GLOBAL ENVIRONMENTAL SATELLITE DATABASE BASED ON NETWORKS
PROJECT AND RELATED ACTIVITIES
AT THE SCIENCE UNIVERSITY OF TOKYO

MIKIO TAKAGI

Department of Applied Electronics
Faculty of Industrial Science & Technology
Science University of Tokyo
Noda, Chiba 278-8501 Japan
Tel: +81-471-20-1700  FAX: +81-471-20-1702
e-mail: takagi@te.noda.sut.ac.jp

Abstract

A project "Global Environmental Satellite Database Based on Networks", connecting six institutions, which are very active in data utilization of environmental satellites NOAA and GMS, via high speed networks has started. The aim of this project is to construct AVHRR (Advanced Very High Resolution Radiometer) of NOAA satellite and VISSR (Visible and Infrared Spin Scan Radiometer) of GMS image databases and to create scientific data sets for land, ocean and atmosphere, vegetation index, sea surface temperature, cloud distribution maps and so on. It is expected that these data sets generated by high speed and huge volume data processing will promote academic researches on long term variations of land, ocean and atmosphere in Asia. In this paper the brief of this project and the related activities at the Science University of Tokyo are introduced.

1. INTRODUCTION

Earth observation from satellites offers huge information on global environment. And it is expected that long term, various and complex phenomena of global land, atmosphere and ocean can be analyzed utilizing the data sets derived from satellite information. A project "Global Environmental Satellite Database Based on Networks" has started, connecting six institutions, which are very active in data utilization of environmental satellites NOAA and GMS; Iwate University, Center for Atmospheric and Oceanic Studies, Faculty of Science, Tohoku University, National Institute for Environmental Studies, Science University of Tokyo, Center for Environmental Remote Sensing, Chiba University, and Institute of Industrial Science, University of Tokyo, via high speed networks. The aim of this project is to construct AVHRR (Advanced Very High Resolution Radiometer) of NOAA satellite and VISSR (Visible and Infrared Spin Scan Radiometer) of GMS image databases and to create scientific data sets for land, ocean and atmosphere, vegetation index, sea surface temperature, cloud distribution maps and so on generated by high speed and huge volume data processing for the promotion of academic researches on long term variations of land, ocean and atmosphere in Asia.
The role of the Science University of Tokyo is mainly focused on generation of cloud parameter and sea surface temperature maps using VISSR. As the basic first step, geometric correction of VISSR images has been investigated and come to the level for practical utilization. In parallel, basic studies for cloud classification, sea surface temperature and rainfall monitoring using TRMM data are carried on.

2. ORGANIZATION

NOAA satellite data are received and archived at the Institute of Industrial Science, University of Tokyo, Center for Atmospheric and Oceanic Studies, Faculty of Science, Tohoku University, National Institute for Environmental Studies, Center for Environmental Remote Sensing, Chiba University, and Asian Institute of Technology and GMS satellite data is received and archived at the Institute of Industrial Science, University of Tokyo as shown in Table 1. Since these data are archived and processed independently at each facility, it has been difficult to promote long-term analysis and studies covering wide area merging these data. In this project, connecting the above mentioned six institutes in Japan and one institute in Thailand via high speed networks, NOAA AVHRR and GMS VISSR data are integrated on a cyberspace and scientific data sets of land, ocean and atmosphere by processing these data are generated and archived. These archives covers wide area from East Asia to South East Asia for more than 10 years. Applying high speed huge volume data processing using latest physical parameter estimation algorithms to the AVHRR data base, daily vegetation index map and sea surface temperature map are generated at 1 km spatial resolution. Cloud distribution map at every hour is generated using the VISSR data base. And long-term variations of land, ocean and atmosphere in wide Asian region are studied using these data base.

