EFFECT OF THE TREE CANOPIES IN MICROWAVE RADIOMETRIC REMOTE SENSING OF SNOWPACK

Seyedmohammad Mousavi, Roger De Roo, Kamal Sarabandi, and Anthony W. England

ABSTRACT

Effective management of the freshwater reservoir requires almost daily monitoring the spatial and temporal distribution of the snow water equivalent (SWE) and snowpack wetness. Both microwave radar and radiometers systems have long been proposed and implemented as powerful remote sensing tools in retrieving the physical parameters of interest due to their all-weather operation capability. In case of microwave radiometry, microwave remote sensing of dry snowpack is based on frequency-dependent differential scattering by the ice grains in the snowpack, referred to as scatter darkening. Scatter darkening has been developed as a SWE remote sensing technology over the last three decades. However, the presence of tree canopies in a given scene can affect the SWE estimation of snowpack. Hence, the knowledge of the brightness temperature of tree canopies is important in order to better predict and recover the SWE of the snowpack. We have used the microwave radiometers at three different frequencies; namely, 1.4 GHz, 19 GHz, and 37 GHz, mounted on our boom truck to look at the snowpack. The measurements have been done in Grand Mesa National Forest in Colorado as the NASA SnowEx campaign in Feb 2017. In this paper, the effect of the snow on tree canopies on their brightness temperature is discussed. Moreover, the elevation angular dependence of the brightness temperature of the tree canopies is investigated. (KEYWORDS: brightness temperature, microwave radar, tree canopy, snowpack)

INTRODUCTION

The brightness temperature of a snowpack measured by a microwave sensor is composed not only of the snowpack emission itself in the field of view of the antenna but also from other objects in its field of view. Examples are tree canopies as well as possible reflected emissions from sources and objects that are possibly outside the field of view. This scenario is more common for satellite microwave radiometry since the footprint of the sensor is large; as a result, it encompasses many different objects. Indeed, the snow properties are different in open and forested areas (De Roo, 2007 and Derksen, 2005). The brightness temperature of a snowpack measured at 19 and 37 GHz has been used routinely to estimate the snow water equivalent (SWE) and the snowpack depth, but the microwave emission at these frequencies is sensitive to the snowpack's conditions (Markus, 2006). To investigate the effect of the tree canopies on the microwave emission of the snowpack observed from a satellite, the University of Michigan performed radiometric measurements at the local scale observation site (LSOS) of the NASA SnowEx campaign in Grand Mesa, CO in Feb 2017.

The LSOS is located at the Jumbo Campground at the Grand Mesa National Forest at N39º 3.2′ W105º 5.6′ and at an elevation of 2987 m. The selected region for microwave radiometric observation was about 15 × 15 m. It was adjacent to a single evergreen tree and bunch of evergreen trees towards southeast and southwest, respectively. On the northeast side of the region, there was a smooth gravel pad under the snowpack, which was about 3 × 3 m and bounded by curbs. On the west, it was bounded by a trail, which was not one of the main targets of interest; however, further to the west, there was a stand of aspen trees for which observations have been performed. Our radiometers operated at 1.4 GHz, 19 GHz, and 37 GHz, all with H- and V- polarizations, mounted on the University of Michigan boom truck. The truck was parked during the whole experiment period, and it was faced northeast where the gravel pad was located. This configuration is shown in Figure 1. The half-power beamwidth of the dual

Paper presented Western Snow Conference 2017

[1] Electrical Engineering and Computer Science Department, University of Michigan, Ann Arbor, MI, mousavis@umich.edu

[1] Electrical Engineering and Computer Science Department, University of Michigan, Ann Arbor, MI, saraband@umich.edu

[1] Climate and Space Sciences and Engineering Department, University of Michigan, Ann Arbor, MI, deroo@umich.edu

[1] College of Engineering and Computer Science, University of Michigan, Dearborn, MI, england@umich.edu

Figure 1. Photo mosaic of the measurement setup in which microwave radiometric observations of snowpack were made. Southwest is at the left, northeast is at the top right, and north is at the bottom right.

polarized 1.4 GHz radiometer is about 20^{o}. The other two radiometers are equipped with separate standard gain horns for H- and V-polarizations. All four of these antennas have half-power beamwidth of about 10^{o}. Despite the fact that these beamwidths permit exclusions of the direct emission from the trees, trees emit microwave radiation toward the footprint on the snowpack. Hence, it is important to understand the signatures observed by different tree canopies to minimize their effects to simplify the analysis of the observation.

