Kananaskis Valley Temperatures in Summer

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ABSTRACT

Application of temperature observations depends on assessment of the difference in temperature between points of observation and points of application. As an aid to estimating temperature variations in valleys, particularly in Rocky Mountain forest land, summer season observations in 1960 from 21 thermohygrographs were analyzed. Daily maximum and minimum temperatures were the main variables considered.

Temperature differences between successive 20-day periods were generally greater than those due to elevation, aspect or crown cover within a period. A nocturnal inversion of 9F in the first 300 ft above valley bottom occurred on the average clear summer night, with a nearly isothermal layer 500 ft or more thick above that. Literature reports indicate that nocturnal inversions in other valleys on clear nights usually differ by less than a factor of 2 from the Kananaskis data. An inversion of 3F in daily maximum temperature was also found in the first 300 ft above valley bottom; this is attributed, with reason, to a difference in evapotranspiration between slope and valley bottom.

1. Introduction

The usefulness of an observation of air temperature depends on how well it represents the temperature at points other than where it was observed. The temperature observed in a Stevenson screen at a climatological station (in an area relatively free of obstructions to horizontal air movement) has been found remarkably representative of the temperature that would be observed in a screen over similar surfaces for miles around.

Rough topography impedes air movement and introduces other complexities due to variations in elevation and aspect of the surface intercepting sunshine and participating generally in radiation exchanges. It also complicates the distribution pattern of hydrologic factors, such as the availability of moisture for evapotranspiration, which in turn affects the partition of energy between sensible and latent heat.

Local differences in temperature, occasioned by topography, have not only direct effects on the survival and growth of vegetation but also indirect effects through generation of local winds, which direct the spread of seeds, spores, insects and forest fires, among other things.

As an indication of the magnitude of topographic effects on "surface air temperature," this paper reports summer-season observations taken in 1960. Previous experience (1954–57) in the Kananaskis Valley assists the interpretation, although none of the earlier data are quoted. The observations were part of a study of the variations with topography of meteorological factors affecting forest flammability. Previous reports have dealt with relative humidity (MacHattie, 1966) and surface wind (MacHattie, 1968).

2. Area and observational network

The observational area was along the Kananaskis and adjacent valleys, on the east edge of the Rocky Mountains, 40 mi west of Calgary, Alberta. Its topography is shown in Figs. 1 and 2 and is given in more detail in MacHattie (1966). The locations of the observation stations are shown in Fig. 1 and described in Table 1.

The observational network was planned to give 1) detailed data on a cross section of the lower Kananaskis valley (stations 8–14), and 2) comparative data from neighboring valleys. Most of the cross-section stations were located in uniform stands of young lodgepole pine (*Pinus contorta* var. *latifolia*); temperature differences between stations could thus be attributed to differences in elevation, uncomplicated by differences in forest type. Two supplementary stations (6, 7) were located in mature forest to show how much crown cover moderated temperature.

3. Instruments

The temperature observations were made with 21 thermohygrographs exposed in Stevenson screens 4.5 ft above the ground. Because of the thin crown and conical shape of young lodgepole pine, the Stevenson screens were exposed to about half of full sunshine at all stations with tree heights less than 40 ft except Moose 56 and Elk Hill.

Before being set out at field stations, the thermographs were adjusted and compared over a 2-week period in a closed room with a fan stirring the air. The diurnal range in this room was about 15F. After adjustment, 95% of the thermograph readings were within 1F of the group average; the other 5% showed 2F de-

