Connecting earth system models with applications: AgMIP and the broader VIACS communities

Alex Ruane, NASA Goddard Institute for Space Studies, New York and AgMIP/VIACS Collaborators Around the World

Interagency Group on Integrative Modeling
January 18th
In coming decades, the world is asking the agricultural sector to take on a quadruple challenge\(^1\):

1. Produce more to provide healthy food for growing and developing populations
2. Adapt to climate change and ongoing climate extremes
3. Mitigate emissions from agricultural lands
4. Maintain financial incentives for agriculture

The Agricultural Model Intercomparison and Improvement Project (AgMIP) was created to provide a community for systematic improvement and application of multi-disciplinary, multi-model, multi-scale frameworks for agricultural development and food security.

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\(^1\) Augmented from Cynthia Rosenzweig, NASA GISS
Translate earth system models and related earth information products into agricultural sector metrics to:

- Identify vulnerability
- Project impacts
- Prioritize adaptation strategies
- Understand agricultural pressures on water, energy, and land

To do this we need to understand biological and social systems of the agricultural sector and the implications of change for food security.
The Agricultural Model Intercomparison and Improvement Project (AgMIP) is a major international collaborative effort to improve the state of agricultural simulation and to understand climate impacts on the agricultural sector at global and regional scales.

**Agricultural risks are growing.** Decision-makers need probabilistic risk analysis to identify and prioritize effective adaptation and mitigation strategies.

**Consistency is key.** AgMIP is establishing research standards so future studies no longer use different assumptions across regions and models.

**Ongoing solutions.** AgMIP is developing a rigorous process to evaluate agricultural models, which results in continuous model improvement.
Agricultural Modeling Community is eager to understand the implications of Earth System Model results, but systematic approach needed to provide robust information.

- **Introduction to AgMIP**

- AgMIP Global, site-based, and networked approaches help characterize production and yield response to climate change factors

- Great potential for US applications using agricultural models as a connecting piece between ESMs and applications
The Agricultural Model Intercomparison and Improvement Project (AgMIP)
AgMIP Approach Enables Testing of Farm and Policy Strategies

Rosenzweig et al., 2013 AgForMet
AgMIP is an international community of 880+ climate scientists, agronomists, economists, and IT experts working to improve assessments of future food security and agricultural development.

Visit www.agmip.org for more information.
Crop response to core climate change factors
Representative Networks for Multi-model Analysis

Sites where 34 Wheat Models have been configured for analysis by the AgMIP Wheat Team Phase 3 (Senthold Asseng, Frank Ewert, Pierre Martre, et al.)

AgMIP is planning to construct similar networks for maize, rice, soybean, potato, sugarcane
AgMIP’s Overlapping Activities

% Major Crop Area

- Wheat1
- Wheat2
- Wheat3
- Maize1
- Maize2
- Rice1
- Rice2
- Rice2
- Potato
- Canola
- Livestock
- R1A
- C3MP
- IRS1

0 5 10 15 20 25 30 35 40 45 50
The AgMIP Global Gridded Crop Model Intercomparison (GGCMI)
Agricultural Impact Projections and Uncertainty Estimates

Modeled Changes in RCP8.5 Corn Yield (2080s – present)

Note that all land areas with agricultural outputs were modeled – not all are economically viable

5 GCMs, 7 GGCMs; hatched = 70% agreement in sign of change

Many sources of overlapping biases and uncertainties
Markets Adapt to Changing Conditions by Shifting Production Areas and Prices

Future with climate change vs. Future without climate change

9 Global Economic Models simulated by AgMIP; Nelson et al., 2014
The AgMIP Global Gridded Crop Modeling Initiative (GGCMI) has developed protocols for full-world CO₂-temperature-water-nitrogen-adaptation sensitivity tests across multiple crops and crop models – designed for emulator and response function creation (connections to ACME, GCAM, etc.)

