REGIONAL DIFFERENCES IN SNOWPACKS IN THE NORTHERN U.S. AS SEEN BY THE NIMBUS-7 SMMR

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ABSTRACT

Scanning Multichannel Microwave Radiometer (SMMR) satellite data have been employed for analysis of snowcover since the launch of the Nimbus-7 satellite in October 1978. Using SMMR data, snowcovered area and snow depth can be estimated over large areas. However, significant differences in regional snowpack conditions which result from topographic, climatic and vegetation differences among areas cause the SMMR signatures in various snowcovered areas to be quite different even when snow depths are similar. A comparison of 37 GHz brightness temperature (T_B) for January through March 1979 in three areas: New England, Minnesota and the North Slope of Alaska was undertaken. The T_Bs of the Minnesota and New England snowpacks fluctuated considerably more than did the T_Bs of the North Slope snowpack. This is because the snow, topography and vegetation are highly uniform on the North Slope as compared to the other areas. Graphs of horizontally and vertically polarized T_B, air temperature and snow depth, versus time are plotted for each of the three areas.

Introduction and Methodology

Scanning Multichannel Microwave Radiometer (SMMR) satellite data have been employed for analysis of global and regional snow cover since the launch of Nimbus-7 in October of 1978 (Kunzi et al., 1980; Foster et al., 1984). Results have shown that snowcovered area and liquid water content of snow over large areas can be estimated using SMMR data. However, significant differences in regional snow conditions result from topographic, climatic and vegetation differences among areas. Thus the SMMR signatures in various snowcovered areas are quite different.

In this paper, we present SMMR data of three areas in the northern United States: a portion of New England, northern Minnesota and the North Slope of Alaska. We intend to show how differences in brightness temperature, T_B (a measure of the emissivity and physical temperature of the material in °K), relate to air temperature and snow depth in the three areas. Comparison of SMMR data of the three areas reveals differences in the snow that cannot be accounted for by temperature and/or snow depth.

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^o (Gloersen and Barath, 1977). Other pertinent information is given in Table 1. Only 37 GHz data were used in this study 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). All available Nimbus-7 overpasses (daytime and nighttime) were used from January through March 1979.

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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

Study Areas

The three study areas have quite different climatic, topographic and vegetation conditions and thus the snow has different characteristics in terms of temperature, depth, water content and structure. No ground truth measurements (snow depth, water equivalent, etc.) were available during these overpasses, however meteorological data and snow depths were available from local meteorological stations (USDC, 1979).

The New England study area extends from approximately 43.5° - 45°N latitude and 69.5° - 74°W longtidue covering portions of Maine, Vermont and New Hampshire. The vegetation is characterized by northern hardwoods and spruce and fir forests. The topography of New England is more rugged than that of the other study areas and the snow tends to be wetter and the crystals larger since snowfall generally occurs at higher temperatures. The snowpack is subject to periods of freezing and thawing throughout the winter.

The Minnesota study area covers the area between 44.5° - 49°N latitude and 93.5° - 97°W longitude in northern Minnesota. The area is characterized in winter by a persistent snow cover (> 50 cm) and cold temperatures. Occasional influxes of warm air may alter the structure of the snowpack. Vegetation consists of spruce-fir, pine and maple-basswood forests. The relief is gentle with some irregular plains and small hills.

The Alaskan study area (latitude 69.5° - 71°N, longitude 43.5° - 55°W), is located on the North Slope which is the relatively flat, treeless area between the Brooks Range and the Arctic Ocean. The North Slope does not receive much snowfall (< 50 cm) in a typical winter, but the snow that does fall tends to remain because winter temperatures are so cold. The vegetation consists mainly of low shrubby plants. Slaughter and Crook (1974) characterize the snow cover on the North Slope as having: 1) intense depth hoar development in response to steep temperature gradients and vapor migration within the snowpack, and 2) high snow density resulting from intense wind action.

