Tropical Cyclone Track and Intensity Forecasting Using Remotely-Sensed Images

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***Abstract*—A tropical cyclone disaster is one of the most destructive natural hazards on earth and the main cause of death or injury to humans as well as damage or loss of valuable goods or properties, such as buildings, communication systems, agricultural land, etc. To mitigate severe impacts, track and intensity forecasting is a world-widely adopted process. With accurate forecasting, proactive measures can be appropriately applied on time to reduce both human and property losses. However, Thailand has insufficient meteorological data to apply the NWP model. In fact, the forecasting is done manually in Thailand. This makes the forecasting unreliable and time consuming, which leaves not enough time to prepare a good warning bulletin. To address these problems, this paper proposes an integrated short-range tropical cyclone track and intensity forecasting system by using only 11 features which were extracted from satellite images with improvement of the traditional statistical methods. The performance of the model is satisfactory, giving an average of 4.12 degrees of 6 hours, 12 hours and 24 hours track forecasting errors from best track data and the average errors is lower than traditional techniques by 14.16% on Mercator projection map and the average intensity forecasting errors of 6 hours, 12 hours and 24 hours lower than traditional techniques by 25.18%.**

Keywords— natural disasters; natural hazards; tropical cyclone track and intensity forecasting; image processing; remote sensing.

I. INTRODUCTION

Todays, there are various phenomenon of natural disasters on earth such as various kinds of storms, volcano eruptions, earthquakes, tsunamis, floods, droughts, fires and wildfire, landslides and mudslides, blizzard and avalanches, human epidemics, animal diseases, etc. Theses natural disasters are causes of death or injury to humans, damage or loss of valuable goods, such as buildings, communication systems, agricultural land, forest region, natural environment, economic losses, etc. Especially, the tropical cyclone is one of the most destructive natural hazards on earth and potentially has large scaled impact because it often causes damaging winds, torrential rainfall, flooding, etc. Moreover, tropical cyclones tend to be more damaging and more frequent in the future due to climate change and human behaviors. [1,2,3,4,5]

A tropical cyclone (TC) is an area of low pressure that develops over tropical or subtropical waters. These systems form over the tropical oceans (except the South-Atlantic Ocean region) between latitude 23.5 degree North and South. There are seven tropical cyclone basins where tropical cyclones form on a regular basis: Atlantic basin, Northeast Pacific basin, North Indian basin, Southwest Indian basin, Southeast Indian/Australian basin, Australian/Southwest Pacific basin and Northwest Pacific basin. In their most intense state, these storms are called hurricanes in the Atlantic, typhoons in the western North Pacific, and cyclones in the Bay of Bengal [6,7]. Furthermore, Thailand is one of the country that located in tropical area and near both Pacific and Indian basin which also was effected by severe tropical cyclone several time [8] such as Typhoon Harriet [9], Typhoon Gay [10], Typhoon Linda [11]. However, warning system is still quite delayed and could not evacuated in time and lack of accuracy of storm position forecasting. These causes of many death or injury of humans, damage or loss of valuable good and national economic.

So far, there are many techniques for tropical cyclone forecasting but these can be grouped into three main classes of forecasting models. First, statistical models which based on an analysis of storm behavior using climatology and correlate a storm's position and date to produce a forecast that is not based on the physics of the atmosphere at the time. Second, dynamical models are numerical models that solve the governing equations of fluid flow in the atmosphere; they are based on the same principles as other limited-area numerical weather prediction models (NWP model) but may include special computational techniques such as refined spatial domains that move along with the cyclone and third models that use elements of both approaches are called statistical-dynamical models. [12]

Furthermore, tropical cyclone track and intensity forecasting are so important for risk area evaluation that will be affected by the tropical cyclone due to accuracy of tropical cyclone track and intensity forecasting can reduce both human and property losses. However, in Thailand, there are two primary techniques for tropical cyclone forecasting in operation. First, the statistical method which is a conventional method used in Thai Meteorological Department [13]. Although, this technique gives a satisfactory results, but it takes much time because the officer has to calculate manually. This causes unreliability and gives not enough to prepare a good warning bulletin for government agency and media. Another method is dynamical model which run on a well-known WRF software (Weather Research and Forecasting [14]). The WRF model requires various meteorological features of which Thailand lacks. As the result, tropical cyclone track forecasting still have high errors. Although recently, Sugunyanee Yavinchan, et al. [15] developed and improved WRF model with insufficient data techniques.

Hence, tropical cyclone track and intensity forecasting requires various meteorological features for prediction. To provide meteorological data to the NWP model is a high volume in various measure equipment investment/maintenance and weather observation. On the other hand, this paper suggests an

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alternative solution for tropical cyclone track and intensity forecasting which is economical and gives satisfactory forecasting results and the proposed technique only uses satellite images data for analysis with improvement of statistical methods. This paper is organized into the following sections: Section II satellite image and historic tropical cyclone data. Tropical cyclone detection and location identification model and intensity analysis in section III. Tropical cyclone track and intensity forecasting model with improvement of statistical methods in section IV. Tropical cyclone track and intensity forecasting model performance in section V and a conclusion and remark is drawn in section VI.

