REMOTE ON LINE SNOW COVER PROFILING IN AVALANCHE RELEASE ZONES USING MICROWAVE RADAR.

H. Gubler, M. Hiller and P. Weilenmann[I]

ABSTRACT

Microwave FMCW Radar is used for automatic remote snow cover profiling in avalanche release zones. The radars are buried in the ground below the snow cover and are therefore not subjected to snow and avalanche forces. Data are transmitted together with additional snow and meteorological parameters by radio to a base station using a commercial logger system. Radar data of the electromagnetic snow cover stratigraphy are converted to a bitmap representation of the stratigraphy or are available as time series of spectra showing reflectivity of snow layers in function of distance from ground. The amount of new snow, snow settlement, fracture height of slab avalanches and meltwater percolation in the beginning phase of snow melt can easily be determined.

INTRODUCTION

In 1981 a research program has been started at our institut (FISAR) to develop an automatic microwave radar snow cover profiler. The work is based on preliminary experiments of Ellerbruch and Boyne (1980). Already first experiments showed the suitability of X-band FMCW radar for profiling static snow covers as well as for flow height measurements in dense flow dry snow avalanches. Sledge mounted radars were used to record continuous snow profiles along lines or for profiling deposits behind snow fences (Schmidt, 1984). Today 1 sledge mounted movable radar, 4 radars buried in avalanche tracks to measure flow height and slope perpendicular avalanche speed profiles, 2 remote on line radars in avalanche release zones and 2 radars in the study plot of FISAR are in operational use. In this report we will concentrate on the operational on line use of buried radars at remote sites.

APPLICATIONS

The main purposes of FMCW radar applications can be summarized as follows: Continuous monitoring of the development of the snow cover at remote, during winter inaccessible sites as avalanche release zones. The radars are buried in the ground below the snow cover and therefore not endangered by snow and avalanche forces. Data are automatically recorded and transmitted to a base station either by radio or cable. Data are either presented in bitmap form as an evolution plot of the snow cover stratigraphy or as time series of spectra. Additional computer codes allow for a fast quantitative analysis for

I. Federal Institute for Snow and Avalanche Research, Davos, Switzerland

different parameters of a dry snow cover as new snow height, total waterequivalence of the snow cover, settling rate, localization of slush layers originating from dammed meltwater, fracture height in case of an avalanche occurrence, and qualitative classification of characteristic layers and of the snow surface mainly with respect to density.

TECHNICAL ASPECTS

The basic technics of the FMCW snow profiling radar has been described by Gubler (1984, 1986). The radar electronics have partly been redesigned 1987 with the aim of reducing complexity, power consumption and to eliminate electromechanical parts such as relays. Additional electronics have been built to interface the radar to a Campbell CR10 logger module. The logger controls the radar to perform measurements periodically at 1 to 4h intervals, reads the digitized audio signal on a synchronous input channel from the radar-logger interface and immediately performs a Fast Fourier Transform (FFT) to reduce data. The spectra together with meteorological and snow cover data (wind, temperature, humidity, global radiation, acoustic emission of snow cover, snow height measured with ultrasonic gauge etc.) are temporarily stored in the logger. The remote stations are called in regular intervals by the base station on Weissfluhjoch. Power consumption of the logger including radio and radar is 5Wh per day. This power can easily be supplied for a winter season by a 25kg 100Ah battery.

The PC equipped base station at the institute transmits the data to a system of interconnected HP workstations. Incoming data are checked for completeness and appended to database files. The radar spectra are converted into bitmaps and appended to the corresponding files. Data can be tabulated, plotted or analyzed for any time interval on any workstation connected to the network.

RADAR DATA ANALYSES

Theory and sensitivity test for the FMCW radars are described by Gubler (1986). Depth resolution and usable dynamic range of the radar depend mainly on FFT-windowing and on the complexity of the snow cover stratigraphy. Basically each specular reflection from a layer interface produces a peak in the distance domain spectra. The heights of the peaks depend on the reflectivity of the interface. Each peak produces satellite peaks of about 1/20 of the main peak. This mathematical noise together with signals from multiple reflections and interferences limit the usable relative dynamic range to about 5 to 10% of the maximal spectral amplitude. Spectral amplitudes are corrected for amplitude dependence on distance. Ice layers of 0.5 mm thickness as well as buried surface hoar layers can by resolved if no high reflectivity interfaces are located nearby in the same snow cover. Automatic peak recognition and classification to calculate the bitmap works with variable discriminating levels determined from corresponding convoluted spectra. Sometimes this system is not able to recognize the small reflection from the surface of a thin, low density new snow layer on a strong reflecting old snow surface. The fact that thin surface or internal layers often are easily determinable in the spectra but are not shown in the bitmap, indicates that further software improvements are possible. The physical distance resolution (about 30mm in snow) depends on the frequency sweep period and on the index of refraction of the snow. The chosen numerical resolution amounts to 0.5 times the physical resolution.

