THE THERMAL CLIMATE OF THE H. J. ANDREWS EXPERIMENTAL FOREST, OREGON

by

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A THESIS

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"The Thermal Climate of the H. J. Andrews Experimental Forest, Oregon," a thesis prepared by Lynn D. Rosentrater in partial fulfillment of the requirements for the Master of Science degree in the Department of Geography. This thesis has been approved and accepted by:

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Air temperature is a dynamic part of the natural environment which is influenced by the complexity and interaction of terrain, advection, differences in surface type and seasonal changes of the input of heat by radiation. In order to describe and analyze the natural variability of monthly and seasonal temperature regimes within the H. J. Andrews Experimental Forest—one of 18 sites in the Long-Term Ecological Research Program, the goal of which is to understand general ecological phenomena that occur over longer temporal and spatial scales—sequences of monthly mean, mean maximum and mean minimum air temperature records for the period 1981-1990 at 22 monitoring sites within the watershed were examined. The core of the study is the presentation of a detailed body of descriptive statistics and the development of maps of monthly mean air temperature; a mountain microclimate simulation model is also tested for estimating air temperatures beneath the forest canopy.

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CHAPTER I

INTRODUCTION

Since its inception in 1948, the H. J. Andrews Experimental Forest has been the subject of intensive study in forest ecology, geomorphology, hydrology and effects of land use change (McKee et al., 1987; Blinn et al., 1988). It is currently one of 18 sites in the Long-Term Ecological Research Program, a collaborative effort funded by the National Science Foundation, the goal of which is to understand general ecological phenomena that occur over longer temporal and spatial scales (Franklin et al., 1990).

While climate data are among the longest data sets available at the H. J. Andrews forest (referred to simply as Andrews from now on), there have been relatively few studies examining their spatial and temporal patterns. Greenland (1994) has described the regional context of Andrews' climate in addition to calculating the potential radiation within the watershed (Greenland, 1996) and Daly is currently implementing a method for deriving precipitation maps for Andrews (Chris Daly, pers. comm.). But while temperature is arguably the most pervasive environmental factor affecting vegetation growth, its distribution within the Andrews forest has yet to be examined.

Temperature is a dynamic part of the natural environment which is influenced by the complexity and interaction of the terrain, advection, differences in surface type and the changes of the input of heat by radiation, and other fluxes, accompanying the different seasons. Several ongoing studies at Andrews could benefit from temperature information on a better spatial resolution than is currently observed in the field. For example, the log decomposition and trace gas flux studies seek to better understand how climate affects soil processes at the watershed scale; a spatial analysis of Andrews' thermal environment will benefit the development of basin-scale models of soil processes. The primary goal of this thesis, therefore, is to describe and analyze the natural variability of monthly and seasonal temperature regimes within the Andrews forest. The core of the study is the presentation of a detailed body of descriptive statistics from a network of thermograph sites located throughout the forest and the development maps of monthly mean air temperatures for the watershed. A secondary goal of the project is to test the applicability of a mountain microclimate simulation model for estimating air temperatures beneath the forest canopy.

The Study Area

The Andrews forest is located about 80 km east of Eugene, Oregon in the Blue River Ranger District of the Willamette National Forest (44°15' north latitude and 122°10' west longitude). The forest occupies a well defined watershed about 6400 hectares in size, bounded by ridges on the east, the south and the northwest. Slopes in the area are steep and stream drainages deeply incised. Elevation ranges from 410 m to 1630 m (Figure 1). The diverse forest communities within the watershed are characteristic of Oregon's central Cascade Mountains. Two major vegetation zones are stratified against elevation and temperature gradients: the Tsuga heterophylla zone below 1050 m and the Abies amabilis zone above 1050 m (Zobel et al., 1976). Andrews' vegetation has been described in detail by Dyrness et al. (1976) and Hawk et al. (1978). Lower elevation stands are dominated by Douglas fir (Pseudotsuga menziesii), western hemlock (Tsuga heterophylla) and western red cedar (Thuja plicata). As elevation increases, western hemlock is gradually replaced by Pacific silver fir (Abies amabilis) and Douglas fir and western red cedar decline in importance. Upper elevation stands consist of mixtures of true firs (Abies) and mountain hemlock (Tsuga mertensiana). Gap and understory vegetation consist primarily of rhododendron (Rhododendron macrophyllum) and young conifers. Approximately 45% of the watershed is old growth conifer forest with dominant trees more than 400 years old;

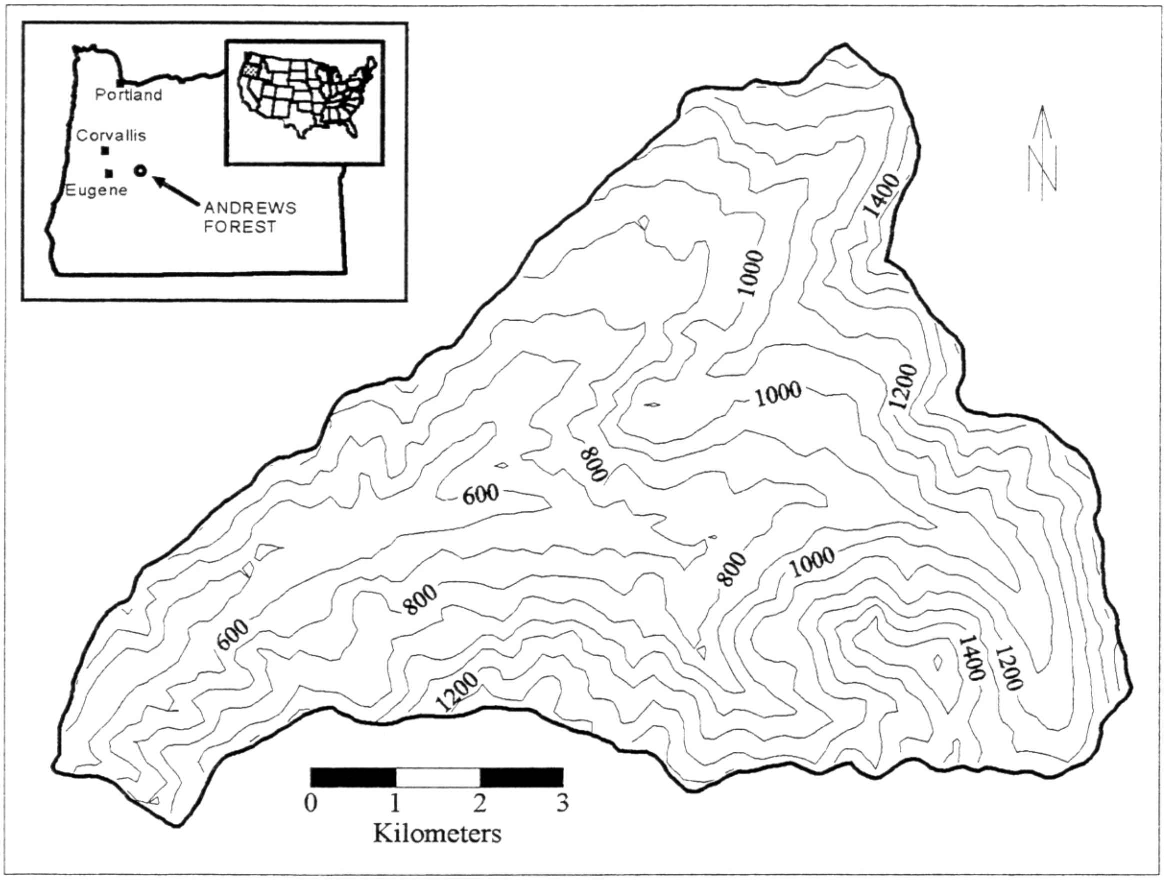

FIGURE 1. Topography of the H. J. Andrews Experimental Forest
(Contour Interval is 100 m)

25% is considered mature forest with dominant stands of 100-130 years old. The difference in stand age from old growth to mature forest is attributed to wild fire that swept through the area in the mid 1800s (Dyrness et al., 1976). Young stands which have grown up following experimental logging during the past 40 years cover 30% of the watershed.

The general climate is controlled by the forest's proximity to the Pacific Ocean and the orientation of the Coast and Cascade Mountains. Bierlmaier and McKee (1989) describe Andrews' climate as wet and fairly mild during winter, and warm and dry in summer. They emphasize the role of the polar jet stream in funneling low pressure zones and frontal storms into the area, one after another during winter months; the storms are slowed by the Coast and Cascade ranges and are consequently of low intensity and long duration. The summer season is dominated by the establishment of a ridge of high pressure along the coast in the eastern Pacific which brings highly stable air and little precipitation to the region during summer months. For the period 1972 to 1984 average temperature at Andrews' primary meteorological station (PRIMET) was 8.5°C; mean temperatures ranged from 0.6°C in January to 17.8°C in July. The average annual precipitation was 2302 mm, 70% of which fell between November and March. Above 1050 m a persistent snowpack up to 4 m deep may form and last into June (Bierlmaier and McKee, 1989). Further details of Andrews' climate may be found in Emmingham and Lundburg (1977), Waring et al. (1978), McKee and Bierlmaier (1987) and Greenland (1994).

Data

Meaningful comparisons and descriptions of climate are best drawn from a large data base representing a uniform time period. Accepted convention for climatological normals, as adopted by the World Meteorological Organization (WMO), is the 30 year period currently defined as 1961-1990. Unfortunately, use of a 20 year or even a 15 year period for this study would cause a drastic reduction in the number of continuous records available from around the forest and thus a less complete geographic representation of the thermal climate. Considerable effort went into assembling a data set that not only includes as many sites as possible, but also one for which data collection and management techniques at all sites remain constant over time. The next two sections describe the methods used to develop the data set for a 10 year base period, 1981-1990.

History and Development of the Monitoring Network

The first climatic monitoring device at Andrews was set up in 1952 with the installation of a rain gauge; a temperature sensor was added at the same location in 1959. In the early 1970s, 19 quarter-hectare "reference stands" were established as points of reference for research and experimentation. These sites were selected to represent the various vegetation zones and habitat types found at Andrews (Hawk et al., 1978). Most of these reference stands were equipped with instruments for monitoring air and soil temperature. In 1972, PRIMET was established as the primary meteorological station for the forest and began recording observations of solar radiation, air temperature, dew point temperature, wind speed and precipitation at the forest headquarters along the valley floor (Waring et al., 1978). Upgrades to the monitoring network, including the designation of additional sites and the replacement of old sensors and recording devices, began in 1980 and continues today. Currently there are four benchmark stations throughout the forest—PRIMET, Vanilla Leaf, Upper Lookout Creek and Central Met. These stations crown the hierarchy of a three-tiered nested network of monitoring sites in the watershed.

Data Management

Climate data are processed and managed by the Forest Science Data Bank, a partnership between the Department of Forest Science at Oregon State University and the

US Forest Service Pacific Northwest Research Station in Corvallis. Throughout the 1970s and for much of the 1980s, air temperatures at all sites with the exception of PRIMET [1] were recorded continuously on circular Partlow charts. The charts were processed by hand and digitized then summarized to daily averages. For sites in operation between 1970 and 1972, summaries of mean, maximum and minimum air temperature were based on a sunrise to sunrise day. Mean daytime and mean nighttime temperatures were also taken off the charts; daytime length was determined for the 15th of the month and used for the entire month. In 1973 an algorithm was developed to determine daily day length. As a result of this change in the digitizing program the measured parameters for 1973-1980 were changed to mean sunrise to sunrise temperature, mean and maximum daytime temperature, and mean and minimum nighttime temperature. In 1981, maximum and minimum sunrise to sunrise temperature were added to the output parameters. Campbell Scientific CR-10 data loggers replaced the circular chart installations for 8 sites in 1987. For sites not receiving the equipment upgrade a revised digitizing program was implemented. The revised program produced output similar to the CR-10 data loggers and for the first time true daily (midnight to midnight) summaries were available.

A massive redigitizing project was undertaken in the early 1990s in an effort to make earlier data compatible with later data. One-fourth of the sites have been redigitized to produce midnight to midnight summaries back to 1981. While true daily summaries for most sites do not begin until 1987, tests reveal that at the monthly scale the error between data collected on a sunrise to sunrise basis versus a midnight to midnight basis is trivial (Don Henshaw, pers. comm.). At the time of this writing, data for the period 1973-1980 has not been redigitized and is not included in the monthly summaries distributed by the data manager.

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[1] Waring et al. (1978) describe the processing and management of PRIMET data, and Bierlmaier and McKee (1989) update the documentation after equipment and procedures changed.

Of concern with regard to the sampling design for sites in this study is the positioning of instruments in the environment. Temperature probes were originally placed one meter above the ground and sensors at four sites were moved higher in winter to keep one meter above the snow pack. In October, 1991 all sensor heights noted in the record were edited as a result of data and field checking. Prior to the field checking sensor heights were listed as one meter above the surface, while after the field checking sensor heights range from 85 cm to 325 cm. It is unclear when sensors were repositioned so it was decided to err in favor of the record and deal with a period where sensor heights are equal across the network.

In light of the management issues raised here it is prudent to emphasize the need for observation standards in the field. Extreme thought and care should be exercised in the future if the manner of making temperature measurements (or those of any other variable) is to be changed. Thus, based on a compromise between data availability, management and changes in sensor height, the 10 year period 1981-1990 was selected as the period of record for this study. In the rest of the study this period is referred to as the base period.

Data Network

Monthly records of mean, mean maximum and mean minimum air temperatures were obtained for use in the study. Data sets for all stations were inventoried to determine the amount of missing data for the 10 year period. Any station with more than 5% of the monthly values absent was eliminated from further consideration. Stations where more than 5% of the monthly values were based on less than 25 days of daily summaries were also eliminated. With regard to missing values comprising less than 5% of a station's record, interpolation by the method of first differences (Lineacre, 1992) was used. Completion of this survey yielded a final network of 22 data sites (Table 1, Figure 2). The majority of sites in the data network are located under the canopy in old-growth stands while a few are in

TABLE 1. Characteristics of the Data Network

Site ID	Elevation (m)	Aspect (°)	Slope (°)	Exposure	Stand Age	Notes
LOOK	975	330		closed		stream site
MACK	756	310		closed		stream site
MCRAE	829	220		closed		stream site
PRIMET	430	-	0	open		maintained clearing
RS01	490	200	41	closed	460	canopy
RS02	490	285	22	closed	460	canopy
RS03	945	315	22	closed	460	canopy
RS04	1310	270	27	closed	460	canopy
RS05	880	10	12	closed	460	canopy
RS07	460	1	19	closed	460	canopy
RS10	610	170	6	closed	460	canopy
RS12	1010	282	11	closed	460	canopy
RS13	1310	270	20	closed	135	canopy, Wildcat Mtn.
RS14	1430	1	32	closed	145	canopy, Wildcat Mtn.
RS15	760	350	33	closed	460	canopy
RS16	640	202	29	closed	460	canopy
RS17	490	315	14	closed	135	canopy
RS20	683	180		closed	450	canopy
RS26	1040	180	20	closed	150	canopy
RS86	610	215	28	open		Clearcut 1975
RS89	460	315	37	open		Clearcut 1975
TS38	1000	170		open		Clearcut 1975 (?)

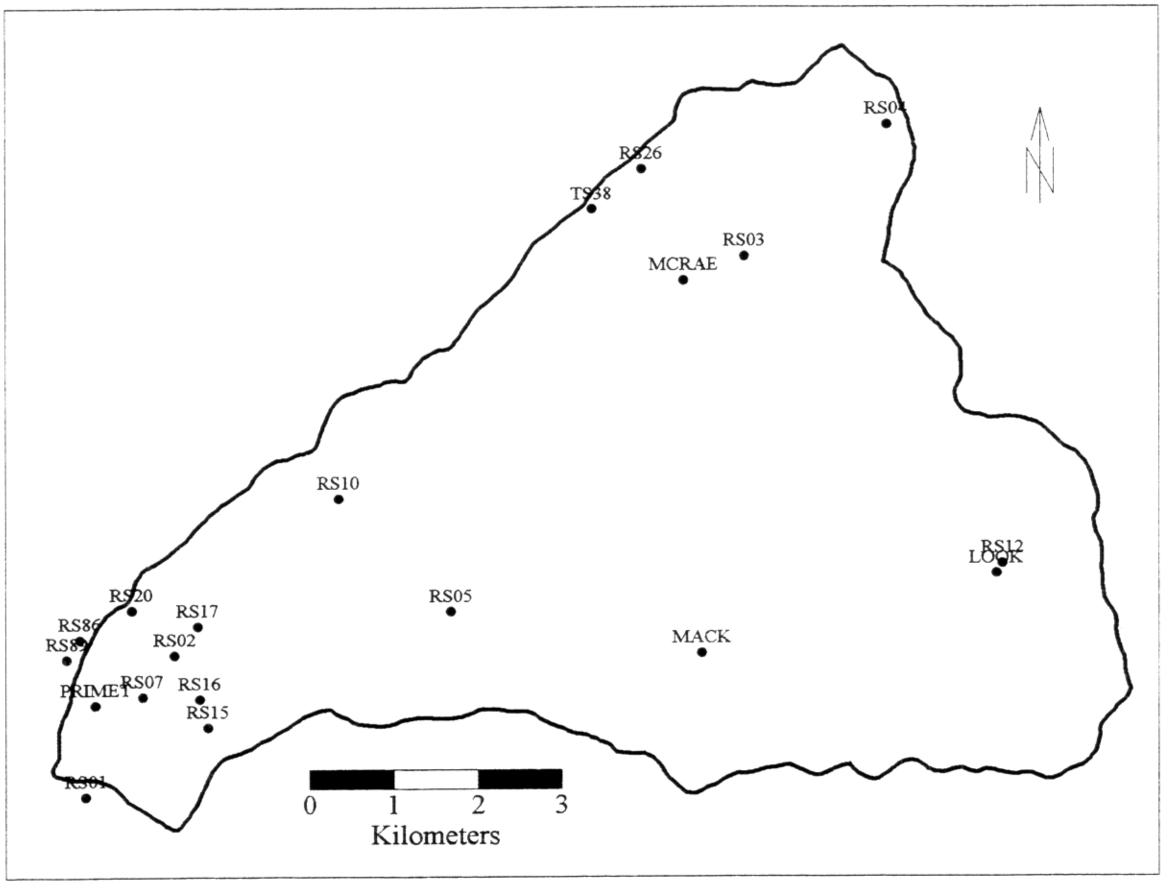

FIGURE 2. Sites in the Data Network

stands of mature forest. Four treated sites are used in the analysis: PRIMET is located in a maintained clearing on the valley floor and RS86, RS89 and TS38 were each experimentally logged in the 1970s. The physical diversity of the forest is further represented by the inclusion of three sites recording air temperatures above the streams that dissect the watershed, Lookout Creek (LOOK), Mack Creek (MACK) and McRae Creek (MCRAE).

While sites in Andrews' monitoring network were originally selected to represent the various vegetation zones and habitat types, it is interesting to note the actual representativeness of the data network. In the field, the Tsuga heterophylla zone covers about 60% of the Andrews forest and the Abies amabilis zone comprises the other 40% (Waring et al., 1978). Based on elevations given in Table 1 for stations within the watershed, 75% of the sites lay in the Tsuga heterophylla zone and only 25% in the Abies amabilis zone. There are few high elevation stations available for analysis which is a persistent problem in climatological research in mountainous terrain. To offset this shortcoming two high elevation sites located in the Wildcat Mountain Research Natural Area, about 10 km north of Andrews, have been included in the data set—RS13 and RS14.

It is also relevant to consider the topographical representativeness of the data network. A given point along the lines in Figure 3 indicate the area of land that falls below the corresponding elevation. For example, 70% of the regional topography is 1100 m or less while 87% of the sites in the data network fall below this point, indicating that elevations below 1100 m are underrepresented by the data network. With the addition of the Wildcat Mountain sites the data network nearly matches regional topography above 1300 m. There are no sites between 500 m and 600 m, nor between 1100 m and 1300 m. These difficulties in sampling the actual meteorological diversity within Andrews should be borne in mind by the reader throughout subsequent data analysis presented in this thesis.

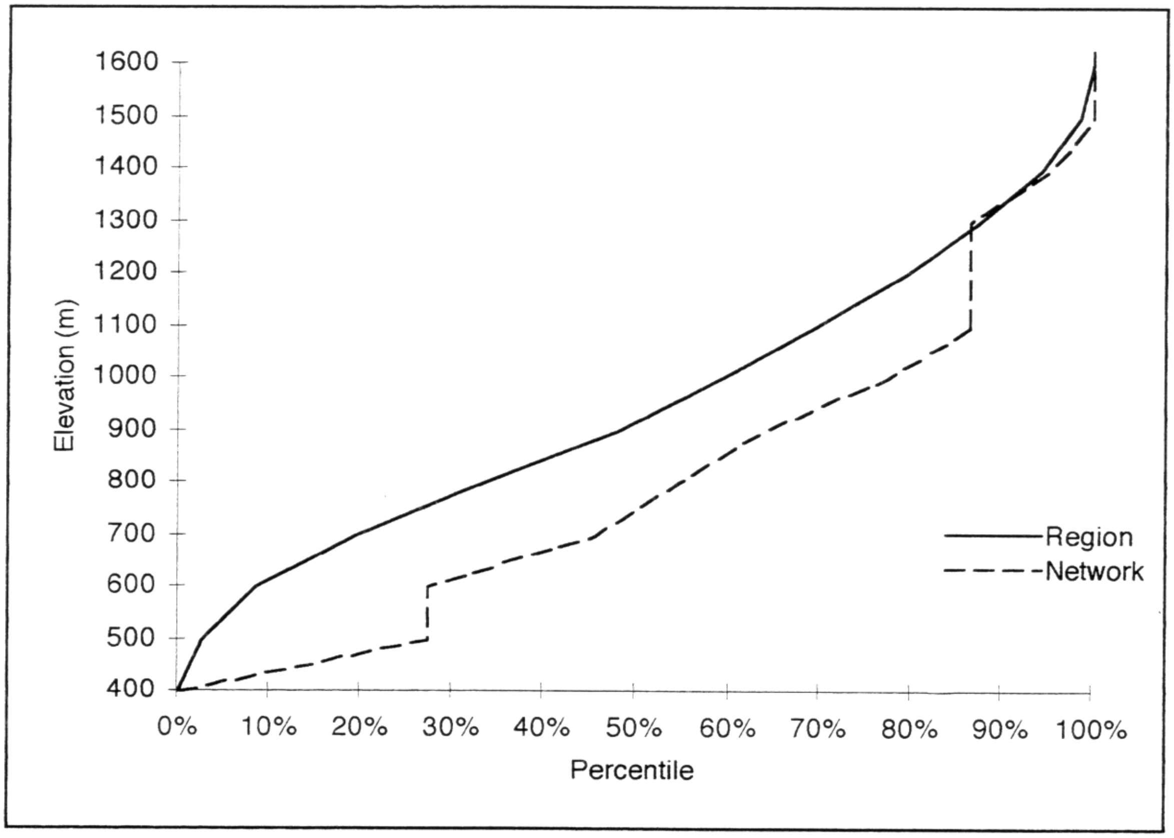

FIGURE 3. Comparison of Regional Topography and Station Network Topography

Summary

The basic data, then, are the sequences of monthly mean, mean maximum and mean minimum air temperatures in degrees Celsius for the period 1981-1990 at 20 individual sites within the boundaries of the Andrews forest and 2 sites located just to the north of Andrews. The following chapters describe temperature and its primary controls which provide the framework for subsequent analysis (Chapter II), discuss the descriptive statistics generated from the data set (Chapter III), present a method for deriving maps of mean temperature for the base period (Chapter IV), and evaluate a model for estimating daily temperatures in the watershed (Chapter V); the thesis concludes with general remarks and suggestions for further research (Chapter VI).

CHAPTER II

TEMPERATURE AND ITS CONTROLS

Temperature is arguably the most pervasive environmental factor to which all living things respond. There are many things which affect the temperature in a given place at any given time and these factors fall broadly into the categories of radiant and turbulent heat exchange, air movement and the physical constraints of the site in question.

On a global scale the radiant heat exchange between the earth-atmosphere system and space is paramount. The sun's heat streams out through space as short-wave radiation, a form of energy which penetrates most of the earth's atmosphere without heating it. The land (or sea) receives this short-wave energy which is converted to long-wave radiation and re-emitted by the earth in such a way that the atmosphere can be warmed. The magnitude of this exchange and its seasonal variation depend primarily on latitude which affects both the intensity of the exchange (the sun's angle above the horizon) and its duration (length of daylight period) (Oke, 1987). Air in direct contact with the heated surface of the earth gains heat by conduction then expands and rises in convection currents and is replaced by colder, denser air which is in turn heated. In these three ways—through radiation, conduction and convection—heat is eventually distributed throughout the lower layers of the earth's atmosphere in what is measured as air temperature. Latent heat flow is also important in heating the atmosphere, especially the upper troposphere.

Clouds and the moisture content of air are the most important aspects of the state of the atmosphere affecting heat exchanges. Clouds are highly reflective to short-wave radiation from the sun and highly absorbent of long-wave radiation from the earth. A consistently cloudy, moist atmosphere, as is characteristic of Andrews during winter months, will moderate both extremes of temperature thereby reducing maximum temperatures during the day and preventing excessively low minimum temperatures at night. Under clear, dry conditions like that which prevail at Andrews during summer months, the earth receives more energy than it sends out. During the day when skies are clear there is a net gain in heat from the sun resulting in high surface temperatures; at night when no solar energy is received but long-wave radiation from the earth escapes freely and unchecked, there is a loss of heat and temperatures fall rapidly.

Large-scale deviations from the average global energy exchange are induced by the state of the atmosphere and the nature of the underlying surface. Atmospheric motion, both advection and convection, often become the dominant control of temperature. Air masses in the middle latitudes have widely varying characteristics and sit in juxtaposition to one another across the polar front; they sweep across the earth and account for nearly all the day-to-day variation in surface air temperatures (Barry and Chorley, 1992). The broad-scale control of temperature by such things as latitude and land-sea differences set the background for general temperature changes that can be expected seasonally, but daily variations are almost completely a function of the local advection of air masses (Barry and Chorley, 1992; Barry, 1992; Geiger, 1965). Advection not only influences the spatial variability of air temperatures but also greatly affects atmospheric conditions, particularly cloudiness and humidity, which as noted above, have profound effects on insolation receipts and radiation exchanges between the earth and the atmosphere.

The physical characteristics of a site are also important to consider in a discussion of temperature and its controls. Latitude has already been mentioned for its importance to the seasonal rhythm of the heat exchange (i.e. solar incidence and duration); solar and net radiation, and therefore temperature, generally decrease with increasing latitude. Land-sea differences, or continentality, are also important to the heat exchange for effects caused by the differences in the heat capacity of land and water. Barry (1992) reports that the heat capacity of a sandy soil is 2x (when it is wet) to 3x (when it is dry) that of water. As a result, the annual and diurnal ranges of surface and air temperature are much larger in continental climates than over the oceans, however, the predominance of maritime air masses in west coast mountain ranges extends the oceanic influences inland.

Latitude and continentality are factors which affect climate on a regional scale, however, altitude plays a major role in defining climates on a more local scale. Altitude is of primary importance for its general affect on the atmosphere (i.e. pressure and density) as well as for variations in the receipt of solar radiation. In mountain areas in particular, the effect of decreasing temperatures with height has been widely studied (Geiger, 1965; Barry 1992). The rate of change in temperature with gain in elevation is called the lapse rate and approximates -6°C/km in the free atmosphere. Average lapse rates vary considerably in relation to climatic zone as well as to season. In addition, the gradient may be temporarily reversed over limited vertical distances in a layer of temperature inversion. This may occur due to nocturnal radiative cooling at the surface, large-scale subsidence in an anticyclone, or advection of a warm air mass over a colder surface (Barry, 1992).

Furthermore, observed temperatures are greatly affected by varying heat exchanges over different surface types. Heat conduction, albedo and the evaporation rate of water—all important factors in the energy balance of a location—vary greatly depending on whether that surface is, for example, wet soil, dry desert sand, green vegetation, snow cover or old growth forest. Geiger (1965) writes at length about the importance of surface cover to microclimates and several studies have described the relationship between albedo and surface type (Oke, 1987).

In summary, location, topography and land-surface combine in different ways (and at varying scales) with the heat exchanges at the earth's surface and turbulence in the atmosphere to influence temperatures at a given point in space and time. It is within this context that the following chapter seeks to describe the thermal climate of the Andrews forest.

CHAPTER III

DESCRIBING THE THERMAL CLIMATE

The annual variation of temperature, as shown by the average of all sites in the data network, indicates a typical variation for a mid-latitude maritime climate (Table 2, Figure 4). Descriptive statistics were generated for each site in the data network and are presented in Appendix A.

Winter temperatures are mild with a low occurring in December when the radiant heat exchange at the surface is negative. The low sun angles and fewer hours of daylight during the northern hemisphere winter solstice create a reduction of incoming solar radiation to the earth's surface and as such limit the means by which the atmosphere is heated. Across the network mean December temperature is 1.1°C with a standard deviation of 1.1°C. Mean minimum temperatures range from -3.1°C at RS14 to 1.2°C at RS16 and mean maximum temperatures range from 1.0°C at RS04 and Lookout Creek to 6.9°C at RS86. Extreme December values for the period 1981-1990 were -8.2°C recorded at RS13 in 1983, and 12.0°C at RS86 recorded in 1989. Temperatures warm slightly in January but dip again in February. Mean maximum temperatures show a typical upward trend from the winter low toward the summer high but topographical shading keeps minimum temperatures low, especially at sites along the valley floor. February mean minimum temperatures range from -3.2°C to 1.1°C (that is 0.1°C lower December's range) but the overall temperature regime for the month is moderated by a greater range in mean maximum temperatures, from 1.3°C to 8.6°C. The February mean temperature across the network is 1.8°C with a standard deviation of 1.4°C. The lowest temperature for the base period was recorded in February, 1989 with a mean minimum temperature of -10.5°C at RS86.

TABLE 2. Summary of the Descriptive Statistics; Average of all Sites in the Data Network

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly Mean												
Mean	1.9	1.8	3.6	6.0	9.3	13.2	16.0	16.5	12.7	8.8	3.4	1.1
Max	3.7	3.7	5.7	8.5	11.9	15.7	18.2	18.8	15.3	10.7	5.0	2.7
Min	-0.1	-0.9	0.0	1.7	4.7	9.7	12.6	13.6	10.1	6.7	0.4	-0.9
Stdev	1.1	1.4	1.8	2.2	2.2	1.8	1.7	1.6	1.6	1.3	1.4	1.1
Hi Max	9.0	8.3	9.4	13.2	15.4	19.3	22.5	22.9	18.0	16.2	10.3	7.4
Lo Min	-4.3	-6.4	-3.2	-2.4	1.4	4.8	7.1	10.8	6.3	1.1	-4.1	-6.1
Mean Maximum												
Mean	4.0	4.6	7.1	10.6	14.4	19.1	22.6	23.4	18.5	13.2	5.7	3.4
Max	7.8	8.6	11.8	16.2	20.6	25.7	29.7	30.5	24.6	18.3	8.9	6.9
Min	1.4	1.3	2.3	4.7	7.9	13.6	16.8	17.7	13.8	9.0	2.4	1.0
Stdev	1.8	2.3	3.1	3.6	3.5	3.3	3.4	3.6	3.4	2.7	1.9	1.6
Hi Max	11.4	13.1	16.7	21.6	23.9	30.0	33.4	34.2	28.3	26.3	13.2	12.0
Lo Min	-2.8	-3.0	-1.6	-0.3	4.4	8.3	10.2	14.4	9.7	3.1	-2.5	-4.2
Mean Minimum												
Mean	0.0	-0.5	0.9	2.5	5.0	8.4	10.7	11.2	8.3	5.5	1.4	-0.8
Max	1.2	1.1	2.6	4.2	6.8	10.0	12.5	13.2	10.5	7.6	3.2	1.2
Min	-2.5	-3.2	-2.1	-1.0	1.7	6.0	8.7	9.5	6.6	3.9	-1.5	-3.1
Stdev	1.1	1.2	1.3	1.5	1.6	1.3	1.2	1.1	1.2	1.1	1.3	1.1
Hi Max	7.0	6.3	5.3	8.5	11.0	13.2	15.9	17.0	13.7	14.1	8.3	6.4
Lo Min	-6.4	-10.5	-5.0	-4.3	-1.7	1.4	4.0	7.1	2.8	-1.2	-6.0	-8.2

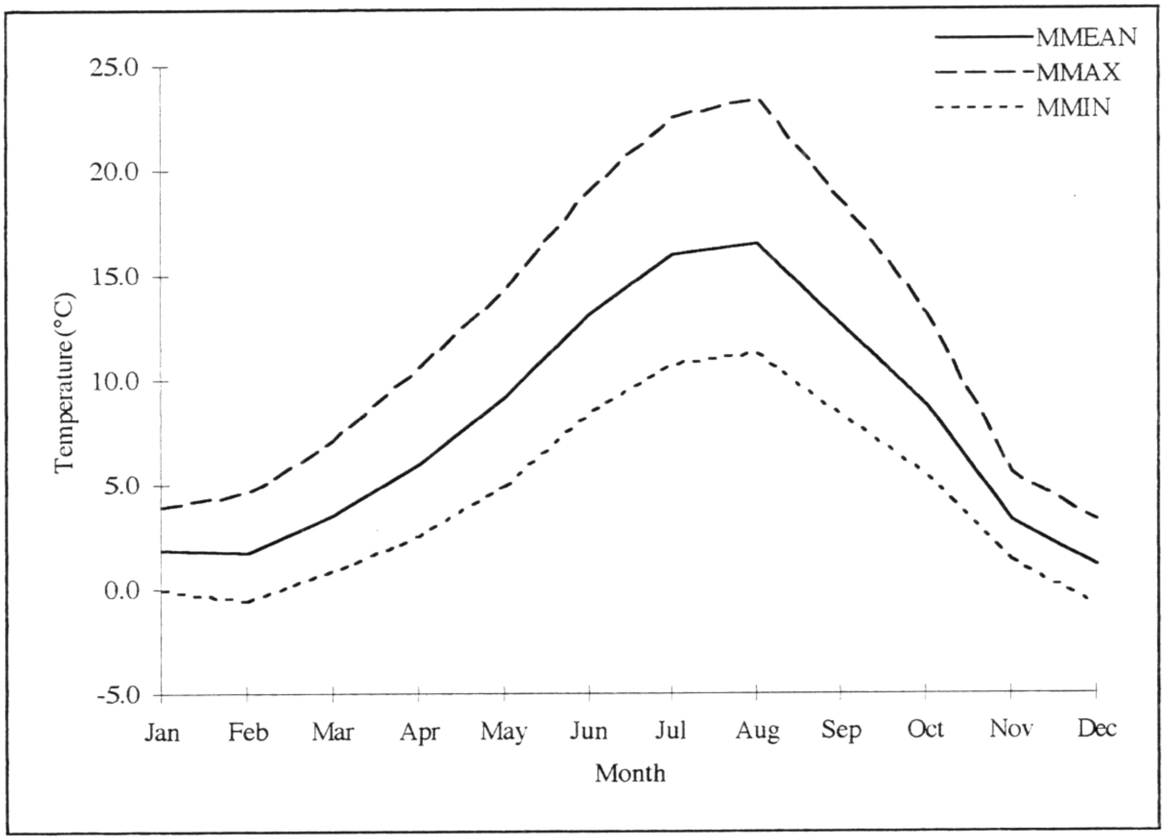

FIGURE 4. Composite of Monthly Mean Temperatures, 1981-1990

As insolation activity increases through the spring temperatures rise steadily and peak in August (Figure 4); it is probable that an August maximum occurs instead of a July maximum because of the greater cloud cover existing in July. Mean August temperature is 16.5°C. August minimum temperatures range from 9.5°C at PRIMET to 13.2°C at RS15. Maximum temperatures range from 17.7°C at RS14 to 30.5°C at RS89. In contrast to having the lowest mean minimum temperature in August, PRIMET has the second highest mean maximum temperature for the month at 29.1°C. This is a function of the nature of the adjacent ground surface, a grassy clearing along the valley floor. During summer days with the sun high in the sky and many hours of daylight, the surface of the earth receives more solar energy than it sends out as terrestrial radiation. When skies are clear, as is typical at Andrews during the summer, nothing can prevent this gain of heat from proceeding at its maximum rate which results in high maximum temperatures. During the clear, starry nights this heat escapes freely from the atmosphere and the temperature falls rapidly. Low minimum temperatures are common, particularly at sites along the valley floor where cold air drains off adjacent slopes and pools to form a cold air lake. Consequently, over treated sites where there is no canopy to filter incoming radiation or trap outgoing energy mean maximum temperature are generally higher and mean minimum temperatures are generally lower.

Through the fall, temperatures decrease rapidly with the largest change in absolute values occurring between October and November; mean October temperature is 8.8°C while mean November temperature is 3.4°C. Maximum temperatures change the most dropping from 13.2°C in October to 5.7°C in November. This change coincides with two things affecting the radiant heat exchange: 1) net radiation is less after the equinox; and 2) cloudiness increases as the polar front dips further into the region for the winter.

The Geography of Temperature Inversions in the Watershed

Temperatures generally vary with elevation, decreasing with height at a rate of approximately -6°C/km; however, in mountainous areas temperature inversions are common and numerous studies have observed the dynamics which give rise to them (Geiger, 1965; Barry, 1992). Inversions are the increase of temperature over limited vertical distances and are due to the sinking of colder, denser air under the forces of gravity. In mountain environments, especially at night when there are no clouds, the air cools as the underlying surface emits long-wave radiation. This air flows down mountain slopes and forms a pool of cold air along the valley floor such that temperatures can be higher than at points just below. Bierlmaier and McKee (1989) note the occurrence of temperature inversions at Andrews so a subset of the data network comprised of only closed canopy sites—RS07, RS01, RS02, RS17, RS10, RS16, RS20, RS15, RS05, RS03, RS04, RS13, RS14—was examined to better understand the geography of the zone of inversion in the Lookout Creek watershed.

Elevation and temperature profiles of mean minimum temperature for selected months (Figure 5) indicate the presence of temperature inversions during most months. With the exception of late winter and early spring, mean minimum temperatures increase with elevation up to about 750 m, above which temperatures begin to decrease as elevation increases. During late winter and spring when skies over Andrews are seldom clear and clouds absorb and re-emit energy back to the surface, inversions are weak if they exist at all. January temperatures show only a slight increase with elevation up to 750 m and an inversion intensity of about 1.0 °C/100 m. There is little variation among the lower elevation sites indicating uniformly cold temperatures along the valley floor regardless of site factors like aspect. April's profile indicates no significant change with elevation below 750 m and there is more variability between the sites due to microclimatic influences like

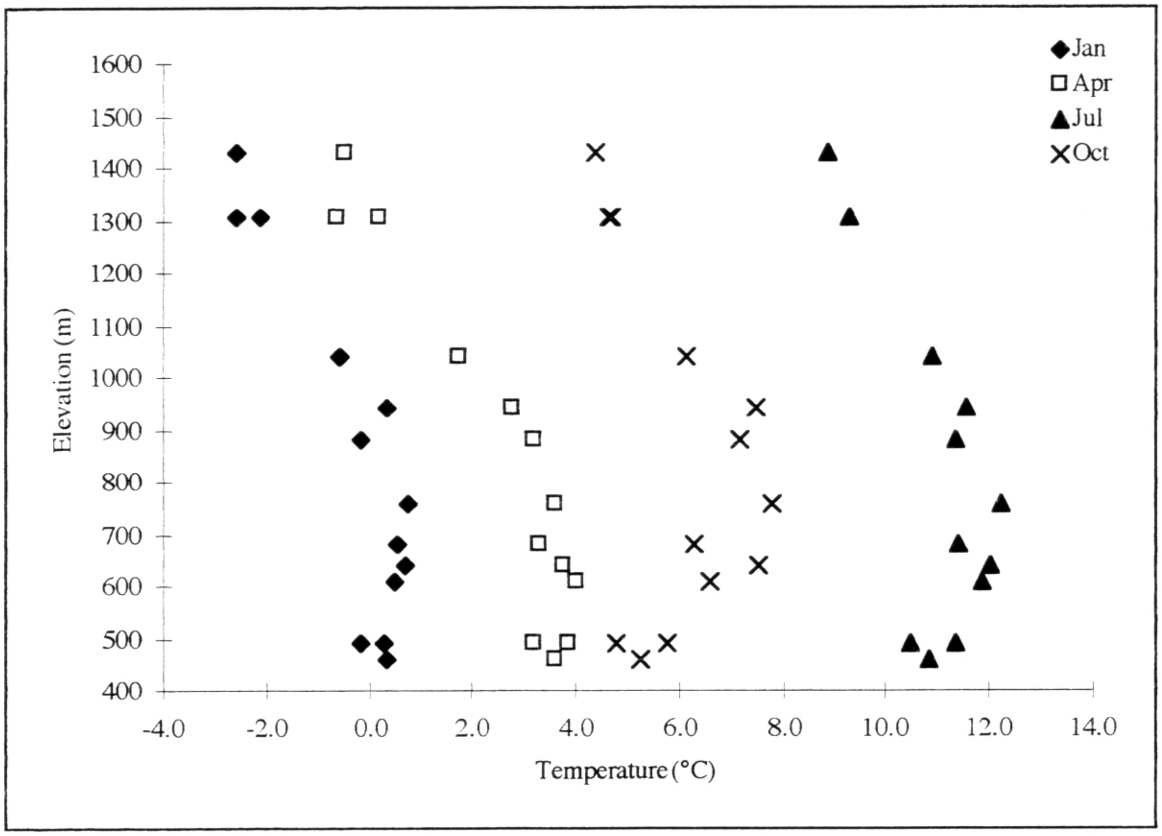

FIGURE 5. Temperature Profiles of Mean Minimum Temperature for Selected Months

aspect and slope. In the summer and early fall the atmosphere above Andrews is generally clear and calm and temperature inversions are most pronounced. In July a characteristic inversion of minimum temperatures is clear: temperatures increase with elevation at an intensity of almost 2.0 °C/100 m. August and September have similar profiles while the inversion gets steeper until it peaks in late September. The steep increase in temperature with height still occurs in October which is shown in the figure. There is more variability between sites than is evident earlier in the summer but the intensity is more than 3.0 °C/100 m and the height of the inversion has risen to about 800 m.

The patterns of variability in the profiles of maximum temperature (Figure 6) are due to differences among slope and aspect and the seasonal changes in direct radiation. Weak inversions are evident in late fall and winter but the top of the inversions extend only to about 650 m. In January there is some increase in maximum temperatures with height to about 650 m, and above that point temperatures generally decrease with elevation. There is no obvious temperature inversion in April and in July temperatures show a clear negative trend with elevation at all heights. A slight inversion returns in October in very low elevations. The intensity of direct solar radiation is high on steeper slopes during winter as evidenced by an apparent secondary inversion at mid-elevation sites in January; RS26 indicated in Figure 6 (elevation 1040 m, slope 37°) really draws the trend out. As the season changes, shifts in the intensity of direct radiation is reflected at south and west facing slopes. In April, just after the equinox, topographic shading is less at lower elevation sites, potential temperatures are greater and temperature inversions do not occur. Throughout the summer, sites on south facing slopes have the highest mean maximum temperatures and by October, after the fall equinox, a temperature inversion returns as west and north facing slopes tend to be cooler as a result of the change in the angle of solar declination.

