NOTES AND CORRESPONDENCE

Surface-Induced Brightness Temperature Variations and Their Effects on Detecting Thin Cirrus Clouds Using IR Emission Channels in the 8–12-μm Region

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ABSTRACT

A method for detecting cirrus clouds in terms of brightness temperature differences between narrowbands at 8, 11, and 12 μm has been proposed by Ackerman et al. In this method, the variation of emissivity with wavelength for different surface targets was not taken into consideration. Based on state-of-the-art laboratory measurements of reflectance spectra of terrestrial materials by Salisbury and D'Aria, it is found that the brightness temperature differences between the 8- and 11-μm bands for soils, rocks and minerals, and dry vegetation can vary between approximately −8 and +8 K due solely to surface emissivity variations. The large brightness temperature differences are sufficient to cause false detection of cirrus clouds from remote sensing data acquired over certain surface targets using the 8–11–12-μm method directly. It is suggested that the 8–11–12-μm method should be improved to include the surface emissivity effects. In addition, it is recommended that in the future the variation of surface emissivity with wavelength should be taken into account in algorithms for retrieving surface temperatures and low-level atmospheric temperature and water vapor profiles.

1. Introduction

Thin cirrus clouds are difficult to detect in images taken from current satellite platforms. Ackerman et al. (1990) developed a method for detecting thin cirrus clouds using ΔBT(8 − 11), the brightness temperature difference between 8-μm (8.3–8.4 μm) and 11-μm (11.06–11.25 μm) channels, and ΔBT(11 − 12), the brightness temperature difference between 11-μm (11.06–11.25 μm) and 12-μm (11.93–12.06 μm) channels. The method, referred to as the "8–11–12-μm method" hereinafter, was based on the analysis of data acquired with the Cloud and Aerosol Lidar System (CALS) (Spinhirne and Hart 1990) and the High Spectral Resolution Interferometer Sounder (HIS) (Revercomb et al. 1988) on board an ER-2 aircraft over areas covered by vegetation and water in Wisconsin during the first FIRE [First ISCCP (International Satellite Cloud Climatology Project) Regional Experiment] cirrus field experiment in October 1986 (Starr 1987). It was found that the cloud-free regions had negative ΔBT(8 − 11) values, while the areas covered by cirrus clouds had positive ΔBT(8 − 11) values, typically greater than 1.5 K. The additional use of ΔBT(11 − 12) was for the purpose of separating cirrus clouds from low-level water clouds. When applying the 8–11–12-μm method to a similarly measured dataset but over a different geographic location, the method failed to detect thin cirrus clouds (S. A. Ackerman 1992, personal communication).

During their development of the 8–11–12-μm method, Ackerman et al. (1990) carefully considered the absorption and scattering properties of water and ice particles, and the absorption and emission effects of atmospheric water vapor. The variation of surface emissivity with wavelength was not taken into consideration, however.

Recently, Salisbury and D'Aria (1992) have made state-of-the-art laboratory measurements of reflectance spectra of terrestrial materials between 2 and 14 μm. We have studied surface-induced brightness temperature variations in the 8–14-μm region using these spectra. Some of our findings relevant to remote sensing of cirrus clouds are presented in this note.

2. Surface reflectance spectra

Directional hemispherical reflectance spectra of a variety of rocks and minerals, soils, green and dead

