# The AVHRR Data Processing System in the Center for Atmospheric and Oceanic Studies in the Tohoku University



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# *The AVHRR Data Processing System in the Center for Atmospheric and Oceanic Studies in the Tohoku University*

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*Abstract* : AVHRR data processing system has been developed in order to investigate various phenomena in the ocean, over the land and in the atmosphere using AVHRR data in the HRPT received at the Center for Atmospheric and Oceanic Studies in the Tohoku University. The system extracts the AVHRR data from the HRPT data in the optical disk, processes them to obtain the brightness temperature and albedo, and produces geographically corrected images using the satellite orbit information. By using ground control points, the accuracy of geographic location in the processed image is achieved to be 1-1.5 km. The resultant output of the system is enough to be utilized for studies of atmospheric correction of the radiometric parameters and quantitative scientific researches.

## 1. Introduction

The NOAA series satellites have been used to monitor the atmosphere and the earth surface using remote sensing sensors since 1978 when TIROS-N was launched as the first of the series (Schwalb, 1978). This series of satellites continued with NOAA-A (renamed NOAA-6), NOAA-C (NOAA-7), NOAA-E (NOAA-8), NOAA-F (NOAA-9), NOAA-G (NOAA-10), NOAA-H (NOAA-11) and NOAA-D (NOAA-12) (Kidwell, 1991). All the satellites carried the Advanced Very High Resolution Radiometer (AVHRR), which is one of the most successful sensors for the earth observation.

The AVHRR represents an improvement over the VHRR sensor flown aboard the ITOS series of operational satellites (the last of which was NOAA-5). The AVHRR is a cross-track scanning system similar to the VHRR, but features four or five spectral channels, compared to just two for the VHRR. The AVHRR flown aboard TIROS-N, NOAA-6, NOAA-8, and NOAA-10 has four channels, and the AVHRR aboard NOAA-7, NOAA-9, NOAA-11 and NOAA-12 have five channels (Kidwell, 1991). Parameters of the AVHRR sensors are shown in Table 1.

The Earth Observing Satellite Center (EOSC) of the Tohoku University was established in 1988 as a receiving station of the HRPT data. The EOSC developed into a new

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Table 1. Parameters of the AVHRR sensors.

| | | | |
|---|---|---|---|
| Number of channels | | visible 2, infrared 2 or 3 | |
| Cross-track scan angle | | +55.4 (deg) | |
| Swath width | | 2930.2 (km) | |
| Line rate | | 360 (line/min.) | |
| Number of steps | | 2048 | |
| Step angle | | 0.054 (deg) | |
| Step time | | 0.0813 (ms) | |
| Optical FOV | | 1.3 (mr) | |
| Ground IFOV (nadir) | | 1.1 (km) | |
| Band width (m) | | | |
| | TIROS-N | NOAA−6, −8, −10 | NOAA−7, −9, −11, −12 |
| channel 1 | 0.55 − 0.90 | 0.58−0.68 | 0.58 − 0.68 |
| channel 2 | 0.725− 1.10 | 0.725− 1.10 | 0.725− 1.10 |
| channel 3 | 3.55 − 3.93 | 3.55 − 3.93 | 3.55 − 3.93 |
| channel 4 | 10.50 −11.50 | 10.52 −11.50 | 10.30 −11.30 |
| channel 5 | / | / | 11.50 −12.50 |

research organization, Center for Atmospheric and Oceanic Studies (CAOS) in 1990. The HRPT data reception has been continued, and a large number of the HRPT data are stored in the CAOS (Kawamura *et al.*, 1993a). The AVHRR processing system has been developed to utilize the large data set of the archived HRPT. In this paper, the AVHRR processing system is described together with several analyzed results. In the CAOS, the HIRS/2 data processing system was also developed (Kawamura *et al.*, 1991).

## 2. AVHRR processing system

### *2.1 Flow of the AVHRR data from the HRPT to images*

In the CAOS, the archived HRPT data are stored in a optical disk with recording capacity of 5 gegabyte. In order to process and analyze the HRPT data, the main computer (MS-4120 produced by NEC corporation) for the HRPT data archive is used (Kawamura *et al.*, 1993a). The computer is connected to the Local Area Network of the glass fiber, called TAINS (Tohoku University Academic Allround Advanced Information Network System), to exchange information including the processed images.

For analyses of the processed images, a image processor (N7835/NEC) compatible with the main computer is used. The image processor enables us to create and display various types of the satellite images through image processing techniques installed in the hardware.