II. SATELLITE IMAGE AND HISTORIC TROPICAL CYCLONE DATA

In this paper, there are two types of data for experiment, i.e., historic tropical cyclone data or best track data were derived from RSMC Tokyo-Typhoon Center and satellite image data from Japan Meteorological Agency's Satellite (GMS, MTSAT-1R, and MTSAT-2 Series). RSMC Tokyo-Typhoon Center provides Best Track Data [16] which includes time of analysis (UTC), levels of storm intensity, latitude and longitude of the center (Unit: 0.1 degree), central pressure (Unit: hPa), maximum sustained wind speed (MSW) (Unit : knot), etc., as shown in figure 1. Historic tropical cyclone data is reported every 6 hours following the World Meteorology Organization (WMO) regulation. It should be noted that RSMC Tokyo is organization that works under control of World Meteorology Organization (WMO) and is responsible for monitoring and warning on tropical cyclones in Pacific Ocean.

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66666 1330  033 0036 1330 0 6   HAIYAN     20131218
13110400 002 3 061 1522 1002  035    00000 0000 90060 0060
13110406 002 3 062 1504 1000  035    00000 0000 90060 0060
13110412 002 3 063 1488  998  040    00000 0000 90100 0100
13110418 002 3 065 1472  992  045    00000 0000 90120 0120
13110500 002 4 065 1459  985  055    90030 0030 90120 0120
13110506 002 4 065 1446  980  060    90040 0040 90120 0120
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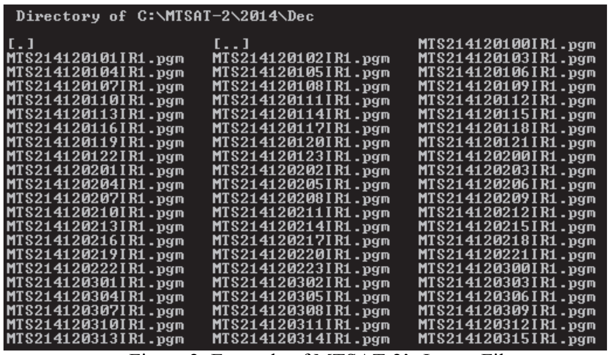
Figure 1: Example of tropical cyclone historic data

Japan Meteorological Agency's Satellite or JMA's Satellite has operated geostationary meteorological satellites since 1978, producing data that helps to prevent and mitigate weather-related disasters based on monitoring of typhoons and other weather conditions in the Asia-Oceania region [17,18]. JMA's GMS, MTSAT-1R and MTSAT-2 operated at coordinate N70 - S20 and E70 - E160 with 5 channels whose detail is shown in table I. and all channels will scan image every hour with the resolution of 1800 x 1800 pixels. PGM (Portable Gray Map) format with Gzip compression. Each image file contains name of satellite, date, month, year, time of image taken and channel of image as shown in figure 2 and 3.

TABLE I. JMA'S MTSAT-1R AND MTSAT-2 SATELLITE PROPERTIES

Channel	Wavelength (micrometer)
Visible Channel	0.55 - 0.90
Infrared Channel 1 (IR1)	10.3 - 11.3
Infrared Channel 2 (IR2)	11.5 - 12.5
Infrared Channel 3 (IR3)	6.5 - 7.0
Infrared Channel 4 (IR4)	3.5 - 4.0



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Directory of C:\MTSAT-2\2014\Dec

[.]                    [..]                   MTS214120100IR1.pgm
MTS214120101IR1.pgm    MTS214120102IR1.pgm    MTS214120103IR1.pgm
MTS214120104IR1.pgm    MTS214120105IR1.pgm    MTS214120106IR1.pgm
MTS214120107IR1.pgm    MTS214120108IR1.pgm    MTS214120109IR1.pgm
MTS214120110IR1.pgm    MTS214120111IR1.pgm    MTS214120112IR1.pgm
MTS214120113IR1.pgm    MTS214120114IR1.pgm    MTS214120115IR1.pgm
MTS214120116IR1.pgm    MTS214120117IR1.pgm    MTS214120118IR1.pgm
MTS214120119IR1.pgm    MTS214120120IR1.pgm    MTS214120121IR1.pgm
MTS214120122IR1.pgm    MTS214120123IR1.pgm    MTS214120200IR1.pgm
MTS214120201IR1.pgm    MTS214120202IR1.pgm    MTS214120203IR1.pgm
MTS214120204IR1.pgm    MTS214120205IR1.pgm    MTS214120206IR1.pgm
MTS214120207IR1.pgm    MTS214120208IR1.pgm    MTS214120209IR1.pgm
MTS214120210IR1.pgm    MTS214120211IR1.pgm    MTS214120212IR1.pgm
MTS214120213IR1.pgm    MTS214120214IR1.pgm    MTS214120215IR1.pgm
MTS214120216IR1.pgm    MTS214120217IR1.pgm    MTS214120218IR1.pgm
MTS214120219IR1.pgm    MTS214120220IR1.pgm    MTS214120221IR1.pgm
MTS214120222IR1.pgm    MTS214120223IR1.pgm    MTS214120300IR1.pgm
MTS214120301IR1.pgm    MTS214120302IR1.pgm    MTS214120303IR1.pgm
MTS214120304IR1.pgm    MTS214120305IR1.pgm    MTS214120306IR1.pgm
MTS214120307IR1.pgm    MTS214120308IR1.pgm    MTS214120309IR1.pgm
MTS214120310IR1.pgm    MTS214120311IR1.pgm    MTS214120312IR1.pgm
MTS214120313IR1.pgm    MTS214120314IR1.pgm    MTS214120315IR1.pgm
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Figure 2: Example of MTSAT-2's Image Files

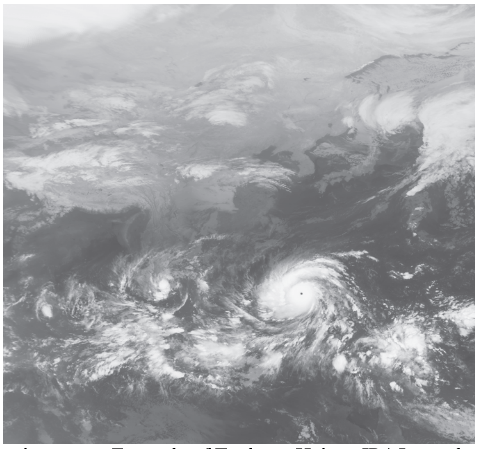


Figure 3: Environments Example of Typhoon Haiyan IR1 Image by MTSAT-2 on 7 November 2013

III. TROPICAL CYCLONE DETECTION AND LOCATION IDENTIFICATION MODEL AND INTENSITY ANALYSIS

In satellite meteorology, each channel or band are used for different objective of weather observation. For example in table II and for more detail at [19,20].