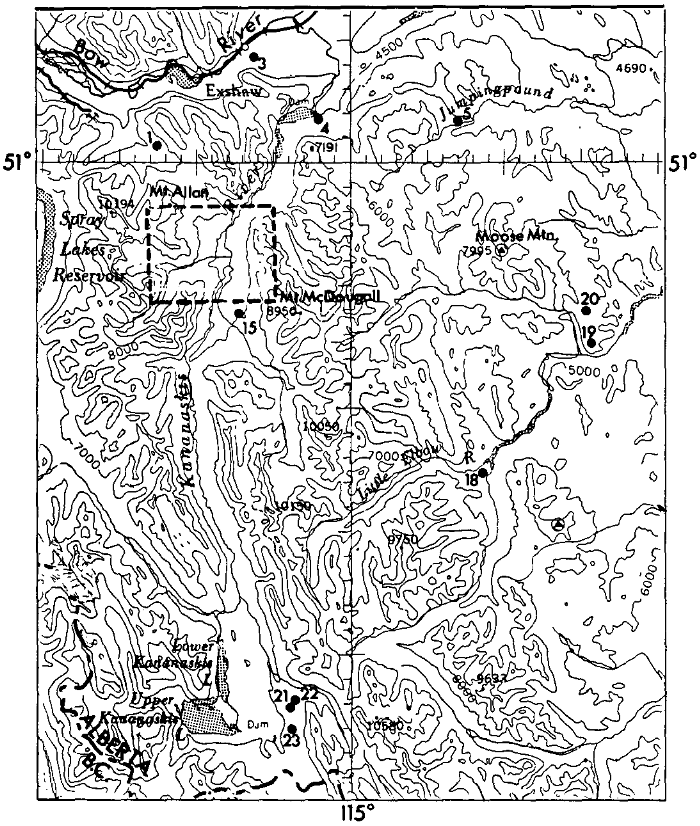
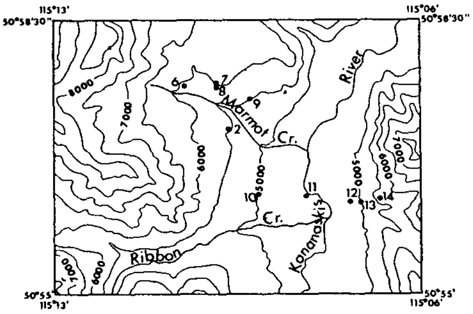


FIG. 1. The Kananaskis valley with observation stations identified by serial number (as in Table 1). The contour interval is 1000 ft above 5000 ft and 500 ft below. Scale: 1⅛ inch = 10 mi. The area of intensive observations is shown below (left) with 500-ft contours and a scale of ¾ inch = 2 mi.



partures from group average. During the summer, spot checks with a ventilated psychrometer were made at least once a week at each station. While these check data confirmed the absence of consistent large errors, they could not be used for a closer check on thermograph calibration because the response of the psychrometer to temperature changes was faster than that of the thermograph, i.e., differences in indicated temperature of several degrees commonly occurred.

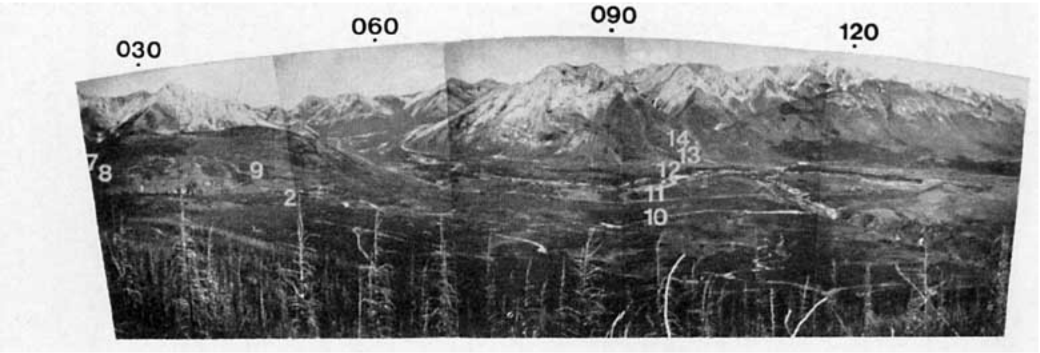


FIG. 2. Panorama looking eastward over the area of intensive observations from 6600 ft. Observation stations are shown by numbers. The fire-killed trees in the foreground are relics of the 1936 fire.

TABLE 1. Descriptions of thermohygrograph station locations.

