The Agricultural
Model Intercomparison
and Improvement Project

Protocols for AgMIP Regional Integrated Assessments

VERSION 7.0

AgMIP gratefully acknowledges the UK Department for International Development's UKaid for major project funding, and the US Department of Agriculture for its sustained support. AgMIP additionally thanks the CGIAR Research Program on Climate Change, Agriculture and Food Security and the United States Agency for International Development (USAID) for project support.

AgMIP additionally acknowledges support from The International Life Sciences Institute/The Center for Integrated Modeling of Sustainable Agriculture & Nutrition Security, Monsanto, University of Florida, The National Oceanic and Atmospheric Administration, iPlant, Bill and Melinda Gates Foundation, Columbia University/Earth Institute, and The National Aeronautics and Space Administration.

AgMIP extends a special thank-you to Columbia University and The Earth Institute for hosting AgMIP Coordination at its Center for Climate System Research. AgMIP appreciates significant in-kind contributions from many organizations and institutions (see also inside back cover).

Suggested Citation:

Rosenzweig, C., J.M. Antle, A.C. Ruane, J.W. Jones, J. Hatfield, K.J. Boote, P. Thorburn, R.O. Valdivia, K. Descheemaeker, C.H. Porter, S. Janssen, W.-L. Bartels, A. Sulivan, and C.Z. Mutter. (2016). *Protocols for AgMIP Regional Integrated Assessments Version 7.0.*

AgMIP extends a special thank-you to Columbia University and The Earth Institute for hosting AgMIP Coordination at its Center for Climate System Research. AgMIP appreciates significant in-kind contributions from:

Agricultural Research Council, South Africa
Alliance for a Green Revolution in Africa, Burkina Faso
Chinese Academy of Agricultural Sciences, China
Columbia University, USA
Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia
Consultative Group on International Agricultural Research (CGIAR), France
Dartmouth College, USA
Department of Agriculture, Fisheries and Forestry, Australia
Democritus University of Thrace, Greece
Empresa Brasileira de Pesquisa Agropecuária, Brazil
Food and Agriculture Organization of the United Nations, Italy
Foundation for Environment, Climate, and Technology, Sri Lanka
Imperial College London, UK
Institut National de la Recherche Agronomique, France
Institute of Crop Science and Resource Conservation, Germany
International Center for Tropical Agriculture, Kenya
International Crops Research Institute for the Semi-Arid Tropics, India
International Fertilizer Development Center, USA
International Food Policy Research Institute, USA
International Livestock Research Institute, Kenya
International Maize and Wheat Improvement Center, Mexico
International Potato Center, Peru
International Research Institute for Climate and Society, USA
International Rice Research Institute, the Philippines
International Water Management Institute, Sri Lanka
Joint Research Center European Commission, Belgium
Macaulay Land Use Research Institute, UK
Massachusetts Institute of Technology, USA
Modelling European Agriculture with Climate Change for Food Security (MACSUR), Germany
Michigan State University, USA
MTT Agrifood Research, Finland
NASA-Goddard Institute for Space Studies, USA
National Center for Atmospheric Research, USA
National Engineering and Technology Center for Information Agriculture and Nanjing Agriculture University, China
National Institute for Agro-Environmental Sciences, Japan
National Institute for Environmental Studies, Japan
Oregon State University, USA
Organisation for Economic Co-operation and Development, USA
Pacific Northwest National Laboratory, USA
Potsdam Institute for Climate Impact Research, Germany
Project Directorate for Farming Systems Research, India
South African Sugarcane Research Institute, South Africa
Tamil Nadu Agricultural University, India
United States Department of Agriculture, USA
Universidad Politécnica de Madrid, Spain
University of Agriculture, Faisalabad, Pakistan
University of Chicago, USA
University of Florida, USA
University of Ghana, Ghana
University of Illinois at Urbana-Champaign, USA
Universidade de Passo Fundo, Brazil
University of Wisconsin-Madision, USA
University of Nebraska, USA
Wageningen University and Alterra Centre for Geo-Information, the Netherlands
Washington State University, USA
World Meteorological Organization, Switzerland

Protocols for AgMIP Regional Integrated Assessments

Version 7.0

AgMIP International Leaders
Cynthia Rosenzweig[1,2], Jim Jones[3], John Antle[4], and Jerry Hatfield[5]

AgMIP Team Leaders
Climate: **Alex Ruane[1,2] and Sonali McDermid[6,1]**
Crops: **Ken Boote[3], Peter Thorburn[7], John Dimes[7], and Gerrit Hoogenboom[3]**
Livestock**: Katrien Descheemaeker[8]**
Regional Economics: **John Antle[4] and Roberto Valdivia[4]**
Information Technologies: **Cheryl Porter[3] and Sander Janssen[8,9]**
Stakeholders: **Wendy-Lin Bartels[3] and Amy Sullivan[10]**
Communications: **Shari Lifson[2]**

AgMIP Science Coordinator**: Alex Ruane[1,2]** (science@agmip.org)
AgMIP International Coordinator**: Carolyn Mutter[2]** (info@agmip.org)

AgMIP Regional Research Team Principal Investigators
South Asia: **Nataraja Subash[11], Ashfaq Ahmad Chatta[12], Vellingiri Geetalakshmi[13]**
Sub-Saharan Africa: **Dilys McCarthy[14], Lieven Claessens[15], Sabine Homann[16], Wiltrud Durand[17], Olivier Crespo[18]**

AgMIP Resource People
Guillermo Baigorria[19] Gerrit Hoogenboom[3], Sonali McDermid[6,1], Myriam Adam[20], Caleb Dickson[4], Katrien Descheemaeker[8], Davide Cammarano[21]

[1]NASA Goddard Institute for Space Studies, New York, USA
[2]Columbia University Center for Climate Systems Research, New York, USA
[3]University of Florida, Gainesville, USA
[4]Oregon State University, Corvallis, USA
[5]US Department of Agriculture, Agricultural Research Service, Ames, USA
[6]New York University, New York, USA
[7]Commonwealth Scientific and Industrial Research Organisation, Brisbane, Australia
[8]Wageningen University, Wageningen, the Netherlands
[9]Alterra Centre for Geo-Information, Wageningen, the Netherlands
[10]Bridgewater Consulting, Pretoria, South Africa
[11]Indian Council for Agricultural Research and Indian Institute of Farming Systems Research, Modipuram, India
[12]University of Agriculture, Faisalabad, Pakistan
[13]Tamil Nadu Agricultural University, India
[14]University of Ghana, Accra, Ghana
[15]International Crops Research Institute for the Semi-Arid Tropics, Nairobi, Kenya
[16]International Crops Research Institute for the Semi-Arid Tropics, Bulawayo, Zimbabwe
[17]Agricultural Research Council, Cape Town, South Africa
[19]University of Nebraska, Lincoln, USA
[20]French Agricultural Research Centre for International Development (CIRAD), Mali
[21]James Hutton Institute, Scotland

February 18th, 2018

Protocols for AgMIP Regional Integrated Assessments[1]

Table of Contents

i. Introduction 3
ii. Key Attributes of an AgMIP Regional Integrated Assessment 4
iii. Stakeholder Engagement 4
iv. Core Climate Impact Questions 5
v. Key Regional Research Team Outputs 7
vi. AgMIP Standardized Formats and Tools 8
vii. Guidelines for Activities for AgMIP Regional Research Teams 11

Task Protocols for AgMIP Regional Integrated Assessments
1. Scoping of production systems and developing/refining research work plan for regional integrated assessment 15
2. Develop Representative Agricultural Pathways (RAPs) for use in regional analysis of climate impact and adaptation 18
3. Develop system adaptations for use in regional analysis of climate impact and adaptation 22
4. Assemble existing data from sentinel sites and calibrate crop models for regionally-relevant cultivars and soils 24
5. Assemble existing data and calibrate livestock models for regionally-relevant livestock breeds 25
6. Assemble and quality-control current climate series 26
7. Assemble survey data and simulate using crop models for analysis of yield variations for current climate and current production system (CM0) 29
8. Analyze Carbon-Temperature-Water-Nitrogen (CTWN) responses 32
9. Assemble data and simulate livestock models for analysis of livestock productivity at the household level 34
10. Assemble economic data for regional economic analysis and develop skills for using the regional economic model 35
11. Create downscaled climate scenarios 36
12. Conduct multiple crop/livestock model simulations 39
13. Analyze regional economic impacts of climate change without and with interventions and adaptations using the regional economic model 41
14. Archive data and analyze results for integrated assessments 42
15. Disseminate integrated assessment results 44
References 45

Appendix 1. End-to-End Connections and Priorities for Decision Support 47
Appendix 2. Calculating Statistics for Climate Impact Assessments Using Crop/Livestock Model Simulations with the TOA-MD Model 48
Appendix 3. User's Guide to Crop Model Simulations for Integrated Assessments 59
Appendix 4. Fast-Track Activities to Demonstrate Integrated Framework 72
Appendix 5. Guidelines for Engaging Stakeholders in Integrated Modeling Efforts 74

[1] Note that previous versions of this document were entitled: "Guide for Regional Integrated Assessments: Handbook of Methods and Procedures"
Cover photos by Shari Lifson and Alex Ruane

i. Introduction

The purpose of this handbook is to describe recommended protocols for a trans-disciplinary, systems-based approach for regional-scale (local to national scale) integrated assessment of agricultural systems under current and future climate, bio-physical and socio-economic conditions, and potential interventions and adaptations. These assessments are designed to evaluate climate impact, adaptation and vulnerability of farming systems and farm households in support of stakeholder decision processes. The methods presented here are designed to represent the population of farm households operating in a recognized farming system in a geographic region, typically comprising one or more agro-ecological zones within a country, with larger-scale assessments possible given data availability.

Readers who wish to learn about the overall process should read through the main sections, and others may want to go directly to the numbered sections below that provide a step-by-step description of the procedures. This handbook is written to guide a consistent set of integrated assessments that can be applied to any region globally. A list of the key characteristics of an AgMIP regional integrated assessment (RIA) is provided in the next section. These protocols were created to guide stakeholder-oriented climate, crop and livestock modeling, economic modeling of farming systems, and information technology components of its projects, and are the regional manifestation of approaches first outlined by Rosenzweig et al. (2013).

Various research teams have conducted regional assessments following AgMIP protocols and integrated assessment procedures, either independently or as part of AgMIP's Coordinated Global and Regional Assessments (Rosenzweig et al., 2016; http://www.agmip.org/research/research-pillars/cgra/). This Handbook is a living document that is periodically updated based on what has been learned from the use and evaluation of the methods in prior versions. However, it is important to recognize that the procedures for regional integrated assessments presented here were designed for the data available to the AgMIP regional teams in Sub-Saharan Africa and South Asia, for implementation of two crop models per integrated assessment region (at least DSSAT and APSIM), and for use of one socio-economic model (TOA-MD) in the integrated impact assessments. We recommend the use of multiple crop, livestock, and economic models when feasible, based in large part on lessons learned in the various crop model intercomparisons (e.g., Rosenzweig et al., 2013; Asseng et al. 2013, 2015; Martre et al., 2014; Bassu et al., 2014; Li et al., 2015; Fleisher et al., 2017), global gridded crop model intercomparisons (Rosenzweig et al., 2014; Elliott et al., 2015; Müller et al., 2017), and global economic model intercomparisons (Nelson et al., 2014; von Lampe et al., 2014; Wiebe et al., 2015). We envision that specific choices of multiple models may vary among regions, but that a core set of models should be used such that results can be aggregated and compared across regions. This version of the protocols reflects the approaches taken in Phase 2 of the AgMIP SSA and SA regional integrated assessments supported by the UK Department for International Development (DFID), and thus differ slightly from the protocols used for Phase 1 assessments (Rosenzweig and Hillel, 2015).

Regional integrated assessments using the AgMIP RIA methods require close coordination among economic, climate, and crop modelers, IT team members, and stakeholder liaisons within each regional research team (RRT). Many teams are also integrating livestock modeling into their assessments and thus this version includes new information about the technical approach for livestock representation. Assessments begin with regional teams working with stakeholders to define what outcomes are to be evaluated and then developing details of the specific production systems that need to be quantified. Each RRT should focus on impacts related to, at minimum, food production, income, and poverty in their regions as influenced by changing climate, technologies, and socio-economic development; emphasizing important food crops and livestock systems and quantifying relevant uncertainties. Then a work plan should be developed by teams that will include AgMIP-recommended methods and procedures to accomplish integrated assessments and desired compatibility of outputs across regions.

This handbook was written such that it represents a minimum approach that can be expanded upon in regions where available data and resources allow. The methods and core approach used by all interdisciplinary research teams need to be consistent in order to enable meta-analyses and large-scale studies, such as the Coordinated Global and Regional Assessments (Rosenzweig et al., 2016). Particular care must therefore be taken in introducing new methods and models that could potentially limit the ability of results to be compared beyond the immediate region.

ii. Key Attributes of an AgMIP Regional Integrated Assessment

- Designed with input from stakeholders, policymakers, and/or other end-users
- Based upon production systems approach (rather than specific crops or fields) potentially including multiple crops, livestock, aquaculture, and other sources of income that may be linked with the farm household system in some economic models.
- Transdisciplinary in its linking of climate, biophysical, and socio-economic conditions and responses.
- Flexible in that its framework allows for the testing of adaptations and alternative models and methods within a given region.
- Addresses core questions of climate impact on current and future production systems (detailed in the next section)
- Allows evaluation of production system adaptations co-developed with regional stakeholders for application under current and future climate.
- Calibrated on current production systems using available data with documentation sufficient to enable replication of results.
- Examines the impact of both mean climate changes and potential interactions with climate variability
- Presents results in a probabilistic manner with accounting of major uncertainties.
- Utilizes consistent terminology across disciplines and among various AgMIP assessments and initiatives.
- Uploads results to an online AgMIP database using specified formats for archival, cross-regional analyses, and dissemination with full attribution of data providers and intellectual contributions.
- Publishes findings in peer-reviewed journals and disseminates information to stakeholders via direct engagement and a spectrum of media.

iii. Stakeholder Engagement

Stakeholder engagement in AgMIP aims at informing decision and policymaking to improve the conditions for farming and positive agricultural sector outcomes, enabling better farm management and agricultural policy under current conditions, and adaptation to future conditions. For this reason co-development and analyses of scenarios, interventions, and adaptation options across a spectrum of stakeholders (from farmers and researchers to agri-business and policy makers) is crucial. Enduring engagement with decision makers with different disciplinary backgrounds, decision domains, and affiliations is carried out by an interdisciplinary research team of experts in crops, livestock, economics, social science, and stakeholder engagement to facilitate comprehensive dialogue and iterative analyses about the future of farming systems. The *AgMIP Guidelines for Stakeholder Engagement* (described in tools section below) provides tips and approaches to build successful and sustained stakeholder relationships that further decision processes and scientific relevance.

While the end-goal of the AgMIP RIA is the dissemination of findings and messages to stakeholders, stakeholders play an important role throughout the assessment. Sustained engagement is vital to build trust in the approach, and stakeholder feedback also directly contributes to the RIA process by providing crucial inputs and prioritization for model simulations (**Figure 1**). In conducting the RIA tasks described below, teams should engage stakeholder for co-development and co-analysis to:

- Clarify key questions where analysis would aid decision making,
- Elucidate regional context, history, and development challenges,
- Build narratives of potential change,
- Prioritize elements of development, intervention, and adaptation for assessment,
- Provide feedback on the validity of assumptions in scenarios and model parameters,
- Classify strata that help interpret patterns in distributional outcomes across households,
- Refine key messages for dissemination and engagement with wider audiences.

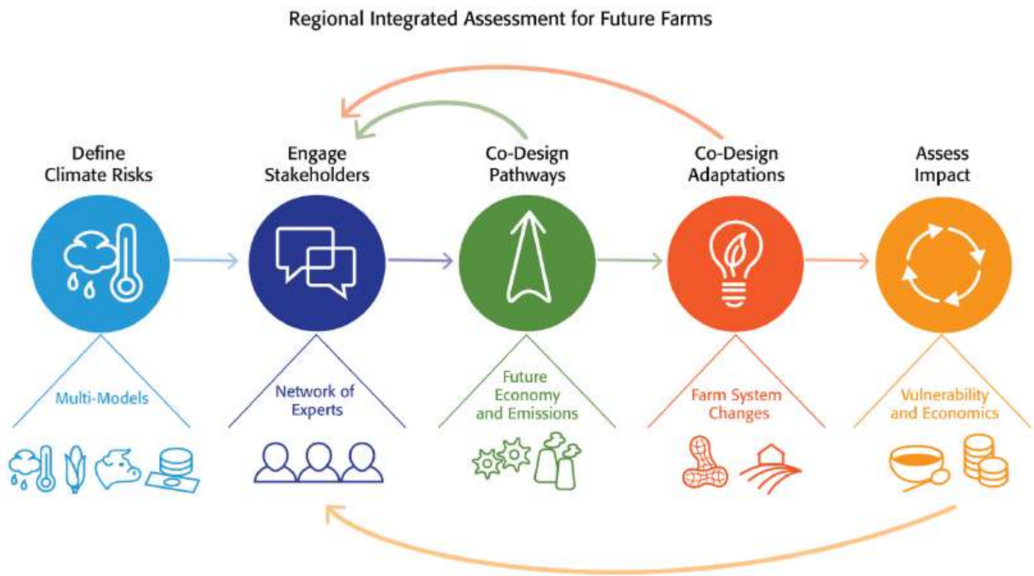


Figure 1. Overview of iterative approach whereby stakeholders co-design development pathways, interventions, and adaptations to improve outcomes and enhance resilience given current and projected climate risks. Co-analysis focuses on adaptations for future farms as well as interventions for current farming systems; all in support of stakeholder decision contexts.

iv. Core Climate Impact Questions

AgMIP has identified four core research questions[2] that motivate research activities for regional integrated assessments (**Figure 2**):

1) What is the sensitivity of current agricultural production systems to climate change? This question addresses the isolated vulnerability to climate change assuming that current production systems do not change.
2) What are the benefits of intervention in current agricultural systems? This question addresses the benefits (e.g., economic and food security resilience) of potential intervention options to current agricultural systems given current climate. Results may also form a basis for comparison when they correspond to climate adaptations tested in Core Question 4 below, as the proposed interventions may have a higher or reduced benefit when the climate changes.
3) What are the impacts of climate change on future agricultural production systems? This question evaluates climate vulnerability within the future production system, which will

[2] Note that previous versions of this handbook (prior to v6.0) and Antle et al., 2015, defined only three core questions. Core question #2, as presented here, was added, resulting in the renumbering of core question #3 (previously #2) and core question #4 (previously #3).

differ fro-m the current production system due to developments in the agricultural sector not directly motivated by climate changes.

4) What are the benefits of climate change adaptations? This question analyzes the benefit of potential adaptation options in the production system of the future, which may offset or capitalize on climate impacts identified in Core Question 3 above.

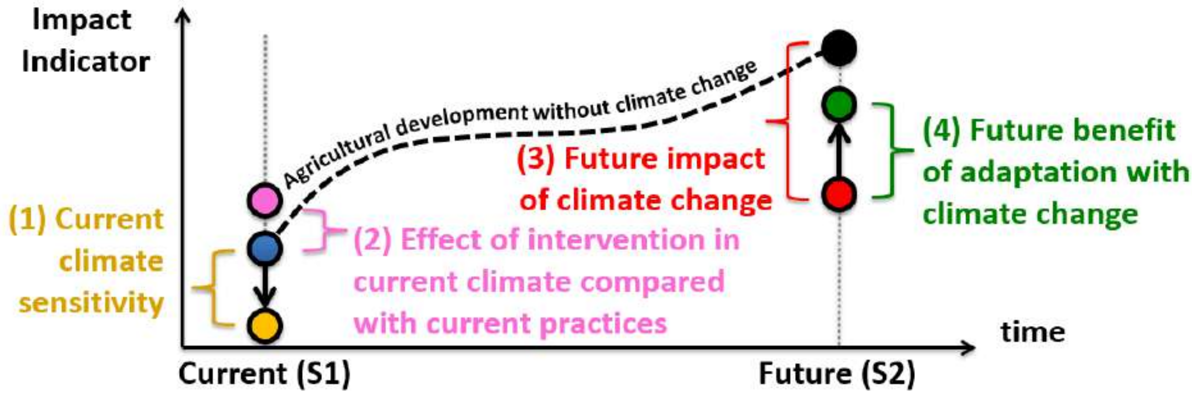


Figure 2. Overview of core climate impact questions and the production system states that will be simulated. Impact indicators may include crop and livestock yields, value of production, poverty, or net farm or household income. The current climate and production system is represented by the blue dot, while the future production of the system is represented in three ways: assuming that there is no climate change (black), assuming that there is climate change and no adaptation (red), and assuming that there is climate change and adaptation (green). The dashed line represents the evolution of the production system from its current state (S1) in response to development in the agricultural sector that is not directly motivated by climate change (arriving at S2). To understand the sensitivity of the current production system to anticipated changes, production in the current period is also estimated responding to an instantaneous climate change (orange) or using proposed adaptation strategies under present climate (pink). Six combinations of simulations, each represented by a colored dot (see Table 1), are needed to address the four core questions (see Table 2).

As each question is designed to allow a comparison between two different production system states, **Table 1** describes the key climate, crop, livestock, and economic modeling components that will describe and compare these states, and **Table 2** describes the comparisons corresponding to each core question.

Table 1. Overview of crop/livestock model simulations needed to represent the systems of interest for the four core questions, along with the climate, agricultural pathway, and adaptation that characterizes each simulation. Note that the agricultural system (colored dot) for each simulation corresponds to the diagram of core questions in Figure 2, and for this table the future period is recommended to be the Mid-Century (2040-2069). Note: Additional climate scenarios and crop/livestock configurations may be needed for each RAP (Representative Agricultural Pathway).

System	Crop / Livestock Simulation	Driving Climate (# scenarios passed to Economic Model Analysis)	Crop/Livestock Management configuration	Major Climate Adaptation
(blue)	CM1	Current (1)	Current	None
(orange)	CM2	ΔClimate (5)	Current	None
(pink)	CM3	Current (1)	Current	Adaptation
(black)	CM4	Current (1)	Future (RAP)	None
(red)	CM5	ΔClimate (5)	Future (RAP)	None
(green)	CM6	ΔClimate (5)	Future (RAP)	Adaptation

Table 2. Overview of economic model simulations corresponding to the four core questions for AgMIP RIA. Each economic simulation set contrasts two systems (represented by colored dots as in Figure 2 and Table 1) to evaluate the economic impacts of potential changes in the agricultural system.

Core Question	Name	RAP	Climate Adaptation	Relative Change in Yield/Productivity from Agricultural Model Runs
#1	Climate Vulnerability in Current World	No	No	CM2/CM1
#2	Climate Adaptation in Current World	No	Yes	CM3/CM1
#3	Climate Vulnerability in Future World	Yes	No	CM5/CM4
#4	Climate Adaptation in Future World	Yes	Yes	CM6/CM5

v. Key Regional Team Outputs

A number of outputs are anticipated from the sum of RRT activities described in this Handbook. This list of anticipated activities is intended to be used for RRT planning, and thus specific outputs and methods are provided in the material that follows. In addition, there are several overarching outputs that should be targeted by each RRT. These overarching outputs are summarized below, along with questions that help motivate the construction of these outputs.

a. ***A network of sites where multiple crop and livestock models have been calibrated using locally representative management, soils, cultivars, animal breeds, and climate (including at economic survey locations) to simulate food production regions that are important for regional food security, with analysis of calibration uncertainties.*** Key questions include:
- Which important farm systems, crops, and agricultural sub-regions are to be targeted for simulating regional food security?
- What data are available for calibration of crop and livestock models and to estimate parameters for the economic model?
- How do crops respond to applied levels of fertilizer nitrogen?
- How do livestock respond to variability in the feed composition resulting from climate variability?
- What adaptation measures should be analyzed in the study?

b. ***A set of Representative Agricultural Pathways (RAPs) for each region for use in analyses of regional climate impacts and adaptation.*** Key questions include:
- What RAP narrative(s) best describe the future world that the analyst wants to characterize?
- What output variables from global economic models and analyses are key drivers of agricultural trends in the region (e.g., commodity prices, population growth and GDP growth from Shared Socio-economic Pathways, and global representative agricultural pathways)?
- What key regional variables are likely to be affected by the higher level drivers (policy, socioeconomic, and technology)?
- What quantitative trends in each of the variables (including fertilizer, improved cultivars and breeds, improved management, forage availability, farm size, etc.)

are needed to parameterize agricultural models (crop, livestock, and economic) for the regional integrated assessment of future production systems?

c. ***Characterization of historical agro-climate, sensitivity to climate shifts, and climate change scenarios downscaled for use at the regional scale.*** Key questions include:
- How is climate currently changing in the region?
- What are the most important climate factors that impact a given farm or region?
- Do climate models reasonably capture these climate factors?
- What types of climate changes are projected to impact the region in the future and how certain are these projections?
- What are the vulnerabilities of crops and livestock to current and future climate variability, and what are the sensitivities of the multiple crop models to climate changes in temperature, CO_2, and rainfall?
- Where are agro-climatic impacts likely to be most acute?

d. ***Assessment of economic impacts and vulnerability for a subset of agricultural regions under future climate change, adaptation and socio-economic scenarios.*** Key questions include:
- How will climate change affect the distribution of production, income, and poverty in the farming systems of a given region if adaptations do not occur?
- What are the projected adoption rates of climate-adapted systems? How will various adaptations affect the impacts of climate change? How will alternative future socio-economic scenarios affect the impacts of climate change?
- How do uncertainties in key economic parameters affect the projected climate change impacts?

e. ***Adaptation packages including agronomic, animal husbandry, economic, and policy adaptations that improve outcomes under current and future conditions.***
Key questions include:
- What farm-level management adaptations would be beneficial under current and future climate conditions?
- What changes to the production system would increase resilience under present climate variability and future climate challenges?
- What policy shifts or socio-economic trends would build farm resilience?
- How can these adaptations be represented consistently in crop, livestock, and economic models?

f. ***Documentation for communication to the scientific community and to stakeholders.*** This includes linkages into the AgMIP Impacts Explorer, web sites, databases, scientific publications, and reports that have been communicated to stakeholders.

vi. AgMIP Standardized Formats and Tools
To ensure consistency in the archival and translation of data and results from AgMIP integrated assessment regions, several resources, tools, and standardized data formats have been created that will be referenced in the activities below. These standardized formats also ensure compatibility with stand-alone and web-based tools that will facilitate the execution of research activities and the dissemination of integrated assessment results.

Stakeholder Tools
- **AgMIP Guide for Stakeholder Engagement** – Provides recommended approaches and tips for sustained stakeholder engagement by regional research teams for

agricultural assessments and applications in support of stakeholder decision processes. These guidelines form a basis with the understanding that RRTs will adapt and tailor to local stakeholder interests, motivations, decision contexts, and personalities.

Climate Tools

- **.AgMIP climate data format –** Standardized format for climate series at a single location, featuring daily climate data and variables needed for crop modeling. These are described in Ruane et al. (2015a).
- **Guide for Running AgMIP Climate Scenario Generation Tools with R –** This "AgMIP Climate Scenarios Guidebook" describes how to access the data and suite of scripts required to produce AgMIP climate scenarios using the AgMIP methodologies, using .AgMIP-formatted climate data for both inputs and outputs. This guide is available at http://www.agmip.org/wp-content/uploads/2013/10/Guide-for-Running-AgMIP-Climate-Scenario-Generation-with-R-v2.3.pdf, or as Hudson and Ruane (2015).
- **AgMIP Historical Bias Correction and Gap Filling Worksheet –** Fills in gaps in historical station observations using bias-corrected AgMERRA gridded climate data. Worksheet and Instructional Guide are available at: www.agmip.org/climate-team

Agroclimatic Sensitivity Tools

- **C3MP Protocols –** The Coordinated Climate-Crop Modeling Project (C3MP; Ruane et al., 2014; McDermid et al., 2015) has established a set of standardized sensitivity tests of crop and livestock models response to carbon dioxide, temperature, and water changes. These sensitivity tests have been conducted on 1100+ simulation sets within C3MP, allowing local responses to be compared against a broad array of sites, agro-ecological zones, and crop models. Protocols may be downloaded at www.agmip.org/c3mp-downloads.
- **CTWN Batch DOME file –** This generates multi-model simulation files for evaluating response to changes in [CO_2], temperature, rainfall, and N fertilization levels. The CTWN Batch DOME uses QuadUI with a given single survey farm setup, the field overlay, and a seasonal strategy file to allow simulation using 30-year current climate data. The results from 32 simulations (each at 30 years of weather) are visualized with the AgView Tool which matches up the results from the two crop models, thus allowing a good visualization of response curves with box-and-whiskers showing how the crop models differ in response to these four factors.

