SPATIO-TEMPORAL PATTERNS OF RICE SUBMERGENCE IN NORTH-EASTERN THAILAND WITH TERRA-MODIS

Yann Chemin[1], Surajit Phupak[2]

[1]International Water Management Institute
[2]Faculty of Agriculture, Ubon Ratchathani University

[1]127 Sunil Mw, 12120 Pelawatta, Sri Lanka;
Tel: +94 11 (0) -288-0000; Fax. +94 11 (0) -278-6854
E-mail: y.chemin@cgiar.org

[2]Varin Chamrab, Ubon Ratchathani, 34190, Thailand;
Tel: +66 45 (0) -353-552; Fax. +66 45 (0) -288-373
E-mail: sura@agri.ubu.ac.th

KEY WORDS: Rice, submergence, open water, occurrence, spatio-temporal, NDVI, MODIS, Isarn, Thailand

Abstract: Rice submergence is the condition by which the water level rises above the rice crop canopy. In general, rice plant response to submergence is to elongate its shoots above the rising water level. This costs in energy and eventually has a direct impact in terms of reducing yields. A specific gene, called Sub1, when introgressed into popular rice varieties by Marker Assisted Back-crossing, nearly stops the natural elongation process and permits a given local rice variety to sustain submerged conditions for a generally recognized period of about 2 weeks. Plant breeders now look for well-identified and location-accurate submergence areas in order to disseminate such improved local rice varieties. Remote sensing is proposed to provide surface water maps at high temporal resolution, determining a percentage of occurrences of surface water for a given pixel. Occurrence is defined as the count of days of identified surface water within a given period, returned in a percentage on that period. Rice area maps and knowledge of crop calendars are proposed to add to the assessment of submergence prone areas in the Northeastern Thailand.

INTRODUCTION

Rice is often grown in the lowest parts of the landscape because these areas are relatively flat, fertile, and humid, and facilitate the creation of bunded fields that are flooded with water from rainfall and lateral water flow, and in many places from additional irrigation. Being in the lowest part of the landscape makes rice vulnerable to periods of excess water which can lead to flooding of the fields and submergence of the rice crop. Submergence occurs when the water level rises above the crop canopy. Most rice varieties can survive only a few days under water and respond to submergence by increased elongation, which may allow the plants to emerge above the water. This is a necessary response for rice plants growing in an environment where the water level steadily increases throughout the first part of the growing season.

A clear example of this are the “deep-water rice” varieties that the capacity for extreme elongation and can grow in fields that get as much as 5 m of standing water. For most varieties, the elongation response is effective if it allows the plants to emerge within a week or so. However, if they cannot grow out of the water within that period the plants die (Adkins et al., 1990).

This is a widespread problem; submergence stress is considered the third most important a biotic stress (after drought and salinity) in rice production in India that frequently affects over 15 million ha (Widawsky and O’Toole, 1990). A few varieties have a different adaptation to submergence (Xu and Mackill, 1996, Xu et al., 2006 and Siangliw et al., 2003). They hardly elongate when submerged, and in that way they save energy to recover after the water recedes. It has been shown that this is a good strategy to flash-flood like submergence events that are characterized by high water levels during a relatively short period (up to 17 days; Singh et al., 2009).

This “submergence-tolerance” trait, has recently been introgressed into widely used rice varieties (Septiningsih et al., 2009). Estimating the potential benefits of these varieties and designing effective dissemination programs is not trivial. Among other things, it requires information about the spatial and temporal distribution of submergence events in rice fields, and their duration. It is particularly important to distinguish flash flood prone areas from areas with steadily increasing water levels.

Here we explore the used of satellite remote sensing to detect and quantify the extent of flash flooding in rice fields.

Remote sensing has been used to monitor major flood events (e.g., Smith, 1997 and Brakenridge et al., 2003), but not much work has been done or more localized flooding of rice fields. Moreover, the preferred way to detect water is active remote sensing using radar, because the emitted radiation measured by passive approaches is obscured by the cloud cover (and submergence and high cloud cover often co-occur). An operational system based on Radarsat-2 imagery (GISTDA, 2012) is operated by GISTDA in Thailand, with a temporal resolution of 15 days. However, radar remote sensing products are not in the public domain (as in free to download), and generally available for specific locations and time periods, at a high cost (financially and human-time).

