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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service

Practical Application of a Graphical Method of Geostrophic Wind Determination

C. B. Johnson

CENTRAL REGION
Kansas City, Mo.

NOV. 1971

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U. S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE

NOAA Technical Memorandum NWS CR-47

PRACTICAL APPLICATION OF A GRAPHICAL METHOD OF GEOSTROPHIC WIND DETERMINATION

C. B. Johnson

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KANSAS CITY, MISSOURI
November 1971

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C. B. Johnson
WSFO, Chicago, Illinois

1. INTRODUCTION

The geostrophic wind value over an area is frequently of use to forecasters. This derived wind value is usually obtained from the isobaric analysis of sea-level pressure over an area of interest using a geostrophic wind scale appropriate to the latitude, and the isobaric interval of the analysis. This method has some disadvantages: the need of a carefully analyzed surface map, the time lag from the observations of pressure to the completed map, and the subjective estimate of the geostrophic wind. The graphical method of geostrophic wind determination overcomes these disadvantages.

It is possible to obtain the geostrophic wind value over an area of forecast interest by graphical means using the pressures at the vertices of a triangle (Hovde and Reber, 1952). This method has advantages of speed and objectivity since the computations are made directly from hourly pressure reports. The graph developed for a forecast area will quickly yield the geostrophic wind, at any hour, from the pressure difference values of the stations forming the triangular area. It is especially applicable to areas such as the Great Lakes where ship weather reports are limited and the adjacent land wind reports are considerably influenced by friction and changes in air stability. Weather Service Offices in the Great Lakes area that have responsibility for recreational boating forecasts and advisories should find this method of obtaining geostrophic winds useful. It can also be useful for offices away from the Lakes for such things as air pollution, mountain lee waves, etc.

2. THE TRIANGLE METHOD

To obtain the magnitude and direction of the geostrophic wind in a uniform pressure field (straight, parallel, and equally spaced isobars), a triangle is constructed with station pressures (or constant pressure heights) at each vertex (Fig. 1). In such a pressure field the geostrophic wind vector AD is proportional to the pressure gradient, parallel to the isobars, and in such a direction that low pressure is to the left when one is facing in the direction of the wind (Buys Ballot's law).

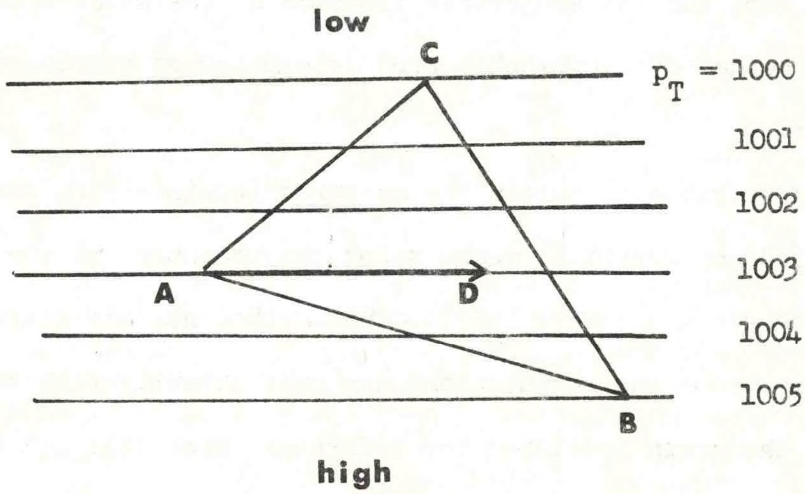


Figure 1

The total pressure field (p_T) over the area may be resolved into two component pressure fields (p_1 and p_2) constructed so that the corresponding geostrophic winds are parallel to sides AB and AC, respectively, and $p_T = p_1 + p_2$ (see Figs. 2 and 3). Now it is clear that the geostrophic wind corresponding to the total pressure field may be computed by the simple vector addition of the geostrophic winds corresponding to the component pressure fields p_1 and p_2. In Fig. 2 the wind component AB' is proportional to the pressure difference between points A and C divided by the perpendicular distance c, parallel to the isobars, and directed from point A toward B. In Fig. 3 the wind component AC' is proportional to the pressure difference between points A and B divided by the perpendicular distance b, parallel to the isobars, and directed from point A toward C.

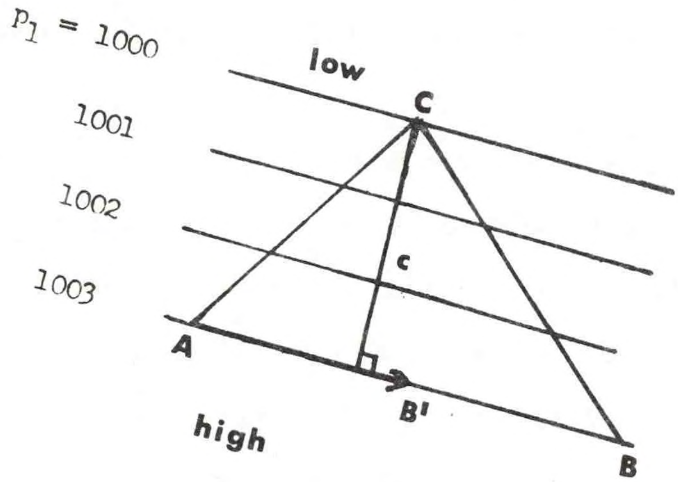


Figure 2

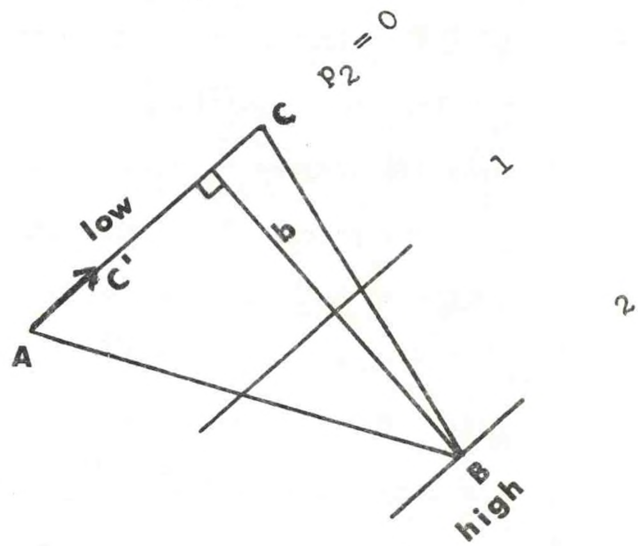


Figure 3

The component wind vectors of the triangle are obtained from the geostrophic wind equation: $V_g = \frac{1}{f\rho} \frac{\partial p}{\partial h}$, where f is the Coriolis parameter and ρ is the air density. The geostrophic wind equation expressed in reference to wind component AB' (Figure 2) is: $V_g = \frac{1}{f\rho} \frac{P_a - P_c}{c}$, and is directed from point A toward point B if $P_a - P_c$ is positive (or directed point B toward point A if $P_a - P_c$ is negative) by use of Buys Ballot's law. Similarly, wind component AC' (Figure 3) is $V_g = \frac{1}{f\rho} \frac{P_a - P_b}{b}$, and is directed from point A toward point C if $P_a - P_b$ is negative (or directed point C toward point A if $P_a - P_b$ is positive).

The Smithsonian Meteorological Tables (List, 1951) are the most convenient source for obtaining the geostrophic wind component values. The tables (pp 124-125)* give the geostrophic wind speed in knots for a constant

*Note that the titles on these pages are incorrect--"level" should be substituted for "pressure".

level surface using a 3 millibar isobaric interval, at various latitudes, and isobaric spacing in degrees of latitude or other length units. The indicated wind speed is for air density of 1 kg. m.$^{-3}$ (about 2 km. above sea level) and must be corrected, as shown in the table heading, for the altitude of the desired geostrophic wind. The computed wind values are then used to develop the computation graph. The tables on pp. 120-123 are used if constant pressure surface heights are used.

For practical use the triangle selected over an area of interest should be chosen such that the angle CAB is neither too large nor too small and of such a size that the pressure field in most cases may be considered uniform. Sides AB and AC should not be so short as to make the computations overly sensitive to errors in the pressure values. A further consideration is the requirement that hourly reporting stations be selected for each apex of the triangle, or that the pressure at the selected point be estimated with accuracy.

