Enhancing the Quality of Typhoon Image Database Using NOAA AVHRR Data Received in Thailand

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Abstract

The Japanese geostationary meteorological satellite GMS-5, or also known as ”Himawari,” is positioned at 140°E above the equator, and serves as a powerful tool for monitoring typhoons on the Pacific Ocean. This satellite is best suited for the monitoring of typhoons because of frequent observation, wide coverage, and fixed scan range. However, the degradation of effective resolution due to earth curvature arises as a limitation to the monitoring of typhoons in South East Asia. To improve the quality of typhoon imagery over those areas, here we propose to solve this problem by means of combining GMS satellite data with NOAA polar orbiting satellite data, in particular those received at Asian Institute of Technology (AIT), Thailand. We compare the characteristics of satellite imagery from those two satellites with an example, and demonstrates ideas on the comprehensive collection of typhoon imagery.

Keywords: Typhoon Image Database, Typhoon Analysis, Geostationary Satellite, Polar Orbiting Satellite, South East Asia

> *”If there is a hurricane, you always see the signs of it in the sky for days ahead, if you are at sea.” — Ernest Hemingway, ”The Old Man and the Sea”, 1952*

1 Introduction

Typhoon is a regional term given to mature tropical cyclones that originate in the western north pacific ocean [1]. Typhoons are basically the same meteorological phenomenon with hurricanes in the Atlantic Ocean and the east Pacific Ocean, or cyclones in the Indian Ocean and in Oceania; however, among them, typhoons are known to be the most active tropical cyclones. The ”cradle” of typhoons appears to be off the coast of Philippines as illustrated in Figure 1. In particular, the grid $(10°N, 120°E)$ – $(20°N, 130°E)$ has seen most typhoons, as many as 433 typhoons among 1320 typhoons developed from year 1951 through 1999. This means that nearly one thirds of the typhoons has ever entered into this grid. If we are also reminded of the fact that very strong typhoons, or *super-typhoons*, are often found in this area of the Pacific Ocean, we may assume that the most dangerous country to typhoon attack may be Philippines[1].

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[1] In terms of country-based statistics, however, China suffers from more landfalls than all other countries in the world.