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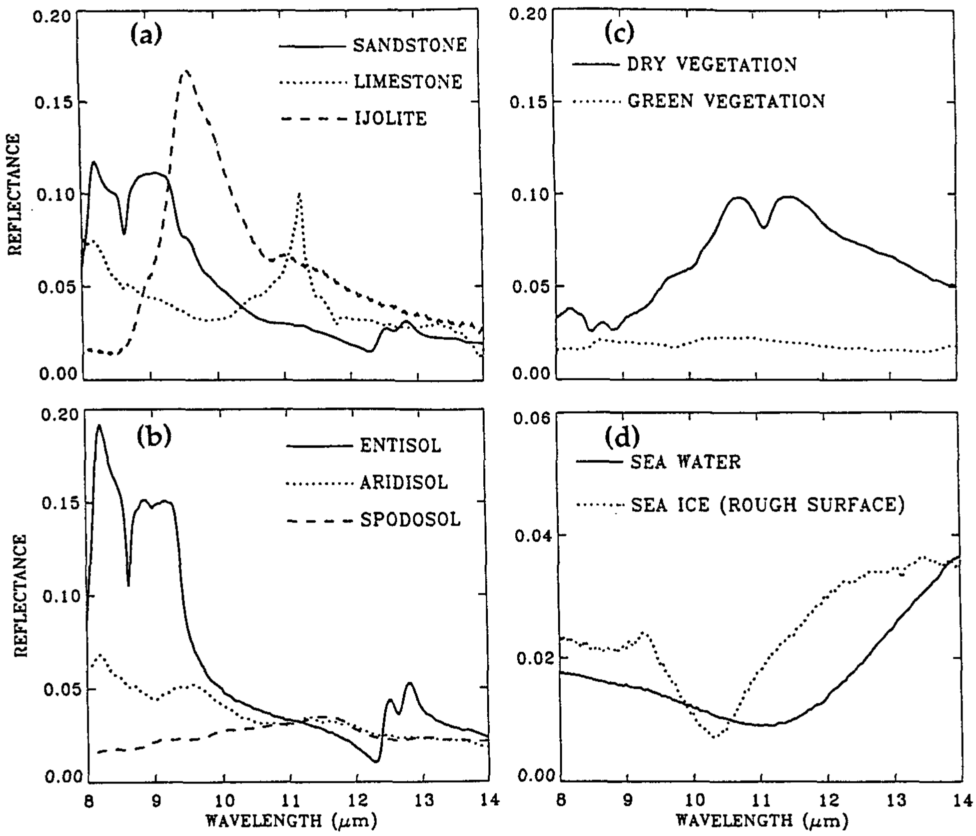

FIG. 1. Examples of reflectance spectra of (a) minerals, (b) soils, (c) green vegetation, and (d) seawater and ice (Salisbury and D'Aria 1992).

vegetation, water, and ice have been made and summarized by Salisbury and D'Aria (1992). They were measured using Fourier transform spectrometers with integration sphere attachments. Figure 1a shows examples of reflectance spectra of three types of rocks; various absorption features due to vibrational band transitions can be seen. The reflectances in the 11-μm (11.06–11.25) region for ijolite and limestone are greater than those in the 8-μm (8.3–8.4) region, while the converse is true for sandstone. Figure 1b shows examples of reflectance spectra of three types of soils in which various absorption features can be seen. Figure 1c shows sample reflectance spectra of green and dry vegetation. The green vegetation has a nearly constant reflectance value (0.02) in the 8–14-μm region, while the dry vegetation has several absorption bands. Figure 1d shows sample reflectance spectra of seawater and sea ice (rough surface); the reflectances are small (between approximately 0.01 and 0.04). The reflectance minimum for seawater is located near 11 μm, and that for sea ice near 10.3 μm. The emissivity is defined as 1 minus reflectance. It is easy to see from Figs. 1a, 1b, 1c, and 1d that the emissivities for soils, rocks and minerals, and dry vegetation in the 8–14-μm region vary significantly with wavelength. The emissivities for green vegetation, water, and ice do not vary much with wavelength and are generally greater than 0.96.

3. Sensitivity of brightness temperature to emissivity

The brightness temperature of a surface is a function of both its kinetic temperature and emissivity. We have studied the sensitivity of the Planck function to changes in temperatures for surface temperatures of 270, 280, 290, and 300 K. From these sensitivities, we have derived the sensitivities of brightness temperatures to emissivities. The results show that, for kinetic temperatures between 270 and 300 K, an error of 0.01 in assumed surface emissivity results in errors of approximately 0.48 K in surface temperature at 8.35 μm, 0.63 K at 11.155 μm, and 0.67 K at 11.995 μm.

4. Results

Based on the sensitivity of brightness temperatures to surface emissivity described in section 3 and using the reflectance data from Salisbury and D'Aria (1992), we have quantified the surface-induced brightness temperature variations in the 8-, 11-, and 12-μm region for soils, rocks and minerals, green and dry vegetation,