3. CONSTRUCTION OF THE GRAPH

The area over eastern Lake Superior defined by the reporting stations MQT, SSM, and WR is a suitable triangle for computation. MQT is used to correspond to point A, SSM to point B, and WR to point C of Figure 1. The distances b and c measure 106 and 125 nautical miles and the azimuth angles of sides MQT-WR and MQT-SSM are 35 degrees and 90 degrees from true north respectively (from Lambert Conformal map base of scale 1:3,000,000, Figure 4). The computed component wind values for the 3 millibar isobaric interval obtained from the Smithsonian Tables and corrected for air density at the altitude of the Great Lakes (1.2kg. m^{-3})* are 23 knots at 35 degrees and 20 knots at 90 degrees.

*Usually the standard atmosphere density at sea level (1.23 kg. m.$^{-3}$) is used, since sea-level pressures are involved. In this case the difference is of no great consequence.

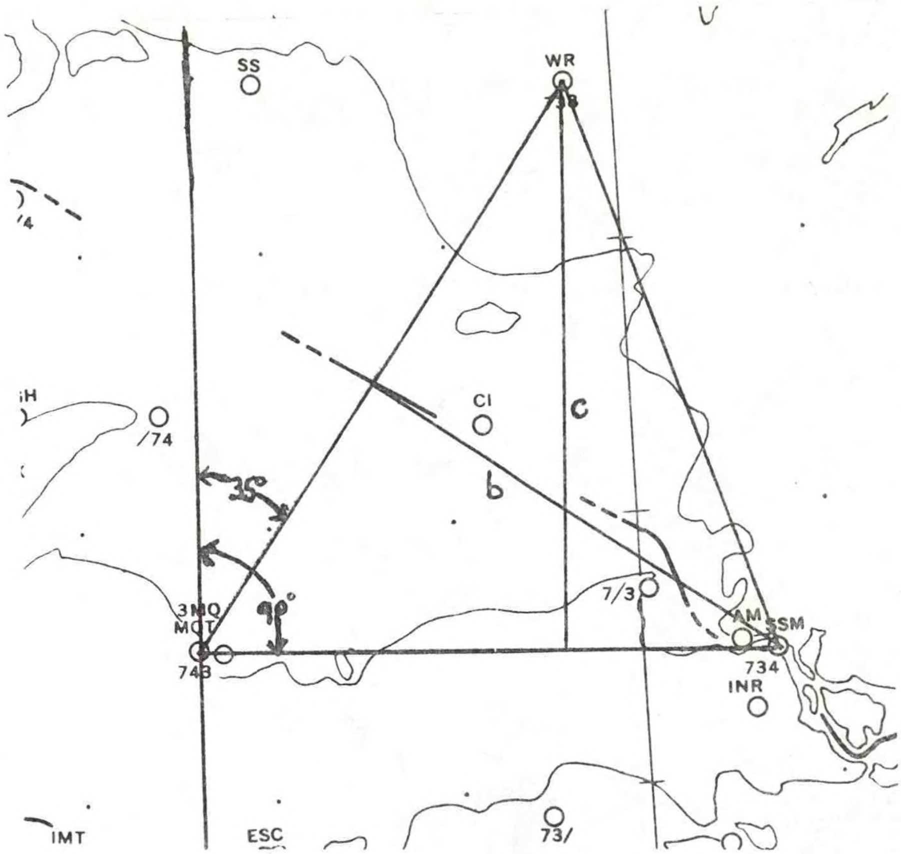


Figure 4

A convenient way to obtain the sum of these two vectors is to use a polar coordinate graph or hodograph (Figure 5). The concentric circles are scaled in knots and point A (MQT) of the triangle is located at the center. The two wind components are drawn on the hodograph to a distance equal to the wind speed in knots at the indicated azimuth angle. Note that the lines forming this vector parallelogram are at the 3 mb isobaric interval used in the Smithsonian Tables, with the pressure difference between MQT and SSM negative and the pressure difference between MQT and WR positive.

The actual working graph is prepared for the given set of stations by drawing two sets of lines at 1 millibar interval for all positive and negative pressure differences, each set being parallel to the sides of the

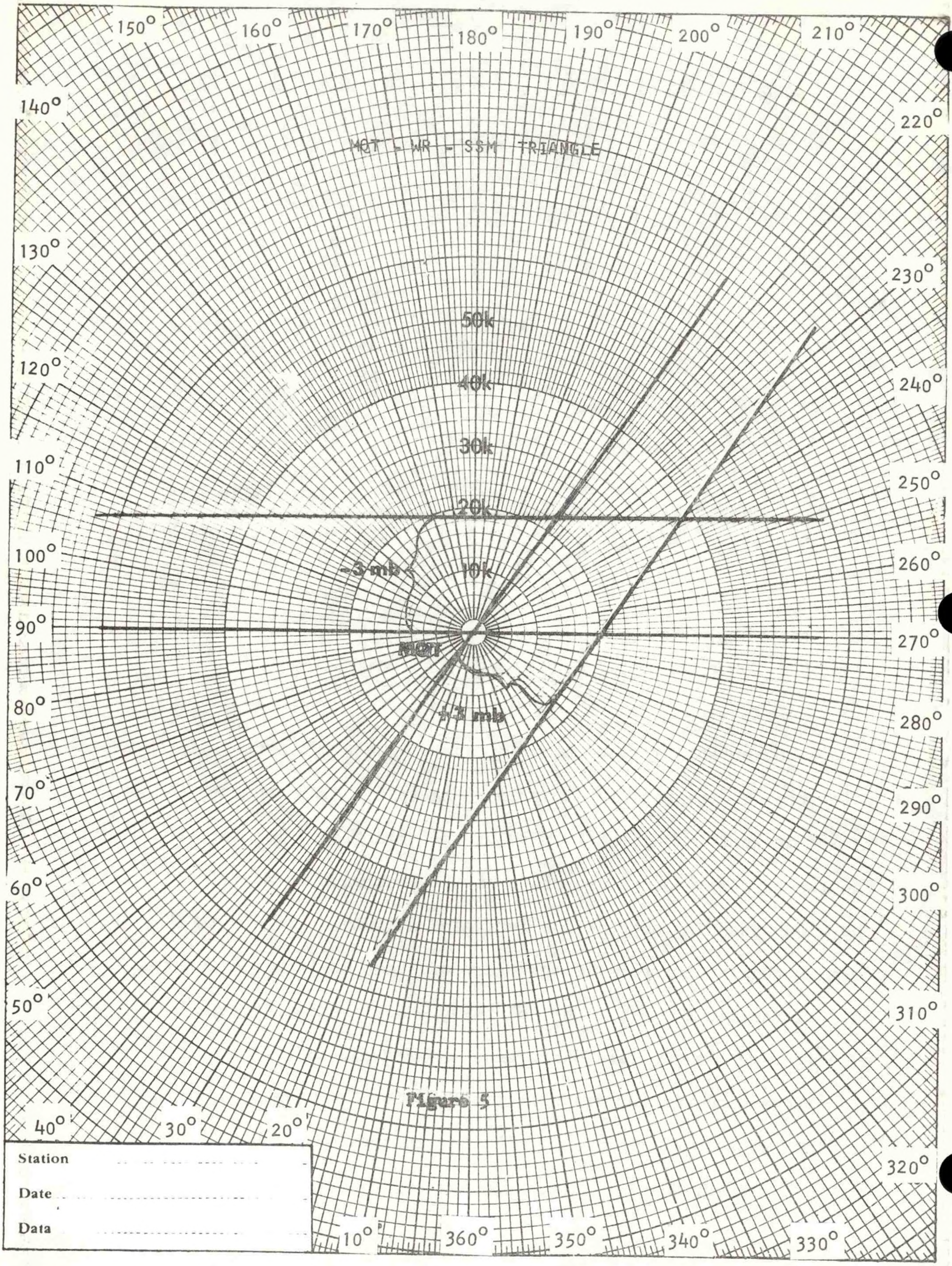

MQT - WR - SSM TRIANGLE
50k
40k
30k
20k
10k
-5 mb
MQT
+3 mb
Station
Date
Data

Figure 5

triangle used for computation (Figure 6). This graph is a permanent analysis tool and will yield the geostrophic wind for all possible pressure values at the stations defining the triangular area without further computation. The geostrophic wind vector is easily obtained by locating the point on the diagram corresponding to the two known pressure differences. This procedure computes the geostrophic winds corresponding to the component pressure fields and adds them graphically in one step. Care must be used to be sure the sign of the pressure difference is used correctly. As an example, with a positive pressure difference of 4.5 millibars between MQT and SSM and a positive pressure difference of 3.0 millibars between MQT and WR the resultant wind is 360 degrees at 29 knots (see Figure 6).

