UNDERSTANDING A CLIMATE CHANGE IMPACT ON RAINFED RICE PRODUCTION IN NORTHEASTERN THAILAND

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ABSTRACT

Nowadays, the impacts of climate change on crop production become evidently adverse and location-specific. In our study, real-time weather and flux observation systems were developed and operated in a large rainfed rice field in Trakan Phutphon and Det Udom Districts in Ubon Ratchathani Province to monitor and understand the climate fluctuation in the area. Various observation systems have supplied the data necessary for impact analysis using agro-hydrological crop models. This study has successfully developed a method of identifying crop model parameters from remote sensing (RS) data such as the Moderate Resolution Imaging Spectra-radiometer (MODIS) data used in retrieving the leaf area index, actual evapotranspiration (ET_a) and water stress maps from satellite images. ET_a was estimated from satellite data using the so-called Surface Energy Balance Algorithm for Land (SEBAL) model. The results concluded that the estimated satellite ET_a was fairly accurate. In addition, a methodology to calibrate the agro-hydrological model called Soil-Water-Atmosphere-Plant or SWAP model through data assimilation (Genetic Algorithm) using RS data or the so-called RS-SWAP-GA method has been successfully developed. A well-calibrated SWAP using a time series of good quality satellite data can be simulated using reliable soil moisture, water stress and yield information. The calibration does not require intensive field observation or field sample testing, thus the methodology is attractive to other rainfed rice cultivation areas or for expansion to other regional applications.

INTRODUCTION

Food security has become a hot issue for many decades, with the effects of climate change – increasing temperature, recurrence of long dry spell or droughts and so on, accelerating the problem (UNESCAP, 2004). In Northeastern Thailand, the rainfed rice production area which covers more than half of the rice cultivated area of the country is being at risk. The recurrence of serious dry spell and drought conditions has caused a negative impact on rice yield and consequently food scarcity, resulting in many farmers losing their jobs in the agricultural sector. In fact, many affected farmers have shifted to new careers in the city such as construction works or very low cost jobs while some remain jobless and turn to earning money illegally. It is evident that the impacts of climate change have broadened to the society. Hence, there is an urgent need to recognize the impact of climate change on rice production towards developing a response plan for farmers and related stakeholders in dealing with their works under the climate variability. Towards understanding the impact of climate change on rice production, an effective method is required which could initially be based on a small scale model for implementation later to a larger scale. In this connection, the Thailand Research Fund (TRF) has been supporting the development of real time weather monitoring systems, agro-hydrological crop models and simulation of drought scenarios in order to better understand the impacts of climate change especially on rainfed rice cropping.

STUDY AREA

One-half of the rice cultivated area of Thailand is located in the northeastern region, but less than 20% of the total irrigated area of the country is also found in this region (International Rice Research Institute, 2004). Rainfed rice cropping is a major activity in this region, which has also been recorded as a drought prone area. In this study, Ubon Ratchathani Province, one of the provinces in northeastern Thailand and known as drought prone was selected as a representative of the region (DPMP, 2006). Two real-time weather stations were set up in Trakan Phutphon District (15◦ 42’ 22” N 105◦ 00’ 21” E) in the upper part of Ubon Ratchathani Province and another in Det Udom District in the lower part of the province (Figure 1).

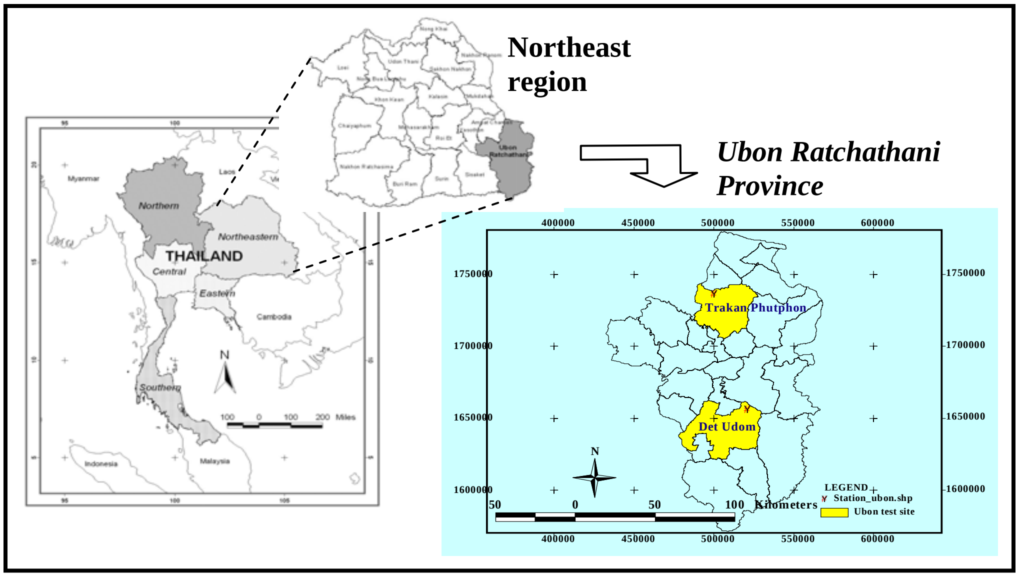


Figure 1. The study area.