Crop and Livestock Tools

- **AgMIP Crop Experiment (ACE) harmonized data format** provides an efficient storage and transfer protocol for site-based crop experiment (e.g., calibration data) and farm survey data. Crop modeling data can be translated from raw formats to ACE and from ACE to crop model-ready formats using the QuadUI desktop utility. These data are archived in ACE format on the online Crop Site Database which can be accessed through the AgMIP Data Interchange (https://data.agmip.org).
- **Data Overlay for Multi-model Export (DOME)** refers to field overlays and seasonal strategies. Field overlay DOMEs contain information related to field conditions which were not recorded at the survey sites, but are needed for crop modeling exercises (e.g., plant population, initial soil water content). These data are estimated based on the best agronomic knowledge of cultural practices and environmental conditions in the region. Seasonal Strategy DOMEs contain baseline and future management and climate inputs which are used to modify existing site data for analysis of hypothetical scenarios. Each DOME dataset will be linked to one or more survey sites. These data are archived in the DOME online database through the AgMIP Data Interchange (https://data.agmip.org).
- **AgMIP Crop Model Output (ACMO)** data are the harmonized outputs from AgMIP ensemble crop model simulations. ACMO data are linked to both ACE and DOME data. These data are archived in the ACMO online database through the AgMIP Data Interchange (https://data.agmip.org).
- **User's Guide to Crop Model Simulations for Regional Integrated Assessments** – contains complete guidelines and crop modeling advice relative to entering experimental and farm survey yield data into the ACE template, use of DOME files to input standard

assumptions, creation of model-ready files, running of the multiple crop models, and storage of output into ACMO files (http://research.agmip.org/display/cropmodelingwiki/User%27s+Guide+for+Crop+Model+Simulations+for+Integrated+Assessments)

- **User's Guide to Livestock Model Simulations for Regional Integrated Assessments** – contains guidelines and advice related to creating livestock model input files, running the livestock model LivSim, and consulting and exporting model output for further analysis.

Economics Tools

- **Economic model input and output archives** – This repository will store input and output data for the economic models. Each file will be associated with one or more ACMO datasets via the metadata. Data are accessible through the AgMIP Data Interchange (https://data.agmip.org).
- **TOA-MD Model Software and Apps** – many AgMIP RRTs in Africa and South Asia, and in other regions, are using the TOA-MD model to implement RIAs. Information about the TOA-MD model and the model software are available at http://tradeoffs.oregonstate.edu. Three application tools were developed to be used with TOA-MD to develop Representative Agricultural Pathways and climate adaptations, and to estimate TOA-MD model parameters.
    - **DevRAP** – Provides a structure to guide the process to develop Representative Agricultural Pathways (RAPs), to record and document the information systematically, and to translate RAPs into model-specific scenarios. The DevRAP v1.0 provides a structured format for the parameters needed to run the TOA-MD model as well as crop models.
    - **DevAdapt** – An Excel worksheet that provides a structure to guide the development of adaptation packages.
    - **TOA-Parm** – An Excel worksheet that is used to using outputs of crop and livestock models, price and productivity data from global integrated assessment models, and farm survey data, to estimate TOA-MD model parameters.

IT Tools

- **AgMIP ftp site** – An ftp site has been established to archive data for review or processing prior to upload to the AgMIP Data Interchange databases. This ftp site can be accessed at ftp://data.agmip.org using the usernames and passwords assigned to each team.
- **Data Journal** – will be used to publish and permanently archive datasets which are complete and form the basis of journal articles, web visualizations, or other references. These published datasets will be assigned a DOI and can be cited with credit given to data authors, as in any other published work (http://library.wur.nl/ojs/index.php/odjar/).
- **FACE-IT** – An online workflow system which allows the intensive computations required for the RIA system to be performed using chains of applications, deployed on a cloud-server. This system, FACE-IT (Framework to Advance Climate, Economic and Impact Investigations with Information Technology) provides an alternative to using the AgMIP desktop utilities for data translation and allows simulations using DSSAT and APSIM for complex workflows, including multiple climate scenarios, sensitivity analyses, and adaptation scenarios. Procedures for using this system are not covered herein, but interested users are encouraged to learn more at www.learnfaceit.org.
- **The AgMIP Impacts Explorer** – Web-based tool designed to present AgMIP findings to a variety of stakeholders. Visitors are able to explore a spatial dashboard containing results from AgMIP regional integrated assessments all over the world, pages containing main findings and key messages, and a data exploration tool that allows analysis of additional detail and illustrative comparisons within the results archive. The Impacts Explorer is built upon routines that draw harmonized AgMIP outputs, metadata, and analysis from an AgMIP Data Interchange.
- **AgMIP Research Site** – This site contains information of interest to AgMIP researchers including wikis, discussion forums and document sharing. The site was set up for the

research teams to contain technical documentation regarding AgMIP research methods (http://research.agmip.org/display/research/Welcome+to+AgMIP+Research).

- **AgMIP Toolshed** – Clearing house for AgMIP data, climate, and analysis tools. http://tools.agmip.org/

vii. Guidelines for Activities for AgMIP Regional Research Teams

A list of characteristic activities for AgMIP Regional Projects includes 14 categories of activities along with methods that integrate across climate, crop modeling, livestock modeling, economics, and IT teams. These are listed in **Table 3** and presented in the sections below. **Figure 3** shows a schematic of the overall components of the integrated assessment process and their relationship to global scenarios. Because of the importance of close collaboration among different disciplines (climate, crop, economic, livestock, information technologies, stakeholders), regional teams may want to define a subset of the overall analysis to make sure that all team members learn how to best interact with other team members to achieve the overall results. **Figure 4** therefore presents research tasks as organized by discipline, highlighting information flows. Here, we present the overall activities needed to perform the entire integrated assessment. Full documentation of steps and procedures are provided in the sections below, with additional detail provided in the Appendices. In particular, **Appendix 1** presents a useful perspective on the RIA approach's emphasis on orientating research around supporting stakeholder decisions through a combination of input/output flows and foundational analyses that build context and credibility.

Table 3. Overview of tasks necessary to complete and disseminate regional integrated assessment. The section describing protocols for each task is also identified, as well as the disciplinary team primarily responsible for execution of each task (also marked by color). Sections are organized in approximate work flow order, however work may begin on many tasks without waiting for previous tasks to be completed.

Section	Task	Team Responsible
1	Scoping of production systems and developing/refining research work plan for stakeholder-oriented regional integrated assessment	All, led by PI and Stakeholder Liaison
2	Develop Representative Agricultural Pathways (RAPs) for use in regional analysis of climate impact and adaptation	All, led by Economic Team and facilitated by Stakeholder Liaison
3	Develop system adaptations for use in regional analysis of climate impact and adaptation.	Crop, Livestock, and Economic Teams; led by PI and facilitated by stakeholder Liaison
4	Assemble existing data from experiments and calibrate crop models for regionally-relevant cultivars	Crop Modeling Team
5	Assemble existing data and calibrate livestock models for regionally-relevant livestock breeds	Livestock Modeling Team
6	Assemble and quality-control current climate series	Climate Scenarios Team
7	Assemble survey data and simulate using crop models for analysis of yield variations for current climate and current production system (CM0)	Crop Modeling Team
8	Analyze Carbon-Temperature-Water-Nitrogen (CTWN) responses	Crop/Livestock Modeling and Climate Scenarios Teams
9	Assemble farm-survey livestock data and compare with livestock model outputs for analysis of livestock productivity variations	Livestock Modeling Team
10	Assemble economic data for regional economic analysis and develop skills for using the regional economic model	Economic Team
11	Create downscaled climate scenarios	Climate Scenarios Team
12	Conduct multiple crop/livestock model simulations	Crop and Livestock Modeling Teams
13	Analyze regional economic impacts of climate change without and with interventions and adaptation using the regional economic model	Economic Team
14	Archive data and analyses results for integrated assessments	All, led by Information Technology Team
15	Disseminate integrated assessment results	All, led by PI with Stakeholder Liaison

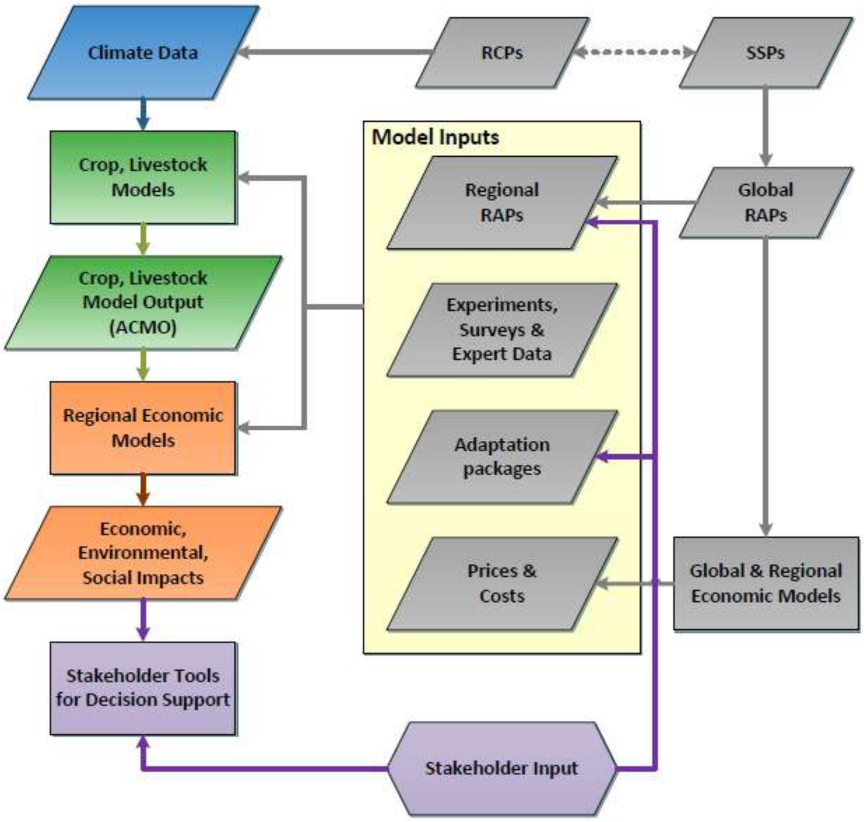


Figure 3. AgMIP Regional IA Framework: Parallel development of system design, data and modeling to couple crop & livestock models with TOA-MD, including input from and outputs to stakeholders.

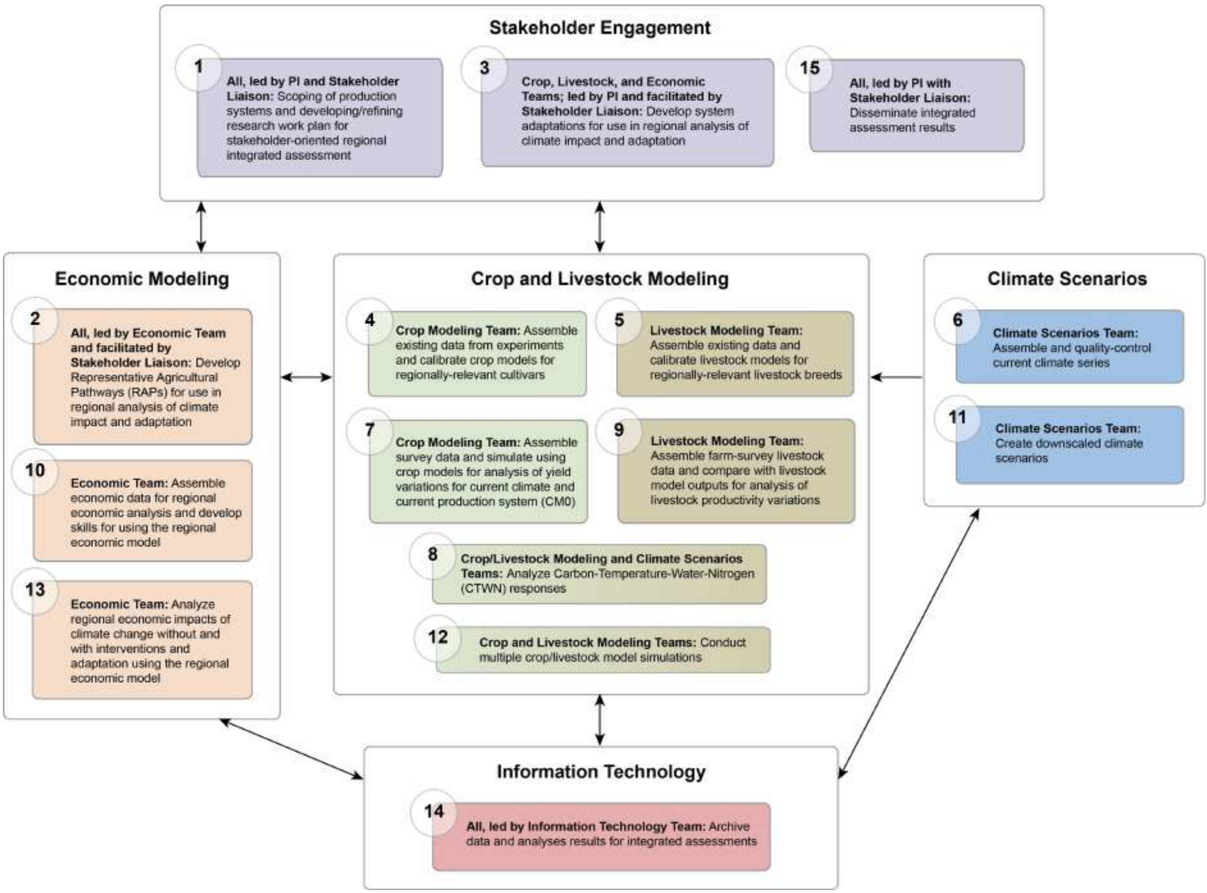


Figure 4. Overview of RIA tasks (as also summarized in Table 3), organized by discipline and information flow to show relationship between teams and the overall plan for multi-team activities orchestrated by project leadership.

Task Protocols for AgMIP Regional Integrated Assessments

1. Scoping of production systems and developing/refining research work plan for stakeholder-oriented regional integrated assessment.
The overall outputs from this set of activities is a report describing the region, crops and livestock system components selected for explicit modeling, characteristics of the broader agricultural systems, the availability of data (climate, crop, soil, livestock, and socio-economic), the questions driving stakeholder decision-making, and their most pressing needs for agricultural information. Suggested components of this phase of the projects are as follows.

a. **Review key project objectives, develop or refine research questions**, determine relevant stakeholders and policymakers, and assign team roles.

b. **Engage Stakeholders** to determine their perspective of the current context of agricultural development, investment, challenges, policy development, opportunities, and pressing needs. Stakeholders play a key and recurring role in AgMIP regional integrated assessments, helping to co-develop and co-analyze representative agricultural pathways and adaptation packages and their effects on rural households and agricultural systems. Stakeholder engagement is enriched by the inclusion of stakeholders from a range of spatial scales (local, district, national, regional, and international) and those occupying a variety of leverage points in the agricultural sector (farm, inputs, markets, trade, policy, development, relief).

c. **Define key production systems** to be studied in consultation with stakeholders, identify how they influence food security in the region, and identify current questions and ongoing considerations for long-term planning and investment. Select crops and livestock that will be explicitly modeled in the study, other important components of the production system that must also be represented (e.g., rangelands for livestock grazing), and important sub regions that will be modeled in the study (**Figure 5**).

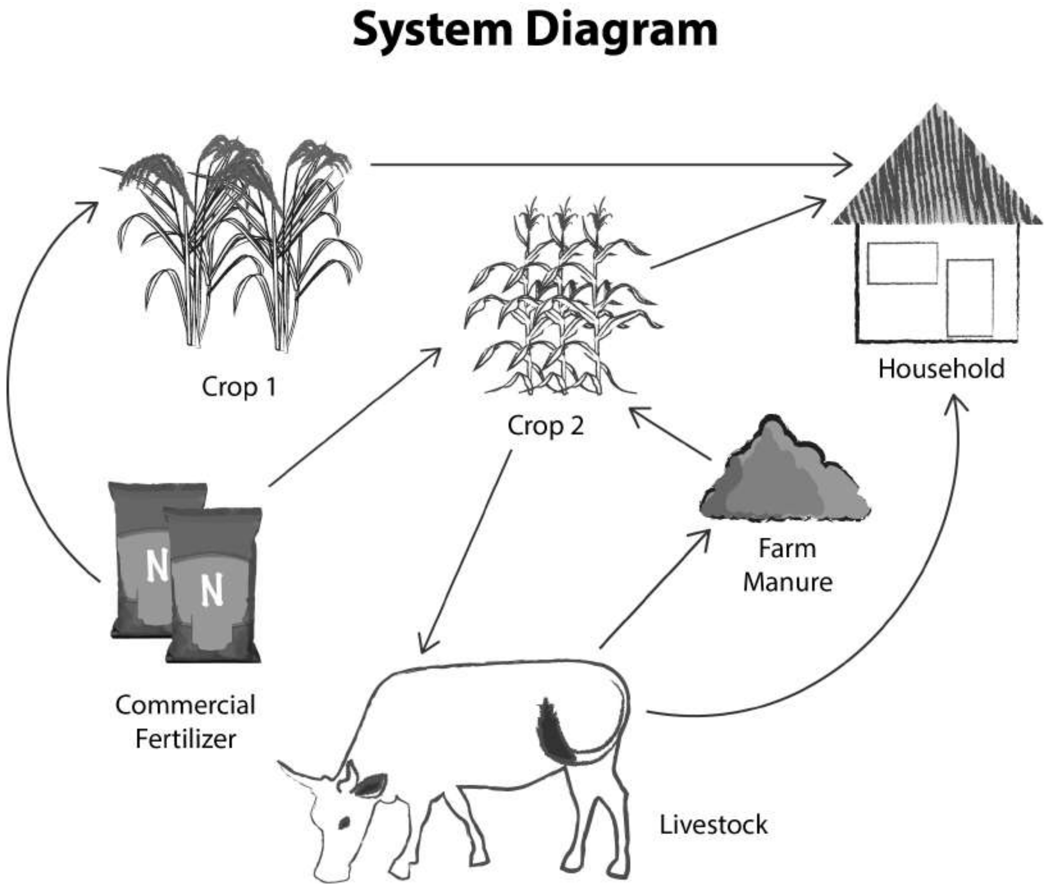


Figure 5. Example diagram describing the major elements and interactions of a production system. Additional factors may include household labor, off-farm income, and market linkages.

d. **Select (multiple) crop models that will be used**, keeping in mind that the aim is to use at least the DSSAT and APSIM cropping system models across all regions. Assess the level of experience among team members with the selected models and identify additional capacity building needs.

e. **Select (multiple) livestock models that will be used,** with the aim to use at least LivSim across the regions. Potentially a rangeland production model could be included as well (e.g. SAVANNA). Assess the level of experience among team members with the selected models and identify additional capacity building needs.

f. **Build capacity in the team of economists to use the Tradeoff Analysis Model for Multi-Dimensional Impact Assessment Model (TOA-MD)**, the economic model that has been used in prior regional efforts, or equivalent regional economic model(s). Identify project team members who will work with the regional economic model. Evaluate regional economic model capacity-building needs and team members in the RRTs who would participate in trainings.

g. **Produce a work plan that includes responsible persons, activities, time lines, and maps** of regions showing administrative boundaries, regions that will be studied, and points showing where climate and crop data are available. The report will include specifics of the information obtained in the above points, including the plan for stakeholder engagement.

h. Decide on relevant metadata which will describe the various analyses. These metadata must be consistent throughout the simulation workflow, from climate to crop and livestock modeling to economic modeling. The metadata that define a particular simulation include the following:

- REG_ID – region identifier (required for all Crop and Economic analyses)
- CLIM_ID – climate identifier (using codes described in Ruane and Hudson, 2016, required for all Climate, Crop and Economic analysis
- RAP_ID – RAP identifier (required for Crop Simulations CM4-CM6 and Economic analyses Q3-Q4)
- MAN_ID – management (or adaptation) identifier (required for adaptation analyses, Crop Simulations CM3 and CM6, and Economic analyses Q2 and Q4).
- Crop_Model or Livestock_Model – short name for models used to generate analyses (e.g., DSSAT, APSIM, LIVSIM)
- Stratum – socioeconomic, geographic or other population category (optional)

2. Develop Representative Agricultural Pathways (RAPs) for use in regional analysis of climate impact and adaptation.

RAPs (Valdivia et al., 2015) provide an overall narrative description of a plausible future development pathway, and also contain key variables with qualitative storylines and quantitative trends, consistent with higher-level pathways (e.g. SSPs, global RAPs developed by the AgMIP Global Modeling Group), see **Box 1**, **Box 2**, and **Figure 5**. Prices, policy and productivity trends should be consistent with the higher-level RAPs or scenarios that are available (SSPs, global RAPs, CCAFS regional scenarios). RAPs are translated into one or more scenarios (parameterizations) for the TOA-MD model and crop and livestock models. These RAPs represent a set of technology and management changes that will occur over time independent of climate change. These scenarios, developed for specific RAPs, will typically include changes in the types of crops or livestock produced and the way they are managed (e.g., use of fertilizers and improved crop cultivars).

Procedures for RAPs development are based on a step-wise process as shown in **Box 1**, with input from all components (climate, crop, livestock, economic) of the AgMIP Regional Team. Outside experts may need to be consulted if there is an important area of expertise not represented within the team. Stakeholder feedback is incorporated into RAPs, as described below.

Box 1. Overview of Step-wise Process for RAPs Development

1. A multi-disciplinary team of scientists and other experts is established.
   - Team members need to have knowledge of the agricultural systems and regions to be covered
2. The team reviews general goals and define the time period for analysis and selected higher-level pathways (Shared Socio-economic Pathways, Global RAPs) to follow the nested approach (**Figure 6**)
3. Main drivers from higher level pathways are identified (and quantified if possible, e.g. outputs from global models)
4. Based on drivers and specific agricultural systems, a draft of a title and a short narrative of a RAP is constructed
5. Based on the draft narrative, the team identifies key parameters that will likely be affected by driving forces
6. The team draft storylines for each one of the parameters (see **Figure 7**)
7. The team checks for consistency within the RAP components and with higher level pathways and models' outputs
8. Based on consistency check, agreement and confidence levels among team participants, steps 4 -7 are repeated until an acceptable draft of consistent storylines and levels of agreement and confidence are achieved.
9. The team identifies parameters that will need additional revision (expert opinion, modeled data, etc.) or that will likely be subject to sensitivity analysis.
10. The team elaborates full RAP narrative
11. The RAP narrative is documented and distributed to other experts, scientists and key stakeholders for comments.
    - A workshop is organized to discuss the RAP narratives with key stakeholders and obtain their feedback.
12. The final RAPs are distributed to the modeling teams for parameters quantification (for crop and economic models) and scenario development

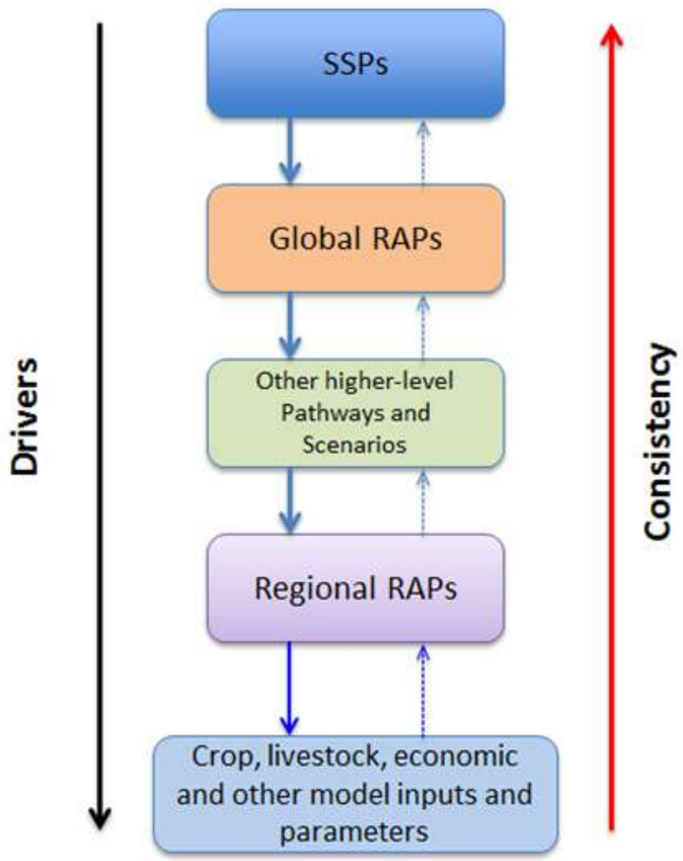


Figure 6. Developing RAPs and Scenarios: Use of a nested approach to assure consistency

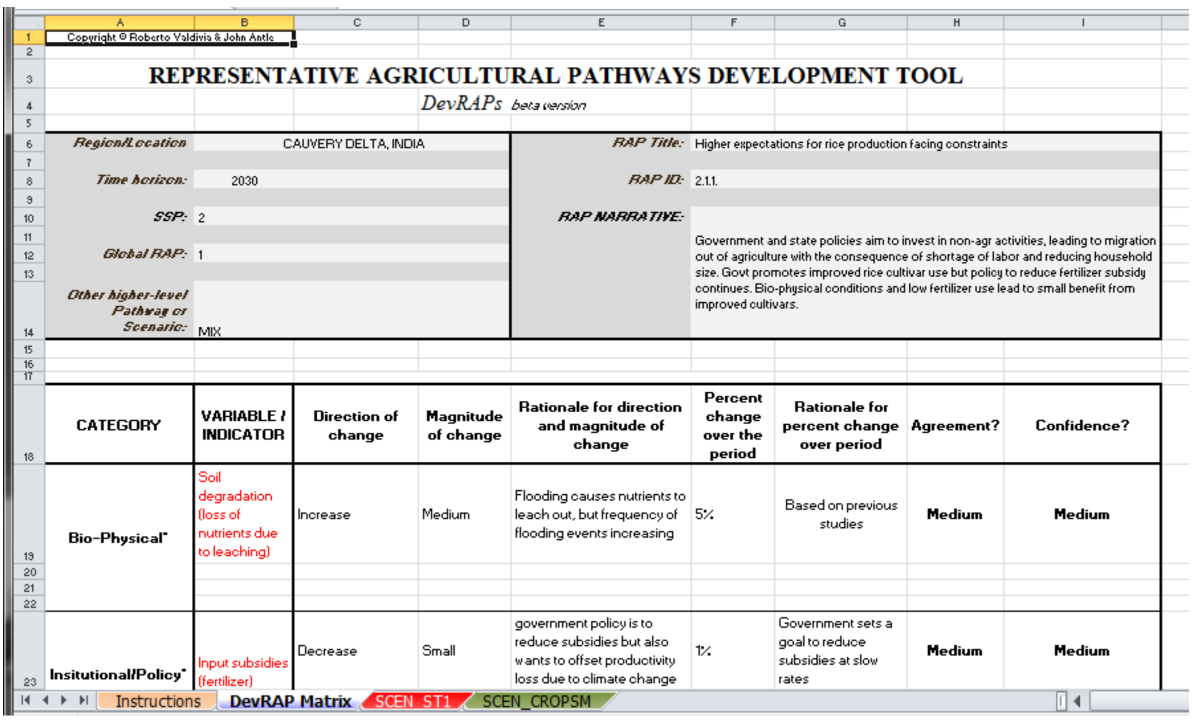


Figure 7. Screenshot of the DevRAP tool v1.0

a. **Building the RAP narratives and quantitative trends.** In this section we outline the steps to build RAPs narratives for AgMIP's regional teams. RRTs should use the DevRAP tool (See **Figure 6**) to develop and document RAPs (Valdivia and Antle 2015).

