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THESIS

RAINFALL ESTIMATION IN THAILAND USING FY-2C SATELLITE DATA

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Remote sensing technology provides good spatial resolution for rainfall estimation which is very important for monitoring, prediction and mitigation of rain disaster. Today, data from infrared channel of meteorological satellite have capability to estimate rainfall, while rain gauge and radar should be utilized for calibration. The infrared channel is used for rainfall estimation by the relationship of brightness temperature (BT) from satellite data and surface rainfall from rain gauge, but it is widely accepted that a specific satellite rainfall technique is not necessarily applicable to another climatic region due to differences in dynamic rain processes from region to region and the relationship between infrared channel measurement of cloud top temperature and surface rainfall from rain gauges is non-linear, algorithm must be studied and specifically developed for Thailand.

For improve rainfall estimation accuracy in Thailand, this study provide Rainfall Estimation Framework that can use to find mask out non-raining information technique for identify rain cloud and rainfall estimation model from the relationship between data from FengYun-2C (FY-2C) infrared channel and surface rainfall from rain gauge that suitable for estimate rainfall in Thailand and using FY-2C numerical data instead of satellite images in the study.

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TABLE OF CONTENTS

	Page
TABLE OF CONTENTS	i
LIST OF TABLES	ii
LIST OF FIGURES	iii
LIST OF ABBREVIATIONS	v
INTRODUCTION	1
OBJECTIVES	3
LITERATURE REVIEW	4
MATERIALS AND METHODS	11
Materials	11
Methods	11
RESULTS AND DISCUSSION	22
Results	22
Discussion	25
CONCLUSION AND RECOMMENDATION	26
Conclusion	26
Recommendation	27
LITERATURE CITED	28
APPENDICES	30
Appendix A FY-2C Satellite Image	31
Appendix B Rain Analysis Software	36
CURRICULUM VITAE	41

LIST OF TABLES

Table **Page**

Table		Page
1	The relationship between the Cloud Height and Temperature	9
2	The results from the correlation analysis	10
3	FY-2C Major Instrument Characteristics	12
4	Arrangement of FY-2C S-VISSR2.0 Data	14
5	Structure of The Information Sectors	15
6	Summarize Techniques Used for Rain Cloud Identification	22
7	R^2 values for Rain Estimation Model	24
8	Spectral Statistics for Rain/No-Rain Cloud	24

LIST OF FIGURES

Figure **Page**

1 Fill color Infrared image from FY-2C 5
2 Water Vapor image from FY-2C 6
3 Visible image from FY-2C 7
4 Cumulonimbus Cloud Image 8
5 The structure of the DVB-S 12
6 Data format of FY-2C 14
7 Conversion of Infrared Brightness Temperature 16
8 Rainfall Estimation Framework 19
9 Structure of Convert FY-2C Raw Data to Numerical Data 20
10 Structure of Generate Training Data Set 21
11 Structure of Data Analysis and Rainfall Estimation 21
12 Locations of TMD 110 Rain Gauge Stations 23

Appendix Figure

A1 IR1 Image from FY-2C 32
A2 IR2 Image from FY-2C 32
A3 IR3 Image from FY-2C 33
A4 IR4 Image from FY-2C 33
A5 VIS Image from FY-2C 34
A6 Relationship between IR Radiance and Brightness Temperature (K) 35
A7 Relationship between VIS Radiance and Albedo (%) 35
B1 Rain Analysis Software 37
B2 Diagram of Rain Analysis Software 37
B3 Open Numerical Data Dialog 38
B4 Rain Cloud Identification Parameter Dialog 38
B5 Result from Rain Cloud Identification 39

LIST OF FIGURES (Continued)

Appendix Figure **Page**

B6 Relationship Graph 39
B7 Rainfall Estimation Model Dialog 40
B8 Rainfall Map 40

LIST OF ABBREVIATIONS

APSCO = Asia-Pacific Space Cooperation Organization
BT = Brightness Temperature
BTD = Brightness Temperature Difference
CMA = China Meteorological Administration
CRC = Cyclic Redundancy Check
CTT = Cloud Top Temperature
DVB-S = Digital Video Broadcasting System
EWBMS = Energy and Water Balance Monitoring System
GMSoft = Geostationary Meteorological Satellite Data Receiving and Processing Software
HAII = Hydro and Agro Informatics Institute
IR = Infrared
IPR = Infrared Power Law Rain Rate
ITR = Infrared Threshold Rainfall
K = Kelvin
m = meter
mm = millimeter
MICT = Ministry of Information and Communications Technology
RS = Remote Sensing
S-VISSR = Stretched - Visible Infrared Spin Scan Radiometer
SNR = Signal to Noise Ratio
TMD = Thailand Meteorological Department
VIS = Visible
WV = Water Vapor

RAINFALL ESTIMATION IN THAILAND
USING FY-2C SATELLITE DATA

INTRODUCTION

Agriculture is the most important occupation in Thailand. More than 80% of the area in Thailand is used for agricultural propose and it is widely accepted that the important factor to get a good crop is water management. The problems that come from water always occurred. In rainy season, many areas have faced severe flooding several times and widespread corruption. It has the impact to the economic, society in the more violent way than before. We can say that the flooding problem come primarily from rain. Especially the heavy rain that continued in long-term would be a severe flood. Meteorological conditions of heavy rain that most resembles tropical storm, monsoon, wind storm, variable weather, and etc. In dry season, many areas do not have enough for consumer and crop yield is got damaged.

Therefore, rainfall estimate are urgently needed to prevent flooding and mitigate the severity of flood events. For estimate rainfall in Thailand we need both the temporal and the spatial variability. Rain gauge provides good temporal resolution but it is a single point in space and it has limitation of the number of rain gauge over the country then it does not cover wide areas. In other words, the quality of spatial resolution from rain gauge is weakness.

Remote sensing technology provides good spatial resolution for rainfall estimation but the rainfall estimate by radar has limitation. The areas that you want to estimate rainfall by using radar must not have state space barrier such as construction, mountains and for used radar in wide areas we need a lot of radar to cover wide areas. Then you must be paid in the high cost. Rainfall estimate by using satellite data can be used in very wide area and satellite data are public information. Output of this analysis can be no charge. For use satellite data to estimate rainfall, the analysis of this new method is also need to improve.

In January 2007, Thailand received Digital Video Broadcasting System (DVB-S) from China Meteorological Administration (CMA) under the convention of Asia-Pacific Space Cooperation Organization (APSCO). The system has been successfully installed at Kasetsart University, located in Bangkok, in August 2007 with some grant supported by Ministry of Information and Communications Technology (MICT) and is currently operating well. Over 4 GB data are received from FengYun-2C (FY-2C) and kept in storage per day. These data are very useful in the field of meteorology, water conservancy and agriculture, generating huge economics and social benefits through weather forecast, climate prediction, disaster monitoring, and environmental remote sensing.

Now, several countries use meteorological satellite data to estimate rainfall in advance. Satellite data has been used in combination with radar and rain gauge data to estimate rainfall. Since it is widely accepted that a specific satellite rainfall technique is not necessarily applicable to another climatic region due to differences in dynamic rain processes from region to region, algorithm must be specifically developed for Thailand. In Thailand, the use of satellite data in meteorology to estimate rainfall is much less research and development. This research proposes technique to mask out non-raining information by using FY-2C infrared data to identify rain cloud to improve rainfall estimation accuracy and for use as a guide to estimate rainfall in other areas.

OBJECTIVES

The objectives of this rainfall estimation in Thailand by using FY-2C satellite data are as follows

1. study the generality of rainfall in Thailand

2. study rainfall estimation in Thailand by using meteorological satellite data

3. use FY-2C numerical data instead of satellite images to estimate rainfall in Thailand to improve rainfall estimation.

LITERATURE REVIEW

1. Satellite data from meteorological satellites

Remote sensing (RS) can provide a variety of forms and be applied in many areas such as climate prediction, surveillance and warning, or agriculture, etc. The information that generally uses in the study of climate coming from the meteorological satellite data. This is often used in the visible and infrared channels where each channel shows different information of the world, oceans, and climate. Therefore, researchers will rely on data from both channels of meteorological satellite together to understand the deep relationship and affect each other between earth, cceans, and atmosphere.

2. Satellite data in the Infrared Band (Infrared Satellite Imagery)

Image data from the infrared sensor which is installed on the satellite will measure the amount of energy from infrared (Infrared Energy) or infrared rays that radiate from the earth and atmosphere. Depending on the surface temperature of various. Therefore, infrared data (IR) can be used to observe the temperature properties of the earth or atmosphere. In general, areas with low temperature or cold clouds, such as high mountains, the ground at night are white or gray. While black or dark gray area indicates a temperature higher than the low ground, such as clouds in daytime so that the interpretation is easier. Often we add different colors to the image by using Color Table and a popular color scheme that use is a gray bar for the intensity or color temperature or followed by a brightness color (Vibrant) than the cloud top temperature instead. This makes it easier to interpret images that do the low clouds or ground fog or cloud at high levels. The example is shown in Figure 1.

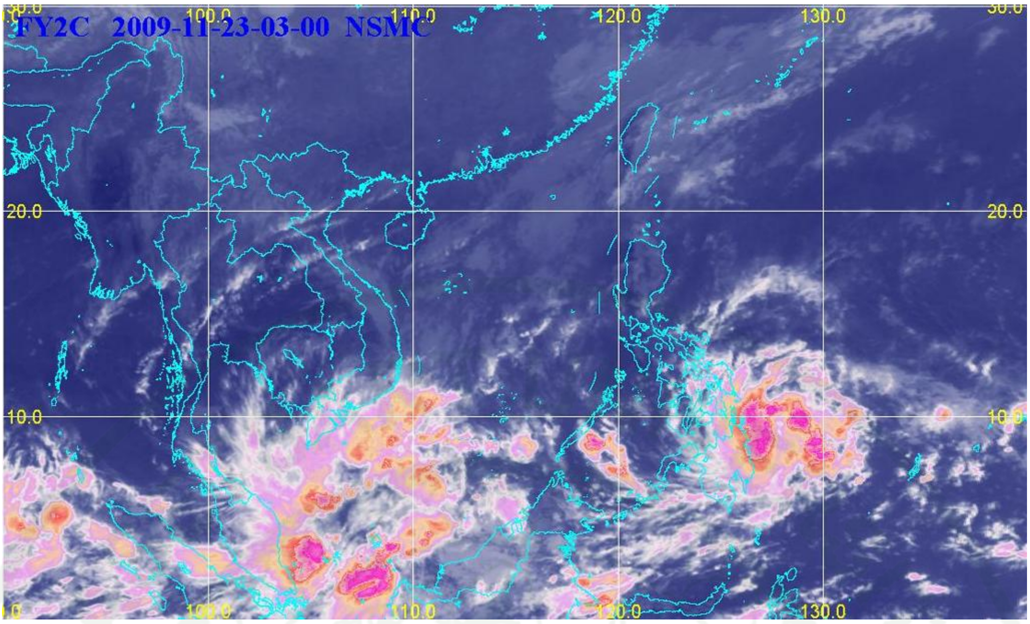


Figure 1 Fill color Infrared image from FY-2C.

