Evaluation of GCAM Agricultural Land Use Modeling: A Hindcasting Experiment Comparing Model Behavior to History

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Introduction

This exercise is part of a broader effort to evaluate the GCAM model behavior against history, Including major aspects such as economic choices in the energy and agricultural system

This effort serves multiple objectives:

1) The evaluation itself, providing an appropriate and useful level of model validation for a long-term integrated assessment model.

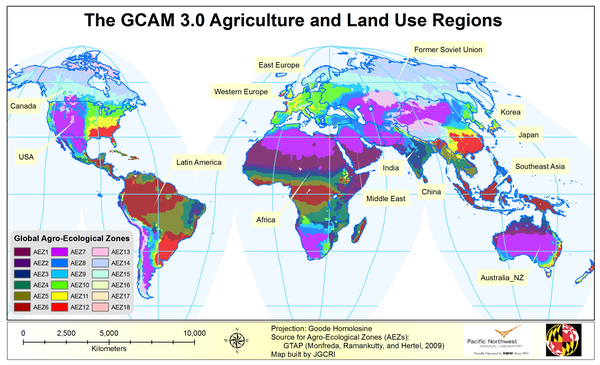
2) Improved transparency and understanding to the community about how the model operates given key assumptions.

3) Serves as a learning exercise for identifying modeling approaches and data that are most critical for long-term modeling, as well as areas that could be improved.

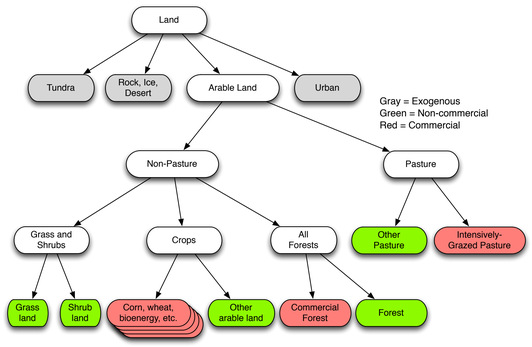
The GCAM Model

The Global Change Assessment Model (GCAM) is a global integrated assessment model that links together submodules of the economy, energy system, agriculture, land use, and climate.

The GCAM 3.0 Agriculture and Land Use Regions



Land Type and Use Categories within each of the current 151 Land Regions



- The model structure and mathematics are constructed to combine the economic modeling of land use with explicit representation of physical land characteristics and agricultural technologies.
  - This modeling design is key to GCAM's functioning in the integrated Earth System Model (iESM).
  - Changes in land productivity, whether driven by technology or climate change, are incorporated into the economic decisions.

GCAM Ag/Land Use Hindcasting Study

We have constructed a set of model test cases for running GCAM annually in historical years back to 1990. For this study, we assume that population, income, technology, and crop yields are known in each modeled year – so that the evaluation can isolate the economic choice of crop production and land use.

We compare GCAM modeled historical global and regional crop production and harvested land area to FAO data for major crops, using the cases in the table below.

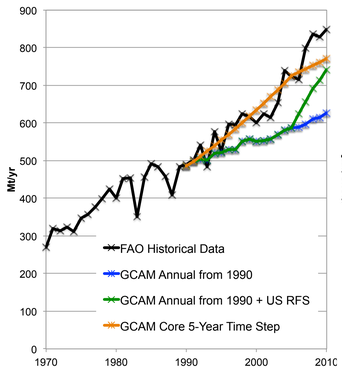
Case	Description
GCAM Annual from 1990	GCAM Calibration to 1990 as the Base Year. GCAM is run forward annually for 20 years. GCAM makes annual land allocations given data for population, income, and crop yields.
GCAM Annual from 1990, + US RFS	Same as GCAM Annual from 1990 (above), but the US Renewable Fuels Standards are imposed (which would not have been known in 1990).
GCAM Core, 5-Year Time Step	GCAM is calibrated first to 1990 and then to 2005. GCAM is run in time steps of 1990, 2005, and then 5-year periods after.

Evaluation: Global Crop Production and Land

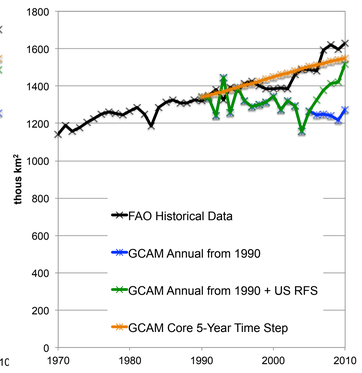
Global production levels are primarily driven by our modeling of agricultural demand (though land does have an impact).

- Demands modeled for food grains, fiber, non-food demands for agriculture, meat, feed, forest products, bioenergy.
- We have typically assumed global markets for crops.
- Human demands are calibrated to current levels and evolve with changes in future population, income, and crop prices.