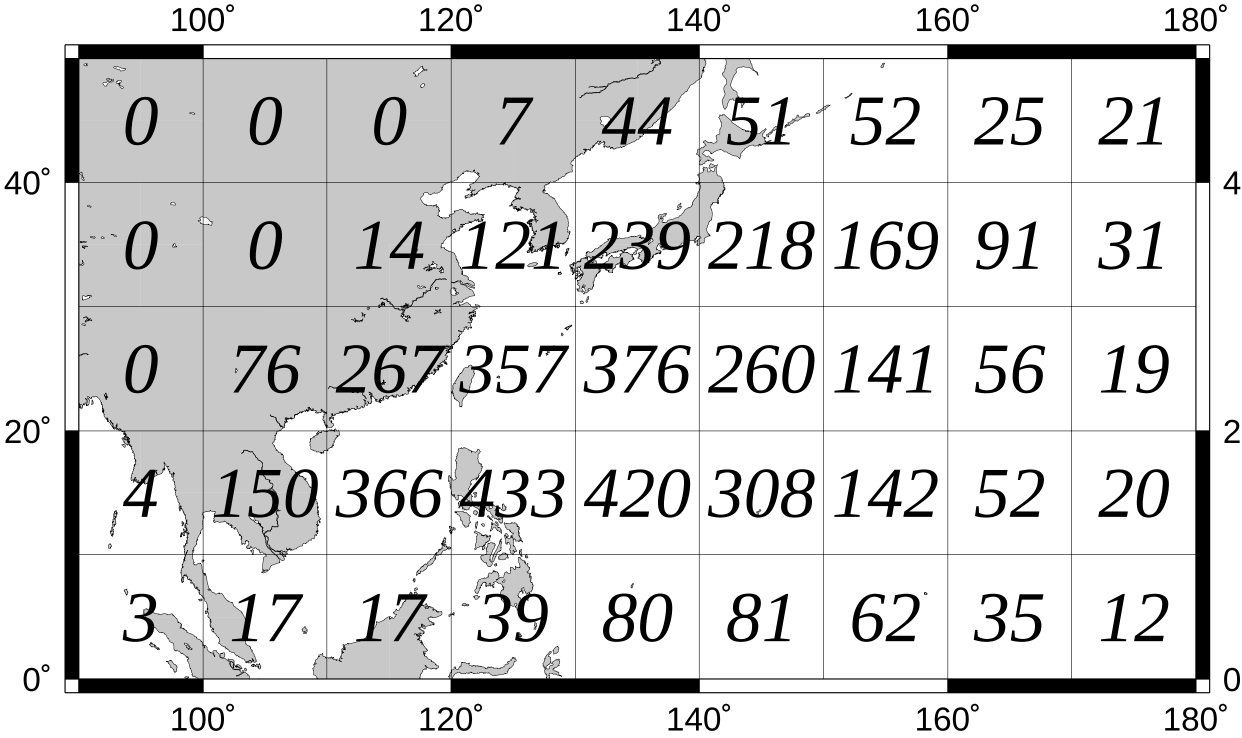

Figure 1: Number of typhoons entered into each grid. Total number of typhoons formed in the period from 1951 through 1999 is 1320. One typhoon is counted only once in each grid, but may be counted in multiple grids.

Among 27 typhoons formed in a year on average, typhoons moving towards north bring approximate landfall frequency of three times a year over the mainland Japan. However, the regions we will focus on in this paper are not Japan but South China Sea and South East Asia. These regions are almost as frequently attacked as Philippine region; the grid $(10°N, 110°E)$ – $(20°N, 120°E)$ has seen 366 typhoons or as many as 28% of typhoons formed in these 49 years. After passing through this grid, more typhoons head towards north to attack the southern part of China, but some of them keep going west towards such countries as Vietnam, Malaysia and Thailand. Although not many of them are very strong typhoons, they usually bring strong winds, heavy rainfall, and tidal waves, causing devastating destruction on people's daily lives and the wide range of industry; for example, agriculture may be the most vulnerable industry against typhoons in South East Asian countries. Therefore, the analysis and prediction of typhoons is an important subject of research [2, 3, 4].

This paper is organized as follows. Firstly, Section 2 describes various aspects of a typhoon such as disasters caused by typhoons, typhoon forecast and our approaches to these problems. Then Section 3 discuss some design considerations on making typhoon database. The next section, Section 4, describes the specific challenge of this paper for enhancing the quality of typhoon imagery by combining two types of satellite data, geostationary satellites and polar orbiting satellites. Section 5 moreover discusses network infrastructure that supports the acquisition and exchange of satellite imagery over the Internet, and finally Section 6 concludes the paper.

2 Various Aspects of a Typhoon

2.1 Disasters Caused by a Typhoon

Typhoons are the source of many types of devastating disaster. Representative sources of disaster can be listed as follows:

Strong Winds By definition, typhoons come with strong winds. On the land, weak buildings and houses are destroyed by the strong winds, while on the sea, the strong winds make big waves, leading to shipwreck with many victims[2].

Heavy Rainfall Typhoons also bring heavy rainfall, leading to floods in low lands and landslides in mountainous areas. Also some industry, in particular agriculture (rice crop, etc.) in South East Asia, are severely affected by floods.

Tidal Waves Tidal waves are caused by the mixed influence of strong winds and low pressure. Tidal waves sometimes cause extraordinary devastation on low lands along the coast, such as in Bangladesh.

These disasters, however, can be prevented or reduced with an early typhoon warning system that submits advice on taking evacuation procedures or special measures in advance. To submit these warnings in a swift manner, the accurate forecast of typhoons is a fatal issue.

2.2 Typhoon Forecast

Unfortunately, typhoon forecast has not yet reached to mature level. One fundamental reason is the chaotic nature of the atmosphere – the deficiency of observation stations in the middle of the ocean leads to unreliable estimation of initial conditions for numerical weather prediction models. Three main issues in typhoon forecasting can be listed as 1) cyclogenesis forecast, 2) intensity forecast, and 3) track forecast. The difficulty of those forecast differs from case to case. For example, Emanuel [6] remarks on intensity forecast as follows:

> Forecasters claim little skill in predicting the intensity of hurricanes beyond simple extrapolation and climatological experience. For many hurricanes, extrapolation is good enough because they strengthen or weaken slowly. However, in some situation, a phenomenon known as 'rapid deepening' occurs – the central, sea-level pressure fell suddenly as winds increased.

So, simple extrapolation is usually enough for the forecast of typhoons. However, some cases such as rapid deepening are far more important than cases when simple extrapolation is enough, because this is when disasters happen. Here a question arises: how can we tell such rare cases by discovering some (hidden) signs from the typhoon cloud pattern evident on satellite imagery?

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[2] *The Perfect Storm*[5] and its recent movie by Warner Brothers Pictures describes shipwreck happened on the Atlantic Ocean caused by an unexpectedly intensified hurricane.