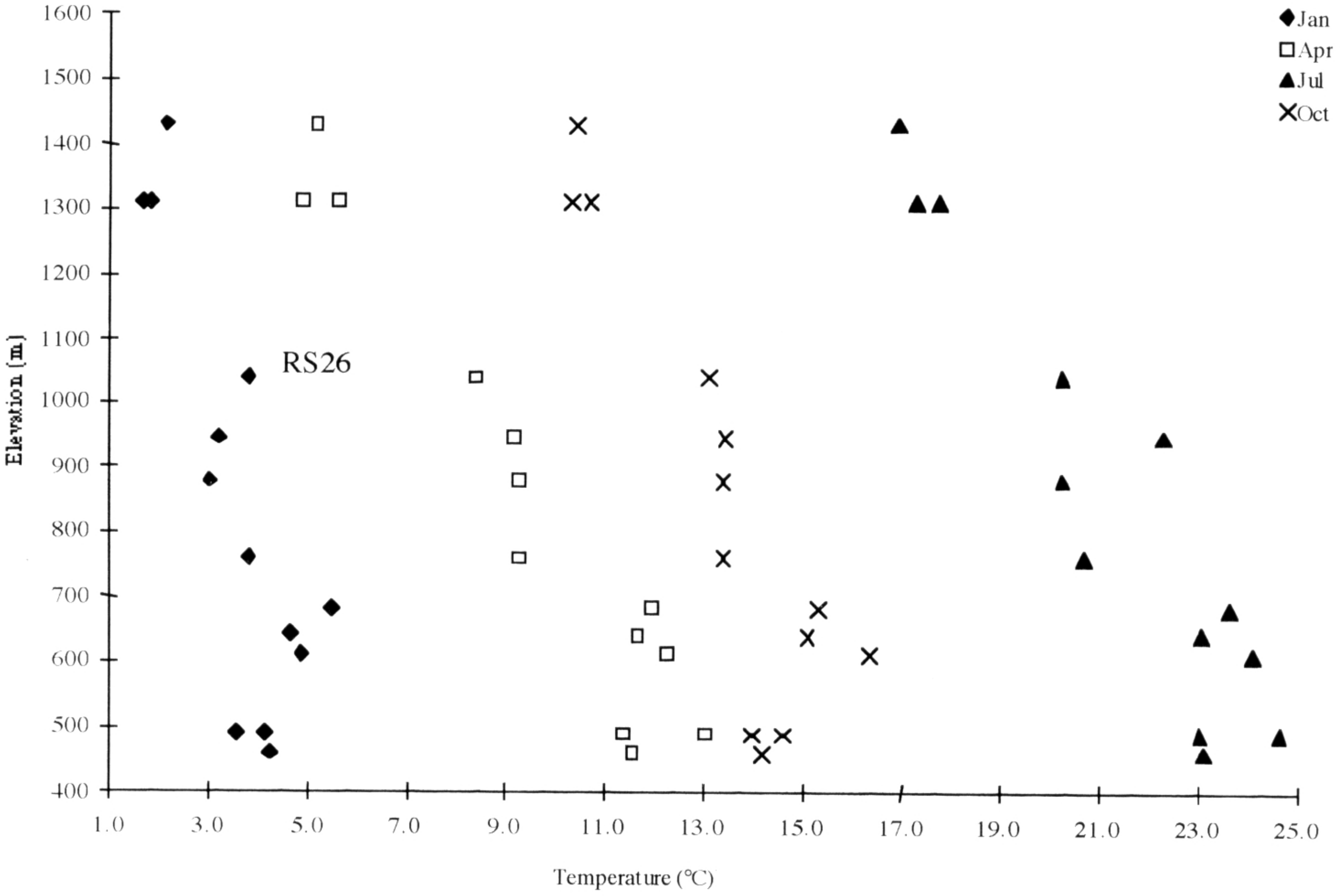

FIGURE 6. Temperature Profiles of Mean Maximum Temperature for Selected Months

Monthly mean temperatures (Figure 7) are more influenced by the seasonal patterns of mean minimum temperatures rather than mean maximum temperatures, although characteristics of both variables can be seen. Temperature inversions are most pronounced during summer and fall with an intensity of about 2.0 °C/100 m which extends to a height of 700 m. In Chapter IV, maps of monthly temperature are presented in which the areas of temperature inversions are shaded to better visualize the changing patterns throughout the year.

Lapse Rates

The presence of temperature inversions in the watershed raises the question of what value lapse rate to apply. Lapse rates are the variation of temperature per unit height which as previously noted is assumed to be -6°C/km in the free atmosphere. They are a useful measure for interpolating between sites as well as interpreting maps; but since they vary spatially and temporally it is important to understand their variability before applying lapse rates to any analysis.

Free air lapse rates are generally measured in a vertical profile over a fixed point using weather balloons. The data in this study come from surface observations along an elevational gradient (the same subset of closed canopy sites illustrating the temperature and elevation profiles above were used to describe the surface lapse rates in the watershed). The relationship between temperature and elevation is similar in the free air and at the surface, however, surface lapse rates are more likely to be influenced by site characteristics.

If one assumes a linear relationship between temperature and elevation the lapse rate is the slope of the line fitted between all data points (Table 3). Some variability due to aspect is built into the relationship but it does not describe any temperature inversions. Such information may be useful in describing relationships between valley floor sites and upper elevation sites, but should be used with the standard errors as a measure of confidence.

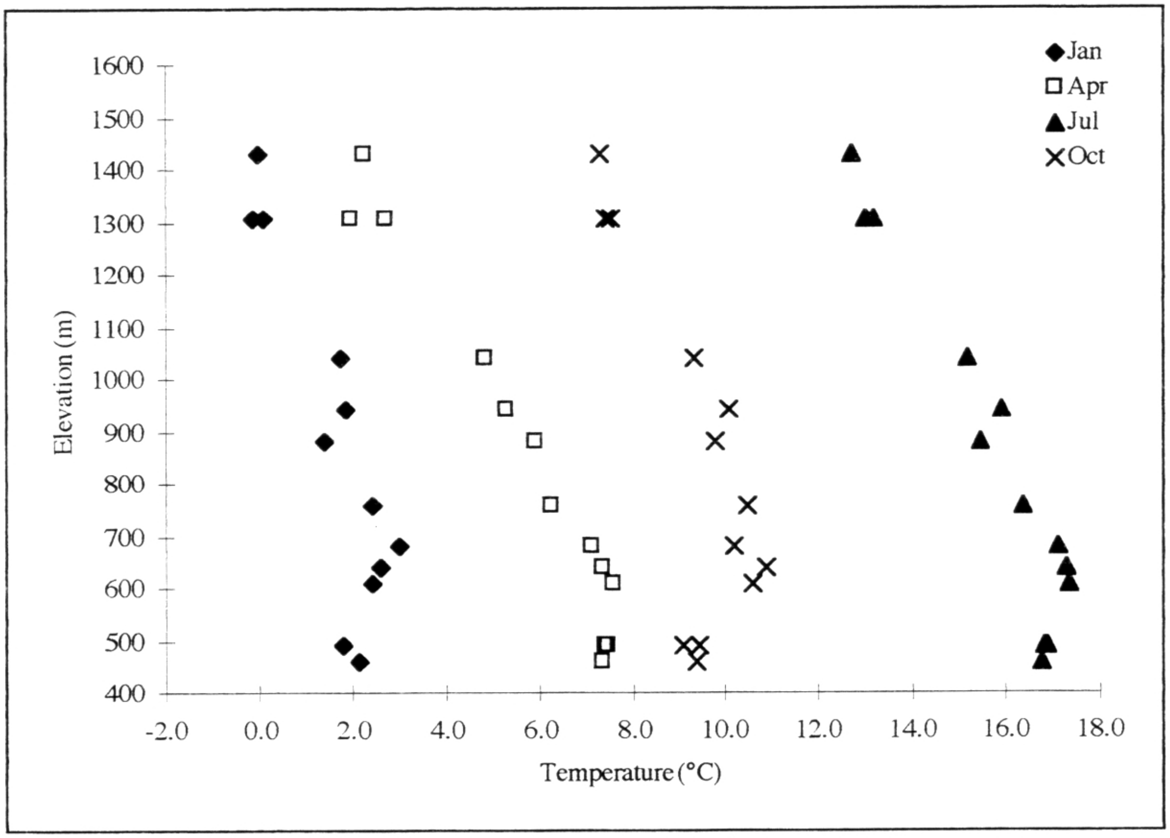

FIGURE 7. Temperature Profiles of Mean Temperature for Selected Months

TABLE 3. Generalized Lapse Rates for Moving Between Valley Floor and High Elevation Sites

	MMEAN		MMAX		MMIN	
	Δ°C/km	SEE	Δ°C/km	SEE	Δ°C/km	SEE
January	-2.54	0.6	-2.84	0.7	-3.23	0.6
February	-3.61	0.6	-4.60	0.8	-3.36	0.6
March	-4.97	0.5	-6.68	0.9	-3.79	0.6
April	-6.10	0.5	-8.06	0.8	-4.68	0.7
May	-6.34	0.6	-8.32	1.0	-4.68	0.7
June	-5.30	0.4	-7.21	0.8	-3.73	0.7
July	-4.82	0.5	-7.43	1.0	-2.41	0.8
August	-4.02	0.6	-7.25	1.1	-1.13	0.9
September	-3.18	0.8	-6.35	1.2	-0.91	1.1
October	-2.65	0.8	-5.01	0.9	-1.36	1.2
November	-4.20	0.5	-4.41	0.5	-4.10	0.7
December	-2.65	0.6	-2.64	0.6	-3.06	0.7

In order to describe lapse rates in the watershed more accurately the presence of temperature inversions must be taken into account. Based on the monthly profiles described in the previous section the inversion height extends to about 750 m but varies between the temperature parameters and throughout the year. On average, monthly mean temperature inversions reach to about 700 m, mean maximum to approximately 650 m and mean minimum to about 750 m. Calculation of the lapse rates is described by Conrad and Pollack (1950) as the temperature difference between two sites divided by the corresponding difference in elevation. Two lapse rates were calculated—one above and one below the top of the inversion—as the change in temperature per 100 m based on the following equation

$$\Delta T = T_1 - T_2 * 100 / (E_1 - E_2) \quad (1)$$

where ΔT is the lapse rate expressed as °C/100m; T_1 is the temperature in °C at one site and T_2 is the temperature in °C at the second site, and E_1 and E_2 are the elevation in meters for the first and second sites respectively. A generalized view of annual lapse rates (Figure 8) shows a moderate inversion for all variables below 750 m.

Lapse rates for mean minimum temperatures (Table 4) start the year with a slight temperature inversion in lower elevations and a moderate decrease with elevation at higher sites. The inversion becomes gradually less obvious through spring until May when there is no noticeable change in minimum temperatures with height below 750 m; instead temperature differences are related to aspect. By July there is a pronounced minimum temperature inversion with changes at a rate of +4.6°C/km below 800 m. This inversion gets steeper through the summer until it peaks in September at a rate of +8.9°C/km below 800 m. It is similarly high in October but lessens dramatically through November and December before the annual cycle begins again. While the top of the inversion fluctuates somewhat, the lapse rates for mean minimum temperature above the inversion are fairly constant through the year.

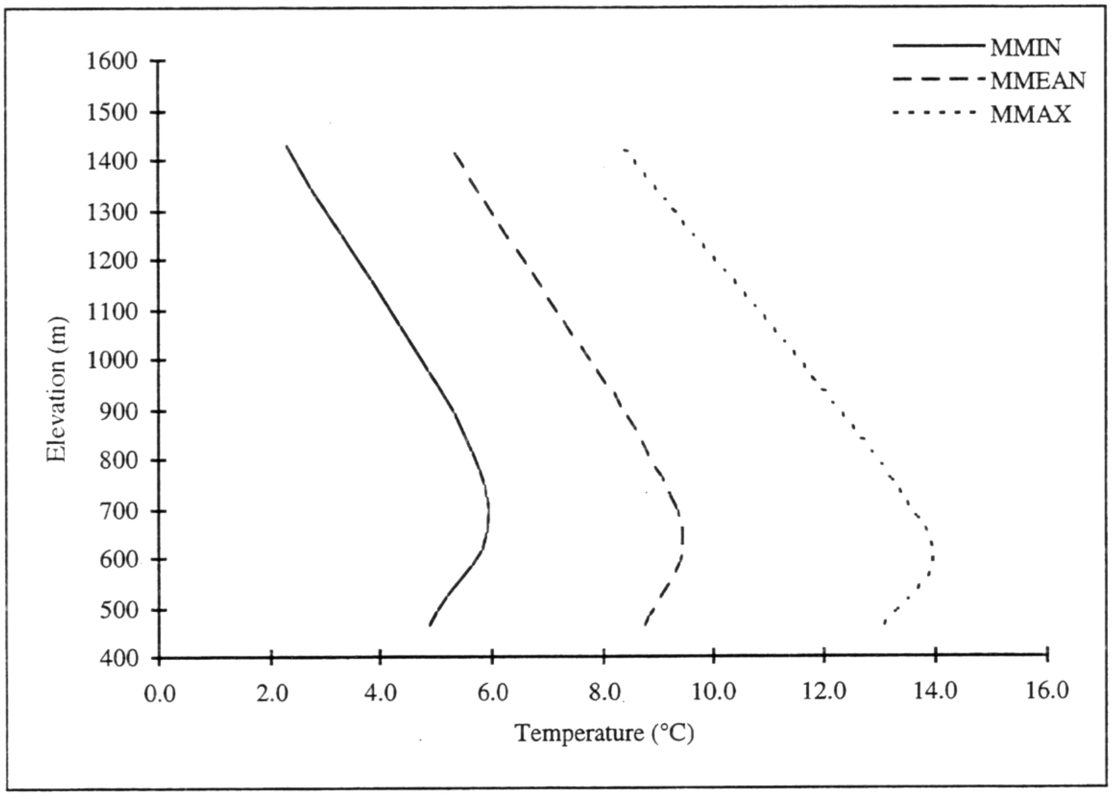

FIGURE 8. Annual Temperature Profiles

TABLE 4. Top of the Inversion Zone (m) and Corresponding Lapse Rates (°C/100m) Above and Below that Point

	MMEAN			MMAX			MMIN		
	Break	Below	Above	Break	Below	Above	Break	Below	Above
January	700	0.39	-0.40	650	0.56	-0.45	700	0.14	-0.50
February	700	0.32	-0.54	650	0.67	-0.71	700	0.12	-0.47
March	700	0.13	-0.54	650	0.40	-0.79	700	0.12	-0.53
April	650	0.15	-0.65	400		-0.84	700	0.08	-0.54
May	650	0.24	-0.70	400		-0.88	700	0.01	-0.50
June	650	0.15	-0.59	400		-0.79	750	0.08	-0.57
July	700	0.28	-0.58	400		-0.82	800	0.46	-0.50
August	700	0.21	-0.52	400		-0.83	800	0.69	-0.43
September	700	0.59	-0.51	400		-0.70	800	0.89	-0.47
October	700	0.37	-0.38	650	0.52	-0.66	800	0.86	-0.52
November	700	0.20	-0.52	650	0.23	-0.50	750	0.34	-0.55
December	700	0.23	-0.32	650	0.32	-0.37	750	0.17	-0.49

Mean maximum temperature lapse rates show steep changes with height through the year. In January, February and March there are steep inversions (about +5.4°C/km) but the inversion height is only 650 m. Above this point even larger changes with height occur. In April no obvious inversion exists and the lapse rates reported are based on the difference between temperatures at 460 m and 1430 m. The lapse rates are high and reflect the potential range of temperatures from low and high elevation sites. In October a maximum temperature inversion returns and persists through the end of the year. Again there is a large difference between October and November lapse rates due in part to a decrease in the amount of potential radiation and related surface warming after the equinox and the seasonal fluctuation of the polar jet stream which starts to bring less atmospheric stability, increased cloudiness and frontal storms to the area about this time.

Controls on the Spatial Variability

In Chapter II the radiative heat exchange, atmospheric motion and the physical characteristics of a site were discussed as fundamental controls of temperature. The data evaluated here show that mean maximum temperatures vary with elevation and are more variable due to effects of aspect, especially during spring and summer months while mean minimum temperatures are influenced primarily by elevation and the seasonal synoptic climatology. This section will address the complexities of relationships between topography, land surface and radiation to illustrate that the controls on the variability of Andrews' thermal climate are surface characteristics, elevation, aspect and seasonality.

The characteristics of the land surface exert a direct control on net radiation and changes to the surface affect the controls on radiant energy exchanges, the sensible heat exchange between the surface and the air, and the latent heat exchange through evapotranspiration (Oke, 1987; Sellers, 1969). When a forest cover is removed the surface will exhibit a new set of controls on the radiation balance. More solar radiation will reach the surface because the filtering effect of the forest has been removed. However, more solar radiation will be reflected because the albedo of the surface is increased. Albedo is a reflection coefficient in the energy balance equation and controls the amount of solar radiation which is lost directly through reflection. The albedo of coniferous forests is low compared to most other natural surfaces (see Oke 1987, page 12). McCaughey (1981) found that for a coniferous forest in Quebec, logging increased albedo from 0.08 to 0.18; also there was increased loss of long-wave energy particularly under dry conditions.

With about 30% of the Andrews forest having been experimentally logged in recent decades the land surface of a site is extremely important to spatial patterns of temperature on a small scale. Sites in the data network can be grouped broadly into three categories: closed canopy, open or treated sites and streams. When moving between groups large temperature differences can be seen (Figure 9). Sites that have been treated show considerably more range in temperatures throughout the year than canopied sites, while air temperatures above streams have less range. These differences are a direct function of the adjacent surface. As previously described at the beginning of this chapter, treated surfaces exhibit a greater range in temperatures because there is no canopy present to filter incoming energy or trap out-going energy; the result is higher maximum temperatures and lower minimum temperatures. The stream sites on the other hand are generally below the canopy but the higher moisture content of the air adjacent to the stream moderates the extremes of temperature and thus its range.

In the context of site characteristics elevation is also an important control on the spatial variability of air temperatures. This has been demonstrated in the elevation and temperature profiles presented earlier in the chapter. F-statistics generated from the lapse rates in Table 3 are high (for individual months they range from 61.5-111.9) and indicate that elevation is a reasonable predictor of temperature in the watershed; this theory will be further developed in the following chapter. Aspect is also an important control on temperature for it is the

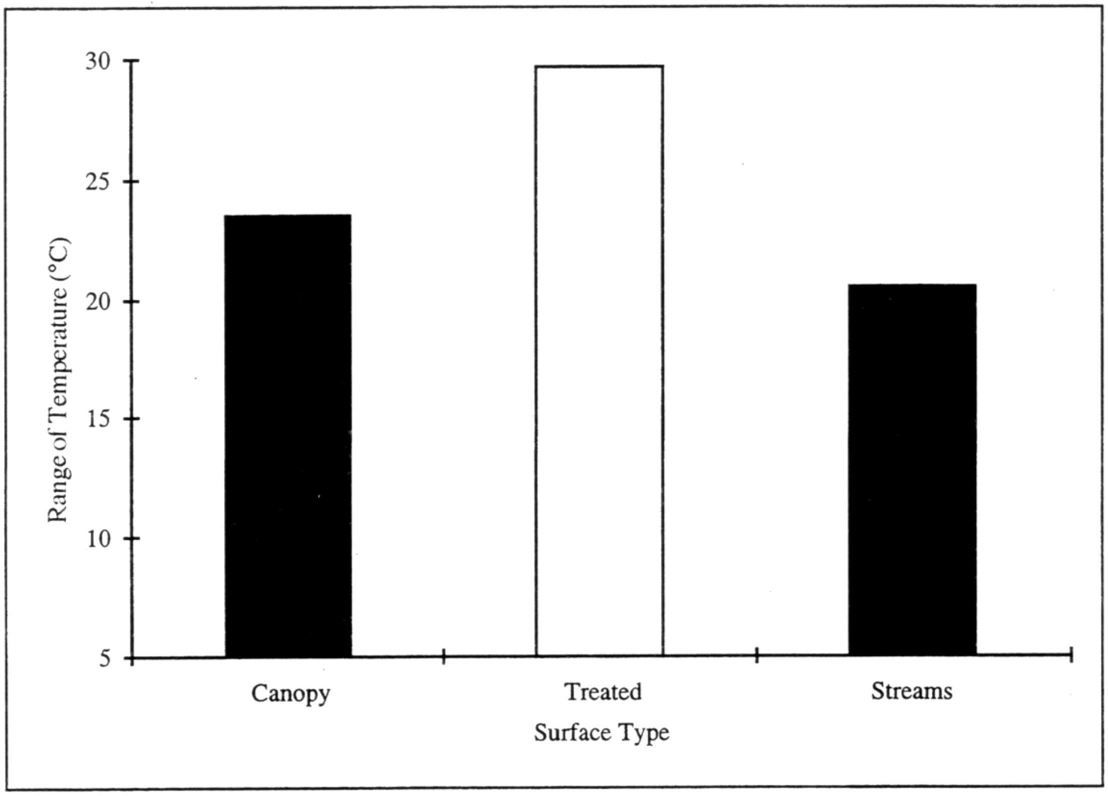

FIGURE 9. Average Annual Range of Temperature over Different Surface Types

direction in which a surface faces and controls the amount of solar radiation received at the surface. For example, south facing slopes receive more solar energy than north facing slopes while east and west facing slopes have a maximum solar intensity that shifts according to both the angle of declination as well as the topographical slope of the surface. At Andrews, aspect is a critical control during spring and summer months when insolation is greatest due to the season and lack of cloud cover.

Finally the synoptic climatology, particularly as it relates to cloudiness, is another important temperature control. The cool, wet winters and warm, dry summers that dominate the region translate into generally cloudy winters and clear summers. The effect of moderated temperatures during winter and rapid radiative losses during summer relating to the presence or absence of clouds is extremely important to Andrews thermal climate.

In sum, variability of the thermal climate is associated with (1) land surface, (2) elevation, (3) aspect and (4) seasonality. Assuming a baseline of closed canopy, old-growth forest the following generalizations can be made: harvesting or maintaining clearings have the effect of increasing maximum temperatures and decreasing minimum temperatures; proximity to streams have lowering effects on both maximum and minimum temperatures; increases in elevation have a lowering effect on maximum temperatures whereas minimum temperatures show an increasing effect below 750 m and a lowering effect above 750 m; north facing slopes have a lowering effect on maximum and minimum temperatures and south facing slopes have an increasing effect. Effects of westerly slopes exhibit more seasonal variation as maximum temperature shows more increases during summer and minimum temperature more decreases during winter. Temperature inversions occur with the greatest intensity during the summer and early fall when clear, calm weather dominate the region while winter temperatures are moderated by cloudy, moist conditions.

CHAPTER IV

MAPPING THE THERMAL CLIMATE

Maps provide the best means by which the spatial distribution of surface temperatures can be illustrated. With sometimes sharp temperature gradients over short distances and significant seasonal variability among temperature parameters it would be useful to have a method for describing temperatures in the watershed with maps of monthly temperature.

As noted in the preceding chapters, the affect of altitude on temperature is significant. Simply contouring between observation sites to produce maps without accounting for elevation does not provide a reasonable representation of temperature because it does not account for the physical processes which control temperature distributions; in addition, with sites being clustered in the southwest corner of the forest (Figure 2, page 11), the network at Andrews is too sparse and spatially unrepresentative for this method to be feasible. Historically, a common means of mapping temperature conditions has been by the reduction of temperature to a given level, frequently sea level or the average level of a valley bottom (Conrad and Pollack, 1950). This method also requires a dense, evenly spaced network and may be more appropriate where there are small differences in height that are more or less negligible in comparison to the corresponding horizontal distance. Several investigations of mountain temperatures have used regression analysis to relate temperature to altitude but do not separate between effects of slope and aspect (see Steinhauser, 1967 in particular), however, Barry (1992) reports that there have been few attempts to describe mountain temperature variations with more than just a general statistical model.

Pielke and Mehring (1977) recommend a method for contouring temperature fields in mountainous terrain by fitting data points in a series with linear regression and plotting the estimated temperatures on a topographical map in place of elevation. Following the same technique that allows temperatures to be reduced to a given level, they used the best-fit linear regression model to describe the variation of mean monthly surface temperatures with station elevation.

Linear regressions in the form

$$T = b_0 + b_1 Z \tag{2}$$

where T is the estimated surface temperature, b_0 the intercept, b_1 the slope and Z elevation, were calculated and draped over a digital elevation model to produce mesoscale mappings of mean temperatures. The advantages of this method are its straightforward approach which is easily automated and a general improvement over maps that are based solely on contouring between reporting stations since the primary physical control of the variability of temperatures—altitude—drives the model.

As noted in the preceding chapter aspect is one important control on temperature, and although the resolution and accuracy of the model above are limited by failing to consider aspect it is thought that since Andrews is cloudy for a significant part of the year that aspect plays less of a role than it otherwise might in determining air temperatures. Therefore, Pielke and Mehring's method for estimating a spatial representation of temperature is an adequate first approximation of the thermal climate in the watershed.

Methods

Eleven closed canopy sites were used in the analysis—RS07, RS17, RS10, RS16, RS20, RS15, RS05, RS03, RS26, RS04, and RS14. Treated, stream and associated sites were not considered and two closed canopy sites were set aside to validate the model's estimates after the analysis. Owing to the presence of temperature inversions in the watershed two statistical relationships are necessary to describe the variation of temperature with elevation, one above and one below the inversion heights reported in Table 4; as such two linear regressions in the form of Equation 2 were applied to each month's data, one below and one above the estimated height of the inversion. Calculations were made for the period of 1981-1990 of the intercept, slope, regression coefficient, standard error of the estimate and the uncertainty of the estimate (Tables 5, 6 and 7). The uncertainty of the estimate is a conservative measure defined at $|2S_e/b_1|$ (Hennessey, 1979). Note: since no inversions are present in mean maximum temperatures from April to September, inclusive, only one regression was performed during these months (between 460 m and 1430 m).

Results

The correlations are highest above the point of temperature inversions where the relationship between temperature and elevation is strongest and there is less variability between the sites. At lower elevations correlations are strongest during winter, spring and summer months (January, April, July) but vary during transition months and through the fall. The month of May has lowest correlations where inversions are nearly absent and the high degree of variation over short distances is attributed to microscale influences such as aspect and the affect of decreased cloudiness rather than to elevation.

The change of temperature with height (b_1) is greatest during the early fall at lower elevations; this is the time when temperature inversions are strongest, the diurnal range of temperatures is greatest and cold air ponding is common. Above the level of inversion, slopes in the relationship are greatest during spring and summer. The magnitude of the lapse rate may be due to the warming of lower levels after the equinox when upper elevation sites are still buried in snow. Once those sites start to warm at a rate similar to

TABLE 5. The Values of the Sea Level Value b_0, Lapse Rate b_1, Correlation Coefficient r, Standard Error of Estimates S_e, and Uncertainty in Elevation $|2S_e/b_1|$ for Mean Temperature 1981-1990

	Below approximately 700 m					Above approximately 700 m				
	b_0 (°C)	b_1 (°C/km)	r	S_e (°C)	$\|2S_e/b_1\|$ (m)	b_0 (°C)	b_1 (°C/km)	r	S_e (°C)	$\|2S_e/b_1\|$ (m)
January	-0.07	4.25	0.91	0.2	104	5.42	-3.90	-0.96	0.3	179
February	1.46	3.05	0.82	0.2	154	7.02	-5.19	-0.97	0.4	144
March	3.60	2.68	0.74	0.3	199	8.57	-5.54	-0.99	0.2	71
April	6.62	1.58	1.00	0.0	15	11.55	-6.59	-1.00	0.2	51
May	10.03	1.75	0.57	0.3	314	15.66	-7.16	-0.98	0.4	122
June	13.39	1.65	0.98	0.0	43	17.97	-5.88	-0.99	0.3	91
July	15.20	3.33	0.96	0.1	60	20.95	-5.82	-0.99	0.3	97
August	15.91	3.03	0.79	0.3	176	21.27	-5.13	-0.97	0.4	141
September	10.26	6.84	0.95	0.2	71	17.75	-4.69	-0.95	0.5	201
October	6.72	5.81	0.83	0.4	150	13.76	-4.52	-0.96	0.4	178
November	3.50	2.08	0.94	0.1	75	7.83	-5.01	-0.98	0.3	131
December	-0.04	3.09	0.79	0.3	171	4.48	-3.67	-0.96	0.3	189

TABLE 6. The Values of the Sea Level Value b_0, Lapse Rate b_1, Correlation Coefficient r, Standard Error of Estimates S_e, and Uncertainty in Elevation $|2S_e/b_1|$ for Mean Maximum Temperature 1981-1990

	Below approximately 650 m					Above approximately 650 m				
	b_0 (°C)	b_1 (°C/km)	r	S_e (°C)	$\|2S_e/b_1\|$ (m)	b_0 (°C)	b_1 (°C/km)	r	S_e (°C)	$\|2S_e/b_1\|$ (m)
January	0.93	6.33	0.85	0.4	137	7.11	-3.74	-0.85	0.7	379
February	2.75	6.16	0.87	0.4	128	10.22	-5.95	-0.91	0.8	278
March	6.05	4.89	0.75	0.5	199	12.76	-6.83	-0.93	0.8	237
April						15.87	-7.42	-0.95	0.8	209
May						20.39	-7.68	-0.92	1.1	276
June						23.43	-6.69	-0.94	0.8	246
July						27.22	-6.92	-0.92	1.0	295
August						28.25	-6.72	-0.89	1.1	337
September						23.67	-5.89	-0.85	1.2	420
October	10.83	7.22	0.73	0.8	211	19.02	-6.21	-0.95	0.6	199
November	5.27	2.74	0.82	0.2	149	10.02	-5.12	-0.96	0.4	170
December	0.94	5.05	0.84	0.4	142	6.42	-3.61	-0.89	0.6	312

TABLE 7. The Values of the Sea Level Value b_0, Lapse Rate b_1, Correlation Coefficient r, Standard Error of Estimates S_e, and Uncertainty in Elevation $\lvert 2S_e/b_1 \rvert$ for Mean Minimum Temperature 1981-1990

	Below approximately 750 m					Above approximately 750 m				
	b_0 (°C)	b_1 (°C/km)	r	S_e (°C)	$\lvert 2S_e/b_1 \rvert$ (m)	b_0 (°C)	b_1 (°C/km)	r	S_e (°C)	$\lvert 2S_e/b_1 \rvert$ (m)
January	-0.40	1.49	0.93	0.1	100	4.66	-5.10	-0.98	0.3	124
February	0.11	1.12	0.88	0.1	123	4.95	-5.24	-0.98	0.3	133
March	0.53	2.75	0.83	0.2	145	5.30	-4.68	-0.97	0.4	155
April	2.63	2.23	0.87	0.1	126	7.42	-5.41	-0.98	0.4	133
May	5.03	2.73	0.54	0.5	337	10.58	-5.82	-0.97	0.5	159
June	7.74	3.28	0.81	0.3	163	12.76	-4.69	-0.96	0.4	180
July	9.40	3.62	0.81	0.3	186	16.09	-5.11	-0.99	0.2	77
August	8.61	5.70	0.85	0.4	158	16.39	-4.33	-0.99	0.2	97
September	4.53	7.94	0.93	0.4	100	14.06	-4.57	-0.97	0.4	154
October	2.01	7.42	0.86	0.6	154	12.12	-5.54	-0.98	0.3	120
November	1.20	2.70	0.93	0.1	83	6.14	-5.20	-0.95	0.6	213
December	-2.38	4.59	0.91	0.2	98	3.52	-4.45	-0.94	0.5	218

lower elevation sites (approximately in May), the lapse rate is less.

The lapse rates indicated by the regression analysis compare favorably with those reported in Chapter III. In the zone of inversion, lapse rates indicated by the regression analysis are steeper, especially during late winter and late summer months, but show the same general trend: a small inversion during winter which becomes slight during spring marked by a low in April; summer months show a steep inversion with a high in September then moderating to a small inversion through the fall. Above approximately 750 m the lapse rates compare very well. Differences between lapse rates defined in Tables 5, 6 and 7 and those discussed in Chapter III are due to the different methods used in their construction. In Chapter III, lapse rates were described as the relationship between two sites (one low and one high elevation site either below or above the inversion height), whereas the regression analyses describe the relationships between all sites on either side of the estimated height of the inversion. The lapse rates reported in Tables 5, 6 and 7 are probably the most representative of reality since they are derived from a larger sample.

The variance of the data about the fitted regression line (S_e) is converted to an uncertainty in height by doubling the magnitude of the standard error and dividing by the slope of the regression (Pielke and Mehring, 1977). This determines the resolution of the estimates (i.e. a contour interval that is statistically appropriate for plotting). More confidence in the estimated temperature for a given elevation is expressed during months when the standard error is less and the lapse rate is greater. The largest uncertainty in elevation, 420 m, was for September mean maximum temperatures; in fact, there are large uncertainties in most of the estimates for mean maximum temperature due to the influences of insolation and aspect described in the previous chapter and the failure of the model to account for them. The uncertainties for monthly mean and mean minimum temperatures are more reasonable in terms of the contour interval they suggest and the amount of information that may be read from derived maps. Again, this is a conservative measure.

Pielke and Mehring describe the uncertainty as $|S_e/b_1|$ such that ~68% of the observed temperatures will be within $\pm S_e$ of the estimated temperature. The conservative measure used here reduces the resolution in the temperature field by half which seems prudent given the influences that create temperature variation over short distances (i.e. aspect), especially for mean maximum temperatures.

Two sites were kept out of the regression analysis so that they could be compared with model estimates, RS02 at 490 m and RS13 at 1310 m. The differences between estimates derived from the regression analysis and the 1981-1990 observed data are generally to within 0.5°C (Table 8); only six out of the seventy-two cases have errors ≥1.0°C. Estimates for mean temperature are consistently good while there is more variability in the extreme values. Mean minimum temperatures are over-estimated while mean maximum temperatures are under-estimated in low elevations and over-estimated in high elevations.

Researchers working in parts of the forest where direct temperature measurements are not made can refer to Tables 9, 10 and 11 to get an estimate of temperatures for selected heights. Using a digital elevation model at 120 m intervals the estimated temperatures corresponding to a given elevation can be contoured and displayed in place of elevation (Figure 10) as an alternative to the tables. The contour interval on the maps is based on the uncertainty of estimates made above the temperature inversion. For example, for mean January temperatures made above 750 m, the uncertainty of the estimate is 179 m so that a contour interval of 0.8°C (corresponding to 200 m) is statistically useful for this month. Select maps are discussed below; a full set of maps—mean, mean maximum and mean minimum temperatures for all months—is included in Appendix B. It is worth repeating that based on the analysis in Table 8 most of the data on these maps are accurate to within ±0.5°C.

TABLE 8. Difference (°C) Between Estimated and Observed Temperature at Two Sites Not Used in the Regression Analysis

	MMEAN		MMAX		MMIN	
	RS02	RS13	RS02	RS13	RS02	RS13
January	0.2	0.5	-0.1	0.5	0.5	0.6
February	0.3	0.0	-0.3	-0.1	0.6	0.1
March	0.0	0.7	-1.2	0.6	0.5	0.7
April	-0.1	1.0	-0.8	1.2	0.6	1.0
May	-0.1	0.9	-0.6	1.4	0.6	0.7
June	-0.1	0.6	-0.9	0.9	0.7	0.6
July	0.0	0.4	-0.8	0.9	0.7	0.1
August	0.0	0.4	-0.9	0.9	0.8	0.2
September	0.0	0.5	-0.7	0.8	0.9	0.5
October	0.5	0.3	-0.2	0.2	0.9	0.3
November	0.6	0.4	0.0	0.3	1.0	0.4
December	0.3	0.4	-0.1	0.3	0.6	0.5

TABLE 9. 1981-1990 Monthly Mean Temperature at Selected Heights

ELEV (m)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
475	1.9	2.9	4.9	7.4	10.9	14.2	16.8	17.3	13.5	9.5	4.5	1.4
550	2.3	3.1	5.1	7.5	11.0	14.3	17.0	17.6	14.0	9.9	4.6	1.7
625	2.6	3.4	5.3	7.6	11.1	14.4	17.3	17.8	14.5	10.3	4.8	1.9
700	2.9	3.6	5.5	7.7	11.3	14.5	17.5	18.0	15.0	10.8	5.0	2.1
775	2.4	3.0	4.3	6.4	10.1	13.4	16.4	17.3	14.1	10.3	4.0	1.6
850	2.1	2.6	3.9	5.9	9.6	13.0	16.0	16.9	13.8	9.9	3.6	1.4
925	1.8	2.2	3.5	5.5	9.0	12.5	15.6	16.5	13.4	9.6	3.2	1.1
1000	1.5	1.8	3.0	5.0	8.5	12.1	15.1	16.1	13.1	9.2	2.8	0.8
1075	1.2	1.4	2.6	4.5	8.0	11.7	14.7	15.8	12.7	8.9	2.4	0.5
1150	0.9	1.1	2.2	4.0	7.4	11.2	14.3	15.4	12.3	8.6	2.1	0.3
1225	0.6	0.7	1.8	3.5	6.9	10.8	13.8	15.0	12.0	8.2	1.7	0.0
1300	0.3	0.3	1.4	3.0	6.3	10.3	13.4	14.6	11.6	7.9	1.3	-0.3
1375	0.1	-0.1	1.0	2.5	5.8	9.9	12.9	14.2	11.3	7.5	0.9	-0.6
1450	-0.2	-0.5	0.5	2.0	5.3	9.4	12.5	13.8	10.9	7.2	0.6	-0.8
1525	-0.5	-0.9	0.1	1.5	4.7	9.0	12.1	13.4	10.6	6.9	0.2	-1.1
1600	-0.8	-1.3	-0.3	1.0	4.2	8.6	11.6	13.1	10.2	6.5	-0.2	-1.4
1675	-1.1	-1.7	-0.7	0.5	3.7	8.1	11.2	12.7	9.9	6.2	-0.6	-1.7

TABLE 10. 1981-1990 Mean Maximum Temperatures at Selected Heights

ELEV (m)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
475	3.9	5.7	8.4	12.3	16.7	20.3	23.9	25.1	20.9	14.3	6.6	3.3
550	4.4	6.1	8.7	11.8	16.2	19.8	23.4	24.6	20.4	14.8	6.8	3.7
625	4.9	6.6	9.1	11.2	15.6	19.3	22.9	24.1	20.0	15.3	7.0	4.1
700	5.4	7.1	9.5	10.7	15.0	18.7	22.4	23.5	19.5	15.9	7.2	4.5
775	4.2	5.6	7.5	10.1	14.4	18.2	21.9	23.0	19.1	14.2	6.1	3.6
850	3.9	5.2	7.0	9.6	13.9	17.7	21.3	22.5	18.7	13.7	5.7	3.4
925	3.7	4.7	6.4	9.0	13.3	17.2	20.8	22.0	18.2	13.3	5.3	3.1
1000	3.4	4.3	5.9	8.4	12.7	16.7	20.3	21.5	17.8	12.8	4.9	2.8
1075	3.1	3.8	5.4	7.9	12.1	16.2	19.8	21.0	17.3	12.3	4.5	2.5
1150	2.8	3.4	4.9	7.3	11.6	15.7	19.3	20.5	16.9	11.9	4.1	2.3
1225	2.5	2.9	4.4	6.8	11.0	15.2	18.7	20.0	16.5	11.4	3.8	2.0
1300	2.2	2.5	3.9	6.2	10.4	14.7	18.2	19.5	16.0	10.9	3.4	1.7
1375	2.0	2.0	3.4	5.7	9.8	14.2	17.7	19.0	15.6	10.5	3.0	1.5
1450	1.7	1.6	2.9	5.1	9.3	13.7	17.2	18.5	15.1	10.0	2.6	1.2
1525	1.4	1.1	2.3	4.6	8.7	13.2	16.7	18.0	14.7	9.5	2.2	0.9
1600	1.1	0.7	1.8	4.0	8.1	12.7	16.1	17.5	14.2	9.1	1.8	0.6
1675	0.8	0.2	1.3	3.4	7.5	12.2	15.6	17.0	13.8	8.6	1.4	0.4

TABLE 11. 1981-1990 Mean Minimum Temperatures at Selected Heights

ELEV (m)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
475	0.3	0.6	1.8	3.7	6.3	9.3	11.1	11.3	8.3	5.5	2.5	-0.2
550	0.4	0.7	2.0	3.9	6.5	9.5	11.4	11.7	8.9	6.1	2.7	0.1
625	0.5	0.8	2.2	4.0	6.7	9.8	11.7	12.2	9.5	6.6	2.9	0.5
700	0.6	0.9	2.5	4.2	6.9	10.0	11.9	12.6	10.1	7.2	3.1	0.8
775	0.7	0.9	1.7	3.2	6.1	9.1	12.1	13.0	10.5	7.8	2.1	0.1
850	0.3	0.5	1.3	2.8	5.6	8.8	11.7	12.7	10.2	7.4	1.7	-0.3
925	-0.1	0.1	1.0	2.4	5.2	8.4	11.4	12.4	9.8	7.0	1.3	-0.6
1000	-0.4	-0.3	0.6	2.0	4.8	8.1	11.0	12.1	9.5	6.6	0.9	-0.9
1075	-0.8	-0.7	0.3	1.6	4.3	7.7	10.6	11.7	9.1	6.2	0.6	-1.3
1150	-1.2	-1.1	-0.1	1.2	3.9	7.4	10.2	11.4	8.8	5.8	0.2	-1.6
1225	-1.6	-1.5	-0.4	0.8	3.5	7.0	9.8	11.1	8.5	5.3	-0.2	-1.9
1300	-2.0	-1.9	-0.8	0.4	3.0	6.7	9.4	10.8	8.1	4.9	-0.6	-2.3
1375	-2.3	-2.3	-1.1	0.0	2.6	6.3	9.1	10.4	7.8	4.5	-1.0	-2.6
1450	-2.7	-2.7	-1.5	-0.4	2.1	6.0	8.7	10.1	7.4	4.1	-1.4	-2.9
1525	-3.1	-3.0	-1.8	-0.8	1.7	5.6	8.3	9.8	7.1	3.7	-1.8	-3.3
1600	-3.5	-3.4	-2.2	-1.2	1.3	5.3	7.9	9.5	6.8	3.3	-2.2	-3.6
1675	-3.9	-3.8	-2.5	-1.6	0.8	4.9	7.5	9.1	6.4	2.8	-2.6	-3.9

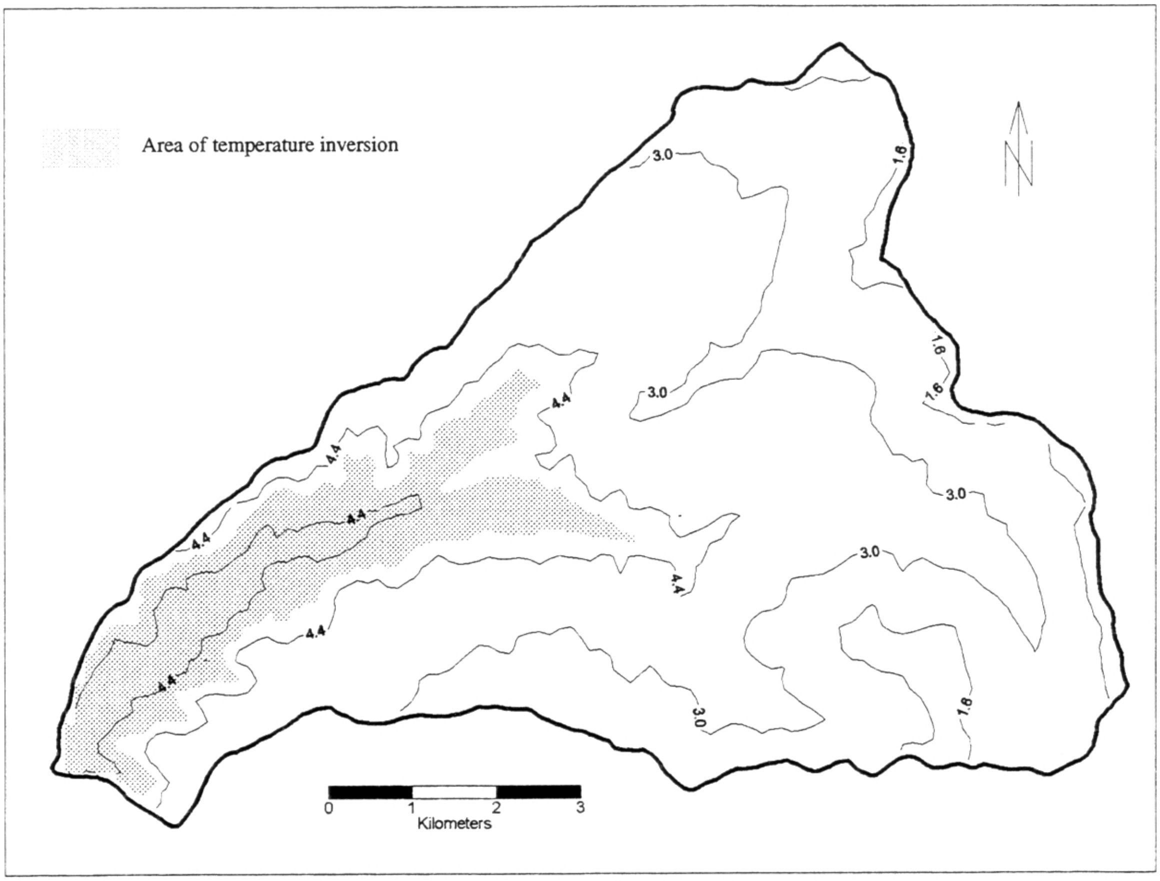

FIGURE 10. January Mean Maximum Temperature, 1981-1990
(Contour Interval 1.4 °C)

The Maps

The map of January mean maximum temperature (Figure 10) shows a temperature inversion to about 650 m indicated by the area of gray shading. There is generally a high degree of variability between the sites both above and below the ceiling of the inversion which accounts for the high level of uncertainty in the estimates. The temperature range across the watershed is relatively small, probably a function of the frequent cloud conditions over the area during this month. In April (Figure 11) the inversion has disappeared and the relationship between temperature and elevation is strong. The lapse rate indicated by the model is high (-7.85°C/km) and reflects the seasonal warming in lower elevations while the upper elevations still experience winter-like conditions. July mean maximum temperatures display similar patterns (Figure 12) but the upper elevation sites have warmed to nearly their annual maximum. Uncertainties in elevation are high owing to the variability between sites due to aspect and slope at this time of year. In October (Figure 13) the temperature inversion returns but still breaks at about 650 m. With a stronger relationships between temperature and elevation, October mean maximum temperatures can be meaningfully contoured at only 1.2°C.

