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The HIRS/2 Data Processing System in the Earth Observing Satellite Center of Tohoku University

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Abstract: The second version of the High resolution Infrared Radiation Sounder (HIRS/2) on board the NOAA satellite series has been used to monitor vertical profiles of temperature and moisture in the global atmosphere. In order to utilize the HIRS/2 data for various types of scientific studies, we have developed a HIRS/2 processing system, which extracts the HIRS/2 data from NOAA-HRPT data, and processes them to obtain the brightness temperature and makes geocoded images. This paper describes the HIRS/2 data processing system. Some processed results are also shown.

1. Introduction

The TIROS-N series of the NOAA environmental satellites was introduced with the launch of the protoflight satellite TIROS-N on October 13, 1978. This satellite was followed by the NOAA-6 and -7 satellites launched on June 27, 1979 and June 23, 1981, respectively, and since then the two-satellite system has been operational with their orbital planes approximately 90 degrees apart. NOAA series satellites are in solar synchronous polar orbits with an inclination of 98.7 degrees from equatorial plane. The altitude of the satellites is about 833 km and the orbital period is 102 minutes. At present (March, 1991), the NOAA-10 and NOAA-11 satellites are in operation. NOAA-10 passes over Japan at around 9 UT (18 Japan Standard Time, JST) and 22 UT (7 JST), while NOAA-11 passes at around 3 UT (12 JST) and 17 UT (2 JST).

The sensors on board the NOAA satellites are the Advanced Very High Resolution Radiometer (AVHRR), TIROS Operational Vertical Sounder (TOVS), the Space Environment Monitor (SEM), the Data Collecting System (DCS), the Solar Backscatter Ultraviolet Radiometer (SBUV/2), and so on.

The TOVS consists of three instruments: 1) the second version of the High resolution Infrared Radiation Sounder (HIRS/2), 2) the Microwave Sounding Unit (MSU), and 3) the Stratospheric Sounding Unit (SSU). The TOVS is a vertical sounding instrument capable of providing complete global coverage of vertical temperature data between the surface and the stratopause, and the total column moisture content of the stratosphere

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(Smith *et al.*, 1979). The HIRS/2 data are recorded on a tape recorder on board the NOAA satellites, and transmitted to the NOAA receiving station while passing over the United States. The HIRS/2 data observing a local area are transmitted while the Satellite is passing over that area. In Japan, the Meteorological Satellite Center of the Japan Meteorological Agency has been receiving the data and using them for their operational work (Meteorological Satellite Center, 1983).

The Earth Observing Satellite Center (EOSC) of Tohoku University has been receiving the NOAA-High Resolution Picture Transmission (HRPT) containing the data obtained from these instruments since April, 1988. In this paper, we describe our HIRS/2 data processing system, and show some processed results. This system is produced as a part of the NOAA-HRPT data processing system of the EOSC, so it is well matched with the received HRPT data and the other systems like the AVHRR data processing system.

2. HIRS/2 on Board the NOAA Satellite Series

The nominal instrumental parameters of HIRS/2 are listed in Table 1. The HIRS/2 is a scanning type radiometer with 20 channels (19 channels operating in the infrared region and one channel in the near infrared region). One scan line consists of 56 spots. The geometry of HIRS/2 sampling spots on the ground is shown in Fig. 1. The angle between two successive instantaneous fields of view (IFOV's) is 1.8 degrees, which gives a separation of about 26.6 km between centers of the two adjacent ground spots at the satellite nadir. One HIRS/2 scan crossing the satellite track covers ±49.5 degrees, which corresponds to a swath of about ±1,120 km on the ground. A scan time is 6.4 sec in which 5.6 sec is allotted to a sampling of 56 spots (0.1 sec for 1 spot) and the remaining 0.8 sec is left for sampling of supplemental data. The IFOV is 1.25 degrees and the corresponding ground resolution is about 17.4 km at the satellite nadir point. The distance between centers of two successive spots along the satellite ground track is 42

