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THE UNIVERSITY OF ALBERTA

SUMMER TEMPERATURE VARIATIONS IN A SMALL MOUNTAIN VALLEY IN WEST-CENTRAL ALBERTA

by

PAUL RODNEY OLSON

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

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ABSTRACT

Paired observations of maximum and minimum temperatures from ground-based screens and standard-level screens during the period 1 June to 30 September, 1979 from 14 stations in the Drystone Creek Valley, northeast of Jasper, Alberta, were used to investigate the nature and magnitude of the influences of elevation, slope, aspect, and vegetation on temperature in mountainous terrain. When appropriate, the contributions of large-scale processes to the total variations are removed by expressing temperatures as differences between network stations and the standard climatological station at Jasper Park East Gate. Observations at Jasper Park East Gate are compared also with those from the Town of Jasper.

The most significant environmental factors controlling daily maximum temperatures within the Drystone Valley are the density and dimensions of the tree cover. Vegetation masks the temperature variations that might otherwise be expected due to changes in aspect and elevation within the valley. The influence that aspect exerts on the observed maximum temperatures is the next most important climatic control.

The variations of minimum temperatures among the Drystone Valley stations are much less than those of the maxima. A relatively intense thermal belt exits at the mid-slope sites. Vegetation cover and aspect do not exhibit strong influences on night temperatures in comparison with the controls they have on daytime highs. Elevation is important in relation to height of the nighttime thermal belt. The factor that influences minimum temperatures the most is the specific topographic characteristics of each station site. The channeling of cool air drainage flows at night in the avalanche track and along the valley floor results in significantly lower temperatures at these locations.

Mean daily minimum temperatures are less at ground-level stations than at nearby co-located standard-height screens while mean daily maxima exhibit lapse or inversion conditions. Site characteristics account for the variability in the

maximum temperatures. Shortcomings in the control of the climate influencing factors between the sites under consideration, the small number of paired stations, and the inherent limitations of one data collection season preclude difinitive quantitative conclusions about these factors.

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CHAPTER 1: INTRODUCTION

1.1 Introduction

The climate of mountainous areas cannot be described solely in terms of macro- and meso-scale processes (Barry and Van Wie 1974). The effect of mountain topography is to create countless small-scale climates which differ in response to the effects of slope, aspect, elevation and vegetation cover (Geiger 1965, Thornthwaite 1954). Barry (1981) questions whether the present concept of a regional "mountain climate" has validity at all because local topographic variations give rise to such large contrasts in climate conditions.

Climatologists have not treated the study of mountain climate adequately, primarily because of the remoteness of most mountainous regions. Physical access is usually very difficult. This inhibits the installation and maintenance of climate stations. And, the nature of mountain terrain sets up such a variety of local weather conditions that any station is likely to be representative of only a limited range of sites (Barry 1981).

1.2 Value of Climate Information in Mountainous Areas

Concerns over natural resources, food, energy, and urbanization pose major challenges for applications of climate knowledge. Climate data and information are used in decision making, planning, design, policy setting, operational procedures and research involving disciplines other than meteorology. Forestry agencies and other land management services must consider climate because the distribution of many natural resources is determined by its vagaries. The control and use of prescribed burning in forests, as well as scheduling of planting, harvesting and the application of pesticides are among forestry related activities requiring climatological information. Resource managers utilize climate data for calculating such parameters as the carrying capacity for grazing animals or in determining water-yield relationships.

Climate of mountainous areas in western Alberta is of particular interest to the operation of national parks (Janz and Storr 1977). It is one of the most important factors in the management decision making process when planning for outdoor recreational facilities such as campgrounds, roads or ski areas (Thomas 1982). Comprehension of the ecology of the parks requires knowledge of climate in the mountains. Differences in climate between areas only a few centimeters apart are reflected by the distribution of certain plant species (Whittaker 1975). Lichens or mosses which are well adapted to life in shaded areas may be unable to survive on adjacent south-facing sides of rocks and trees.

Meteorologists divide orographic effects on atmospheric processes into micro-, meso-, synoptic- and planetary-scale perturbations. The interactions among these scales is now considered essential for understanding the physical processes involved with the barrier and thermal effects that mountainous areas have on climate (Reiter 1981). The significance attributed to the influence that these regions have on climate variability has recently lead to programs such as the Alpine Experiment (ALPEX) in Europe, the Atmosperic Studies in Complex Terrain (ASCOT) in United States and the joint American-Chinese Tibet-Rocky Mountain Experiment (TIRMEX). The general objectives of these studies are to determine the airflow and mass field over and around mountain complexes under various synoptic conditions (Kuettner 1982).

The benefits of a good climatological data base in the mountainous regions will be noticeable in the fields of severe weather prediction, short-range forecasting, weather modification, impact assessments of industrial development and the analysis of weather and climate anomalies. But, all scales of interaction between mountainous terrain and the atmosphere will have to be explored in detail to accomplish these long-range goals (Reiter 1981).

1.3 Background and Objectives of Study

It is desireable to locate meteorological stations at sites which are representative of their surrounding environment. The observations from a well selected station site on Alberta's prairies may be representative of the atmospheric conditions found in a radius of 40-80 km. But in mountainous terrain different climate regimes can exist within a very small area (Lester 1974, Yoshino 1975, Janz and Storr 1977). This is ultimately due to the unequal partitioning of energy as a result of varying topographic and vegetative characteristics (Geiger 1965).

The meteorological stations in the Cordilleran and Foothills regions of west-central Alberta are usually maintained by the Atmospheric Environment Service or by the Alberta Forest Service. The stations are located along valley bottom access corridors or on topographic rises where forest fire lookout towers are situated. But, the atmospheric observations from these stations might not be representative of the conditions at nearby sites (Barry 1981, Janz and Storr 1977). Care must be taken when identifying the values from these meteorological stations as being typical of the surrounding areas, especially if there are differences in aspect, slope angle, elevation or vegetation cover (Powell and MacIver 1978, MacHattie 1970).

Powell and MacIver (1978) suggested that emphasis should be placed on mapping climate phenomena in mountainous or hilly terrain in order to quantitatively determine the variations. To date there have been few dense station networks in the mountainous areas of western Canada, even though they are required for measurements of small-scale climate variability (Meeres 1978). Five years of climate data are desired for these studies but a shorter period could be used to ascertain some of the relationships that exist among topography, vegetation and climate (Janz and Storr 1977).

A study of the influences of topography and vegetative cover on climate in one location should be representative of the conditions over a whole region if it has similar topographic features (Powell 1970). And, if the synoptic meteorological patterns are similar, then small-scale climate phenomena will be correlative (Yoshino 1975).

1.3.1 Purpose of Study

Proven techniques for determining the optimum placement of climate stations are available for regions with homogeneous features, but not for areas with complex terrain. The effects of topography on atmospheric variables must be understood to adapt these techniques to mountainous terrain (McCutchan *et al.* 1981).

The purpose of this study was to measure and delineate local climate differences in an area of diverse topography and vegetation cover, and to compare the results with observations measured in a nearby government-agency climate station.

CHAPTER 2: THE STUDY AREA AND ITS ENVIRONMENT

2.1 Introduction

The study area was the valley drained by the Drystone Creek. This valley has an array of contrasting aspects, elevations and vegetation covers. Slope angles on the opposing valley sides are similar.

Jasper Park East Gate climatological station is a short distance to the west and downstream from the study site. It is near the Drystone Creek but in the larger, main valley of the Athabasca River.

2.2 Location and Physiography of the Study Area

The Drystone Creek drainage basin is located at 117°46' W longitude and 53°14' N latitude. It is 47 km northwest of Jasper, Alberta and borders the eastern edge of Jasper National Park (Figure 1).

The basin is approximately 6 km long, northwest to southeast and 4 km wide, northeast to southwest (Figure 2). Drystone Creek exits this tributary valley at an elevation of about 1140 meters above sea level (a.s.l.) (Plate 1). Two kilometers to the west, in the main valley, the creek flows into a widening of the Athabasaca River, called Brûlé Lake, at an elevation of 985 m a.s.l. (Plate 2). The Fiddle Range forms the southwest boundary of the Drystone Creek valley. Roche à Perdrix is in this range and its summit is 2134 m a.s.l. (Plate 3). Folding Mountain, at 2117 m. a.s.l., and its ridge to the northwest form the northeast, and southeast boundaries (Plate 4).

2.3 Bedrock and Surficial Geology

The study area is in the Front Ranges of the Rocky Mountain Division of the Western Cordillera physiographic region (Atlas of Alberta 1965). The ranges are composed of intensly folded and faulted sedimentary strata. Roche à Perdrix consists of Upper Devonian limestone strata from the Perdrix Formation

Figure 1: Location of study area.

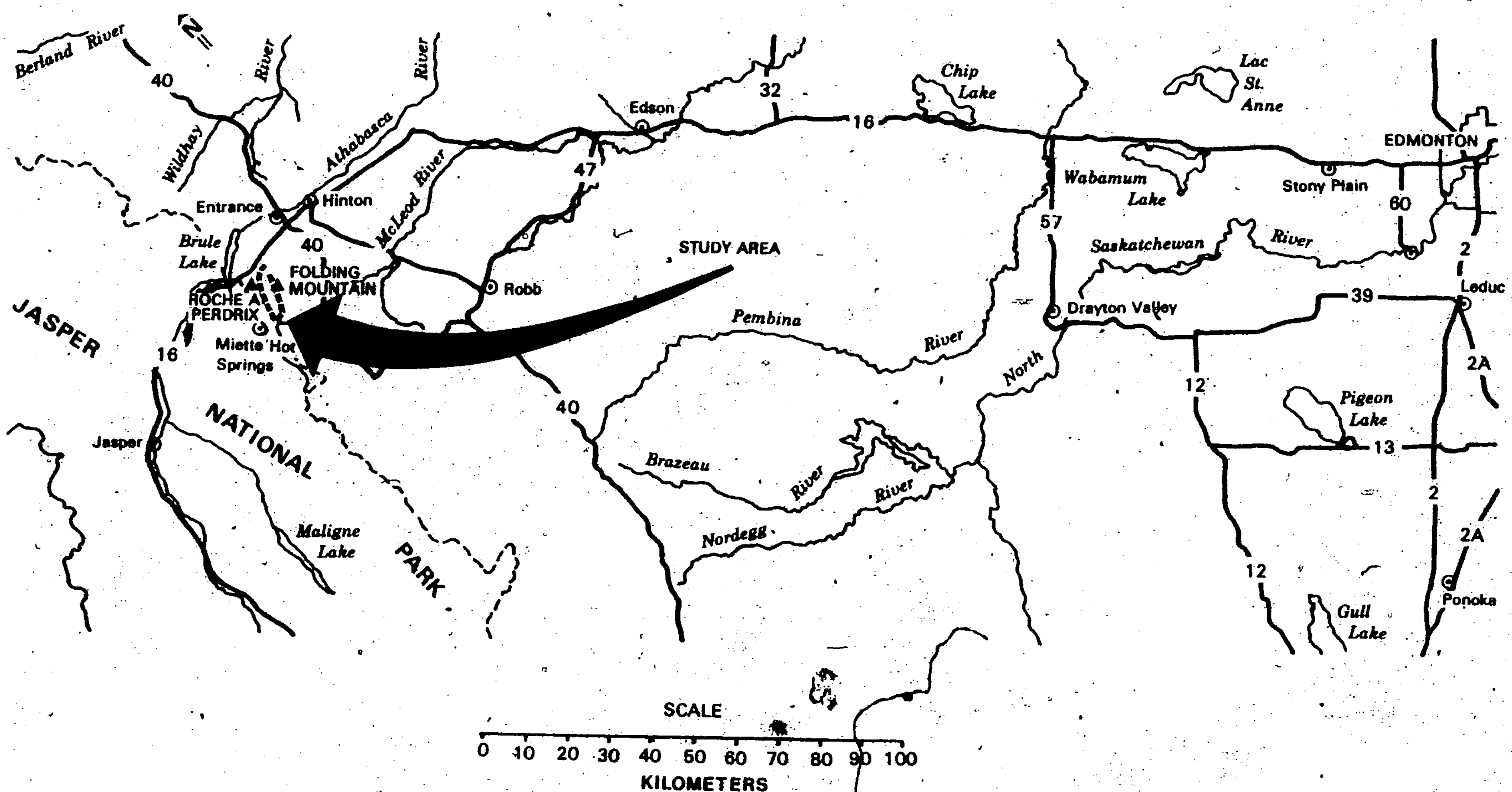


Figure 2: Physiography of the Drystone Creek drainage basin.

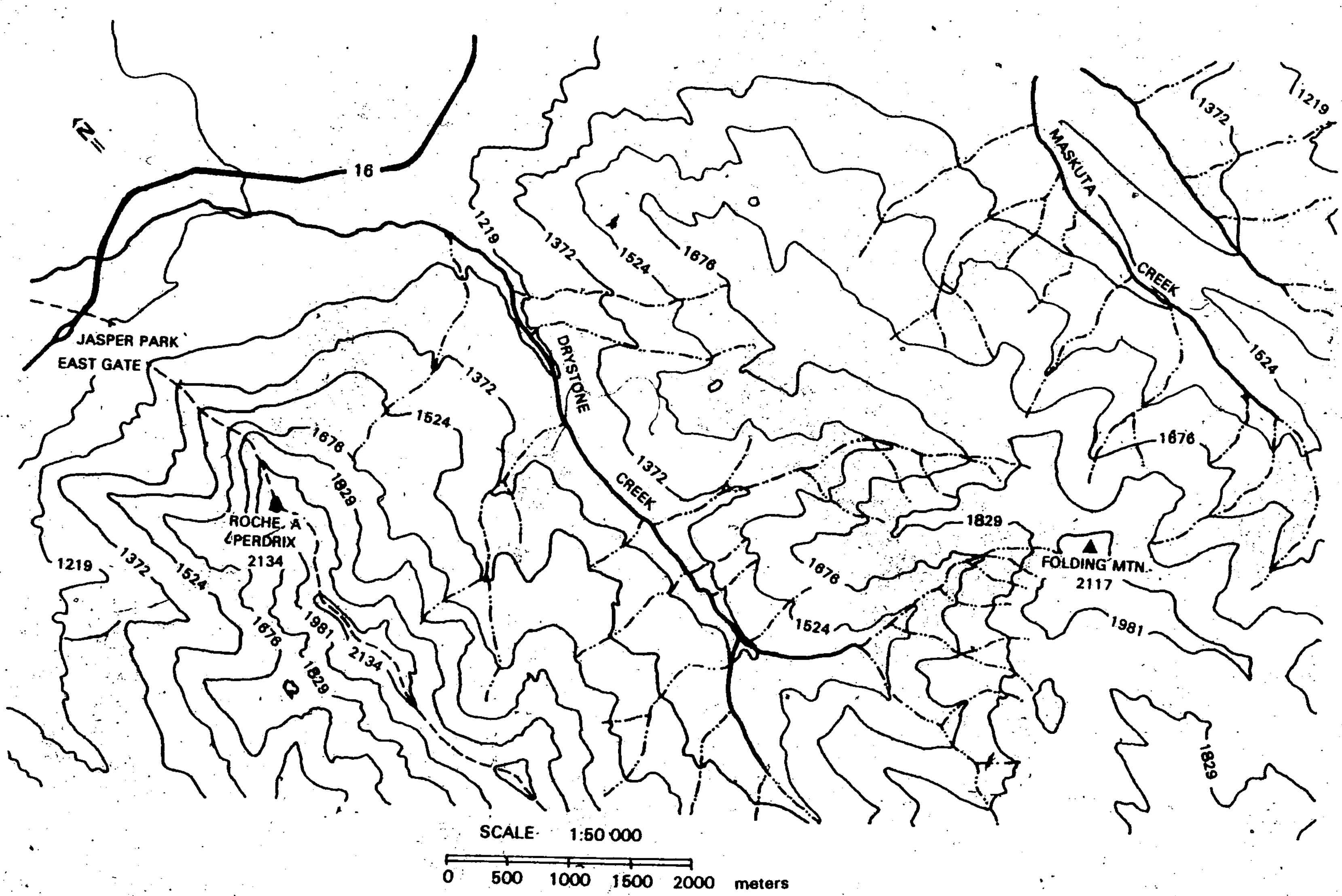


Plate 1: Foot of Drystone Creek Valley. View is towards the southeast with Roche à Perdrix on the right and Folding Mountain on the left.

Plate 2: The Athabasca River Valley. Drystone Creek is bottom left center and Brûlé Lake is in the background.

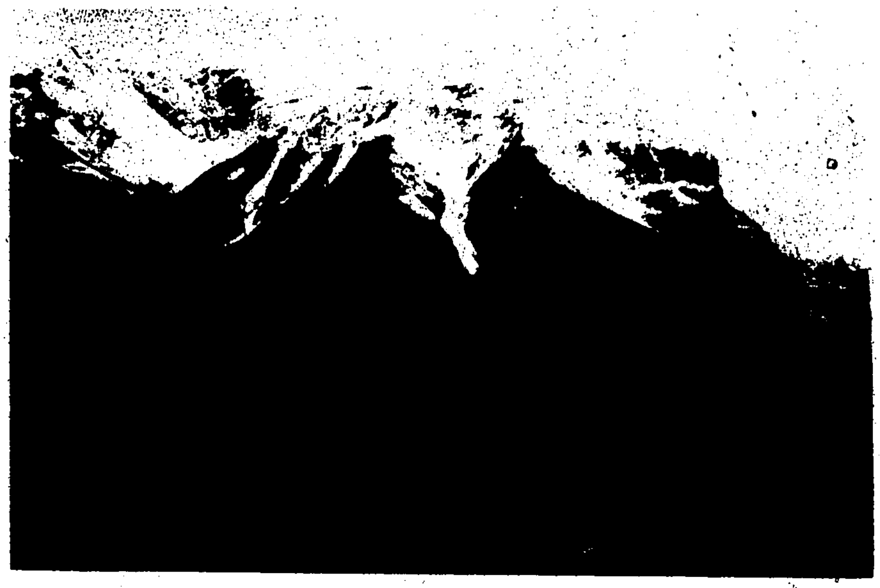


Plate 3: Roche à Perdrix from Folding Mountain Ridge. Avalanche track is in the center.

Plate 4: Drystone Creek Valley with Folding Mountain in the background. View from summit of Roche à Perdrix looking towards the east.

(Irish 1965). Folding Mountain is composed of shales, siltstones and sandstones of Jurassic epoch (Irish 1965, Atlas of Alberta 1969).

The surficial deposits of the Hinton–Jasper region are a complex and diverse assemblage of sediments from both Cordilleran and Laurentide ice sheets. In the Drystone Valley local alpine glaciers deposited Drystone Creek Till over previously lain down stratigraphic units (Roed 1975). The deposition of this till in the study area represents the most recent glacial event in the Front Ranges.

Deposits of postglacial aeolian materials mantle the study area. They are derived from the shores of Brûlé Lake and the floodplain of the Athabasca River in Jasper National Park. They have been transported by strong winds which periodically funnel down the Athabasca River Valley (Dumanski *et al.* 1972).

2.4 Soils

Dumanski *et al.* (1972) have mapped the soils of this region. A heterogeneous complex of soils are found along drainage channels. They are termed Alluvium and are usually developed on Recent sand or gravel alluvial deposits. These soils are highly variable in chemical and physical characteristics.

Above the floodplain are the soils of the Hinton Association. They are developed on calcareous aeolian materials and are distinguished by the presence of carbonates in all soil horizons. They consist of fine and very fine sand. This association thins with increased elevation above the Athabasca River Valley.

At even higher elevations are the Robb and Muskuta Associations, respectively. They are developed on parent materials of Cordilleran origin that are mixtures of till, colluvium and bedrock. The steepness of the topography and the processes of downslope mass wastage strongly influence their genesis.

2.5 Vegetation

The study area lies within the Boreal–Cordilleran phytographic region described by Moss (1955). Rowe (1972) has placed the lower elevations of the study area in the Montane Forest Region and the upper areas in the Subalpine Forest Region.

The area is dominated by white spruce (*Picea glauca*) x engelmann spruce (*P. engelmanni*) hybrid associations. Other conifers present include lodgepole pine (*Pinus contorta*), Douglas–fir (*Psuedotsuga menziesii*) and sub–alpine fir (*Abies balsamia*). Balsam poplar (*Populus balsamifera*) and trembling aspen (*P. tremuloides*) can be found in mixed as well as relatively pure stands (Redgate 1978).

Stelfox *et al.* (1976) indicated that the understory closely resembles the shrub–herb faciation described by Moss (1953). The small tree and shrub strata are highly variable and include *Salix* spp., *Cornus stolonifera*, *Lonicera involucrata*, *Viburnum edule*, and *Vaccinium* spp. The willows (*Salix* spp.) and alders (*Alnus tenuifolia*, *A. crispa*) dominate the more moist sites.

The herb strata is rich in species but is quite variable. It is characterized by *Linnaea borealis*, *Cornus canadensis*, *Equisetum arvense*, *E. scirpoides*, *Mitella nuda*, *Petasites palmatus*, *Pyrola* spp., *Actaea rubra* and *Lycopodium annotinum*. There is a rich, deep floor carpet of feather mosses, especially *Hylocomiam splendens*, *Ptilium crista-castrensis* and *Calliergaonella schreberi*, with scattered lichens, mostly *Peltigera aphthosa* (Moss 1953).

2.6 Climate of West–central Alberta

The stations with the longest periods of record in the region are operated by the Atmospheric Environment Service at Entrance and Jasper (Figure 1). The Alberta Forest Service maintains a network of summer fire–weather stations in the area. Generally, the summers are short and cool with occasional hot spells, while winters are long with occasional cold spells.

The climate of west-central Alberta has been classified according to Köppen's system using data from the 1921-50 and 1931-60 periods (Atlas of Canada 1957, Longley 1970, Powell 1978). The lower elevational areas have been placed in the sub-arctic or cold "snowy-forest" (Dfc) climate type. The upper regions fall into the polar tundra (ET) regime.

Temperature data from the 1951-80 normals for Entrance, Jasper, and Jasper Park East Gate are presented in Figure 3. In terms of temperature the climate regime of Jasper is not as continental as it is at Entrance. This is determined by the ranges of means and extremes of temperature at Jasper compared to those at Entrance. Janz and Storr (1977) attribute this to Jasper, the more westerly station, being closer to the moderating effects of the Pacific Ocean. Also, the Front Ranges are a barrier to the westward movement of cold arctic air masses.

Powell and MacIver (1976) have compiled maps of the 1961-70 May to September mean seasonal temperature and precipitation for west-central Alberta. Their analysis is based on mean daily temperature, monthly precipitation, frequency of days above -2.2°C, water deficiency, elevation, latitude and longitude. The values used in their analysis were extracted from 20 stations in the region which had 6 or more years of climate data during the time period studied.

The warmer areas are found at the relatively low elevations of the Athabasca River Valley. The warmest station is Jasper, with a 12.2°C mean temperature for the May to September period. The coolest stations are at the higher elevations of the mountains and foothills. The mean seasonal temperatures (May to September) in these areas range from about 6 to 8°C (Figure 4). The geographic distributions of temperatures in the area during the individual summer months are similar to this general pattern (Powell and MacIver 1976). The mean May to September temperature for the 1961-70 period in the Drystone Creek basin was estimated from these maps to be approximately 7°C.

Figure 3: Temperatures for Jasper Park East Gate (J.P.E.G.), Entrance and Jasper.
Source: Atmospheric Environment Service (1982).

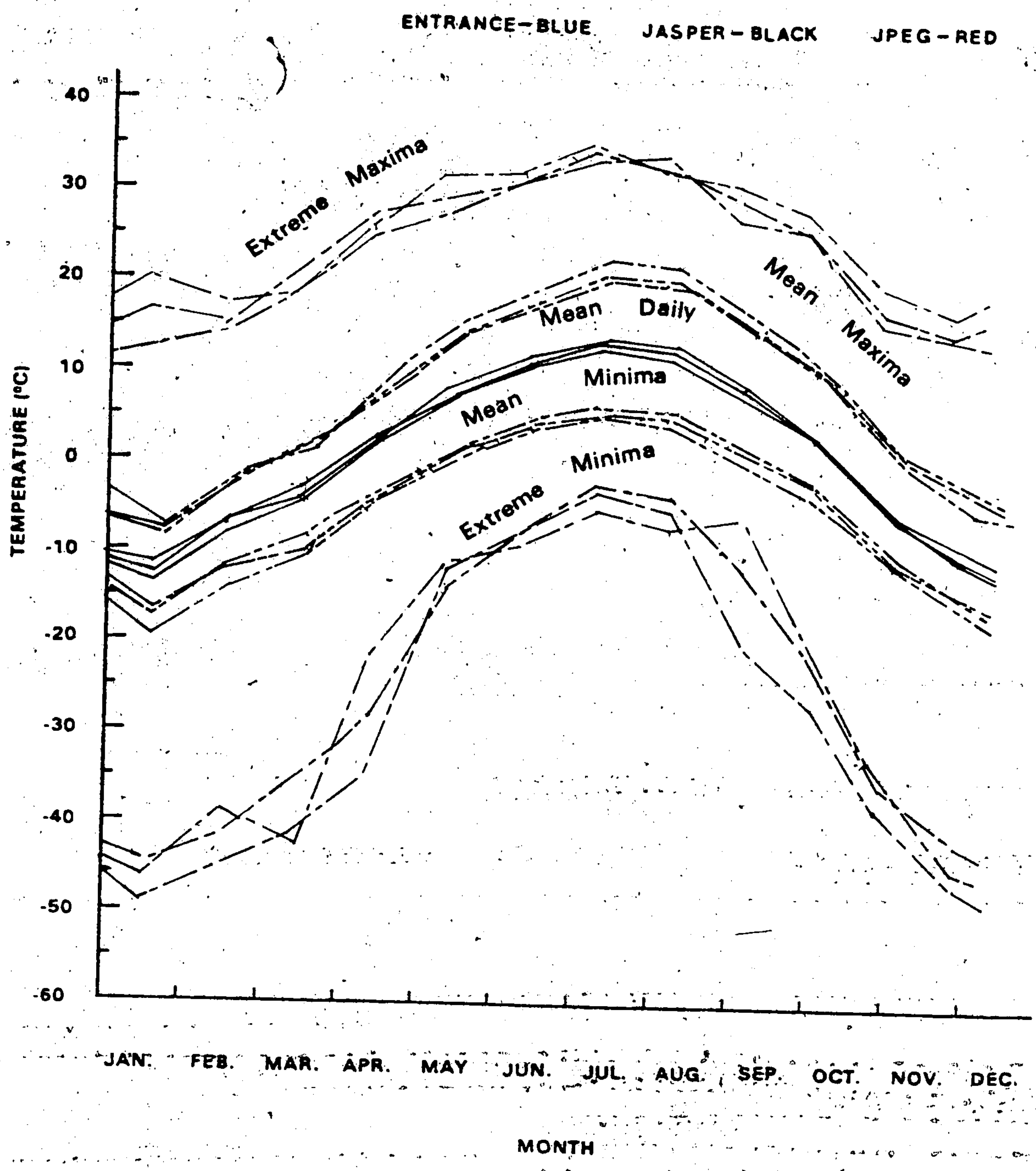
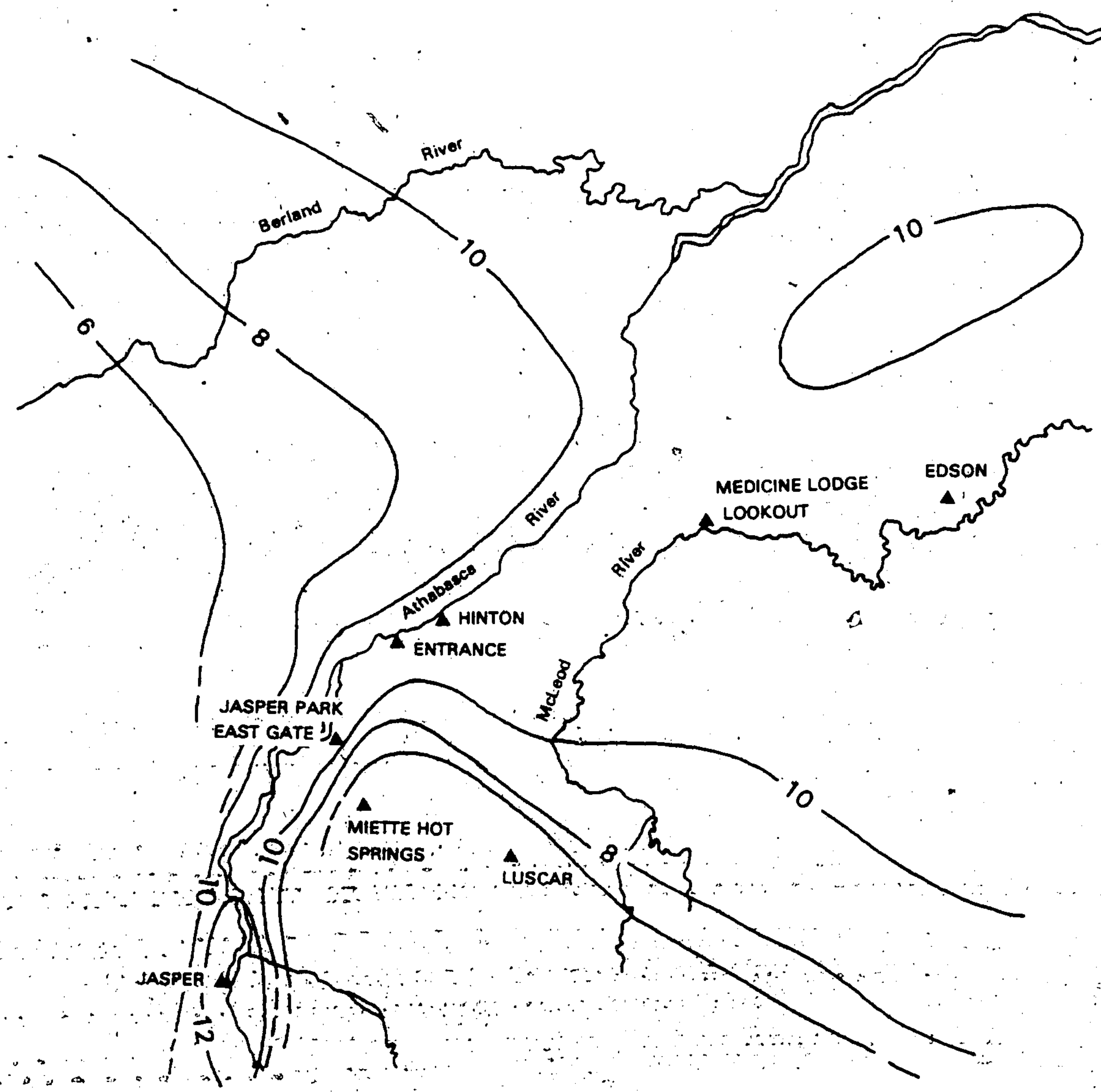


Figure 4: Mean May to September seasonal temperature (°C) 1961 - 1970.
Source: Powell and MacIver (1976).



The annual precipitation regimes for Entrance, Jasper, and Jasper Park East Gate are presented in Figure 5. The distribution of monthly precipitation reflects marine and continental climate components. These stations have a large summer maximum and a relatively large winter maximum also.

Many of the main valleys in Banff and Jasper must be considered semi-arid (Janz and Storr 1977). In particularly dry years, such as 1941, total annual precipitation in eastern parts of the parks has been as low as 175 mm. Jasper is the driest station in west-central Alberta, and it has the greatest variation of annual precipitation in the contiguous mountain parks. The range has been from 219 to 580 mm (Janz and Storr 1977). Jasper averages 409 mm annually while Entrance receives 513 mm. This 20% difference in annual totals is due to the rainshadow effect and is typical of the main valleys in the mountainous areas (Laycock 1978).

Often there is a well defined relationship between total annual precipitation and its frequency. But long-term records do not support this. Jasper averages 104 mm less than Entrance, yet Jasper has 33% more days per year with precipitation (A.E.S. 1981). Lake Louise gets nearly twice as much moisture as Jasper, but it too has fewer days with measureable precipitation than Jasper.

Powell and MacIver (1976) have mapped the distribution of the 1961-70 May to September seasonal precipitation for west-central Alberta (Figure 6). Interpolating from this map the Drystone Creek basin appears to have a mean precipitation of about 325 mm during this period.

Dumanski *et al.* (1972) conclude that the climate of west-central Alberta has been an "elusive" variable. It is a function of and reflects, the combined effects of a rise in elevation from east to west, differences in local relief and the rainshadow effect of the mountains.

Figure 5: Annual precipitation regimes at Jasper Park East Gate (J.P E G), Entrance, and Jasper.
Source: Atmospheric Environment Service (1982).

