An Elucidation System for the Climatic Change Effect on Agriculture in the Asian Monsoon Region

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ABSTRACT

Most of the countries in the Asian monsoon region are agricultural areas, and the impact of climate change on this region is very significant. Rainfed areas in particular are very vulnerable to extreme weather events such as floods and droughts. Moreover, the change of the onset and period of the rainy season causes serious effects on yields and farming plans. We are developing an evaluation system for major crops in the Asian monsoon region affected by climate changes that can simulate the growth of major crops in this region. We selected Thailand as a target country, and DSSAT as a crop model. In 2012, we developed a prediction system to optimize the double cropping of rice and cassava in northeastern Thailand. We developed this system to identify and recommend bonus crops that can be grown during the dry season, and to simulate the effects of climate change in northeastern Thailand's rainfed farming areas. In 2014, to simulate the effects of climate changes in the mountainous area of Thailand, we expanded the target area of the system to the northern mountain area, and we increased the number of crops in the model. The system executes a crop model 365 times, while the start date is moved by one day each time, to identify the best start date using meteorological data that take climate change into consideration. The best start date and yield are summarized and shown on a map of the area being studied. The system is flexible and can be applied to other areas, as users are able to select crop models such as SIMRIW and ORYZA2000. The current areas of concern for the model include the execution time of several days needed to simulate tens of thousands of grid points and the handling of the huge number of files output by the crop model. We are trying to apply multi-thread, Hadoop, and other devices to address these issues.

Keywords: Climate change, crop yield prediction, rice, vegetables, DSSAT, Thailand

1. INTRODUCTION

The climate changes predicted to occur in the present century are of maximum concern in the agricultural sector. Sixty percent or more of the world's population lives in the Asia monsoon region, and the effects of climate changes on the region are expected to be quite serious, since most of the countries in the region are developing countries and agrarian economies. Rainfed areas in particular are very vulnerable to extreme weather events such as floods and droughts. Moreover, any change in the onset and period of the rainy season will have serious effects on yields and farming plans.

A Japanese research project titled, "Climatic changes and the evaluation of their effects on agriculture in the Asian monsoon region" (CAAM, 2012) couched under the "Green network of excellence — environmental information" (GRENE-ei, 2011) program of Japan's Ministry of Education, Culture, Sports, Science and Technology (MEXT) was started in 2011 and will be conducted until 2015. The dual purposes of this project are to improve the reliability of climate prediction (CCR: climate change research) and to develop the necessary information platform to design strategies for the agricultural sector to adapt and mitigate to the predicted climatic changes in the Asia monsoon region (AER: agricultural effect research). Four countries (Thailand, Indonesia, Philippines, and Vietnam) were selected as our research target countries. The CCR team observes the present meteorological data (air temperature, precipitation, and solar radiation) that are required to execute a crop growth model in these countries and calculates grid data and future data using a statistical model. The AER team observes the field data and executes a crop growth model to elucidate the change in crop yield.

The purpose of our sub-team of the AER team is to develop an evaluation system for major crops in the Asian monsoon region affected by climate change that can simulate the growth of major crops in this region. In our research seeking to elucidate the effects of climatic change on agriculture, we chose the area from the northeast to the north of Thailand from among the four target countries as our research target area, because the construction of the weather and field observation network is advanced. Northeastern Thailand is a rainfed farming area, and the difference in precipitation between this area's rainy season and dry season is quite pronounced. Rice is cultivated during the rainy season, and drought-tolerant crops such as sugarcane and cassava are cultivated during the dry season. Northern Thailand is a mountainous area, and its cooler temperatures allow the cultivation of several types of vegetables that cannot be grown in the plains areas.

In 2010, before the start of this project, we developed a simulator of the cultivation possibility of rice (SIMRIW 2010, Tanaka 2011), shown in Figure 1, for the Data Integration and Analysis System (DIAS 2005) project. This system executes the rice model SIMRIW (Horie 1995a, 1995b) for worldwide data on a one-degree grid (only for land, about 15,000 points). It was difficult to put this system into practical use because SIMRIW is a simple rice growth model that can simulate only potential growth, and the data grid interval was 100km. However, developing this simulator clarified the problems that had to be solved in order to construct a similar system that could be applied in practice including problems with large-scale grid execution and with handling the huge number of files.

