NAS 8-32694 - Frontogenesis
Final Report

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THE DISTRIBUTION OF BAROCLINITY WITHIN THE ATMOSPHERE

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ABSTRACT

A three dimensional numerical interpolation scheme which resolves frontal gradients with high fidelity has been developed and is being applied to the study of atmospheric upper baroclinic zones.

INTRODUCTION

The aim of our research is to improve understanding of the structure and evolution of atmospheric fronts. Achievement of this goal requires the representation of frontal intensity with a dynamically significant parameter for which we have selected the baroclinity,

$$\vec{B} = \frac{g}{\theta} \vec{\nabla}_p \theta \qquad (1)$$

where $\vec{B}$ is the baroclinity vector, g the acceleration of gravity, and θ and $\vec{\nabla}_p\theta$ are the potential temperature and its isobaric gradient. Furthermore, we may define local frontogenesis to be the local tendency of the baroclinity which may be shown to be (to good approximation)

$$\frac{\partial \vec{B}}{\partial t} = \frac{g}{\theta} \vec{\nabla}_p \left[\frac{d\theta}{dt} - \vec{\nabla}_p \cdot (\vec{V}\theta) - \frac{\partial}{\partial p} (\omega\theta) \right] \qquad (2)$$

where $\omega = \frac{dp}{dt}$.

Because of the small horizontal scale of fronts compared with the spacing of sounding stations the magnitude of the baroclinity may be considerably underestimated in the vicinity of intense fronts if only horizontal or isobaric data are utilized. This difficulty may be largely obviated through use of cross-section analyses which effectively apply the high resolution information available in the vertical over each sounding station to improvement of horizontal resolution. (Shapiro, 1970).

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METHOD

The considerable expenditure of effort required for manual analysis of cross-sections has led to the development of successful numerical interpolation schemes for cross-section analysis (Shapiro and Hastings, 1973 and Whittaker and Petersen, 1975); however, these are two dimensional techniques from which one can obtain isobaric analyses only by laborious combination of many independently analysed cross-sections. We propose instead to apply a fully three dimensional scheme based on a straight forward extension of the Barnes (1973) horizontal method.

We extend the Barnes scheme by redefining his weight as

$$W_i = \frac{1}{4\pi kD} \exp\left[\frac{-d_i^2}{4k} - \frac{Z_i^2}{4D}\right] \qquad (3)$$

where W_i is the weight factor for the i^{th} observation, d_i and Z_i are the horizontal and vertical distances between the observation and a given grid point, and k and D are weight parameters controlling the smoothness of the output. To facilitate selection of k and D, we have coded a two dimensional cross-section analysis method based on (3) having a horizontal grid spacing of one latitude degree (111 km) and a vertical spacing of 50 mb.

The resulting potential temperature analysis on a cross section through the complex hyperbaroclinic zone studied by Frank and Barber (1977) is shown in Fig. 1 together with the component of the baroclinity in the plane of the cross-section estimated by finite difference method. For comparison, Fig. 2 reproduces the careful manual analysis of Frank and Barber. The numerical scheme has reproduced not only the gross features, but also most of the details with considerable fidelity. Further improvement would be possible (at the expense of more computer time) if the vertical resolution were increased.

A quantitative demonstration of the efficacy of the cross-section scheme is illustrated in Fig. 3. The baroclinity estimated from the cross section at the 500 and 800 mb levels is shown by the dashed lines. The solid lines are the results obtained through application of a horizontal Barnes analysis on a one latitude degree by one longitude degree grid. The magnitude of the baroclinity estimated from the cross-section program is fifty to one hundred percent greater in the hyperbaroclinic zones than that obtained from the isobaric analyses.

CURRENT WORK

We are now coding the full three dimensional scheme for application to the AVE II data. Furthermore, we intend to demonstrate its usefulness through application to operationally available

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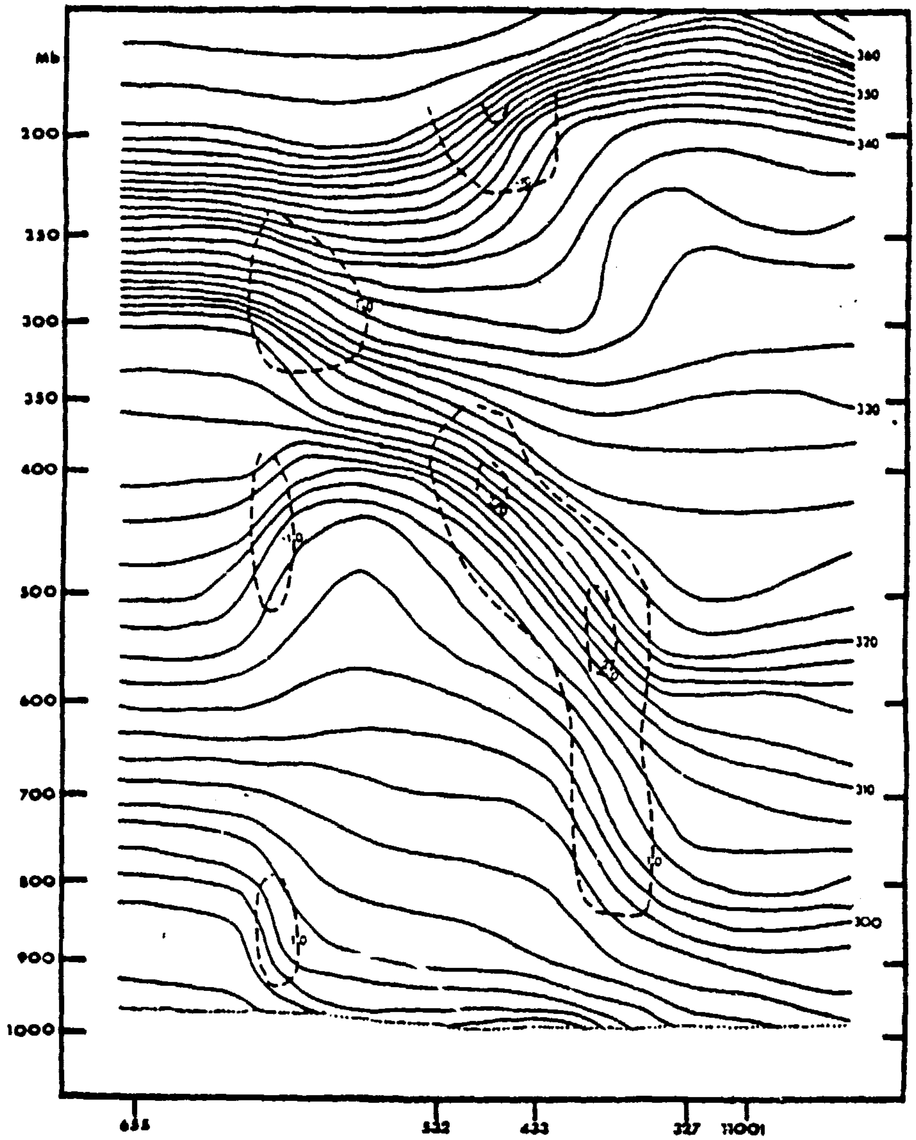

Fig. 1. Objectively analyzed cross-section through hyper-baroclinic zone. Isentropes (κ) solid and baroclinity (10^{-7} s^{-2}) dashed. 1115 uT, 12 May 1974.

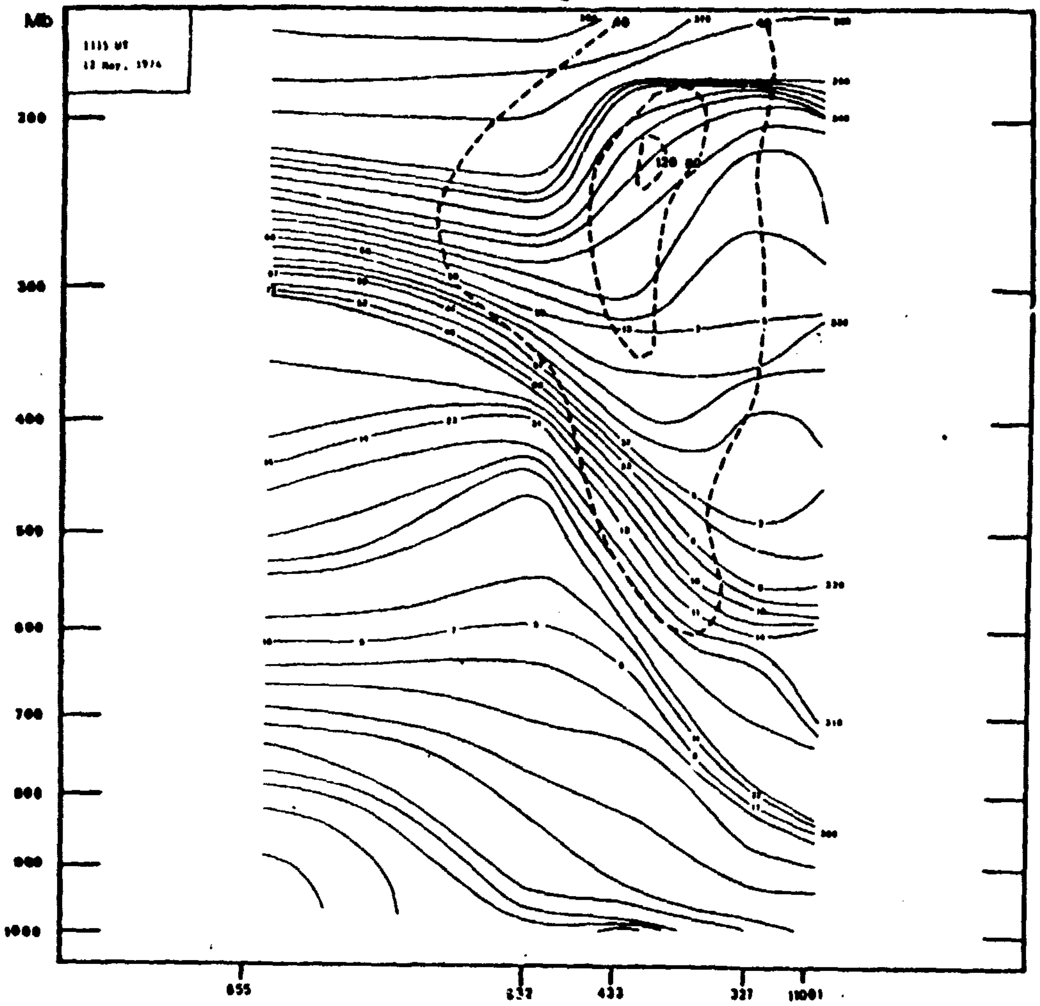

Fig. 2. Manually analyzed cross-section along same line as Fig. 1. Isentropes (K) solid and isotachs (kt) dashed of flow normal to section (Frank and Barber, 1977).

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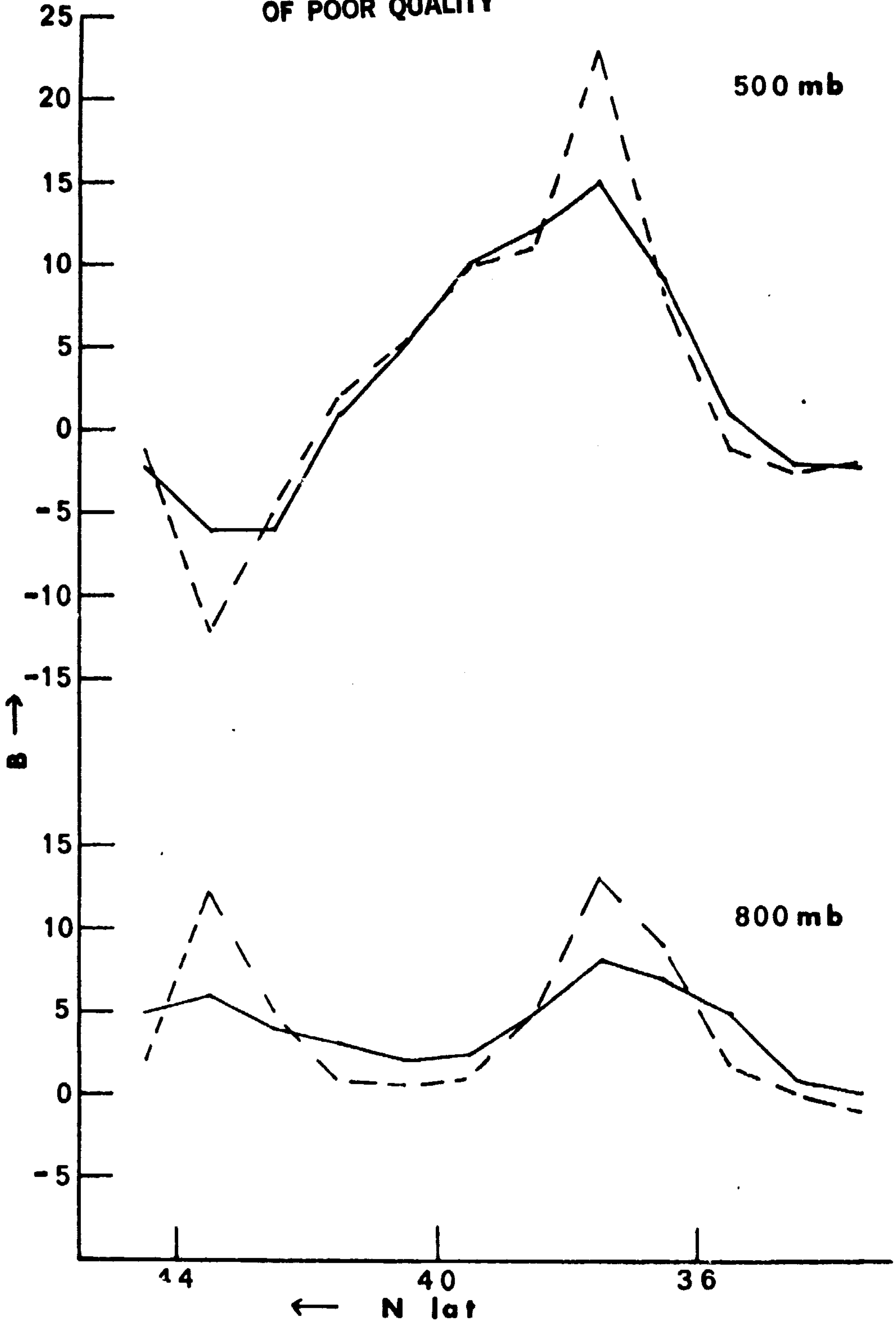

Fig. 3. Baroclinity (10^{-7} s^{-2}) from objective isobaric analysis (solid) and from objective cross-section (dashed) as a function of latitude along line of Fig. 1.

teletype data and comparison with National Weather Service analyses.