4. APPLICATION TO GREAT LAKES FORECASTING

As an aid to forecasting winds and related wave heights three triangular areas were selected for Lake Superior, four areas for Lake Michigan, and two for Lake Huron, as shown in Figures 7 and 8, which are worksheets used to organize the data for the computation. They can also serve as a record of the computation for later use. Pressure values at the selected locations are available from hourly reports, except that the pressure at point X on Lake Michigan must be estimated. Usually the average of the MKE and MKG pressures is a suitable estimate. Computation graphs for all these triangles are attached.

This method of obtaining geostrophic winds has been in daily use for the past two years by forecasters at WSFO, Chicago and has proved to be a valuable aid in preparing forecasts for Lake Superior and Lake Michigan.

Weather Service Offices in the Great Lakes area may find that other triangular areas are more suitable for their use in the preparation of recreational boating forecasts. For example, the MKE-MKG-SBN triangle

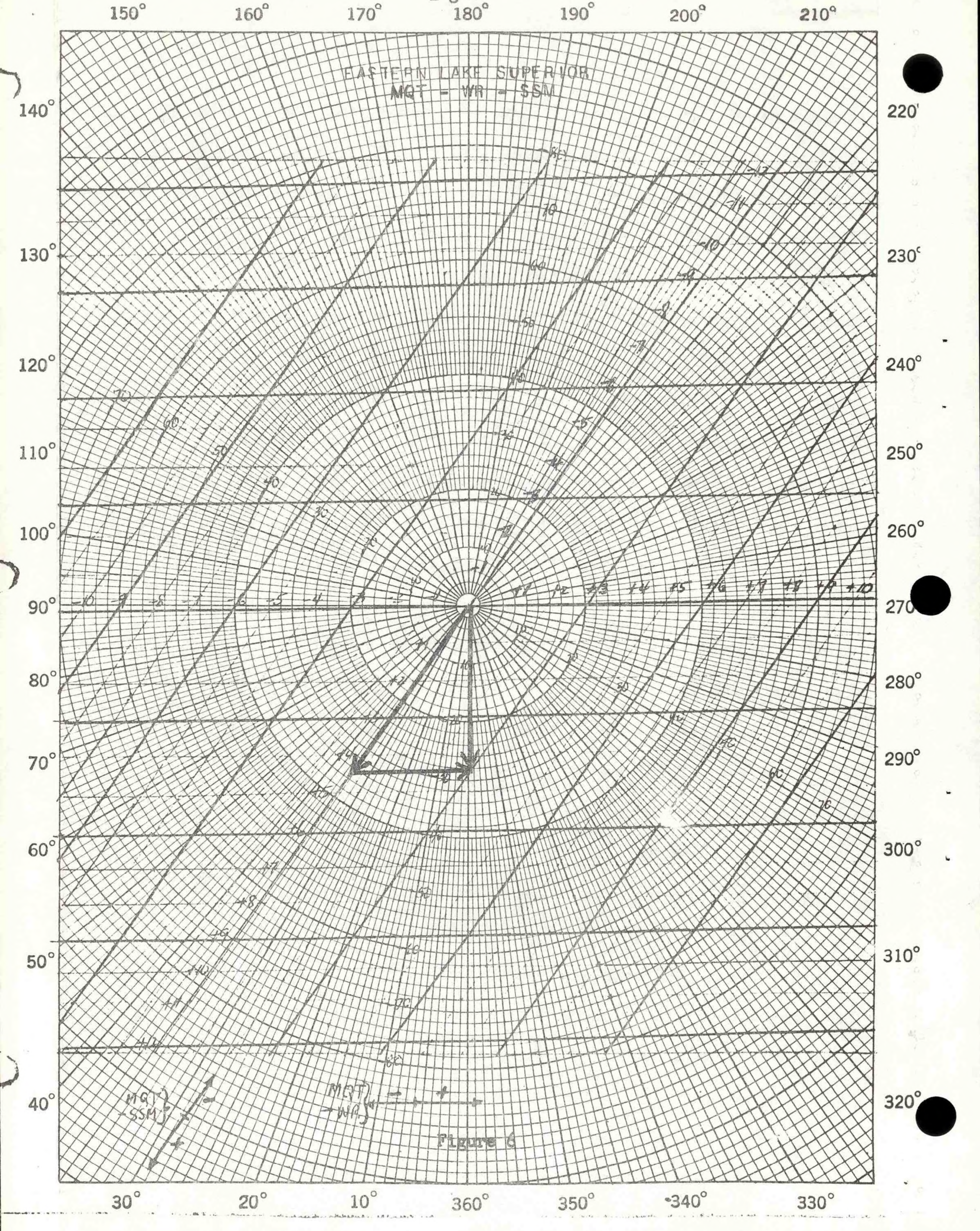
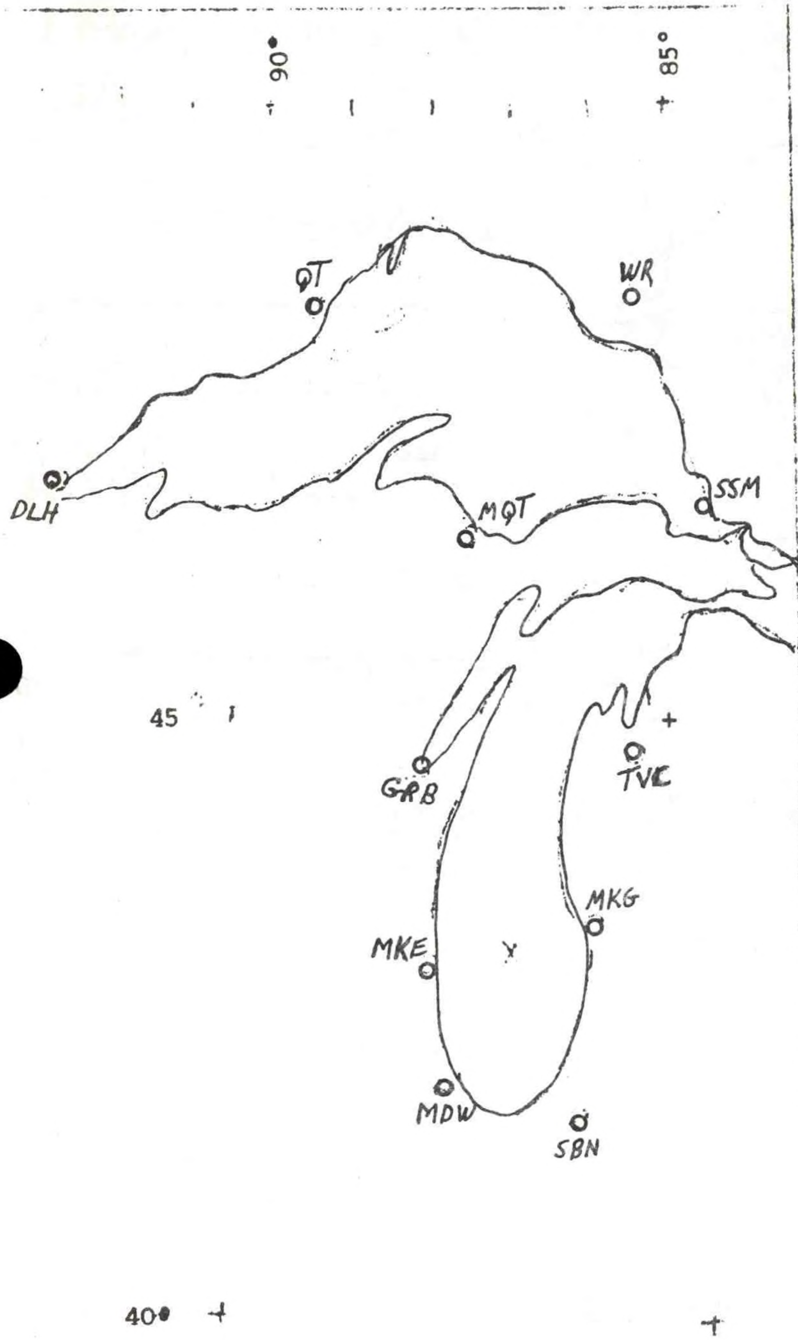

