Global gridded crop modelling: methodology, evaluation and applications

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PIK – an Overview

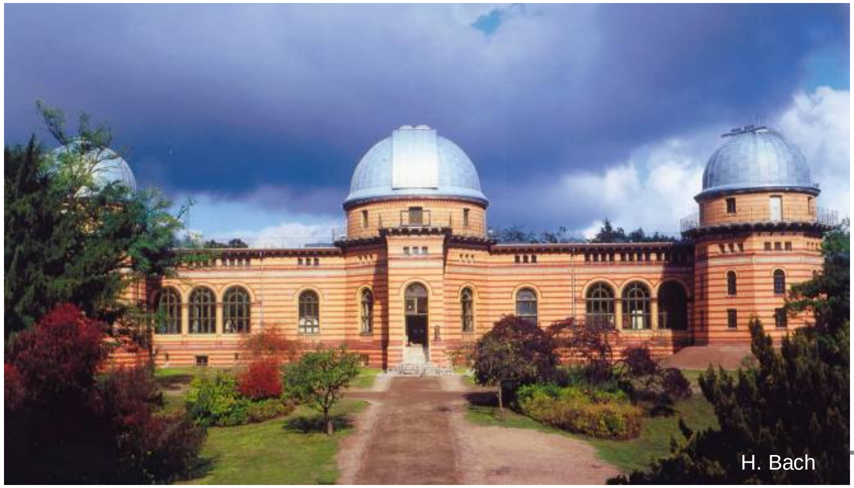
Potsdam Institute for Climate Impact Research

Founded: 1992 - Member of Leibniz Association

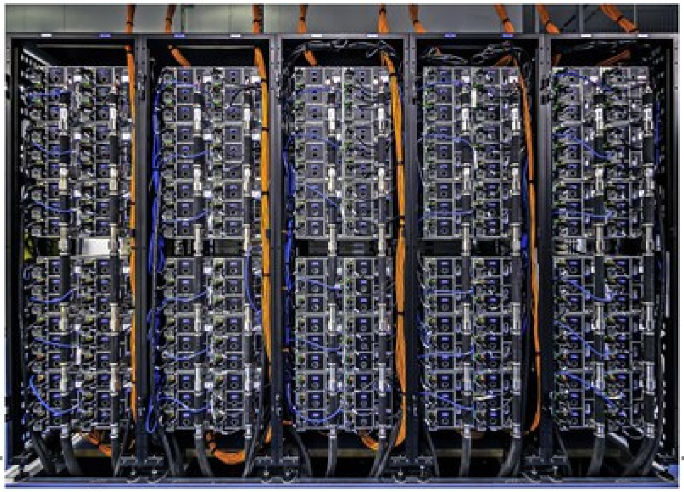
Resources: ~270 employees (ca. 170 scientists; 20 student assistants/interns)

Mission: interdisciplinary insights on global change, climate change and sustainable development; policy advice

Main tool: high-performance computer with 258 TeraFlops: system & scenario analysis, qualitative & quantitative modeling

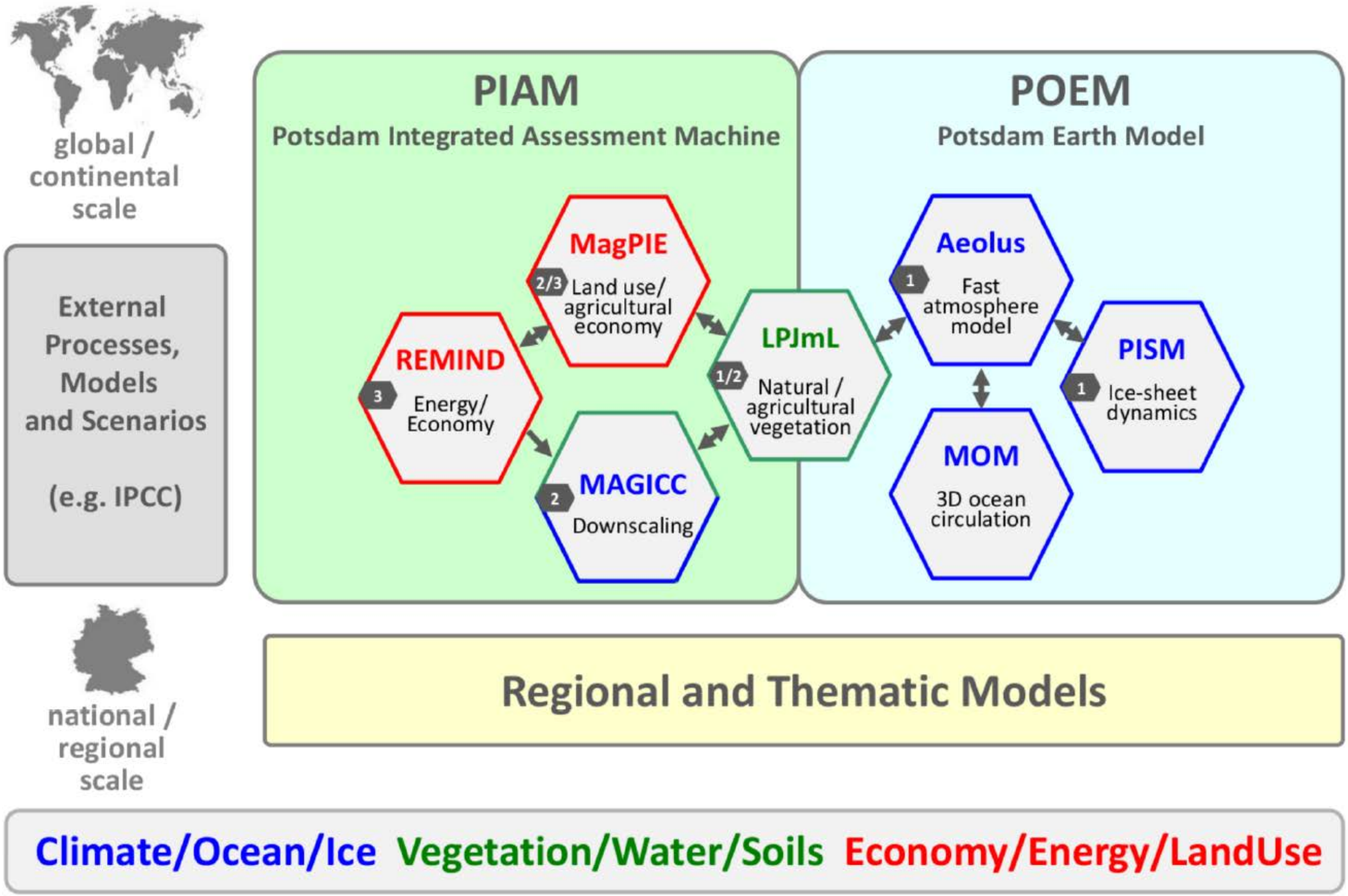


Michelson House



IBM nextscale cluster

PIK modeling portfolio



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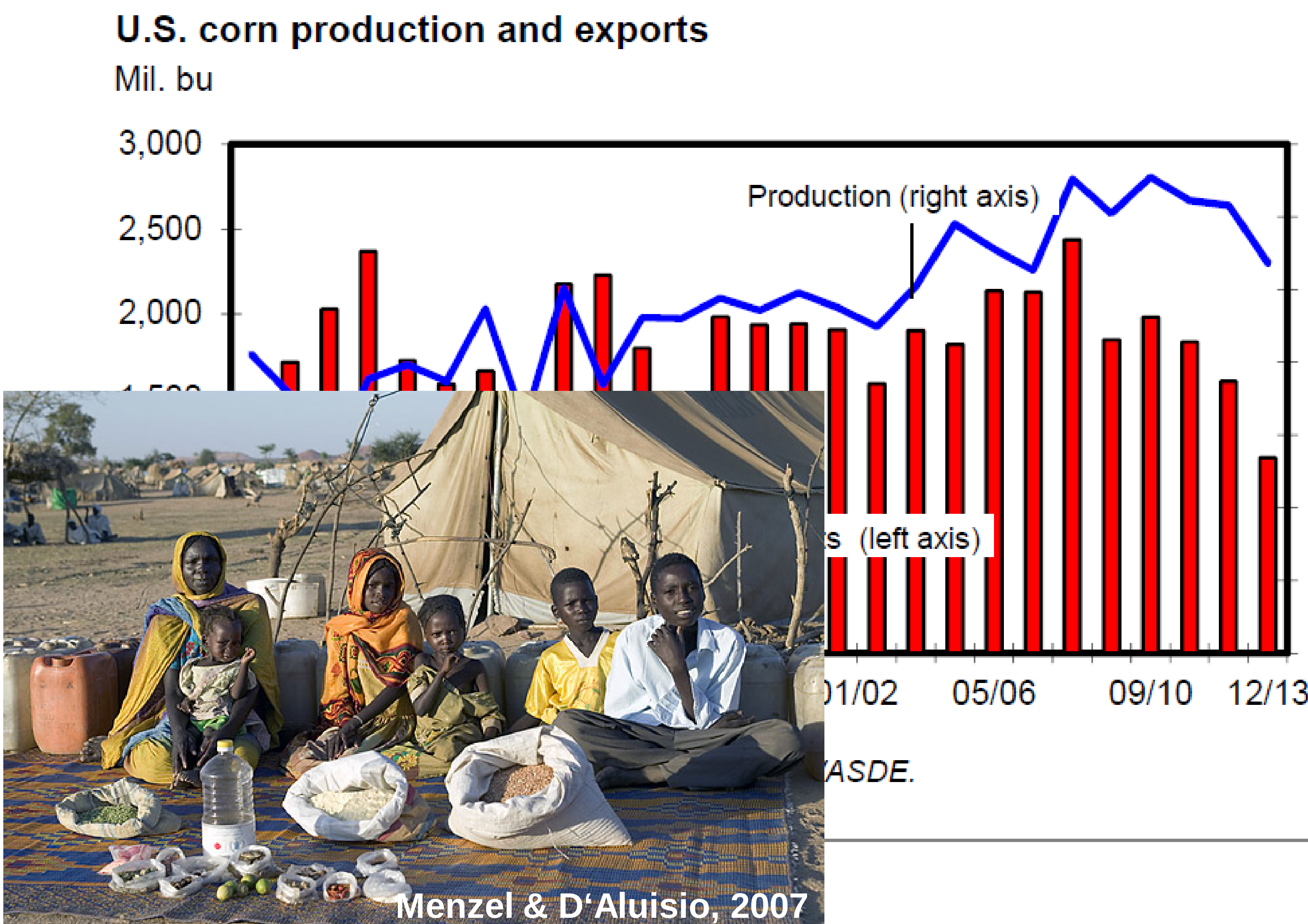
Food and weather

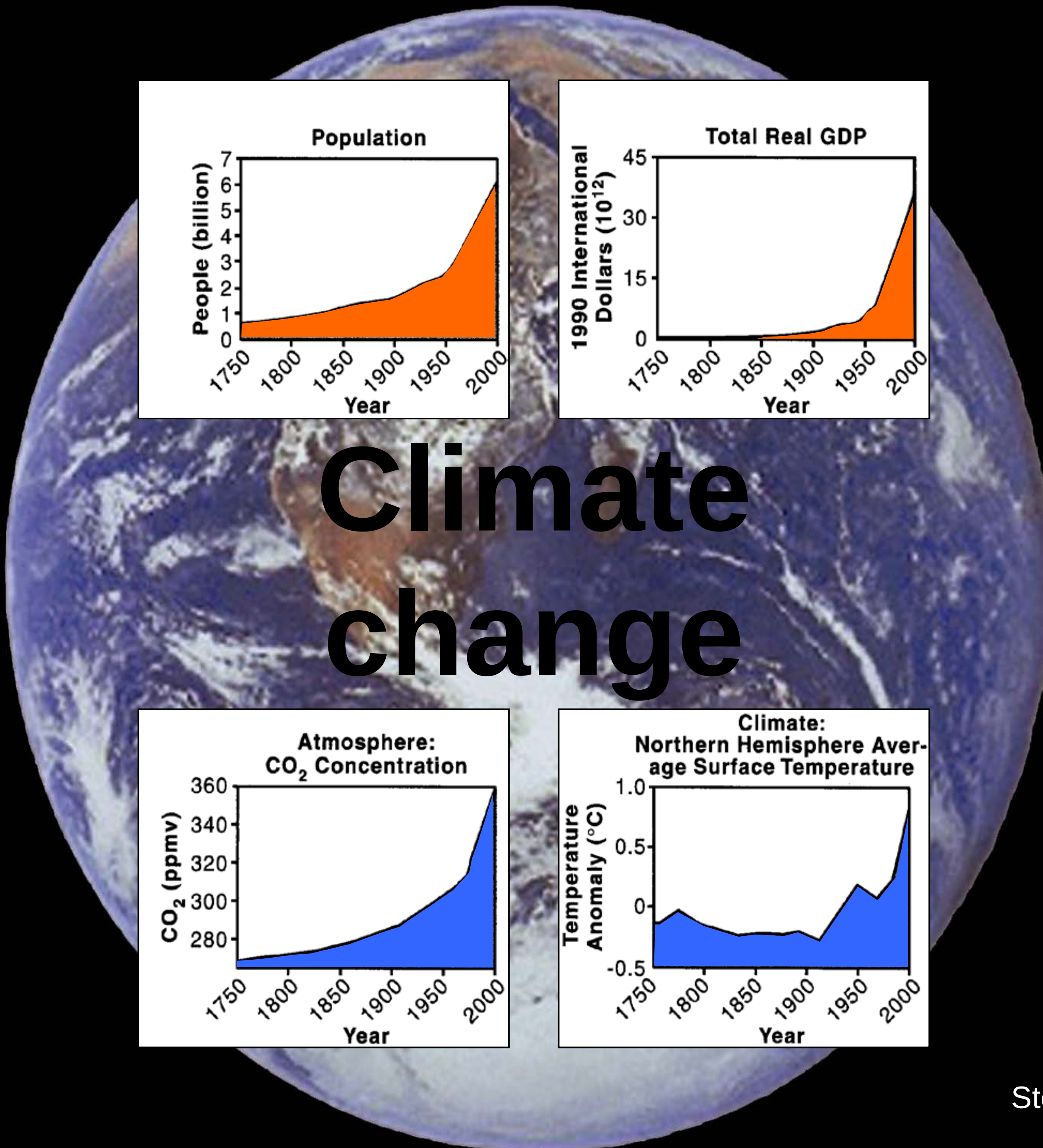
Climate, Agriculture, Markets



Menzel & D'Aluisio, 2007

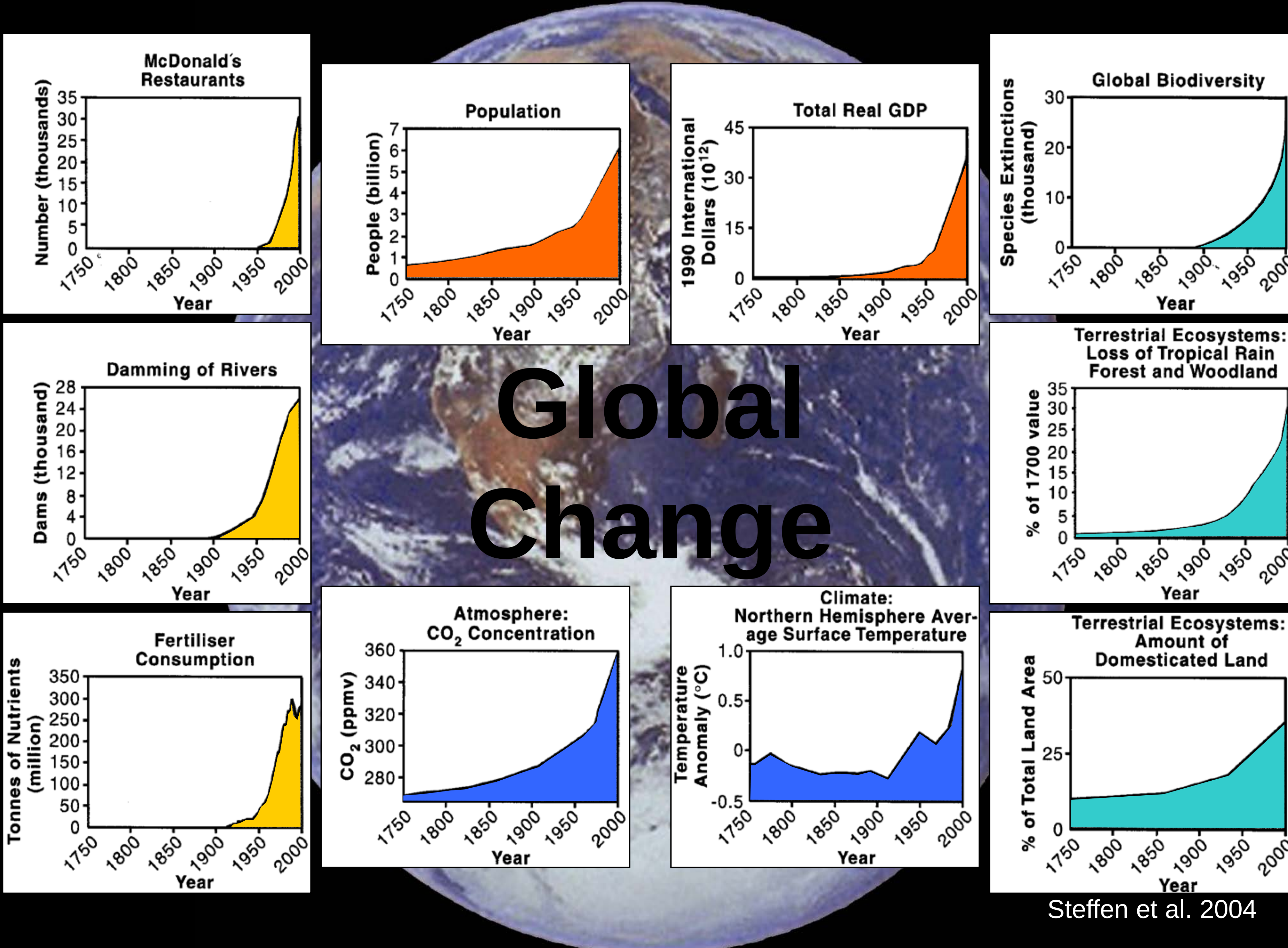
http://foodsecuritygroup.com/wp-content/uploads/2011/04/headlines2.jpg

