



Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

Understanding potential climate impacts and adaptation: Agricultural process models

ALLISON THOMSON

PNNL/JGCRI

July 23, 2014

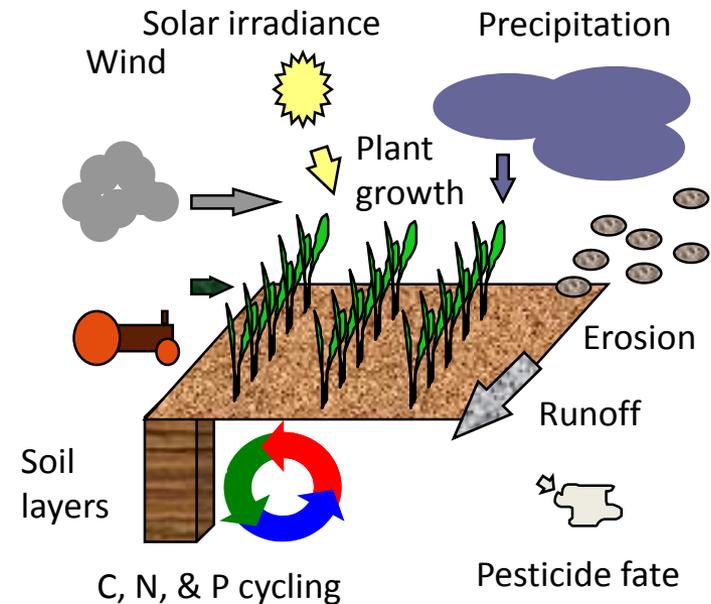
Integrated Impacts, Snowmass, CO

- ▶ Climate impacts studies using agricultural process models
 - First studies date back to the early 1990's as applications of existing crop models
 - Crop models differ based on the original purpose driving their development
 - Limited attempts at model inter-comparison until recently
- ▶ Current activities
 - Spatial scale of applications
 - Meta-analyses
 - Model intercomparisons
- ▶ Intersections with Integrated Assessment
 - Methods for incorporating process model results

What is an agricultural process model?

- ▶ Models of the processes of plant growth and crop stages, sometimes also soil processes
- ▶ There are a number of well regarded models developed over time
 - AgMIP wheat compared 27 models
 - Variety of regions, crops and purposes
- ▶ Typically operate at the field scale and require detailed inputs
 - Soils
 - Weather
 - Crop parameters
 - Crop management
- ▶ Validation of the modeling system using historical weather and statistics is important for assigning confidence to impacts studies

Example: EPIC is a process-based model built to describe climate-soil-management interactions at point or small watershed scales, originally developed by USDA for erosion and soil conservation studies

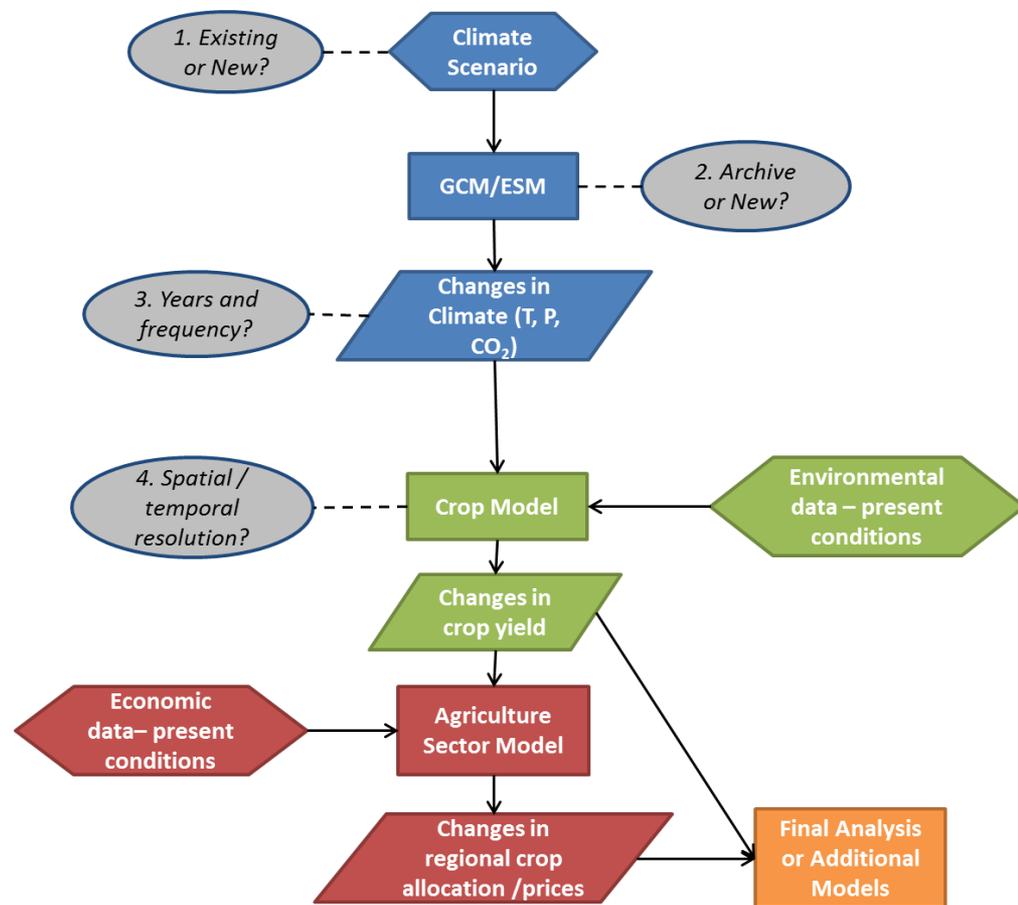


Representative EPIC modules

Methodology for Agricultural Impacts Assessments

- ▶ Impacts assessment requires developing appropriate datasets for environmental conditions and management practices in the future
 - Adaptation?
 - Spatial scale and extent?
 - Time period and frequency?
- ▶ RCM/GCM archives: valuable for mean monthly T and P changes
 - Typically either a selection of models that span the range of climate response, or an ensemble mean is used
- ▶ Custom climatologies or CM model results for specific projects also used
- ▶ Methods for use
 - Bias correction – use historical climate observations to adjust future projections for a seamless record from past to future
 - Delta method – apply the change in T and P projected by the climate model onto a historical climate period
 - Direct application of daily climate model projections

