ATMOSPHERIC EFFECTS AGAINST THE SURFACE TEMPERATURE MEASUREMENT BY AVHRR IN THE POLAR REGION

Shinya TANAKA[1], Kazuya SUZUKI[2], Takashi YAMANOUCHI[3]
and Sadao KAWAGUCHI[3]

[1]*Space Systems Department, Fujitsu Ltd., 17–25, Shinkamata 1-chome, Ota-ku, Tokyo 144*
[2]*University of Electro-Communications, 5–1, Chofugaoka 1-chome, Chofu-shi, Tokyo 182*
[3]*National Institute of Polar Research, 9–10, Kaga 1-chome, Itabashi-ku, Tokyo 173*

Abstract: Atmospheric effects against the surface temperature measurement by the AVHRR infrared sensors in the polar region are simulated by the LOWTRAN-6 computer program. The atmospheric transmittance and radiance are calculated using the monthly average of the aerological data at Syowa and Mizuho Stations, Antarctica, and those at Tateno Aerological Observatory for comparison. The atmospheric transmittance at Syowa and Mizuho Stations is larger than 0.9 throughout the year and the brightness temperature detected by the AVHRR infrared sensors is within 1.0 of difference from the surface temperature.

1. Introduction

The Advanced Very High Resolution Radiometer (AVHRR) on the NOAA polar-orbiting satellites detects emitted radiance in the window channels at 3.7, 11 and 12 μm. The accuracy of the surface temperature measured by AVHRR is limited primarily by uncertainties in the correction for atmospheric effects. These atmospheric effects dependent on the atmospheric structure vary zonally and seasonally, and it is difficult to consider the atmospheric effect generally.

In order to retrieve the surface temperature from satellite measurement, multiple window methods have been proposed by many authors (*e.g.*, MCMILLIN and CROSBY, 1984; LLEWELLYN-JONES *et al.*, 1984). However, these reports describe retrieval coefficients mainly for mid-latitude and tropical regions. It is necessary to study atmospheric effects of the polar atmosphere.

This paper reports preliminary estimates of atmospheric effects against the surface temperature measurements by the AVHRR infrared sensors which are simulated by using the LOWTRAN-6 computer program (KNEIZYS *et al.*, 1983). As a model of the atmosphere for calculations of the transmittance and radiance, the data at Syowa Station (69°00′S, 39°35′E) are used as representative of the coastal area and the data at Mizuho Station (70°42′S, 44°20′E) are used to represent the inland area of Antarctica. For comparison, the data at Tateno Aerological Observatory (36°03′N, 140°08′E) are used to represent the mid-latitude atmosphere.

2. Calculations

The spectral radiance I_ν at the wave number ν looked from the satellite is expressed as

$$I_\nu = \varepsilon_\nu B_\nu(T_s)\tau_\nu - \int_0^{p_s} B_\nu(T)\frac{\partial \tau_\nu}{\partial p}\mathrm{d}p\,, \tag{1}$$

where ε_ν, B_ν, τ_ν, T and p are the surface emissivity, Planck function, transmittance, temperature and pressure, respectively and suffix s denotes the surface. The first term in the right-hand side of eq. (1) is the surface component and the second term is the atmospheric component.

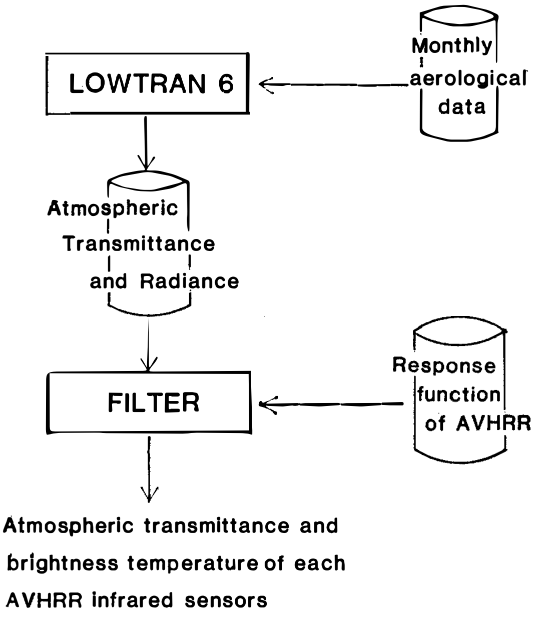

Fig. 1. Flow chart of data processing.

