PRECIPITATION FORECASTING DURING THE SNOW-MELT PERIOD

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The purpose of this paper is twofold; first, to outline the requirements for accuracy in forecasting precipitation amounts during the spring-melt period, using the Gouin watershed as an example; second, to describe in general terms one method of long range weather forecasting which will cover the time interval of the spring-melt period, and meet at least some of the requirements for accuracy.

A preceding paper during the Conference showed a correlation between various antecedent conditions in the Gouin watershed and the resulting streamflow. It was pointed out that significantly better estimates of streamflow could be made if precipitation amounts during the spring-melt period were included. It is very probable that a denser rain gauge network in the watershed would establish more accurate measurements of actual precipitation, and would thus result in an even better correlation than that now reached.

The question arises, how accurate must precipitation forecasts be in order to produce significantly better streamflow estimates? Too often the industrial application of weather forecasts has been made without a firm understanding of what is required by industry and what can be done by meteorology. Preliminary studies can serve two purposes; first, to eliminate hopeless efforts to fill a need for exactness in forecasting far beyond the limits of known meteorological techniques; second, to encourage the development of new techniques through research to extend these limits.

A major error to be avoided is to refer uncritically to a certain "percentage accuracy" being required to effect improvement in the streamflow regression equation without giving thought to what is actually meant. In the ordinary way of speaking, a precipitation forecast "75% accurate" would mean that, say, 4 inches of precipitation occurred when only 3 inches were forecast, making an accuracy of 3 in 4. The disadvantage of this way of looking at the matter is that the base of calculation — the actual precipitation which occurs — varies. Thus in a wet year (say, 16 inches total) a 75% forecast means an error of 4 inches, whereas in a dry year (say, 4 inches total) the same percentage accuracy means an error of 1 inch.

There is, of course, the further confusion that "percentage accuracy" could mean the percentage of times exactly right which is something entirely different.

The soundest way of expressing requirement of accuracy is to refer to the allowable error in inches. If the frequency distribution of precipitation amounts during the period from the snow survey to the end of the freshet were normal, an evaluation could be rigorously accomplished. However, the plotted histogram (Figure 5) shows a non-normal complex form.

If the complexities of the distribution are ignored, the percentages of years respectively 1 inch, 2 inches, 3 inches and 4 inches above and below (above plus below) normal are as follows:

1	inch	deviation	includes	74.1%	of	years
2	"	"	"	63.6%	"	"
3	"	"	"	55.6%	"	"
4	"	"	"	33.3%	"	"

It can be shown that the 50% point corresponds to a deviation of about 3.25 inches. Thus a "guess" of normal precipitation will be wrong more than half of the time if the forecast error is anything less than 3.25 inches. Putting this another way, the maximum allowable average error in precipitation forecasts is 35.6% (3.25/9.125 x 100).

The above approximate calculation ignores, of course, the nodal points at the 5 inch and 16 inch intervals in the frequency distribution; a somewhat better measure of the error involved in using normal is the standard deviation — 4.219 inches. This figure gives an allowable average error in precipitation forecasts of 46.2% (4.219/9.125 x 100).

It should be mentioned that the forecast problem is complicated by the requirement for what amounts to two concurrent forecasts: (1) the length of time which will elapse from the end of the snow survey to the end of the spring freshet, and (2) the precipitation which will fall during this period.

On the Gouin watershed the period for which precipitation forecasts are required averages 95 days (snow survey to the end of freshet period). Thus a forecast of the order of two to four months is required.

One long range forecasting method (Reference 1, 2, 3, 6) which is capable of producing outlooks for this extended period is that developed at the California Institute of Technology. Studies carried out there in the 1930's led to the conclusion that weather trends in North America were predictable from the position and orientation of the eastern lobe of the Pacific anticyclone. This portion of this permanent centre of high pressure will be referred to as the reference cell.

Two problems had to be solved before forecasts based on this hypothesis could be made; first, a method of forecasting the movements of the reference cell had to be worked out; second, a technique was required to relate the motion and position of the reference cell to the sequence of day to day weather at a given point as a function of the migratory cyclones moving along the polar front across the continent.

The solution to the second problem was attacked first. From synoptic studies it was found that there are characteristic weather types or pressure patterns passing through a definite sequence over North America; these types depend on the position of the reference high cell. There are eleven of these basic weather types, each passing through a more or less regular cycle of events at any one place during a period of six days.

It is believed that cyclones set up in the western Pacific Ocean off the Japanese coast are responsible for periodic impulses which in turn cause eastward moving three-day troughs and ridges in the upper atmosphere. It is further believed that the regularity of the movement of these three-day upper distrubances produces the six-day weather type cycle by a combination of two of these three-day upper waves. The surface reflections of these upper waves, as they travel eastward, generate storms on the polar front at points which favor storm development.

Examples of three of the eleven basic weather types, each of which runs its course at any given point in six days, are shown. The phase I position has been chosen so that the surface trough from the first three-day pressure wave of the weather type illustrated appears between the 130th and 140th meridian West longitude on the morning synoptic chart. This is convenient in establishing the weather types for North America, but is purely arbitrary and may be adjusted to any other convenient meridian in studying conditions in other parts of the world.