Just after the NOAA satellite passage over the station, the received HRPT data exist on the hard disk of the computer, and then transferred to the optical disk for permanent storage. Since the HRPT data must be on the hard disk for processing the HRPT data, the archived data are read from the optical disk and then all the AVHRR

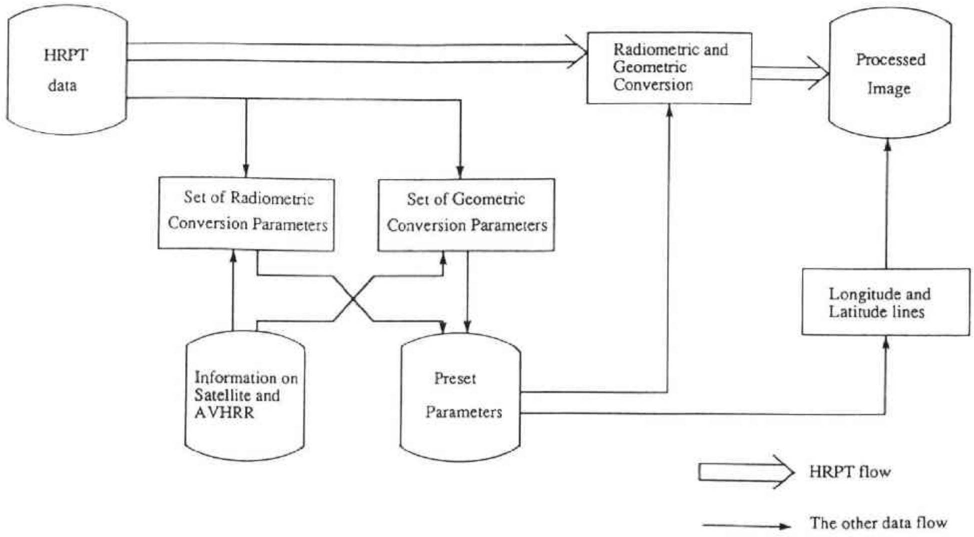


Fig. 1. Data flows associated with the HRPT data processing after tranfer from the optical disk.

data processing start. It takes about 20 minutes to transfer the data from the optical disk because of the large volume of the HRPT data (about 100 megabyte). This data transfer process takes time rather longer than the other processes and limits the number of the HRPT data to be analyzed here.

Fig. 1 shows data flows associated with the HRPT data processing after the transfer from the optical disk. In order to produce images for researches, radiometric and geometric conversion of the AVHRR data need to be made. The flow of the HRPT data shows the conversion processes. Parameters for the radiometric and geometric conversions are set before the HRPT data processes using the satellite and AVHRR information and the TBUS data added to the HRPT data (Kawamura *et al.*, 1993a). The preset parameters are referred in the AVHRR data processing and further modification of the processed image, such as addition of longitude and latitude lines (Fig.1).

### *2.2 Radiometric conversion*

Radiometric conversion involves determination of a relationship between the output of the radiometer and the intensity of the incident radiation and conversion of the sensor output to the radiometric parameters of the observation targets. All the radiometers flown on the NOAA satellites undergo extensive prelaunch testing and calibration by their manufactures to characterize their performance (Planet, 1988).

For the visible channel 1 and 2 of the AVHRR, the pre-launch calibration information is used to convert the count data to the radiation parameter. The target albedo (A) expressed as a percentage of that for a perfectly reflecting Lambertian surface illuminated by an overhead sun is linearly related to the count level ($X$) as

$$A = MX + I. \tag{1}$$

Values of the slope $M$ and the intercept $I$ are given for each AVHRR by the prelaunch calibration (Planet, 1988; Kidwell 1991). In fact, it is not occurred that the ground targets in the HRPT data in the CAOS are illuminated by the overhead sun, but in the conversion processes, eq. (1) is used to obtain the radiation parameter. It can be considered that the obtained parameter (A) is corresponding to reflectance, but sometimes called as albedo because of the definitions associated with eq. (1).

The infrared channels 3, 4, and 5 of the AVHRR perform in-orbit calibration, in which the sensors acquire the data of the space and the internal warm-blackbody target (IWT) as part of their normal scan sequences in orbit. Since the radiation of space is known as a constant ($N_{sp}$) and the IWT temperature is monitored by four platinum resistance thermistors, radiometric slopes and intercepts can be calculated for the infrared channels (Planet, 1988).