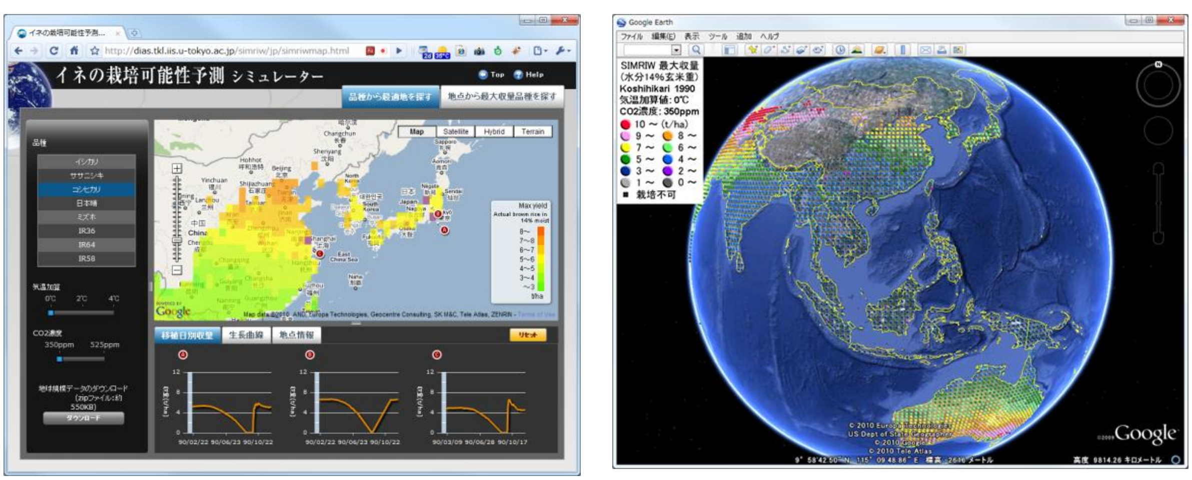

Figure 1. Simulator for the Cultivation Possibility of Rice

In 2012, we developed a prediction system to optimize the double cropping of rice and cassava in northeastern Thailand. We created this system to identify and recommend crops that can be grown during the dry season, and to simulate the effects of climate change in northeastern Thailand's rainfed farming areas. This system uses the Decision Support System for Agrotechnology Transfer (DSSAT, Jones 1998, 2003, ICASA 2004) because it provides modules for major crops and is used frequently in Thailand. The system uses the 0.05-degree grid meteorological data prepared by the National Institute for Agro-Environmental Sciences (NIAES) to provide a more accurate simulation than the previous system.

These data were generated from actual data observed by the Meteorological Department of Thailand (TMD), the World Meteorological Organization (WMO), and the Tropical Rainfall Measuring Mission (TRMM) using the spatial interpolation method shown in Figure 2. TMD has 1200 weather stations for precipitation and 120 weather stations for other meteorological elements in Thailand. WMO collects observation data at 90 weather stations in the Indo-China region. The resolution of the TRMM is a 0.25-degree grid. Figure 3 compares the between 1-degree (left) and 0.05-degree (right) grid intervals.

We applied our system to simulate the growth of rice and cassava. Regions where the rice and cassava yields were greater than those in other regions are shown in yellow circles in Figure 4. These results were developed based on the evaluation conditions for double cropping, such as the harvest date and the yields of rice and cassava.