1) *Identify members of the RAPs development team.* Key members of the research team representing climate, crops & livestock, and economics. Outside members may be solicited if additional expertise is needed.
2) *Define time period for analysis*: AgMIP has designated four "time slices" analysis, current, near-term (2010-2039), mid-century (2040-2069) and end-of-Century (2070-2099). Primary focus is placed on the mid-century period.
3) *Select higher-level pathways:* Following the concept of a nested approach, relevant narratives and quantitative information from selected higher level pathways (e.g. SSPs, Global RAPs) need to be extracted. AgMIP regional teams are recommended to begin using SSP2 (see **Box 2** for a summary description).
4) *RAPs research process:*
    a. First meeting:
        - Start with a "Business as usual" (BAU) RAP
        - Team members identify key parameters that will likely be affected by higher level pathways and draft RAP narrative
        - Team members are assigned variables for research
        - Team members conduct research –use of templates for reporting and supporting documentation. These templates can be distributed to experts for feedback
    b. Second meeting:
        - Team members report findings and discuss storylines for each variable
        - BAU RAP is finalized using the DevRAP tool and complete the following information:
            - Complete information for each parameter:
            - Direction, magnitude & rate of change
            - Narrative logic for changes
            - Check for internal consistence and with higher-level pathways and models' variables
            - Level of agreement among participants
            - Level of confidence among participants
            - If level of agreement and/or confidence are low, repeat process until acceptable levels are achieved.
            - Assess whether one or more parameters need to be revised by other experts or selected for sensitivity analysis.
            - Document source of information (pathway, model, literature, expert).
        - *Additional RAPs are identified*
        - *Process similar to BAU is carried out with additional background research*
    c. *Meeting or workshop to present and distribute RAPs to stakeholders and outside experts to obtain their feedback.*
    d. *Meeting(s) to create additional RAPs –Follow similar steps as in a, b and c.*
5) *Modelers develop Scenarios* (see section below)

Box 2. Shared Socioeconomic Pathway #2 (SSP2) Summary: Middle of the Road

In this world, trends typical of recent decades continue, with some progress towards achieving development goals, reductions in resource and energy intensity at historic rates, and slowly decreasing fossil fuel dependency. Development of low-income countries proceeds unevenly, with some countries making relatively good progress while others are left behind. Most economies are politically stable with partially functioning and globally connected markets. A limited number of comparatively weak global institutions exist. Per-capita income levels grow at a medium pace on the global average, with slowly converging income levels between developing and industrialized countries. Intra-regional income distributions improve slightly with increasing national income, but disparities remain high in some regions. Educational investments are not high enough to rapidly slow population growth, particularly in low-income countries. Achievement of the Millennium Development Goals is delayed by several decades, leaving populations without access to safe water, improved sanitation, and medical care. Similarly, there is only intermediate success in addressing air pollution or improving energy access for the poor as well as other factors that reduce vulnerability to climate and other global changes.

Source: O'Neill et al. (2012).

b. **Quantifying economic model parameters.** RAP narratives are used to construct parameter sets for crop, livestock, and economic models, including the TOA-MD. Here we discuss creating parameters for TOA-MD using the DevRAP tool; research teams can create other parameter sheets for other models they may be using. The sheet SCEN_STi (where i=strata 1,2…) in the DevRAP tool is designed to create and document scenarios for the TOA-MD model. One or more scenarios can be constructed for each RAP as follows:
   1) *Create name and short narrative to describe the scenario*: It is important to document the key characteristics of the scenario, thus the narrative and scenario name must contain elements to understand what the scenario is about.
   2) *Identify model parameters*: The DevRAP tool includes the list of parameters used in the TOA-MD. The team will identify the parameters that will be quantified for the specific scenario.
   3) *Quantify each parameter*: use RAP information to assign a value to each parameter. Data for these parameters can be obtained from the literature, modeled or from expert judgment, and these need to be documented.

c. **Quantifying management and technology parameters for crop models**. Similar to the economic model parameterization process, the team will use the SCEN_CROPSM sheet in the DevRAP tool to quantify specific crop model parameters/inputs (fertilizer level, sowing density, improved cultivars, etc.) based on the RAP narratives and scenario details (e.g., RAPs packages).

3. Develop system adaptations for use in regional analysis of climate impact and adaptation.

Adaptations are designed by RRTs in collaboration with stakeholders. A devAdapt tool is available to assist the design and document adaptations. Each adaptation will be run with climate and socio-economic scenarios according to core questions 2 and 4. A process similar to RAPs development is recommended, to identify technically and economically feasible adaptations that would be likely to improve system performance in the future world with climate change.

Key features of adaptations:

1. Adaptation packages in core question 2 are changes in the production system under the current climate (***no climate change***)
2. Adaptation packages in core question 4 are changes in the future production system (as characterized through RAPs) that would be developed and used in response to climate change.
3. Adaptation packages are not specific to RAPs: Any adaptation package can be analyzed under any RAP.

Development of Adaptation packages

An adaptation package can have elements that change within and/or between systems. These can include economic or policy elements in addition to agronomic elements. For example:

Within-system adaptations:

- Management changes for crop models
    - Crop varieties, fertilizer, plant density, others.
- Management changes for livestock models
    - Breeds, feeding strategy, others.
    - Different species, etc.
- Changes in resource (land) allocation among activities

Between-system adaptations:

- Change crops or livestock

Economic adaptations:

- Both with- and between-system adaptations above can be motivated by economic considerations, especially between-system when there are large changes in productivity or prices due to climate change.
- Land allocation within system
- Off-farm labor, off-farm income from non-ag sources as a result of a specific policy aimed at offset climate change impacts. (Note: these should not be confused with the RAPs parameters that are climate independent).

Adaptation/intervention consistency across core questions 2 and 4 and RAPs

As mentioned above adaptation packages are distinct from RAPs – recall, RAPs define future socio-economic conditions that could occur with or without climate change, whereas adaptations are changes in production systems designed to improve performance under the changed climate. Also note that the system changes (interventions) analyzed for Core Question 2 (current climate) may be different from those analyzed under Core Question 4 (future climate); however it is useful to have some consistency in the types of adaptations that are being analyzed for the two questions. Adaptations should be designed with elements that could potentially be analyzed under different worlds (current or future), but could take on different values under current world and future world conditions.

Table 4 provides an example. The table shows the current world, and two RAPS (4 and 5) that characterize two future worlds (i.e., RAP4 and RAP5). In this example we assume that the team has developed 3 adaptation packages. Adaptation package 1 is based on changing planting dates and cultivars, adaptation package 2 is based on planting density, fertilizer use and change in livestock breeds, and adaptation package 3 is based on changing the production system (e.g., adding new crops) accompanied by a climate change policy intervention. We could potentially analyze the three adaptation packages under both current and future worlds. However the configuration (or parameter values) for the specific adaptation elements might be different in each 'world' (see the examples in the table). Note that there may be combinations that might not be possible.

There may be a tendency for RRTs to focus on marginal within-system agronomic management adaptations. To get beyond this type of analysis, RRTs could strive to include at least one agronomic adaptation, one economic adaptation on farm adaptation, and one policy intervention that could facilitate implementation. When multi-dimensional adaptation packages are analyzed, it will be important to evaluate each component's contribution to the performance of the system as well as combinations of those components, to facilitate understanding of the role each plays.

Table 4. Adaptation consistency across current and future worlds. *Note: Adaptation packages and elements shown in this figure are for illustration purposes only*

	Adaptation 1 (e.g. Planting dates, Cultivars)	Adaptation 2 (e.g. Planting density, fertilizer, improved livestock)	Adaptation 3 (changed system + CC policy)
Current World	Planting date=-30 days Cultivar = improved (Analyzed in CQ2)	Planting density= +20% Fertilizer use=+50% Improved livestock=+100% (Analyzed in CQ2)	Not possible (Analyzed in CQ2)
RAP 4: Sustainable Low Growth (Future World)	Planting date=-45 days Cultivar = improved (Analyzed in Q4)	Planting density= +10% Fertilizer use=+25% Improved livestock=+100% (Analyzed in CQ4)	Change subsistence crops with cash crops Policy: fertilizer subsidy (Analyzed in CQ4)
RAP5: Unsustainable High Growth (Future World)	Planting date=-45 days Cultivar = improved drought tolerant (Analyzed in Q4)	Planting density= +50% Fertilizer use=+100% Improved livestock=+200% (Analyzed in Q4)	Change subsistence crops with cash crops Policy: fertilizer subsidy, increase off farm labor opportunities (Analyzed in Q4)

4. Assemble existing data from sentinel sites and calibrate crop models for regionally-relevant cultivars and soils.

The target outputs from this set of activities are high quality data that are entered into the AgMIP Crop Site Database and used for calibration of multiple crop models for selected sites. The data and model simulations will provide scientific evidence that the models are adapted to the crops and environmental conditions in the region and have cultivar characteristics/parameters that can be used to simulate the crops that are to be studied in the region. This is what is typically done in crop modeling training programs and in research projects. It is likely that the RRTs already have accomplished this for some subset of crops and crop models to be used in the studies. This activity is intended to document those data and past efforts, bring together new data, and ensure that the models to be used have gone through this phase of work. It is anticipated that there will be relatively few site-years with data for any of the selected crops, but those data will be archived in the Crop Site Database and used to calibrate cultivars and improve the adaptation of crop models for the regions. Suggested components of this activity are as follows.

a. **Assemble data from past experiments for calibration of regionally-relevant cultivars for selected crop models** for selected crops. This includes crop, soil, and climate data for site-specific experiments and field trials in the region. This will require input from agronomists, crop modelers, climate, and IT project team members.

b. **Input data into Excel data templates** for use by multiple crop models.

c. **Using the AgMIP IT tools, translate data to model ready input files for each crop model**. QuadUI and ADA are used to convert data from Excel to csv (comma-delimited) to ACE to the specific formats needed by multiple crop models.

d. **Using methods provided by each crop modeling group (e.g., DSSAT, APSIM, perhaps others), simulate the sentinel site experiments** and estimate cultivar-specific parameters to best simulate the experimental results. These results will help set cultivar characteristics and perhaps soil conditions for regional simulations to be carried out by the teams (see below).

e. **Secondary focus will be estimation of productivity parameters**, relative to initial conditions, crop residue, soil organic matter pools, and soil fertility for the site-specific sentinel data. (NOTE: these steps will be repeated for the household survey and regional simulations where site-specific information is not available.)

f. **Document model simulations** (site data, management, observations, outputs, soil, climate, cultivar coefficients) by placing them in the Crop Site Database, along with explanatory text and appropriate tables and figures showing the quality of the calibration of cultivar coefficients.

5. Assemble existing data and calibrate livestock models for regionally-relevant livestock breeds.
The target outputs from this set of activities are high quality data that can be used for calibration of livestock (and rangeland production) models for selected sites. The data and model simulations will provide scientific evidence that the models have (i) breed parameters that allow simulating the common animal breeds of the region, and (ii) feed quantity and quality input data that characterize the on-farm and off-farm (rangeland) fodder production of the region.

This activity is intended to compile existing data and past efforts, identify gaps and collect the necessary new data, and ensure that the models have been properly calibrated.

The necessary data falls into four broad categories (*with indication of potential data sources in italics)*. Data (including metadata) will be stored in an AgMIP database.

a. Feed trial data, in which body weight, calving rate, milk production and feed input (quantity and quality of feed that was offered to the animals) is recorded

(Experimental data from existing databases, reports, publications).

b. Information on **feeding practices** by farmers and the average feed calendar and feed availability in the area of interest. The following questions should be answered for this aspect

i. In which months do farmers feed crop residues, forages, etc., from which crops, and to which types of animals?
ii. In which months are the herds relying on rangelands (100% or to a certain degree), and does that differ between different animals?

(Data from household surveys, focus group discussions, expert consultations)

c. Information on **rangeland biomass productivity** in relation to climatic variability

(Data from biomass productivity assessments, remote sensing analyses, from databases, reports, publications)

d. Information on the **feed quality** of the different feed sources (forages, crop residues, concentrates, and rangeland) over time (as this varies in the different seasons). Minimum feed quality information requirements include dry matter content, dry matter digestibility, crude protein content, and metabolizable energy.

(Data from laboratory analyses assessments, remote sensing analyses, from databases, reports, publications)

Model calibration will be conducted by estimating the breed specific parameters that result in the closest simulation of important livestock performance indicators such as body weight, calving rate, and milk production. Sensitivity analysis for a number of animal breed and feed input parameters will add confidence that the obtained parameter values are acceptable and result in reasonable model predictions for the region.

Proper documentation of the sensitivity and calibration exercises should include explanatory text, appropriate model performance statistics, and tables and figures showing the quality of the calibration.

6. Assemble and quality-control current climate series.
The key products from this activity will be a high-quality version of in-situ climate observations in .AgMIP format for each location where crop models will be used, a file documenting the changes made to the original raw observations, and summary maps and statistics characterizing the region being analyzed. It is crucial that this current period climate series be used for crop calibration and as the basis for future climate changes, assuring that the only difference between current and future climates are the changes imposed by climate change as opposed to any biases that would result by using differing current period climate datasets. The following methods, which build upon those introduced in Ruane et al. (2015a), are recommended:

a. Assemble and assess quality of station observations.

- Identify weather stations that best represent selected crop modeling regions.
- Obtain as much of the 1980-2010 period as possible (Daily precipitation, maximum and minimum temperatures, solar radiation or sunshine duration, wind speed, dew point temperature, vapor pressure, and relative humidity).
- Convert to .AgMIP units and format with missing data given a value of -99. The AgMIP format is described in Ruane et al., 2015a.
- Name the climate series site with a 4-character code (first 2 characters from internet country code and second 2 characters representing location) following the guidelines in Ruane et al., 2015a (e.g. "NLHA" for Haarweg, Netherlands).
- Begin a text file to document changes made in the quality assessment and quality control of the raw files (e.g., "NLHA.info").
- Identify outlying (+/- 3 standard deviations probably deserves a closer look) and questionable data that may be corrupted. The best approach remains plotting out the dataset elements as time series to see if anything looks amiss.
- Check to see if data are plausible physically (e.g., questionable value supported by other variables), temporally (e.g., questionable value supported by preceding or following values), or spatially (e.g., questionable value supported by neighboring stations). If values are not plausible, replace with a value of -99.
- If vapor pressure, dewpoint temperature, or relative humidity correspond to a time of day other than mid-afternoon (~maximum temperature), approximate values at the time of day of maximum temperature will be computed, by conserving more robust dewpoint temperature or vapor pressures (which can be calculated using temperature at time of measurement) and then recalculating relative humidity using maximum temperature.

b. Obtain background daily climate time series (1980-2010) from the AgMERRA dataset provided by the AgMIP Climate Team (Ruane et al., 2015b). This dataset serves as a first-guess complete set of estimated daily climate data for use in filling in missing data for observation stations. (If the observational dataset is fully complete this step may not be necessary). AgMERRA data are available at http://data.giss.nasa.gov/impacts/agmipcf and are described in Ruane et al. (2015b), but an individual location's .AgMIP-formatted time series may be extracted using either FACE-IT workflow tools or via an email to Alex Ruane (alexander.c.ruane@nasa.gov) providing the latitude and longitude, elevation, and site (name and country).

c. Fill in missing/flagged observation data using station observations and the AgMERRA estimated climate series. This process is facilitated by the AgMIP Historical Bias-Correction and Gap-Filling Worksheet. Note that two overlapping observational sets may be combined in a similar manner. This set of activities will provide a continuous, complete, physically-consistent daily climate series from 1980-

2010 in .AgMIP format for use with the crop models. Go through station observations and fill in all data gaps as follows:

- Use simple interpolations for short data gaps (e.g., if 3 or less days are missing fill in by interpolating from good values on either side). Use caution if strong outlier exists on either side as this may not be an effective approach (e.g., if strong rain event precedes data gap we can't assume that it will have persisted throughout gap. If rainfall gaps are short and rare they can often be replaced with zeros, but this causes dry biases if gaps are frequent.
- For moderate gaps (e.g., 4-10 days) use background dataset to fill in gaps and bias-correct using surrounding good data (adjust mean to ensure approximate continuity with beginning and end points).
- For longer gaps use background datasets to fill in gaps and bias-correct using climatological biases calculated by comparing background dataset to good station observations (e.g., if July Tmax in background dataset is typically 0.6˚C too warm, subtract 0.6˚C from background dataset when filling in a July data gap; if observed rainfall is typically only 90% of background rainfall in October, multiply background dataset by 0.9 to fill in October gaps).
- Ensure that filled in data are physically plausible by checking the following:
    - Relative humidity does not exceed 100%
    - Relative humidity, vapor pressure, and dewpoint temperature are physically consistent at time of day of maximum temperature.
    - Solar radiation is not greater than astronomical maximum (can use historical monthly maximum as proxy) or below zero.
    - Maximum temperature is at least 0.1˚C above minimum temperature.
- Place historical climate data into .AgMIP format using the Excel template provided by Alex Ruane (alexander.c.ruane@nasa.gov).

d. Approximate climate time series in regions for integrated assessments. This set of activities produces a set of climate time series that corresponds to each crop or livestock modeling location in an integrated assessment region and forms the 1980-2009 (current) climate series identified in Table 1. (Note that this procedure is automated in the AgMIP Climate Scenarios Guidebook using the "farmclimate" routine; be sure to list station data first as described in the Guidebook). Working with the crop and economic modeling teams, recommended methods include:

- Obtain desired latitudes and longitudes for each integrated assessment site to be modeled. Name each station with a 4-character code.
- Identify as many weather stations in (or nearby) region as possible. Quality control these datasets following methods above, then assign each of the integrated assessment locations to the most representative weather station ("corresponding station" may not always be selected by geographic distance alone, but may also factor in climatic zones and/or elevation).
- If there are additional precipitation gauges (where other variables are not observed), determine which integrated assessment locations correspond to these and start with this precipitation record.
- Estimate differences in monthly climatologies between integrated assessment locations and corresponding station location using AgMERRA dataset (if distances are greater than ~50km) or WorldClim dataset (if distances are less than ~50km). Adjust corresponding station in a manner similar to the gap-filling bias adjustment to estimate integrated assessment climate series.
- Depending on the number of farms, it may be suitable to categorize each farm into a smaller number of groups that experience nearly the same climate and then create climate series for these groups rather than each individual farm.

e. Create an AgMIP Agro-climatic Atlas for Current Period Climate for eventual publications and integration in AgMIP Impacts Explorer. This atlas will contain maps and plots of important agro-climatic variables for the region. Recommended methods include:

- Generate regional maps of mean temperature and precipitation during historical baseline period from observational data and from GCMs to be used in scenario generation.
- Identify agriculturally important climate metrics. If region is affected by a prominent monsoon, determine which monsoon metrics are important to regional agriculture. Compare climate information with planting rules of thumb from farmers and/or crop model configurations if possible.
- Calculate these metrics and produce maps using observational products during the historical baseline period (in consultation with local experts and stakeholders).
- Identify trends in historical record (utilizing a Mann-Kendall test for statistical significance), most importantly for temperature and precipitation within the growing season.
- Analyze uncertainty among observational products (if available) as reference for future uncertainties.

7. Assemble survey data and simulate using crop models for analysis of yield variations for current climate and current production system (CM0).

In this action we assemble suvey data and simulate the yield variations by undertaking a fitting exercise (due to the multitude of model input gaps) ensuring 'identical' inputs across crop models in CM0. Table 2 lists the crop model simulation sets CM1 through CM6 which are used to answer the four Core Questions. But there are some preliminary simulations that must be done first. Crop model simulation set CM0 involves simulation of the conditions under which the farm survey data were collected. For crop models, this is typically a single season simulation using historical weather data where simulated outputs are compared to observed farm survey data. Because household survey data is limited to one year, the opportunity to correlate yields to interannual weather variability is lost in CM0 step, although CM1 simulations produce results averaged over 30 years (these use the current climate series created in Section 6). For livestock models, a run time of at least 10-12 years is recommended because the livestock models take a longer time to stabilize and yield a reasonable average value of livestock productivity. The comparison of observed to simulated yields from the historical simulation allows researchers to evaluate the models and input parameters, and to compute biases and probability of exceedance. This is the only simulation for which comparison to observed crop yields and livestock productivity is relevant.

There are two types of data used in the crop simulations. Matched analyses involve actual farm survey data and unmatched analyses involve aggregated historical production numbers at the regional, national or sub-national level. The following paragraphs describe the ways the each case is handled.

Matched case. Ideally, regional projects will use on-farm survey data for which the crop models can be used to simulate each field that was surveyed. This will provide simulated results for the "matched" case where the models use climate, soil, and management for each field to simulate productivity that is then "matched" with observed yields for each field. In order to simulate each field, the teams will need to make assumptions about crop model inputs that are needed but not collected in the farm surveys. These assumed inputs should be developed with advice from agronomists in the region, and they will be documented along with the observed field survey data for each simulated result. Assumed inputs are combined with the survey data by means of a field overlay DOME file (see **Appendix 3**).

Crop modeling team members should analyze these matched results to be sure that they were correctly produced with well-defined and documented inputs and to be sure that simulated results are reasonable. Invariably, there will be biases between simulated and observed survey data, and the modelers should analyze means, variances, biases, probability distributions, and other characteristics of the results prior to confirming that they are ready for use in the economic analyses.

Unmatched case. If farm survey data are not available, crop modelers should work with multiple years of historical yield statistics at a district level. In this "unmatched" case, simulated yields cannot be matched one-to-one with observed farm field survey data, and variations in climate, soils, and management inputs across the region will need to be defined in order to create a population from which to sample for simulations. This should be done in a representative manner based on available information and expert opinion, particularly about variations in management practices and soils across farms within the district. In this case, comparisons of crop model results will be aggregated to a district level and analyzed for comparison with district yields. Also, a report should be written on methods and results of crop model calibration, aggregation methods, uncertainty associated with seasons, and biases relative to regional aggregated yields.

For both matched and unmatched cases, crop simulation outputs from multiple models will be formatted to the AgMIP harmonized Crop Model output (ACMO) format by the crop modeling team for use by the economists. This file will document key inputs and the metadata describing the simulated scenario as well as provide a summary of crop productivity outputs (e.g., yield).

Recommended steps include:

a. **Matched Case.** Assemble matched yield case data from household farm survey from sub-regions, where crop yield and minimal management (sowing date, fertilization, etc.) are available along with household economics information for 50 to 200 farmers. If it is not possible to simulate each field to produce matched outputs, crop modelers will need to use procedures for unmatched results (see section 7b below and **Appendix 3**).

- Download the latest AgMIP Tools (ADA, QuadUI and ACMOUI) from the http://tools.agmip.org/ website.
- Enter yield survey data into spreadsheet templates, following the more detailed instructions in **Appendix 3.**
- Work with regional Agronomists and Soil Scientists to identify the most likely soils for each field in the survey. These data can be added to a separate worksheet in the survey data spreadsheet template.
- Field Overlay spreadsheets can be used to fill in any information that is missing from the survey, but required by the crop models, such as initial soil water, initial nitrate and ammonium, soil organic carbon degradation, manure application dates, fertilization dates, prior crop residue, etc.
- Work with Climate colleagues to identify climate information/sites.
- Use the ADA and QuadUI applications to convert these spreadsheets into model-ready input files for multiple crop models.
- Use crop cultivar coefficients that have been calibrated with independent sentinel site data in the region (from Section 4 above).
- Simulate the matched case survey data with multiple models. Compute means and standard deviation of observed and simulated yields and other variables. Analyze simulated results by computing various statistics and compare with observed statistics, including comparison of yield distributions, means, variances, and characteristics of bias between observed and simulated yields and outliers. Depending on these analyses, crop modelers may decide to accept these inputs as baseline soils and management conditions for further analyses or they may need to make changes in the assumptions in conjunction with agronomists familiar with production in the region. Standard output files (ACMO) are used to provide crop model inputs and outputs for use in the AgView application, which can be used to create some standard RIA visualizations.

b. <u>Unmatched Survey and Simulation Fields (or Regional Historic Yields).</u> If there are no yield data available from household surveys, it will not be possible to simulate a yield for each farm as in the matched data case. In this case, crop modelers will need to work with economist team members and agronomists in the region to assemble information on variations in management and soils in the region for this “unmatched” case. Assemble soil, typical management, and typical cultivar information for the region along with long-term historical crop statistics data (for district level or higher) for use in evaluating crop model abilities to simulate regional yields and production. Methods for doing this are:

- Yield statistics of crops will be collected for the region over historical time periods of 30 years.
- Cultivar life cycle information will be assumed correct from the site-specific sentinel site data.

- Survey information will be collected with input of agronomists and soil scientists, to represent the distribution of weather stations, soils information, sowing dates, cultivars, residue return, soil organic matter pools, and fertilization that represents the region being predicted.
- Use software tools (as above) to create model-ready input files for multiple crop models to simulate historic observed years.
- Similar to the matched case (6.b), crop modelers will create ACMO files and prepare reports and publications that describe and interpret biophysical results of the study.
- For purposes of evaluating crop model abilities for simulating regional or district-level yields, crop model teams should aggregate yearly simulated results (over climate sites, soils, sowing dates, cultivars, management) to the district level yield for comparison with historical district yields (e.g., comparing distributions of simulated and observed yields, mean annual bias, etc.).
- Document model simulations (inputs, management, outputs, soil, climate, cultivar coefficients) by placing them in the Crop Site Database, along with explanatory text and appropriate tables and figures showing the yield distributions, analyses of interannual and spatial variations.
- Create maps and summary statistics e.g., spatial distribution of climate, soils, management, and yields illustrated in GIS mapping methods

8. Analyze Carbon-Temperature-Water-Nitrogen (CTWN) responses.
To establish understanding and credibility of the results of crop and livestock model applications, climate, crop, and livestock experts will undertake analyses of agricultural responses to changes in key climate and nitrogen factors. This analysis will help to identify vulnerabilities and the importance of various uncertainties in the modeling framework.

a. **Select Representative Farmer Field from Phase 1:** RRT teams will select one or more "representative" farmer fields from their farm-survey data, where the yield is relatively median/typical of the farms and where model yield predictions for that farm are reasonably close. For the selected fields, accept the soil, cultivar, and DOME data as configured CM0 analyses.
    - Because the yield distribution can mask huge differences between models in predicting yield of any given farm, it may be helpful to use the Observed vs Predicted yield plot for the selection process, not simply the yield distribution. That is, locate the median farm yield on the observational axis, identify the predicted yield points for each model, if they are far apart, ignore the median farm as basis for selection, and instead locate in this yield vicinity a yield point for which the two model predictions are quite close on the same farm. This will ensure that there is an equal starting point for the two models on the CTWN plots.
    - Selection of up to three farms per survey site may be appropriate in some cases for the CTWN, because CTWN responses differ where there are large differences in soil fertility or water-holding capacity.

b. **Verify simulations run for that single farm** and document key attributes, including the soil, initial conditions for soil water, NO3, NH4, root residue, prior crop residue, farmer fertilization with N, and manure application, the soil SOC, the SOC method used, and SOC pools.

c. **CTWN Factor Variation:** for each single farm site, using 30 years of historical weather, we will vary one at a time (Table 5): [CO_2], Tmax and Tmin, rainfall, and fertilizer N over a range for each variable. Results will be used to interpret different responses of the crop models to climatic factors and N, and especially to document correct starting point for that field and the adequacy of the assumed soil organic C pools that impact yield response to N. Indeed, the N response obtained is often used to inform the setting of available soil organic C pools for the entire survey data set. *The CTWN is not a climate impact assessment exercise, but rather to interpret how and why the models differ and to analyze the sensitivity of each particular system to the selected environmental variables.* C3MP sensitivity tests may also be utilized to explore combination effects (such as increases in both [CO_2] and temperature).

d. **Special case of low N systems:** AgMIP analyses in sub-Saharan Africa have shown that under low N conditions there can be strong interactions with climate inputs in determining yield. Where survey yields are dominated by farms with inputs < 30kgN/ha, the temperature and rainfall variations should be evaluated at both N limiting (30 kg N/ha) and N non-limiting conditions, (i.e. similar to the [CO_2] at 180kgN/ha) with the test at high N to establish the site yield response to each climate factor without complication from N deficiency. Then proceed to the median farm situation to explore the extent of climate interaction at low N conditions and impact on model yield predictions. This procedure is not yet available in QUADUI and graphing routines, but will be forthcoming.

A CTWN "Batch DOME" file is available which generates simulation files for the 32 single factor levels. Use QuadUI with the single farm survey data, the field overlay, a seasonal strategy file to allow simulation using 30-year current climate data, and the CTWN DOME.

Run the crop model simulations and use ACMOUI to write harmonized crop model outputs. Be sure to check for any model warning messages or log files.

Table 5. Description of single factor analyses of CTWN response.

CTWN Single Factor analyses	$[CO_2]$ (ppm) at N=30 kg/ha	$[CO_2]$ (ppm) at N=180 kg/ha	Tmax/Tmin (˚C)	Rainfall (% of current)	Fertilizer (kg/ha)
	360 450 540 630 720	360 450 540 630 720	-2 0 +2 +4 +6 +8	25% 50% 75% 100% 125% 150% 175% 200%	0 30 60 90 120 150 180 210

Creating Graphs and Interpreting Differences between Models: The AgView visualization application (tools.agmip.org/agview.php) reads the ACMO files and creates x-y plots of yield (and other variable) responses in same graphs as a function of the single factors of temperature, $[CO_2]$, rainfall, and N fertilization.

