THE PREPARATION OF MONTHLY STREAMLINE CHARTS

by

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PREPARATION OF MONTHLY STREAMLINE CHARTS

Introduction

With the establishment of long range forecasting as a definite possibility, there has been created a need for some means of picturing the mean transport of air masses over a longer period of time than that represented by the daily synoptic chart. In answer to this need, there have been developed mean monthly streamline charts, which show the mean net flow of air at a given level over a period of a month. It is the purpose of this thesis to describe in detail the construction of these charts, and to give some indication of the methods employed in their interpretation.

A streamline chart is drawn in such a way that at any given point on a streamline the resultant transport of mass for the month in question is in the direction indicated by the streamline. Through the use of a streamline analysis as described in this paper, it is possible to locate zones of deformation, convergence and divergence, and cyclonic and anticyclonic curl. These so-called "centers of action" are the elements in which the long range forecaster is interested, since their position at any time in relation to their average or normal positions, help explain weather anomalies for the month, and give some indication of the anomalies to be expected in the following month.

In order to quickly obtain a rough streamline picture, one may merely plot resultant winds for a given month, and draw the streamlines so they are tangent at every point to the direction of the wind at that point. This method is not as accurate, however, as that involving an isogonal analysis, and this paper is concerned only with the drawing of streamline charts by means of an isogonal process.

Throughout the discussion in this thesis, it must be remembered that the final result obtained is not an instantaneous picture, nor is it an average one. It is a resultant picture obtained by using vectorial resultant values for the winds involved.

Choice and Source of Data

In choosing a base level for data in an analysis of this type, it is desired that a wind level be selected such that the results obtained show as much convergence, divergence, curl, etc. as possible. At the same time, however, the level must be high enough that purely local low-level orographical effects are minimumized, since each point of observation represents conditions for many square miles on each side of it.

Before a wind level was selected for use in this thesis, streamline charts were drawn for surface level, and for a number of higher elevations. As would be expected, the surface chart showed strong centers of action, but so distorted by surface orographical effects as to give an inaccurate if not erroneous picture. In one instance, surface effects were sufficient to give the wrong sign to the curl of one of the principal centers of action. Extremely high level winds showed so little convergence and divergence, curl, etc. as to be virtually worthless.

From a consideration of the boundaries established by this investigation, a level of approximately 2000 feet above the station was chosen for the taking of wind data. Thus at Miami the wind was taken at an elevation of 2000 feet, and at Cheyenne, at 10,000 feet. This level may not be an optimum, but it is such as to eliminate minor orographical effects, while at the same time preserving effects due to large features such as the Rocky Mountains, which affect large masses of air. Following is a list of the stations used as sources of data, together with the elevation at which the data were taken for each station.

Seattle, Wash.	2000'	Albuquerque	6000'
Portland, Ore.	2000'	El Paso, Tex.	6000'
Medford, Ore.	2000'	Winnipeg, Can.	4000'
Redding, Calif.	2000'	Bismarck, No. Dak.	4000'
San Francisco, Calif.	2000'	North Platte, Neb.	4000'
Fresno, Calif.	2000'	Amarillo, Tex.	6000'
Burbank, Calif.	2000'	Del Rio, Tex.	2000'
San Diego, Calif.	2000'	Fargo, No. Dak.	2000'
Spokane, Wash.	4000'	Omaha, Neb.	2000'
Pendleton, Ore.	4000'	Kan. City, Mo.	2000'
Winnimucca, Nev.	6000'	Wichita, Kan.	2000'
Reno, Nev.	6000'	Okla. City, Okla.	2000'
Las Vegas, Nev.	6000'	Fort Worth, Tex.	2000'
Missoula, Mont.	6000'	Abilene, Tex.	4000'
Boise, Idaho	6000'	Houston, Tex.	2000'
Modena, Utah	8000'	Brownsville, Tex.	2000'
Havre, Mont.	6000'	St. Paul, Minn.	2000'
Billings, Mont.	6000'	Moline, Ill.	2000'
Rock Springs, Wy.	10000'	St. Louis, Mo.	2000'
Salt Lake, Utah	8000'	Memphis, Tenn.	2000'
Winslow, Ariz.	8000'	New Orleans, La.	2000'
Tucson, Ariz.	4000'	Chicago, Ill.	2000'
Phoenix, Ariz.	4000'	Evansville, Ind.	2000'
Cheyenne, Wy.	10000'	Nashville, Tenn.	2000'
Denver, Colo.	10000'	Montgomery, Ala.	2000'

Pensacola, Fla.	2000'	Spartansburg, S.C.	2000'
Detroit, Mich.	2000'	Charleston, S.C.	2000'
Columbus, Ohio	2000'	Jacksonville, Fla.	2000'
Knoxville, Tenn.	2000'	Burlington, Ve.	2000'
Atlanta, Ga.	4000'	Albany, N.Y.	2000'
Tampa, Fla.	2000'	Boston, Mass.	2000'
Miami, Fla.	2000'	La Guardia Fld., N.Y.	2000'
Key West, Fla.	2000'	Washington, D.C.	2000'
Buffalo, N.Y.	2000'	Richmond, Va.	2000'
Pittsburgh, Pa.	2000'	Indianapolis, Ind.	2000'
Kylertown, Pa.	4000'	Sault St. Marie, Mich.	2000'
Greensboro, N.C.	2000'	Caribou, Maine	2000'

It will be noted that virtually every station making pibal observations was used as a source of data. The few stations which were omitted were those which were so close to other stations as to make recording of their data practically a duplication.

