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# Nimbus-7 SMMR Polarization Responses to Snow Depth in the Mid-Western U.S.

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Analysis of January and February 1979 Scanning Multichannel Microwave Radiometer (SMMR) data has revealed discrepancies in the responses of vertically and horizontally polarized brightness temperature ($T_B$) data to snow in the state of Indiana. Ten satellite overpasses were analyzed between January 8 and February 21, 1979. In four cases, the horizontally polarized $T_B$s correlated with snow depth significantly better than did the vertically polarized $T_B$s. These four overpasses occurred either when the snowpack was building up or when it had metamorphosed and/or was melting. For example, on February 17, the coefficient of correlation, $R$, between vertically polarized $T_B$ and snow depth was $R$ = -.46 while it was $R$ = -.86 for the horizontally polarized $T_B$ data. Just prior to February 17, air temperatures rose above 0°C in the study area causing melting of the snowpack. On February 17, air temperatures dropped well below 0°C and the snow and water in the snowpack froze causing a metamorphosis of the snowpack. It is concluded that horizontally polarized $T_B$ data may be more useful than vertically polarized data for analysis of snow in regions in which there are a range of snowpack conditions, or where a snowpack undergoes rapid metamorphosis. However, analysis of both polarizations may reveal information concerning the structure of a snowpack.

## Introduction

Satellite remote sensing is highly suited to analysis of snow conditions on global and regional scales. Nimbus-7 SMMR (Scanning Multichannel Microwave Radiometer) data have been employed for analysis of global snow covered area (Kunzi

1982). There are also strong indications that such multifrequency microwave data are useful for determination of other snowpack properties such as liquid water content and depth (Foster et al. 1980; Burke et al. in press). However, many snowpack properties are known to influence the microwave emission of snow, and these effects are not well-understood. In addition, the vertical and horizontal polarizations respond differently to the same snowpack. In this paper, differential responses of the horizontally and vertically polarized brightness temperatures ($T_B$) to snow depth are analyzed for the State of Indiana in the mid-western U.S. during the winter of 1979.

Indiana is part of the central or interior lowlands which consist of gently sloping plains. The area is intensively cultivated with grains being the primary crop. Although snowfall occurs regularly during most winters, a seasonal snowpack lasting more than 60 days is unusual. During the winter of 1979, snow was on the ground in the mid-west during most of January and February because temperatures were considerably below normal.

## Sensor Characteristics and Background

The SMMR is a dual polarized, five channel microwave radiometer operating in a near polar orbit with a conical scan mechanism and an earth incidence angle of approximately 50° (Gloersen and Barath 1977). Other pertinent information is given in Table 1.

Previous studies have shown that the microwave brightness temperature at certain wavelengths for both vertically and horizontally polarized data is significantly correlated to snow depth for areas with relatively low and homogeneous vegetation during non-melting conditions (Rango et al. 1979). Tiuri and Hallikainen (1981) found a correlation between $T_B$ and snow depth in the presence of 70 percent forest cover. Burke et al. (in press) found the 37 GHz SMMR data to be sensitive to snow depth under dry snow conditions in Nebraska, and that the 37 and 18 GHz frequencies were useful for delineating areas of melting snow. In all of these studies, both the vertically and horizontally polarized data were employed and assumed to be of similar value for correlation with snow depth.

Table 1 – Some characteristics of the SMMR (after Gloersen and Barath 1977)

| | | | | | |
|---|---|---|---|---|---|
| Wavelength (cm) | 0.81 | ~1.43 | 1.66 | 2.80 | 4.54 |
| Frequency (GHz) | 37.00 | 21.00 | 18.00 | 10.69 | 6.60 |
| Spatial resolution (km) | 30 | 60 | 60 | 97.5 | 156 |
| Temperature resolution $T_{rms}$ (°K) (per IFOV) | 1.5 | 1.5 | 1.2 | 0.9 | 0.9 |
| Antenna beam width (degree) | 0.8 | 1.4 | 1.6 | 2.6 | 4.2 |

## Methodology

For the Indiana study area, 28 or 29 resolution cells of SMMR data were analyzed for 10 satellite overpasses which occurred between January 8 and February 21, 1979. Each resolution cell, in this study, represents an area that is 1/2° longitude × 1/2° latitude in area. The average snow depth for each cell was determined by connecting points of equal snow depth on a map, and then estimating the average snow depth for each resolution cell by analysis of these isolines. Snow depth values and meteorological data were obtained from USDC (1979).

Only 37 GHz data were used because this frequency has been shown to be the most useful of the SMMR frequencies for analysis of a range of snowpack properties including depth (Rango et al. 1979; Hall et al. 1978).

