Measurement of Boundary-Layer Temperature Profiles by a Scanning 5-MM Radiometer During the 1999 Winter NSA/AAO Radiometer Experiment and WVIOP 2000

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Introduction

A scanning 5-mm-wavelength radiometer was deployed during two Intensive Operational Periods (IOPs) at the Atmospheric Radiation Measurement (ARM) Program's Cloud and Radiation Testbed (CART) facilities. The first was conducted at the North Slope of Alaska (NSA) and Adjacent arctic Ocean (AAO) site near Barrow, Alaska, during March 1999. One goal was to evaluate the ability of an oxygen-band 5-mm microwave radiometer for measuring sharp temperature inversions typical during Arctic conditions. In addition to measuring the temperature profiles, the radiometric data can be used in the tip cal calibration procedures. The second IOP was conducted at the ARM Southern Great Plains (SGP) CART site during September - October 2000. In this experiment, a modified radiometer with an internal reference load was used. This modification allows calibration of the radiometer using an air temperature sensor. Results on temperature profiling and evaluation of the accuracy are presented.

Millimeter-Wave Radiometer Arctic Winter Experiment

The Millimeter-Wave Radiometer Arctic Winter Experiment was conducted in March 1999, and details of the experiment are discussed by Racette et al. (2000). The 5-mm radiometer, Figure 1, was installed on the top of the ARM instrument facility 4 m above ground level. It operated in a scanning mode by rotating a flat mirror in front of a corrugated horn antenna. We deployed a step motor with 2.5 revolution per second and recorded data every 0.9-degree of elevation angle. We averaged every five samples during the scan and radiometer scans for 15 minutes. The standard deviation of the radiometer output after averaging corresponds to radiometer sensitivity of 0.005 K.

Two ground-based temperature sensors, as well as temperature and pressure profiles from radiosondes were used for radiometer calibration. A radiometer calibration parameter, G, was determined by least-square comparison of the measured and calculated angular dependence of brightness temperature. We derived brightness temperature at given angle, Tb(a), by:

$$Tb(a)=[V(a)-V(90)]*G +Ttwr,$$

where, V(a) and V(90) are output voltages corresponded to angle "a" and 90 degree from zenith, Ttwr is the air temperature measured by the CART tower temperature sensor at 2-m altitude.

The ARM radiosondes were launched once per day at roughly 10 a.m. local time. Because of the strength of the 5-mm O_2 band, uncertainties in humidity measured by the Vaisala RS80 sensor contribute less than 0.05 K to the computed brightness temperature. A given radiosonde was used as a first guess in the radiometric temperature profile during the next 24 hours. We used Rosenkranz's absorption model and Twomey-Tikhonov's inversion method (1996) for calculations of the atmosphere temperature profiles.

Examples of radiometer data and radiosonde observations are shown in Figure 2. This figure shows a typical daytime condition during March. Surface heating due to solar radiation removes some of the persistent thermal inversion up to about 100-m altitude. This first inversion corresponds to the minimum of brightness temperature in radiometer response around 70-degree angle.

Using radiometric data we can perform continuous monitoring of the thermal boundary layer (Troitski et al. 1993). In Figure 3, we show a time-height-temperature cross section taken by a 5-mm wavelength radiometer and important temporal features of the boundary layer are revealed. For instance, the thermal warming of the first 50 to 100 m is readily apparent, as well as is the strong thermal inversion whose maximum is about 300 m. A 183-GHz radiometer-spectrometer was also deployed in this experiment to provide continuous measurements of small water vapor concentrations in Arctic conditions. The continuous temperature measurements can also improve the tip cal calibration of the 183-GHz radiometer by providing nearly continuous measurements of the mean radiating temperature.

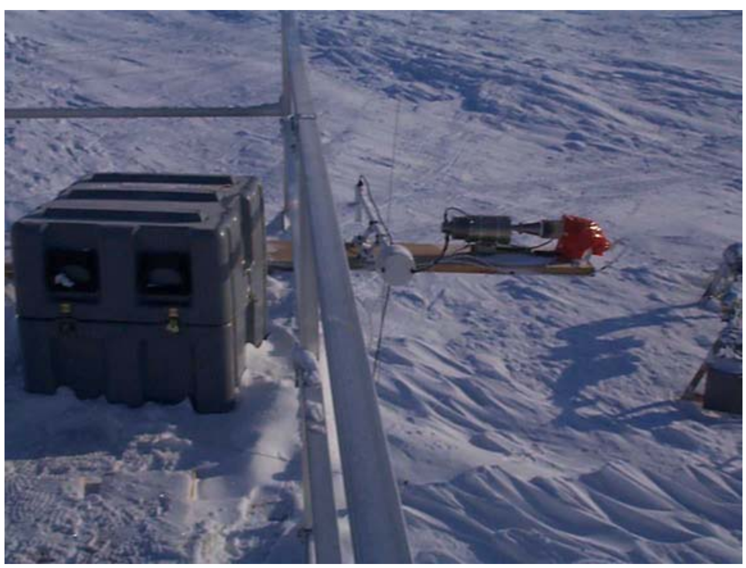

Figure 1. Photo of the 5-mm radiometer operated during the 1999 Arctic Winter Radiometer Experiment at the NSA/AAO.