In this study, the large continuous rainfed rice fields in Trakan Phutphon and Det Udom were considered as the specific the target study areas (Figure 2), where the common rice varieties grown are KDML105 and RD15, respectively. The average yield is around 400 kg/rai in both areas. With reliance on irregular rainfall in the northeastern region, the start of the rainfed rice cropping in Ubon Ratchathani could be shifted between May to August and harvesting between October to January. After harvesting, most of the cultivated areas lay fallow.

Figure 2. Large continuous rice fields in Trakan Phutphon and Det Udom Districts.

STUDY FRAME WORK

To develop a near real time drought monitoring system and impact assessment on rice cropping in Ubon Ratchathani based on agro-hydrological model, the framework used in the study consisted of 3 parts as presented in Figure 3, namely: observations, model simulation and results of the model validations, and the generated dry spell or drought scenarios for estimating the impacts on the rice yield.

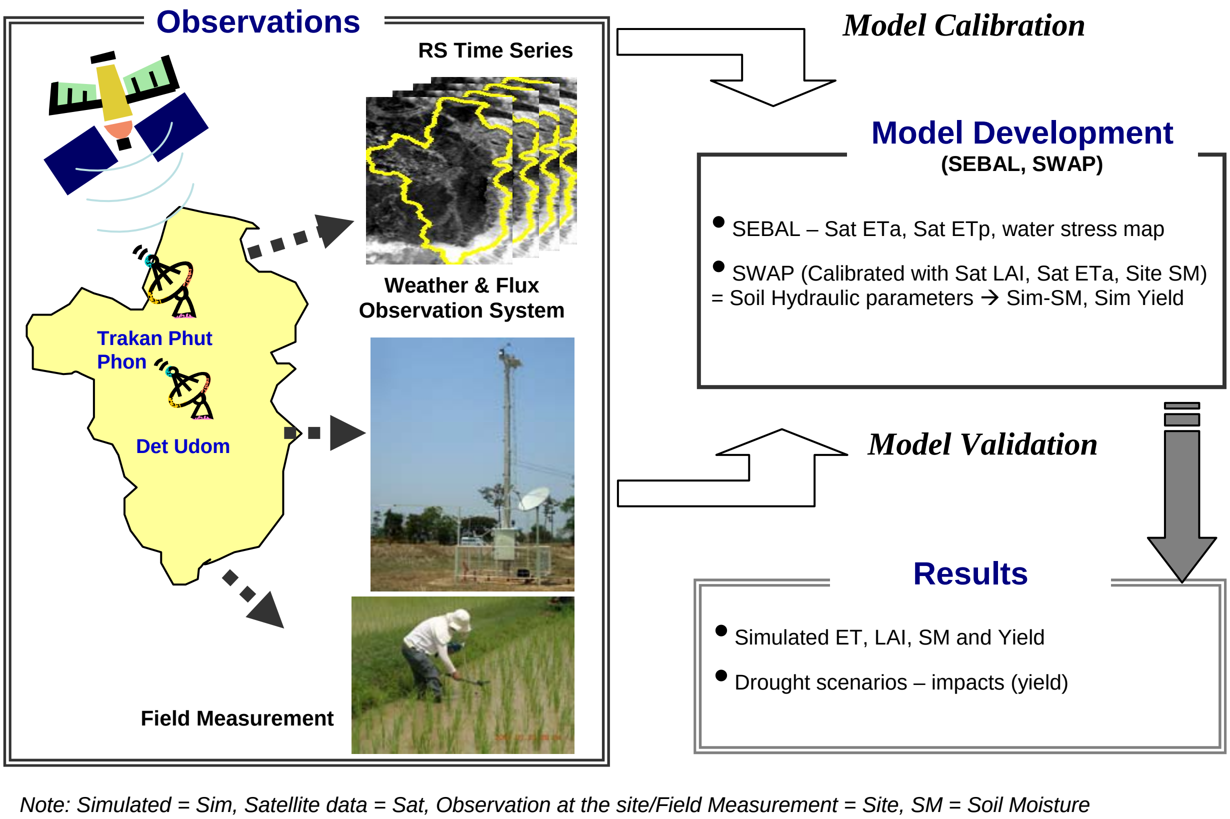
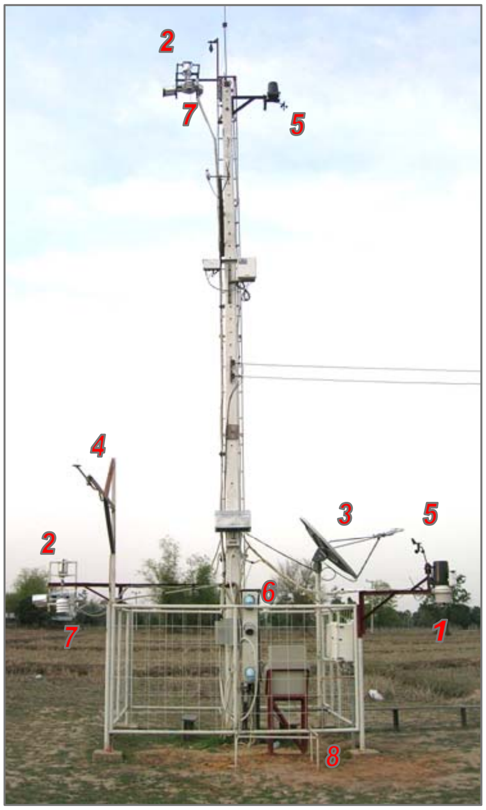


Figure 3. Frame work used in the study.

