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Application of Remote Sensing for Tropical Cyclone Track Forecasting Based on Statistical Methods

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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 injuries to humans as well as damages or losses of valuable goods or properties, such as buildings, communication systems, agricultural land, etc. To mitigate severe impacts, the accuracy of track forecasting model is world-widely developed and improved. The accuracy of tropical cyclone track forecasting is very important for risk area evaluation that will be affected by the tropical cyclone due to evacuation in time can reduce both human and property losses. However, Thailand has insufficient meteorological data to apply the numerical weather prediction models. In fact, the forecasting in Thailand is done manually. This makes the forecasting unreliable and time consuming, which leaves not enough time to prepare a warning bulletin. To address these problems, this paper proposes an integrated short-range tropical cyclone track forecasting system which analyzes tropical cyclone tracks from available satellite images. The performance of the model is satisfactory, giving an average of 4.92 degrees of 6 hours, 12 hours, 24 hours, 48 hours and 72 hours forecasting errors from best track data and the average error is lower than traditional techniques by 25.45% on Mercator projection map.**

Keywords— natural disasterss; tropical cyclone track forecasting; image processing; remote sensing; decision support system.

I. INTRODUCTION

Today, the environment on earth has been rapidly changed and causes of severe natural disasters such as various kinds of storms, volcano eruptions, earthquakes, tsunamis, floods, droughts, fires, wildfires, landslides, mudslides, blizzard, avalanches, human epidemics and animal diseases, etc. These natural disasters can cause of death or injuries to humans, damages or losses to buildings, communication systems, agricultural land, forest region, natural environment, economy, etc. Among these, 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, storm surge, flooding, etc. Evidently, 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 a storm system characterized by a low pressure center and numerous thunderstorms that produce strong winds and flooding rain. These systems form over the tropical oceans between latitude 23.5 degree North and South except the South-Atlantic Ocean region. 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, the inaccuracy of tropical cyclone forecasting, warning system is quite delayed and could not evacuated in time, these are causes of many death or injury of humans, damage or loss of valuable good and national economic.

So far, tropical cyclone forecasting can be classified into three main classes of forecasting models. First, statistical models which base 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. The third is models that use elements of both statistical and dynamical approaches, which are called statistical-dynamical models. [12]

In Thailand, Thai Meteorological Department (TMD) uses two primary techniques for tropical cyclone forecasting in operation. First, the traditional statistical methods which is a conventional method is used in TMD [13]. Although, this technique gives a satisfactory results, but it takes much time because the officer has to calculate and forecast manually. This causes unreliability and gives not enough time 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.

To provide meteorological data to the NWP model is a high volume in various measure equipment investment/maintenance and weather observation. Although recently, Arthit Buranasing et al. [16] developed and improved short-range statistical

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method which is economical model but short-range forecasting with 6 to 24 hours is not enough time for warning bulletin and evacuation. On the other hand, this paper suggests an alternative solution for tropical cyclone track forecasting which also is an economical and gives satisfactory up to 72 hours (3 days) forecasting result and the proposed technique only uses satellite images data for analysis. This paper is organized into the following sections: Section II satellite image and historic tropical cyclone data. Automatic tropical cyclone detection and location identification model in section III. Tropical cyclone track forecasting model with improvement of traditional statistical methods in section IV. Tropical cyclone track forecasting model performance in section V and a conclusion and remark is drawn in section VI.

II. Satellite Image and Historic Tropical Cyclone Data

The experiments in this paper used two types of data, i.e., satellite image data from Japan Meteorological Agency's Satellite (GMS, MTSAT-1R, and MTSAT-2 Series) and historic tropical cyclone data or best track data were derived from RSMC Tokyo-Typhoon Center.