EASTERN LAKE SUPERIOR
MQT - WR - SSM
150°
160°
170°
180°
190°
200°
210°
140°
130°
120°
110°
100°
90°
80°
70°
60°
50°
40°
220°
230°
240°
250°
260°
270°
280°
290°
300°
310°
320°
30°
20°
10°
360°
350°
340°
330°

Figure 6

Geostrophic Wind Computations

Time________ Date________



Scale of above map is 1:7.5 M

Air density 1.2 KG per M^3

Figure 7

Western Lake Superior

QT -MQT________ QT -DLH________

Geostrophic Wind:

Central Lake Superior

QT -MQT________ QT -WR________

Geostrophic Wind:

Eastern Lake Superior

MQT -SSM________ MQT -WR________

Geostrophic Wind:

Northeastern Lake Michigan

MQT -SSM________ MQT -TVC________

Geostrophic Wind:

Northwestern Lake Michigan

GRB -MQT________ GRB -TVC________

Geostrophic Wind:

Central Lake Michigan

GRB -X________ GRB -TVC________

Geostrophic Wind:

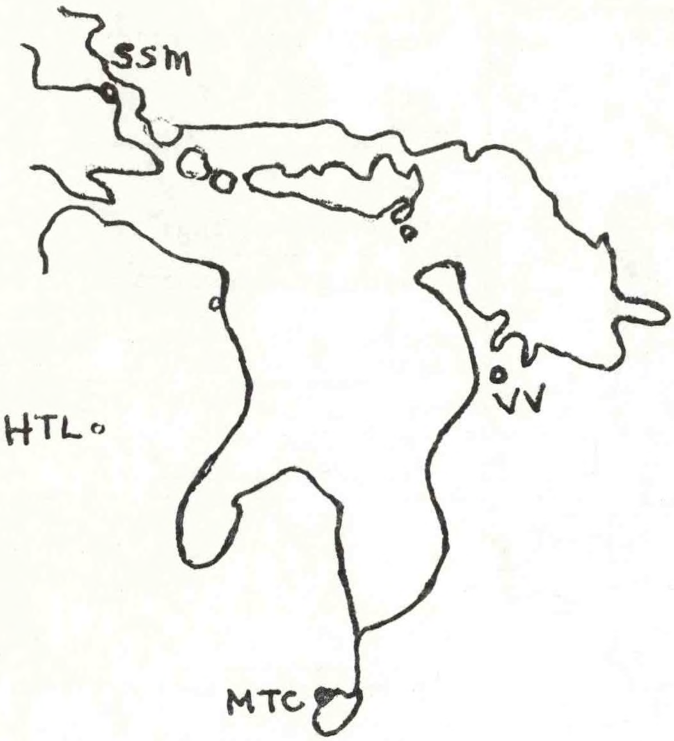
Southern Lake Michigan

MDW -SBN________ MDW -X ________

Geostrophic Wind:

Geostrophic Wind Computations

Time ______ Date ____________



Northern Lake Huron

HTL - VV ____ HTL -SSM ____

Geostrophic Wind:

____

Southern Lake Huron

MTC -HTL ____ MTC - VV ______

Geostrophic Wind:

____

Scale of above map is 1:7.5 M

Air density 1.2 KG per M^{-3}

Figure 8

effectively covers the southeastern Lake Michigan coastal area. A computation graph can be quickly constructed for such an area by following the procedure given above.

The graphs provide the duty forecaster with a quick and accurate measure, at any hour, of the geostrophic wind. It is useful in making periodic checks on wind warnings and wave height estimates, in evaluating lake breeze effects, and local lake snow potential. Any available ship reports may be used to determine a correction factor for the effect of air stability over the lake and the curvature of the pressure field (see CR T.M. 21 and 41, and News and Views, April 6, 1971, pp. 7-8).

ACKNOWLEDGEMENT

This report was written from notes, diagrams, and graphs prepared for use at WSFO, Chicago, by Mr. John E. Hovde. It is believed that other offices will find this quick method of obtaining the geostrophic wind over a small area useful in preparing wind forecasts.

REFERENCES

Hovde, J. E., and C. M. Reber, 1952, Graphical determination of the geostrophic wind over a point or small area. Bull. Amer. Meteor. Soc., 33, 326-328.

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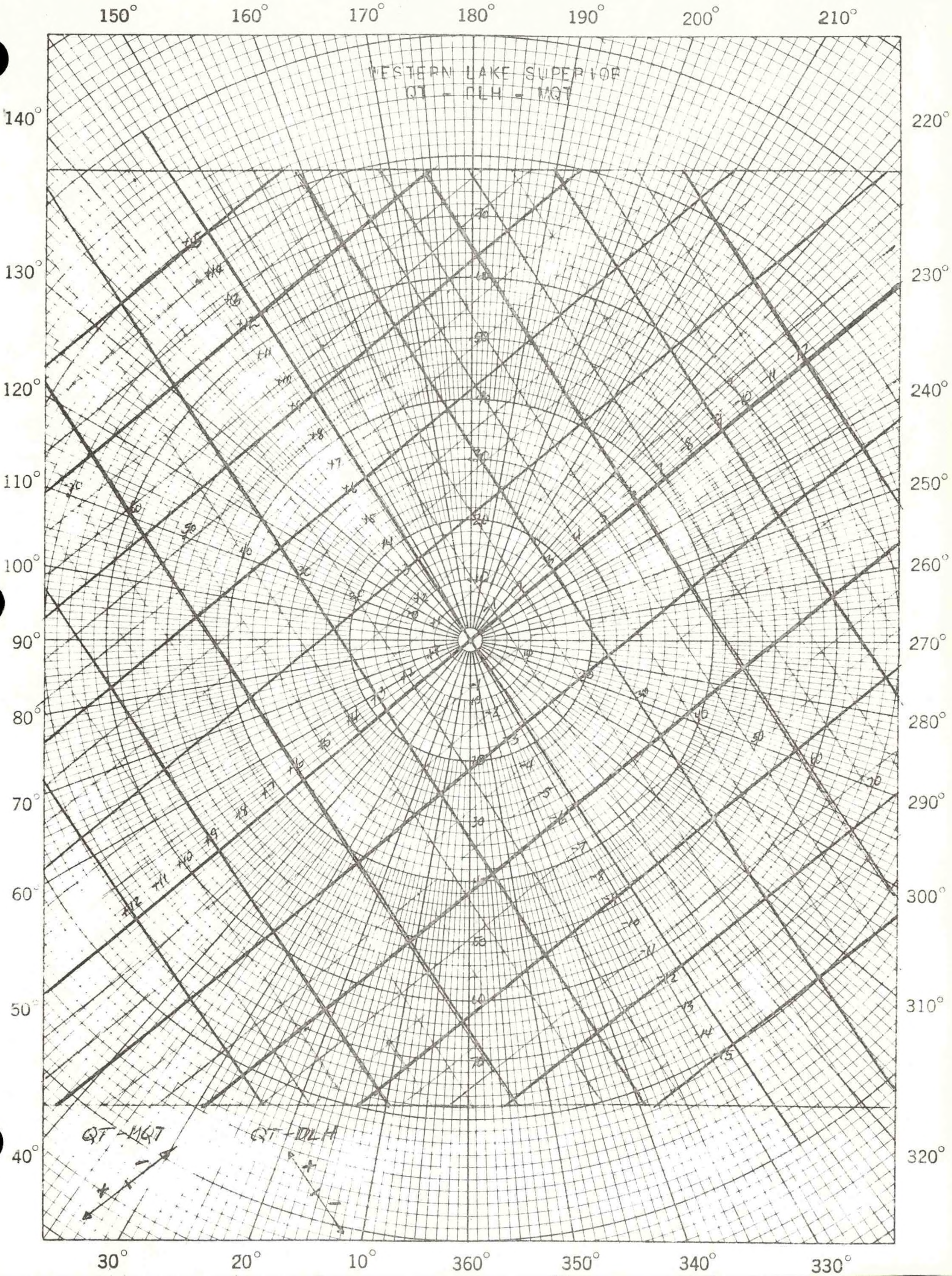
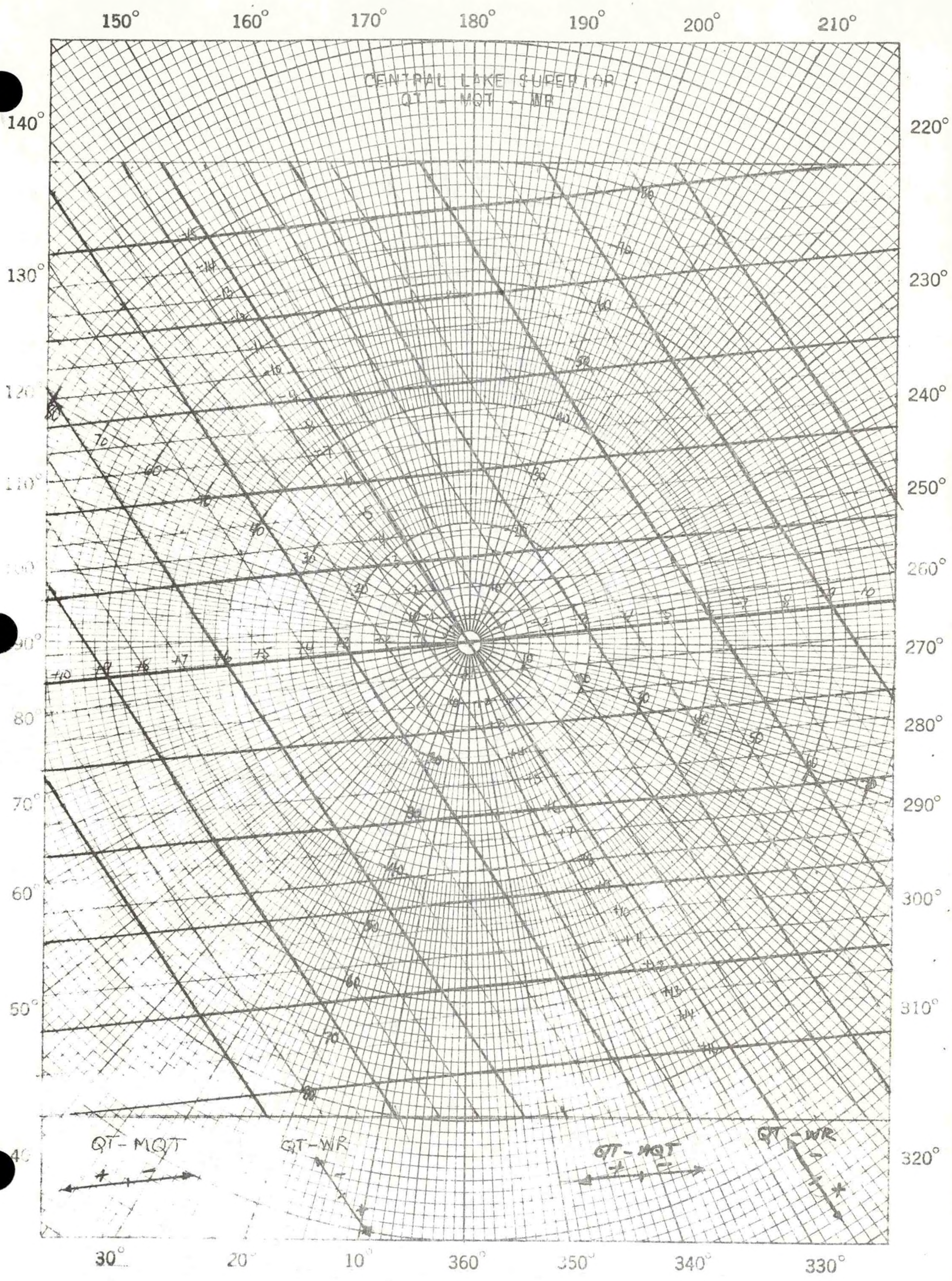