When the averaged IWT temperature is given as $T$, the radiance ($N_t$) sensed in a particular channel from the IWT at temperature T can be calculated as the weighted mean of the Plank function over the spectral response function of the channel. The observed radiance ($N$) is a linear function of the count output ($X$) of each channel, so that

$$N = MX + I \tag{2}$$

where $M$ is the slope, and I is the intercept. The quantity $M$ (in units of radiance/count) is calculated for each channel from the equation

$$M = (N_t - N_{sp})/(X_t - X_{sp}), \tag{3}$$

where $X_{sp}$ and $X_t$ are the mean counts associated with several observation of space and the IWT, respectively. The intercept is calculated for each channel as,

$$I = N_{sp} - MX_{sp}. \tag{4}$$

In the AVHRR data processing system, 5-scans of the AVHRR are sampled with a constant sampling interval from one scene of the HRPT data. As an average of 50 samples included in the 5-scans, we obtain $T$, $X_t$, $X_{sp}$ to determine a set of M and I for each of channel of the scene.

The non-linearity in the calibration is accounted for through the addition of a correction term to the brightness temperature of the scene. The appropriate correction term is determined by interpolation in a table of correction terms vs. scene brightness temperatures specified at 10-degree intervals between approximately 200 and 320°K. The corrections are also functions of the IWT temperatures, and given for the IWT temperatures of 10, 15, and 20°C for each channel (Planet, 1988; Weinreb *et al.*, 1990).

Fig. 2 indicates the corrections to be added to the scene temperature vs. scene temperature as a function of the IWT temperature for the AVHRR/NOAA11. The non-linearity correction procedure for the AVHRRs on board the NOAA satellites prior to the NOAA 9 is different from the above mentioned. The present AVHRR processing system can perform both the non-linearity correction procedures.

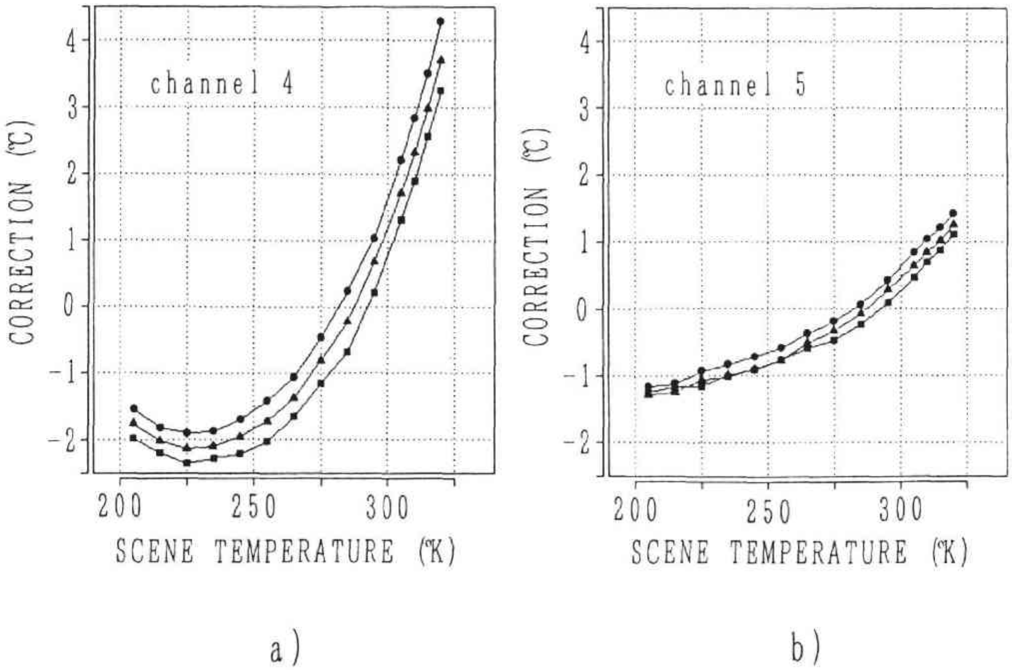


Fig. 2. Corrections to be added to the scene temperature vs. the scene temperature as a function of the IWT temterature. a) Channel 4, and b) channel 5 of the AVHRR/NOAA11. ●: IWT temperature 10°C, ▲: 15°C, ■: 20°C.

Fig. 3 shows the relation between the counts of the infrared channels and the corrected brightness temperatures. The system is designed so that the output temperature ranges from −55 to 47.3°C with resolution of 0.1°C, which corresponds to the 10-bits expression. This range is set for the standard products, but it is possible to change the output temperature range if necessary.

Fig. 4 demonstrates a computer-terminal display associated with the radiometric conversion. Information on the HRPT data reception is indicated in the upper column, and the lower parts show the IWT temperature, the corresponding radiation for each of the three channels, and the averaged counts for the space and the IWT ("OUTPUT" in the figure).

