METEOROLOGICAL AND SNOW COVER MEASUREMENTS AT GRAYLING, MICHIGAN

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ABSTRACT

U.S. Army Cold Regions Research and Engineering Laboratory is currently conducting research programs directed toward determining potential effects of airborne snow, snow cover and various meteorological parameters on electromagnetic systems. These programs required extensive-meteorological and snow cover characterization during the winter of 1982-83 and 1983-84 at Camp Grayling, Michigan, which are summarized in this report.

The paper also gives a description and discusses the cold weather accuracy and reliability of the automatic recording systems and sensors employed at the snow experiments. Descriptions are given of snow cover measurement techniques, sensors utilized and their accuracy for providing the physical properties of snow cover backgrounds.

INTRODUCTION

Field operations in winter frequently depend heavily on some form of detection and recognition of targets — either through the eyes of human observers or by interpretation of data and images received from an electro-optical device. One of the more difficult scenarios is that presented in cold regions where snow is present as an airborne obscurant and/or as a background and cover for terrain features. The necessity of characterizing this snow/winter environment for purposes of understanding and predicting the functional capabilities of electro-optical systems is well documented in the literature and has been particularly highlighted in the CRREL SNOW Symposium series.

The advent of SNOW-TWO presented an excellent opportunity to extend the characterization efforts of CRREL research programs to include support for various other projects, thereby enriching the quality and quantity of data available for CRREL projects as well as providing supplemental data for other programs.

MAIN SITE MEASUREMENTS

The principal focus of SNOW-TWO/Smoke-Week VI experiments was on Ranges 7 and 8 at Camp Grayling, Michigan (Redfield et al., 1984). Some of the features of this main site are shown in Fig. 1. Jordan (1984, Vol. 1, Overview) includes additional details of the area. Because of the concentration of operations in this area, much of CRREL's meteorological effort was also centered there for the airborne snow measurement portion of the field experiment, Jordan (1984 Vol. 1, Part 1-3).

Routine Measurements

Meteorological and/or snow cover measurements were made by CRREL at the 300 m, 600 m, 900 m, and 1200 m range positions on the main site. Meteorological instruments and sensors used and their specifications are given in Table 1.

The primary meteorological site was located approximately midway of the transmission range (600 m position) just to the east of the line of sight. A meteorological van with associated recording systems (Fig. 2) and meteorological tower (Fig. 3) were located at

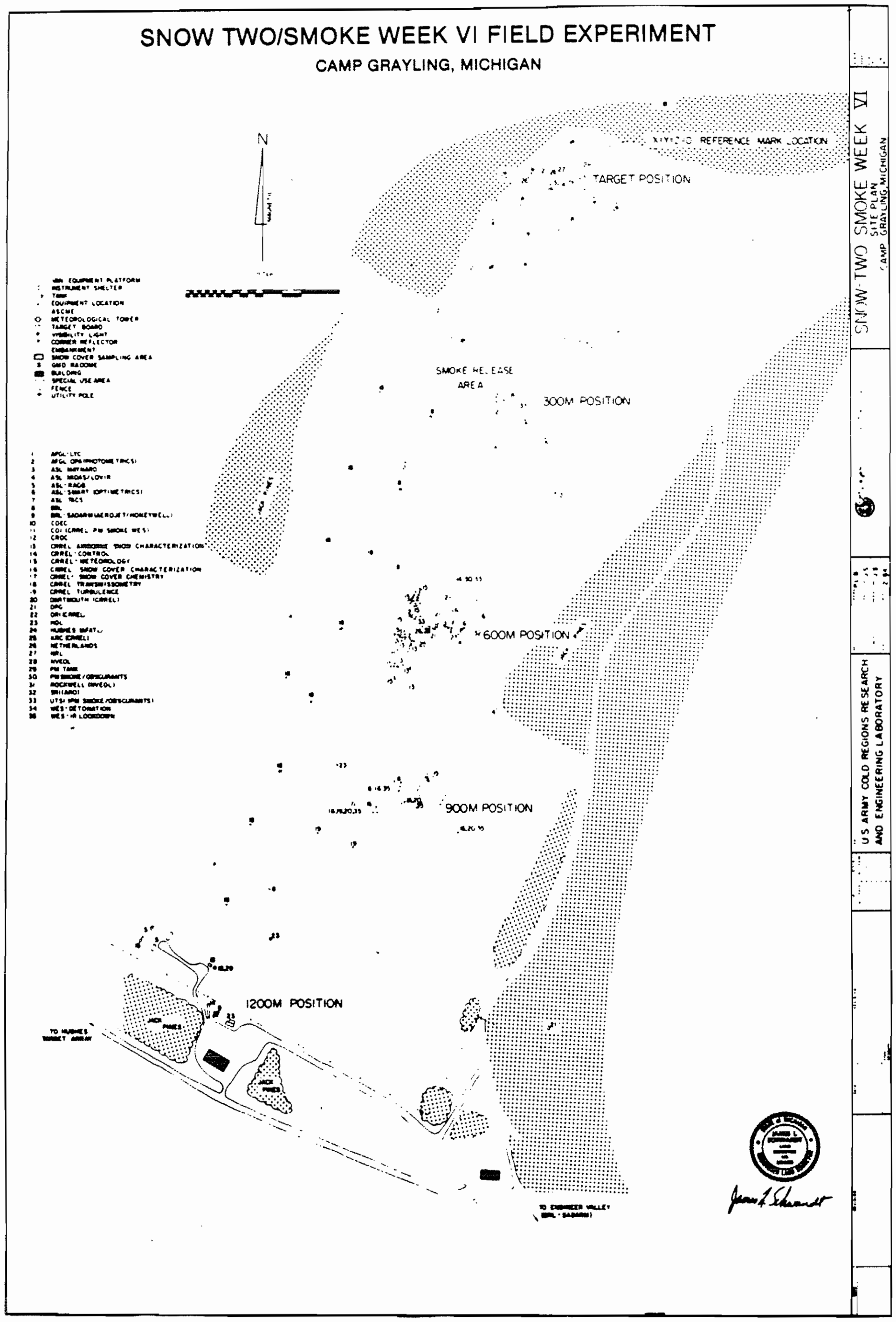
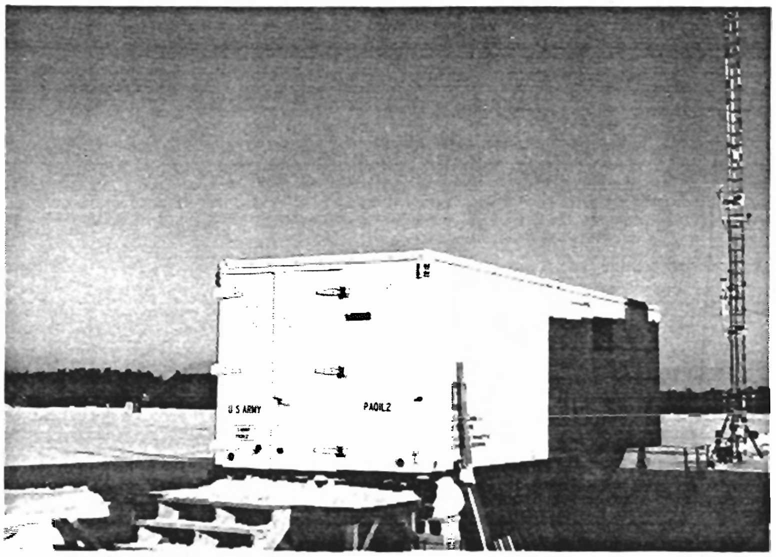
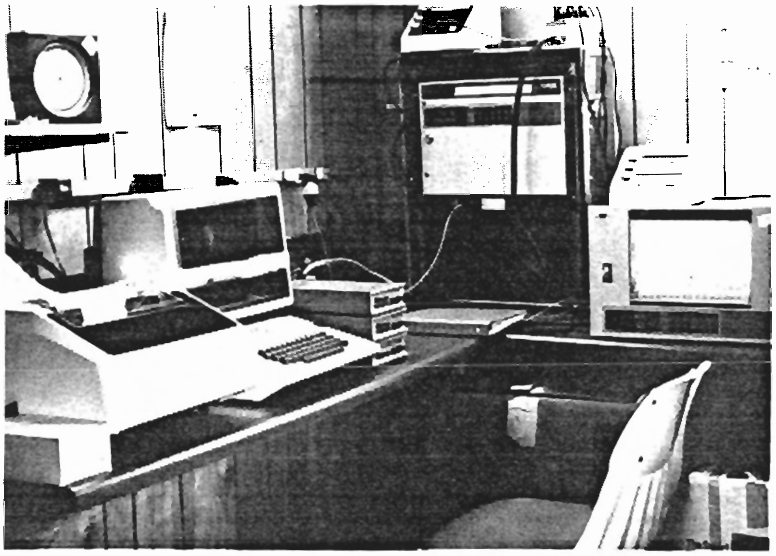