WESTERN LAKE SUPERIOR
QT - DLH - MQT
150° 160° 170° 180° 190° 200° 210°
140° 130° 120° 110° 100° 90° 80° 70° 60° 50° 40°
220° 230° 240° 250° 260° 270° 280° 290° 300° 310° 320°
30° 20° 10° 360° 350° 340° 330°
QT-MQT
QT-DLH


CENTRAL LAKE SUPERIOR
QT - MQT - WR
150°
160°
170°
180°
190°
200°
210°
140°
130°
120°
110°
100°
90°
80°
70°
60°
50°
40°
220°
230°
240°
250°
260°
270°
280°
290°
300°
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350°
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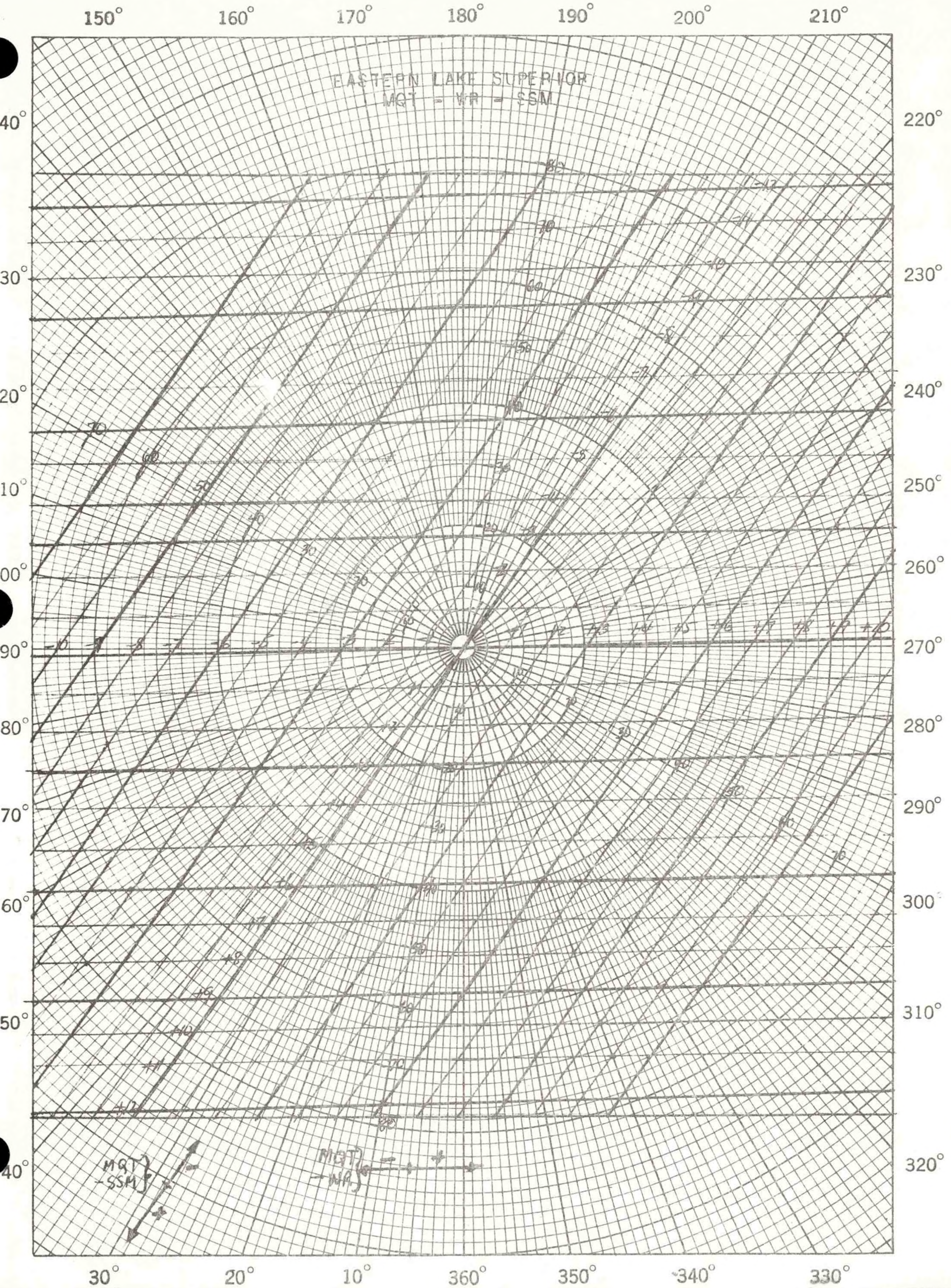
QT-MQT
QT-WR
QT-MQT
QT-WR



