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ANALYSIS OF NORMAL MONTHLY PRECIPITATION OVER ALASKA AND WESTERN CANADA

BY

E.R. WALKER

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ABSTRACT:

Normal monthly precipitation amounts for weather stations in Alaska and western Canada were subjected to Fourier analysis. The amplitudes of the harmonics, and their phase angles, were charted to show the variations in space of the time changes over the annual cycle of precipitation. The Fourier techniques were supplemented by maps of normalized precipitation changes. The techniques were shown to be a sensitive method of classifying climatic regimes in addition to highlighting the areal extent of components in the annual march of precipitation.

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ANALYSIS OF NORMAL MONTHLY PRECIPITATION OVER ALASKA AND WESTERN CANADA

by

E. R. Walker*

1. INTRODUCTION

This paper shows aspects of the course of the normal annual cycle of precipitation over Alaska and western Canada. Two methods were used. First, Fourier analysis was carried out on the normal monthly precipitation amounts at 75 weather stations in Alaska and western Canada. The phase angles and amplitudes of the Fourier harmonics were charted. This method of using the results of Fourier analysis was developed by Bryson (1957) in a study of precipitation in Australia. Horn, Bryson and Lowry (1957) applied the method to data from the continental United States. While the present paper was in its final stages the techniques were applied by Sabbagh and Bryson (1962) to data from Canada. The charting of amplitudes and phase angles of the Fourier components of the precipitation cycle has the advantage of showing clearly the spatial variations in these components.

The second method involved computing a normalized month to month precipitation change. The process of normalization related the magnitude of the change to the annual precipitation amount. This allowed charting of the intermonthly changes in a form which avoided difficulties due to differences in annual amounts at different weather stations.

Use of these techniques provides a more objective and precise measure of the annual precipitation cycle than is sometimes found in the literature as plots of areas of "spring maximum" and so on.

2. METHODS

For the weather stations indicated by the solid-circles in Figure 1 the normal monthly precipitation amounts were obtained. Data for Alaskan stations were obtained through the courtesy of C. E. Watson, Alaska State Climatologist. The normals were in most cases over the years 1921 - 1950. The source of data for weather stations in western Canada was Temperature and Precipitation Normals for Canadian Weather Stations based on the period 1921 to 1950, published by the Meteorological Branch in 1959.

These monthly precipitation normals were used in a Fourier analysis: the expression for the annual cycle of precipitation upon decomposition into the Fourier sine series is:

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$$P = P_o + P_1 \sin\left(\frac{2\,\Pi\, t}{12} + \phi_1\right) \; P_2 \sin\left(\frac{4\,\Pi\, t}{12} + \phi_2\right) \quad \ldots\ldots + P_6 \sin\left(\frac{12\,\Pi\, t}{12} + \phi_6\right) \quad (1)$$

where P is the precipitation at time t (inches per month)

P_o is the mean precipitation (inches per month)

P_1 is the amplitude of the first harmonic, etc. (inches per month).

ϕ is the phase angle of the first harmonic, etc. (degrees of arc)

t is the time in units of one month, with Jan. 15 = 0

The computation was done on a medium speed electronic computer, the Stantec Zebra. Before carrying out the Fourier analysis the monthly precipitation amounts were adjusted by an interpolation routine to obtain values at intervals of exactly one-twelfth of a year.

The amplitudes and phase angles of the components were plotted and isolines drawn. The amplitudes were in inches of precipitation per month. The phase angles were in degrees of arc. Appendix 1, allows conversion of the phase angle values to dates of maximum, and minimum precipitation.

An intermonthly precipitation change was defined by P where

$$P = \frac{P_o - P_{-1}}{\overline{P}} \times 100 \quad (2)$$

where P_o is the normal precipitation for one month

P_{-1} is the normal precipitation for the preceding month

$\overline{P}$ is the normal annual precipitation

These quantities were computed for each weather station in Figure 1, and were charted. In these charts increases are shown by solid lines, decreases by dashed lines. Only odd values of the isopleths are drawn.

3. FOURIER ANALYSIS OF NORMAL PRECIPITATION

The Fourier analysis was carried out on data from the weather stations shown in Figure 1. Figure 1 also indicates the percentages of the variance of the monthly normal precipitation that were accounted for by the first three harmonics. Over most of Alaska and northwestern Canada this percentage was well over 90 per cent. Where it was less, the annual precipitation either showed small variation so that the amplitudes of all harmonics are small, or there were short period precipitation changes which emphasized the higher harmonics. The former is true of the Aleutians and the Kodiak area. The latter holds in the intermountain regions of southern British Columbia.

Figure 2 gives the ratio of the amplitude of the second harmonic to that of the first harmonic. Low values of this ratio, indicating greater relative importance of the first harmonic in the annual precipitation cycle occur along the Pacific coast, in the Aleutians and over the interior of Canada. Large values of this ratio occur in the intermountain areas of the Canadian cordillera and extend westward through central Alaska.

Figure 3 shows the amplitude of the first harmonic with its annual period. As it is usually proportional to the precipitation amounts, it is large along the Pacific coastline and smaller in the continental interior.

Figure 4 shows the phase angle of the first harmonic. In the Alaskan panhandle the time of the maximum precipitation as indicated by the first harmonic occurs in October (180°). Southward along the Pacific coast the time of maximum is later. Over Vancouver Island it occurs in December (120°). The interior of Canada is continental in climate with a summer (270°) maximum. A narrow band of transition between winter maximum and summer maximum extends along the Pacific coastal mountains, or just inland of them. Western Alaska and the Canadian eastern Arctic have August maxima (240°).

In Figure 5 are shown the amplitudes of the second harmonic with its six month period. It is large along the Pacific coast where precipitation is heavy. In the inter-mountain valleys of British Columbia, it is large considering the small precipitation amounts there. Here zones of oceanic winter maximum and continental precipitation summer maximum overlap to emphasize the amplitude of the second harmonic. The amplitude of the second harmonic is large in western Alaska. Here, too, the effect is the result of processes just mentioned, except that the summer maximum of precipitation in western Alaska is basically caused by the shunting northward of the Pacific storm tracks in summer.

The phase angle of the second harmonic is shown in Figure 6. The continental interior has second harmonic maxima in late winter and late summer (60° - 120°). Along the Pacific coastline, spring and autumn maxima are emphasized (210° - 270°).

The amplitude of the third harmonic, with a four-month period, is shown in Figure 7. Amplitudes are greatest along the Pacific coast. They are appreciable in western Alaska but quite small elsewhere. The phase angles of the third harmonic is shown in Figure 8. In western Alaska they indicate maxima in April, August and December (180°). Over northern Alaska, March, July and November maxima are stressed (240°). Along the coast of the Gulf of Alaska maxima occur in February, June and October (360°).

The higher order harmonics have small amplitude and intricate patterns of phase angle. They supply embroidery to the large scale effects shown by the first three harmonics.

The technique of plotting Fourier components of the annual precipitation cycle has several uses. By such decomposition it is frequently possible to associate physical causes with certain components. By examining plots of harmonic components thus identified it may be possible to judge the areal extent of the action of the physical mechanism. This could be of practical use for estimating maximum probable precipitation over a river basin.

The technique of plotting Fourier components can rather sensitively distinguish the degree of continentality of climate. Insofar as continentality may be expressed by the form of the annual precipitation cycle, the continental climate in the area of our study is marked by a summer maximum of precipitation. The maritime climate is denoted by winter rainfall. The ratio of the second harmonic amplitude to the first harmonic amplitude in Figure 2 and the phase angle of the first harmonic in Figure 4 show very well continental and maritime regimes and the boundary between. The same type of analysis may be extended to other areas, and if necessary to the mesoscale in rugged terrain.

4. INTERMONTHLY PRECIPITATION CHANGE MAPS

Charts of intermonthly precipitation changes show the spreading of patterns of precipitation from month to month over Alaska and northwestern Canada. Similar studies have been carried out for the continental United States by Horn, Bryson, and Lowry (1957) and for Canada by Walker (1963).

During the winter the intermonthly changes in precipitation are small over much of Alaska and northwestern Canada. From April to May spring comes to much of the area. Figure 9 indicates marked increases in precipitation over the interior of Alaska, and northwestern Canada. Slight decreases show along the coastlines of the Pacific and Arctic oceans. Figure 10 shows that the increase in the interior of Alaska and northwest Canada continues from May to June. Decreases continue along the Pacific coast as the winter precipitation mechanisms weaken. Changes in the high Arctic are still small.

In Figure 11 are shown the changes from June to July. Increased precipitation occurs in western Alaska. A marked increase appears in the high Arctic. Only small changes are indicated along the Pacific Coast. From July to August (Figure 12), the precipitation in western Alaska increases. Irregular areas of decreased precipitation occur over northwestern Canada. Slight increases are shown over parts of the high Arctic.