Radiate energy from the earth's surface and atmosphere are absorbed by clouds and aerosol (Water Vapor) at some wavelength range, while the energy in other wavelengths is not absorbed but will transmitted to the atmosphere. The most of infrared sensor rely on property transfer energy to the atmosphere to detect heat radiate out from different surfaces. However, some sensor on the satellite will be able to detect the absorption energy of particles in the atmosphere at specific wavelength range. This will not be disturbed by various surface features. The wavelength range that applied to this idea is in the 6.3 - 7.6 µm, which is energy absorbed by water droplets in the atmosphere. We use data in this wavelength range to identify areas where the density of water vapor or droplets in the intermediate floor level on the Troposphere that most important for weather prediction because it will show the formation and growth of the storm. Typically, the information that is dark- colored in water vapor (WV) indicates a region where water vapor is relatively small and the light-colored would mean that more water vapor or high humidity, as shown in Figure 2. This information is useful in analyzing and forecasting climate significantly because the meteorologists can tell the moisture in the atmosphere with cloud top temperature and the change of weather pattern, although they not see any cloud.

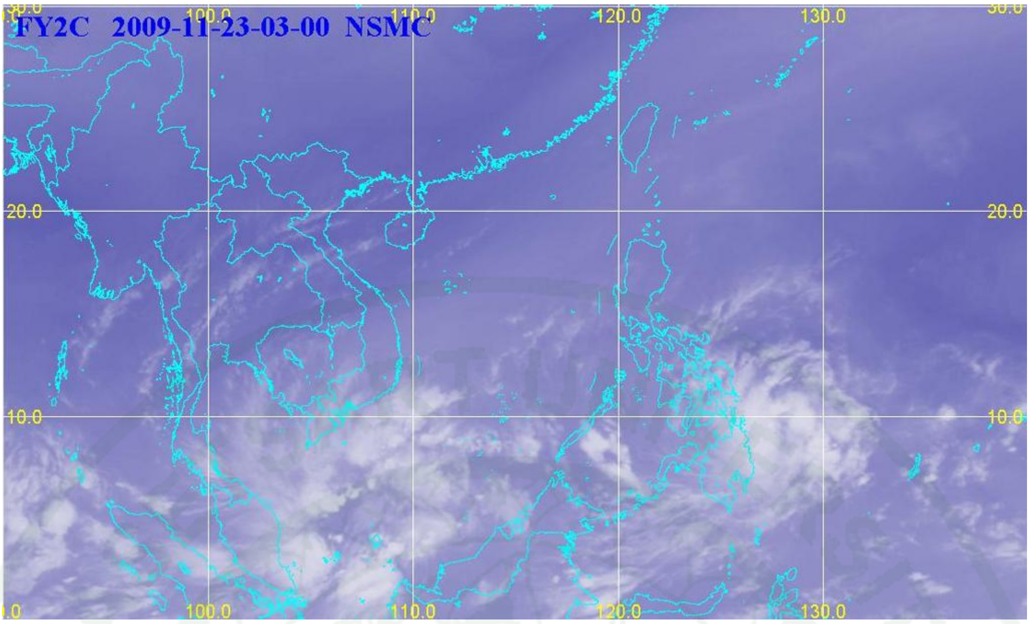


Figure 2 Water Vapor image from FY-2C.

In general, IR gray scale image have 256 levels from white (lowest temperature) to black (maximum temperature), and the relationship between level of the color and the value of temperature is not linear. Therefore, the information from IR image is in the form of Brightness Temperature (BT), it differences from Visible image that measure from reflective of the object. The information from IR image has been selected to use in analysis or applied to more information because it does not require sunlight like Visible image, that is not restricted at night. Then, we can use IR image to track storm path at any time. It also can be used to identify characteristics and differences between ground and water by detected temperature. In addition, IR image easier to see information than Visible image because the temperature does not change rapidly compared to the reflected from various surfaces.

3. Satellite data in the Visible Band (Visible Satellite Imagery)

Visible image from meteorological satellite is the information obtained from the detection energy radiation of the sun (Solar Radiation) reflected from the earth's surface to the Visible sensor on the satellite. In General, Visible image are used to estimate Earth's Albedo, that is the percentage of reflected from the earth's surface.

So high level (bright) in Visible image are instead areas that are very reflective of radiation and low level (dark) in the Visible image means the area that is less reflective of radiation because the amount of radiation reflected by different features of the earth's surface or atmosphere, then Visible image can tell the difference in each area, for example where the clouds are thick or larger will have more features reflected radiation and in Visible image is displayed in white. While some areas of clouds will appear as light gray or in the ocean are reflected rays of the sun appears less dark gray or black as well as parts of the ground will be the distinguishing characteristics of the surface with Albedo percent as well, as shown in Figure 3.

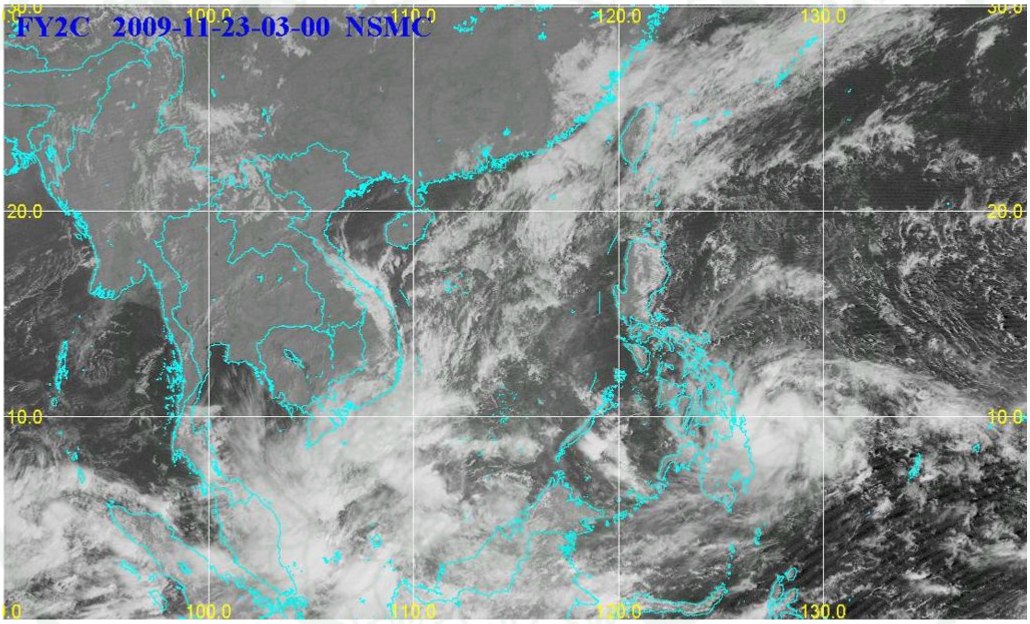
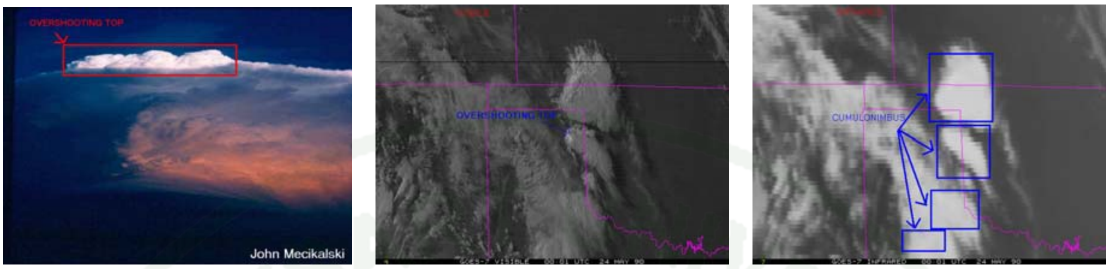


Figure 3 Visible image from FY-2C.

4. Application of Meteorological Satellite Data for Rainfall Estimation

Because satellite data can indicate different types of clouds, like a Cumulonimbus clouds that cause thunderstorms, which is formed from moisture in the atmosphere when interacting with the cold and floating up due to heat from the sun. You can see the clouds of this type in Visible image and it can tell altitude of the clouds. IR image can tell the cloud top temperature. The data from both of Visible and

IR image are see very bright white areas, because the cloud are floating on the high and has low temperatures, as shown in Figure 4.



(a) By eye (b) Visible image (c) IR image

Figure 4 Cumulonimbus Cloud Image.

Because rainfall is associated with different types of clouds and from being able to use satellite data to study the characteristics of clouds, allowing the satellite data used to forecast the occurrence of different storm and estimated rainfall would be. The researchers have studied the relationship between satellite data and rainfall data and bring the relationship to create a model to estimate rainfall from satellite data directly. Many study and research in meteorology in the past found that the Cloud Top Temperature (CTT) from satellite data is correlated with rainfall. There is also have many research study the ways to calculate CTT according Visible image and Infrared image, but many research provide that Infrared image have accuracy in estimating rainfall better than Visible image and the technique of detecting distance with microwave (MW Remote Sensing) by installing a sensor wave form Passive MW Radiometry on satellites that can provide direct data about clouds and rain in another dimension, with this we also analyzed data and research projects. The satellite data led to estimated rainfall and create a map showing the rainfall (Rainfall Map) in various ways for apply to the following relevant, such as the Agriculture Predicting Drought - Flood Surveillance and alarm etc.

The study of article titled "*The Rainfall Estimation Using Remote Sensing in Thailand*" by Dr. Preeyaporn Kosa and Assoc. Dr. Kobkiat Pongput with the concept of applying studies of rainfall measurements by weather stations measure various The advantages of data analysis time (Temporal Resolution) with the use of remote sensing satellite (Remote Sensing), which has advantages in storing spatial data (Spatial Resolution) by studying the data measured from Infrared detection devices in the area (Infrared Sensor) that can detect the size of the cloud altitude and interpret the format of the cloud top temperature. As shown in Table 1, which included information on two components together can be used to analyze the relationship and create a model estimated rainfall expected to fall (In the area and duration of the study) by equation.

$$P = aT^b \tag{1}$$

P is the Precipitation Estimate

T is the Cloud Top Temperature

a, b is the Coefficient from the relationship between Cloud Top Brightness Temperature and Surface Rainfall

Table 1 The relationship between the Cloud Height and Temperature

Cloud Height (meters)	**Temperature (^{o}Celsius)**
0	15
1,250	8
2,500	-1
3,750	-6
5,000	-13
6,250	-24
7,500	-34
8,750	-41
10,000	-50
11,250	-57

The results from the study that approach in Thailand Using regression analysis for nonlinear (Nonlinear Regression) to examine the relationship, shown in Table 2 can be seen that the accuracy is quite high. We expect to take that approach in this study and further analysis in applications for mapping rainfall with greater accuracy.

