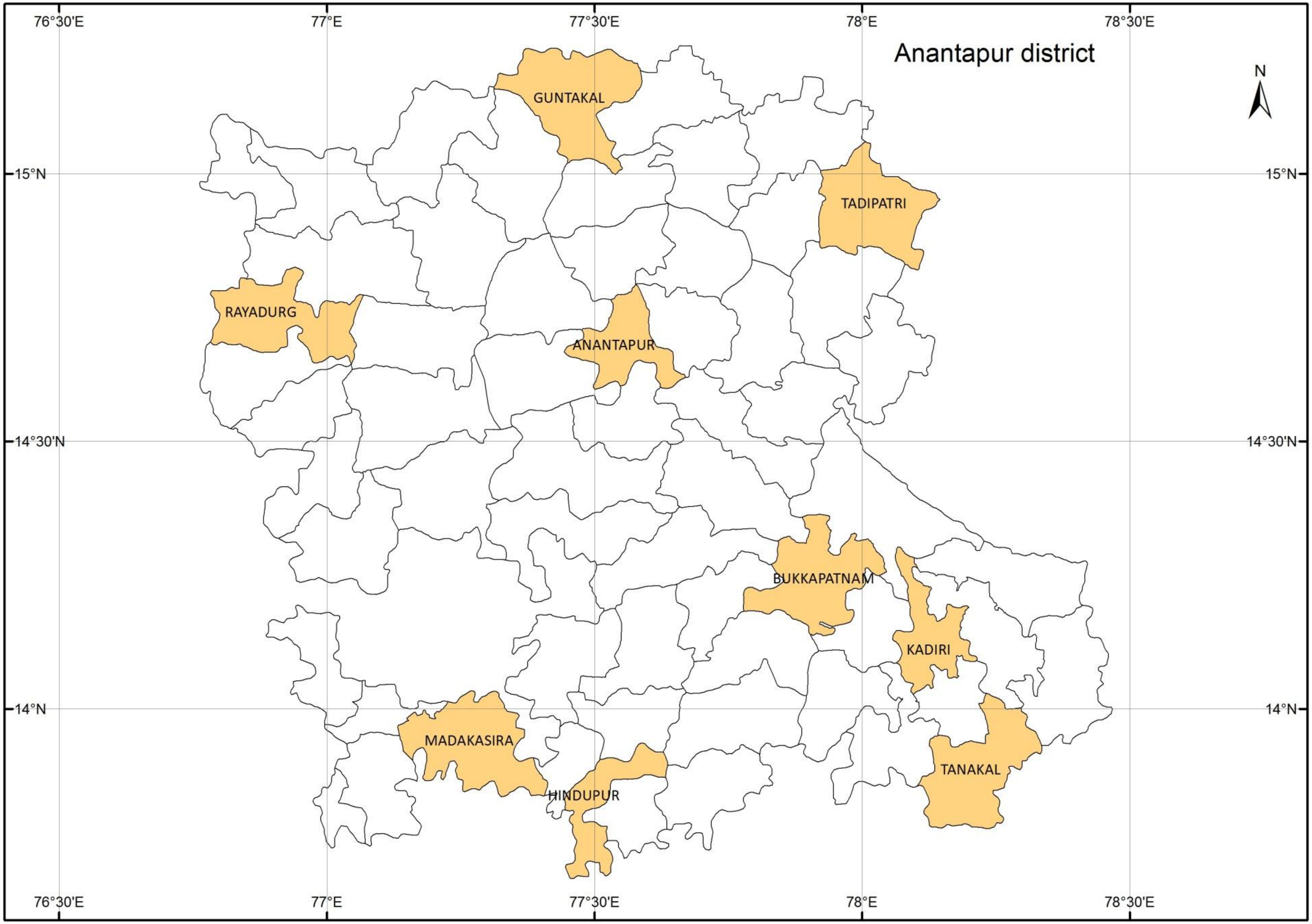
Maize (corn) Monthly Price - US Dollars per Metric Ton

Range 6m 1y 5y 10y 15y 20y 25y 30y   Jul 1992 - Jun 2012: 164.840 (160.99 %)

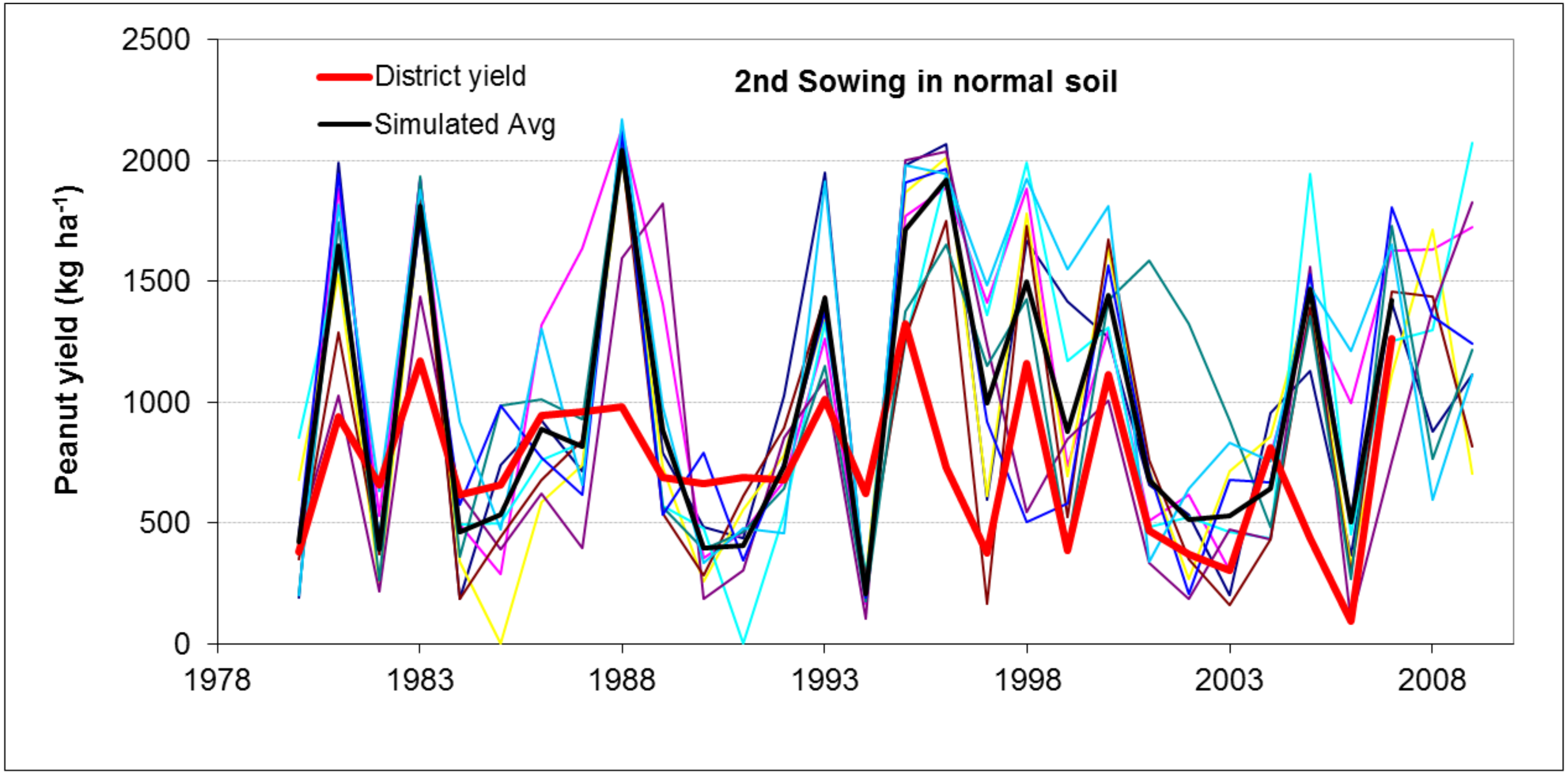


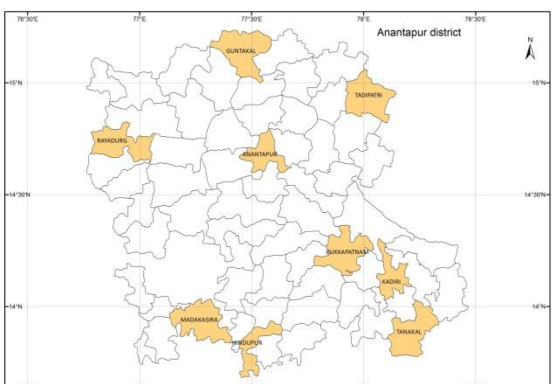
Plants grown on small scale

Anantapur (India) Peanut Simulations



Anantapur (India) Peanut Simulations



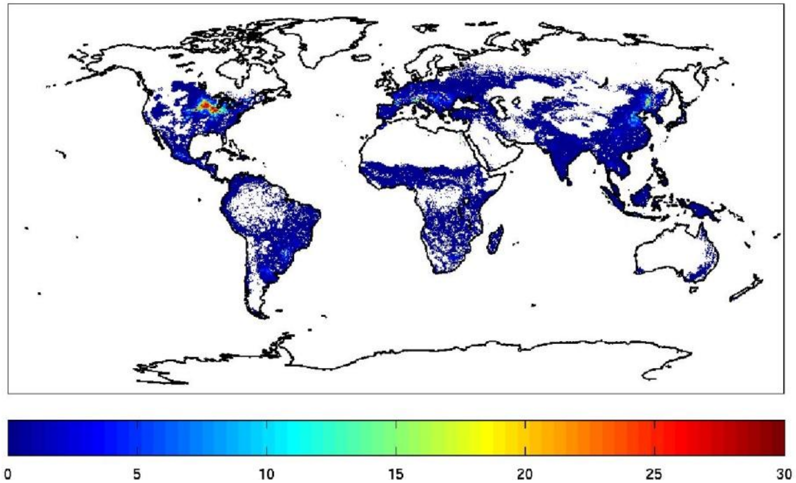


Peanut simulations using 9 different precipitation gauges in Anantapur district reveal substantial differences

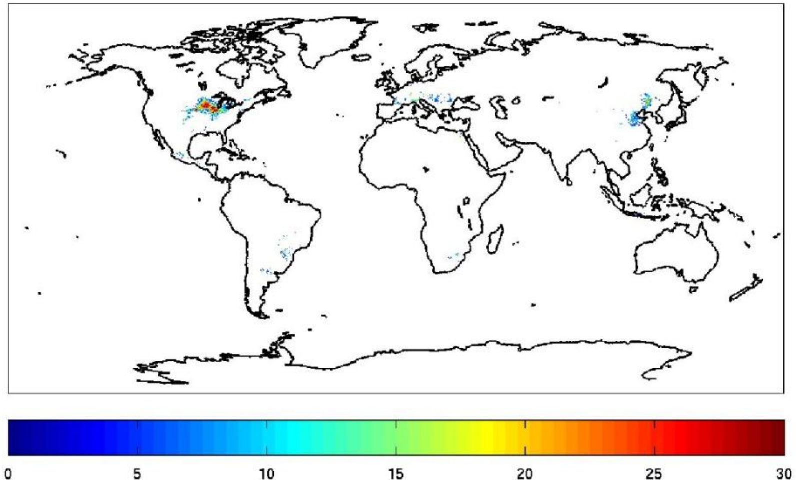
Agricultural products are traded in a world market with a large number of commodities and many additional pressures

Simulating a Global Commodity

Maize Production (1000s of kg)

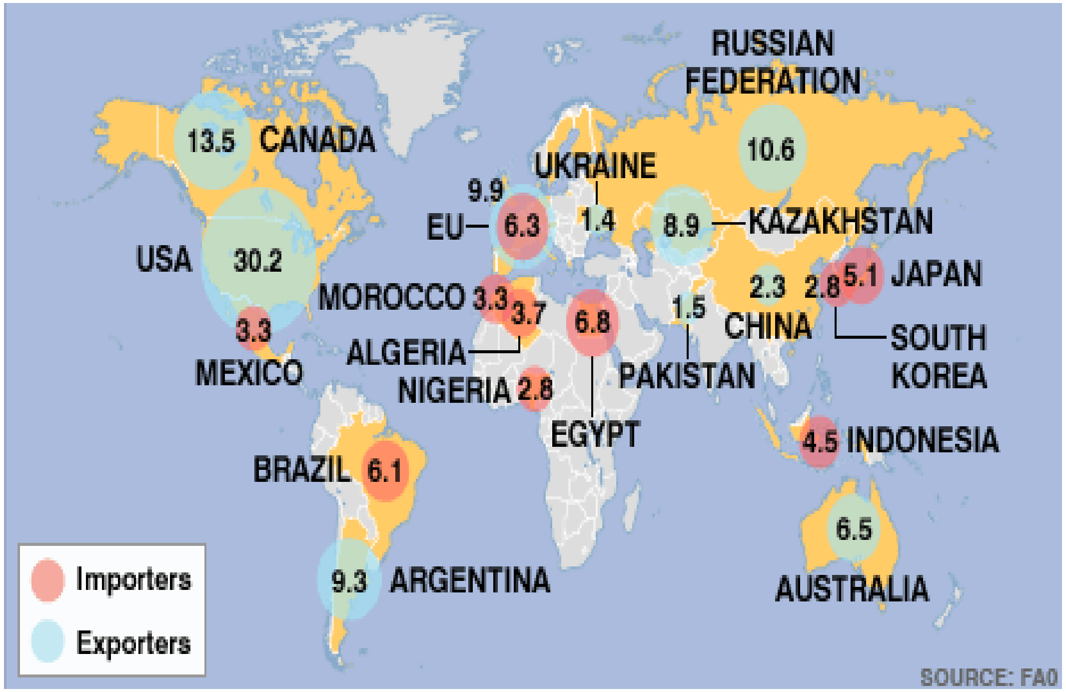


Top Regions Accounting for 90% of World Maize Production



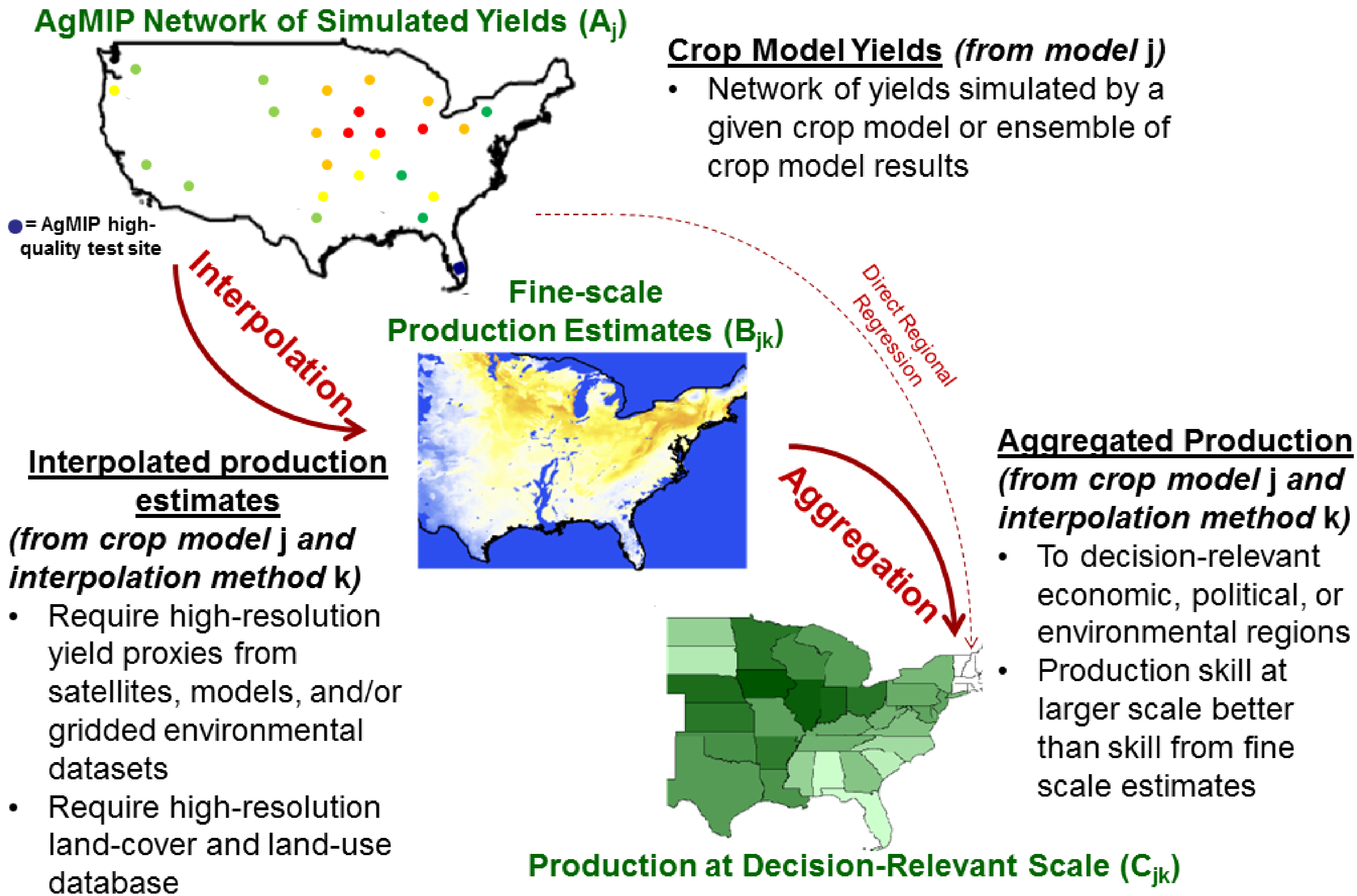
Data from Monfreda et al., 2002

Wheat Imports and Exports



Wheat: From BBC Newsnight, 04/15/2008

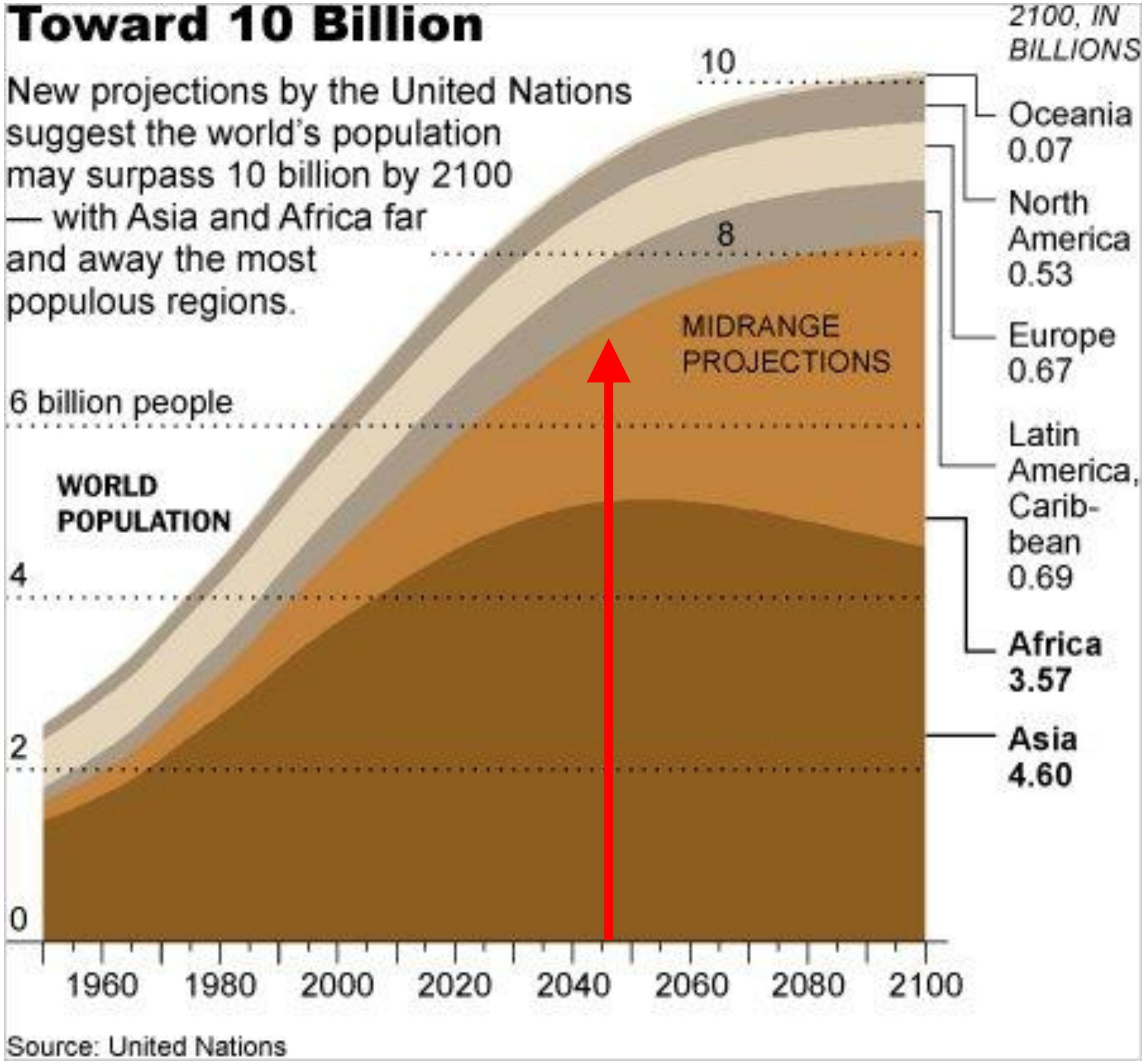
Aggregation to Decision-Relevant Spatial Scales



Agricultural Risk Factors

- Declining food stocks – world stocks were at their lowest in 2008 since the 1970s
- Poor harvests in major producing countries linked to extreme weather events
- High oil and energy prices raising the cost of fertilizers, irrigation and transportation
- Lack of investment in the agricultural sector
- Subsidized production of bio-fuels that substitute for food production
- Speculative transactions, including large commercial traders hedging in futures markets and small traders hedging and building up storage
- Export restrictions, potential domino effect
- Longer-term issues: population growth; changes in demand; land availability; yield plateaus; yield gaps; climate change

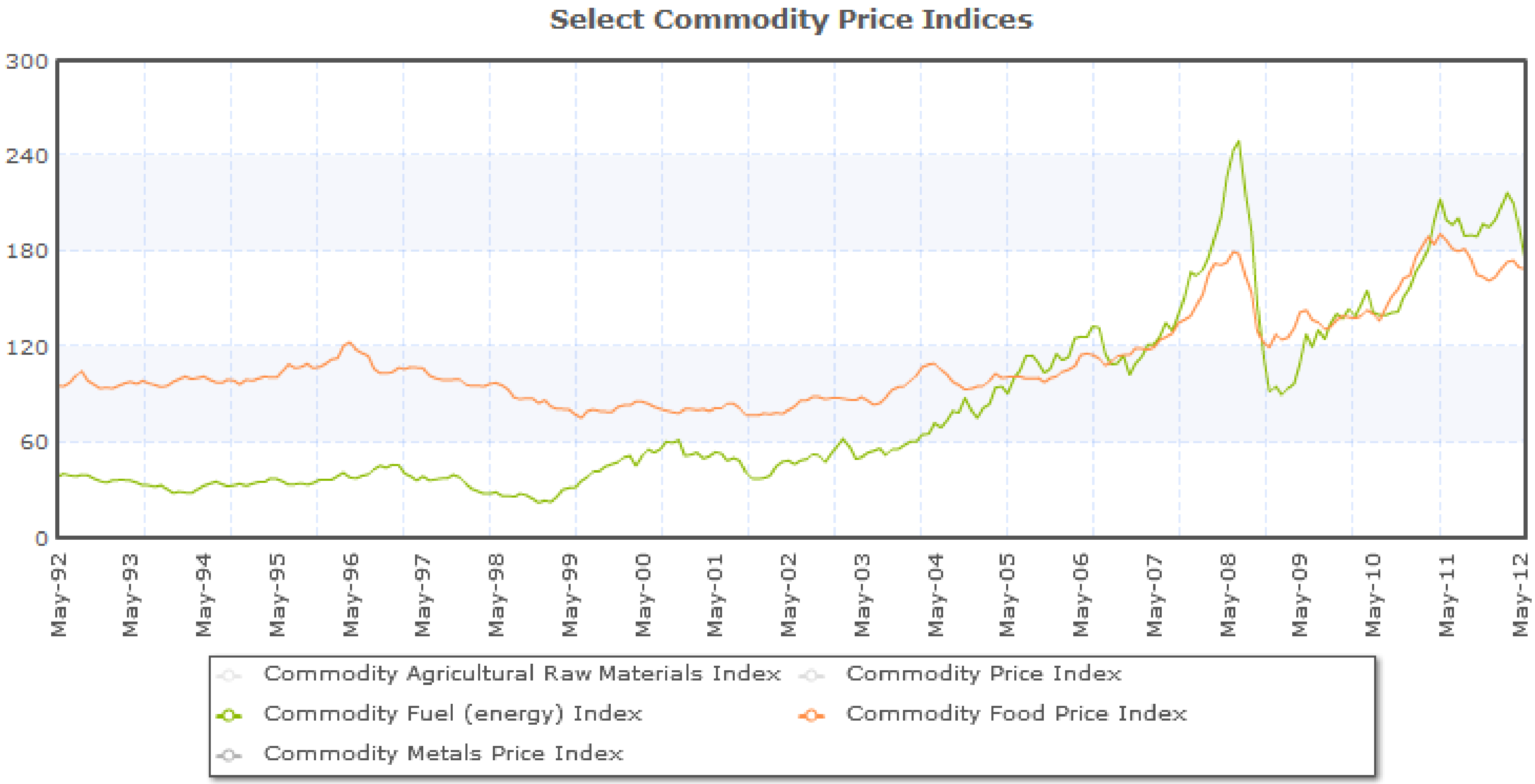
Global Population Projections



Large challenges for the agricultural sector:

