STUDIES ON PHYSICAL PROPERTIES OF SNOW BASED ON MULTI CHANNEL MICROWAVE RADIOMETER*

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ABSTRACT

The analysis of the data observed over a snow field with a breadboard model of MSR (Microwave Scanning Radiometer) to be installed in MOS-1 (Marine Observation Satellite-1) indicates the following features.

(1) The influence of incident angle on brightness temperature is larger in horizontal polarization component than in vertical polarization component. The effect of incident angle depends upon the property of snow with larger value for dry snow. (2) The difference of snow surface configuration consisting of artificially made parallel ditches of 5 cm depth and 5 cm width with spacing of 10 and 30 cm respectively which are oriented normal to electrical axis do not affect brightness temperature significantly. (3) There is high negative correlation between brightness temperature and snow depth up to the depth of 70 cm which suggests that the snow depth can be measured with a two channel microwave radiometer up to this depth.

INTRODUCTION

As a part of Japan/US Cooperative Research Program on Snow Properties/Evapotranspiration, the first field experiments on snow properties using a breadboard model of 2 channel MSR (Microwave Scanning Radiometer) to be installed in Japanese first earth observation satellite, MOS-1 (Marine Observation Satellite-1) were made in January of 1982 the result of which was presented by Tsuchiya (1982) at the first Japan/US Workshop held in March 1982 at Tokyo.

The result of the first experiment indicated that in spite of the fact that the general tendency of the brightness temperature vs snow property relationship was similar to that obtained by other investigators, i.e., England (1975), Hofer and Shanda (1978), Rango and et al (1979), Stiles and Ulaby (1980), Tiuri and Schultz (1980) etc., there was a discrepancy in absolute values.

In an attempt to clarify the discrepancies as well as characteristics of snow for microwave radiation, the second experiements were made in the winter of 1983 in the test site of Hokkaido University. The result of the experiments is reported in the following sections.

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CHARACTERISTICS OF MSR USED IN THE EXPERIMENT

The characteristics of MSR (Microwave Scanning Radiometer) used in the experiments are shown in Table 1 and Fig. 1 respectively.

Table 1
Characteristics of MSR (Microwave Scanning Radiometer)
to be Installed MOS-1, the Breadboard Model of Which was Used.

Frequency	23.8 GHz	31.4 GHz
RF Bandwidth	400 MHz	500 MHz
Beam width	1.99 deg.	1.45 deg.
Integration Time	10 & 47 msec	10 & 47 msec
Radiometric Resolution	1.0 K at 300 K	1.0 K at 300 K
Dynamic Range	30 - 330 K	30 - 330 K
Polarization	Horizontal	Vertical

