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Near concurrent MIR, SSM/T-2, and SSM/I observations over snow-covered surfaces

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Abstract

The airborne Millimeter-wave Imaging Radiometer (MIR) and MODIS Airborne Simulator (MAS) measurements over the Arctic region and the Midwest region of the US are used to derive surface emissivities $\xi(v)$ for three frequencies, $v = 89$, 150, and 220 GHz, as well as Normalized Difference Snow Index (NDSI) and R87 (0.87-μm reflectance). These derived parameters are compared with parameters estimated from near concurrent measurements made by the SSMI and SSM/T-2 over snow-covered areas. It is shown that the MIR-estimated $\xi(v)$ values at $v = 89$ and 150 GHz agree well with those estimated from the SSM/T-2 at $v = 91$ and 150 GHz, respectively. Low MIR-estimated $\xi(v)$ values are generally associated with high NDSI and R87 over the snow-covered areas. Over forested areas, more fluctuations in the values of MIR-estimated $\xi(v)$, NDSI and R87, as well as a reduction in polarization index (PI) at 37 and 85 GHz are observed.

Both observations and results from radiative transfer calculations show a change in the difference between brightness temperatures (T_b) at 19 and 37 GHz, as well as PI at 37 and 85 GHz, when measured at satellite altitudes and at the surface. The amplitude of the T_b difference and PI is reduced by about 10–15% from surface to high altitudes when integrated water vapor is ≤ 1.5 g/cm^2. This effect is readily correctable and requires consideration when validating satellite retrieval algorithms based on surface and low-elevation aircraft measurements.

Keywords: MIR; SSM/T-2; SSM/I

1. Introduction

Remote measurements of snow surface characteristics have been conducted extensively from both satellites and aircraft. The sensors on board these platforms operate in the visible-infrared and microwave regions of the electromagnetic spectrum (Chang et al., 1997; Foster, Chang, & Hall, 1997; Hall, Foster, Chang, Benson, & Chien, 1998). Remote measurements using sensors sampling the visible and infrared wavelengths generally provide mapping of the extent of snow cover (Hall et al., 1998), while those using microwave radiometers generally provide an estimation of snow depth (SD) or snow water equivalent (SWE) (Chang et al., 1997). For snow cover mapping, both the Normalized Difference Snow Index (NDSI), as derived from the reflectance at ~ 0.55 and ~ 1.62 μm, and the reflectance at ~ 0.87 μm are used (Hall et al., 1998). For estimation of SD or SWE, the brightness temperatures (T_b) measured at 19 and 37 GHz are used (Chang et al., 1997; Foster et al., 1997). Snow cover and snow depth are likely useful indicators of regional or global climate change and basin scale water storage in mountain areas (Foster et al., 1997) so it is extremely important to ensure that these parameters are measured accurately and timely.

The microwave algorithms using the T_b measurements at 19 and 37 GHz to estimate SD and SWE depend strongly on the assumption of the size of the snow crystals (Foster et al., 1997). As a consequence, the estimation of these snow parameters is subject to significant uncertainty based on the measurements from these two channels alone. In addition, the presence of trees affects the T_b values and, therefore, the estimated SD and SWE. In an effort to characterize the radiative effect of trees, a fractional forest cover is introduced in the SD and SWE retrieval algorithms (Foster et al., 1997). Thus, it is useful to explore additional measurements

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that are currently available, which may help improve the estimation of SD or SWE. The Special Sensor Microwave/Imager (SSM/I) has additional channels (both vertical and horizontal polarizations) of measurements at 85 GHz that are considerably different from the 19- and 37-GHz channels in terms of wavelength scale. These channels are expected to reveal properties of scattering from snow crystals that are distinctly different from those at 19–37-GHz channels. The usefulness of these channels has previously been explored using aircraft data acquired at a slightly different frequency of ~ 92 GHz (Chang et al., 1997; Wang, Chang, & Sharma, 1992). However, more extensive analysis and exploration of the potential usefulness of the SSM/I measurements is scarce, presumably due to the fact that the radiometer measurements at the 85–92-GHz frequencies are more sensitive to the radiative contributions of atmospheric water vapor and liquid clouds. These atmospheric effects are often difficult to characterize quantitatively when satellite measurements are made over land.