Results

Figures 1, 2 and 3 show plots of vertical and horizontal T_B, snow depth and air temperature for the New England, Minnesota and Alaska study areas respectively. Dates and frequency of coverage by the Nimbus-7 varied among the three areas. The snow depth and air temperature data represent an average of data from available meteorological stations in each study area.

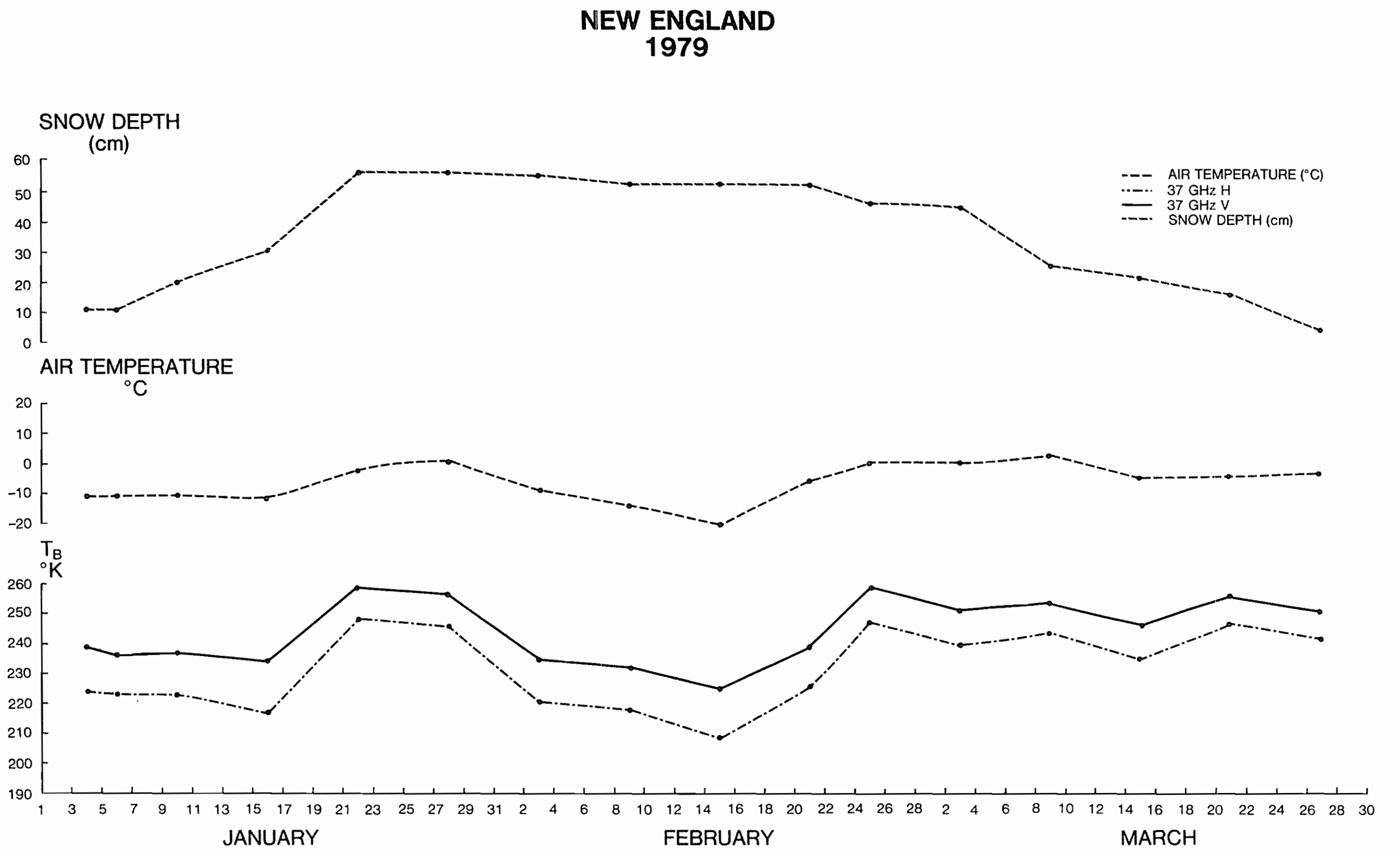

Figure 1. Brightness temperature, air temperature and snow depth January - March 1979 - New England.