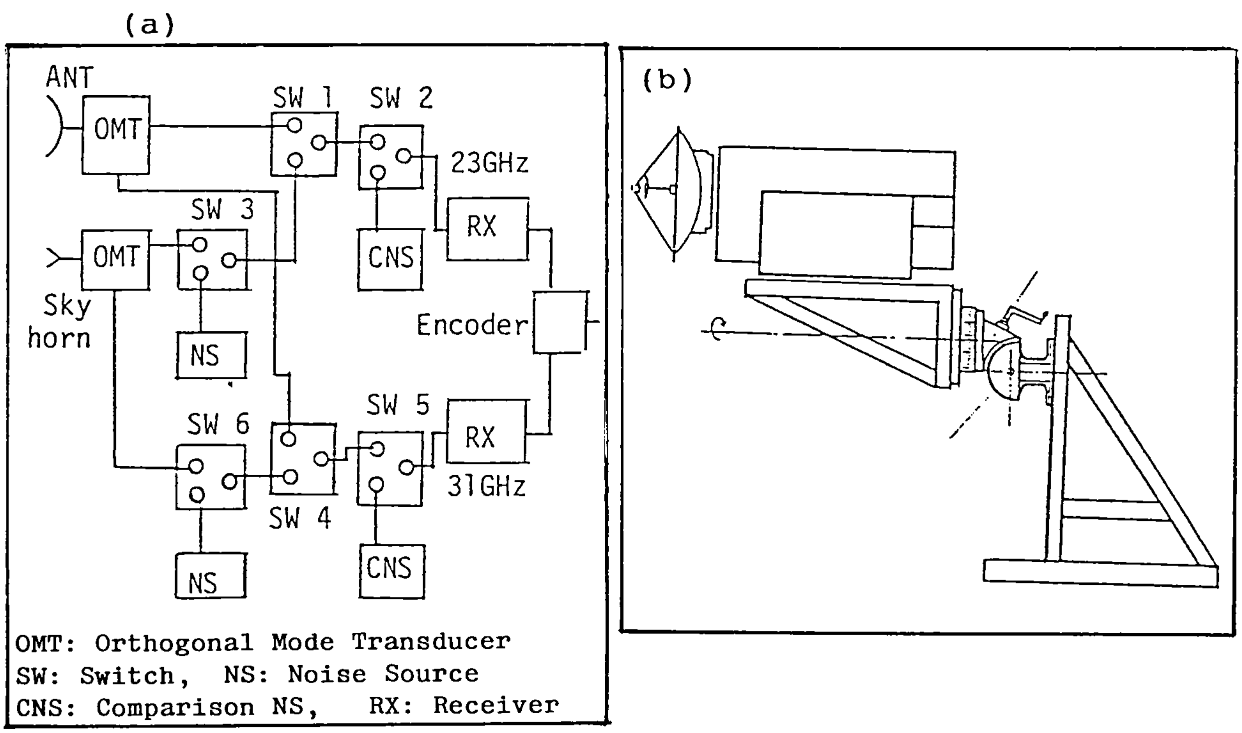


Figure 1. (a) Block Diagram of MSR Used in the Experiment,
(b) A Schematic Representation of MSR Fixed on a Frame.

As is indicated in the table, 23 GHz horizontal component and 31 GHz vertical component are observed simultaneously. Although MSR is kept at incident angle 10 degrees onboard MOS-1 with conical mode of scanning, it was decided to conduct the experiments for various incident angles. The MSR was mounted on a frame extended from the top of 5 meter height tower with capability of adjustable elevation angle with a handle.

Polarization was also adjustable by rotating the radiometer about its electrical axis thus it was possible to measure brightness temperature of snow surface with the incident angle ranging from 0 to 75 degrees in both vertical and horizontal polarization.

In parallel with the brightness temperature observation of snow surface, ground truth data indicated in Table 2 were also acquired.

Table 2
Ground Truth Data Obtained in the Experiments

parameter	Instrument	Parameter	Instrument
Snow Depth	Snow Pole	Solar Radiation	Pyrheliometer
Water Equiv.	Snow Sampler	Radiation Budget	Net Radiometer
Density	Density Gauge	Wind	Anemometer
Snow Surface Temp.	Thermometer	Air Temp.	Thermometer

BRIGHTNESS TEMPERATURE VS INCIDENT ANGLE

Many observations were made for different conditions of snow surface and weather. The analyses of the data indicate a pronounced effect of incident angle on the brightness temperature. A few examples are shown in Fig. 2 (a) through (d). It should be stated that it took about 80 minutes to complete one cycle of observation since rotation of the radiometer about its electrical axis is required to change polarization from horizontal to vertical and vice versa.

When weather condition was unfavorable longer observation time was required, thus the snow surface was not strictly constant during the observation. Consequently careful ground truth observation was made simultaneously.

The figures (a) through (c) are for dry snow while (d) is for wet snow. It can be seen from the figures brightness temperature decreases more sharply in horizontal component than that of vertical. It can also be seen that brightness temperature is higher over wet snow surface than over dry snow surface. This fact indicates the difficulty of interpretation of the data of microwave sensor for measurement of snow.