Here we evaluate the use MODIS satellite data, because it has a global coverage, high temporal resolution (daily) and reasonable spatial resolution (250 m). We used 8-day composite images to estimate the spatial and temporal extent of flooding in rice fields in Northeast Thailand. There is about 8.8 million ha of rice (about 57% of the rice area in Thailand), producing about 45% of the national total (OAE, 2008). Most rice is grown on rainfed, typically flooded fields, with only about 10% of the area receiving irrigation water. The average annual rainfall is about 1300 mm. The rainy season normally starts beginning of May and ends by mid-October (TMD, 2007). In this season, there is a bi-modal rainfall pattern, with dry spells common in June and early July. Most rice is transplanted and seedbed preparation starts at the first or second rains, in May or June (Table 1, Jompradit, 2007), transplanting being one month later (Sawano et al., 2008).

Table 1: North-East Thailand cropping calendar after Jornpradit (2007)

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Rainfed rice	■					■	■	■	■	■	■	■
Irrigated dry season rice	■	■	■	■	■							

Since the dominant rice varieties are photoperiod-sensitive, flowering is largely independent of the planting date, occurring by the end of September, and harvesting takes place in November. Submergence and drought are major constraints to rice production in Thailand, but submergence is more important. For example, in Thailand, the rice area that was lost due to flooding between 1989 and 2010 was 1.1 million ha (Figure 1). In the worst year, 2001, flooding resulted in the loss of about 4 million ha of rice (DDPM, 2008; NESDB, 2012).

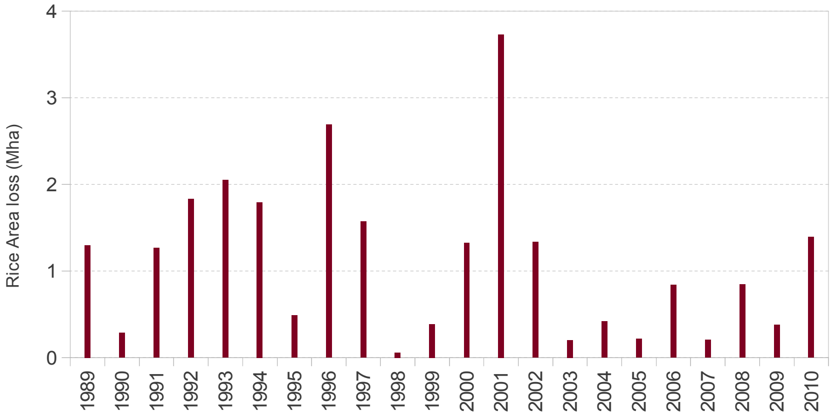

Figure 1: Rice area losses due to flooding in Thailand (1989-2010) Source: NESDB (2012)

RATIONALE

For each pixel (grid cell) we determine the occurrence of surface water this information is then combined with rice crop areas and known cropping calendars to provide an estimate of the area possibly affected by submergence. Multiple years coverage of flood extents should be investigated to determine the occurrence of surface water for each pixel.

This permits to discover hazardous events that come as a "surprise" to the farmers. Indeed, if it happens every year, farmers either do not grow rice, or do but in another season, or use permanently rice with longer straw varieties. Occurrence is defined as the count of days of identified surface water within a given period, returned as a percentage for that period. This information is then combined with rice crop areas and known cropping calendars to provide an estimate of the area affected by submergence. This work should form a basis for identifying priority areas for submergence-tolerant variety testing and dissemination across rice-growing areas.

METHODS

The processing of this large dataset was made into a High-Performance Computing framework adapted from those found in Akhter et al., (2006, 2007, 2008) and Chemin (2012). The distributed framework is a Linux system based on GDAL library (2012) and C programming, enhanced with a distributed language called OpenMP (2012), used essentially for data distribution as in Chemin (2011). We used a 48 threads machine (2 cpus with hexa-cores having 4 threads each). Large datasets can then be processed in a "more human" amount of time (i.e. few hours or minutes) than if processed in a single working element. A general perspective is to gain one order of magnitude in processing speed (months become days, days become hours, or hours become minutes).