Table 1. The HIRS/2 Instrumental Parameters

Channels	IR-19 ; Visible-1
Calibration	Stable blackbodies (2-IWT, ICT) and space background
Cross-track scan	±49.5° (±1,120 km)
Scan time	6.4 seconds per line
Number of scan steps	56
Optical field of view	1.25°
Step angle	1.8°
Step time	0.1 seconds
Ground resolution	17.4 km (nadir)
Distance between IFOV's	42 km along-track (nadir)
Data rate	2,880 bits/second

(IFOV — Instantaneous field of view)

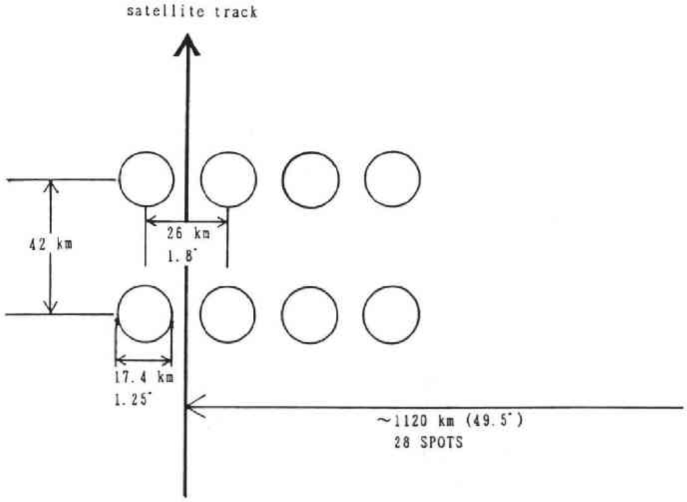


Fig. 1 The geometry of HIRS/2 sampling spots at the ground near the satellite nadir.

Table 2. Characteristics of HIRS/2 Sounding Channels

HIRS channel number	Channel central wavenumber	Central wavelength (μm)	Principal absorbing constituents	Level of peak energy contribution	Purpose of the radiance observation
1	668	15.00	CO_2	30 mb	
2	679	14.70	CO_2	60 mb	
3	691	14.50	CO_2	100 mb	
4	704	14.20	CO_2	400 mb	Temperature sounding
5	716	14.00	CO_2	600 mb	
6	732	13.70	CO_2/H_2O	800 mb	
7	748	13.40	CO_2/H_2O	900 mb	
8	898	11.10	Window	Surface	Surface Temperature and cloud detection
9	1028	9.70	O_3	25 mb	Total ozone concentration
10	1217	8.30	H_2O	900 mb	
11	1364	7.30	H_2O	700 mb	Water vapor sounding
12	1484	6.70	H_2O	500 mb	
13	2190	4.57	N_2O	1,000 mb	
14	2213	4.52	N_2O	950 mb	
15	2240	4.46	CO_2/N_2O	700 mb	Temperature sounding
16	2276	4.40	CO_2/N_2O	400 mb	
17	2361	4.24	CO_2	5 mb	
18	2512	4.00	Window	Surface	Surface temperature
19	2671	3.70	Window	Surface	
20	14367	0.70	Window	Cloud	Cloud detection

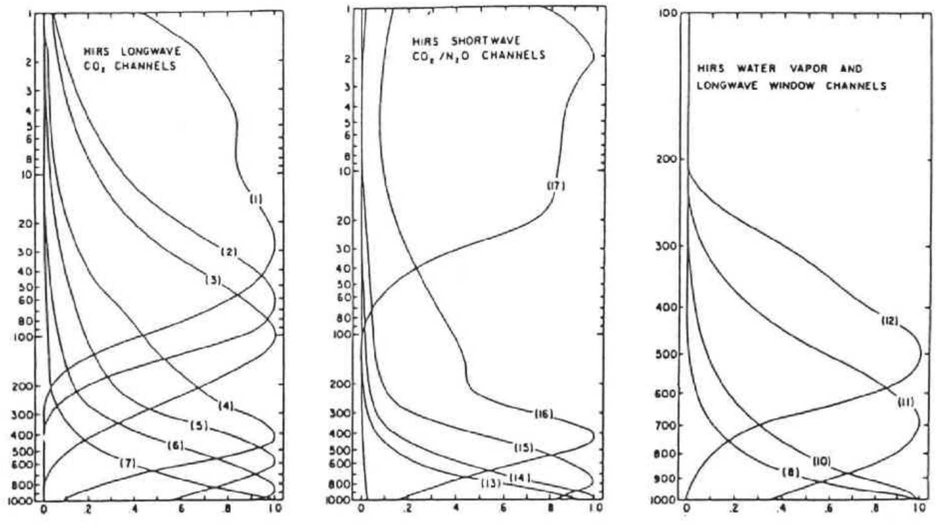


Fig. 2 HIRS/2 weighting functions. (from Smith *et al.*, 1979)

km at the satellite nadir.