The SMMR data used for this study were acquired both in the daytime and at night. The 10 overpasses represent all available SMMR data for that area between January 8 and February 21, 1979. (Note: data from 4 overpasses were omitted because of heavy snowfall or rapid melting and thus there was uncertainty concerning the published snow depths at the time of the overpass.)

## Results

For the study area in Indiana, the coefficients of correlation, $R$, coefficients of determination, $R^2$, standard errors of estimate, $SEE$, standard deviations, $S_D$ and equations of the lines were calculated between snow depth for each cell and vertically polarized $T_B$ and horizontally polarized $T_B$ for each of the 10 satellite overpasses. The $R$ values along with other pertinent information, are shown in

Table 2 – Coefficient of correlation, $R$, values between snow depth and vertically polarized 37 GHz $T_B$ and, horizontally polarized 37 GHz $T_B$, and average snow depths in the study area for the 10 satellite overpasses ($n \equiv 28$ or 29).

| Date of overpass 1979 | D (daytime) or N (nighttime) overpass | vertical vs. snow depth – $R$ value | horizontal vs. snow depth – $R$ value | snow depth (cm), $\bar{x}(s_x)$ |
|---|---|---|---|---|
| January 08 | N | -.50 | -.80 | 9.69(± 6.27) |
| January 20 | N | -.82 | -.87 | 7.64(± 9.49) |
| January 22 | D | -.92 | -.91 | 6.00(± 6.24) |
| January 26 | N | -.51 | -.62 | 14.50(± 11.54) |
| February 03 | D | -.73 | -.69 | 24.28(± 7.79) |
| February 09 | D | -.68 | -.66 | 25.48(± 6.94) |
| February 11 | N | -.65 | -.64 | 25.38(± 7.69) |
| February 15 | D | -.89 | -.91 | 25.75(± 12.13) |
| February 17 | N | -.46 | -.86 | 24.82(± 14.63) |
| February 21 | D | -.16 | -.59 | 20.34(± 10.71) |

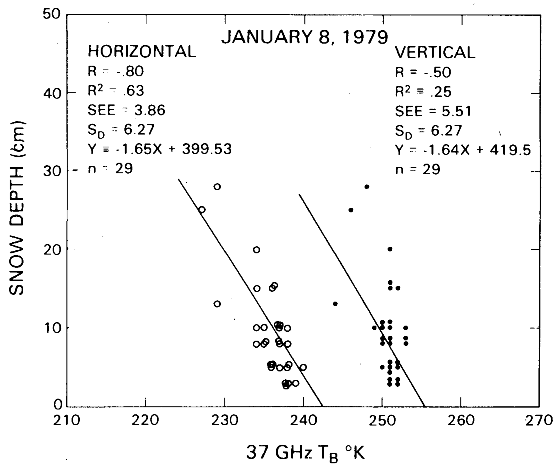


Fig. 1. 37 GHz horizontal and vertical polarizations versus snow depth in Indiana – January 8, 1979.

Table 2. For the 10 overpasses studied, the horizontal polarization was considerably better for snow depth determination in 4 cases in which there was a large difference in the response of the vertically and horizontally polarized data to snow depth.

The following observations can be made regarding the data set summarized in Table 2. As the snowpack began to build up, on January 8, the vertical polarization did not respond to the snow depth as well as did the horizontal polarization (Fig. 1). The mean snow depth was 9.69 cm (± 6.27). By January 20, the snowpack was quite well established with a mean depth of 7.64 cm (± 9.49) and there were quite good correlations with snow depth using both horizontal and vertical polarizations. The same is shown for the January 22, 26, February 3, 9, 11 and 15 overpasses as well. On February 17, the horizontally polarized data gave a correlation of $R$ = -.86 while the vertically polarized data rendered an $R$ = -.46 (Fig. 2). Just prior to February 17, there had been some snowpack melting (February 15) and refreezing (February 17) that had undoubtedly caused snowpack metamorphism. Then, by the February 21 overpass, air temperatures were all well above freezing in most of the study area and the snowpack was beginning to melt. The horizontally polarized data correlated negatively with snow depth with $R$ = -.59 while the vertically polarized data gave a positive correlation of $R$ = .16 (Fig. 3).