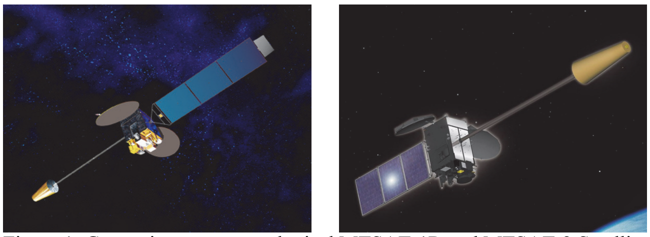

Figure 1: Geostationary meteorological MTSAT-1R and MTSAT-2 Satellite

Japan Meteorological Agency's Satellite or JMA's Satellite (figure 1) 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 35,800 km above the equator on 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. The image format type is 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

RSMC Tokyo-Typhoon Center provides historic tropical cyclone data or best track data [19] 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 4. 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.

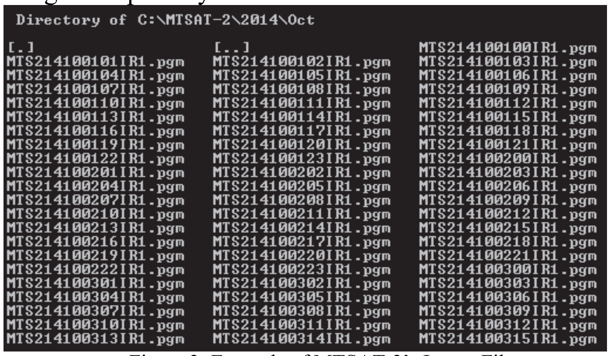

Figure 2: Example of MTSAT-2's Image Files

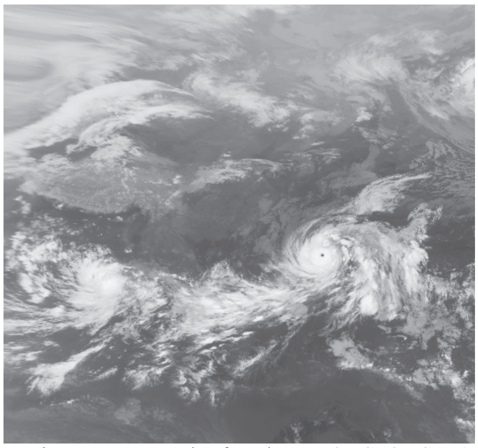

Figure 3: Environments Example of Typhoon VONGFONG IR1 Image by MTSAT-2 on 8 October 2014

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66666 1422  048 0024 1422 0 6    HAGUPIT    20150109
14120112 002 3 055 1507  994    040    00000 0000 90120 0120
14120118 002 3 059 1489  990    045    00000 0000 90120 0120
14120200 002 4 059 1469  985    050    00000 0000 90180 0180
14120206 002 4 061 1451  980    055    90050 0050 90180 0180
14120212 002 4 062 1435  975    060    90050 0050 90180 0180
14120218 002 5 066 1421  965    070    90050 0050 90180 0180
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Figure 4: Example of tropical cyclone historic data

III. Automatic Tropical Cyclone Detection and Location Identification Model

In satellite remote sensing, each channel or band is used for different objective of weather observation. For example in table II and more detail at [20,21].

TABLE II. Wavelength and Primatry Use in Remote Sensing

Channel/Band	Range: Wavelength (micrometer)	Primary Use
4	0.545–0.565	Green vegetation
16	0.862–0.877	Aerosol properties
27	6.535-6.895	Mid troposphere humidity
31	10.780-11.280	Cloud temperature, Surface temperature
32	11.770-12.270	Cloud height, forest fires and volcanoes, surface temperature

Japan Meteorological Agency's Satellite contains 5 channels and satellite image data from IR1 (10.3 - 11.3 micrometer) are suitable and used for detection and observation tropical cyclone due to cloud structures of tropical cyclone is observable by cloud temperatures in images [22,23]. In our methodology, satellite image data from Japan Meteorological Agency's Satellite in 6 hour interval is used to extract the center of the tropical cyclone as shown in figure 6. Each column includes the number of tropical cyclone in each year, year, month, date, time of image taken, latitude and longitude respectively. To get the storm latitude and longitude position, the model for detection and location identification [24,25,26] is applied, but the most simple traditionally in image processing theory is model of Wong Ka Yan, et al. as shown in figure 5 and more detail at [27] which was applied in this work for detection and extraction location of tropical cyclone.