Table 2 The results from the correlation analysis

Area	**Duration**	**Correlation**	**R^2**
North	03/93 - 05/93	$P = 4.3932 \times 10^{58} T^{-24.80}$	0.97
	08/94 - 09/94	$P = 1.8462 \times 10^{22} T^{-8.93}$	0.62
North	01/94 - 12/94	$P = 1.1102 \times 10^{13} T^{-4.8288}$	0.71
Northeast		$P = 4.4905 \times 10^{10} T^{-3.8012}$	0.73
East		$P = 5.2384 \times 10^{12} T^{-4.6683}$	0.70
South		$P = 2.4916 \times 10^{58} T^{-4.0840}$	0.71

MATERIALS AND METHODS

Materials

1. DVB-S Satellite Data Receiver
2. Computer
3. Network Storage
4. Giga-Bit Switch
5. 16-Port Switch
6. Geostationary Meteorological Satellite Data Receiving and Processing Software
7. Python (Programming Language) and Software Development Tools

Methods

1. Synthesis of FY-2C Satellite Data

The structure of Digital Video Broadcasting System (DVB-S) is shown in Figure 5. FY-2C satellite data are ingesting and map-projecting at the FrontEnd PC. The raw data and projection data files are then transferred to the BackEnd PC which is installed with the main processing software for imagery processing, product generation, overlay GIS information etc. This software came together with the DVB-S and is called the GMSoft (Geostationary Meteorological Satellite Data Receiving and Processing Software).

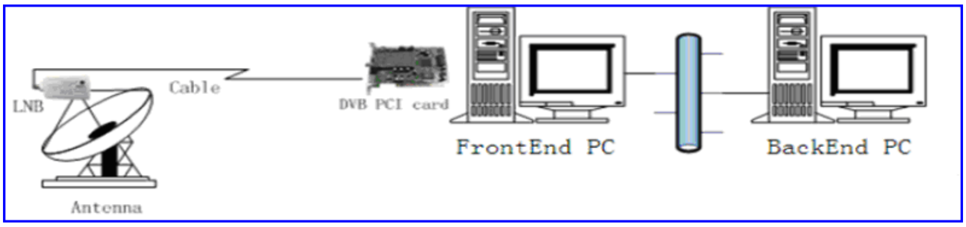


Figure 5 The structure of the DVB-S.

The limitation of using GMSoft to estimate rainfall over Thailand is that GMSoft precipitation estimate coverage area does not include the southern part of Thailand. It is difficult to improve the accuracy of software algorithm since the source code is not available.

1.1 FY-2C Specification

The FY-2C data received through DVB-S are from five radiometer scanning channels. It covers the daytime data of infrared band and visible bands, night-time data of infrared bands only. Major characteristics of each instrument, including spectral wavelengths and spatial resolutions, are shown in Table 3.

Table 3 FY-2C Major Instrument Characteristics

Major	**Detail**
Channel Name	VIS: Visible IR1: Long Wave Infrared IR2: Split Window IR3: Water Vapor IR4: Medium Wave Infrared
Wavelength (µm)	VIS: 0.55-0.90 IR1: 10.3-11.3 IR2: 11.5-12.5 IR3: 6.3-7.6 IR4: 3.5-4
Resolution (KM)	VIS: 1.25 IR: 5

Table 3 FY-2C Major Instrument Characteristics (Continue)

Major	**Detail**	
Noise performance	VIS	S/N=1.5 (Albedo=0.5%) S/N=50 (Albedo=95%)
	IR1/IR2	NEDT=0.4-0.2K(300K)
	IR3	NEDT=0.5-0.3K(300K)
	IR4	NEDT=0.6-0.5K(300K)
Quantification precision (bit)	VIS: 6 IR: 10	

According to the remote sensing characteristics, Long Wave Infrared channel (IR1) and Split Window channel (IR2) of FY-2C can discriminate cloud area and underlying surface. The Water Vapor channel (IR3) can indicate deep convective clouds. Visible channel (VIS) has greater spatial resolution, it is useful for the detection of low clouds, but their temporal availability is limited to daylight hours. Medium Wave Infrared channel (IR4) is sensitive to objects with higher temperature. It is usually used for the estimation of underlying surface temperature and detection of fog and low-level clouds. However, great efforts are needed to eliminate the influence of visible light on the brightness temperatures of IR4 channel. For this reason, this study will focus on numerical data from three infrared channels: IR1, 10.3-11.3 μm; IR2, 11.5-12.5 μm; IR3 6.3-7.6 μm.

1.2 Data Structure

Satellites data transmission format of FY-2 series defined as S-VISSR (Stretched - Visible Infrared Spin Scan Radiometer), including SYNC Code, Document Sector, and Image Data Sectors. As the improved successor of previous experimental GEO satellites FY-2A and FY-2B which were launched on 10 June 1997 and 25 June 2000, respectively. FY-2C was placed in the geostationary orbit over 105o E with a field of view that covers the areas of Asian and Pacific Region. FY-2C is spin-stabilized with a rotation velocity 100 rpm. The main payload onboard, the upgraded data transmission format to S-VISSR2.0, more feature spectral band than previous GEO satellites from 3 spectral bands (1 VIS and 2 IR) to 5 spectral bands (1 VIS and 4 IR).

New specifications of the sensor improve the instrumental observation functions: 1) improved temperature resolution of the IR bands and Signal to Noise Ratio (SNR) of the VIS band; support of split window application; 2) improved the capability of detecting and calculating water vapor contents, to support semi-transparent ice cloud detecting, and to have a better accuracy of atmospheric absorption correction for better sea temperature estimation; 3) the data quantization level of the IR bands has been increased from 256 (8 bit) to 1024 (10 bit), and the arrangement of FY-2C S-VISSR2.0 data is shown in Table 4.

Table 4 Arrangement of FY-2C S-VISSR2.0 Data

S-VISSR 2.0 imagery data stream			
Sector 1	**Sector 2**	**Sector 3**	**Sector 4**
IR1-IR3 8-bit data (Upper bits)	VIS1-VIS4 6-bit data	IR1-IR3 2-bit data (Lower bits)	IR4 10-bit data

Each scan acquires a set of observation data including 4 lines of visible channel data, one line of 4 IR channels data. These observational data and documentation data are put into the S-VISSR2.0 format to be transmitted as S-VISSR image data stream. The data stream of one scan line contains 364848 bits and transmitted at 660Kbps, beginning with the 10000-bit SYNC code, and ends with PN code whose length is variable with the change of the spin cycle of the satellite.

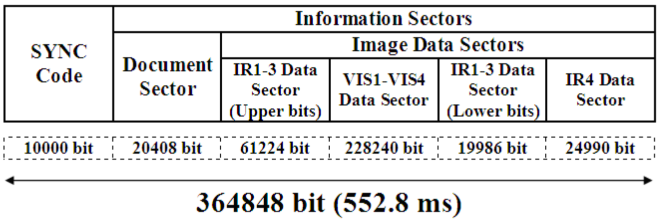

Information Sectors
Image Data Sectors
SYNC Code
Document Sector
IR1-3 Data Sector (Upper bits)
VIS1-VIS4 Data Sector
IR1-3 Data Sector (Lower bits)
IR4 Data Sector
10000 bit
20408 bit
61224 bit
228240 bit
19986 bit
24990 bit
364848 bit (552.8 ms)

Figure 6 Data format of FY-2C.

1.3 Information Sectors

The S-VISSR2.0 has 12 information sectors with the leading 8 sectors being compatible with the FY-2B S-VISSR format. The 1st sector is Documentation sector. The 2nd to the 4th sectors are the upper 8 bits of IR1-IR3 image data. The 5th to 8th sectors are visible (VIS1-VIS4) image data. The 9th and 11th sectors are the lower bits of IR1-IR3 image data. The 12th sector is IR4 image data. Each information sector has its discrimination code (ID code) at the beginning of the sector, to be followed by the information contents and then the 16 bits Cyclic Redundancy Check (CRC) code and 2048 bits of logic zeros (Filler) at the end, as show in Table 5.

Table 5 Structure of The Information Sectors

Sector No.	Sector Name	ID Code	Information	CRC	Filler
1	Documentation sector	16	18328	16	2048
2	IR1 upper 8 bits sector	16	18328	16	2048
3	IR2 upper 8 bits sector	16	18328	16	2048
4	IR3 upper 8 bits sector	16	18328	16	2048
5	VIS1 sector	12	54984	16	2048
6	VIS2 sector	12	54984	16	2048
7	VIS3 sector	12	54984	16	2048
8	VIS4 sector	12	54984	16	2048
9	IR1 lower 2 bits sector	16	4582	16	2048
10	IR2 lower 2 bits sector	16	4582	16	2048
11	IR3 lower 2 bits sector	16	4582	16	2048
12	IR4 sector	16	22910	16	2048

From Table 5, sector 2-4 and sector 9-12 are infrared image data sectors. Each infrared sector includes 2,291 pixels as one line of image data. The spatial resolution of the IR pixel is 5 km at the sub-satellite point. Quantization of IR channels are expressed using 10 bits but upper 8 bits in the IR1-IR3 data are provided in the sectors 2-4 to maintain compatibility with FY-2B S-VISSR. The lower 2 bits of IR1-IR3 data are provided in the sectors 9-11. We can combine them to recover the complete pixel data. The IR4 data are provided in the sector 12. This 10 bits information is mapped to Brightness Temperature (BT) in Kelvin (K) using conversion table in Document Sector which can be shown by graph in Figure 7.