In addition to depicting the full three dimensional baroclinity distribution, we plan to apply the method to the wind field. In the case of the wind field, some smoothing of the vertical wind field is desirable (see Schmidt and Johnson, 1972). Therefore, a different set of weight parameters (k and D) will be appropriate.

Finally, we shall apply the improved three dimensional wind and temperature analyses to the evaluation of terms in the frontogenesis equation (2).

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Schmidt, P. and D. Johnson, 1972: Use of approximating polynomials to estimate profiles of wind, divergence, and vorticity. Mon. Wea. Rev., 100, 345-353.

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Whittaker, T. and R. Petersen, 1975: Objective cross-section analysis incorporating thermal enhancement of the observed winds. In Project Report: Meteorological Applications of Satellite Indirect Soundings. L.H. Horn, Principal Investigator. Dept. of Meteorology, University of Wisconsin, Madison.

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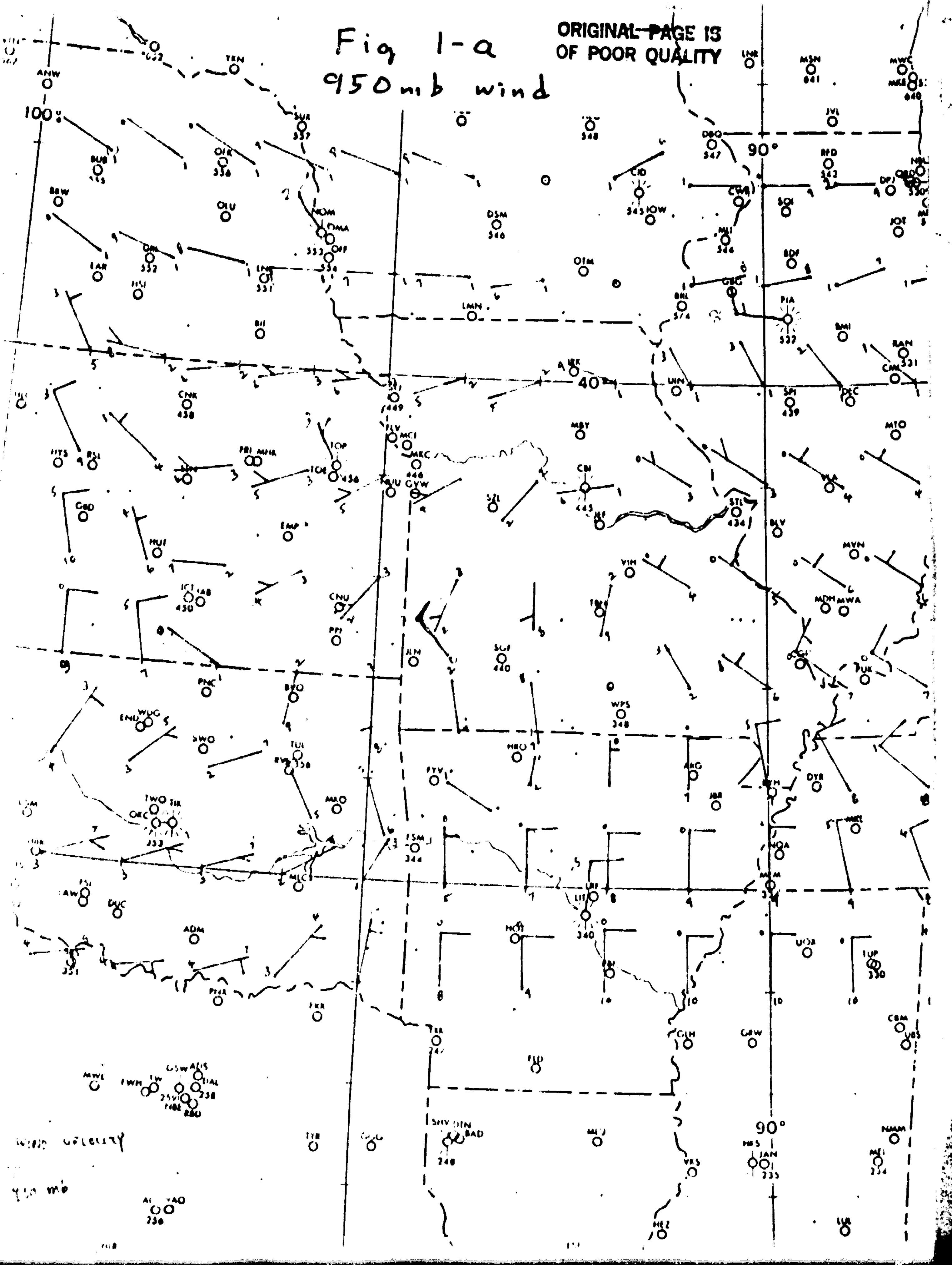
Fig 1-a
950mb wind



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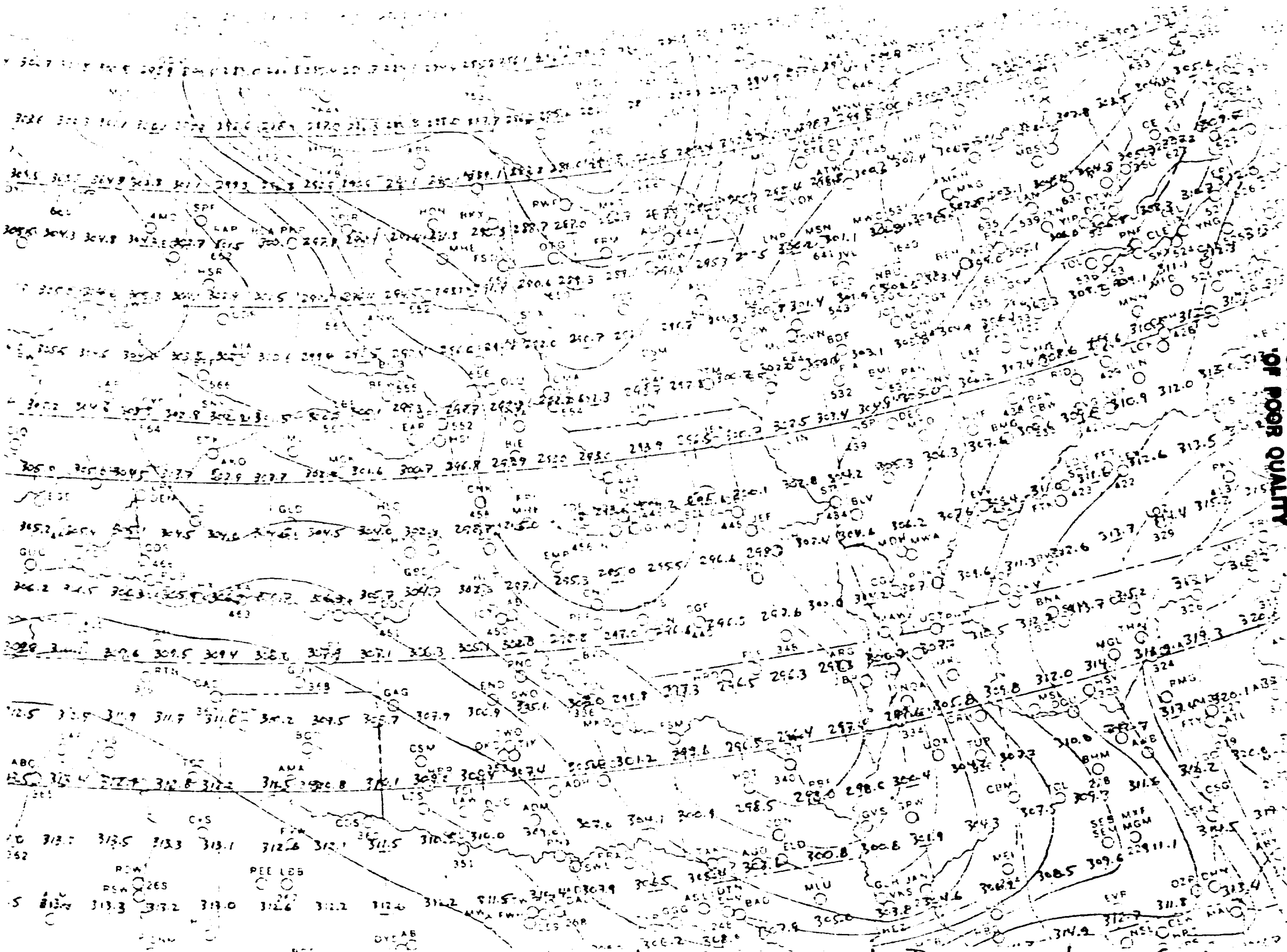
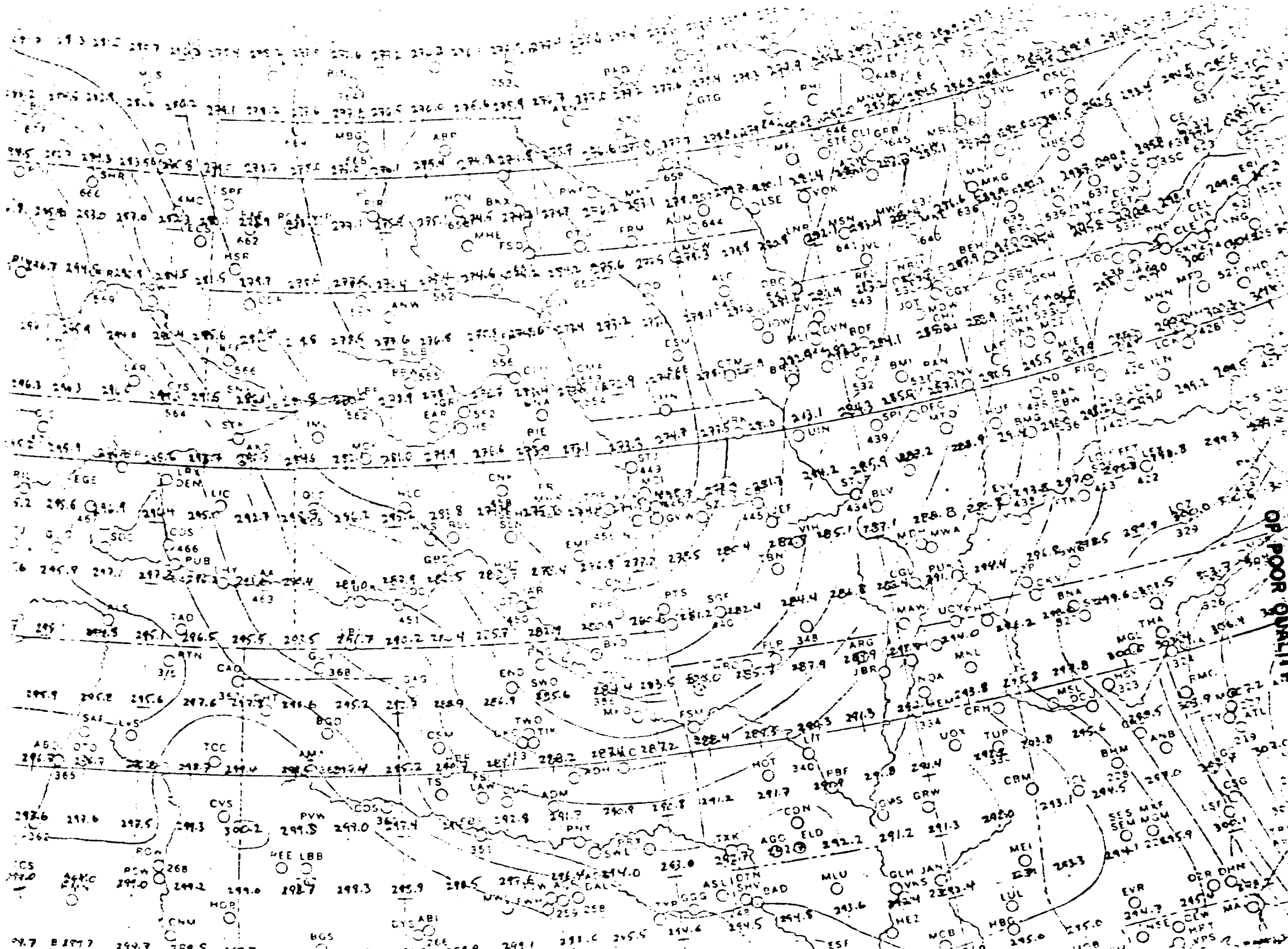


00 UT 26 Jan 1979 500 mb Potential Temperature (K)



00UT 26 Jan 1978 700mb Potential Temperature

RECENT PROGRESS ON WORK UNDER CONTRACT NAS 8-32694 HAS INCLUDED THE FOLLOWING MAJOR ITEMS.

