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MANUSCRIPT REPORT SERIES
(OCEANOGRAPHIC and LIMNOLOGICAL)
No. 151

Transport Computations for the North Pacific Ocean

1952

by
N. P. Fofonoff and F. W. Dobson

Pacific Oceanographic Group
Nanaimo, B.C.

March 5, 1963

Programmed
by
THE CANADIAN COMMITTEE ON OCEANOGRAPHY

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Introduction

Sverdrup (1947), Stommel (1948), and Munk (1950) have shown that the total steady-state transport of the mass in the ocean depends primarily on the curl of the wind stress components acting on the surface of the ocean. The theory has been applied to compute the transports in the North Pacific Ocean from 1955 to 1961 (Fofonoff, MSS, 1960, 1961), and to the North Atlantic Ocean from 1950 to 1961 (Fofonoff and Ross, MSS, 1962). Similar calculations have been applied to the data for the North Pacific Ocean from 1950 to 1954, and are being published in the present MS series. The transport components for many years are necessary to determine the averaging period necessary for steady-state conditions and the variability of transport with time and latitude.

Monthly means (averaging twice daily observations) of sea-level atmospheric pressure at a regular set of grid points are issued by the Extended Forecast Section of the U.S. Weather Bureau. The pressures from the region 15° N to 65° N and 115° E to 100° W were read from the charts and the resulting geostrophic winds computed. The surface stresses were estimated from the geostrophic winds by a method similar to that used by Montgomery (1935).

The computations at a grid point are made in terms of the mean pressure at that point and the six surrounding grid points. The geostrophic velocity vector is computed first. It is rotated 15° to the left of the downwind direction and reduced to 70% of its original magnitude to represent surface wind. The stress vector is assumed to be in the direction of the surface wind and to be proportional to the square of the wind speed. The stress law used is $|\tilde{\tau}_s| = \rho_a C_D v^2$ where ρ_a is the air density taken as 1.22×10^{-3} gm/cm^3, C_D is a non-dimensional drag coefficient chosen to be 2.6×10^{-3} and v is wind speed in centimetres per second.

From the geostrophic velocity, using the transformation for surface velocity and the stress law, the components of Ekman and total transport are computed. Details of the calculations and a description of the computer program are contained in the program manual M-1 (Fofonoff and Froese, MS, 1960).

Errors in the absolute values of the transports arise due to uncertainty in surface stresses calculated from the geostrophic winds. The surface stress is dependent on variation of wind with altitude as well as velocity. Further error is encountered by using the square of the mean velocity rather than the mean of the velocity squared in the stress law. The error will be proportional to the variance of the atmospheric pressure gradients.

Care must be exercised in interpreting the transport charts. As the calculations for each month are carried out independently of other months, the transports so obtained must refer to the limiting case of the transports resulting from a pressure distribution persisting without change for an indefinitely long period of time. The computed transports may, therefore, be thought of as indices indicating the relative range and frequency of variations applied to the ocean by the atmosphere. Long-term averages of transport computed from the pressure distribution should converge to the mean transport observed in the ocean within the limits of accuracy of the method. It should be remembered that the transports are very sensitive to the proportionality factors used in relating geostrophic to surface wind and to surface stress. Numerical equivalence of computed and observed transports is not anticipated.

Description of Transport Charts

Section I - Atmospheric pressure

The mean monthly sea-level atmospheric pressure is calculated from twice-daily observations. The charts are obtained from the Extended Forecast Section of the U.S. Weather Bureau. The pressures plotted are the anomalies from 1000 millibars given in units of 1/10 millibar.

Section II - Meridional component of Ekman transport V_E

The Ekman transport is computed directly from the surface stress induced by the geostrophic wind and is directed at right angles to the stress. The meridional component of Ekman transport is given by

$$V_E = -\tau_\lambda / f$$

where τ_λ is the zonal component of stress in dynes per square centimetre and f is the coriolis parameter in radians per second. The charts show the component in units of 10 metric tons per second per kilometre.

Section III - Zonal component of Ekman transport U_E

The zonal component of Ekman transport is given by

$$U_E = \tau_\phi / f$$

where τ_ϕ is the meridional component of stress. U_E is given in units of 10 metric tons per second per kilometre.

Section IV - Meridional component of total mass transport V

The total meridional component of mass across a unit length of a latitude circle is given by

$$V = (\mathrm{curl}_z \, \tau) / \beta$$

where $\beta = df/R d\phi$. Allowing the total transport to satisfy the continuity equation, it is possible to define a transport function Ψ such that

$$U = \frac{1}{R}\frac{\partial \Psi}{\partial \phi}$$

$$V = -\frac{1}{R\cos\phi}\frac{\partial \Psi}{\partial \lambda} = (\mathrm{curl}_z \tilde{I}/\beta)$$

Section V - IIntegrated total transport

The meridional component of total transport along the latitude under consideration is integrated westward from the eastern shoreline. For simplicity in programming the integration is continued across the Aleutian Island chain. Thus, values of Ψ in the Bering Sea require subtraction of the transport function value at the Island chain. No provision has been made for calculating the western boundary currents. It may be assumed that the net transport across any line of latitude is zero and thus the value at the western shores of the ocean represents the transport of the western boundary currents.

The charts of integrated total transport are given in units of 100,000 metric tons per second.

Section VI - Integrated geostrophic transport Ψ_g

The net mass of water Ψ_g transported by the geostrophic current across latitude circles is obtained from the difference between the meridional component of total transport and the meridional component of Ekman transport. The geostrophic mass transport is proportional to the zonal component of the gradient of potential energy χ according to the equation

$$-\frac{1}{R\cos\phi}\frac{\partial \Psi_g}{\partial \lambda} = V - V_E = -\frac{1}{f\cos\phi}\frac{\partial \chi}{\partial \lambda}, \quad \Psi_g = \frac{\chi_{\lambda_0} - \chi_\lambda}{f}$$

where λ_0 is the longitude of the eastern boundary grid point.

The integration is carried out using zero as the boundary condition for Ψ_g at the grid point nearest the eastern coast. Thus, although the east-west changes of potential energy are given by the geostrophic transport function, the north-south components are not correctly represented. The difference between values of the total transport and the geostrophic transport functions at any grid point represents the contribution of the meridional Ekman transport to the integrated total transport eastward of the point.

The integrated geostrophic transport is given in units of 100,000 metric tons per second.

Annual means and standard deviations

Included at the end of each section is a chart of the annual means and standard deviations. Both these charts are in the same units as the other charts in the section. The means are the arithmetic averages of

the values for the 12 months of the year. The standard deviation, is computed by

$$\sigma = \sqrt{\frac{N\Sigma x_i^2 - (\Sigma x_i)^2}{N(N-1)}}$$

where N = number of months of data being averaged = 12
x_i = values of data being averaged.

Acknowledgement

Charts of mean sea-level atmospheric pressure were made available through the courtesy of Mr. Jerome Namais, Chief of the Extended Forecast Section and Mr. Roy Fox, Director of the National Weather Records Centre of the U.S. Weather Bureau. The computer programs for obtaining transport components, means and standard deviations were constructed by Dr. Charlotte Froese of the Department of Mathematics, University of British Columbia. The computer tapes were prepared by Miss Mary Cairns. The assistance of these individuals and all others who helped in the preparation of the charts is gratefully acknowledged.

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Section I

Atmospheric Pressure

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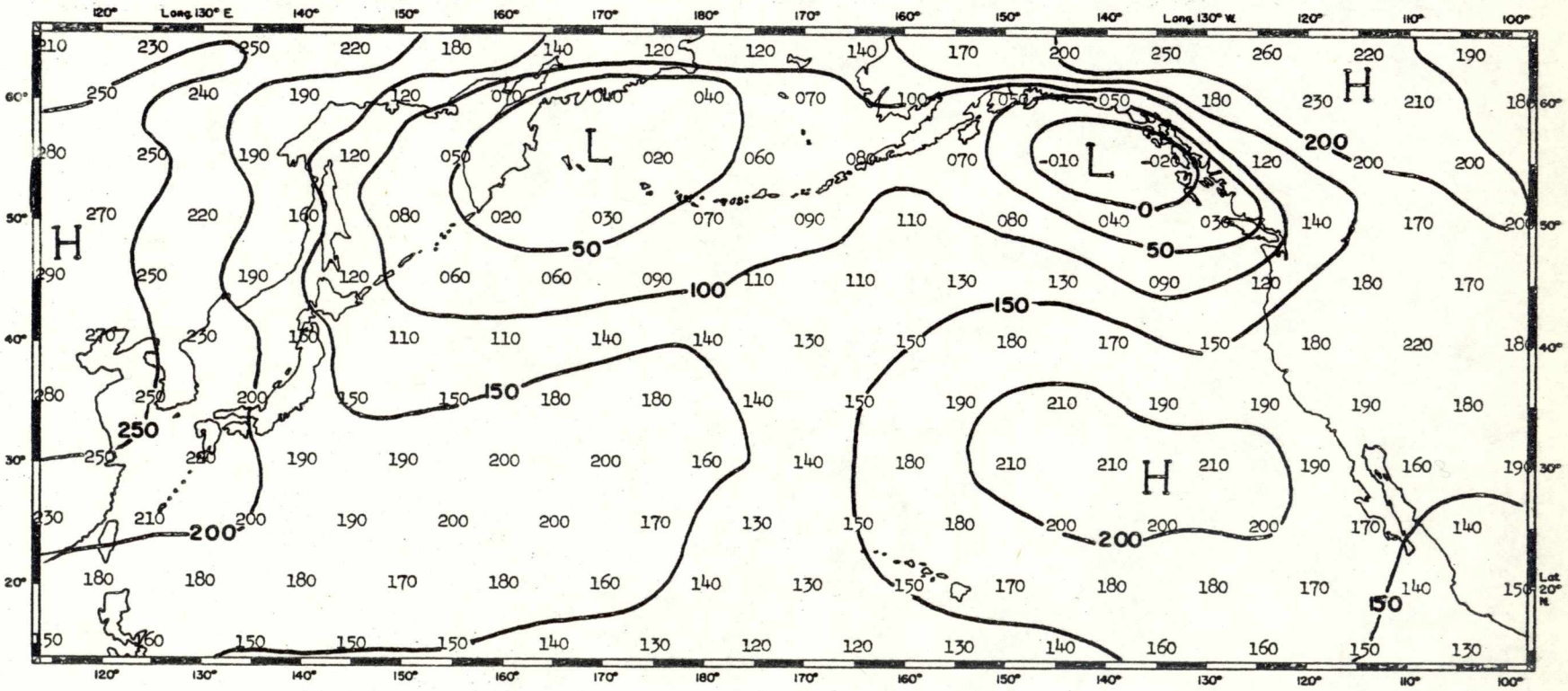

I. Atmospheric Pressure

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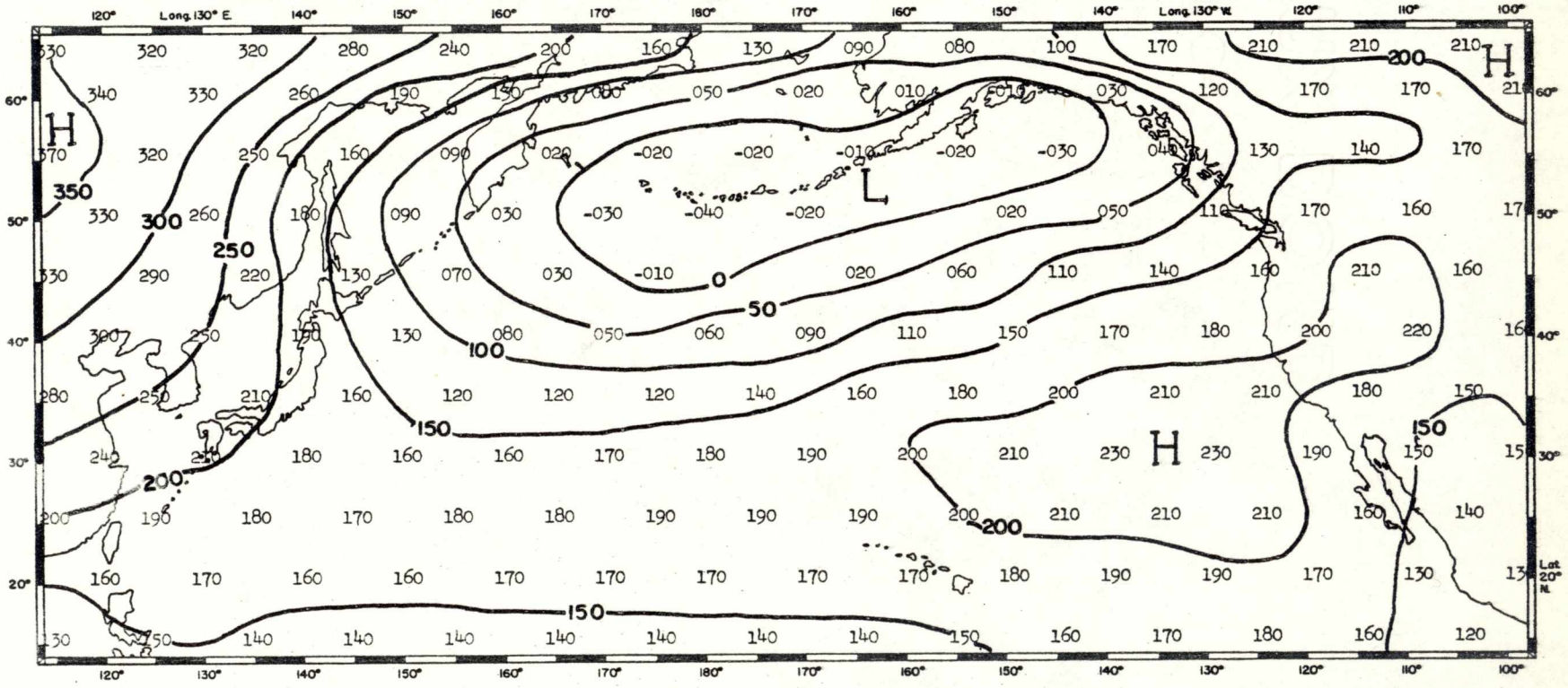

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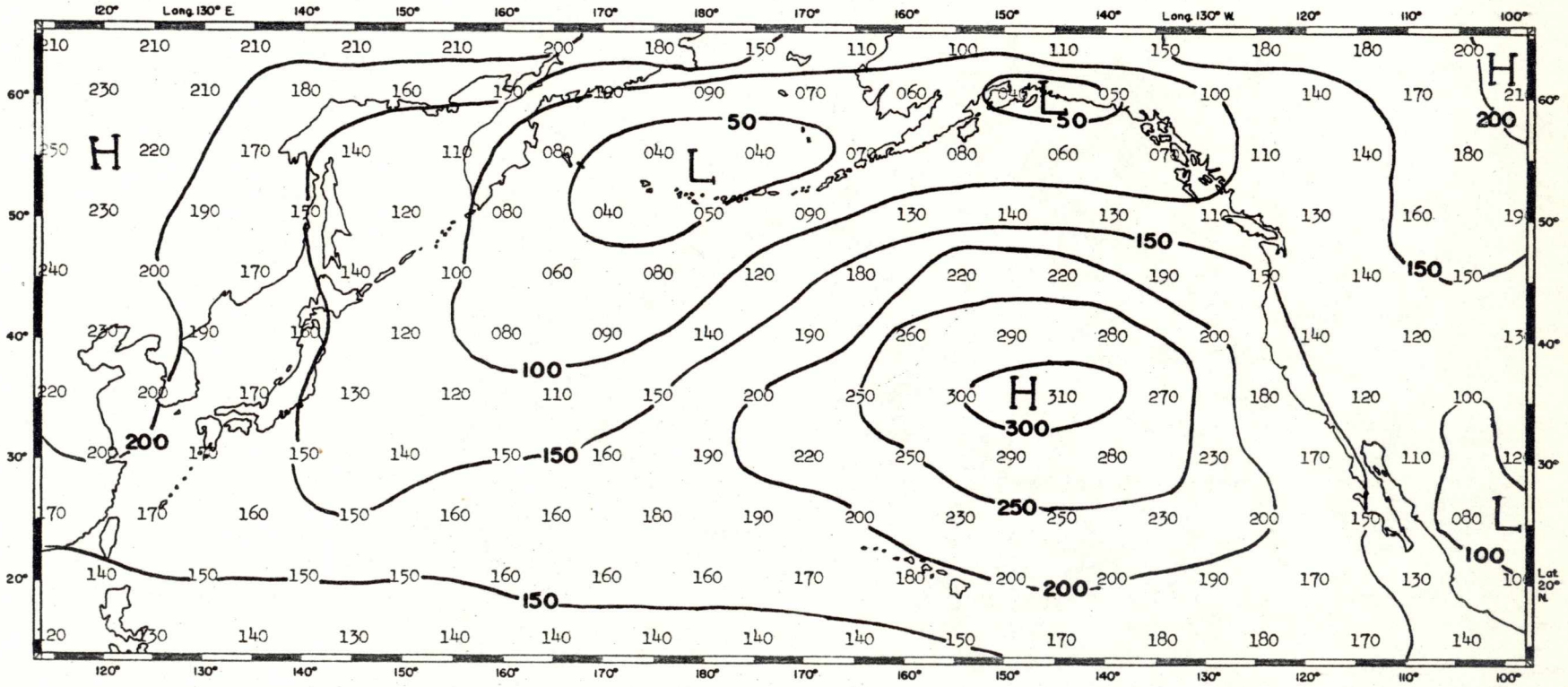

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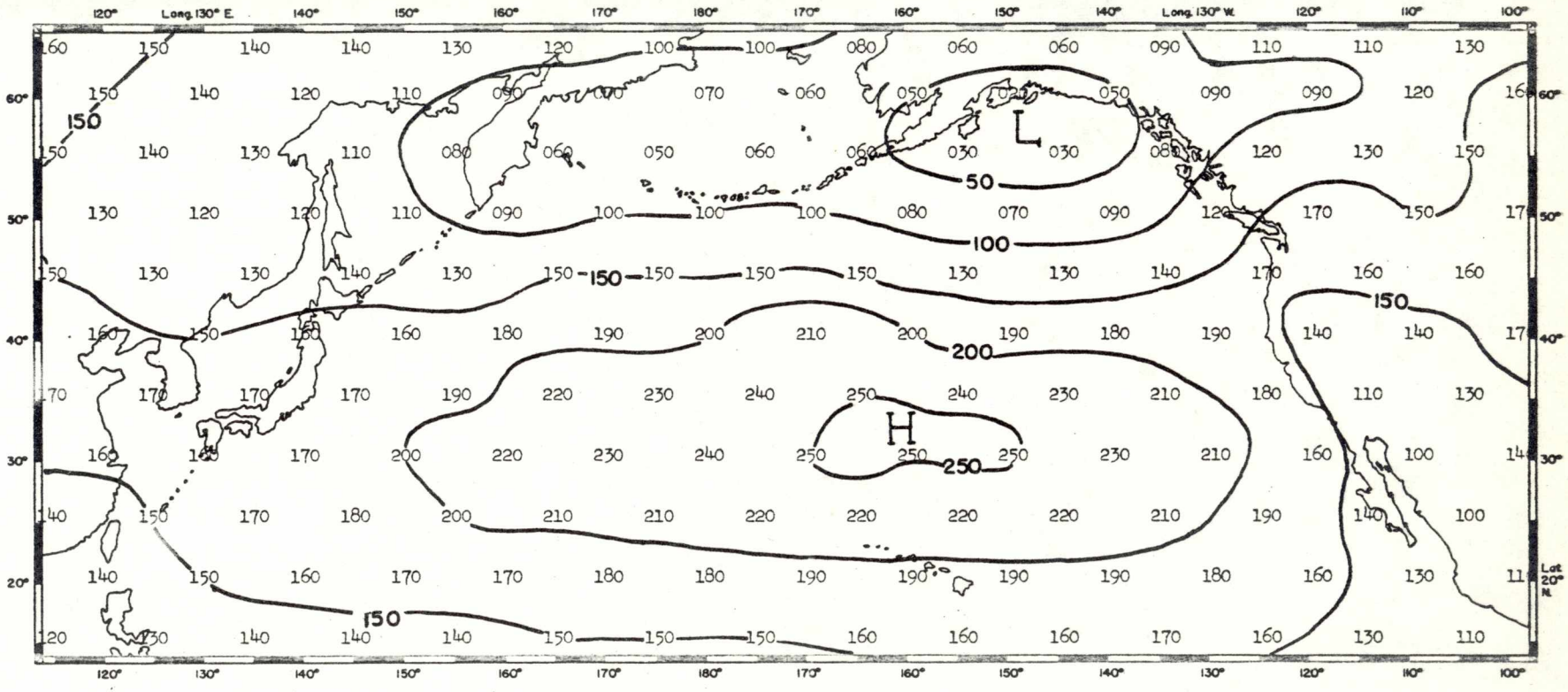

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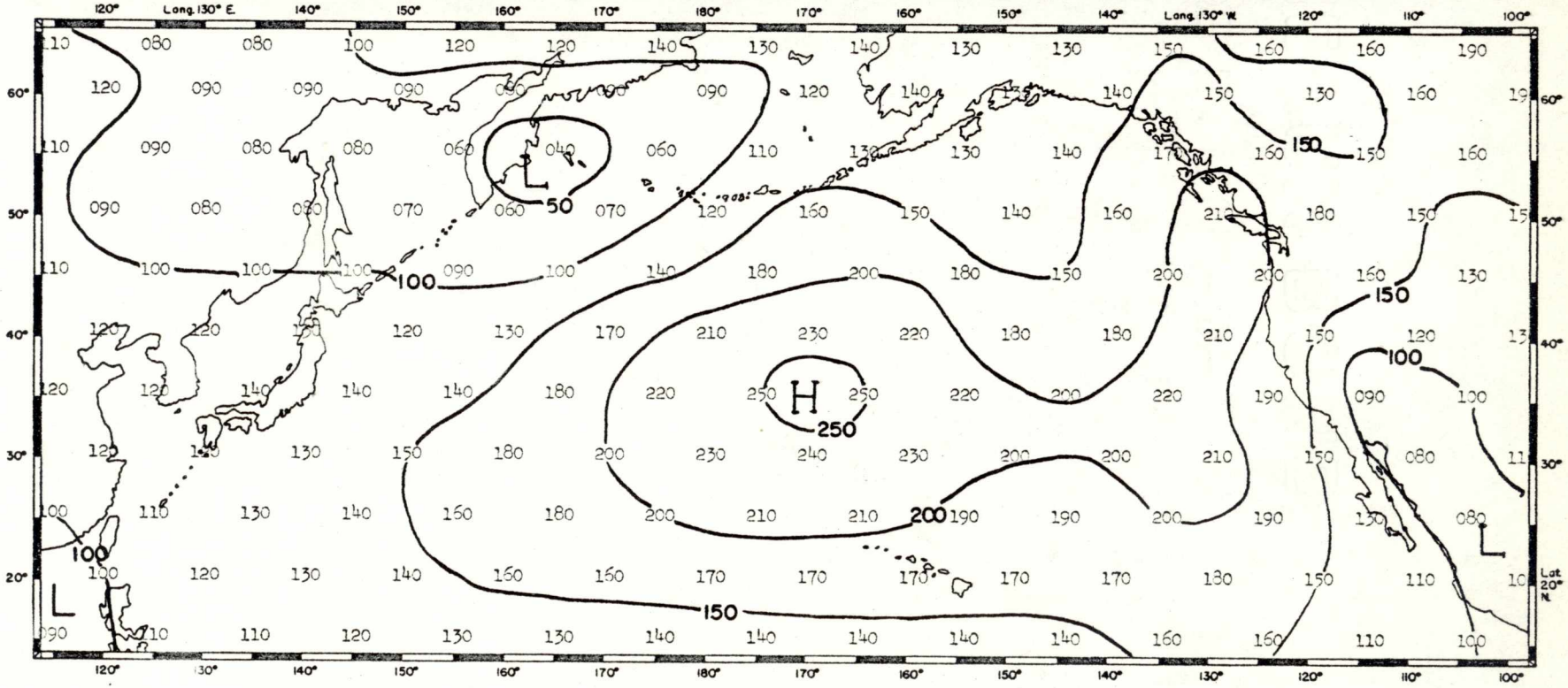

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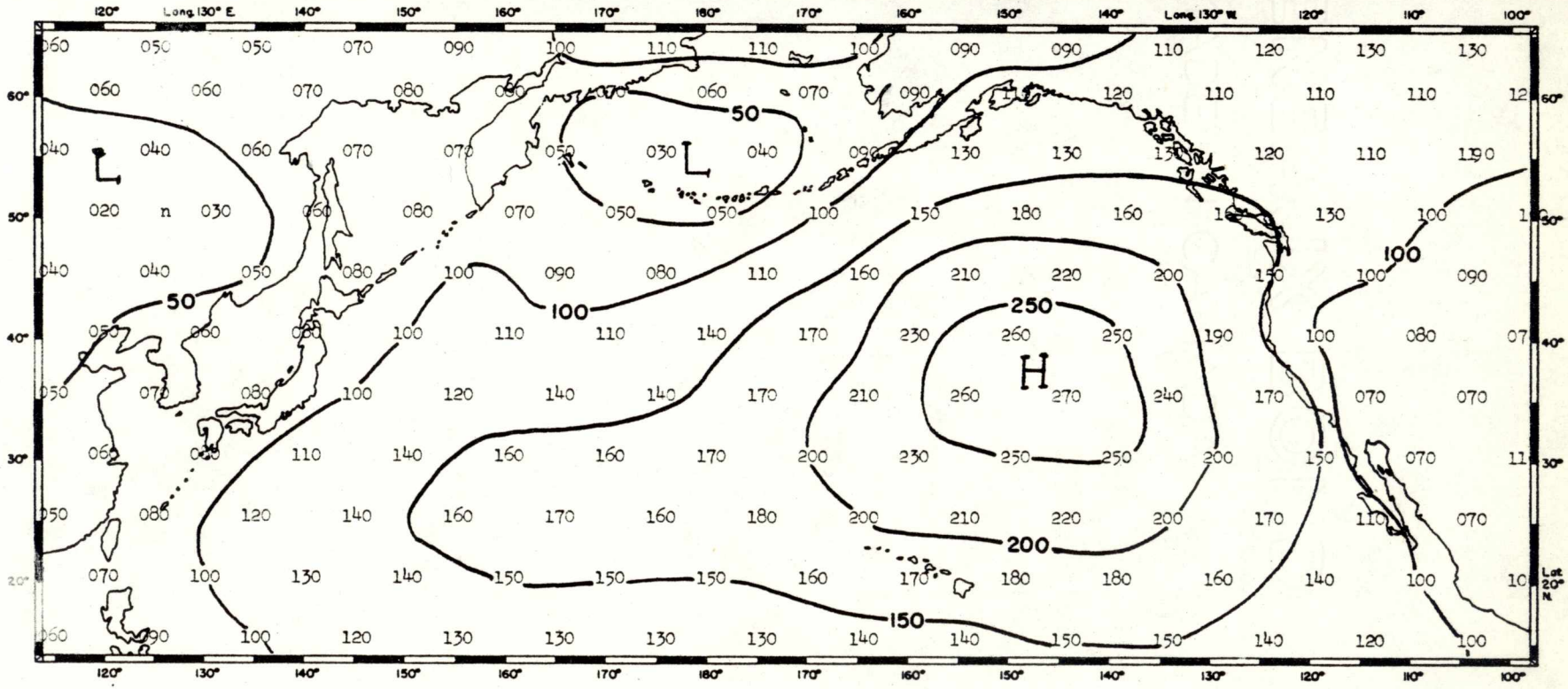

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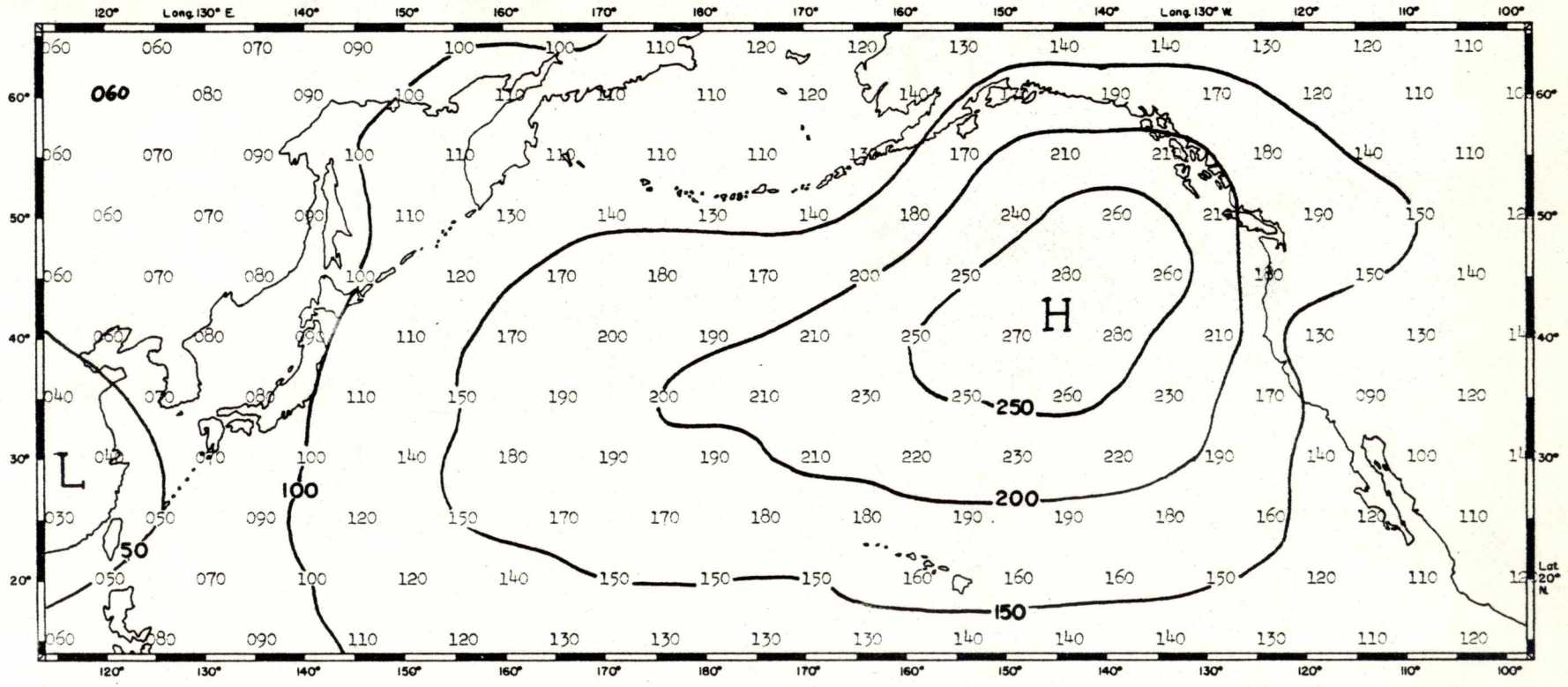

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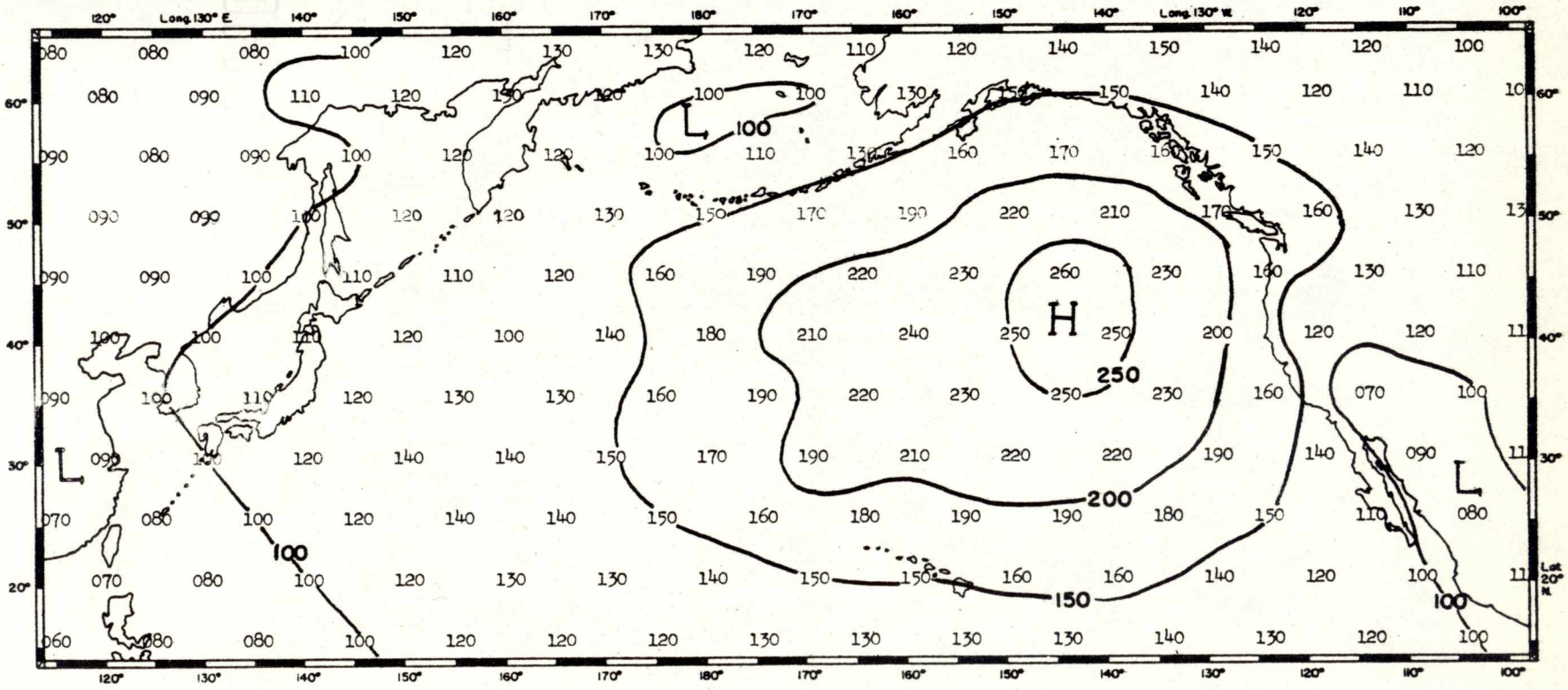

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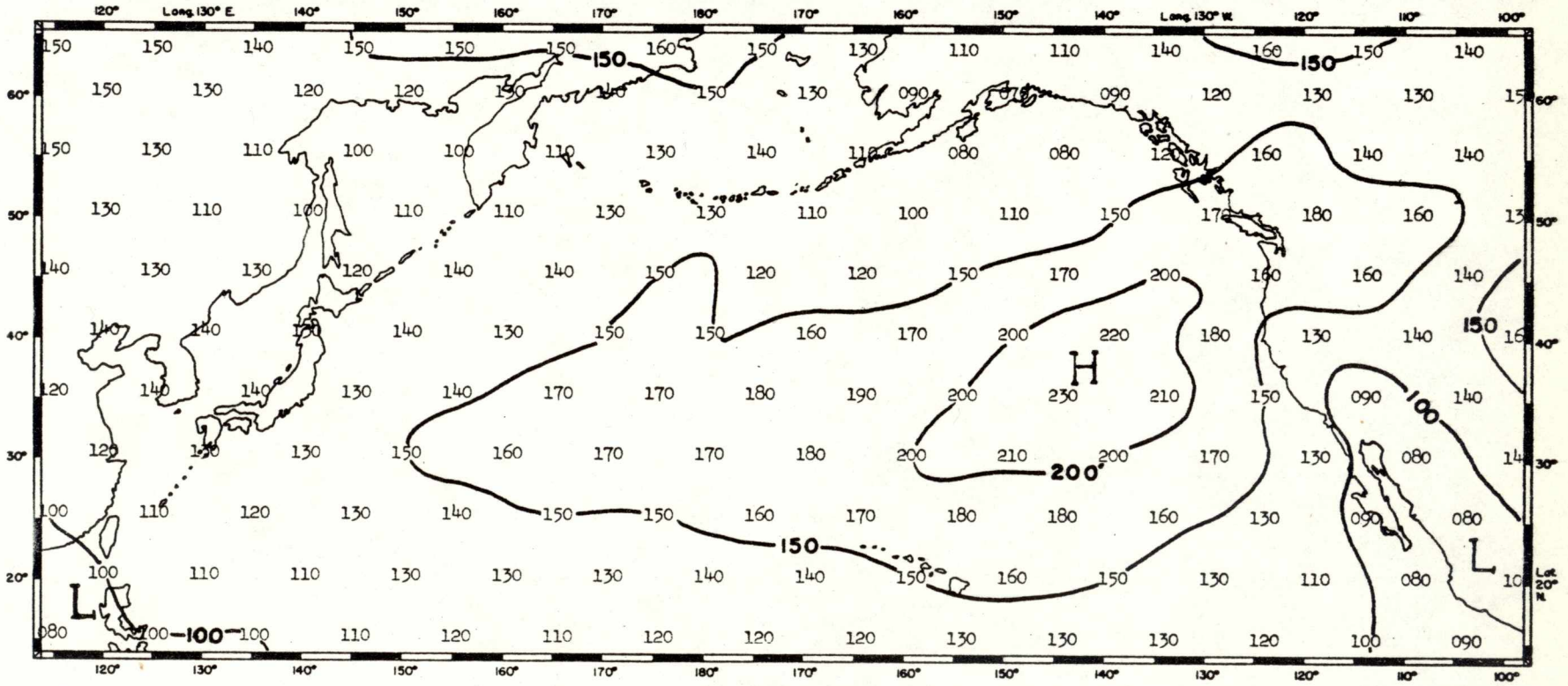