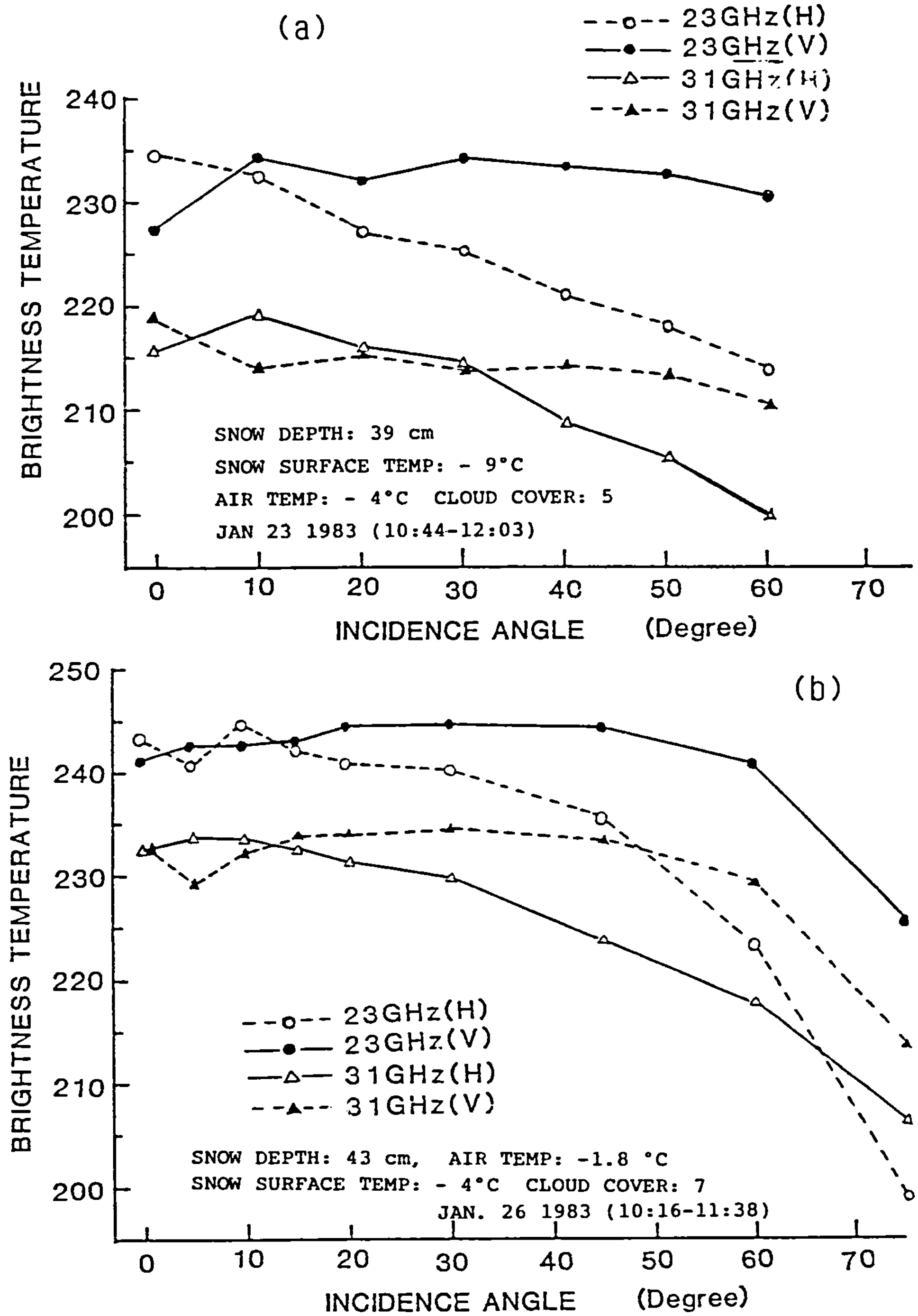


Figure 2. Incident Angle vs Brightness Temperature at 23 & 31 GHz. In the Figure V and H Stand for Vertical and Horizontal Polarization Respectively. The Combination of 23 GHz H+31 GHz V or 23 GHz V and 31 GHz H is Operated Simultaneously. The Figures (a), (b) and (c) are for Dry Snow While (d) is for Wet Snow.

