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A COMPARISON OF GEOPOTENTIAL VS. WIND INPUT FOR A DIAGNOSTIC NUMERICAL MODEL

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A COMPARISON OF GEOPOTENTIAL VS. WIND INPUT

FOR A DIAGNOSTIC NUMERICAL MODEL

by

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ABSTRACT

A diagnostic multi-level, non-linear balance model, which can be used in either tropical or mid-latitude regions, is applied to a case study in a mid-latitude region on 15, 16 and 17 November 1966. The model accepts actual geopotential heights or geopotential heights derived from a non-divergent stream function which is computed from the actual wind field as input data.

A comparison is made between non-divergent stream functions computed from the wind field and those computed from the actual geopotential height field. A second comparison is made between the actual geopotential height field and the geopotential height field computed from the wind field. Qualitative and quantitative comparisons are made between the stream functions and geopotential heights, respectively, computed by the two different methods.

By making the above mentioned comparisons, a determination is made as to the accuracy of the model using wind data and finally the accuracy of the model in the tropics. The results indicate that use of the wind field as input data may not produce accurate results.

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TABLE OF SYMBOLS AND ABBREVIATIONS

f	Coriolis parameter
g	Acceleration of gravity
$\mathbb{K}$	Unit vector in the z-direction
$\mathbb{V}_H$	Horizontal velocity vector
z	Geopotential height
ϕ	Geopotential, gz
χ	Velocity potential for the irrotational component of velocity
ψ	Stream function for the non-divergent component of velocity
∇	Del operator
∇^2	Laplacian operator
J	Jacobian operator
u	Zonal component of the wind
v	Meridional component of the wind
ζ	Relative vorticity
Mb	Millibar
x	Distance along zonal direction
y	Distance along meridional direction
$\bar{f}$	Mean value of Coriolis parameter
$\Delta\psi$	Difference between stream function computed from the geopotential field and stream function computed from the wind field
Δz	Difference between actual geopotential height field and geopotential height field computed from the wind field
p	Atmospheric pressure

I. INTRODUCTION

Recently, Charney (1963) argued that synoptic scale vertical motions in the tropics were small and could be neglected. Further investigation (Baumhefner, 1968) has shown that, even though small in magnitude, the synoptic scale vertical motions may play an important role in the dynamics of the tropics.

In studying the three dimensional motions of the atmosphere a multi-level, non-linear balance model (Charney, 1962) can be very useful. Such a model has been successfully used by Krishnamurti (1968) in tropical and mid-latitude studies and by Baumhefner (1968) in a tropical study.

The original data may be inserted into such a model in two different ways, using either actual geopotential heights or geopotential heights derived from the wind field. In most tropical regions the large scale flow patterns are most reliably established by analysis of the wind field rather than analysis of the pressure field because pressure gradients become weak. In fact, diurnal and small scale factors can contribute as much as large scale dynamic effects.

To compute geopotential height from the wind field, a non-divergent stream function must be first computed and the geopotential height is then computed from the stream function using the balance equation. In this paper a comparison is made between non-divergent stream functions computed from the wind field and those computed from the actual geopotential field. A second comparison is made between the actual geopotential field and the geopotential field computed from the wind field.

Since the lack of conventional data hinders analysis in the tropics, the analysis of the non-divergent stream functions and the geopotential heights is made in an area outside the tropics where wind and geopotential data are reasonably dense. In mid-latitudes the synoptic conditions can be adequately described by using either geopotential data or wind data. However, in the tropics the synoptic conditions are best described by using the wind field rather than the geopotential field. Thus, by making the above mentioned comparisons, a determination can be made as to the accuracy of the model using wind data and finally the utility of the model in the tropics.

Baumhefner (1968) made similar comparisons between non-divergent stream functions calculated from the balance equation using geopotential heights and from the method described by Hawkins and Rosenthal (1965) using the wind field and computing the non-divergent stream function from the field of vorticity. The comparisons were made only for a tropical case and computing the stream function from the wind, as expected, was found to give the best results.

The results in areas outside the tropics should be applicable to the tropics because only instantaneous wind and geopotential parameters are involved in the analysis.

II. PROCEDURE

The method used to compute the non-divergent stream function (consult table of symbols for definitions) is the procedure suggested by Thompson (1961), which begins with a field of isotachs and isogons. The Helmholtz theorem,

$$\mathbb{V}_H = \mathbb{K} \times \nabla \psi + \nabla \chi, \tag{1}$$

allows decomposition of the wind vector into non-divergent and irrotational components. By taking the vertical component of the curl of eq. (1) the equation

$$\nabla^2 \psi = \mathbb{K} \cdot \nabla \times \mathbb{V}_H = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} \equiv \zeta \tag{2}$$

can be derived, which may be solved as a Poisson equation for the stream function where the relative vorticity is computed from the wind analysis. The boundary conditions for solving eq. (2) are given by

$$\psi = \frac{gz}{\bar{f}} \tag{3}$$

where $\bar{f} = 1.03 \times 10^{-4}\ \mathrm{sec}^{-1}$, which was determined by varying $\bar{f}$ until the north-south gradient of the non-divergent stream function was proportional to the north-south gradient of the geopotential height. Using a simultaneous method of relaxation for the field of the vorticity with suitable boundary conditions, the non-divergent stream function on an isobaric surface is obtained. This stream function is then assumed to be related to a geopotential height distribution from the balance equation,

$$\nabla^2\phi = \nabla \cdot f\, \nabla\psi + 2J\left(\frac{\partial\psi}{\partial x}, \frac{\partial\psi}{\partial y}\right). \qquad (4)$$

The boundary conditions for solving eq. (4) are the actual geopotential heights of the isobaric surfaces.

The second method is to compute the non-divergent stream function from the balance equation (5) using only geopotential heights.

$$\nabla \cdot f\, \nabla\psi = \nabla^2\phi - 2J\left(\frac{\partial\psi}{\partial x}, \frac{\partial\psi}{\partial y}\right) \qquad (5)$$

The boundary conditions for solving eq. (5) are those given by eq. (3).

Since the actual wind field is available, insertion of U and V in place of $\frac{\partial\psi}{\partial y}$ and $\frac{\partial\psi}{\partial x}$ into the Jacobian term for the stream function (ψ) should be investigated.

For solving eq.(5) a multi-level, non-linear balance model (Krishnamurti, 1968) was utilized, using only the computational features for the geopotential fields and non-divergent stream functions. The model contains 33 grid points in the zonal direction and 15 grid points in the meridional direction spaced 2.5 degrees apart at 6 levels in the vertical. The grid is bounded by the 55W and 135W meridians and the 25N and 60N parallels. Actual grid values are inscribed at 27 grid points in the zonal direction, but an artificial cyclical continuity is provided by extending the grid over 6 extra points by fitting a polynomial through the boundary conditions. This region is numerically of no interest in diagnostic studies but becomes essential in prediction studies.

Calculations of the input values to solve the equations are standard. Five point schemes are used for the Laplacian, the Richardson simultaneous method of relaxation is used for eqs. (2) and (4), the Liebmann forward extrapolation technique of relaxation is used for eq. (5), Jacobians are of the standard form and all derivatives are evaluated over a distance of two grid points.

Isotach, isogon and geopotential height analyses were made for the 1000, 850, 700, 500, 300 and 200 mb levels for 15, 16 and 17 November 1966, 1200 GMT. Isotachs were analyzed at 5 knot intervals, isogons analyzed at 5 degree intervals and geopotential heights analyzed at 5 meter intervals.

The analysis of the wind field has to be very accurate. A 5 degree error in wind direction can create about a 9% error in either the meridional or zonal directional component of the wind. A 5 knot error in the wind speed can create about a 16% error in either the meridional or zonal velocity component of the wind. A combination of a 5 degree error in wind direction added to a 5 knot error in wind speed can produce about a 26% error in either the meridional or zonal components of the wind.

The numerical model accepts data at the above mentioned 6 levels and utilizes the x, y, p coordinate system. The analyzed geopotential and stream function fields appear at the 1000, 800, 600, 400 and the 200 mb surfaces. These levels, as recommended by Krishnamurti (1968), are convenient for analysis of the vertical velocity field. Although the effect of different types of input on the vertical velocity field is an ultimate objective, the effects will not be discussed in this paper.

III. SYNOPTIC SITUATION

The synoptic meteorological situation for 15, 16 and 17 November 1966, is characterized by a blocking high extending from northwestern Canada to Hudson Bay to the eastern United States coast and another high in the Central Pacific at 160 degrees west longitude. A deep low pressure system is located in the Gulf of Alaska on 15 November and has moved southward to a position 500 miles west of Oregon on 17 November.

At the 500 mb level a quasi-stationary low pressure system is located about 300 miles northwest of Hudson Bay. Another low is located in the Eastern Pacific about 500 miles west of British Columbia on 15 November and has moved southwest to a position 700 miles west of Portland, Oregon, on 17 November. A fairly stationary high pressure system is located across the southern United States for the period.

IV. CASE STUDY

Individual computations of the non-divergent stream functions and geopotential heights were made for three cases: 15, 16 and 17 November 1966, 1200 GMT. Since each case investigated yielded similar results, the following discussion will be a summation of the three cases, with illustrations for the 15 November 1966, 1200 GMT case.

In comparing the non-divergent stream function computed from the wind field to the non-divergent stream function computed from the actual geopotential height field several similarities and differences, at all levels, are evident (Figs. 1-8). The similarities between the two methods of computing the stream functions are the locations, on the boundary, of the high and low centers. The high and low centers, respectively, have the same position and intensity in both methods of computation because the same boundary conditions are imposed upon the solution of each method. Upon examining the qualitative differences, the stream functions computed from the wind field exhibit, at all levels, a smaller amplitude of the trough and ridge associated with the low and high respectively, weaker gradients of the stream functions, a different direction of flow in the eastern mid-latitude region and a more zonal flow in low latitudes when compared to the stream functions computed from the actual geopotential height field.

To make a quantitative comparison of the two methods the stream functions computed from the wind field were graphically subtracted from the stream functions computed from the actual geopotential height

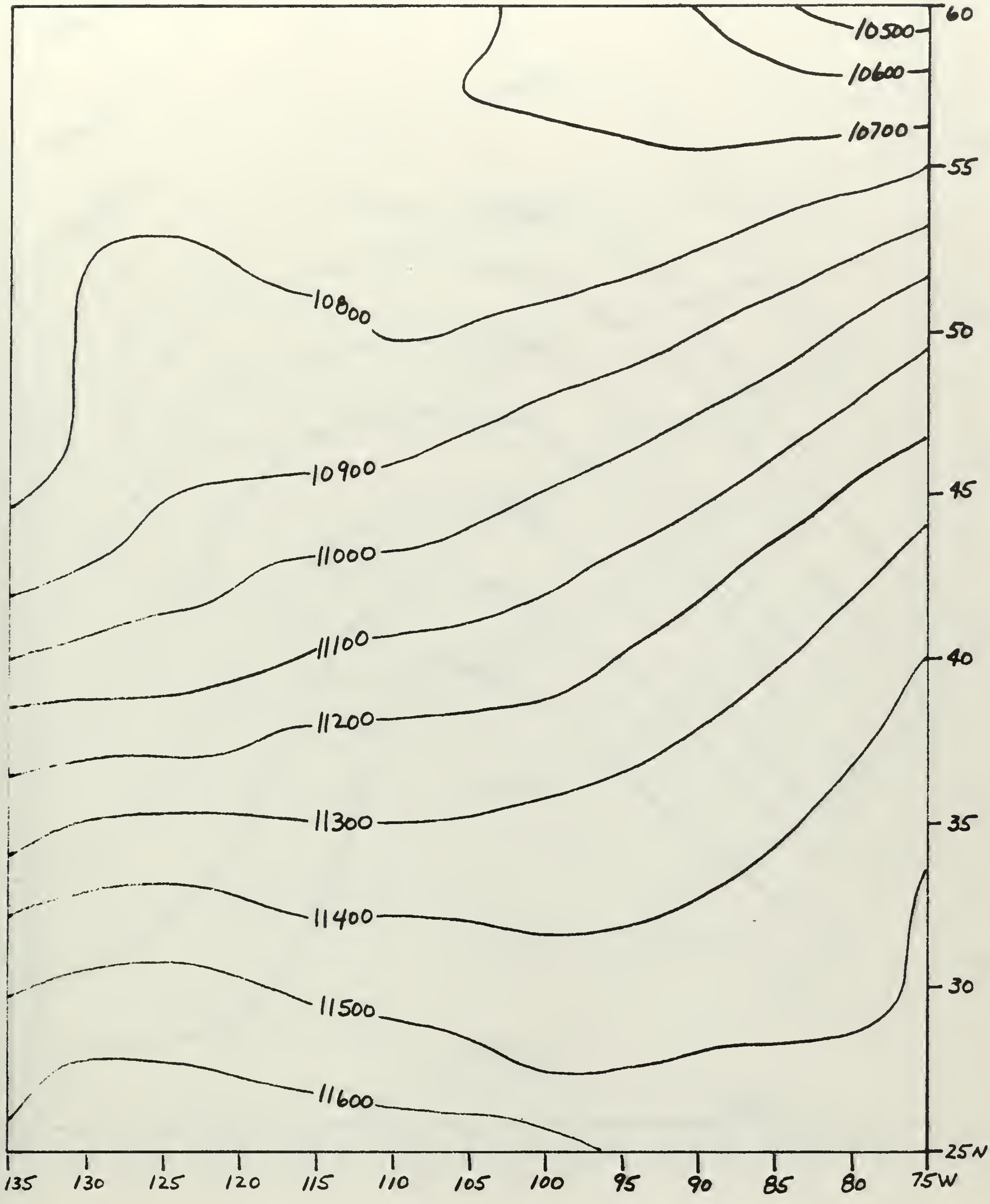

Fig. 1. Non-divergent stream function computed from wind field at 200 mb, 15 November 1966, 1200 GMT. Stream function interval 100 $\times 10^5$ m^2 sec^{-1}.

