On the Use of Synoptic Weather Map Typing to Define Solar Radiation Regimes

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ABSTRACT

A synoptic approach to the analysis of solar radiation regimes is undertaken with the aim of developing a synoptic solar radiation climatology. Synoptic weather types for an area including British Columbia and the adjacent regions of the northeastern Pacific are defined using an objective correlation classification technique. These weather types are shown to determine statistically distinct solar radiation distributions.

However, further analysis shows that the distinctiveness of the solar radiation regimes is not sufficient to be used in practical applications such as interpolation between measurement stations, estimation of solar radiation inputs in the absence of observed data or in the explanation of the interannual variability of solar radiation.

As a result, attempts to base a solar radiation climatology solely on the synoptic regimes defined using the readily available data and techniques employed in this study are not justified. However, the statistical analyses do suggest that the use of more appropriate synoptic data and typing techniques may overcome many of the inadequacies in the present study.

1. Introduction

The actual and anticipated use of solar energy to supplement more conventional energy sources has led to increased interest in the spatial and temporal variability of solar radiation. Bennett (1967) and Hay (1976) have acknowledged that substantial variability exists in solar radiation and that current observational and analytical programs do not allow a complete evaluation of such variability. In this paper, an attempt is made to show that a synoptic approach to the analysis of solar radiation regimes may be more appropriate than using calendar periods (weeks, months) and yield more meaningful information on the solar radiation climate. The ultimate aims would be to associate distinctive solar radiation regimes with distinctive synoptic weather patterns (types) and to develop a climatology based on the spatial and temporal characteristics of the weather types. This somewhat indirect approach (through weather types rather than directly through solar radiation types) is necessary and perhaps desirable. The necessity arises from a spatially and temporally more restricted data base for solar radiation and from the knowledge that, in general, solar radiation is probably spatially less coherent than synoptic weather patterns. The desirability is a consequence of the benefits which result from an analysis of the parameters influencing the distribution (e.g., anticyclonic, frontal depression) rather than simply describing the distribution itself.

The associations between synoptic weather conditions and the spatial and temporal characteristics of radiation and energy flows have been recognized in recent studies including those of Vowinckel and Orvig (1969a, 1969b, 1971). In the present study a synoptic approach to radiation climatology will be tested using 100 kPa height data and measured and modeled solar radiation information for British Columbia, Canada.

2. Preliminary analysis

a. *Synoptic weather types*

The classification of synoptic weather maps provides a convenient means of summarizing the complexities of day-to-day weather patterns and for combining the individual days into a limited number

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of categories or types for purposes of relating particular atmospheric characteristics to the synoptic-scale events. Ideally the typing scheme is designed such that, for a given characteristic such as solar radiation, the differences between days of one type are small compared to the differences between days of different types.

In the present study the objective correlation typing technique of Lund (1963) was used. Techniques similar to Lund's have also been adopted by Paegle and Kierulff (1974) for the western United States and Singh *et al.* (1978) for India. For the period 1963–72, values of the 100 kPa heights at 0000 GMT for a 113 point grid (Fig. 1) were analyzed with 0.7 as the correlation coefficient threshold. The size of the data set meant that the typing analysis was initially performed one year at a time resulting in 25 types per year. The combined 250 types for the 10 years were in turn analyzed yielding the final 28 types. In the final assignment, an individual day was allocated to the type with which it had the highest correlation. To qualify as a final type, a minimum of 37 days (about 1% of the total 3653 days) had to be allocated.

In addition to the 28 types, which fell into five basic groups subjectively named after the dominant map features (ocean highs, ridges, land highs, troughs, ocean lows), there were unclassified and missing data groups which amounted, respectively, to 23.8 and 2.5% of the total number of days. The unfortunately large number of unclassified days could be reduced by lowering the correlation coefficient threshold. However, this in turn would increase the pattern variability within a given type.

b. Solar radiation data

The analysis of solar radiation regimes concentrated on the year 1972. This was the year which had the greatest number of radiation measuring

