LARGE SCALE ATMOSPHERIC CIRCULATIONS AFFECTING FLOODS ON THE FRASER RIVER

By

J. P. Bruce[1/]

INTRODUCTION

For some years now meteorologists have conceived of local weather and climate at the earth's surface as manifestations of the large-scale flow patterns in the middle and upper levels of the troposphere, and have been gaining increasing skill in predicting these patterns. At the same time, hydrologists have been learning a great deal about the response of rivers to the weather and climate at the ground within their drainage areas. However, rather few studies have been undertaken which consider hydrologic phenomena, such as floods, as consequences of the large-scale motions in the "free" atmosphere.

Large-scale motions of the atmosphere are, of course, reflected more directly in the behaviour of rivers with large drainage basins rather than of small watersheds. Rivers with small drainage areas are much more responsive to local severe storms and to snow melt periods of very short durations, and these weather phenomena are connected more tenuously with the large-scale circulations than are the longer duration weather phenomena necessary for floods on large basins.

The present study is concerned with atmospheric circulations leading to floods on a large watershed, the Fraser, with drainage area of 83,700 square miles above the stream gauging station at Hope, B. C. (Fig. 1). While the report does not in itself yield a method of forecasting floods, it is hoped that the results will point the way towards further research to make longer-range predictions possible.

Fraser River Floods

A discussion of the meteorological factors directly responsible for major floods on the Fraser River is contained in the Fraser River Board report of June 1958 (1). Five factors were examined; (i) the moisture content of the soil before the snowpack begins to melt (ii) the water equivalent of the accumulated snowpack (iii) the prolongation of below-freezing winter temperatures into the spring, (iv) the rate and amount of temperature rise in the spring and (v) precipitation during the period of melting in the spring. Data available suggested that the major factors in producing the great floods of record in 1894 and 1948 were (iii) and (iv). That is, a temperature sequence which inhibits substantial snow melt prior to the latter part of May, and then causes very rapid snowmelt, appears to be the dominant factor in major flood production, although rainfall occurring just before the time of the peak flow, and the water equivalent of the accumulated snow pack can at times be significant factors.

This is illustrated in Fig. 2 which shows (i) the peak daily discharge and the total runoff volume April-June, of the river at Hope, for the period 1945 to 1963, and, as well, gives (ii) the snowpack water equivalent at the end of March for the Blue River snow course in the eastern part of the basin, and (iii) the winter snowfall at Barkerville. Barkerville is in the north-central part of the basin at an elevation of 4180 feet, within a few hundred feet of the mean elevation of the basin (about 3800 ft.). It is seen from the Blue River data that a number of years had greater snowpack water equivalents at the beginning of April than did the major flood year of 1948. Similarly, at the only other snow course location with observations dating to 1945 or earlier, Cypress Lake (See Fig. 1), a greater than average snowpack water equivalent was observed at the first of April 1948, but substantially larger amounts than in 1948 were present in April 1949, 1950, 1955 and particularly in 1956. Snowfall at Barkerville was about equally high in the winters of 1945-46, and 1947-48. Both sets of data suggest that a season of relatively high, but not necessarily excessive, snowfall and deep snow cover

1/ Superintendent of Hydrometeorology, Meteorological Branch, Department of Transport, Toronto, Canada.