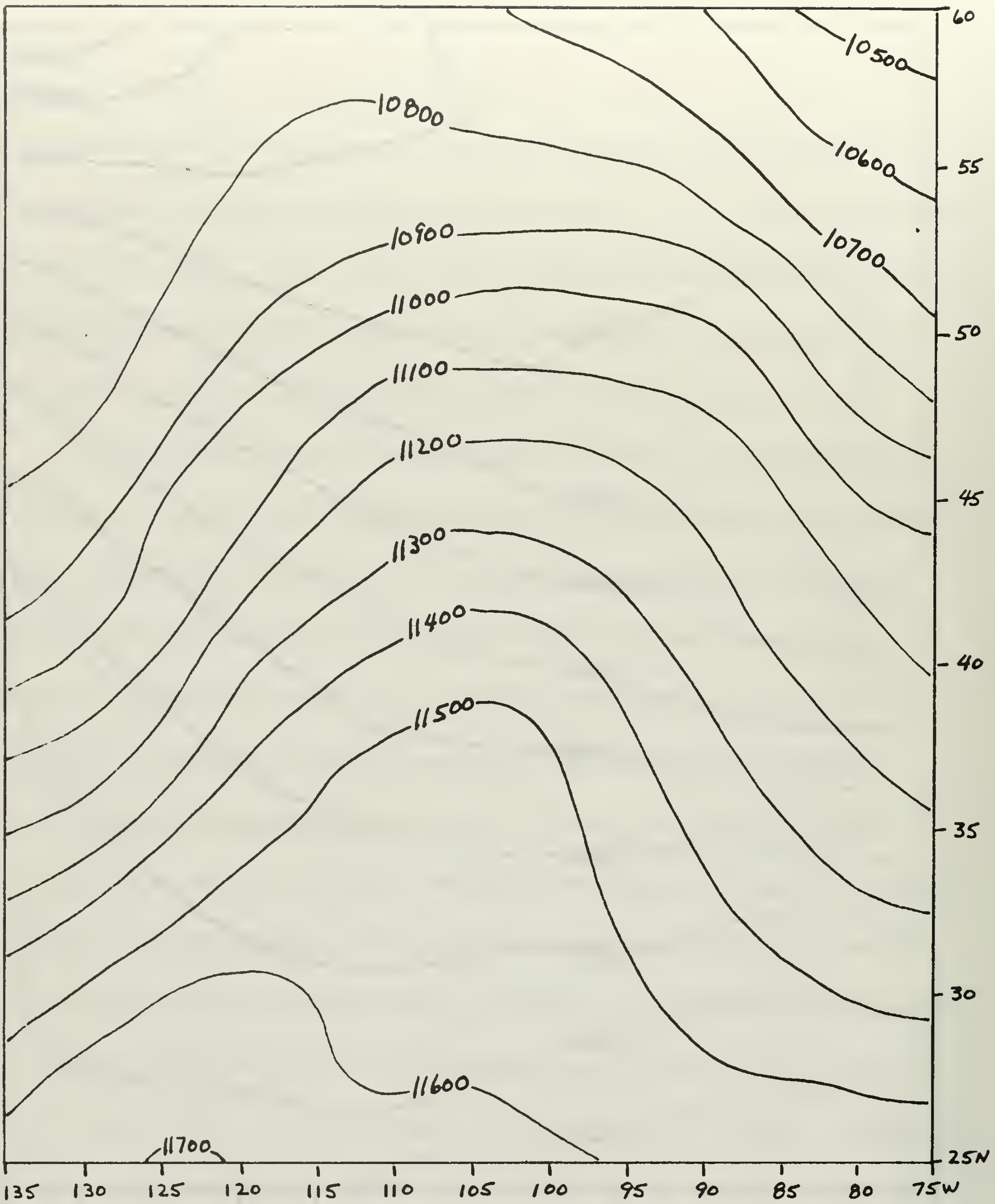

Fig. 2. Non-divergent stream function computed from geopotential height at 200 mb, 15 November 1966, 1200 GMT. Stream function interval 100 x 10^5 m^2 sec^{-1}.

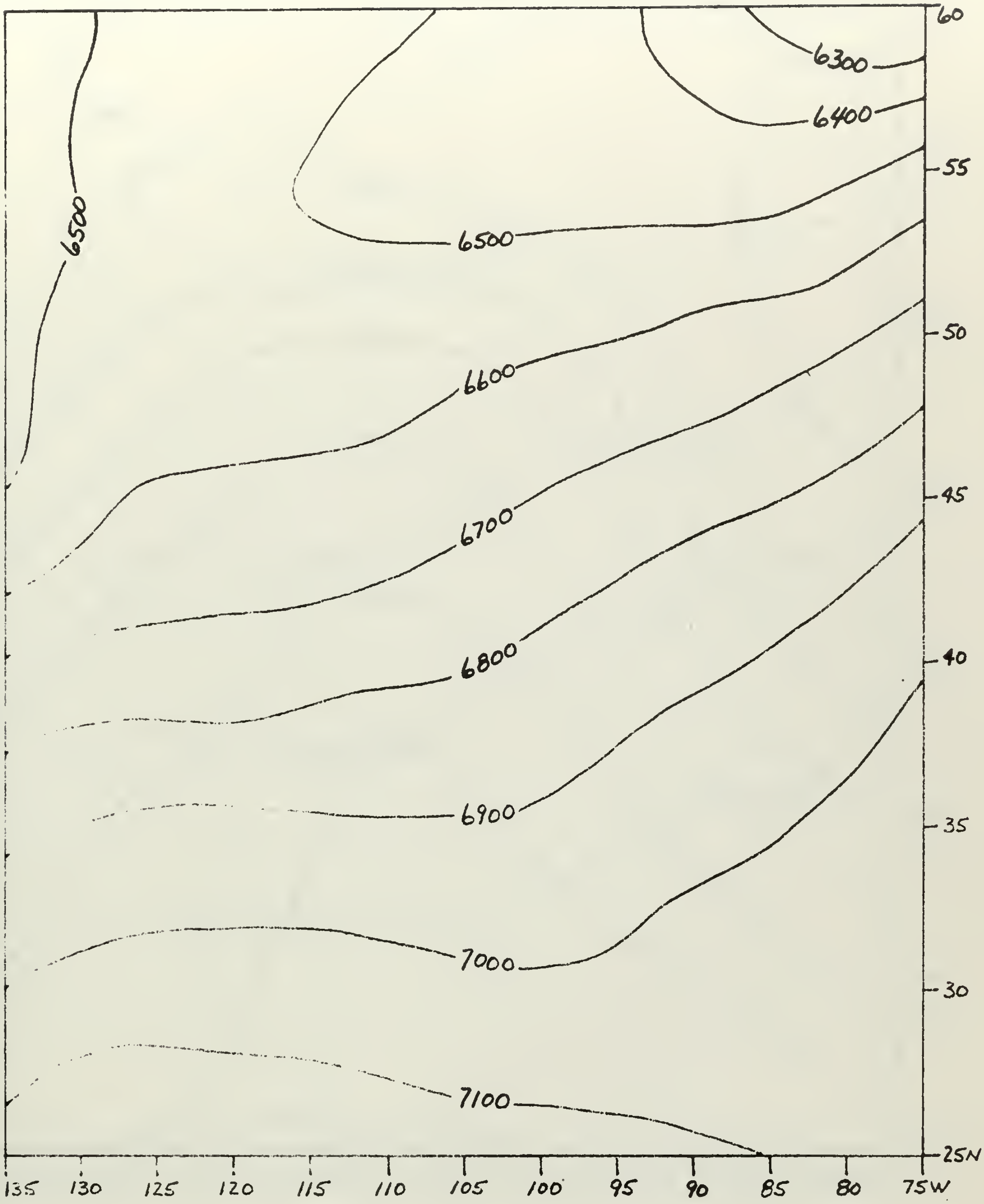

Fig. 3. Non-divergent stream function computed from wind field at 400 mb, 15 November 1966, 1200 GMT. Stream function interval 100×10^5 m^2 sec^{-1}.

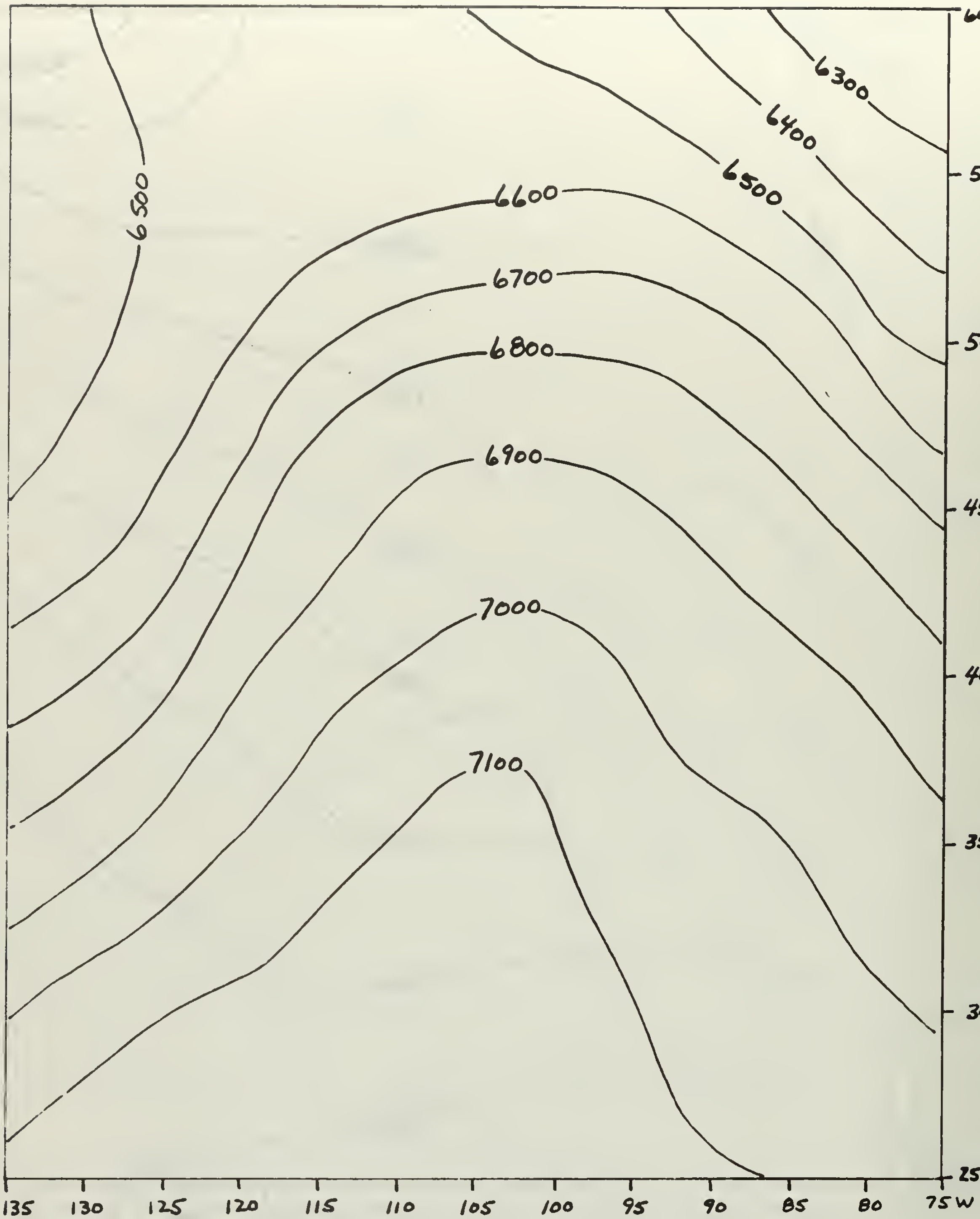

Fig. 4. Non-divergent stream function computed from geopotential height at 400 mb. 15 November 1966, 1200 GMT.
Stream function interval 100×10^5 m2 sec^{-1}.

Fig. 5. Non-divergent stream function computed from wind field at 600 mb, 15 November 1966, 1200 GMT. Stream function interval 100 x 10^5 m^2 sec^{-1}.

