研究論文

The Collection of Typhoon Image Data and the Establishment of Typhoon Information Databases Under International Research Collaboration between Japan and Thailand

日本とタイの国際共同研究に基づく台風画像データの収集および台風情報データベースの構築

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ABSTRACT

This paper describes our ongoing project under international research collaboration between Japan (National Institute of Informatics) and Thailand (Asian Institute of Technology) for the collection of typhoon image data and the establishment of typhoon information databases. Statistics on past typhoon records reveal that approximately one thirds of the typhoons formed in the Northwest Pacific basin have entered into South East Asia and this fact indicates the importance of the research into the analysis and prediction of typhoons in order to prevent or reduce massive damage from typhoons in this vulnerable region. Our challenge to this goal is unique in that our approach is mainly based on the informatics paradigm, namely based on ideas and techniques developed in the informatics community, in contrast to the traditional paradigm based on meteorology. The underlying infrastructure in this new paradigm is the large collection of typhoon images created from Japanese meteorological satellite GMS-5 *Himawari*. However, when observing South East Asia through this satellite, satellite images tend to show degradation in effective resolution and shape distortion due to earth curvature. Hence we demonstrate that satellite images from another type of satellite called NOAA can compensate the drawbacks of GMS-5, and can provide high quality typhoon imagery over South East Asia. We also point out that NOAA data received in Thailand are relevant data source for this combination, and that effective infrastructure for exchanging huge amount of satellite data is the SINET international link between Thailand and Japan.

要旨

本論文は、日本（国立情報学研究所）とタイ（アジア工科大学）の国際共同研究として進められているプロジェクト、すなわち台風画像データの収集および台風情報データベースの構築に関する報告である。過去の統計データによると東南アジア地域は、北西太平洋で発生する台風の約3分の1が通過する。この危険地域における台風災害を防止し損害を軽減するためには、台風解析と予報という問題に徹底的に取り組むことが重要である。本プロジェクトのユニークな点は、この問題に対して気象学の手法に基づく従来のパラダイムではなく、情報学の分野で発展したアイデアや手法を援用した情報学パラダイムに基づき、台風画像の大規模コレクションを研究の土台として挑戦するという点にある。本論文ではこのコレクションを主に気象衛星 GMS-5「ひまわり」の衛星画像から作成する。ただし GMS-5 を用いて東南アジア地域を観測する場合、衛星画像の実質的な解像度が低下し、雲形状が歪むという欠点が避けられない。そこで本論文では、別の種類の衛星画像、すなわちタイで受信する

NOAA 衛星画像を組み合わせることにより、お互いの欠点を補完しつつ高品質な台風画像が生成できることを示す。さらにこのような大量の衛星データをネットワーク経由で交換するための基盤として、日本とタイの間で運用される SINET 国際回線が有効であることを述べる。

[Keywords]
Typhoon Image Database, Geostationary Satellite, Polar Orbiting Satellite, South East Asia, International Research Collaboration

[キーワード]
台風画像データベース、静止衛星、極軌道衛星、東南アジア、国際共同研究

"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

"NACSIS[1]-Thai Project" is the name of the project whose purpose is to promote international research collaboration between Japan and Thailand through the intensive usage of 2 Mbps SINET international link between two countries. Since the inception of this project in 1994, National Institute of Informatics (NII) and Thai research institutions have established several joint research projects, and the authors have also been involved in this project for a few years under an individual project on exchanging satellite data through the Internet with collaborators in Asian Institute of Technology (AIT), which has been operating the reception and the archive of satellite data since 1997. Our ongoing research, "digital typhoon" [1]-[3] benefits from this collaborative research in terms of two points.

1. In South East Asia, as well as in Japan, typhoons often cause massive damage and devastating losses, which leads to shared interest in the analysis and prediction of typhoons.
2. For the monitoring of typhoons over South East Asia, the Japanese geostationary satellite GMS-5 has a limited capability in obtaining high quality data. To solve this problem, satellite data from a polar orbiting satellite, received in Thailand, can be combined with GMS-5 satellite data to enhance the quality of typhoon imagery.

Here GMS-5 (Geostationary Meteorological Satellite 5), which is also well known by its nickname *Himawari*, is the most popular geostationary satellite in Japan. As will be stated later, this satellite is the most powerful satellite for the monitoring of typhoons because of favorable properties such as wide coverage, frequent observation, and fixed scan range; its data are therefore utilized as our main data source. However we will also discuss feasibility for enhancing the quality of typhoon imagery created from GMS-5 over South East Asia by incorporating satellite data from another type of satellite called NOAA.

This paper is organized as follows. Firstly, Section 2 reminds you of what is typhoon, and its influence in South East Asia. Its influence, from the viewpoint of disasters caused by typhoons, is then briefly sketched in Section 3, and some research issues on typhoon analysis and forecast are introduced as well. Next Section 4 addresses design considerations necessary to be settled before actually making typhoon image databases. The next section, Section 5, describes the main challenge in this paper; that is, we try to enhance the quality of typhoon imagery through the combination of satellite data from two different types of satellites — geostationary satellites and polar orbiting satellites. Section 6 summarizes our international research collaboration between Japan and Thailand, and the history of our joint research called NACSIS-Thai project. Finally Section 7 concludes the paper.