No.	Name	Elevation (ft MSL)	Aspect (deg)	Slope (deg)	Height above valley (ft)	Distance to bottom (mi)	Direction and distance from Meadow (deg)	(mi)	Vegetation Type	Height (ft)	Density
8	Allan 60	5960	230	13	1230	1.4	320	1.9	pine	15	medium
9	Allan 55	5520	165	12	790	1.0	330	1.4	pine	15	medium
10	Allan 50	4980	210	9	250	0.7	280	0.6	pine	15	medium
11	Meadow	4730	level		0	0.0	0	0	grass	0.4	medium
12	McDougall 48	4800	245	9	70	0.2	110	0.7	grass	0.4	medium
13	McDougall 50	5010	270	28	280	0.4	110	0.9	pine	15	dense
14	McDougall 56	5600	240	27	870	0.7	100	1.2	pine	15	medium
15	Moraine	5000	level		200	1.0	170	2.7	pine	15	medium
2	Marmot 55	5500	155	24	770	1.1	310	1.2	pine	20	dense
6	Marmot 60	5950	090	8	1220	2.0	310	2.2	spruce	100	medium
7	Allan F	5990	225	14	1260	1.5	320	2.0	pine	65	medium
1	Pigeon 53	5320	190	18	800	0.9	320	7	pine	25	sparse
3	Bow Pond	4370	level		150	0.5	010	10	grass	0.4	medium
4	Headquarters	4560	knoll		60	0.2	040	8	grass	0.2	medium
5	Sibbald	4920	knoll		60	0.1	060	14	pine	45	medium
18	Elbow	5320	220	6	100	0.2	130	16	pine	35	sparse
19	Moose 51	5070	level		200	0.3	100	18	pine	25	sparse
20	Moose 56	5610	ridge		700	0.5	100	18	pine	20	dense
21	Elk Hollow	6130	270	6	230	0.5	170	21	shrubs	1	medium
22	Elk Hill	6100	knoll		200	0.5	170	21	pine	30	medium
23	Lookout	6800	ridge		900	1.0	170	22	shrubs	1	sparse

Notes. Moraine was on a steep-sided, flat-topped table raised about 75 ft. above the surrounding terrain. Thermohygrographs were interchanged between Allan F and Allan 60 on 18 July, between McDougall 50 and 56 on 28 July, and between Elk Hollow and Lookout on 16 August.

Surface wind was recorded with an anemograph of Meteorological Service of Canada design, Type 45 (Canada Department of Transport, 1951), exposed 33 ft above ground at Meadow Station. The duration of bright sunshine was recorded at Meadow Station with a Campbell-Stokes instrument. Recording raingages were in operation at Meadow and five other stations.

TABLE 2. Twenty-day means of daily extreme temperatures (°F).

Station	Elevation (ft MSL)	Day maximum 11–30 June	1–20 July	21 July –9 Aug.	10–29 Aug.	Night minimum 11–30 June	1–20 July	21 July –9 Aug.	10–29 Aug.
Allan 60	5960	58	74	69	60	39	45	46	41
Allan 55	5520	59	75	70	61	42	48	50	44
Alllan 50	4980	61	78	73	64	42	48	49	45
Meadow	4730	60	74	70	62	39	40	44	41
McDougall 48	4800		75	70	63		47	49	45
McDougall 50	5010	63	78	73	64	43	48	50	46
McDougall 56	5600	60	76	71	62	43	49	51	45
Moraine	5000		79	73			48	49	
Marmot 55	5500	59	75			41	48		
Marmot 60	5950			63	56			47	42
Allan F	5990	54		64	56	39		48	42
Pigeon 53	5320			68	60			51	45
Bow Pond	4370			73	66			52	46
Headquarters	4560	62	76	71	64	42	44	47	44
Sibbald	4920		73	70	63		49	49	46
Elbow	5320		77	72	66		44	46	43
Moose 51	5070		76	75	68		49	51	46
Moose 56	5610		70	67	61		50	50	46
Elk Hollow	6130		70	64	58		36	37	36
Elk Hill	6100		70	66	57		45	46	40
Lookout	6800		71	65	55		50	49	40
National network		0700–0700 maximum				1900–1900 minimum			
Calgary 51°06′N, 114°01′W	3540	67	79	76	72	47	52	52	46
Anthracite 51°11′N, 115°30′W	4495	66	79	76	68	42	47	49	44
Banff 51°11′N, 115°34′W	4583	65	79	74	67	43	47	49	44

TABLE 3. Mean maximum temperatures and minimum humidities for different types of days between 25 June and 7 September 1960.