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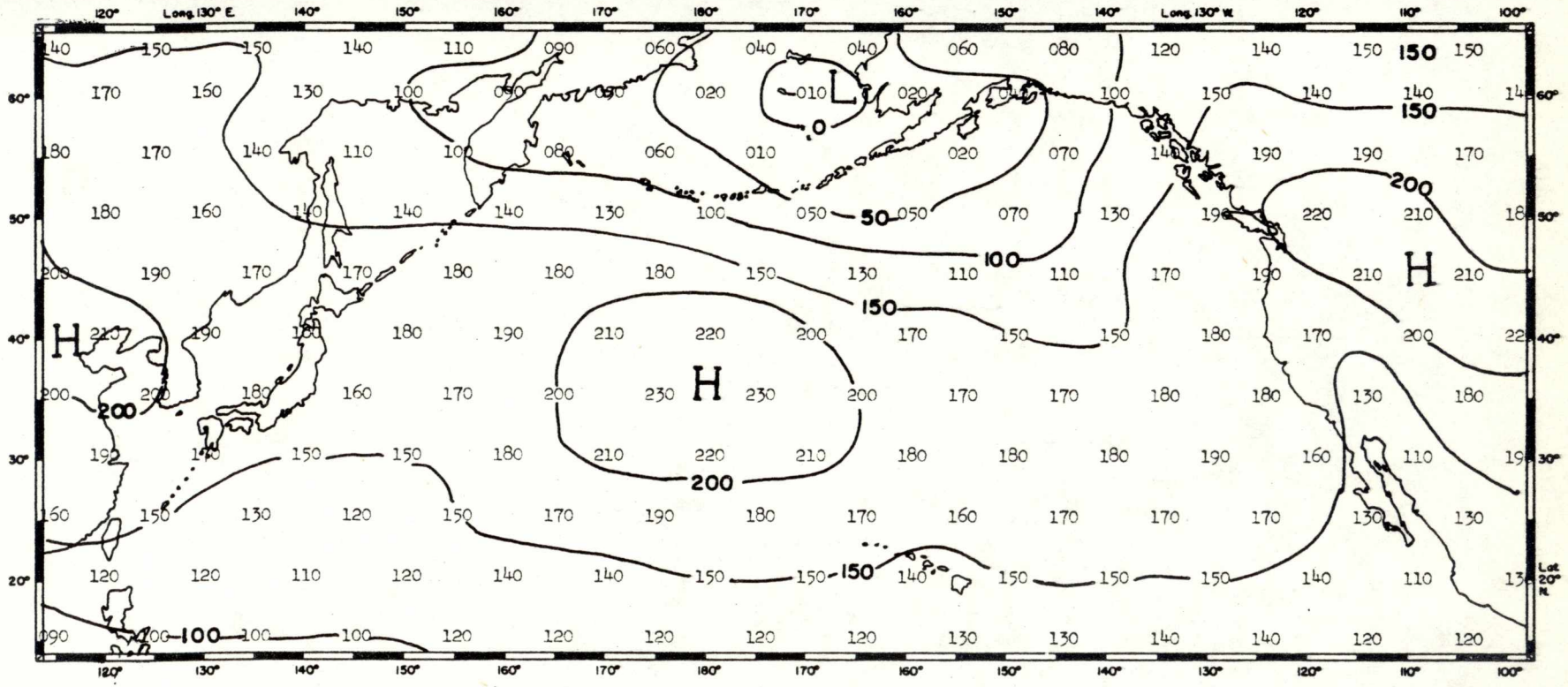

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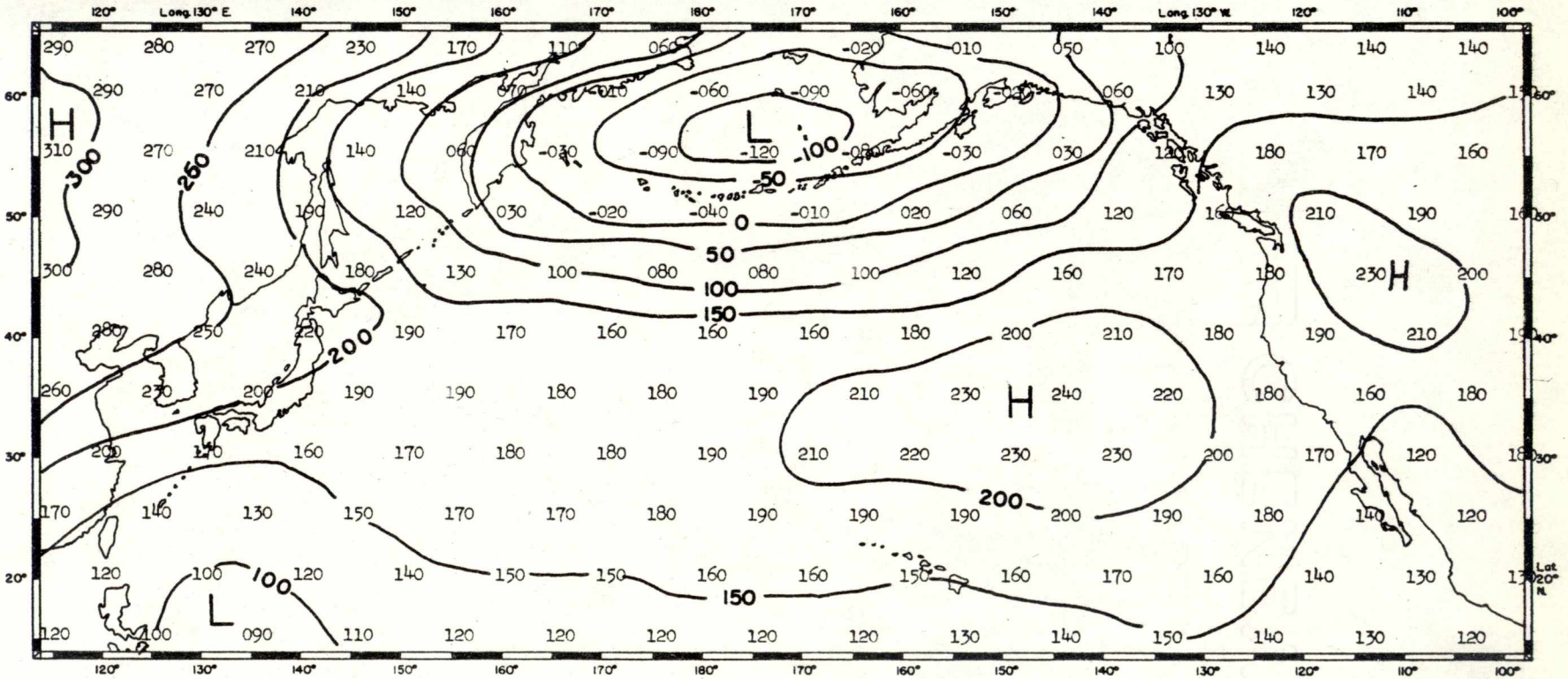

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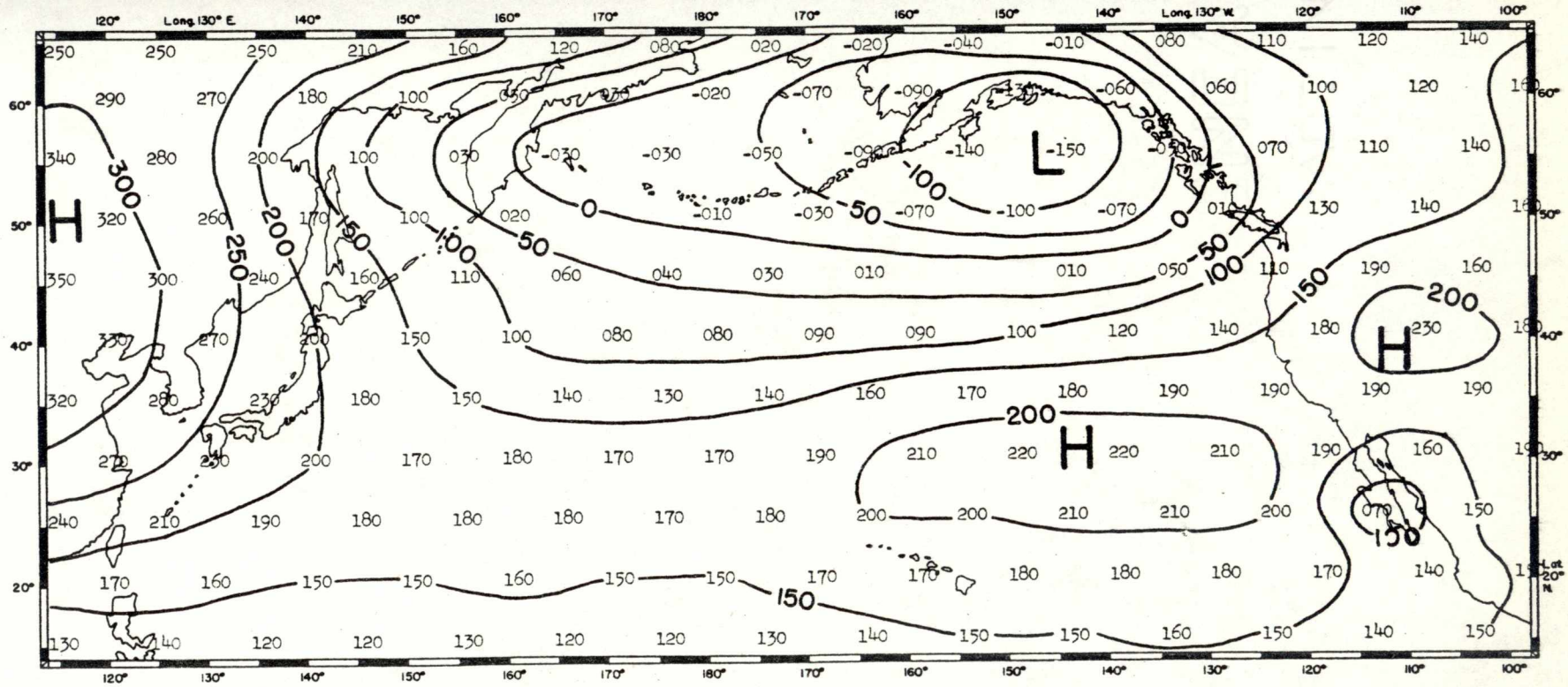

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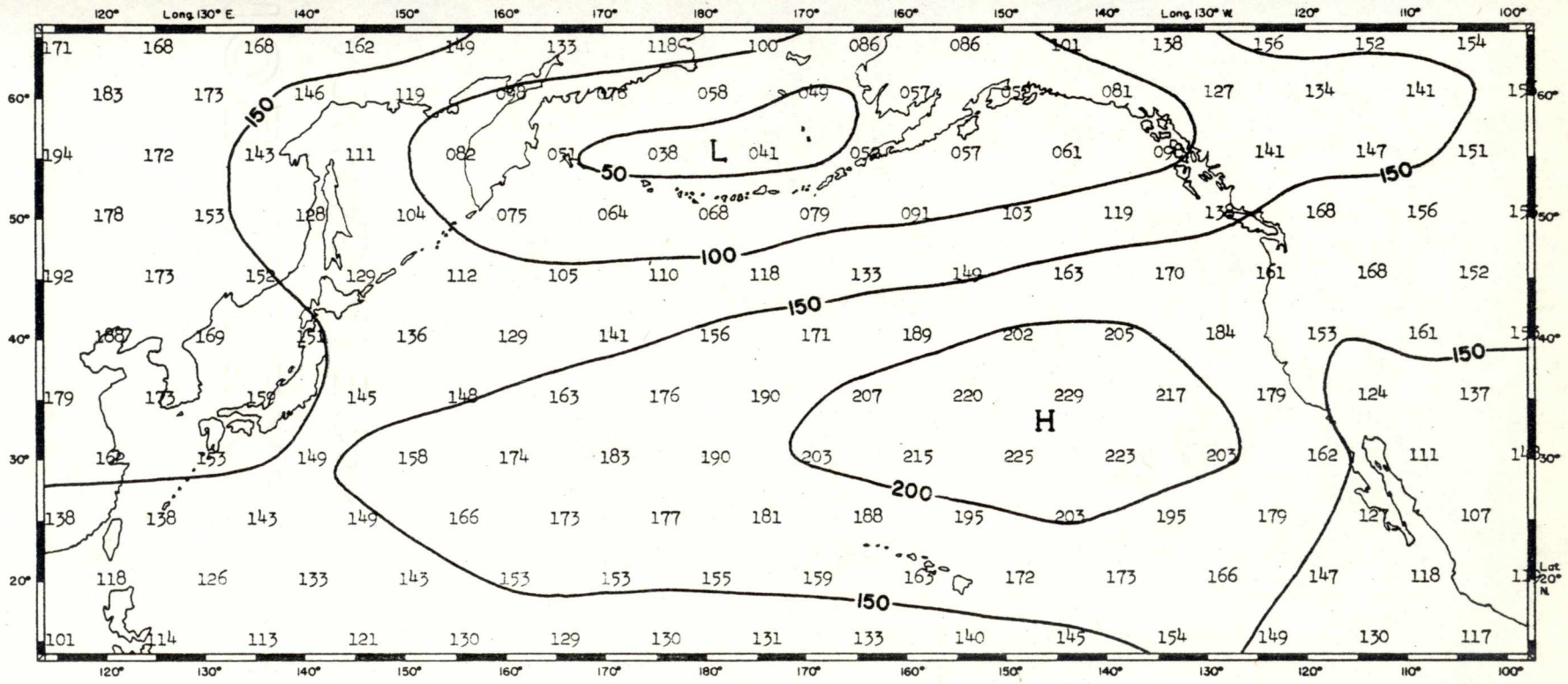

I. Atmospheric Pressure

ANNUAL MEAN 1952

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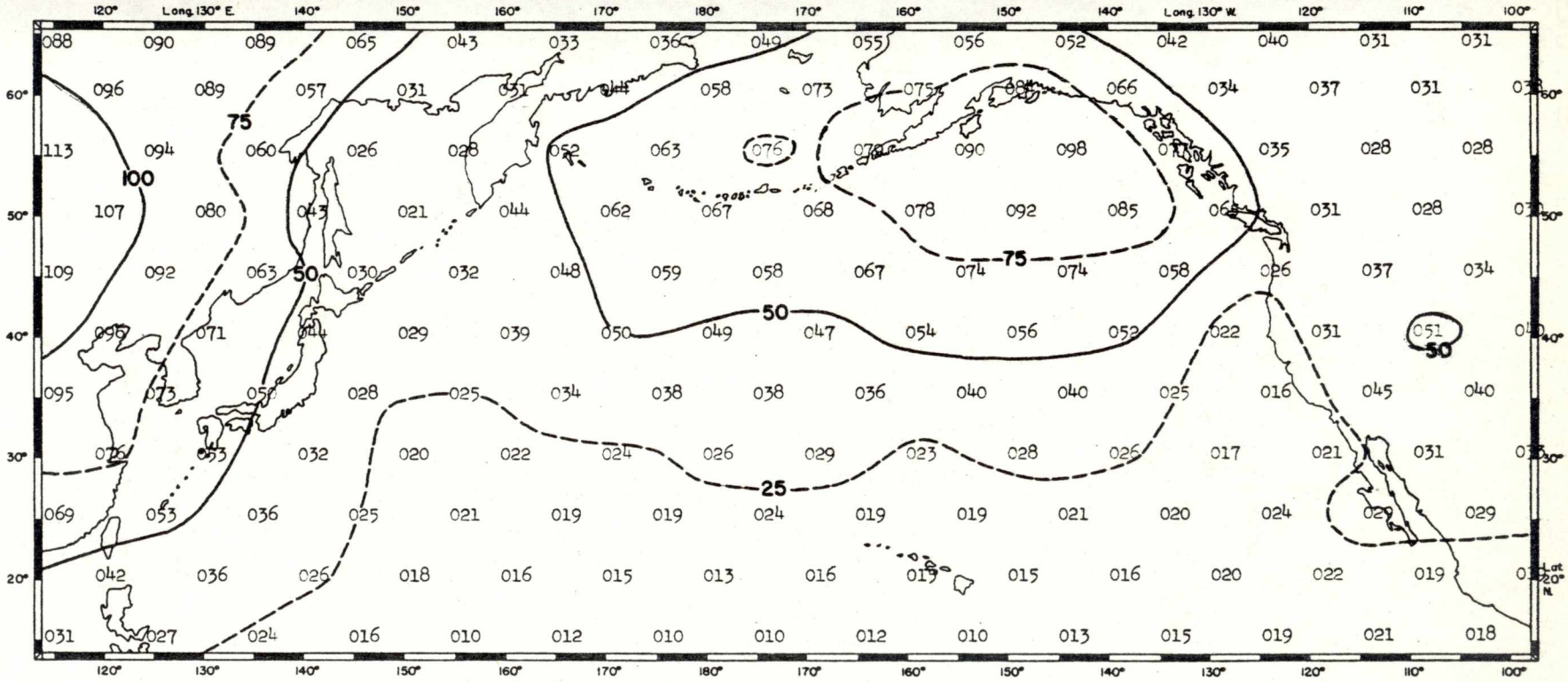

I. Atmospheric Pressure

STANDARD DEVIATION 1952

Section II

Meridional Component of Ekman Transport

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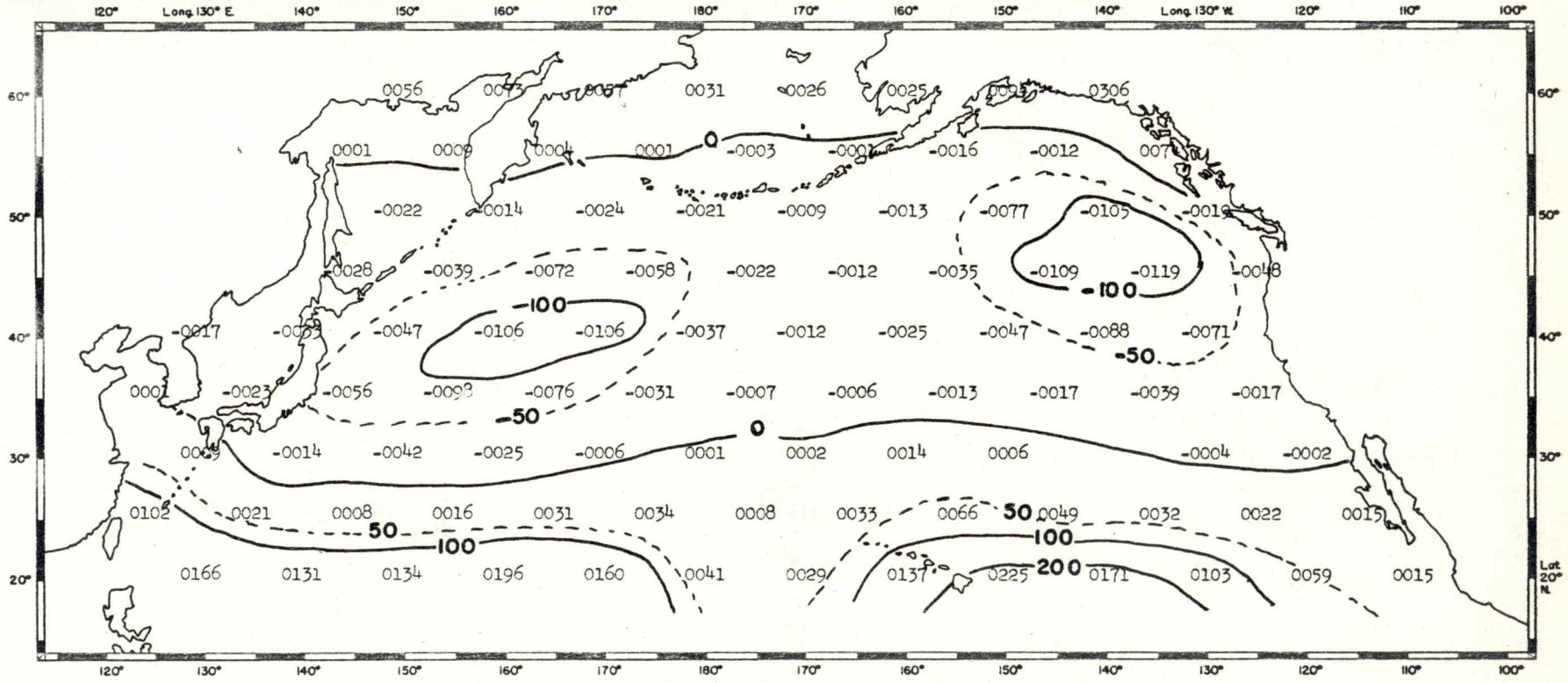
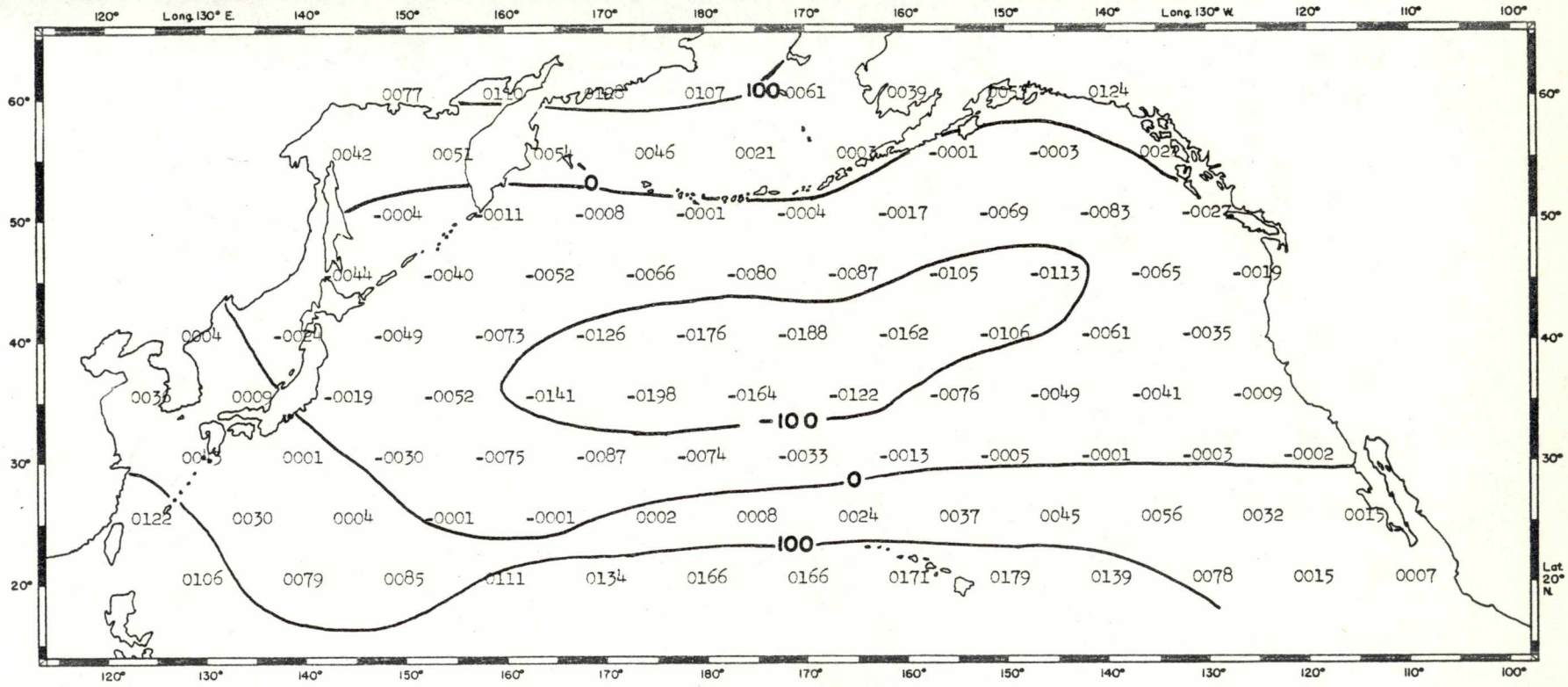


II. Meridional Component of Ekman Transport

Feb 1 Mar 1 1952



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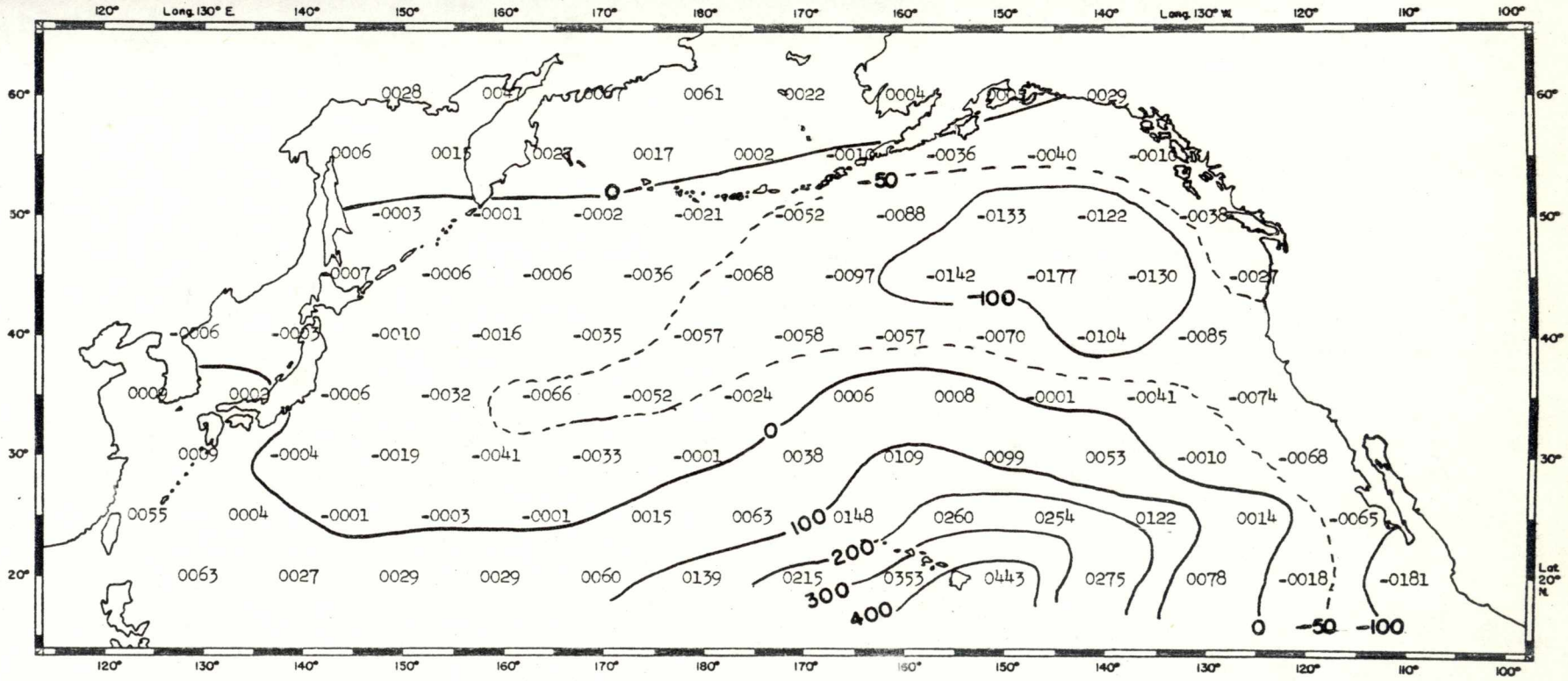

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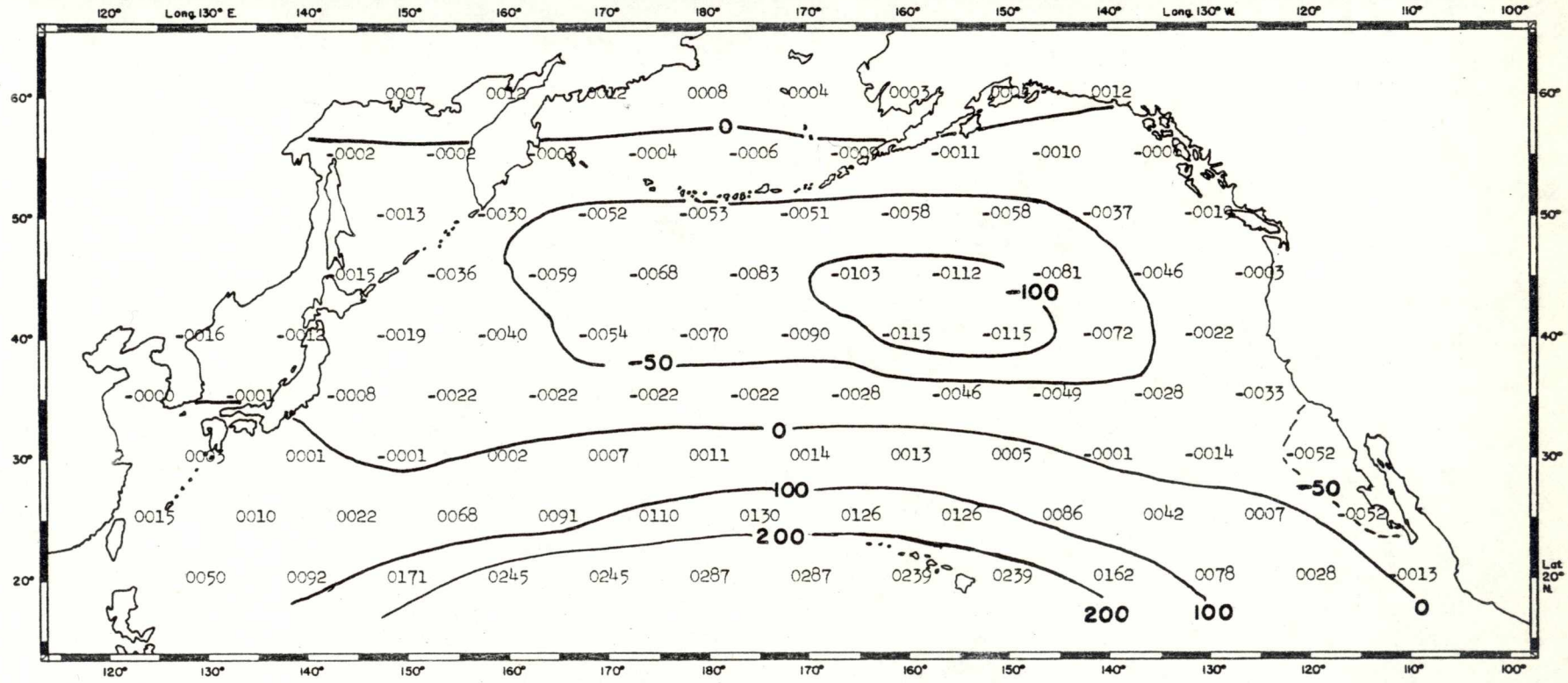

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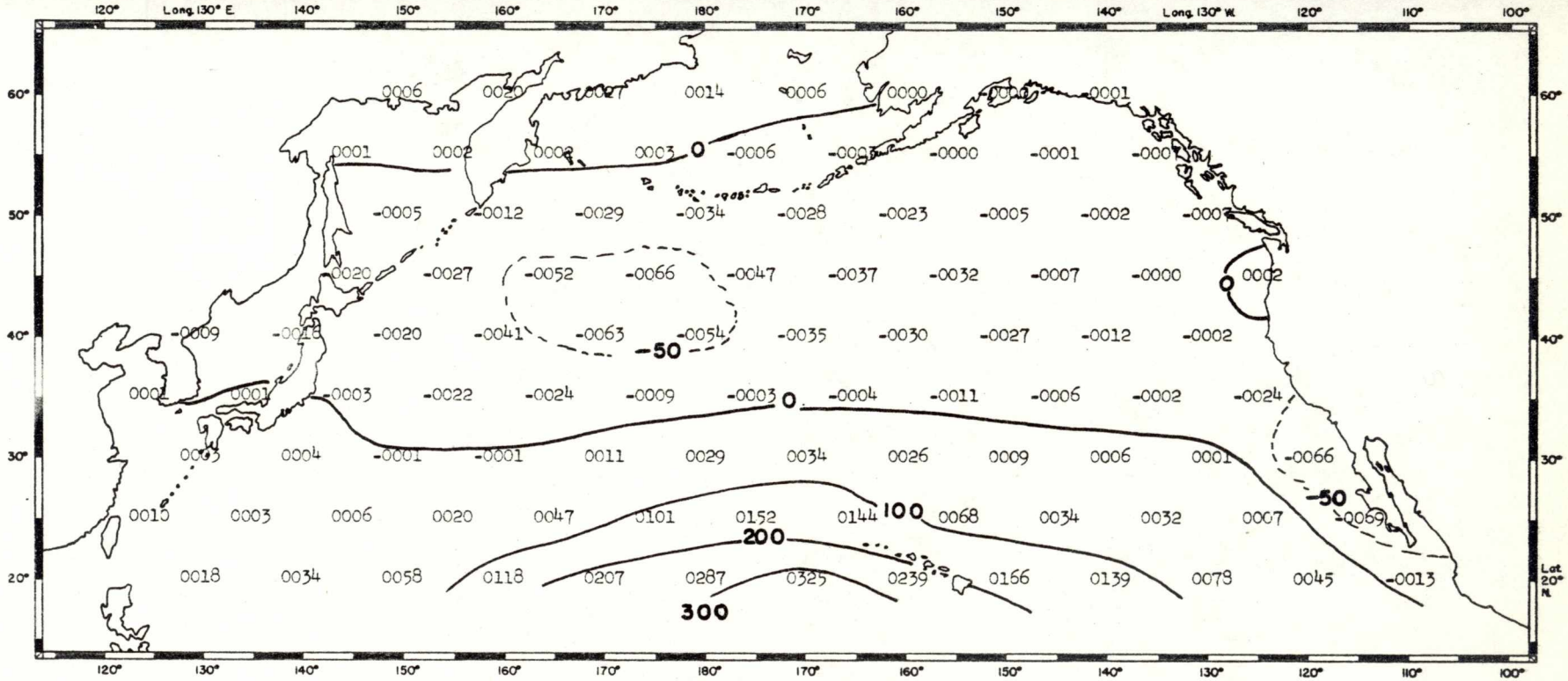

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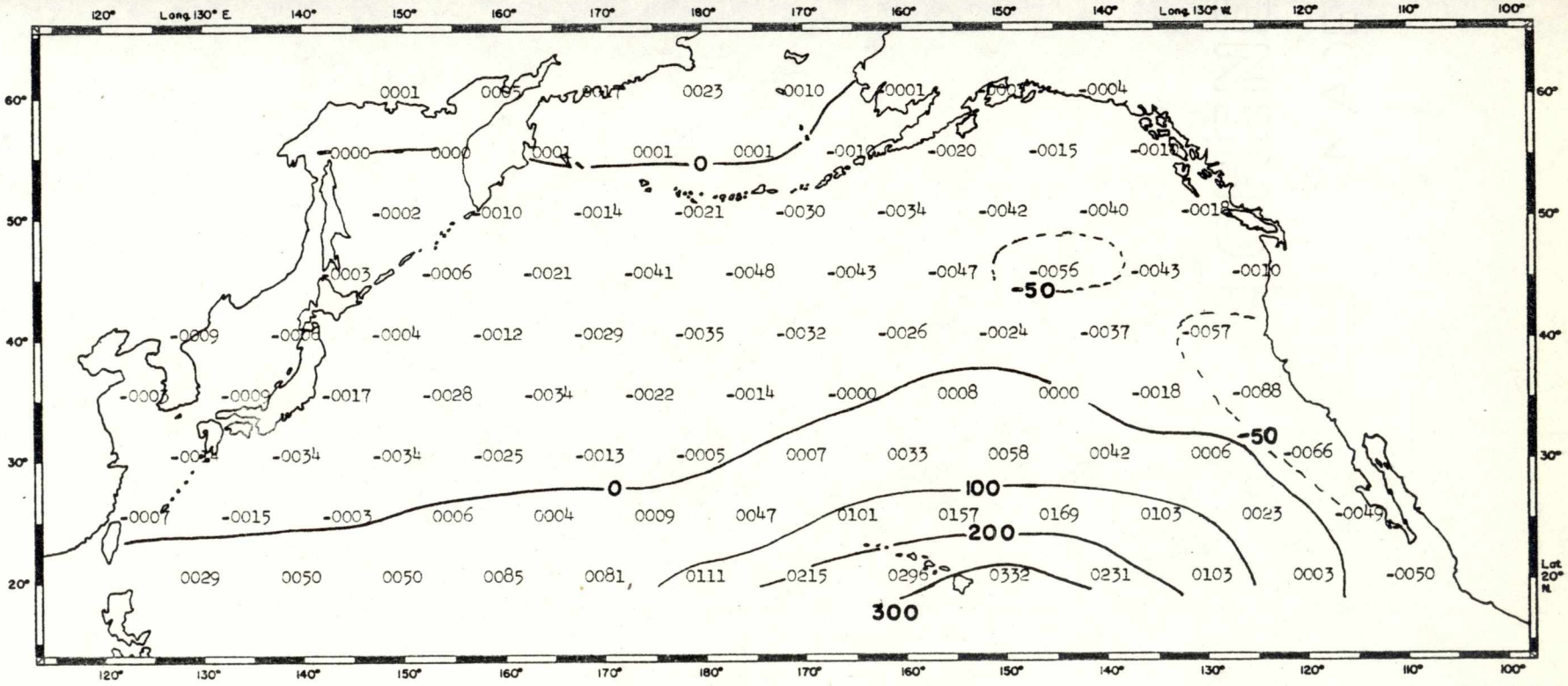

