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AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
L. G. HANSCOM FIELD, BEDFORD, MASSACHUSETTS

The Constancy of the Winds in the Lower Stratosphere and Constant - Level Balloon Flight Planning

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Abstract

Values of constancy of the wind at the 30-mb level over most of North America, derived from coefficients of variation of the wind, are analyzed for each month. High values of constancy exist during the summer months with low values appearing in apparently well-defined patterns during the other months. These patterns of low constancy values, called areas of maximum wind variability, are especially persistent over the western United States during late winter and early spring. The data and analyses presented can be of aid to meteorologists planning probable trajectories for long duration, constant-level balloon flights, and can also serve as a basis for the level of confidence the operational forecaster places on long-duration flight trajectory predictions.

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The Constancy of the Winds in the Lower Stratosphere and Constant-Level Balloon Flight Planning

1. INTRODUCTION

Constant-level balloons, ranging in diameters from a few feet to lengths comparable to that of a football field, are increasingly being used for a multitude of atmospheric applications. The superpressure balloon, which can maintain a constant flight altitude for over a month, is emerging as a possible solution in the search for an economical method of measuring atmospheric parameters over oceanic areas of the world where observations are sparse. Zero-pressure balloons can now carry payloads of a ton or more to altitudes above 100, 000 ft with flight duration limited only by the amount of ballast that is carried. The balloon, therefore, is an excellent vehicle for gathering environmental and astronomical data. However, it is the environment, particularly the winds, which largely determines the success or failure of a balloon flight. Consequently, not only is it important that accurate wind forecasts be made prior to every balloon launch, but it is also essential that proper planning, based on meteorological studies, precede the scheduling of balloon flights.

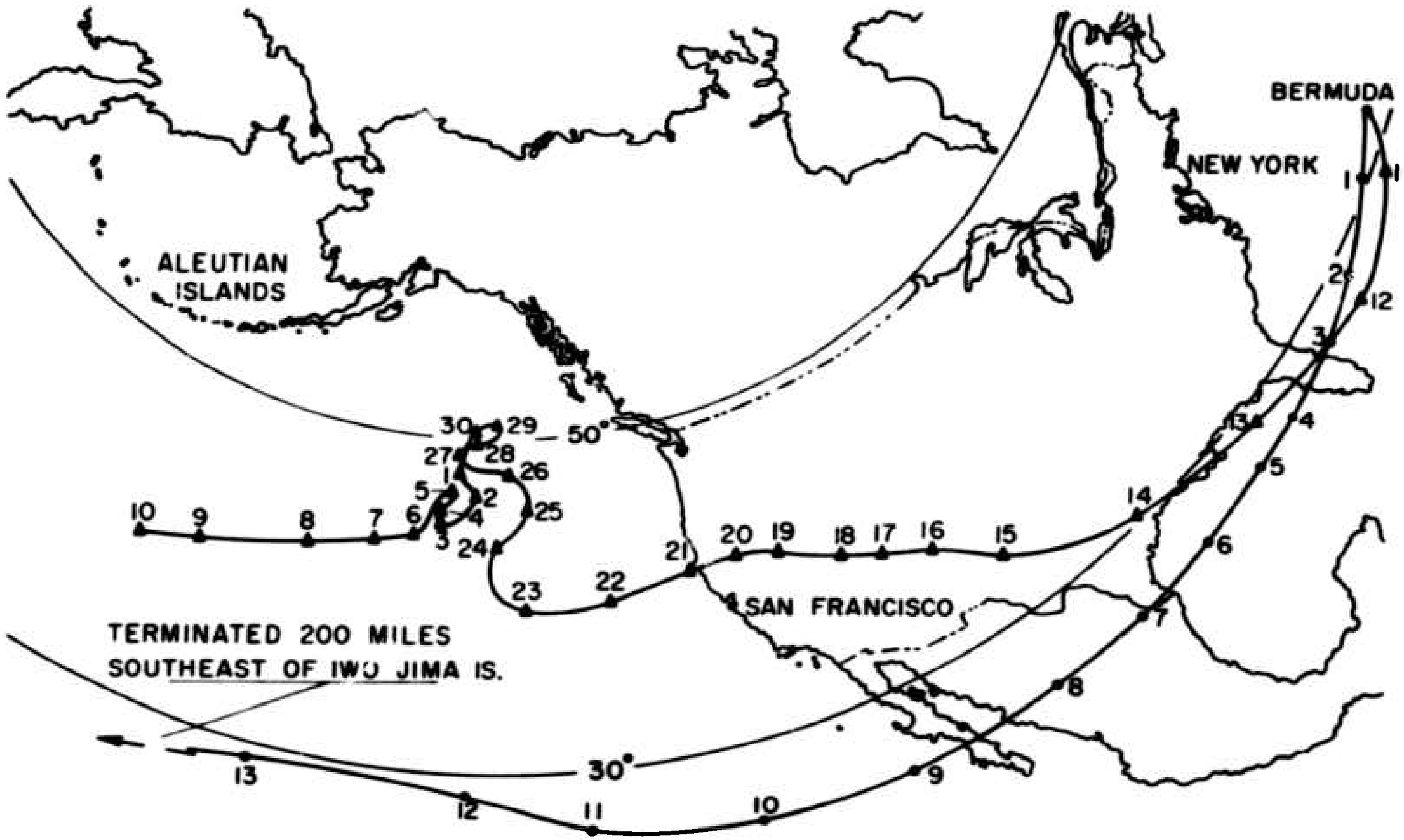
It is a basic fact that the longer the flight duration the more difficult are the meteorological tasks involved in flight planning and execution. This is due to the variability of the winds in time and space; a phenomenon which is not well understood. Nevertheless, the balloon meteorologist must provide information on probable trajectories and impact areas and also make recommendations on the best time of the year and the best location for conducting flights. He then must furnish predictions of the balloon's trajectory and of payload impact area, for air safety as well as operational considerations

A number of superpressure balloon flights conducted by the Aerospace Instrumentation Laboratory at Air Force Cambridge Research Laboratories have been flown in the lower stratosphere within the altitude range of 60,000 to 80,000 ft. Figure 1 gives the trajectories of two superpressure balloon flights launched from Bermuda. The trajectory of flight P-27 demonstrates the quasi-straightline flow that exists in the lower stratosphere during the summer. This suggests that during the summer the winds at a particular level in the stratosphere are highly correlated in space and time along latitudes, and that the winds at a particular level and location have a high degree of constancy. There is, however, a lower boundary on these persistent summertime winds at about 66,000 ft, near which the winds become light and variable (Nolan and Smith, 1964). This phenomenon is demonstrated by portions of the trajectory of P-29 which floated at about 66,000 ft, just a few thousand feet below the floating altitude of P-27. The experience gained from flights such as these, and the information presented by the large number of stratospheric maps and climatological summaries which are now available, clearly show that meteorological planning and forecasting is relatively straightforward for long duration balloon flights which are to be conducted during the summer at altitudes above approximately 66,000 ft. This is not the case for the other months of the year.

It is the purpose of this study to present information on the monthly variability of the winds in the lower stratosphere over North America, represented by the 30-mb level (approximately 78,000 ft), and to offer some remarks on its relation to long-duration balloon flight planning and forecasting.

2. PROCEDURE

This study has made use of the statistical summarization of winds for a five-year period over most of North America made by the U.S. Weather Bureau and the Sandia Corporation (1959). Forty-eight stations with locations in Canada, the Caribbean, and the United States were selected for data sources. Data used in this study consist of the magnitude and direction of the mean vector wind and its standard vector deviation. The quotient of the standard vector deviation and the magnitude of the mean vector wind for each station for each of the 12 months was computed. This quotient, σ/V_R, is the coefficient of variation of the wind, where σ is the standard vector deviation of the wind and V_R is the magnitude of the mean vector wind. These were plotted and analyzed using conventional methods. Assuming that the winds have a circular normal distribution, the coefficients of variation were converted to values of constancy. Details of this conversion process are given by Brooks, et al. (1946).