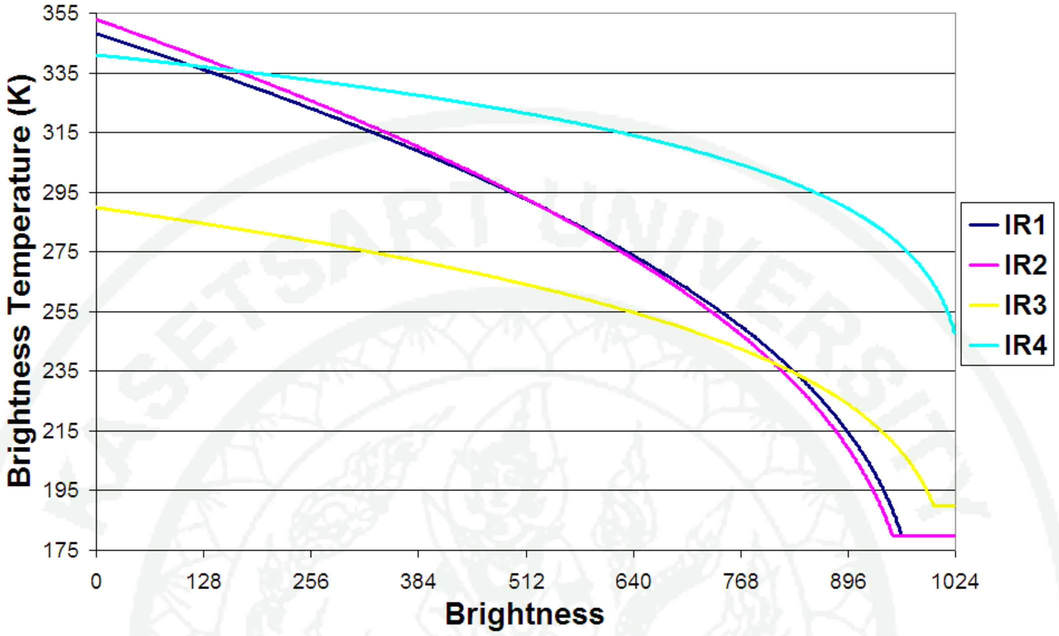


Figure 7 Conversion of Infrared Brightness Temperature.

2. Rainfall Estimation Framework

2.1 Rain Cloud Identification

Rain cloud identification is accomplished by the discrimination of high level cloud characteristics, associated with the rain or no-rain classes because the temperature on the top of cloud is much lower than the land surface in Long Wave Infrared channel (IR1), and the reflectivity of cloud is extremely high in Visible channel. Therefore, the cloud detection can be accomplished by simple threshold method with IR1 and Visible channel.

However, a single channel could not show a good result of rain cloud identification because there are always exceptions. For example, some time thick cirrus cloud shows the similar Brightness Temperature (BT) as cumulonimbus cloud (rain cloud) or underlying surface shows the similar BT in IR1 channel as thin cirrus and for Visible channel desert, snow, and ice shows the same reflectance as cloud. This algorithm is not sufficient for improving rain cloud identification. But, we have more than simple threshold method available for FY-2C data in today, for example:

1) *Spilt Window Technique*: According to the research issued by Saunders, cirrus cloud shows different measurements in different IR channels. Therefore, we can use FY-2C data from IR1 channel with data from IR2 channel to detect cumulonimbus could by setting threshold for Brightness Temperature Difference (BTD) between these two channels to remove cirrus cloud.

2) *Water Vapor Technique*: The radiation in Water Vapor channel (IR3) measured by FY-2C instruments mainly comes from radiation emitted by vapor in the atmospheric layer between 200 and 500hPa, underlying surface radiation is not often detected by the sensor because it is absorbed by the upper atmospheric layers. Therefore, cloud on or above this layer shows a lower BT than clear pixel, this makes it possible to set a threshold to perform detection for high cloud. This algorithm was applied to MODIS data at southeast coastline in China or GMS-5 data of Gansu Province and also showed a good result in high cloud detection.

3) *BTD between IR1 and IR4*: Cirrus cloud shows a larger transmittance in Medium Wave Infrared channel (IR4) than Long Wave Infrared channel (IR1), so we can also use FY-2C data from IR1 channel with data from IR4 channel to detect cumulonimbus could by setting threshold for BTD between these two channels to remove cirrus cloud. However, the influences of visible light on the BT from IR4 channel are needed to eliminate before using it.

For Thailand, it is required to study more to find or develop a new method which is suitable for rain cloud identification for Thailand because it is accepted that a specific algorithm is not necessarily applicable to another climatic region.

2.2 Rainfall Estimation

Long Wave Infrared channel (IR1) of FY-2C is used for the estimation of rainfall by a non-linear equation or Power Law:

$$P = aT^b \tag{1}$$

Where *T* is Brightness Temperature (K) from IR1 channel of FY-2C and *P* is rainfall (mm). In the target area, BT and rainfall are collected, and they are plotted to find *a* and *b* coefficients. Thereafter, the Power Law equation is created for each characteristic area. This equation is used to predict rainfall in that area when BT is determined from FY-2C data. The confidence of this equation can be defined from the coefficient of determination (r^2). The selected *a* and *b* are importance for the accuracy of created Power Law equation. This equation should be calibrated by using rainfall from rain gauge and coefficients *a* and *b* have to be adjusted.

However, it was found that this technique led to promising and acceptable rainfall estimation in some region of Thailand, the polynomial relationship also provided good results in many cases.

$$P = xT^2 + yT + z \tag{2}$$

Where *T* is Brightness Temperature (K) from IR1 channel of FY-2C and *P* is rainfall (mm). In the target area, BT and rainfall are collected, and they are plotted to find *x*, *y* and *z* coefficients. Therefore, both models were used in our work for comparison and analytical purposes.

2.3 System Design

In the study of rain cloud identification and relationship between Brightness Temperature (BT) from IR1 and surface rainfall from rain gauges we found that using only statistical tool is hard to improve rainfall estimation in Thailand, because it can only find the relationship between BTIR1 and surface rainfall, it cannot show other important result such as rain cloud area from rain cloud identification, etc. So for improving rainfall estimation in Thailand we setup Rainfall Estimation Framework and develop Rain Analysis Software that can show rain cloud area from rain cloud identification technique and capable of showing the relationship graph between BTIR1 and surface rainfall.

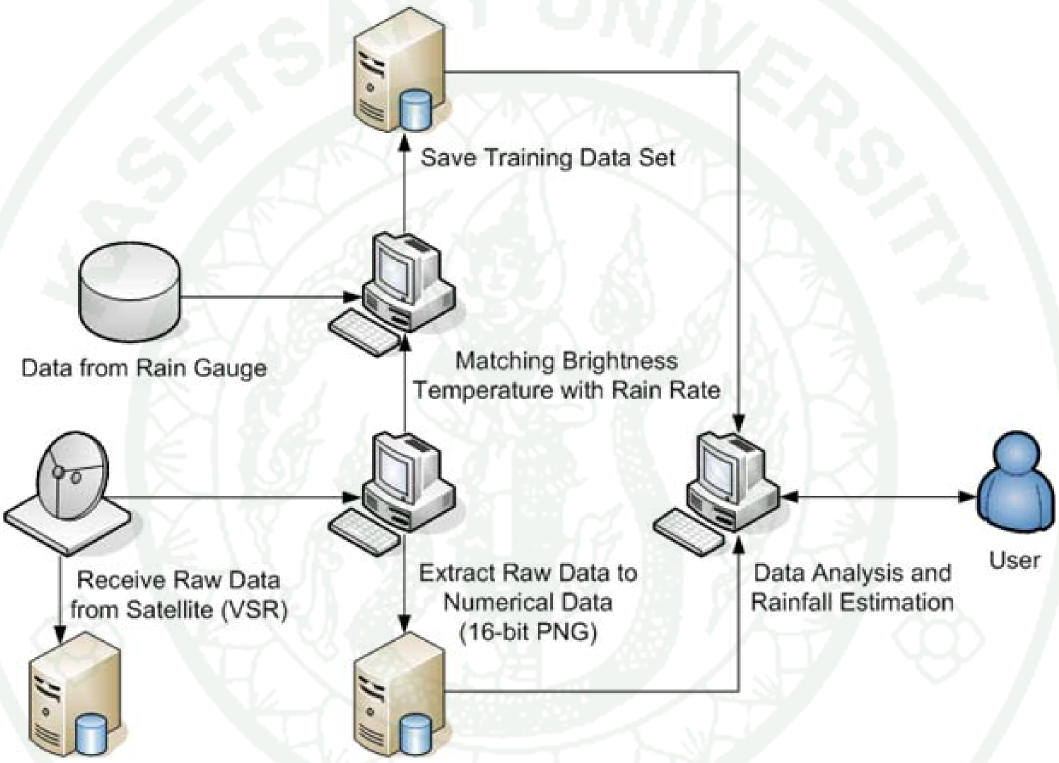

Save Training Data Set
Data from Rain Gauge
Matching Brightness Temperature with Rain Rate
Receive Raw Data from Satellite (VSR)
Extract Raw Data to Numerical Data (16-bit PNG)
Data Analysis and Rainfall Estimation
User

Figure 8 Rainfall Estimation Framework.

From Figure 8, Rainfall Estimation Framework can be separate to 3 parts: 1) Convert FY-2C Raw Data to Numerical Data (16-bit PNG); 2) Generate Training Data Set; 3) Data Analysis and Rainfall Estimation.

1.) *Convert FY-2C Raw Data to Numerical Data*: This part is used for projection of satellite data that received from FY-2C via DVB-S, select the target area, and convert raw data to numerical data. Data from infrared channel will convert to 16bit-PNG because we want to use all 10 bit (1024 level) of the data in infrared channel that will increase accuracy of rain cloud identification and rainfall estimation, and for visible channel raw data will be converted to 8bit-PNG because visible channel has only 6 bit (64 level), as show in Figure 9.

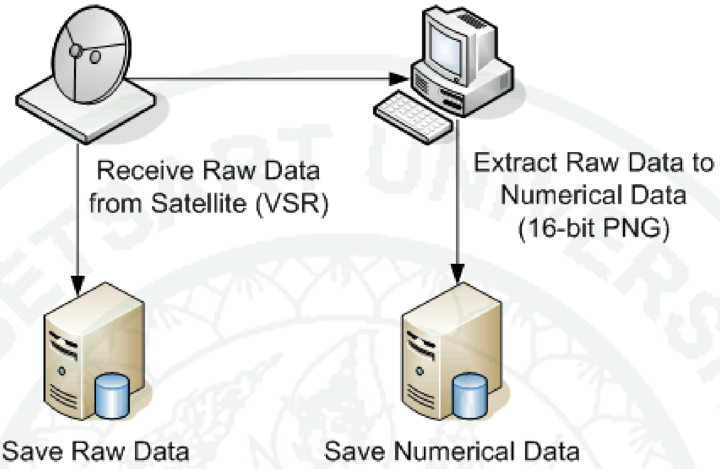

Receive Raw Data
from Satellite (VSR)
Extract Raw Data to
Numerical Data
(16-bit PNG)
Save Raw Data
Save Numerical Data

Figure 9 Structure of Convert FY-2C Raw Data to Numerical Data.

2.) *Generate Training Data Set*: This part is used to generate training data set by matching brightness temperature (K) from numerical data (16bit-PNG) that come from the first-part and surface rainfall (mm) from rain gauge provided by Thailand Meteorological Department (TMD) and Hydro and Agro Informatics Institute (HAII). These training data sets will be used for rain cloud identification and to find the coefficients of Power Law and Polynomial equation in the last-part.