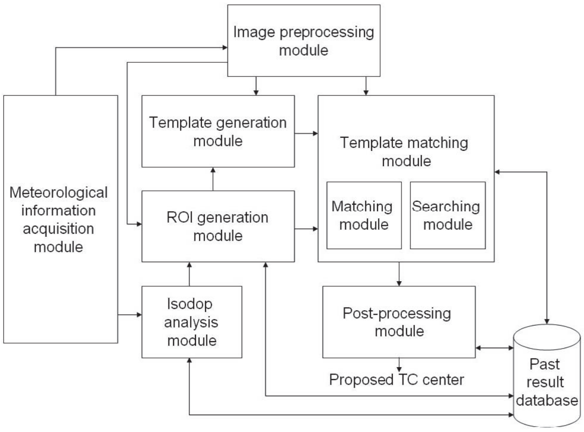

Figure 5: Wong Ka Yan, et al. Model [27]

However, most of automatic tropical cyclone location identification leads to high errors 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. The error of location identification often occur during formative and decaying phase because, at these phases, it is difficult to locate the cyclone's eyes in the satellite images, 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 dataset.

1	2	3	4	5	6	7
1	10	3	26	6	17.6000	131.8000
1	10	3	26	12	17.7000	132.1000
2	10	7	11	12	13.9000	132.6000
2	10	7	11	18	14.2000	131.8000
2	10	7	12	0	14.3000	130.3000
2	10	7	12	6	14.1000	129.3000
2	10	7	12	12	14.3000	127.7000
2	10	7	12	18	14.3000	126.5000
2	10	7	13	0	14.3000	124.8000
2	10	7	13	6	14.4000	123.5000
2	10	7	13	12	14.5000	122.3000
2	10	7	13	18	14.3000	120.9000

Figure 6: Sample's Features Data Extraction from Satellite Image

IV. Tropical Cyclone Track Forecasting Model with Improvement of Traditional 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 and longitude over past 12hrs, latitude and longitude over past 24hrs, Avg. Speed over past 12hrs, and 24hrs, (current) maximum sustain wind and initial storm intensity. CLIPER uses multiple regression techniques and is capable of forecasting up to 72 hours in advance. However, traditional CLIPER technique (called, T-CLIPER or CLIPER 5) is only based on historic data and gives an unsatisfactory result when it is used for the forecast more than 24 hours. Recently, Arthit Buranasing et al. [16] developed and improved short-range tropical cyclone track forecasting with statistical method (ISA-CLIPER). This techniques give a satisfied result and the average error lower than T-CLIPER about 14.16% in 6 to 24 hours forecasting, but there are still have a high error when forecast up to 72 hours. Herein, the traditional CLIPER model is modified to adapt to errors in forecasting. It is called Self-Adjustment Regression CLIPER or SAR-CLIPER. SAR-CLIPER uses only 9 features were extracted from satellite images in section III as shown in Table III.

TABLE III. List of Predictor Variables

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

In SAR-CLIPER, the model created multiple regression equation from historic tropical cyclone data which was a statistical based equation (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 statistical based equation as follows.

$$F\_LAT = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_i x_i + \ldots + \beta_9 x_9 \quad (1)$$

$$F\_LONG = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_i x_i + \ldots + \beta_9 x_9 \quad (2)$$

Where F_LAT is next latitude tropical cyclone position. F_LONG is next longitude tropical cyclone position. Note that, x_1 to x_9 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. Where β_0 to β_9 in (1) and (2) can be separately calculated as follows.