2 Typhoons in South East Asia

The terms "hurricane" and "typhoon" are regionally specific names for a strong "tropical cyclone." A tropical cyclone is the generic term for a non-frontal synoptic scale low-pressure system over tropical or sub-tropical waters with organized convection and definite cyclonic surface

1 National Center for Science Information Systems (NACSIS) is the name of the antecedent of National Institute of Informatics (NII).

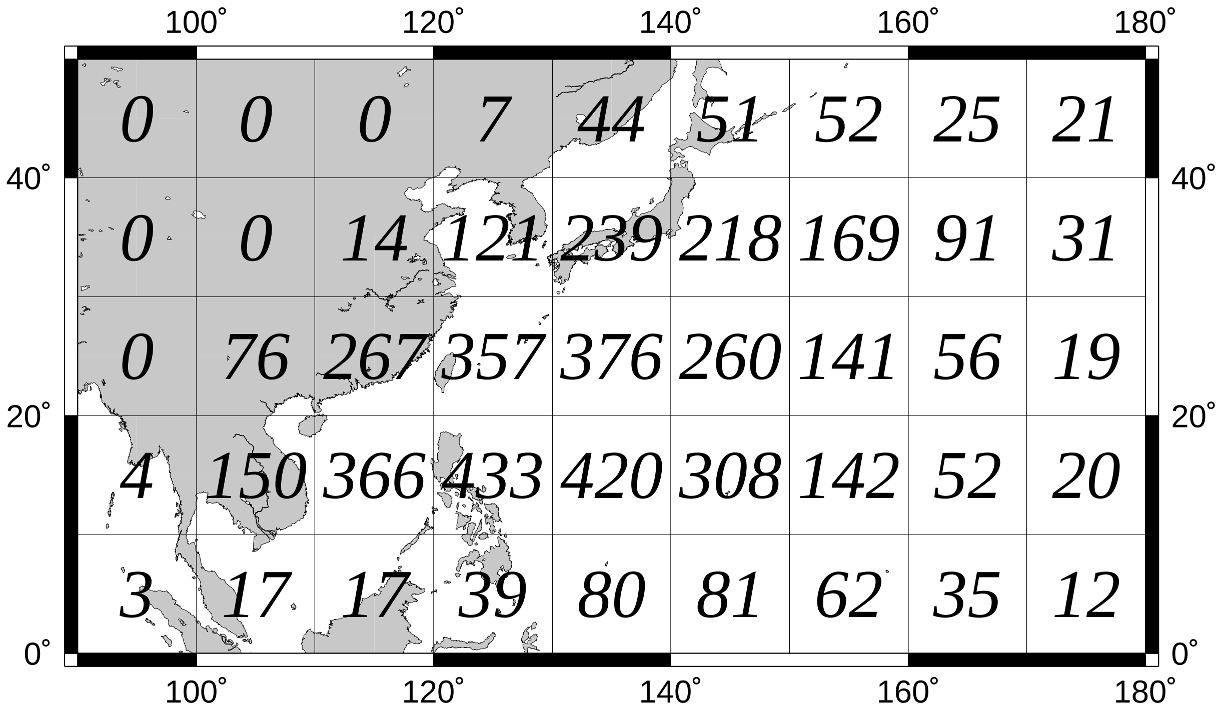


Figure 1: Grid-based occurrence profile of typhoons (tropical cyclones from Category 3 through 5). Total 1,320 typhoons formed in the period from 1951 through 1999 are analyzed, where one typhoon is counted once in one grid but may be counted in several grids along with its motion.

wind circulation. The term "typhoon" is specifically given to tropical cyclones occurred in the Northwest Pacific (NWP) basin, and among severe tropical cyclones in the world such as hurricanes, cyclones, etc., typhoons are known to be the most active ones.

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 more typhoons than any other grids, as many as 433 typhoons among 1,320 typhoons formed from 1951 through 1999. 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, the most dangerous and vulnerable country against the strike of typhoons is likely to be Philippines[2].

However, if you also pay attention to other regions such as South China Sea and South East Asia, you may notice that those regions are almost as frequently struck by typhoons as the Philippine region. For example, 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. Typhoons found in this grid tend to choose one of two courses; either heading north towards the southern part of China or going west towards such countries as Vietnam, Malaysia and Thailand. They are usually not very strong typhoons, but at least they are typhoons with strong winds, heavy rainfall, and tidal waves. Hence they often cause devastating destruction on people's daily lives and the wide range of industry, among which agriculture may be the most vulnerable industry in South East Asian countries. Assuming that some of the disasters can be prevented from early warning, we claim that typhoon analysis and prediction are important subjects of research in order to reduce extensive losses from typhoons.