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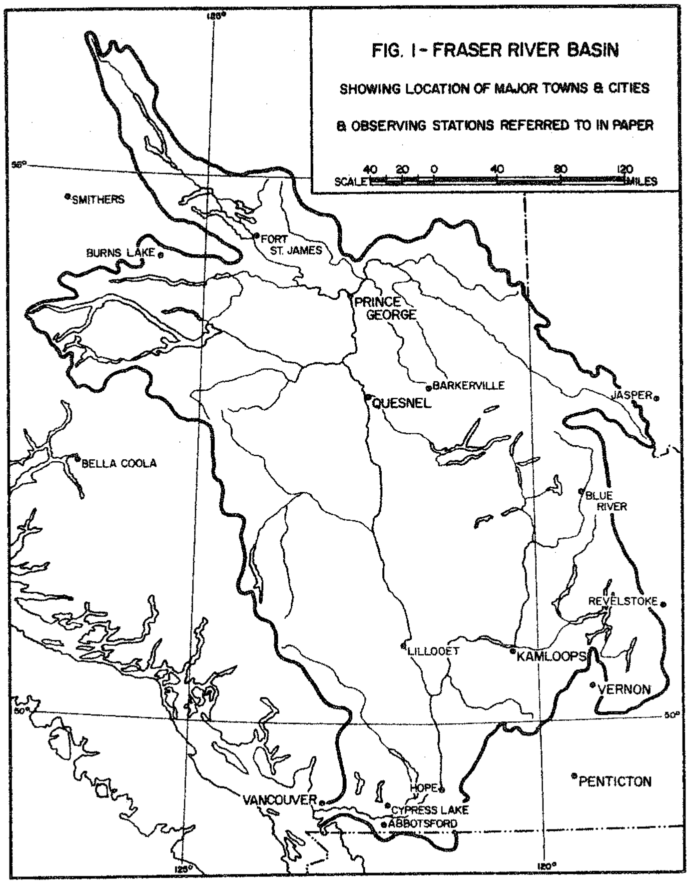


FIG. I - FRASER RIVER BASIN

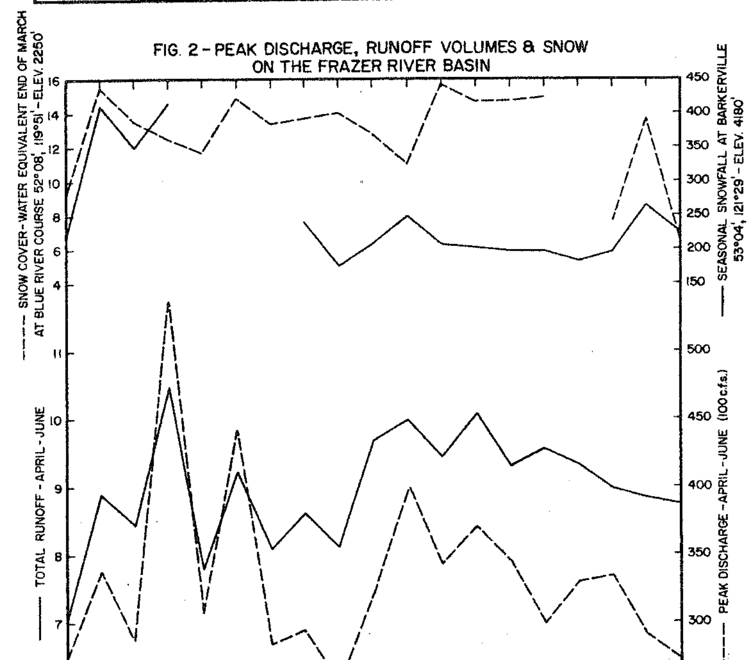


FIG. 2 - PEAK DISCHARGE, RUNOFF VOLUMES & SNOW ON THE FRAZER RIVER BASIN

by April 1 precedes flooding conditions. However, greater than normal snow accumulation is not a sufficient condition for a serious flood.

As far as rainfall is concerned, the total fall April to June appears to be a relatively unimportant factor. For example, more than 2½ times as much rain fell in these three months at Barkerville in 1947 than in 1948. However in 1948 it appears that about 0.5 inch of rain fell in the central and northern part of the basin a few days before the peak discharge on June 9. This suggests that individual falls might reinforce a peak discharge although, on the Fraser River, rainfall alone appears to be ineffective in producing a major flood.

This brief analysis gives some idea then of the relative importance of the ground level temperature and precipitation sequences that lead to flood or non-flood conditions on the river. We now must ask, "In what way are these surface level manifestations related to large-scale atmospheric flow patterns, and what was the nature of middle tropospheric circulations in flood and non-flood-years on the Fraser?"

Middle Tropospheric Circulations 1948 and 1953

From Fig. 2 it can be seen that 1948 is the year of the greatest flood of recent record, at least since radiosonde observation networks made possible construction of upper level charts of atmospheric conditions. The spring runoff of 1953 had the lowest peak discharge of any year between 1945 and 1963. Accordingly, the circulations in these two years, 1948 and 1953, were carefully examined to determine the major features in April, May and June in a major flood year and in a low flow year. The study was confined to these three months since the temperature sequence in this period appears to be the most critical factor in determining whether or not a flood will occur.