In 2013, we added a rice growth model called ORYZA2000 (Bouman 2001, IRRI 2000) that was developed by International Rice Research Institute (IRRI) to the system to expand the applicable region of the system to the Philippines. ORYZA2000 is used in the "Climate Change Adaptation in Rainfed Rice Areas" (CCARA) project under an IRRI-Japan collaboration. ORYZA2000 can simulate rice growth not only under various potential conditions but also under water and/or

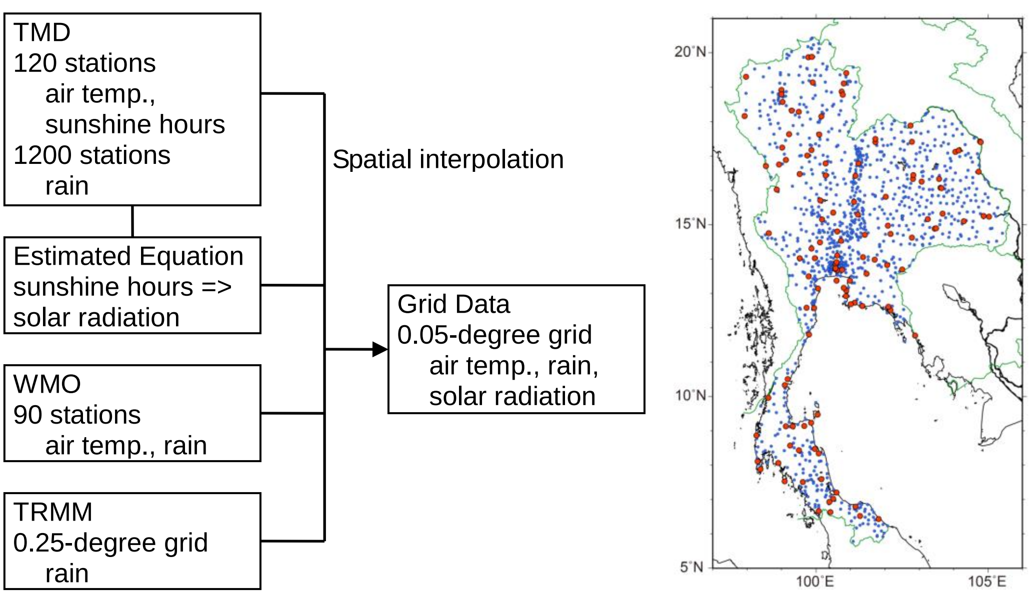

Figure 2. (left) Generation procedure of grid meteorological data for Thailand (right)Weather stations in Thailand

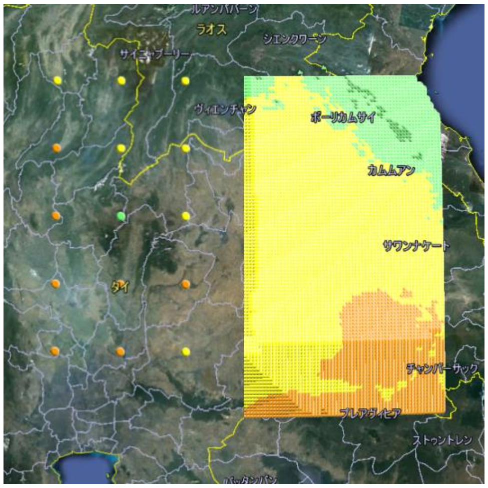

Figure 3. Comparison of numbers of meteorological grid data points.
left: 1-degree grid
right: 0.05-degree grid

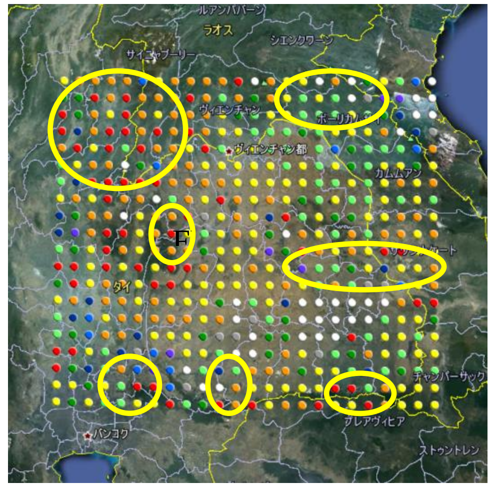

Figure 4. Results of the prediction system for double cropping optimization
(displayed in 0.2-degree grid)

nitrogen limitations as well as DSSAT. The suitable crop models differ according to the application country or area. The water limitation function is necessary for rainfed areas. The nitrogen limitation function is necessary for areas with insufficient fertilization. The flexibility to vary crop models according to the area to which they are applied is a characteristic of the system (Figure 5). For example, SIMRIW is used for Japan, DSSAT is used for Thailand, and ORYZA2000 is used for the Philippines.

