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THESIS

RICE CULTIVATION AND HARVEST DATE ESTIMATION USING
MODIS NDVI TIME-SERIES DATA



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Rice cultivation and harvest dates are very useful information since they are the key factors in rice monitoring, yield estimation and damage assessment. This paper proposes a new approach to estimate rice cultivation and harvest dates by using the eight-day composite normalized difference vegetation index (NDVI) derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) data. However, the NDVI time-series data suffered from cloud contamination. Using the filter to reconstruct to the cloud-free NDVI data can introduce the artifact that may result in incorrect estimation of cultivation harvest dates. As a result, we employ the hidden Markov models to characterize the rice growth states and atmospheric conditions. Here, we divide the rice growth states into four states, nothing, growing, mature, and harvest in which two atmospheric conditions, namely, the clear and cloudy skies can occur. The optimum growth states and atmospheric conditions are determined using the Viterbi algorithm (Viterbi, 1967). In the experiment, we compared with the ground truth data with the estimated cultivation and harvest dates, and found average error around 14 to 17 days for rain-fed rice and around 17 to 19 days for irrigated rice.

Student's signature

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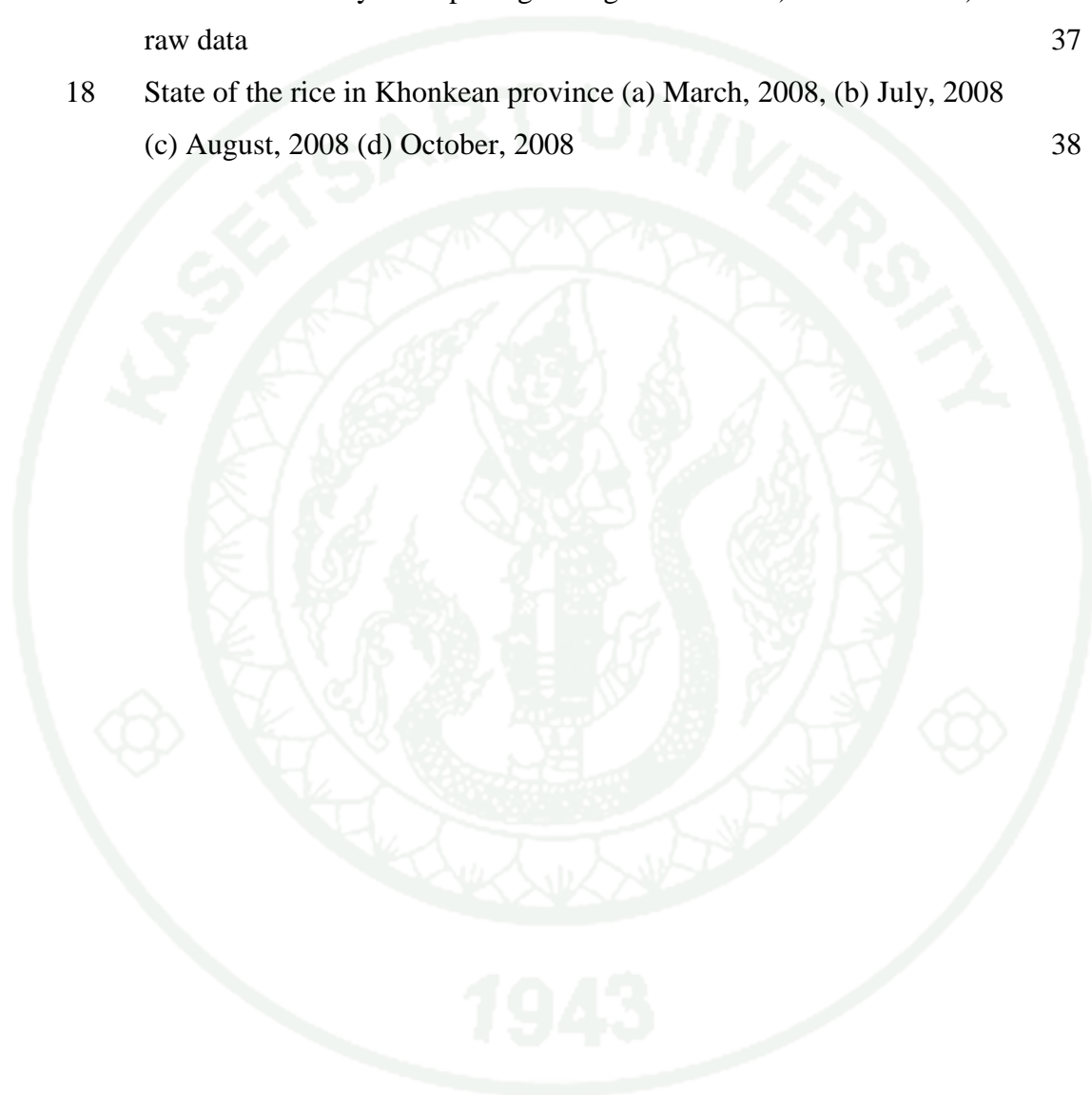
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RICE CULTIVATION AND HARVEST DATE ESTIMATION USING MODIS NDVI TIME-SERIES DATA

INTRODUCTION

Thailand is well-known for its agricultural productivity. Due to its diversified and specialized agriculture products exports are very successful internationally. Thailand's growth rely on agriculture as one of the important driver for a long period of time. Among many industrial crops in Thailand, rice is the most important crop since it is a major exporting vegetation product of Thailand. The major of rice production in Thailand are from the central and north-east regions which are low-land and flat areas (Tingting *et al.*, 2010). Due to its low attitude and flatness, the rice cultivation in these areas can be easily damaged by natural disaster such as floods.

In 2011, Thailand faced its worst flooding in half a century, leaving severe impairments to the country's economy, industrial sector, and society. The flood inundated ninety billion square kilometers of land, more than two-thirds of the country. Ten thousand square kilometers of damaged areas are rice field. To ease the financial burden to Thai farmers, Thai government issued a policy to subsidize the damaged rice fields depending on the development stage of the rice. In order to accurately estimate the growth of the rice, the key factor is the cultivation date and harvest date of the rice. Since the rice cultivation areas are expanses, ground surveys would require huge resources.

By using the satellite image such as the moderate resolution imaging spectroradiometer (MODIS) can help monitoring the rice field area in the whole county-wide area. The MODIS is a key instrument aboard the Terra and Aqua satellites. The Terra MODIS and Aqua MODIS scan the Earth's entire surface every one to two days and acquire data at thirty-six spectral bands. The raw and processed MODIS data are free to access. In many researches, the widely used vegetation index

from MODIS product are normalized difference vegetation index (NDVI) and the enhanced vegetation index (EVI) which can indicate the vegetation density and conditions.

Sakamoto (Sakamoto *et al.*, 2005) proposed that the EVI has a higher sensitive than that of the NDVI in high biomass areas, but on MODIS imagery the original EVI have only 500 meter resolution which is too coarse to be used for most rice field in Thailand. The NDVI is more commonly used and have a higher resolution than EVI (250-m resolution). However, the NDVI data qualities still suffered from various noises such as clouds, aerosols and bidirectional reflectance distribution factors.

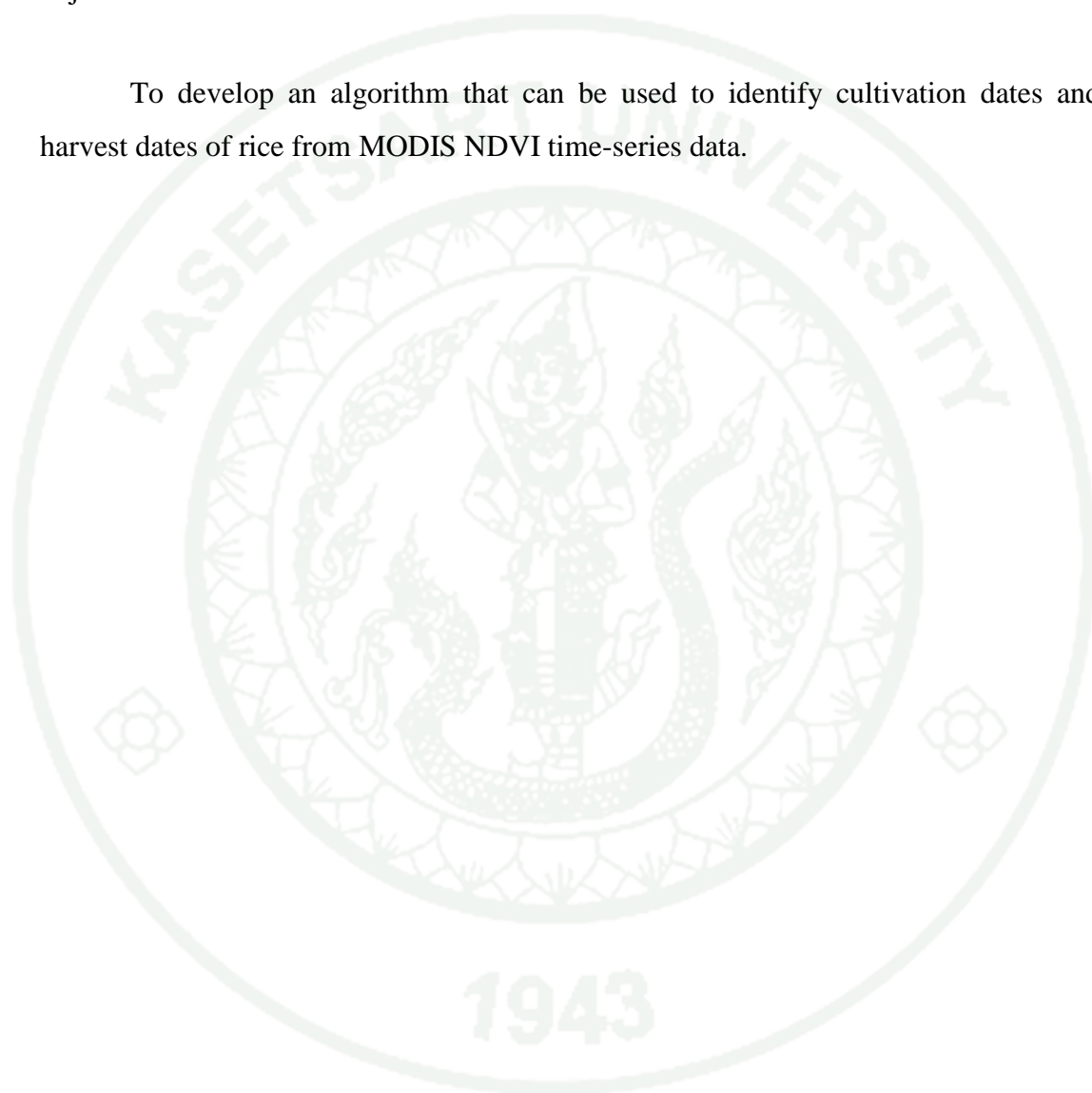
The problem with the data qualities which were affected by cloud contamination and atmospheric variability occurs in many studies. Most of the studies proposed the algorithm to reconstruct the noisy time-series data such as using filter or wavelet operation. These methods may be suitable for low cloud areas. However, this method may not perform well in the high cloud contaminated areas such Thailand. The extremely changes in highly noise NDVI time-series data could cause the reconstruct data too deviated from the original raw NDVI time-series data.

The purpose of this thesis is to use the raw NDVI time-series data to estimate the rice cultivation and harvest dates. From our study, we discovered that the NDVI time-series data of rice have almost the same characteristic every year. If there are not any abnormally events happened such as flooded or drought, the NDVI time-series data of rain-fed rice and irrigated rice will have the similar characteristic. Due to this peculiarity, we define the ideal NDVI time-series data of rice in a cultivation period to be divided into 4 stages (nothing, growing, mature, harvest) with two atmospheric conditions (cloudy and clear skies) to handle the cloud contamination data. Then, the Viterbi algorithm is then applied to find the optimum growth states and atmospheric condition on the raw NDVI data. After obtaining the rice growth state, the cultivation and harvest dates are then carried out.

