SUMMER CLIMATE OF THE UPPER COLUMBIA RIVER VALLEY NEAR INVERMERE, BRITISH COLUMBIA

by

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ABSTRACT

The summer climate of a portion of the Rocky Mountain Trench north of Invermere, British Columbia, was studied in 1960 and 1961 through a network of 16 stations. Emphasis is given in this report to a comparison of the climate of the Frances Creek valley with that of a station in the main Columbia River valley at Invermere in 1961. Stations in the north-south aligned Frances Creek valley included a transect of five stations at elevations between 3,390 and 4,800 ft and two valley bottom stations downstream from this transect. Air temperature, relative humidity, soil temperature, soil moisture content, precipitation and evaporation were observed from May to November. General sky conditions at Invermere and the types of air masses over the area were also recorded.

The means of average monthly, maximum, minimum, diurnal range, and hourly temperatures were calculated for each station for each month. An analysis was made of the development and dissipation of nocturnal inversions under different air masses, the occurrence of frosts, the duration of the frost-free period, and the number of degree days and hours during the growing season. The other climatic factors observed were analysed and briefly discussed.

Frances Creek valley bottom stations were prone to have frosts throughout the summer months, and inversions existed every night, there being marked nocturnal thermal belts on the slopes. Maximum temperatures were higher at west-facing stations than east-facing stations, maximum and minimum daily temperatures occurring earlier at east-facing stations. Nocturnal inversions were deeper and stronger under maritime Tropical

air than under maritime Polar air. The frost-free period lasted over 120 days at slope stations and stations in the main Trench but ranged from 17 to 59 days at valley bottom stations in the Frances Creek valley in 1961. From May to September the station at Invermere received about 15% more degree hours than any slope station in Frances Creek valley, and 50% more than the transect valley bottom station, which received fewer degree hours than the two other Frances Creek valley bottom stations. Soil temperatures were highest at valley bottom stations and coolest at the higher elevation stations. Soil moisture was highest at the higher east-facing station, which also received the greatest amount of precipitation. Valley bottom stations received least precipitation, though deposition of dew occurred on many nights but was absent from slope stations. High humidities occurred every night at valley bottom stations, but diurnal humidity range at slope stations was small especially on clear days. Evaporation at the Invermere station was high, with Frances Creek valley transect stations only recording a third of the amount.

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INTRODUCTION

In recent years, many climatic studies have been carried out in North America, usually with the aim of elucidating some climatic phenomenon of an area, or of helping explain certain biological features of the environment. Studies involving climatic networks in the northern Rocky Mountain area have been few (Hayes, 1941; McLeod, 1948; Parker, 1952; Lloyd, 1961; MacHattie, 1966, 1970), and none have been reported for the mountain areas of the Rocky Mountain Trench of British Columbia[2]. Areas having similar topographic features in the region probably experience similar climatic regimes; thus, a small study in one area of a region may be fairly representative of conditions over the whole region with similar topographic features.

In 1960 and 1961, a climatic study was carried out in a portion of the upper Columbia River valley, which it was hoped would help explain the relation of climate to the distribution of tree species and of outbreaks of the mountain pine beetle (Dendroctonus ponderosae Hopkins) in

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[2] A further study has been carried out in this general area by J. R. Marshall, British Columbia Department of Agriculture, since the study of the author.

the area. Studies to investigate the habitat temperatures of the mountain pine beetle (Powell, 1967) and the history of outbreaks and their relation to seasonal weather (Powell, 1966, 1969) were run concurrently.

The main objective of the present study was that of examining the relation between the summer climate of a portion of the upper Columbia River valley, and that which occurred in tributary valleys. Climatic data were collected from 19 stations covering an area of over 250 sq miles, but only the 16 stations with the most complete data were analysed. This paper compares the 1961 summer climate at Invermere, a station representative of climate in this portion of the Columbia River valley, with the climate of the Frances Creek tributary valley. Seven stations were analysed in detail in the Frances Creek valley, five of which formed a cross section and gave information of the effect of aspect and elevation above valley floor on the summer climate. Comparative information for the remaining eight network stations is given in the Appendix.

AREA OF STUDY

Physiography

The area of study and the physiographic features of the study area are shown in Figs. 1 and 2. The area centers on a portion of the Rocky Mountain Trench in the drainage of the Upper Columbia River, to the north of Invermere (lat. 50° 30'N, long. 116° 01'W). The Columbia River meanders northward over a valley bottom 1 to 2 miles wide and

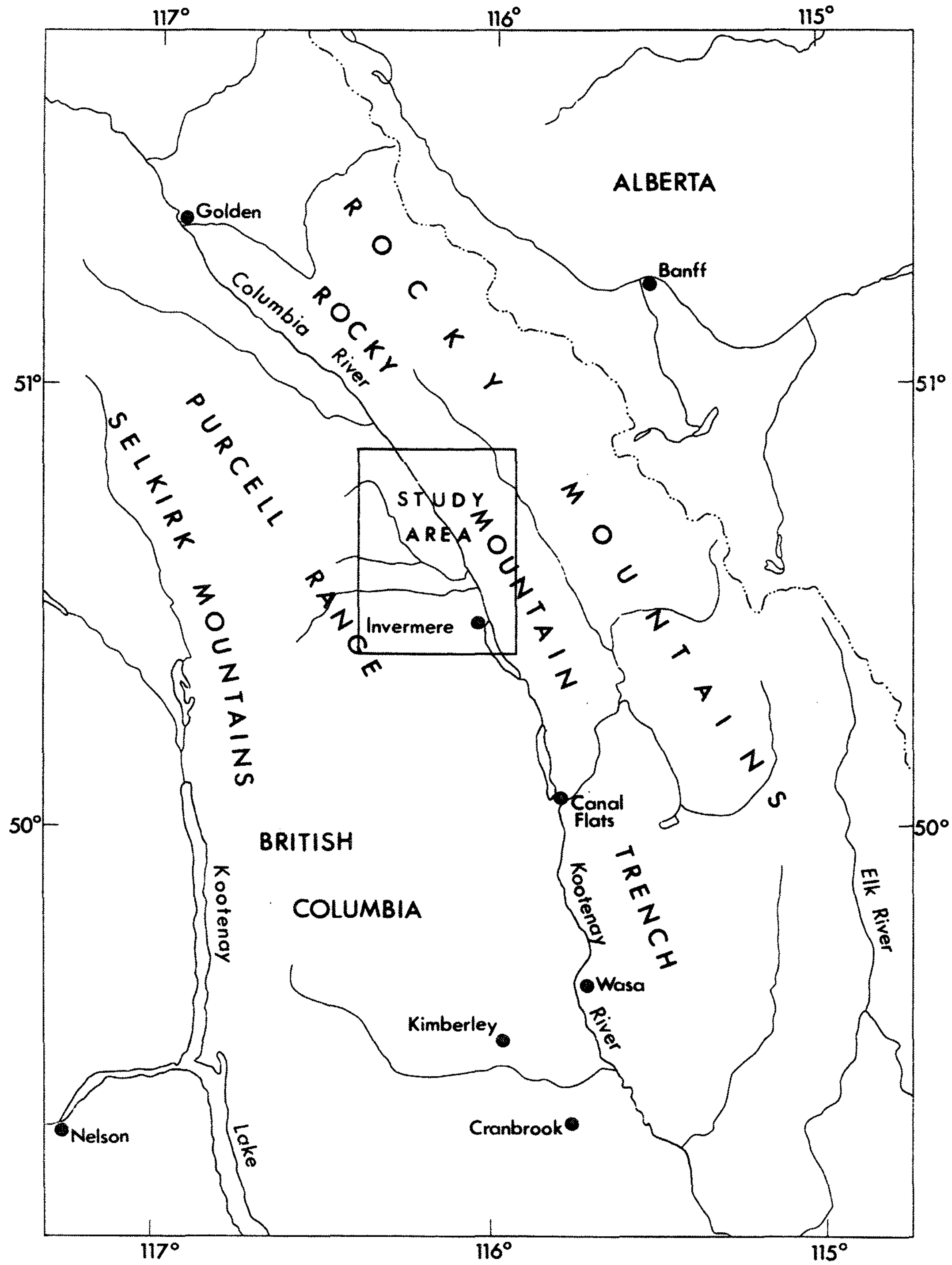

Fig.1. Physiographic features of the Rocky Mountain Trench of southeastern British Columbia, and the position of the study area.

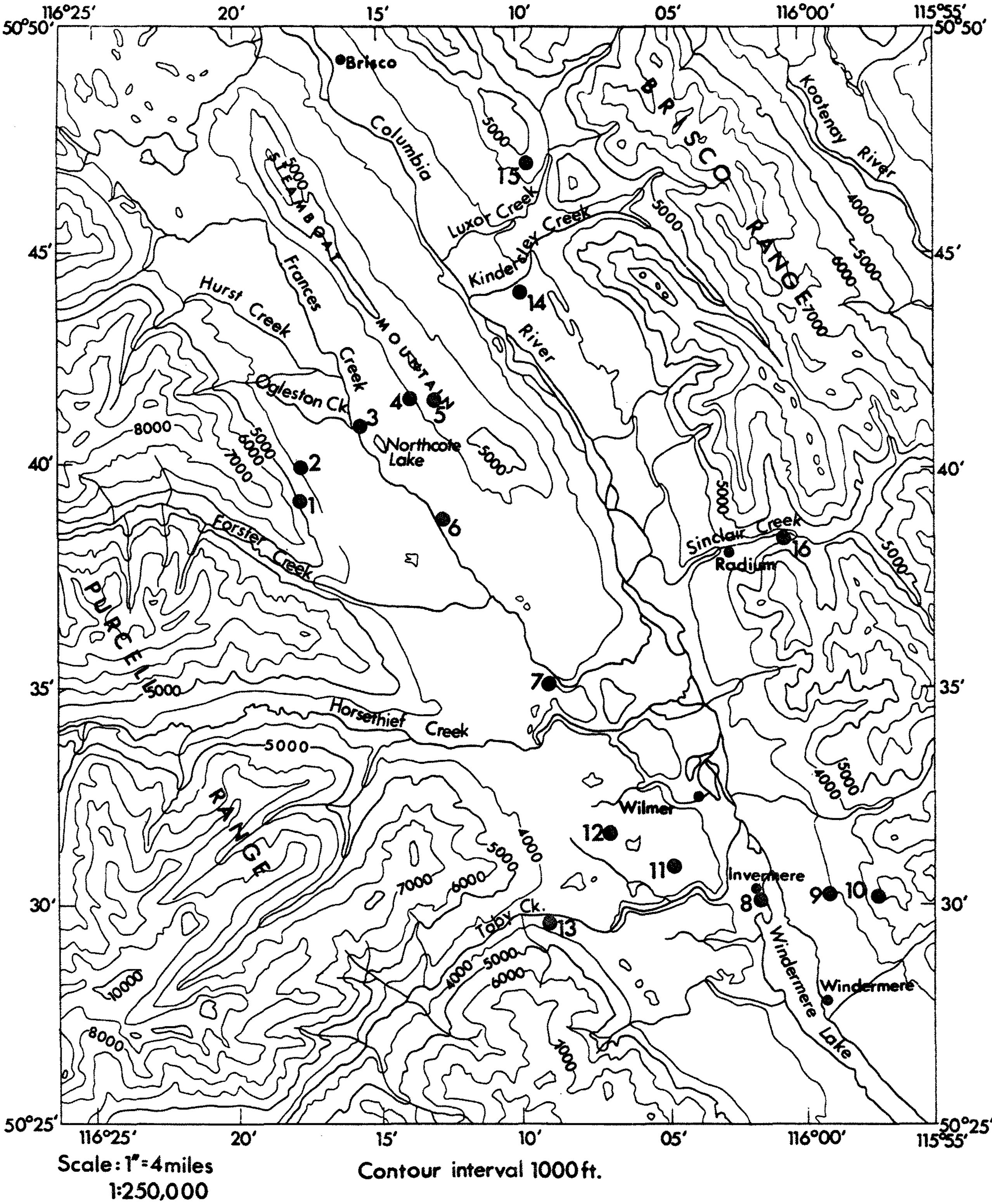

Fig.2. Physiographic features of the study area, and the location of the 16 stations.

characterized by large marshes and alluvial flats. The whole Trench depression is flanked by a series of dissected glacio-lacustrine silt terraces, occurring at elevations between 2,700 and 3,000 ft, which were deposited at various times during the recession of ice when the Trench was probably occupied by a lake (Walker,1926). The town of Invermere is on a gravel-sand terrace at the northwest end of Windermere Lake (2,625 ft a.s.l.) and some 120 ft above the lake. The Trench is flanked on the east by the westernmost ranges of the Rocky Mountains, the peaks of which rise to between 7,500 and 8,750 ft. On the west the easternmost range of the Purcell Mountains rises to between 7,500 and 9,500 ft. The Purcell Range is dissected by large eastward flowing streams - Toby Creek, Horsethief Creek, Forster Creek, and the Spillimacheen River - which are the main tributaries of the Columbia River in this part of the Trench.

The Frances Creek valley is a main tributary of Forster Creek. The confluence of Frances and Forster Creeks lies about 6 miles from where Forster Creek joins the Columbia River opposite the town of Radium, and 8 miles northwest of Invermere. Part of Frances Creek occupies a major north-northwest to south-southeast valley on the west side of Steamboat Mountain, a small mountain ridge some 15 miles long, 6,300 ft high and situated within the main Trench area. The Frances Creek valley bottom averages about 2 miles wide, is of undulating topography, and consists of a till plain with drumlinized and morainic areas. Several shallow lakes are present in the valley bottom and these usually have associated swamps or remain practically dry throughout the year. The valley bottom meets the Purcell Range and Steamboat Mountain at an elevation of about 3,700 ft, from where steep slopes rise on the west to over

9,000 ft in the outer range of the Purcell Mountains, and on the east from 4,800 to 6,300 ft on Steamboat Mountain.

Soils

The soils of the area have been discussed by Kelley and Holland (1961) and by McLean and Holland (1958). The soils of Frances Creek valley are largely Gray Wooded soils with some areas of podzolization in the north and on the east side of the valley. Various areas of gravel, stony terraces, and loam have been deposited as Frances Creek has continued to cut down its bed, or where streams, such as Hurst and Ogleston Creek, entering the valley, have brought down material and developed fan aprons. Along the valley bottom of Frances Creek and on much of the undulating drumlinized areas south of Steamboat Mountain to Invermere and farther south, Brown Wooded soils have developed. The town of Invermere lies on an area with a mixture of Dark Brown and Brown Wooded soils.

Vegetation

The area lies within the Montane Forest Region, Ponderosa Pine and Douglas Fir Section, with the higher slopes of the Trench falling within the Subalpine Forest Region, Interior Subalpine Section (Rowe, 1959). The two corresponding bioclimatic zones of Krajina (1959) are the Interior Douglas Fir Zone and the Subalpine Engelmann Spruce - Subalpine Fir Zone. Timberline in this part of the Trench and in the Purcell Range generally, is at about 8,000 ft; thus, some of the summits of the mountains of the Purcell Range facing the Frances Creek valley fall within the higher zones of the Subalpine Forest, alpine vegetation areas being found mainly on the summits of the inner parts of the Range. The flora of the region was discussed by Ulke (1935) and Eastham (1949), and the vegetation of this part of the Upper Columbia valley by McLean and Holland (1958).

The distribution of the vegetation in the Frances Creek valley is influenced by differences in elevation on the east and west valley slopes, and with variations existing because of topography, soils, and climate. Two sub-zones of Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) are present in the Frances Creek and main Trench area (McLean and Holland, 1958). The Douglas fir groveland sub-zone, a zone of an open park-like appearance with areas of grassland, is found on the east side of the main Trench just north of Kindersley Creek to Windermere, and on the west side south of Forster Creek to Invermere, and on an isolated area just south of Northcote Lake in the Frances Creek valley. Rocky Mountain juniper (*Juniperus scopulorum* Sarg.), lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.), and aspen (*Populus tremuloides* Michx.) are the only other trees that occur, the latter two usually only on the more mesic sites. The Douglas fir forest sub-zone extends throughout the Frances Creek valley bottom and up the slopes to various levels. It also occurs on the east side of Steamboat Mountain and at higher levels on both sides of the Trench. The main associated tree species are lodgepole pine, aspen, and white spruce (*Picea glauca* (Moench) Voss). The lodgepole pine appears dominant over large areas, but it is primarily a pioneer species after fire. Aspen, present where grassland is found, is prevalent on south-facing slopes, and on the steeper west-facing slopes of Steamboat Mountain. White spruce is an important member of this zone, especially along the stream courses, on alluvial fans, or near swamps, and again at the higher elevations on podzolized Gray Wooded soils. White spruce is quite abundant on Steamboat Mountain and on the west side of Frances Creek valley from about the 3,600 ft level. This Douglas fir-pinegrass association occurs largely on Brown Wooded soils. Black cottonwood (Populus trichocarpa Torr. & Gray), willows (Salix spp.), and western white birch (Betula papyrifera Marsh. var. commutata (Regel) Fern.) are often associated with white spruce along the water courses, while white birch is also present at the higher elevations of the zone.