*2.3 Geometric correction*

The geometric conversion includes correction for geometric distortions due to the earth shape and the earth rotation. The ground instantaneous field-of-view (IFOV) with a constant solid angle (Table 1) depends on the scanning angle of AVHRR sensor. Fig. 5 shows the relationships between the AVHRR spatial resolution at the ground and the scan angle in the satellite path and the scan directions. Though the spatial resolution at the nadir is 1.1 km, it degrades to 6.5 km and 2.3 km at the scan angle of 54.4° in the satellite path and the scan directions, respectively. Geometric relation of the AVHRR

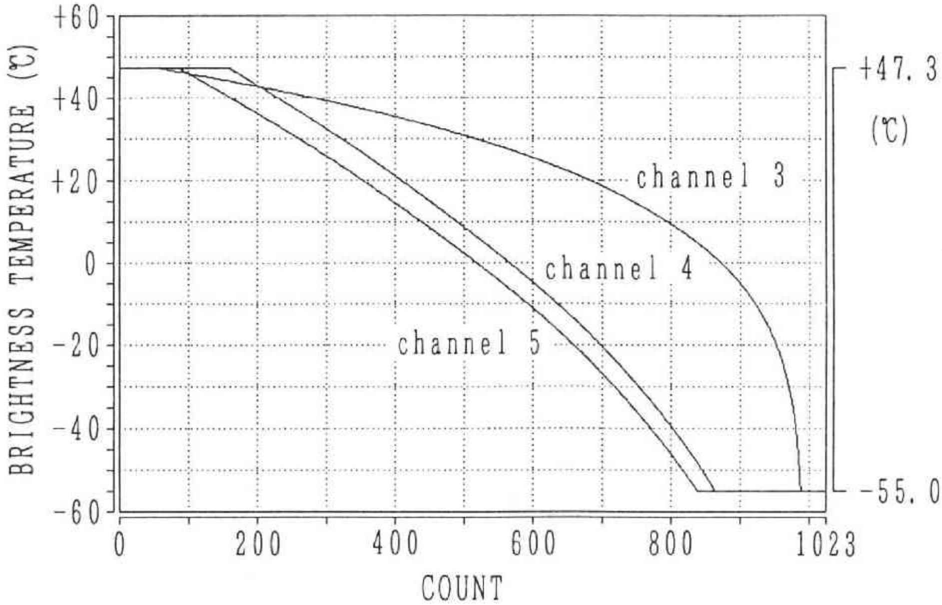


Fig. 3. Relation between the counts of the AVHRR/NOAA11 infrared channels and the corrected brightness temperatures for the IWT temperature of 14.958°C

```
 1993/06/14 0844:12.976 MON
>NOAA>NC>BU>NCRAD
**************************************************
*           RADIOMETRIC CONV. PREPARATION        *
*   SATELLITE NAME                     NOAA-12   *
*   ORBIT NUMBER                         10819   *
*   ASCEND / DESCEND                DESCENDING   *
*   RECEIVE TIME              1993/06/13 22:54   *
*   MINOR FRAMES                   4499 FRAMES   *
**************************************************
       WAIT!! CALIBRATION TABLE MAKING NOW
 ==============================================
  I.W.T TEMP.         289.381 (°K)  16.231 (°C)
                        CH3      CH4       CH5
  I.W.T RADIATION     0.437    96.465   110.495
        OUTPUT      731.620   387.440   381.540
  SPACE OUTPUT      998.140   995.060   999.160
 ==============================================
       CALIBRATION TABLE COMPLETION
STOP
```

Fig. 4. An example of the computer-terminal display associated with the radiometric conversion. The HRPT data was received at 22 : 54 on June 13, 1993.