1. A preliminary test of the full three dimensional numerical interpolation scheme has been applied to the wind field for 0600 UT, 12 May 1974, over a limited region of the midwest. The area is restricted so that testing of the scheme may be accomplished without undue expenditure of computer time. The results are shown in Figures 1-7 a, b and c. These figures show the wind speed and direction (a), the isobaric divergence (b), and the isobaric vorticity (c) for 7 selected pressure levels on a 1 latitude degree by 1 longitude degree grid.

With two important exceptions, these figures demonstrate excellent vertical and horizontal continuity and quite reasonable fields of the kinematic variables. We believe that, when applied to a larger sample of data, the method will prove a significant improvement over existing techniques.

The two exceptions noted above are related to horizontal and vertical boundary problems. The first of these will be substantially overcome by merely including a larger area within the analysis domain. The second results from difficulty near the surface of the earth. This problem was encountered in earlier tests of the scheme for analysis of the potential temperature field; it was overcome by including bogus data points below the earth's surface obtained by downward extrapolation based on data above the surface. This device has not been successful in the wind case.

2. We have obtained a small grant of computer time from the Oregon State University Computer Center for the testing of the three dimensional scheme on a case involving use of standard teletype transmissions of sounding data. The temperature data for 00 UT, 26 January 1978, have been punched for this purpose. While this work is not directly supported by NAS 8-32694 it will demonstrate

the usefulness of the three dimensional scheme applied to conventional, operationally available data.

3. The often frustrating efforts to convert the data tape for the every contact AVE II rawinsonde data to a format combatable with our local CDC computer have continued. The OSU Computer Center has been unable to perform this task so we have sent the tape elsewhere for conversion.

Immediate future work will emphasize the following items:

1. Improvement of the bottom boundary condition for the analysis scheme.
2. Preparation of programs to compute vertical velocity by the kinematic method including standard correction procedures.
3. Enlarging the area for testing the analysis scheme and adding temperature data to the wind data for the test case.
4. Testing schemes to reduce the running time of the analysis scheme.
5. Preparation to run analyses on several time periods of AVE II data when the data tape has been converted.
6. Running the analysis program on the 26 January 1978 case to illustrate the usefulness of the technique when applied to conventional data.

Fig 1-a
950mb wind

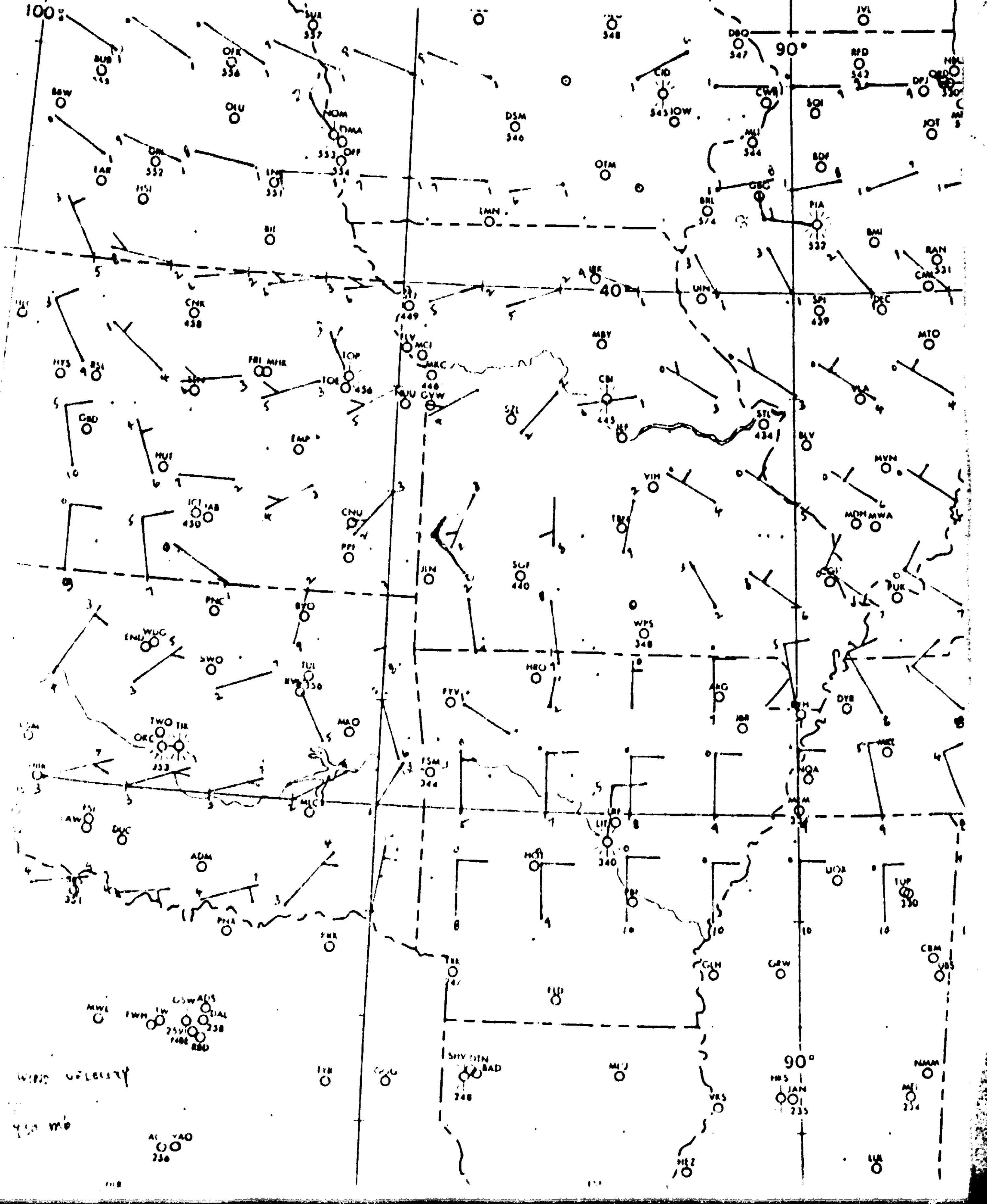


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Fig. 1-b
950 mb vorticity

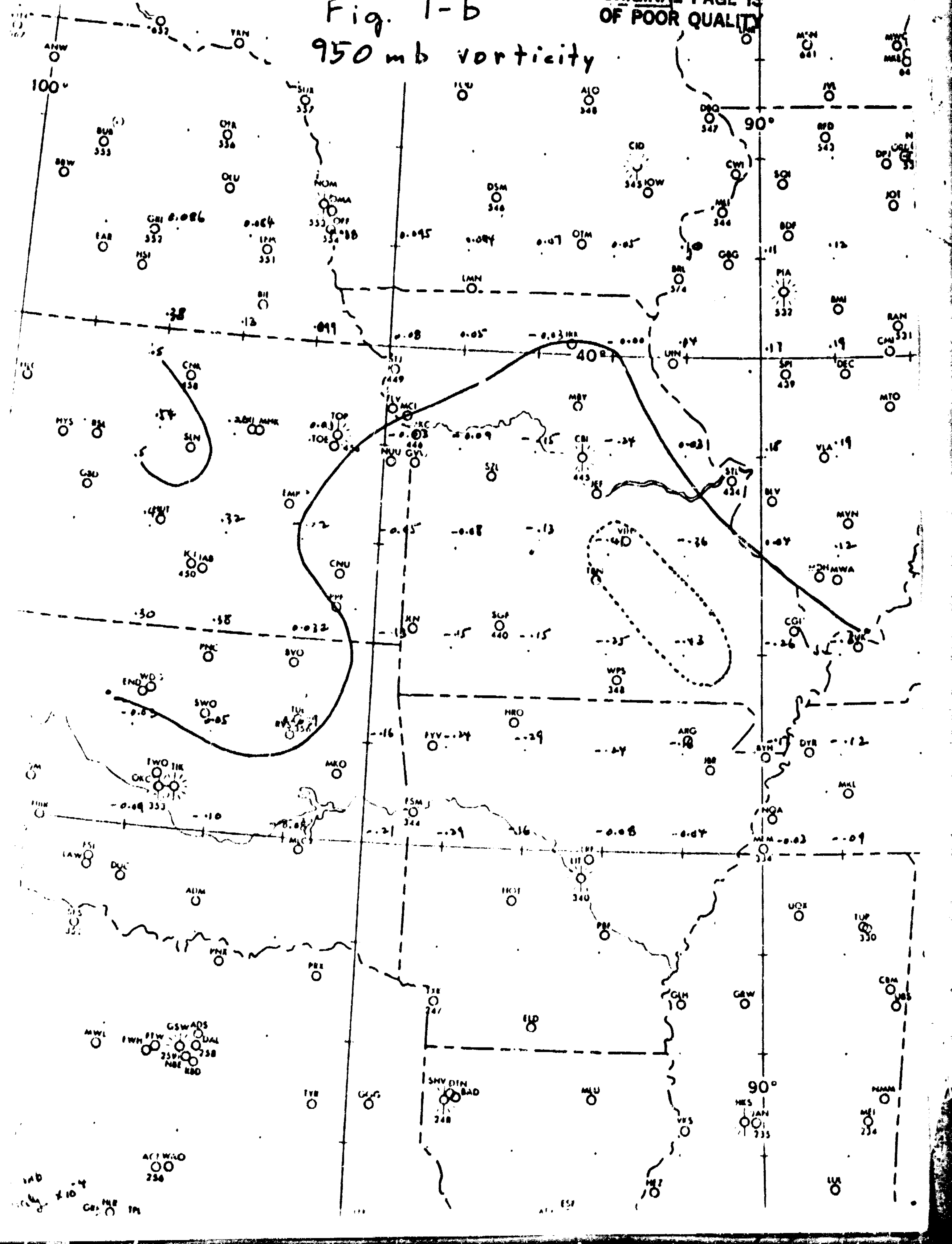

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Fig 1-c
950 mb divergence

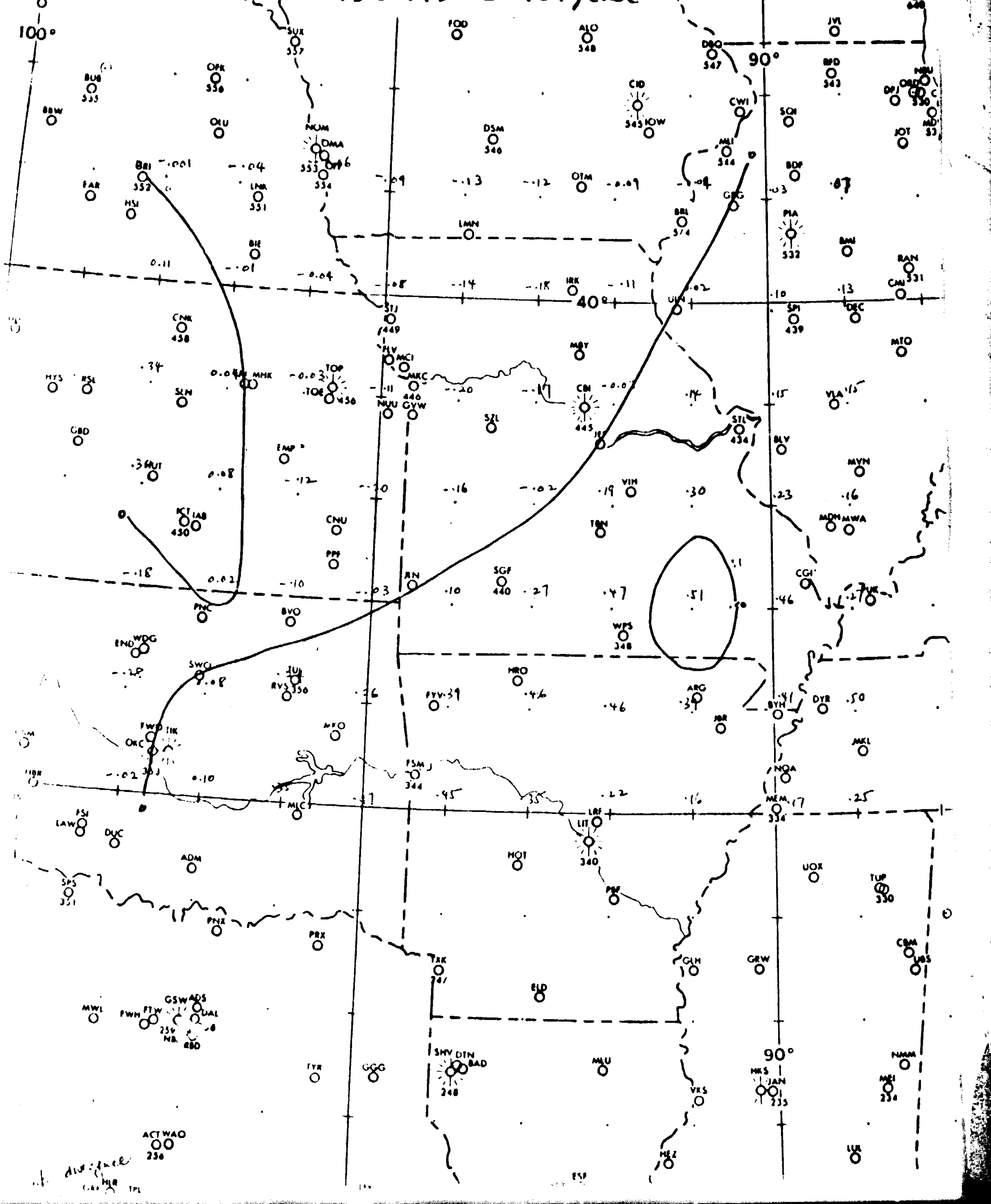
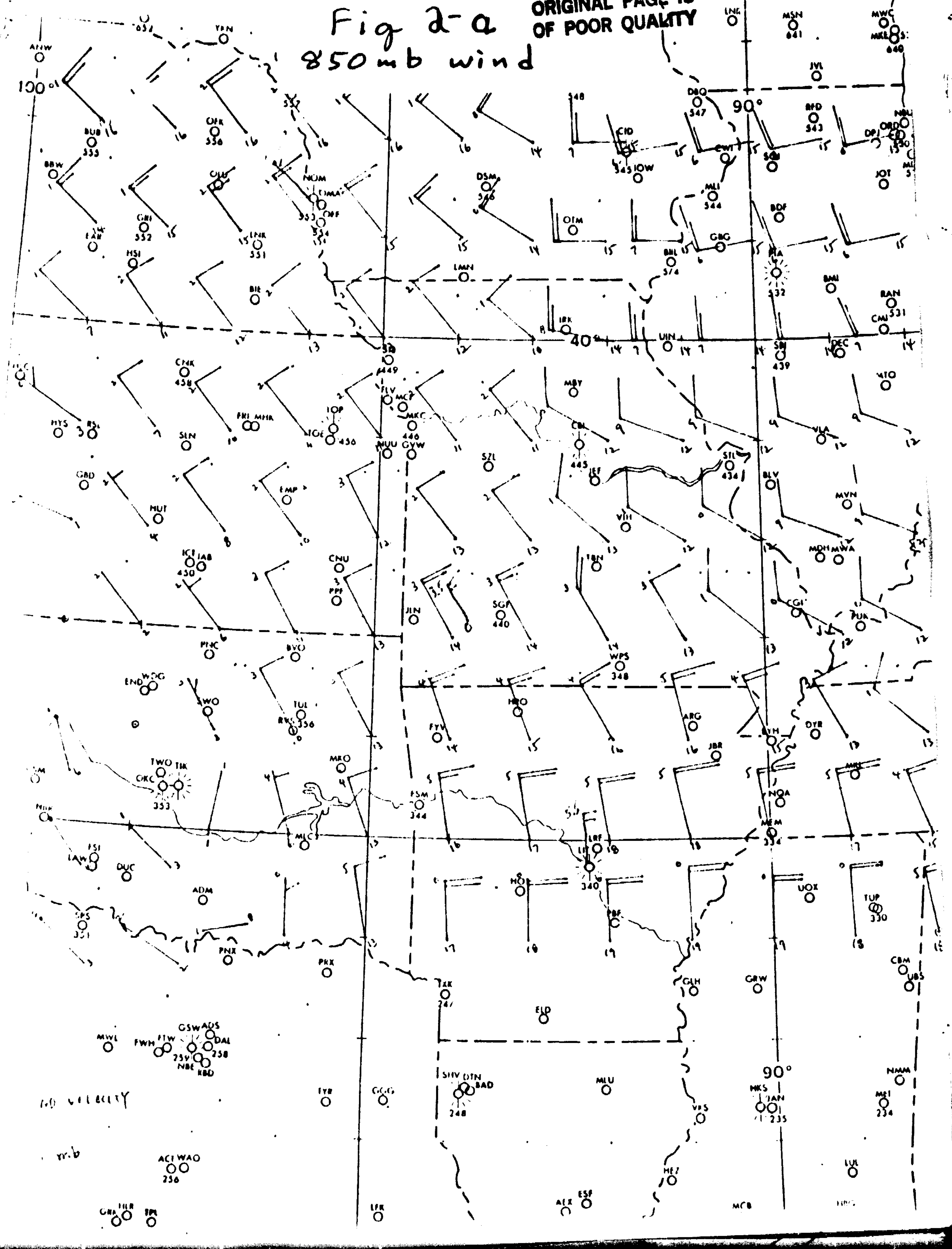