150°
160°
170°
180°
190°
200°
210°
EASTERN LAKE SUPERIOR
MQT - WR - SSM
140°
130°
120°
110°
100°
90°
80°
70°
60°
50°
40°
220°
230°
240°
250°
260°
270°
280°
290°
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310°
320°
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20°
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360°
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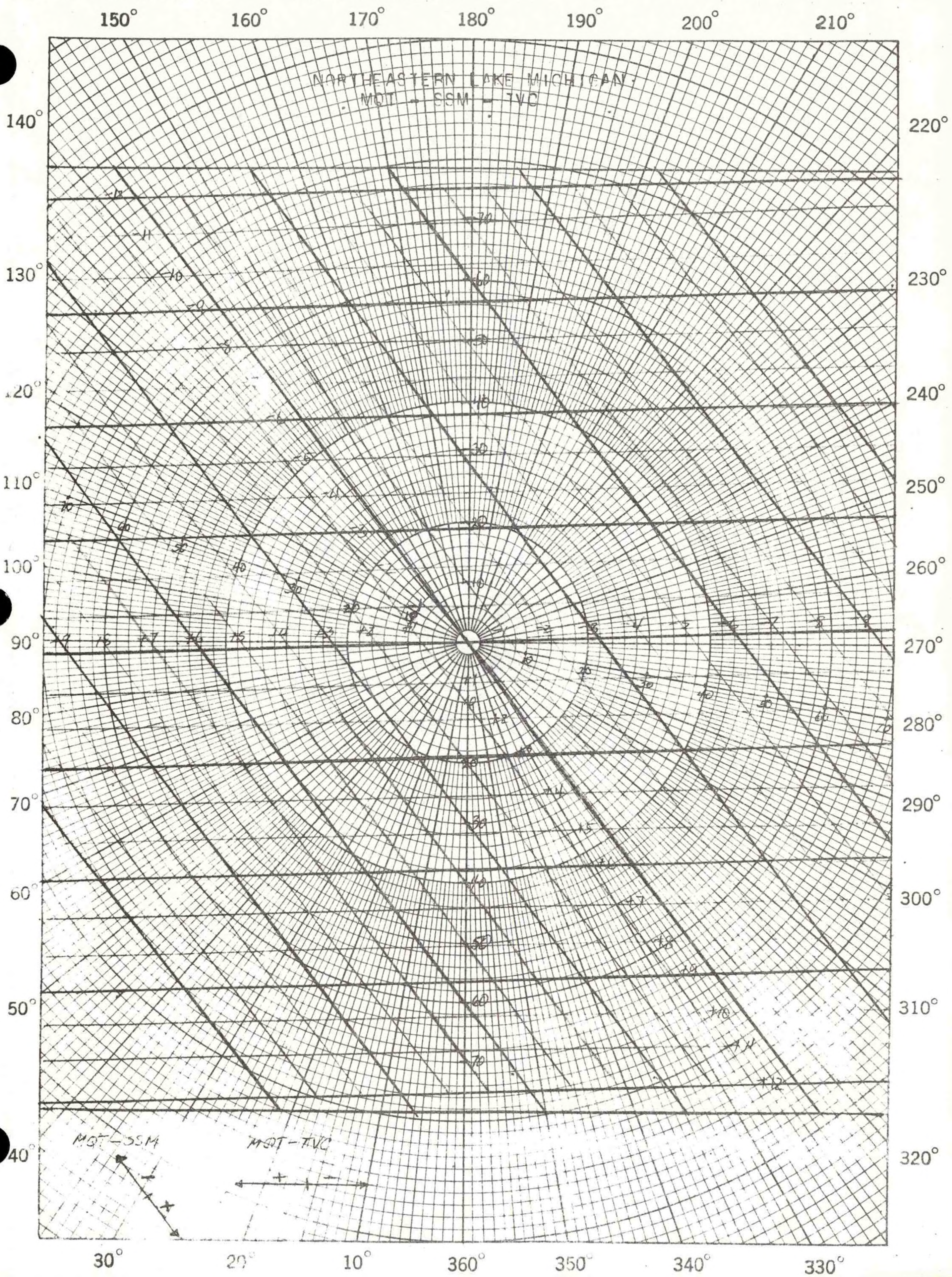
340°
330°
MQT
-SSM
MQT
-WR