In 2014, we have been modifying the system to apply to the mountainous areas in Thailand, because it is thought that the influence of climate change in mountainous areas is greater than in plains areas. The main modification was to add several kinds of cool-weather vegetables as simulation target crops and to incorporate the meteorological data of the mountainous areas.

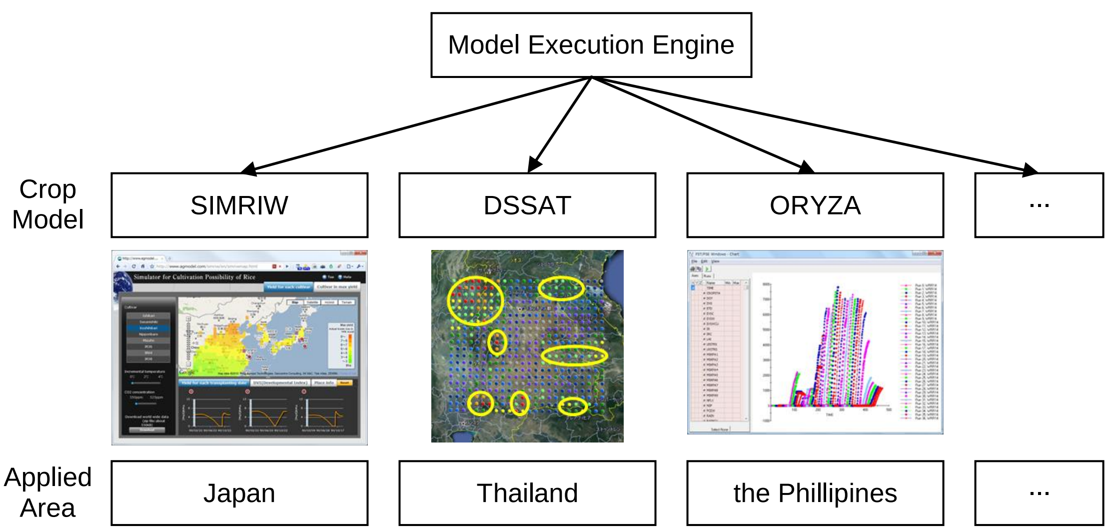

Figure 5. Crop model selection mechanism according to applied area

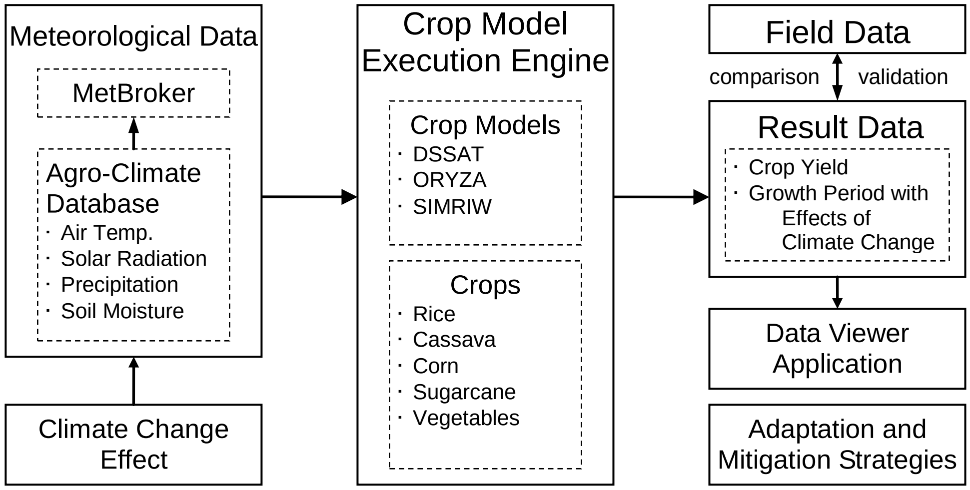

Figure 6. Structure of the crop yield prediction system

2. MATERIALS AND METHODS

The structure of the crop yield prediction system is shown in Figure 6. The system includes three main components: (1) A meteorological data acquisition function and a weather data generator that reflects the effects of climate change on the data, (2) crop models and a crop model execution engine that executes the crop models, (3) save, display, and comparison functions for the result data.