Figure 1 shows the data processing flow chart. The first step is the calculation of the atmospheric transmittance τ_ν and radiance I_ν of eq. (1) by the computer code LOWTRAN-6 using the atmospheric temperature, surface temperature and humidity of the aerological data. This computer code calculates the atmospheric transmittance and radiance averaged over 20 cm^{-1} intervals in steps of 5 cm^{-1} from 350 to 40000 cm^{-1} (0.25 to 28.5 μm). This code uses a single parameter band model for molecular absorption, and includes the effects of continuum absorption, molecular scattering and aerosol extinction. Refraction and earth curvature are included in the calculation of an atmospheric slant path.

In this step, monthly aerological data at Syowa Station from 1980 to 1982 (JAPAN METEOROLOGICAL AGECNY, 1982, 1983, 1984), aerological data at Mizuho Station for the clear sky estimated by YAMANOUCHI and KAWAGUCHI (1984) and 5 year means of aerological data at Tateno Aerological Observatory (TAKAHASHI, 1983) are used as atmospheric models. Table 1 shows the typical temperature and water vapor pressure at three stations in winter. Calculations are made only for the nadir looking path from the satellite at 850 km height, for the surface emissivity of unity and for the clear atmosphere without aerosols. The atmospheric transmittance and radiance averaged over 20 cm^{-1} are calculated between 3.5 and 12.5 μm.

Table 1. Typical temperature and water vapor pressure at three stations in winter.

	Tateno (January) average 1976–1980		Syowa (July) average 1980–1982		Mizuho (July) 1979	
Pressure	Temperature	Vapor pressure	Temperature	Vapor pressure	Temperature	Vapor pressure
Surface	283.2 K	4.6 mb	257.9 K	1.14 mb	224.8 K	0.078 mb
1000 mb	274.4	4.6	—	—	—	—
850	269.8	2.8	255.6	0.99	—	—
700	260.8	1.2	249.2	0.51	245.5	0.334
600	—	—	244.7	0.32	239.1	0.154
500	247.8	0.28	234.2	0.11	231.6	0.073
400	—	—	223.8	—	221.7	0.024
300	227.7	—	211.6	—	211.0	0.006
200	—	—	202.6	—	202.5	—
150	218.2	—	200.7	—	200.0	

The second step is the calculation of the effective average transmittance $\bar{\tau}$ and radiance $\bar{I}$ measured by AVHRR infrared sensors using the response function F_ν of the sensors. $\bar{\tau}$ and $\bar{I}$ are given by

$$\bar{\tau}=\frac{\int \tau_\nu F_\nu B_\nu \,\mathrm{d}\nu}{\int F_\nu B_\nu \,\mathrm{d}\nu}, \tag{2}$$

and

$$\bar{I}=\frac{\int I_\nu F_\nu \,\mathrm{d}\nu}{\int F_\nu \,\mathrm{d}\nu}. \tag{3}$$

The brightness temperature T_B is defined as

$$\bar{I}\equiv\bar{B}(T_\mathrm{B}). \tag{4}$$

In this step, the effective average atmospheric transmittance and radiance for three infrared sensors of AVHRR, channel 3: 3.5–4.0 μm, channel 4: 10.3–11.3 μm and channel 5: 11.5–12.5 μm, are calculated.

3. Atmospheric Transmittance

Figure 2 shows the transmittance of the AVHRR infrared sensors for the monthly mean atmosphere and column water vapor amount at Tateno Aerological Observatory, Syowa Station and Mizuho Station. Since a large difference in water vapor amount exists among the stations, the transmittance varies greatly.