P-27, LAUNCHED 31 MAY 1962 AT 0915 GMT, TERMINATED 19 JUNE 1962 AT 1156 GMT
P-29, LAUNCHED 10 JUNE 1962 AT 2052 GMT, TERMINATED 10 JULY 1962 AT 1158 GMT
POSITIONS ARE FOR 1200 GMT

Figure 1. Trajectories of Superpressure Balloon Flights P-29 and P-27

Table 1. Values of σ/V_R in Terms of q (percent)

q	1	10	20	30	40	50	60
σ/V_R	113	11.3	5.62	3.68	2.64	2.04	1.66
q		70	80	90	95	97.5	100
σ/V_R		1.24	0.93	0.64	0.47	0.37	0.00

Table 1, taken from the same reference, gives values of σ/V_R in terms of q, the constancy.

The results are presented in Figures 2 through 13. These figures give estimates of the fields of constancy of the 30-mb winds for the 12 months of the year. Mean vector wind directions and magnitudes are also given. The arrows in the figures give direction of the mean vector wind and are centered at the locations of the stations used for data.

3. INTERPRETATION OF CONSTANCY VALUES

The constancy of the wind can range in value from zero percent to 100 percent. It is zero percent when the winds blow with equal frequency and with the same average speed from all directions. The constancy is 100 percent when they blow from exactly the same direction (not necessarily all with the same speed). Now, q can also be obtained by multiplying by 100 the ratio of the magnitude of the mean vector wind, V_R, and the scalar mean velocity of the wind, V_S; that is

$$q = 100\, V_R/V_S .$$

We can see that two situations are possible when q and V_R have small or zero values: (1) the region under consideration has light and variable winds, in which case σ and V_S are also small; or (2) when the region is one where the winds are strong but undergo frequent and large changes in direction (such as are observed in the stratosphere during winter over the far western states) in which case σ and V_S may be large.

Thus, for purposes of balloon flight planning, we must exercise care in interpreting small and zero values of constancy. However, we know that two situations can exist and are thus warned that additional study has to be made. Here we can examine the standard deviation of the wind, σ. If σ is small and the constancy is close to zero, then the winds are light and variable. When q and V_R approach zero, then σ is approximately equal to $1.13\, V_S$, assuming a normal distribution

(Brooks and Carruthers, 1946). Estimates of σ can be made from the data given in Figures 2 through 13 and by using Table 1. A useful relation for large values of q is the following: a rough geometrical interpretation of the proportion of vector ends lying within a circle of radius V_R of the center of a distribution of winds can be made by squaring the constancy divided by 100. These interpretations can be helpful when using the data given in Figures 2 through 13.

4. DISCUSSION

Belmont (1963) was interested in describing the change of easterly flow to westerly flow in the stratosphere and investigated the frequency values of prevailing direction and of speed for the 30-mb level and other levels on a hemispheric basis. He worked with the components of the wind, and consolidated all winds having easterly components and all winds having westerly components. For example, a wind from the northeast was considered an easterly wind. He then evaluated (1) which zonal direction is the relatively prevailing one and by how much, and (2) the mean zonal component of the prevailing direction. A study by Ratner (1959) gives a climatology of seasonal mean vector winds and standard deviations for the 30-mb level over the United States. These data can easily be converted to values of constancy. However, we find that, except for the summertime, the month-to-month variability of the winds at 30 mb is not adequately represented by seasonal considerations.

While one can obtain insight on the variability of the winds at 30 mb from the studies of Belmont and Ratner and other similar studies, this study uses a different approach and the results are presented in a format more directly applicable to balloon flight planning and operations.

5. MAIN FEATURES OF THE FIELD OF CONSTANCY AT 30 MILLIBARS

For the purpose of discussion, areas of constancy having values of less than 50 percent are designated as zones or areas of maximum wind variability.

5.1 Summer (Figures 2 through 4)

The field of constancy over the United States reaches its highest values in July, with values of about 97 percent at southern latitudes and about 90 percent along the Canadian border. June and August have almost identical patterns of constancy over the United States. However, during August over western Canada and Alaska, the winds become more variable with increasing latitude. The appearance of low constancy values at high latitudes during August signals the breakdown of the summertime easterlies and the advent of westerly winds.