As August turns to September (Figure 13) Autumn comes to the northwestern part of the continent. Increases in precipitation caused by frontal action are appearing along the Pacific coast. Large decreases in precipitation occur over central and northern Alaska, northwestern Canada, and the high Arctic. As September passes into October (Figure 14) precipitation increases along the Pacific Coast, but decreases over the continental interior and in the Arctic. From October to November (Figure 15), precipitation continues to decrease over northern Alaska and in the Arctic. The time of maximum

precipitation is past for much of the Aleutian Chain, and coastline of the Gulf of Alaska. From November through the winter to April intermonthly changes in precipitation are small over Alaska and Northwestern Canada. Most pronounced are local changes in the early winter, undoubtedly caused by the freezing over of lakes and other bodies of water. No charts are shown of changes through the winter months.

These intermonthly precipitation change charts bring out the advances and recessions of the large scale precipitation regimes over the northwestern part of the continent.

5. CONCLUSIONS

The use of the Fourier techniques, the charting of harmonic amplitudes and phase angles indicate the spatial variation of the temporal components of the annual cycle of precipitation over Alaska and northwestern Canada. When combined with intermonthly precipitation change maps they highlight the changes in precipitation through the course of the year. Most of the features revealed in this study are explainable in terms of pressure pattern changes, shifts of frontal activity and so on. Some features of the analysis presented here may need revision when a more representative data sample has been obtained, as from stations in the Arctic Islands.

The techniques used have value for the classification of climates. Objective indices of continentality may be set up, based upon material such as that shown in Figure 2 and Figure 4. The technique could be extended to other weather elements. It will not, however, provide much information when the annual cycle is dominated by one harmonic component. An example is a pilot study, using the technique, carried out on monthly temperature normals for the area covered in the present study. The first harmonic completely dominated the temperature series. At all stations in the area the first three harmonics explained almost 100 percent of the variance. The amplitude of the first harmonic was at least ten times that of the second harmonic at almost all stations. However, for other weather elements not so dominated by the annual cycle the present techniques should provide worthwhile results.

This work was carried out under a Defence Research Board Project. Permission of the Defence Research Board, and the Director of the Meteorological Branch, Department of Transport, Canada, to publish this note is gratefully acknowledged.

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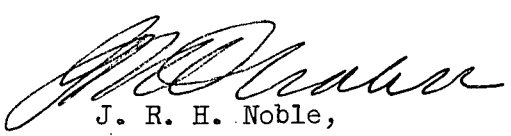

J. R. H. Noble,
Acting Director.

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(2) Horn L. H., R. A. Bryson and W. P. Lowrey, 1957: "An Objective Precipitation Climatology of the United States," Department of Meteorology, University of Wisconsin, Scientific Report No. 6 U.S.A.F. Contract AF 19(604)-992.

(3) Meteorological Branch, 1959: "Temperature and Precipitation Normals for Canadian Weather Stations Based on the Period 1921-1950," Meteorological Branch, Department of Transport, Canada, CIR-3208, CLI-119.

(4) Sabbagh, M. E. and R. A. Bryson, 1962: "An Objective Precipitation Climatology of Canada," Technical Report No. 8 Task No. NR 387-022, ONR Contract No. 1202(07), Department of Meteorology, University of Wisconsin.

(5) Walker, E. R., 1963: "Intermonthly Precipitation Changes in Canada," Meteorological Branch, Department of Transport, Canada, CIR-3807, TEC-458.

Appendix 1

Tables to Convert Phase Angles to Dates of Maxima and Minima

1st Harmonic

Phase Angle	Maximum	Minimum
0°	Apr 15	Oct 15
30	Mar 15	Sep 15
60	Feb 15	Aug 15
90	Jan 15	Jul 15
120	Dec 15	Jun 15
150	Nov 15	May 15
180	Oct 15	Apr 15
210	Sep 15	Mar 15
240	Aug 15	Feb 15
270	Jul 15	Jan 15
300	Jun 15	Dec 15
330	May 15	Nov 15

2nd Harmonic

Phase Angle	Maximum	Minimum
0°	Mar 1	Sep 1
30	Feb 15	Aug 15
60	Feb 1	Aug 1
90	Jan 15	Jul 15
120	Jan 1	Jul 1
150	Dec 15	Jun 15
180	Dec 1	Jun 1
210	Nov 15	May 15
240	Nov 1	May 1
270	Oct 15	Apr 15
300	Oct 1	Apr 1
330	Sep 15	Mar 15

3rd Harmonic

Phase Angle	Maximum	Maximum	Maximum
0°	Feb 15	Jun 15	Oct 15
30	Feb 15	Jun 5	Oct 5
60	Jan 25	May 25	Sep 25
90	Jan 15	May 15	Sep 15
120	Jan 5	May 5	Sep 5
150	Dec 25	Apr 25	Aug 25
180	Dec 15	Apr 15	Aug 15
210	Dec 5	Apr 5	Aug 5
240	Nov 25	Mar 25	Jul 25
270	Nov 15	Mar 15	Jul 15
300	Nov 5	Mar 5	Jul 5
330	Oct 25	Feb 25	Jun 25

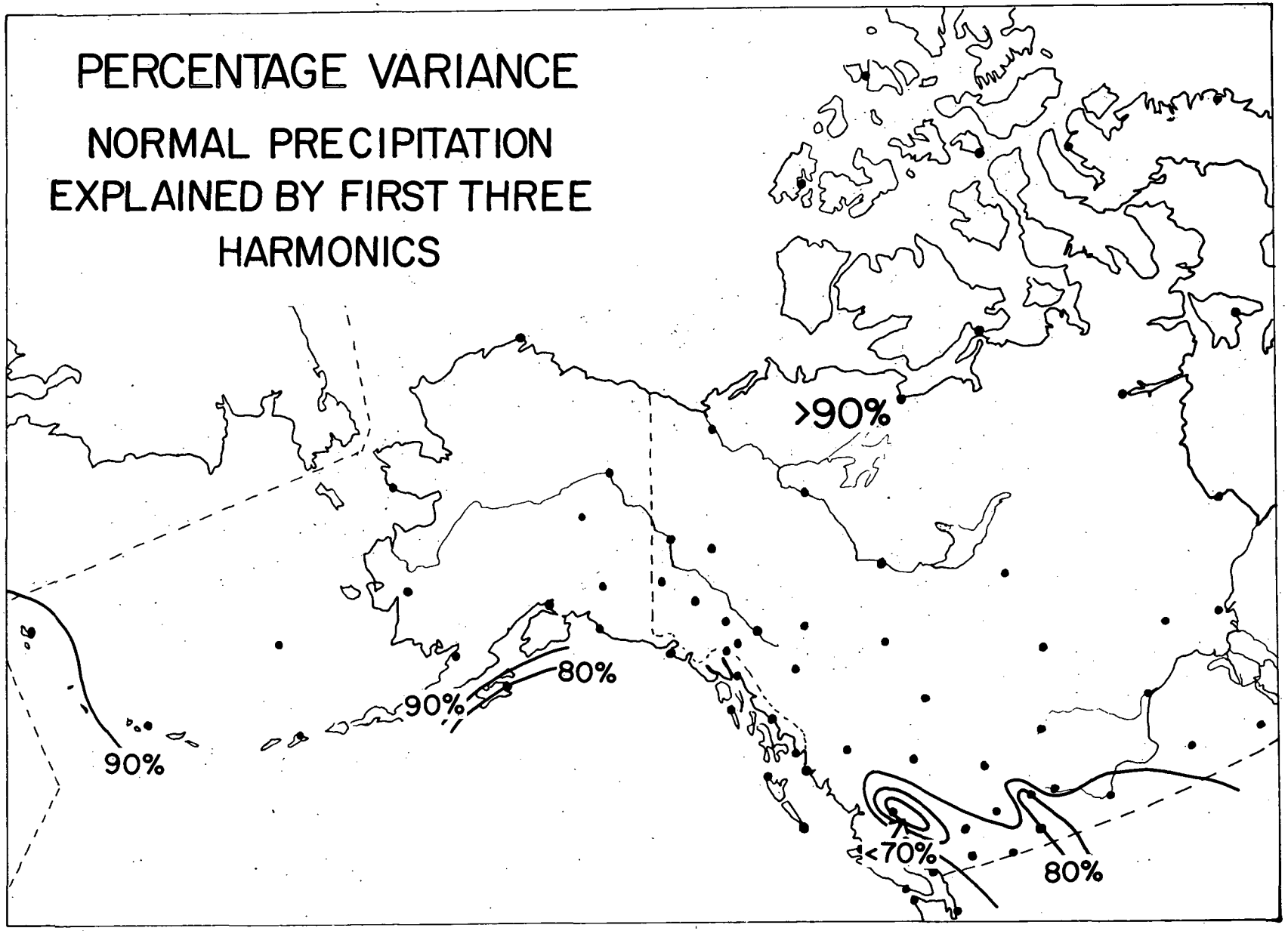

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Fig. 1
Percentage of Variance of Monthly Precipitation Normal Explained by First Three Harmonics. Stations For Which Normals Were Analyzed.