3 Motivation of the Project

3.1 Disasters Caused by Typhoons

Not only South East Asian countries but also many countries in the world are suffered widespread and massive damage from typhoons. Phenomena listed in the following are likely to bring massive disasters during or after the strike of typhoons.

2 In terms of country-based statistics, however, China suffers from more landfalls than any other countries in the world.

Strong Winds By definition, strong winds are the symbol of typhoons. On the land, weak buildings and houses are directly destroyed by strong winds or partly damaged by flying debris; while on the sea, strong winds make storm surges, resulting in shipwreck in the middle of the ocean without any havens nearby[3].

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

Tidal Waves Tidal waves, or storm surges, are caused by the mixed influence of strong winds and low barometric pressure, of which the former plays the major role. Tidal waves sometimes result in extraordinary devastation on low-lying deltas, such as that occurred in Bangladesh in 1970 that killed at least 300,000 people.

However, those phenomena can be predicted to some extent by means of the state-of-the-art weather prediction technology. Moreover, appropriate weather advisory, subsequent evacuation procedures, and other special precautions before the strike of the typhoon, are important factors for the significant reduction of possible damage that may otherwise be caused. One of the reasons of dramatic decrease in recent years in the amount of losses from typhoons can be ascribed to technological advances in early warning systems, and to the development of communication via radio and television, as well as the improvement of infrastructure against extreme weather events. However, we hope that early warning systems will play further important role in the future as the world evolves to more efficient and sophisticated society with increased vulnerability to natural disasters. In this regard, we are interested in developing an early warning system that might be less reliable than orthodox numerical weather prediction models, but more foreseeable so as to provide some information on the confidence of the forecast and the risk we should have in mind before taking or not taking some actions in the very early stage of typhoon's life cycle. As Ernest Hemingway put it, we believe that "if there is a hurricane, you always see the signs of it in the sky for days ahead," and we want to discover some signs from satellite images.

3.2 Typhoon Forecasts

Unfortunately, typhoon forecasts have not yet reached to mature level. One of the fundamental reasons 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. However, the importance of typhoons stimulated meteorologists to investigate and improve typhoon forecasts in three domains as follows:

1. Cyclogenesis forecast
2. Intensity forecast
3. Track forecast

For example, tropical cyclogenesis has long been an important topic in meteorological research and there are several conditions thought to be necessary for tropical cyclogenesis. However, a particular tropical disturbance may never develop to a typhoon although all the necessary conditions are met. [5] Thus you cannot tell a chance of a particular cloud cluster developing to a typhoon or ending as a short-lived cluster, which fact indicates that sufficient conditions for tropical cyclogenesis are still unclear. On the other hand, 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.

Thus simple extrapolation, which gives fairly good forecast in most cases, may suddenly provide fallacious forecast in rare cases such as rapid deepening[4]. This failure suggests an ironic situation that rare cases, or the most unpredictable cases, are in fact the most dangerous and the most important cases. Here one fundamental question arises: how can we tell such rare cases by discovering some hints on typhoon cloud patterns in satellite imagery?

3 *The Perfect Storm* [4] and its recent movie (by Warner Brothers Pictures) illustrates the dreadful shipwreck occurred on the Atlantic Ocean caused by an unexpectedly re-intensified (recovered) hurricane.

4 "Rapid deepening" is defined as a decrease in the minimum sea-level pressure of a tropical cyclone of 1.75 hectopascals (hPa) / hr or 42 hPa for 24 hours.

3.3 Informatics Paradigm

This question is difficult to answer, or to put it correctly, we do not have any answers for the time being. However, various techniques that have been developed in the meteorology community are definitely the most important and reliable reference to begin with. For example, in terms of intensity estimation for tropical cyclones, there is a standard technique established by Dvorak. [7][8] Even before his research, satellite imagery has been the most powerful data source since the launch of meteorological satellites in 1960s. The long history of experiences on satellite image interpretation that had been accumulated from the epoch leads to his technique for typhoon analysis which is now utilized operationally at most of the 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 the current technique depends on the human perception of experts, namely subjective judgment of the cloud pattern, and is not based solely on rigorous theoretical foundations, or in other words, quantitative and objective judgment.