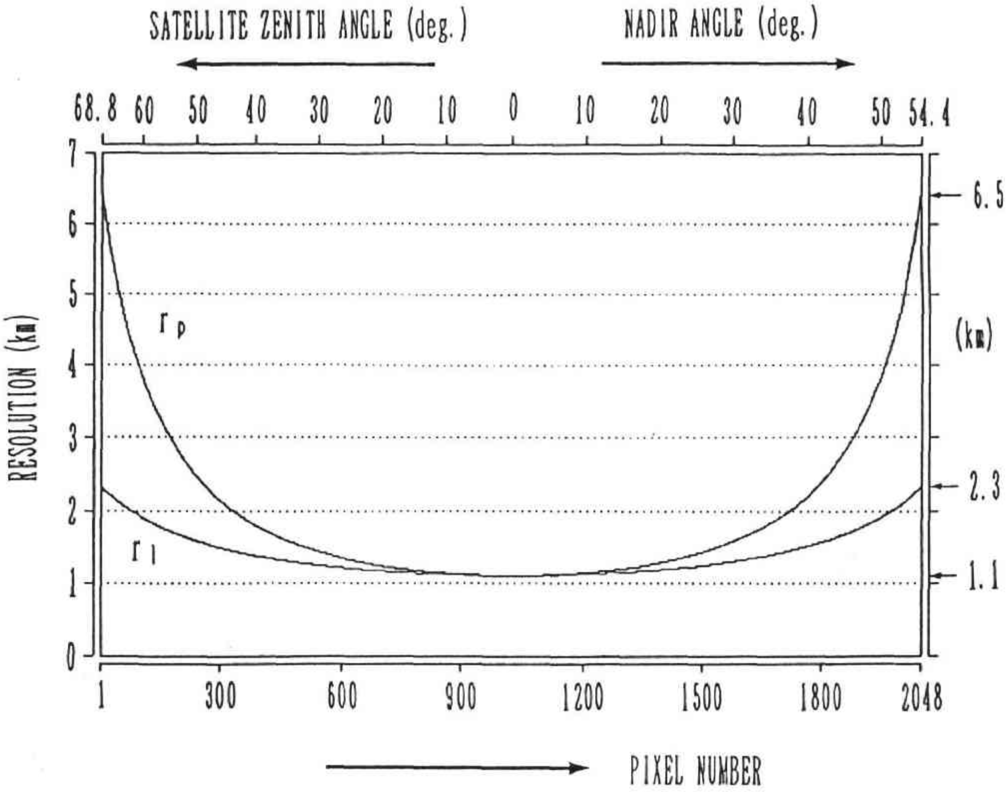


Fig. 5. Relationships between the spatial resolution at the ground and the scan angle in the satellite path direction and the scan direction.

observation in a scene of the HRPT data is illustrated in Fig. 6.

The distortions of the AVHRR data due to the earth shape and the earth rotation are corrected by using ground position of each pixels relative to the satellite path. The TBUS data obtained through the JMG radio transmission (Kawamura *et al.*, 1993a) is used to calculate the NOAA satellite orbit, which relates the relative ground position to the geographic location of each pixel. However, though using the highly accurate satellite ephemeris data, the obtained geographic location is not always correct because of variation in the satellite orbit. Fig. 7 shows the location error due to the orbital variation. The error is estimated using geographic features clearly visible in the AVHRR channel-2 images (called Ground Control Points, GCPs). The number of the HRPT data examined to estimate the location error is 320, of which 225 were obtained by NOAA11 around noon and 95 by NOAA10 and 12 in the morning. The points are randomly scattering in the satellite path direction, but biased toward west in the scanning direction. The averaged location error is 0.80 pixel in the path direction and −2.86 pixel in the scan direction. It is widely known for AVHRR users community that the HRPT receiving time gets later and later. Kawamura *et al.* (1993a) have shown this tendency appearing in the archived HRPT data in CAOS. It is suggested that the

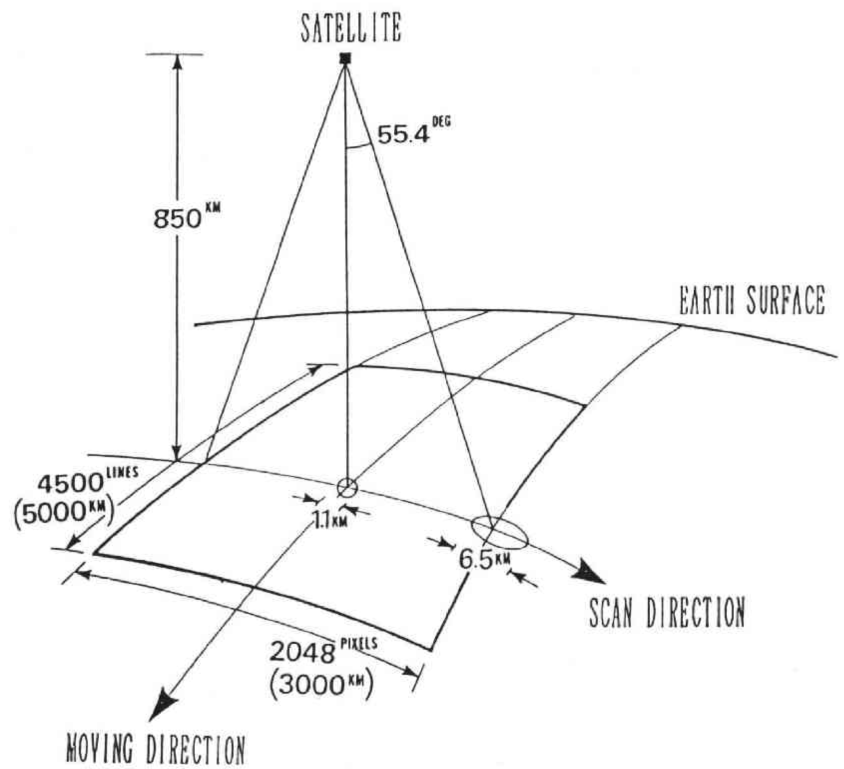


Fig. 6. A schematic picture of geometric relation of the AVHRR observation in a scene of the HRPT data.

westward bias of the location error may be associated with the shift of the HRPT receiving time.