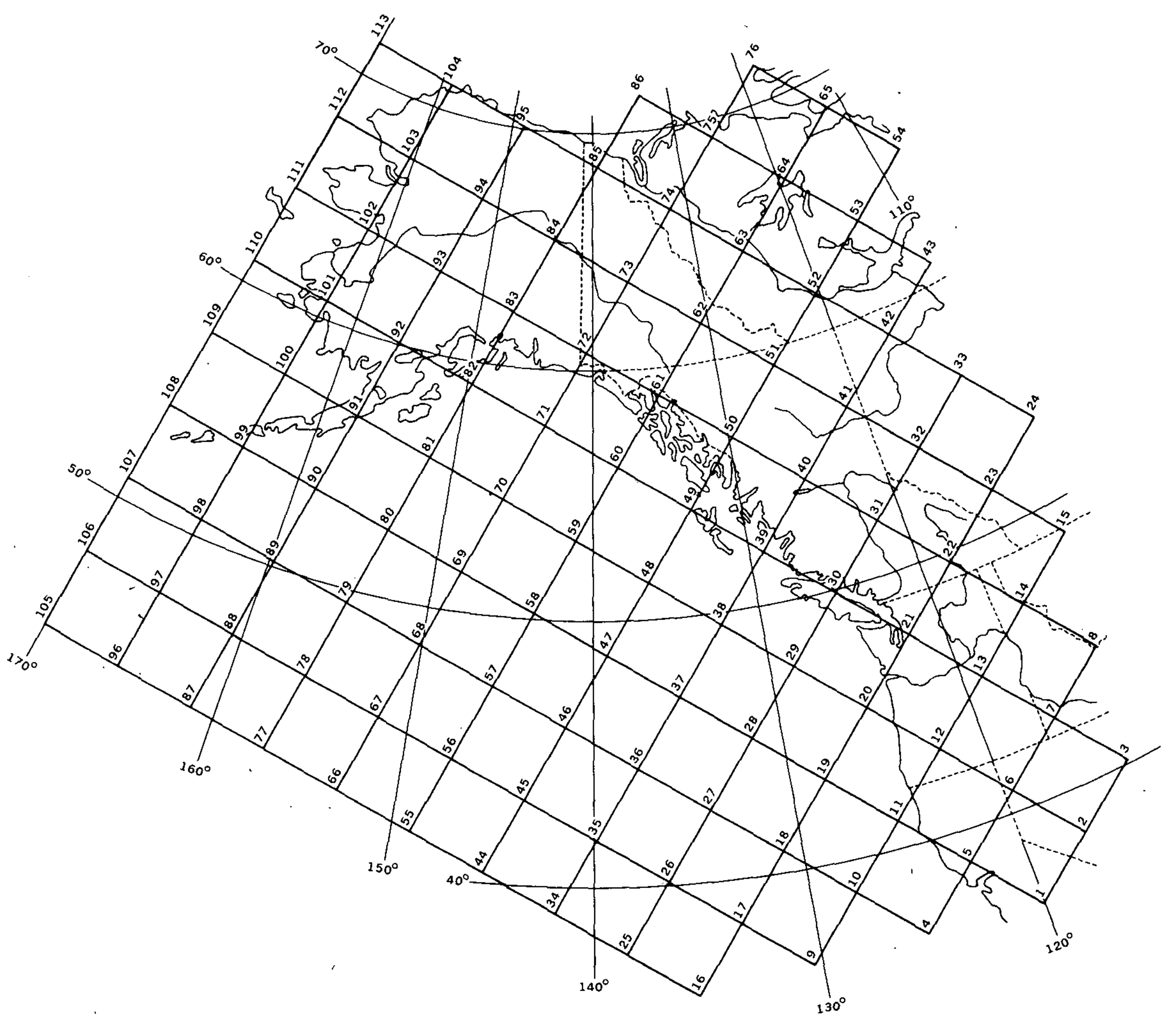

FIG. 1. The 113-point data grid for British Columbia and adjacent areas of the northeastern Pacific Ocean.

stations operating in the study area and for which grid-point height data were available. Ten stations (eight in British Columbia and one each in the adjacent areas of Alberta and the Yukon Territory) routinely measured solar radiation during 1972 (see Fig. 2). In order to improve this solar radiation data base, additional values were calculated using a numerical model which requires hourly meteorological and sunshine data as input. Details of this model are given in Suckling and Hay (1976a, 1977). For 1972, 13 locations could be added to the solar radiation network through the use of this model (Fig. 2). Of the ten measuring stations, five also measured the appropriate cloud and sunshine parameters (for Summerland, the cloud data were obtained from Penticton ~20 km southeast) which enabled independent testing of the solar radiation model. For daily solar radiation values for all five stations, the rms error for the calculated values was less than 1.7 MJ $m^{-2}day^{-1}$ or within ±18% of the observed values.

3. Synoptic analyses of the radiation data

a. Determination of solar radiation regimes

Solar radiation data for the 23 locations shown in Fig. 2 were divided by the appropriate extraterrestrial values in order to provide normalized solar radiation "transmissions", and thereby reduce the effects of season and latitude. The average solar radiation transmissions for each of the synoptic weather types were calculated for the year 1972 and over longer periods of time for selected solar radiation measuring stations. These data were then analyzed to determine whether the synoptic types (based on the 100 kPa height data) were associated with distinctive solar radiation regimes (based on the transmission data). An analysis of variance was performed in two ways: first with respect to time and second with respect to space.

With respect to time, the within and between synoptic type variances were analyzed by calculating F ratios (Panofsky and Brier, 1958) for each loca-