Fig 2-a 850mb wind



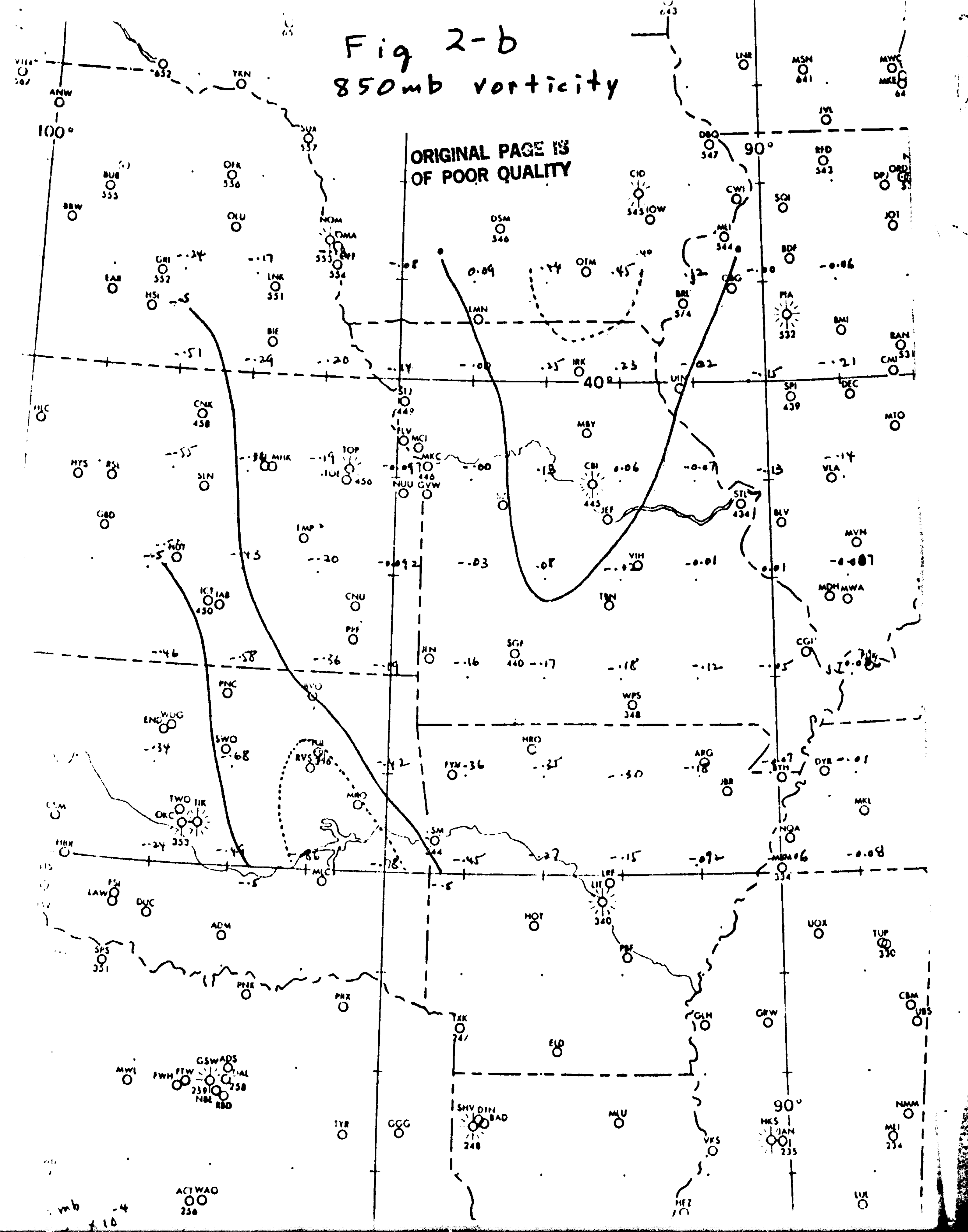


Fig 2-b
850mb vorticity

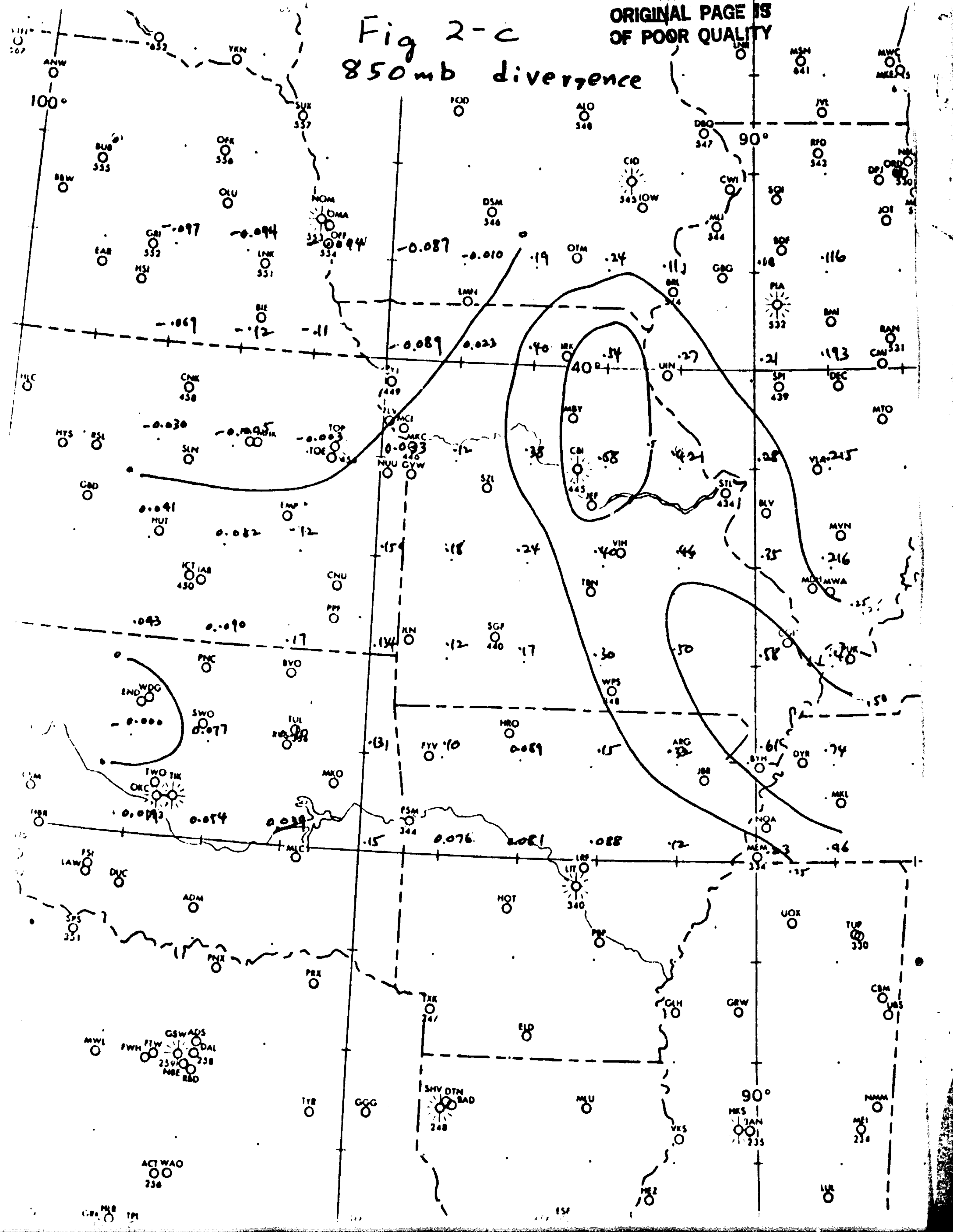


Fig 2-c
850mb divergence

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Fig 3-a

700mb wind

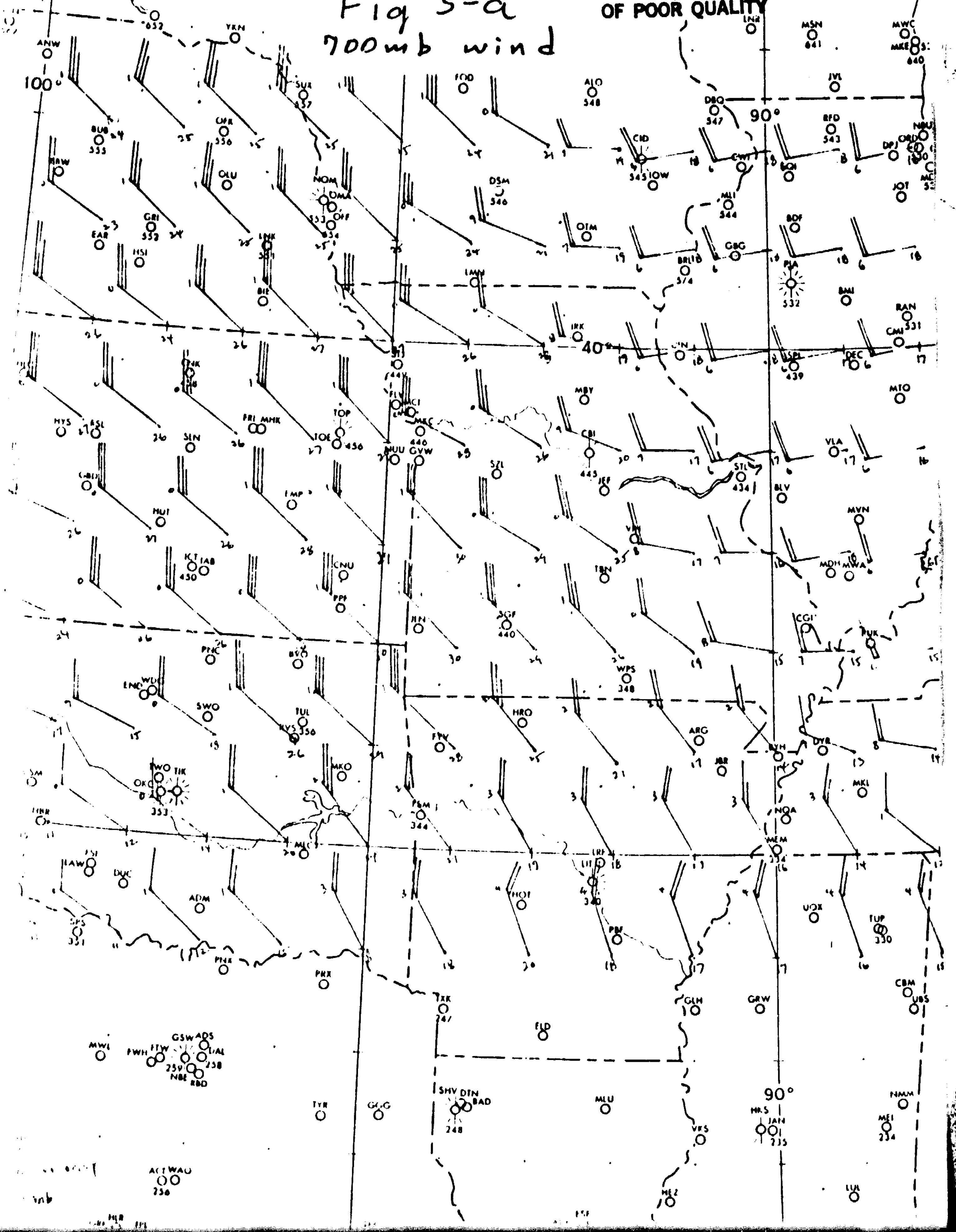

Fig 3 b
700mb vorticity