In addition to the elimination of orographical effects, it is also desired that diurnal effects, such as monsoon winds (in coastal regions) and drainage effects (in mountainous regions) be eliminated as far as possible. In order to do this, data were taken for both 3:00 A.M. and 3:00 P.M. PST, times when diurnal effects are at a maximum or near-maximum in both positive and negative directions, thus tending to cancel in a monthly picture.

Data were obtained from upper wind charts of the U.S. Army Air Corps and the U.S. Weather Bureau. Army charts were obtained from the Weather Office at March Field, California, and any missing data such as the first four months of 1941 were supplied through the courtesy of Mr. French, of the Los Angeles Office of the U.S. Weather Bureau.

More accurate data may be obtained through the recording of every pibal observation directly from the teletype sequences, since in this way errors due to plotting and reading may be eliminated. However, since time was an important element in this investigation, data were taken from the upper air charts, rather than from the teletype sequences.

An important addition to the data in future years would be the inclusion of as many Canadian stations as possible. In this way exact location of the Polar front in summer, and an Arctic or secondary Polar front in winter might be possible. On the charts included in this thesis these fronts may be found only in an approximate manner through an unwarranted extrapolation of available data.

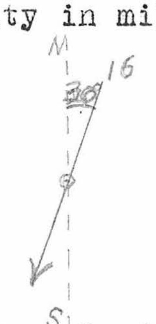
Recording of Data

Recording of the data is by far the most tedious portion of the entire streamline analysis, since data must be recorded for some seventy five stations, twice a day, for a month. As will be seen later, it is necessary that the winds be resolved into north-south and west-east components. Just as a vector is resolved into its components, so is the wind resolved into its components and recorded, all north and west components being recorded as positive, and all south and east components being recorded as negative. The table below shows how the data were entered for this investigation.

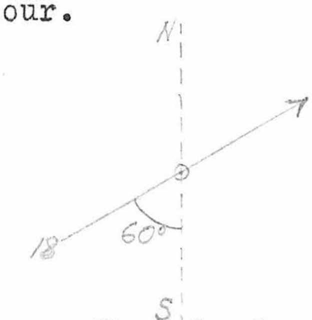
		Station A		Station B		Station C		
Date		N	W	N	W	N	W	
	AM	-6	+4	-7	-13	+6	-6	
1	PM	+9	+16	+5	-9	+6	+0	
	AM	+7	-7	+7	+12	-4	+7	
2	PM	-3	-5	-0	+8	-5	-9	
.	.	.	.	.	.	.	.	
.	.	.	.	.	.	.	.	
.	.	.	.	.	.	.	.	
	AM	+5	-1	+0	+6	-8	+5	
31	PM	-8	+8	-1	-7	+10	-4	
								No. entries at each station
								Sum of wind components (vector)
								Net component in miles per hour

At the bottom of each column is entered the number of entries, the vectorial total of the components, and finally the net component, which is the total of each column divided by the number of entries. It is to be noted that when the wind has but one component (i.e. blowing directly from the north, south, east, or west), the second component is entered as zero, and is counted as an entry. In this way, for a given station, there should be the same number of entries for a month in both the north-south column and the west-east column.

Teams for the recording of data were composed of three men: a reader, a computer, and a recorder. The reader reads the station, the quadrant from which the wind is blowing, the angle the wind direction makes with a north-south line (to the nearest 10 degrees), and the velocity in miles per hour.



Example A
(Seattle)



Example B
(Abilene)

In the examples above, (A) would be read "Seattle, north-east, 30-16", and (B) would be read "Abilene, south-west, 60-18". An accuracy of ten degrees in reading is probably not justified, because of errors in plotting, and because readers tend to read to angles of 60 degrees, 30 degrees, and 45 degrees.

The computer now takes this information, and with the aid of Table I, resolves the wind into its components. Table I is merely a sine-cosine table so arranged that for any given angle with the north-south line, and for any velocity up to and including fifty miles per hour, the first half of the column gives the north-south component and the second half the west-east component. The computer then reads the components to the recorder, always giving the north-south component first.

The recorder enters the numbers given him by the computer in the correct columns on the data sheet, obtaining the correct signs from having listened to the quadrant read by the reader. In the examples cited, Seattle would be entered as a positive 14 in the north-south column, and a negative 8 in the west-east column. Similarly Abilene would be entered as a negative 9 in the north-south column, and a positive 16 in the west-east column. A table such as Table I is used in preference to a graphical method such as Table II, as it proved faster and yielded more uniform components for a given wind direction and velocity.

To complete the data for one month required approximately ten hours for a team of three men, although this time was somewhat reduced as readers became accustomed to the sequence of stations, with their various elevations, and computers had somewhat memorized Table I. It is possible to operate a two man team if either the reader or the recorder has memorized Table I completely. By the time this investigation was completed, several of the men had memorized the table, thus enabling the completion of data sheets to be accomplished in a much shorter time.