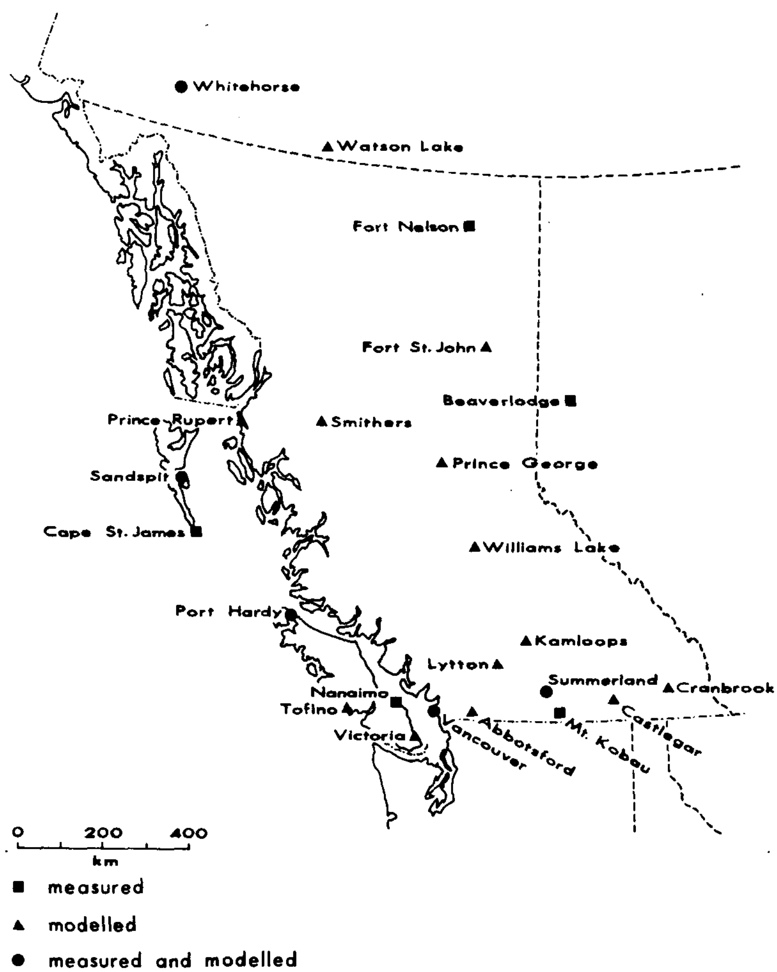

Fig. 2. Solar radiation measuring and modeling stations in British Columbia and adjacent areas.

TABLE 1. *F* ratios for the synoptic-type solar radiation distribution analysis for the British Columbia study area.

Period	Location	*F* ratios: 1% critical value	*F* ratios: Calculated value
1963–72	Vancouver	1.69	13.5
	Summerland	1.69	8.8
	Beaverlodge	1.69	1.87
1968–72	Port Hardy	1.69	7.9
	Cape St. James	1.69	7.9
	Sandspit	1.69	6.5
	Edmonton	1.69	1.42
1972	Abbotsford	1.74	3.5
	Castlegar	1.74	3.5
	Cranbrook	1.74	1.84
	Fort Nelson	1.74	2.1
	Fort St. John	1.74	3.1
	Kamloops	1.74	3.9
	Lytton	1.74	3.0
	Mt. Kobau	1.74	2.1
	Nanaimo	1.74	4.7
	Prince George	1.74	3.7
	Prince Rupert	1.74	3.7
	Smithers	1.74	3.0
	Tofino	1.74	4.6
	Victoria Airport	1.74	4.4
	Watson Lake	1.74	2.5
	Whitehorse	1.74	1.93
	Williams Lake	1.74	2.5

tion. For Vancouver, Summerland and Beaverlodge the available solar radiation data permitted calculations for ten years (1963–72) while a five-year period (1968–72) was possible for Port Hardy, Cape St. James, Sandspit and one additional station adjacent to the study area, namely, Edmonton, Alberta. For the remaining 17 stations *F* ratios were calculated for 1972 only. The results are given in Table 1 and indicate that the calculated *F* ratios are consistently above the critical values for a 1% confidence level (obtained from Panofsky and Brier, 1958). The only exception is Edmonton where the analysis indicates that the solar radiation variances within synoptic types are greater than those between types. Since Edmonton is just outside the synoptic study area, such an exception is expected. Moreover, the localities with the lowest but still significant *F* ratios (Cranbrook, Beaverlodge and Whitehorse) are all located near the boundaries of the synoptic study area.

The spatial distinctiveness of the synoptic solar radiation regimes was assessed by way of a *t*-test using matched pairs. This involved the comparison of the solar radiation transmissions for each synoptic type with every other synoptic type, thereby deriving 29 values of the *t* statistic for each synoptic type (there were 28 types plus unclassified and missing data groups making a total of

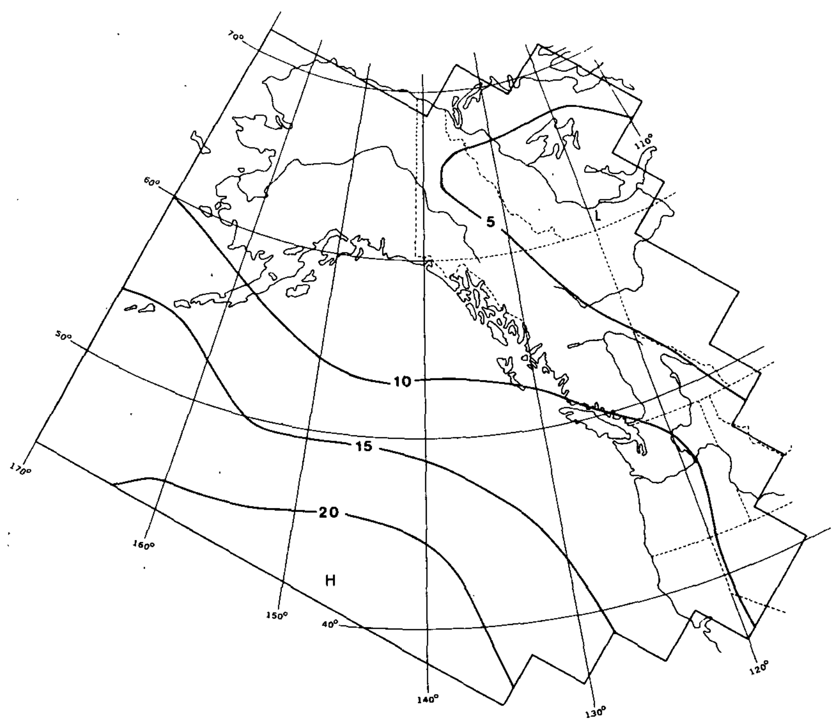

FIG. 3. One hundred kPa height distribution (dam) for the type day (5 July 1964) for synoptic weather Type 2.