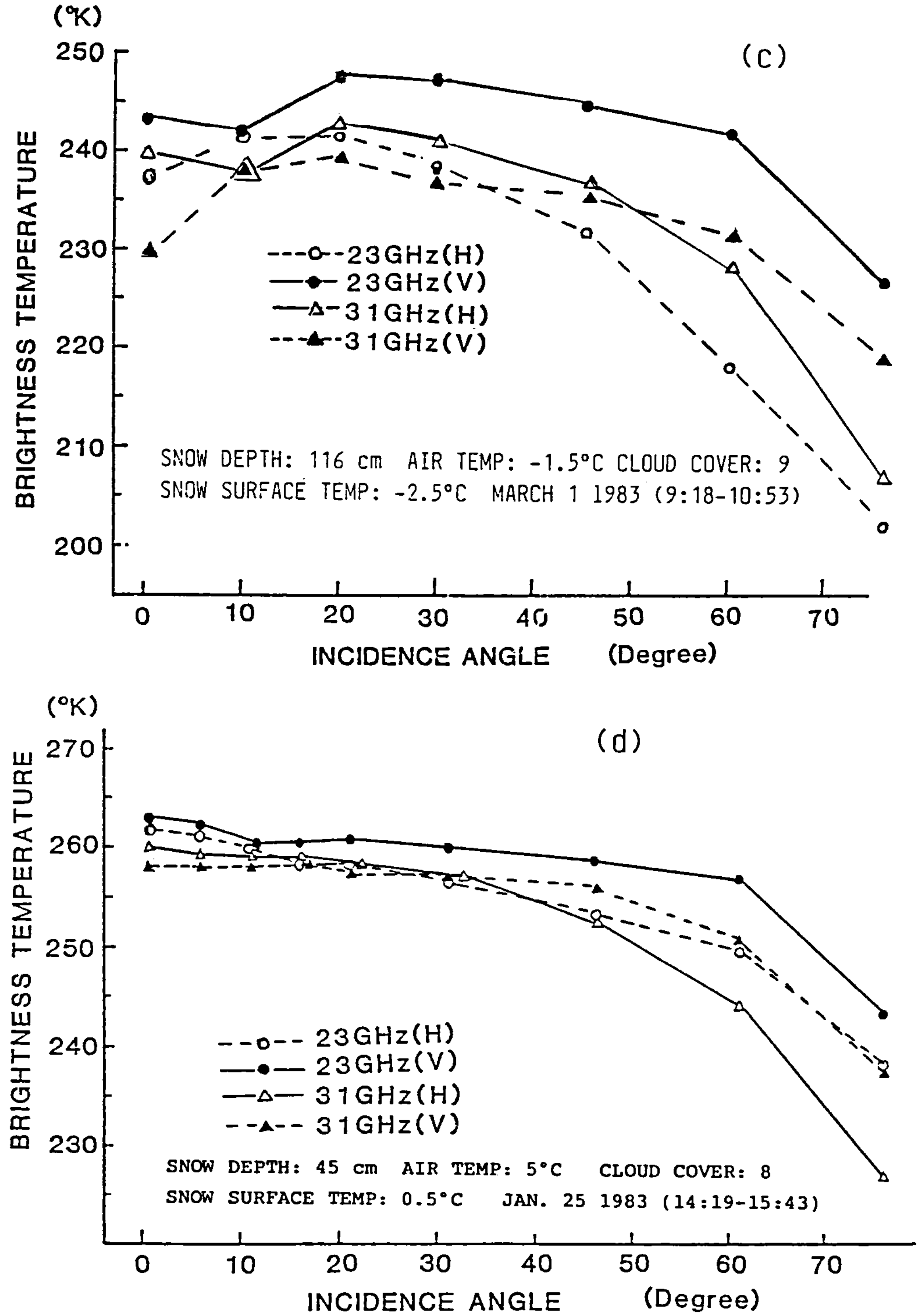


Figure 2. (c) and (d)

BRIGHTNESS TEMPERATURE VS SNOW SURFACE CONFIGURATION

Brightness temperature was measured with different incident angle over, (1) snow surface with parallel ditches of 5 cm depth and 5 cm width of 30 cm and 10 cm spacing respectively, which are oriented perpendicularly to electrical axis of the radiometer, (2) the snow surface after the ditches were pressed to level surface.

The incident angle dependence over dry snow under cold air temperature indicates a similar feature of dry snow while that made under warm air temperature indicates a feature of wet snow.

The influence of surface condition is shown in Fig. 3 (a) and (b) for dry and wet snow surface conditions respectively. Figure (a) indicates that spacing of ditches does not affect the brightness temperature except the case of 60 degrees incident angle. The figure also indicates that the brightness temperature of the pressed snow surface is higher regardless of incident angle which may lead to a conclusion that a pressed snow surface gives higher brightness temperature.

It should be stated that at the time of brightness temparture measurement, both air and snow surface temperatures rose significantly as is indicated in the figure, therefore it is considered that the rise of the brightness temperature is caused at least partly by the rise of both air and snow surface temperature.

Figure (b), a case of wet snow surface indicates a feature different from that of Fig. (a). It appears that the brightness temperature over 30 cm spacing is a little higher than that over 10 cm spacing. It is extremely interesting to notice that different from the previous case, the brightness temperature over the pressed snow surface is the lowest regardless of the incident angle. It should be again stressed that both air and snow surface temperature continuously fell as is well recognized in the figure.

The analysis of these two cases suggests that both air and surface effects must be taken into account in the interpretation of brightness temperature over the snow surface.

POLARIZATION ANGLE DEPENDENCE

The experiments on the polarization angle dependence were made at incident angle of 10, 30 and 45 degrees. As was pointed out in the previous report by Tsuchiya (1982) there was not a large difference in brightness temperature due to variation of polarization angle. In case of 23 GHz channel data brightness temperature increased corresponding to the increase of polarization angle while the opposite tendency was recognized for 31 GHz channel data.