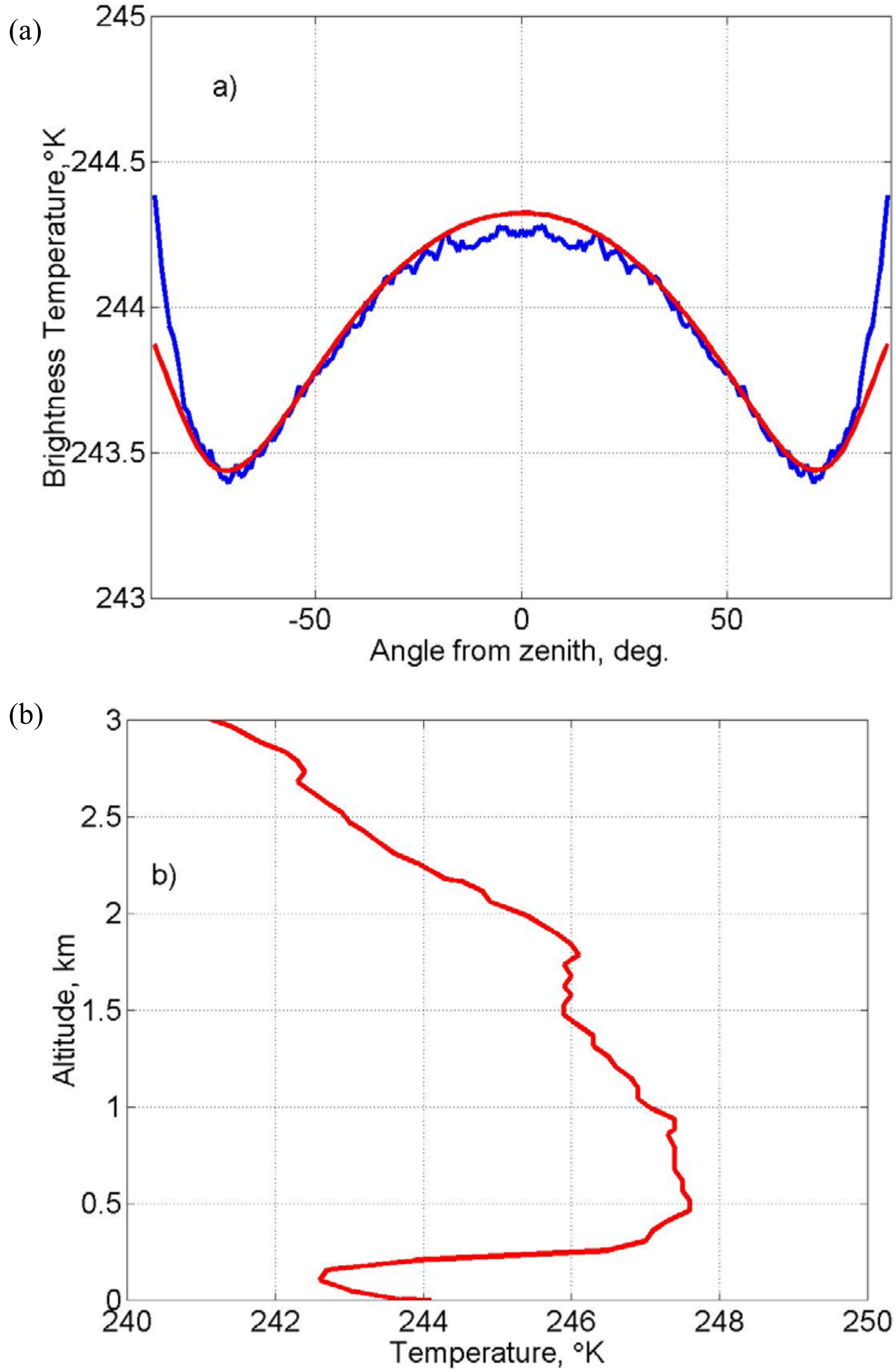

Figure 2. Brightness temperature measured by (a) the 5-mm radiometer and (b) the corresponding radiosonde measurement of air temperature. The red curve in Figure 2a is calculated from the radiosonde profile shown in Figure 2b.