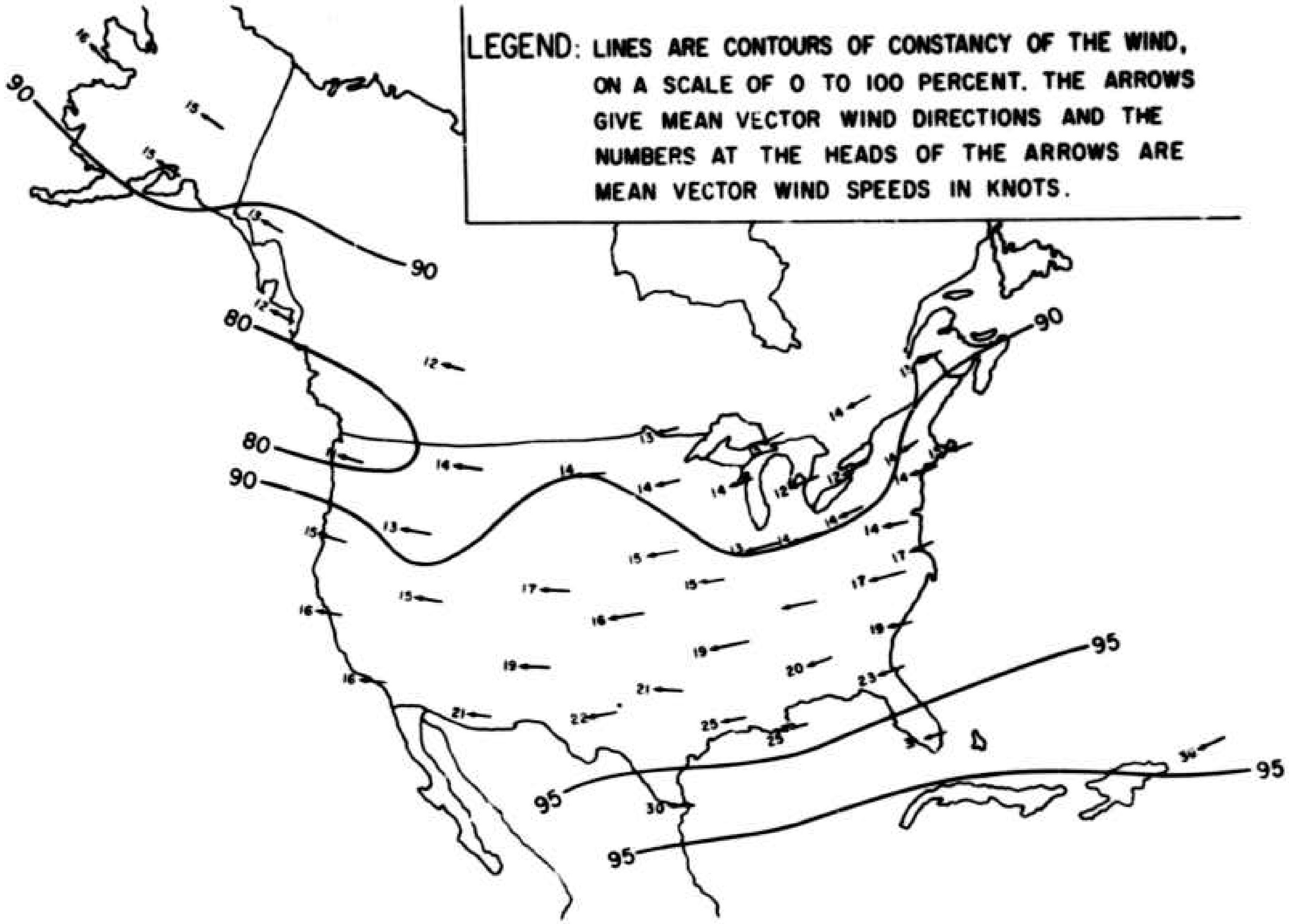


Figure 2. The 30-mb Level Field of Constancy, June

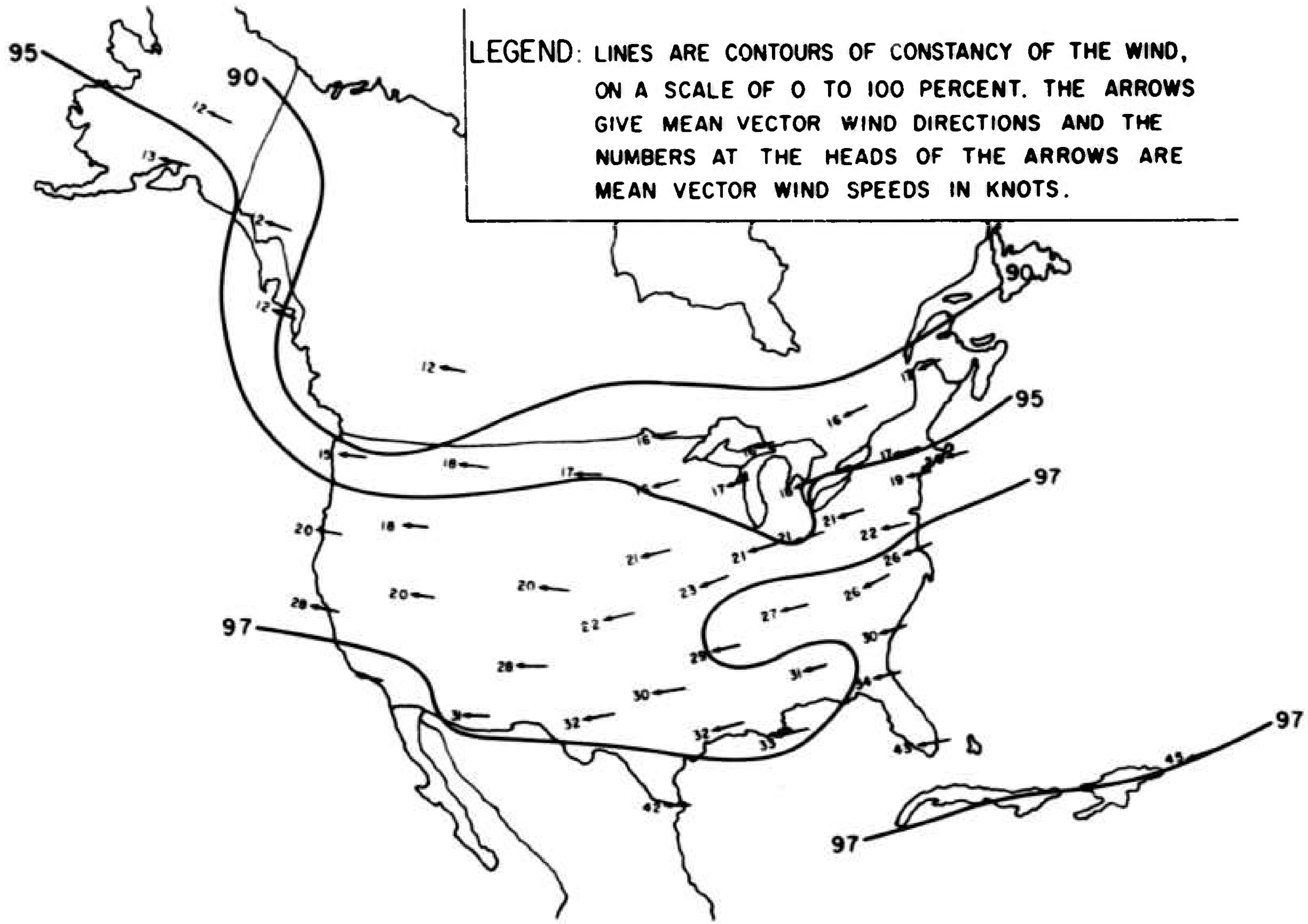


Figure 3. The 30-mb Level Field of Constancy, July

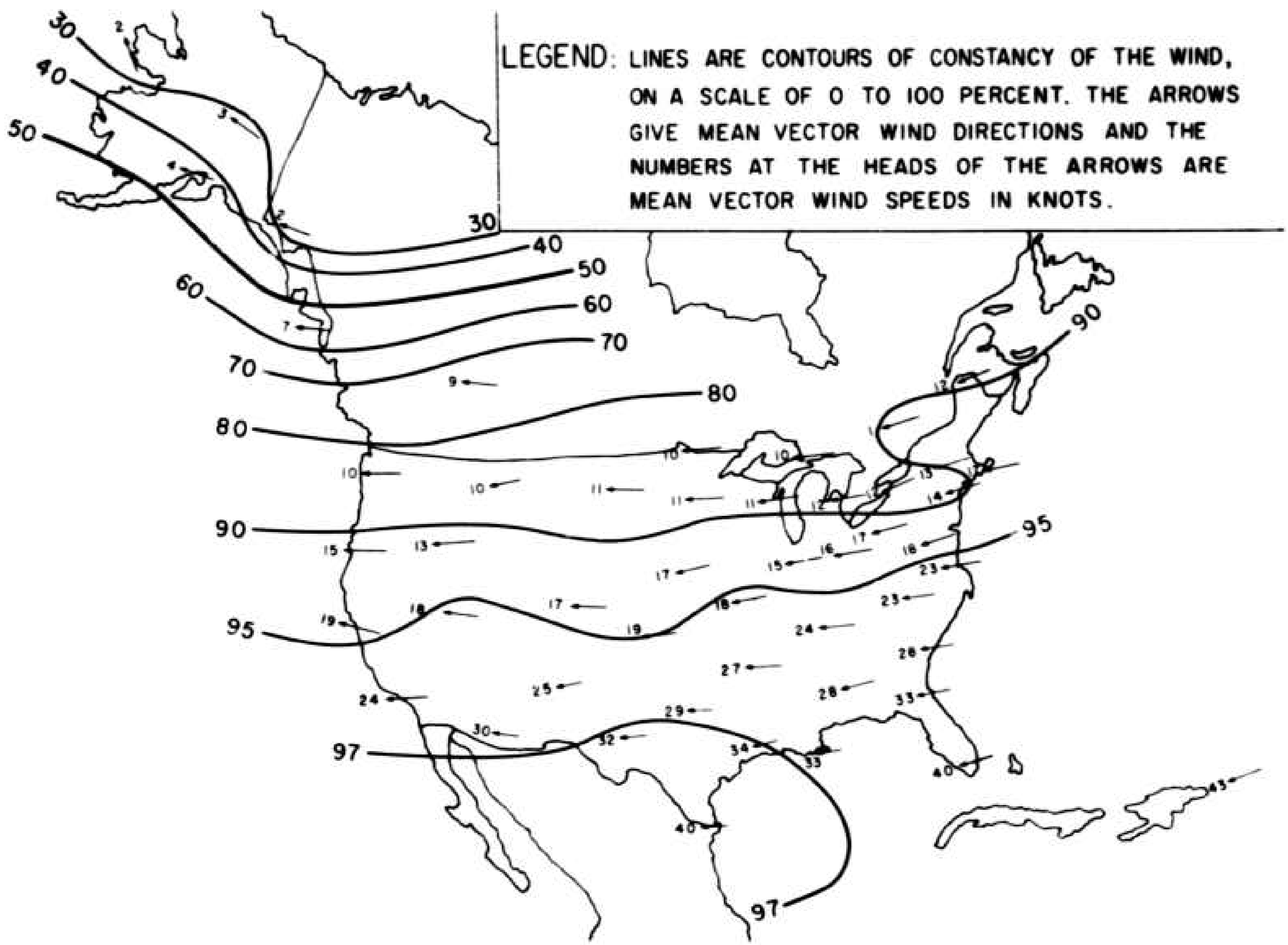


Figure 4. The 30-mb Level Field of Constancy, August

If a meteorologist is planning for a balloon flight during August at the 30-mb level which requires a long duration but small net horizontal displacement from the launch site, he could choose an Alaskan location and have a high degree of confidence in expecting the achievement of these requirements. This is based both on the data presented and the fact that, for this region, the maximum standard vector deviation is only 11 knots. For balloon flights requiring straight-line trajectories, the month of July is best: the last two weeks in June and the first two weeks in August are also good periods for precision ballooning. During the summer months at the 30-mb level, the wind speeds show a progression from high values to low values with increasing latitude. Reviewing the standard vector deviations for all stations in the basic data, we find that during the summer their average is 9 knots and only in 3 cases out of a possible 144 is 11 knots exceeded. These relatively small values of standard vector deviations and high values of constancy make the summer season especially well suited for obtaining straight-line trajectories and, of course, allow the forecaster to place a high degree of confidence on his forecasts. These same conclusions can be applied to balloon altitudes above the 30-mb level. However, speeds will increase with altitude.