Computing of Data

Teams of two men were required for the computing of the data, one man reading data and recording, and the other man computing on a Marchant calculator. All positive values in a column are added, then from these are subtracted the negative values. The resulting total is then divided by the number of entries in the column, and the quotient, which is the mean resultant, is entered in the proper position on the data sheet.

It required two men approximately four hours to compute the data for one month.

Drawing of Isoboreales and Isoaustrales

When the mean resultants have been computed, they are then plotted on conformal conic projection maps, the north-south values on one map, and the west-east values on another map. On both maps lines are now drawn through points of equal value, much as isobars are drawn, for increments of two miles per hour on both positive and negative sides of the zero line. These iso-lines on the north-south chart are known as <u>isoboreales</u> and those on the west-east chart as <u>isoaustrales</u>. For ease in reading these lines when the two maps are superimposed (see Drawing of Isogones), the isoboreales are drawn in blue, and the isoaustrales are drawn in red.

In the drawing of these iso-lines, it is necessary that they be drawn to conform exactly to the data, and that no data be disregarded. This must be done, since even a minor deviation which appears on the mean <u>monthly</u> picture may have a considerable significance, and any adjustment of the data is impossible, since one cannot determine in which direction the correction should be made. One must pay particular attention to the exact placing of the zero iso-lines, since it is the intersections of the zero isoboreales and zero isoaustrales which determine the position of the centers of action.

Because data are available only for the continental United States, the isoboreales and isoaustrales should not be extended more than one inch beyond either east or west coastlines, and should never be extrapolated in a direction parallel to the coastline. In Figure I, therefore, the dotted lines should not be drawn. Extrapolation of this type, particularly of the zero lines on the west coast, frequently yields several complex centers of action which have no real existence. In the region near the coast of the Gulf of Mexico, however, where the picture is relatively a simple one, the isoboreales and isoaustrales may be safely extrapolated across the Gulf.

Drawing of Isogones

The isoboreale and isoaustrale maps are now stapled together with a third blank map on top. It is upon this blank map that we draw the isogones. The first step is to trace through onto the blank map the zero isoboreales and zero isoaustrales in their appropriate colors (blue for isoboreales and red for isoaustrales).

An isogone is by definition the locus of all consecutive points whose air transport is in the same direction. Isogones are drawn through points whose north and west components have ratios of ± 1 to ± 1, ± 1 to ± 2, and ± 2 to ± 1, thus having slopes of 45, $26\frac{1}{2}$, and $63\frac{1}{2}$ degrees respectively. For examples, see Figure II and the more complicated Figure VII. By definition the zero isoboreales and isoaustrales are also isogones. In general, there will be three isogones to be drawn in each quadrant of a center of action. A careful study of Figures II and VII will give the reader a fair conception of the many and varied cases which can and do occur in the physical picture.

There are many refinements which can only be developed by drawing the charts themselves, but it is only by keeping in mind the physical picture that confusion can be avoided in the drawing of the isogones. When one has drawn one or two isogonal charts, he is suddenly confronted with the fact that closed isogones do exist and are very real. They should always be drawn as they are caused by such factors as foehn winds on the lee side of mountain ranges. It will be noted later that closed and U-shaped isogones cause only an inflection in the streamlines (see Figure V).

In the drawing of isogones great care should be taken with the zero isoboreales and zero isoaustrales, since the curvature of these lines near points where they intersect determines whether or not one will get convergence or divergence, and of what magnitude.

A physically impossible picture may be obtained, as in Figure VI, where we have divergence with cyclonic rotation. In case one obtains this type of picture, the best solution is to adjust the zero isoboreales and zero isoaustrales so that they do not intersect. Usually the data on the isoboreale and isoaustrale charts will be of such a nature that this adjustment may be made without disregarding any of the data. This difficulty will be noted especially at the edges of the data. Frequently centers of action will appear along the Pacific coast, which are not always real, but are due only to the drawing of intersections of the zero isoboreales and isoaustrales, where such intersections do not actually exist.

If one wishes to draw a large scale and very accurate streamline chart, and the data are good enough, one can draw isogones through points where the direction of transport has values of ±1 to ±3, ±2 to ±3, ±3 to ±2, ±3 to ±1, etc. This process would not be simple, as can be seen by now, and would not be justified unless the data were much better than any existing at the present time, but it would undoubtedly give compatible results in any case.

Drawing of Arrows on Isogones

After the isogones are drawn, small arrows are placed on them, indicating the wind direction represented by the isogone. (See Figure VII). It will be noted that the wind direction along a zero isoboreale will be wither due east or west, and along a zero isoaustrale from due north or south. In each case the direction may be readily determined when the isoboreale and isoaustrale charts are superimposed on a light table.

It will be further noted that the wind direction, that is, the direction of mean net transport, along a zero isoboreale or zero isoaustrale will shift 180 degrees as the zero line passes through a center of action.

Drawing of the arrows on the isogones is facilitated if the arrows are drawn first on the zero isoboreales and zero isoaustrales, since the arrows on isogones between the zero isoboreale and isoaustrale will have orientations intermediate between the north-south value on the zero isoaustrale and the west-east value of the zero isoboreale. (See Figure VII).