DATA SET COLLECTION

The primary goal was to observe the microwave emission of the tree canopies at different incident angles in order to understand their angular behavior. In addition to the direct observation of the emission from the tree canopies, a number of measurements were made from the snowpack itself in the surrounding area of the target. The elevation angle was either varied by changing the boom height or rotating the head of the boom in elevation. In Figure 1, the radiometers are shown installed on the boom and looking at the tree canopies at different heights. The observation angles in elevation plane varied between about 30^{o} up to about 70^{o}. It should be noted that the observation angles for the snowpack on the northeast side (on gravel pad) was restricted by the possible influence of the ground heterogeneity. Hence, there were not much of a freedom for observation angles for this target.

The majority of the measurements were made during the Intensive Observation Period (IOP), which took place from February 6 to 24, 2017 [day-of-year (DOY) 37 to 55]. During this time, the snowpack depth was varied from about 140 cm up to 160 cm in the selected area around the truck. The air temperatures during this period ranged from about -12.0 ºC to about +5.0 ºC. Above freezing temperatures occurred through the three weeks of the IOP except the last two days. It should be also mentioned that the air temperature was warmer mostly in the first week of the IOP. For the calibration of the radiometers, clear sky (at about zenith) and microwave absorber were used as cold and warm external targets, respectively. Moreover, all radiometers have a reference load as internal calibration target (warm target) of which temperature is always monitored. The L-band radiometer has also a Cold Field-effect Transistor (Cold-FET) as another internal calibration target (cold target) for an accurate calibration. After doing the calibration, one can convert the output voltage of the radiometer to the brightness temperature of the object in the field of view of the antenna.

RESULTS AND DISCUSSION

There was a lone evergreen tree on the southeast as well as bunch of evergreen trees close together on the southwest side. First, the measured brightness temperatures, T_B, of the bunch of evergreen trees as a function of incident angle at three different frequencies and different polarizations H- and V-pol, are shown in Figure 2. These set of measurements were done on Feb 10, 2017. The air temperature was about +5.0 ºC, and there was no snow on the trees. It can be observed that the T_B is lower at 37 GHz than at 19 GHz. This is the same as the expected T_B from the snowpack itself, where it is lower at 37 GHz than at 19 GHz. Moreover, T_B is lower at 1.4 GHz in comparison with the other two frequencies. It can also be observed from Figure 2 that at both 19 GHz and 37 GHz, the H- and V-polarizations both have same behavior with respect to the incident angle. Indeed, at angles closer to nadir, $T_B$is colder, and it gets warmer as the incident angles increases, and this is due to the fact that at angles closer to nadir, there are more branches and leaves in the field of view of the antenna, which causes more scattering and lower brightness temperature. In addition, the sky reflection off of the snow surface to the radiometer's antenna is lower at angles closer to nadir since the sky brightness temperature is decreasing with decreasing the zenith angle. At angles above 55º, the brightness temperature starts to get cooler again since more sky radiation, which is colder, received by the radiometers. In addition, the brightness temperature at both H- and V-polarizations are getting closer at angles closer to nadir for both 19 GHz and 37 GHz frequencies. It can also be observed that the brightness temperature at 37 GHz starts getting cooler after about 30º, while it starts getting cooler after about 45º at 19 GHz. This is because of the fact that the 37 GHz is installed higher than the 19 GHz on the boom; hence, the 37 GHz radiometer sees the sky sooner than the 19 GHz radiometer.

On the other hand, the brightness temperature has different behavior at 1.4 GHz. In fact, at V-pol, the brightness temperature is increasing from about the nadir up to about 45º, whereas at H-pol, the brightness temperature is warmer at about the nadir, and it is decreasing up to about 45º, after which it starts to get warmer. We suspect that this behavior in H-pol is due to the orientation of the needle leaves of the evergreen trees, as shown in Figure 3, which causes more scattering in H-pol as compared to V-pol. The electric field is more parallel to the leaves of the evergreen trees in H-polarizations at angles closer to nadir and grazing, which makes the brightness temperature to be warmer in H-pol. It should be also noted that the orientation of the leaves is more evident at 1.4 GHz. These results are valuable for modeling the evergreen trees in order to find the brightness temperature, which is beyond the scope of this paper, and it will be more investigated in future papers.