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

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

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

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

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

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

$$\beta_0 \sum_{i=1}^{n} x_{i,6} + \beta_1 \sum_{i=1}^{n} x_{i,6}x_{i,1} + \beta_2 \sum_{i=1}^{n} x_{i,6}x_{i,2} + \dots + \beta_9 \sum_{i=1}^{n} x_{i,6}x_{i,9} = \sum_{i=1}^{n} x_{i,6}y_i \quad (9)$$

$$\beta_0 \sum_{i=1}^{n} x_{i,7} + \beta_1 \sum_{i=1}^{n} x_{i,7}x_{i,1} + \beta_2 \sum_{i=1}^{n} x_{i,7}x_{i,2} + \dots + \beta_9 \sum_{i=1}^{n} x_{i,7}x_{i,9} = \sum_{i=1}^{n} x_{i,7}y_i \quad (10)$$

$$\beta_0 \sum_{i=1}^{n} x_{i,8} + \beta_1 \sum_{i=1}^{n} x_{i,8}x_{i,1} + \beta_2 \sum_{i=1}^{n} x_{i,8}x_{i,2} + \dots + \beta_9 \sum_{i=1}^{n} x_{i,8}x_{i,9} = \sum_{i=1}^{n} x_{i,8}y_i \quad (11)$$

$$\beta_0 \sum_{i=1}^{n} x_{i,9} + \beta_1 \sum_{i=1}^{n} x_{i,9}x_{i,1} + \beta_2 \sum_{i=1}^{n} x_{i,9}x_{i,2} + \dots + \beta_9 \sum_{i=1}^{n} x_{i,9}x_{i,9} = \sum_{i=1}^{n} x_{i,9}y_i \quad (12)$$

From all equations above (3) – (12), β_0 to β_9 are able to solve equations by using matrices method [29] and n is all tropical cyclone in database. Second, error elimination by using Adjustment Regression Equation (ARE) which are calculated as follows.

$$\mathrm{Y_i} = \mathrm{F\_LAT_i} - \mathrm{LAT_i} \quad (13)$$

$$\mathrm{X_i} = \mathrm{F\_LONG_i} - \mathrm{LONG_i} \quad (14)$$

Where Y_i is an error on latitude at time i in latest t time windows hours. X_i is an error on longitude at time i in latest t time windows hours. F_LAT_i is latitude forecasting in the past at time i. F_LONG_i is longitude forecasting in the past at time i. LAT_i is latitude at time i. $LONG_i$ is longitude at time i and t is time windows. In addition, t is 36 hours in this paper. Next, error regression equation are calculated as follows.

$$\varphi_y = \left(\mathrm{t}\sum_{i=1}^{t} \mathrm{iY_i} - \sum_{i=1}^{t} \mathrm{i} \sum_{i=1}^{t} \mathrm{Y_i}\right) \Big/ \left(\mathrm{t}\sum_{i=1}^{t} \mathrm{i}^2 - \left(\sum_{i=1}^{t} \mathrm{i}\right)^2\right) \quad (15)$$

$$\varphi_x = \left(\mathrm{t}\sum_{i=1}^{t} \mathrm{iX_i} - \sum_{i=1}^{t} \mathrm{i} \sum_{i=1}^{t} \mathrm{X_i}\right) \Big/ \left(\mathrm{t}\sum_{i=1}^{t} \mathrm{i}^2 - \left(\sum_{i=1}^{t} \mathrm{i}\right)^2\right) \quad (16)$$

$$\alpha_y = \left(\sum_{i=1}^{t} \mathrm{Y_i} \Big/ \mathrm{t}\right) - \left(\varphi_y \sum_{i=1}^{t} \mathrm{i} \Big/ \mathrm{t}\right) \quad (17)$$

$$\alpha_x = \left(\sum_{i=1}^{t} \mathrm{Y_i} \Big/ \mathrm{t}\right) - \left(\varphi_x \sum_{i=1}^{t} \mathrm{i} \Big/ \mathrm{t}\right) \quad (18)$$

Where φ_y is a regression coefficient of latitude. φ_x is regression coefficient of longitude. α_y is a regression constant of latitude. α_x is a regression constant of longitude. Then, error prediction are calculated as follows.