Figure 1. Location of meteorological/snow-characterization sites at Camp Grayling.

this site. The meteorological van was equipped with snow cover characterization and direct-sensing equipment as well as with data acquisition systems including a minicomputer. This served as a central data-collection point as well as a field repair/calibration facility for CRREL meteorological and snow cover characterization instrumentation. Air temperature, dew point, wind speed and wind direction were automatically recorded from sensors on the tower at 2, 4, 8 and 16 m above the ground. Duplicate sensors were installed at each level so that each height would have valid data points in the



a. Meteorological van.

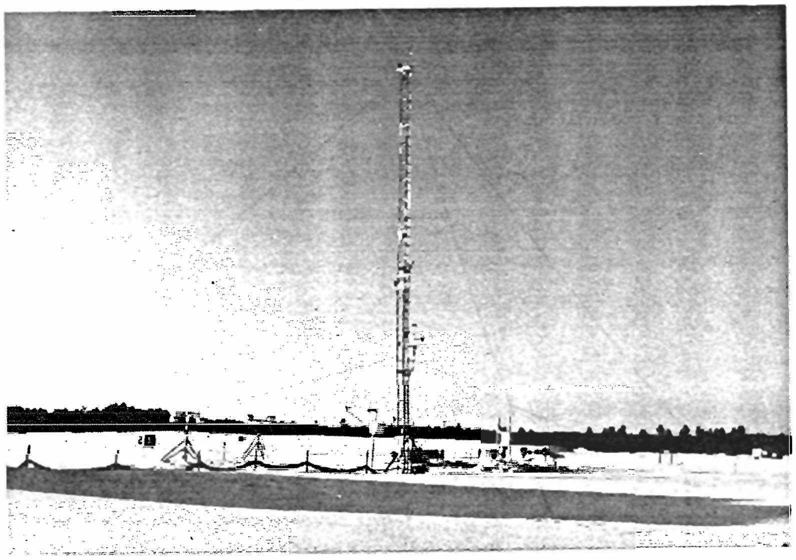


b. Data acquisition system.

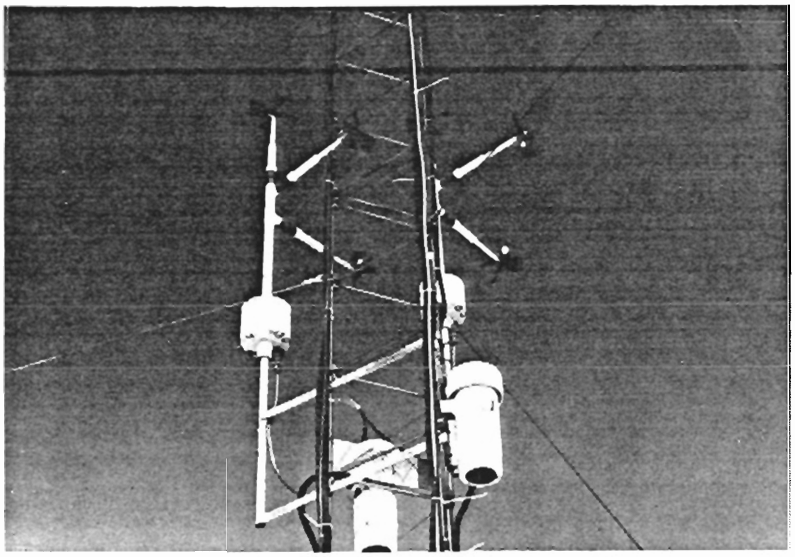
Figure 2. Primary meteorological site at 600 m position.

case of sensor breakdowns, calibration shifts, freeze-ups, etc. Millivolt signals from the tower-mounted sensors were transmitted to a Kaye DIGI-Link data-logger for conversion to engineering units and then transmitted via modem to an Apple II mini-computer where the data were stored on disc. This system scanned each sensor every minute. The data stored were for 10-minute sampling intervals, except that during obscuration periods, or while electro-optical measurements or special tests were being conducted, one-minute data were recorded.

Baseline meteorological stations were operated at 600 m and 1200 m for field calibration checks. These stations included a standard Weather Bureau shelter containing a max/min thermometer and hygrothermograph, recording 8-in. (20-cm) orifice precipitation gauge, and a frost tube.



a. Tower.



b. Tower-mounted sensors.

Figure 3. Primary meteorological site.

Water-equivalent precipitation was measured by two potentiometer-weighing-type automatic gauges approximately 300 m apart near the 600 m range location. Snowfall and snow depth records were maintained near each precipitation gauge and at many other site locations throughout the test. Standard surface meteorological observations were maintained according to U.S. Dept. of Commerce FMH No. 1. Rawinsonde flights were provided by an ASL meteorological team located at the south end of the range (1200 m position).

WINTER ENVIRONMENTAL EFFECTS ON ELECTRONIC INSTRUMENTATION

Table 1 gives a listing of meteorological sensors used, operating ranges, and accuracy for the SNOW Experiment series of winter tests. Many problems have been encountered

Table 1. Meteorological Instruments.