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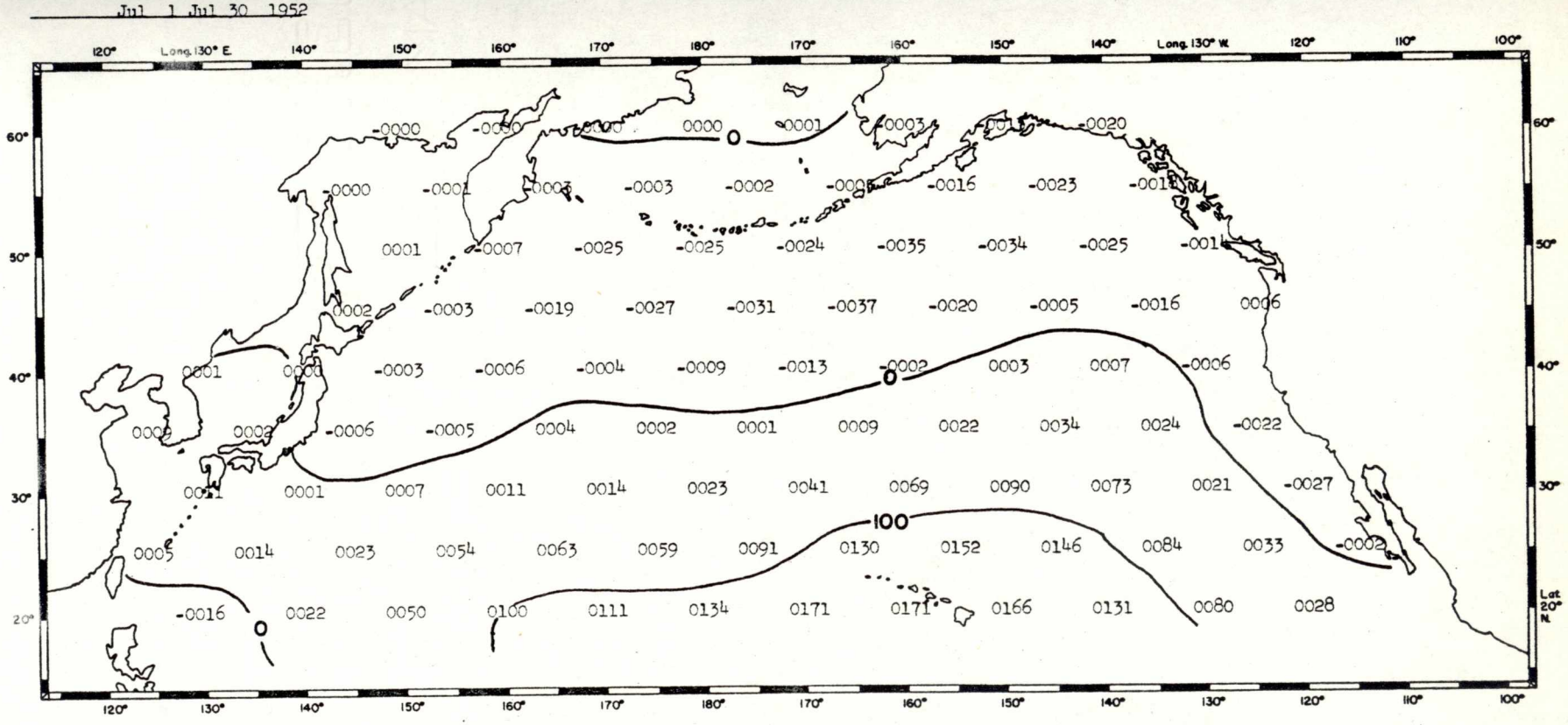

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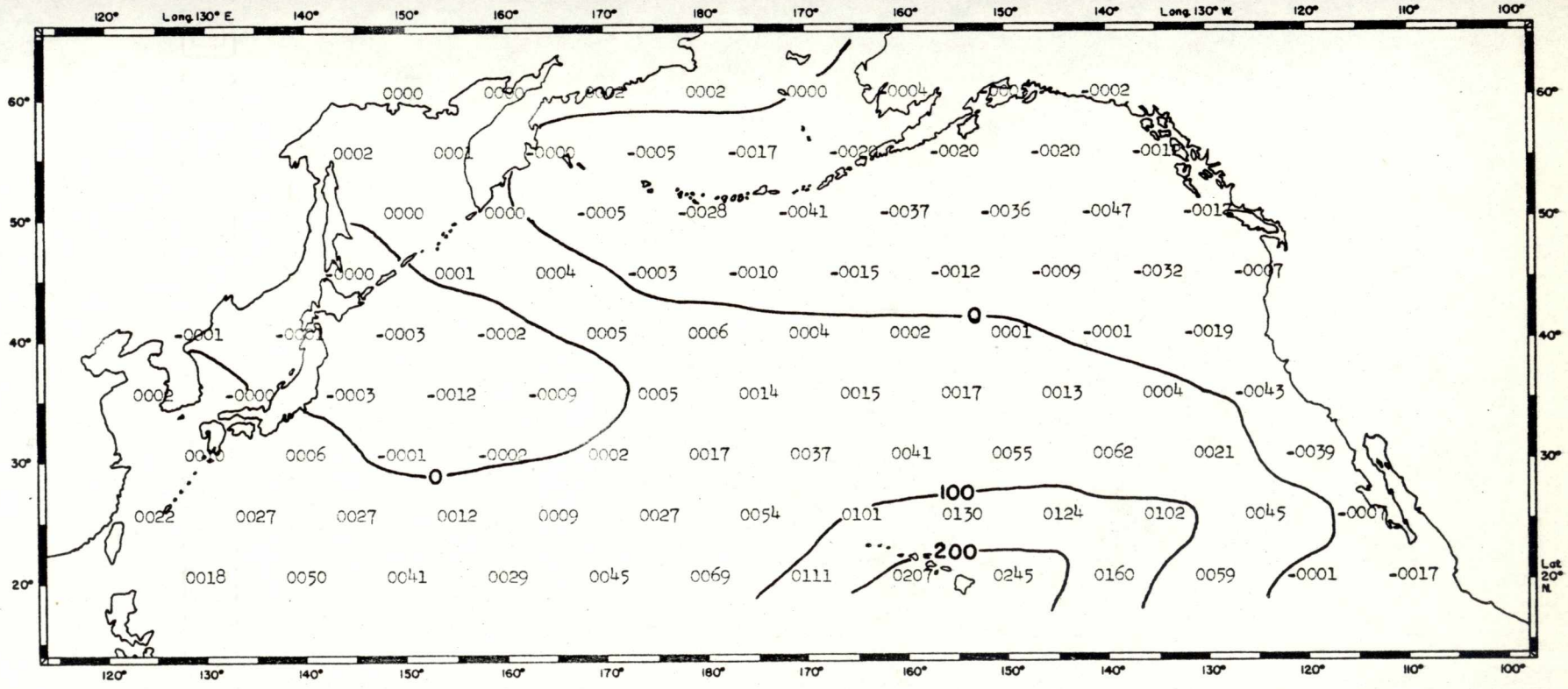

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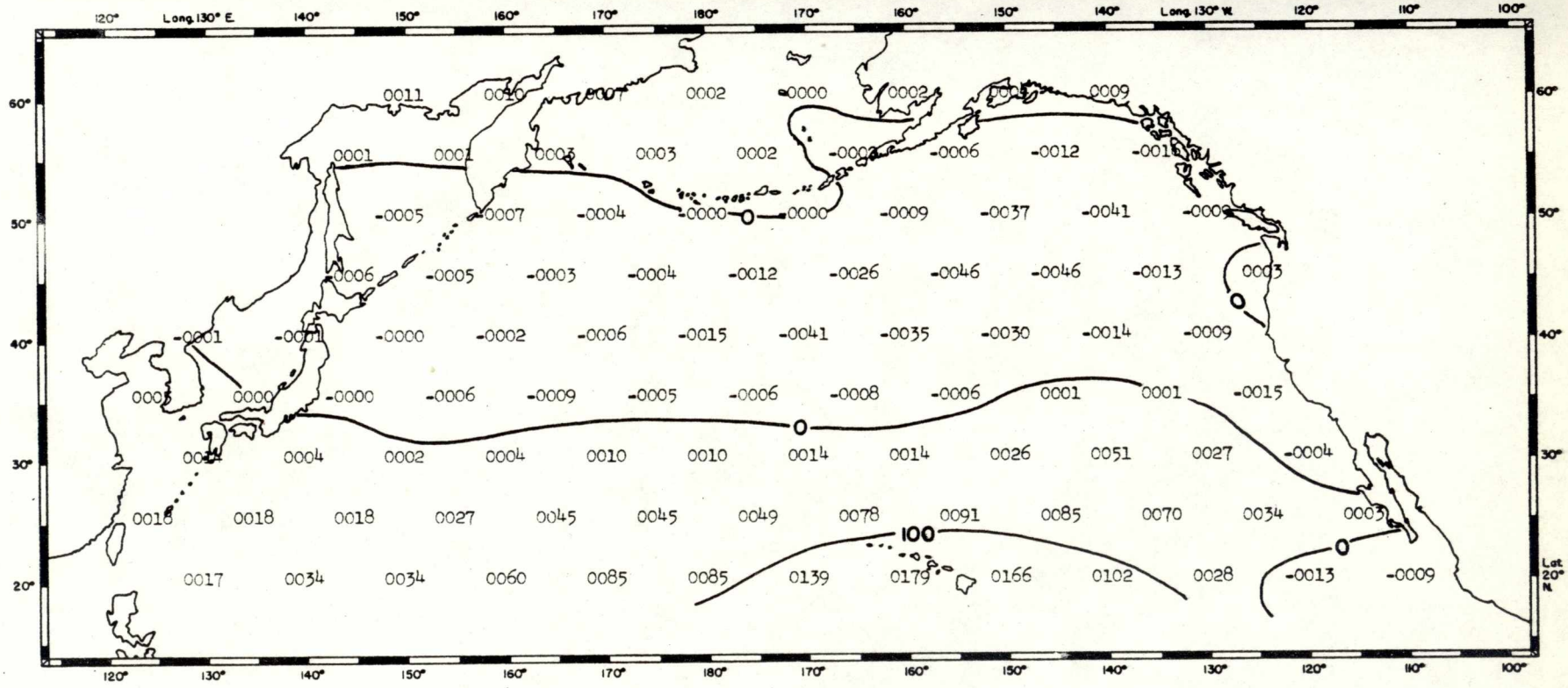

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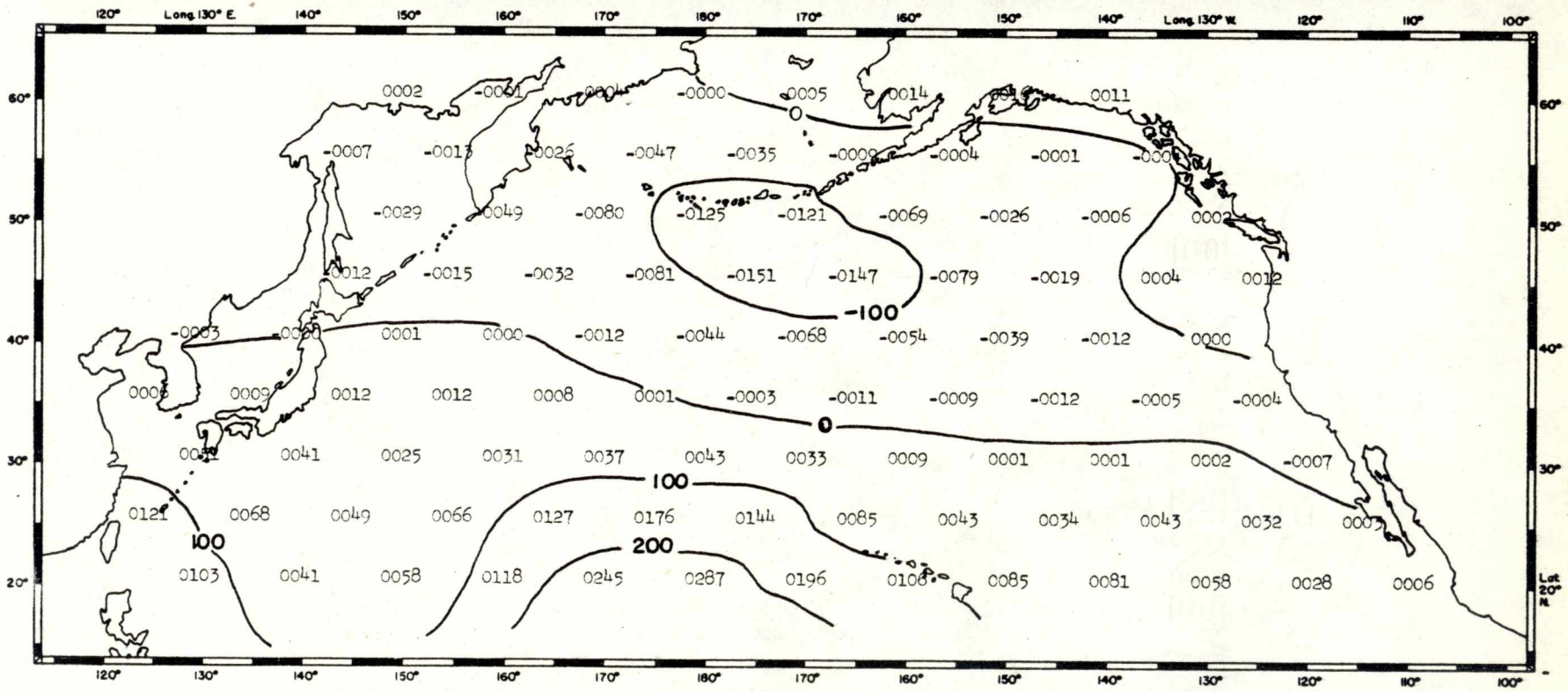

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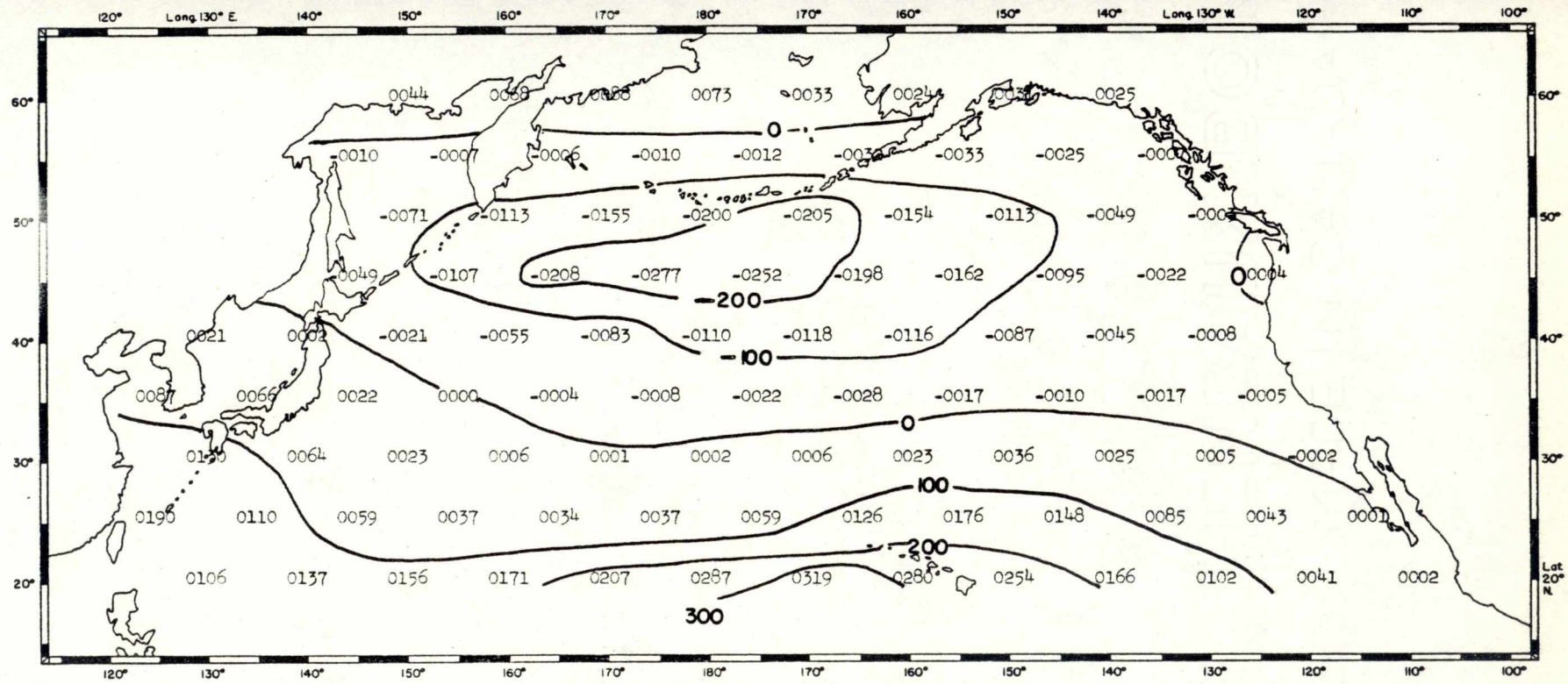

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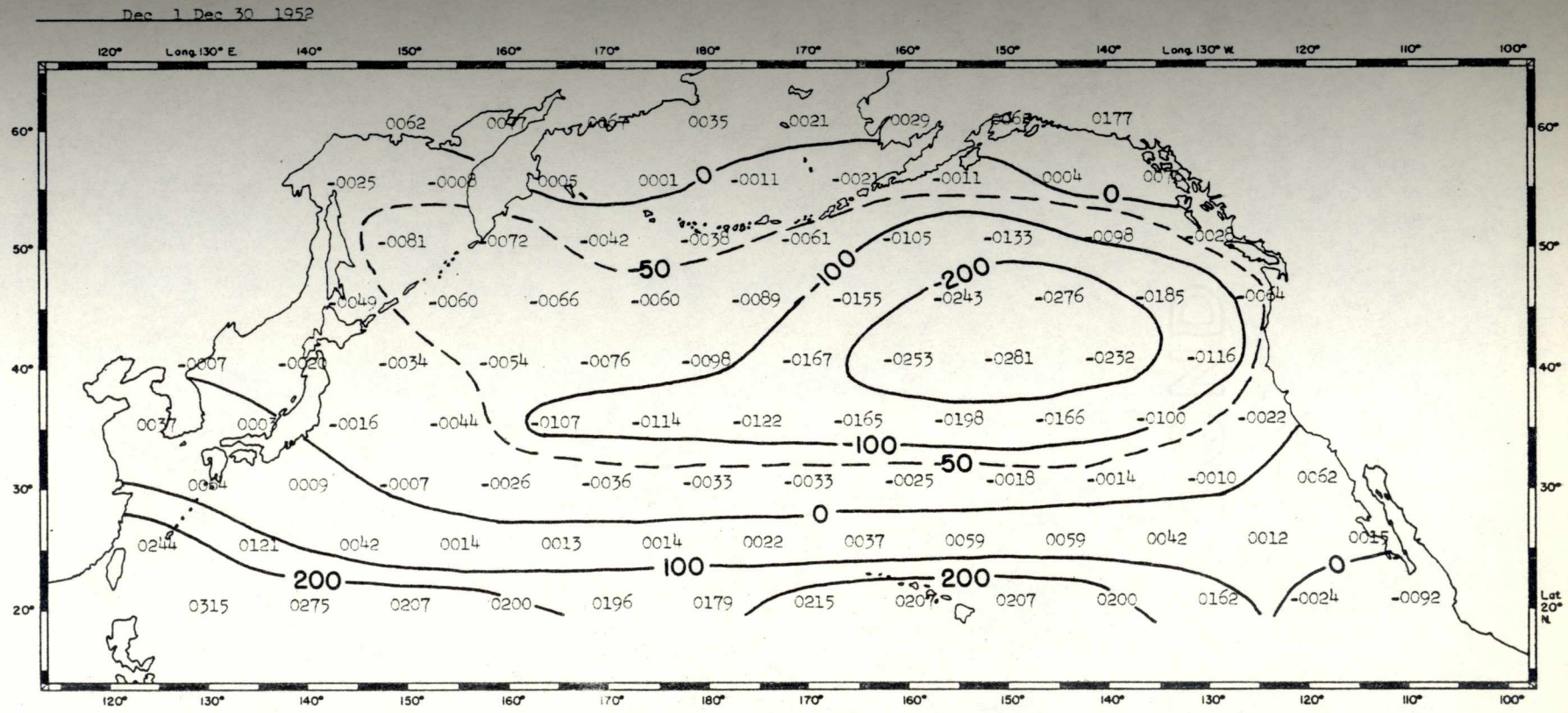

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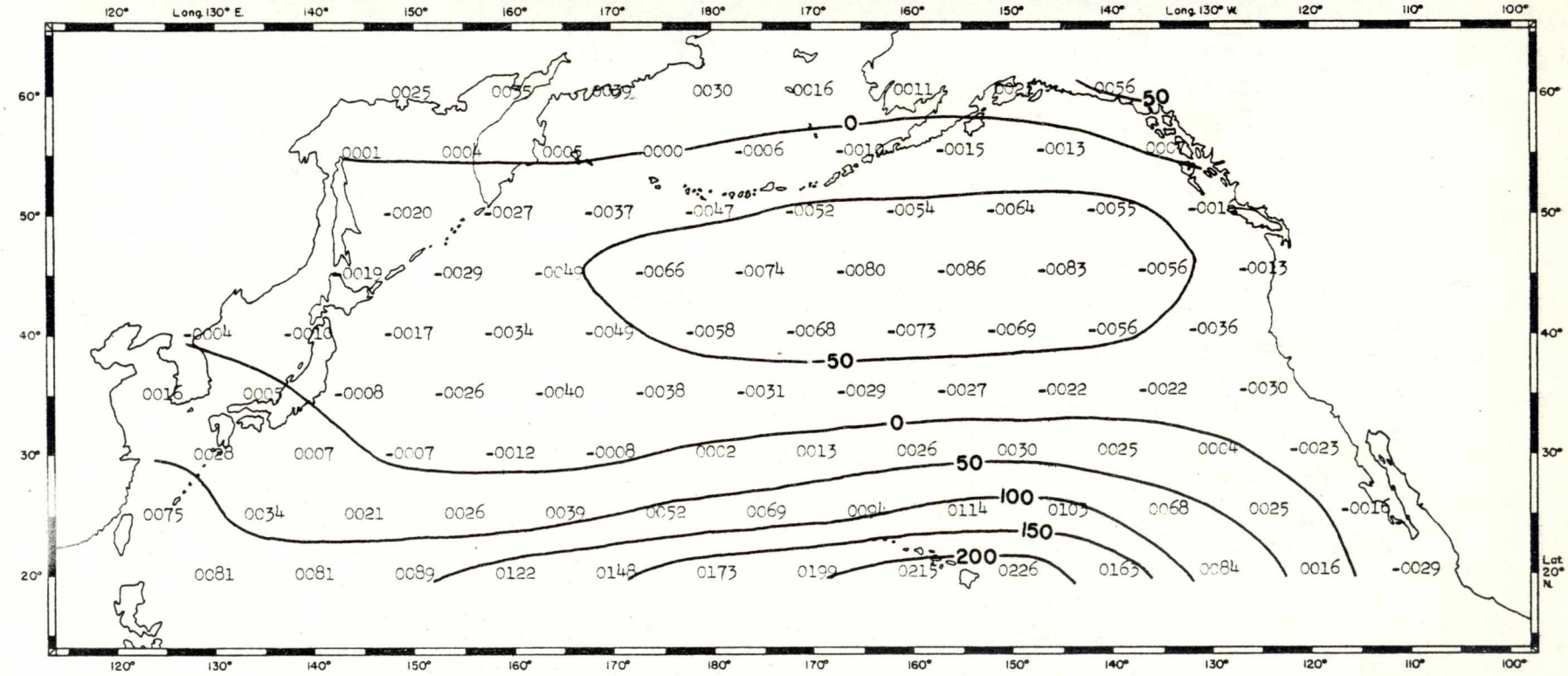
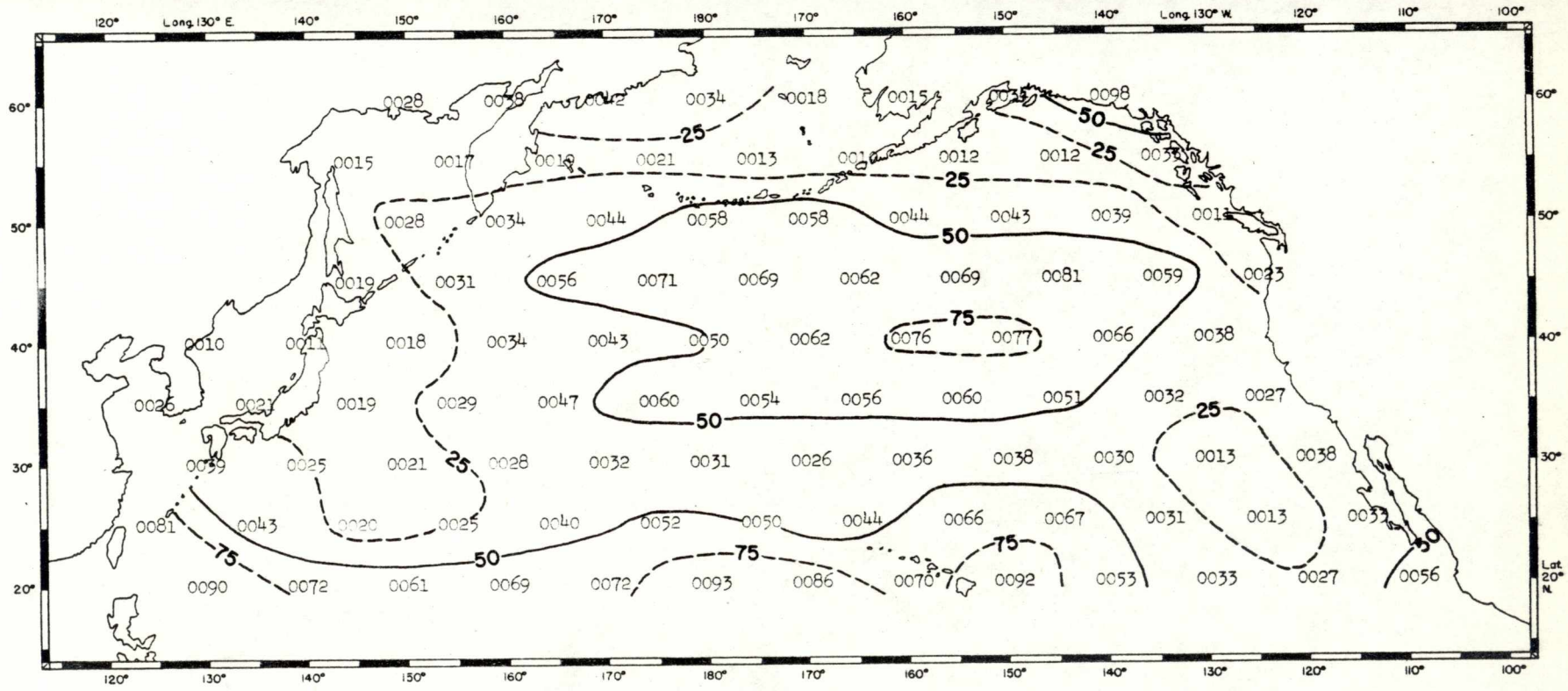


II. Meridional Component of Ekman Transport ANNUAL MEAN 1952

2s Sep 1 Sep 30 1952



II. Meridional Component of Ekman Transport

STANDARD DEVIATION 1952

Section III

Zonal Component of Ekman Transport

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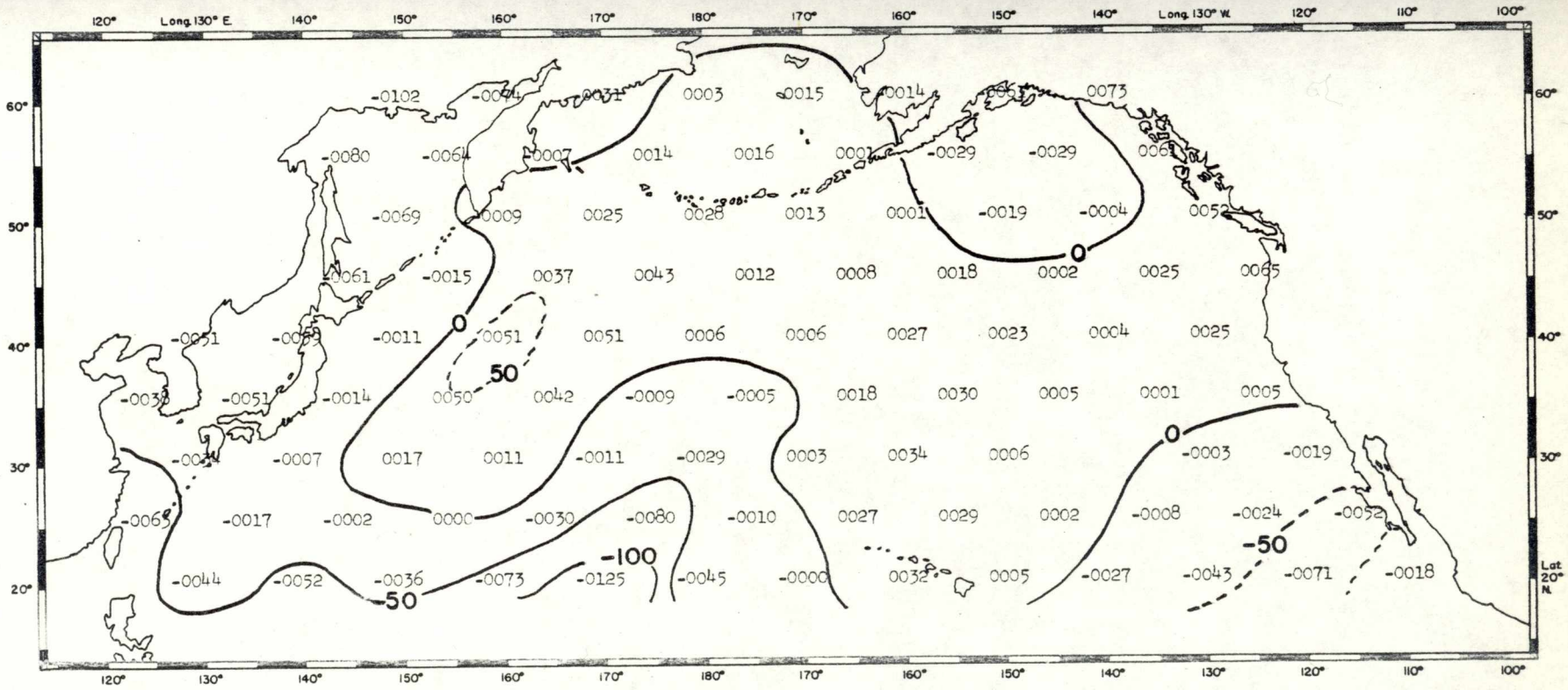
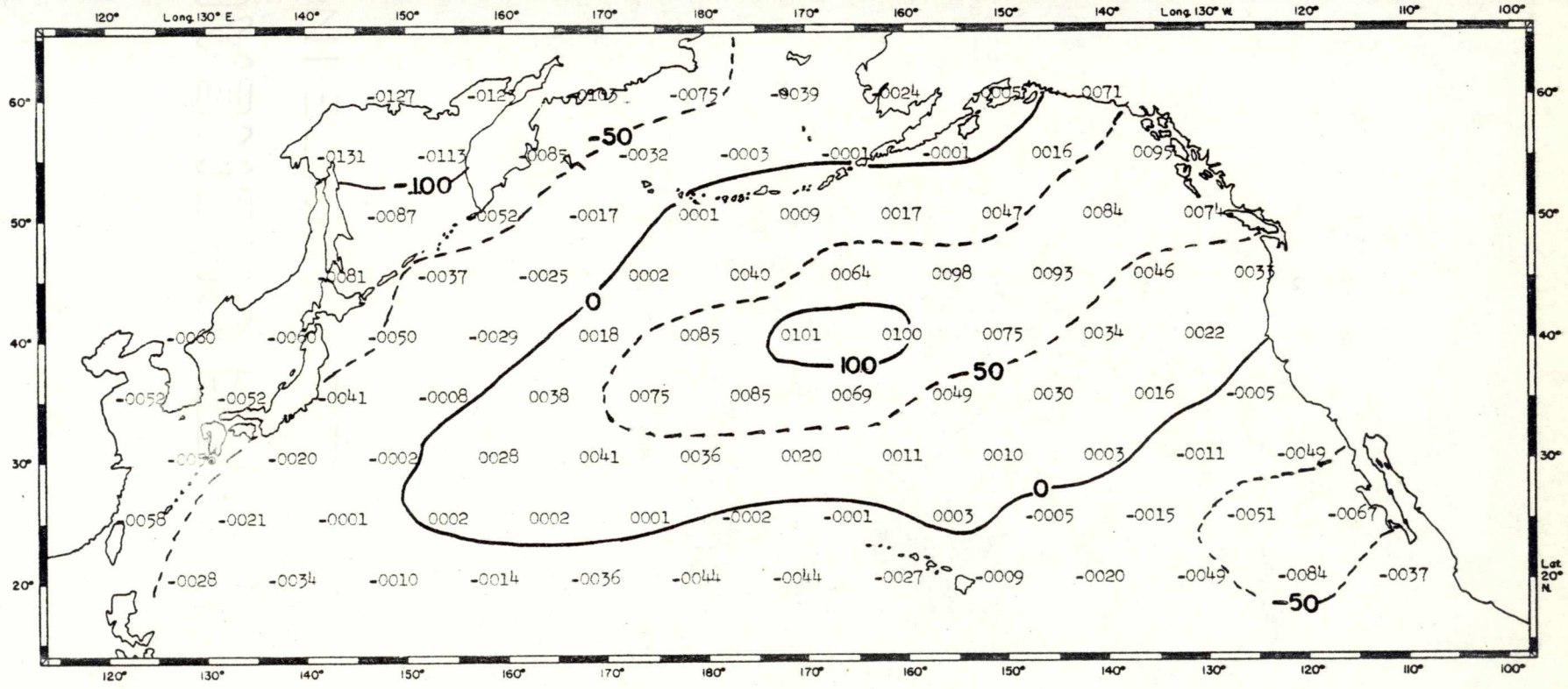