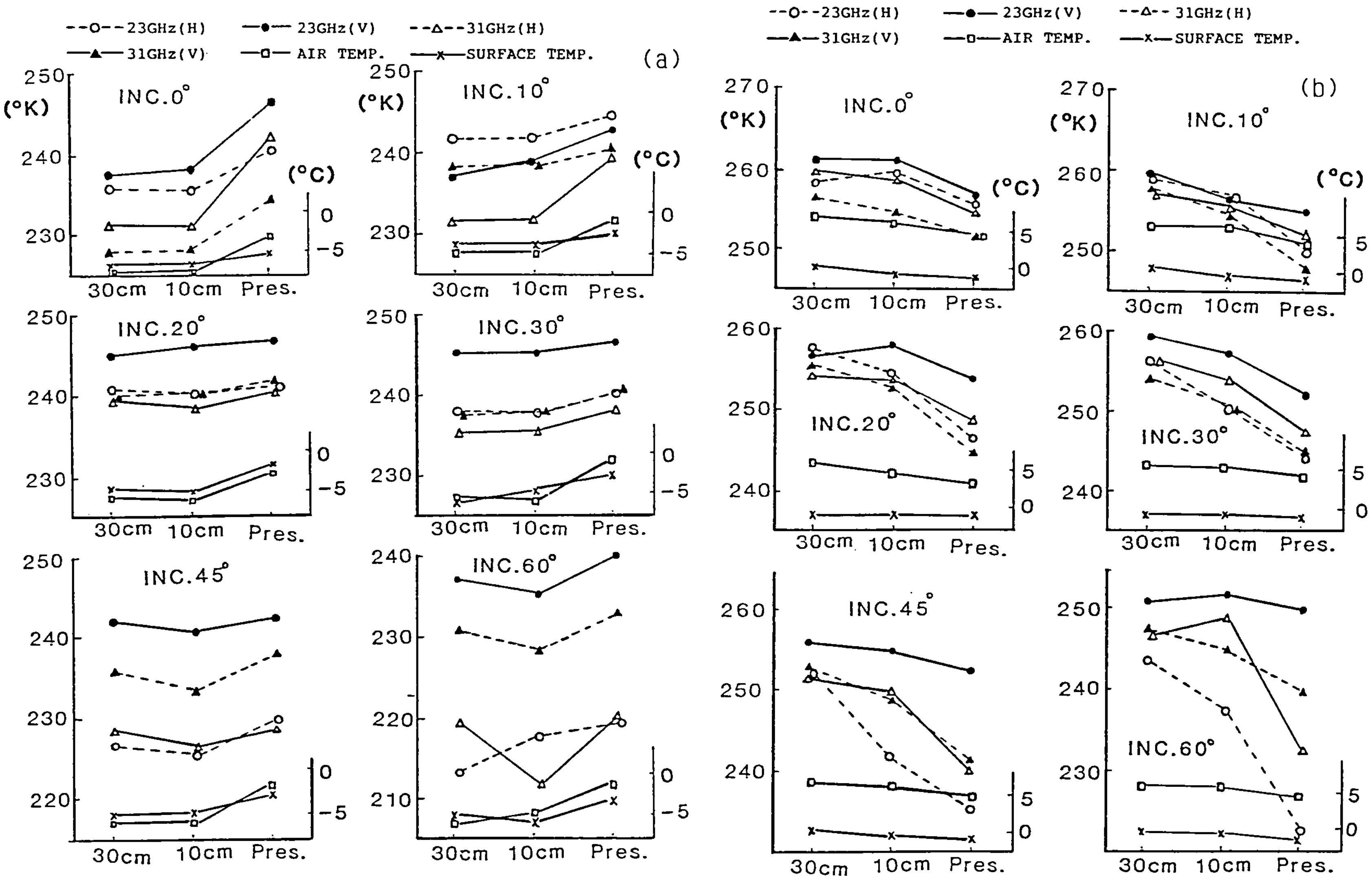


Figure 3. Brightness Temperature vs Incident Angle over Different Snow Surface Condition. 30 and 10 are Spacing of Ditches of 5 cm Depth and 5 cm Width. Pres Means Pressed Snow Surface. (a) is Dry Snow (March 4, 1983) and (b) is Wetsnow (Jan 28 '83).

DIURNAL VARIATION

There was a diurnal variation in the brightness temperature with the maximum value in the daytime with higher value in lower incident angle. The measure of variation depends upon the snow surface and meteorological conditions. A few typical examples are shown in Fig. 4.

Fig. 4 (a) is a case of comparatively small diurnal variation while the figure (b) is the case with a sharp rise in the early afternoon. Figure (c) is a case with a large variation which is considered due to freezing of the snow surface. Comparing the three figures it can be easily seen that when both the snow surface and air temperature are low brightness temperature variation is also small. It can be also seen that the brightness temperature is affected by both air and surface temperature.