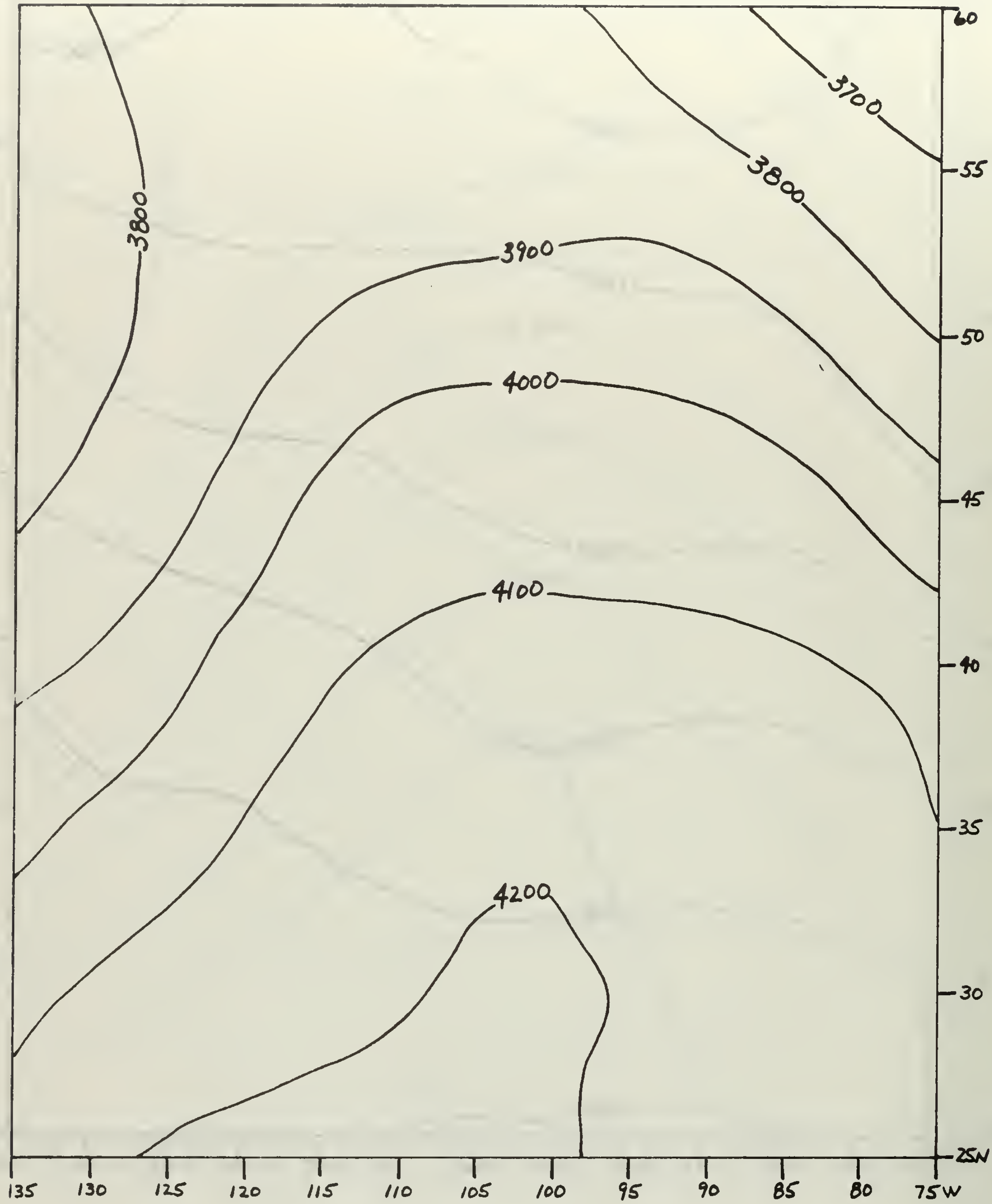

Fig. 6. Non-divergent stream function computed from geopotential height at 600 mb, 15 November 1966, 1200 GMT.
Stream function interval 100 x 10^5 m^2 sec^{-1}.

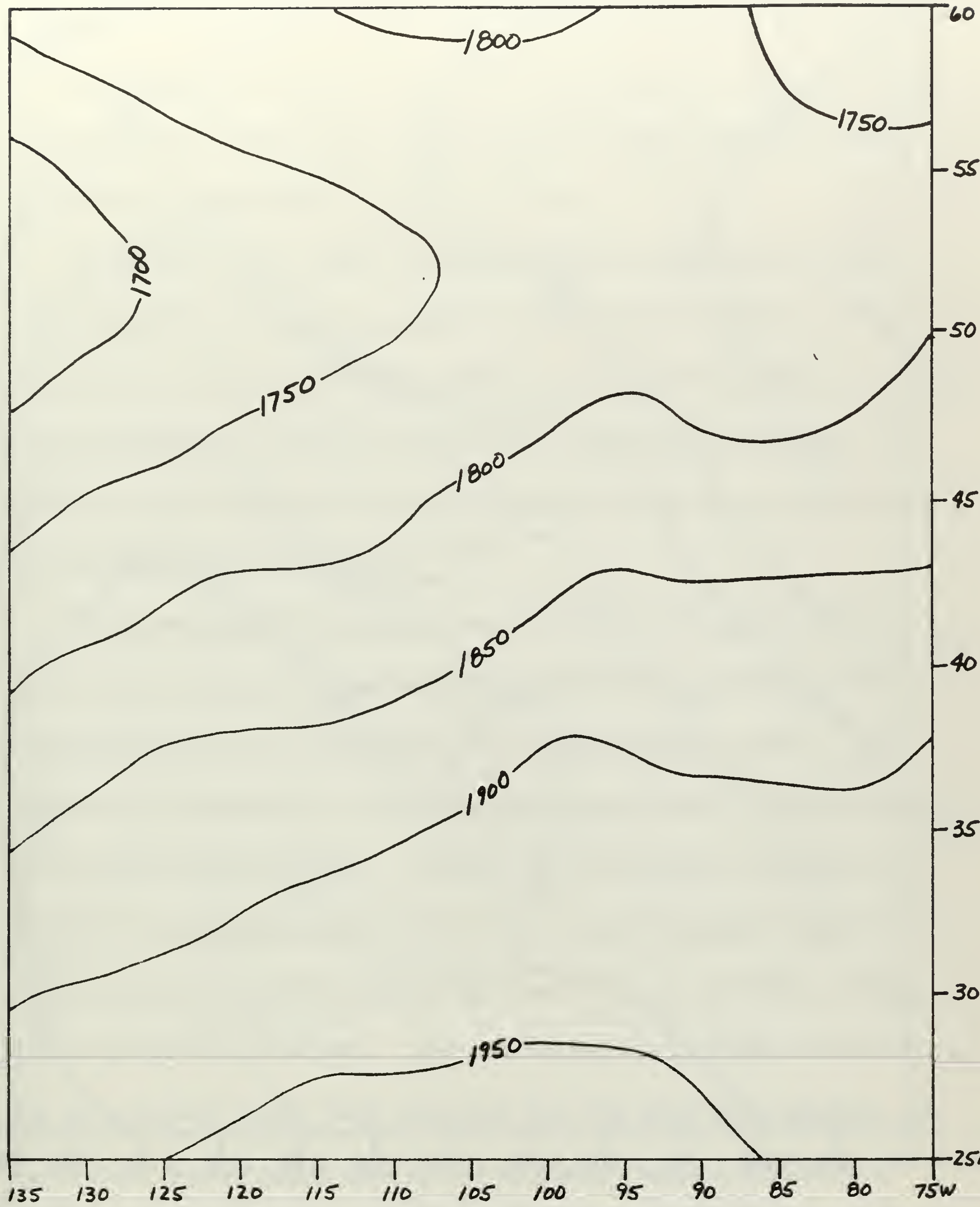

Fig 7. Non-divergent stream function computed from wind field at 800 mb, 15 November 1966, 1200 GMT. Stream function interval 50 $\times 10^5$ m^2 sec^{-1}.

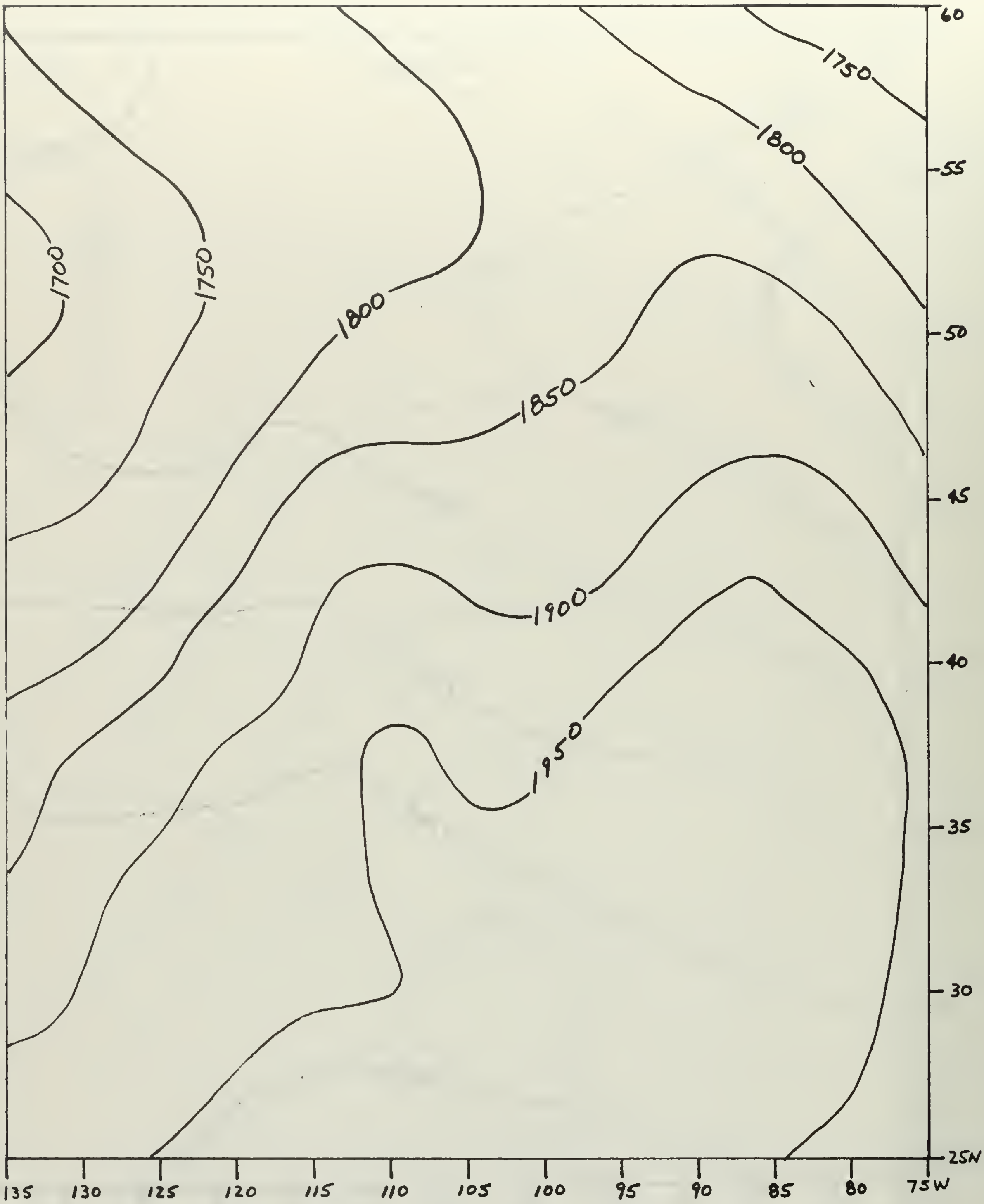

Fig. 8. Non-divergent stream function computed from geopotential height at 800 mb, 15 November 1966, 1200 GMT.
Stream function interval 50 x 10^5 m^2 sec^{-1}.

field (hereafter denoted $\Delta\psi$). At all levels (Figs. 9-12) the field of $\Delta\psi$ exhibits a positive center near the ridge and a negative center near the trough in the stream function field computed from the actual geopotential height field (Figs. 2, 4, 6, 8).

At all levels the stream functions computed from the wind field have a smaller magnitude in regions of anticyclonic flow and a larger magnitude in regions of cyclonic flow than the stream functions computed from the actual geopotential height field. The difference between the stream functions computed by the two different methods increases with increasing geopotential height.

Upon comparing the geopotential height field computed from the wind field to the actual geopotential height field several similarities and differences are, at all levels, also evident (Figs. 13-20). The similarities between the two geopotential height fields are the locations of the high and low centers. The high and low centers, respectively, have the same position and intensity because the boundary conditions for computing the geopotential height field from the wind field are the actual geopotential heights. Upon examining the qualitative differences, the geopotential height field computed from the wind field exhibits, at all levels, greater zonal flow in low latitudes, weaker gradients of geopotential height and smaller amplitudes of the ridge and trough when compared to the actual geopotential height field.