EXAMPLES

On line bitmap presentation of radar data from 3 remote sites (avalanche starting zones at Stillberg and Mattenwald and FISAR studyplot near Weissfluhjoch) have been available at the institute for the first time during winter 87/88. The starting zone at Stillberg is situated above timberline on 2200m a.s.l. in a wind exposed small bowl on a NE facing slope. The Mattenwald starting zone is located on 2000m a.s.l. just below timberline in a low density larch forest on a N facing slope. The 2 starting zones are only about 2 km apart at a distance of about 5 km from the FISAR study plot (2500m a.s.l.) which is situated on a SE facing slope. At the Mattenwald site additional parameters as acoustic emission (Sommerfeld and Gubler, 1983), global radiation, wind, air temperature and humidity are recorded. The 3 electromagnetic profiles for the time period mid January to mid April are shown in figure 1. This winter was very special with respect to a long melting period in December and beginning of January. This lead to hard, highly reflective crusts near the ground-snow interface. Because of the resulting high spectral amplitudes from these crusts sensitivity of the bitmap determination for low reflecting layers, especially the snow surface, was reduced for the whole winter. A lower frequency C-band radar installed in the study plot next to the X-band radar with a filter reducing signals from near ground reflections therefore produced more accurate bitmaps (figure 2a) compared to the X-band radars during winter 87/88. The bitmap of winter 86/87 of the X-band radar at the study plot (figure 2b) shows that under normal high winter conditions X-band radars, even if data are collected only every 6h, produce usable bitmap data. Figure 3 shows the determination of new snow height from spectra using interactive software. The spectra for the time period of interest are displayed and markers are assigned to characteristic peaks (layer interfaces) and to the snow surface reflection. These markers, except new surface markers, have only to be assigned once, they are automaticaly assigned in subsequent spectra. To calculate geometrical depth from electromagnetic depth, estimates for snow density of the layers have to be introduced. Fortunately the dependence of geometrical distance determination on density for low density snow is low, therefore a rough estimate ($100\pm50 kg/m^3$) results in a new snow height determination of ±4%. Because the markers assigned to different layer interfaces are moved automatically from spectrum to spectrum, their decreasing distance from the ground can be used to determine snow settling quantitatively using an equation given by Gubler (1986). If estimates of mean density are assigned to the different layers in the snow cover, the spectra can also be plotted in function of geometrical distance enabling a direct comparison with traditional morphological and density profiles (Gubler, 1986).

The intercomparison of the 3 profiles shows a clear dependence of total snow accumulation on height a.s.l. If one takes wind and other meteorological data measured at Mattenwald and Weissfluhjoch into account (figure 4a, b), it follows that snow redistribution is very important at Stillberg and has no effect in the forested starting zone Mattenwald. During a first period from mid January to mid February a lot of snow was blown into the bowl at Stillberg resulting in a much higher accumulation rate compared to Mattenwald and even Weissfluhjoch. It seems that an equilibrium surface was reached on the Stillberg radar by mid February. This is also shown by the strong reflections from a windcrust that has built at this surface. New snow started to accumulate again in late March and finally resulted in a slab release clearly shown in the profile in early morning of March 28. The radar profile shows a fracture height of 1.6m with a shear fracture in the early winter depth hoar layer.

CONCLUDING REMARKS

FMCW radars combined with a powerful logger system provide a useful tool to continuously monitor high alpine dry snow covers in avalanche starting zones. The main advantage of the system compared to ultrasonic snow depth gauges is that the sensor is not exposed to snow forces others than snow load on the ground and that it provides additional information on layering and settling. Disadvantages are: the system only works in dry snow (also the C-band system does not show significantly improved penetrability in wet snow), more data have to be transmitted, and elaborated software has to be applied for data analyses and interpretation. If continuous measurements are performed during high danger periods, the system can also be used to monitor avalanche releases or avalanche flows (if located in an avalanche track) usable for direct warnings. The fracture height, which is important for the estimation of run-out distance, can be obtained too.