III. Zonal Component of Ekman Transport

Feb 1 Mar 1 1952



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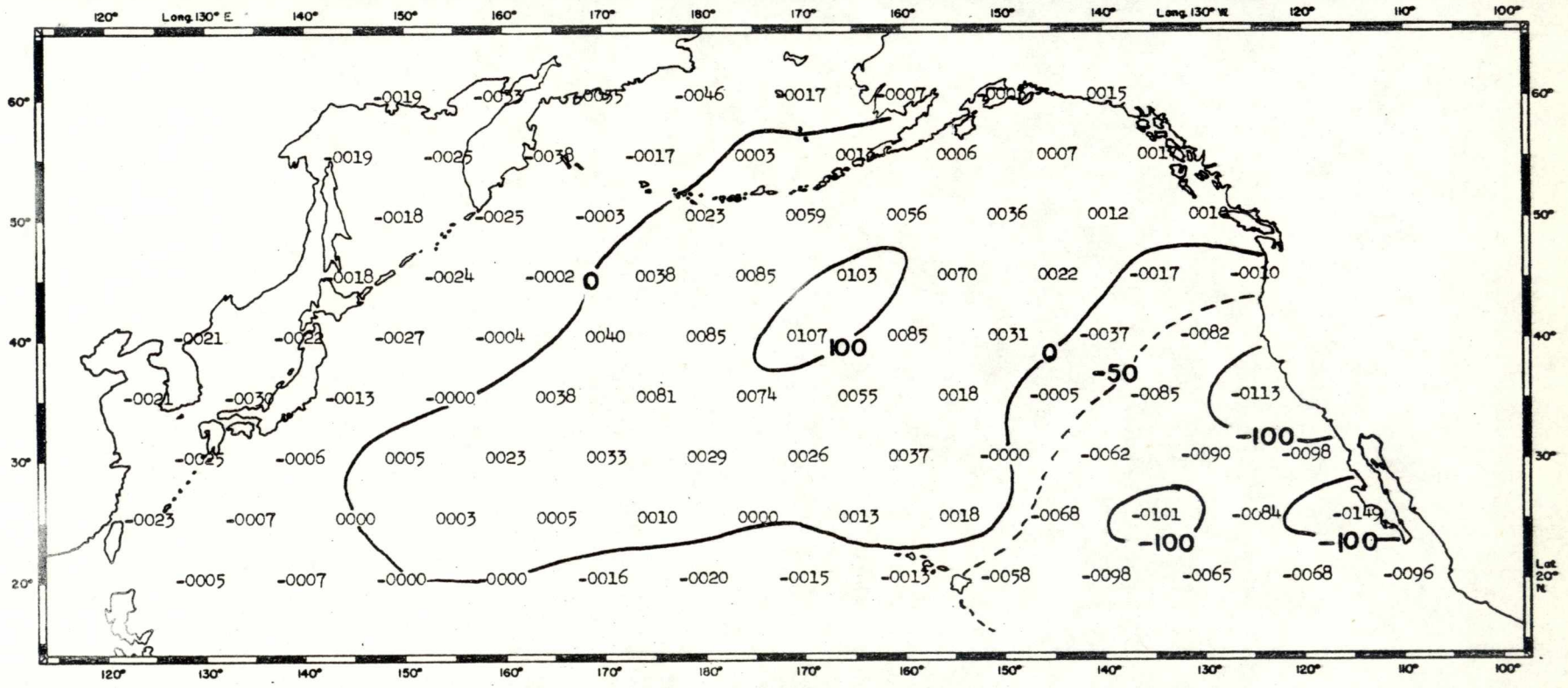

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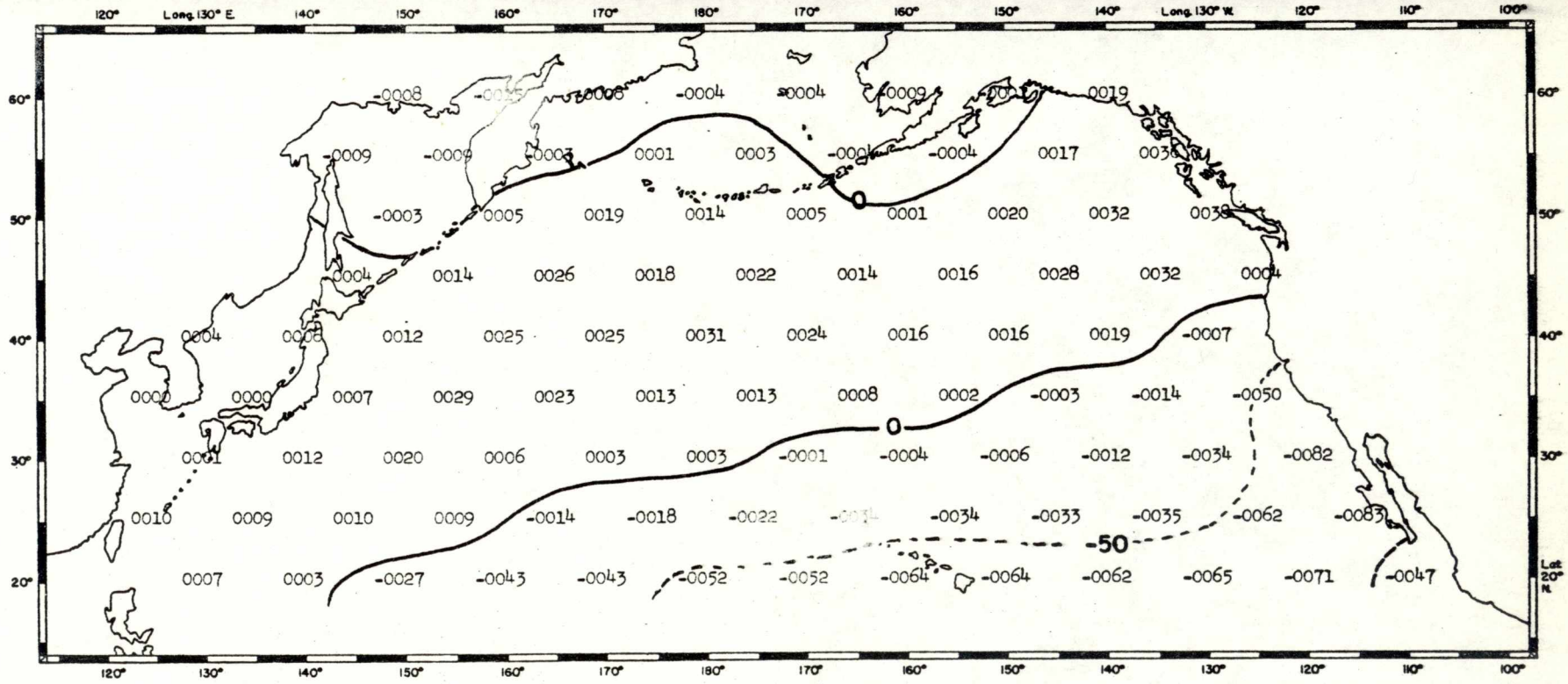

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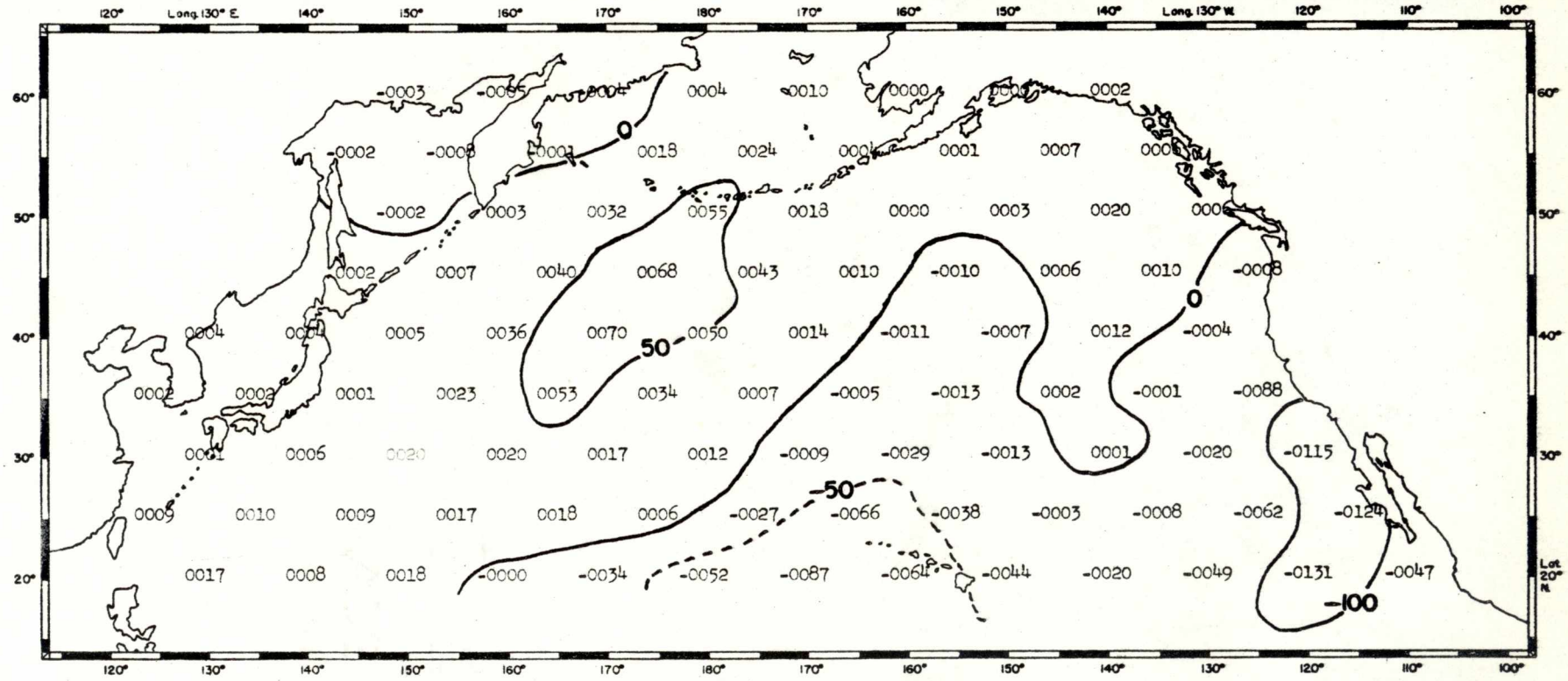

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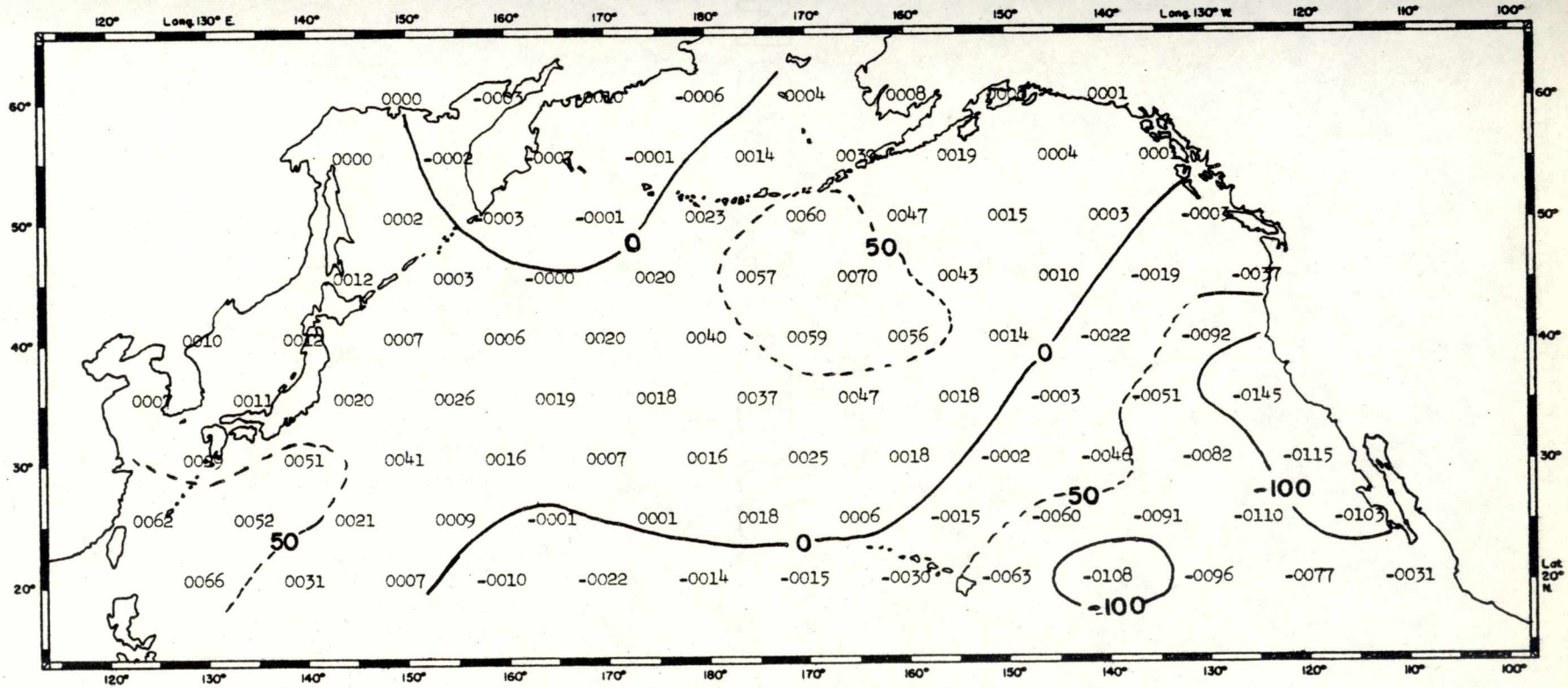

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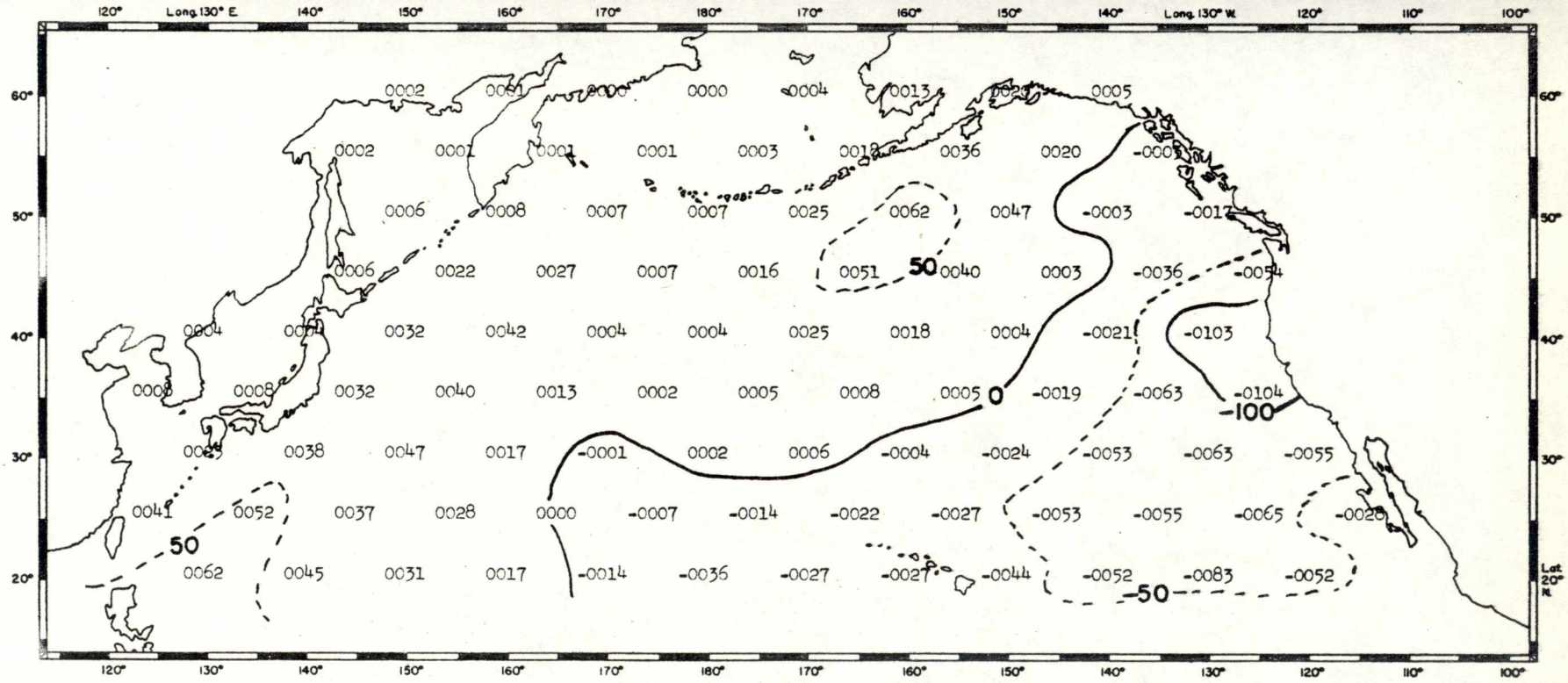

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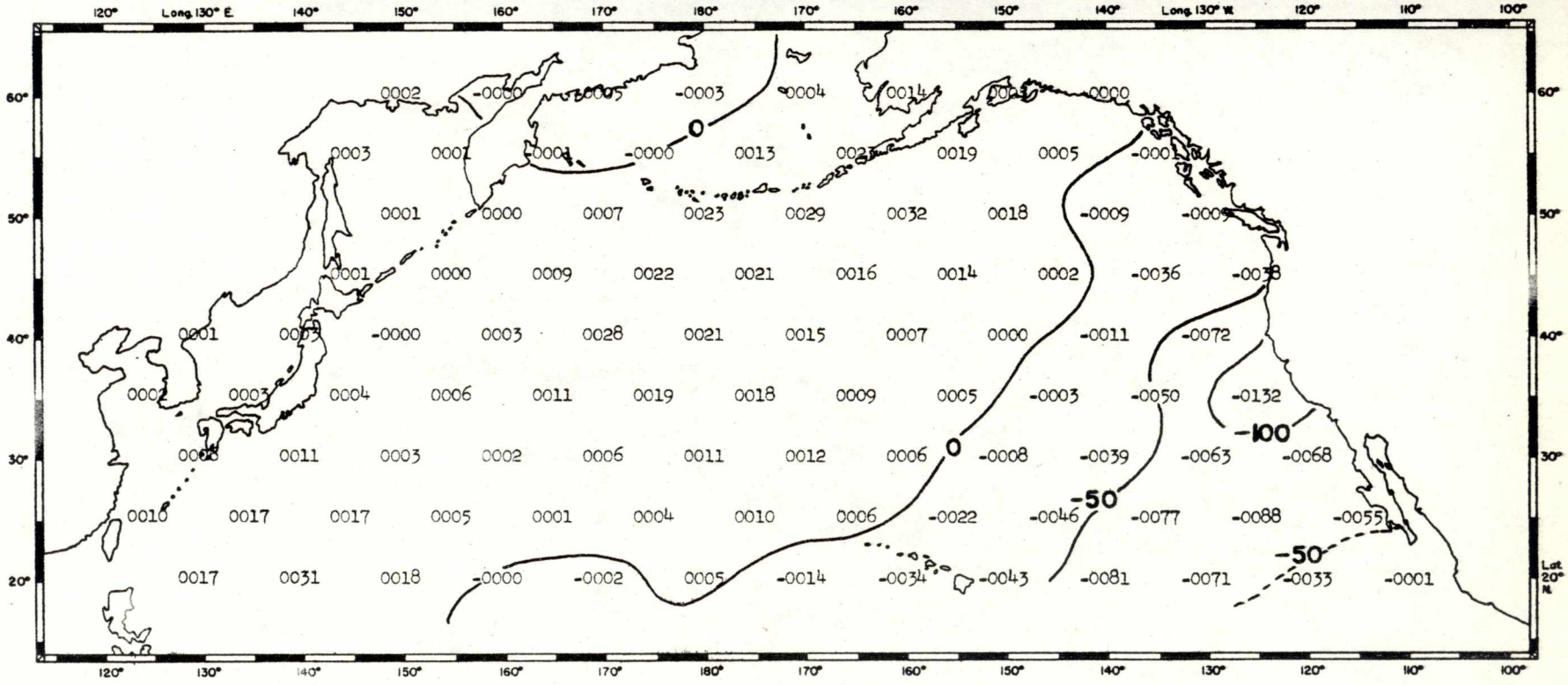

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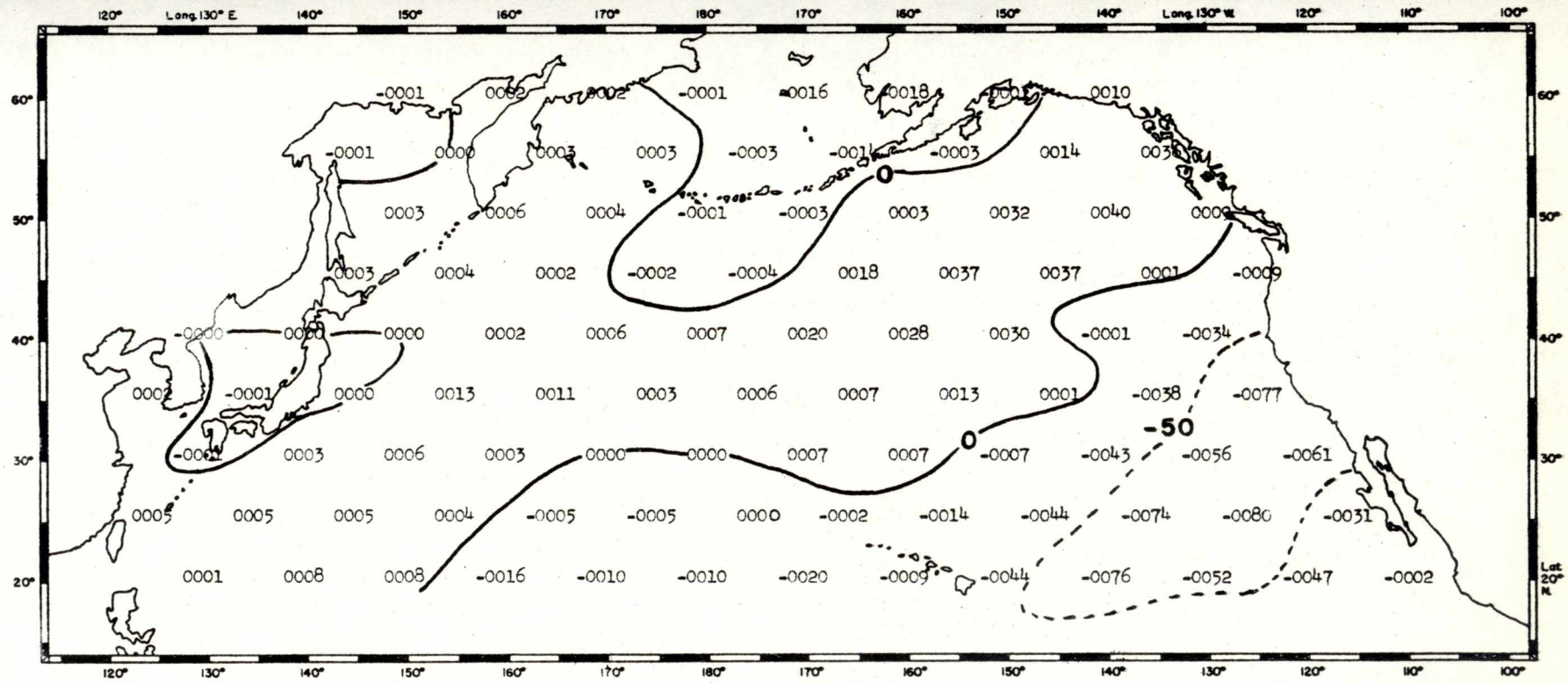
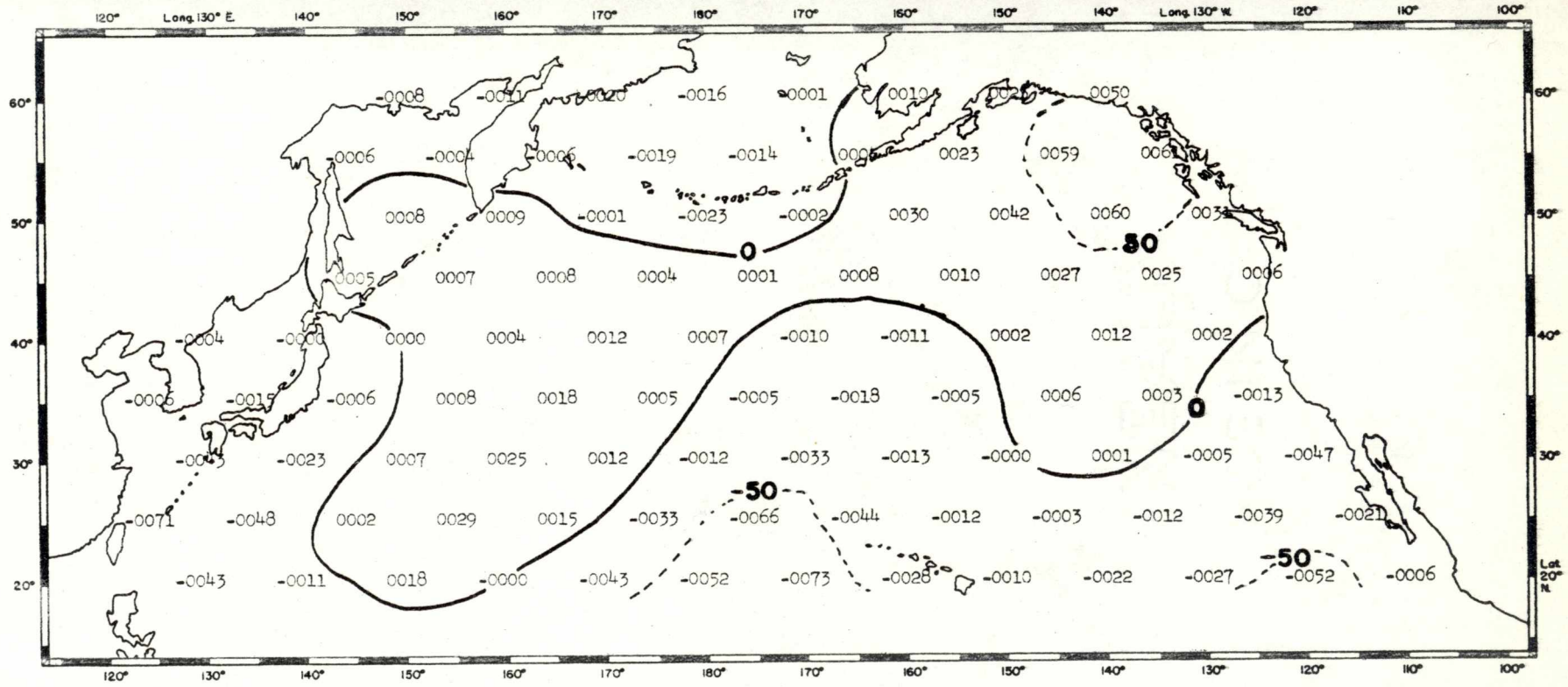


