

ON THE SATELLITE REMOTE MEASUREMENTS
OF VERTICAL TEMPERATURE PROFILE
OF THE ANTARCTIC ATMOSPHERE

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Abstract: A receiving system for High Resolution Picture Transmission (HRPT) data of the TIROS-N/NOAA series meteorological satellites has been installed at Syowa Station, Antarctica.

One of the TIROS Operational Vertical Sounder (TOVS)—HIRS/2—data were analyzed and the vertical temperature profiles were derived. The statistical method and the minimum information method were used to retrieve the temperature, and the average errors were estimated as 3°C and 6°C respectively compared to the radiosonde observations made at Syowa Station.

1. Introduction

In 1980, a receiving system for the High Resolution Picture Transmission (HRPT) data from TIROS-N/NOAA series meteorological satellites has been installed at Syowa Station (69°00'S, 39°35'E), Antarctica by the 21st Japanese Antarctic Research Expedition (TANAKA and YOSHINO, 1980). Although the Automatic Picture Transmission (APT) of NOAA (National Oceanic and Atmospheric Administration) satellites had been available at Syowa Station, the new system is indispensable for providing not only high resolution pictures but also information on the vertical distribution of the atmospheric temperature and constituents. It was reported by WIESNET *et al.* (1980) that an HRPT data receiving system had also been installed at McMurdo Station, Antarctica in 1980.

Under the program of POLEX (Polar Experiment)-South (KUSUNOKI, 1981), data acquisition was started from February 1980 and will be continued throughout the Middle Atmosphere Program (MAP), Antarctica (FUKUNISHI and KAWAGUCHI, 1980). The main purposes of acquiring the HRPT data were to derive, from visible and infrared pictures, a snow surface albedo, extent of sea ice, and distribution of clouds, and from the TIROS Operational Vertical Sounder (TOVS), the vertical temperature distribution, column amount of ozone and water vapor, and then to

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estimate the radiation budget and atmospheric circulation.

In the present paper, analysis of the vertical temperature profile was tried as the first step concerning the Antarctic data. Mean temperatures of four pressure levels: 50, 100, 150 and 200 mb were estimated from the radiance measured by three channels of the High-Resolution Infrared Radiation Sounder (HIRS/2). Temperature patterns of part of East Antarctica around Syowa Station were presented, and experimental uncertainties were discussed.

2. Data Processing

PCM-signals received through the S-band (1698 or 1707 MHz) were recorded on high density magnetic tapes (14 orbital data on each) and brought back to Japan once a year. From these magnetic tapes, computer compatible tapes (CCT) were made by the data processing system, as shown in Fig. 1, of the Information Processing Center of the National Institute of Polar Research.

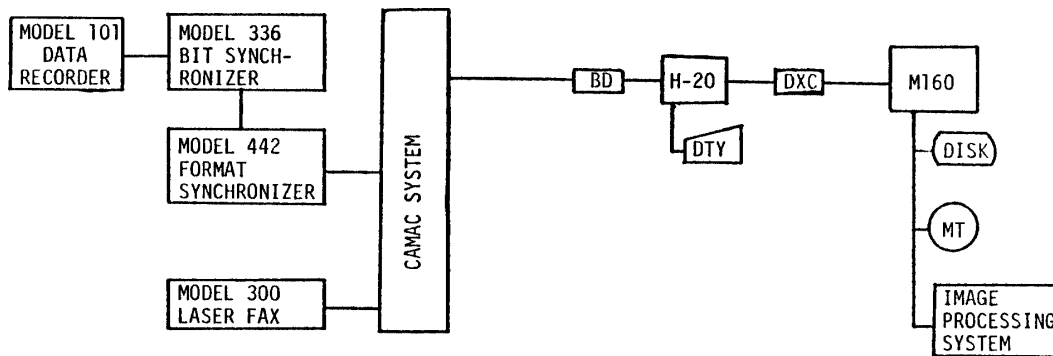


Fig. 1. Data processing system for HRPT of TIROS-N/NOAA series satellites.

According to the HRPT tape format, TOVS data are extracted. General descriptions of the TOVS have been reported elsewhere (SMITH *et al.*, 1979; WERBOWETZKI, 1981). As the next step, construction of the measured count of each radiometer, estimation of the earth-location of the measured spot, calibration of the radiance and normalization of the limb effect—correction for the slant path—are made by the aid of the “TIROS-N Sounding Data Processing System” (WOOLF, 1979).