REFERENCES

Ellerbruch, D.A. and H.S.Boyne (1980). Snow stratigraphy and waterequivalence measured with active microwave system. Symp. Snow in Motion. J. of Glaciol. Vol. 26, No. 94, p. 225-233.

Gubler, H. and M.Hiller (1984). The use of microwave radar in snow and avalanche research. Cold Region Science and Technology Vol. 9, No. 2, p. 109-119.

Gubler H., M.Hiller and R.A.Schmidt (1985). FMCW radar for snow cover investigations. Internal Report No. 627, FISAR.

Schmidt, R.A., H.Gubler and M.Hiller (1984). Swiss improvements of the FMCW radar for snow measurements. Proceedings of the 52nd Annual Western Snow Conference, April 1984, at Ketchem, Idaho.

Gubler H. and P. Weilenmann (1986). Seasonal snow cover monitoring using FMCW radar. Proc. of International Snow Science Workshop, Tahoe 86. p. 87-97, October 1986.

Figure 1 Bitmap representations of electromagnetic snow cover profiles (mid January to mid April 1988) from X-band FMCW radars at FISAR study plot (A) and starting zones Mattenwald (B) and Stillberg (C). Markers are plotted every Sunday, date is given in European format. An approximate height scale is given in addition to the frequency scale.

Figure 2 Bitmap representation of electromagnetic snow cover profiles from C-band radar (winter 87/88) (A) and from X-band radar for winter 86/87 (B).

Figure 3 Screen dumps from the determination of new snow heights using an interactive program. In spectra taken at different times markers are assigned to the different peaks (snow layer interfaces) and to the snow surface. The spectra show reflected microwave power in function of electromagnetic distance given in units of frequency for the two upper sets and in function of approximated geometrical height above ground for the bottom spectrum.

Figure 4a Meteorological data from Mattenwald logger.

Figure 4b Wind an snow depth data (ultrasonic gauge) from Weissfluhjoch.