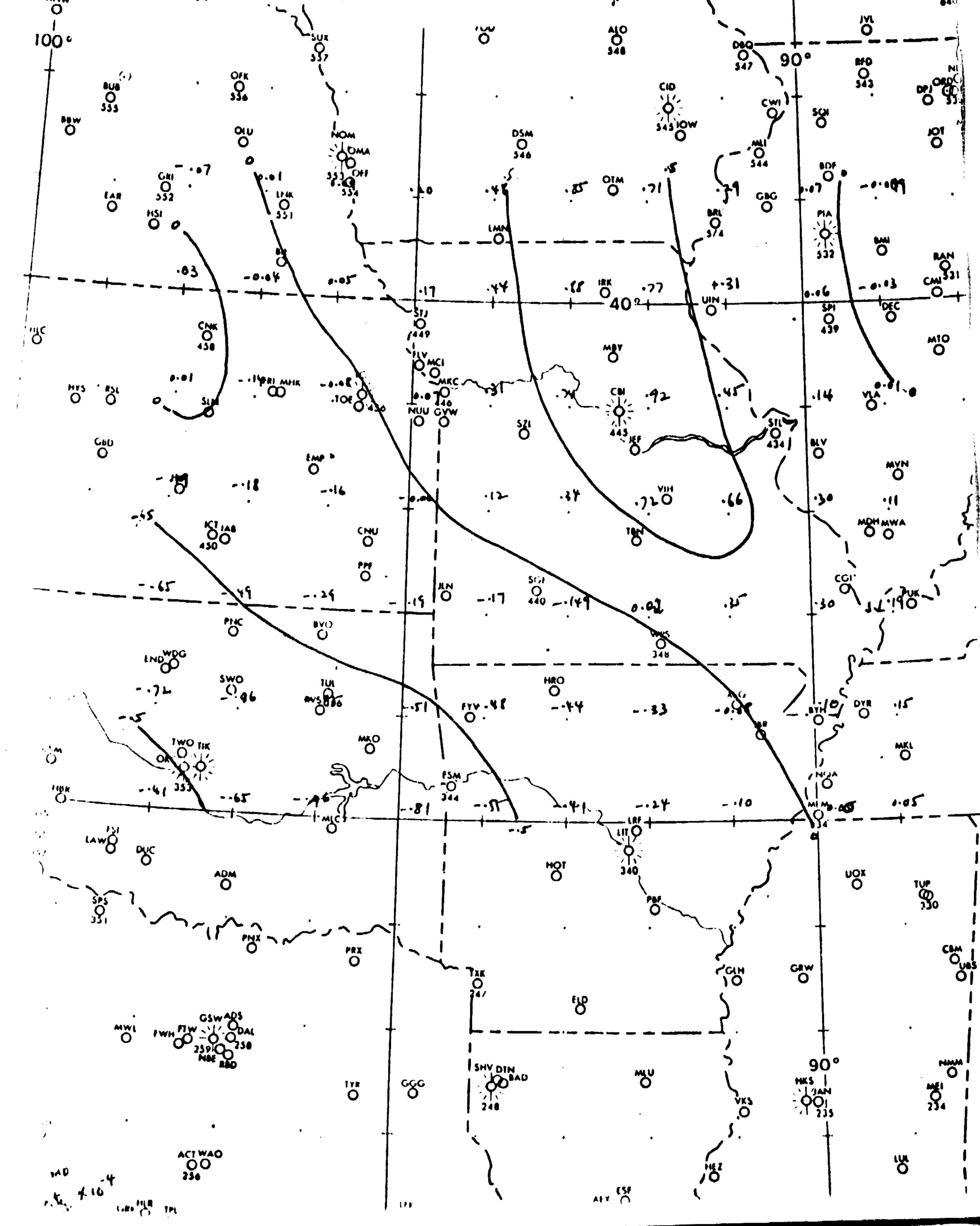

Fig 5-C

700 mb divergence

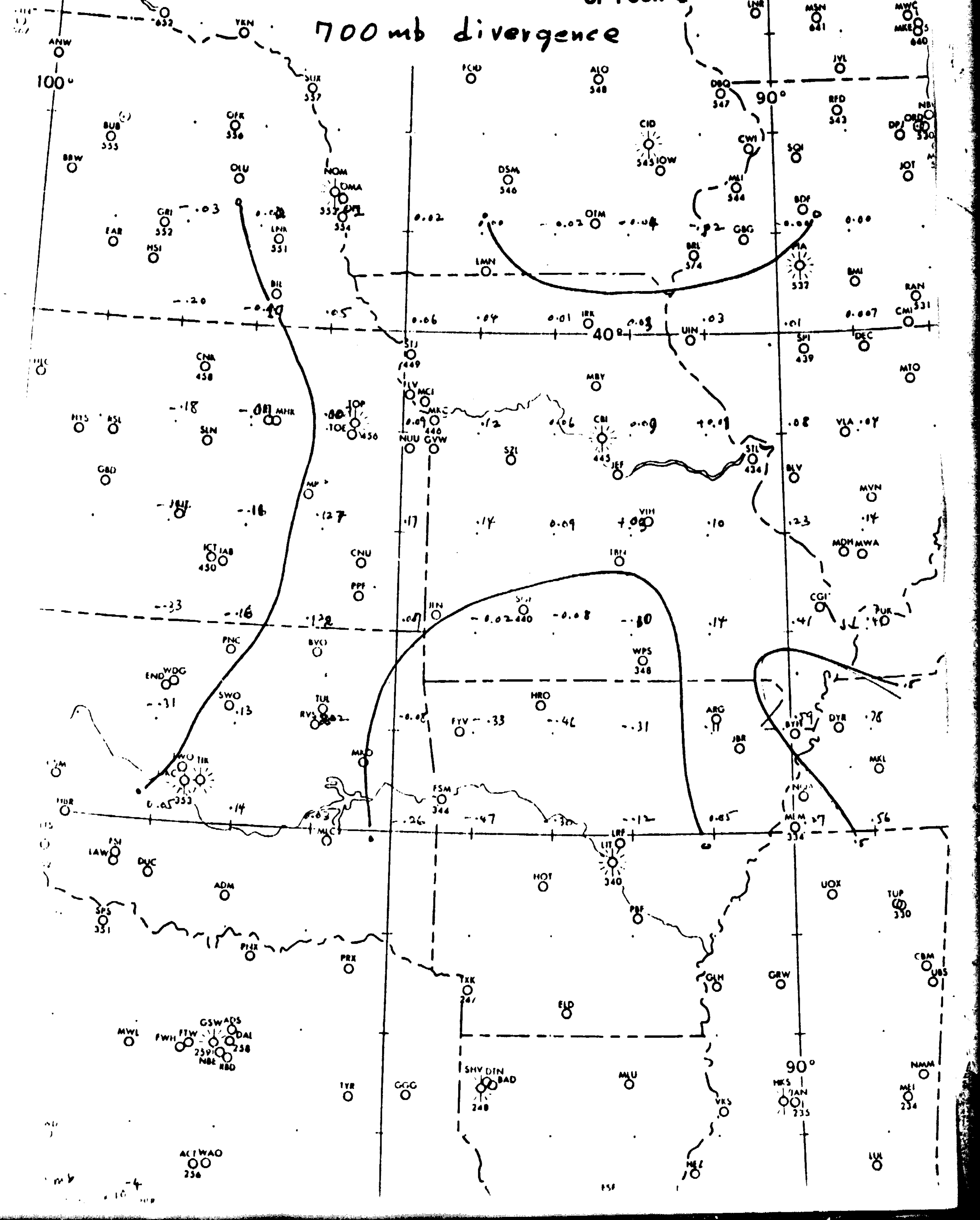

Fig 4-a

500 mb wind

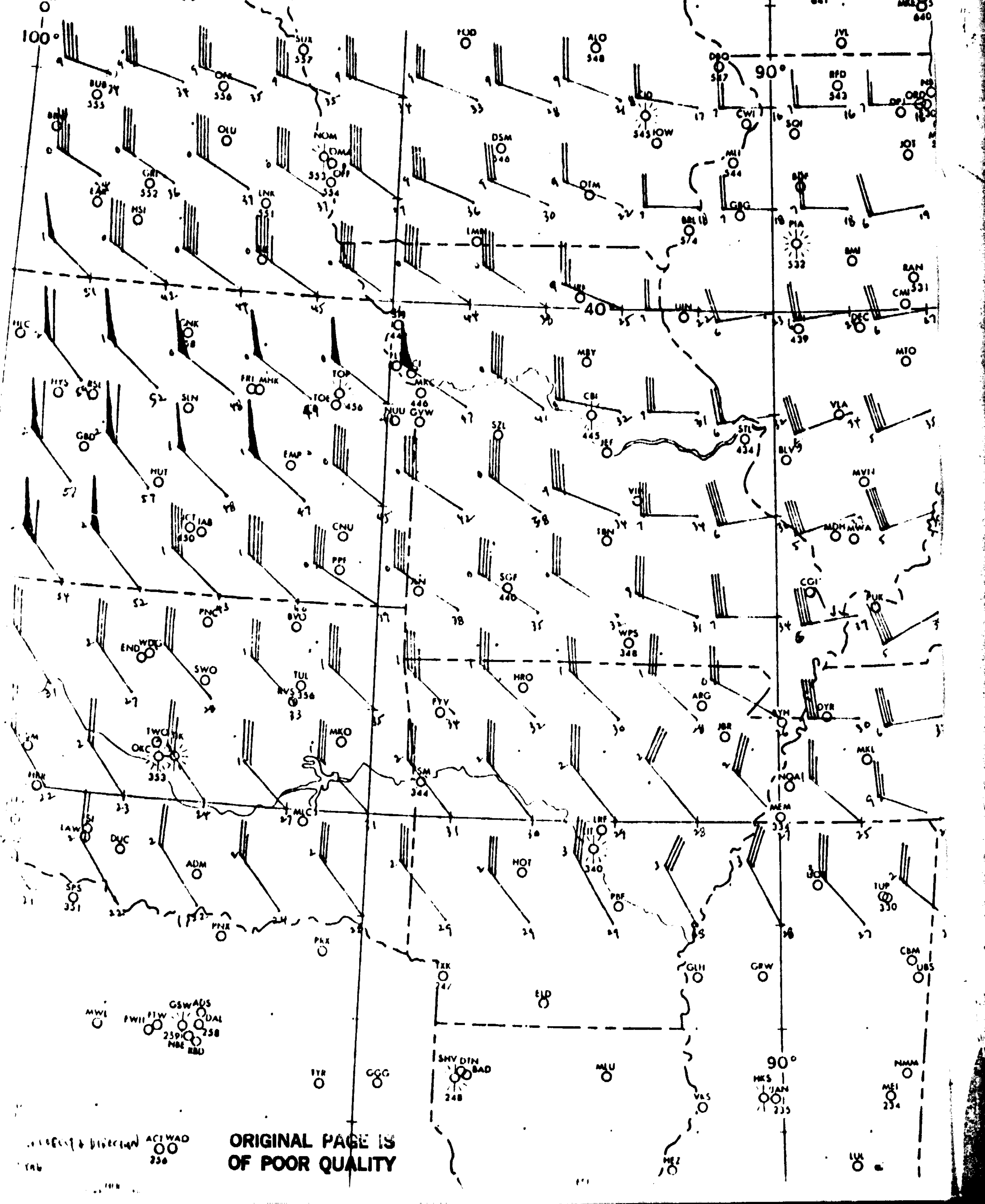

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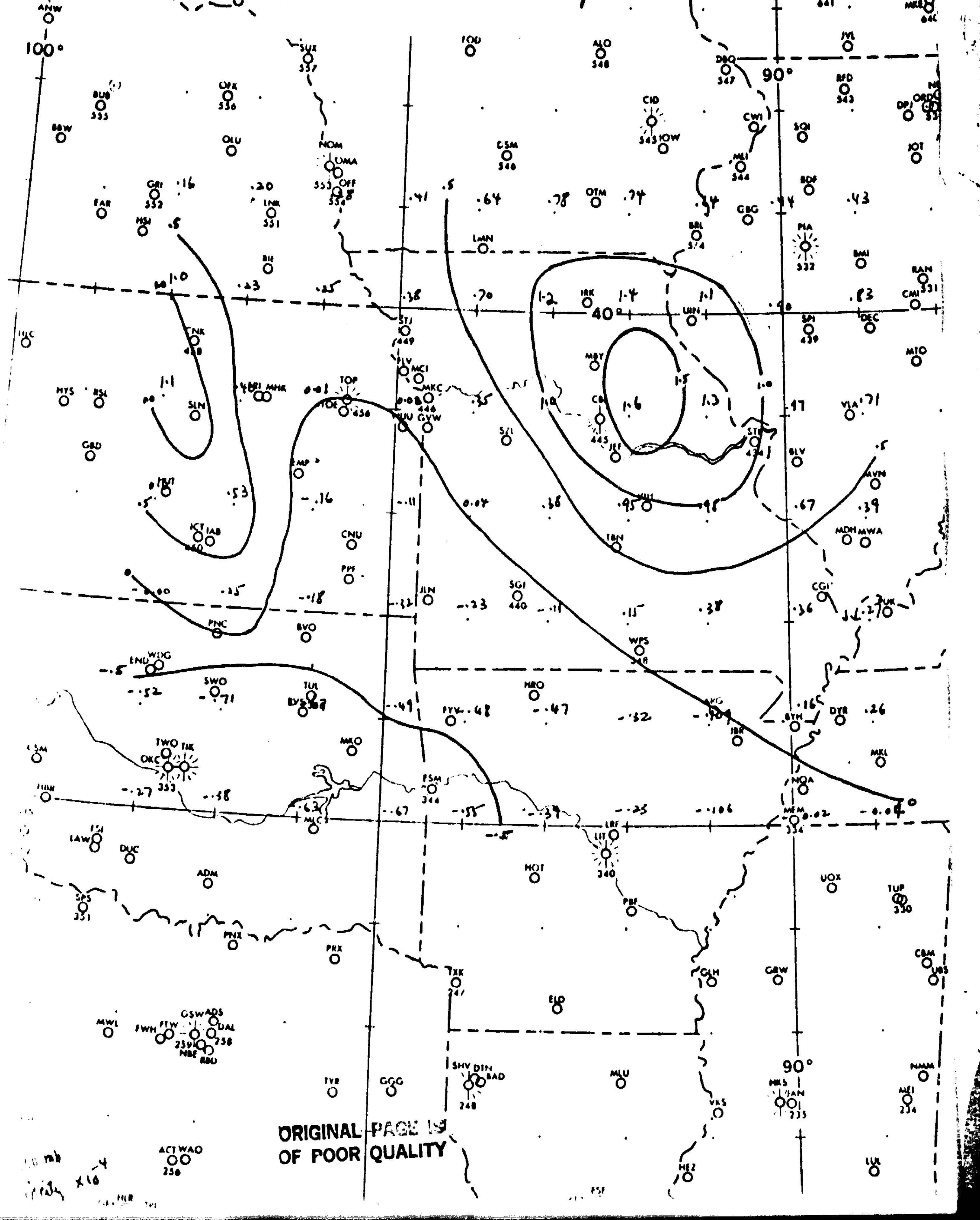
