ATMOSPHERIC CORRECTION MODEL FOR GROUND SURFACE TEMPERATURE USING A SINGLE IR CHANNEL DATA OF SATELLITE

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ABSTRACT

A new atmospheric correction model was developed to determine ground surface temperature using single infrared channel satellite data. It had been apparent from observation and simulation using LOWTRAN6, that atmospheric effect largely depends on temperature difference between ground surface and air, as well as on water vapor content and view angle. Consideration of this effect caused the model to be more accurate when the surface temperature was lower than the air temperature.

Key Words: Atmospheric correction, Surface Temperature, Land Area.

1 INTRODUCTION

Any method of determining surface temperature from satellite observed brightness temperature requires some atmospheric correction procedure. In oceanographic applications, atmospheric correction models, such as that of McClain *et al.*(1983), which use a multi-channel thermal infrared sensor, for example NOAA/AVHRR, are recommended. These models have the ability to evaluate atmospheric effects accurately without knowledge of atmosphere and optical path. On the other hand, in some micrometeorological or regional applications in land area, it is often necessary to determine ground surface temperatures frequently or in high spatial resolution. In these cases, such sensors as Landsat/TM and GMS (Geostationary Meteorological Satellite, Japan) /VISSR, which have only one thermal infrared channel, are used. Atmospheric correction models for single infrared channel data, for example these of Smith *et al.*(1970) or Abe and Yamamoto(1979), are functions of water vapor content of atmosphere (precipitable water), optical path length (satellite zenith angle) and observed brightness temperature. A significant difficulty in use of these models is obtaining atmospheric information at a certain point and time. In general, vertical observations of atmosphere are held for one meteorological station every 100 km twice a day. It is clear that the lack of atmospheric information leads to the uncertainty of these models.

The difficulties in determining ground surface temperature was also presented by Cooper and Asrar(1989), who tried to apply some models that had been developed for sea surface temperatures to grassland. They concluded that the uncertainty of the best model was 3.0 K, which is rather high in comparison with estimation of sea surface temperature. Possible reasons for this are the differences in surface emissivity between sea and ground, in range of ground surface temperature, and in variation of atmosphere near ground surface.

The object of this study is to determine the problems in using single infrared channel satellite data to determine ground surface temperature and to develop a new atmospheric correction model. Ground surface temperature derived from GMS/VISSR infrared data was compared with that measured on the ground. Atmospheric effects were simulated using LOWTRAN6 and a new atmospheric correction model was determined from the result.

2 METHOD

2.1 Ground Based Observation

The study site was located in Hokkaido University experimental forest in Tomakomai (42°40'N, 141°36'E), Japan (Fig.1). The experimental forest is in the Pacific coastal region of Hokkaido, which belongs to the northern part of the temperate climatic zone. Its vegetation is mixed forest of deciduous and coniferous trees and its terrestrial feature is comparatively flat. From July to September 1989, surface temperature of the forest crown was measured using a portable infrared radiative thermometer (OPTEX model HR-1) mounted on a 13 m tower. The instrument has a wave length range from 8 to 13 μm. It was set on a scanning machine in order to obtain area-averaged surface temperature. The surface emissivity of the site was not known and was assumed to be 1.0, therefore observed surface temperature was actually equal to equivalent blackbody temperature. Air temperature at 2.0 m above the forest crown was also measured using a ventilated thermometer. These temperatures were averaged over 5 minutes and were recorded continuously on a data logger. The recorded surface temperature was corrected according to a calibration equation that had been determined in a laboratory.

2.2 Satellite Data

96 clear sky infrared brightness temperatures of GMS/VISSR were obtained during the study period, and surface temperatures of the site were then calculated using the GMS atmospheric correction model that was developed by Abe and Yamamoto(1979) to estimate sea surface temperature), as follows,

$$T_s = T_{bb} + \Delta T,$$

$$\Delta T = \sec\theta \{0.189Aw + 4.0(1-A)\},$$

$$A = \frac{1400}{(310-T_{bb})^2 + 1400}, \qquad (1)$$

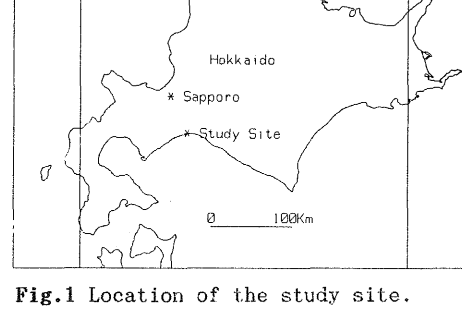

Fig.1 Location of the study site.