OBJECTIVES

According to the problem presented in section introduction, this thesis has the objective as follows.

To develop an algorithm that can be used to identify cultivation dates and harvest dates of rice from MODIS NDVI time-series data.



LITERATURE REVIEW

Crop Phenology Date Estimation

Satellite images can be very useful in agricultural study, since a satellite image can cover the large scale area making it is easier to monitoring the agriculture in the large scale. One of the comprehensively use satellite images are moderate resolution imaging spectroradiometer (MODIS). MODIS is a 36 band spectrometer providing a global data set every 1-2 days with a 16-day repeat cycle. The spatial resolution of MODIS is 250 meters for RED and NIR, 500 meters for 5 bands from the Visible to the Shortwave Infrared (450 - 2200nm), and 1000 meters for the remaining 29 bands covering the full spectral range from Visible to Thermal Infrared (400 – 14 000nm). The normalize difference vegetation index (NDVI) use in this study can be calculate from RED (620-670nm) and NIR (841-867nm) band available in 250-meters resolution which is the most appropriate for rice field in Thailand since the area of 500×500 meters and 1000×1000 meters is too coarse for the effective rice monitoring system in Thailand.

The MODIS NDVI time-series data have been widely used in vegetative study. However, there are few researches proposed the crop phenology date estimation. The study by Chumkesornkulkit *et al.* (Chumkesornkulkit *et al.*, 2013) proposed to model the MODIS NDVI data as a triply modulated cosine function to identify the cultivation date estimation on rain-fed and irrigated rice. Then, they used the extended Kalman filter (EKF) to smooth the data and estimate the parameters of the cosine function. The reported that 75.56% of the estimated cultivation dates of rain-fed rice are with 16 days of the actual dates whereas 83.33% the estimated cultivation dates for irrigated rice are within 16 days.

Sakamoto *et al.* (Sakamoto *et al.*, 2005) used the MODIS enhanced vegetation index (EVI) smoothed by wavelet operation to detect the rice phenology. They estimate the cultivation date by identify the heading date (peak of the NDVI curve), the minimal point (the first derivative equals 0 and changes from negative to positive

at this point), and inflection point (the second derivative equals 0 and changes from negative to positive at this point). The minimal point and the inflection point are only the point that earlier than 60 days from the heading date. The later one of these two points was automatically taken as the estimated cultivation date. However, by fixing the estimate date in between 60 days from the heading date made the algorithm is not flexible to accommodate different kind of rice. The heading date can also be effect by the noise and can cause the estimation errors. Especially, the noisy NDVI data in Thailand can cause a lot of these errors.

Another crop phenology date estimation by Zhao *et al.* (Zhao *et al.*, 2009) used the MODIS NDVI time-series data to estimate the phenology date of the corn and soybean in State of Iowa, USA. The Savitzky-Golay filter (Savitzky and Golay, 1964) have been used to smooth the NDVI time-series data and compared them with a method using a double logistic function. After that, they used the derivatives of the smoothed data to detect the vegetative to reproductive period, the emerged dates and harvest dates using their own defined characteristics.

There are also a small number of studies that applied the Hidden Markov Model (HMMs) with the NDVI time-series data. The study by Shen *et al.* (Shen *et al.*, 2012) uses their model HMMs to estimate corn progress percents in state of Iowa, USA. Three different time-series data, fractal dimension (FD), mean NDVI, and Accumulated Growing Degree Days (AGDDs), are used in their modified HMMs to access the corn progress in the area.

Even though most of the studies encountered a problem with the data qualities which were affected by cloud contamination and atmospheric variability, most of the studies solve this problem by using filter or wavelet operation to reconstruct the smoother time-series data. This method may be suitable for low cloud areas. However, this method may not perform well in the high cloud contaminated areas such Thailand. The distortion by cloud contamination causes the NDVI data drop drastically since cloud reflect both red and near-infrared spectrums in the similar level. However, this sharp drop of the NDVI can be caused from other factors such the harvest. Hence, the

smooth NDVI data in high cloud coverage areas such as Thailand might cause some changes to be smooth out. As a result, the estimate of cultivation and harvest dates in these smooth data can be very poor. For example, in Figure 1, the red dot shows the rice cultivation date estimated by the expert using the smooth data by Savitzky-Golay filter and the black dot shows the actual cultivation date. The date estimation error is nine samples which is equal to twenty-seven days. The estimation errors is quite high because of the rapid change of the NDVI data which have characteristics same as noises and cause the filter to reconstruct these data.

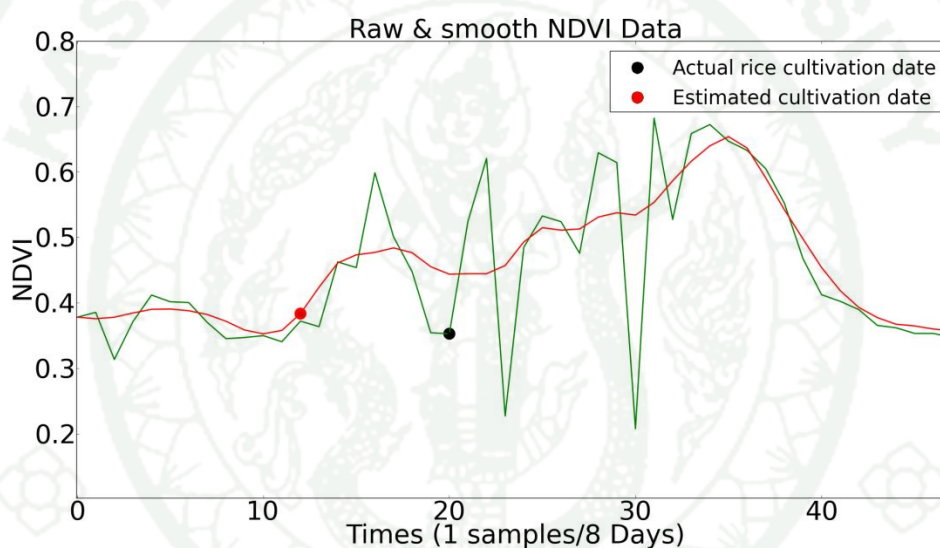


Figure 1 Raw and smooth NDVI time-series data of rain-fed rice in 2004 from Khonkean province. The red line is the smooth data and the green line is raw data.

Rice Phenology

Rice in Thailand can be divided into two types, namely, rain-fed and irrigated rice. The rain-fed rice or major rice is the highest quality rice which can be cultivated only one time in a year. They are planted in rainy season and have a crop cycle of about six months. Almost all irrigated rice or out-of-season rice are grown in the central of Thailand. They can be cultivated many times in a year with a cultivation period of about four months. The irrigated rice has many characteristics such as two crop cycles

in a year and three crop cycles in a year. Examples of the rice phenology are showed in Figure 2 for rain-fed and irrigated rice.

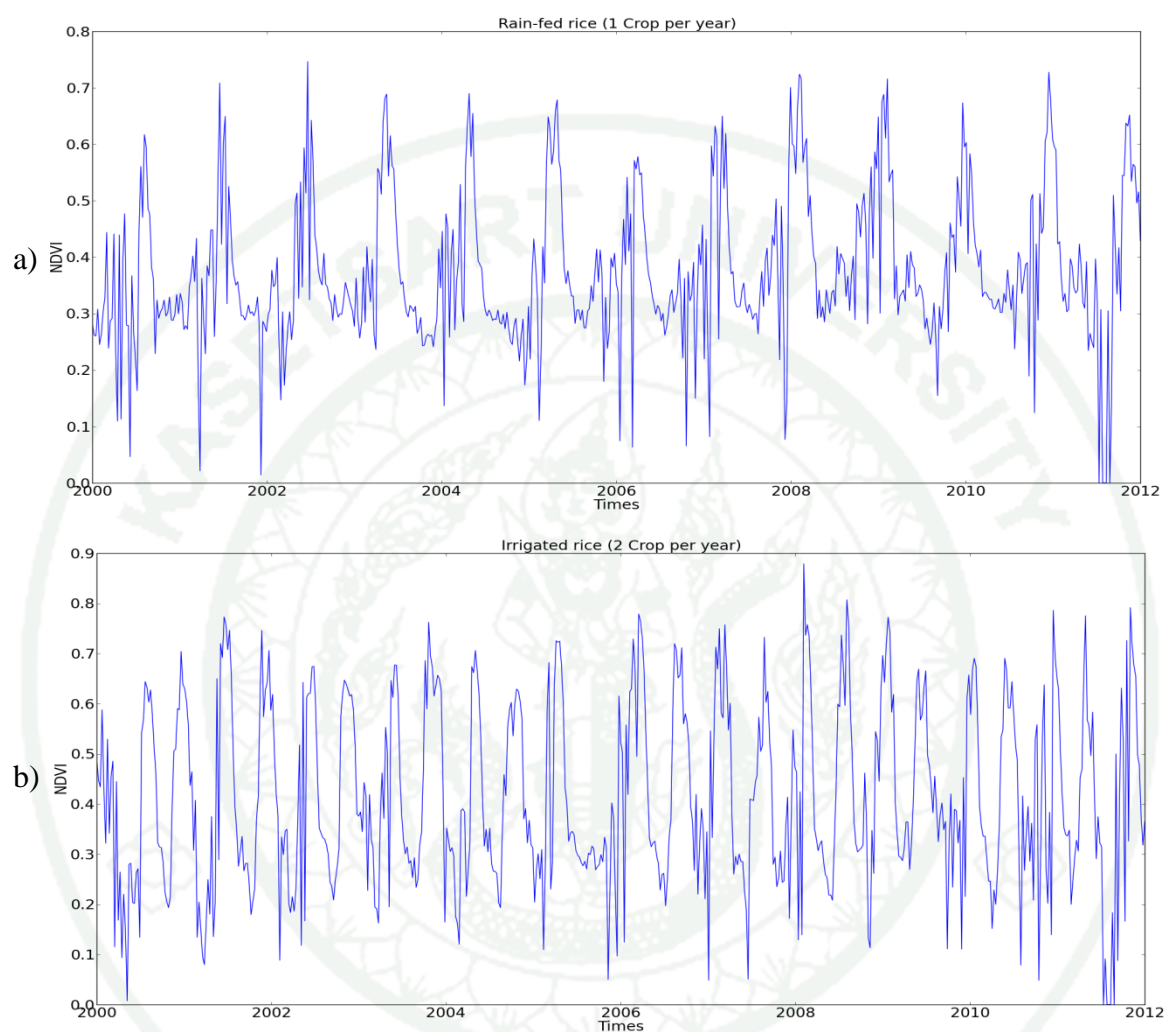


Figure 2 NDVI rice phenology (a) rain-fed rice; (b) two crops cycle in a year.

MATERIALS AND METHODS

This chapter is started by materials used in this study. Then, the methods of investigation and implementation of proposed approach are presented.

Materials

Software

1. Envi
2. ArcGis 10.1
3. MODIS Reprojection tool

Programming Language

1. Python

Programming Libraries

1. Gdal
2. Numpy
3. Matplotlib
4. Datetime
5. Utm

Methods

MODIS Data

The 8-day MODIS/Terra composited data (MOD09Q1) acquired from NASA from 2000 to 2012 were used as the experiment data. The experimental image data used in this study are 250-meter resolution which can be obtained every 8 day in the red and near infrared (NIR) spectral bands (0.6 μ m - 0.9 μ m). This data can also download freely via the Earth Observing Data Gateway. The data were re-projected to the Geographic coordinate over Thailand.