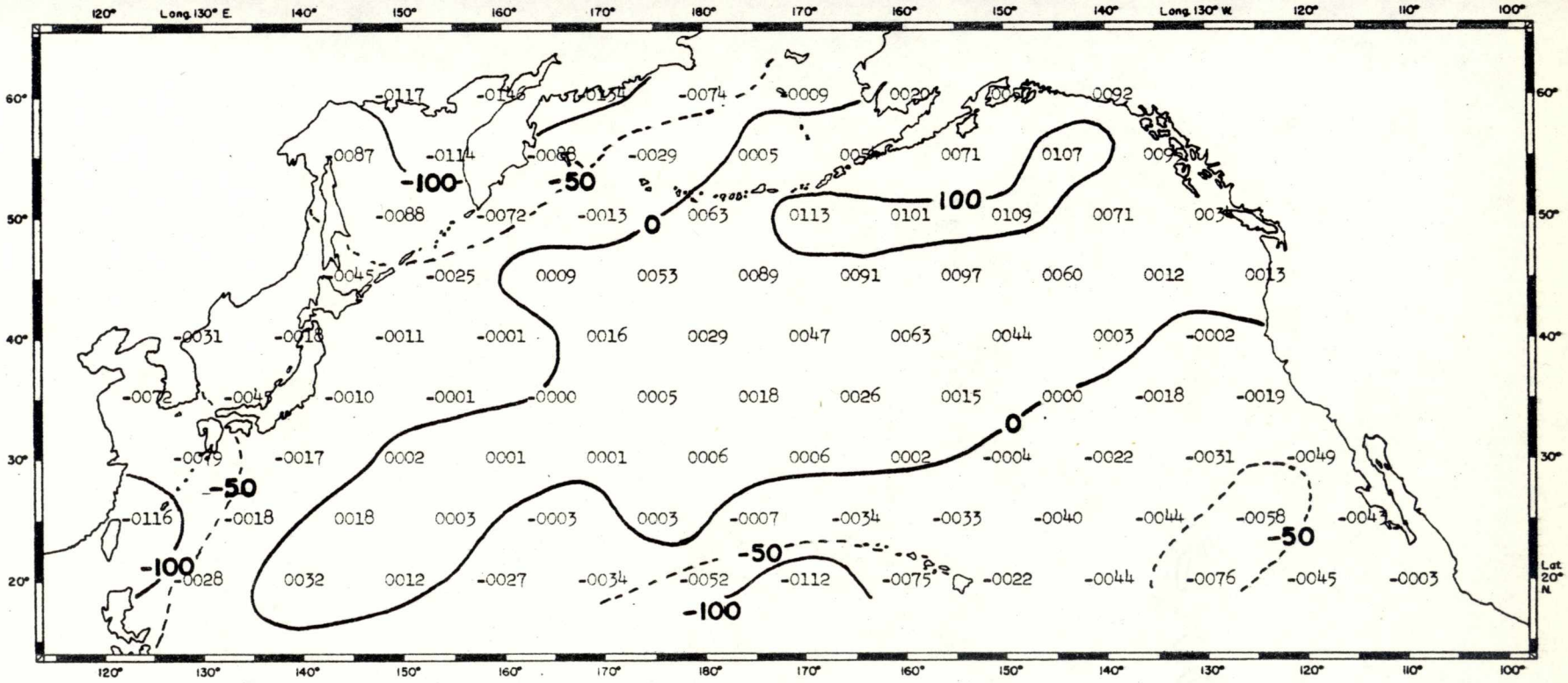
III. Zonal Component of Ekman Transport

Oct 1 Oct 30 1952



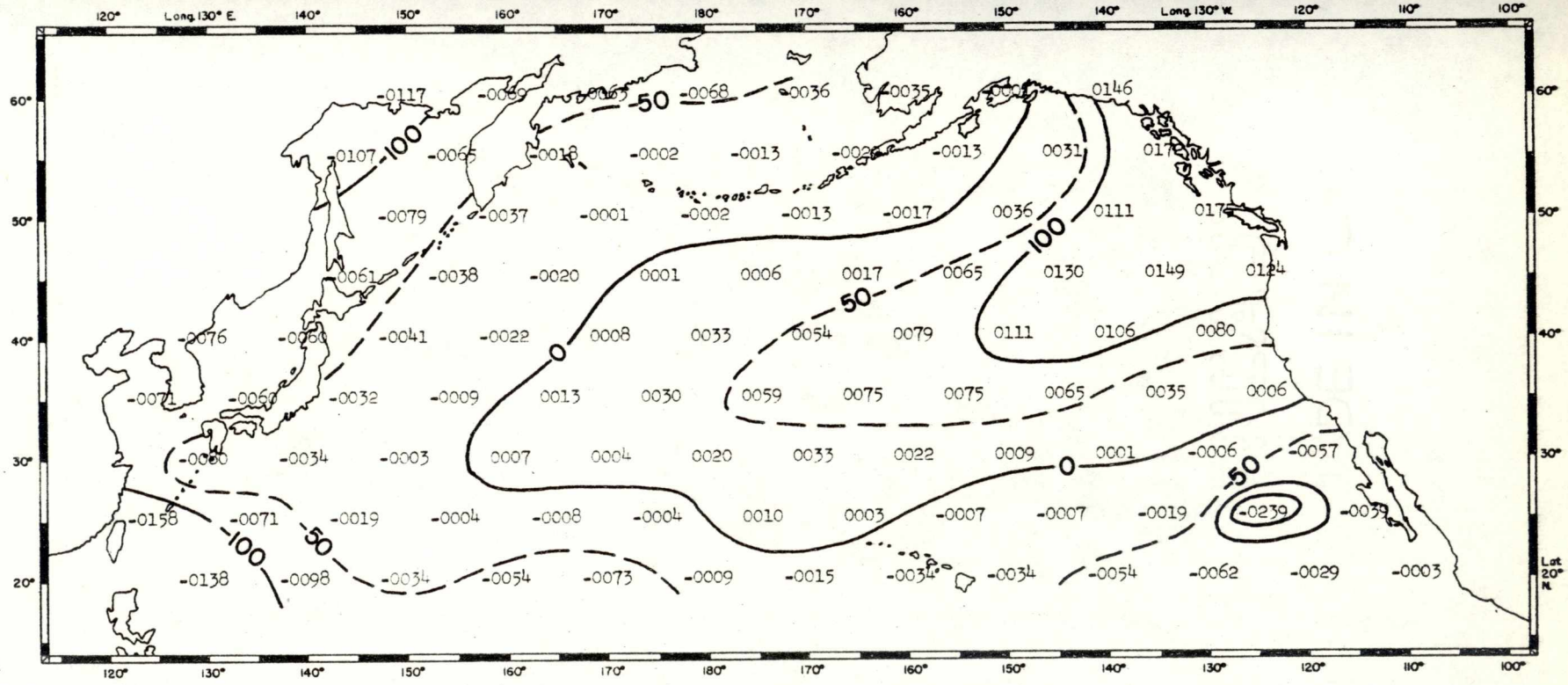
III. Zonal Component of Ekman Transport

Nov. 1 Nov. 30 1952



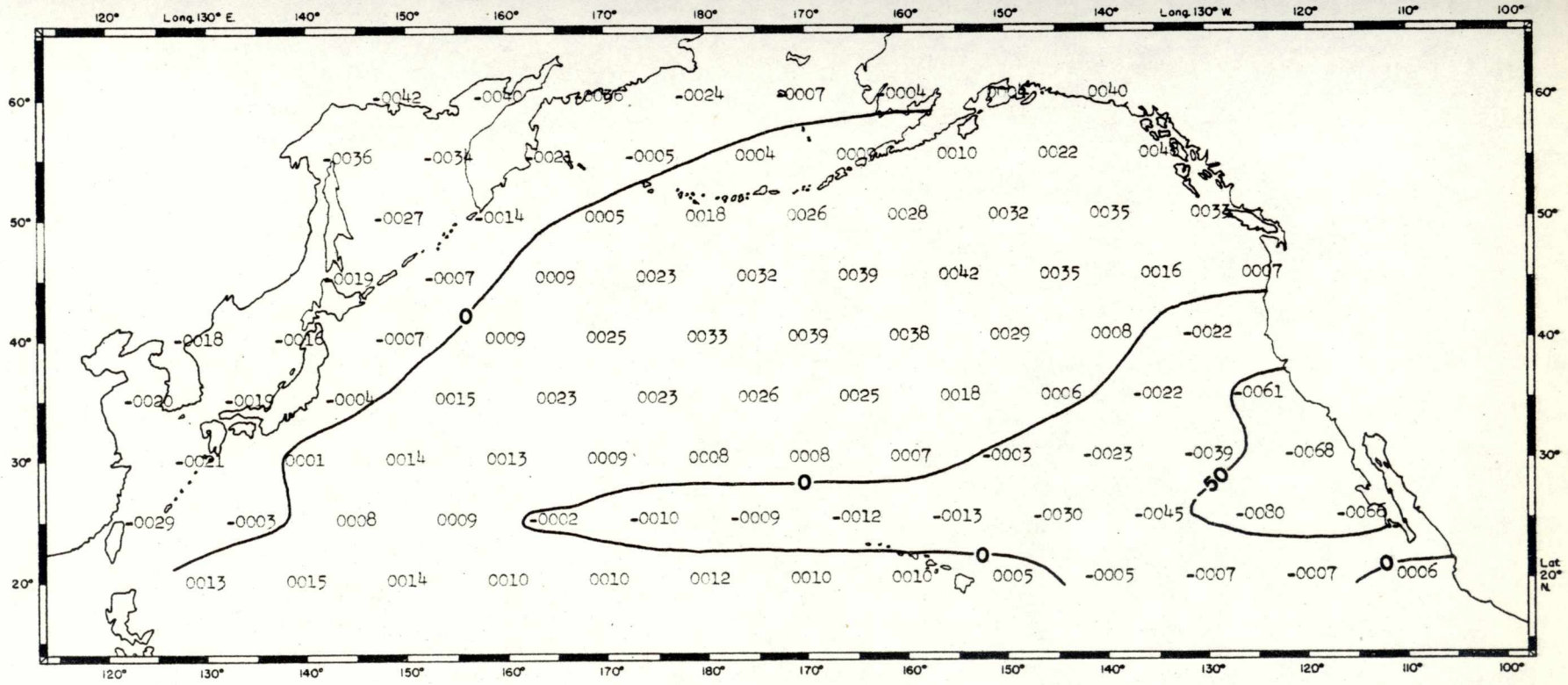
III. Zonal Component of Ekman Transport

Dec 1 Dec 30 1952



III. Zonal Component of Ekman Transport

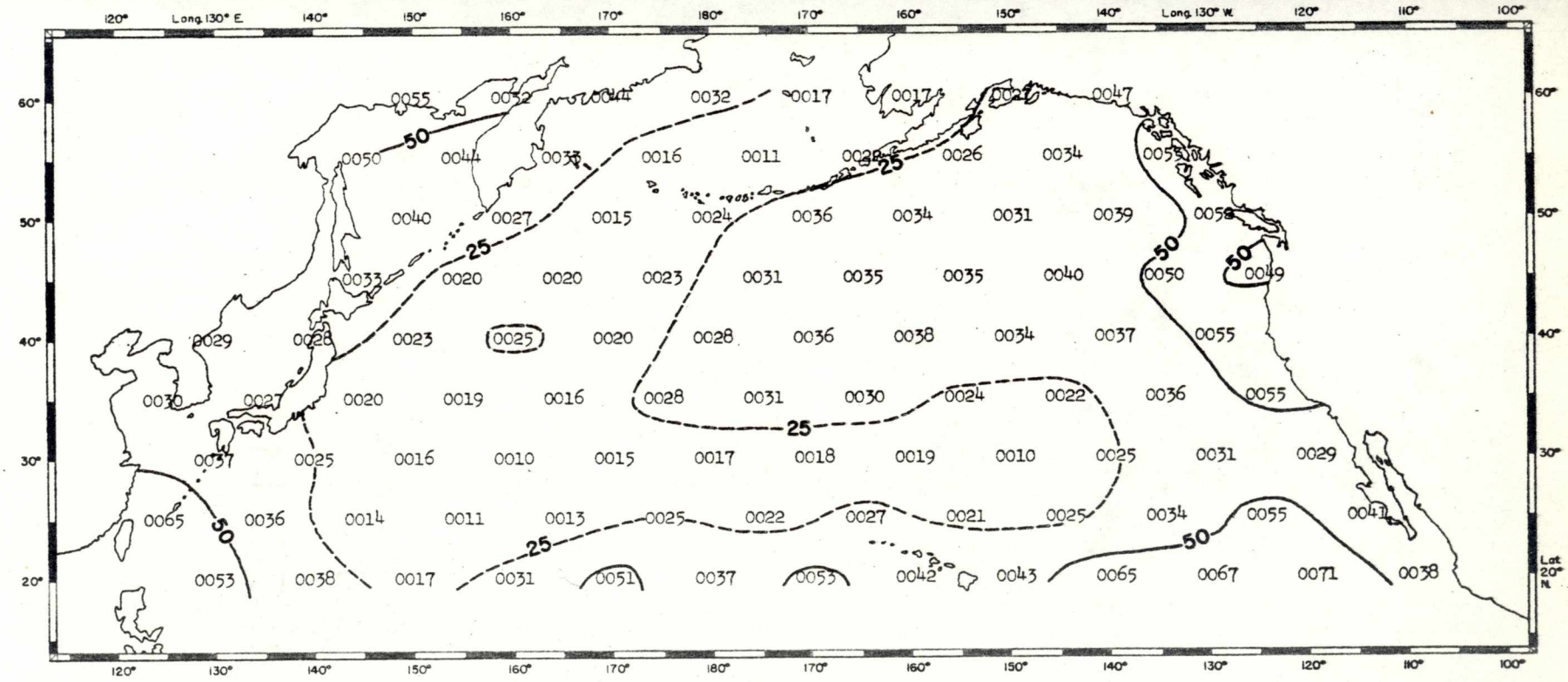
3m Sep 1 Sep 30 1952



III. Zonal Component of Ekman Transport

ANNUAL MEAN 1952

3s Sep 1 Sep 30 1952



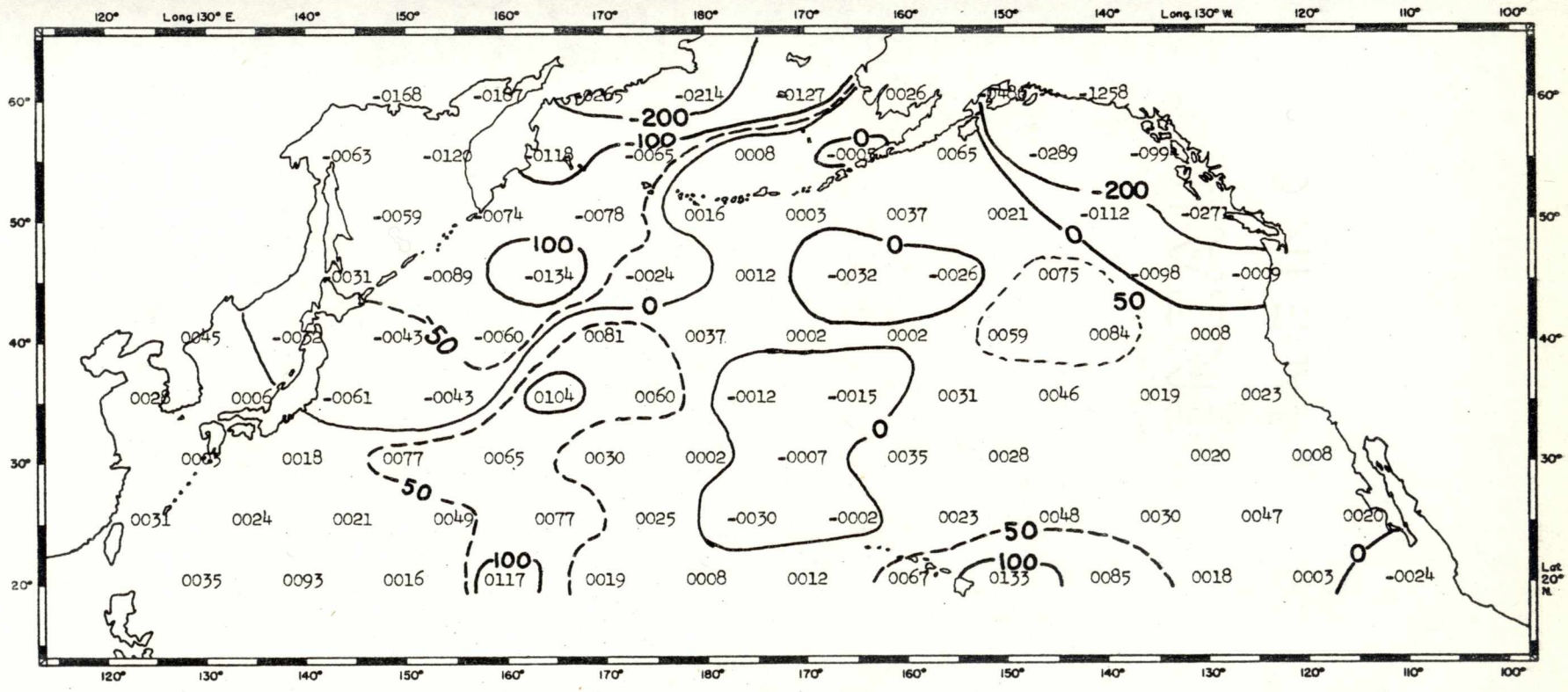
III. Zonal Component of Ekman Transport

STANDARD DEVIATION 1952

Section IV

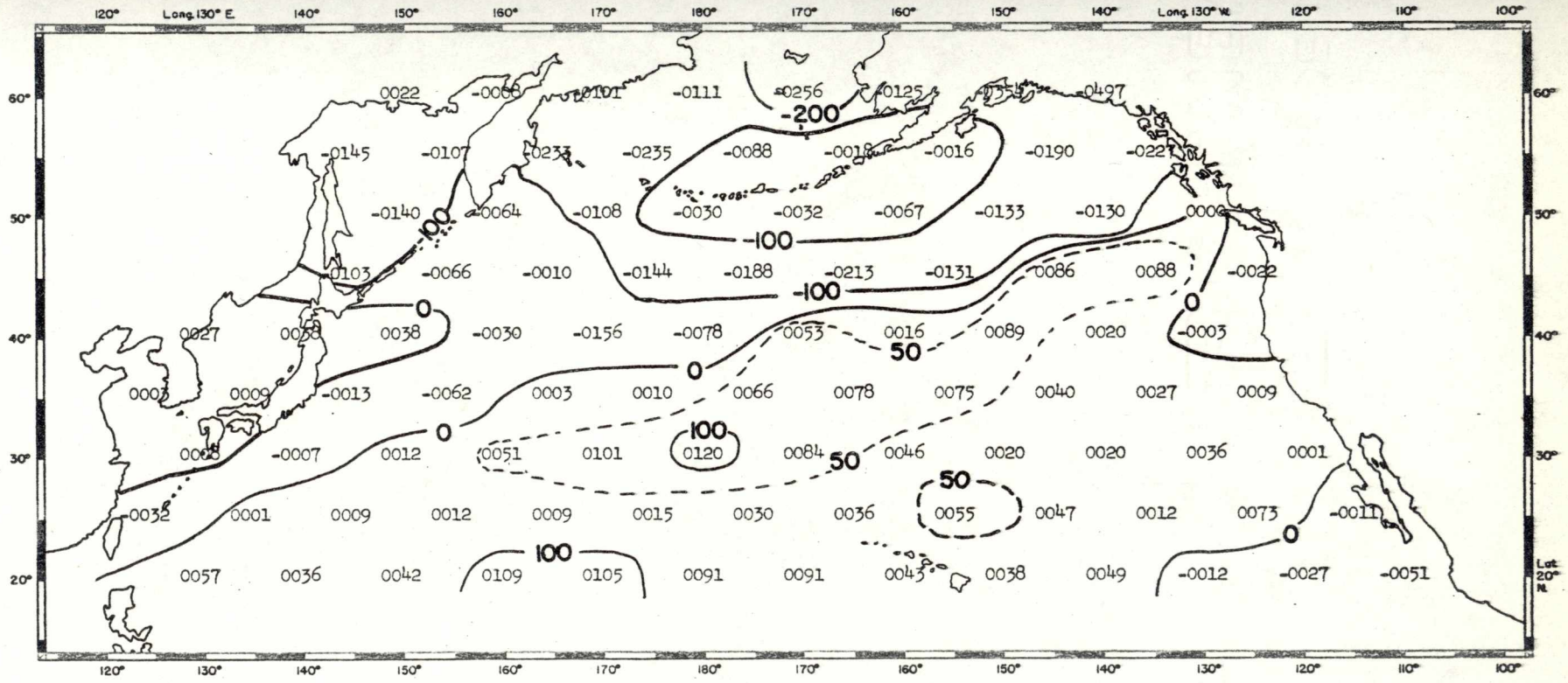
Meridional Component of Total Transport

Jan 1 Jan 30 1952



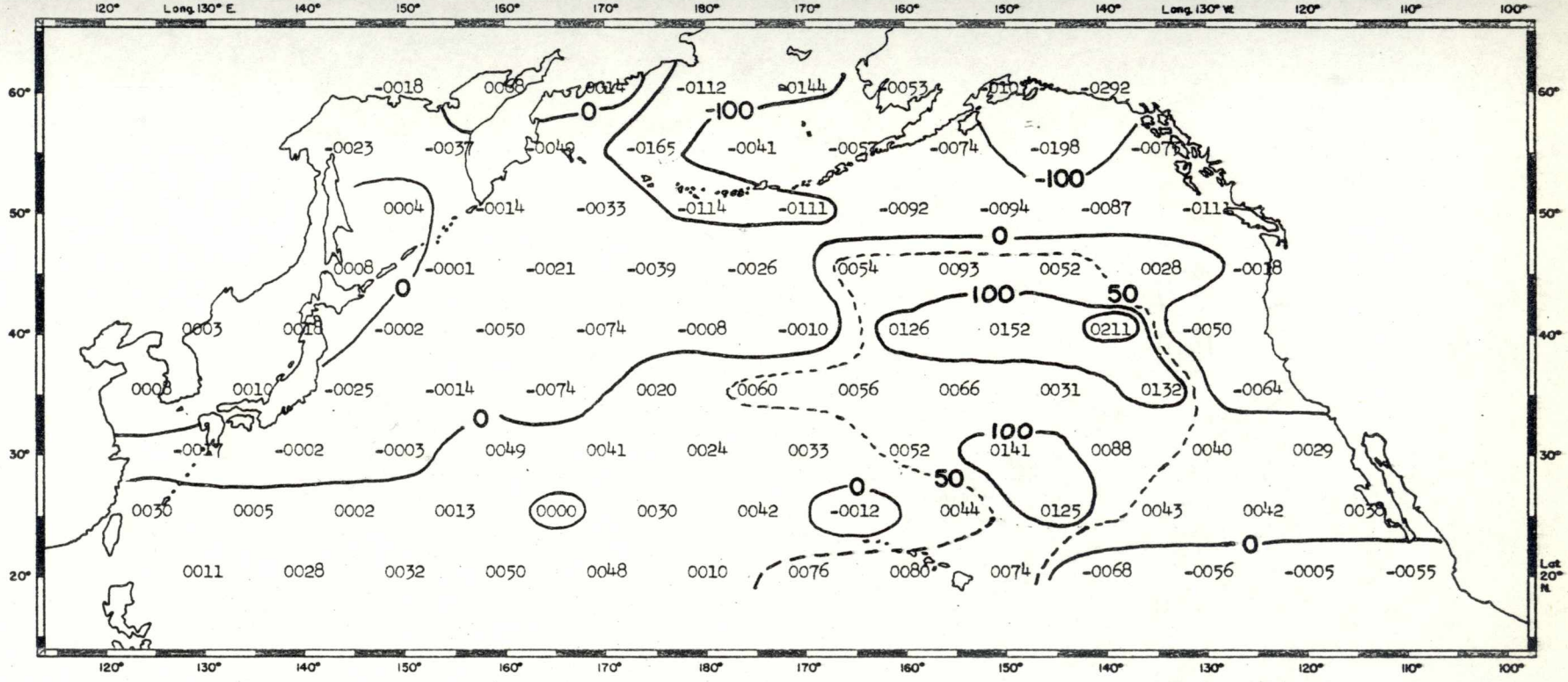
IV. Meridional Component of Total Transport

Feb 1 Mar 1 1952



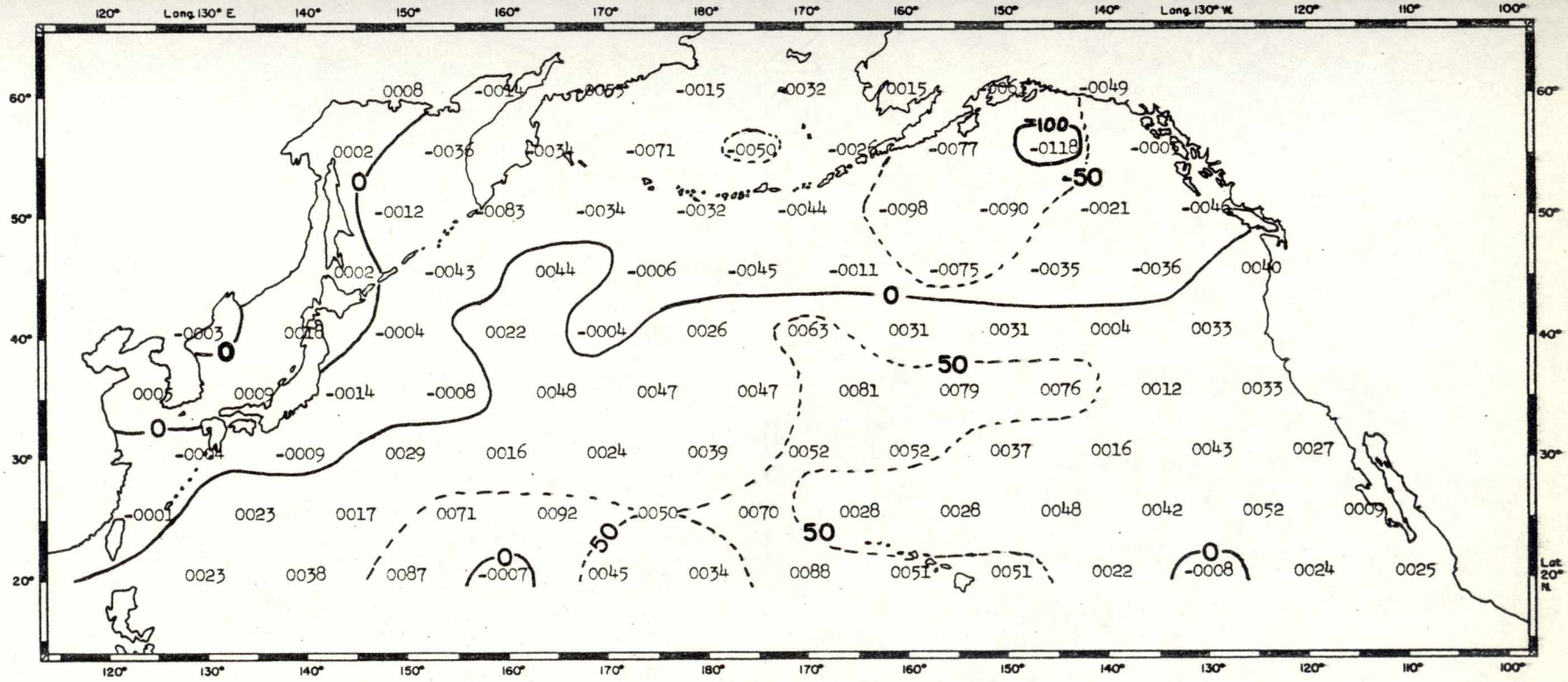
IV. Meridional Component of Total Transport

Mar 1 Mar 30 1952



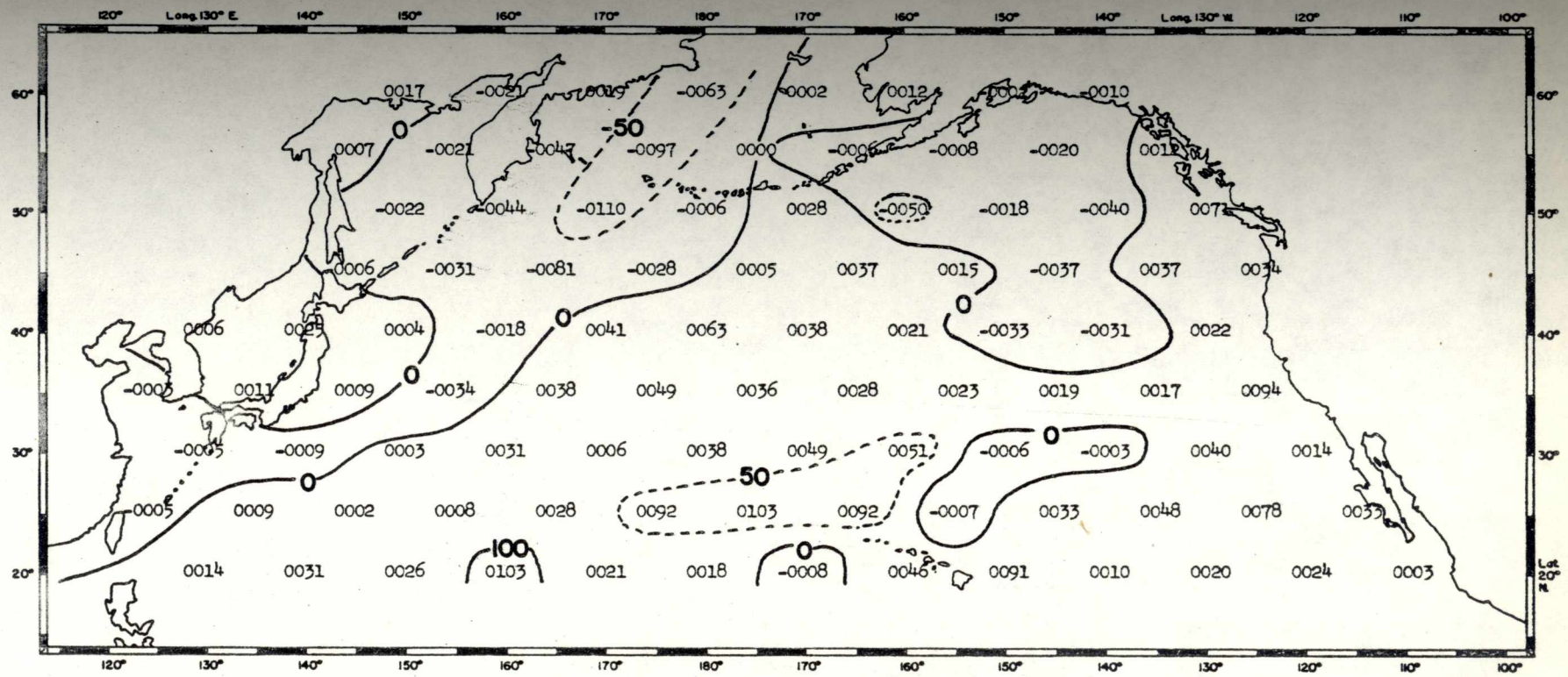
IV. Meridional Component of Total Transport

Apr 1 Apr 30 1952



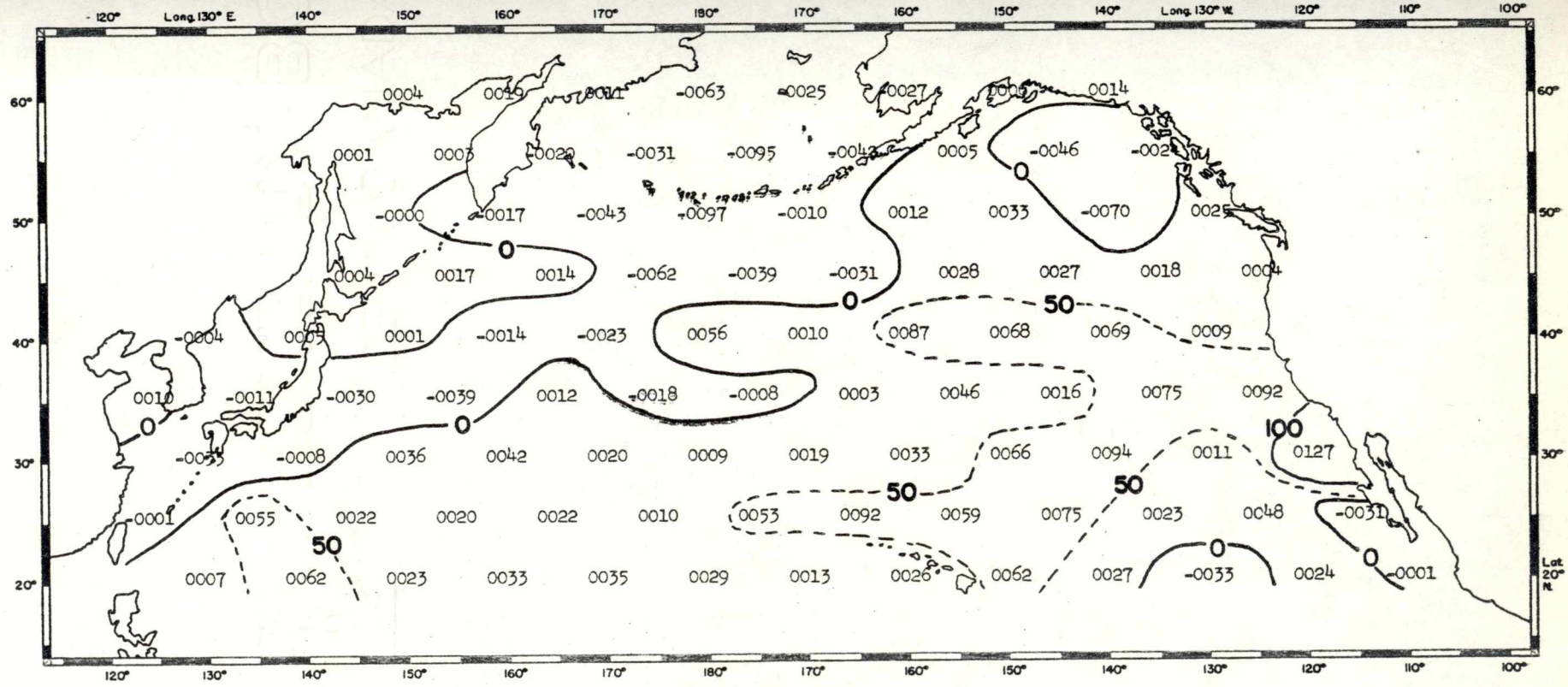
IV. Meridional Component of Total Transport

May 1 May 30 1952



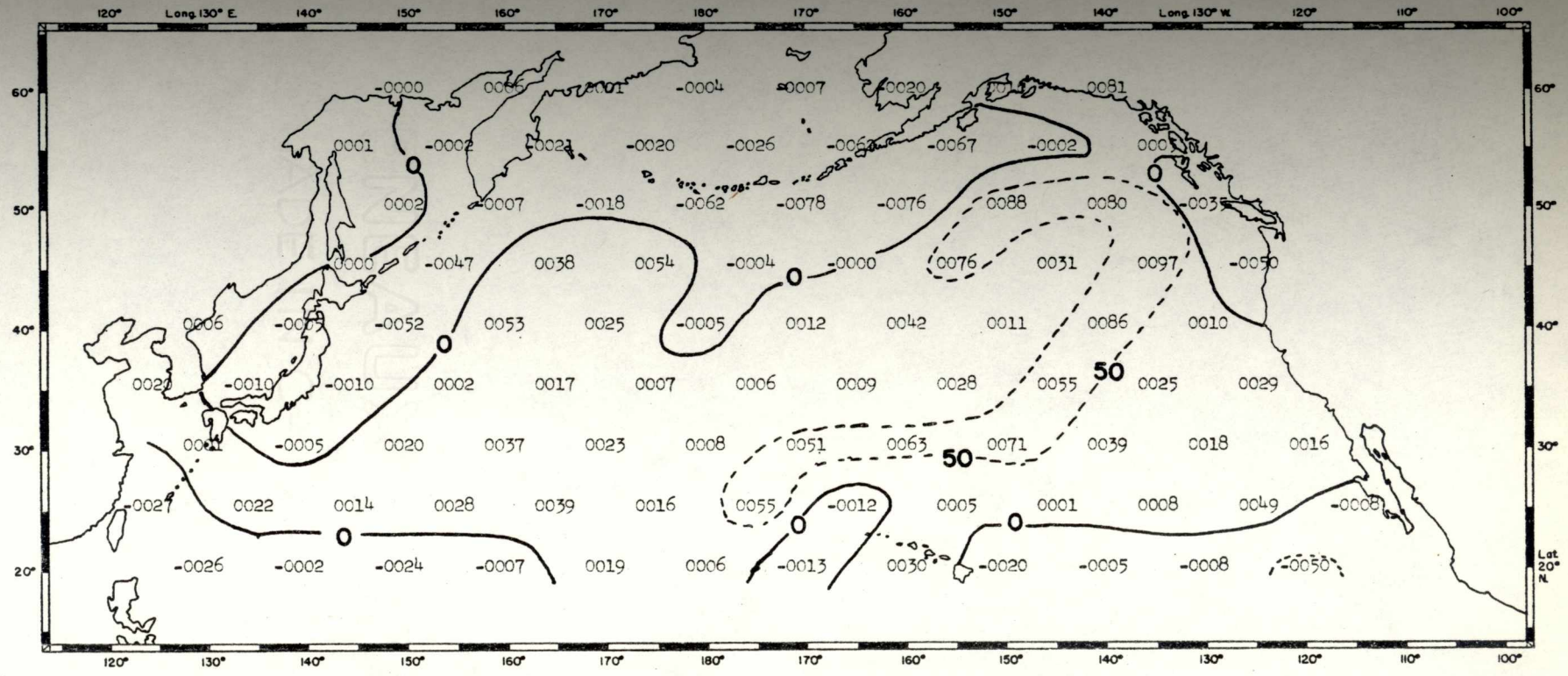
IV. Meridional Component of Total Transport

Jun 1 Jun 30 1952



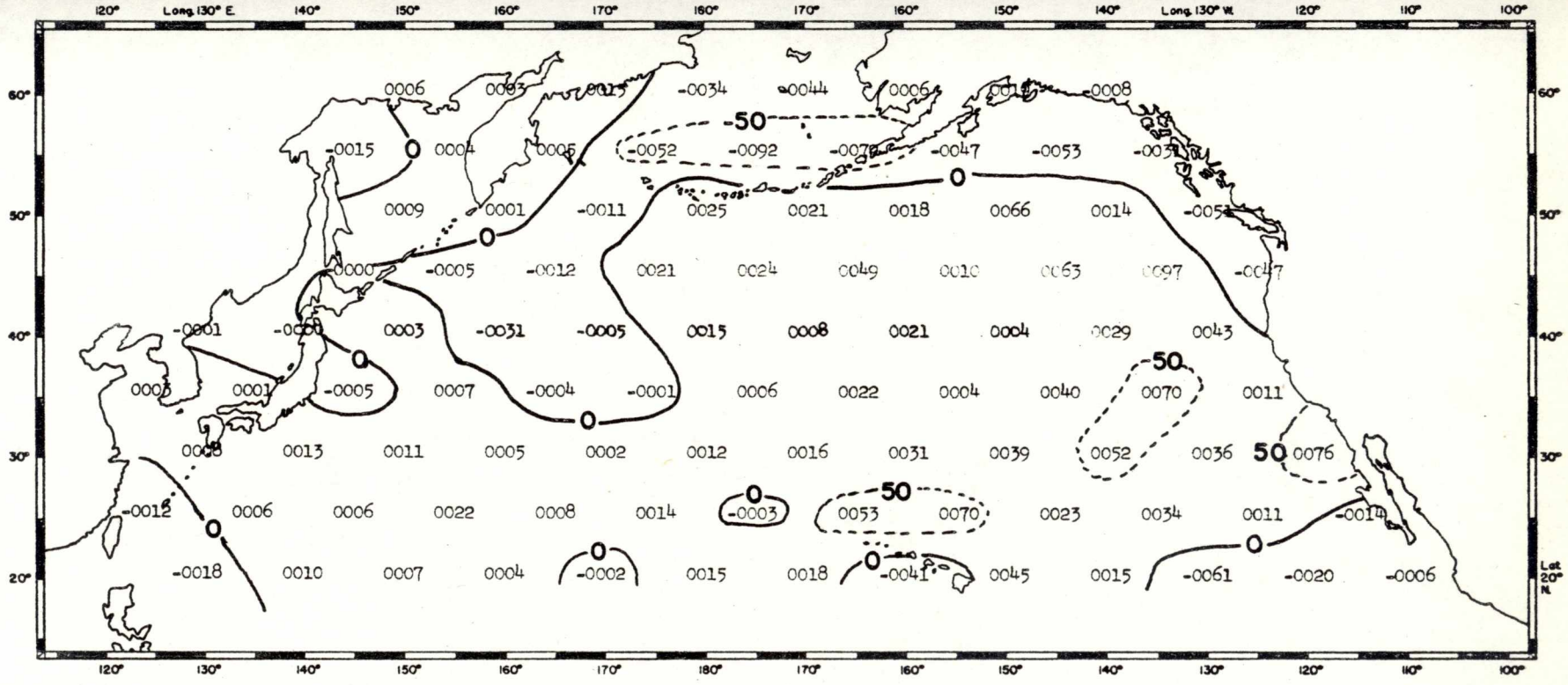
IV. Meridional Component of Total Transport

Jul 1 Jul 30 1952



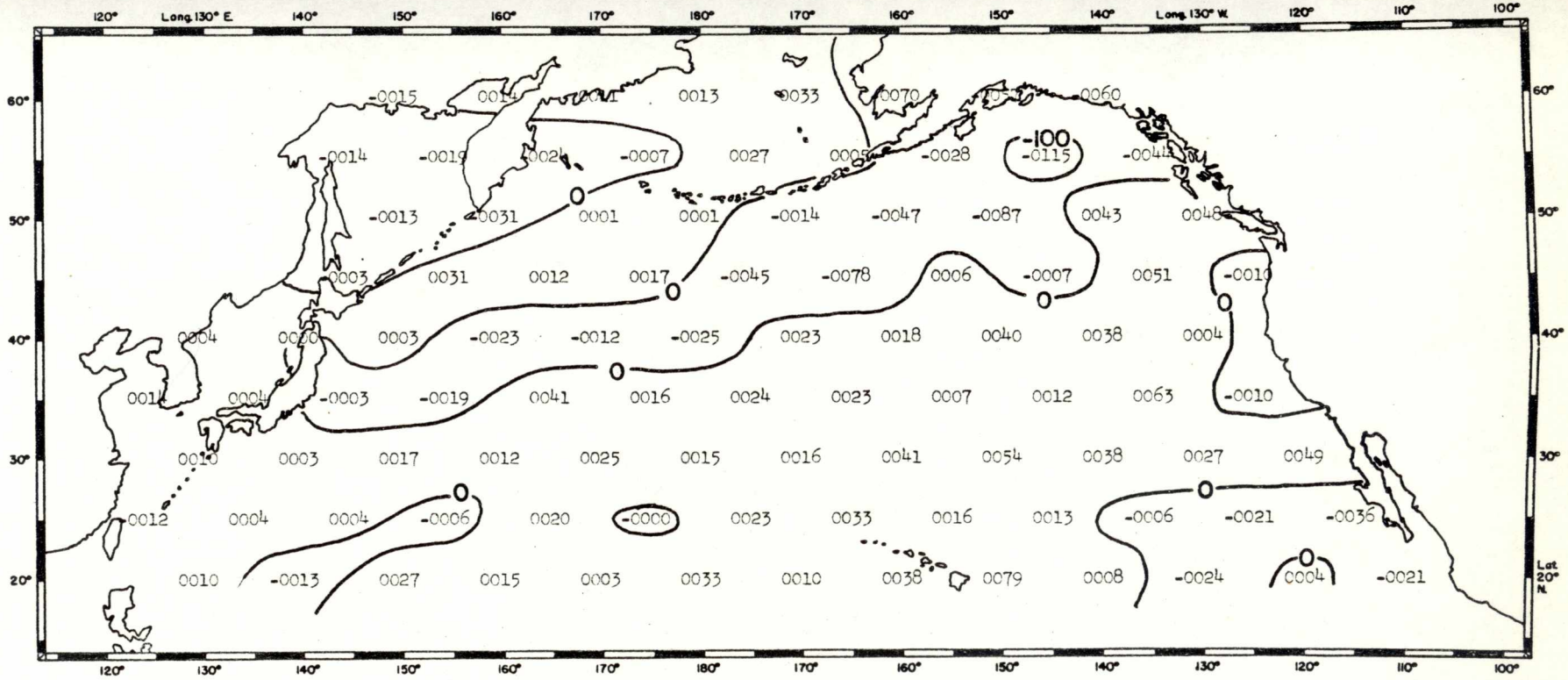
IV. Meridional Component of Total Transport