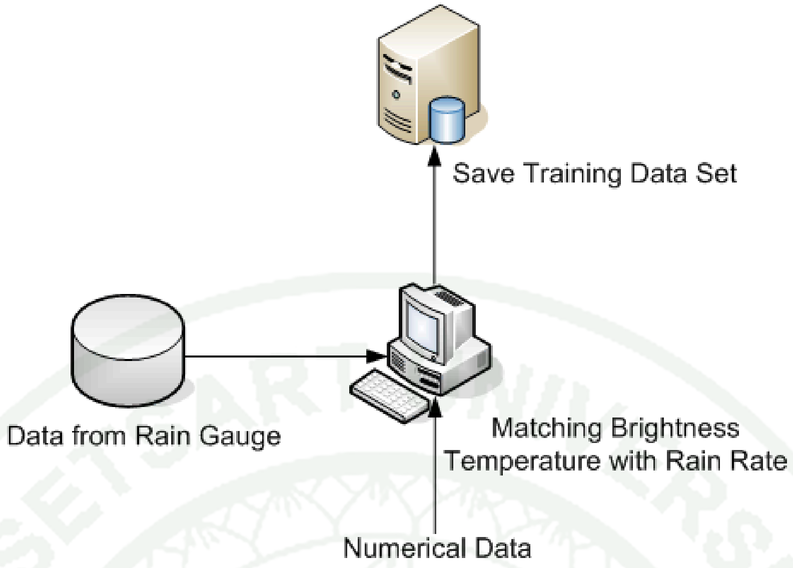

Save Training Data Set
Data from Rain Gauge
Matching Brightness Temperature with Rain Rate
Numerical Data

Figure 10 Structure of Generate Training Data Set.

3) *Data Analysis and Rainfall Estimation*: This part is the one to be connected to user. User can use Rain Analysis Software in this part to find rain cloud area from rain cloud identification, analysis relationship between brightness temperature (K) from numerical data (16bit-PNG) and surface rainfall (mm) and make rainfall estimation model from that relationship, and generate rainfall map for testing accuracy of each model.

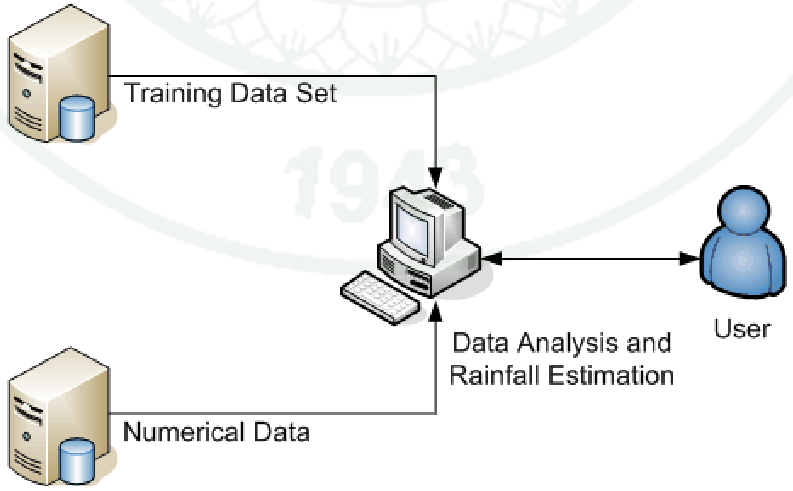

Training Data Set
User
Data Analysis and Rainfall Estimation
Numerical Data

Figure 11 Structure of Data Analysis and Rainfall Estimation.

RESULTS AND DISCUSSION

Results

1. Rain Cloud Identification

Rain cloud identification is accomplished by the discrimination of high level cloud characteristics, associated with the rain or no-rain classes. Raining pixels are identified by thresholding of the IR1 (Long Wave Infrared) channel in combination with filtering process based on Brightness Temperature Difference (BTD) between IR1 and IR3 (Water Vapor) channel. The Infrared Threshold Rainfall (ITR) technique assumes all clouds colder than 253 K to be active convection. However, cirrus contamination in the high level cloud results in overestimation of convective rainfall. Therefore, BTD filtering technique is applied to refine rain cloud identification by discriminating cirrus clouds. In the use of BTD, we found that the areas with Water Vapor and Infrared Temperature difference less than or equal to 0 K corresponded to deep convection. For this study, BTD threshold at -3 K was chosen as suggested in and to be adapted later according to spectral statistical analysis in the future. The algorithms used in this paper are summarized in Table 6.

Table 6 Summarize Techniques Used for Rain Cloud Identification

Techniques	Rain Cloud Identification	FY-2C data channel
Thresholding	IR < 253 K	IR1
Filtering	BTD < Threshold	IR1, IR3

It is worth noting that the ITR technique also tends to neglect warm coastal and orographic rain which is fundamentally due to Infrared threshold. This may result in underestimation of rain rate due to warm cloud. In this case, threshold has to be suitably adapted for the region of Thailand to gain more accuracy for rainfall estimation in the future.

2. Rainfall Estimation

A regression relation converts Infrared brightness temperature numerical data to rainfall rates on the pixel identified to be raining. The Infrared Power Law Rain Rate (IPR) technique is applied to the residual cloud filter pixels, for estimating hourly rain rate. The power law relationship was derived from a statistical nonlinear regression of co-located surface rain gauge data and FY-2C Infrared temperature (K) obtained from satellite raw data. Although it was found that this technique led to promising and acceptable rainfall estimation in some region of Thailand, the polynomial relationship also provided good results in many cases. Therefore, both models were used in our work for comparison and analytical purposes.

Thailand Meteorological Department (TMD) has provided rain gauge data obtained from 110 stations over the northern part of Thailand during the dry season (May 2008). Figure 12 shows the locations of TMD ground-based rain gauge stations mentioned above.

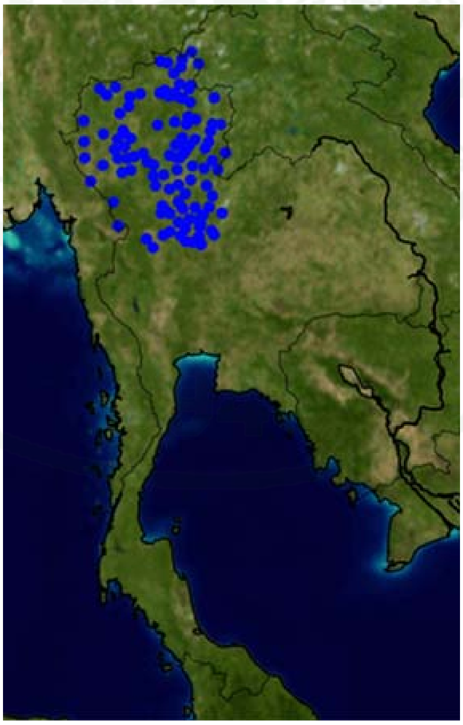


Figure 12 Locations of TMD 110 Rain Gauge Stations.

Data analyses were taken in 3 levels: station, province, and regional. Three stations (Khaokuo-Petchaboon, Klonglan-Kampangpetch and Pobpra-Tak) were chosen to study the tendency of rain estimate improvement using thresholding and filtering method. The results show that Thresholding with IR1 at 253 K does improve the correlation between rain gauge data and Infrared numerical values. However, it was not obvious that BTD filtering could improve the estimation at station level. Therefore, data were further analyzed at province level. Three provinces (Petchaboon, Kampangpetch, and Tak) were chosen. The results are similar to the case of station level. This might be an effect from small amount of data on rainy pixels. However, when all data from 110 stations were analyzed at regional level the result was more positive. We can see an improvement of filtering with BTD over only ITR method by increment of R^2 values for both power law and polynomial models as in Table 7.

Table 7 R^2 values for Rain Estimation Model

Cloud Identification	**Power Law**	**Polynomial**
Thresholding	0.481	0.3783
Thresholding & Filtering	0.658	0.6618

Since the value of R^2 are pretty low, the statistics of Infrared channels for rain and no-rain cases computed from 80,410 sample pixels with 3,163 rainy pixels from 110 rain gauge stations are shown in Table 8. This could be used to adjust thresholds for both steps (IR1 and BTD) of rain cloud identification in the future.

Table 8 Spectral Statistics for Rain/No-Rain Cloud

Case	**Band**	**Min**	**Max**	**Mean**	**S.D.**
Rain	IR1	180	296.161	254.0991	25.4252
	IR3	199.852	255.413	239.1151	11.60858
	IR3-IR1	-47.223	23.287	-14.9789	14.62227
No-Rain	IR1	180	302.374	270.6871	18.28181
	IR3	199.852	256.362	244.4057	7.465542
	IR3-IR1	-53.204	22.753	-26.2812	11.94687

Discussion

One reason for low value of R^2 might be that the TMD rain-gauge data used in this research are without validation. However, the results have shown tendency that the methodology used in this work are appropriate. Our algorithm for rainfall estimation, using Infrared numerical data together with thresholding and filtering techniques, has more opportunity for improvement especially by validating rain gauge measurement and finding more suitable thresholds.

CONCLUSION AND RECOMMENDATION

Conclusion

Today, data from infrared channel of meteorological satellite have capability to estimate rainfall, while rain gauge should be utilized for calibration. Infrared channel is used for the rainfall estimation by the relationship of Brightness Temperature from satellite data and surface rainfall from rain gauge, but it is widely accepted that a specific satellite rainfall technique is not necessarily applicable to another climatic region due to differences in dynamic rain processes from region to region and the relationship between IR band measurement of cloud top temperature and surface rainfall from rain gauges is non-linear, algorithm must be studied and specifically developed for Thailand.

The results of this study imply an improvement in methodology for rainfall estimation by using Infrared numerical data extracted from FY-2C satellite raw data. However, rain gauge data must be validated before use as input for regression analysis. Also, IR1 and BTD thresholds should be suitably adapted for more accuracy. The split window technique using Brightness Temperature Difference between IR1 and IR2 channels may be considered for discriminating cirrus cloud. Microwave observation may be used to improve estimation of warm cloud rain. Precise rainfall estimation can make great contribution to agricultural country as Thailand.

This methodology can be applied to other sets of satellite data such as FY-4 series as well and should be easily adjusted for other climatic region of the whole country. Also, experience gained by using satellite numerical data instead of satellite images could be applied further to find other products such as sea surface temperature, outgoing long-wave radiation, solar radiation, etc. which could be used in other research areas i.e. energy and power balance monitoring system, fire detection, flash flood warning, drought morning, and crop yield forecast as well.

