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Climate-Agriculture-Modeling and Decision Tool (CAMDT): A software framework for climate risk management in agriculture

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ABSTRACT

Seasonal climate forecasts (SCFs) have received a lot of attention for climate risk management in agriculture. The question is, how can we use SCFs for informing decisions in agriculture? SCFs are provided in formats not so conducive for decision-making. The commonly issued tercile probabilities of most likely rainfall categories i.e., below normal (BN), near normal (NN) and above normal (AN), are not easy to translate into metrics useful for decision support. Linking SCF with crop models is one way that can produce useful information for supporting strategic and tactical decisions in crop production e.g., crop choices, management practices, insurance, etc. Here, we developed a decision support system (DSS) tool, Climate-Agriculture-Modeling and Decision Tool (CAMDT), that aims to facilitate translations of probabilistic SCFs to crop responses that can help decision makers adjust crop and water management practices that may improve outcomes given the expected climatic condition of the growing season.

Software and/or data availability

Name of software	CAMDT (Climate-Agriculture-Modeling and Decision Tool)
Developer	International Research Institute for Climate and Society, Columbia University, NY, 10964, USA/ Michigan State University, East Lansing, MI, USA 48824
Contact	Eunjin Han/Amor VM Ines, International Research Institute for Climate and Society, Columbia University, NY, 10964, USA. E-mail address eunjin@iri.columbia.edu or inesamor@msu.edu
Year first available	2015
Hardware required	PC
Software required	Windows 2007 or higher version
Program language	Python and Fortran
Availability	CAMDT Graphical User-Interface has been written in the Python programming language. Except for the Fortan codes, CAMDT is open-source. It can be freely downloaded from https://github.com/EunjinHan/CAMDT_Philippines
Cost	N/A

1. Introduction

The long-term impacts of climate change on food security have been studied extensively (Brown and Funk, 2008; Lobell et al., 2008; Schmidhuber and Tubiello, 2007). From a farmer's perspective, however, adaptation to climate change is more closely related to addressing risks associated with inter-annual climate variability than long-term changes or shifts in climate. During the past decades, advances in seasonal climate predictions have brought a great potential for improving climate risk management in agriculture (Capa et al., 2015; Hansen, 2005; Hansen et al., 2011; Shafiee-Jood et al., 2014). Seasonal climate forecast information have proven especially valuable in developing countries, particularly in tropical regions, which depend on rainfed agriculture and are vulnerable to climate extremes (flood, drought, and heat waves) due to limited technologies or infrastructure (Hansen, 2005).

Unlike weather forecasts, which are reliable at most for about one week in the future, seasonal climate anomalies can be predicted with a longer lead time (e.g., a few months) because they are linked to interactions between atmosphere and sea surface such as El-Niño-Southern Oscillation (ENSO) (Barnston et al., 2000). Due to the inherent uncertainty in climate prediction, most of the

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publically accessible seasonal climate forecasts (SCF) released by the NOAA-Climate Prediction Center, the International Research Institute for Climate and Society (IRI) or the UK Met Office are provided in tercile probabilities of the most likely category, i.e., below normal (BN), near normal (NN) and above normal (AN), for rainfall and temperature.

Seasonal climate forecasts alone can fall short in providing actionable information for improving farm-level decisions and policy-level interventions. However, if SCFs are linked with a decision support system (e.g., with crop simulation models), they could help farmers improve strategic and tactical decisions to maximize benefits and minimize climate-related risks in the growing season. Yield Prophet (Hochman et al., 2009; http://www.yieldprophet.com.au) and AgroClimate (Fraisse et al., 2006; www.agroclimate.org) are some examples of Decision Support System (DSS), which can provide information on impacts of climate on crop growth/yield, disease occurrence, and recommended management practices based on several simulation models; climate forecasts used are often ENSO-based.

A major obstacle in integrating crop simulation models and SCFs is the mismatch of scales (space and time). Crop models require weather-scale inputs while SCFs provide seasonal climate information. Weather generators can generate synthetic daily weather data that crop models can use to run simulations (Buishand and Brandsma, 2001; Clark et al., 2004; Kim et al., 2016; Verdin et al., 2015; Wilks, 2002; Yates et al., 2003). However, they are not readily designed for linking probabilistic SCFs with crop models. Notwithstanding, by repurposing weather generators, several studies linked SCFs with crop simulation models by disaggregating SCF into daily weather sequences. Hansen and Indeje (2004) and Apipattanavis et al. (2010) applied stochastic disaggregation approaches to create daily weather sequences from SCFs to produce crop yield forecasts using DSSAT (Decision Support System for Agro-technology Transfer) crop simulation models (Jones et al., 2003; Hoogenboom et al., 2015).

