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Upper-Air Climatology of the United States

Part 3—Vector Winds and Shear

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TABLE OF CONTENTS

UPPER-AIR CLIMATOLOGY OF THE UNITED STATES

PART 3 - VECTOR WINDS AND SHEAR

Benjamin Ratner

INTRODUCTION

The ever increasing capabilities of modern jet aircraft, as well as the interest of those engaged in rocket and missile design, ballistics studies, radioactive fallout investigations, and the many phases of high altitude research, all impose requirements for newer and better summarizations of upper air winds. However, these requirements have in the past been hampered by the scarcity of wind data at high elevations, and by the fact that the sparse observational data available for those altitudes must be considered a selected and therefore biased sample. This bias is due to the fact that certain meteorological conditions permit the tracking of a relatively few instruments to higher altitudes than is possible under other conditions.

Although soundings taken recently generally reach higher altitudes than those of several years ago, due to improved equipment and the use of larger balloons, the bias toward higher altitude soundings during conditions of low wind speed continues. Low elevation angles of instruments carried by high speed winds and the inability of the instrumental equipment to function accurately at low elevation angles result in records containing more data on days of low speed winds.

To provide more representative data, the Office of Climatology of the Weather Bureau developed and placed on punched cards a complete wind record for a 5-year period (March 1951 through February 1956) at 51 stations (fig. 1). Data for each day consist of wind speed and direction for 13 pressure surfaces from 950 to 30 mb., for the 1500 GMT observation at each location. This unique card deck was the result of a carefully designed study which started with all observed data for the period, and then filled in the gaps wherever observations were missing. The missing records were reconstructed using a number of techniques. Geostrophic winds were scaled from the National Weather Analysis Center analyzed charts, and corrections made for curvature where necessary. Data were interpolated between map surfaces where necessary and were extrapolated where required at those surfaces above the highest National Weather Analysis Center charts. Extrapolations were performed by making use of all observed data and considering data before and after as well as at the selected time of observation, both at the station and at surrounding stations. These procedures were supplemented by use of a series of mean climatological patterns which were analyzed especially for the purpose.

The larger amount of information thus available, particularly at high altitudes, and the methods of extrapolating data solve some of the difficulties described in the valuable contributions by Kochanski [1] and Chiu [2]. Thus, for example, these methods successfully eliminated small cells of higher or lower wind speed often presented in the earlier works. These cells were most prevalent at the highest elevations where the smallest amount of information was available.