Parameter	Instrument and tower location	Type sensor	Range	Accuracy
Ambient temperature	General Eastern Model 650/612A; 2,4,8,16 m levels	100-ohm platinum RTD (linear)	-45° to +66°C	±1°C response: 2 min.
Dewpoint	General Eastern Model 650/611A; 2,4,8,16 m levels	Saturated lithium chloride; platimum-wrapped stainless steel bobbin	-40° to +60°C Relative humidity 12%-100%	±1°C response: 2-5 min.
Ambient temperature and dew/frost point	General Eastern Model 1200 MPS; 2 m level	100-ohm platinum RTD Thermoelectrically-cooled mirror, optically detected sensor	-75° to +50°C -75° to +50°C	±0.3°C ±0.3°C
Relative humidity	Vaisala Hmp-25U; 16 m level	Humicap	0-100%	±2%
Wind speed and wind direction	Teledyne Geotech Wind System Model 101, Model 1564 and 5 Transmitter; 2 and 8 m levels	Three-cup vane	0-45 m/s 0-540°	±1% ±3%
Wind speed and direction (east, north, vertical components)	R.M. Young Gill 3-axis anemometer; 4 m level	Polystyrene propellor molded to form a true helicoid	0-30 m/s 0-360°	±0.13 m/s ±3°
Wind speed	Environmental Ins. Model 320 dual range air flow sensor; 16 m level	Hot wire probe	0-50 m/s	±2%
Wind speed and direction	Environmental Ins. Model 200 dual axis meteorological system, probe 200M008, 8 and 16 m level	Two static pairs heated resistive sensing elements mechanically supported at right angles to each other	0-50 m/s Azimuth: 360°	±2% ±2% Air temp: ±0.5°C Pressure: ±0.1 mb
Wind speed and direction	Environmental Ins. Model 200 dual axis meteorological system, probe 200M001*	Two static pairs of heated resistive sensing elements mechanically supported at right angles, includes a heated cage to melt ice	0-50 m/s Azimuth: 360°	±3% ±3% Air temp: ±0.5°C Pressure: ±0.1 mb
Water equivalent (including snowfall)	Belfort model 5915-12 20-cm potentiometer electronic gage; 2 m level	Automatic weighing millivolt output	0-150 mm	±0.1 mm

Table 1 (cont'd). Meteorological Instruments.

Parameter	Instrument and tower location	Type sensor	Range	Accuracy
Shortwave solar radiation (vertical and reflected)	Eppley Precision Solar (pyranometer)	Radiometer	0.3-3 μm	± 1%
Infrared longwave radiation (vertical and reflected)	Eppley Precision Solar (pyregeo meter)	Radiometer	3-50 μm	± 3%
Ambient temperature	Hygrothermograph Model 5-594	Aged bimetallic strip	60° adjustable	± 1%
Relative humidity		Human hair bundles	0-100%	± 0.1% 20 to 80% R.H., ±3% at extremes
Station pressure	Microbarograph Model 971	Dash pot	945-1045 mb	± 0.15%
Pressure	Air tethersonde and airsonde with receiver Model TS-2A	Aneroid capacitance	0-100 mb	± 1 mb
Dry bulb temperature		Aspirated thermistor	-50° to +50°C	± 0.5°C
Wet bulb temperature		Aspirated thermistor	-50° to +50°C	± 0.5°C
Wind speed[2]		Cup anemometer	0.5°-20 m/s	± 0.25 m/x
Wind air[2]		Magnetic compass	0°-360°	± 5°

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[1] System includes sensors for air temperature (°C) and atmospheric pressure (mb)

[2] theodolite must be used to obtain wind data with an airsonde.

using all measurement systems and obtaining accurate data in the extreme climatic conditions of the winter environment. However, every winter field experiment solves more of these problems, and we learn how to place a greater variety of sensors and equipment in the harsh environment to obtain reliable data. A report on using electronic measurement equipment in winter was written by Atkins (1981), and the winter field environment was defined as:

- Nighttime temperatures around -12° to -18°C, but occasionally as low as -30° or -40°C.
- Daytime temperatures -5°C, but occasionally as high as +5°C.
- Low relative humidity.
- Days with bright sunshine and some dark days with low visibility.
- A foot or two of dense snow on the ground, periodically topped off by snowfall of lighter fluffy snow.
- Occasional blowing snow, usually fine and powdery.
- Occasional thaw periods with above-freezing temperatures, thick ground fog, and rain.

The SNOW field experiments have illustrated numerous problems encountered, when continuous, accurate real-time field measurements are to be made. Examples of these problems are:

1. Icing and riming events cause freeze-up of moving, turning, or weighing mechanisms rendering sensors inoperative. This effect is seen frequently in wind measurement devices and other sensors whose operation depends upon moving mechanical components.

2. Periods of high relative humidity (90 to 100%) with air temperatures 0 to -10°C. Since it is frequently difficult to ascertain the presence of fog in falling snow, the relative humidity is sometimes used to evaluate the probability of concurrence of fog in snow. Since current state-of-the-art relative humidity sensors are only accurate to +3% even when calculating relative humidity from dew-point/temperature relationships, this constitutes an undesirable restriction on the quality of observations.

3. Slightly below freezing air temperature, freeze/thaw cycles, and high solar radiation induce snow metamorphic change which, together with days of blowing or drifting snow, causes surface roughness, complicating the background in remote sensing applications.

Other field measurement problems which are aggravated by the winter environment are:

1. Site/sensor location: i.e., exposure effects, exposed vs sheltered terrain and turbulence effects. The question is, Is a point measurement representative of the area being studied?

2. Sensor calibration must be done according to standards in the laboratory, carried to the field, re-calibrated to some standard, and installed with a calibration check at least daily while in operation.

3. Hardware interfaces (cable, etc.) which are subjected to extreme cold temperatures may become brittle or may develop ice in connectors.

4. Data loggers, computers, and software appear to have no problem when standard operating procedures are followed and if they are installed in an area where temperature is maintained over 5-7°C.

SNOW COVER MEASUREMENTS

In the undisturbed snow area southeast of the primary meteorological site and just north of the 900 m site Fig. 1, data were obtained on incident and reflected solar radiation in both the 0.3-3.0 μm and 3.0-50 μm spectral bands. A roped-off area was maintained for making routine snow depth, snowfall and snow property measurements, including liquid water content measurements using both a capacitance probe and alcohol calorimetric techniques. (Additional details on snow cover methodology are deferred to the discussion of Engineer Valley measurements.) This site also contained a thermistor string to measure ground, snow and air temperatures at 14 levels from 30 cm beneath the ground/snow interface through the snow cover up to 1 m above the snow. These temperature data (± 0.1°C) were continuously recorded on a Kaye DIGI III data logger and stored on Apple disc.

ENGINEER VALLEY MEASUREMENTS

Unique details of snow-cover and meteorological conditions were measured during the period 1 February through 9 March 1984 at Camp Grayling, Engineer Valley location (Table 2). These measurements were for the purpose of providing "ground-truth" or "direct sensing" data for verification and/or interpretation of overflight remote sensing. Snow measurements included areal distributions of snow surface temperatures, depths, and temperature profiles, as well as pit measurements of snow stratigraphy, density, hardness, grain size and liquid-water content.

The area selected for these overflights lies about a kilometer southeast of the SNOW-TWO main site. Engineer Valley slopes gently in a southerly direction from a stretch of Howe Road just east of the main site. It is relatively wide open in its northern sector but becomes increasingly encroached upon by clumps of small trees as it gradually curves toward the southeast. There are several vehicle trails in the valley, one of which

Table 2. Engineer Valley measurements.

A. Fixed instrumentation

1. Grid temperature instrumentation: thermocouples with programmable scanning capability.

   a. Snow/surface: 121 sites at 1-m intervals
   b. Snow/ground interface: 9 sites at 50-m intervals
   c. Ground (30-cm depth): 9 sites at 50-m intervals
   1 special, under road
   d. Target/calibration sites 2 each

2. Snow depth: 44 locations; 35 in grid, 9 near outside targets.
3. Radiometric: vertical and inverted, VSBL and IR, located within the grid.
4. Meteorological tower: Temp., winds, humidity and dew point at 3, 9 and 15 m height.
5. Calibrated thermistor temperature profile near grid; 30 cm below ground to 100 cm above ground. Thermistors located at 5 cm intervals from the ground/snow interface up to 35 cm.
6. Frost tube.
7. Precipitation gauge.
8. Station pressure sensor
9. Base meteorological station (includes hygrothermograph and max-min thermometers)

B. Manual Snow Cover Characterization

1. Snow depth and surface temperature at two points (shaded and unshaded) at each target/calibrator location.
2. Snow density (water equivalent), every 100 m.
3. Snow liquid water content, every 100 m.
4. Radiometric snow surface temperature.
5. Snow pit (standard measurements,* plus microscopic crystal structure profile).
6. Snow grain size every 100 m over grid.
7. Snow surface roughness local to each target.