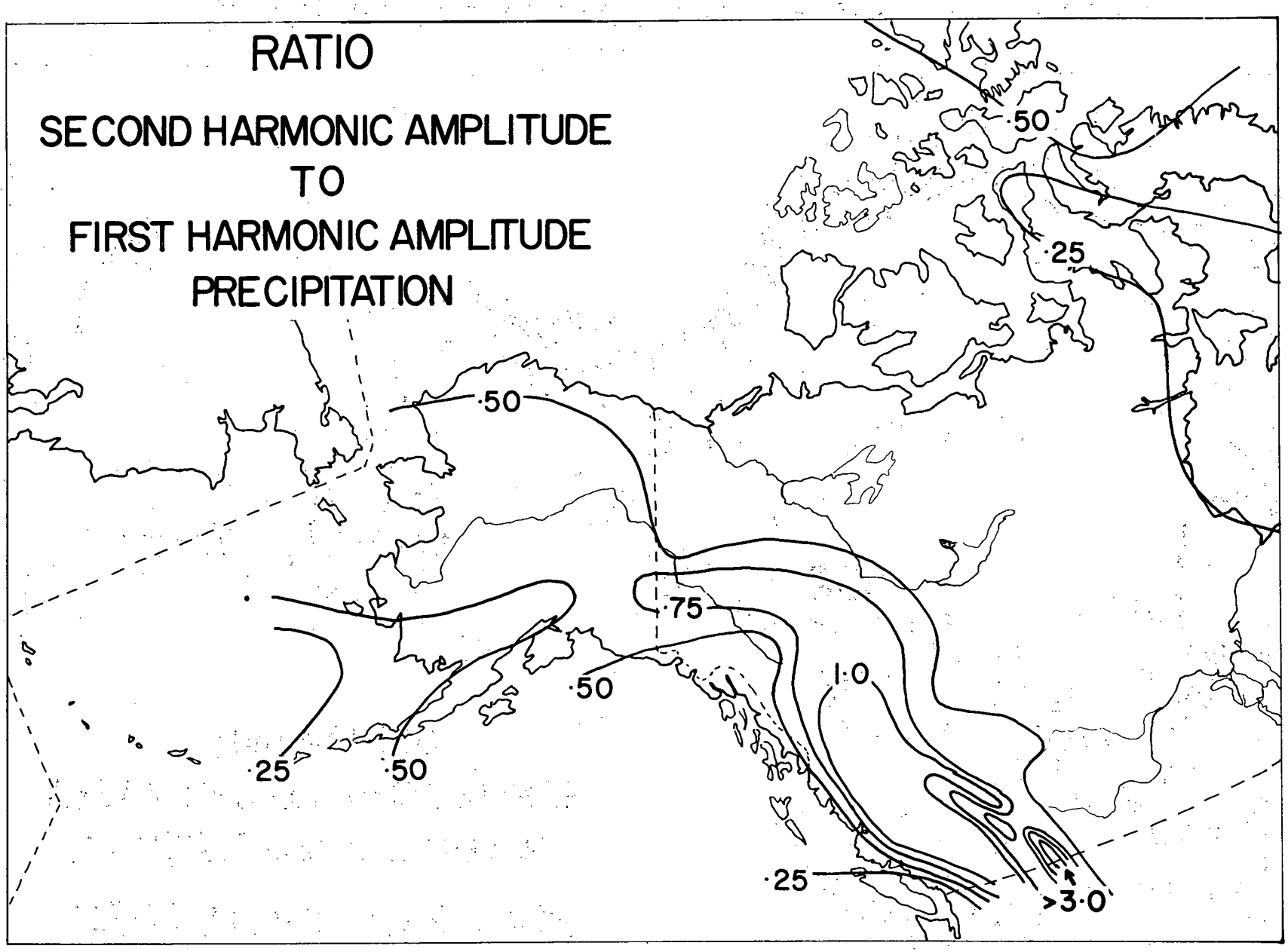

Fig. 2
Ration of Second Harmonic Amplitude to Amplitude of First Harmonic.

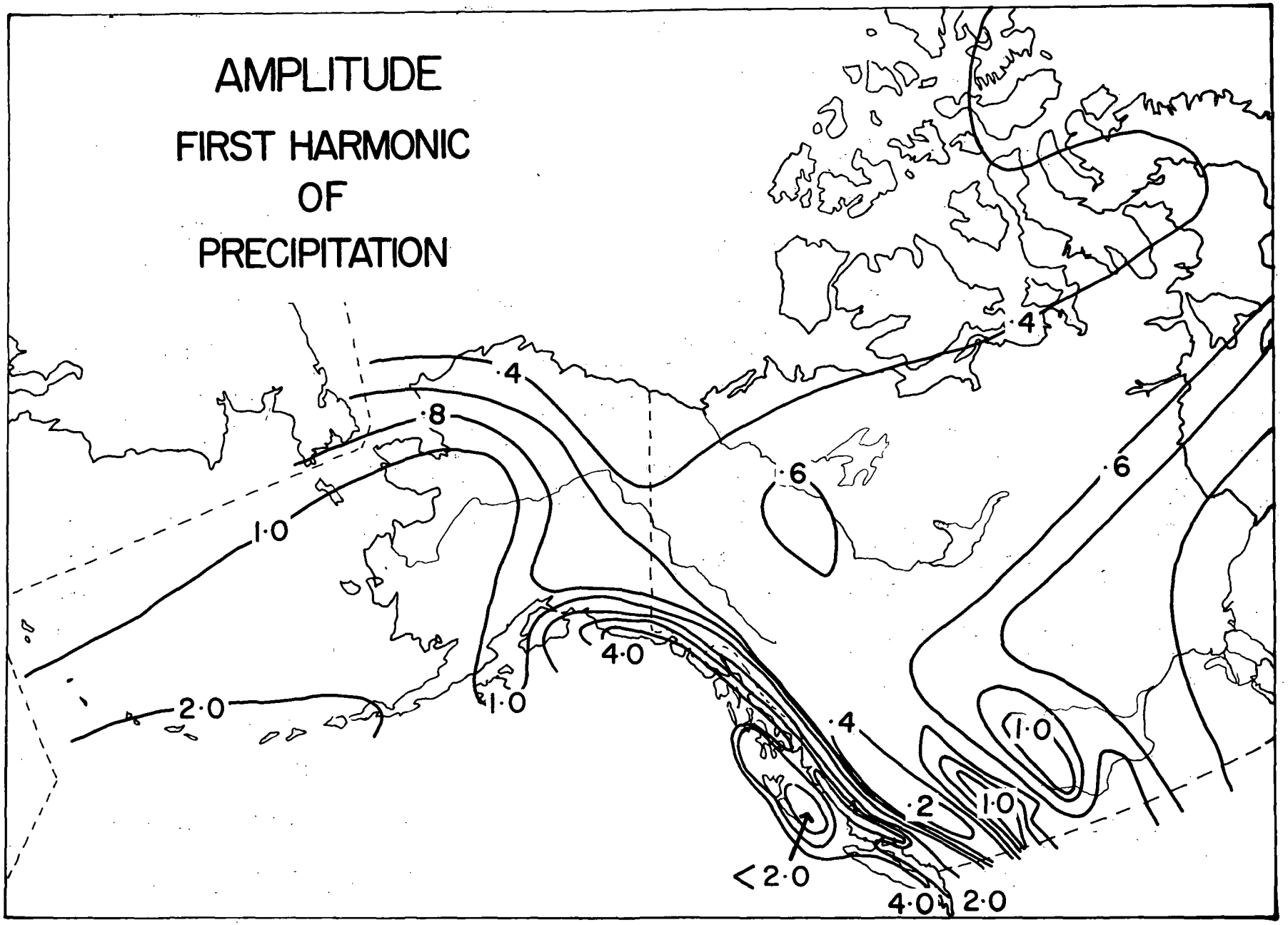

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Fig. 3
Amplitude of First Harmonic in Fourier Analysis of Monthly Precipitation Normals (Inches).