	Cloudy[a]	Windy[b]	Sunny[c]	
Daily sunshine (hr)	<2	3–7	12	
Average wind (mph) 1200–1800	4.4	10.1	6.8	
Number of days	6	5	14	
	Mean max temperature (°F)			Adiabatic difference[d] (°F)
Allan 60	55.8	56.0	79.6	2.4
Allan 55	58.0	58.4	79.5	2.9
Allan 50	60.3	60.4	83.0	1.4
Meadow	60.0	58.4	79.4	0.4
McDougall 48	60.0	59.8	79.7	1.2
McDougall 50	60.2	61.4	84.9	3.1
McDougall 56	57.8	58.8	82.4	
	Mean minimum relative humidity (%) reduced[e] to 5000 ft			
Allan 60	58		23	
Allan 55	57		22	
Allan 50	59		24	
Meadow	59		23	
McDougall 48	59		25	
McDougall 50	59		23	
McDougall 56	55		22	

[a] All days with ⩽2 hr sunshine in the period 25 June–7 September inclusive; namely, 31 July, 1, 4, 14 August, 4, 7 September.

[b] All days with 3–7 hr sunshine and average surface wind >9 mph from 1200–1800; namely 5, 6, 19, 21, 26 August.

[c] All days with 11.7–12.5 hr sunshine; these occurred between 7 and 29 July.

[d] Temperature difference at dry adiabatic rate for height difference between adjacent stations.

[e] Reduction based on U. S. Forest Service, Pacific N. W., Res. Paper 43 by Cramer (1961).

4. Form of temperature data

Daily maximum and nightly minimum temperature are the main data analyzed in this paper. These, however, are not instantaneous peak values but 2-hr averages. The daily maximum temperature is the average temperature for the 2 hr between 0800 and 2000 MST, when the temperature was highest. These 2 hr may be a single period, or may be made up of two or more shorter periods of high temperature. Similarly, the minima are for the period 2000–0800 MST.

Graphs of diurnal variation of temperature on east and west slopes are also given.

5. Twenty-day averages

The general manner in which temperature varied through the summer over the Kananaskis area is shown in Table 2, which displays 20-day averages of daily maximum and nightly minimum temperatures. Data from three stations of the national climatological network are also included, though the use of extreme thermometers at these stations means their readings are not strictly comparable with the thermograph data.

The effect of station elevation on daily maximum temperature is slight and easily masked by other factors (see below). Daily minimum temperature, however, shows a response to relative elevation above valley bottom.

The difference in temperature between 20-day periods is usually greater than the difference between stations within a period; that is, the topographic variation is usually less than the time variation of temperature. The period 1–20 July was exceptionally sunny, averaging 10.4 hr day^{-1} at Meadow; the other periods each averaged between 6.9 and 7.6 hr day^{-1}.

Because of differences in cloudiness from one valley to another, analysis of the effect of sunshine and wind on the temperature relationships between stations is difficult to do for the whole observational area. With easterly winds, Moose, Elbow and Sibbald stations may be overcast while the Kananaskis valley is clear. Over the limited area of the Kananaskis cross section, it is possible to segregate various types of days with fair accuracy.

6. Daily maximum temperature on the cross section

Table 3 gives temperatures for three types of days: cloudy, windy and sunny. The specific criteria are given in footnotes to the table. Daily minimum relative humidity (reduced to 5000 ft) for the same groups of cloudy and sunny days are also shown in Table 3; apparently on sunny days relative humidity varies less over the cross section than temperature (or dew point).

The uniformity of temperature at the same elevation on the two sides of the valley on the cloudy days is quite marked. With increasing sunshine on the windy and sunny days, progressively larger differences in temperature between stations appear; on the windy days the wind was insufficient to maintain uniformity of temperature in the face of the greater sunshine.

One might expect the lapse rate to be dry adiabatic at the time of daily maximum temperature on the sunny and windy days. This is the case between Allan 55 and 60 on the windy days. Generally, however, the lapse rate is less than dry adiabatic, and below 5000 ft there is an inversion. This inversion is more intense on the sunny than on the windy days.

7. Cause of daytime inversion

Possibly the inversion is only apparent (resulting from a warm skin of air along the mountain slope) and not real in the free air vertically above the valley bottom. This could be the case if the coefficient of turbulent diffusion at screen height were much less among the young pine trees on the slopes than over the valley bottom meadow. On consideration, the apparent inversion is only partly attributed to this cause. The balance is attributed to a difference in evapotranspiration between valley bottom and slope sites. The reasoning and justification are as follows.

TABLE 4. Daily maximum temperature (°F) for successive days after a substantial rain (average of three dry spells).