In this respect, we propose that, in addition to the traditional paradigm based on meteorology as summarized above, the informatics paradigm can also contribute to this challenge with novel solutions, because the informatics community has a long history dealing with this kind of pattern recognition 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. There have been not many, but at least a few, attempts to typhoon analysis that can be categorized into the informatics paradigm. For example, the motion of clouds is analyzed from image sequences based on fluid dynamics [10]-[12] and tropical cyclone patterns are interpreted on satellite images using dynamic link architecture and active contours. [13] Referring to research without satellite images, we can also point out such references as typhoon data mining by neural network, [14] and typhoon track prediction by fuzzy modeling. [15]

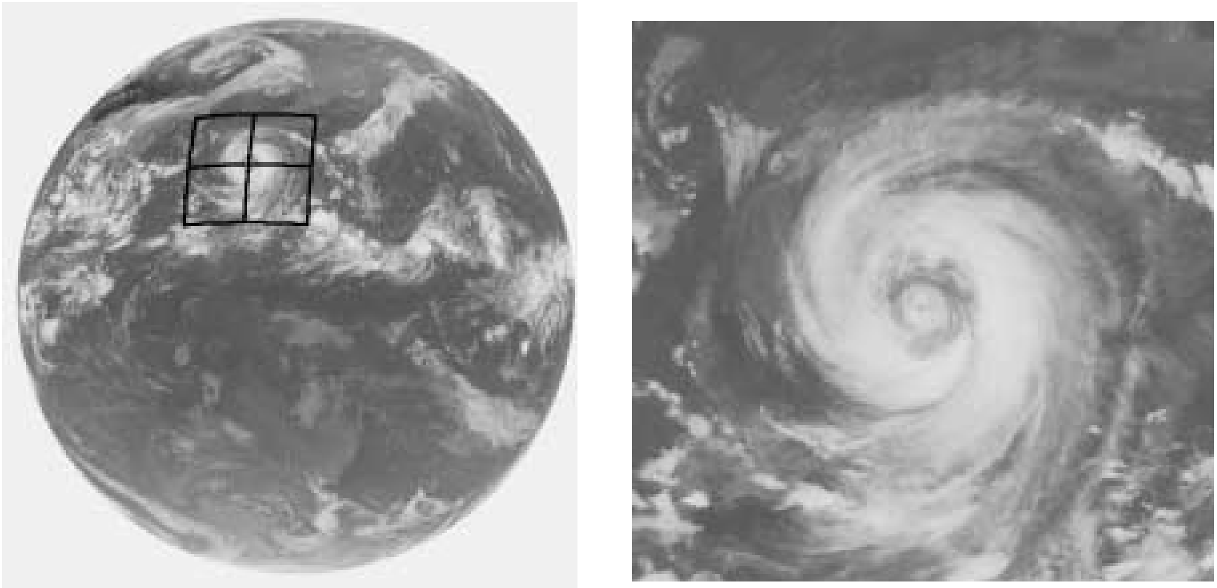
However, it seems that most of the research mentioned above makes just a minor impact on meteorology due to their lack of meteorological frame of reference; in other words, their research regard meteorology as one application of informatics-based methods available to them, but they do not have much interest in truly combining both informatics and meteorological frame of reference, which is our goal. We also conjecture that, in the informatics paradigm, the huge collection of typhoon related data such as typhoon imagery and the best track database should serve as the underlying infrastructure of the research. In this collection, the quality control of the databases should be done in accordance with requirements set for meteorological applications.

4 Typhoon Database

4.1 Best Track

The basic information for typhoon analysis is the center position of a typhoon, because it is the representative point on which most of typhoon analysis techniques depend. When the eye of a typhoon can be observed in a clear form, the tracking of a typhoon is just simple; however even professionals have trouble with determining the position of the typhoon when a typhoon cloud pattern takes an irregular form. The automatic determination of typhoon center is an important challenge; however, as far as off-line typhoon analysis is concerned, we do not have to automate this painstaking task and can refer to external datasets called *best track*.

Since 1951, official records on tropical cyclones in the NWP basin are compiled by the Japan Meteorological Agency (JMA) as a best track database. This database contains records such as center position, central barometric pressure, and maximum sustained wind for every three to six hours. Since those data records are determined by experts after all information on the typhoons is received and assessed, we can rely on the quality and stability of the data, and regard them as "quasi" ground truth data. The best track dataset allows us to 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 on Typhoon 9713 are created from the infrared image (IR1) taken on 1000 UTC August 16, 1997. GMS-5 observes the earth in the form of (a). The edges of the square in (a) is 2,500km, which we define as the size of typhoon imagery. The region within this square is then cropped from the original satellite image to make a "well-framed" typhoon image illustrated in (b). Note that the square captures almost entire cloud pattern of this relatively large typhoon. The approximate measurements of the typhoon are: the central barometric pressure of 945 hPa and the maximum sustained wind of 85 knots (about 40 meters/second).

4.2 Selection of Viewpoints

The viewpoint employed for creating a “well-framed” typhoon image differs from the one commonly used for the presentation of meteorological imagery. Borrowing a frame of reference from the field of flow dynamics, a well-framed typhoon image is one example of “Lagrangian point of view.” This viewpoint focuses on the time evolution of a particular mass or object over a specified time period. The coordinate system of the typhoon image moves along the typhoon so that the center of the image always coincides with that of the typhoon. In this manner, we can separate the evolution of typhoon cloud pattern from the global motion of typhoon cloud system, of which the former is our main concern.