30 types for statistical analysis). At the 1% confidence level, 304 of the 435 combinations were significantly different. Generally, pairings which were not significantly different involved types which were in the same subjective grouping, such as "ocean high" or "ocean low". Thus for a substantial majority of the types it can be shown that there are statistically significant differences in the spatial patterns of solar radiation between synoptic weather types.

b. Selected examples of synoptic solar radiation regimes

Average values of solar radiation transmission for each synoptic type have been calculated. Maps for three of the most common types (Types 2, 4 and 6) are presented here. Figs. 3 and 4 show the 100 kPa distribution and solar radiation transmissions for Type 2, an anticyclonic type or "ocean high". Transmissivities are relatively uniform and generally above average with this particular pressure distribution. The 100 kPa distribution and solar radiation transmissions for Type 4 are given in Figs. 5 and 6. This is a cyclonic type or "ocean low" and Fig. 6 shows that transmissions are consistently low on the coast with substantially less reduction in the interior of the province. For Type 6, Fig. 7 shows that this is an anticyclonic type with the center of high pressure located on the coast. The solar radiation transmissions are shown in Fig. 8. Values are similar to that for Type 2 except for notably higher values along the coast.

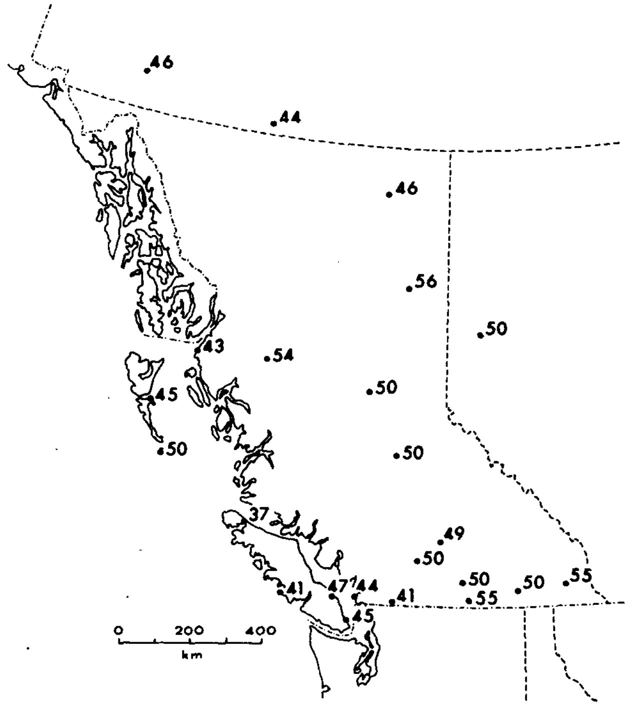

FIG. 4. Solar radiation transmission factors (%) for synoptic weather Type 2.

Marked seasonal variations in the frequency of specific synoptic types associated with distinctive

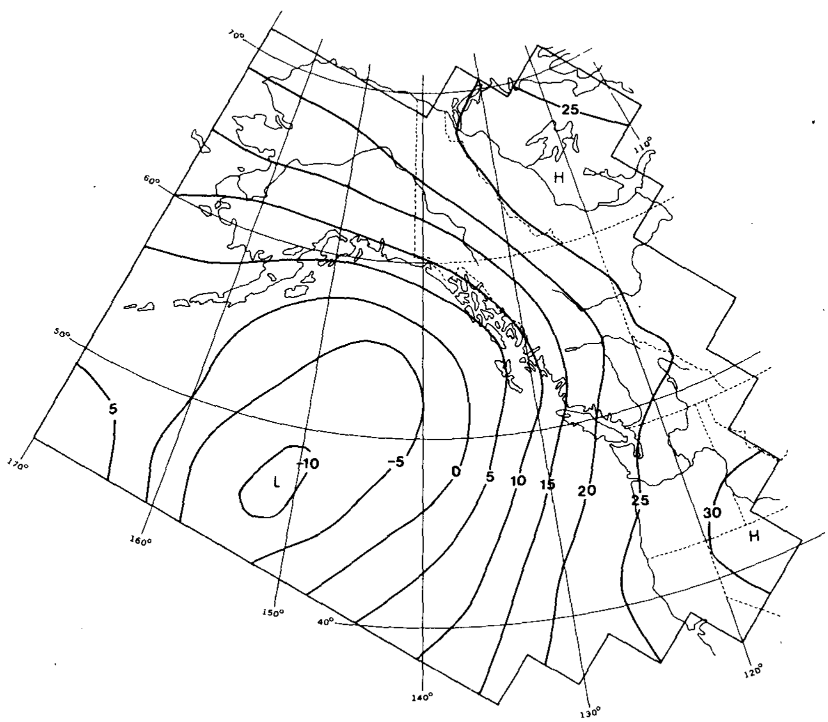

FIG. 5. As in Fig. 3 except for 19 November 1969 for synoptic weather Type 4.