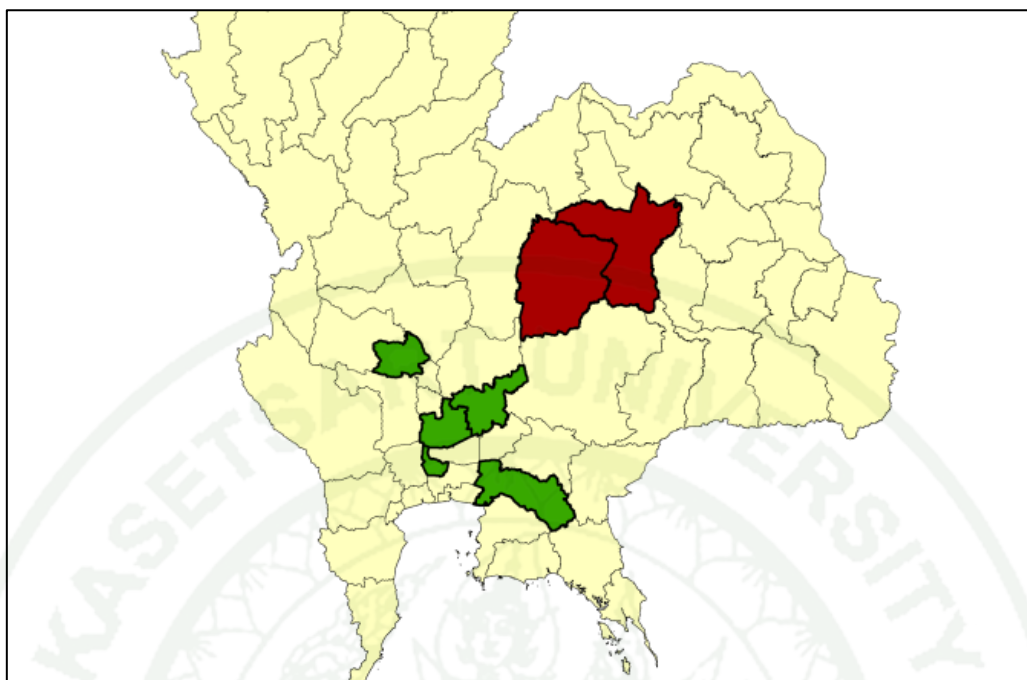


Figure 3 The 7 study areas, Ayutthaya, Chachoengsao, Nonthaburi, Saraburi, Chainat, Khonkean and Chaiyaphum provinces, Thailand. Red and green label shows the provinces that mainly growing rain-fed rice and irrigated rice, respectively.

As shown in Figure 3, the data collected around Khonkean and Chaiyaphum provinces are used in this experiment for rain-fed rice. These two provinces are located in Northeastern region of Thailand which is the rice major production area. Most of the rice cultivated in these areas is rain-fed rice which is high quality rice and can be grow only one crop per year. The rice in these areas is planted during the rainy season and takes about six months before ready to harvest. The other five provinces located in central region of Thailand are Ayutthaya, Chachoengsao, Nonthaburi, Saraburi, and Chainat provinces. These provinces are known to cultivate irrigated rice which can be cultivated many times in a year with period about four months. In this study, we only experiment with the irrigated rice that is cultivated 2 crops per year. Since the 8-day composite data in this study is too coarse to detect the rapidly changing of the NDVI time-series data for the rice that cultivated more than 2 crop per year (Chumkesornkulkit *et al.*, 2013).

Ground Truth Data

Ground data that are used as a reference to evaluate the classification performance were obtained from the Thai national rice department. This ground truth data provided by Thailand's rice department consist of location information (UTM coordinates and province), cultivation and harvest dates of rice. The obtained data provide rice information which consists of 40 areas which have cultivation date and harvest dates of rain-fed rice and another 25 areas for cultivation and harvest date of two crop cycles per year rice (Figure 4). This data will be used to access the accuracy of the date estimation by our algorithm. Furthermore, to identify rice and non-rice we employ the land-used data that separate Thailand mapping into three classes such as rain-fed rice, irrigated rice and non-rice area, which the land-used data provide from Thailand Geo-Informatics and Space Technology Development Agency (GISTDA) (Figure 5).

	A	B	C	D	E	F
1	X	Y	Planting_Date	Harvesting_Date	type	Province
2	264283	1816316	30/5/47	8/11/47	R	Khonkean
3	262695	1814648	1/6/47	8/11/47	R	Khonkean
4	271028	1814140	2/6/47	9/11/47	R	Khonkean
5	242121	1750818	15/6/47	9/11/47	R	Khonkean
6	808835	1842110	3/6/47	25/11/47	R	Khonkean
7	263499	1813990	3/5/47	8/11/47	R	Khonkean
8	274057	1809142	7/6/47	12/11/47	R	Khonkean
9	272929	1828561	16/9/47	22/11/47	R	Khonkean
10	198662	1866463	10/6/47	20/11/47	R	Khonkean
11	812371	1841183	4/6/47	25/11/47	R	Khonkean
12	256217	1780232	11/6/47	9/11/47	R	Khonkean
13	266511	1801562	20/5/47	12/11/47	R	Khonkean
14	256226	1773278	24/5/47	9/11/47	R	Khonkean
15	273601	1814721	9/6/47	10/11/47	R	Khonkean
16	682030	1580485	14/2/52	19/6/52	I	Ayutthaya
17	649318	1585785	2/6/51	30/8/51	I	Ayutthaya
18	649318	1585785	3/1/52	21/4/52	I	Ayutthaya
19	667028	1613938	30/1/52	1/5/52	I	Ayutthaya
20	667028	1613938	23/5/52	27/8/52	I	Ayutthaya

Figure 4 Ground-truth data from Thailand Rice Department

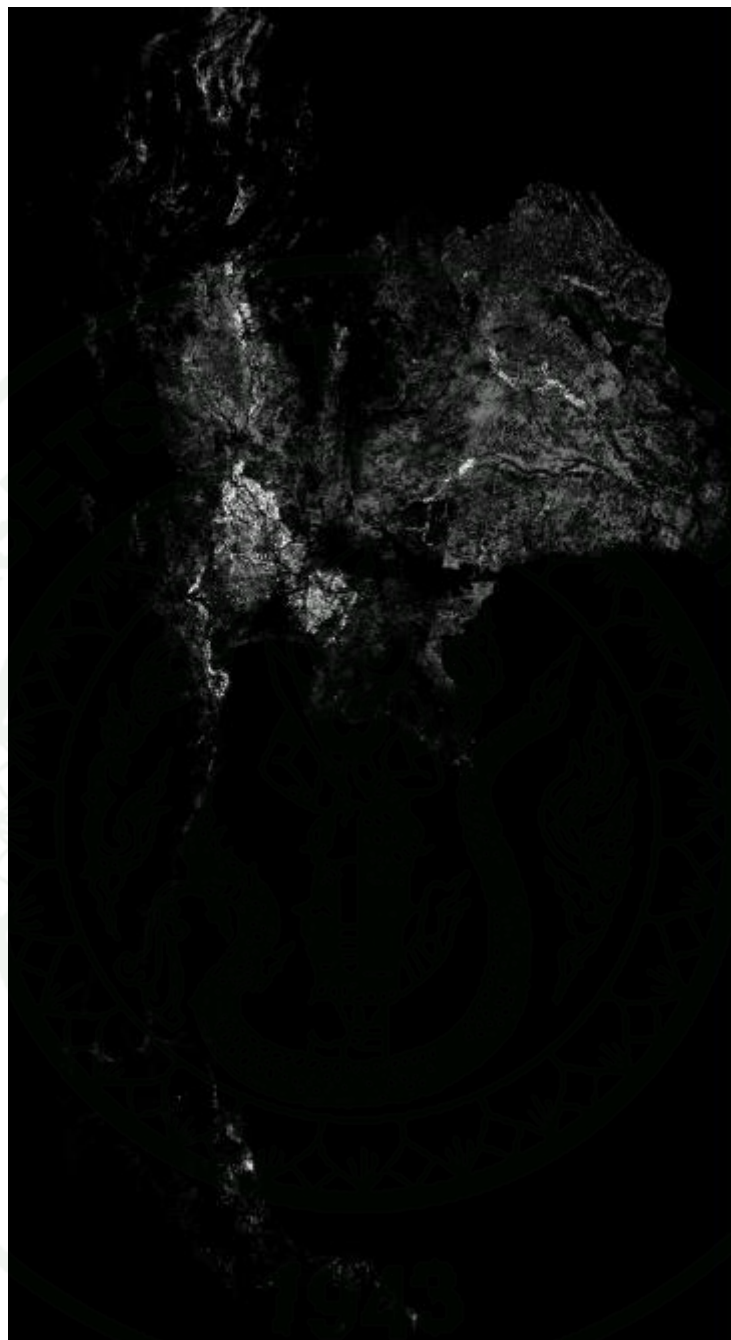


Figure 5 Land-used data including rain-fed rice, irrigated rice and non-rice.

The NDVI Time-series Data

The NDVI is used in remote sensing to evaluate whether the observed area have high intensity green vegetation or not. The NDVI is normalized transform of the near-infrared to red reflectance ratio follow as

$$NDVI = \frac{(NIR - RED)}{NIR + RED} \quad (1)$$

Where *NIR* and *RED* are the digital numbers in near-infrared and red spectral bands, respectively. Since vegetation reflect the NIR color spectral better than the red color, the NDVI has a higher value if there is more vegetation, and NDVI is low when a scene does not have any vegetation. NDVI values are represented as a ratio ranging in value from -1 to 1. The extreme negative NDVI values represent water, values around zero represent bare soil and values over 6 represent dense green vegetation. The NDVIs for every 8 day cycle MODIS data were computed to create the time-series dataset for this 13 year period. The NDVI data start from Feb. 18, 2000 to Dec. 11, 2012 in total of 587 NDVI sample in a pixel. The examples of time-series NDVI data are show in Figure 6.

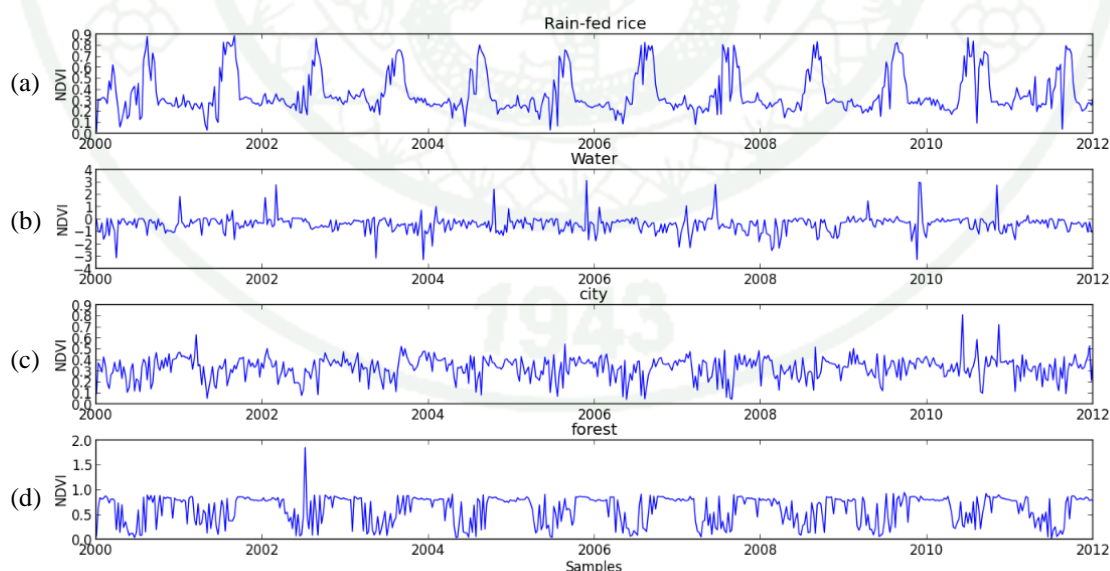


Figure 6 NDVI pattern; (a) Rain-fed rice; (b) Water;(c) City; and (d) Forrestr.