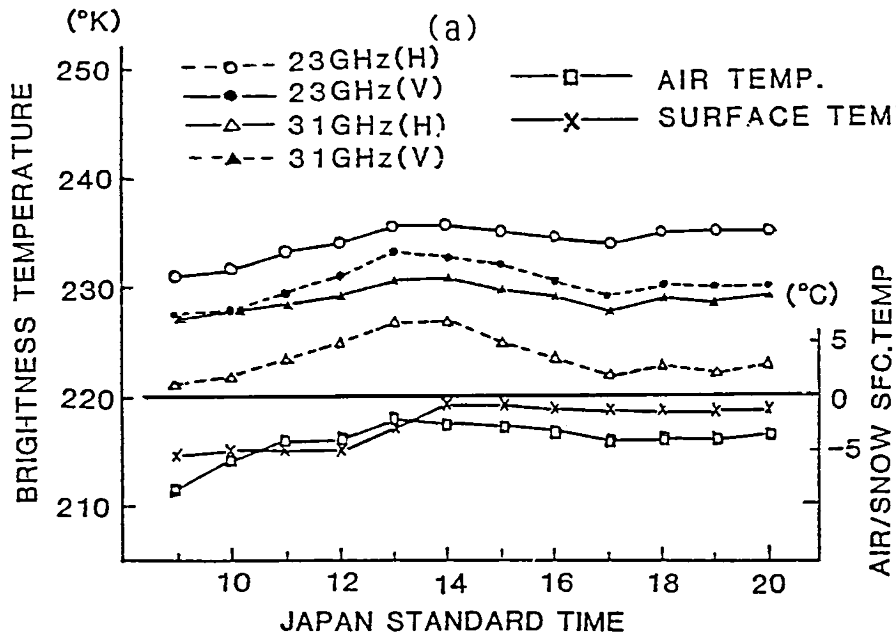


Figure 4. Diurnal Variation of Brightness Temperature is at Incident Angle at 10° on March 2, 1983, (b) is at Incident Angle 45° on Jan 27 '83 and (c) is at Incident Angle 10° on Jan 25 '83 Respectively. (a) and (b) are for Dry Snow While (c) is for Wet Snow Respectively.