Station	Days after rain 1st	2nd	3rd	4th	5th
Allan 60	56.7	63.7	66.7	74.3	74.0
Allan 55	58.0	64.3	68.3	75.7	76.3
Allan 50	61.0	66.3	70.7	78.3	78.3
Meadow	60.0	63.3	67.3	74.3	73.7
McDougall 48	60.3	64.0	68.0	75.3	75.3
McDougall 50	61.7	66.0	69.7	77.0	77.0
McDougall 56	59.7	63.7	67.0	74.3	76.3
	Difference in maximum temperature				
Allan 50–Meadow	1.0	3.0	3.4	4.0	4.6
McDougall 50–Meadow	1.7	2.7	2.4	2.7	3.3

Immediately after a substantial rain, soil moisture would be adequate at all sites and transpiration differences would be minimized. During a dry spell, differences in evapotranspiration between slope and valley bottom could develop (and result in a progressive change in relative temperature) if soil moisture reserves were exhausted sooner on the slopes than in the valley bottom. This might arise from differences in runoff, seepage or soil moisture capacity, or from greater advection of energy to slope stations than to the valley bottom. With respect to this last factor, the average nightly maximum relative humidity from 1 July to 29 August was only 83% at Allan 50 and McDougall 50 compared with 94% at Meadow (MacHattie, 1966).

To substantiate this explanation, the valley bottom inversion would need to show progressive development during a dry spell. To test this, periods were sought when a soil-wetting rain was followed by a dry spell of at least 5 days. A soil-wetting rain was arbitrarily defined as either 1) one-third of an inch or more of rain in 1 day, or 2) three-quarters of an inch or more of rain in 3 days, with at least one-tenth of an inch on the last day. Between 14 June and 7 September there were only three such dry spells: 25–29 June, 2–6 July and 7–11 August. Table 4 shows daily maximum temperatures averaged by successive days during these dry spells.

TABLE 5. The frequency of various degrees of inversion (°F) in the lowest 70 ft of the valley for all nights 1 July–8 September 1960 and the associated cloudiness (estimated) and wind speed at 33 ft.

Difference in minimum temperature between McDougall 48 and Meadow	Number of nights	Cloudiness (estimated)	Wind speed (mph) Average (0000–0600)	Lowest hour (0000–0600)
0	7	0.6	8.0	6.6
1	3	0.8	2.9	1.3
2	4	0.7	4.5	2.2
3	6	0.8	2.6	1.0
4	9	0.8	3.0	1.2
5	9	0.2	3.3	1.6
6	7	0.3	2.7	2.0
7	12	0.3	2.9	2.2
8	3	0.2	3.2	2.0
9	6	0.3	3.5	2.5
10	3	0.2	3.1	2.7
11	1	0	2.3	1

It is seen that the inversion between valley bottom (4730 ft) and 5000 ft increased progressively during the 5-day dry spells, i.e., from 1.0F to 4.6F on the Allan slope. This is taken as confirmation of a difference in evapotranspiration between valley bottom and the slopes. The 1–2F inversion on the first day after rain remains to be accounted for by the supposed difference in coefficient of turbulent diffusion.

8. Night minimum temperature on the cross section

The average nocturnal inversion is shown in Table 2 to be 6F in the lowest 300 ft, with an isothermal layer about 500 ft thick above that. The amounts of inversion on individual nights are classified in Table 5 for the lowest 70-ft layer, the layer in which most of the temperature difference occurs. The estimated cloudiness and observed surface (33 ft) wind at Meadow, in the valley bottom, are also given.

Note should be made of the constancy of average wind speed from 0000–0600 MST for inversions of 3–10F. Because the minimum temperature is likely to occur during the hour of the night when wind speed is lowest, the lowest of the hourly speeds for each night were averaged by inversion class and included in Table 5. The increase of this lowest-hour wind with increasing inversion from 3–10F suggests it is some measure of the down-valley drainage wind. Since the drainage wind should increase with lowering temperature during the night, a check was made to see if the hour at which the observed wind was lowest became later as inversion intensity increased. No such relation was found.

When clear nights only were considered, the data in Table 6 were obtained. A night was assumed to be clear

TABLE 6. Average minimum temperatures (°F) for clear nights 1 July–8 September 1960.