On the west side of the Frances Creek valley, and at points farther south, the Douglas fir forest sub-zone gives way to a seral association at a number of points at varying levels between 4,000 and 5,000 ft. The two important tree species in this association which are not found at the lower levels are western larch (Larix occidentalis Nutt.), and western red cedar (Thuja plicata Donn).

The Subalpine zone is found on the west slopes of the Trench and Frances Creek and commences at an elevation varying between 4,000 and 5,000 ft depending on whether the zone adjoins directly the Douglas fir zone, or whether there is an intermediate cedar-larch zone. The Subalpine zone is little represented on the central and southern summit areas of Steamboat Mountain, the vegetation there being typical of a Douglas fir-white spruce association. On the east side of the Trench, the zone occurs at a slightly higher elevation. The Subalpine zone on both sides of the Trench extends to the timberline or summits of the mountains and is characterized by the dominance of Engelmann spruce (Picea engelmannii Parry), and alpine fir (Abies lasiocarpa (Hook.) Nutt.) though Douglas fir and lodgepole pine are still present.

Macroclimate of the Upper Columbia River Valley

The Trench area falls within the Dfb zone of Köppen's classification (Chapman, 1952) which is characterized by cold, snowy climates where the mean temperature of the coldest month is less than 26.6 F., and of the warmest month more than 50 F. The summers are cool with the mean temperature of the warmest month less than 71.6 F, and there are no distinct dry seasons, the driest month of the summer having more than 1.2 inches of precipitation. The upper levels of the area would fall within the Dfc zone which has cool short summers, where there are less than 4 months with mean temperatures more than 50 F.

In the area of the Trench around Invermere, there have been several climatological stations, but only the station at Windermere (1913 to 1948) covered 30 years, the length of record recommended by the World Meteorological Organization for establishing "normals". The stations in the British Columbia portion of the Trench with the longest records of temperature and precipitation are Cranbrook and Golden, both over 60 miles from the area of study. Long records of precipitation are also available from Brisco, Canal Flats, and Wasa. The annual and monthly long-term means for temperature and precipitation for these stations are shown in Table 1. The mean monthly hours of sunshine at Windermere (Table 1) are slightly less than those at Kamloops (2046) and slightly

TABLE 1. Mean Annual and Monthly Temperature (°F), Precipitation (Inches) and Hours of Sunshine for a Number of Long Recording Stations in the Rocky Mountain Trench.

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yr	No. of years	Elevation (ft)
TEMPERATURE															
Golden	13	19	31	42	52	58	64	61	52	41	28	17	40	67	2,583
Windermere	13	19	31	42	51	58	63	60	51	41	27	16	40	35	2,840
Cranbrook	16	22	32	42	51	58	64	62	53	42	29	20	41	63	3,013
Kimberley	17	24	30	42	51	58	64	62	54	42	28	20	41	25	3,016
PRECIPITATION															
Golden	2.34	1.38	0.92	0.80	1.12	1.61	1.36	1.42	1.40	1.54	1.84	2.39	18.12	62	2,583
Brisco	1.62	1.02	0.67	0.86	1.43	2.06	1.17	1.44	1.20	1.29	1.25	1.90	15.91	45	2,750
Windermere	0.81	0.56	0.42	0.56	1.16	1.83	1.09	1.40	1.16	0.89	0.72	0.99	11.59	35	2,840
Canal Flats	1.32	1.17	0.97	0.83	1.60	2.06	1.12	1.42	1.15	1.16	1.42	1.78	16.00	34	2,680
Wasa	1.20	1.01	0.79	0.84	1.49	2.05	0.98	1.31	1.24	1.29	1.15	1.56	14.91	45	3,050
Cranbrook	1.70	1.15	0.89	0.75	1.18	1.88	1.05	1.04	1.11	1.02	1.41	1.88	15.06	61	3,013
Kimberley	1.60	1.07	0.85	0.69	1.37	2.04	0.80	1.27	0.95	1.05	1.43	1.71	14.83	25	3,016
SUNSHINE															
Windermere	64	102	158	208	240	230	300	262	182	138	63	48	1,993	27	2,840

more than those of Summerland (1972) and Oliver (1951) (British Columbia Department of Agriculture, 1967), but summer temperatures are lower than at Kamloops, Summerland, and Oliver, partly a reflection of the increased elevation.

The area is dominated at all times by maritime air moving in an easterly direction from the Pacific Ocean, but the air masses have been greatly modified by the time they reach the Trench. The north-south alignment of the mountain systems acts as a principal barrier to the penetration of the air masses into the Trench. Moist air is able to enter and spread into the Trench in the north near Boat Encampment, and in the south below the 49th parallel. There is also some evidence that moist air is able to penetrate into the Trench via the Spillimacheen valley and possibly through other valleys that penetrate the Purcell and Selkirk ranges. There is a marked rain-shadow effect within the East Kootenay part of the Trench. This effect is most marked in the Invermere area, where more precipitation is received in summer than in winter, while least occurs in spring. The change of monthly precipitation patterns from Golden to Invermere was shown by Kelley and Holland (1961). Amounts of summer precipitation were similar throughout the area, but there was a noticeable decrease in winter precipitation from Golden to Invermere. Kerr (1950) applied Thornthwaite's moisture index to British Columbia and showed the area around Invermere to be in the semi-arid region with an index of -20 to -40.

In summer, warm, dry continental air from the Great Basin area of the United States sometimes penetrates into the southern portion of the Upper Columbia River valley, bringing to the area its hottest weather. Because the area is mountainous, summer daytime temperatures are warm or moderate and nights are cool. The Trench area has the most continental features of any of the southern interior valleys of the Province. This fact is supported from a recent study by MacKay and Cook (1963), who showed a continentality of between 40 and 50% for the area, the degree of continentality being based on the mean annual temperature range.

The main wind directions in the Trench are very much governed by the alignment of the Trench with winds mainly from the northwest, or from the southeast (Table 2). In summer, there is also a strong component from the northeast. Average wind speeds are higher in summer and there are few periods of calm.

LOCATION OF STATIONS

The locations of the climatic stations are shown on the map of the study area (Fig. 2). The latitude, longitude, and the elevation of each station are given in Table 3. Stations 1 to 5 occur in a transect about a mile wide, crossing the Frances Creek valley. The cross-section profiles of the valley on either side of this mile-wide band are shown in Fig. 3. The alignment of Frances Creek valley parallels that of the main Trench and is from the north-northwest to the south-southeast. The transect of stations is approximately perpendicular to this axis. Station 6 is situated about 4 miles south of the transect stations and about $1\frac{1}{2}$ miles to the north of the confluence of Frances and Forster Creeks, while station 7 is situated about 2 miles to the south of the confluence. Stations 3, 6, and 7 are all valley-bottom stations. Station 8 is some 8 miles to the southeast of station 7, on a terrace in the main Trench.

TABLE 2. Annual and Monthly Percentage Frequency of Winds and Mean Wind Speed in Miles Per Hour, by Direction, for Windermere During the Period January 1930 to August 1940 (after Boughner and Thomas, 1948)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yr.
Percentage Frequency (by directions)													
North	6	5	5	3	3	3	3	5	5	3	3	3	4
Northeast	8	7	8	12	15	17	20	21	17	14	9	7	13
East	2	3	3	3	2	2	1	2	2	2	2	2	2
Southeast	22	27	42	32	28	31	23	19	22	27	30	32	28
South	1	3	3	2	3	1	1	2	3	2	2	2	2
Southwest	3	3	4	5	6	6	7	9	8	6	3	3	5
West	2	3	2	2	1	1	1	2	1	1	3	1	2
Northwest	34	30	26	36	39	36	40	35	36	35	33	31	34
Calm	22	19	7	5	3	3	4	5	6	10	15	19	10
Mean Wind Speed in Miles per Hour (by directions)													
North	1.8	2.6	4.0	4.1	3.9	3.9	3.7	2.4	3.8	5.7	2.0	2.0	3.3
Northeast	2.7	2.1	3.7	3.9	3.8	3.8	3.0	3.2	3.1	3.5	2.0	2.9	3.1
East	2.3	3.1	5.0	5.3	3.7	5.3	6.9	3.0	4.9	6.0	3.1	2.0	4.2
Southeast	9.4	8.9	8.5	8.6	8.5	8.4	10.7	11.1	7.9	6.6	6.4	8.6	8.6
South	3.1	4.8	5.6	5.3	8.7	5.9	8.1	2.1	7.4	10.9	2.8	2.9	5.6
Southwest	2.4	2.4	3.4	4.6	5.1	4.5	3.5	4.1	3.7	4.2	2.1	2.1	3.5
West	1.3	2.0	3.0	3.7	3.8	5.2	2.8	3.0	2.8	2.3	1.9	1.7	2.8
Northwest	2.4	3.0	4.6	5.5	5.9	5.4	5.0	6.2	4.3	4.5	2.8	2.8	4.4
Average Wind Speed in Miles per Hour													
	3.3	3.8	5.8	5.9	6.1	5.8	5.6	5.6	4.7	4.6	4.0	4.0	4.9

TABLE 3. The Location and Description of the Climatic Stations of the Study Area.

Stn. No.	Lat.°N	Long.°W	Elev.ft (a.s.l.)	Slope per cent	Slope direction	Elev.ft above valley bottom	Soils	Vegetation type
				MAIN STATIONS				
1	50°38.9'	116°17.8'	4800	45-50	ENE	1400	---	Douglas fir/lodgepole pine/ Engelmann spruce/w.red cedar/ w. larch
2	50°39.7'	116°17.7'	4000	20	ENE	600	Gray Wooded- Kinbasket Silt Loam	Douglas fir/pinegrass/lodgepole pine
3	50°41.3'	116°16.0'	3390	flat	-	-	Alluvium- Wigwam Complex	White spruce/aspen/willow
4	50°41.9'	116°14.2'	4000	18	WSW	600	Gray Wooded	Douglas fir/pinegrass/aspen/ lodgepole pine
5	50°41.7'	116°13.0'	4600	10	WSW	1200	---	Douglas fir/w.spruce/lodgepole pine
6	50°38.2'	116°12.0'	3240	5	WSW	30	Brown Wooded- Misko Loam	Douglas fir/lodgepole pine
7	50°35.5'	116°09.2'	3030	flat	-	20	Brown Wooded- Elko Loam	Douglas fir/grassland/ Rocky Mt. juniper
8	50°30.5'	116°01.6'	2740	3	WNW	120	Brown Wooded- Dark Brown- Elko-Saha	Grassland/Douglas fir
				OTHER STATIONS				
9	50°30.7'	115°59.2'	2960	8	WSW	340	Brown Wooded- Wycliffe Silt Loam	Douglas fir/grassland
10	50°30.2'	115°57.2'	5000	20	SW	2380	---	Douglas fir/pinegrass/lodge- pole pine
11	50°31.7'	116°04.2'	3180	15	ESE	550	Brown Wooded- Wycliffe Silt Loam	Douglas fir/grassland
12	50°31.1'	116°06.0'	3240	5	SE	610	Brown Wooded- Wycliffe Silt Loam	Douglas fir/grassland
13	50°29.3'	116°08.5'	3500	10	NE	230	---	Lodgepole pine/aspen/w.spruce
14	50°46.2'	116°09.4'	2900	5	SW	310	Gray Wooded- Kinbasket Silt Loam	Douglas fir/pinegrass
15	50°46.5'	116°09.3'	4800	15	SW	2220	---	Douglas fir/pinegrass/lodge- pole pine
16	50°38.5'	116°01.0'	3612	10	SSE	40	---	Douglas fir/lodgepole pine/ w.red cedar

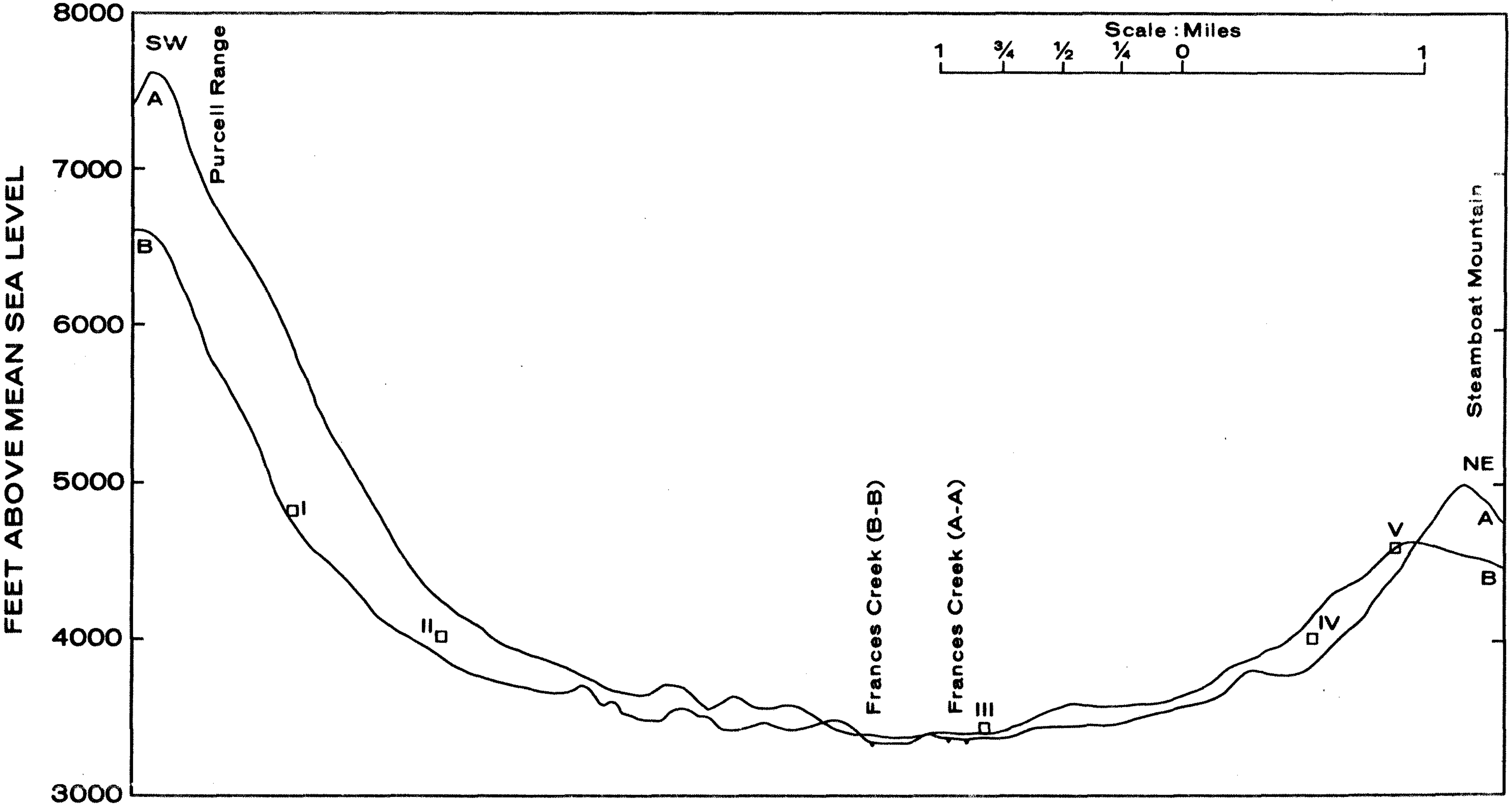

Fig.3. Valley profiles of Frances Creek valley, 1¼ miles apart, showing the five stations of the valley transect.

Also summarized in Table 3 are the descriptive features of each station. In addition to these tabulated data, all stations except stations 1 and 3 were essentially dry sites. Station 1 was a mesic site and station 3 was a wet site, the latter being subject to spring flooding by Frances Creek. Stations 7 and 8 were in exposed grassland areas. At station 6, there was considerable regeneration after fire and logging. Station 3 was in a clearing close to the creek on the site of some old farm buildings. Each of the slope stations (nos. 1, 2, 4, and 5) had been the site of some selective logging operations in the past, but none of very recent origin, and a considerable canopy from mature trees existed at each station. At station 4, the distribution of the trees was typical of open-grown parkland. A small gully, which lay just to the north of station 5, may have acted as a passage for cold air drainage, causing the station to be more favorably situated in this respect. The station was near the saddle summit of Steamboat Mountain. The profiles of the valley bottom at stations 3, 6, 7, and 8 are shown in Fig. 4. Station 8 was some 25 yards southeast of the British Columbia Forest Service, Ranger Station building at Invermere.