5.2 Fall (Figures 5 through 7)

During September, a well-defined zone of maximum variability is centered, essentially in an East-West direction, along 42N. Values of constancy increase northward and southward from this latitude, with the higher values being located at southern latitudes. Westerly winds have now become established at the higher latitudes and easterlies still persist at the lower latitudes. The center line of this zone of maximum variability shifts southward during October and is found along 33N. Values of constancy have increased at high latitudes and decreased at low latitudes relative to the values exhibited during September. During November, the zone of maximum variability loses its symmetry: it persists over the southwestern United States but it has moved southward and has become centered along 27N east of the Rocky Mountains. The winds over Alaska have now become highly persistent westerlies.

The balloon flight planner can use the information presented on this zone of maximum variability in the sense of a caution area in determining probable balloon trajectories based on climatology. The operational forecaster can use the same information as a basis for placing a low degree of confidence on a long-range trajectory forecast for flights that may occur within this area. The standard vector deviations within this zone of maximum variability, and indeed for the entire area considered, are relatively small during September, averaging 10 knots and never exceeding 13 knots. Therefore, while it would be more difficult to plan and operationally forecast balloon trajectories within this zone, especially directions, the

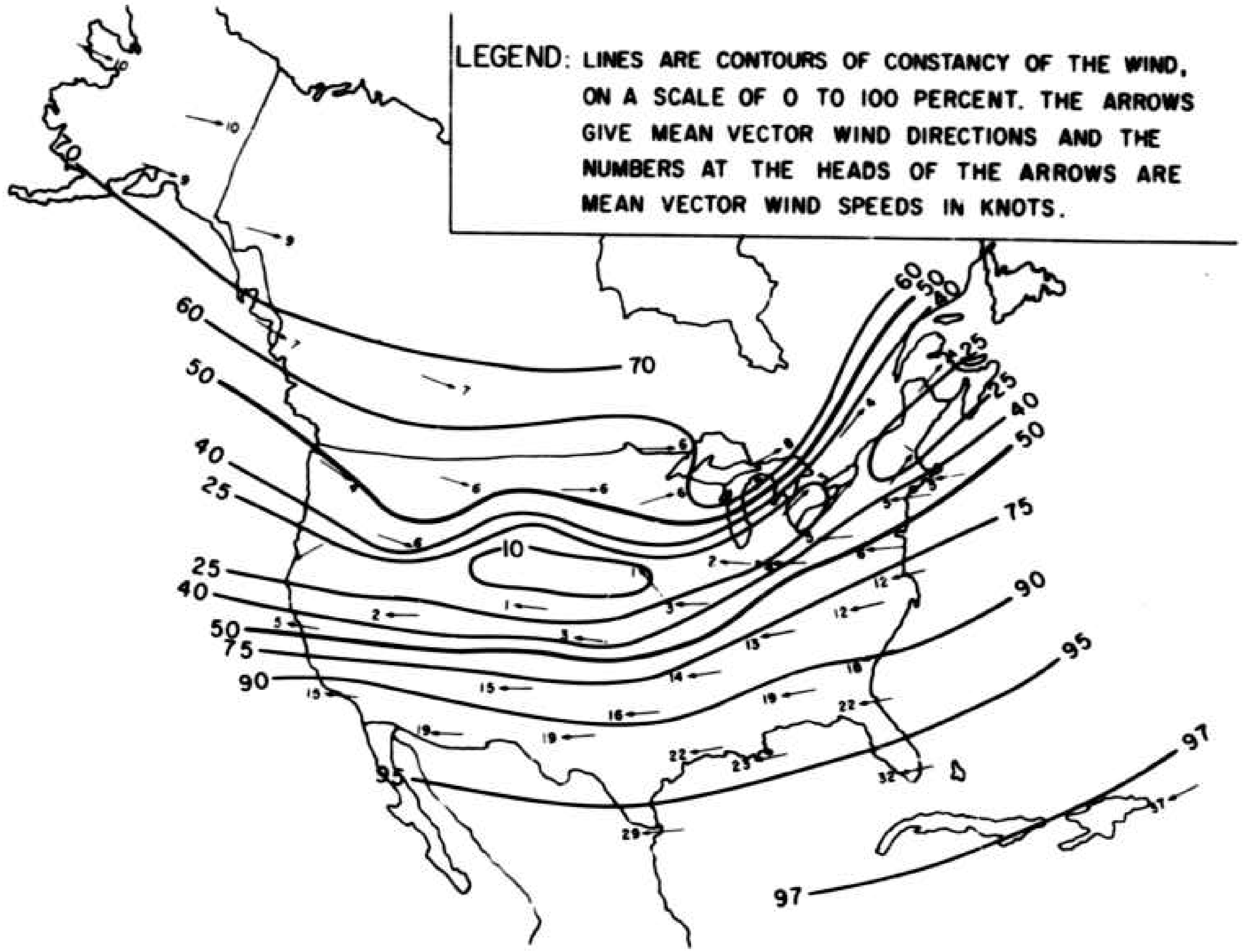


Figure 5. The 30-mb Level Field of Constancy, September

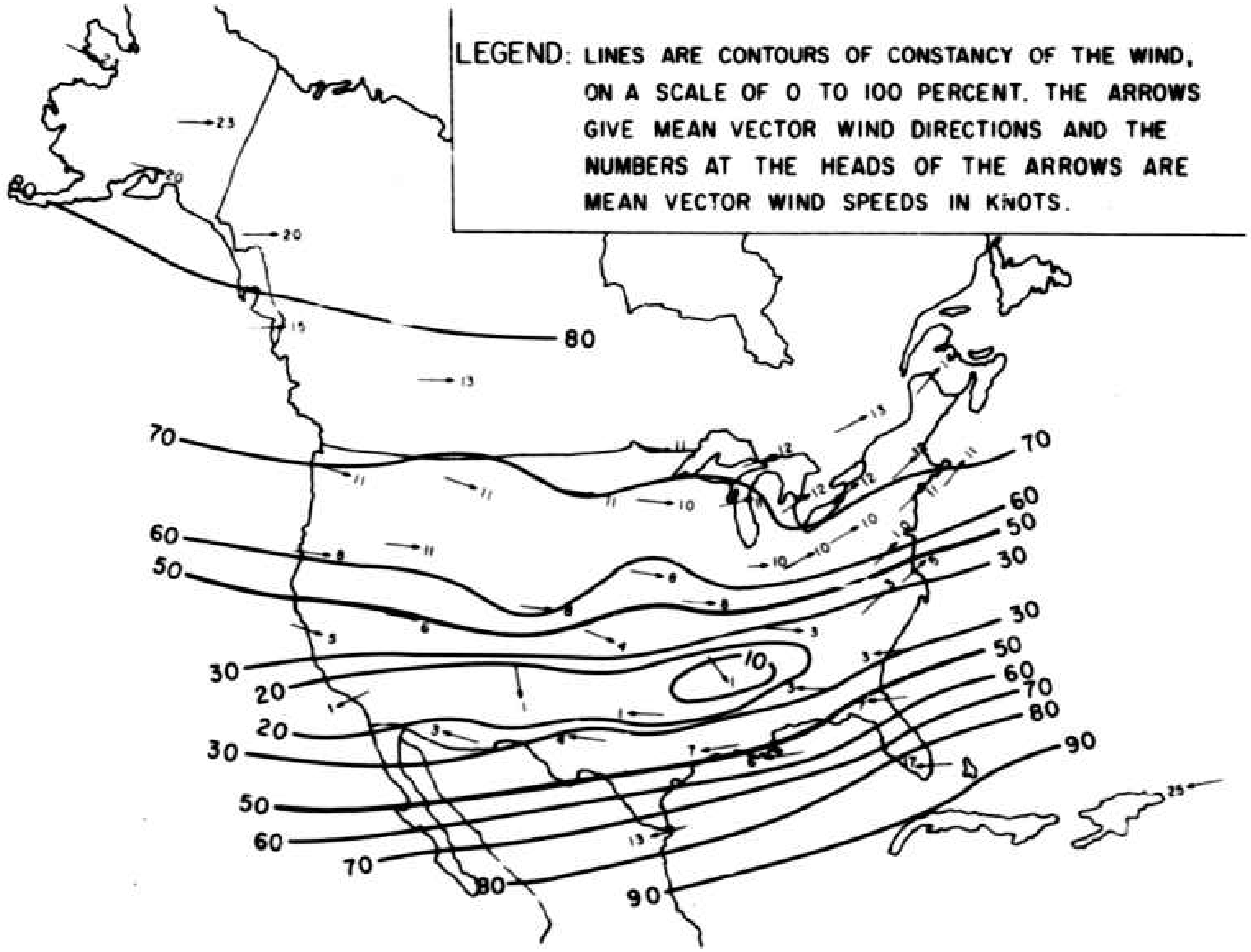


Figure 6. The 30-mb Level Field of Constancy, October

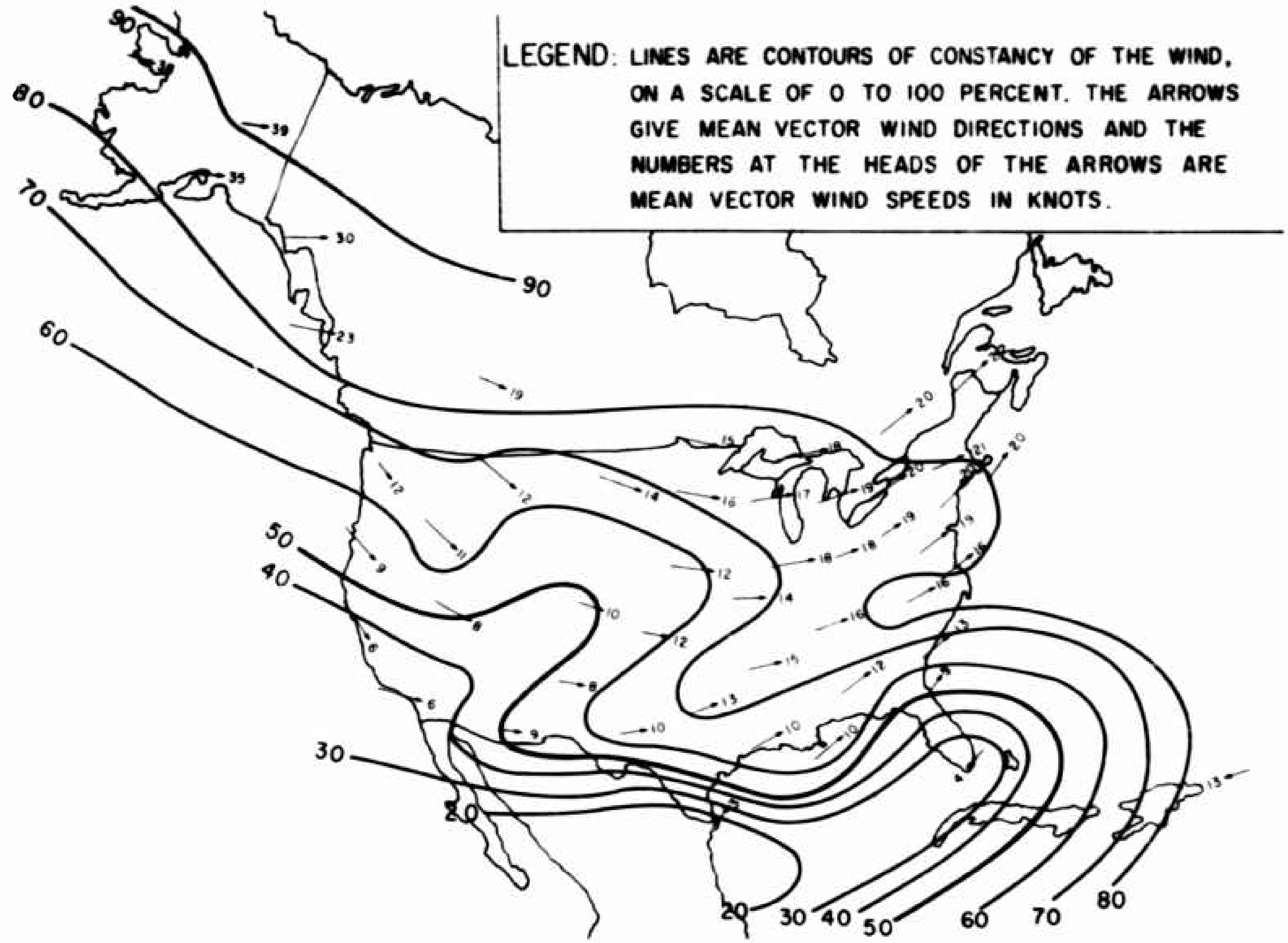


Figure 7. The 30-mb Level Field of Constancy, November

probability would be higher here of a smaller net displacement of a long-duration balloon flight. Similar arguments can be made relative to the zone of maximum variability during October and November. There is, however, an increase in the magnitudes of the standard vector deviations within the zone from September to November.

5.3 Winter (Figures 8 through 10)