Whistler 20.9.88 /USERS/GUBLER/TEXT/Whistler:REMOTE

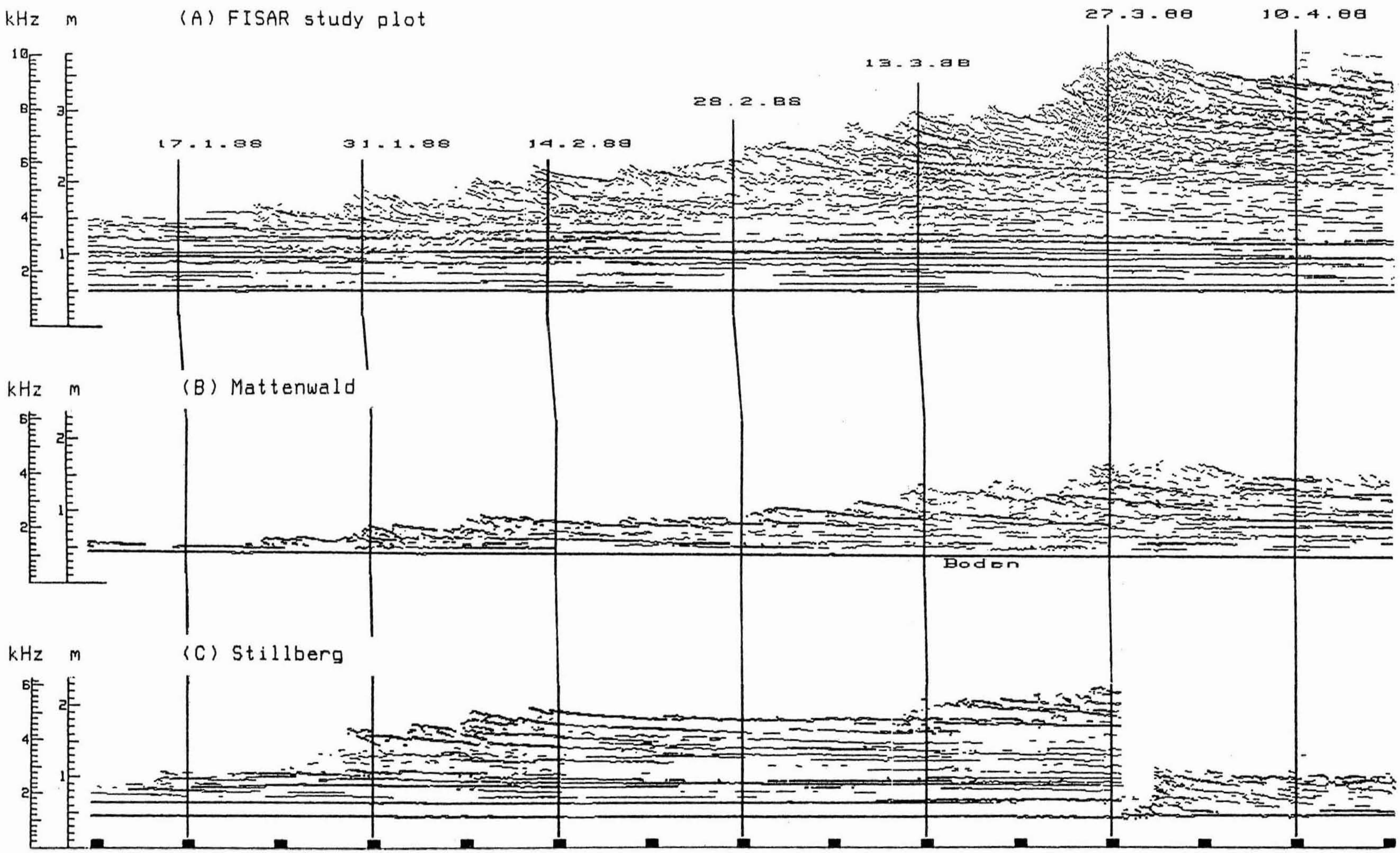


Figure 1 Bitmap representations of electromagnetic snow cover profiles (mid January to mid April 1988) from X-band FMCW radars at FISAR study plot (A) and starting zones Mattenwald (B) and Stillberg (C). Markers are plotted every Sunday, date is given in European format. An approximate height scale is given in addition to the frequency scale.