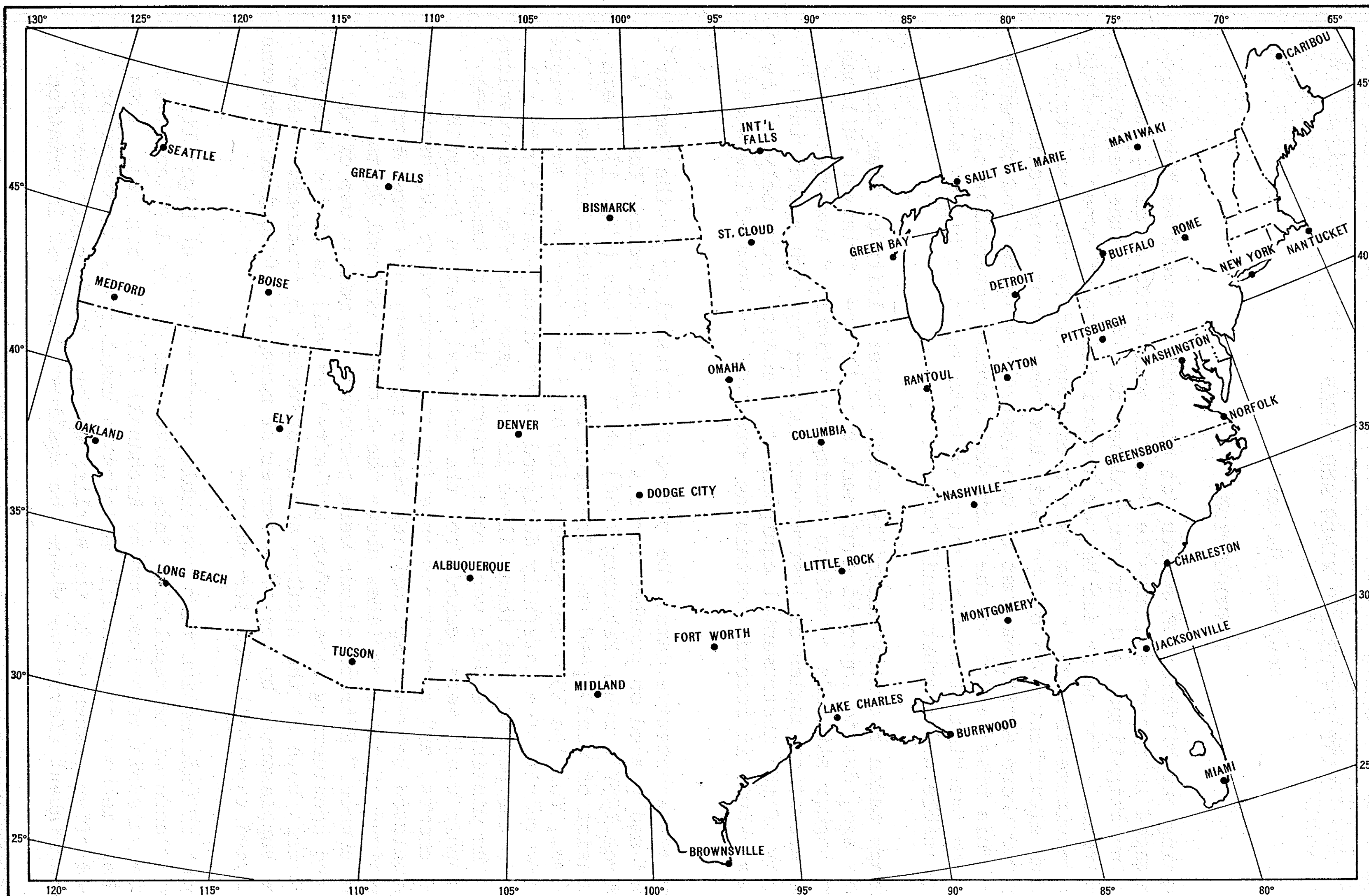

Figure 1. - Location of stations used.

The final card deck was summarized by the Sandia Corporation, in a cooperative project with the Weather Bureau. Portions of these summarizations, as they apply primarily to the United States, have been analyzed and are presented here.

MEAN VECTOR WINDS

Charts 1 through 24 show the mean vector winds at a network of stations over the United States. They are presented for each of the four seasons at 500 mb., 300 mb., the surface of maximum speed, 100 mb., 50 mb., and 30 mb. The surfaces selected are those customarily used for map analysis. The surface of maximum speed is in most cases at or very close to the 200-mb. surface, and appears to obviate a requirement for analysis at 200 mb. The 30-mb. surface was selected because it represents the highest altitude for which data are available in this project.

The isotachs of mean seasonal wind speed are drawn as solid lines on the charts. The arrow at each station for which the data were prepared shows the mean vector direction, the length of the arrows having no relation to speed. The numerical value by each station arrow is the standard vector deviation for the season, which is discussed more fully in the next section. It is again desired to emphasize that the isotachs are drawn to mean vector speeds entered on a series of work charts, and not to the numerical values shown on the published charts. The latter are values of standard vector deviations. Speeds and standard deviations are in knots. The charts for surface of maximum speed (9-10-11-12) contain an additional set of figures to indicate the pressure surface at which the maximum wind speed occurred; i.e., 200 indicates that the maximum wind speed of the 13 surfaces for which wind values were available occurred at 200 mb. The symbols I and D indicate that the vector wind speed is increasing or decreasing, respectively, from the nearest isotach.