Aug 1 Aug 30 1952

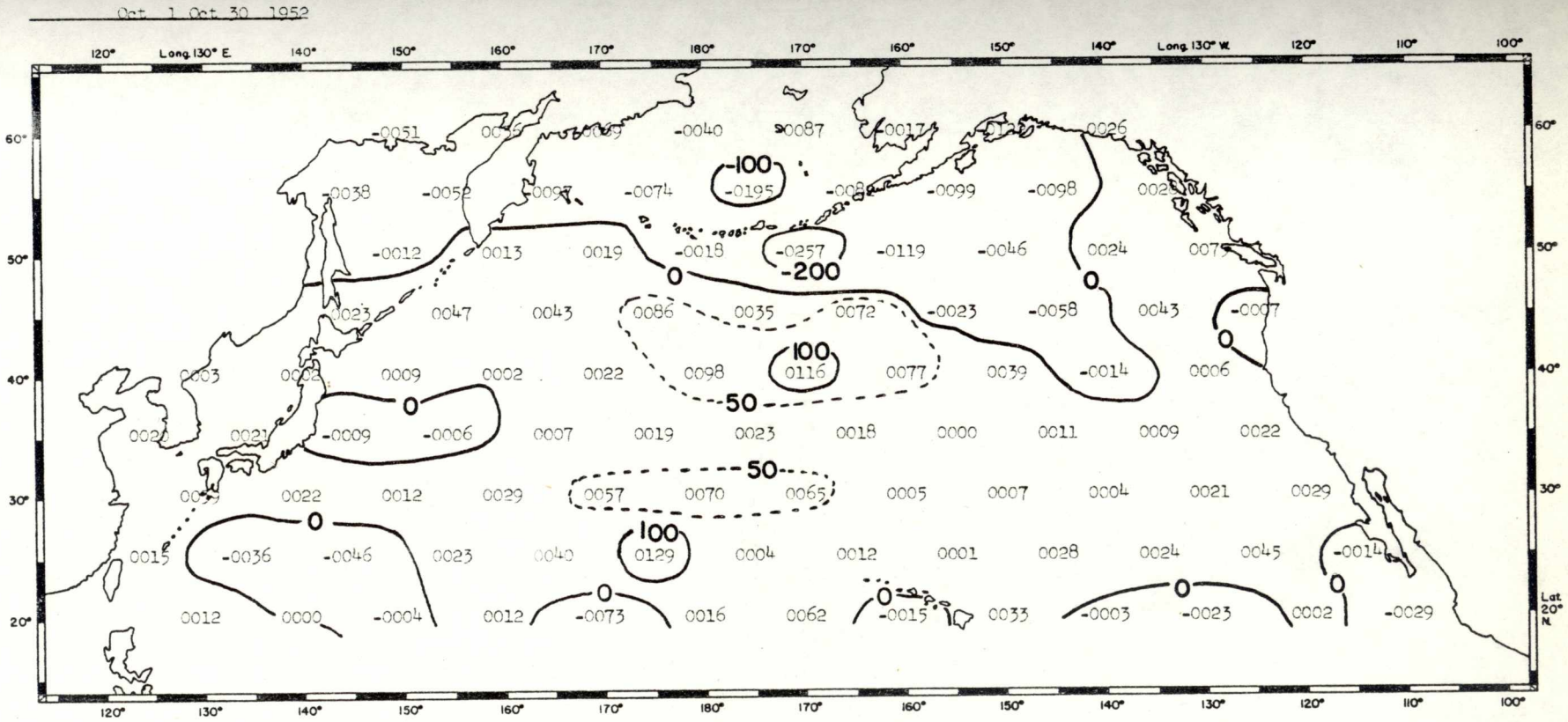


IV. Meridional Component of Total Transport

Sep 1 Sep 30 1952

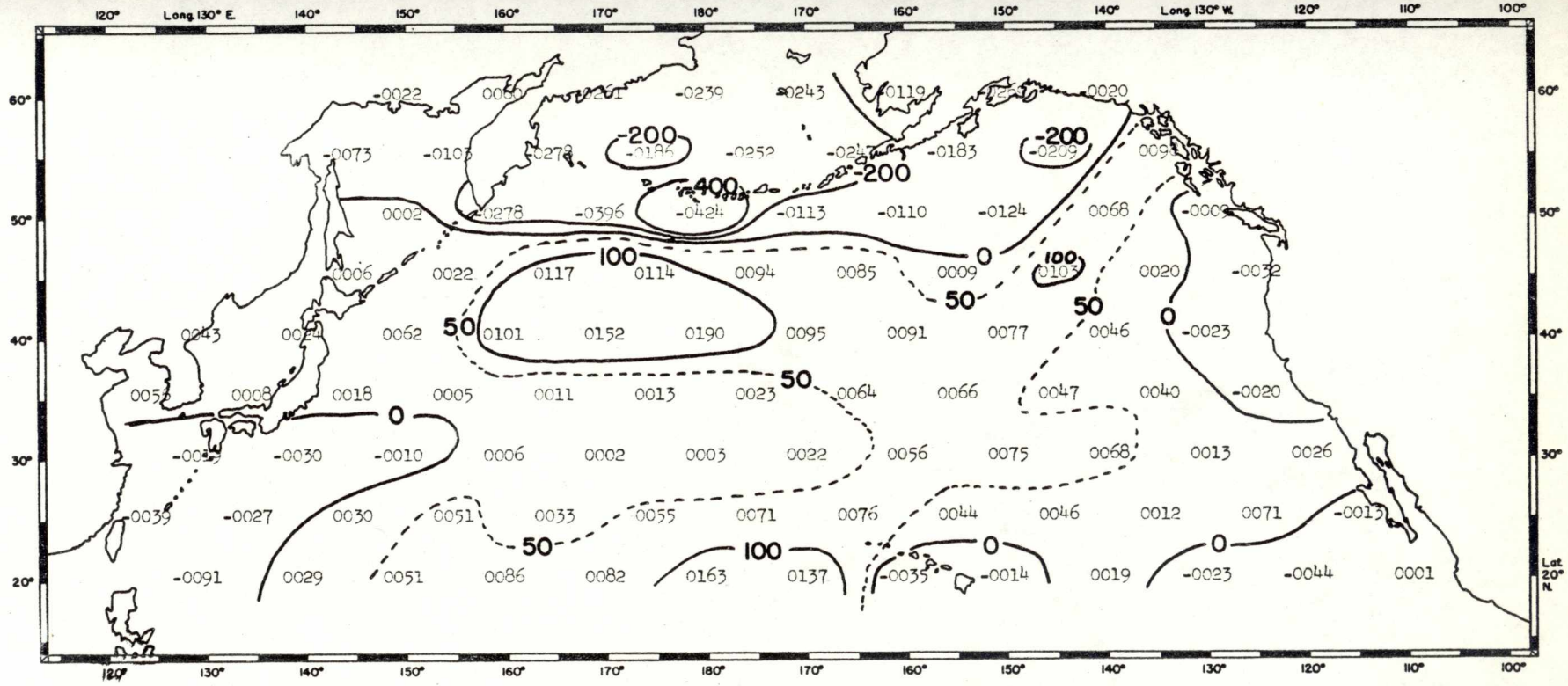


IV. Meridional Component of Total Transport



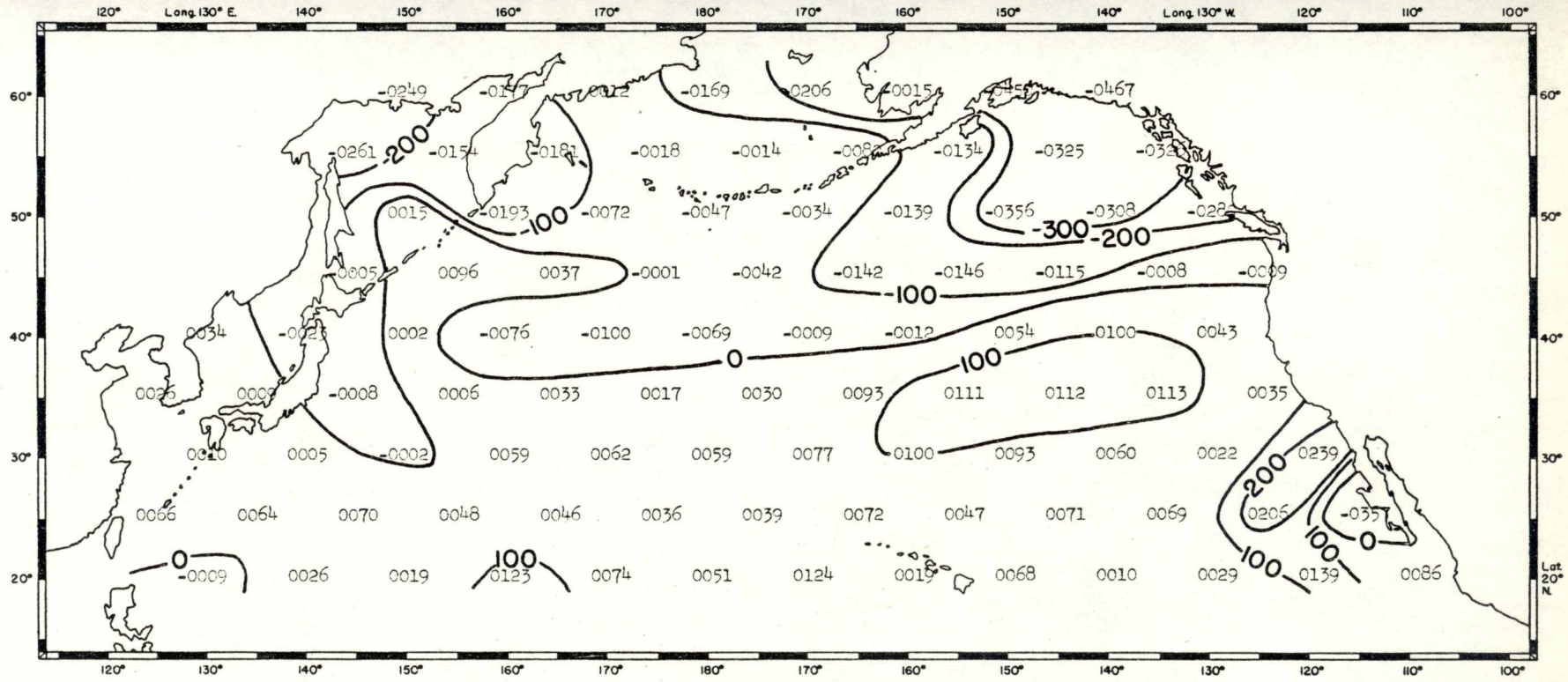
IV. Meridional Component of Total Transport

Nov. 1 Nov 30 1952



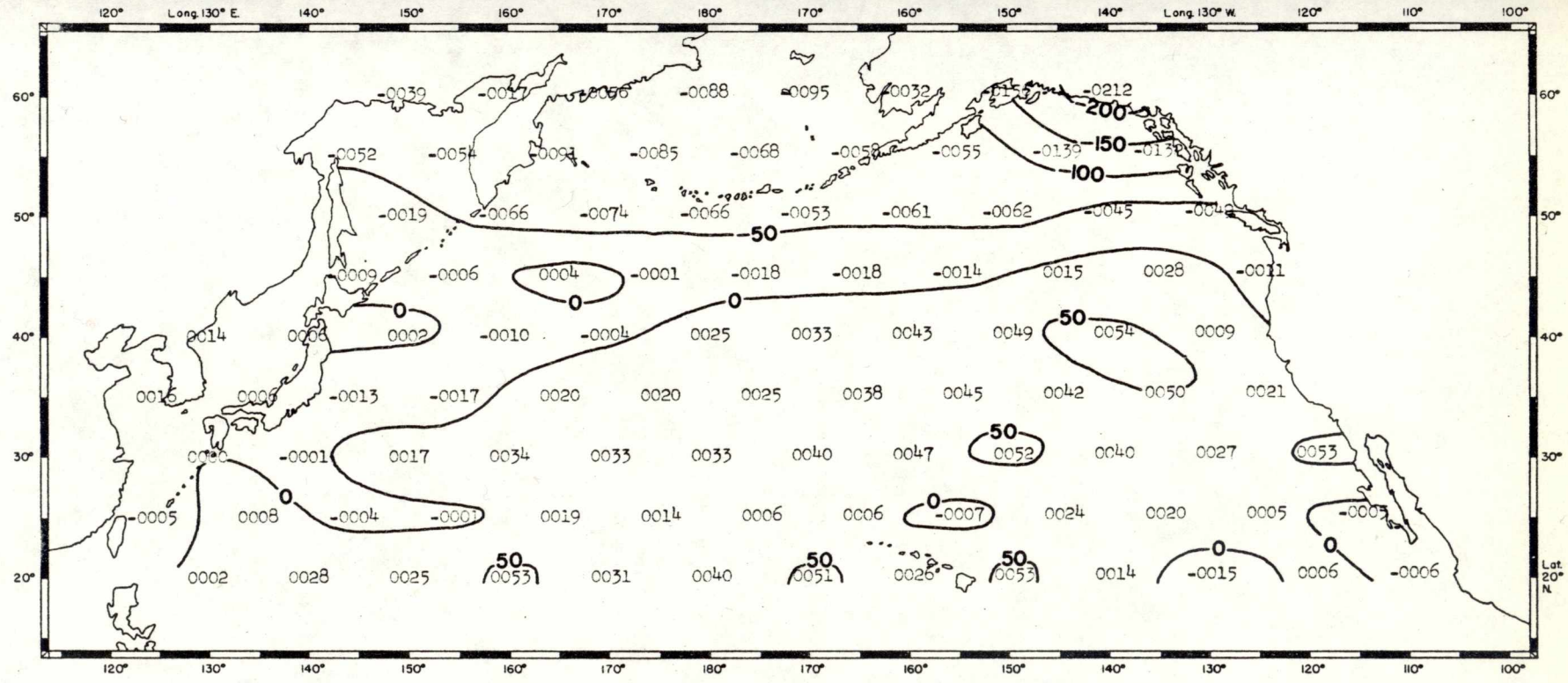
IV. Meridional Component of Total Transport

Dec 1 Dec 30 1952



IV. Meridional Component of Total Transport

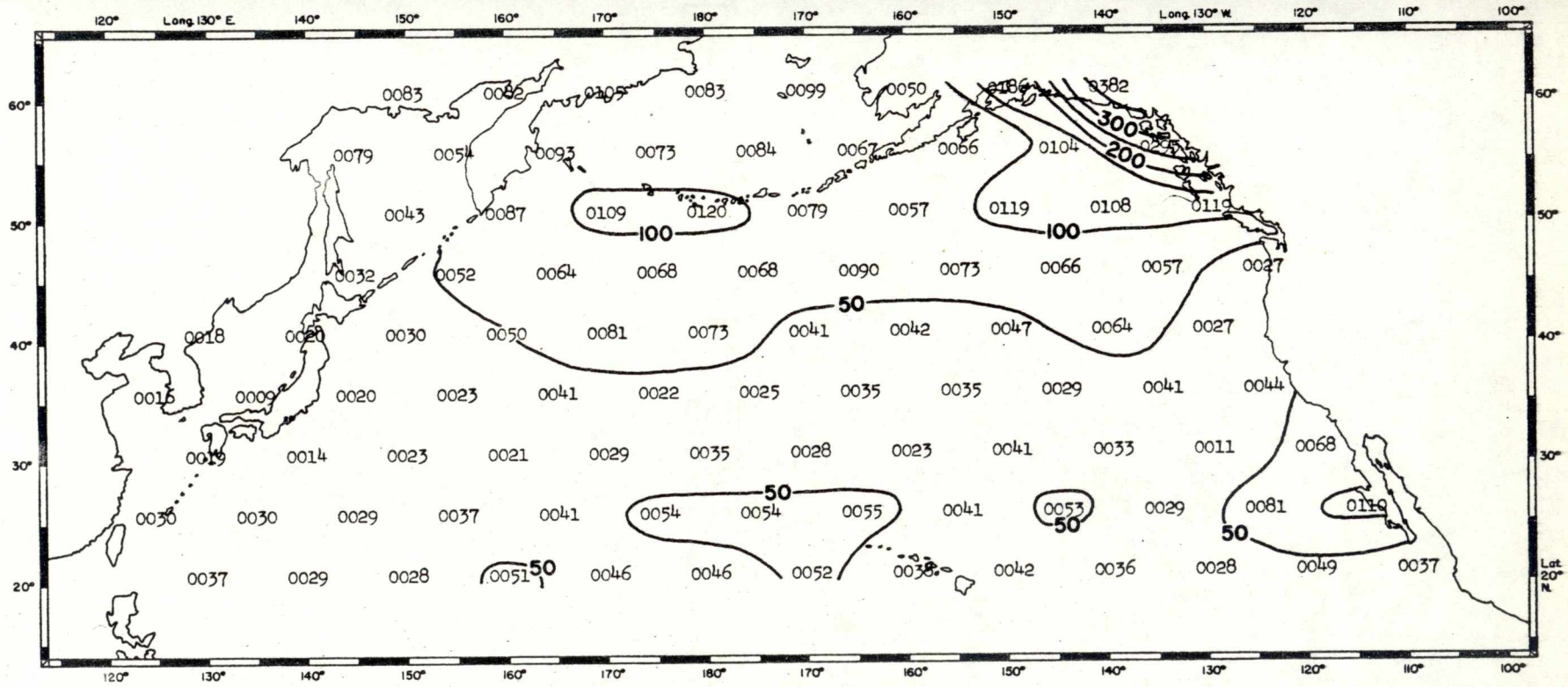
4m Sep 1 Sep 30 1952



IV. Meridional Component of Total Transport

ANNUAL MEAN 1952

4s Sep 1 Sep 30 1952



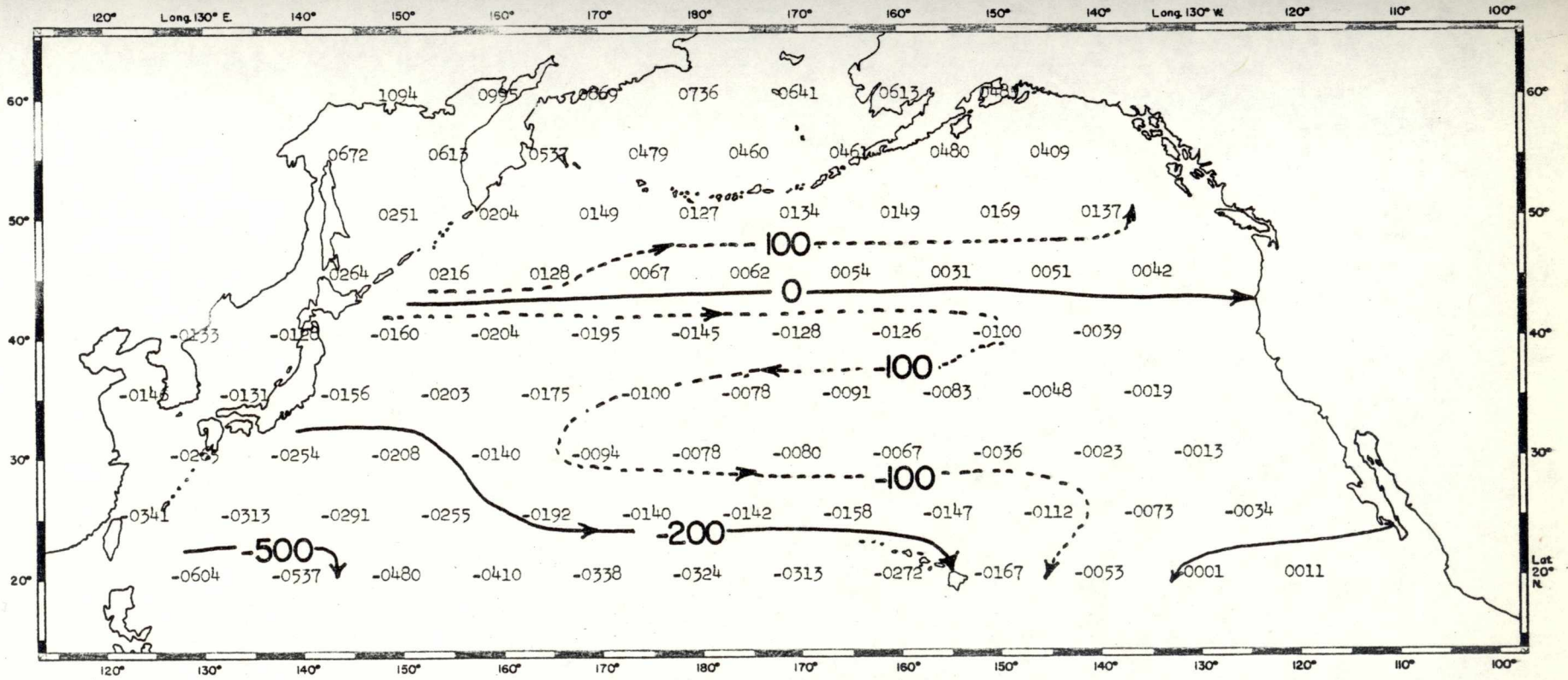
IV. Meridional Component of Total Transport

