# SIMPLE-G model, data, parameters, and implementation

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**Abstract**

This paper will illustrate how a gridded equilibrium model can be parameterized. The model is constructed based on the SIMPLE-G framework (a Simplified International Model of agricultural Prices, Land use, and the Environment- Gridded version), using geospatial information of All-crops in the US for the year 2017 at 5 arc-min (squares of side 9.26km at the equator). The paper introduces the main variables, parameters, assumptions, and equilibrium conditions. It also introduces some useful computational techniques, tools, and lessons learned in the parameterization of such a large model within a couple of applications. The first application will focus on the global unintended consequences of local sustainability and conservation policies in the US (Figure 1). The purpose of the second application is to decompose the global drivers of the US land and water stresses at each grid cell.

## Introduction

Many of the global sustainability challenges are tied to climate change, water, land, and food production. Understanding these challenges requires a holistic view of interlinkages between environmental and social systems and dealing with scientific problems with different spatial and temporal scales. Economists and biophysical scientists have been trying to construct a computable and traceable integrated system for this purpose. However, there has been little success in employing rich spatially heterogeneous biophysical information in a global economic framework.

Due to the complexity of global economic models, biophysical scientists tend to ignore many important economic components which can lead to biases in results. Conversely, economists working on sustainability and food security typically omit key elements of biophysical heterogeneity in resources, as well as local institutions. Bringing these two communities together requires a multiscale framework for the integration of economic and biophysical determinants of sustainability that can be computable, traceable, and understandable. This paper illustrates the parameterization of such a modeling framework aimed at improving our understanding of the interplay between local hydro-climatic variations and global socio-economic changes and their implications for food security and environmental sustainability.

**Model**

The focus of this paper is SIMPLE-G-US-Allcrops-2017 -- one of the members of the SIMPLE-G model family (Baldos et al., 2020; Haqiqi et al., 2022; Liu et al., 2017). In brief, it models the consumption and production of food at the global level with gridded production in the US and aggregating all the crops in a single composite commodity (Allcrops). The model is focused on global food production and works based on multiple strong assumptions commonly used in computable general equilibrium models. This includes market clearing, zero-profit conditions, imperfect substitutability of imports, and income balances. However, the income and population are given, and the production of non-food commodities is not modeled. The consumption and production of food are modeled at 17 global regions, while the crop production in the US is disaggregated and modeled within over 75,000 grid cells. Each grid cell in the US has its specific Allcrops production function that determines the input demand and crop supply. The supply and demand for land and water are grid specific based on production function and supply elasticities. However, the supply of fertilizer and other inputs are models at a subregional scale based on USDA (US Department of Agriculture) Farm Resources Regions.

***Trade module***.

Each grid cell produces a slightly different variety of Allcrops and the grid-cell outputs are not perfectly substitutable. The total production of each region will go either for local consumption or exports. The regional consumption of food is a function of population, income, and relative prices. The model employs an Armington-type function to determine imports and domestic demands based on relative prices and trade parameters.

***Gridded production module***.

There are two Allcrops production functions at each grid cell, one for irrigated and one for non-irrigated practices. It is a nested CES (constant elasticity of substitution) function of land, nitrogen fertilizer, water (groundwater, surface water, irrigation inputs), and a composite of all other inputs. This function is calibrated and parameterized this function based on multiple geospatial datasets that will be discussed. There are multiple substitution parameters including land-water, groundwater-surface water, and fertilizer-all other inputs. This talk will illustrate how the parameters are calculated based on agronomic relationships and economic information. The USDA Census of Agriculture is used for cost shares and total revenues.

***Land and water modules***.

The gridded cropland supply elasticity is empirically estimated based on multiple variables such as cash rents and satellite scans. Then, the total cropland is allocated to irrigated and rainfed practices assuming a quantity preserving CET (constant elasticity of substitutions). The gridded water supply elasticity is empirically estimated based on the estimated value of water and irrigation, reported water withdrawal by USGS (US Geological Survey), and simulated water balances.