Figure 1 shows a composite chart of Type A. This type is clearly identified with the Pacific reference cell oriented northwest-southeast, and with a polar continental high pressure area over British Columbia and Alaska. The outflow of very cold polar air over the water along the west coast of British Columbia in contrast to the warmer Pacific air, develops an ideal frontogenetical field. On phases I and IV, active cyclones develop in this area and move southward into Nevada during the winter. As these waves move eastward and finally northeast, the polar continental air from the north reacts with the tropical air from the Gulf of Mexico and develops these cyclones into major systems in the Mississippi and Ohio valleys; the cyclones then move northeastward through New England or Southern Quebec and Ontario. The average winter position of the reference high cell for an A type is 41°30' North and 145°03' West. This type gives normal or above normal precipitation up along the east coast through to the Gulf of St. Lawrence, and it produces well below normal temperatures in Southern Canada.

Figure 4 shows the break-down of the composite Type A chart into the day by day sequence of ideal A types in the winter. The development of low pressure areas on the Pacific coast in phases I and IV is clearly evident as well as development of low pressure areas in central Canada and the Mississippi valley on phases III and VI; the second of these is a major development moving through the Great Lakes region and on into the Gulf of St. Lawrence.

Another major type, illustrated in Figure 2 is Type D. This type has the most northwesterly Pacific reference cell position of all types. During the winter, a large crescent-shaped polar high extends from northwestern Canada west through Alaska and south over the Aleutians. A major storm centre develops off the coast of Washington and persists during the period, with apparently a new front developing each day. Only the two major troughs progress eastward across the continent.

As the two major troughs move eastward across the United States, each is followed by a polar outbreak. The first moves rapidly southward to the Gulf of Mexico; the second, of weaker intensity, curves off over the Great Lakes towards the east coast.

The final general type illustrated is Type E (Figure 3). This type is limited to the colder seasons of the year, when the general circulation pattern is shifted to the south. The reference cell is in fairly low latitudes and has a west to east orientation. Type E has three sub-classifications, depending on the pressure distribution over Western Canada and Alaska. With a Type E-H and E-M this region is occupied by high pressure; with E-L the pressure field is low. The intensity of the high pressure determines the E-H (high) of the E-M (moderate) classification. The E-M and E-H types are relatively dry throughout except along the west and east coasts. The E-L type in contrast produces considerable rain throughout the eastern half of the country in addition to large amounts along the west coast.

It is hoped that these three examples will give a general idea of the method of typing which, as stated before, groups the sequence of weather events across the North American continent into eleven basic types.

The next important point is that, although the patterns on the synoptic charts for similar phases of the same weather type are essentially analogs, still, even at different seasons of the year, the resulting weather conditions (which are a function of the temperature of the interacting air currents) will show considerable variation. It was necessary, therefore, to tabulate the anomalies of temperature and precipitation — that is, the departures from normal — for each phase of each type during every season of the year. Once this was done a very potent forecasting tool was provided, since, with the establishment of phase I on the west coast, any type must continue throughout the remaining five phases, producing their characteristic weather anomalies. This immediately provides the forecaster with a method of predicting for six-day intervals, since with the establishment of a given type he need merely refer to previous examples of the same type at the same season of the year to ascertain the essential weather accompanying each storm type on the chart. In eastern sections of North America forecasts of nine or ten days are made possible after a type has entered the western limits of the continent.

It was mentioned earlier that two problems had to be solved before long range forecasts could be made. The first problem was to forecast the movements of the reference high cell in the Pacific Ocean. The second was to work out the sequence of day to day weather events through the medium of the weather types. (Reference 3) To go back now to the first problem, if the movements of the reference cell can be forecast then it is merely necessary to predict the phase I positions of the reference cell and from them to determine the corresponding weather type transitions for as long a period as the predicted movements of the reference cell are deemed reliable. The first step in determining the predictability of the movements of the reference cell was to establish a means of plotting its movements. A curve was plotted (Figure 6) showing the latitudes at which the reference cell crossed the reference axis or approached it most closely in its oscillations. The mean monthly positions of the cell determined from this plot were in turn plotted and a periodogram analysis of the latter curve was made. From it a composite curve was constructed which was called the control curve since it is assumed to reflect the fundamental changes in circulation pattern which control the weather. This curve, (Figure 6) shows the fluctuations of the mean position of the Pacific high cell northward and southward throughout a number of past years which have been analyzed. The regular fluctuations which are apparent in this curve then serve as a basis for projection once it has been established to which point on the curve the present situation corresponds. The predicted monthly mean position of the reference cell obtained from the extrapolated control curve indicates the predominant weather type, (Figure 7) and therefore the outstanding weather anomalies for the month. Published anomaly charts for the month chosen as most representative of the forecast interval are then utilized for determining the basic temperature and precipitation anomaly patterns. This then results in a forecast of anomalies for the succeeding months.

This approach, however, does not produce the day to day sequence of weather for any given spot a month in advance which is an essential element to most business and industrial enterprises. In order to produce the timing or sequence of weather events it is necessary to introduce the weather type transitions during the month. This is accomplished through a knowledge of the magnitude of the fluctuations of the movement of the reference cell during successive phase I positions.