Fig. 3, 4 and 5 are mean monthly maps of the height of the 500 millibar surface for April, May and June 1948. In April, the main feature affecting the Fraser River region was the marked North-South trough just off the coast at about 127°W. For such a trough to appear so sharply on a mean monthly map it must have been a dominant feature of the month's weather. During May 1948, a trough is still seen to persist along the west coast but it is now oriented in a NW-SE line about through Vancouver Island, with a marked ridge developing over Alberta and the Mackenzie River basin. This map is a composite of two regimes, one the continuation of the sharp west coast trough early in the month, with a marked change to a ridge aloft over the Fraser watershed region after about 19 May. In June the ridge is further west, persisting over British Columbia, although rather weak over the Fraser River watershed.

By contrast, the mean 500 mb map for April 1953 (Fig. 6) shows a weak ridge over the Fraser basin which persists during May (Fig. 7), although examination of weekly charts during May indicates that rapid fluctuations between trough and ridge conditions featured the month's circulation over southwestern British Columbia. In June (Fig. 8), the situation is somewhat changed with a mean trough position lying NNE-SSW over the Fraser Basin.

To illustrate the differences in the two years more vividly, departures from the mean values at that time of year at the heights of the 700 mb surface, for five day periods April to June, are shown in Fig. 9. It is evident that 1953 was characterized by frequent fluctuations from above normal height anomalies (ridge conditions) to below normal anomalies (troughs), with a greater tendency for negative anomalies in the latter part of May and in June. 1948 was a remarkably different kind of year. Negative anomalies persisted until about May 19 except for a brief weak positive anomaly in mid-April. The dramatic change to persistently above normal heights (ridge conditions) occurred between 17 May and 21 May.

These 700 mb height anomalies were obtained from 5-day mean maps prepared by the U. S. Weather Bureau's Extended Forecast Section. The plotted height anomaly values from the U.S.W.B. charts were values at the centre of the area bounded by 50° -55°N, and 120-130°N, (Fig. 8), that is near the north-western boundary of the Fraser River drainage.