2.3 Informatics-based Approach

This question is difficult to answer directly; however, regarding the intensity estimation of tropical cyclones, there is a standard technique established by Dvorak [7, 8]. Satellite imagery has been the most powerful data source since the launch of meteorological satellites in 1960s, and from experiences of satellite image interpretation that had been accumulated from the epoch, Dvorak developed a technique for typhoon analysis which is now utilized operationally by tropical analysis organizations around the world. This technique basically relies on the image pattern recognition of satellite observations along with analyst interpretation of empirically-based rules, regarding the vigor and organization of convection surrounding the storm center [9]. Dvorak maintains that it is the pattern formed by the clouds of a tropical cyclone that is related to the cyclone's intensity and not the amount of clouds in the pattern [8]. Hence research on ”cloud pattern”, or pattern recognition, plays a vital role in typhoon analysis. However, the reliability of current technique depends on human perception of experts, namely subjective judgment of the cloud pattern, and is not based solely on rigorous theoretical foundations.

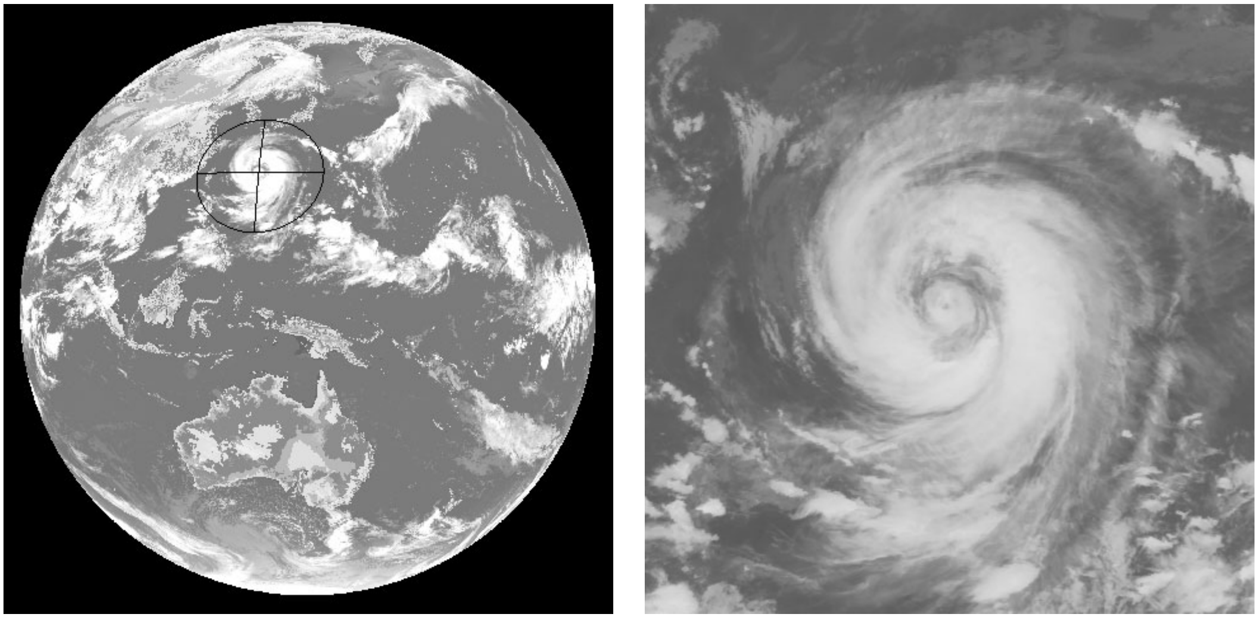
In this respect, we propose that, in addition to meteorology-based approach, informatics-based approach can contribute to this problem with novel solutions, since informatics has a long history about dealing with this kind of problems. Related research fields include image pattern recognition, computer vision, computer graphics, artificial intelligence, knowledge discovery & data mining, information retrieval, database systems, network systems, and so on. We also consider that, in informatics-based approach, the most important and basic infrastructure is the collection of typhoon related data such as typhoon imagery and typhoon track records. By collecting those datasets with keeping its quality at high level, we will construct the comprehensive collection of typhoon data.

3 Typhoon Database

3.1 Best Track

The basic information in typhoon database is the center location of a typhoon, because it is the representative point which most of typhoon analysis techniques depend on. When the eye of a typhoon can be observed in a clear form, the tracking of a typhoon is simple; however even professionals have trouble with determining typhoon center when typhoon clouds take an irregular form. Thus the real-time determination of the typhoon center is laborious and hard to automate; however, for off-line determination, we have very useful dataset called ”Best Track.”