Observations

The observations in this study cover 3 sources of data for the analysis, such as weather and flux observation system, satellite data and field measurements. Information on weather and flux are necessary for the analysis of the impact of climate change on rice production, however most of the available information from the existing meteorological stations are not good enough to be used as reference since the observations are collected from systems installed in the city or far away from the rice fields. In order to acquire real representative information from rice cultivated areas, two agro-meteorological stations were developed and operated during 2007-2009 in Trakan Phutphon and Det Udom Districts. At the rice fields, the located **observation systems** have supplied semi real-time weather and flux data such as temperature, relative humidity, wind, solar radiation, rainfall, sensible heat, latent heat, among others. In addition, soil moisture and soil temperature are measured using sensors at four depths: 3 cm, 12 cm, 28 cm and 60 cm (Figure 4). The acquired data are transferred to a field server in the control and further transmitted to the main server at the Asian Institute of Technology in Pathumthani Province, Thailand (Honda K., et. al, 2009, Honda K., et. al, 2008).



List of observation instruments:

1. Davis Weather Station
2. Bowen Ratio Instrument (2 m, 10 m)
3. IP Star (Fix IP)
4. Net Radiometer (2.5 m)
5. Wind speed (2 m, 10 m) and wind direction (2 m) and rain gauge (2 m and 10m)
6. Control Box
7. Temperature and humidity (Sensirion) sensors (2 m, 10 m)
8. Soil moisture sensors and thermocouple (at 3 cm, 12 cm, 28 cm and 60 cm - depths)

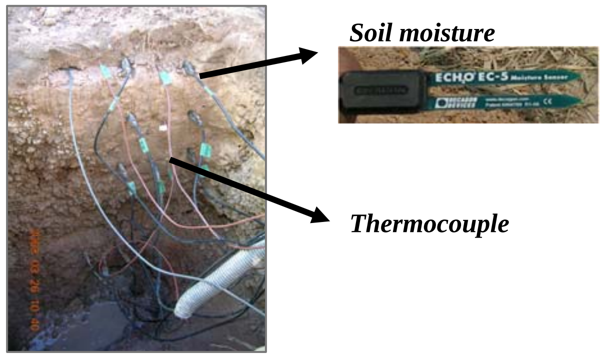


Figure 4. Real-time weather and flux observation system.

Satellite data plays an important role not only as a source of land covers/uses and cropping status of the study area, but also as input parameters required for calculating the evapotranspiration in the study's analysis model. In this study, the available Moderate Resolution Imaging Spectra-radiometer (MODIS) accessible at the website of the National Aeronautics and Space Administration (NASA) was used. **Field measurements** of the cropping activities such as water level, sowing date, fertilizer applications, harvest date, crop heights and leaf area index (LAI) were collected during the 2007-2008 cropping season (Figure 5). Soil samples from the rice fields were simply taken for soil hydraulic conductivities analysis. The observed data were utilized as input parameters in the process of the model calibration and simulation, while some of the data were also applied during the validation part as well.

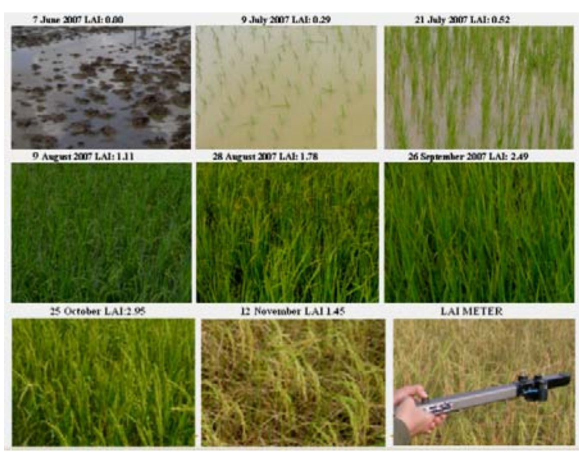


Figure 5. LAI measurements in the rice fields at different stages of growth using LAI meter.

Models Development

In this study, a water balance known as Surface Energy Balance Algorithm for Land (SEBAL) and agro-hydrological crop model called the Soil-Water-Atmosphere-Plant Model (SWAP) with internal built-in WOrld FOod Studies (WOFOST) crop model were applied and put into practice using the time series remote sensing (RS) for estimating the actual evapotranspiration (ET_a) and simulating the soil moisture and yield under the different weather conditions. For calculating the evapotranspiration at the sites, the required input parameters in the newly developed SEBAL in C source code (Kamthonkiat et al., 2009) include the MODIS daily surface reflectance products (MOD09GA) 500 m from Band 1 to Band 7, solar zenith angle, quality control band, land surface temperature, and emissivity from MODIS daily land surface temperature product (MOD11A1) at 1 km. In addition, weather data at Julian day, wind speed, height of vegetation and altitude of target area and locations of hot and cold areas were also required in the process. The derived time series satellite ET_a was validated to confirm the observed ET_a from the Bowen Ratio equipment at the observation site and produced as water stress map of the study area.