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* Generally according to USACRREL Instruction Manual No 1 (1962). However, this manual is currently undergoing revision to up-date its recommended techniques and in some measurements the current methodology is not described in the manual.

leads more-or-less directly down the middle of the valley, which is designated "target road."

Both the geography of the site and required overflight patterns were considered in locating the primary test area. The area selected was on the road near where the clumps of trees converged to both sides of it. Flight lines passing over this area covered a variety of terrain types. The proposed confluence of flight lines was selected as the approximate site for a 100 m x 100 m temperature grid. The grid was offset slightly from the flight line confluence because of operational requirements. Circumstances dictated that the van/tower site be located west of the target road and the sloping terrain placed some limitations on accessibility. However, a site was located which was approximately 100 m from the target road and which, with some bulldozing to construct an access road and pads for van(s) and tower, was deemed satisfactory for the meteorological and snow cover characterization support equipment. The tower and supporting meteorological sensors were sited to measure conditions representative of a semi-open area somewhat similar to the target area, with some clumps of trees nearby. When the tower was extended to 15 meters the data taken by the top sensors were above the tree canopy.

The Grid

A 100 x 100 m grid was laid out at the site with marker stakes every 10 m within the grid. A schematic chart was made (Fig. 4) in which the grid markers are designated by

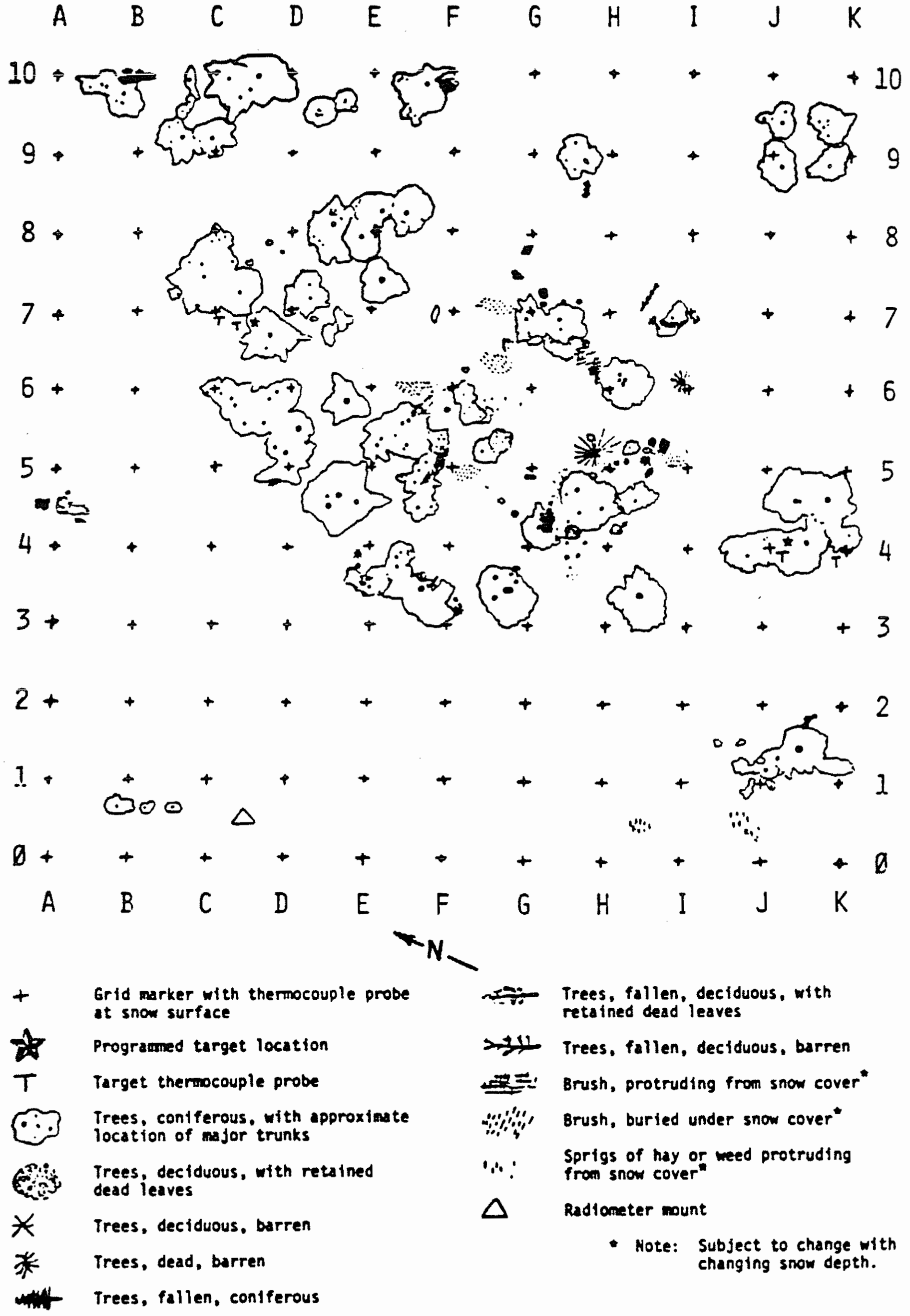

Figure 4. Schematic diagram of Engineer Valley grid area.