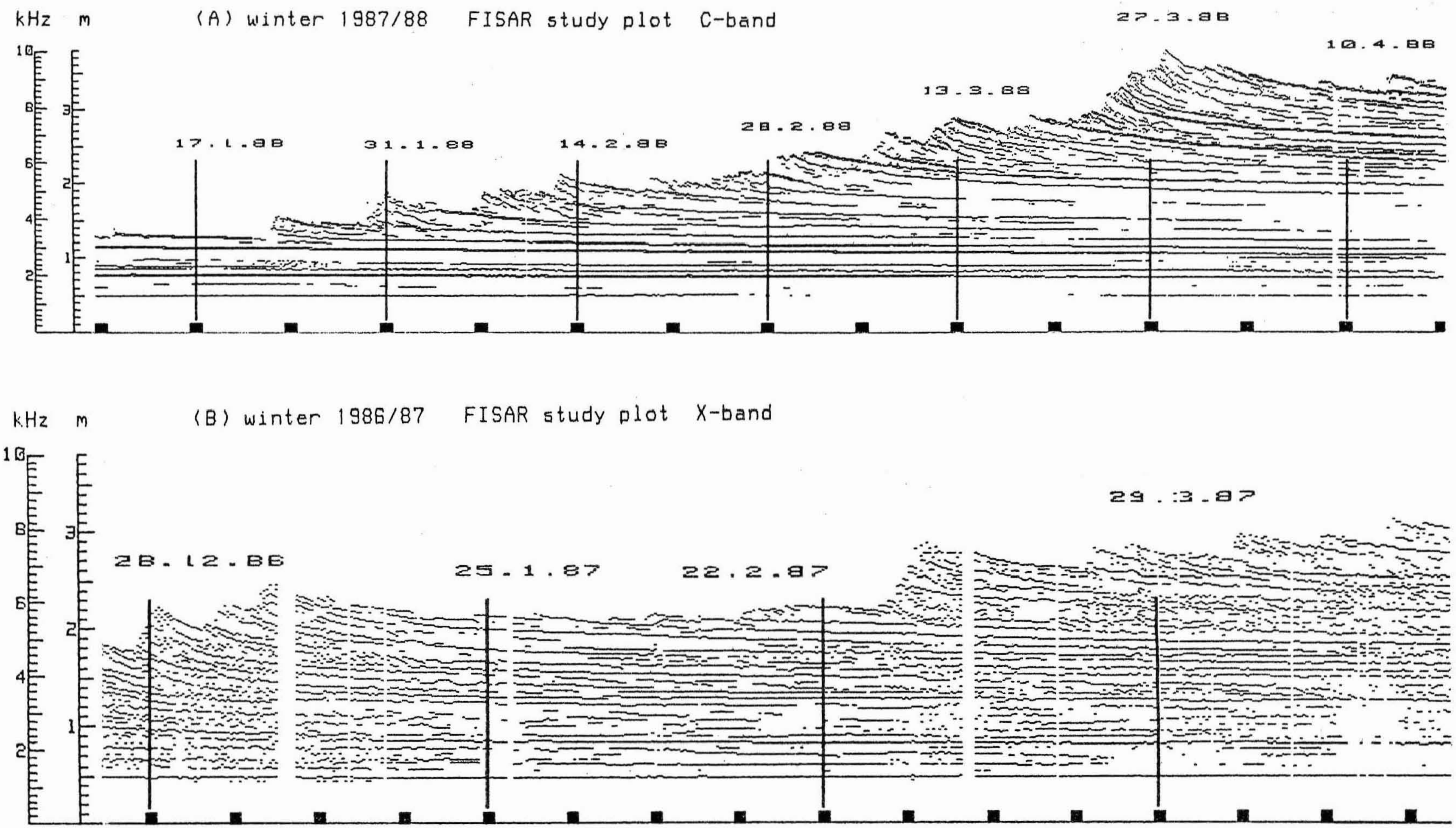
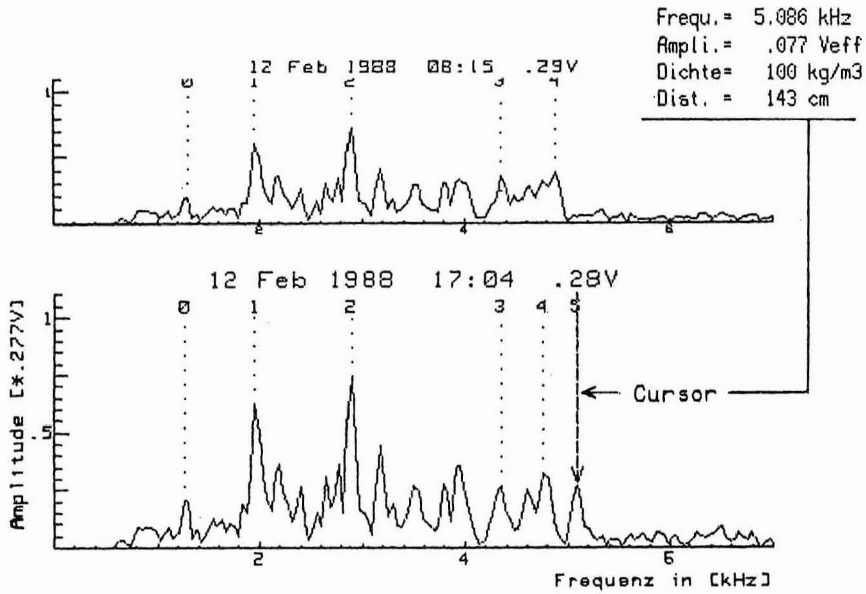
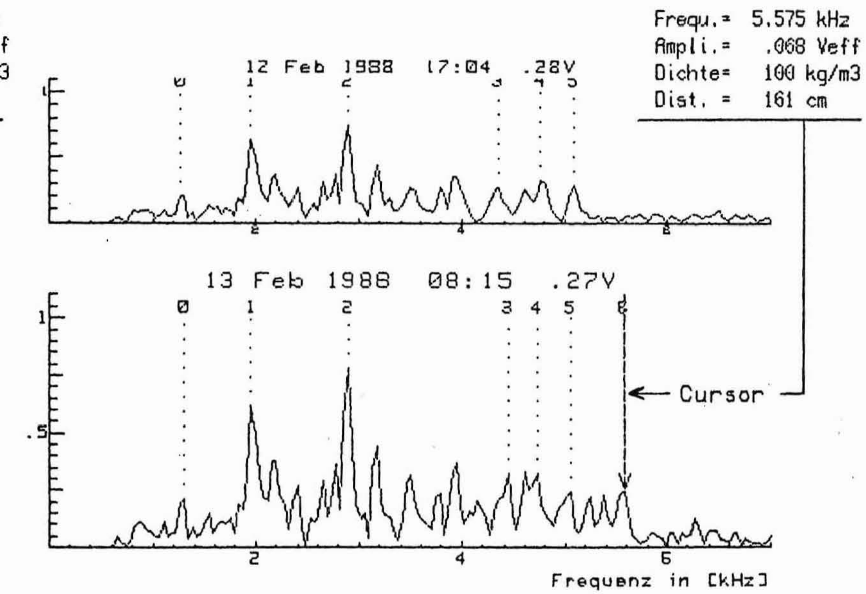