Recently, an algorithm was developed to retrieve integrated water vapor W from the Special Sensor Microwave/Temperature-2 (SSM/T-2) 150–183-GHz measurements (Miao, 1998; Miao, Kunzi, & Heygster, 2001; Wang, Racette, & Triesky, 2001; Wang, Racette, Triesky, & Manning, 2002). The W retrievals are robust for a dry atmosphere with $W \leq 0.8$ g/cm^2. The corrections for surface temperature variations are shown to be manageable, and the effect due to frequency dependence of surface emissivity $\xi(v)$ is relatively small (Wang & Manning, submitted for publication). After W is retrieved, $\xi(v)$ at any frequency v with a reasonable atmospheric transparency is readily determined (Wang, 2002). The analysis presented in the following is focused on the $\xi(v)$ values estimated at v = 37, 85, 89, 91, 150, and 220 GHz from the measurements of SSM/I, SSM/T-2, and the airborne Millimeter-wave Imaging Radiometer (MIR); the W values needed for the atmospheric corrections are first retrieved from the SSM/T-2 and the MIR. Four days of near concurrent brightness temperature data composed from the airborne MIR, SSM/T-2 and SSM/I are used in the analysis. The Moderate Resolution Imaging Spectrometer (MODIS) Airborne Simulator (MAS) (King et al., 1996), which flies on board the same ER-2 aircraft as the MIR and provides measurements at three visible-infrared frequency bands commonly used for snow area mapping (Hall et al., 1998), complements the analysis performed using the microwave data.

7. Conclusion

Four days of nearly concurrent radiometric measurements from the MIR, SSM/T-2, and SSM/I acquired over the Midwest region of the US during February 1997 and over the Arctic region during May 1998 are analyzed and compared. It is demonstrated that the values of surface emissivity $\xi(v)$ near 90 and 150 GHz estimated from the MIR and SSM/T-2 measurements compare reasonably well. The $\xi(v)$ values retrieved from the 85-GHz channels of both the vertical and horizontal polarization of the SSM/I closely follow the variations of those estimated from the MIR and SSM/T-2 measurements near 90 GHz. Additionally, the MIR-estimated values of $\xi(89)$, $\xi(150)$, and $\xi(220)$ are compared with two indices commonly used for mapping snow cover, the Normalized Difference Snow Index (NDSI) and 0.87-μm reflectance (R87) (Hall et al., 1998), derived from MAS on board the same aircraft. Low 89–220 GHz $\xi(v)$ values generally correspond with high NDSI and R87, which meets the criteria for the presence of snow. The combined radiative signatures of $\xi(v)$, NDSI, and R87 also show skill in separately distinguishing bare and snow-covered lake ice.

The horizontally polarized SSM/I measurements at 19 and 37 GHz are used to estimate the snow depth SD along the flight paths of the MIR and MAS according to the algorithm of Foster et al. (1997). The estimated SD values, as well as the SD values reported by ground stations, are compared with the $\xi(v)$, NDSI, and R87 derived from the MIR and MAS, as well as the 37- and 85-GHz polarization index PI derived from the SSM/I. The values of $\xi(v)$ between 89 and 220 GHz, NDSI, and R87 display more variation over the forested regions with comparable SD; the PI values are clearly reduced over these regions as well. These features could prove useful in delineating the forested from open areas, and thus help refine the fractional forest cover in the retrieval of snow depth (Foster et al., 1997).

Finally, a comparison is made between the parameters estimated at the surface and satellite altitudes. It is shown that the T_{bp} differences between the 19- and 37-GHz channels of the SSM/I at either polarization, which are used to estimate snow depth as well as the PI values from these channels, differ when measured at the surface and at satellite altitudes. The magnitude of the T_{bp} differences and the amplitude of the PI values directly measured at the surface are reduced when measured at satellite altitudes. Results of radiative transfer calculations at these frequencies confirm these observations. The reduction factor is shown to be as large as 10–15%, depending weakly on atmospheric moisture when column water vapor is ≤ 1.5 g/cm^2. Even under a totally dry atmosphere, the effect of continuum absorption is not negligible. This suggests that careful consideration is required when comparing these parameters measured at the surface and at satellite altitudes. In particular, when validating satellite microwave algorithms for retrieving parameters like SD (Foster et al., 1997) using low-elevation aircraft or ground-based microwave measurements, the effect of atmospheric absorption requires careful consideration.