Schematic of models and data for decision support applications and the key questions for stakeholder discussion



▶ Strengths

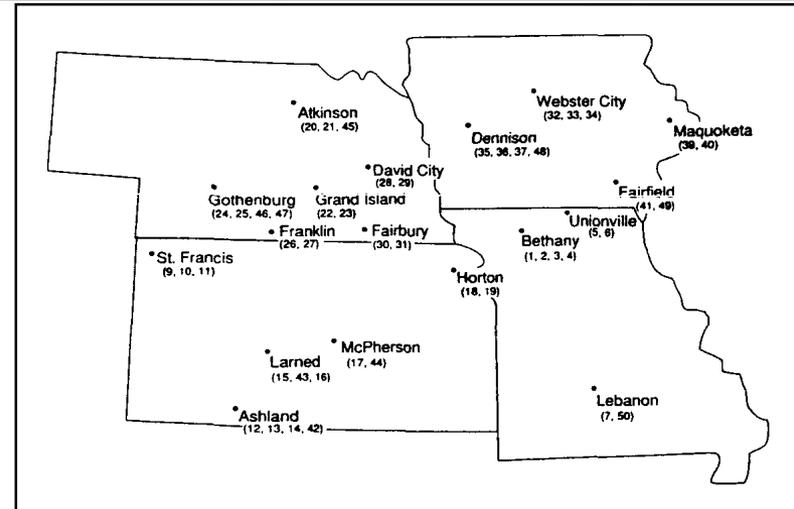
- Adjustments of planting and harvesting dates
 - Can be automatic based on temperature
- Flexible for irrigation and fertilizer adjustments
 - Can also be made automatic for “optimal” applications
- Customizable: USDA EPIC group developing parameters for adapted crop cultivars (e.g. drought resistant varieties) to test in climate impacts simulations

▶ Weaknesses

- Generally crop models cannot model damage due to pests and disease in a mechanistic way
- While some have ability to evaluate detailed crop management (rotations, tillage operations, residue management, etc) this requires extensive user input so suited to regional/local impacts and adaptation studies
- Similarly, detailed irrigation application based on available water is possible, but currently not feasible for large geographic extents

Historical Analog Climates - MINK

- ▶ Study region chosen for its
 - Physiographic homogeneity
 - Socio-economic and natural-resource vulnerability to climate change
- ▶ Research approach used
 - Historical climate records as analog of climate change (1930s “**Dust Bowl**”)
 - Biophysical modeling with EPIC previously adapted to deal with CO₂ effects on photosynthesis and evapotranspiration
 - A set of representative farms
 - Weather parameters
 - Soils
 - Farm management practices

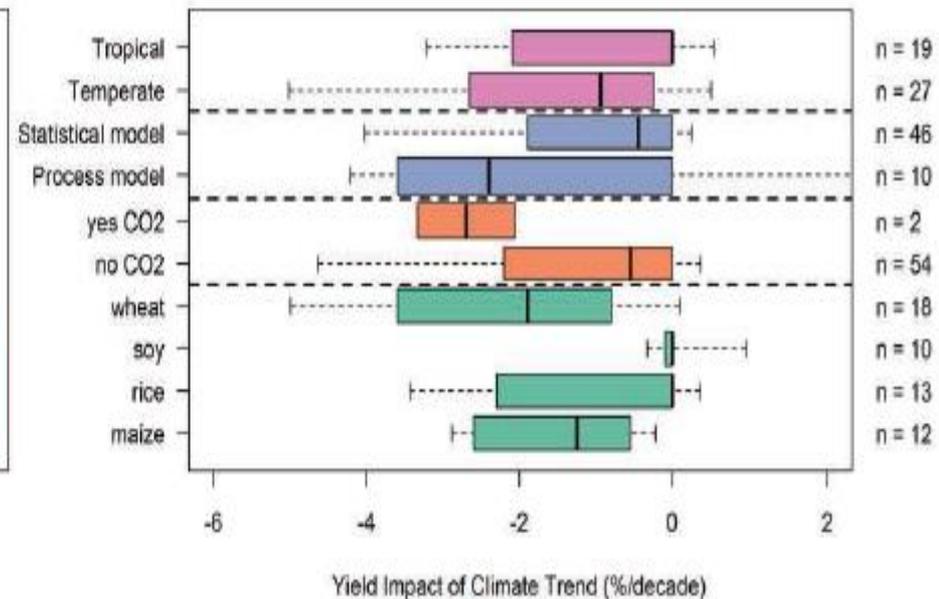
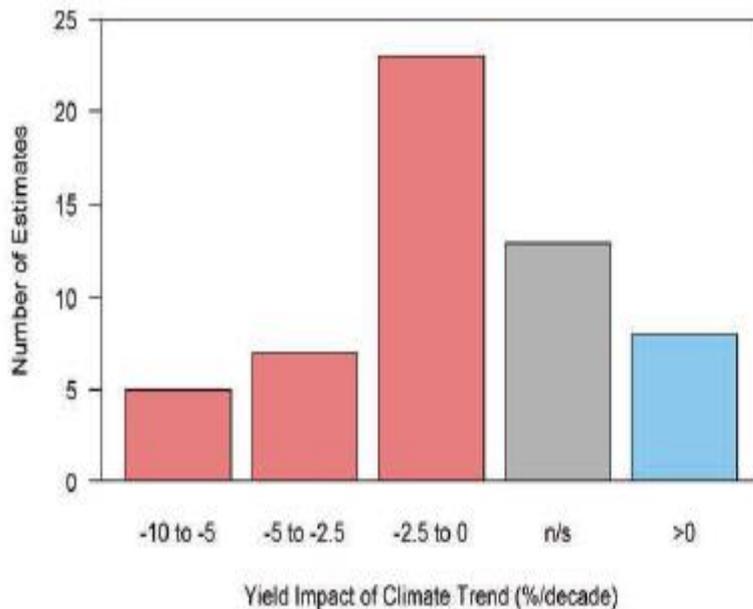