STANDARD DEVIATION 1952

Section V

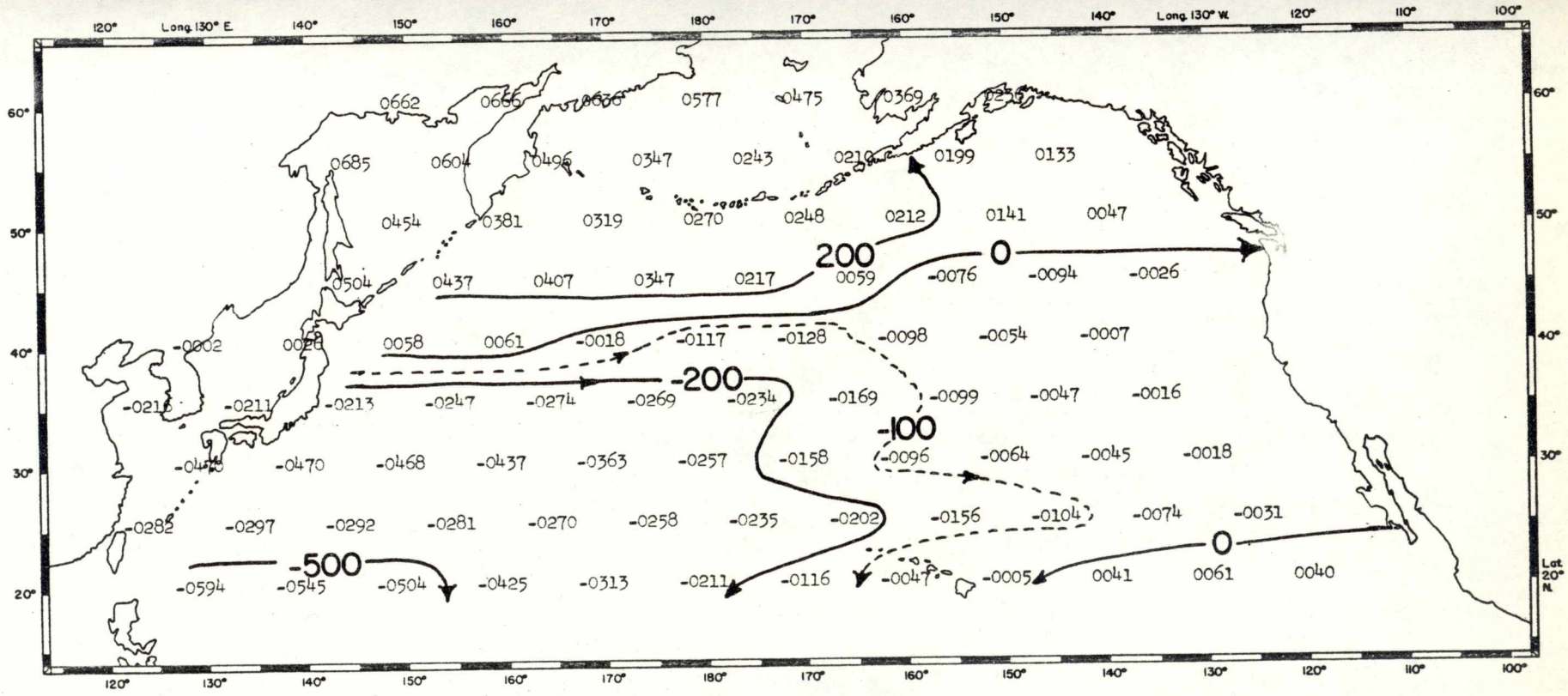
Integrated Total Transport

Jan 1 Jan 30 1952



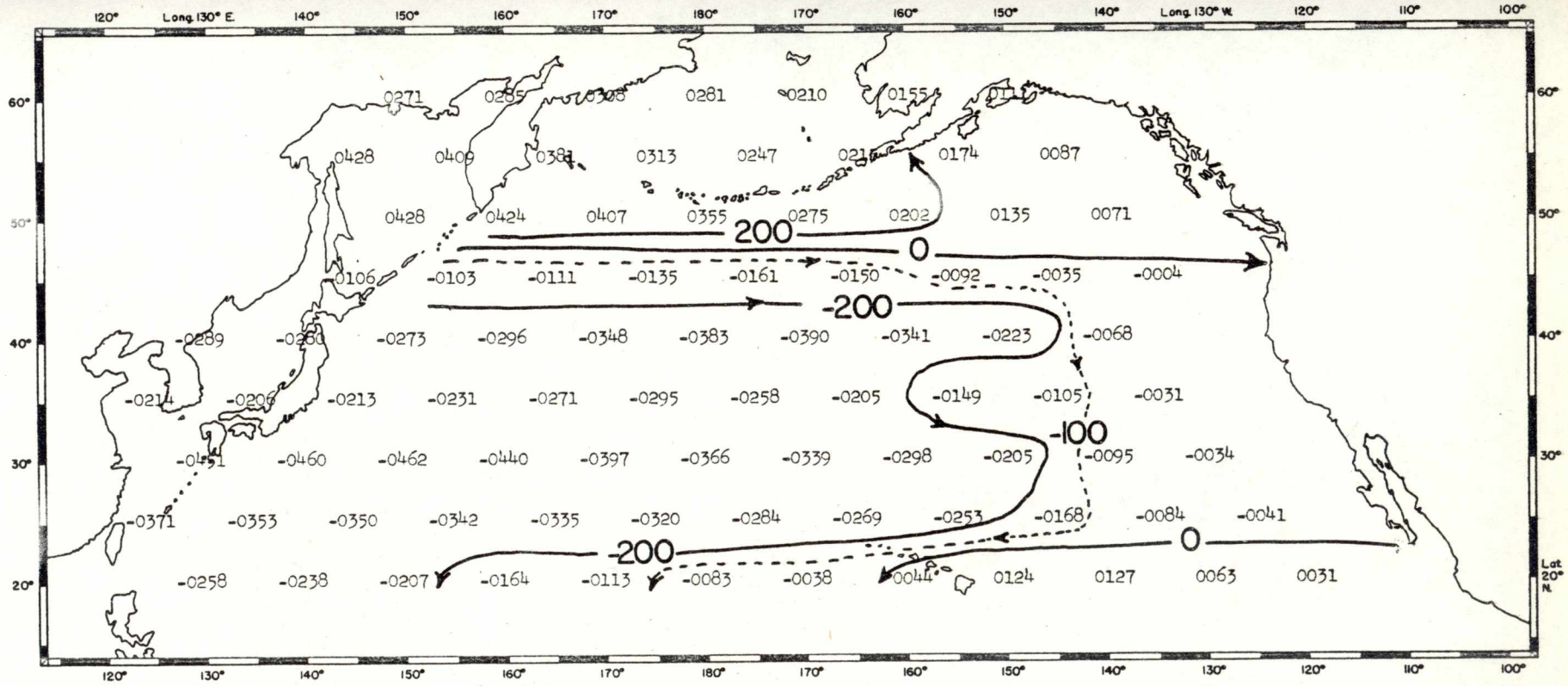
V. Integrated Total Transport

Feb 1 Mar 1 1952



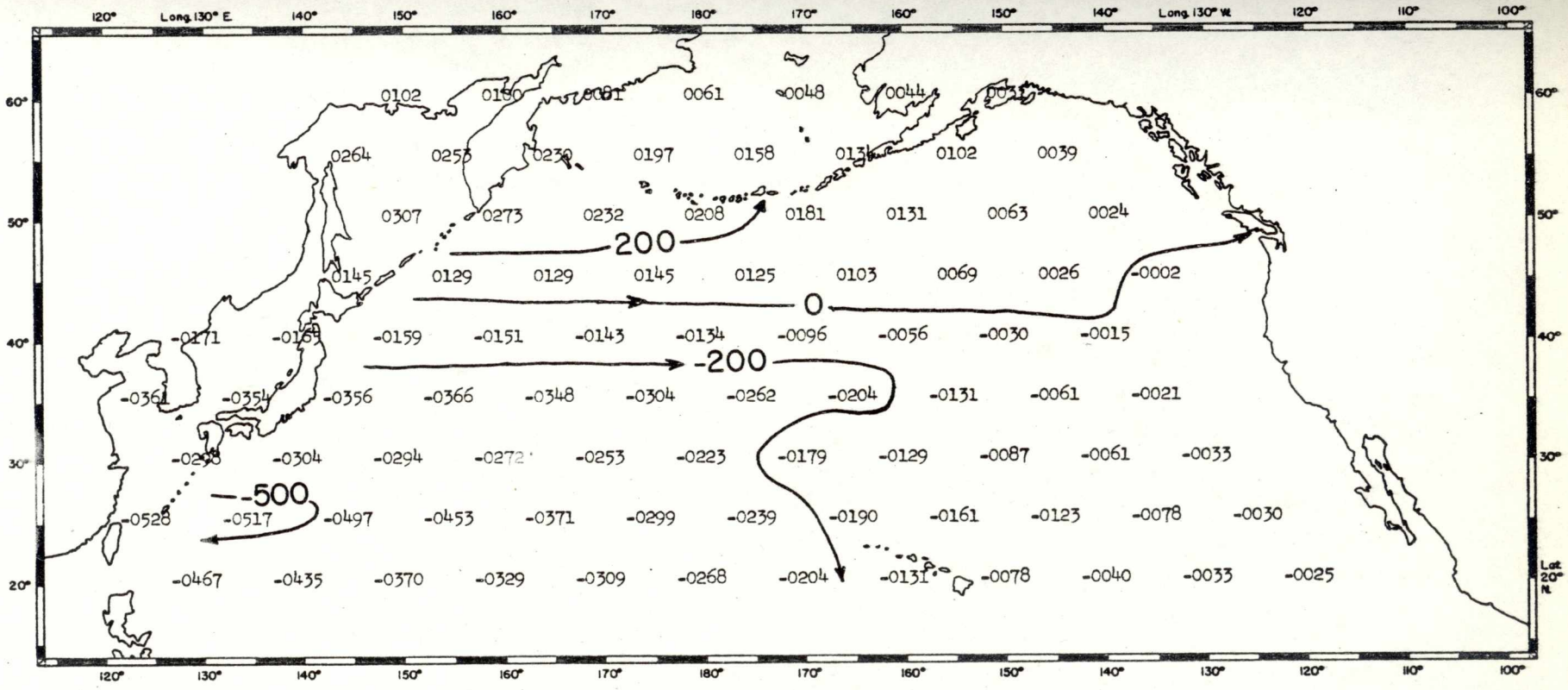
V. Integrated Total Transport

Mar 1 Mar 30 1952



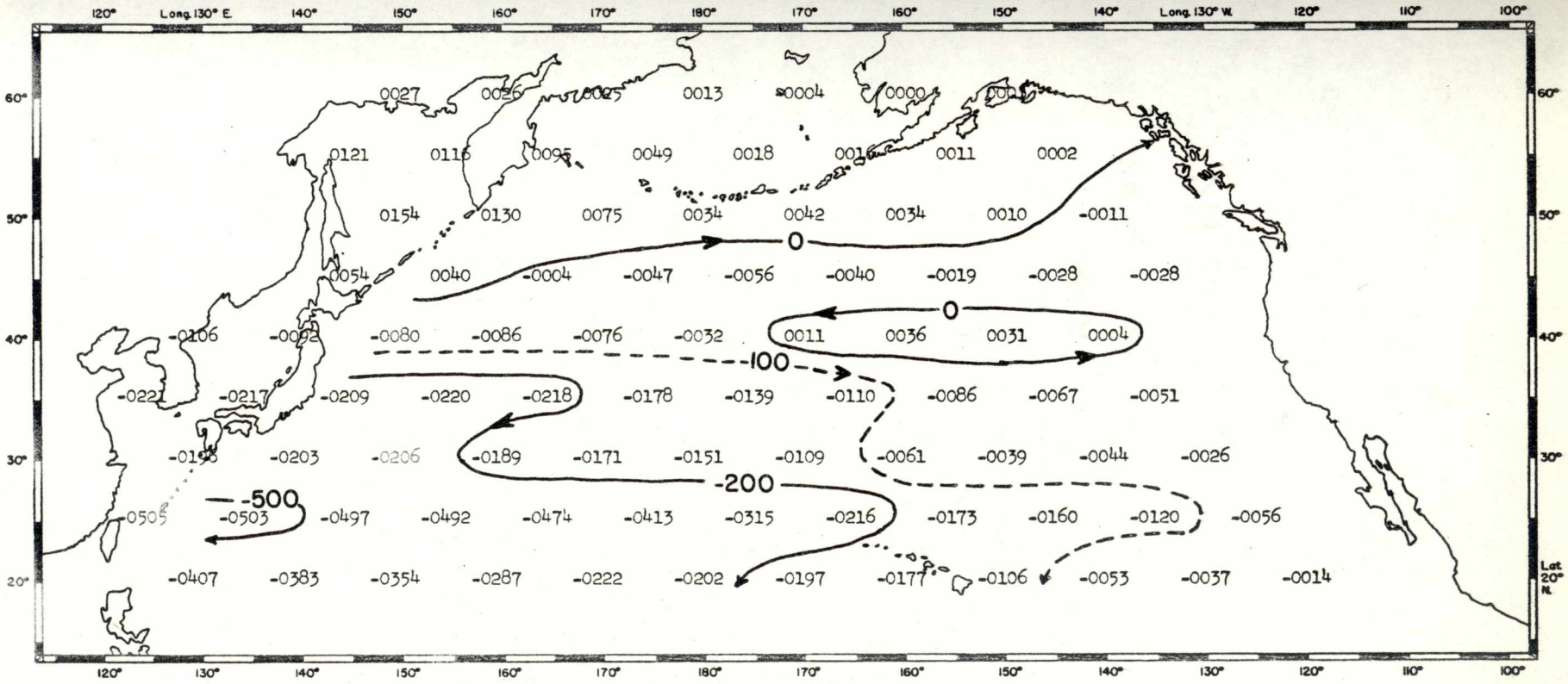
V. Integrated Total Transport

Apr 1 Apr 30 1952



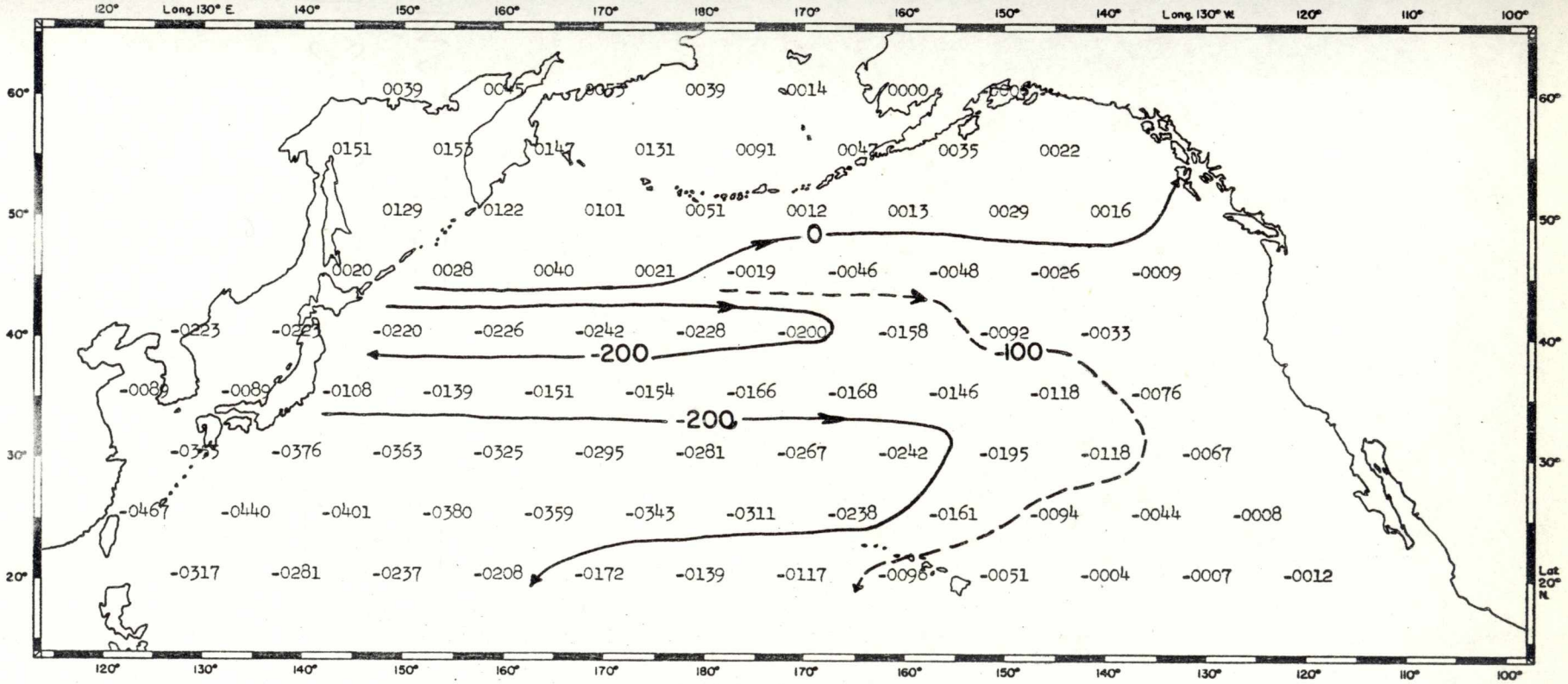
V. Integrated Total Transport

May 1 May 30 1952



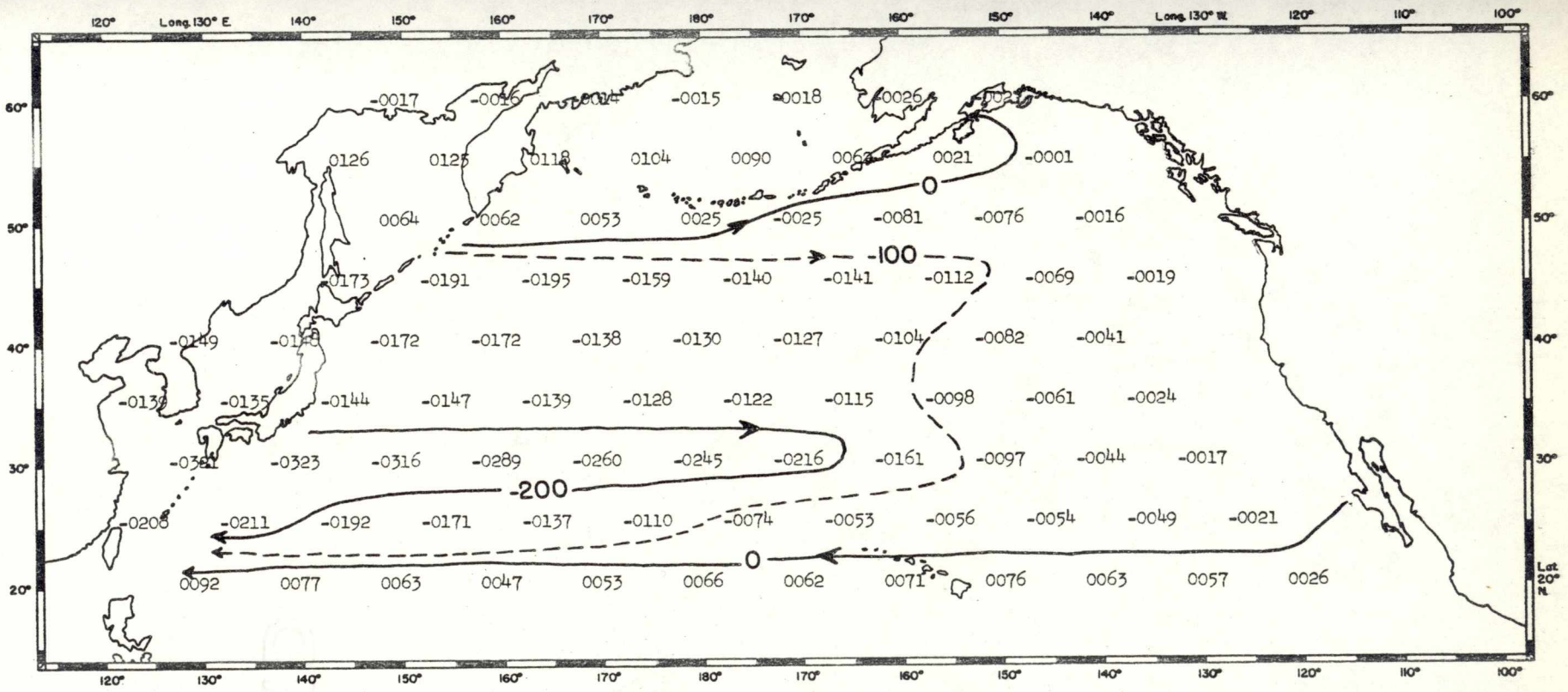
V. Integrated Total Transport

Jun 1 Jun 30 1952



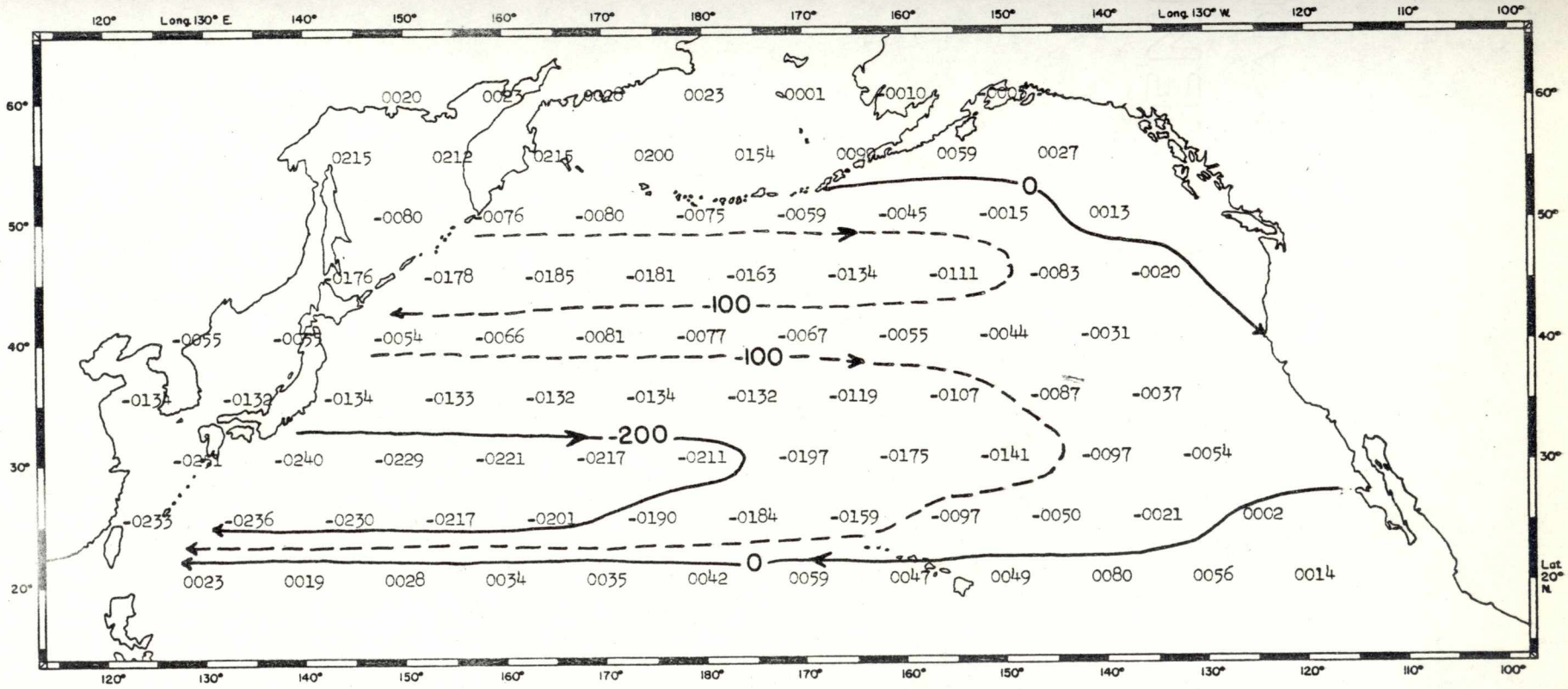
V. Integrated Total Transport

Jul 1 Jul 30 1952



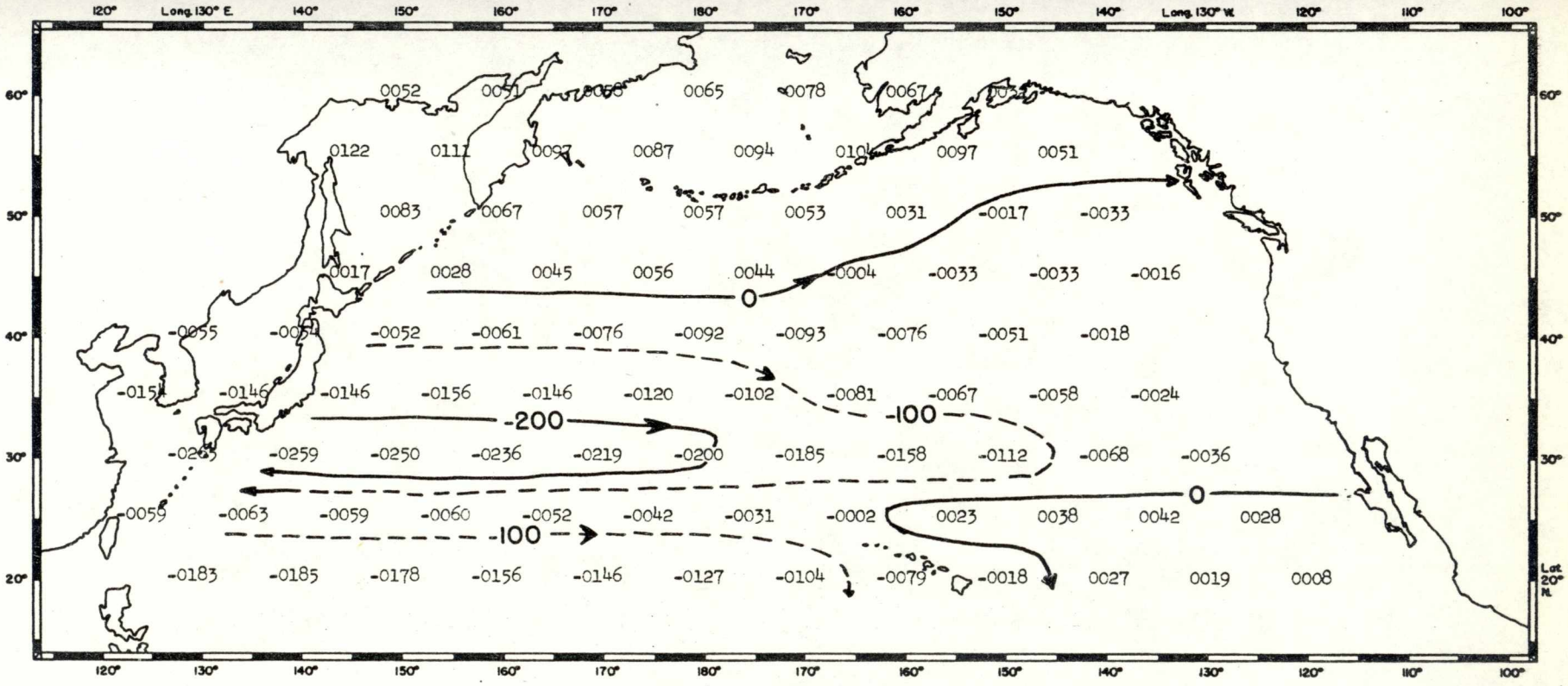
V. Integrated Total Transport

Aug 1 Aug 30 1952



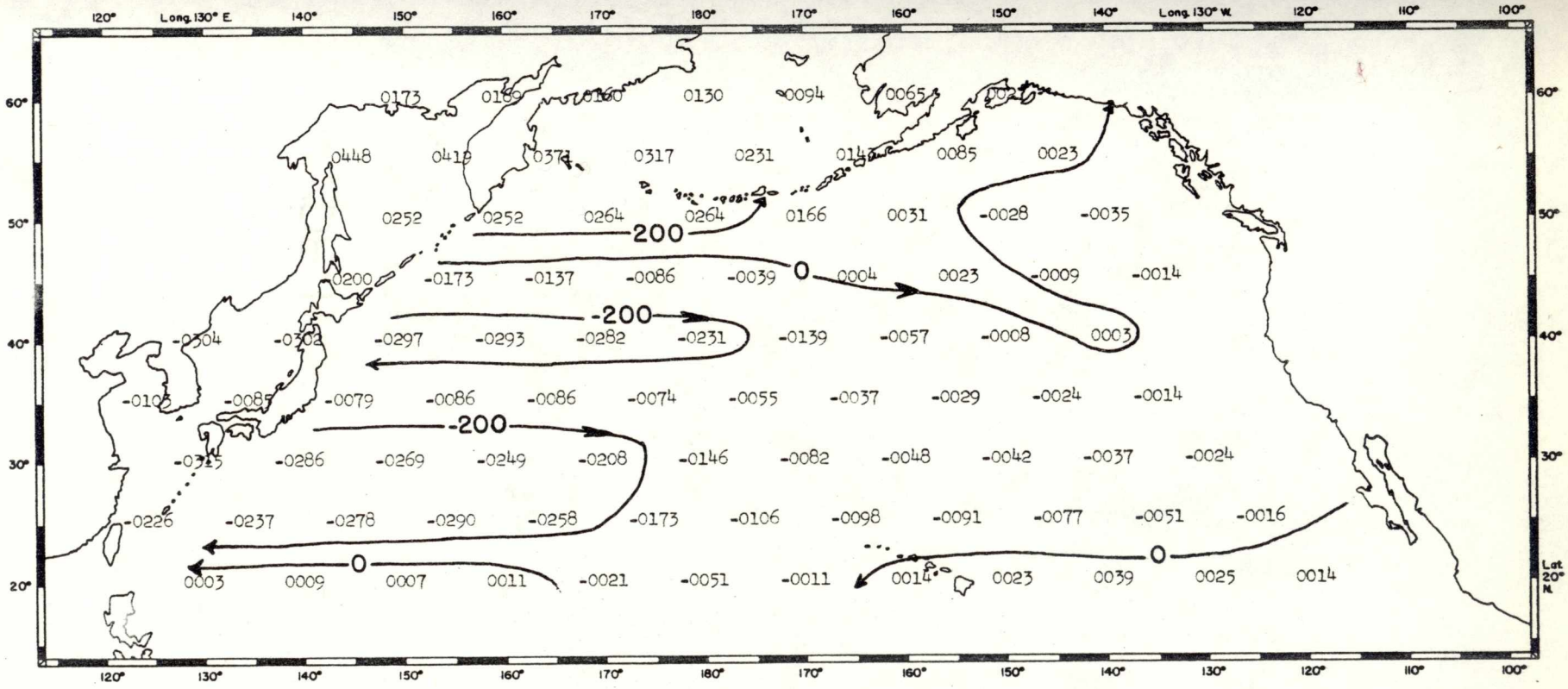
V. Integrated Total Transport

Sep 1 Sep 30 1952



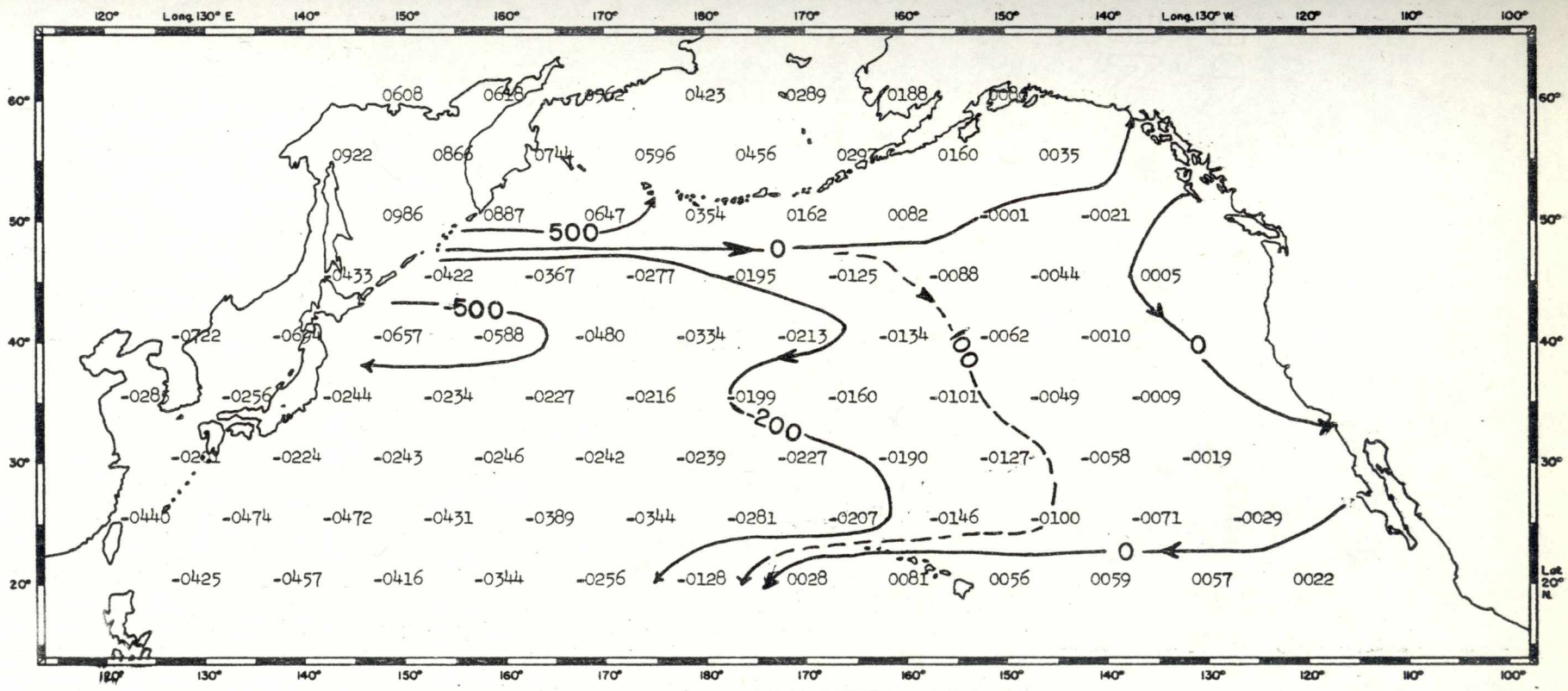
V. Integrated Total Transport

Oct. 1 Oct. 30 1952



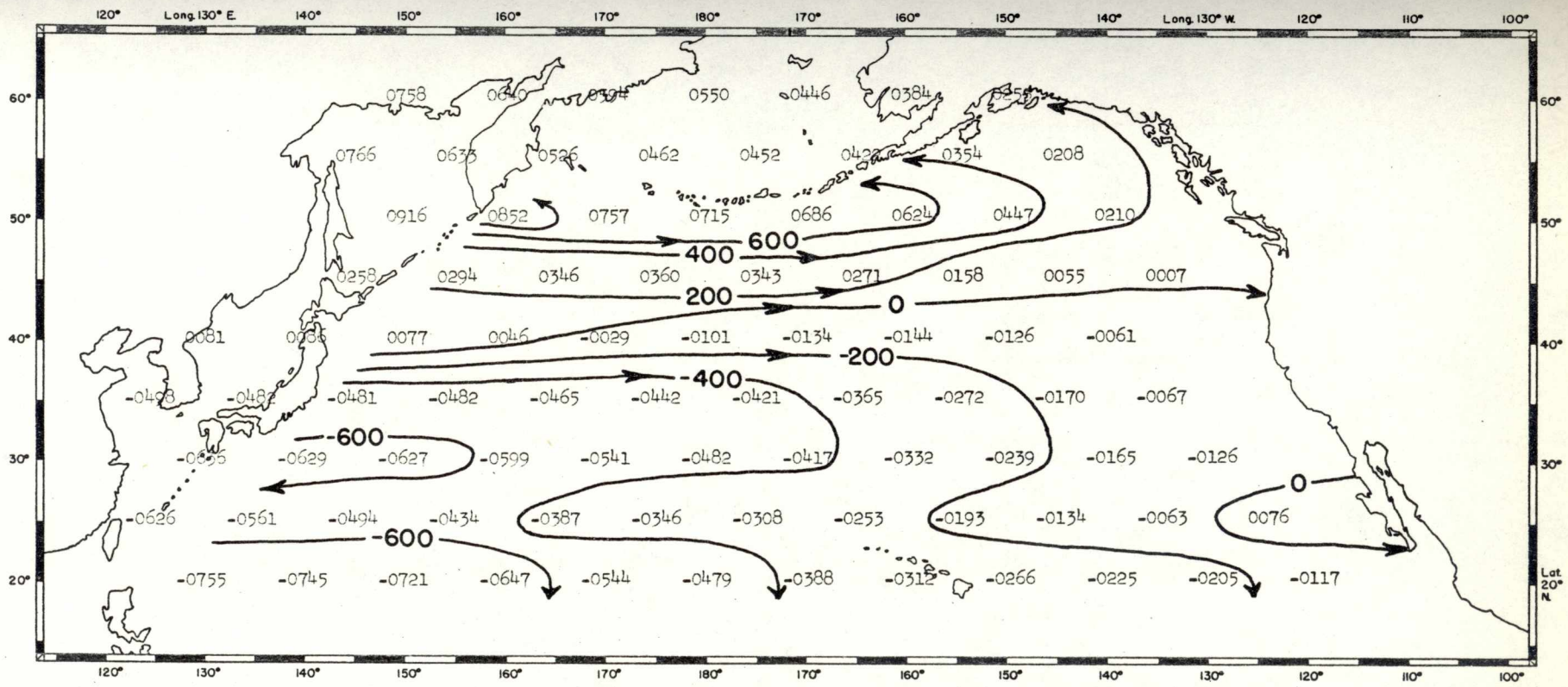
V. Integrated Total Transport

Nov 1 Nov 30 1952



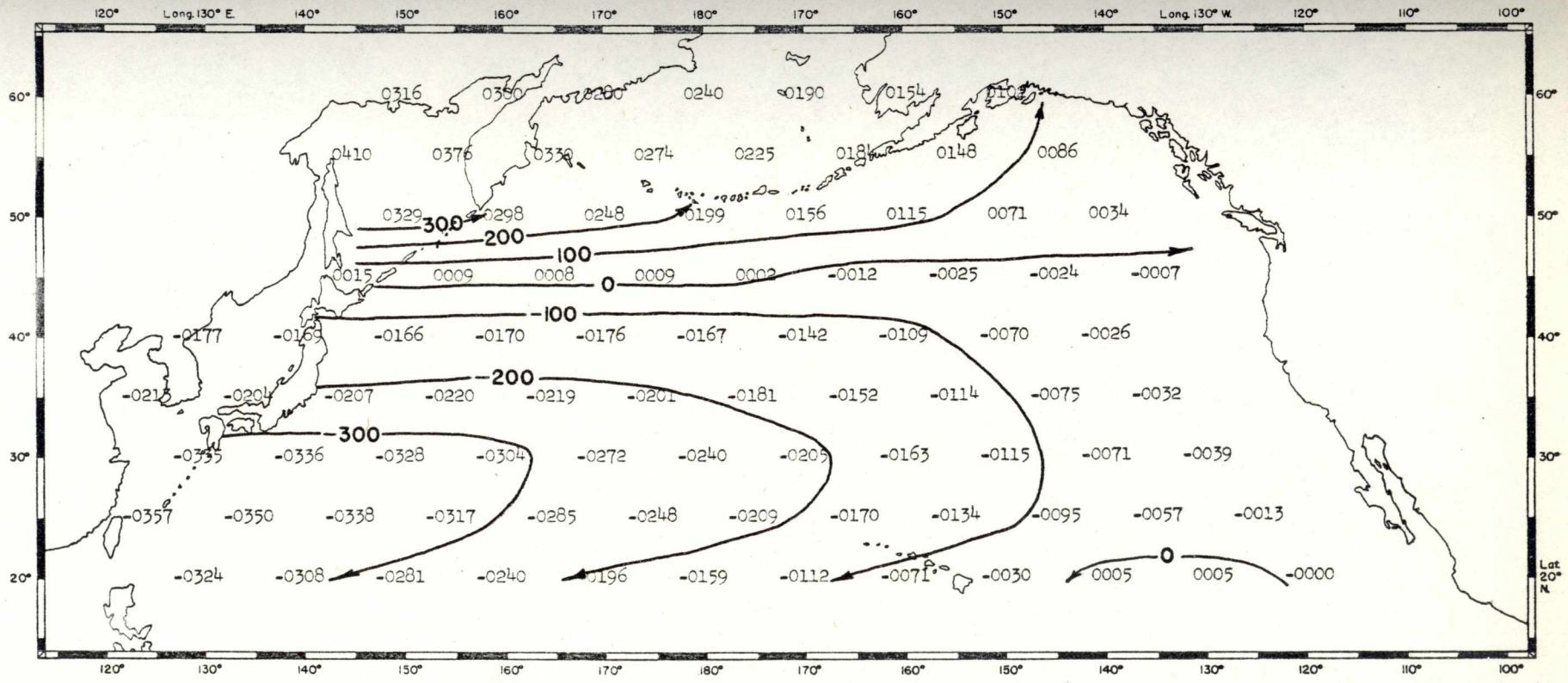
V. Integrated Total Transport

Dec. 1 Dec 30 1952



V. Integrated Total Transport

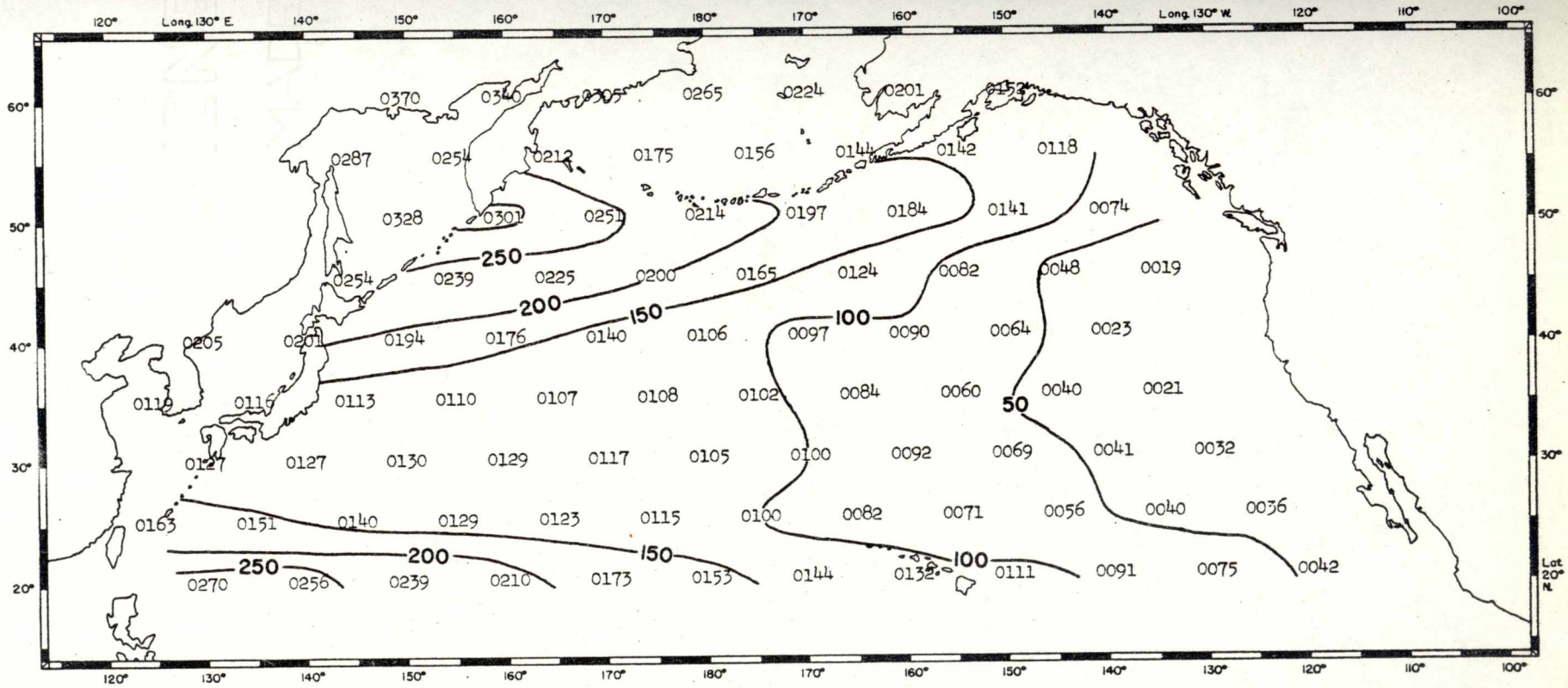
5m Sep 1 Sep 30 1952



V. Integrated Total Transport

ANNUAL MEAN 1952

5s Sep 1 Sep 30 1952



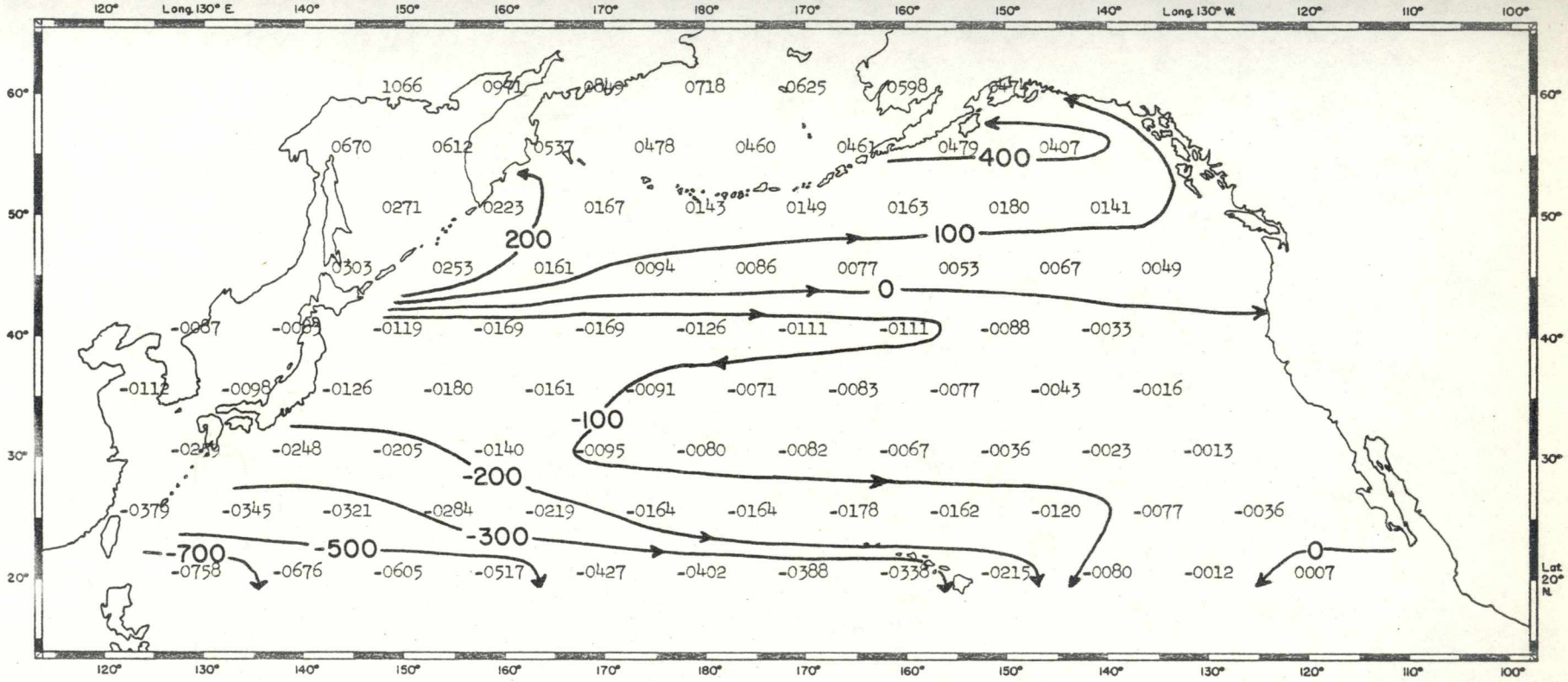
V. Integrated Total Transport

STANDARD DEVIATION 1952

Section VI