$$\varepsilon_y = \alpha_y + \varphi_y(t/2) \quad (19)$$

$$\varepsilon_x = \alpha_x + \varphi_x(t/2) \quad (20)$$

Where ε_y is an error prediction on latitude at time t/2. ε_x is an error prediction on longitude at time t/2. Finally, error elimination are calculated by

$$\mathrm{F\_LAT} = \mathrm{F\_LAT} - \varepsilon_y \quad (21)$$

$$\mathrm{F\_LONG} = \mathrm{F\_LONG} - \varepsilon_x \quad (22)$$

From equation (21) – (22), F_LAT, F_LONG are next latitude and longitude forecasting of tropical cyclone position respectively which are errors eliminated by self-adjustment regression methodology.

V. TROPICAL CYCLONE TRACK FORECASTING MODEL PERFORMANCE

All methodology in this paper can be drawn into the flowchart of tropical cyclone track forecasting model which is shown in figure 7 and the performance of model was evaluated in Table IV - IX. The experiment of tropical cyclone track 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 (SBE) 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 (SBE) 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 SAR-CLIPER model and compared with traditional CLIPER and ISA-CLIPER. All tropical cyclone are within coordinate N70 - S20 and E70 - E160 or in Pacific Ocean. The experiments were tested and forecasted in 6 hours, 12 hours, 24 hours, 48 hours and 72 hours. 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.

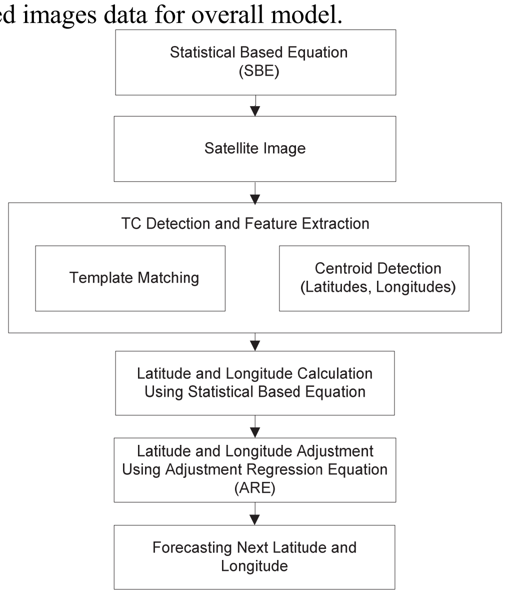

Figure 7: Tropical Cyclone Track Forecasting Model

In the table IV - IX show the experiment results of T-CLIPER, ISA-CLIPER and SAR-CLIPER forecasting with unknown tropical cyclone data between years 2012-2014. In first experiment, using historic TC data (Best track data), T-CLIPER, ISA-CLIPER and SAR-CLIPER gives an average 6.60, 5.77 and 4.92 degrees of 6 to 72 hours forecasting errors from best track data respectively on Mercator projection map and average errors of SAR-CLIPER is lower than T-CLIPER and ISA-CLIPER about 25.45% and 14.73% respectively.

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

Forecasting / Model	6 hrs	12 hrs	24 hrs	48 hrs	72 hrs
T-CLIPER	3.20	4.46	6.49	9.00	10.07
ISA-CLIPER	2.63	3.88	5.90	7.60	9.04
SAR-CLIPER	2.51	3.34	4.72	6.78	7.99

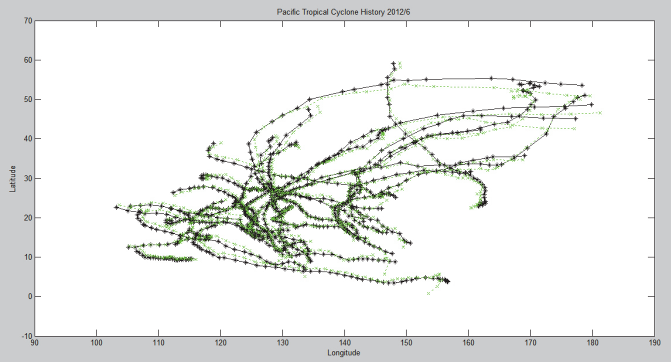

Figure 8: Graph of SAR-CLIPER Forecasting (Y2012 – 6Hrs).