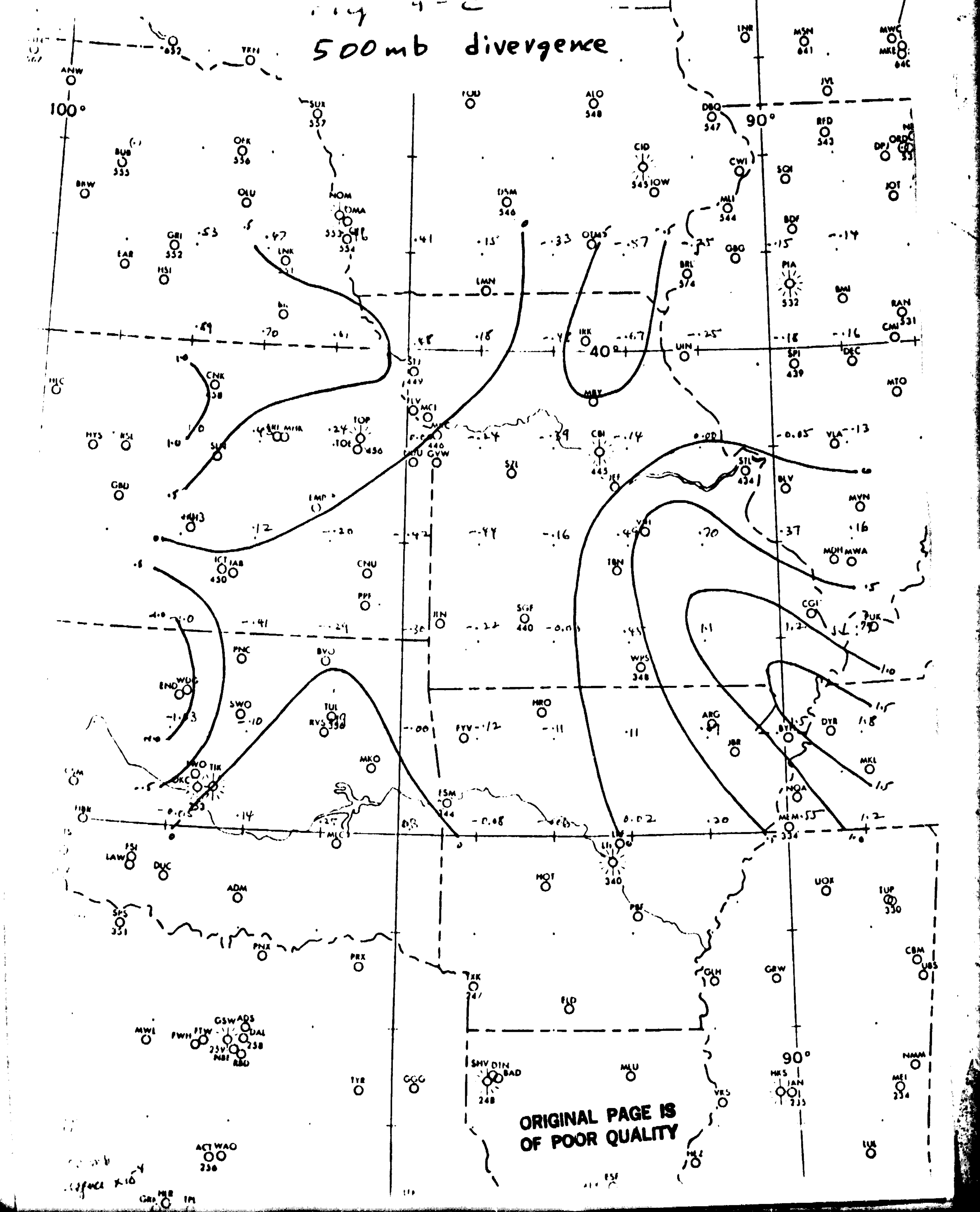
Fig 4-b 500 mb vorticity





500 mb divergence

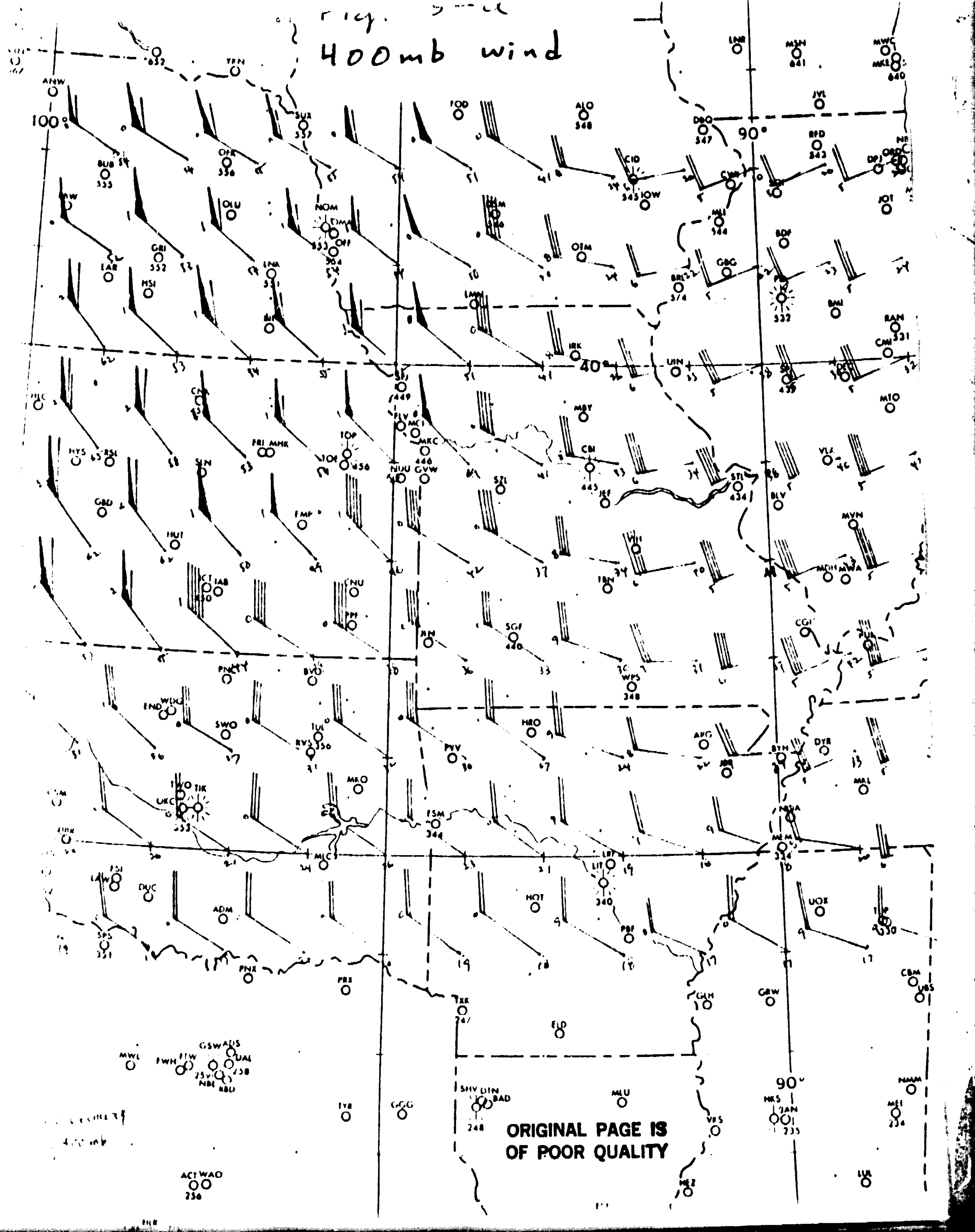


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Fig 5 b
400mb vorticity

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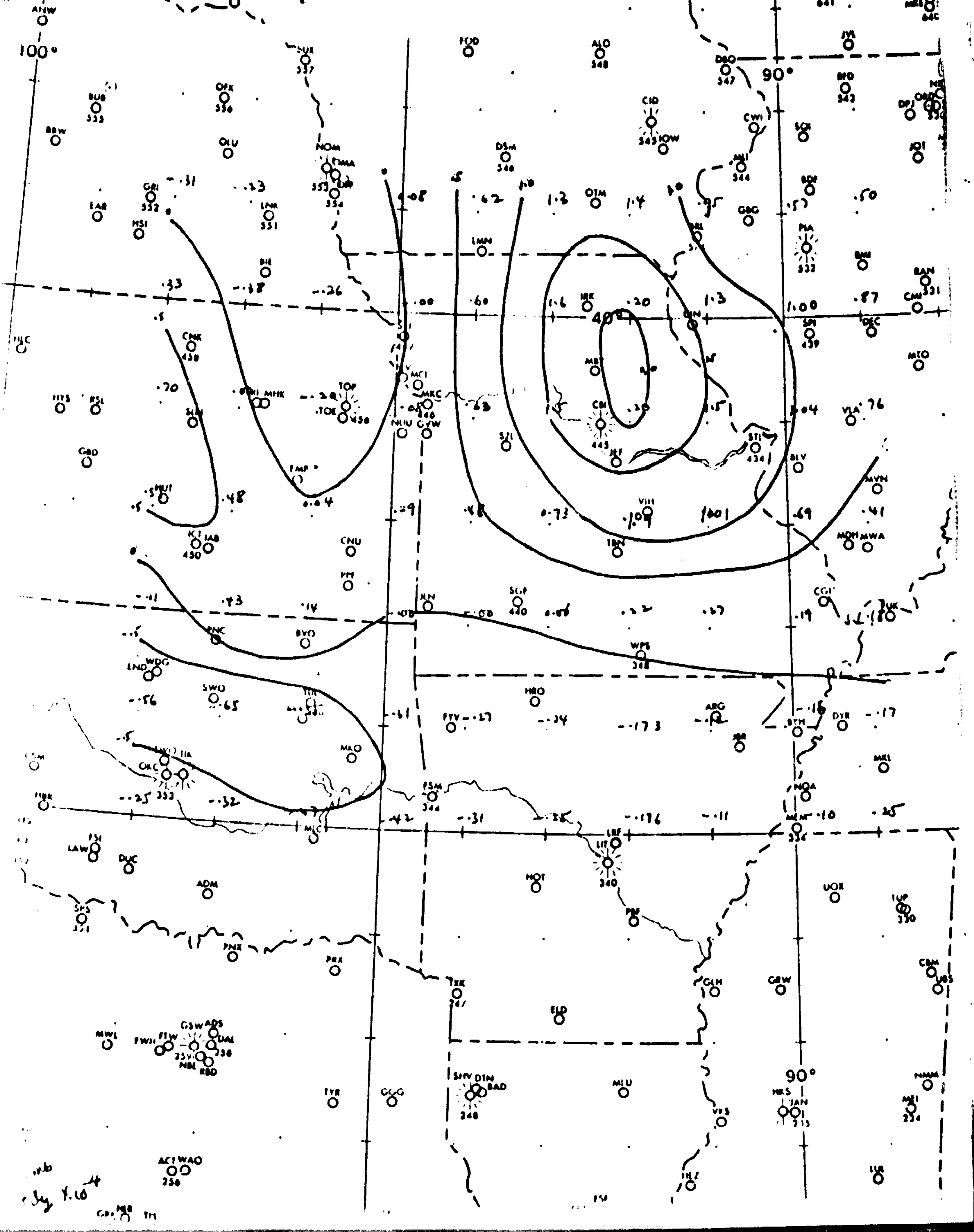