For all the typhoons after 1951, the official record of typhoons are compiled by the Japan Meteorological Agency (JMA) as the best track dataset. This dataset contains records such as center location, central barometric pressure, and maximum wind speed for every three to six hours. Those data are determined by experts after investigating the life cycle of the typhoon with support from additional meteorological data. Hence we can rely on the quality of the data and regard them as a kind of ground truth data. Although the automatic determination of the typhoon center deserves another challenge, as far as off-line typhoon analysis is concerned, the usage of best track dataset allows us to omit one laborious task from analysis procedures and concentrate solely on the analysis of cloud pattern.



(a) Eulerian Point of View

(b) Lagrangian Point of View

Figure 2: Two viewpoints associated with the typhoon. Those images are produced from the infrared image (IR1) of Typhoon 9713 on 1000 UTC August 16, 1997. GMS observes the earth in the form of (a), and we extract regions around the typhoon to make a typhoon imagery. The diameter of the black circle on (a) is 2,500 km, which we define as the size of typhoon cloud pattern. The region of this diameter is extracted from the original satellite image to make a typhoon imagery represented by (b). Note that the black circle captures almost entire cloud pattern of this relatively huge typhoon. The approximate measurements are: the central barometric pressure of 945 hectopascals and the maximum wind speed of 85 knots (about 40 meters/second).

3.2 Selection of Viewpoints

The viewpoint of the typhoon imagery is unique from the conventional presentation of meteorological imagery. Borrowing a frame of reference from the field of flow dynamics, the typhoon imagery we make in this research can be characterized as ”Lagrangian point of view.” This point of view focuses on the time evolution of a particular mass or object over a specified time period. In typhoon imagery, we also use a coordinate system that moves along the typhoon with the constraint that the center of the image always coincides with the center of the typhoon. In this manner, we can separate the evolution of typhoon cloud pattern from the global movement of typhoon cloud system, of which the former is our main concern.

The counterpart of this viewpoint is called ”Eulerian point of view.” In this view, the time evolution of cloud pattern is presented in such a way that all of the measurement is taken from a fixed location. Presentation of satellite imagery on TV weather programs usually take this form because it naturally corresponds to the way a geostationary satellite observes the earth, and also because people are usually interested in the change of weather at a particular geographical location, such as Bangkok or Tokyo. However, this view is not suitable for describing the evolution of a moving object, such as a typhoon.

Figure 2 shows the difference of those two viewpoints. The geostationary satellites always observes the earth from a fixed location above the equator, so we always obtain a disk image of the earth. To make a typhoon imagery, we extract the region around the center of the typhoon, and apply a map projection method to make a mapped image appropriate for typhoon analysis. In the following, we also discuss design considerations associated with this process.

3.3 Other Design Considerations

The selection of mapping projection is another design consideration to make a typhoon imagery. The mapping projection we selected in this paper is azimuthal equivalent projection (Lambert azimuthal equal-area projection) [10]. This mapping is suitable for the description of typhoon imagery because of two reasons.

1. This projection is equal area, so the area of typhoon clouds can be fairly compared between different images, irrespective of the geographical location of the typhoon.
2. The distortion of shape is expected to be in proportion to the distance of a pixel from the image center. This indicates that the effect of distortion is less harmful to circular objects such as typhoons.

In terms of mapping area, following parameters are selected.

1. The width of super-typhoons sometimes reaches beyond 2,000 km. Hence, with some margins, we set the diameter of typhoon imagery to be 2,500 km.
2. Considering the usage of GMS-5 satellite data for typhoon imagery, the ground resolution of VISSR at the subsatellite point is around 5.0 km in infrared images. Hence the image size of 512×512 is chosen so that it fits the diameter of typhoon imagery (5.0 km / pixel$\times 512$ pixels $\sim$ 2,500 km).

On the validity of this selection, one example of a typhoon image in Figure 2 (b) demonstrates that these design parameters are reasonable choices. In addition, we should also discuss the selection of channels basically used for typhoon imagery. In general, a visible channel is said to have superior property in terms of greater ground resolution and better readability for the manual inspection of thin clouds such as cirrus and thick clouds with vivid three-dimensional structure. However, infrared channels have the following properties which are more important.

1. Infrared channels can keep observation even in nighttime.
2. The altitude of cloud top can be derived from the radiance of thermal infrared channels with the wavelength of around 10μm.

Thus typhoon images can be made on any time, and with taking above design considerations, we have already collected more than 20,000 typhoon images for approximately 110 typhoon sequences from 1995 through 1999, currently being used for many purposes, such as diurnal cloud pattern analysis, typhoon eye detection, content-based typhoon image retrieval system, and so on.

Table 1: Channels, wavelength and IFOV and GFOV of VISSR on GMS-5.