\[
[\text{CO}_2] = 360, 510, 660, 810 \text{ ppm}
\]

\[
\Delta T = -1 \ +0 \ +1 \ +2 \ +3 \ +4 \ +6 \ ^\circ C
\]

\[
\Delta W = -50\% \ -30\% \ -10\% \ +0\% \ +10\% \ +30\% \ +50\%
\]

\[
N = 10, 60, 200 \text{ kg N/ha}
\]

\[
A = \text{Fixed cultivars,}
\]

Cultivars selected to restore growing season length
The AgMIP Coordinated Climate-Crop Modeling Project

[CO₂] (330-900ppm) \[\Delta T\ (-1 - +8 ^\circ C)\]

No change in Precipitation

Mavromatis et al., in prep.
AgMIP is working with ESM groups around the world to improve the representation of agriculture within ESMs
- GISS, NCAR, LBNL, ACME, Hadley Centre, IPSL

Also of note:
- recent JAMES review of crops in GCMs (McDermid et al., in review)
- “Lessons from climate modeling on the design and use of ensembles for crop modeling” (Wallach et al., 2016)

Collaborating with IAM community (beginning with PNNL) to develop more applications-ready outputs for food security and nutrition
The Coordinated Global and Regional Assessments (CGRA) of Climate Impacts on Agriculture and Food Security
Building Blocks allow telescopic scales, feedbacks, and details.

Regional research on farming systems using biophysical and socioeconomic models.

Production systems and regional economics to respond to price changes.

High-resolution gridded crop modeling for gap-filling and aggregation in each region.

Coordinated Global and Regional Assessments.

Global economics with analysis of world and regional prices.
Recognizing Decision-maker’s Role in Agricultural Impacts

Representative Agricultural Pathways and Representative Dietary Pathways

Weather Shocks and Climate Change → Biophysical Changes and Responses → Actor-based Responses

Global Economic Changes and Responses → Regional Economic Changes and Responses → Global and Regional Decisions

Food And Nutrition Security Metrics Toolbox
Representative Dietary Pathways

From Hugo Valin, IIASA
AgMIP Crop, Livestock, and Stakeholder experts want to help develop exogenous technology trends and development/adaptation pathways for agricultural areas.
Agricultural Modeling Tools for the US
Crop Model-based estimates

- May be configured under a variety of management types
- Establish systematic and consistent approach around the world
- Utilize multi-model ensemble and data-centric approach

- High potential to assimilate in situ and remotely-sensed observational data
- Can integrate seasonal forecasts for probabilistic assessment
- Can be evaluated in hindcast or retrospective analysis mode
- Can be utilized for future assessments and explorations
We can use models to anticipate shocks

Right: 1980-2010 Correlations between National Agricultural Statistics Service (NASS) County-level production and that simulated by pDSSAT using AgCFSR climate data. (from Glotter et al., 2016)

- Real-time monitoring and long-term outlooks both benefit from establishing high-quality agricultural modeling frameworks
- Need to understand that crops and society both behave differently under extreme stress – **multi-breadbasket failures**
- Open access and iterative model development will accelerate applications
• Hindcast 1979-2011 with detailed parameterizations of technology

• Counterfactual of 1988 with 2012 weather and 2012 with 1988 weather, shows that 2012 drought was notably more severe.

• ~5 percent better/worse in 2012/1988 if they had 1988/2012 weather.

• Accuracy at state level comparable to USDA NASS forecasts.
Data assimilation for agricultural models

Fluorescence from OCO-2 & NDVI

Soil Moisture anomalies from SMAP/SMOS

GEOS-5 and MERRA-2 from GMAO

CHIRPS Precipitation anomalies

FLDAS soil water anomalies

IMERG Precipitation

High-resolution NDVI

Crop Monitoring – GEOGLAM or elsewhere

Thanks to John Bolten, Christa Peters-Lidard, Joanna Joiner, Sibiry Traore, GEOGLAM Crop Monitor, Joshua Elliott, George Huffman, GMAO
An understanding of drought’s impact on state economies needs a combination of modular impact sector models and integrated assessment models.