where T_s is surface temperature (K), T_{bb} is brightness temperature at satellite (K), ΔT is atmospheric correction (K), θ is satellite zenith angle and w is precipitable water (mm). This model was determined empirically from statistical atmospheric profiles and sea surface temperatures, and emissivity of surface was assumed to be 1.0. Precipitable water was required in the model but was not available near the site, so it was estimated from air temperature and dew-point temperature measured in a meteorological station in the experimental forest which was about 2 km from the study site using a simple regression equation that had been derived from the atmospheric profiles described in the next section. The validity of this will be discussed later.

2.3 Simulation of Atmospheric Effects using LOWTRAN6

In order to develop a new atmospheric correction model, brightness temperature at the satellite under various atmospheric conditions and surface temperatures was calculated using a LOWTRAN6 computer program. Monthly average atmospheric profiles at 09 and 21 LST observed by rawinsondes at Sapporo district meteorology observatory, which is about 50 km from the study site, in 1989 were input to the LOWTRAN6 program as atmospheric models. 5 different surface temperatures were selected for each atmospheric profile so that they range from 10 K lower to 10 K higher than the air temperature at ground height. LOWTRAN6 was computation performed also in 5 different slant optical paths, of which the secant satellite zenith angle ranged from 1.0 to 2.0. Wave length range was matched with GMS/VISSR infrared channel (10.5-12.5 μm) and emissivity of surface was set to 1.0 in the computation. Thus 600 brightness temperatures were derived for various conditions.

3 RESULT AND DISCUSSION

3.1 Estimation of Precipitable Water from Water Vapor Content at Surface

The atmospheric profile data required to calculate precipitable water can be obtained only sparsely both spatially and temporally, as already mentioned. Fig.2 shows some water vapor profiles used in LOWTRAN6 simulation in relative value. Water vapor in the atmosphere is most concentrated near the ground and more than 90% of it exists in the lowest 4 km. Seasonal and diurnal changes in the relative features are rather small, and they probably don't change much in the 100 km region without significant climatic difference. Therefore precipitable water can be estimated from measurement on the ground. Fig.3 shows the relationship between water vapor content at the surface and precipitable water in Sapporo, which is almost linear. This relationship can be used to estimate precipitable water in the study site.

3.2 Effect of Temperature Difference at Surface in Use of GMS Model

Surface temperature calculated using the GMS model was compared with that measured on the ground (Fig.4). Rmsd between observed and calculated surface temperature using the GMS model was 6.5 K, which is rather large. The model tends to overestimate in regions of low surface temperature. Fig.5 shows the relationship between the estimation error and the temperature difference between surface and air (T_s-T_a, K). The estimation error is proportional to the temperature difference.

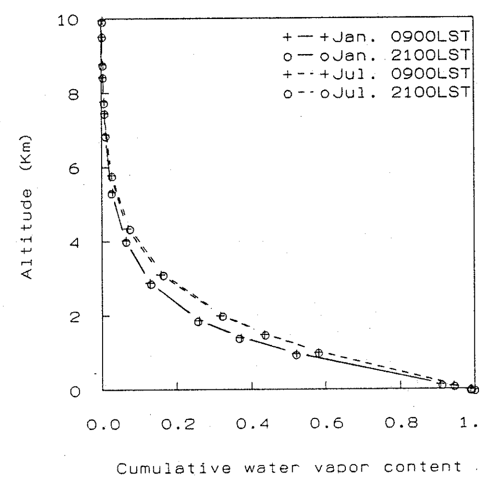

Fig.2 Vertical distribution of water vapor in relative value for 4 atmospheric profiles.