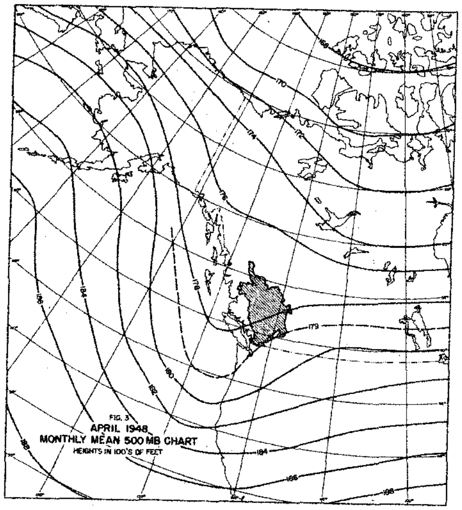


FIG. 3
APRIL 1948
MONTHLY MEAN 500 MB CHART
HEIGHTS IN 100'S OF FEET

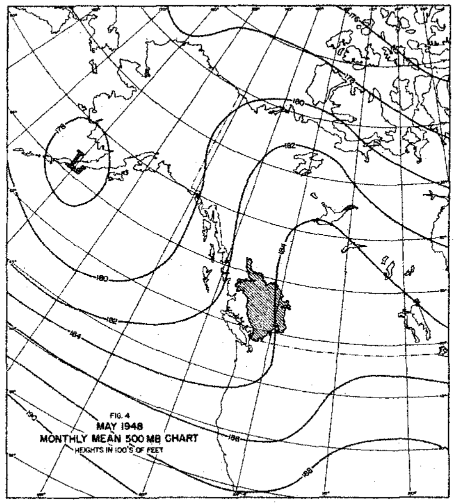


FIG. 4
MAY 1948
MONTHLY MEAN 500 MB CHART
HEIGHTS IN 100'S OF FEET

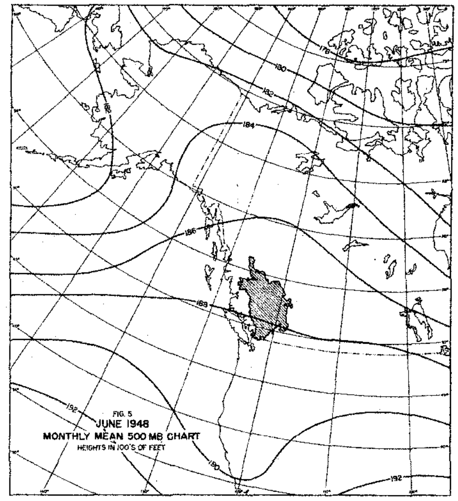


FIG. 5
JUNE 1948
MONTHLY MEAN 500 MB CHART
HEIGHTS IN 100'S OF FEET

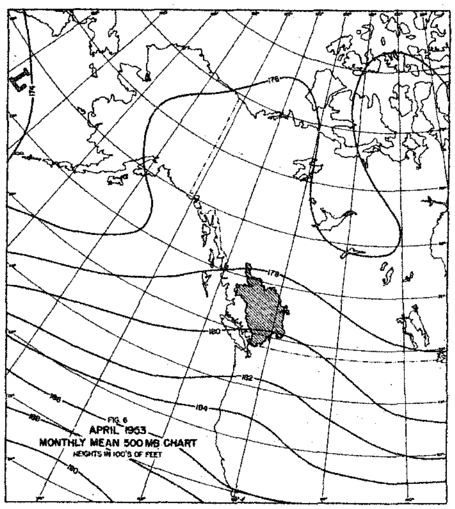


FIG. 6
APRIL 1953
MONTHLY MEAN 500 MB CHART
HEIGHTS IN 100'S OF FEET

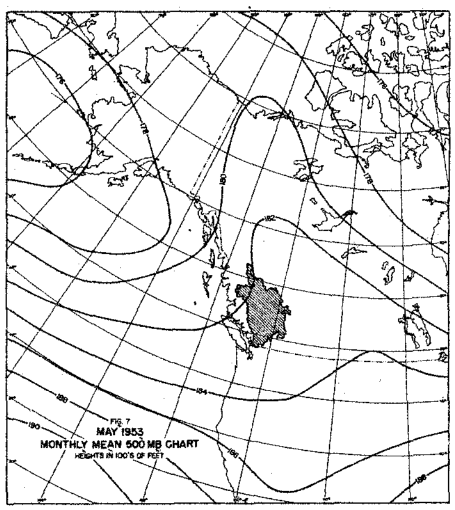


FIG. 7
MAY 1953
MONTHLY MEAN 500 MB CHART
HEIGHTS IN 100'S OF FEET

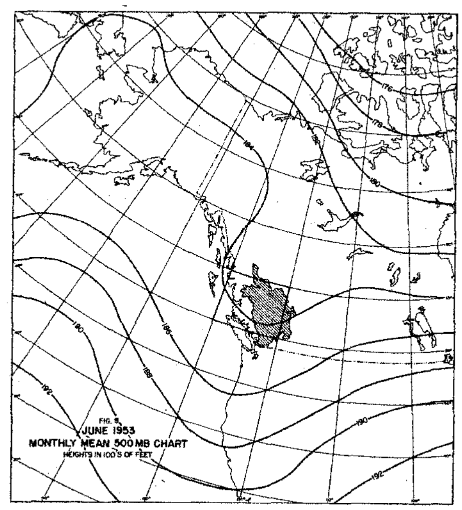


FIG. 8
JUNE 1953
MONTHLY MEAN 500 MB CHART
HEIGHTS IN 100'S OF FEET

Temperatures Associated with Circulation Patterns in 1948 and 1953

The temperatures associated with the above and below normal heights of the 700 mb surface and the flow patterns shown in Fig. 3 to 8 are illustrated in Fig. 10 and 11. Figure 10 shows mean upper-air temperatures from the radiosonde ascents at Prince George in the north-central portion of the basin. The set of 3 full-line curves for April, May and June 1953 illustrate a gradual warming from winter conditions. The mean curve for April 1953 is 5°C warmer at lower levels than the March curve but only 1 or 2°C warmer aloft. The mean curve for June is only slightly warmer than that for May; in the lower levels only a degree warmer.

By contrast the 4 dashed lines for 1948 show an April which is as cold or colder than February and March, an early May curve substantially colder than the mean May curve for 1953, but very warm conditions at the ground and aloft in late May and June, the June curve being 3-5 degrees C higher than in June 1953.