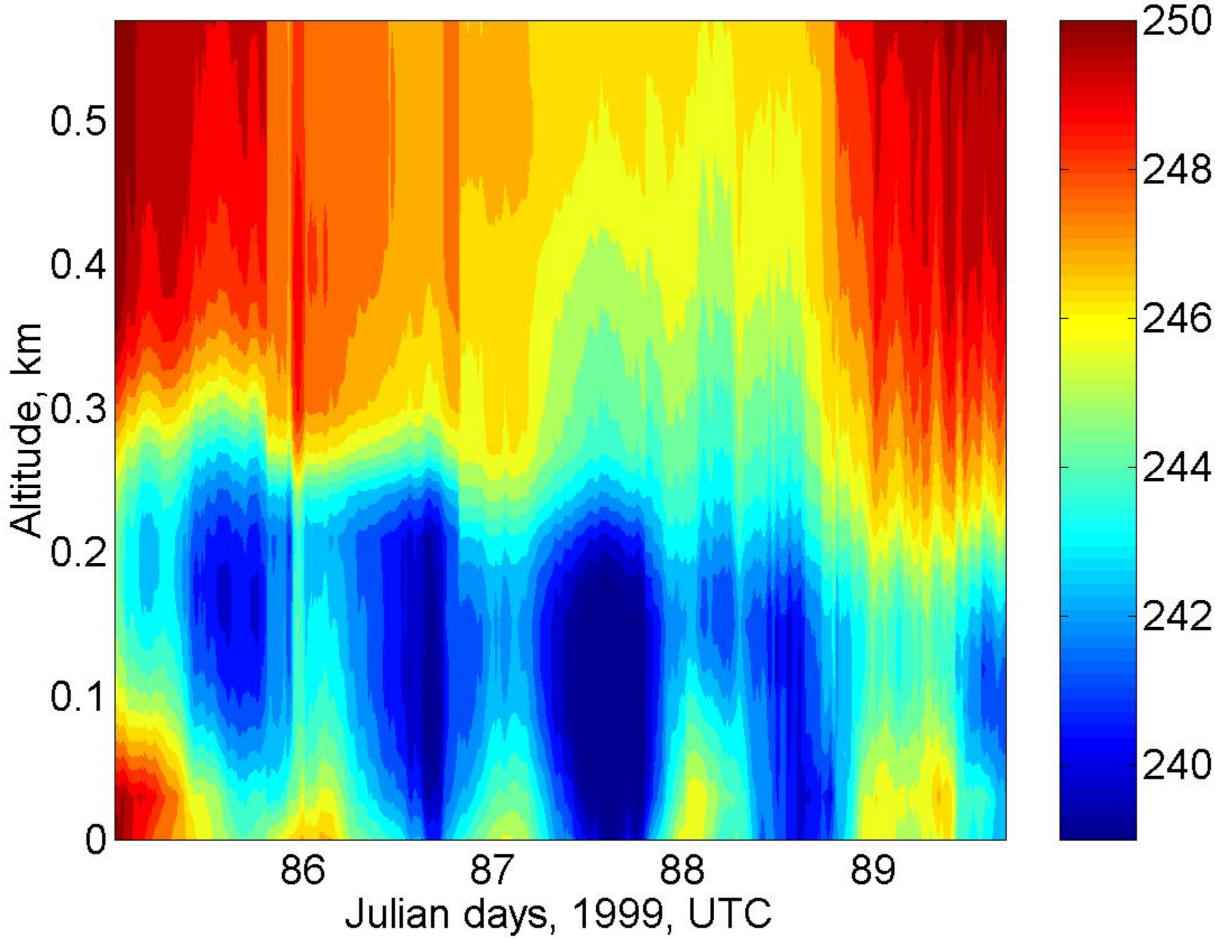

Figure 3. Temperature time-height cross sections derived from 5-mm radiometer data at the Arctic Winter Experiment at the NSA/AAO during the period March 26-30, 1999.

Radiometric Observations at the SGP CART Site

We deployed an improved model of the 5-mm wavelength radiometer that included a ferrite switch and waveguide reference loads. The radiometer operated in a scanning mode with a period of 0.4 sec. The reference load is connected to the receiver during 50 msec in each scanning period. The physical temperature of the reference load was measured by a thermistor and used for radiometer calibration. We operated the radiometer from the top of a seatainer at 3-m altitude. Temperature sensors of the CART facility and 8 radiosonde launches every day allow comparison of retrieved temperature profiles with in situ data. The two radiometer calibration coefficients, G and To, were determined by a least square comparison of the day-night variation of the air temperature with the radiometer output for horizontal direction. The brightness temperature vs. angle, Tb(a), is given by:

$$Tb(a)=[V(a)-Vr]*G+Tr+To.$$

where, V(a) and Vr are output voltages corresponding to antenna and reference load states, and Tr is physical temperature of the reference load.