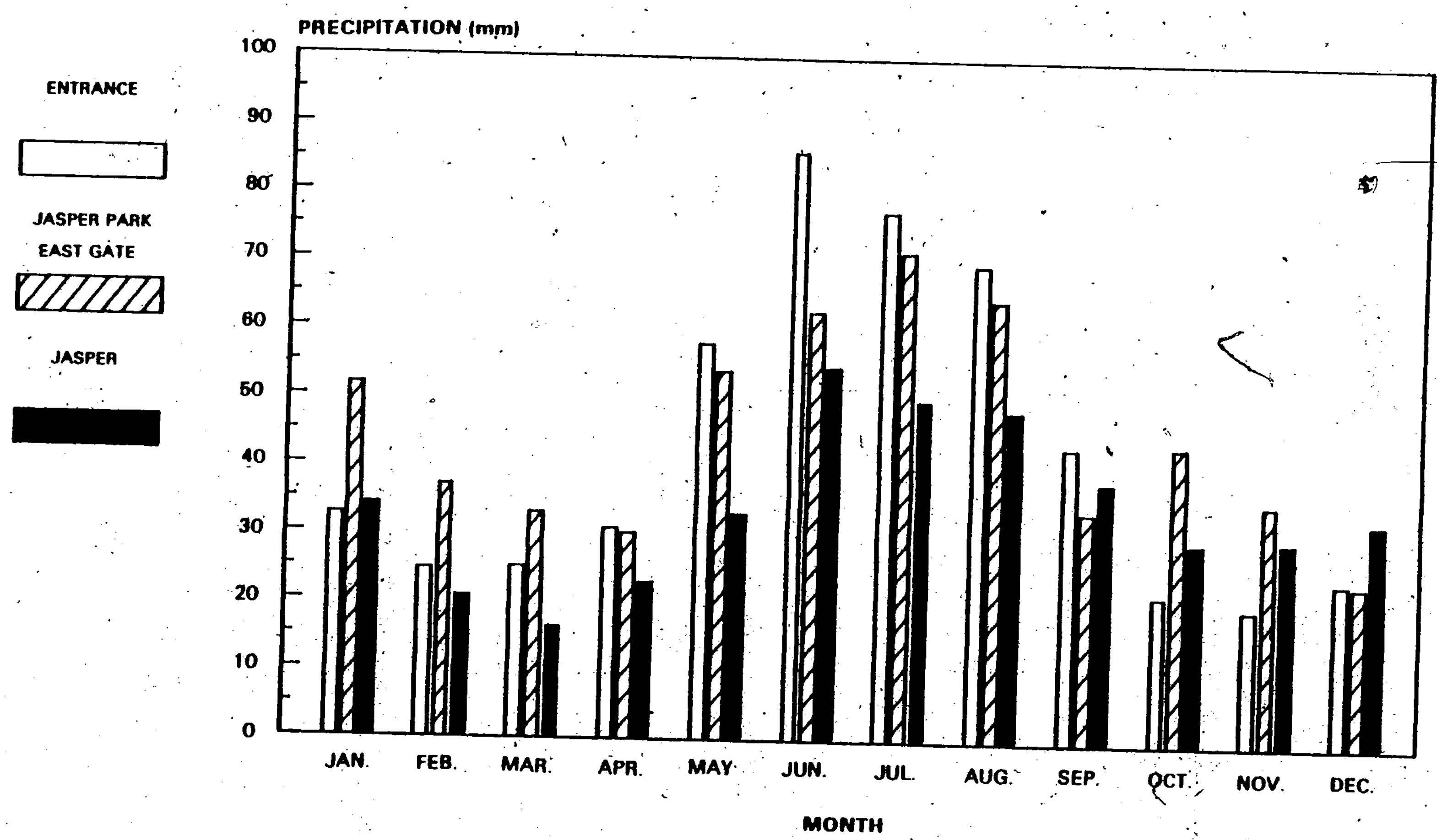
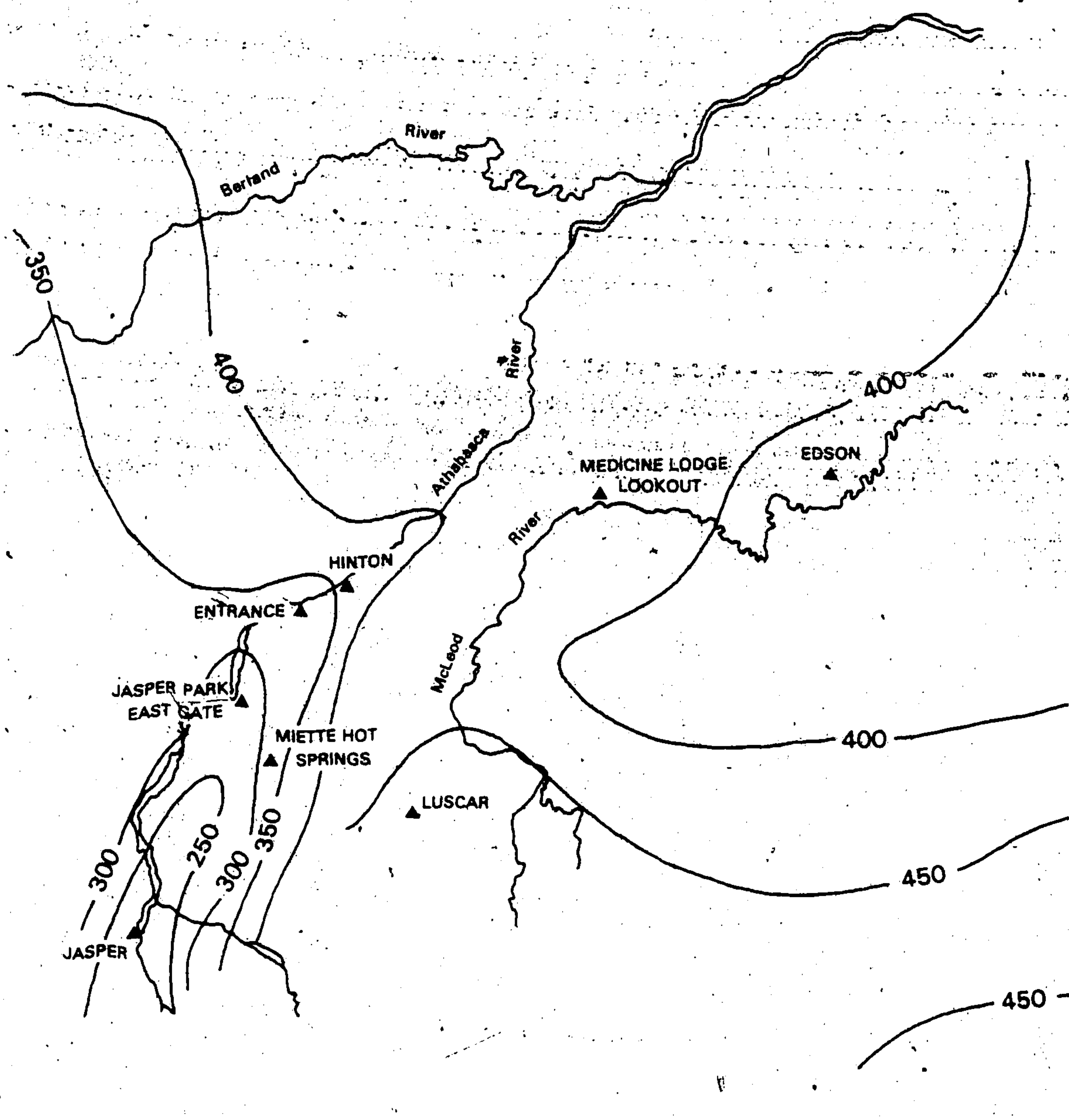


Figure 6: Mean May to September seasonal precipitation (mm) 1961 - 1970.
Source: Powell and MacIver (1976)



CHAPTER 3: INSTRUMENTATION AND PROCEDURES

3.1 The Climate Network

Climatological stations were set up in the Drystone Creek basin during the summers of 1978 and 1979. Stevenson screens and measuring devices were placed at each site. Their locations and the Jasper Park East Gate Station are indicated in Figure 7.

Ground reconnaissance, airphoto interpretation, and maps of forest cover and topography constituted the means for evaluation of the station locations. The criteria for the site selections were aspect, slope angle, elevation, and vegetation cover. Slope angles of the station sites along the sides of the valley were similar. Contrasting aspects, elevations, and vegetation covers, however, provided the opportunity for comparisons of local climate conditions.

Stevenson screens were placed on the ground surface (ground-level) at each location. Some of these sites also had screens at a height of 1.5 meters[1]. Yoshino (1975) has discussed the scales of climate measurement at these and other levels above the ground surface. He defines the scale of microclimate to encompass a horizontal distance of 10^{-2} to 10^{2} m and a height of 10^{-2} to 10^{1} m. Local climate, the next larger scale of investigation, is synonymous with topoclimate and forest climate. They have a horizontal distribution of 10^{-1} to 10^{3} m and a vertical dimension of 10^{1} to 10^{3} m. According to the definitions of Yoshino the present study incorporates measurements from within both microclimate and local climate dimensions.

3.1.1 The Climate Observation Stations

3.1.1.1 The Perdrix Stations

Five climate stations were installed on the northeast side of Roche à Perdrix (Plate 5 and Table 1). The angle of the slope in the area

[1] If the last letter of the station's name is an "M" then that station was at standard-height. If an "M" does not appear, then the station was at ground-level.

Figure 7: Location of climatological stations in Drystone Creek Basin and Jasper Park East Gate station.

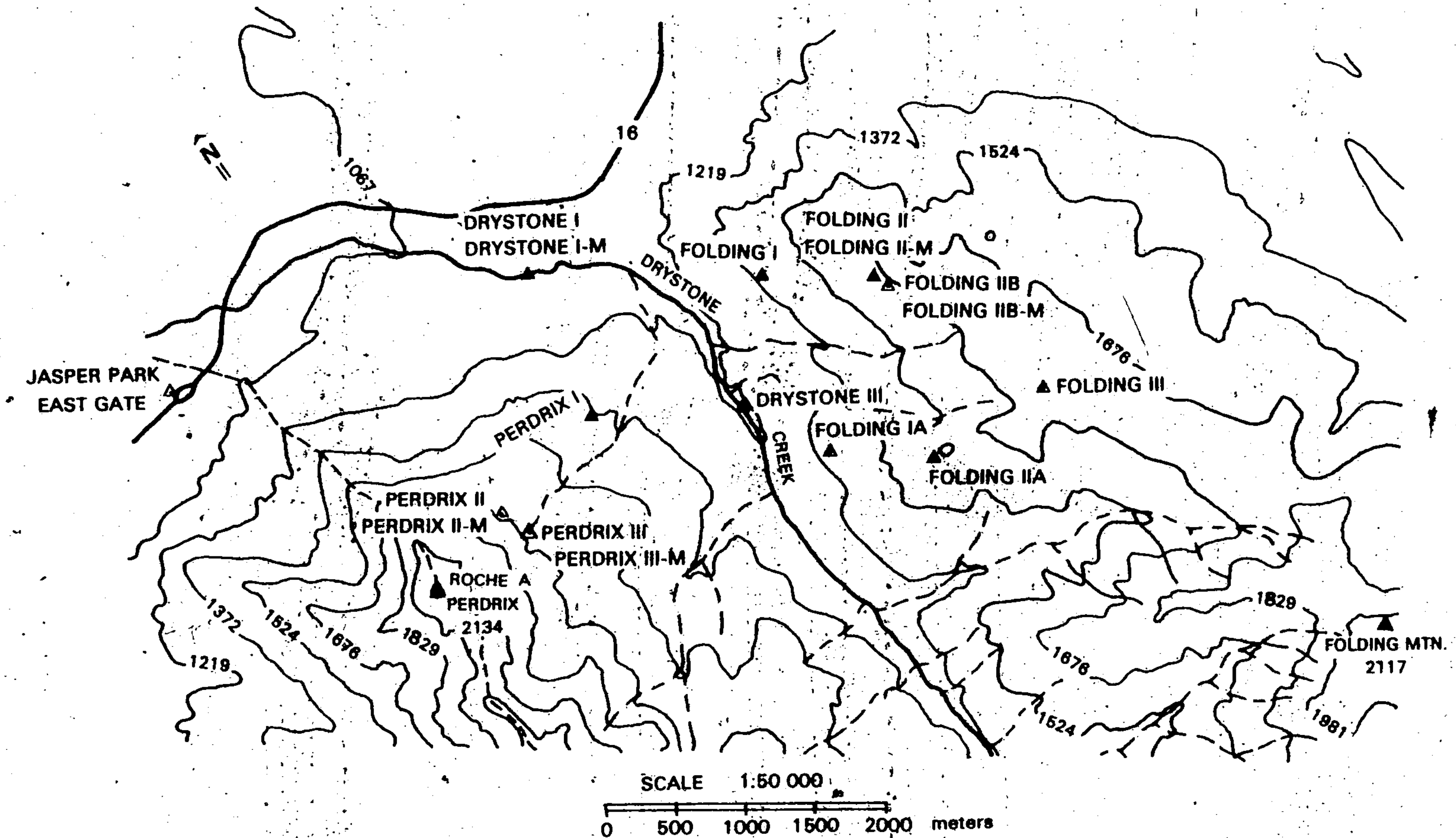


Plate 5: The lower slopes of Roche à Perdrix.

Table 1: Site characteristics of Drystone Creek network, Jasper Park East Gate, and Jasper stations.

Station Site	Elevation (1)	Aspect	Slope (2)	Relief (3)	Crown Cover (4)	Tree Heights (5)
Drystone I/I-M	1132	–	–	129	70	20
Drystone III	1239	–	–	236	75	15
Folding I	1372	SW	20	369	20	3
Folding IA	1390	SW	16	387	75	25
Folding II/II-M	1598	SW	26	595	15	3
Folding IIA	1603	SW	30	600	70	20
Folding IIB/IIB-M	1598	SW	25	595	75	12
Folding III	1770	SW	12	767	70	10
Perdrix I	1352	NE	14	349	80	25
Perdrix II/II-M	1594	NE	16	594	70	11
Perdrix III/III-M	1593	NE	18	590	15	2
Jasper Park East Gate	1003	–	–	–	20	6
Jasper	1061	–	–	58	–	–

(1) Meters above sea level.
(2) Degrees of slope.
(3) Meters of elevation above Jasper Park East Gate station
(4) Estimated percent crown cover.
(5) Mean heights of the tree stratum.

where the Perdrix stations were located was approximately 20°. Near the 1595 m a.s.l. contour there were two sites. Each had ground-level and standard-height screens. Perdrix II and Perdrix II-M were situated within a forest covering of spruce and fir (Plate 6). Perdrix III and Perdrix III-M were approximately 200 m to the south in an avalanche track (Plates 3 and 7). The vegetation cover in the avalanche chute consists of a disturbed assemblage of grasses, shrubs and small trees which had survived repeated snow slides (Plate 8).

Above these two locations the angle of slope increased. The bare limestone face of Roche à Perdrix was approximately 300 m higher than the station sites.

Perdrix I was halfway between the valley bottom and the other Perdrix stations. It was at ground-level within a mature spruce-fir forest (Plate 9).

3.1.1.2 The Drystone Stations

The Drystone stations were on the relatively narrow and gently sloping floodplain of Drystone Creek (Table 1). Drystone I and Drystone I-M were near the foot of the basin where the Drystone Creek Valley enters the main valley of the Athabasca River (Plates 1 and 10). There was a dense cover of spruce and poplar surrounding the screens.

Drystone III was 2 km upstream from Drystone I and I-M and 107 m higher in elevation. It also was placed on the floodplain of Drystone Creek (Plate 11).

3.1.1.3 The Folding Mountain Stations

Eight Stevenson screens were sited on the southwest-facing slope of the ridge (Folding Ridge) which extends towards the northwest from Folding Mountain peak (Plate 12). The slope angle was generally about 23°.

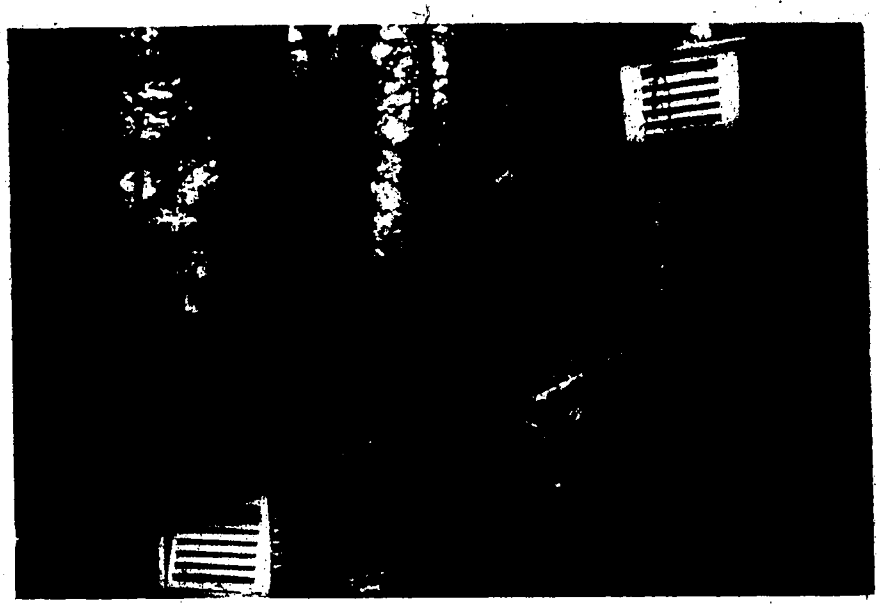


Plate 6: Perdrix II and Perdrix II-M.

Plate 7: Aerial view of the avalanche track on Roche à Perdrix.

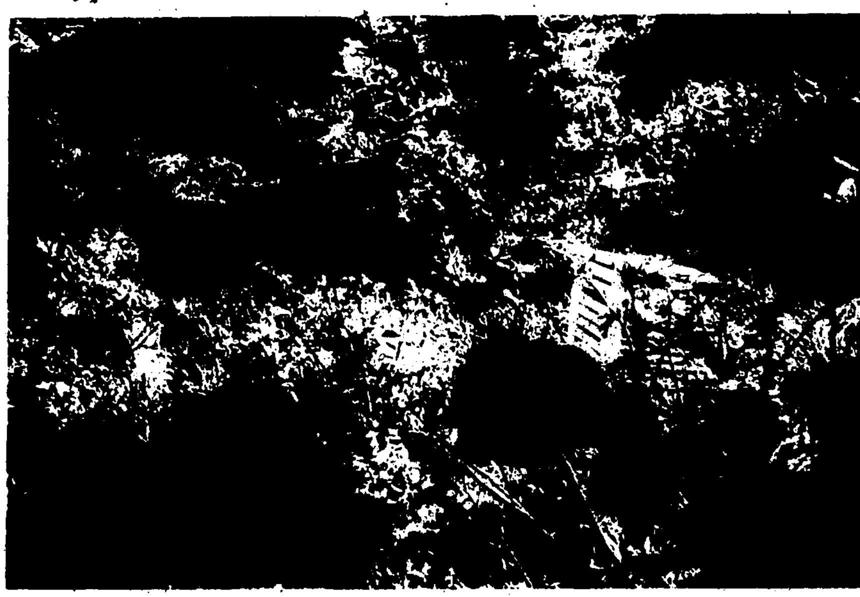


Plate 8 Perdrix III.

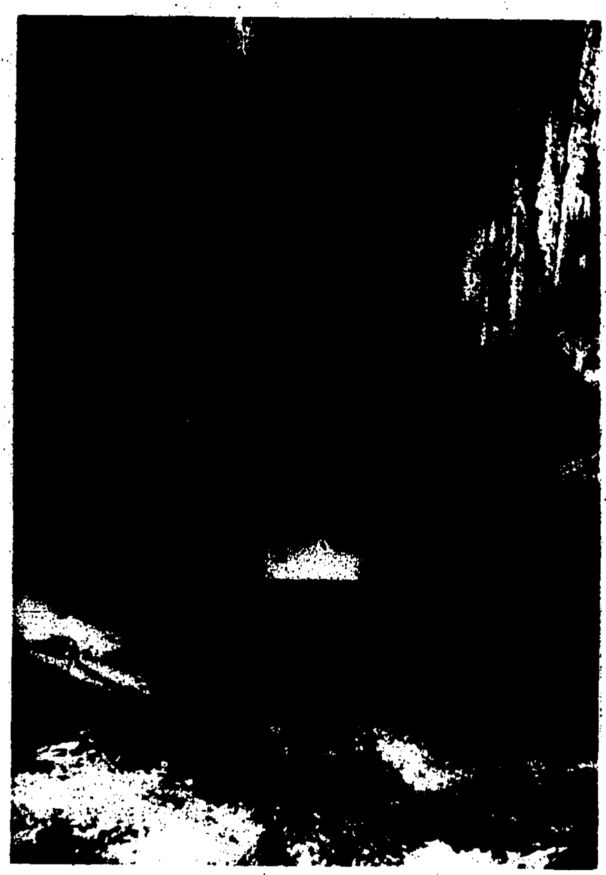


Plate 9: Perdrix I.

Plate 10: Drystone I and Drystone I–M.

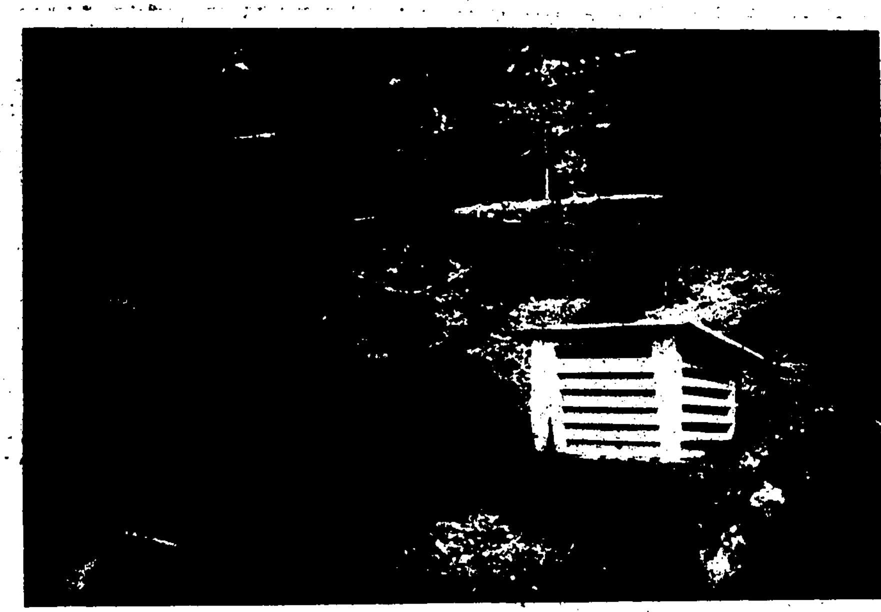


Plate 11: Drystone III.

Plate 12: Folding Mountain Ridge from summit of Roche à Perdrix, looking northeast.

This was steeper than the slope of Roche à Perdrix in the vicinity of the Perdrix stations. Unlike the physical setting on Roche à Perdrix, the uppermost stations on Folding Ridge were near the highest point of the surrounding terrain. They were approximately 100 m below the crest of the ridge.

On Folding Ridge, three elevation levels were instrumented (Table 1). The highest station was Folding III, at 1770 m a.s.l. It was at ground-level within a spruce-pine forest (Plate 13). The middle elevation was near the 1660 m a.s.l. contour. There were three sites at this elevation with five screens in total. Folding II and Folding II-M were in an open meadow. It had a scattered distribution of spruce, pine and poplar (Plates 14 and 15). Folding IIB and IIB-M were along the same contour and approximately 75 m to the southeast of these 2 stations. Folding IIB and IIB-M were just to the right of the area seen in Plate 14. They were in a heavily wooded spruce-pine-poplar forest (Plate 16).

One kilometer to the south, along a spur that protrudes from Folding Ridge, was Folding IIA. It was in a dense stand of spruce and at the same elevation as the other Folding II-level stations (Plate 17).

Below Folding IIA on the same spur, but at an elevation of 1390 m a.s.l., was Folding IA. It was situated in a thick cover of spruce and fir (Plate 18). To the north of this station and at a similar elevation was Folding I. It was at ground-level, in a small forest opening surrounded by a forest association of pine, spruce, and poplar (Plate 19).

3.1.1.4 Jasper Park East Gate Station

Jasper Park East Gate station is maintained and operated by Parks Canada. Each day maximum and minimum temperatures, and precipitation are measured. The Stevenson screen does not have forced ventilation.

Jasper Park East Gate station is at the east entrance to Jasper National Park. It is immediately to the north of the Highway #16 road allowance and it

Plate 13: Folding III.

Plate 14: Aerial view of Folding II and Folding II-M. Folding IIB and IIB-M are located to the right of view in the forested area.

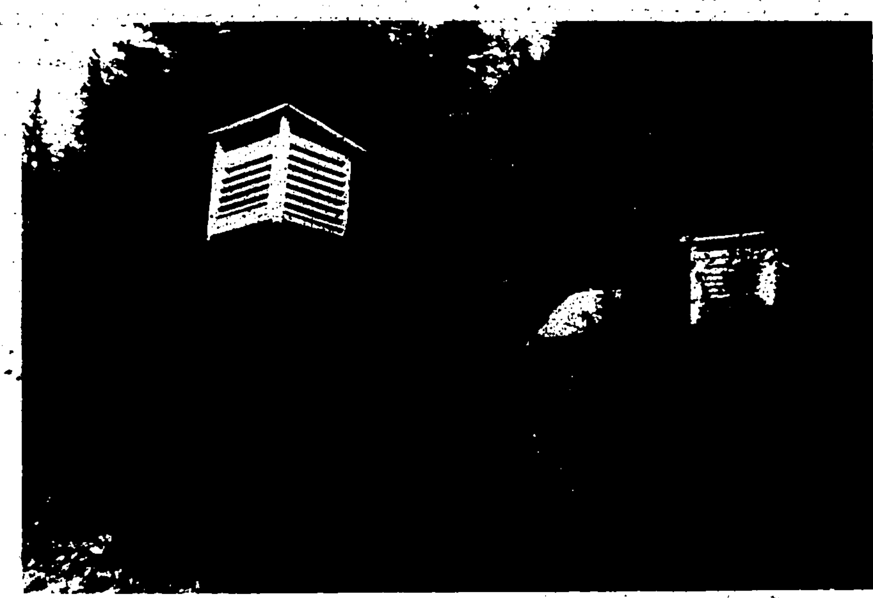


Plate 15: Folding II and Folding II-M.

Plate 16: Folding IIB and Folding IIB-M.

Plate 17: Folding IIA.

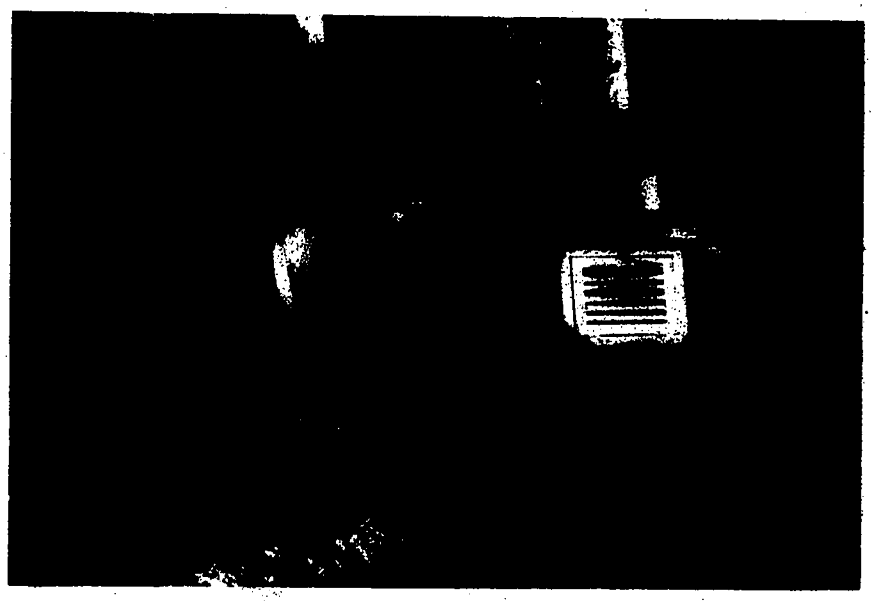


Plate 18: Folding IA

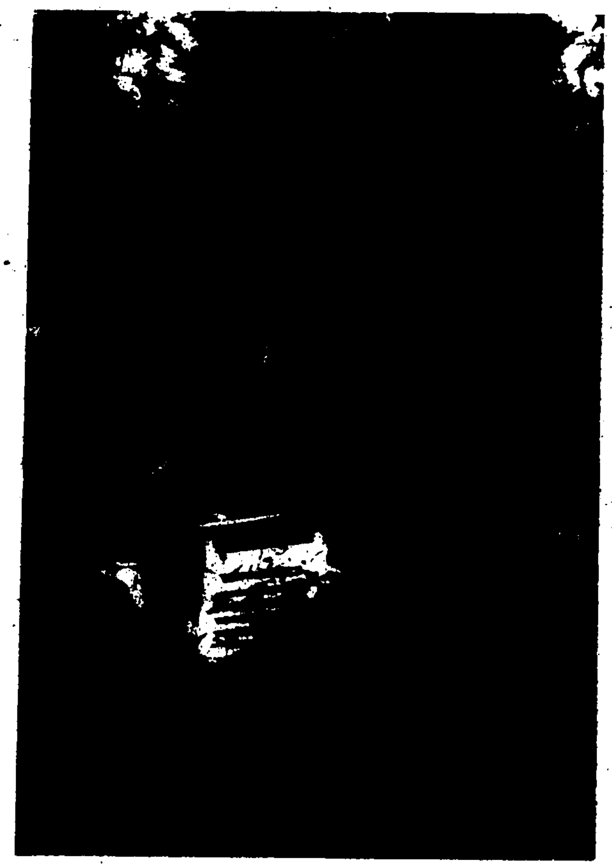


Plate 19 Folding I

is a short distance from Drystone Creek and Brûlé Lake (Figure 7). The terrain slopes gently to the north in the area of the station. Its elevation is 1003 m a.s.l. There is a dense cover of spruce and poplar on the north side of the station. The south side opens to the road-allowance of the highway (Plate 20).

3.2 Instrumentation

3.2.1 Air Temperature

Maximum and minimum temperatures were measured with Taylor, Weksler and Zeal thermometers. Each station was equipped with either a Fuess, Cassella, or Weathermeasure thermograph. A Bendix aspirated psychrometer was used periodically to measure dry- and wet-bulb temperatures.

3.2.1.1 The Stevenson Screens

Air temperatures were measured by exposing the instruments in Stevenson screens. Two of the screens were double-louvered. All others were single. The louvres prevent radiation from proceeding in a direct line to the sensor.

All the screens were repainted in early June 1979. This was to ensure a highly reflective surface in order to minimize the absorbtion of radiation (Stringer 1972). If possible, screens should be artificially ventilated to reduce the effects of radiation that is absorbed. This was not feasible in the Drystone Creek network but it was consistent with the lack of artificial ventilation in the Jasper Park East Gate station.

The louvered construction of the screens allows the free flow of air over the sensors. However, an optimum naturally ventilated screen has not yet been designed (Sparks 1972). Potential errors associated with naturally ventilated screens should be recognized. Köppen (1913, cited in Sparks 1972) studied the exposure of thermometers in naturally ventilated

Plate 20: Jasper Park East Gate climatological station.

Stevenson screens compared to artificially ventilated. Naturally ventilated screens overheat in bright sunshine. The magnitude of the error depends on the windspeed and wind direction relative to the azimuth of the sun. D'Jackova and Kaulin (1965, cited in Sparks 1972) compared forced to non-forced ventilated screens. During summer months there was a negligible difference in their mean temperatures; the standard deviation was 0.12°C. The mean wind speed over the period was 3.4 m per second, with few calms. Janz and Storr (1977) state that afternoon temperatures may be more than 5°C too high and readings taken after clear calm nights may be a little too low without forced ventilation. Stringer (1972) reported that screen temperatures are up to 2°F (1.1°C) too high on sunny afternoons, and up to 1°F (0.6°C) too low on clear, calm nights because of conduction from the outer walls of the Stevenson screen.

3.2.1.2 Standardization of Measurements

The probable error of data derived from the sensors is an important consideration. Thermometers housed in Stevenson screens can be read to within ±0.1°F (±0.06°C). However, the data should not be regarded as closer to the true temperature than ±0.5°F (±0.3°C) because there are short period temperature fluctuations of 0.5° to 1°F (0.3° to 0.6°C) in observations of representative temperatures (Stringer 1972).

Thermographs do not respond to changes in air temperature as rapidly as liquid-in-glass thermometers, and the recorded maxima may be too low and their minima too high if the air temperature reached those points very briefly. This is not a serious error, however, for most purposes (Janz and Storr 1977).

The bimetal thermographs require considerable care to produce data that have a high level of accuracy (Janz and Storr 1977). To ensure quality data the thermographs were adjusted and compared over a 10-day period before being set out in the field. But their placement at the network sites involved long hikes over very rough terrain, often without trails.

Errors in chart data can result from such handling procedures. Inaccuracies can also be introduced in periods of high humidity. The chart paper can become damp by absorbing moisture from the air. Upon drying, it will contract. This causes distortion of the chart because it pulls away from the flange at the base of the clock drum. This results in readings that are lower than the true values. An error of 1° to 2°C is possible (Janz and Storr 1977).

Calibrated maximum and minimum recording thermometers where housed in each screen as a check against the values on the thermograms. The data from these and the air temperatures when the charts were changed were used with the corresponding values on the thermograms to derive regressions that could be applied to the chart data to compensate for any possible inaccuracies. The regressions and derived statistics are listed in Appendix 3A. In addition, an example of the procedure is outlined for the data from one of the stations.

The relative humidity values were adjusted in a similar manner to the air temperature corrections. However, relative humidities calculated from the wet- and dry-bulb readings and the saturation levels on the charts were used to solve the linear regressions. The value for saturation was considered to be the level on the chart where the traces reached an uppermost plateau on the chart. These values must have been recurrent before they were assumed to be the saturation levels.

3.3 Vegetation Analysis

Vegetation analysis followed a modified Braun-Blauquet method (Gill 1971). In ten-1 m² plots the flora at the ground, shrub and tree layers were recorded and their percentages of ground cover of each species was estimated (Plate 21). Voucher samples were collected at each site for later positive identification.

Plate 2.1 Quadrat procedure of the vegetation analyses

3.4 Data Extraction and Analysis

Originally the thermograph data were extracted and placed on magnetic tape simultaneously. This system was particularly advantageous because it reduced the possibility of operator error which could result when manually extracting the data. The input into the computer for the extraction process was the change in resistance across a potentiometer. The potentiometer was connected to a direct-drive belt which had a cursor mounted on it. The cursor was positioned linearly over the trace on the thermograph chart and then the circuit was opened, and an instantaneous signal was sent to the computer. The chart was then advanced either 1 or 2 hours depending on the timing marks of the various charts. Prior to digitizing the thermograph traces were calilbrated according to the change in resistance across the potentiometer by means of three equally spaced known values from the charts. However, this system was not without limitations. Extreme diurnal temperature data were not extracted if they did not correspond to a time bar on the chart. This necessitated the manual extraction of all the maximum and minimum temperatures.

Emphasis was placed on the quality control of the manually extracted data. Each datum was recorded on the thermograph chart before being tabulated. Data measured in degrees Fahrenheit were converted to degrees Celsius and then the correction factors were applied. They were then entered into a computer file. The file was compared to the tabulated data. Scattergrams were plotted for each statistical derivation discussed herein. All suspect data points on these graphs were investigated to determine if operator errors were involved.

Statistical analyses were accomplished using Michigan Interactive Data Analysis Systems (MIDAS) statistical programs (Fox 1976, Fox and Guire 1976) which are available through Computing Services, University of Alberta. Descriptive statistical methods were employed to condense the air temperature data from the study network. They included estimations of means, deviations, and regressions.

The standard deviation, *s*, is a measure of the scatter of a series of measurements about their mean value. It is the principal measure of dispersion (Brooks and Carruthers 1953). The correlation coefficient, *r*, is a standard descriptive measure for indicating the strength of a linear relationship between pairs of variables (Fox 1976). In climatology, correlation analysis attempts to account for some of the effect of interrelationship between climate series (Thom 1966). A regression is a functional interrelationship between an independent variable and a dependent variable. In climatology a regression analysis is used to estimate the constants in functional interrelationships where they are not measured directly as physical quantities (Landsberg 1968, Thom 1968). The tool can be used to determine whether, and to what extent, case values of one variable may be predicted by observed values of another variable for those cases (Fox 1976). The user must first choose one variable to be the dependent variable. It is the one which is to be predicted by values of the so-called independent variables (Fox 1976). In the Drystone Creek network the ground-level stations were usually considered as the independent variables because there were more stations on the surface than at the 1.5 m height. Jasper Park East Gate was the independent variable if a regression was computed using it and a Drystone Valley station. The sign test (Keeping 1962) was employed as a measure of the significance of the observed effects in paired samples.