***Data***.

In a globally gridded economic analysis, the data integration involves processing heterogeneous geospatial data across different domains including economics, agronomy, hydrology, sustainability, food security, and land use. Major processed data sets employed in this study are the annual cropland data from satellite scans at 30-meter resolution from the USDA Cropland Data Layer (CDL) family, Cultivated Layer (Boryan et al., 2012); the annual irrigated area from satellite and reported data at 250-meter resolution (Brown & Pervez, 2014) from the USGS Moderate Resolution Imaging Spectroradiometer (MODIS) Irrigated Agriculture Dataset for the United States (MIrAD-US); daily surface water and groundwater withdrawals at 6 arc-min resolution from the Water Balance Model (Grogan et al., 2022); county-level information on the average yield of crops, annual labor information, sales and expenses from the USDA; annual international trade of agricultural commodities from FAO; and gridded nitrogen fertilizer applications at 5 arc-min. This talk will focus on three types of information for parameterization. First, is the land supply elasticity informed by satellite observations and surveys. Second is the water supply elasticity informed by a hydrological model (WBM) and economic water value. And third is the fertilizer substitution elasticity informed by an agronomic model (AgroIBIS).

***Computation***

The SIMPLE-G framework can comprise a large system of equations with up to half a billion unknowns. Solving this model can be computationally expensive even with High-Performance Computation due to the impossibility of parallelization. This paper discusses common issues and some of the solutions including the condensation methods used to speed up the calculations. It also discusses the challenges and opportunities in the GEMPACK environment for this type of analysis.

## Contribution

This paper contributes to the global-local-global sustainability analysis by illustrating how to integrate heterogeneous economic and biophysical features of sustainability challenges at global, regional, and local scales across different temporal scales. It describes new developments in highresolution modeling and data processing of food production and land-water use. It will demonstrate how gridded sales and expenses are linked to yields, labor, fertilizer, water, and land. This work shows how to distinguish economic water supply/demand from hydrologic water supply and agronomic water demand. It also shows how economic activities in different grid cells are interlinked via local and global agricultural markets. It emphasizes on the importance of interdisciplinary communications while integrating geospatial data.



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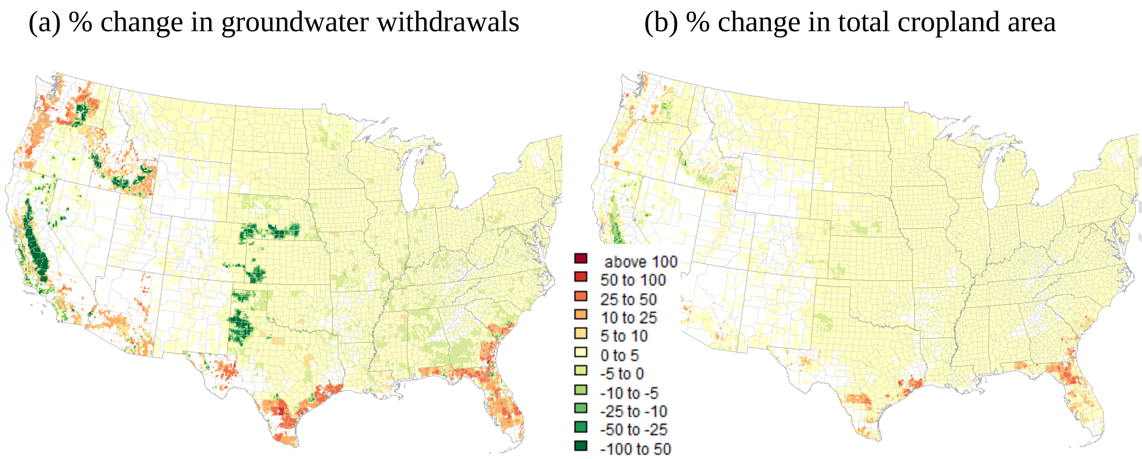


**Figure 1**. The spatial impacts of groundwater sustainability policy in the US as computed by SIMPLE-G-US-Allcrops. Panel (a) shows the percentage change in irrigation groundwater withdrawals by 5 arc-min grid cells in response to a policy restricting groundwater withdrawals to the level of average annual groundwater recharge. The dark green coloring shows the targeted locations. The orange and red coloring show increase in groundwater withdrawals in locations where the groundwater is not reached the sustainability limit. Panel (b) shows the response of total cropland area to the policy. In the central US, the decline in total cropland is negligible due to conversion of irrigated area to rainfed. Note: white areas are not cultivated.