The other eight stations (nos. 9 to 16) of the network for which data were analysed are also indicated on Fig. 2. Stations 9, 11, 12, and 14 were all situated on various terraces of the main Trench. Stations 10 and 15 were on the upper slopes of mountains forming the range on the east side of the Trench. Station 13 is situated near the exit of Toby Creek into the main Trench, and the climatological station, Radium Hot Springs (no. 16), is near the exit of Sinclair Creek into the main Trench. Additional descriptive information for these stations is contained in Table 3,

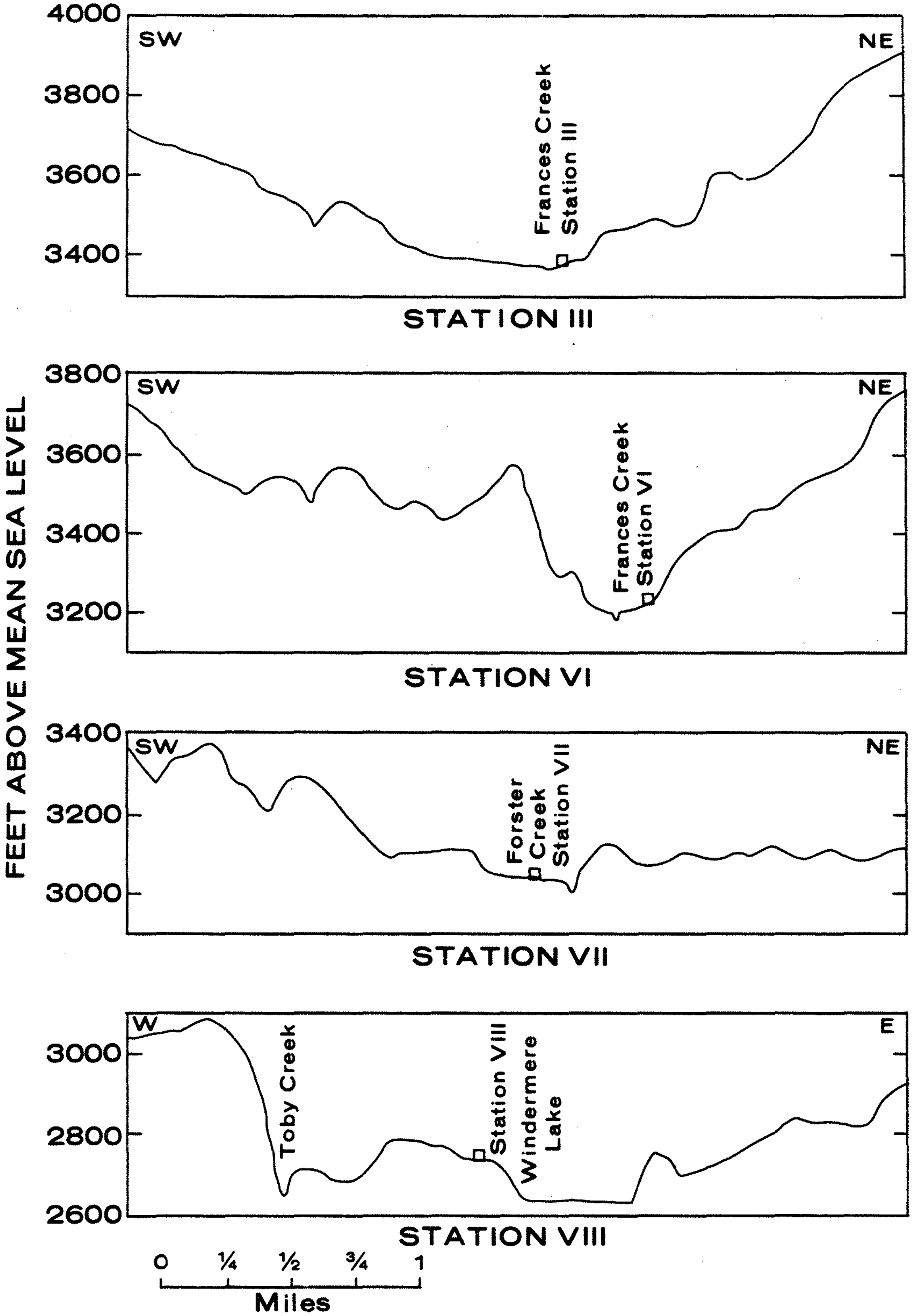

Fig.4. Profiles of the valley bottom near stations 3,6,7, and 8.

but all tabulated climatic data are contained in Appendix I., Tables A - G.

INSTRUMENTS AND METHODS

Temperature and Humidity

Each network station was equipped with a Fuess or Short and Mason hygrothermograph with a weekly chart. Hygrothermographs were maintained at stations 3, 7, and 8 from April 27 to November 3; at station 5 from May 1 to November 3; at stations 1, 2, and 4 from May 18 to November 3; and at station 6 from June 1 to November 3, 1961. At the beginning and end of the field season, all the hygrothermographs were test-run under the same conditions to ensure that they were reading correctly and that each instrument was in agreement with the others. Throughout the period of observation, spot checks of a sling psychrometer against the hygrothermographs were made at least every other week to show up any gross errors in the humidity recordings. Maximum and minimum thermometers were maintained at all stations as a check against the maximum and minimum temperatures recorded by the hygrothermographs during each week. The hygrothermographs and the thermometers were exposed in Stevenson or similar type screens, with the floor of the screen approximately 4 ft above the ground surface at each of the sites. An attempt was made to place screens in the open where this was possible.

Hourly values of temperature and relative humidity were extracted and tabulated from the hygrothermograph charts for the entire period of record at each station. Hourly, daily, monthly, and means for the whole period were calculated for all temperature data. Monthly and hourly means of humidity were calculated for some stations. The number of degree days above 42 F were calculated for all stations and the number of degree hours above 32 F were calculated for stations 1, 3, 5, and 8.

Precipitation

Stations 1 to 8 were each supplied with a rain gauge for their period of operation. Rainfall at station 3 was measured with a standard Canadian 3.57-inch-diameter gauge having a receiving area of 10 sq inches, at station 8 with a U.S. Weather Bureau 8-inch stick gauge as employed by the British Columbia Forest Service for their forest fire reporting stations; and the gauges at the other stations were of the plastic wedge-type with an approximate $2\frac{1}{2}$ sq inch opening. Huff (1955) compared this wedge gauge with standard gauges and found them to compare most favorably with the standard gauges. Precipitation was measured once a week, except at station 8 where it was measured daily. It was noticed during the present study that in one week, the plastic wedge gauge was prone to lose a certain amount of water by evaporation. All gauges were placed vertically; thus, those on the slopes probably recorded less than what actually fell, as a truer catch had been shown to be recorded when gauges were perpendicular to the slope (Hamilton, 1954). Snow that collected in the gauges was melted to obtain a water equivalent.

Evaporation

Three copper evaporation pans, each with a diameter of 12 inches and a depth of 6 inches with a center pin, were used to estimate the amount of evaporation from a water surface. The pans were shielded from direct insolation and from rain by a thin sheet of plywood placed over the supporting stand, and were covered with 1-inch diameter wire mesh to prevent objects such as leaves from entering the pan and to prevent animals and birds from drinking the water. The pans were about 4 ft above the ground. Evaporation was recorded at stations 3 and 5 from June 21 to September 27; at station 8 from June 28 to August 9; and at station 1 from August 9 to September 27, 1961. Evaporation from a water surface was calculated as the amount of water lost (cc) from the pan. At each weekly visit, the pan was refilled so that the center pin just broke the meniscus of the water level. The amount of water necessary to refill the pan, therefore, equalled the amount of water evaporated during the previous week.

Soil Temperature

Soil temperatures were recorded at the 4 inch level by means of Weston dial thermometers or bent-stem thermometers (station 8). Soil temperatures were recorded at weekly intervals at stations 1 to 5, and 7 from June 14 to September 27; and at station 8 on July 26 and from August 16 to September 27.

Soil Moisture

Soil moisture was determined by the gravimetric method as follows: every 2 weeks, two soil samples, each about 500 g, were collected from the top 6 inches of soil from each site. Two samples were taken at each station to reduce individual sample variations. The samples were sealed in cans, weighed to give fresh weight, oven-dried to constant weight at 105 C, and re-weighed for dry weight. All pebbles over 2.5 mm were screened from the dried samples and their weight was subtracted from the fresh and ovendry weights of the sample. The gravimetric water content is calculated as loss of weight on drying divided by dry weight and is expressed as a percentage. Samples were taken at stations 1 to 5, and 7, on May 25 and June 8, and at stations 1 to 7 on June 21, July 5, 19, August 2, 16, 30, September 13, 27, and November 3. No measurements were taken by this method at station 8.

Air masses

The types of air masses present were classified according to the 0000Z and 1200Z h upper air charts for the 500 and 700 mb levels for western North America, for the period of study. The temperatures at these levels were extracted for the following radiosonde stations: Prince Rupert, Port Hardy, Tatoosh Island, Seattle, Spokane, Prince George, Edmonton, Calgary, and Great Falls. Data for the 700 mb level were only complete from May 1 to August 11, 1961. Data for Calgary were only available for the 0000Z reading from July 7 to September 8, 1961. From this temperature data and the maps indicating direction of movement of the air masses, upper air temperatures were interpolated for the area of study. These temperatures were then classified into air mass temperatures according to the values given by Godson (1950), Penner (1955), Meteorological Branch (1956), and Walker (1961) for the latitudes 45°-50°N for each air mass. These values are summarized in Table 4, and the temperature limits used for each air mass are given in brackets. The

TABLE 4. Typical Air Mass Summer Temperatures for Middle Latitudes (45°- 50°N), with the Temperature Classes Used to Classify Air Masses in Brackets. (Data from Godson (1950), Penner (1955), Meteorological Branch (1956), and Walker (1961)).

Pressure level (mb)	AIR MASS			
	Maritime Tropical	Maritime Polar	Maritime Arctic	Continental* Tropical
700	8 to 12 C (4 & warmer)	0 to 1 C (3 to -6)	-10 to -14 C (-7 and cooler)	10 C
500	-7 to -9 (-13 & warmer)	-17 to -19 (-14 to -24)	-28 to -33 (-25 & cooler)	-11

*Only given by Godson (1950), and not used as a separate category in the present study.

TABLE 5. Monthly Maximum, Minimum and Mean Temperatures (°F) for May to October 1961, Compared with the Averages for the Period 1956 to 1962, at Station 8.

Period	TEMPERATURE °F																	
	May			June			July			August			September			October		
	Mx	Mn	M	Mx	Mn	M	Mx	Mn	M	Mx	Mn	M	Mx	Mn	M	Mx	Mn	M
1961	67	41	54	83	48	65	80	51	66	83	51	67	60	36	47	49	30	40
1956 - 1962	67	40	53	73	47	60	81	50	65	77	48	63	66	39	53	52	32	42*

* Data for 1957 missing

TABLE 6. Monthly Precipitation Totals for the Months May to October and the Six-Month Total for the Periods 1961, and 1956 to 1961, at Station 8.

Period	PRECIPITATION (INCHES)						
	May	June	July	August	September	October	6-mths
1961	2.28	1.67	1.90	0.97	2.68	0.60	10.10
1956 - 1961	1.04	2.14	1.19	0.94	1.34	0.94*	7.59

* Data for 1957 missing

months May to October were accepted as falling within the temperature range of the typical summer air mass. Perhaps intermediate temperature values would have been more suitable for the transition months May and October. This was tried for May, but the pattern was similar except that there were three more days classified as having maritime Tropical (mT) air, two less with maritime Polar (mP), and one less with maritime Arctic (mA). In October, the use of an intermediate value would increase the number of days with mT and mP air, and reduce those with mA air. The temperature regime under the different air masses was analysed, and mean values of maximum and minimum temperatures at each station under the summer air masses were obtained.

The general daily condition of the sky was recorded at station 8[1], and these were grouped into four categories: clear; sunny, few clouds; cloudy with few sunny periods; overcast, or cloudy with rain; and correlated with air mass type.

RESULTS

Comparison of 1961 Summer Climatic Conditions at Invermere with the Average Conditions for the Area

The monthly maximum and minimum, and mean temperatures at station 8 (Invermere) during the summer of 1961 were compared with average conditions at that station for the period 1956-1962 (Table 5). Similarly, the monthly precipitation totals were compared for the summer of 1961 and for the period 1956-1961 (Table 6). Temperatures in June and August in 1961

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[1] Observations by Mr. A. Davidson, Dispatcher, Forest Ranger Station, Invermere, who was kind enough to maintain the hygrothermograph and rain gauge at station 8, and who made substantial notes on the daily weather conditions, far above and beyond those required for Forest Fire Danger Surveys.

were well above average, mainly owing to much higher mean maximum temperatures, the minimum in each case being within 2 F of the average for the 5-year period. Temperatures were considerably below average in September and October 1961, especially those in September when the mean maximum was 6 F below average. The monthly precipitation showed considerable variation in the 6 years. Only the May and September totals of 1961 were wetter than for the period 1956-1961, and no months in 1961 were excessively dry.

Six or 7 years is not usually considered long enough to show average trends because of the great variation from year to year. Data are therefore summarized in Tables 7 and 8 for other stations with records of varying length available in the Invermere area and for nearby stations in the Trench with longer records. Station 8, during the period 1956-1962, had a higher monthly mean temperature from May to August and higher precipitation in June and September than other earlier Invermere-area stations, while August was considerably drier. However, it is misleading to generalize when comparing different periods of record. From the 1956-1961 average amounts, the summer precipitation regime for station 8 was slightly lower than at nearby stations in the Trench, such as Brisco, Spillimacheen and Canal Flats. Averages for the 6-month period, May to October, for these latter three stations were all at least 1 inch more than for the Invermere area stations (Table 8). Sinclair Pass and Radium Hot Springs, a few miles into the Rocky Mountain Range east of Steamboat Mountain, both recorded greater average summer precipitation than the stations in the Trench. As will be shown later (Table 24), no

TABLE 7. Mean Monthly Temperature (°F) for May to October, 1961, and for the Period 1956-1962 for Station 8, Compared With Other Stations in the Area.

Station	Period of observation	Elevation (ft)	TEMPERATURE °F					
			May	Jun	Jul	Aug	Sep	Oct
8	1961	2740	54	65	66	66	47	38
8	1956-62	2740	53	60	65	63	53	42
Windermere	1913-49	2840	51	57	63	61	52	41
Wilmer	1909-25	3100	51	58	64	61	52	41
Spillimacheen	1958-68	2615	51	58	63	61	53	42
Radium Hot Springs	1955-68	3570	49	56	62	60	51	40

TABLE 8. Average Monthly Precipitation (Inches) for May to October at Station 8, Compared With Other Stations in the Area.

Station	Period of observation	Elevation (ft)	PRECIPITATION (INCHES)						
			May	Jun	Jul	Aug	Sep	Oct	6-mths
8	1956-61	2740	1.04	2.14	1.19	0.94	1.34	0.96	7.61
Windermere	1913-49	2840	1.16	1.83	1.09	1.40	1.16	0.89	7.53
Invermere Hts.	1913-25	--	1.21	1.53	1.19	1.50	1.14	0.68	7.25
Invermere Comfort Ranch	1915-30	--	1.15	1.78	0.99	1.56	1.18	0.91	7.57
Wilmer	1909-25	3100	1.20	1.64	1.29	1.53	1.10	0.78	7.54
Spillimacheen	1958-68	2615	1.57	2.16	1.72	1.48	1.52	1.20	9.65
Brisco	1924-68	2750	1.43	2.06	1.17	1.44	1.20	1.29	8.59
Radium Hot Springs	1955-68	3570	1.93	2.88	2.40	1.83	1.97	1.52	12.53
Sinclair Pass	1935-55	4410	2.36	3.01	1.91	2.03	1.59	1.68	12.58
Canal Flats	(1924-50 (1962-68	2680	1.60	2.06	1.12	1.42	1.15	1.16	8.51

comparably large totals of summer precipitation occurred in the Frances Creek valley, which is in the rain-shadow of the Purcell Range.