In making quantitative comparisons of the gradients of the geopotential height fields, the geopotential height computed from the

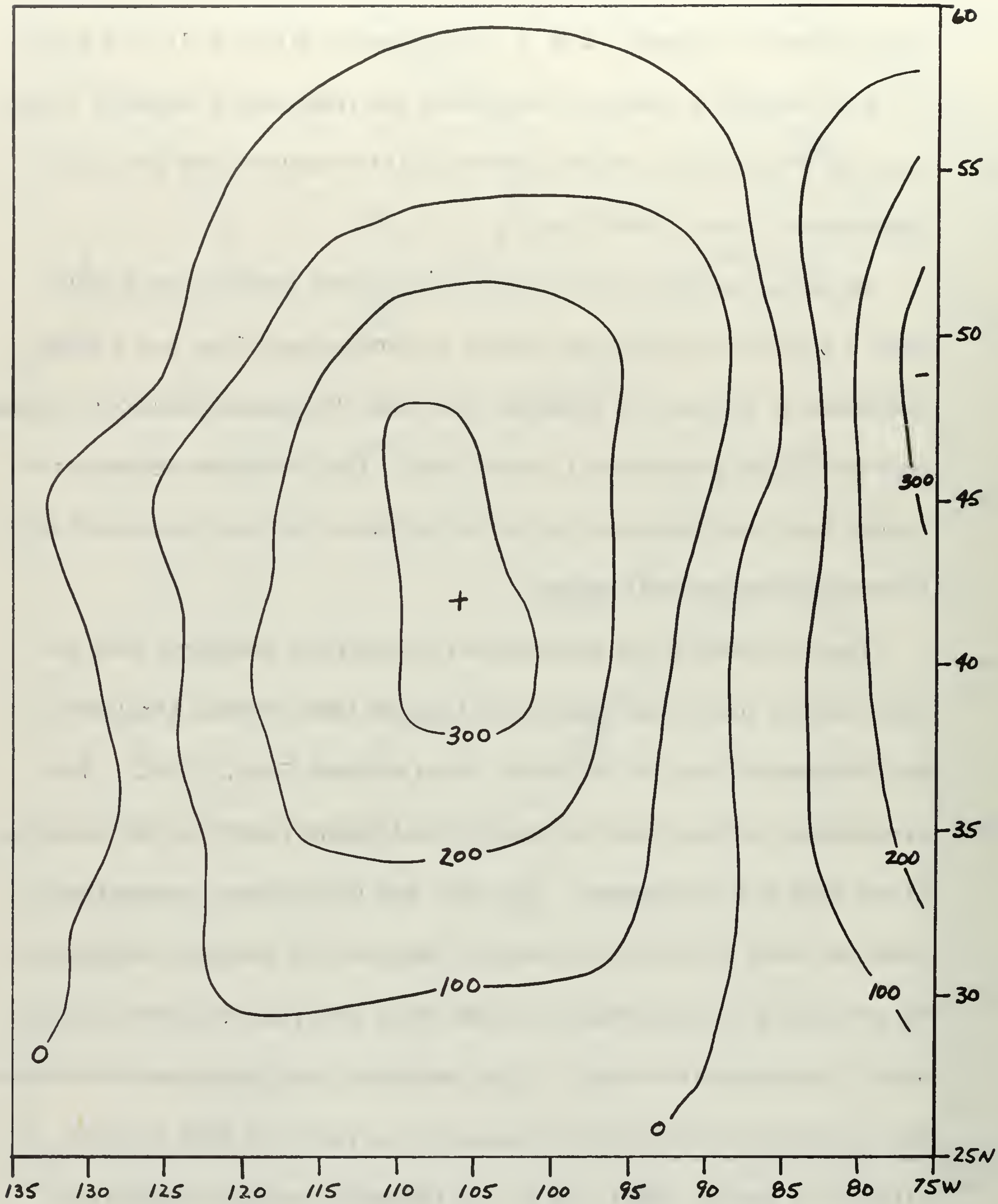

Fig. 9. Difference between stream functions computed from geopotential field and wind field at 200 mb 15 November 1966, 1200 GMT. Difference interval 100 m^2 sec^{-1}.

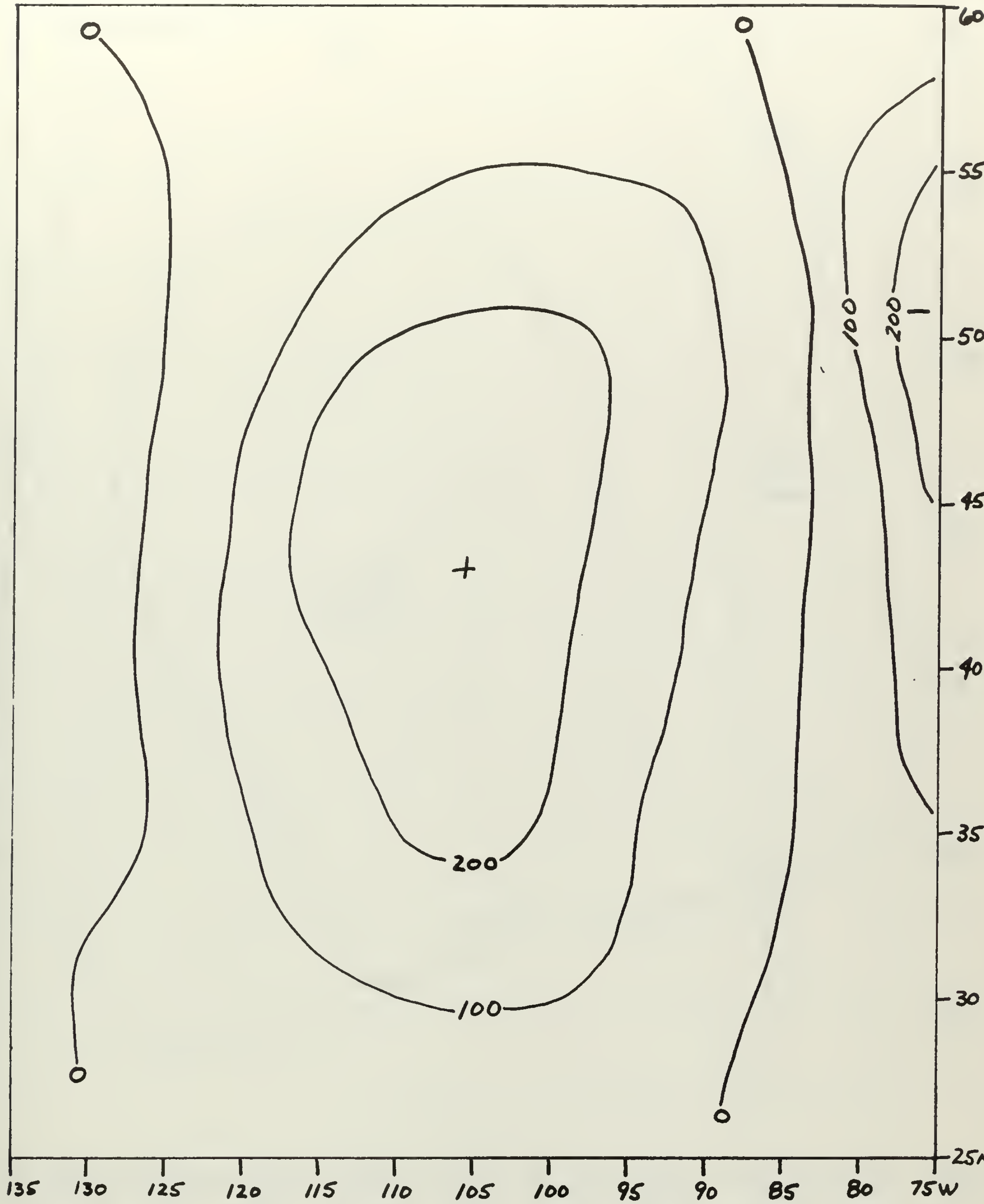

Fig. 10. Difference between stream functions computed from geopotential field and wind field at 400 mb, 15 NOvember 1966, 1200 GMT. Difference interval 100 m^2 sec^{-1}.

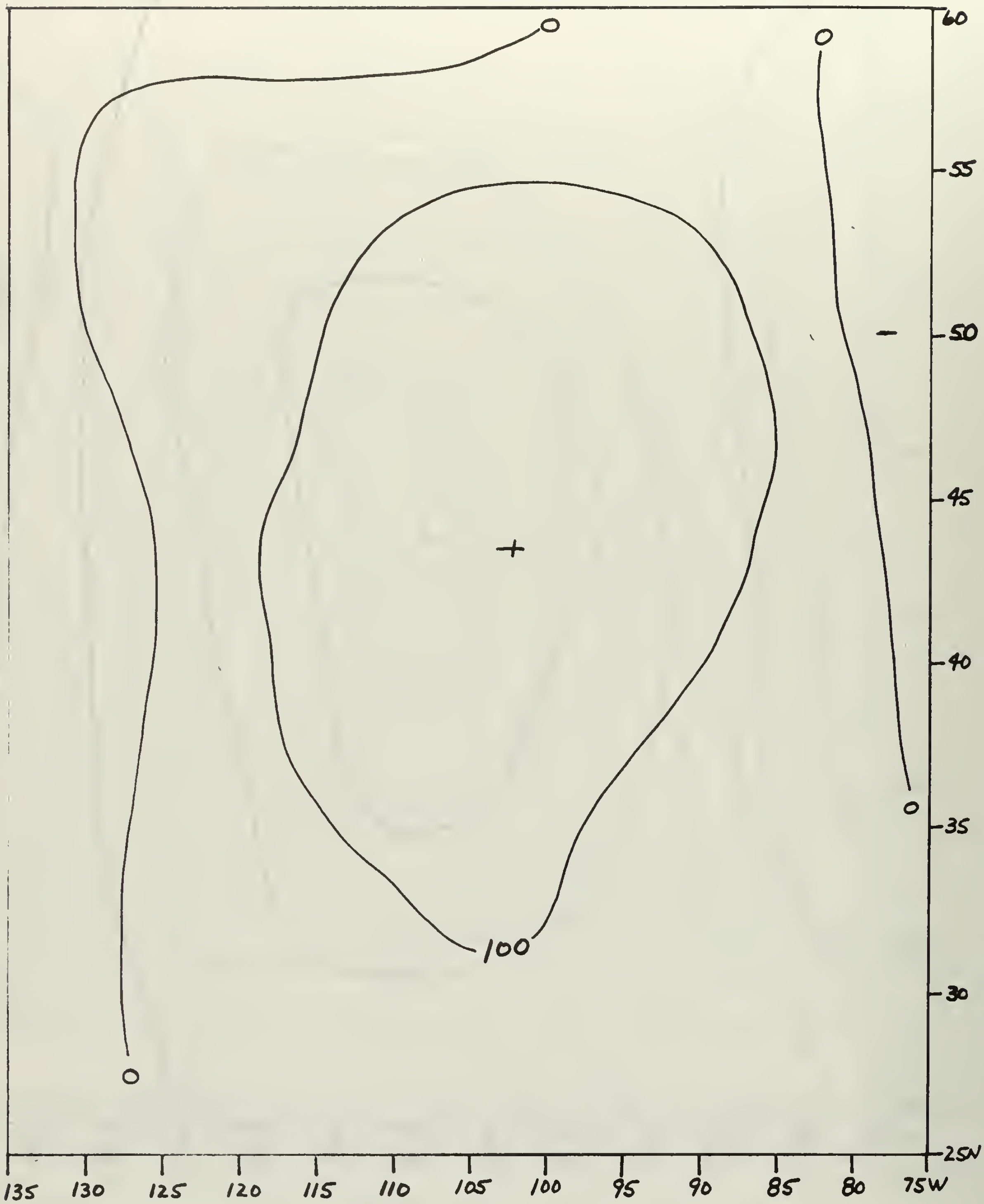

Fig. 11. Difference between stream functions computed from geopotential field and wind field at 600 mb, 15 November 1966, 1200 GMT. Difference interval 100 m^2 sec^{-1}.

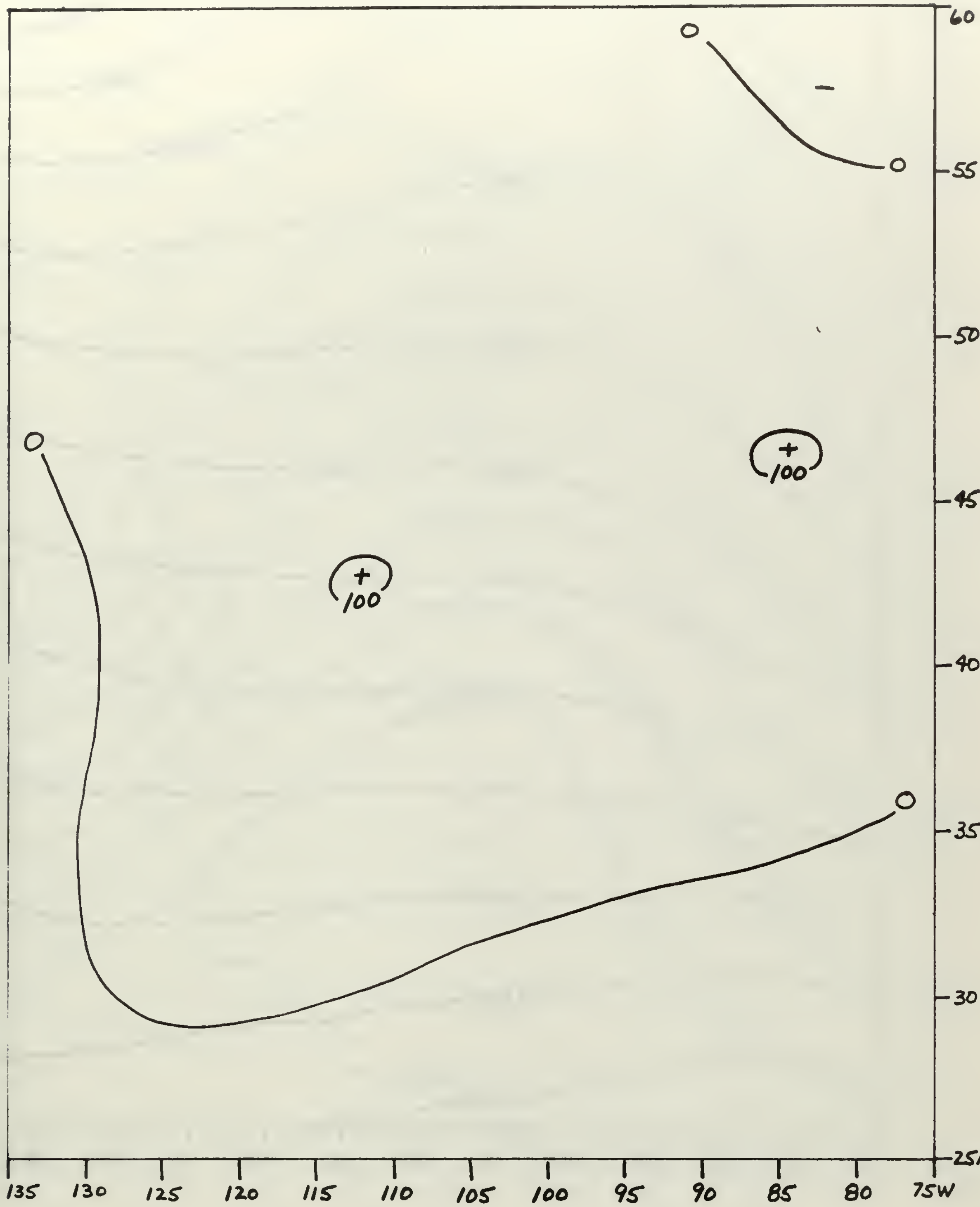

Fig. 12. Difference between stream functions computed from geopotential field and wind field at 800 mb, 15 November 1966, 1200 GMT. Difference interval 100 m^2 sec^{-1}.