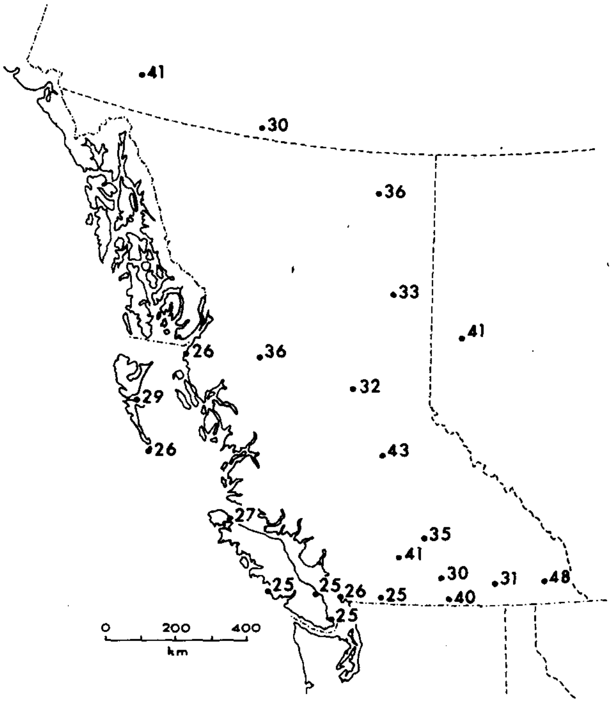

FIG. 6. As in Fig. 4 except for synoptic weather Type 4.

solar radiation transmissivities will be important to solar radiation receipt at the earth's surface. The well-developed seasonal variations in the frequency of a selected synoptic type are evident in Table 2.

4. Discussion of results

The foregoing analyses imply that synoptic weather types do generally discriminate the spatial and temporal characteristics of the distributions of solar radiation transmissions. However, specific application of these results indicates that while the discrimination is statistically significant, it is not sufficient to make the synoptic typing approach a viable alternative to other descriptive techniques. The inadequacies may be demonstrated for both the spatial and temporal characteristics.

a. Spatial variability

Under specific synoptic weather types the spatial variability of solar radiation may be small and coherent, resulting in acceptable interpolation errors for a given measurement network density and thereby avoiding the necessity for supplementing the observational data by numerical modeling or other means. If such synoptic regimes were associated with high energy demand and high solar energy availability, there would be obvious advantages when evaluating the solar energy resource.

A synoptic weather type which is associated with these energy supply and demand characteristics is Type 6, an anticyclonic type with the center of high pressure located near land (see Fig. 7). This type occurs throughout the year but has its highest frequency of occurrence in September. For days be-

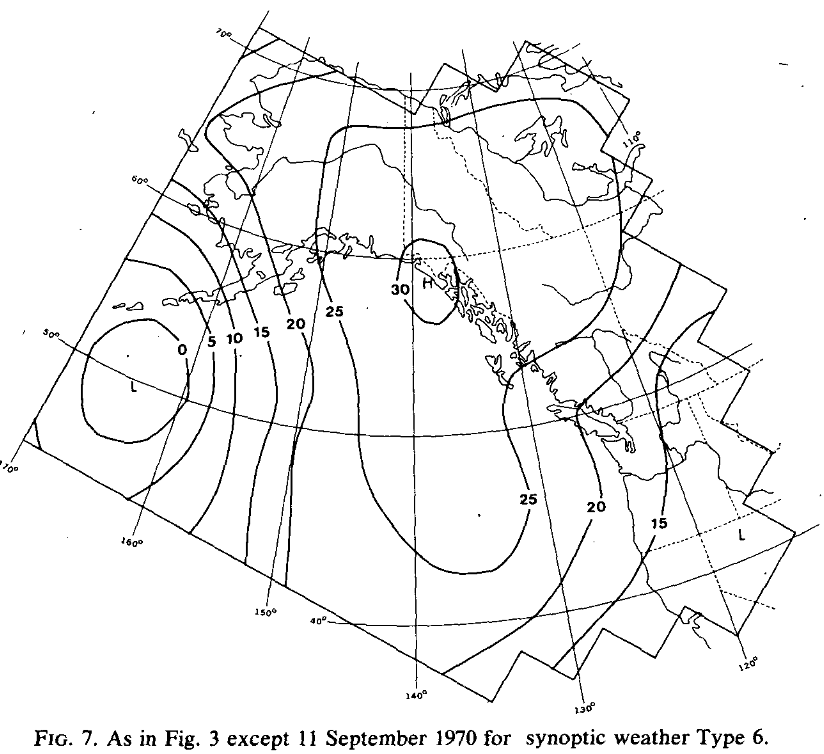

FIG. 7. As in Fig. 3 except 11 September 1970 for synoptic weather Type 6.

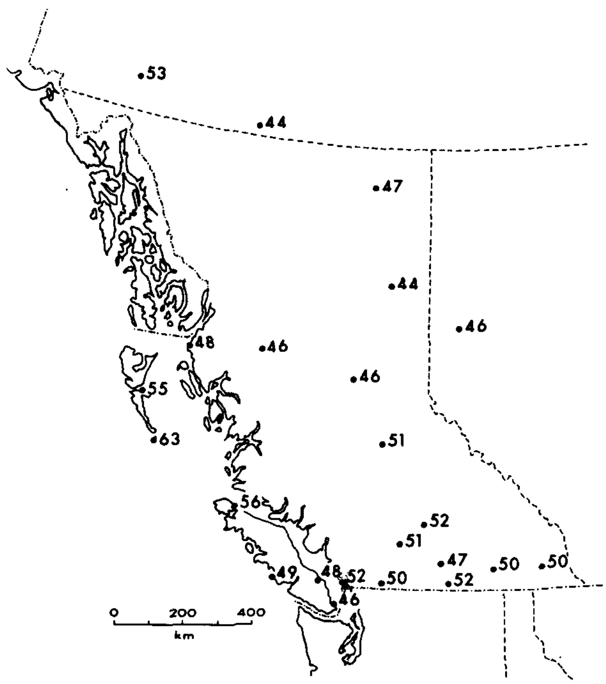

Fig. 8. As in Fig. 4 except synoptic weather Type 6.