Channel	Wavelength (μm)	IFOV (μrad)	GFOV (km)	Quantization
VIS (VISible)	0.55 ~ 0.90	35×31	1.25	6 bits
IR1 (InfraRed)	10.5 ~ 11.5	140×140	5.0	8 bits
IR2 (InfraRed)	11.5 ~ 12.5	140×140	5.0	8 bits
IR3 (Water Vapor)	6.5 ~ 7.0	140×140	5.0	8 bits

Table 2: Channels, wavelength and IFOV and GFOV of AVHRR on NOAA POES.

Channel	Wavelength (μm)	IFOV (mrad)	GFOV (km)	Quantization
CH1 (visible : green)	0.58 ~ 0.68	1.39	1.1	10 bits
CH2 (reflected infrared)	0.725 ~ 1.05	1.41	1.1	10 bits
CH3 (reflected/thermal infrared)	3.55 ~ 3.92	1.51	1.1	10 bits
CH4 (thermal infrared)	10.3 ~ 11.3	1.41	1.1	10 bits
CH5 (thermal infrared)	11.5 ~ 12.5	1.30	1.1	10 bits

4 Enhancing the Quality of Typhoon Imagery

4.1 Geostationary and Polar Orbiting Meteorological Satellites

The overview of the typhoon database in the preceding section was based on satellite imagery from GMS-5, because, in general, the geostationary satellite is the best satellite to monitor typhoons in terms of frequent observation, wide coverage and fixed scan area. A well known geostationary satellite in Japan is Geostationary Meteorological Satellite (GMS) 5, or also well known by its nickname *Himawari*. Visible and Infrared Spin Scan Radiometer (VISSR), operating on the GMS, has one visible channel and three infrared channels as shown in Table 1. The visible channel and infrared channels have different instantaneous field of view (IFOV) and ground field of view (GFOV), where the GFOV of infrared channels is 5 km at nadir from a height of 35,790 km above the equator at $140°E$. Usually it operates hourly observation, which takes about 25 minutes to have a full disk picture of the earth. We can manage to track the global movement of the typhoon cloud pattern with the observation frequency of one hour, but this frequency is not sufficient for the accurate estimation of strong surface winds blowing around the typhoon center.

Another type of meteorological satellites of interest are called polar orbiting environmental satellites (POES), among which a satellite series operated by National Oceanic and Atmospheric Administration (NOAA) in the United States is most widely used in the world. On board it has Advanced Very High Resolution Radiometer (AVHRR) and through High Resolution Picture Transmission (HRPT) we can acquire observation data with relatively high resolution as shown in Table 2; an average IFOV of 1.3 miliradians, and its GFOV of about 1.1 km at nadir; 6+ km at edge of scan when viewed from the nominal orbit altitude of 833 km.

Polar orbiting satellites observe the Earth from lower altitude than geostationary satellites do, and, roughly speaking, this altitude difference leads to higher resolution of satellite imagery we can obtain from polar orbiting satellites. Moreover, there are some areas where polar orbiting satellites are better suited for meteorological monitoring. One representative example is arctic regions which are invisible from geostationary satellites due to earth curvature, while polar orbiting satellites can observe those regions from zenith. Hence we have an idea that by bridging the gap between those two types of satellites, it may be possible to improve the quality of typhoon imagery.