The Moderate Resolution Imaging Spectroradiometer (MODIS) is a sensor aboard the TERRA and AQUA satellites. These satellites cover each part of the earth every one to two days, acquiring data in 36 spectral bands with wavelength ranging from 0.4 µm to 14.4 µm. The spatial resolution varies from 250m to 1000m. Over 100 MODIS products can be accessed for free through the NASA websites (NASA, 2008).

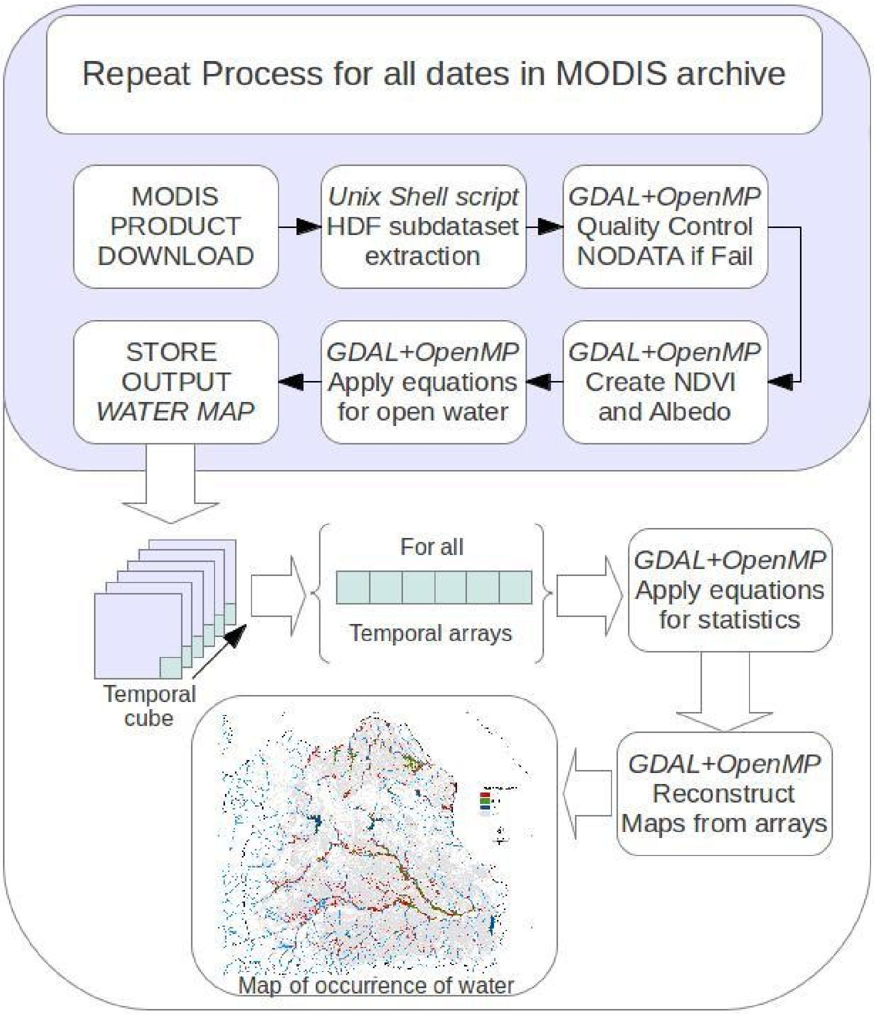

Figure 2: Chain processing of MODIS products, temporal cubes of water maps, statistical output maps

For this study (Figure 2), we used MODIS surface reflectance products, i.e., MOD09Q1 and MOD09A1 from 2000 to 2008. MOD09Q1 provides surface reflectance of the composites of the 8-day data for band 1 (red, 620-670nm), band 2 (NIR, 841-876nm) and quality control flags at 250m. It gives the amount of light reflected by the surface of the earth. We used the quality control flags to provide information on data correction, about data quality, errors or problems in the data and clouds state (MLSR-SCF, 2008) and removed unusable pixels from processing. MOD09A1 is a composite of the best observations during an 8-day period. The data includes surface reflectance for seven wavelengths, from 459nm (blue) to 2155nm (SWIR$_2$) and a state quality control flag for identifying the cloudy pixels, which we used to remove pixel values. We used band 7 (2155 nm) to detect water. The pixel values for both surface reflectance products ranges from -100 to 16000. We applied the standard scaling factor of 0.0001 to derive surface reflectance values with a normal range of 0 to 1.0 (MLSR-SCF, 2008) (values below 0 and above 1 were truncated).