The fields of constancy during December and January have configurations similar to that of November with higher values at northern latitudes and lower values at southern latitudes; but here again, the values show the existence of a higher degree of variability in the southwest section of the United States than at similar latitudes in the southeast. February shows an enlargement of the southwestern area of high variability, which now encompasses practically all that area of the United States west of a line from the Great Lakes to El Paso, Texas. The values of constancy now have decreased over Alaska. The increase of variability over the western United States results from the high frequency of anticyclonic activity which is observed over this region in the stratosphere during January and February.

Planning for long-duration balloon flights which are to be conducted during the winter months in the western United States is difficult due to the high degree of wind variability which exist there. This difficulty also will be experienced by forecasters attempting to predict a balloon trajectory of long flight duration in this area. There have been, and undoubtedly will be, times when, under the influence of the leading edge of anticyclonic flow, the winds shift as much as 180 degrees in a period of 48 hours or less with no apparent forewarning. While it is difficult to plan balloon trajectories based on climatology for flights to be conducted in the west during the winter, there are periods when strong cyclonic or anticyclonic flow persists for as much as a month; and, if the balloon launch date is not critical, most flight operations can be carried out. This requires a synoptic watch on the circulation and temperature fields: the latter can give forewarnings of circulation changes. However, even apparently stable circulations have been disrupted in a short period of time by sudden stratospheric warmings. In summary, planning balloon operations during winter months is a challenge.

5.4 Spring (Figures 11 through 13)

The constancy pattern during March shows areas of high variability over the northwest and over the Caribbean, and an area of minimum variability over the Gulf States. If we assign the term "highly variable" to values of constancy of less than 50 percent, then during the month of April the winds at 30 mb over the entire