Global Corn Production



Global Corn Harvested Area



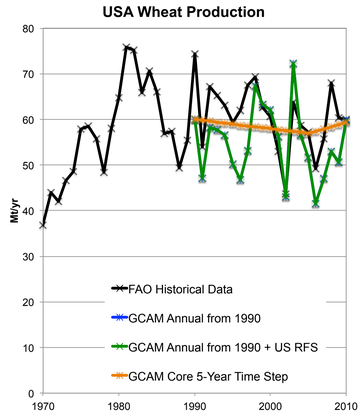
- GCAM Annual from 1990 cases clearly misses demand growth when it does not know that the US RFS is coming.
- GCAM Core 5-Year Time Step captures trend much better, but still needs to account for growth in corn from RFS beyond 2005 and other demands.
- GCAM tracking of corn harvested land area is similar to production. The lower slope of increase in harvested area versus crop production shows the rate of increase in average corn yields over time.

Evaluation: Regional Crop Production and Land

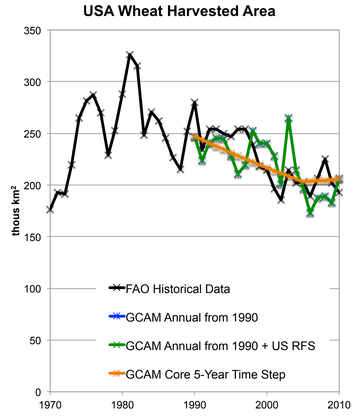
- GCAM Regional Production and Land Use in GCAM is directly driven by the approach to economic land use allocation.
- Non-linear functions are used represent distributions of profits for competing uses of land (logit or logistics equations).
  - These functions are readily calibrated. Future periods deviate from history to the extent that changes in key economic drivers (such as demand growth, yields, policies) change relative prices from history.
  - These non-linear profit functions reflect diminishing returns to expansion.
  - There is no need to place constraints on economic land allocation to avoid over-optimization in future model years.
- GCAM typically assumes global integrated market for agricultural products.
  - Unlike models that use Armington approaches, historical trade preferences are not calibrated into future periods
  - Production among regions is based on comparative advantage relationships rather than on absolute advantage or regional demand.

Hindcasting USA Wheat

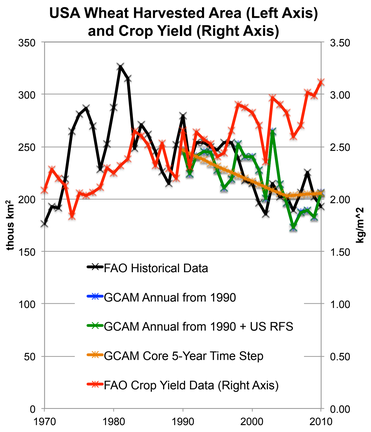
USA Wheat Production



USA Wheat Harvested Area



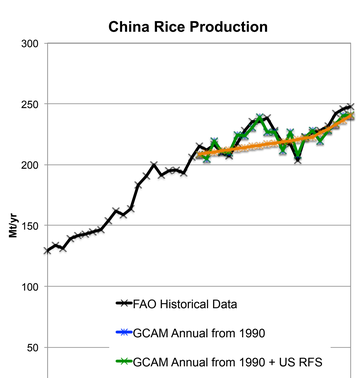
USA Wheat Harvested Area (Left Axis) and Crop Yield (Right Axis)



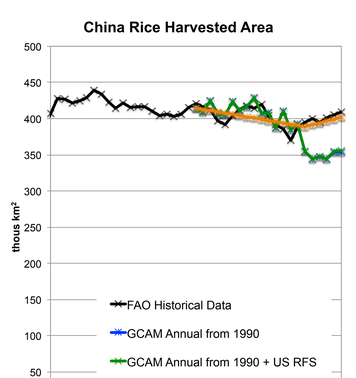
- From Left, historical annual production is volatile, while GCAM Core averages through the volatility.
- From Middle, land area is volatile, but less so than production. GCAM Annual follows the trend fairly well, but can tend to overstate the volatility. GCAM Core again averages through the volatility.
- From Right, crop yields are added to the chart. Since the GCAM Annual from 1990 knows the yield fluctuations, it acts opportunistically to allocate more/less land, but the real-world land allocations would not know the annual yield changes.

Hindcasting China Rice

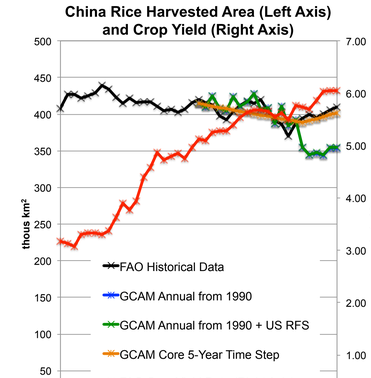
China Rice Production



China Rice Harvested Area



China Rice Harvested Area (Left Axis) and Crop Yield (Right Axis)



- For Chinese Rice, historical yields are less volatile for much of the period. GCAM Annual tracks historical production and harvested land area very well, while the GCAM Core gets trend well but misses the uptick in the late 1990s in its averaging.
- Though production still matches historical well, GCAM Annual understates harvested area after 2005 due to intra-China differences as well as data difficulties such as multiple cropping in a year. The GCAM Core recalibrates to data in 2005.
- An important finding here is that, for modeling annual time steps, using expectations of yields rather than actual yields, especially when they are inherently volatile, will allow better tracking of real-world land allocation decisions.

U.S. DEPARTMENT OF ENERGY

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