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Fig 5-C

400mb divergence

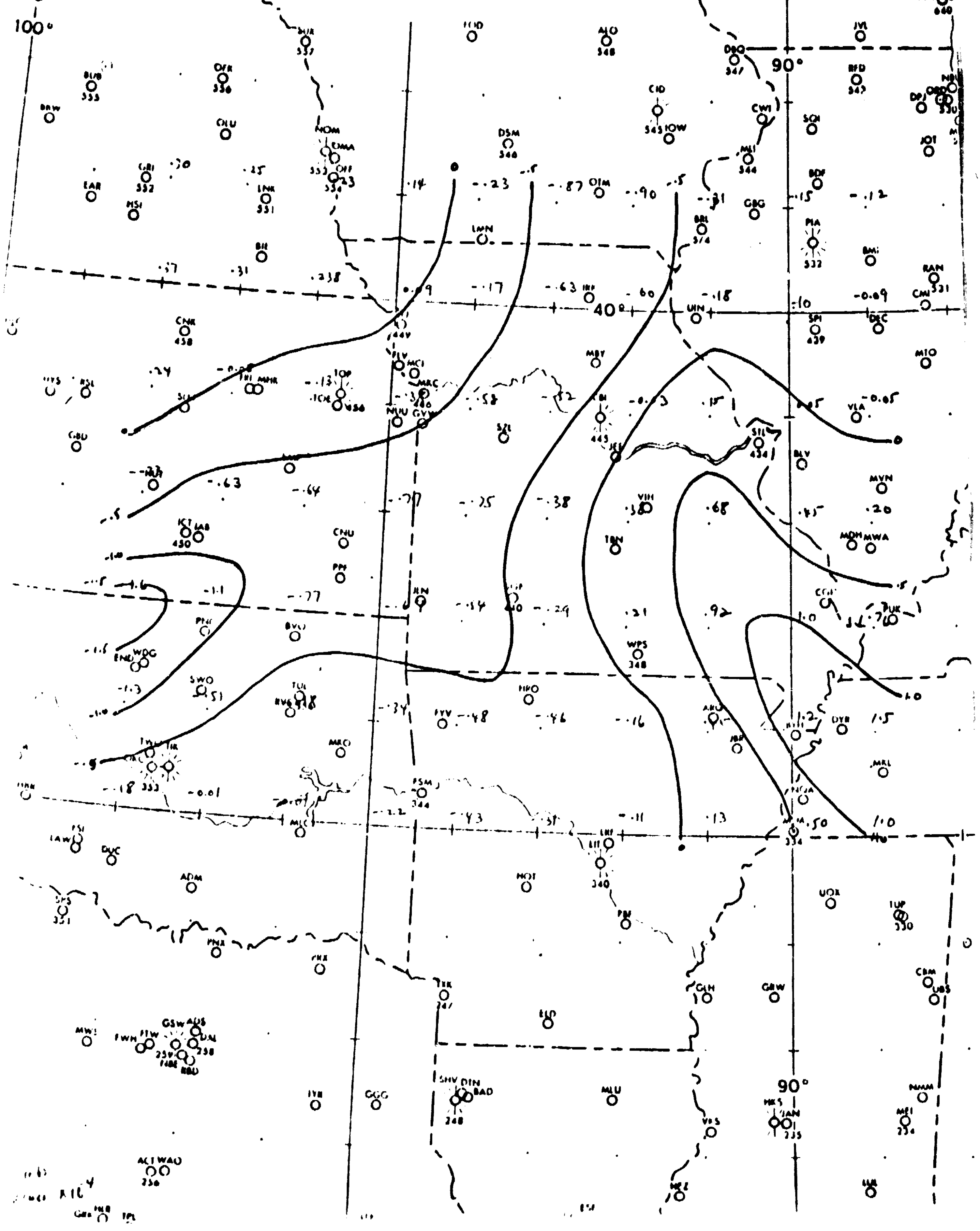


Fig 6-a 300mb wind

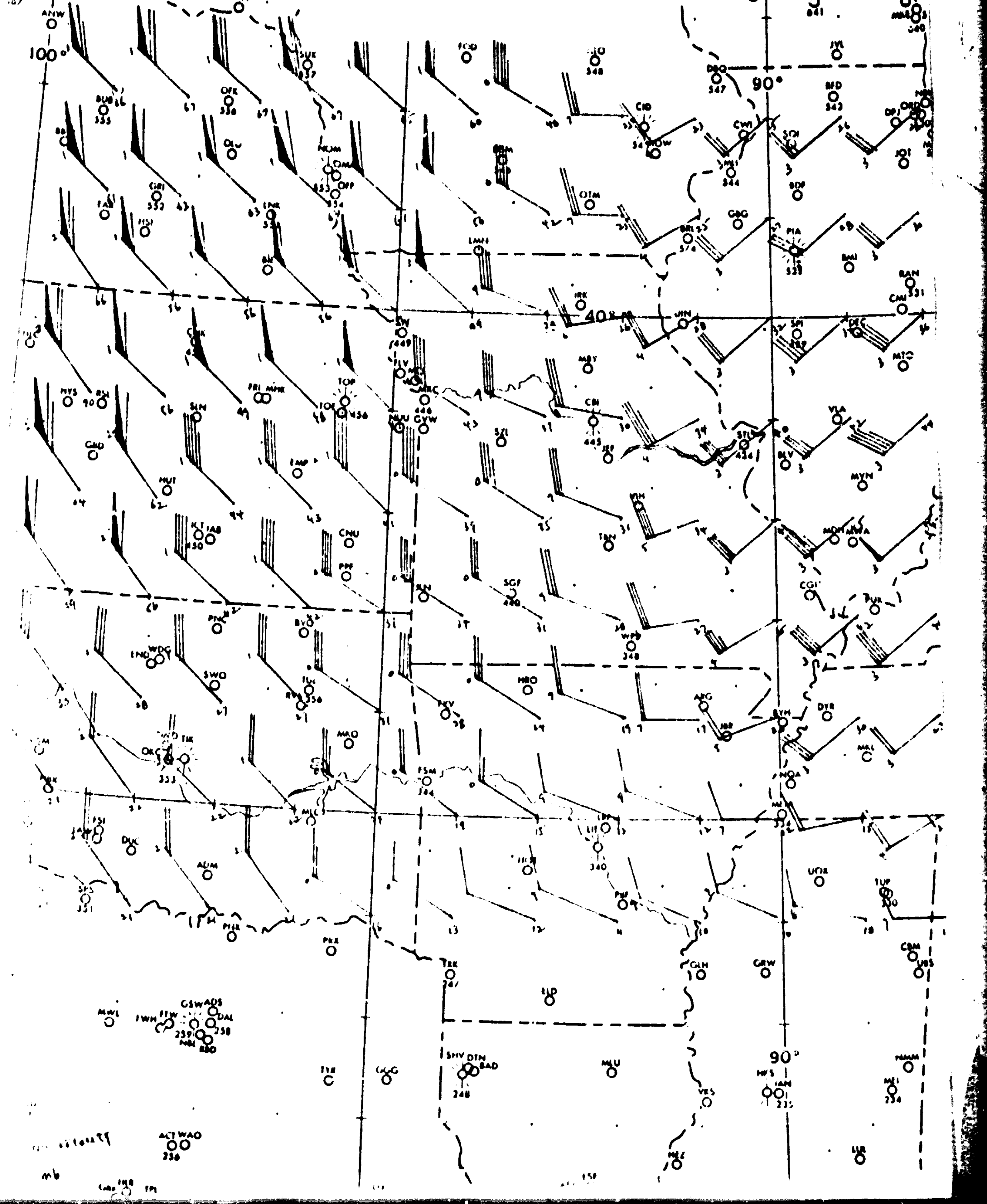


Fig 6-b
300mb vorticity

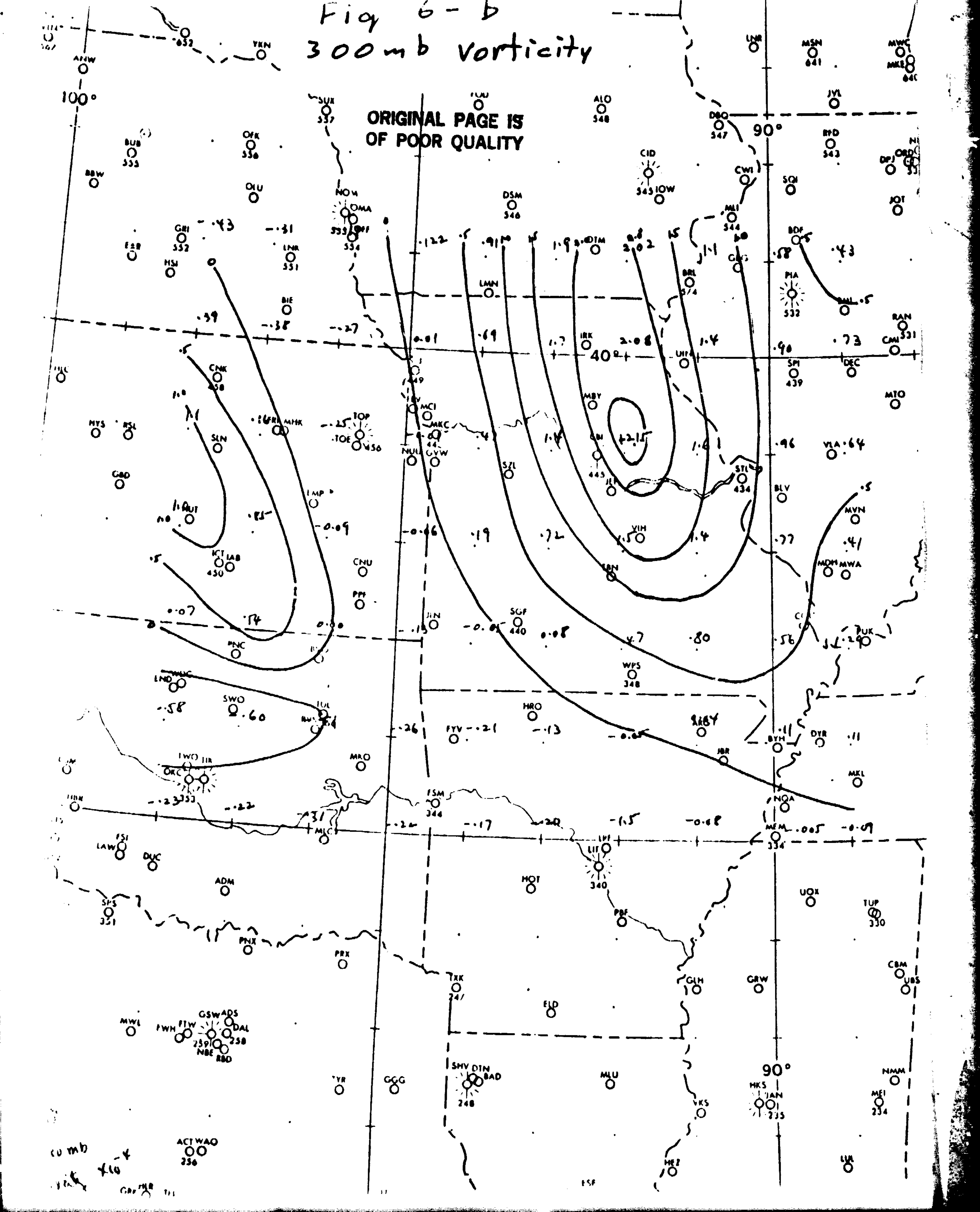
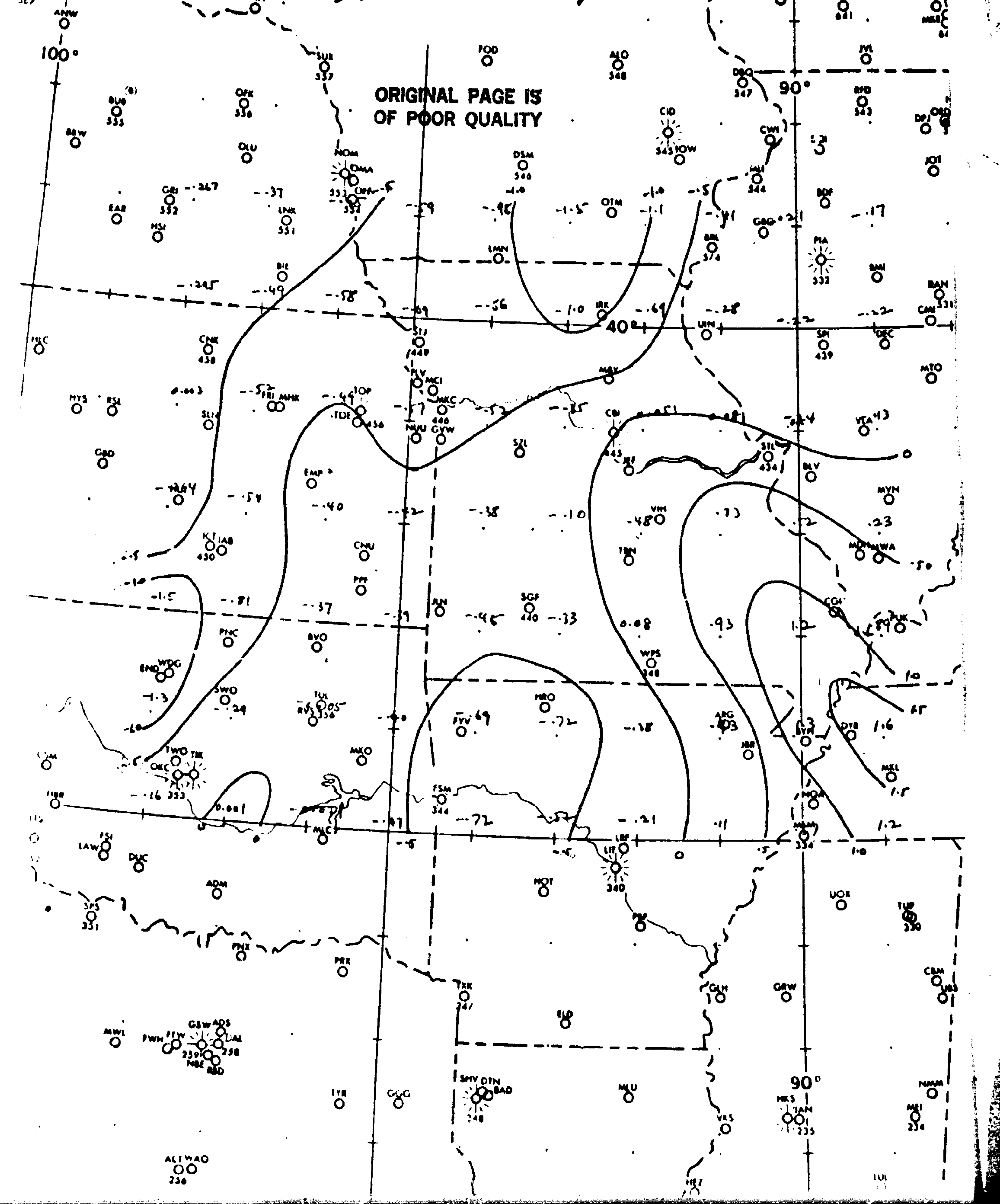
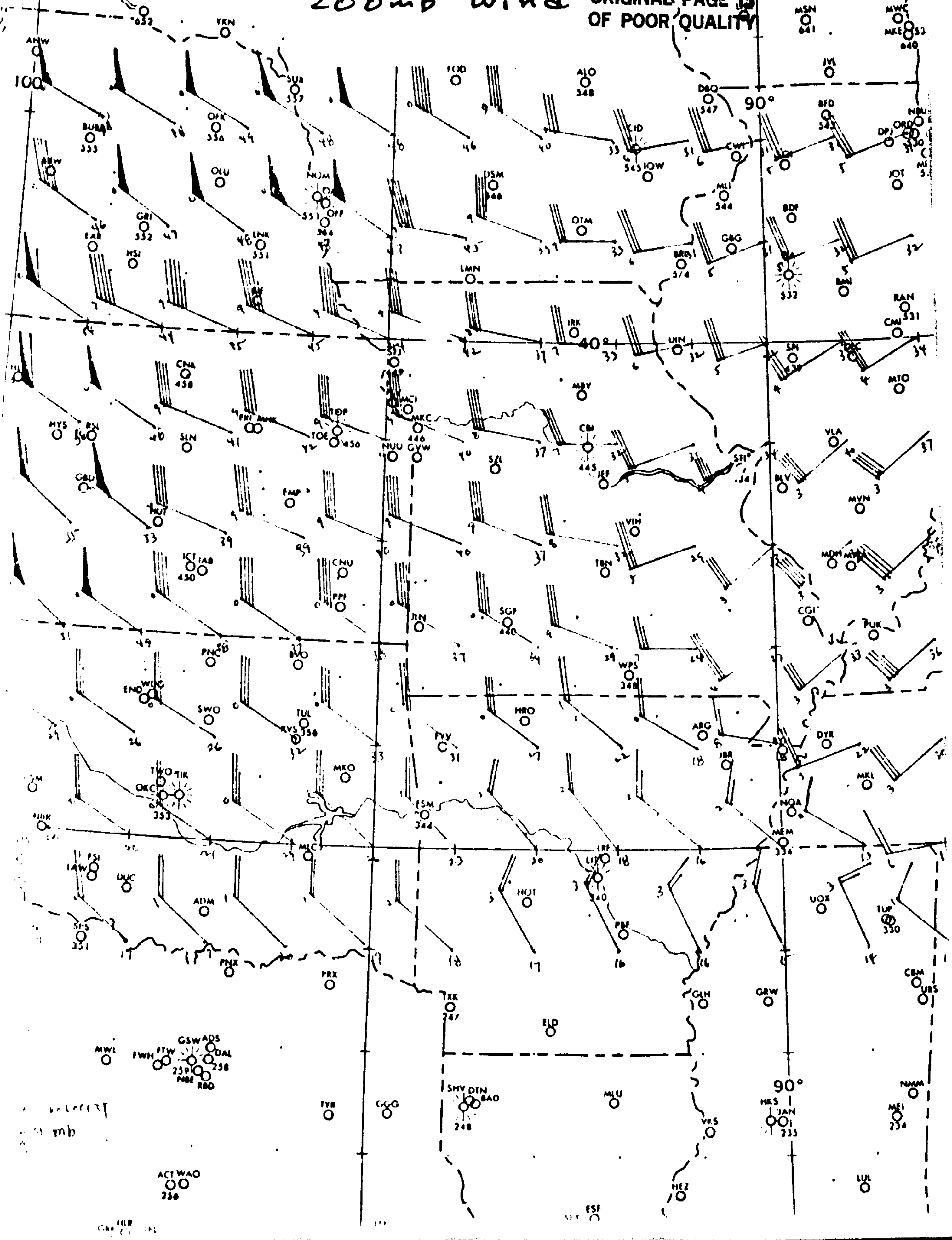