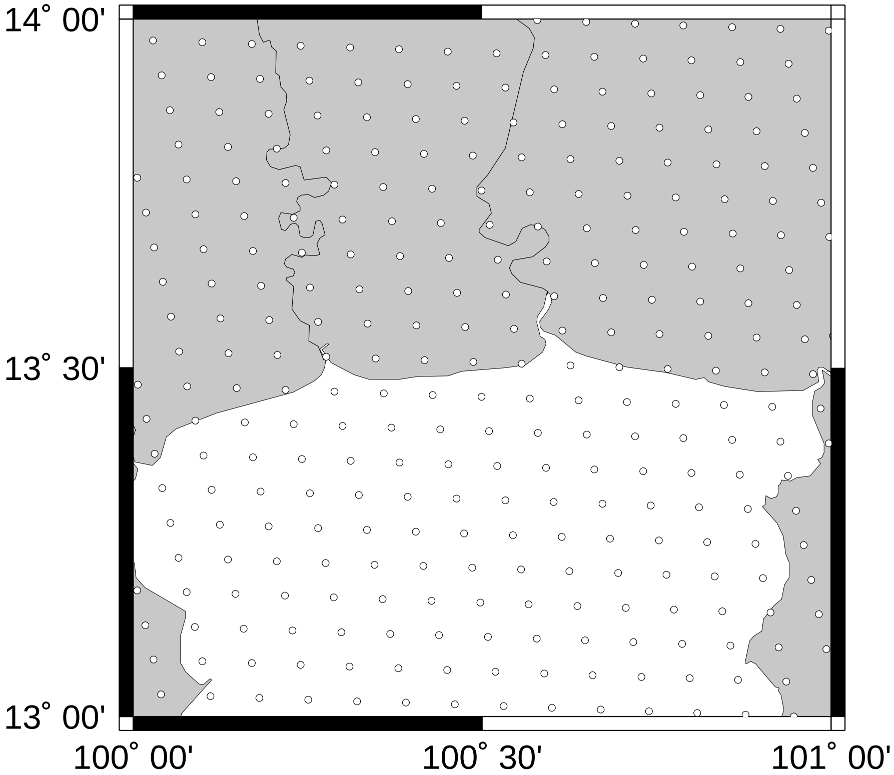


Figure 3: Scan spots of VISSR around Bangkok area (0000 UTC December 12, 1998). A white circle represents scan spots, whose diameter is equivalent to the GFOV of AVHRR, about 1.1 km.

4.2 Combination of Satellite Data from Two Satellites

In general, as addressed above, the geostationary satellites are more appropriate for the monitoring of typhoons than polar orbiting satellites. However, in the monitoring of typhoons in South East Asia, typhoon imagery made from GMS tends to be degraded in terms of resolution, and distorted in the shape of cloud. This is because, due to earth curvature, the effective resolution of each pixel is degraded in the edge of scan. For example, Figure 3 illustrates scan spots of VISSR around Bangkok area. This shows that separation of neighboring scan sports increases to around 7.5 km, which is 1.5 times larger than that at the subsatellite point, and much worse than the ground resolution of NOAA AVHRR, about 1.1 km[3].

To remove this limitation and improve the quality of typhoon imagery in terms of resolution and distortion, one possible solution is to use another geostationary satellite called INSAT. This Indian satellite is positioned at $74°E$ and especially useful for monitoring tropical cyclones in the Indian Ocean, where about 6 typhoons are formed in a year. The location of satellite is relatively closer to South East Asia, but the availability and reachability of the data may be the problem.

Another solution, which we employ in this paper, is the usage of polar orbiting satellites as mentioned above. NOAA AVHRR has better ground resolution of 1.1 km as shown in Table 2. The comparison is more clearly illustrated in Figure 3, in which the diameter of white circles representing the ground resolution of AVHRR at the subsatellite point is much smaller than the separation of scan spots of VISSR. Hence in terms of resolution, AVHRR provides higher resolution imagery than