A time series of ground-level temperatures from tower temperature sensor, radiometer horizontal Tb, and radiosondes are shown in Figure 4. A scatter plot of these data is presented in Figure 5. The difference in radiosonde and thermometer calibration corresponds to standard deviation of 0.74°C. The same parameter for radiometer is a much better -0.25°C.

Examples of temperature profiles from four consecutive radiosondes over 12 hours and the brightness temperatures corresponding to these profiles are shown in Figures 6 and 7. We can see large variations of air temperature (up to 17 degrees) during day-night cycles. These temperature profiles characterize the typical daily temperature variation for the observation period. During a few hours, a thermal inversion is transformed to a lapse style profile and gives a significantly different signature of the radiometer output.

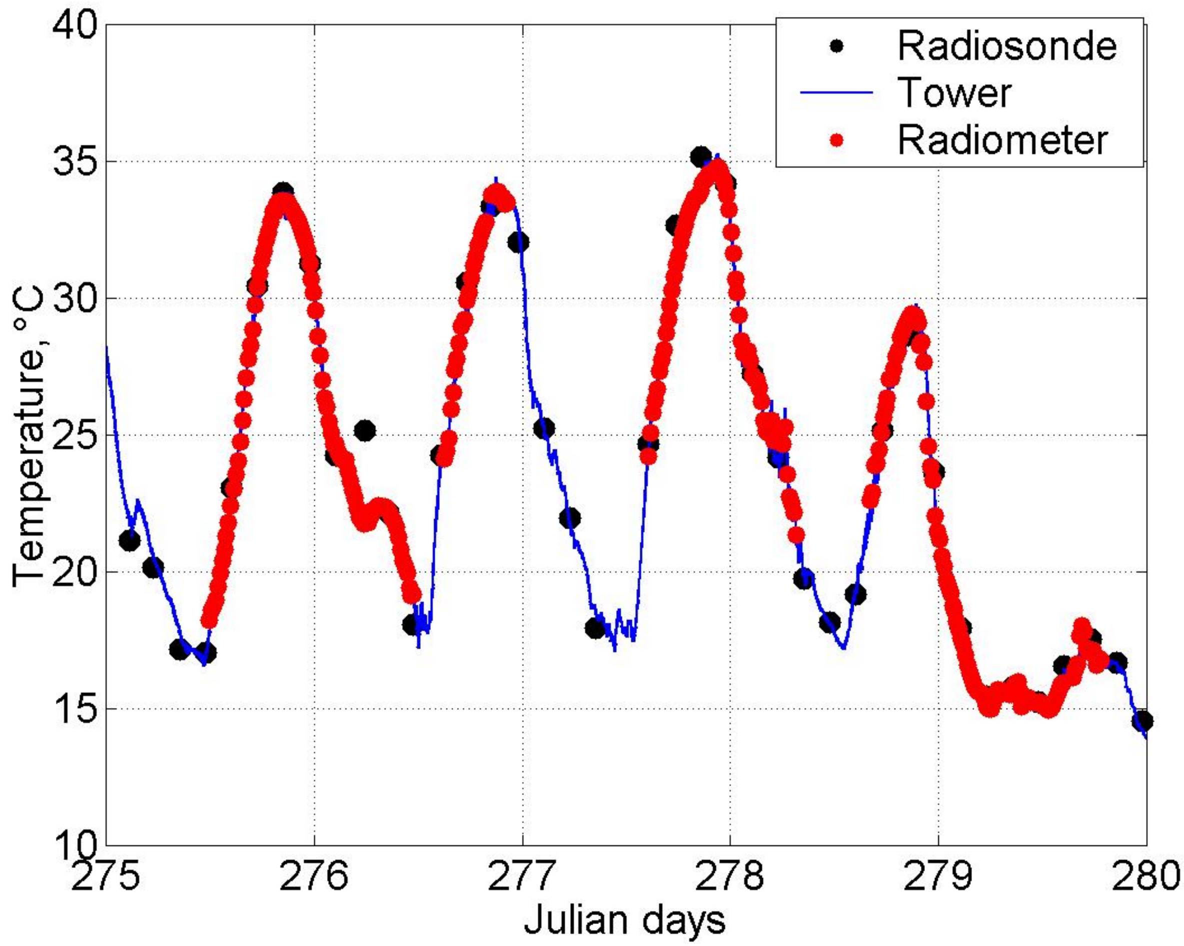

Figure 4. Near-surface temperature measured by in situ and 5-mm radiometer during the water vapor intensive operational period (WVIOP) 2000.