The 95% confidence intervals were calculated for the mean daily minimum and mean daily maximum temperatures. The method used for computing these values has the property that if the same procedure was repeatedly applied to many samples from the same population then approximately 95% of the resulting computed intervals would include the unknown population mean (Fox and Guire 1976). The standard confidence interval for the mean of the sample is based on a Student's *t*-distribution and the standard error of the mean statistic. There is a close tie between these confidence intervals and hypothesis testing. If the confidence interval does not include some hypothesized mean then a Student's t-test would lead to a rejection of the hypothesis that the mean of the variable was equal to this hypothesized value. If the interval does include the hypothesized mean, the t-test would not lead to a rejection at the level associated with the confidence interval (95%) (Fox and Guire 1976).

It must be stressed that all statistical tests that were used in this study assume random sampling of independent events and that all samples originate from normal populations. None of the tests, however, require a knowledge of the population variance and the tests are considered robust. In most cases the results from a small number of paired observations (N=24) are compared with the results of larger samples.

CHAPTER 4: ANALYSIS AND DISCUSSIONS

4.1 1979 Weather in West-central Alberta

The winter months of 1978/79 were cold and dry compared to the long-range normals (A.E.S. 1973, 1982). The accumulated snowpack at the end of March in west-central Alberta was about 50% of the usual amount. January and February were colder than the long-range values quoted in the 1941-70 normals (A.E.S. 1973). The January temperature anomaly at Jasper was -3.9°C, and February's anomaly was -2.2°C. March was mild, with a +2.7°C anomaly, but precipitation was lighter than normal. In April precipitation approximated the long-term average. However, cool and unsettled weather prevailed (A.E.S. 1979a).

Phenologic development during mid-spring was reported to be at least three weeks late at Jasper National Park (A.E.S. 1979b). The mean temperature and precipitation were both below normal during May. There were 12 days with 1.0 mm or more of precipitation and 12 cm of snow fell near the end of the month.

The period from June to September was characterized by warm and dry conditions over west-central Alberta. A.E.S. data from Jasper and Jasper Park East Gate for these months are presented in Tables 2 and 3. The first of June was relatively cool, but it was a dry month (A.E.S. 1979c). July was hot, with small amounts of precipitation. There was a record setting heat wave in western Alberta during the third week of July (A.E.S. 1979d). A relatively warm blocking ridge (Knox 1982) persisted over western Canada at the 500 mb height for much of the month. Precipitation was 61% of normal at Jasper (A.E.S. 1979e).

August was warm but this was accompanied by significant amounts of rain from thunderstorm activity. The warm conditions were a result of upper-air ridging and a strong south-westerly air flow at the surface and aloft (A.E.S. 1979f).

Table 2: June to September 1979 temperatures at Jasper Park East Gate (JPEG) and Jasper, Alberta (°C). Source: Atmospheric Environment Service (1979c,e,f,g; 1981).

Month in 1979	Station	Mean	Anomaly	Highest	Lowest
June	Jasper	12.1	−0.4	28.6	0.0
	JPEG	12.4	−0.6	31.0	−5.0
July	Jasper	16.3	1.1	34.5	1.4
	JPEG	16.5	1.1	35.5	1.0
August	Jasper	15.7	1.6	28.5	2.5
	JPEG	14.8	0.1	29.5	1.0
September	Jasper	11.7	1.8	26.7	−1.2
	JPEG	12.6	2.4	28.0	0.5

Above normal temperatures continued into September. The departure at Jasper was +1.8°C. Precipitation for the month was 56% of normal (A.E.S. 1979g). This dry and sunny month was characterized by high daytime temperatures and cool nights. The first frost of the fall was not until 29 September at Jasper (A.E.S 1979h) and 8 October at Jasper Park East Gate (A.E.S. 1979i).

The Town of Jasper is 45 km to the south of Jasper Park East Gate (Figure 1) and it is approximately 60 m higher in elevation than the Park entrance. Temperature and precipitation measurements have been recorded at Jasper since 1931. Harris (1982) stated that climate data from Jasper, and most other stations in Banff and Jasper National Parks, are of limited value for ecological and process studies because of the unrepresentativeness of these sites. Nevertheless, Jasper is one of the few places in Alberta's mountainous region that has relatively long-term records. Following is a comparison of Jasper and Jasper Park East Gate for the period 1 June to 30 September 1979.

Table 3: June to Septemper 1979 climate data for Jasper, Alberta. Source: Atmospheric Environment Service (1979c,e,f,g).

	June	July	August	September
Snowfall (cm)	0.0	0.0	0.0	0.0
Percent Normal Snowfall	–	–	–	–
Total Precipitation (mm)	42.6	29.2	60.4	19.4
Percent Normal Precipitation	86	61	126	56
Days with Precipitation > 1 mm	12	5	6	7
Hours of Bright Sunshine	258	299	286	175
Percent Normal Sunshine	51	59	63	68
Degree Days Less Than 18°C	177.9	71.9	73.0	187.6
Mean Sea Level Pressure (KPa)	101.6	101.6	101.6	101.7
Mean Vapor Pressure (KPa)	0.75	0.91	1.01	0.84

4.1.1 Town of Jasper Compared to Jasper Park East Gate

The mean temperatures at Jasper and Jasper Park East Gate for the 4-month period were 14.0° and 13.8°C, respectively (Atmospheric Environment Service 1979c,e,f,g). The mean daily maxima at Jasper Park East Gate was 22.5°C, and at Jasper it was 21.5°C while the mean daily minima were 5.0° and 6.4°C, respectively.

Scatter diagrams of the corresponding values for the mean, minima, and maxima are presented in Figures 8 to 10. Linear regression and the coefficients of determination, R^2, are presented in the figures. The

Figure 8: Scatter diagram of maximum temperatures at Jasper and Jasper Park East Gate for the period 1 June to 30 September 1979 (°C). Source: Atmospheric Environment Service (1979 c,e,f,g).

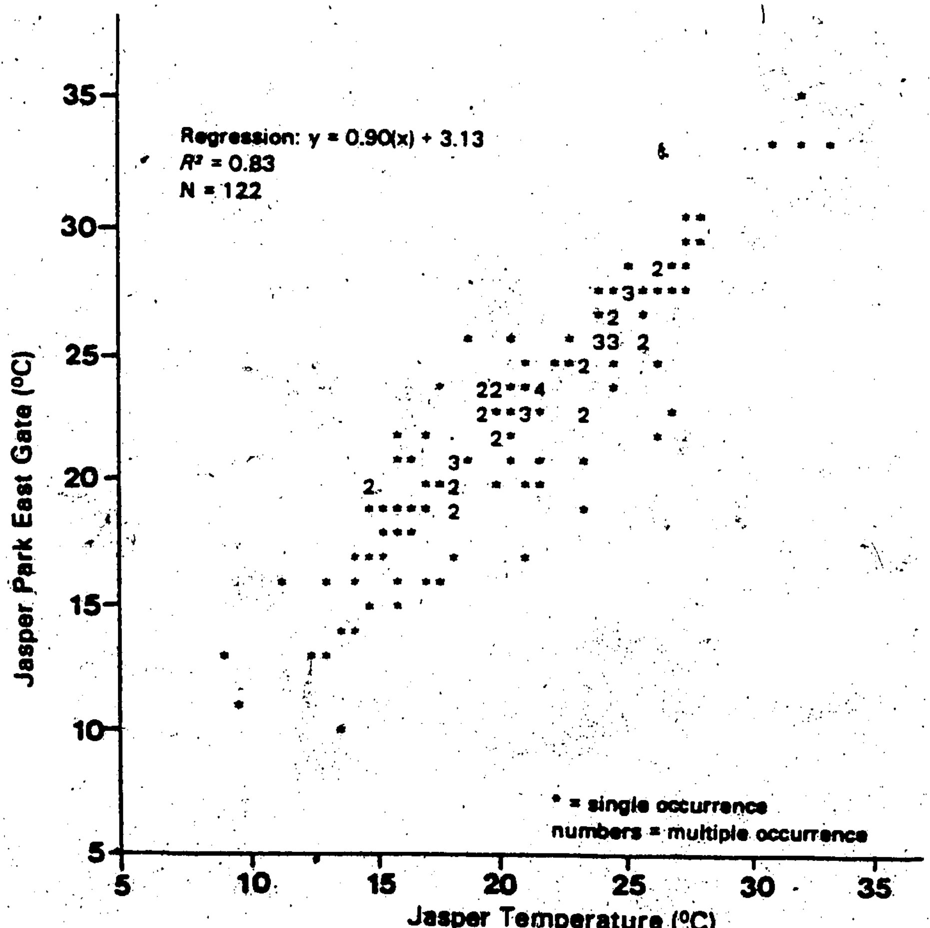


Figure 9: Scatter diagram of mean temperatures at Jasper and Jasper Park East Gate for the period 1 June to 30 September 1979 (°C). Source: Atmospheric Environment Service (1979 c,e,f,g).

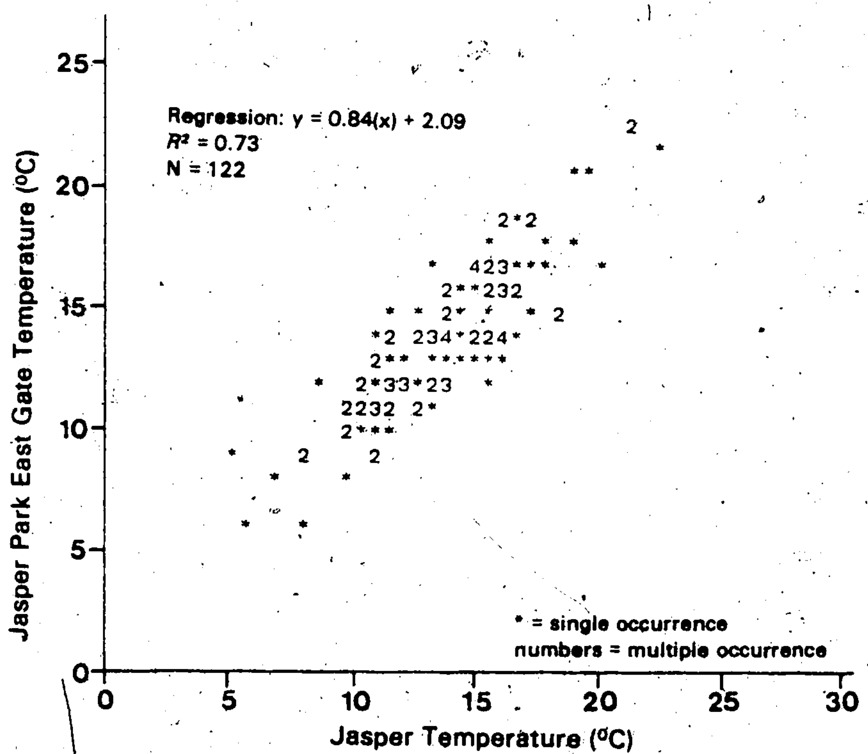
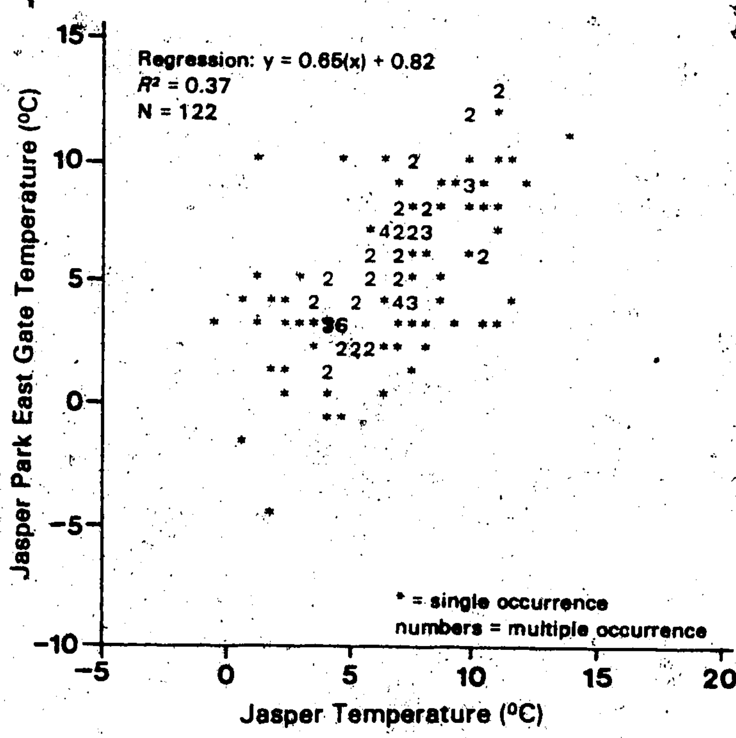


Figure 10: Scatter diagram of minimum temperatures at Jasper and Jasper Park East Gate for the period 1 June to 30 September 1979 (°C). Source: Atmospheric Environment Service (1979 c,e,f,g).



coefficients of determination for the maxima indicate that 83% of the variability in Jasper and Jasper Park East Gate's daytime highs can be attributed to the large-scale variations that are common to both stations. However, only 37% of the variability in the minima can be attributed to common factors.

4.2 Air Temperatures

Temperature is more than a descriptive environmental parameter. It is the key to understanding energy exchanges in the biosphere and it is the most useful tool in environmental measurement (Campbell 1977).

Characteristics of air temperature data are presented in the following sections. The discussions will consider differences between ground-level and standard-height stations, the influences of vegetation cover, aspect, and elevation on local climate within the valley, and the representativeness of Jasper Park East Gate climate station compared to the nearby Drystone Creek Valley stations.

4.2.1 Ground-level vs Standard-height Stations

The World Meteorological Organization (WMO) prescribes temperature observations to be made with the sensor at any level between 1.25 and 2 m above the ground (Sparks 1972). In Canada, the Stevenson screens are generally mounted 1.5 m above the surface, but measurements within the ranges specified by the WMO are archived (A.E.S. 1978). According to Geiger (1965), when the screens are at these heights the chance influences of site selection are reduced. But, measurements from within the WMO approved range of heights do not necessarily give consistent results, even when other conditions are equal (Sparks 1972).

Hellmann (1922, cited in Sparks 1972) compared observations from screens which were 2.3 m apart. One was 2.08 m above the ground, the other 1.4 meters. The screen nearest the ground usually had higher daily maxima and lower daily minima. The largest difference in their mean monthly maxima was 0.4°C. It occurred during the month of May. For the mean monthly minimum the greatest difference was in July, at 0.28°C. The range of diurnal temperatures was usually larger in the lower screen. The greatest difference in mean monthly ranges was 0.66°C. This was measured in both May and July. The least mean monthly temperature range difference was 0.09°C, in November.

At all eleven sites in the Drystone Creek network the instrument shelters were placed on the ground surface. Logistic constraints precluded having all stations mounted within the range of A.E.S. (1978) recommended heights. To determine relative differences between ground-level and standard-height measurements five of the sites had screens at both ground-level and the 1.5 m level. These sites were chosen for their representativeness of valley conditions and for their accessibility. The number of concurrent, or isochronic temperature measurements (cases) between each pair of screens ranged from 16 to 63. These occurred during the period 27 July to 30 September 1979. Scattergrams of the daily minima and maxima between each pair and regression analyses are presented in Appendix B.

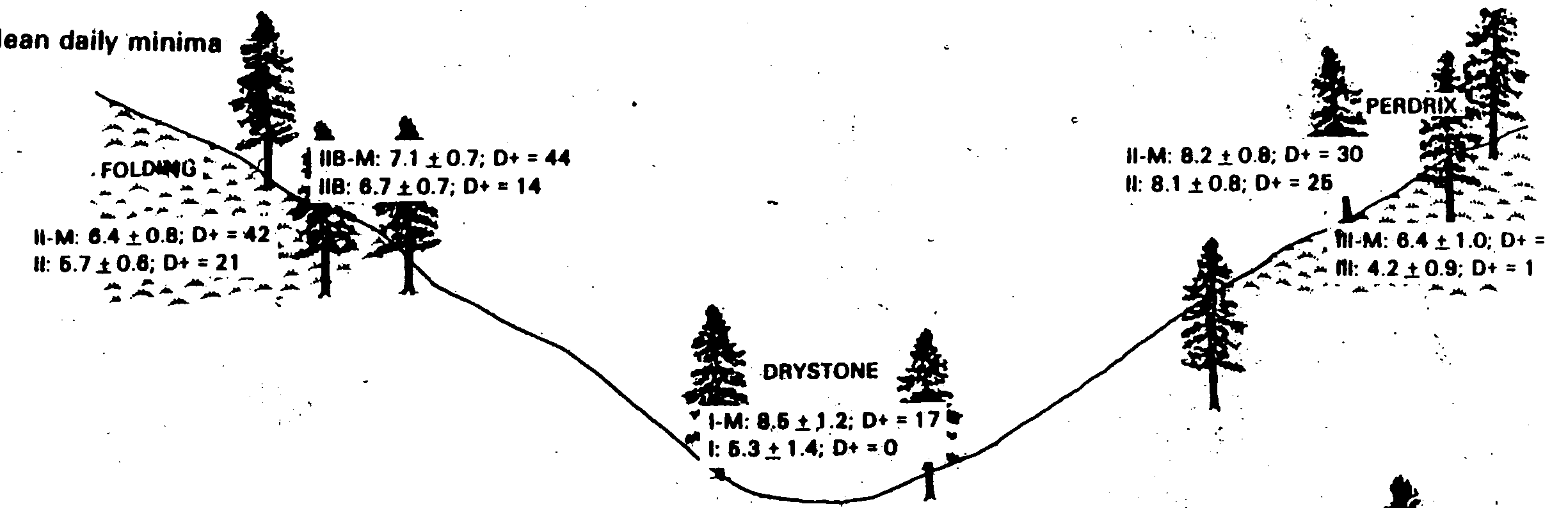
Geiger (1965) stated that the daily average temperatures are 1.3°C cooler in the air layer 0.2 m above the ground in a fir forest in July compared to the 1.5 m level. He attributed the difference "...to the extent that sunlight and wind penetrate the forest canopy". His measurements were on flat terrain but he recognized that differences in this pattern are likely with variations in slope, aspect and vegetation cover.

4.2.1.1 Mean Daily Minimum Temperatures

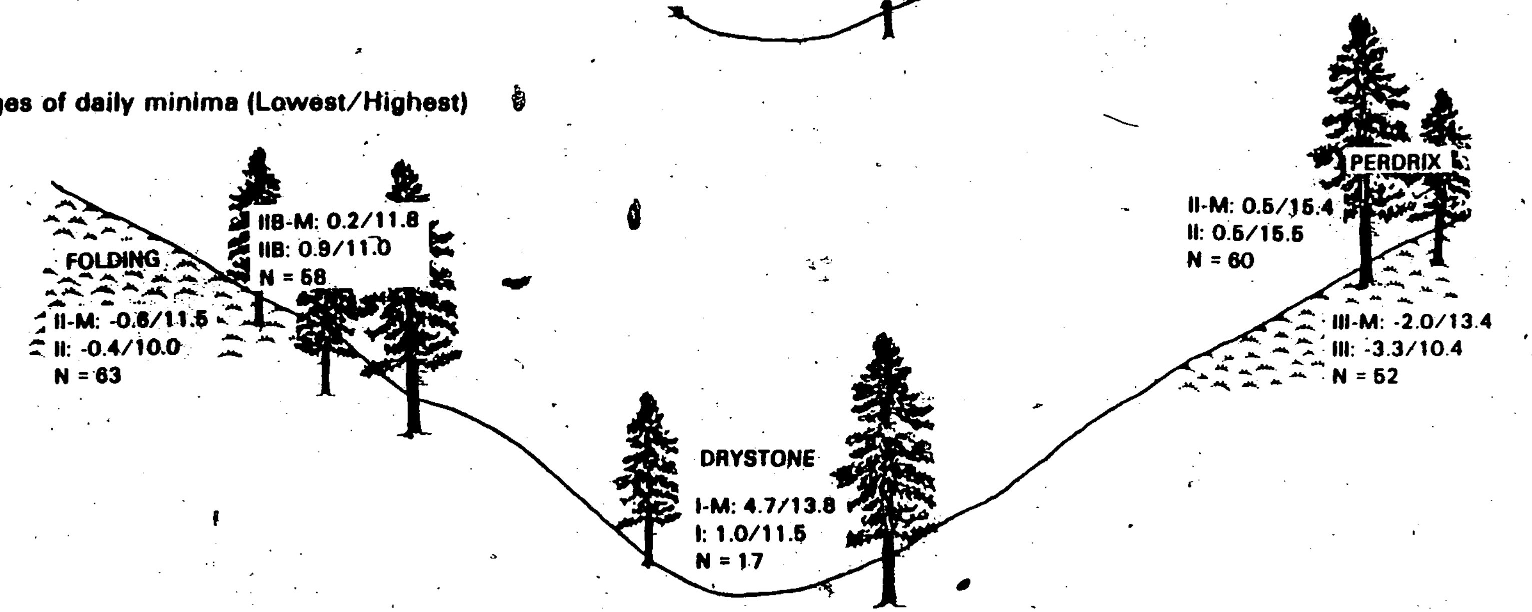
The mean daily minimum temperatures were higher at the standard-height screens than at ground-level for each pair of co-located stations (Figure 11). The relatively low temperatures at ground-level were a result of the radiation flux and the increase of temperature with height is typical of a nighttime negative radiation balance (Geiger 1965). Radiational cooling of a sloping surface causes the air adjacent to the ground-layer to

Figure 11: Descriptive statistics of minimum tmperatures (°C) for isochronic cases between each pair of co-located stations. (Note: cases among sites are not isochronic. D+ = number of positive differences between standard height and ground level stations).

(a) Mean daily minima



(b) Ranges of daily minima (Lowest/Highest)



cool more than the free air at the same elevation. This results in a pressure gradient which drives the layer of cooled air down the slope. This driving force is eventually balanced by friction losses and compressibility effects (Doran and Horst 1981).

Drystone I and I-M had the greatest difference in their mean daily minimum temperatures (3.2±0.5°C) (N=16). This pair of screens was in low lying, forested, flat terrain alongside Drystone Creek. Cool air flowing down into the Drystone Valley during the night and net radiation differences resulted in lower temperatures at ground-level compared to standard-height.

The project campsite was about 200 m downstream from these stations. Virtually every night throughout the summer cold air currents were experienced. On most nights the rising campfire smoke was blown in the downslope direction by the steady drainage winds. The exceptions were overcast and windy nights.

One of the larger temperature differences between ground- and standard-level screen pairs was measured in the avalanche track. The early morning air temperatures averaged 2.2±0.4°C higher at standard-level than at ground-level for 55 corresponding cases (N=55). The physical setting of the avalanche track caused cold air drainage currents to converge. The track was concave in both its longitudinal and cross-sectional dimensions and thus, the cooler air would funnel down the general slope and towards its center. Radiation differences may also account for the differences.

Folding II and II-M were situated in an exposed area where crown cover averaged 15%. The same cover percentage was estimated for the Perdrix III site in the avalanche track. At the Folding site the difference between mean minimum daily temperatures at ground and standard levels was 0.7±0.3°C (N=63). This value and the 2.2±0.4°C difference between the Perdrix III station sites are comparable because these same differences recurr using identical cases for all four stations (N=51). Thus, the 1.5°C variation can be attributed to topographic and aspect dissimilarities between the two mountain slopes and the effects that they had on the radiation flux. Folding II was on a slightly convex slope. Cold air density flows are divergent on this form of topography (Spurr and Barnes 1973). The headwall of the avalanche track is a large, nearly vertical surface (Plate 3). As with any other blackbody it emits long wave radiation. The typical nighttime situation is for the outgoing flux to exceed the incoming flux. Thus, the net radiation is negative and cooling occurs (Lee 1978). Air near the surface of the headwall was cooled and sunk downward. The Folding II site was near the crest of Folding Ridge (Plate 12) and thus, the density flows were not augmented by cooler air from upslope to the extent that they were in the avalanche track.

Perdrix II and II-M had 60 cases in common. They were on the same contour as the co-located stations in the avalanche track, but about 150 m to the north, and with a 70% crown cover. The difference between the average minima at Perdrix II and II-M was negligible, at 0.1±0.1°C. This was the least difference measured among the pairs of co-located screens. The results of the sign test indicated that the observations were not significantly different at the 95% confidence level (Figure 11). The remaining station pairs attained 99% significance in their paired observations.

There were 63 isochronic cases between Folding IIB and IIB-M. This site was in a forest that had an estimated 75% crown cover. There was a 0.4±0.2°C difference between the minimum temperatures for the two screens.

The vertical profiles of the mean daily minimum temperatures at Folding IIB and IIB-M were similar to the average conditions that Bergen (1969) found on a forested mountain slope in Colorado. His ground-level stations averaged approximately 0.5°C cooler than at 1.7 m above the surface. The trees act as a source and sink for long wave radiation during the night (Spurr and Barnes 1973). The energy radiating from the surface layer is absorbed by the vegetation which, in turn, re-radiates it. The effect is that the layer of air near the surface cools less rapidly in forested than in non-forested areas. Forested mountainous terrain is not influenced by katabatic winds to the extent that open slopes are (Bergen 1969). But, nighttime drainage currents are subject to the overriding effects of general circulation dynamics (Yoshino 1975). High humidities, mixing of the air by synoptic-scale winds, or cloudy weather (even without rain), tend to minimize or eliminate density flows (Albright and Stocker 1944).

4.2.1.2 Mean Daily Maximum Temperatures

For climatological purposes an active surface is defined as the principal plane of climate activity in a system (Oke 1978). This is the level where the main transformations of energy (e.g., radiant to thermal, sensible to latent), and mass (change of state of water) occur. The canopy of a well developed forest is an active surface but it is not an inpenetrable barrier to the transfer of heat and water vapor (Munn 1964). In summer diurnal warming begins at tree top level and propagates downwards with decreasing amplitude. This temperature wave can be detected on the forest floor, which is evidence for an active heat exchange process within the stand (Munn 1966).

In open areas, the active surface is much closer to the earth-atmosphere interface compared to forested sites. It is the plane of positive net radiation absorption by day and has an energy surplus. Hence, air adjacent to this surface should have higher temperatures (Oke 1978). The mean daily maximum temperature anomalies between the paired stations in the Drystone network generally followed this pattern. But, some were warmer at standard-height (inversion conditions) while others were warmer at ground-level (lapse conditions). Folding II and II-M had lapse conditions. The difference in their mean daily maximum temperatures was 2.3±0.4°C (N=63). The site was an open, grassed meadow (Plate 14). The warmer values at ground-level were a reflection of the active surface being nearer the ground and, perhaps, poorer ventilation of the lower screen.

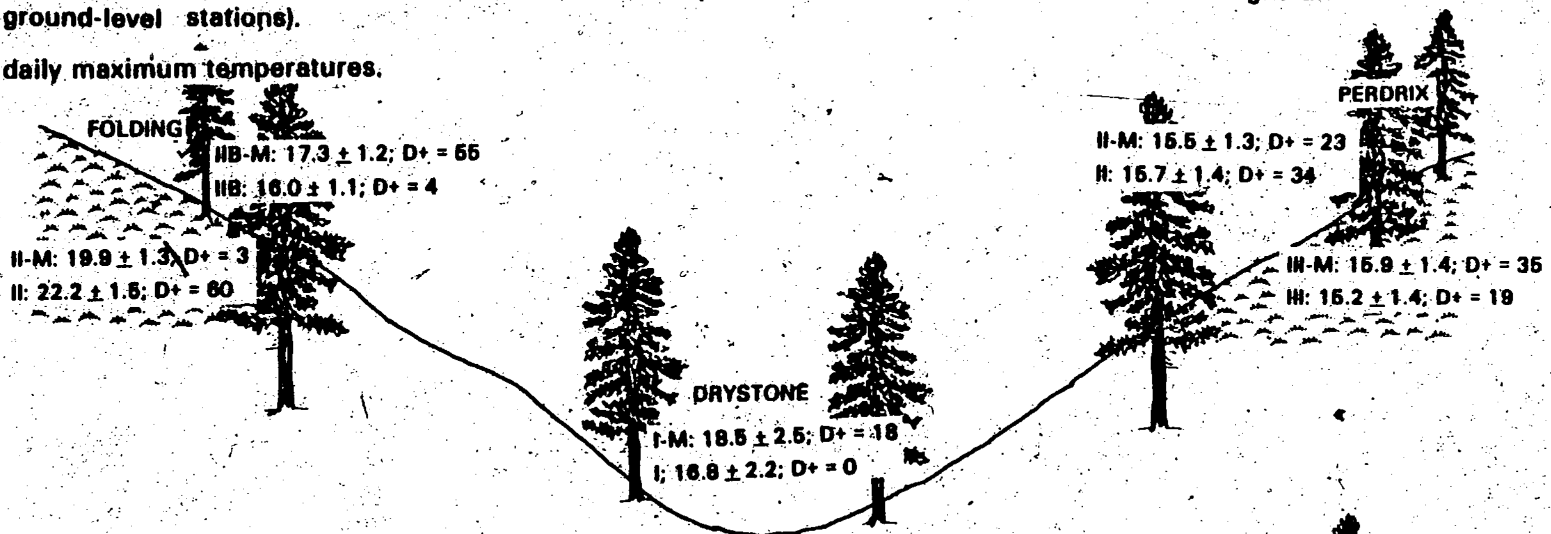
A short distance away from Folding II there were inversion conditions during the afternoons. Folding IIB-M was 1.3±0.3°C warmer than the ground-level station Folding IIB. This same trend was measured at the valley bottom stations, Drystone I and I-M. The difference at these stations was 1.7±0.4°C (N=14) Both the Folding IIB and Drystone I sites were situated within forests that had crown covers of 65 to 70%, respectively (Table 1). Relatively high afternoon temperatures are usually the case above the ground surface in forested sites (Hannel 1956, Munn 1966).

There were lapse conditions during the afternoon at the Perdrix II site. The difference in mean maxima between these ground-level and standard-height stations was 0.2±0.1°C. Inversion conditions during the afternoon are common in a forest, but there are exceptions to this, especially in clearings or when dew forms (Munn 1966). Perdrix II and II-M were within a forest that had a 70% crown cover. But, directly above Perdrix II the celestial hemisphere was more open than at Perdrix II-M, which was only a few meters away (Plate 6). Additionally, Perdrix II-M was suspended differently than the standard method of the Atmospheric Environment Service (A.E.S. 1978). It was resting on two poles which were between two trees, instead of being supported by a prefabricated wooden stand. The screen was within the lower branches of the fir trees and hence, it was never in the sun. However, Perdrix II was observed to be in direct solar radiation during part of the daily high-sun period. Over the 60 cases throughout the summer these factors contributed to producing higher temperatures at Perdrix II than at Perdrix II-M. However, at the 95% confidence interval the values from the two sites are not significantly different (Figure 12).

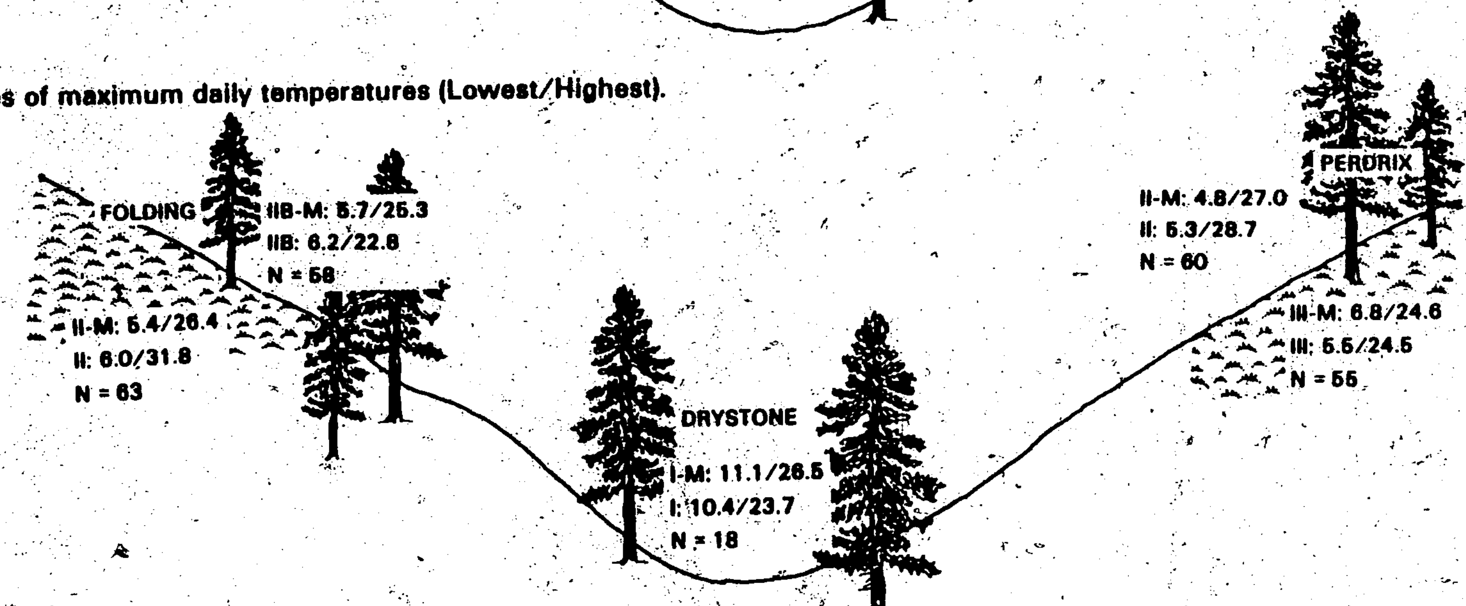
On a flat, grassed surface the highest temperatures during mid-day are usually at ground-level because it is the site of the active surface. However, the avalanche track site had an inversion condition of 0.7±0.5°C (N=55) on average during mid-day even though it had a crown covering of 15%, the same as Folding II. But this latter site had lapse conditions. A reason for higher temperatures at the 1.5 m level in the avalanche chute may be attributed to the "effective" active surface. The avalanche track was vegetated by a

Figure 12: Descriptive statistics of maximum temperatures (°C) for isochronic cases between each pair of co-located stations. (Note: cases are not isochronic. D+ = number of positive differences between standard-height and ground-level stations).

(a) Mean daily maximum temperatures.