- **X-Y Graphs with Boxplots of Linear Factor Analysis: Yield versus C, T, W, N** where the x-axis is the C, T, W, or N variable. Mean yields and box plots (over 30 years) will be computed for each level of the single factors of $[CO_2]$, temperature, rainfall, and fertilizer N, and plotted against the factor $[CO_2]$, temperature, rainfall, and N level on the x-axis. The means and box-plots for multiple models will be shown on the same x-y graphs to allow intercomparison of the different models.
    - Mean yields and box plot (over 30 years) will be computed for each level of the single factors of $[CO_2]$, temperature, rainfall, and fertilizer N, and plotted against the factor $[CO_2]$, temperature, rainfall, and N level on the x-axis. The R-program shows the two crop models for comparison (e.g., side-by-side boxplots at each x-axis level (e.g., +2 degrees Celsius).
    - As appropriate, other variables such as ET, E, T, and N uptake of both models will be plotted against the corresponding CTWN factors.

9. Assemble data and simulate livestock models for analysis of livestock productivity at the household level.
In this activity household survey information and outputs from the crop models need to be combined to generate the necessary livestock model input data.

Firstly, the livestock model requires feed availability information coming from the crop models and, if available, rangeland models. These yield data need to be combined with information from household surveys on field sizes to calculate total farm-level feed production. Secondly, household survey information will also serve to derive the initial herd size and composition for each household, which is needed as input data for the model.

For the grazing component of the livestock data, rangeland models could be used if available and well calibrated. If these are not available, or if confidence in modelling results is not (yet) satisfactory, other options exist to estimate the grazing component. One option is to use a crop model like APSIM or DSSAT to simulate tropical grass productivity in response to climate. Outputs from these crop models should be checked against reported rangeland biomass availability figures from the literature before use. A third option for estimating annual productivity of grazing lands, is to use rainfall use efficiency values from the literature in combination with seasonal rainfall. A final option, which does not allow incorporating annual biomass variability, is to work with reported average values of biomass availability. In all cases, rangeland productivity estimates have to be combined with information on rangeland area and stocking density to derive feed availability per animal.

On-farm crop residue and forage production can be derived from the crop modelling results. Biomass yields have to be multiplied with field sizes (from household surveys) to calculate total farm-level feed production and combined with the actual herd size of a particular year in the simulation, to obtain feed availability per animal, which is the final input used by the livestock model.

Simulated livestock productivity in terms of herd size and dynamics (number of animals born, sold, died) and milk production should be compared with information derived from the household survey. Invariably, there will be biases between simulated and observed survey data, and the modelers should analyze means, variances, biases, and other characteristics of the results prior to confirming that they are ready for use in the economic analyses.

When running the LivSim model with the run_LivSim_AgMIP.r script, an ALMO file will be created with the simulated output of all households and a selected number of output variables (herd size, herd dynamics indicators related to animals born, sold, and deceased, milk production, manure production). Additionally, raw output containing information about each individual animal over time is stored and can be used for more detailed analysis to understand observed patterns, as well as a number of summary .csv files per household and per year.

10. Assemble economic data for regional economic analysis and develop skills for using the regional economic model.
Outputs from this set of activities include at least two economist members per project team that are capable of performing economic analyses in their respective regions and data assembled on baseline socioeconomic and agricultural production data in their regions. An output will be crop modelers and economists with experience in interdisciplinary collaboration in co-developing data sets for use by both teams (e.g., historical yields and socioeconomic survey data), with the data input to the AgMIP database. Another output is the TOA-MD model set up to simulate economic outcomes for the region, using baseline socioeconomic data. Specific steps include:

a. **Identify economic data and corresponding study components (see the TOA-MD model and supporting documents for further details).**

b. **Work with the climate and crop model teams** to produce and analyze baseline crop simulations for sites that are jointly selected for the region, based on available data from regional statistics and/or on-farm surveys. This step requires direct cooperation among disciplinary team members and relies on the above steps on collecting climate series and calibration of crop models for regional yields.

c. **Estimate economic model parameters using the available data (see the Appendix 2 and TOA-MD model and supporting documents for details)**. It is recommended that the TOA-Parm tool be used, in conjunction with parameters obtained from the DevRAP and DevAdapt tools (for parameters that cannot be estimated with observational data or with crop or livestock models).

d. **Prepare a report (**following AgMIP template) describing the existing systems and documenting the data used for regional economic analysis and parameter estimates.

11. Create downscaled climate scenarios
Create downscaled climate scenarios based on AgMIP protocols (Ruane et al., 2015a), for use in the assessments of climate change studies, and provide future scenarios for use with crop models in the AgMIP database. Note that these procedures are captured in scripts contained in the AgMIP Guidebook for Climate Scenarios and available on the AgMIP Toolshed (tools.agmip.org/acsgtr.php), much of which can be run in FACE-IT. A key output from this set of activities will be future climate scenarios derived from the latest IPCC climate models and downscaled for use in the target regions. These scenarios will be in the .AgMIP climate data format and ready for multiple crop model simulations of impacts and agricultural adaptation for each region. In addition, a climate atlas will be produced of important climate variables and derived agriculturally-important indices. These atlases will include maps for use in scientific publications and for communication of results to stakeholders.

a. Select subset of GCMs for full analysis and create AgMIP Agroclimatic Atlas showing future climate change scenarios with uncertainties using maps with probabilities. The subset of models is a necessary step considering the limited resources and large number of combinations possible in further combination with crop, livestock, and economics models. We will focus on the Mid-Century (2040-2069) period, using a high-emissions scenario (RCP8.5) and a moderate-emissions scenario (RCP4.5). Maps and summary results will be published and also communicated to stakeholders via the Impacts Explorer Tool. Specific methods are:

- Make plot of growing season temperature and precipitation change from full GCM ensemble. When multiple cropping seasons are cultivated by regional households, different cropping seasons may be handled by producing scatterplots for each season individually, or combined across the various growing seasons. The latter is more straightforward to implement with Econ analysis as both seasons factor into economic outcomes. Highlight models chosen for representative subset, drawing a relatively hot/dry, hot/wet, cool/dry, and cool/wet GCM as well as a GCM representing the middle of the ensemble projected changes (more detail on this approach is provided by Ruane and McDermid, 2017). It is critical to recognize that these scenarios are relative to the full GCM ensemble projection, so “relatively cool” is likely still warmer than present, just not as warm as the median of other GCM projections for a given location. Note the weights given to each GCM as these will be used by economic and crop modelers in the final analyses. This can be created using the R CMIP5_TandP script.
- Create monthly box-and-whisker diagram to show current climate and projected range of future climates for mid-century RCP8.5. This can be created using the Matlab ‘CMIP5_TandP’ script.
- Produce region-wide maps of CMIP5 climate change projections, including median changes in mean quantities, variability, and extremes (along with corresponding uncertainties) for temperatures and precipitation.
- Also produce maps for agriculturally important climate metrics under future climate conditions for comparing with those produced for historical baseline climates.

b. Create CMIP5 mean and variability change scenarios. This activity will produce .AgMIP-formatted climate scenarios including both monthly and sub-monthly changes in temperature and precipitation. These procedures are described in Ruane et al., 2015a, and are captured in the “agmipsimple_mandv” scripts in the AgMIP Guidebook for Climate Scenario Generation. In many regions there are not sufficient resources or available regional climate model (RCM) results to capture important uncertainty in climate projections, however where these are available they are particularly helpful for their representation of sub-seasonal metrics that are often affected by smaller-scale atmospheric dynamics. In all cases, for future scenario generation it is critical that the basis of current climate be identical to the file developed in Section 6, as this ensures that only projected climate changes differentiate future and current climates (as opposed to any biases resulting from different current climate series). Suggested methods include:

- Calculate monthly changes in mean maximum temperature, minimum temperature, and precipitation by comparing future 30-year climate periods to the current (1980-2009) climate period from the same GCM/RCM combination (where available).
- Calculate monthly changes in the standard deviation of maximum temperature, the standard deviation of minimum temperature, and the number of rainy days (precipitation>0.1 mm) by comparing future 30-year climate periods (AgMIP defines three main time periods: "near-term"=2010-2039; "mid-century"=2040-2069; and "end-of-century"=2070-2099) to the current climate period (1980-2009; use RCP 4.5 for 2006-2009 period) from the same GCM/RCM combination (where available). These statistics are calculated by making a distribution of all days within a given month (e.g., April) over all years in the scenario (30 years x 30 days in April = 900 days). The shape parameter of the gamma distribution for wet events may also be of interest from RCM results, but is generally not of sufficient quality in GCM simulations.
- Impose these monthly changes on baseline climate series for all sites used in the analyses (developed in Section 6) using a stretched distribution approach that adjusts each event by comparing existing and desired values by distributional percentiles.
- Assume that solar radiation, winds, and relative humidity daily variables from the historical daily climate records are unchanged. Ensure that vapor pressure, and dew point temperatures are physically consistent with relative humidity at the time of day as the new scenario's maximum daily temperatures.
- Produce mean and variability change scenarios for all CMIP5 GCMs at the best-calibrated site in each region, and then create future scenarios at every farm site using the 5-GCM subset identified above to drive crop and livestock model simulations.
- Use the .AgMIP climate naming convention (described in the Guidebook for Climate Scenario Generation and Ruane et al., 2015a) as climate identifiers for metadata to be used by crop, livestock, and economic modelers.

c. Create CMIP5 delta-based climate scenarios *(optional – these are less complicated scenarios that may be made with only monthly outputs)***.** These scenarios will be based on historical baseline daily climate data, with each day's weather variables perturbed using the changes in climate model outputs for future time periods versus those same model outputs for the historical time period. These scenarios are made using the "agmipsimpledelta" routines in the AgMIP Guidebook for Climate Scenarios and may be compared against the more complex mean-and-variability change scripts above. This is a simpler but more straight-forward approach that some teams may want to examine and/or compare against the mean-and-variability approach detailed above. Specific methods include:

- For each of these sites, calculate monthly changes in corresponding mean maximum temperature, minimum temperature, and precipitation by comparing future 30-year climate periods to the same GCM's current climate period (1980-2009; use RCP 4.5 for 2006-2009 period). The Mid-Century RCP8.5 (high emissions scenario) is the priority future scenario period for assessment.
- Impose these monthly changes on baseline climate series for all selected sites (developed in Section 6) by adding temperature changes to the baseline record and multiplying by a precipitation change factor.

- Assume that solar radiation, winds, and relative humidity are fixed at the same values that were in the historical time series. Ensure that vapor pressure, dewpoint temperatures, and relative humidity are physically consistent at time of maximum daily temperatures (warmer temperatures have higher vapor pressures and dewpoint temperature at same relative humidity).
- This will result in a 30-year .AgMIP-formatted climate series for a given future period and GCM.
- Use the .AgMIP climate naming convention (described in the Guidebook for Climate Scenario Generation and Ruane et al., 2015a) as climate identifiers for metadata to be used by crop, livestock, and economic modelers.

12. Conduct multiple crop/livestock model simulations

The major outputs of this series of activities include simulations of yields by multiple crop and livestock models for multiple sites within the study region. Table 1 depicts six crop and livestock modeling simulation sets, and Table 2 identifies four associated climate change ratios for resulting economic questions, that are needed to address the **Core Climate Impact Questions** described in the Introduction.

A description of Simulation Sets CM1 through CM6 are listed below. Each simulation represents a 30-year analysis. For crop models, the years are assumed to be independent, with no carry-over of soil state variables from one year to the next (i.e., all years begin with exactly the same initial conditions, as defined in CM0). Differences in yields within the 30 years represent effects of weather variability only. Livestock models must be run as a sequence of 30 continuous years to get long-term average production.

a) *CM1: Current climate with current production systems technology*: Simulate current period climate series (identified as planting years 1980-2009 in **Table 6**) for all farms using:
   - The 30-year current climate series created in Section 6 above,
   - Current production systems, represented by the survey data and field overlay data from the historical simulation (CM0, see Section 7) and calibrated cultivars and livestock breeds from the calibration simulations (Section 4).
   - A CO_2 concentration of 360 ppm for all years (see Table 6),
   - Seasonal strategy DOMEs used to generate the 30-year crop model simulations.

b) *CM2: Climate change scenario(s) with current production technology* (no adaptation or RAPs): Simulate mean-and-variability-based climate change scenarios (beginning with RCP8.5 Mid-Century, identified as planting years 2040-2069 in Table 6) for all farms using:
   - The five 30-year, future climate series created in Section 11 above, working in consultation with climate team.
   - Current production systems, represented by the survey data and field overlay data from the historical simulation (CM0, see Section 7) and calibrated cultivars and livestock breeds from the calibration simulations (Section 4).
   - A CO_2 concentration corresponding to the central year for all simulations (see Table 6).
   - The same seasonal strategy DOME used in CM1, except that the CLIM_ID is changed to represent the scenario being modeled.

c) *CM3: Crop and livestock model simulations with current climate, using adaptation package(s) created via collaboration between the crop, livestock, and economic modeling teams*. Adaptations could be the same as (or directly related to) those used in CM6 to contrast the value of climate-related adaptations in current climate versus future climate. Examples include heat or drought-tolerant cultivars; added irrigation; subsidies for improved seed, inclusion of heat-tolerant forage crops, economic incentives, etc. requiring major investments. Alternatively, teams could design adaptation/interventions for present climate and present technology. The same survey data and field overlay are used to generate the simulation, but additional DOMEs may be used to superimpose changes to management for the selected adaptation package.

d) *CM4: Crop and livestock models will be simulated with current climate for future production technology* (e.g., improved cultivars and livestock breeds, additional N fertilization, use of feed concentrates, altered management) informed by RAPs and technology trends.

e) *CM5: Climate change scenario(s) with future production technology* (improved cultivars and livestock breeds, additional N fertilization, use of feed concentrates, altered management) informed by RAPs and technology trends.
f) *CM6: Climate change scenario(s) with future production technology, plus an adaptation package.* Create and document adaptation package(s) via collaboration between the crop, livestock, and economic modeling teams. Adaptations should be connected to climate-related vulnerabilities identified in a comparison between CM4 and CM5 results (also CM1 and CM2) such as heat or drought-tolerant cultivars; added irrigation; subsidies for improved seed, inclusion of heat-tolerant forage crops, economic incentives, etc. requiring major investments). Do not attempt improved management options associated with representative agricultural pathway and technology trends that define future production systems.

For each simulation, outputs from the multiple models are organized into harmonized ACMO (crop model) and ALMO (livestock model) formats. All outputs should be reviewed by crop and livestock modeling team members working closely with economic and climate team members to ensure the results are plausible, e.g., that there are no unexplained outliers. Summarize crop yield and livestock productivity impacts in tables, graphs, and maps for publication and communication to stakeholders. Included in these tables, graphs, and maps should be:

- within-region variability in impacts, and
- uncertainties associated with crop, livestock, and climate models
- Interpret reasons for variations among crop, livestock, and climate models as well as between regional households

Table 6. Central year carbon dioxide concentrations for AgMIP climate scenarios and time periods, with the Current and RCP8.5 Mid-Century time periods highlighted as they will be the primary focus of integrated assessment. These are the concentrations (drawn from observations and the RCP driving datasets) to be used for all years in a given scenario experiment.

Scenario and Time Period	Planting Year Coverage	Mid-year	[CO_2]
Current	**1980-2009**	**1995**	**360 ppm**
RCP4.5 Near-term	2010-2039	2025	423 ppm
RCP8.5 Near-term	2010-2039	2025	432 ppm
RCP4.5 Mid-Century	2040-2069	2055	499 ppm
RCP8.5 Mid-Century	**2040-2069**	**2055**	**571 ppm**
RCP4.5 End-of-Century	2070-2099	2085	532 ppm
RCP8.5 End-of-Century	2070-2099	2085	801 ppm

The following **analysis simulation sets** are performed for a single, best-calibrated and representative site in each integrated assessment region. These results are not used to answer the **Core Climate Impact Questions**, but are used to more fully understand the dynamics of the cropping system, and to interpret causes for differences among crop model responses to climate and management factors.

- **Full GCM simulations.** Examine the full GCM ensemble for a single farm. The outputs from the single location GCM ensemble simulations will be used by the climate team members to place the subset of GCMs in context.

FACE-IT workflows for RIA. Note that FACE-IT workflows provide an alternative to using the AgMIP desktop utilities for data translation and allows simulations using DSSAT and APSIM for complex workflows for this activity.

13. Analyze regional economic impacts of climate change without and with interventions and adaptations using the regional economic model.

Outputs will be impacts of climate change, interventions, and adaptations on agricultural production, farm income and poverty, and projected rates of adoption of adapted systems. To the extent possible, teams should use results of these sub-national analyses to draw implications for the national impacts, e.g., by extrapolating impacts to regions with similar production systems. The AgMIP regional integrated assessment framework is summarized in **Figure 2**.

Economist team members will use the TOA-MD model (or similar) following the procedures in Appendix 2 to estimate the economic model parameters. Results from the RIA analyses will be summarized with graphs and reports for scientific publications and for dissemination to stakeholders.

14. Archive data and analyses of results for integrated assessments

An important output of integrated assessments will be databases which include data for climate, soil, management, experiments, surveys, regional economic model parameters, and historical yields used in the RIA. These datasets will be highly valuable for additional future analyses as models improve, research and policy questions change, and adaptation approaches evolve. Archived data uploaded to the AgMIP Data Interchange (data.agmip.org) will be made available for broad use, although it is recognized that some data used in the projects (such as daily climate data in some cases, or confidential survey data) may not be archived due to intellectual property rights and data policies. Additionally, archived results from climate, crop models, livestock models, and economic models will serve as the source for various publications and presentations, including web-based information that will be made available for stakeholders. For this reason, it is possible to "freeze" datasets for a period of up to one year. Metadata for "frozen" datasets will be viewable, but people will be directed to the project PI for access to the data. A well-documented archive of AgMIP experiments, outputs, and analysis tools will facilitate future improvements in capabilities to perform integrated assessments of climate change impacts and adaptation at site and aggregated scales.

Figure 6 presents a data flow diagram for AgMIP Regional Integrated Assessments. Data created using the tools and procedures outlined in this document should be archived in AgMIP databases. Research teams shall contribute data to ACE (AgMIP Crop Experiment), DOME (Data Overlay for Multi-model Export), ACMO (AgMIP Crop Model Output), ALMO (AgMIP Livestock Model Output) and Regional Economic databases. The AgMIP IT Team will provide tools and training through the regional workshops and web tutorials so that RRTs can interact with the ACE, DOME, ACMO, ALMO and regional economic databases directly through the AgMIP Data Interchange (data.agmip.org) which connects to AgMIP data nodes. This will allow for storage of standardized databases of crop experiments and yield trials for the region and outputs of crop model simulations.

Data to be archived includes:

a. Climate data
   - Observed weather data for crop model calibration
   - 1980-2010 quality-controlled daily climate data for use in the AgMIP regional assessment
   - Ensembles of daily future climate scenarios

b. Crop Modeling
   - Harmonized (aceb, dome and alnk) data files associated with detailed calibration data from field experiments or other sources.
   - Calibrated cultivar parameters
   - Soil parameters as used in simulations
   - Harmonized data associated with farm survey sites for regional assessments using baseline and future conditions (aceb, dome and alnk files)
   - Crop model outputs for survey, baseline, sensitivity tests, and various future climate conditions (ACMO files)
   - Text summary of climate impacts on yield, considering crop management in survey fields

c. Livestock Modeling
   - Harmonized data files with information from feeding trials, breed-specific productivity indicators, farmer feeding practices, rangeland biomass availability, feed quality
   - Calibrated livestock breed parameters
   - Feed input data (on-farm and grazing land) and herd size and composition as used in simulations

- Livsim input files (.xlsx format) used for the simulations of each scenario and each system
- Livestock model outputs (milk production, herd dynamics) for baseline, future climate and adaptation conditions (ALMO files)

d. Economic data
  - Inputs to regional economic models (including survey metadata)
  - DevRAP matrix spreadsheet including output data from global economic models used in the RAPS and productivity trends.
  - Regional economic model outputs - Impacts of climate change and adaptations on agricultural production, farm income and poverty, proportion of households vulnerable to climate change and predicted adoption rates of adapted technologies.

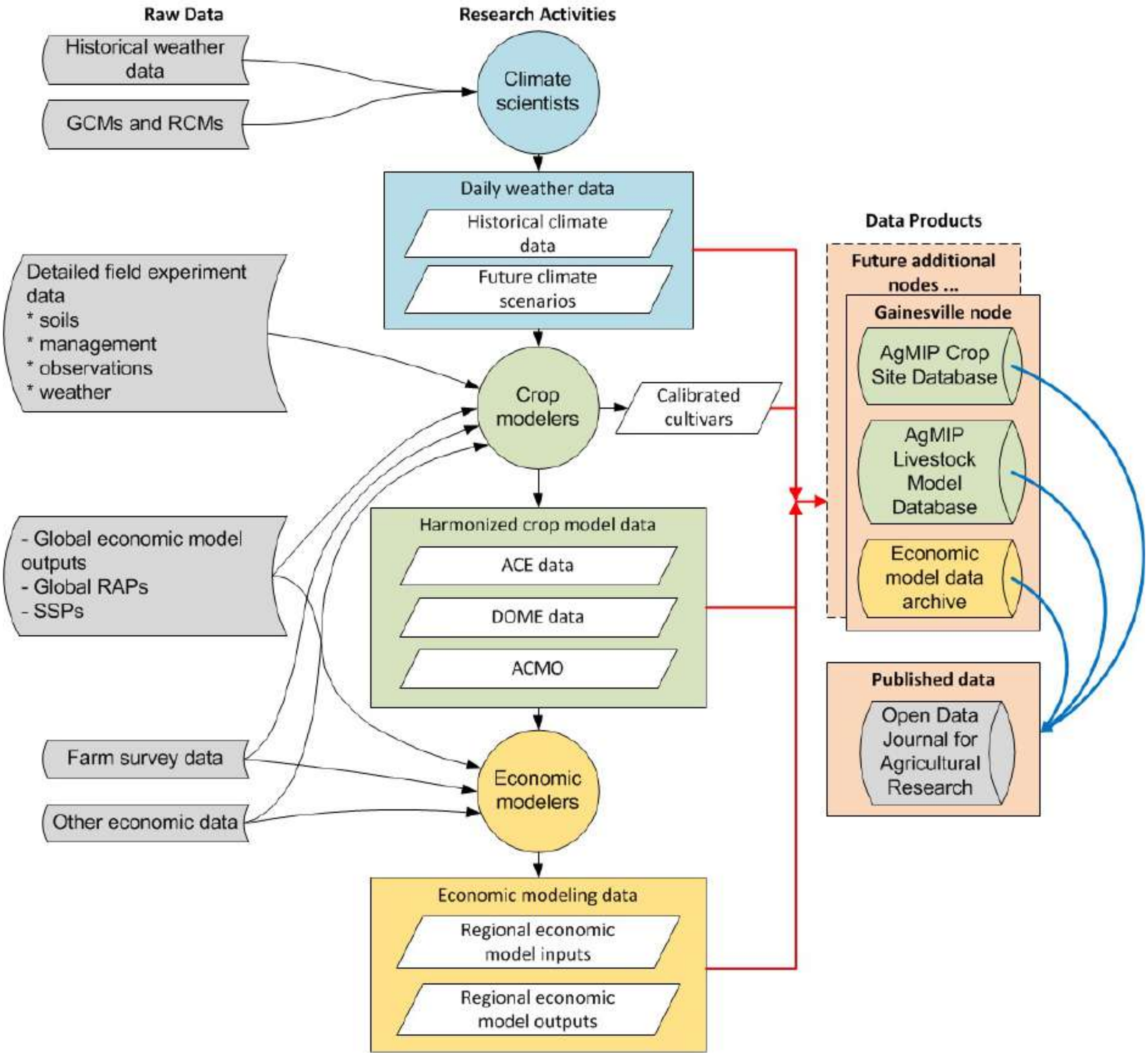


Figure 6. Data flow diagram for AgMIP Regional Integrated Assessments showing AgMIP data products and archive databases

15. Disseminate integrated assessment results.
The key outputs from this set of activities include scientific publications, project reports, results summarized on regional web pages linked to the AgMIP web site, and workshops with stakeholders. Initial and ongoing interaction with stakeholder and policymaking communities are likely to be as valuable as the dissemination of results to these communities, as early and consistent interactions increase buy-in and help develop a more useful and efficient research project

a. Develop RRT-specific web pages for the AgMIP web site. The AgMIP IT Team will provide information on how to create region-specific web pages and will give regional IT team members access to create and maintain that web information. Each region will have its project goals and methods on the site as well as pictures of project activities, output tables, maps, and graphs, as well as news items, for example.

b. Conduct project workshop with stakeholders.

- Invite stakeholders to SSA and SA workshops
- Organize stakeholder sessions at a region-specific workshops to keep them informed and learn from them what information they need for their planning and policy-making responsibilities

c. Prepare scientific publications. AgMIP research is designed to provide results that are well-suited for peer-reviewed journal publications and informing national and regional publications related to climate vulnerabilities, economic development, and adaptation/mitigation planning relative to food production and food security.

References

Antle, J.M., R.O. Valdivia, K. Boote, S. Janssen, J.W. Jones, C.H. Porter, C. Rosenzweig, A.C. Ruane, and P.J. Thorburn, 2015: AgMIP's transdisciplinary agricultural systems approach to regional integrated assessment of climate impacts, vulnerability, and adaptation. In Handbook of Climate Change and Agroecosystems: The Agricultural Model Intercomparison and Improvement Project (AgMIP) Integrated Crop and Economic Assessments, Part 1. C. Rosenzweig, and D. Hillel, Eds., ICP Series on Climate Change Impacts, Adaptation, and Mitigation Vol. 3. Imperial College Press, 27-44, doi:10.1142/9781783265640_0002.

Asseng, S., et al., 2013: Uncertainty in simulating wheat yields under climate change. Nature Clim. Change, 3, 827-832, doi:10.1038/nclimate1916.

Asseng, S., et al., 2015: Rising temperatures reduce global wheat production. Nature Clim. Change, 5, no. 2, 143-147, doi:10.1038/nclimate2470.

Bassu, S., et al., 2014: Do various maize crop models give the same responses to climate change factors? Global Change Biology, Global Change Biology 20, 2301–2320, doi: 10.1111/gcb.12520.

Elliott, J., C. Müller, D. Deryng, J. Chryssanthacopoulos, K.J. Boote, M. Büchner, I. Foster, M. Glotter, J. Heinke, T. Iizumi, R.C. Izaurralde, N.D. Mueller, D.K. Ray, C. Rosenzweig, A.C. Ruane, and J. Sheffield, 2014: The Global Gridded Crop Model Intercomparison: Data and modeling protocols for Phase 1 (v1.0). Geosci. Model Dev., in press, doi:10.5194/gmdd-7-4383-2014.

Fleisher, D.H., B. Condori, R. Quiroz, A. Alva, S. Asseng, C. Barreda, M. Bindi, K.J. Boote, R. Ferrise, A.C. Franke, P.M. Govindakrishnan, D. Harahagazwe, G. Hoogenboom, S Naresh Kumar, P. Merante, C. Nendel, J.E. Olesen, P.S. Parker, D. Raes, R. Raymundo, A.C. Ruane, S. Stockle, I. Supit, E. Vanuytrecht, J. Wolf, and P. Woli, 2017: A potato model inter-comparison across varying climates and productivity levels. Glob. Change Biol., 23, no. 3, 1258-1281, doi:10.1111/gcb.13411.

Hudson, N.I., and A.C. Ruane, 2015: Appendix 2. Guide for Running AgMIP Climate Scenario Generation Tools with R in Windows, Version 2.3. In Handbook of Climate Change and Agroecosystems: The Agricultural Model Intercomparison and Improvement Project (AgMIP) Integrated Crop and Economic Assessments, Part 1. C. Rosenzweig, and D. Hillel, Eds., ICP Series on Climate Change Impacts, Adaptation, and Mitigation Vol. 3. Imperial College Press, 387-440.

Li, T., T. Hasegawa, X. Yin, Y. Zhu, K. Boote, M. Adam, S. Bregaglio, S. Buis, R. Confalonieri, T. Fumoto, D. Gaydon, M. Marcaida, III, H. Nakagawa, P. Oriol, A.C. Ruane, F. Ruget, B. Singh, U. Singh, L. Tang, F. Tao, P. Wilkens, H. Yoshida, Z. Zhang, and B. Bouman, 2015: Uncertainties in predicting rice yield by current crop models under a wide range of climatic conditions. Glob. Change Biol., 21, no. 3, 1328-1341, doi:10.1111/gcb.12758.