The MINK region: Missouri, Iowa, Nebraska, and Kansas

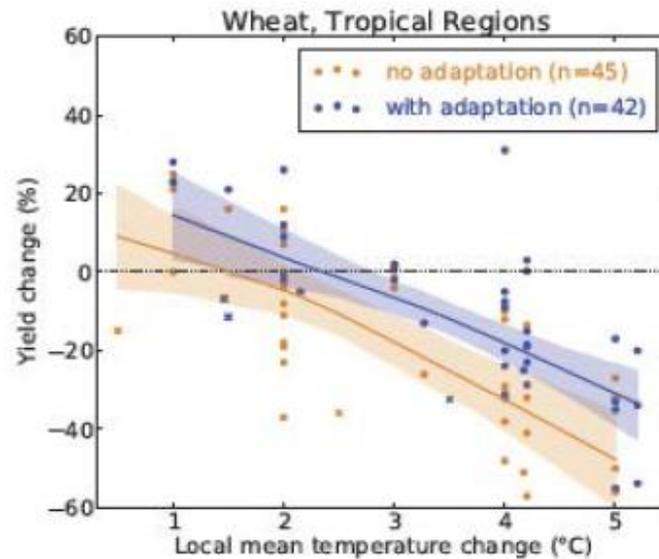
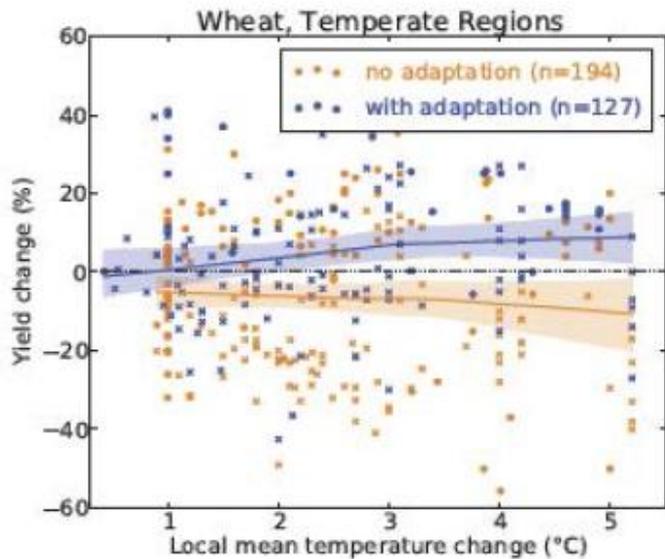
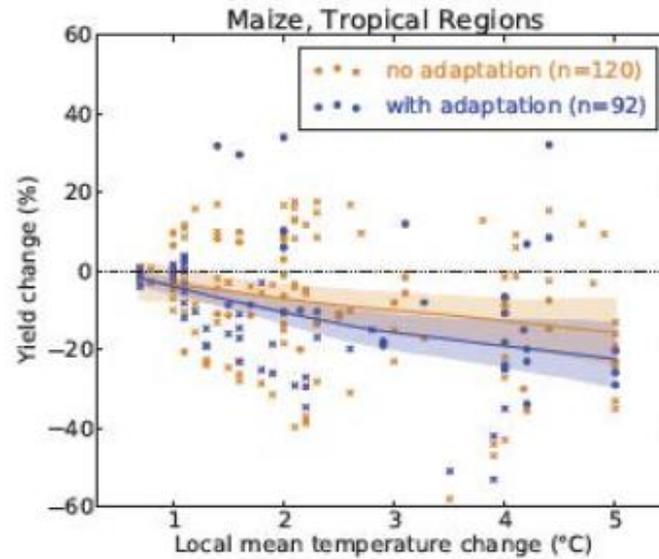
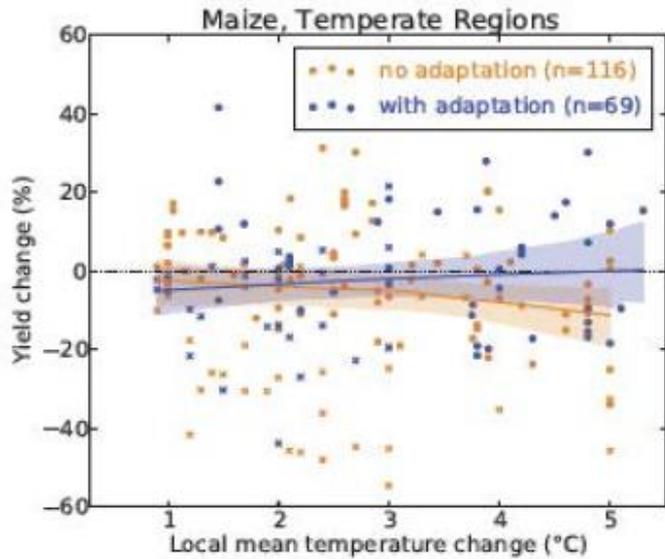
- ▶ Crop yield reductions ranged from 7% for irrigated corn to 25% for dryland corn and soybean
- ▶ Simulated yields of dryland wheat remained unchanged by the analog climate
- ▶ Simulated “CO₂ fertilization effect” alleviated yield losses
- ▶ Simulated adaptations with current technology (e.g. early planting, longer-season cultivars, and furrow diking) partially offset yield losses
- ▶ Advanced adaptations (e.g. cultivars with higher Light Use Efficiency) ameliorated and even increased yields

Meta analyses for discerning large scale trends

- ▶ Proliferation of studies in the past 15 years on national and regional climate impacts on agriculture primarily using SRES scenarios
- ▶ Meta analyses in 2007 and 2014 aligned with IPCC
 - IPCC AR4 WG2 Chapter 5 – meta analysis of 70 publications using crop models for maize, rice and wheat
 - AR5 WG2 chapter 7 – cite improvements in quantification and presentation of uncertainty, particularly the uncertainty arising from the use of climate projections.