Recommendation

Only statistical tool is not enough for improving rainfall estimation, because it can only be used to find the relationship between the brightness temperature from IR1 and surface rainfall from rain gauges. It cannot show other important result such as rain cloud area from rain cloud identification, etc. Therefore, Rainfall Estimation Framework and Rain Analysis Software that can identify rain cloud and find the relationship between the IR band measurement of cloud top temperature and surface rainfall will be useful for improving rainfall estimation, because it can help researchers study and development of suitable rainfall estimation algorithm for Thailand easier.

In addition, this Rainfall Estimation Framework can be applied to other sets of meteorological satellite data such as FY-2D as well and should be easily adjusted for other climatic region of the whole country. Also, experiences gained by using satellite numerical data instead of satellite images could be applied further to find other products such as the one estimating the sea surface temperature, outgoing long-wave radiation, solar radiation, etc. which could be used in other research areas i.e. Energy and Water Balance Monitoring System (EWBMS), fire detection, flash flood warning, drought morning, and crop yield forecast as well.

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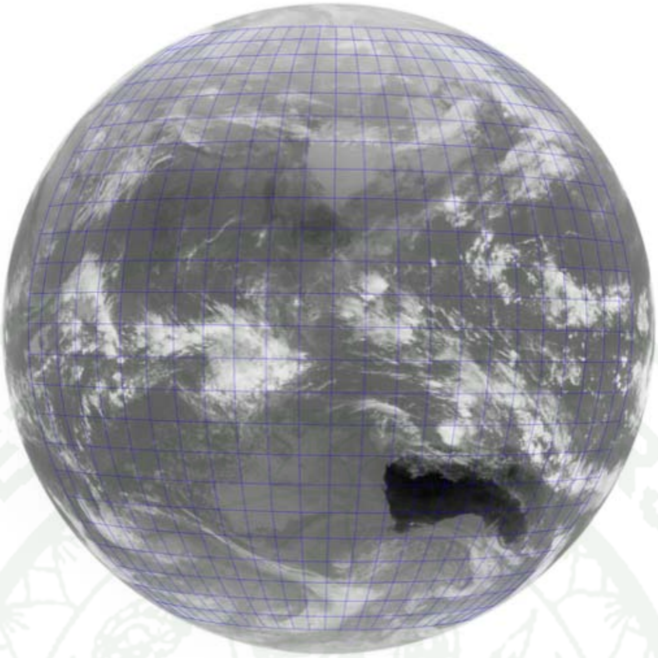
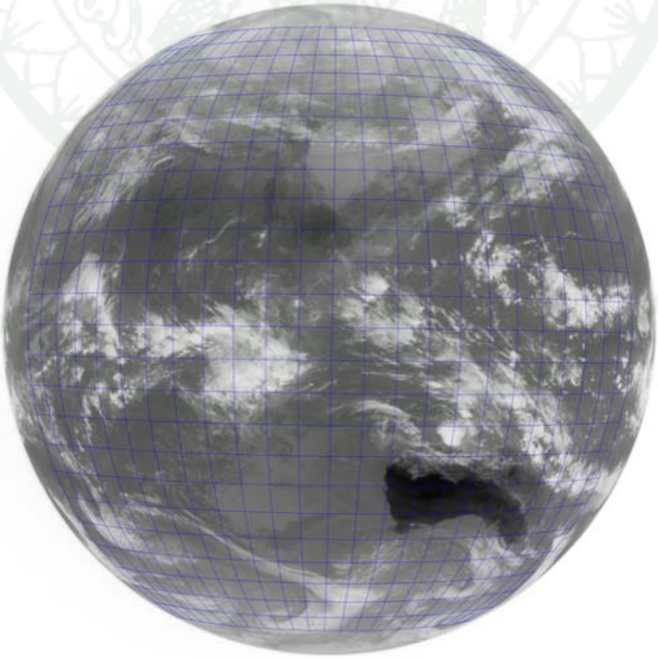
APPENDICES

Appendix A

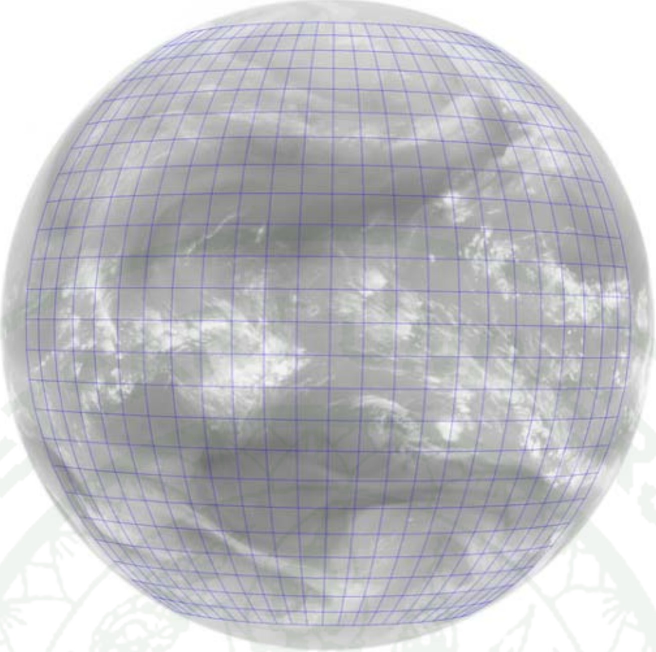
FY-2C Satellite Image



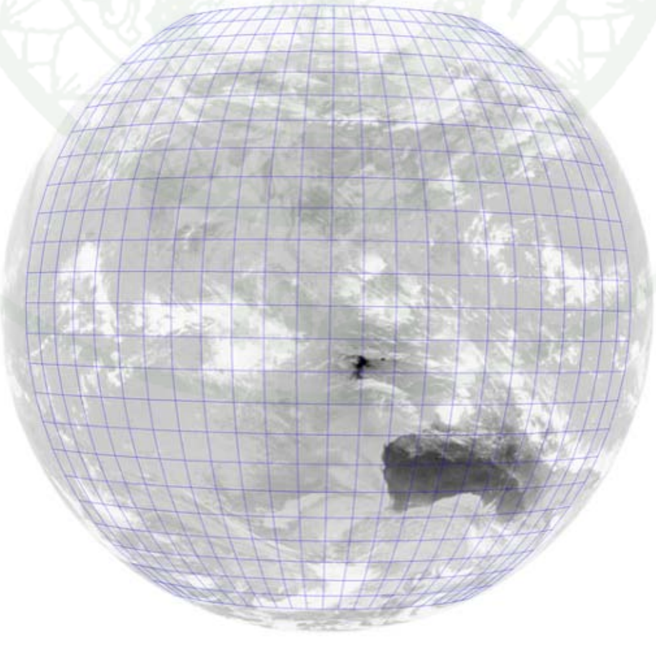
Appendix Figure A1 IR1 Image from FY-2C.



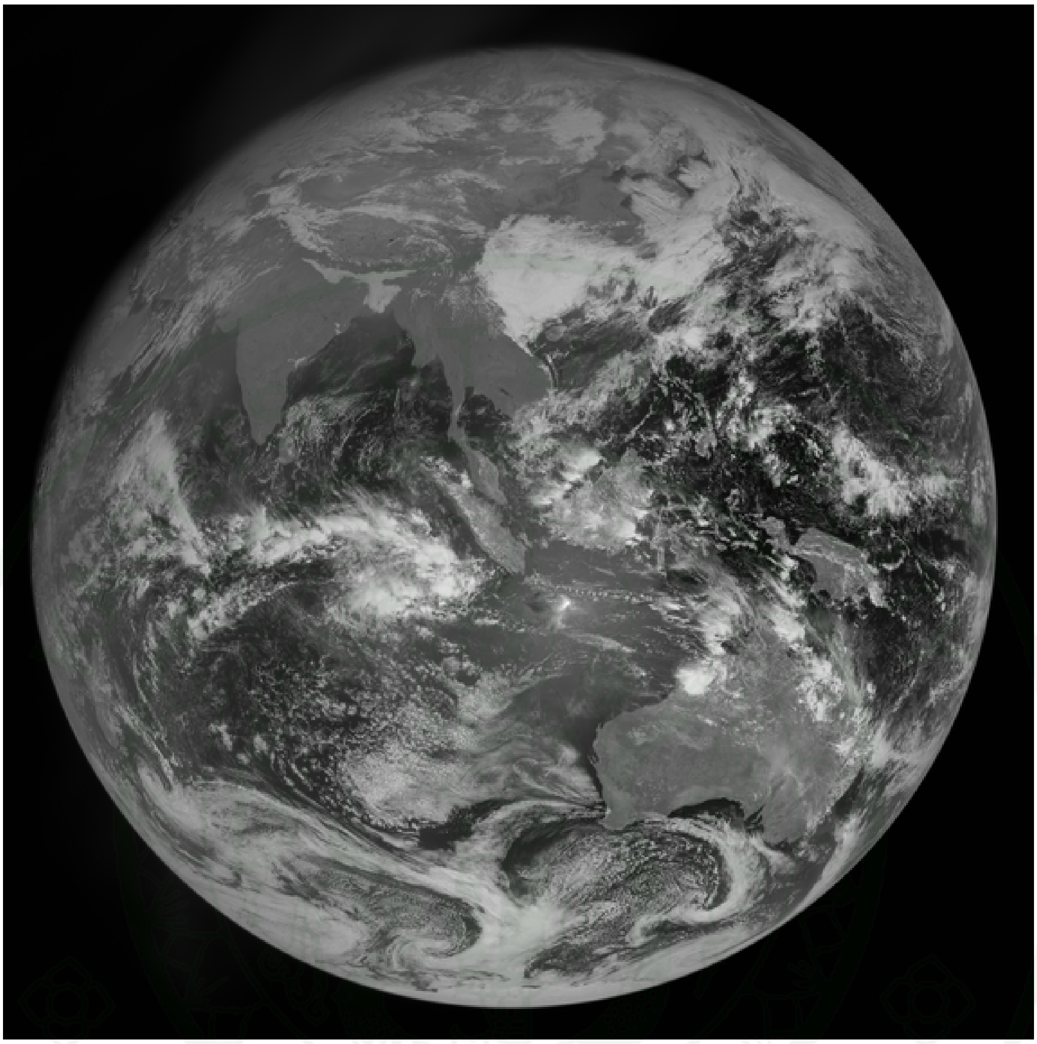
Appendix Figure A2 IR2 Image from FY-2C.