The arrows are drawn using small triangles with appropriate angular values (i.e. a 45 degree triangle and a 26½-63½ degree right triangle). These triangles must be small, not over 2" on a side, because of the curvature of the coordinate system, and may be easily cut from a sheet of celluloid.

Drawing of Streamlines

After the arrows are placed on the isogonal charts, a blank map is stapled on top, and the two charts are placed on a light table. The streamlines are drawn by simply following the arrows. In other words, wherever a streamline crosses an isogone it must cross in the direction represented by the arrows on that isogone. In a region between two isogones the direction of the streamline is naturally somewhere between the directions of the arrows on the two bounding isogones. Whenever a streamline crosses a closed or U-shaped isogone, there must be an inflection in the streamline, as in Figure V. It can be seen that the drawing of the streamlines is a relatively simple part of the process of constructing the final chart, but a good deal of care is necessary in order not to break any of the above rules.

This streamline picture is in reality a two-dimensional projection of a three-dimensional phenomenon. In a true streamline chart, the gradient across the streamlines is proportional to the velocity along the streamlines. From Figures III, IV, and VI it might be concluded that the velocities at the centers of action would be infinite, but this is not the case, for in order to satisfy the law of conservation, there must be considerable vertical motion taking place. For this reason, streamlines need not be carried into the center of action, but can stop at some distance away from the center.

Velocity Profiles

The streamline charts by themselves indicate only the direction of the transport and give no indication whatsoever of the magnitude of the transport. Therefore the divergence and convergence shown by the chart can only be the components normal to the streamlines. It is highly desirable that some way be found to show the other independent component of devergence and convergence--that is, the component along the streamlines themselves. It is to satisfy this need that velocity profiles are superimposed on the streamline charts. The velocity profiles show one at a glance where divergence and convergence take place along the streamlines, and what the relative magnitudes are.

In order to draw these velocity profiles, one must obtain first the magnitude of the mean resultant wind at each of the stations used as sources of data. This mean resultant wind may be calculated mathematically by squaring the mean resultant north-south value at each station, adding to it the square of the mean resultant west-east value, and extracting the square root of the sum.

This method is, however, a relatively long and unnecessarily precise method. Sufficiently accurate results may be obtained through the use of a graphical solution as indicated in Table II, in which the abscissa is the absolute magnitude of the west-east mean resultant component, and the ordinate the absolute magnitude of the north-south mean resultant component.

The magnitude of the mean resultant wind may then be read from the circles of value on the chart. In the plotting of velocity profiles one is interested only in the absolute magnitude of the wind, and not in the direction.

The values for the mean resultant winds are now plotted on a separate map, and lines of equal velocity are drawn for increments of two miles per hour. The Streamline chart is now superimposed on the velocity chart, and the iso-velocity lines are traced onto the streamline chart in dotted red lines. It can now be seen that at any point the streamline will give the direction of transport, and the velocity profile will give the magnitude of the transport.

In tracing the velocity profiles, it will be noted that inflections of the velocity profiles will occur along lines of convergence and divergence. These inflections are real and should be made as definite as possible without neglecting any of the data. Furthermore, the velocity profiles should be adjusted so that the zero velocity profile coincides with the various centers of action.

Assuming continuity of flow and the indestructability of matter, one has in the streamline chart with the velocity profiles superimposed, an excellent representation of a three-dimensional phenomenon, that of the net monthly transport of air with its correspondind horizontal and vertical motions.

A much more detailed discussion of supplementary charts, such as velocity profiles, vorticity charts, etc. is given in the paper by Werenskiold published in Geofysiske Publikationer Vol. II, No. 9 Utgit Av Den Geofysiske Kommission. It is Werenskiold's method of drawing streamline charts which was used throughout this entire investigation.

Work Accomplished

During the third quarter in 1941 at the California Institute of Technology, the data, streamline charts, and velocity profiles for the years 1938, 1939, 1940, and the first four months of 1941 were recorded, computed, and drawn up by a group of seventeen men working for their Master's degree. There was no time available for interpretation of the streamline charts, although this is the most important part of the analysis as far as long range forecasting is concerned. However, the interpretation will undoubtedly be done in the coming year. The main purpose of this thesis was merely to present a method which has been used and which seems to be acceptable and efficient.

The research described in this thesis was carried out by the following men:

John A. Battle
*Sidney C. Bruce
*Delmar L. Crowson
Darrell Dieter
Samuel J. Easley
Robert H. Ehrke
*Edward A. Hall
Daniel S. Hamway
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*Greenup B. Patterson
*Isadore I. Porush
William H. Rempel
Clyde T. Standridge
*William W. Stone, Jr.
*Bernard M. Tobin
*Gilbert R. Van Dyke, Jr.
*Gordon B. Weir