The map of January mean minimum temperature (Figure 14) compares well to the discussion of temperature inversions in Chapter III. There is a slight inversion in the lower elevations reaching to a height of about 700 m above which temperatures decrease with height at about -5°C/km. The uncertainty in height is similar above and below the point of inversions and remains so through April. The area of inversion in April (Figure 15) reaches to a height of about 700 m and the lapse rate indicated by the regression analysis (see Table 7) is probably greater than what is observed considering the discussion of the elevation and temperature profiles in the previous chapter. Minimum temperatures indicate more warming at lower elevations than higher elevations compared when compared to January. By July

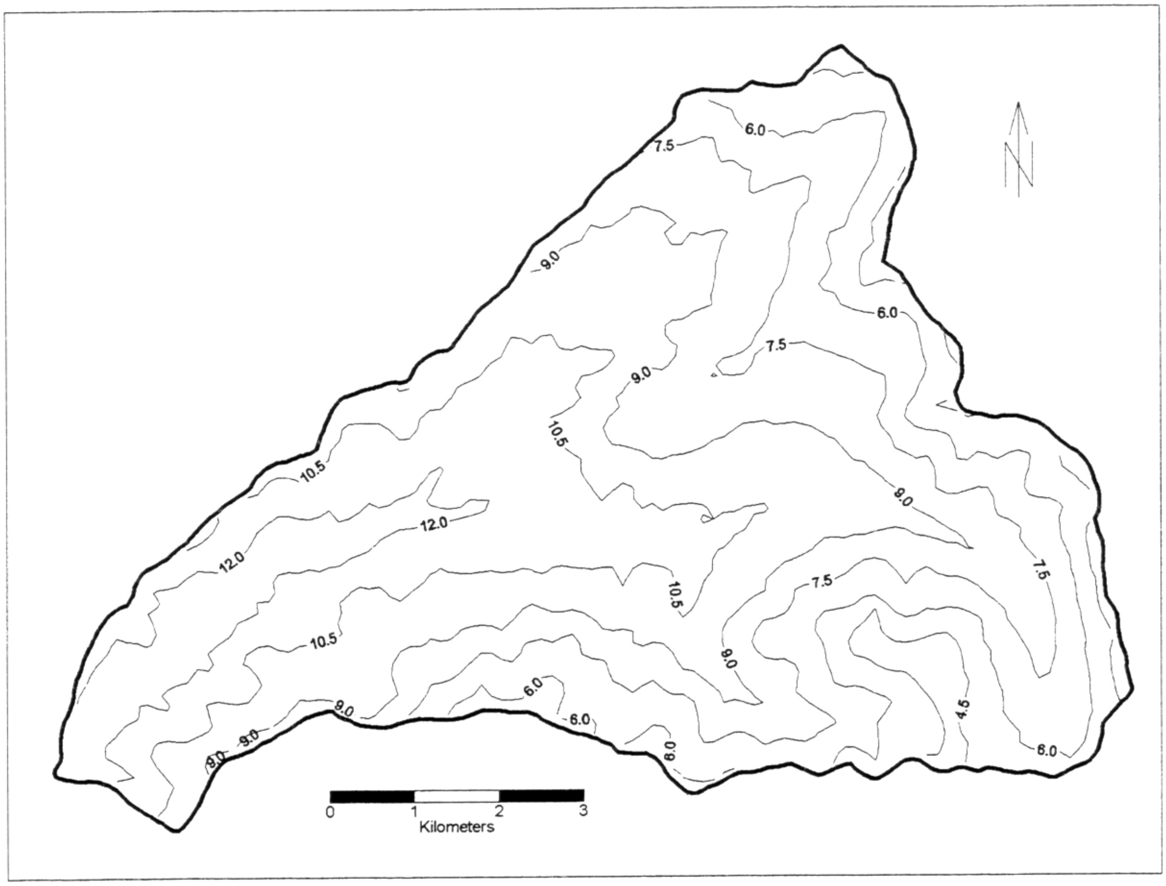

FIGURE 11. April Mean Maximum Temperature, 1981-1990
(Contour Interval 1.5 °C)

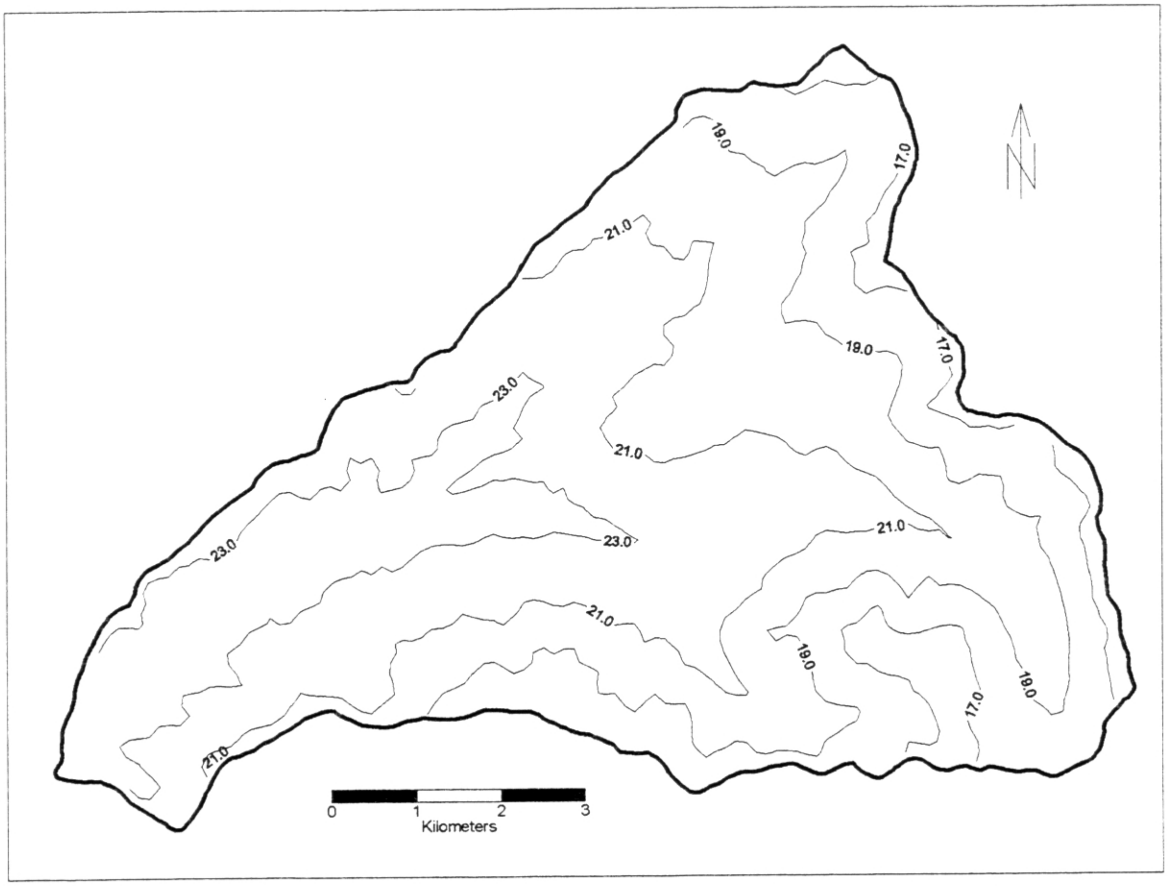

FIGURE 12. July Mean Maximum Temperature, 1981-1990
(Contour Interval 2.0 °C)

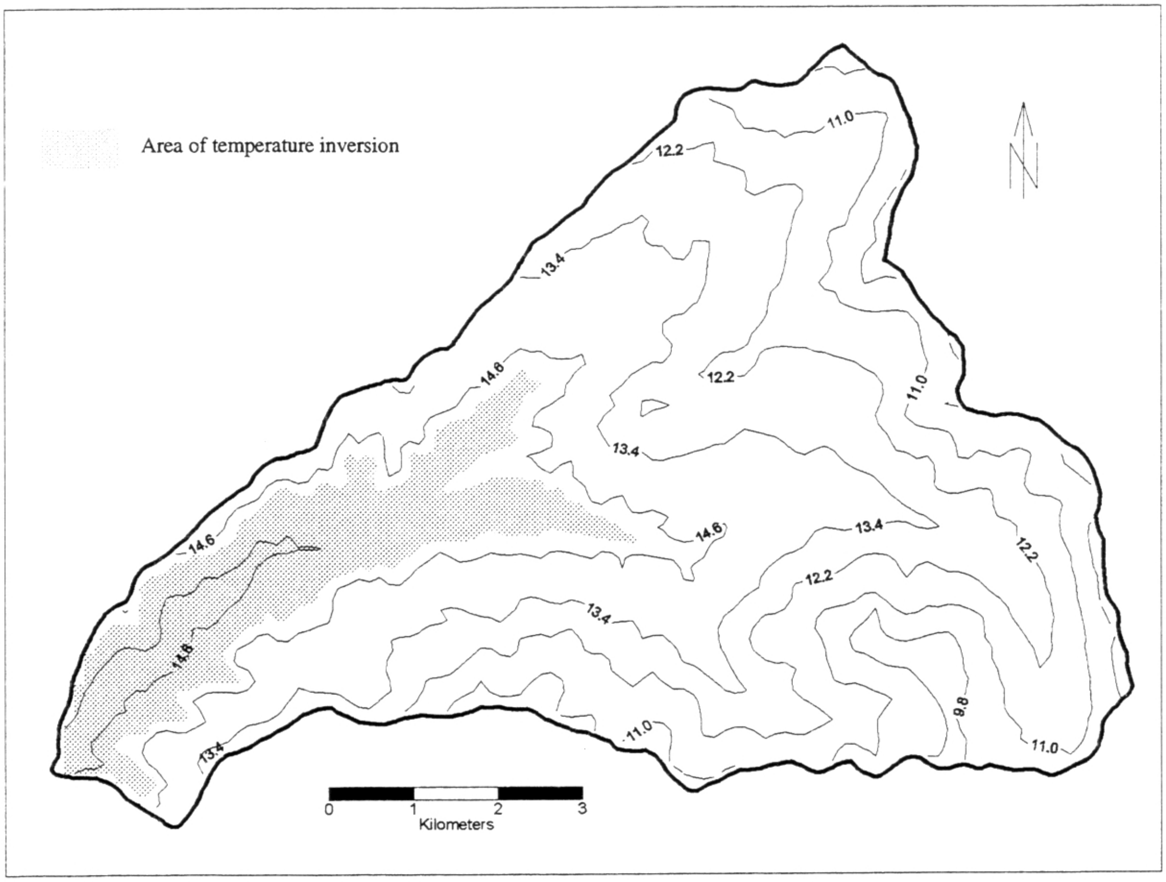

FIGURE 13. October Mean Maximum Temperature, 1981-1990
(Contour Interval 1.2 °C)

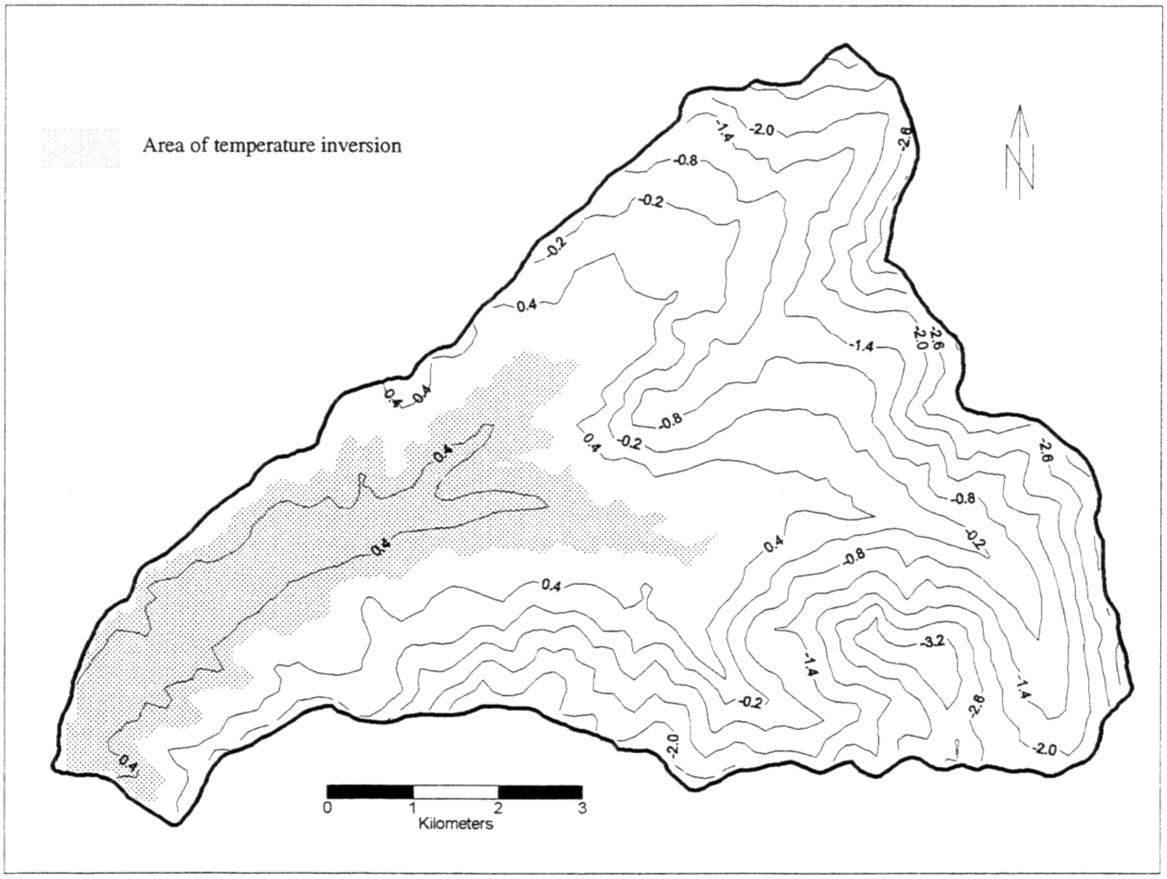

FIGURE 14. January Mean Minimum Temperature, 1981-1990
(Contour Interval 0.6 °C)

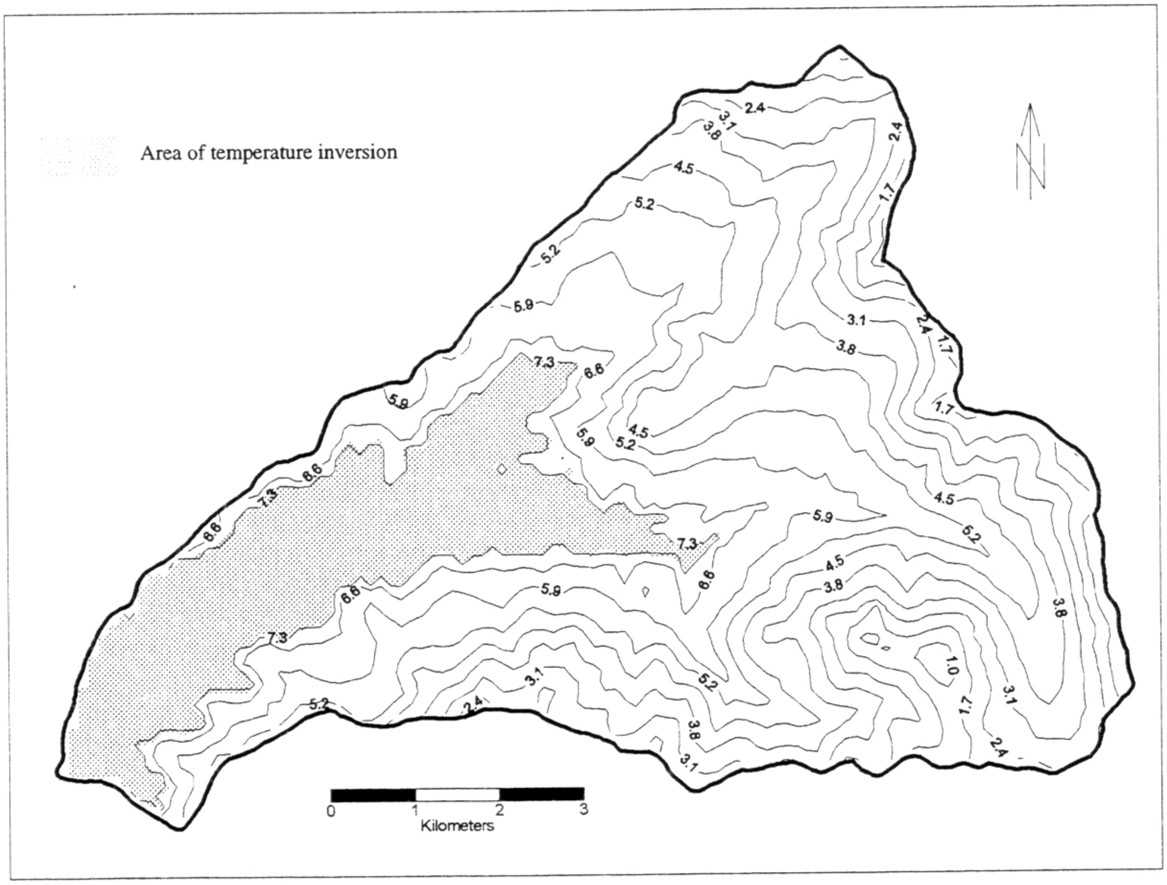

FIGURE 15. April Mean Minimum Temperature, 1981-1990
(Contour Interval 0.7 °C)

(Figure 16) there is a strong inversion up to 800 m. There is a large range in minimum temperature across the watershed during July and the relationship between temperature and elevation is strongest resulting in a meaningful contour of just 0.4°C. In October (Figure 17) the temperature inversion extends to just over 800 m and is quite steep; the lapse rate used below 800 m is +7.42°C/km. There is considerably less uncertainty with height in estimates of mean minimum temperature. Most maps can be contoured equal to or less than 0.7°C; maximum temperature varies considerably more due to aspect at different times of the year which is reflected by the relatively large contour intervals used on these maps.

The temperature distributions on the maps are primarily a function of elevation, however, the seasonal variability of lapse rates determined in Chapter III and fluctuation of the height of inversions add complexity to the spatial patterns. These maps could not have been derived without first establishing the lapse rates and the inversion locations throughout the year. As the maps indicate, the zone of inversion moves up and down the valleys as the seasons progress. Ecologists are encouraged to consider ways in which the area of cold air ponding might affect the ecosystem; one implication may be that since the cold air in the zone of inversion is inherently stable, atmospheric transport of aerosols such as pollen will be minimized during the times when the inversion is strong.

Based on the differences between estimated and observed temperatures presented in Table 8, in addition to the review of the preceding maps, this method provides a reasonable representation of the thermal climate for the watershed. Future work should consider variations with aspect and other optimizations that would decrease the uncertainties with height.

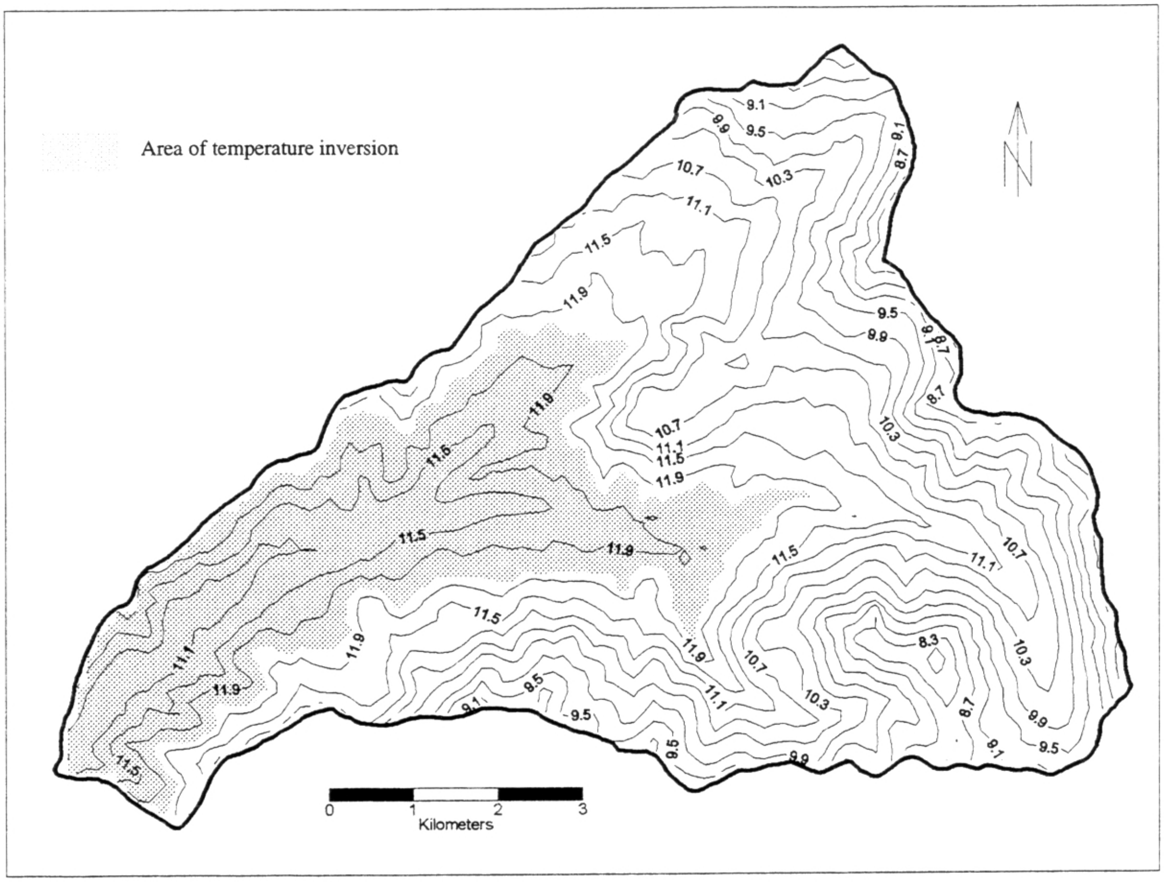

FIGURE 16. July Mean Minimum Temperature, 1981-1990
(Contour Interval 0.4 °C)

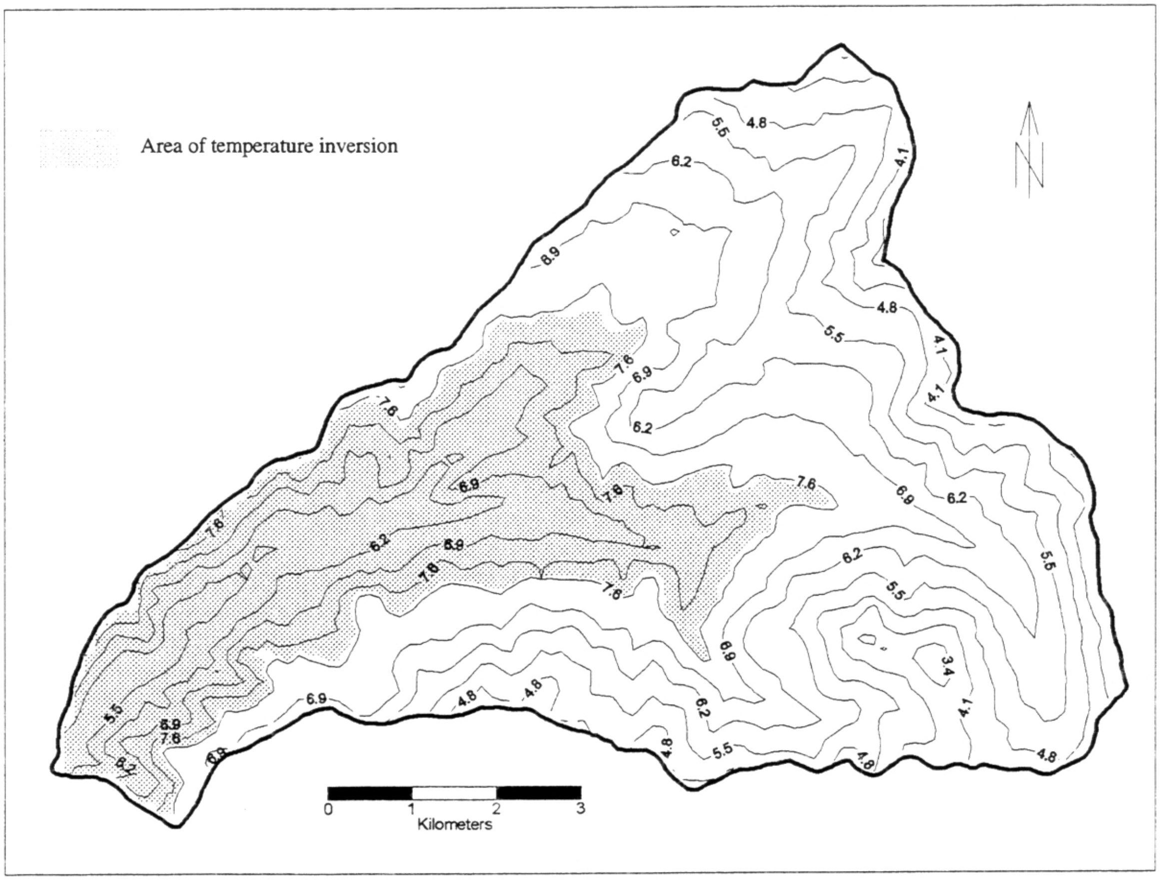

FIGURE 17. October Mean Maximum Temperature, 1981-1990
(Contour Interval 0.7 °C)

CHAPTER V

SIMULATING THE THERMAL CLIMATE

Despite Andrews' extensive meteorological monitoring network, data are not always available for a given site of interest. Therefore, it would be convenient if there were a method for estimating temperature at sites where no observed data exists. There are several methods for estimating temperatures. In the preceding chapter, for example, elevation was used as a predictor for temperature. More sophisticated computer models can now take many physical controls into account. This portion of the study evaluates the accuracy of a model for estimating air temperatures at Andrews. The model, MTCLIM (Running et al., 1987), extrapolates observed meteorological data to adjacent mountainous terrain. It has utility in situations where weather data are needed but observations are unavailable. MTCLIM generates daily output which has been used as input to existing ecosystem models (Running & Coughlan, 1988).

MTCLIM Logic

MTCLIM is a mountain microclimate simulation model that extrapolates values of meteorological variables from a point of observation, referred to as the base station, to a study site of interest, making corrections for differences in elevation, slope and aspect. Data inputs include base station and site characteristics; lapse rates; and daily maximum, minimum and dew point temperatures and precipitation from the base station. A description of the temperature calculation follows; other subroutines include solar radiation, humidity and precipitation and are reviewed elsewhere (Glassy and Running, 1994; Hungerford et al., 1990; Running et al., 1987).

An average air temperature is calculated from the maximum and minimum points given by data from the base station then corrected for elevation using input lapse rates. The ratio of slope to flat surface radiation is computed in the radiation submodel and used as a multiplier to adjust air temperatures for differences among aspect and slope. The predicted temperature is then adjusted by a multiplier based on the leaf area index (LAI) of the study site; this moderates slope related differences between bare slopes and closed canopy forests. Thus, the temperature calculations is written generally as

$$T_{site} = T_{avg} * f(\mathrm{elev}) * f(\mathrm{slope/flat}) * f(\mathrm{LAI}) \qquad (3)$$

where T_{site} is the final calculated site temperature, °C; T_{avg} is the base station average air temperature, °C; f(elev) is the elevational lapse rate correction, °C/km; f(slope/flat) is the ratio of slope radiation to flat surface radiation; and f(LAI) is the site leaf area index correction, °C/LAI. Hungerford et al. (1990) provide additional details on the model's logic including source code for the executable. The computer code for the MTCLIM model was kindly provided by Dr. Steve Running.

Model Evaluation

Observed data from several sites were selected to test the accuracy of MTCLIM estimates (Table 12). The sites represent a range of elevations from low valley sites to upper elevation sites. Two sets of simulations were run: the first with data from PRIMET to evaluate model performance in moving from a valley floor to adjacent slopes, the second run used data from the Vanilla Leaf Met Station (VANLEAF) as base station inputs to evaluate estimates derived from an upper elevation site.

Initial runs of the model indicate that estimates during late fall and throughout the winter do not track well probably due to the persistent low clouds in the area which moderate the extremes of temperature. An alternative to looking at year-round performance

TABLE 12. Characteristics of the Sites Used in MTCLIM Simulations

	Elevation (m)	Aspect (° from north)	Slope (°)	Site Description
Study Sites				
RS17	490	315	14	Mature forest canopy
RS10	610	170	6	Old growth canopy
RS15	760	350	33	Old growth canopy
RS05	880	10	12	Old growth canopy
RS26	1040	180	20	Mature forest canopy
RS13	1310	270	20	Mature forest canopy
Base Station Sites				
PRIMET	430	-	0	Maintained clearing
VANLEAF	1250	180	10	Clearcut 1985

is to evaluate the model over the period of the growing season, an estimate of which can be gauged by examining the number of months with mean temperature above 0°C. At Andrews, however, most stations report mean temperatures above 0°C year-round (the growing season at sites above approximately 1100 m is March-November). The most active time of the growing season is during the summer, consequently the period from May-September was chosen to evaluate the model. This is the period described by Alsop (1989) as the natural summer in Oregon and Washington (weeks 21-38 in the calendar year or May 21- September 17); note: the model was developed primarily as a tool for calculating forest evapotranspiration and photosynthesis therefore limiting the period of evaluation to the most active part of the growing season is an accurate reflection of the model's capacity.

Figure 18 describes a sample initialization file used to run the simulations. Daily data for weeks 21-38 in 1992 were used as inputs to the model. Simulations were run for individual months so that observed lapse rates could be used. The model does not consider temperature inversions so the generalized lapse rates described in Chapter III (Table 3) were used. The daily estimates for each month were concatenated to create an estimated data series from May-September for each site. Assessment of the model's overall accuracy was based on linear regression analysis.

Results

Calculations of the seasonal mean maximum and mean minimum temperatures show that the model is capable of providing a general characterization of summer temperatures (Table 13). Seasonal averages of maximum temperature have smaller standard errors than those of minimum temperature. Both PRIMET and VANLEAF simulations overestimate maximum temperature although they track the daily fluctuation well (Figure

```
MTCLIM DATA FILE FOR INITIALIZATION DATA: COMMENTS IN LINES 1 AND 2.
FREE FORMAT READS EXCEPT FOR FILE NAMES (A12) ON NEXT TWO LINES.
7VAN92.MTC   INPUT DATA FILE
7VAN17.CLM   OUTPUT DATA FILE
S            ENGLISH OR SI UNITS. [E OR S]
N            DEW POINT TEMPERATURE SUPPLIED [Y OR N]
1            NUMBER OF PPT STATIONS [1 OR 2]
N            USE THRESHOLD RADIATION [Y OR N]
T            TOTAL OR AVERAGE RADIATION [T OR A]
Y            USE YEARDAY (JULIAN) IN PLACE OF MONTH & DAY [Y OR N]
31           NDAYS INTEGER VARIABLE; ALL THE REST ARE REAL
44.3         LATITUDE
490          SITE ELEVATION (METERS FOR SI OR FEET FOR ENGLISH)
1250         BASE ELEVATION (METERS FOR SI OR FEET FOR ENGLISH)
315          SITE ASPECT 0 to 360 degrees (0 = NORTH; 180 = SOUTH)
25           SITE SLOPE (PERCENT)
6.3          SITE LAI (ALL SIDED)
228.9        SITE ISOHYET (PRECIPITATION)
228.9        BASE ISOHYET STATION 1
0.0          BASE ISOHYET STATION 2 (OPTIONAL)
5.1          SITE EAST HORIZON (DEGREES)
1.0          SITE WEST HORIZON (DEGREES)
0.16         SITE ALBEDO (.2 = 20%)
0.60         TRANCF (SEA LEVEL ATMOSPHERIC TRANSMISSIVITY)
0.45         TEMPCF (TEMPERATURE CORRECTION FOR SINE APPROX)
4.82         TEMP LAPSE RATE (DEGREES / 1000 METERS)
7.43         LAPSE RATE FOR MAX TEMP (DEGREES / 1000 M OR FT)
2.41         LAPSE RATE FOR MIN TEMP (DEGREES / 1000 M OR FT)
2.73         DEW LAPSE RATE (DEGREES / 1000 M OR FT)
```

FIGURE 18. Initialization File for July, 1992 Simulation at RS17 Using Base Station Inputs from VANLEAF

TABLE 13. Seasonal Means of Observed and Estimated Maximum and Minimum Temperature and Standard Errors

Site	Observed	PRIMET Estimated	VANLEAF Estimated	PRIMET SEE	VANLEAF SEE
		Maximum Temperature			
RS17	23.4	25.8	25.8	1.81	1.76
RS10	22.9	27.0	27.0	1.3	1.2
RS15	19.7	23.3	23.4	1.5	1.7
RS05	19.4	22.9	22.9	1.5	1.3
RS26	21.8	23.5	23.7	1.6	0.9
RS13	18.9	19.8	19.8	1.6	0.9
		Minimum Temperature			
RS17	10.8	8.8	11.7	0.9	3.9
RS10	10.4	8.4	11.4	1.6	3.0
RS15	11.2	8.0	11.0	2.3	2.0
RS05	10.7	7.8	10.7	2.3	1.8
RS26	11.5	7.4	10.3	2.7	1.3
RS13	10.0	6.7	9.6	2.7	1.1

19), however, errors associated with estimates of minimum temperatures are greater (Figure 20). The patterns in Figure 20 are representative of estimates at other sites. PRIMET data inputs lead to an underestimate of minimum temperatures and VANLEAF data inputs overestimate minimum temperatures, although the standard errors of the estimates indicate that PRIMET may be a better choice estimating temperatures at lower elevation sites and VANLEAF is the better choice for upper elevation sites.

Results from the regression analysis (Table 14) show that both base station sites estimate maximum temperatures well. A scatter diagram of observed versus estimated maximum temperatures at RS05 (Figure 21) indicate a nearly 1:1 relationship using data inputs from VANLEAF. There is some variability in the lower temperatures and a slight tendency to overestimate them, but the fit is quite good. The standard error for this regression is 1.3°C. The regressions of minimum temperature simulations indicate that they are harder to estimate. The best relationships are estimates from PRIMET at lower elevations and those from VANLEAF at upper elevations. At RS10 a scatter diagram of observed versus PRIMET estimated minimum temperatures (Figure 22) is representative of the relationship between observed and estimated minimum temperatures for all sites. The extreme values are better estimated while there is considerable variability in the mean estimates.

The effect of cold air drainage at Andrews is more important to the thermal climate than the effect of local heating during the summer. As such, the strength of the estimates of maximum temperature compared to those of minimum temperature point to the model's major weakness for simulations within the Lookout Creek watershed: its inability to account for temperature inversions.

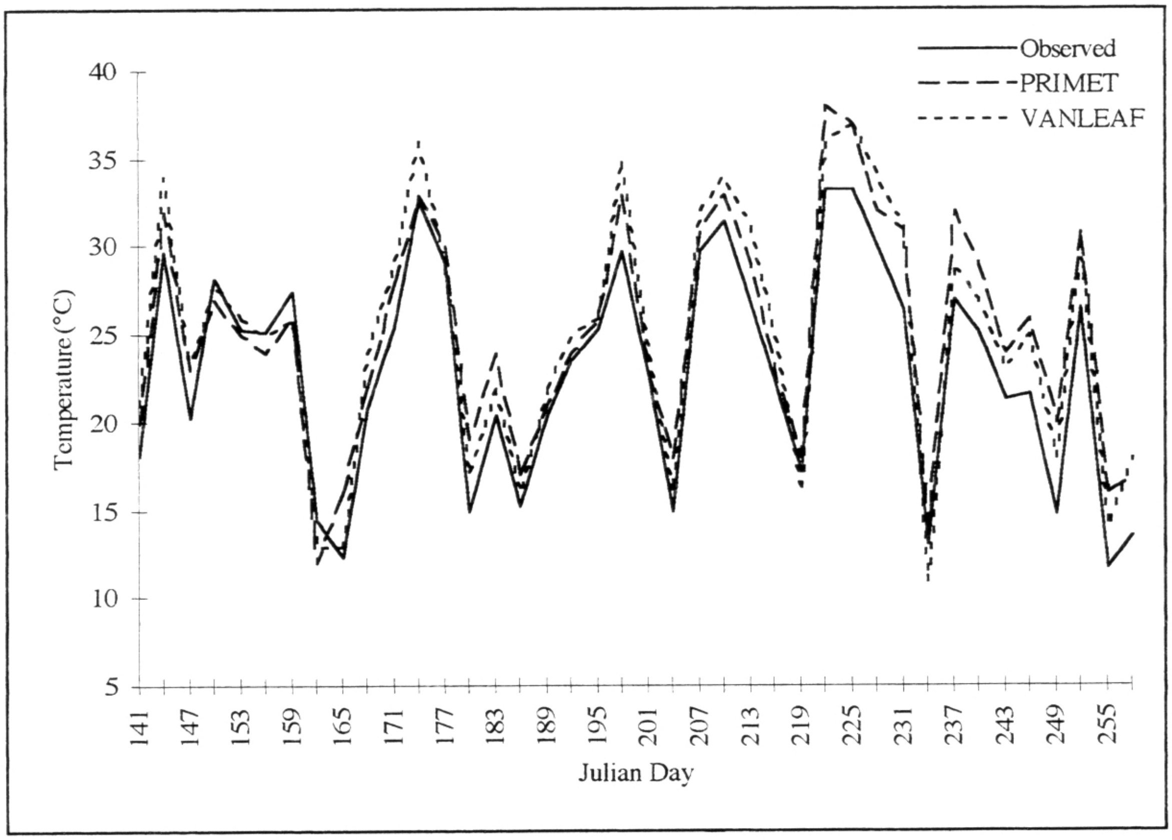

FIGURE 19. Comparison of Observed and Estimated Daily Maximum Temperatures at RS17

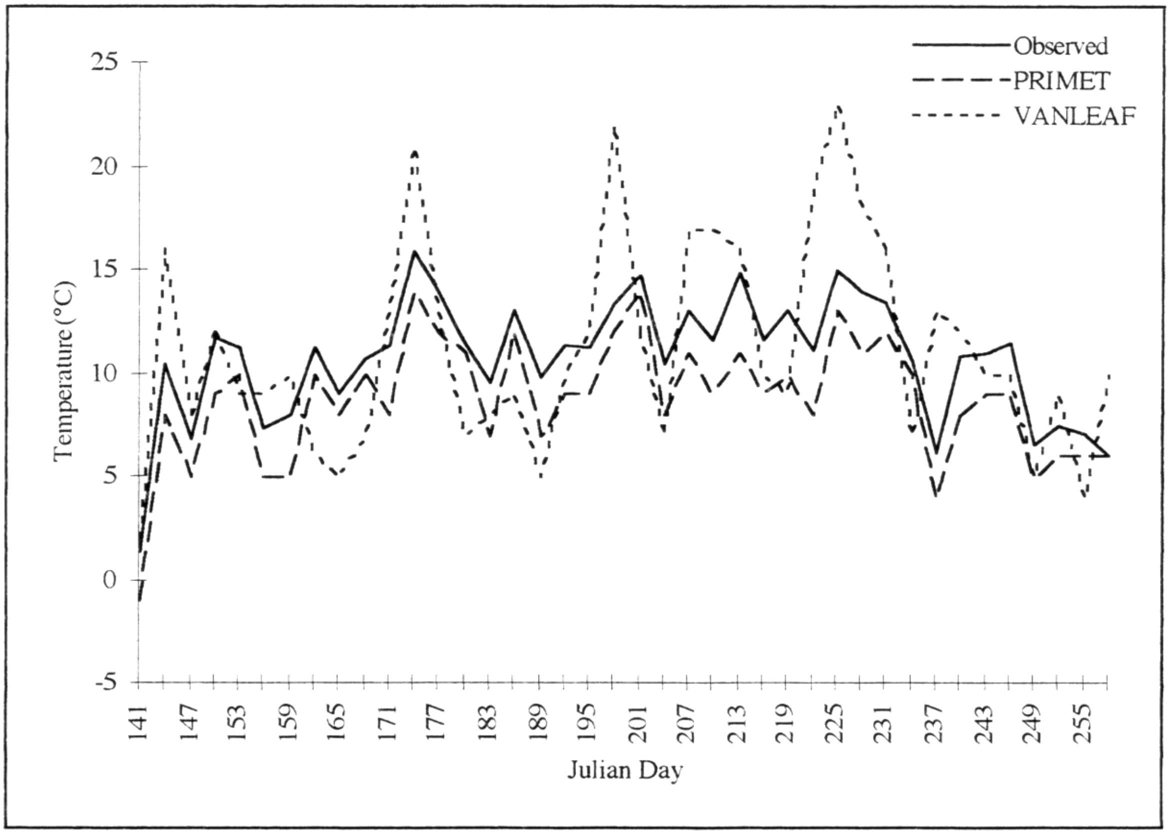

FIGURE 20. Comparison of Observed and Estimated Daily Minimum Temperature at RS17

TABLE 14. Results of the Regression Analysis (n=119)

Site	PRIMET Slope	PRIMET Intercept	PRIMET R^2	VANLEAF Slope	VANLEAF Intercept	VANLEAF R^2
		Maximum Temperature				
RS17	0.99	2.58	0.92	1.08	0.46	0.93
RS10	0.99	4.34	0.96	1.07	2.41	0.97
RS15	1.12	1.12	0.94	1.22	-0.79	0.94
RS05	1.07	2.18	0.94	1.16	0.35	0.96
RS26	1.01	1.55	0.94	1.12	-0.80	0.98
RS13	0.99	1.03	0.94	1.10	-0.93	0.98
		Minimum Temperature				
RS17	0.96	-1.55	0.91	1.00	0.86	0.38
RS10	0.89	-0.86	0.74	1.30	-2.17	0.64
RS15	0.60	1.33	0.44	1.32	-3.83	0.84
RS05	0.59	1.51	0.46	1.30	-3.22	0.87
RS26	0.38	3.00	0.27	1.13	-2.68	0.93
RS13	0.34	3.29	0.26	1.03	-0.62	0.95

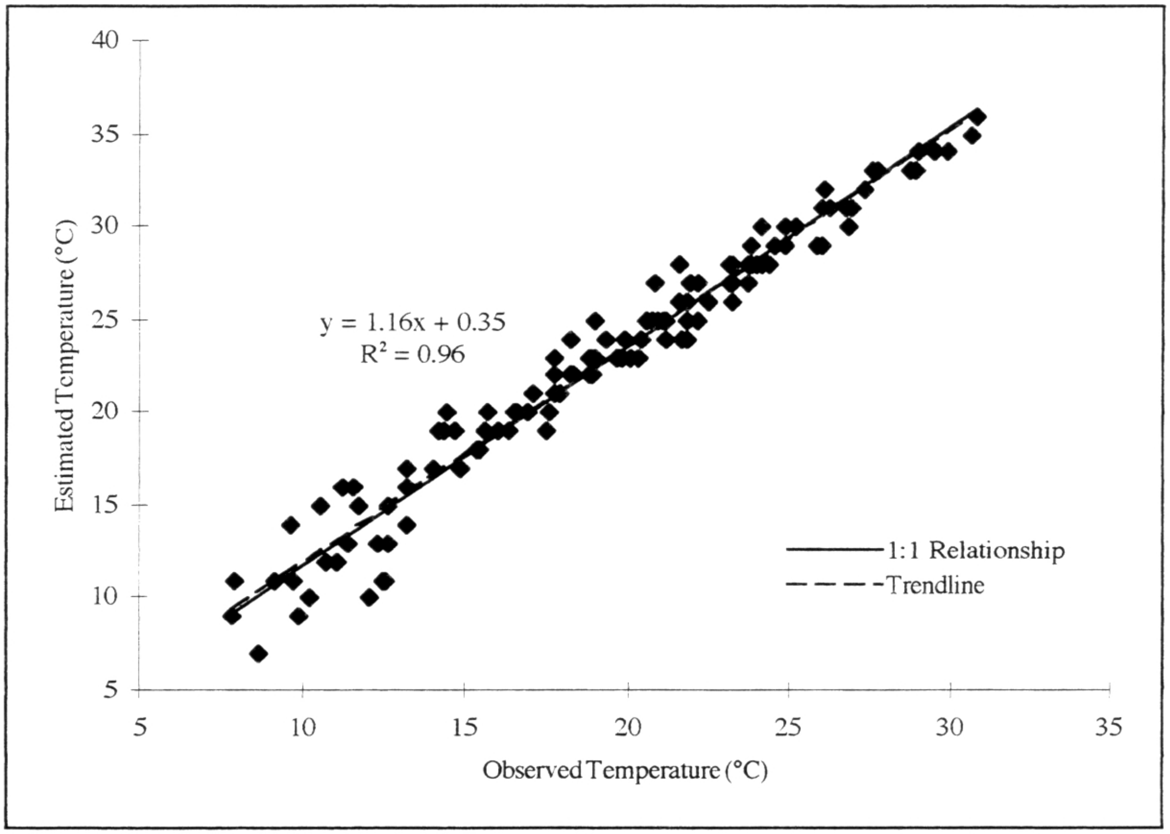

FIGURE 21. Relationship Between Observed and VANLEAF Estimated Maximum Temperatures at RS05

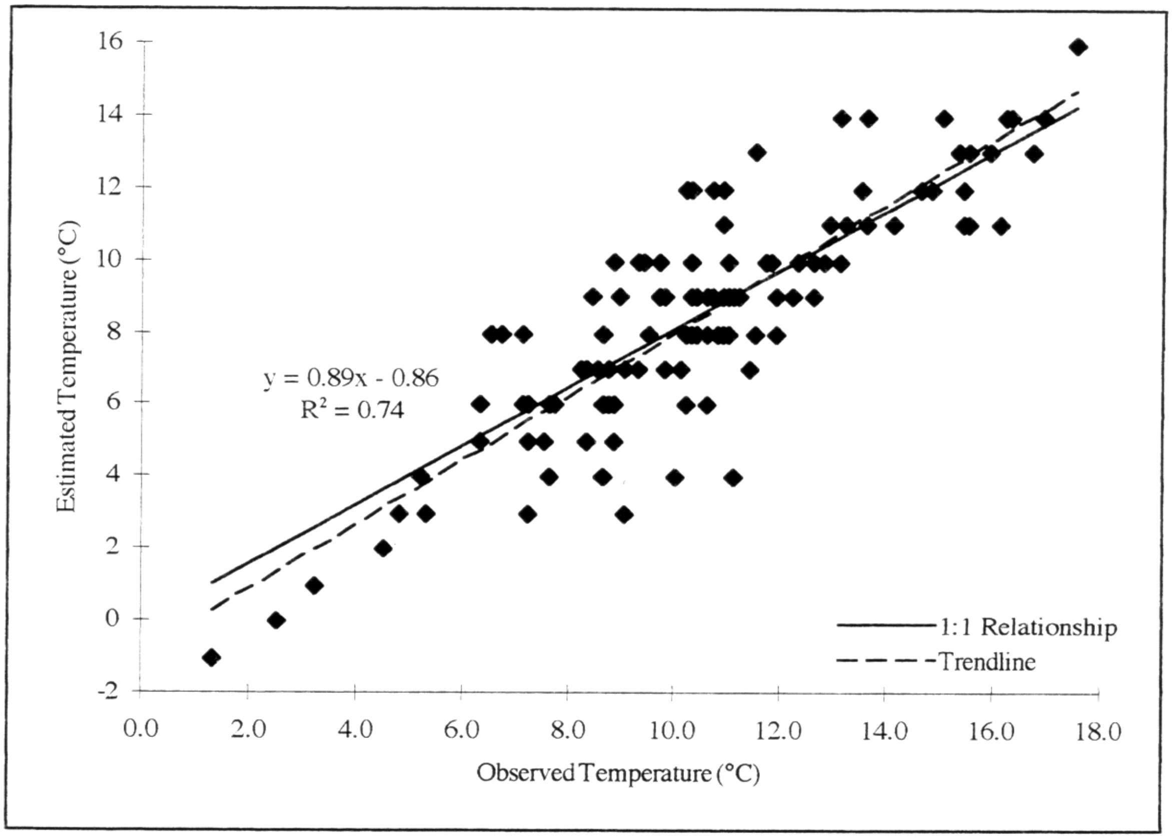

FIGURE 22. Relationship Between Observed and PRIMET Estimated Minimum Temperatures at RS10

Suggestions for Using MTCLIM at Andrews

The model estimates can be optimized with careful selection of the base station. A valley floor site like PRIMET may adequately estimate temperatures at sites below 700 m while an upper elevation site would be more appropriate for sites above 700 m. With the nested hierarchy of monitoring stations and four primary meteorological stations now on-line—PRIMET, VANLEAF, Upper Lookout Creek and Central Met—obtaining appropriate base station inputs should be easy; investigators should choose the station with the least altitudinal difference from the study site of interest.