Frequency of the Various Air Mass Types During the Period May to October 1961

In Table 9 are summarized the number of days particular air masses were present over the area from May to October 1961. During June, July, and August, there were twice as many days with mT air as with mP air, and mA air was absent. During the transitional months, May and September, mP air predominated with both the Polar and Arctic Fronts present over the area. In June, July, and August, the Polar Front dominated the area, but frontal activity occurred only on about 50% of the days, the percentage being much higher in winter (90%) (Walker, 1961). In summer, cold air that enters the mountain valleys is rapidly modified by insolational heating whereas in winter, the cold air remains. Kendrew and Kerr (1955) commented that in summer, continental Tropical (cT) air may invade southern British Columbia on the surface as well as aloft. There was evidence that cT air was probably present twice (see Appendix II), but cT was not set up separately because at the 500 and 700 mb levels there was little temperature difference between the cT and mT air masses (Table 4).

Mean Monthly Temperatures

The mean monthly daily temperatures (mean of 24 hourly values for each day) for the eight stations from May to October 1961, are shown in Table 10. Of the valley transect stations (1 to 5), the valley bottom

TABLE 9. Number of Days Each Air Mass Type Was Present in the Invermere Area During May to October 1961.

Air mass	No. of days air mass present					
	May	Jun	Jul	Aug	Sep	Oct
maritime Arctic	7	0	0	0	2	11
maritime Polar	23	11	11	3	23	13
maritime Tropical	1	19	20	23	5	7

TABLE 10. Mean Monthly Temperatures (°F) For All Stations, May to October 1961.

Station No.	Elev-ation (ft)	TEMPERATURE (°F)					
		May	Jun	Jul	Aug	Sep	Oct
1	4800	--	60.3	60.2	63.0	42.0	32.4
2	4000	--	62.3	61.5	63.0	46.2	37.6
3	3390	45.5	54.8	55.5	55.9	39.3	30.1
4	4000	--	61.1	60.7	63.5	44.0	33.6
5	4600	49.8	61.7	61.2	64.5	45.1	36.4
6	3280	--	59.0	60.0	59.3	41.9	32.1
7	3030	47.4	53.7	59.1	59.5	41.3	31.8
8	2740	53.7	65.4	65.8	66.8	47.1	33.4

TABLE 11. Mean Monthly Maximum and Minimum Temperatures (°F) From May to October 1961, For All Stations.

Stn. No.	TEMPERATURE (°F)											
	May		June		July		August		September		October	
	Mx	Mn	Mx	Mn	Mx	Mn	Mx	Mn	Mx	Mn	Mx	Mn
1	-	-	71.0	51.1	69.6	52.0	72.0	55.2	47.9	36.1	36.8	28.0
2	-	-	74.9	51.0	72.6	52.4	74.6	54.1	54.2	40.3	43.4	33.4
3	60.9	30.6	73.9	35.6	74.4	39.1	76.6	38.1	54.1	27.8	43.5	21.3
4	-	-	76.0	49.3	75.7	50.4	79.1	52.7	55.5	36.0	43.5	29.3
5	62.3	42.0	77.2	51.6	76.0	52.6	78.7	55.1	54.8	38.5	43.0	31.3
6	-	-	80.4	38.0	80.8	40.5	84.3	41.2	59.4	27.4	46.5	21.8
7	63.5	31.8	80.0	37.8	77.8	40.2	81.7	40.9	56.9	28.3	45.5	21.8
8	66.5	40.9	82.5	48.4	79.8	51.3	83.1	50.6	59.6	36.3	49.4	30.4

station (3) consistently had lower mean monthly temperatures than the others. The difference amounted to more than 5F in June, July, and August. On the east-facing slope of the valley, the lower station (2) had higher mean temperatures than the higher station (1), but on the west-facing slope the position was reversed, with station 5 having higher means than station 4. The differences between the pairs of slope stations became greater during September and October than during the 3 summer-months. The two valley-bottom stations (6 and 7) downstream from station 3 also had lower means than the slope stations, but they were usually several degrees warmer than station 3. Station 8 had mean monthly temperatures 2 or more degrees F warmer in the summer than any of the stations in the Frances Creek valley.

Maximum and Minimum Temperatures

Mean monthly daily maximum and minimum temperatures for the eight stations are shown in Table 11. At the transect stations, higher maximum temperatures were recorded on the west-facing slope than on the east-facing slope, while maximum temperatures in the valley bottom were intermediate. Maximum temperatures at station 1 were consistently lower than at other stations by over 3F. This was expected, because the angle of insolation was more acute on the east-facing slope than on the west-facing slope during the afternoon when maximum temperatures were usually achieved. By October, the range between the daily mean maximum at stations 2 to 5 was small (0.5F). The maximum temperatures at stations 6, 7, and 8 were higher than those of the valley transect stations. The mean monthly daily minimum temperatures were markedly lower at the valley bottom stations (3, 6, and 7) than at stations on the slope or in the main Trench. From June to August, they were often over 10 F cooler. The minimum temperatures on the slopes of Frances Creek were usually slightly higher than those at station 8. From June to August, the highest minimum in the Frances Creek valley were recorded at station 5, followed closely by stations 1 and 2. In September and October, the highest minimum of the Frances Creek stations were recorded at station 2 with temperatures over 10 F warmer than those at station 3, just 600 ft lower. Generally, there was greater local variation in minimum temperatures than in maximum temperatures, though under calm, clear conditions there may be considerable variation in the maximum at the various stations. The seasonal trends of temperature from May to October 1961 are illustrated in Fig. 5. These show the 5-day running means of maximum and minimum temperatures for stations 1, 3, and 5. The trends of the maximum temperatures at the three stations were similar, with station 5 usually having the highest minimum and station 1 the lowest, while the minimum was consistently cooler at station 3.

The maximum and minimum temperatures for the 3 summer-months were sorted with regard to the type of air mass present on that day for stations 1 to 5, and 8. The mean maximum and minimum temperatures for the two prevailing summer air masses are shown in Table 12 for these stations. There is a pronounced difference in the maximum temperatures between the two air masses, and days with mT air were considerably higher than days with mP air. There was less difference between the minimum temperatures under the two air masses. The differences ranged from

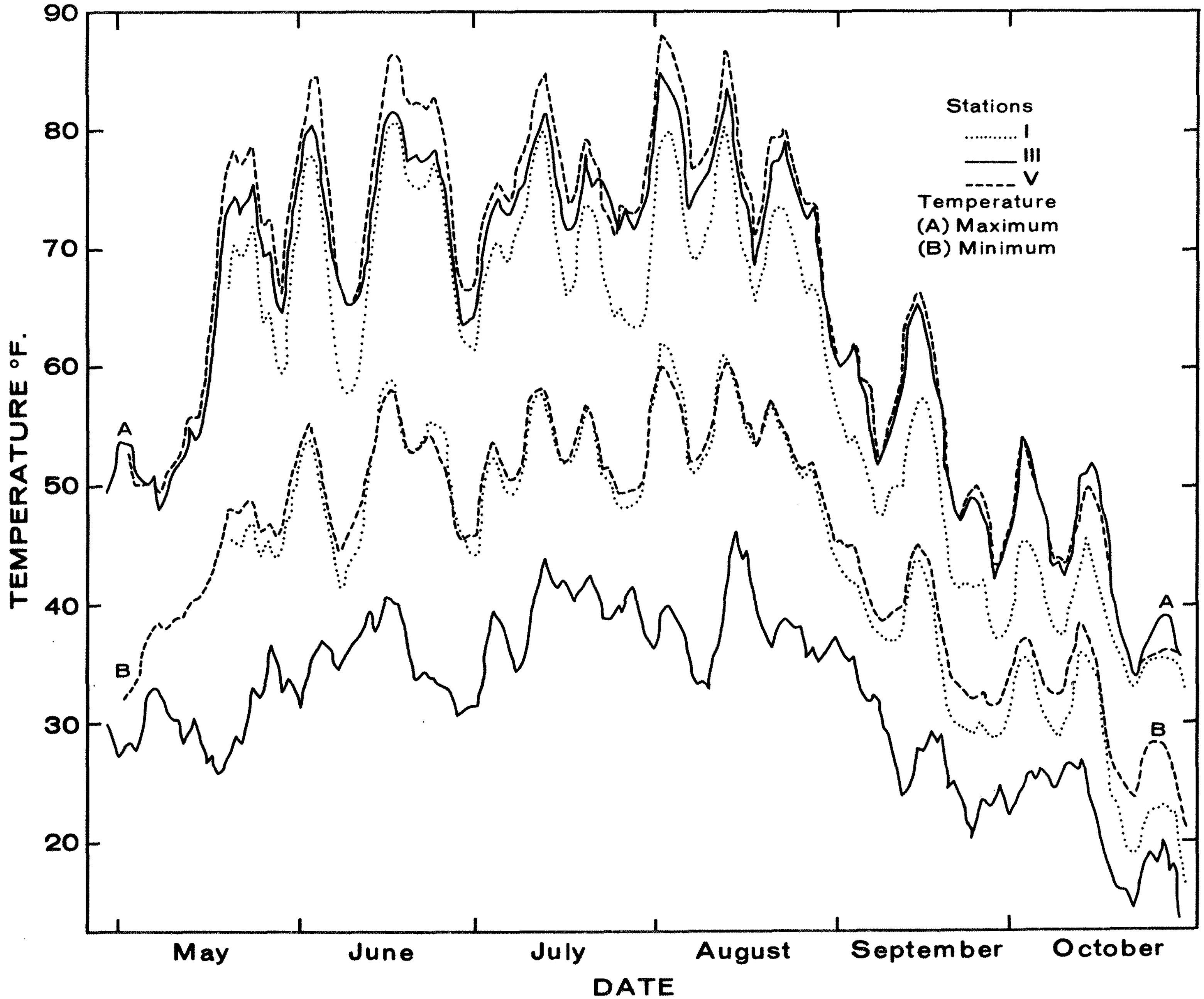


Fig.5. Five-day running means of maximum and minimum temperature (°F), May to October 1961, for stations 1,3, and 5 in the Frances Creek valley.

2.8 F at the valley bottom station (3) to 8.3 F at the higher east-facing slope station (1). Differences in the maximum temperatures under the two air masses ranged from 9.8 F at the lower east-facing slope station (2) to 12.9 F at the higher east-facing slope station (1). The stations on the east-facing slope recorded the lower maximum temperatures of the transect stations, the highest being recorded at the higher west-facing slope station (5).

Diurnal Temperature Range

The mean daily temperature range (Table 13) in the various months reflected the diurnal extremes of temperature. The greatest range was at the three Frances Creek valley-bottom stations (3, 6, and 7), this range often being twice that of the slope stations. Least range was on the east-facing slope, the range on the west-facing slope being 5 to 8 F higher from June to August, and 2 to 5 F higher in September and October. The daily temperature range at station 8 was greater than that on the slopes, but usually 5 to 6 F less than that at station 3, the valley bottom station that showed the least range. A range of 50 to 60 F was not uncommon at the valley bottom stations, but a range of only about 30 F was experienced at east-facing slope stations from May to August.

Table 14 shows the mean daily temperature range under different air masses for the 3 summer-months. Ranges were considerably greater under the mT air, than under the mP air. This was probably due to the greater amount of cloudiness that was associated with the mP air.

TABLE 12. Mean Maximum and Minimum Temperatures (°F) at Six Stations Under the Two Dominant Summer Air Masses, During June to August 1961.

Air mass type	No.of days	Maximum Temperature Station no. 1	2	3	4	5	8	Minimum Temperature Station no. 1	2	3	4	5	8
mP	30	62.2	67.4	67.0	68.6	69.0	73.2	47.1	49.5	35.6	46.1	48.2	46.6
mT	62	75.1	77.2	78.8	81.0	81.5	85.7	55.4	54.4	38.4	53.1	55.5	51.6

TABLE 13. Mean Monthly Daily Temperature Range (°F) At All Stations May to October 1961.

	Daily Temperature Range (°F)					
Stn. no.	May	June	July	August	September	October
1	--	19.9	17.6	16.8	11.8	8.8
2	--	23.9	20.2	20.5	13.9	10.0
3	30.3	38.0	35.3	38.5	26.3	22.2
4	--	26.7	25.3	26.4	19.5	14.2
5	20.3	25.6	23.4	23.6	16.3	11.7
6	--	42.4	40.3	43.1	32.0	24.7
7	31.7	42.2	37.6	40.8	28.6	23.7
8	25.6	34.1	28.5	32.5	23.3	19.0

TABLE 14. Mean Daily Range of Temperature (°F) (June to August) Under the Two Summer Air Masses at Six Stations.

Air mass type	Daily Temperature Range (°F) Station no. 1	2	3	4	5	8
mP	15.1	17.9	31.4	22.5	20.8	26.6
mT	19.7	22.8	40.4	27.9	26.0	34.1

Exact data on cloudiness were not available, but general daily summations of degree of cloudiness were available for station 8, and these were arbitrarily divided into four categories (Table 15).

Hourly Temperatures

The mean daily hourly temperatures from May 19 to October 31, 1961 for stations 1 to 5 are shown in Fig. 6. Most notable is the marked temperature range for station 3. The periods of maximum and minimum temperatures show some variation. Minima were recorded at station 1 between 0400 and 0500 hours, at stations 2 and 3 at 0500 hours, but not until 0600 hours at stations 4 and 5. The earliest maxima (1300 hours) occurred at station 1, and the latest (1500 hours) at station 4, with maxima at other stations being recorded at 1400 hours. The actual times of the maxima and minima varied with the month of the year and this is illustrated in Table 16, which shows the mean hour of maxima and minima temperature at each station. The earliest minimum usually occurred at the east-facing slope stations. In September and October, there was a 3-hour spread in the times of the minima, varying from 0500 to 0700 hours. The minima were usually latest at stations 5 and 8. The maxima were earliest at station 1 in all months, and in certain months this station was joined by station 2 in having the earliest maxima. This was as one would expect, for after mid-day these east-facing stations were in an unfavorable position for receiving direct solar radiation. Usually, the maximum occurred latest at station 4 of the transect stations, but later maxima were experienced at stations 7 and 8. The maximum at station 8 usually occurred three hours after the maximum at station 1, and was some 10F higher.

TABLE 15. Number of Days with Certain Sky Conditions Under the Two Summer Air Masses for June to August 1961.

Sky conditions	Air mass	
	mP	mT
Clear	0	9
Sunny, few clouds	12	41
Cloudy, with few sunny periods	11	9
Overcast; Cloudy with rain	7	3

TABLE 16. Hour of the Maximum and Minimum Temperatures in the Different Months at the Eight Stations.

