DETERMINATION OF SNOW STORAGE FOR SMALL EASTERN HIGH ARCTIC BASINS

by

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ABSTRACT

A snow survey was carried out before the melt season of 1976 in four small basins near Resolute, Cornwallis Island, N.W.T. The study was undertaken to determine the error involved in estimating basin snow storage using climatological data. Results indicate that basin storage was about twice the amount recorded by the climatological station. The explanation for such a discrepancy lies in the variability of snow depth and density over different types of terrains. The climatological station was representative of only the more exposed flat-lying areas. Elsewhere in the basins, there was a systematic snow storage increase from hilltops to flats, to slopes, to gullies and valleys. The possibility of relating snow depth and density to terrain characteristics offers a means of computing basin snow storage based on a sampling of snow conditions over a selected number of terrain types.

INTRODUCTION

A large part of the error arising from water balance computations for Arctic basins is often attributed to inaccuracies in precipitation measurements (Cogley, 1975; Findlay, 1969; Hare and Hay, 1971, 1974; Jackson, 1960; Walker and Lake, 1973). The major problem is the lack of basin snowfall data and therefore point measurements of snowfall obtained at weather stations have to be substituted. However, weather station data are generally considered to underestimate total snowfall because of several problems in the sampling technique, including (1) snow gauge deficiencies in catching snow (Jackson, 1960), (2) the large number of trace events which are not recorded by the gauge (Findlay, 1969; Jackson, 1960) and (3) the inability to distinguish between falling snow and blowing snow (Hare and Hay 1974).

Although many studies indicate a large probable error in precipitation measurements, few have attempted to determine the exact magnitude of the error. Cogley (1975) and Findlay (1969) both used a water balance approach to estimate winter precipitation, but there are no direct measurements of the total snow accumulation in High Arctic basins. The present study provides field measurements of basin snow storage which can be compared with snow gauge records from a nearby weather station in order to assess the error in transposing site data to the basins.

OBJECTIVES OF THE STUDY

The present study has two objectives:
(1) to determine snow storage in several small basins in the High Arctic at the end of winter so as to obtain accurate information for basin water balance

computations.

(2) based on the basin snow storages thus obtained, to evaluate the error involved in transposing the snowfall record from a nearby meteorological station to the drainage basins.

There are two major assumptions in the study. One of them is that no melting occurred during the long Arctic winter so that a detailed snow survey carried out prior to the melt season will provide data on the total amount of snow accumulated in winter. This assumption is valid because of the lack of energy input to the basins to produce snowmelt. The other assumtpion is that topography exerts a strong control on the distribution of snow so that various terrain units will have their characteristic amount of snow storage. In this case, basin snow cover can be obtained as the areally weighted mean of the snow storages in various types of terrain in the basin. An accurate snow survey will then require a partitioning of the basin into a number of terrain units with representative snow density and snow depth measurements obtained for each unit.

STUDY AREA

At Resolute, Cornwallis Island, Northwest Territories, the Atmospheric Environment Service maintains a first class meteorological station which records snowfall with a Meteorological Service of Canada snow gauge and which carries out snow surveys at the station two times each winter month (Fig. 1). To compare snow storages in small drainage basins with the record of the meteorological station, four basins approximately 5 km northeast of the station were selected as the study area. These basins nest within one another (Fig. 2). Basin size ranges from 0.5 to 33 km^2 and elevation ranges from 75 to over 200 m (Fig. 3). The basins are fringed with exposed plateaus or rounded ridge-tops and are occupied by rolling to genetly sloping areas at lower elevations. Vegetation is scanty to non-existent, but patterned ground is prevalent in the basins (Cruickshank, 1971).

METHODS OF STUDY

From aerial photographs taken in summer, the basins were subdivided into various terrain units which were then confirmed in the field. Fifty-three snow survey traverses were carrried out across various terrain units. Each transect consisted of 10 to 50 sample points and the transect lines spanned the entire lengths of the terrain units. A 3 m steel pole was used to measure snow depth and a Meteorological Service of Canada snow sampler was used to determine snow density. Several densities thus determined were checked against the density obtained by taking a series of 250 cm^3 sample cores from vertical profiles exposed in snow pits, and the results were comparable.

The snow survey was expedited by a snowmobile to carry a party of two surveyors during the period May 17 to June 6, 1976. The snowpack did not undergo any melting during this period though several snow storms occurred between May 19 and May 26. Fortunately, this new snow can be easily distinguished from the older snow (Fig. 4). For consistency, the new snow was ignored and all snow data refer to the condition as of May 19, 1976. Due to