Table 2 shows spectral characteristics of the 20 channels of HIRS/2 (Smith *et al.*, 1979). Channels 1 to 7, used for the determination of vertical temperature profiles, are in the CO_2 15 μm spectral band. Channel 8 is in the 11 μm atmospheric window region and monitors surface or cloud-top temperature. Channel 9 is in the 9.7 μm band and the data are used for derivation of total ozone amounts. Channels 10 to 12 are used to determine vertical moisture distributions and to provide the other channels with information needed to make corrections for water vapor. Levels of peak energy contributions (weighting functions) for each channel are shown in Fig. 2.

3. HIRS/2 Data Processing System

The Tohoku University EOSC, which was established in 1988, has been receiving High Resolution Picture transmission (HRPT) data from the NOAA statellites. All of the received HRPT data have been stored in optical disks since April, 1988 (Kawamura and Toba, 1991). The HRPT data transmitted from the NOAA satellites include the data observed by all sensors and all supplemental data.

Figure 3 shows a flow of HIRS/2 data processing. There are seven steps in the data processing ; (1) HIRS/2 data extraction from the original HRPT data, (2) rewriting the HIRS/2 data, in which both the observation data and supplemental instrument data are stored in a file (HIRS. HI), (3) preparation for geometric conversion, (4) preparation for radiometric conversion, (5) radiometric conversion from the raw digital counts observed by each channel to the brightness temperature or albedo values, which are stored in an HIRS.RS file, (6) geometric correction to produce an image file in order to project the data on a map, and (7) extracting to data at ground locations at specified latitude and