- Increased population
- changing appetites
- competition for land use

Oil prices affect many agricultural commodities



Source: http://www.indexmundi.com/commodities/

Longer Term Issues: Yield Plateaus

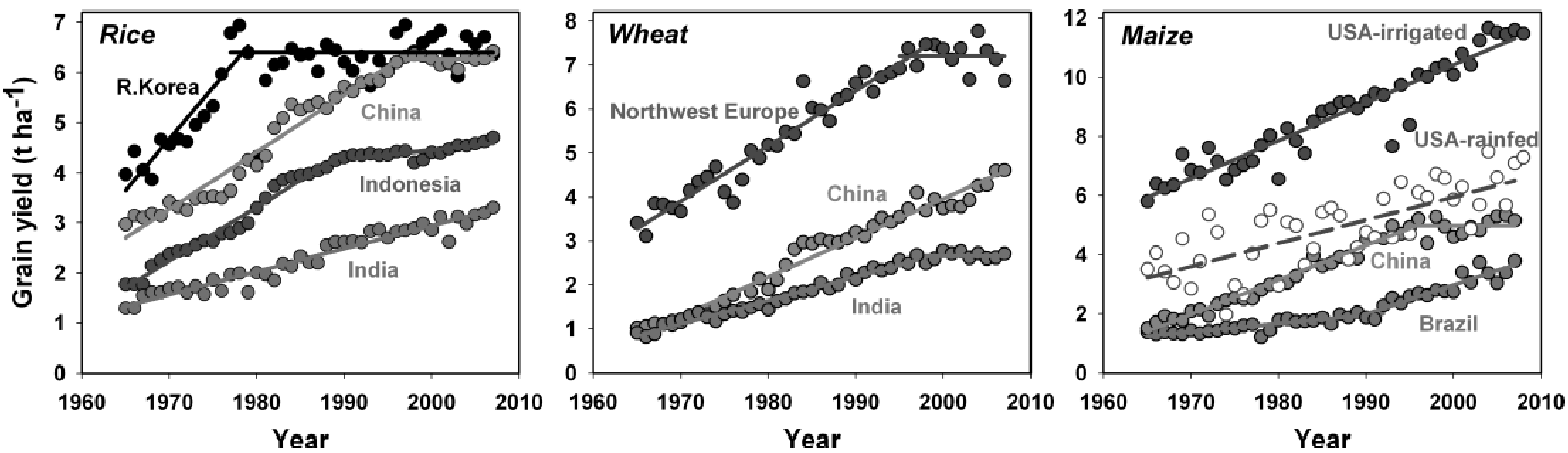
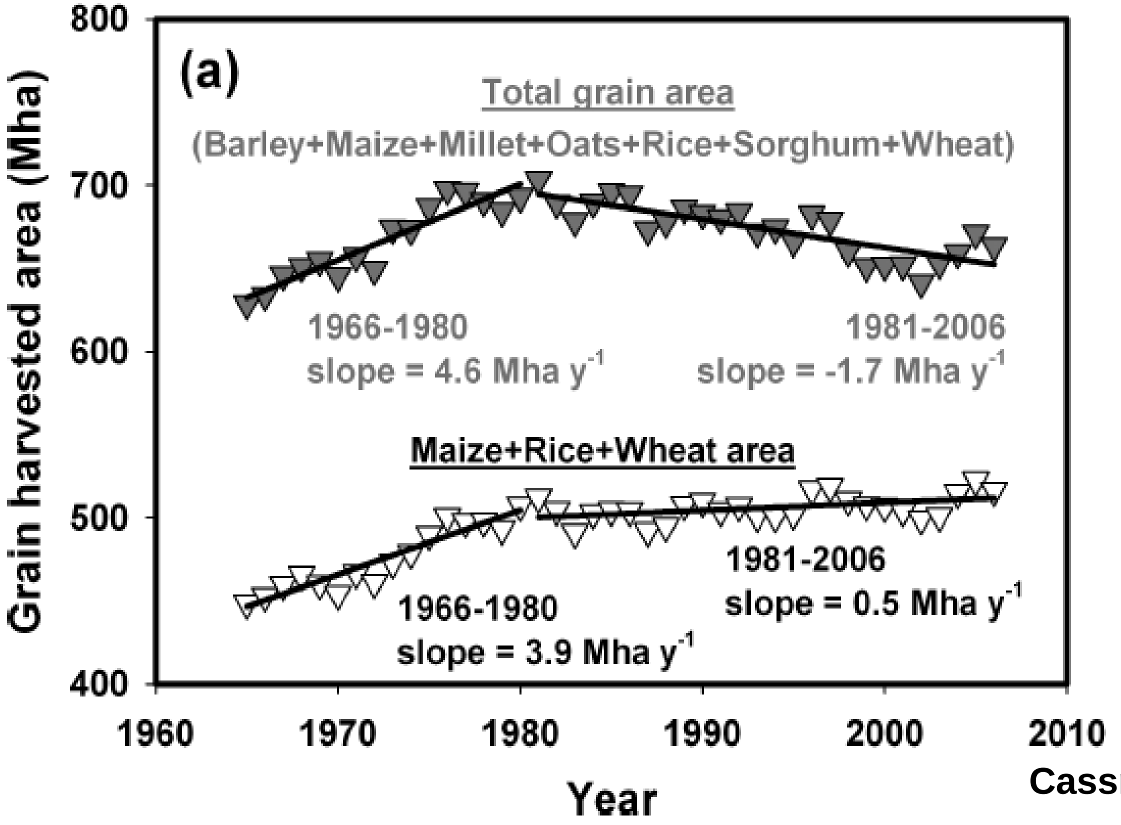


Fig. 2. Grain yield trends of the three major cereals in selected countries. USA maize yields are means for the western Corn Belt and Great Plains states: CO, KS, NE, ND, OK, SD, TX, and WY.

Cassman et al., 2011

Longer Term Issues: Land Availability



Cassman et al., 2011

Fig. 1. (a) Global land area used in cereal production.

Longer Term Issues
Land Availability & Yield Plateaus

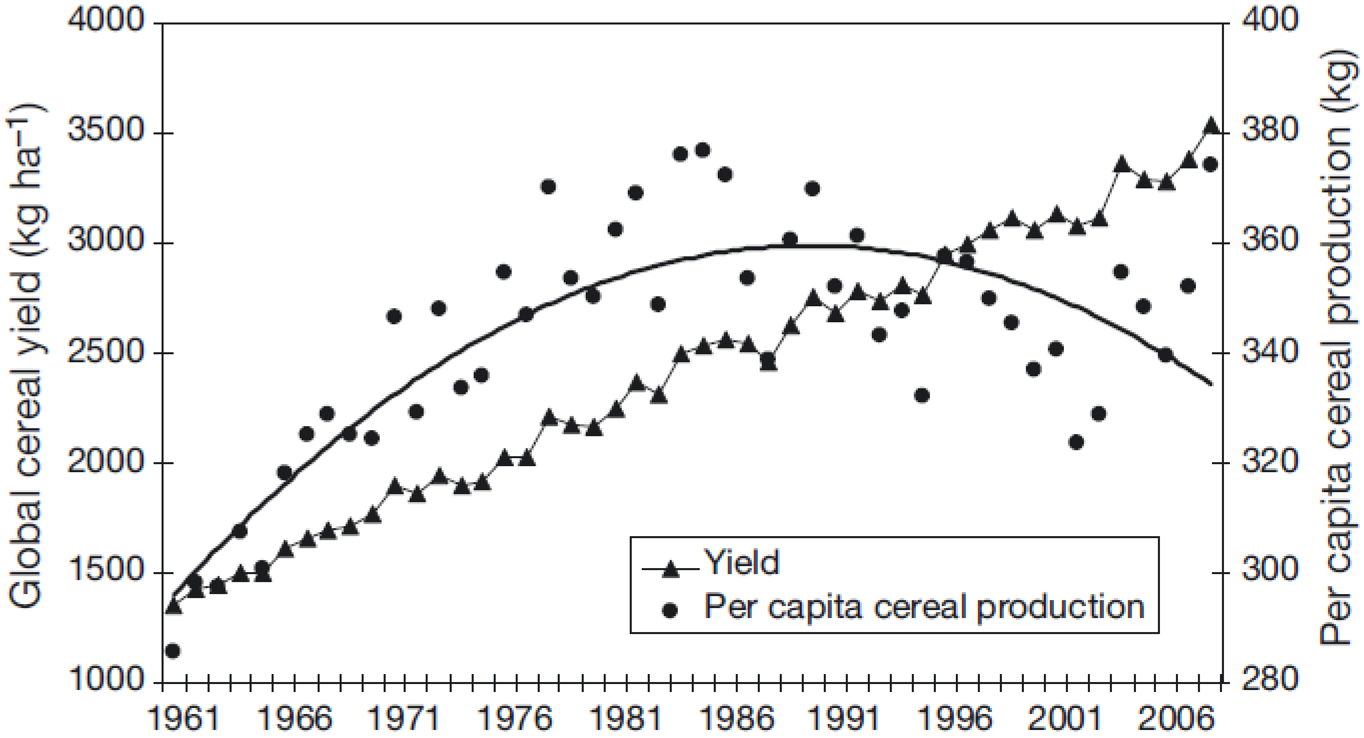
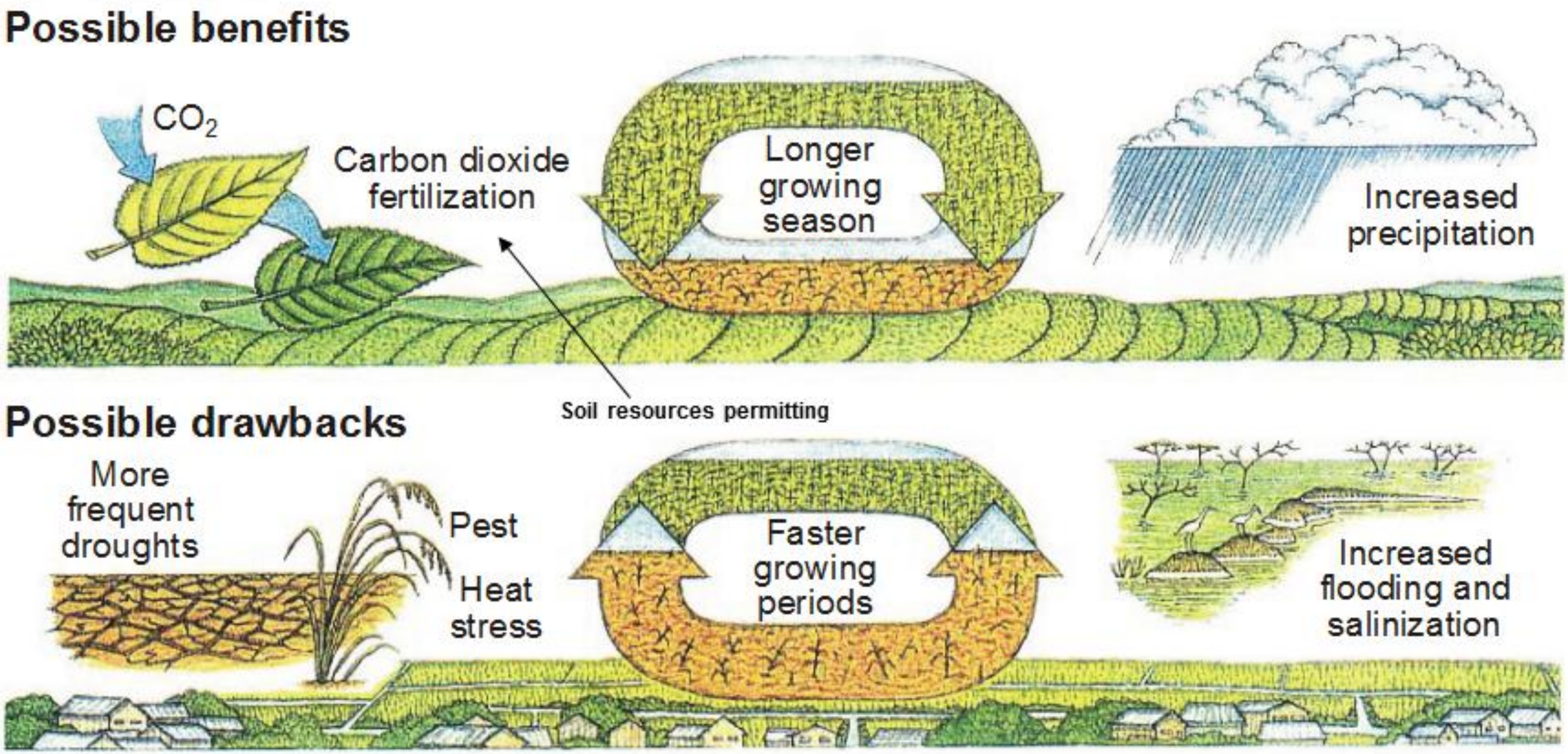


Fig. 1. Average global cereal yields and per capita cereal production (kg) for 1961–2008 (annual global per capita cereal production, calculated as total global production for a given year divided by total global population for that year) (FAO 2010a)

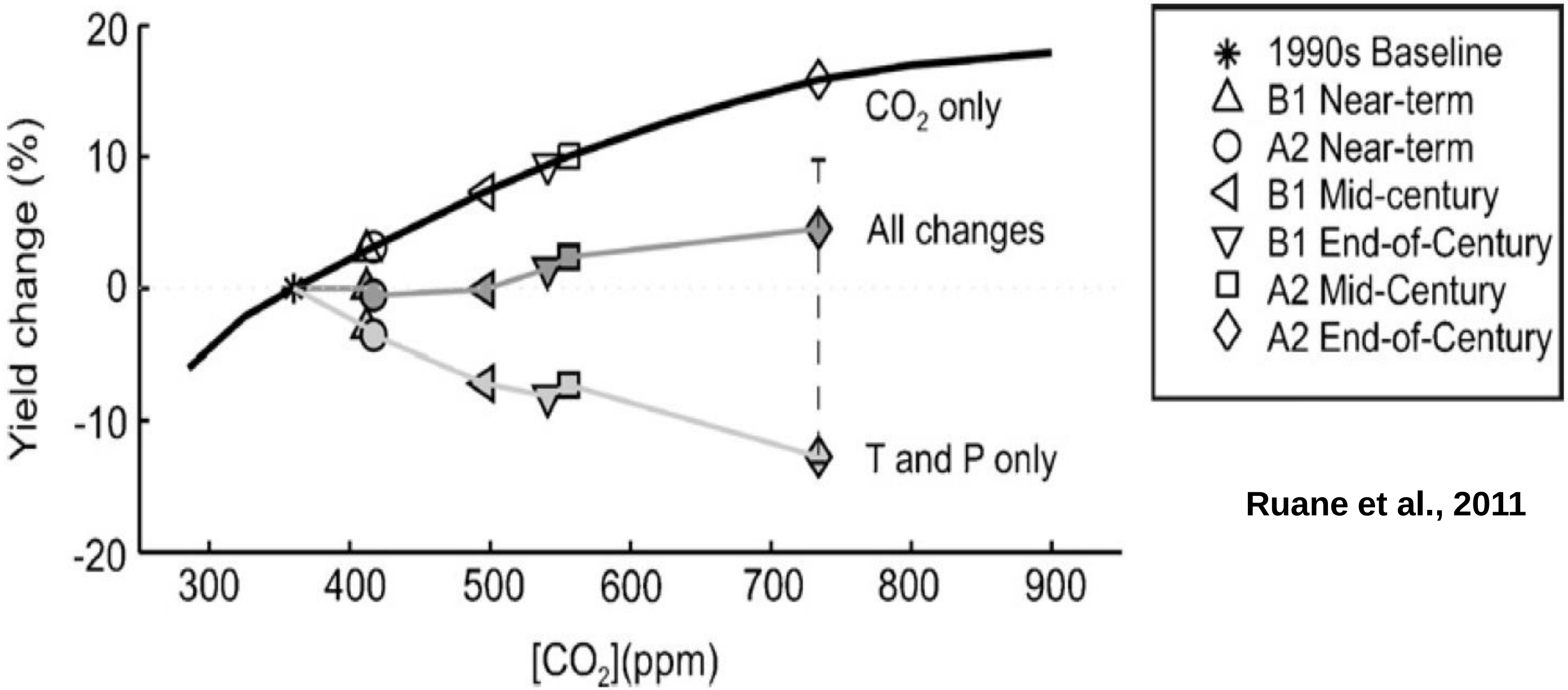
Selvaraju et al., 2011

Climate Change Impacts – Agriculture



Bongaarts, J., Scientific American, 1992

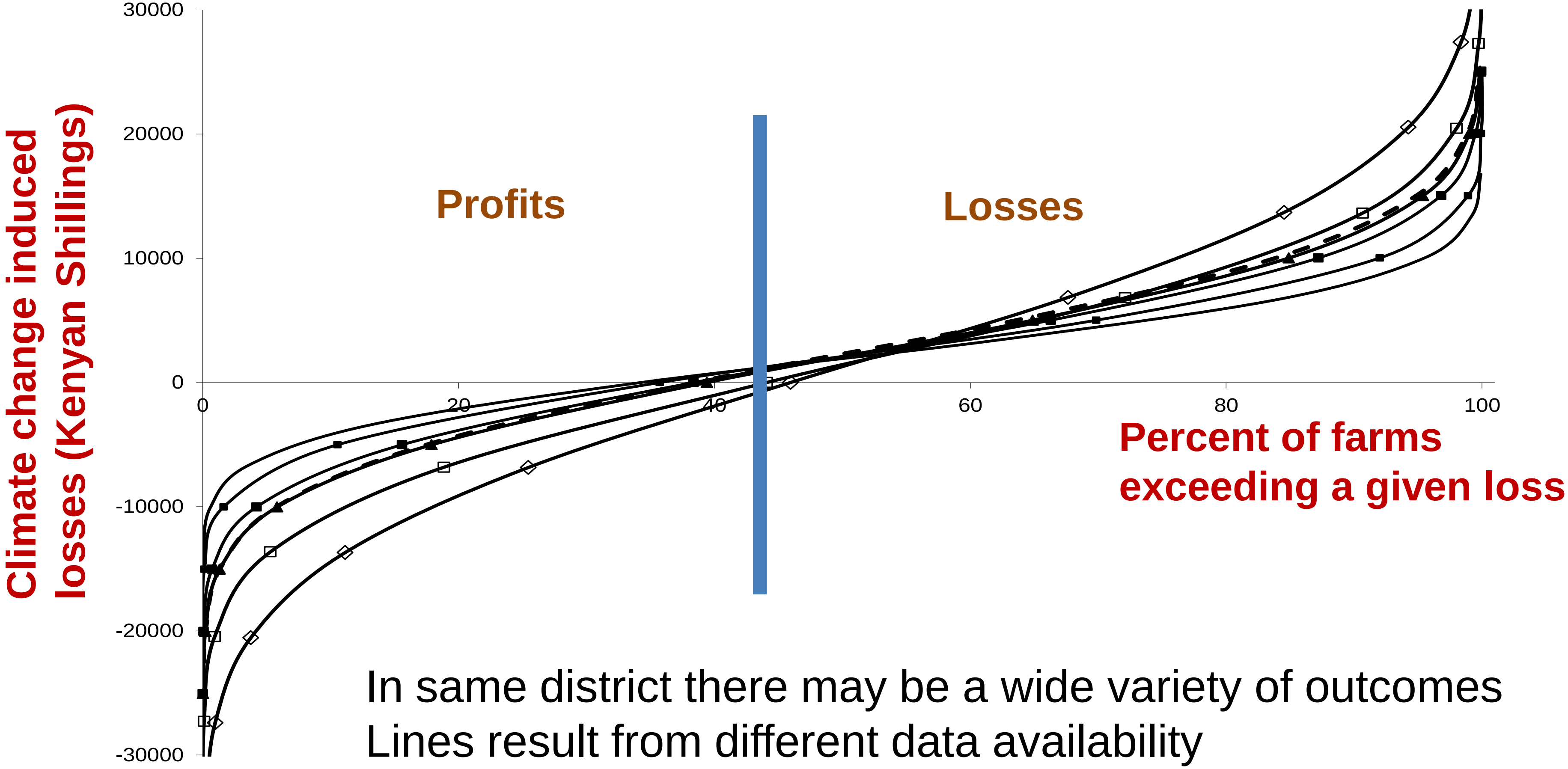
Climate Change – Dueling Effects



Ruane et al., 2011

Production and prices affect rich and poor people differently

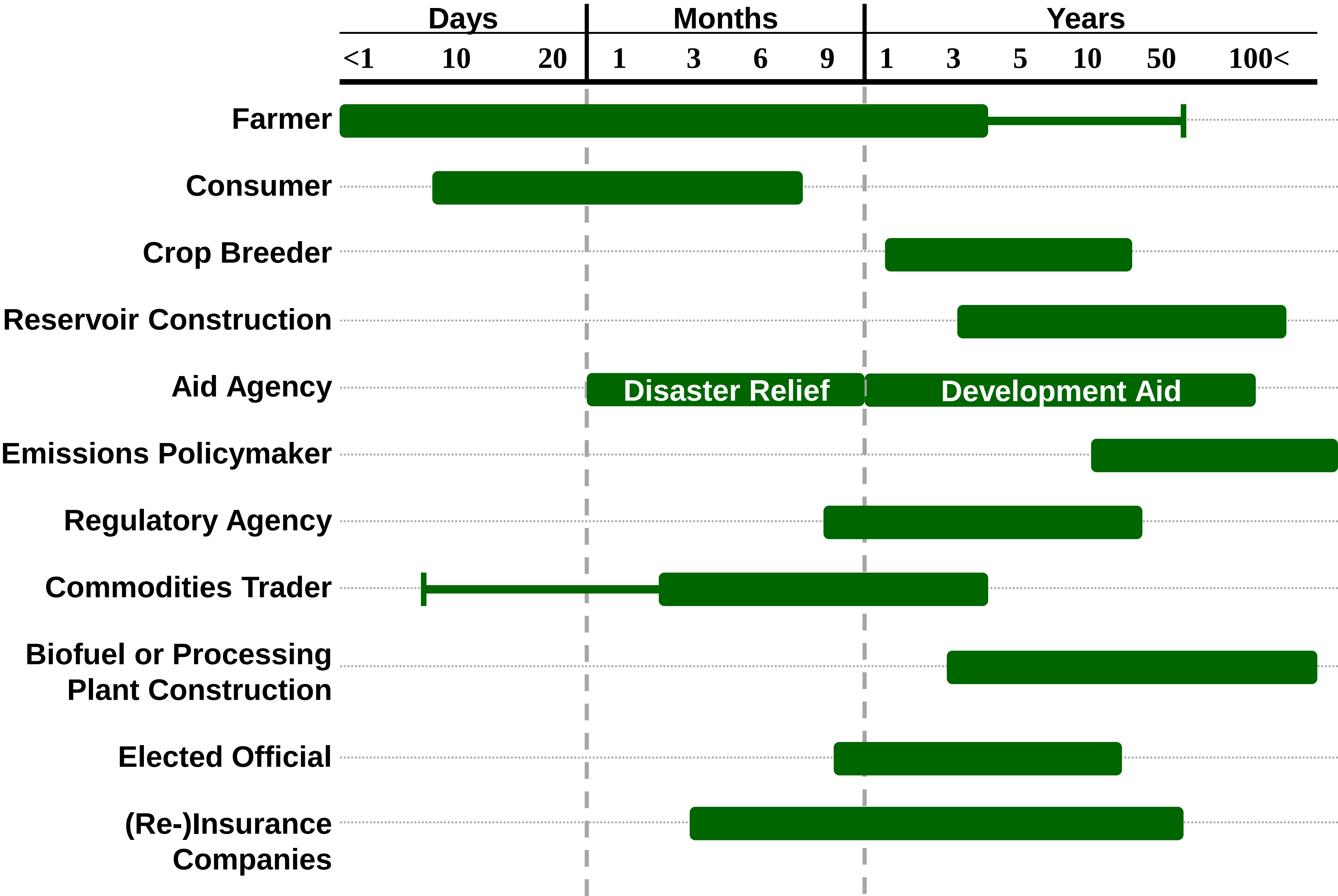
Cumulative distribution of climate change induced losses for farmers in Machakos, Kenya



In same district there may be a wide variety of outcomes
Lines result from different data availability

Antle et al., in preparation

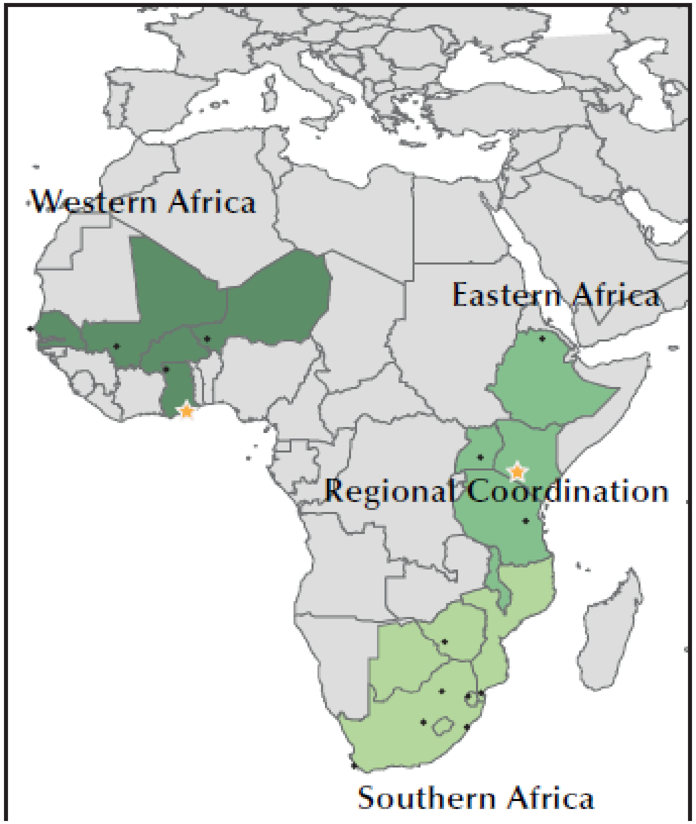
DRAFT Concept for identifying climate processes and time scales: Temporal Scale of Agricultural Sector Stakeholder Interest

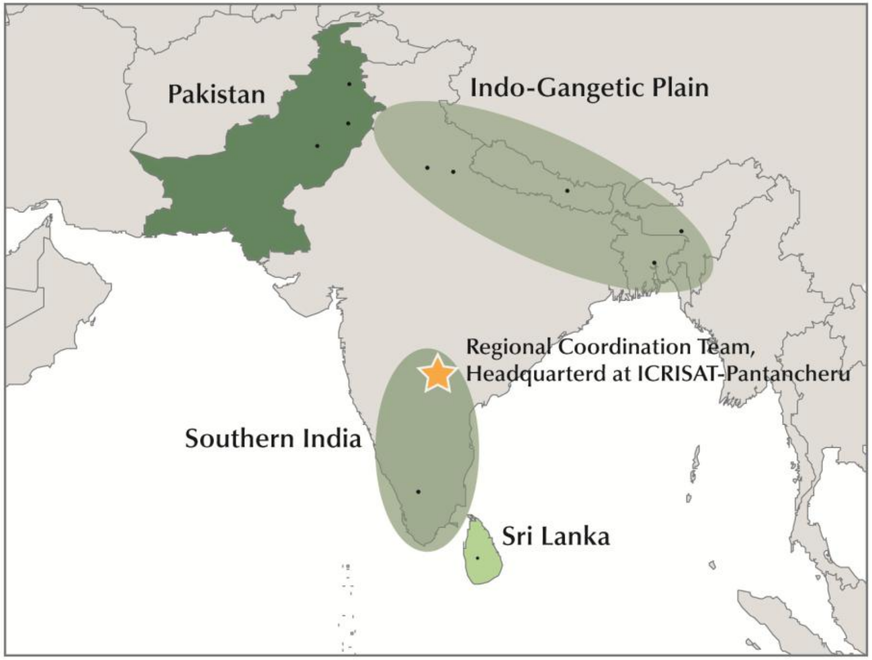


Motivation and organization of the Agricultural Model Intercomparison and Improvement Project (AgMIP)

AgMIP The Agricultural Model Intercomparison and Improvement Project

Led by Cynthia Rosenzweig (NASA GISS)
Jim Jones (University of Florida)
and Jerry Hatfield (USDA-ARS; Ames, Iowa)
With collaborators around the world