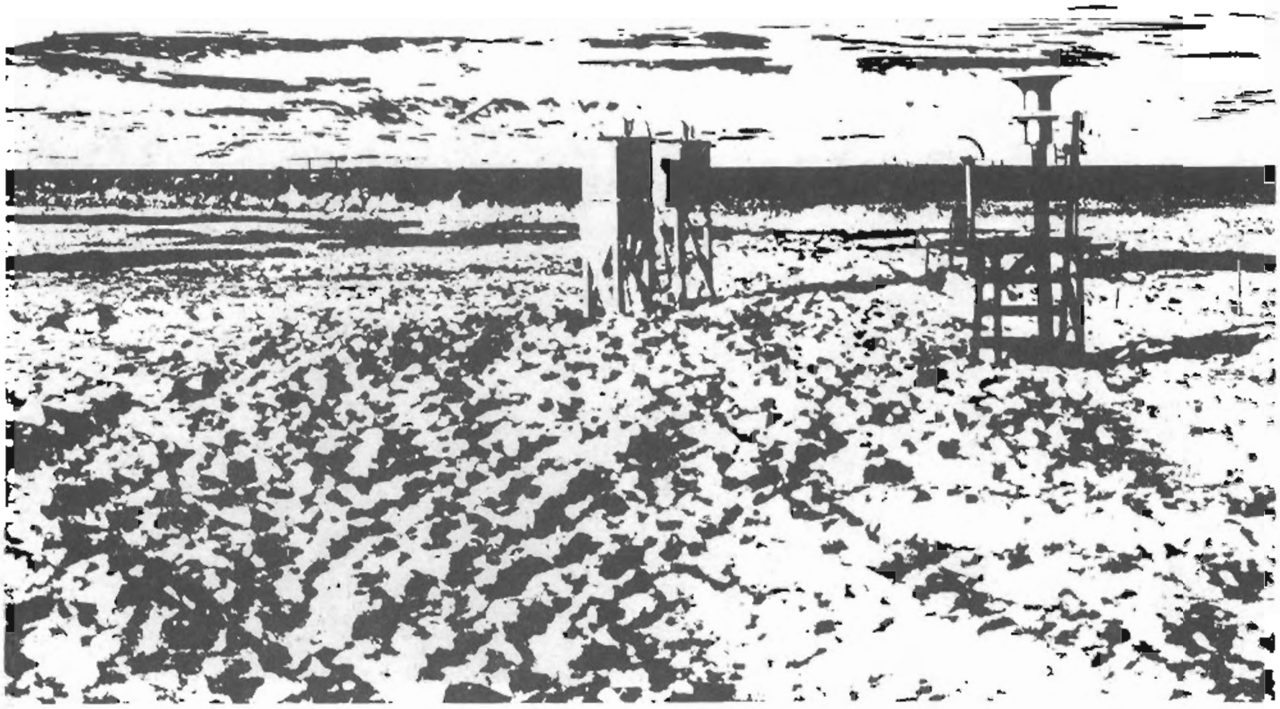

Fig. 1 Atmospheric Environment Service meteorological station at Resolute, N.W.T. The site is located at the western side of an air strip shown in the middle ground. Also shown at the right is a M.S.C. snow gauge with a nipher shield.

Fig. 2 Aerial view of the study area (outlined in black) of the Resolute meteorological station. Photograph was taken in early August with late-lying snow occupying the valleys.

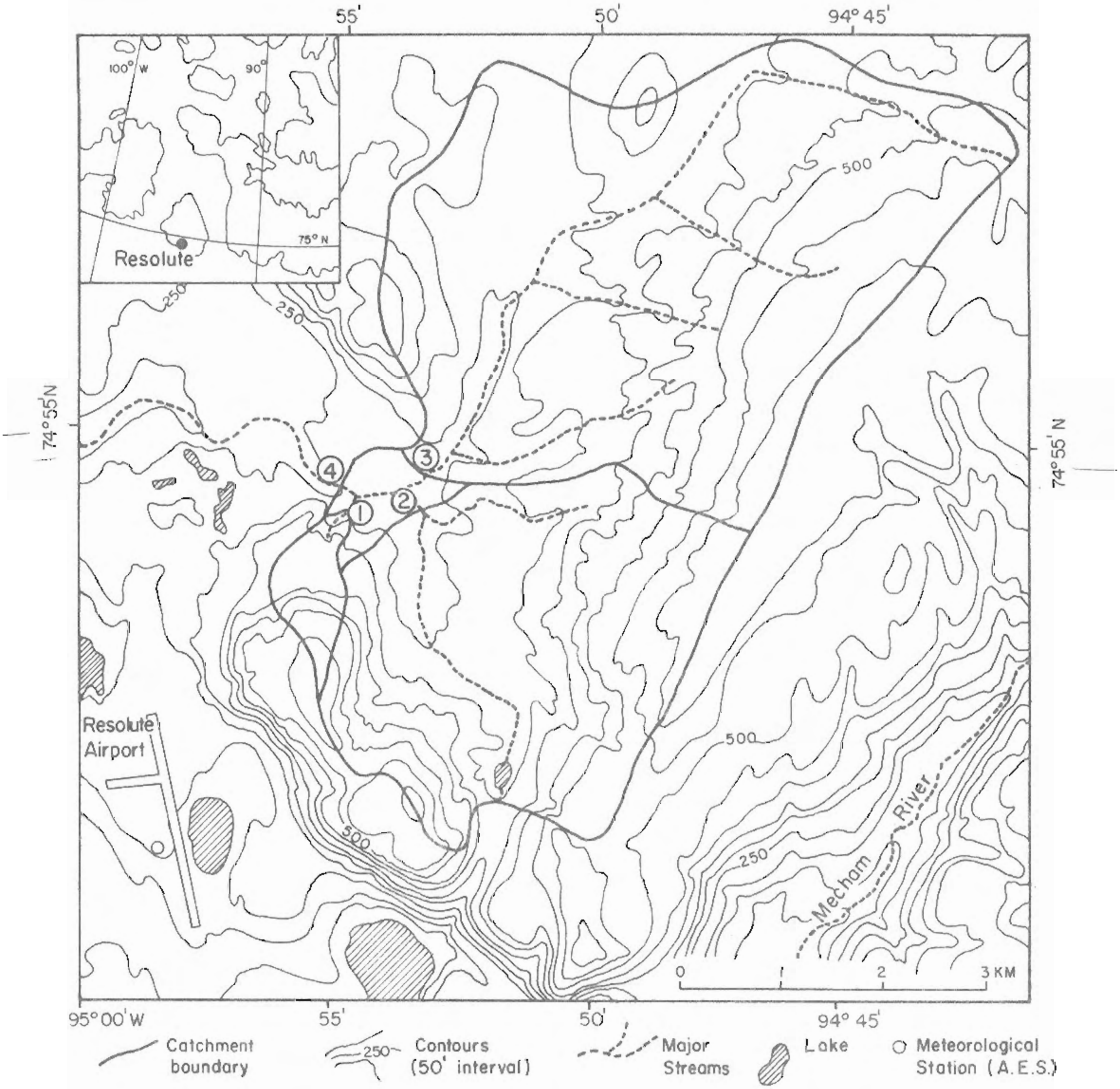

Fig. 3 Topography of the study area. Areas of various basins are: (1) 0.5 km^2, (2) 10 km^2, (3) 21 km^2, (4) 33 km^2.