At Tateno Observatory (a), water vapor amount is large and its seasonal variation is also large. Then, the transmittance of channels 4 and 5 varies greatly from about 0.3 to 0.9 according to the water vapor amount; however, the transmittance of channel 3 does not vary greatly. The influence of water vapor amount on the transmittance is greatest in channel 5, and smallest in channel 3.

At Syowa Station (b), the column water vapor amount is smaller than about 0.5 g/cm^2 throughout the year. The transmittance of three channels is higher than 0.9.

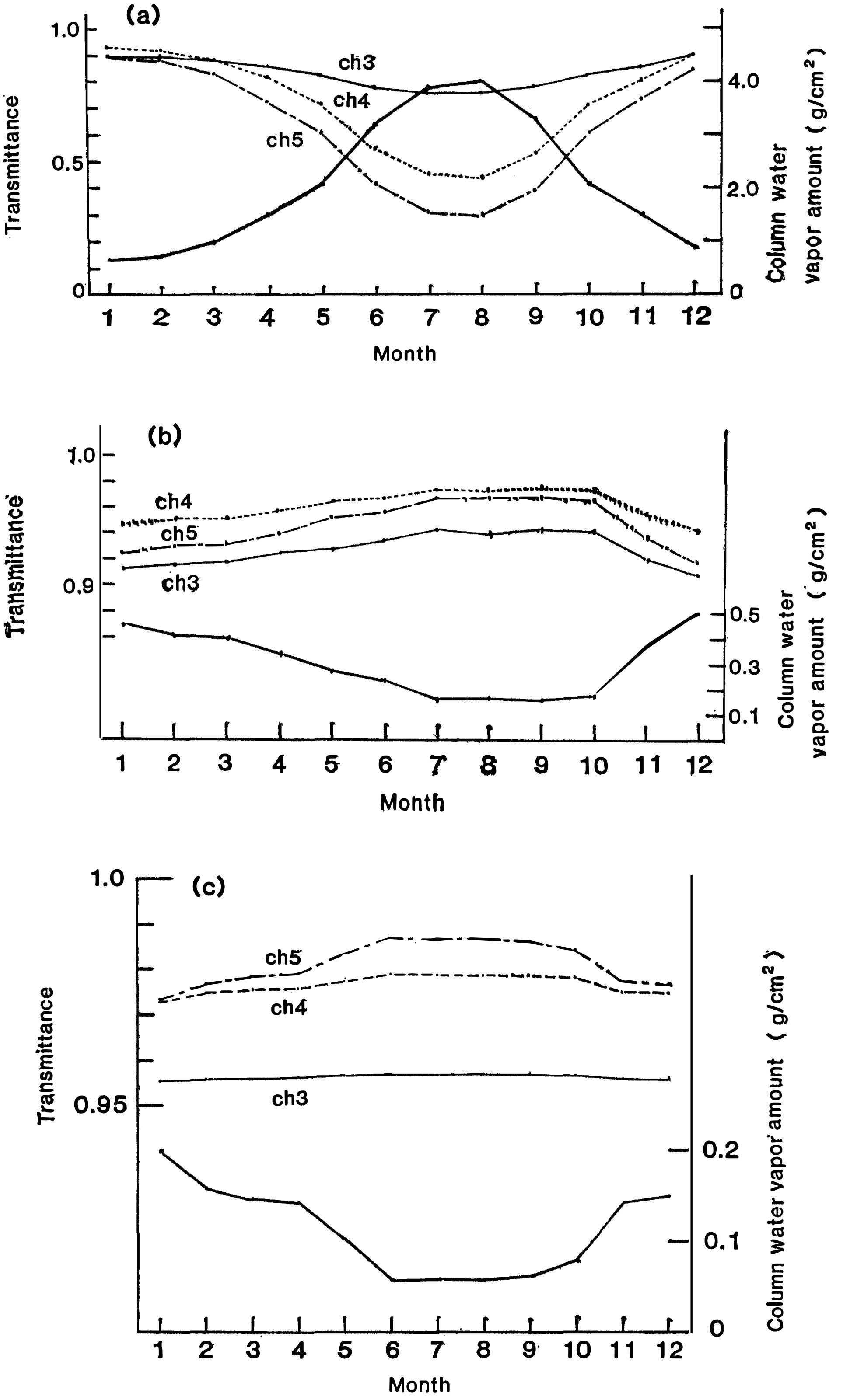

Fig. 2. Transmittance for AVHRR sensors, channel 3 to 5, for monthly mean atmospheric models and column water vapor amounts (thick solid lines) at (a) Tateno Aerological Observatory, (b) Syowa Station and (c) Mizuho Station.