MINNESOTA
1979

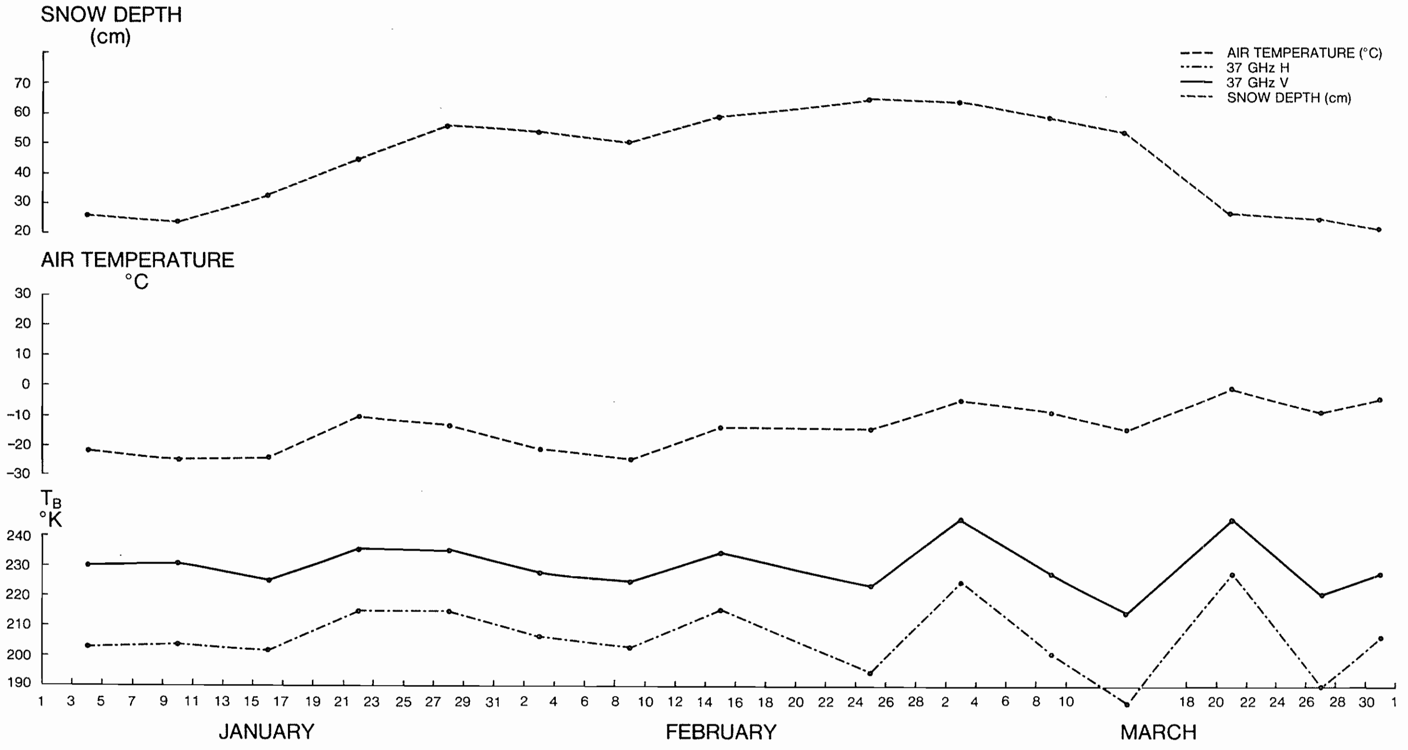

Figure 2. Brightness temperature, air temperature and snow depth January - March 1979 - Minnesota.