Climate change



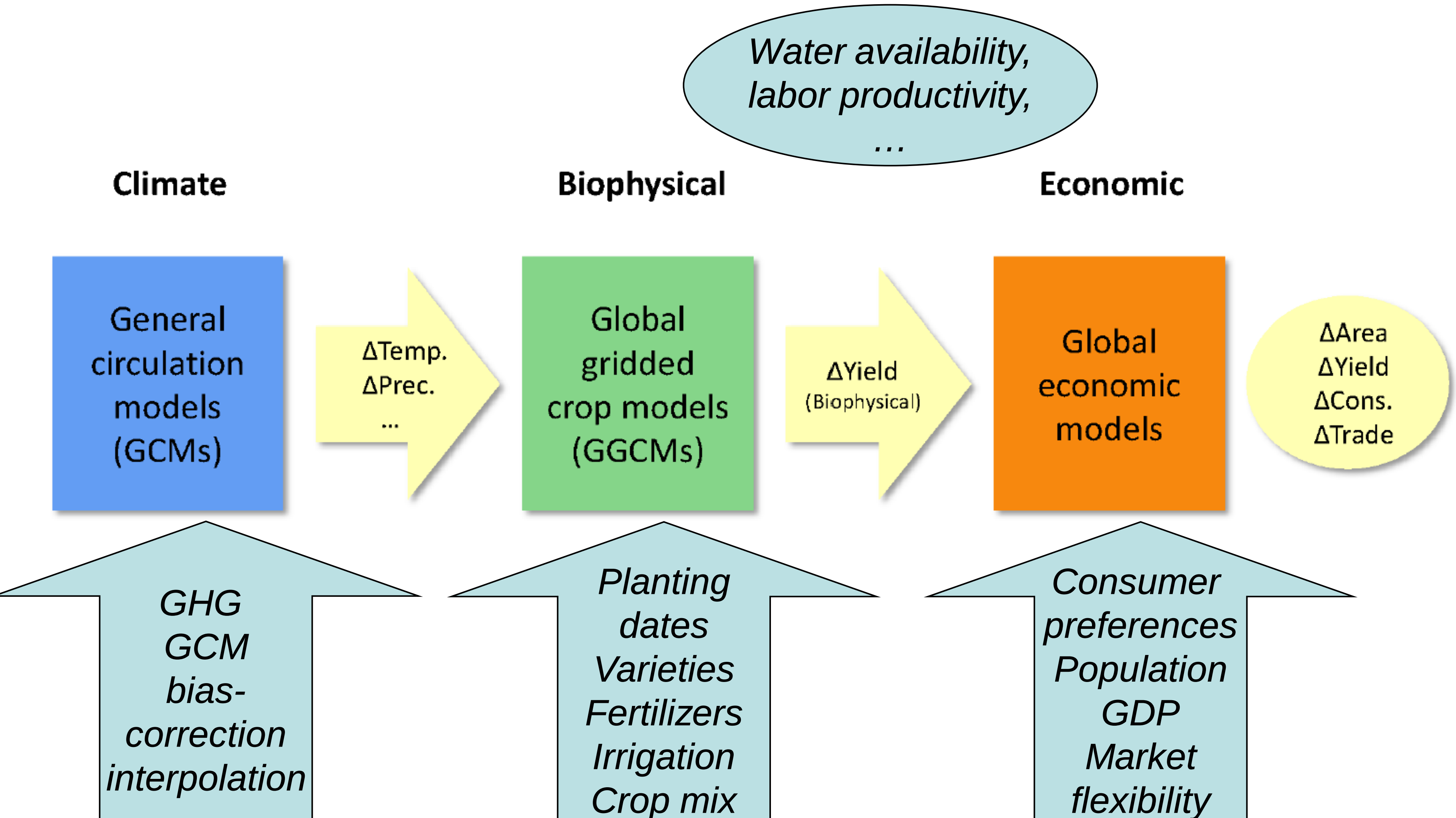
Steffen et al. 2004

Global Change



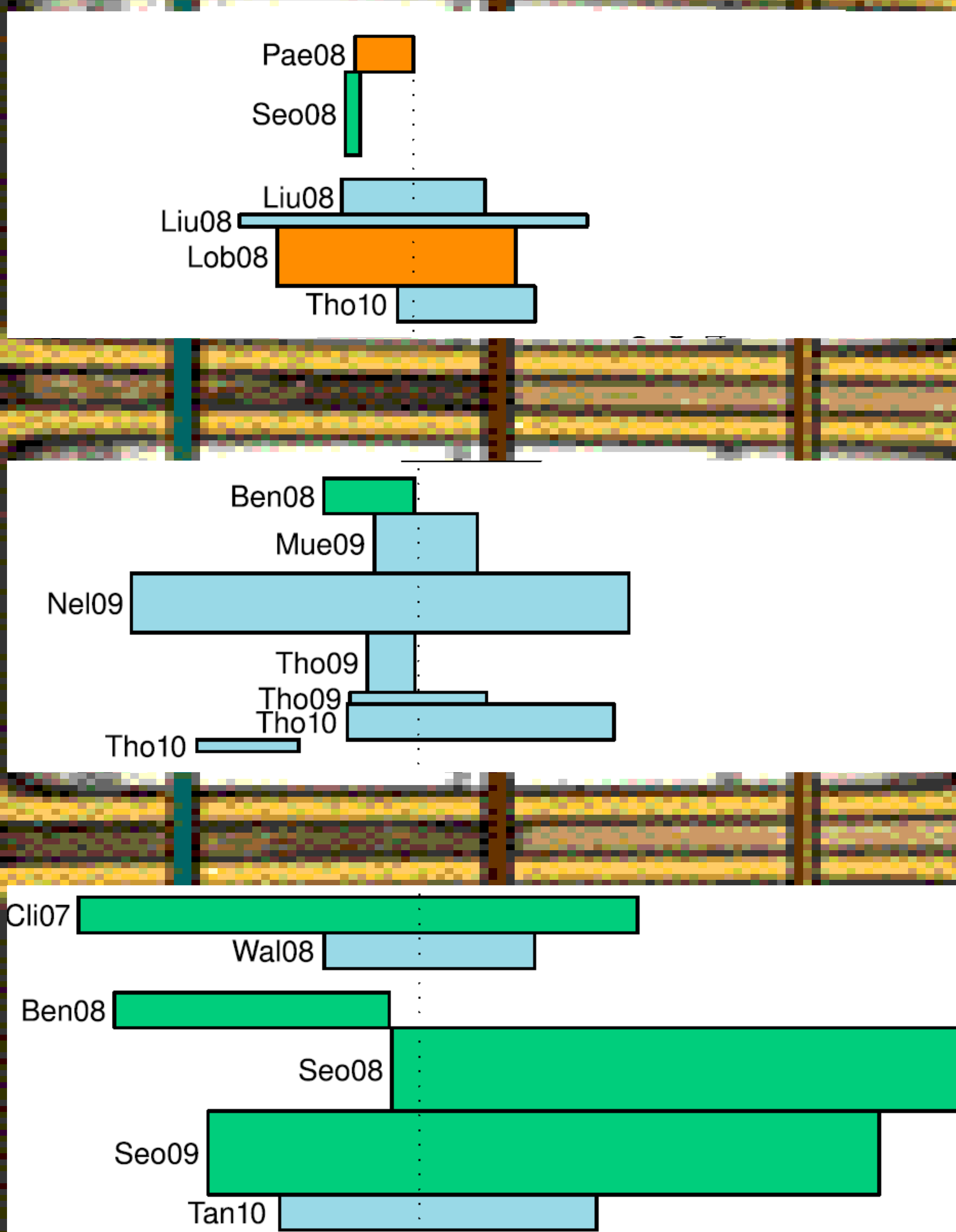
Steffen et al. 2004

Climate change impacts on agriculture



Nelson et al. 2014

Modeling agricultural productivity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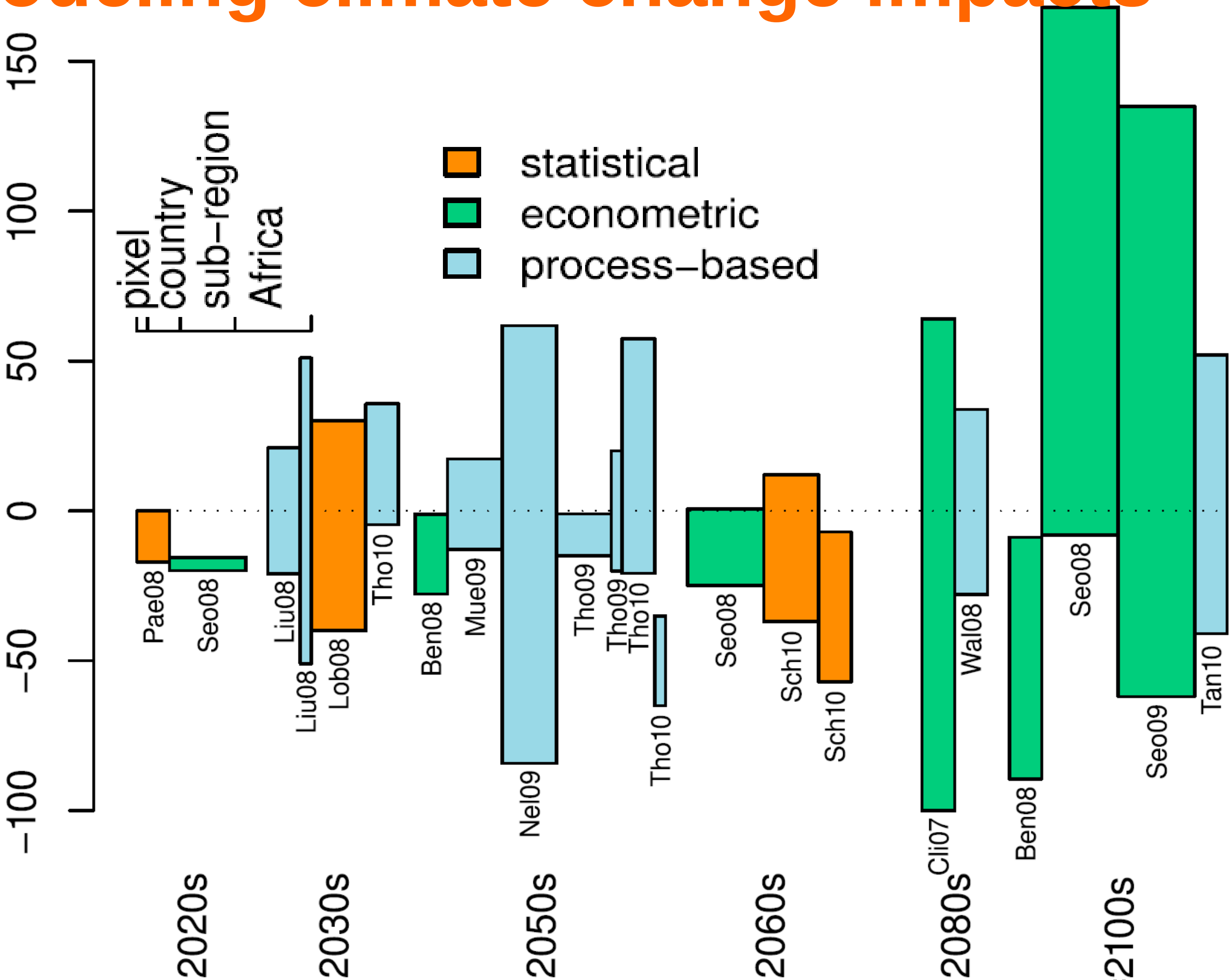
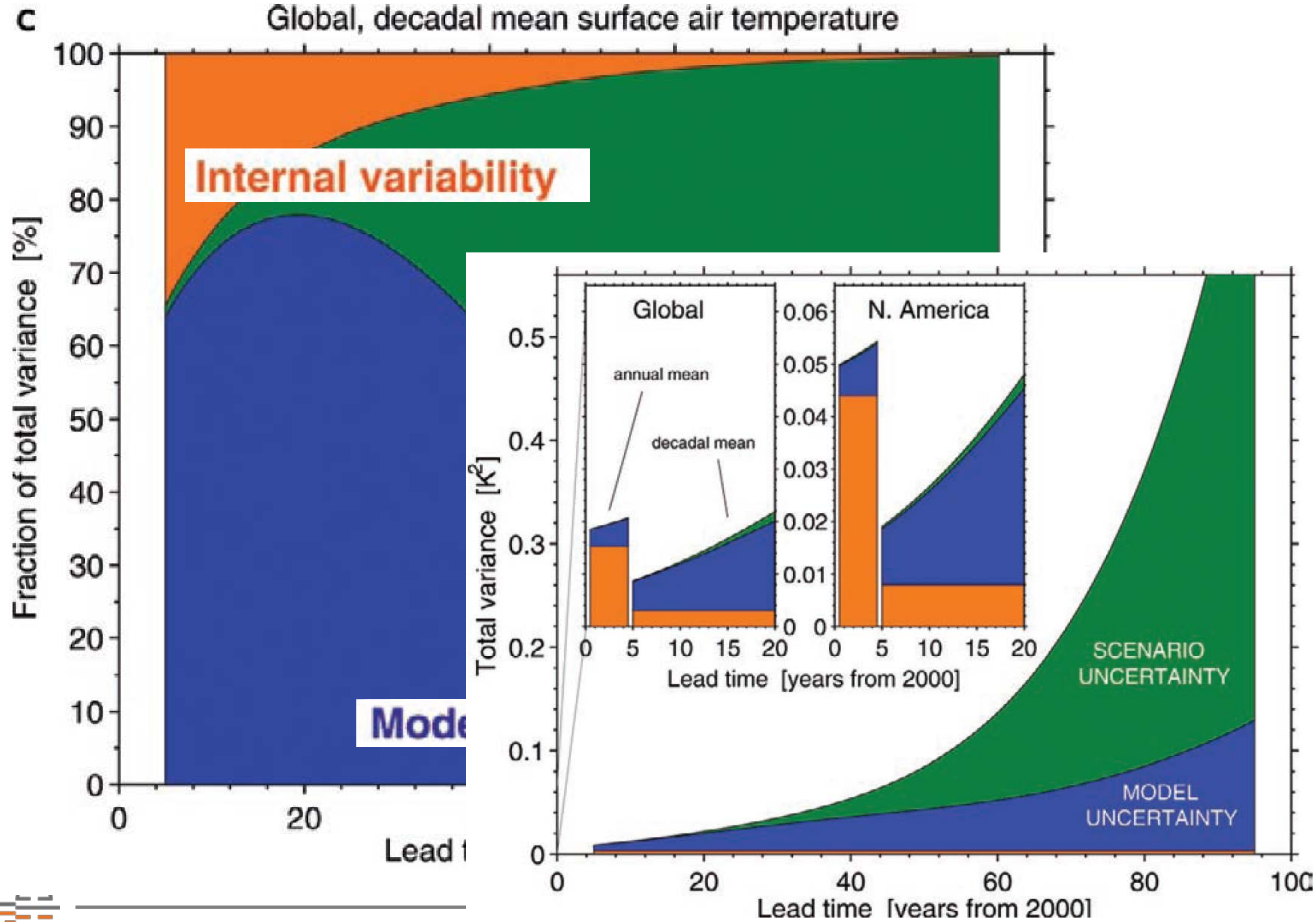
Modeling climate change impacts