Station	24 July	All other clear nights
Allan 60	39	46.0
Allan 55	45	48.2
Allan 50	49	47.1
Meadow	48	39.2
McDougall 48	48	46.2
McDougall 50	47	48.6
McDougall 56	47	50.3
Number of nights	1	24

Note. 24 July was the only clear night when 1) Meadow minimum temperature was not 5F or more lower than McDougall 48, and 2) the wind speed for the lowest hour 0000–0600 was *not* 3 mph or less; on 24 July it was 6 mph.

if no appreciable cloud could be detected in the evening or early morning by the sunshine recorder at Meadow, or in weather observations taken at 1800 and 0800 at Headquarters. The data of 24 July indicate that a 6-mph wind is sufficient to prevent an appreciable inversion from forming, though inversions became intense with a 3-mph surface wind.

To indicate the usual variation of temperature on both the Allan and McDougall slopes on clear nights, the histograms of Fig. 3 were prepared. Separate tabulations (not shown) indicated that on the McDougall slope the stronger the inversion was below 5000 ft the stronger it was in the 5000–5600 layer as well. On the Allan slope, however, there was very little correlation between the lapse rates in the layers below and above 5000 ft.

9. Diurnal variation

To supplement the daily maximum and minimum data already given, the average shape of the diurnal temperature cycle at the cross-section stations for six clear days is shown in Figs. 4–6. The curves were plotted from averages of hourly values read from the thermograph charts. The six days 4–6 July and 8–10 August were selected on the basis of 1) smooth thermograph traces, all days having 11 hr or more of sunshine, and 2) low pressure gradients, the 700-mb gradient being less than 10 kt.

Fig. 4 shows that daytime warming begins in the valley bottom and progresses upward. Although the valley bottom is much colder (8-11F) at night and has a lower daily maximum temperature than the 5000-ft slope stations, it is only after the temperature at Meadow has nearly equalled that on the lower slopes that the rapid phase of slope warming takes place. This is all the more noteworthy when it is remembered that sunrise is earlier and insolation more intense on the Allan slope than on the valley bottom. That the upper part of the trace (1100-1800 local time) is flatter at Meadow than at the slope stations is attributed to the two reasons already given for its lower maximum temperature: greater evapotranspiration and greater coefficient of eddy diffusion.

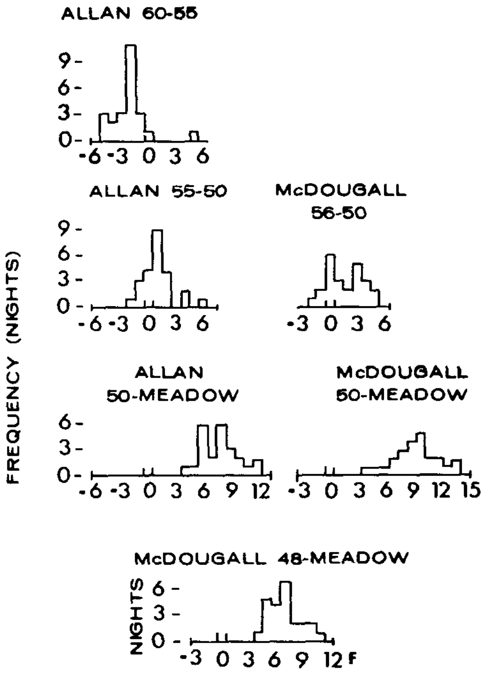


Fig. 3. Histograms of differences in nightly minimum temperatures for all clear nights (excluding the night of 24 July), 1 July–8 September 1960.

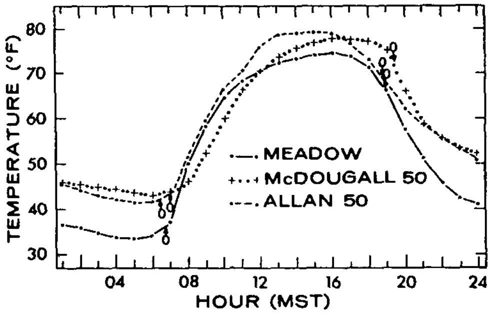


Fig. 4. Diurnal temperature variation near valley bottom for an average of six clear days. The average times of sunrise and sunset are shown by arrows.

Through the afternoon, temperatures on the west aspect (McDougall) slope lagged behind those on the east aspect (Allan) by $1\frac{1}{2}$ hr. The rapid temperature fall began at sunset on the west aspect slope, but 1–2 hr before sunset on the east aspect (even with allowance for the difference in sunset).