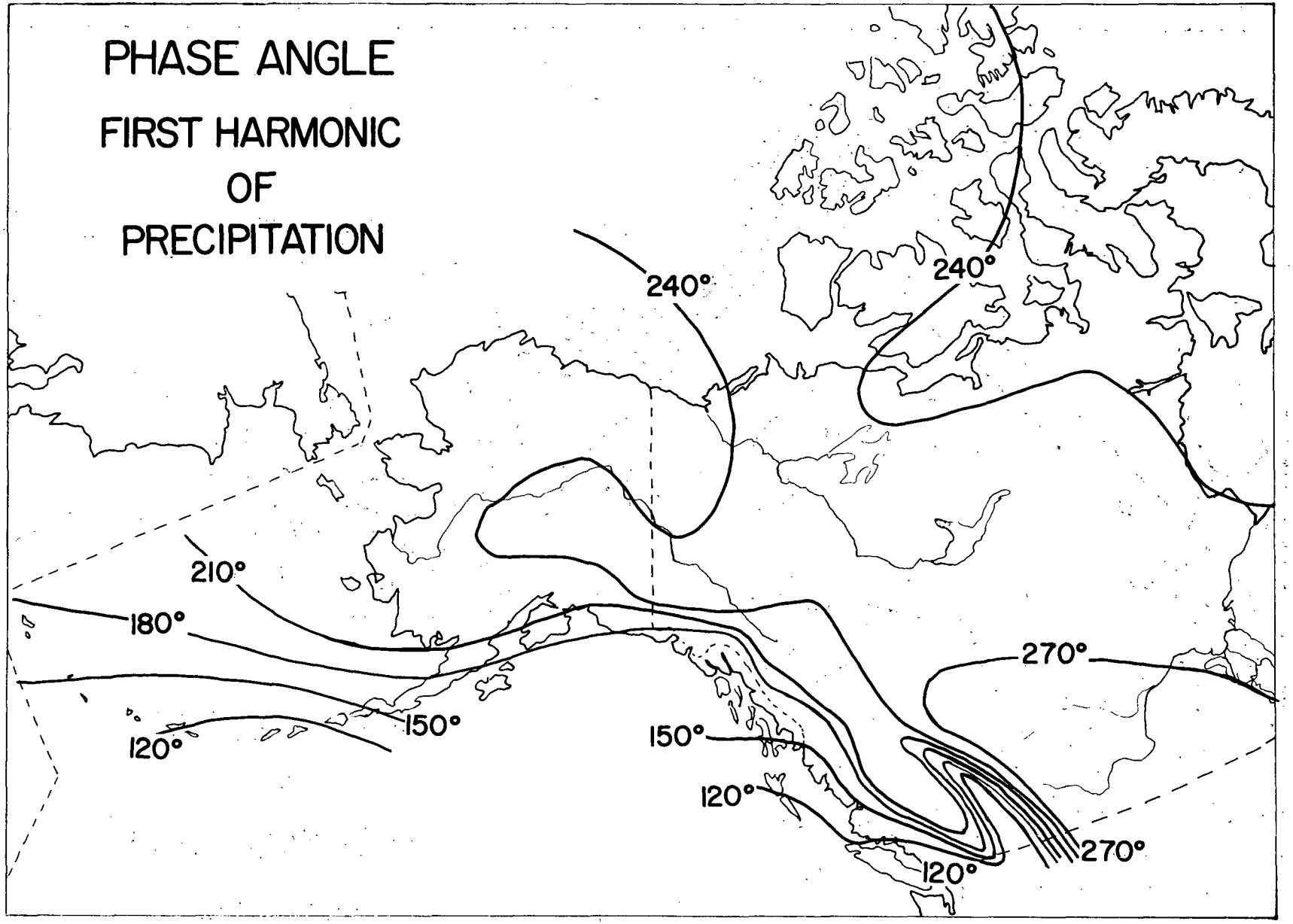

Fig. 4
Phase Angle of First Harmonic In Fourier Analysis
of Monthly Precipitation Normals (Degrees).

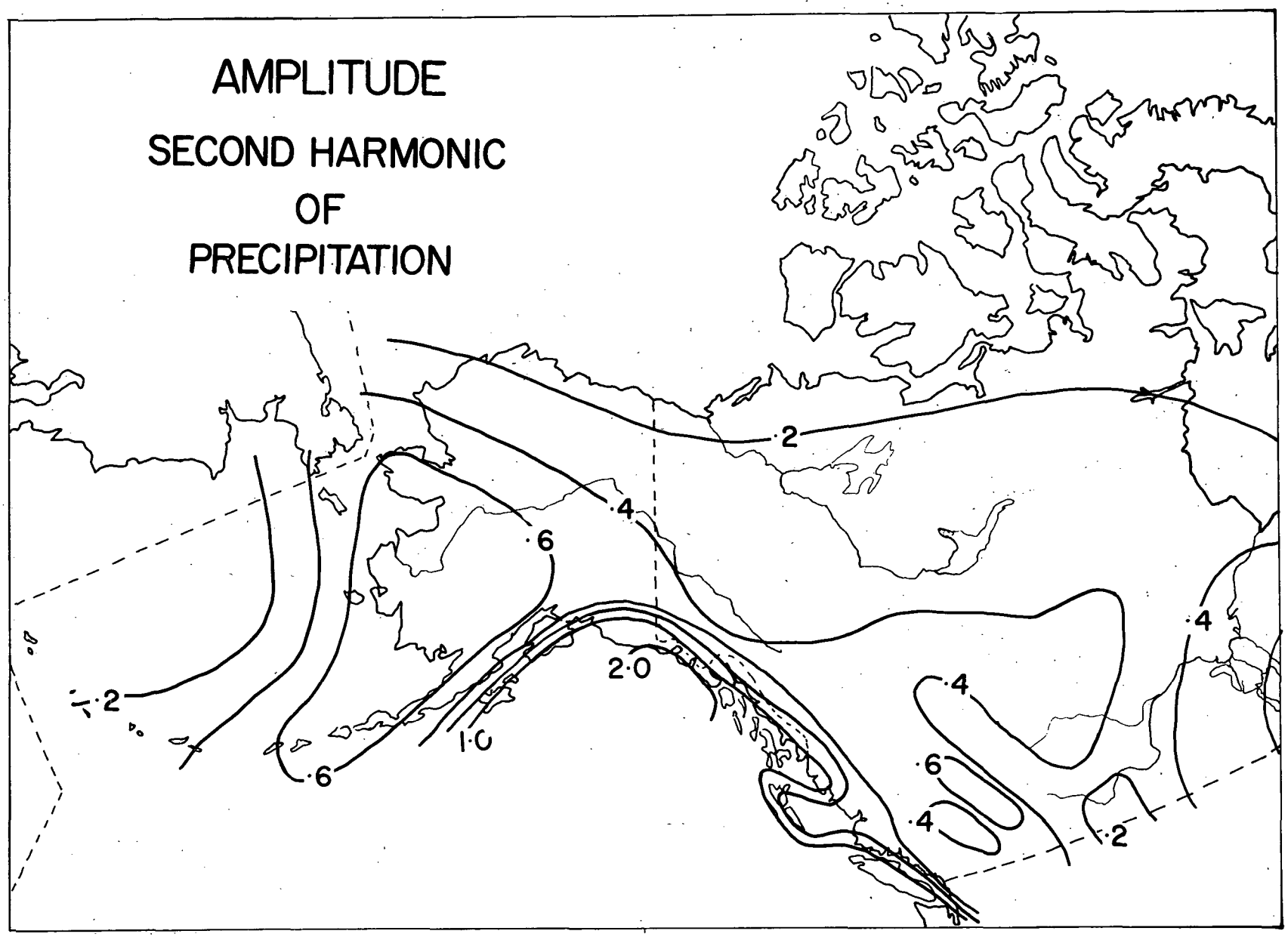

Fig. 5
Amplitude of Second Harmonic In Fourier Analysis
of Monthly Precipitation Normals (Inches).

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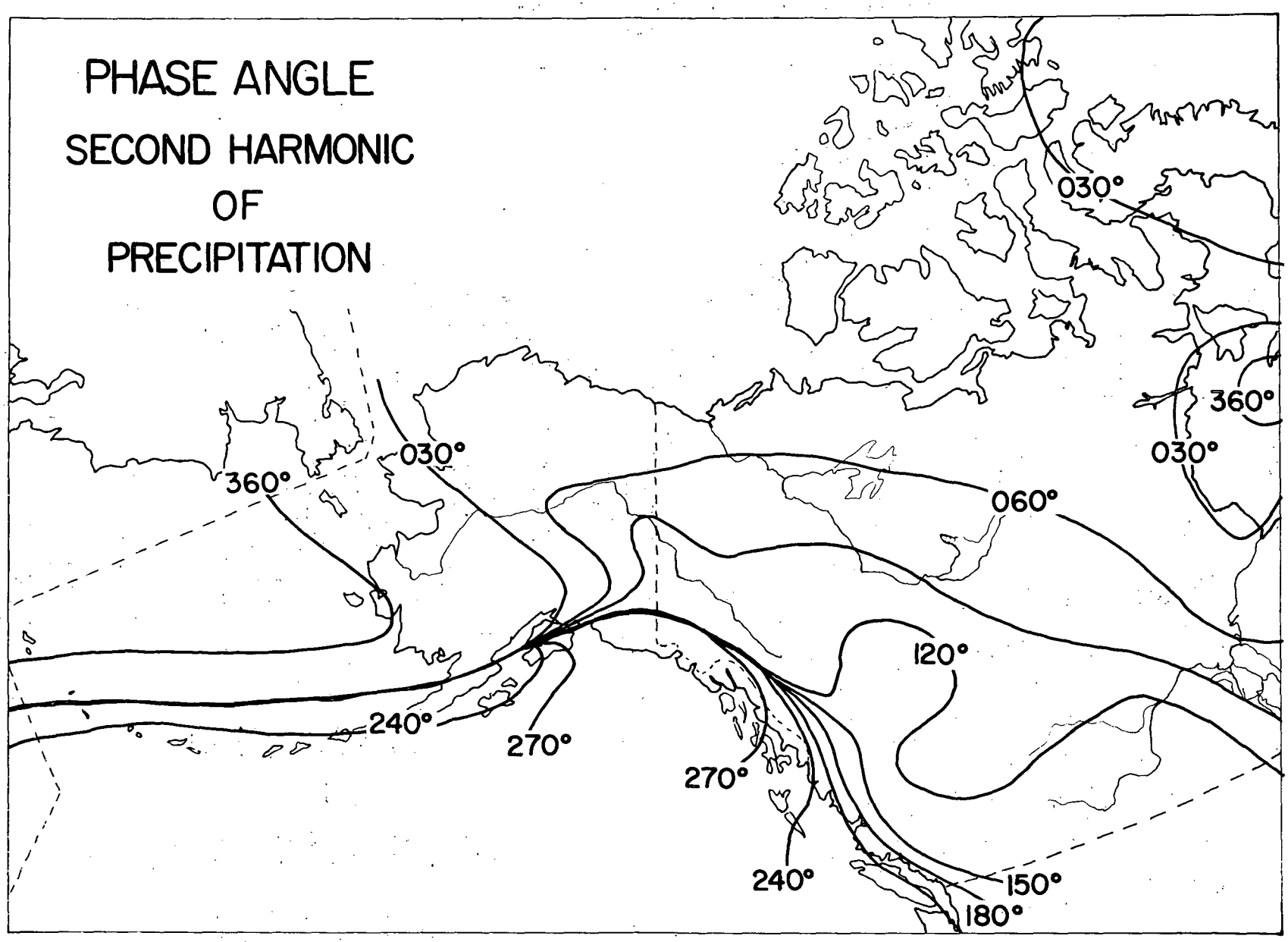

Fig. 6
Phase Angle of Second Harmonic In Fourier Analysis
of Monthly Precipitation Normals (Degrees).