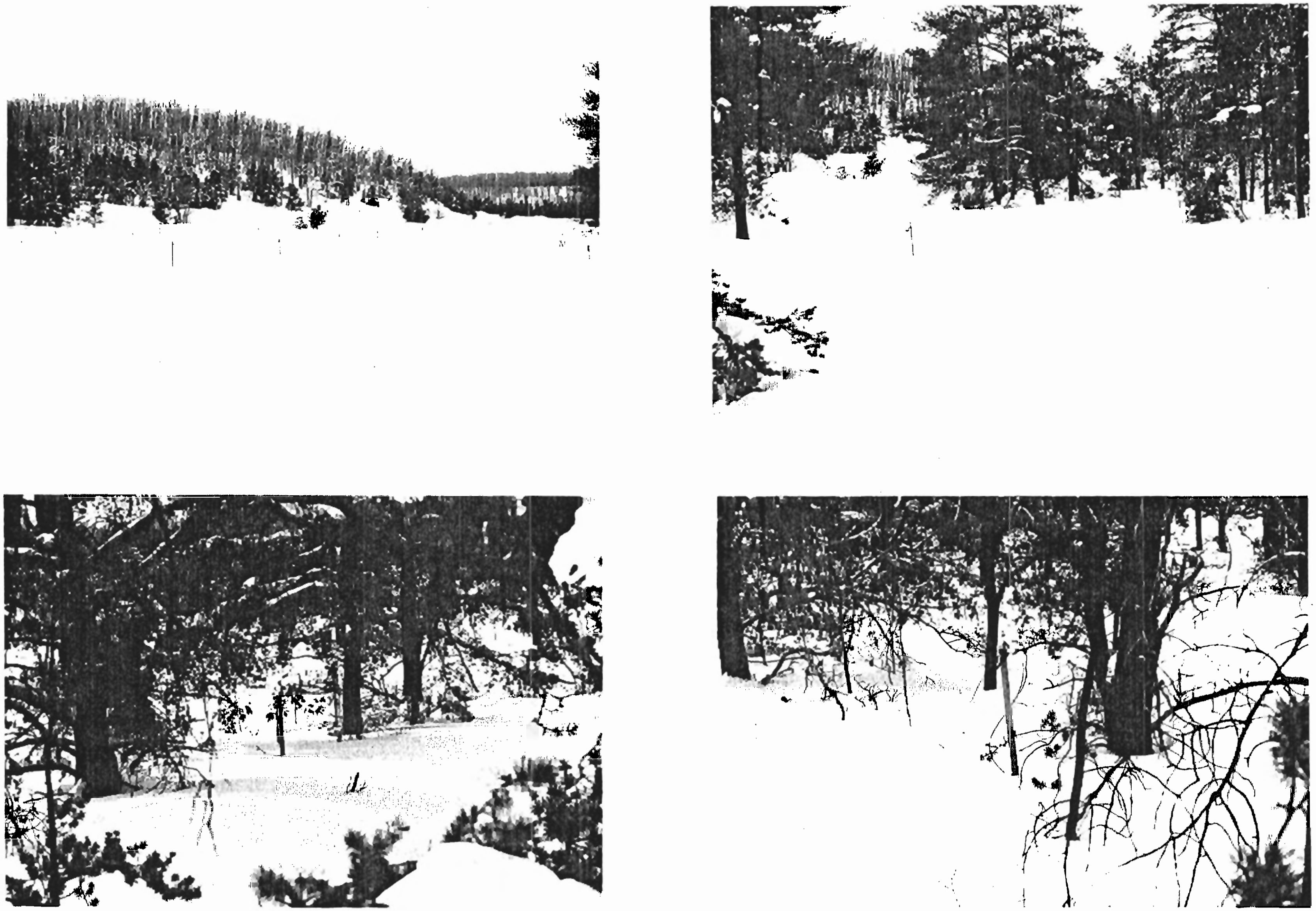

Figure 5. Typical views of terrain within grid area. Thermocouple probes were not inserted at the time of the photo and some may be seen coiled up at their marker stakes.

rows (numbered zero through ten) and columns (lettered A through K) which depict the location, size and shape of trees and shrubs, standing and fallen, within the grid area. The variety of terrain features in which measurements were made are shown in the photos on Fig. 5.

Because of the requirement for a large number of snow temperature measurements over a considerable area, and the desirability of frequent and nearly simultaneous readings during overflights, a thermocouple network was installed throughout the grid. Twelve 12-pair, 20 AWG, Type T, shielded, PVC insulated thermocouple cables were installed between programmable scanning recorders in the meteorological van and various junction boxes within the grid. From the junction boxes individual thermocouples were distributed and located as follows:

1. Snow-surface probes: One at each juncture of row and column, totaling 121 thermocouples at 10-m intervals. Approximately 1.5 m of probe was left free so that prior to each test overflight, if changing snow conditions warranted, the probes could be reinserted in the snow cover as close to the surface as possible.

2. Temperature-profile monitors: In addition to snow-surface thermocouples already in place, thermocouples were installed at the ground/snow interface and at a 30.5-cm depth in the ground at nine sites in the grid: at each corner, the mid-point of each side, and grid center. One additional thermocouple was installed just beneath the ground surface at junction K3 because the slight curve of the road caused this point to fall within the road and it was considered desirable to note temperature differences which would occur in the track should a vehicle pass over this point.

Snow-depth stakes were located at numerous points within the grid, including at the nine temperature-profile-monitoring sites, each of the thermocouple-junction-box locations, each corner of the two grid squares containing potential target positions, and at 12 other row-column intersections selected for various reasons such as topography, brush cover or general areal distribution. The depth markers were (5 cm x 5 cm) 1.5 m high wood stakes, painted white to reduce solar effects on the adjacent snow cover, with an affixed metric scale graduated in millimeters from zero (at ground surface level) to about 1 m height.

The equivalent blackbody temperature of the snow surface was measured periodically with a hand-held Ranger II Infrared Thermometer.

Meteorological Instrumentation (Fixed Installation)

The meteorological van was placed approximately 100 m west of the grid. This van contained the programmable scanning recorders used for both meteorological sensors and the thermocouple grid, and two aneroid barometers for atmospheric pressure measurements which were used in setting the helicopter altimeter, as well as providing shelter for the crews between overflights. After 31 January this became the primary meteorological site for the remainder of SNOW-TWO.

A portable (trailer-mounted) meteorological tower was raised in a small clear area just north of the van. The tower was instrumented at 3, 8 and 15 m heights for measurements of air temperature, wind speed and direction, and either humidity or dew point. Sensors also measured air temperature and wind speed at 9 m, and atmospheric pressure at 15 m.

In an area between the meteorological tower and the northwest corner of the grid, additional instrumentation was installed. This area was selected as a compromise, being as close to the grid as possible, yet avoiding interference with or disturbance by vehicular movements associated with target placement, rearrangement, etc. A frost tube was inserted in the ground and a snow-depth stake set nearby. An instrument shelter containing a hygrothermograph and max/min thermometer was set up and a precipitation gauge mounted a short distance away. Closer to the grid (only a few meters from the northwest corner) calibrated thermistor-profile sensors were installed in an undisturbed area which provided temperature data at 11 levels, from 30 cm deep in the ground to 1 m above the ground throughout entire test period.

Finally, just inside the grid in area CD01 (Fig. 4), a radiometer set was installed which included vertical and inverted measurements of radiation from 0.3 to 3 and 3 to 50 µm in wavelength.

Snow-Cover Methodology

Snow-cover characterization includes observations and measurements of numerous parameters. The fixed instrumentation previously described provided many of these measurements, including areal distribution of snow surface temperatures, air-snow-ground temperature profiles, target-surrounding temperatures, and a means for relatively rapid observation of areal distribution of snow depth. Other than temperature, visual observation techniques and measurement of most snow-cover characteristics require manual, and often tedious, methodology which is not amenable to automatic data recording. Among the features of snow that are observed is the stratigraphy, noting the depth, thickness and grain size of each layer and, where possible, the density, temperature, hardness and liquid-water content of each layer. The roughness of the snow surface is observed and recorded. Other general observations of unusual or irregular conditions are usually logged and might include notations as to inclusions in the snow (e.g. ice lenses, dirty or smoky layers, etc.). Some specifics of the measurements and observations made are briefly described below.

Snow pits. These observations and measurements, as the name implies, involved the digging of a pit through the entire snow cover to the ground. At least one wall of the pit was cut as cleanly and as vertically as possible. Stratigraphic measurements, as listed above, were then performed.

Snow density. Where layer thickness permitted, a 5.8-cm-diameter, 18.9-cm-long stainless steel "snow tube" was inserted perpendicularly into the vertical face of a snow pit, extracting a known volume of snow. Determining the net weight of the snow in the tube permitted calculation of the density of the layer. An adjunct to this method, useful when some layers of the snow cover are too thin to measure accurately or when an average density of the entire snow cover is desired, was the use of a CRREL-modified Adirondack-type snow tube. This tube, which is about 8.4 cm in diameter and 1.5 m long, was inserted vertically downward through the undisturbed snow cover (usually near the recently dug snow pit). As before, the density of the snow was determined from weight and volume measurements.