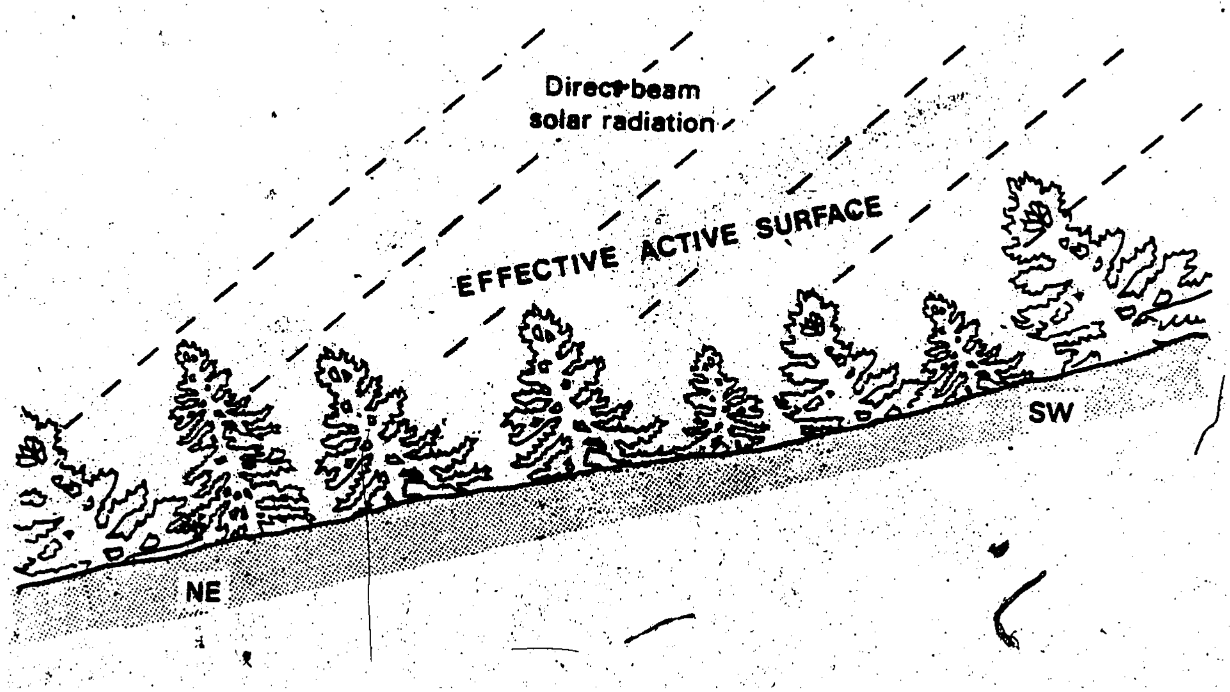
(b) Ranges of maximum daily temperatures (Lowest/Highest).



shrub layer that was about one meter high (Plates 7 and 8). The woody shrubs were deformed by the seasonal avalanches and were bent downslope, toward the northeast. The angle of the sun's rays determines the intensity of insolation upon the ground. Because of the track's angle away from the sun the solar radiation would spread over a relatively large area of the intercepting surface. But, the direct beam radiation would "see" the layer of shrubs moreso than the ground itself. The radiation would have to pass through an effectively deep layer of vegetation before reaching the ground (Figure 13). Even though the shrub layer was low in stature it would be operative in intercepting much of the short wave energy because of the angle of the sun's rays.

Another reason for the standard-height station at Perdrix III being warmer than the ground-level station could be due to errors introduced into the measurements because of the standard level screen's stand. The station was attached to the base of what was once a medium sized fir tree.

Figure 13: The effective active surface during mid-day in the avalanche tract.



This cylindrical base presented a wide, vertical surface to direct solar radiation and therefore, it may have experienced daytime heating. Convective currents would have moved up into the Stevenson screen which would result in elevated temperatures at Perdrix III-M. (The same may have occured at Folding II-M).

Daytime air temperatures near the surface are determined from the interplay of net radiation balance at the surface, transfer rates of sensible heat up into the atmosphere and down into the ground, and absorption of latent heat by processes of evapotranspiration (Sellers 1965, Munn 1966). The effect of these is that day to day atmospheric conditions will have more measureable effects in a clearing than beneath a forest canopy. For example, the flux of direct shortwave energy that is excluded by clouds would be greater for a clearing than for a treed covering. This is because a forest floor already has a shortened effective day length for direct-beam solar radiation due to shading (Lee 1978).

The effects of wind are important in advectional heat exchange because wind can either accentuate or modify meteorological elements (Martin 1971; MacHattie and Schnelle 1974). But, wind speeds near the ground within a forest are usually less than above a canopy or within a forest clearing (Haupt 1979). Thus, the daily variability of clouds and winds produce greater differences in temperatures between ground-level and standard-height stations in clearings than within forests.

4.2.2 The Drystone Valley Network vs Jasper Park East Gate

Climate data that are collected through the auspices of federal and provincial agency networks are usually meant to be representative of larger areas than each climate station's immediate location. But, the nature of mountainous topography creates such a variety of small-scale climate conditions that any station is likely to be representative of only a limited range of sites (Barry 1981).

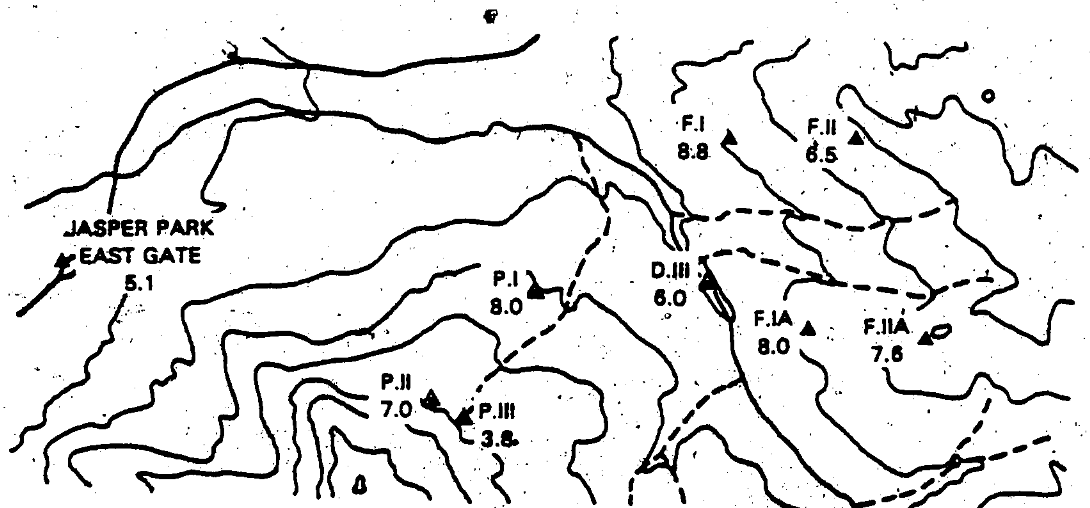
It is often up to the user of climate data to adapt these values to the surrounding topographic features. For example, Strong and Leggat (1981) mapped nine ecoregions in Alberta. Five of these were identified within 2 km of Jasper Park East Gate. Each of them reflect characteristics of a distinctive large-scale climate regime as expressed by vegetation (Subcommittee of Biophysical Land Classification 1969). At the 1:1 500 000 map scale Jasper Park East Gate station is at the spot where the montane, subalpine and boreal foothills ecoregions converge. This representation is not consistent with the definition of the climate of an ecoregion because one station can only measure one particular climate regime at a time. Strong and Leggat acknowledge that the detail of their surveys cannot be adequately shown on a map of this scale. Still, the problem is that Jasper Park East Gate can not mirror the climate conditions of these five ecoregions.

The Drystone Creek network provides an indication of the variations of climate within a macroclimate setting and within several ecoregions according to Strong and Leggat's (1981) map. Following is a discussion of air temperatures measured in the Drystone Creek Valley, compared to those measured at Jasper Park East Gate. For comparative purposes the case values from Jasper Park East Gate station have been transformed to ground-level equivalencies. The regressions discussed in the preceding section for the daily minima and daily maxima at Folding II/II-M (Appendix B) were used for the transformation. The two stations at this site had a relatively long record of comparison, and their vegetation covers were similar to Jasper Park East Gate's.

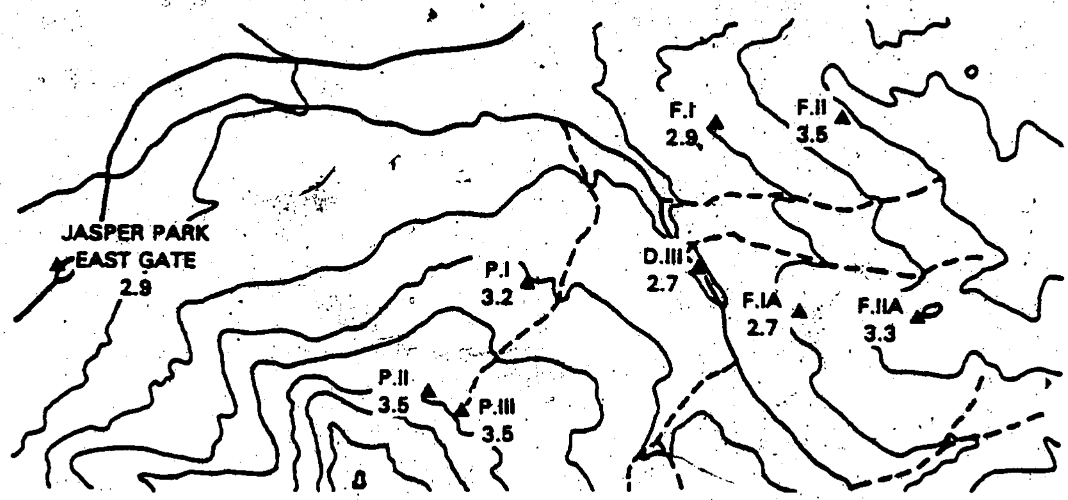
There were 24 days in which thermographs at 7 contrasting Drystone network sites and Jasper Park East Gate were simultaneously in operation. These cases were recorded between late-June and mid-July 1979. The stations included Drystone III, Folding I, Folding IA, Folding IIA, Perdrix I, Perdrix II, and Perdrix III. Descriptive statistics of their daily maximum and daily minimum temperatures are illustrated in Figures 14 and 15. The highest mean daily maximum temperatures were found at Jasper Park East Gate and at network sites that had low percentages of tree covers. Most of the mean daily minimum temperatures were higher at the valley sites than at Jasper Park

Figure 14: Descriptive statistics of isochronic minimum temperatures from the Drystone Creek network and Jasper Park East Gate station (°C, N = 24).

(a) Mean of the Minima



(b) Standard deviation of the minima



(c) Lowest/Highest of the minima

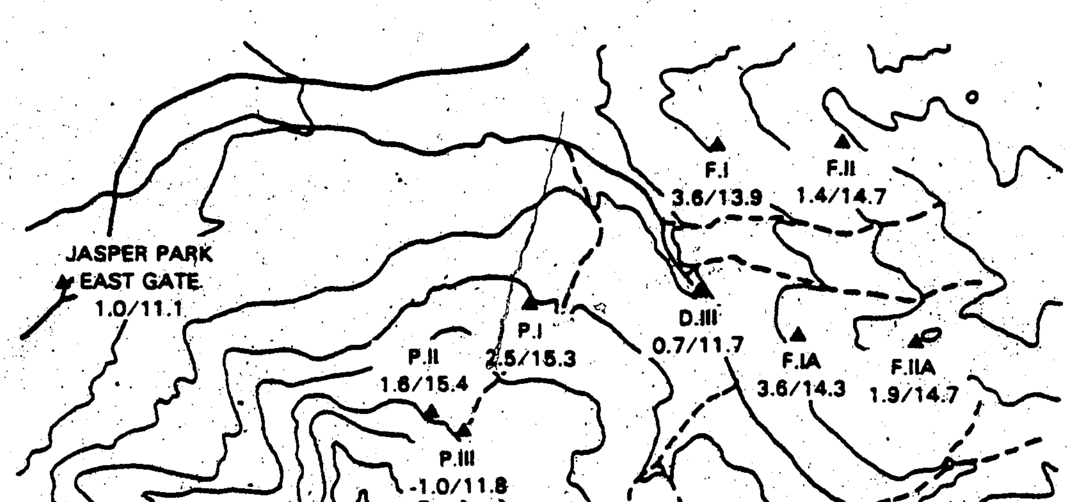
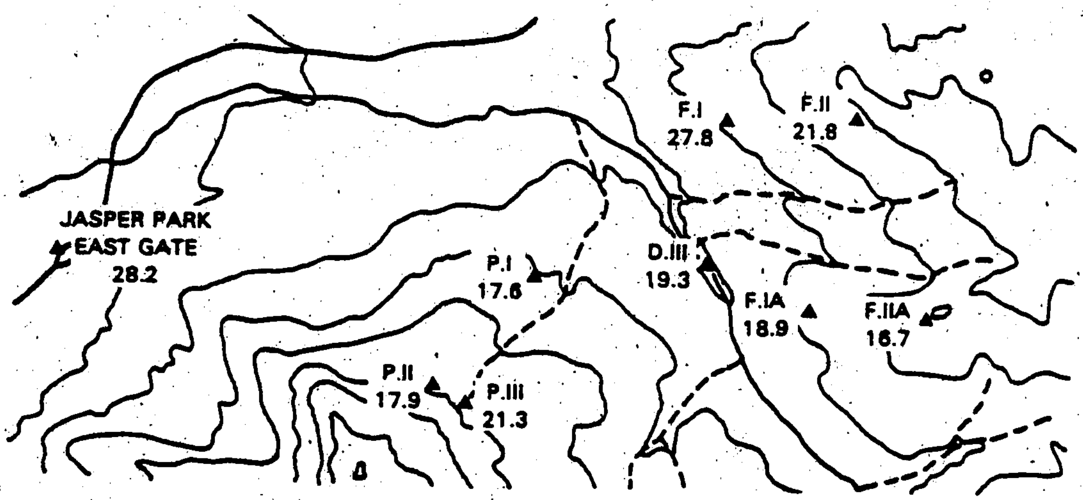
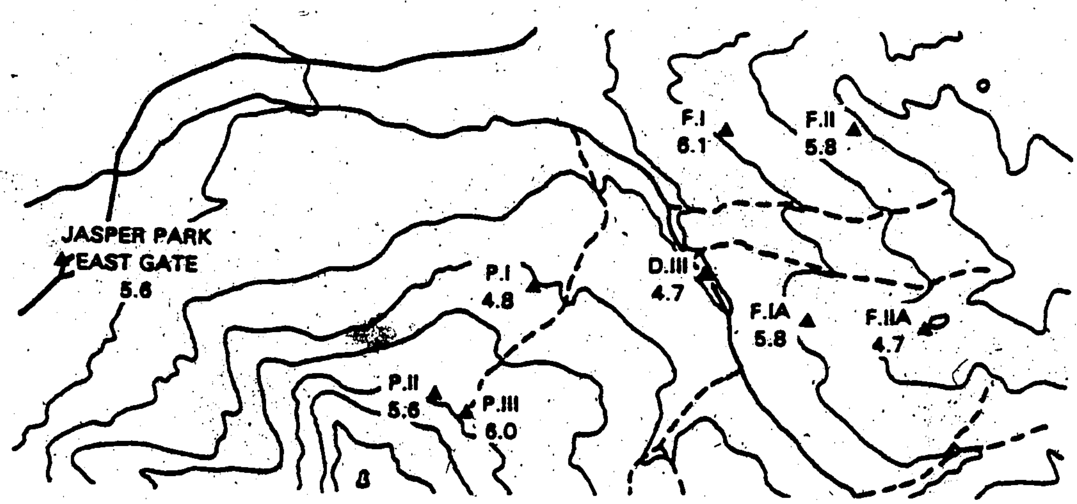


Figure 15: Descriptive statistics of isochronic maximum temperatures from the Drystone Creek network and Jasper Park East Gate station (°C, N = 24).

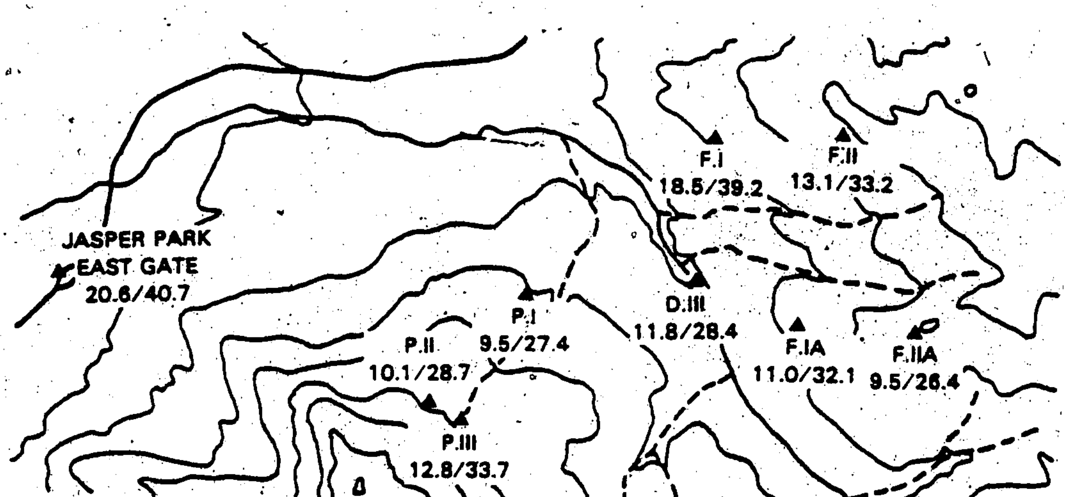
(a) Mean of the maxima



(b) Standard deviation of the maxima



(c) Lowest/Highest of the maxima



East Gate. The exception was Perdrix III.

The differences in temperatures at Jasper Park East Gate and the network stations have been computed in order to reduce the network data to a standard reference. These relative differences for mean daily maximum and minimum temperatures, and their associated 95% confidence levels for mean differences, are plotted in Figures 16 and 17. There were relatively large dissimilarities between maximum temperatures at Jasper Park East Gate and the forested sites, and these differences were generally greater with increasing elevation. The mean daily maximum temperature at Folding I was the most similar to Jasper Park East Gate, while the mean daily minimum temperature field from Drystone III was the most similar of the mean daily minima. The factors that contributed towards these differences in valley temperatures included, among others, elevation, slope, aspect, the characteristics of the vegetation cover, small-scale topographic features, and small water bodies (Lester 1974). In the following sections these factors will be singled out and their relative influence determined. Scattergrams of each paired variable of the 24 isochronic cases appear within the text or, within Appendix C if all cases for the paired temperatures are discussed. In these diagrams a "*" is one datum, a numerical value corresponds to the number of multiple occurrences overlapping that point. In these diagrams the error bars (± one standard deviation) intersect at the mean temperature difference between the station and Jasper Park East Gate.

4.2.2.1 Climate-vegetation Interrelationships

The forest communities surrounding the Drystone Creek network stations were not similar among all sites. In the Front Ranges the distribution of vegetation is determined by a combination of physiographic, historic, interactive and stochastic factors (Hettinger 1975). Floristic characteristics of the tree and shrub covers near the sites are presented in Tables 4 and 5. Unless cited otherwise, all ecological characteristics of the plant species are referenced from Hultén (1968).

Figure 16: Differences in mean daily maximum temperatures between Drystone Valley network stations and Jasper Park East Gate (JPEG), and associated 95% confidence intervals of mean differences (°C, N = 24).

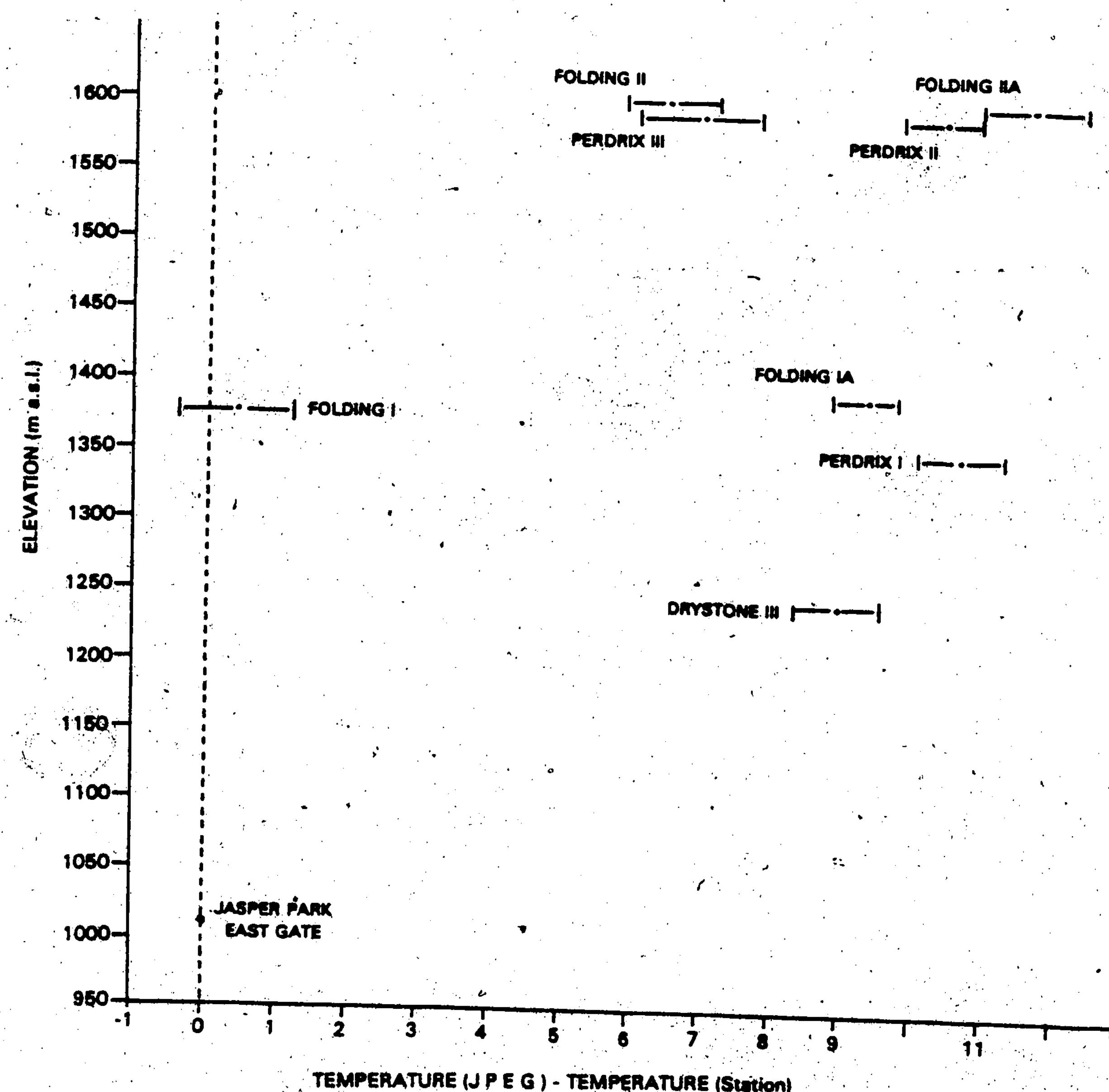


Figure 17: Differences in mean daily minimum temperatures between Drystone Valley network stations and Jasper Park East Gate (J P E G),and associated 95% confidence intervals of mean differences (°C, N = 24).

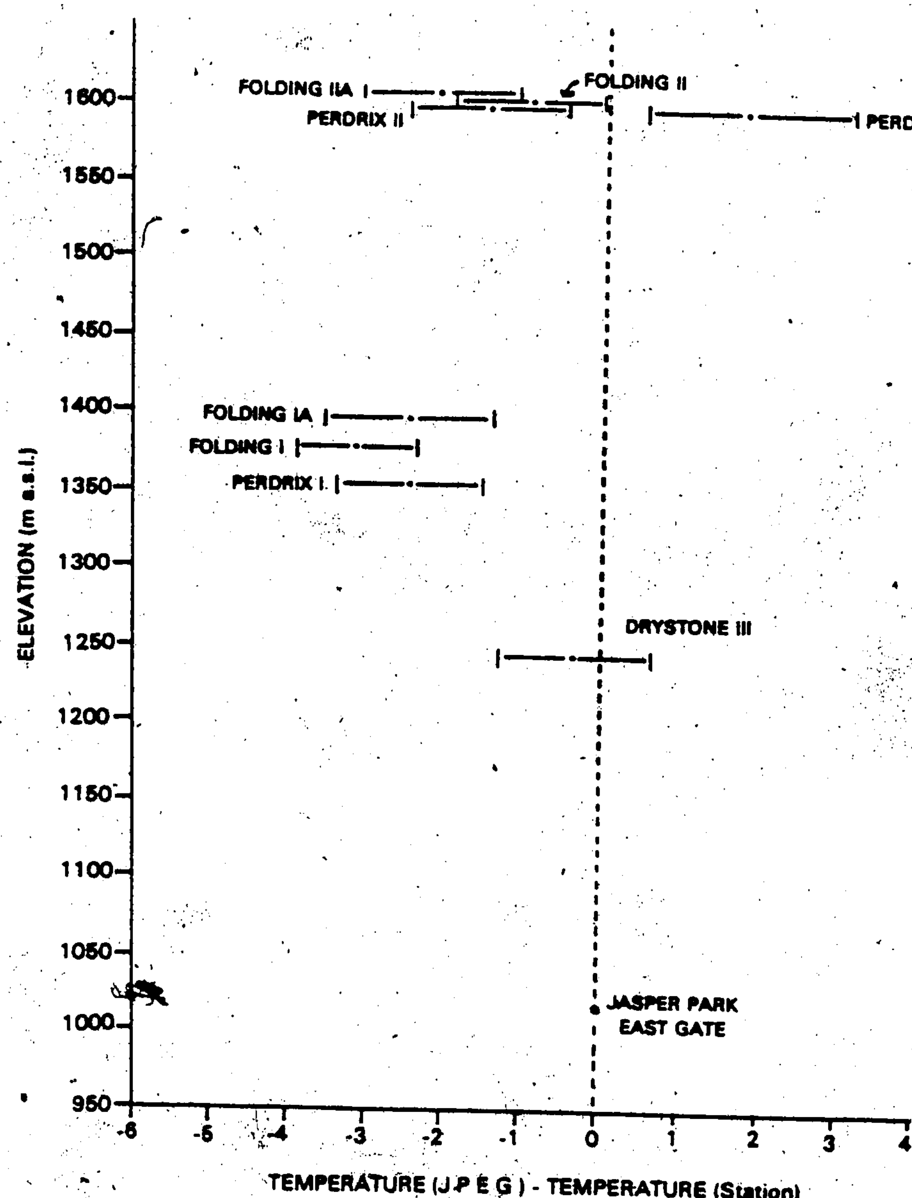


Table 4: Cover-abundance class of tree stratum by station site[1].

Tree Species	Folding I	Folding IA	Folding II/II-M	Folding IIA	Folding IIB	Drystone I/I-M	Drystone III	Perdrix I	Perdrix II/II-M	Perdrix III/III-M
Abies balsamea	–	4	–	4	1	–	4	5	4	–
Alnus crispa	–	–	–	–	–	+	–	–	–	–
Betula papyrifera	–	–	–	–	–	1	–	–	–	–
Picea engelmanni	–	–	–	–	–	–	–	–	4	–
P. glauca	3	4	–	4	–	5	4	4	–	2
P. engelmanni x P. gluaca	–	–	2	–	4	–	–	–	–	–
Pinus contorta	+	–	1	–	1	–	–	1	–	–
Populus balsamifera	+	–	–	–	2	–	+	+	–	–
P. tremuloides	–	–	–	–	–	+	–	–	–	–

(1) Cover classes: R=rare; +=1%; 1=1-5%; 2=6-15%; 3=16-25%; 4=26-50%; 5=51-75%; 6=76-95%; 7=96-100%.

Table 5: Cover-abundance class of shrub species by station site[1].

Shrub Species	Folding I	Folding IA	Folding II/II-M	Folding IIA	Folding IIB/IIB-M	Drystone I/I-M	Drystone III	Perdrix I	Perdrix II/II-M	Perdrix III/III-M
Abies balsamea	–	2	–	3	–	–	2	+	+	3
Alnus crispa	–	–	–	–	–	–	+	–	R	1
Arctostaphylos uva-ursi	4	–	4	–	–	–	–	–	–	–
Betula glandulosa	–	–	–	–	+	–	–	–	–	–
B. papyrifera	–	–	–	–	–	+	–	–	–	–
Cornus stolonifera	–	–	–	–	–	+	–	–	–	–
Juniperus communis	3	–	3	–	+	–	–	–	–	–
J. horizontalis	+	–	R	–	–	–	–	–	–	–
Lonicera dioica	–	–	–	–	5	2	–	–	–	–
L. involucrata	–	–	–	–	5	2	–	–	–	–
Picea glauca	+	+	–	–	+	+	+	–	–	–
Populus balsamifera	R	–	R	–	R	–	–	–	–	–
Potentilla fruticosa	1	–	2	–	–	+	+	–	–	–
Ribes lacustre	–	–	–	–	–	–	–	+	–	–
R. oxyacanthoides	–	2	–	+	–	–	–	–	–	–

Table 5 (Cont'd): Cover-abundance class of shrub species by station site[1].

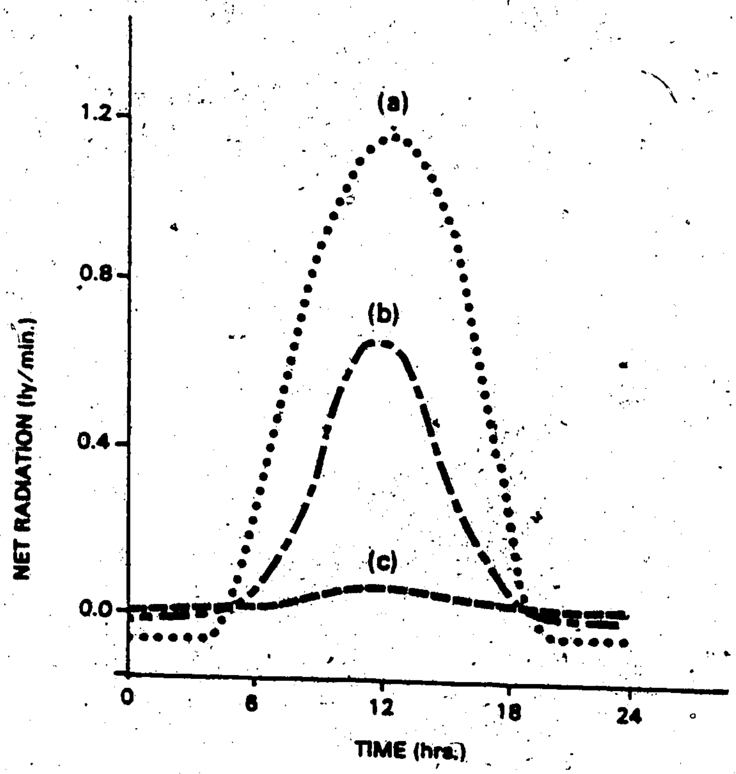
Shrub Species	Folding I	Folding IA	Folding II/II-M	Folding IIA	Folding IIB/IIB-M	Drystone I/I-M	Drystone III	Perdrix I	Perdrix II/II-M	Perdrix III/III-M
R. spp.	–	–	–	–	–	–	+	–	–	–
R. triste	+	+	–	–	–	–	–	–	–	–
Rosa acicularis	2	+	–	–	–	2	–	R	–	–
R. woodsii	–	–	1	–	2	–	–	–	–	–
Rubus strigosus	–	1	–	–	–	–	–	–	–	–
Salix spp.	+	+	+	–	R	+	1	–	–	3
Shepherdia canadensis	2	–	2	–	2	+	–	–	R	–
Vaccinium vitis-idaea	–	–	–	–	–	R	–	–	–	–
Viburnum edule	–	–	–	+	–	2	+	–	–	–

(1) Cover classes: R=rare; +=1%; 1=1-5%; 2=6-15%; 3=16-25%; 4=26-50%; 5=51-75%; 6=75-95%; 7=96-100%.

Lee (1978) stated that a dense forest canopy modifies air temperatures near the ground. Net radiation at the surface is reduced during clear days and is increased at night relative to the top of the trees (Figure 18). During periods of positive net radiation temperatures near the forest floor are not as extreme as those above the canopy. At night the layer near the ground is warmer than above the forest because the upper-level has a relatively large negative net radiation flux.

A dense canopy and an open site are similar in that they are both the principal plane of climate activity in their respective systems (Oke 1978). Therefore, curve "a" in Figure 18 is analogous to the net radiation balance over a non-forested site. *A priori*, near-surface air temperature

Figure 18 : Net radiation (a) over a forest canopy (b) within the upper crown stratum (c) at the forest floor. Source: Lee (1978), based on data from Baumgartner (1956).



differences between juxtaposed open (non-forested) and closed (forested) sites should be indicative of the dissimilarities in their radiation regimes.

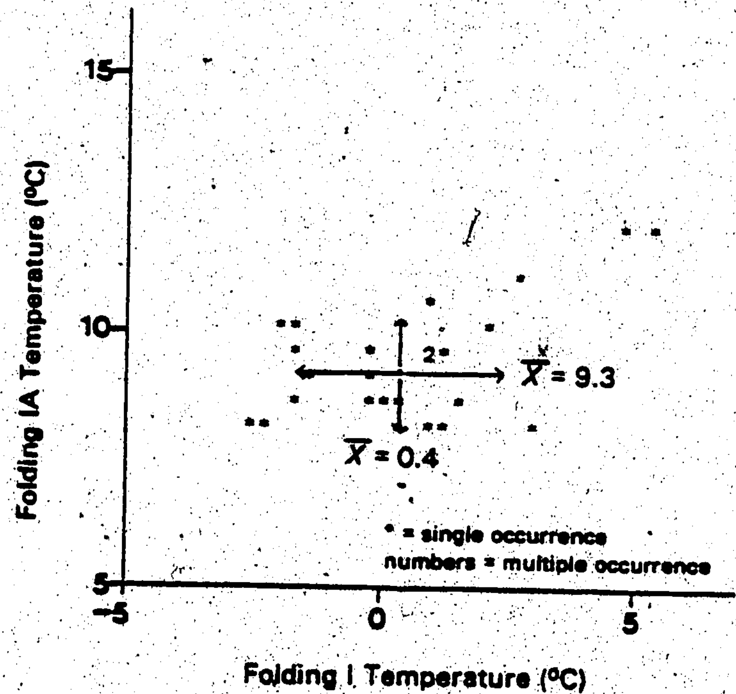
4.2.2.1.1 Folding I vs Folding IA

Slope orientations and elevations were similar at Folding I and Folding IA (Table 1). A dominant tree species at both sites was white spruce yet, their vegetation communities were otherwise different according to the cover-abundance scales (Table 4). At Folding I, which was a small opening in the forest canopy, the crown cover was 20%, at Folding IA it was 75%. The spruce and fir trees at Folding IA were approximately 25 m tall, at Folding I the spruce were 2 to 5 m high. Folding I was essentially a non-forested site, while Folding IA was a forested location.