Winter

Winter is the season of highest mean vector speeds at all altitudes through the 100-mb. surface. Maximum values for the season generally occur along the mid-eastern coast. However, it is interesting to note that at the surface of maximum speed (chart 9), the area of highest winds is farther inland and slightly southward, with an extreme value of 81 knots at Montgomery, Ala. The authenticity of this position is borne out by the development of the area during spring (chart 10), and has been further verified by a study of 200-mb. wind data in "Tables of Winds" [3]. Above the 200-mb. surface, all vectors begin decreasing in speed with height, but retain their westerly component through the 30-mb. surface. Maximum winds occur at 250 mb. north of approximately 40°N. latitude and at 200 mb. south of that parallel (chart 9). The area of highest vector speeds moves to the northeast at 50 and 30 mb.

Spring

Winds are lighter in spring than in winter. They are higher in spring than in fall south of a latitudinal line ranging between 40° and 45°N. except at the 30-mb. surface, and lighter in spring than in fall north of that line. Maximum wind speeds again occur at 200 mb. during this season except at the northern locations where they are at 250 mb. (chart 10). On the charts for lower levels, the highest speeds are along the mid-eastern coast, moving farther southwest at the surface of maximum speed. The extreme mean vector speed for spring is 65 knots at Midland, Tex. at 200 mb. Seasonal vectors have westerly components at all stations and surfaces except Brownsville and Miami where at 30 mb. (chart 22) the vector directions are southeasterly.

Summer

Mean vectors remain westerly in the northern half of the United States from 500 through 100 mb. during the summer season. At about 35°N. latitude, the wind begins to veer clockwise and becomes easterly at the southernmost stations. Chart 11 is of special interest. Here the surface of maximum wind speed is at 200 mb. at practically all stations above the dashed line running roughly from San Diego to Hatteras. At all stations north of this line vectors have westerly components. However, at all stations south of that line, vectors have easterly components and the surface of maximum speed is at 30 mb. It is further interesting to note that winds with a westerly component generally increase with increasing latitude while those with easterly components increase with decreasing latitude. At the two uppermost surfaces (50 and 30 mb., charts 19 and 23) all vectors are from the east and the speed increases southward. At these levels, wind speeds at southern stations are higher in summer than during the other seasons.

Although summer is usually considered the season of lowest wind speed, vector speeds even at northern stations are in many cases higher than during spring and fall. In the area over Great Falls, Boise, Ely, Bismarck, International Falls, and St. Cloud, vector speeds at the surface of maximum wind (chart 11) are higher in summer than during either spring or fall. Highest wind speeds in the summer occur in the north. Winds in the southern United States are extremely light until they become easterlies and start to increase with height. This increase of speed with height is constant and rather rapid.

Fall

In fall, the highest winds occur in the northeastern area. As mentioned previously, wind speeds at the northernmost stations are higher than during spring but are lighter elsewhere. The 30-mb. chart (chart 24) shows a rather cleancut dividing line between westerlies in the north and the easterlies in the south.

STANDARD VECTOR DEVIATIONS

The figures beside the vector arrows on charts 1 to 24 are the standard vector deviations, $\sqrt{S^2(U) + S^2(V)}$, where S(U) and S(V) are the standard deviations from the mean zonal and meridional components which are computed as follows: $U = \frac{\sum u_i}{n}$ and $V = \frac{\sum v_i}{n}$; u_i and v_i are the daily zonal and meridional components for each day of the season under consideration; and n is the number of cases.

Although the maximum standard vector deviations occur between 300 and 200 mb.

during all seasons, they are at a higher altitude in summer than in winter, and at a higher altitude at the southern stations than at the northern.

Winter

During the winter season, standard vector deviations in the troposphere are greatest in the northeastern area, centered roughly over Nantucket. They decrease slowly toward the west and more rapidly toward the south. An isoline chart would indicate a north-south trough through the west-central part of the country, with values again increasing along the west coast. The position of the maximum standard vector deviation moves inland from the east coast in the stratosphere, and is centered over Detroit at 50 and 30 mb. The range in standard vector deviation values diminishes greatly at higher altitudes and is only 9 knots at 30 mb., as compared to 22 knots at 300 mb.

Summer

In the summer season, standard vector deviations decrease generally with lower latitudes in the troposphere. However, at 100 mb. maxima are indicated both in the northeastern and southwestern portions of the country. A belt of slightly lower values runs through the center of the country at 50 mb., with standard vector deviations increasing toward both north and south. However, there is only a 5-knot range in values at this level as compared to a 25-knot range at 300 mb. The 30-mb. chart is quite similar to the 50-mb. chart with the range in values increasing to 7 knots.