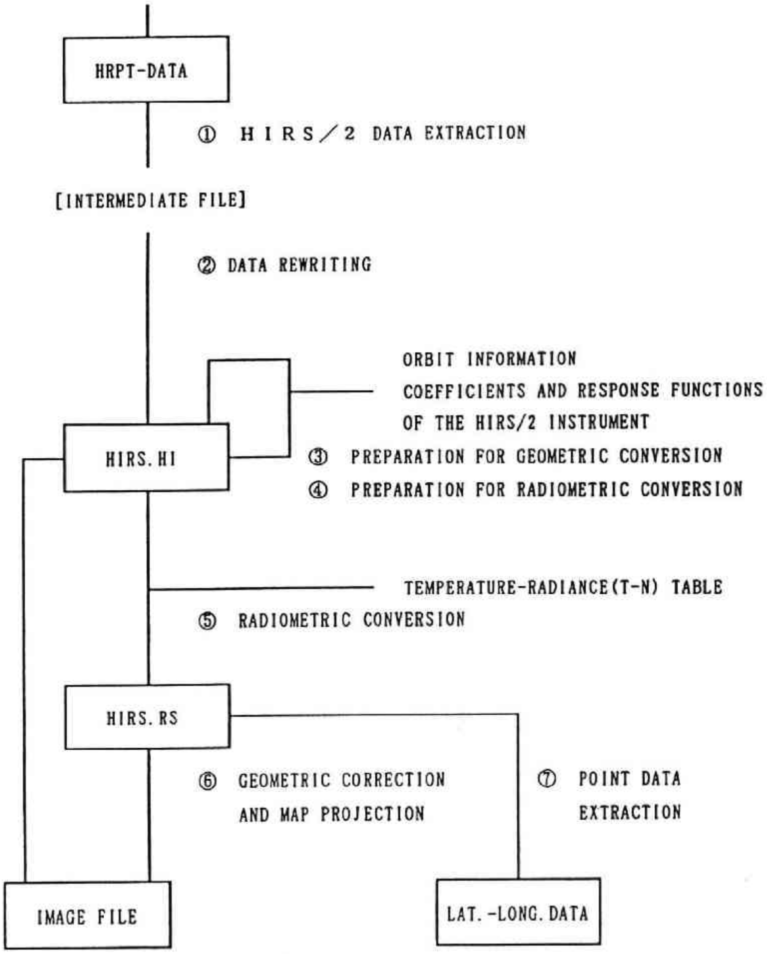
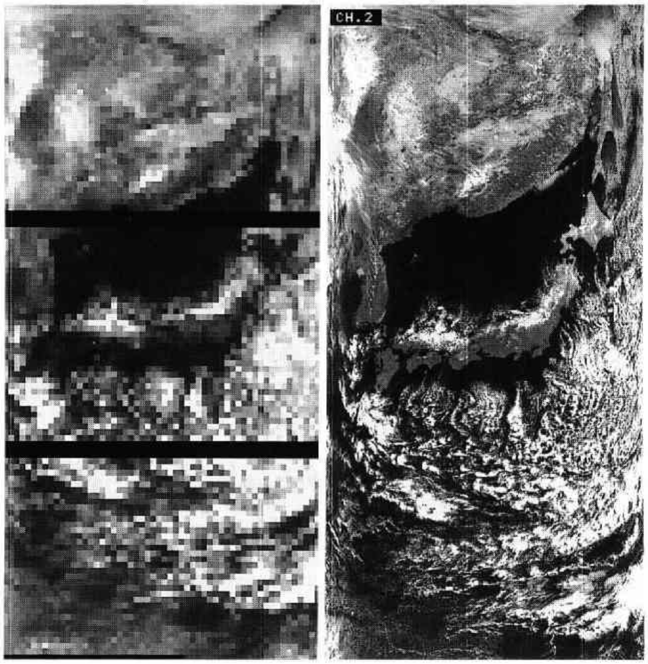


Fig. 3 The outlines of HIRS/2 data processing at the EOSC of Tohoku University.

longitude. The original HRPT data files are about 100 MByte, but the HIRS.RS files are reduced to about 2 MByte.

Figure 4(a) shows an example of an image constructed form the HIRS/2 channel 20 data stored in an HIRS.HI file, and (b) is the corresponding AVHRR-channel 2 (0.725-1.10 μm spectral band, in the near infrared region) image. Since the spectral regions of both the HIRS/2 channel 20 and AVHRR channel 2 are about the same, the difference in the images shown in Fig. 4 is due to the difference in the spatial resolution of both the sensors. Due to the low spatial resolution of the HIRS/2, it is difficult to see detailed structures of land and clouds when compared with AVHRR images. A final image of HIRS/2 channel 20 data, for which the preliminary data is shown in Fig. 4(a), is presented in Fig. 5. Every pixel of the image has been converted to a radiance value, and projected on a map. For the convenience of later analyses, coastal lines are superimposed. Good agreement between the processed HIRS/2 image and coastlines can be seen in Fig. 5 (and



(a) (b)

Fig. 4 (a) An image from HIRS/2 channel 20 constructed from the data in an HIRS.HI file. The data were obtained from NOAA-11 at 04 (UT) on February 14, 1989. Two sets of calibration lines are seen (shown in black). (b) An image of AVHRR channel 2 (visible channel) corresponding to (a).

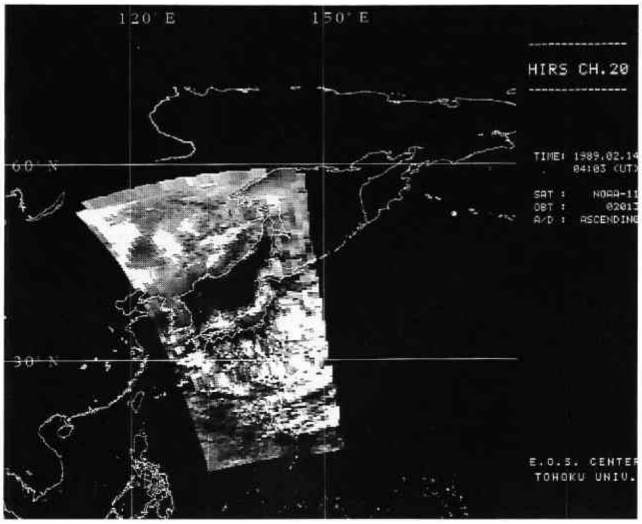


Fig. 5 A result of geometric conversion and map projection. Data from HIRS/2 channel 20, which are the same as those shown in Fig. 4(a), are used. Coastlines are also superimposed.

also in Fig. 4).