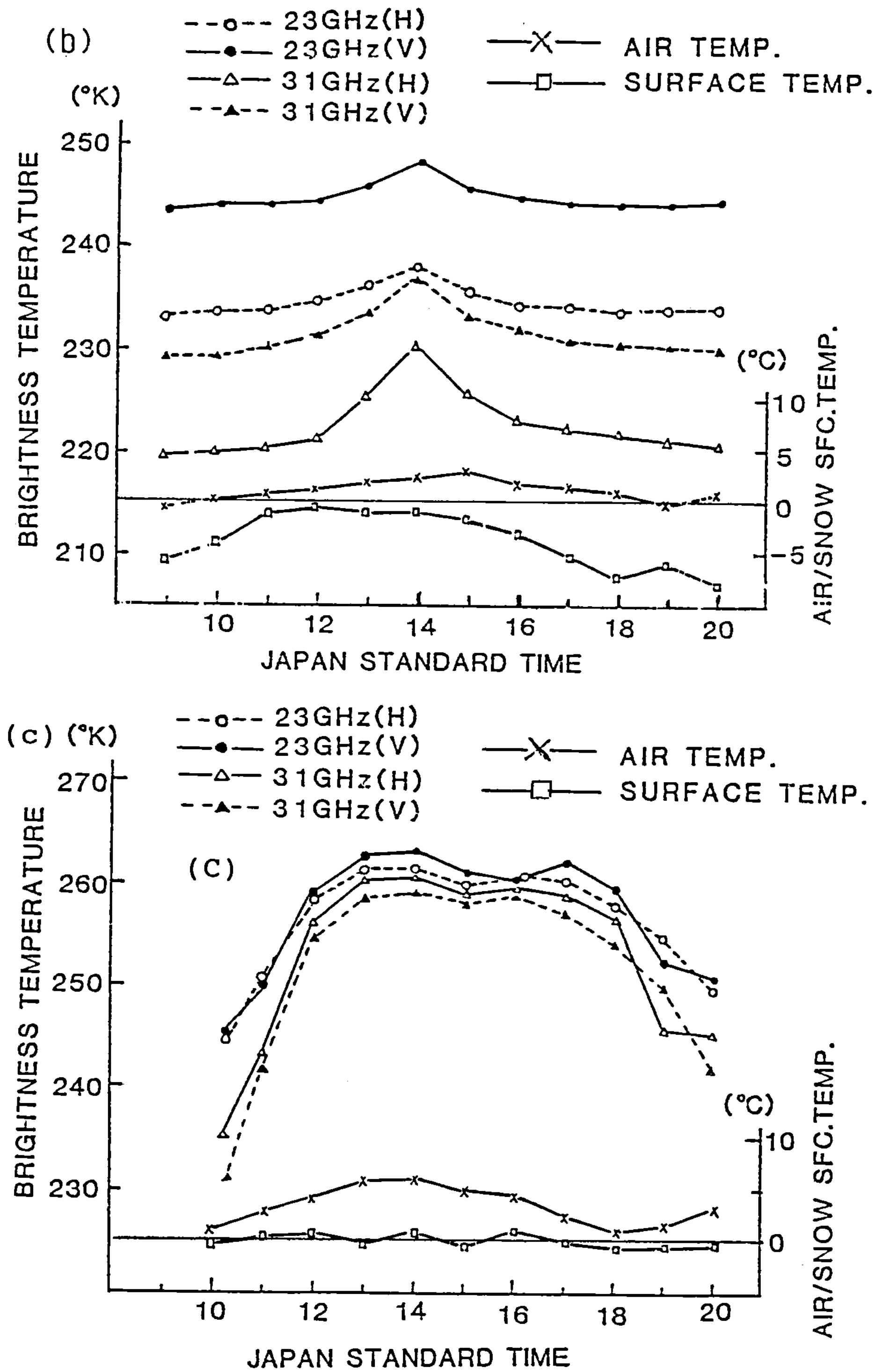


Figure 4. (b) Jan 27 '83. Incident Angle at 45° for Dry Snow. (c) Jan 25 '83 at Incident Angle 10° for Wet Snow.

BRIGHTNESS TEMPERATURE VS SNOW DEPTH AND SNOW EQUIVALENT WATER

To obtain the relationship between brightness temperature and snow depth, the brightness temperature was observed by removing snow at incident angles of 10 and 45 degrees respectively. The result of the observations for two cases is shown in Fig. 5.

It can be seen that the rate of decrease of the brightness temperature corresponding to the increase of snow depth is widely different depending on the snow surface and meteorological conditions. The brightness temperature decrease corresponding to the snow depth is recognized up to the depth of 70 cm for both 23 and 31 GHz horizontal polarization component while in case of vertical polarization component, decrease of brightness temperature ceased at the depth of 60 cm for both channels as is indicated in Fig. 5 (b) and (c).

It should be stated that in spite of the fact that as extreme care was taken to remove the snow, the physical properties of the snow surface must have been affected and the obtained brightness temperature for the respective snow depth might be a little different from that of natural condition. In spite of this defect a qualitative feature of snow depth vs brightness temperature relationship obtained in these experiments will be of an extreme value for understanding snow properties and microwave radiation of the snow surface.

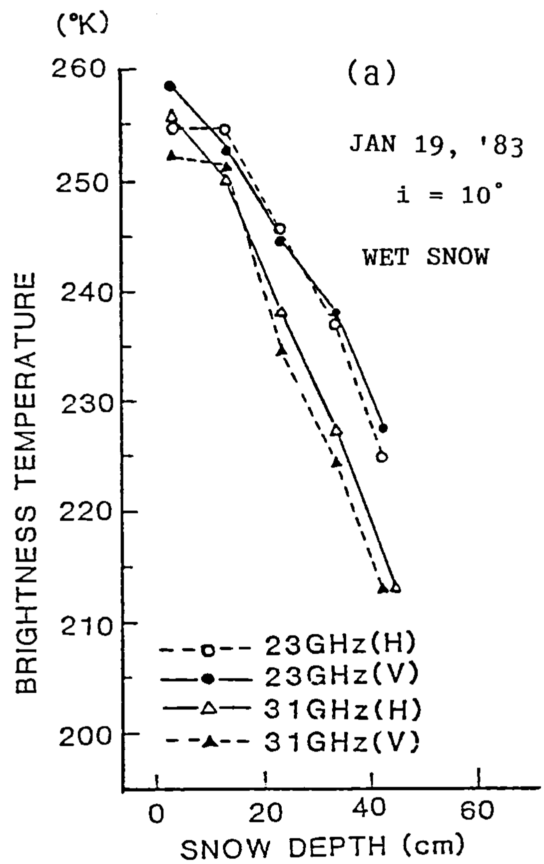
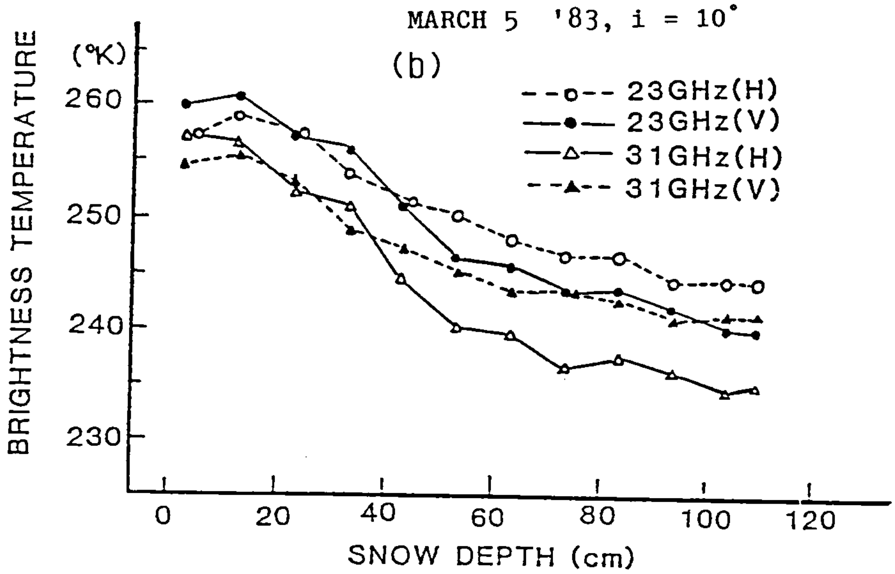