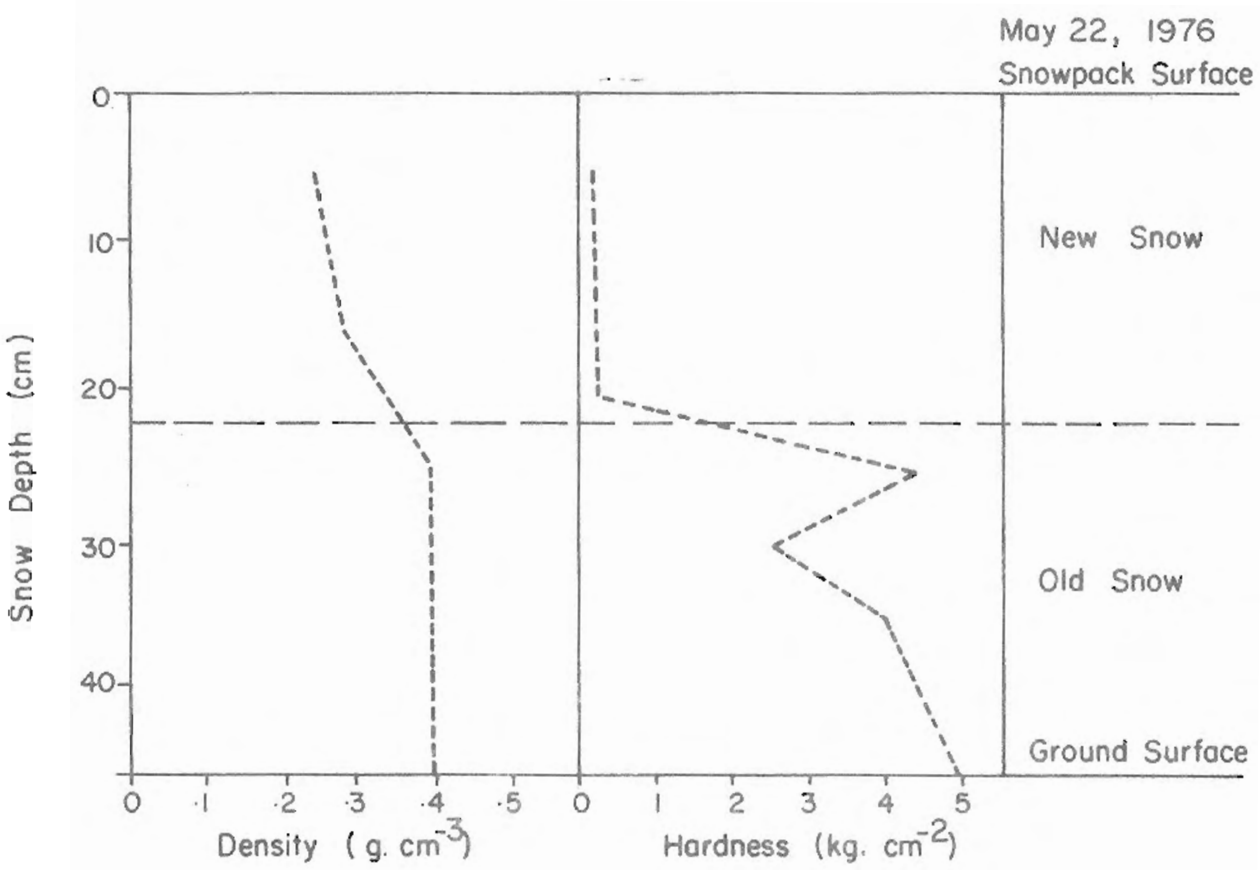

Fig. 4 New snow falling during the snow survey period can be easily distinguished from the winter snow by their differences in snow hardness and in density.

the absence of melting in winter, the snow storage determined by the survey represents total snowfall since September 1, 1975 (the ground was bare on August 31, 1975).

TERRAIN UNITS

Six major terrain types were found to possess distinctive snow density and depth values. These terrain types include

(1) Hilltops: normally rounded or rolling areas which are fairly exposed and which occur as ridge crests or hilltops grading into valleys or long slopes.
(2) High flats: extensive, exposed areas which correspond with the plateaus in the basins.
(3) Low flats: lowlying flat areas which are often less exposed than the high flats due to the presence of low hills or valley walls nearby.
(4) Gullies: troughs with a depth of less than 4 m, being usually broader than they are deep.
(5) Valleys: troughs which are larger than the gullies.
(6) Long slopes: slopes which dip to one general direction and which are sufficiently extensive both in length and in width.

Figure 5 is a terrain map of the study area showing a subdivision of the basins into various terrain units. The percentage distribution of each terrain type in the basins is summarized in figure 6.

SNOW DEPTH AND DENSITY

In a small basin in Axel Heiberg Island, Young (1969) observed extreme spatial variability in snow depth, but such variations could be related to various measures of the land surface geometry. Topographically, the Axel Heiberg basin is more rugged than the study area near Resolute, though a detailed snow survey of the smallest basin (area 0.5 km^2) revealed extreme range of snow depth occurring within short distances: from bare hilltops to a completely snowfilled valley with snow depth exceeding 2.5 m (Fig. 7). The variability of snow depth within each terrain unit depends on the terrain type. Hilltops and flat areas, for instance, showed a lesser degree of variability (Fig. 8) compared with the large variations in snow depth across river valleys (Fig. 9). On individual slopes, the presence of rock ledges and local depressions led to snow depth variations from one sample point to another, but this source of variation was eliminated when only the average depth from each transect across a terrain unit was considered. Using the averages from all the transects, figure 6 shows that hilltops had the thinnest snow cover, followed by the flats and the slopes, while the deepest packs occurred in the gullies and the valleys.

Figure 10 compares the distribution of snow density in various terrain types. Densities increased from the exposed hilltops to the more sheltered lowlying flats. In the gullies and the valleys, however, the snow was more compacted and the densities increased. For snow lying on slopes, the lowest densities occurred at the south-facing aspect while the highest occurred at the north-facing aspect. Intermediate densities occurred on east- and west-facing slopes.