Hidden Markov Model for Rice NDVI Time-series Data

Because of the simple characteristics NDVI of the rice, we declare the ideal NDVI profile of rain-fed rice and irrigated rice in a year as shown in Figure 7 which includes the nothing state where NDVI value is the value of bare soils (≈ 0.3), the growing state where NDVI value is increasing, the mature state where NDVI is saturation, and the harvest state where NDVI value is decreasing.

Let x_k be the state of rice at the k -th sample (Figure. 7(a) and Figure. 7(b)) It is clear that the possible states of x_k are nothing, growing, mature and harvest which are denoted as n , g , m , and h , respectively. This rice growing states are just our idea to divide the rice growth profile. These states may or may not link to the actual growing stages of rice. Furthermore let $P_{i \rightarrow j}$ be the transition probability from the state i to the state j . In this study, we assume that the rice states can only change from nothing to growing, growing to mature, mature to harvest, and harvest to nothing. Figure.8 depicts the state transition considered in this thesis. In each state, there are two possible atmospheric conditions, namely, cloudy and clear skies. In the cloudy sky, the NVDI is lower than those in the clear sky due to cloud contamination in a pixel. We assume that the atmospheric conditions of cloudy and clear also follow another hidden Markov model as shown in Figure.9. Combining the rice state and the atmospheric conditions as a result shown in Figure.10, there are the total of 8 states, nothing and cloudy sky, nothing and clear sky, growing and cloudy sky, growing and clear sky, mature and cloudy sky, mature and clear sky, harvest and cloudy sky and harvest and clear sky.

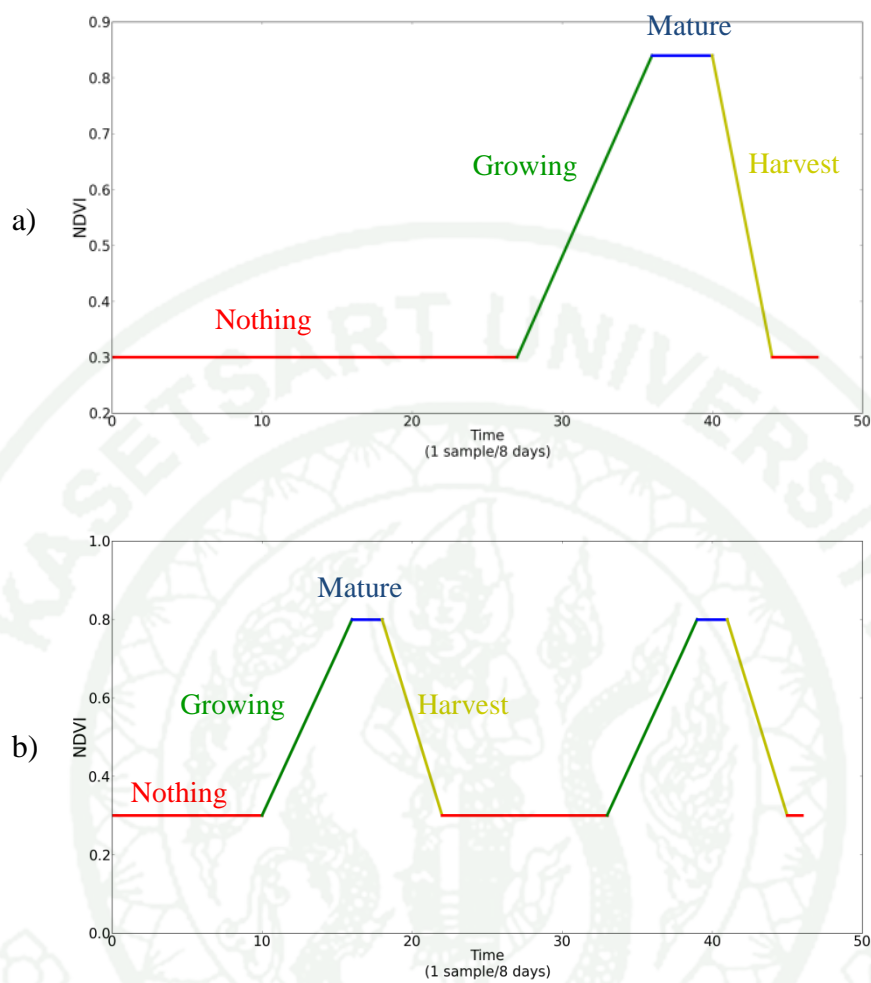


Figure 7 Ideal NDVI profile of rain-fed rice (a) and irrigated rice (b) in a year and its states.

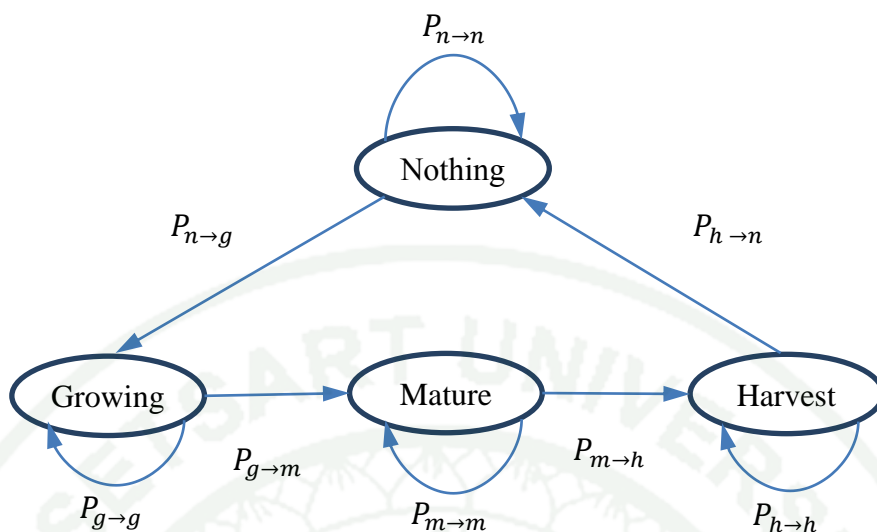


Figure 8 Hidden Markov Model of 4 states in NDVI data

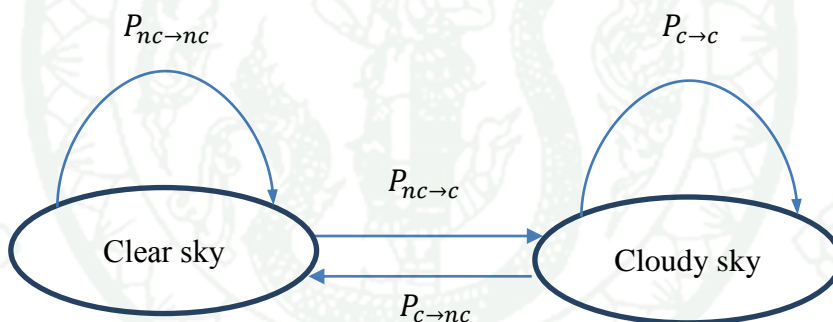


Figure 9 Hidden Markov Model for state with cloud and without cloud for state nothing, growing, mature and harvest.

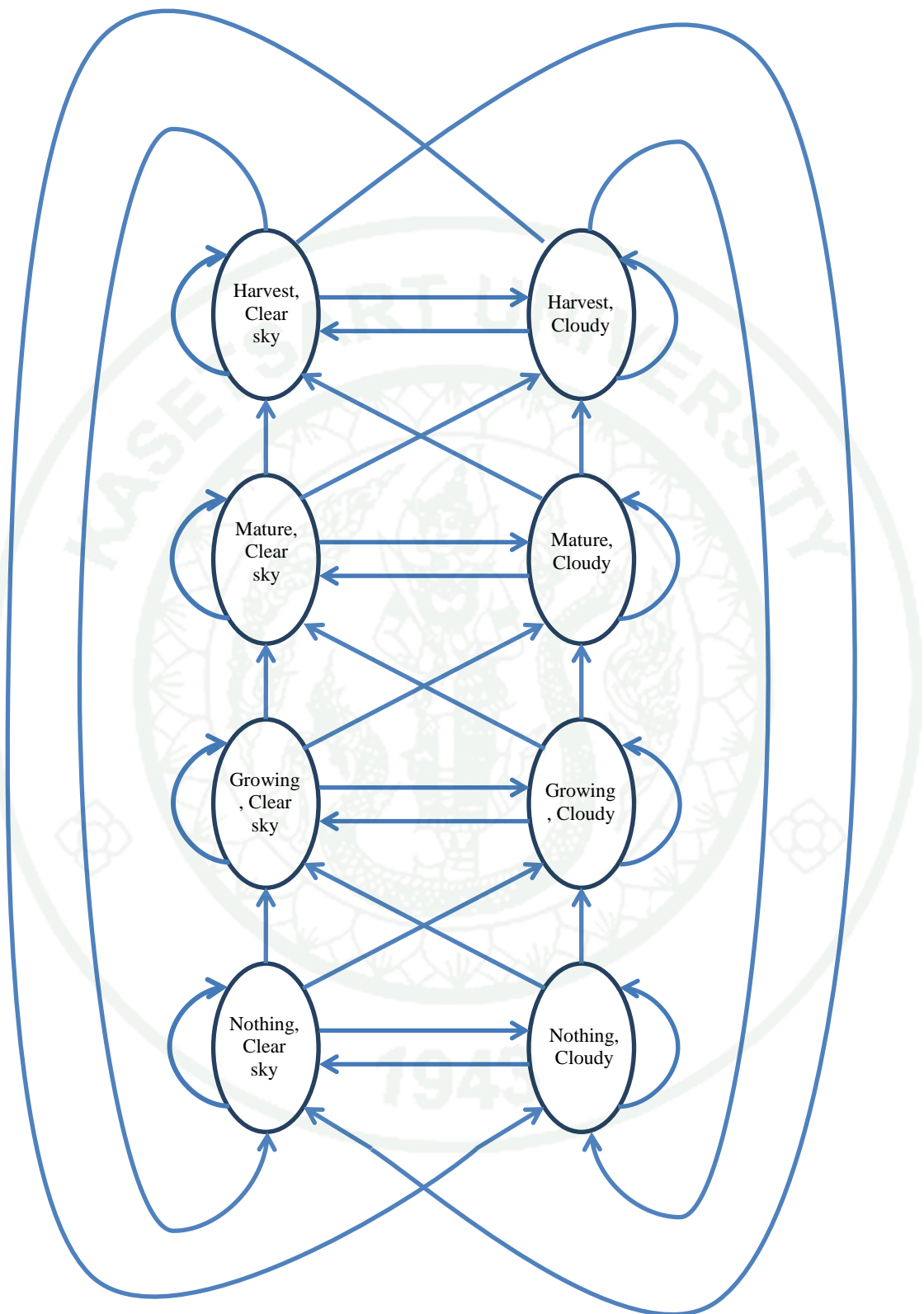


Figure 10 Hidden Markov Model of 4 states in NDVI data combine with atmospheric conditions

The Transition probability

Next, we estimated the transition probabilities from the actual observed NDVI data from 20 different samples, and found that, on average, the length of nothing, growing, mature, and harvest states in a year ($356/8 \approx 46$ samples) for rain-fed rice (one crop per year) are 28.55, 9.1, 2.7, and 5.85 samples, respectively. Since the average number of samples that rice remains in a given state i is equal to $1 + \frac{P_{i \rightarrow i}}{1 - P_{i \rightarrow i}}$, the transition probabilities are given in Table 1.