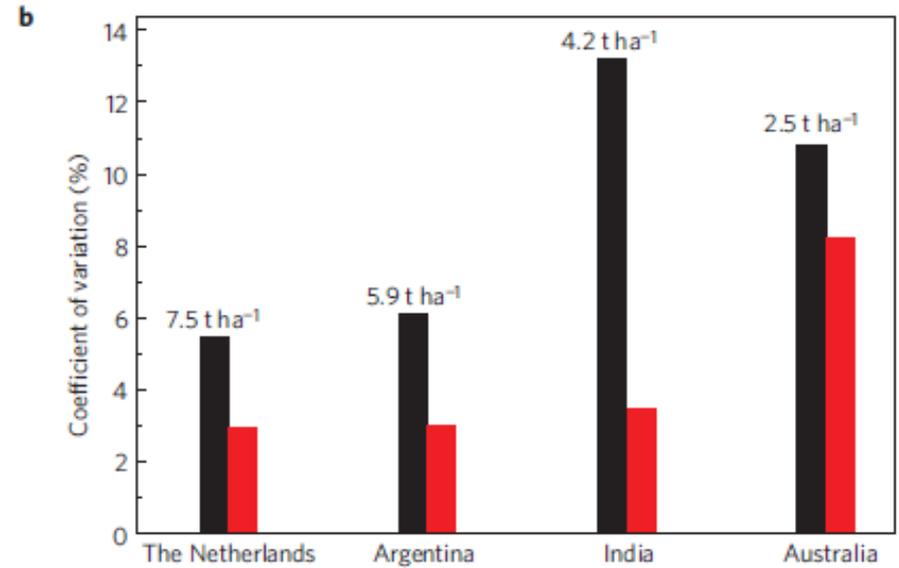
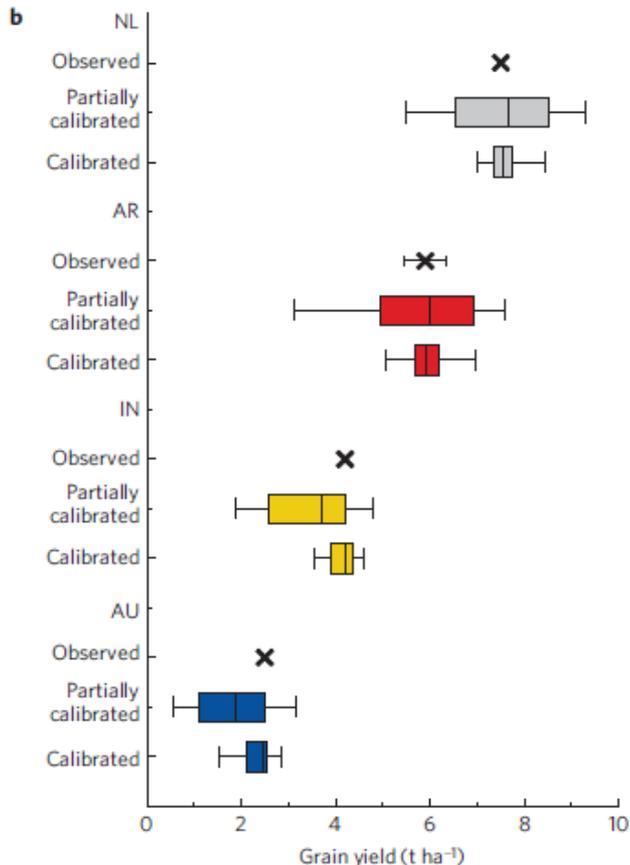
AR5 meta analysis for maize and wheat



AgMIP Crop Model Intercomparisons

- Asseng et al 2013 assessed 27 models for 4 sentinel wheat experiments

Accuracy of models was improved with full calibrations to the sites



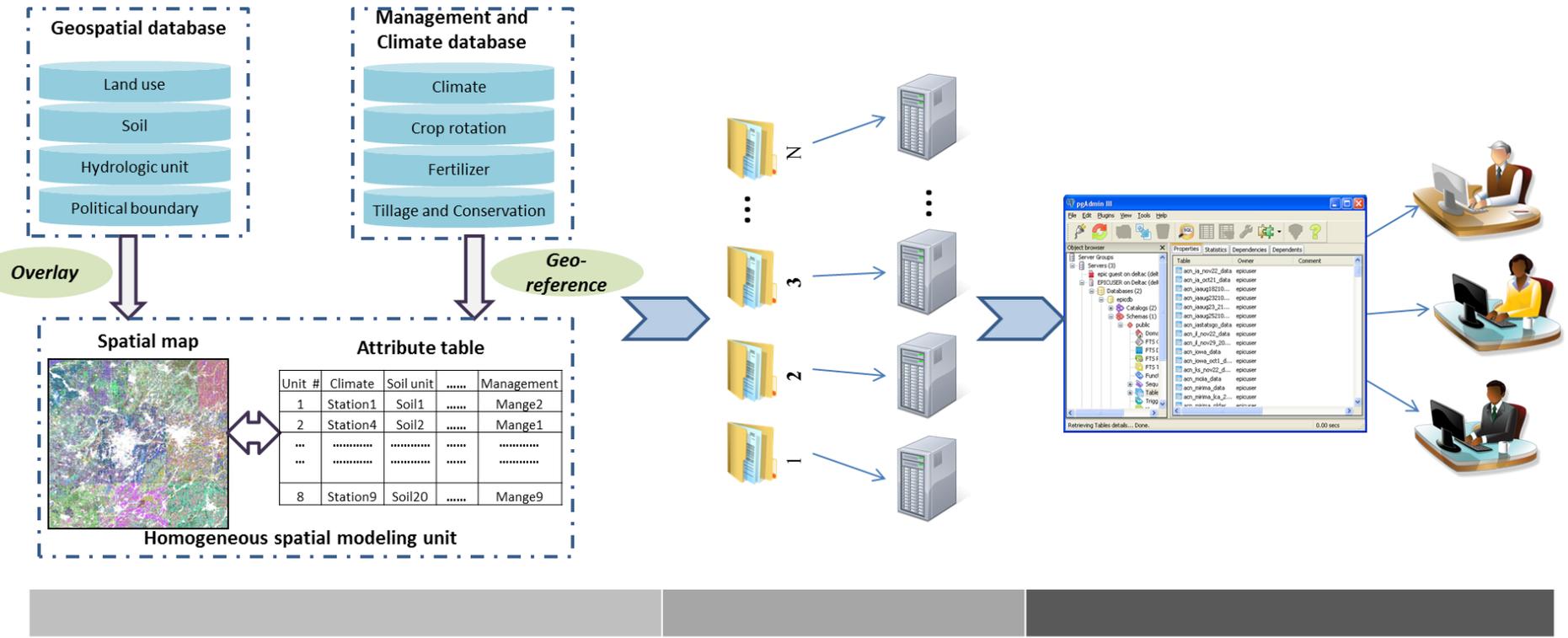
Black: CV due to crop model uncertainty in 30 yr average yield