* Non-flying Cadets in U.S. Army Air Corps

TABLE I

MPH	10°		20°		30°		40°		45°		50°		60°		70°		80°	
	N	W	N	W	N	W	N	W	N	W	N	W	N	W	N	W	N	W
1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	0	1	0	1
2	2	0	2	1	2	1	2	1	1	1	1	2	1	2	1	2	0	2
3	3	1	3	1	3	2	2	2	2	2	2	2	2	3	1	3	1	3
4	4	1	4	1	3	2	3	3	3	3	3	3	2	3	1	4	1	4
5	5	1	5	2	4	3	4	3	4	4	4	4	3	4	2	5	1	5
6	6	1	6	2	5	3	5	4	4	4	4	5	3	5	2	6	1	6
7	7	1	7	2	6	4	5	4	5	5	4	5	4	6	2	7	1	7
8	8	1	7	3	7	4	6	5	6	6	5	6	4	7	3	7	1	8
9	9	2	8	3	8	5	7	6	6	6	6	7	5	8	3	8	2	9
10	10	2	9	3	9	5	8	6	7	7	6	8	5	9	3	9	2	10
11	11	2	10	4	10	6	8	7	8	8	7	8	6	10	4	10	2	11
12	12	2	11	4	10	6	9	8	9	9	8	9	6	10	4	11	2	12
13	13	2	12	4	11	7	10	8	9	9	8	10	7	11	4	12	2	13
14	14	2	13	5	12	7	11	9	10	10	9	11	7	12	5	13	2	14
15	15	3	14	5	13	8	11	10	11	11	10	11	8	13	5	14	3	15
16	16	3	15	5	14	8	12	10	11	11	10	12	8	14	5	15	3	16
17	17	3	16	6	15	9	13	11	12	12	11	13	9	15	6	16	3	17
18	18	3	17	6	16	9	14	12	13	13	12	14	9	16	6	17	3	18
19	19	3	18	6	16	10	15	12	13	13	12	15	10	16	6	18	3	19
20	20	3	19	7	17	10	15	13	14	14	13	15	10	17	7	19	3	20
21	21	4	20	7	18	11	16	13	15	15	13	16	11	18	7	20	4	21
22	22	4	21	7	19	11	17	14	16	16	14	17	11	19	7	21	4	22
23	23	4	21	8	20	12	18	15	16	16	15	18	12	20	8	21	4	23
24	24	4	22	8	21	12	18	15	17	17	15	18	12	21	8	22	4	24
25	25	4	23	8	22	13	19	16	18	18	16	19	13	22	8	23	4	25
26	26	5	24	9	22	13	20	17	18	18	17	20	13	22	9	24	5	26
27	27	5	25	9	23	14	21	17	19	19	17	21	14	23	9	25	5	27
28	28	5	26	10	24	14	21	18	20	20	18	21	14	24	10	26	5	28
29	29	5	27	10	25	15	22	19	21	21	19	22	15	25	10	27	5	29
30	30	5	28	10	26	15	23	19	21	21	19	23	15	26	10	28	5	30
31	31	5	29	11	27	16	24	20	22	22	20	24	16	27	11	29	5	31
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35	35	6	33	12	30	18	27	22	25	25	22	27	18	30	12	33	6	35
36	36	6	34	12	31	18	28	23	25	25	23	28	18	31	12	34	6	36
37	37	6	35	13	32	19	28	24	26	26	24	28	19	32	13	35	6	37
38	38	7	36	13	33	19	29	24	27	27	24	29	19	33	13	36	7	38
39	39	7	37	13	34	20	30	25	28	28	25	30	20	34	13	37	7	39
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41	41	7	38	14	35	21	31	26	29	29	26	31	21	35	14	38	7	41
42	42	7	39	14	36	21	32	27	30	30	27	32	21	36	14	39	7	42
43	43	7	40	15	37	22	33	28	30	30	28	33	22	37	15	40	7	43
44	44	8	41	15	38	22	34	28	31	31	28	34	22	38	15	41	8	44
45	45	8	42	15	39	23	34	29	32	32	29	34	23	39	15	42	8	45
46	46	8	43	16	40	23	35	29	33	33	29	35	23	40	16	43	8	46
47	47	8	44	16	41	24	36	30	33	33	30	36	24	41	16	44	8	47
48	48	8	45	16	42	24	37	31	34	34	31	37	24	42	16	45	8	48
49	49	9	46	17	43	25	35	31	35	35	31	38	25	43	17	46	9	49
50	50	9	47	17	43	25	38	32	35	35	32	38	25	43	17	47	9	50