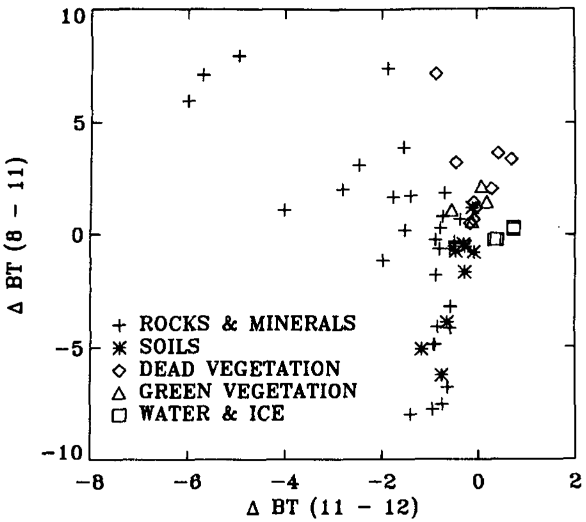

FIG. 2. Scatter diagram of surface-induced ΔBT(8 − 11) versus ΔBT(11 − 12) for rocks and minerals, soils, dead and green vegetation, and water and ice (rough surface).

and water and ice. Figure 2 shows the scatter diagram of the ΔBT(8 − 11) versus ΔBT(11 − 12). The surface-induced ΔBT(8 − 11) can vary between approximately −8 and 8 K for rocks and minerals, 0.5 and 7 K for dead vegetation, and −6 and 1 K for soils.

The large differences in the surface-induced ΔBT(8 − 11) are sufficient to cause confusion if the 8–11–12-μm method (Ackerman et al. 1990) was used straightforwardly for detecting cirrus clouds. For example, if the measurements were made from high-altitude aircraft or satellite platforms over areas covered by dead vegetation but no cirrus clouds, the application of the 8–11–12-μm method might misidentify the areas as being covered by cirrus clouds. On the other hand, if the same measurements were made over areas covered by bare soils with a −4-K surface-induced ΔBT(8 − 11) and also covered by very thin cirrus clouds with a 1.5-K cirrus-induced ΔBT(8 − 11), the application of the 8–11–12-μm method might identify the areas as being clear.

5. Discussion

Because of the traditional lack of reliable IR emissivity measurements (Salisbury and D'Aria 1992) of terrestrial materials, algorithms developed for retrieving atmospheric temperatures and surface temperatures from satellite IR emission channels typically assume constant values of emissivity (about 0.96) in the 8–14-μm spectral region. As a result, errors of 10 K or greater exist in the surface temperatures derived from current satellite IR emission measurements (Wu and Chang 1991).

6. Summary

We have studied surface-induced brightness temperature variations in the 8–12-μm spectral region using laboratory measurements of emissivity of terrestrial materials (Salisbury and D'Aria 1992). It is found that the brightness temperature differences between the 8- and 11-μm bands for soils, rocks and minerals, and dry vegetation can vary between approximately −8 and 8 K. The large differences in the surface-induced ΔBT(8 − 11) are sufficient to cause false detection of cirrus clouds from remote sensing data acquired over certain surface targets if the 8–11–12-μm method (Ackerman et al. 1990) is straightforwardly used. We suggest that the 8–11–12-μm method should be improved to include the surface emissivity effects. We also suggest that the variation of surface emissivity with wavelength should be taken into account in algorithms for retrieving surface temperatures and low-level atmospheric temperature and water vapor profiles.

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REFERENCES

Ackerman, S., W. L. Smith, J. Spinhirne, and H. Revercomb, 1990: The 27–28 October FIRE IFO cirrus case study: Spectral properties of cirrus clouds in the 8–12-μm window. *Mon. Wea. Rev.*, **118**, 2377–2388.

Revercomb, H., H. Buijs, H. Howell, D. LaPorte, W. L. Smith, and L. Sromovsky, 1988: Radiometric calibration of IR Fourier transform spectrometer: Solution to a problem with the High-spectral resolution Interferometer Sounder. *Appl. Opt.*, **27**, 3210–3218.

Salisbury, J., and D. D'Aria, 1992: Emissivity of terrestrial materials in the 8–14 μm atmospheric window. *Remote Sens. Env.*, **42**, 83–106.

Spinhirne, J., and W. Hart, 1990: The 27–28 October 1986 FIRE cirrus case study: ER-2 lidar and spectral radiometer cirrus observations. *Mon. Wea. Rev.*, **118**, 2329–2343.

Starr, D., 1987: A cirrus cloud experiment: Intensive field observations planned for FIRE. *Bull. Amer. Meteor. Soc.*, **67**, 119–124.

Wu, M.-L., and L. Chang, 1991: Differences in global data sets of atmospheric and surface parameters and their impact on outgoing longwave radiation and surface downward flux calculations. *J. Geophys. Res.*, **96**, 9227–9262.