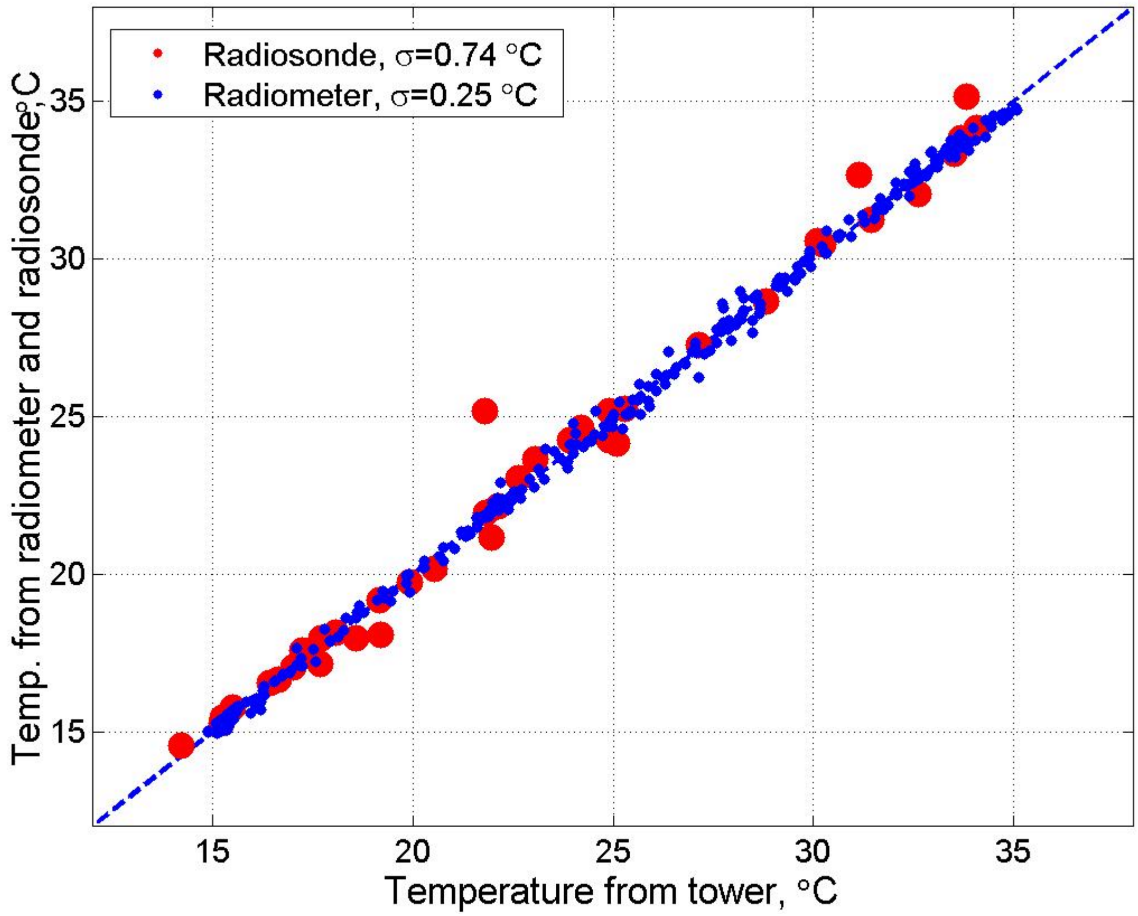

Figure 5. Scatter plot of near-surface temperature measured during the SGP WVIOP 2000.

The same retrieval techniques discussed in Millimeter-Wave Radiometer Arctic Winter Experiment Section were used for temperature profile retrieval. We used a linear approach for the first guess of temperature profile, Tg = K*h – To, where the parameters (K = 7.7°C/km, To=35°C) correspond to the mean of the temperature lapse rate from a few radiosonde observations. We evaluated the performance of the radiometer using 26 radiosonde samples over five days (275-280 Julian day). The differences between temperature at the given altitude and ground level were used for comparison of the calculated and measured temperature profiles. In Figure 8, a scatter plot for 60-m altitude is shown. The standard deviations between retrieved data and radiosonde measurements for different values of the Lagrangian multiplier used in the Twomey-Tikhonov equation are shown in Figure 9. It is apparent that a single value of the parameter is not optimum for all altitudes. Previous work (Westwater et al. 1998), based on statistical retrieval methods, and using data from a similar radiometer (without the internal calibration load), showed comparable accuracy vs. radiosonde measurements at 60-m altitude.