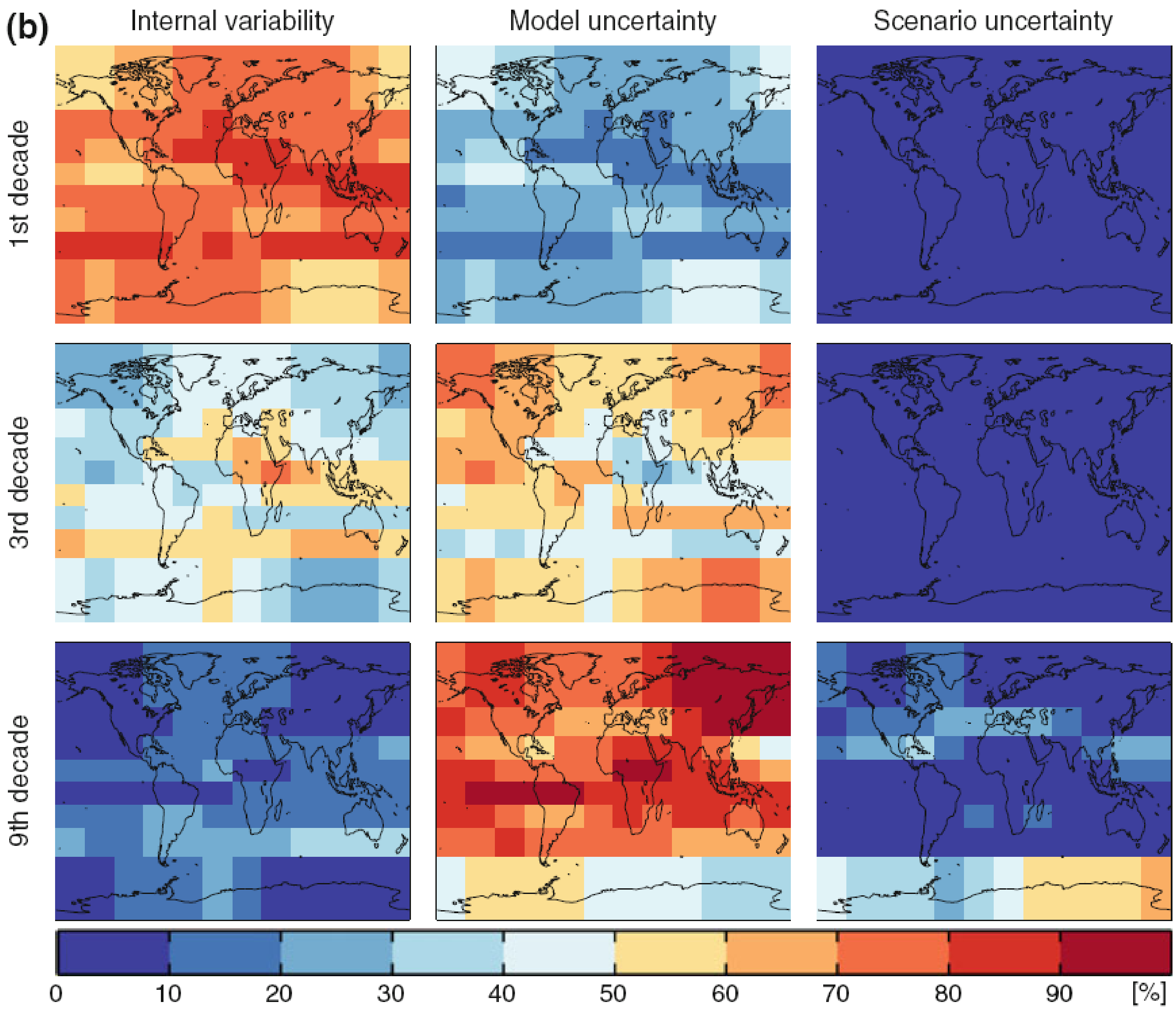
Müller et al. 2011

Sources of uncertainty: climate, T



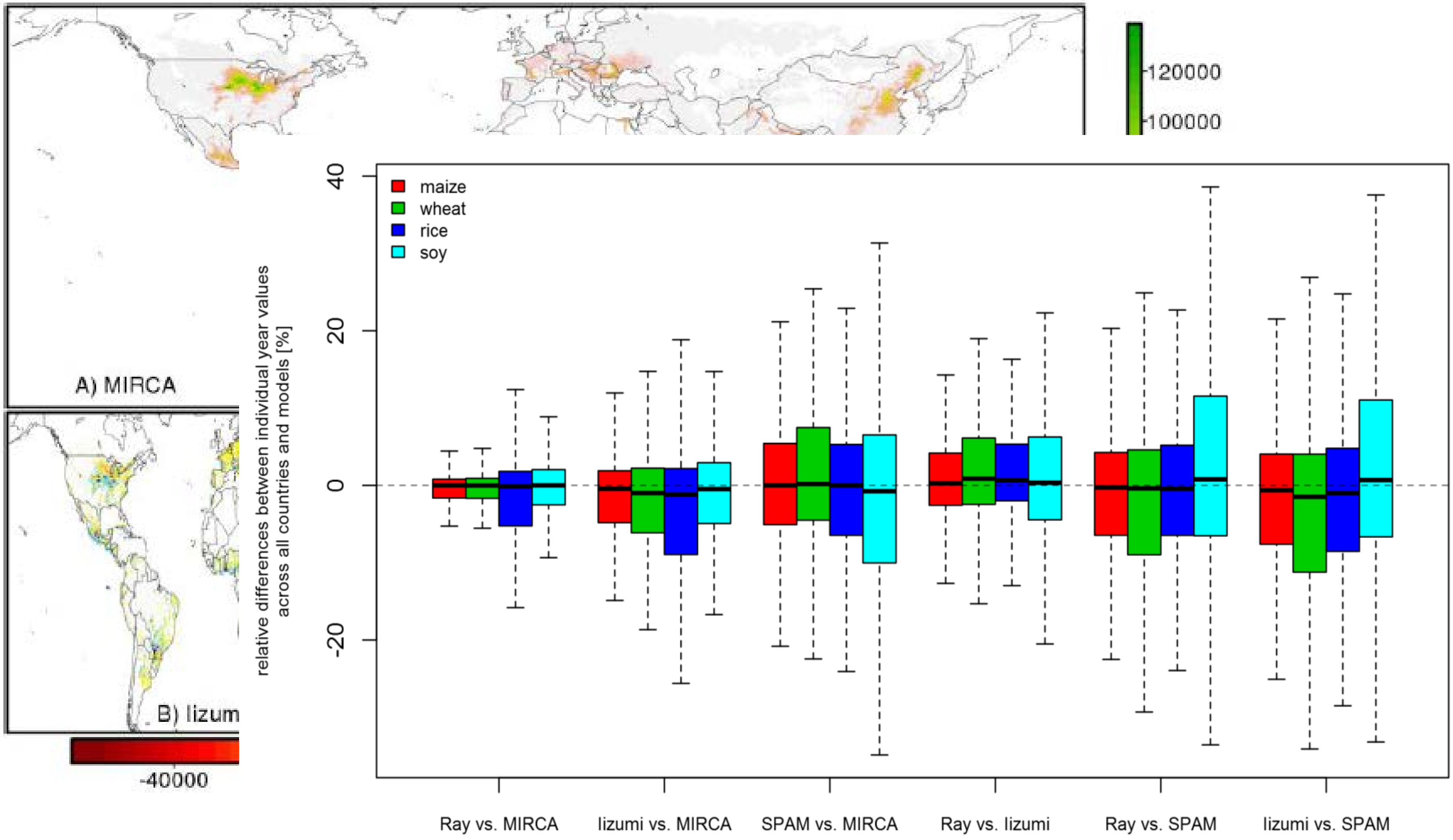
Hawkins & Sutton 2009

Sources of uncertainty: climate, P



Hawkins & Sutton 2011

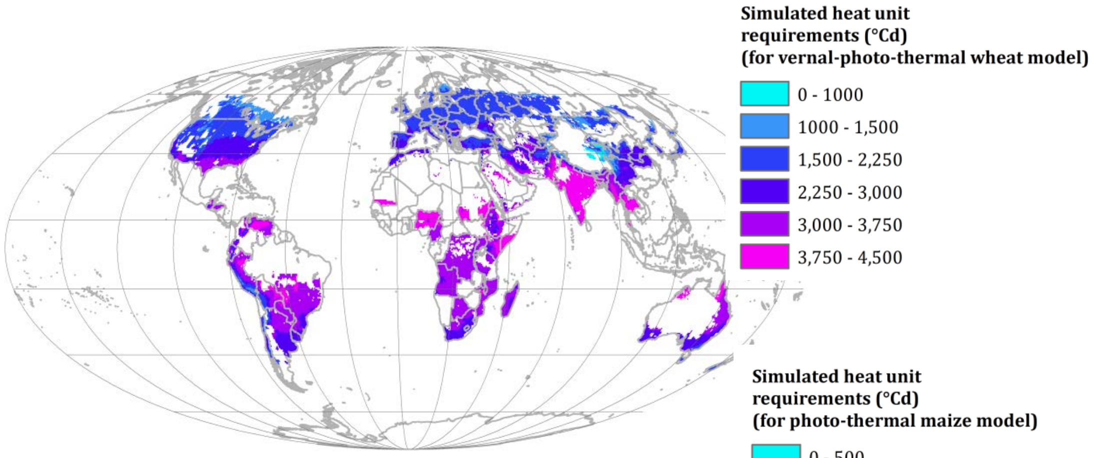
Don’t know much about history…

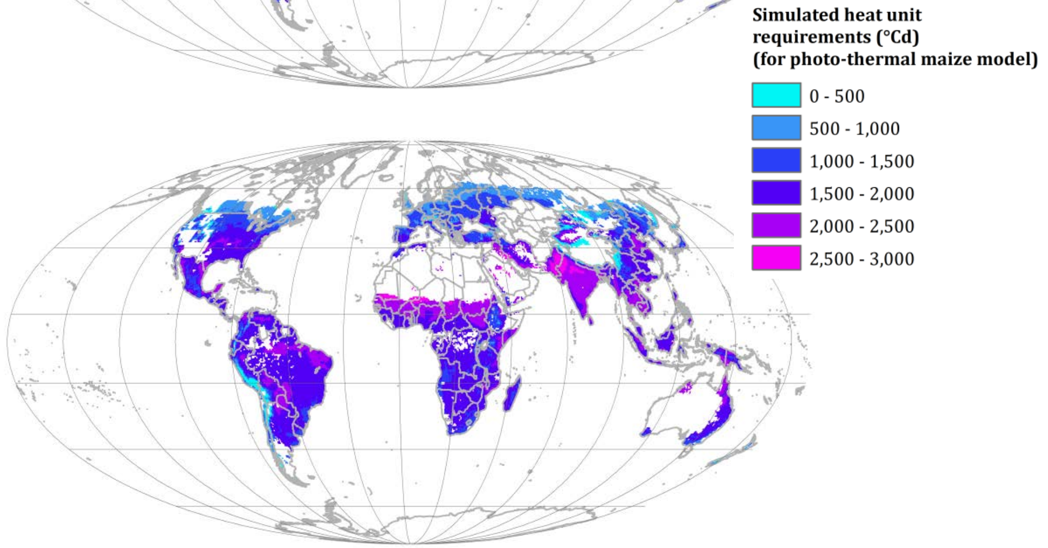


Porwollik et al. 2016

Sources of uncertainty: data

- Crop patterns
- Irrigation
- Varieties
- Fertilizers
- Soil managemer
- Rotations
- Intercrops
- Residues
- …





van Bussel et al. 2015

Sources of uncertainty: models

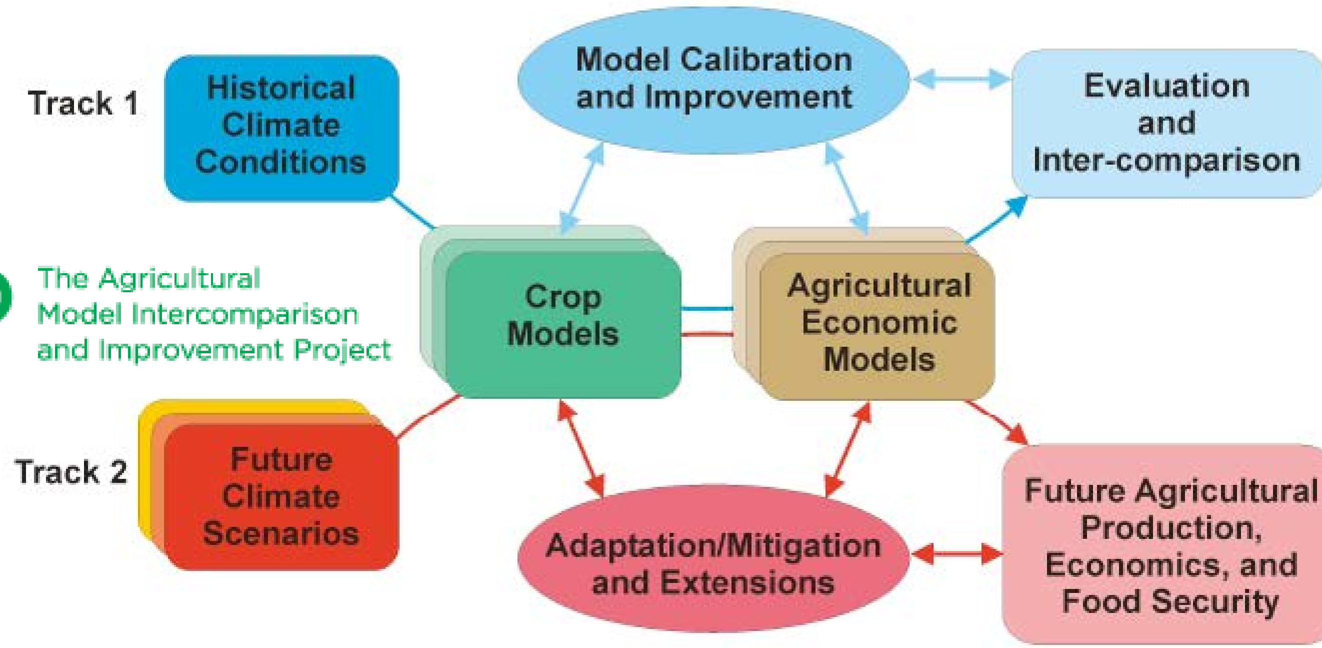
COMMENTARY:

Crop–climate models need an overhaul

Reimund P. Rötter, Timothy R. Carter, Jørgen E. Olesen and John R. Porter

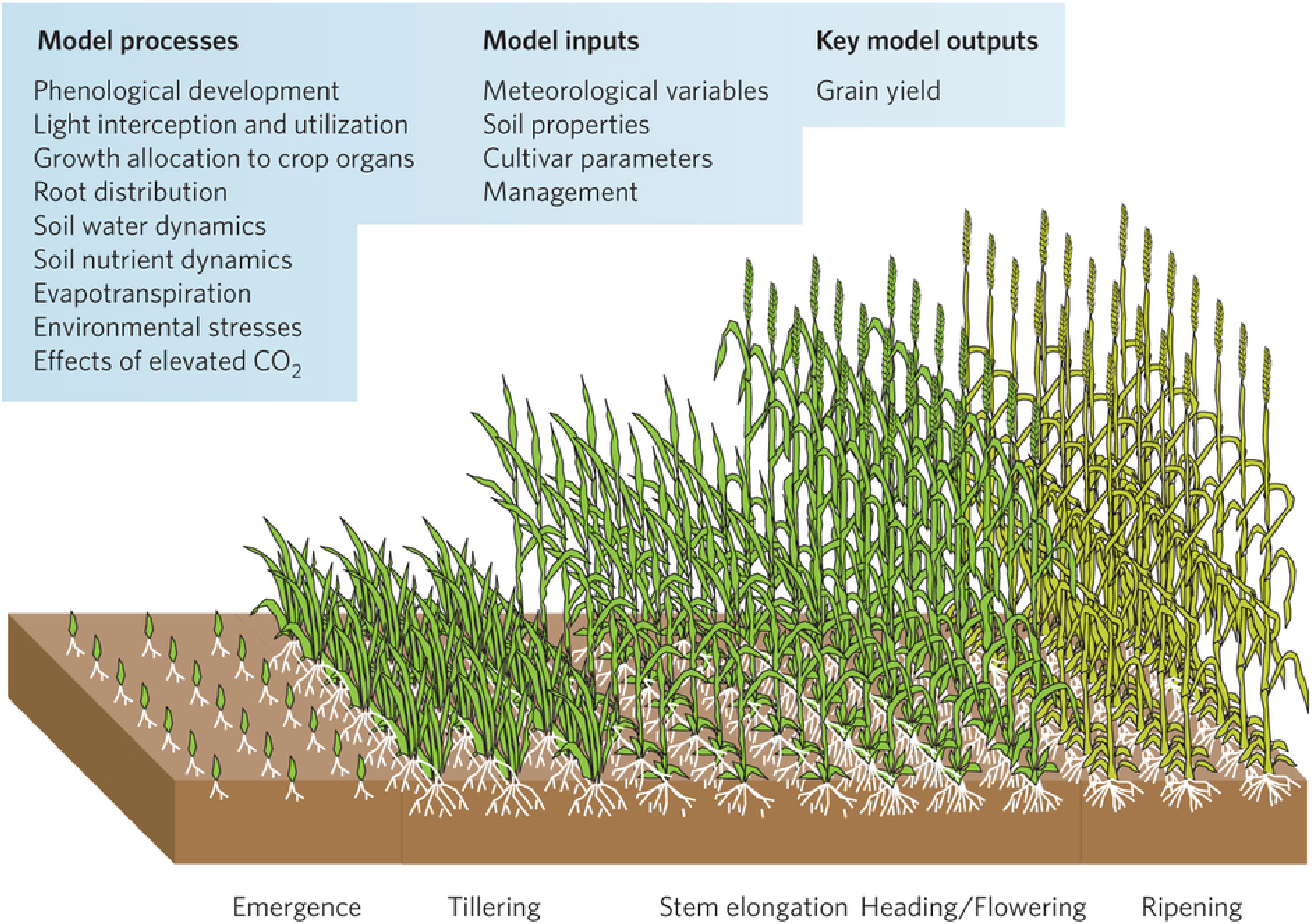
Estimates of how much food we
to more rigorous multi-model e