The volume of archived raw data is over 10 TB and the volume of processed data it is estimated to be from 20 to 30 TB. Exchanging these satellite data by network and merging, the following new researches become possible:

<table>
<thead>
<tr>
<th>Institution</th>
<th>Receiving Station</th>
<th>Starting Year of Reception</th>
<th>Data Volume (TB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOAA Data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Institute of Industrial Science, University of Tokyo</td>
<td>Tokyo</td>
<td>1983</td>
<td>2.5</td>
</tr>
<tr>
<td>Center for Atmospheric and Oceanic Studies, Faculty of Science, Tohoku University</td>
<td>Sendai</td>
<td>1988</td>
<td>2.0</td>
</tr>
<tr>
<td>Center for Environmental Remote Sensing, Chiba University</td>
<td>Mongola Chiba</td>
<td>1997</td>
<td>0.3</td>
</tr>
<tr>
<td>National Institute for Environmental Studies</td>
<td>Tsukuba Kuroshima</td>
<td>1995</td>
<td>0.3</td>
</tr>
<tr>
<td>Asian Institute of Technology</td>
<td>Bangkok</td>
<td>1997</td>
<td>0.5</td>
</tr>
<tr>
<td>GMS Data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Institute of Industrial Science, University of Tokyo</td>
<td>Tokyo</td>
<td>1995</td>
<td>4.5</td>
</tr>
</tbody>
</table>
(1) Merging AVHRR data received by stations of this project, a long-term and continuous data base is generated for long-term observation of changes of phenomena.

(2) Merging data received by stations in Japan, Mongolia and Thailand, observations of land, ocean and atmosphere covering wide Asia region as shown in Figure 1.

(3) AVHRR features observation with high spatial resolution and multiple wave lengths and VISSR features frequent observation every hour. Merging both features high spatial and temporal observations become possible.

As for networks, SINET (Science information Network) is fully utilized. SINET is dedicated to academic researches and operated by NACSIS (National Center for Science information Systems; National Institute for Informatics from April, 2000) and its backbone from Hokkaido to Kyushu has very wide band width and is connected to major academic computer centers. And SINET has the dedicated channel between Tokyo and the United States, Europe, and Bangkok. Owing to the channel between Bangkok and Tokyo, the NOAA AVHRR data received at the Asian Institute of Technology located in the suburbs of Bangkok is transferred to the Institute of Industrial Science, University of Tokyo, immediately after its reception.

The network configuration of this project is shown in Figure 2.
3. RESEARCH PLAN
The following 6 sub-themes are planned:

1) AVHRR and VISSR image data transfer via high speed network (SINET) and data base construction
University of Tokyo, Iwate University, National Institute for Environmental Studies
● Masaru Kitsuregawa (University of Tokyo)
  Network design
● Kiyoshi Honda (Asian Institute of Technology)
  Processing of data received at AIT

2) Generation AVHRR basic data set of Asian region
University of Tokyo, Iwate University, National Institute for Environmental Studies
● Yoshimine Yasuoka (University of Tokyo)
  Vegetation index
● Ryosuke Shibasaki (University of Tokyo)
  Geometric correction
● Ryuzo Yokoyama (Iwate University)
  Atmospheric correction
● Masayuki Tamura (National Institute for Environmental Studies)
  Mosaicing

3) Generation of land cover map of Asian region based on AVHRR data
Chiba University
● Yasuhiro Sugimori and Yoshiaki Honda
  Land cover classification

4) Generation of sea surface temperature maps of sea surrounding Asian region and Western North Pacific
Tohoku University
● Hiroshi Kawamura
  Estimation of sea temperature

5) Generation of cloud parameter and sea surface temperature maps using VISSR
Science University of Tokyo
● Mikio Takagi
  Estimation of cloud and sea surface temperature

6) Environmental change studies of Asian region using long-term, wide and high spatial resolution vegetation index, sea surface temperature and cloud parameter
All institutions

4. ACTIVITIES AT THE SCIENCE UNIVERSITY OF TOKYO
4.1 High speed data transfer via SINET
VISSR and AVHRR data received and archived at the Institute of Industrial Science, University of Tokyo, are transferred to the Science University of Tokyo in Noda via SINET. And it was proved that a GMS VISSR image received every hour can be transferred within several minutes without error.