10. Effects of crown cover and ground contour

The contrast in the diurnal temperature regime between the trunk space of a mature pine forest and the same height above ground among young pine crowns is shown in Fig. 6. As expected on sunny days, the latter is much warmer. At night (2000–0400) the cooling rate is nearly identical at the two stations. The mature crown appears to act as a heat valve; air cooled around the

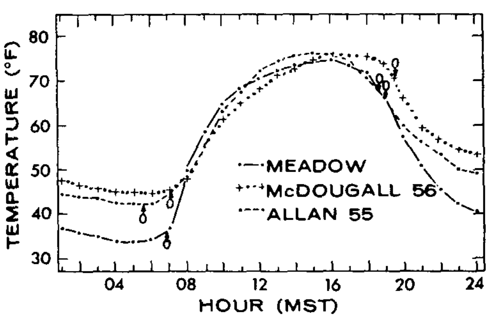


Fig. 5. Diurnal temperature variation at mid-slope for an average of six clear days.

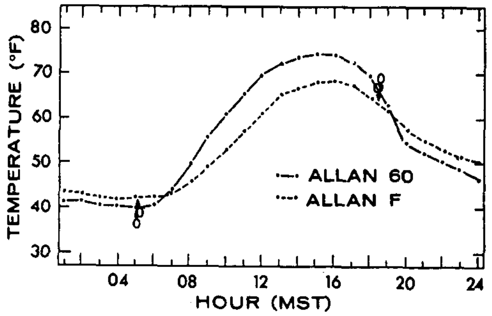


FIG. 6. Diurnal temperature variations in mature and young pine forests on the upper slope for an average of six clear days.

crown at night sinks down, whereas air heated in the sunlit crown rises.

The similarity of Marmot 60 and Allan F temperatures (and in contrast to Allan 60) in Table 2 suggests that the effect on trunk-space temperature of ground slope and curvature is negligible, compared with the effect of crown cover. Marmot 60 is in a concave area while Allan F is on a slightly convex slope.

The similarity of Marmot 55 and Allan 55 temperatures in Table 2 indicates that the difference in steepness of slope has a negligible effect.

11. Discussion

The general question of temperature variation with topography is discussed systematically by Geiger (1961) and many sample data are quoted. (In view of the pervasive influence of topography, it is surprising how few textbooks give any quantitative data on its effect on temperature or other meteorological elements.) Baumgartner (1960, 1961, 1962, 1964) reports detailed observations from valley to peak of Grosse Falkenstein mountain (2000–4300 ft MSL) along a narrow cleared strip on the forested west slope; he also discusses the general effect of relative ground elevation on air temperature.

Regarding daily maximum temperatures, there is no sign of an inversion in the valley bottom in Baumgartner's reports nor in those of Hayes (1941), Tanner (1963) and Urfer-Henneberger (1964). An inversion of 0.9–1.6F in the mean daily maximum temperature is reported by Aulitzky (1968) in the first 330 ft above valley bottom for each month May through September. J. M. Powell (1964)[1] observed some inversion of daily maximum temperature in a tributary to the Columbia valley, as shown in Table 7. His concurrent soil-moisture observations showed soil moisture to be much higher in the valley bottom and somewhat higher on the upper ENE slope than at the other stations, which suggests that a difference in evapotranspiration may be the chief reason for the inversion.

The variation of daily minimum temperature with elevation is shown in Table 8 for several valleys reported on in the literature. Height intervals have been standardized in the table for comparative purposes; when the interpolations were made, temperature was assumed to vary as the logarithm of elevation above valley bottom. Monthly-mean temperature inversions are generally smaller in the European data than in the North American data quoted, presumably because of the greater frequency of cloudy nights in Europe. When clear nights are segregated, there is remarkable agreement between Harrison's English data and the data from the two Alberta sites, i.e., an inversion of 7F in the first 100 ft above valley bottom for the average of several nights, 11F for an extreme night. The comparatively small inversion Urfer-Henneberger found for clear nights is attributed to the large height interval (1411 ft) over which temperatures were measured and the steep slope (7%) along the Dischma valley. The slope of the Kananaskis and Frances Creek valleys is about 1%.