On the other hand, another viewpoint, “Eulerian point of view,” describes the time evolution of cloud pattern in such a way that all 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 weather change at a particular geographical location such as Tokyo. However, the analysis of a moving object requires creating image sequences that always capture a moving object within the frame; thus Eulerian viewpoint is, in general, not suitable for the time-series analysis of a moving object, such as a typhoon.

Figure 2 compares two different viewpoints associated with the typhoon. Since a geostationary satellite always observes the earth from a fixed location above the equator, we always obtain the disk image of the earth. On the other hand, the well-framed typhoon imagery always capture the typhoon cloud pattern inside its frame in a concise manner. In the following, we discuss additional design considerations associated with the creation of typhoon imagery in Lagrangian point of view.

4.3 Additional Design Considerations

Mapping Projection The selection of mapping projection scheme is another design consideration for the creation of typhoon imagery. The mapping projection we have chosen in this paper is azimuthal equivalent projection

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

Channel	Wavelength (μ m)	IFOV (μ rad)	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, IFOV and GFOV of AVHRR on NOAA satellite.

Channel	Wavelength (μ m)	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

(Lambert azimuthal equal-area projection) [16]. This mapping projection is suitable for the description of typhoon imagery because of the following two reasons.

1. Since this projection is equal area, the area of typhoon clouds can be directly compared with that in other images by counting the number of image pixels, irrespective of the geographical location of typhoons.
2. The distortion of shape is in proportion to the distance between a pixel and the image center. This property indicates that the effect of distortion is less harmful to circular objects such as typhoons.

Size Parameters The creation of a well-framed typhoon image involves determining a few parameters related to the size of a framed image. The following describes parameter values we have chosen.

1. The width of super-typhoons sometimes reaches beyond 2,000 km. Hence, with some margins, we choose the actual size of the frame to be 2,500 km.
2. The ground resolution of GMS-5 at the subsatellite point is approximately 5.0 km for infrared images. Then the image size of 512×512 is almost equivalent to the actual size of 2,500 km ×2,500 km as mentioned above.

Figure 2 (b) validates the selection of parameters, where most of the core cloud systems of the typhoon is captured in the image. Note here that we do not perform any further normalization in terms of scale, because the actual size of the cloud pattern itself suggests some hints on the intensity of the typhoon.

Sensor Wavelength In terms of sensor selection, we select infrared channels because of the following properties favorable for typhoon analysis.

1. Infrared channels enable the analyst to monitor the activity of a storm continuously night and day.
2. The altitude of cloud top can be derived from the radiance of thermal infrared channels.

On the other hand, a visible channel has superior properties in terms of greater ground resolution and better readability for the manual inspection of cloud texture for thin clouds and convective clouds. Hence we utilize visible channel data as additional datasets.

Size of the Database We have already collected more than 20,000 typhoon images for approximately 110 typhoon sequences from 1995 through 1999. This database has been used for several types of typhoon analysis such as diurnal cloud pattern analysis, typhoon eye detection, the content-based typhoon image retrieval system, and so on.

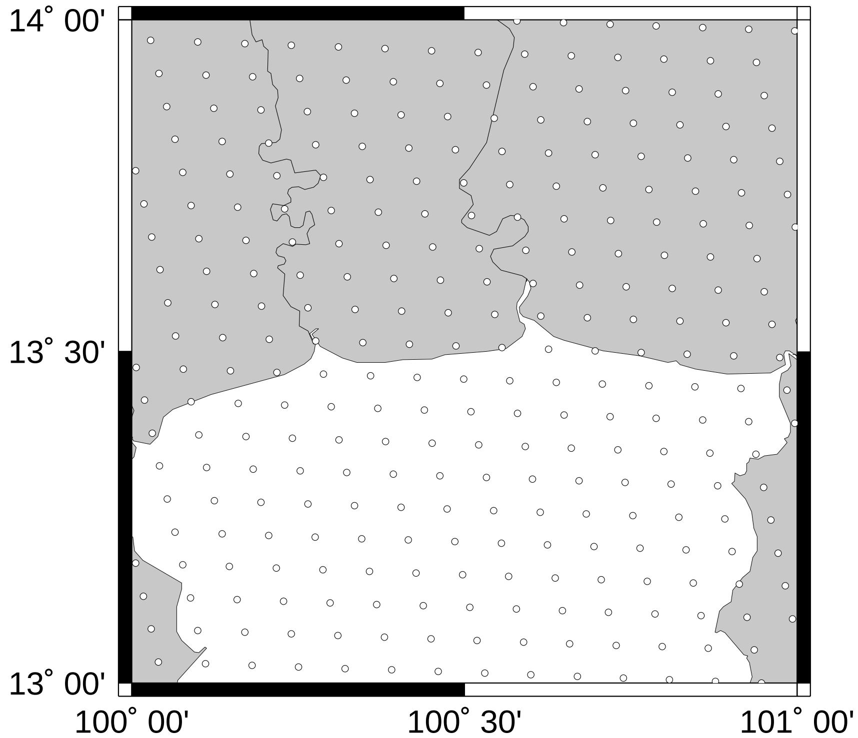


Figure 3: Scan spots of GMS VISSR in Bangkok area on 0000 UTC December 12, 1998. A white circle represents a scan spot, whose diameter is equivalent to the GFOV of NOAA AVHRR, about 1.1km.