We now describe the processing of HIRS/2 data in detail. The HIRS/2 data along with the SSU, MSU, SEM, DCS, SBUV/2 are included in the TIROS Information Processor (*TIP*) data which is a part of the HRPT data. One record of the HRPT data (1 minorframe of HRPT data) includes one scanning line of the AVHRR sensor and 5 *TIP* data (5 minorframes of *TIP* data). The same *TIP* data are included in the 3 successive minorframes of HRPT data. One minorframe of *TIP* data includes the HIRS/2 data of 20 channels observing one scan spot, and 64 minorframes of *TIP* data constitute the HIRS/2 data corresponding to one scanning line, in which 56 minorframes are allotted to 56 observational spots and the remaining 8 minorframes include the supplemental instrument data. In the HIRS/2 data extraction shown in Fig. 3 (step (1)), the HIRS/2 data are extracted from the HRPT data and written in an intermediate file, with each HIRS/2 scanning line written together with the satellite navigation information. The formats of HRPT and *TIP* data are described in NOAA/NESDIS (1988).

The data in the intermediate file are rewritten to the HIRS.HI file in a form convenient for later processing (step (2)). In the process of preparation for geometric conversion, the orbit of the NOAA satellite is calculated and, at the same time, latitudes and longitudes are calculated for every seven HIRS/2 observing spots and every nine scanning lines. The coefficients of polynomial expressions for an approximation of the orbit of the NOAA satellite and the calculated latitudes and longitudes are also written in the HIRS.HI file (step (3)).

In the process of radiometric conversion preparation (step (4)), coefficients are calculated in order to convert count data from the HIRS/2 sensor into radiances. The relation between the radiance (N) observed by the HIRS/2 sensor and the digital count output (X) is expressed as,

$$N = G \cdot X + I, \tag{1}$$

where G and I are the calibration coefficients which are determined in this process. In order to perform internal calibration, the HIRS/2 sensor looks at two internal blackbodies and the space background while scanning 3 lines every 40 scanning lines. In Fig. 4(a), two black stripes indicate the 3 scanning lines for calibration. The two internal blackbodies are the Internal Warm Target (IWT) and the Internal Cold Target (ICT), whose temperatures are about 290 K for the IWT (specified as T_{IWT}) and from 260 K to 270 K for the ICT. These temperatures are monitored by eight thermistors, four embedded in the IWT and four in the ICT, and the observed temperatures are recorded in the supplemental instrument data. It is known that the ICT temperature changes in one orbital cycle because of solar heating and that it cannot be monitored reliably. Therefore, only the IWT and space-viewing data are used for the determination of calibration coefficients (NOAA/NESDIS, 1988). When T_{IWT} is converted into radiance (N_{IWT}) for each of HIRS/2 channels, the calibration coefficients G and I are determined as follows,

$$G = (N_{SP} - N_{IWT}) / (X_{SP} - X_{IWT}), \tag{2}$$

and

$$I = N_{SP} - G \cdot X_{SP}, \tag{3}$$

where N_{SP}, X_{SP} and X_{IWT} are the radiance of space, the mean counts for space-viewing and the mean counts of IWT-viewing samples, respectively. The value of N_{SP} is zero. The radiance N_{IWT} for a channel is obtained from the blackbody temperature T_{IWT} by calculating the weighted mean of the Planck function over the spectral response function of the channel. Detailed descriptions about the determination of T_{IWT} and N_{IWT} can be found in NOAA/NESDIS (1988).