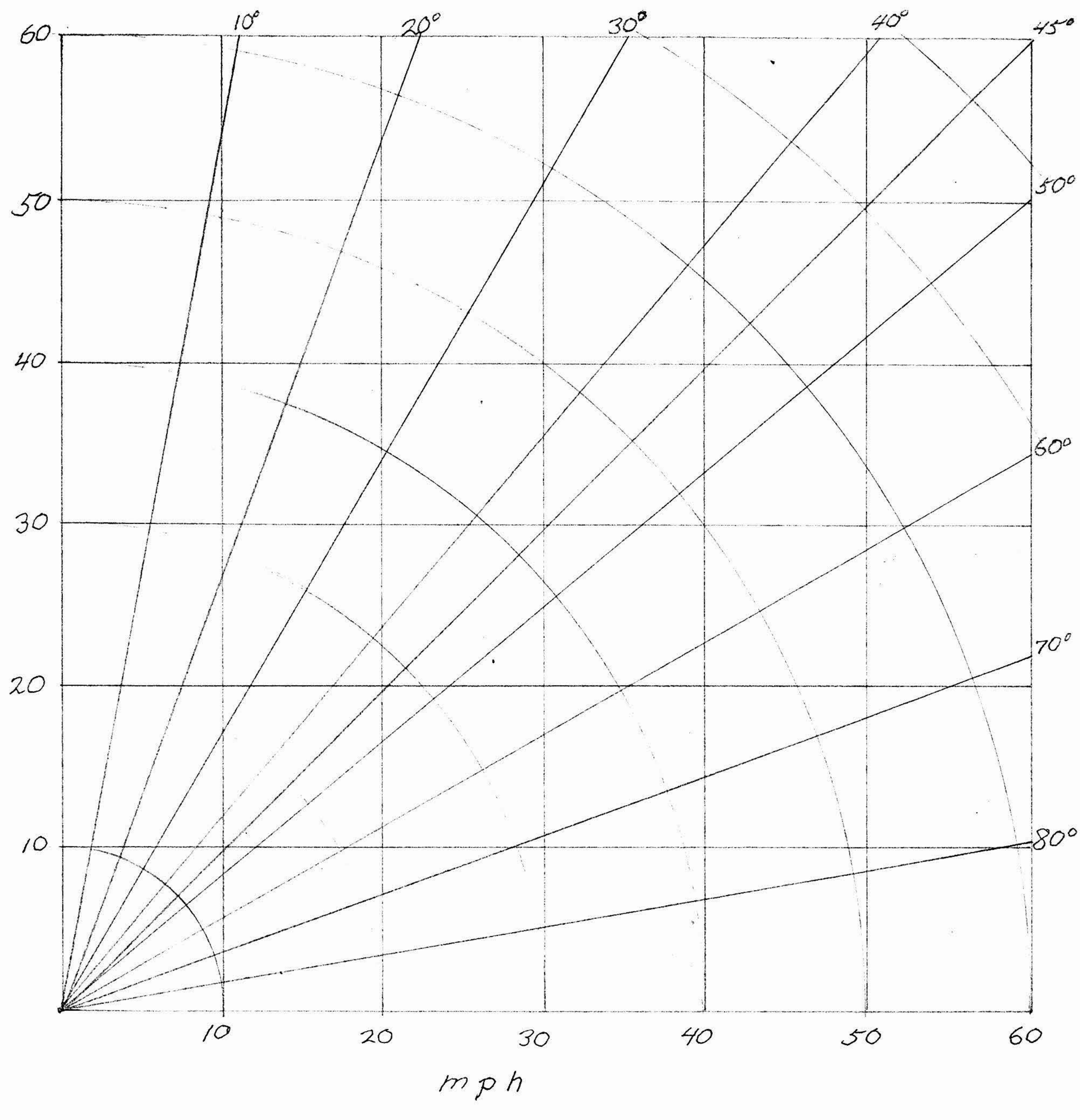

Chart for Resolving Winds

Table II

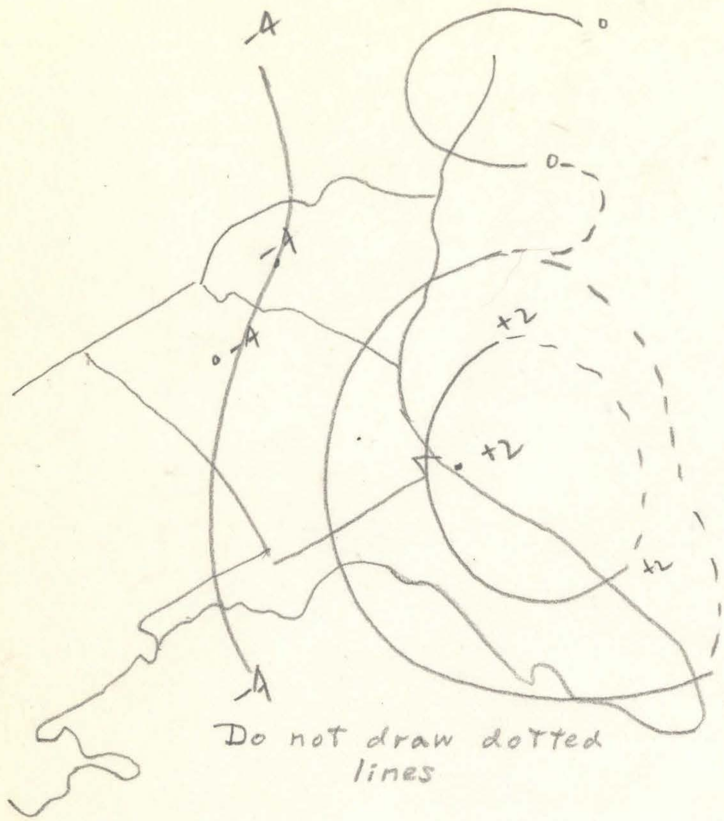

Fig I