In another part of the time series of MODIS 8 day composite leaf area index or LAI (MOD15A2 or Leaf Area Index and Fraction of Photosynthetically Active Radiation, with 1 km spatial resolution) was induced in the process of SWAP calibration using the Genetic Algorithm (GA). GA is an optimizer process of data assimilation between the model and RS to estimate the model parameter so that SWAP can explain the RS data (Figure 6). This method which is known as the RS-SWAP-GA (Remote Sensing – Soil Water Atmosphere Plant – Genetic Algorithm), with multi-criteria assimilation procedure developed in our study, was used to identify the soil parameters and plant parameters in the study area such as the soil hydraulic parameters, LAI, ET, soil moisture and yield (Ines, et al., 2006, Chemin, et al., 2005).

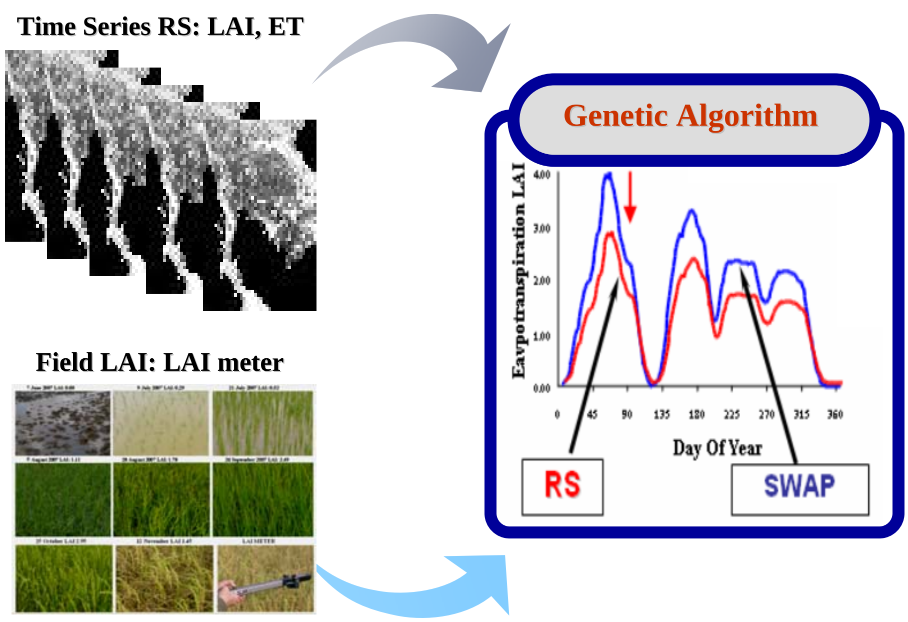


Figure 6. The RS-SWAP-GA concept.

The estimated ET_a from satellite using SEBAL model was validated using the site ET_a from the Bowen Ratio method. The simulated LAI, soil moisture and LAI using SWAP were validated with the observed data from our monitoring system while the estimated yield was compared to the actual harvest in the study area.

RESULTS

The discussion of the results of this study is separated into 3 parts. **First** is the development and operation of the real-time weather and flux observation systems. Two observation systems were installed in Trakan Phutphon and

Det Udom Districts, Ubon Ratchathani Province. Both stations have been operating and providing the real-time/near real-time weather-soil-crop data from two large homogeneous rice fields for almost two years. The observed data include rainfall, temperature, humidity, net radiation, wind direction and wind speed, soil moisture, soil temperature, sowing date, dates of fertilizer applications, harvesting date, crop heights (weekly), LAI (bi-weekly-monthly), water height (daily), and yield. Figure 7 presents the sample plot of 7-day weather and flux data observed from our monitoring system.