TABLE II. WAVELENGTH AND PRIMATRY USE IN REMOTE SENSING

Channel/Band	Range: Wavelength (micrometer)	Primary Use
4	0.545-0.565	Green vegetation
21	3.929-3.989	Forest fires and volcanoes
27	6.535-6.895	Mid troposphere humidity
31	10.780-11.280	Cloud temperature, Surface temperature
32	11.770-12.270	Cloud height, Surface temperature

Japan Meteorological Agency's Satellite contains 5 channels and satellite image data from IR1 (10.3 - 11.3 micrometer) are suitable for detection and observation tropical cyclone due to cloud structures of tropical cyclone is observable by cloud temperatures in images [21,22]. As a consequence, in our methodology, satellite image IR1 data from Japan Meteorological Agency's Satellite in 6 hour interval is used to analysis maximum sustain wind (intensity) and extract the center of the tropical cyclone as shown in figure 5. In the table, each column include; no. of tropical cyclone in each year, year, month, date, time of image taken, latitude, longitude and maximum sustain wind, respectively. To get the storm position, the model for detection and location identification [23,24,25], is applied. but the most simple traditionally in image processing theory is research of Wong Ka Yan, et al. as shown in figure 4 and more detail at [26] which was applied in this work for detection and extraction location of tropical cyclone. However, most of automatic tropical cyclone location identification leads to larger error during formative and decaying phase of tropical cyclone due to the absence of robust pattern in the images or the spiral/eyes of tropical cyclone are not present in the cloud pattern. The error of location identification often occur during formative and decaying phase because, at these phases, it is difficult to locate the tropical cyclone's center in the satellite images due to unstable of cloud formation, even with human interpretation. This is still a challenging research issue. As the result, tropical cyclone forecasting in section V will show the experiments both data from extracted images with maximum level of tropical cyclone and data from historic data files for testing accuracy of TC forecasting model because only data of the maximum tropical cyclone level in best track is quite small.

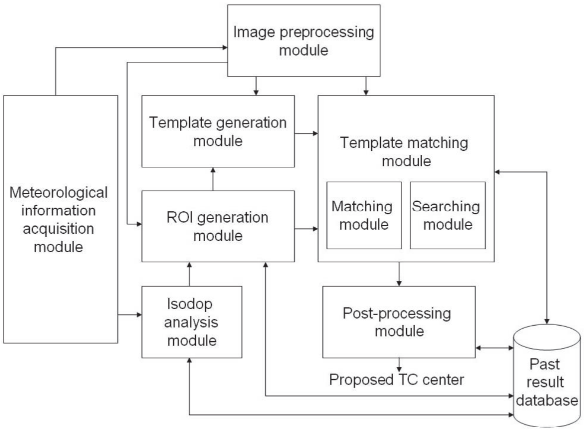
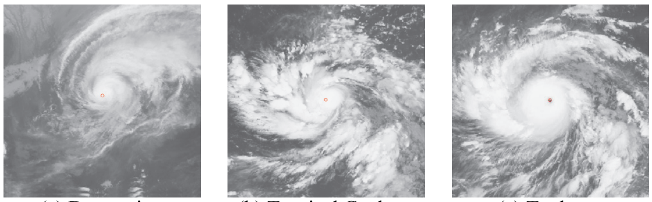


Figure 4: Wong Ka Yan, et al. Model [26]

1	2	3	4	5	6	7	8
2	10	7	12	0	14.3000	130.3000	64.8200
2	10	7	12	6	14.1000	129.3000	83.3400
2	10	7	12	12	14.3000	127.7000	101.8600
2	10	7	12	18	14.3000	126.5000	120.3800
2	10	7	13	0	14.3000	124.8000	120.3800
2	10	7	13	6	14.4000	123.5000	120.3800
2	10	7	13	12	14.5000	122.3000	120.3800
2	10	7	13	18	14.3000	120.9000	111.1200
2	10	7	14	0	14.7000	119.6000	101.8600
2	10	7	14	6	15.3000	118.3000	92.6000
2	10	7	14	12	16.1000	117.7000	83.3400
2	10	7	14	18	16.1000	116.1000	83.3400

Figure 5: Sample's Features Data Extraction from Satellite Image

In intensity analysis, methodology for tropical cyclone intensity is demonstrated in two parts as follows. a) First phase, image extraction and reconstruction phase, satellite image data from Japan Meteorological Agency's Satellite in 6 hours interval which were extracted center of the storm in images were mapped and reconstructed tropical cyclone image with size 400x400 pixels with center of image are position at x=200, y=200 which is TC center and classified in 3 levels; Tropical Depression (TD), Tropical Cyclone (TC) and Typhoon (TY) as shown in figure 6 and b) Second, each image from first phase were analyzed by Dvorak techniques and more detail at [27], analyzed images were recorded wind speed (km/h) in column 8 in figure 5.