Hardness index. Gauges used for this measurement were push-type spring balances provided with several sizes of interchangeable discs. An appropriate size disc was chosen and was pressed gently against a perpendicular snow surface. The force applied was gradually increased until penetration of the snow was achieved. This was usually done in each sufficiently thick layer of the snow-pit wall and/or vertically downward on the snow surface. Noting the readings on the balance scale, applying a correction factor for disc size and averaging several trials gave the hardness index of the layer.

Liquid-water content. Obviously snow is a form of water in its frozen or solid state. The distinction between the solid and liquid states of water often poses minor semantic confusion in some discussions. So, although it admittedly seems redundant to refer to "liquid water," this term is used here in referring to water in its liquid state when present in a layer of snow.

Since quantitative determination of the amount of liquid water in snow is quite tedious and time consuming, routine screening observations were made to qualitatively check for the presence of liquid water. Rosanaline hydrochloride, a greenish-black crystalline substance, was sprinkled on a freshly cut snow surface. In the presence of liquid water, the powdered dye turns red, indicating the presence, location and extent of wetness. These observations must be made immediately upon application of the dye; otherwise, absorption of solar energy by the dye may cause melting and consequently false positive indications.

During conditions of melting or rainfall, liquid water will be present in the snow. As previously mentioned, measurement of the fraction (by weight) of liquid in a snow sample is extremely difficult, especially under field conditions. Alcohol calorimetry is probably one of the best methods currently in use. This methodology was developed at USACRREL and was used in the program. In this procedure, described by Fisk (1983), the liquid water content of the snow is related to the temperature depression observed when a sample of snow is dissolved in methyl alcohol.

Grain size. Snow particles from various layers were placed on a millimeter-grid card and examined using a magnifying glass (microscope, whenever possible). The size and apparent crystal type was recorded.

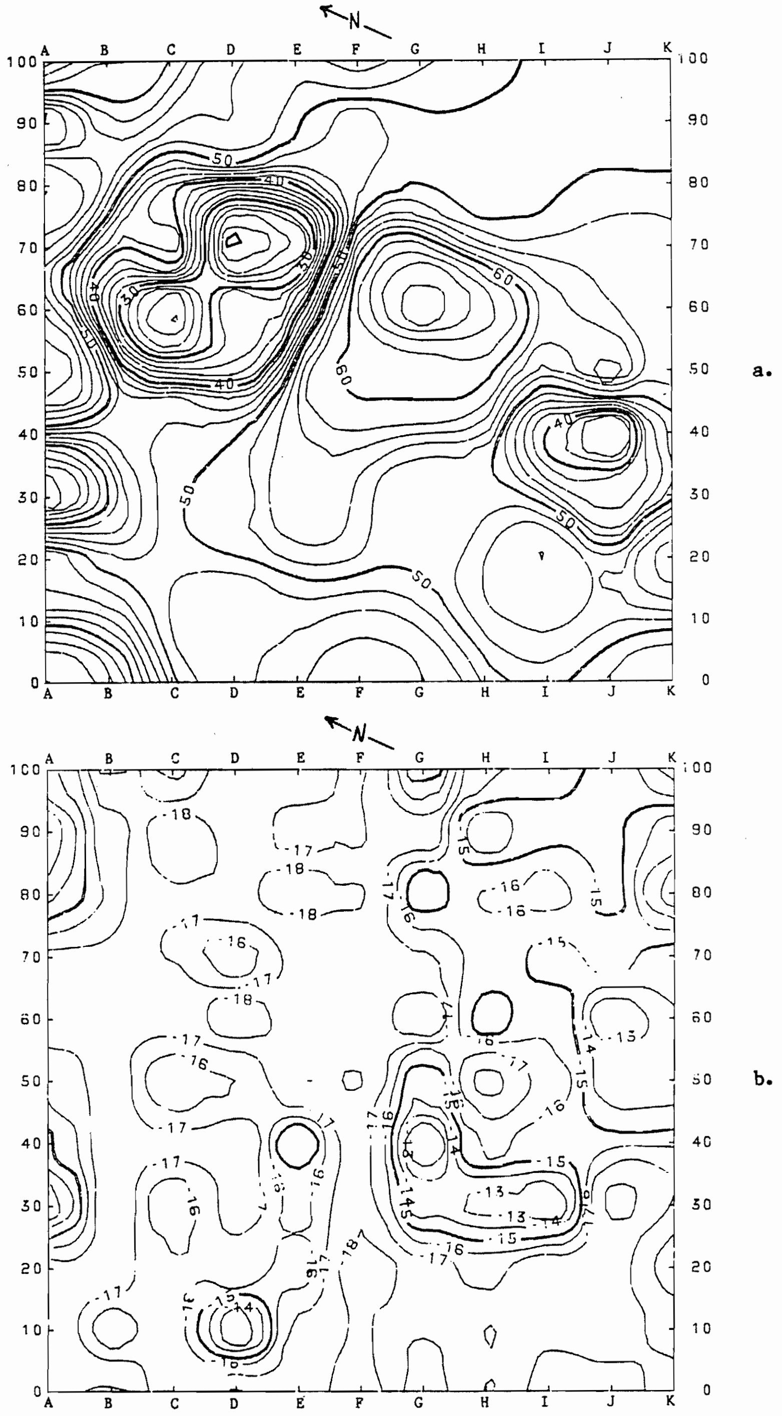

Figure 6. Areal distribution of (a) snow depth and (b) snow surface temperatures. Engineer Valley grid; 0830 hr, 7 Feb 1984.

Engineer Valley Data

Data collection. Those sensor systems which were connected to the programmable scanning recorders in the meteorological van were read at 30-minute intervals, 24 hours a day, from 1 February through 9 March 1984, and recorded on magnetic tape cassettes. Data are missing during periods when the power generator was down. Hourly meteorological summaries are presented in Jordan (1984 Vol. 1, Part 1-3). During sensor overflights the scan rate was increased to 5-minute intervals. Sensor systems served by the automatic retrieval included the meteorological tower instrumentation, the grid thermocouple network, the thermistor air-snow-ground profile string, and the vertical and inverted radiometers.

Measurements requiring manual read-out or which involved a series of manual operations were generally performed once during each overflight. Measurements in this category included: all of the 55 snow depth stakes in the grid area and near each target, the grid thermocouples, a new snow pit with all its attendant parameters, the mean snow density every 100 m using an Adirondack tube, liquid water content of the snow (unless conditions assured that no liquid would be present) and frost depth, snow surface roughness and any other notable features.

Snow-surface equivalent blackbody temperatures were observed at several sites in the grid and target areas during overflights.

Data analysis. A preliminary study of the area distribution of snow surface temperature and snow depths during overflights of the Engineer Valley grid is illustrated by the isopleths in Figs. 6a and b. The data represented in Figure 6 were taken during a cold spell (air temperature approximately -20°C) at a time when the grid was covered with fairly deep snow. Transparencies of these profiles, when reproduced at the proper scale, can be overlaid on Figure 4 to visualize the inter-relationship between vegetative cover, snow depth and snow temperature. In many instances prevailing wind patterns may also be deduced from such a comparison.

Another method of displaying the areal distribution data is shown in Figs. 7a and b. These three-dimensional representations lend a different perspective to the data. Through appropriate selection of the arbitrary "elevation" scale, certain features may be emphasized which were unnoticed or appeared relatively innocuous in the other graphics.