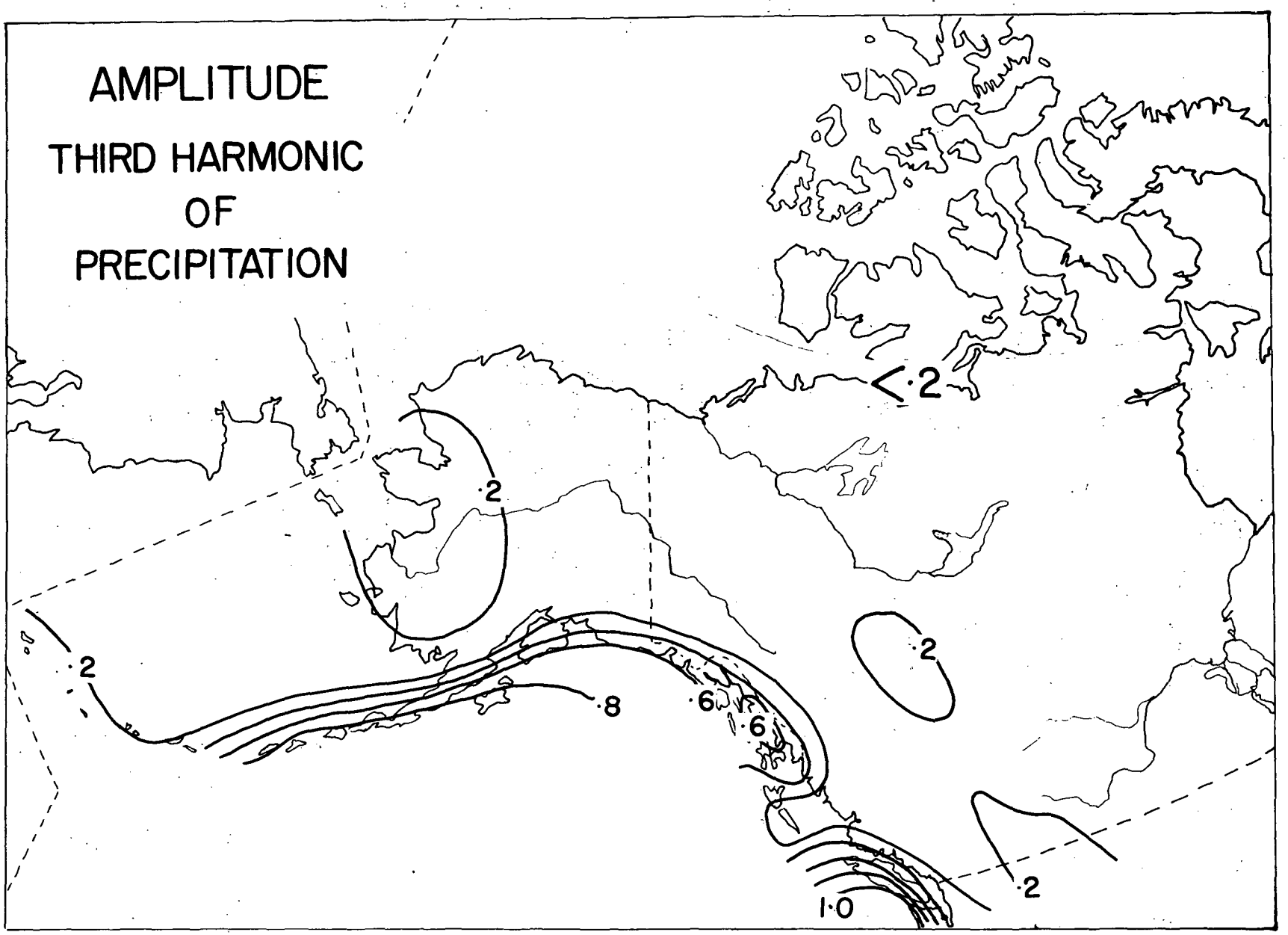

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Fig. 7
Amplitude of Third Harmonic In Fourier Analysis
of Monthly Precipitation Normals (Inches).

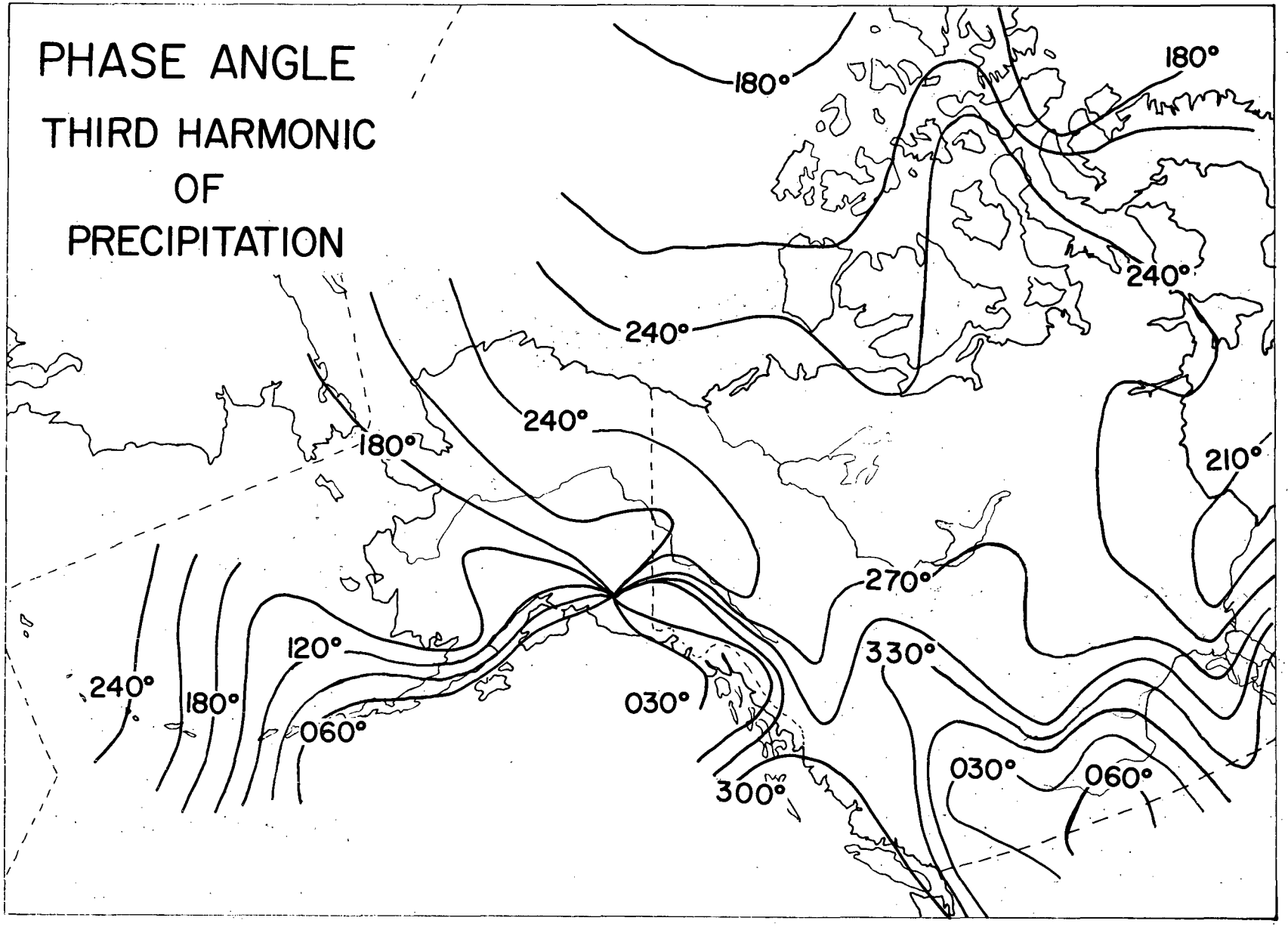

Fig. 8
Phase Angle of Third Harmonic In Fourier Analysis
of Monthly Precipitation Normals (Degrees).