Stn. no.	Temp. and Hour	TEMPERATURE (°F) May Mx	May Mn	June Mx	June Mn	July Mx	July Mn	August Mx	August Mn	September Mx	September Mn	October Mx	October Mn
1	T	--	--	68.7	51.9	67.3	52.9	70.5	56.8	46.6	37.6	35.4	29.6
	H	--	--	13	04	13	04	14	05	13	05	13	06
2	T	--	--	71.7	52.6	69.9	53.0	73.0	55.0	54.7	43.3	44.3	36.5
	H	--	--	16	05	15	04	14	05	14	05	13	05
3	T	58.3	31.2	70.8	36.1	70.3	39.7	74.0	39.3	52.2	29.3	41.5	22.8
	H	15	05	16	05	14	05	15	05	14	05	14	05
4	T	--	--	73.5	50.4	72.1	50.4	76.7	53.8	53.7	37.8	41.8	31.3
	H	--	--	15	06	15	05	15	06	15	06	15	07
5	T	59.7	41.8	76.6	52.3	71.8	52.4	76.5	56.1	53.1	40.0	42.2	33.5
	H	14	05	15	05	14	05	14	06	14	07	14	07
6	T	--	--	76.7	38.7	76.6	41.7	80.4	41.9	56.3	31.1	44.5	25.3
	H	--	--	15	05	14	05	15	06	16	06	15	07
7	T	61.1	32.7	75.8	38.8	74.0	42.0	78.0	42.2	54.5	30.6	43.7	24.8
	H	16	05	16	04	17	05	15	06	15/16	06	15	06
8	T	64.2	42.3	79.1	49.8	76.3	51.6	80.5	50.6	57.9	39.2	46.7	32.9
	H	16	05	16	05	16	05	17	06	15	06	16	07

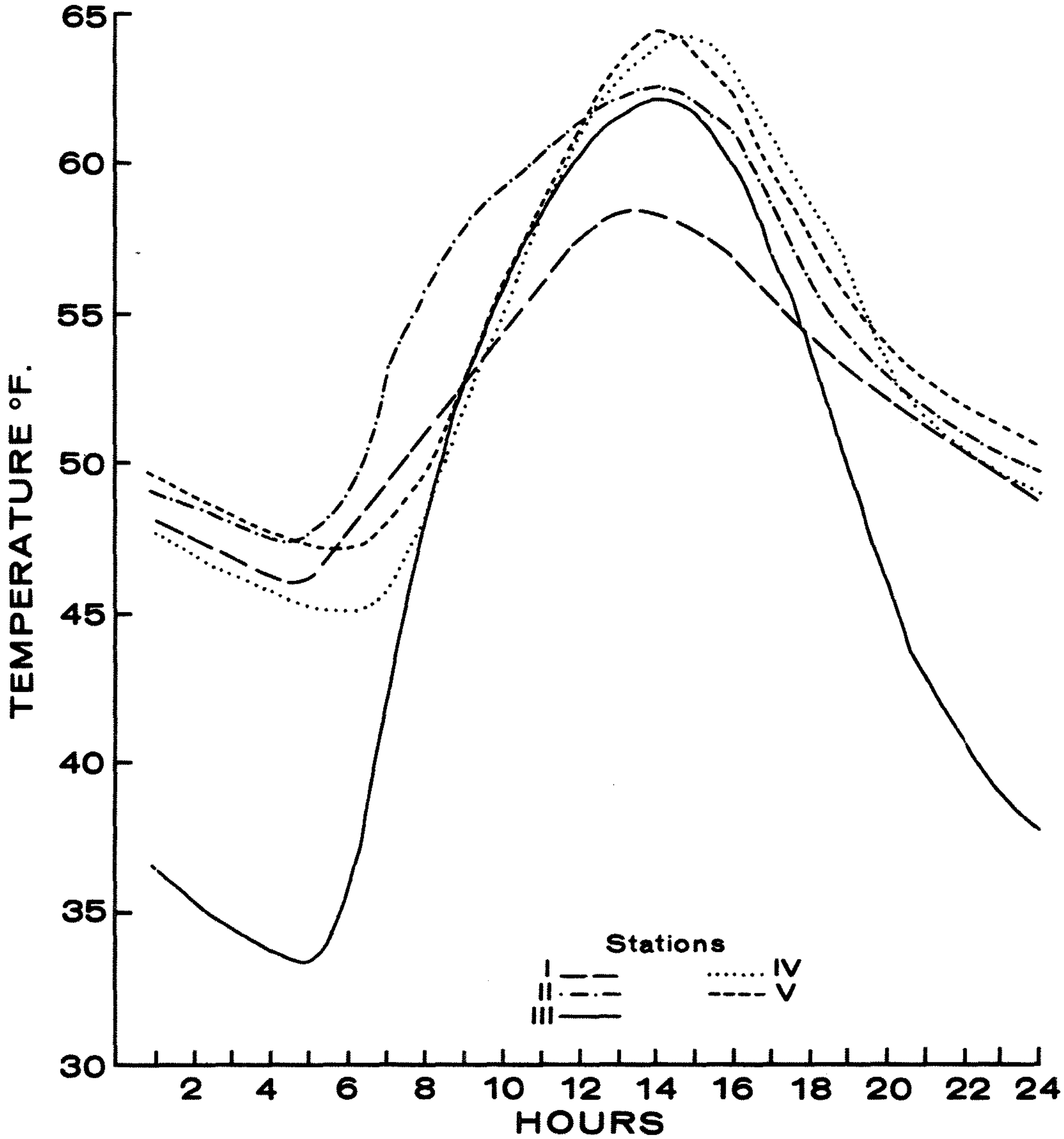


Fig. 6. Mean daily hourly temperatures (°F) from May 19 to October 31,1961, for stations 1 to 5.

Nocturnal Inversions

Inversions occurred every night in the Frances Creek valley. Temperatures were lower in the valley bottom than on the slopes but there was some variation relative to the position of the slope stations. On the east-facing slope, 47 out of 166 nights were warmer at the higher level (stn.1) than at the lower level (2). All but one of these warmer nights at station 1 occurred in June, July, or August, usually when mT air was present. In August, more than two-thirds of the nights were warmer at the higher level. On the west-facing slope, only on May 26 was the night temperature higher at the lower level (4); the higher station (5) was warmer on all other occasions. When minimum temperatures on the west- and east-facing slopes, from June to August were compared, temperatures were higher on 25 nights at station 1 on the east-facing slope than at station 5 on the west-facing slope, and on a further 24 nights the minimum temperatures were the same. During September and October, temperatures were usually warmer at station 5, for only on 4 nights were temperatures cooler than station 1, and on only 5 nights were temperatures the same. On 133 nights, the temperature was warmer at station 2 than at station 4; the reverse occurred on 21 nights. Occasionally, the inversions were associated with valley fogs; these were more frequent during the early autumn.

The nocturnal inversion under the different air masses in summer in the valley transect is shown as the difference between station 3 and the slope stations (Table 17). Under mP air, the greatest difference existed at station 2, with a decrease of temperature upwards, which suggests that the maximum thermal belt on the east-facing slope existed

TABLE 17. Average Amount of Nocturnal Inversion (°F) Between Stations (3 as base) Under Different Air Masses During June to August 1961.

Air mass	Amount of Nocturnal Inversion (°F) Station no. 1	2	4	5
mP	11.5	13.9	10.5	12.6
mT	17.0	16.0	14.7	17.1

near the 4,000-ft level. On the west-facing slope, the maximum thermal belt existed at the higher level (4,600 ft). This suggests that the inversion was tilted. Under mT air, the inversion was deeper, though temperatures were similar at 4,600 to 4,800 ft. On the average, the temperature inversion was 5 F deeper under mT air than mP air at the higher levels and thus, was more strongly developed. Usually, therefore, the higher the maximum temperature during the previous day, the greater the chance of a strongly developed inversion and, therefore, the greater the chance that station 1 would be warmer than station 2. The relation between amount of temperature inversion and daily range in temperature was still more marked. Sky cover lowered the magnitude of an inversion especially under mP air. The average inversion magnitude under mP air for the days with overcast conditions was 10 F, for the cloudy days 15 F, and for the basically sunny days 17 F.

Figure 7 presents a series of cross-sections of temperature distribution at 3-hour intervals to show the development and dissipation of the nocturnal inversion in the Frances Creek valley, under each

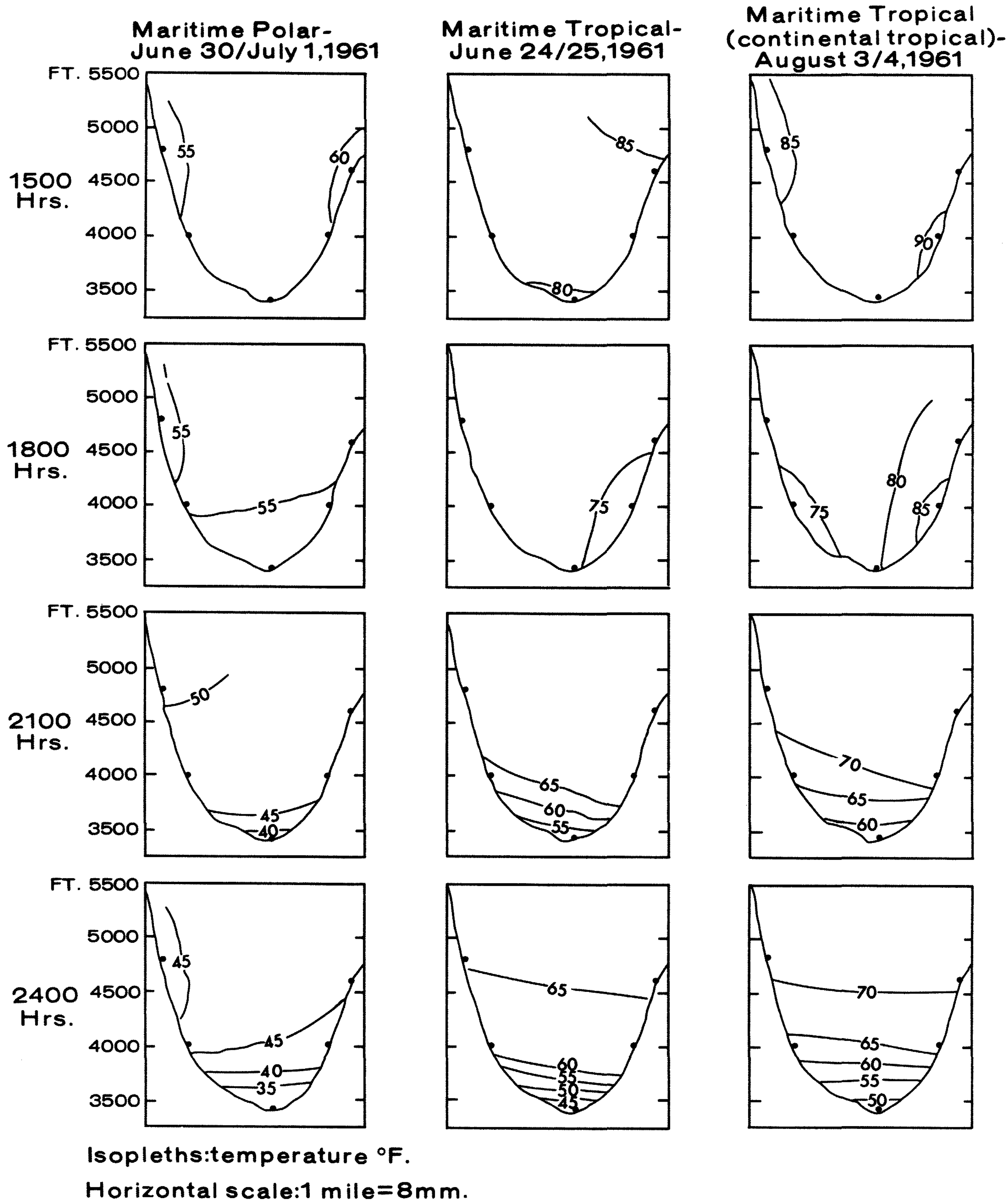
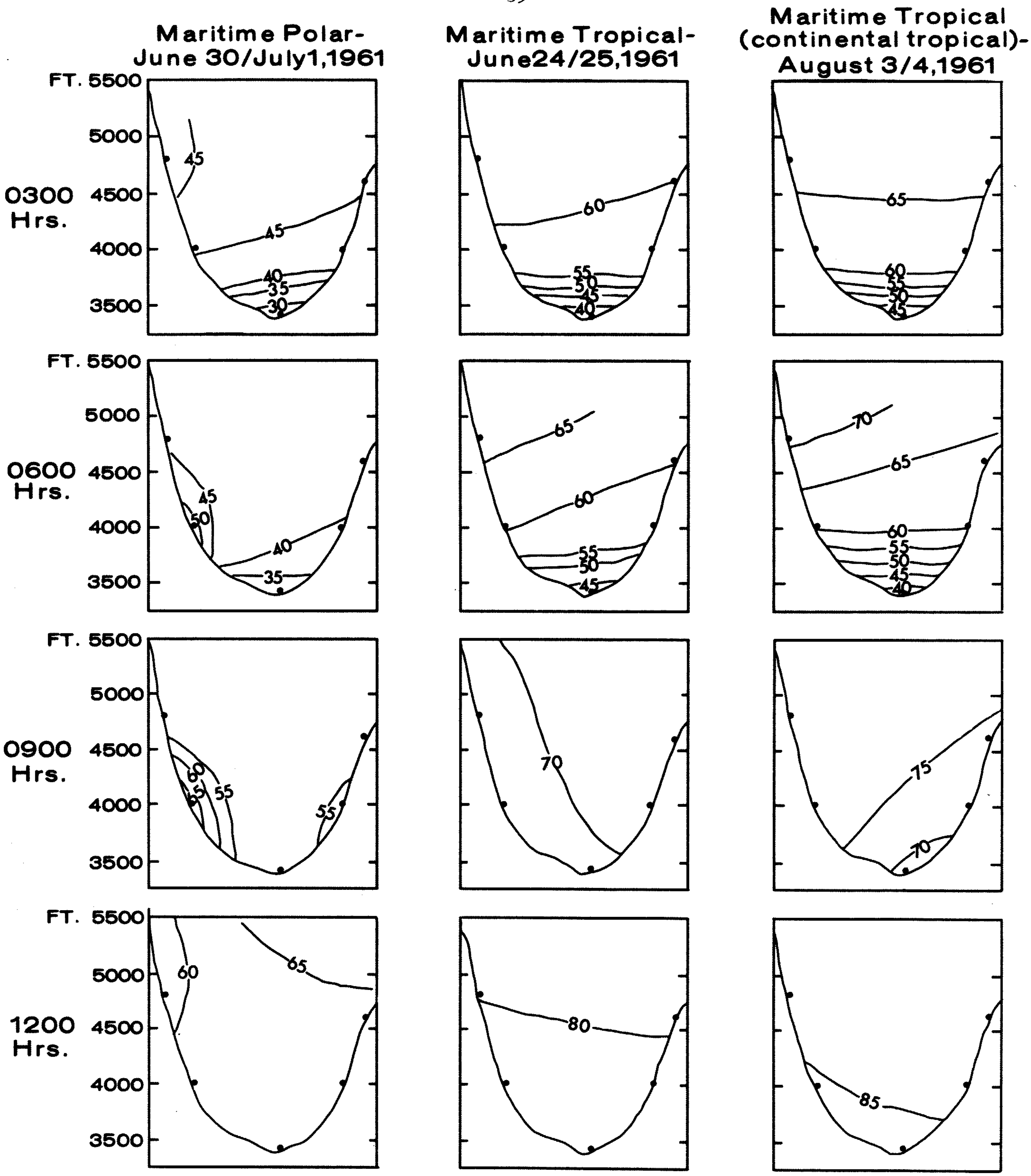


Fig.7. Profiles of the Frances Creek valley, with isotherms (°F) at 3-hour intervals showing development and dissipation of nocturnal inversions under different summer air masses.



Isopleths:temperature°F.

Horizontal scale:1mile=8mm.

Fig.7. (cont'd.) Profiles of the Frances Creek valley, with isotherms(°F) at 3-hour intervals showing development and dissipation of nocturnal inversions under different summer air masses.

air-mass type, typical days being chosen for each type. The inversion was less developed under mP air, and most strongly developed under cT air. On each occasion, the lag in the cooling of the west-facing slope at 1800 hours was most noticeable, and this effect continued until 2000 hours; and under mT and cT air, even until 2200 when there was still a noticeable tilt in the inversion layers. The most pronounced development of the inversion took place between 2000 and 0200 hours after which there was a steady increase or strengthening of the inversion until around sunrise. The development of the inversion, therefore, set in before sunset and lasted until after sunrise; net outward radiation increased progressively early in the evening and generally reached a maximum shortly after sunset after which net radiation remained constant the entire night. By 0600 hours the warming of the east-facing slope had commenced and by 0800, under the examples of mP and mT air, the inversion had been dissipated. This was not true under the cT air example, but this was because the example occurred some 6 weeks after the summer solstice, and sunrise was later than in the other examples which were close to the solstice. By 1000 hours, the east-facing slopes were considerably warmer, which shows the dominating effect of incoming solar radiation; but by midday, the west-facing slopes were as warm or warmer.