Paddy rice area (i.e. excluding "upland rice") for NE Thailand was derived from a land use database for 2003 (LDD, 2003) by selecting all polygons for which rice was the principal land use. For the northeast Thailand, we used 360 8-days composite water images during the period of 2000-2008 (MODIS tiles h27v07/h28v07).

We used the surface water detection methods by Xiao et al., (2006) and Roy et al., (2005). It is a MODIS based threshold system, where if NDVI < 0.1 and surface reflectance in Band 7 is less than 0.04, then the pixel is given a value of 1. Non-water pixels are set to 0. Faulty pixels (failed to process because of cloud, low sun angle, etc) were removed from further calculations. We computed averages over time for the binary (0/1) water occurrence values for each pixel.

RESULTS

Initial mapping took an overview standpoint (Figure 3), using all available information and averaging the binary values over time. We refer to this [0-1] range as the relative frequency of detectable surface water occurrence. "Detectable water" refers to water that is above the crop canopy, unlike the desired situation in flooded rice fields, where there is surface water below the top of the canopy. In other words, Figure 3 shows the percentage of surface water occurrence (2000-08) resulting in an end-to-end occurrence of surface water. The red color in Figure 3 above is a surface water occurrence of 1-10% for all images analyzed.

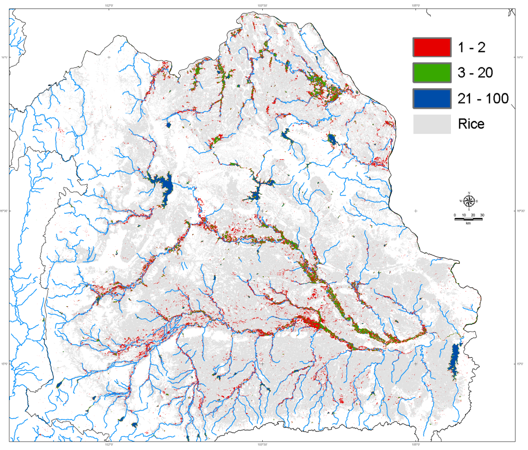

Figure 3: Relative frequency of detectable surface water occurrence (2000-08)

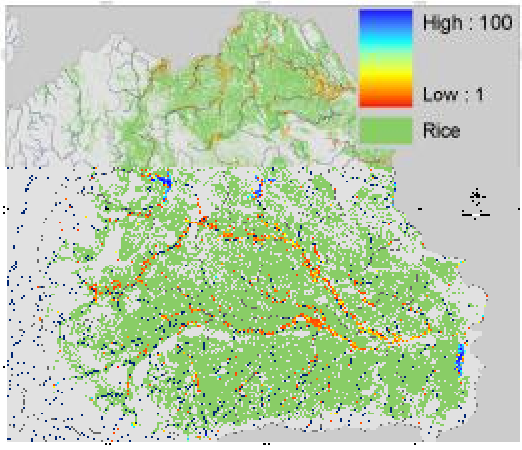

Figure 4: Average occurrence (2000-2008) of detectable surface water, month of September.

We also computed values for the few flooding prone months in the cropping season. Local cropping calendar (Table 1) was used to separate cropping seasons prior to process the occurrence of surface water, this provides convenient basis for seasonal events. We identified August-September-October as the recurrent surface water season by combining information derived from Table 1 and monthly statistics from the remote sensing processing (Figure 4). We combined the surface water maps with rice area maps to provide location targeting for submergence-tolerant rice variety dissemination. If only the 3 months rainfall peak is taken (August-October, not shown) the occurrence on the same areas expands to a range of about 5-30%. This can be stronger (Figure 4) on a single month period of September occurrences ranging 10-75%.