Website, forum, and list-serve at http://www.agmip.org

UKaid from the Department for International Development

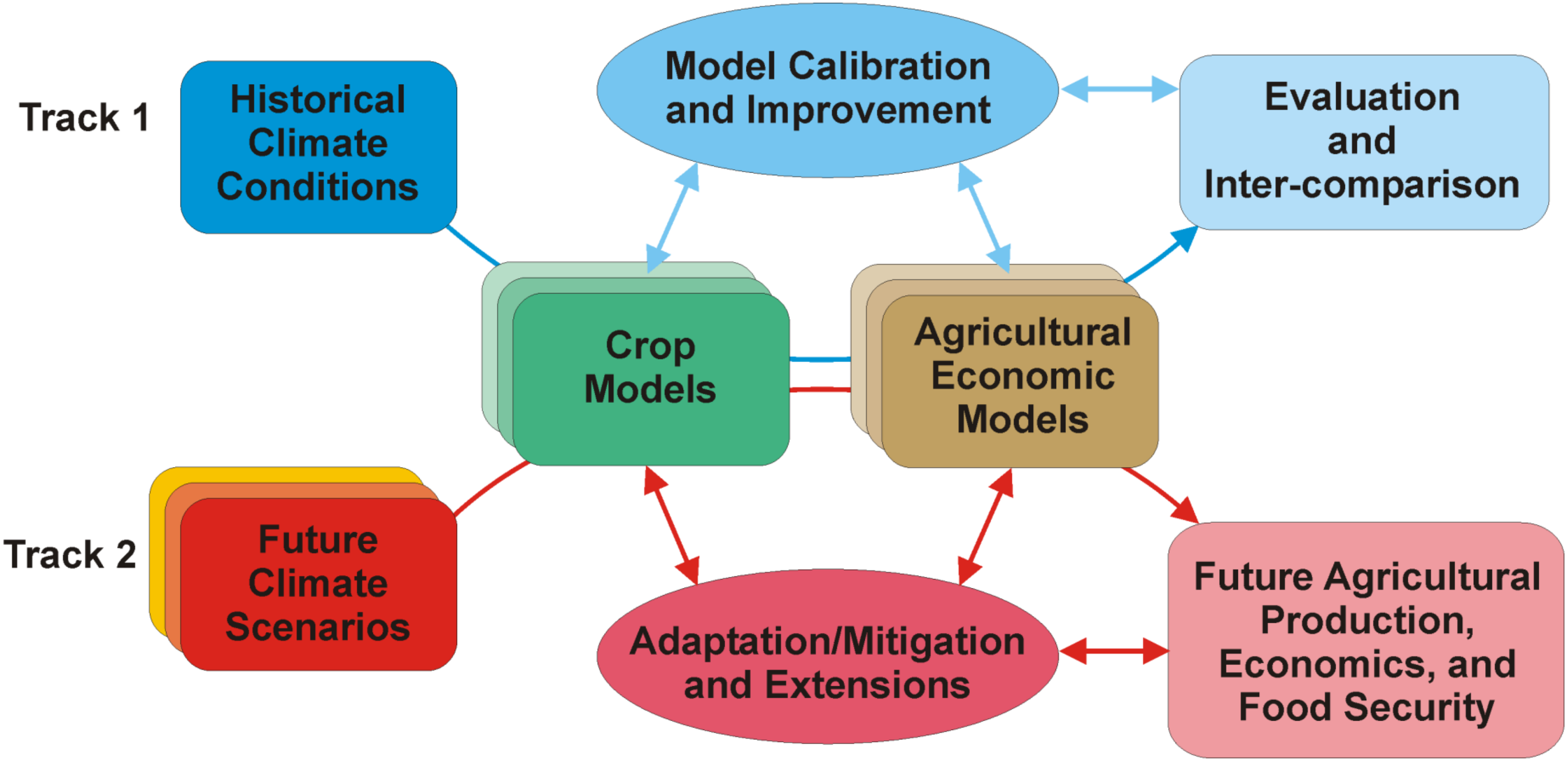
USDA

AgMIP Objectives

- **Incorporate state-of-the-art climate products as well as crop and agricultural trade model improvements in coordinated regional and global assessments of future climate impacts**
- **Include multiple models, scenarios, locations, crops and participants to explore uncertainty and impact of data and methodological choices**
- **Collaborate with regional experts in agronomy, economics, and climate to build strong basis for applied simulations addressing key climate-related questions**
- **Improve scientific and adaptive capacity for major agricultural regions in the developing and developed world**
- **Develop framework to identify and prioritize adaptation strategies**
- **Link to key on-going efforts**
  - **CCAFS, Global Futures, MOSAICC, Yield Gap Analysis, SERVIR**
  - **National Research Programs, National Adaptation Plans, IPCC, ISI-MIP**




AgMIP Two-Track Science Approach

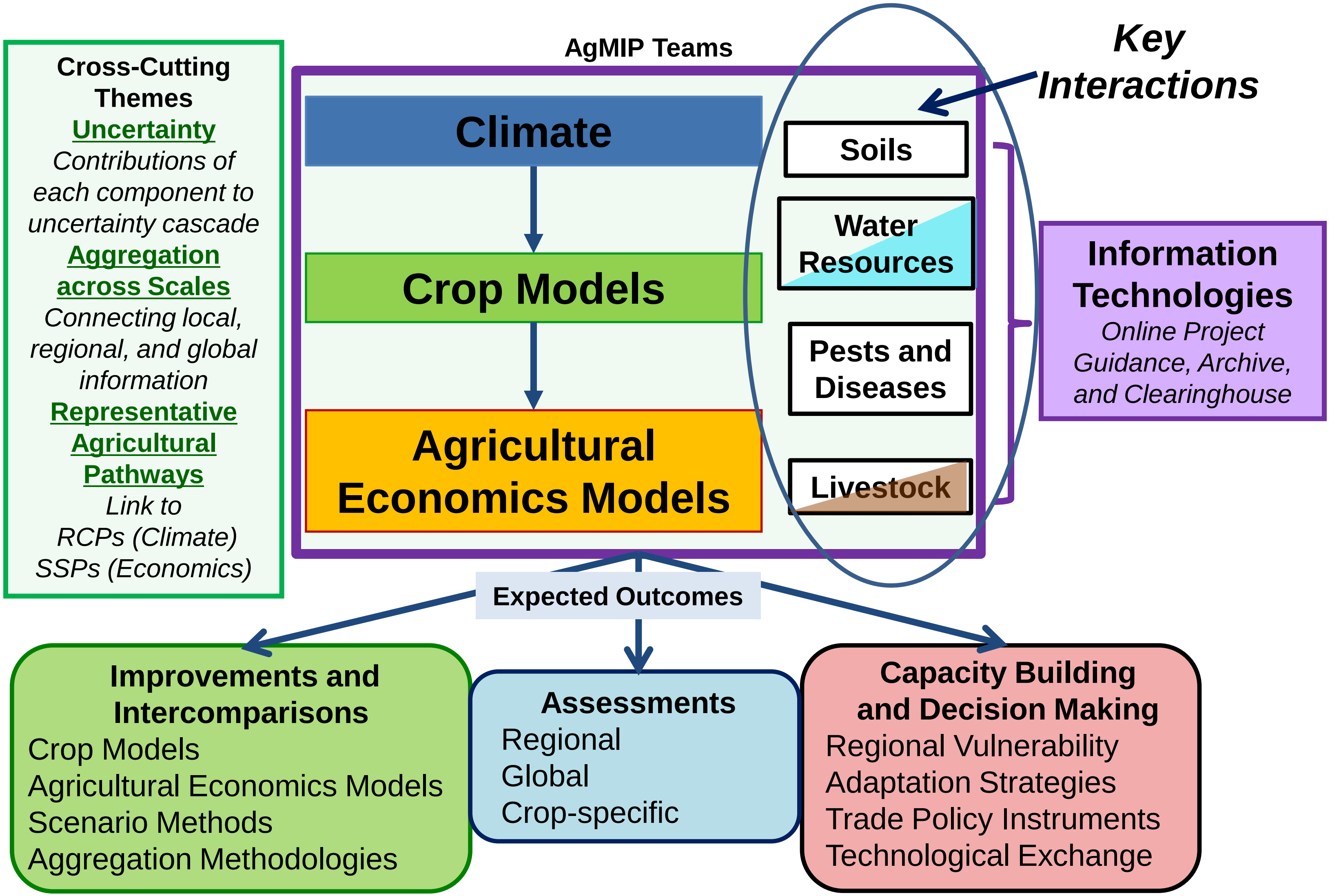


Track 1: Model Improvement and Intercomparison

Track 2: Climate Change Multi-Model Assessment

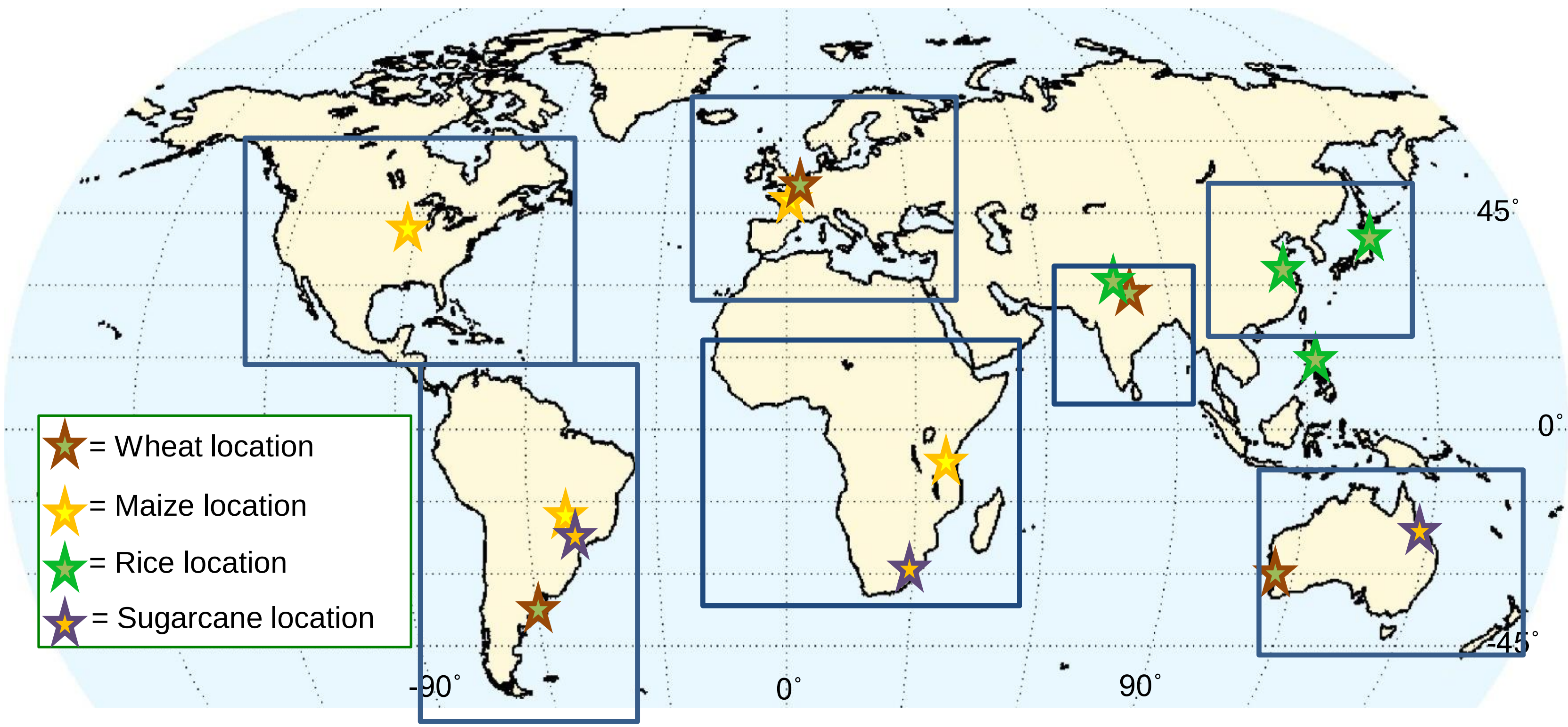
Rosenzweig et al., 2012

AgMIP Teams, Linkages, and Outcomes



Rosenzweig et al., 2012

AgMIP Crop Model Intercomparison Pilot Studies



- Wheat (27 models), Maize (25), and Rice Model (~15) Pilots underway
- Pilots under development for sugarcane, millet/sorghum, soybean, groundnut, potato, and livestock

Rosenzweig et al., 2012

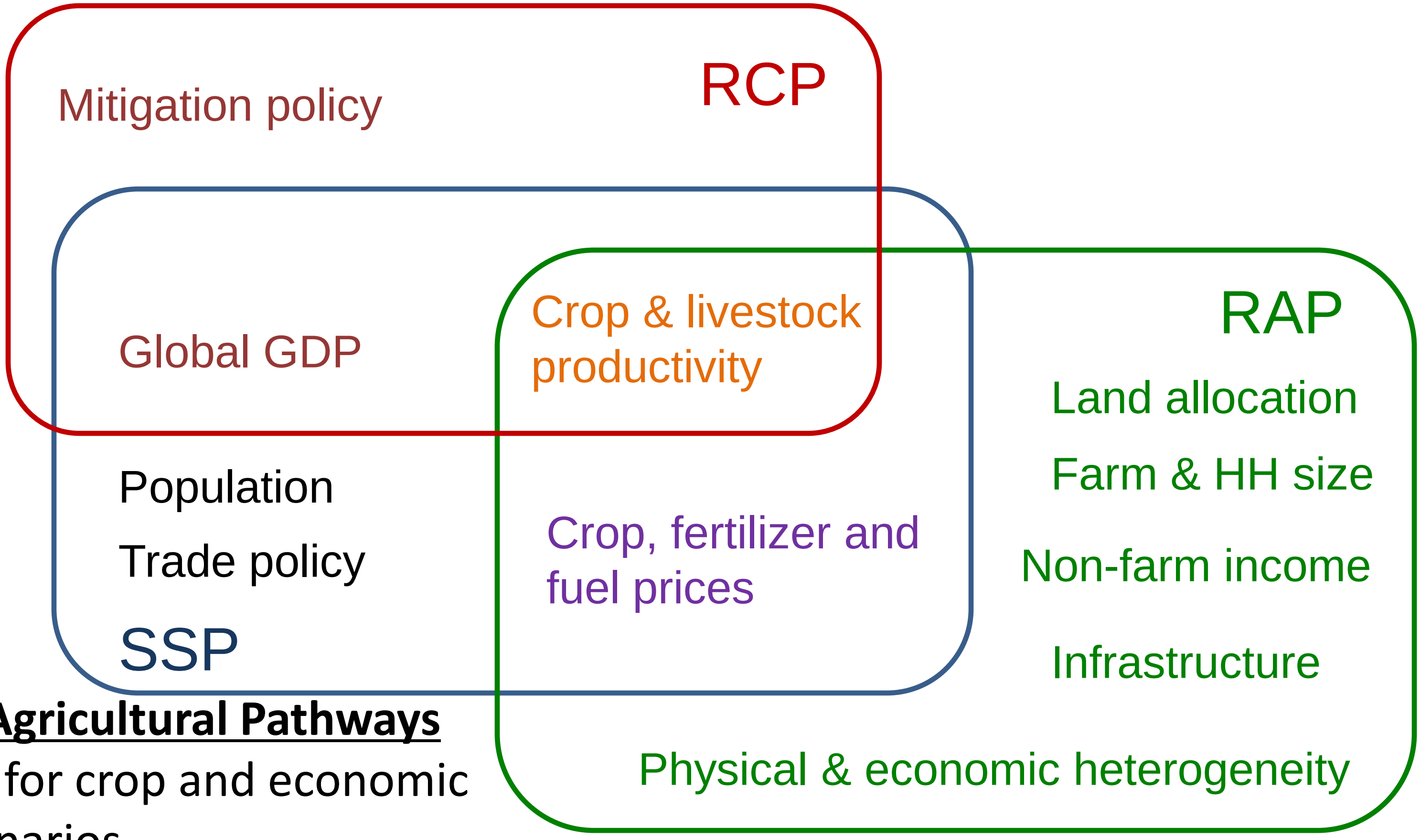
Uncertainty Challenges

1. **Give a projection (e.g., maize price in 2050s) <u>and</u> an estimate of its reliability**
2. **Distinguish between uncertainty and error**
   - **Error must be related to a true observation**
   - **Uncertainty range contains plausible values that may (but does not always) contain true value**
3. **Identify critical sensitivities to prioritize data collection**
   - **Are particular climate metrics most important for yield response?**
   - **Are particular field observations most helpful for calibration**
4. **Identify model shortcomings to prioritize areas for model improvement**
   - **Simulation of external factors (pests, diseases, weeds)**
5. **Understand the effects of methodological choices and assumptions**
   - **Downscaling, aggregation, scenario generation**
6. **Help in assessing risk for adaptation strategies**

Agricultural impacts depend on a variety of uncertain development factors before we even get to modeling

- Emissions Scenario / Representative Concentrations Pathway
- Shared Socio-economic Pathway
- Representative Agricultural Pathway

Representative Agricultural Pathways: Representative Concentration Pathways (RCPs), Shared Socio-economic Pathways (SSPs), and Representative Agricultural Pathways (RAPs)

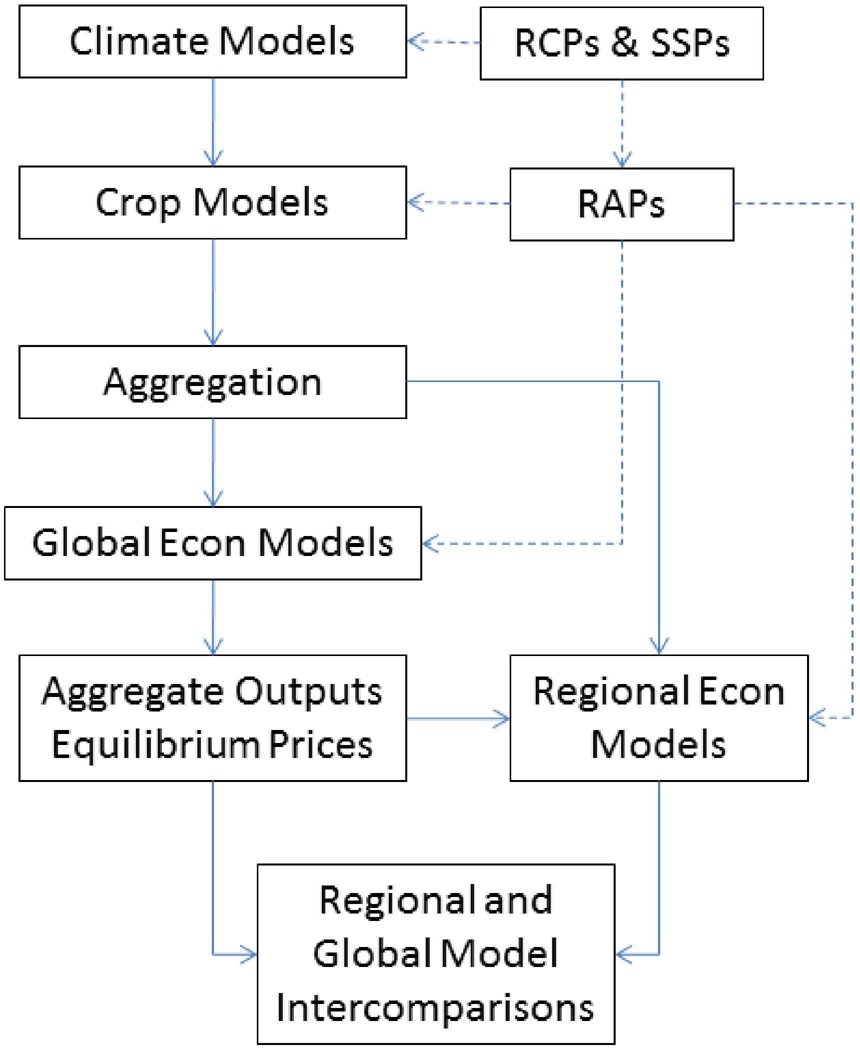


<u>Representative Agricultural Pathways</u>

- RAPs needed for crop and economic modeling scenarios
- Similar scenarios may be useful for other impacts sectors

Antle, 2011; Arnell and Kram, 2011

Societal Uncertainties in AgMIP Framework



Flowchart of modeling efforts in the AgMIP framework, demonstrating that AgMIP results will be determined by specified climate scenarios from various climate models, societal pathways (RCPs and SSPs), and representative agricultural pathways (RAPs).

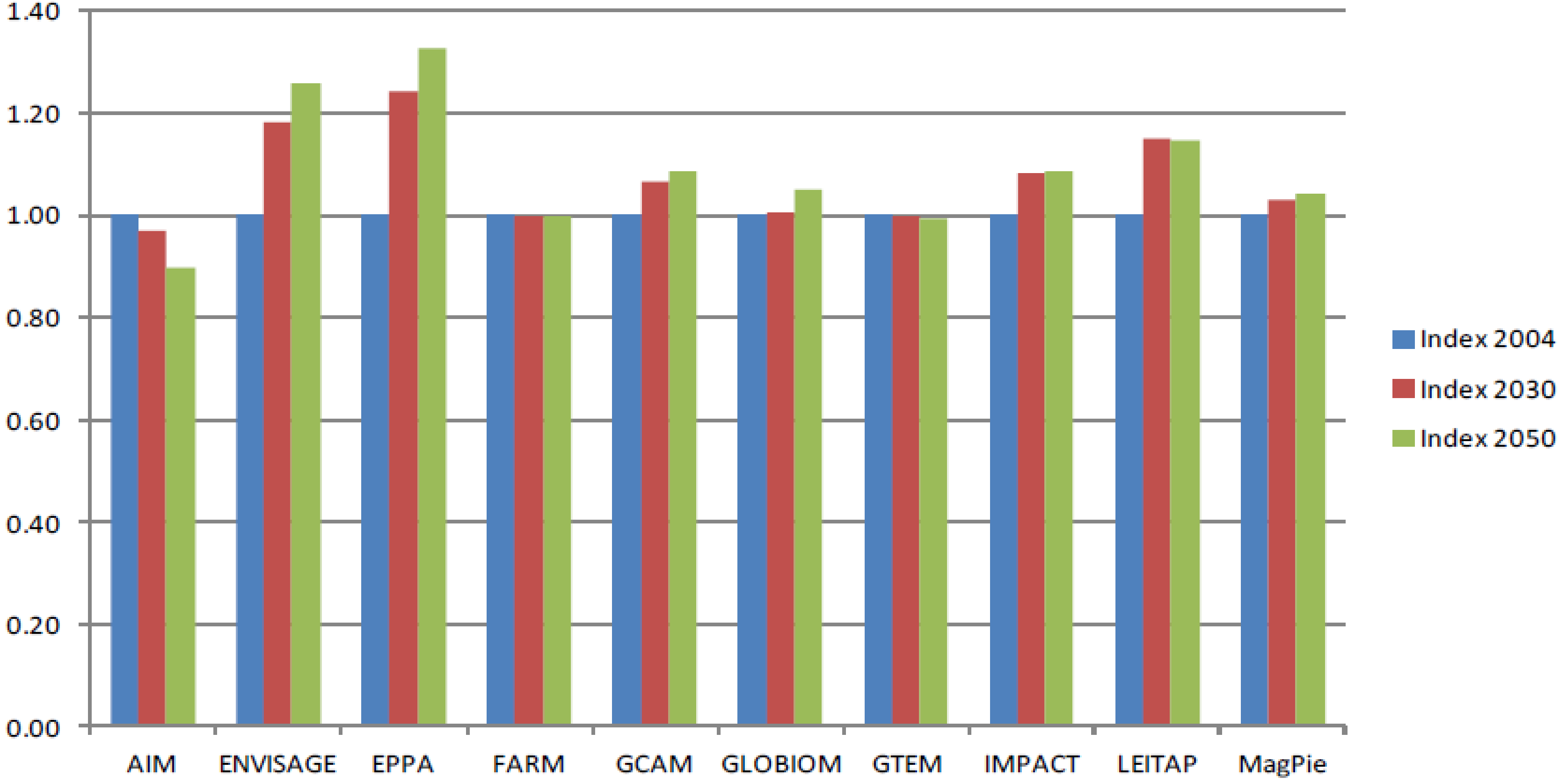
Rosenzweig et al., 2012

Global and Regional Agricultural Economic Models

- Global Ag Econ models that integrate diverse market supplies and demands
- Regional models capable of more precise investment prioritization