Figure 8 illustrates the rapid fall of temperature on a number of clear days for station 3 when solar insolation no longer reached the station, and the rapid rise in the morning when solar insolation again fell on the station. The pattern of temperature change was similar on all these clear days even though it covers a range from May 19 to September 14. There was always a marked drop from after 1600 hours to 2000 or 2200

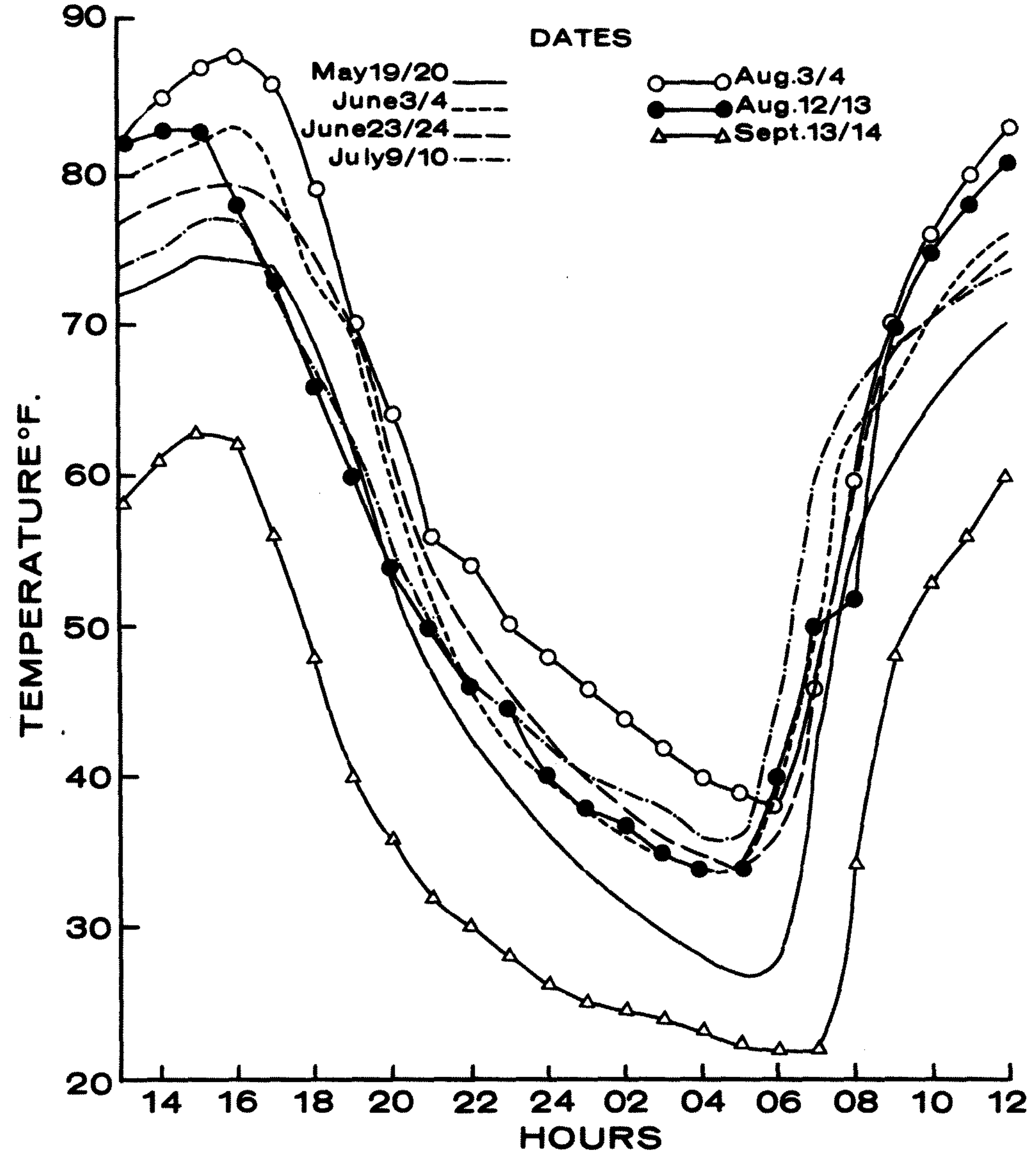


Fig.8. Diurnal patterns of temperature (°F) on a number of days throughout the summer at station 3.

hours depending on time of season, then a gradual fall throughout the rest of the night until 0500 hours after which a rapid rise occurred. The diurnal temperature change at eight stations on June 23/24 is shown in Fig. 9. The pattern of change at the valley bottom stations (3, 6, and 7) was very similar as was that at the slope stations (1, 2, 4, and 5). Stations on east-facing slopes tended to have a very short period with temperatures around the maximum but stations on level ground, such as 6, 7, and 8, had a much longer period with temperatures near the maximum.

Occurrence of Frosts

Frosts only occurred at the three valley-bottom stations during the three summer months (June to August), being recorded in each month at stations 3 and 7 and in June and July, at station 6 (Table 18). Even in May, stations 3 and 7 recorded 20 and 18 days of frost, respectively, when other stations recorded very few. During the 184 days from May to October, frosts were recorded at the valley bottom stations on almost half the days but slope stations only recorded frosts on about 20% of the period. This was also the position for station 8. If station 5 was typical, the slope stations in the Frances Creek valley were frost-free for 125 to 140 days, a similar length to that recorded at station 8 in the main Trench. Table 19 shows that the length of the frost-free period in 1961 at station 8 was longer than the average from 1956 to 1962. However, the average duration of the frost-free period at station 8 and at the nearby stations of Wilmer and Windermere (about 110 days) was considerably longer than for other stations in the Trench, which indicates

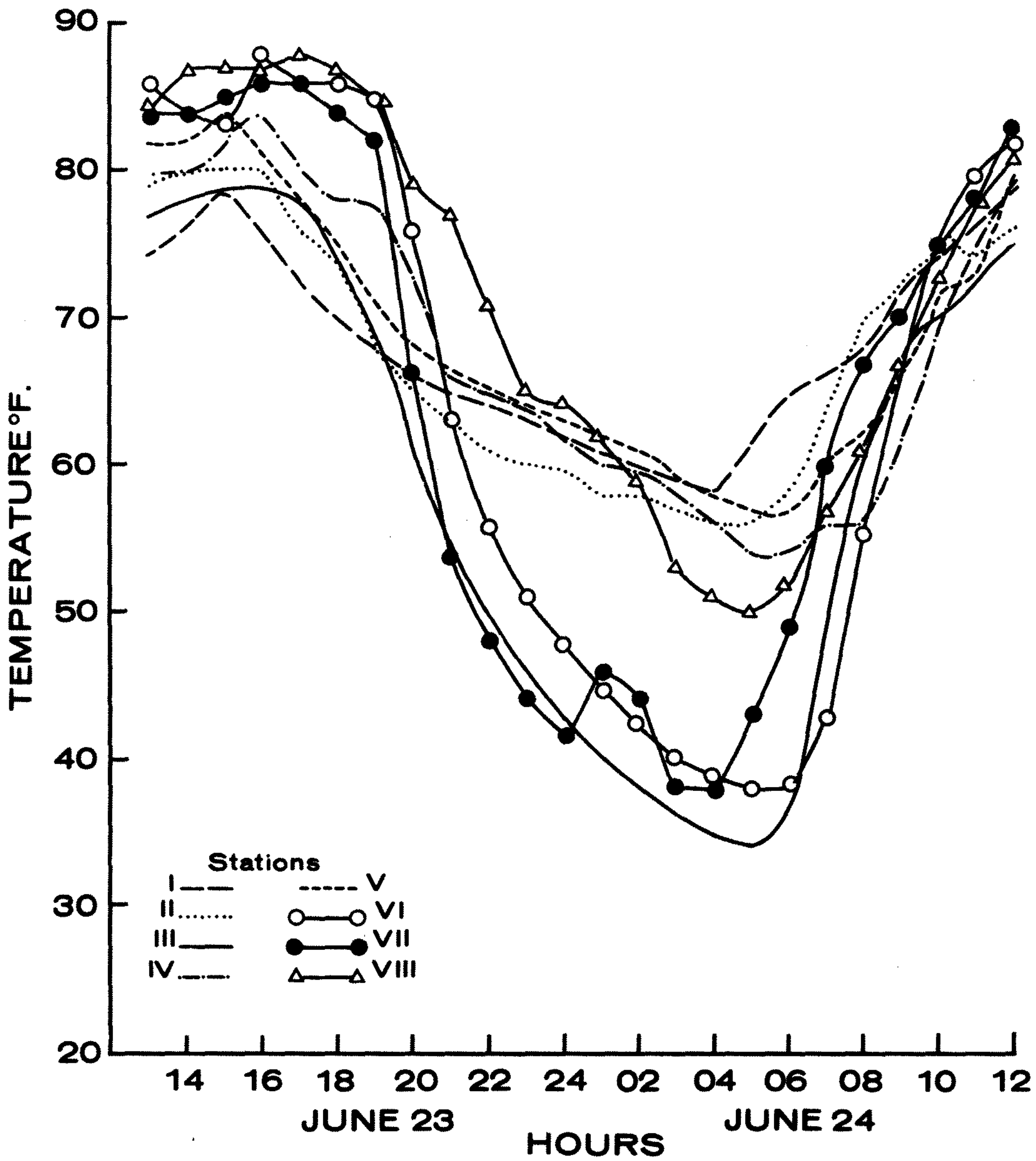


Fig.9. Diurnal patterns of temperature (°F) on a clear day, June 23/24,1961, for eight stations.

TABLE 18. Number of Days of Frost (Temperature 32°F or Below) and Length of Frost-free Period at All Stations in the Period May to October 1961.

Stn. no.	No. of Days of Frost							Length of frost-free period(days)
	May	June	July	Aug	Sept	Oct	Total	
1	0[a]	0	0	0	11	24	35[b]	114[d]
2	0[a]	0	0	0	3	16	19[b]	127[d]
3	20	8	5	5	21	31	90	17
4	0[a]	0	0	0	9	24	33[b]	126[d]
5	2	0	0	0	8	20	30	141
6	-	4	3	0	25	31	63[c]	59
7	18	4	3	2	22	31	80	49
8	2	0	0	0	7	20	29	132

[a] Only data for May 18-31; [b] Only data for 167 days;
[c] Only data 153 days; [d] A longer frost-free period is probable.

TABLE 19. Dates of Last and First Frost and Duration of the Frost-free Period for Station 8 and Average Dates and Length of the Frost-free Period for a Number of Other Stations in the Rocky Mountain Trench.

Stn.	Period	Date of Last Frost			Date of First Frost			Mean duration of frost-free period
		Mean	Earliest	Latest	Mean	Earliest	Latest	
8	1961	May 12			Sep 22			132
8	1956-62	May 15	Apr 26	Jun 12	Sep 12	Sep 1	Sep 29	118
Windermere	1913-49	May 27	May 10	Jun 23	Sep 12	Jul 20	Oct 7	108[1]
Wilmer	1909-25	May 27	May 4	Jul 10	Sep 18	Sep 2	Oct 7	114[1]
Sinclair Pass	15 yr.	Jun 24	May 27	Jul 13	Aug 18	Jul 20	Sep 8	55[1]
Golden	47 yr.	Jun 5	May 6	Jul 13	Sep 8	Jul 17	Oct 6	95[1]
Cranbrook	32 yr.	Jun 10	May 17	Jul 7	Aug 27	Jul 19	Sep 20	78[1]
Cranbrook Airport	12 yr.	Jun 6	May 15	Jul 12	Sep 10	Aug 20	Oct 8	96[1]
Kimberley Airport	8 yr.	May 31	May 10	Jun 27	Sep 4	Jul 29	Sep 19	96[1]

[1] from Boughner et al. (1956)

that more favorable frost-free conditions were present in the Windermere Lake area. Similar favorable conditions were also experienced on the slope areas of the tributary valleys (cf. Table 18).

Degree Days and Degree Hours During the Growing Season

At most stations, the growing season (based on period when temperatures are above 42F) does not begin until well into May; it is only likely to start near the end of April in the main Trench. At many stations the growing season ended on September 6/7 in 1961 but at other stations it continued for a further two weeks. The valley bottom station (3) had the shortest growing season. During May to September, station 8 received about 9% more day degrees above 42F than station 5, the station in the Frances Creek valley with the highest number of day degrees (Table 20). The valley bottom stations (3, 6, and 7) all had less day degrees than the slope stations, and at station 3 this was particularly marked. Station 7, at the entrance to the valley, had 400 or about 30% more day degrees than did station 3, some 8 miles up the valley.

Station 8 received 15% more degree hours above 32 F than station 5 and 50% more than station 3, from May 1 to October 31 (Table 21). Of the Frances Creek stations, stations 1 and 5 received, respectively, 22 and 31% more than station 3 in the period May 19 to October 31.

Soil Temperatures

The maximum soil temperatures were not recorded until the middle of August (Table 22). After the beginning of September, there was

TABLE 20. Number of Growing Day Degrees Above 42 F (Based on Mean of Hourly Readings) During the Summer of 1961 at the Stations.

Station no.	No. of Degree Days Above 42 F Apr	May	Jun	Jul	Aug	Sep
1	--	175*	548	564	654	85
2	--	241*	609	606	649	141
3	--	151	381	420	434	38
4	--	220*	574	578	667	118
5	--	255	590	596	698	139
6	--	--	509	557	557	75
7	--	191	502	530	546	61
8	35	361	710	705	754	180

*Only data for May 19-31.

TABLE 21. Number of Degree Hours Above 32 F at Four Stations During the Period May to October 1961.

Month	No. of Degree Hours Above 32 F Station no. 1	3	5	8
May	-	10254	13306	15919
(May 19-31)	(7324)	(6247)	(8204)	-
June	20348	16702	21350	24241
July	20978	17570	21727	24361
August	23136	17852	24203	25522
September	7359	6405	9539	11012
October	2507	2133	2454	5424

TABLE 22. Soil Temperatures (°F) For Seven Stations Taken at Weekly Intervals from June 14 to September 27, 1961.

Stn. no.	Time of observation (hours)	SOIL TEMPERATURES (°F) June 14	June 21	June 28	July 5	July 12	July 19	July 26	August 2	August 9	August 16	August 23	August 30	September 6	September 13	September 20	September 27
1	1300-1600	45.9	46.4	45.3	46.6	46.6	47.8	48.2	48.9	52.2	48.9	50.9	48.2	45.1	42.8	43.0	39.6
2	1200-1500	50.9	52.7	51.1	52.3	53.4	53.4	52.5	54.7	53.2	54.7	53.8	52.2	51.6	51.8	45.7	41.4
3	0930-1130	58.3	59.9	57.7	59.7	62.1	59.4	57.9	60.6	60.3	62.1	59.5	58.1	52.3	49.1	49.5	41.7
4	1030-1230	56.8	56.3	53.4	56.8	57.7	57.0	55.2	58.5	57.9	60.3	58.5	56.7	50.7	48.9	48.9	42.4
5	1030-1230	52.5	54.0	52.2	52.7	53.6	54.0	53.4	54.5	55.0	56.3	55.4	54.3	50.5	46.8	47.1	41.9
7	1330-1630	60.4	63.9	63.0	61.7	65.1	63.7	63.7	65.1	64.2	65.8	63.1	61.3	54.0	52.7	52.0	45.3
8	0800-0900	--	--	--	--	--	--	67.3	--	--	70.0	62.4	61.2	51.8	47.8	50.5	44.1

a fairly rapid fall in temperature with the onset of cooler air temperatures and smaller amounts of daily insolation. Valley bottom stations had higher soil temperatures, and there was a considerable difference between east- and west-facing slopes, with the east-facing slope the cooler. On this cooler slope, the higher station was usually 2 or more degrees F cooler than the lower station.

Soil Moisture

The rapid fall of the soil moisture levels in the spring was most noticeable (Fig. 10). During the summer, there was a response of soil moisture levels to precipitation. The replenishing of the soil moisture content in the autumn was apparent. The soil moisture at station 3 was exceptionally high from late June to the end of August (40-55% moisture by ovendry weight); this was caused by a high water table as the adjacent area was subject to flooding by Frances Creek. Station 1 at the higher level on the east-facing slope had the highest soil moisture level of the other stations.

Precipitation

Precipitation was measured at weekly intervals and the totals are given for 3-week periods in Table 23. Station 1, situated at the highest elevation and on the west side of the valley in the lee of the mountain ridge, received more precipitation than other transect stations. Amounts at stations 2 to 5 were very similar with a slight tendency for the lowest station (3) to receive the least amount. When the records

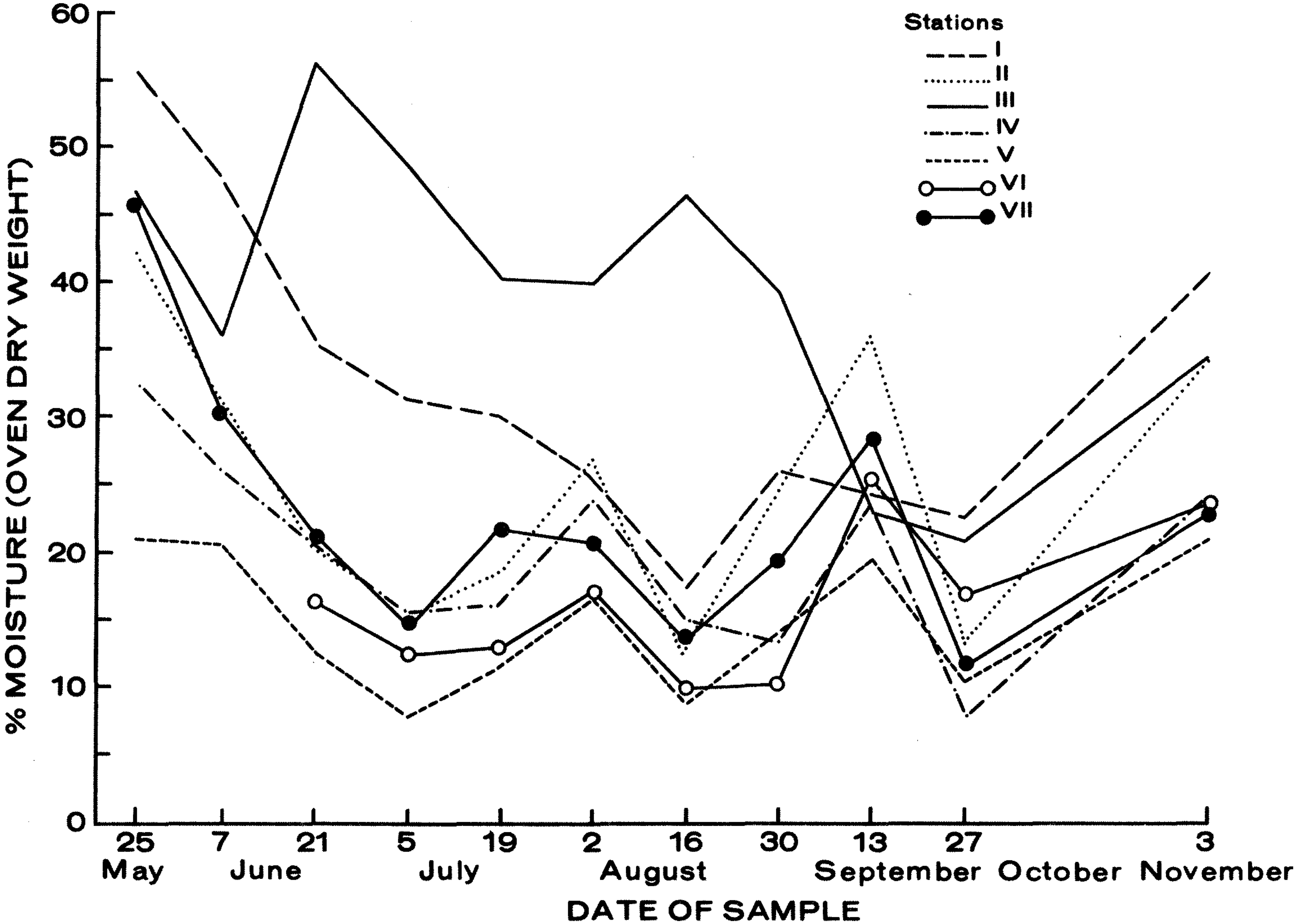


Fig.10. Soil moisture (% ovendry weight), May 25 to November 3,1961, at seven stations in the Frances Creek valley.