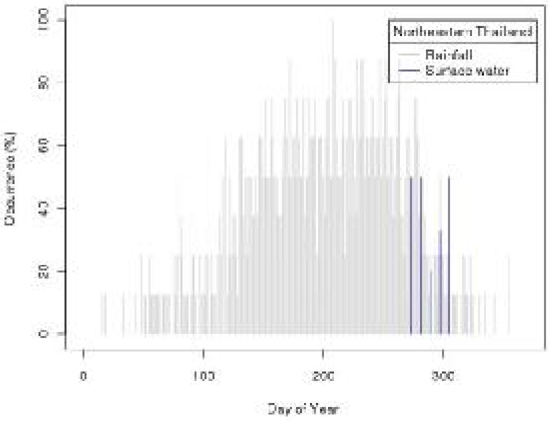

Figure 5: 8-daily open water occurrence, random pixel.

On the other hand, the Left-side map of Figure 6 is showing Ubon Rat Dam (top left) and Lam Pao Dam (top right), which are having downstream command areas under various threat (10-50% occurrence of surface water in August-October period). We found that in Northeastern Thailand, 6% of the rice areas had between 1 to 100% occurrence of surface water for the period of 2000 to 2008.

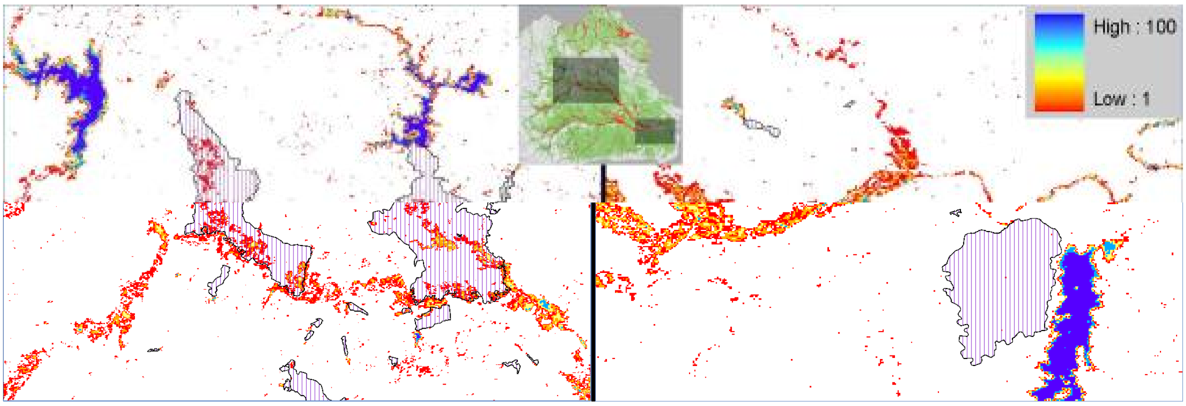

Figure 6: Submergence occurrence (%) in August-October with irrigated areas

The distribution of the rice area covered with surface water is shown in Figure 7 below. Figure 7 shows that most of the surface water in rice land is having an occurrence less than 10-20% of the time. Over the 9 years of this study, that means 300-400 days estimated of surface water. While this is useful for the sensitivity of the rice land system in North East Thailand, Figure 7 only shows the spatial distribution, not the temporal distribution of surface water occurrence. When the detectable water occurrence is getting closer to 100%, nobody will grow rice at that location.

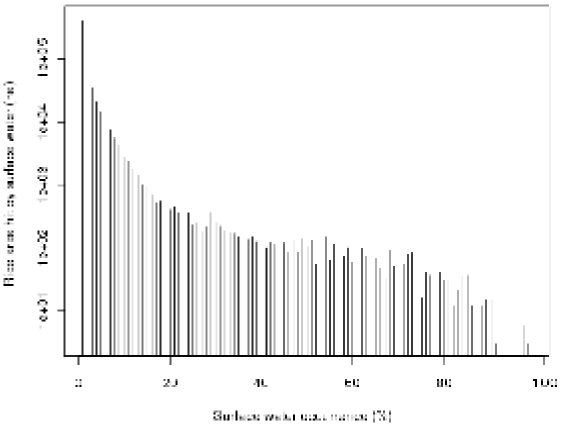

Figure 7: Distribution rice area affected by detectable surface water occurrence (note the logarithmic y-axis)

The average area of rice that was found to be hit by some submergence at some point into the 9 years studied (i.e. probability of occurrence of submergence not null) is of 530,005 ha. When compared with information found in Figure 1, this is 50% of the total flood affected area of Thailand (1,013,670 ha) for the same period.