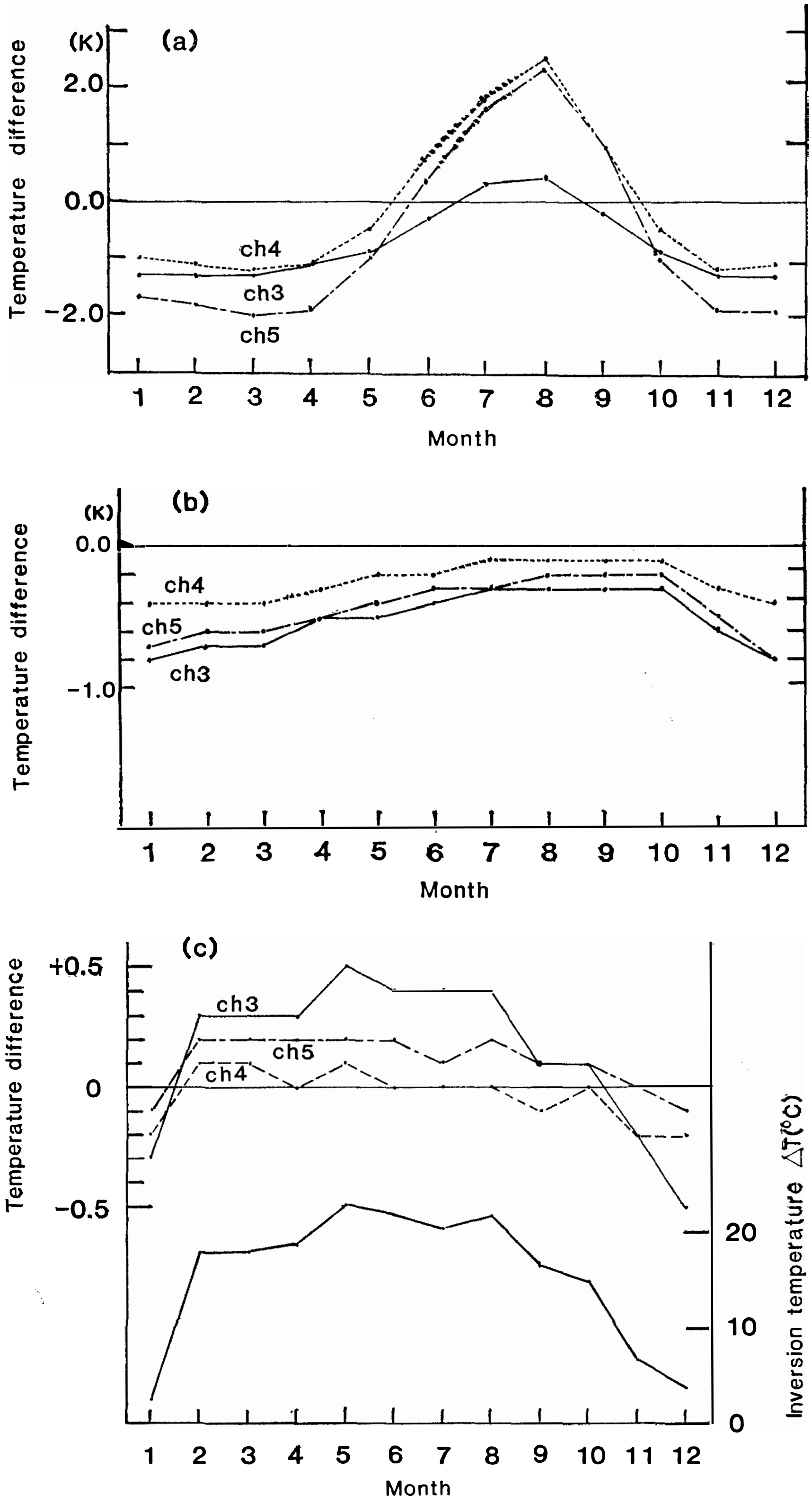

Fig. 3. Temperature difference T_B-T_S for AVHRR sensors, channel 3 to 5, for monthly mean atmospheric models at (a) Tateno Aerological Observatory, (b) Syowa Station and (c) Mizuho Station with the strength of temperature inversion (thick solid line).

The transmittance of channel 5 varies most greatly and becomes nearly as high as that of channel 4 in winter.

At Mizuho Station (c), the water vapor amount is much smaller than at Syowa Station. The transmittance of three channels is higher than 0.95. The transmittance of channel 5 becomes the highest owing to the small amount of water vapor. The channel 3 transmittance is the smallest and shows only a small seasonal variation. In channel 3, the absorption by other constituents than H_2O is mainly contributing. In channel 4, CO_2 and O_3 contribute to the larger absorption than in channel 5 where the water vapor amount is extremely small. The greatest sensitivity of the channel 5 transmittance to the water vapor amount is certified again.

4. Brightness Temperature

Differences of the brightness temperature of each channel of AVHRR sensors from the surface temperature assuming the emissivity to be unity are shown in Fig. 3 (hereafter called temperature difference). Among three stations (a, b and c), temperature difference is variable, sometimes negative and sometimes positive. In eq. (1), when the transmittance becomes small, the surface component becomes small and reduces the brightness temperature. However, most part of the reduction of the brightness temperature is compensated by the atmospheric emission (the second term in the right-hand side of eq. (1)). When the air temperature at low level becomes much higher than the surface skin temperature, the second term becomes greater than the reduction of the first term and the brightness temperature becomes higher than the surface temperature.

For the atmospheric model at Tateno Aerological Observatory, where the surface temperature is set constant at 283 K, temperature difference is mostly negative and positive in channels 4 and 5 from June to September, and positive in channel 3 in July and August (Fig. 3a).