Shrubs are small woody plants less than three meters in height (Whittaker 1975). White spruce was the only species within the shrub stratum that was common to both Folding I and Folding IA, and it only occupied 1% of this layer at these sites (Table 5). The shrub layer at Folding I had species such as common mountain juniper (*Juniperus communis*) and kinnikinnick (*Arctostaphylos uva-ursi*). The dominant shrub at Folding IA was *Ribes oxyacanthoides* which is usually found in moist woods. *R. triste* and *Rosa acicularis*, both typical of moist to wet sites, were recorded at Folding IA.

The influence that vegetation cover exerts on maximum temperatures can be investigated using the case values from Folding I and Folding IA. Site dissimilarities between these two locations are primarily due to tree cover differences. The mean daily maximum temperature differences relative to Jasper Park East Gate at these two sites differed significantly from one another (Figure 18). A scattergram of the corresponding values is provided (Figure 19). The departures in maximum temperatures between these two sites appear to be interrelated to vegetation cover differences because it is the one major discrepancy in their site characteristics.

Figure 19 : Scattergram of daily maximum temperatures (relative to Jasper Park East Gate) at Folding I and Folding IA (°C, N = 24).



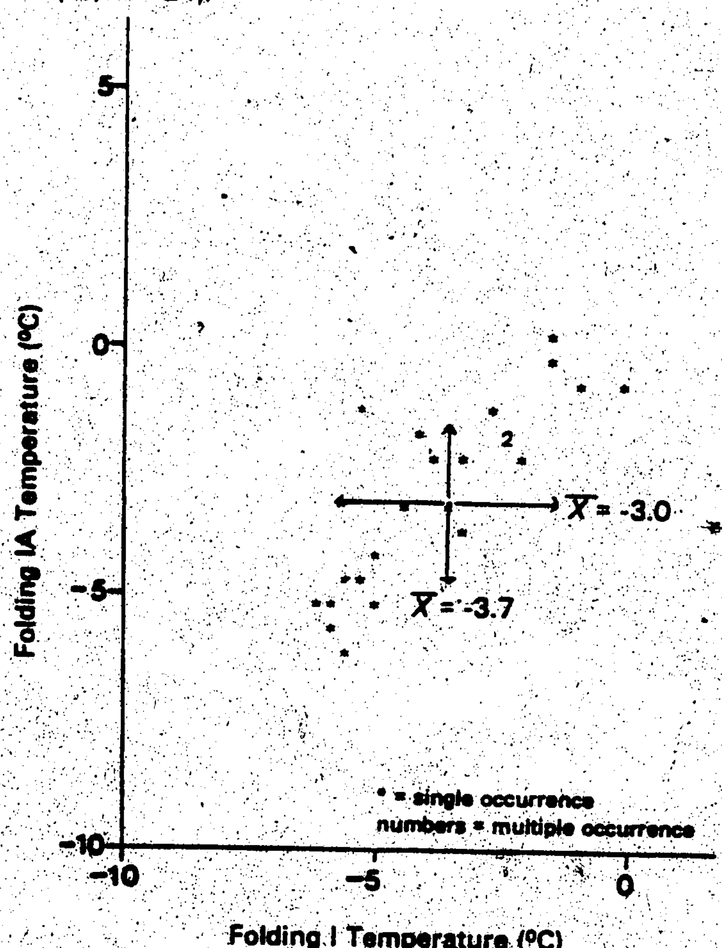
Derived statistics from corresponding temperature data for Folding I and Folding IA for all available cases (N=42) are presented in Table 6. The mean daily maximum was higher at Folding I. There was an 8.4±0.7°C difference. Lee (1978) reported that daily maxima are generally higher in a non-forested site compared to a forested site. Oke (1978) attributes the differences in maximum temperatures to the position of the active surface relative to the sensors.

Vegetation does not play a role in determinimg the mean daily minimum temperature fields at Folding I and Folding IA. The mean daily minimum temperatures between these two sites were not significantly different for the 24 corresponding cases (Figures 17 and 20) nor for all available cases (Table 6). Lee (1978) reported that daily minima are generally lower in an open site than in a forested site, the difference being due to heat storage capabilities of the forest (Munn 1966), and the variations in cold air drainage (MacHattie and Schnelle 1974).

Table 6: Descriptive statistics of differences, relative to Jasper Park East Gate, at southwest-facing Folding I, a non-forested site, and Folding IA, a forested site (°C, N=42).

Variable	Station	Least	Greatest	Mean
Minima	Folding IA	−6.9	0.9	−3.2±0.7°C.
	Folding I	−6.8	−0.4	−3.8±0.6°C.
Maxima	Folding IA	2.5	12.4	8.6±0.6°C.
	Folding I	−4.8	5.0	0.2±0.7°C.

Figure 20: Scattergram of daily minimum temperatures (relative to Jasper Park East Gate) at Folding I and Folding IA (°C, N = 24).



The difference in the mean daily maximum between Folding I and Folding IA was relatively large compared to the difference in their minimum. This may be explained in terms of Lee's (1978) comments that maximum temperatures are more sensitive to daily changes in atmospheric phenomena than minimum temperatures. Variability in maximum temperatures is especially observable during warm, sunny periods (Lee 1978). The 24 corresponding cases at Folding I and IA were measured between 13 June and 24 July 1979, a relatively mild period in west-central Alberta compared to most years (A.E.S. 1979c,d,e). This may have contributed to the large daytime temperature discrepancies between the forested and non-forested sites. Additionally, the size of the forest opening may have resulted in unrepresentative measurements (Lee 1978) at Folding I. According to Lee (1978), measurements obtained in forest openings are poorly representative of atmospheric phenomena because microclimate at the center of a small forest opening is influenced by the relative size of the plot compared to the tree heights.

Extremes in temperature are generally less in a forest than in an adjacent non-forested area (Spurr 1957). This was observed at the Folding I-level stations. The ranges in the actual observed temperatures were 36.9°C at Folding I and 28.7°C at Folding IA.

4.3.2.2.1 Folding II vs Folding IIA

Folding II and Folding IIA had approximately the same elevations, aspects, and slope angles, but their percent crown covers were different (Table 1).

The cover-abundance classifications for the two forested Folding Ridge stations, Folding IA and Folding IIA, and for the two non-forested stations, Folding I and Folding II, had many similarities (Tables 4 and 5). Scattergrams of the mean daily maximum and minimum temperatures for the 24 isochronic cases between Folding II and Folding IIA, relative to

Jasper Park East Gate, are presented in Figures 21 and 22. The clustering of the scatter points for Folding II/Folding IIA reflects the trend of higher maximum temperatures in the non-forested sites than in the forested sites (Figure 17). However, their relative differences in maximum temperatures were not as great as those between Folding I/Folding IA.

If corresponding stations have uniform vegetation covers, aspects, elevations, and slopes, then similar small-scale climate patterns can be expected (Janz and Storr 1977). The relatively large discrepancies in mean daily maximum temperatures between Folding I/Folding IA compared to Folding II/Folding IIA, relative to Jasper Park East Gate (Figure 16), may be partly as a result of unrepresentative station siting. Folding I was in a small opening while Folding II was in a relatively large opening. The size of the

Figure 21: Scattergram of daily maximum temperatures (relative to Jasper Park East Gate) at Folding II and Folding IIA (°C, N= 24).

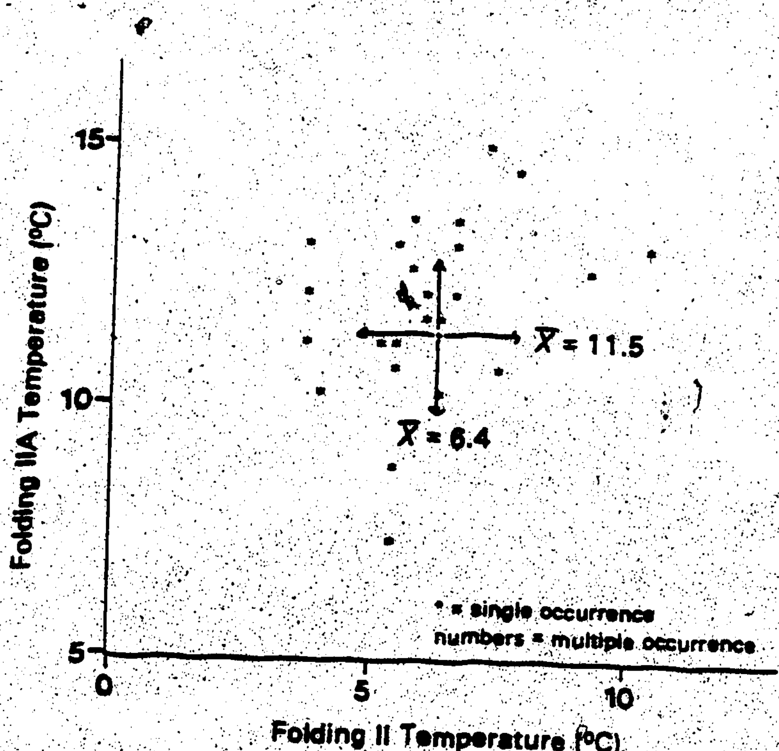
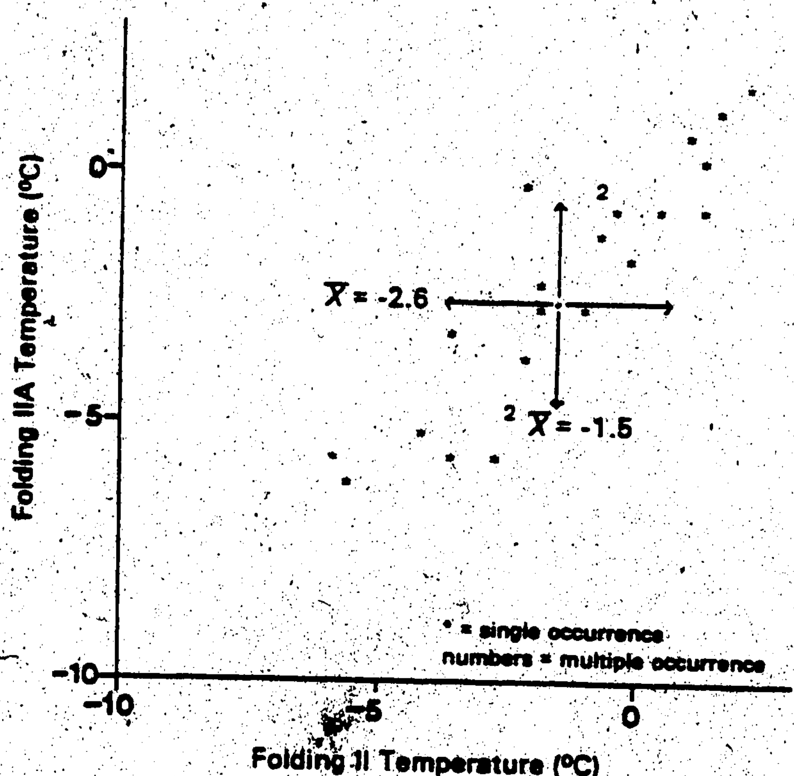


Figure 22: Scattergram of daily minimum temperatures (relative to Jasper Park East Gate) at Folding II and Folding IIA (°C, N = 24).



forest opening at Folding I was much smaller than that of Folding II (and Perdrix III) and, therefore, the mean daily maximum temperatures obtained at this site may not be directly comparable to those obtained from Folding II (Lee 1978).

The minimum temperatures for the 24 isochronic cases at Folding II and Folding IIA were not significantly different (Figure 17). Therefore, vegetation differences did not influence nighttime temperatures, which was also the situation at the two lower stations on the same slope, Folding I and Folding IA.

Using all available case measurements between Folding II and Folding IIA the same patterns emerged as those from the 24 isochronic cases (Table 7). There were differences in mean daily maxima, but not in their mean daily minima. Parallelisms in the temperatures between the Folding II/Folding IIA sites (Table 7) and between the Folding I/Folding IA sites (Table 6) were observed in the data. The mean daily maximum was 5.5±0.6°C higher at Folding II than at Folding IIA, which approaches the differences in the values recorded between Folding I and IA. The ranges of the extreme maximum and minimum differed by 7.5°C between Folding II and Folding IIA; Folding I and Folding IA had a comparable 8.2°C difference in their ranges over the same isochronic interval.

Folding IIB was a forested site near Folding II but its trees were not as tall as Folding IIA's (Plate 14 and Table 1). The 24 isochronic cases were not recorded at Folding IIB but over the course of the summer there were 81 corresponding cases between it and Folding II (Table 8). The relative richness (species diversity) in number of shrub species at Folding IIB is evident in Table 5. This forested site had more species and more individuals per unit area than Folding IIA.

Temperature data from Folding II/Folding IIB are presented in Table 8. Trends in temperature patterns were similar to those observed for Folding II/Folding IIA. Folding II's mean minimum relative to

Table 7: Descriptive statistics of differences, relative to Jasper Park East Gate, at southwest-facing Folding II, a non-forested site, and Folding IIA, a forested site (°C, N=47).

Variable	Station	Least	Greatest	Mean
Minima	Folding IIA	-6.6	2.1	-2.6±0.7°C
	Folding II	-5.8	3.0	-1.5±0.7°C
Maxima	Folding IIA	6.2	14.7	11.2±0.7°C
	Folding II	0.3	10.4	5.7±0.6°C

Table 8: Descriptive statistics of differences, relative to Jasper Park East Gate, at southwest-facing Folding II, a non-forested site, and Folding IIB, a forested site (°C, N=81).

Variable	Station	Least	Greatest	Mean
Minima	Folding IIB	−6.1	5.0	−1.6±0.5°C.
	Folding II	−5.8	4.8	−1.1±0.5°C.
Maxima	Folding IIB	4.3	15.9	9.2±0.5°C.
	Folding II	−4.0	10.4	3.6±0.5°C.

Folding IIB was approximately the same, at 0.5±0.5°C, and the mean maximum was higher than Folding IIB, by 5.6±0.5°C while the range of the extreme temperatures was 5.6°C more at Folding II than at Folding IIB.

The major dissimilarity between tree covers at Folding IIA and Folding IIB was that the latter site had tree heights that were about 8 m lower (Table 5). Therefore, the active surface would be further from the ground surface at Folding IIA than at Folding IIB. The shrub layer was rich in species at Folding IIB, but species diversity was limited at Folding IIA (Table 5). *R. oxyacanthoides*, which is common in moist sites, was present at Folding IIA. The shrubs at Folding IIB, such as *Shepherdia canadensis* and *R. woodsii* are more common of drier sites.

The slope angle at Folding IIA was 30°, and at Folding IIB it was 25°. There were 19 cases in common between these two sites (Table 9). At Folding IIA the mean minimum and mean maximum were 1.6±0.3°C higher and 1.7±0.6°C less, respectively, compared to Folding IIB. The difference in their mean minima may be explained in terms of topography and radiative fluxes. Cooler air drains downslope from the non-forested area above Folding IIB, and then percolates through the trees to reach Folding IIB (Plate 14). At Folding IIA the upslope fetch was only about 50 m, and at that point there

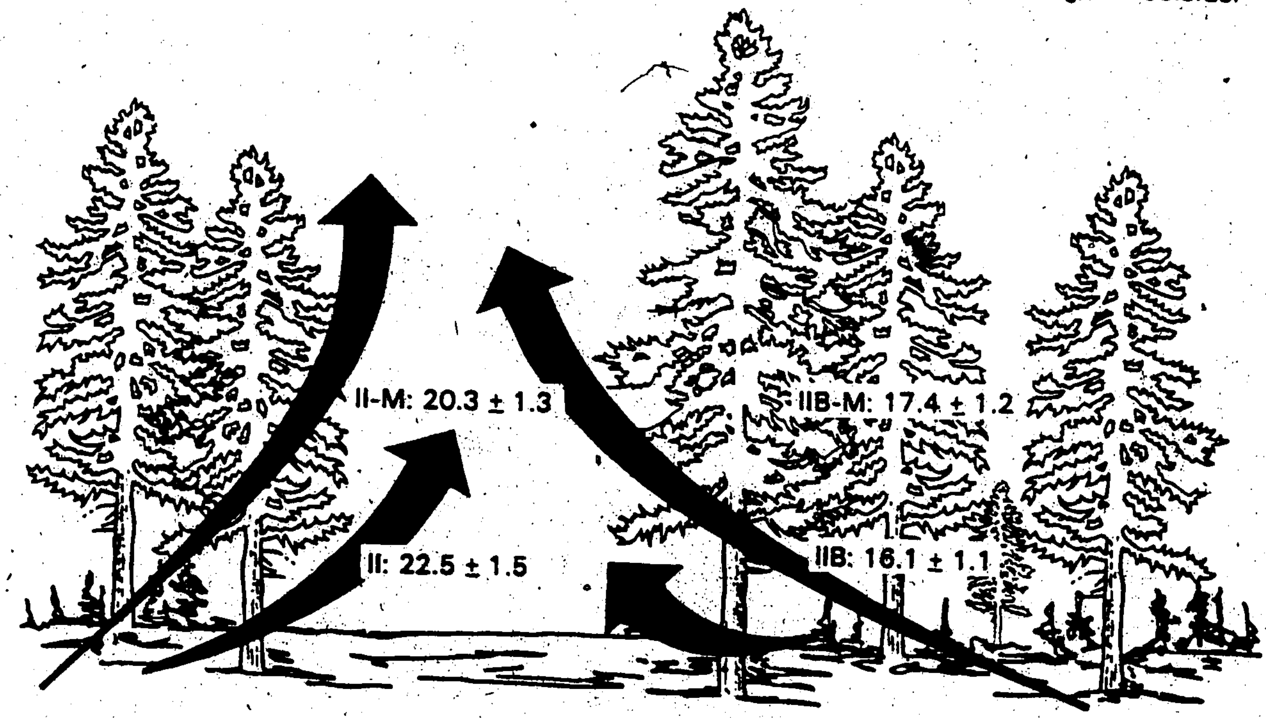
Table 9: Descriptive statistics of differences, relative to Jasper Park East Gate, at two southwest-facing, forested sites, Folding IIA and Folding IIB (ºC, N=19).

Variable	Station	Least	Greatest	Mean
Minima	Folding IIB	−4.3	1.9	−1.8±0.8ºC.
	Folding IIA	−5.9	−0.5	−3.3±1.0ºC.
Maxima	Folding IIB	7.8	11.8	9.9±0.6ºC.
	Folding IIA	7.0	14.6	11.7±0.8ºC.

was a near vertical drop of 200 m (Figure 2). Due to topographic dissimilarities these two sites would have differences in the extent to which they were affected by the cold air density flows that originated upslope from each of them. Thus, surrounding topographic features seem to play a relative role in determining nighttime temperatures. The relatively warm afternoon values at Folding IIB compared to Folding IIA are due to the differences in their surrounding vegetation covers. The forest floor at Folding IIA did not heat up as much during the day because it was further from the active surface.

There is another factor besides vegetation height which may have been operative in producing higher temperatures near the forest floor at Folding IIB compared to Folding IIA. The side of the mountain up the slope from Folding IIB and the area along the contour towards Folding II did not have a continuous tree cover. Openings such as these which are near a moderate to dense timber stand may become warm air-pockets during the day. They act as natural "chimneys" under conditions of strong heating (Schroeder and Buck 1970). Cooler air near the forest floor replaces the rising air in the opening. This type of circulation system would draw some of the relatively warm air from above the forest floor down to a lower level. Figure 23 illustrates this phenomenon with actual data from the corresponding temperature

Figure 23: Thermal field producing the "chimney effect" between Folding II and Folding IIB (N = 57). Adapted from Schroeder and Buck (1970). Temperatures in degrees Celsius.



fields at standard-height and ground-level within the "chimney" area and adjacent forested site. The effect of the surrounding vegetation on temperature at Folding IIB was that this site would be warmer than Folding IIA during afternoons.

4.2.2.1.3 Perdrix II vs Perdrix III

Perdrix II and Perdrix III had approximately the same elevations, aspects, and slope angles, but their percent crown covers were different. Perdrix II had a dense forest canopy composed of balsam fir and white spruce which were approximately 10 to 12 m tall. Perdrix III had a thin covering of white spruce (Table 4). The shrub layers had few similarities (Plates 6 and 8, and Table 5). Most of the shrubs at Perdrix III were species that would develop into trees if left undisturbed. A characteristic of the vegetation at both is that the trees and shrubs were associated with moist habitats.

The daily maxima for the 24 isochronic cases at Perdrix III were significantly higher than at the nearby forested site, Perdrix II (Figures 16 and 24). Using all available cases (N=94) this same pattern recurred, with the mean daily maximum averaging 2.0±0.4°C higher in the avalanche chute (Table 10).

The mean daily minimum temperatures for the 24 isochronic cases were not similar between these two adjacent sites, Perdrix II and Perdrix III (Figures 17 and 25). At the 95% confidence level, the mean daily minimum temperature at Perdrix III was significantly less than that at Perdrix II. Using all available cases (N=94) the average difference between

Figure 24: Scattergram of daily maximum temperatures (relative to Jasper Park East Gate) at Perdrix III and Perdrix II (°C, N= 24).

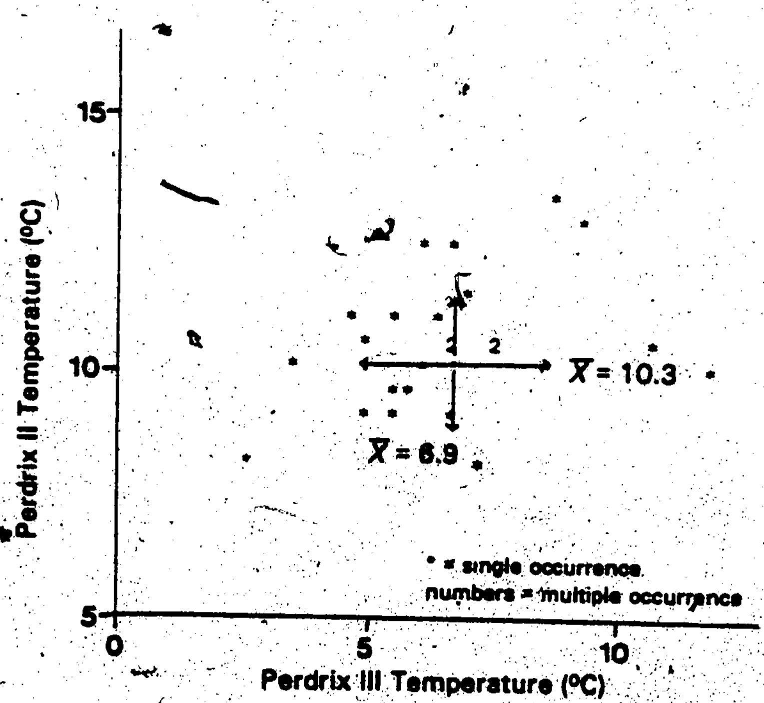
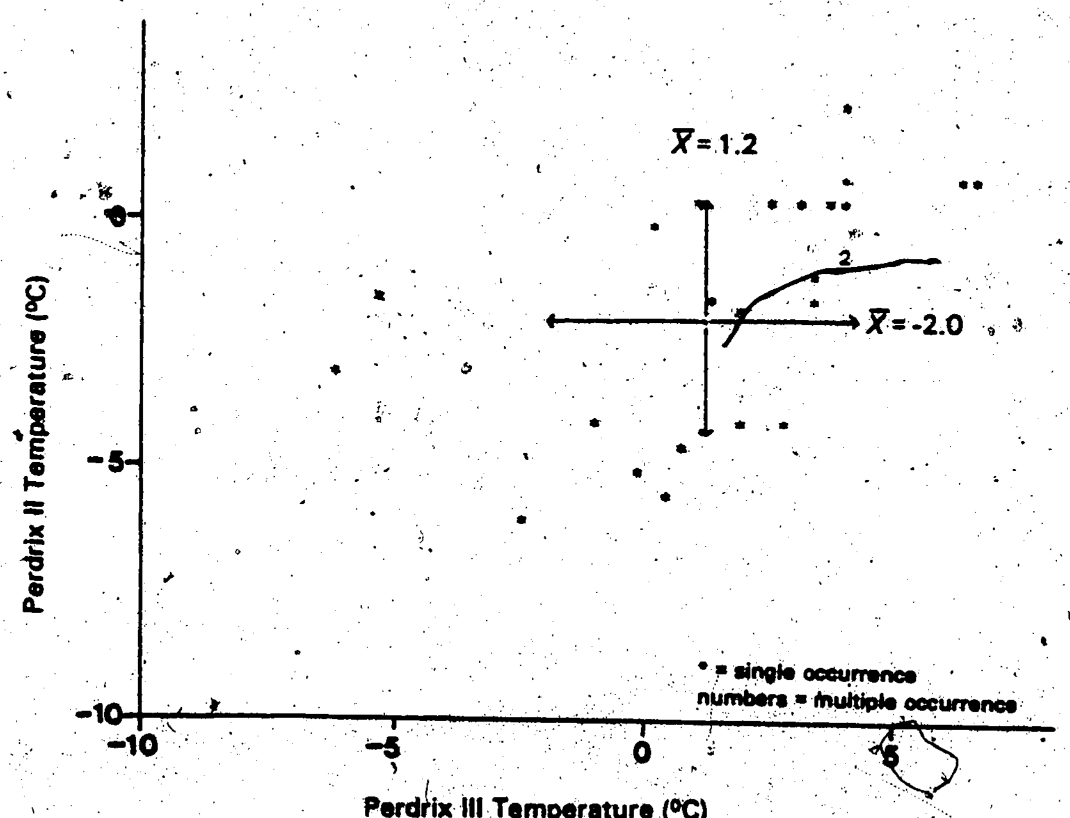


Table 10: Descriptive statistics of differences, relative to Jasper Park East Gate, at two northeast-facing, forested sites, Perdrix II and Perdrix III (°C, N=94).

Variable	Station	Least	Greatest	Mean
Minima	Perdrix III	-7.5	7.2	0.6 ±0.6°C.
	Perdrix II	7.7	3.4	-2.3±0.6°C.
Maxima	Perdrix III	1.3	17.8	8.5±0.6°C.
	Perdrix II	3.3	19.3	10.5±0.5°C.

Figure 25: Scattergram of daily minimum temperatures (relative to Jasper Park East Gate) at Perdrix III and Perdrix II (°C, N = 24).



these two adjacent sites was 2.8±0.2°C. The range in temperatures was 8.6°C greater at Perdrix III than at Perdrix II. This was more than the ranges between any of the Folding Ridge stations discussed above and was due in part to the relatively cool temperatures at night in the avalanche track compared to its surrounding area. For example, the lowest temperature at Perdrix III was -3.3°C, and at Perdrix II it was 0.3°C, a range of 3.6°C. At the Folding stations the differences between the minimum values were not as extreme. They ranged from 0.2°C at Folding I/Folding IA to 1.5°C at Folding IIA/Folding IIB.

Of the three paired sites that had vegetation cover as their major dissimilarity only Perdrix II/Perdrix III had a significant difference in their mean daily minimum temperatures (Figure 17 and 24). At these latter sites the differences in their minima may be accounted for by another causal factor; local topographic dissimilarites. Supportive evidence for this is the differences in mean daily minimum temperatures between Folding IIA and Folding IIB. The tree heights at Folding IIA and Folding IIB were not identical but it has already been demonstrated (viz. Folding I/Folding IA and Folding II/Folding IIA) that differences in vegetation cover do not significantly influence minimum temperatures on Folding Ridge. The other site characteristics, slope, elevation, and aspect, were similar, the exception being in their topographic settings upslope from each of these two stations. Up the slope from Folding IIB there was a long fetch, while up the slope from Folding IIA there was a relatively short fetch. Therefore, due to topographic dissimilarities, these two sites would have differences in the degree to which they were affected by cold air density flows which originated upslope from them. Both pairs of sites, Folding IIA/Folding IIB and Perdrix II/Perdrix III, had significantly different minima using corresponding cases at all four stations (N=17). The mean daily minimum at Folding IIA, with its short upslope fetch, was 1.5±0.3°C higher than Folding IIB, and Perdrix II was 2.5±1.5°C higher than Perdrix III, the avalanch site.

Vegetation dissimilarities cannot always account for the temperature differences in mean daily minimum temperatures between a forested and non-forested site at all sites in the Drystone Valley. Another climate influencing factor must have been involved at Perdrix II/Perdrix III (and Folding IIA/Folding IIB). Perhaps the channelling of the katabatic flow in the avalanche chute magnified the temperature discrepancies at night between Perdrix II and Perdrix III, and the relatively long upslope fetch at Folding IIB influenced night temperatures there compared to Folding IIA. More study is needed to clarify these observed differences in mean minimum temperatures.

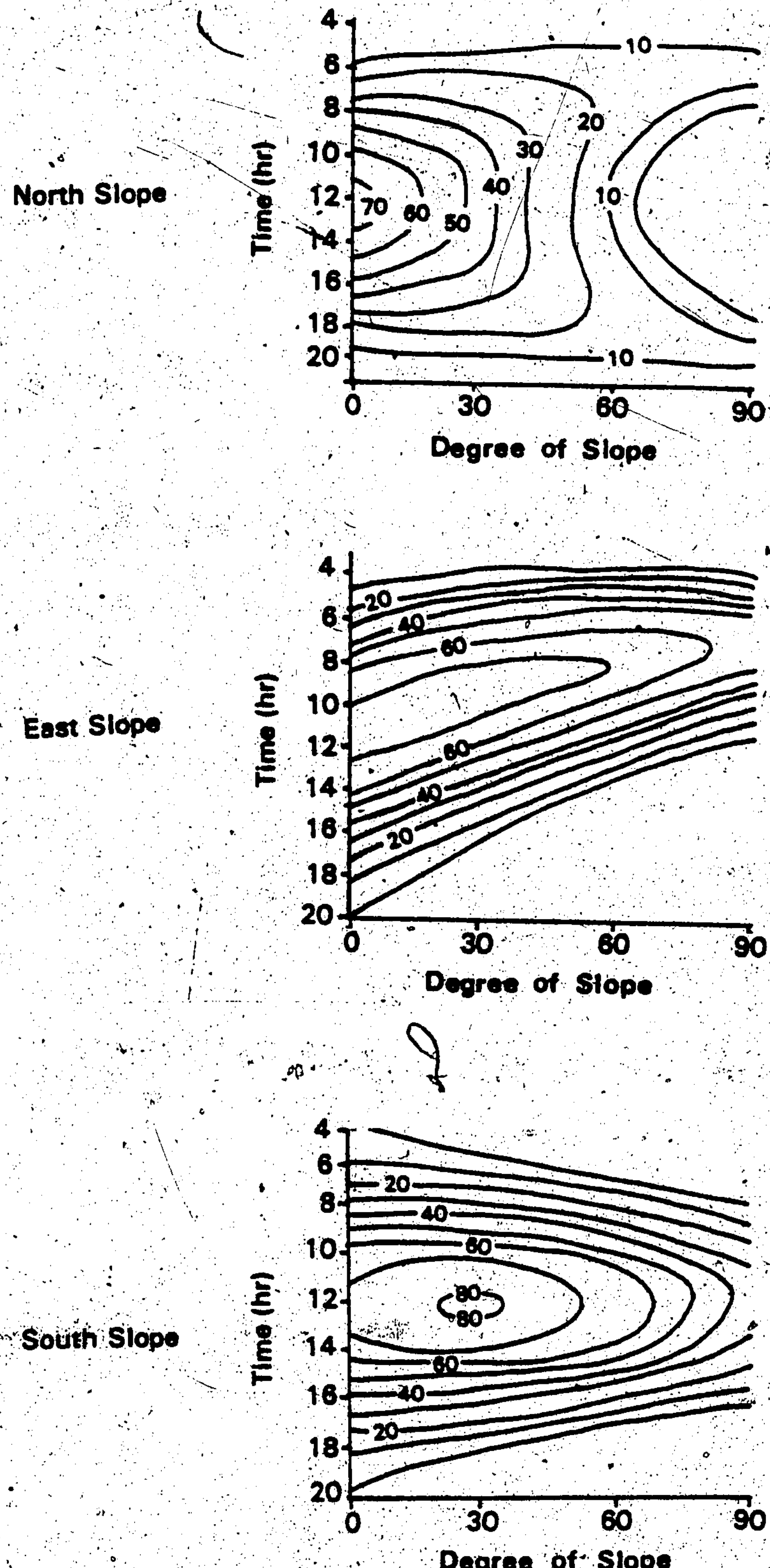
4.2.2.2 Climate-aspect Interrelationships

Aspect, or orientation, and angle of slope have fundamental effects on radiation income and temperature fields in mountainous areas (Barry 1981). This is because the flux density of radiation on a sloping surface is different from that on a horizontal surface. It is primarily the direct beam component that is modified but minor differences occur because the flux of diffuse sky radiation is affected, and shortwave radiation is reflected from adjacent portions of the landscape (Lee 1978). The total shortwave radiation incident on a sloping surface is specified by the sum of the direct, diffuse, and reflected radiation components incident on the particular sloping surface (Hay 1977). However, the effect of slope in terms of net radiation is much more complex when the infra-red fluxes are considered (Barry 1981).

The effects of slope and aspect on direct solar radiation in cloudless weather are illustrated in Figure 26 for sites at 50° North latitude. The left hand margins of each show the radiation received on the horizontal and so they are identical for all three slope orientations. The right hand margins indicate the radiation received on vertical slopes. A west-facing slope would be a mirror image of the east-facing slope. Cloudiness, however, reduces the differences among the sites presented in this figure (Geiger 1965).

In this section the climate observed at locations with contrasting aspects is compared. The sites were selected so that the effects

Figure 26: Direct solar radiation (cal. cm^{2} hr^{-1}) on cloudless days on north, east and south slopes for all inclinations on the 22 June at 50°N latitude (Source: Geiger 1965).



of other climate-influencing factors, elevation, slope angle, and vegetation cover, were minimized. There were three pairs of sites that had relatively similar characteristics except for aspect. The slope angles, tree coverings, and elevations were approximately the same at each of Perdrix I/Folding IA, Perdrix II/Folding IIA, and Perdrix III/Folding II. Differences in climate between each pair can, therefore, be largely attributed to aspect.

4.2.2.2.1 Folding IA vs Perdrix I

Elevations, slope angles, and tree crown covers and heights at Folding IA and Perdrix I were the most similar of the three pairs of sites mentioned above. They should be considered the paired sites most indicative of aspect effects because of this. The slope orientation at Folding IA was southwest and at Perdrix I it was northeast.