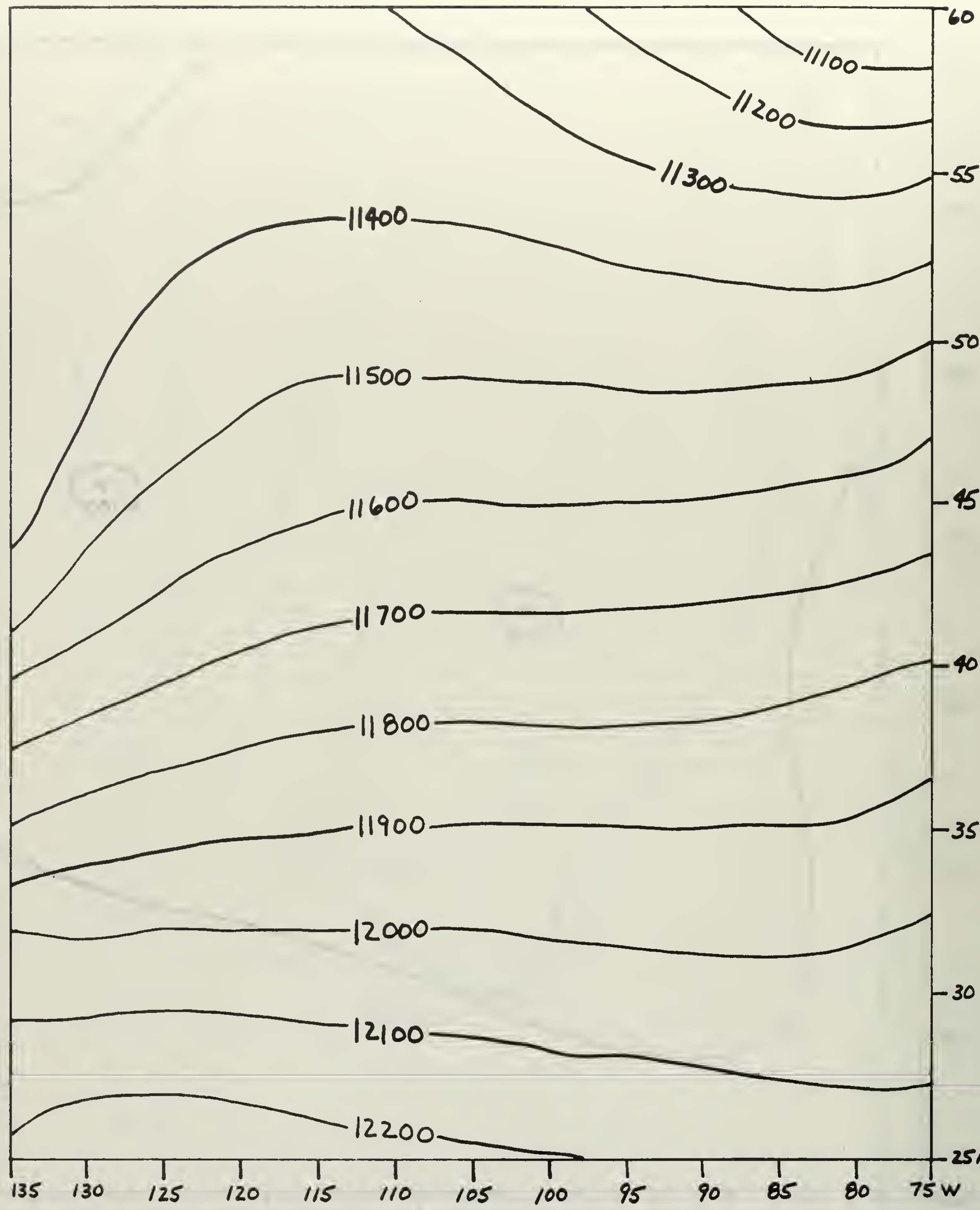

Fig. 13. Geopotential height computed from wind field at 200 mb, 15 November 1966, 1200 GMT. Heights in meters. Interval, 100 meters.

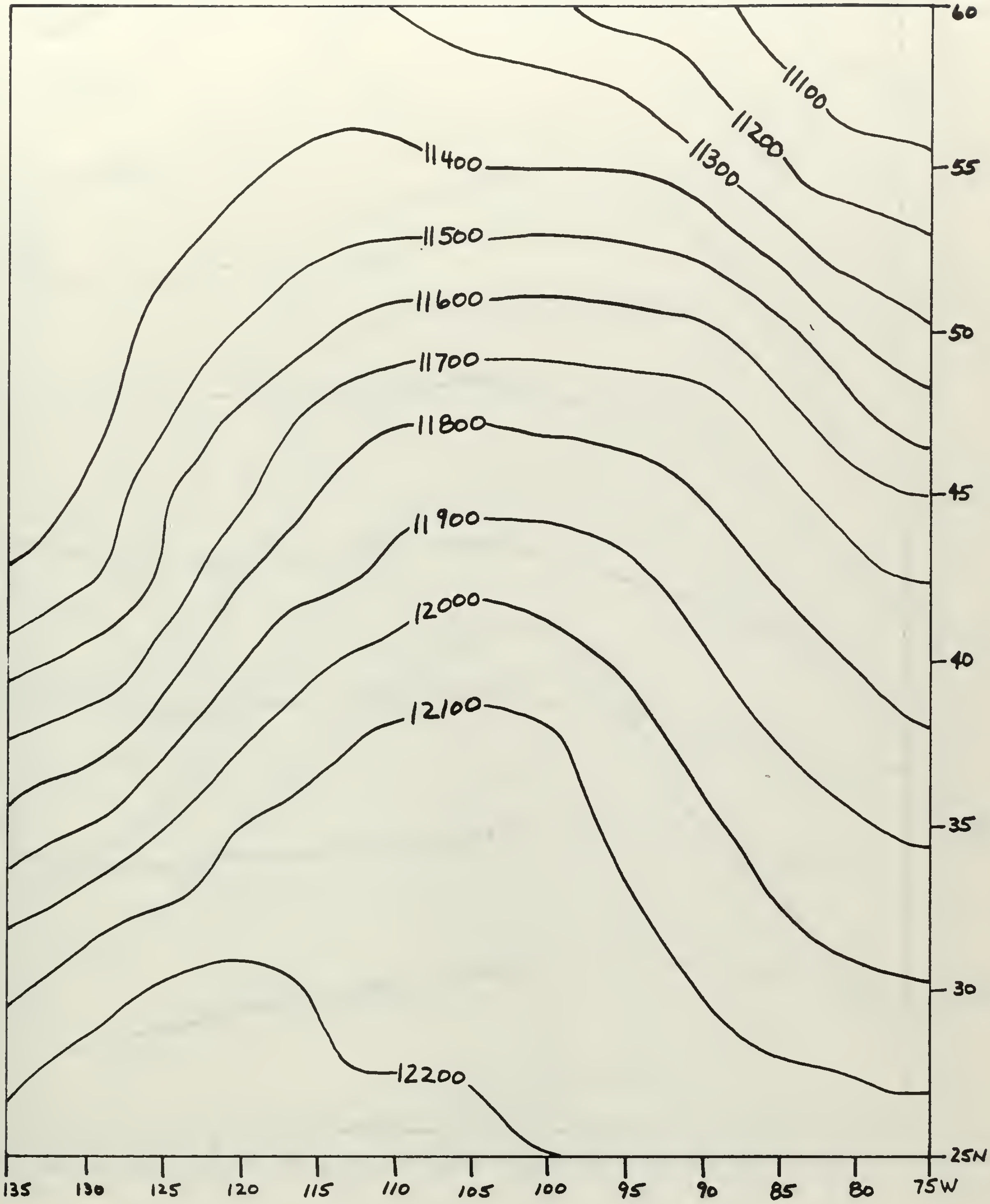

Fig. 14. Geopotential height at 200 mb, 15 November 1966, 1200 GMT.
Heights in meters. Interval, 100 meters.

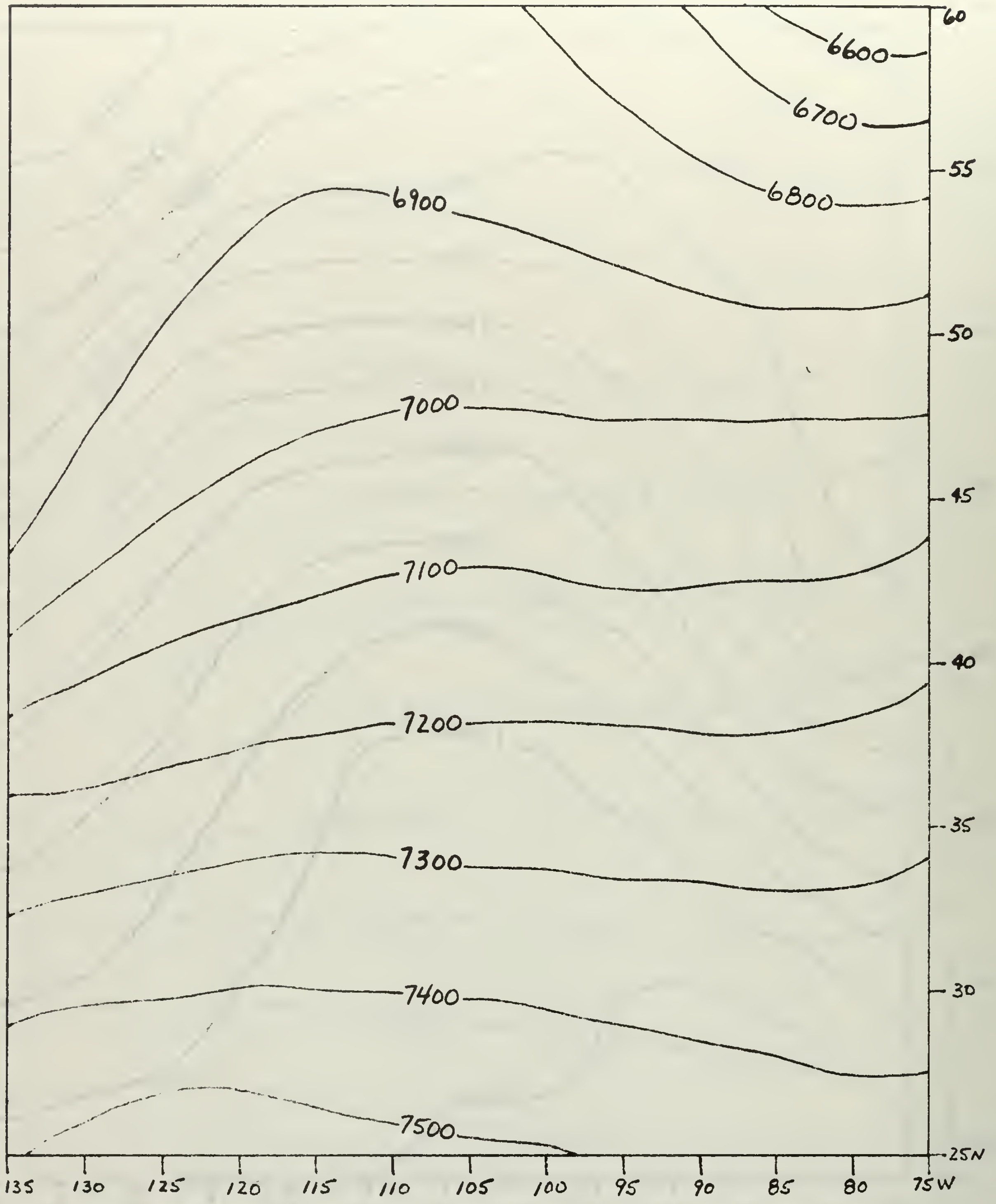

Fig. 15. Geopotential height computed from wind field at 400 mb, 15 November 1966, 1200 GMT. Heights in meters. Interval, 100 meters.