Table 2. Monthly frequency of occurrence for selected synoptic types during the period 1963–72.

Month	Type 2	Type 4	Type 6
January	6	51	4
February	5	54	0
March	9	27	5
April	33	9	7
May	27	12	6
June	55	1	9
July	80	0	1
August	58	2	9
September	15	10	15
October	22	29	3
November	6	34	0
December	2	59	6
Total	318	288	65

tween 1968 and 1972 when this type occurred, Fig. 9 gives the coefficient of variability of the differences in daily solar radiation totals for pairs of stations in the British Columbia area. These are plotted against the distance between the corresponding station pair. The line in Fig. 9 represents a curve fitted by eye to the points resulting from a similar

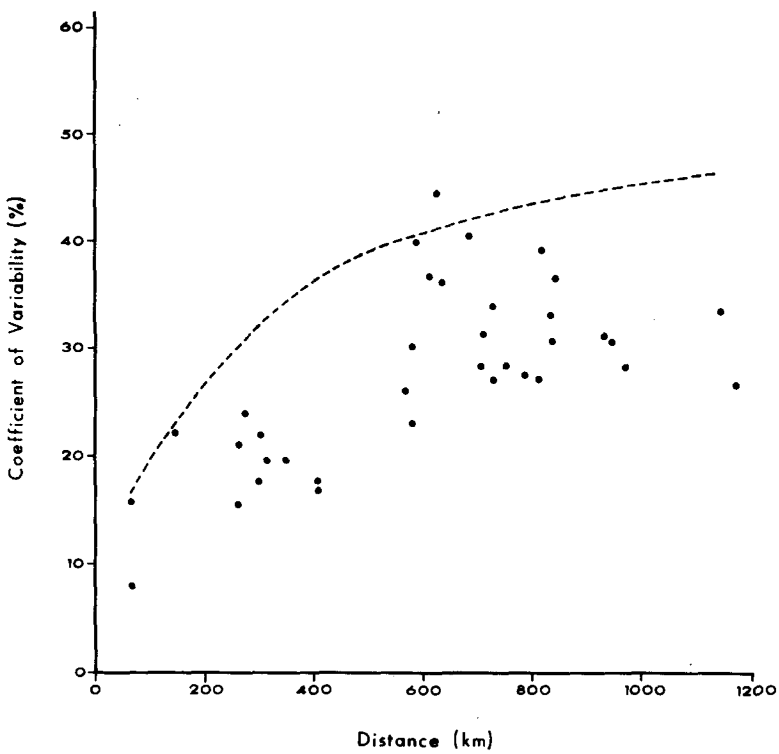

Fig. 9. Coefficient of variability of differences in daily values of solar radiation for given station pairs as a function of the distance between the station pair. The dashed curve is a generalized relationship for all days between 1968 and 1972 while the individual points are for days when synoptic weather Type 6 occurred.

TABLE 3. Average and standard deviation for solar radiation transmissivity for selected synoptic weather types at selected locations.

Location	Type	Average transmissivity (percent)	Standard deviation (percent)
Whitehorse	2	46	15
	6	53	14
	1	52	18
	10	64	16
	4	41	17
	all days	47	17
Prince George	2	50	16
	6	46	20
	1	46	17
	10	49	14
	4	32	15
	all days	48	19
Sandspit	2	45	16
	6	55	13
	1	39	19
	10	39	18
	4	29	15
	all days	41	18
Vancouver	2	44	17
	6	52	13
	1	39	20
	10	40	18
	4	26	20
	all days	44	22
Summerland	2	50	16
	6	47	18
	1	44	20
	10	51	15
	4	30	14
	all days	49	20
Cranbrook	2	55	18
	6	50	17
	1	51	22
	10	60	18
	4	48	17
	all days	54	19

analysis for *all days* in the same period (Suckling and Hay, 1976b). In that analysis all data points deviated from the curve by a coefficient of variability of less than 6%. It is clear that the spatial variability in solar radiation when this anticyclonic type (Type 6) prevails is substantially less than that for average conditions. Thus greater accuracy in specifying the distributional characteristics of the solar energy will be possible for this synoptic type. However, the reduced spatial variability is restricted to selected anticyclonic types. The curve in Fig. 9 has been used by Suckling and Hay (1976b) and Hay and Suckling (1978) to show that in British Columbia the solar radiation measurement network is generally of insufficient density to provide adequate resolution of the spatial variability of solar radiation over the province. A small consolation is that it is at the time of greatest solar energy input that the network is most adequate.

b. Temporal variability

If, for a given synoptic type, there is little variation in solar radiation transmission for different days at a given location, then it would be possible to estimate the solar radiation simply from a knowledge of the synoptic type for that day. This would eliminate the need for other measurement or modeling and would allow the direct use of a prognostic chart in forecasting solar radiation inputs in a manner similar to that employed by Paegle (1974) and Knowles and Jehn (1975) to forecast precipitation.