In the present AVHRR processing system, the geometric conversion is made in two ways ; 1) to calculate the satellite orbit and determine the geographical location of each pixel, 2) to calculate the satellite orbit and then use a GCP for correction of the errors due to the orbit determination. The first method includes the location errors shown in Fig. 7. However the error is not so serious to investigate large-scale phenomena, such as the oceanic fronts and the cloud. The second method is used for researches, which require a precise geographical location, such as land researches in Japan (Kawamura and Edamatsu, 1993b). After the geometric conversion using the second method, the location error is estimated to be 1-1.5 km.

Parameters requested to perform the geometric conversion are a center location (latitude and longitude) of the image to be created, a size of one pixel at the ground, a size of the image in pixel and line, and map projection methods (the Mercator or Polar stereo methods). In the case of the Polar stereo projection, a location of the projection center is requested to be input. Examples of the images processed using various parameters are shown in Fig. 8, and the used parameters are listed in Table 2.

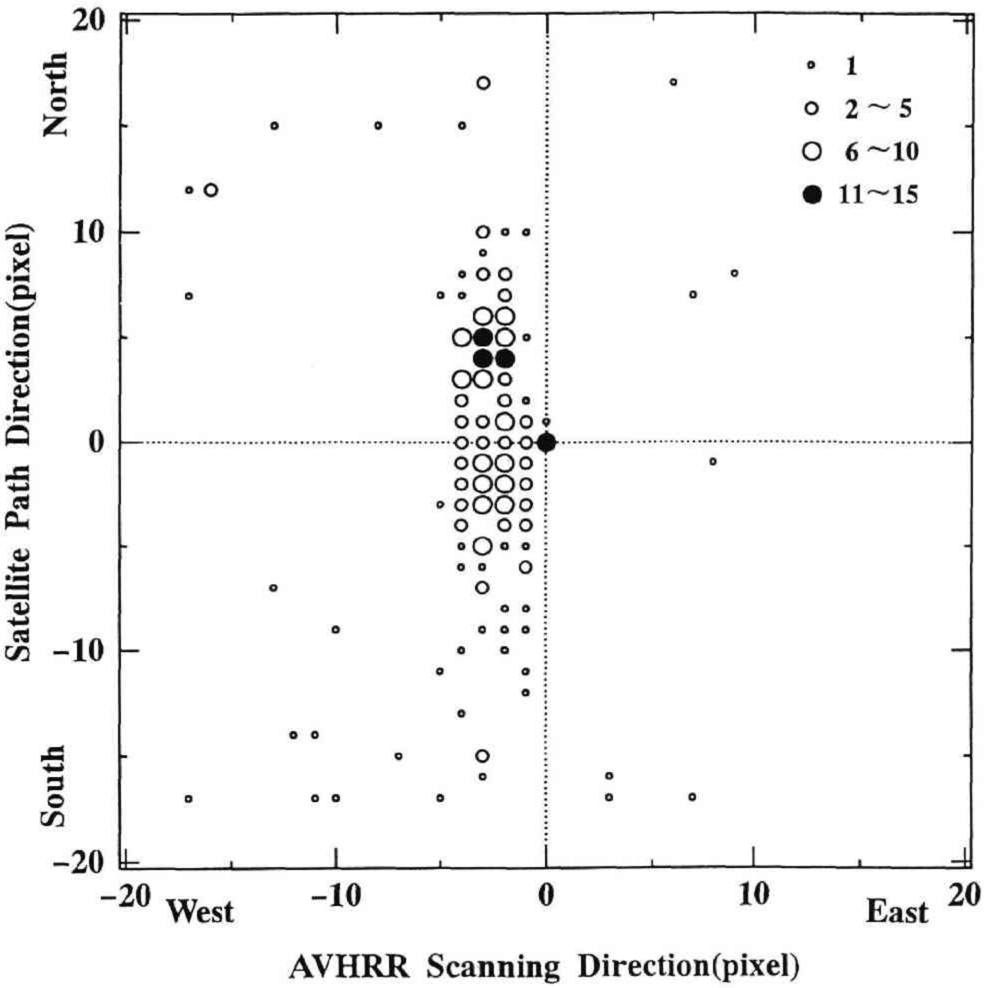


Fig. 7. Location errors due to the orbital variation (see the text).