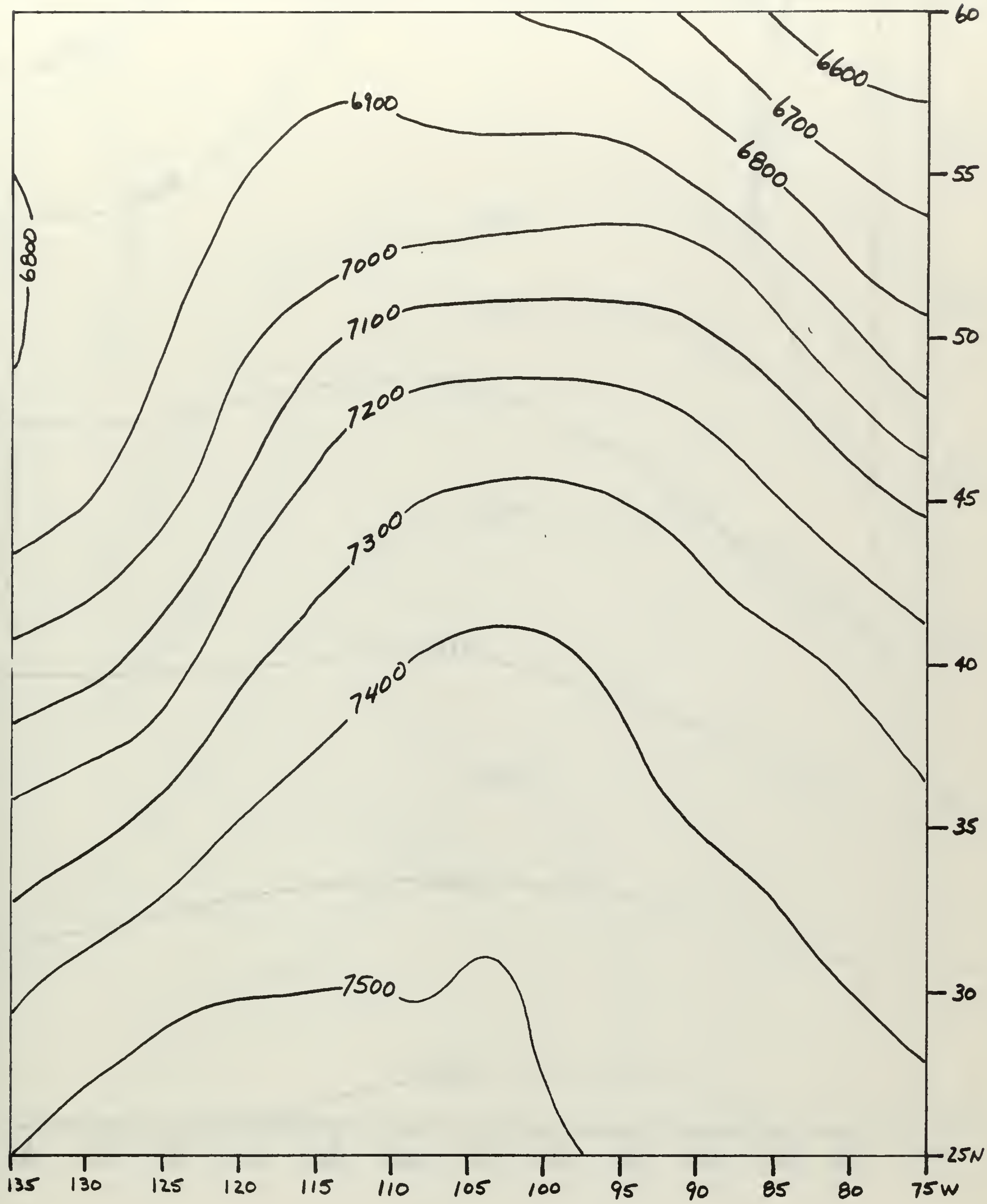

Fig. 16. Geopotential height at 400 mb, 15 November 1966, 1200 GMT.
Heights in meters. Interval, 100 meters.

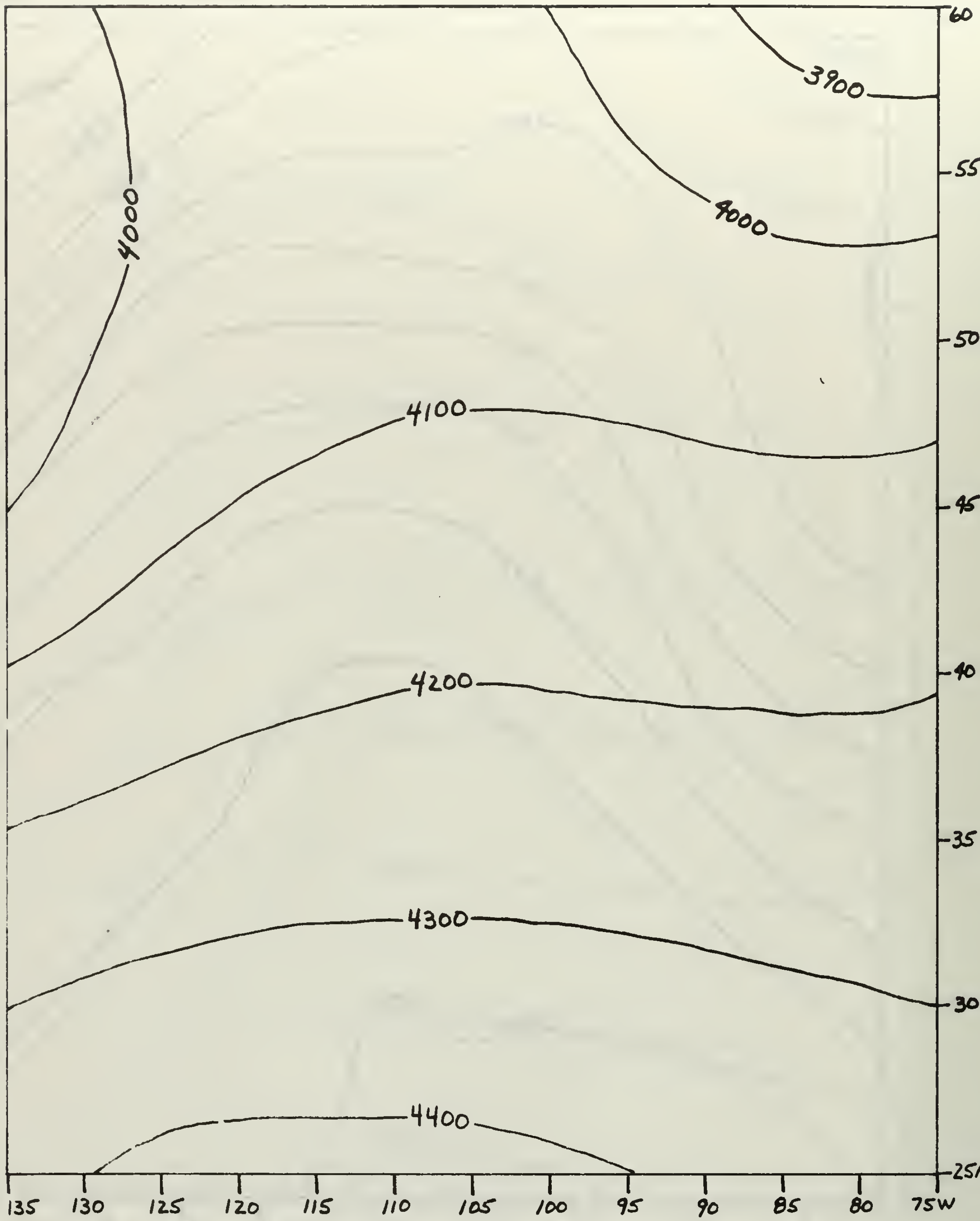

Fig. 17. Geopotential height computed from wind field at 600 mb. 15 November 1966, 1200 GMT. Heights in meters. Interval, 100 meters.

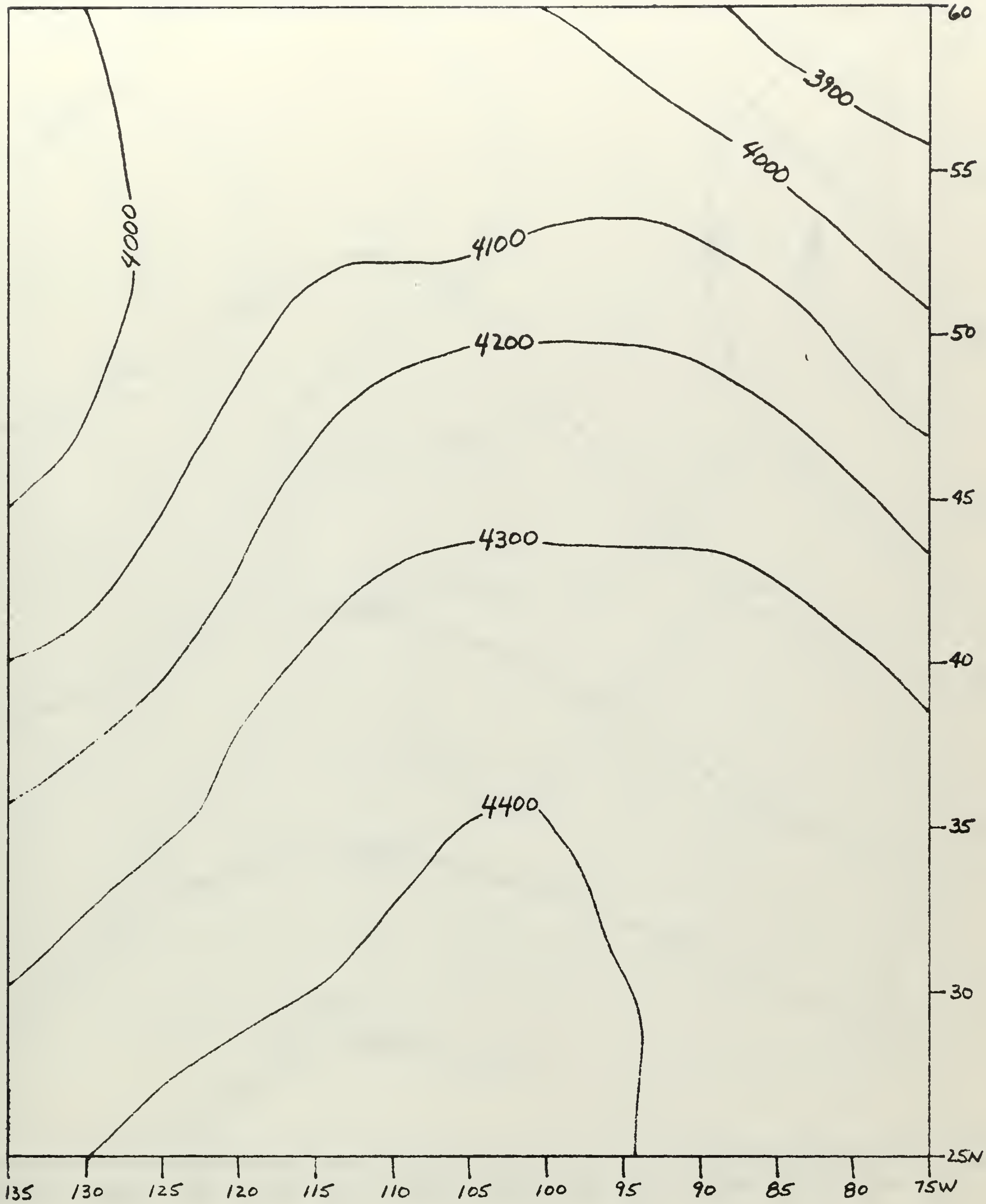

Fig. 18. Geopotential height at 600 mb, 15 November 1966, 1200 GMT.
Heights in meters. Interval, 100 meters.