The differences in mean daily maxima between Folding IA and Perdrix I, relative to Jasper Park East Gate, were significant at the 95% confidence levels (Figure 16). A scattergram of the case values is presented in Figure 27. The southwest-facing station, Folding IA, was warmer than the northeast-facing station, Perdrix I. The differences, however, were much less than those between sites with the same aspects but contrasting crown covers (Figure 16).

The mean daily minimum temperatures were nearly identical between Folding IA and Perdrix II (Figures 17 and 28). They were both in the thermal belt above the valley bottom, and were 2.9±1.0°C higher than Jasper Park East Gate.

Using all available cases there were 39 days with corresponding data between Folding IA and Perdrix I. The patterns in these cases were similar to the 24 isochronic cases. The average maximum was higher at Folding IA than Perdrix I by 1.2±0.4°C (Table 11) but, there was no significant difference in their mean daily minima (0.1±0.3°C). The range in the actual extreme temperatures was 2.8°C greater at Folding IA than at Perdrix I.

Figure 27: Scattergram of daily maximum temperatures (relative to Jasper Park East Gate) at Folding IA and Perdrix I (°C, N = 24).

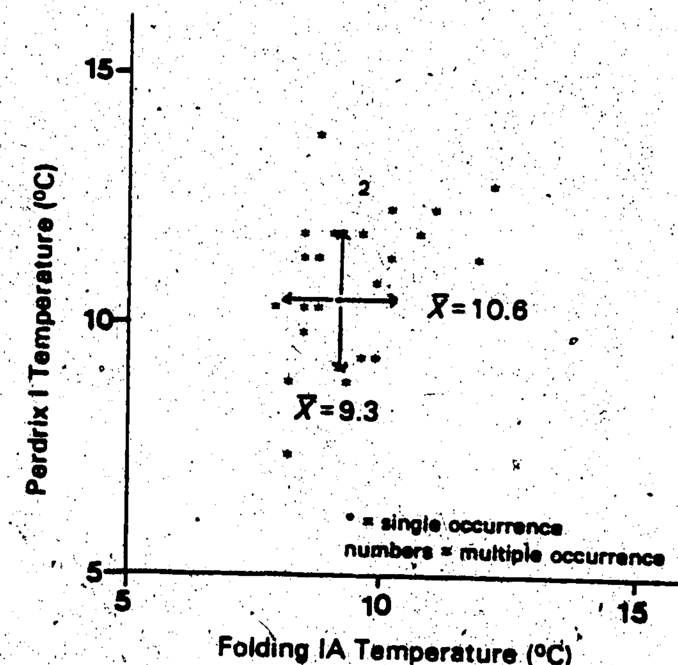


Figure 28: Scattergram of daily minimum temperatures (relative to Jasper Park East Gate) at Folding IA and Perdrix I (°C, N = 24).

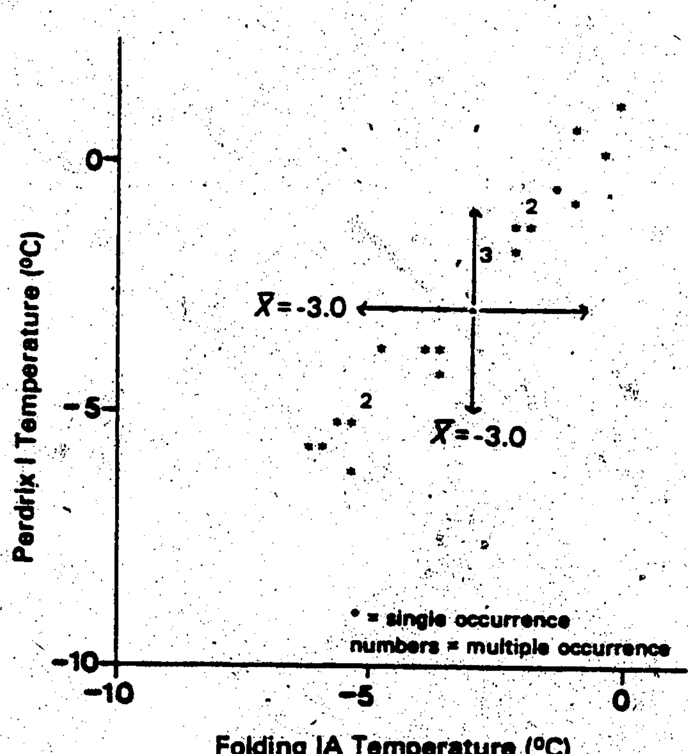


Table 11: Descriptive statistics of differences, relative to Jasper Park East Gate, at two forested sites, the northeast-facing Perdrix I, and the southwest-facing Folding IA (°C, N=39).

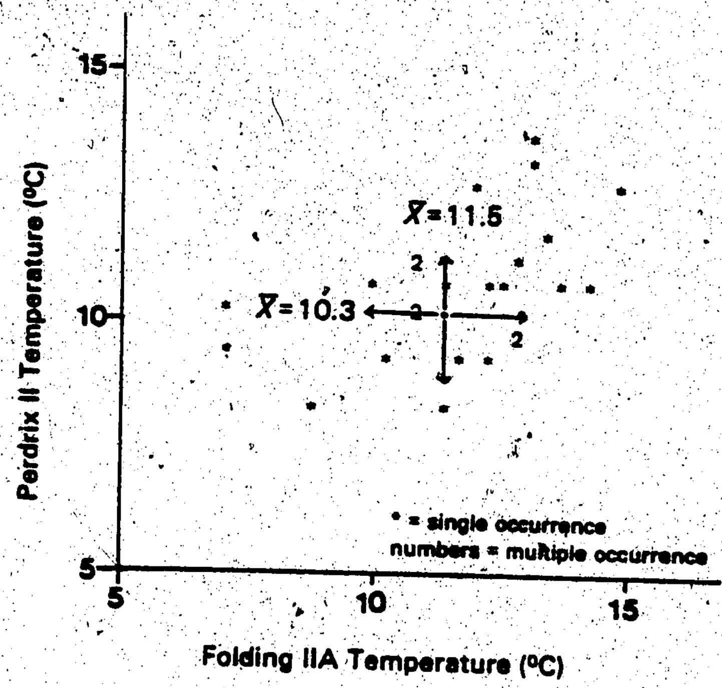
Variable	Station	Least	Greatest	Mean
Minima	Perdrix I	−6.4	1.3	−2.9±0.8°C.
	Folding IA	−6.1	0.9	−3.1±0.7°C.
Maxima	Perdrix I	4.0	13.3	9.9±0.7°C.
	Folding IA	3.9	12.4	8.7±0.6°C.

4.2.2.2.2 Folding IIA vs Perdrix II

Folding IIA and Perdrix II were forested sites on opposite sides of the valley. The trees at Folding IIA were 20 m high and at Perdrix II they were 11 m. There was a significant difference in the mean daily maximum temperatures between the upper stations. Unlike the mid-slope stations, the northeast-facing Perdrix II was warmer than the southwest-facing Folding IIA (Figure 29). Vegetation differences between Folding IIA/Perdrix II relative to those differences between Folding IA/Perdrix I appear to account for the mid-slope station on Folding and the upper station on Perdrix being the warmer sites. The justification for this is that Folding IIB, which had average tree heights of 12 m, was 1.5±0.9° higher than Perdrix II (N=17). Thus, the effects of a tall, dense tree cover were influential in ameliorating the daytime temperatures near the ground even on a southwest-facing slope.

Mean daily minimum temperature differences between Folding IIA and Perdrix II (Figure 30) followed the same trend as those observed between the other sites that had contrasting aspects as their major site dissimilarities. Even though the vegetation cover can affect daily maximum temperatures it did not exert an observable effect on minimum temperatures at sites with contrasting aspects (Figure 17). Using all available cases (N=44), these same patterns were observed (Table 12).

Figure 29. Scattergram of daily maximum temperatures (relative to Jasper Park East Gate) at Folding IIA and Perdrix II (°C, N = 24).



4.2.2.2.3 Folding II vs Perdrix III

Folding II and Perdrix III were the only pair of non-forested stations that had all site characteristics similar except for aspect. For the 24 isochronic cases there was no significant difference in their mean daily maximum temperatures (Figures 16 and 31). Because of the relatively high amount of radiation received on a southwest-facing slope compared to a northeast-facing slope (Figure 26) it might be expected that there would have been a larger difference in maximum temperatures. Several factors account for this. In the mornings during that time of year the rays from the sun strike the avalanche track before they do the southwest-facing slope on Folding Ridge. Daytime heating, which reverses the downward diurnal cycle in temperature, begins sooner in the day at Perdrix III than Folding II. Also, during this period, which encompassed a record breaking warm spell in west-central Alberta (A.E.S.

Figure 30: Scattergram of daily minimum temperatures (relative to Jasper Park East Gate) at Folding IIA and Perdrix II (°C, N = 24).

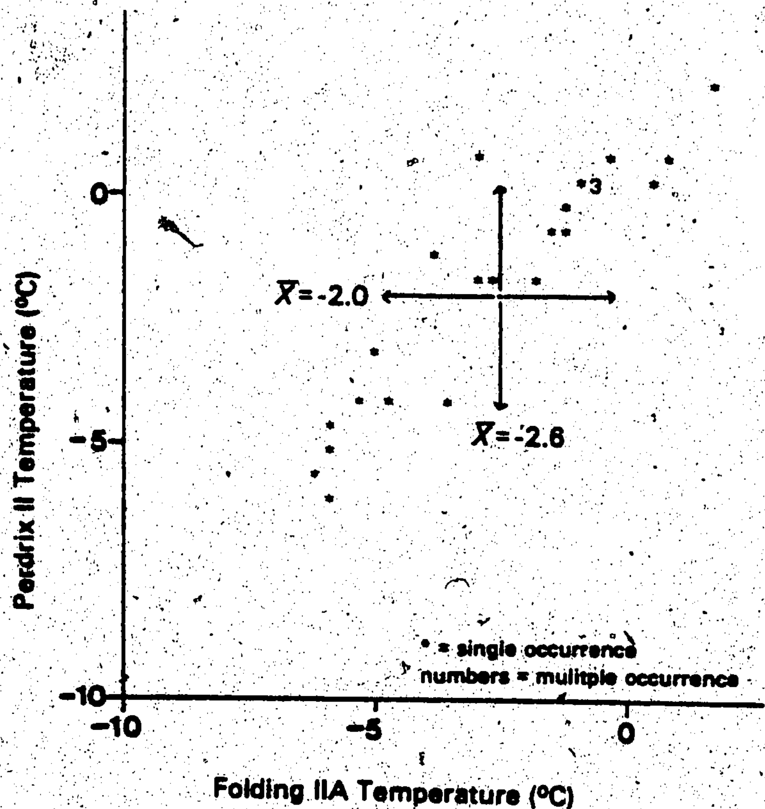
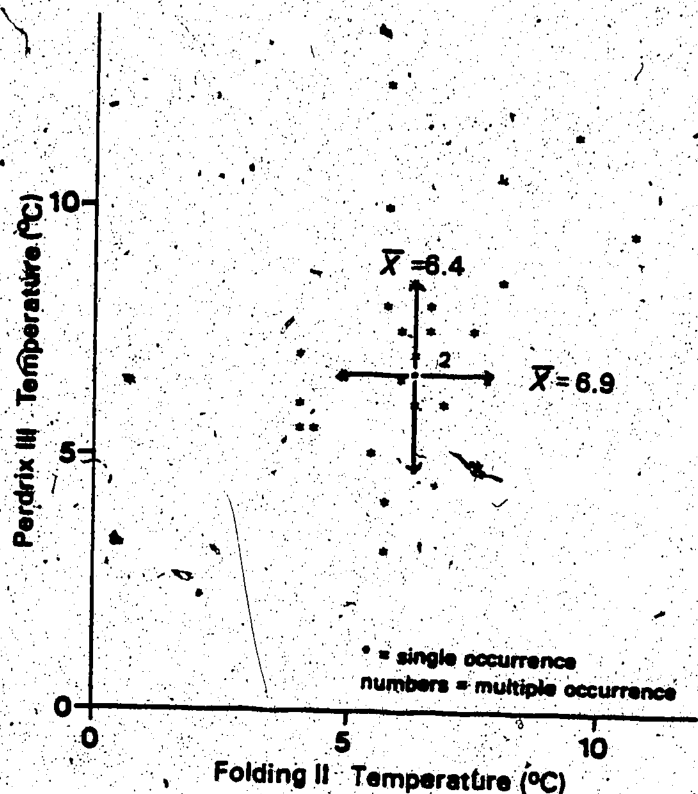


Table 12: Descriptive statistics of differences, relative to Jasper Park East Gate, at two forested sites, the northeast-facing Perdrix II, and the southwest-facing Folding IIA (°C, N=44).

Variable	Station	Least	Greatest	Mean
Minima	Perdrix II	-7.0	3.0	-2.0±0.8°C.
	Folding IIA	-6.6	2.1	-2.5±0.8°C.
Maxima	Perdrix II	3.3	13.0	9.9±0.6°C.
	Folding IIA	6.2	14.7	11.1±4.6°C.

Figure 31: Scattergram of daily maximum temperatures (relative to Jasper Park East Gate) at Folding II and Perdrix III (°C, N = 24).



1979d), there were 10 days with rain (A.E.S. 1979h,i) from convective storms and many others when fair-weather clouds developed. The clouds and storms usually occurred in the late-afternoons, which was the time of day that Folding II would have been receiving a maximum amount of radiation. It seems that the shading from the afternoon cloud retarded the upward cycles in the daily maximum temperatures at Folding II, but not to the same extent at Perdrix III. Daytime maxima were recorded earlier at Perdrix III during these days because the balance between incoming and outgoing radiation would be attained earlier on a northeast-facing slope than on a southwest-facing slope (Rosenburg 1974). However, over the course of the summer there was, in fact, a significant difference in their mean daily maximum temperatures. Folding II averaged 4.4±0.8°C higher than Perdrix III (N=99) (Table 13).

Table 13: Descriptive statistics of differences, relative to Jasper Park East Gate, at two non-forested sites, the northeast-facing Perdrix III, and the southwest-facing Folding II (°C, N=99).

Variable	Station	Least	Greatest	Mean
Minima	Perdrix III	-7.5	7.2	0.6±0.6°C.
	Folding II	-5.8	4.8	-1.0±0.4°C.
Maxima	Perdrix III	1.3	17.8	8.5±0.6°C.
	Folding II	-0.6	10.4	4.1±0.5°C.

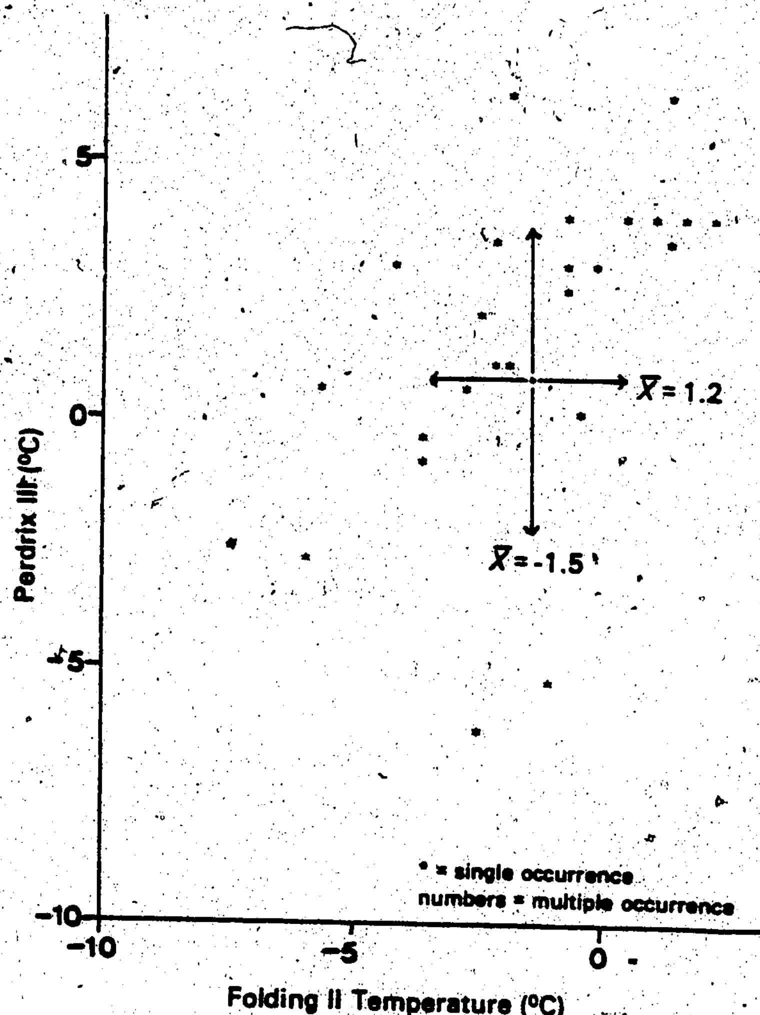
Mean daily minimum temperatures were significantly different between these two sites during the period that the 24 isochronic cases were measured (Figures 17 and 32). The geometry of the avalanche track, as discussed previously, appears to have accentuated the temperature differences between Folding II and Perdrix III. Over the course of the summer there was a relatively small difference in their mean minima (1.6±0.4°C), compared to the larger difference in their mean maxima. Thus, the effects of a nighttime negative radiation flux were not as intense as the effects of a daytime positive flux at these two non-forested sites.

4.2.2.3 Climate-elevation interrelationships

Elevation is of primary importance in the study of climate in mountainous regions (Barry 1981). The variation of temperature with height above a mountain valley floor is important in the vertical exchange of heat, moisture, and momentum (Lester 1974). The effects of elevation on atmospheric variables must be understood to develop models that can be used to extrapolate data to specific operational sites (McCutchan *et al.* 1981).

A comparison of mean daily minima and maxima July temperatures, and elevation in Jasper National Park is presented in Figure 33.

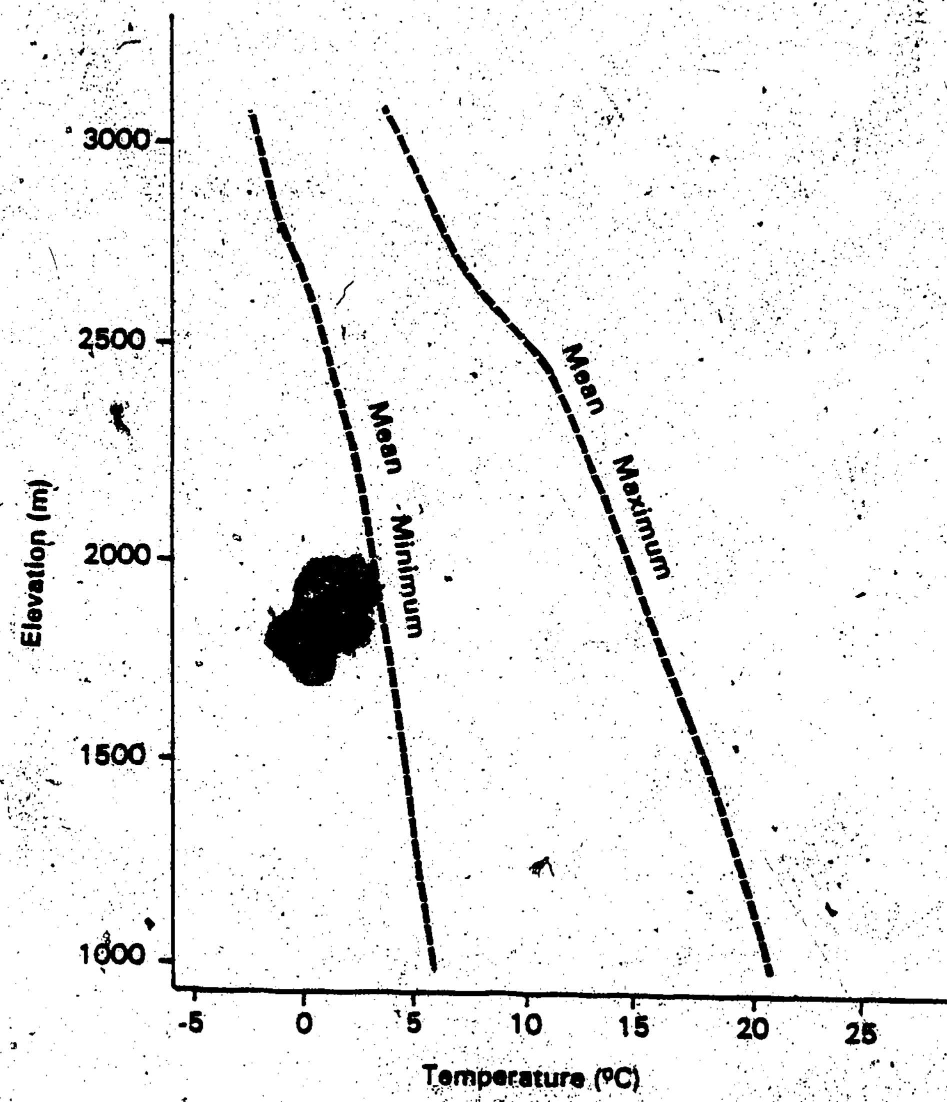
Figure 32: Scattergram of daily minimum temperatures (relative to Jasper Park East Gate) at Folding II and Perdirx III (°C, N = 24).



The curves were synthesized from measurements taken at Marmot Creek Basin in southwestern Alberta, and mean free air temperatures from radiosonde flights above Edmonton, Alberta and Vernon and Prince George, British Columbia (Janz and Storr 1977). In general, higher elevations are associated with increases in precipitation and wind, lower temperatures, and a decreasing range in diurnal temperatures (Janz and Storr 1977).

Storr (1970) found that surface air temperatures at Marmot Creek Basin were slightly higher than temperatures in the free atmosphere at

Figure 33: Estimated temperature - elevation relationship in Jasper National Park in July (Source: Janz and Storr 1977).



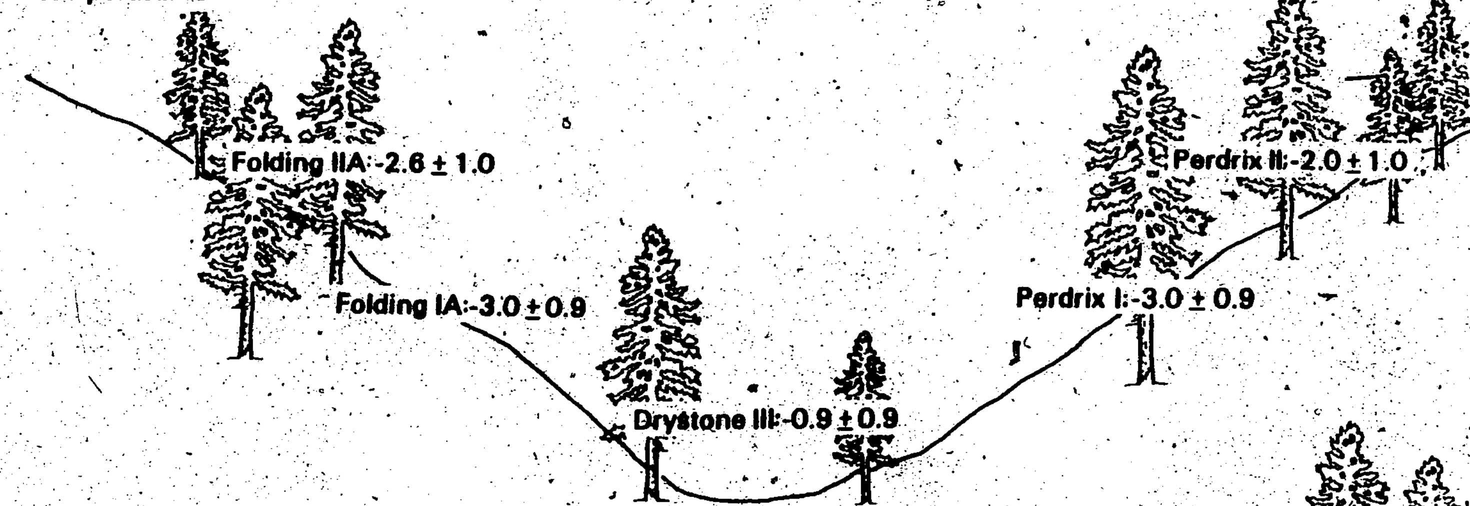
the same height. By comparison with the surrounding atmosphere, the air over a mountain slope is affected by radiative and turbulent heat exchanges. These processes modify the temperature structure over the ground surface so that lapse rates on a mountain slope may differ from those in the free atmosphere according to the time of day (Barry 1981).

Five stations in the Drystone Creek Valley, Perdrix I, Perdrix II, Folding IA, Folding IIA, and Drysone III, and Jasper Park East Gate station had relatively similar vegetation covers but contrasting topographic settings. The differences in air temperature measurements for the 24 isochronic cases at these sites relative to Jasper Park East Gate (*i.e.* Jasper Park East Gate = 0.0°C) are presented in Figure 34. Drystone III, the valley bottom station, had a mean daily minimum temperature which was approximately the same as Jasper Park East Gate's while the mid-slope stations were significantly warmer than Jasper Park East Gate (Figure 17). The higher-level stations were about 1°C less than the mid-slope sites. The implications of this temperature field is that there was a pronounced valley inversion and thermal belt (Schroeder and Buck 1970) during the 24 isochronic cases period. Nighttime inversions are a common occurrence during summer in the Rocky Mountains of Alberta and British Columbia (MacHattie 1970, Powell 1970). In the Marmot Creek Basin they were especially well developed under conditions of light winds and clear skies. MacHattie (1970) reported that inversions were usually concentrated in the lowest 91 m (300 feet) of the atmosphere. They had an average temperature increase of 5.0°C within this layer. Above this the air was approximately isothermal for another 150 m (500 feet).

The combination of elevation and vegetation on Folding Ridge indicates that a forest cover tends to ameliorate daily minimum temperatures (Figure 17). This is because Folding IA/Folding IIA (Figure 35), the forested sites, had similar temperatures but, Folding I/Folding II (Figure 36) had significantly different values for the 24 isochronic cases period. Perdrix I/Perdrix II (Figure 37) also had minimum temperatures which were virtually the same as the four Folding sites. Therefore, for all the forested sites on the valley slopes, aspect was not influential in determining night temperatures (Figures 14 and 17). The same results were not observed, however, for the non-forested Perdrix III. Because aspect, elevation, and vegetation cover did not exert a pronounced effect on the mean daily minima at the other stations the conclusion can be made that another factor was involved at Perdrix III. As discussed previously, the topographic setting of the

Figure 34: Differences in temperatures at selected sights relative to Jasper Park East Gate (i.e. T°C JPEG — T°C STATION) (N = 24).

(a) Minimum temperatures



(b) Maximum temperatures

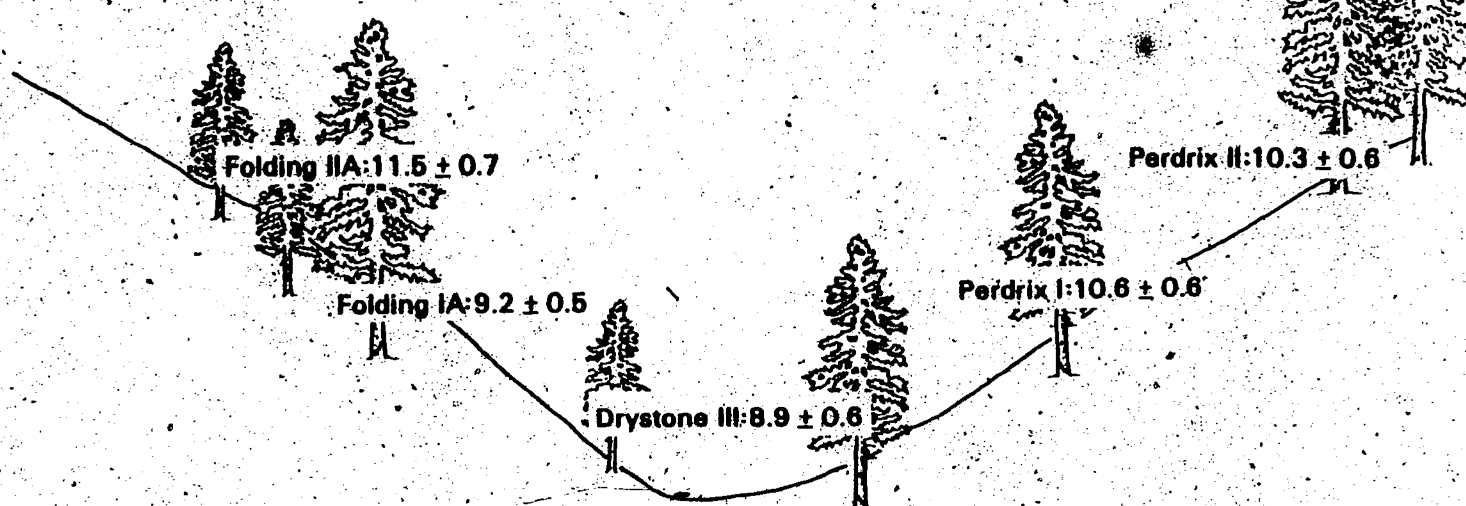


Figure 35: Scattergram of daily minimum temperatures (relative to Jasper Park East Gate) at Folding IIA and Folding IA (ºC, N = 24).

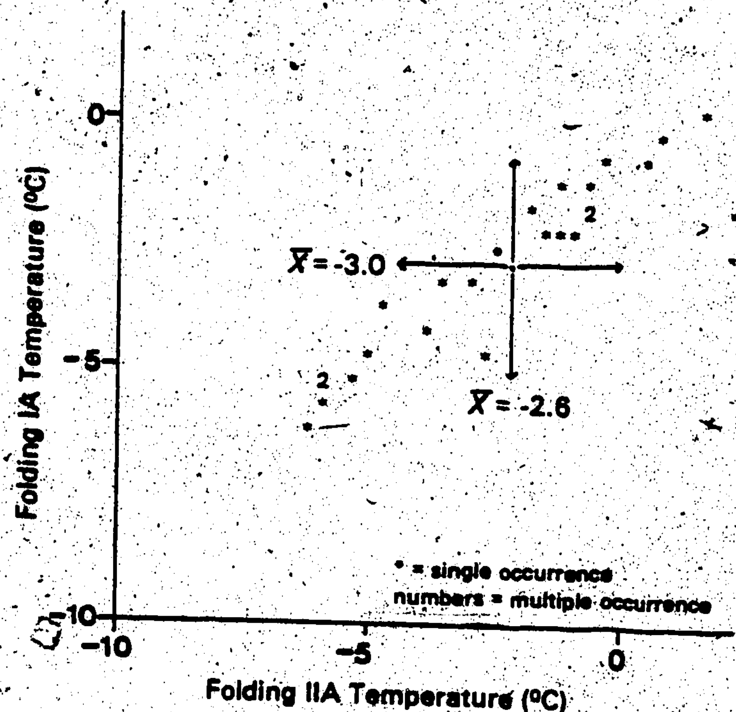


Figure 36: Scattergram of daily minimum temperatures (relative to Jasper Park East Gate) at Folding II and Folding I (ºC, N = 24).

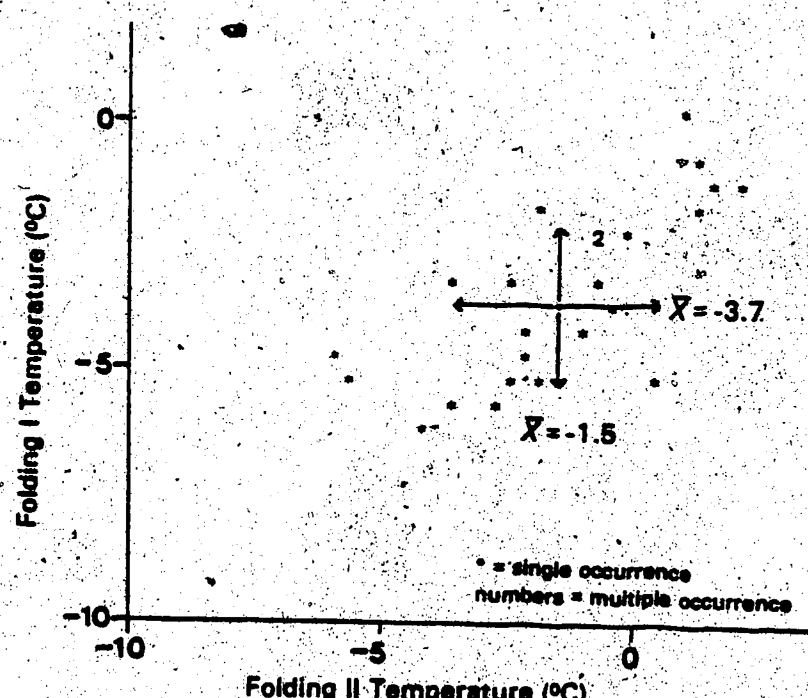
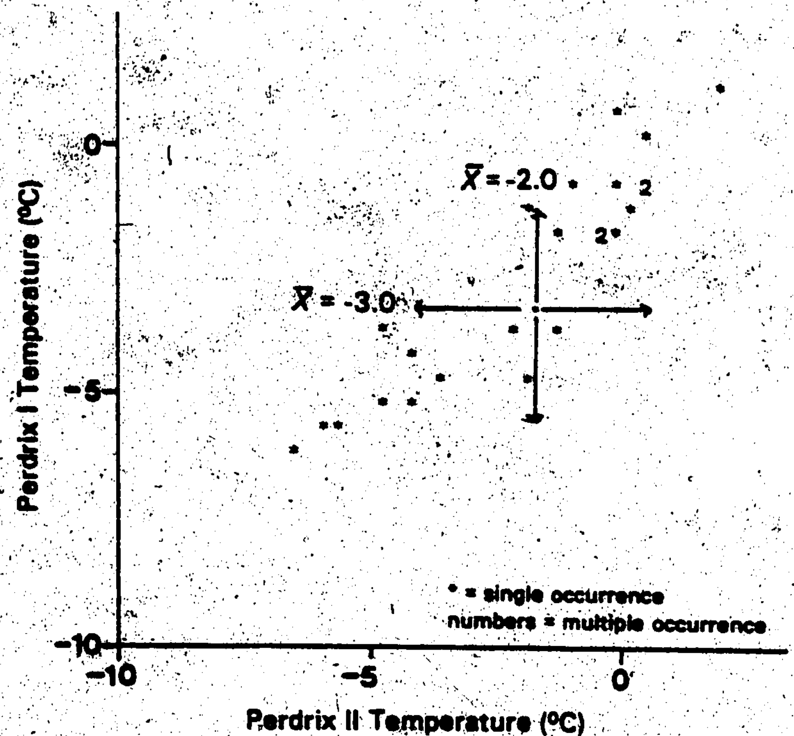


Figure 37: Scattergram of daily minimum temperatures (relative to Jasper Park East Gate) at Perdrix II and Perdrix I (°C, N = 24).



avalanche track appears to modify temperatures by reducing them relative to the other Drystone network stations on the slopes of the valley. The cold air drainage flow in the avalanche chute outweighed the ameliorating effect of the thermal belt measured at the other stations.