(a) Depression (b) Tropical Cyclone (c) Typhoon

Figure 6: Example of tropical cyclone historic data mapping with satellite image with 400x400 pixels

IV. Tropical Cyclone Track and Intensity Forecasting Model with Improvement of Statistical Methods

CLIPER (Climatology and Persistence) statistical method [28] is a tropical cyclone track forecasting technique, which includes 13 predictors as follows; Julian date, Initial latitude, Initial longitude, Current latitude, Current longitude, Latitude over past 12hrs, Longitude over past 12hrs, Latitude over past 24hrs, Longitude over past 24hrs, Avg. Speed over past 12hrs, Avg. Speed over past 24hrs, (Current) Maximum Sustain Wind and Initial Storm Intensity. CLIPER is able to forecast 6 to 72 hours by using multiple regression techniques. In tropical cyclone intensity forecasting based on SHIFOR (Statistical Hurricane Intensity Forecast model) [29] which includes 6 predictors as follows; Julian date, Initial latitude, Initial longitude, (Current) Maximum Sustain Wind, Avg. Speed over past 12hrs. SHIFOR is able to forecast 6 to 72 hours by using multiple regression techniques. However, traditional CLIPER and SHIFOR technique (called, T-CLIPER/CLIPER 5 and T-SHIFOR respectively) is only based on historic data equation and gives an unsatisfied result when forecast more than 12 hours. Therefore, improvement of the model (called, Integrated Self-Adjustment CLIPER or ISA-CLIPER) in this paper selected 11 features which were extracted and analyzed from satellite images from section III as follows.

TABLE III. List of Predictior Variables in ISA-CLIPER

Predictors	Description
Julian_Date	Julian date
Initial_LAT	Initial latitude
Initial_LONG	Initial longitude
Current_LAT	Current latitude
Current_LONG	Current longitude
P12h_LAT	Latitude over past 12hrs
P12h_LONG	Longitude over past 12hrs
P24h_LAT	Latitude over past 24hrs
P24h_LONG	Longitude over past 24hrs
Current_MSW	Current Maximum Sustain Wind
AVG12h_SPEED	Avg. Speed over past 12hrs

ISA-CLIPER is separated forecasting in two phases; track phase and intensity phase. However, ISA-CLIPER in two phase are run parallel in processing time. In ISA-CLIPER track phase, the model created multiple regression equation from historic tropical cyclone data which is a track statistical based equation (T-SBE) for tropical cyclone track forecasting and the model is separated in two part for latitude and longitude calculations as follows.

First, calculate next latitude and longitude position from track statistical based equation as follows.

$$\mathrm{F\_LAT} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_i x_i + \ldots + \beta_9 x_9 \tag{1}$$

$$\mathrm{F\_LONG} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_i x_i + \ldots + \beta_9 x_9 \tag{2}$$

Where F_LAT is next latitude tropical cyclone position. F_LONG is next longitude tropical cyclone position. Where β_0 to β_9 can be calculated as follows.

$$n\beta_0 + \beta_1 \sum_{i=1}^{n} x_{i,1} + \beta_2 \sum_{i=1}^{n} x_{i,2} + \ldots + \beta_9 \sum_{i=1}^{n} x_{i,9} = \sum_{i=1}^{n} y_i \tag{3}$$

$$\beta_0 \sum_{i=1}^{n} x_{i,1} + \beta_1 \sum_{i=1}^{n} x_{i,1}x_{i,1} + \beta_2 \sum_{i=1}^{n} x_{i,1}x_{i,2} + \ldots + \beta_9 \sum_{i=1}^{n} x_{i,1}x_{i,9} = \sum_{i=1}^{n} x_{i,1}y_i \tag{4}$$

$$\beta_0 \sum_{i=1}^{n} x_{i,2} + \beta_1 \sum_{i=1}^{n} x_{i,2}x_{i,1} + \beta_2 \sum_{i=1}^{n} x_{i,2}x_{i,2} + \ldots + \beta_9 \sum_{i=1}^{n} x_{i,2}x_{i,9} = \sum_{i=1}^{n} x_{i,2}y_i \tag{5}$$

$$\beta_0 \sum_{i=1}^{n} x_{i,3} + \beta_1 \sum_{i=1}^{n} x_{i,3}x_{i,1} + \beta_2 \sum_{i=1}^{n} x_{i,3}x_{i,2} + \ldots + \beta_9 \sum_{i=1}^{n} x_{i,3}x_{i,9} = \sum_{i=1}^{n} x_{i,3}y_i \tag{6}$$

$$\beta_0 \sum_{i=1}^{n} x_{i,4} + \beta_1 \sum_{i=1}^{n} x_{i,4}x_{i,1} + \beta_2 \sum_{i=1}^{n} x_{i,4}x_{i,2} + \ldots + \beta_9 \sum_{i=1}^{n} x_{i,4}x_{i,9} = \sum_{i=1}^{n} x_{i,4}y_i \tag{7}$$

$$\beta_0 \sum_{i=1}^{n} x_{i,5} + \beta_1 \sum_{i=1}^{n} x_{i,5}x_{i,1} + \beta_2 \sum_{i=1}^{n} x_{i,5}x_{i,2} + \ldots + \beta_9 \sum_{i=1}^{n} x_{i,5}x_{i,9} = \sum_{i=1}^{n} x_{i,5}y_i \tag{8}$$