NORTHEASTERN LAKE MICHIGAN
MQT - SSM - TVC
MQT-SSM
MQT-TVC
150°
160°
170°
180°
190°
200°
210°
140°
130°
120°
110°
100°
90°
80°
70°
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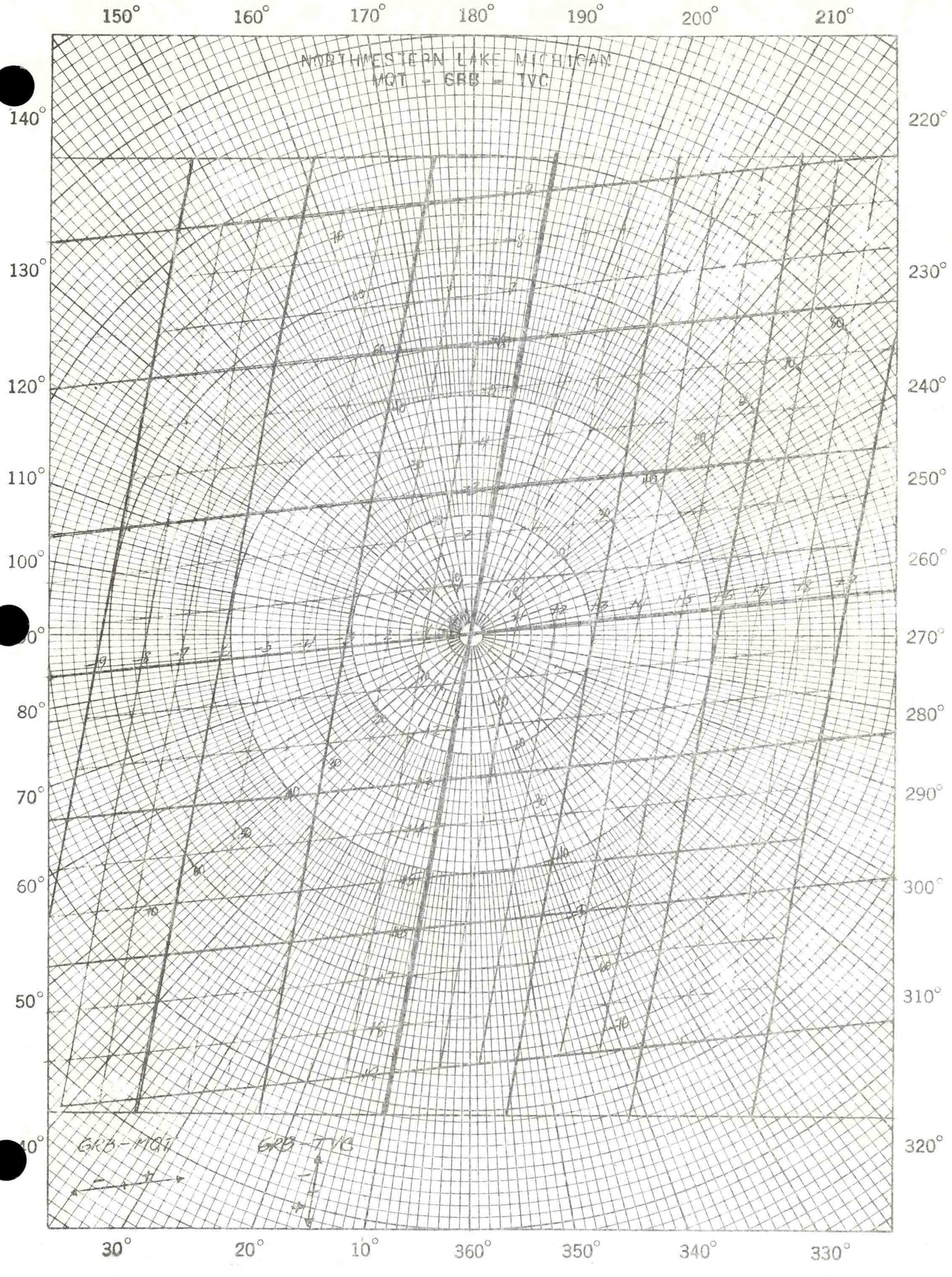
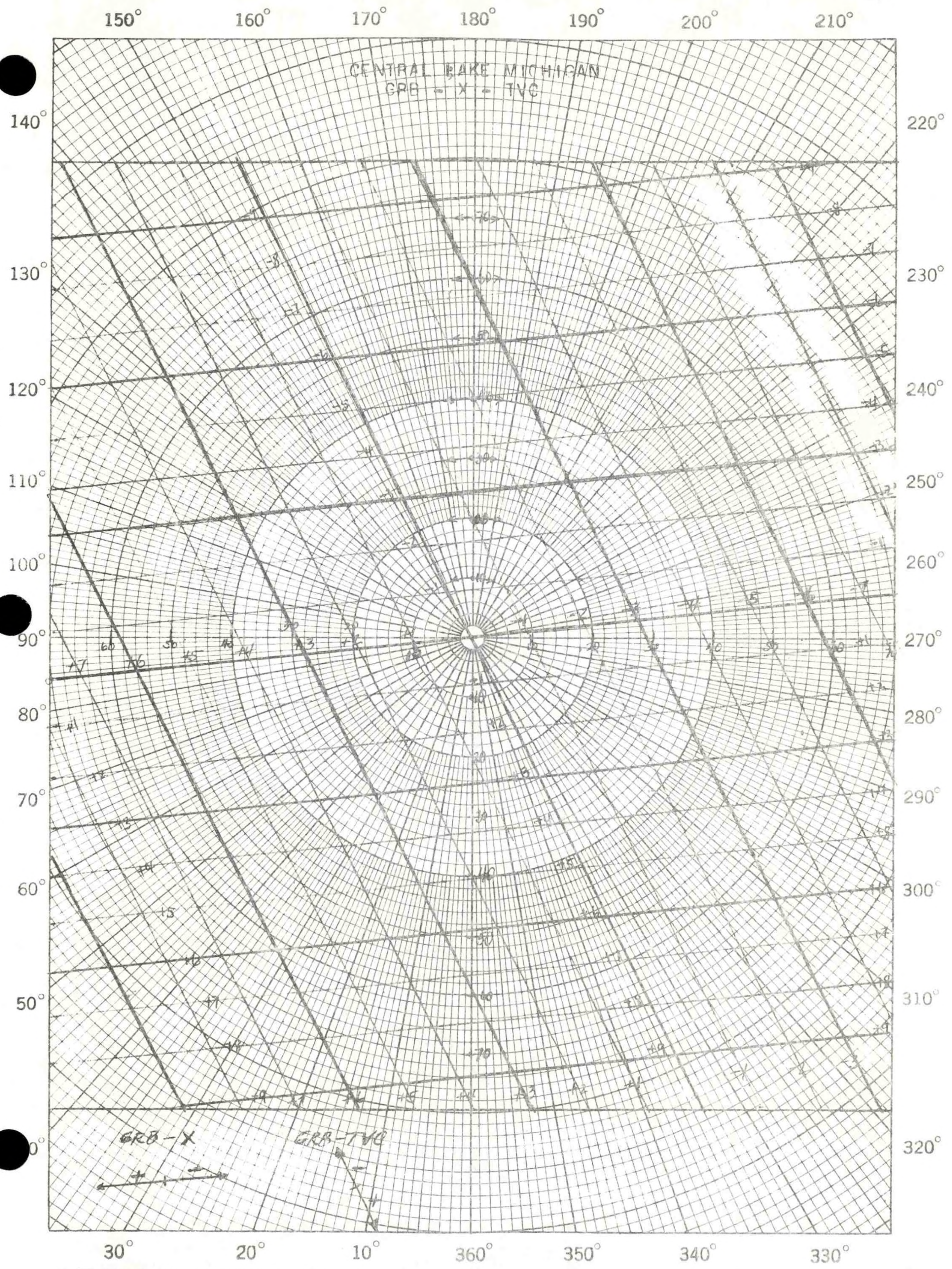
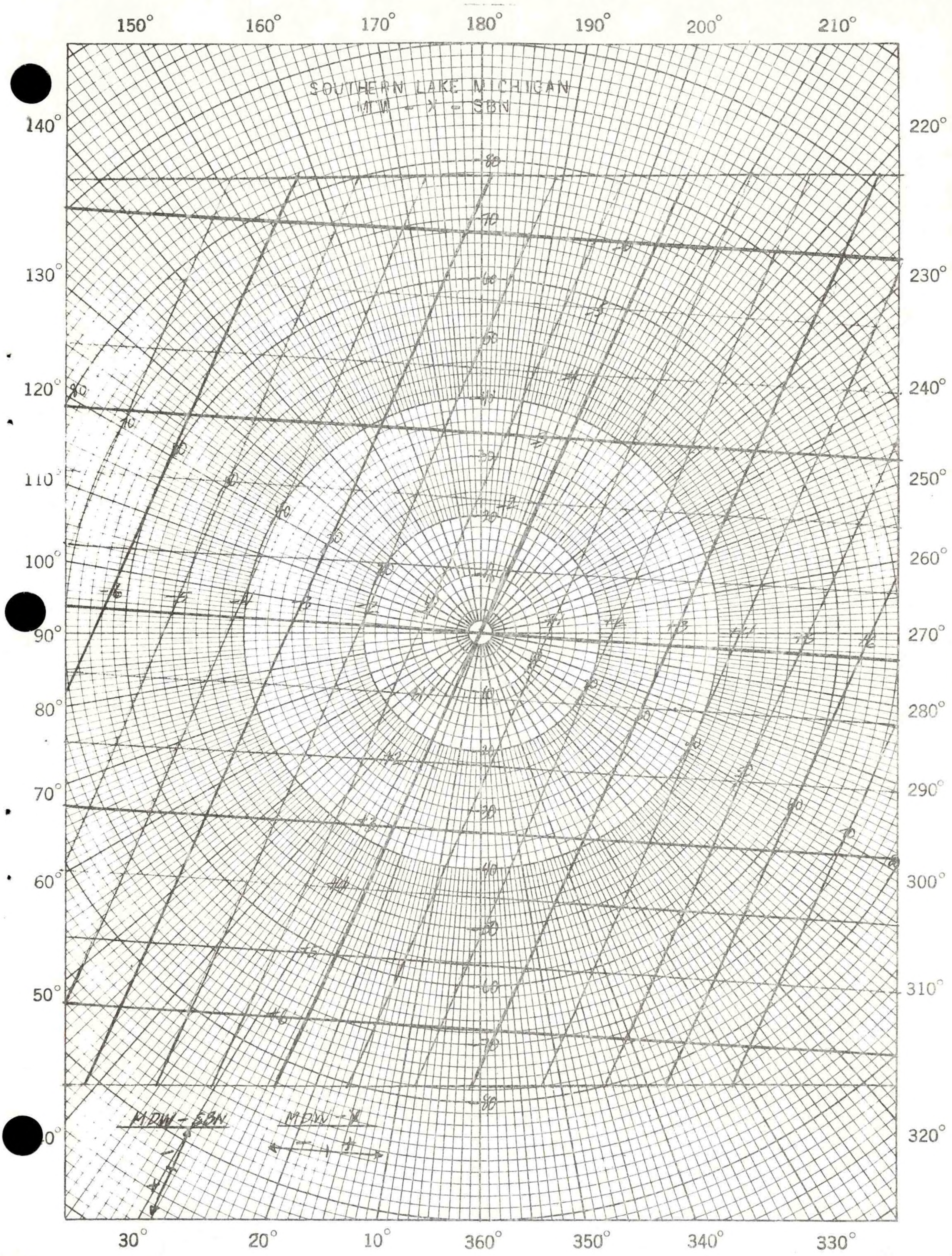


NORTHWESTERN LAKE MICHIGAN
MQT - GRB - TVC
GRB-MQT
GRB-TVC
150° 160° 170° 180° 190° 200° 210°
140° 130° 120° 110° 100° 90° 80° 70° 60° 50° 40°
220° 230° 240° 250° 260° 270° 280° 290° 300° 310° 320°
30° 20° 10° 360° 350° 340° 330°


CENTRAL LAKE MICHIGAN
GRB - X - TVC
GRB - X
GRB-TVC
150° 160° 170° 180° 190° 200° 210°
140° 130° 120° 110° 100° 90° 80° 70° 60° 50°
220° 230° 240° 250° 260° 270° 280° 290° 300° 310° 320°
30° 20° 10° 360° 350° 340° 330°