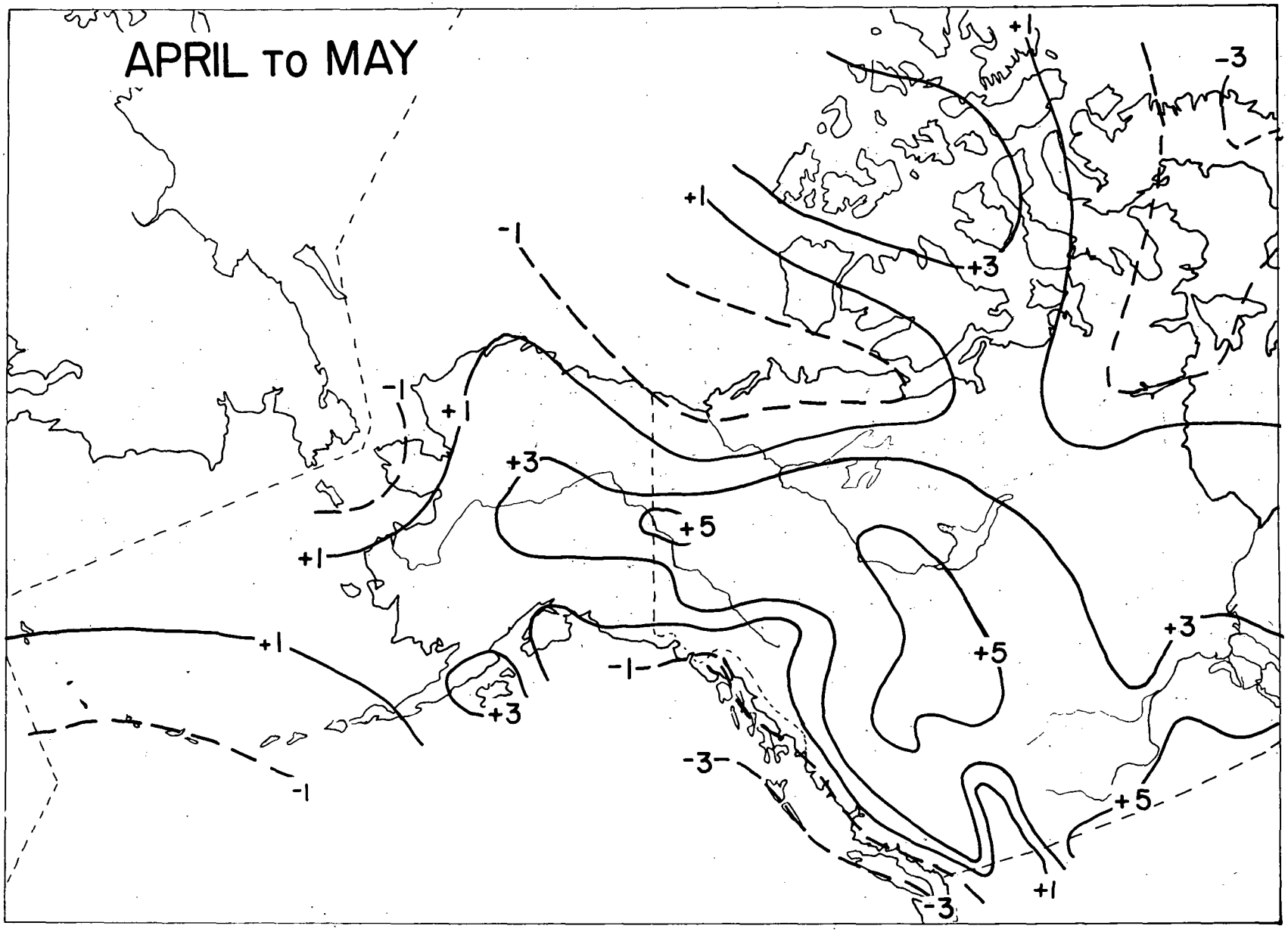

Fig. 9
Intermonthly Change In Normal Precipitation,
April to May.

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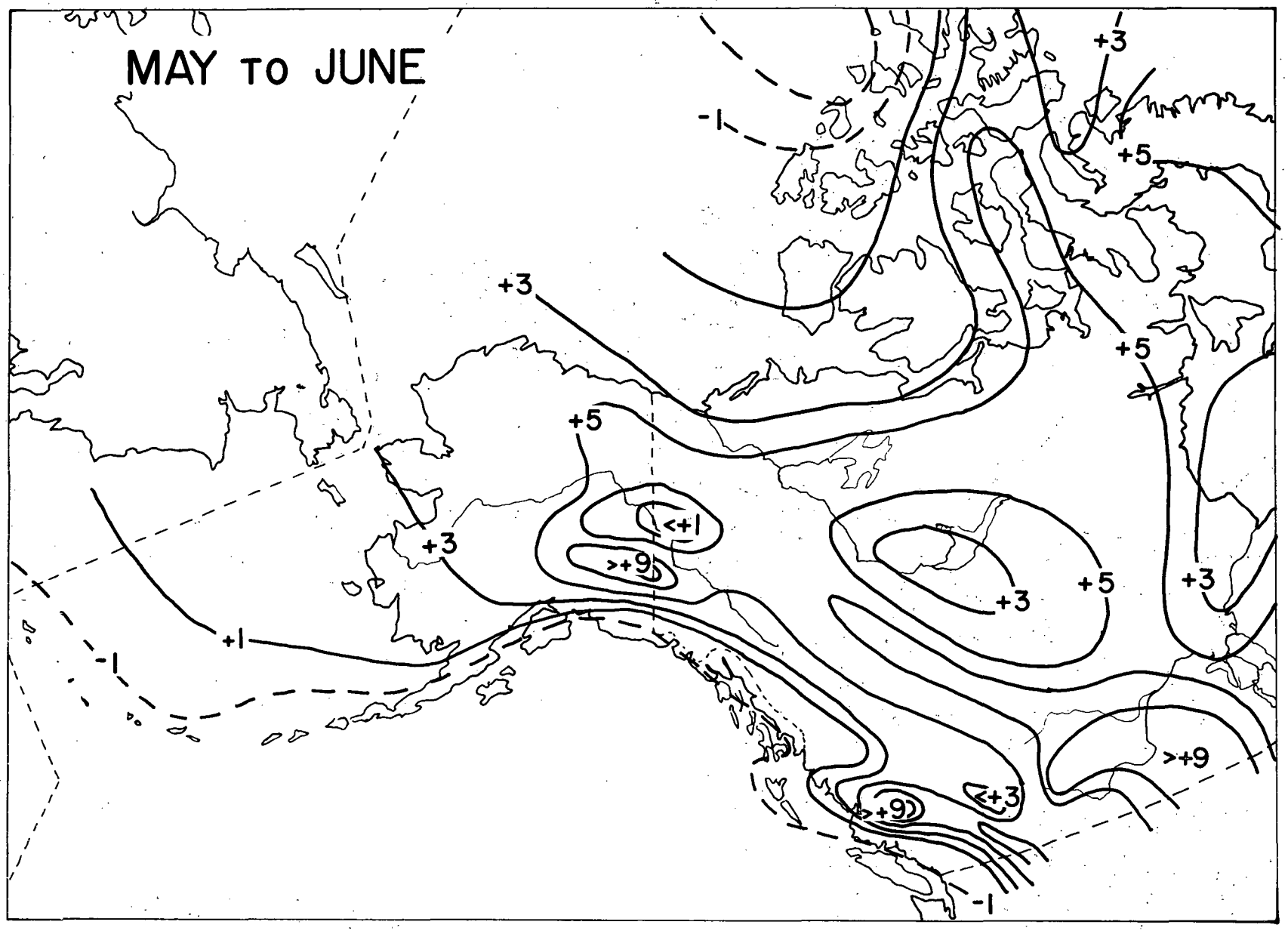

Fig. 10
Intermonthly Change In Normal Precipitation,
May to June.