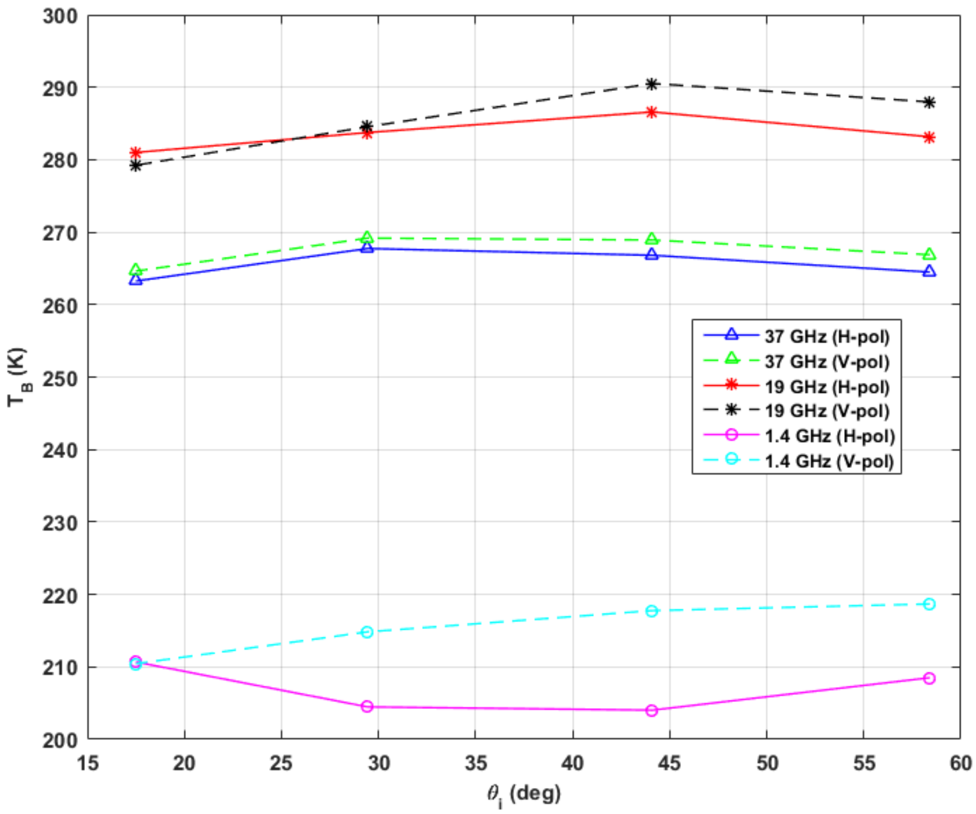

Figure 2. The measured brightness temperature (T_B) of the bunch of evergreen trees close together at different incident angles. The measurements were done at three different frequencies, 1.4 GHz, 19 GHz, and 37 GHz, and at both H- and V-polarizations. The air temperature is above freezing, and there is no snow on the trees (Feb 10, 2017).

Figure 3. The evergreen trees brightness measurement by the microwave radiometer on Feb 10, 2017. The air temperature is above freezing, and there is no snow on the trees.

In order to observe the consistency of the behavior of the brightness temperature of the bunch of evergreen trees with respect to the incident angle at different frequencies, same measurement setup was made on another day, Feb 22, 2017, as shown in Figure 4. The air temperature was about +2.0 ^{o}C, and there was a little snow on the tree branches. It can be observed from Figure 3 that the brightness temperature has the same behavior with respect to the incident angle at different frequencies and different polarizations. It can also be observed that the brightness temperature is about the same at 19 GHz and 37 GHz in both polarizations on Feb 22 as on Feb 10 since there was a little bit snow on the trees branches on Feb 22, and it was mostly on the lower branches, as shown in Figure 5. On the other hand, at 1.4 GHz, the brightness temperature on Feb 22 increases in H-pol and V-pol as compared to the brightness temperature on Feb 10. It could be due to the fact that on Feb 10, the air temperature was higher, and the snow was wet; hence, the surface of the snowpack became like a smoot reflector at longer wavelength, and reflects more sky.