From Table 2 it can be seen that the horizontally and vertically polarized data correlated quite well (and equally) with snow depth when the snowpack was well established. However, early in January when the snowpack was building up and late in February when the snowpack was metamorphosed and melting, the horizontally polarized data displayed considerably more sensitivity to snow depth than

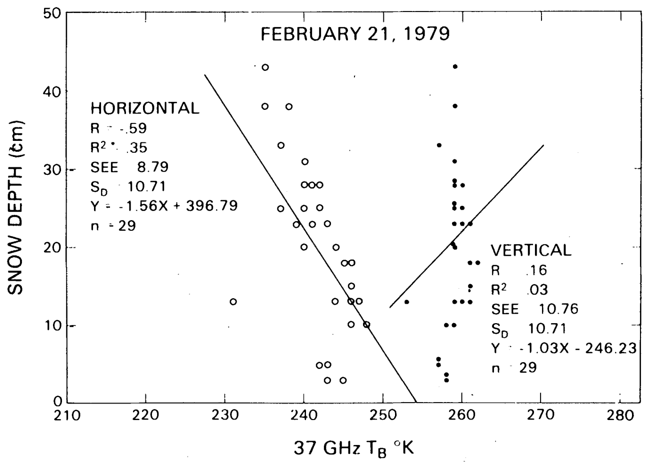


Fig. 2. 37 GHz horizontal and vertical polarizations versus snow depth in Indiana – February 17, 1979.

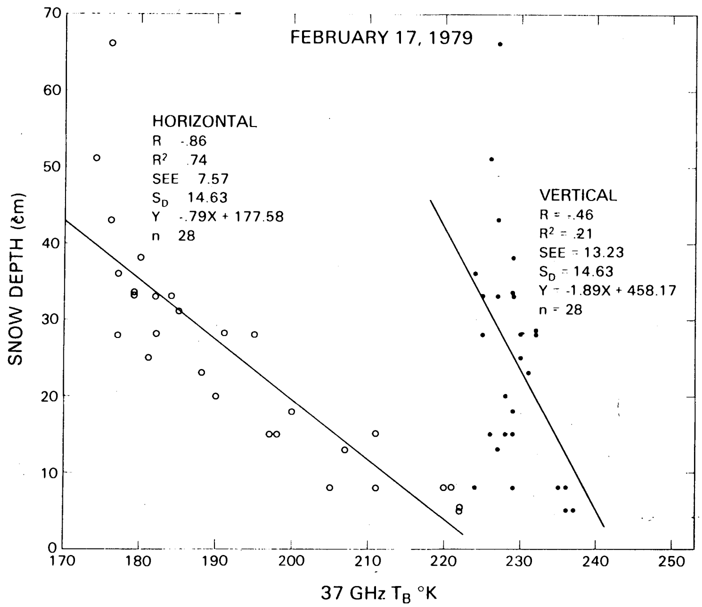


Fig. 3. 37 GHz horizontal and vertical polarizations versus snow depth in Indiana – February 21, 1979.

Table 3 – Coefficient of determination, $R$, values for snow depth versus $T_B$ for the eastern U.S. study area ($n = 62$).

| Frequency GHz | 19 February | |
|---|---|---|
| | Vertical | Horizontal |
| 37 | 0 | -.75 |
| 21 | -.20 | -.79 |
| 18 | -.37 | -.75 |

did the vertically polarized data. Thus, for a range of snow conditions one must use caution in using the vertically polarized data alone to analyze snowpack conditions.

The discrepancy in the correlations between the vertical and horizontal polarizations of SMMR data has also been observed in other snow covered areas. An area in Pennsylvania and Maryland was analyzed for the February 19, 1979 SMMR overpass. The overpass occurred during the daytime just after a major snowstorm occurred in the eastern U.S. Sixty-two resolution cells (1/4° longitude × 1/4° latitude) were analyzed and correlated with snow depth values in the same manner that was done for the Indiana study area. The correlations between snow depth and 37 GHz $T_B$ were -.75 for the horizontally polarized data and 0 for the vertically polarized data (Table 3).

## Discussion

It has been shown that for the Indiana study area and for a study area in the U.S., the horizontally polarized $T_Bs$ generally correlated better with snow depth than did the vertically polarized $T_Bs$ for a wide range of snow depths and conditions. It is clear that the polarizations are responsive to different conditions associated with the snowpack.

It is also known that when a snowpack is melting the effect of free water is so strong that the regression relationships can be reversed so that a deeper snowpack can have a higher $T_B$ than a shallow snowpack (Rango et al. 1979). This effect may be accentuated in the vertically polarized data.

Analysis of a time series of SMMR data for an area such as Indiana during the winter of 1979 has shown that it is important to analyze the responses of both the vertical and horizontal polarizations for snowpack studies. There is no single frequency and polarization combination that will give all the snowpack information desired for a particular area. Additional analysis with surface measurements is required in order to ascertain which characteristics affect the horizontally polarized $T_Bs$ and which affect the vertically polarized $T_Bs$ most strongly.

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