Table 1 The transition probability of the rain-fed rice.

Transition probability	Value of transition probability
$P_{n \rightarrow n}$	27.55/28.55
$P_{n \rightarrow g}$	1/28.55
$P_{g \rightarrow g}$	8.1/9.1
$P_{g \rightarrow m}$	1/9.1
$P_{m \rightarrow m}$	1.7/2.7
$P_{m \rightarrow h}$	1/2.7
$P_{h \rightarrow h}$	4.85/5.85
$P_{h \rightarrow n}$	1/5.85

For irrigated rice (2 crop per year), the average length of nothing, growing, mature and harvest state are 18.75, 12.05, 5.3, 11.25, respectively. Similar with the rain-fed rice, the transition probabilities of irrigated rice are shown in Table 2.

Table 2 The transition probability of the irrigated rice.

Transition probability	Value of transition probability
$P_{n \rightarrow n}$	17.75/18.75
$P_{n \rightarrow g}$	1/18.75
$P_{g \rightarrow g}$	11.05/12.05
$P_{g \rightarrow m}$	1/12.05
$P_{m \rightarrow m}$	4.3/5.3
$P_{m \rightarrow h}$	1/5.3
$P_{h \rightarrow h}$	10.25/11.25
$P_{h \rightarrow n}$	1/11.25

For transition probability of the atmospheric conditions of cloudy and clear skies, we follow the same procedure as for rice cultivation states and found that, on average, the cloudy and clear skies contains for 3.25 and 10.45 consecutive samples, respectively. The transition probabilities are shown in Table 3.

Table 3 The transition probability of the atmospheric conditions of cloudy and clear Skies

Transition probability	Value of transition probability
$P_{c \rightarrow c}$	2.25/3.25
$P_{c \rightarrow nc}$	1/3.25
$P_{nc \rightarrow nc}$	9.45/10.45
$P_{nc \rightarrow c}$	1/10.45

Atmospheric conditions (cloudy and clear skies)

In this paper, for a given pixel s_k , we assume that observed NDVI is a function of the cloud-free NDVI value, Z_k , the portion of cloud-contamination, the NDVI value of pure cloudy pixel, and a measurement noise, i.e.,

$$Y_k = \gamma_k Z_k + (1 - \gamma_k)C + N_k \quad (2)$$

where Y is an observed NDVI value, γ_k is the portion of cloud in s_k , C is the NDVI value of a pure cloudy pixel, and N_k is a measurement noise. Since cloud reflects the red and near-infrared spectrums similarly, the NDVI value of a pure cloud pixel is assumed to be zero. Furthermore, if a pixel is cloud-contaminated, the portion of cloud in this pixel is assumed to be uniformly distributed between zero and one. Hence, $\gamma_k Z_k$ is uniformly distributed between zero and Z_k . Next, we assume further that N_k has Gaussian distribution with zero mean and variance of σ_n^2 . Hence, the probability density function (PDF) of y_k can be written as

$$\begin{aligned} f_{Y_k}(y_k) &= f_{\gamma_k Z_k}(\gamma_k Z_k) * f_{N_k}(n_k) \\ &= \int_{Y_k - Z_k}^{Y_k} \frac{e^{-\frac{\lambda^2}{2\sigma_n^2}}}{\sqrt{2\pi\sigma_n^2}} d\lambda \end{aligned} \quad (3)$$

By using the definition of error function where $\text{erf}(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt$, Eq.(3) can be rewritten as

$$f_{Y_k}(y_k) = \frac{1}{2Y_k} \left[\text{erf}\left(\frac{Y_k}{\sqrt{2}\sigma_n}\right) - \text{erf}\left(\frac{Y_k - Z_k}{\sqrt{2}\sigma_n}\right) \right] \quad (4)$$

Next, the NDVI value in the nothing, growing, mature and harvest stages are denoted by μ_n , μ_g , μ_m and μ_h , respectively. Since, in the nothing state, most of ground cover is bare soil or light vegetation, the value of μ_n is assumed to be a constant. In the growing state, the area covered by rice leaf increases from one sample to another. Hence, we assume that $\mu_g = \mu_n + \alpha g_k$ where g_k is the number of samples in the growing state, and α is the incremental rate of the NDVI value. When the rice reaches the mature state, the NDVI value is saturated and constant. Lastly, during the

harvest, the NDVI value drops sharply. As a result, we assume $\mu_h = \mu_m - \beta h_k$ where h_k is the number of samples in the harvest state, and β is the rate of decrease of the NDVI value.

Optimum solution

To determine the rice growth state, we employ the maximum *a posteriori* (MAP) criteria, i.e.,

$$X_{1:N}^{opt} = \arg \max_{X_{1:N}} \Pr(X_{1:N} | Y_{1:N}) \quad (5)$$

where $X_{1:N} = \{x_1, \dots, x_N\}$ and $Y_{1:N} = \{Y_1, \dots, Y_N\}$. By using the Bayes' rule, and the fact that $\Pr(Y_{1:N})$ is independent of the choice of $X_{1:N}$, Eq. (5) can be modified to

$$X_{1:N}^{opt} = \arg \max_{X_{1:N}} [\Pr(Y_{1:N} | X_{1:N}) \Pr(X_{1:N})] \quad (6)$$

Furthermore, we assume that the observed NDVI from any distinct samples are statistically independent when X_N are given, and depends only on the previous and current state of rice. By applying the chain rule, the MAP criteria becomes

$$X_{1:N}^{opt} = \arg \max_{X_{1:N}} \left[P(x_1) \prod_{k=1}^N \Pr(Y_k | X_{1:k}) \Pr(x_k | X_{1:k-1}) \right] \quad (7)$$

Since $\log(\cdot)$ is monotonically increasing function, Eq. (7) can be rewritten as

$$X_{1:N}^{opt} = \arg \min_{X_{1:N}} \left[\sum_k E_k(Y_k, X_{1:k}) \right] \quad (8)$$

where

$$E_k(Y_k, X_{1:k}) = - \begin{cases} \log \Pr(x_1) + \log \Pr(Y_1 | x_1) & k = 1 \\ \log \Pr(x_k | X_{1:k-1}) + \log \Pr(Y_k | X_{1:k}) & k \neq 1. \end{cases} \quad (9)$$

To find the solution of Eq. (8), we used the Viterbi algorithm (A. J. Viterbi., 1967, G. D. Forney, 1972) and create the trellis diagram (Figure.11) that collects all the possible paths of the rice growth in time-series data. Each path has its own weight.

The weight of each path is calculated by the sum of the all branches the path passing through. The weight computation depends on the observed NDVI value and the next state. For example, if the NDVI value is about 0.3, the weight of paths that are in state nothing will be low and the weight of paths that are in state mature will be high. If a particular node is reached by two or more path the Viterbi algorithm will keep the path with lowest cost and ignore the rest. Then, weight of all final possible paths are compared to find the path that has the lowest weight and use the state that this path go through as the state of NDVI time-series data. In fact, we assign the weight of each path equal to $E_k(Y_k, X_{1:k})$.

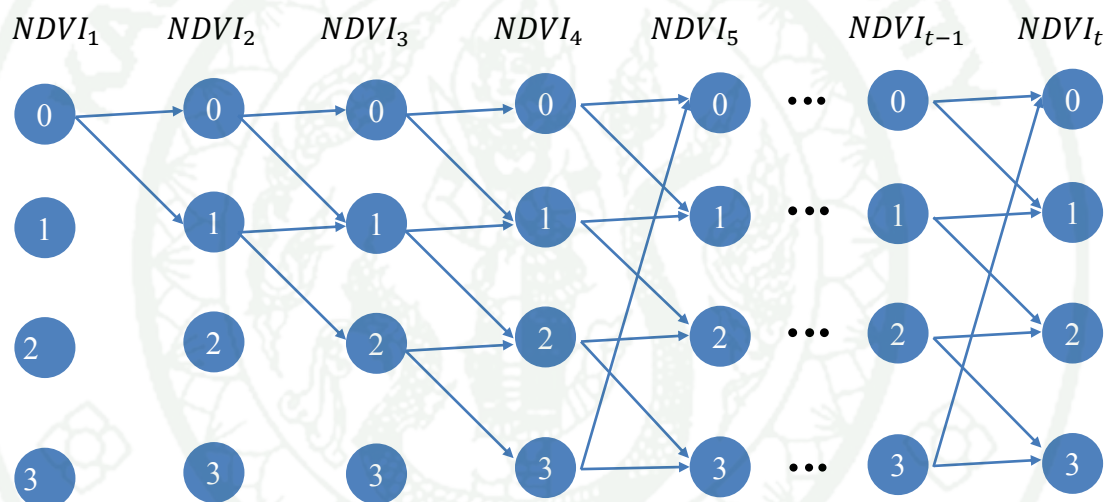


Figure 11 The example trellis diagram of Viterbi algorithm uses to define state of each NDVI value ($NDVI_1, NDVI_2, \dots, NDVI_t$). 0 = nothing state with cloud and without cloud, 1 = growing state with and without cloud, 2 = mature state with cloud and without cloud, 3 = harvest state with cloud and without cloud.

Parameter Determination

In order to have better accuracy in state definition for the NDVI time-series data, the parameters use in computation are required to have closest value to the actual value in each data. From our experiment, these parameter are different for each location and type of rice. In this work, the unknown parameters ($\alpha, \beta, \mu_n, \mu_m, \sigma^2$) are estimated by using selective 50 sample data of each rice area. These training sample data are from each provinces and each type of the rice. In our study, since μ_n has a lot of effect in state nothing which will be used to estimate the cultivation and harvest date. The parameters used in experiment are shown in Table 4.

Table 4 Parameter use in computation

Province	α	β	μ_n	μ_m	σ^2
Rain-fed rice					
Khonkean	0.0349	0.0502	0.4156	0.7549	0.0457
Chaiyaphum	0.0314	0.0485	0.3667	0.7285	0.0423
Irrigated rice					
Ayutthaya	0.0681	0.0830	0.3231	0.8115	0.0679
Chachoengsao	0.0693	0.0815	0.2919	0.7986	0.0841
Nonthaburi	0.0722	0.0892	0.2568	0.7870	0.0876
Saraburi	0.0697	0.0822	0.3364	0.7638	0.0784
Chainat	0.0748	0.0871	0.2605	0.8076	0.0833

Cultivation and Harvest Date Identification

Before cultivation, the rice field is clear of vegetation as a result, the NDVI is low. As rice grows, more vegetation covers the rice field and the NDVI increases. In the harvest period, the vegetation in the area has been harvest swiftly and the NDVI deceases drastically. Hence, the rice cultivation date should be the sample that is the last sample of the nothing state before the beginning of growing state. Similarly, we define the harvest date as the last sample of harvest state before moving to the nothing state as shown in Figure 12.