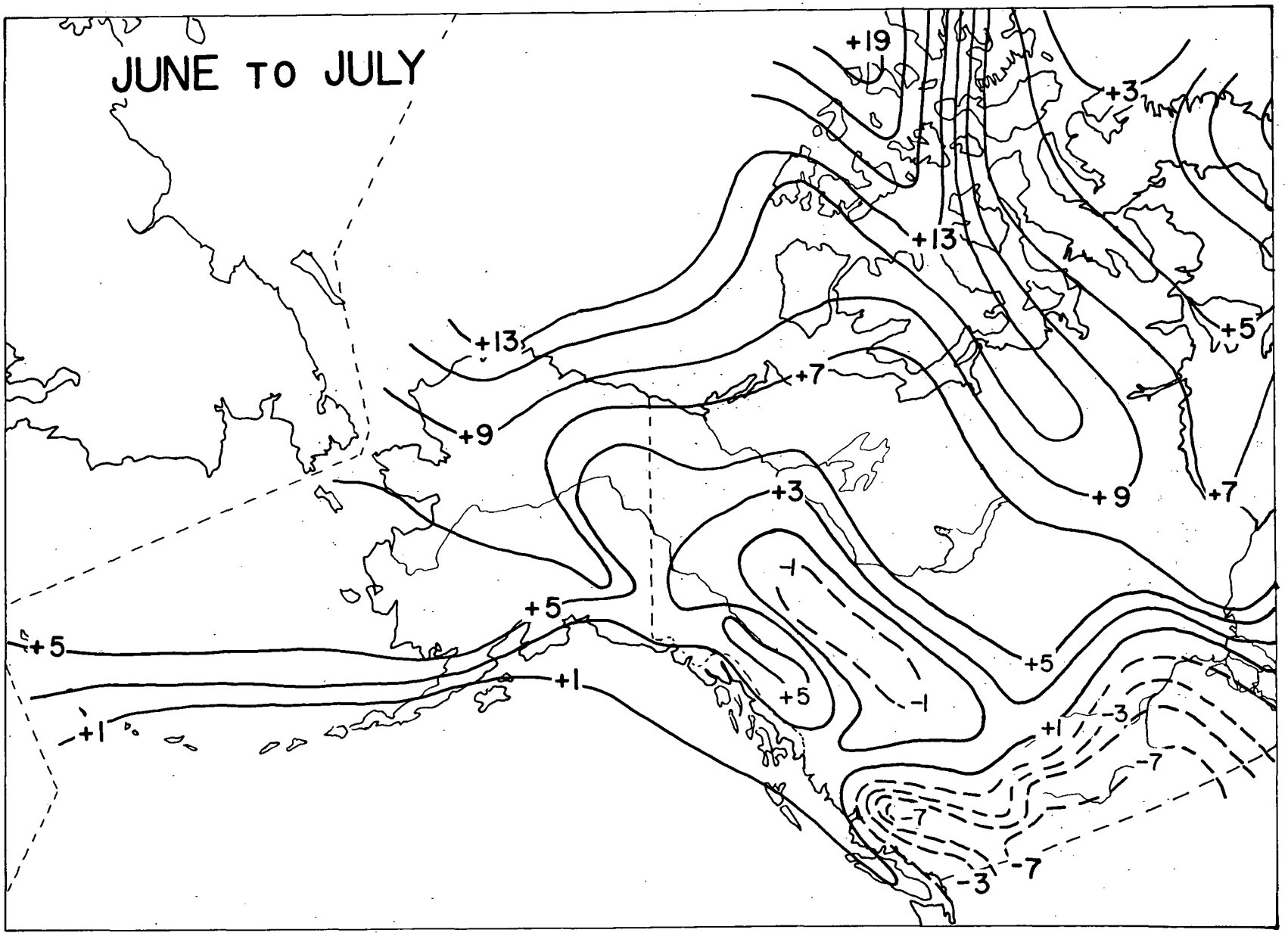

Fig. 11
Intermonthly Change In Normal Precipitation,
June to July.

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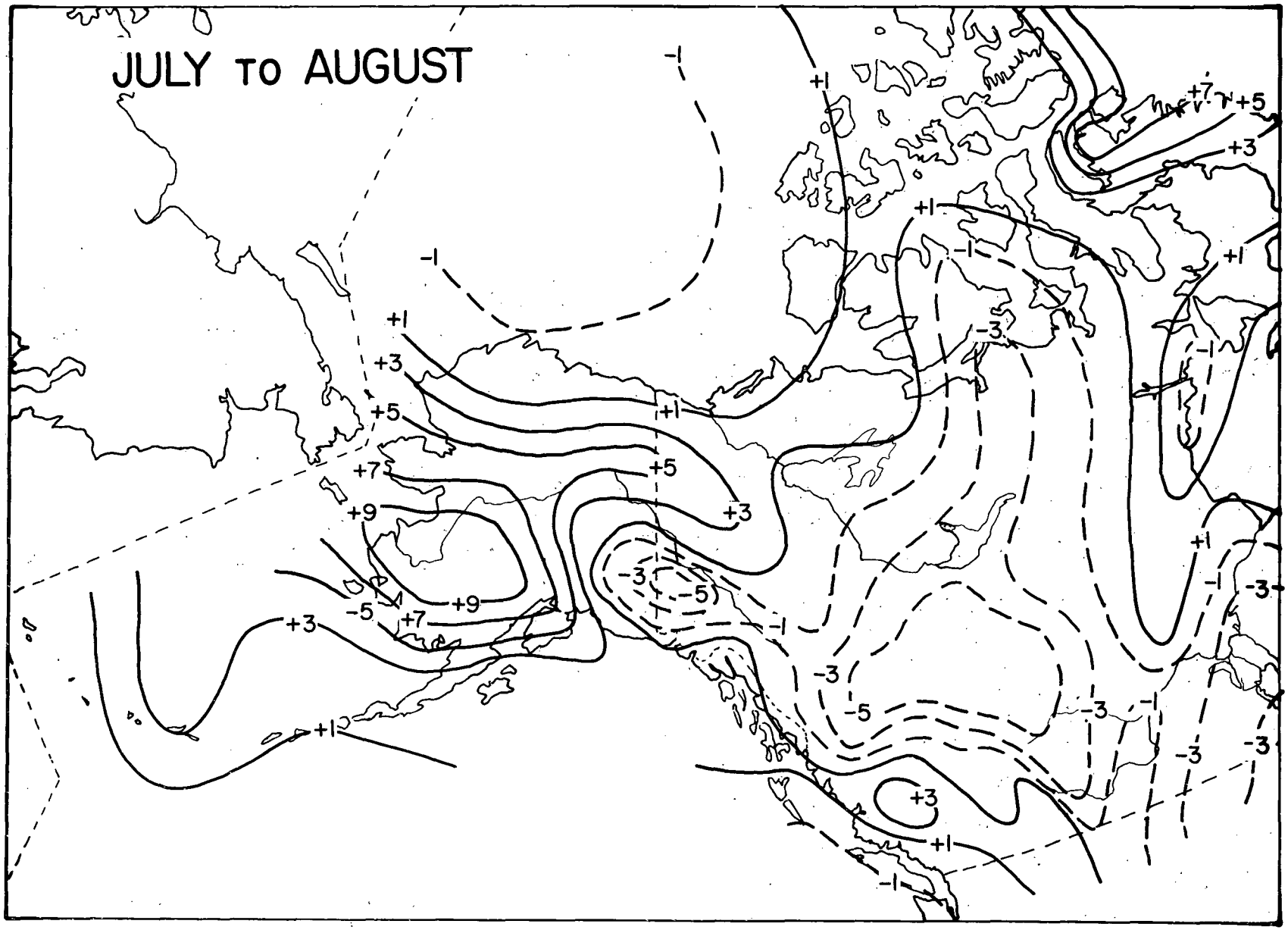

Fig. 12
Intermonthly Change In Normal Precipitation,
July to August.

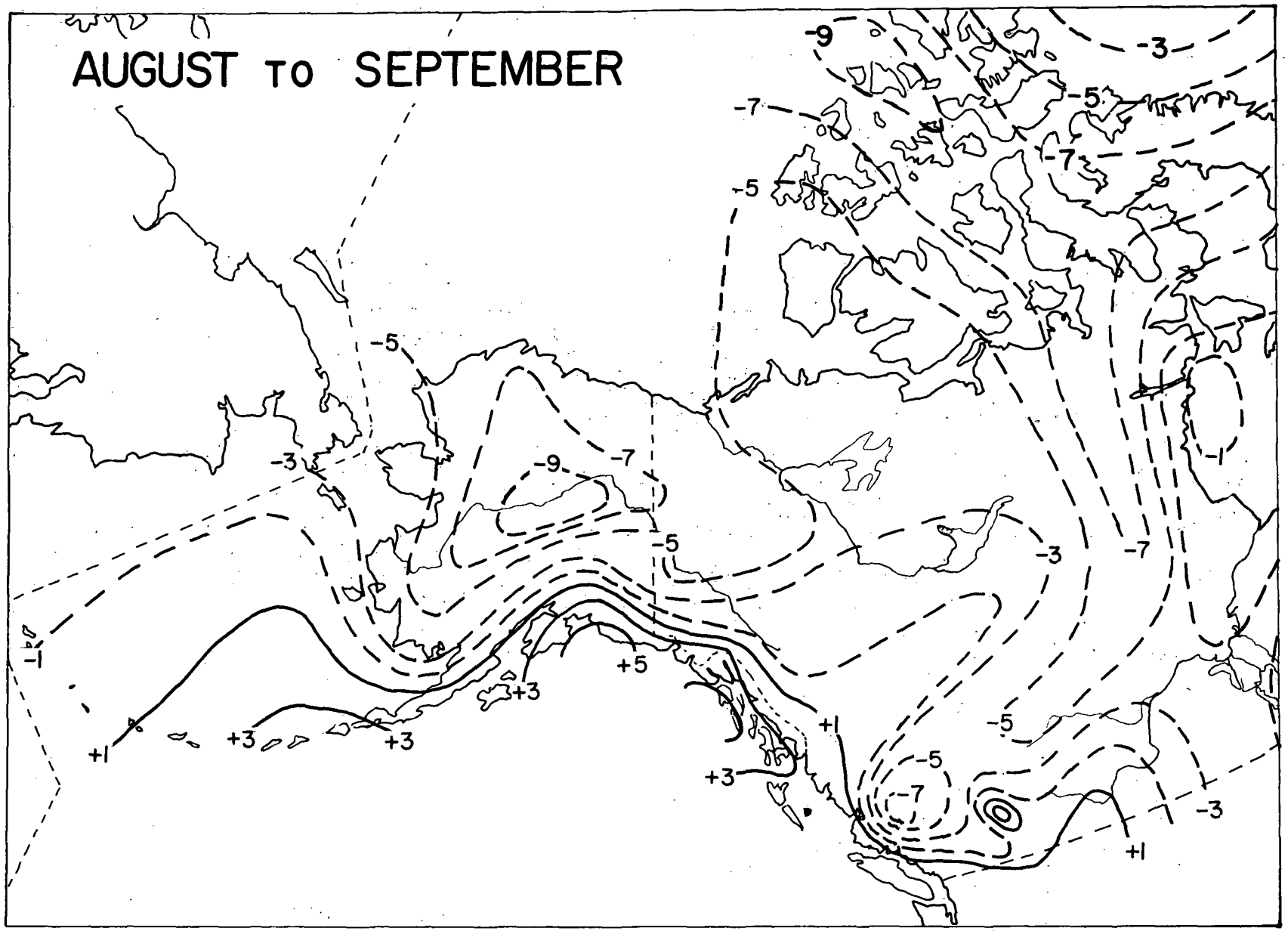

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Fig. 13
Intermonthly Change In Normal Precipitation,
August to September.