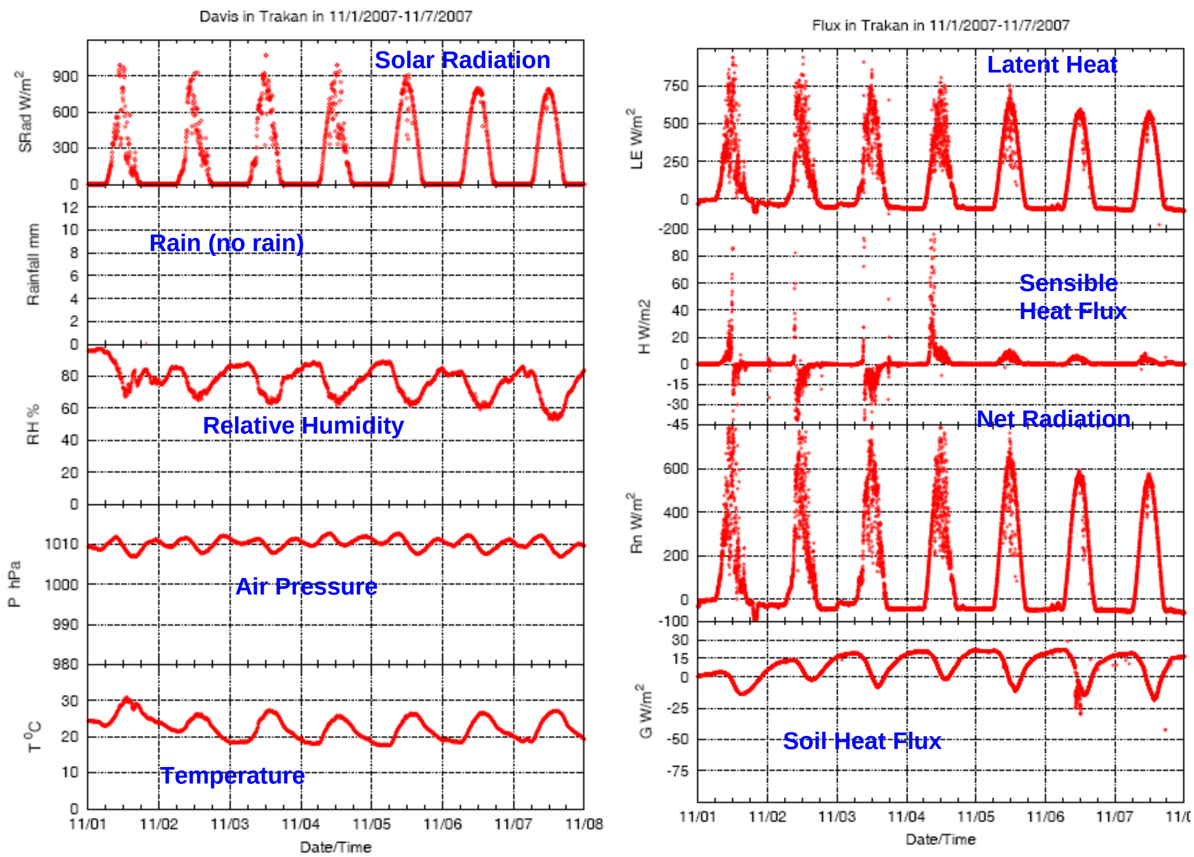


Figure 7. Weather and flux data observations from Trakan Phutphon District: Year 2007.

The observed data was produced for easy visualization (as shown in the above samples/figures) in various time scale such as yearly, monthly, weekly, daily and hourly. However, some data were not available especially during the rainy season because the unstable electricity and internet services in the study area interrupted the on-site computer servers in both stations and sometimes even putting them out of service. Nevertheless, during the operation, the observed weather data from DAVIS instrument was published and accessible via internet in real time (Figure 8).

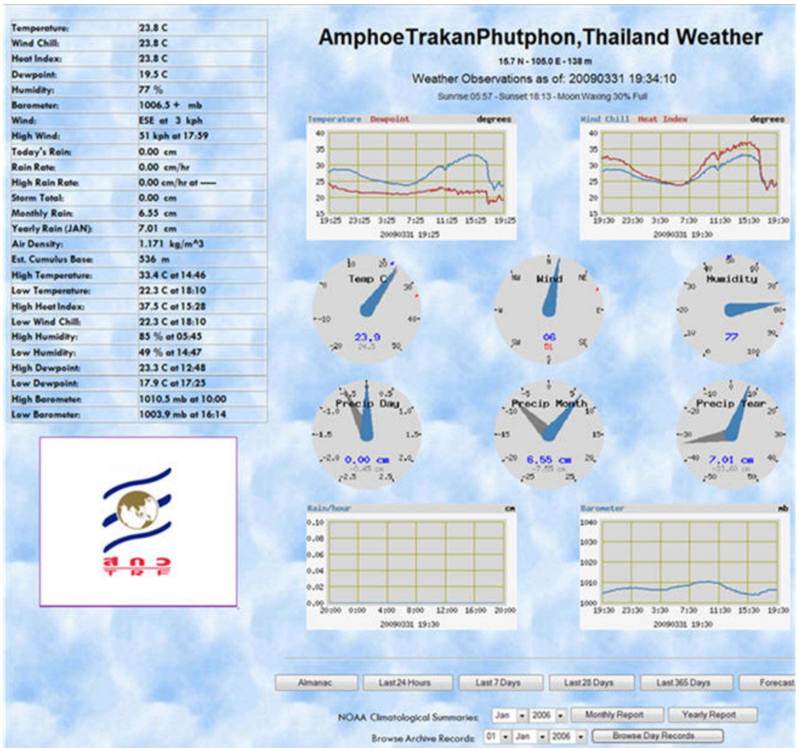


Figure 8. The online observed data from the study area.

The **second** part involves the calculation of ET_a from satellite data using SEBAL and the simulated ET_a, LAI, soil moisture and yield from SWAP. The derived parameters from the models were validated and its pattern with the same parameters observed by the monitoring system in the rice field. The calculated evapotranspiration rate from agricultural fields is around 0-3 mm per day in dry season while during the crop growing season (September 2007) the evapotranspiration rate is around 5-7 mm per day. Figure 9 shows a sample ET_a map at 500 x 500 m^2 spatial resolution during dry season. Based on this map, it has been observed that the point-based ET_a from Bowen ratio method, is higher than the estimated of area-based ET_a from MODIS imageries (1 pixel = 500 x 500 m^2). The RMSE is 1.71 cm/day, with R^2 equal to 0.68.