SOUTHERN LAKE MICHIGAN
MDW - X - SBN
MDW - SBN
MDW - X
150°
160°
170°
180°
190°
200°
210°
140°
130°
120°
110°
100°
90°
80°
70°
60°
50°
220°
230°
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20°
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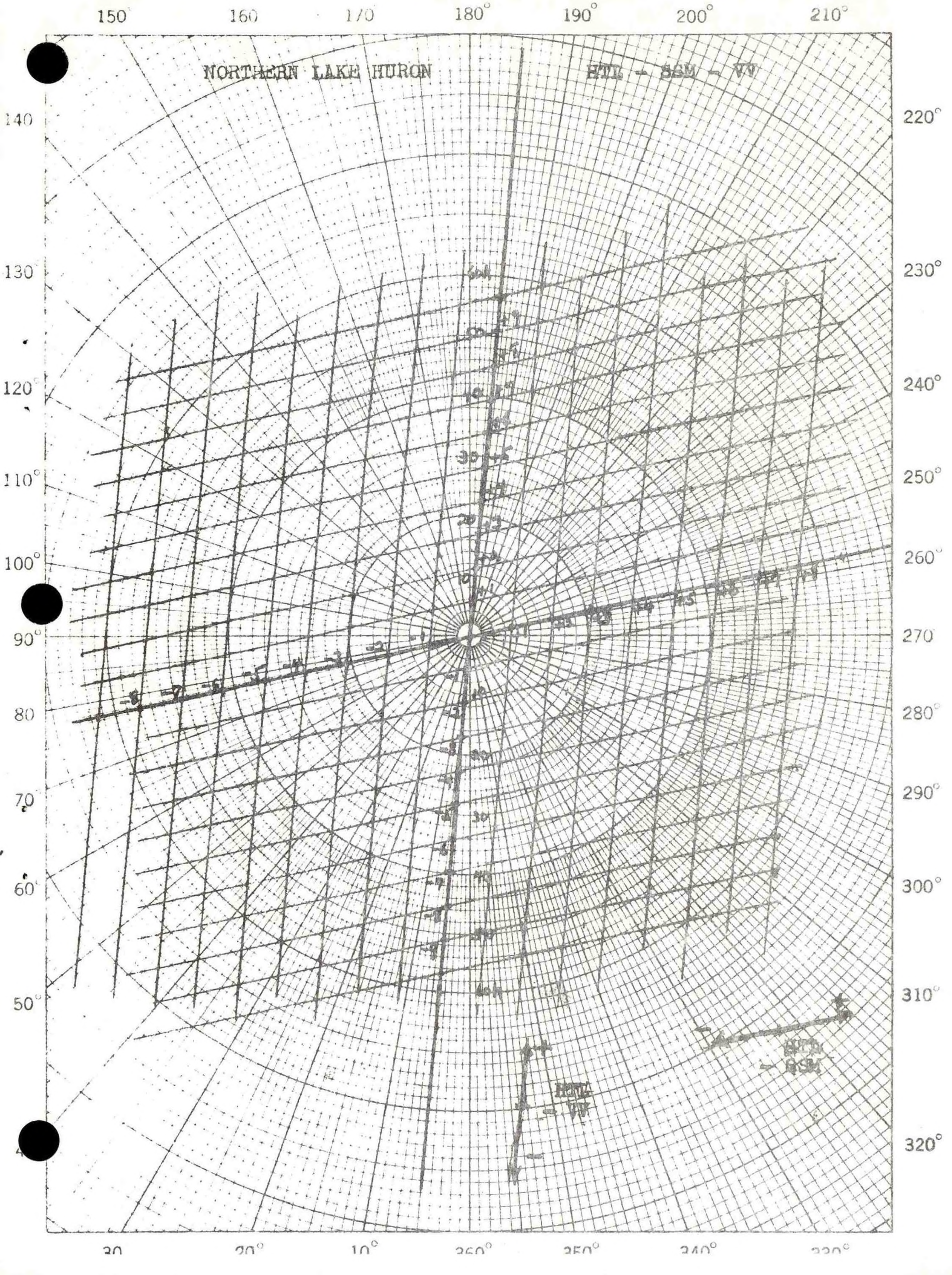
360°
350°
340°
330°


NORTHERN LAKE HURON
HTL - SSM - VV
HTL - SSM
HTL - VV
150°
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170
180°
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220°
230°
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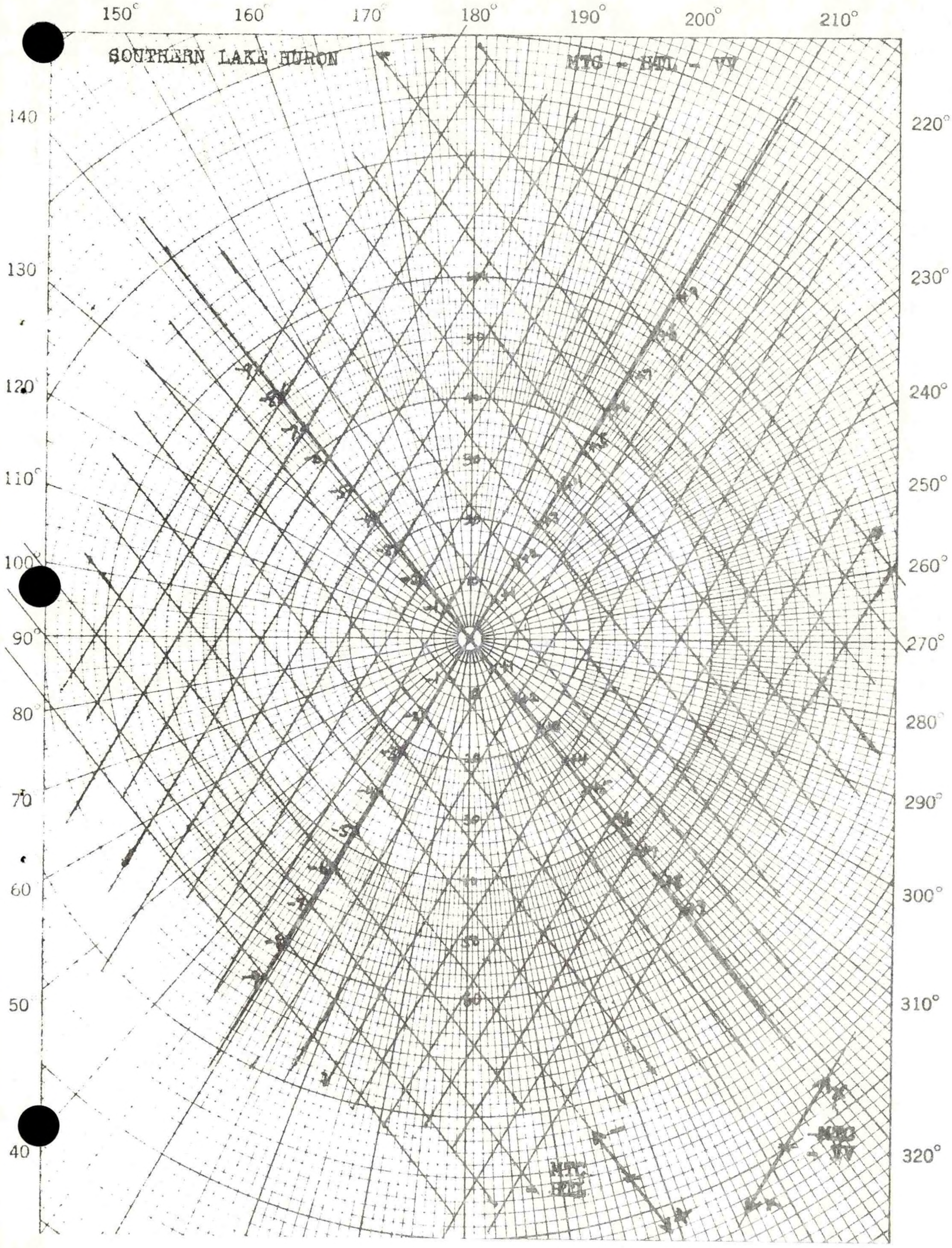
340°

HODOGRAPH



SOUTHERN LAKE HURON
MTG - HTL - VV
150°
160°
170°
180°
190°
200°
210°
220°
230°
240°
250°
260°
270°
280°
290°
300°
310°
320°
140
130
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110
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90°
80
70
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50
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29 An Aid for Tornado Warnings.

30 An Aid in Forecasting Significant Lake Snows.

31 A Forecast Aid for Boulder Winds.

32 An Objective Method For Estimating The Probability of Severe Thunderstorms.

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35 A Note On The Categorical Verification of Probability Forecasts.

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41 The Temperature Cycle of Lake Michigan 1. (Spring and Summer).

42 Dust Devil Meteorology.

43 Summer Shower Probability In Colorado As Related To Altitude.

44 An Investigation Of The Resultant Transport Wind Within The Urban Complex.

45 The Relationship of Some Cirrus Formations To Severe Local Storms.

46 The Temperature Cycle of Lake Michigan 2. (Fall and Winter).