3. Derivation of Vertical Temperature Profile

Using the transmittance τ , Planck function B and the surface emissivity ε , the radiance I is expressed as

$$I = \varepsilon B\tau(P_s) + \int_{P_s}^0 B \frac{\partial \tau}{\partial P} dP, \quad (1)$$

where P_s is the surface pressure. For the infrared region, the measured radiance should be considered as an average amount with the weight of response function of radiometer. However, for rather narrow spectral width, the same type equation as eq.(1) holds for the average value of I and τ and some equivalent value of ε and B .

From the measured radiance I , the temperature profile can be derived by solving eq.(1) for B . With

$$h(P) = T(P) - \bar{T}(P),$$

$$r(\nu) = I - \left\{ \varepsilon B(T_s) \tau(P_s) + \int_{P_s}^0 B(\bar{T}) \frac{\partial \tau}{\partial P} dP \right\},$$

where $\bar{T}(P)$ is an average (or climatic) temperature profile and T_s is the surface temperature, eq.(1) is transformed to

$$h = Cr, \quad (2)$$

where

$$h = \{h_i\}, \quad C = \{c_{ij}\}$$

$$r = \{r_j\}$$

and h_i are discrete expression of $h(P)$ for level i , and r_j are discrete expressions of $r(\nu)$ for channel j .

In order to obtain the regression coefficient matrix C , two types of method were applied. One was the statistical method. C was determined by the least-squares method through the data of radiosonde observations made at Syowa Station as h , and the radiance data of satellite at the nearest time and orbit as r . Another was the minimum information method to solve the inversion. C is written with the weighting function matrix W , its transposed matrix W^T and the identity matrix E as

$$C = (W W^T + \gamma E)^{-1} W^T, \quad (3)$$

where γ is constant related to the ratio of uncertainties of radiance and temperature measurements (AOKI and YAMAMOTO, 1973). As for the transmission function required in order to derive a weighting function, the expression given by WEINREB *et al.* (1981) was used.

In the present paper, only three channels in the CO₂ 15 μ m band of HIRS/2 whose weighting function has less information below 400 mb were chosen (WERBOWETZKI, 1981; ITO *et al.*, 1982). Characteristics of HIRS/2 sounding channels

Table 1. Characteristics of nine of HIRS/2 sounding channels.

Channel number	Channel central wavenumber (cm ⁻¹)	Central wavelength (μ m)	Principal absorbing constituents	Level of peak energy contribution (mb)
1	668	15.0	CO ₂	30
2	679	14.7	CO ₂	60
3	691	14.5	CO ₂	100
4	704	14.2	CO ₂	250
5	716	14.0	CO ₂	500
6	732	13.7	CO ₂ /H ₂ O	750
7	748	13.4	CO ₂ /H ₂ O	900
8	898	11.1	Window	Surface
9	1028	9.7	O ₃	25

are shown in Table 1. The infrared radiation around $15 \mu\text{m}$ is influenced by clouds, and we have not developed a sophisticated enough technique to distinguish the cloud region from the clear region above the Antarctic snow surface. The effect of surface elevation—a large part of the Antarctic ice sheet is more than 2000 m—is also another problem in the case of the statistical method.

4. Results and Discussions

By the statistical method, regression coefficients were determined for two

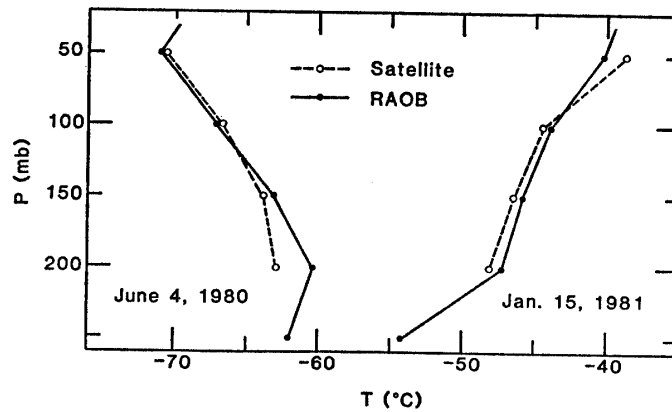


Fig. 2. Comparisons of a retrieval and a nearby radiosonde observation for the vertical temperature profile around Syowa Station, Antarctica.