AgMIP The Agricultural Model Intercomparison and Improvement Project



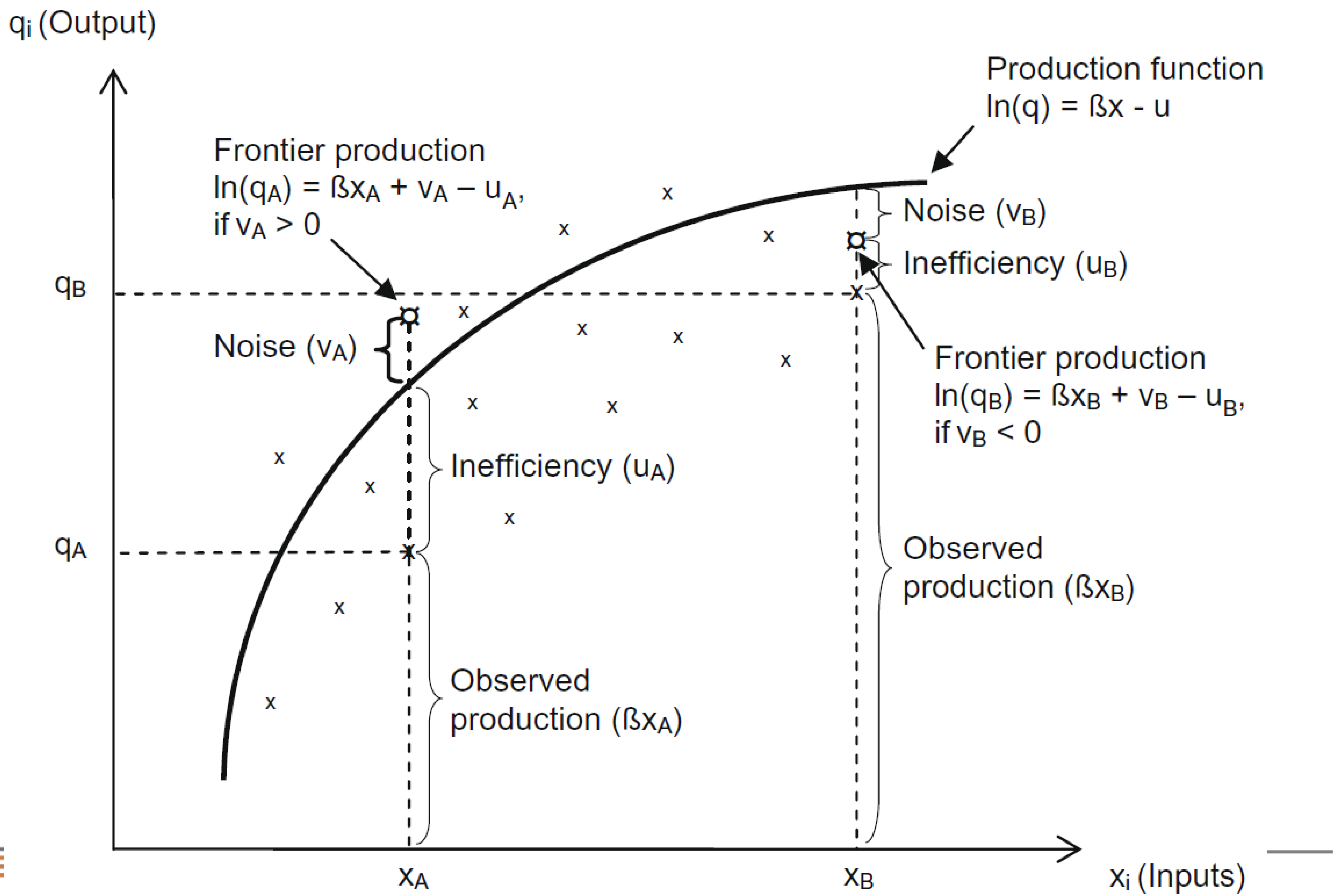
Rötter et al. 2011, Rosenzweig et al. 2013