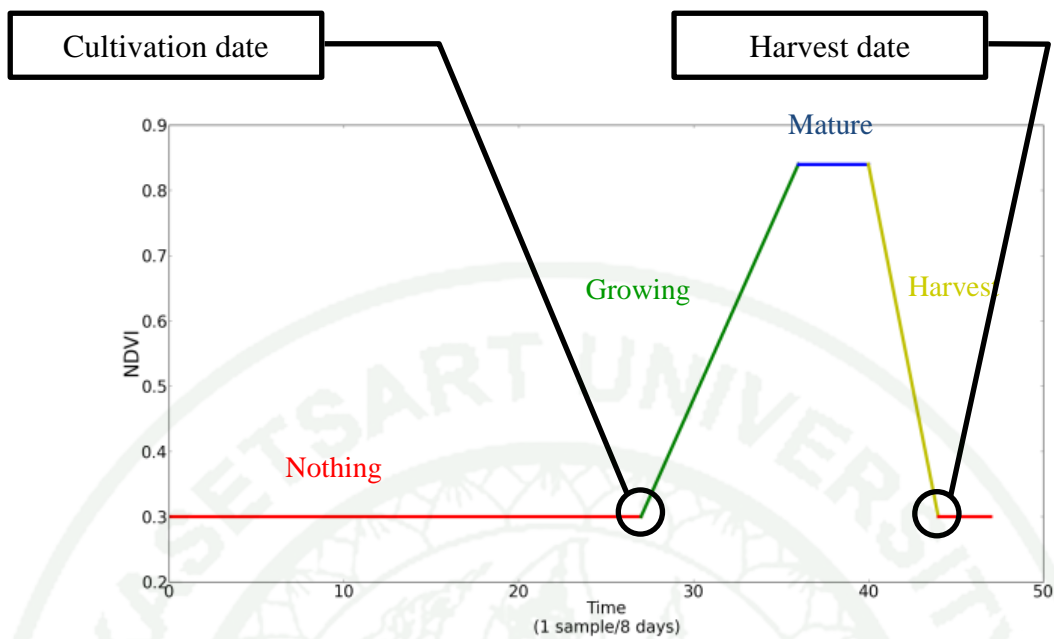


Figure 12 The rice cultivation and harvest date Identification from defined state

Experimental Design

We have proposed a rice cultivation date estimation technique for satellite images based on Hidden Markov Model. In this study, in order to show the different result between using the raw and reconstruct data, we have two approaches to identify the rice cultivation date and harvest date.

1. Using the data filtered by Savitzky-Golay filter (Jin Chen *et al.*, 2004) applied on Hidden Markov Model without atmospheric conditions (cloudy and clear skies) (Figure 8). In Figure.13 shows the reconstruct filter data and the state defining result represent in 4 colors which stand for nothing, growing, mature, and harvest respectively.

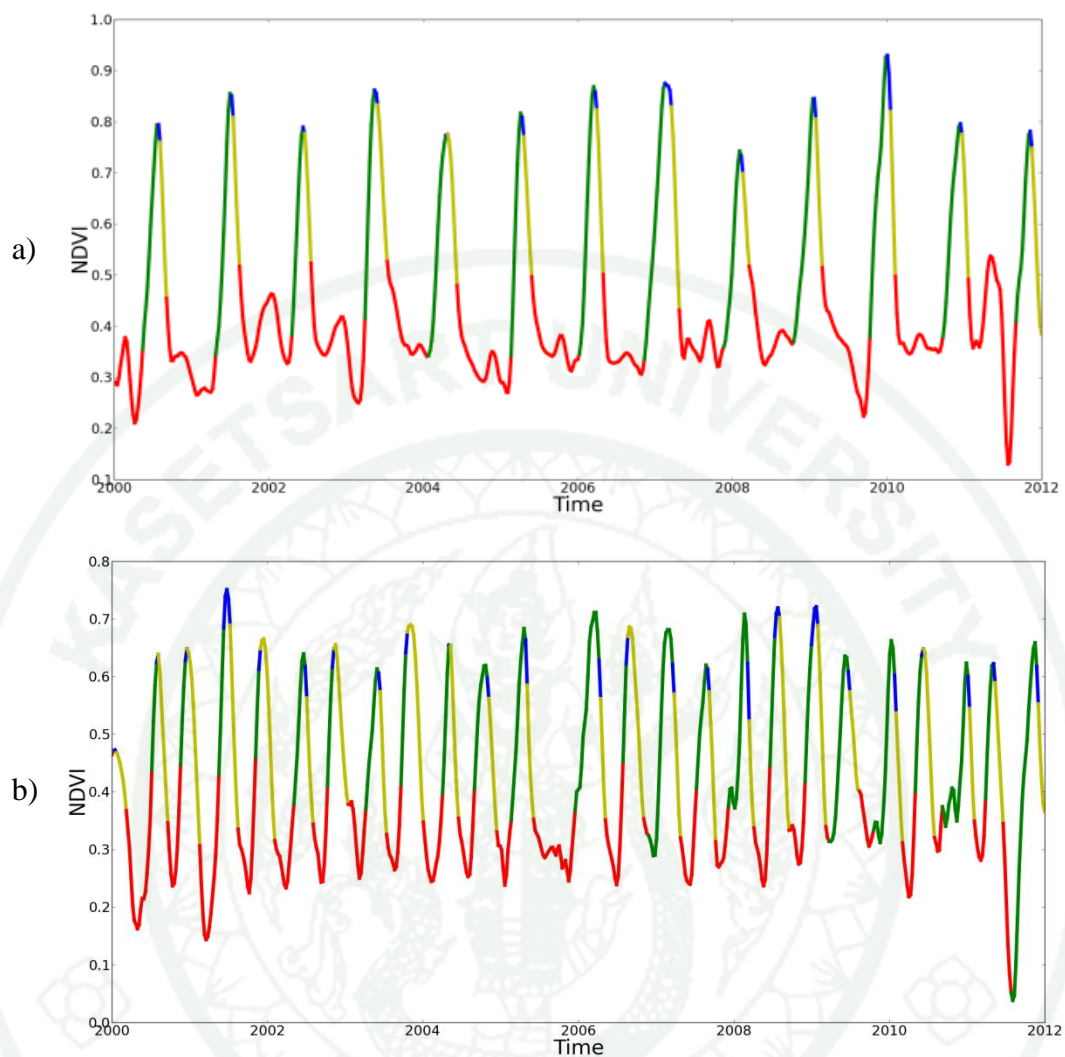


Figure 13 The reconstruct filter data and its state a) rain-fed rice b) irrigated rice.

2. Using the raw time-series data applied on the time-series data and Hidden Markov Model with atmospheric conditions (Figure.10). In Figure.14 shows the raw data and the state defining result represent in 4 colors similar with the first experiment.

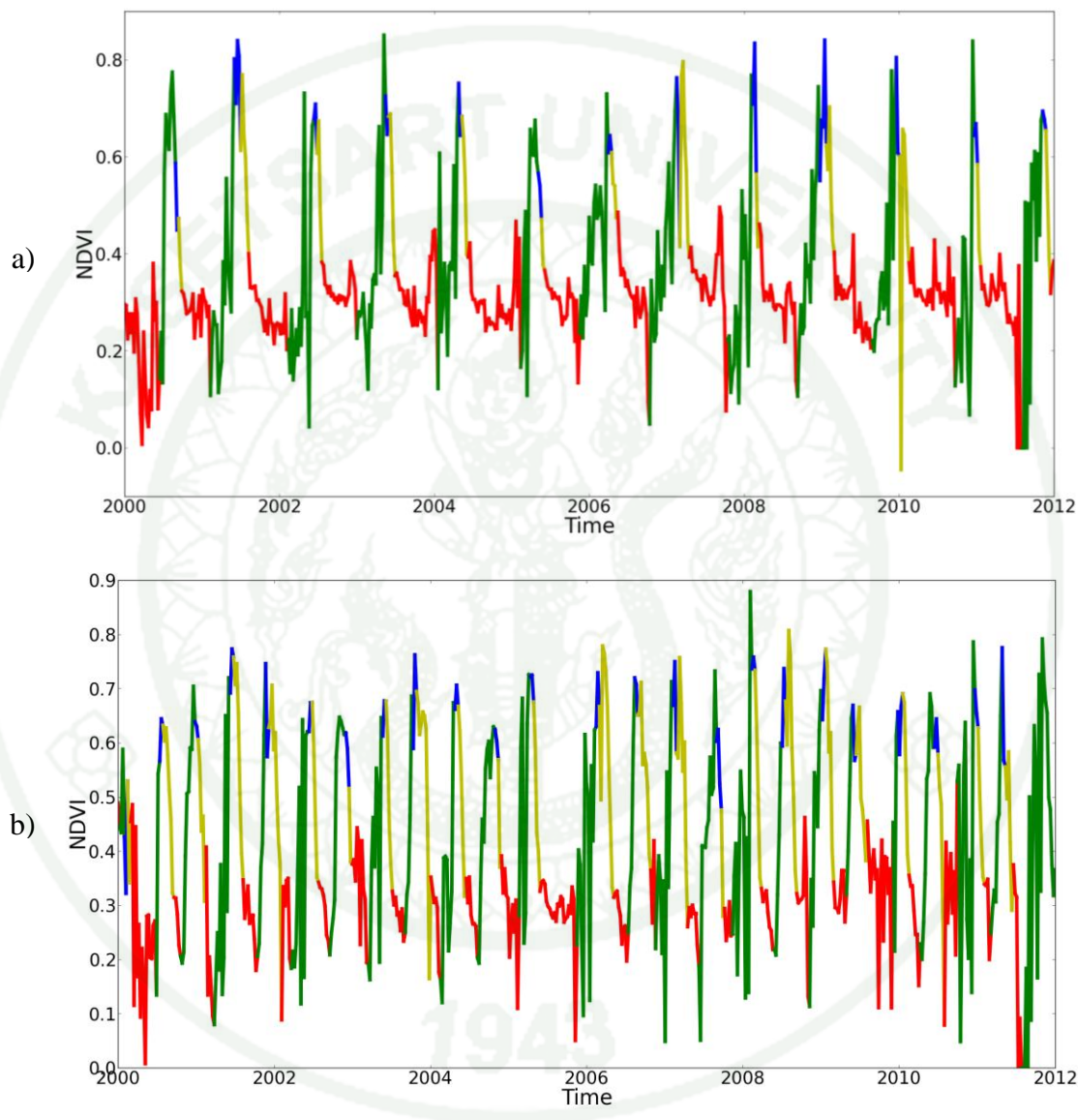


Figure 14 The raw data and its state a) rain-fed rice b) irrigated rice.

RESULTS AND DISCUSSION

Results

The results in Tables 5 and 6 show that the error date of rain-fed and irrigated rice cultivation in each area between ground-truth and estimated date and the computation time using the proposed HMM without atmospheric condition.

Table 5 Result in computation time & estimation error date of rain-fed rice using the filtered data with hmm without atmospheric condition.

Area No.	UTM coordinates			Computation time (Seconds)	Estimation Error date (days)	
	X	Y	Zone Number		Cultivation	Harvest
1	199578	1856598	47	0.873	23	1
2	251816	1808312	47	0.843	17	15
3	296124	1842225	47	0.765	31	12
4	249501	1783098	47	0.777	9	5
5	265234	1857927	47	0.848	28	17
6	262738	1862652	47	0.855	15	6
7	240205	1771015	47	0.818	25	6
8	195058	1843440	47	0.866	17	5
9	295643	1850155	47	0.878	23	7
10	216920	1836972	47	0.841	20	14
11	225042	1853080	47	0.830	18	16
12	260902	1794391	47	0.776	21	23
13	259717	1819717	47	0.725	11	11
14	248014	1804030	47	0.725	8	24
15	225679	1851235	47	0.733	8	9
16	259915	1855172	47	0.712	9	14
17	264283	1816316	47	0.743	20	2

Table 5 (Continued)

Area No.	UTM coordinates			Computation time (Seconds)	Estimation Error date (days)	
	X	Y	Zone Number		Cultivation	Harvest
18	263499	1813990	47	0.716	25	11
19	274057	1809142	47	0.836	15	20
20	198662	1866463	47	0.779	13	3
21	812371	1841183	48	0.709	8	12
22	266511	1801562	47	0.748	23	3
23	256226	1773278	47	0.727	25	21
24	181379	1740807	47	0.799	17	17
25	191999	1737069	47	0.708	8	19
26	217793	1816734	47	0.804	19	9
27	214480	1758611	47	0.806	44	8
28	810978	1783923	48	0.719	28	17
29	809731	1784251	48	0.760	8	18
30	200398	1819329	47	0.847	3	20
31	803994	1737824	48	0.813	11	2
32	820273	1722016	48	0.842	22	1
33	181379	1740807	47	0.871	30	11
34	191999	1737069	47	0.776	10	5
35	217793	1816734	47	0.864	14	6
36	810978	1783923	48	0.722	40	24
37	809731	1784521	48	0.706	4	11
38	200398	1819329	47	0.810	4	9
39	801859	1778143	48	0.746	2	2
40	820273	1722016	48	0.741	25	11

Table 6 Result in computation time & estimation error date of Irrigated rice using the filtered data with HMM without atmospheric condition.