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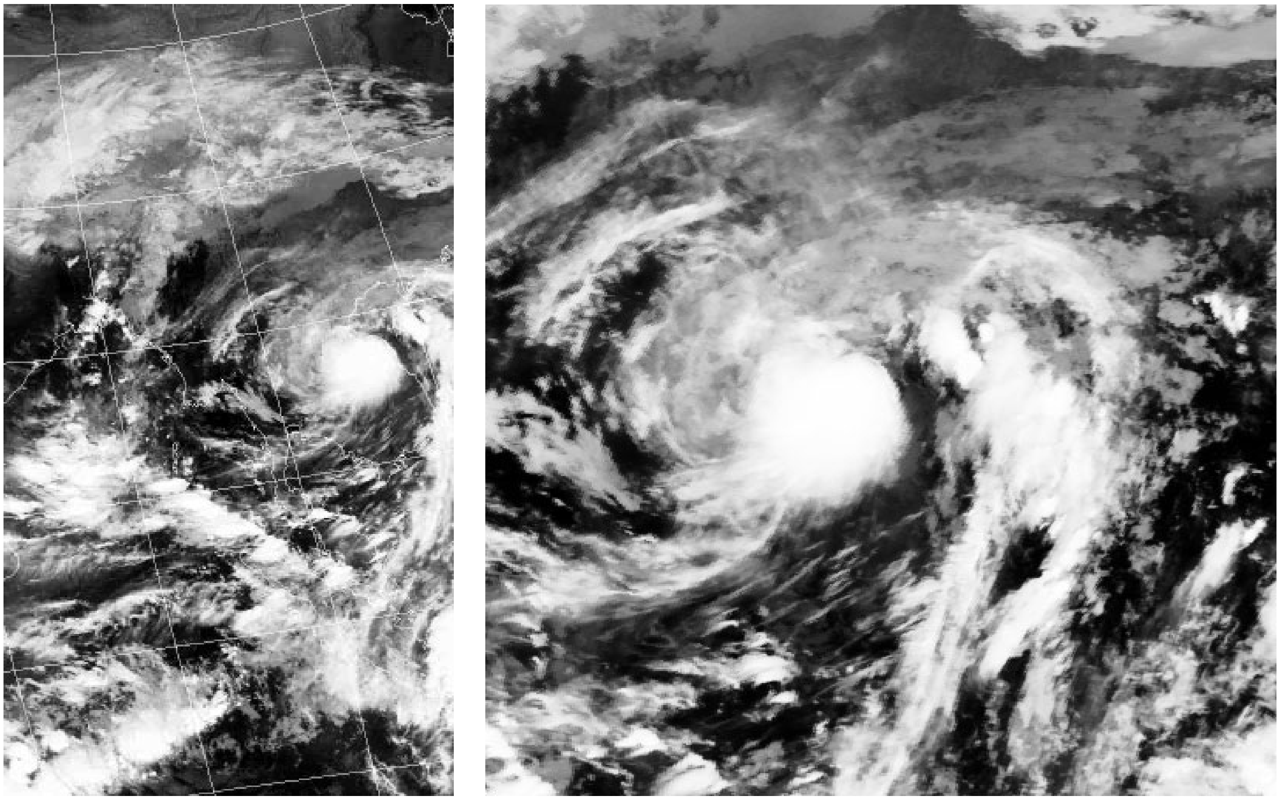
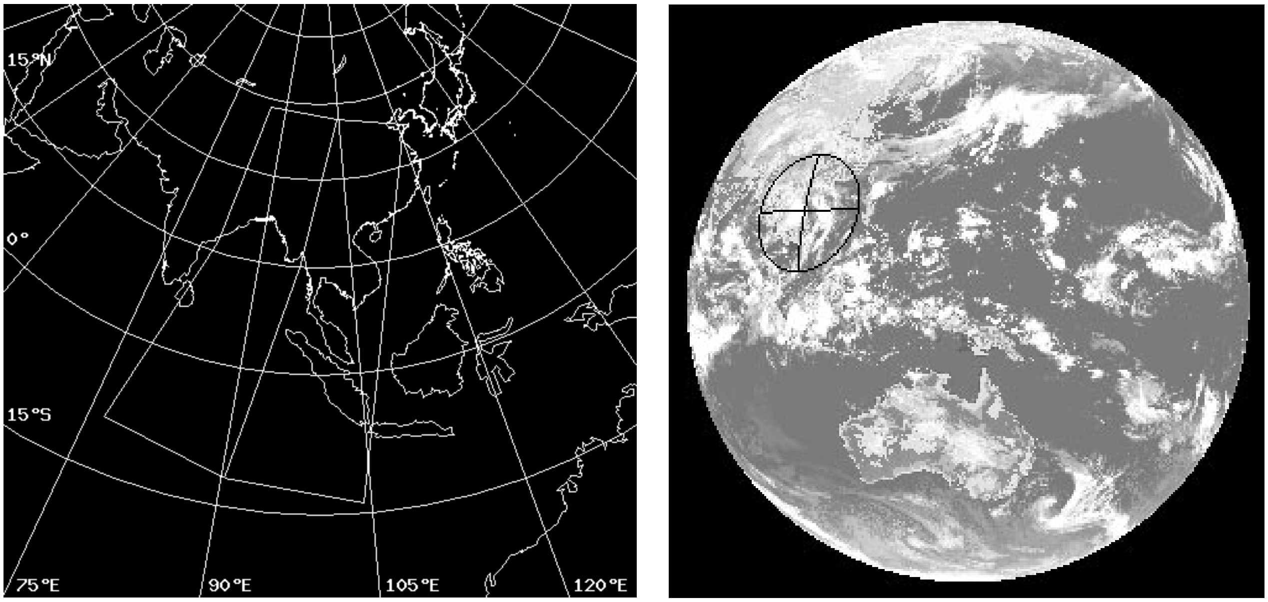
[3] The size of a scan spot of AVHRR (1.1 km) can be compared to a huge public ground in front of the Grand Palace called *Sanam Luang* in central Bangkok, which, in length, has approximately half the size of a scan spot.



(a) NOAA AVHRR (CH4)

(b) GMS VISSR (IR1)



(c) Scan range of (a)

(d) Scan range of (b)

Figure 4: Comparison of NOAA AVHRR and GMS VISSR. These images (Typhoon 9921) were taken on around 2100 UTC October 19, 1999 around $(17.1°N, 107.3°E)$, near the city of Hué (Vietnam). The measurement of typhoon is not available on this exact observation time; however by means of interpolation, it is approximately measured with the central barometric pressure of 996 hectopascals and the maximum wind speed of 35 knots. Scan range of (a) and (b) is represented by (c) and (d) respectively.