5 Enhancing the Quality of Typhoon Imagery

5.1 Geostationary and Polar Orbiting Meteorological Satellites

Now we summarize the properties of interesting satellites and how we take advantages of both satellites to enhance the quality of typhoon imagery. Firstly, the geostationary satellite is, in general, the best satellite for the monitoring of typhoons because of frequent observation, wide coverage, and fixed scan range. The Japanese geostationary satellite, GMS-5, has a sensor called Visible and Infrared Spin Scan Radiometer (VISSR) with one visible channel and three infrared channels as shown in Table 1. The ground field of view (GFOV) of infrared channels is approximately 5 km at nadir from a height of 35,790 km above the equator at 140° *E*. Normally it operates in hourly observation mode, which frequency is fairly sufficient for tracking the global motion of the typhoon cloud system, but not enough for the accurate estimation of surface winds whirling around the typhoon center.

Another type of meteorological satellites of interest is a 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 a sensor called Advanced Very High Resolution Radiometer (AVHRR), from which we can acquire observation data in relatively high resolution through High Resolution Picture Transmission (HRPT) as shown in Table 2. An average IFOV (Instantaneous Field of View) of 1.3 miliradians or an average GFOV of 1.1 km at nadir when viewed from the nominal orbit altitude of 833 km degrades to an average GFOV of 6+ km at edge of scan.

Polar orbiting satellites observe the earth from lower altitude than geostationary satellites do, and, roughly speaking, this lower altitude leads to higher resolution satellite images from polar orbiting satellites. Moreover, there are some areas where polar orbiting satellites are better suited to the monitoring of the earth. One representative example is arctic regions invisible from geostationary satellites due to earth curvature, while polar orbiting satellites can observe those regions from zenith. However, polar orbiting satellites are usually inferior to geostationary counterparts in terms of low observation frequency and narrow scan range. In summary, those two types of satellites have their own advantages and disadvantages, and our idea is to compensate the degradation of GMS-5 imagery with high resolution NOAA imagery.

5.2 Combination of Satellite Data from Two Satellites

Now we describe our main challenge in this paper; namely the combination of two satellites for creating the comprehensive collection of high quality typhoon imagery. Typhoon imagery created from GMS-5 tends to show degradation in resolution and distortion in cloud shape especially over South East Asia, because pixels in the edge of scan are skewed from the sensor due to earth curvature.

For example, in Figure 3, white circles represent the location of scan spots of GMS VISSR around Bangkok (Thailand) area, where the separation of neighboring scan sports increases to about 7.5 km, which is 1.5 times larger than that at the subsatellite point. On the contrary, the diameter of white circles represents the ground resolution of NOAA AVHRR at the subsatellite point[5], namely 1.1 km, which figure shows much better resolution than that of VISSR.

This comparison indicates an advantage in using polar orbiting satellites for improving the quality of typhoon imagery in terms of higher resolution and less distortion. The biggest disadvantage here lies in narrow scan range; the scan range of 2,800 km is only marginally larger than 2,500 km, which is the size of typhoon cloud pattern. Therefore, unless the center of the typhoon is positioned very close to nadir, we cannot capture the whole picture of the typhoon. Moreover, we may lose track of cloud motion due to the low frequency of observation — just a few times a day.

5.3 Experimental Results

Figure 4 compares two types of typhoon imagery created from two meteorological satellite data. These images take the cloud pattern of Typhoon 9921 on 2100 UTC October 19 1999. The position of the typhoon was around (17.1° *N*, 107.3° *E*), near the city of Hué (Vietnam). Figure 4 (a) shows the image received from NOAA AVHRR, and Figure 4 (c), its scan range. Since Typhoon 9921 is positioned in the right edge of the scan range, overall cloud pattern is not observable through this sensor. In contrast, Figure 4 (b) shows the map projected typhoon imagery and Figure 4 (d), its scan range, in which overall cloud pattern is captured because of the wide coverage GMS VISSR. However, notice that some pixels in the left edge of Figure 4 are slightly blurred.