$$\beta_0 \sum_{i=1}^{n} x_{i,6} + \beta_1 \sum_{i=1}^{n} x_{i,6}x_{i,1} + \beta_2 \sum_{i=1}^{n} x_{i,6}x_{i,2} + \ldots + \beta_9 \sum_{i=1}^{n} x_{i,6}x_{i,9} = \sum_{i=1}^{n} x_{i,6}y_i \tag{9}$$

$$\beta_0 \sum_{i=1}^{n} x_{i,7} + \beta_1 \sum_{i=1}^{n} x_{i,7}x_{i,1} + \beta_2 \sum_{i=1}^{n} x_{i,7}x_{i,2} + \ldots + \beta_9 \sum_{i=1}^{n} x_{i,7}x_{i,9} = \sum_{i=1}^{n} x_{i,7}y_i \tag{10}$$

$$\beta_0 \sum_{i=1}^{n} x_{i,8} + \beta_1 \sum_{i=1}^{n} x_{i,8}x_{i,1} + \beta_2 \sum_{i=1}^{n} x_{i,8}x_{i,2} + \ldots + \beta_9 \sum_{i=1}^{n} x_{i,8}x_{i,9} = \sum_{i=1}^{n} x_{i,8}y_i \tag{11}$$

$$\beta_0 \sum_{i=1}^{n} x_{i,9} + \beta_1 \sum_{i=1}^{n} x_{i,9}x_{i,1} + \beta_2 \sum_{i=1}^{n} x_{i,9}x_{i,2} + \ldots + \beta_9 \sum_{i=1}^{n} x_{i,9}x_{i,9} = \sum_{i=1}^{n} x_{i,9}y_i \tag{12}$$

From all equations above (3) – (12), β_0 to β_9 are able to solve equations by using matrices method [30] and n is all tropical cyclone in database. Note that, x_1 to x_9 in (1) - (12) will be replaced by list of predictor variables; Julian_Date, Initial_LAT, Initial_LONG, Current_LAT, Current_LONG, P12h_LAT, P12h_LONG, P24h_LAT, P24h_LONG, respectively. Finally, calculate error elimination or T-Adjustment equation as follows.

$$\varepsilon_y = [\sum_{i=1}^{t} \mathrm{F\_LAT_i} - \mathrm{LAT_i}] / t \tag{13}$$

$$\varepsilon_x = [\sum_{i=1}^{t} \mathrm{F\_LONG_i} - \mathrm{LONG_i}] / t \tag{14}$$

$$\mathrm{F\_LAT} = \mathrm{F\_LAT} - \varepsilon_y \tag{15}$$

$$\mathrm{F\_LONG} = \mathrm{F\_LONG} - \varepsilon_x \tag{16}$$

Where ε_y is an average error on latitude in latest t time windows hours. ε_x is an average error on longitude in latest t time windows hours. $\mathrm{F\_LAT_i}$ is latitude forecasting in the past at time i. $\mathrm{F\_LONG_i}$ is longitude forecasting in the past at time i. $\mathrm{LAT_i}$ is latitude at time i. $\mathrm{LONG_i}$ is longitude at time i and t is time windows. In addition, t is 24 hours in this paper. From equation (15) – (16), F_LAT, F_LONG are next latitude and longitude forecasting of tropical cyclone position respectively which are errors eliminated by self-adjustment methodology.

In ISA-CLIPER intensity phase, the model created multiple regression equation from historic tropical cyclone data which is an intensity statistical based equation (I-SBE) for tropical cyclone intensity forecasting and can be calculated as follows.

$$\mathrm{F\_MSW} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 \tag{17}$$

Where F_MSW is next maximum sustain wind (MSW) of tropical cyclone. Where β_0 to β_5 can be calculated as follows.

$$n\beta_0 + \beta_1 \sum_{i=1}^{n} x_{i,1} + \beta_2 \sum_{i=1}^{n} x_{i,2} + \ldots + \beta_5 \sum_{i=1}^{n} x_{i,5} = \sum_{i=1}^{n} y_i \tag{18}$$

$$\beta_0 \sum_{i=1}^{n} x_{i,1} + \beta_1 \sum_{i=1}^{n} x_{i,1}x_{i,1} + \beta_2 \sum_{i=1}^{n} x_{i,1}x_{i,2} + \ldots + \beta_5 \sum_{i=1}^{n} x_{i,1}x_{i,5} = \sum_{i=1}^{n} x_{i,1}y_i \tag{19}$$

$$\beta_0 \sum_{i=1}^{n} x_{i,2} + \beta_1 \sum_{i=1}^{n} x_{i,2}x_{i,1} + \beta_2 \sum_{i=1}^{n} x_{i,2}x_{i,2} + \ldots + \beta_5 \sum_{i=1}^{n} x_{i,2}x_{i,5} = \sum_{i=1}^{n} x_{i,2}y_i \tag{20}$$

$$\beta_0 \sum_{i=1}^{n} x_{i,3} + \beta_1 \sum_{i=1}^{n} x_{i,3}x_{i,1} + \beta_2 \sum_{i=1}^{n} x_{i,3}x_{i,2} + \ldots + \beta_5 \sum_{i=1}^{n} x_{i,3}x_{i,5} = \sum_{i=1}^{n} x_{i,3}y_i \tag{21}$$

$$\beta_0 \sum_{i=1}^{n} x_{i,4} + \beta_1 \sum_{i=1}^{n} x_{i,4}x_{i,1} + \beta_2 \sum_{i=1}^{n} x_{i,4}x_{i,2} + \ldots + \beta_5 \sum_{i=1}^{n} x_{i,4}x_{i,5} = \sum_{i=1}^{n} x_{i,4}y_i \tag{22}$$

$$\beta_0 \sum_{i=1}^{n} x_{i,5} + \beta_1 \sum_{i=1}^{n} x_{i,5}x_{i,1} + \beta_2 \sum_{i=1}^{n} x_{i,5}x_{i,2} + \ldots + \beta_5 \sum_{i=1}^{n} x_{i,5}x_{i,5} = \sum_{i=1}^{n} x_{i,5}y_i \tag{24}$$