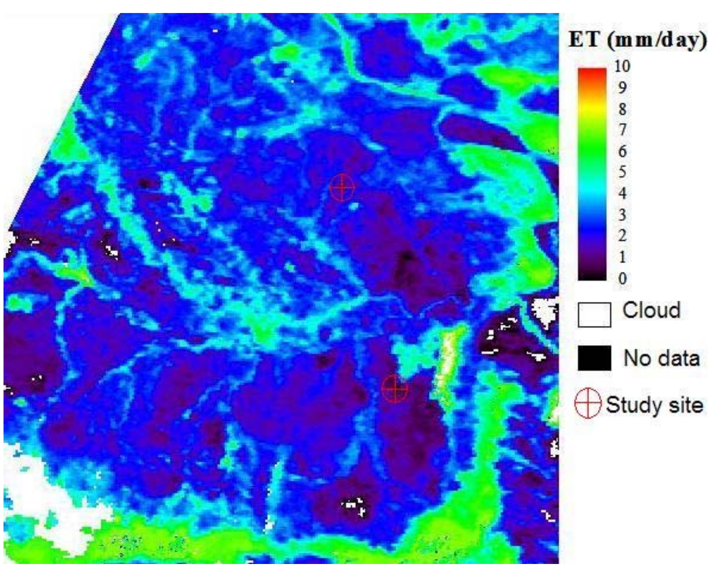


Figure 9. Satellite Actual Evapotranspiration map in dry season (March 4, 2008).

SEBAL assumed a clear sky condition in the estimation of ET but in reality, the sky would not always be clear. Under this condition, the calculated crop water stress index appeared too high compared with the field observation as presented in Figure 10. Therefore, a method to estimate ET from a combination of satellite and ground data was proposed, i.e. actual sunshine hour or actual solar radiation. As a result, more reliable data could be generated as shown in Figure 11.

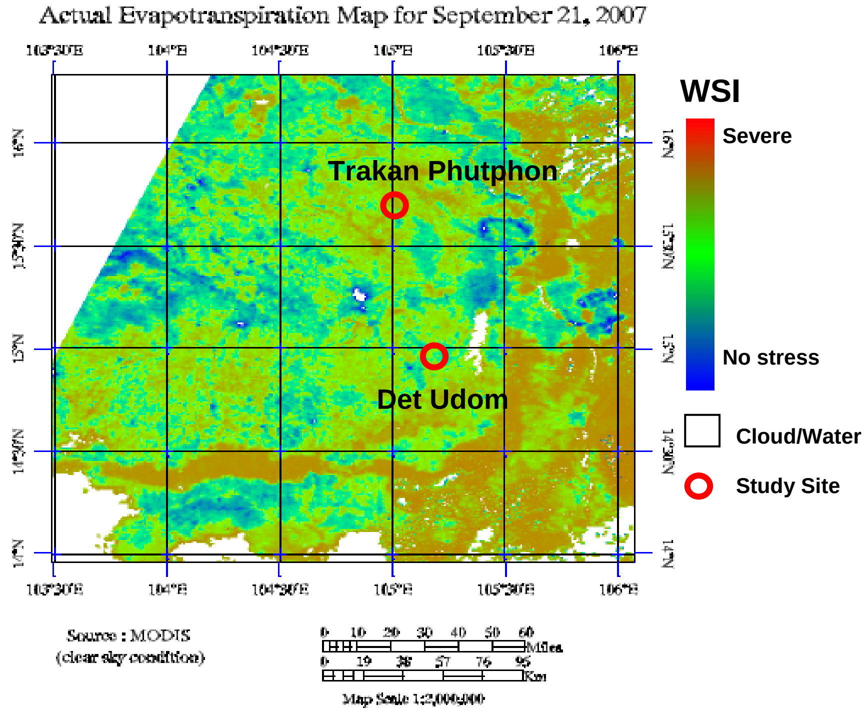


Figure 10. Water stress index map, assuming clear sky condition in a whole day.