4.2 GCP (Ground Control Point) database
The shore line data base for GMS observation area (80 North to 80 South and 60 East to 140 West) is generated, using DCW (Digital Chart of the World), and it is hierarchical in multi-resolution (0.01, 0.04, 0.16 and 0.64 degrees), considering to overlay different resolution images, which users prefer. Ground control points are necessary to check the accuracy of geometric correction and to measure the residual error vector of each GCP to be used for precise geometric correction. GCP data base has been generated in 0.01 degree scale for NOAA AVHRR and GMS visible data and 0.04 degree scale for GMS infrared data and 1,422 GCP's have been selected. Each GCP template is a piece of 32x32 picture elements and each entry of GCP data base has parameters such as GCP number, name, latitude, longitude, and height. This data base is open for public use. Please visit the following
Figure 3  Examples of Ground Control Points

site:
(http://labul21.te.noda.sut.ac.jp/~kaibai/research/coastline/coastline.html)

Figure 3 shows examples of GCP's, which have features in shape for easier template matching and Figure 4 shows the distribution of selected GCP's in GMS coverage.

Using this GCP template, residual error vector is measured by template matching of 64x64 picture element satellite observed image and GCP template of 32x32 picture elements using SSDA (Sequential Similarity Detection Algorithm). Each matching result is also put into error measurement data base, where original 64x64 image, its histogram and characteristics such as threshold level, separation measure and variance, coincidence measure, error vector, and success or not. This data base is used to discriminate confident GCP error vectors.

4.3 Geometric correction of GMS images

Geometric correction algorithm for GMS VISSR images are under development. A raw round full disc GMS image is mapped into map coordinate. In our system, equi-longitude and equi-latitude map coordinate system is used as shown in Figure 5. The region from 70 degree North to 70 degree South and from 70 degree East to 150 degree West is mapped at the resolution of 0.01 degree for visible image (14,000x14,000 picture elements) and that of 0.04 degree for infrared image (3,500x3,500 picture elements). Geometric correction is the basis to register the mapped images for the analysis of time-varying phenomena. The geometrically corrected data is used to generate data sets of sea surface temperature map and cloud classification.

Geometric correction of GMS images is processed in two steps. First step is systematic correction and second one is precise correction. In systematic correction the correspondence of an image picture element and its earth coordinate (longitude and latitude) and vice versa is calculated using orbit and scan information. If this process is applied to every point, 14,000x14,000 operations (196 M operations) are required. Therefore, to save the time, dividing an image into small blocks, accurate correspondence is calculated only at four corner points of a block and correspondence of the points within the block is simply calculated using bilinear interpolation. The block size is determined under the condition that the error due to bilinear
(a) Geometric Correction without Height Compensation

(b) Geometric Correction with Height Compensation

Figure 5 Effect of Height in Geometric Correction

(a) Without Height Compensation
(b) With Height Compensation

Figure 6 Effect of Height Compensation in Systematic Geometric Correction
interpolation is less than 0.5 picture elements. It is found that the height should be taken into account, if a point is located far from the nadir of the satellite and its altitude is very high, because the viewing angle from the satellite is large and image is much distorted. Figure 5 shows the effect of height compensation in systematic geometric correction using GTOPO30. And Figure 6 shows the residual error vectors in systematic geometric correction. In Figure 6 (a) Without Height Compensation, very large errors are found in Himalayan area. And they are much improved in (b) With Height Compensation.

After the systematic geometric correction, there still remain a fairly large residual errors as shown in the third column of Table 2. Therefore, precise geometric correction is needed as the second step. Measuring residual errors using GCP's and selecting the succeeded matching GCP's, precise geometric correction using Affine transform is applied to systematically corrected image. The algorithm to collect reliable error vectors automatically has been investigated using binary and ternary thresholding and line template matching. And the measurement of residual errors in map coordinate and that of in image coordinate are compared to calculate Affine transform coefficients and it was shown that error vector measurement in image coordinate results in much better, as expected, because map coordinate has much distortion. As the result, residual errors are less than 1 picture element in average and 2-3 picture elements in maximum, as shown in Table 2.