From all equations above (18) – (24), β_0 to β_5 are able to solve equations by using matrices method and n is all tropical cyclone in database. Note that, x_1 to x_5 in (17) – (24) will be replaced by list of predictor variables; Julian_Date, Initial_LAT, Initial_LONG, Current_MSW, AVG12h_SPEED, respectively. Finally, calculate error elimination or I-Adjustment equation as follows.

$$\varepsilon_{\mathrm{MSW}} = [\sum_{i=1}^{t} \mathrm{F\_MSW_i} - \mathrm{MSW_i}] / t \tag{25}$$

$$\mathrm{F\_MSW} = \mathrm{F\_MSW} - \varepsilon_{\mathrm{MSW}} \tag{26}$$

Where $\varepsilon_{\mathrm{MSW}}$ is an average error of MSW in latest t time windows hours. $\mathrm{F\_MSW_i}$ is MSW forecasting in the past at time i. $\mathrm{INT_i}$ is MSW at time i. In addition, t is 24 hours in this paper.

From equation (26), F_MSW are next MSW forecasting of tropical cyclone intensity which are errors eliminated by self-adjustment methodology. Note that, intensity forecasting were divided by maximum sustain wind (MSW) into 3 classes following Thai Meteorological Department regulation i.e. Tropical Depression (TD) Less than 63 (km/hr), Tropical Cyclone (TC) 63-118 (km/hr) and Typhoon (TY) 118 or greater (km/hr).

V. Tropical Cyclone Track and Intensity Forecasting Model Performance

All methodology in this paper can be rewrite into the sequence of tropical cyclone track and intensity forecasting model which is shown in figure 7 and the performance of model was evaluated in Table IV - XII. The experiment of tropical cyclone track and intensity forecasting model was divided into 2 classes, one is training class which the result is absented in this paper due to objective of training class is only create statistical based equation and another is testing class. In training class, the model used all historic tropical cyclone data between years 2000 - 2011 (12 years or 80%) to create statistical based equation and testing class used historic tropical cyclone data between years 2012-2014 (3 years or 20% with over 78 tropical cyclones) which are unknown data to testing the ISA-CLIPER model and compared with traditional CLIPER. All tropical cyclone are within coordinate N70 - S20 and E70 - E160 or in Pacific Ocean. However, the experiments were tested both data from historic files data for accuracy test of only statistical method improvement and only extracted images data for overall model. However, intensity forecasting with extracted images data is absented in this paper due to there is only one level.

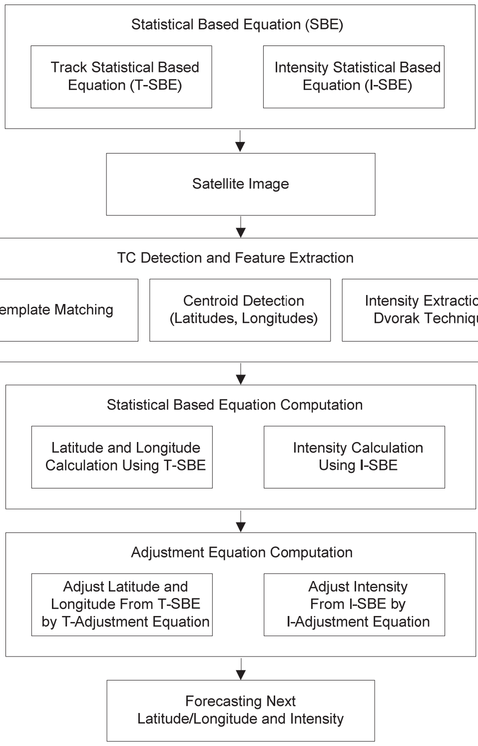


Figure 7: Tropical Cyclone Track and Intensity Forecasting Model

In the table IV - XII show the experiment results of T-CLIPER/T-SHIFOR and ISA-CLIPER forecasting with unknown tropical cyclone data between years 2012-2014. In first experiment, using historic TC data (Best track data), T-CLIPER and ISA-CLIPER gives an average 4.80 and 4.12 degrees of 6 to 24 hours forecasting errors from best track data respectively on Mercator projection map or ISA-CLIPER is lower than T-CLIPER about 14.16% as shown in table IV - VI. Furthermore, an average intensity errors of ISA-CLIPER lower than T-SHIFOR about 25.18% (km/h) as shown in table VII - IX. Note that, black solid line is historic TC best track data and blue dashed line is ISA-CLIPER track forecasting model. In addition, green/yellow/red dot in graph means TD, TC, TY intensity level forecasting respectively. Second experiment as show in table X - XII, using only maximum TC level data which were extracted from satellite images, T-CLIPER and ISA-CLIPER gives an average 2.31 and 1.92 degrees of 6 to 24 hours forecasting errors from best track data respectively on Mercator projection map or ISA-CLIPER lower than T-CLIPER about 16.88% in overall model.