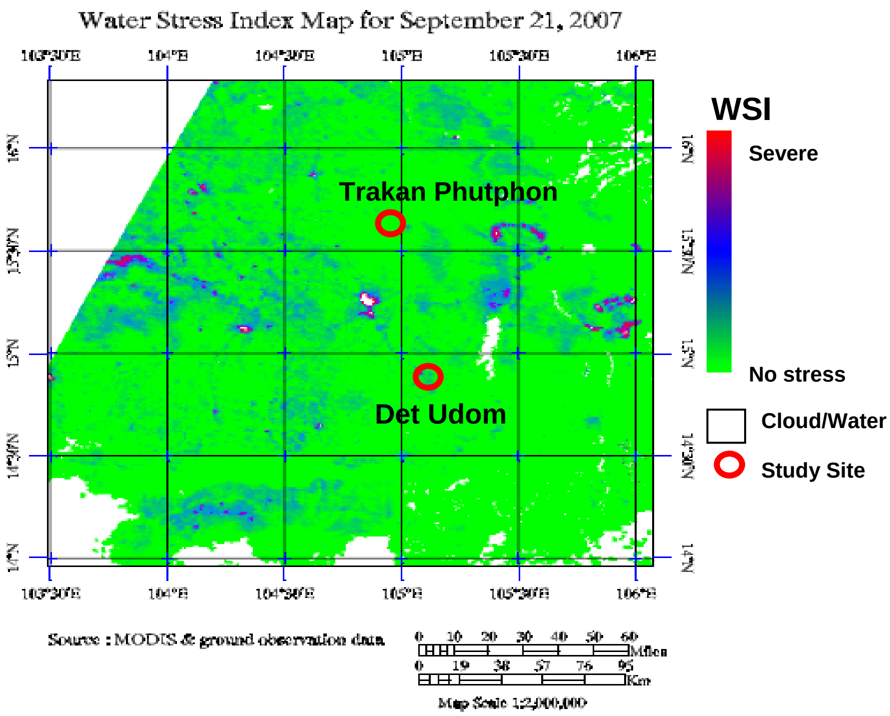


Figure 11. Water stress index map, assuming no clear sky condition in a whole day.

In the **third** part which involves the process of computing the RS-SWAP-GA, MODIS LAI was calibrated with the observed or measured LAI in the field using a LAI meter. The calibrated LAI presented high correlation of the simulated LAI from SWAP (R^2 = 0.96). Considering that soil hydraulic parameters can be extracted after assimilation process in SWAP using LAI, ET_a and soil moisture independently or by their combinations, these were then put back into the inverse process in the SWAP to simulate LAI, ET_a, soil moisture and yield. The simulated parameters were compared with the field observed data. Figure 12 presents the comparison of the soil moistures at different soil layers from SWAP and soil moisture sensors. The period of calibration/validation was from 23 March to 15 May 2007. Using satellite data; ET from SEBAL and MODIS LAI, the simulated soil moistures show good matching with the observed data at 3 and 12 cm, fair at 28 cm but rather poor matching at 60 cm of soil depths.

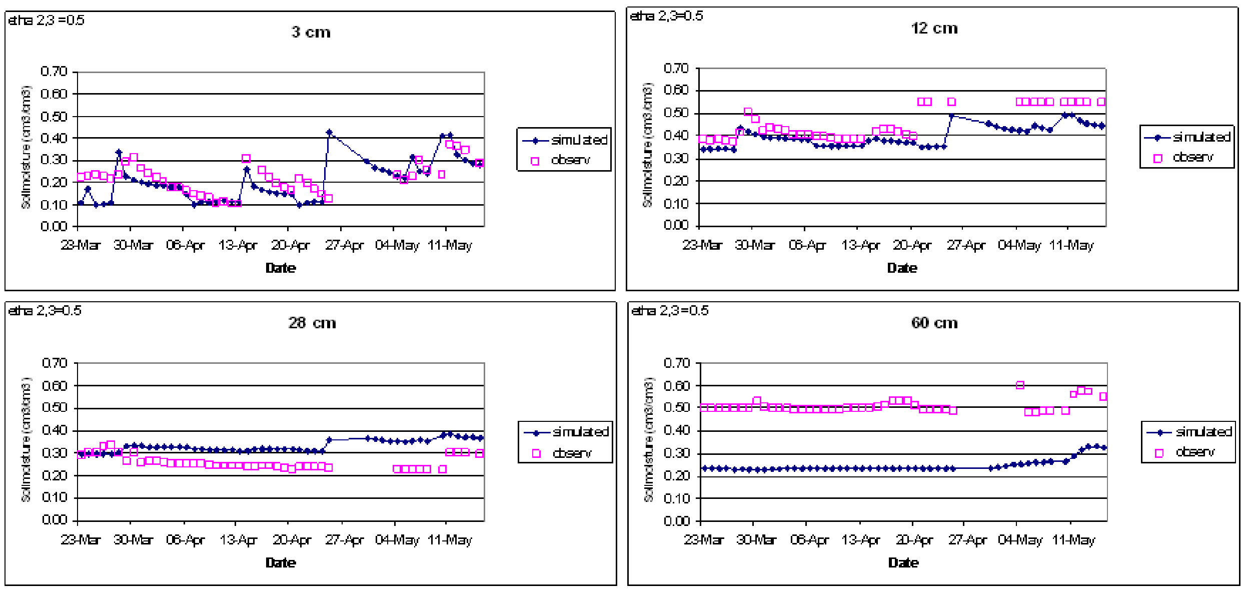


Figure 12. Simulated soil moisture using satellite data - ET and LAI.

At the same period, Figure 13 shows more matching patterns at every soil layers using a combination of LAI and ET from satellite data including the observed soil moisture.