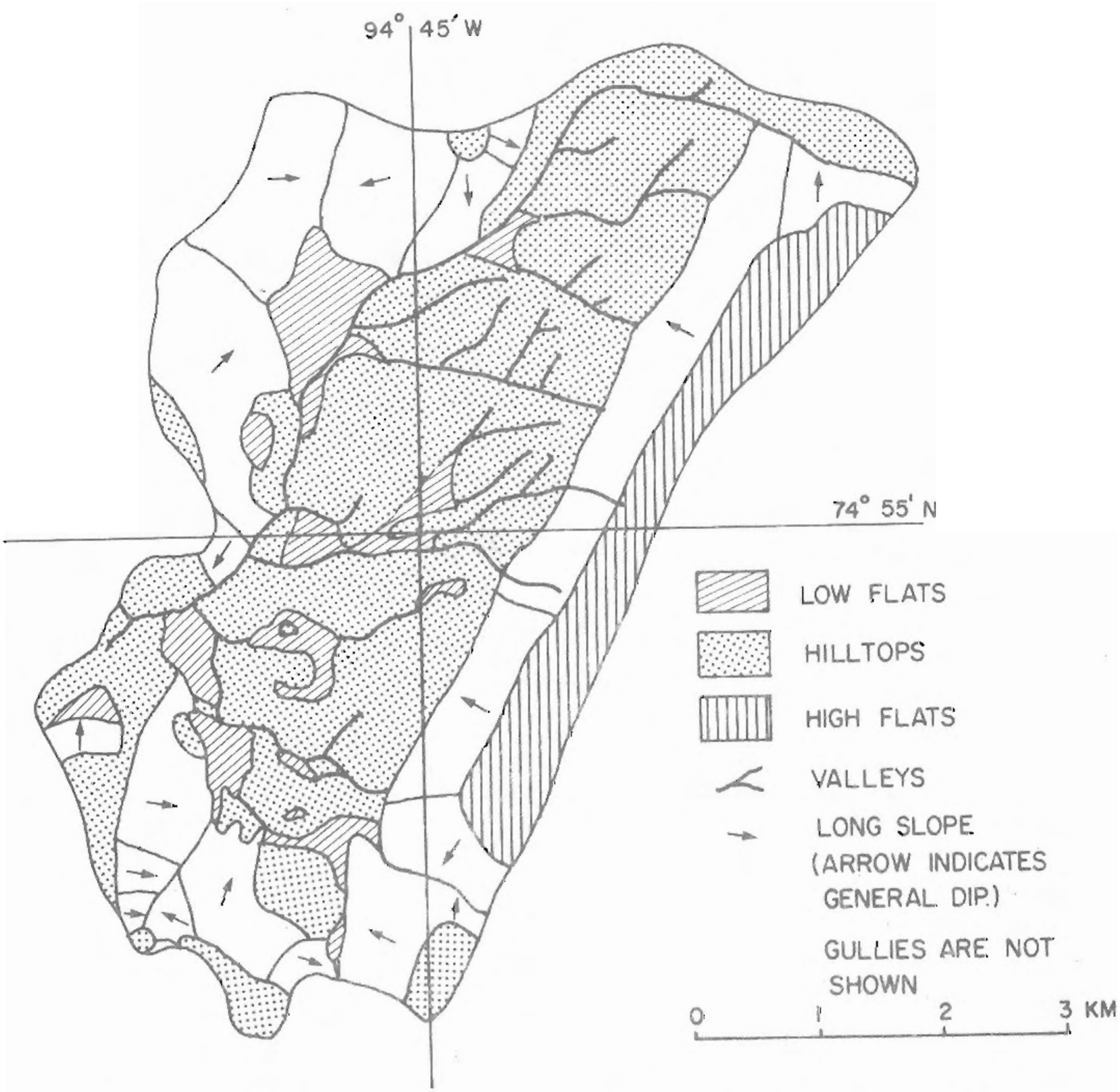

Fig. 5 Distribution of major terrain units in the study area. Gullies are omitted from the map.