TABLE 23. Three Weekly Totals of Precipitation from April 23 to November 3, 1961, and the Total from May 19 to November 3, for the Stations.

	PRECIPITATION (INCHES)									Total
Stn. no.	Apr 28 May 18	May 19 Jun 8	Jun 9 Jun 28	Jun 29 Jul 19	Jul 20 Aug 9	Aug 10 Aug 30	Aug 31 Sep 20	Sep 21 Oct 11	Oct 12 Nov 3	May 19- Nov 3
1	--	0.66	0.67	1.27	1.01	1.25	1.84	0.92	1.09	8.71
2	--	0.62	0.58	0.97	0.89	1.14	1.42	0.81	0.67	7.10
3	1.51	0.68	0.69	0.81	0.84	1.09	1.30	0.69	0.60	6.70
4	--	0.88	0.70	0.90	1.10	0.96	1.21	0.73	0.52	7.00
5	--	0.79	0.72	1.00	0.88	1.22	1.15	0.80	0.56	7.12
6	--	--	0.72	0.66	0.63	0.89	1.24	0.48	0.38	--
7	1.56	--	--	1.16	0.52	1.04	1.17	0.45	0.32	--
8	2.16	0.36	1.22	1.14	1.13	0.75	2.21	0.81	0.39	8.01

TABLE 24. Three Weekly Totals of Precipitation from May 31 to November 2, 1960, and the Total from June 11 to November 2, for Nine Stations.

	PRECIPITATION (INCHES)								Total
Stn. no.	May 31* Jun 11	Jun 11 Jun 29	Jun 29 Jul 20	Jul 20 Aug 10	Aug 10 Aug 31	Aug 31 Sep 21	Sep 21 Oct 12	Oct 12 Nov 2	Jun 11- Nov 2
1	--	0.59	0.08	0.27	0.50	0.80	0.89	0.60	3.73
2	--	0.25	0.11	0.19	0.33	0.86	1.25	0.59	3.58
3	0.36	0.46	0.11	0.20	0.39	0.61	1.28	0.39	3.44
4	0.26	0.36	0.10	0.20	0.42	0.52	1.56	0.39	3.55
5	0.00**	0.59	0.16	0.21	0.40	0.61	1.25	0.38	3.60
7	--	0.25	0.05	0.15	0.30	0.55	1.30	0.20	2.80
8	0.35	0.90	0.30	0.23	0.19	0.89	1.61	0.41	4.53

* Two-week period only

** One-week period only

were comparable, stations 6 and 7 received less precipitation than the other valley stations. When rain clouds were present in the area, they tended to parallel the slopes and did not always cover the whole area. It is probable that during the week some evaporation of rainfall occurred from the rain gauges, especially when only small total amounts fell or when rain fell early in the week[1]. It was likely, therefore, that the totals at stations 1 to 7 were lower than the amount that actually fell. This may help to explain why a larger amount was recorded at station 8 where precipitation was measured daily. A comparison of the actual 3-week totals at station 8 and the rest of the stations suggests that often different rainfall regimes existed over the area. In 1960, from June 6 to November 2, station 8 received 0.66 inch more precipitation than any of the transect stations (1-5), and 1.46 inch more than station 7. In 1960, station 3 again received slightly less precipitation than the slope stations (Table 24).

Relative Humidity

Mean monthly humidity values (Table 25) were usually higher at station 3, except in September. Generally, conditions on the slopes and at station 8 were much drier. The use of monthly means hides much of the daily moisture conditions of the individual sites. Figure 11 shows the diurnal moisture pattern for four of the stations on one of the hottest days of the year (August 3/4) and on one of the days with considerable overcast conditions and rain (July 27/28). On the overcast day, all stations had essentially the same moisture regime though the actual period

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[1] On one occasion 0.70 inch of rain was noted at station 6 but 3 days later only 0.62 inch was recorded.

TABLE 25. Mean Monthly Relative Humidity (%) May to September 1961, for Six Stations.

Stn. no.	Relative Humidity (%) May	Jun	Jul	Aug	Sep
1	56.5*	53.1	59.3	54.6	68.8
2	--	61.3	70.4	70.3	85.3
3	73.4	68.1	74.4	73.4	79.5
4	50.4*	55.5	63.7	57.6	74.5
5	64.4	55.3	66.2	57.3	73.7
8	65.6	55.9	63.2	62.1	77.3

*Only data for May 19-31

TABLE 26. Weekly Evaporation Amounts (c.c.) from 12-inch Diameter Evaporation Pans Maintained at Four Stations Between June 21 and September 27, 1961.

Stn. no.	Weekly Evaporation (c.c.) June 28	July 5	12	19	26	August 2	9	16	23	30	September 6	13	20	27
1	--	--	--	--	--	--	--	1650	870	1000	410	280	650	270
3	1455	1200	1660	1280	1050	1020	1585	1600	875	1130	670	490	772	415
5	1500	1165	1665	1245	1130	910	1700	1950	950	1250	680	400	865	357
8	--	3242	4582	3428	3004	2524	4434	--	--	--	--	--	--	--

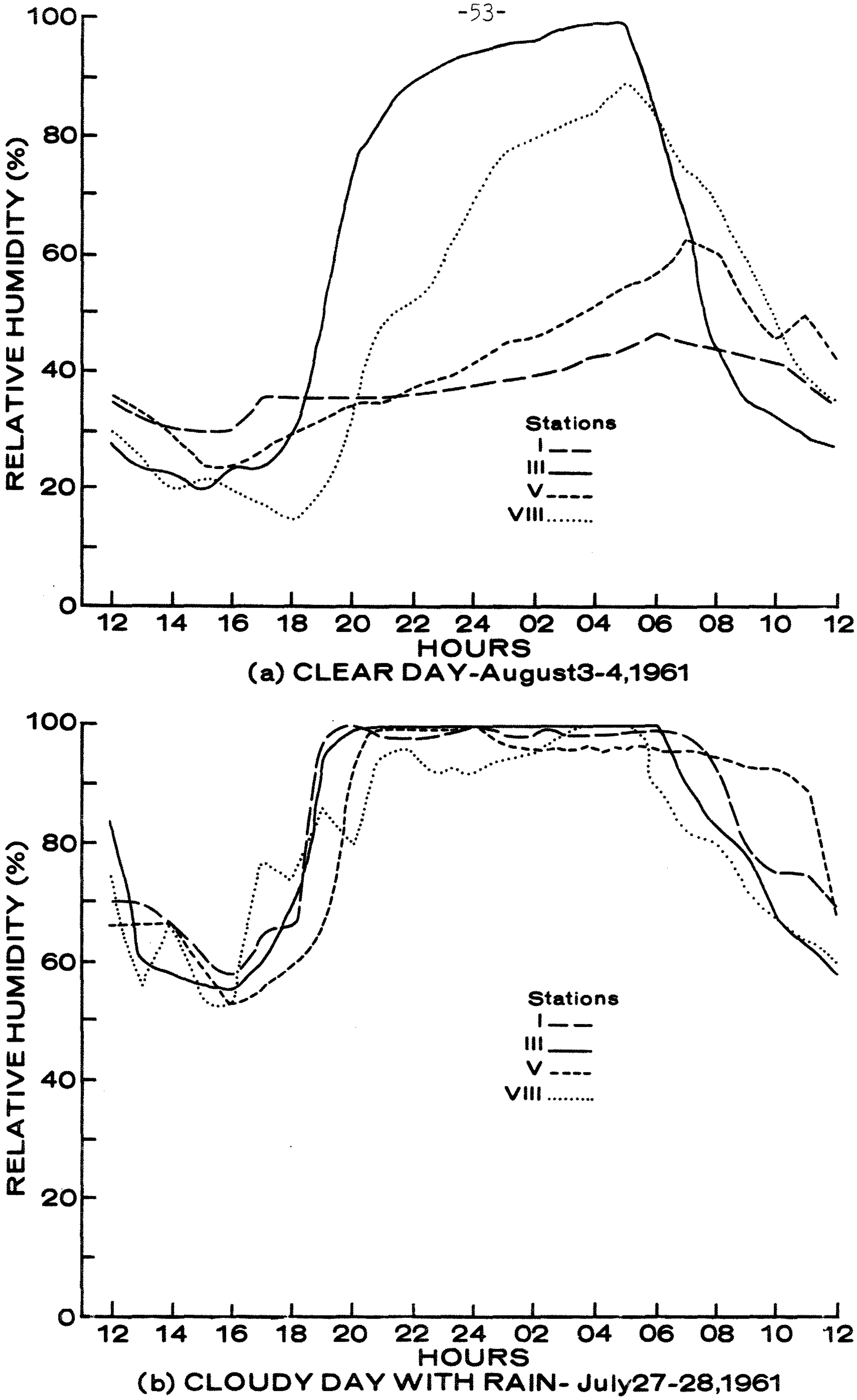

Fig.11. Diurnal relative humidity patterns for four stations on a clear day (August 3/4,1961), and a cloudy day with rain (July 27/28,1961).

with 100% relative humidity conditions varied. On the whole, conditions of 100% relative humidity were rarely measured at slope stations. On a clear, dry, warm day, 100% moisture conditions still occurred at station 3 in the valley bottom and there was a trend towards these conditions at station 8. At the slope stations, the atmosphere remained much drier, at least at 4 ft above the ground. The diurnal range, therefore, was considerable at valley bottom stations but small at slope stations. One may note the variations in the time and duration of maximum and minimum humidity. Higher moisture levels exist later on the slopes than in the valley bottom and it is probably caused by the warmer moist air rising up the slopes from the valley bottom with the onset of up-slope winds. The pattern of diurnal humidity in the valley bottom suggested that condensation of moisture in the form of dew was very important at such stations and that dew formation probably occurred on all clear nights and many cloudy nights.

Evaporation

An attempt was made to estimate the relative rates of evaporation at some of the stations (Table 26). Only three evaporation pans were available. After one pan had been used at station 8 for 6 weeks, it was moved to station 1 to enable a comparison between the valley bottom and the two slopes of Frances Creek valley.

During July and August, the amount of evaporation at station 8 was almost three times that at stations 3 and 5. The amount of evaporation at these other stations usually varied by less than 100 cc during the whole study. From the end of August, the amount of evaporation at station 1 was less than at stations 3 and 5, although for 2 weeks in August the amount of evaporation was similar to that at station 3. The difference probably resulted from less direct insolation, lower maximum temperatures, and a higher percentage cloud cover. Overall evaporation at station 5 was higher than at station 3 because the former had a drier atmosphere and higher maximum temperatures and wind speed.

DISCUSSION

The differences between north-facing and south-facing slopes have long been known, their differences being equivalent to a marked change in latitude, for both means and extremes of temperatures are greatly affected. The main difference between east- and west-facing slopes is that the diurnal cycle is distorted, emphasizing the morning as against the afternoon or vice versa. This has some effect on extremes, e.g., higher maximum temperatures on west-facing slopes but little effect on mean values.

A striking feature of the summer climate of the Frances Creek valley was the occurrence of inversions every night. McLeod (1948) and MacHattie (1970) found inversions to occur on most summer nights in the Kananaskis River valley, Alberta, while Hayes (1941) reported inversions to occur 94% of the time from May to September during a 4-year study at Priest River, Idaho. Hayes also noted that the magnitude of the inversion increased in July, August and September. Young (1921) noted the relationship between temperature inversion and the daily range of temperature, and also that the highest minimum temperatures occurred at points 200 to 1,500 ft above the valley floor. Pierce (1934) found that the height of the "thermal belt" depended on the length of the night, rate of radiation, cloudiness, and wind velocity, as well as local topography. Thompson and Dickson (1958), in a study near Salt Lake City, found "that sky cover lowers the magnitude of an inversion only if cloud cover of at least six-tenths has been predominant for more than eight daylight hours." They also found that the two most prominent factors related to the development of inversions were the existence of areas allowing the pre-cooling of air, and the warming effect of the descending air which counteracts further radiational cooling. In Frances Creek valley, the east-facing slope and then the valley bottom would act as areas for pre-cooling of air and it is probable that a similar up-and-down valley wind circulation was in operation. Cold air drainage to the valley bottom is probably restricted to a very small thickness of air (Geiger, 1957; Molga, 1962), and would not necessarily be recorded by a station 4 ft above the ground. The basic cause of the nocturnal cold air drainage is the steady net discharge of heat by radiation from solid surfaces, including foliage, to cold clear sky. Foliage plays an important role (Brooks and Berggren, 1943) as it is a poor retainer of heat. The exposed leaves quickly become cooler than the surrounding air and, therefore, continue to absorb heat from the air. This steady withdrawal of heat from the air causes an extra large amount of chilling. As chilled air is denser than unchilled, it tends to underrun the lighter air causing a fast flow of cold air down the slope. The process of air drainage is most active before midnight (Pierce, 1934), though the inversion slowly grows in intensity until sunrise. The regularity of the period of down-valley wind at night and the up-valley wind during the day has been noted in a number of studies in western Canada (Hewson and Longley, 1944; MacHattie, 1968; Munn and Storr, 1967). The descent of warm air from the east-facing slope into the valley bottom after sunrise was well shown in the profiles of Fig. 6, where the upper isotherms became tilted and then were dissipated completely as the valley bottom was suddenly warmed and the daytime up-valley and up-slope wind was again restored.

MacHattie (1966) noted that low humidities occurred more frequently on the steeper slope of the Kananaskis River valley and that the mean nightly maximum humidity decreased sharply with elevation above the valley floor. Lloyd (1961) noted that the humidity at 2 ft above the ground on slopes, near Priest River, Idaho, never reached 100% and that dew occurred in the valley bottom, but not on north and south slopes 65 ft above the creek.

The altitudinal and slope-aspect variations of forest fire danger factors were not generally recognized until a study by Hayes (1941). The results from a microclimatic network can greatly aid the local forest ranger in his efforts at fire protection by giving him a knowledge of seasonal and diurnal changes in the fire hazards of the various vegetational zones and slopes. The thermal belts on the slopes with their generally low humidities have the most dangerous burning conditions during the night, the least dangerous being in the valley bottoms where humidities are high, winds light, and temperatures low. During the day, the greatest fire danger would exist in the thermal belt on the west-facing slope, but high burning conditions may also be present in the valley bottom. Thus, the exposure of each station to drying influences is most important, and the inversion is a significant phenomenon contributing to fire danger variations at night.