Crop modeling



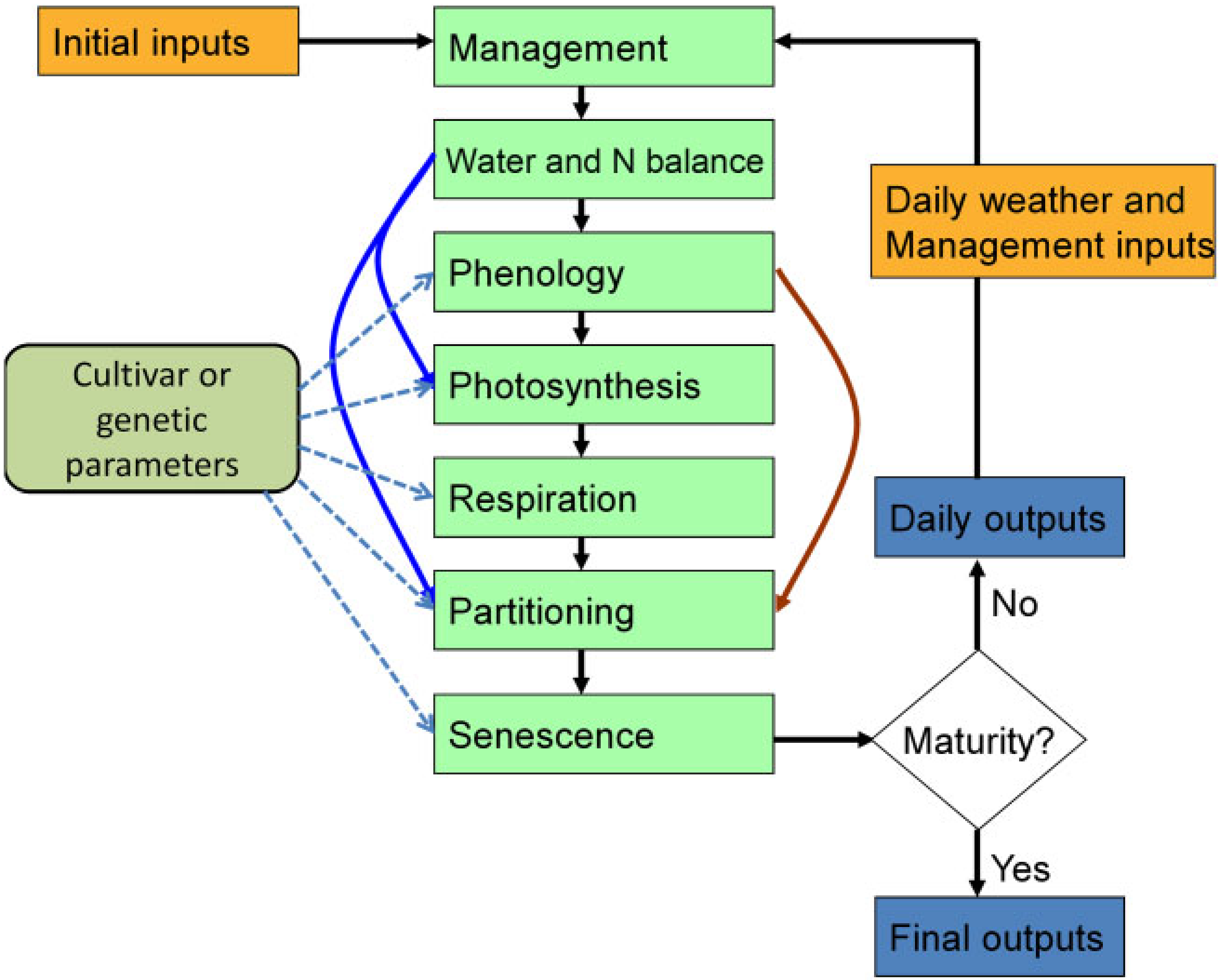
Carter et al. 2013

Statistical modeling

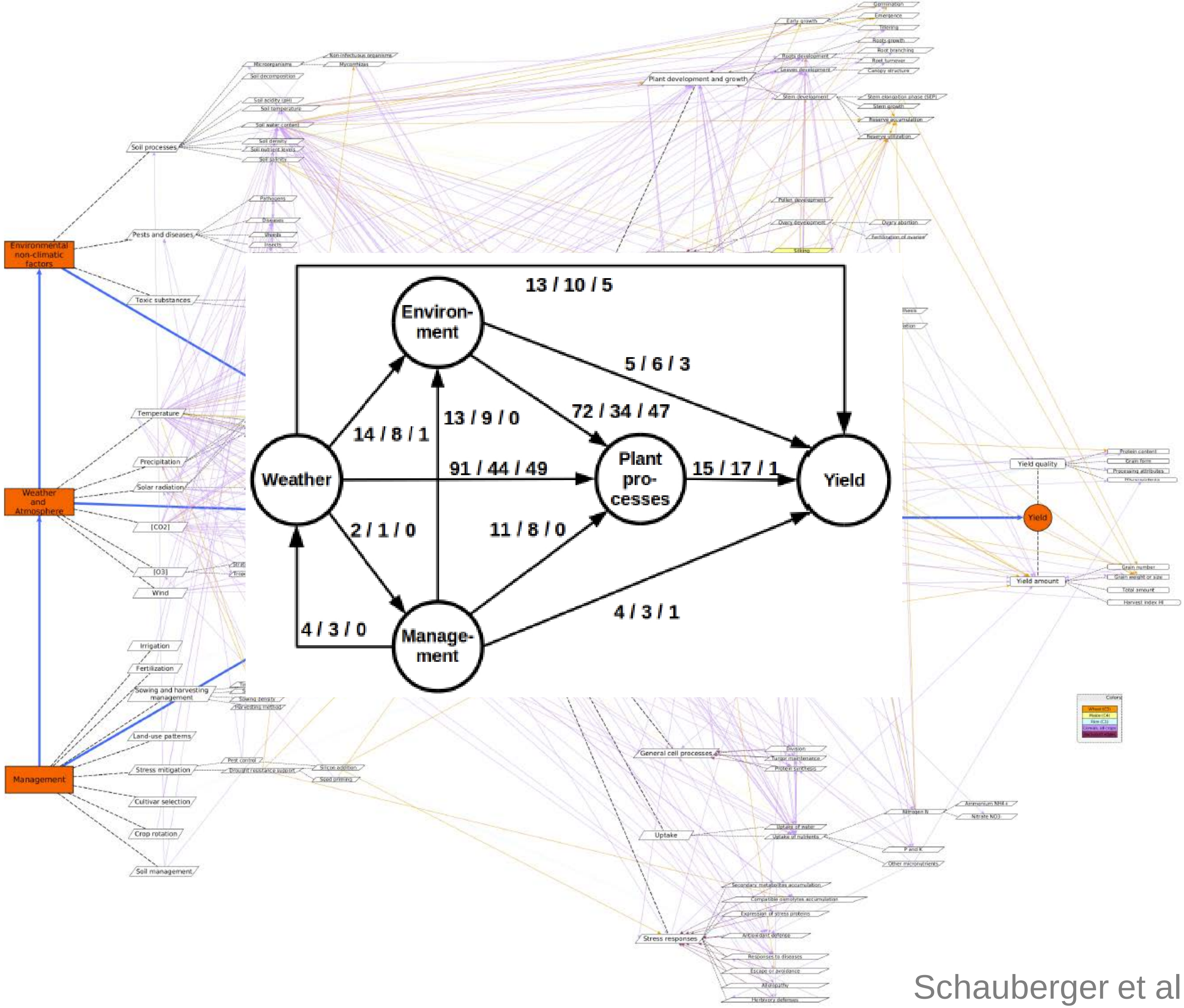


Neumann et al. 2010

Process-based modeling



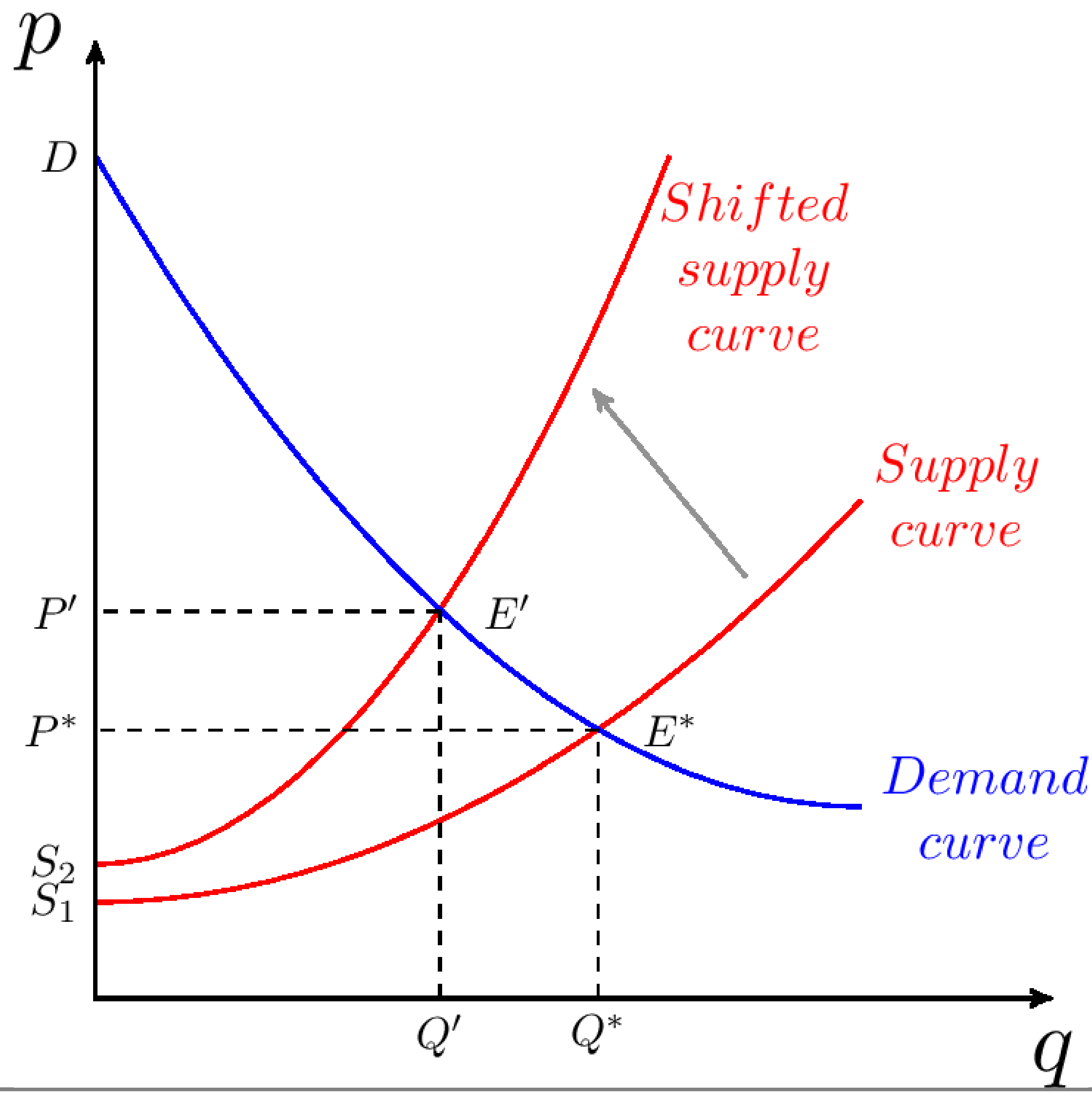
Boote et al. 2013



Schauberger et al. 2015

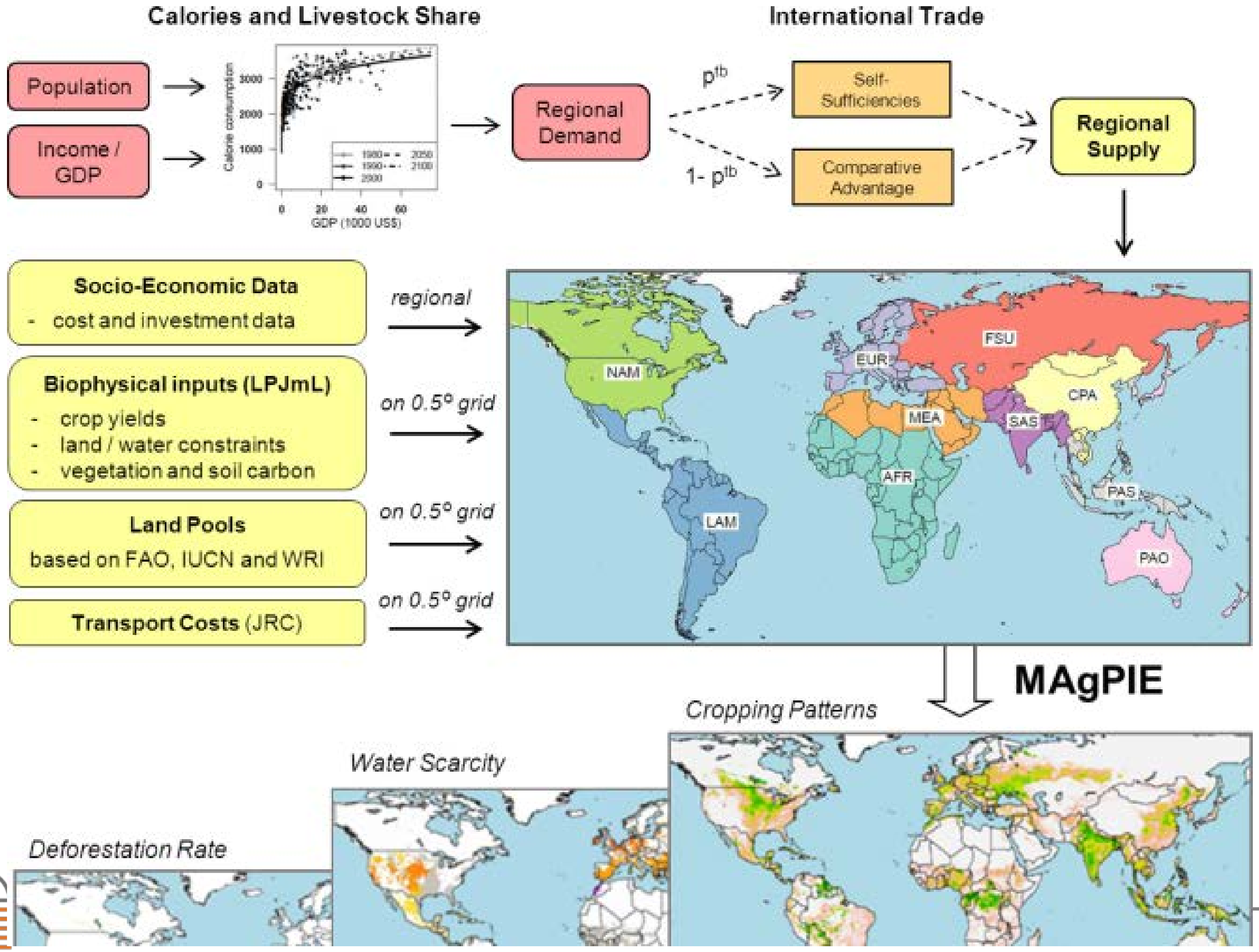
Beyond productivity: production

Economic agricultural modeling



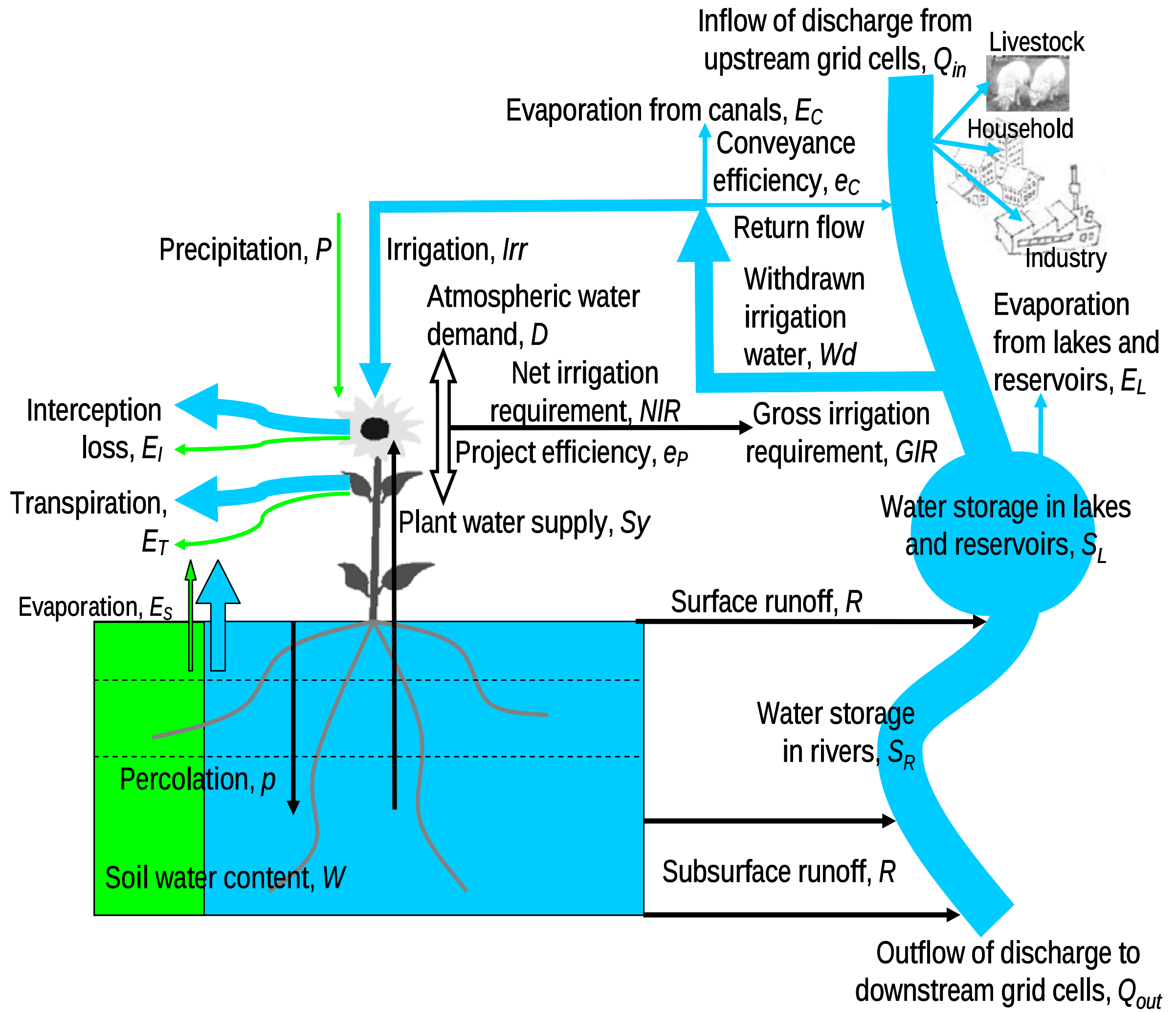
Stevanovic et al. 2016

Biophysics meet economy



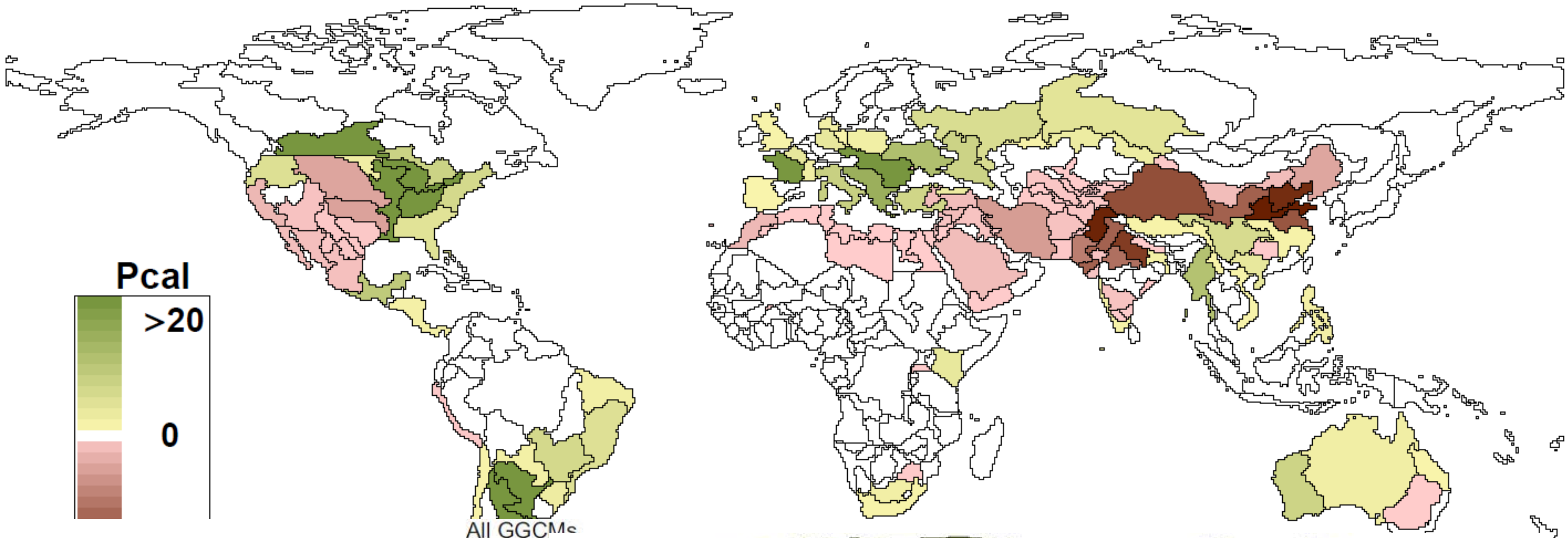
Schmitz et al. 2013

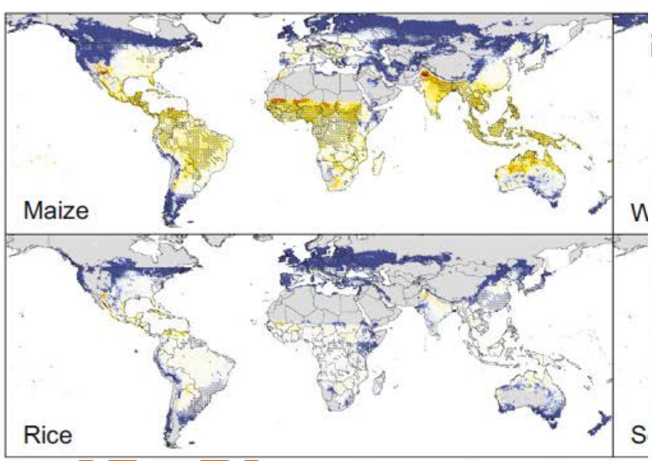
Irrigation also matters downstream

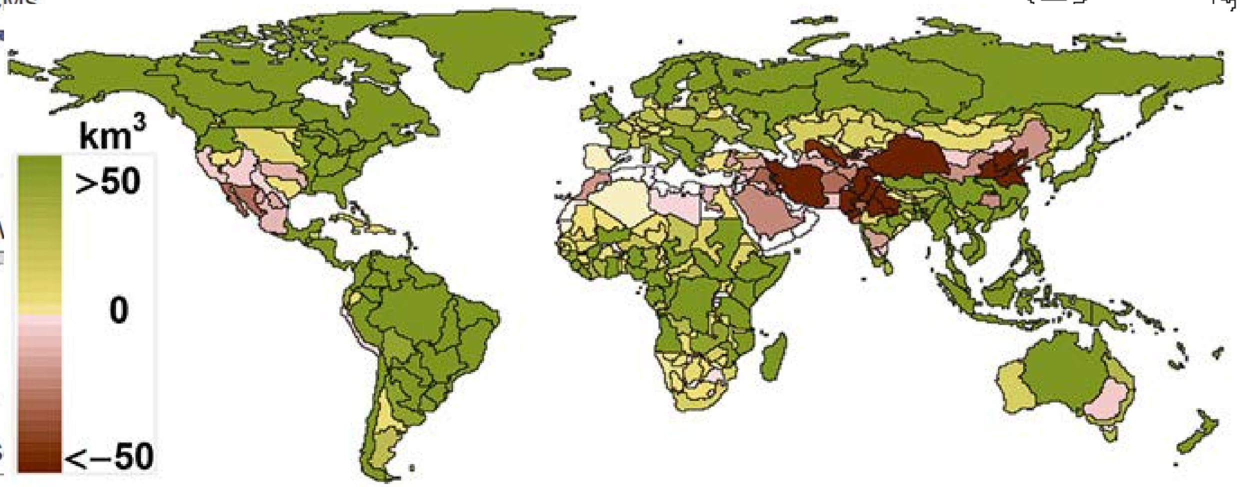


Rost et al. 2008

Indirect impacts, limits to adaptation

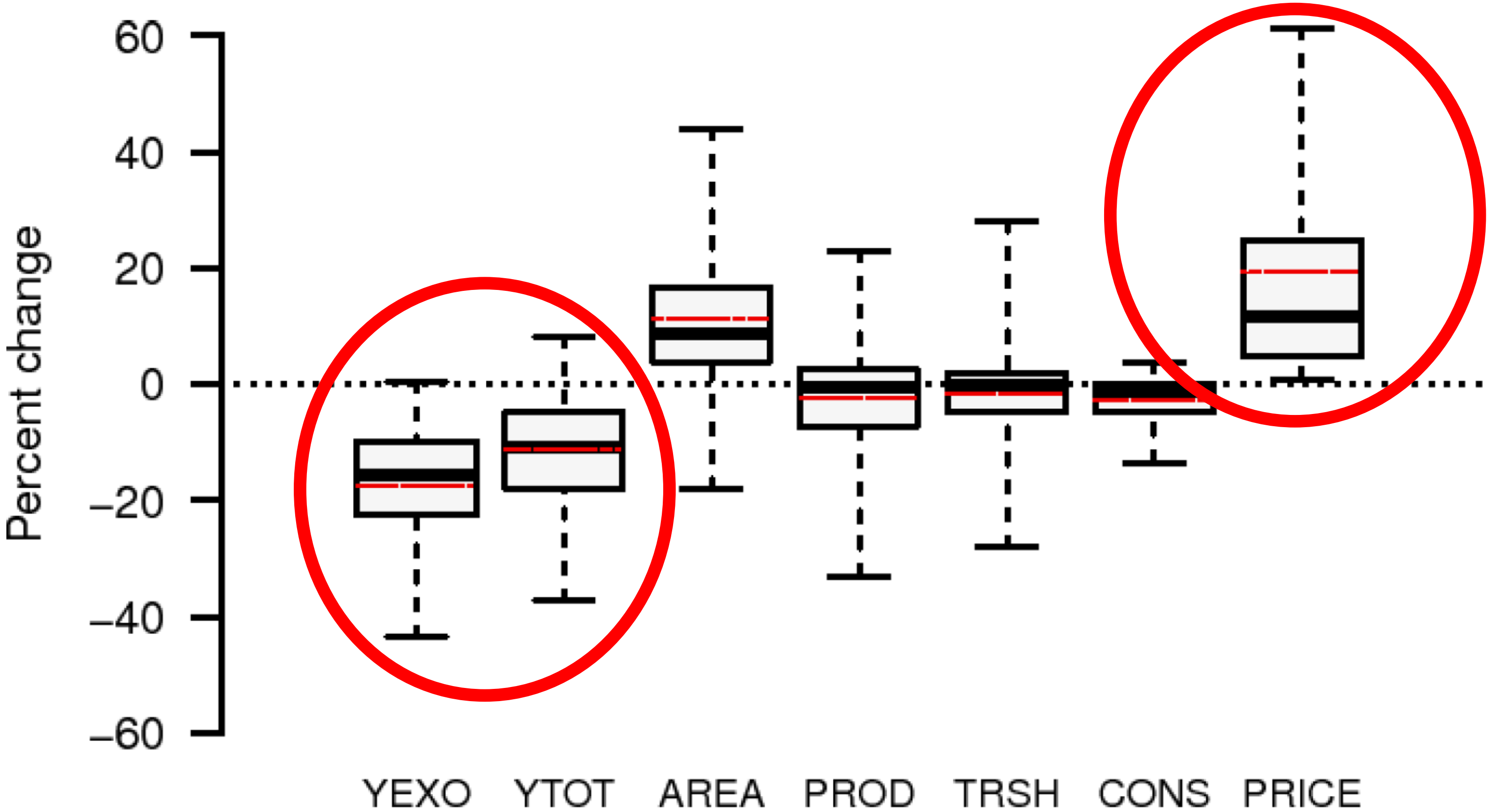






Elliott et al. 2014

Agricultural Econmics in AgMIP/ISI-MIP

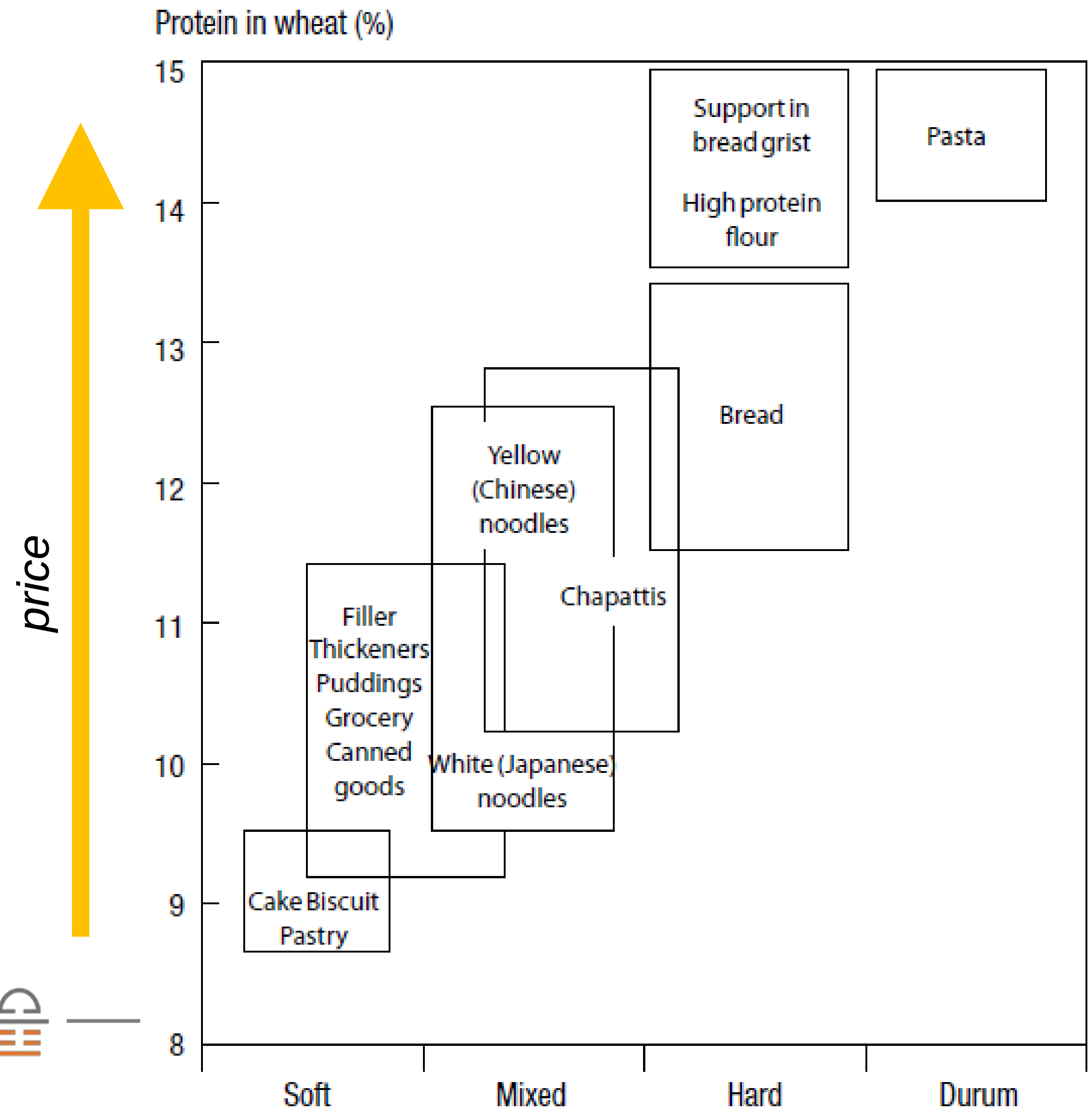


	YEXO	YTOT	AREA	PROD	TRSH	CONS	PRICE
n	2891	2891	2891	2891	2891	2891	2891
Mean	–0.17	–0.11	0.11	–0.02	–0.01	–0.03	0.2
SD	(0.13)	(0.17)	(0.25)	(0.25)	(0.26)	(0.06)	(0.24)