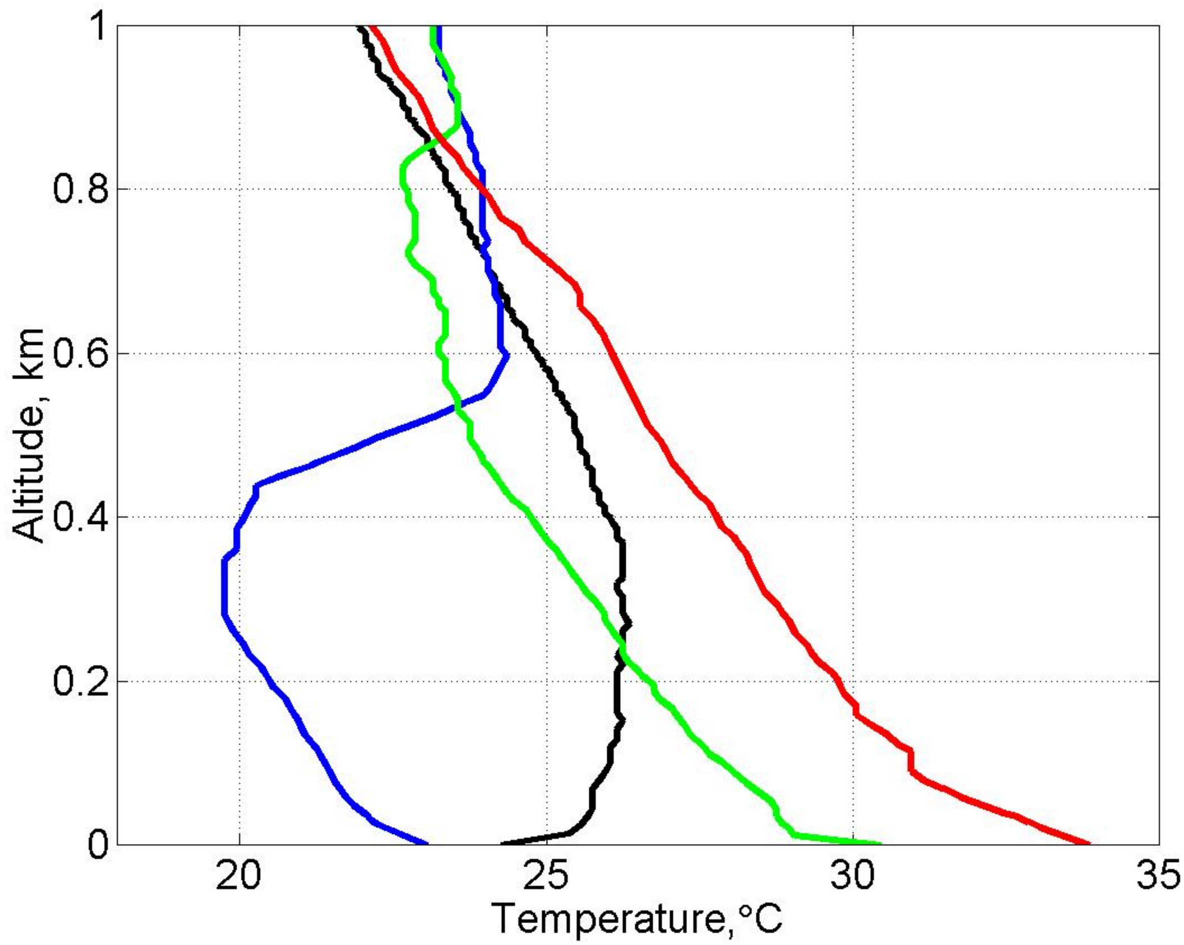

Figure 6. Radiosonde temperature profiles during 12 hours at the SGP CART site. October 1, 2000.