IFPRI IMPACT model;
http://www.ifpri.org/book-751/ourwork/program/impact-model

World agricultural land, perfect mitigation

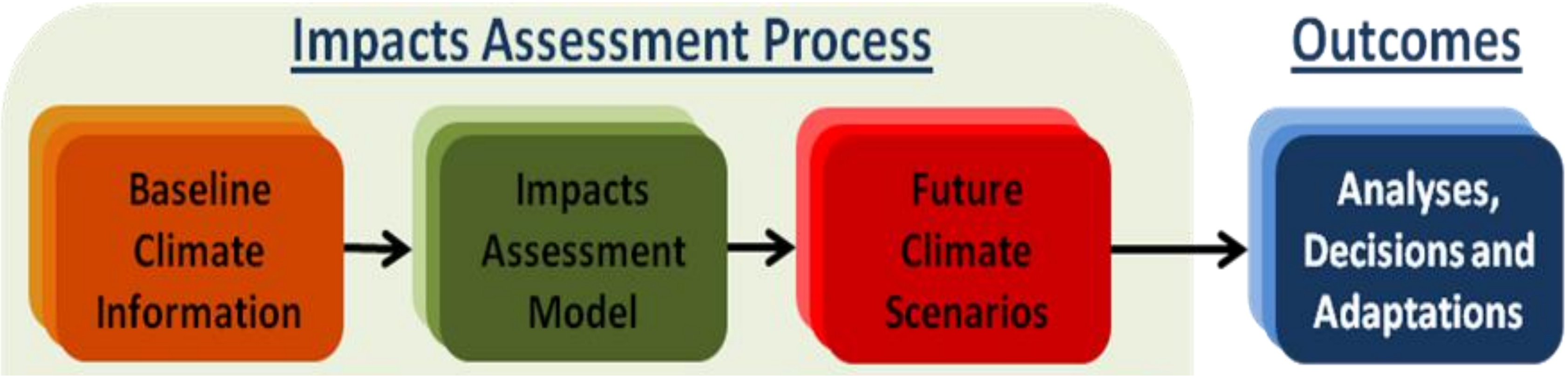


From Jerry Nelson, IFPRI

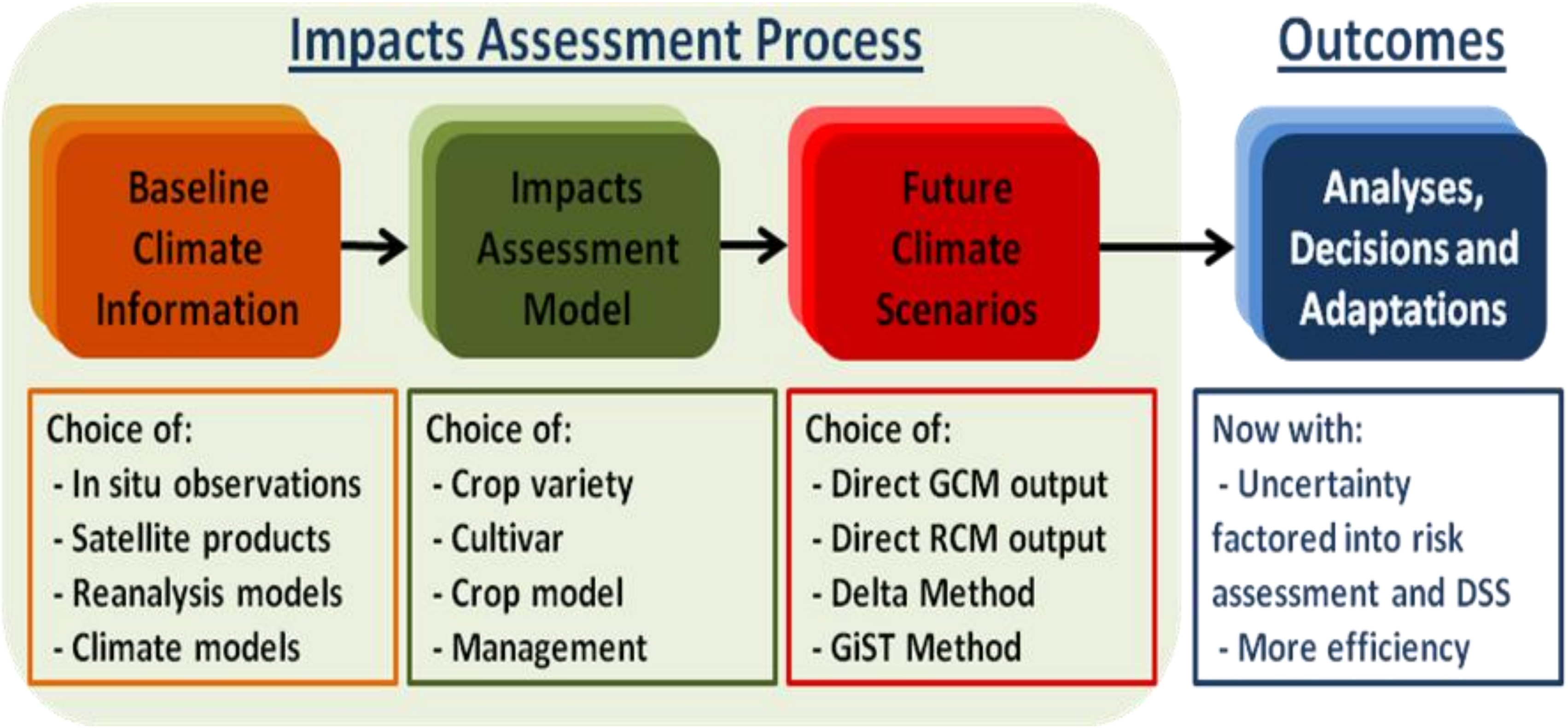
Agricultural Impacts assessments have multiple sources of uncertainty

- Baseline
- Agricultural model
- Future
- Analysis

Uncertainty in Assessment Methods



Uncertainty in Assessment Methods



Agricultural Impacts assessments have multiple sources of uncertainty

- Baseline
- Agricultural model
- Future Scenarios
- Analysis

Agricultural processes may be particularly sensitive to specific climate metrics

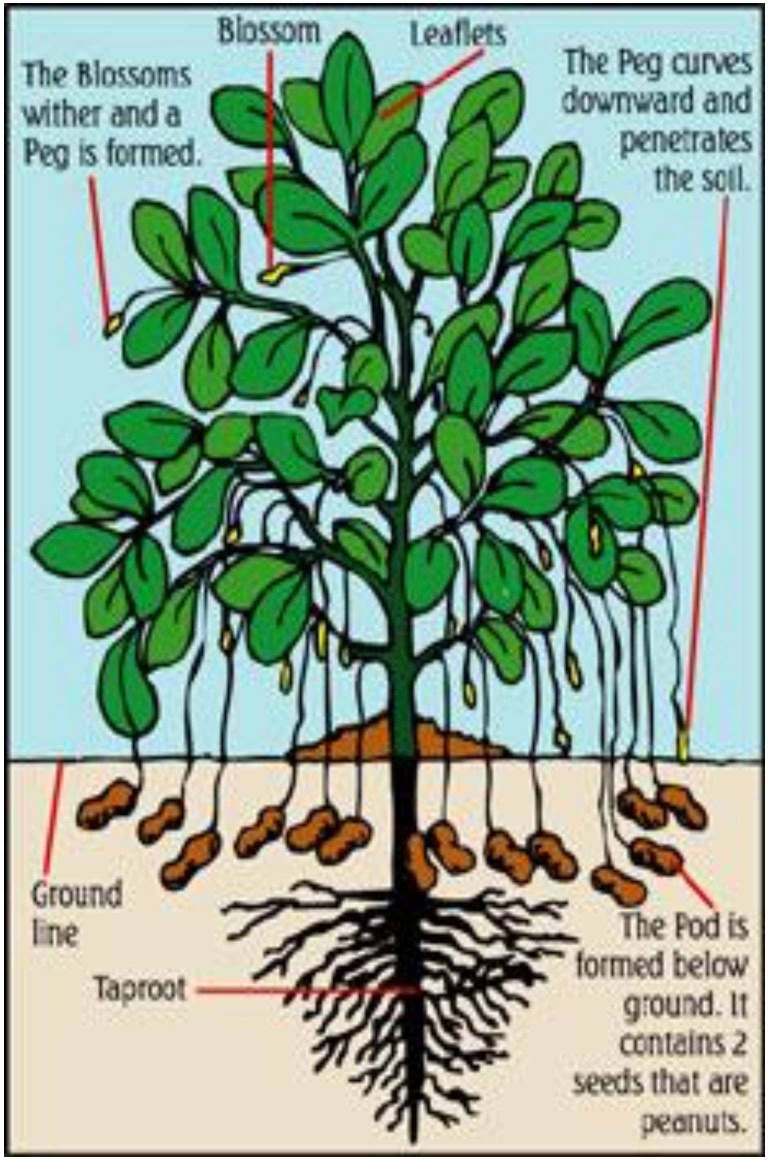
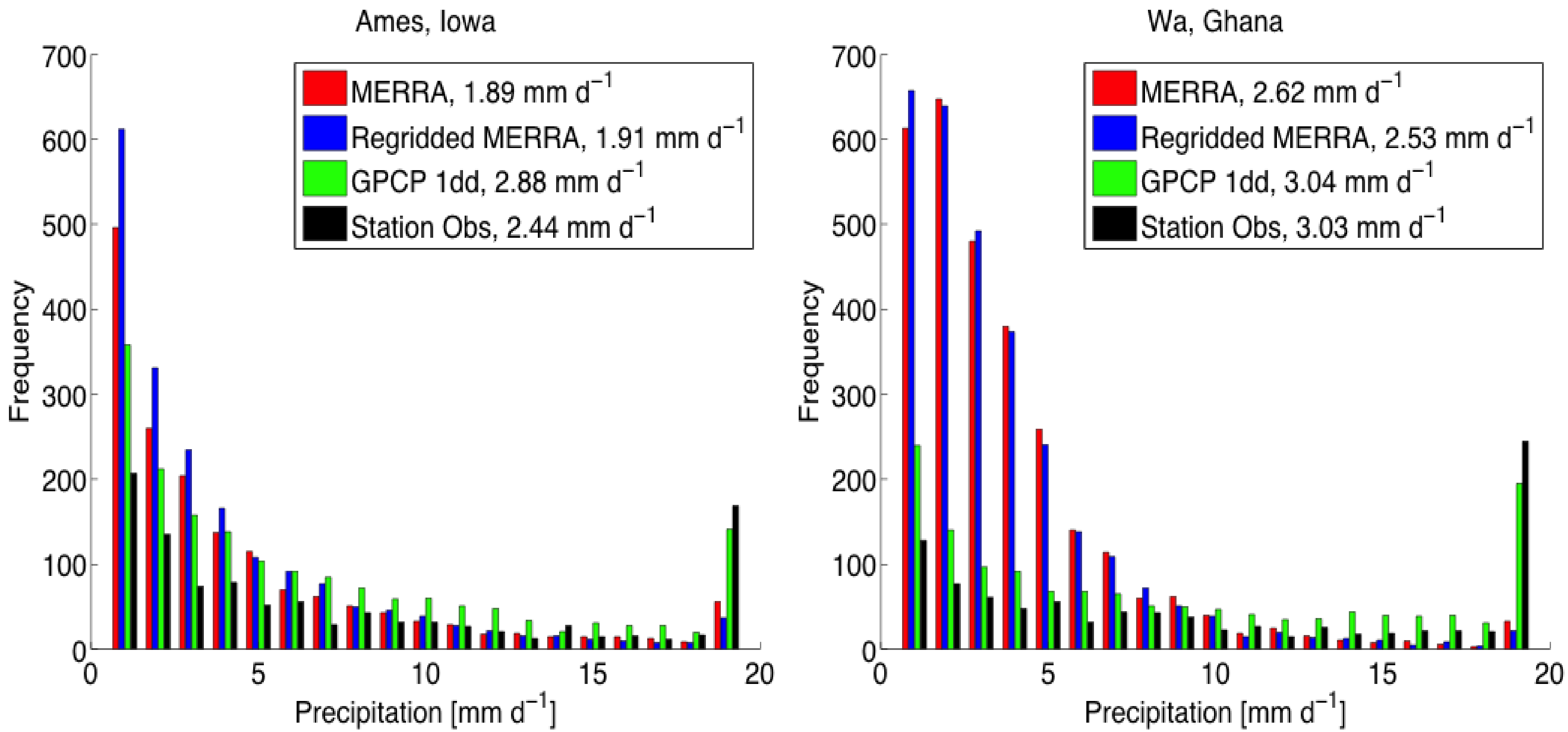
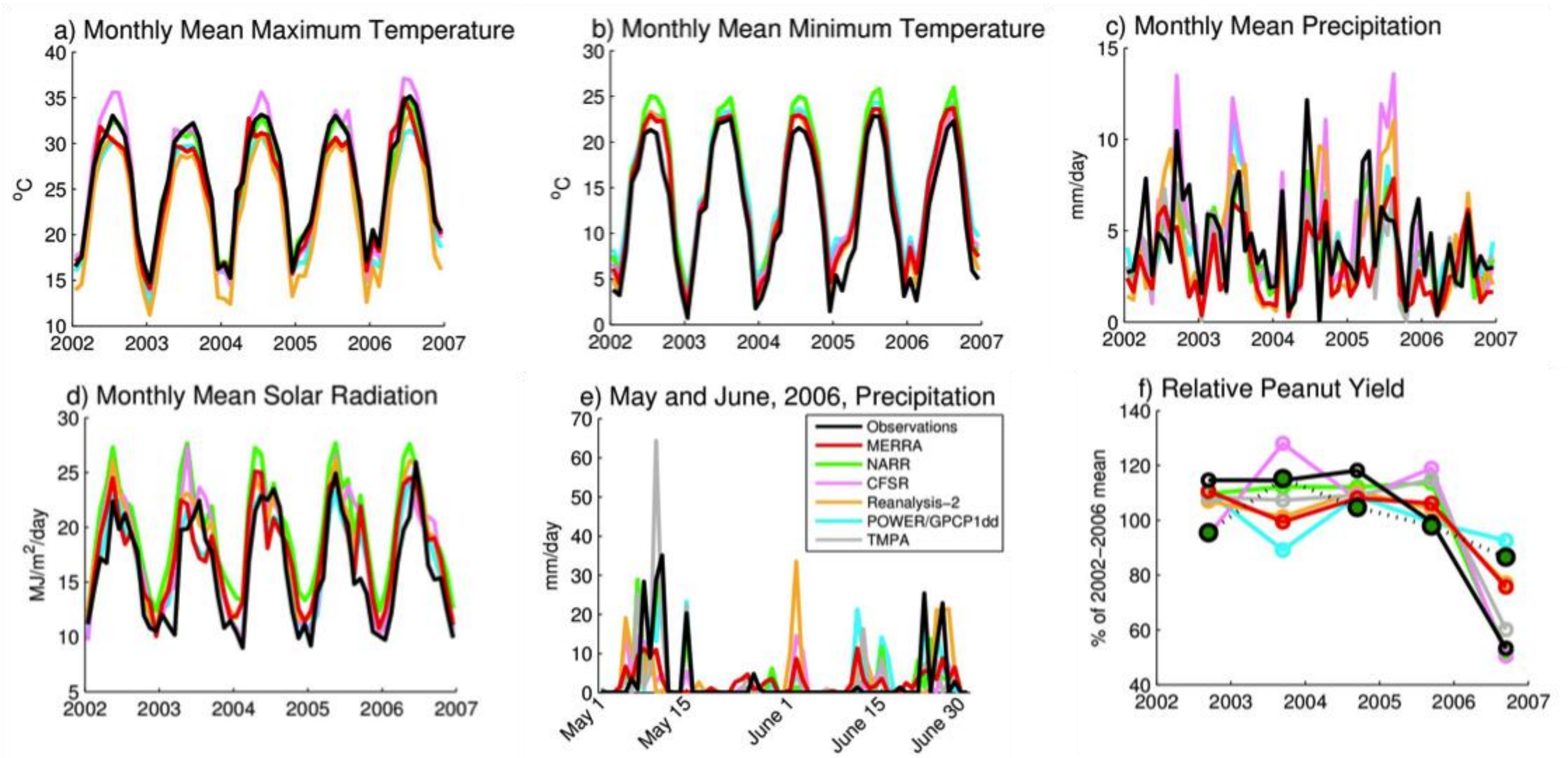


Figure from Aunt Ruby's Peanuts: http://www.auntrubyspeanuts.com/howgrow



Histogram of daily precipitation for 1997-2008 across reanalyses and observed datasets at two sites. Long-term mean precipitation values are shown in the legend, days with <0.75 mm d^{-1} rainfall are excluded, and the last bin (centered at 19 mm d^{-1}) contains all precipitation events greater than 18.5 mm d^{-1}.



Comparison of climate datasets and simulated peanut yields in Jackson County, Florida. The dotted black line with green-filled dots in (f) shows county-level peanut yields from the USDA National Agricultural Statistics Service.

Agricultural Impacts assessments have multiple sources of uncertainty

- Baseline
- Agricultural model
- Future
- Analysis

Review of African Yield Change Projections

Different

- **crops**
- **regions**
- **farming systems**
- **methods**
- **models**
- **scales**
- **timeframes**
- **assumptions**

lead to different projections of climate impacts

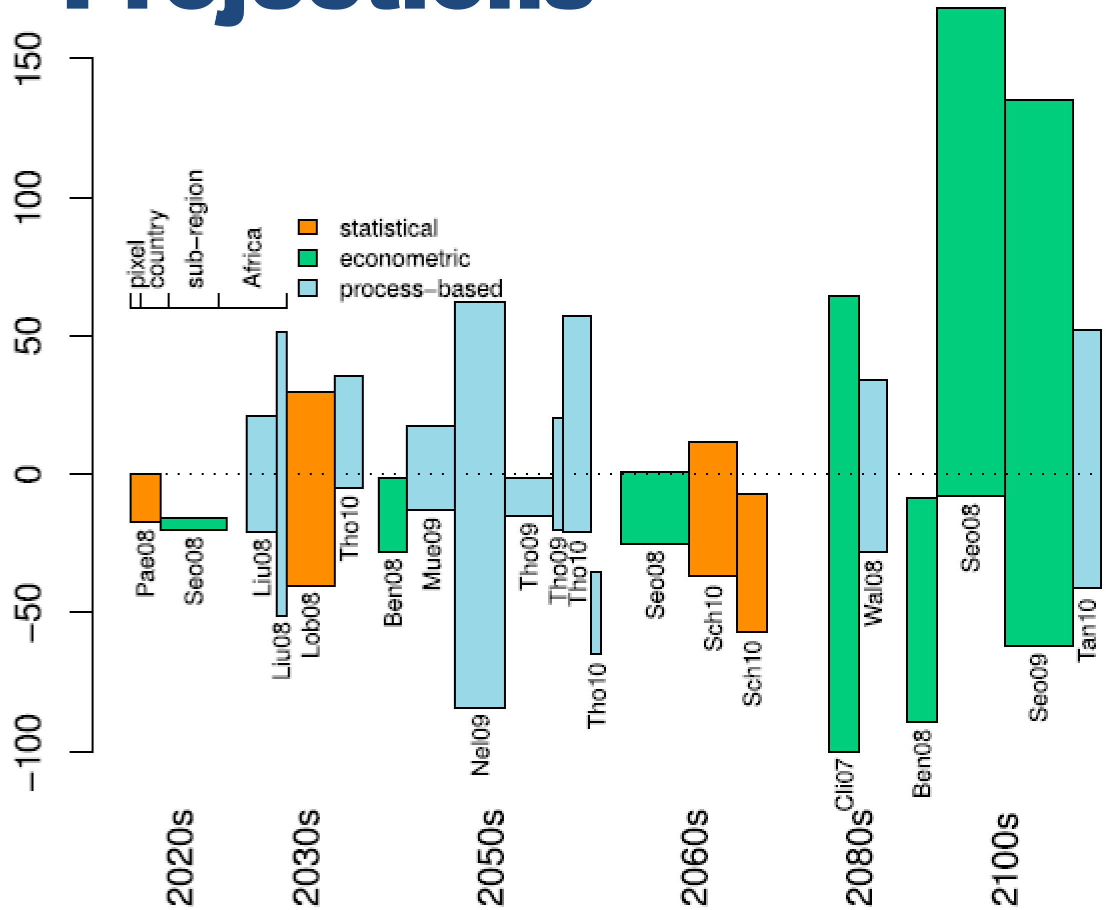


Fig. 1. Projected ranges of climate change impacts on African agriculture, expressed as change in percent relative to present conditions. Bar widths indicate the spatial extent of the projection, and shading depicts the methodology. Sources: Pae08 (10), Seo08 (9), Liu08 (7), Lob08 (11), Ben08 (12), Mue09 (13), Nel09 (8), Tho09 (14), Tho10 (15), Sch10 (16), Cli07 (5), Wal08 (17), Seo09 (18), and Tan10 (19).

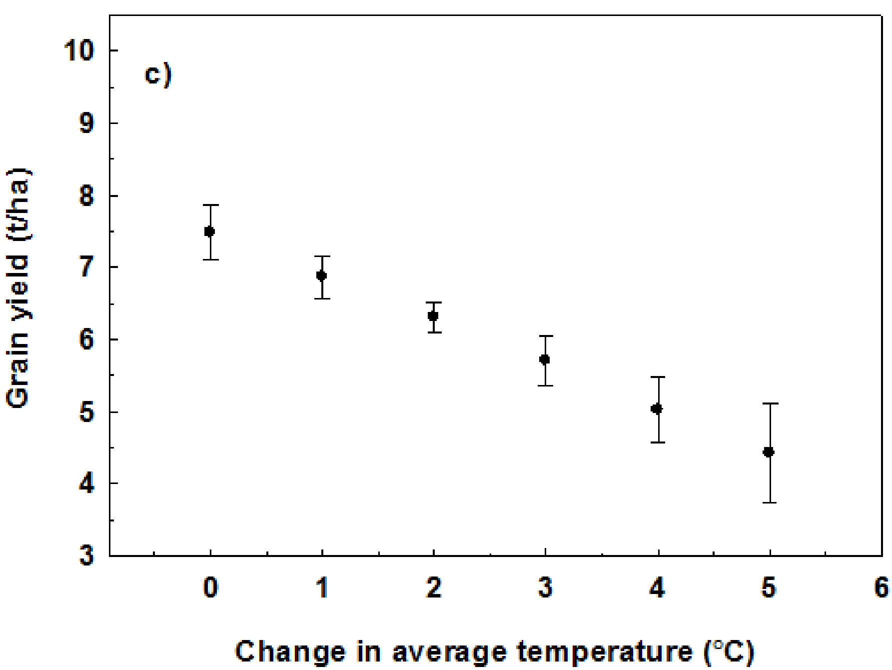
08

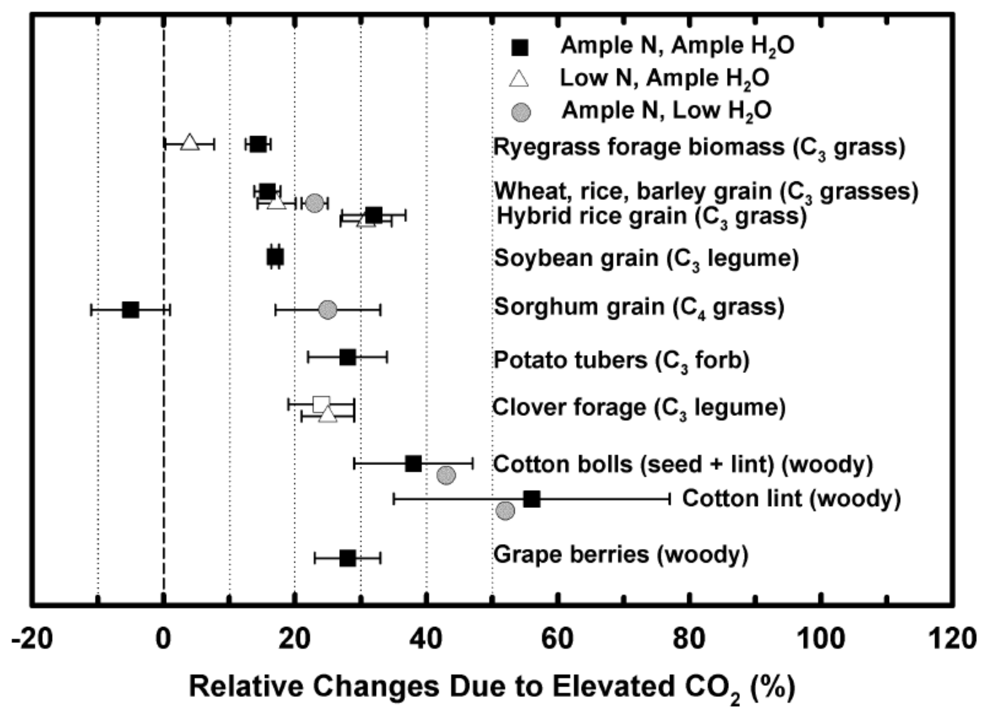
from Müller et al., 2011

AgMIP Research Teams

- **Sensitivity of crops to Temperature, Precipitation, and CO_2 changes is a key ongoing research question**

Median % change in peanut yield (A2 2050s)





Wheat at Obregon, Mexico
Irrigated, no N-stress; Rosenzweig et al., 2011

Yield response to +200 ppm CO_2
Kimball, 2010; in Hillel and Rosenzweig, 2010

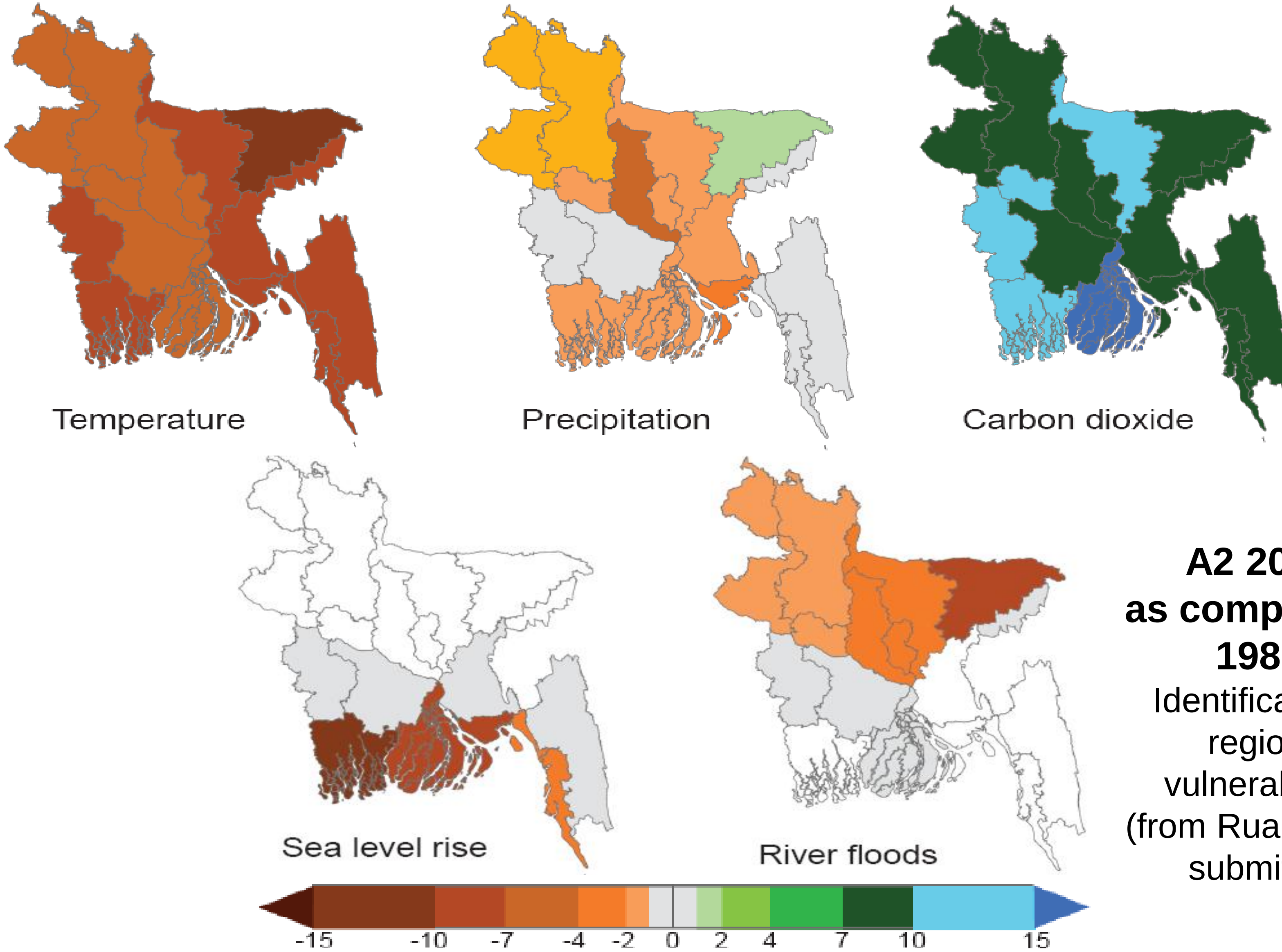
Unresolved Processes and Yield Gaps
Diseases, Weeds, and Pests

Black Rust of Wheat, from Stella Coakley, Oregon State University

Weed response to CO_2, from Lew Ziska, USDA ARS

Rice Brown Plant Hopper, from Richard Harrington, Rothamsted Research, UK

Unresolved Processes – Coastal and River Floods



A2 2050s as compared to 1980s

Identification of regional vulnerabilities (from Ruane et al., submitted)