Lapse rates are also critical when using the model. Initial runs of the model indicate that observed lapse rates as discussed in Chapter III improve model performance over simulations with lapse rates suggested by the model's authors. The model would be greatly improved if it could account for temperature inversions. This could be done by running the model either under or over the inversion ceilings or in steps, first up to the inversion ceiling then above it where elevational distances are great. A better multiplier for the effects of clouds may also extend the model's utility to year-round estimates.

CHAPTER VI

CONCLUSION

The annual variation of air temperatures at Andrews indicates a typical variation for a mid-latitude maritime climate: the wet winters are accompanied by cool temperatures while the drought-like months of summer are generally warm. Temperatures generally vary with elevation, however, a persistent zone of inversion adds complexity to spatial patterns throughout the year. Mean minimum temperature inversions are present for all months of the year while inversions of mean maximum temperature appear only during fall and winter months. On average, monthly mean temperature inversions reach to about 700 m, mean maximum to approximately 650 m and mean minimum to about 750 m, however, the zone of inversion moves up and down the valleys as the seasons progress beginning with very weak inversions in the spring and reaching peak heights in late fall. Surface lapse rates were found to be +1.3 to +8.9°C/km below approximately 750 m and from -3.8 to -8.8°C/km above that point. Important controls on the thermal climate are the nature of the adjacent ground surface, elevation, aspect and the synoptic climatology of the region. Topography and the land-surface, in particular, combine in different ways with the heat exchanges at the earth's surface to influence temperatures. Significant changes in the annual range of temperature can be seen when moving between canopied, treated or stream sites within the forest.

A method for mapping the thermal climate was described which relates temperature to elevation using the bet-fit linear regression model. Maps for the watershed and tables of estimated temperature at selected heights are included for reference. Differences between the estimates derived from the regression analysis and the observed data are generally to within ±0.5°C, however, future work should consider variations in temperature as they relate to aspect which would increase the reliability of this method. A model that does consider difference in aspect to estimate temperature was reviewed. The mountain microclimate simulation model MTCLIM was evaluated for its estimates of daily maximum and minimum temperature derived from two separate base station inputs. Estimates of summer-time maximum temperatures are better than those of minimum temperature, although the model is capable of providing a general characterization of summer temperatures. The model's major weakness limits its utility for year-round use; it does not account for temperature inversion and requires a better multiplier for the effect of clouds for optimization at Andrews.

The monthly temperature variations described in this thesis reflect the physical principles underlying the energy balance of the earth as described in Chapter 2. In recent years, the large-scale energy exchanges between the sun, the earth-atmosphere system and space have been measured with increasing accuracy using remote sensing technology thus opening a new realm from which surface observations may be made and analyzed. The knowledge of local energy exchanges at Andrews continues to grow as studies such as this, recent radiation data (Greenland, 1996) and other modeling experiments emerge. By combining and interpreting these data together scientists may gain a better understanding of the patterns of vegetation and other ecological phenomena as they relate to the thermal climate in the watershed.

APPENDIX A

TABLES OF MEAN TEMPERATURE ACROSS THE MONITORING SITE, 1981-1990

TABLE 15. Descriptive Statistics 1981-1990 at PRIMET

	MEAN	MEDIAN	STDEV	VAR	RANGE	MIN	MAX
Monthly Mean Temperature							
JAN	1.7	1.1	1.54	2.37	4.0	-0.3	3.7
FEB	2.5	3.5	2.06	4.24	6.2	-1.6	4.6
MAR	5.3	5.4	1.30	1.69	10.4	2.9	7.5
APR	8.4	8.5	1.58	2.49	16.2	5.9	10.3
MAY	11.5	11.2	0.84	0.71	23.5	10.5	13.0
JUN	15.1	15.2	1.10	1.21	30.3	13.6	16.7
JUL	17.4	17.1	1.28	1.65	35.5	16.0	19.5
AUG	17.7	17.6	0.97	0.94	35.7	16.4	19.3
SEP	13.4	13.3	1.30	1.69	27.3	11.4	15.9
OCT	8.8	8.4	1.41	1.98	18.4	6.7	11.7
NOV	4.2	5.0	1.47	2.16	6.3	0.9	5.4
DEC	0.8	1.3	1.43	2.05	4.3	-1.4	2.9
Mean Maximum Temperature							
JAN	5.1	5.4	1.74	3.02	10.1	2.4	7.7
FEB	7.2	7.8	1.93	3.71	14.5	4.6	9.9
MAR	11.6	11.6	1.62	2.61	23.6	9.3	14.3
APR	16.0	15.2	2.69	7.26	30.9	11.4	19.5
MAY	19.2	19.4	1.40	1.95	38.9	17.4	21.5
JUN	23.8	23.6	2.11	4.45	48.4	21.3	27.1
JUL	27.4	27.6	2.85	8.10	55.2	23.4	31.8
AUG	29.1	28.8	2.27	5.14	58.5	25.8	32.7
SEP	23.8	24.4	2.93	8.60	46.5	19.5	27.0
OCT	16.7	15.8	3.44	11.86	36.1	12.6	23.5
NOV	7.9	7.9	1.90	3.61	13.8	3.8	10.0
DEC	3.8	4.2	1.31	1.72	7.3	1.9	5.4
Mean Minimum Temperature							
JAN	-0.5	-1.0	1.46	2.14	4.0	-2.5	1.5
FEB	-0.6	0.1	2.30	5.30	7.6	-5.5	2.1
MAR	1.3	1.2	1.33	1.78	3.9	-0.8	3.1
APR	2.8	3.3	1.21	1.45	3.9	0.1	3.8
MAY	5.2	5.2	0.96	0.93	10.3	3.4	6.9
JUN	8.1	8.1	0.76	0.58	16.2	7.0	9.2
JUL	9.4	9.5	0.93	0.86	18.8	7.7	11.1
AUG	9.5	9.5	1.19	1.43	18.9	7.6	11.3
SEP	6.6	6.5	1.02	1.04	14.4	5.3	9.1
OCT	3.9	3.7	1.17	1.37	8.2	2.1	6.1
NOV	1.5	1.9	1.58	2.51	5.4	-1.9	3.5
DEC	-1.4	-1.1	1.60	2.54	5.4	-4.5	0.9

TABLE 16. Descriptive Statistics 1981-1990 at Reference Stand 1

	MEAN	MEDIAN	STDEV	VAR	RANGE	MIN	MAX
Monthly Mean Temperature							
JAN	3.3	3.4	1.83	3.35	5.7	0.0	5.7
FEB	3.7	3.8	1.67	2.80	8.1	1.4	6.7
MAR	5.7	5.5	1.91	3.65	11.5	3.0	8.5
APR	8.4	8.2	2.91	8.49	17.0	4.7	12.3
MAY	11.5	11.6	1.53	2.35	24.0	9.6	14.4
JUN	15.2	15.8	2.09	4.39	30.2	12.1	18.1
JUL	17.9	18.2	2.23	4.98	34.5	13.9	20.6
AUG	18.5	18.5	1.98	3.93	38.6	16.1	22.5
SEP	14.7	14.2	2.21	4.90	28.9	11.4	17.5
OCT	10.6	9.3	2.93	8.57	23.1	7.7	15.4
NOV	5.0	5.0	2.17	4.72	9.3	1.7	7.6
DEC	2.2	2.3	2.33	5.41	6.6	-1.2	5.4
Mean Maximum Temperature							
JAN	6.0	6.3	1.84	3.39	10.8	2.6	8.2
FEB	7.8	8.0	2.12	4.51	15.4	4.4	11.0
MAR	10.8	10.3	2.09	4.35	22.6	8.3	14.3
APR	14.3	13.8	3.43	11.77	28.0	8.6	19.4
MAY	17.4	17.5	1.47	2.15	35.2	14.9	20.3
JUN	21.7	22.0	2.66	7.09	43.8	17.9	25.9
JUL	25.1	24.8	3.08	9.46	48.4	19.3	29.1
AUG	26.7	26.5	2.94	8.62	54.7	22.6	32.1
SEP	22.8	22.4	2.91	8.47	45.8	19.3	26.5
OCT	16.8	14.6	4.24	17.96	36.5	12.3	24.2
NOV	7.9	8.2	2.21	4.87	15.6	4.4	11.2
DEC	5.0	4.8	2.77	7.65	10.1	1.3	8.8
Mean Minimum Temperature							
JAN	0.9	0.8	1.73	2.99	5.4	-1.8	3.6
FEB	1.0	1.2	1.69	2.85	5.6	-1.7	3.9
MAR	2.2	2.1	1.82	3.31	5.7	-0.7	5.0
APR	4.1	3.4	2.79	7.76	7.5	-0.2	7.3
MAY	6.5	6.3	1.97	3.90	13.1	3.5	9.6
JUN	9.7	10.0	1.90	3.59	19.2	6.9	12.3
JUL	11.9	12.3	1.92	3.68	23.2	9.0	14.2
AUG	12.0	11.7	1.54	2.38	24.6	9.9	14.7
SEP	9.1	9.0	2.03	4.14	18.0	5.8	12.2
OCT	6.4	5.5	2.48	6.15	14.9	3.6	11.3
NOV	2.7	2.9	2.36	5.55	6.5	-0.9	5.6
DEC	0.0	0.2	2.25	5.07	6.7	-3.6	3.1

TABLE 17. Descriptive Statistics 1981-1990 at Reference Stand 2

	MEAN	MEDIAN	STDEV	VAR	RANGE	MIN	MAX
Monthly Mean Temperature							
JAN	2.1	2.7	1.71	2.92	5.4	-0.5	4.9
FEB	2.3	3.2	2.36	5.56	7.3	-1.7	5.6
MAR	4.7	4.5	1.86	3.47	9.9	2.2	7.7
APR	7.5	7.4	2.30	5.29	15.6	3.9	11.7
MAY	10.6	10.2	1.51	2.28	23.1	9.2	13.9
JUN	14.3	14.1	2.01	4.05	29.7	11.7	18.0
JUL	16.8	16.6	1.78	3.17	32.8	13.5	19.3
AUG	17.2	17.4	1.61	2.58	36.7	15.7	21.0
SEP	13.2	13.2	1.52	2.32	27.2	11.3	15.9
OCT	8.9	8.3	1.97	3.88	18.6	6.6	12.0
NOV	3.9	4.3	1.64	2.68	7.6	1.0	6.6
DEC	1.0	1.3	1.70	2.90	6.1	-2.2	3.9
Mean Maximum Temperature							
JAN	4.3	4.8	1.90	3.60	8.2	0.8	7.4
FEB	5.6	6.2	2.40	5.75	10.7	2.1	8.6
MAR	9.1	9.1	2.21	4.86	19.3	6.6	12.7
APR	13.2	12.4	3.33	11.11	26.7	8.7	18.0
MAY	16.3	16.2	1.55	2.40	32.7	13.8	18.9
JUN	20.8	21.0	2.78	7.72	41.9	17.1	24.8
JUL	24.1	23.5	3.17	10.03	47.7	18.6	29.1
AUG	25.3	25.6	2.50	6.23	52.4	22.4	30.0
SEP	20.4	20.0	2.82	7.98	42.1	17.0	25.1
OCT	14.1	12.9	3.48	12.10	30.9	10.2	20.7
NOV	6.3	6.2	2.02	4.08	12.4	3.0	9.4
DEC	3.4	3.7	1.89	3.58	6.9	0.4	6.5
Mean Minimum Temperature							
JAN	0.2	0.4	1.46	2.14	4.2	-1.8	2.4
FEB	-0.2	-0.1	2.36	5.58	7.7	-4.5	3.2
MAR	1.4	0.9	1.77	3.14	5.5	-0.9	4.6
APR	3.0	2.8	2.02	4.10	7.7	-0.7	7.0
MAY	5.5	5.1	1.73	3.01	12.7	3.3	9.4
JUN	8.6	8.6	1.63	2.66	18.2	6.6	11.6
JUL	10.5	10.9	1.16	1.35	20.4	8.1	12.3
AUG	10.6	10.2	1.36	1.85	22.2	8.8	13.4
SEP	7.5	7.3	1.38	1.89	16.2	5.8	10.4
OCT	4.7	4.3	1.47	2.15	10.3	2.7	7.6
NOV	1.5	1.7	1.68	2.82	5.5	-1.4	4.1
DEC	-0.9	-0.6	1.76	3.10	6.4	-4.8	1.6

TABLE 18. Descriptive Statistics 1981-1990 at Reference Stand 3

	MEAN	MEDIAN	STDEV	VAR	RANGE	MIN	MAX
Monthly Mean Temperature							
JAN	2.3	2.2	1.83	3.35	5.7	-0.8	4.9
FEB	1.5	1.7	1.64	2.67	5.6	-1.5	4.1
MAR	3.3	3.4	1.67	2.78	6.4	0.6	5.8
APR	5.5	4.6	2.62	6.87	12.4	2.4	10.0
MAY	9.7	9.3	1.81	3.29	20.9	7.6	13.3
JUN	13.3	13.6	1.79	3.21	26.0	10.6	15.4
JUL	16.1	16.1	2.23	4.99	32.1	12.6	19.5
AUG	17.1	16.7	1.81	3.29	37.0	15.6	21.4
SEP	13.6	12.5	2.55	6.50	28.0	10.9	17.1
OCT	9.6	8.2	3.46	11.99	21.2	5.5	15.7
NOV	3.6	3.1	2.16	4.65	6.9	-0.3	6.6
DEC	1.2	1.3	2.50	6.27	8.5	-3.8	4.7
Mean Maximum Temperature							
JAN	3.5	3.9	1.84	3.38	6.5	0.2	6.3
FEB	3.2	3.1	1.61	2.60	7.1	1.2	5.9
MAR	5.8	6.1	2.24	5.03	11.5	2.3	9.2
APR	9.6	8.6	3.47	12.03	20.3	5.1	15.2
MAY	14.8	14.4	2.33	5.43	31.9	11.9	20.0
JUN	18.9	19.1	2.30	5.28	37.3	15.7	21.6
JUL	22.5	22.6	3.45	11.87	44.5	16.9	27.6
AUG	24.0	23.5	2.08	4.31	49.6	21.3	28.3
SEP	18.8	17.1	3.46	11.99	39.3	14.6	24.7
OCT	12.8	11.2	3.93	15.45	27.1	7.9	19.2
NOV	5.3	4.8	2.25	5.05	9.8	1.5	8.3
DEC	2.8	2.9	2.65	7.00	8.8	-2.1	6.7
Mean Minimum Temperature							
JAN	0.7	0.8	1.44	2.07	4.8	-1.9	2.9
FEB	-0.1	0.4	1.75	3.06	6.1	-3.4	2.7
MAR	1.4	1.2	1.41	1.98	3.9	-0.8	3.1
APR	2.8	1.9	2.25	5.05	6.5	0.0	6.5
MAY	5.8	5.8	1.54	2.37	12.2	3.9	8.3
JUN	9.1	9.4	1.54	2.37	17.7	6.7	11.0
JUL	11.8	11.5	1.79	3.21	23.7	9.5	14.2
AUG	12.8	12.1	1.70	2.90	28.0	11.3	16.7
SEP	10.2	9.2	2.29	5.25	21.3	7.9	13.4
OCT	7.1	5.8	3.30	10.90	16.6	3.6	13.0
NOV	2.1	1.7	2.18	4.76	7.2	-2.3	4.9
DEC	-0.3	-0.2	2.57	6.63	8.8	-5.8	3.0

TABLE 19. Descriptive Statistics 1981-1990 at Reference Stand 4

	MEAN	MEDIAN	STDEV	VAR	RANGE	MIN	MAX
Monthly Mean Temperature							
JAN	0.1	-0.1	1.75	3.06	6.1	-2.6	3.5
FEB	-0.7	-0.6	2.41	5.80	7.4	-4.7	2.7
MAR	0.6	0.8	1.99	3.95	5.5	-2.1	3.4
APR	2.8	2.8	2.89	8.34	9.1	-0.8	8.3
MAY	5.4	5.2	1.75	3.06	13.1	3.6	9.5
JUN	10.1	9.9	2.60	6.74	20.1	5.7	14.4
JUL	13.1	12.8	2.57	6.60	24.2	7.8	16.4
AUG	14.3	13.7	2.18	4.75	30.5	12.1	18.4
SEP	10.8	10.3	2.95	8.69	21.5	6.7	14.8
OCT	6.9	5.7	3.77	14.22	14.9	2.1	12.8
NOV	0.6	1.3	2.91	8.48	8.1	-4.1	4.0
DEC	-0.9	-1.1	3.45	11.92	10.1	-5.8	4.3
Mean Maximum Temperature							
JAN	1.7	1.9	1.46	2.12	5.6	-1.2	4.4
FEB	1.3	1.6	2.49	6.22	7.7	-2.2	5.5
MAR	2.8	3.1	2.42	5.84	7.1	-0.7	6.4
APR	5.7	5.6	3.31	10.95	13.5	1.5	12.0
MAY	8.7	8.9	1.87	3.49	18.9	6.3	12.6
JUN	14.1	14.4	2.98	8.91	27.9	8.9	19.0
JUL	17.5	17.3	3.26	10.64	31.9	10.5	21.4
AUG	18.7	18.2	2.67	7.12	39.1	15.9	23.2
SEP	14.5	13.7	3.70	13.70	29.7	10.0	19.7
OCT	9.7	8.5	4.25	18.11	20.5	4.0	16.5
NOV	2.4	3.0	3.10	9.63	8.4	-2.5	5.9
DEC	1.0	0.8	3.66	13.41	11.1	-4.1	7.0
Mean Minimum Temperature							
JAN	-2.1	-2.1	1.22	1.48	4.6	-4.5	0.1
FEB	-2.8	-2.7	2.37	5.60	7.2	-6.8	0.4
MAR	-1.4	-1.5	1.89	3.59	5.5	-4.1	1.4
APR	0.2	0.0	2.73	7.46	8.8	-3.5	5.3
MAY	2.3	2.0	1.95	3.82	7.1	0.2	6.9
JUN	6.3	6.4	2.23	4.96	12.6	2.4	10.2
JUL	9.2	8.7	2.25	5.07	17.1	4.6	12.5
AUG	10.6	10.3	1.96	3.85	22.8	8.4	14.4
SEP	7.5	7.4	2.65	7.01	13.9	3.2	10.7
OCT	4.3	3.0	3.58	12.80	9.9	-0.1	9.8
NOV	-1.2	-0.5	2.73	7.45	7.9	-6.0	1.9
DEC	-2.7	-2.7	3.29	10.79	9.2	-7.5	1.7

TABLE 20. Descriptive Statistics 1981-1990 at Reference Stand 5

	MEAN	MEDIAN	STDEV	VAR	RANGE	MIN	MAX
Monthly Mean Temperature							
JAN	1.7	2.2	2.02	4.08	6.9	-3.5	3.4
FEB	1.6	0.9	2.35	5.53	7.5	-2.0	5.5
MAR	3.5	3.6	2.69	7.25	9.3	-1.3	8.0
APR	6.4	6.8	3.44	11.82	11.4	0.2	11.2
MAY	8.9	9.0	2.29	5.26	18.2	5.7	12.5
JUN	12.9	13.9	3.09	9.53	25.5	8.8	16.7
JUL	15.8	16.4	2.85	8.12	30.4	11.4	19.0
AUG	16.2	16.1	2.50	6.27	33.7	12.8	20.9
SEP	12.6	12.2	2.67	7.13	23.8	8.0	15.8
OCT	9.0	7.9	3.54	12.53	19.9	4.9	15.0
NOV	3.5	2.6	2.02	4.09	8.0	1.4	6.6
DEC	1.6	0.6	2.81	7.87	8.3	-2.5	5.8
Mean Maximum Temperature							
JAN	3.3	3.9	2.11	4.46	7.3	-1.9	5.4
FEB	4.0	3.2	2.43	5.89	8.3	0.4	7.9
MAR	6.5	6.4	2.90	8.42	13.0	1.5	11.5
APR	10.0	10.3	4.21	17.73	19.4	3.6	15.8
MAY	12.6	12.8	2.80	7.83	24.6	8.0	16.6
JUN	17.4	18.2	3.47	12.07	34.5	12.8	21.7
JUL	20.7	20.8	3.30	10.88	39.9	15.2	24.7
AUG	21.1	21.1	3.39	11.50	41.7	14.9	26.8
SEP	16.3	16.2	3.63	13.17	32.0	11.3	20.7
OCT	12.4	11.0	4.15	17.19	27.0	8.3	18.7
NOV	5.3	4.4	2.03	4.13	12.0	3.3	8.7
DEC	3.4	2.3	2.89	8.36	8.2	-0.6	7.6
Mean Minimum Temperature							
JAN	0.1	0.3	1.99	3.97	6.9	-4.8	2.1
FEB	-0.3	-1.0	2.41	5.82	7.7	-4.0	3.7
MAR	1.2	1.4	2.57	6.61	8.6	-3.3	5.3
APR	3.5	4.0	3.05	9.30	10.2	-2.6	7.6
MAY	5.4	5.7	2.35	5.52	10.9	1.8	9.1
JUN	9.1	10.3	2.82	7.95	17.8	5.4	12.4
JUL	11.7	12.6	2.61	6.80	22.5	7.9	14.6
AUG	12.1	12.4	2.39	5.70	24.4	8.0	16.4
SEP	9.1	9.4	2.67	7.12	17.3	5.3	12.0
OCT	6.5	5.6	3.29	10.86	15.2	2.7	12.5
NOV	1.8	1.1	2.07	4.28	5.2	-0.5	4.7
DEC	0.2	-0.9	2.89	8.37	8.6	-4.3	4.3

TABLE 21. Descriptive Statistics 1981-1990 at Reference Stand 7

	MEAN	MEDIAN	STDEV	VAR	RANGE	MIN	MAX
Monthly Mean Temperature							
JAN	2.4	2.7	1.82	3.30	5.0	-0.1	4.9
FEB	3.0	3.1	2.02	4.09	6.2	-0.1	6.1
MAR	4.9	4.9	2.04	4.17	10.2	1.9	8.3
APR	7.5	7.2	2.91	8.47	15.3	3.1	12.2
MAY	10.3	10.2	1.86	3.45	20.4	6.6	13.8
JUN	14.4	14.5	2.01	4.04	27.7	10.5	17.2
JUL	16.9	16.8	1.96	3.82	31.9	12.6	19.3
AUG	17.2	17.2	1.48	2.20	35.6	15.5	20.1
SEP	13.1	13.2	1.87	3.50	25.4	9.8	15.6
OCT	9.0	7.8	2.40	5.78	19.9	6.7	13.2
NOV	4.5	4.6	2.04	4.15	8.2	1.5	6.7
DEC	1.5	2.4	2.14	4.59	6.2	-1.8	4.4
Mean Maximum Temperature							
JAN	4.6	4.9	1.72	2.98	8.2	1.0	7.2
FEB	5.7	6.2	2.15	4.62	11.7	2.6	9.1
MAR	8.3	8.2	2.45	5.98	16.1	4.6	11.5
APR	12.1	12.1	3.50	12.27	24.7	6.9	17.8
MAY	15.1	15.1	1.95	3.81	30.1	11.3	18.8
JUN	20.1	20.4	2.70	7.27	39.3	15.0	24.3
JUL	23.3	23.0	2.98	8.91	44.4	17.5	26.9
AUG	24.2	23.5	2.31	5.36	50.1	21.6	28.5
SEP	19.0	18.7	2.73	7.46	37.9	15.3	22.6
OCT	13.4	11.6	3.67	13.46	29.7	9.4	20.3
NOV	6.6	7.1	2.26	5.10	12.5	3.3	9.2
DEC	3.8	4.4	2.39	5.73	7.2	0.3	6.9
Mean Minimum Temperature							
JAN	0.6	1.3	1.85	3.44	4.7	-1.8	2.9
FEB	0.6	0.6	2.13	4.52	6.1	-2.3	3.8
MAR	1.8	2.0	1.76	3.10	6.4	-1.2	5.2
APR	3.5	3.0	2.71	7.32	8.2	-0.6	7.6
MAY	5.6	6.0	2.14	4.60	11.4	2.0	9.4
JUN	9.2	9.5	1.98	3.91	16.9	5.7	11.2
JUL	10.9	10.4	1.82	3.30	20.8	7.8	13.0
AUG	11.0	11.2	1.42	2.00	21.3	8.7	12.6
SEP	8.0	8.3	1.68	2.82	15.0	4.8	10.2
OCT	5.1	4.3	2.00	4.00	12.6	3.0	9.6
NOV	2.4	2.2	2.11	4.43	6.0	-0.9	5.1
DEC	-0.3	0.6	2.16	4.67	6.2	-4.0	2.2

TABLE 22. Descriptive Statistics 1981-1990 at Reference Stand 10

	MEAN	MEDIAN	STDEV	VAR	RANGE	MIN	MAX
Monthly Mean Temperature							
JAN	2.9	2.6	1.84	3.40	6.2	0.0	6.2
FEB	2.8	3.1	2.06	4.23	5.9	-0.1	5.8
MAR	5.6	5.2	2.02	4.07	11.9	2.5	9.4
APR	8.1	8.0	2.60	6.74	16.1	4.5	11.6
MAY	11.2	11.5	1.36	1.85	22.5	9.4	13.1
JUN	14.8	15.1	1.91	3.64	30.3	12.5	17.8
JUL	17.7	17.2	1.61	2.60	35.9	15.8	20.1
AUG	17.8	17.6	2.05	4.22	37.0	14.7	22.3
SEP	14.1	13.8	1.47	2.17	28.6	12.5	16.1
OCT	10.1	9.8	2.43	5.90	20.8	7.0	13.8
NOV	4.8	5.1	2.00	3.98	9.4	1.5	7.9
DEC	2.1	2.3	2.60	6.76	8.6	-3.0	5.6
Mean Maximum Temperature							
JAN	5.4	6.0	1.92	3.67	10.3	1.8	8.5
FEB	6.0	6.4	2.69	7.25	12.3	2.4	9.9
MAR	9.7	9.5	2.48	6.13	21.4	6.8	14.6
APR	13.1	12.9	3.12	9.76	26.1	8.4	17.7
MAY	16.6	16.5	1.49	2.22	32.6	14.0	18.6
JUN	20.7	21.0	2.58	6.63	42.2	17.6	24.6
JUL	24.5	24.1	2.33	5.44	49.5	21.6	27.9
AUG	25.2	24.9	2.92	8.55	50.7	20.0	30.7
SEP	20.7	20.7	2.36	5.59	42.3	17.9	24.4
OCT	15.6	14.6	3.69	13.61	34.1	11.4	22.7
NOV	7.1	6.7	2.12	4.49	14.6	4.2	10.4
DEC	4.5	4.0	3.01	9.08	9.3	-0.7	8.6
Mean Minimum Temperature							
JAN	1.1	0.8	1.77	3.13	5.7	-1.4	4.3
FEB	0.6	0.8	1.83	3.36	5.3	-1.7	3.6
MAR	2.6	2.6	1.70	2.89	5.4	-0.2	5.2
APR	4.2	4.0	2.30	5.31	7.5	0.3	7.2
MAY	6.8	7.4	1.47	2.17	13.0	4.3	8.7
JUN	10.0	9.8	1.60	2.57	20.5	8.0	12.5
JUL	12.2	12.0	1.13	1.27	24.4	10.4	14.0
AUG	12.2	11.9	1.41	2.00	26.0	10.3	15.7
SEP	9.3	9.2	0.97	0.93	18.4	7.9	10.5
OCT	6.4	6.3	1.98	3.90	13.4	3.5	9.9
NOV	2.8	3.0	2.00	4.02	6.2	-0.5	5.7
DEC	0.3	0.6	2.56	6.54	8.7	-5.3	3.4

TABLE 23. Descriptive Statistics 1981-1990 at Reference Stand 12

	MEAN	MEDIAN	STDEV	VAR	RANGE	MIN	MAX
Monthly Mean Temperature							
JAN	1.0	0.7	1.92	3.67	5.5	-1.7	3.8
FEB	0.2	0.7	2.07	4.29	6.8	-3.3	3.5
MAR	1.6	1.5	1.96	3.85	5.9	-0.9	5.0
APR	3.5	3.4	2.74	7.51	9.8	0.3	9.5
MAY	7.2	6.7	2.29	5.24	16.4	4.9	11.5
JUN	11.2	11.5	2.00	4.01	23.6	8.5	15.1
JUL	14.2	13.9	1.80	3.25	27.7	10.9	16.8
AUG	14.6	14.2	1.89	3.56	31.6	12.6	19.0
SEP	10.7	10.5	2.04	4.16	21.6	7.8	13.8
OCT	7.2	6.6	2.73	7.44	14.7	3.5	11.2
NOV	1.9	2.3	1.85	3.44	5.2	-0.8	4.4
DEC	-0.1	-0.4	2.41	5.83	6.6	-3.3	3.3
Mean Maximum Temperature							
JAN	2.4	2.3	1.83	3.35	6.0	-0.5	5.5
FEB	2.1	2.2	2.01	4.02	6.0	-0.8	5.2
MAR	4.1	3.9	2.15	4.64	9.7	1.5	8.2
APR	7.1	6.4	3.53	12.45	16.3	2.3	14.0
MAY	12.1	12.0	2.48	6.15	25.8	8.9	16.9
JUN	16.8	17.1	2.79	7.77	35.0	13.2	21.8
JUL	20.7	20.2	2.94	8.63	40.1	15.0	25.1
AUG	21.2	20.6	2.71	7.32	44.8	18.6	26.2
SEP	15.6	14.7	2.96	8.79	30.7	11.3	19.4
OCT	10.5	9.6	3.46	11.96	21.8	5.7	16.1
NOV	3.7	3.9	2.07	4.28	7.5	1.0	6.5
DEC	1.5	1.3	2.59	6.69	6.8	-1.7	5.1
Mean Minimum Temperature							
JAN	-0.7	-0.8	1.71	2.91	5.4	-3.3	2.1
FEB	-1.6	-1.2	2.25	5.08	7.6	-5.4	2.2
MAR	-0.2	-0.6	1.86	3.44	6.2	-2.8	3.4
APR	0.9	0.7	2.33	5.41	8.3	-2.3	6.0
MAY	3.5	3.0	2.19	4.82	8.6	1.1	7.5
JUN	6.6	6.8	1.81	3.29	14.5	4.3	10.2
JUL	9.3	9.2	1.29	1.66	19.0	7.4	11.6
AUG	9.8	9.7	1.55	2.41	20.8	7.6	13.2
SEP	7.0	7.0	1.81	3.28	14.6	4.7	9.9
OCT	4.5	3.8	2.43	5.91	9.9	1.5	8.4
NOV	0.3	0.7	1.75	3.06	5.4	-2.7	2.7
DEC	-1.7	-2.0	2.40	5.78	6.9	-5.3	1.6

TABLE 24. Descriptive Statistics 1981-1990 at Reference Stand 13

	MEAN	MEDIAN	STDEV	VAR	RANGE	MIN	MAX
Monthly Mean Temperature							
JAN	-0.1	-0.4	2.09	4.36	7.8	-4.3	3.5
FEB	-0.4	-0.4	2.31	5.34	6.9	-3.8	3.1
MAR	0.0	0.0	2.39	5.70	7.6	-3.1	4.5
APR	1.7	1.8	3.01	9.04	9.7	-2.4	7.3
MAY	4.7	5.1	2.19	4.80	10.0	1.4	8.6
JUN	9.7	10.0	3.31	10.97	19.3	5.5	13.8
JUL	12.9	12.1	3.15	9.92	26.2	7.6	18.6
AUG	13.9	14.1	2.33	5.41	29.5	11.1	18.4
SEP	10.2	9.0	3.23	10.44	21.5	6.9	14.6
OCT	7.0	5.9	4.14	17.18	14.7	1.1	13.6
NOV	0.5	1.2	2.76	7.64	7.0	-2.8	4.2
DEC	-0.8	-2.1	4.14	17.13	10.9	-6.1	4.8
Mean Maximum Temperature							
JAN	1.5	1.4	2.17	4.71	8.4	-2.8	5.6
FEB	1.6	1.8	2.58	6.65	8.1	-2.0	6.1
MAR	2.3	2.4	2.60	6.77	8.1	-0.9	7.2
APR	4.7	4.6	3.27	10.69	11.0	-0.3	10.7
MAY	7.9	8.4	2.47	6.12	16.2	4.4	11.8
JUN	13.7	14.5	3.82	14.62	27.1	8.8	18.3
JUL	17.1	16.2	3.64	13.23	33.9	10.6	23.3
AUG	18.1	18.5	2.58	6.68	37.8	15.1	22.7
SEP	13.9	12.1	4.05	16.44	29.5	10.1	19.4
OCT	10.0	9.0	4.78	22.84	20.6	3.1	17.5
NOV	2.5	3.0	3.04	9.24	8.0	-1.3	6.7
DEC	1.2	-0.1	4.34	18.86	11.9	-4.2	7.7
Mean Minimum Temperature							
JAN	-2.4	-2.7	1.88	3.52	7.2	-6.1	1.1
FEB	-2.6	-2.7	2.43	5.89	6.6	-6.2	0.4
MAR	-2.1	-2.3	2.19	4.79	6.7	-5.0	1.7
APR	-1.0	-0.8	2.88	8.30	8.6	-4.3	4.3
MAY	1.7	1.9	2.22	4.95	7.6	-1.7	5.9
JUN	6.1	6.3	2.95	8.72	11.7	2.1	9.6
JUL	9.2	8.6	2.90	8.43	19.0	4.6	14.4
AUG	10.3	10.2	2.24	5.00	22.0	7.4	14.6
SEP	6.9	6.0	2.94	8.65	14.3	3.3	11.0
OCT	4.2	3.0	3.98	15.87	12.0	-1.2	10.8
NOV	-1.3	-0.8	2.66	7.06	6.6	-4.5	2.1
DEC	-2.9	-3.9	4.08	16.65	10.8	-8.2	2.6

TABLE 25. Descriptive Statistics 1981-1990 at Reference Stand 14

	MEAN	MEDIAN	STDEV	VAR	RANGE	MIN	MAX
Monthly Mean Temperature							
JAN	0.0	0.4	2.11	4.47	6.9	-4.2	2.7
FEB	-0.9	-1.0	2.40	5.78	7.2	-5.5	1.7
MAR	0.4	-0.1	2.02	4.10	6.3	-2.5	3.8
APR	2.2	2.5	2.85	8.10	8.2	-1.4	6.8
MAY	4.9	4.6	1.85	3.44	12.1	3.1	9.0
JUN	9.7	9.4	2.96	8.77	18.8	4.8	14.0
JUL	12.6	11.6	2.98	8.86	25.1	7.1	18.0
AUG	13.6	13.5	2.08	4.32	28.4	10.8	17.6
SEP	10.1	9.6	2.97	8.80	20.6	6.3	14.3
OCT	6.8	6.0	3.40	11.53	15.1	2.6	12.5
NOV	0.4	0.3	2.23	4.98	6.7	-2.9	3.8
DEC	-0.8	-1.9	3.45	11.88	9.0	-4.4	4.6
Mean Maximum Temperature							
JAN	1.9	1.5	2.27	5.13	7.6	-2.5	5.1
FEB	1.3	1.1	2.13	4.54	5.7	-1.7	4.0
MAR	2.8	2.9	2.24	5.00	6.8	-0.3	6.5
APR	5.2	5.4	3.19	10.20	11.3	1.4	9.9
MAY	8.2	8.1	1.89	3.57	17.5	5.6	11.9
JUN	13.6	13.7	3.32	11.04	26.7	8.3	18.4
JUL	16.8	15.9	3.34	11.14	32.8	10.2	22.6
AUG	17.7	17.7	2.34	5.47	36.1	14.4	21.7
SEP	13.8	12.9	3.63	13.15	28.2	9.7	18.5
OCT	9.7	9.2	3.79	14.33	21.1	4.9	16.2
NOV	2.5	2.2	2.61	6.81	7.6	-0.9	6.7
DEC	1.5	0.3	3.66	13.38	10.2	-2.5	7.7
Mean Minimum Temperature							
JAN	-2.5	-2.6	1.88	3.52	6.4	-6.4	0.0
FEB	-3.2	-3.5	2.59	6.69	8.1	-7.9	0.2
MAR	-2.0	-2.7	1.92	3.67	5.7	-4.7	1.0
APR	-0.6	-0.6	2.84	8.08	8.4	-4.2	4.2
MAY	1.7	1.3	2.14	4.59	7.1	-0.4	6.7
JUN	6.0	5.8	2.71	7.32	11.6	1.4	10.2
JUL	8.7	8.0	2.72	7.38	17.9	4.0	13.9
AUG	10.0	9.6	1.84	3.40	20.9	7.1	13.8
SEP	6.8	6.2	2.70	7.31	13.7	2.8	10.9
OCT	3.9	3.2	3.22	10.36	9.2	0.1	9.1
NOV	-1.5	-1.6	2.18	4.75	7.0	-5.3	1.7
DEC	-3.1	-3.9	3.38	11.45	9.5	-7.1	2.4

TABLE 26. Descriptive Statistics 1981-1990 at Reference Stand 15

	MEAN	MEDIAN	STDEV	VAR	RANGE	MIN	MAX
Monthly Mean Temperature							
JAN	2.8	3.1	2.05	4.21	7.1	-2.1	5.0
FEB	2.8	2.7	1.73	3.00	6.2	0.3	5.9
MAR	4.1	3.9	1.84	3.39	9.0	1.7	7.3
APR	6.6	6.8	2.90	8.43	13.7	2.5	11.2
MAY	9.8	9.3	1.93	3.72	19.9	7.0	12.9
JUN	13.8	14.1	2.55	6.49	27.3	9.9	17.4
JUL	16.7	16.4	2.30	5.28	33.0	13.1	19.9
AUG	17.4	16.9	1.91	3.66	36.9	15.2	21.7
SEP	13.6	12.7	2.13	4.55	27.6	11.2	16.4
OCT	10.1	9.4	3.41	11.61	20.4	5.3	15.1
NOV	3.8	4.0	2.48	6.17	9.4	-1.3	8.1
DEC	1.9	1.4	2.46	6.05	7.2	-2.1	5.1
Mean Maximum Temperature							
JAN	4.2	4.7	2.19	4.79	7.7	-0.9	6.8
FEB	4.8	4.8	1.87	3.48	9.5	1.7	7.8
MAR	6.5	5.9	2.00	4.00	14.5	4.2	10.3
APR	9.9	10.2	3.24	10.49	20.7	5.5	15.2
MAY	13.6	13.4	2.18	4.76	28.2	10.4	17.8
JUN	17.9	17.9	2.89	8.38	35.6	13.6	22.0
JUL	21.2	20.3	2.88	8.27	41.7	16.4	25.3
AUG	22.2	22.1	2.26	5.09	45.5	18.7	26.8
SEP	17.4	16.2	2.47	6.12	34.7	14.2	20.5
OCT	13.1	12.2	3.89	15.17	27.1	7.6	19.5
NOV	5.5	5.7	2.59	6.70	10.3	0.2	10.1
DEC	3.6	2.9	2.60	6.74	7.6	-0.3	7.3
Mean Minimum Temperature							
JAN	1.0	1.4	1.83	3.35	7.0	-3.4	3.6
FEB	1.1	0.9	1.73	3.01	5.3	-1.0	4.3
MAR	2.0	2.3	1.81	3.27	5.3	-0.6	4.7
APR	3.8	3.9	2.69	7.24	8.0	-0.3	7.7
MAY	6.4	6.3	1.87	3.48	13.2	3.6	9.6
JUN	10.0	10.3	2.26	5.13	20.0	6.8	13.2
JUL	12.5	12.7	1.98	3.93	24.7	9.3	15.4
AUG	13.2	13.0	1.77	3.12	27.8	10.8	17.0
SEP	10.5	9.8	1.97	3.87	21.3	8.3	13.0
OCT	7.6	7.0	3.11	9.64	15.4	3.5	11.9
NOV	2.3	2.4	2.48	6.15	9.2	-3.0	6.2
DEC	0.4	0.2	2.51	6.32	7.4	-4.0	3.4