Red: CV due to variation in the 16 GCMs used for A2 simulations

Uncertainty due to choice of crop model is just as, if not more, important as climate model selection

Applying a point based model to a regional assessment

Example of a Spatially Explicit Modeling System for Regional Applications
(Zhang et al., 2011)



Spatially-explicit modeling map and geo-referenced attributes

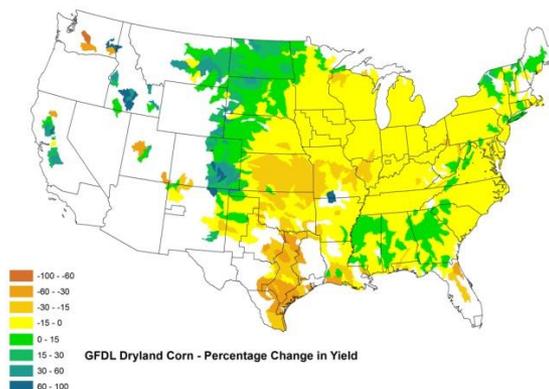
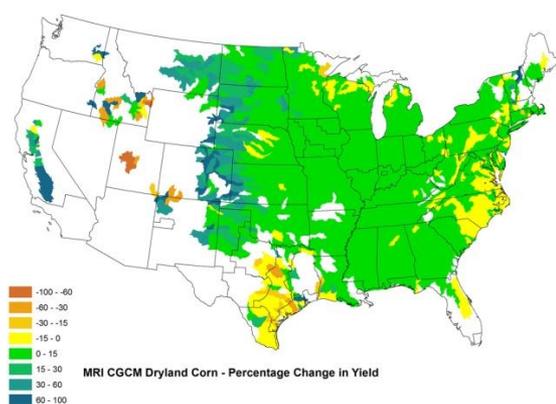
EPIC Parallel computing

Geo-database analysis and visualization

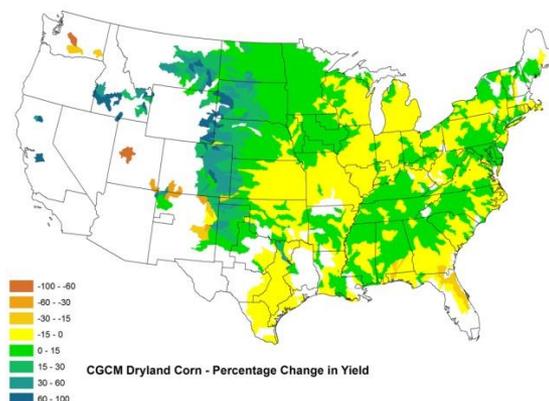
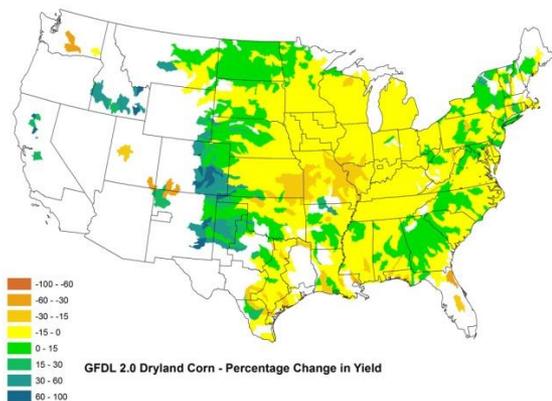
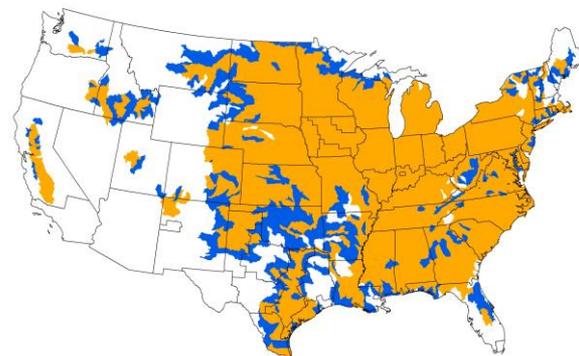
Develop database → Test Runs & Debug → Run Simulations → Evaluate

Example – National EPIC simulation for USDA Crop Insurance

- ▶ Four GCMS under the A1B scenario for 2045-2055 (daily)
- ▶ Spatial units of hydrologic basins; multiple representative farms in each based on soil heterogeneity; 89,000 runs per scenario