Agricultural Impacts assessments have multiple sources of uncertainty

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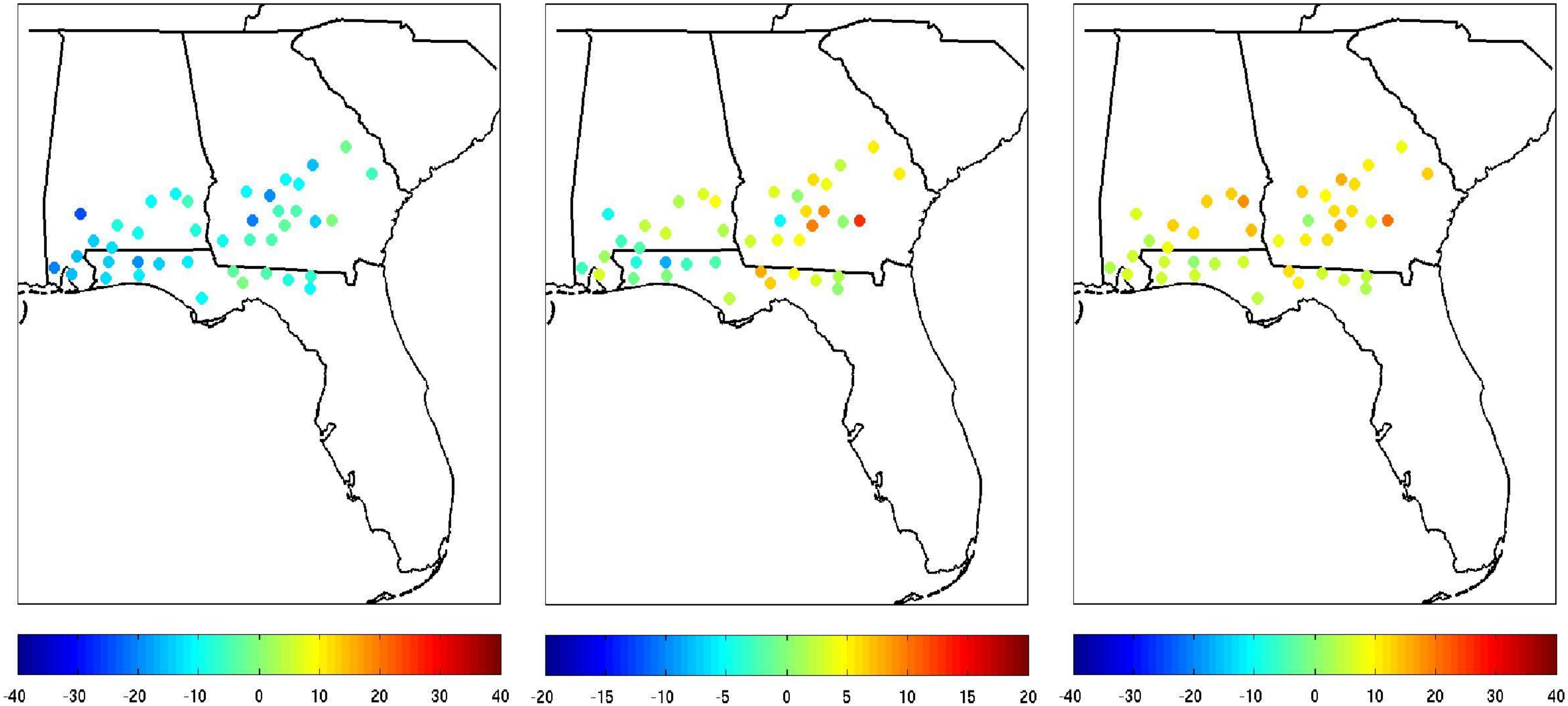
GCM Uncertainty

25th percentile of % change in peanut yield

Median % change in peanut yield (A2 2050s)

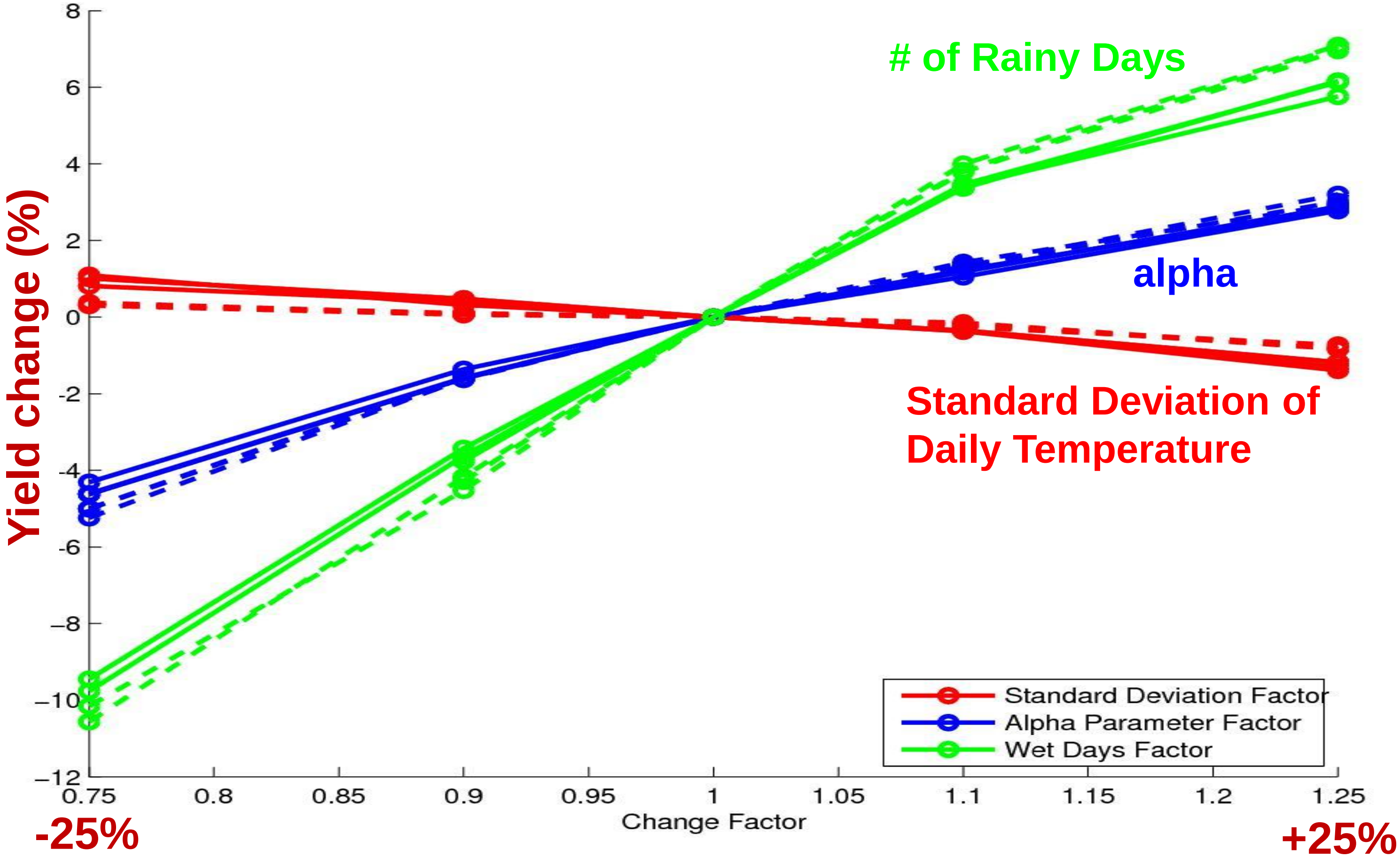
75th percentile of % change in peanut yield



Peanut production highly sensitive to rainfall changes

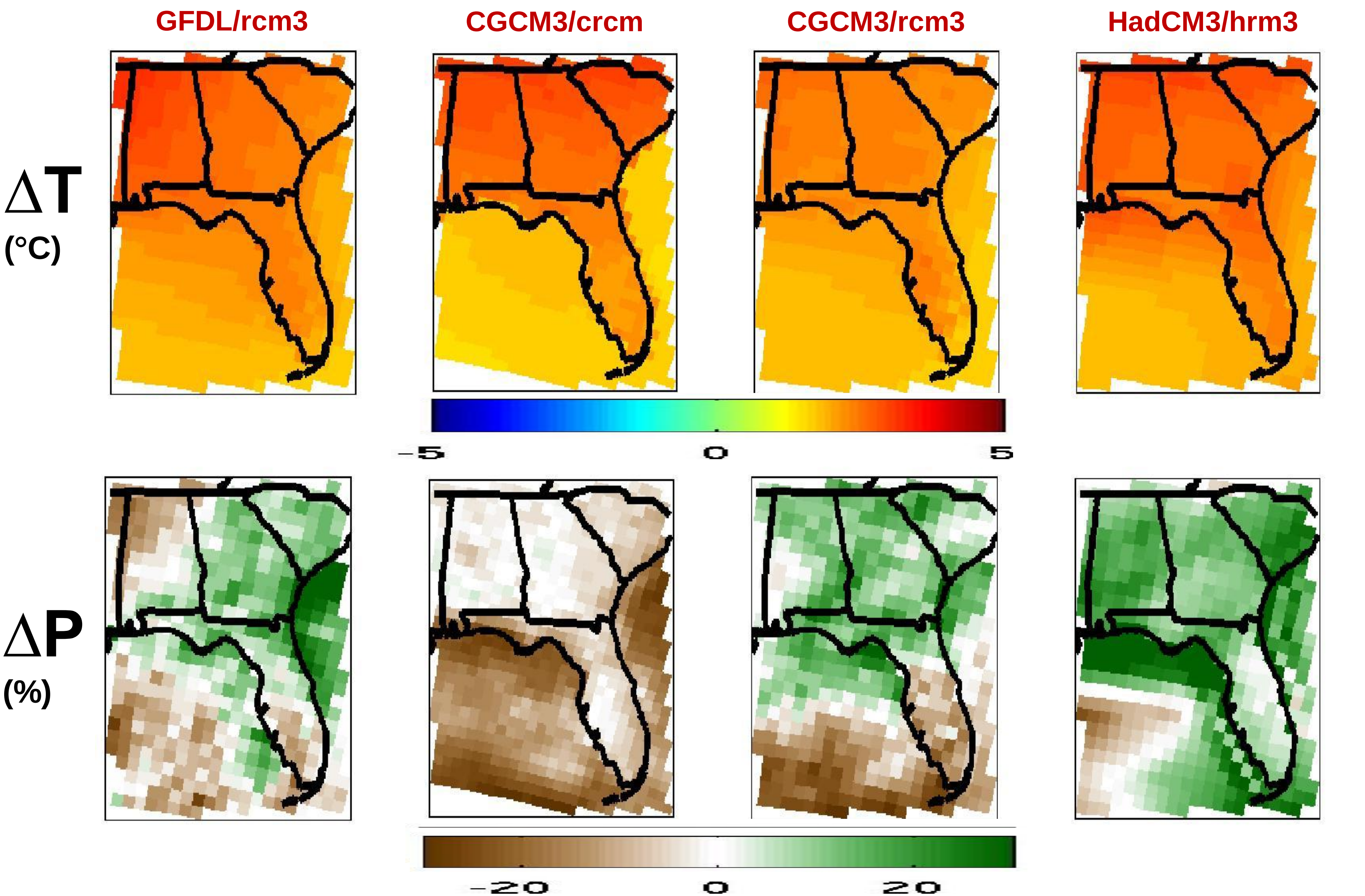
- a lot of variability between 16 GCMs with output for the A2 2050s

Sensitivity of Southeastern US Corn to variability change factors

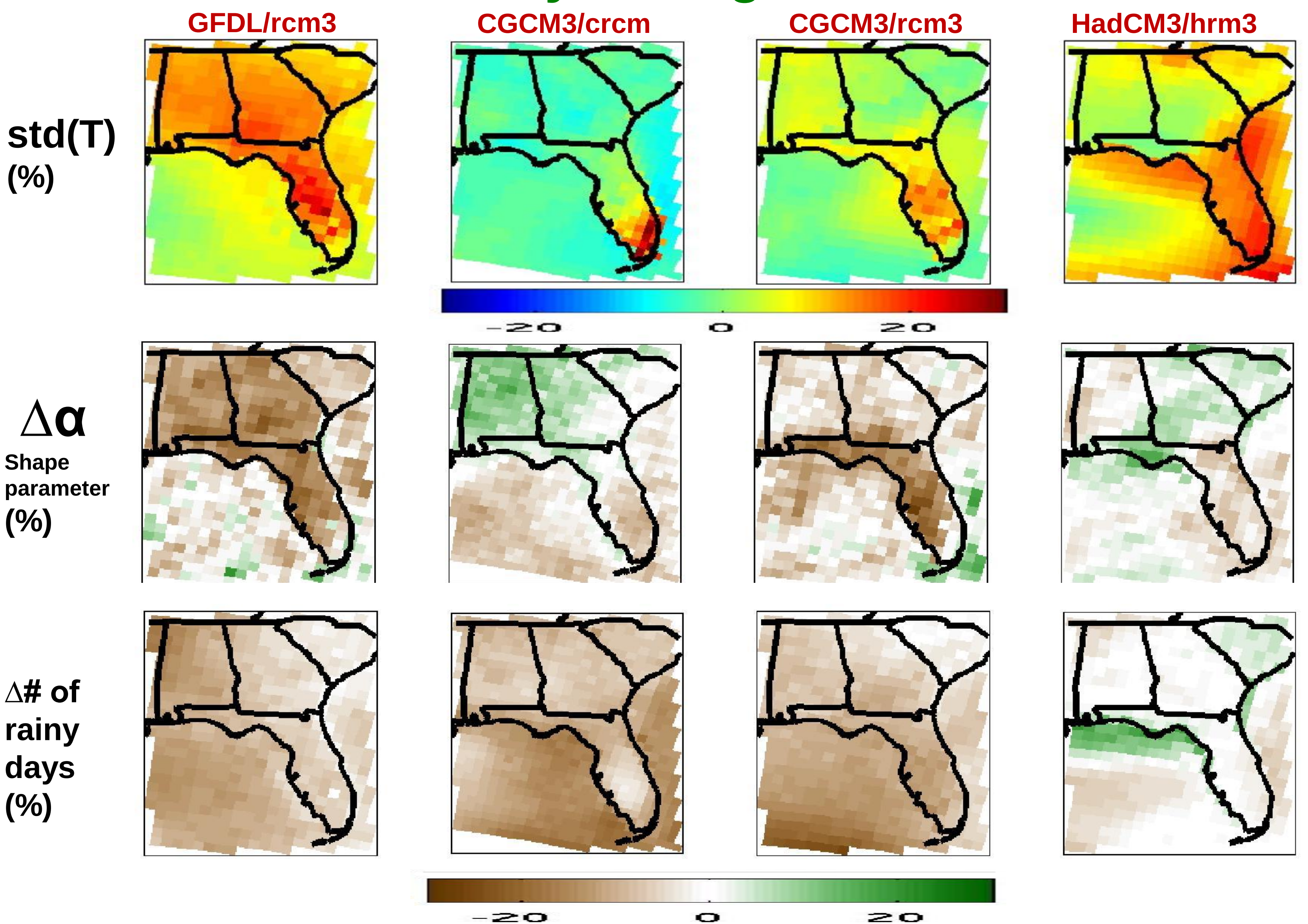


Uncertainty in Downscaled Climate Scenarios

NARCCAP Mean Changes – A2 2050s compared to 1980s

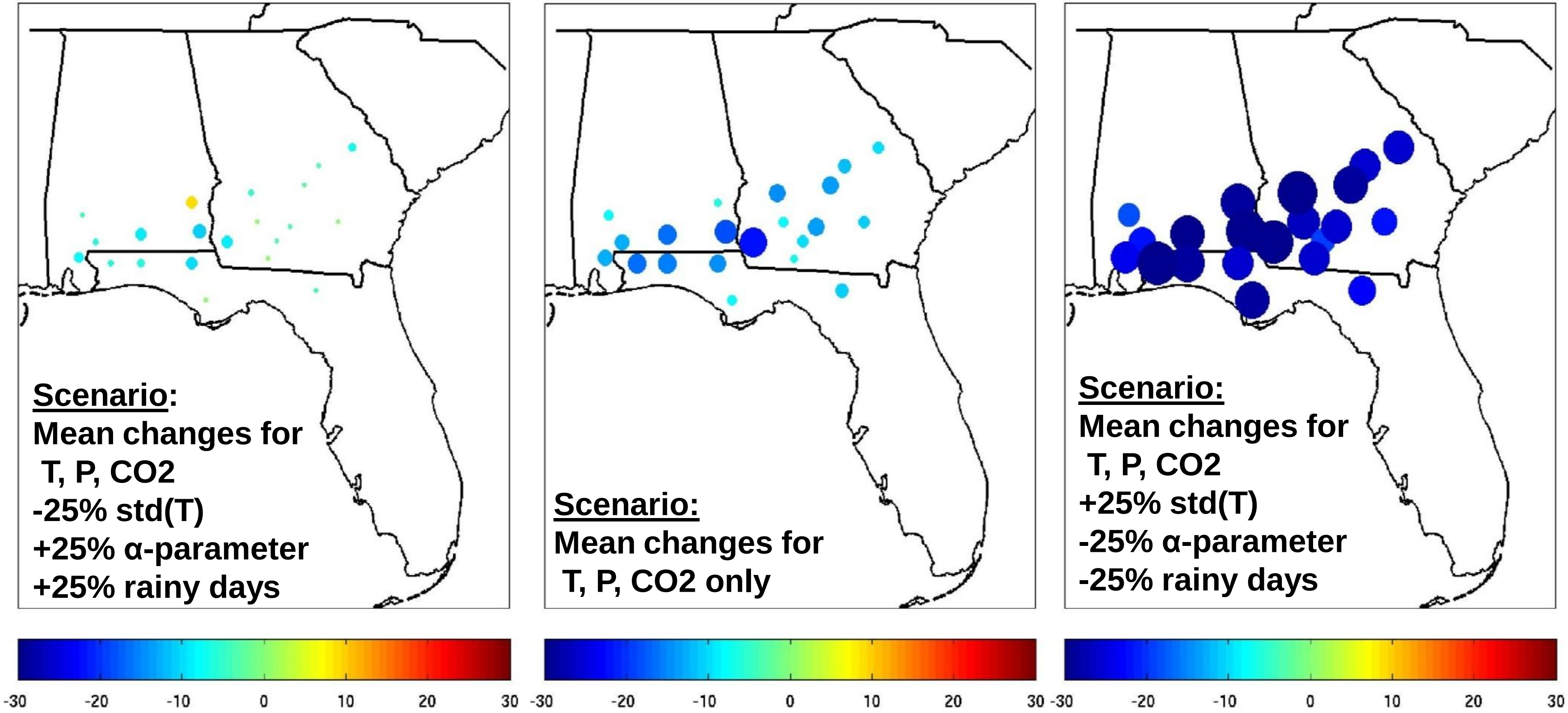


Uncertainty in Downscaled Climate Scenarios
NARCCAP Variability Changes – A2 2050s vs. 1980s



Variability Changes Can be Substantial

a) Maximal variability benefits **b) No variability changes** **c) Maximal variability damages**



Mean percentage changes (A2 2050s vs. 1980s baseline) in corn yield a) when variability adjustments maximize yield; b) with no variability adjustments; and c) when variability adjustments minimize yield. Note that only the mean shifts from the GFDL 2.1, CGCM3, and HadCM3 GCM were examined.

Agricultural Impacts assessments have multiple sources of uncertainty

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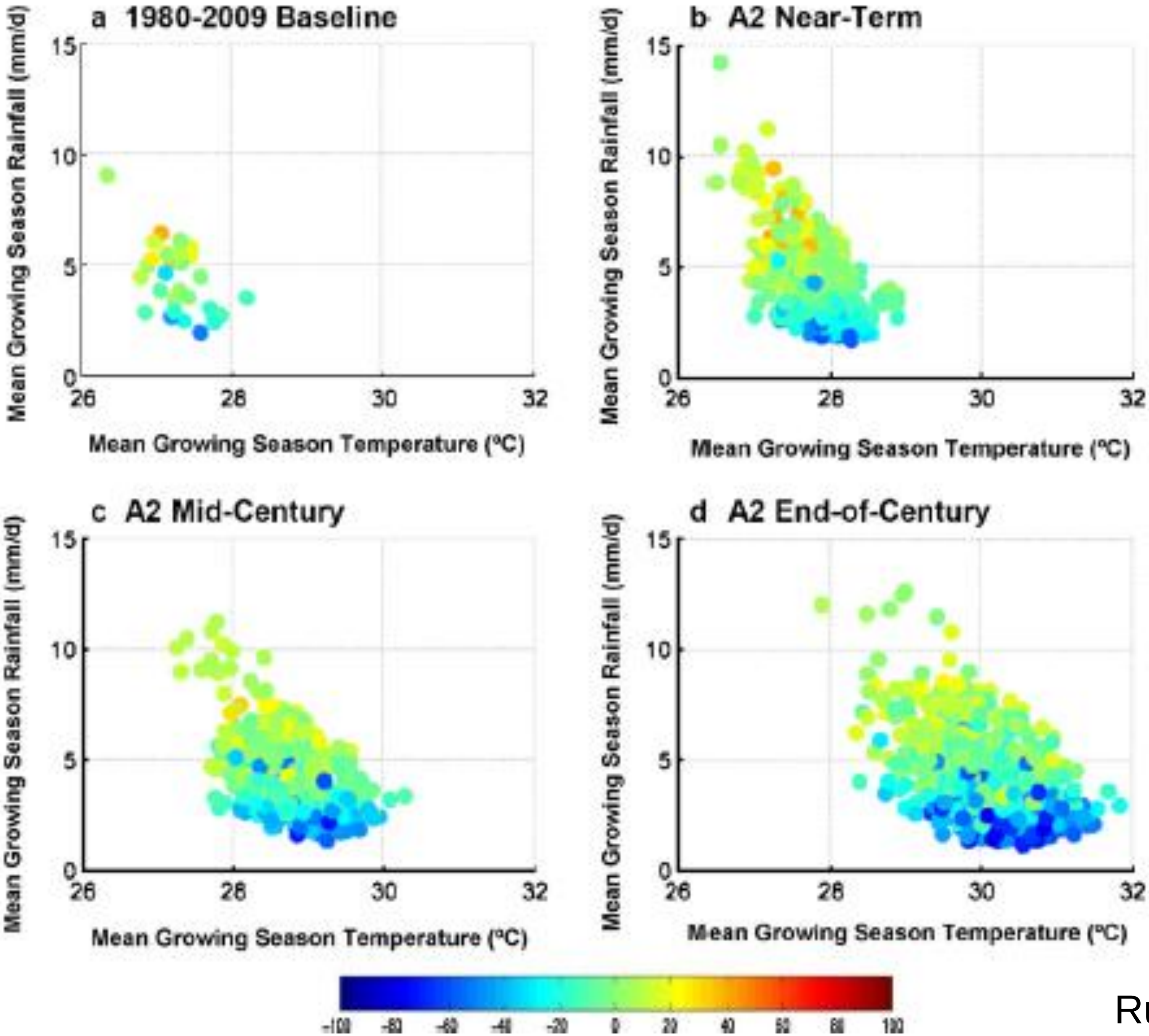
Baseline and Future Analysis
Growing Climate Uncertainty via Ag Impacts



Maize Simulations in Los Santos, Panama

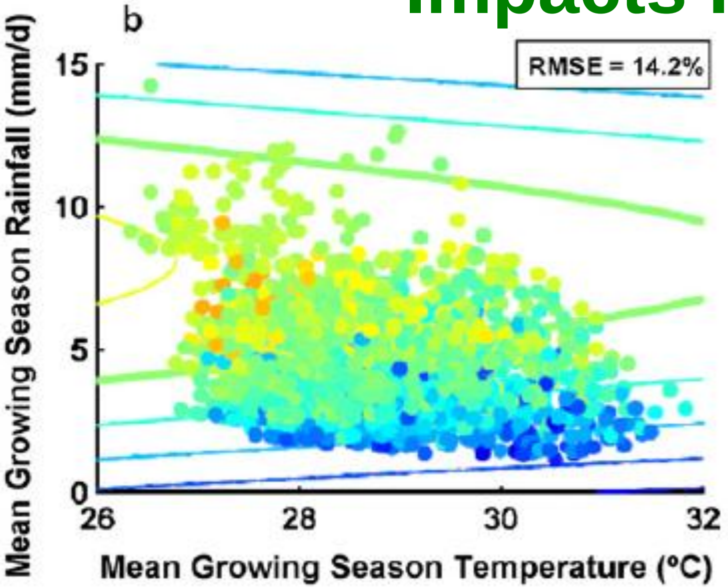
Each dot represents a particular season

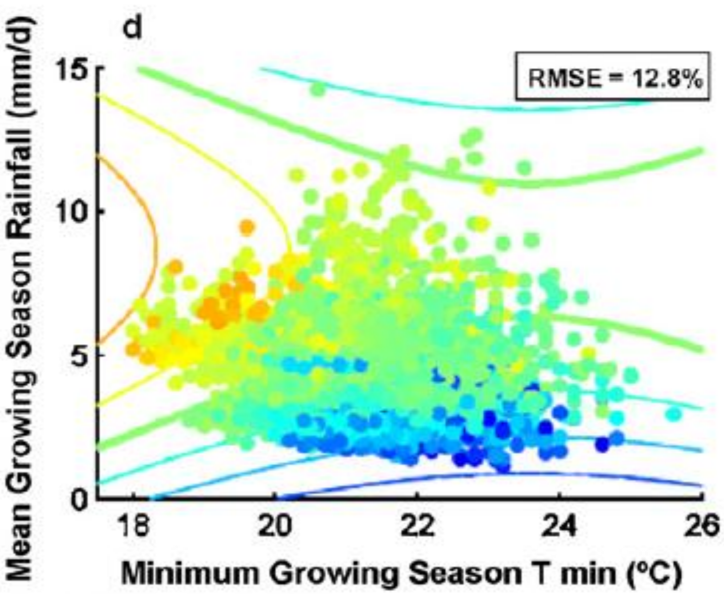
Spread shows climate uncertainty

Color shows change in crop yields

Ruane et al., 2011

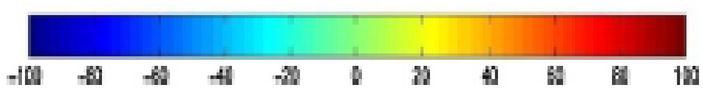
Climate Sensitivity Scenarios
Impacts Response Surfaces





Crop model simulations can help identify critical sensitivities to address with adaptation

- Crop model simulations in Los Santos respond particularly to:
  - ➢ growing season rainfall
  - ➢ minimum temperatures in December (correlated with end-of-season drought)
- Sensitivity of agriculture can be compared to uncertainty of climate projections