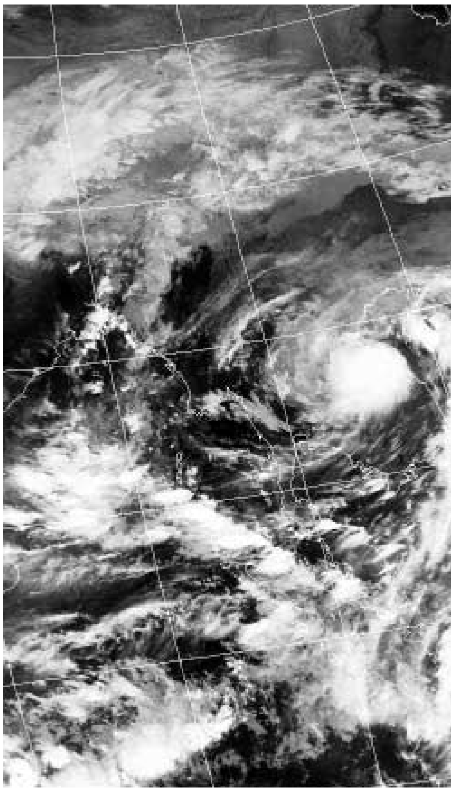
Hence the NOAA data and the GMS-5 data taken on approximately the same observation time can be integrated together for enhancing the quality of typhoon imagery. In this scheme, the collection of typhoon imagery is composed of low resolution but frequent observation data from GMS-5 and high resolution but less frequent data from NOAA.

Here we also point out that the comparison of Table 1 and Table 2 shows that IR1, IR2 of GMS VISSR and CH4, CH5 of NOAA AVHRR represent almost the same wavelength. This property allows us to compare typhoon images created from two satellites. Although the quantitative comparison of two typhoon images is left for future works, in qualitative evaluation, we conclude that NOAA satellite data can provide complement data for the creation of high quality typhoon image collection over South East Asia.

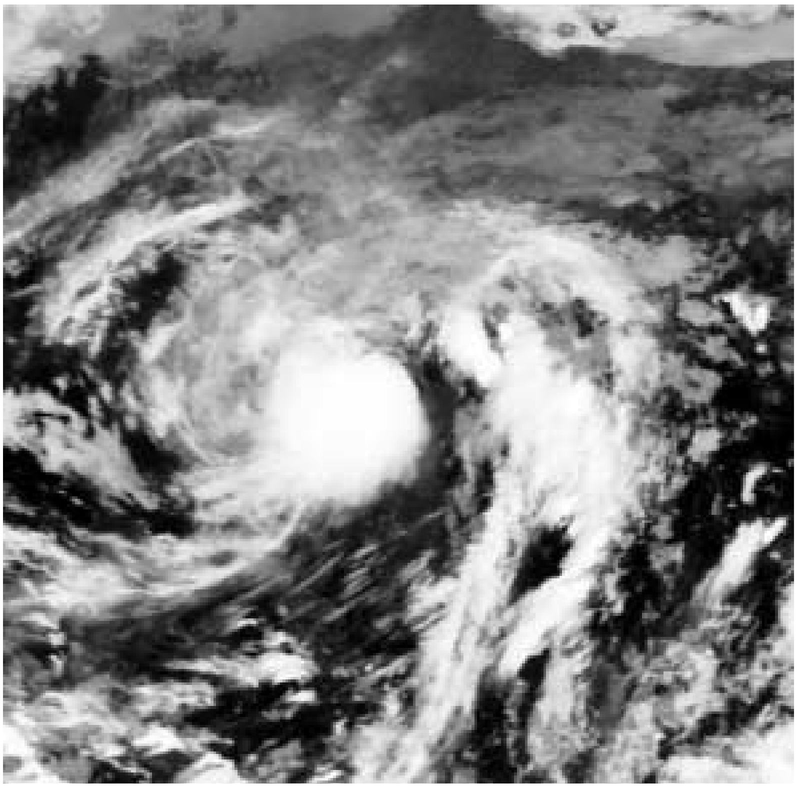
6 International Research Collaboration between Japan and Thailand

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 NOAA AVHRR satellite data over South East Asia. Upon the reception of satellite data, part of them are transferred to Japan through the Internet and concurrently archived in Japan. On its route to Japan, SINET 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 by 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 works as an indispensable part of this collaborative research.

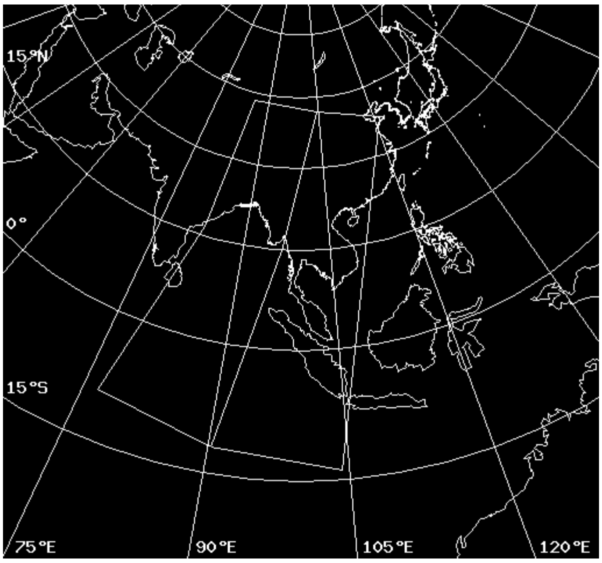
5 The size of a scan spot of AVHRR (1.1 km) may be compared with a huge public ground in front of the Grand Palace called *Sanam Luang* in central Bangkok, which, in length, has approximately half the size of a scan spot.