Although SCFs are important for climate risk management, translating tercile-based (probabilistic) SCFs into agricultural terms is not straightforward. It requires some technical expertise, not only for running crop simulation models using the SCF median, but also in data science, computing and agronomy. It should be noted that all tercile probabilities of likely rainfall categories in the SCF (i.e., BN, NN and AN) comprise the full distribution (hence, information) of the forecast, opposite to the notion of taking the rainfall category with highest probability for convenience. When SCF is disaggregated to daily weather sequences, uncertainties in weather/climate are reflected in the weather realizations. For instance, downscaling a 50% BN, 30% NN and 20% AN forecast can include 50 weather realizations extracted from the dry category, 30 from normal and 20 from wet, with a total of 100 realizations. Converting these weather realizations to model-specific format and running the crop model by the number of realizations can be a tedious and time-consuming task. Producing useful information from SCFs for decision support in agriculture is therefore a challenging task.

To help overcome these challenges, we developed a model-based DSS tool, which can seamlessly integrate these procedures: disaggregate a given SCF, run a crop simulation model with the former and visualize model outputs such as expected yields or gross margins. Here, we present a DSS tool called Climate-Agriculture-Modeling and Decision Tool (CAMDT) that can aid in developing tailored information for agricultural decision-making using SCFs. CAMDT links SCFs with DSSAT crop models. In addition to a user-friendly graphical interface, CAMDT allows a user to run “what-if” scenarios, considering different climate forecasts or crop management options. CAMDT also includes a simplified integrated climate–crop-economic modeling system that can translate crop model outputs into economic terms.

2. Software description

CAMDT is a DSS tool with a simple, user-friendly interface, which aims to integrate SCF temporal downscaling tools (predictWTD or FResampler1, will be described later) and DSSAT. This version of CAMDT is linked with DSSAT-CSM-Rice model, although there is a potential of including other crop models in the future. A Graphical User Interface (GUI) serves as a wrapper that integrates SCF and crop model based on user's inputs. CAMDT requires lesser inputs from users compared with the regular DSSAT interface. Users with little experience in DSSAT or SCF downscaling methods can use CAMDT to generate tailored information for agricultural decisions. In addition, the software is designed to help users avoid the tedious tasks of creating format-sensitive DSSAT input files, and extracting target output variables out of several DSSAT output files for analysis. CAMDT can easily display direct DSSAT outputs (e.g., yield and water stress), as well as translated outputs (e.g., risk of water stress and gross margins). It is envisaged that the software can contribute to developing better informed climate adaptation strategies by providing users the ability to easily assess scenarios of various agronomic practices, given an expected seasonal climate. SCF downscaling only includes rainfall in this version, but a similar approach can be easily expanded to include other variables such as temperature.

2.1. DSSAT-CSM-rice model

The DSSAT-Cropping System Model (CSM) is a modular-based application package, which can simulate at least 16 different crops (Hoogenboom et al., 2015; Jones et al., 2003). The crop models simulate crop growth and development, soil moisture, carbon and nitrogen dynamics under specific management practices at a spatially uniform field. Weather data including daily maximum and minimum air temperature (T_{max} and T_{min}), solar radiation and precipitation, are fundamental forcing variables to simulate hydrological processes and crop phenology. Temperature is used to estimate growing degree-days which determine the rate of crop development (Jones et al., 2003). Soil properties are also critical variables to simulate water, carbon and nitrogen dynamics in the soil and their impacts on crop growth. Soil information required by DSSAT includes physical, chemical and morphological characteristics of each soil layer. Crop growth stages are simulated based on user-determined genetic coefficients which vary with different cultivar types. Therefore, genetic coefficients of a target cultivar should be properly calibrated and tested using field experimental data before the models are used for any application. Biomass production of a crop is determined mainly by intercepted photosynthetically active radiation (PAR), and penalized by several stress factors, such as extreme temperature or limited water or nitrogen availability.

As mentioned, this version of CAMDT linked DSSAT-CSM-Rice model with SCF to simulate rice growth and development. To simulate irrigated low-land rice, transplanting dates and detailed irrigation schedules need to be provided. More details on the rice model can be found in Ritchie et al. (1998) and Jones et al. (2003). Like other crop simulation models, DSSAT-CSM-Rice model has been used on a wide range of applications including: identifying optimal management options (Ahmad et al., 2012; Amiri et al., 2013); estimating rice yields (Mahmood et al., 2003); assessing impact of climate change on rice yields (Basak et al., 2009; Saseendran et al., 2000), simulating interactions between pest damage and rice yields (Pinnschmidt et al., 1995), among others.