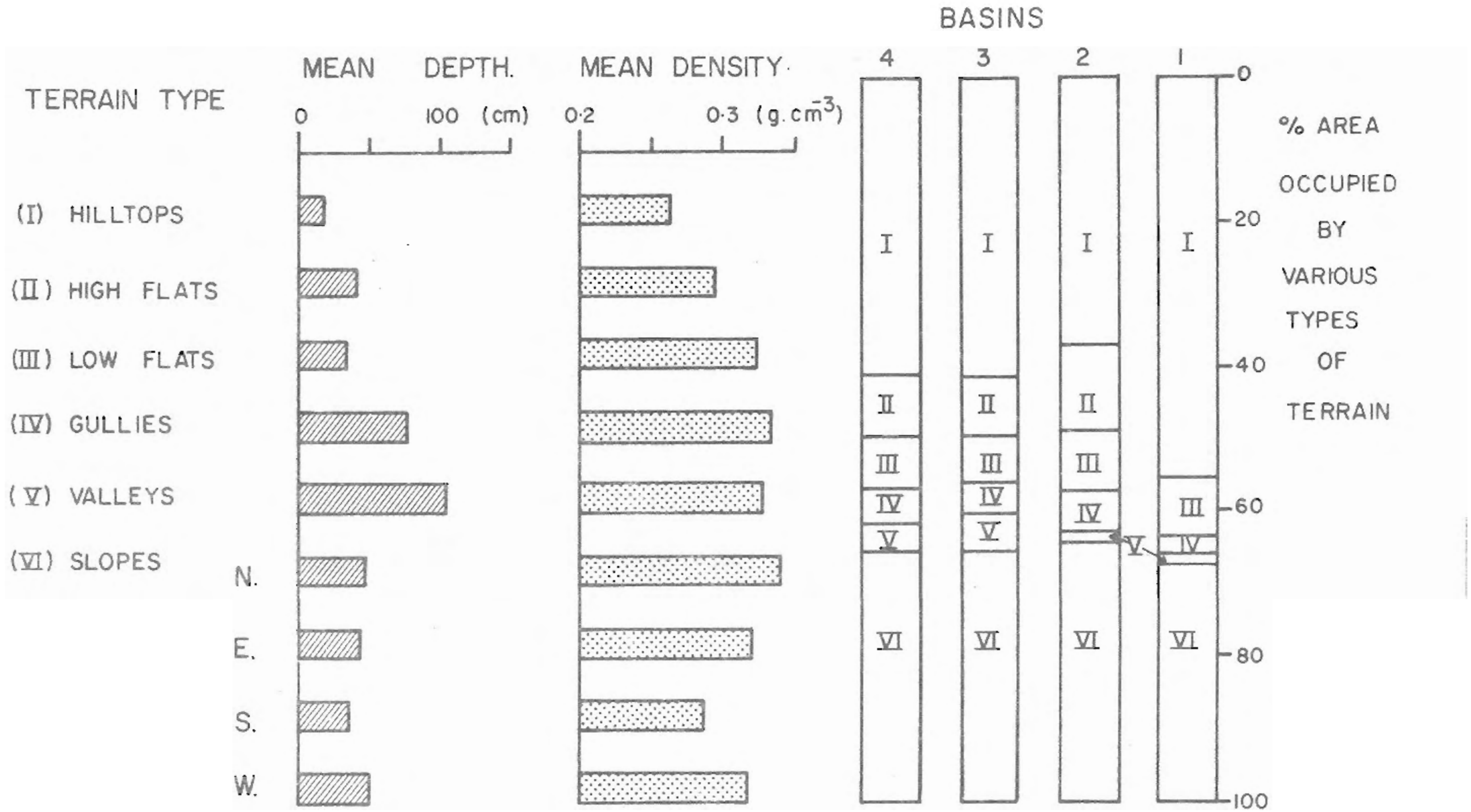

Fig. 6 Mean snow depth and density for various terrain types, and percentage distribution of various types of terrain in the study basins.

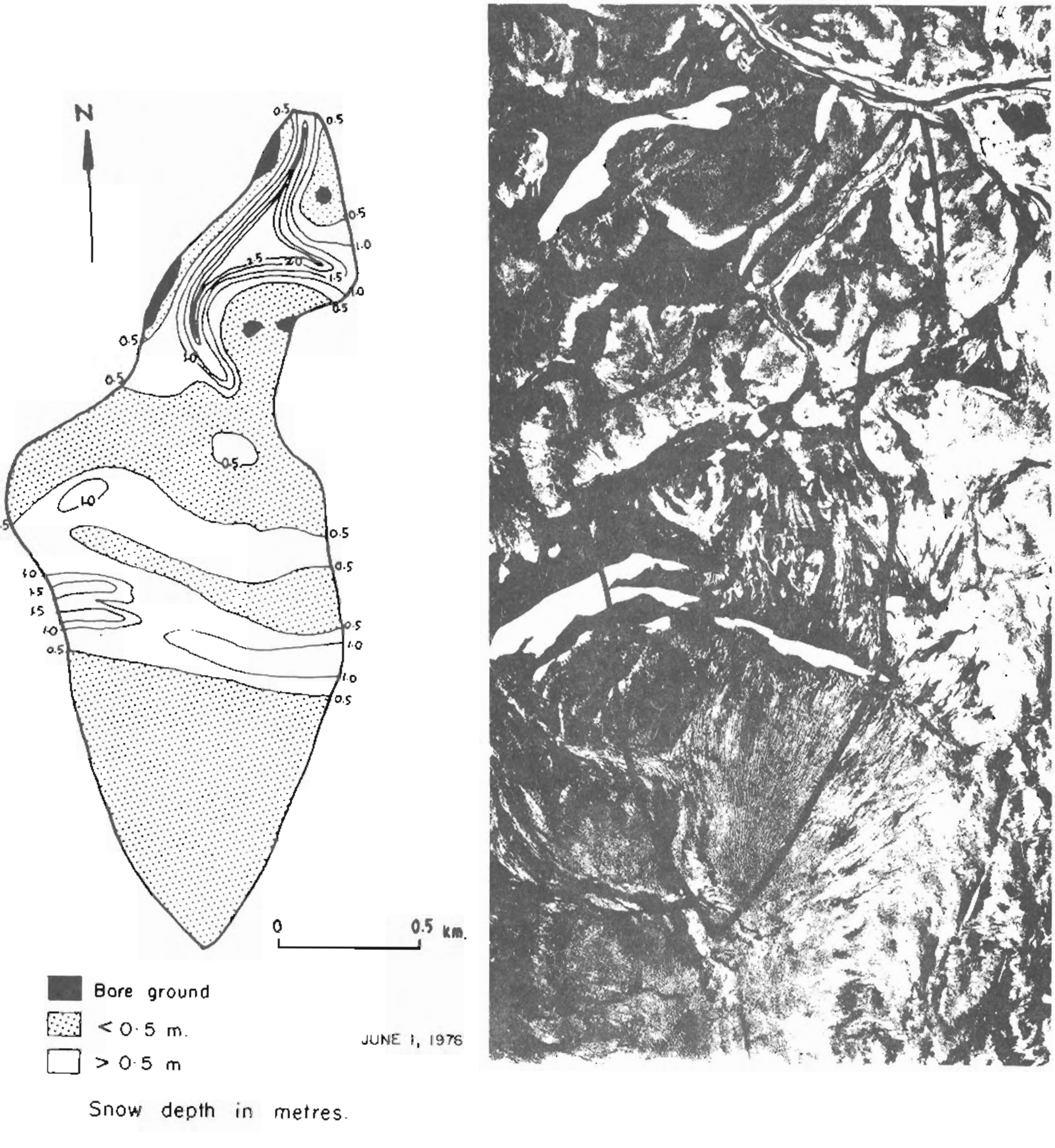

Fig. 7 Snow depth distribution in a small basin (area 0.5 km^2) on June 3, 1976. Depth is in metres. Bare areas are shown in black and areas with snow depth less than 0.5 m are stippled.