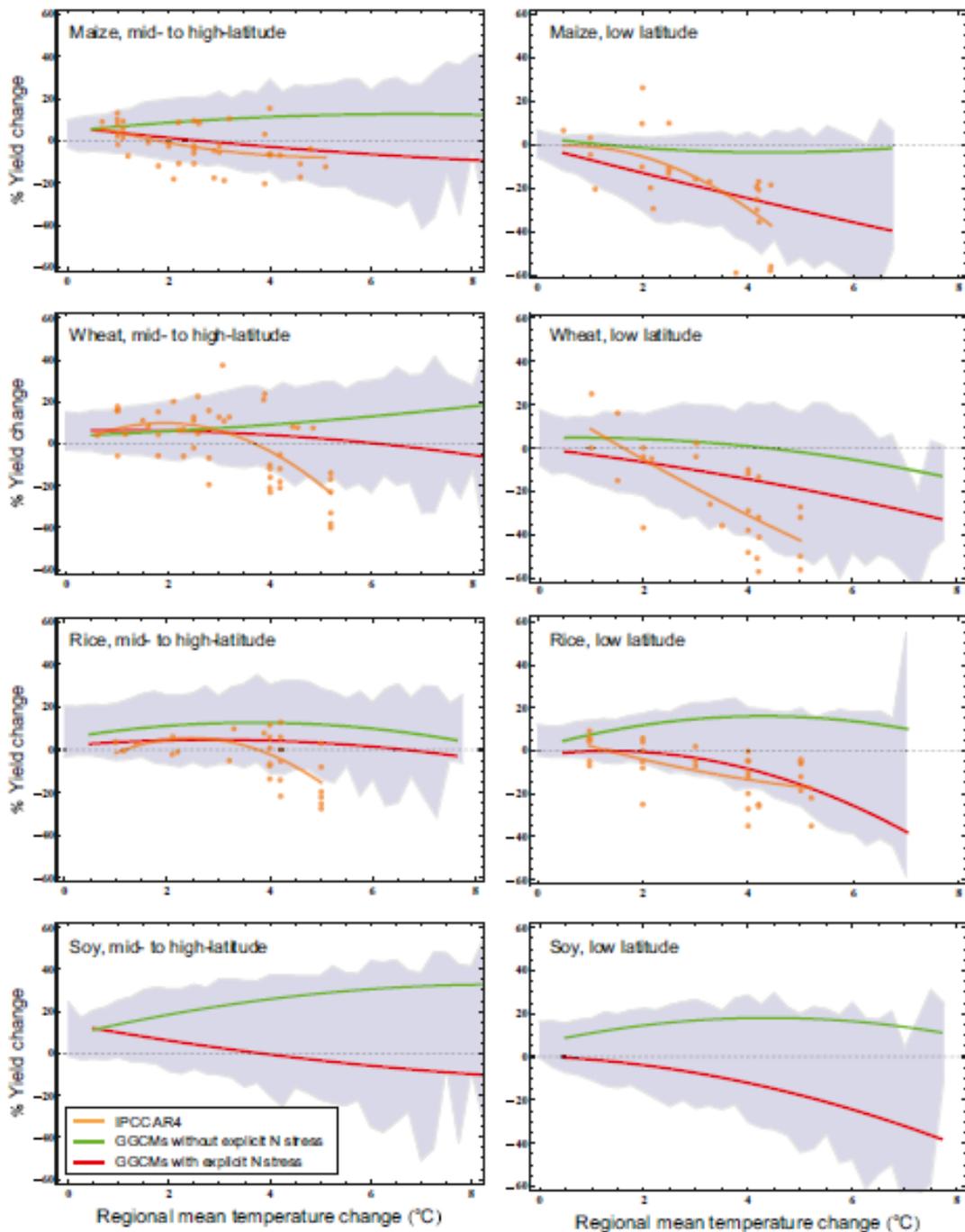


Corn



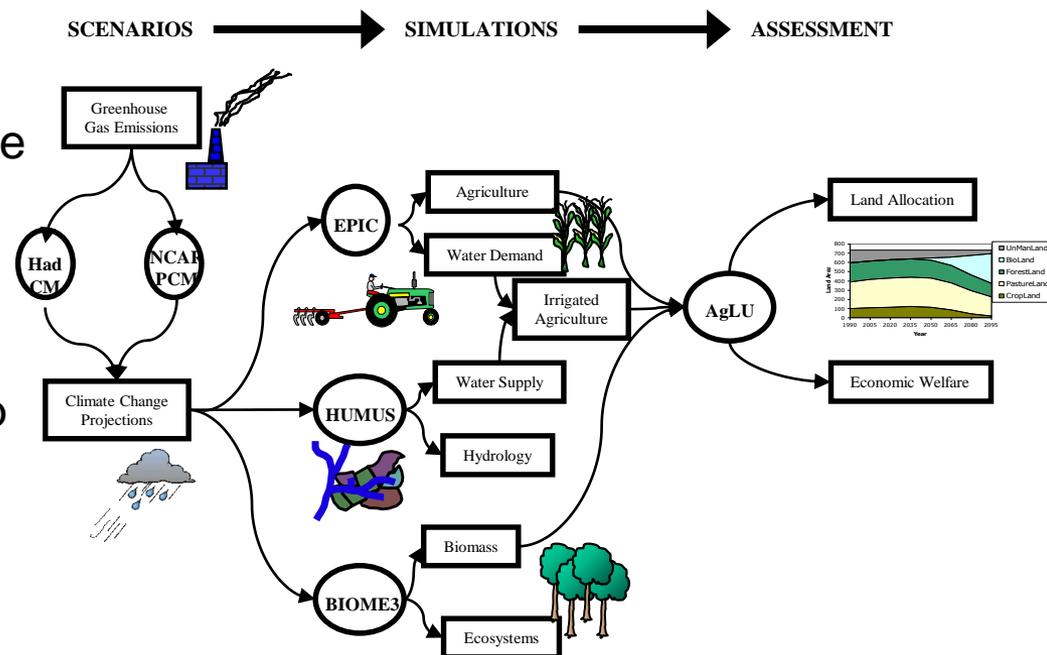
Global Crop Modeling

- ▶ Global Gridded Crop Model Intercomparison – fast track experiment by AgMIP and ISI-MIP
 - 7 models participated; 3 process models, 4 models with origins in dynamic vegetation modeling
 - Large difference between model types – models that consider N limitation have more negative climate impact projections
- ▶ Identified main uncertainties related to representation of CO₂ fertilization, N and T effects on yield.
- ▶ More agreement in high and low latitude regions than in the mid-latitudes