These temperature effects are further illustrated in Fig. 11 which shows the mean values of freezing levels in 1953 and 1948. In 1948 below freezing temperature existed down to ground level from January to April inclusive. The freezing level then rose in early May (1-18) to 820 mb (about 5800 ft) and in late May to 680 mb (about 10,700 ft) and remained at about the 10,000-ft level on the average in June.

The implications of these freezing levels in producing snowmelt are more apparent when it is realized that about 90% of the basin is at an elevation higher than the ground level at Prince George (2218 ft.), 40% is above 4000 ft., about 10% above 6000 ft. and 2% above 8000 ft. In other words, using the average temperatures for the month, some melting was likely occurring in 1953 over about one half of the basin in March, over about 3/4 of the basin in April and over about 97% of the basin in May. In 1948, only the lowest elevations of the basin had above freezing temperatures, on the average, until May, at which time virtually the whole basin changed to above freezing temperatures.

It is seen from these sets of figures that trough conditions aloft over or just west of the basin, and consequent negative height anomalies of the upper level pressure surfaces, results in below normal temperatures at the surface and aloft over the watershed. On the other hand, a ridge aloft over the basin brings warmer air at the ground. The marked difference between the non-flood year 1953 and the flood year 1948 lay in the remarkable persistence of early season cold-trough conditions and the late season warm-ridge situation in 1948, as contrasted with frequent and rapid fluctuations between ridge and trough conditions in 1953 and a tendency for a persisting trough aloft in the late part of the snowmelt season.

Temperatures in Other Years

So far, the differences between the recent years with greatest and least peak discharge have been studied. The upper-level temperatures in less extreme years might also throw some light on the general problem of the types of circulation which lead to floods. From Fig. 2 it is seen that 1950 had the second highest one-day peak discharge during the period 1945-1963, and 1951 was a year with relatively low peak discharge, actually the 4th lowest.

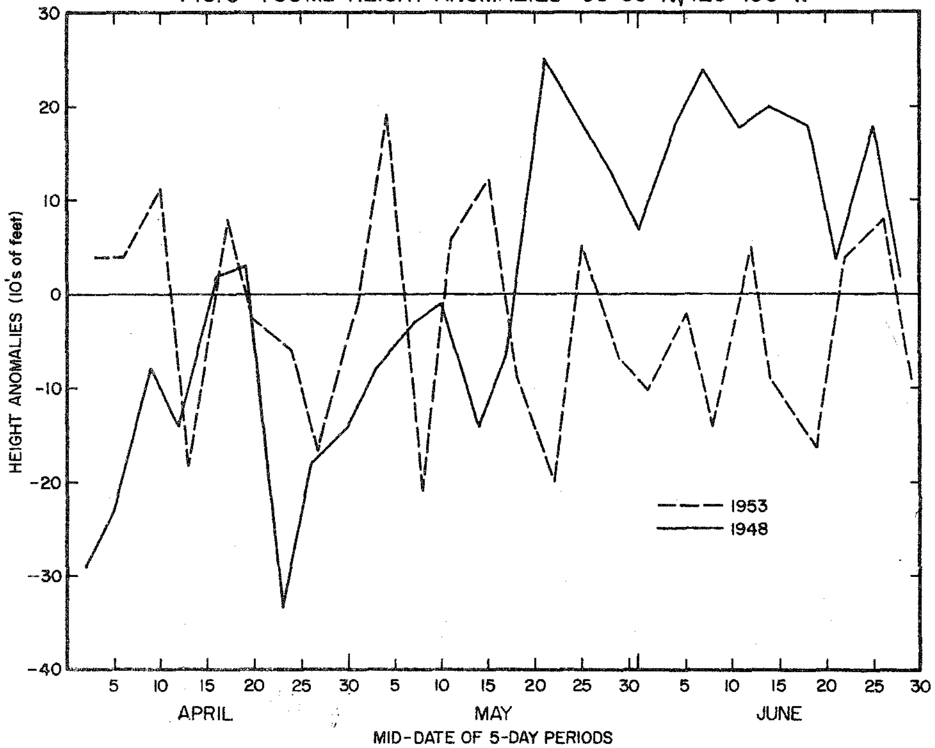
In table 1 are given the mean monthly temperatures, April, May and June for Prince George at the 850-mb (about 5000 ft.) and 700-mb (about 10,000 ft.) levels for the years in question, in order of decreasing peak discharge.