TABLE IV. THE PERFORMANCE OF TROPICAL CYCLONE TRACK FORECASTING MODEL IN YEAR 2012 (24 TC)

Forecasting / Model	6 hrs.	12 hrs.	24 hrs.
T-CLIPER	3.20	4.46	6.49
ISA-CLIPER	2.63	3.88	5.90

TABLE V. THE PERFORMANCE OF TROPICAL CYCLONE TRACK FORECASTING MODEL IN YEAR 2013 (31 TC)

Forecasting / Model	6 hrs.	12 hrs.	24 hrs.
T-CLIPER	3.52	4.82	6.84
ISA-CLIPER	2.94	4.05	5.91

TABLE VI. THE PERFORMANCE OF TROPICAL CYCLONE TRACK FORECASTING MODEL IN YEAR 2014 (23 TC)

Forecasting / Model	6 hrs.	12 hrs.	24 hrs.
T-CLIPER	3.16	4.43	6.30
ISA-CLIPER	2.59	3.66	5.55

TABLE VII. THE PERFORMANCE OF TROPICAL CYCLONE INTENSITY FORECASTING MODEL IN YEAR 2012 (KM/H)

Forecasting / Model	6 hrs.	12 hrs.	24 hrs.
T-SHIFOR	8.07	8.54	13.75
ISA-CLIPER	4.31	7.27	10.70

TABLE VIII. THE PERFORMANCE OF TROPICAL CYCLONE INTENSITY FORECASTING MODEL IN YEAR 2013 (KM/H)

Forecasting / Model	6 hrs.	12 hrs.	24 hrs.
T-SHIFOR	9.69	9.23	14.66
ISA-CLIPER	5.07	7.79	12.22

TABLE IX. THE PERFORMANCE OF TROPICAL CYCLONE INTENSITY FORECASTING MODEL IN YEAR 2014 (KM/H)

Forecasting / Model	6 hrs.	12 hrs.	24 hrs.
T-SHIFOR	8.56	9.43	14.20
ISA-CLIPER	4.40	7.19	13.02

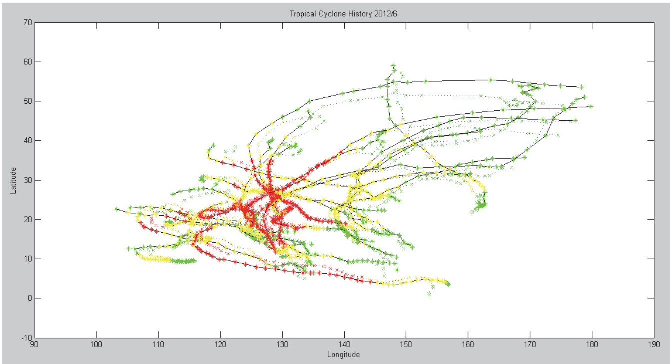


Figure 8: Example of ISA-CLIPER Forecasting Graph (Y2012 - 6Hrs).

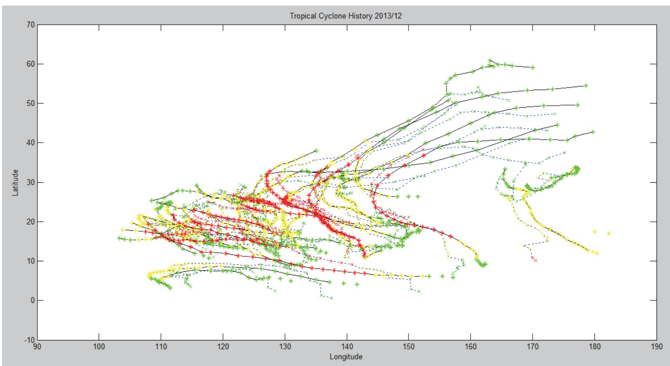


Figure 9: Example of ISA-CLIPER Forecasting Graph (Y2013 - 12Hrs).

TABLE X. THE PERFORMANCE OF TROPICAL CYCLONE TRACK FORECASTING MODEL IN YEAR 2012 WITH EXTRACTED IMAGE DATA

Forecasting / Model	6 hrs.	12 hrs.	24 hrs.
T-CLIPER	1.21	2.01	3.42
ISA-CLIPER	0.85	1.69	3.11

TABLE XI. THE PERFORMANCE OF TROPICAL CYCLONE TRACK FORECASTING MODEL IN YEAR 2013 WITH EXTRACTED IMAGE DATA

Forecasting / Model	6 hrs.	12 hrs.	24 hrs.
T-CLIPER	1.40	2.09	3.25
ISA-CLIPER	1.11	1.76	2.82

TABLE XII. THE PERFORMANCE OF TROPICAL CYCLONE TRACK FORECASTING MODEL IN YEAR 2014 WITH EXTRACTED IMAGE DATA

Forecasting / Model	6 hrs.	12 hrs.	24 hrs.
T-CLIPER	1.48	2.30	3.69
ISA-CLIPER	1.10	1.80	3.05

VI. CONCLUSION AND REMARK

This paper proposed the integrated short-range tropical cyclone track and intensity forecasting system with improvement of the traditional statistical methods by using only 11 features which were analyzed and extracted from satellite images data as input. The performance of the model gives an average of 4.12 degrees of 6 to 24 hours forecasting errors from best track data and average errors is lower than traditional methods by 14.16%. In overall model, an average errors is lower than traditional methods by 16.88% and the model in this paper also used less variable than traditional methods. Also, an average intensity errors of 6 to 24 hours is lower than traditional techniques by 25.18%. However, there are lacks of automatic tropical cyclone detection and location identification in image and leads to larger error during formative and decaying phase of cyclone due to the absence of robust pattern in the images or the spiral/eyes of tropical cyclone are not present in the cloud pattern. This is still a challenging research issue for remote sensing in automatic tropical cyclone detection and identification. In future work, the model should be experimented and improved in long-range forecasting (more than 72 hours or 3 days), as long as the model is able to predict in long-range, there are have enough time to prepare a good warning bulletin and evacuation. Decision support system in this paper can be caused of humans and properties losses decreased.