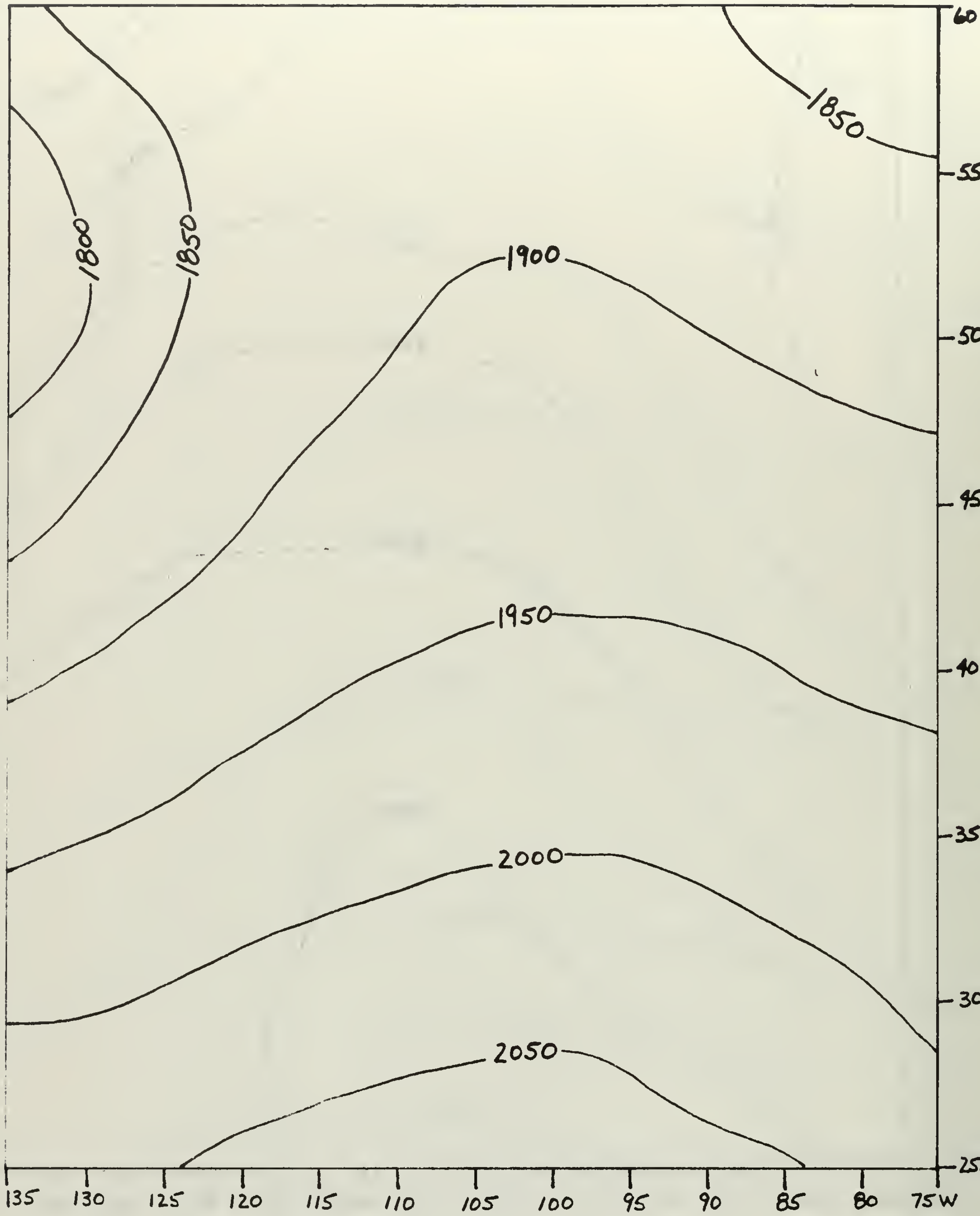

Fig. 19. Geopotential height computed from wind field at 800 mb, 15 November 1966, 1200 GMT. Heights in meters. Interval, 50 meters.

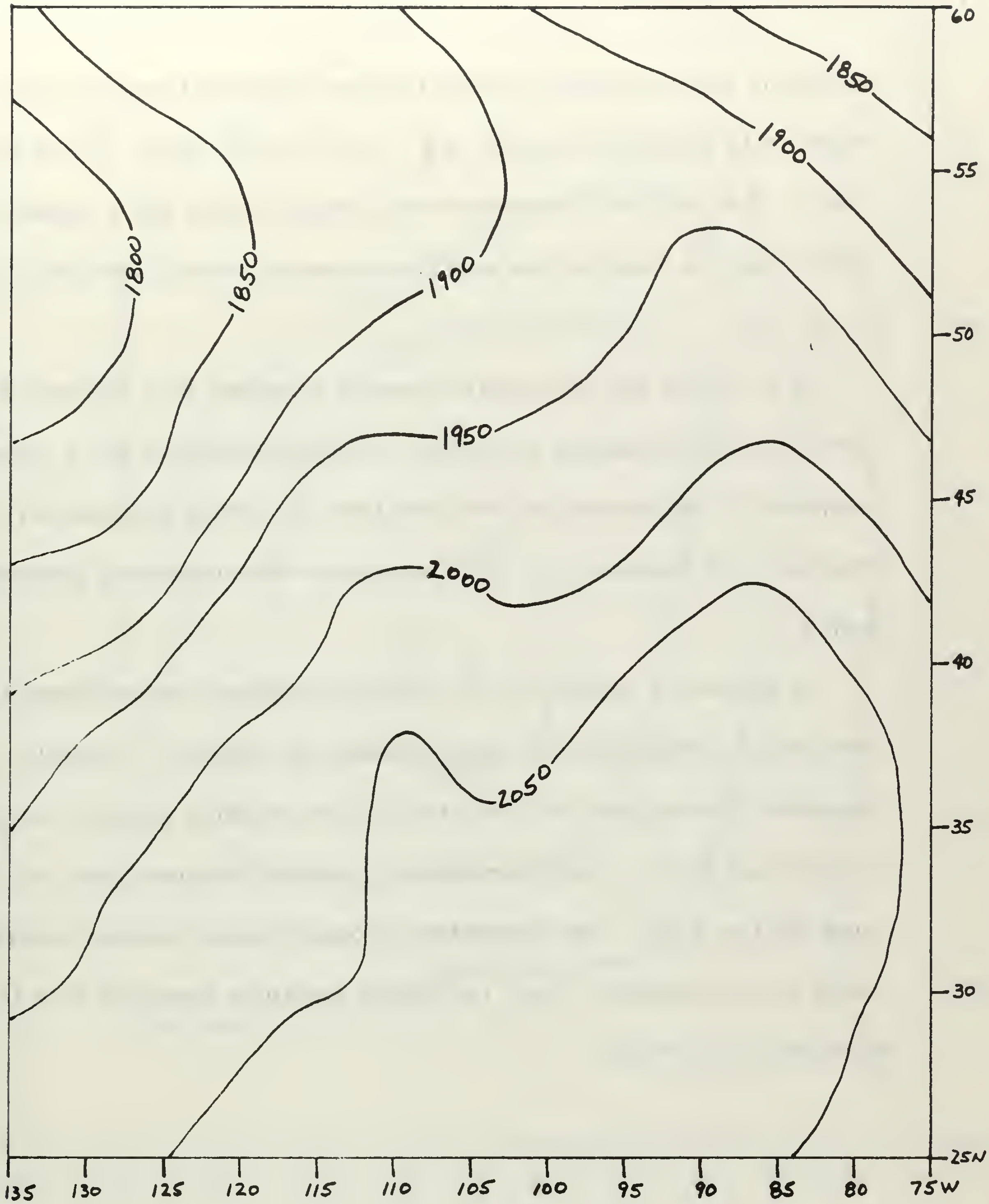

Fig. 20. Geopotential height at 800 mb, 15 November 1966, 1200 GMT.
Heights in meters. Interval, 50 meters.

wind field was graphically subtracted from the actual geopotential height field (hereafter denoted Δz). At all levels (Figs. 21-24) the field of Δz exhibits a positive center near the ridge and a negative center near the trough in the actual geopotential height field (Figs. 14, 16, 18, 20).

At all levels the geopotential heights computed from the wind field have a smaller magnitude in regions of anticyclonic flow and a larger magnitude in regions of cyclonic flow than the actual geopotential heights. The magnitude of Δz increases with increasing geopotential height.

To ensure the accuracy of the stream functions computed from the wind field a comparison was made between the relative vorticity computed directly from the wind field and the relative vorticity computed by inverting eq. (2), using the stream functions computed from the wind field as input. The comparison showed the two relative voriticity fields to be identical. Thus, the stream functions computed from the wind field are correct.

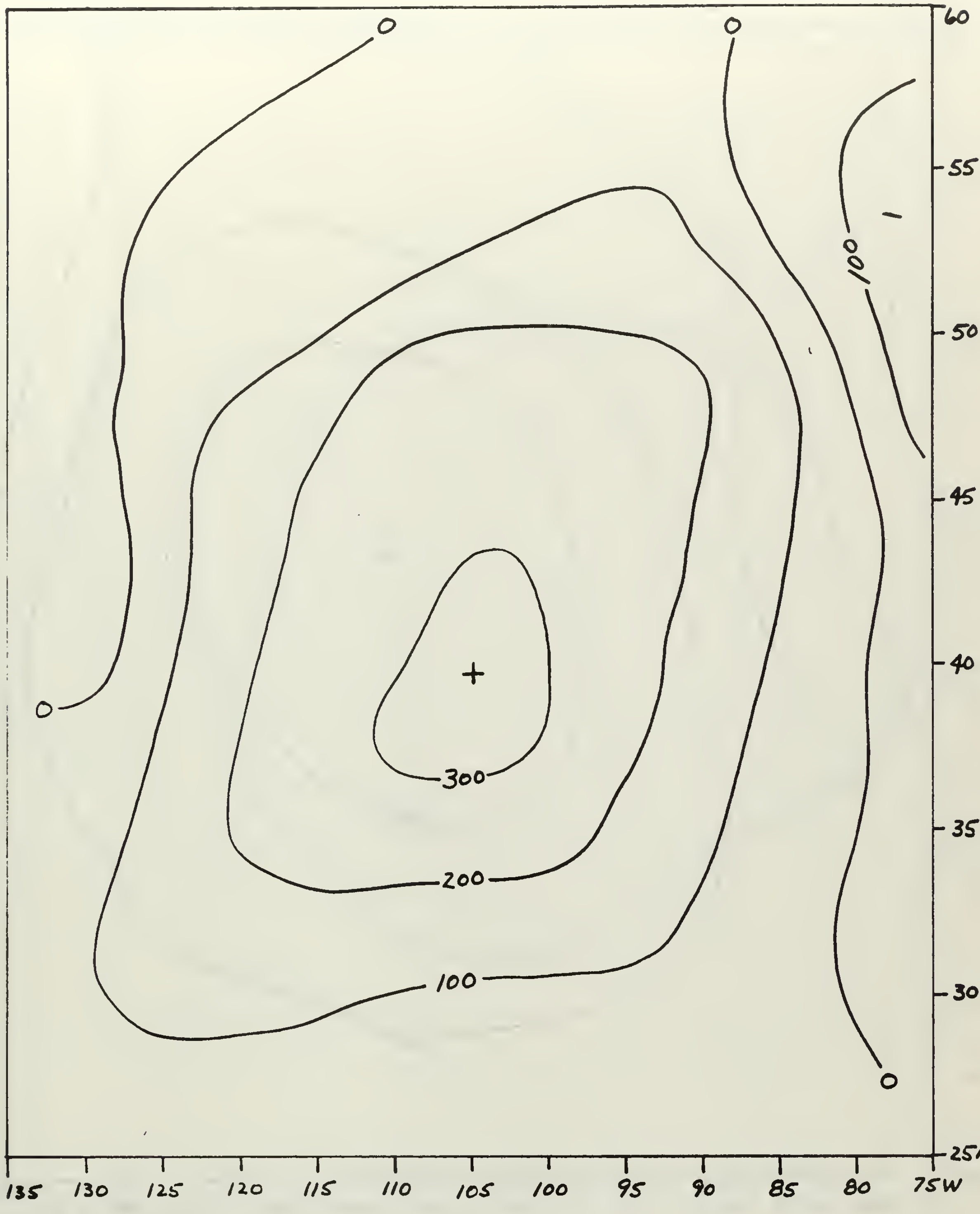

Fig. 21. Difference between actual geopotential field and geopotential field computed from wind field at 200 mb, 15 November 1966, 1200 GMT. Difference interval 100 meters.

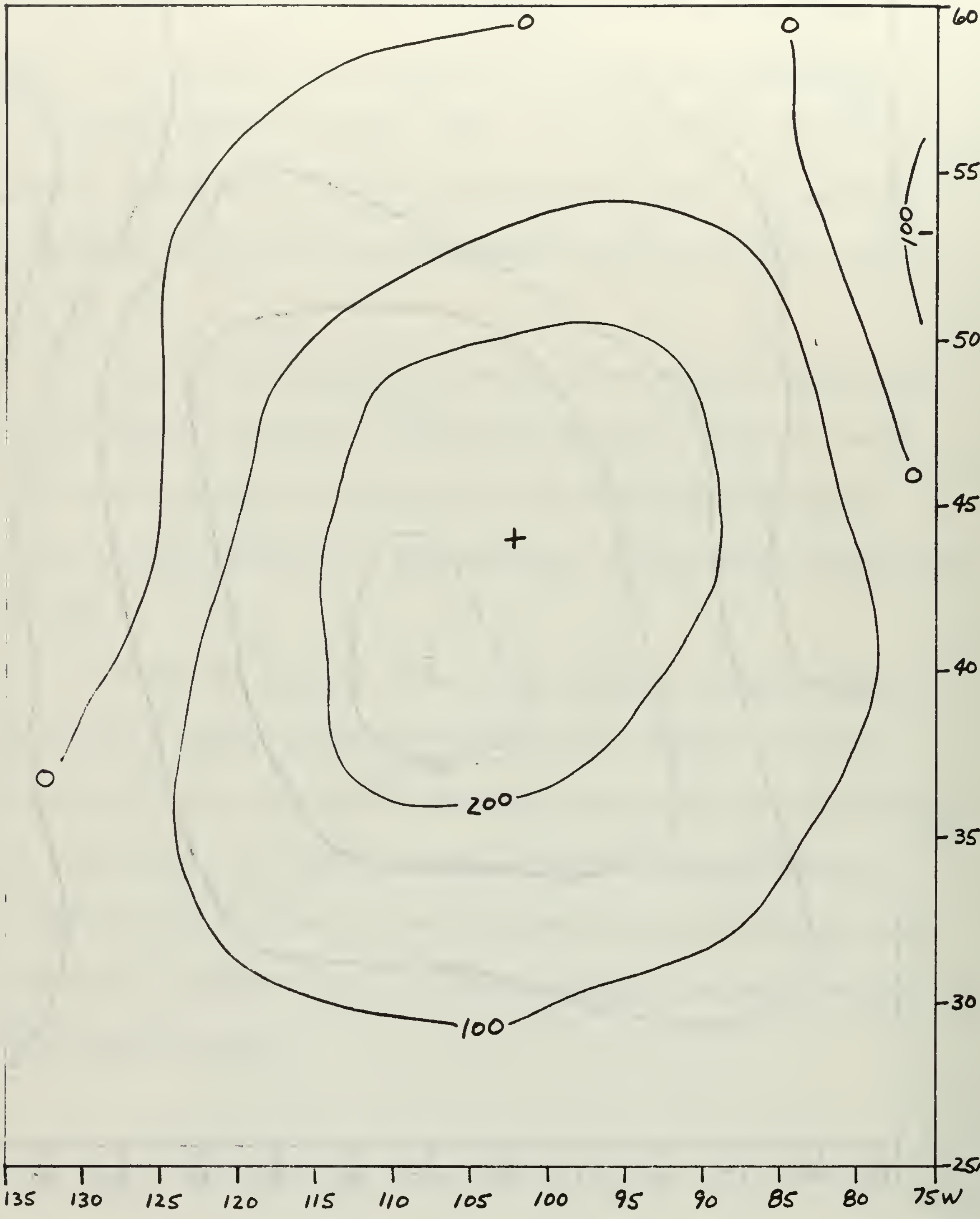

Fig. 22. Difference between actual geopotential field and geopotential field computed from wind field at 400 mb, 15 November 1966, 1200 GMT. Difference interval 100 meters.