Team effort (including Ron Sands) at USGCRP Workshop on Multi-Model Frameworks (held at JGCRI, June, 2016)
Questions on AgMIP?
The Vulnerability, Impacts, Adaptation, and Climate Services (VIACS) Advisory Board for CMIP6

Co-Chairs: Alex Ruane\(^1,2\) and Claas Teichmann\(^3\)

and the VIACS Advisory Board

\(^1\)NASA Goddard Institute for Space Studies, New York City
\(^2\)Columbia University Center for Climate Systems Research
\(^3\)Climate Service Center, HZG, Hamburg

Building bridges between the Modeling and Applications communities

IGIM Presentation, January 18\(^{th}\), 2017
Designed to help form more coherent and productive link between the climate modeling community and users of CMIP6 outputs from the applications community.

- Facilitates two-way communication around science and application goals:
  - construction of model scenarios and simulations
  - informed use of model outputs
  - design of online diagnostics, metrics, and visualizations of relevance to society.
Vulnerability, Impacts, Adaptation

Charged with understanding how climate changes affect natural and human systems

- **VIA Sectors:**
  - Agriculture
  - Forestry
  - Energy
  - Water Resources and Hydrology
  - Oceans/Fisheries
  - Coastal
  - Biomes/Ecology
  - Urban
  - Health
  - Infrastructure/Transportation

- **Projects and Programs:**
  - TGICA, CORDEX, ICONICS
  - WCRP Working Group on Regional Climate
  - ISI-MIP, AgMIP, WaterMIP
  - Others...
Climate Services

Operationalizes climate and VIA information as user-oriented products and tools.

- **Climate Service Organizations:**
  - Public Agencies
  - Private Organizations
  - Academic Institutions

- **Projects and Programs:**
  - Climate Services Partnership
  - Global Framework for Climate Services
  - Others…
VIACS Community is Diverse and Largely Independent
Different regions, projects, sectors, scales, organization levels

CMIP6

VIACS Communities
VIACS Community is Diverse and Largely Independent

Interactions with CMIP6 diverse, difficult and inefficient
Mutual Benefit to Coordinated Interactions

CMIP6

VIACS Communities
VIACS Advisory Board – Allows for additional coordinated interaction between CMIP6 and VIACS Communities

CMIP6

Engagement by Project or Region

VIACS AB
Projects, Regions, Sectors, Communities

Engagement by Sector

VIACS Communities
VIACS Advisory Board

Climate Models
Science of Climate

Applications

VIACS Advisory Board

Vulnerability
Impacts
Adaptation
Science of System Behavior

Climate Services
Operationalization of Climate Information
<table>
<thead>
<tr>
<th>Name</th>
<th>Community</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alex Ruane (co-chair)</td>
<td>Agriculture/AgMIP</td>
<td>NASA Goddard Institute for Space Studies, USA</td>
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<td>Climate Services</td>
<td>Climate Service Center, Hamburg, Germany</td>
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<tr>
<td>Nigell Arnell</td>
<td>WaterMIP</td>
<td>University of Reading, UK</td>
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<tr>
<td>Tim Carter</td>
<td>TGICA</td>
<td>Finnish Environment Institute (SYKE), Finland</td>
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<tr>
<td>Kristie Ebi</td>
<td>ICONICS/Health</td>
<td>University of Washington, USA</td>
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<tr>
<td>Katja Frieler</td>
<td>ISI-MIP</td>
<td>Potsdam Institute for Climate Impacts Research, Germany</td>
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<tr>
<td>Clare Goodess</td>
<td>WGRC</td>
<td>University of East Anglia, UK</td>
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<tr>
<td>Bruce Hewitson</td>
<td>CORDEX</td>
<td>University of Cape Town, South Africa</td>
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<td>Radley Horton</td>
<td>Urban/Coastal</td>
<td>Columbia University, USA</td>
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<td>Sari Kovats</td>
<td>Health</td>
<td>London School of Hygiene and Tropical Medicine, UK</td>
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<td>Katharine Vincent</td>
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<td>Kulima Integrated Development Solutions, South Africa</td>
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Motivation, initial activities, and plans for VIACS Advisory Board
900+ CMIP5 Variables assessed for VIACS applications