TABLE 27. Descriptive Statistics 1981-1990 at Reference Stand 16

	MEAN	MEDIAN	STDEV	VAR	RANGE	MIN	MAX
Monthly Mean Temperature							
JAN	2.9	3.1	1.69	2.86	6.0	-0.5	5.5
FEB	3.0	3.5	1.88	3.52	6.4	0.3	6.1
MAR	5.0	4.8	1.71	2.93	10.1	2.1	8.0
APR	7.8	7.2	2.65	7.00	16.3	4.2	12.1
MAY	10.9	10.9	1.54	2.39	22.7	9.0	13.7
JUN	14.4	14.5	2.05	4.21	29.2	11.1	18.1
JUL	17.6	17.3	1.96	3.83	34.0	14.1	19.9
AUG	18.4	18.1	1.92	3.68	39.1	16.3	22.8
SEP	14.7	14.4	1.99	3.97	29.5	12.2	17.3
OCT	10.5	10.0	3.12	9.73	20.4	5.4	15.0
NOV	5.0	4.8	2.79	7.78	10.3	0.0	10.3
DEC	2.7	2.7	1.70	2.90	5.5	0.3	5.2
Mean Maximum Temperature							
JAN	4.8	5.4	1.77	3.13	8.4	0.9	7.5
FEB	5.8	6.0	1.98	3.93	12.4	3.4	9.0
MAR	8.6	8.1	2.06	4.23	18.3	5.8	12.5
APR	12.5	12.0	3.15	9.93	25.4	7.5	17.9
MAY	15.9	15.4	1.87	3.49	32.7	13.6	19.1
JUN	19.6	19.7	2.53	6.39	39.4	15.6	23.8
JUL	23.4	23.3	2.60	6.76	45.3	18.8	26.5
AUG	24.7	24.4	2.62	6.86	51.3	21.6	29.7
SEP	20.3	20.0	2.63	6.93	41.3	16.9	24.4
OCT	14.5	14.2	3.93	15.42	29.4	8.2	21.2
NOV	7.1	6.9	3.06	9.36	15.0	1.8	13.2
DEC	4.8	5.0	2.08	4.32	9.3	1.8	7.5
Mean Minimum Temperature							
JAN	1.1	1.2	1.50	2.26	5.7	-1.9	3.8
FEB	0.5	0.8	1.96	3.86	6.2	-2.5	3.7
MAR	2.0	2.2	1.58	2.50	5.3	-0.9	4.4
APR	3.9	3.2	2.20	4.83	7.8	0.6	7.2
MAY	6.6	6.9	1.44	2.08	14.2	4.9	9.3
JUN	9.7	10.0	1.68	2.84	20.5	7.5	13.0
JUL	12.3	12.7	1.42	2.01	24.4	10.2	14.2
AUG	13.1	12.4	1.35	1.81	28.2	12.0	16.2
SEP	10.1	10.0	1.57	2.45	20.8	8.4	12.4
OCT	7.3	6.7	2.71	7.33	14.4	3.1	11.3
NOV	3.2	3.0	2.80	7.86	10.4	-2.1	8.3
DEC	1.2	1.0	1.59	2.53	4.1	-0.9	3.2

TABLE 28. Descriptive Statistics 1981-1990 at Reference Stand 17

	MEAN	MEDIAN	STDEV	VAR	RANGE	MIN	MAX
Monthly Mean Temperature							
JAN	2.3	2.0	1.67	2.78	4.4	-0.1	4.3
FEB	2.6	2.8	1.85	3.42	5.9	-0.9	5.0
MAR	4.7	4.8	1.76	3.08	9.3	1.4	7.9
APR	7.6	7.3	2.47	6.10	15.6	3.9	11.7
MAY	11.1	10.8	1.90	3.62	23.5	8.1	15.4
JUN	14.3	14.3	1.71	2.92	29.0	12.2	16.8
JUL	16.8	16.7	1.30	1.69	33.6	14.8	18.8
AUG	17.5	17.4	1.56	2.44	36.8	15.4	21.4
SEP	13.5	13.3	1.42	2.02	27.8	11.7	16.1
OCT	9.0	8.8	1.81	3.29	19.0	6.6	12.4
NOV	4.4	4.6	1.81	3.26	8.9	1.1	7.8
DEC	1.3	1.0	2.05	4.22	6.5	-2.5	4.0
Mean Maximum Temperature							
JAN	4.0	4.1	1.88	3.55	7.4	1.0	6.4
FEB	5.3	6.1	1.85	3.44	9.7	1.9	7.8
MAR	8.0	7.9	2.02	4.09	16.5	4.7	11.8
APR	11.9	11.9	3.08	9.50	23.5	6.6	16.9
MAY	15.7	15.4	2.15	4.63	32.4	12.3	20.1
JUN	19.8	20.0	2.65	7.01	39.9	16.6	23.3
JUL	23.0	23.0	2.51	6.30	45.9	18.8	27.1
AUG	24.1	23.5	2.25	5.07	50.7	21.7	29.0
SEP	19.1	18.8	2.19	4.79	37.9	15.8	22.1
OCT	13.3	12.6	2.79	7.79	26.7	9.3	17.4
NOV	6.3	6.1	2.01	4.05	12.9	2.8	10.1
DEC	3.0	2.8	2.10	4.43	6.4	-0.5	5.9
Mean Minimum Temperature							
JAN	0.8	0.8	1.61	2.60	4.2	-1.1	3.1
FEB	0.4	0.4	1.98	3.91	6.2	-3.3	2.9
MAR	1.9	1.8	1.59	2.53	5.5	-0.9	4.6
APR	3.7	3.7	2.04	4.17	7.9	0.8	7.1
MAY	6.8	6.7	1.84	3.39	15.3	4.3	11.0
JUN	9.6	9.6	1.22	1.50	19.8	8.3	11.5
JUL	11.4	11.5	0.96	0.92	22.1	9.3	12.8
AUG	11.8	11.7	1.58	2.50	24.0	9.5	14.5
SEP	8.9	8.5	1.22	1.49	19.1	7.6	11.5
OCT	5.6	5.4	1.53	2.34	12.2	3.5	8.7
NOV	2.5	2.6	1.80	3.25	6.6	-0.8	5.8
DEC	-0.3	-0.2	2.07	4.29	6.7	-4.4	2.3

TABLE 29. Descriptive Statistics 1981-1990 at Reference Stand 20

	MEAN	MEDIAN	STDEV	VAR	RANGE	MIN	MAX
Monthly Mean Temperature							
JAN	3.1	2.8	2.99	8.97	11.2	-2.2	9.0
FEB	3.2	3.2	2.65	7.05	8.8	-0.5	8.3
MAR	4.4	4.3	2.00	3.99	8.4	0.7	7.7
APR	7.2	7.0	3.25	10.57	15.5	2.4	13.1
MAY	10.2	10.1	2.09	4.39	22.4	7.4	15.0
JUN	13.9	14.0	2.68	7.18	27.5	9.8	17.7
JUL	16.9	15.9	2.65	7.00	35.1	13.7	21.4
AUG	17.5	17.3	1.82	3.31	35.4	14.9	20.5
SEP	14.0	13.1	2.48	6.15	28.5	11.2	17.3
OCT	9.6	8.7	3.08	9.46	21.2	6.2	15.0
NOV	3.7	3.5	1.99	3.95	6.9	0.6	6.3
DEC	1.5	1.1	2.30	5.30	6.4	-1.3	5.1
Mean Maximum Temperature							
JAN	5.4	4.6	3.13	9.78	12.0	-0.6	11.4
FEB	6.5	6.8	2.69	7.21	13.4	2.5	10.9
MAR	8.6	8.1	2.47	6.12	17.3	4.8	12.5
APR	12.1	11.6	3.94	15.56	25.7	7.0	18.7
MAY	15.4	15.7	2.18	4.76	31.3	11.6	19.7
JUN	19.5	20.1	3.36	11.29	38.3	14.1	24.2
JUL	23.2	21.8	3.34	11.12	47.3	18.7	28.6
AUG	24.4	24.3	2.56	6.53	48.9	20.8	28.1
SEP	20.0	19.0	3.48	12.14	40.3	15.9	24.4
OCT	14.5	13.2	4.17	17.43	32.4	9.9	22.5
NOV	6.4	5.9	2.35	5.50	12.3	2.9	9.4
DEC	4.2	3.6	2.89	8.33	9.2	0.5	8.7
Mean Minimum Temperature							
JAN	0.7	0.3	2.94	8.62	11.0	-4.0	7.0
FEB	0.4	0.5	2.88	8.29	9.8	-3.5	6.3
MAR	1.2	1.1	1.68	2.83	5.9	-2.3	3.6
APR	3.1	3.1	2.93	8.61	10.2	-1.7	8.5
MAY	5.5	5.7	2.25	5.08	13.3	2.4	10.9
JUN	8.9	9.3	2.02	4.10	17.4	5.6	11.8
JUL	11.3	11.4	2.09	4.36	22.9	8.4	14.5
AUG	11.7	11.5	1.37	1.87	23.4	9.5	13.9
SEP	9.1	8.3	2.05	4.21	19.2	6.9	12.3
OCT	5.8	5.1	2.52	6.37	12.7	2.6	10.1
NOV	1.4	1.7	1.85	3.43	5.4	-1.6	3.8
DEC	-0.6	-0.9	2.02	4.08	5.9	-3.6	2.3

TABLE 30. Descriptive Statistics 1981-1990 at Reference Stand 26

	MEAN	MEDIAN	STDEV	VAR	RANGE	MIN	MAX
Monthly Mean Temperature							
JAN	1.7	1.4	2.05	4.21	7.1	-2.2	4.9
FEB	1.4	1.4	2.31	5.33	6.6	-1.6	5.0
MAR	2.5	1.8	2.20	4.84	6.5	-0.4	6.1
APR	4.9	4.5	3.16	9.97	10.6	0.3	10.3
MAY	7.9	8.0	1.93	3.74	16.3	4.9	11.4
JUN	12.2	12.2	2.85	8.14	24.7	8.5	16.2
JUL	15.1	14.9	2.67	7.12	30.4	10.6	19.8
AUG	16.1	16.2	2.28	5.19	34.1	13.3	20.8
SEP	12.6	11.9	2.60	6.75	25.5	9.6	15.9
OCT	8.8	7.5	3.69	13.64	18.3	3.6	14.7
NOV	2.6	2.9	2.38	5.66	6.5	-1.0	5.5
DEC	1.2	0.1	3.64	13.24	8.6	-3.1	5.5
Mean Maximum Temperature							
JAN	3.6	3.6	2.09	4.37	8.3	-1.0	7.3
FEB	3.8	3.6	2.58	6.66	8.9	0.6	8.3
MAR	5.4	4.6	2.49	6.22	11.9	2.3	9.6
APR	8.5	8.0	3.83	14.70	17.2	2.6	14.6
MAY	12.0	12.4	2.05	4.20	23.5	8.6	14.9
JUN	16.8	17.4	3.36	11.28	33.7	12.5	21.2
JUL	20.1	19.8	3.35	11.25	39.8	14.1	25.7
AUG	21.4	21.8	2.73	7.48	44.4	17.8	26.6
SEP	17.1	15.9	3.27	10.66	35.3	13.7	21.6
OCT	12.4	11.1	4.45	19.84	25.7	6.0	19.7
NOV	4.8	4.8	2.67	7.14	9.1	1.0	8.1
DEC	3.5	2.2	4.03	16.24	9.8	-1.4	8.4
Mean Minimum Temperature							
JAN	-0.6	-0.6	1.57	2.46	6.2	-3.8	2.4
FEB	-1.0	-1.0	2.24	5.02	7.1	-4.3	2.8
MAR	0.0	-0.5	1.99	3.96	6.6	-3.0	3.6
APR	1.7	0.9	2.95	8.73	8.9	-1.9	7.0
MAY	4.1	4.1	2.13	4.54	9.6	1.1	8.5
JUN	8.1	8.4	2.59	6.71	15.9	4.5	11.4
JUL	10.8	10.5	2.26	5.09	21.9	7.4	14.5
AUG	11.7	11.7	1.93	3.73	24.8	9.2	15.6
SEP	8.8	8.2	2.41	5.80	17.9	5.9	12.0
OCT	5.6	4.3	3.39	11.51	12.3	1.2	11.1
NOV	0.6	1.1	2.28	5.22	6.6	-3.2	3.4
DEC	-0.8	-1.7	3.47	12.05	8.2	-5.0	3.2

TABLE 31. Descriptive Statistics 1981-1990 at Reference Stand 86

	MEAN	MEDIAN	STDEV	VAR	RANGE	MIN	MAX
Monthly Mean Temperature							
JAN	3.3	3.3	1.77	3.12	6.5	0.0	6.5
FEB	2.7	3.5	3.46	11.94	11.7	-5.5	6.2
MAR	5.5	5.3	1.95	3.80	12.2	3.1	9.1
APR	8.5	8.6	2.80	7.86	17.7	4.5	13.2
MAY	11.6	11.5	1.67	2.79	23.9	9.5	14.4
JUN	15.7	16.2	2.53	6.38	31.4	12.1	19.3
JUL	18.2	18.1	2.41	5.83	36.8	14.3	22.5
AUG	18.8	18.8	1.96	3.83	39.6	16.7	22.9
SEP	15.3	14.5	2.10	4.41	30.8	12.8	18.0
OCT	10.7	9.7	3.34	11.14	22.9	6.7	16.2
NOV	4.7	5.0	1.90	3.59	9.2	2.1	7.1
DEC	2.4	2.3	2.52	6.37	7.0	-1.4	5.6
Mean Maximum Temperature							
JAN	7.8	7.8	1.95	3.80	15.9	5.2	10.7
FEB	8.6	9.3	3.20	10.27	15.3	2.2	13.1
MAR	11.8	11.4	2.66	7.07	23.8	7.1	16.7
APR	15.9	15.3	3.24	10.47	31.5	10.2	21.3
MAY	19.3	19.0	1.62	2.63	39.1	17.0	22.1
JUN	23.9	23.6	2.95	8.71	47.8	19.9	27.9
JUL	27.0	27.2	3.15	9.91	54.6	22.1	32.5
AUG	28.4	28.2	2.73	7.46	57.6	24.0	33.6
SEP	24.6	24.2	2.65	7.01	49.7	21.4	28.3
OCT	18.3	16.5	4.66	21.72	38.7	12.4	26.3
NOV	8.9	9.0	2.03	4.13	17.8	6.2	11.6
DEC	6.9	5.8	3.47	12.03	15.2	3.2	12.0
Mean Minimum Temperature							
JAN	0.2	0.2	1.66	2.75	6.0	-2.7	3.3
FEB	-1.1	-0.3	3.84	14.73	13.2	-10.5	2.7
MAR	1.3	1.5	1.62	2.62	4.8	-1.4	3.4
APR	3.0	2.6	2.48	6.14	7.9	-0.9	7.0
MAY	5.3	5.2	1.86	3.47	11.0	2.9	8.1
JUN	8.7	9.5	1.91	3.65	17.0	5.8	11.2
JUL	10.5	10.4	1.73	2.99	21.9	8.5	13.4
AUG	11.0	10.8	1.49	2.22	22.7	9.0	13.7
SEP	8.6	8.4	1.90	3.62	17.6	6.3	11.3
OCT	5.7	4.9	2.47	6.09	13.3	3.1	10.2
NOV	1.9	1.9	1.99	3.97	5.3	-1.1	4.2
DEC	-0.6	-0.3	2.24	5.03	6.7	-4.6	2.1

TABLE 32. Descriptive Statistics 1981-1990 at Reference Stand 89

	MEAN	MEDIAN	STDEV	VAR	RANGE	MIN	MAX
Monthly Mean Temperature							
JAN	1.6	1.8	1.86	3.47	5.1	-0.8	4.3
FEB	2.1	2.9	3.39	11.46	12.0	-6.4	5.6
MAR	5.0	5.4	1.92	3.68	9.3	1.8	7.5
APR	7.8	7.8	1.97	3.90	17.1	5.1	12.0
MAY	11.9	12.0	1.52	2.31	24.8	9.9	14.9
JUN	15.0	15.1	1.40	1.97	30.0	12.6	17.4
JUL	17.5	17.3	1.00	1.00	35.5	16.2	19.3
AUG	17.6	17.5	1.32	1.73	35.6	15.7	19.9
SEP	12.7	12.4	1.26	1.59	26.3	11.4	14.9
OCT	9.0	8.5	2.07	4.27	18.9	6.1	12.8
NOV	4.1	4.3	1.77	3.14	8.1	1.2	6.9
DEC	0.8	0.6	1.80	3.26	5.7	-2.0	3.7
Mean Maximum Temperature							
JAN	4.6	4.1	1.63	2.67	9.6	2.3	7.3
FEB	5.9	7.2	3.68	13.54	12.6	-3.0	9.6
MAR	11.7	11.0	2.45	5.99	25.8	9.1	16.7
APR	16.2	15.6	3.05	9.31	32.5	10.9	21.6
MAY	20.6	20.8	1.85	3.44	42.0	18.1	23.9
JUN	25.7	25.7	2.66	7.09	51.9	21.9	30.0
JUL	29.7	29.1	2.88	8.32	58.7	25.3	33.4
AUG	30.5	31.2	2.58	6.67	61.0	26.8	34.2
SEP	23.1	23.2	2.31	5.34	46.8	19.9	26.9
OCT	15.4	14.2	3.33	11.10	31.7	10.7	21.0
NOV	7.4	7.8	2.14	4.60	15.2	4.5	10.7
DEC	4.2	3.6	2.80	7.83	11.5	1.1	10.4
Mean Minimum Temperature							
JAN	-0.3	0.0	1.60	2.57	5.1	-3.3	1.8
FEB	-1.2	-0.2	3.52	12.39	12.1	-9.3	2.8
MAR	1.4	1.9	1.74	3.04	5.9	-1.7	4.2
APR	3.1	2.6	2.13	4.54	6.7	-0.4	6.3
MAY	5.9	5.7	1.90	3.60	12.5	3.3	9.2
JUN	8.0	8.5	1.44	2.07	14.3	5.0	9.3
JUL	9.8	10.0	1.12	1.25	20.1	8.4	11.7
AUG	10.0	9.7	1.35	1.84	21.5	8.3	13.2
SEP	6.7	6.4	1.25	1.56	14.7	5.2	9.5
OCT	4.6	4.1	1.74	3.02	11.6	3.0	8.6
NOV	1.8	2.1	1.92	3.70	5.6	-1.4	4.2
DEC	-1.2	-0.8	1.92	3.68	5.9	-4.9	1.0

TABLE 33. Descriptive Statistics 1981-1990 at Thermograph Site 38

	MEAN	MEDIAN	STDEV	VAR	RANGE	MIN	MAX
Monthly Mean Temperature							
JAN	3.7	3.9	1.78	3.17	6.1	0.1	6.0
FEB	3.4	3.5	1.46	2.13	7.5	1.4	6.1
MAR	4.9	4.3	1.88	3.55	10.3	2.6	7.7
APR	7.3	6.1	2.98	8.86	15.0	3.4	11.6
MAY	10.2	10.3	1.64	2.70	20.9	7.9	13.0
JUN	14.3	14.3	2.34	5.48	28.6	11.2	17.4
JUL	17.1	16.5	2.30	5.29	34.6	13.3	21.3
AUG	17.9	17.9	1.95	3.79	37.1	15.3	21.8
SEP	14.0	13.3	2.12	4.50	29.4	11.9	17.5
OCT	10.1	9.0	3.26	10.63	21.3	5.8	15.5
NOV	4.1	4.3	2.32	5.40	7.8	-0.2	7.6
DEC	2.3	1.8	3.11	9.66	8.8	-2.8	6.0
Mean Maximum Temperature							
JAN	7.6	7.0	1.77	3.12	16.0	5.0	11.0
FEB	8.2	8.3	1.62	2.61	16.1	5.5	10.6
MAR	9.8	9.0	2.17	4.72	20.1	6.8	13.3
APR	13.4	12.1	3.36	11.28	26.4	8.1	18.3
MAY	16.3	16.6	1.90	3.62	32.1	13.0	19.1
JUN	21.3	21.4	3.24	10.53	42.9	17.1	25.8
JUL	24.8	23.7	3.29	10.85	49.7	19.2	30.5
AUG	26.3	26.5	2.84	8.04	54.2	22.5	31.7
SEP	21.4	20.4	3.05	9.32	44.3	18.2	26.1
OCT	16.3	15.2	4.52	20.43	33.5	10.1	23.4
NOV	7.6	7.6	3.11	9.67	14.6	2.0	12.6
DEC	6.4	5.1	3.79	14.35	12.3	0.9	11.4
Mean Minimum Temperature							
JAN	0.3	0.5	1.66	2.74	5.8	-2.8	3.0
FEB	0.0	0.3	1.56	2.42	4.9	-2.4	2.5
MAR	1.2	1.3	1.60	2.54	4.6	-1.3	3.3
APR	2.6	1.6	2.69	7.25	7.0	-0.4	6.6
MAY	4.9	4.8	1.57	2.48	10.3	2.8	7.5
JUN	8.2	8.8	1.60	2.56	15.8	5.5	10.3
JUL	10.5	10.3	1.56	2.42	21.6	8.5	13.1
AUG	11.1	11.2	1.15	1.31	22.8	9.5	13.3
SEP	8.4	7.8	1.56	2.43	17.9	7.0	10.9
OCT	5.5	4.8	2.59	6.70	13.2	2.7	10.5
NOV	1.5	1.9	1.92	3.68	6.5	-2.3	4.2
DEC	-0.6	-0.7	2.86	8.20	8.4	-6.0	2.4

TABLE 34. Descriptive Statistics 1981-1990 at Lookout Creek

	MEAN	MEDIAN	STDEV	VAR	RANGE	MIN	MAX
Monthly Mean Temperature							
JAN	0.5	0.6	2.29	5.23	6.7	-2.7	4.0
FEB	0.6	1.2	2.05	4.22	6.5	-3.5	3.0
MAR	1.3	1.5	2.24	5.01	7.5	-3.2	4.3
APR	3.2	3.6	2.77	7.66	8.7	-0.3	8.4
MAY	6.9	7.1	2.19	4.78	15.1	3.7	11.4
JUN	11.4	11.1	2.33	5.41	22.5	7.9	14.6
JUL	14.1	14.6	2.09	4.37	27.4	10.0	17.4
AUG	14.0	14.0	1.44	2.09	28.5	11.8	16.7
SEP	10.3	10.3	1.44	2.07	20.8	8.2	12.6
OCT	6.7	6.0	2.51	6.28	15.9	4.2	11.7
NOV	2.3	2.3	2.42	5.84	7.0	-1.7	5.3
DEC	-0.1	-0.9	2.50	6.24	7.0	-3.4	3.6
Mean Maximum Temperature							
JAN	1.4	1.4	2.43	5.92	7.2	-1.9	5.3
FEB	2.0	2.1	2.52	6.34	9.2	-2.5	6.7
MAR	2.8	2.9	2.54	6.44	8.2	-1.6	6.6
APR	5.4	5.9	3.23	10.45	13.8	1.6	12.2
MAY	10.7	10.6	2.09	4.35	23.0	7.9	15.1
JUN	16.0	15.9	3.22	10.38	32.4	11.7	20.7
JUL	19.3	18.9	2.93	8.56	38.0	13.5	24.5
AUG	18.6	18.6	2.26	5.09	38.2	15.7	22.5
SEP	13.8	13.6	1.85	3.41	28.2	11.4	16.8
OCT	9.0	8.2	2.86	8.19	20.3	6.2	14.1
NOV	3.7	3.7	2.47	6.09	7.2	-0.1	7.1
DEC	1.0	0.2	2.39	5.70	6.5	-1.8	4.7
Mean Minimum Temperature							
JAN	-0.4	-0.5	2.16	4.65	6.2	-3.5	2.7
FEB	-0.7	-0.2	1.83	3.34	5.8	-4.1	1.7
MAR	0.0	0.3	2.06	4.26	7.1	-4.5	2.6
APR	1.4	1.6	2.50	6.27	7.5	-2.2	5.3
MAY	4.0	4.0	2.14	4.58	9.2	0.8	8.4
JUN	7.6	7.5	1.83	3.35	15.0	4.8	10.2
JUL	9.9	10.2	1.73	3.01	18.8	7.0	11.8
AUG	10.2	10.4	1.13	1.28	20.3	8.1	12.2
SEP	7.3	7.4	1.38	1.92	14.3	5.1	9.2
OCT	4.5	3.6	2.50	6.24	11.7	2.0	9.7
NOV	1.0	1.0	2.44	5.98	7.3	-3.4	3.9
DEC	-1.3	-1.9	2.70	7.29	7.4	-4.9	2.5

TABLE 35. Descriptive Statistics 1981-1990 at Mack Creek

	MEAN	MEDIAN	STDEV	VAR	RANGE	MIN	MAX
Monthly Mean Temperature							
JAN	2.2	2.3	1.68	2.81	5.1	-0.3	4.8
FEB	1.9	2.0	1.23	1.52	4.4	-0.4	4.0
MAR	3.3	3.3	1.69	2.85	6.1	0.3	5.8
APR	5.2	4.9	2.31	5.32	11.3	1.9	9.4
MAY	8.9	9.0	1.59	2.52	18.5	6.7	11.8
JUN	12.8	12.9	1.93	3.72	26.1	10.1	16.0
JUL	15.3	15.0	1.91	3.64	30.3	12.5	17.8
AUG	15.4	15.3	1.42	2.03	31.0	13.3	17.7
SEP	11.7	11.2	1.63	2.67	22.9	9.1	13.8
OCT	8.3	7.8	2.25	5.08	18.5	5.6	12.9
NOV	3.7	3.8	2.18	4.76	7.2	-0.5	6.7
DEC	1.5	1.3	2.52	6.33	7.9	-2.8	5.1
Mean Maximum Temperature							
JAN	3.0	2.9	1.88	3.54	6.3	0.3	6.0
FEB	2.8	2.8	1.35	1.83	5.4	0.3	5.1
MAR	4.6	4.7	1.99	3.95	8.7	1.1	7.6
APR	7.2	7.0	2.77	7.69	16.5	3.7	12.8
MAY	12.8	12.4	1.90	3.60	25.9	9.8	16.1
JUN	17.5	18.0	2.52	6.34	35.2	14.1	21.1
JUL	20.4	20.5	2.71	7.34	39.8	15.8	24.0
AUG	19.9	19.3	1.72	2.96	41.1	18.2	22.9
SEP	14.2	13.8	1.80	3.22	27.9	11.1	16.8
OCT	10.0	9.3	2.36	5.56	21.4	7.0	14.4
NOV	4.9	5.2	2.16	4.66	8.5	0.9	7.6
DEC	2.5	2.2	2.46	6.04	7.5	-1.3	6.2
Mean Minimum Temperature							
JAN	1.2	1.4	1.50	2.25	4.5	-1.1	3.4
FEB	0.9	1.1	1.23	1.52	4.2	-1.3	2.9
MAR	2.0	2.0	1.48	2.19	4.8	-0.8	4.0
APR	3.4	2.8	2.09	4.35	7.3	0.4	6.9
MAY	6.3	6.5	1.59	2.54	13.4	4.1	9.3
JUN	9.7	9.6	1.87	3.51	20.2	7.2	13.0
JUL	12.0	11.3	1.76	3.10	24.5	10.1	14.4
AUG	12.4	12.7	1.42	2.01	24.7	10.3	14.4
SEP	9.4	9.0	1.66	2.74	18.9	7.1	11.8
OCT	6.6	5.9	2.37	5.64	15.5	4.0	11.5
NOV	2.5	2.6	2.25	5.08	7.7	-2.1	5.6
DEC	0.4	0.2	2.63	6.93	8.2	-4.3	3.9

TABLE 36. Descriptive Statistics 1981-1990 at McRae Creek

	MEAN	MEDIAN	STDEV	VAR	RANGE	MIN	MAX
Monthly Mean Temperature							
JAN	0.8	1.0	1.45	2.10	4.2	-0.9	3.3
FEB	0.6	0.9	1.70	2.91	6.0	-2.6	3.4
MAR	2.8	2.6	1.87	3.51	6.2	0.4	5.8
APR	4.9	4.7	2.58	6.67	12.0	1.6	10.4
MAY	8.4	7.7	2.09	4.38	17.2	4.9	12.3
JUN	12.9	13.9	1.99	3.94	25.2	10.2	15.0
JUL	15.3	15.2	2.42	5.83	30.3	11.1	19.2
AUG	15.2	15.2	1.38	1.90	30.6	13.2	17.4
SEP	11.4	10.8	2.17	4.70	25.0	9.0	16.0
OCT	7.4	6.1	3.39	11.52	19.7	4.1	15.6
NOV	3.1	2.5	2.42	5.85	8.2	0.2	8.0
DEC	1.0	0.5	2.88	8.31	10.6	-3.2	7.4
Mean Maximum Temperature							
JAN	2.4	2.5	1.69	2.85	5.7	0.4	5.3
FEB	2.6	3.0	1.69	2.87	5.7	-0.1	5.6
MAR	5.8	6.0	2.38	5.65	12.7	3.0	9.7
APR	9.6	9.1	3.15	9.94	23.2	6.2	17.0
MAY	15.0	15.7	2.94	8.62	27.8	8.3	19.5
JUN	21.5	22.2	2.91	8.50	42.9	17.6	25.3
JUL	24.9	24.6	3.63	13.17	49.0	17.9	31.1
AUG	23.9	23.7	2.23	4.99	49.0	21.1	27.9
SEP	17.0	16.4	2.26	5.10	34.1	14.2	19.9
OCT	11.1	9.9	3.96	15.72	23.2	5.3	17.9
NOV	4.9	4.6	2.26	5.09	10.6	2.1	8.5
DEC	2.4	2.1	2.87	8.22	10.0	-1.4	8.6
Mean Minimum Temperature							
JAN	-0.5	-0.5	1.30	1.69	4.1	-2.2	1.9
FEB	-0.9	-0.8	1.77	3.14	6.2	-4.4	1.8
MAR	0.8	0.9	1.55	2.41	4.9	-1.5	3.4
APR	2.0	1.6	2.26	5.11	7.7	-1.6	6.1
MAY	4.2	3.3	2.02	4.09	9.7	1.6	8.1
JUN	7.6	7.5	1.75	3.06	15.2	5.3	9.9
JUL	10.0	9.4	2.74	7.49	22.9	7.0	15.9
AUG	10.1	9.7	1.92	3.70	22.3	7.9	14.4
SEP	7.5	7.0	2.67	7.12	18.1	4.4	13.7
OCT	4.5	3.0	3.68	13.56	15.8	1.7	14.1
NOV	1.5	0.7	2.73	7.45	9.4	-1.8	7.6
DEC	-0.4	-1.0	2.98	8.90	11.5	-5.1	6.4

APPENDIX B

MAPS OF MONTHLY TEMPERATURE, 1981-1990

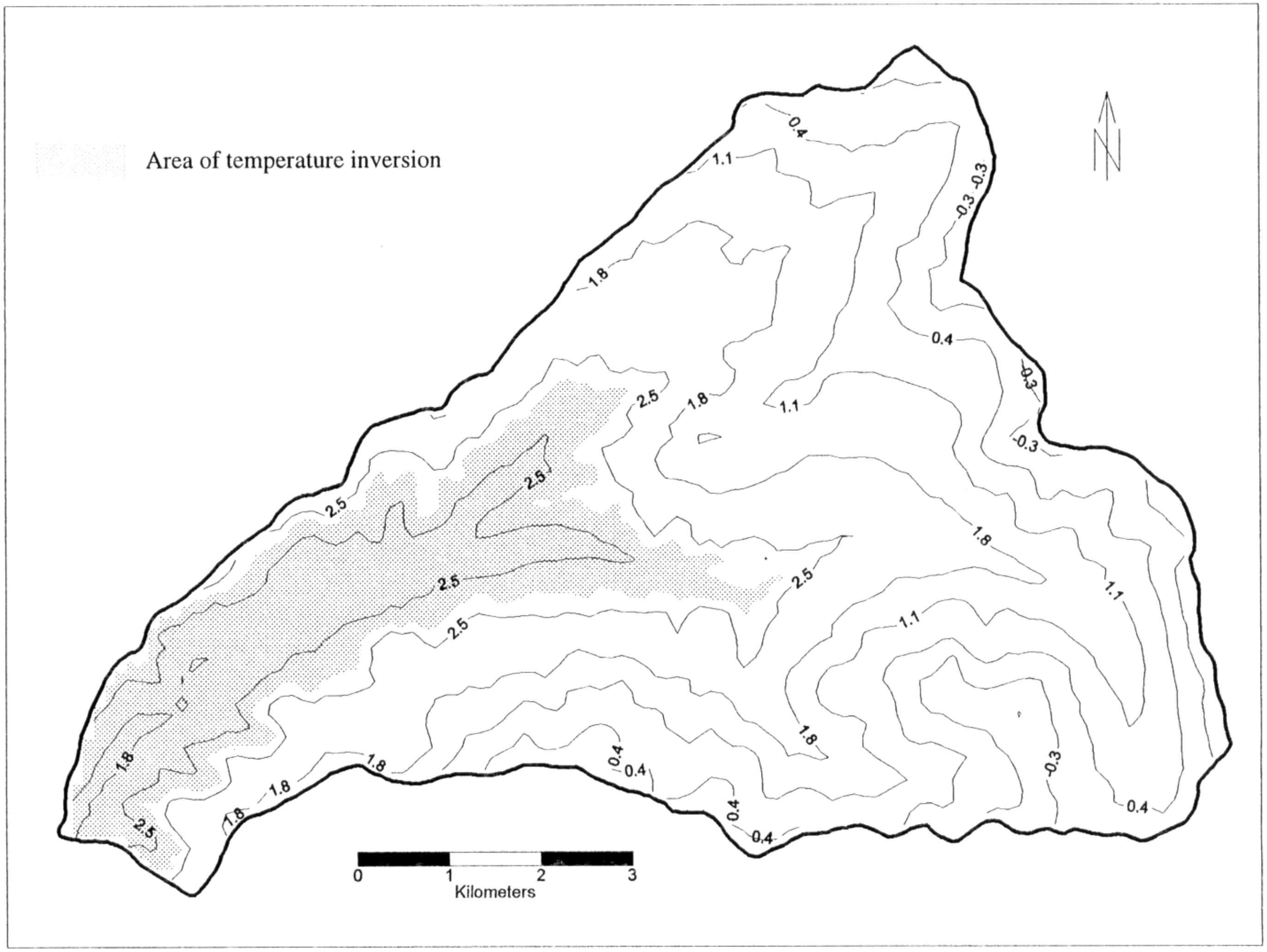

FIGURE 23. Mean January Temperature, 1981-1990 (Contour Interval 0.7° C)

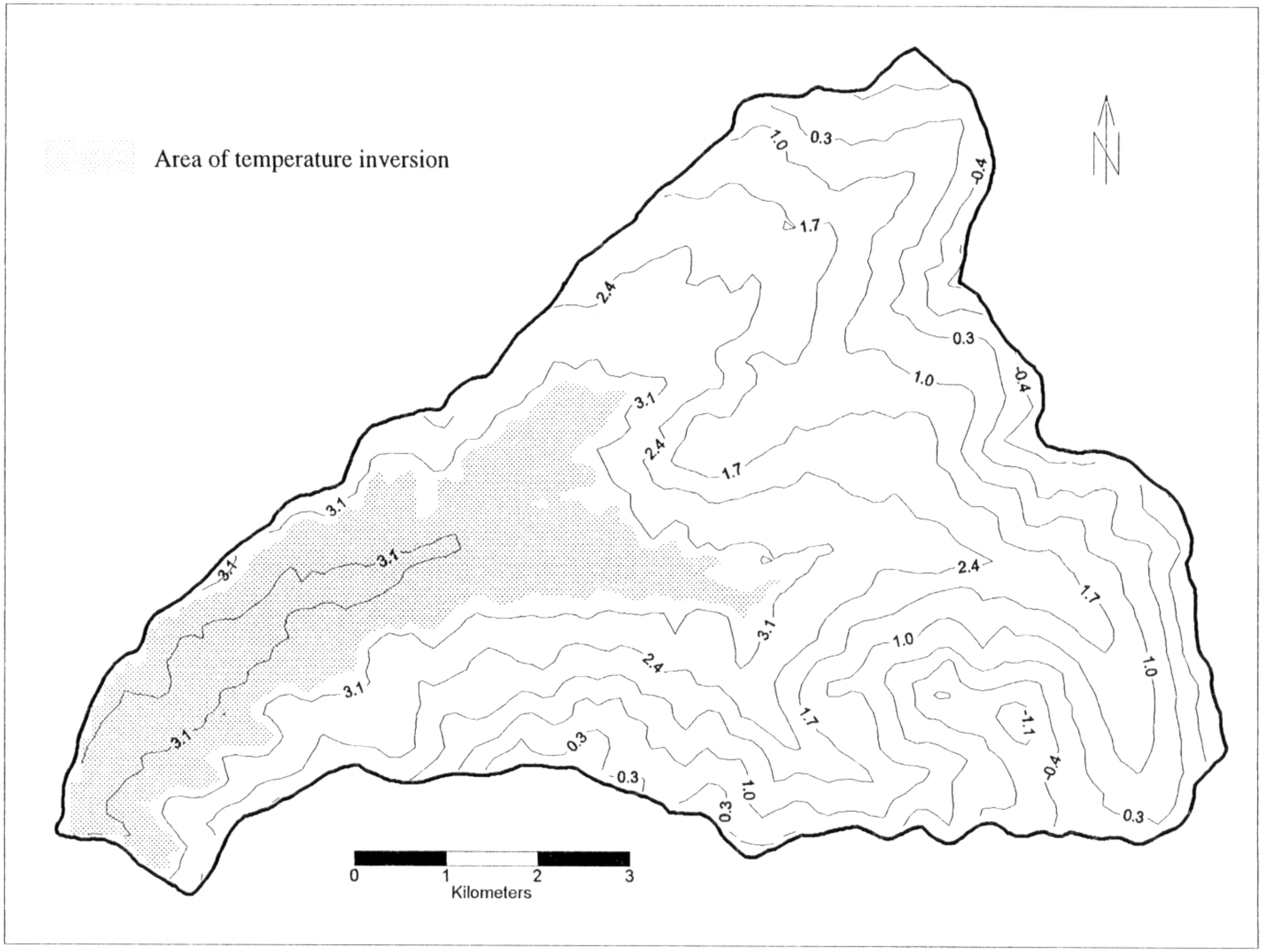

FIGURE 24. Mean February Temperature, 1981-1990 (Contour Interval 0.7° C)

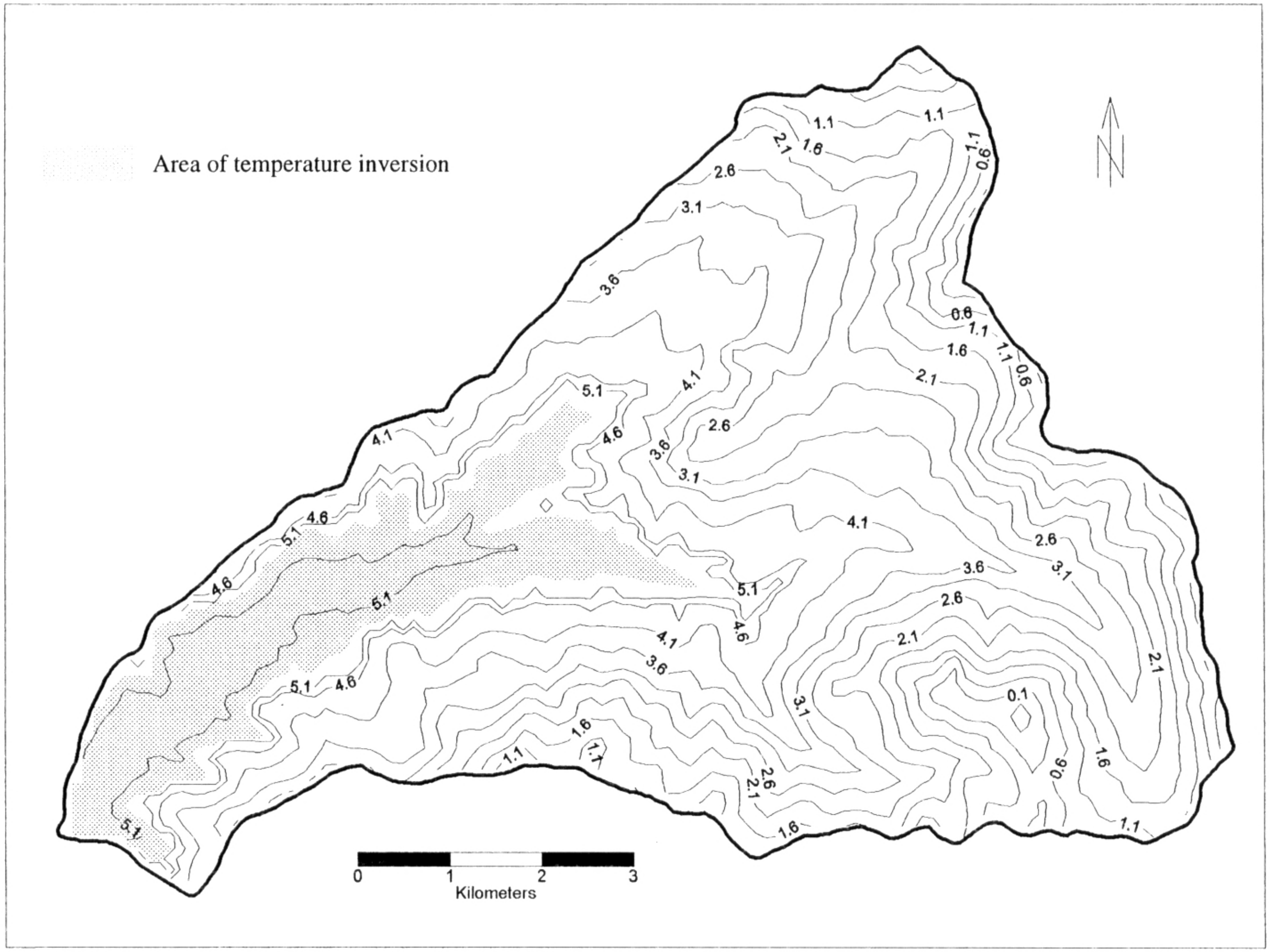

FIGURE 25. Mean March Temperature, 1981-1990 (Contour Interval 0.5° C)