Figure 2 Bitmap representation of electromagnetic snow cover profiles from C-band radar (winter 87/88) (A) and from X-band radar for winter 86/87 (B).



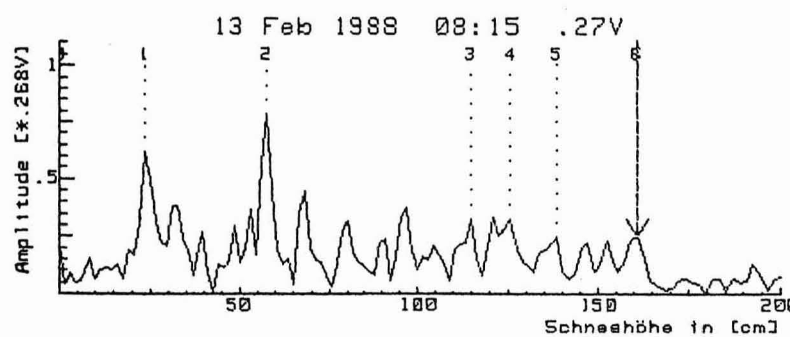
difference between markers 4 and 5 -> +0.14m



difference between markers 5 and 6 -> +0.23m

total in 24h -> +0.37m

Figure 3 Screen dumps from the determination of new snow heights using an interactive program. In spectra taken at different times markers are assigned to the different peaks (snow layer interfaces) and to the snow surface. The spectra show reflected microwave power in function of electromagnetic distance given in units of frequency for the two upper sets and in function of approximated geometrical height above ground for the bottom spectrum.