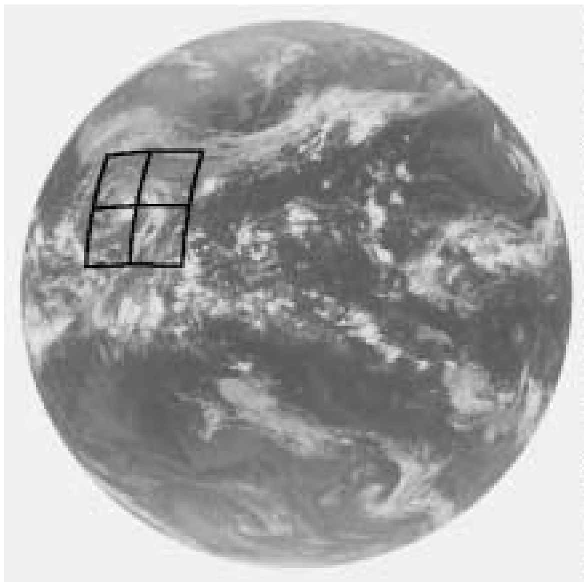
(a) NOAA AVHRR (CH4)



(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 2100 UTC October 19, 1999. The position of the typhoon was around (17.1° *N*,107.3° *E*), near the city of Hué(Vietnam). The interpolated measurements of the typhoon are: the central barometric pressure of 996 hPa and the maximum sustained wind of 35 knots. Scan range of (a) and (b) is represented by (c) and (d) respectively. Note the similarity of typhoon cloud shape between (a) and (b) that are taken almost on the same time.

This international link is also used by other researchers both in Japan and Thailand, some of which have been taking part in the joint research project called “NACSIS-Thai Project.” As mentioned earlier, the purpose of this project is to promote international research collaboration between Japan and Thailand through the usage of the international network between those two countries. Since its establishment in 1994, “NACSIS-Thai Project” covered diverse research areas such as multi-lingual and multimedia delivery system, digital library, the collaborative development of online dictionary, satellite data exchange using high-speed network and advanced network technology. Another activity under this project is an annual forum called “International Workshop on Academic Information Networks and Systems” (WAINS) for exchanging research achievement on these topics. Since 1994, we have held 7 annual workshops either in Japan or in Thailand. In the future, we are planning to extend this project to include new areas such as bioinformatics, robotics, and distance learning.

The individual project we are involved under “NACSIS-Thai Project” deals with the exchange of satellite data through the Internet. Although this exchange has currently reached to a stable level with a bottleneck inside Thailand, we should also notice that there is a tendency of remarkable increase in the amount of satellite data necessary to be exchanged, because new sensors tend to have more channels with wider bandwidth coverage, better spatial resolution, and higher radiometric resolution. Hence the performance of the network should be improved in accordance with the amount of satellite data distributed through the network. To maintain a global network on which such huge amount of satellite data can be exchanged without too much congestion, we need to develop high performance broadband network technology such as caching or multicast. Experiments on these network issues are left for future work.

7 Conclusion

We have described our ongoing research, namely the collection of typhoon image data and the establishment of typhoon information databases under “NACSIS-Thai Project.” This project has undergone approximately seven years of international research collaboration between NII and Thai research institutions, and along with research collaboration we also had annual international workshops, WAINS, for exchanging ideas and results about individual projects. SINET international link between Japan and Thailand serves as the infrastructure for this research collaboration; in terms of our individual project, we benefit from this international network for exchanging satellite data between the receiving station at Asian Institute of Technology and NII.

The main part of this paper discussed methods and ideas towards the comprehensive collection of typhoon imagery. To prevent or reduce damage from typhoons, indispensable are powerful techniques that can analyze current cloud patterns and predict typhoon evolution in the very early stage of the life cycle of the typhoon. The uniqueness of our research can be characterized by the “informatics paradigm,” which is based on various techniques that have been developed in the informatics community. The specific challenge in this paper was to enhance the quality of typhoon imagery over South East Asia. The idea was to combine satellite data from two types of satellites, namely geostationary satellites and polar orbiting satellites. The disadvantages in using GMS-5 in terms of resolution and distortion can be compensated by the incorporation of NOAA AVHRR data received in Thailand. The ultimate goal of this solution is to create the comprehensive collection of high quality typhoon imagery.

An important future work is to apply data mining approaches to this typhoon databases to discover relevant, possibly hidden rules or knowledge, that ultimately lead to novel typhoon analysis and prediction techniques. Among research issues stated in Section 2, cyclogenesis forecast and intensity forecast are the most interesting research issues. In terms of typhoon disasters, we should also point out that the integration of typhoon information databases with geographic information systems (GIS) will be an important part of our research under the conception that meteorological data are one example of geographical data. Finally, we need to develop novel network technologies for the efficient exchange of satellite data through the Internet.

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