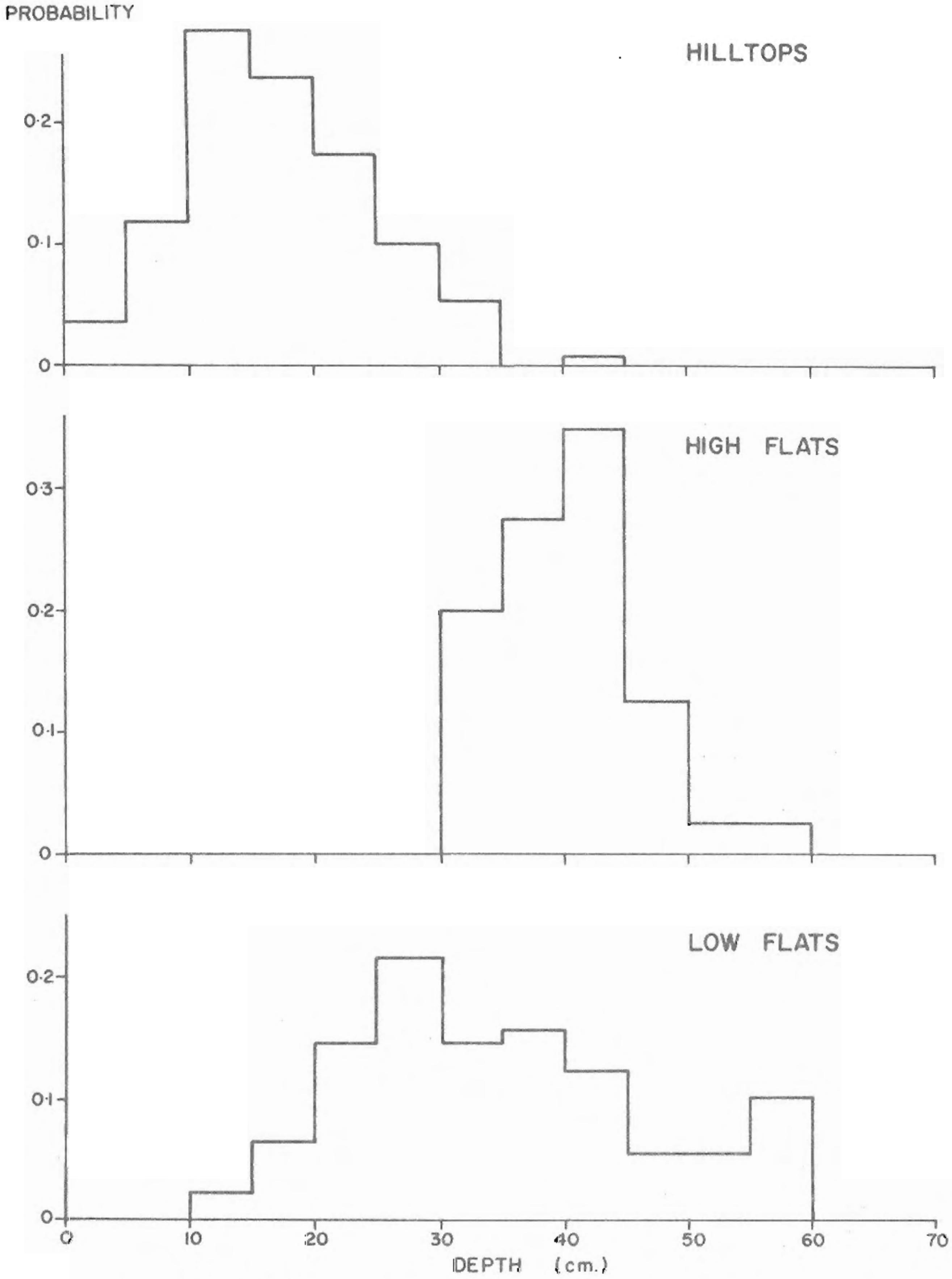

Fig. 8 Probability distributions of snow depths on hilltops, high and low flats.