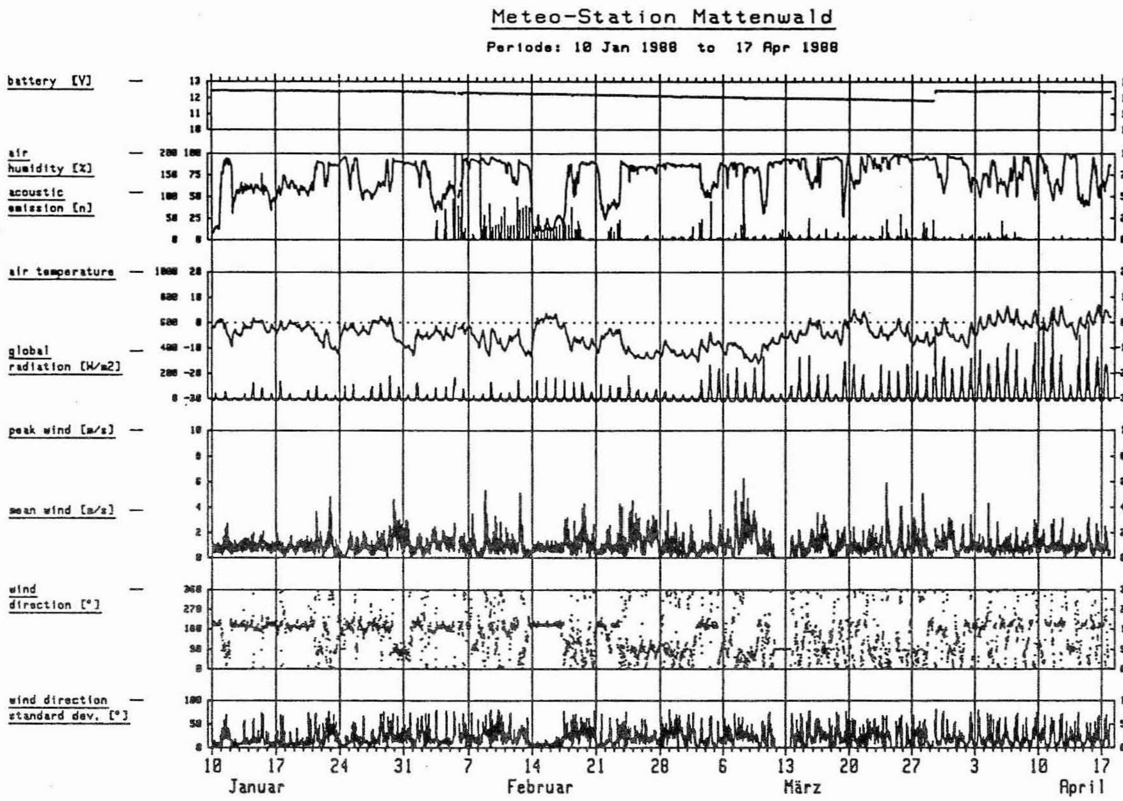


Figure 4a Meteorological data from Mattenwald logger.

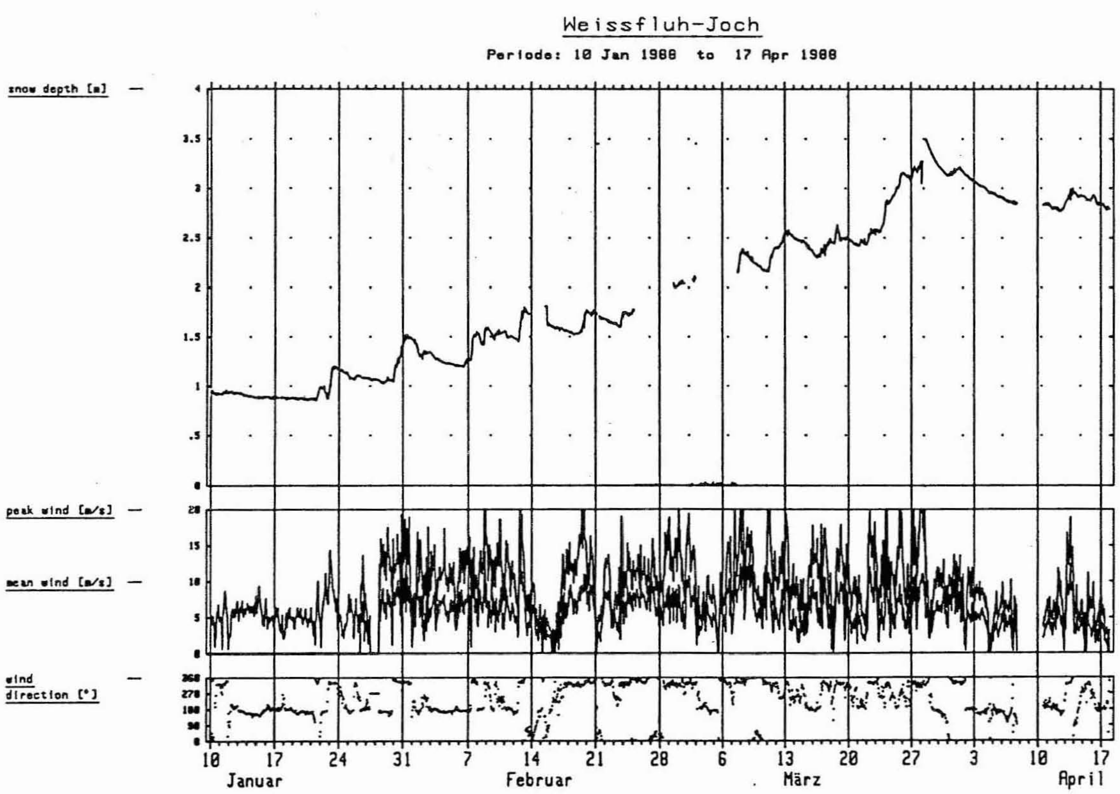


Figure 4b Wind an snow depth data (ultrasonic gauge) from Weissfluhjoch.