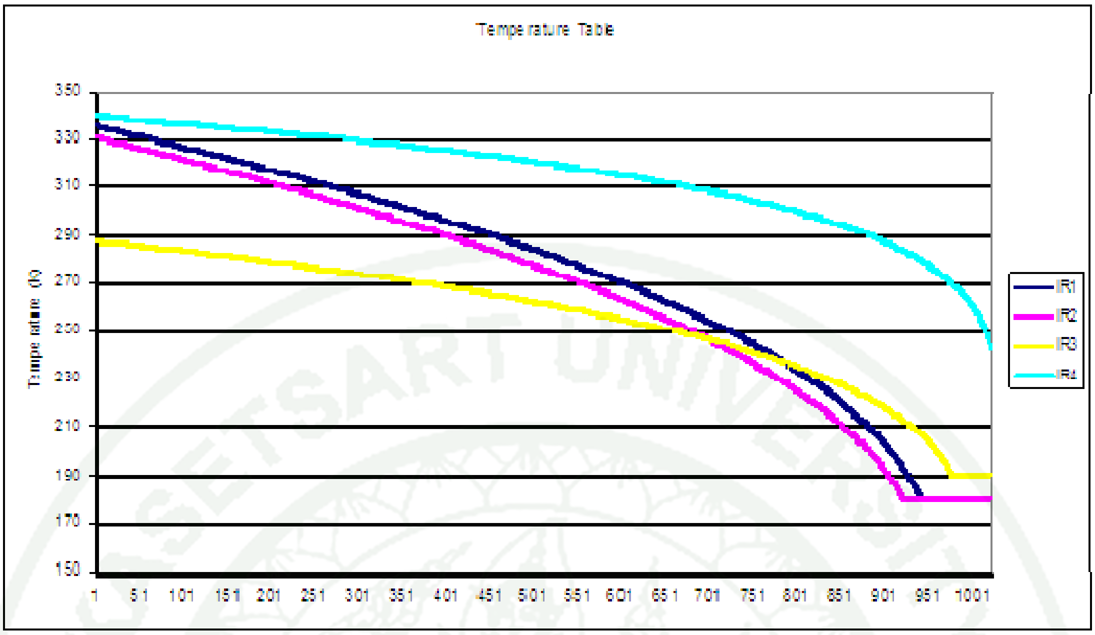
Appendix Figure A3 IR3 Image from FY-2C.



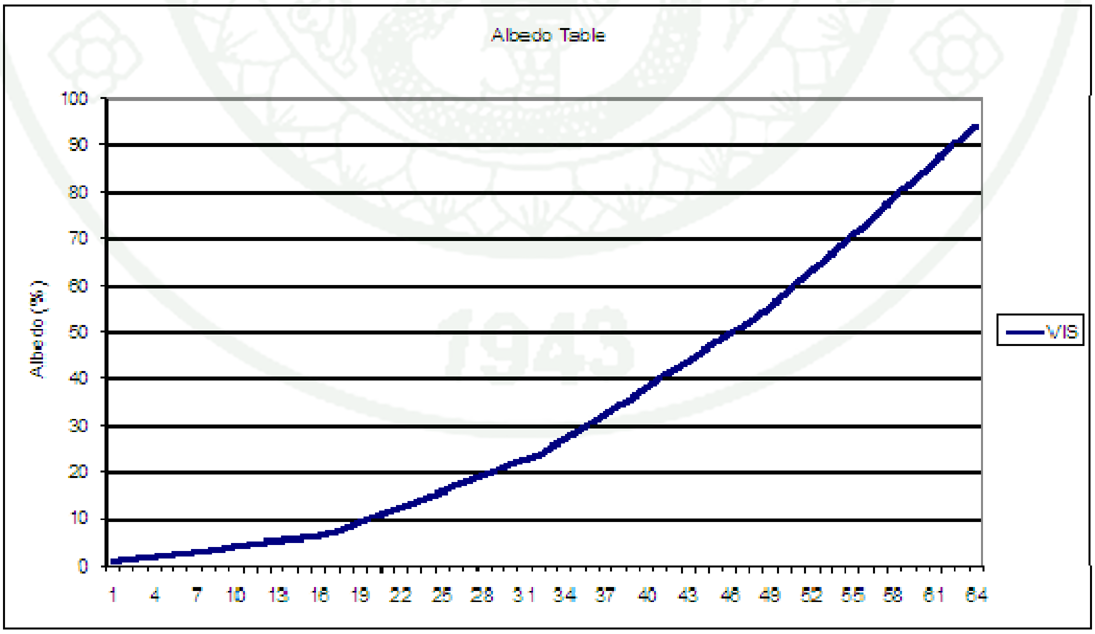
Appendix Figure A4 IR4 Image from FY-2C.



Appendix Figure A5 VIS Image from FY-2C.



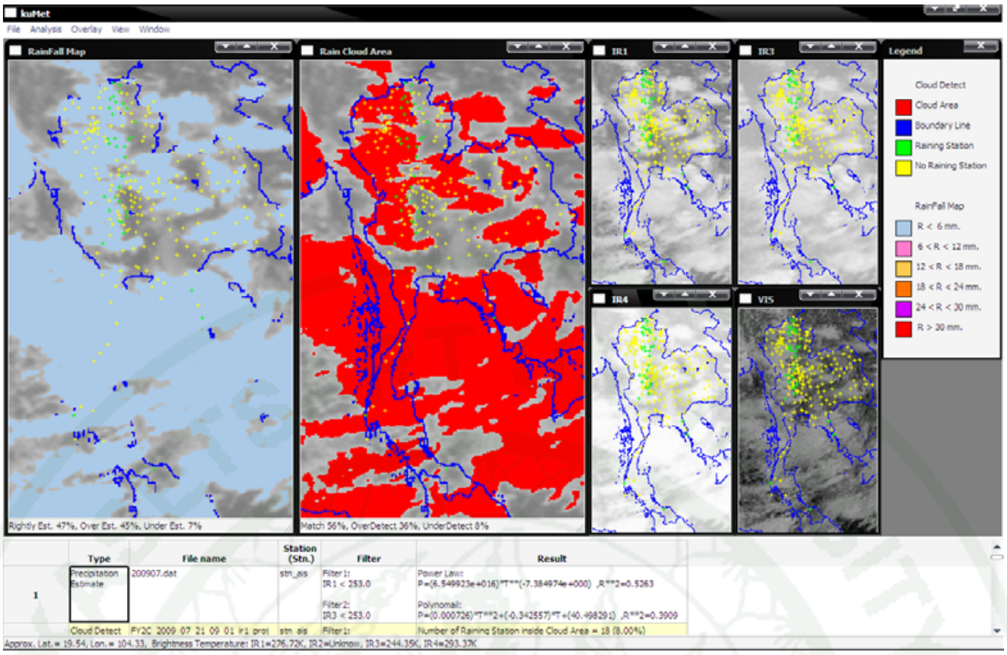
Appendix Figure A6 Relationship between IR Radiance and Brightness Temperature (K).



Appendix Figure A7 Relationship between VIS Radiance and Albedo (%).

Appendix B

Rain Analysis Software


kuMet
File Analysis Overlay View Window
RainFall Map
Rain Cloud Area
IR1
IR3
IR4
VIS
Legend
Cloud Detect
🟥 Cloud Area
🟦 Boundary Line
🟩 Raining Station
🟨 No Raining Station
RainFall Map
🟦 R < 6 mm.
🟪 6 < R < 12 mm.
🟨 12 < R < 18 mm.
🟧 18 < R < 24 mm.
🟪 24 < R < 30 mm.
🟥 R > 30 mm.

Rightly Est. 47%, Over Est. 45%, Under Est. 7%

Match 56%, OverDetect 36%, UnderDetect 8%

	Type	File name	Station (Stn.)	Filter	Result
1	Precipitation Estimate	200907.dat	stn_ais	Filter1: IR1 < 253.0 Filter2: IR3 < 253.0	Power Law: P=(6.549923e+016)*T**(-7.384974e+000) ,R**2=0.5263 Polynomail: P=(0.000726)*T**2+(-0.342557)*T+(40.498291) ,R**2=0.3909
	Cloud Detect	FY2C_2009_07_21_09_01_ir1_proj	stn_ais	Filter1:	Number of Raining Station inside Cloud Area = 18 (8.00%)

Approx. Lat.= 19.54, Lon.= 104.33, Brightness Temperature: IR1=276.72K, IR2=Unknow, IR3=244.35K, IR4=293.37K

Appendix Figure B1 Rain Analysis Software.

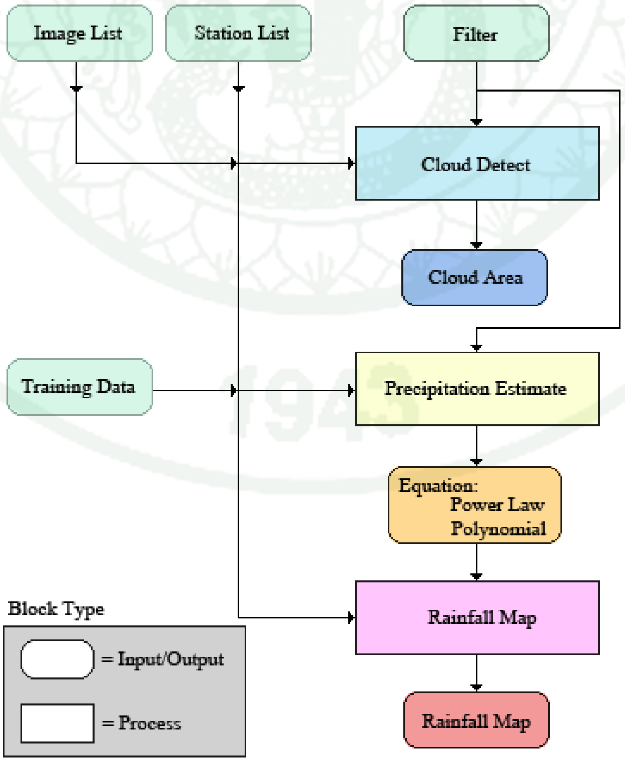
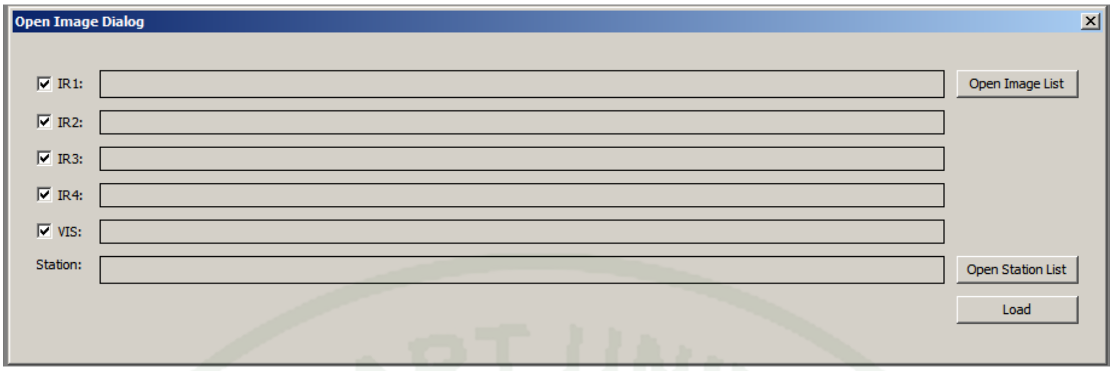


Image List
Station List
Filter
Cloud Detect
Cloud Area
Training Data
Precipitation Estimate
Equation:
Power Law
Polynomial
Rainfall Map
Rainfall Map
Block Type
= Input/Output
= Process

Appendix Figure B2 Diagram of Rain Analysis Software.