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

Model \ Forecasting	6 hrs	12 hrs	24 hrs	48 hrs	72 hrs
T-CLIPER	3.52	4.82	6.84	9.31	9.93
ISA-CLIPER	2.94	4.05	5.91	7.61	8.96
SAR-CLIPER	2.72	3.48	4.69	6.46	7.31

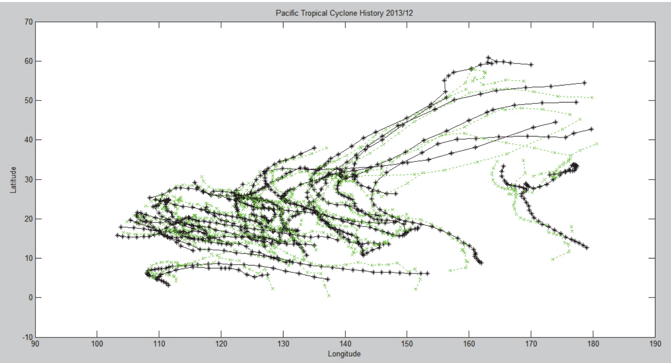

Figure 9: Graph of SAR-CLIPER Forecasting (Y2013 – 12Hrs).

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

Model \ Forecasting	6 hrs	12 hrs	24 hrs	48 hrs	72 hrs
T-CLIPER	3.16	4.43	6.30	8.44	9.03
ISA-CLIPER	2.59	3.66	5.55	7.51	8.73
SAR-CLIPER	2.43	3.22	4.56	6.35	7.34

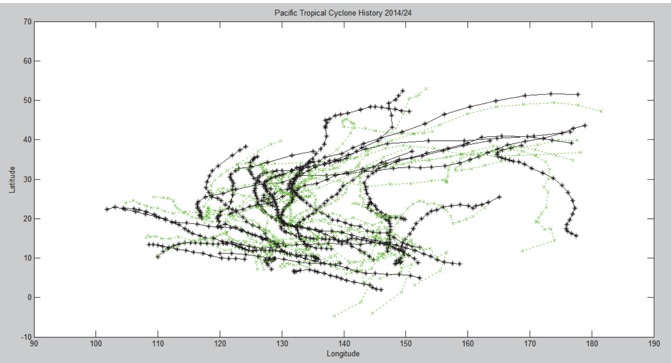

Figure 10: Graph of SAR-CLIPER Forecasting (Y2014 - 24Hrs).

Second experiment, using only maximum TC level data which were extracted from satellite images in section III, T-CLIPER, ISA-CLIPER and SAR-CLIPER gives an average 3.68, 3.18 and 2.78 degrees of 6 to 72 hours forecasting errors from best track data respectively on Mercator projection map and average errors of SAR-CLIPER is lower than T-CLIPER and ISA_CLIPER about 24.45% and 12.57% respectively in overall model. Note that, black solid line is historic TC best track data and green dashed line is SAR-CLIPER forecasting model.

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

Model \ Forecasting	6 hrs	12 hrs	24 hrs	48 hrs	72 hrs
T-CLIPER	1.21	2.01	3.42	5.47	6.62
ISA-CLIPER	0.85	1.69	3.11	4.52	5.58
SAR-CLIPER	0.65	1.09	2.50	4.24	5.53

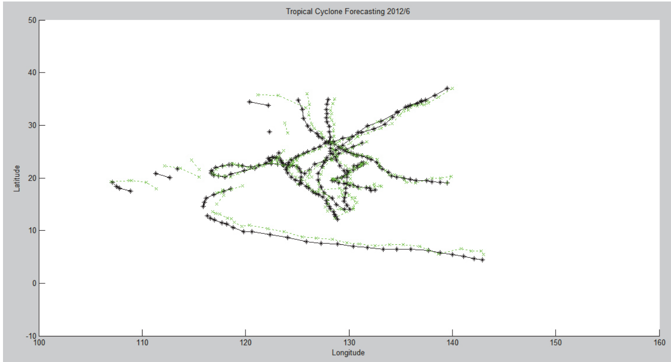

Figure 11: Graph of SAR-CLIPER Forecasting with Only Maximum Level of TC from Extracted Image Data (Y2012 - 6Hrs).