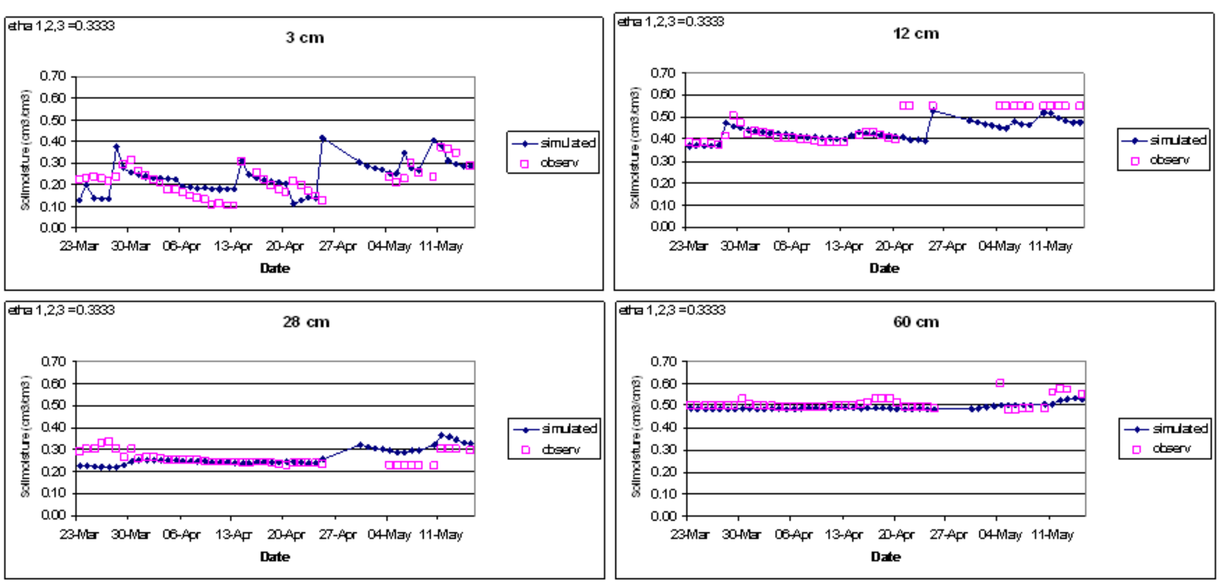


Figure 13. Simulated soil moisture using multi-criteria: ET, LAI and Field Soil Moisture

RS-SWAP-GA is therefore, a promising method for estimating soil hydraulic properties and simulating the soil moisture using the combination of satellite data (ET and LAI). Field data is a key to improving the accuracy of soil moisture simulations at deeper layers. The calibrated SWAP with satellite and field data were estimated for about 393 kilograms per rai (1 rai = 0.60 ha) of rice yield for the 2007 cropping. While the actual harvested yield in our study area in Trakan Phutphon District was around 350 kilograms per rai. Yields under different rainfall scenarios were also simulated in order to understand the impacts of rainfall and dry spell. Table 1 presents the estimated rice yields under different rainfall scenarios during April to November when a 30-day dry spells was expected to occur. The simulated yields implied that a 30-day dry spell in October will bring the most drastic impact to the rainfed rice yield. Since no drought hit Ubon Ratchathani during the period of our study, longer observations, more simulations and validations have therefore been suggested. SEBAL and SWAP should be calibrated longer with high quality data such as time series and noise (cloud) free data from satellite and weather observation system at the study area or rainfed rice field. Aside from the yield, other crop response characteristics during the crop growth (e.g., biomass, flowering dates, etc.) should be considered as well.

Table 1. Yields estimation under a 30-day dry spell (Apr-Nov)

Month	**Rice Yield (kg/rai)**
April	393.28
May	393.12
June	393.12
July	384.80
August	389.12
September	403.04
October	**191.68**
November	392.96

Framed in October, a 7-day dry spell in the second week of October shows the estimations of rice yield under the 7-day dry spell scenarios in the month of October. The estimated yields using SWAP has been dramatically reduced if a 7-day dry spell happen in the second week of October. Moreover, yield estimations under different cropping practices such as shifting of the sowing date, fertilizing date and harvesting date should be observed for better understanding of the impact of cropping activities on the rice yield.

CONCLUSIONS

Our study has successfully developed a new methodology to calibrate an agro-hydrological model (Soil-Water-Atmosphere-Plant or SWAP model) through data assimilation by GA using RS data, known as the RS-SWAP-GA. The model could simulate soil moisture, water stress and yield in rainfed paddy fields in order to evaluate the impacts of dry spell or drought scenarios. The calibration does not require intensive field observations or field sample testing, thus the methodology can be applied at regional scale. As source of the model parameters, which provide a real represented weather in rice cultivated areas, two stations of real-time weather and flux observations were setup in rainfed paddy fields in Trakan Phutphon and Det Udom in Ubon Ratchathani Province. General meteorological observation, energy flux observation including evapotranspiration, soil moisture observation, soil sampling test and rice growth monitoring were carried out. The system directly measured 23 items while 7 items were derived.

MODIS data was analyzed to retrieve the LAI, ET_a and water stress maps using the SEBAL model, which concluded that the estimated satellite ET_a was reasonable. In addition, the data from the field observations and RS became important as reliable data for the calibration, simulation and validation of the models as well as the results.

Although no drought phenomenon occurred in Ubon Ratchathani during the study period 2007-2008, the usefulness of the methodology can be demonstrated using historical weather and yield records. Meanwhile, the synthesized drought scenarios were evaluated to understand the characteristics of the impacts of drought to the yield. The results demonstrated that the methodology has fairly high potential to be a part of a drought monitoring system as well as the agricultural decision support system in Thailand. It can also provide useful and near real-time information such as soil moisture, water stress and their impacts on the rice yield.

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