- Necessary variables for most applications already exist
- Determined priorities – strong desire for more validation studies
- Identified complete sets needed to allow particular applications (e.g., ocean ecosystems requires many unique variable sets)
- Variables may now be downloaded from the CMIP6 Data Request according to community (e.g., several AgMIP packages)

<table>
<thead>
<tr>
<th>Variable Category</th>
<th>Time Resolution</th>
<th>Long Name</th>
<th>Units</th>
<th>AgMIP</th>
<th>CSP</th>
<th>Arctic</th>
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<tbody>
<tr>
<td>2(e) Monthly land biogeochemistry, soil and land cover data</td>
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VIACS Advisory Board Engagement with CMIP6 Variable Design

60+ new variables requested
- Requirement of different time periods or heights
- Need for low-frequency reports of high-frequency statistics (e.g., monthly output file showing number of days where precipitation exceeded a given heavy rain threshold)
- Interest in tile information, if simulated (e.g., agricultural tile of broader grid box)

<table>
<thead>
<tr>
<th>Time resolution</th>
<th>Name (plus description as needed)</th>
<th>Units</th>
<th>Additional notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monthly</td>
<td>Surface concentration of ozone</td>
<td>ppm</td>
<td>Also for use ecosystem and health sectors</td>
</tr>
<tr>
<td>Daily, monthly</td>
<td>Cropland tile maximum temperatures</td>
<td>K</td>
<td>Tile contains information from agricultural fraction of land in a given GCM grid box.</td>
</tr>
<tr>
<td>Daily, monthly</td>
<td>Cropland tile minimum temperatures</td>
<td>K</td>
<td></td>
</tr>
<tr>
<td>Daily, monthly</td>
<td>Cropland tile precipitation</td>
<td>kg m(^{-2}) s(^{-1})</td>
<td></td>
</tr>
<tr>
<td>Daily, monthly</td>
<td>Cropland tile minimum relative humidity</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>Daily, monthly</td>
<td>Cropland tile wind speed</td>
<td>m s(^{-1})</td>
<td></td>
</tr>
<tr>
<td>Monthly</td>
<td>Number of precipitation days where accumulation was above 1 kg m(^{-2})</td>
<td>No.</td>
<td>These two variables combine to describe the intensity of rainfall when it does occur.</td>
</tr>
<tr>
<td>Monthly</td>
<td>Average precipitation accumulation on days where accumulation was above 1 kg m(^{-2})</td>
<td>kg m(^{-2})</td>
<td></td>
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</tbody>
</table>

Photo: constructionweekonline.com
VIACS Advisory Board Engagement with CMIP6 MIP Application

188 MIP Experiments assessed for VIACS applications

- Determined priorities
- Identified specific experiments within MIPs that VIACS community is interesting in exploring for broader implications

- Historical and ScenarioMIP experiments most widely sought, followed by Decadal Climate Prediction Project (DCPP)
- Nearly all MIPs had at least one experiment that generated VIACS interest
The Vulnerability, Impacts, Adaptation, and Climate Services (VIACS) Advisory Board of CMIP6 is designed to enhance communication between the climate modeling and climate applications communities.

- Helps ensure that earth system models produce outputs that are of interest to climate application community
- Eager to engage coupled modelers and VIACS experts for more robust and societally-relevant climate applications
- Currently working on VIACS-relevant metrics for ESM evaluation (e.g., precipitation distributions, 100 meter winds, and 2D surface fields)
- Proposed Obs4VIACS to provide observations for more robust and standardized calibration and validation of impacts models and applications
Thanks!

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