REFERENCES

[1] A.Buranasing and A.Prayote. “Storm Intensity Estimation Using Symbolic Aggregate Approximation and Artificial Neural Network.” 2014 International Computer Science and Engineering Conference (ICSEC 2014: International Track) , Khon Kaen, Thailand

[2] A.Buranasing, “Storm Intensity Prediction using an Artificial Neural Network.” International Conference on Southeast Asian Weather and Climate 2013 (ICSA-WC2013), Chiang Mai, Thailand

[3] A.Buranasing and A.Prayote. “Tropical Storm Disaster Management in Thailand.” The National Geo-Informatics and Space Technology Conference 2014 (GEOINFOTECH 2014), Bangkok, Thailand

[4] Thai Meteorological Department. Weather Forecasting [Online] Available from URL: http://www.tmd.go.th/en (accessed May 17, 2014).

[5] Smith Thamsaroch, “Natural Disaster in Thailand,” Printing House of Thai Meteorological Department, 1991

[6] Rita Kovordányi and Chandan Roy, “Cyclone Track Forecasting Based on Satellite Images Using Artificial Neural Networks.” ISPRS Journal of Photogrammetry and Remote Sensing, November 2009.

[7] Butsakorn Kongaed and Dusadee Sukawat, "A Parametric Tropical Cyclone Wind Model for Thailand." Department of Mathematics, KMUTT, 2005

[8] Climatological Center, Meteorological Development Bureau, "Tropical Cyclones in Thailand Historical Data 1951-2010", Thai Meteorological Department

[9] Typhoon Harriet [Online] Available from URL: https://en.wikipedia.org/wiki/1962_Pacific_typhoon_season#Tropical_Storm_Harriet (accessed July 14, 2015).

[10] Typhoon Gay [Online] Available from URL: https://en.wikipedia.org/wiki/Typhoon_Gay_(1989) (accessed July 14, 2015).

[11] Typhoon Linda [Online] Available from URL: https://en.wikipedia.org/wiki/Tropical_Storm_Linda_(1997) (accessed July 14, 2015).

[12] Richard Pasch, Jessica Schauer Clark, et al. “Technical Summary of the National Hurricane Center Track and Intensity Models.” National Oceanic and Atmospheric Administration (NOAA).

[13] Prawit Jampanya, "Tropical Storm Forecasting Technique in Thailand," ACTS Workshop, Taiwan, 6-7 June 2013

[14] The Weather Research & Forecasting Model. Weather Forecasting [Online] Available from URL: http://www.wrf-model.org (accessed accessed July 14, 2015

[15] Sugunyanee Yavinchan. “Tropical Storm Track Prediction for Thailand by a High Resolution Numerical Weather Prediction Model” The Meteorological Department, Weather Forecast Bureau, Bangkok, Thailand

[16] RSMC Tokyo-Typhoon Center [Online] Available from URL: http://www.jma.go.jp/jma/jma-eng/jma-center/rsmc-hp-pub-eg/trackarchives.html (accessed July 14, 2015).

[17] Meteorological Satellites - Japan Meteorological Agency (JMA) [Online] Available from URL: http://www.jma.go.jp/jma/jma-eng/satellite/index.html (accessed July 14, 2015).

[18] The history of meteorological satellites at JMA [Online] Available from URL: http://www.jma.go.jp/jma/jma-eng/satellite/introduction/history.html (accessed July 14, 2015).

[19] R. R. Kelkar. "Satellite Meteorology." Department of Atmospheric and Space Sciences University of Pune, BS Publications 2007

[20] Paul M. Mather. "Computer Processing of Remotely-Sensed Images." A John Wiley & Sons, Ltd., Publication, Fourth Edition 2011

[21] Ján Kaňák. "Overview of the IR channels and their applications." EUMeTrain, 14 June 2011

[22] Martin setvak. "Enhancement of the IR imagery." EUMeTrain 14 June 2011

[23] Neeru Jaiswal and C.M.Kishtawal. “Automatic Determination of Center of Tropical Cyclone in Satellite-Generated IR Images.” IEEE Geoscience and Remote Sensing Letters, May 2011.

[24] Neeru Jaiswal and C. M. Kishtawal. “Objective Detection of Center of Tropical Cyclone in Remotely Sensed Infrared Images.” IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, April 2013

[25] Q.P. Zhang, L.L. Lai and W.C. Sun. “Intelligent Location of Tropical Cyclone Center.” Proceedings of the Fourth International Conference on Machine Learning and Cybernetics, August 2005.

[26] Wong Ka Yan, Yip Chi Lap, Li Ping Wah and Tsang Wai Wan. “Automatic Template Matching Method for Tropical Cyclone Eye Fix.” The 17th International Conference on Pattern Recognition (ICPR’04)

[27] Timothy L. Olander and Christopher S. Velden. “ The Advanced Dvorak Technique: Continued Development of an Objective Scheme to Estimate Tropical Cyclone Intensity Using Geostationary Infrared Satellite Imagery.” American Meteorological Society 2007.

[28] Yiming Xu, Charles J.Neumann. “A Statistical Model for the prediction of Western North Pacific Tropical Cyclone Motion.”

[29] John A. Knaff. “Statistical, 5-Day Tropical Cyclone Intensity Forecasts Derived from Climatology and Persistence.” American Meteorological Society 2003.

[30] George W. Collins. “Fundamental Numerical Methods and Data Analysis.” 2003