Table 2: Rice area loss in Northeastern Thailand (MoA, 2012)

Year	2005	2006	2007	2008	2009	2010	2011
Rice area loss (ha)	82,286	267,289	252,972	438,531	97,968	471,070	593,630

When comparing with information from Table 2, which is from a different period, the average of Table 2 is 315,000 ha, lower than what was estimated for the period 2000-2008 with this study.

CONCLUSIONS & RECOMMENDATIONS

Estimating the occurrence of open water provides information that can be related to known rice cropping areas in order to determine potential threat of submergence. However, we cannot ascertain the timing or the duration of surface water at this stage. To remedy to that, another and last geographic modeling is necessary, that is the combination of the cropping calendar and the temporal succession of surface water appearance using daily MODIS images that may provide a welcome support to enhance the quality of detection. Some of the limitations found when attending to the processing of the statistics of occurrence of surface water are that the identification models are simple relationships (which is also an advantage) and that we did not perform any temporal cloud filling procedure (i.e. interpolating binary information of presence or absence of surface water). This will change statistics, though the large number of pixels analyzed is helping in terms of statistical meaning. This research work gives ground to target location-based dissemination of Sub1 introgressed varieties of rice, to alleviate yield loss in case of submergence of rice by uncontrolled ponding water beyond the height of the plant. Some further work is required to find ways to interpolate binary information of the presence/absence of surface water in a given pixel along the temporal axis.

Further work involves the use of Terra-AQUA afternoon overpass to double the temporal pixel density, the use of heuristics for replacing cloudy pixels under very high probability of open water remaining in the pixel. Another direction for rice submergence research improvement would be to follow the crop stage development stages as the events of submergence develop, so as to ascertain the rice crop variable survival chances.

ACKNOWLEDGEMENTS

The author would like to acknowledge the sponsors of this study, the CGIAR Climate Change Food Security and Agriculture (CCAFS) initiative and IRRI core funding. Also the authors would like to thank the Philippines part of the study (not described here but part of the project): Ms Sonia Asilo (now Doctorate Candidate, ITC) and the research coordinator: Robert Hijmans (now Associate Professor, UCDavis).

REFERENCES:

Adkins, S. W., Shiraishi, T., and McComb, J. A., 1990, Submergence Tolerance of Rice - A New Glasshouse Method for the Experimental Submergence of Plants. *Physiol*, Plant, 80, 642-646.

Akhter, S., Jangjaimon, I., Chemin, Y., Uthayopas, P., and Honda, K., 2006, Development of a GRIDRPC Tool for Satellite Images Parallel Data Assimilation in Agricultural Monitoring. *International Journal of GeoInformatics*, (2)3: 29-33.

Akhter, S., Sarkar, I., Rabbany, K. G., Akter, N., Akhter, S., Chemin, Y., and Honda, K., 2007, Adapting the LMF Temporal Splining Procedure From Serial to MPI/Linux Clusters. *Journal of Computer Science* 3(3): 130-133.
Akhter, S., Aida, K., and Chemin, Y., 2008, Asynchronous Grid LMF Processing of Vegetation Index for Asia. *International Journal of GeoInformatics*. (4)4: 39-45.

Brakenridge, G. R., Andersona, E., Nghiemb, S. V., Caquard, S., and Shabaneh, T. B., 2003, Flood Warnings, Flood Disaster Assessments, and Flood Hazard Reduction: The Roles of Orbital Remote Sensing. In *Proceedings of the 30th International Symposium on Remote Sensing of Environment*.

Chemin, Y., 2011, Remote Sensing Raster Programming. Second Edition, Lulu Publishers. ISBN 978-1-4092-6689-1, France, 89. http://www.lulu.com/content/6138603.

Chemin, Y., 2012, A Distributed Benchmarking Framework for Actual ET models. In Evapotranspiration – Remote Sensing and Modeling, ISBN 978-953-307-216-6, December 2011, Chapter 19, 421-436.