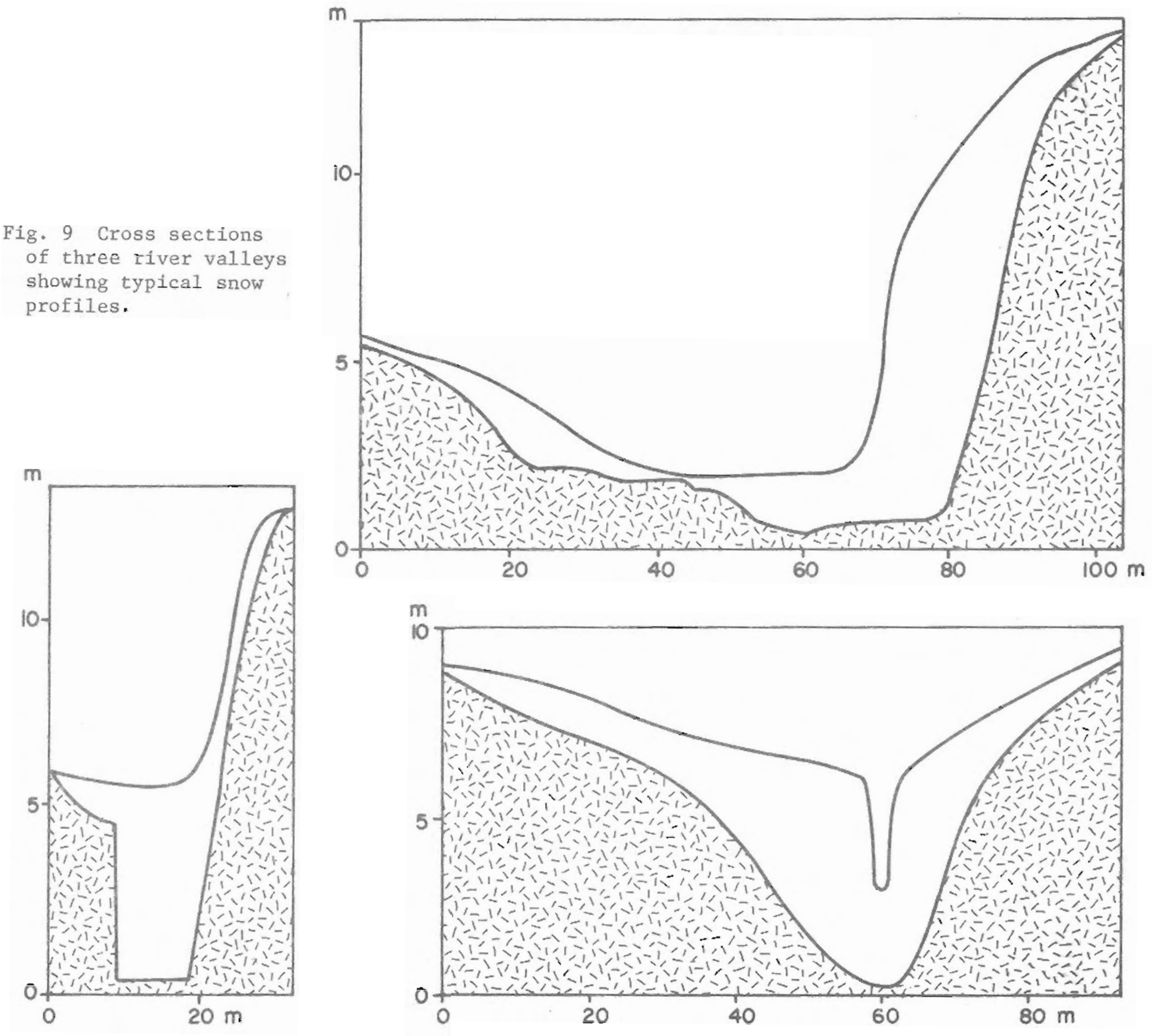

Fig. 9 Cross sections of three river valleys showing typical snow profiles.

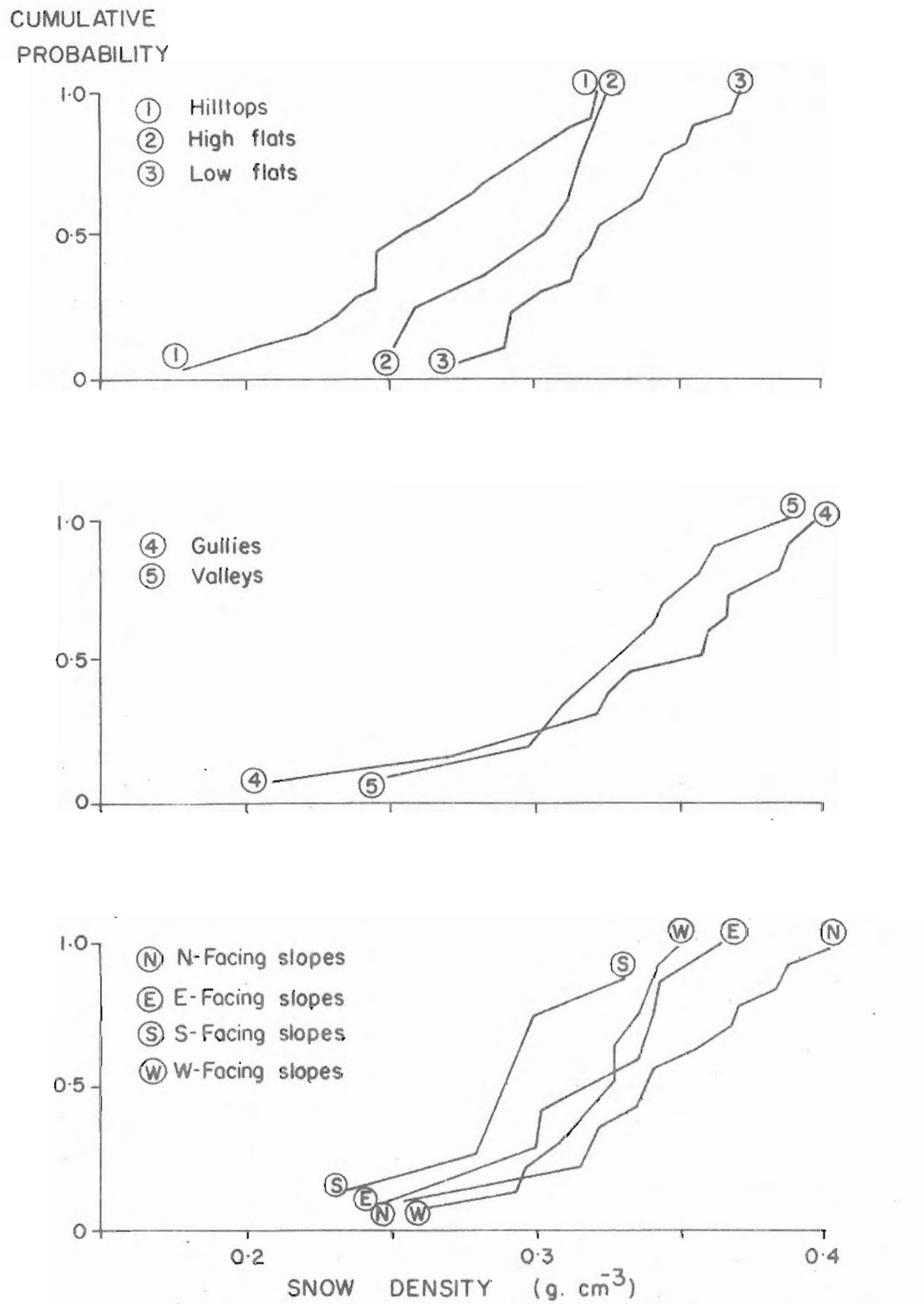

Fig. 10 Cumulative probably distributions of snow densities in various types of terrain.

BASIN SNOW STORAGES AND COMPARISON WITH METEOROLOGICAL STATION SNOWFALL

Snow storage in a basin is computed as

$$S = \sum_{i=1}^{m} \rho_i \, d_i \, a_i$$

where S is snow storage expressed in water equivalent unit
i is the i^{th} terrain type, with a total of m terrain types in the basin
ρ_i is mean snow density in terrain type i
d_i is mean depth in terrain type i
a_i is the area of terrain type i expressed as a fraction of total basin area

Using this equation, mean snow storage for the four basins are found to be 122 mm (basin 1), 109 mm (basin 2), 119 mm (basin 3) and 116 mm (basin 4). These represent the snow accumulated between September 1, 1975 and May 19, 1976.