Martre, P., et al., 2015: Multimodel ensembles of wheat growth: Many models are better than one. Glob. Change Biol., 21, no. 2, 911-925, doi:10.1111/gcb.12768.

McDermid, S.P., 2015: The AgMIP Coordinated Climate-Crop Modeling Project (C3MP): Methods and protocols. In Handbook of Climate Change and Agroecosystems: The Agricultural Model Intercomparison and Improvement Project (AgMIP) Integrated Crop and Economic Assessments, Part 1. C. Rosenzweig, and D. Hillel, Eds., ICP Series on Climate Change Impacts, Adaptation, and Mitigation Vol. 3. Imperial College Press, 191-220, doi:10.1142/9781783265640_0008.

Müller, C., J. Elliott, J. Chryssanthacopoulos, A. Arneth, J. Balkovič, P. Ciais, D. Deryng, C. Folberth, M. Glotter, S. Hoek, T. Iizumi, R.C. Izaurralde, C. Jones, N. Khabarov, P. Lawrence, W. Liu, S. Olin, T.A.M. Pugh, D. Ray, A. Reddy, C. Rosenzweig, A.C. Ruane, G. Sakurai, E. Schmid, R. Skalsky, C.X. Song, X. Wang, A. de Wit, and H. Yang, 2017: Global gridded crop model evaluation: Benchmarking, skills, deficiencies and implications. Geosci. Model Dev., 10, 1403-1422, doi:10.5194/gmd-10-1403-2017.

Nelson et al., 2014: Climate change effects on agriculture: Economic responses to biophysical shocks, Proceedings of the National Academy of Sciences, 111, 3274-3279, doi: 10.1073/pnas.1222465110.

O'Neill, B., et al., 2012. Meeting Report of the Workshop on the Nature and Use of New Socioeconomic Pathways for Climate Change Research. November 2–4, 2011, Boulder, CO. National Center for Atmospheric Research (NCAR), Boulder, CO, USA, Available at: https://www2.cgd.ucar.edu/sites/default/files/iconics/Boulder-Workshop-Report.pdf

Rosenzweig, C., and D. Hillel (Eds.), 2015: Handbook of Climate Change and Agroecosystems: The Agricultural Model Intercomparison and Improvement Project (AgMIP) Integrated Crop and

Economic Assessments. ICP Series on Climate Change Impacts, Adaptation, and Mitigation Vol. 3. Imperial College Press, doi:10.1142/p970.
Rosenzweig, C., et al., 2013: The Agricultural Model Intercomparison and Improvement Project (AgMIP): Protocols and Pilot Studies. Ag. For. Meteor., 170, 166-182. http://dx.doi.org/10.1016/j.agrformet.2012.09.011
Rosenzweig, C., et al., 2014: Assessing agricultural risks of climate change in the 21st century in a global gridded crop model intercomparison. Proc. Natl. Acad. Sci., 111, no. 9, 3268-3273, doi:10.1073/pnas.1222463110.
Rosenzweig, C., J.W. Jones, J.L. Hatfield, J.M. Antle, A.C. Ruane, and C.Z. Mutter, 2015: The Agricultural Model Intercomparison and Improvement Project: Phase I activities by a global community of science. In Handbook of Climate Change and Agroecosystems: The Agricultural Model Intercomparison and Improvement Project (AgMIP) Integrated Crop and Economic Assessments, Part 1. C. Rosenzweig, and D. Hillel, Eds., ICP Series on Climate Change Impacts, Adaptation, and Mitigation Vol. 3. Imperial College Press, 3-24, doi:10.1142/9781783265640_0001.
Rosenzweig, C., J. Antle, and J. Elliott, 2016: Assessing impacts of climate change on food security worldwide. Eos, 97, no. 8, 11, doi:10.1029/2016EO047387.
Ruane, A.C., and S.P. McDermid, 2017: Selection of a representative subset of global climate models that captures the profile of regional changes for integrated climate impacts assessment. Earth Perspect., 4, 1, doi:10.1186/s40322-017-0036-4.
Ruane, A.C., S. McDermid, C. Rosenzweig, G.A. Baigorria, J.W. Jones, C.C. Romero, and L.D. Cecil, 2014: Carbon–Temperature–Water change analysis for peanut production under climate change: a prototype for the AgMIP Coordinated Climate-Crop Modeling Project (C3MP). Global Change Biology, doi: 10.1111/gcb.12412
Ruane, A.C., J.M. Winter, S.P. McDermid, and N.I. Hudson, 2015a: AgMIP climate datasets and scenarios for integrated assessment. In Handbook of Climate Change and Agroecosystems: The Agricultural Model Intercomparison and Improvement Project (AgMIP). C. Rosenzweig, and D. Hillel, Eds., ICP Series on Climate Change Impacts, Adaptation, and Mitigation Vol. 3. Imperial College Press, 45-78, doi:10.1142/9781783265640_0003.
Ruane, A.C., R. Goldberg, and J. Chryssanthacopoulos, 2015b: Climate forcing datasets for agricultural modeling: Merged products for gap-filling and historical climate series estimation. Agr. Forest Meteorol., 200. doi:10.1016/j.agrformet.2014.09.016
Valdivia, R.O., J.M. Antle, C. Rosenzweig, A.C. Ruane, J. Vervoot, M. Ashfaq, I. Hathie, S.H.-K. Tui, R. Mulwa, C. Nhemachena, P. Ponnusamy, H. Rasnayaka, and H. Singh, 2015: Representative agricultural pathways and scenarios for regional integrated assessment of climate change impacts, vulnerability, and adaptation. In Handbook of Climate Change and Agroecosystems: The Agricultural Model Intercomparison and Improvement Project (AgMIP) Integrated Crop and Economic Assessments, Part 1. C. Rosenzweig, and D. Hillel, Eds., ICP Series on Climate Change Impacts, Adaptation, and Mitigation Vol. 3. Imperial College Press, 101-156, doi:10.1142/9781783265640_0005.
von Lampe, M.,Willenbockel, D.,Ahammad, H., Blanc, E., Cai,Y., Calvin, K., Fujimori, S., Hasegawa, T., Havlik, P., Heyhoe, E., Kyle, P., Lotze-Campen, H., d'Croz, D. M., Nelson, G. C., Sands, R. D., Schmitz, C., Tabeau, A., Valin, H., van der Mensbrugghe, D., and van Meijl, H.. 2014: Why do global long-term scenarios for agriculture differ? An overview of the AgMIP Global Economic Model Intercomparison, Agric. Econ., 45(1), 3–20.
Wiebe et al., 2015: Climate change impacts on agriculture in 2050 under a range of plausible socioeconomic and emissions scenarios, Environmental Research Letters, 10, 085010, doi: 10.1088/1748-9326/10/8/085010.

Appendix 1

End-to-End Connections and Priorities for Decision Support

AgMIP Regional Integrated Assessments are motivated by the need for cutting-edge scientific information that will aid stakeholders considering various options for policy change or investment. Figure A1.1 demonstrates how this decision support requires a modeling framework connecting economics, crop/livestock, and climate model inputs and outputs, but is also built upon a foundation of credibility established through key validation and analyses (**Figure A1.1**). The protocols and activities described in this document provide credible information and context in support of a range of stakeholders around the world according to this model.

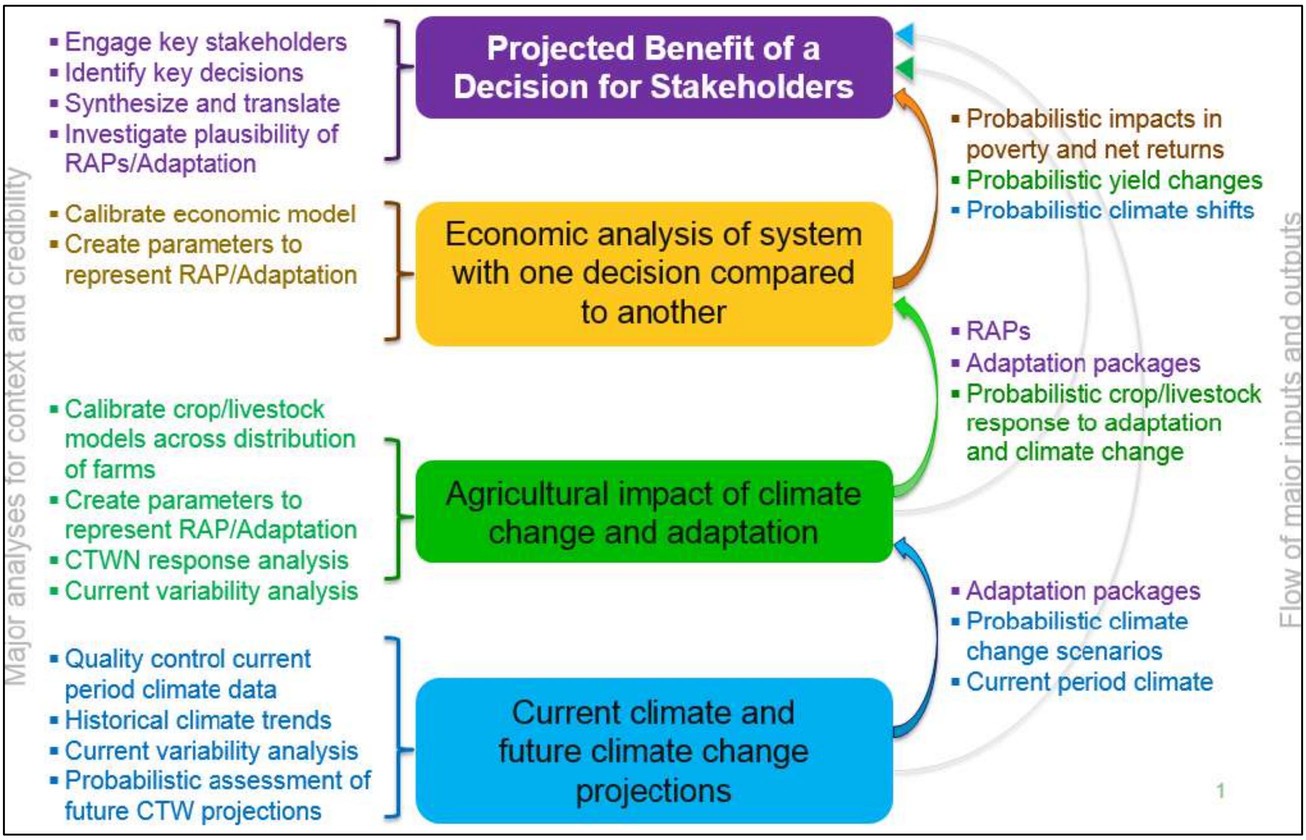


Figure A1.1: Overview of AgMIP Regional Integrated Assessments end-to-end project design. *Center:* To inform stakeholder decisions we need economic simulations driven by crop/livestock models driven by climate information. *Right:* Flow of the major inputs and outputs to enable the end-to-end regional integrated assessment. *Left:* Major analyses that are needed to give context and credibility to the outputs of each disciplinary component of the regional integrated assessment. Colors indicate the RRT project teams responsible for each activity (purple=stakeholder unit; gold=economics; green=crop/livestock; blue=climate), and all arrows will be facilitated by IT infrastructure and project communications.

Appendix 2

Calculating Statistics for Climate Impact Assessments Using Crop/Livestock Model Simulations, RAPs and the TOA-MD Model

John Antle and Roberto Valdivia

November 2015

Introduction

This document describes how crop and livestock model simulations and Representative Agricultural Pathways can be used with TOA-MD to implement assessments of climate change impact and adaptation using "matched" and "unmatched" data from crop or livestock simulation models. We use the case of a population of heterogeneous farms with a single stratum and one production activity to illustrate the methods but this can be generalized to multiple activities and multiple strata. This appendix presents methods for the use of data from crop or livestock models to simulate climate impacts by averaging data over time within the "current period" and within the "future period" defined for the analysis.

It is important to recognize that the methods presented here are not designed to represent temporal variability within the current period or within the future period. We focus on the time averaged case because of key limitations of the data that are usually available. In most cases, we *do not* observe yields or management over enough years to measure variation over time for individual farms. Thus, our methodology is designed to use cross-sectional survey data to estimate spatial heterogeneity reflecting bio-physical differences and management differences across farms.

The first section presents concepts and definitions. The second section describes the calculations used to estimate the parameters of the TOA-MD model.

A2.1. Concepts, Definitions and Assumptions

The Four Core Questions

The methods described here can be used to answer the "core questions" described in the first part of this Handbook. Note that Questions 1 and 3 involve assessing climate impacts, and so the TOA-MD model is used as an impact assessment tool. Questions 2 and 4 involve adaptation, in either a current or future period. Analysis of adaptation involves procedures similar to a standard technology adoption analysis as discussed in the TOA-MD documentation.

It is also important to recognize that these Core Questions are not the only logically possible or useful questions that can be investigated with the methods described here. For example, Core Question 2 can be modified to use a changed climate rather than the current or historical climate; also, Core Question 3 can be modified so that the technology specified for System 2 in the economic analysis is adapted to the future climate rather than a technology adapted to the current or historical climate.

Incorporating Spatial and Temporal Variability

We know yields and related outcomes (economic returns) vary over space and time, and this variation is important to understand vulnerability of farms to climate change. Therefore we need to project these distributions into the future for climate impact assessment.

We can describe a variable such as a yield for a production system h used at location j at time t as y_{jt}. Let μ_j be the mean for farm j obtained by averaging its values of y_{jt} over time and let μ_t be the mean for year t obtained by averaging y_{jt} over all farms in that year. We will say that μ_j is the *time-averaged* mean for farm j and μ_t is the *spatially-averaged* mean for year t. Similarly, we can decompose the variance of y_{jt} into spatial and temporal components. To obtain meaningful approximations to the distribution of outcome variables for the TOA-MD model, we often need to stratify populations of farms that come from different sub-populations or different time periods. For example, we may need to stratify farms geographically or by socio-economic characteristics such as size or ownership of livestock.

Our goal is to use the available data to estimate distributions of realized or expected returns to a farming system using the available data. The data needed are:

- Farm survey data that provide observations of current yields, management and other socio-economic variables such as prices, production cost, farm and household size, off-farm income.
- Secondary data on average yields for the study region.
- Projected yield growth rates from global agricultural economic models or RAPs.
- Current and future simulated yields of crops and livestock obtained from the crop and livestock teams.

A key limitation of the data is that, in most cases, we *do not* observe yields or management over enough years to measure variation over time for individual farms. Thus, our methodology is designed to use cross-sectional survey data to estimate spatial heterogeneity reflecting bio-physical differences and management differences across farms.

Defining the Study Region and Time Periods

The presentation here is for the analysis of a farm population in an "integrated assessment region," i.e., a study area defined geographically and possibly in terms of other socio-economic characteristics. Our convention for time t is that it represents a calendar year within a time "period." The current period H covers a specified number of years, and the future period F is some number of years ahead.

In most cases available farm survey data will come from a year (or years) near the end of the current period used for climate data and bio-physical model simulations, and management data used in these simulations will come from these survey data. For example, AgMIP's Regional Research Teams are using 1980-2009 as the current period for climate data and crop and livestock simulations. However, most survey data being used are from 2005 or later. For the economic analysis, using a 30-year period as "current" is not practical due to data limitations, the challenges of dealing with real and nominal trends, etc. Therefore, for the economic analysis, we are using the most recent 5-year period centered as closely as possible on the year(s) of the economic survey data for purposes of defining the current period for economic data.

Interpretation of TOA-MD Systems

Following the TOA-MD terminology, every simulation experiment involves two systems, denoted in TOA-MD as System 1 and System 2. Note that the interpretation of system 1 and system 2 depends on the type of analysis being done. For example in core question 1, to assess the effects of climate change on productivity, we interpret system 1 as the current production system in the current period and system 2 as the same system if it were observed in use with the future climate. However, for analysis of the four questions of Table 1, system 1 and system 2 are constructed to represent various combinations of climate change effects, socio-economic conditions and technologies.

To further simplify this presentation, we consider the case of a production system that has a single activity (say, a crop). More generally, the same types of calculations would be applied to each activity in each sub-system (i.e., to all crops, all livestock, all aquaculture activities).

Definition of Climate and Technology

We define a climate as a distribution of weather outcomes, and denote it with the parameter γ_t, where t = H or F. Note that in the Core Questions 1 and 2, a "future" climate is used under current-world socio-economic conditions. This is done for two purposes. First, it can be useful for evaluating how a change in climate could affect current systems; second, the "future" climate can be defined as a climate different from the historically observed climate, e.g., with an increase in extreme events, that could be occurring now under current socio-economic and technological conditions.

Production system technology is defined here in two dimensions: the period when it is used, and the climate it was developed for and presumed to be adapted to. This means that a given technology, e.g., a specific seed variety, performs best in the climate it is adapted to. However, this does not mean that there cannot be a better-performing technology in that climate, even one adapted to a different climate. Technology is represented as T_{ti} where t = H or F represents the time period the technology is used and i = H or F denotes the climate it is adapted to. Note that in the experimental design of the simulations, the technology T_{HF} is used in analysis of Core Question 2 with current climate, so we interpret this technology to be better adapted to a future climate, but could be better performing in the current climate than the current technology.

Technology and Climate Combinations Used in the Four Core Questions

According to this definition, there are four possible combinations of time period and technology adaptation that are used to parameterize the crop, livestock and economic models. These are combined with climates according to Table A2.1 to construct the simulations for analysis of the Four Core Questions.

Table A2.1. Technology and Climate Combinations Used in Analysis of the Four Core Questions

Core Question	System 1	System 2
1	T_{HH}, γ_H	T_{HH}, γ_F
2	T_{HH}, γ_H	T_{HF}, γ_H
3	T_{FH}, γ_H	T_{FH}, γ_F
4	T_{FH}, γ_F	T_{FF}, γ_F

Variable Definitions

t = individual year or time period

H = current time period

F = future time period

j = farm index, $j = 1,\ldots,J$ farms in data sample representing the integrated assessment region study area

$t = 0$ = base year(s) for the analysis, typically the year(s) when survey data were collected

τ_{ti} = technology and management used in period t = H or F, adapted to climate i = H or F

γ_t = climate in period t = H or F

p_t = representative output price (currency units/kg), t = H or F

y_{jt} = crop yield in year t (kg/ha)

$\mu_j(\tau_{ti}, \gamma_t)$ = time-averaged mean of yields for farm j using technology τ_{ti} with climate γ_t

Y_0 = mean of observed yields in the survey data for base year $t = 0$

Y_H = mean of yields averaged over all farms and years in the current period, obtained from secondary data in the study area

$\beta_{y0} = Y_H/Y_0$ = normalization factor used to scale survey data yields to the current period mean

$s_j(\tau_{ti}, \gamma_t)$ = simulated crop yield for farm j using technology τ_{ti} with climate γ_t

r_{jk} = relative yield for farm j used for Core Question k.

$r_{j1} = s_j(\tau_{HH}, \gamma_F) / s_j(\tau_{HH}, \gamma_H)$ = relative yield for analysis of Core Question 1

$r_{j2} = s_j(\tau_{HF}, \gamma_H) / s_j(\tau_{HH}, \gamma_H)$ = relative yield for analysis of Core Question 2

$r_{j3} = s_j(\tau_{FH}, \gamma_F) / s_j(\tau_{FH}, \gamma_H)$ = relative yield for analysis of Core Question 3

$r_{j4} = s_j(\tau_{FF}, \gamma_F) / s_j(\tau_{FH}, \gamma_F)$ = relative yield for analysis of Core Question 4

a_{jt} = total crop area on the farm in period t (ha)

R_{jt} = revenue = $p_t \cdot y_{jt} \cdot a_{jt}$ (currency units/farm/time)

R_{jqs} = time-averaged revenue for question q and system s (currency units/farm)

C_{jt} = production cost for period t (currency units/farm/time)

C_{jqs} = time-averaged production cost for question q and system s (currency units/farm)

C_t = mean of production cost averaged over all years in the current period (t = H), or the mean production cost for the base year (C_0) obtained from secondary data in the study area (if available)

$\beta_{c0} = C_H/C_0$ = normalization factor used to scale production cost survey data to the current period mean (note, If β_c can't be estimated, then use $\beta_{c0} = \beta_{y0}$ to assume that production costs from survey data deviates from what is representative for the current period and costs are normalized by the same factor as yields; or use $\beta_{c0} = 1$ when cost data is representative for the current period).

$G_{jt} = C_{jt}/R_{jt}$ = production cost relative to revenue (unit-free)

$G_{jqs} = C_{jqs}/R_{jqs}$ = time-averaged production cost relative to time-averaged revenue for question q and system s

$V_{jt} = R_{jt} – C_{jt}$ = crop net returns for the farm (currency units/time)

V_{jqs} = time-averaged net returns for question q and system s (currency units)

Bias12 = factor used to adjust RHO12 for bias (see discussion below).

The Relative Yield Model

We use both survey data and simulated data to represent the effects of climate change on productivity using the *relative yield model.* The idea behind this model is as follows: suppose we interpret system 2 as the current system being used under conditions of a future climate, and we interpret system 1 as the current system being used under conditions of the current climate. The average yield under climate change can then be related to the mean of the current system as $\mu_j(\tau_{HH}, \gamma_F)/ \mu_j(\tau_{HH}, \gamma_H) \equiv r_{j1}$ (this is the comparison used in Core Question 1). We define r_{j1} as the *relative yield under climate change*. We assume that we can approximate a yield impacted by climate change by estimating r_{j1} with crop model simulations as $r_{j1} = s_j(\tau_{HH}, \gamma_F) / s_j(\tau_{HH}, \gamma_H)$ where $s_j(\tau_{HH}, \gamma_F)$ is the time-averaged simulated yield for farm j under climate change, and $s_j(\tau_{HH}, \gamma_H)$ is the time-averaged simulated yield for farm j in the current period climate and technology. Then we project the yield with climate change and technology τ_{HH} as $\mu_j(\tau_{HH}, \gamma_F) = r_{j1} \cdot \mu_j(\tau_{HH}, \gamma_H)$ where $\mu_j(\tau_{HH}, \gamma_H)$ is the time-averaged yield for the current period. Since $\mu_j(\tau_{HH}, \gamma_H)$ is not observable in most cases, we approximate it with the observed yield from a farm survey in the current period for farm j, and scale the observed yields if necessary so that they represent the current period population mean.

Calculating the Between-System Correlation in the TOA-MD Model (RHO12)

The TOA-MD model requires an estimate of the correlation between the returns to each system (parameter RHO12 in the TOA-MD data sheet RHO). As noted above for Core Question 1, we estimate system 2 yields by assuming that $\mu_j(\tau_{HH}, \gamma_F) = r_{j1} \cdot \mu_j(\tau_{HH}, \gamma_H)$ where $\mu_j(\tau_{HH}, \gamma_H)$ is the mean observed yield from a farm survey in the current period for farm j. Note that we typically estimate $\mu_j(\tau_{HH}, \gamma_H)$ with the observed base year yield y_{j0} (adjusted by β_{y0} if necessary). We can write base year yield as $y_{j0} = \mu_j(\tau_{HH}, \gamma_H) + e_{j0}$, where $\mu_j(\tau_{HH}, \gamma_H)$ is the mean yield and e is a random component. The problem with the relative yield procedure for the calculation of RHO12 is that by correlating $\mu_j(\tau_{HH}, \gamma_F) = r_{j1}\, y_{j0}$ with y_{j0} we overestimate the correlation (note, the true RHO12 is the correlation between $\mu_j(\tau_{HH}, \gamma_F)$ and $\mu_j(\tau_{HH}, \gamma_H)$, but our procedure gives RHO12 equal to this correlation plus r_{j1} times the variance of e_{j0}). We can show that the bias that results is equal to Bias12 = $\mathrm{var}[\mu_j(\tau_{HH}, \gamma_H)] / \mathrm{var}(y_{j0})$. These variance components can be estimated with panel data using a fixed effects model. If panel data are not available, we suggest using Bias12 = 0.85 which is the approximately the value that has been obtained from several panel datasets.

Matched and Un-Matched Data

Two situations may be encountered with analysis using this type of farm survey data:

Matched Data*:* a crop yield can be simulated for each survey farm, for each crop in the system for which a crop model is available. This is true when weather and soil data can be associated with each survey farm, and some crop management data are included in the survey.

Data matching is possible in most cases where farm survey data are available and some kind of information is included in the survey to identify the survey farms' locations. Ideally, the spatial identifier is the farm's spatial coordinates (or even better, the centroids of individual fields). Note that when spatial coordinates are not included in a survey, they can be approximated with other location identifiers. For example, a legal address or village name may be available, and this may be used to approximate the spatial coordinates of the farm.

It is important to note that the matching of weather and soil data to survey farms will typically require using the *best approximation possible given available data*, because farm-specific weather and soils data are almost never available. Nevertheless, **as long as weather and soil data can be assigned to each survey farm through some reasonable procedure, the term "matched data" is used**, because with the farm specific management data, it is possible to simulate yields for each farm.

Un-Matched Data: a distinct crop yield ***cannot*** be simulated for each survey farm; however, spatially varying weather and soil data are available to run crop model simulations with representative management for the region.

Note that in the un-matched case, it is possible to estimate a simulated yield *distribution* that corresponds to the population of farms represented by the survey; however, it is not possible to match simulated yields to the survey farms.

Accounting for Future World Conditions: RAPs and Future Scenario Data from Global Economic Models

RAPs are used to represent future conditions, including productivity trends and effects of future economic conditions on output prices and costs of production. Regional RAPs must incorporate trends (e.g. yield trends from global econ models) following the methodology presented below, to translate current production systems into the future conditions defined by a RAP. If the analysis is linked to a global pathway and economic model scenario, data from that scenario (e.g., prices, productivity trends) should be linked to the regional RAP and scenario assumptions.

To parameterize the TOA-MD model to analyze the Core Questions, the analyst must construct parameters to reflect the effects of climate and adaptations on yields and costs, and also must adjust all other economic parameters to match the conditions of current world (Questions 1 and 2) or a future world defined by the RAP (Questions 3 and 4). Note that for Question 1, only yields are adjusted for System 2 to quantify climate impacts under current world conditions. For Question 2, the analysis is implemented as a technology adoption analysis under current world conditions. Questions 3 and 4 are the same logical structure as Questions 1 and 2, but are implemented with economic data projected into the future world conditions.

The following parameters are used to project from current to future world conditions. They can be derived from model projections or RAPs as appropriate.

Γ = compounded yield growth factor between current and future periods. Used to estimate trended parameters of system 1 for Core Question 3 **(**e.g. use AgMIP Reference scenario data from IMPACT global model).

$\boldsymbol{\phi_t}$ = compounded price growth factor between current and future periods. Used to estimate trended output price parameters.

- $\boldsymbol{\phi_H}$ is the price growth factor **without climate change** and it is used to estimate parameters for system 1 for **Core Question 3** (e.g. use AgMIP Reference scenario data from IMPACT global model**).**

- $\mathbf{\Phi_F}$ is the price growth factor **with climate change** and it is used to estimate parameters for **system 2 for Core Question 3** and for **system 1 and 2 parameters for Core Question 4.**

$\mathbf{\Psi}$ = compounded variable production cost growth factor between current and future periods. Used to estimate trended parameters of **system 1 for Core Question 3** and for **system 1 and 2 parameters for Core Question 4.** This factor should be defined as part of the RAPs.

Key Assumptions

A1: *The distribution of $\mu_j(\tau_{HH}, \gamma_H)$ (the true time-averaged mean of farm j in the current period) is approximated by the distribution of y_{jt} in the current year t in which the spatial yield distribution is observed.* This assumption allows us to use the observed yield in year t, scaled to the mean of the current period, as a proxy for $\mu_j(\tau_{HH}, \gamma_H)$. However, since we know that the observed yields for each farm will vary from the average in the current period, we know that the projected future yields include this variation. Thus, we need to take care in using data from the current period. The more years of data that can be used, the more we can average out the individual-year variation from the current period data, and doing so should result in better estimates of $\mu_j(\tau_{HH}, \gamma_H)$ and thus better projections of future yields.