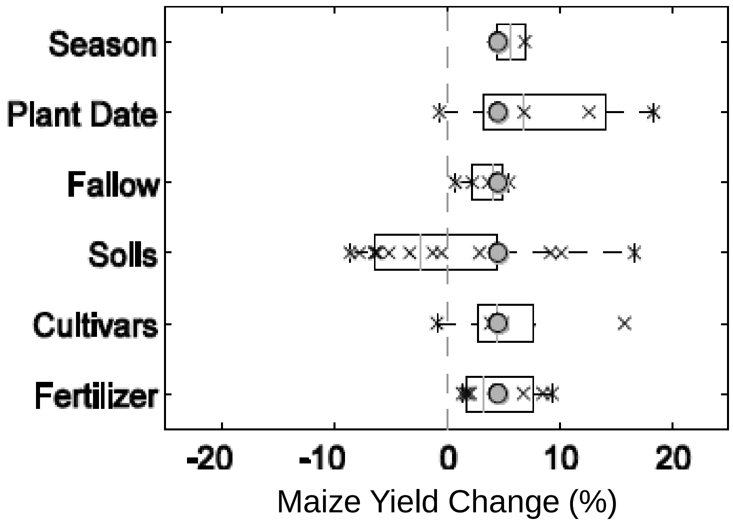


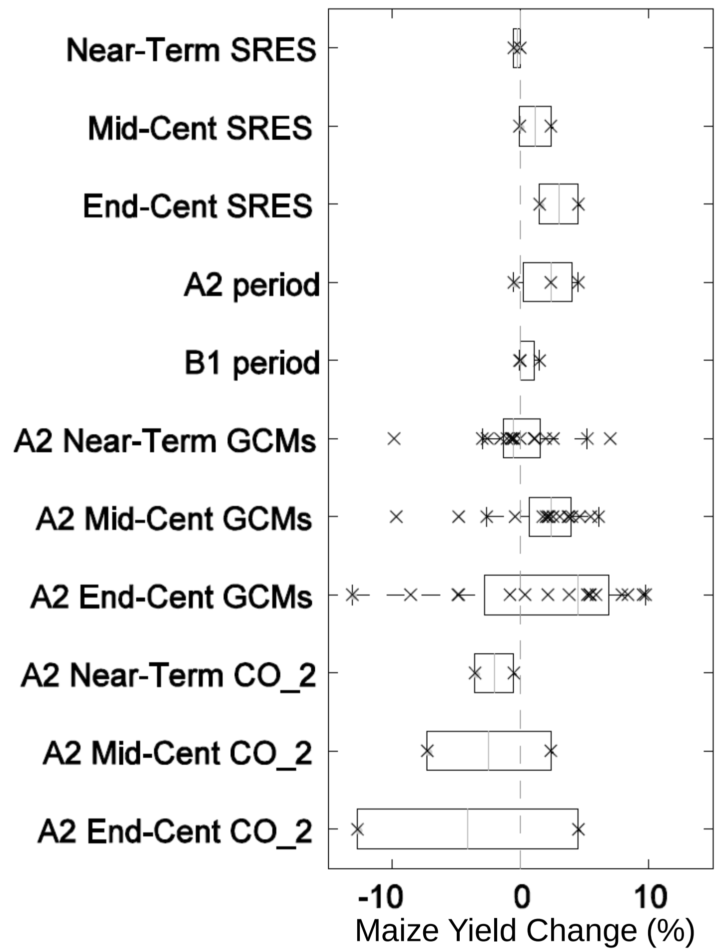
Yield (% of baseline mean)

Ruane et al., 2011

Compare various sources of uncertainty in terms of their effects on climate change impact

- **Where are uncertainty bottlenecks?**

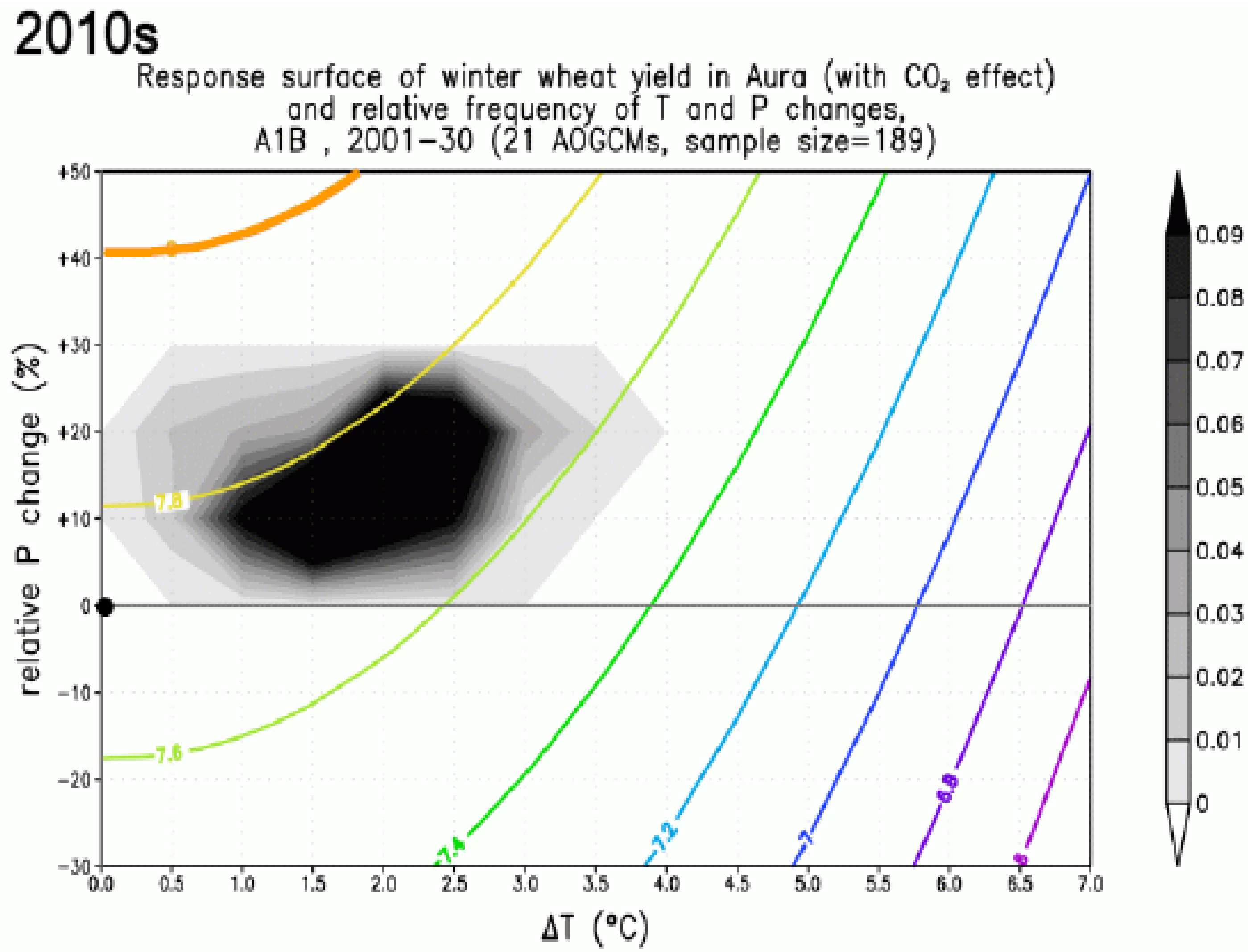




- Non-additive, but informative

CERES-Maize results for Los Santos, Panama, Ruane et al., 2011

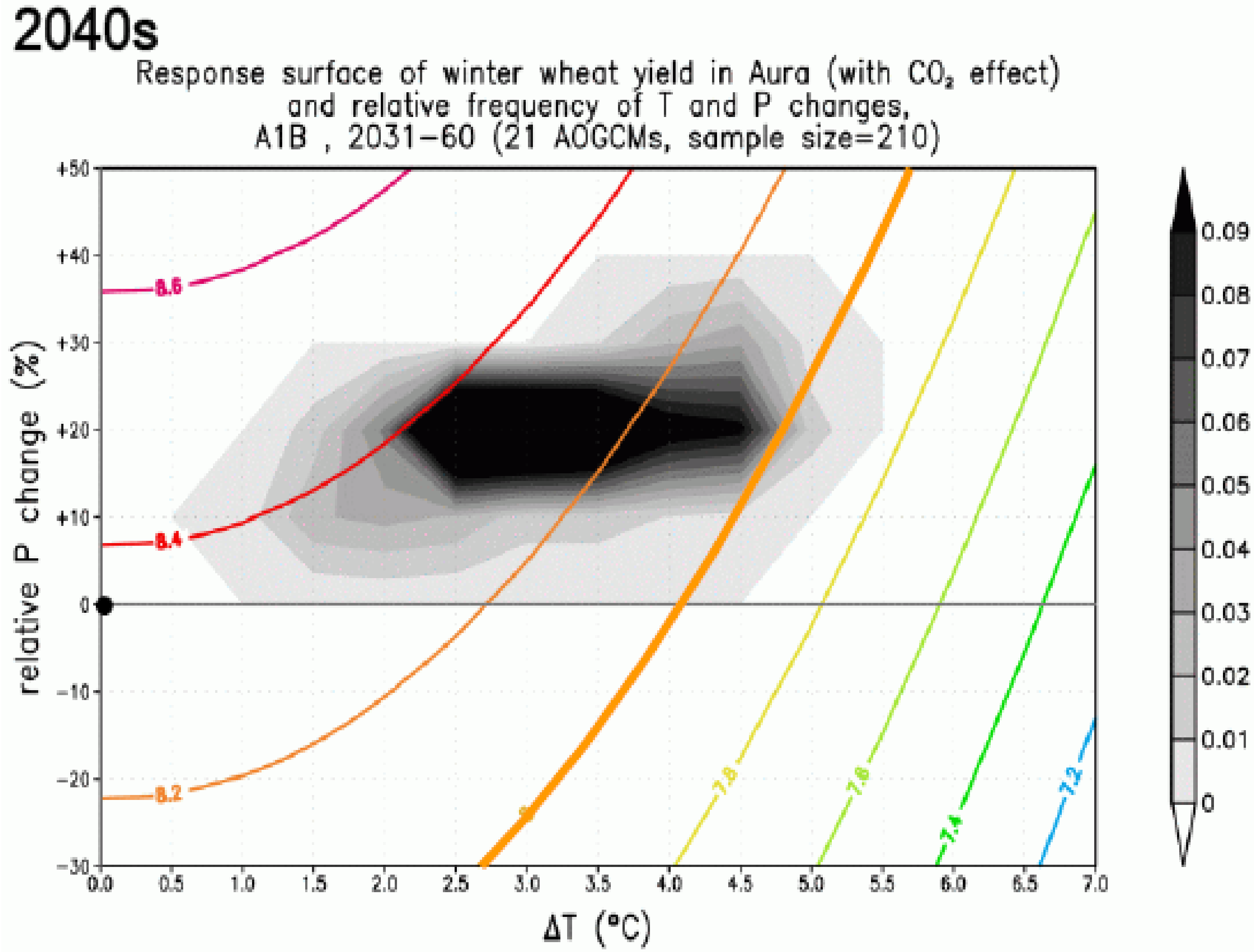
Yield Impacts Response Surfaces



Sources: Räisänen & Ruokolainen (climate changes)
Fronzek et al. (yield response surface)

This slide courtesy of Tim Carter, SYKE, Finland

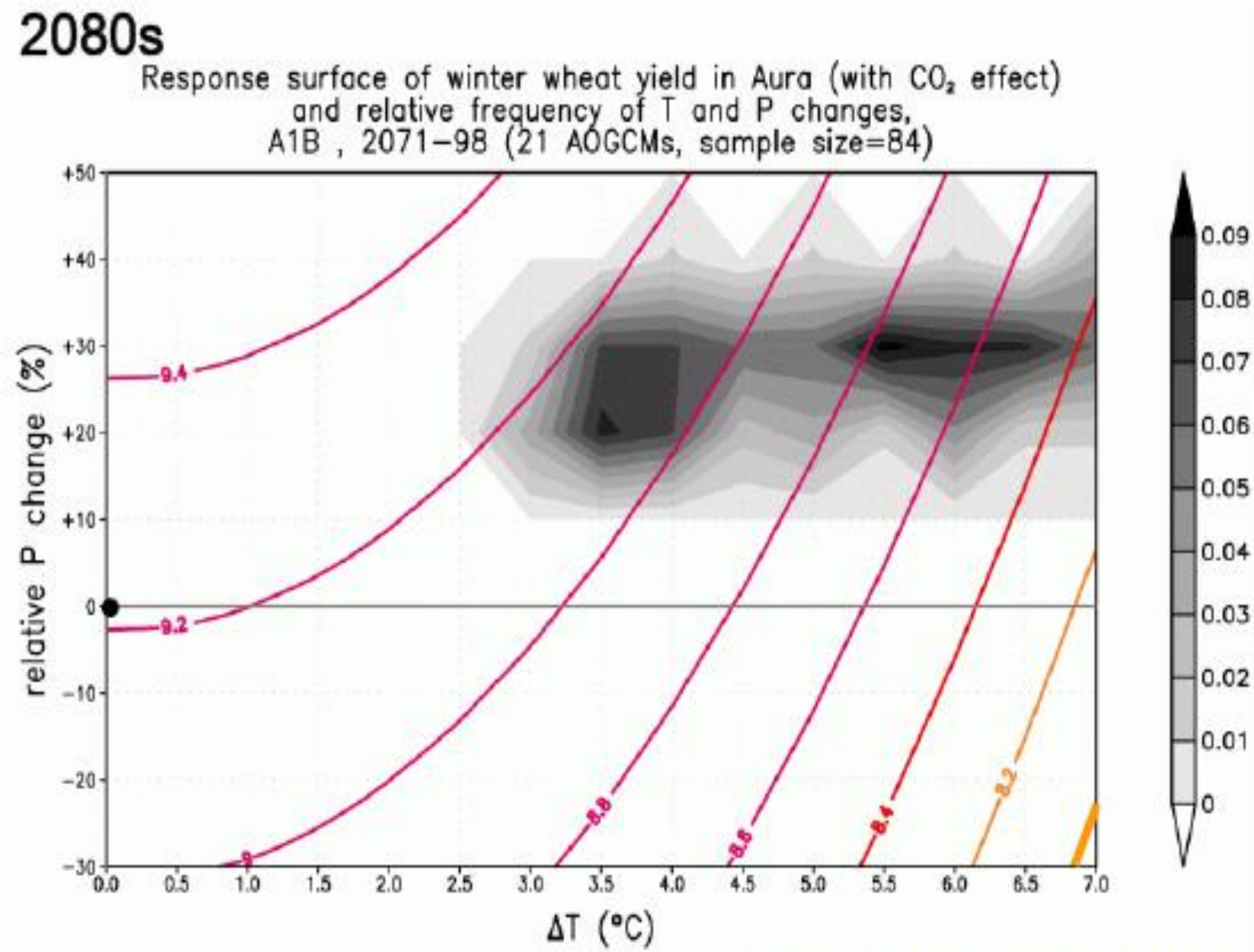
Yield Impacts Response Surfaces



Sources: Räisänen & Ruokolainen (climate changes)
Fronzek et al. (yield response surface)

This slide courtesy of Tim Carter, SYKE, Finland

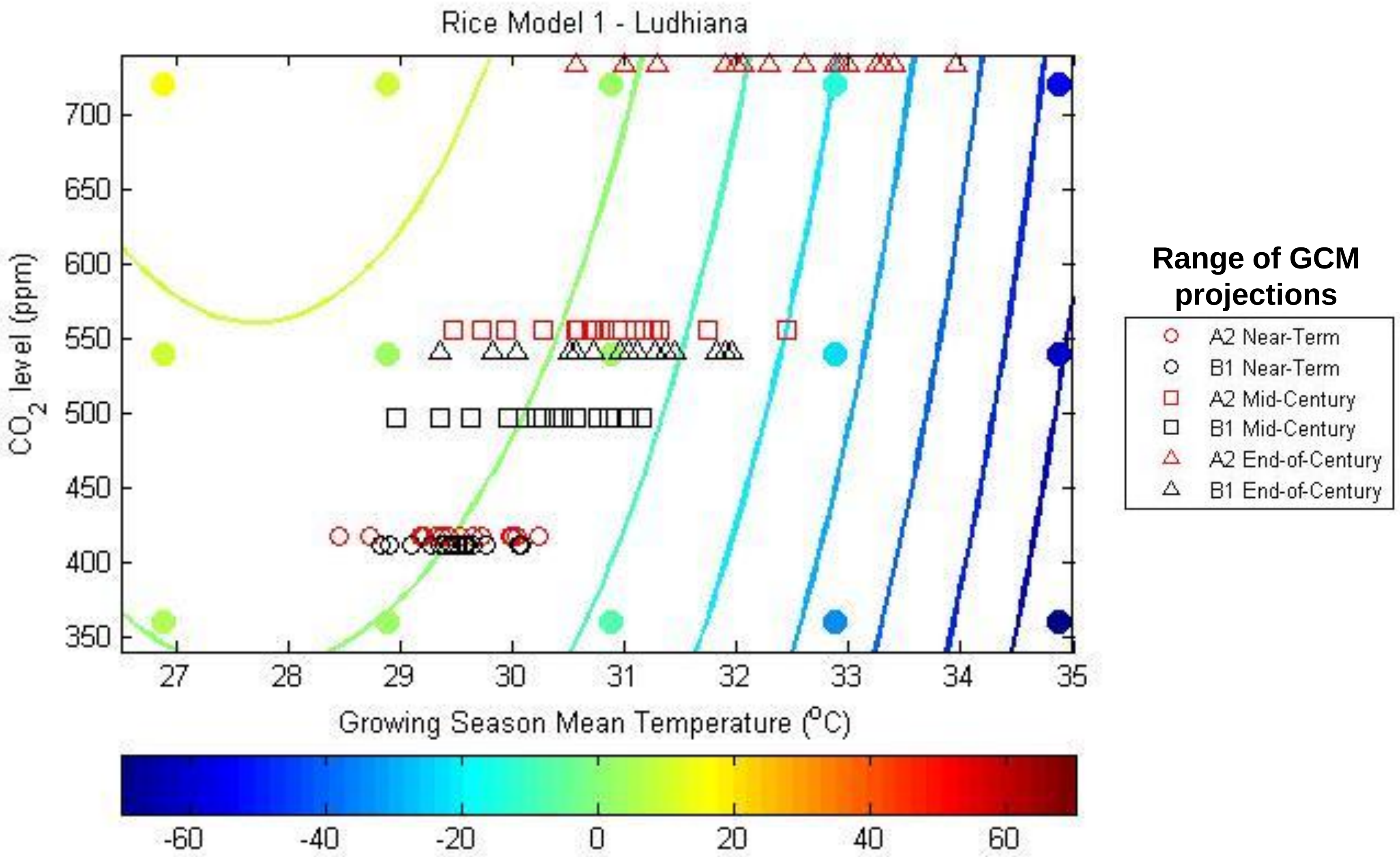
Yield Impacts Response Surfaces



Sources: Räisänen & Ruokolainen (climate changes)
Fronzek et al. (yield response surface)

This slide courtesy of Tim Carter, SYKE, Finland

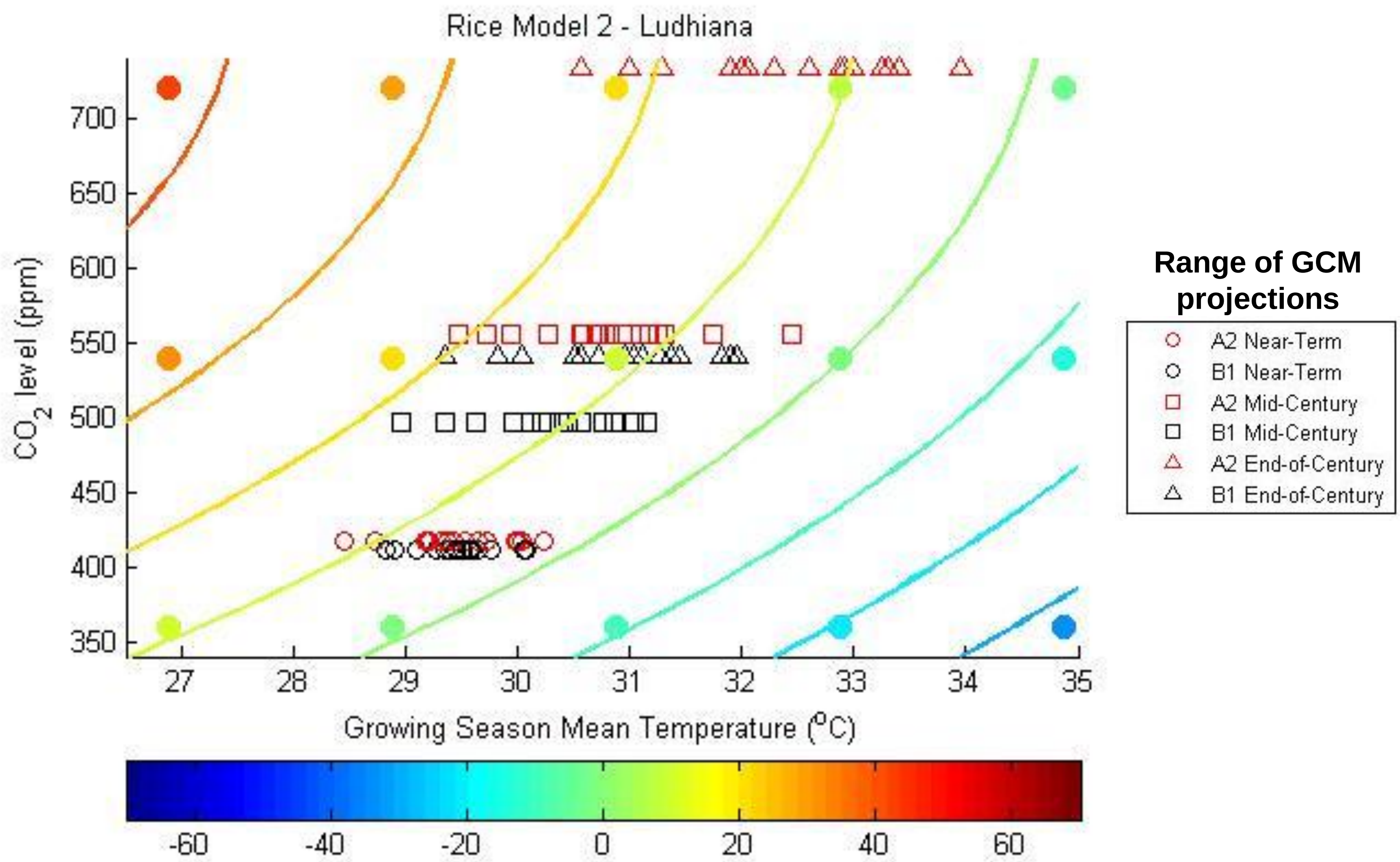
Yield Impacts Response Surfaces – Indian Rice



% Yield change (from baseline average)

Preliminary Results from AgMIP South Asia Regional Workshop: not for reference of publication

Yield Impacts Response Surfaces – Indian Rice

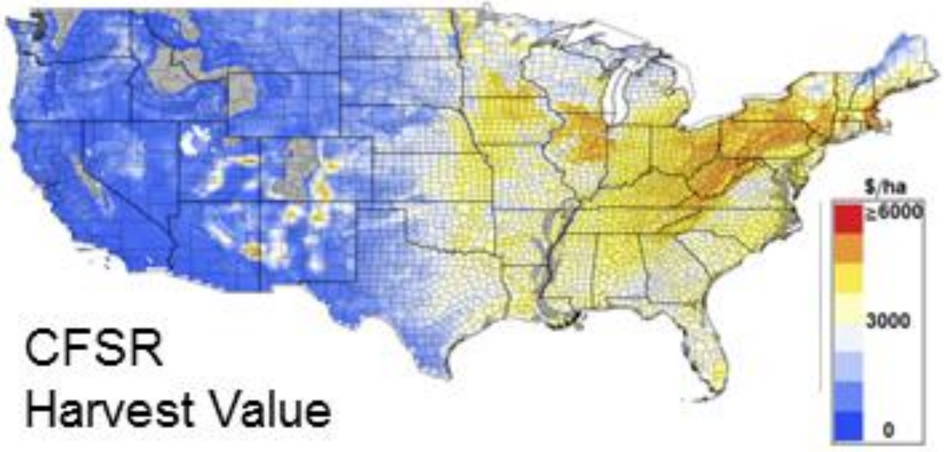


% Yield change (from baseline average)

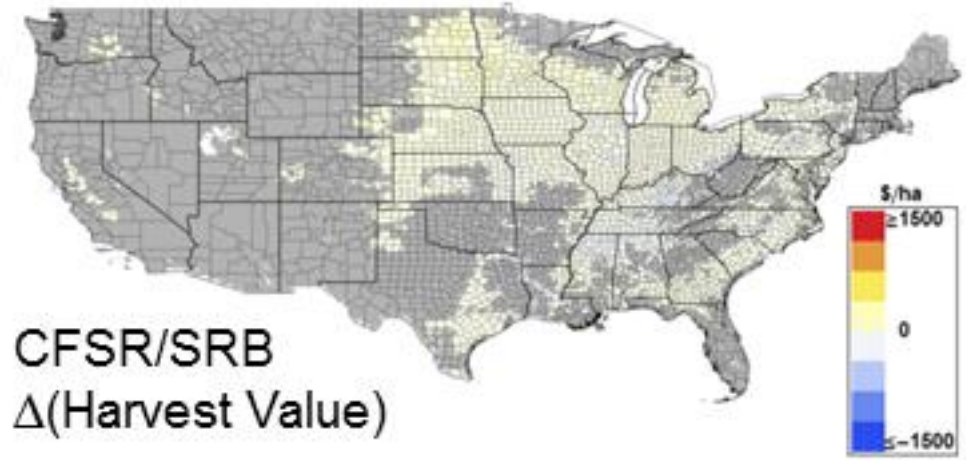
Preliminary Results from AgMIP South Asia Regional Workshop: not for reference of publication

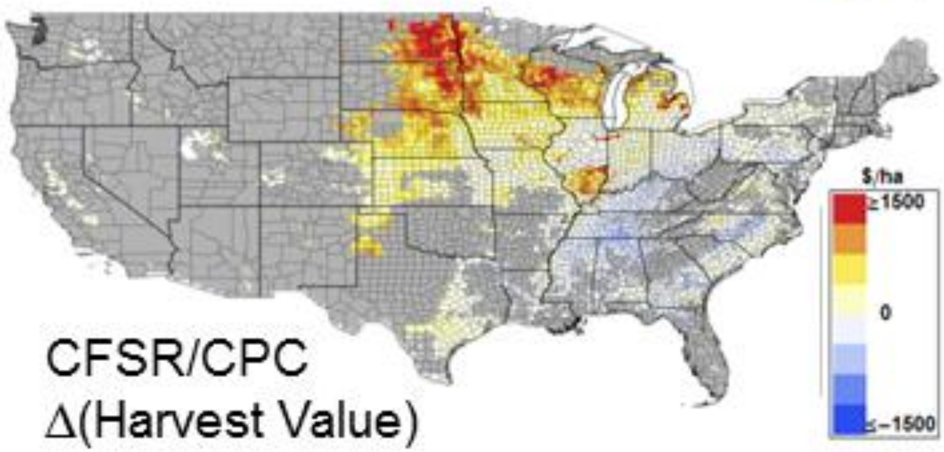
Value of Earth Information – Baseline Observational Datasets