An overnight measurement of bunch of evergreen trees has been made from Feb 18 to Feb 20. The incident angle was 52.7^{o}. The measurement started at 05:22 pm on Feb 18 and continued until 08:06 am on Feb 20. The radiometers were set to do measurement every fifteen minutes. The air temperature was about -0.5 ^{o}C on Feb 18. There was a winter storm on Feb 18 night, and it continued till morning on Feb 20. The air temperature was about -0.1 ^{o}C during the day, and it got colder during the night. The air temperature was about -5.4 ^{o}C in the morning on Feb 20. The measured brightness temperature with respect to the time at the three different frequencies and different polarizations is shown in Figure 6. It can be observed that the brightness temperature has the same behavior with respect to the frequency of operation; indeed, T_B is lower at 19 GHz compared to at 37 GHz, and it is the lowest at 1.4 GHz. From 5:22 pm on Feb 18 until midnight, T_B decreases at both 19 GHz and 37 GHz radiometers and both H- and

V-polarizations since it was snowing and the branches became heavier; hence, the radiometers observed more sky in their field of view. On the other hand, T_B at 1.4 GHz decreases slightly in V-pol, while it increases slightly in H-pol due to the change in the orientation of the leaves, as discussed before. From midnight until about 6:00 am on Feb 19, the brightness at all the frequencies and both polarizations is almost constant. At about 11:07 am on Feb 19, there is a peak in the T_B for 19 GHz and 37 GHz at both polarizations since the air temperature increased, and the snow on the trees started to fall down; hence, there was more tree branches in the radiometers' field of view. Moreover, since the snow started melting, it makes the branches more wet; hence, the brightness temperature increases. On the other hand,