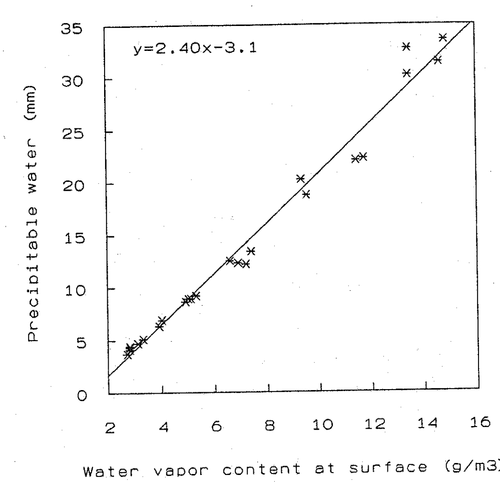

Fig.3 Relationship between water vapor content at surface and precipitable water in Sapporo in 1989.

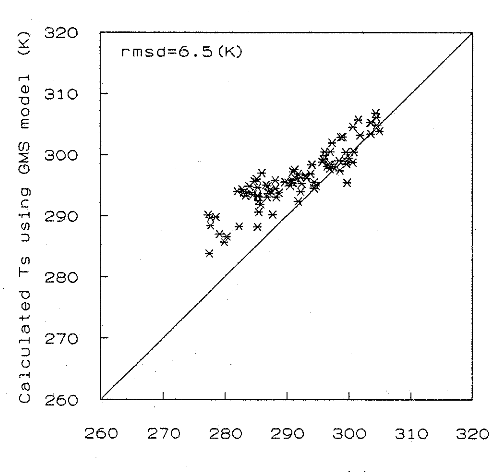

Fig.4 Surface temperatures observed and calculated from GMS data using GMS model.

This fact was also apparent from the simulation of atmospheric effect using LOWTRAN6. Fig.6 shows relationship between surface temperature defined in LOWTRAN6 simulation and that calculated using the GMS model. Rmsd is 3.5K, and the model tends to overestimate, particularly in the region of surface temperature from 280 K to 290 K, which is similar to Fig.2. These points represent conditions in which atmosphere is thick and surface temperature is lower than air temperature. As already mentioned, the GMS model has been developed to determine sea surface temperature, and does not consider situations with large temperature differences between surface and air. Therefore, it cannot determine ground surface temperature, and a new atmospheric correction model that considers this effect is required.

3.3 Development of A New Model

In order to develop a new atmospheric correction model, 600 values of temperature calculated by LOWTRAN6 were used. At first, atmospheric effect in different view angles was determined using the least square method as follows,

$$\Delta T(\theta)=\{1+0.64(\sec\theta-1)\}\Delta T(\theta=0) \quad (2).$$

Next, atmospheric effect is almost linear to precipitable water under the special condition in which surface temperature is equal to air temperature, as shown in Fig.7. Then the next equation was obtained,

$$\Delta T'=\{1+0.64(\sec\theta-1)\}(0.111w+0.3) \quad (3),$$

where $\Delta T'$ (K) represents atmospheric effect when $T_s=T_a$. Eq.(3) does not explain the atmospheric effect entirely and there remained the effect of temperature difference at surface. The remaining effect can be explained in terms of (T_s-T_a), as shown in Fig.3, but in general this value cannot be used. Brightness temperature can explain the remaining effect approximately, as shown in Fig.8, that indicates the relationship between T_{bb} and the effect. Each line represents the relationship for the same atmosphere and view angle in this figure, and is linear. The gradient and the interception of these lines can be defined as functions of $\Delta T'$ as shown in Figs. 9 and 10. Thus a new atmospheric correction model has been obtained as follows,

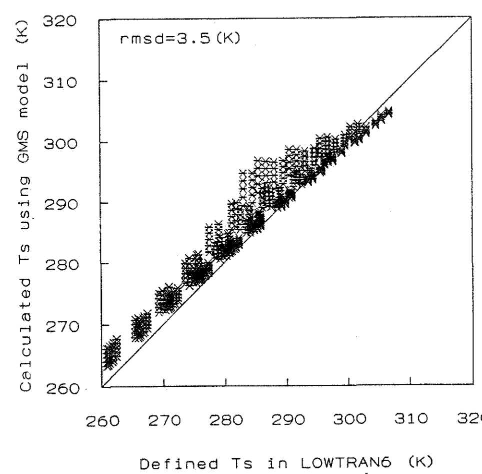

Fig.6 Simulated accuracy of GMS model using LOWTRAN6.