Figure 5. Brightness Temperature vs Snow Depth. (a) Jan 19 '83 at Incident Angle 10° Over Wet Snow Surface. (b) and (c) are Dry Snow.



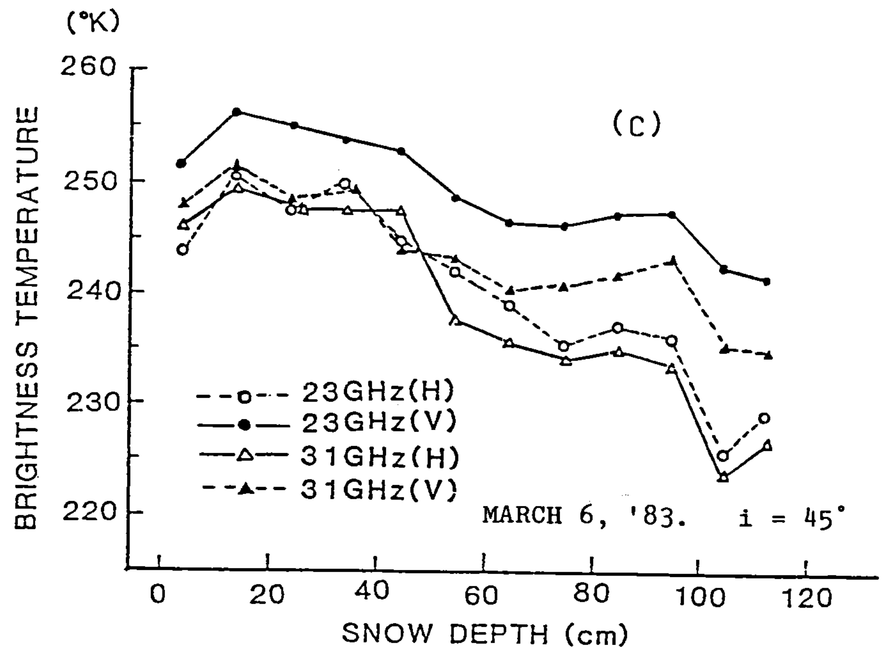


Figure 5. (b) and (c). Dry Snow Surface.

Based on the experimental data, an attempt is made to express the brightness temperature as a function of snow equivalent water for incident angles of 10 and 45 degrees in a form of Eq. (1).

$$T = a + b \exp(-cW) \tag{1}$$

where W is snow equivalent water in the unit of gr/cm^2.

Applying the least square method, the coefficients a, b and c are determined. The obtained values of the coefficients vary in wide range as can be expected. Just for the sake of interest a few examples are shown in Table 3.

Table 3
The Values of the Coefficients of Eq. (1).

		Incident angle: 10°			Incident angle: 45°		
		Jan 29 1983			March 6 1983		
		a	b	c	a	b	c
23 GHz	H	257.7	-2.9	0.244	243.8	- 0.007	0.247
	V	282.2	-28.9	0.073	251.6	- 0.033	0.187
31 GHz	H	276.9	-21.4	0.109	246.2	- 0.367	0.130
	V	271.7	- 20.0	0.107	251.6	- 3.726	0.050

H: Horizontal, V: Vertical

CONCLUDING REMARKS

Foregoing analyses lead to the following conclusion. The brightness temperature of the snow surface is influenced by various factors which suggest complexities of deducing snow properties from microwave radiometer data.

Although limited in number and volume, the data obtained during the present experiments are extremely valuable for obtaining dependable algorithm to deduce geophysical parameters from MOS-1 MSR data.

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