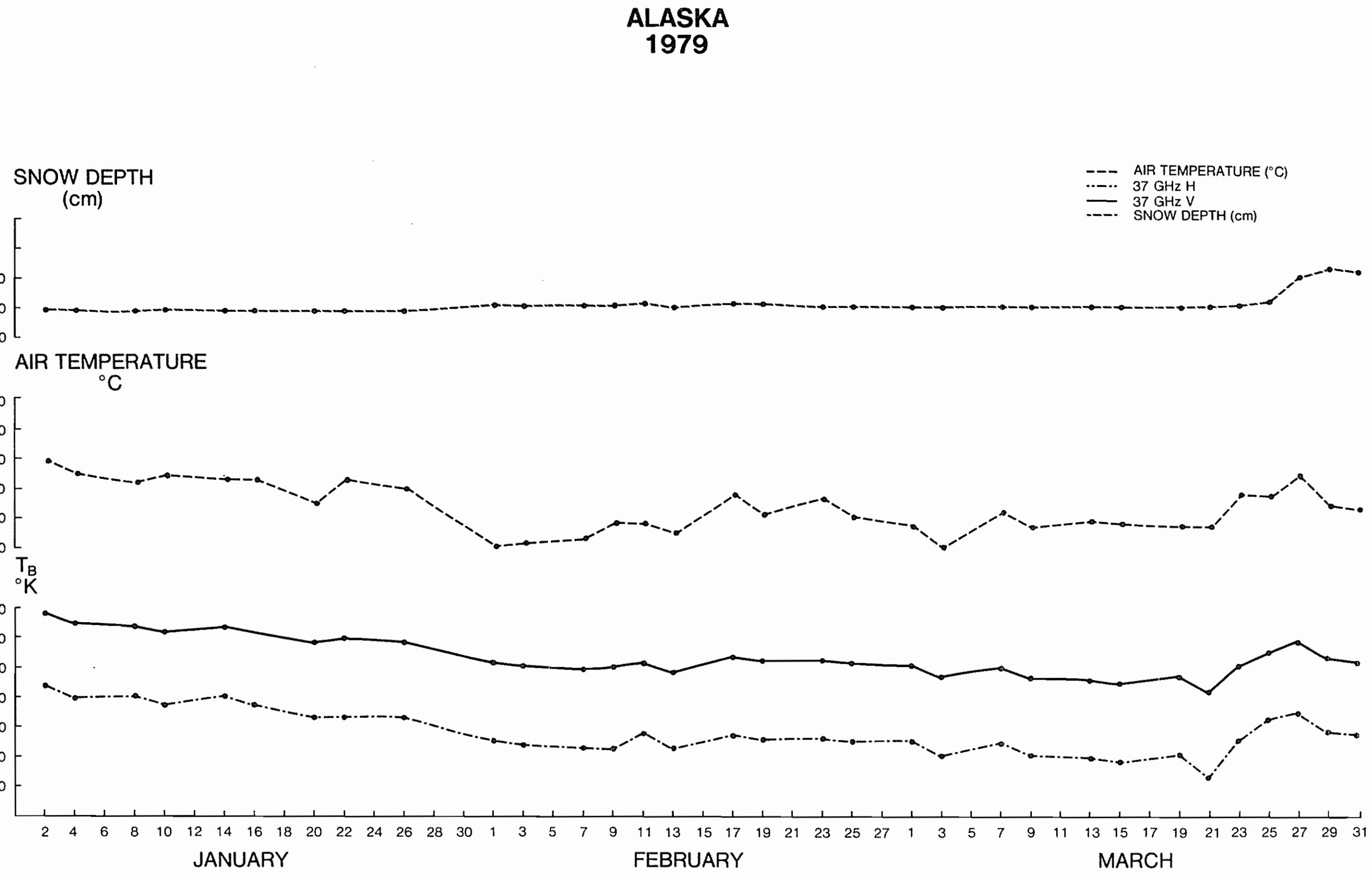

Figure 3. Brightness temperature, air temperature and snow depth January - March 1979 - Alaska.