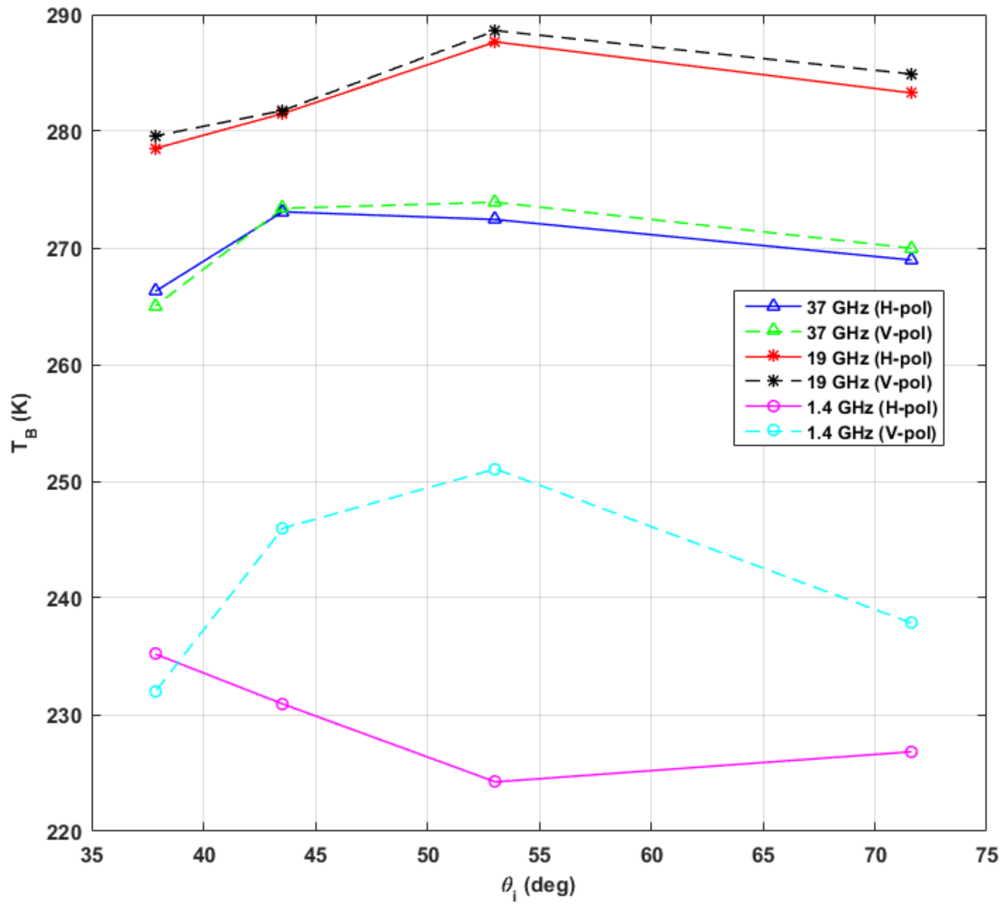

Figure 4. The measured brightness temperature (T_B) of the bunch of evergreen trees close together at different incident angles. The measurements were done at three different frequencies, 1.4 GHz, 19 GHz, and 37 GHz, and at both H- and V-polarizations. The air temperature is close to freezing, and there is a little bit snow on the trees and mostly on lower branches (Feb 22, 2017).

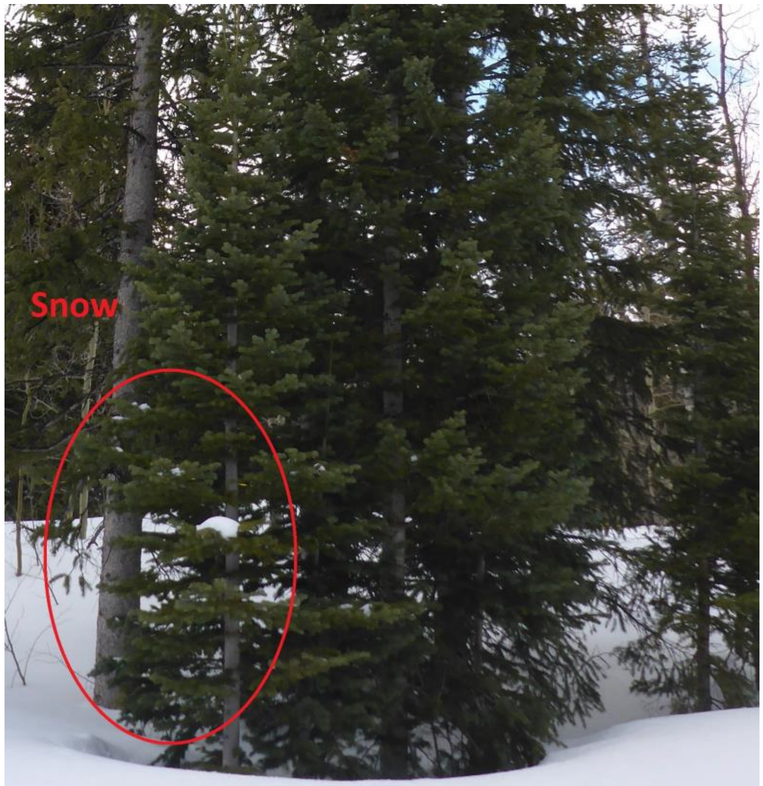

Figure 5. The evergreen trees brightness measurement by the microwave radiometer on Feb 22, 2017. The air temperature is close to freezing, and there is a little bit snow on the trees and mostly on lower branches.