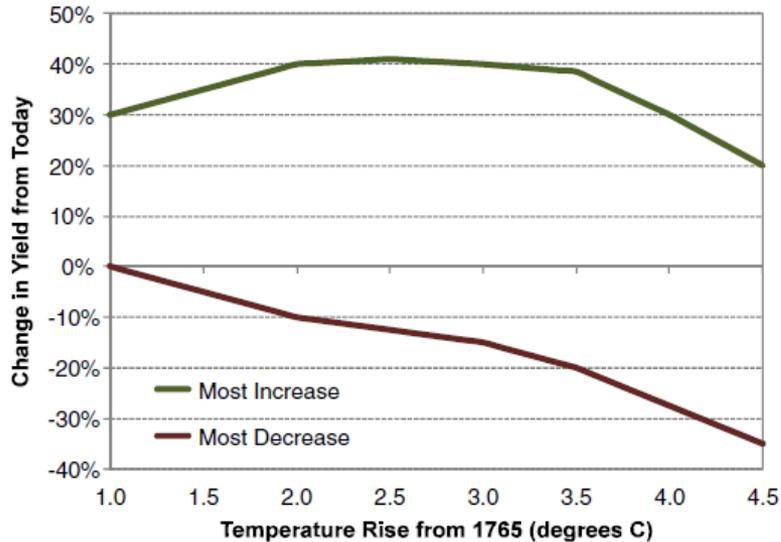


- ▶ Issues of scale: Global crop modeling is still relatively new and data intensive
- ▶ Issues of uncertainty: AgMIP has shown that crop models do not all agree
- ▶ Potential methods:
 - Flexible use of multi-model synthesis outputs
 - Direct use of ensemble means
 - Use of meta-analysis trends
 - Direct coupling between a crop and an economic model
 - Nested regional assessments within global IAMs
 - Use of global crop models within IAMs
 - EPIC-GLOBIOM approach
 - Dynamic coupling of IAMs with ESM models that incorporate crops

- ▶ 2005: EPIC-GCAM, USA only
 - The presence or absence of a CO₂ fertilization effect was a main determinant for yield change and economic welfare
 - Crop model results were available for US, so assumptions about yields in ROW were needed
- ▶ Economic based models retain their base year calibration to observations and use the change projected in crop models to adjust future yield expectations
 - Connect level of climate impact with IAM pathway
 - Assumes no feedbacks between crop systems and climate change



Example – IPCC Meta-analysis in GCAM

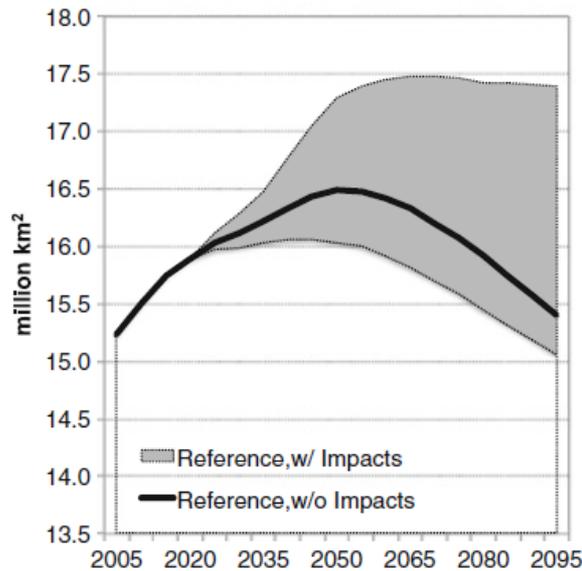


Projected change in wheat yield in the mid/high latitudes

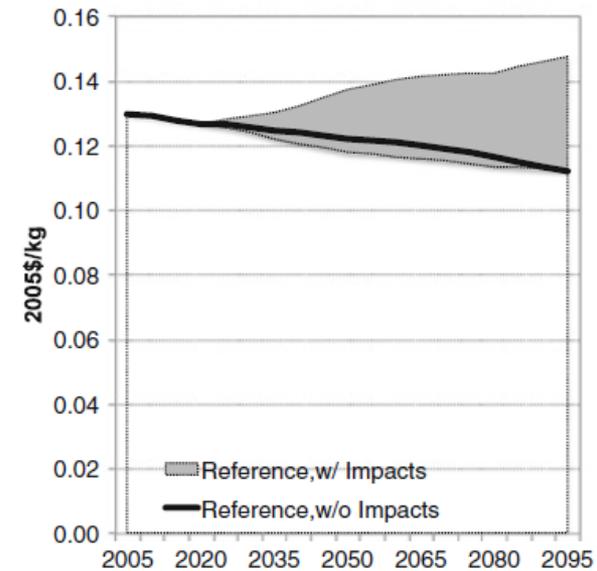
Application of the full range of yield responses to bound and understand the scale of impacts and importance to IA

GCAM reference scenarios results

c: Global Cropland Area



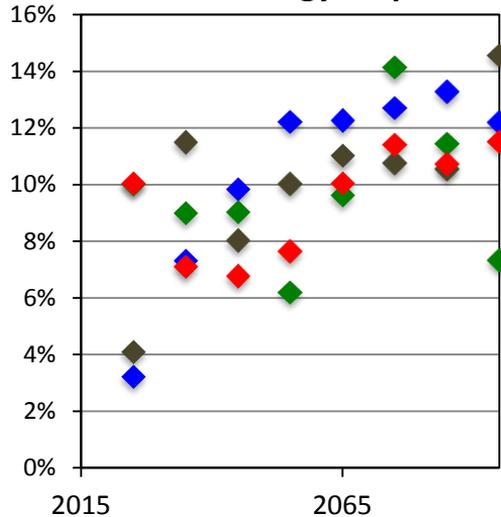
d: Wheat Price



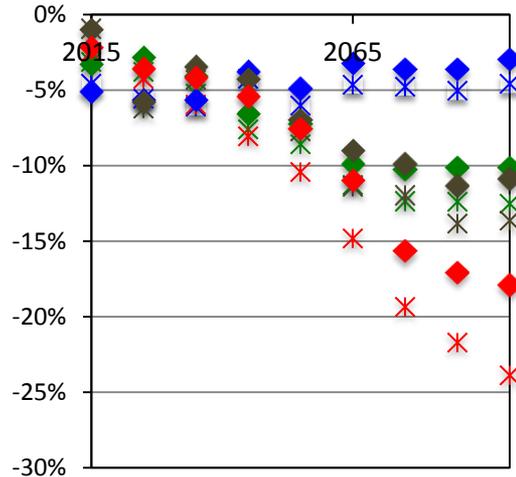
Example – Global Gridded Crop Model results application in GCAM

Replicated the RCP pathways with climate impacts on agriculture parameterized based on the LPJml models used in ISI-MIP/AgMIP