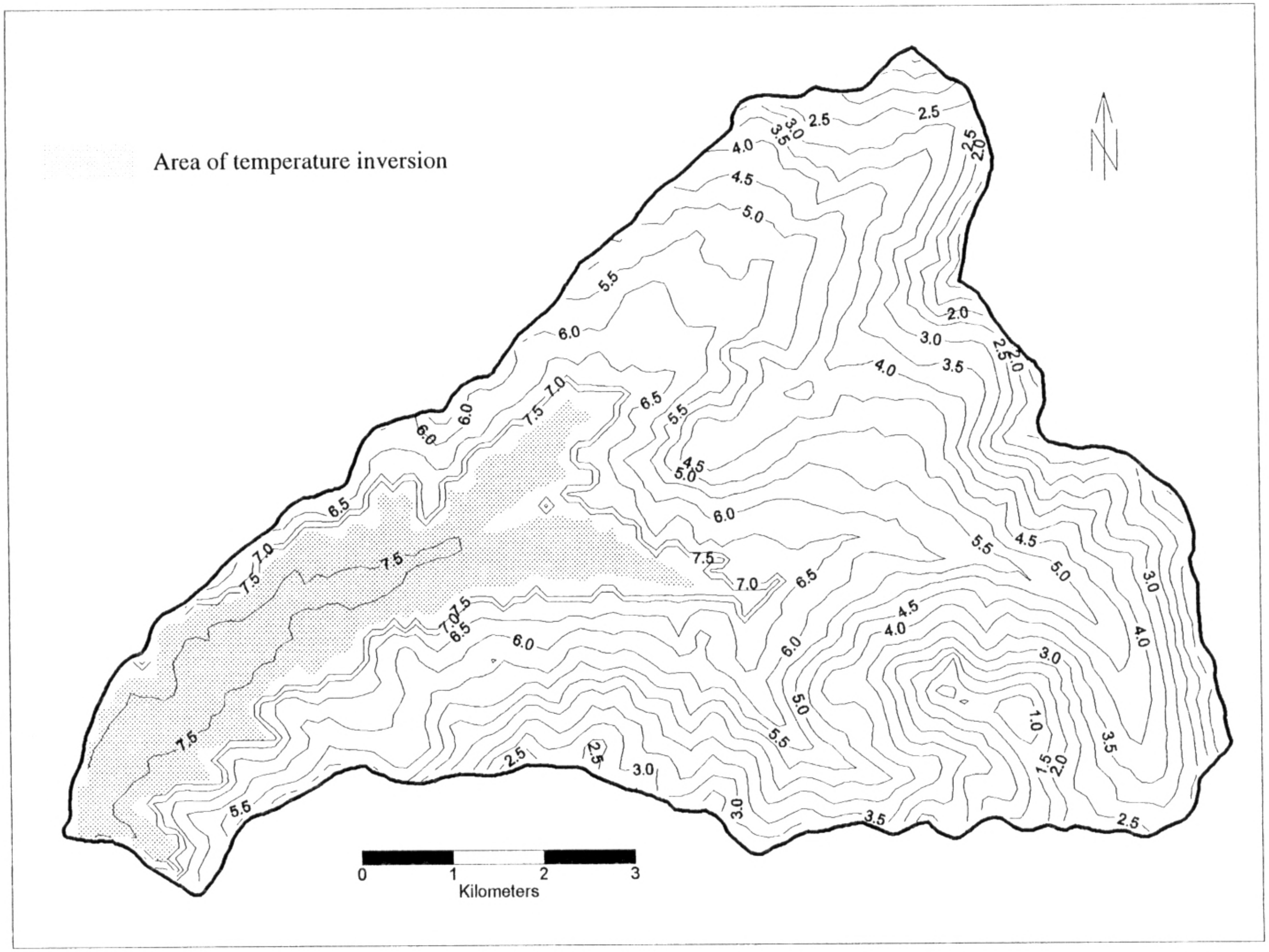

FIGURE 26. Mean April Temperature, 1981-1990 (Contour Interval 0.5° C)

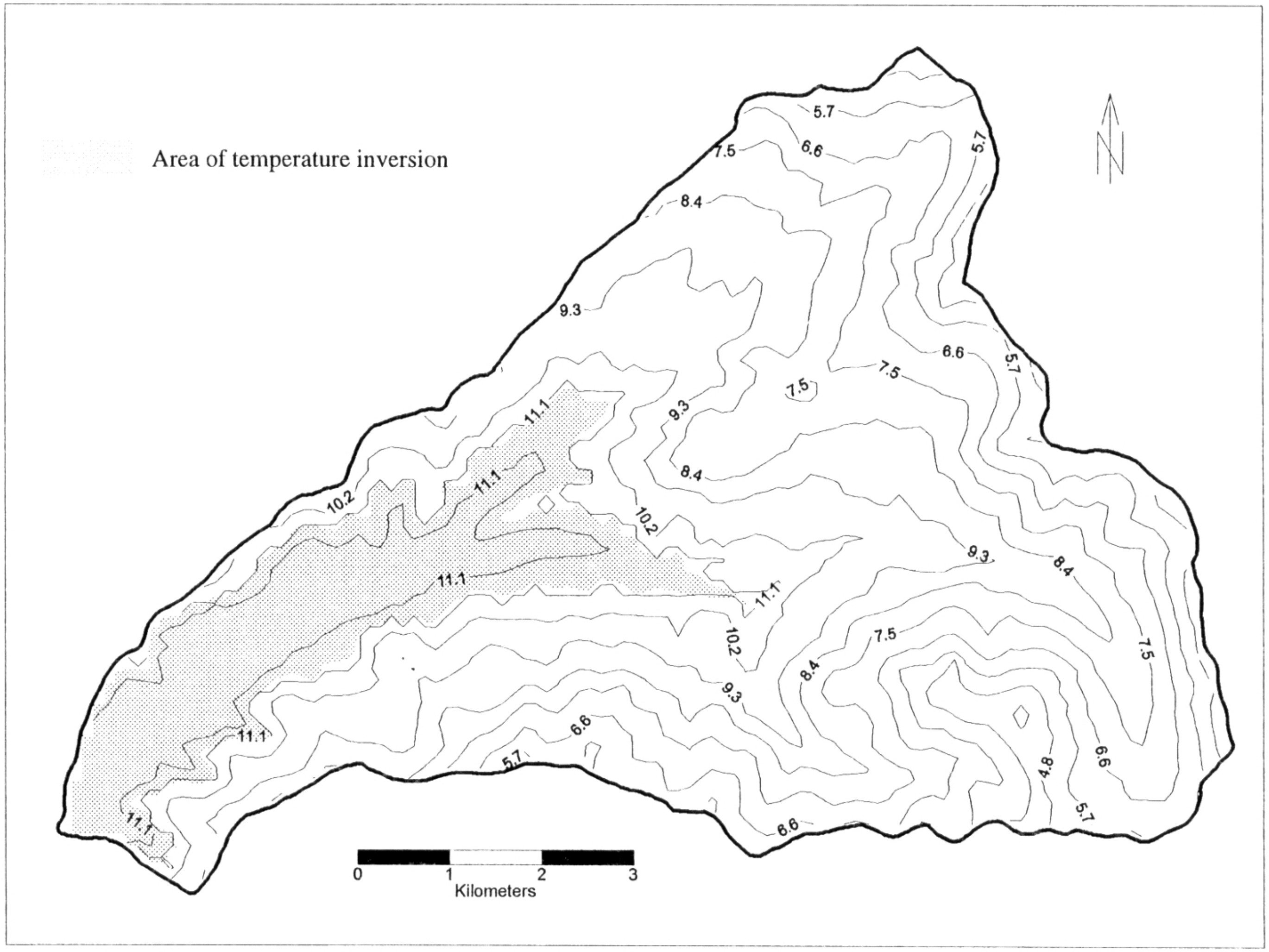

FIGURE 27. Mean May Temperature, 1981-1990 (Contour Interval 0.9° C)

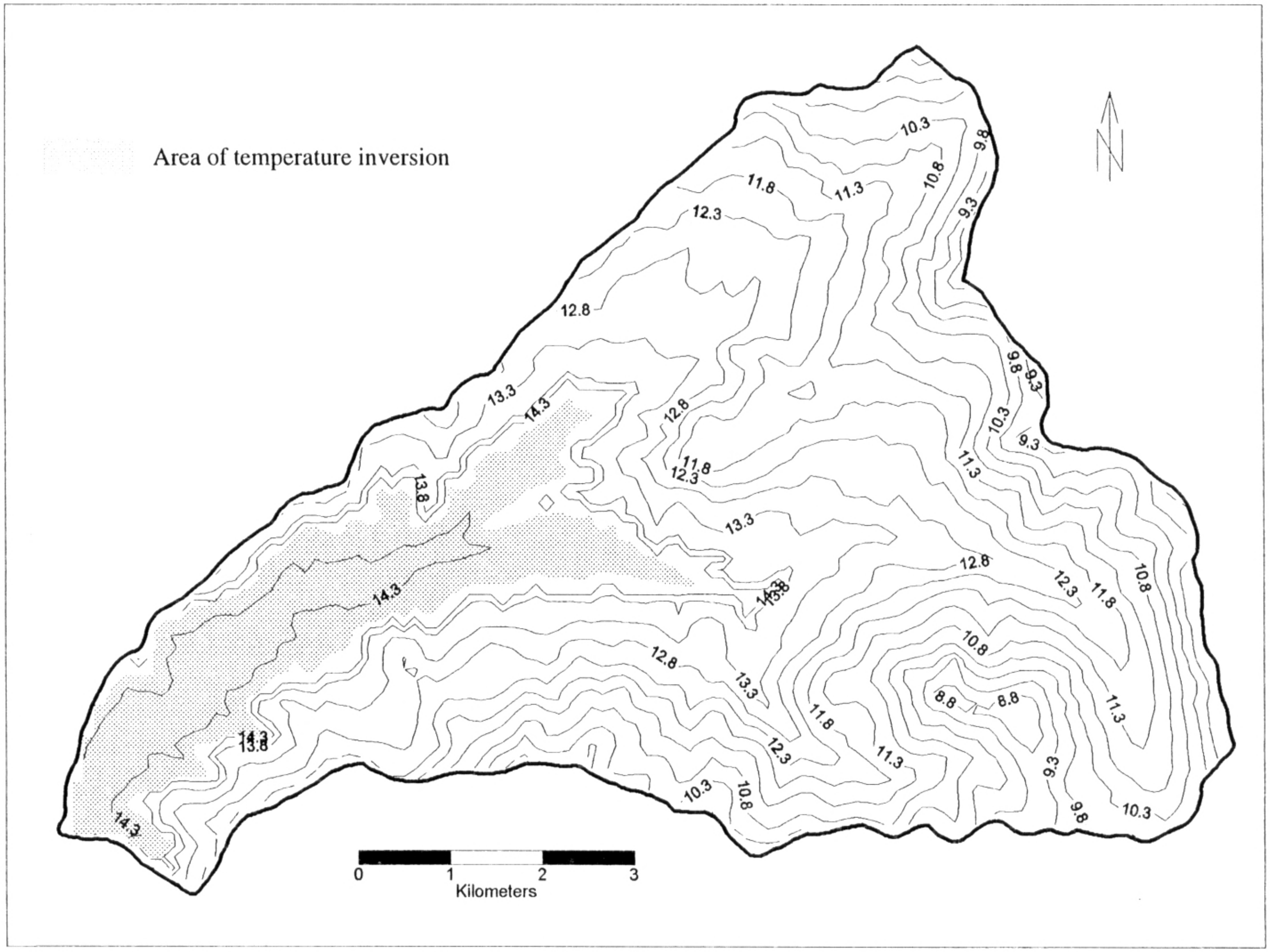

FIGURE 28. Mean June Temperature, 1981-1990 (Contour Interval 0.5° C)

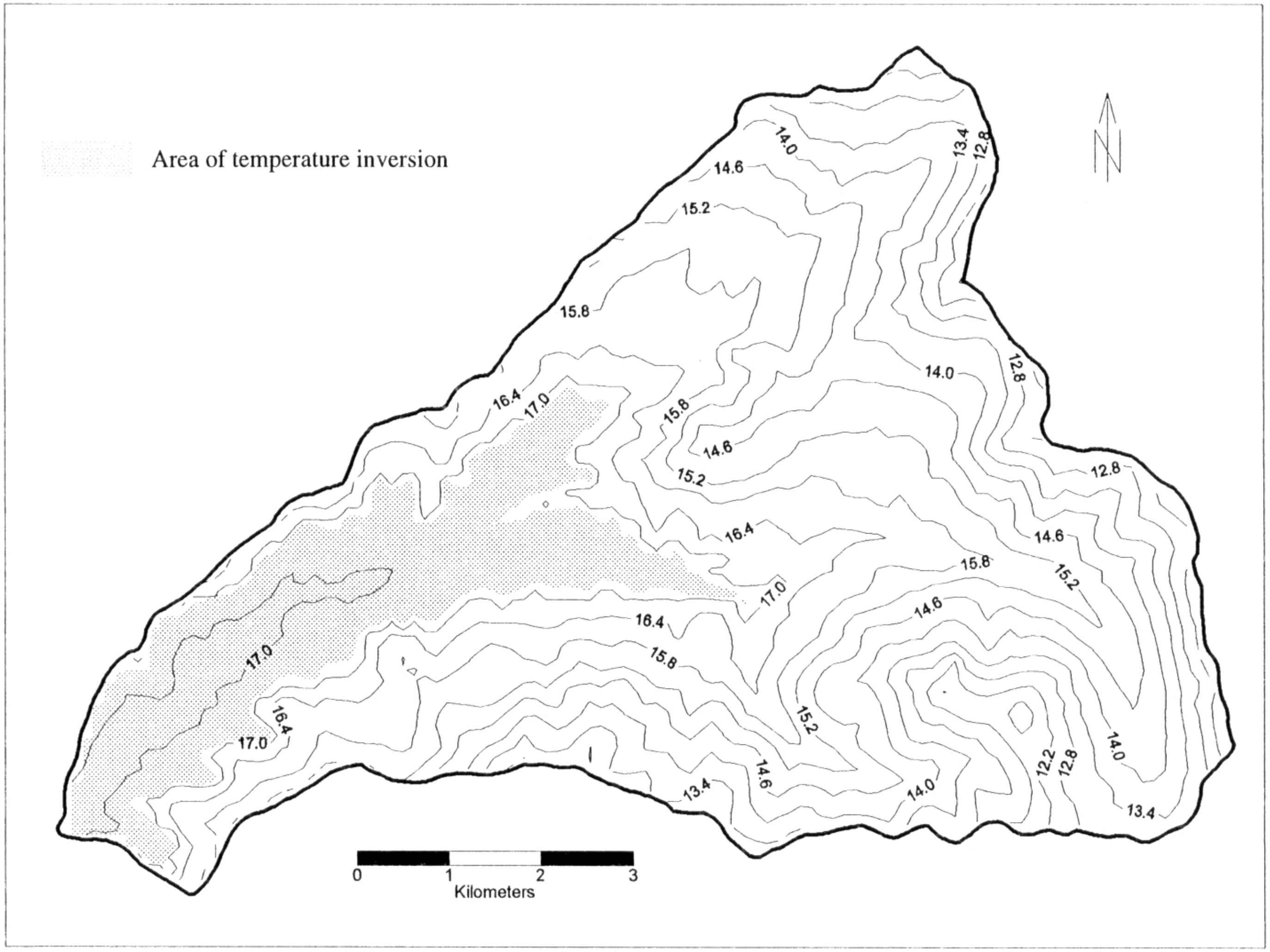

FIGURE 29. Mean July Temperature, 1981-1990 (Contour Interval 0.6° C)

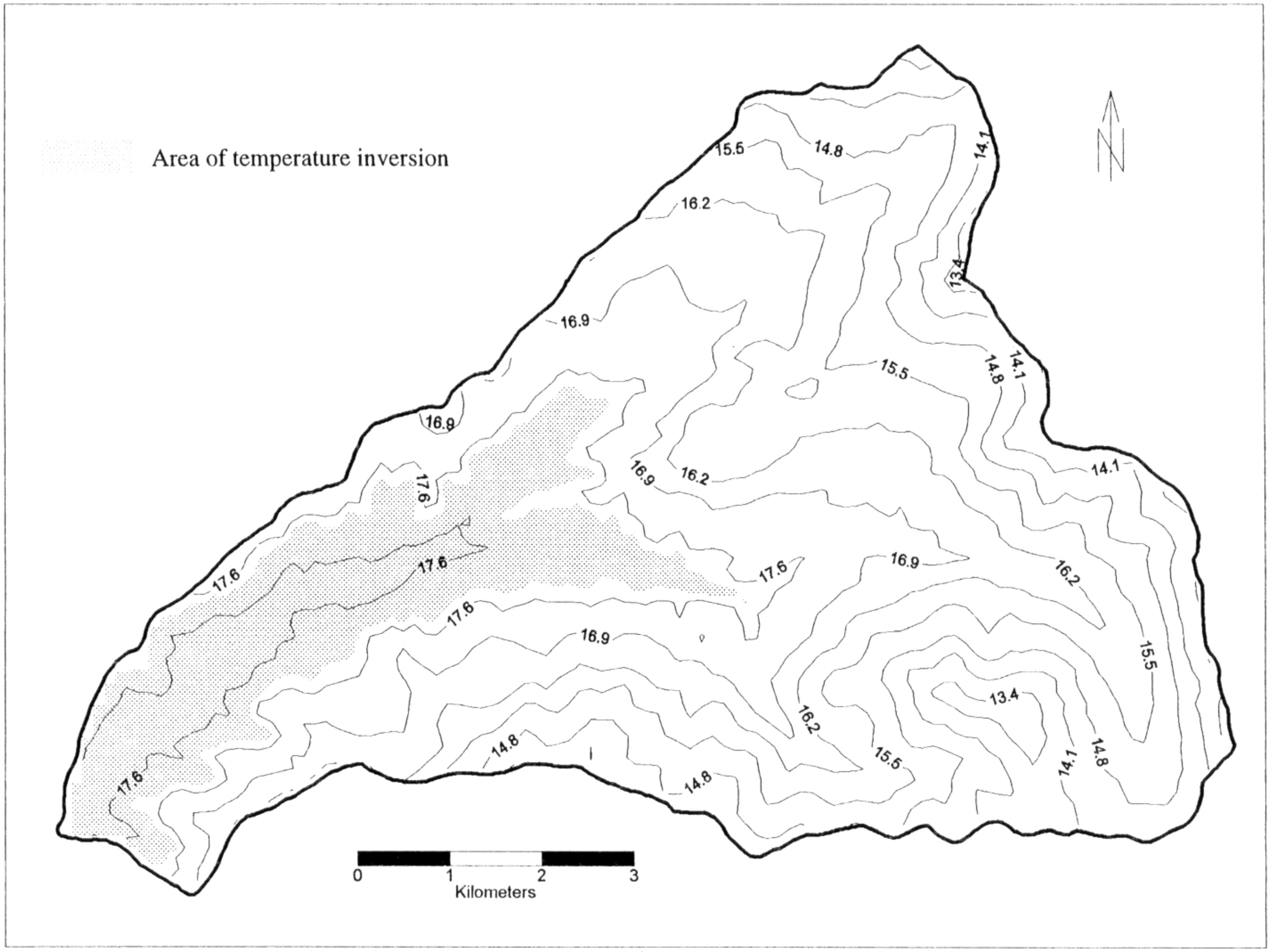

FIGURE 30. Mean August Temperature, 1981-1990 (Contour Interval 0.7° C)

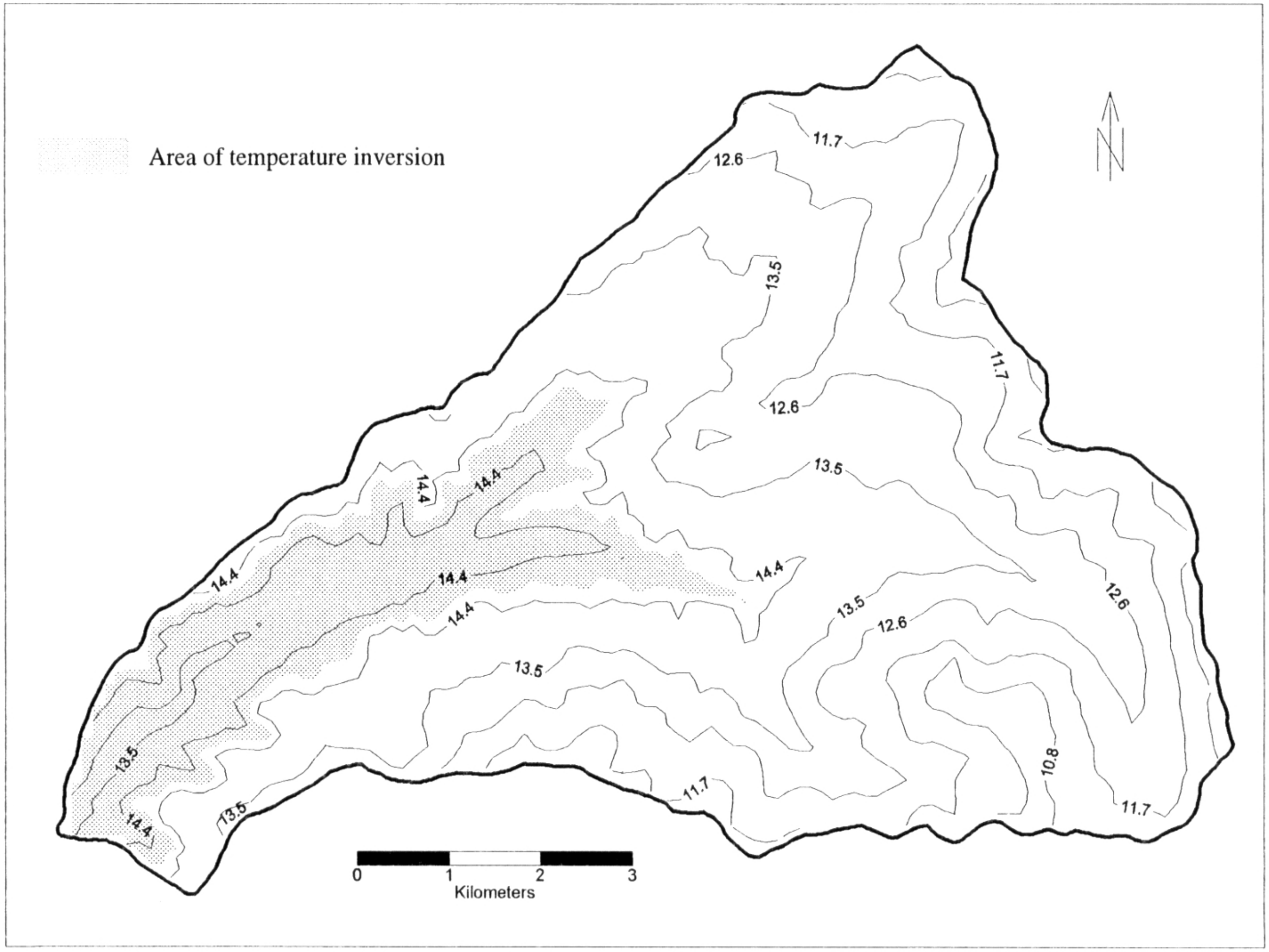

FIGURE 31. Mean September Temperature, 1981-1990 (Contour Interval 0.9° C)

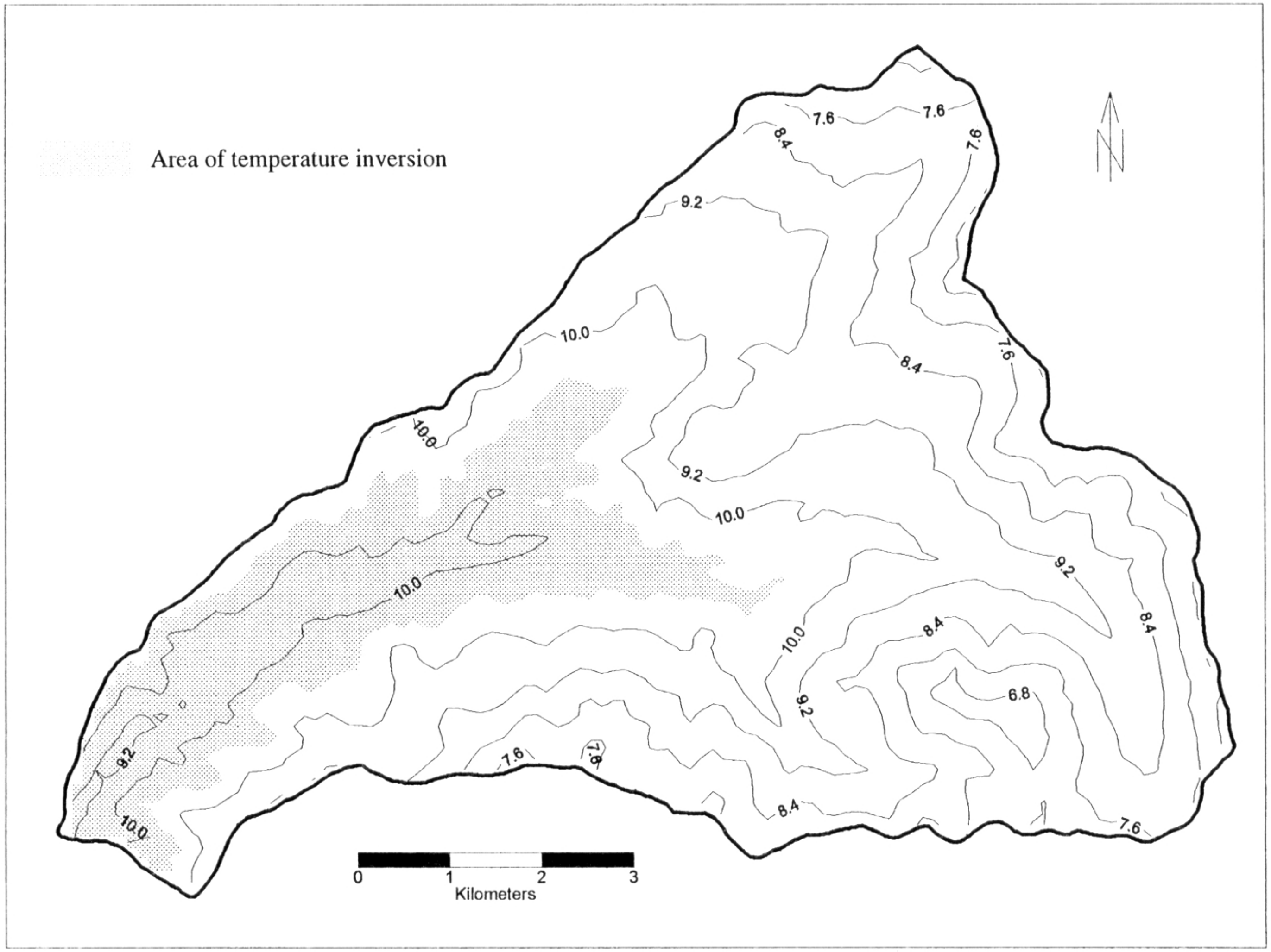

FIGURE 32. Mean October Temperature, 1981-1990 (Contour Interval 0.8° C)

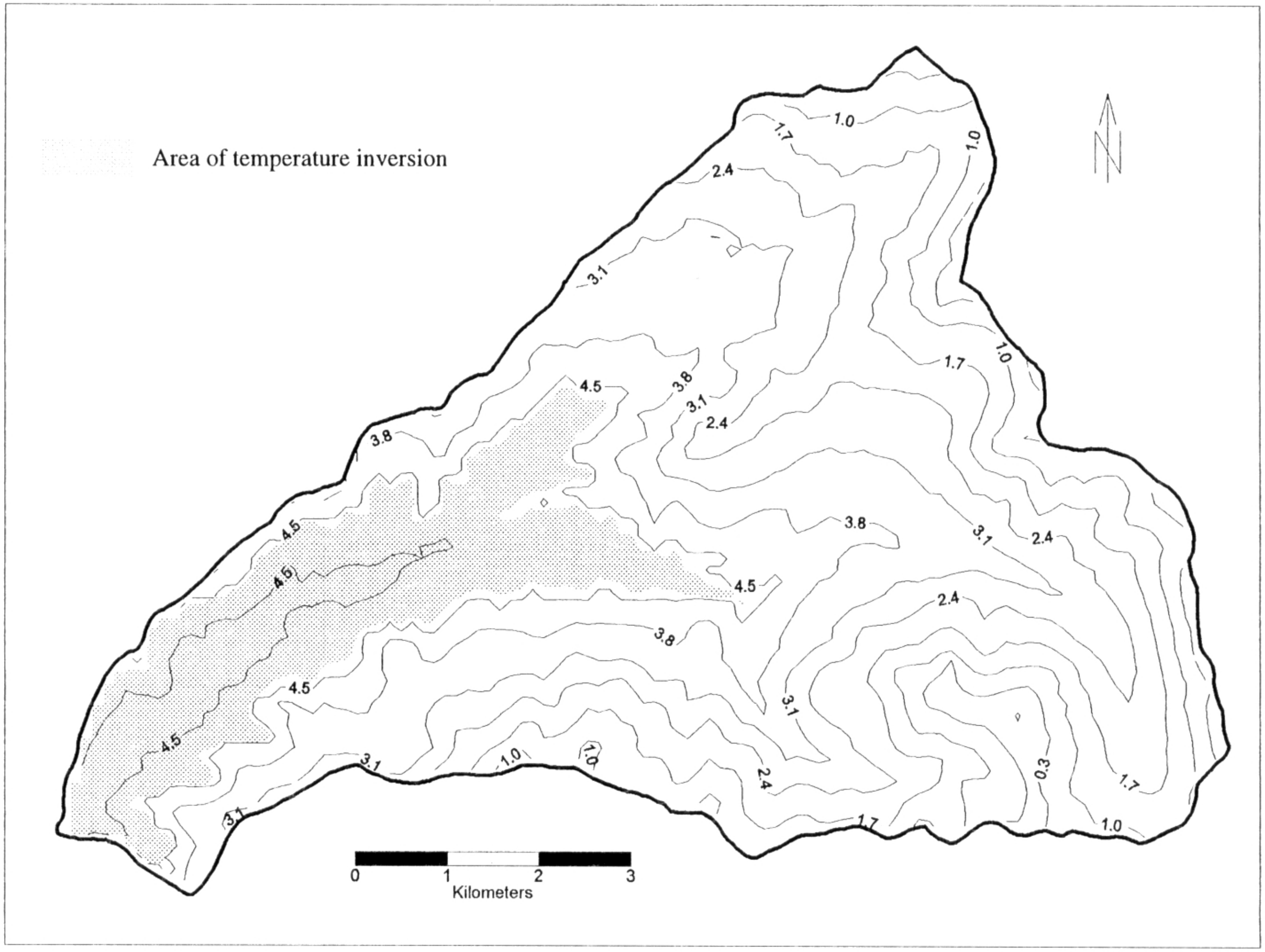

FIGURE 33. Mean November Temperature, 1981-1990 (Contour Interval 0.7° C)

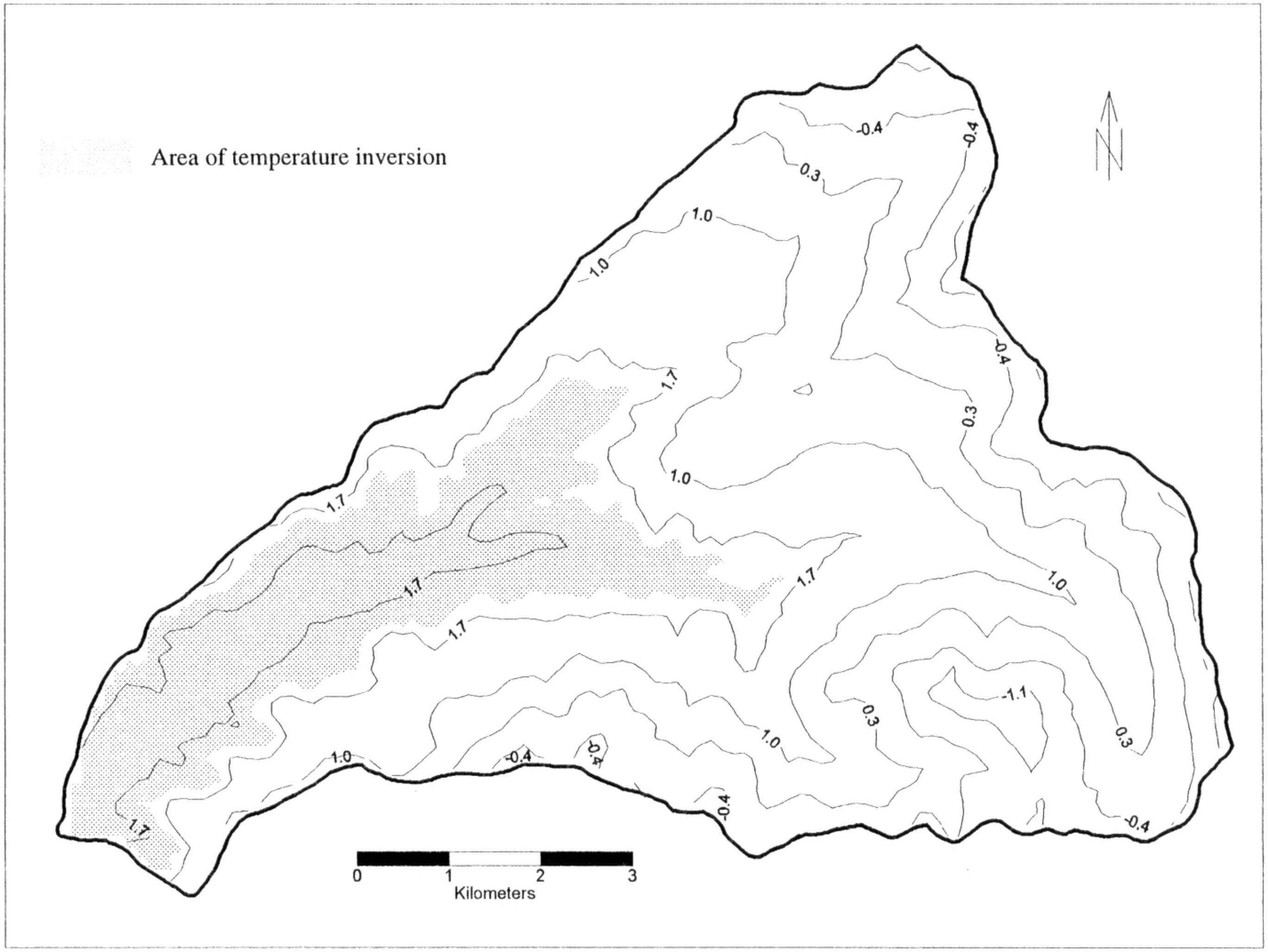

FIGURE 34. Mean December Temperature, 1981-1990 (Contour Interval 0.7° C)

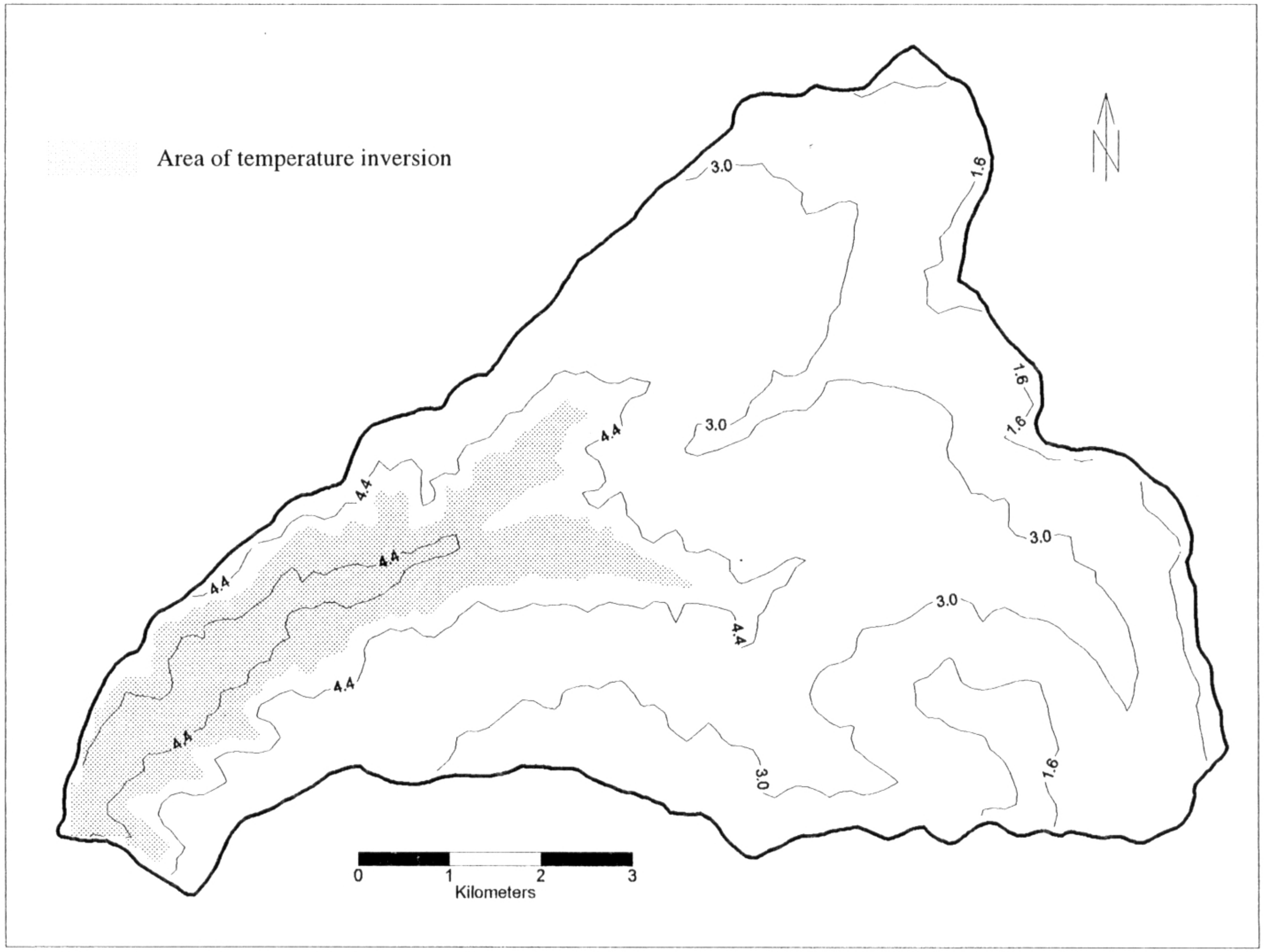

FIGURE 35. January Mean Maximum Temperature, 1981-1990 (Contour Interval 1.4° C)

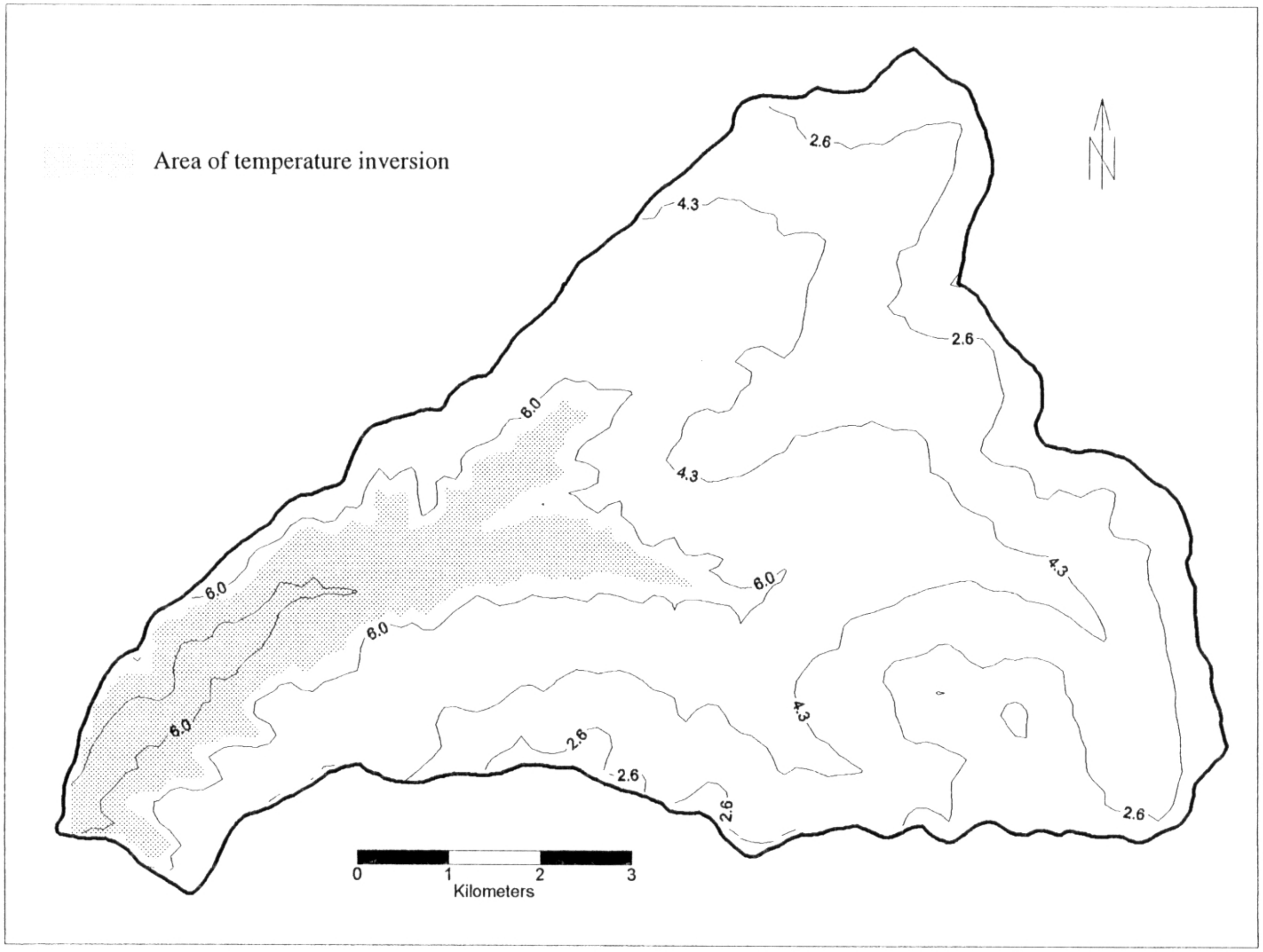

FIGURE 36. February Mean Maximum Temperature, 1981-1990 (Contour Interval 1.7° C)

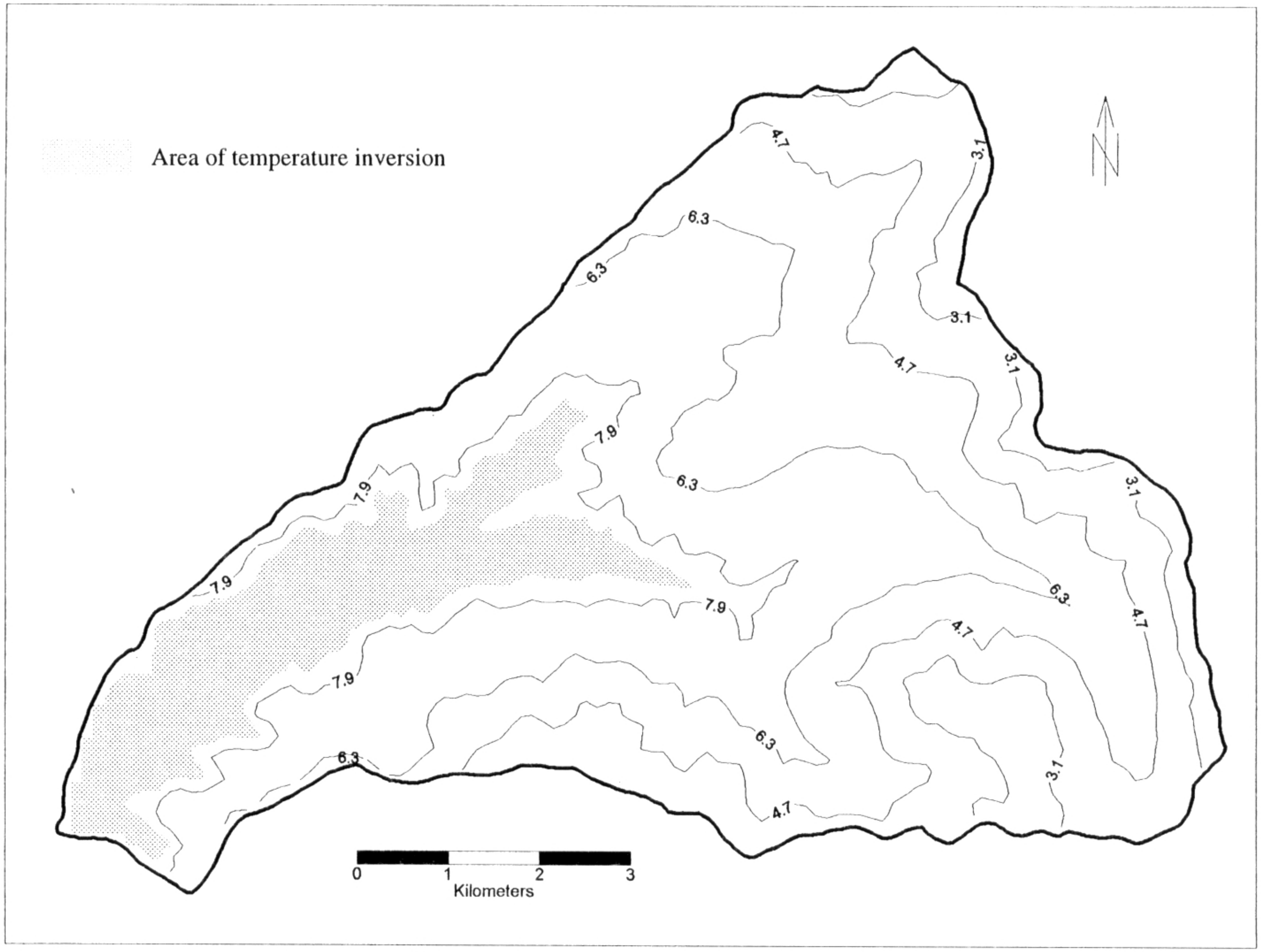

FIGURE 37. March Mean Maximum Temperature, 1981-1990 (Contour Interval 1.6° C)