The geometric conversion using a GCP, the GCP address (line and pixel) in the original AVHRR data and the location (latitude and longitude) of the GCP are needed to be input. In the actual process, we employ a edge detection of coast in the channel 2 image and a template matching method to obtain the GCP address. The template data of 66 GCPs at the coast of Japan are prepared. In the actual conversion process, we look at the quick-look image of the HRPT, find a clearly seen GCP among the 66 GCPs, and then input the number of the GCP to start the conversion.

## 4. Concluding remarks

AVHRR data processing system was developed to study various phenomena in the ocean, over the land and in the atmosphere using AVHRR data in the HRPT data

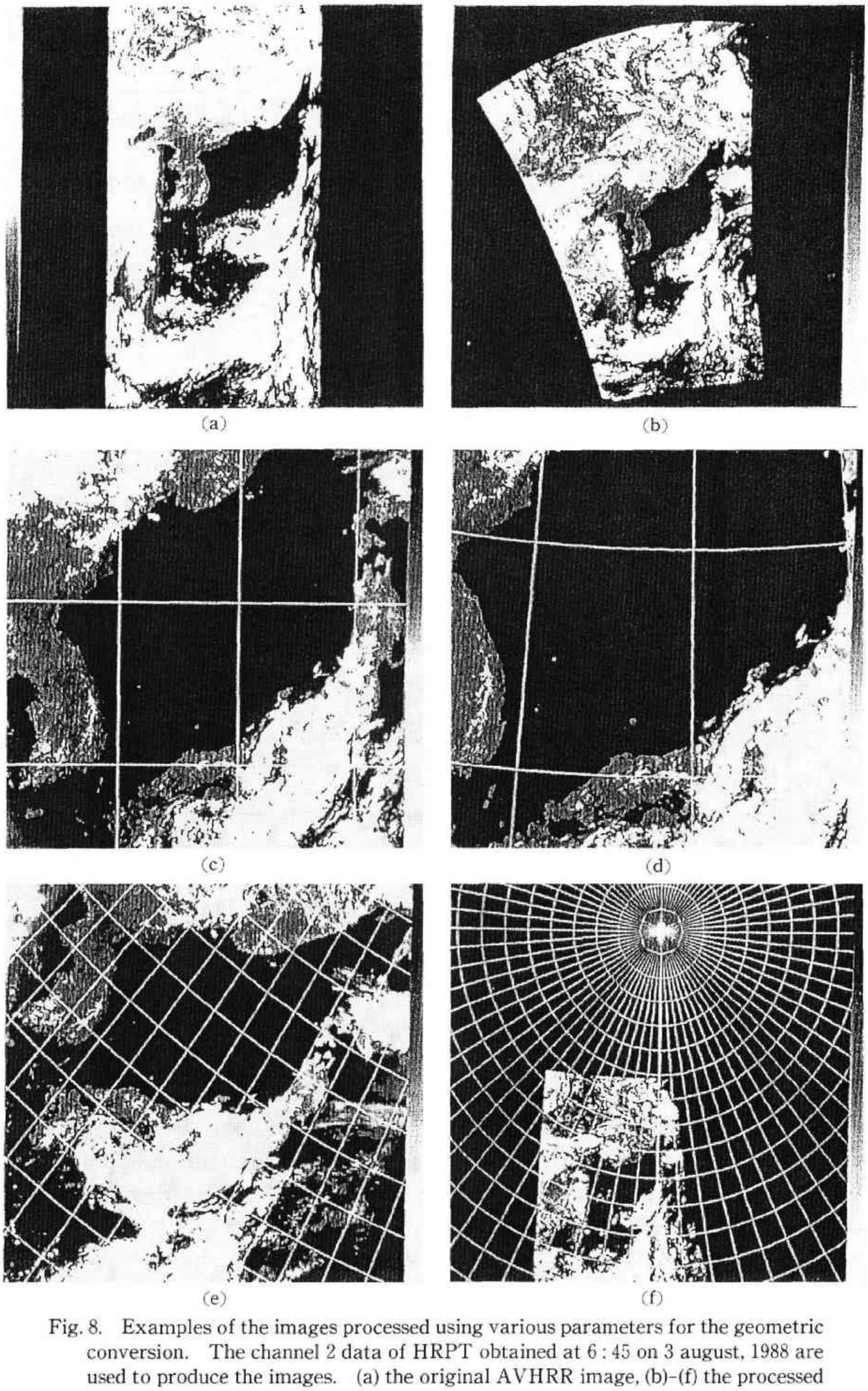

Fig. 8. Examples of the images processed using various parameters for the geometric conversion. The channel 2 data of HRPT obtained at 6 : 45 on 3 august, 1988 are used to produce the images. (a) the original AVHRR image, (b)-(f) the processed images.