VISSR. The disadvantage of using AVHRR as the data source lies in the scan range, which means that the scan range of 2,800 km is only marginally larger than the size of the typhoon cloud pattern, namely 2,500 km as we have chosen. Therefore, unless the typhoon center is positioned very close to one of subsatellite points, we cannot capture the whole picture of the typhoon. Low frequency of observation, a few times a day, can also be a problem for detecting the change of cloud patterns.

4.3 Preliminary Experimental Results

Figure 4 compares two types of typhoon imagery made from two meteorological satellites. These images take typhoon 9921 on 2100 UTC October 19, 1999 around $(17.1°N, 107.3°E)$, near the city of Hué (Vietnam). (a) shows the image received from AVHRR, and (c), its scan range. Since typhoon 9921 is positioned in the right side of the scan range, the entire cloud pattern is not observable by this sensor. In contrast, (b) shows the mapped typhoon imagery and (d), its scan range. As is shown, the advantage of using a geostationary satellite is in wide coverage that the entire cloud pattern can be captured without failure. However, there appears to be slightly blurred pixels in the right side of (b) due to the degradation of effective resolution. Hence, by combining satellite data from two types of satellites, we can occasionaly get higher resolution typhoon imagery for a part of typhoon cloud pattern; while a geostationary satellite provides relatively low resolution but high frequency observation; thus they compensate each other's drawbacks.

Here we also point out that the comparison of Table 1 and Table 2 shows that IR1, IR2 of VISSR and CH4, CH5 of AVHRR represent almost the same wavelength. This property allows us the comparison of typhoon imagery made from two satellite images. Although quantitative comparison of two typhoon images are left for future works, in qualitative evaluation, we can conclude that NOAA AVHRR satellite imagery has potential for compensating the degradation of resolution that arises when monitoring typhoons in South East Asia.

5 Network for Satellite Data Distribution

Since polar orbiting satellites move around the earth, the acquisition of satellite imagery over Thailand requires having at least one receiving station in Thailand or its proximate regions. The receiving station operating at Asian Institute of Technology (AIT), Asian Center for Research on Remote Sensing (ACRoRS), thus plays an important role in obtaining high quality AVHRR satellite imagery over South East Asia. After the receipt of satellite data, they are transferred to Japan through the Internet, and concurrently archived in Japan. On its route to Japan, NACSIS-Thai International Link, 2 Mbps international link devoted to the distribution of academic information between two countries, serves as the infrastructure for exchanging huge amount of satellite data. The distribution of satellite data will otherwise be realized as sending tape media by a snail mail; in this way, near real-time monitoring of the earth environment, such as typhoons, cannot be realized. Hence this international link is an indispensable part of this collaborative research.

There is a tendency of steady increase in the amount of satellite data that we receive, because new sensors tend to have many channels with wide coverage of bandwidth, better spatial resolution, and higher radiometric resolution. Therefore, the amount of satellite data necessary to be exchanged through the network also grows rapidly in these years. To maintain a global network on which such huge amount of satellite data can be exchanged without too much network congestion, we need to establish high performance network systems that keep up with the growing trend of the amount of data transfer. In addition, advanced network applications such as caching or multicast will also help to enhance the quality of service of the network. Experiments on these issues are left for future work.

6 Conclusion

In this paper, we presented ideas on the comprehensive collection of typhoon data and procedures for development. To prevent or alleviate disasters originating in typhoons, we should develop techniques to analyze and predict the evolution of typhoons in its early stage. The uniqueness of this project can be characterized as informatics-based approach, utilizing various techniques that has been developed so far and also will be developed in the framework of informatics. The specific challenge of this paper is to tackle the problem of GMS-5 when observing South East Asia, namely the degradation of effective resolution and the distortion of cloud shape due to earth curvature. For this purpose, our solution is to combine satellite imagery from two data sources, namely geostationary satellites and polar orbiting satellites. They can compensate each other's drawbacks and provide high quality satellite imagery that leads to the comprehensive collection of typhoon data.

An important future work is to apply data mining approaches to this database to discover relevant, possibly hidden rules or knowledge, and establish novel typhoon analysis and prediction techniques. Among research issues stated in Section 2, cyclogenesis forecast and intensity forecast are the most interesting subject for making early warning system to typhoon disasters. In terms of typhoon disasters, we should also point out that the integration of typhoon database testbed with geographic information systems (GIS) will be an important part of our research. Finally, we need to develop novel network technologies for the smooth exchange of satellite data through the Internet.

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