Table 1

Mean Temperatures °C
Prince George

Year	Pressure level	April	May	June
	850 mb	- 2.2	8.9	13.3
1948	700 mb	-13.0	-4.1	- 0.1

FIG. 9 - 700MB HEIGHT ANOMALIES - 50-55°N, 120-130°W



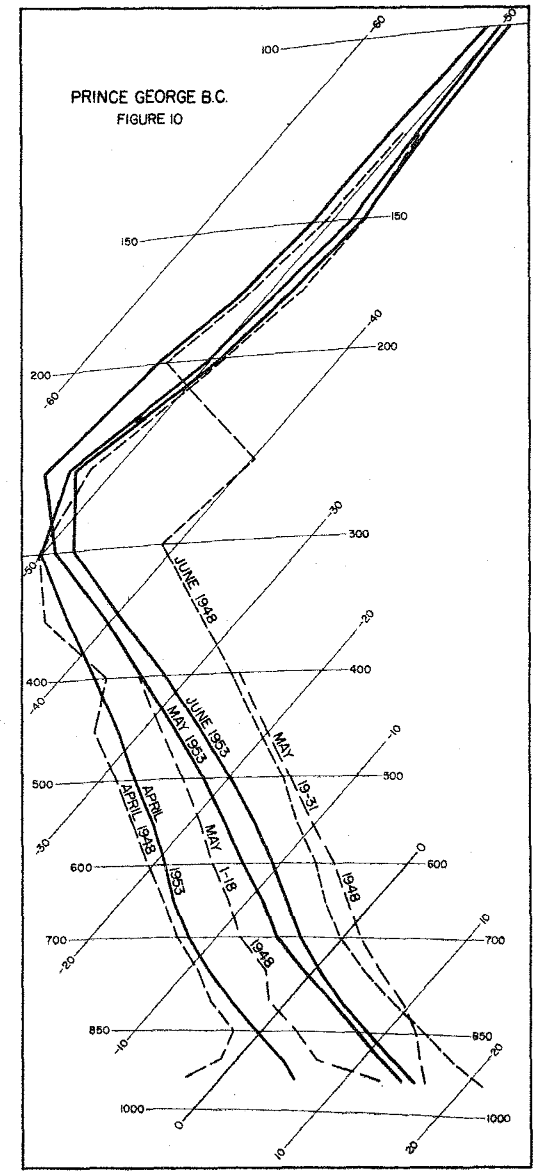
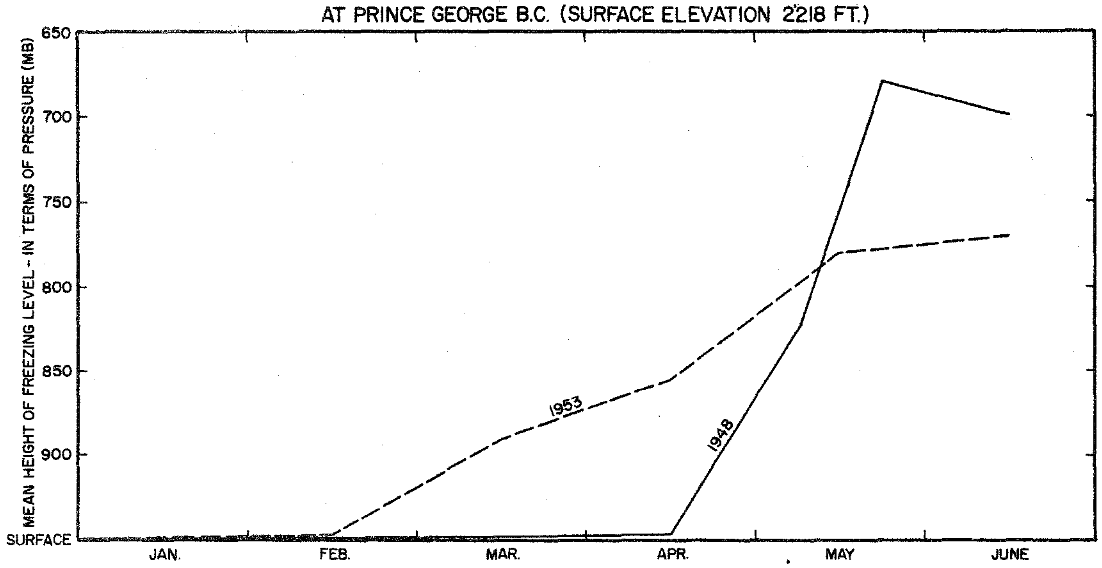