Table 2 shows the mean and standard deviations of snow depth, air temperature and horizontally polarized T_B for each study area. The North Slope study area has the lowest average T_B ($\overline{x}$ = 189.0^{o}K) and the lowest snow depth. The Minnesota study area has the deepest snow and the next lowest average T_B ($\overline{x}$ = 206.3^{o}K). As shown in previous work (eg. Rango et al., 1979), the T_B normally decreases with increasing snow depth because of increased scattering by the more numerous crystals and grains in the deeper snowpack. But in the present study, the shallowest snowpack (North Slope) has the lowest T_B of all three areas. This is partly because the physical temperature of the snow is very cold and influences the T_B in the following manner:

$$T_B = \varepsilon T$$

where ε is the emissivity and T is the physical temperature of the snow. (Since the physical temperature of the snow was not measured, the air temperature must be used to approximate it.)

Table 2. Mean ($\overline{X}$) and Standard Deviations (S_X) of Snow Depth, Air Temperature and Horizontally Polarized T_Bs of the Three Study Areas

	New England	Minnesota	Alaska
Snow Depth (cm)			
$\overline{X}$	35.31	44.27	21.69
S_X	18.56	15.63	3.71
Air Temp. (°C)			
$\overline{X}$	-6.13	-13.53	-26.06
S_X	6.42	7.91	7.89
T_B (Horiz.)(°K)			
$\overline{X}$	232.5	206.3	189.0
S_X	13.32	11.51	7.10
n	16	15	32

Note in Figure 3 that the snow depth of the Alaskan study area is quite constant for the time period studied. Similarly, the T_B (both in the vertical and horizontal polarizations) is not highly variable. The changes in T_B (horizontal polarization in this case) correlate quite well with air temperature with an $R^2 = .79$ as seen in Table 3 for the Alaskan study area.

Table 3 shows the correlation between average air temperature and T_B for each of the study areas. It can be seen that the air temperature in all three areas is influencing the T_B to varying degrees. The air temperature appears to be more influential in Alaska and New England than in Minnesota.

Table 3. Coefficient of Correlation (R) Between Air Temperature and Horizontally Polarized T_B for the Three Study Areas

	R	n
New England	.89	16
Minnesota	.40	15
Alaska	.79	32

Difference in the responses of the vertical and horizontal polarizations can be detected in each study area as well. Though the trends of T_B variations in the horizontal and vertical polarizations follow quite closely (Figures 1, 2 and 3), the average difference (in $^{\circ}$K) between the horizontal and vertical polarizations is much smaller for the New England study area than for the Minnesota or Alaskan study areas as seen in Table 4. This difference may be due, at least partially, to vegetation differences among the three areas.

Table 4. Mean Difference Between Vertical and Horizontal Polarizations (°K) for All Dates - Three Study Areas

	Mean (°K)	n
New England	12.69	16
Minnesota	23.47	15
Alaska	24.37	32

Conclusions

Comparison of 37 GHz brightness temperatures in three widely separated geographic areas has shown that the brightness temperatures of the Minnesota and New England study areas fluctuate considerably more than the T_Bs of the Alaskan study area over the time period studied. This is because the snow, topography and vegetation are highly uniform on the North Slope as compared to the other study areas. In addition, in the North Slope study area, there is very little thawing once the snowpack has been established.

While the T_B is observed to correlate with air temperature (an approximation of snow temperature) especially in the New England and Alaska study areas, the snow, topographic and vegetation conditions are influencing the T_B as well. Deeper snow in Minnesota relative to New England is probably largely responsible for the lower T_Bs seen in the Minnesota data; dense snow and cold physical temperatures are responsible for the very low T_Bs observed in the North Slope study area.

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