A preliminary study of the occurrence of some of the major forest insects and diseases in the area showed some interesting distribution patterns. Damage by the Douglas-fir bark beetle (Dendroctonus pseudotsugae Hopk.) was restricted to isolated trees in the drier, warmer areas of the valley, to the south of station 6. The past and present outbreaks of the mountain pine beetle (Dendroctonus ponderosae) on lodgepole pine in the Frances Creek valley have occurred largely on the west-facing slope of Steamboat Mountain and on the slopes just above the valley bottom (Powell, 1961). Outbreaks or infestations have been rare on the east-facing slope of the valley, probably because of the wet condition of the stands which helps to maintain a high tree vigour, and the low maximum temperatures which would be less favorable for the development of the beetle (Reid, 1962; Powell, 1967). On this wetter, cooler slope of the valley, the incidence of lodgepole pine dwarf mistletoe (Arceuthobium americanum Nutt.) and western gall rust (Endocronartium harknessii (J. P. Moore) Y. Hiratsuka) was greater but this may have been because of the condition of the stand, the former occurring in overmature stands and the latter in young regeneration, rather than some climatic features of the site. On the dry valley bottoms and terraces of the main Trench, the growth of Douglas-fir was exceedingly slow but the bushy growth was sufficient to provide good Christmas trees, an important industry of this area. The Douglas-fir needle cast (Rhabdocline pseudotsugae Syd.), however, is an important problem to this industry, and was found on the drier sites, especially on the terraces around Invermere and extending northwards to around station 7 and on the east side of the Trench to north of station 14. Parker[1] has shown that the build-up of the disease depends on very high humidities at the time of ascospore dispersal. Dispersal of the spores takes place in June and thus, all areas of the valley bottom or gullies on the slopes, which are likely to have long periods of high humidity, may be continuous areas of infection. In such areas, the disease is able to persist from year to year and only infects very large areas when very favorable conditions for spread and infection occur.

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1 Dr. A. K. Parker, Forest Research Laboratory, Dept. of Fisheries and Forestry, Victoria, British Columbia. Personal communication, 1961.

REFERENCES

Boughner, C. C., R. W. Longley and M. K. Thomas. 1956. Climatic summaries for selected meteorological stations in Canada. Vol. III. Frost data. Can. Dep. Transport, Meteorol. Div., Toronto. 94 p.

Boughner, C. C. and M. K. Thomas. 1948. Climatic summaries for selected meteorological stations in Canada, Newfoundland and Labrador. Vol. II. Humidity, wind speed and direction. Can. Dep. Transport, Meteorol. Div., Toronto. 88 p.

British Columbia Department of Agriculture. 1967. Climate of British Columbia. Tables of temperature, precipitation and sunshine. Report for 1966. 53 p.

Brooks, F. A. and W. P. Berggren. 1943. Analytical interpretation of density-currents of air chilled by nocturnal radiation. Trans. Amer. Geophys. Union. 24: 189-204.

Chapman, J. D. 1952. The climate of British Columbia. In Trans. 5th. British Columbia Natur. Resources Conf., Victoria. p. 1-47.

Eastham, J. W. 1949. Observations on the flora of the southern Rocky Mountain Trench in British Columbia. Trans. Roy. Soc. Can., Sect. V, 43: 1-19.

Geiger, R. 1957. The climate near the ground. A translation by M. N. Stewart and others. (2nd Edition). Cambridge, Mass., Harvard Univ. Press. 494 p.

Godson, W. L. 1950. The structure of North American weather systems. Centen. Proc. Roy. Meteorol. Soc. 89-106.

Hamilton, E. L. 1954. Rainfall sampling on rugged terrain. U.S. Dep. Agr., Tech. Bull. 1096. 41p.

Hayes, G. L. 1941. Influence of altitude and aspect on daily variations in factors of forest-fire danger. U.S. Dep. Agr., Cir. No. 591.

Hewson, E. W. and R. W. Longley. 1944. Meteorology theoretical and applied. New York, J. Wiley & Sons. 468 p.

Huff, F. A. 1955. Comparison between standard and small orifice raingages. Trans. Amer. Geophys. Union. 36: 689-694.

Kelley, C. C. and W. D. Holland. 1961. Soil survey of the Upper Columbia River valley in the East Kootenay District of British Columbia. Report No. 7. British Columbia Soil Surv., Dep. Agr., Ottawa. 107p. plus maps.

Kendrew, W. G. and D. Kerr. 1955. Climate of British Columbia and Yukon Territory. Ottawa. Queen's Printer. 222p.

Kerr, D. P. 1950. The regional climatology of southern British Columbia. Univ. Toronto, Ph.D. Thesis. 280p.

Krajina, V. J. 1959. Bioclimatic Zones in British Columbia. Univ. British Columbia. Bot. Ser. No. 1. 47p.

Lloyd, M. 1961. The contribution of dew to the summer water budget of northern Idaho. Bull. Amer. Meteorol. Soc. 42: 572-580.

MacHattie, L. B. 1966. Relative humidity in Rocky Mountain Forests of southern Alberta in summer. Can. Dep. Forest., Forest Fire Res. Inst., Inform. Rep. FF-X-1. 54p.

MacHattie, L. B. 1968. Kananaskis valley winds in summer. J. Appl. Meteorol. 7: 348-352.

MacHattie, L. B. 1970. Kananaskis valley temperatures in summer. J. Appl. Meteorol. (in press).

MacKay, D. K. and F. A. Cook. 1963. A preliminary map of continentality for Canada. Geogr. Bull. No. 20: 76-81.

MacLeod, J. C. 1948. The effect of night weather on forest fire danger. Can. Dep. Mines & Resources, Dominion Forest Serv., Forest Fire Res. Note No. 14. 29p.

McLean, A. and W. D. Holland. 1958. Vegetation zones and their relationship to the soils and climate of the upper Columbia valley. Can. J. Plant Sci. 38: 328-345.

Meteorological Branch, Canada Department of Transport. 1956. Characteristic properties of North American air masses. Synoptic Tech. Stud. No. 17, Toronto, Ont.

Molga, M. 1962. Agricultural meteorology. Part II. Outline of agrometeorological problems. (Transl. reprint of Part II (pages 218-517) of Meteorologia rolnicza published by Pañstwowe Wydawnictwo Rolnicze i Lesñe, Warszawa, 1958). Warszawa, Poland. Cent. Inst. Inform. Nauk. Tech. Ekon., 1962. 351p.

Munn, R. E. and D. Storr. 1967. Meteorological studies in the Marmot Creek Watershed, Alberta, Canada, in August 1965. Water Resources Res. 3: 713-722.

Parker, J. 1952. Environment and forest distribution of the Palouse Range in northern Idaho. Ecol. 33: 451-461.

Penner, C. M. 1955. A three-front model for synoptic analyses. Quart. J. Roy. Meteorol. Soc. 81: 89-91.

Pierce, L. T. 1934. Temperature variations along a forested slope in the Bent Creek Experimental Forest, North Carolina. Mon. Weather Rev. 62: 8-12.

Powell, J. M. 1961. The mountain pine beetle, _Dendroctonus monticolae_ Hopk., in western Canada. Can. Dep. Forest., Forest Entomol. & Pathol. Lab., Calgary, Alberta. Interim Rep. May. 35p.

Powell, J. M. 1966. Distribution and outbreaks of _Dendroctonus ponderosae_ Hopk. in forests of western Canada. Can. Dep. Forest., Forest Res. Lab., Calgary, Alta. Inform. Rep. A-X-2. 19p.

Powell, J. M. 1967. A study of habitat temperatures of the bark beetle _Dendroctonus ponderosae_ Hopkins in lodgepole pine. Agr. Meteorol. 4: 189-201.

Powell, J. M. 1969. Historical study of the relation of major mountain pine beetle outbreaks in western Canada to seasonal weather. Can. Dep. Fisheries and Forest., Forest Res. Lab., Calgary, Alta. Inform. Rep. A-X-23. 11p.

Reid, R. W. 1962. Biology of the mountain pine beetle, _Dendroctonus monticolae_ Hopk., in the East Kootenay Region of British Columbia. I. Life cycle, brood development, and flight periods. Can. Entomol. 94: 531-538.

Rowe, J. S. 1959. Forest Regions of Canada. Can. Dep. Northern Aff. & Natur. Resources, Forest. Br., Bull. 123.

Thompson, A. H. and C. R. Dickson. 1958. Ground layer temperature inversions in an interior valley and canyon. Final Rep. Quartermaster Res. & Eng. Command, U.S. Army, Proj. No. 7-83-05-004 B. 195p.

Ulke, T. 1935. List of the vascular plants of the Horsethief Creek - Purcell Range, B. C. Can. Field Natur. 49: 49-55, 71-76.

Walker, E. R. 1961. A synoptic climatology of parts of the Western Cordillera. McGill Univ., Publ. in Meteorology, No. 35. 218 p.

Walker, J. F. 1926. Geology and mineral deposits of Windermere Map area, British Columbia. Can. Geol. Surv., Mem. 148. 69 p.

Young, F. D. 1921. Nocturnal temperature inversions in Oregon and California. Mon. Weather Rev. 49: 138-148.

APPENDIX I

CLIMATIC DATA FOR STATIONS 9 TO 16

Table A. Mean Monthly Temperatures (°F) from May to October 1961 for Stations 9 to 16.

Station No.	Elevation (ft)	Temperature °F May	Jun	Jul	Aug	Sep	Oct
9	2960	--	62.4	62.9	63.5	44.5	36.6
10	5000	--	58.7	57.6	61.4	46.3	31.9
11	3180	--	64.5	62.9	65.8	48.7	39.6
12	3240	--	65.6	65.5	66.8	49.1	40.2
13	3500	47.7	58.7	59.0	60.8	40.5	31.5
14	2900	--	60.0	62.0	62.8	45.7	36.7
15	4800	--	--	--	--	45.5	36.5
16	3612	45.1	61.3	61.6	63.4	45.4	37.1

Table B. Mean Monthly Maximum and Minimum Temperatures (°F) From May to October 1961, for Stations 9 to 16.

Station	Temperature °F May		June		July		Aug		Sept		Oct	
No.	Mx	Mn	Mx	Mn	Mx	Mn	Mx	Mn	Mx	Mn	Mx	Mn
9	--	--	80.5	44.9	80.1	48.2	80.3	45.3	57.6	34.2	46.7	28.6
10	--	--	72.2	48.0	73.1	47.5	77.6	50.9	52.1	33.0	40.6	26.4
11	--	--	77.7	50.4	77.7	53.5	78.2	53.5	55.8	40.7	44.7	34.1
12	--	--	80.6	52.5	79.2	54.9	81.2	55.5	58.7	42.5	46.3	34.5
13	61.4	36.0	74.3	46.4	73.2	47.5	75.4	48.7	49.9	32.4	39.3	24.8
14	--	--	82.1	44.6	82.5	46.5	84.8	46.0	61.3	33.6	48.5	27.8
15	--	--	--	--	--	--	--	--	57.5	37.8	46.5	31.4
16	63.0	37.1	77.3	45.3	76.5	46.6	79.3	47.5	55.5	35.3	45.3	28.9

Table C. Mean Monthly Daily Temperature Range (°F) From May to October 1961, at Stations 9 to 16.

Stn. no.	Daily Temperature Range (°F)					
	May	Jun	Jul	Aug	Sep	Oct
9	-	35.6	31.9	34.5	23.4	18.1
10	-	24.2	25.5	26.7	19.1	14.2
11	-	27.3	24.2	24.7	15.1	10.6
12	-	28.1	24.3	25.7	16.2	11.8
13	25.7	29.3	25.7	26.7	17.5	14.5
14	-	37.5	36.0	38.8	27.7	20.7
15	-	-	-	-	19.7	15.1
16	25.9	32.0	29.9	31.8	20.2	16.4

Table D. Hour of the Maximum and Minimum Temperatures in the Different Months at Stations 9 to 14.

Stn. no.	Temp and Hour	May		June		July		Aug		Sept		Oct	
		Mx	Mn	Mx	Mn	Mx	Mn	Mx	Mn	Mx	Mn	Mx	Mn
9	T	--	--	78.6	46.5	77.1	46.1	80.5	50.6	57.9	39.2	46.7	32.9
	H	--	--	16	06	15	06	17	06	15	06	16	07
10	T	--	--	70.7	50.3	68.3	49.7	74.5	52.0	50.0	35.1	38.5	28.6
	H	--	--	16	08	15	06	15	06	15	06	14	06
11	T	--	--	76.7	51.9	76.0	53.9	76.9	53.8	55.3	42.9	44.2	36.1
	H	--	--	16	05	14	06	13	06	15	07	16	07
12	T	--	--	79.2	53.7	77.4	52.8	80.5	55.6	56.3	42.7	45.8	36.6
	H	--	--	15	06	15	06	15	07	15	07	15	07
13	T	59.4	36.6	72.4	46.1	70.9	47.8	74.1	49.9	48.6	34.2	37.9	27.0
	H	15	05	15	05	15	05	15	05	14	06	13	07
14	T	--	--	79.6	44.4	78.2	46.9	82.2	46.9	58.2	37.1	46.9	31.1
	H	--	--	15	05	15	05	14	05	15	06	15	06

Table E. Number of Days of Frost (Temperature 32F or below) and Length of Frost-Free Period at Stations 9 to 16 in the Period May to October 1961.

Stn. no.	No. of Days with Frost							Length of frost-free period (days)
	May	Jun	Jul	Aug	Sep	Oct	Total	
9	-	0	0	0	15	22	37[a]	99[c]
10	-	0	0	0	16	25	41[a]	99[c]
11	-	0	0	0	2	12	14[a]	118[c]
12	-	0	0	0	4	12	16[a]	114[c]
13	9	0	0	0	18	25	52	111
14	-	0	0	0	15	24	39[a]	97[c]
15	-	-	-	0	8	18	26[b]	-
16	7	0	0	0	12	22	41	98

[a] Only data for 153 days

[b] Only data for 77 days

[c] A longer frost-free period probable

Table F. Number of Growing Day Degrees Above 42 F (Based on Mean of Hourly Readings) During the Summer of 1961 at Stations 9 to 15.

Stn. no.	No. of Degree Days above 42 F				
	May	June	July	August	September
9	-	617	679	666	122
10	-	505	483	600	67
11	-	677	691	738	212
12	-	711	729	746	225
13	202	508	526	666	56
14	-	600	622	628	142
15	-	-	-	326*	152

*Only data for August 16-31

Table G. Three Weekly Totals of Precipitation from April 23 to November 3, 1961, For Stations 13, 14 and 16.

	PRECIPITATION (INCHES)									Total
Stn. no.	Apr 28 May 18	May 19 Jun 8	Jun 9 Jun 28	Jun 29 Jul 19	Jul 20 Aug 9	Aug 10 Aug 30	Aug 31 Sep 20	Sep 21 Oct 11	Oct 12 Nov 3	May 19 Nov 3
13	2.12	0.41	0.94	0.83	1.52	1.13	1.75	0.82	0.31	7.71
14	-	-	-	-	0.68*	1.42	1.50	0.66	0.45	-
16	1.95	0.85	0.72	1.64	1.44	1.36	2.05	1.02	0.93	10.01

* Only data for July 26 - August 9.

APPENDIX II

CLASSIFICATION OF AIR MASSES OVER THE INVERMERE AREA FROM TEMPERATURES (TABLE 4) OF THE 500 AND 700 mb LEVELS, FOR THE PERIOD MAY TO OCTOBER 1961.

Date	May	June	July	August	September	October
1	mP	mT	mP	mT	mP	mP
2	mP	mT	mP	mT	mP	mP
3	mA	mT	mT	mT(cT)	mP	mP
4	mA	mT	mT	mT(cT)	mT	mT
5	mA	mT	mT	mT(cT)	mT	mT
6	mA	mT	mT	mT	mP	mP
7	mA	mP	mP	mT	mP	mA
8	mA	mP	mP	mT	mP	mP
9	mP	mP	mT	mP	mT	mP
10	mP	mP	mT	mP	mP	mP
11	mA	mP	mT	mT	mP	mA
12	mP	mP	mT	mT	mT	mA
13	mP	mP	mT	mT	mT	mP
14	mP	mT	mT	mT	mP	mT
15	mP	mT	mT	mT	mP	mT
16	mP	mT(cT)	mP	mP	mP	mT
17	mP	mT(cT)	mP	mP	mP	mP
18	mP	mT(cT)	mP	mP	mP	mT
19	mP	mT	mT	mP	mP	mP
20	mP	mT	mT	mP	mP	mP
21	mP	mT	mT	mT	mA	mA
22	mP	mT	mT	mT	mA	mA
23	mP	mT	mT	mT	mP	mA
24	mP	mT	mT	mT	mP	mA
25	mP	mT	mT	mT	mP	mA
26	mT	mT	mT	mT	mP	mA
27	mP	mP	mP	mT	mP	mA
28	mP	mP	mP	mT	mP	mA
29	mP	mP	mP	mT	mP	mP
30	mP	mP	mP	mT	mP	mP
31	mP		mT	mP		mT

mA - maritime Arctic; mP - maritime Polar; mT - maritime Tropical; cT - continental Tropical.