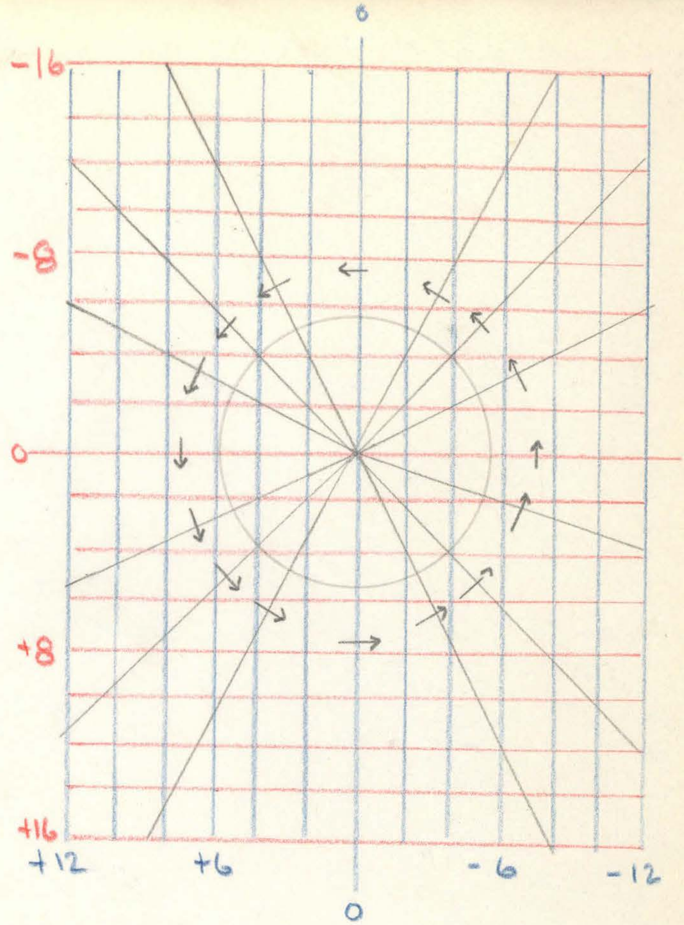

Fig II

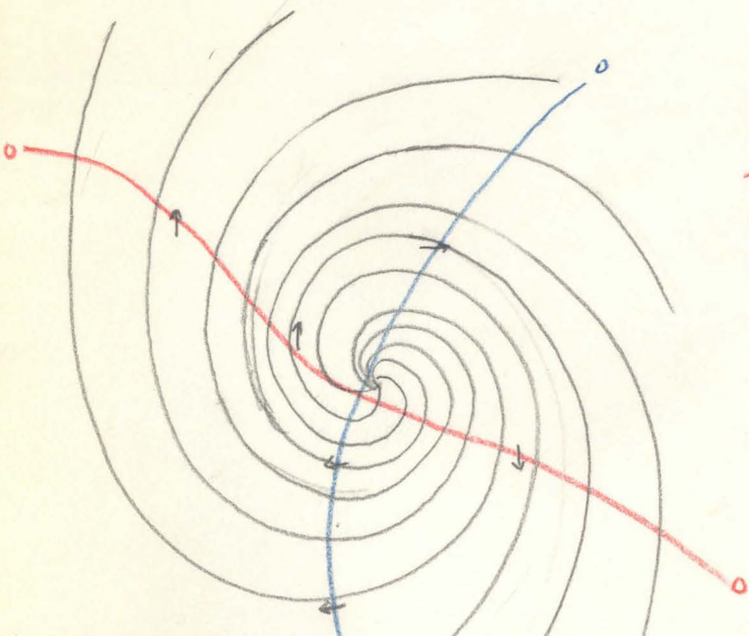

Fig III

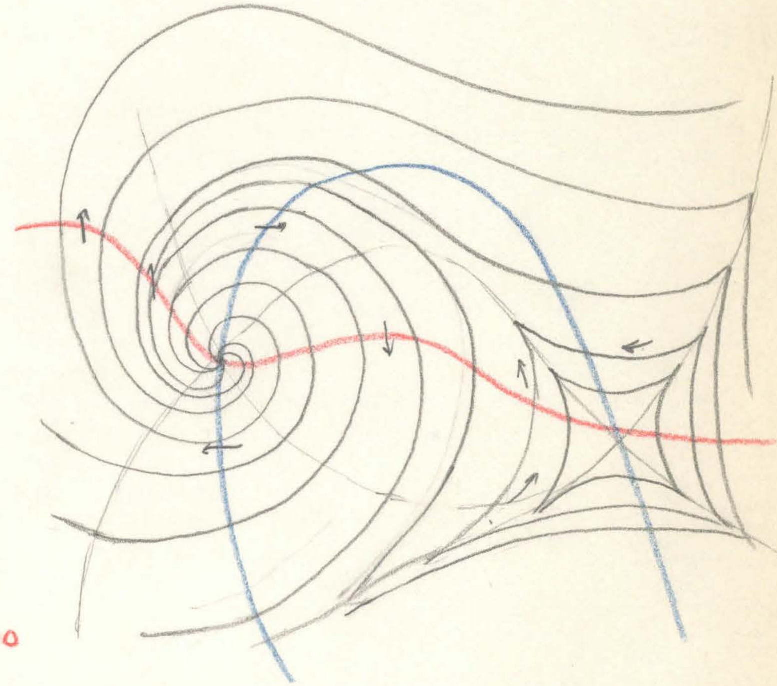

Fig IV