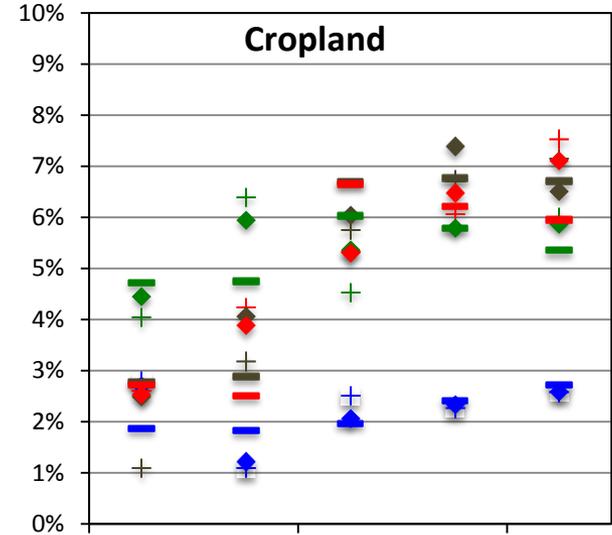
Bioenergy crops



Wheat



Cropland



LPJml results: Positive trend for bioenergy crops strongly influences the IAM solution for mitigation scenarios

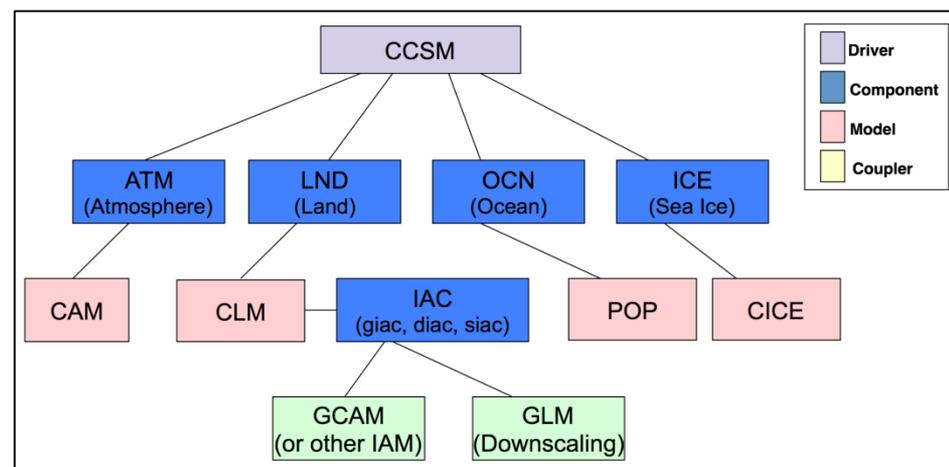
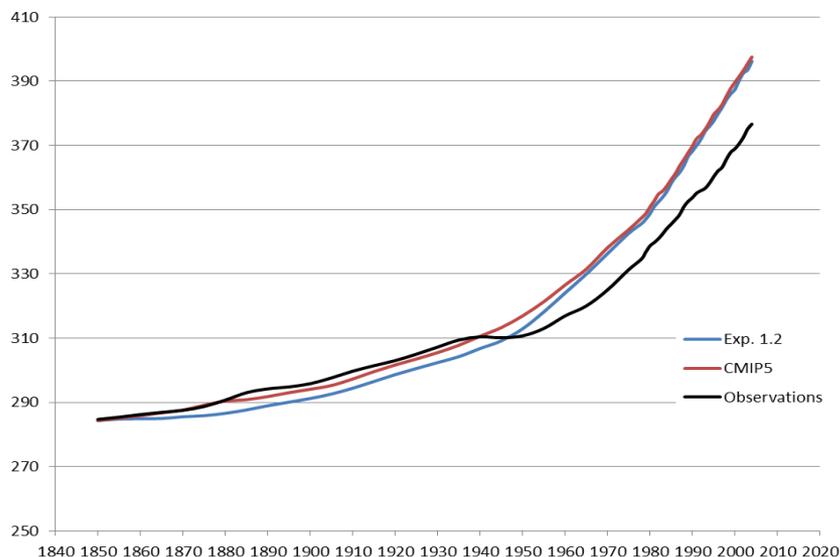
Percentage difference in global cropland from 2050 to 2095 for scenarios with 5-, 10-, and 30-year climate impact timesteps, compared with corresponding scenarios with no climate impacts.

- + 2.6_CCI_5yr + 4.5_CCI_5yr + 6.0_CCI_5yr
- + 8.5_CCI_5yr ◆ 2.6_CCI_10yr ◆ 4.5_CCI_10yr
- ◆ 6.0_CCI_10yr ◆ 8.5_CCI_10yr ◆ 2.6_CCI_30yr
- 4.5_CCI_30yr — 6.0_CCI_30yr — 8.5_CCI_30yr

Emerging model class – integrated human and Earth systems

- ▶ Direct coupling between climate models with crop modeling capabilities and integrated assessment models
 - Early coupling results demonstrated several hidden inconsistencies in the CMIP5 protocols which have been corrected
- ▶ Advantage is that this approach will fully capture the feedbacks of climate impacts on crops → Land use change → climate consequences of LUC
- ▶ Disadvantages are the complexity and time required to develop these approaches, and the computational requirement of running the system

Predicted vs. observed atmospheric CO₂ concentration (ppmv)



Preliminary results

Looking forward – opportunities and caveats

- ▶ AgMIP Intercomparison opens the door to more robust understanding of the impacts projections from process models
 - The level of disagreement so far is a caution
 - It's not just about the underlying data
- ▶ Pests and disease are major potential risks to agriculture from climate change
 - Not adequately treated in current crop models
- ▶ At global scale, dynamic vegetation models and land models are beginning to incorporate more details on crop types and crop management
 - Currently, process models better capture nutrient limitation and soil dynamics and their influence on yields
- ▶ What do IAMs really need?
 - Is high spatial resolution long term process model output appropriate as an IAM input?
 - How can we guide inclusion of impacts understanding in IAMs?



Pacific Northwest
NATIONAL LABORATORY

*Proudly Operated by **Battelle** Since 1965*

QUESTIONS?