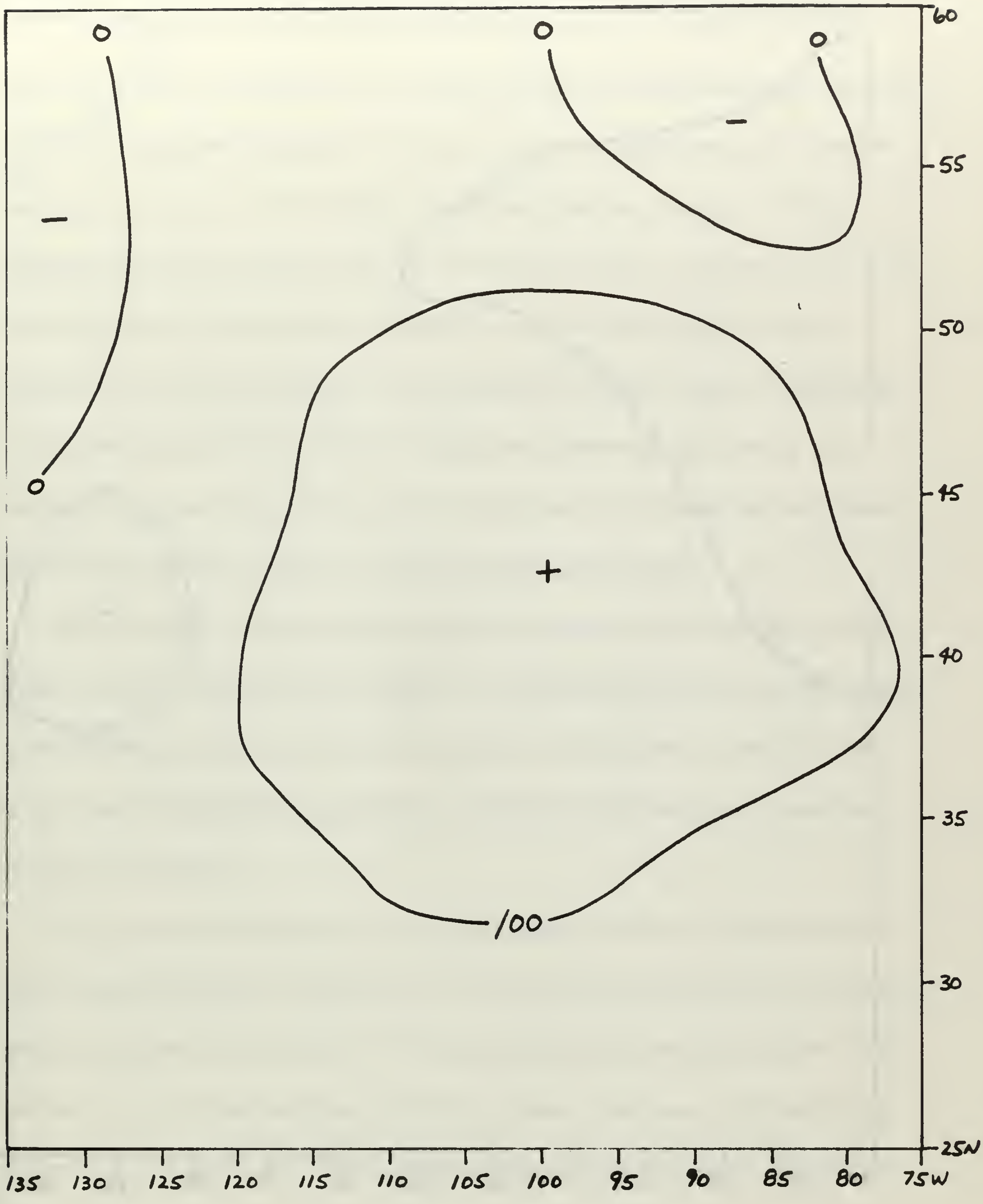

Fig. 23. Difference between actual geopotential field and geopotential field computed from wind field at 600 mb, 15 November 1966, 1200 GMT. Difference interval 100 meters.

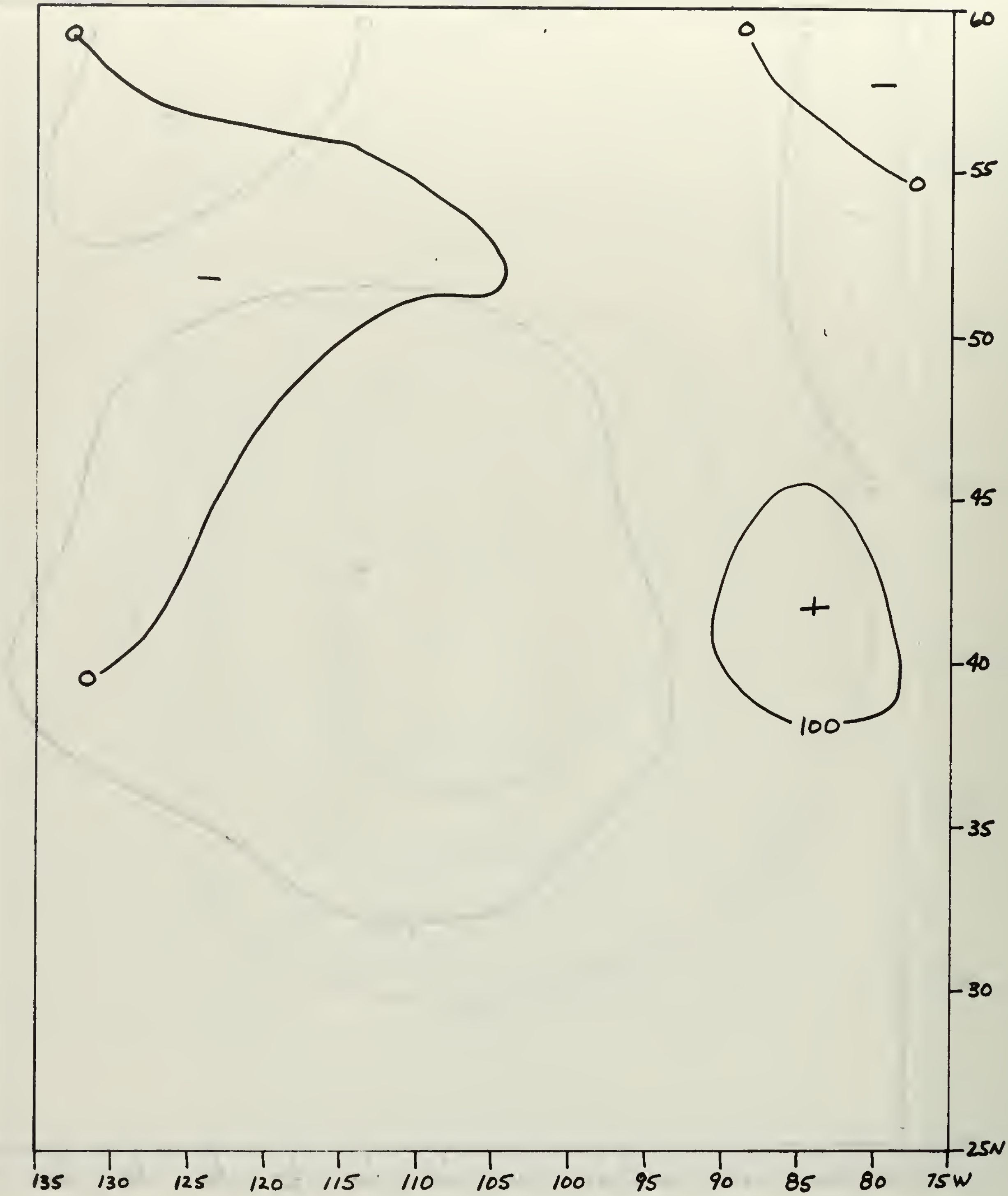

Fig. 24. Difference between actual geopotential field and geopotential field computed from wind field at 800 mb, 15 November 1966, 1200 GMT. Difference interval 100 meters.

V. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDY

At all levels examined, the stream function computed from the wind field has a greater magnitude in regions of cyclonic flow and a lesser magnitude in regions of anticyclonic flow than the stream function obtained from the actual geopotential height field. The stream function computed from the wind field exhibits a greater zonal flow in low latitudes, smaller amplitudes of troughs and ridges, weaker gradients in the stream function field and a different direction of flow in the region of the eastern mid-latitude trough than is evident in the stream functions computed from the actual geopotential field.

The analysis of the stream function computed from the wind field shows the best agreement in regions of closed circulation, in the region of the inflection point between a trough and ridge and at the 800 mb level when compared to the stream function computed from the actual geopotential field.

The differences between the wind-derived stream functions and the stream functions computed from the actual geopotential height field become progressively larger with increasing geopotential height to the 200 mb level. This indicates that the stream function computed from the wind field probably becomes increasingly inaccurate as the wind speed increases.

At all levels examined, the geopotential height computed from the wind exhibits a greater magnitude in regions of cyclonic flow and a lesser magnitude in regions of anticyclonic flow than the actual geopotential height field. The geopotential height computed from the wind field exhibits greater zonal flow in low latitudes, weaker gradients of geopotential height and smaller amplitudes of the ridges and troughs than present in the actual geopotential height field.

Since the geopotential height field is derived from the stream function field, all conclusions reached in analysis of the stream functions computed from the wind field are also applicable to the geopotential heights computed from the wind field when compared to the actual geopotential field.

In reference to Figs. 9-12, 21-24 the values of $\Delta\psi$ and Δz appear to be too large. As previously mentioned, the non-divergent stream functions computed from the wind field were proven to be correct by recovering the original relative vorticity field from the computed stream function field. The large values of $\Delta\psi$ may be attributed to either errors in the analysis of the original wind field, which has to be very accurate, or to errors inherent in the balance equation (5) due to approximations made in the original derivation. Computing the non-divergent stream functions from the balance quation using the actual geopotential heights as input produces a stream function field very similar to the geopotential height field.

The large values of Δz can be attributed to the fact that accurate geopotential heights may not be able to be computed from the balance equation using stream functions computed from the wind field as input.

The discrepancies between the two methods utilized here lead to some apparently discouraging conclusions. Either the wind field is not specified accurately enough or the approximations inherent in the balance equation lead to significant errors in the computed stream functions. In either case, the two methods outlined here are not presently interchangeable. Until the cause for this discrepancy is clarified, the assumed interchangeability of these methods for analysis in the tropics is highly questionable.

Further investigations should be made in determining the cause of these apparent discrepancies by trying new test cases, using different boundary conditions, testing the effect of inserting U and V in place of $\frac{\partial \psi}{\partial y}$ and $\frac{\partial \psi}{\partial x}$ into the Jacobian term for the stream function in the balance equation, and computing the non-divergent stream functions using reanalyzed wind fields.

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13. ABSTRACT

A diagnostic multi-level, non-linear balance model, which can be used in either tropical or mid-latitude regions, is applied to a case study in a mid-latitude region on 15, 16 and 17 November 1966. The model accepts actual geopotential heights or geopotential heights derived from a non-divergent stream function which is computed from the actual wind field as input data.

A comparison is made between non-divergent stream functions computed from the wind field and those computed from the actual geopotential height field. A second comparison is made between the actual geopotential height field and the geopotential height field computed from the wind field. Qualitative and quantitative comparisons are made between the stream functions and geopotential heights, respectively, computed by the two different methods.

By making the above mentioned comparisons, a determination is made as to the accuracy of the model using wind data and finally the accuracy of the model in the tropics. The results indicate that use of the wind field as input data may not produce accurate results.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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