To sum up, the development of the weather types provides a means of forecasting for six to nine days. For longer periods it is necessary to predict the movement of the reference cell and the consequent type transitions as the cell moves along its orbit. An exact method of plotting the latitudinal movements of the reference cell is available. This provides for the extrapolation of the control or reference cell curve permitting the forecaster to anticipate weather type transitions for a reasonable length of time. This information coupled with a knowledge of weather anomalies for each phase of each weather type at all seasons of the year forms the basis for predictions for any given location.

It is worth noting that the method is based on a carefully analyzed and properly catalogued file of weather charts going back as far as fifty-five years. This method, therefore, provides for the use of all previously constructed charts. A great deal of variation is often noted in forecasts prepared by individuals using the same basic weather data. This is due essentially to a lack of method and results in forecasts which are based to a great extent on personal judgement and experience. In general, this favors forecasters with the best memory and the most experience. The weather type technique systematizes the basic method of all synoptic forecasters which is to recall type situations from past experience. The control curve analysis allows for a projection of this well into the future and the relation of this to well established weather types and weather anomalies puts a tremendous fund of past records of the behaviour of the weather systems at the fingertips of the forecaster.

This brief outline has been an attempt to delineate the essential principles of forecasts for periods of from a week to several months ahead by weather type methods. It has of necessity been elementary; there are, of course, many refinements which are incorporated into the method, among which might be mentioned the break-down of the basic six-day types into three-day types, which has been found of great use in some complex situations. (Reference 7) A second development has been the establishment of the patterns in the upper air charts at approximately ten thousand feet relative to the surface weather types. (Reference 4) Since the upper air charts extend back only relatively few years, the use of upper air cataloguing is just beginning to be applied to the problem of long range forecasting.

It is hoped that the impression has not been given that this type of long range forecasting is the final answer to the problem, nor indeed, that it is the only answer. However, the method has some distinct and unique advantages, the principal ones of which are the ability to time the sequence of expected events for periods ahead, and also, the periods over which the forecast may be successfully extended. Meteorological science is, of course, far from attaining 100 percent accuracy in this field; indeed, such accuracy is not now even within sight. However, long range forecasts based on the method described have been produced now for a considerable number of years and have been employed by a large number of leading business and industrial firms. It is felt that the application of such methods to watershed spring run-off is a sound approach to a serious and economically important industrial problem.

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(2) Paulhus, J., and Blewitt, S., "Six Day Weather Types of North America." Meteorology Department, California Institute of Technology, 1943.

(3) Krick, I.P., "A Dynamical Theory of the Atmospheric Circulation and Its Use in Weather Forecasting." Meteorology Department, California Institute of Technology, 1942.

(4) Lewis, C.H.,"3000 Dynamic Meter Ideal Charts Corresponding to the Ideal Surface Types for Zone 3 and 4." Meteorology Department, California Institute of Technology, 1947.

(5) Pagava, S.T., and others, "Basic Principles of the Synoptic Method of Long Range Weather Forecasting." 3 Vols., Leningrad, U.S.S.R.

(6) Elliott, R.D.,"Studies of Persistent Regularities in Weather Phenomena." Meteorology Department, California Institute of Technology, 1942.

(7) Elliott, R.D., "Extended Weather Forecasting by Weather Type Methods." U.S. Navy Department, Long Range Weather Forecasting Unit, Washington, D.C., 1944.

Sources of Figures

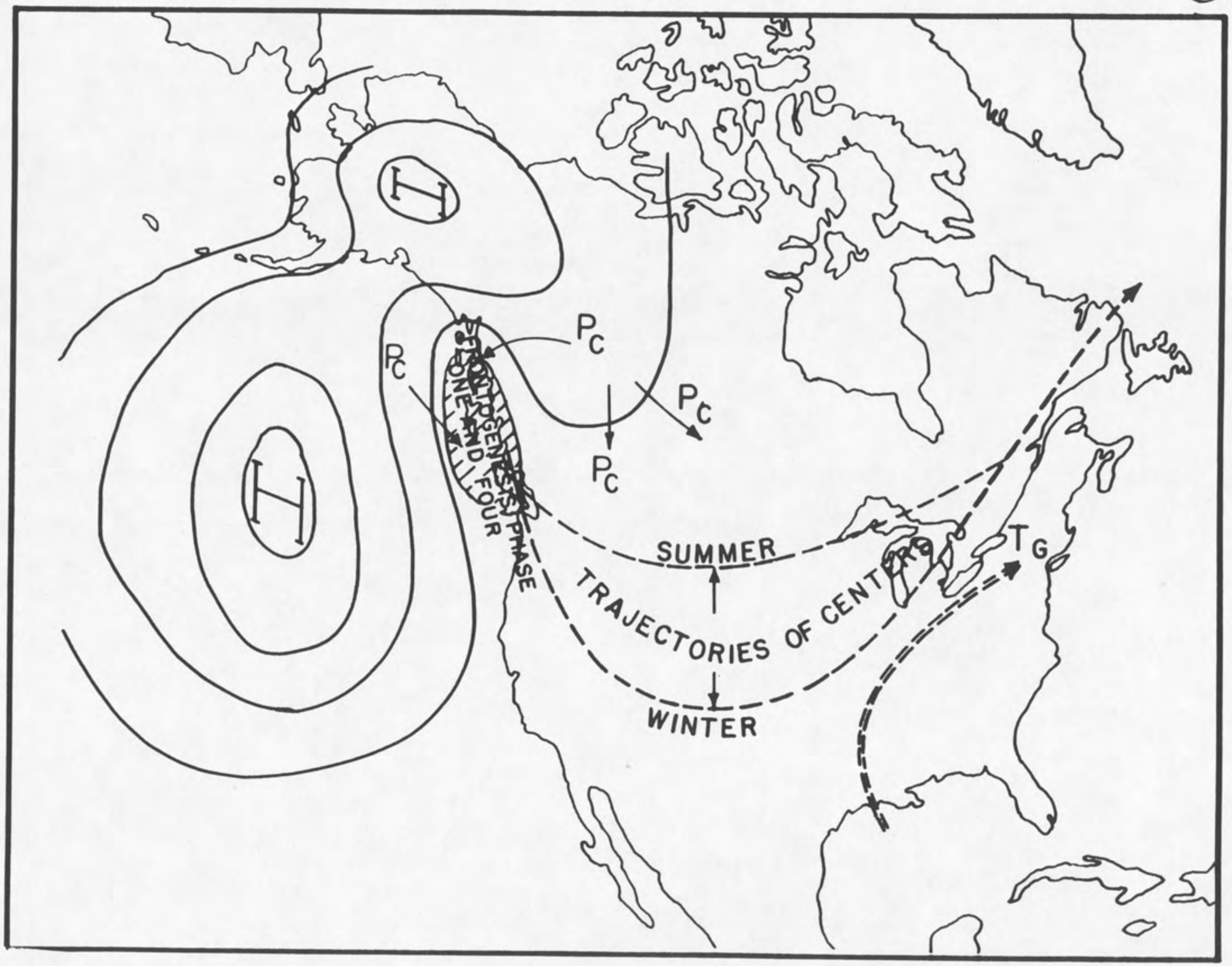
1, 2, 3, 4 - from "Synoptic Weather Types of North America" Reference 1