<table>
<thead>
<tr>
<th>Table 2 Residual Error of Geometric Correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systematic Correction (Latitude, Longitude)</td>
</tr>
<tr>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>GMS599021407</td>
</tr>
<tr>
<td>Average</td>
</tr>
<tr>
<td>GMS599122905</td>
</tr>
<tr>
<td>Average</td>
</tr>
</tbody>
</table>

Cloud Classification

Figure 7 Classification Result
4.5 Cloud classification and sea surface temperature

Using 3 infrared channels (IR1, GMS VISSR, clouds are classified. Based on the fact that a cloud, which has higher cloud top height, has lower temperature, clouds are classified by height using IR1 (10.5 to 11.5 μm) radiance temperature which has less atmospheric affects. Optically thin clouds with high transparency have larger radiance temperature difference between IR1 and IR2 (11.5 to 12.5 μm) and thick clouds with high cloud top height have less radiance temperature difference between IR1 and IR3 (6.5 to 7.0 μm), because absorption by water vapour is strong in IR3 and the sensor detects the radiation from high and middle clouds and from the upper and mid-tropospheric atmosphere.

Generation of sea surface temperature data set from GMS thermal infrared images is studies. To remove clouds, composite images of highest temperature at each picture element during a certain period were processed as shown in Figure 8. Here, 1 day composite image means that the image is composed of highest temperature data at each picture element in 24 one day images. Since 5 day composite images has less clouds, these images are produced as a standard data set.

4.6 Composite sea surface temperature map

Also, this composite sea surface temperature image offers a good reference to generate cloud mask. Since sea surface temperature differs according to latitude, current and location, it is difficult to find a threshold to distinguish lower cloud temperature and sea surface temperature; especially in night time data, where visible data cannot be available and cloud mask should be generated by using thermal infrared data; Using this composite image as a reference, rough threshold can be determined according the location. Cloud mask generation algorithm is under investigation, in which first probable clouds are detected by locally varying threshold using this composite sea surface temperature, then contour following adaptive thresholding eliminates ambiguity around cloud edges. Figure 9 shows an example of cloud mask generation algorithm.

![Figure 8 Composite Sea Surface Temperature image](image-url)
Figure 9 Cloud Mask Generation
4.7 Rainfall estimation using TRMM and GMS data

Cloud information can be obtained by GMS infrared and visible images, but it is very hard to estimate rainfall from visible and infrared images. Precipitation Radar (PR) on board TRMM (Tropical Rainfall Monitoring Mission) satellite can observe precipitation under cloud and measure the height distribution of rainfall. Rainfall was estimated, combining cloud classification based on brightness temperature described in 4.5 and rainfall data observed by PR. Figure 10 shows IR1 image, cloud classification, mean rainfall intensity, and percentage of rainfall.

4.8 Other activities

As for the application of GMS images, a study on typhoon data base has started. Automatic tracking algorithm is under development; after detecting its eye back tracking to its birth and tracking until its death.

Also, activities on NOAA satellite not mentioned here are continued.

Figure 10  Estimation of Rainfall Using TRMM and GMS Date
5. CONCLUSION

A project, to connect five institutions receiving and archiving environmental satellites NOAA and GMS via high speed networks, to construct AVHRR of NOAA satellite and VISSR of GMS databases, and to create scientific data sets for land, ocean and atmosphere, vegetation index, sea surface temperature, cloud distribution maps and so on, is introduced. This five year project started two years ago.

This project demonstrates huge volume high speed satellite image data transfer via networks and generate fundamental spatial data sets based on satellite observation by high speed and huge volume data processing for studies on long term variations of land, ocean and atmosphere in Asia. And it is expected to contribute international programs such as IGBP, IHDP and so on.