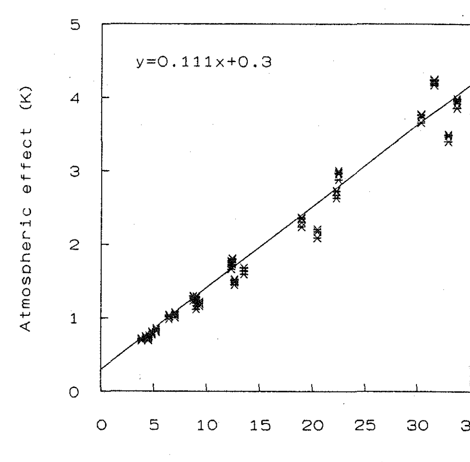

Fig.7 Relationship between precipitable water and atmospheric effect.

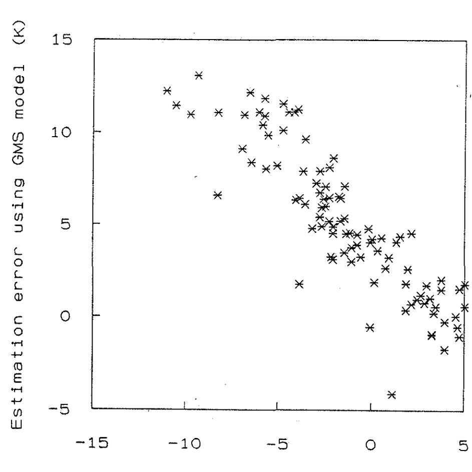

Fig.5 Relationship between temperature difference at surface and estimation error of GMS model.

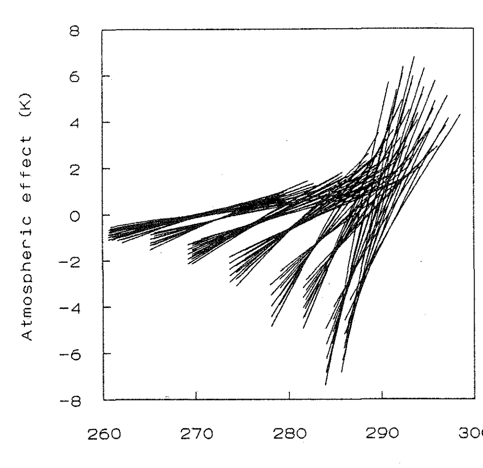

Fig.8 Relationship between brightness temperature at satellite and remaining atmospheric effect.

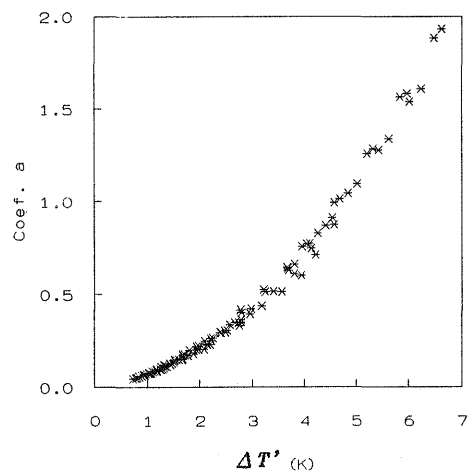

Fig.9 Relationship between $\Delta T'$ and coefficient *a*.

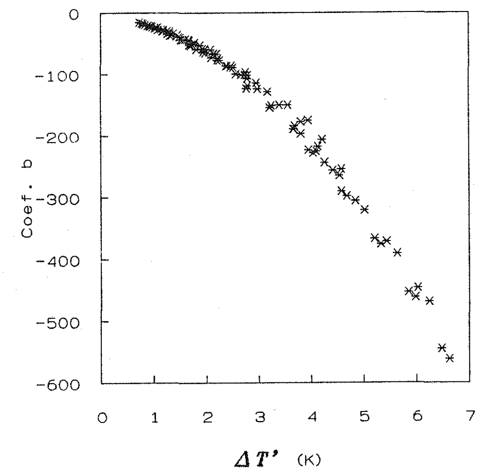

Fig.10 Relationship between $\Delta T'$ and coefficient *b*.