Open Image Dialog
Open Image List
Open Station List
Load

☑ IR1:

☑ IR2:

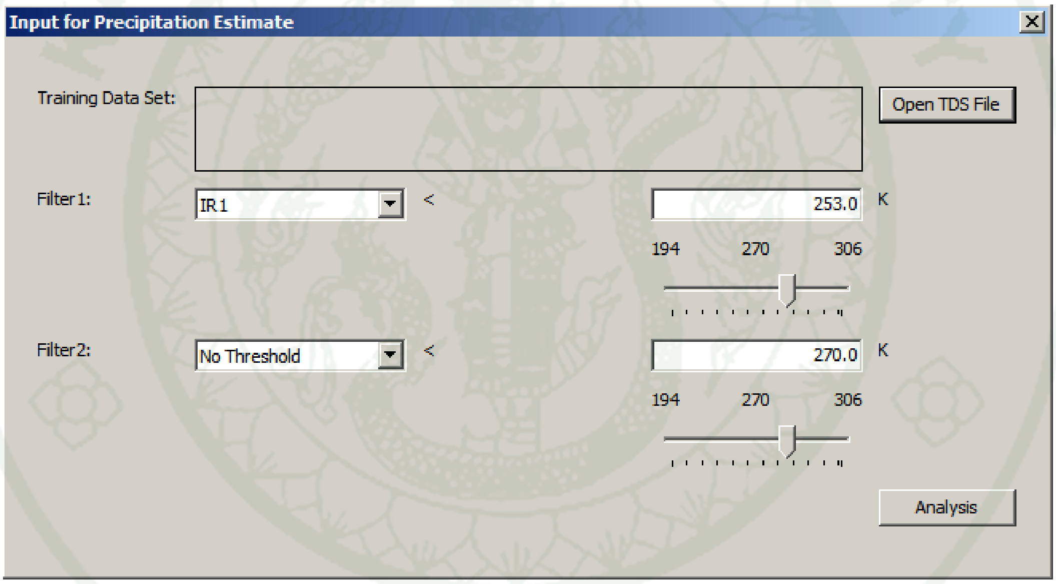
☑ IR3:

☑ IR4:

☑ VIS:

Station:

Appendix Figure B3 Open Numerical Data Dialog.

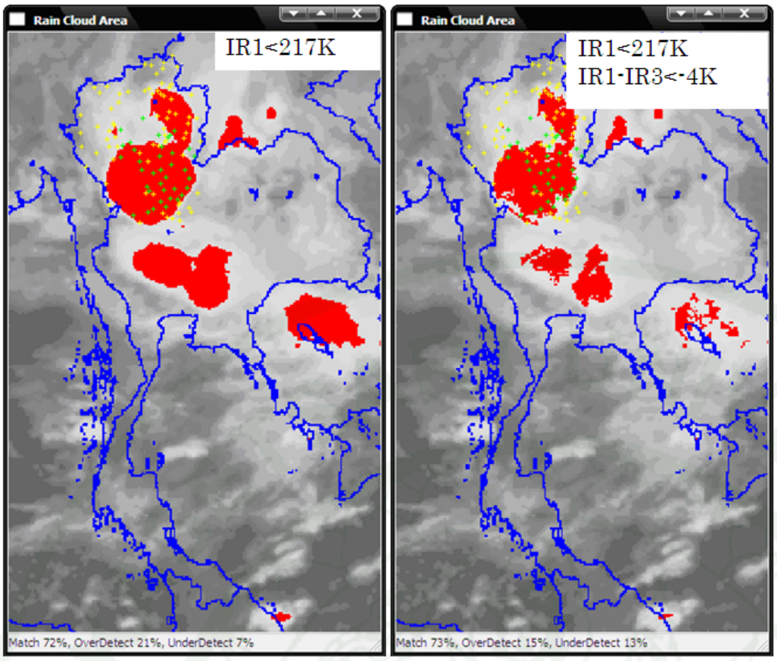

Input for Precipitation Estimate
Open TDS File
194
270
306
194
270
306
Analysis

Training Data Set:

Filter1: IR1 < 253.0 K

Filter2: No Threshold < 270.0 K

Appendix Figure B4 Rain Cloud Identification Parameter Dialog.


Rain Cloud Area
IR1<217K
Rain Cloud Area
IR1<217K
IR1-IR3<-4K

Match 72%, OverDetect 21%, UnderDetect 7%

Match 73%, OverDetect 15%, UnderDetect 13%

🟥 Cloud area

🟦 Boundary line

🟩 Weather station that measure rainfall more than 0 mm

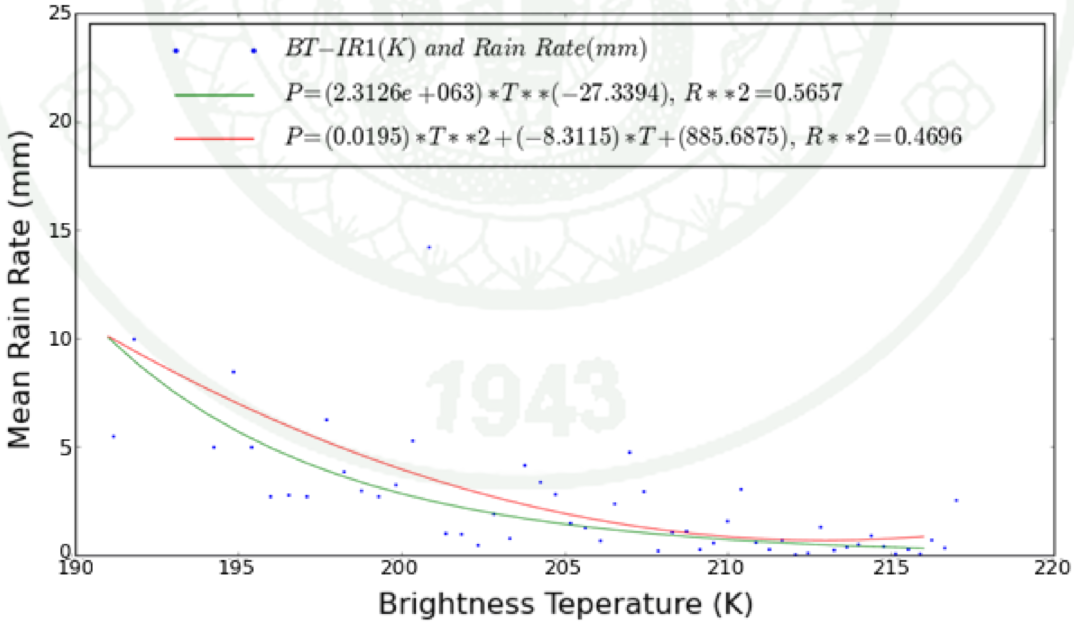
🟨 Weather station that measure rainfall equal to 0 mm

Match: Number of green point in red area and yellow point out of red area

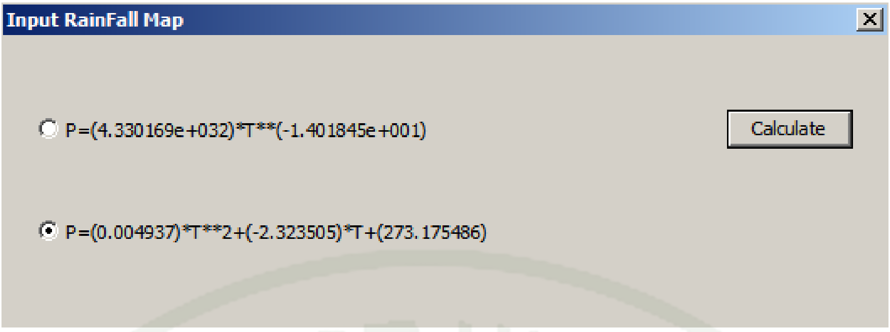
OverDetect: Number of yellow point in red area

UnderDetect: Number of green point out of red area

Appendix Figure B5 Result from Rain Cloud Identification.



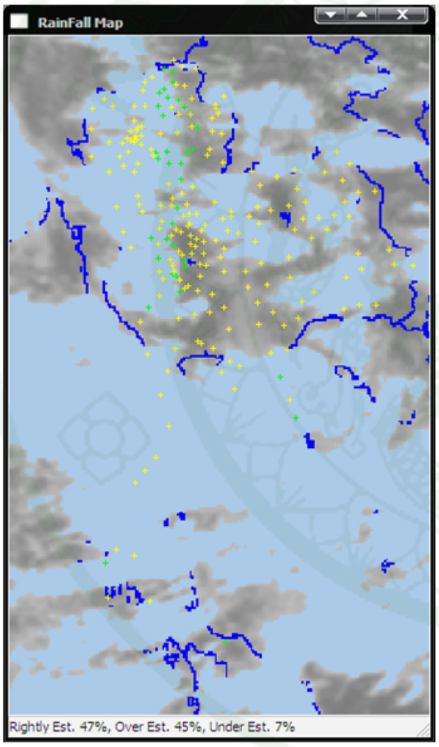
Appendix Figure B6 Relationship Graph.



○ P=(4.330169e+032)*T**(-1.401845e+001)

● P=(0.004937)*T**2+(-2.323505)*T+(273.175486)

Appendix Figure B7 Rainfall Estimation Model Dialog.



Rightly Est. 47%, Over Est. 45%, Under Est. 7%

🟦 Boundary line

🟩 Weather station that measure rainfall more than 0 mm

🟨 Weather station that measure rainfall equal to 0 mm

🟦 0 mm < P ≤ 6 mm 🟪 6 mm < P ≤ 12 mm

🟧 12 mm < P ≤ 18 mm 🟧 18 mm < P ≤ 24 mm

🟪 24 mm < P ≤ 30 mm 🟥 P > 30 mm

Rightly Est.: Number of rain gauge that measure rainfall in range of precipitation estimate

Over Est.: Number of rain gauge that measure rainfall less than range of precipitation estimate

Under Est.: Number of rain gauge that measure rainfall more than range of precipitation estimate

Appendix Figure B8 Rainfall Map.

CURRICULUM VITAE

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POSITION/TITLE : -

WORK PLACE : -

SCHOLARSHIP/AWARDS : TAIST ICTES Master Degree Scholarship

PUBLICATION : ICICTES 2010 and ANSCSE14