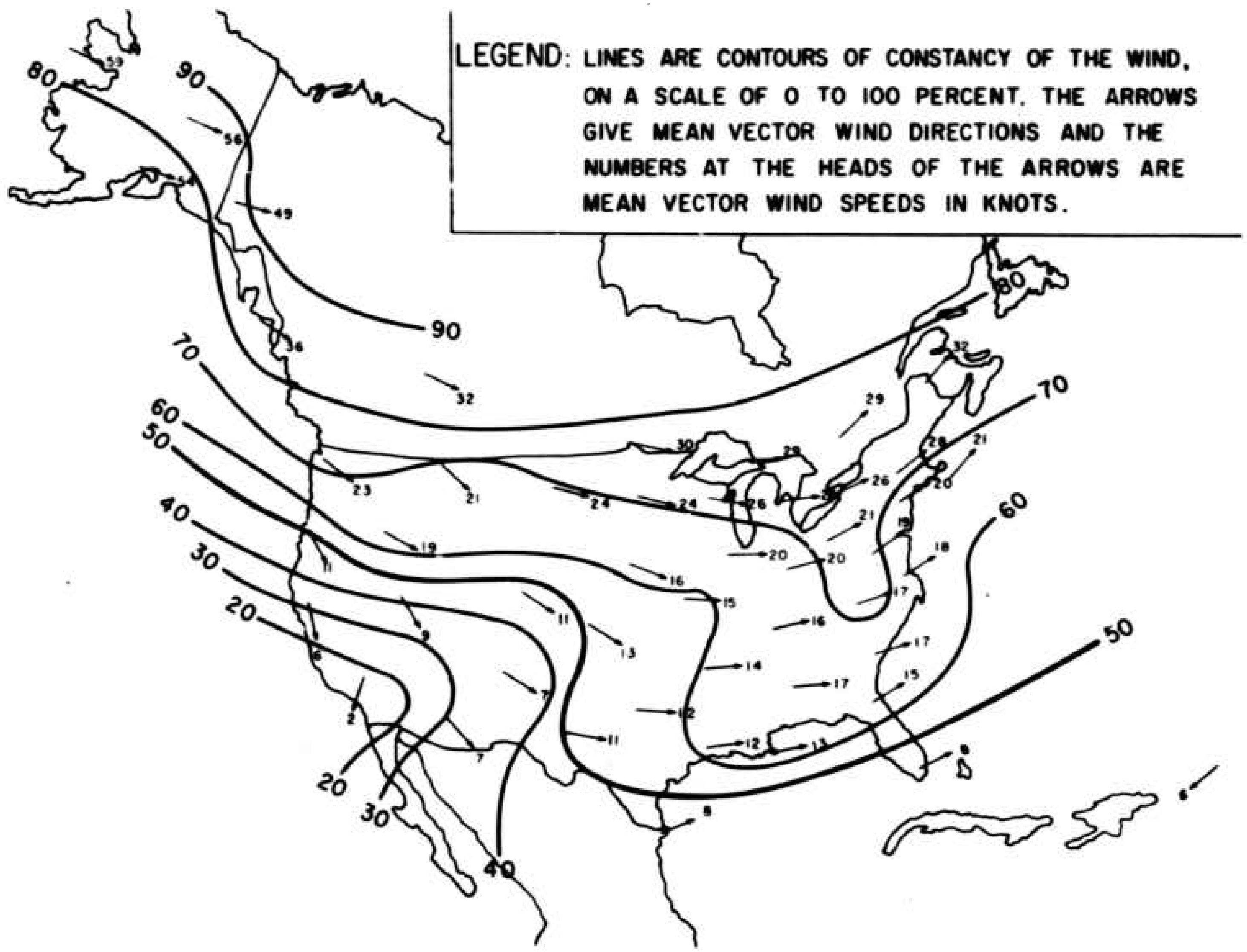


Figure 8. The 30-mb Level Field of Constancy, December

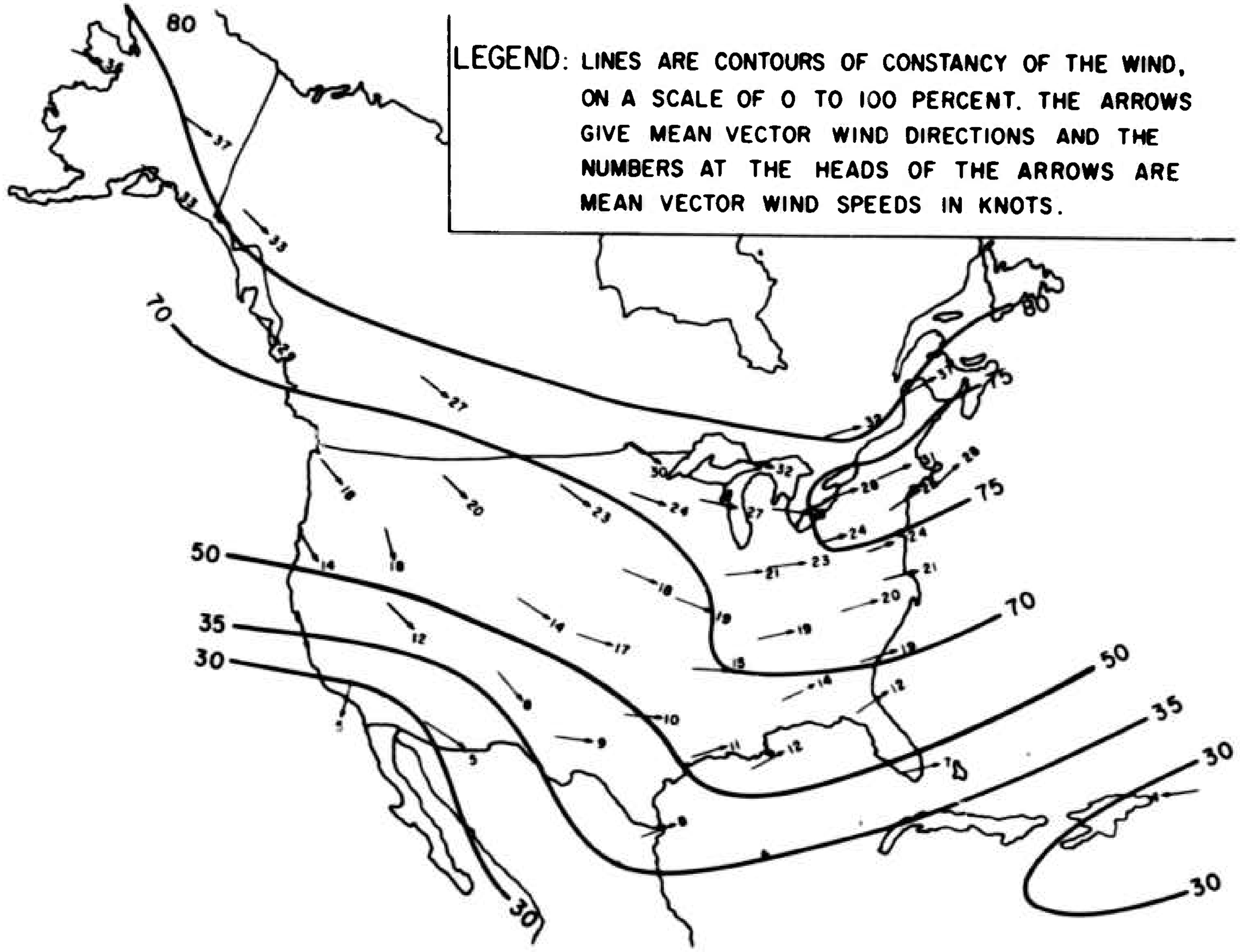


Figure 9. The 30-mb Level Field of Constancy, January

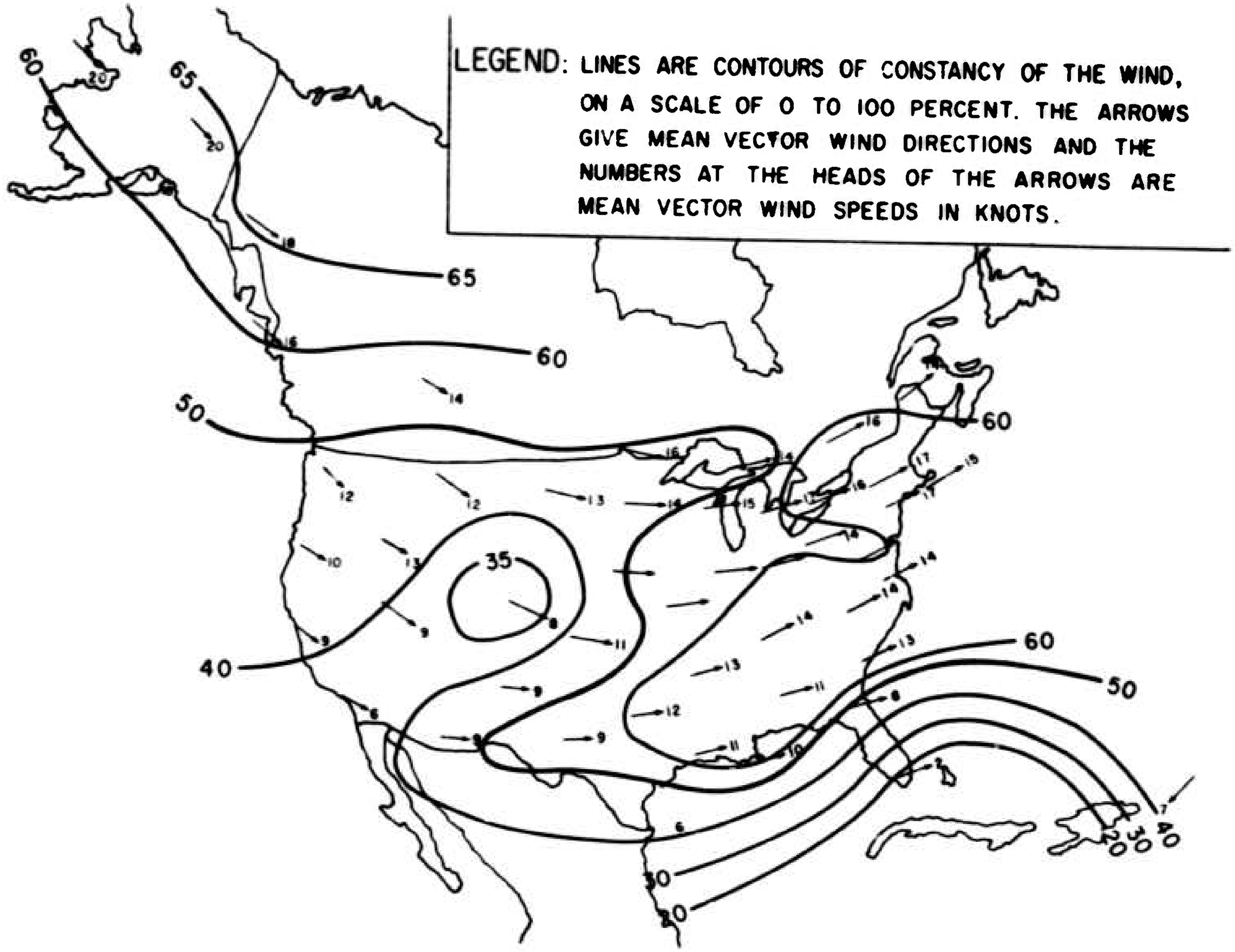


Figure 10. The 30-mb Level Field of Constancy, February

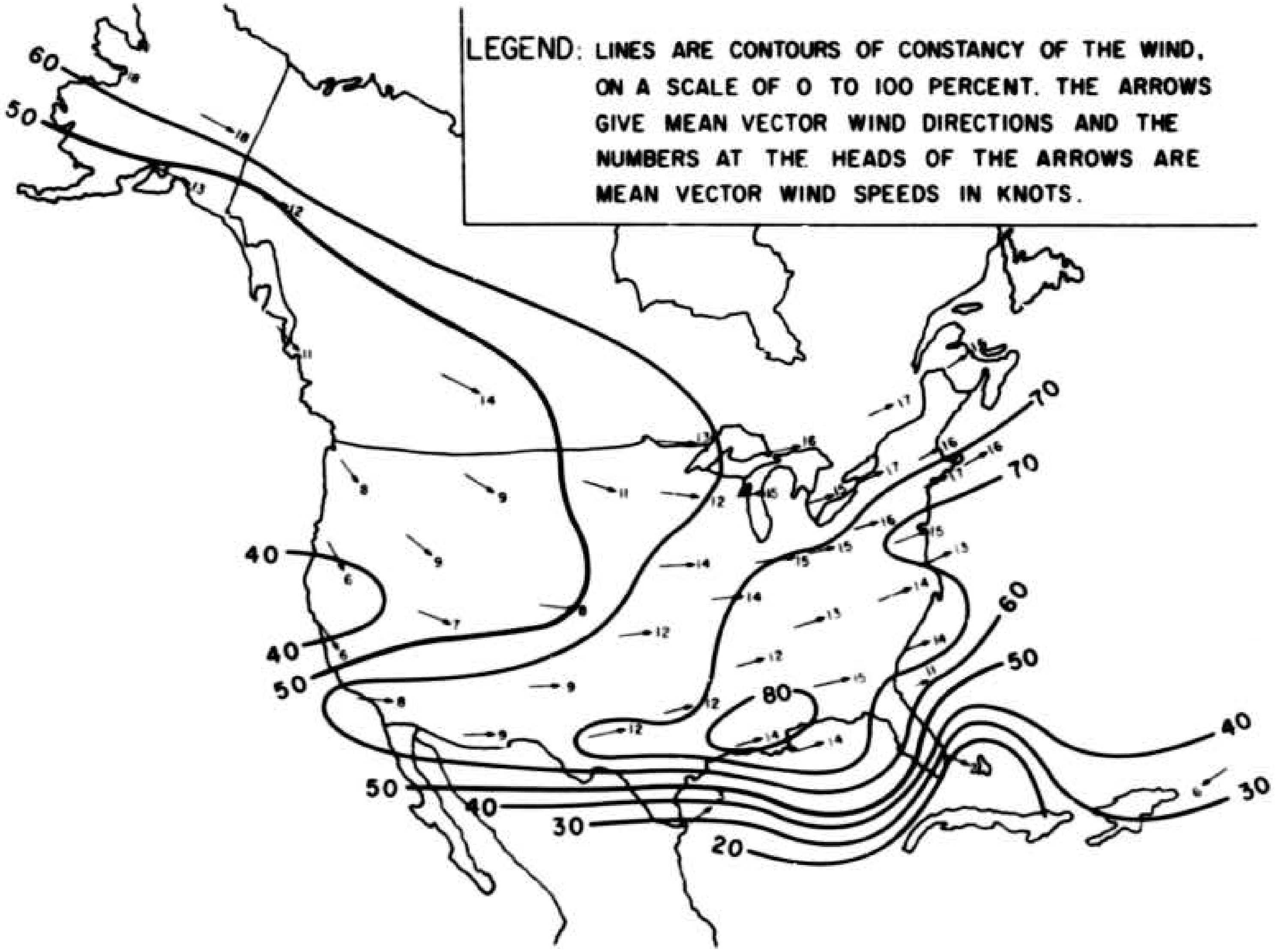


Figure 11. The 30-mb Level Field of Constancy, March

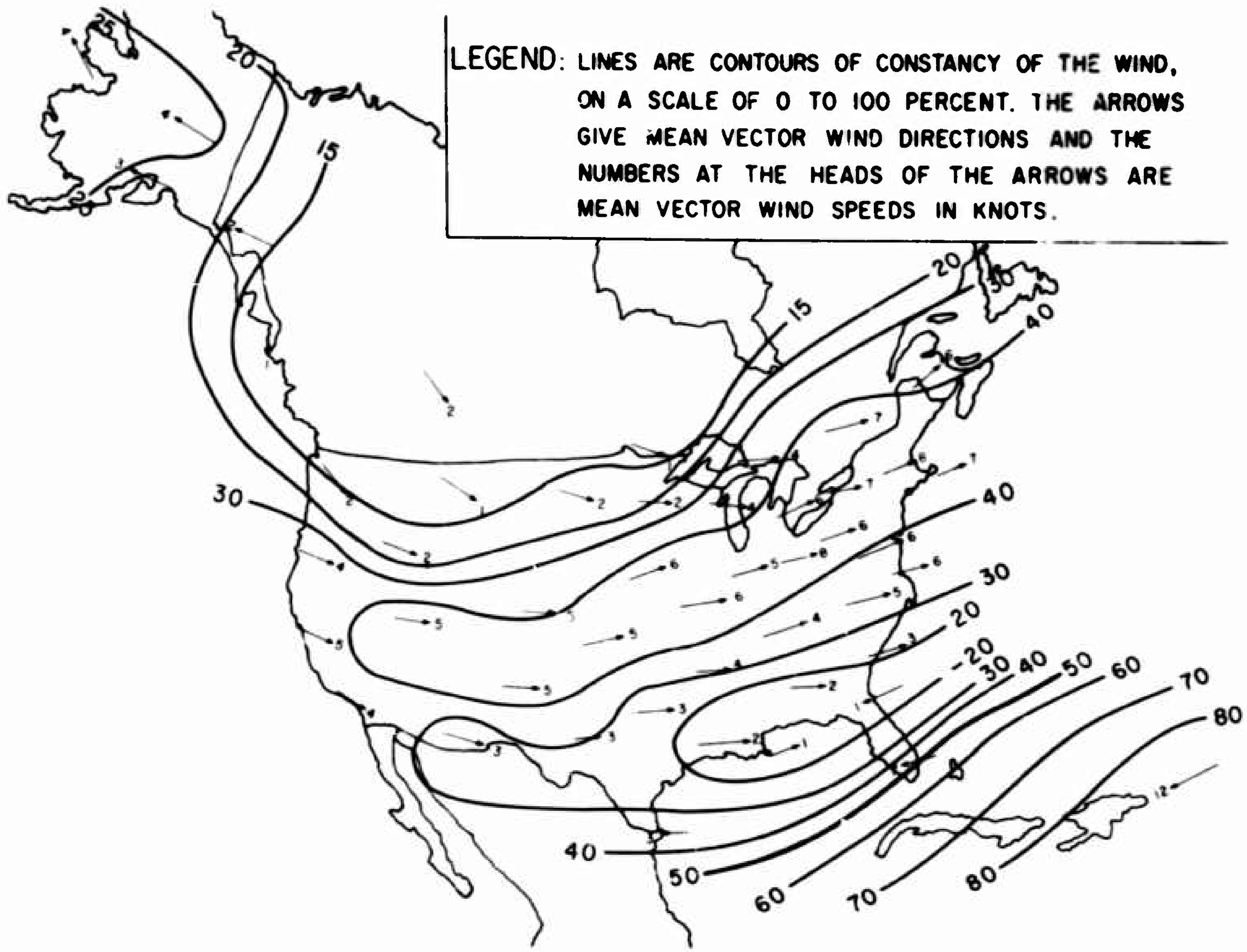


Figure 12. The 30-mb Level Field of Constancy, April

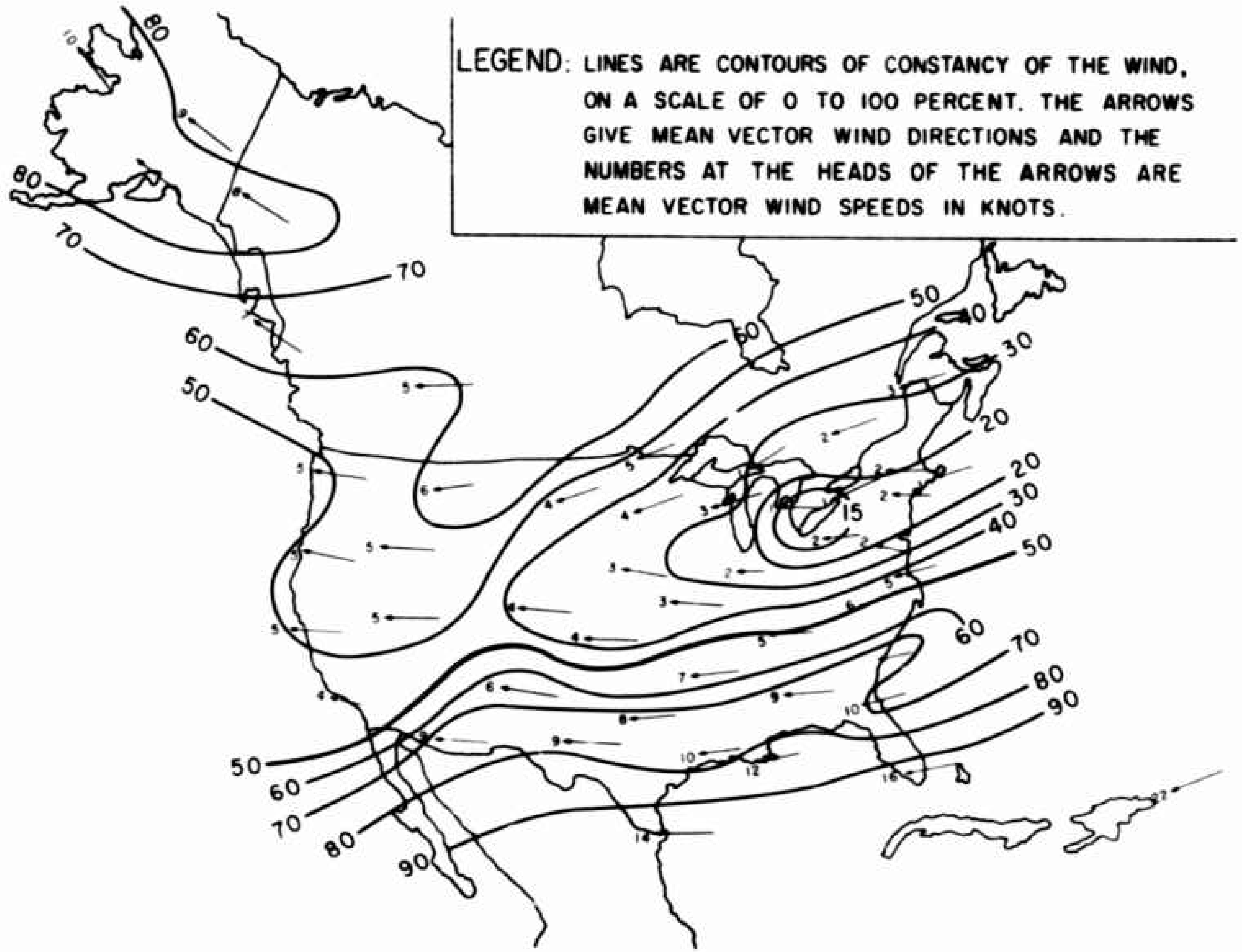


Figure 13. The 30-mb Level Field of Constancy, May

United States, Alaska, and apparently most of Canada are indeed highly variable. This is the most difficult period of the year anywhere in the areas considered relative to planning constant-level balloon operations that require straight-line trajectories. However, April is a good month for obtaining long-duration flights with small horizontal displacements.

During May, the stratospheric easterlies appear at high and low latitudes and the center line of the zone of maximum variability is now slanted from southwest towards northeast over the United States. These events herald the advent of the amazingly persistent stratospheric easterlies which cover the northern hemisphere during the summertime. It is important to note the asymmetry of the zone of maximum variability which is found during May. This can be a reflection of the observed fact that, when a year-to-year comparison is made, the circulation transition in the stratosphere is much more disorderly during the spring than during the fall.