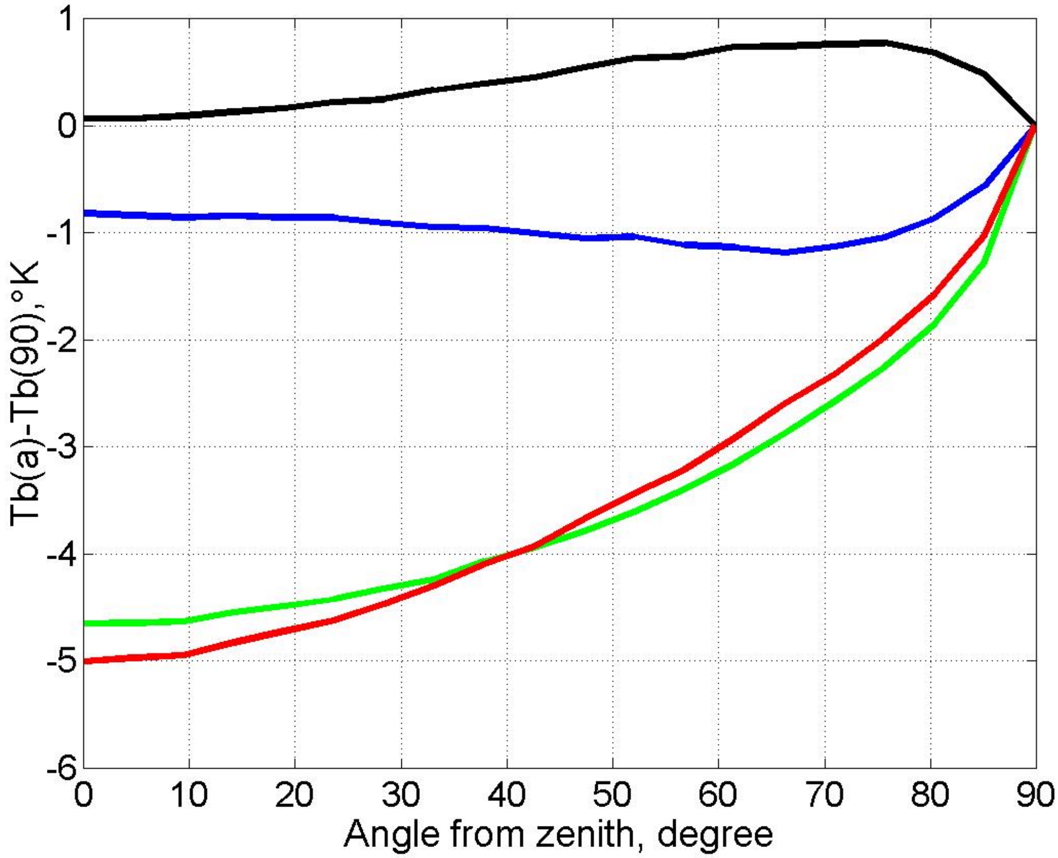

Figure 7. Angular response of 5-mm radiometer corresponded to temperature profiles shown in Figure 6. Corresponding Profile-Tb curves have the same color.

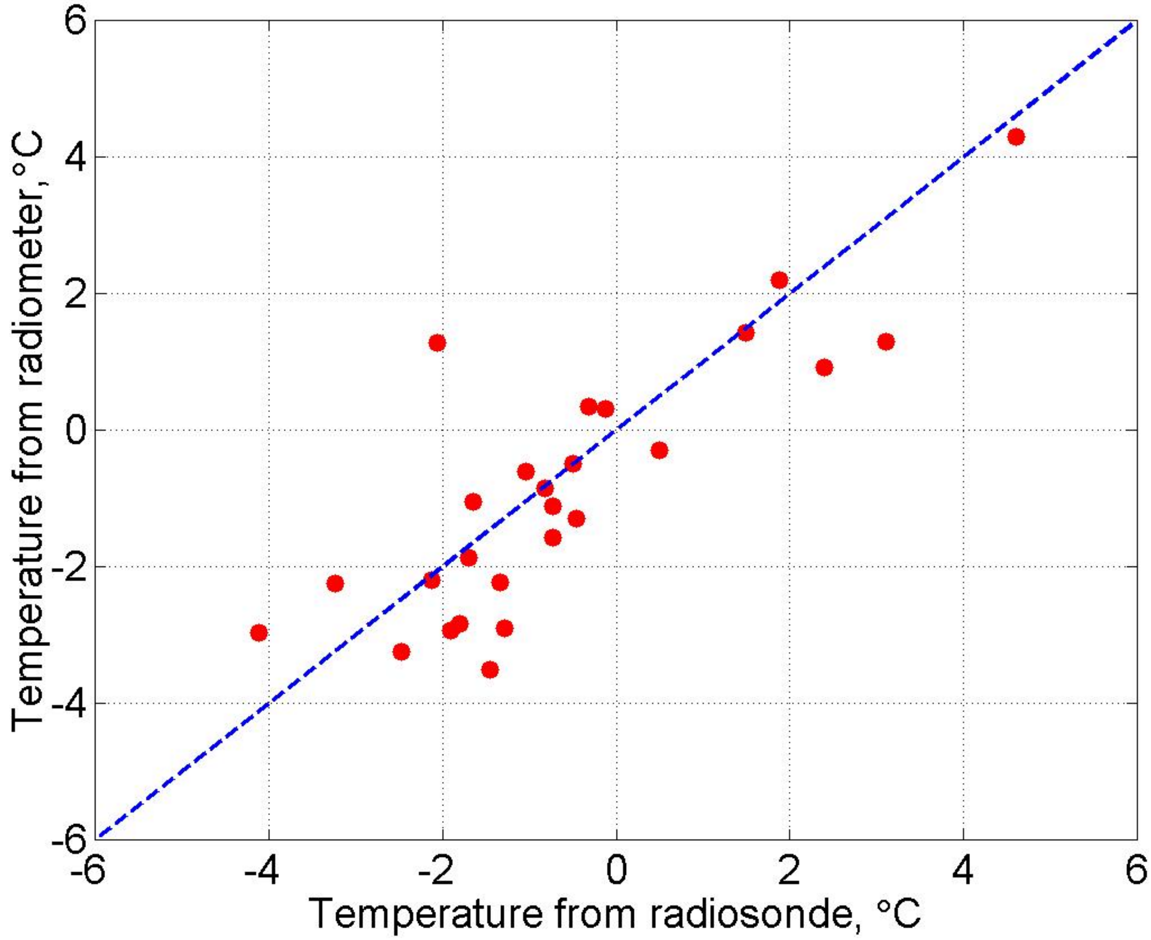

Figure 8. Scatter plot of retrieved temperatures.