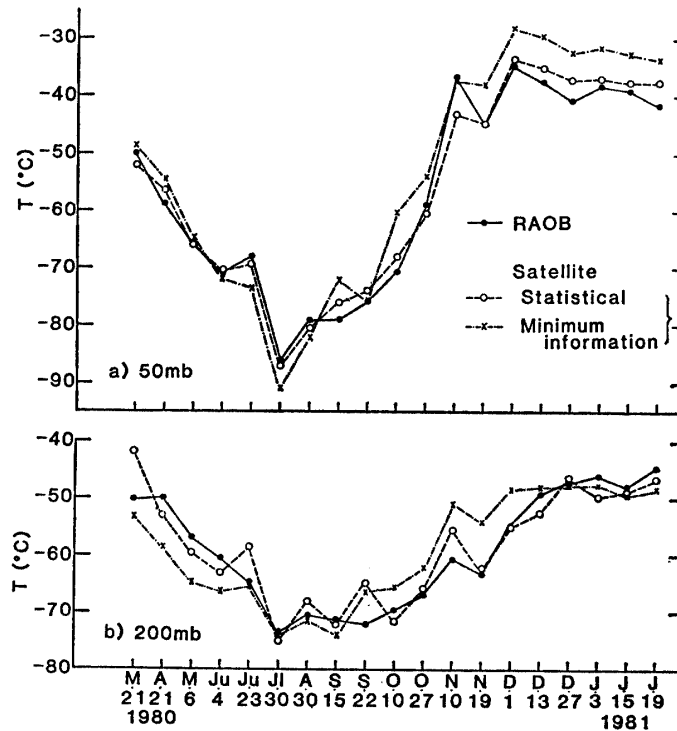


Fig. 3. Comparisons of annual variation of satellite soundings and radiosonde observations for 50 and 200 mb level temperature at Syowa Station, Antarctica.

groups of observations, one for the winter season (April–September), and another for the summer season (October–March), and the number of orbits used was seven for each. Data of radiosonde observations made in the nearest time with the satellite path at Syowa Station (JAPAN METEOROLOGICAL AGENCY, 1982) were used. Typical examples of the retrieved vertical temperature profile (SAT) are shown in Fig. 2, compared with the radiosonde observations (RAOB). The vertical profiles are expressed excellently in these examples. The annual variations of remote measured temperature of 50 and 200 mb layer are shown in Fig. 3 with the radiosonde observations. Though there are some discrepancies in all of the data, overall variations in the long term can be illustrated. Root mean square errors for

Table 2. Root mean square errors of the retrieved temperature ($^{\circ}\text{C}$).

Level (mb)	Statistical method			Minimum information method		
	Winter	Summer	Total	Winter	Summer	Total
50	1.6	2.9	2.5	4.0	6.7	5.7
100	1.5	3.5	3.0	8.6	5.7	7.1
150	2.2	2.7	3.0	6.5	4.6	5.5
200	3.1	2.5	3.6	5.1	4.9	5.0