Raw Reanalysis

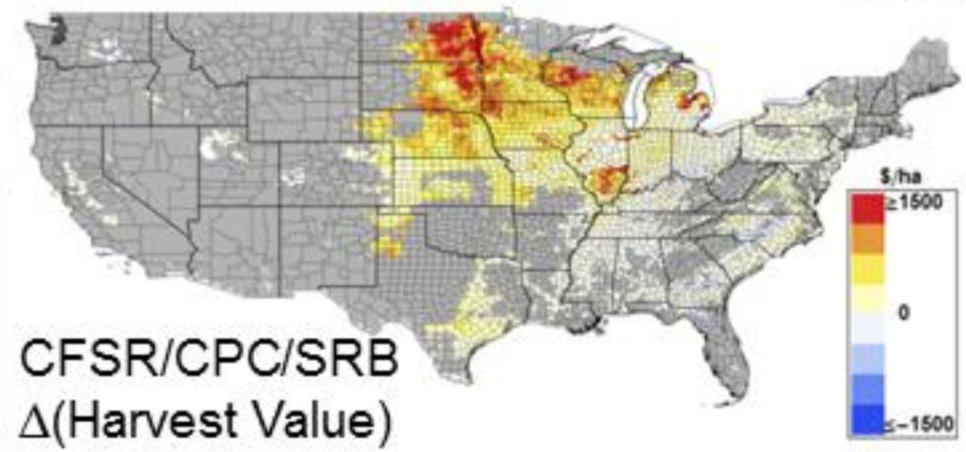


Improved Solar Radiation





Improved Rainfall



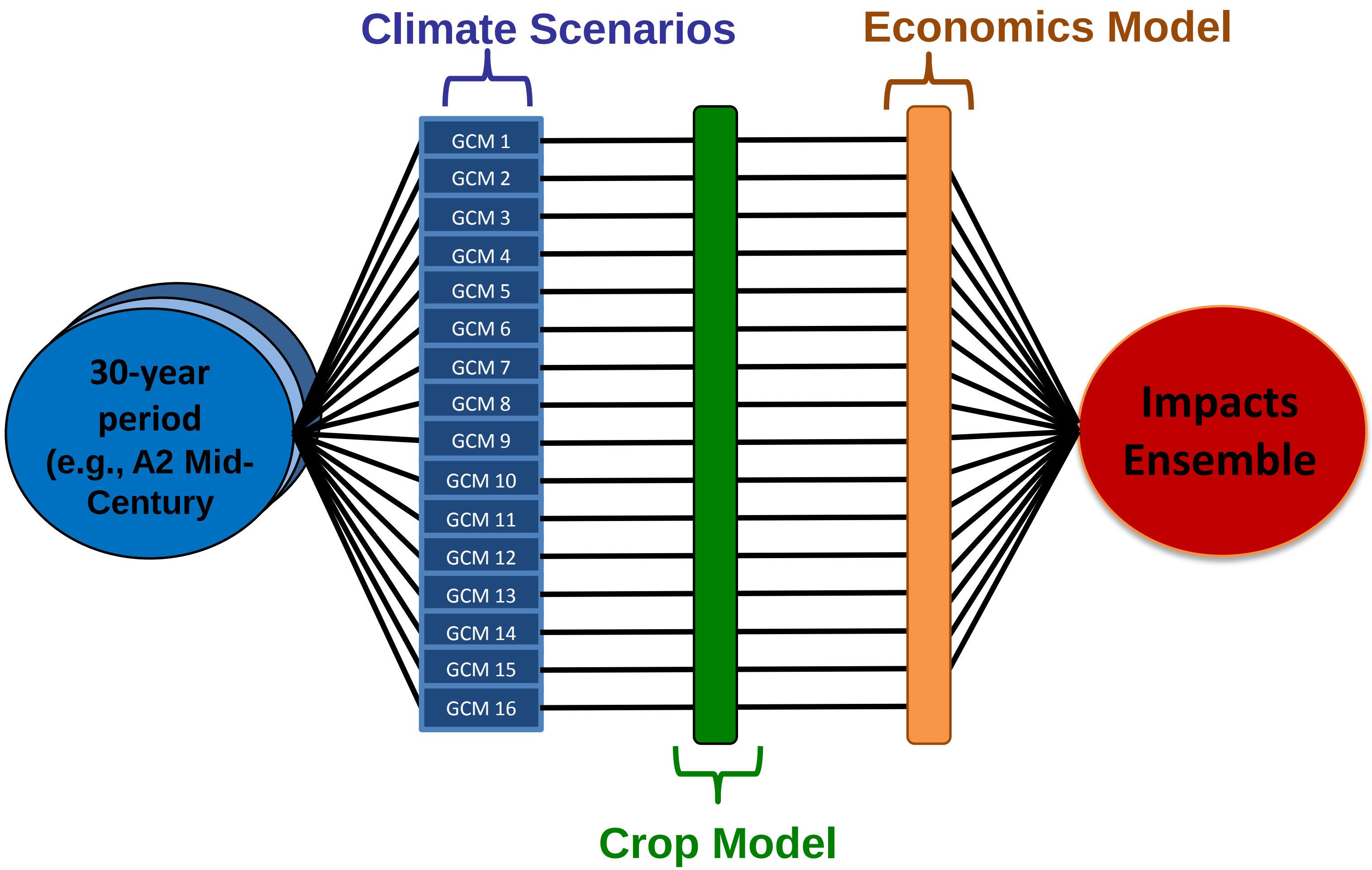
Improved Rainfall and Solar Radiation

Per hectare corn value ($/ha) as simulated by the DSSAT crop model (2011 corn price of $500/ton from USDA; areas with low corn acreage are not shown).

Continuing Uncertainty Challenges

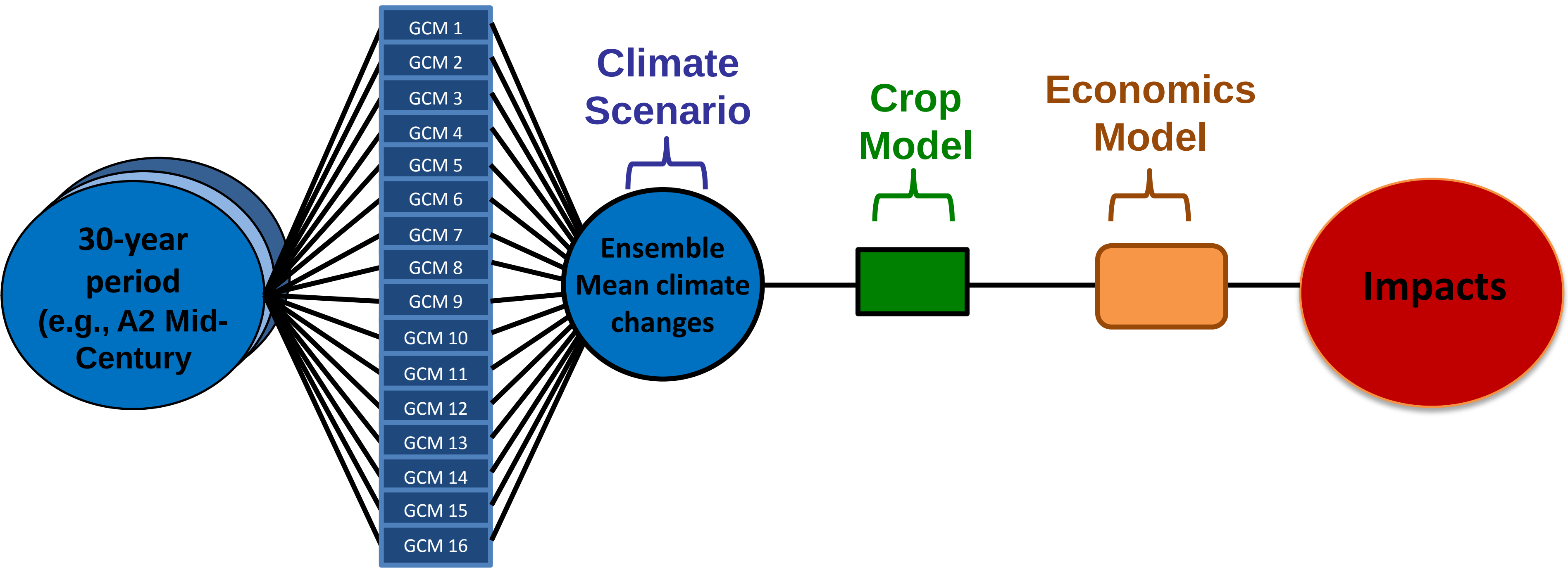
Uncertainty

- At what point is ensemble uncertainty assessed?



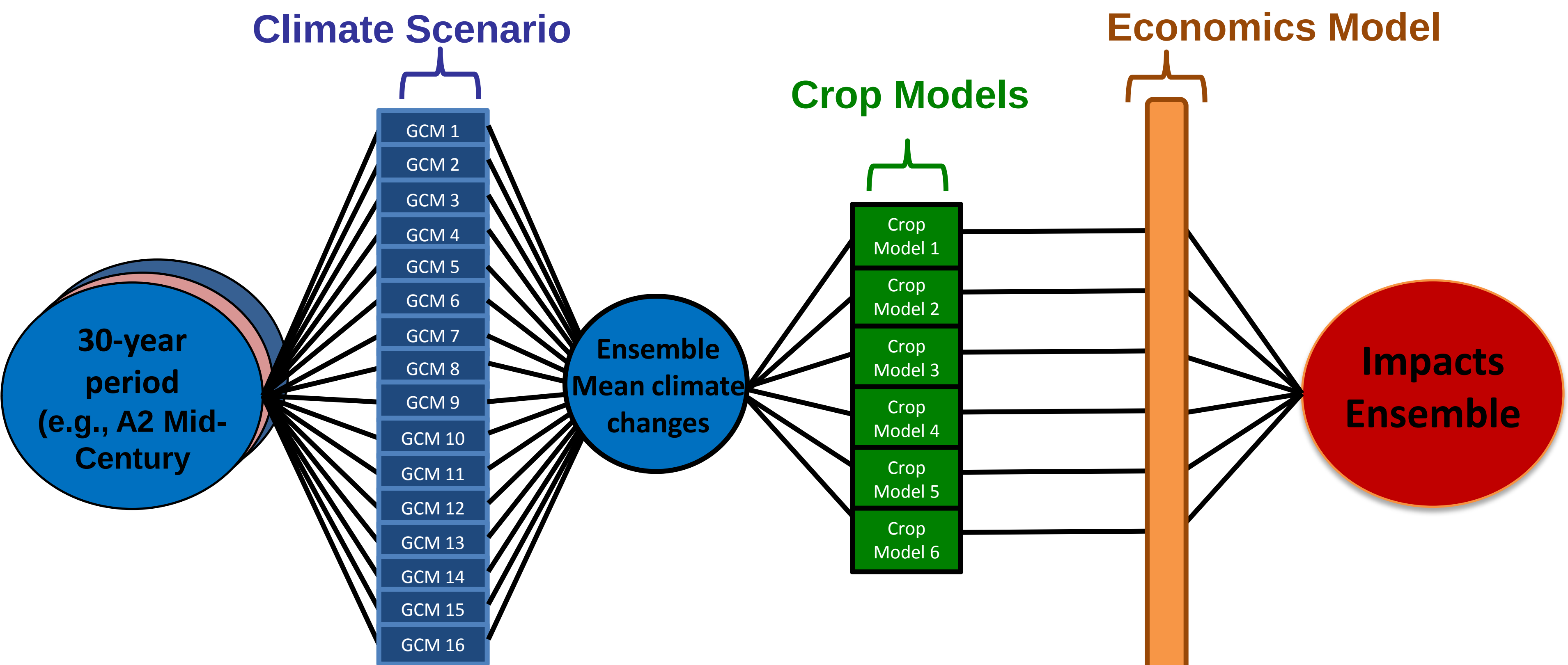
Uncertainty

- **At what point is ensemble uncertainty assessed?**

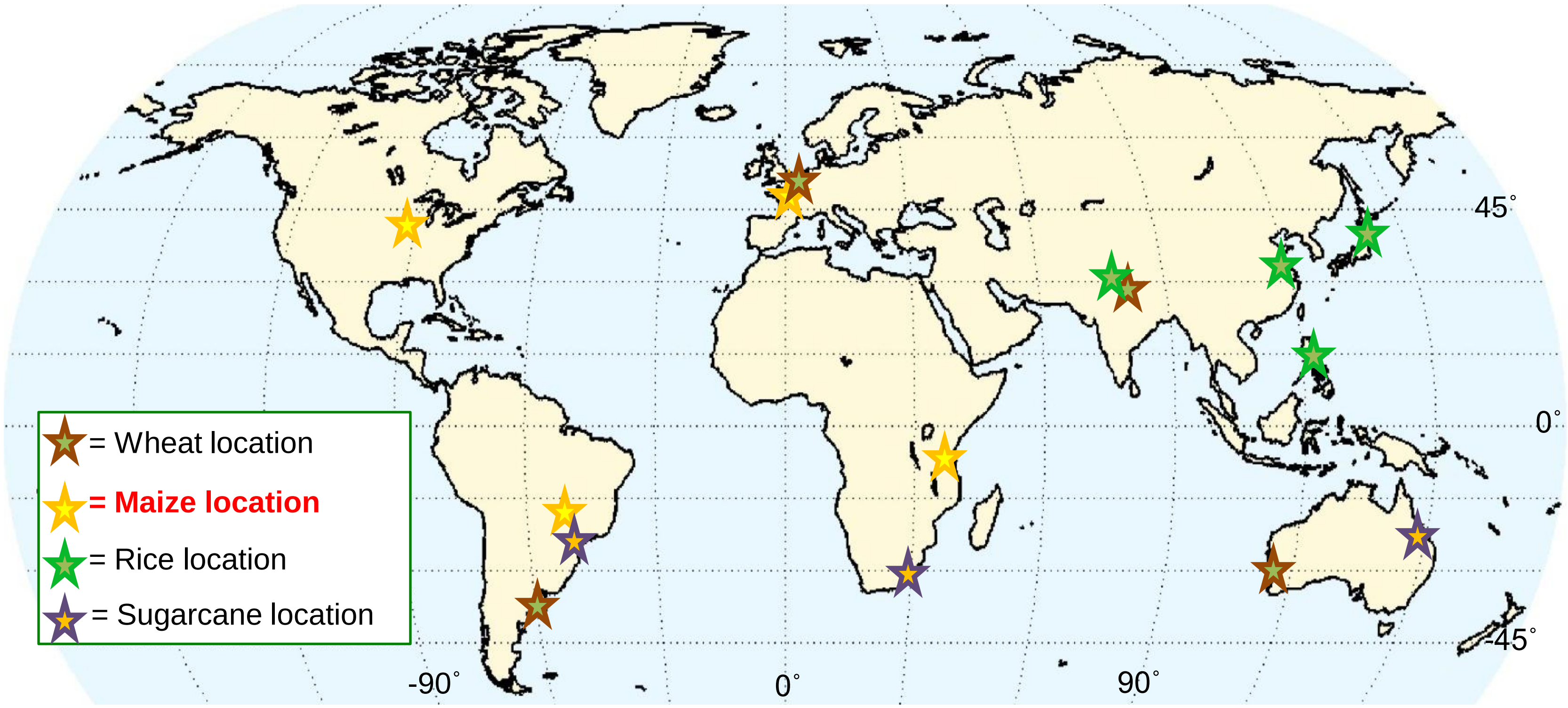


Uncertainty

- At what point is ensemble uncertainty assessed?



AgMIP Maize Model Pilot Intercomparison

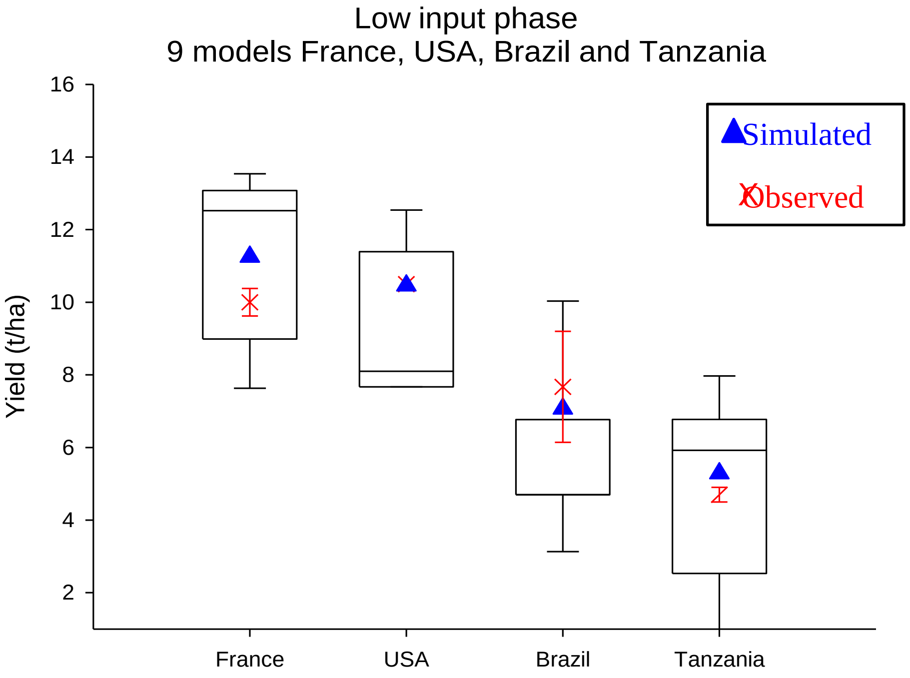


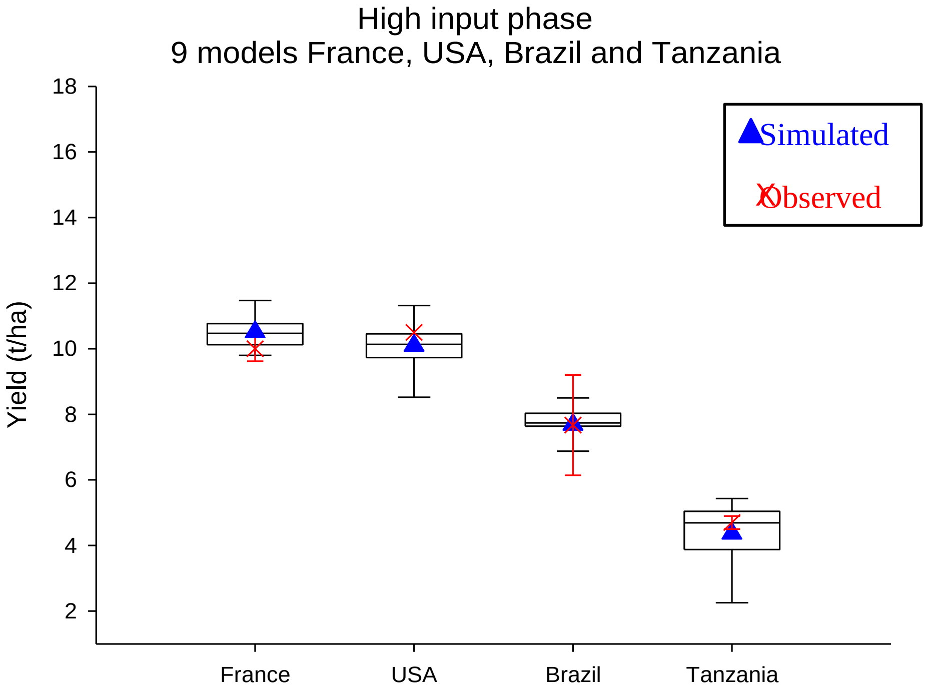
- 25-model Maize Pilot underway
  - Bassu Simona, Durand Jean-Louis, Boote Ken, Lizaso Jon, Adam Myriam, Baron Christian, Basso Bruno, Biernath Christian, Boogaard Hendrik, Conijn Sjaak, Deryng Delphine, De Sanctis Giacomo, Gayler Sebastian, Grassini Patricio, Hoek Steven, Izaurralde Cesar, Jongschaap Raymond, Kemanian Armen, Kersebaum Kurt Christian, Müller Christoph, Nendel Claas, Priesack Eckart, Sau Federico, Shcherbak Iurii, Tao Fulu, Teixeira Edmar, Timlin Dennis, Waha Katharina, Jerry Hatfield, Marc Corbeels
- Wheat and rice pilot results to be released soon…

AgMIP The Agricultural Model Intercomparison and Improvement Project

Uncertainty analyses (eventually 25 models)

Low and High input phase,
France (1996), USA (2010), Brazil (2003-04), Tanzania (2009-10)

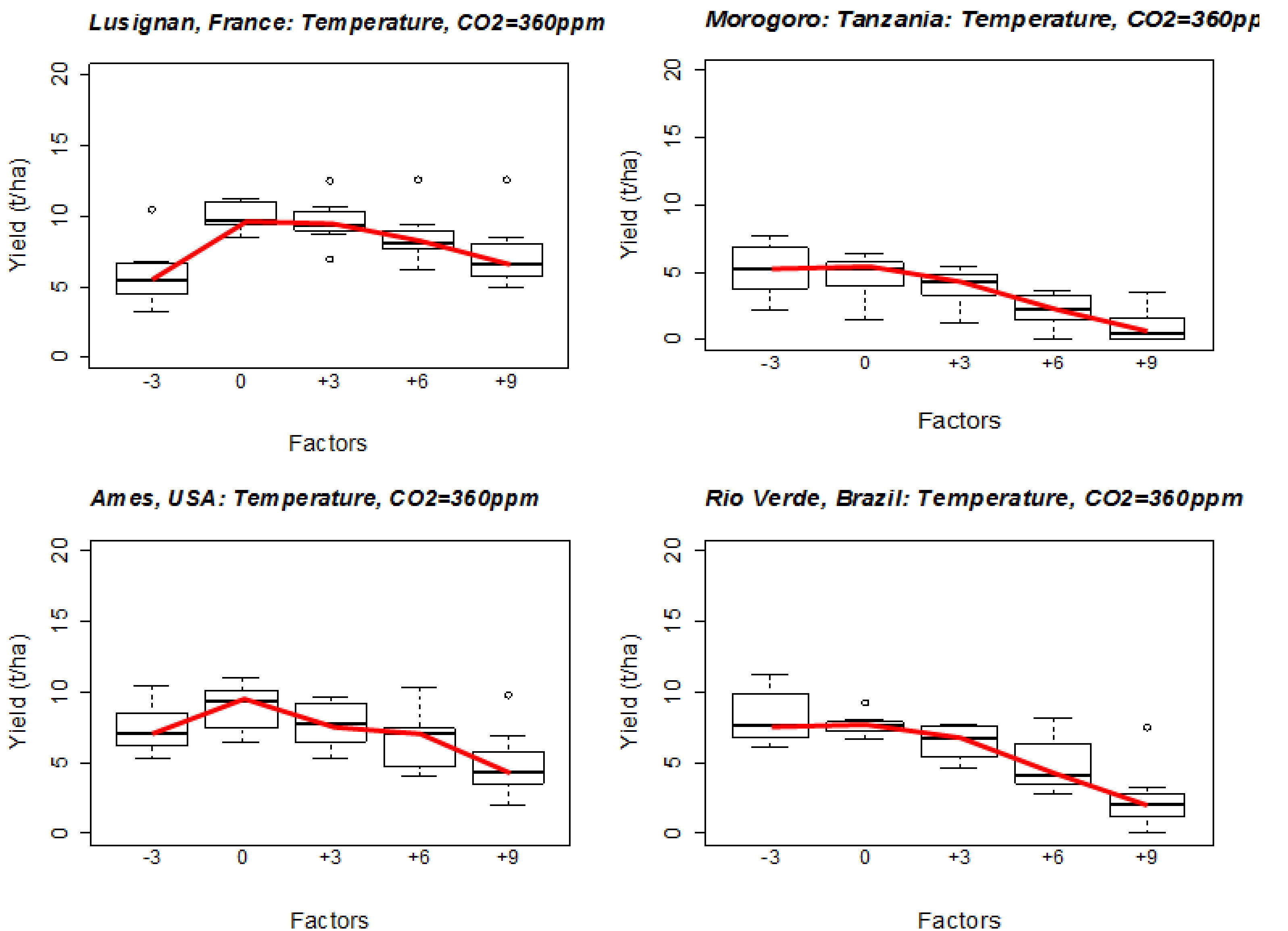




The Agricultural Model Intercomparison and Improvement Project

Slide courtesy of Simona Bassu and the AgMIP Maize Pilot Team

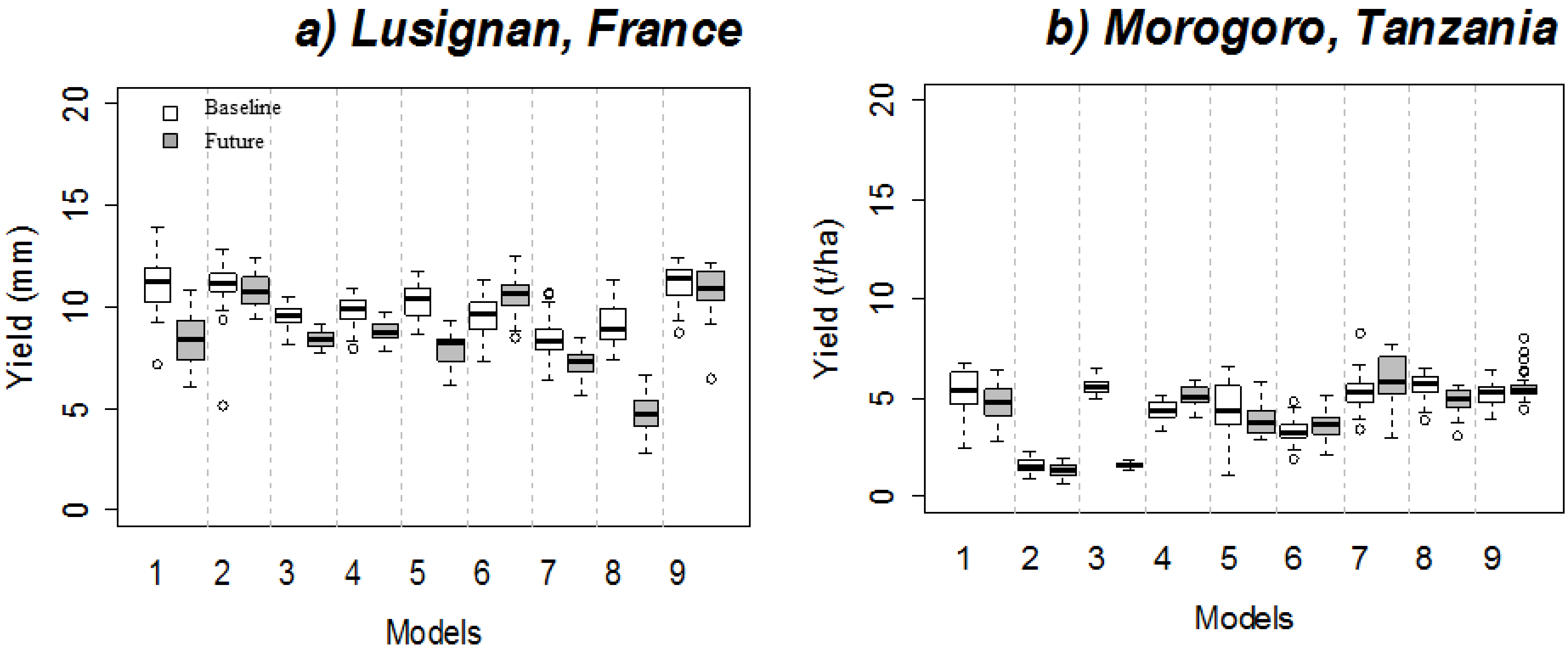
Simulated yield response to temperature – 9 models