A2: *For each Core Question, crop simulation biases are equal for each System.* For each technology and climate combination, we can define the bias in the crop model, e.g., let $b_{jH} = s_j(\tau_{HH}, \gamma_H)/\mu_j(\tau_{HH}, \gamma_H)$ for current period technology and climate. Now also define $b_{jF} = s_j(\tau_{HH}, \gamma_F)/\mu_j(\tau_{HH}, \gamma_F)$. If $b_{jH} = b_{jF}$, then it follows that

$$r_{j1} = s_j(\tau_{HH}, \gamma_F) / s_j(\tau_{HH}, \gamma_H) = b_{jF}\, \mu_j(\tau_{HH}, \gamma_F)/ b_{jH}\, \mu_j(\tau_{HH}, \gamma_H) = \mu_j(\tau_{HH}, \gamma_F)/\mu_j(\tau_{HH}, \gamma_H),$$

and thus $\mu_j(\tau_{HH}, \gamma_F) = \mu_j(\tau_{HH}, \gamma_H)\, r_{j1}$, proving that the relative yield provides an unbiased prediction of the System 2 mean yield.

A3: *$G_{jq1} = G_{jq2}$. The ratio of cost/revenue is the same for both systems in the analysis.* This assumption means that the profit margin is the same for the two systems being compared. This assumption provides a standardized way to project future cost based on current costs, or to project cost for an alternative system based on an observed system, but note that this assumption can be modified to fit a future situation where costs are expected to deviate from this relationship.

A4: *Yields in the integrated assessment region grow at compound rate Γ, and crop model simulations for the future period do not incorporate factors accounting for this growth between the current and future periods.* In the approach presented here, we assume that there is an independent yield growth factor associated with technological change that is not accounted for in crop model simulations.

A5: *Total land (Area in the TOA-MD model) allocated to the farming system in the population being modeled is constant within the current and within the future time period (but not necessarily the same between the two periods).* This assumption is based on the premise that data on area variation over time are not available within the current period, and are not modeled for the future period; alternatively, the analyst can use year-specific data if such information is available.

A2.2. Calculating TOA-MD Model Parameters

For Core Questions 1 and 2, the analysis is done assuming that the survey and other observational data represent the current world conditions of the analysis so set $\mathbf{\Gamma = 1, \phi_H = 1, \phi_F = 1, \Psi = 1.}$

Matched Data

Question 1

Step MA11: Calculate the relative yields r_{j1} for each farm j = 1,…,J in the survey.

Step MA12: Survey data observations of y_{j0} (base year) provide information to calculate the parameters for the historical period and historical technology (System 1):

$$\mu_j(\tau_{HH}, \gamma_H) = \beta_{y0} \cdot y_{j0}$$

$$R_{j11} = p_H \cdot a_{jH} \cdot \mu_j(\tau_{HH}, \gamma_H)$$

$$C_{j11} = \beta_{c0} \cdot C_{jH}$$

$$V_{j11} = R_{j11} - C_{j11}$$

Note: recall that p_H is a representative price, adjusted to the historical period average as necessary. β_{y0} is the normalization factor used to adjust observed yields in the data to the historical period population average, and β_{c0} is used to adjust observed costs to the historical average. *The historical period is defined as the five-year period centered as closely as possible on the year(s) of the economic survey data.*

Step MA13: calculate parameters with climate change for each farm in the survey data as follows:

$$\mu_j(\tau_{HH}, \gamma_F) = r_{j1} \cdot \mu_j(\tau_{HH}, \gamma_H)$$

$$R_{j12} = p_H \cdot a_{jH} \cdot \mu_j(\tau_{HH}, \gamma_F)$$

$$G_{j12} = C_{j11}/R_{j11}$$

$$C_{j12} = G_{j12} \cdot R_{j12}$$

$$V_{j12} = R_{j12} - C_{j12}$$

Step MA14: Using the data from MA12 and MA13, calculate the means for R_{j11}, C_{j11}, R_{j12} and C_{j12}, and the standard deviations of V_{j11} and V_{j12}.

Step MA15: Calculate RHO12 as the correlation between V_{j11} and V_{j12} times the bias factor Bias12. If this bias factor cannot be estimated, set it equal to 0.85.

Question 2

Step MA21: Calculate the relative yields r_{j2} for each farm j = 1,…,J in the survey.

Step MA22: Survey data observations of y_{j0} (base year) provide information to calculate the parameters for the historical period and historical technology (System 1):

$$\mu_j(\tau_{HH}, \gamma_H) = \beta_{y0} \cdot y_{j0}$$

$$R_{j21} = p_H \cdot a_{jH} \cdot \mu_j(\tau_{HH}, \gamma_H)$$

$$C_{j21} = \beta_{c0} \cdot C_{jH}$$

$$V_{j21} = R_{j21} - C_{j21}$$

Note: these are the same calculations as step MA12.

Step MA23: calculate parameters with adaptation for each farm in the survey data as follows:

$\mu_j(\tau_{HF}, \gamma_H) = r_{j2} \cdot \mu_j(\tau_{HH}, \gamma_H)$

$R_{j22} = p_H \cdot a_{jH} \cdot \mu_j(\tau_{HF}, \gamma_H)$

$G_{j22} = C_{j21}/R_{j21}$

$C_{j22} = G_{j22} \cdot R_{j22}$

$V_{j22} = R_{j22} - C_{j22}$

Step MA24: Using the data from MA22 and MA23, calculate the means for R_{j21}, C_{j21}, R_{j22} and C_{j22}, and the standard deviations of V_{j21} and V_{j22}.

Step MA25: Calculate RHO12 as the correlation between V_{j21} and V_{j22} times the bias factor Bias12. If this bias factor cannot be estimated, set it equal to 0.85.

Question 3

Step MA31: Calculate the relative yields r_{j3} for each farm j = 1,…,J in the survey.

Step MA32: Survey data observations of y_{j0} (base year), RAPs, and global economic models provide information to calculate the parameters for the future period without climate change.

$\mu_j(\tau_{FH}, \gamma_H) = \Gamma \cdot \mu_j(\tau_{HH}, \gamma_H) = \Gamma \cdot \beta_{y0} \cdot y_{j0}$

$R_{j31} = \phi_H \cdot p_H \cdot a_{jF} \cdot \mu_j(\tau_{FH}, \gamma_H)$

$C_{j31} = \Psi \cdot \beta_{c0} \cdot C_{jH}$

$G_{j31} = C_{j31}/R_{j31},$

$V_{j31} = R_{j31} - C_{j31}$

Step MA33: calculate parameters with climate change for each farm in the survey data as follows:

$\mu_j(\tau_{FH}, \gamma_F) = r_{j3} \cdot \mu_j(\tau_{FH}, \gamma_H)$

$R_{j32} = \phi_F \cdot p_H \cdot a_{jF} \cdot \mu_j(\tau_{FH}, \gamma_F)$

$G_{j32} = G_{j31}$

$C_{j32} = G_{j32} \cdot R_{j32}$

$V_{j32} = R_{j32} - C_{j32}$

Step MA34: Using the data from MA32 and MA33, calculate the means for R_{j31}, C_{j31}, R_{j32} and C_{j32}, and the standard deviations of V_{j31} and V_{j32}.

Step MA35: Calculate RHO12 as the correlation between V_{j31} and V_{j32} times the bias factor Bias12. If this bias factor cannot be estimated, set it equal to 0.85.

Question 4

Step MA41: Calculate the relative yields r_{j4} for each farm j = 1,…,J in the survey.

Step MA42: Survey data observations of y_{j0} (base year), RAPs, and global economic models provide information to calculate the parameters for the future period without climate change.

$$\mu_j(\tau_{FH}, \gamma_F) = r_{j3} \cdot \mu_j(\tau_{FH}, \gamma_H)$$

$$R_{j41} = \phi_F \cdot p_H \cdot a_{jF} \cdot \mu_j(\tau_{FH}, \gamma_F)$$

$$G_{j41} = G_{j31}$$

$$C_{j41} = G_{j41} \cdot R_{j41}$$

$$V_{j41} = R_{j41} - C_{j41}$$

Note: these are the same calculations as used for Question 3, System 2.

Step MA43: calculate parameters with climate change for each farm in the survey data as follows:

$$\mu_j(\tau_{FF}, \gamma_F) = r_{j4} \cdot \mu_j(\tau_{FH}, \gamma_F)$$

$$R_{j42} = \phi_F \cdot p_H \cdot a_{jF} \cdot \mu_j(\tau_{FF}, \gamma_F)$$

$$G_{j42} = G_{j41}$$

$$C_{j42} = G_{j42} \cdot R_{j42}$$

$$V_{j42} = R_{j42} - C_{j42}$$

Step MA44: Using the data from MA42 and MA43, calculate the means for R_{j41}, C_{j41}, R_{j42} and C_{j42}, and the standard deviations of V_{j41} and V_{j42}.

Step MA45: Calculate RHO12 as the correlation between V_{j41} and V_{j42} times the bias factor Bias12. If this bias factor cannot be estimated, set it equal to 0.85.

Multiple Activities

For systems with multiple activities, we apply the above calculations to each system. In addition, we need to estimate the within-system correlations between the returns to the activities. With matched data we can calculate the within-system correlations for system 2 the same way as for system 1 (i.e., by using the survey data to estimate the within-system average correlation between activities). For unmatched data, we typically assume that within-system correlations are the same for systems 1 and 2.

For trend calculations, yield trends for major crops from global models are used as the starting point, with adjustments to regional conditions as appropriate. Minor crop trends should be defined by the team based on the major crop trends. Livestock trends should be based on global model trends for milk and meat as appropriate, adjusted to regional conditions.

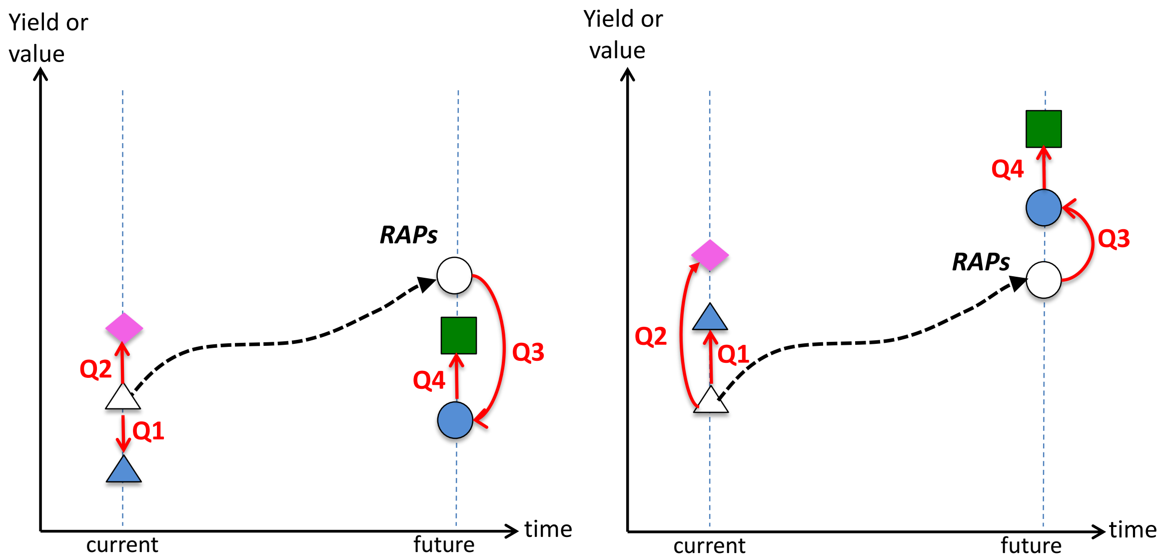


Figure A2.1. Overview of core climate impact questions and the production system states that will be simulated, as in Figure 1, but contrasting situations where climate change has a detrimental impact (left) with those in which climate change has a beneficial impact (right).

	System 1	System 2	Key Outputs
Question #1	Production system in Current Period with Current climate	Production system in Current Period with Future Climate	***% gainers & losers and net impacts*** % change in mean farm income % change in per capita income % change in Poverty rate
Question #2	Production system in Current Period with Current climate	Adapted Production system in Current Period	***Adoption rate (%)*** % change in mean farm income % change in per capita income % change in Poverty rate
Question #3	Production system in Future Period with Current climate **Productivity and price trends with no climate Change and RAPs**	Production system in Future Period with Future Climate **Price trends with climate Change and RAPs**	***% gainers & losers and net impacts*** % change in mean farm income % change in per capita income % change in Poverty rate
Question #4	Production system in Future Period with Future Climate **Price trends with climate Change and RAPs**	Adapted Production system in Future Period with Future Climate **Price trends with climate Change, RAPs and Adaptation Package**	***Adoption rate (%)*** % change in mean farm income % change in per capita income % change in Poverty rate

Figure A2.2. Overview of core climate impact questions and the production system states that will be simulated and key economic components and output indicators for TOA-MD simulation runs.

Appendix 3

User's Guide to Crop Model Simulations for Regional Integrated Assessments

K. J. Boote, C. Porter, C. Villalobos, J. Hargreaves, J. Antle, R. Valdivia, and J. W. Jones

December 3, 2012
revised June 11, 2015

Managing and Documenting Crop Model Inputs

The crop model simulation sets required to answer the four Core Research Questions for the Regional Integrated Assessment are listed below and shown graphically in Figure A3.1.

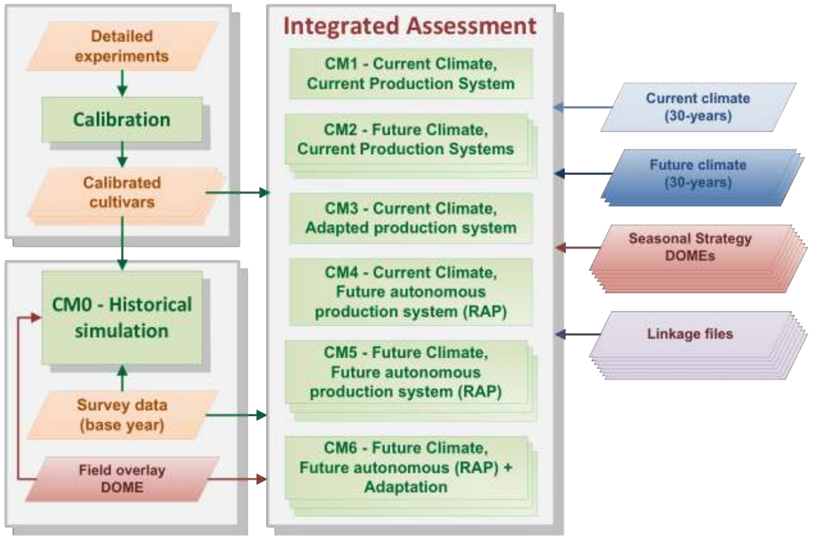


Figure A3.1. Crop model simulation sets required for Regional Integrated Assessments

- **Calibration.** Use sentinel site datasets to calibrate cultivars appropriate for the region.
- **CM0 – Historical.** A simulation of the conditions under which the farm survey data were collected is typically performed for duration of one to two years and uses observed weather data for each site. The comparison of observed to simulated yields from the historical simulation allows researchers to evaluate the models and input parameters, and to compute biases and probability of exceedance. This is the only simulation for which comparison to observed yields is relevant.
- **CM1 – Current.** Simulation of the current climate and current production system uses 30 years of weather data based on current climatology. (Done for each farm in the survey if satisfactory fit to survey yields is achieved with available input data, OR for sets of inputs that represent different categories of farm yields. In the latter case, farm yields in each category cannot be differentiated by the information available as model inputs.
- **CM2 – Future.** Simulation of future climate scenarios with the current production system. A separate simulation is done for each future climate scenario for each farm.
- **CM3 – Current, with intervention.** Simulation using current climate, but with a management system which is specifically designed for climate adaptation. A separate simulation is done for each intervention package. Intervention may be novel or related to adaptation package used in CM6.
- **CM4 – Current, RAP.** Simulation using current climate, but with a management trend which includes production technology change corresponding to a particular RAP. A separate simulation is done for each RAP.
- **CM5 – Future, RAP.** Simulation using future climate scenarios, but with a management trend which includes production technology change corresponding to a particular RAP. A separate simulation is done for each future climate scenario / RAP combination.
- **CM6 – Future, RAP, adapted.** Simulation using future climate scenarios, a management trend corresponding to a RAP, and with management changes which are specifically designed for climate adaptation. A separate simulation is done for each future climate scenario / RAP / adaptation combination.

- **Full GCM simulations.** Examine the full GCM ensemble for a single, best-calibrated and representative site in each integrated assessment region (these latter results will not be passed on to economic analysis; also not shown in Figure A3.1).
- **CTWN sensitivity test simulations** – single farm, 30 years; one at a time vary CO_2, Tmax/Tmin, rainfall, fertilizer N over a range for each variable.
    - **CO_2 –** 360, 450, 540, 630, 720ppm (run for high and low N) - 10 simulations
    - **Tmax/Tmin -** -2, 0, +2, +4, +6, +8 oC – 6 simulations
    - **Rainfall –** 25%, 50%, 75%, 100%, 125%, 150%, 175%, 200% - 8 simulations
    - **Fertilizer N –** 0, 30, 60, 90, 120, 150, 180, 210 kg/ha – 8 simulations

Each simulation is carried out through some combination of survey data, soil data, current and future weather data, assumed model inputs, and hypothetical management regimens. Data types used for these analyses are listed in Table A3.1 and described in the paragraphs below. All data are input to QuadUI, a data translation utility which provides the following functions:

(1) Translates the data to harmonized format, which can then be archived on the AgMIP Crop Site Database (data.agmip.org).
(2) Translates the data to model-ready formats for multiple crop models
(3) Generates metadata which fully describe the simulation and data used to generate model input files. These metadata are passed along to ACMOUI and are included in harmonized crop model output (ACMO) files.

Table A3.1. Description of data files used by AgMIP IT tools to create multiple crop model input files.

Data type	File type	Description	File Formats
Raw data	Survey_Data	Observed field survey data for use in creating multiple model inputs. Survey data include experimental and management data in one file and soils data in a separate file.	Excel Spreadsheet, one line per field, which is exported to a zip archive (*.zip) containing comma-delimited (*.csv) files for import and translation
Raw data	Weather	Daily weather data for historical, current or future climate scenarios	Various formats including .AgMIP, csv, and DSSAT WTH files, compressed into a zip archive (*.zip) file
Raw data	Cultivar	Model-specific cultivar parameter files are passed by the translation utility to the model simulation directory.	Model-specific formats, in zip archive (*.zip)
DOME	Field_Overlay	Data and parameters needed by crop models, but which were not recorded in the field survey data	Excel Spreadsheet, which is exported to a zip archive (*.zip) containing comma-delimited (*.csv) files
DOME	Seasonal_Strategy	Used to set conditions for multi-year model simulation of current or alternative management practices for current or future weather scenarios.	Excel Spreadsheet, which is exported to a zip archive (*.zip) containing comma-delimited (*.csv) files
DOME	Rotation_Strategy	Used to set conditions for multi-year model simulation of crop rotations, having just one set of initial conditions at year 1 (under development)	Excel Spreadsheet, which is exported to a zip archive (*.zip) containing comma-delimited (*.csv) files
Linkage	Linkage	Used to assign one or more DOMEs to each entry in the farm survey data.	Comma delimited (csv)
ACMO	AgMIP Crop Model Output file	Summary of crop model simulation metadata and simulated results.	Comma delimited (csv)

Raw data include survey data, soil data, weather data and cultivar parameters. The survey data are measured at individual sites and stored in a Survey_data file, typically one line per site / season observation. Data include metadata regarding the site location; management data including planting, irrigation, fertilization and harvesting; and observations of crop growth and development, including harvested yield and dates of anthesis and harvest.

Microsoft Excel files are generally used to collate and organize the survey data and to convert units to conform to AgMIP standards. Table A3.2 lists the data that are typically provided in this file. Generally, household survey information includes crop yield (on field moist weight basis and needs to be converted to dry wt basis), some management information, and economic data on a per farm-field basis. Data templates are available, as described below.

Site-specific soil profile information is bundled with the farm survey data, in a separate worksheet, as shown in the survey data templates.

Weather data are stored separately to facilitate re-use of the survey data for multiple climate scenarios, including current climate conditions. These data can be entered in a spreadsheet using the ICASA notations, or supplied in .AgMIP format or DSSAT WTH files.

Model-specific cultivar parameters, from the calibration step, should be supplied with the raw data. These are not converted to harmonized format, but are passed through to the crop model simulation data directory in the formats required by each model.

Table A3.2. List of variables typically found in the household survey data that can be input to crop models.

Survey data variable	Units	ICASA Variable Name
Field/Farm name		EXNAME
Field overlay name(s)		FIELD_OVERLAY
Seasonal strategy name(s)		SEASONAL_STRATEGY
Latitude	dec. degrees	FL_LAT
Longitude	dec. degrees	FL_LONG
Weather station identifier to link to site information		WST_ID
Soil profile identifier		SOIL_ID
Planting date	yyyy-mm-dd	PDATE
Crop ID (see list of codes above)	code	CRID
Total seasonal N applied	kg[N]/ha	FEN_TOT
Manure/Organic matter applied	kg[DM]/ha	OMAMT
Harvest date	yyyy-mm-dd	HDATE
Harvest yield (dry wt)	kg[dry]/ha	HWAH
By-product removed at harvest as dry wt	kg[dry]/ha	BWAH
Indicates whether the field has been irrigated	Y or N	IRRIG
Notes (as desired, optional)		TR_NOTES
Survey data variable	Units	ICASA Variable Name

DOME data. Invariably, some required crop model inputs are not measured and must be assumed. Some crop models have internal assumptions that provide missing inputs but these are “hidden” from users, they vary across models, and they are not likely to be relevant for all regions where the models will be applied. In addition, the hypothetical simulation sets (CM1 through CM6) make use of observed management, soil, and climate, but modify some of these factors to evaluate climate variability effects at a location, to assess impacts of future climate, and to evaluate hypothetical management options. The “Data Overlay for Multimodel Export”, or DOME, is a file type that is used by AgMIP translation tools to provide additional data used by each crop model to simulate crop growth and yield. Table A3.1 describes different types of DOME files currently implemented by AgMIP IT tools. All DOME functions are documented on the AgMIP research site at research.agmip.org/display/itwiki/The+DOME.

The Field_Overlay DOME is used to supply the needed inputs that are missing so that all of the models make use of the same regional or site-specific assumptions. For example, data collected in regional surveys may not include planting density or initial soil water content. Adding these data to a field overlay DOME maintains the integrity of observed values, clearly documents assumptions made for simulation analyses, and ensures consistency across crop models for multi-model applications. My observation was that these inputs were often selected at values very much at odds with the target yield to be simulated.

A second type of DOME, the Seasonal_Strategy file, is used to provide information needed to create synthetic simulation experiments which use multiple seasons of weather data. These files provide information for controlling simulations for multiple years.

Combinations of Field Overlay and Seasonal Strategy DOMEs can provide information to set up baseline management and climate simulations over multiple years, and to set up management associated with Representative Agricultural Pathways (RAPs) or climate change adaptation analyses. In these cases, the soil, climate, and management regimens in DOME files would override existing recorded management and replace those data with the prescribed regimen.

Linkage files are used to associate each entry in the survey data (farm site and season) with one or more DOMEs. The QuadUI utility reads the The Field_Overlay and Seasonal_Strategy DOME files are combined with archived survey data (Survey_Data files) and used by the data translators to produce model-ready crop model input files for multiple crop model. DOMEs are applied in the order listed in the linkage file (each DOME name separated by a “|” symbol).

ACMO files contain a select set of outputs from crop simulations, with metadata describing the simulation. The ACMOUI application is used to generate ACMO files. Current ACMO translators are available for DSSAT and APSIM.

Data templates for survey and DOME inputs are available for download from the AgMIP GitHub site (github.com/agmip/json-translation-samples). These templates contain headers which correspond to variables in the ICASA Master Variable list for which precise definitions and units are listed. Definitions and units are replicated in the templates as comments to help guide the user to the correct form of the input data. Templates can be extended to include additional survey data by consulting the complete list of ICASA variables at www.tinyurl.com/icasa-mvl . The short name “Code_Display” is recognized by the AgMIP input translators for each ICASA variable.

Dome functions can be added to the DOME templates as needed. These functions are documented fully on the AgMIP research site at http://research.agmip.org/display/itwiki/The+DOME .

Examples of data which have been formatted into MS Excel files, then translated to harmonized format can be found on the AgMIP GitHub site (github.com/agmip/json-translation-samples). In each sample folder, raw data are stored in a “Raw” sub-folder.

Software for AgMIP RIAs

All AgMIP software tools are developed as open source projects. Applications can be downloaded from tools.agmip.org/ and source code from github.com/agmip.

QuadUI is a desktop utility that reads survey, cultivar, weather, DOME and linkage files and translates to model-ready formats. In addition to model input data, the utility produces aceb, dome and alnk files, ready for archiving in the AgMIP Crop Site Database. An ACMO metadata file is produced, which is used by ACMOUI to produce ACMO files.

ACMOUI combines the output files produced by crop models with the ACMO metadata created during the data translation phase by QuadUI and produces an ACMO.csv file. These files can then be archived on the Crop Site Database and are permanently linked to the survey data, DOMEs, weather data and cultivar files used to produce the outputs.

ADA is a Windows desktop utility which converts Microsoft Excel files into comma-delimited files (one per worksheet), zipped and ready for input to QuadUI.

AgMIP Workbench. This tool helps the AgMIP RIA crop modeler to validate each crop simulation dataset (consisting of a crop-region combination) and package these data for archive on the Crop Site Database.

Aceb Viewer allows the user to see data in the harmonized aceb files.

AgView is an application which performs various plotting functions for RIA, including box and whisker plots for Core Question visualization, CTWN plots, historical analysis plots (probability of exceedance) and variable correlation scatter plots.

AgMIP Climate scenario generation tools is a group of R scripts to generate scenario climate data file for crop model simulation.

Directory structure

The following list shows the recommended directory structure for each RIA crop modeling dataset, representing a single crop in a single region. This pattern should be followed for each crop - region combination. For each crop, data should be organized by the seven crop simulation data sets required in the Regional Integrated Assessment (labelled CM0 through CM6 below).

CM0-Historical

a) **Survey data** contains survey data plus soils data. Weather data are provided separately. There should be only one set of survey data which are used without modification for all analyses including future scenarios.
b) **Field overlay.** The data should be sufficient to allow simulation of historical conditions for multiple models. Typically, the field overlay DOME for historical conditions will be re-used without modification for all simulations. Additional field overlay DOMEs may be added for hypothetical management inputs for RAPs and adaptation packages.
c) **Linkage**

CM1-Current –This data set uses the survey data and field overlay of the Historical simulation.

a) **Seasonal Strategy**
b) **Linkage**

CM2-Future –This data set uses the survey data and field overlay of the Historical simulation. Sub-directories may be used for each climate scenario.

a) **Seasonal Strategy.** The Seasonal Strategy DOMEs used to simulate future climate conditions and current management should be the same as for simulation set CM1, except that the climate ID and the atmospheric CO_2 levels are specified for each climate scenario modeled. There will be one seasonal strategy file for each climate scenario
b) **Linkage.** A separate linkage file is needed for each climate scenario to connect survey data to the appropriate DOMEs.

CM3-Current, adapted –There should be one directory for each climate adapted management package (e.g., CM3-A1, CM3-A2, etc.). Adaptation packages for current climate conditions may differ from those for future climate scenarios. Modifications to the survey data for climate adapted management should be done through DOMEs.

a) **Field overlay (optional)** DOMEs may be needed to modify data originally provided in the survey data to impose management elements of the adaptation package. These could be used to indicate changes to soil properties or to use different cultivars. Separate soil data may need to be provided, but these should be given unique SOIL_IDs, separate from the original data. (For example, drought resistant cultivar traits have been simulated by using modified soil traits. In this case, the soil ID should be different than the original soil data.) Modified cultivar data should be included in the separate model-specific cultivar data directory with unique names.

b) **Seasonal Strategy (optional)** It may be possible to re-use the CM1 Seasonal strategy files, depending on the adaptation package modeled.

c) **Linkage**

CM4-Current, RAP –Multiple RAPs should be handled in separate directories (e.g., CM4-RAP1, CM4-RAP2, etc.).

a) **Field overlay (optional) -**

b) **Seasonal Strategy (needed)** It may be possible to re-use (modify) the CM1 Seasonal strategy files, updating for management depending on the RAP package modeled. Current climate.

c) **Linkage**

CM5-Future, RAP –Data relevant to each RAP scenario should be maintained in separate directories (e.g., CM5-RAP1, CM5-RAP2, etc.). Under each RAP directory, multiple climate scenarios may be stored in separate folders.

a) **Field overlay (optional)**

b) **Seasonal Strategy (needed)** Must use the same as the CM4 Seasonal strategy file, which specifies management depending on the RAP package modeled. But using future climate.

c) **Linkage**

CM6-Future, RAP, adapted –Data relevant to each RAP / Adaptation scenario should be maintained in a separate directory (e.g., CM6-RAP1-A1, CM5-RAP2-A2, etc.). Under each RAP directory, multiple climate scenarios may be stored in separate folders.

a) **Field overlay (optional)**

b) **Seasonal Strategy (needed)** Start with the CM5 Seasonal strategy file, which specifies management depending on the RAP package modeled, but modified to a climate-adaptation. Uses future climate.

c) **Linkage**

CTWN – Sensitivity Analysis files. This analysis is done using a single farm survey and the same field overlay, linkage, and seasonal strategy files used in the CM1 analysis.

a) **Single farmer survey file**

b) **CTWN batch DOME**

Weather – All weather data should be put in a separate weather directory. Simulation data sets CM0, CM1, CM3 and CM4 share the current climate conditions weather data. (The exception to this rule is when the surveyed data year falls outside the 1980 – 2010 range of the current climate weather data and the historical simulation data set will have a separate weather file.) Each weather data file should contain the climate ID. Sub-directories may be used to separate climate scenario data if many weather stations are used. Note that QuadUI accepts climate data in comma delimited format (csv), .agmip format and DSSAT WTH format; data must be in zip archive regardless of format provided.