Variations of the temperature difference at Syowa Station are shown in Fig. 3b with the surface temperature being equal to the air temperature at the surface. A larger temperature difference in negative sign occurs in summer months when the transmittance is lower. The absolute value of the temperature difference is anyway within 1 degree. At Syowa Station, the reduction of the surface component surpasses the atmospheric component in all seasons.

At Mizuho Station, most results show a positive temperature difference (Fig. 3c). As shown in the bottom of Fig. 3c, there is a large temperature inversion at Mizuho Station except in the summer few months. When the temperature inversion is large, the surface component of eq. (1) becomes small and the atmospheric component large. Then, even though the amount of water vapor is small, the atmospheric component can surpass the reduction of the surface component. The absolute value of difference is within $\pm 0.5°$.

5. Concluding Remarks

Atmospheric effects against the brightness temperature measurement by AVHRR infrared sensors are simulated. The temperature difference of ±2° expected at the mid-latitude decreases to smaller than ±1° in the polar region. Moreover, in the inland of the Antarctic continent represented by Mizuho Station, the temperature difference is within ±0.5°. If the need of accuracy of the surface temperature retrieval is ±1°, atmospheric effects are negligible in the polar region.

However, the temperature difference in this paper expresses only the difference of the brightness temperature by AVHRR and the surface temperature, which is the brightness temperature at the surface, and says nothing about the true surface temperature. In order to retrieve the true surface temperature, the surface emissivity should be examined, since the emissivity of snow is said to be not equal to unity even in the 10 μm window region (DOZIER and WARREN, 1982).

Also this paper presents only simulations of the atmospheric effect. The actual data of satellite should be studied together with ground truth measurements of the surface temperature.

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