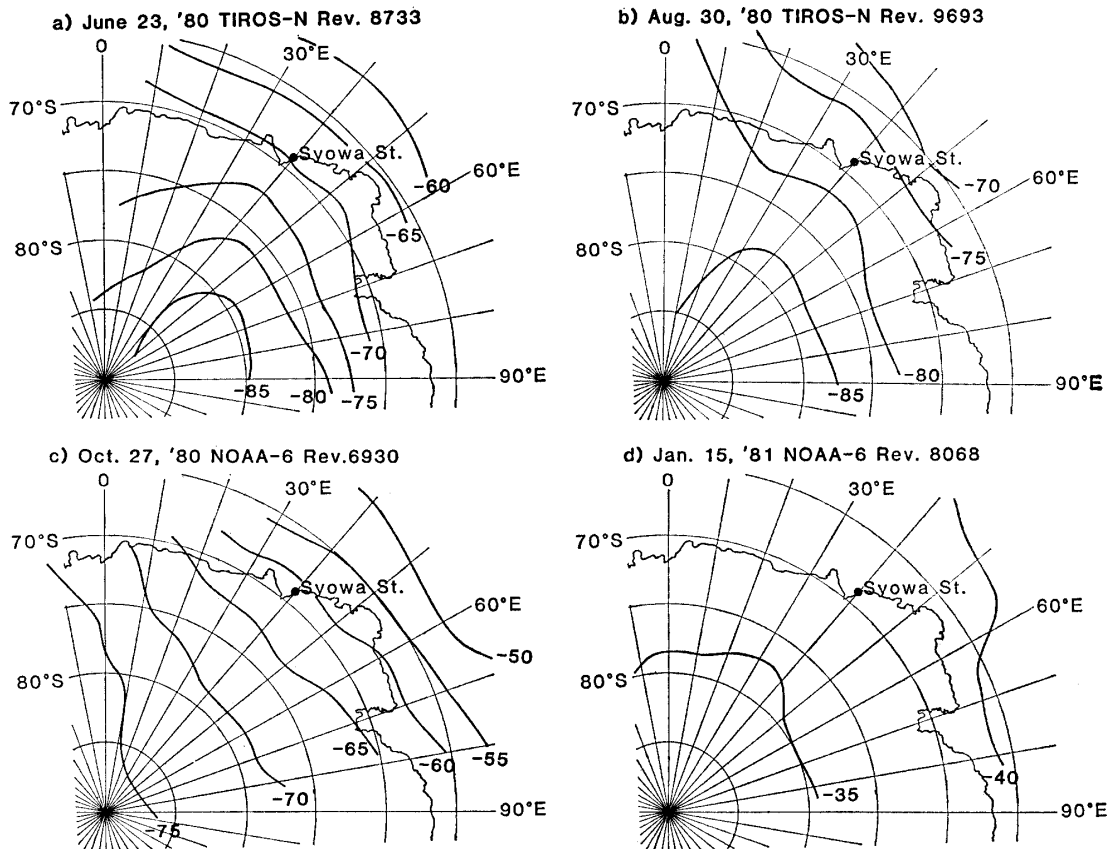


Fig. 4. Satellite soundings of 50 mb atmospheric temperature in northern part of East Antarctica ($^{\circ}\text{C}$).

the data of each layer, which are shown in Table 2, are 2–3°C for those used in the regression and 3–5°C for those not used in the regression.

Calculating the weighting function (WEINREB *et al.*, 1981) for two sets (winter and summer as stated above) of the climatic average temperature profile which were derived from the radiosonde observations, the minimum information solution was obtained. In the analysis, γ was empirically chosen as 0.005. Those results are also plotted in Fig. 3. Discrepancies of these results with the radiosonde observations seem to be larger than those of the statistical results. Root mean square errors for the minimum information solution, which are also listed in Table 2, are 4–9°C, and the average error should be considered to be about 6°C. The error in this method seems to be twice as large as the error in the statistical method in this stage. However, there might be some possibility of improvement by iterations. If the retrieved temperatures were used as the data for calculating the weighting function, then the next retrieved temperature profile might be more realistic than the original one.

The horizontal distributions of 50 mb atmospheric temperature in the northern part of East Antarctica are shown in Fig. 4; these were derived by the statistical method. The temperature at high latitude is lower than that at low latitude in winter (a) and *vice versa* in summer (d). The seasonal variation of the polar temperature field is observed.

Although some field measurements were made on the Antarctic ice sheet on the ground surface, aerological data as a reference for the satellite measurements are scarce. In the present paper, only those data at Syowa Station were used. These are not reliable as a reference for the inland measurements, since the station is located on the coast.

5. Concluding Remarks

The first trial of the remote measurement of the vertical temperature profile in the Antarctic atmosphere was made. The average error was estimated to be about 3°C by the statistical method and about 6°C by the minimum information method, leaving many possibilities to be improved. However, in the present method, though the absolute values were uncertain, the spacial distribution pattern or the relative variation could be efficiently expressed, and satellite data are valuable on account of scarce ground measurements.

One of the subjects for the study in the near future is to assess the reliability of the retrieved temperature field inland compared to the data measured at the inland station. Another is to establish the technique to obtain the clear column radiance from the data of the spots which contain the clouds over the snow surface.

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