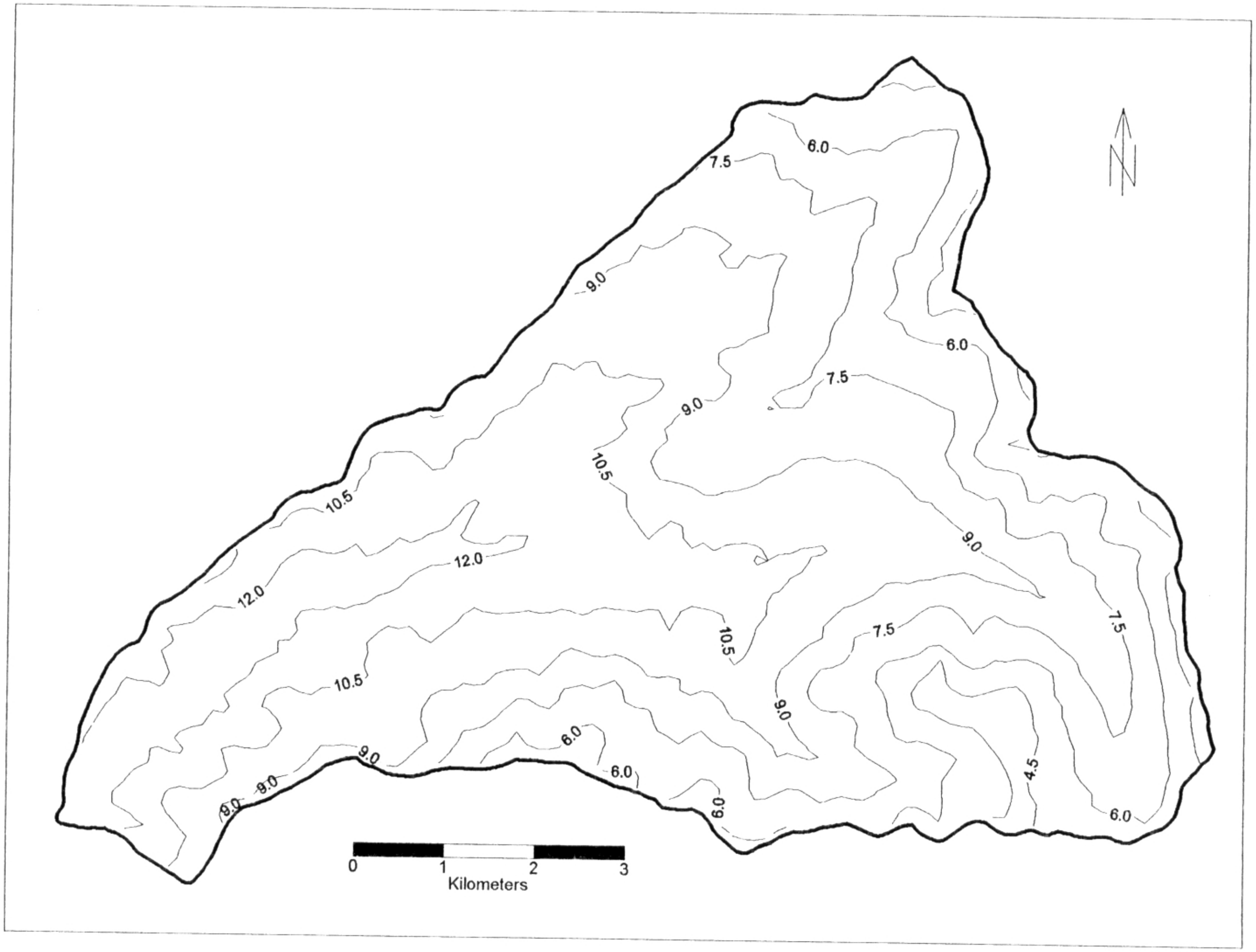

FIGURE 38. April Mean Maximum Temperature, 1981-1990 (Contour Interval 1.5° C)

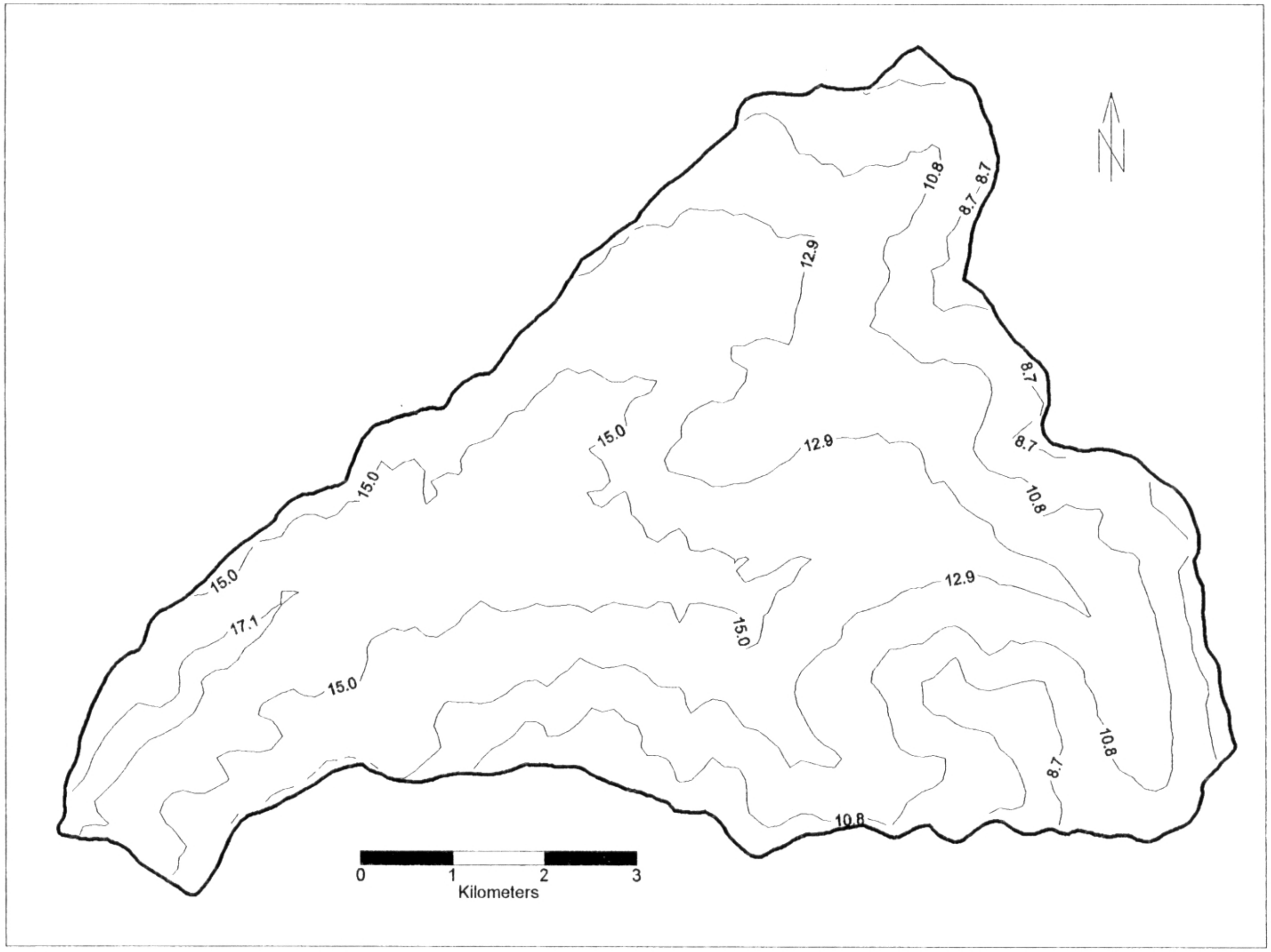

FIGURE 39. May Mean Maximum Temperature, 1981-1990 (Contour Interval 2.1° C)

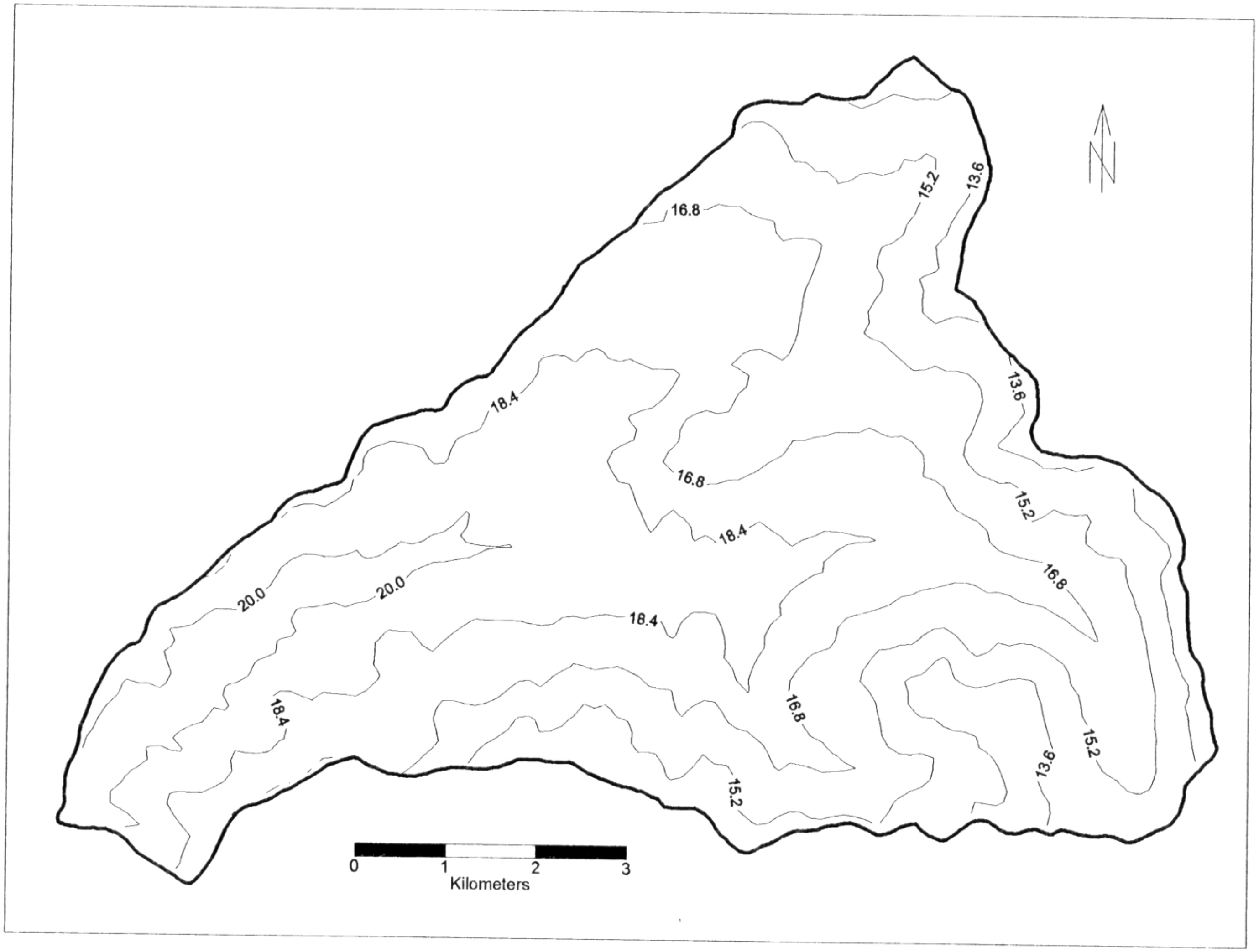

FIGURE 40. June Mean Maximum Temperature, 1981-1990 (Contour Interval 1.6° C)

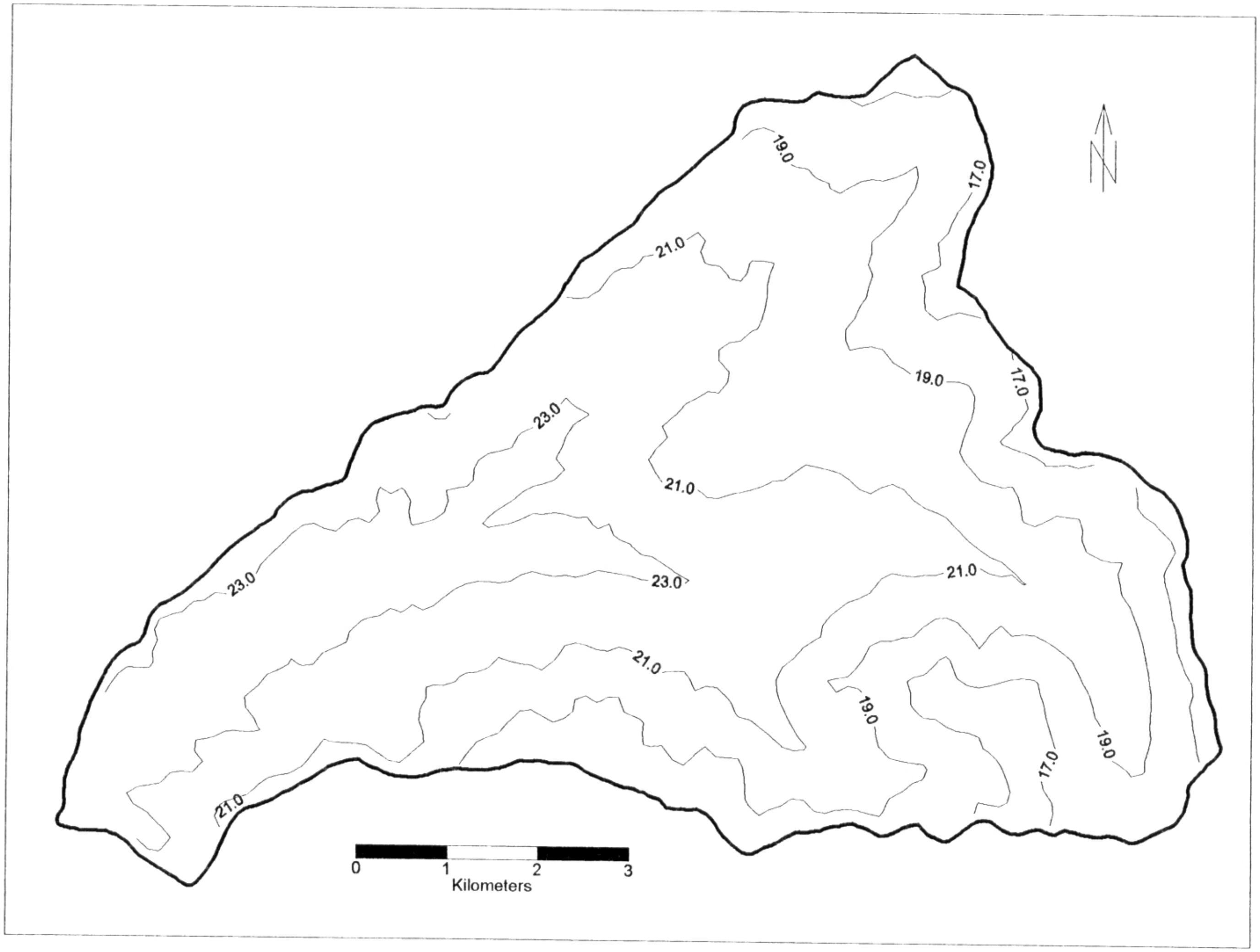

FIGURE 41. July Mean Maximum Temperature, 1981-1990 (Contour Interval 2.0° C)

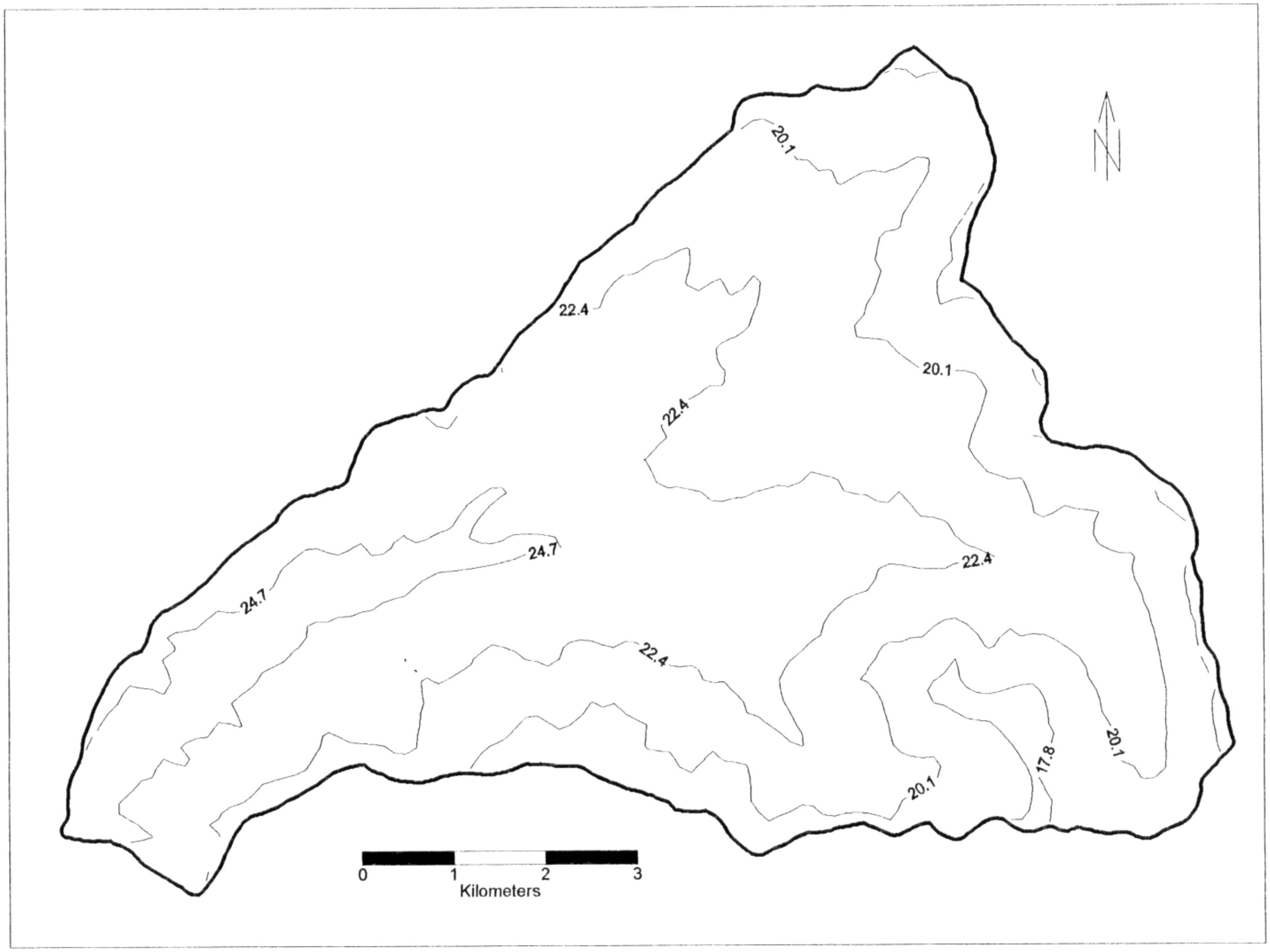

FIGURE 42. August Mean Maximum Temperature, 1981-1990 (Contour Interval 2.3° C)

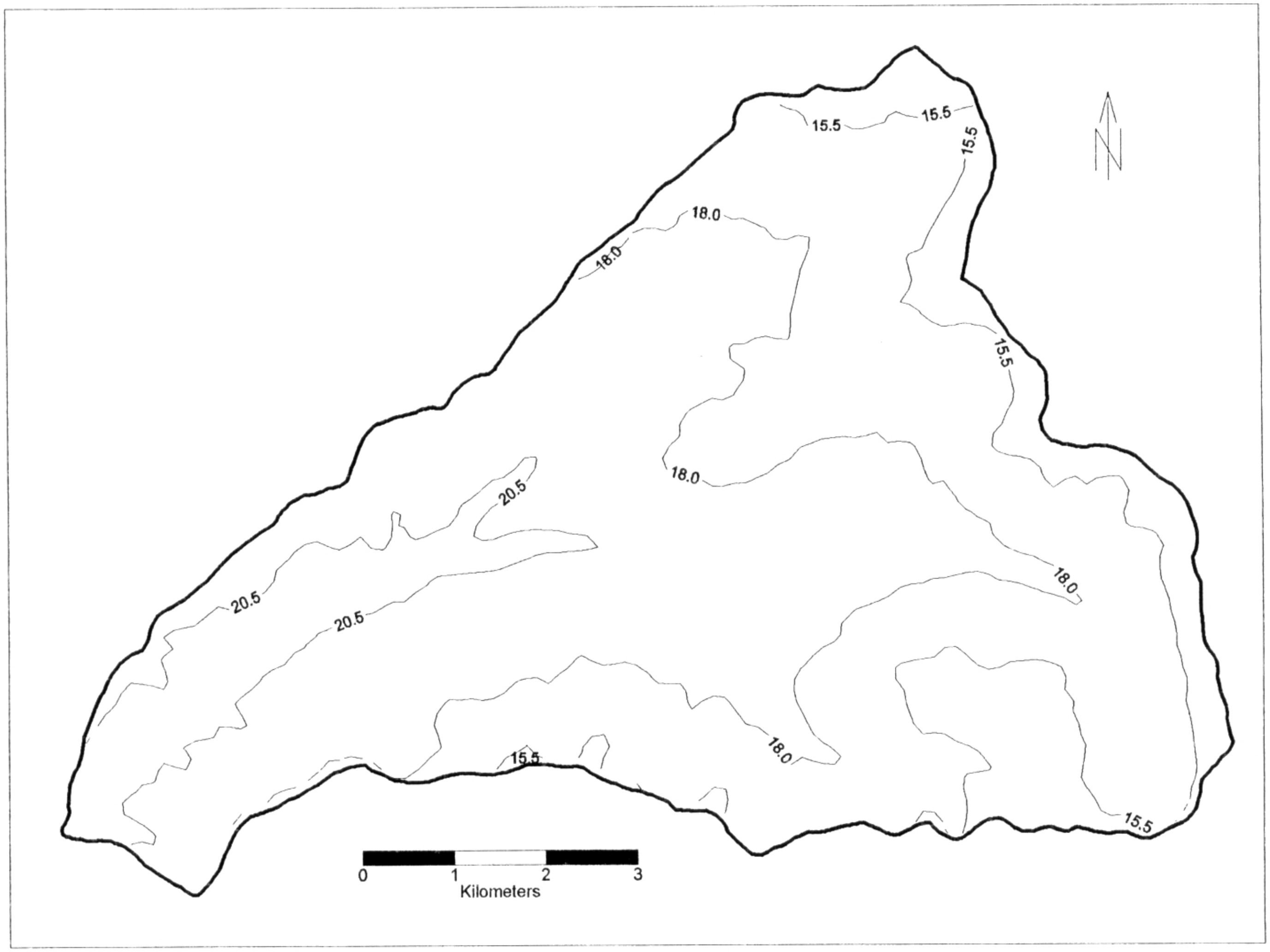

FIGURE 43. September Mean Maximum Temperature, 1981-1990 (Contour Interval 2.5° C)

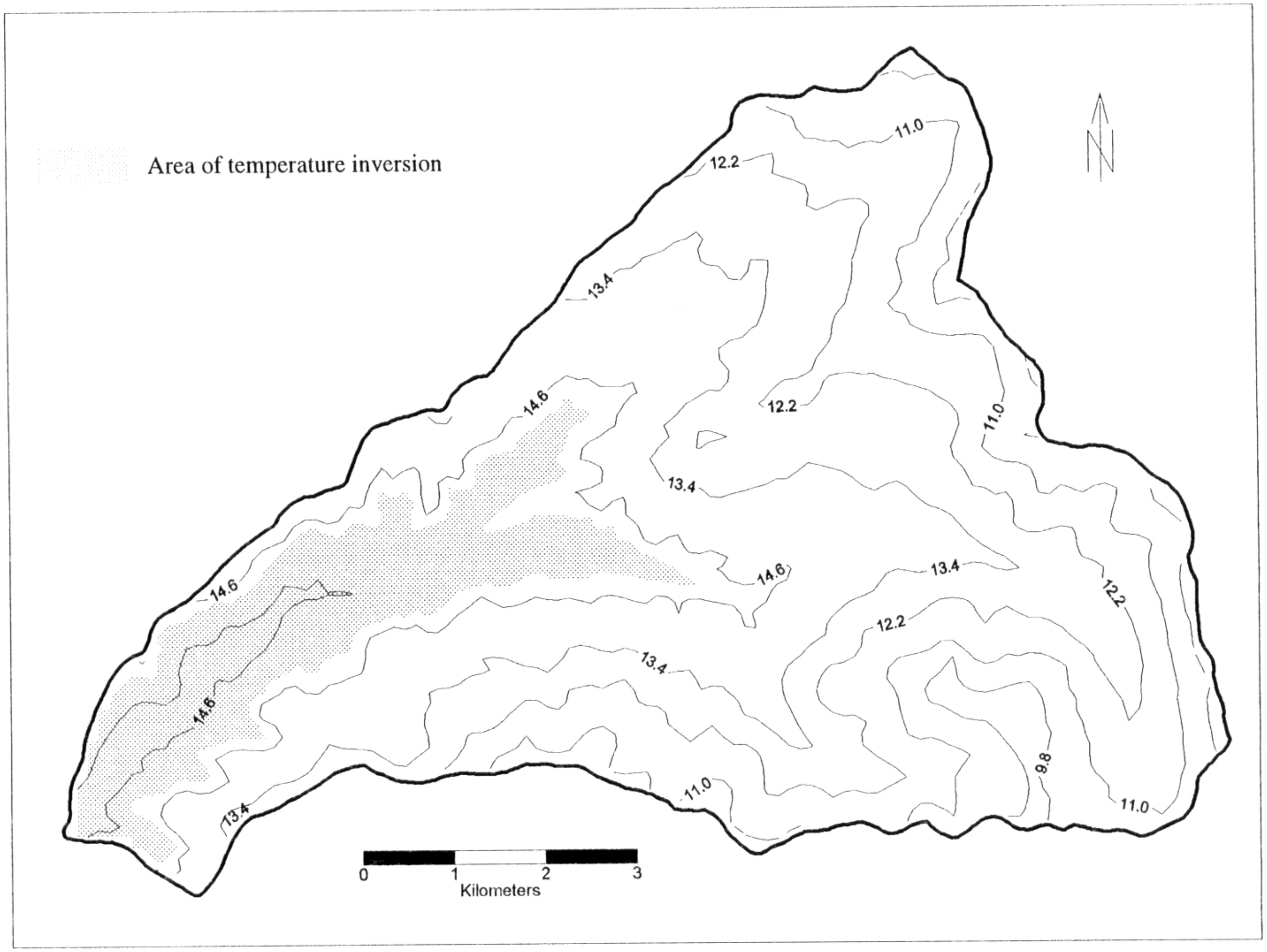

FIGURE 44. October Mean Maximum Temperature, 1981-1990 (Contour Interval 1.2° C)

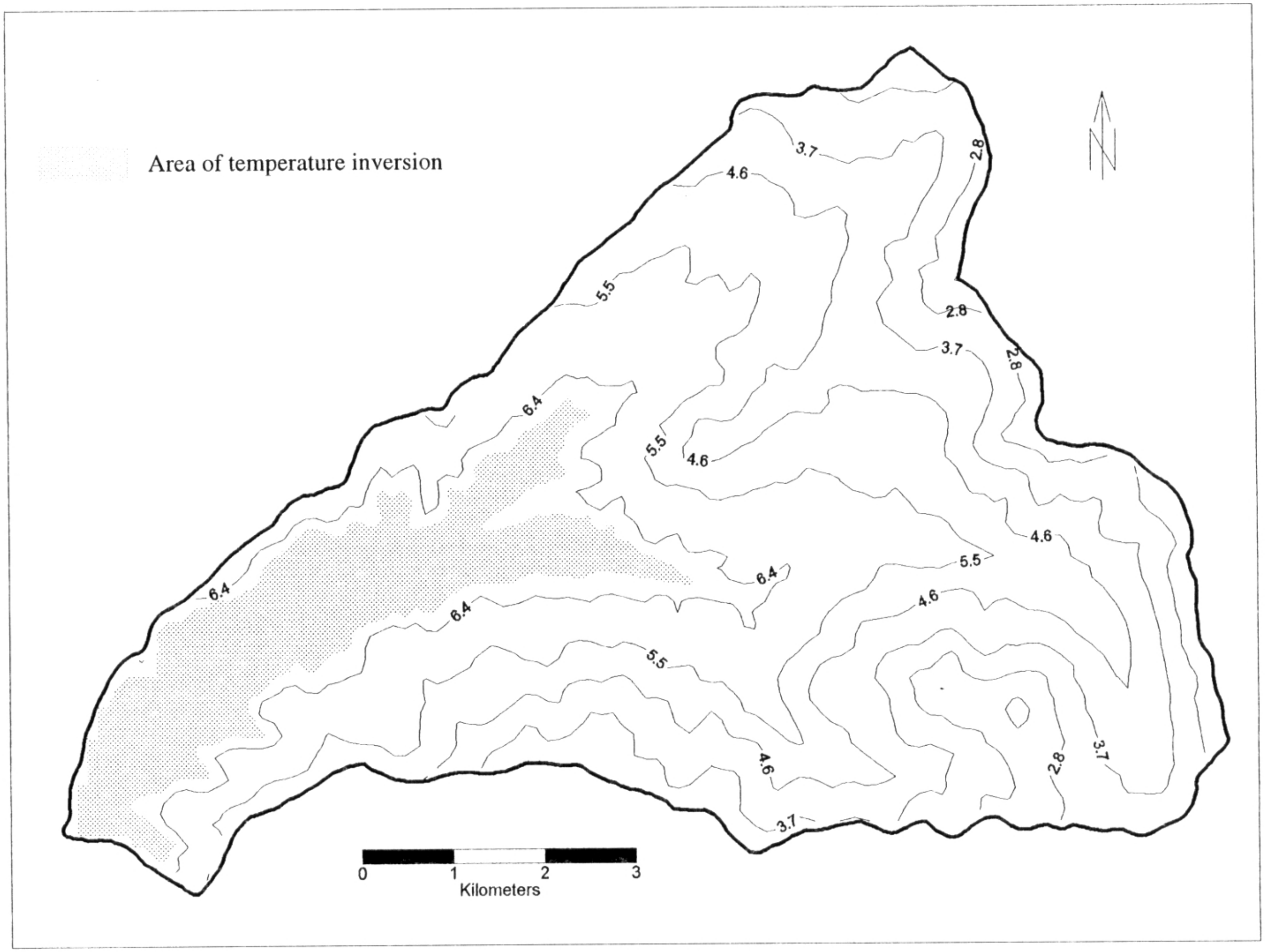

FIGURE 45. November Mean Maximum Temperature, 1981-1990 (Contour Interval 0.9° C)

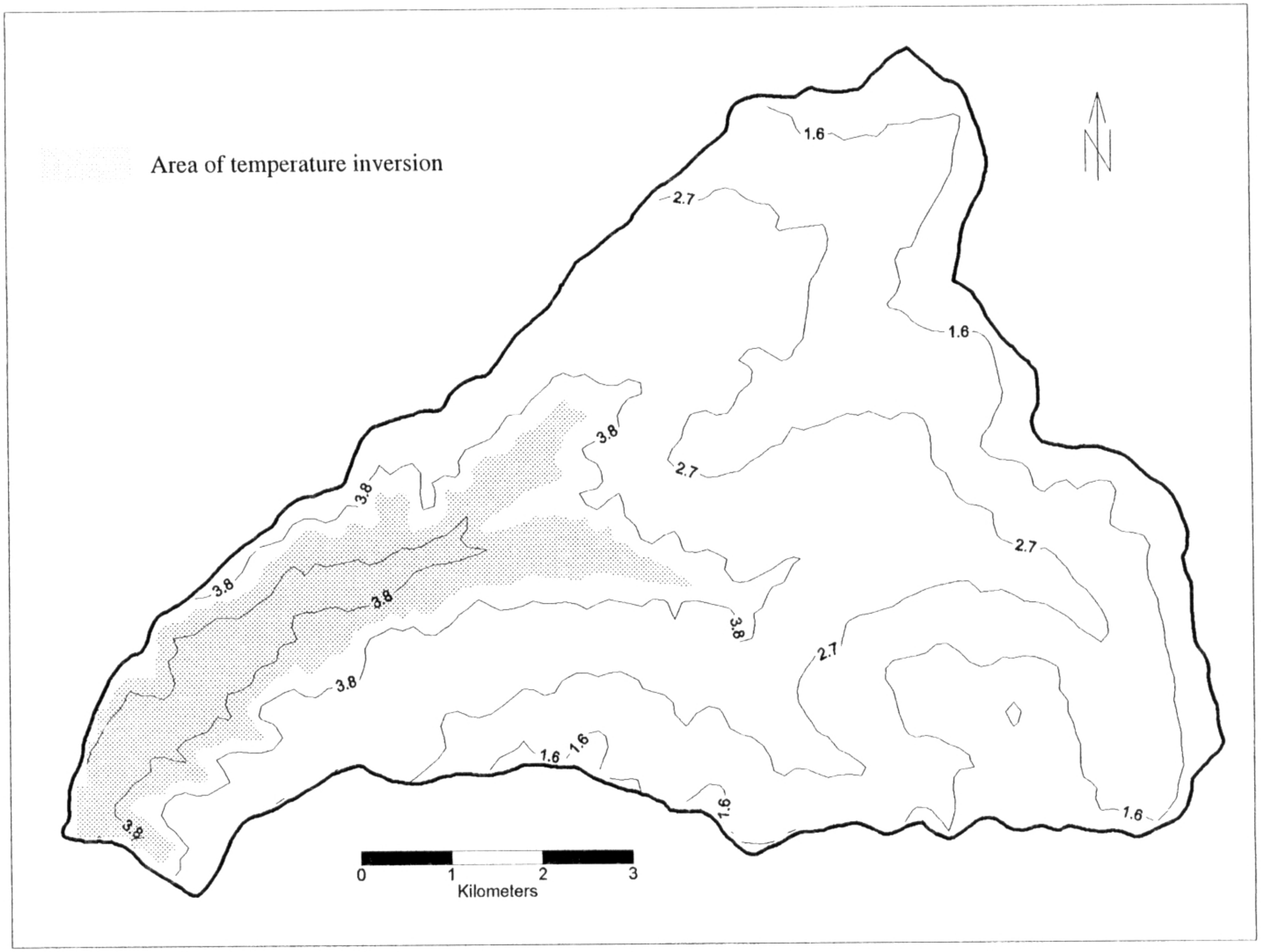

FIGURE 46. December Mean Maximum Temperature, 1981-1990 (Contour Interval 1.1° C)

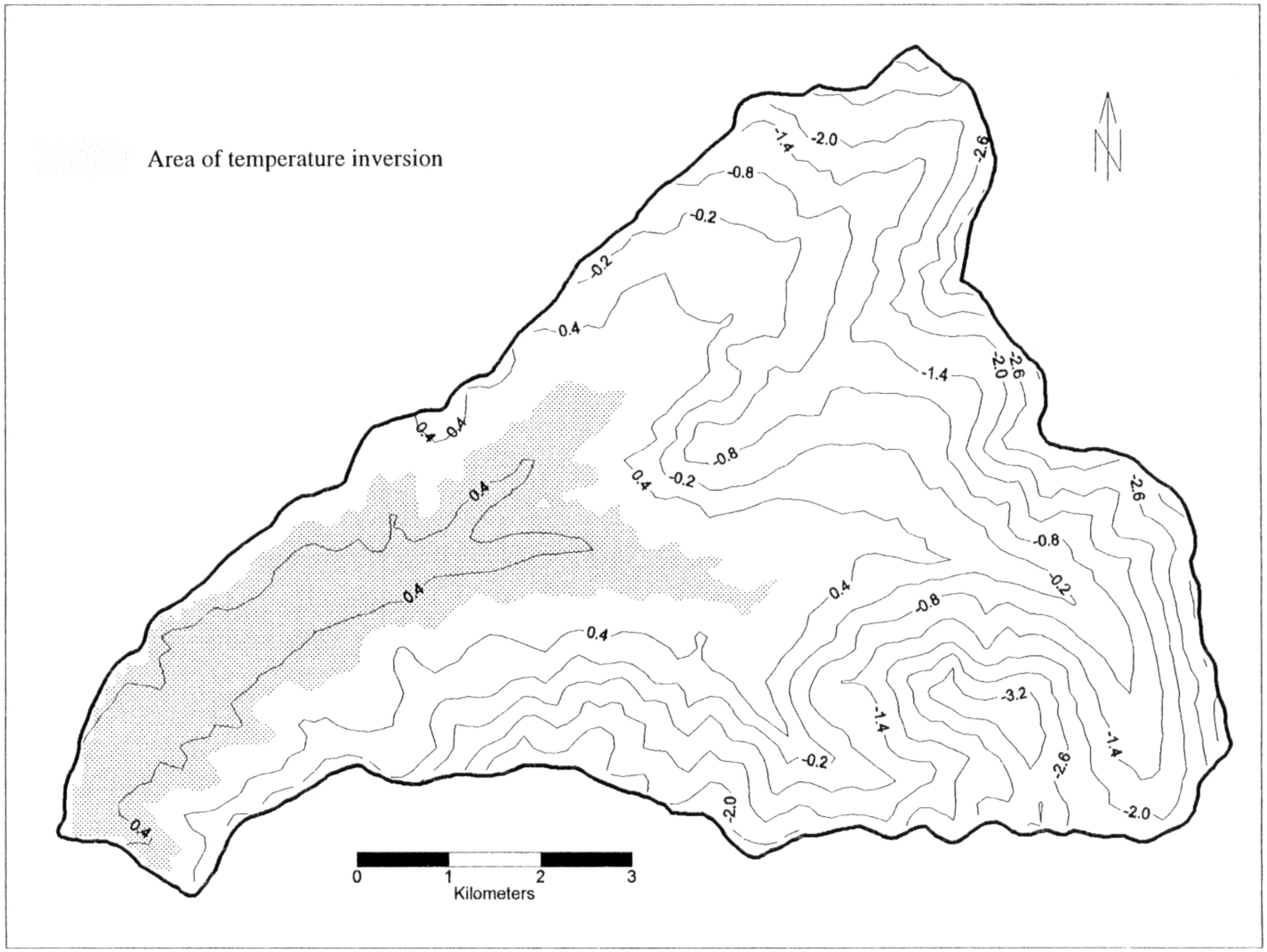

FIGURE 47. January Mean Minimum Temperature, 1981-1990 (Contour Interval 0.6° C)

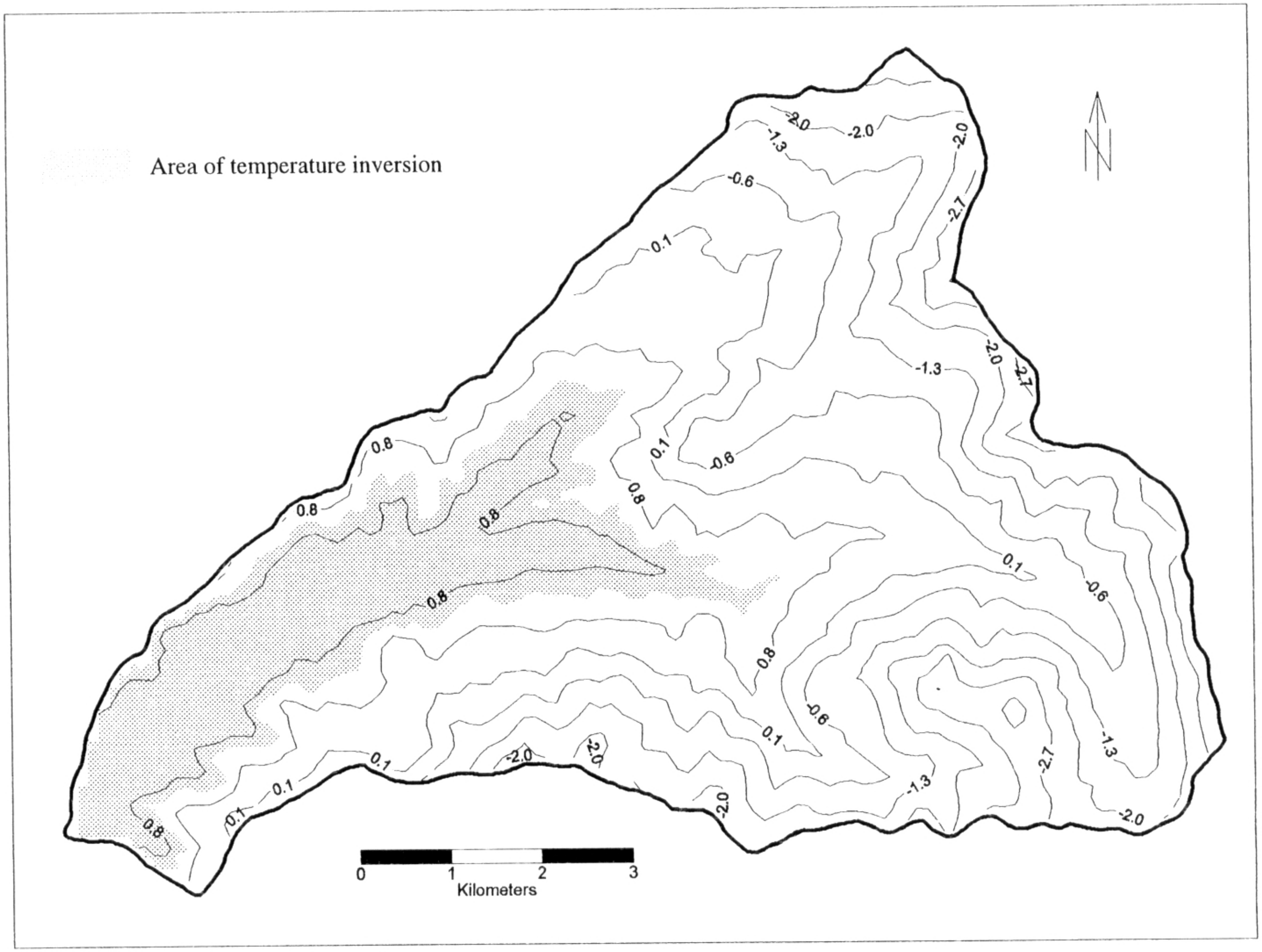

FIGURE 48. February Mean Minimum Temperature, 1981-1990 (Contour Interval 0.7° C)