Fig 6-c
300 mb divergence



200mb wind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200mb vorticity

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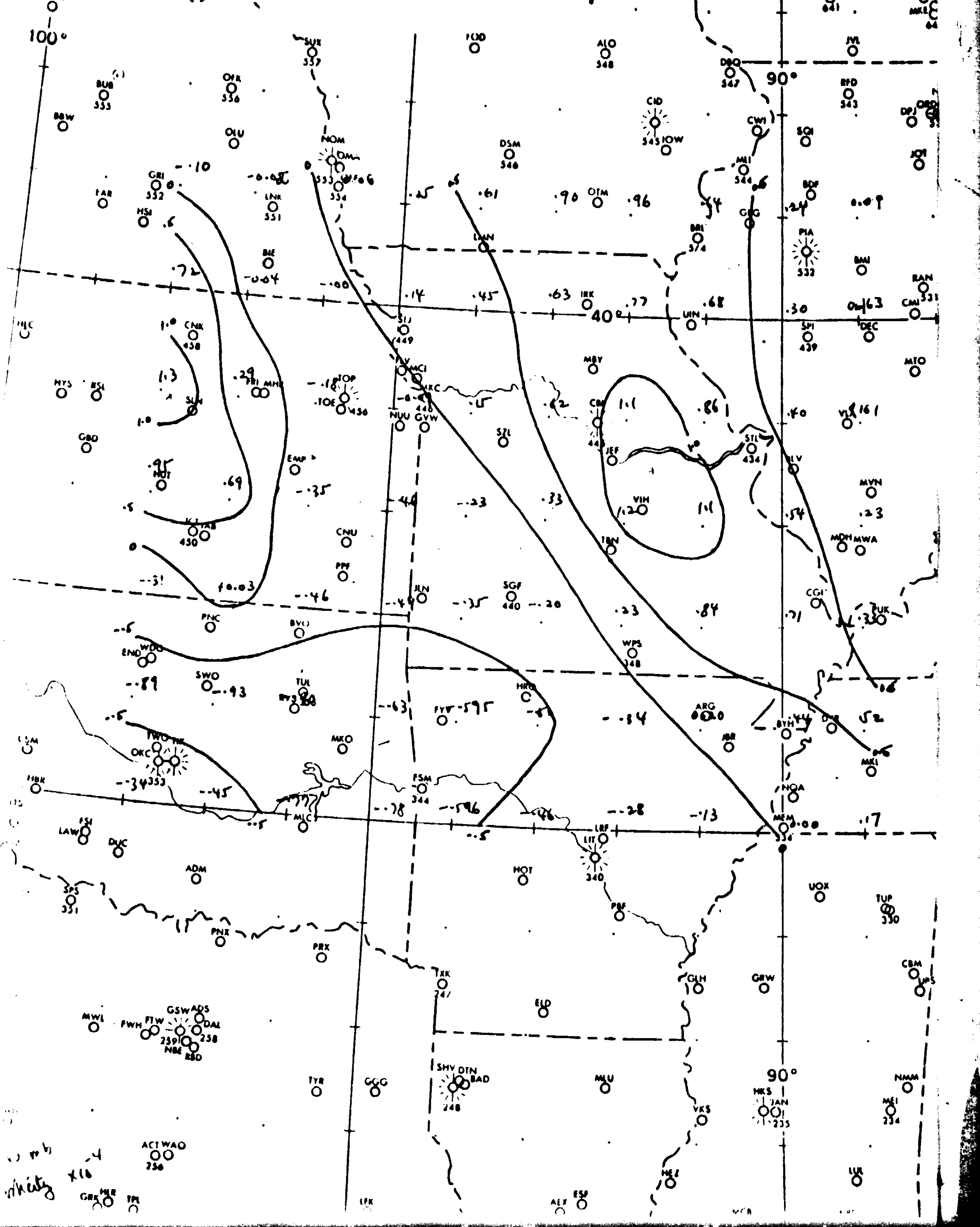

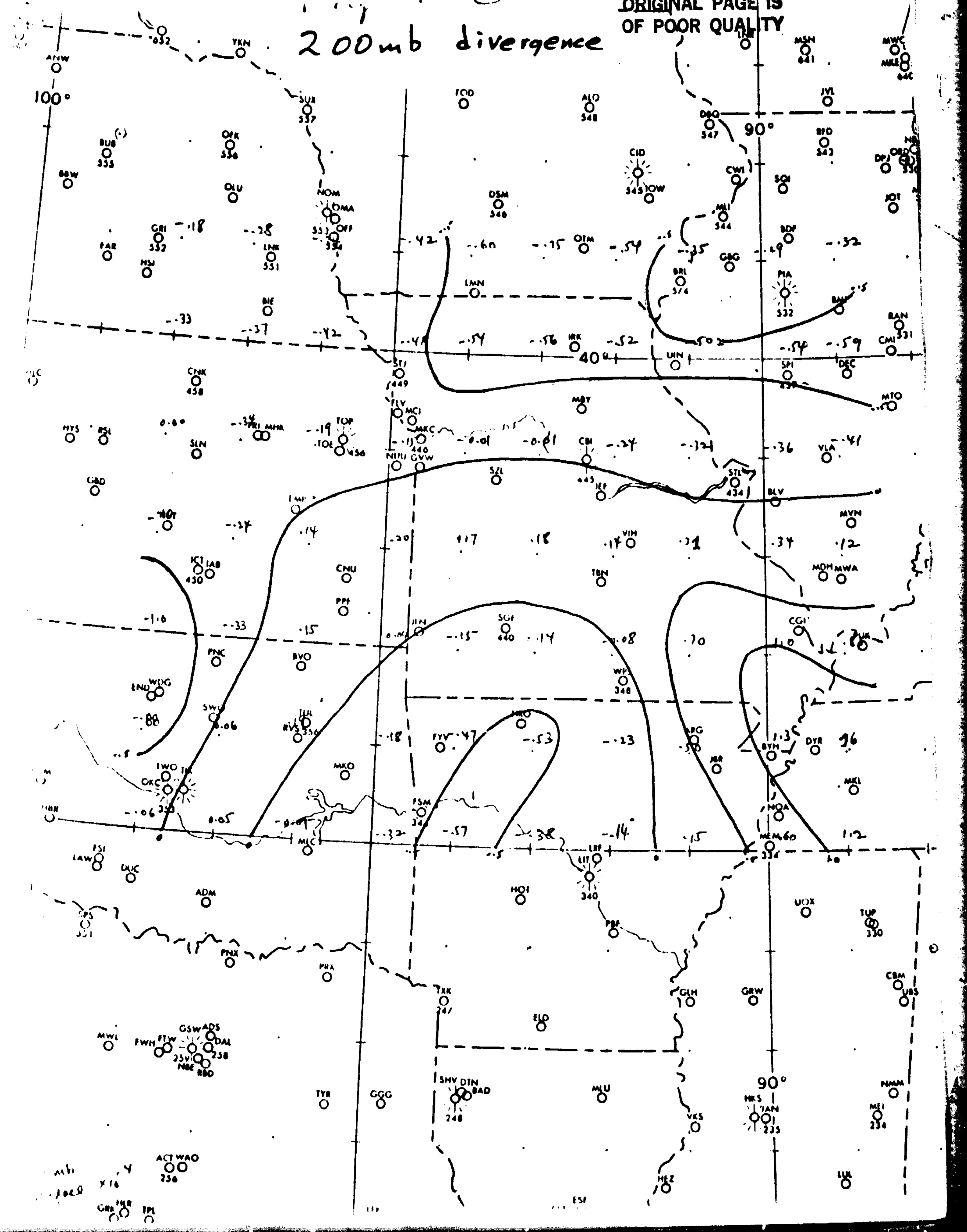
200mb divergence
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