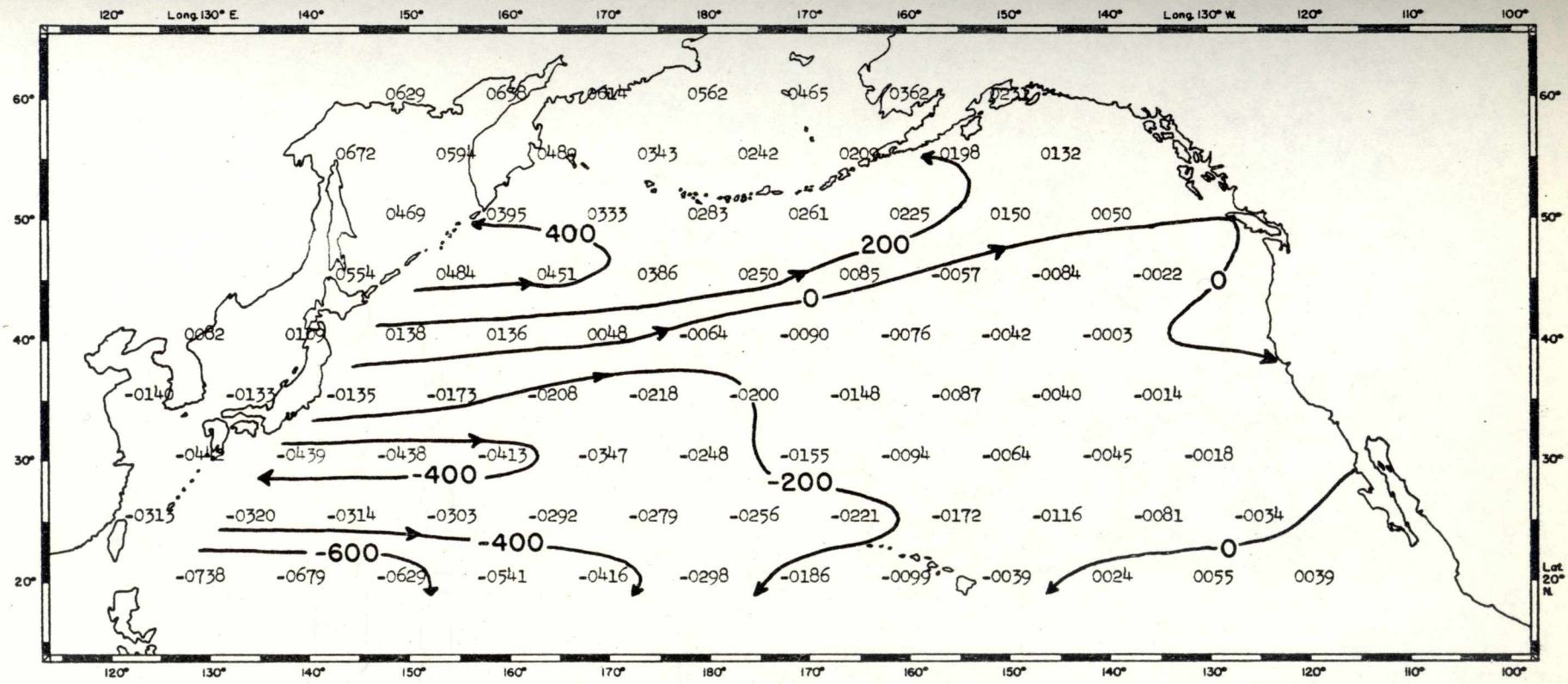
Integrated Geostrophic Transport

Jan 1 Jan 30 1952



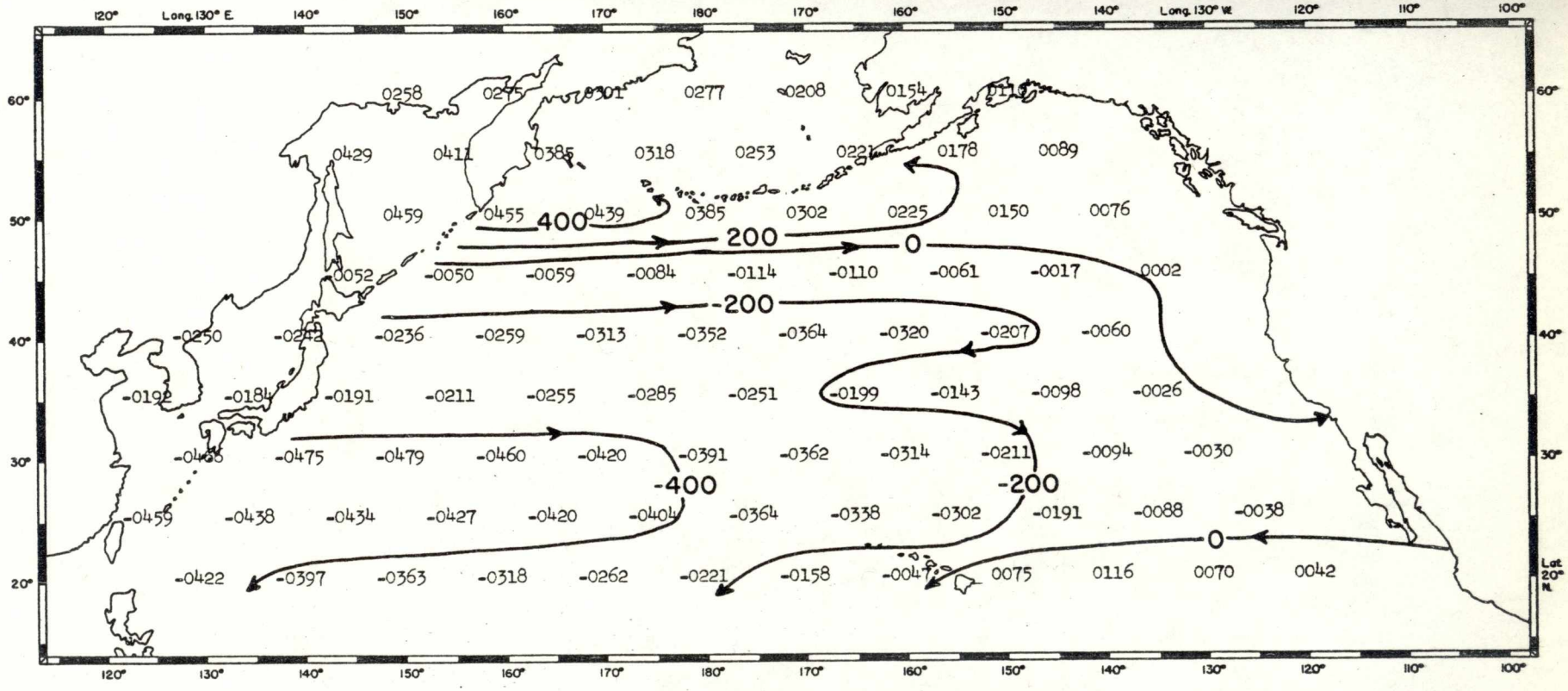
VI. Integrated Geostrophic Transport

Feb 1 Mar 1 1952



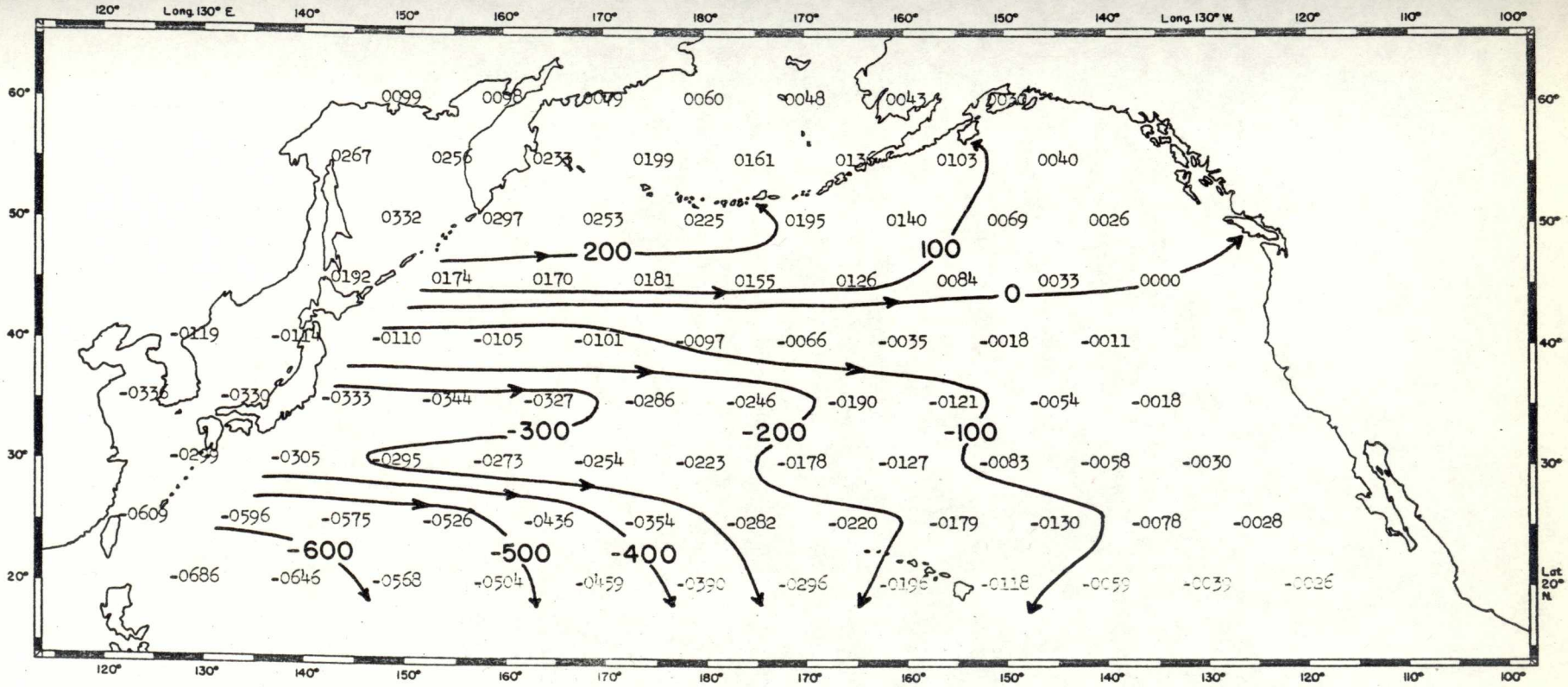
VI. Integrated Geostrophic Transport

Mar 1 Mar 30 1952



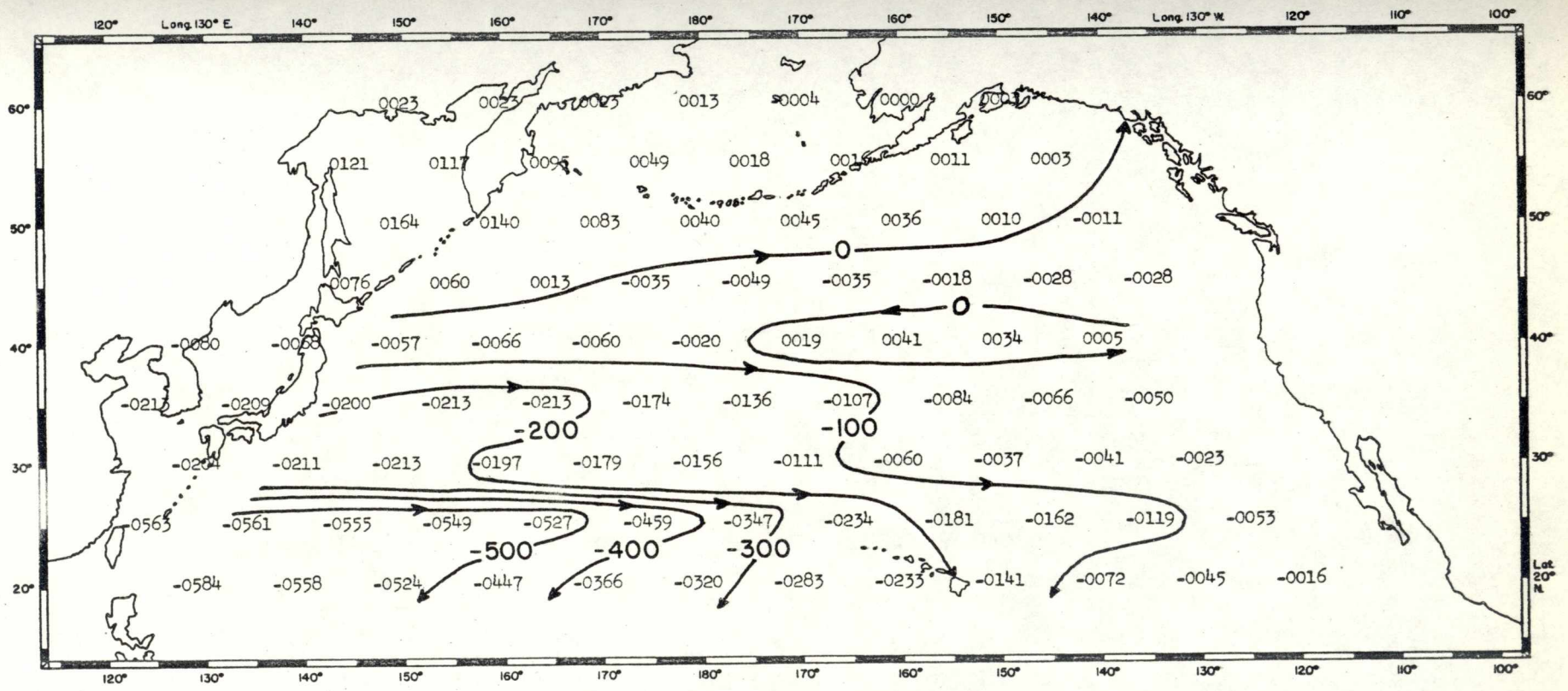
VI. Integrated Geostrophic Transport

Apr 1 Apr 30 1952



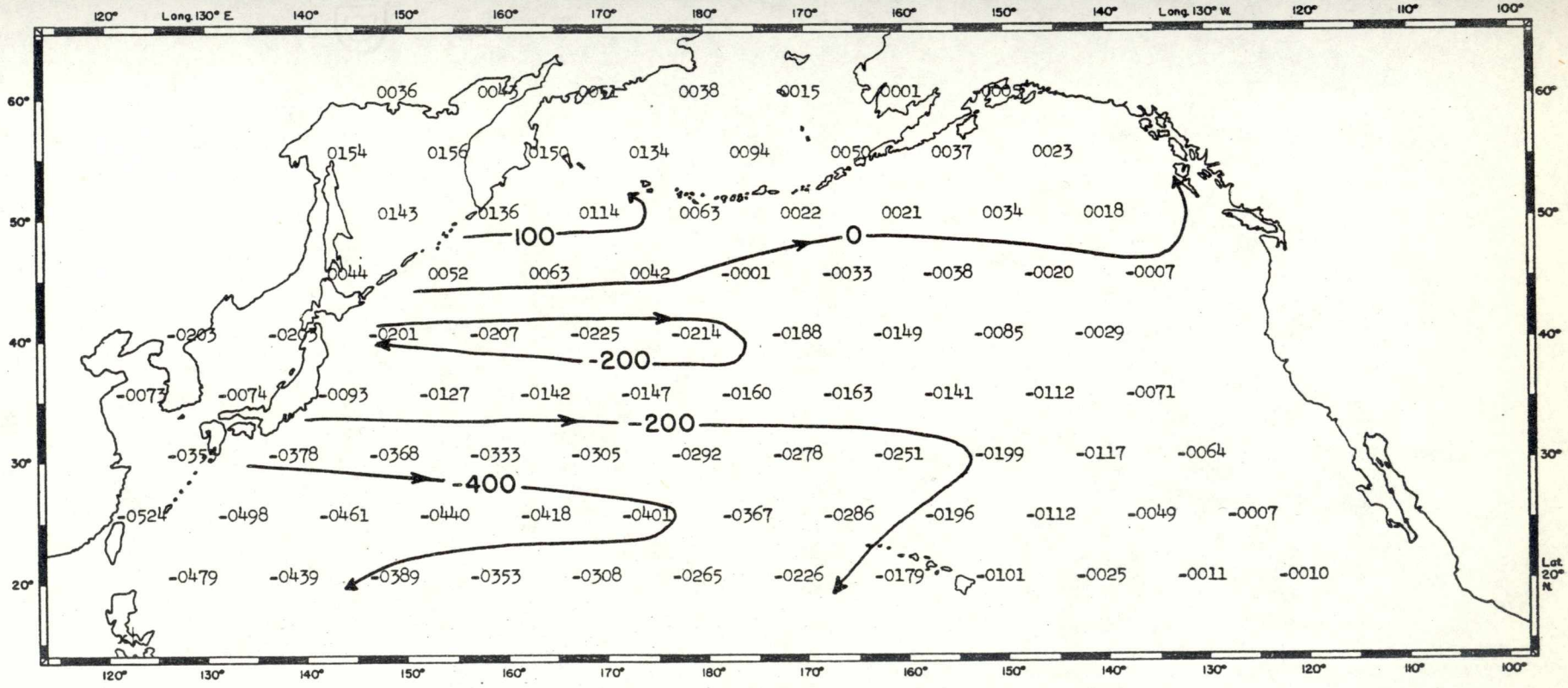
VI. Integrated Geostrophic Transport

May 1 May 30 1952



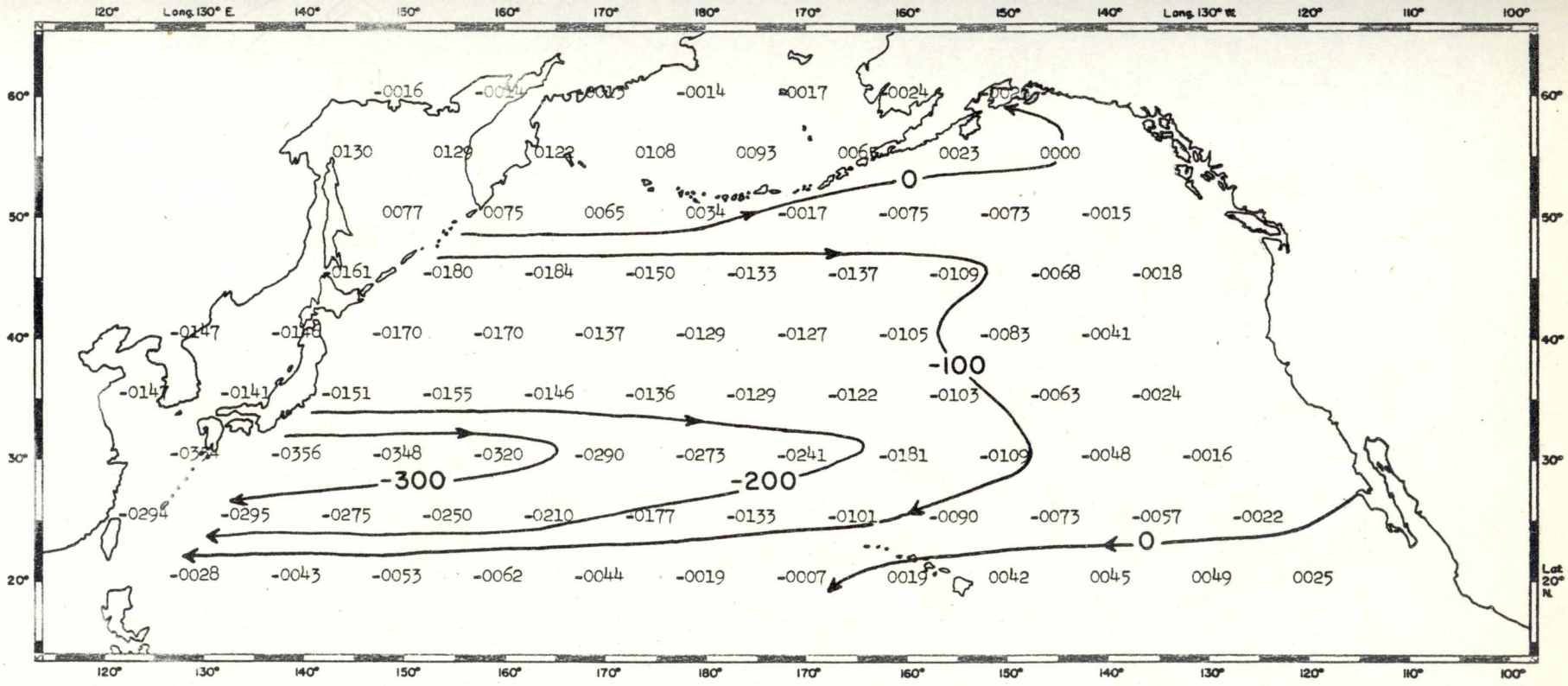
VI. Integrated Geostrophic Transport

Jun 1 Jun 30 1952



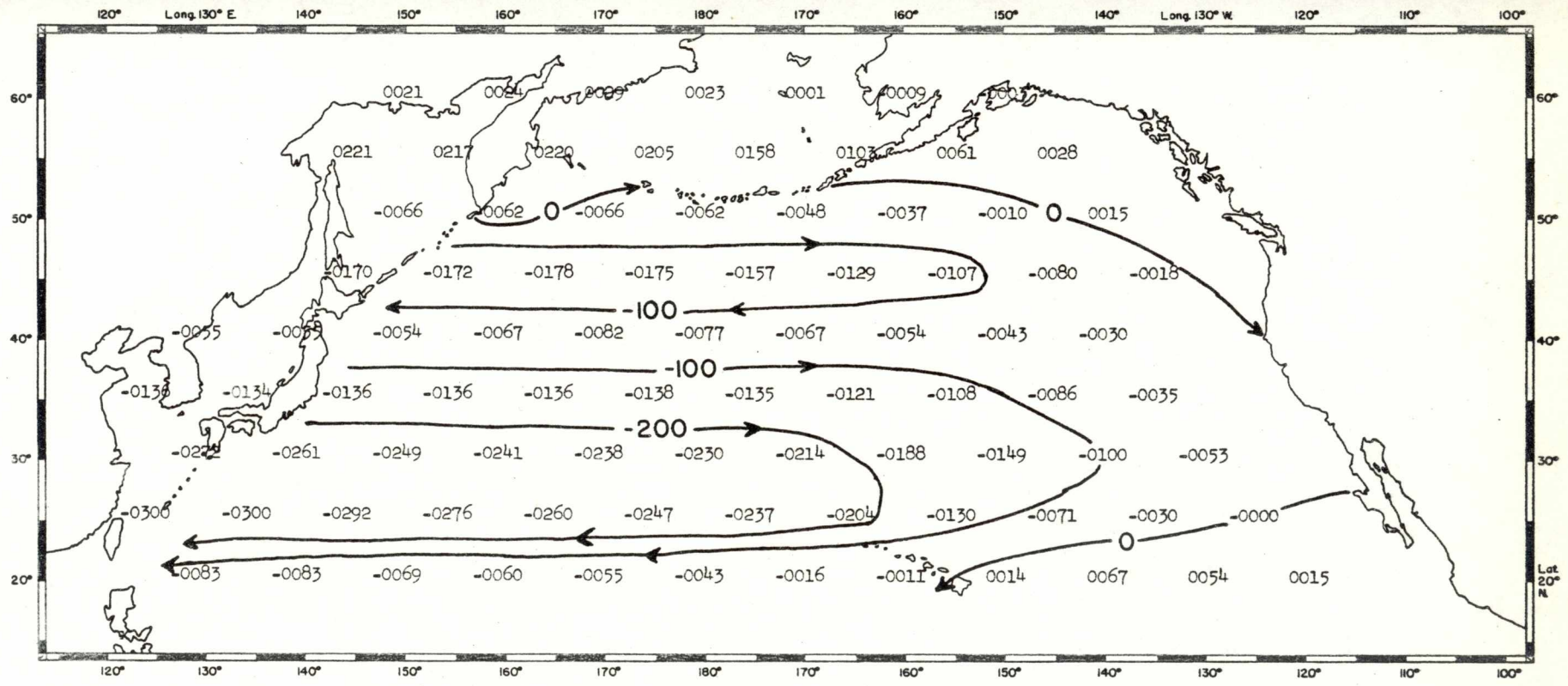
VI. Integrated Geostrophic Transport

Jul 1 Jul 30 1952



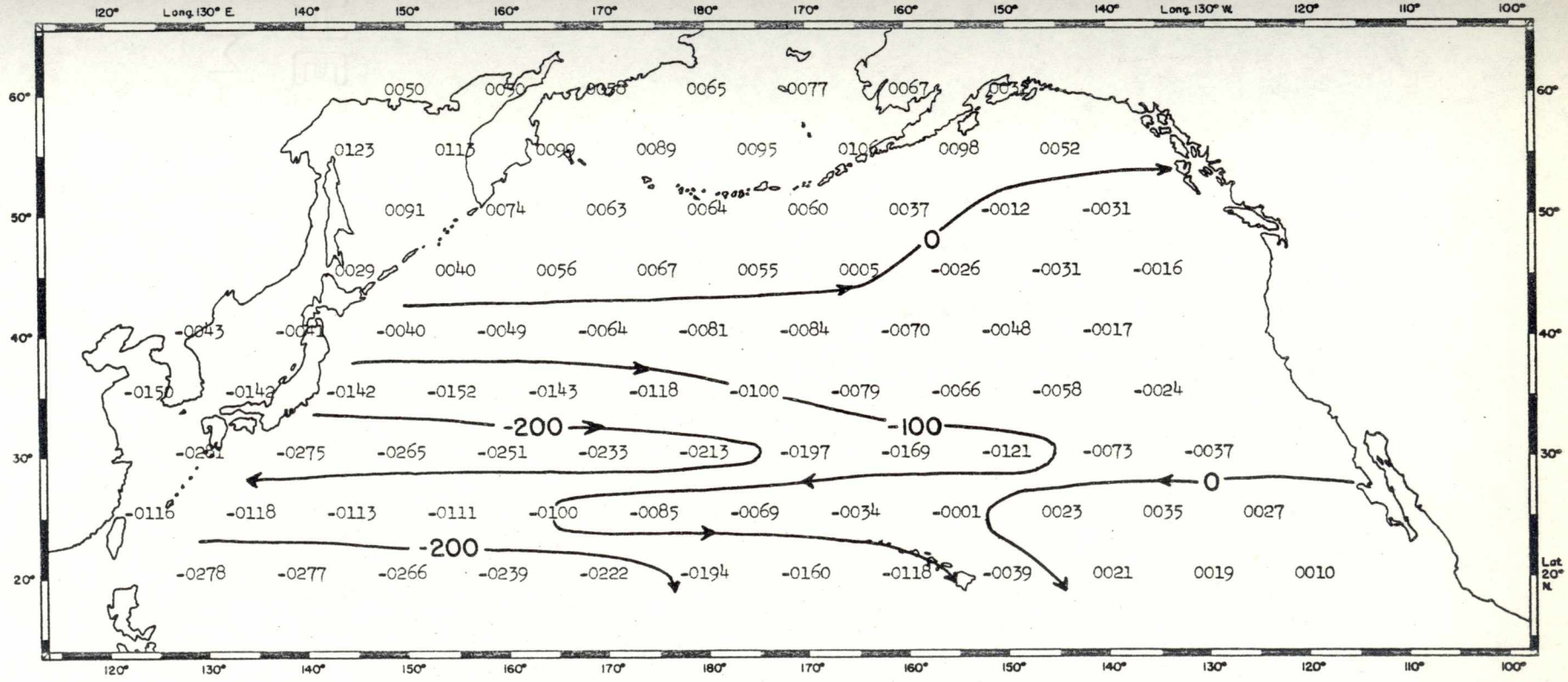
VI. Integrated Geostrophic Transport

Aug 1 Aug 30 1952



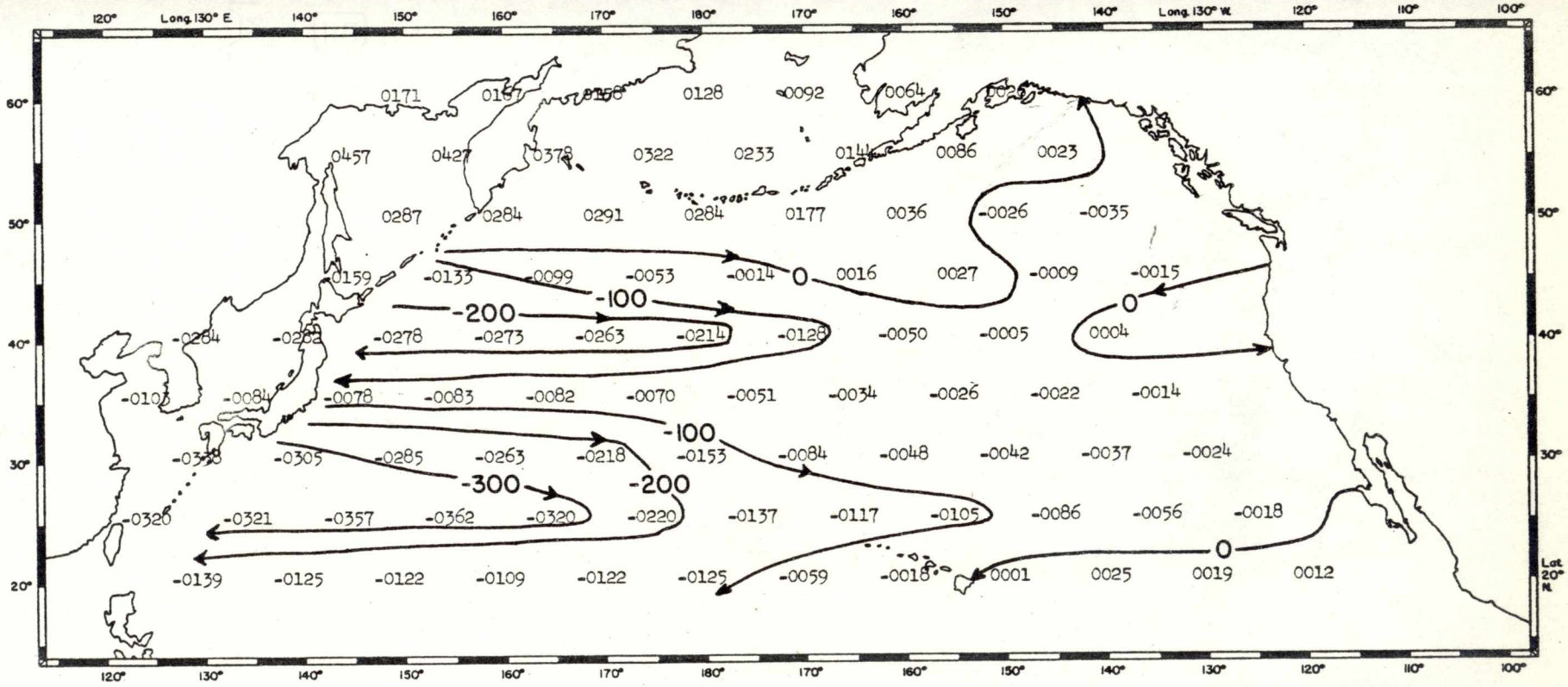
VI. Integrated Geostrophic Transport

Sep 1 Sep 30 1952



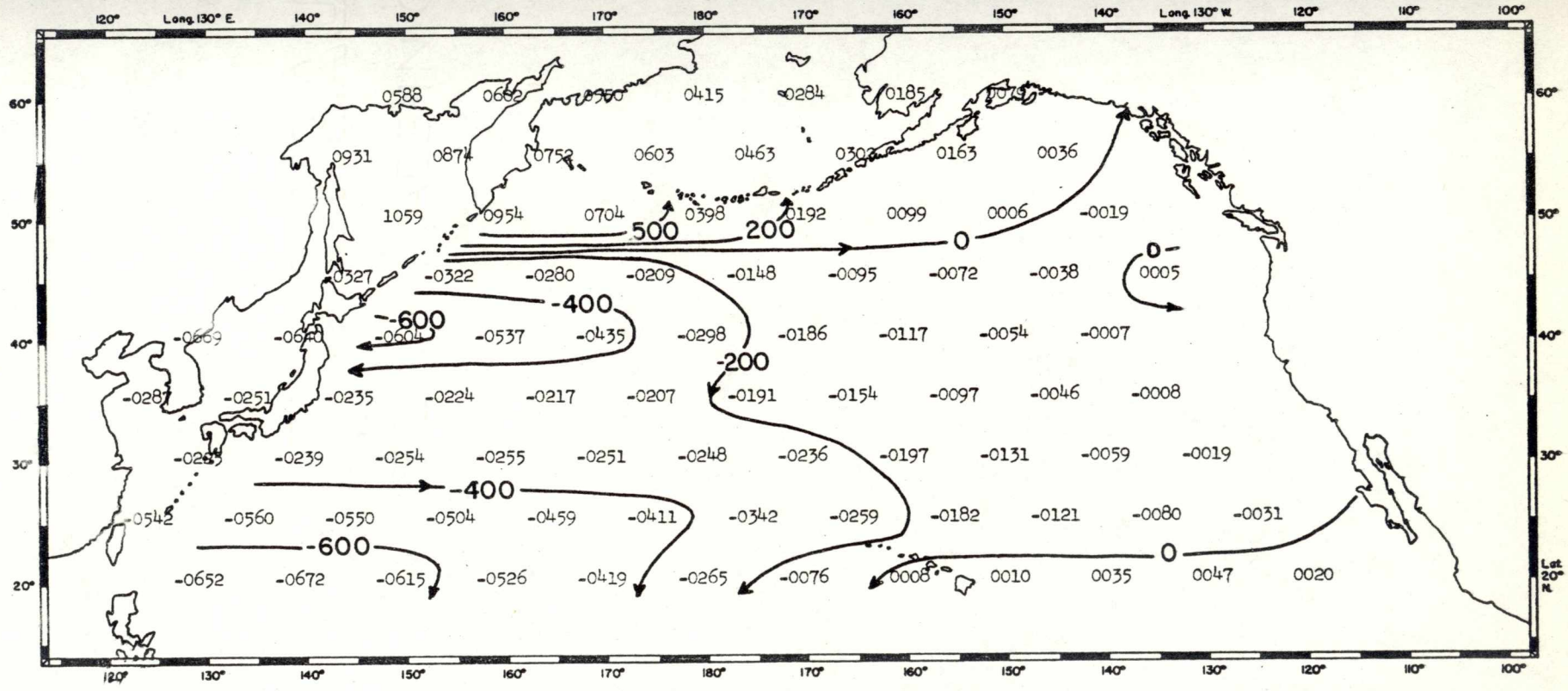
VI. Integrated Geostrophic Transport

Oct 1 Oct 30 1952



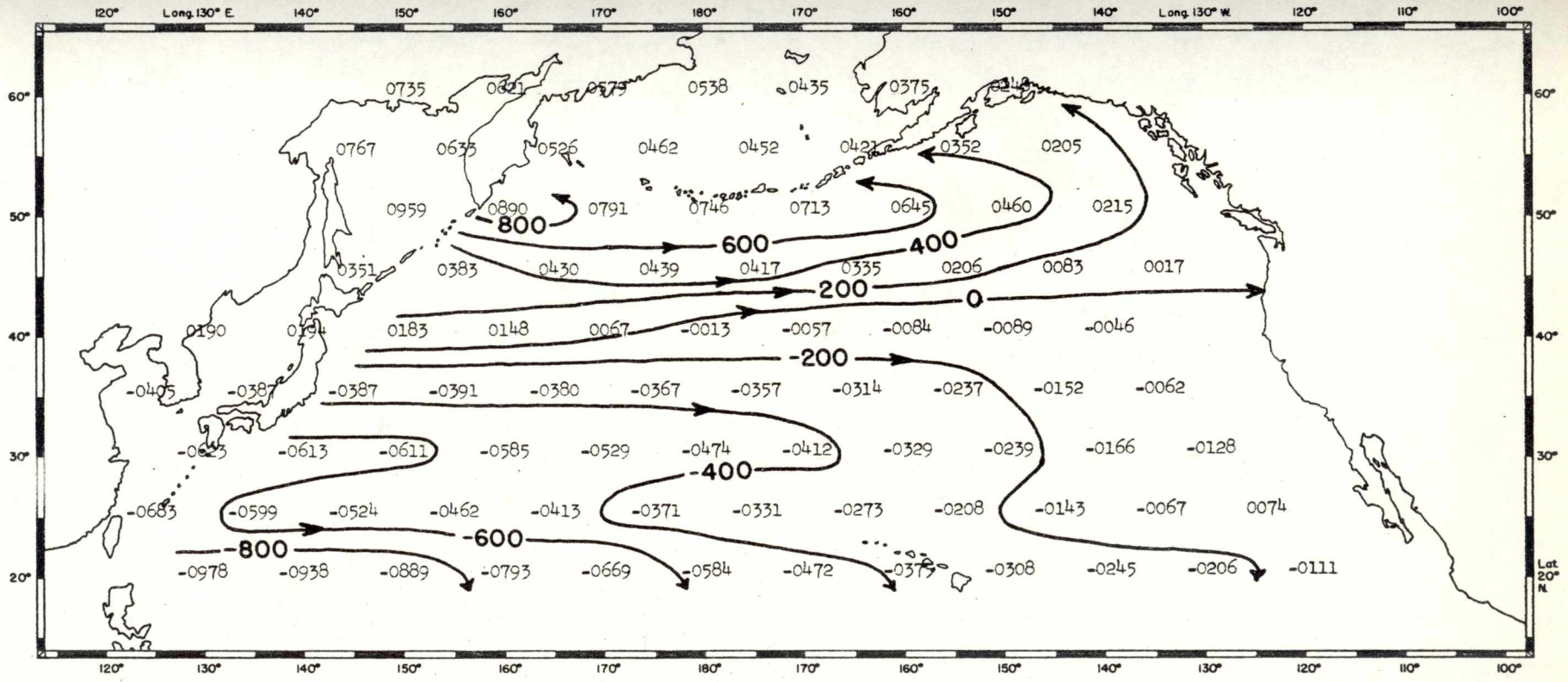
VI. Integrated Geostrophic Transport

Nov 1 Nov 30 1952



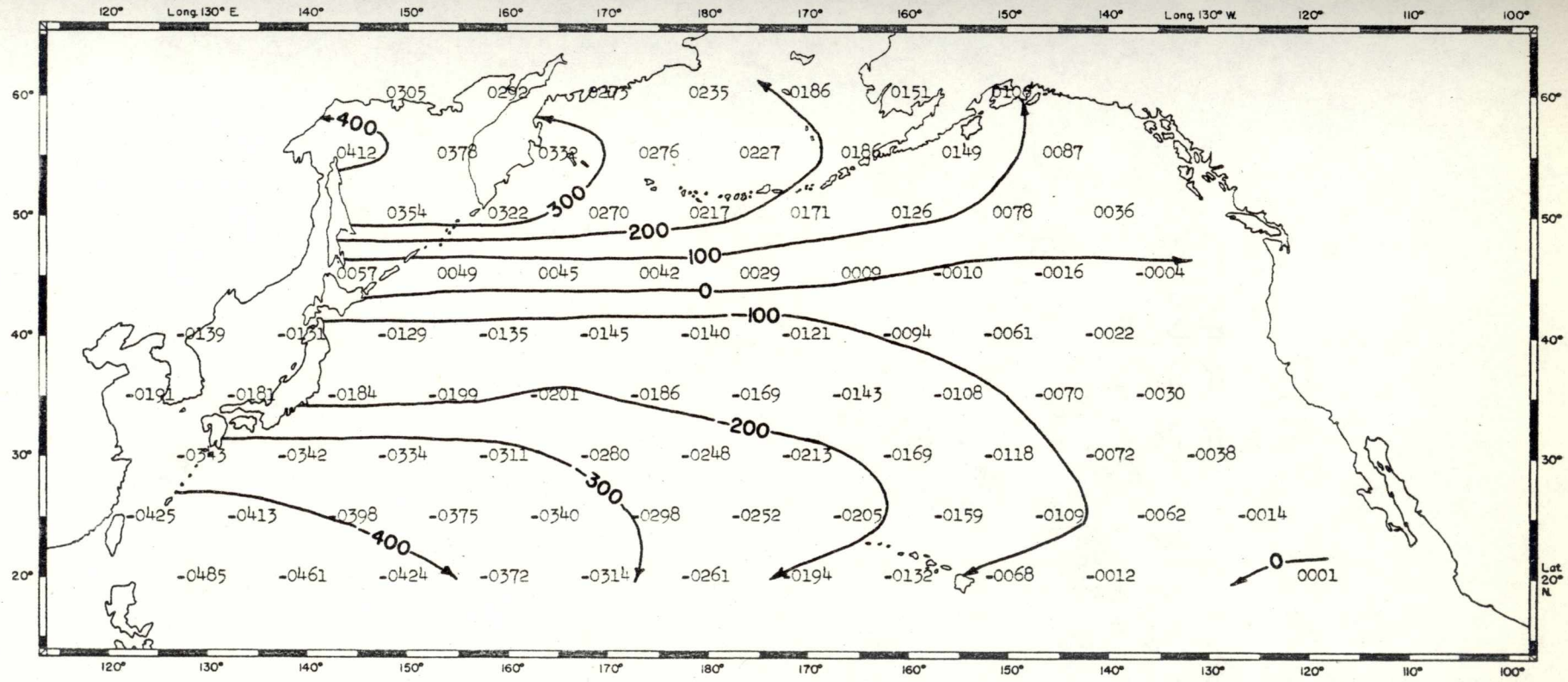
VI. Integrated Geostrophic Transport

Dec 1 Dec 30 1952



VI. Integrated Geostrophic Transport

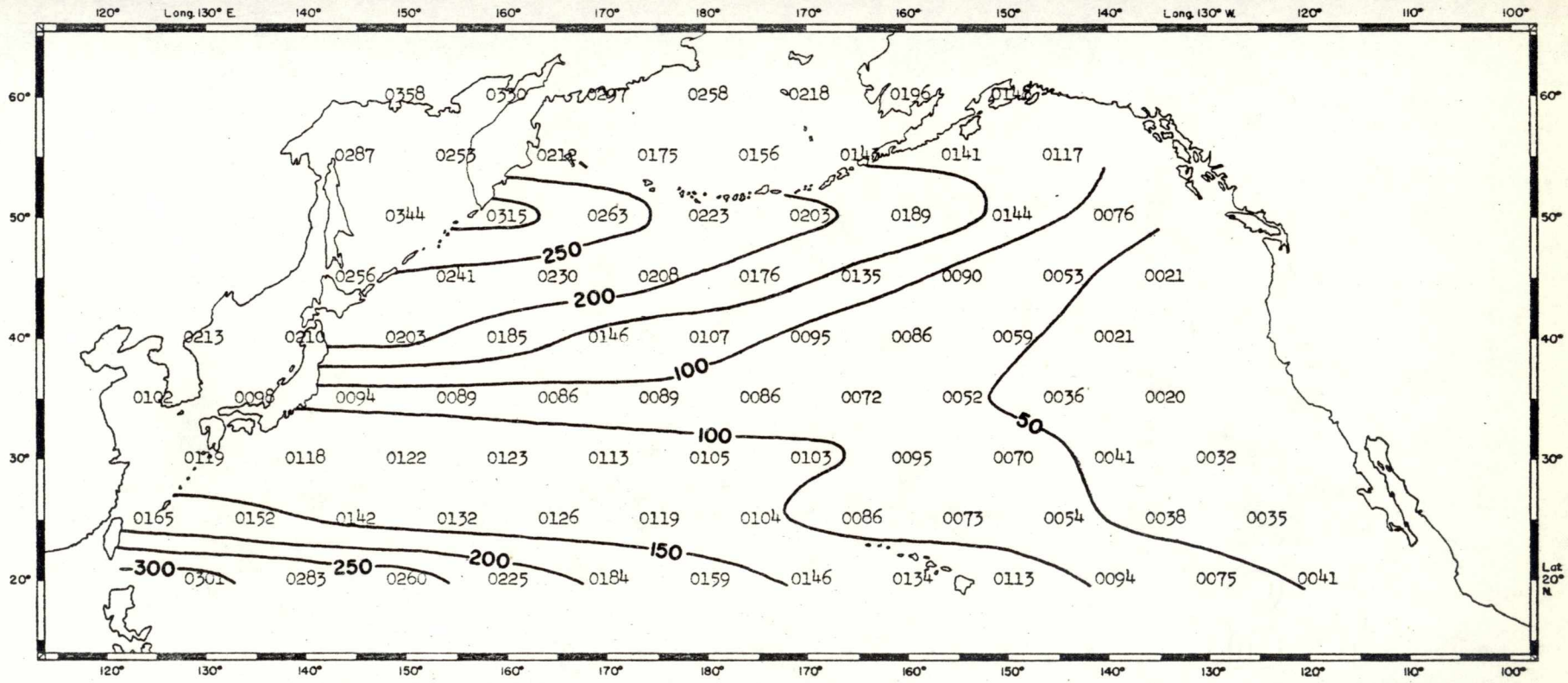
6m Sep 1 Sep 30 1952



VI. Integrated Geostrophic Transport

ANNUAL MEAN 1952

6s Sep 1 Sep 30 1952



VI. Integrated Geostrophic Transport

STANDARD DEVIATION 1952