The following analysis refers to data gathered at SNOW-TWO on days 6, 7, and 10 Feb 1984 but similar analyses are possible on any part or all of the data gathered during SNOW-TWO. Figure 8 presents hourly data measured between 1000 EST on 6 Feb and 0400 EST

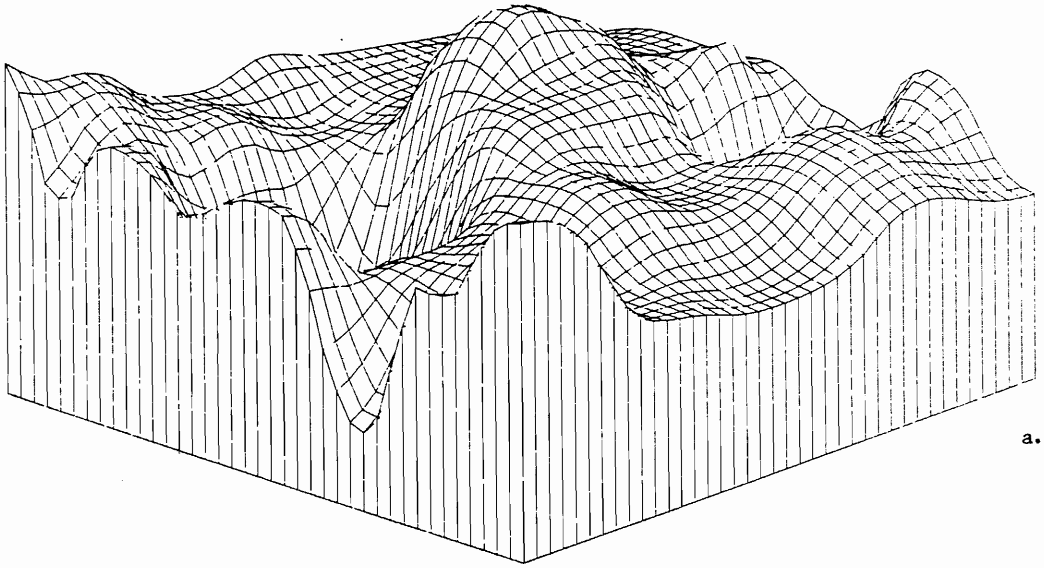

Figure 7. Three-dimensional representation of the data from Figure 6. Arbitrary scale.

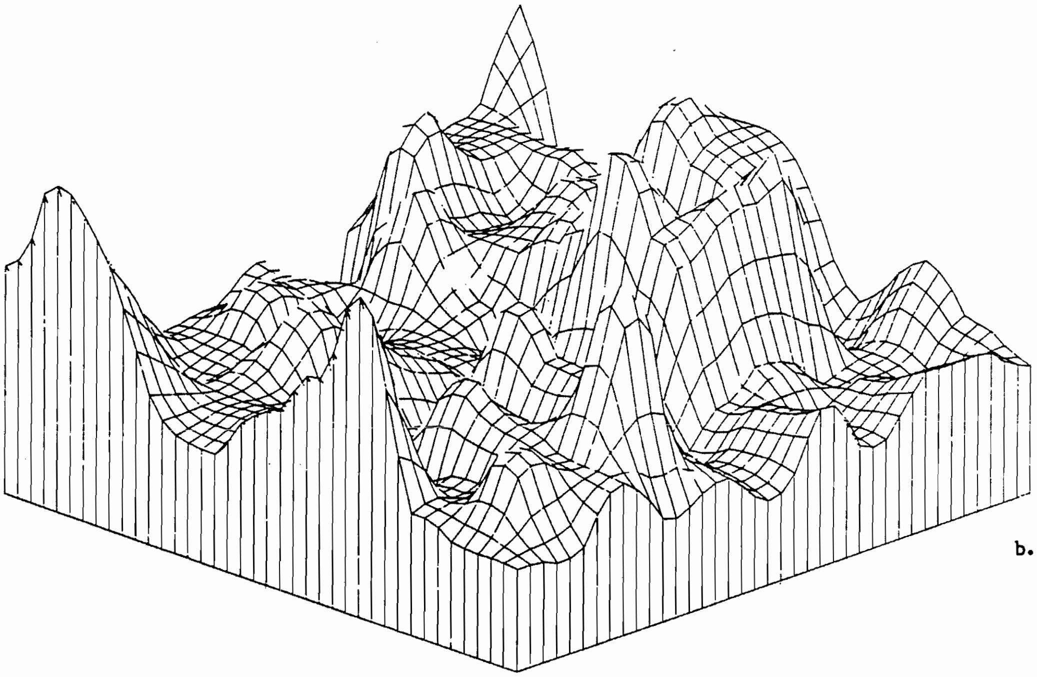

Figure 7 (cont'd).

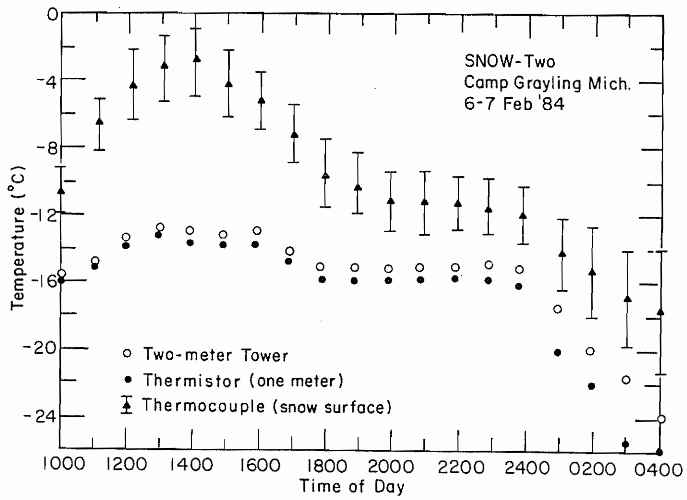

Figure 8. Hourly temperature data 6-7 Feb 1984.

on 7 Feb, including air temperature 2 m tower, air temperature from the thermistor string at 1 m above the ground which was approximately 50 cm above the snow surface, and the average snow surface temperature (plus and minus one standard deviation) gathered from thermocouples in the grid. Note that the areal variability in the average snow temperature increases as the temperature changes and tends to decrease as the temperature stabilizes. This can be attributed partly to the time delay difference between the average snow surface temperature and the rapidly changing air temperature and partly to the fact that each thermocouple does not react the same (time wise) to changes in air temperature. This effect will be more evident later on in this presentation. Note that the average snow surface temperature is much warmer than the air temperature.

Figure 9 presents data gathered between 0800 and 2200 EST on 7 Feb 1984, including the 2 m tower, the 100 cm thermistor, and the average snow surface temperature plus and minus one standard deviation. Again note the variability increases as the temperature changes. The average grid snow temperature does not differ from the 2 m tower and 100 cm thermistor air temperatures as much on the 6-7 Feb plot.

Figure 10 presents data gathered between 1000 EST and midnight on 10 Feb, showing the 2 m tower, the 100 cm thermistor, and the variability in the grid snow surface temperatures. From this figure it becomes even more apparent that as the air temperature stabilizes the snow surface temperature variation decreases significantly. In contrast to the two previous periods (shown in Figs. 8 and 9), we see that the snow cover temperature is now colder than the air temperature.