The mean daily maximum temperatures for the five sites with relatively similar site characteristics, except for elevation, and Jasper Park East Gate are illustrated in Figure 34. The general pattern is a reversal of the mean daily minimum temperature field. The valley bottom site, Drystone III, was milder than the stations on the valley slopes. Using a standard environmental lapse rate of 0.6°C per 100 m (Janz and Storr 1977) the differences in temperatures between Jasper Park East Gate and Drystone III should be about 1.4°C. The actual difference was 8.9±0.6°C and because of such a large discrepancy there appears to be other factors besides elevation differences involved in producing cooler daytime temperatures along the valley bottom. Drystone III was within 10 m of Drystone Creek. Its waters remained cool throughout the summer months and would have acted as a heat sink during the day because of conduction and latent heat exchanges. Additionally, the period of daytime heating is longer at Jasper Park East Gate than at the Drystone site because Folding Ridge casts a shadow over Drystone Creek in the early mornings. The slopes of Roche à Perdrix do the same in the evening. During the summer Jasper Park East Gate is not affected by these shadows.

The mean daily maxima were higher at Jasper Park East Gate than at the Perdrix stations (Figure 16). During the afternoons, using all available cases, the two forested sites, Perdrix I and Perdrix II, were approximately 10.5±0.5°C less than Jasper Park East Gate.

Unlike the forested sites Folding II/Folding IIA the differences in daily maxima between Perdrix I and Perdrix II were not significant (Figure 16). A plot of their maxima relative to Jasper Park East Gate (Figure 38) is more similar to that of the maxima at the two forested sites on Folding Ridge (Figure 39), then it is to the non-forested Folding sites (Figure 40). The height of the trees were greater at Perdrix I than at Perdrix II and this difference may have influenced the maximum temperatures to the extent that the expected cooling, as predicted by a standard environmental lapse rate, was not observed.

The mean daily maximum temperatures were milder at Jasper Park East Gate than at most of the Folding stations (Figure 16). Folding I was the lone exception. It had approximately the same mean daily maximum (±0.4°C) as Jasper Park East Gate. The vegetation cover, aspect, and slope orientation were similar at Folding I and Folding II yet, over the course of the summer Folding II averaged 4.0±0.5°C less than Jasper Park East Gate (N=122) and 4.1±0.5°C less than Folding I (N=117). The relatively large discrepancy between these stations may be due to the effects of the preceding night inversions and site specific characteristics. Folding II was above the

Figure 38: Scattergram of daily maximum temperatures (relative to Jasper Park East Gate) at Perdrix II and Perdrix I (°C, N = 24).

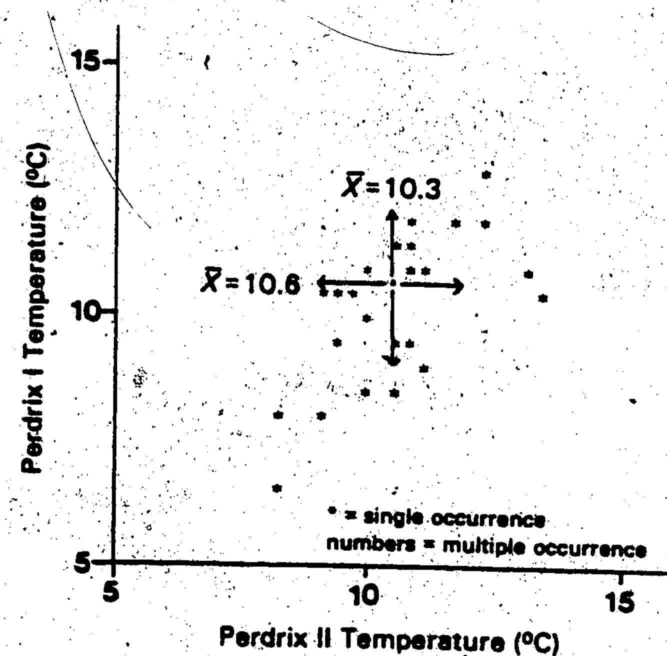


Figure 39: Scattergram of daily maximum temperatures (relative to Jasper Park East Gate) at Folding IIA and Folding IA (°C, N = 24).

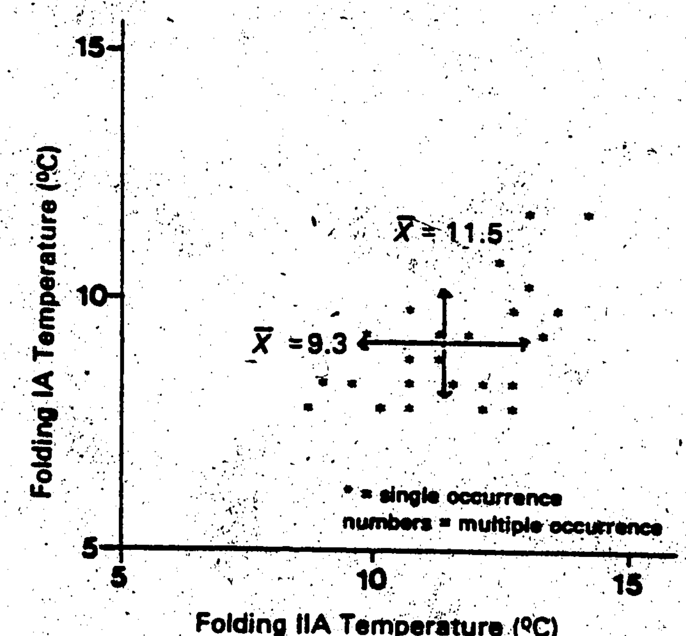
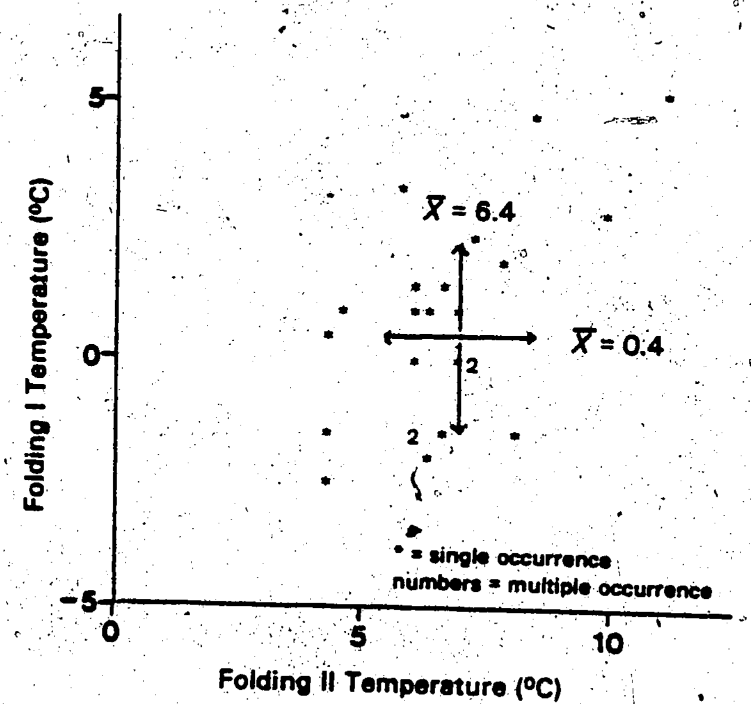


Figure 40: Scattergram of daily maximum temperatures (relative to Jasper Park East Gate) at Folding II and Folding I (°C, N = 24).



warmest layer of the thermal belt and so, dew would have been more common there then at Folding I. It would require a greater proportion of Folding II's radiant energy to be translated into latent heat instead of into sensible heat. Secondly, winds are generally stronger with increasing elevation. The effect of this is that heat would be redistributed better from the surface at Folding II which would result in air temperatures that are not as high as those in sheltered sites, such as Folding I (Lee, 1978). Thus, Folding I's site was acting as more of a "chimney" than was Folding II's site (Figure 23).

Jasper Park East Gate was milder than the remaining Folding sites. Folding IA had similar site characteristics to Folding IIA but it was 213 m lower in elevation. Maximum temperatures, using all available cases, at Folding IA and Folding IIA averaged 8.6±0.6°C (N=42) and 11.2±0.6°C (N=47) less than Jasper Park East Gate, respectively.

CHAPTER 5: CONCLUSIONS

Mountains influence the general circulation of the atmosphere, the formation and the evolution of frontal systems and pressure patterns, and most dramatically, the weather in their vicinity (Scientific and Technological Activities Commision 1982). The importance of mountains' effects on weather related phenomena has been acknowledged by several organizations whose mandates are to further the study of meteorology and climatology. For example, the American Meteorological Society recently established a scientific and technological committee to coordinate and advance our understanding of atmospheric phenomena in orographic regions. One of this committee's main thrusts will be the study of microclimate in mountainous topography.

The climate of a mountainous valley is diverse (Barry 1981, Janz and Storr 1977). Its climate is controlled primarily by the valley's dimensions and orientation, the rise of terrain encircling it, and the slope and aspect of the valley walls (Lester 1974). Climate on a smaller scale is controlled by the morphology of the vegetation cover, local topographic features, water bodies, and soil variations.

The present study examines the variability of small-scale climate in a mountainous valley in west-central Alberta. Temperature data were collected in the Drystone Valley between 1 June and 30 September 1979. The results of the data analysis indicate that daily air temperatures near the ground were variable from one site to another during an isochronic period. Several climate influencing factors appeared to have controlled these observed differences and the relative importance of each did not remain constant throughout the diurnal period.

The most significant environmental factor controlling daily maximum temperatures within the Drystone Valley was vegetation cover, specifically, the density and dimensions of the tree cover. Vegetation can mask the temperature field that might otherwise be expected due to changes in aspect and elevation within the valley. The influence that aspect exerted on the observed maximum temperatures was the next most important climatic control. A non-forested, southwest-facing site, compared to a nearby forested, northeast-facing site showed differences in daily maximum temperatures that could only be reproduced on flat terrain, given other factors being equal, if there were orders of magnitude increases in the distance separating them.

The variations of minimum temperatures among the Drystone Valley stations were much less than those of the maxima and there was a relatively intense thermal belt at the mid-slope sites. Vegetation cover and aspect did not exhibit strong influences on night temperatures compared to the controls they had on daytime highs. Elevation was important in terms of the relative height of the nighttime thermal belt. The factor that influenced minimum temperatures the most was the specific topographic characteristics of each station site. The channeling of cool air drainage flows at night in the avalanche track and along the valley floor resulted in significantly lower temperatures at these locations.

Some of the shrub species recorded in the Drystone Valley were characteristic of relatively dry habitats while other species were more typical of relatively moist sites. The areal distribution of both maximum and minimum air temperatures reflected the autecological requirements for many of the shrub species.

5.1 Recommendations

Knowledge of small-scale atmospheric features are important in the complete understanding of the climate of mountainous valleys. The impending development of mountains' resources and recreational potentials may be accompanied by local climate modification (Lester 1974). Lack of an adequate climate data base will make it difficult to predict the effects of such developments in terms of climate modification.

Climatic data bases from Alberta's mountainous regions are relatively difficult to acquire compared to the provinces's more densely populated areas. This is because of the climate complexity of mountains, their areal extent, and the high cost of data aquisition. The implications of this are that mountain networks should be designed to contribute to the testing or development of climatic principles and interrelationships (Janz and Storr 1977).

There are few long-term climate stations in the mountainous regions of Alberta. Those that have existed for relatively long periods are especially useful and necessary for assessing the present and historic climates of this region. It is important, therefore, that the siting criteria for these key stations be rigidly monitored and controlled. This is because changes in vegetation cover surrounding a climate station can cause a change in the site's climate. For example, modern day forest management practices have eliminated most of the forest fires which now allows the vegetation cover to slowly change. Vegetation cover was identified as a significant factor in controlling the ground-level climate and the progression of a site's vegetation to a climax forest association will result in a corresponding change in the climate being measured by the sensor in the Stevenson screen. Care must be taken that this change in climate will not necessarily be interpreted as a large-scale climate shift.

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APPENDIX A

Standardization of Air Temperature Measurements:

Instantaneous temperature data and isochronic extremes recorded by liquid-in-glass thermometers and bi-metallic thermographs were used to derive correction factors for the values extracted from the thermograph charts. These factors take the form of linear regressions. The dependent variables are the data from the thermometers; the independent variables are the corresponding values from the thermographs. The actual values from one of the Drystone Creek Valley network stations, Perdrix I, are presented in Table A-1. Derived statistics from these data and those from the other network stations are listed in Table A-2.

Table A-1: Simultaneous temperature data from liquid-in-glass thermometers and bi-metallic thermograph at Perdrix I (°C).

Date (1)	Thermometer (2)	Thermograph (3)	Chart Maximum (4)	Thermometer Maximum (5)	Chart Minimum (6)	Thermometer Minimum (7)
25 May	13.9	13.7	17.2	17.1	−0.9	−0.8
3 June	14.3	15.8	19.1	19.7	−1.9	−1.1
3 June	8.6	8.4	14.3	14.7	0.6	1.0
10 June	14.0	14.1	12.3	14.7	1.5	1.7
13 June	8.8	8.6	16.7	17.0	5.3	5.5
22 June	14.4	14.2	16.3	16.9	1.0	1.7
25 June	15.0	15.3	15.7	16.2	2.4	3.0
30 June	16.9	16.1	22.6	23.3	5.9	6.9
5 July	21.7	21.6	23.6	23.2	4.3	5.0
17 July	23.8	23.2	23.0	24.9	3.4	7.5
19 July	24.6	14.5	27.1	26.7	14.4	14.6
22 July	12.8	12.6	–	26.1	–	9.0
26 July	16.6	16.3	16.8	17.4	6.7	7.2
9 August	16.0	16.3	21.2	21.8	4.2	5.0

Table A-1 (Cont'd): Simultaneous temperature data from liquid-in-glass thermometers and bi-metallic thermograph at Perdrix I (°C).

Date (1)	Thermometer (2)	Thermograph (3)	Chart Maximum (4)	Thermometer Maximum (5)	Chart Minimum (6)	Thermometer Minimum (7)
20 August	17.8	17.7	19.2	19.6	9.8	10.0
29 August	15.0	18.5	18.4	18.7	4.3	5.0
11 September	7.3	6.8	16.8	16.8	2.1	2.7
23 September	7.7	6.8	16.9	17.8	2.1	2.8
13 October	11.1	11.3	16.2	18.7	−1.0	−0.4

(1) Date in 1979 chart was changed.
(2) Temperature when Stevenson screen door was opened to change chart on thermograph. Value read from minimum recording thermometer.
(3) Temperature on thermograph when chart was changed. Values read immediately after (2) was observed.
(4) Maximum temperature extracted from weekly chart.
(5) Maximum temperature read from recording maximum thermometer.
(6) Minimum temperature extracted from weekly chart.
(7) Minimum temperature read from minimum recording thermometer.

Table A-2: Derived statistics from isochronic thermometer and thermograph temperatures (°C)

Temperature Sensor	N	(1)	(2)	x (3)	s (4)	r (5)	r@.05	df (6)	b (7)	m (8)
Thermometer	22	-2.4	29.4	14.9	8.6	1.00	0.42	20	-1.32	1.06
Cassella #1		-3.7	28.6	14.5	9.2					
Thermometer	28	-3.2	32.5	-13.9	11.1	1.00	0.37	26	1.60	0.93
Cassella #2		-2.3	31.3	13.3	10.4					
Thermometer	22	-0.6	25.2	14.6	9.0	1.00	0.42	20	0.02	1.00
Cassella #3		-0.8	25.9	14.3	8.9					
Thermometer	11	-14.5	25.7	11.6	12.1	1.00	0.60	9	-0.16	0.98
Cassella #4		-14.4	25.7	11.2	12.3					
Thermometer	40	-2.7	28.9	12.7	10.0	1.00	0.31	38	1.34	0.92
Cassella #5		-1.8	28.0	13.0	9.2					
Thermometer	11	4.2	17.9	11.8	5.4	1.00	0.60	9	0.99	0.91
Cassella #6		5.3	17.5	11.8	4.9					
Thermometer	47	-2.8	28.3	12.0	8.3	1.00	0.29	45	0.53	0.99
Fuess #1		-2.8	27.6	11.9	8.2					

Table A-2 (Cont'd). Derived statistics from isochronic thermometer and thermograph temperatures (°C).

Temperature Sensor	N	(1)	(2)	x (3)	s (4)	r (5)	r@.05	df (6)	b (7)	m (8)
Thermometer	44	−3.6	32.7	16.2	11.5	1.00	0.30	44	−0.20	0.98
Fuess #2		−3.3	32.2	15.7	11.4					
Thermometer	58	−1.9	26.7	12.9	7.4	1.00	0.26	56	−0.37	1.00
Fuess #3		−1.1	27.1	12.5	7.5					
Thermometer	29	−1.3	38.2	13.3	9.6	1.00	0.37	27	1.19	0.93
Fuess #4		−0.1	35.7	13.5	8.9					
Thermometer	49	−4.0	29.6	12.5	9.2	0.99	0.28	47	−1.50	1.01
Weather Measure #1		−6.5	27.0	11.1	9.4					
Thermometer	21	−2.9	25.7	12.5	7.4	0.99	0.43	19	0.48	1.00
Weather Measure #2		−2.9	27.1	12.9	7.5					

(1) Lowest value recorded. (2) Highest value recorded. (3) Mean of the recorded values.
(4) Standard deviation of the temperatures. (5) Correlation coefficient. (6) Degrees freedom.
(7) Intercept of the regression (thermographs on thermometers). from the thermometer.
(8) Slope of the regression (thermographs on thermometers). the temperature from the thermometer.

APPENDIX B

Figure B-1: Scattergrams of daily temperatures (°C) at Perdrix III and Perdrix III-M and derived regressions.

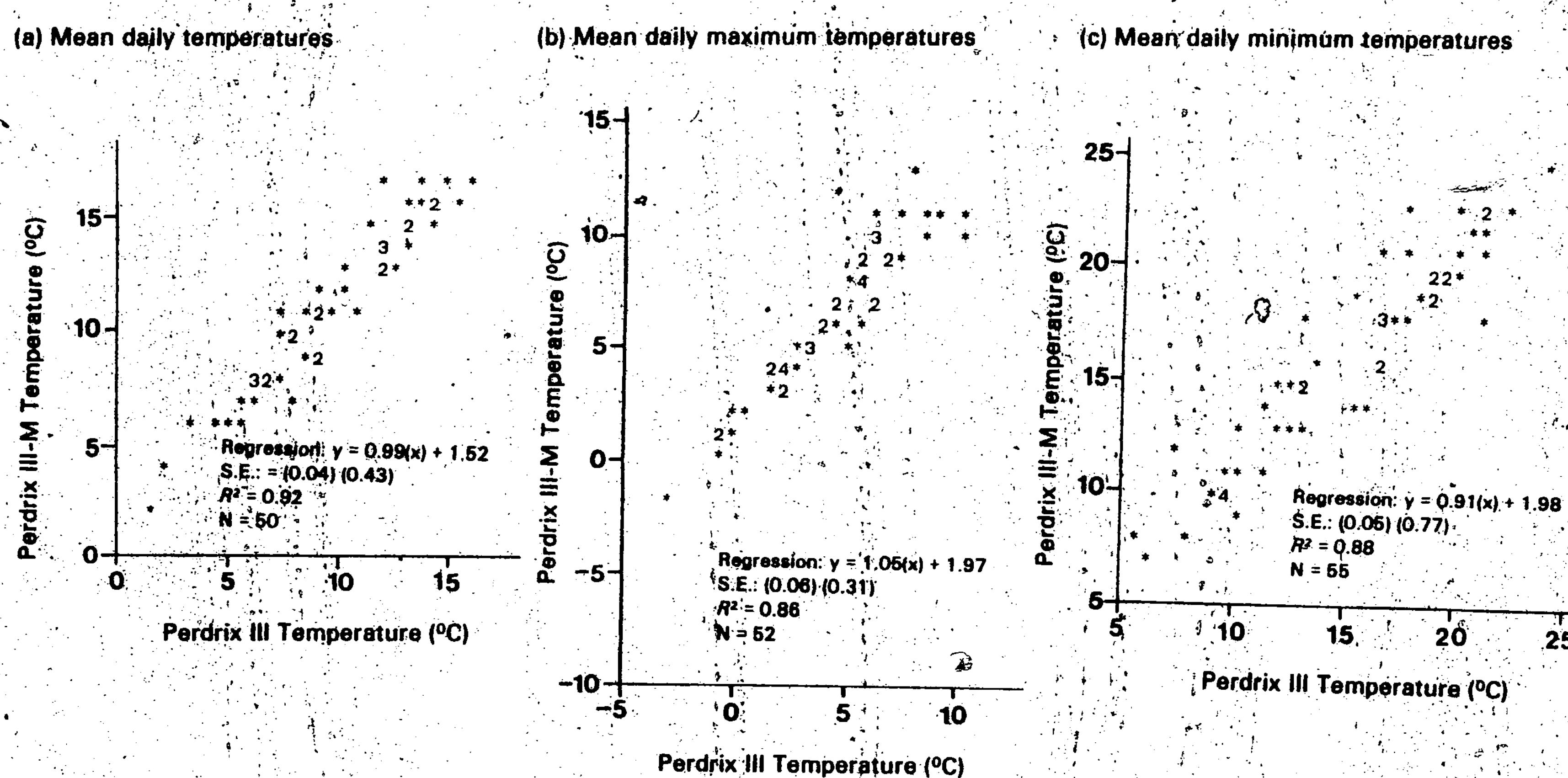
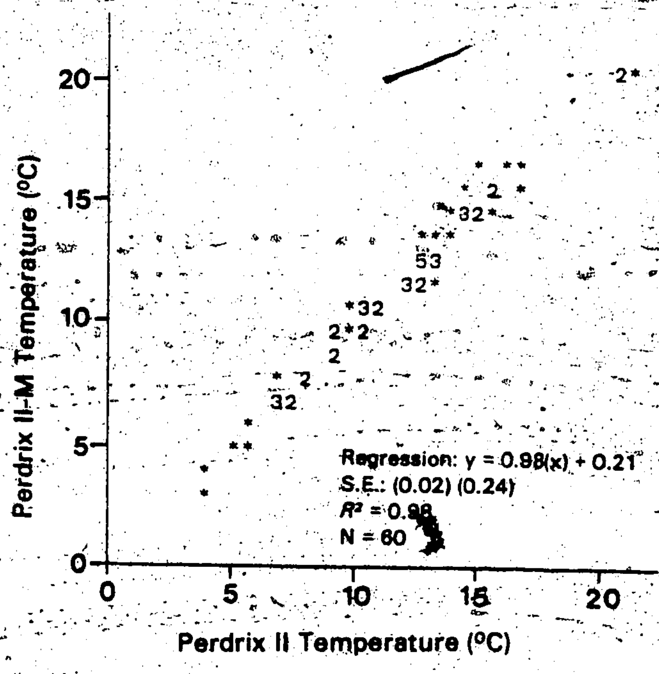
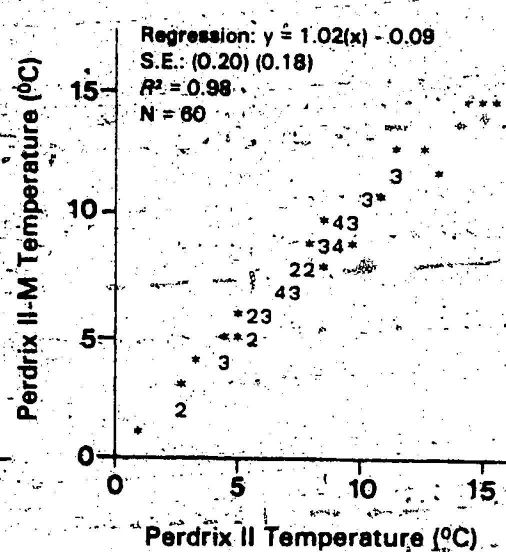


Figure B-2: Scattergrams of daily temperatures (°C) at Perdrix II and Perdrix II-M and derived regressions.

(a) Mean daily temperatures



(b) Mean daily maximum temperatures



(c) Mean daily minimum temperatures

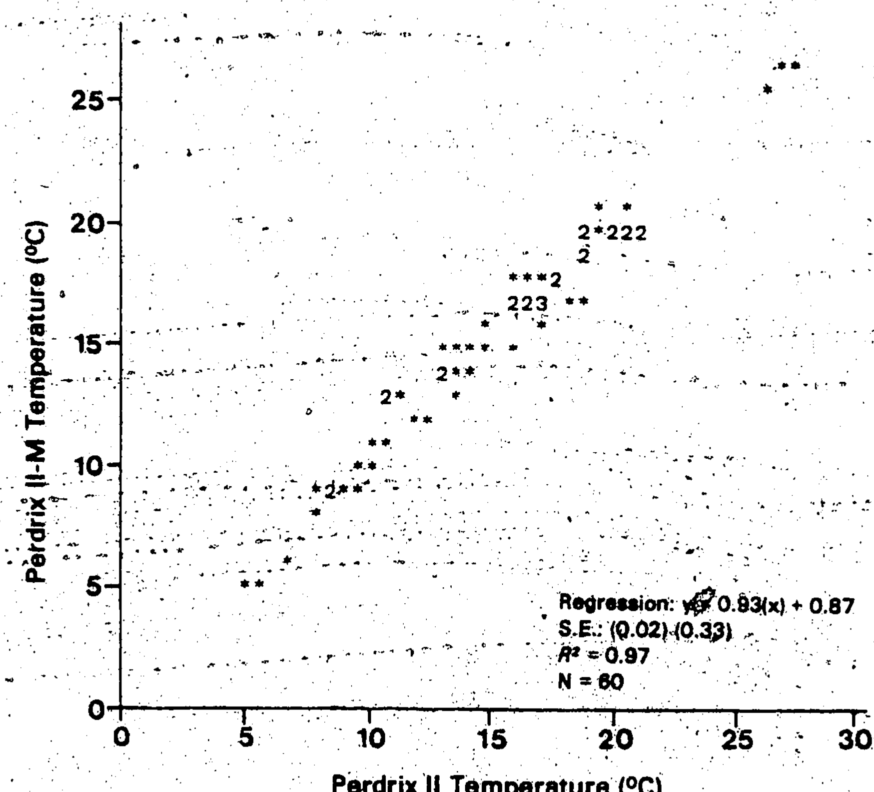
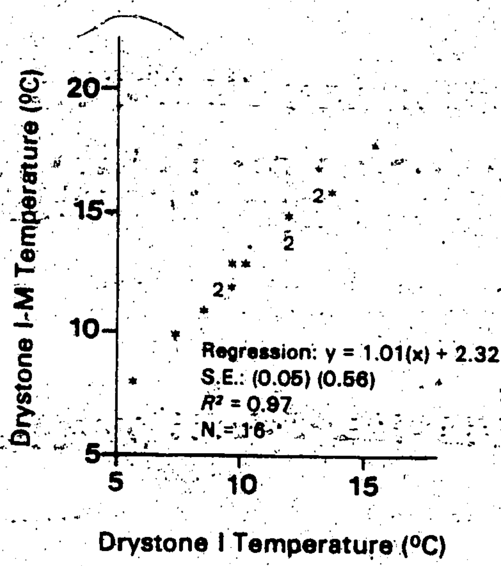
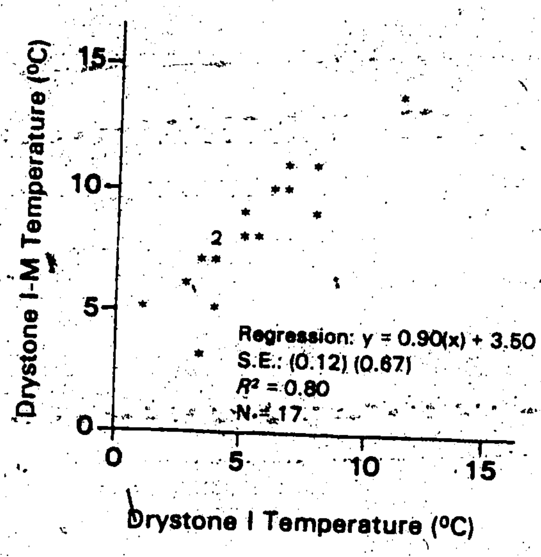


Figure B-3: Scattergrams of daily temperatures (ºC) at Drystone I and Drystone I-M and derived regressions.

(a) Mean daily temperatures



(b) Mean daily maximum temperatures



(c) Mean daily minimum temperatures

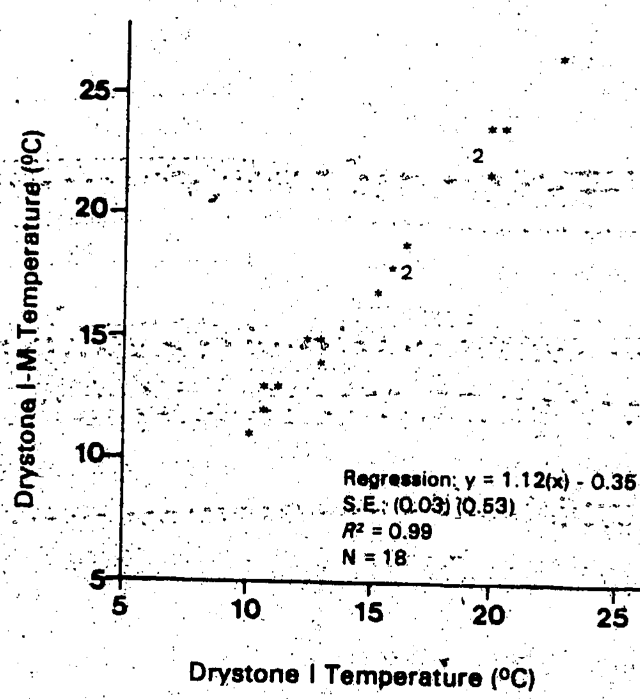
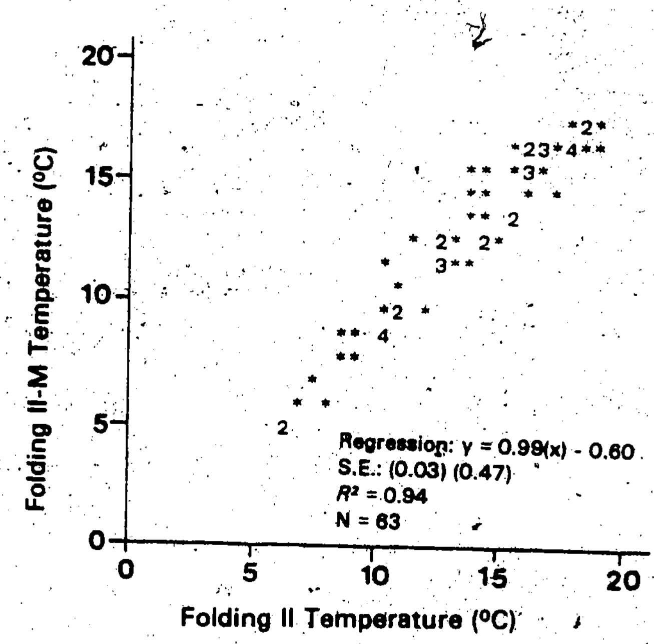
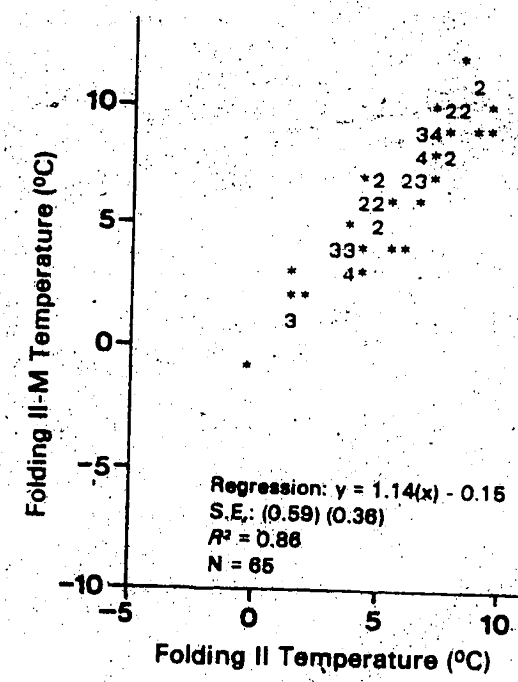


Figure B-4: Scattergrams of daily temperatures (°C) at Folding II and Folding II-M and derived regressions.