Again, the reasoning can be applied that balloon flight planning and operational trajectory forecasting will be difficult in areas having low constancy values; but conversely, these are the areas where the probability is likely to be greatest for achieving relatively small horizontal displacements on long-duration flights, providing the values of the standard vector deviations of the winds are small.

6. CONCLUSIONS

This study has attempted to develop factors of confidence and interpretation that can be placed on the statistics of the wind at the 30-mb level as applied to constant-level balloon flight planning and forecasting. Information is given on the locations of greatest and least stability of the wind fields at this level by considering the constancy of the wind. The results also give a picture of the transition from westerlies to easterlies, and vice versa, during the spring and fall transitional periods.

The idea held by many balloon users, and indeed by some meteorologists, that the stratosphere is a region of predominantly westerly winds during the seasons other than summer is valid only for a few selected regions of the United States. The circulation over the far western states, especially during late winter and early spring, can perhaps be best characterized in the mean as bi-modal, or even tri-modal, with almost equal maximum frequencies of occurrence of wind directions from the west, from the north, and from the east.

There are times of the year and locations in the United States (which can be determined from the results of this study) when the balloon meteorologist forecasting the trajectory of a long-duration balloon flight can rightfully give a low confidence factor to his forecast verifying after the time period of 48 hours or more. His most logical choice in these cases, would be to forecast, after a certain time, that the balloon will be within a radius of so many miles from the launch site. The radius is simply determined by the product of the flight time and a forecast average wind speed.

The basic data used in this study were derived from wind observations taken over a five-year period from 1 March 1953 to 28 February 1958. It is debatable whether or not this relatively short record of data is sufficient to adequately portray the fields of constancy and the statistical parameters of the wind. Based on the author's experience in planning balloon operations and providing operational balloon trajectory forecasts since 1959, it is concluded that the data are representative for the areas studied for the months of June through November. However, for the other months it is questionable that this 5-year period is representative, say, of a 20-year period. This especially applies to the winds over the western half of the United States. The same question may be also raised as to the usefulness, for these months, of a 20-year record of data, if available, in providing reliable wind parameters for determining probable flight trajectories of constant-level balloons during any future month.

This dilemma, if properly understood can be resolved by the balloon operator who has the flexibility and the mobility of conducting balloon launchings from strategically located sites. This has been recognized by the Aerospace Instrumentation Laboratory which has permanent balloon launch sites at Chico, California and Holloman AFB, New Mexico and which also has incorporated the capability of mobility into its balloon operations.

Acknowledgment

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