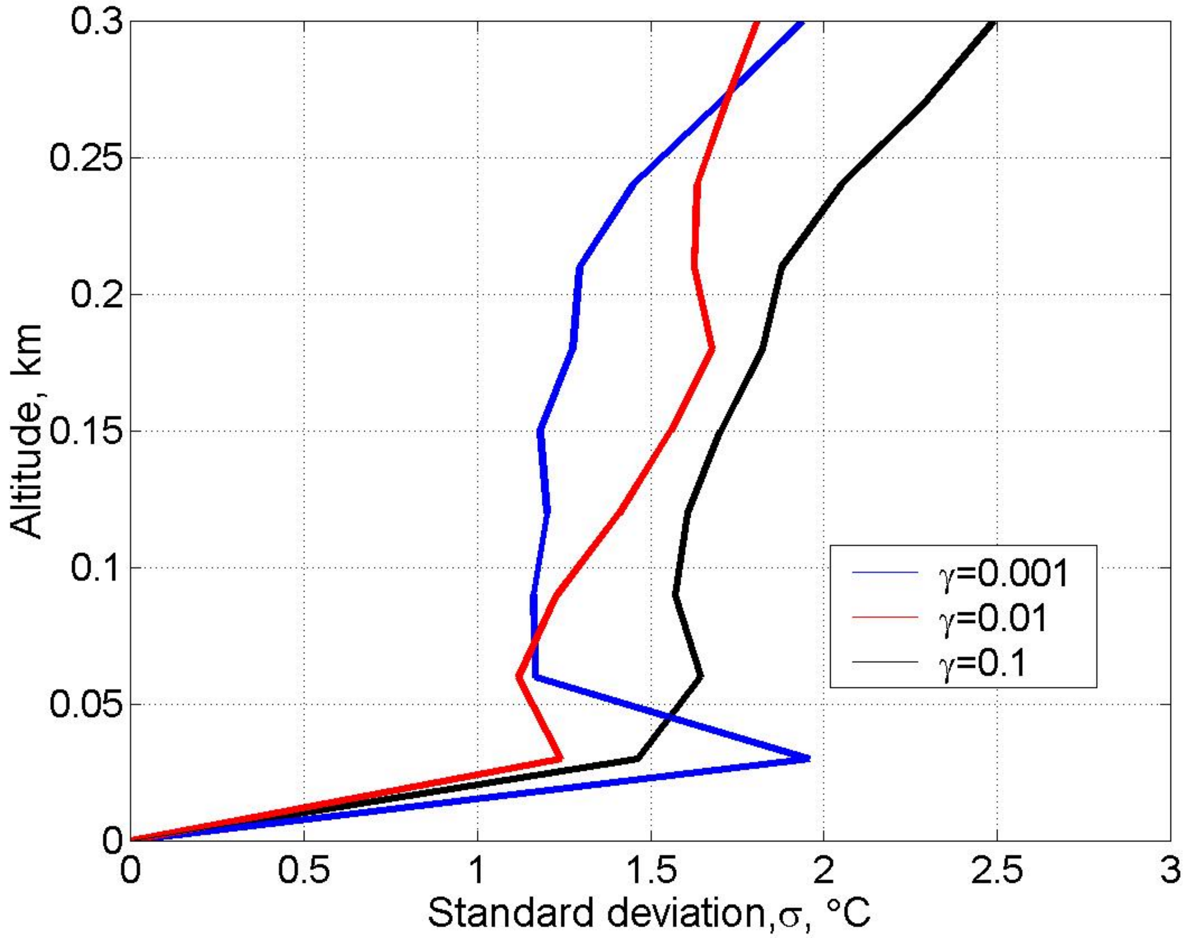

Figure 9. Potential accuracy as a function of the Lagrange multiplier used in the Twomey-Tikhonov temperature retrieval.

Summary

The scanning 5-mm radiometer technique continues to show promise in retrieving low-altitude temperature profiles with accuracy of about 1 to 1.5 K achievable below 500 m. A new application of the data for Arctic deployment is suggested, namely for use in tip cal analysis for millimeter-wave radiometers, where stronger absorption lines make the tip cal procedure more vulnerable to errors in mean radiating temperature. The use of a radiosonde first guess is useful for this type of application and will be investigated using existing datasets.

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