Area No.	UTM coordinates			Computation time (Seconds)	Estimation Error date (days)	
	X	Y	Zone Number		Cultivation	Harvest
1	682030	1580485	47	0.857	14	6
2	649318	1585785	47	0.729	35	12
3	649318	1585785	47	0.772	2	21
4	667028	1613938	47	0.827	29	10
5	752572	1516829	47	0.777	17	9
6	752572	1516829	47	0.863	16	33
7	733604	1525021	47	0.707	23	34
8	744336	1505523	47	0.788	9	0
9	643819	1550250	47	0.794	8	3
10	643819	1550250	47	0.764	13	35
11	652012	1546315	47	0.788	43	11
12	675235	1612684	47	0.803	2	16
13	675235	1612684	47	0.705	30	0
14	691720	1603433	47	0.765	29	24
15	707308	1614507	47	0.738	6	17
16	676880	1618049	47	0.769	11	20
17	622119	1683408	47	0.864	16	24
18	627380	1662018	47	0.746	4	18
19	638815	1682682	47	0.738	14	24
20	627723	1659352	47	0.737	41	21
21	631315	1677302	47	0.795	25	6
22	609387	1678680	47	0.866	32	7
23	634611	1671039	47	0.765	5	24
24	633428	1672703	47	0.771	9	13
25	631693	1674548	47	0.772	31	1

The results in Tables 7 and 8 show that the error date of rain-fed and irrigated rice cultivation in each area between ground-truth and estimated date and the computation time using the proposed HMM with atmospheric condition.

Table 7 Result in computation time & estimation error date of rain-fed rice using the raw data with hmm with atmospheric condition

Area No.	UTM coordinates			Computation time (Seconds)	Estimation Error date (days)	
	X	Y	Zone Number		Cultivation	Harvest
1	199578	1856598	47	1.420	15	12
2	251816	1808312	47	1.417	34	11
3	296124	1842225	47	1.376	31	9
4	249501	1783098	47	1.388	10	9
5	265234	1857927	47	1.385	12	12
6	262738	1862652	47	1.420	22	3
7	240205	1771015	47	1.417	22	12
8	195058	1843440	47	1.395	1	1
9	295643	1850155	47	1.403	3	12
10	216920	1836972	47	1.392	17	3
11	225042	1853080	47	1.423	15	17
12	260902	1794391	47	1.411	10	8
13	259717	1819717	47	1.385	6	17
14	248014	1804030	47	1.401	6	12
15	225679	1851235	47	1.399	29	4
16	259915	1855172	47	1.408	22	12
17	264283	1816316	47	1.363	18	7
18	263499	1813990	47	1.432	21	20
19	274057	1809142	47	1.378	14	0
20	198662	1866463	47	1.404	25	17
21	812371	1841183	48	1.383	19	17
22	266511	1801562	47	1.411	4	3

Table 7 (Continued)

Area No.	UTM coordinates			Computation time (Seconds)	Estimation Error date (days)	
	X	Y	Zone Number		Cultivation	Harvest
23	256226	1773278	47	1.382	8	4
24	181379	1740807	47	1.394	8	8
25	191999	1737069	47	1.373	19	12
26	217793	1816734	47	1.398	4	12
27	214480	1758611	47	1.420	23	9
28	810978	1783923	48	1.532	24	7
29	809731	1784251	48	1.596	6	11
30	200398	1819329	47	1.588	5	8
31	803994	1737824	48	1.512	4	8
32	820273	1722016	48	1.451	8	8
33	181379	1740807	47	1.424	19	17
34	191999	1737069	47	1.479	4	25
35	217793	1816734	47	1.408	13	8
36	810978	1783923	48	1.421	23	12
37	809731	1784521	48	1.440	24	14
38	200398	1819329	47	1.440	9	12
39	801859	1778143	48	1.429	14	7
40	820273	1722016	48	1.437	4	9

Table 8 Result in computation time & estimation error date of irrigated rice using the raw data with hmm with atmospheric condition

Area No.	UTM coordinates			Computation time (Seconds)	Estimation Error date (days)	
	X	Y	Zone Number		Cultivation	Harvest
1	682030	1580485	47	1.336	12	30
2	649318	1585785	47	1.362	17	23
3	649318	1585785	47	1.431	15	20
4	667028	1613938	47	1.322	35	8
5	752572	1516829	47	1.421	16	17
6	752572	1516829	47	1.382	2	16
7	733604	1525021	47	1.459	5	12
8	744336	1505523	47	1.424	4	15
9	643819	1550250	47	1.326	10	27
10	643819	1550250	47	1.480	6	2
11	652012	1546315	47	1.320	22	19
12	675235	1612684	47	1.331	36	3
13	675235	1612684	47	1.490	20	6
14	691720	1603433	47	1.453	13	16
15	707308	1614507	47	1.415	35	2
16	676880	1618049	47	1.333	15	1
17	622119	1683408	47	1.344	30	20
18	627380	1662018	47	1.459	22	3
19	638815	1682682	47	1.324	1	16
20	627723	1659352	47	1.364	36	10
21	631315	1677302	47	1.366	20	17
22	609387	1678680	47	1.337	19	15
23	634611	1671039	47	1.414	25	10
24	633428	1672703	47	1.368	10	11
25	631693	1674548	47	1.449	16	18

Table 9 is the summary of Tables 5, 6, 7 and 8 which show the estimation date errors in terms of method used for each data type and each rice crop type. By using HMM without Atmospheric condition on filtered data, the average cultivation date estimation errors are 17.52 and 18.568 days for rain-fed rice (1 crop/year) and Irrigated rice (2 crop/year), respectively and for the harvest date estimation the average estimation errors are 10.73 and 15.423 days. For the method using HMM with Atmospheric condition on raw NDVI data, the average cultivation date estimation errors are 14.429 and 17.772 days for rain-fed rice and Irrigated rice, respectively. The harvest date estimation the average estimation errors are 10.047 and 13.941 days.

Table 9 The error between ground-truth and estimation date

Experiment	Average Cultivation date estimation error (days)		Average Harvest date estimation error (days)	
	<i>Rain-fed rice</i>	<i>Irrigated rice</i>	<i>Rain-fed rice</i>	<i>Irrigated rice</i>
HMM without Atmospheric condition using filtered data	17.52	18.568	10.73	15.423
HMM with Atmospheric condition using raw data	14.429	17.772	10.047	13.941

From the result in Table 9, the experiment using raw data applied on HMM with atmospheric condition have better overall result in both type of rice. However, in irrigated rice the result from both experiments have comparable result due to lots of data qualities are affected by noises.

The summary of the computation time used in each method for rain-fed rice and irrigated rice are shown in Table 10. The experimental using HMM without Atmospheric condition with filtered data, the average computation time for each pixel are 0.786 and 0.780 for rain-fed rice and irrigated rice, respectively. The experimental

using HMM with Atmospheric condition with raw data, the average computation time for each pixel are 1.423 and 1.388 for rain-fed rice and irrigated rice, respectively.

Tabel 10 The Time used in computation from each experimental

Algorithm	Average computation time (seconds)	
	<i>Rain-fed rice</i>	<i>Irrigated rice</i>
HMM without Atmospheric condition using filtered data	0.786	0.780
HMM with Atmospheric condition using raw data	1.423	1.388

Discussion

The cultivation and harvest date estimation by using our algorithm can be used to estimate the cultivation and harvest dates for both rain-fed and irrigated rice fields. The overall accuracy is acceptable even though the 8-day composites data were employed. By comparing both methods, the HMM without Atmospheric condition on filtered data, and the HMM with Atmospheric condition on raw NDVI data, the overall results of the second method is more accurate than the first method. However, in term of computation time the first method shows slightly better since the model of the atmospheric condition used in the HMM in the second method causing the computation in Viterbi algorithm is more complication than the first one. Even though the first method has to waste time in filter computation, the computation used in Viterbi algorithm are cost a lot more time.

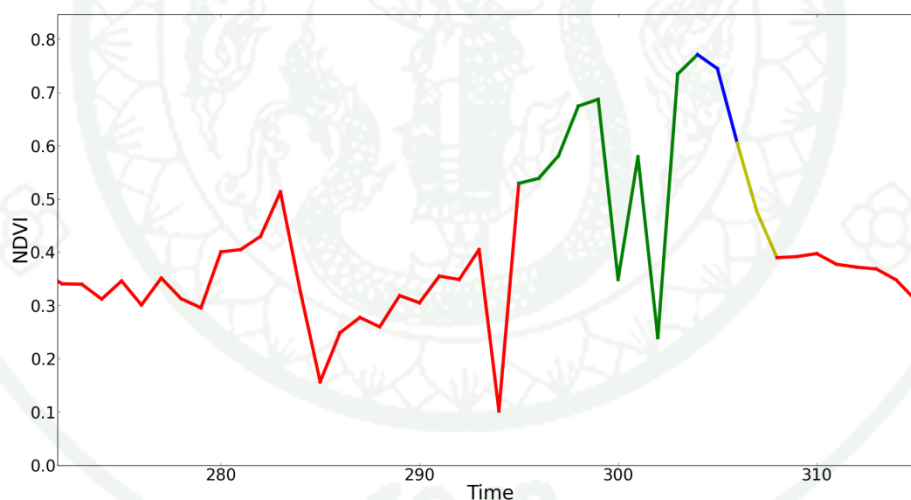


Figure 15 The state define result where state defining for state growing effect by the noisy data

The harvest date estimation has more accurate results than the cultivation date due to the fact that the growing season in rain-fed rice usually start in rainy season which have lots of cloud contaminations. This makes the noises of NDVI data in this period occurs continuously. These continuously noises might affect the state defining process. On the other hand, there are very few cloud contaminations in harvest

periods. Figure 15 shows the state define result where state defining for state growing effect by the noisy data and cause the growing state start too late than it should.