Nelson et al. 2014

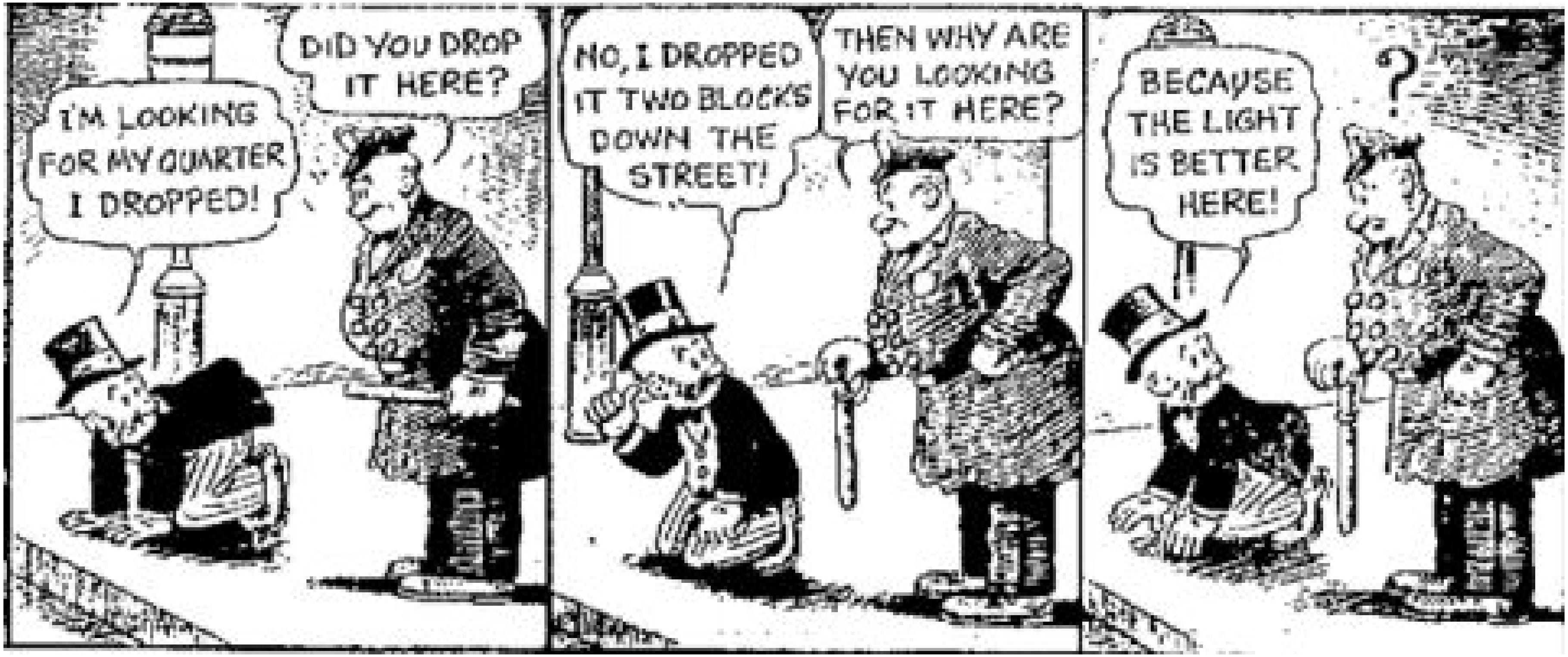
Beyond production: nutrition

Quality matters



www.grdc.com.au/Downloads.ashx?q=/~/media/6F94BAEDAAED4E66B02AC992C70EB776.pdf

The “lamp post problem”?



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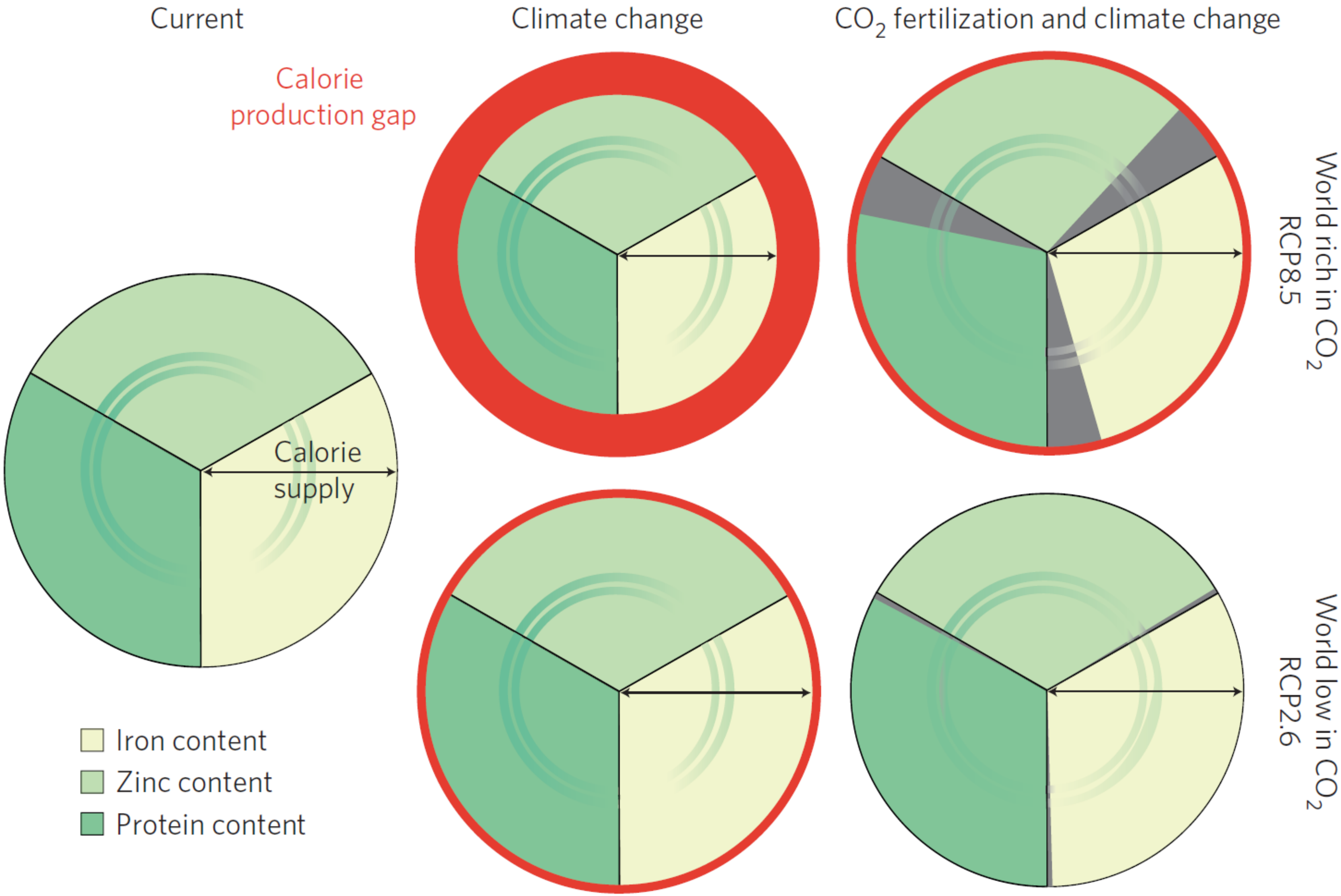


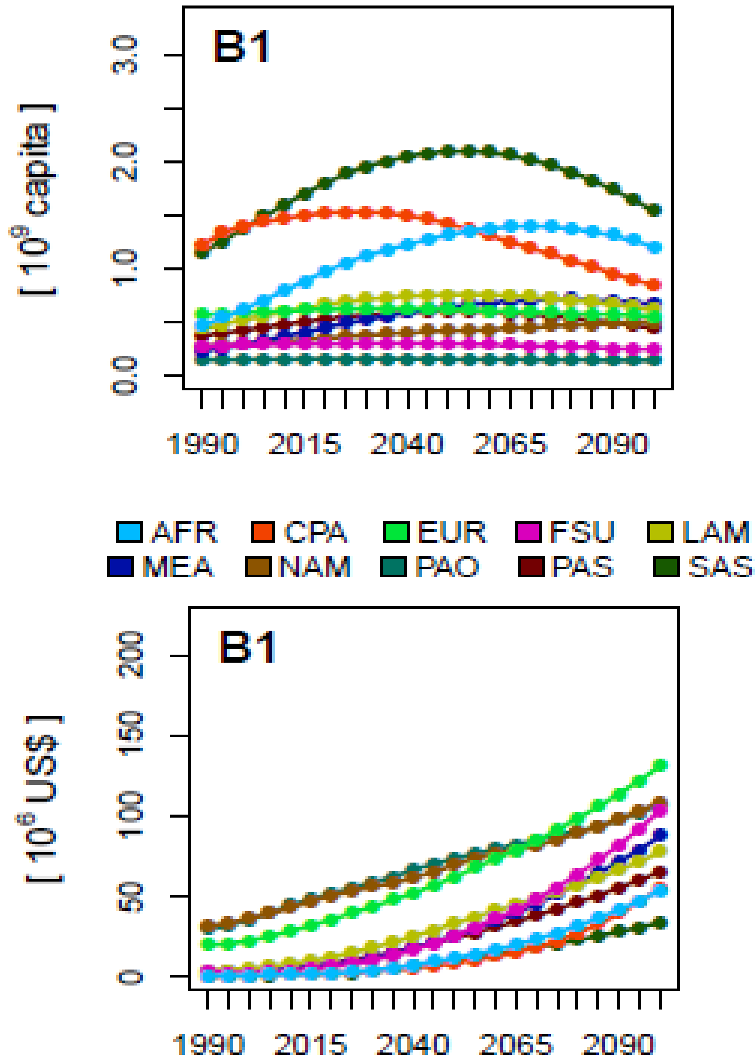
Myers et al. 2014, Müller et al. 2014

Beyond nutrition: multiple objectives

PIK

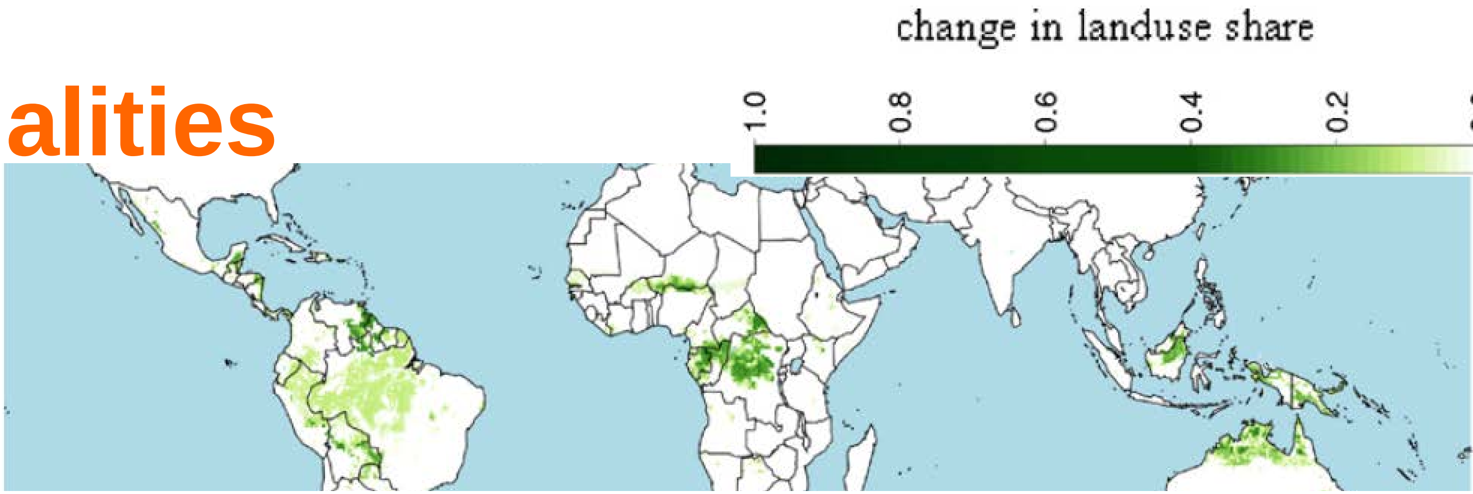
Not just food…

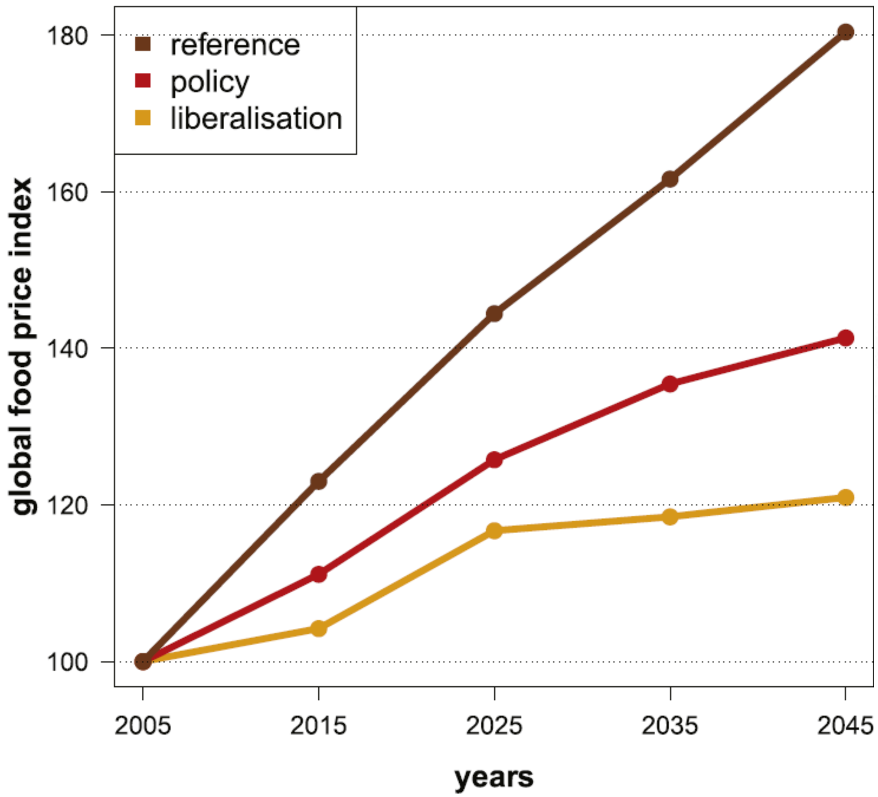
- **Mitigate climate change and looming impacts on agricultural productivity**
- **Food security for a growing and richer population**
- **Bio-economy: increasing demand for fuels and materials**
- **Conservation/ environmental protection**

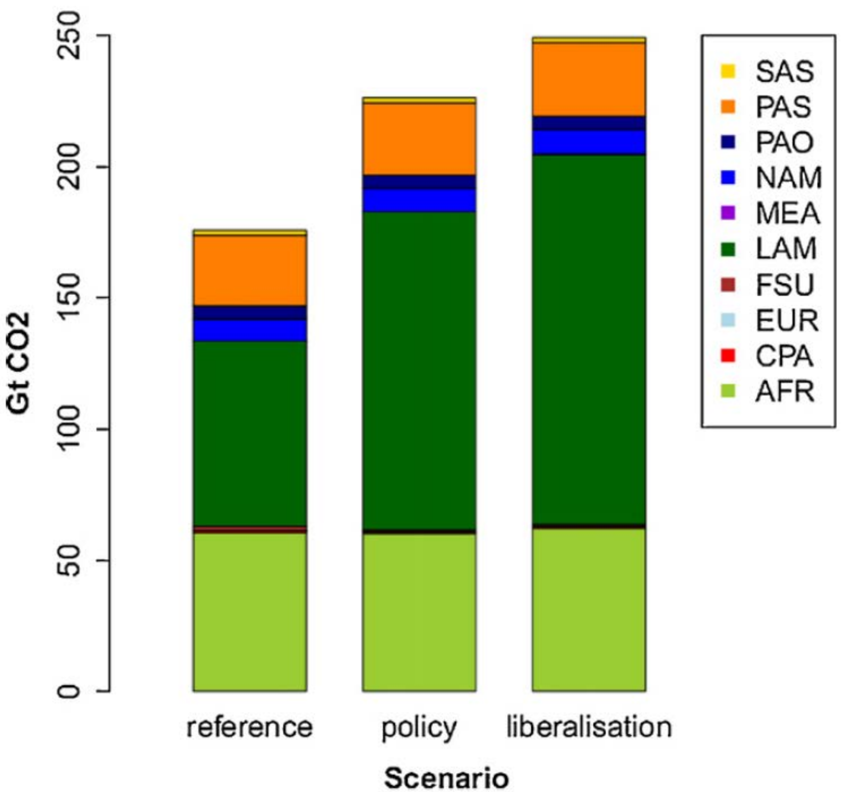


Bodirsky et al. 2015

Externalities







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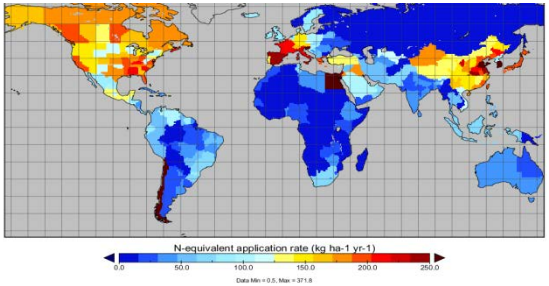
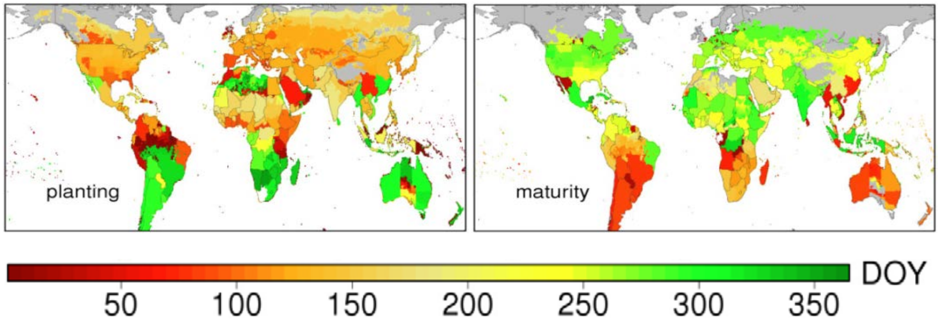
Schmitz et al. 2012