Since about 120 scanning lines of HIRS/2 data can be useful in one overpassing of the NOAA satellite, two to three sets of IWT-viewing and space-viewing samples can be obtained (Fig. 4(a)). The output values of 4 thermistors are included in all scanning lines. These calibration data obtained in one overpassing of the satellite are averaged, to determine X_{SP}, X_{IWT} and T_{IWT}, and a set of calibration coefficients G and I are calculated. The single set of coefficients is applied to convert all earth-observing count data of infrared channels to brightness temperatures. These calibration coefficients for the infrared channels are written in the HIRS.HI file along with the calibration coefficients (provided by NOAA), for the near infrared channel (channel 20) to convert the digital count data into albedos.

In the process of radiometric conversion (step (5)), the count data are converted into brightness temperatures for channels 1 to 19 and into albedos for channel 20 by using the calibration coefficients. For channel 20, equation (1) is directly used for deriving albedo. However, for the channels in the infrared region, a Temperature-Radiance ($T-N$) table is used for deriving brightness temperature. The $T-N$ table has been created for each channel in advance by calculating the weighted mean of the Planck function over the spectral response function. Before the conversion of the observed counts, a count-temperature ($X-T$) table is created for convenience of data processing. First, a range of the measured counts in one overpassing is investigated for each of the channels. Equation (1) is transformed to

$$X = (N - I)/G, \tag{4}$$

and, the value of X is calculated from the radiance N which is included in the $T-N$ table. The calculated values of X are interpolated into integer counts in the range of the measured counts of X to create the $X-T$ table, which is used for the conversion from the counts of earth observation data to brightness temperatures. This conversion procedure is quite useful since there appear large numbers of the same count data. In addition, this $T-N$ table helps to convert the radiance, which is calculated by taking the absorption and emission of the atmosphere into account or by using atmospheric model profiles, into the brightness temperature. The radiances within the $T-N$ table have been calculated in the temperature range from 180 K to 320 K with a temperature resolution of 0.01 K for each channel.

Figure 6 shows the actual temperature resolution for channels 1 to 9, which corre-