Table 2. Parameters used to produce the images shown in Fig. 8.

| Image | Scene Center (Lat., Lng.) | Pixel Size | Image Size (pixel, line) | Method | Projection Center | Int. |
|---|---|---|---|---|---|---|
| (b) | (42°N, 130°E) | 5.9 | (1024×1024) | M | (42°N, 130°E) | - |
| (c) | (39°N, 134°E) | 5.9 | (1024×1024) | M | (42°N, 134°E) | 5 |
| (d) | (38°N, 134°E) | 1.1 | (1024×1024) | P | (38°N, 134°E) | 5 |
| (e) | (38°N, 170°E) | 2.0 | (1024×1024) | P | (38°N, 136°E) | 2 |
| (f) | (60°N, 140°E) | 10.0 | (1024×1024) | P | (60°N, 140°E) | 5 |

M: Mercator projection, P: Polar stereo projection, and Int.: Interval of the latitude and logitude lines.

received at the CAOS in the Tohoku University. The system extracts the AVHRR data from the HRPT data in the optical disk, processes them to obtain the brightness temperature and albedo, and produces geographically corrected images using the satellite orbit information and GCPs. The location accuracy of the geometric conversion using the GCP is 1-1.5 km.

Since the radiometric conversion is made in the standard manner presented by NESDIS/NOAA (Planet, 1988), it is possible to examine atmospheric correction results in comparison with the NOAA's results. Sakaida and Kawamura (1992a, b) have studied estimation method of the sea surface temperature (SST) around Japan, including the atmospheric correction. They compared the satellite-derived SST with the buoy SST, utilizing the GCP geometric conversion method. Precise matching of the locations between the satellite and the ground observations is one of the essential factors in the comparison.

Kawamura *et al.* (1993b) have used the satellite-derived SST to estimate the air-sea fluxes in the ocean south of Japan. Kawamura and Edamatsu (1993) produced a image database for land and coastal researches, in which the precise geographical mapping of the images was quite important. The present AVHRR processing system has provided enough quality results required for these studies.

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## References

Kawamura, H., S. Takahashi, F. Sakaida, S. Okano, and H. Fukunishi, 1991: The HIRS/2 data processing in the Earth Observing Satellite Center of Tohoku University, *Tohoku Geophys. Journal (The science reports of the Tohoku University, Series 5)*, **34**, 1-12.

Kawamura, H., F. Sakaida, S. Kizu, and Toba 1993a: The NOAA-HRPT data receiving system in the Center for Atmospheric and Oceanic Studies in the Tohoku University, *Tohoku Geophys. Journal (The science reports of the Tohoku University, Series 5)*, **34**, 89-102.

Kawamura, H., Kizu, S., Sakaida, F., Ebuchi, N. and Toba, Y., 1993b ; Study on air-sea interactions in the OMLET (Ocean Mixed Layer ExperimenT) area using satellite remote sensing, *in "Remote Sensing of the Oceans" ed. Jones, Sugimori and Stewart.* (in press)

Kawamura, H. and Y. Edamatsu, 1993 : N-Land database for researches of the Japanese land and coastal area with complicated geographical features, *IGARSS '93, Spons. by IEEE, Kogakuin University, Tokyo, Aug. 18-21, 1993,* **4**, 1941-1943.

Kidwell, K.B., 1991 : NOAA polar orbiter data users guide, *NOAA/NESDIS/NCDC/SDSD, Washington, D.C.*, p. 187.

Planet, W.G., 1988 : Data extraction and calibration of TRIOS-N/NOAA radiometers, *NOAA Tech. Memo. NESS 107-Rev. 1, Washington, D.C.*, pp. 58.

Price, J.C., 1991 : Timing of NOAA afternoon passes, *Int. J. Remote Sensing,* **12**, 193-198.

Sakaida, F. and Kawamura, H., 1992a : Estimation of Sea Surface Temperature using AVHRR on NOAA11, *J. Oceanography,* **48**, 179-192.

Sakaida, F. and Kawamura. H, 1992b : Accuracies of NOAA/NESDIS sea surface temperature estimation technique in the oceans around Japan, *J. Oceanography,* **48**, 345-351.

Schwalb, A., 1978 : The TIROS-N/NOAA satellite series, *NOAA Tech. Memo. NESS 95.*

Smith, W.L., H.m. Woolf, C.M. Hayden, D.Q. Wark and L.M. McCMillin, 1979 : The TIROS-N Operational Vertical Sounder, *Bull. Amer. Meteor. Soc.*, **60**, 1177-1187.

Weinreb, M.P., G. Hamilton, S. Brown, and R.J. Koczor, 1990 : Nonlin-earity corrections in calibration of Advanced Very High Resolu-tion Radiometer infrared channels, *J. Geophys. Res.*, **95**, 7381-7388.