Beyond modeling:
the holy grail : learning & informing

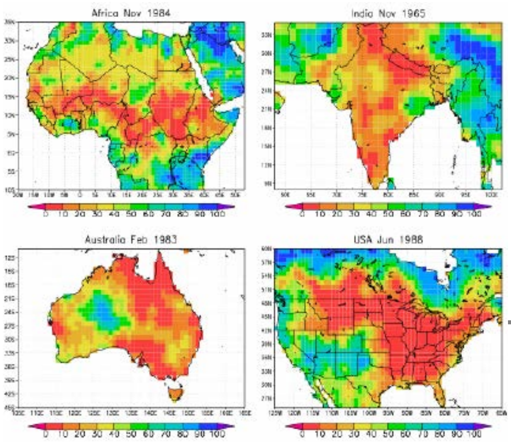
GGCMI Phase 1: understanding the past

- **Ten reanalysis-based historical weather products spanning 1901-2012**
- **14 GGCMs supplying data**
- **Harmonized on fertilizer, sowing, maturity, etc.**

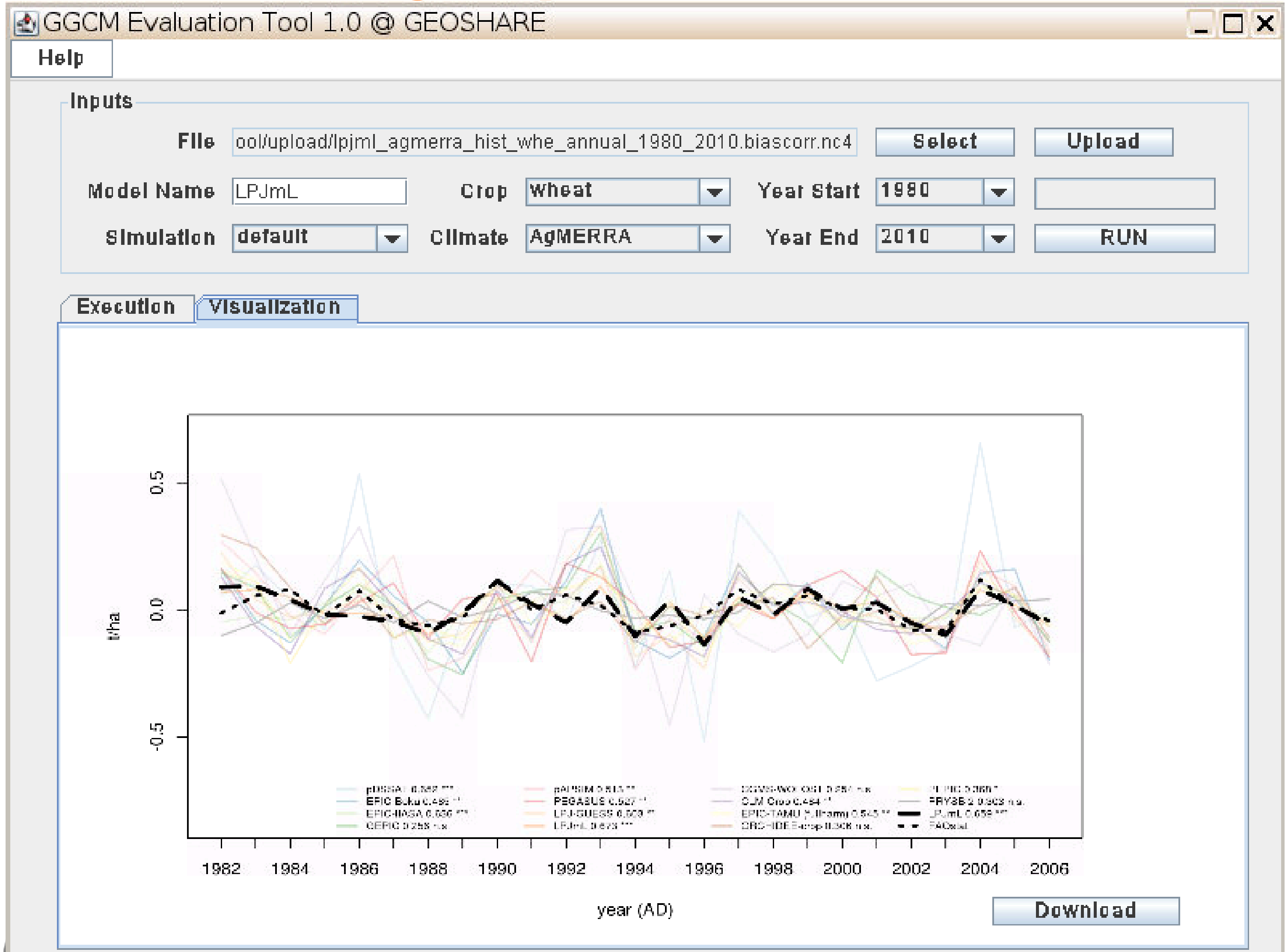




- **Additional focus on large-scale extreme drought/heat events in the historical record.**

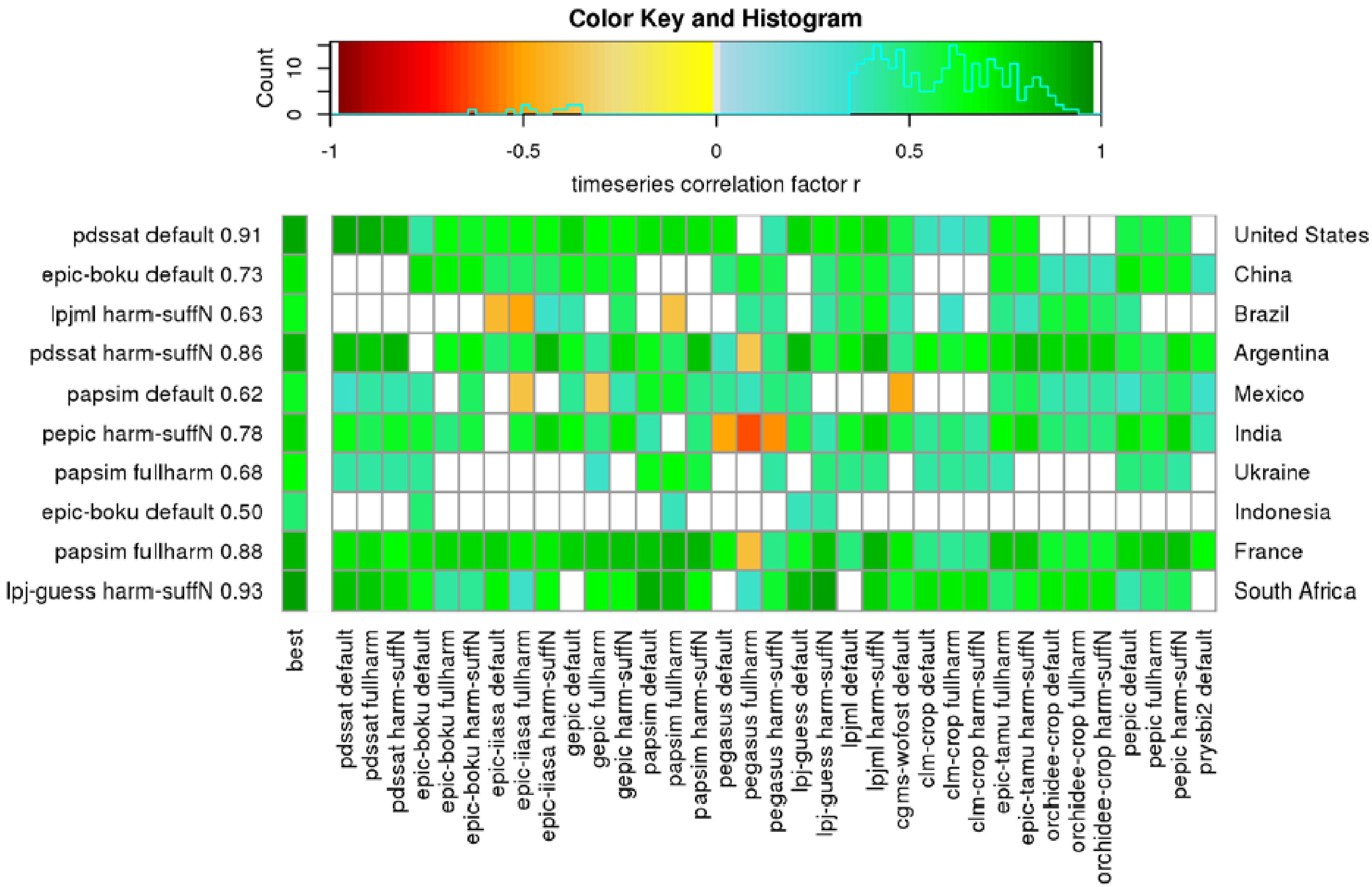


Establishing a public benchmark



Müller et al. 2017

National level



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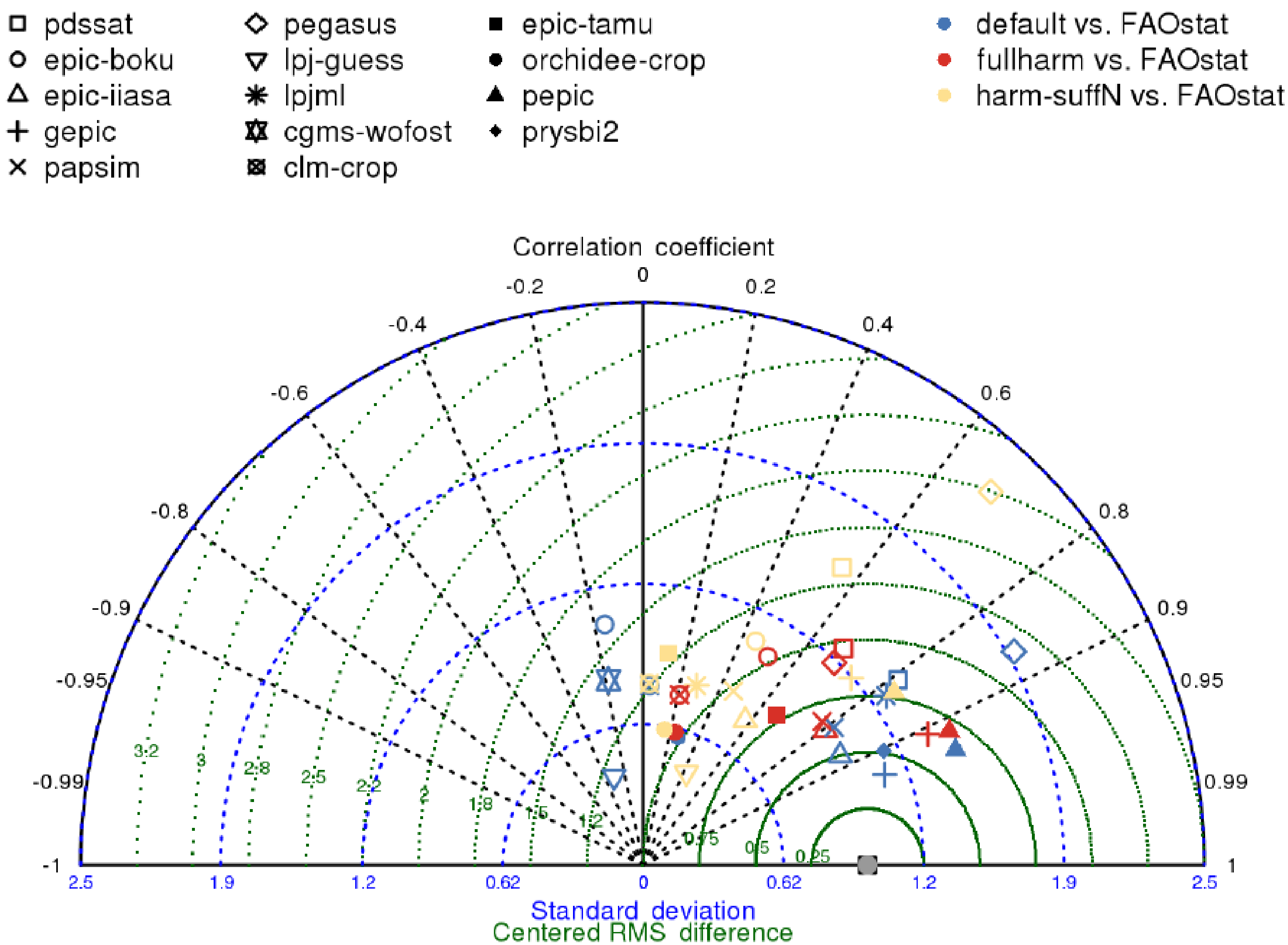
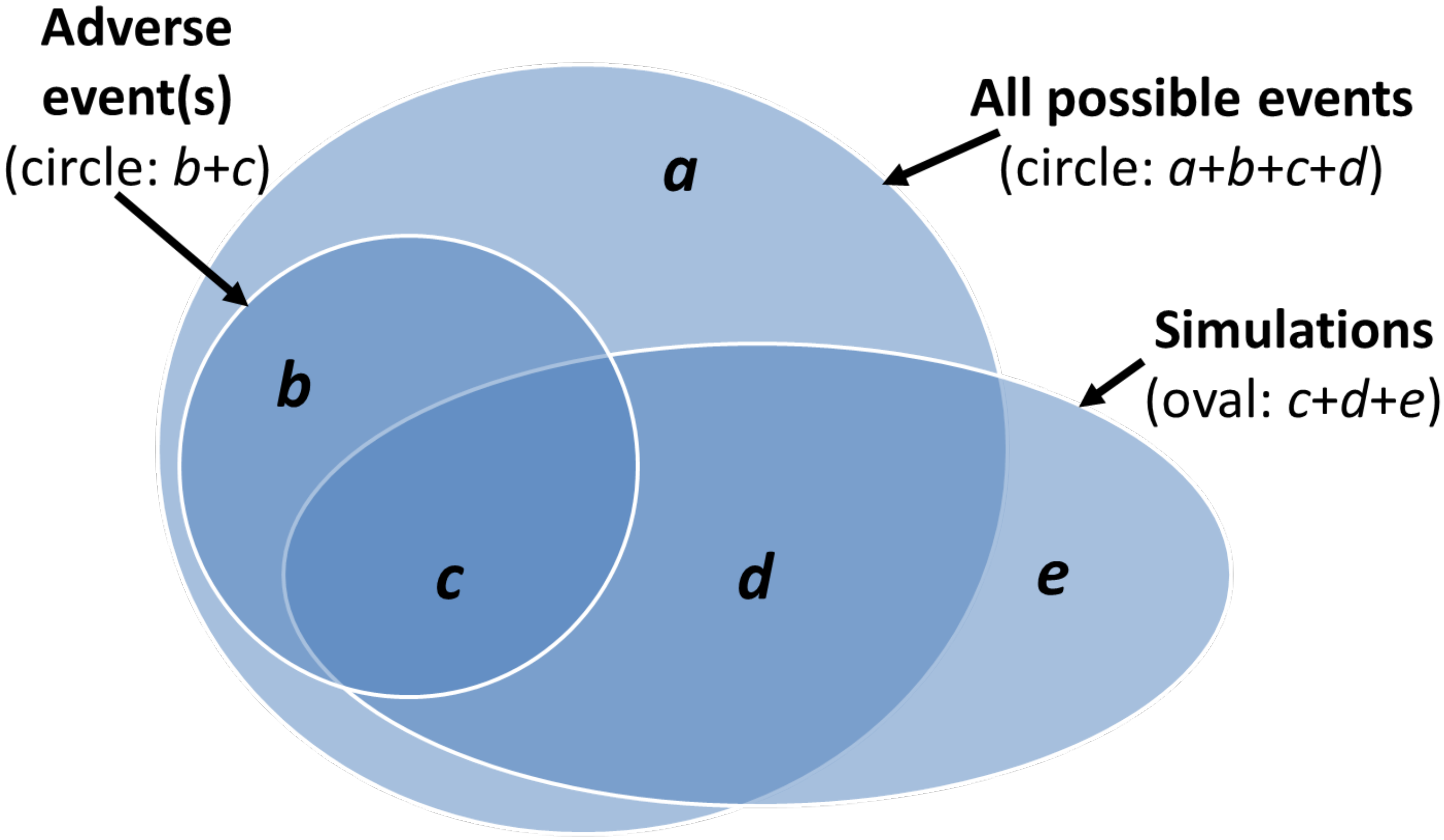
Müller et al. 2017

Spatio-temporal performance



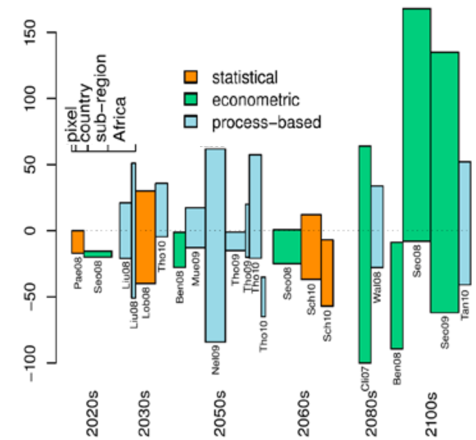
Müller et al. 2017

What do model results represent?