5 - Data courtesy Shawinigan Water and Power Company

6, 7 - "A Dynamical Theory of Atmospheric Circulation and Its Use in Weather Forecasting", Reference 3.

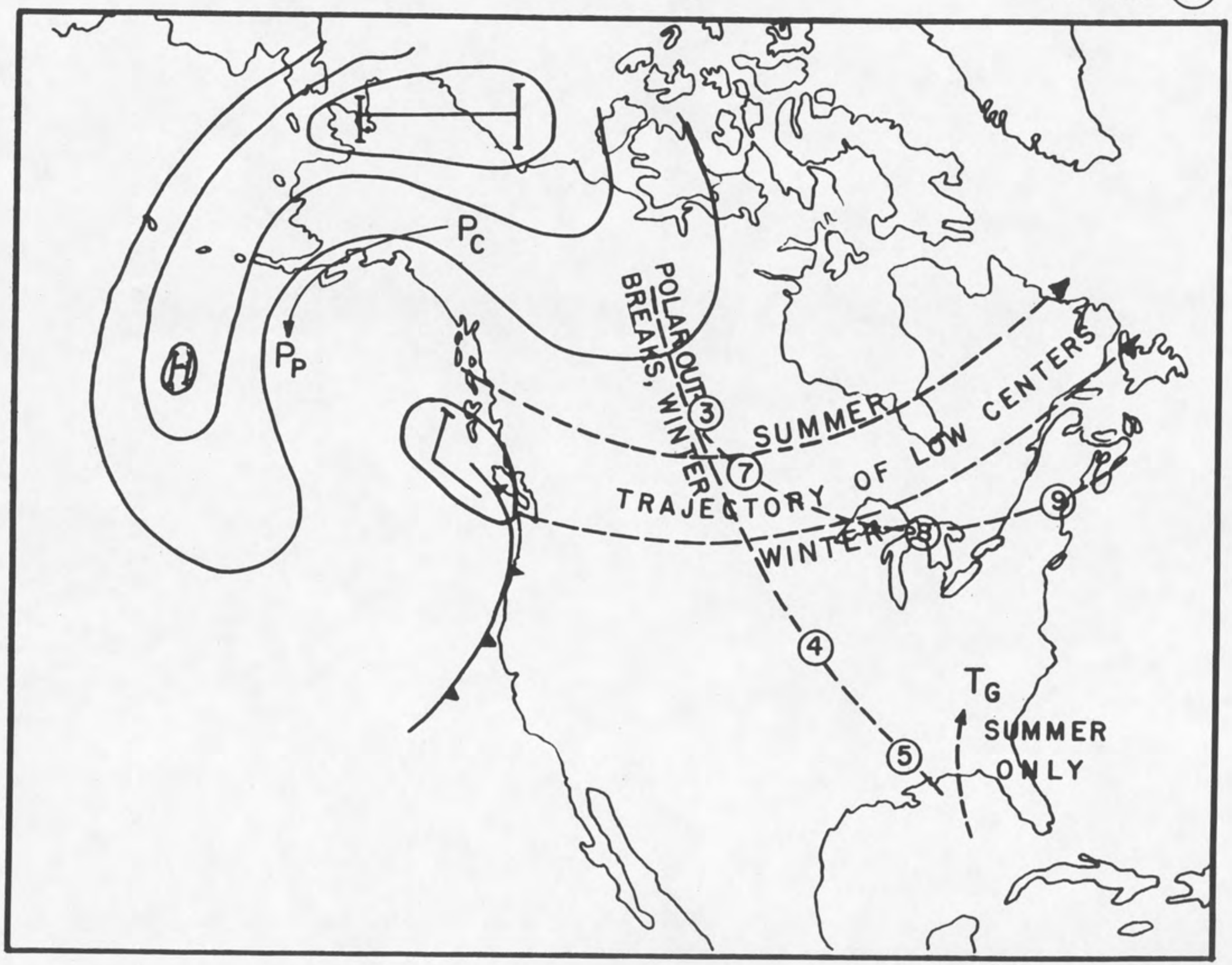
TYPE A

FIG. 1


H
H
P_C
P_C
P_C
P_C
FRONTOGENESIS PHASE
ONE AND FOUR
SUMMER