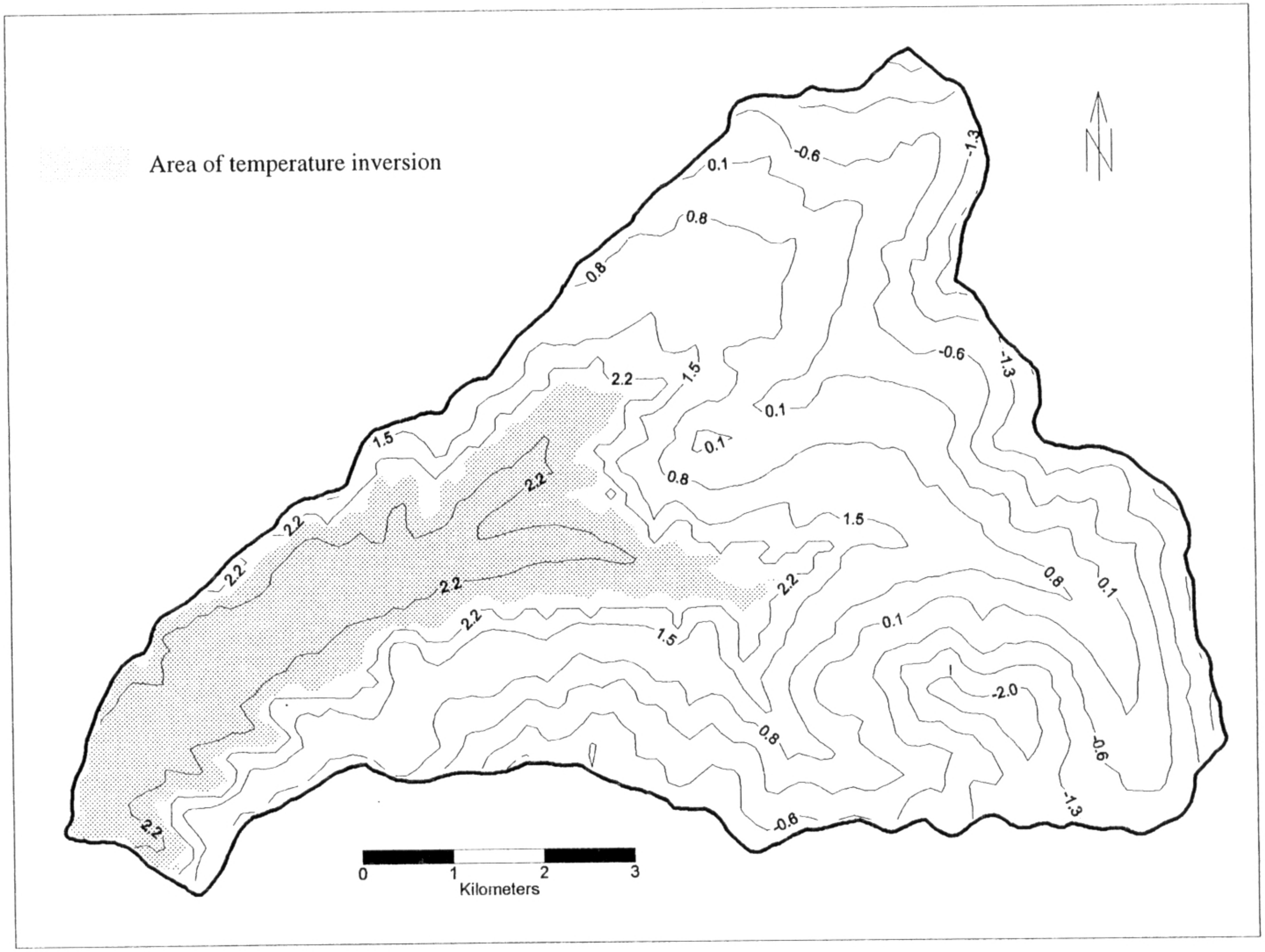

FIGURE 49. March Mean Minimum Temperature, 1981-1990 (Contour Interval 0.7° C)

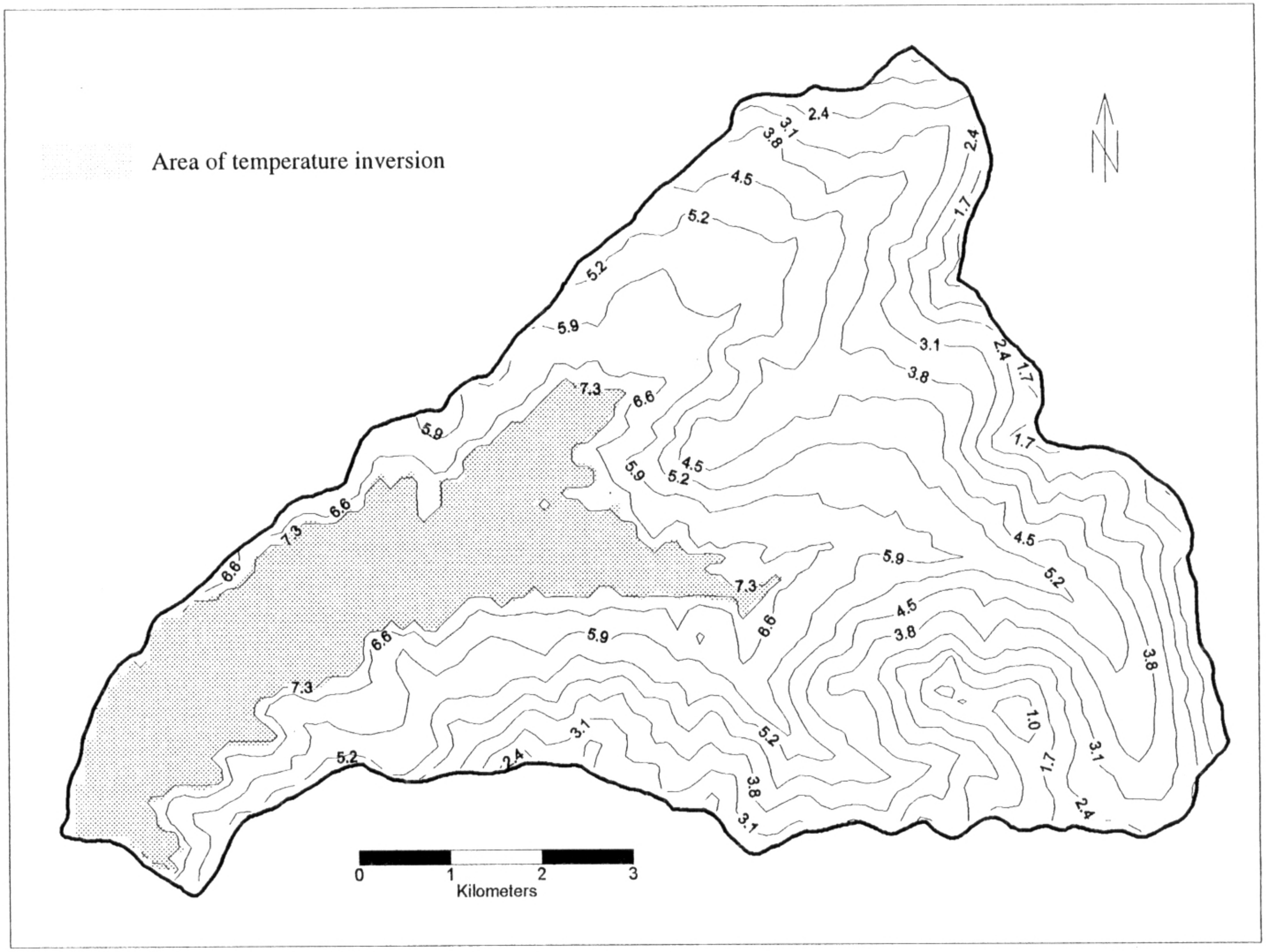

FIGURE 50. April Mean Minimum Temperature, 1981-1990 (Contour Interval 0.7° C)

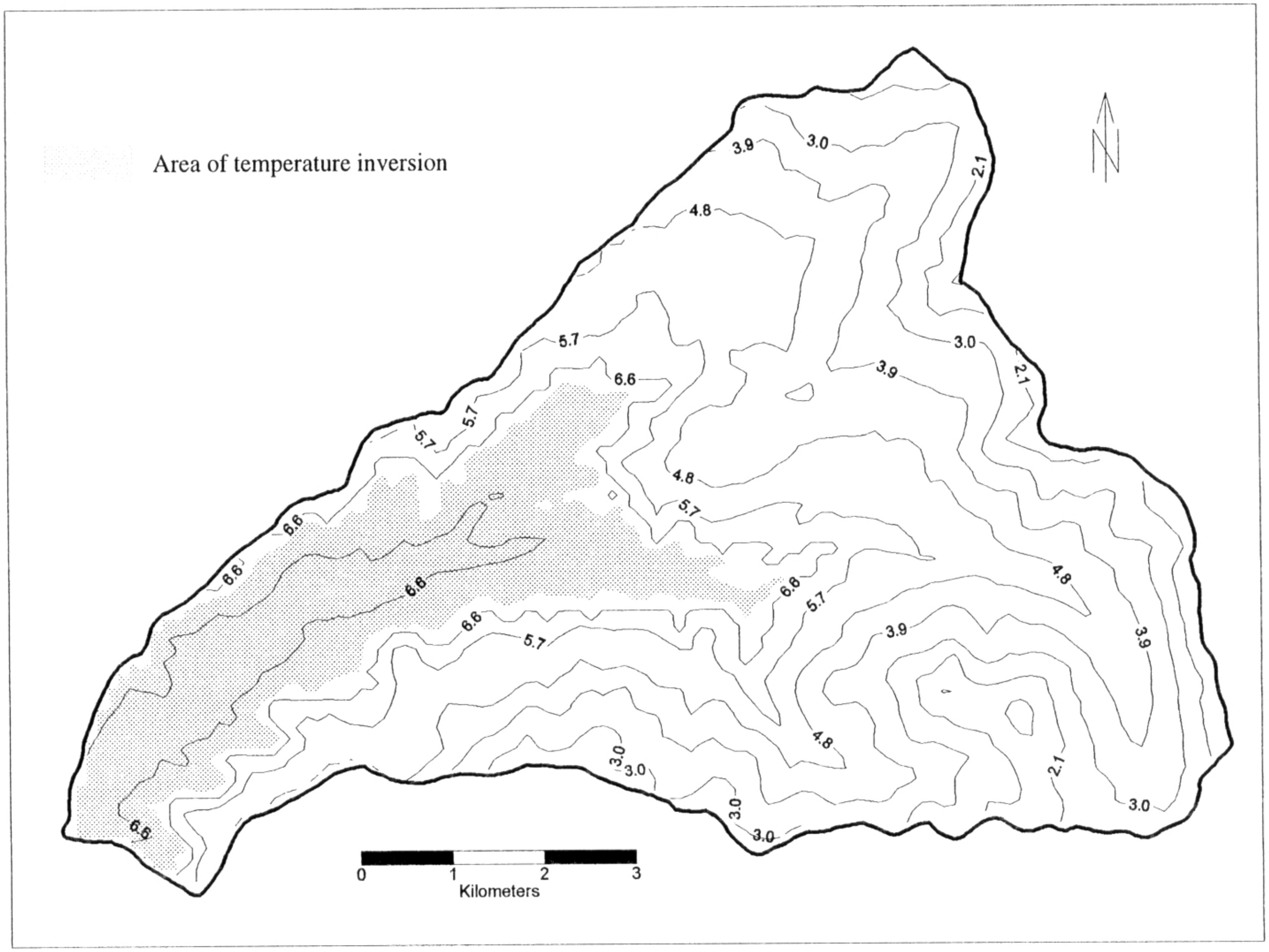

FIGURE 51. May Mean Minimum Temperature, 1981-1990 (Contour Interval 0.9° C)

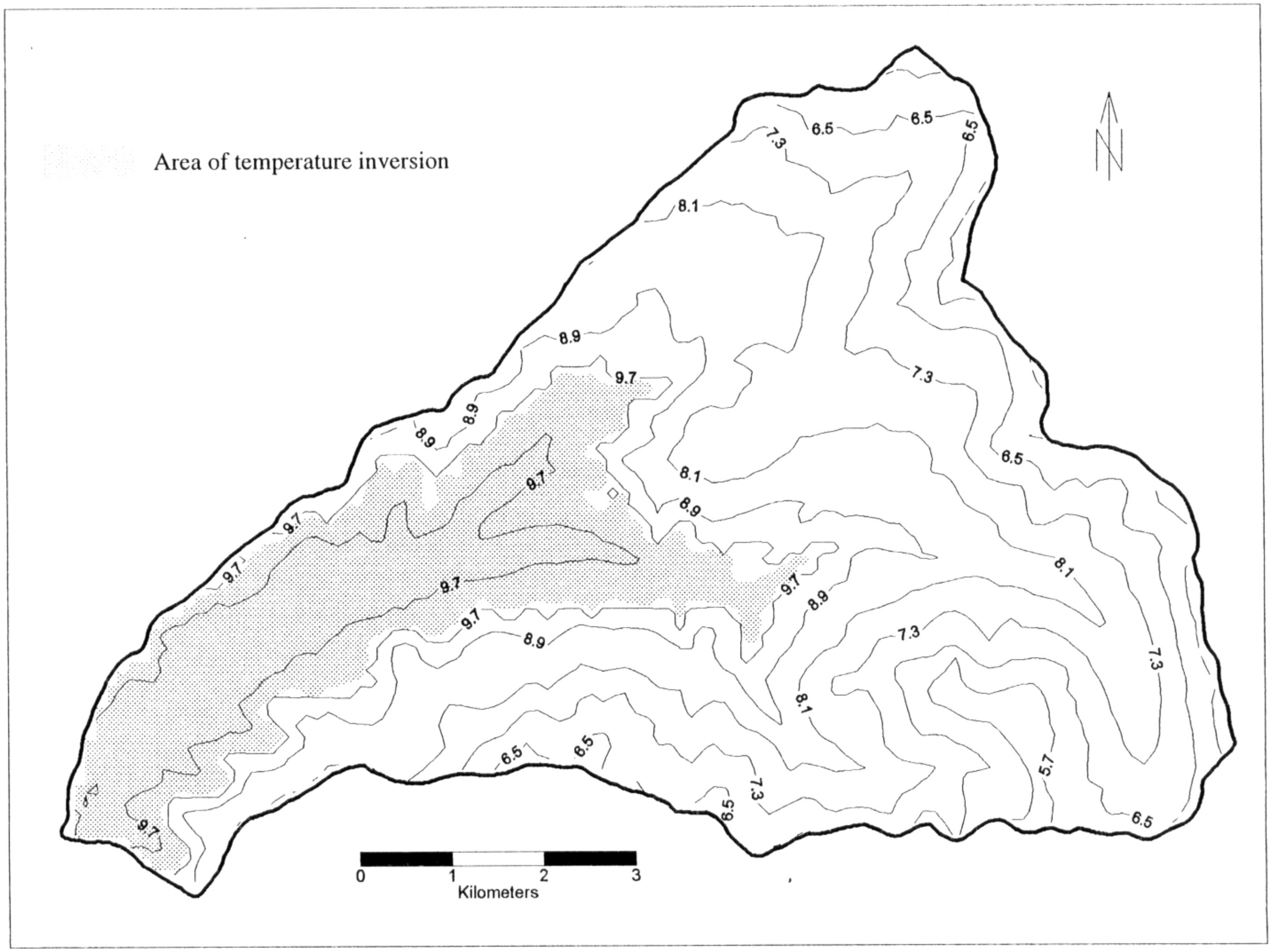

FIGURE 52. June Mean Minimum Temperature, 1981-1990 (Contour Interval 0.8° C)

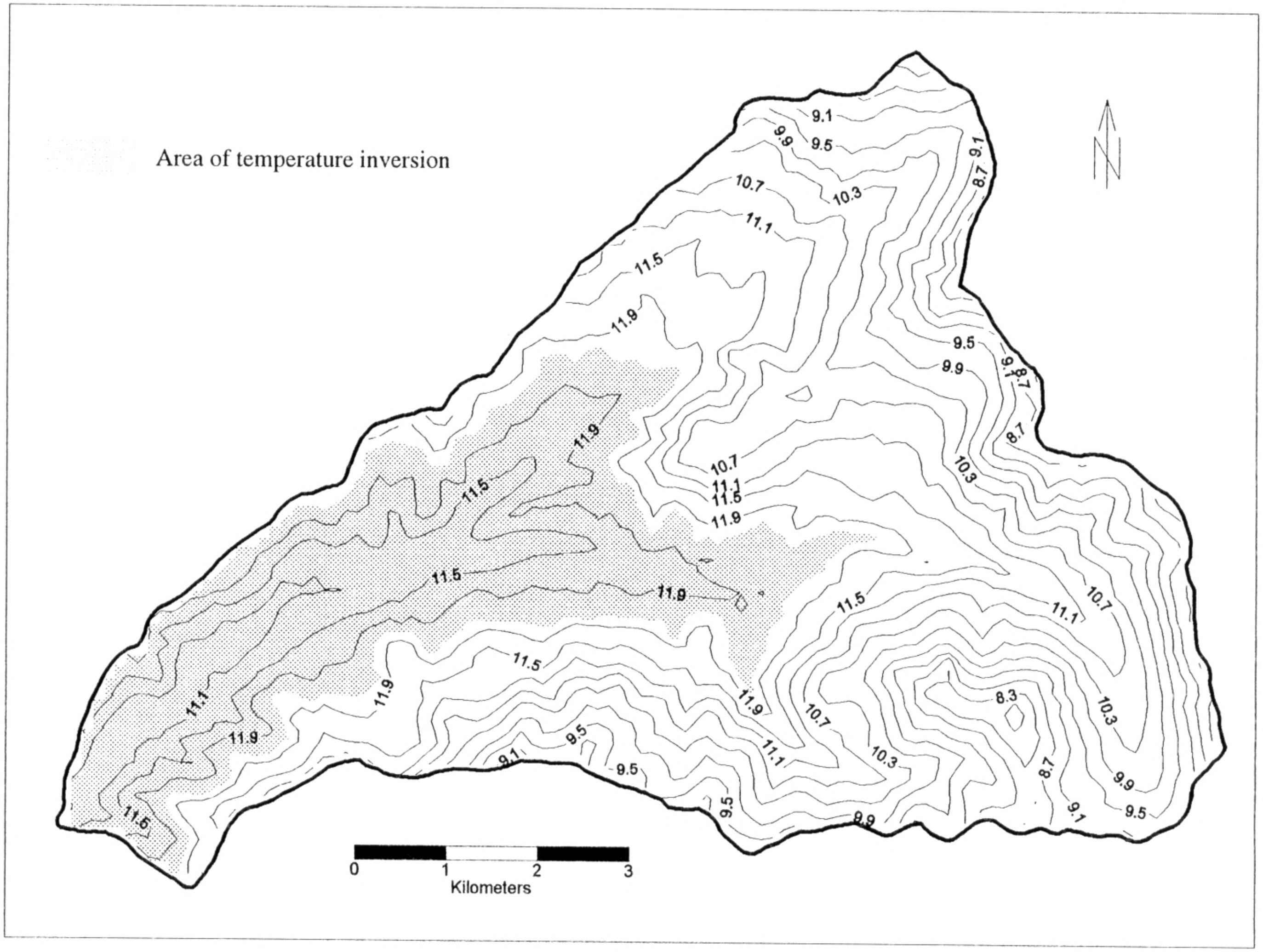

FIGURE 53. July Mean Minimum Temperature, 1981-1990 (Contour Interval 0.4° C)

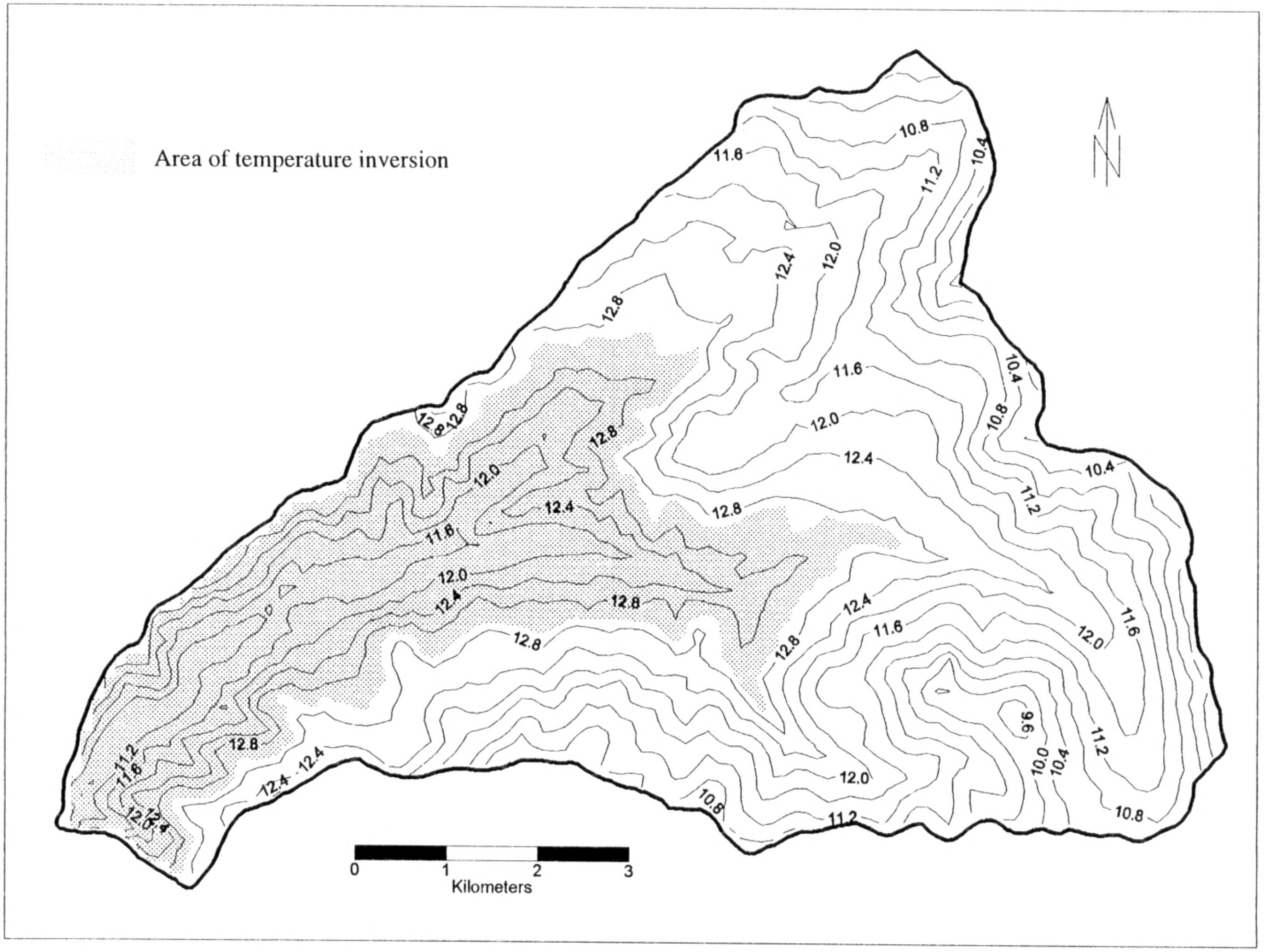

FIGURE 54. August Mean Minimum Temperature, 1981-1990 (Contour Interval 0.4° C)

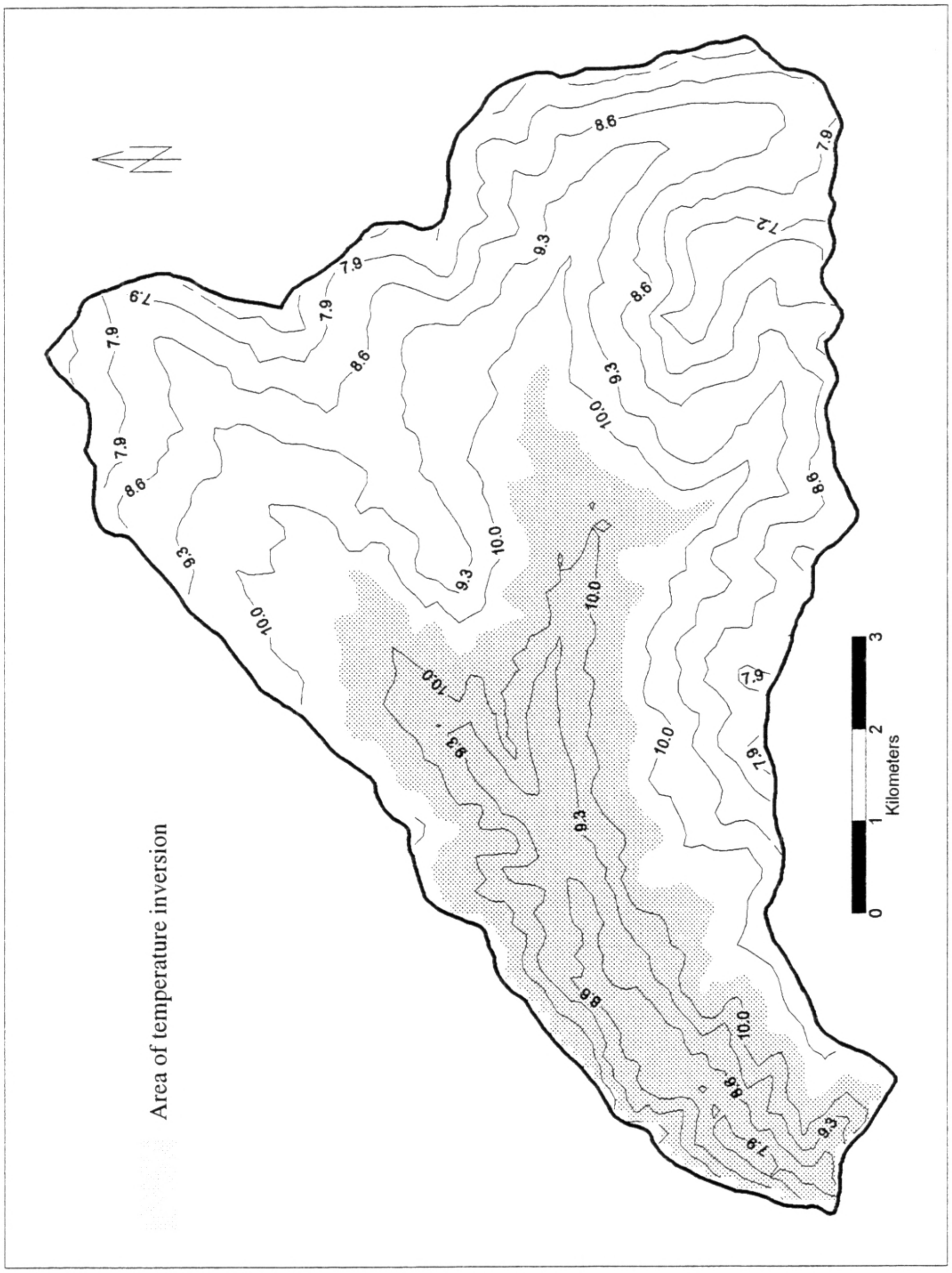

FIGURE 55. September Mean Minimum Temperature, 1981-1990 (Contour Interval 0.7° C)

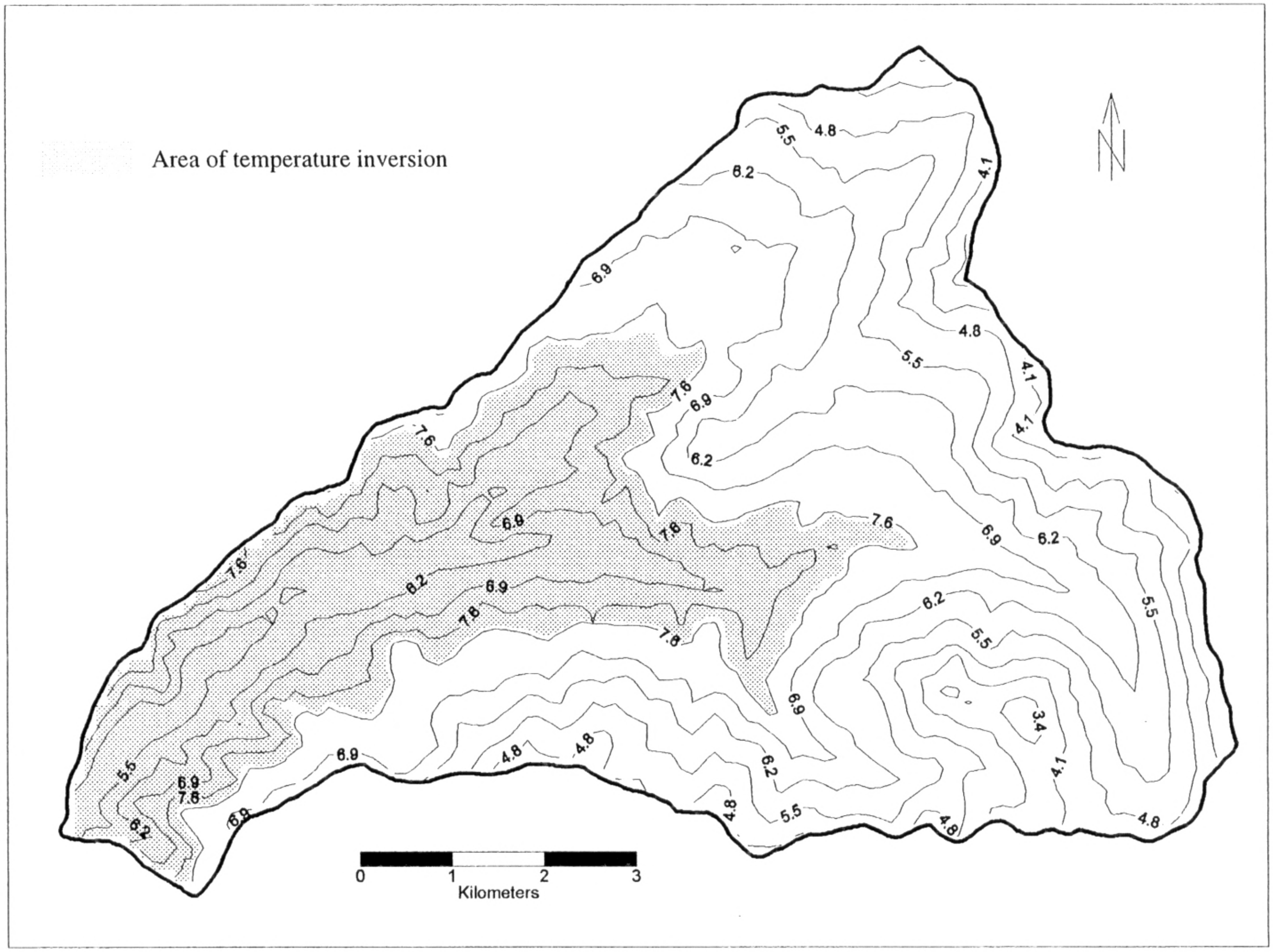

FIGURE 56. October Mean Minimum Temperature, 1981-1990 (Contour Interval 0.7° C)

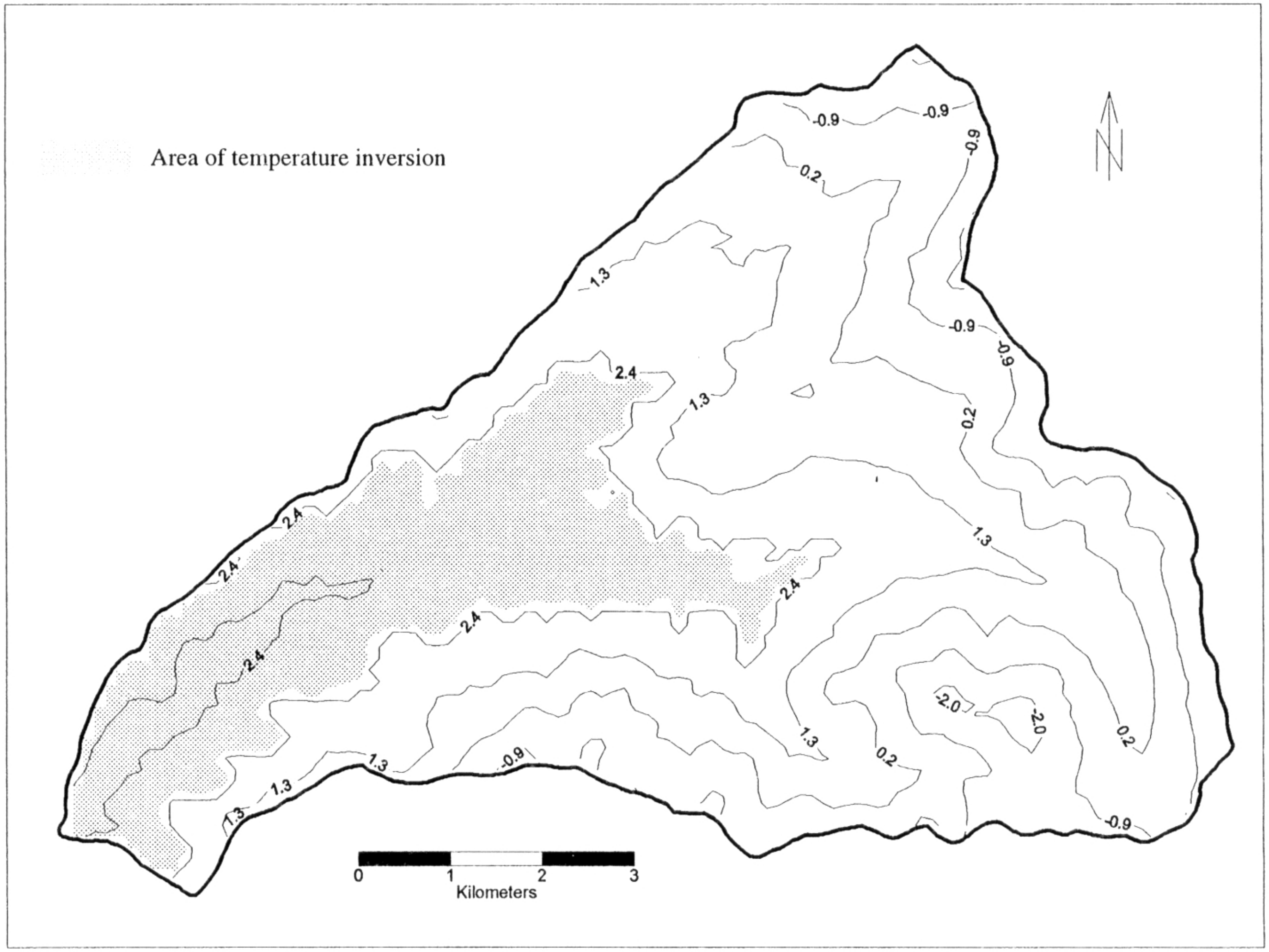

FIGURE 57. November Mean Minimum Temperature, 1981-1990 (Contour Interval 1.1° C)

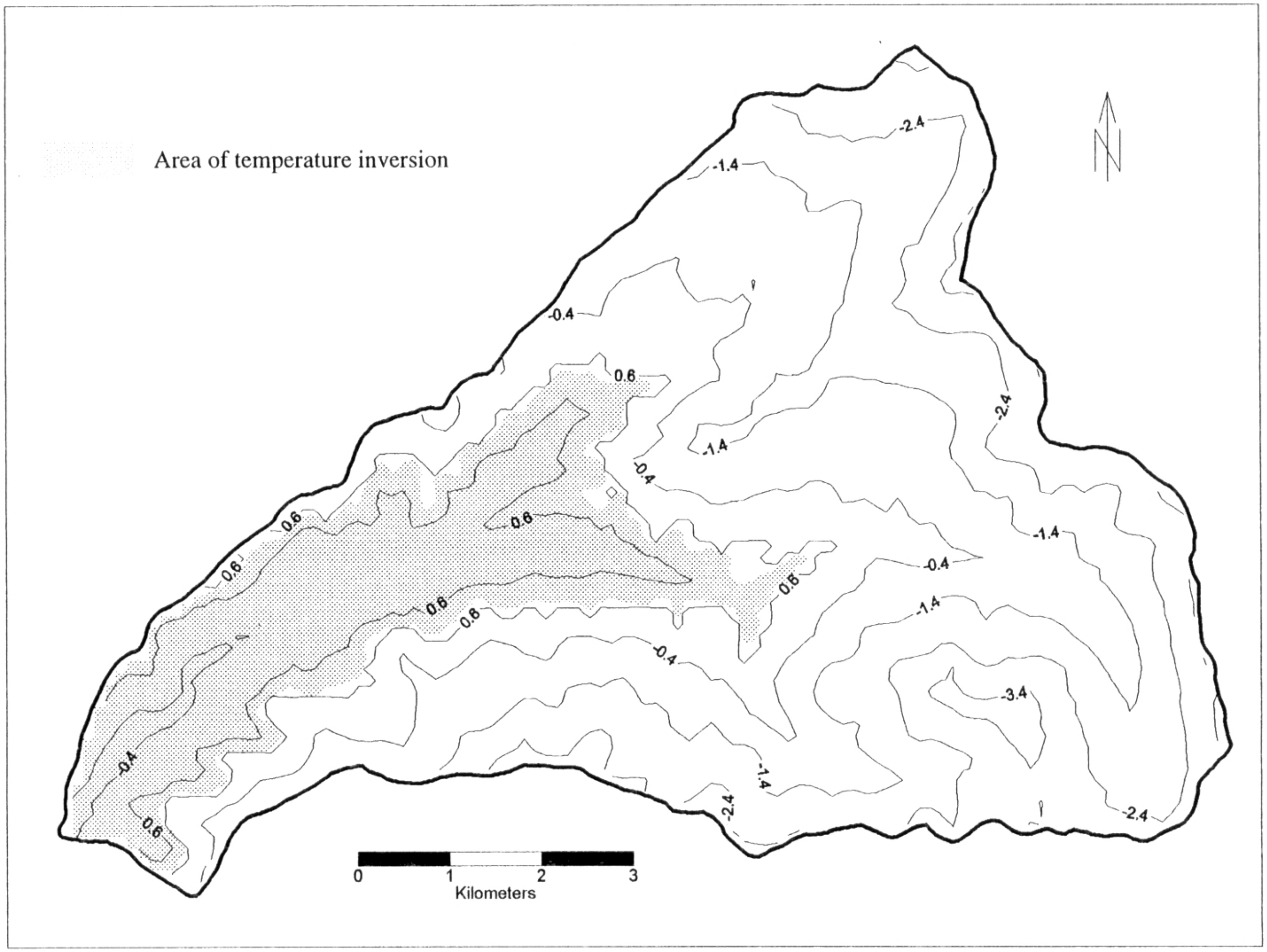

FIGURE 58. December Mean Minimum Temperature, 1981-1990 (Contour Interval 1.0° C)

BIBLIOGRAPHY

Alsop, Ted J. 1989. The Natural Seasons of Western Oregon and Washington. Journal of Climate 2: 888-96.

Baker, Frederick S. 1944. Mountain Climates of the Western United States. Ecological Monographs 14 (2): 223-254.

Barry, Roger G. 1992. Mountain Weather and Climate. London: Routledge.

________ and Richard J. Chorley. 1992. Atmosphere, Weather & Climate. New York: Routledge.

Bierlmaier, Frederick A. and Arthur McKee. 1989. Climatic Summaries and Documentation for the Primary Meteorological Station, H.J. Andrews Experimental Forest, 1972 to 1984. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Blinn, Tawny, Frederick J. Swanson, and Arthur McKee. 1988. Research Publications of the H.J. Andrews Experimental Forest, Cascade Range, Oregon: 1988 Supplement. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Chen, Jiquan, Jerry F. Franklin, and Thomas A. Speis. 1992. Vegetation Responses to Edge Environments in Old-Growth Douglas-Fir Forests. Ecological Applications 2 (4): 387-396.

Conrad, V. and L.W. Pollack. 1950. Methods in Climatology. Cambridge, MA: Harvard University Press.

Dyrness, C.T. 1973. Early Stages of Plant Succession Following Logging and Burning in the Western Cascades of Oregon. Ecology 54 (1): 57-69.

________, Jerry F. Franklin, and W.H. Moir. 1976. A Preliminary Classification of Forest Communities in the Central Portion of the Western Cascades in Oregon. Seattle: University of Washington.

Emmingham, W.H. and G.A. Lundburg. 1977. Climatic and Physiological Data Summaries for the H.J. Andrews Reference Stand Network. Seattle: University of Washington.

Franklin, J.F., C.S. Bledsoe, and J.T. Callahan. 1990. Contributions of the Long-Term Ecological Research Program. Bioscience 40 (7): 509-523.

Geiger, Rudolf. 1965. The Climate Near the Ground. Cambridge, MA: Harvard University Press.

Glassy, J.M. and S.W. Running. 1994. Validating Diurnal Climatology Logic of the MT-CLIM Model Across A Climatic Gradient in Oregon. Ecological Applications 4: 248-257.

Greenland, David. 1994. The Pacific Northwest Regional Context of the Climate of the H.J. Andrews Experimental Forest. Northwest Science 69 (2): 81-96.

________. 1996. Potential Solar Radiation At the H.J. Andrews Experimental Forest: USDA Forest Service, Pacific Northwest Research Station.

Hawk, G.M., J.F. Franklin, W.A. McKee, and R.B. Brown. 1978. H.J. Andrews Experimental Forest Reference Stand System: Establishment and Use History. Seattle: University of Washington.

Hennessey, Joseph P., Jr. 1979. Comments On "Use of Mesoscale Climatology in Mountainous Terrain to Improve the Spatial Representation of Monthly Temperatures". Monthly Weather Review 107 (3): 352-53.

Hungerford, R.D., R.R. Nemani, S.W. Running, and J.C. Coughlan. 1990. MT-CLIM: A Mountain Microclimate Simulation Model: USDA Forest Service, Intermountain Research Station.

Linacre, Edward. 1992. Climate Data and Resources: A Reference and Guide. London: Routledge.

McCaughey, J.H. 1981. Impact of Clearcutting of Coniferous Forest On the Surface Radiation Balance. Journal of Applied Ecology 18: 815-826.

McKee, Arthur and Frederick Bierlmaier. 1987. H.J. Andrews Experimental Forest, Oregon. in the Climates of the Long-Term Ecological Research Sites. Occasional Paper 44, Ed. David Greenland: 11-17. Boulder, CO: Institute of Arctic and Alpine Research, University of Colorado.

________, Gary M. Stonedahl, Jerry F. Franklin, Frederick J. Swanson, Comps. 1987. Research Publications of the H.J. Andrews Experimental Forest, Cascade Range, Oregon, 1948 to 1986. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Oke, T.R. 1987. Boundary Layer Climates. New York: Routledge.

Peilke, Roger A. and Peter Mehring. 1977. Use of Mesoscale Climatology in Mountainous Terrain to Improve the Spatial Representation of Mean Monthly Temperatures. Monthly Weather Review 105 (1): 108-112.

Running, Steven W. and J. C. Coughlan. 1988. FOREST-BGC, A General Model of Forest Ecosystem Processes for Regional Applications; I. Hydrologic Balance, Canopy Gas Exchange and Primary Production Processes. Ecological Modeling 42:125-154.

________, Ramakrishna R. Nemani, and Roger D. Hungerford. 1987. Extrapolation of Synoptic Meteorological Data in Mountainous Terrain and Its Use for Simulating Forest Evapotranspiration and Photosynthesis. Canadian Journal of Forest Research 17: 472-483.

Sellers, William D. 1969. Physical Climatology. Chicago: the University of Chicago Press.

Steinhauser, F. 1967. Methods of Evaluation and Drawing of Climatic Maps in Mountainous Countries. Archiv Für Meteorologie, Geophysik Und Bioklimatologie, Serie B 15: 329-58.

Swift, Lloyd W. and Harvey L. Ragsdale. 1985. Meteorological Data Stations At Long-Term Ecological Research Sites. in the Forest-Atmosphere Interaction, Ed. B.A. Hutchison and B.B. Hicks:25-37. Dordrecht, Holland: D. Reidel Publishing Company.

Waring, R.H., H.R. Holbo, R.P. Bueb, and R.L. Fredrikson. 1978. Documentation of Meteorological Data From the Coniferous Forest Biome Primary Station in Oregon. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station.

Willmott, Cort J. 1982. Some Comments On the Evaluation of Model Performance. Bulletin of the American Meteorological Society 63 (11): 1309-1313.

Zobel, Donald B., W. Arthur McKee, Glenn M. Hawk, and C.T. Dyrness. 1976. Relationship of Environment to Composition, Structure, and Diversity of Forest Communities of the Central Western Cascades of Oregon. Ecological Monographs 46 (2): 135-156.