DDPM, 2008, Disaster Prevention and Mitigation (DDPM), The Ministry of Interior, www.disaster.go.th Access date: October 2007.

DFO, 2008, Dartmouth Flood Observatory Website. (http://www.dartmouth.edu/~floods/). Access date: January 2008

GDAL library, 2012, Geospatial Data Abstraction Library. http://www.gdal.org

GISTDA, 2012, http://flood.gistda.or.th

Jornpradit, E., 2007, The Optimum Planning of Water Resources usage in New Theory of Integrated Farming System by Differential Evolution Algorithm. M.Eng. Dept of Water Resources Engineering. Kasetsart University, Thailand, 265. (http://research.rdi.ku.ac.th/world/showItem.php?itemID=88066)

MoI, 2008, Disaster Prevention and Mitigation (DDPM), under the Ministry of Interior, Thailand

MoA, 2012, Department of Agricultural Extention, Ministry of Agriculture, Thailand, 2012.

MLSR-SCF, 2008, MODIS Land Surface Reflectance – Science Computing Facility Homepage. (http://modis-sr.ltdri.org/). Access date: January 2008

NASA, 2008, NASA Warehouse Inventory Search Tool homepage. (https://wist.echo.nasa.gov-/api/). Access date: January 2008

NESDB, 2012, Office of the National Economic and Social Development Board, http://www.nesdb.go.th/, Access date: 13 Feb, 2012.

OAE, 2008, Agricultural Economic Indication of Thailand Year 2007. www.oae.go.th Access date: December 2008.

OpenMP, 2012, The OpenMP API Specification for Parallel Programming, http://www.openmp.org

Roy, D. P., Jin, Y., Lewis, P. E., and Justice, C. O., 2005, Prototyping a Global Algorithm for Systematic Fire-Affected Area Mapping using MODIS Time Series Data. *Remote Sensing of Environment* 97, 137-162.

Sawano, S., Hasegawa, T., Goto, S., Konghakote, P., Polthanee, A., Ishigooka, Y., Kuwagata, T., and Toritani, H., 2008, Modeling the Dependence of the Crop Calendar for Rain-Fed Rice on Precipitation in Northeast Thailand. *Paddy Water Environment*. 6:83-90.

Septiningsih, E. M., Pamplona, A. M., Sanchez, D. L., Maghirang-Rodriguez, R., Neeraja, C. N., Vergara, G. V., Heuer, S., Ismail, A. M., and Mackill, D. J., 2009, Development of Submergence-Tolerant Rice Cultivars: The Sub1 Gene and Beyond. *Ann. Bot*., 103(2):151-160.

Siangliw, M., Toojinda, T., Tragoonrung, S., and Vanavichit, A. 2003, Thai Jasmine Rice Carrying QTLch9 (SubQTL) is Submergence Tolerant. *Annals of Botany*. 91: 255-261.

Singh, S., Mackill, D. J., and Ismail, A. M., 2009, Responses of SUB1 Rice Introgression Lines to Submergence in the field: Yield and Grain Quality. Field Crops Research 113: 12–23.

Smith, L. C., 1997, Satellite Remote Sensing of River Inundation Area Stage and Discharge: A Review. *Hydrological Processes*, 11:1427-1439.

Xiao, X., Boles, S., Frolking, S., Li, C., Babu, J. Y., Sala, W., Morre III, B., 2006, Mapping Paddy Rice Agriculture in South and South-East Asia using Multi-Temporal MODIS Images. *Remote Sensing of Environment*. 100, 95-113.

Xu, D., and Mackill, D. J., 1996, A Major Locus for Submergence Tolerance Mapped on Rice Chromosome 9. Mol. Breed. 2, 219-224.

Xu, K., Xu, X., Fukao, T., Canlas, P., Maghirang-Rodriguez, R., Heuer, S., Abdelbagi, M., Bailey-Serres, J., Ronald, P., and Mackill, D., 2006, Sub1A is an Ethylene-Response-Factor-Like Gene that Confers Submergence Tolerance to Rice. Nature, (http://dx.doi.org/10.1038/nature04920)

Widawsky, D., and O'Toole, J.C., 1990, Prioritizing the Rice Biotechnology Research Agenda for Western India. The Rockefeller Foundation, New York, USA.