TRAJECTORIES OF CENTERS
WINTER
T_G

TYPE D

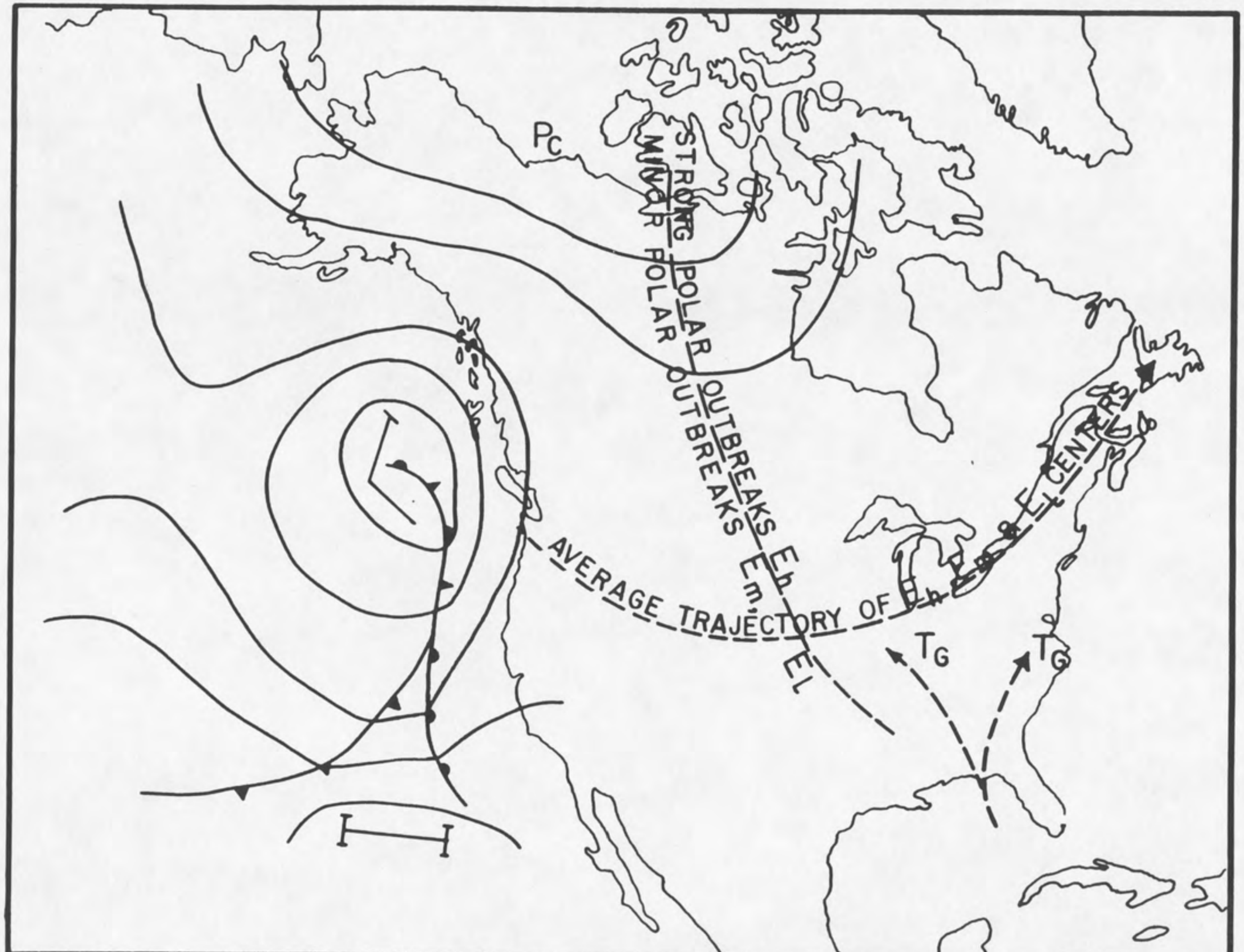
FIG. ②



H
L
P_C
P_P
POLAR OUTBREAKS, WINTER
SUMMER
TRAJECTORY OF LOW CENTERS
WINTER
3
7
8
9
4
5
T_G
SUMMER ONLY

TYPE E

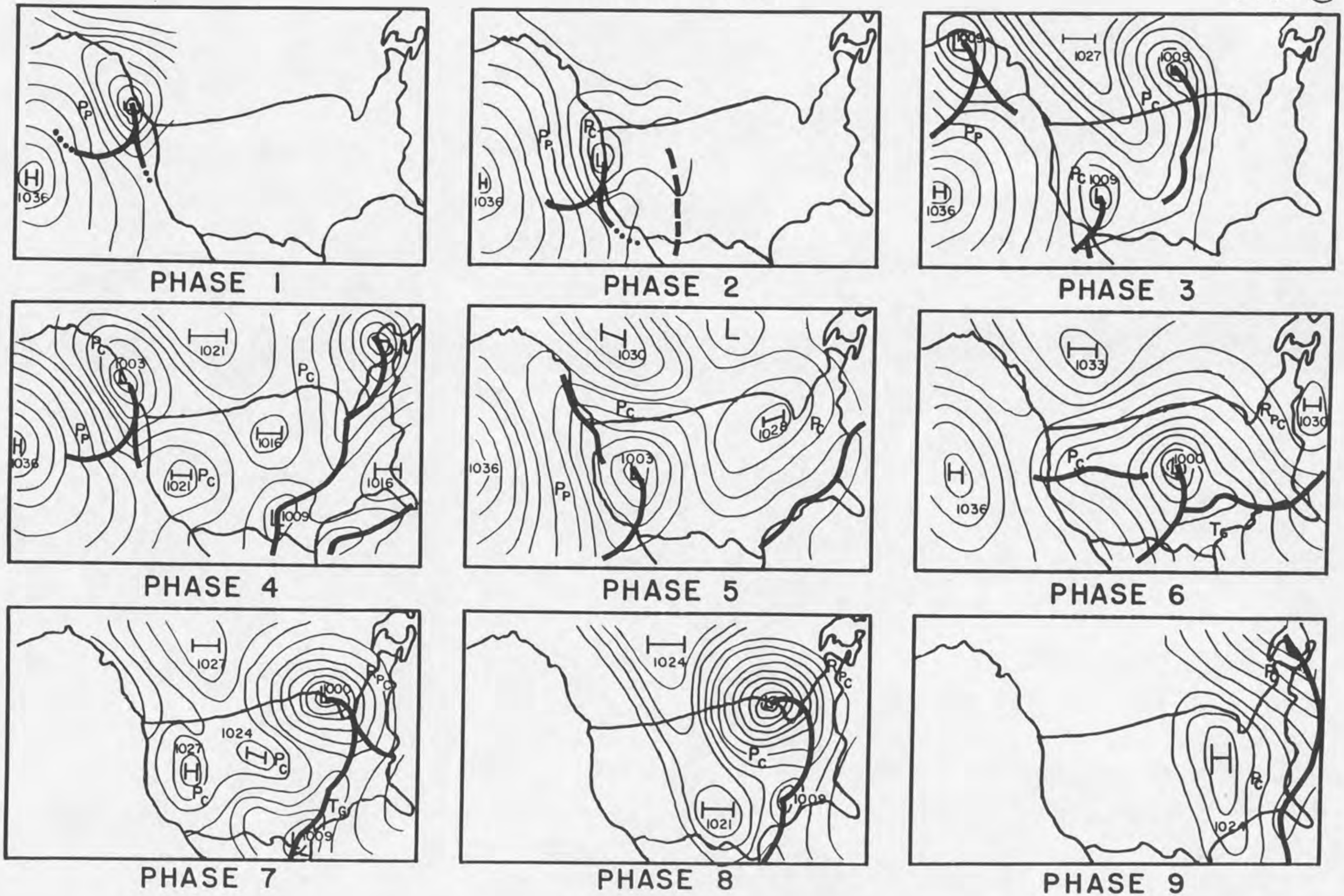
FIG. 3

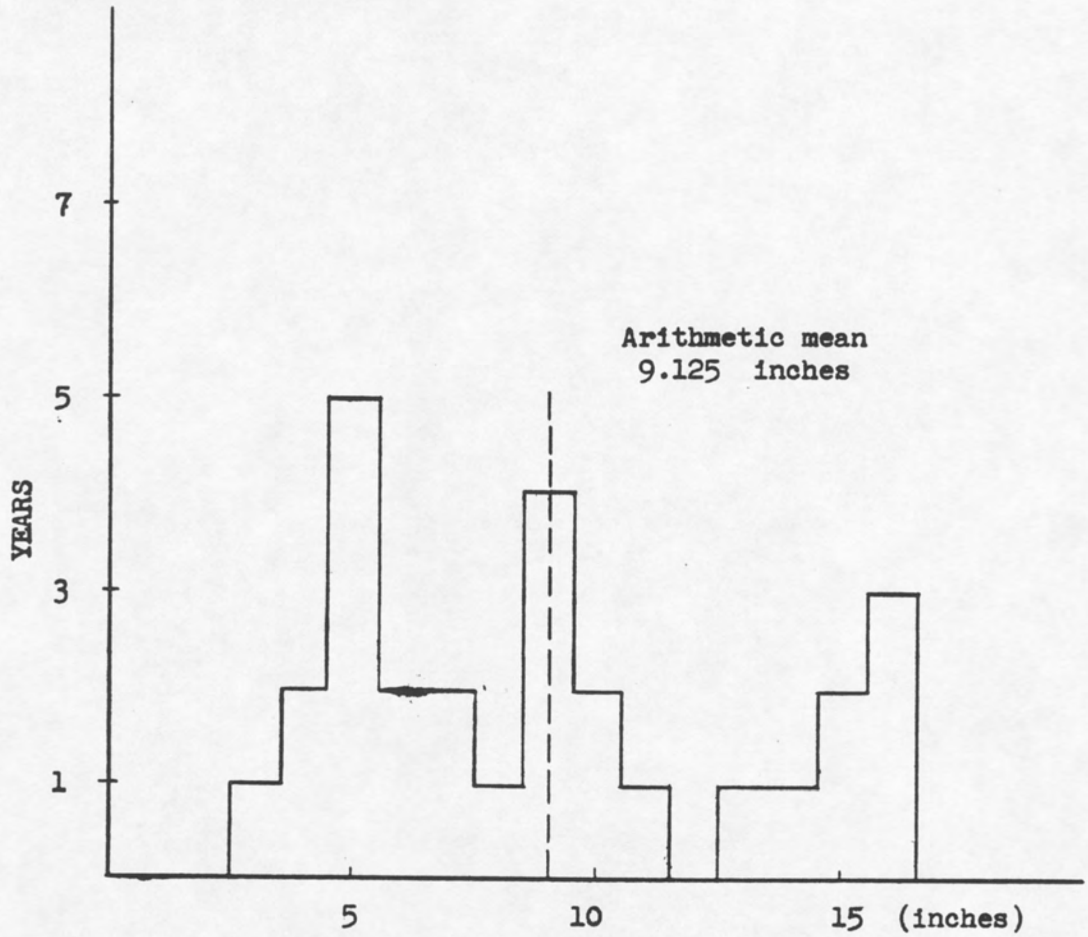