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

Model \ Forecasting	6 hrs	12 hrs	24 hrs	48 hrs	72 hrs
T-CLIPER	1.40	2.09	3.25	4.97	5.63
ISA-CLIPER	1.11	1.76	2.82	4.10	5.59
SAR-CLIPER	0.97	1.37	2.45	3.95	4.74

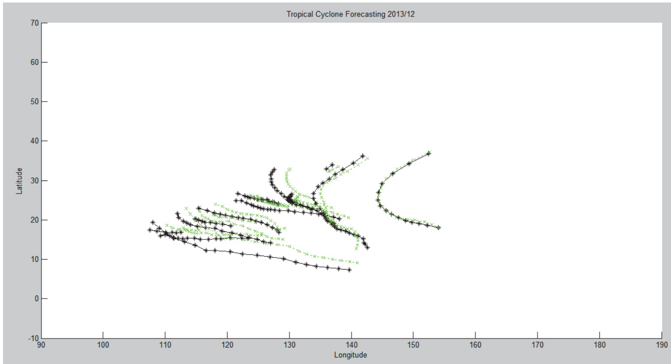

Figure 12: Graph of SAR-CLIPER Forecasting with Only Maximum Level of TC from Extracted Image Data (Y2013 - 12Hrs).

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

Model \ Forecasting	6 hrs	12 hrs	24 hrs	48 hrs	72 hrs
T-CLIPER	1.48	2.30	3.69	5.54	6.13
ISA-CLIPER	1.10	1.80	3.05	4.65	6.05
SAR-CLIPER	0.83	1.28	2.68	4.19	5.27

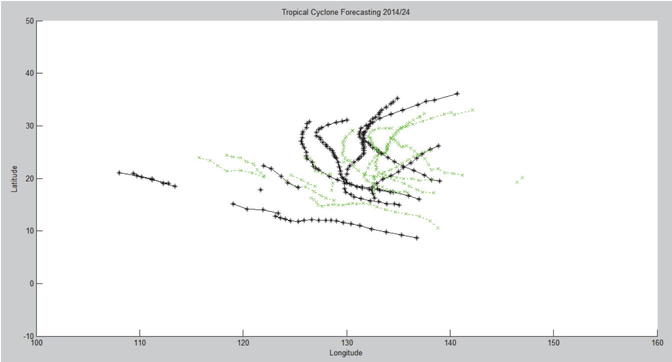

Figure 13: Graph of SAR-CLIPER Forecasting with Only Maximum Level of TC from Extracted Image Data (Y2014 - 24Hrs).

VI. Conclusion and Remark

This paper proposed the integrated short-range tropical cyclone track forecasting system with improvement of the traditional statistical methods by using only 9 features which were extracted from satellite images data as input. The performance of the model gives an average 4.92 degrees of 6 to 72 hours forecasting errors from best track data and average errors is lower than traditional methods about 25.45% on Mercator projection map in overall model and the model in this paper also used less variable than traditional methods. However, there are high errors of automatic tropical cyclone detection and location identification in image 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 challenging research for satellite remote sensing in automatic tropical cyclone detection and identification. In future work, the model should include intensity forecasting in the model and should be experimented and improved in long-range track and intensity forecasting (more than 72 hours or 3 days), as long as the model is able to forecast in long-range, there are have enough time to prepare a warning bulletin and evacuation. This decision support system can be caused of humans and properties losses decreased.

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