During the same period, the Resolute meteorological station recorded 78 cm of cumulative snowfall which converts to 63 mm in water equivalent units (Fig. 11). A snow survey carried out by the Atmospheric Environment Service at the meteorological site in mid-May gave the value of 66 mm; therefore cumulative snowfall and the snow survey data at the meteorological site are comparable. Although cumulative snowfall was higher than the 10-year average for the station reported by Longley (1960), snow depth at the station remained similar to the long-termed average, and this reinforces Longley's observation of a snowpack near Resolute which built up to a characteristic depth in early winter, but remained little changed until the melt season.

A comparison of the meteorological site record with the snow storage data for the four basins indicates that the station record grossly underestimates basin storage, the latter approaching a magnitude twice as large as the station record. This confirms the danger of transposing snowfall data in the Arctic.

The main problem with data transfer is that basin snow storage is an integration of snow conditions over the entire basin which consists of different terrain types while the meteorological station data is only representative of an exposed flat-lying terrain with a cluster of low buildings. To obtain accurate information on winter snow storage in a High Arctic basin, it is therefore necessary to identify various terrain units within the basin. Then a detailed survey will suffice to obtain reliable mean snow densities and depths for each terrain type.

CONCLUSION

A detailed snow survey carried out at the end of the 1975-76 winter

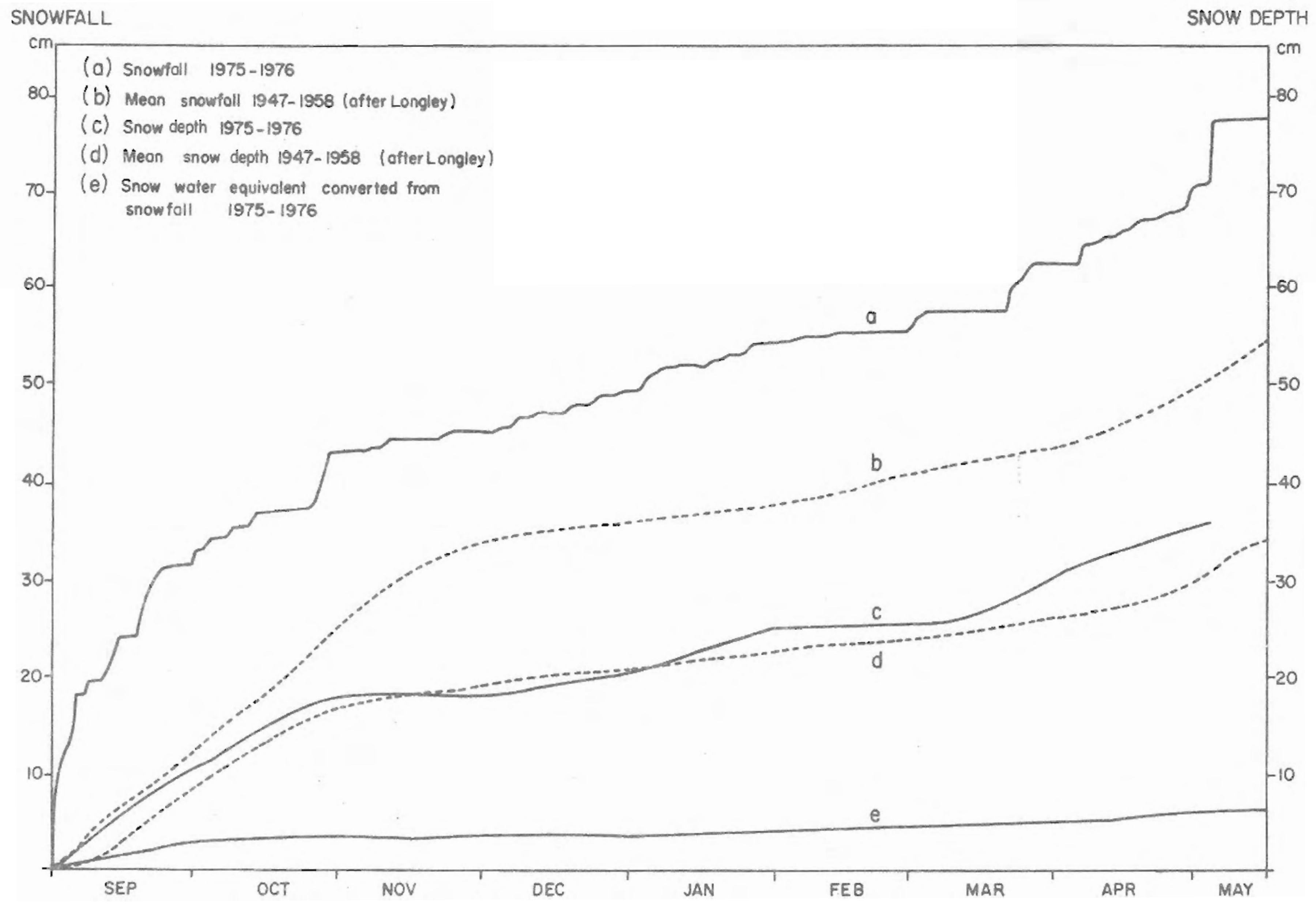

Fig. 11 A comparison of 1975-76 snowfall and snow depth recorded at Resolute meteorological station with the ten-year station mean.

in four small High Arctic basins shows that snowfall at a nearby meteorological station was only half as much as the basin snow storage, thus confirming the danger of snowfall data transfer in the Arctic areas. It was also found that various types of terrain within the basins possessed distinctive characteristic snow depths and densities. This finding, together with the fact that Arctic snowpack undergoes little melting until the end of winter, provides the possibility of basin snow storage determination using only one late winter snow survey to obtain representative snow depths and densities for various terrain types.

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