The crop model execution engine is a backbone function to execute a crop model repeatedly with conditions represented by numerical expressions. The engine can execute various crop models that are implemented or wrapped using the Java Agricultural Model Framework (JAMF, Tanaka 2006). The JAMF provides the option to select and execute an appropriate crop model such as DSSAT, ORYZA2000 and SIMRIW in this system in accord with the application region.

A crop model implemented using JAMF acquires mainly meteorological data through MetBroker (Laurenson 2002). MetBroker can access many meteorological databases by a unified method that does not require a complex database access program. With MetBroker, a crop model can be used worldwide with a meteorological database such as the Automated Meteorological Data Acquisition System (AMeDAS, developed by the Japan Meteorological Agency), WMO, and the grid data generated for our project without the need to code the access program of each database.

Several types of display applications can be used to meet the user’s requirements because the resulting data generated by the system are saved in XML format. In this system, XML files of the result data are transformed into a KML file to display on Google Earth. Moreover, the accuracy of the evaluation system can be verified by comparing the result data with the cultivating data in Thailand observed by the University of Tokyo.

The new system was developed by modifying the prediction system to optimize double cropping developed in 2012. The previous system used the rice and cassava module of DSSAT and 0.05-degree grid meteorological data for northeastern Thailand. To simulate the effects of climate change in the mountainous area of Thailand, we expanded the target area of the system to the northern mountainous area, and increased the number of crops to include several vegetables. Because DSSAT accommodates about 30 crops with different modules, the execution method is essentially the same. Instead, the collection of the parameters for the application area became the most important task.

Figure 7 shows the method of crop model execution used to identify the best start date and maximum yield. The system acquires meteorological data through MetBroker and formats it in a DSSAT form that is a fixed-length file delimited by the space, and outputs the file, the extension of which is WTH. The system executes a crop model 365 times per point, while the start date is moved from Jan. 1 to Dec. 31 one day at a time. DSSAT is executed by specifying an experimental data file whose extension ends with X. Elements of this file such as the start date are edited at each execution. DSSAT outputs 10 or more result files concerning plant growth, weather, and soil, these files carry a file extension of OUT. The system generates an XML file that summarizes yield and growth periods of output files and makes an archive file including the result files and the XML file. Finally, the system generates an XML file that summarizes the results of all grid points and a KML file to display the results.

```
setup  crop, year
for (grid points) {
    acquire and format met. data  =>  THNE0001.WTH
    for (planting date = Jan.1 - Dec.31) {
        modify  THNE0001.RIX (experiment data)
        execute  CSM45.exe
    }
    save  result values (yield, growth period) in XML
}
create  result data files (XML, KML)
```

Figure 7. Crop model (DSSAT) execution method

3. RESULTS AND DISCUSSION

The single-iteration execution time of the crop model was very short. However, it took 30 seconds for the crop model to execute the sequence 365 times for each point. Thus, it took 4 days or more for the calculation of 12,000 grid points. The processing time should be shortened by improving the crop model execution method to run the simulation many times under various conditions. Multithreading is an effective acceleration technique because the calculation of the crop model for each point is independent. Moreover, the introduction of the method to decrease the number of executions is effective, for example, a crop model will be executed at intervals of several days, and will be executed only for the period when it seems to obtain the maximum yield each day.

Another problem is the handling of a huge number of small files. However, if the 10 or more result files that are output at each execution are archived, the number of archived files becomes huge in proportion to the number of executions. There was no difficulty in displaying the result data because one small summary file was generated to be displayed. The problem will be actualized as length of the backup time. We will try to deal with this problem by introducing a Hadoop file system.

4. ACKNOWLEDGEMENT

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