STRONG POLAR OUTBREAKS E_h
MINOR POLAR OUTBREAKS E_m
E_l
AVERAGE TRAJECTORY OF E_h & E_l CENTERS
P_c
T_G
T_G
H

A WINTER
(NOV. — DEC.)
IDEAL TYPE

FIG. 4



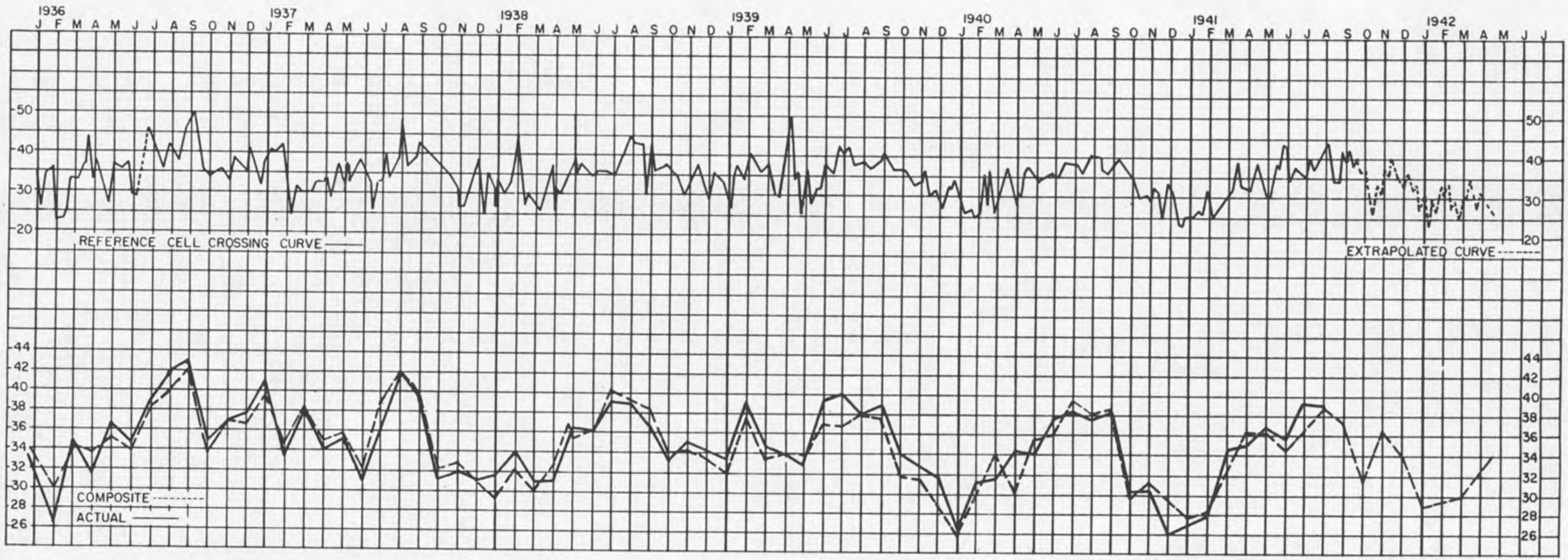


FREQUENCY DISTRIBUTION OF SEASONAL PRECIPITATION AMOUNTS

FROM

SNOW SURVEY TO END OF FRESHET

Fig. 5



PLOT OF REFERENCE CELL POSITION AGAINST LATITUDE AT CROSSINGS OF AVERAGE REFERENCE CELL PATH. **(Upper Curve).**

ACTUAL MEAN MONTHLY LATITUDINAL POSITIONS AND SYNTHETIC CURVE OF MEAN MONTHLY LATITUDINAL POSITIONS OF REFERENCE CELL. **(Lower Curve).**