Challinor et al. In revision

Implications of uncertainties



- Uncertainties cannot be eradicated
- Well-described uncertainties facilitate decision processes
- Climate change impact analysis needs to be
  - more comprehensive (scenarios)
  - more explicit (mean, tails, likelihoods, ...)
  - more cross-sectoral
- Visions of desired states needed

How can large-scale modeling help?

- Extrapolation to unobserved conditions
- Deeper Understanding of processes, complex systems, nonlinear system behavior
- Provides a mechanism to test a set of complex hypotheses
- “Mind Games”: What would happen, if …?
  - different scenarios
  - extreme conditions
- Reducing Uncertainty in system responses
- Consistency for large-scale dynamics

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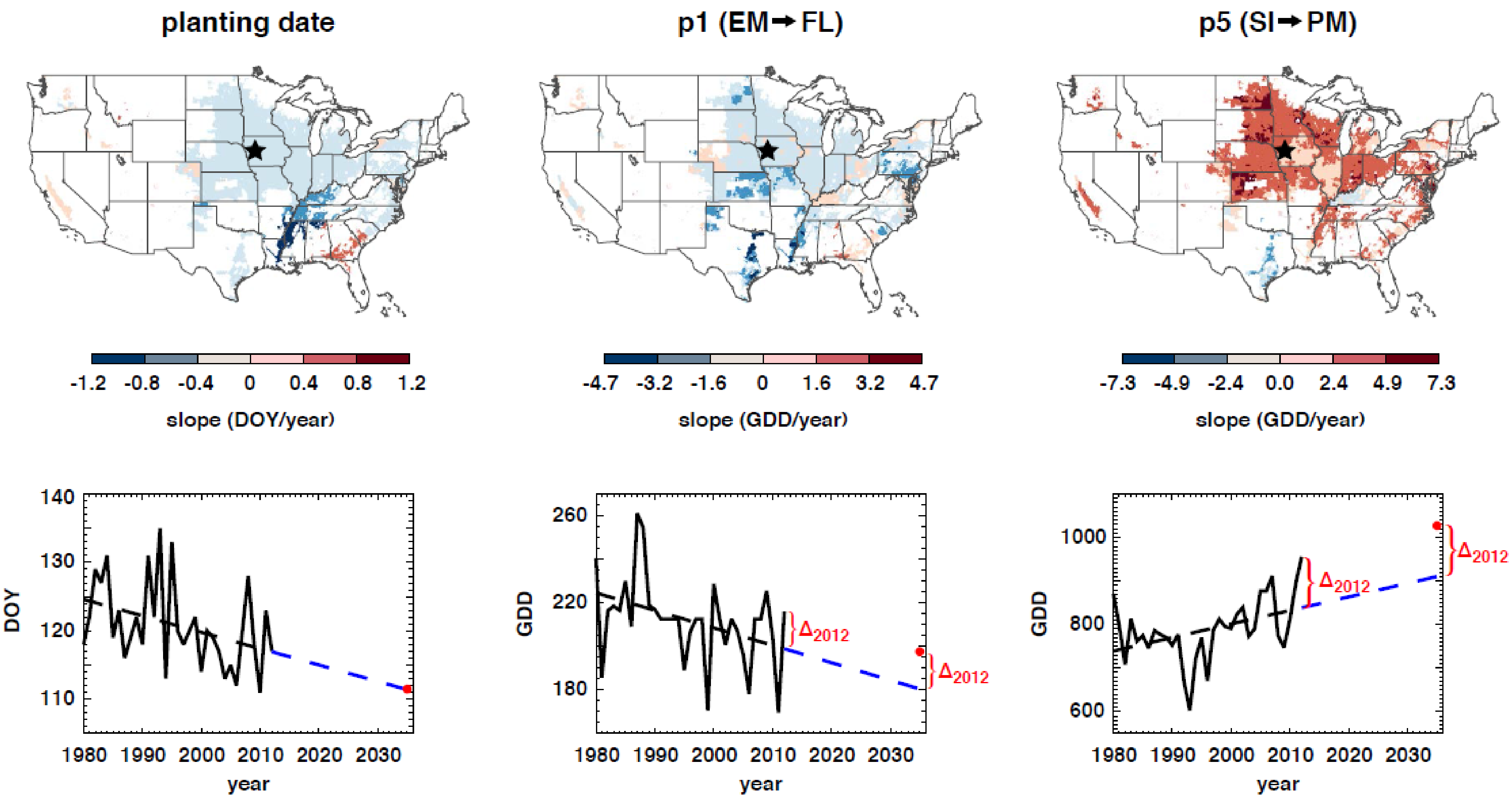
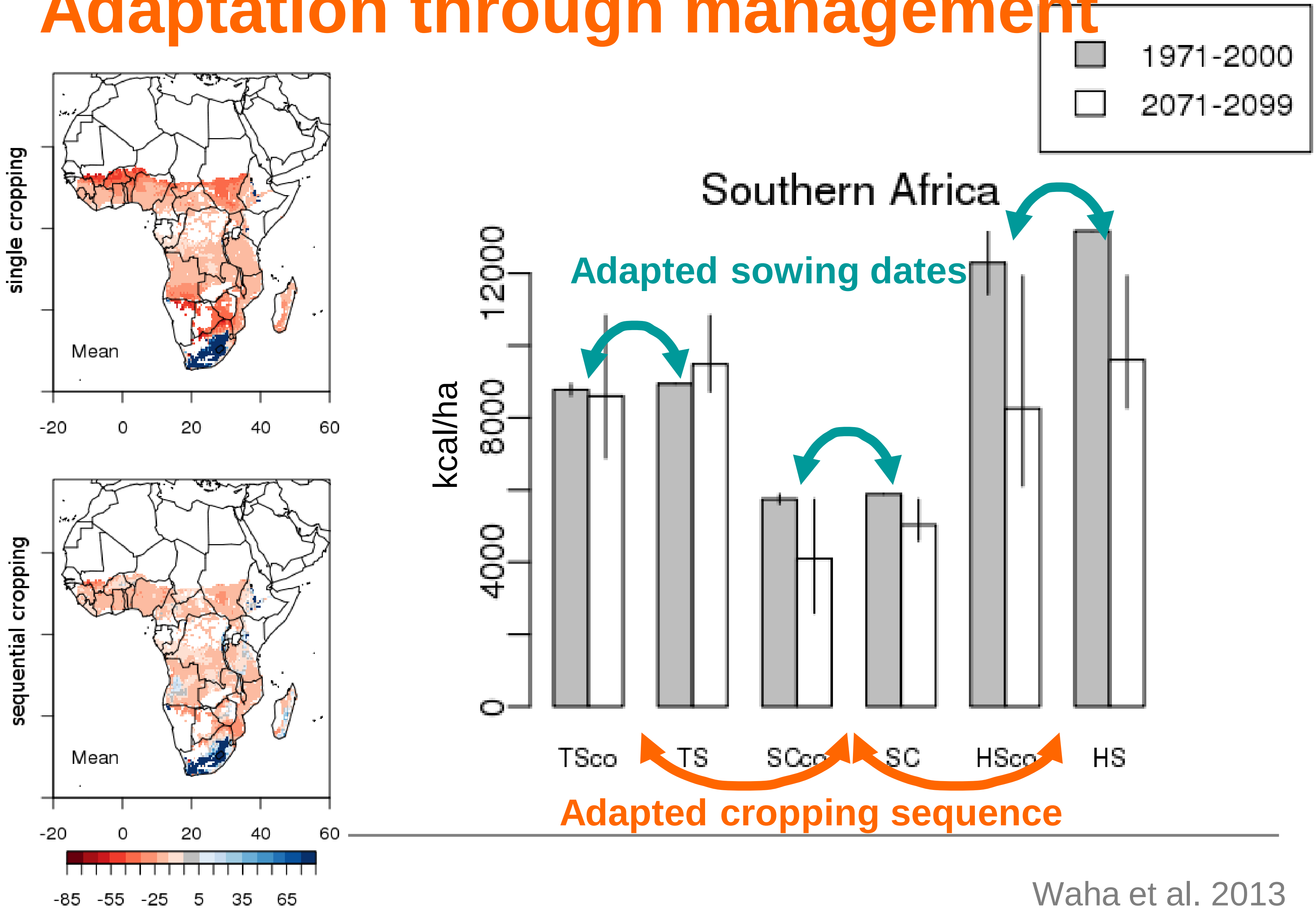
The road ahead:
managing management

Technological change



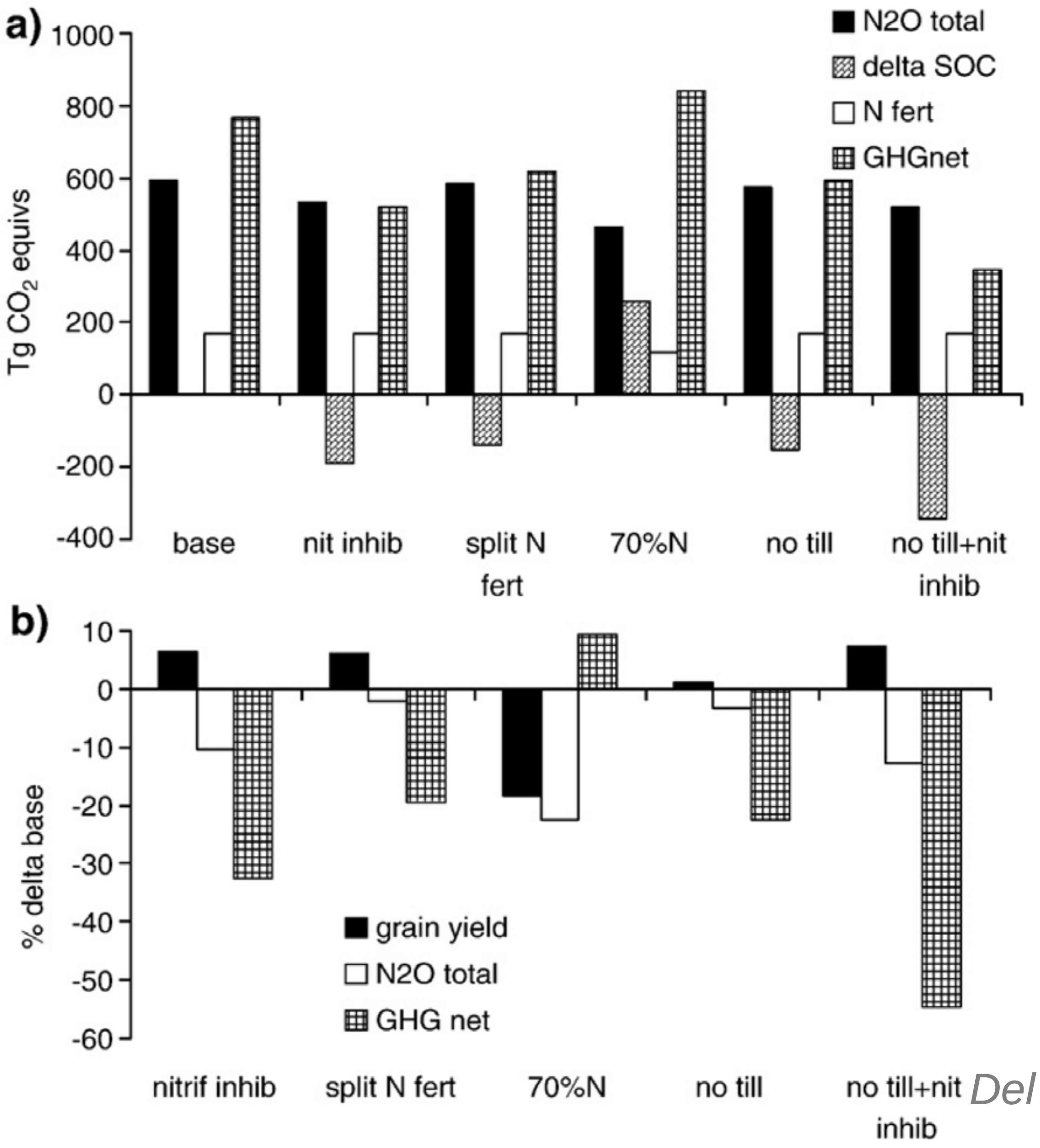
Glotter and Elliott 2016

Adaptation through management



Waha et al. 2013

Mitigation through management



Del Grosso et al. 2009

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Thanks for your attention

References

- Steffen, W. L., Sanderson, A., Tyson, P. et al. Global change and the earth system: a planet under pressure. (Springer, 2004).
- Nelson, G. C., Valin, H., Sands, R. D. et al. (2014). Climate change effects on agriculture: Economic responses to biophysical shocks. Proceedings of the National Academy of Sciences 111, 3274-3279.
- Müller, C., Cramer, W., Hare, W. L. et al. (2011). Climate change risks for African agriculture. Proceedings of the National Academy of Sciences of the United States of America 108, 4313-4315.
- Hawkins, E. & Sutton, R. (2009). The potential to narrow uncertainty in regional climate predictions. Bulletin of the American Meteorological Society 90, 1095-1107.
- Hawkins, E. & Sutton, R. (2011). The potential to narrow uncertainty in projections of regional precipitation change. Climate Dynamics 37, 407-418.
- Porwollik, V., Müller, C., Elliott, J. et al. (2017). Spatial and temporal uncertainty of crop yield aggregations. European Journal of Agronomy 88, 10-21.
- van Bussel, L. G. J., Stehfest, E., Siebert, S. et al. (2015). Simulation of the phenological development of wheat and maize at the global scale. Global Ecology and Biogeography 24, 1018-1029.
- Rötter, R. P., Carter, T. R., Olesen, J. E. et al. (2011). Crop-climate models need an overhaul. Nature Clim. Change 1, 175-177.
- Rosenzweig, C., Jones, J. W., Hatfield, J. L. et al. (2013). The Agricultural Model Intercomparison and Improvement Project (AgMIP): Protocols and pilot studies. Agricultural and Forest Meteorology 170, 166-182.
- Carter, T. R. (2013). Agricultural Impacts: Multi-model yield projections. Nature Clim. Change 3, 784-786.
- Neumann, K., Verburg, P., Stehfest, E. et al. (2010). A global analysis of the intensification potential for grain production. Agricultural Systems 103, 316-326.
- Boote, K. J., Jones, J. W., White, J. W. et al. (2013). Putting mechanisms into crop production models. Plant Cell Environ 36, 1658-1672.
- Schauberger, B., Rolinski, S. & Müller, C. (2016). A network-based approach for semi-quantitative knowledge mining and its application to yield variability. Environmental Research Letters 11, 123001.
- Stevanovic, M., Popp, A., Lotze-Campen, H. et al. (2016). The impact of high-end climate change on agricultural welfare. Science Advances 2, e1501452.
- Schmitz, C., Lotze-Campen, H., Gerten, D. et al. (2013). Blue water scarcity and the economic impacts of future agricultural trade and demand: Blue Water Scarcity-On Agricultural Trade and Demand. Water Resources Research 49, 3601-3617.
- Rost, S., Gerten, D., Bondeau, A. et al. (2008). Agricultural green and blue water consumption and its influence on the global water system. Water Resour. Res. 44, W09405.
- Elliott, J., Deryng, D., Müller, C. et al. (2014). Constraints and potentials of future irrigation water availability on agricultural production under climate change. Proceedings of the National Academy of Sciences 111, 3239-3244.
- Myers, S. S., Zanobetti, A., Kloog, I. et al. (2014). Increasing CO_2 threatens human nutrition. Nature 510, 139-142.
- Müller, C., Elliott, J. & Levermann, A. (2014). Food security: Fertilizing hidden hunger. Nature Clim. Change 4, 540-541.
- Bodirsky, B. L., Rolinski, S., Biewald, A. et al. (2015). Global Food Demand Scenarios for the 21st Century. PLOS ONE 10, e0139201.
- Schmitz, C., Biewald, A., Lotze-Campen, H. et al. (2012). Trading more food: Implications for land use, greenhouse gas emissions, and the food system. Global Environmental Change 22, 189-209.
- Müller, C., Elliott, J., Chryssanthacopoulos, J. et al. (2017). Global gridded crop model evaluation: benchmarking, skills, deficiencies and implications. Geosci. Model Dev. 10, 1403-1422.
- Glotter, M. & Elliott, J. (2016). Simulating US agriculture in a modern Dust Bowl drought. Nature Plants 3, 16193.
- Waha, K., Müller, C., Bondeau, A. et al. (2013). Adaptation to climate change through the choice of cropping system and sowing date in sub-Saharan Africa. Global Environmental Change 23, 130-143.
- Del Grosso, S. J., Ojima, D. S., Parton, W. J. et al. (2009). Global scale DAYCENT model analysis of greenhouse gas emissions and mitigation strategies for cropped soils. Global and Planetary Change 67, 44-50.

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