AgMIP The Agricultural Model Intercomparison and Improvement Project

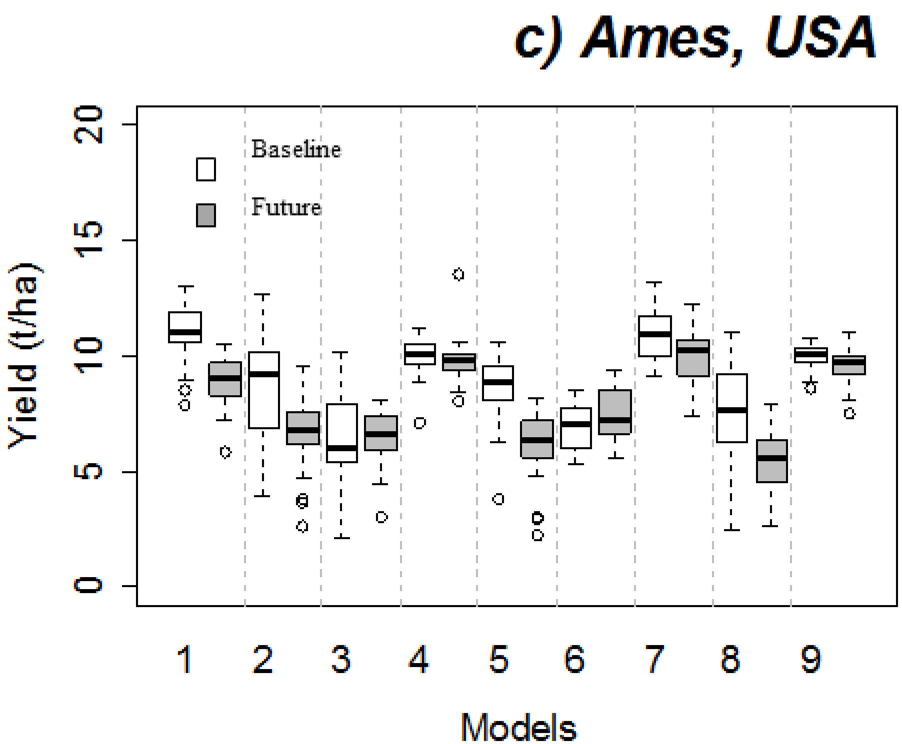
Slide courtesy of Simona Bassu and the AgMIP Maize Pilot Team

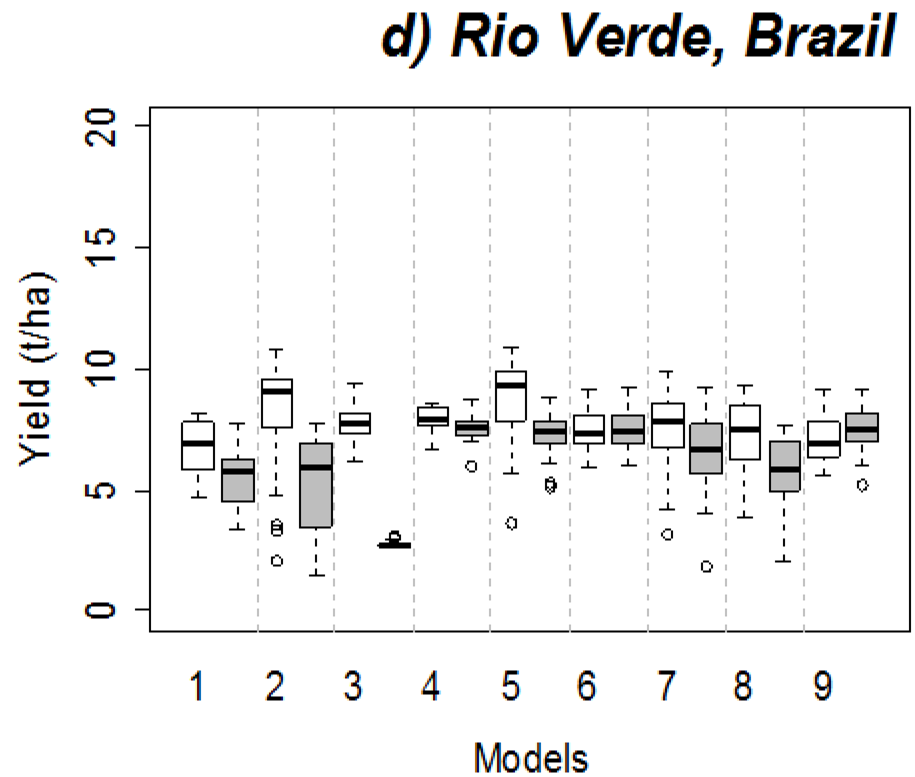
Simulated yield response to climate change - 30-year baseline and future



Slide courtesy of Simona Bassu and the AgMIP Maize Pilot Team

Simulated yield response to climate change - 30-year baseline and future





AgMIP The Agricultural Model Intercomparison and Improvement Project

Slide courtesy of Simona Bassu and the AgMIP Maize Pilot Team

The Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP)

Organized by the Potsdam Institute for Climate (PIK)

Using consistent climate scenarios to drive:

- **biophysical agriculture models (~7)**
- **agricultural economic models (~11)**
- **health models**
- **hydrologic models**
- **ecosystem models**

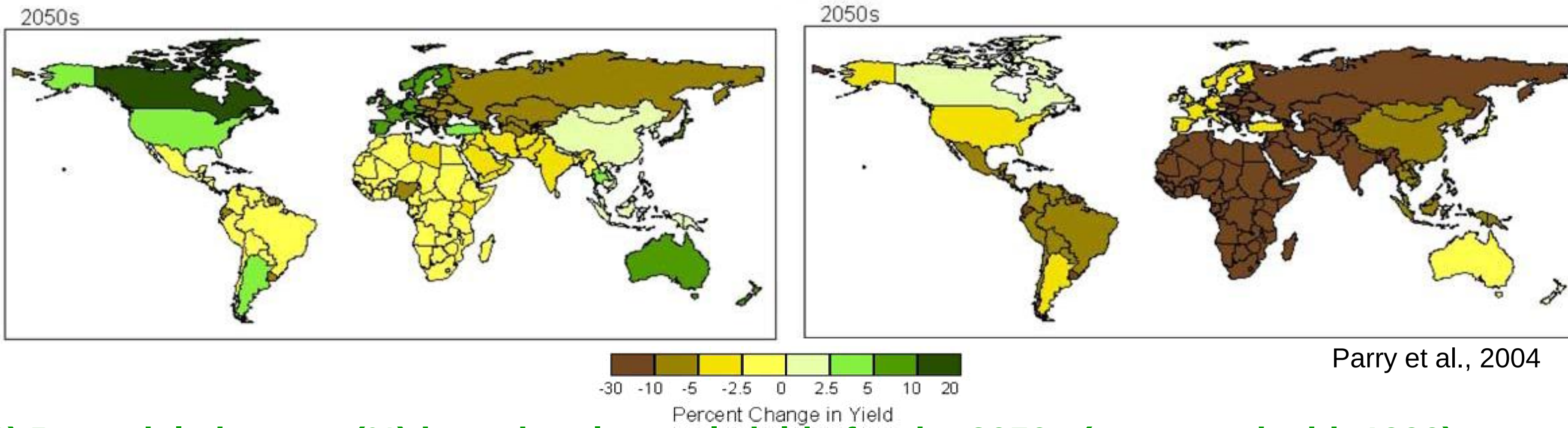
Biggest Remaining Question:

How can we best draw useful information from the huge ensembles that we are generating?

Thanks!

alexander.c.ruane@nasa.gov

Projected Yield Changes 2050s



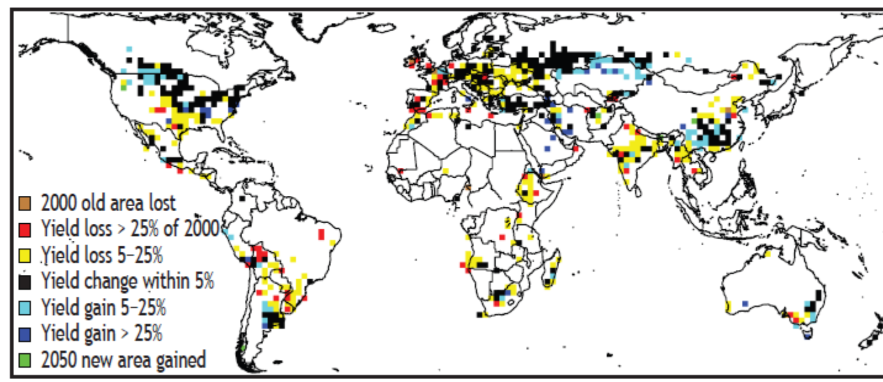
Parry et al., 2004

1) Potential changes (%) in national cereal yields for the 2050s (compared with 1990) under the HadCM3 SRES A2a scenario with and without CO2 effects (DSSAT)

2) IFPRI Yield Effects with CO2, rainfed wheat CSIRO A1B (DSSAT): -25% to +25%

3) GAEZ IIASA 2009 rain-fed cereals Using Hadley GCM and A2 scenario: North America -7 to -1%; Europe -4 to +3%; Central Asia +14 to +19%; Southern Africa -32 to -29%

4) Schlenker & Lobell Africa multi GCMs: -22 to -2% using statistical approach



IFPRI 2011

1) Parry et al.	-30% to +20%
2) IFPRI	-25% to +25%
3) GAEZ	-32% to +19%
4) Schlenker & Lobell (Africa)	-22% to -2%

White et al., 2011 – Survey of Crop Models used for Climate Change Impacts Studies

Which crops were considered in the papers[a]:

Alfalfa[+b]	1.6	Pasture grass	2.3
Bambara	0.9	Pea[+]	0.2
Barley[+]	3.8	Peanut[+]	4.4
Cabbage[+]	0.1	Phaseolus[+]	1.2
Canola, rape and mustard[+]	1.9	Potato[+]	7.0
Cassava[+]	0.3	Rice[+]	24.5
Cauliflower[+]	2.0	Rye[+]	0.1
Chickpea[+]	2.3	Sorghum[+]	3.9
Citrus	0.8	Soybean[+]	15.6
Clover[+]	0.2	Sugar beet[+]	4.0
Cotton[+]	3.3	Sugar cane[+]	2.1
Faba[+]	1.3	Sunflower[+]	0.7
Kiwi	0.3	Switchgrass	0.4
Maize[+]	54.4	Tobacco	0.1
Millet[+]	0.8	Tomato[+]	0.1
Oats[+]	0.5	Wheat[+]	77.1
Onion	0.1	Wheatgrass	0.4
Paspalum sp.	0.3	(generic crop for watershed)	1.0

Table 3
Number of papers considering specific countries or regions. Fractions resulted from papers where multiple countries or regions were considered.

Africa		Europe		North America	
Angola	0.1	Austria	4.5	Canada	5.3
Botswana	1.1	Bulgaria	2.0	US	55.3
Burundi	0.3	Czech Rep.	1.5		
Cameroon	3.0	Denmark	0.8	Latin America	
Dem. Rep. Congo	0.2	Finland	3.2	Argentina	1.0
Ethiopia	0.1	France	3.2	Brazil	4.0
Kenya	0.3	Germany	2.0	Chile	1.0
Lesotho	0.5	Greece	1.0	Mexico	0.3
Malawi	0.2	Hungary	4.2	Venezuela	1.0
Mali	1.0	Ireland	3.2		
Mozambique	0.2	Italy	4.3	Regions	
Nigeria	1.0	Netherlands	0.2	Africa	1.5
Rwanda	0.3	Portugal	0.7	Europe	7.0
South Africa	2.0	Russia	1.5	Latin America	0.5
Swaziland	1.5	Romania	1.0	Former USSR	1.0
Tanzania	0.4	Slovakia	1.0	Global	4.0
Tunisia	1.0	Spain	5.7		
Uganda	0.3	Switzerland	2.0		
Zambia	0.1	Ukraine	0.5		
Zimbabwe	2.1	UK	14.7		
Australasia		Middle East			
Australia	13.0	Iran	1.5		
Bangladesh	1.1	Egypt	2.0		
China	18.5	Israel	2.0		
India	17.1	Syria	1.5		
Indonesia	1.1				
Japan	2.5				
Malaysia	0.1				
Myanmar (Burma)	0.1				
New Zealand	1.0				
Pakistan	1.0				
Philippines	2.5				
South Korea	0.3				
Taiwan	0.1				
Thailand	0.5				

White et al., 2011 – Survey of Crop Models used for Climate Change Impacts Studies

Table 4

Number of papers classified by the simulation model used to assess impacts, how well the selection of a model was justified, and how the model was evaluated for overall suitability. Fractions resulted from papers where multiple models were used.

AFRCWHEAT	2.9	GEPIC	1.0	RICESYS	0.3
APSIM	13.0	GLAM	3.3	SCRI	0.3
AWAH	0.5	GLYCIM	2.0	SIMPOTATO	0.5
BlastSim	1.0	GOSSYM	3.5	SIMRIW	1.5
Broom's barn	2.0	HUMUS	1.5	SIRIUS	4.4
CANEGRO	1.0	InfoCrop	3.0	SOYGRO	3.3
CENTURY	3.0	LINTULCC	1.0	STAMINA	1.0
CERES	63.2	LPJ GUESS	0.3	STICS	3.0
CH Farm	0.3	LPOTCO	1.0	SUBSTOR	2.0
CMSM	2.0	MACROS	0.3	SWAT	0.5
CWHEAT2	0.3	MCWLA	1.0	SWIM	1.0
Climate Soil Yield	1.0	MMF erosion	1.0	Sinclair	5.0
CropGro	6.0	MUST	0.7	SoilN Wheat	0.4
CropSyst	9.1	mVSMB	1.0	WATBAL	0.3
CropWat	0.3	Miami	1.0	WEATHER YIELD	1.0
Cyrus	2.0	NPOTATO	0.5	WECS	0.7
deWit	1.0	Nwheat	0.4	WEPP	6.0
DNDC	3.0	ORYZA1 N	1.0	WOFOST	3.0
Daisy	0.3	POTATOS	0.5	WTGROWS	1.0
EPIC	25.2	PRZM	0.5	Wang Engel	2.0
EuroSunflower	0.5	PaSim	0.3	YIELD	1.0
EuroWheat	1.5	Phygro	0.5	VIP	1.0
FABEAN	1.3	Prarie Ag Bound Layer	1.0	Not named (various)	14.2

White et al., 2011 – Survey of Crop Models used for Climate Change Impacts Studies

Table 6

Number of papers classified by how global circulation model (GCM) or regional climate model (RCM) outputs were downscaled, which weather variables or atmospheric gasses were modified, how weather data were modified, weather generators used (if any), whether scenarios were implemented as continuous change or for discrete time steps, and whether simulations were run continuously or were re-initialized each season.

	How were GCM or RCM outputs downscaled to specific locations:	
	Using only GCM	Using an RCM
Outputs not downscaled	74	38
Interpolated with inverse distance, splines or other methods	27	0
Modeled	11	2
Climate analog	2	0
Unclear	3	1
Not applicable–GCM or RCM not used	63	

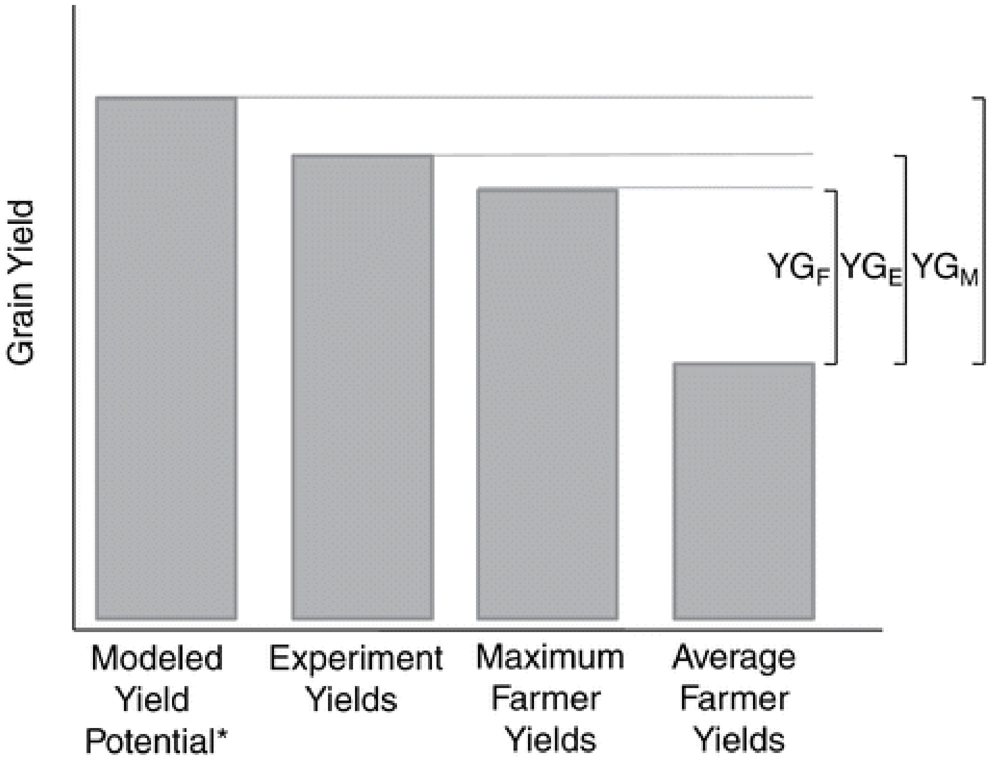
Which weather variables or atmospheric gasses were modified

Temperature	215	Wind	11
CO_2	167	Humidity	19
Precipitation	173	Cloud cover	1
Solar radiation	69	Ozone	1

How were modifications to weather variables introduced:

Adjustment to historic data	141
GCM or RCM used directly	6
Weather generator	68
Climate analog	3
Not applicable	3

Yield Gaps



*Or "water-limited yield potential" in the case of rainfed systems

Lobell et al., 2009

In most major irrigated wheat, rice, and maize systems, yields appear to be at or near 80% of yield potential, with no evidence for yields having exceeded this threshold to date.

Average yields in rainfed systems are commonly 50% or less of yield potential, suggesting ample room for improvement, though estimation of yield gaps for rainfed regions is subject to more errors than for irrigated regions.

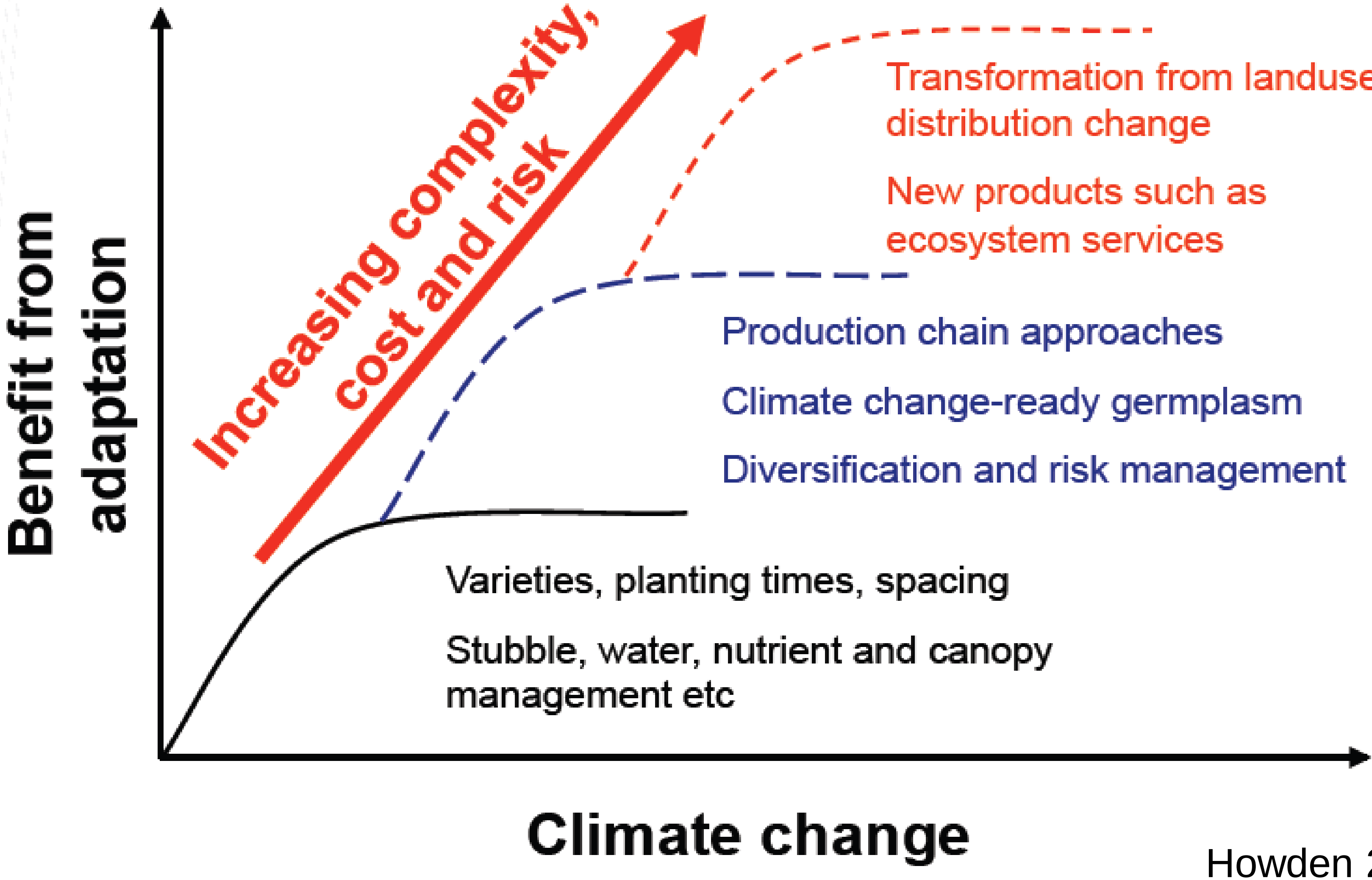
Win-win possibilities for resilience on near- to long-terms

Many developing regions still have large yield gaps to overcome

Climate change may add to these challenges for development

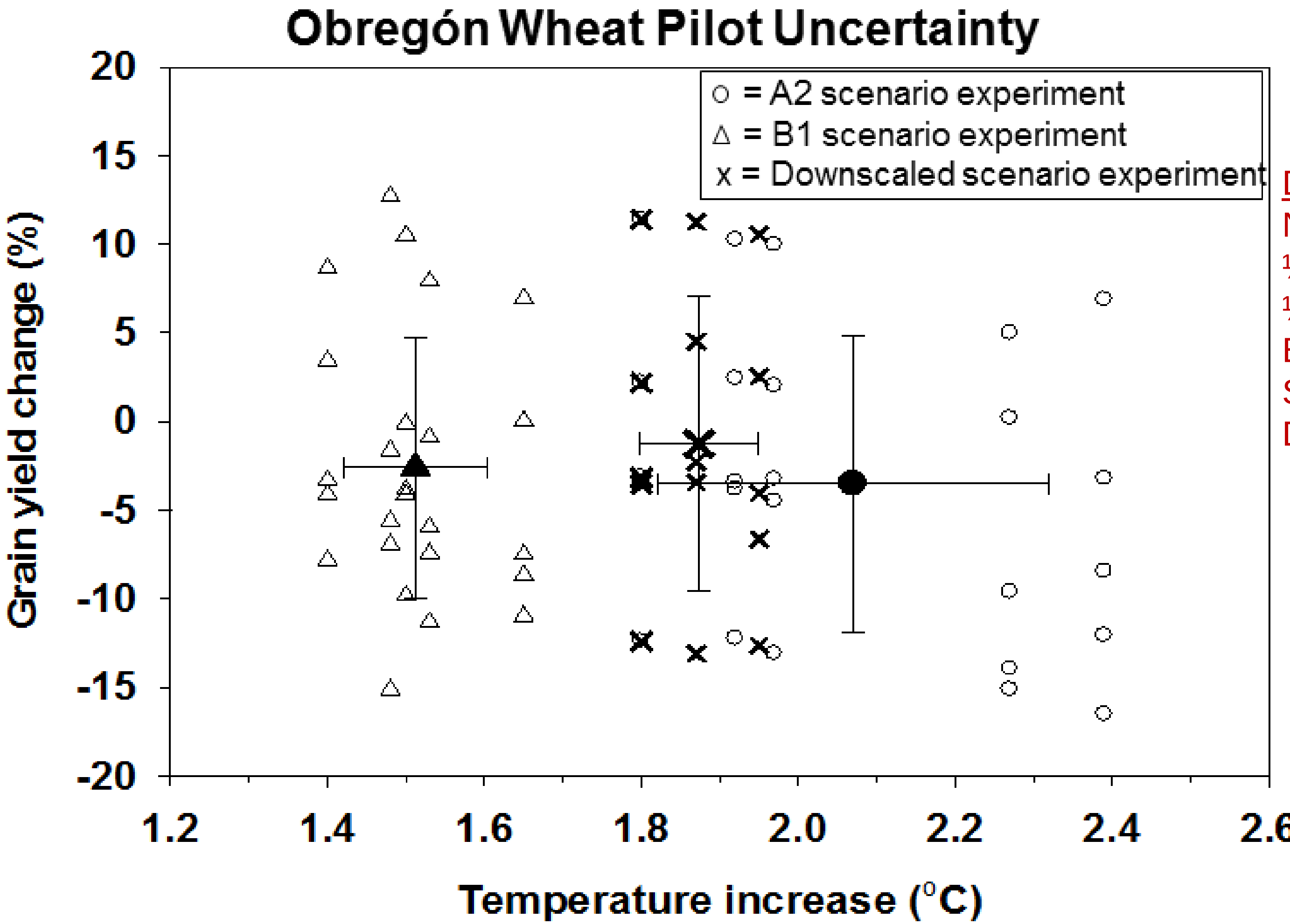
Managing Risks to the Global Agricultural System

Progressive Levels of Adaptation Challenges and Opportunities



Howden 2010

Sensitivities to Crop models, emissions scenarios, and statistical downscaling



Downscaling:
Native (~2˚)
½ degree
¼ degree
Bias-corrected
Statistically-Disaggregated

From Rosenzweig et al., Agricultural and Forest Meteorology (in review)