FIG. 11 - MEAN FREEZING LEVEL PRESSURE ELEVATIONS
AT PRINCE GEORGE B.C. (SURFACE ELEVATION 2218 FT.)



Year	Pressure level	April	May	June
	850 mb	- 0.6	4.9	13.3
1950	700 mb	-11.4	-7.5	- 0.2
	850 mb	1.1	6.8	9.4
1951	700 mb	-10.3	-5.2	- 3.9
	850 mb	- 0.4	7.9	8.7
1953	700 mb	-12.3	-5.0	- 3.4
Mean Values	850 mb	+ 0.2	+6.4	+ 8.5
1951-60	700 mb	-14.6	-5.7	- 3.2

It is apparent that the year with the highest peak (1948) had the coldest April, and warmest May and June. It has been previously noted that the high mean temperature in May 1948 was due mainly to the exceptionally high temperatures late in the month. While the second highest peak discharge year (1950) had a June practically as warm as 1948, it had the coldest May and a warmer April than 1948. The years of low peak discharge (1951 and 1953) are characterized mainly by relatively low mean temperatures in June. These years also had slightly warmer Aprils than 1948 and slightly cooler Mays. It will be noted that the temperatures in 1951 and 1953 are close to the average values for the decade 1951-60.

It thus appears thatthe significant difference between the two high peak years and the low years, lies in the mean June temperatures. When high June temperatures are preceded by high temperatures in late May and relatively low temperatues in April, as in 1948, a serious flood results.

SUMMARY

The foregoing diagrams and discussion indicate that the following statements can be made concerning the relationships between meteorological factors and their effects on spring flows on the Fraser River.

(i) The critical factor in determining whether the spring runoff will result in flooding appears to be the sequence of temperatures from April through June.

(ii) Most favourable conditions for flooding are below normal April and early May temperatures changing rapidly to above normal temperatures in late May and throughout June.

(iii) Higher than normal temperatures on the basin are associated with ridges aloft or positive height anomalies in the middle tropospheric circulation and low temperatures are related to trough conditions or negative neight anomalies over or just west of the basin.

(iv) Major floods on the Fraser, judging from data from the period 1945-1963, are a result of persistent upper level troughs over or just west of the basin throughout April and the first half of May, and a subsequent rapid transition to a persistent ridge aloft in late May and in June.

CONCLUSIONS

The forecasting of the upper level flow patterns for several months in advance is still well beyond the present state of the science of meteorology. However recent advances in computer techniques for prediction of the 500-mb height field on a hemispheric scale gives promise of increasing accuracy and length of forecast period. Even with very accurate prognostic charts for the 500-mb or 700-mb level, though, the problem remains of relating the circulation patterns at these levels to the weather at the ground and to the natural phenomena determined by this weather. It has been the aim of this paper to examine such relationships with particular reference to floods on the Fraser River.

It had been hoped at an early stage in preparation of this report to relate the large scale atmospheric flow patterns to anomalies in surface water temperatures in the Pacific.

However no simple relationship was evident and data were not available to permit a detailed analysis. Judging from recent work by Namias there are close but subtle relationships between these factors, and future meteorological and oceanographic studies should be directed towards studying the relationships which might permit further improvement in prediction of atmospheric circulations.

It is interesting to note that 1953, the year of minimum peak discharge on the Fraser, was a year of serious floods on the South Saskatchewan River basin (3) and in Japan. In other words the large-scale motions of the atmosphere which gave the low peak discharge year on the Fraser at the same time produced serious flood conditions both east and far west of the Fraser River watershed. It is hoped that further consideration of flood events in the context of atmospheric circulations on a hemispheric scale may yield increasingly better methods of predicting these disastrous natural phenomena.

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