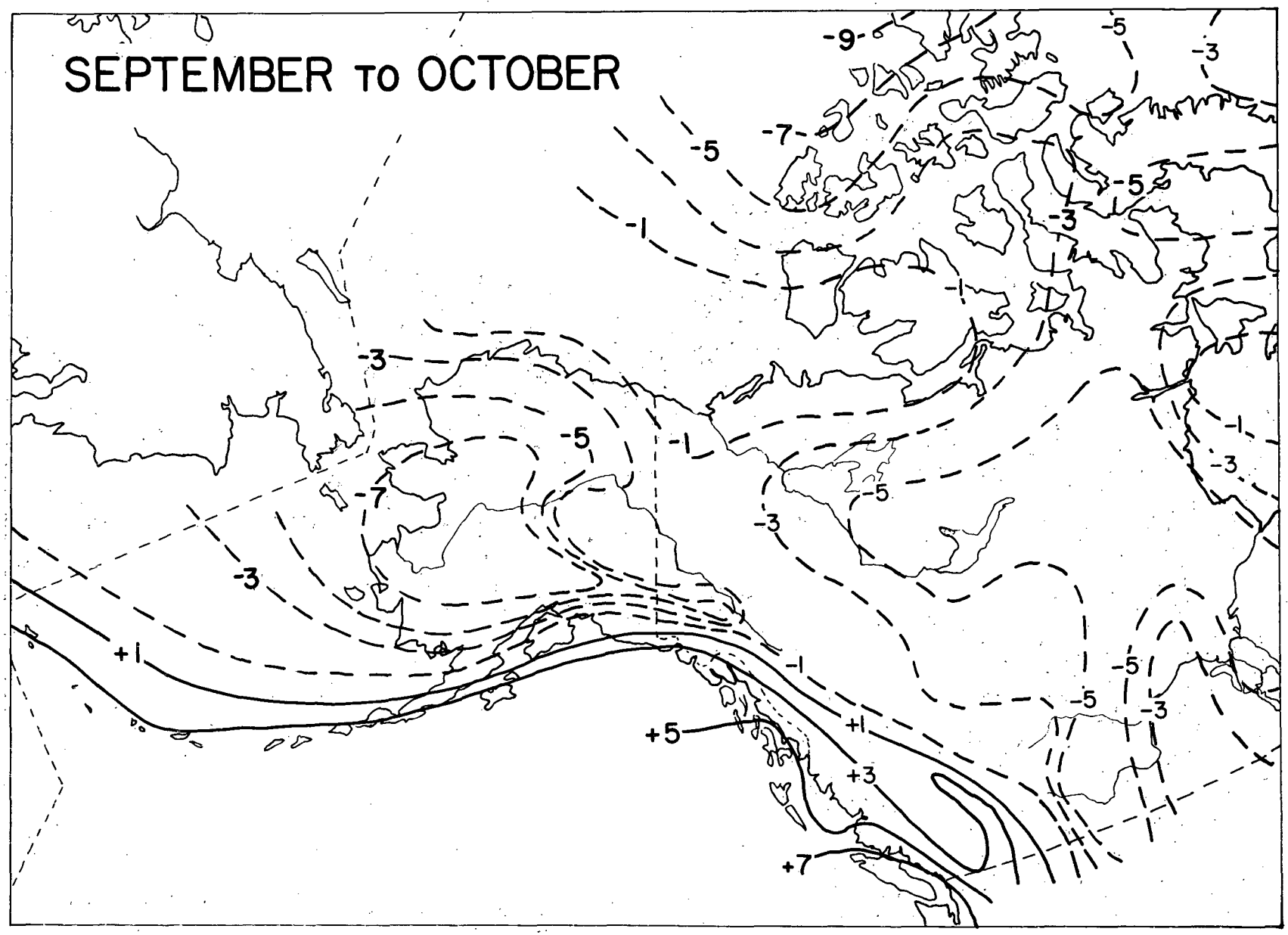

Fig. 14
Intermonthly Change In Normal Precipitation,
September to October.

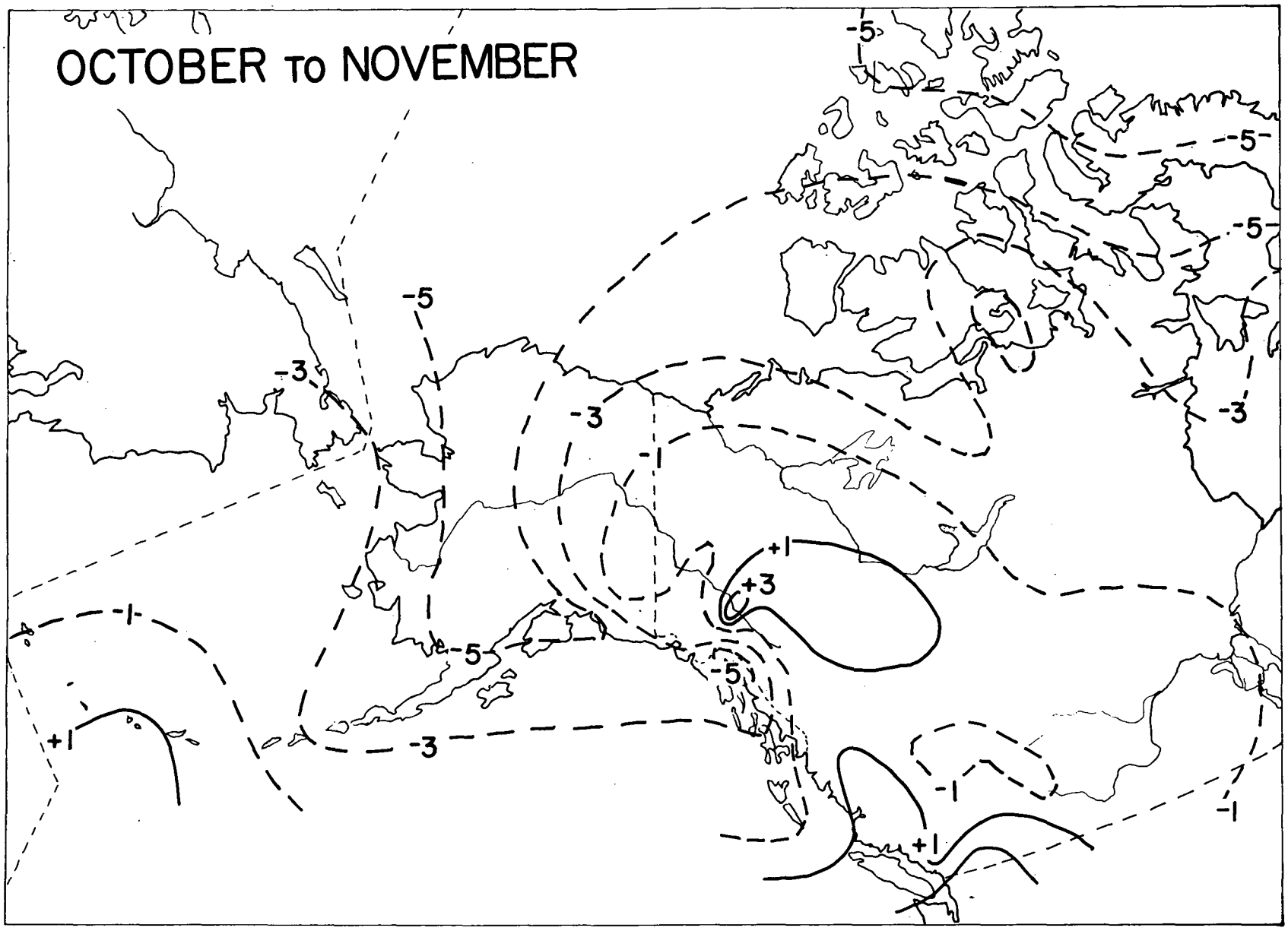

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Fig. 15
Intermonthly Change In Normal Precipitation,
October to November.

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