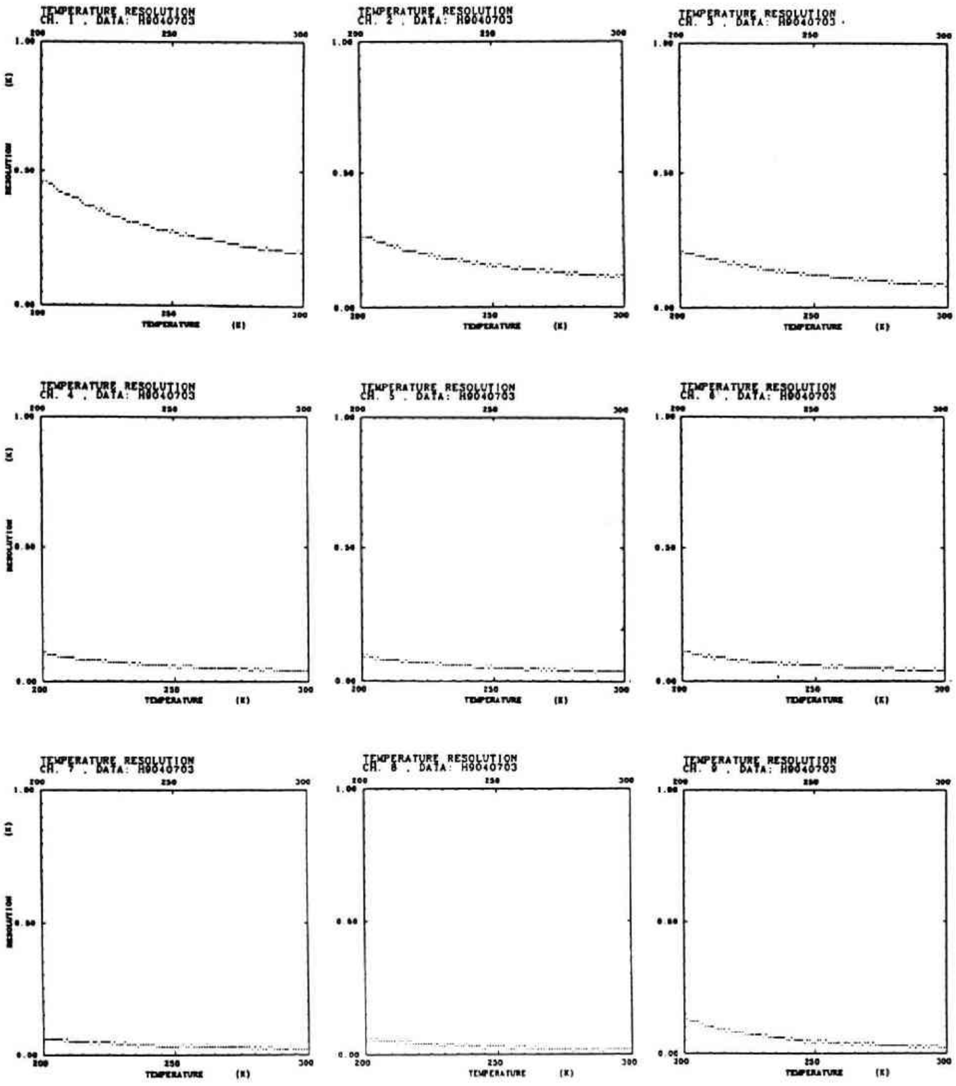


Fig. 6 The temperature resolution for channels 1 to 9 plotted against the brightness temperature.

sponds in the sensitivity of radiance to an increase of one digital count of the HIRS/2 output. The values are plotted against the brightness temperature. The temperature resolution, 0.01 K, of the $T-N$ table is sufficient because the actual temperature resolution of each channel is not as high as 0.01 K. It should be noted that the actual temperature resolution becomes worse when the noise contained in the count data is taken into account or there are large changes in X_{SP} or X_{IWT} values between each calibration line.

In the process of geometric correction (step (6)), a new file (image file) is created to project the data on a map. An example of a map projection is shown in Fig. 5. This map shows the area from 5°N to 85°N and from 100°E to 180°E with an equal grid interval. The lines in the figure are 30°N, 60°N, 120°E and 150°E. The data used in this figure are obtained from channel 20, the visible channel. Albedo is large in the region shown in white color. The coast of Japan is seen near the center of this image. The black stripes associated with the calibration lines shown in Fig. 4(a) are eliminated by interpolation from the data in adjacent lines.