Climatic data and forecasts supplied by national meteorological services are meant for use over an area, though they refer in particular to a climatological observing station (or, by extension, to similar sites). It is left to the user to adapt this information to other types of sites. This paper has given some information on the magnitude of air temperature variations to be expected in a valley at levels 4–6 ft above the ground surface. To

TABLE 7. Monthly means of daily maximum temperature and diurnal range (°F) observed in 1961 by J. M. Powell on an ENE–WSW cross section of the Frances Creek valley (50°41′N 116°15′W).

	ENE facing slope		Valley bottom	WSW facing slope	
Elevation above sea level (ft)	4800	4000	3390	4000	4600
Distance between stations (ft)	4600	12,700	7300	4800	
Slope at station (%)	45	20	0	18	10
	Mean daily maximum temperature				
June	71.0	74.9	73.9	76.0	77.2
July	69.6	72.6	74.4	75.7	76.0
August	72.0	74.6	76.6	79.1	78.7
September	47.9	54.2	54.1	55.5	54.8
October	36.8	43.4	43.5	43.5	43.0
	Mean diurnal range of temperature				
June	20	24	38	27	26
July	18	20	35	25	23
August	17	20	38	26	24
September	12	14	26	20	16
October	9	10	22	14	12

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[1] J. M. Powell, 1964: Some topographic features of the summer climate in the Frances Creek valley, a tributary of the Upper Columbia River valley, British Columbia. University of British Columbia, Geography Department, unpubl. rept.

Table 8. Comparison of valley-bottom inversions (°F) in night minimum temperature observed in screens 4–6 ft above ground for standardized layer thickness.

Author	Date of report	Observation area	Valley-bottom elevation (ft)	Temperature instrument	Type of minimum	Valley inversion in lowest 100 ft	300 ft	1000 ft
Aulitzky	1968	Obergurgl, Austria	5971	Thermograph	Nightly mean June–September		2	
Albright and Stoker	1944	Beaverlodge, Alberta	2366	Minimum thermometers	Nightly mean July and August	6		
					Once a month extreme	11		
Baumgartner	1962	Grosse Falkenstein, Bavaria	2040	Minimum thermometers	July nightly mean	3	4	7
					August nightly mean	4	5	9
Harrison	1967	Marden, England	50	Platinum resistance thermometer mounted on car	Average of six clear nights	7	10	
					Extreme night	10	15	
Hayes	1941	Priest River, Idaho	2300	Thermograph	Median night July–September			15
MacHattie	1970	Kananaskis, Alberta	4730	Thermograph	Nightly mean July and August	5	6	6
					Clear nights July and August	7	9	10
					Extreme night	12	14	17
Powell	1964	Frances Creek, British Columbia	3390	Thermograph	Nightly mean July and August		12	15
Smith	1967	Houghall, England	123	Minimum thermometers	Mean nightly			
					September 1960	2	3	
					September 1959	7	10	
					Extreme two summer nights	15	18	
Urfer-Henneberger	1964	Dischmatal, Switzerland	5577	Thermograph	Clear nights June and September inversion at dawn			5

keep things in perspective, the sometimes large temperature differences that occur between screen height and the ground surface should be remembered. On clear nights, grass minimum temperatures may be as much as 20F colder than screen temperatures, a greater inversion than any reported here as being due to valley topography.

12. Conclusions

In the Kananaskis valley an inversion forms in the valley bottom almost every night. On clear summer nights inversions of 5 to 10F are usual in the lowest 100 ft. The thickness of the inversion plus isothermal layer is roughly 1000 ft; only above this does temperature decrease appreciably with elevation. A surface (33-ft) wind of 3 mph in the valley bottom during the night does not affect the inversion appreciably, but a 6-mph wind does.

A valley-bottom inversion in daily maximum temperature also occurs; it is attributed mainly to evapotranspiration differences between the moist valley bottom and the drier slopes.

A closed lodgepole pine canopy reduced mean daily maximum temperature at screen level about 4F below the temperature in a young stand that does not shade the screen much. This is equivalent to the difference in daily maximum found for a 1000-ft difference in elevation. The forest canopy had much a less modifying effect on night minimum than on daily maximum temperatures in the trunk space.

The measure of agreement between the Kananaskis data and those from other valleys reported in the literature suggests that the temperature gradient with elevation in unmeasured valleys on clear nights will generally differ from the Kananaskis data by less than a factor of 2.

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