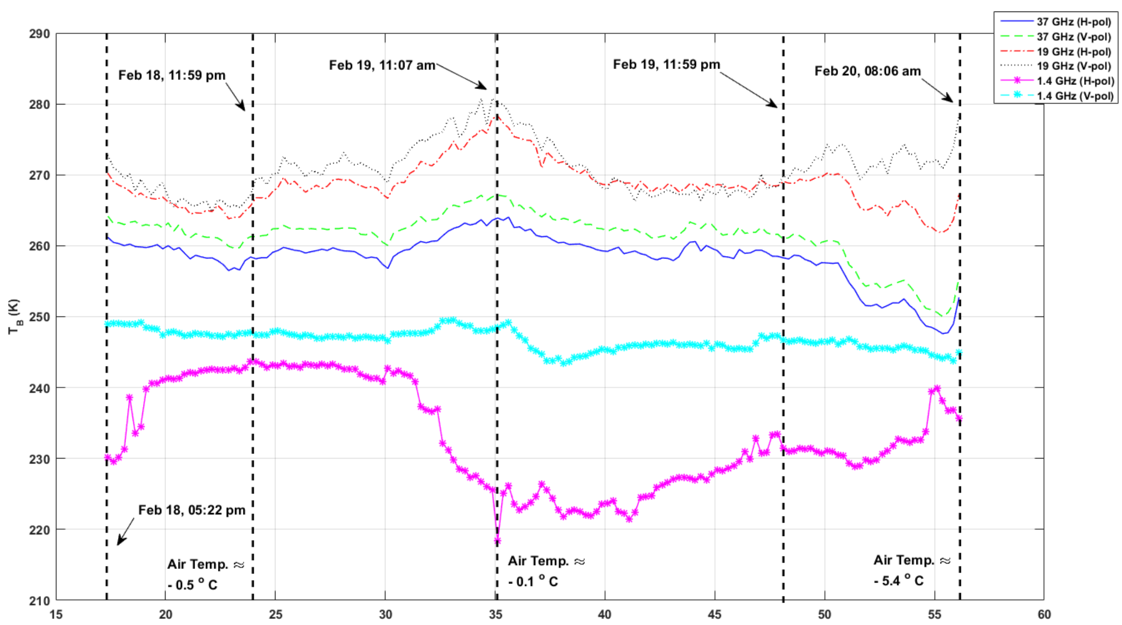

Figure 6. The overnight measured brightness temperature (T_B) of the bunch of evergreen trees close together from Feb 18 to Feb 20, 2017. The incident angle is 52.7°. The measurements were done at three different frequencies, 1.4 GHz, 19 GHz, and 37 GHz, and at both H- and V-polarizations.

there is huge decrease in T_B at 1.4 GHz in H-pol. It could be due to the fact that as the branches went up, the electric field in the H-pol became less parallel to the leaves of the evergreen trees, whereas T_B at 1.4 GHz in V-pol increases slightly since the orientation did not change much for V-pol at this incident angle. Then, after 11:07 am on Feb 19, T_B at 19 GHz and 37 GHz decreases since it was started to snow at that time. Therefore, snow started to accumulate on the tree branches, and the branches went down again. On the other hand, T_B at 1.4 GHz increases in V-pol and H-pol. Again, we can observe the same pattern for T_B for the next day, and the measurement stopped by the operator at about 8:06 am on Feb 20 before observing another peak like before.

CONCLUSIONS

The brightness temperature, T_B, of the tree canopies at 1.4-, 19-, and 37-GHz were measured in order to understand the signature of the tree canopies. In fact, the knowledge about the effect of the tree canopies on the measured brightness temperature would help us to better estimate the SWE. The angular effect of the T_B has been discussed. Moreover, the effect of snow on trees were also discussed. It has also been observed that the brightness temperature could be sensitive to air temperature, snow depth around the tree canopies, and shape and size and orientation of the leaves and branches. Finally, a continuous observation made from Feb 18 to Feb 20, 2017. These results are useful for modeling the evergreen trees to find their brightness temperatures and will be more investigated in future papers.

ACKNOWLEDGEMENTS

The authors hereby express their gratitude to NASA for its support via contract NNX15AB36G. We also thank Ludovic Brucker and the Mesa Lake Lodge for their assistance in the field campaign.

REFERENCES

R. D. De Roo, A. R. Chang, and A. W. England. 2007. Radiobrightness at 6.7-, 19-, and 37-GHz Downwelling From Mature Evergreen Trees Observed During the Cold Lands Processes Experiment in Colorado, IEEE Transactions on Geoscience and Remote Sensing, vol. 45, no. 10, pp. 3224-3229.

C. Derksen, A. E. Walker, B. E. Goodison and J. W. Strapp. 2005. Integrating in situ and multiscale passive microwave data for estimation of subgrid scale snow water equivalent distribution and variability," IEEE Transactions on Geoscience and Remote Sensing, vol. 43, no. 5, pp. 960-972.

T. Markus, D. C. Powell and J. R. Wang. 2006. Sensitivity of passive microwave snow depth retrievals to weather effects and snow evolution," IEEE Transactions on Geoscience and Remote Sensing, vol. 44, no. 1, pp. 68-77.