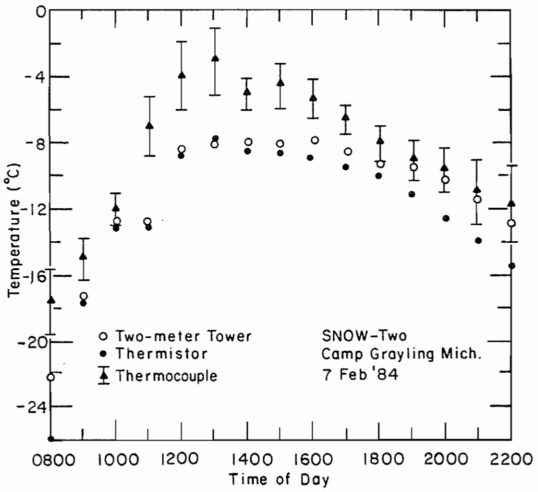

Figure 9. Hourly temperature data 7 Feb 1984.

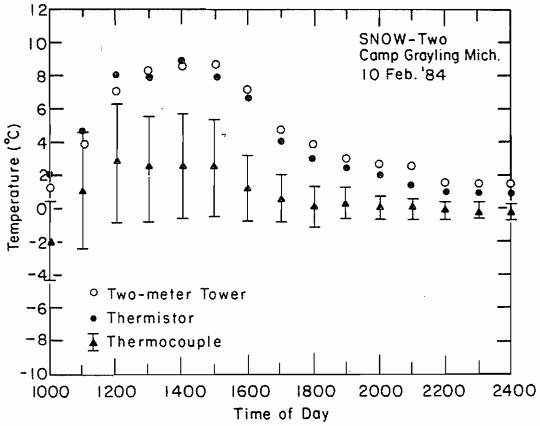

Figure 10. Hourly temperature data 10 Feb 1984.

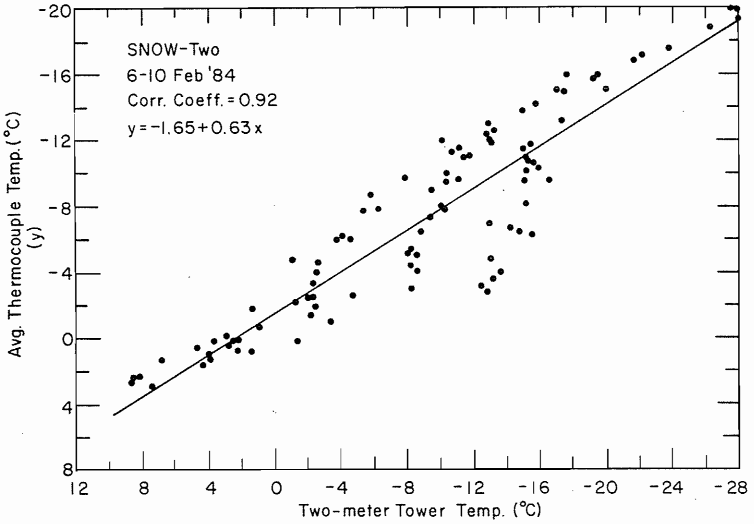

Figure 11. Correlation between average snow surface temperature and two-meter tower air temperature 6-10 Feb 1984.

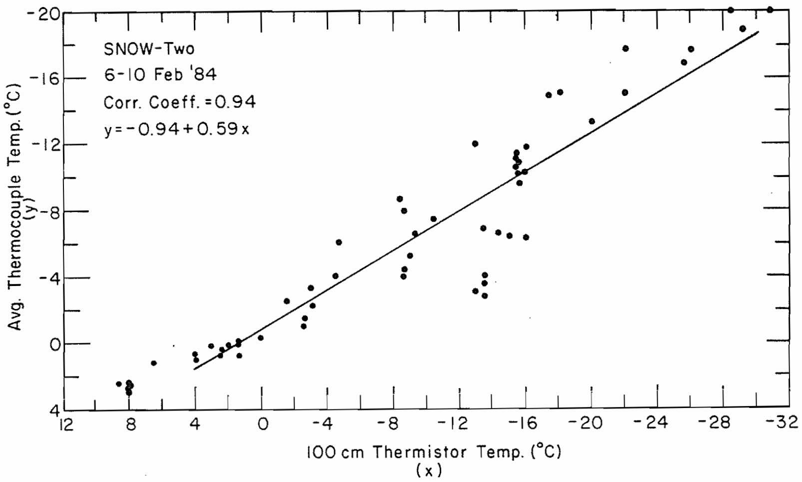

Figure 12. Correlation between average snow surface temperature and 100 cm thermistor temperature 6-10 Feb 1984.

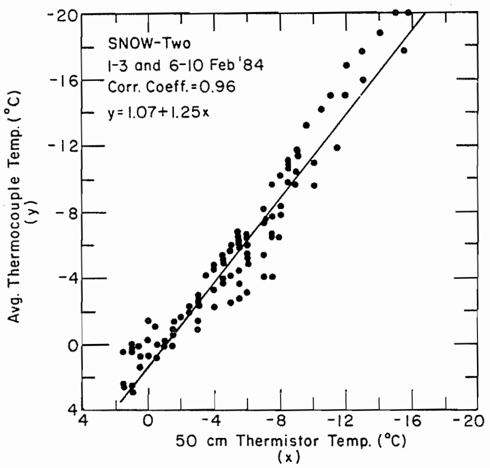

Figure 13. Correlation between average snow surface temperature and 50 cm thermistor temperature 6-10 Feb 1984.

Figure 11 shows a 0.92 correlation of average snow surface (thermocouple) and 2 m tower temperatures. Figure 12 shows the plot of snow-surface thermocouple average and 100 cm thermistor temperature (or 50 cm above the snow surface). The regression correlation coefficient is 0.94 which is slightly higher when compared to the 2 m tower data. Figure 13 shows similar results for the average grid thermocouple and the 50 cm (nearsnow surface) thermistor. As might be expected it appears that the nearer a point measurement is made to the snow/air interface, the higher the correlation coefficient (0.96 in this case).

SUMMARY AND CONCLUSIONS

This paper discusses; 1) winter environmental effects on electronic meteorological instrumentation utilized at the snow field experiments, 2) specific snow cover measurements made and methodology used, 3) relationships between a large number of average surface snow cover measurements over a 100 m^2 grid as compared to near surface air temperatures.

From these measurements it is concluded that taking detailed thermocouple measurements of snow surface temperature over a 100 m grid is cumbersome, costly and time consuming. On the other hand these measurements provide the best feasible description of the snow surface temperatures. However, from these analyses it is quite apparent that a near snow surface single point air temperature measurement can be used to obtain reasonable estimates of upper snow surface temperature. Prior to conducting extensive grid measurements for future tests, the data accuracy requirements as well as the funds and manpower available should be carefully assessed, and a determination made as to the feasibility of substituting near-surface air temperature measurements.

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REFERENCES

Atkins, R. (1981) Using electronic measurement equipment in Winter. Cold Regions Technical Digest No. 81-1.

Bates, R. and J. Govoni (1984), Meteorological Instrumentation for Characterizing Atmospheric Icing, Proceedings of the Second International Workshop on Atmospheric Icing on Structures, Trondheim, Norway.

Fisk, D. (1983) Progress in methods of measuring the free water content of snow. Proceedings the International Society for Optical Engineering, Volume 414, Optical Engineering for Cold Environments, p. 48-51.

Jordan, R., Editor (1984) SNOW-TWO Data Report, USACRREL Special Report 84-20, Vol. 1-1, and Vol. 1-3.

Redfield, R.K., W.M. Farmer and J.F. Ebersole (1984) SNOW-TWO/Smoke Week VI Field Experiment Plan, USACRREL Special Report 84-19.