Table 3 presents the averages and standard deviations of solar radiation transmission values for six selected locations for the most frequent synoptic weather type in each of the five broad, subjectively named groups. While the earlier analysis in Section 3 showed that within-type variability was significantly less than that between types, Table 3 indicates that within-type standard deviations are still rather large. For example, at Vancouver the average transmission for Type 2 is 44%, while the standard deviation is ±17%. For a typical July day with an extraterrestrial radiation of 40 MJ $m^{-2}day^{-1}$, one standard deviation represents a range in calculated solar radiation reaching Vancouver of 10.8 to 24.4 MJ $m^{-2}day^{-1}$, a resolution which is totally unacceptable for most applications. Thus this synoptic typing approach cannot replace the measurement or numerical modeling of solar radiation.

In another application, changing frequency of occurrence of synoptic types might be used to explain the interannual variability of solar radiation. For the months of January and July and the years 1963–72, synoptic-type frequencies are summarized in Tables 4 and 5, while measured mean daily solar radiation values for Vancouver, Summerland and Beaverlodge are provided in Fig. 10. There is a greater success in associating the interannual variability in solar radiation with changes in frequency of synoptic types for January than there is for July. For example, the generally high radiation values in January for 1963 and 1969 for all three stations and for Summerland in 1972 are associated with either increased frequency of the high solar radiation anticyclonic types (e.g., Type 22) or the reduced frequency of cyclonic types with their lower transmissivities (e.g. Type 4). Depressed solar radiation values, most notably for the period 1964–68, were associated with relatively high frequencies of these latter cyclonic types. However, it should be noted that not all cyclonic types are associated with low transmissivities. For example, although in January 1969 lows classified as Types 9 and 14 dominated, high values of solar radiation were re-

TABLE 4. Synoptic-type frequencies for January from 1963 to 1972.

Synoptic group	Type	Year									
		1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Ocean highs	2						2	1		2	1
	5		1								
	19		4			3				1	
	22	16	4	2	3	1			1	3	
	25										
	13						1				
	18										
Land highs	6	2			1						1
	20	2					1	2	6	1	2
	28			1	1					1	
Ridges	1		6		2	4					1
	24							1			
	16		1								
	12			1		1					1
	17										1
Troughs	10	2	1	2	1	1			2		
	11				7			2	3		
	7					1	1	1			
Ocean lows	4		5	12	12	5	2	1	6	9	
	3	1	1	2			1	1	2		
	26		3	2	1		1				1
	15		2			1	1	2		1	3
	8		1			1	1	1	1		
	9	1		5		2	2	5	3	1	
	14					1		4		2	
	23	1				1	3		2	1	2
	21	1			1				1		
	27				1	2	1				
Unclassified		3	2	4	1	5	13	6	4	8	15
Missing data		2				2	1	4		1	3

ported at the three stations. This is because low-transmission conditions are restricted to the outer coast of British Columbia with the smaller offshore lows that these types define.

The associations between interannual variability in solar radiation and synoptic types are not so well developed in July. While the absolute variations in solar radiation are larger (for Vancouver, 4.7 MJ $m^{-2}day^{-1}$ in July compared with 1.5 MJ $m^{-2}day^{-1}$ in January), the relative variability is less (21% as opposed to over 50%, respectively). Moreover, reasons for the substantial differences in measured solar radiation at the three locations for July between 1964 and 1967 are not found in changes in the synoptic weather type frequencies listed in Table 5.

Relevant to this discrepancy is the fact that the synoptic typing technique used in the present study has difficulty resolving smaller scale features and the problem is increased by the large (381 km) average distance between the grid points for the 100 kPa height data (Fig. 1). A consequence of this poor resolution is illustrated by comparing synoptic-type frequencies resulting from the present study with those given by Maunder (1968) who used a subjective classification technique on 1964 and 1965 sea level pressure maps for an area centered on Vancouver Island. Maunder found cyclonic and anticyclonic type frequencies of 54 and 38%, respectively, while the present study indicated frequencies of 28 and 48%, respectively, for the same two-year period. The large discrepancy in the frequency of cyclonic types is best developed in summers when low pressure systems near Vancouver Island are quite frequent. These small but locally significant synoptic features will often be overlooked when the Lund classification technique is performed on a relatively large area.

Further evidence of the poor spatial resolution being a reason for the failure of the synoptic weather types to explain the interannual variability of solar radiation for July is contained in Table 6. For each July between 1963 and 1972, the portions of the daily surface synoptic charts (prepared by the Canadian Atmospheric Environment Service Pacific Weather Centre) bounded by 40 and 55°N and 115 and 130°W were subjectively analyzed for the presence of low-pressure systems. Closed lows (isobar interval of 0.4 kPa) frequently associated with frontal features were counted while thermally in-

TABLE 5. As in Table 4 except for July.

Synoptic group	Type	Year									
		1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Ocean highs	2	17	12	9	11	9	4	15	5	2	1
	5	2	3	3	2		1	6	3	5	3
	19		2	1			1	1	1		2
	22										
	25	2		3	5		2	3	3	3	
	13	2			1	14	2			1	
	18	3		3	3		1	1		1	2
Land highs	6									1	
	20										
	28						1				1
Ridges	1		1				6		1		1
	24		1	2	2				4		1
	16	1	1	1	3				4	1	
	12		1						3	1	
	17		1				4	3			1
Troughs	10						1				2
	11										
	7		2	1	1					1	
Ocean lows	4										
	3							1			1
	26								1		
	15										
	8			1							
	9										
	14									1	1
	23										
	21										
	27										
Unclassified		3	7	7	3	7	8		5	12	14
Missing data		1				1		1	1	2	1

duced lows (quasi-stationary) over the land were excluded. The resulting monthly frequencies of lows are given in Table 6, together with the departure from normal of the monthly mean station pressure (in an attempt to include a more objective parameter in the analysis) and the observed mean solar radiation for Vancouver. The data clearly show that at this scale of analysis relatively low solar radiation input is associated with a high frequency of lows, and the substantial interannual variability in solar radiation in July between 1964 and 1967 is associated with comparable variability in both the frequency of low pressure systems and departures from normal in the station pressures.