$$\Delta T = \Delta T' + aT_{bb} + b,$$

$$\Delta T' = \{1+0.64(sec\theta-1)\}(0.111w+0.3),$$

$$a = 0.041974\Delta T'^2 + 0.00675\Delta T' + 0.0336,$$

$$b = -12.187\Delta T'^2 - 1.95\Delta T' - 8.0 \qquad (4).$$

Fig.11 plots calculated surface temperature using the new model against that defined in LOWTRAN6 simulation. Rmsd is 1.0 K and this is smaller than the result of the GMS model.
In addition, it is recommended to correct calculated surface temperature for surface emissivity less than 1.0, if known.

3.4 Validity of the New Model

Surface temperature was calculated from the GMS data using the new model and was compared with the observed temperature on the ground (Fig.12). Rmsd is 6.2 K and is slightly smaller than that of the GMS model. In the low temperature region the calculated value approaches the perfect fit line, so it can be said that overestimation under a conditionof lower surface temperature than air temperature has been reduced. On the other hand, in high temperature regions, the new model tends to overestimate the atmospheric effects significantly. These points are from 10 to 15 LST on clear days, when the air temperature is more than 298 K and the precipitable water exceeds 35 mm. Such conditions of high temperature and thick atmosphere at near noon had not been considered in the LOWTRAN6 simulation that was used to determine the correction model, because atmospheric profiles were available only at 09 and 21 LST (00 and 12 GMT). The model is very sensitive to brightness temperature in order to detect temperature difference at the surface under thick atmosphere (see Fig.8), and the sensitivity depends on the precipitable water value. Uncertainty of precipitable water within 5 mm may lead to errors in surface temperature greater than 10 K. The possible reason for this problem is the validity of the model constants for high temperature and thick atmosphere.

4 CONCLUSION

Problems in using a single infrared channel satellite data to determine ground surface temperature

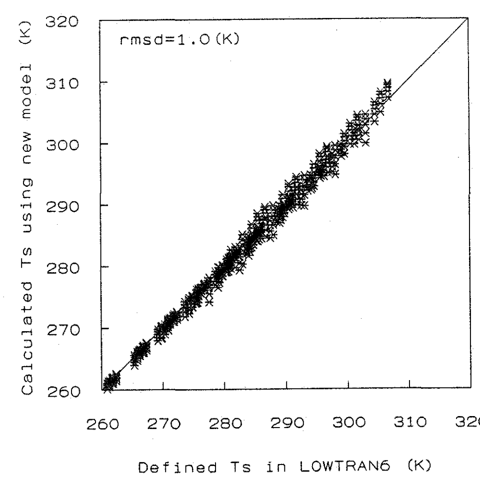

Fig.11 Simulated accuracy of the new model using LOWTRAN6.

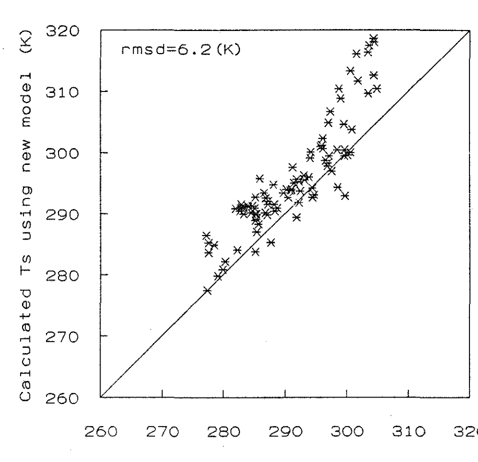

Fig.12 Surface temperatures observed and calculated from GMS data using the new model.

have become apparent through observation and simulation of atmospheric effects, as follows. One problem is that, the water vapor content of the atmosphere, which is required to evaluate the atmospheric effect, varies both in space and in time in land area. This can be overcome by estimating the precipitable water from water vapor content measurements on ground. Another problem is that, atmospheric effect greatly depends on temperature difference between surface and air, particularly under thick atmosphere. A new atmospheric correction model that evaluates this effect using a function of brightness temperature has been developed. This model is fairly accurate in the simulation but not so in the actual application. The validity of the model is still limited and it is necessary to refine the model for various conditions.

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