(a) Mean daily temperatures



(b) Mean daily maximum temperatures



(c) Mean daily minimum temperatures

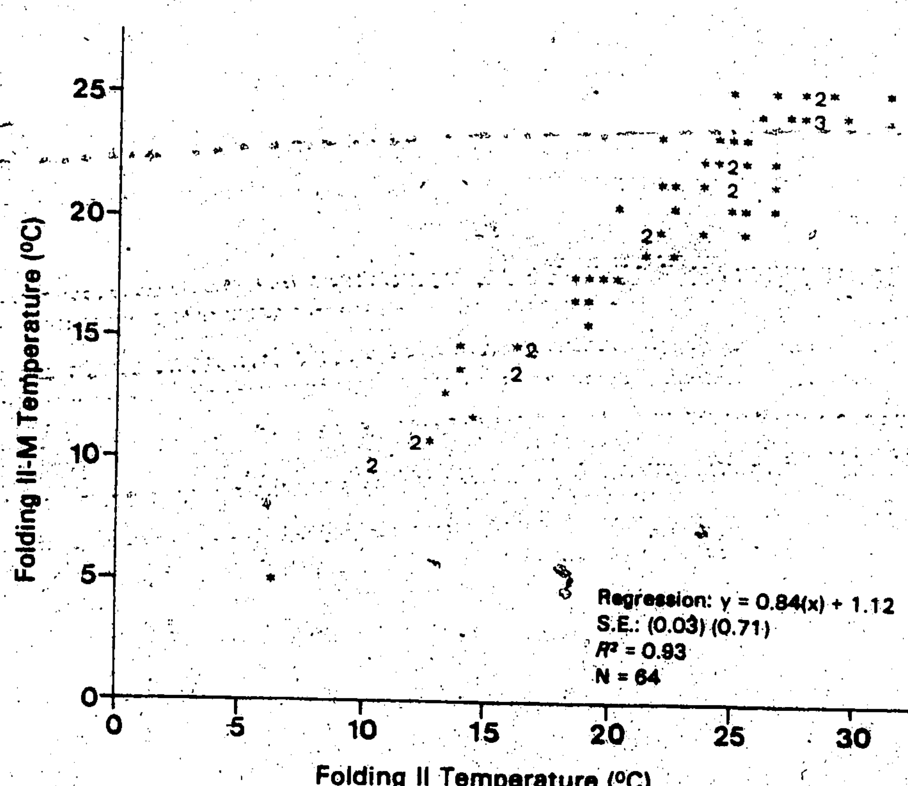
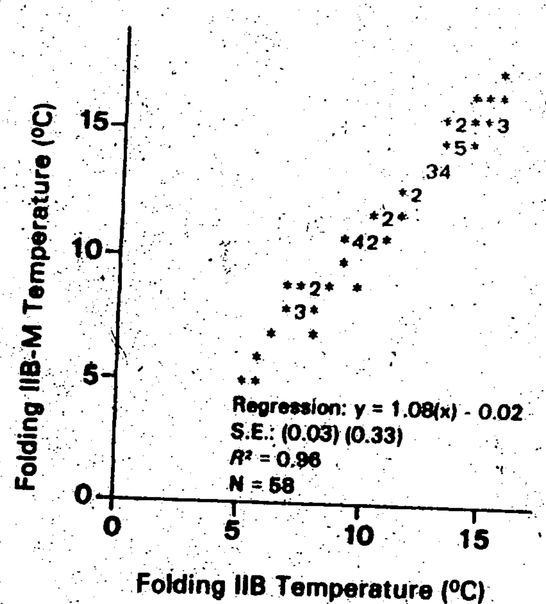
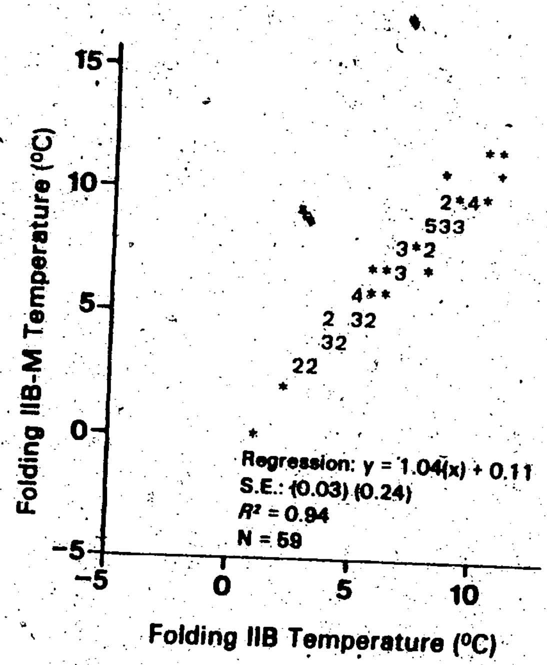


Figure B-5: Scattergrams of daily temperatures (°C) at Folding IIB and Folding IIB-M and derived regressions.

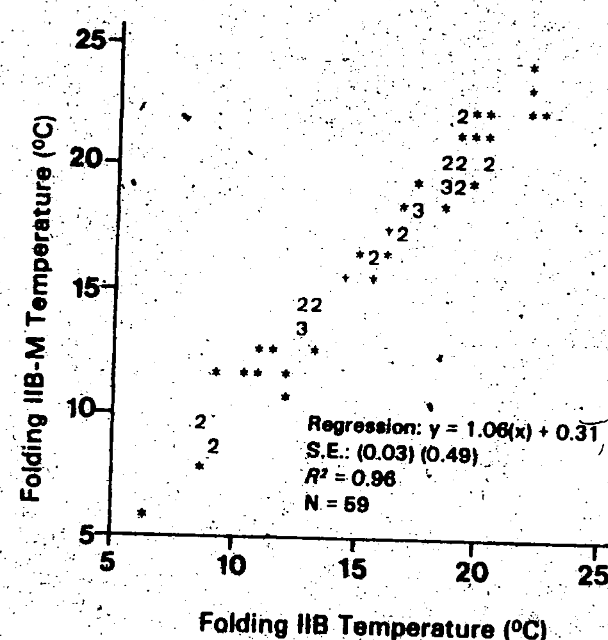
(a) Mean daily temperatures



(b) Mean daily maximum temperatures



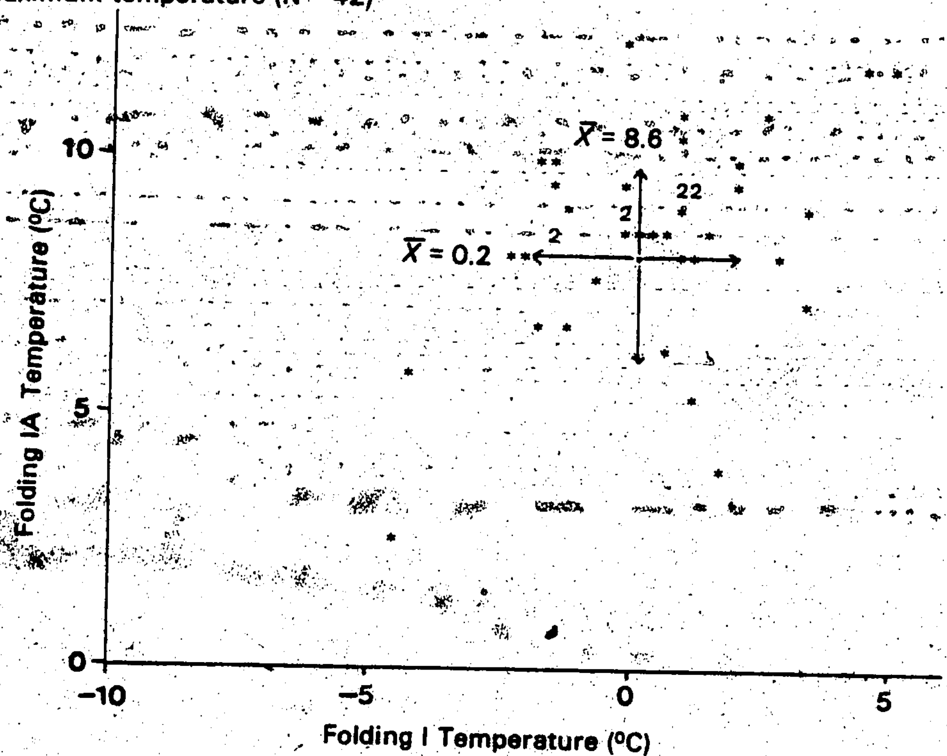
(c) Mean daily minimum temperatures



APPENDIX C

Figure C-1: Scattergrams of daily temperatures (relative to Jasper Park East Gate) at Folding I and Folding IA (°C).

(a) Maximum temperature (N = 42)



(b) Minimum temperature (N = 41)

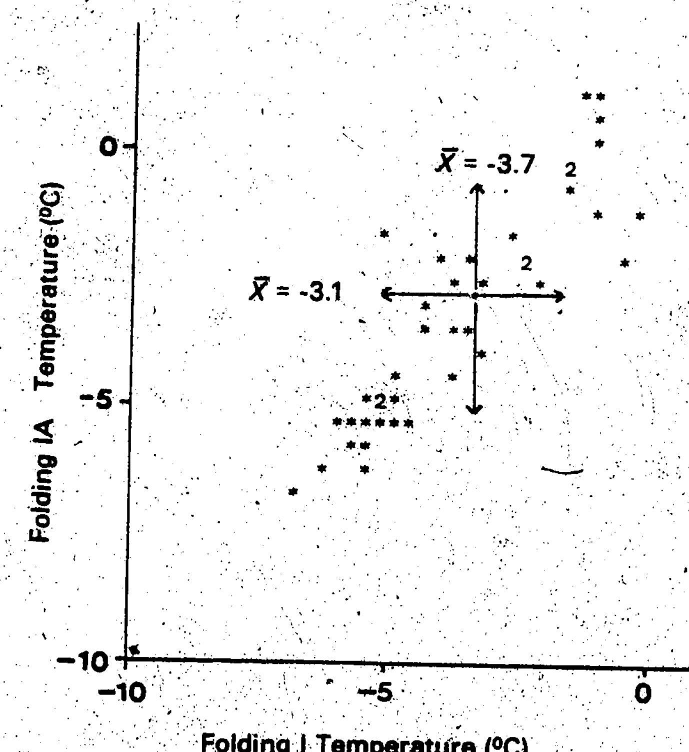
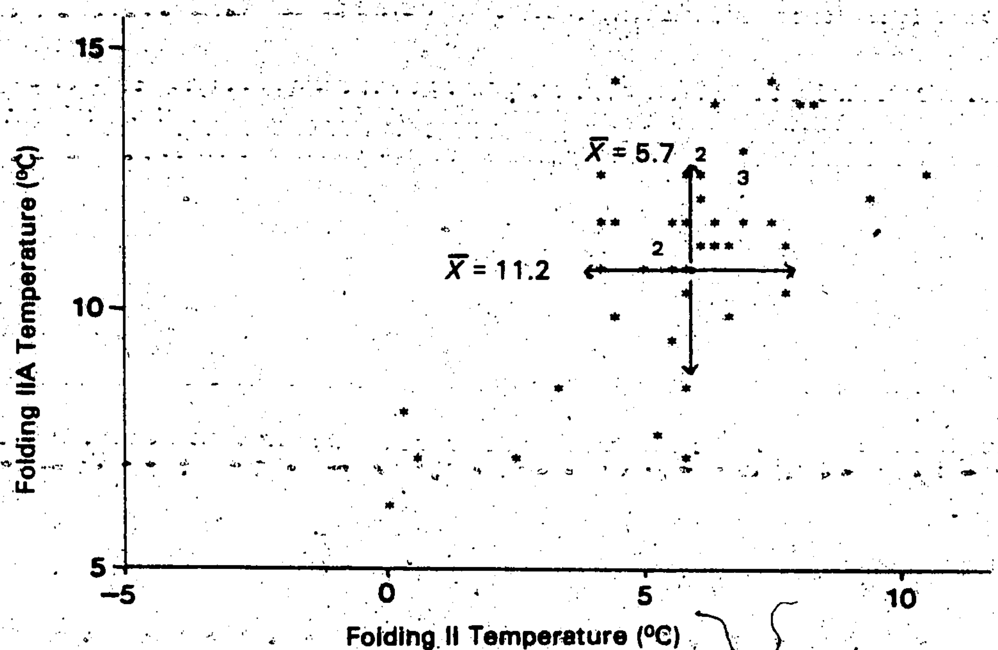


Figure C-2: Scattergrams of daily temperatures (relative to Jasper Park East Gate) at Folding II and Folding IIA (°C).

(a) Maximum temperature (N = 47)



(b) Minimum temperature (N = 47)

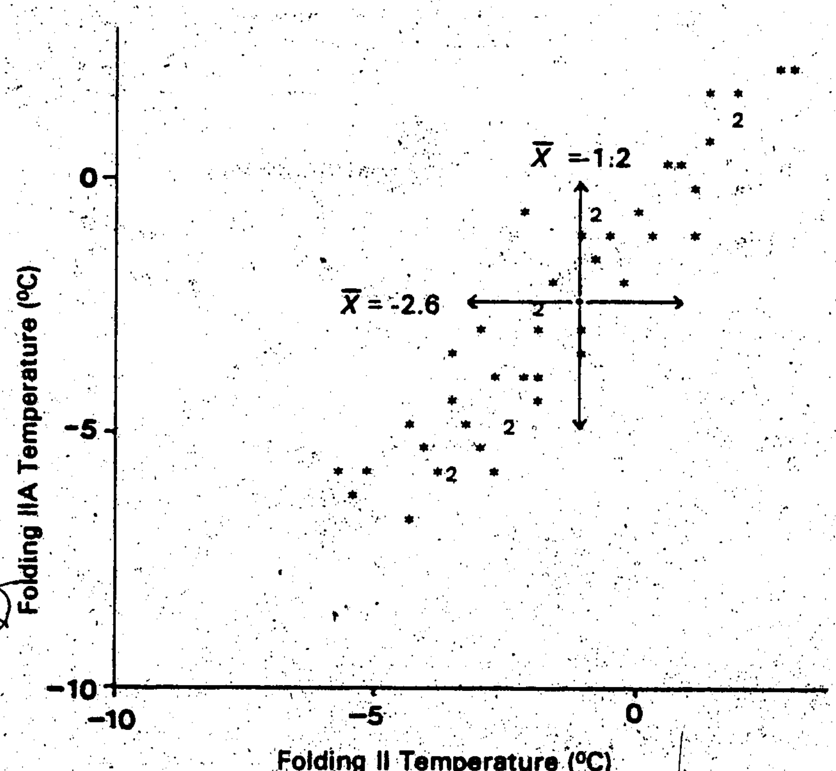


Figure C-3: Scattergram of daily temperatures (relative to Jasper Park East Gate) at Folding II and Folding IIB (°C).

(a) Maximum temperature (N = 80)

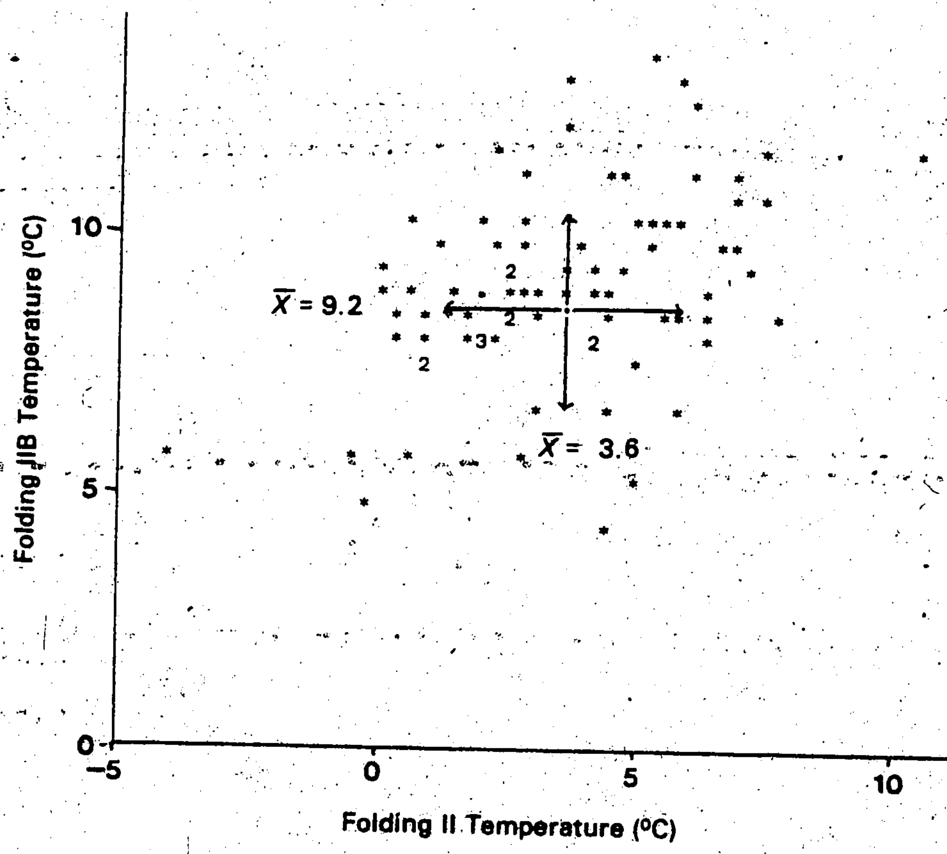


Figure C-3: (cont.'d) Scattergram of daily temperatures (relative to Jasper Park East Gate) at Folding II and Folding IIB (ºC).

(b) Minimum temperature (N = 82)

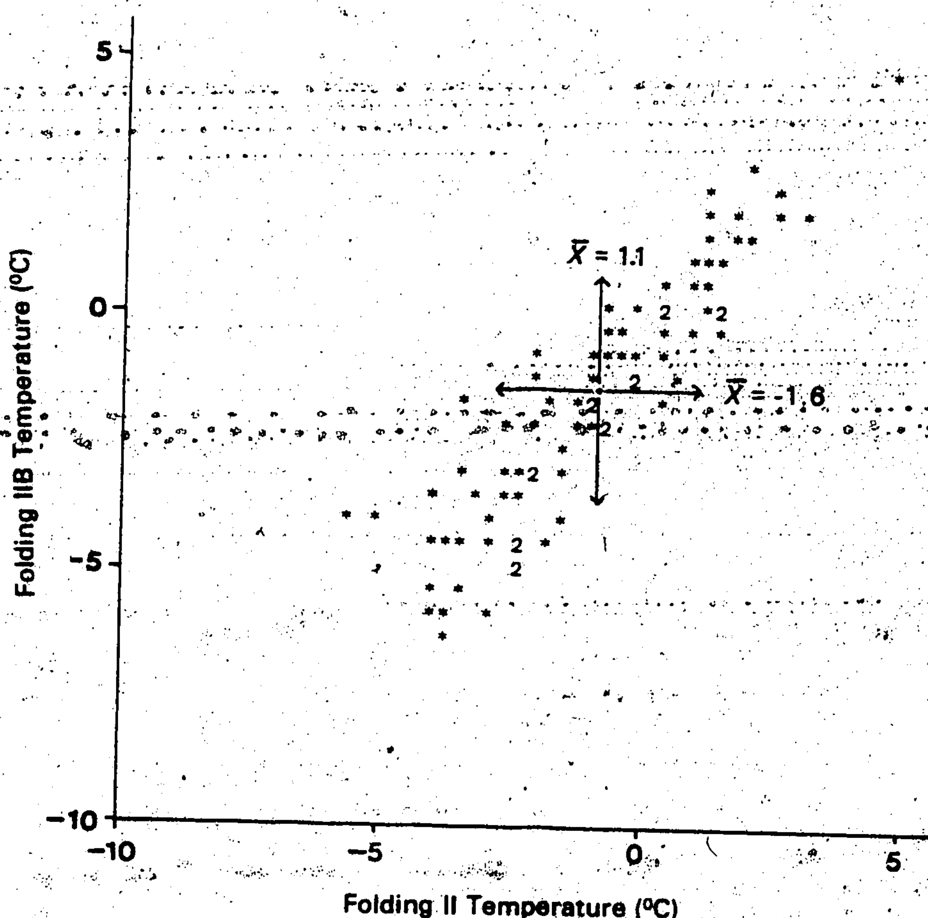
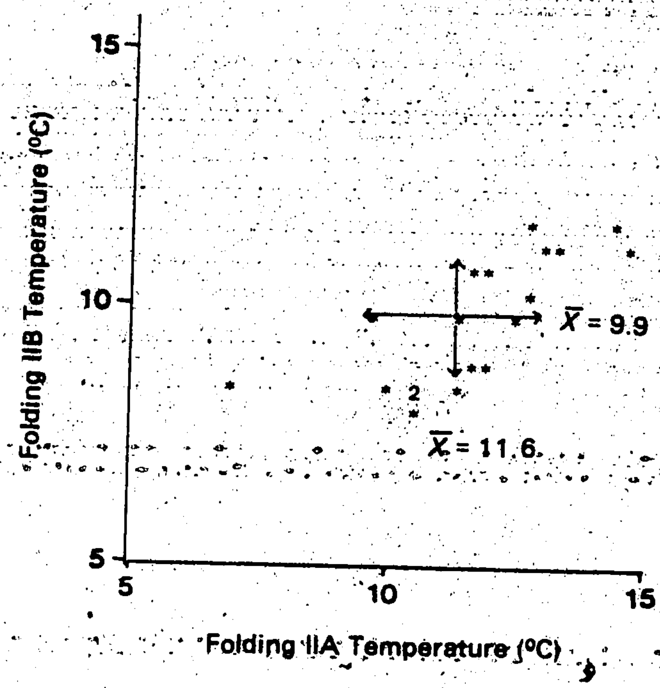


Figure C-4: Scattergrams of daily temperatures (relative to Jasper Park East Gate) at Folding IIA and Folding IIB (ºC).

(a) Maximum temperature (N = 19)



(b) Minimum temperature (N = 19)

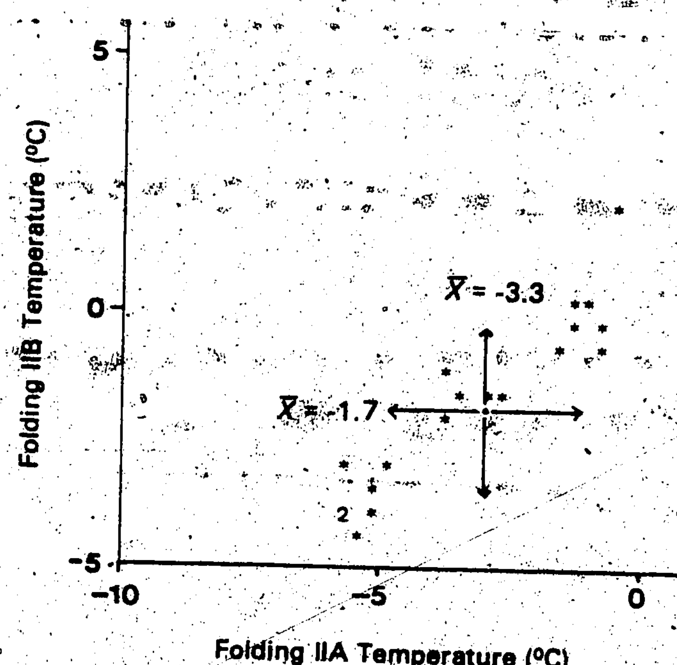


Figure C-5: Scattergram of daily temperatures (relative to Jasper Park East Gate) at Perdrix II and Perdrix III (ºC)

(a) Maximum temperature (N = 88)

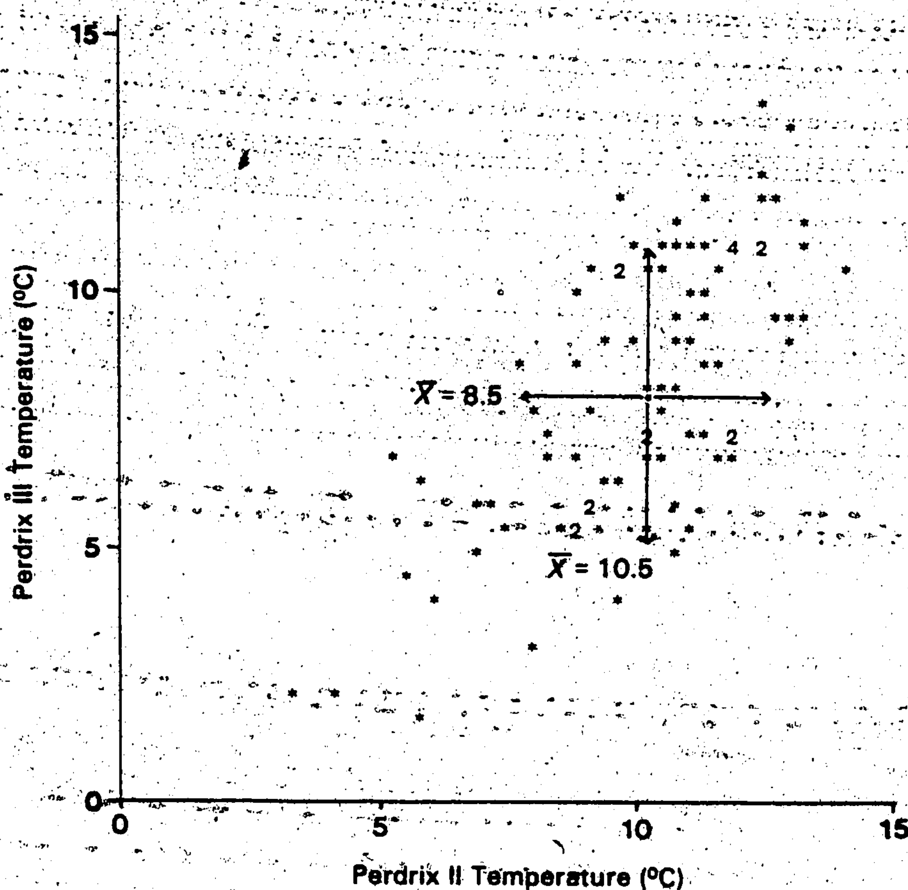


Figure C-5: (cont.d) Scattergram of daily temperatures (relative to Jasper Park East Gate) at Perdrix II and Perdrix III (°C).

(b) Minimum temperature (N = 94)

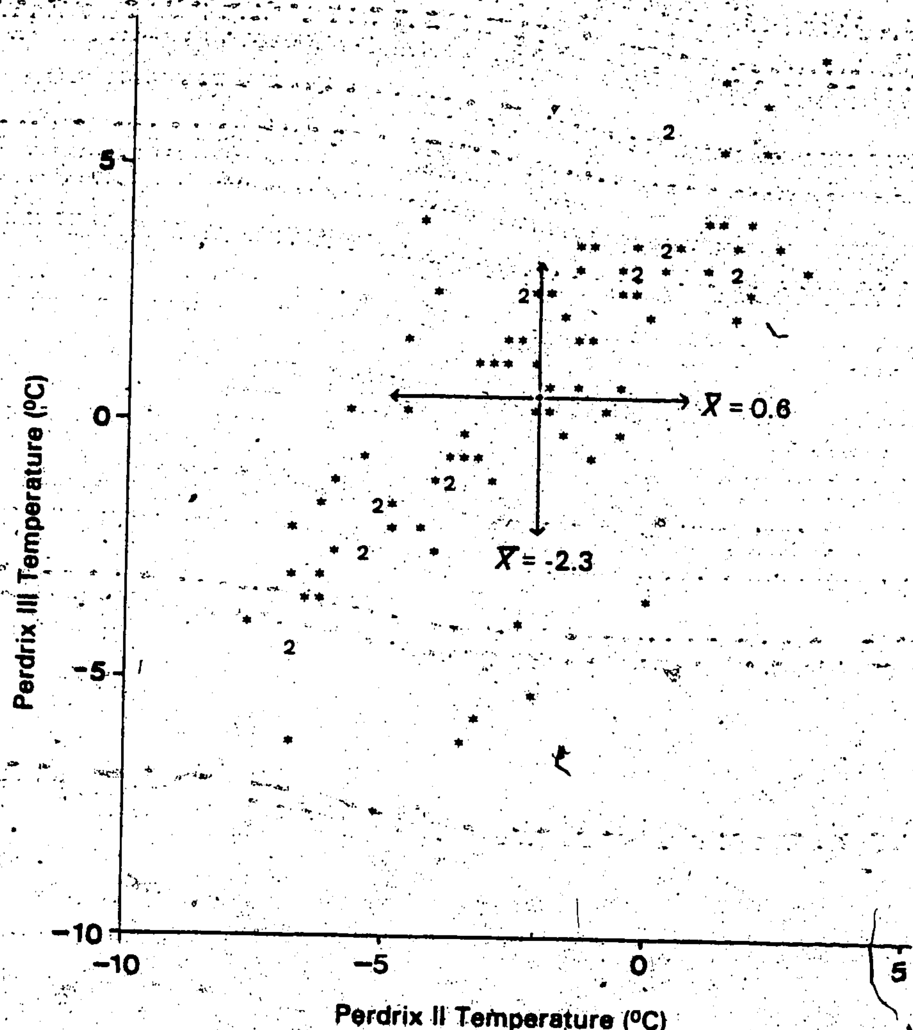
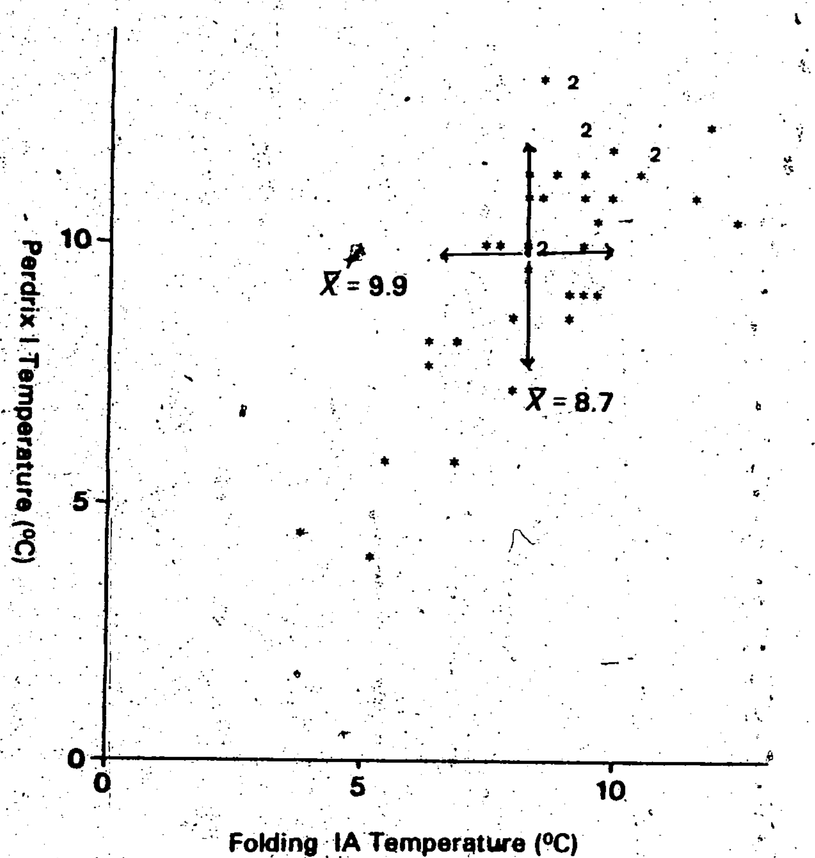


Figure C-6: Scattergrams of daily temperatures (relative to Jasper Park East Gate) at Folding IA and Perdrix I (ºC).

(a) Maximum temperature (N = 40)



(b) Minimum temperature (N = 38)

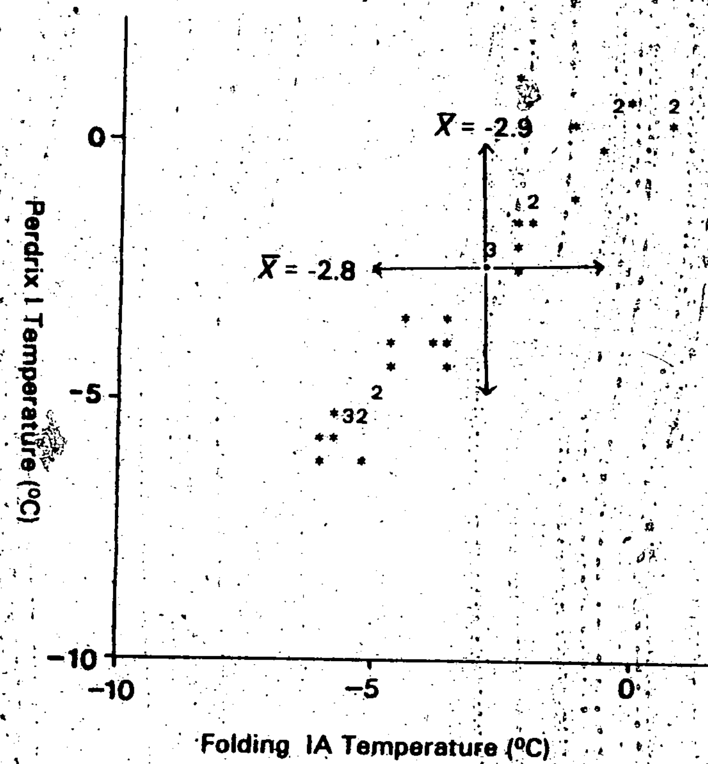


Figure C-7: Scattergram of daily temperatures (relative to Jasper Park East Gate) at Folding II and Perdrix III (°C).

(a) Maximum temperature (N = 100)

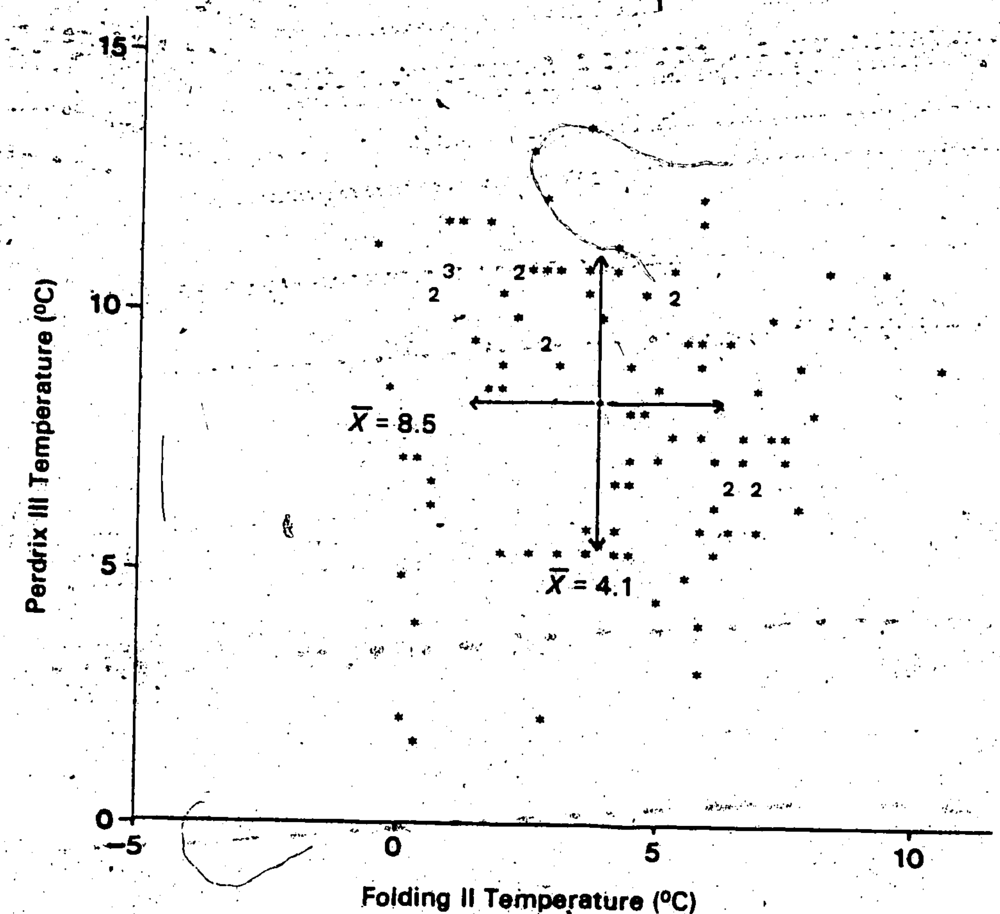


Figure C-7: (cont'd) Scattergram of daily temperatures (relative to Jasper Park East Gate) at Folding II and Perdrix III (ºC).

(b) Minimum temperature (N = 96)