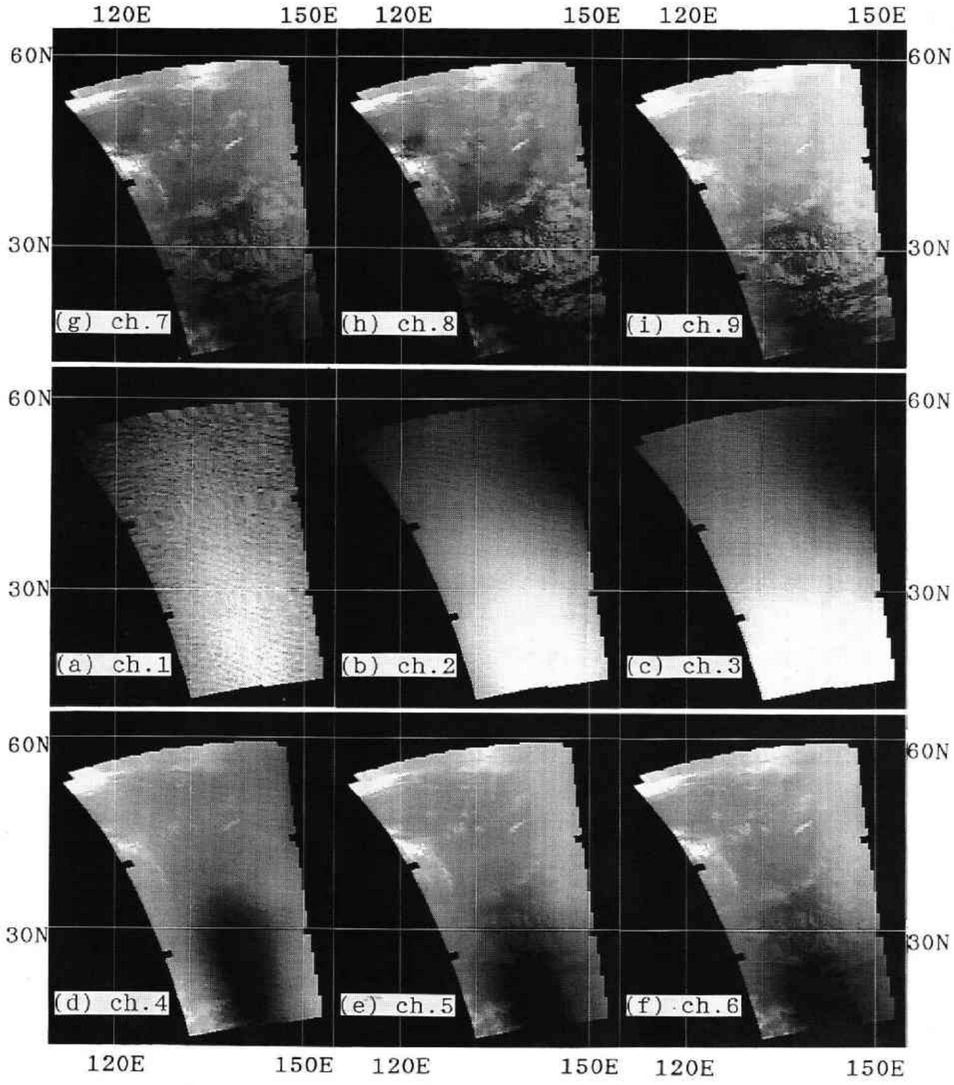


Fig. 7 Examples of images from HIRS/2 channel 1 to 9, showing the horizontal distribution of brightness temperature. The data were obtained by NOAA-11 at 04 (UT) on February 14, 1989.
(a) channel 1, (b) channel 2, (c) channel 3, (d) channel 4, (e) channel 5, (f) channel 6, (g) channel 7, (h) channel 8, and (i) channel 9.

4. Examples of the Processed HIRS/2 Data

Examples of processed images from HIRS/2 channels 1 to 9 are shown in Figs. 7(a)-7(i). They are produced by the process described above, and show the horizontal distribution of measured brightness temperature. The data were obtained from the NOAA-11 at 04 (UT) on February 14, 1989. The brightness temperature is high in the region shown in black, and vice versa.

As shown in Table 2, the peak altitude (pressure level) of the weighting function descends with increasing channel number up to channel 8. These tendencies are seen in Figs. 7(a) to (h). For channels 1, 2 and 3 (Figs. 7(a), (b) and (c)), the temperature is low in low latitudes and high in the north-east region, which corresponds to the temperature distribution in the stratosphere. On the other hand, for channels 4 to 8 (Figs. 7(d) to (h)), temperature is high in the low latitude region, corresponding to the tropospheric temperature distribution. In the image of channel 4 (Fig. 7(d)), clouds are faintly seen in the image. The clouds become clearer with increasing channel number up to channel 8. In the image of channel 8 (Fig. 7(h)), clouds are clearly seen in the low latitudes.

Figure 7(i) shows the image of channel 9. Although the peak altitude of the weighting function for this channel is in the stratosphere, clouds and the coast of Japan are seen. The reason is that the ozone layer does not completely absorb the radiance from the surface.

5. Concluding Remarks

The HIRS/2 data processing system has been developed at the EOSC of Tohoku University. The system is well matched to the NOAA-HRPT data receiving and processing system of EOSC, and the final results, stored in an HIRS.RS file (about 2MByte for one overpassing of the satellite), are useful for various types of scientific studies. A database of HIRS.RS files from many NOAA satellite observations may be a very useful product.

The processed HIRS-2 data were used to investigate ozone concentrations in the atomosphere (Takahashi, 1990), and will be used for the derivation of temperature and moisture profiles and the atmospheric correction of AVHRR SST measurements. The combination of HIRS/2 and AVHRR data is expected to be powerful tool to investigate air-sea interaction processes since both the sensors are operated simultaneously.

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