Cultivar – Model-specific cultivar data files should be put in a cultivars.zip file with an internal directory structure which reflects each appropriate model, as shown in the WinZip example in Figure A3.2. DSSAT cultivars must be put in a folder “dssat_specific” and APSIM cultivars must be put in a folder “apsim_specific”.

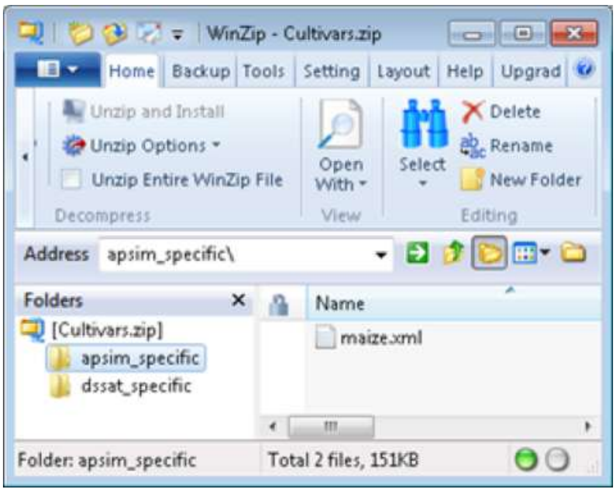


Figure A3.2. Organization of model-specific cultivar data in a zip file.

File naming conventions

In order to keep track of the many different management and climate scenarios modeled, the following file naming conventions should be used so that each data file fully describes its contents and the correct file can be chosen for each translation and simulation.

Crop modeling data:

File_type-Region-Crop-ClimID-RAP_ID-MgmtID.ext
Examples:
Survey_data-REG1-Maize.xlsx (measured field conditions do not include climate or management id)
Field_Overlay-REG1-Maize.xlsx
Seasonal_strategy-REG1-Maize-4IFA-0-0.xlsx (current management)
Seasonal_strategy-REG1-Maize-4IFA-0-A2.zip (adaptation scenario)
Seasonal_strategy-REG1-Maize-4IFA-R4-A1.zip (RAP and adaptation scenario)

ACMO File Naming Convention:
ACMO-*Region-Crop-ClimID-RAP_ID-MgmtID-CropModel*.csv
Example:
ACMO-REG1-Peanut-4IFA-R5-A2-DSSAT.csv
These files are automatically named by ACMOUI.

Metadata

The final product of the crop simulations are the ACMO files. These files will be archived in the Crop Site Database and made available for download or for use in analysis and visualization in the AgMIP Impacts Explorer. Complete metadata to describe each simulation must be included in the ACMO files and these metadata are passed through from DOME files. These metadata are particularly important to identify the climate ID for all climate scenarios and the management ID for the adaptation packages. The Climate ID will be assigned in accordance with the Climate Team protocols and should match the names of the daily weather files generated by the Climate Team. The MAN_ID metadata variable must be used to distinguish between current management and adaptation packages. For scenarios which do not include an adaptation package, MAN_ID should be left blank. Similarly, for scenarios with no RAPs, the RAP_ID should be left blank. The Region, MAN_ID and RAP_ID values must be co-developed with the Economic modeling team such that crop modeling metadata and filenames are associated with the corresponding TOA-MD metadata and filenames. Table A3.3 lists metadata associated with each DOME file.

Table A3.3. Metadata included in DOME “INFO” section:

Metadata	Sample value	Definition
REG_ID	REG1	Region name
STRATUM	2	Assigned by econ modeling teams
RAP_ID	4, 5	Code for RAP being modeled (leave blank if no RAP). Note that the crop models use integer values to identify RAPs, but the economic models may use variations, such as 5.1 and 5.2.
MAN_ID		Code for climate adaptation package being modeled (leave blank if no adaptation package)
RAP_VER		Version code for RAP ID (leave blank if no version)
CLIM_ID	IKFA	Climate ID for scenario being modeled
DESCRIPTION	P1	Short descriptive text for this DOME file (important if there are multiple DOMEs for this scenario)

The DOME name is derived from the values of metadata provided. In this case, the DOME name used in the linkage file would be “REG1-2-R4---IKFA-P1”, which is the concatenation of all metadata fields, separated by hyphens**. Because of this DOME naming convention, it is important that hyphens are not used in the metadata values (i.e., “P1”, not “P-1”)**.

Procedures for Creating Crop Model-Ready Input Files for Survey Fields

Start with generating data for the historical simulation (CM0) which is the simplest case and uses the survey data and a field overlay, but no seasonal strategy DOME. An iterative procedure is usually required to get the correct format and units for the survey data and sufficient field overlay information to produce reliable simulations for multiple crop models.

A crop model simulation "roadmap" can help track which files are used for each simulation set. An example is provided in Table A3.4. In this case the base survey data and field overlay DOME are used for every simulation, without modification. Weather data are supplied based on the climate scenario being modeled. Each simulation, except the historical simulation, requires a seasonal strategy DOME to generate multi-year simulations. Each simulation requires a linkage file to link the survey data to the appropriate DOMEs. The table also lists the associated folder in which the file resides, so that the crop modeler can easily find the file when running QuadUI for data translation.

Additional field overlay DOMEs can be used to describe management imposed by a RAP or an adaptation package. In this example, additional field overlay DOMEs were used for the CM3 adapted management for current climate conditions, the future technology management associated with a RAP (CM4, CM5 and CM6), and with the future climate adaptations (CM6).

Table A3.4. Sample "roadmap" of files used in Crop Modeling analyses. The survey data and field overlay files are used in all simulations.

File Name	CM0 Historical	CM1 Current	CM2 Future	CM3 Current, Adapted	CM4 Current, RAP	CM5 Future, RAP	CM6 Future, RAP, Adapted
Survey_data-Region-MAZ.zip	X	X	X	X	X	X	X
Weather-Region-0XFX.zip	X	X		X	X		
Weather-Region-IxFA.zip			X			X	X
Field_Overlay-Region-MAZ.zip	X	X	X	X	X	X	X
Field_Overlay-Region-MAZ-0XFX-0-Ax.zip (optional)				(X)			
Field_Overlay-Region-MAZ-0-Rx-0.zip (optional)					(X)	(X)	(X)
Field_Overlay-Region-MAZ-X-0-Rx-Ax.zip (optional)							(X)
Seasonal_strategy-Region-MAZ-0XFX-0-0.zip		X		X	X		
Seasonal_strategy-Region-MAZ-IxFA-0-0.zip			X			X	X
Seasonal_strategy-Region-MAZ-0XFX-0-Ax.zip (optional)				(X)			
Seasonal_strategy-Region-MAZ-IxFA-Rx-0.zip (optional)					(X)	(X)	(X)
Seasonal_strategy-Region-MAZ-IxFA-Rx-Ax.zip (optional)							(X)
Linkage-Region-MAZ-historical.csv	X						
Linkage-Region-MAZ-0XXX-0-0.csv		X					
Linkage-Region-MAZ-IxFA-0-0.csv			X				
Linkage-Region-MAZ-0XFX-0-Ax.zip				X			
Linkage-Region-MAZ-0XFX-Rx-0.zip					X		
Linkage-Region-MAZ-IxFA-Rx-0.zip						X	
Linkage-Region-MAZ-IxFA-Rx-Ax.zip							X
Climate_Batch.csv			X			X	X

Notes: For current climate conditions, CLIM_ID = "0XFX" (for this sample).
For future climate scenarios, CLIM_ID is represented generically as "IxFA", where the "x" represents the GCM used for the analysis.
Red highlight indicates files that are repeated for multiple Climate scenarios / GCMs.
Adaptation scenarios are Identified by "Ax", which represents the ID of the adaptation package.
All file names use the convention: *File_type-Region-Crop-ClimID-RAP_ID-MgmtID.ext*

Figure A3.3 presents the workflow for producing a single simulation dataset for the AgMIP Regional Integrated Assessment. The steps correspond to the more detailed descriptions below. In summary, raw data, weather data, linkage files and DOME files are used as inputs to QuadUI, which translates the data, first to ACE format, then to model-ready formats for multiple models. Model simulations are done manually. ACMOUI is run to gather crop model outputs and generate harmonized ACMO files, using the ACMO metadata file created by QuadUI.

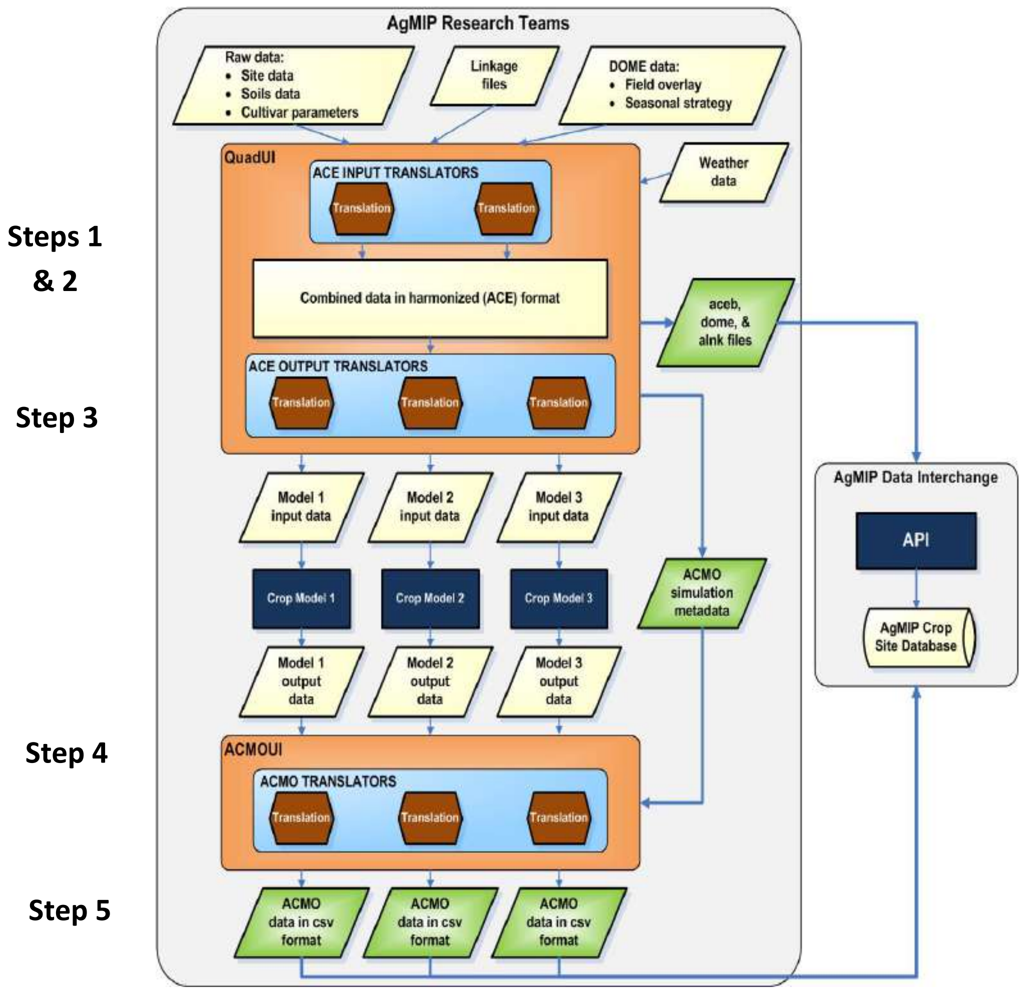


Figure A3.3. Schematic data flow diagram for AgMIP RIA Crop modeling data translation using QuadUI and ACMO UI applications .

Step 1. Gather, assemble and enter data (survey and expert)

- Download data translation tools from http://tools.agmip.org/
    - QuadUI – desktop application for data translation
    - ADA – converts from Excel to csv format for import to QuadUI
    - ACMO_UI – converts model output to ACMO format
    - Sample spreadsheet templates for survey data and DOME data ICASA Variables List– list of variables to extend the survey data template, if needed (http://tinyurl.com/ICASA-MVL)
- Enter survey data into one of the survey data templates, Additional columns can be added to the survey data import template for those data. Note that dates are entered using ISO compliant format: YYYY-MM-DD. Note also the units for all variables. Conversions can be done in the spreadsheet, and unneeded data “commented out” as shown in the template files.

- If some data are missing, one or more Field Overlay templates should be used to FILL in the missing data (examples are dates of N fertilization or manure application). There can be multiple field overlays, if soils and soil initial conditions vary across farms.
- Visit with Soil Scientist experts from the region: Find the appropriate soil for each farm (linking to latitude-longitude or village information), and enter the soils information by soil layer in the soil tab in the Survey_Data file. The soil name is also listed in the field section of the Survey_Data file.

Step 2. Save Survey_Data and Field_Overlay Data to csv format

- Using the ADA utility, save Survey_Data, and field overlay sheets in comma delimited (csv) format. Caution: Do not open the *.csv files again with Excel, as they ARE NOT true spreadsheets and do not correctly convert back into the correct date formats.

Step 3. Translate data files to model-ready formats

- Run QuadUI by double-clicking on the QuadUI.bat file. Respond to the on-screen requests for location of the following data as depicted in Figure A3.4.
  - survey data (zipped csv),
  - weather data (zipped csv, .AgMIP or WTH files),
  - cultivar data (optional, zipped model-specific files),
  - soil data (optional, zipped csv),
  - field overlay DOMEs (optional, zipped csv),
  - seasonal strategy DOMEs (optional, zipped csv),
  - DOME linkage files (csv, not zipped)
  - Batch DOME file for translating multiple GCMs or for CTWN sensitivity analyses.
  - Output file location (optional)
- QuadUI will generate files for running crop models, i.e., Files X, A, SOIL.SOL, *.CUL, *.WTH for DSSAT, and .APSIM and met files for APSIM. In the case of DSSAT or APSIM, simulations can be run by double-clicking the DOS batch file that is created with the translations.

Figure A3.4. QuadUI screenshot showing selection of raw data, DOME data, Linkage file, Output directory and Model formats.

Step 4. Check and correct missing/invalid model input data and run simulations

- Run the crop model.
- Troubleshooting
  - DSSAT: Look at the Error.OUT and the Warning.OUT files.
  - APSIM: Load the simulation and view the log. Also review the *.sum files.
  - Look for missing climate or cultivar files found,
  - Look for missing data such as sowing date or plant population. Typically this means that these were not supplied in the DOME or that the linkage file does not correctly link the field overlay to the experiment or field.
  - Revise the Survey_Data and Field_Overlay files as needed.
- Evaluate the outputs. In DSSAT, look at the Evaluate.Out file which will list both the simulated and the observed yield. In APSIM, there is a single line output for each simulation. The APSIM-simulated yield values will need to be

aggregated (assembled) into one file. The observed yields are in the Survey_Data file and will need to be matched per field.

Step 5. Create AgMIP Crop Model Output (ACMO) File for use by Economic Team Members

The ACMO file is partially created by QuadUI at translation time in the form of the ACMO_meta.dat file which contains metadata and key input data for all of the survey farms. Running ACMOUI, a desktop utility, will complete the ACMO file with the selected crop model simulated outputs.

Note that the ACMO files contain raw simulated results for each field, not aggregated or adjusted in any way. This will ensure integrity of both inputs and model outputs.

Notes on Use of Field_Overlay Files

- Function and Purpose of multiple Field_Overlay files
  - Fill in data required by crop models but are rarely available in farm survey data, such as initial soil water, initial soil nitrate and ammonium, soil organic carbon pools (SOM3 for DSSAT-CENTURY, and inert SOC for APSIM), and rooting depth.
  - Fill in needed data missing from farm survey, such as root residue from prior crop, surface residue from prior crop, sowing date, sowing depth, plant population, amounts and dates of fertilizer or manure applied.
  - Link to cultivar ID and model specific cultivar ID
  - Set automatic sowing rules for each field in the survey, if planting dates were not recorded.
- Where to get Field_Overlay information? First, DO NOT use crop model defaults, as the model defaults may be incorrect for your location and differ among crop models. Often defaults use zero or unity values when not appropriate and these are not region-specific. Secondly, this must be done in close collaboration with local agronomists and soil scientists who know production practices for the crop and region in question.
- Translating RAPS into management DOMEs (RAPs can led to improved crop and soil management practices including improved genetic technology). Specifics include:
  - Auto-sowing, possibly modified for earlier/shorter sowing window because of better machinery
  - changed plant population,
  - improved or alternative crop cultivar,
  - changed N fertilization,
  - increased prior root and surface residue (because of better fertilization-population-cultivar)
  - other adaptation strategies, as needed
  - ranges of likely missing input information.
  - Soil survey information (linking to latitude-longitude coordinates for field).
  - Country-wide statistics (amount of N fertilization per hectare).
  - Soil organic carbon and SOM3 (or inert SOC) pools to mimic the low non-fertilized non-legume yields for the region (requires knowledge of unfertilized yield for region). Take the mineral nitrate and ammonium from the values simulated at the end of the "prior" season.
  - Make sure that the assumed values that you use in the Field_Overlay file are consistent with all of the expert knowledge and soil survey information, and document how these values were developed.

Notes on Use of Seasonal Strategy DOMEs

A Seasonal_Strategy DOME file allows the single year survey data to be used for multi-year simulations for current and future climate scenarios, both with and without RAPs and Adaptation Packages. Examples of DOME functions for seasonal strategy are:

- Auto-sowing rules,
- Links to future scenario Climate IDs,

Guidelines for Analysis of Crop Model Simulated Outputs for Matched Fields

Crop modelers should analyze model outputs prior to use of the data in the regional economic analysis. This is very important to ensure quality control of the process and that crop modelers are able to understand the variability in results. It is also important that crop modelers will be able to conclude that simulated yields are reasonable representations of water and nitrogen-limited yields, recognizing that other factors, such as other soil nutrients and pests, are likely to contribute to actual yields in a region and that these factors could vary considerably over space and time. We have provided suggestions for analyzing crop model outputs, including computation of means, distribution of observed and simulated yields, computation of mean bias between observed and simulated yields, and analysis of outliers.

- Place simulated yield and observed yields into a spreadsheet, computing means and standard deviation. Compute bias of the mean observed yield divided by mean simulated yield. We do not recommend computing bias of individual fields if there are any zero simulated yield values, as that will give error.
- Rank the observed yields and simulated yields from high to low and compute cumulative probability distributions of observed and simulated yields. (Or use AgView to generate the plots.)
- Attempt to identify outliers and reasons for high mean bias as well as large differences between cumulative distributions of simulated and observed yields. These analyses may help crop modelers critically evaluate some of the input assumptions in the Field_Overlay file, for example, relative to the information from regional agronomists and other sources that were used to set the values. If there is a large bias, it would be good to review the inputs and results with agronomists. Be cautious in types of calibration for reducing the bias and base this on knowledge of the soils, initial conditions, and cultivars used. This is intended to improve the reliability of the process and results. These analyses may be useful in reporting and in publishing actual crop model results, although the economists will only be using change ratios described earlier. Some ideas to consider as you analyze results are:
    - If bias (observed over simulated) is dramatically different from 1.00 (for example 0.5 or 1.5), there may be problems in Field_Overlay assumptions. Bias is driven by the mean simulated and observed yields. For example, a high bias of 1.5 or more (model simulates low) could indicate that soil N availability (SOM3, initial nitrate, initial ammonium) or soil water availability (initial or capacity) is not high enough. A low bias of 0.5 (model simulates too high) could indicate too much soil N availability or too much water availability.
    - The full range of the cumulative distribution is driven not just by the management and climate, but also by the extent of range of initial nitrate, ammonium, SOC, SOM, DUL-LL, and initial soil water found across all the farms. If that range of inputs (and soil variability) is small (because of inadequate Field_Overlay entry), then the simulated distribution of yields could be insufficient.
    - Strong left tails in simulated distribution (or observed) are indicators of crop failures (zero and very low yields). If left tails is too strong in simulated, then you may need to increase initial soil water content to reduce the instance of simulated germination failures, or increase rooting depth or DUL-LL to minimize crop failures during reproductive growth.
    - Strong right tails in simulated or observed distributions are indicators of high yields. If simulated right tails are too strong (or too little) where the water and N stresses are minimum, one can make the case that genetic yield potential of the cultivar is too high (or too low). Farmers' cultivars are often not as good as those used in research experiments.

These "indicator" problems are given, not for the purpose of re-calibrating the crop models to fit the distribution, but for the purpose of highlighting the need for obtaining correct Field_Overlay information in the first place.

Appendix 4

Fast-Track Activities to Demonstrate Integrated Framework

Because of the coordination needed among different science disciplines in the AgMIP regional integrated assessment efforts, each new AgMIP regional team should perform a “proof of concept” assessment on a fast track to help everyone on the regional teams to understand their roles and the interactions that must take place among different disciplines. Accomplishing this will ensure that the mechanics of the process are understood and functioning, at which point it will be easier for all teams to proceed with their further, more detailed assessments.

To do the fast track integrated assessment exercise, the team should select only one sub-region, one crop, one crop model, and one climate site location; then simulate crop yields using the historical climate data for that one location and also simulate crop yields for one climate change scenario for the time period of 2040 – 2069 using the methods described above. Additional details are:

a. The entire regional team should identify one small sub-region where the fast track assessment will be performed. Ideally, the sub-region should be an area in which household survey data are available with at least one climate data site within the area and where there are experimental data available in or nearby the area that can be used for calibrating one (or more) crop models.
b. The crop modelers will parameterize the crop models using available data from experiments, if this has not already been done. This will provide parameters for cultivar types that are currently being used in the region.
c. The economists should describe the site characteristics, including a map showing the farms and including management and farm characteristics.
d. Economists will provide the socioeconomic data, including farm site locations, to the crop modelers so that they can assemble the needed crop model inputs to run the crop models. Ideally, the socioeconomic survey data would have data on crop management practices (planting date, N application amounts) and on crop yield. For example, there may have been 80 farms surveyed with such data, and those farms would be used to assemble crop model input data for each farm.
e. The climate team members in the region will prepare and quality-control the historical climate series for one station in the region. This site will act as the baseline climate series for all crop modeling and analysis in the fast-track (including surrounding farms), and will also serve as the basis of one climate change scenario generated using the basic delta method that represents projected GCM changes. These climate series may be used in the crop model runs to compute the impacts of climate change (assuming no adaptation for this fast track).
f. The regional crop modelers will prepare input files for running one selected crop model (DSSAT or APSIM preferably) for each farm location in the selected study site/area. This includes assembling representative soils for the sites. The crop modelers will simulate each of the fields in the farm surveys, analyze simulated results relative to observed yields to evaluate reliability of results, and prepare a model output file ACMO) for documenting model inputs and outputs for use by economists in the TOA-MD analyses.
g. If socioeconomic data do not include farm site yields, then the crop modeling team members will use the procedures for calibrating and evaluating crop models for use in simulating mean yields for district or other administrative unit (see section 6c in this handbook). This alternate procedure will provide crop models ready for use in the region with estimates of average bias.

h. The crop modelers will then simulate yields for each of the farm sites in the selected area using historical climate data (1980-2009 planting years) and repeat the simulations using the one selected climate scenario's climate file. The modelers will assess yield results, evaluating how reasonable they are and produce an AgMIP Crop Model Output file (ACMO) that will be used by the economists in the TOA-MD analysis.
i. The economic team members will take crop model results and use the TOA-MD model to analyze the impacts of the climate change scenario on the distribution of economic impacts for the area using the relative yield model described in appendix 2.
j. The entire team will meet to evaluate the entire process and to discuss and interpret the results.
k. After the proof of concept study, the team will be ready to design its assessments of impacts and adaptation options based on the RAPs, more advanced climate scenarios, and a better representation of climate and crop model uncertainties.

Contents

Knowledge Co-Production through Iterative Engagement: Doing WITH vs. doing TO stakeholders 3
Tips for improving stakeholder engagement toward knowledge co-production 4
The Purpose(s) of Engagement in AgMIP 6
Stakeholder Prioritization: The Interest-Influence Grid Activity 7
Needs Assessment as an On-Going Process 7
Planning a Stakeholder Meeting/Event 8
Tips on AgMIP PowerPoint Presentations 8
Meeting/Event Listening & Reflection Tool 9
The Team "Debrief" 10
Event Report Outline 11
The value of keeping track of engagement 11
Caution: Document stakeholder feedback accurately! 11
Planning a Meeting vs. Developing (& Documenting) an Engagement Strategy 12
Stakeholder Mapping 13
RRT Emerging Insights 14
Elicitation & Dialog in AgMIP: Questions to catalyze climate conversations 14
Assessing & Improving Key Messages *with* Stakeholders 15
Policy Briefs, Fact Sheets & Impacts Explorer: Tailoring materials for different Audiences 16
Background on the AgMIP Stakeholder Unit (SU) 17
Goals of the SU 17
Stakeholder Liaisons: A vision for expanding capacity in AgMIP 17
SL Role 17
Rationale 18
SL Official Job Description/ Function 18
Characteristics of a stakeholder specialist 18

Knowledge Co-Production through Iterative Engagement: Doing WITH vs. doing TO stakeholders

When researchers and decision makers co-produce scientific evidence they engage early and often around research questions, methods, scale, and time frames to ensure that the supply and demand sides of the process speak to each other. True knowledge co-production requires that scientists move beyond interactions designed to coerce, educate, inform or consult stakeholders.

In such a scenario, stakeholder needs assessment is on-going and iterative, which suggests building upon or within existing partnerships and networks. Existing relationships between researchers and decision makers offer excellent entry points for linking evidence to decision making processes. Designing for iteration demands team foresight and associated step-by-step planning, as well as adaptively managing the engagement process. Teams that adopt a "learning-by-doing" approach will optimize success. Figure 1 illustrates the approach to stakeholder engagement that was adopted in Phase II of AgMIP. Teams were encouraged to move through the following steps, learning iteratively over time Step 1: Create and plan, Step 2: Prepare for convening, Step 3: Engage, Step 4: Understand and respond, Step 5: Learn and adapt, Step 6: Repeat & refine

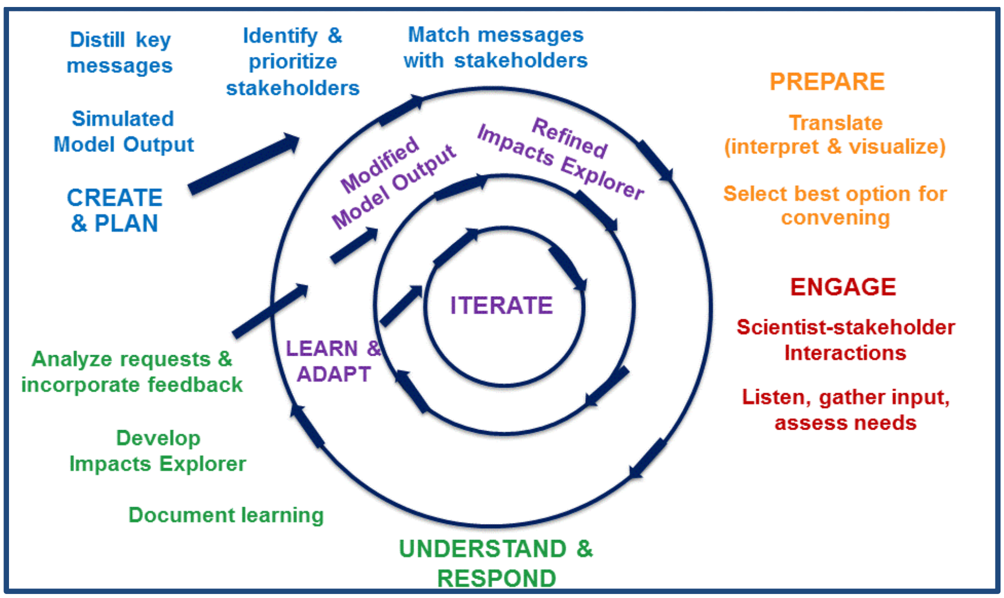


Figure 1. Process diagram of stakeholder engagement in AgMIP Phase II

The *practice* of stakeholder engagement includes the ability to:

- Identify potential stakeholder decision contexts and policy platforms
- Prioritize target audiences
- Leverage partnerships to optimize entry points
- Articulate the specific purpose of engagement
- Establish mechanisms for team planning, resource allocation, documentation & learning
- Interact with stakeholders to link research goals with stakeholder interests
- Frame and visualize research results according to stakeholder decision contexts
- Refine key messages collaboratively with stakeholders and tailor results for specific audiences
- Adapt research directions to maximize relevance to stakeholders
- Develop information briefs that feature team innovations and successes

Tips for improving stakeholder engagement toward knowledge co-production

The following list of "TIPS" was gleaned from insights during AgMIP Phase II.