Figure 6

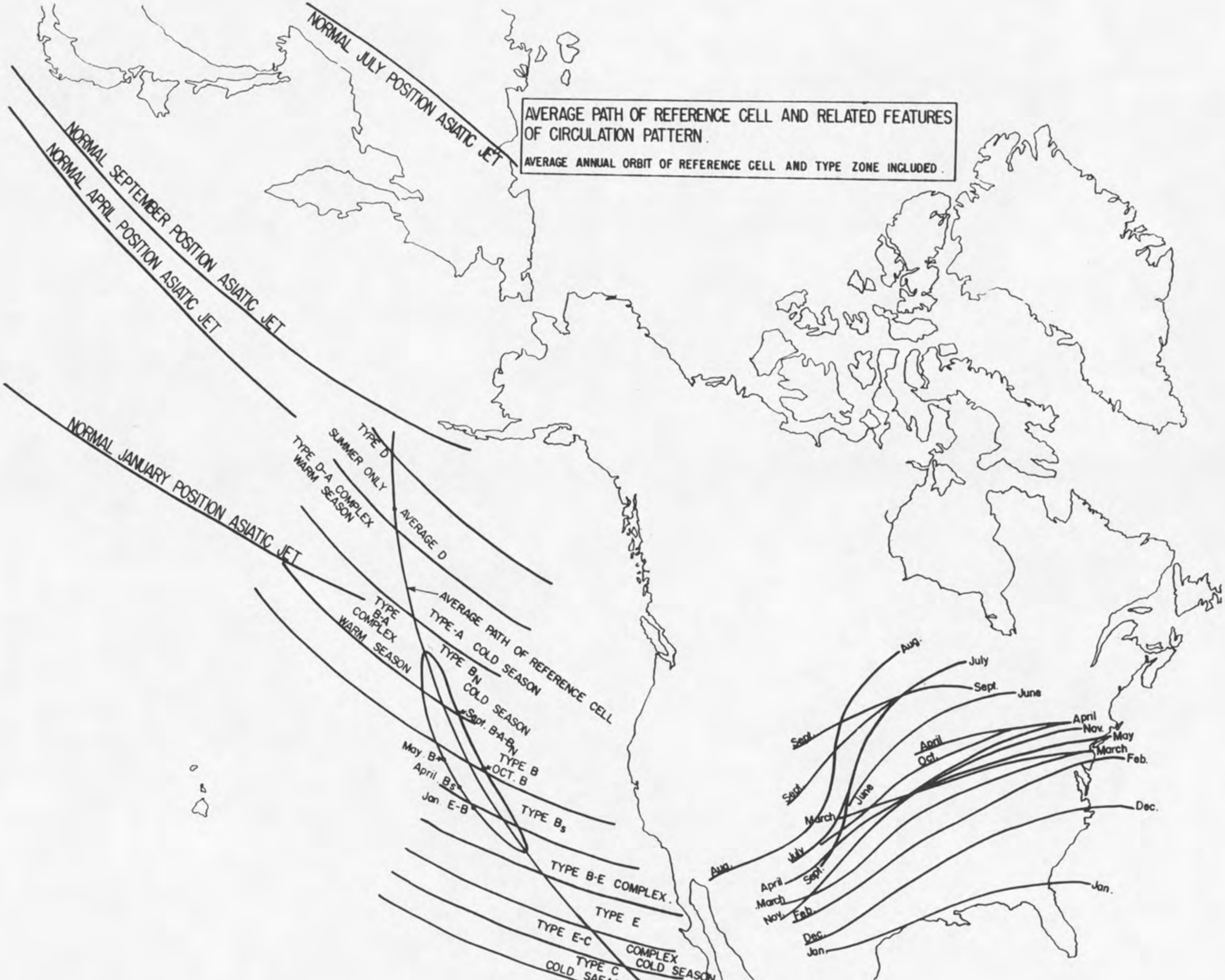

AVERAGE PATH OF REFERENCE CELL AND RELATED FEATURES OF CIRCULATION PATTERN.
AVERAGE ANNUAL ORBIT OF REFERENCE CELL AND TYPE ZONE INCLUDED.
NORMAL JULY POSITION ASIATIC JET
NORMAL SEPTEMBER POSITION ASIATIC JET
NORMAL APRIL POSITION ASIATIC JET
NORMAL JANUARY POSITION ASIATIC JET
TYPE D
SUMMER ONLY
AVERAGE D
TYPE D-A COMPLEX
WARM SEASON
AVERAGE PATH OF REFERENCE CELL
TYPE-A COLD SEASON
TYPE B-A COMPLEX
WARM SEASON
TYPE B_N
COLD SEASON
Sept. B-A-B_N
TYPE B
OCT. B
May. B
April. B_S
Jan. E-B
TYPE B_S
TYPE B-E COMPLEX.
TYPE E
TYPE E-C
COMPLEX
COLD SEASON
TYPE C
COLD SAEASON
AVERAGE. C
Aug.
July
Sept.
June
April
Nov.
May
March
Feb.
April
Oct.
Sept.
Sept.
June
March
July
Aug.
April
March
Nov.
Sept.
Feb.
Dec.
Jan.
Dec.
Jan.

FIGURE 7