The comparatively large spatial dimensions of the winter circulation features results in some success in associating synoptic types and solar radiation regimes but, in summer, the typing scheme and 100 kPa height data used in the present analysis do not facilitate the recognition of features which are significant determinants of the solar radiation climate.

5. Conclusions

The synoptic weather types defined in this study using an objective correlation classification technique were shown to determine statistically distinct solar radiation distributions. Thus there is support for the technique to be used to establish synoptic solar radiation regimes. However, in practical terms the distinctiveness of the solar radiation regimes is not sufficient to be used in such applications as interpolation between measurement stations, estimation of solar radiation inputs in the absence of observed data or in the explanation of the interannual variability of solar radiation.

The data base and analytical techniques adopted in the present study have influenced these conclusions. The Lund objective correlation typing technique is not sensitive to small-scale features and this problem will be exaggerated by the use in the present study of a 113 point grid covering British Columbia and a substantial area of the northeast Pacific Ocean with an average grid-point spacing of 381 km.

The distinctiveness of the synoptic types, and hence of the solar radiation regimes, could be increased by using a correlation coefficient threshold which is higher than the 0.7 value which was adopted in the present study. However, as noted in Section 2a, this would increase the number of unclassified days above the already high value of 24%.

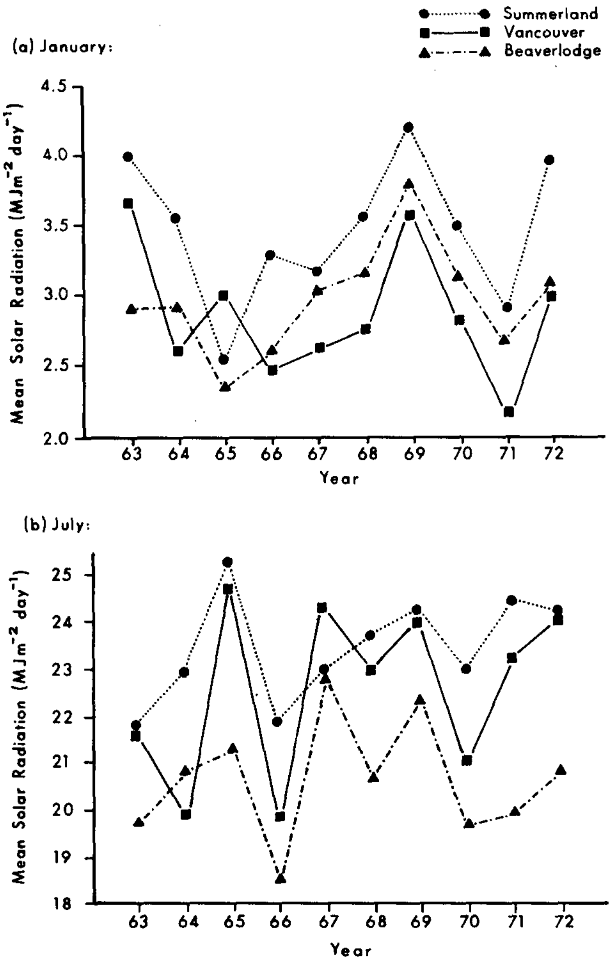

FIG. 10. Mean daily solar radiation for January and July 1963–1972.

The study has illustrated that the distributional characteristics of solar radiation are not totally defined by the large-scale synoptic circulation patterns. Attempts to base a solar radiation climatology solely on the synoptic regimes defined using the readily available data and techniques employed in the present study are clearly not justified. This is true even for a large area. Nevertheless, the statistical analyses do suggest that the use of more appropriate synoptic data and typing techniques, especially those which increase the sensitivity to small-scale synoptic features, may overcome many of the inadequacies inherent in the present study.

Acknowledgments. This study was supported, in part, by the Canadian Atmospheric Environment Service and the National Research Council of Canada. The 100 kPa height data were supplied by the Canadian Meteorological Centre in Montreal.

TABLE 6. Cyclone frequencies and monthly mean pressure departures and solar radiation data for Vancouver, British Columbia, for July.

Year	Cyclone frequency*	Pressure departure from normal (kPa)**	Solar radiation (MJ m^{-2} day^{-1})***
1963	10	−0.12	21.7
1964	11	−0.20	20.0
1965	3	−0.05	24.7
1966	11	−0.14	19.9
1967	5	+0.02	24.3
1968	7	−0.04	23.0
1969	4	+0.04	24.1
1970	9	−0.07	21.0
1971	5	−0.02	23.2
1972	1	−0.12	24.2

* Number of closed lows (isobar interval 0.4 kPa) occurring per month in area between 40 and 55°N and 115 and 130°W.
** Normal pressure at Vancouver in July is 101.75 kPa.
*** Mean solar radiation at Vancouver in July is 23.0 MJ m^{-2} day^{-1}.

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