1. **Reflect on Motivation**
   - Why engage stakeholders? If the answer is for better data, then stop.
   - Do we understand the costs associated with co-development? How willing are we to pay those costs?
   - Revisit the following concepts:
     i. Power
     ii. Partnerships
     iii. Incentives
     iv. Attribution

2. Define exactly **what is meant by co-development** and by whom?
   Where would the approach to co-development fall on this scale?
   - Coercing
   - Educating
   - Informing
   - Consulting
   - Engaging
   - Co-design
   - Co-production

3. Define **the primary target audience** for the investment in RIA protocols and plan for delivering to THAT audience. Change goal posts only in mutually agreed upon ways.
   - Other modelers
   - IPCC
   - Regional bodies engaged in climate change planning and response
   - National bodies engaged in climate change planning and response
   - Sub-national bodies engaged in climate change planning and response
   - Implementing agencies
   - The donor

4. **Build engagement (and learning) functionality** into the multi-disciplinary modeling team
   - Hire a stakeholder liaison or catalyze latent capacity within the team (Consider key skillsets and network embeddedness. Functions include managing facilitation, documentation, coordination, and relationships)
   - Emphasize teamwork: Clarify within-team roles and develop mechanisms to foster integration and learning
   - Learn-by-doing: Prioritize regular exchanges across disciplines for on-going reflection

5. **Identify and come to grips with the trade-offs** associated with inviting others into the scientific process.
   - How far are we willing to go to meet others' needs?
   - How to prioritize feedback and response?
   - Whose comments, needs requests matter most and how to negotiate them?

Prior to bringing in partners, collaborative leadership planning provides an opportunity to build a shared understanding about the purpose for engagement and to clarify roles and expectations for specific contributions of each partner and team member. Discuss the following questions BEFORE proposal development, budgeting and activity allocation.

- **Beliefs & Attitudes:** What personal beliefs about power and collaboration toward outcomes do we have? Co-development means bringing others in at the outset; are we ready and willing to do that?
- **Goals & Expectations:** Is our goal a product or a relationship? What outcomes do we expect from this project/process of co-development? How flexible are our modeling systems? How will we respond when the demands of stakeholders fall outside project goals?
  - Plan a process of negotiating outcomes with potential co-developers.
- **Audiences:** Who would, could, or should be engaged and for what; what incentives are there for others to engage with us? What decision contexts and policy platforms can we access? What aspects of the project resonate with stakeholder interests?
- **Outcomes:** What networks and relationships do we want to develop from this process and why? What is our timeframe? Are we committed beyond the project funding cycle?
- **Feedback:** What kind of feedback or input are we hoping for and what will we do with it?
- **Purpose:** What objectives can we develop that will combine the previous 4 points? (Define a clear purpose for engagement—when, where and why is it co-development?)
- **Purposeful Design:** What type of scientist-stakeholder interactions are most appropriate considering #6. Who should be in the room during each event/interaction? What kinds of activities will allow for cross-boundary dialog and knowledge exchange? What pre-work is needed among modelers?
- **Documentation & Sharing:** How are we going to document these activities and outcomes and share them (within the team, for leadership, with other modelers, with the donor, etc.)?
- **Roles:** What are the roles for various role players and who will take responsibility for highlighting and managing new areas of focus: facilitation, documentation, coordination, relationship management?
- **Ownership:** How will this project improve the degree of ownership that OTHERS have of the research products—getting them used in decision making? What sort of follow up do we envision with these participants?
- **Improved Research:** How will this project improve the quality of our science? (How will we track our own adaptation?)
- **Track Change:** How will we evaluate this undertaking?

The Purpose(s) of Engagement in AgMIP

THE MANY PURPOSES OF STAKEHOLDER ENGAGEMENT IN AGMIP (as perceived by teams) Identified by AgMIP participants at the regional meeting in Zimbabwe, June, 2016 in response to the question: ***What are the reasons for engagement in AgMIP?***		
To understand needs	Understand conditions and perceptions of RAPS	To develop adaptation strategies
To produce a product	Internet Exploder	To increase awareness of AgMIP and climate change
To ameliorate current product	Explore adaptation opportunities	Propagate
Learn and educate	Share information and match ideas	Funding
Share	Contextualize research	Contextualize research
Build consensus	Ensure effective use of outputs	Ensure effective use of outputs
Get feedback	Data collection and data validation	Data collection and validation
It is a request from the donor	Bridge gaps	Buy-in for agreement
Needs assessment	Improve scientific output	Improve decision making
Reflection of applicability	Improve livelihoods and reduce poverty	Spread knowledge
To influence policy	Share information	To understand smallholder view of future world
To improve communication	Understand conditions and perceptions of RAPS	Explore adaptation opportunities
To explore research questions	"Internet Exploder"	Share information and match ideas
Improve scientific output	Improve livelihoods and reduce poverty	Bridge gaps
Share information	Convince	Simplify results
Increase confidence	Spread knowledge	Spread knowledge
Data collection and validation	Convince	

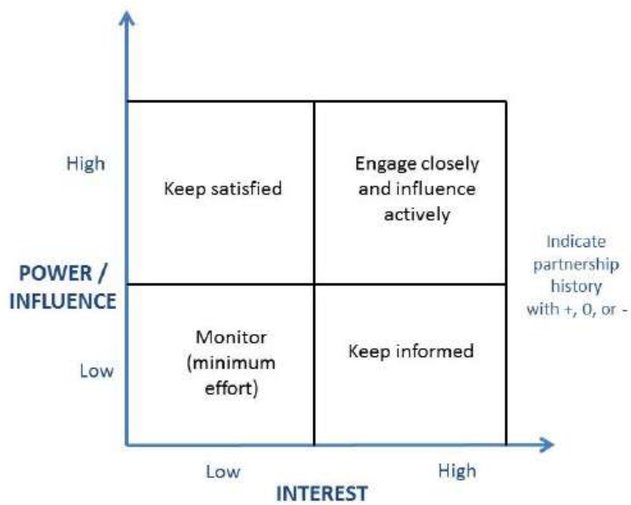
Engagement in AgMIP can occur around the following main purposes

- Seeking inputs for Adaptation Packages and RAPs (data collection to enhance contextual relevance of modeling efforts)
- Communicating AgMIP Phase II Results (for co-interpretation, validation, discovery and learning)
- Refining key messages for the development of the decision support systems
- Managing partnerships (for project visibility and to link outputs or components and methodology with relevant decision & policy processes and entry points; to connect AgMIP Teams to new collaboration partner opportunities beyond AgMIP)
- Periodic reporting to home agencies

Stakeholder Prioritization: The Interest-Influence Grid Activity

In June 2016, teams were asked to arrange stakeholders from Phase I on an influence/interest grid (by name & function) and to prioritize 3 key audiences for Phase II. They were asked to reflect on how to frame key messages from Phase I with different target audiences. Participants agreed that this activity should account for RRTs history with stakeholders. We suggest adding a +, - or 0 on the grid activity to signify the degree to which RRT has worked with stakeholder before (in addition to influence and interest).

Recognize that this grid is a snapshot and that these systems are dynamic – individuals and institutions are constantly changing. A quick version of this analysis could be done periodically as results emerge—to assess how stakeholder interest changes as findings and messages mature. At the end of Phase II, it might be valuable to conduct another similar exercise with each team to determine a focus for Phase III, IV, V…



Needs Assessment as an On-Going Process

Conventional project designs tend to situate "needs assessments" as an initial stage of projects with the goal of orienting activities. However, in reality, as partnerships mature over time, new needs emerge and novel ideas or opportunities reveal themselves. We view needs assessments as iterative and expansive as opposed to the one-time snapshot approach. Therefore, it becomes important to manage expectations during the course of project cycles with a view to long-term knowledge co-production. Teams can benefit from providing stakeholders with explicit feedback regarding the possibility of satisfying their needs. The South India team has innovated a mechanism for managing expectations by categorizing evolving stakeholder needs according to requests that are:

1. already being investigated in AgMIP Phase II
2. could be incorporated into Phase II modeling
3. are critical elements to build into a Phase III project and
4. will never be assessed using AgMIP methodologies, but could be met through other channels.

Consider inventorying stakeholder needs according to these four categories as part of your team's engagement documentation.

Planning a Stakeholder Meeting/Event

Prior to meeting with stakeholders, collaborative RRT planning provides an opportunity to build a shared understanding about the purpose for engagement and to clarify roles and expectations for specific contributions of each team member. Discuss the following 10 questions as a group:

1. What outcomes do we expect from this meeting/event?
2. What technical information do we want to share with stakeholders and why?
3. What kind of feedback or input from them are we hoping for and what will we do with it?
4. What objectives can we develop that will combine the previous 3 points? (Define a clear purpose for engagement)
5. What combination of activities (discussion groups, pair-work, brainstorming, powerpoint presentations, etc.) should be used to help meet the above objectives?
6. What is the best agenda or structure for this session?
7. How are we going to document these activities and outcomes and share them (within the team, for leadership, with other RRTs, with the donor, etc.)?
8. What are the roles for the stakeholder liaison, PI, and other modelers? Who will take notes?
9. How will this meeting improve the quality of our science?
10. How will this meeting improve the degree of ownership that stakeholders have of the AgMIP products—getting them used in decision making? What sort of follow up do we envision with these participants?
11. How will we evaluate this event?

Tips on AgMIP PowerPoint Presentations

The answer to question # 2 can guide the preparation of power point presentations.

- Consider reducing the number of slides! How much time will you have to present? Does this include time for discussion? Be selective about what you include in the presentation, knowing that you cannot convey every aspect of the project (nor should you try). ***What information is essential?***
    - Insert background information in reference slides that are “hidden” at the end of the presentation to review if stakeholders ask for more details.
    - If you are meeting a stakeholder group for a second or third time, include a slide that reminds the audience of previous events and associated outcomes (history of engagement slide).
    - Will the audience benefit from a slide that illustrates the AgMIP methodology (sequence of modeling)? How can this be simplified?
    - If you are hoping for specific feedback, include a slide with questions directed to the audience.
- Appropriately match content level to the stakeholder audience being targeted. Do not expect everyone to be an expert (avoid jargon and acronyms like GHGs, SSPs, RCPs). Do not underestimate your audience either!
- Encourage all team members to review the PowerPoint presentation well in advance of the meeting to ensure that information is being communicated as clearly as possible.
- Consider providing a one-page handout (include contact information and web links)

Meeting/Event Listening & Reflection Tool

The following issues can have significant impacts on the success of engagement activities. Pay attention to them in order to enhance your listening and maximize your observation during the meeting. Review these questions prior to any stakeholder event and reflect back upon them when your team meets to debrief. Lessons learned should be documented, shared throughout the team and incorporated into planning the next event.

- **PURPOSE/OBJECTIVES:** What are you engaging for? What are the objectives of the event/meeting?

- **PARTICIPATION:** Who attends the meeting? Were the *right* people in the room, considering what the team hoped to achieve? Pay attention to body language. Who dominates the discussions? Who is not heard?

- **FACILITATION:** Who did you engage or select as a designated facilitator? Watch and listen with eyes and ears toward opportunities (missed and captured) to enhance engagement through facilitation. How does the process work? What could have been different? (Agenda design, use of time, attention to introductions, format of presentations, visualization of results, management of discussion and stakeholder feedback, note taking, logistics, etc.).

- **SCIENCE TRANSLATION, INTERPRETATION & EMERGING THEMES:** How are presentations received? Are there any challenges with misinterpretations or misunderstandings? What raises concerns or creates confusion? Which aspects of AgMIP stimulate the most discussion? Is anything missing from discussion?

- **STAKEHOLDER NEEDS & FEEDBACK:** How familiar are stakeholders with the AgMIP project and results? What needs and interests do stakeholders express? What insights do stakeholders offer about a) inputs for adaptation packages or RAPs; b) AgMIP results /key messages? What questions do stakeholders ask? In which ways can stakeholder feedback inform AgMIP research and future modeling activities? Which contextual aspects (even if they cannot be included in models) deserve attention?

- **OUTCOMES:** To what extent are the objectives met? What do stakeholders get out of the meeting? What does the AgMIP team achieve? What kinds of follow up/next steps are suggested?

- **POLICY/DECISION ARENA:** Do you gain insights on the policy environment? What key mandates, and institutions, policies (or decisions) do stakeholders discuss? What are current sources of climate, agricultural and economic projection information? What new entry points / potential partnerships or opportunities emerge from the meeting?

- **PARTNERSHIP HISTORY:** What is the engagement history among stakeholders and AgMIP scientists? Considering a team timeline, where in the engagement process does this meeting fit? How does it build on previous meetings? How do previous interactions influence the meeting process and outcomes?

The Team "Debrief"

Shortly after the stakeholder event or meeting, teams are encouraged to "debrief." Debriefing is a powerful and simple tool. A debrief is a reflective discussion on what happened & why, as well as what was learned & its importance. A team debrief is essentially a structured learning process that can help align thinking and reveal key insights. Findings will help teams identify specific implications for future work.

Guiding Questions

1. What happened?
2. What did you notice? (Observations) What surprised you?
3. How did you feel before, during and after the event?
4. What are some key insights?
5. What was missing? What did not happen?
6. Considering what we set out to do: What went as expected and what turned out differently?
7. Were the goals clear to the audience? Were the presentations appropriate? Were instructions clear?
8. Could we have taken a different approach to achieve our goals more effectively and efficiently?
9. What type of follow-up seems most important?
10. What are some implications of this event for future work?

- **Facilitation of the debriefing:** You need somebody to keep people on track or you will get stuck answering question one or two. Give different team members the opportunity to practice facilitating the team debrief.
- **Participation in the debriefing:** Make sure all team members get a chance to offer input into the discussion. (Round Robbin works well to initiate discussions.)
- **Motivation:** A debrief is not the same as an evaluation. It should not be dreaded, overly critical or taken personally. Keep it brief and interesting! The list of questions above is not to serve as a check-off list, but rather to gently guide and promote meaningful reflection.
- **Documentation:** Reflections from each team member will be slightly different. Diversity matters! Take notes and consider adding insights to the event report.

Event Report Outline

Remember, ***"If it is not documented – it never happened!"***

Documenting detailed stakeholder feedback is a critical component of engagement. An event report should contain the following components:

1. Meeting Purpose & Specific Objectives
2. Location, Date, Duration etc.
3. Audience Description (Numbers of participants by stakeholder groups represented, history of interactions with the group - previous meetings)
4. Activities, Discussions and Presentations
5. Photos
6. Outcomes from # 4 - Include ***"quotes"*** from participants and a summary of key findings
7. Conclusions & Follow up – List action items (and deadlines) for next steps
8. Evaluation—need not be complex but should reflect participant assessment of the event
9. Appendices
    - List of participants, institutions, contact information etc.
    - Agenda

The value of keeping track of engagement

Consider why you are writing these event reports. Who is the event report for? Reports are valuable for many reasons, including

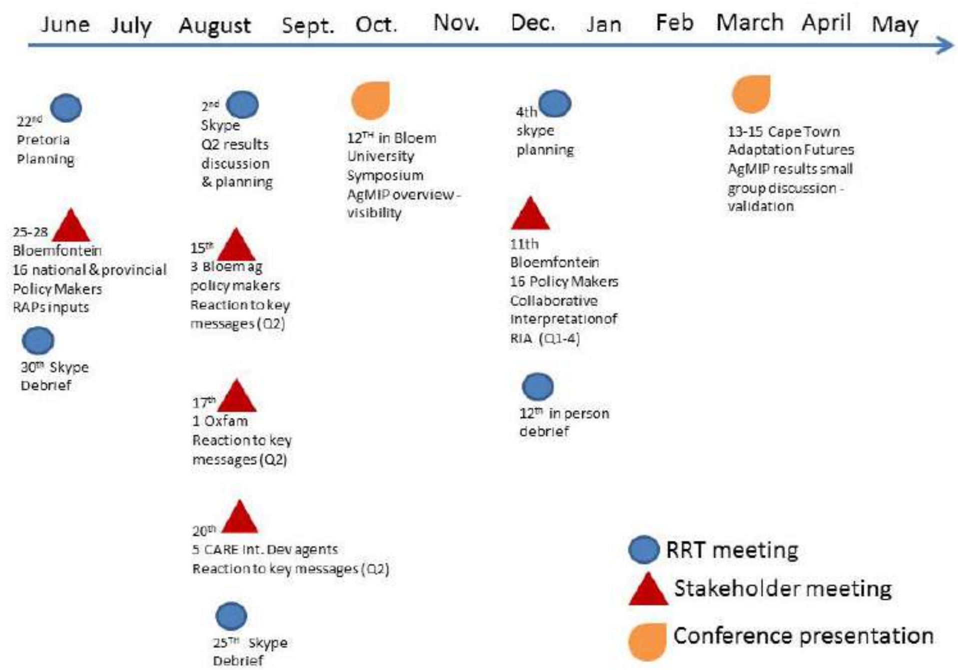
- accountability (to comply with contractual obligations)
- to store valuable information that the RRT can reference later (an institutional memory of engagement)
- to share progress with others and track change over time
- to plan follow-up activities
- to stimulate team discussion and learning
- to share with stakeholders for their own records and in gratitude of their time commitment

Caution: Document stakeholder feedback accurately!

- Although summaries of stakeholder input are valuable, they reflect the note-taker's own filtering process and personal biases. Therefore, we recommend that you document direct quotations (write the exact words people use, not your own interpretation). List all the questions that emerge.
- Make sure you have a <u>good</u> note-taker! (… not the same person as the facilitator!). Ask for permission when taking notes and indicate how that information will be used.

Planning a Meeting vs. Developing (& Documenting) an Engagement Strategy

Instead of planning individual events in isolation, consider stakeholder engagement as a series of meetings and interactions. Develop a long-term strategy so that each activity builds on the previous one. A timeline is a useful visualization tool to summarize engagement over time as shown in the example below.



A table can also be used to record all meetings, including information, such as:

Date & Location	Purpose	Stakeholder Type & Representation	Highlights/Key insights / Quotes & Follow up
22nd June, Pretoria	RAPS planning meeting	RRT Economic modelers, SL and PI = 5 people	Discussed RAPS elicitation process and seating logistics. Reorganized presentation outline. Identified need to invite Mr. Nduna from previous engagement. Find a copy of state action plan for climate change.
25-29th June, Bloemfontein	Inputs for RAPS	16 university experts (3 hydrologists, 1 demographer, 2 economists, 2 agronomists, 3 soil scientists, 1 plant pathologist…	Heavy rain and flooding limited engagement. Electricity not working so no power points. Completed matrix for all but 3 indicators using printed copies. One-on-one interviews suggested. Contact Mr Sly and Dr Djbouti…
Etc.			

Stakeholder Mapping

Stakeholder Mapping (mandates): Given the objectives of the stakeholder engagement, what is the institutional and/or organizational milieu within which the information fits? A thorough understanding of the context of decision making, vis-à-vis the information available must include a picture of the relevant institutions with mandates related to the key messages. Map the range of stakeholders who have a stake in this information. This hierarchy or web can help pinpoint where best to intervene and where best to engage for outcomes and eventual impact with the information that you have.

Prioritization—Specific Stakeholder ID: Match making exercise where the supply (project outputs) and demand (stakeholder needs) are brought together. This step is guided by the previous steps and begins bringing together the best available information with those most likely interested in it for use in planning and delivery. This might be built upon networks and strategic partnerships of those who have accompanied the process (contributing to RAPs for example) this far or may be new or different groups who have not yet engaged with AgMIP RRTs.

RRT Emerging Insights

Elicitation & Dialog in AgMIP: Questions to catalyze climate conversations

The CIWARA team used these questions successfully to stimulate dialog with stakeholders in a panel (Dakar, Senegal, Feb 2016) about climate change, agriculture and the value of visioning the future. Try them!

1. Please introduce yourselves, and explain in 3 minutes how your work relates to, or integrates adaptation to climate change
2. So… what do you think about what you've seen from AgMIP? Like? Dislike? Surprised? More of the same?
3. Is climate changing in this region? Are you experiencing it right now?
4. What are the key climate risks that you have to deal with in your everyday practice? What do you do about these – how do you manage?
5. Where do you normally go to get information about climate change impacts? What do you like about your sources? Don't like? What are you missing, that you would like to get?
6. In 2050, what will [Senegalese] children eat for breakfast? What do they eat now? Where will they get their 2050 breakfast from? What will be the most popular protein source in the Dakar markets in 2050? The most fashionable? In 2050, where will the average citizen work? On farm? Off farm? Will s/he commute? How?
7. In your work and institution, how do you (your colleagues) do fore-sighting? What mechanisms, strengths, weaknesses?
8. Do you think [Senegalese] / African policy instruments / processes for CCA are in touch with local priorities? If yes, how can science leverage them? If not, how can science assist? What are the best conduits?
9. Is current science effective at informing [Senegalese] policy makers for climate change adaptation? If yes, can you give specific examples of successful interactions and influence? If not, how could that be improved?
10. Where do you see adaptation taking place: primarily within systems (e.g. change in agronomic practices) or between systems (e.g. change in livelihood strategies)?
11. Have you been involved in the COP21 (preparation and/or attendance)? What repercussions do you foresee on your own work /work planning? Particular areas of excitement or concern?

Assessing & Improving Key Messages ***with*** Stakeholders

The CLIPS team developed a survey for stakeholders to assess and refine Phase 1 messages. Consider adapting and using these in your work.

WRITE KEY MESSAGE HERE (climate, crop, economic)

1. Based on your experience does this message make sense/seem true to you? (circle yes/no)

Please tell us why --- elaborate. If yes or if no, add on to the discussion. Say you've seen this in action. Or say you've seen the opposite in action. Or that you believe it is only true for this area … etc.

2. What questions arise for you now that you know this?

3. How would you use this message?

4. What would you do differently now if you were to incorporate this into your work?

5. Who do you think needs to know this result and why?

6. Is this your first time interacting with AgMIP scientists Y/N

7. If no, how have you been engaged prior to today?

8. Type of Participant (mark with X)

    Government departments
    Research and university
    NGO staff district level
    Ngo staff provincial level
    Add others here

Policy Briefs, Fact Sheets & Impacts Explorer: Tailoring materials for different Audiences

KEY points to consider:

1. Matching audience and content or content and audience

2. Best medium for messages

3. Stand alone or series?

4. Organizational/institutional publications or blogs (CCAFS, ICRISAT, IWMI, GWP, etc)

Background on the AgMIP Stakeholder Unit (SU)

Goals of the SU

The Stakeholder Unit (SU) has been created within AgMIP in order to increase the utility and relevance of the project's science outputs. As set out in the SU Outcome Logic Model, the unit's vision of the future is that AgMIP contributes to evidence based decision making at continent, region, country and local levels by generating more relevant and robust projections of climate impacts on agricultural systems—of use to decision makers. AgMIP's Stakeholder Unit has enhanced the willingness and ability of leadership and teams to plan and implement projects with users' needs and frame of reference at the forefront--scientists build models that generate outputs or results of use to stakeholders.

The SU has established a number of principles that guide its on-going work:

- Sustainability — building a foundation
- Engagement — on-going communications for building trust and relationships
- Partnerships — essential for getting to outcomes
- Transparency — informed decisions to meet needs
- Inclusivity — all team members must contribute

The SU has designed four main pathways for achieving anticipated outcomes:

1. Capacitate a cohort of scientists who are willing and able to engage decision makers in meaningful ways to increase the relevance of their models to climate/crop/livestock decisions.
2. Develop capacity of all AgMIP project members to build users into the research design and development processes. SU activities contribute to models that are well integrated, coherent, inter-dependent. SU helps change the way models are planned, developed and rolled out -- with particular attention to relevance and context—contributing to their success.
3. Document best practice for building the capacity of researchers to: understand importance of stakeholder engagement; engage next users and end users of scientific research products from inception, and document stakeholder feedback to be incorporated into the research process.
4. Contribute to early generation AgMIP Impact Explorer (and possibly other tools) whose legacy is still relevant to climate change adaptation decision making.

Stakeholder Liaisons: A vision for expanding capacity in AgMIP

SL Role

The role of the SL is to develop interactive spaces that help build meaningful relationships among scientists and stakeholders so that AgMIP results and their applications can be translated effectively and explored collaboratively. SLs will work equally as closely with RRT scientists (information supply side) and stakeholders (information demand side). Although the SL will work with AgMIP teams to translate research findings, they are not tasked with being science messengers. Neither are they expected to convince audiences that climate change is real or that AgMIP modeling and research results are useful for decision making. During Phase II SLs are responsible for collecting specific feedback from stakeholders related to their needs and requests for new types of research outputs. SLs will document how the design of scientist-stakeholder interaction processes affects dialog and outcomes. Furthermore, SLs will explore how modeling changes in response to stakeholder input. Emphasis will be placed on collecting success stories and instances of failure (non-use of information) as well suggestions for future climate research development, packaging and roll-out.

Rationale

AgMIP researchers are focused on building better models. DIFID, the funder of AGMIP Phase II, is focused on guiding rural development through relevant science. In order for these two agendas (AGMIP's & DIFID's) to meet synergistically they must be linked intentionally. Phase 1 of AgMIP in SSA and SA was focused on establishing and demonstrating a multi-model, multi-scenario framework for regional integrated assessment of climate change impacts which required a great deal of technical expertise. Phase 2 will emphasize stakeholder engagement so that we can inform our work to best meet stakeholder needs. During this critical moment as the project transitions from Phase I to Phase II, AGMIP teams will reorient modeling efforts to create products that stakeholders can use and they will explore the utility of their research results with a wide range of decision makers. Considering this modified focus, AGMIP teams will be expected to perform new functions. Doing different things with the models (vs. improving them technically) requires different skills. Furthermore, Phase II activities will demand time for sufficient follow-up with stakeholder partners. Therefore, each RRT is expected to hire an expert or catalyze latent expertise within current team so that one member is responsible for the stakeholder engagement job functions described below.

SL Official Job Description/ Function (distributed to Teams in 2014 to guide hiring of new SL)

Coordinate team efforts so that applications of AgMIP's regional integrated assessment framework and methods answer questions of relevance to adaptation decision makers. The new stakeholder specialist will help prepare country teams for stakeholder-driven research and will work closely with the PI or an identified team expert liaison to initiate and conduct project outreach activities. All team members will facilitate the integration of this new member and will contribute to a successful stakeholder engagement process.

Characteristics of a stakeholder specialist

- Ability and willingness to transcend hierarchies and sectors. This person is comfortable interacting with others from fields to boardrooms. They are able to expand potential stakeholder pools beyond "the usual suspects" with particular attention to gender, age, resources/societal position.
- Well-networked externally (with cross-sectorial legitimacy). This person either has existing direct access to stakeholders or knows who to call. They need to be familiar with regional and national brokers and be able to take advantage of connections they already have.
- Drive for outreach and relationship building (often requiring cold calling and persistent follow-up)
- Talents as a generalist & integrator are more important than technical expertise in any particular field. Ability to integrate results and connect disciplinary silos.
- Communication and interpersonal skills (includes the ability to listen). Conversion & conveyance (translation of user needs (to scientists) and of complex science topics (to stakeholders)
- Willingness and ability to engage in an on-going reflective process, documentation of lessons learned, and sharing results with team and broader AGMIP community
- Familiarity with AgMIP project and outputs would be a bonus (know team members and language of project).