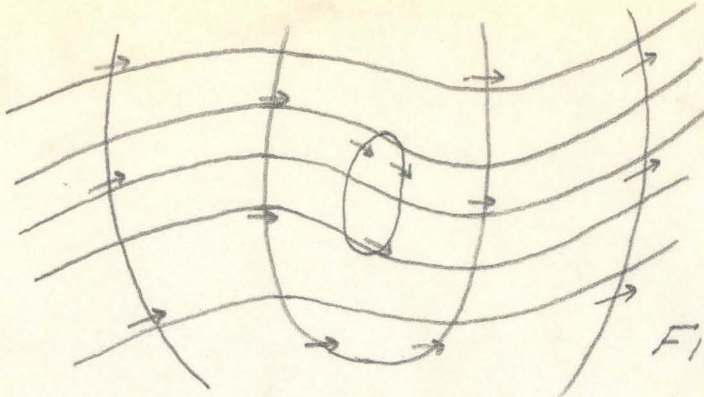

FIG. V

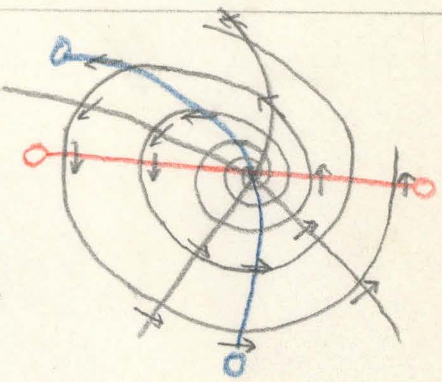

FIG VI

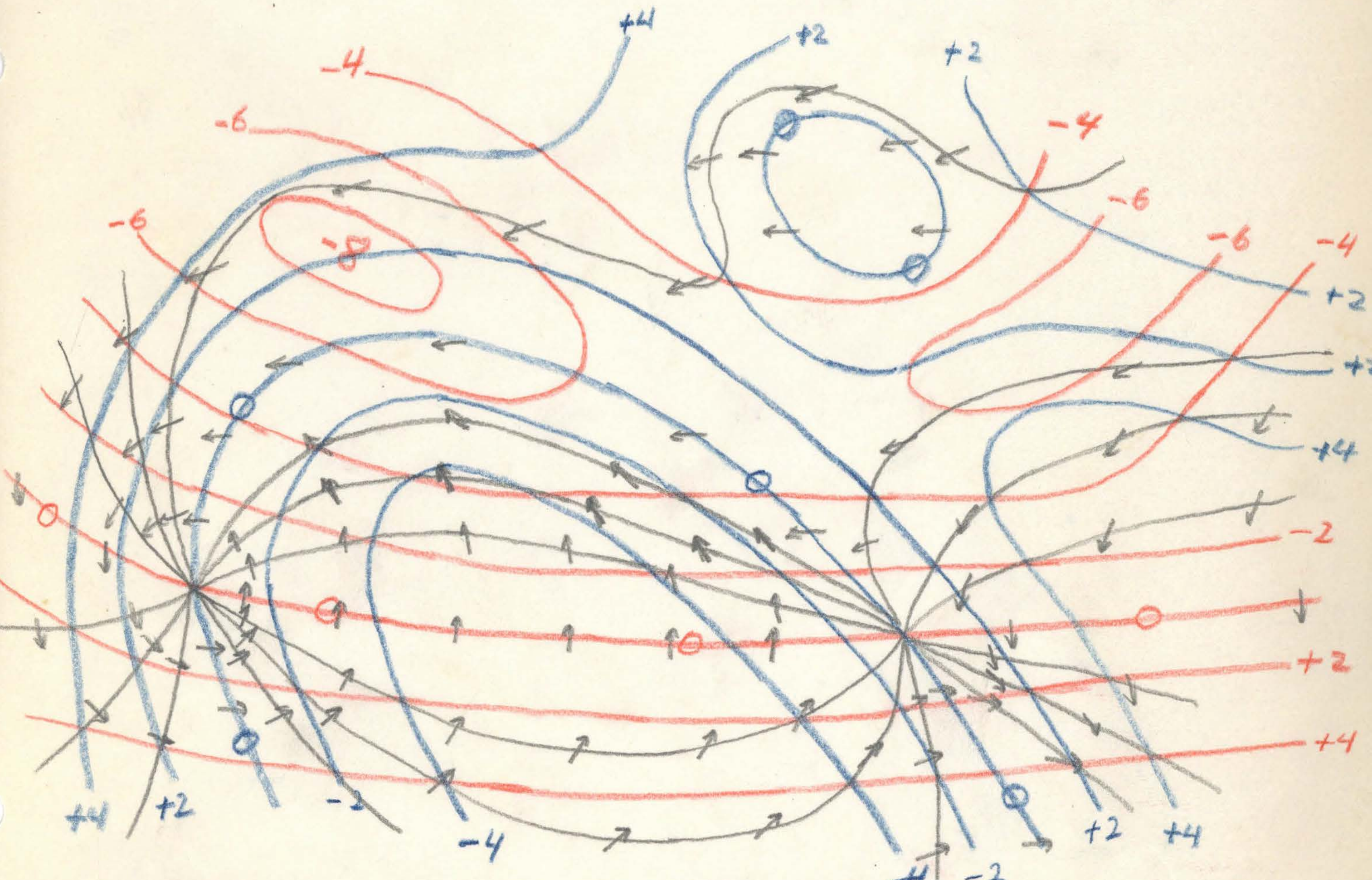

FIG VII