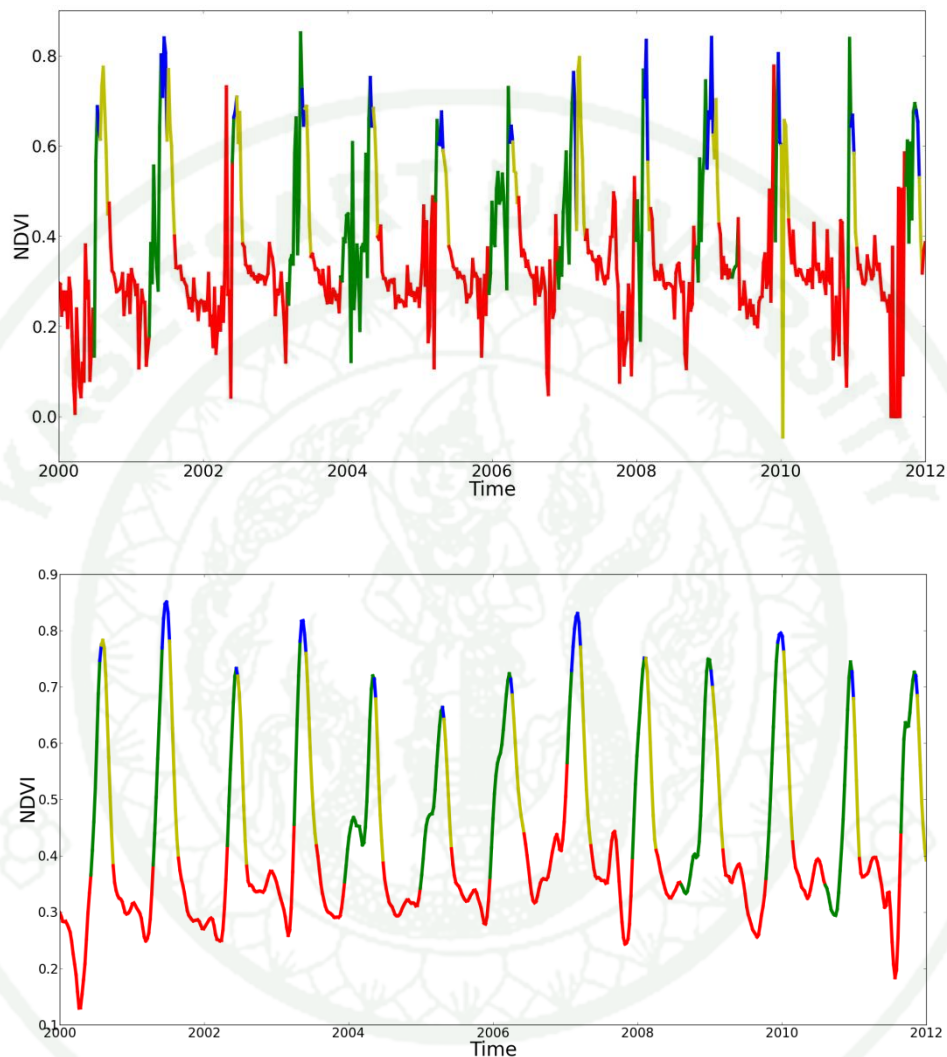


Figure 16 The result between raw data and filtered data in same area.

Because of the rapid change in NDVI data of irrigated rice, sometimes a large amount of noises could cause the data cannot stay in NDVI curve. This explain the reason that the experiment using HMM with Atmospheric condition on raw NDVI data and the experiment using HMM without Atmospheric condition on filtered data have a proximate result. The Savitzky-Golay filter tends to reconstruct the noisy data

to have the smoother NDVI curve which help recovery some lost data. In Figure 16 shows the result between raw data and filtered data in same area.

The other factor that can cause the errors in date estimation process is the unexpected farming of farmer. In some areas, the farmers usually use their fields for growing other plant before growing the rice. When the farmers are ready to plant their rice, they just promptly clear their field for the rice in few days. This will cause the NDVI data increasing for a period of time and then quickly drop back to the NDVI value of the bare soils. After that, the NDVI start to increase again when they start growing the rice. This event can affect the state defining process. As shown in Figure.17, the NDVI start to increase because of other plant in area causing the growing state start too early.

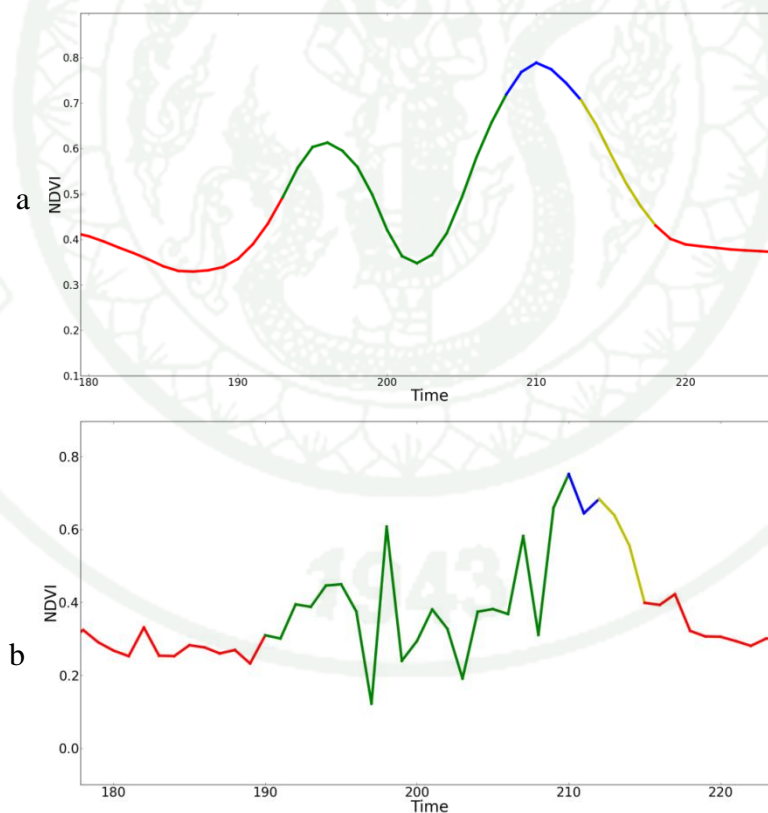


Figure 17 The error cause by other plant growing before rice a) filtered data b) raw data

In Figure.18, we display the state of the rice in Khonkean province in year 2008.

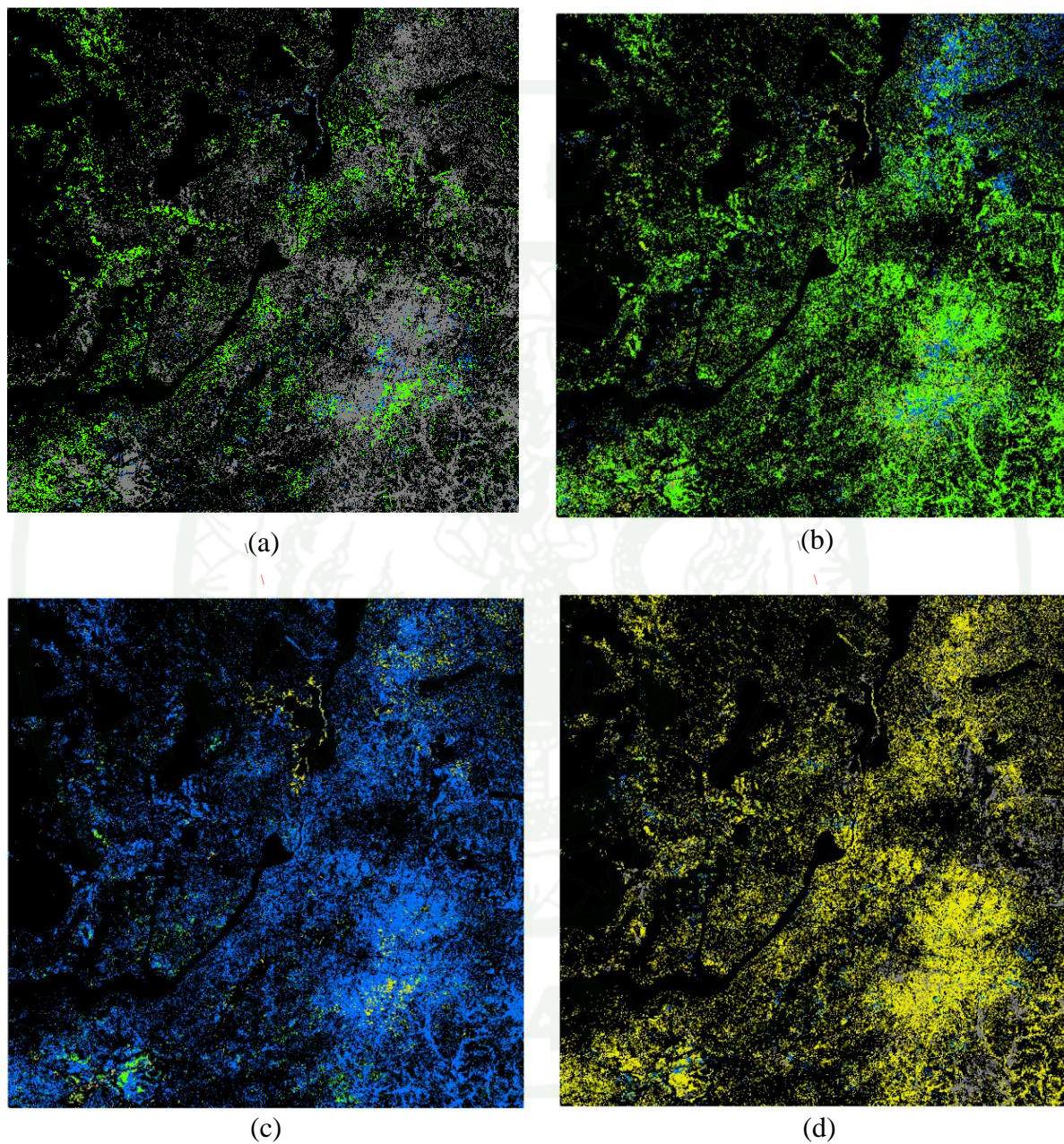


Figure 18 State of the rice in Khonkean province (a) March, 2008, (b) July, 2008 (c) August, 2008 (d) October, 2008

CONCLUSION AND RECOMMENDATIONS

Conclusion

In this study, we proposed a new approach to identify the rice cultivation and harvest dates using the raw NDVI time-series data by dividing the rice's NDVI time-series data into 4 states (nothing, growing, mature, harvest) with two atmospheric conditions, namely, cloudy and clear skies. We used the hidden Markov model to define state transition and its probability. After that, we used the Viterbi algorithm for applying the state into the NDVI time-series data. Then, we found the rice cultivation and harvest dates by using these defined state.

The NDVI time-series in Thailand are very noisy and hard to observe the rice phenology. Various studies solved this problem by using the filter in NDVI data but sometimes the filter could cause the reconstruct data too deviated from the original raw data. In our study, the raw NDVI time-series data are applied to HMM with atmospheric conditions to cope with the noisy data. In order to show the different between using reconstructed NDVI data and raw data, we applied our algorithm to two different experiments.

1. HMM without atmospheric condition applied with the NDVI time-series data filtered by Savitzgy-Golay filter.
2. HMM with atmospheric condition applied with the raw NDVI time-series data

The result are compared in terms of the computation time used and the error in date estimation

In term of computation time used in both methods, the first method shows slightly better result. Although, the first method wasted time in filter processing the complication of HMM in second method cost a lot more time in Viterbi algorithm.

The result cultivation and harvest date estimation result have acceptable accuracy in both methods. However, due to the extremely noise in some data the NDVI data cannot stay in NDVI curve causing the problem in state defining process. The unexpected farming of the farmer is other factor which the errors in date estimation. The overall results of the second method are more accurate than the first method. Though, The average error of harvest date estimation is still nearly 10 days which less than two samples. In cultivation date estimation, the accuracy drops because of noise effect from cloud in growing season but the result still has average error around 14 to 17 days for rain-fed rice and around 17 to 19 days for irrigated rice which are still satisfactory accuracy.

Recommendations

From our experiment in this thesis, there are some limitations in our proposed algorithm. In order to have good accuracy in state defining, the parameters used in computation are required to have closest value to the actual value in each area. In our experiment we used the parameter training from 50 samples for each province. However, some data in each province may have the different characteristic and sometimes can cause some error in date estimation. We may have to improve our model to be more flexibility in parameter used in computation.

Another limitation in our algorithm is the unexpected event in NDVI data. Our proposed algorithm is used for the NDVI data of the rice but in actual data the unexpected event may occurs in the data, such as the natural disaster or unexpected farming. In order to handle these unexpected events, we should add more state in Hidden Markov model to handle these events, such as the flood state or the non-rice state. It should improve the flexibility in algorithm and make better performance and higher accuracy results.

LITERATURE CITED

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