VERTICAL WIND PROFILES

Charts 25 and 26 show seasonal vertical wind profiles for 12 stations selected as a small network within the larger network. Although Alaskan data are not included in the analyzed charts contained in this publication, profiles for three Alaskan stations are included here.

The wind arrows show the vector direction for each of the selected pressure surfaces and do not refer to speed. The value next to each arrow is the vector speed in knots. The number at the bottom of each seasonal column of arrows is the sum of the wind speeds at the 13 pressure surfaces. It is not weighted for the thickness of the stratum represented by each surface nor does it take wind directional changes into consideration. Nevertheless, it provides a handy index to compare total wind speed of the entire column of air, both among stations and seasons. This sum will hereafter be referred to as the total scalar wind and the 12 stations for which vertical wind profiles are shown will be referred to as the network for this portion of the paper.

The total scalar wind is greatest during the winter at all stations in the network except Caribou. The next largest totals occur during fall at the northern stations (chart 25) and during spring at the southern stations (chart 26). The lowest total scalar wind occurs during the summer season at all of the southern stations except Oakland where it occurs in fall, but it occurs in summer only at Annette and Seattle in the north. At Nome, Fairbanks, International Falls, and Caribou, the total scalar wind is lowest during spring.

During the winter season, the maximum total scalar wind value of the network

495303 O -59 -2

(598) occurs at Washington and the lowest (224) at Nome, which has the minimum value during all seasons. The lowest total scalar wind in winter in the continental United States is 332 at Oakland. In spring the highest value is 411 at both Washington and Ft. Worth, while the lowest in the continental United States is at International Falls (220). A reversal occurs in summer when the maximum of 294 occurs at International Falls which has the continental United States minimum during spring, and the continental United States minimum of 97 occurs at Ft. Worth which has the maximum during spring. A maximum total scalar wind of 399 occurs at Caribou in the fall, with a continental United States minimum of 188 at Oakland and Miami.

Wind vector directions are from close to west at most stations and altitudes, excepting a few near the ground. However, all stations in the network have vectors with an easterly component at 50 and 30 mb. during the summer season, with southern stations shifting to easterlies well below the 50-mb. surface. Also, the 30-mb. winds have an easterly component at the southwestern stations during the fall.

The existence of a monsoon circulation is evident in the pattern of wind directional shifts in the vertical profile for Lake Charles during the summer season.

VERTICAL VECTOR WIND SHEAR

Charts 27-58 show the average seasonal vector wind shears (defined below) for the several layers between 700 and 50 mb. The only omission is the 500 to 400-mb. stratum which is not shown due to its similarity to the layers above and below it. The 50 to 30-mb. stratum is not shown because of its extremely narrow range of values; i.e., when rounded to whole numbers all shear values during spring average either 1 or 2 kt. per km, all winter values average 2 kt. per km, etc.

The shear direction is the direction toward which an object propelled upward through the layer would be laterally displaced by the change in wind from the bottom to the top of the layer. This direction is equal to arctan $[(\bar{v}_2-\bar{v}_1)/(\bar{u}_2-\bar{u}_1)]$ where $\bar{v}$ is the mean south to north component, $\bar{u}$ the mean west to east component, and subscripts 2 and 1 refer to the higher and lower altitudes respectively. Shear directions are indicated by the arrows on the charts; the arrows have no relation to magnitude of shear.

The wind shear values are the magnitudes of the differences between the wind vectors at the bottom and top of each layer, per unit thickness of the layer. These values are given by $[(\Delta U)^2 + (\Delta V)^2]^{1/2} / \overline{\Delta z}$, where $\Delta U = \bar{u}_2 - \bar{u}_1$, $\Delta V = \bar{v}_2 - \bar{v}_1$, and $\overline{\Delta z}$ is the mean thickness of the layer. The wind shear values in knots per kilometer are indicated by the isolines in charts 27-58. The symbols I and D indicate areas of increasing and decreasing wind shear, respectively. Standard vector deviations of mean vertical vector wind shear are shown as numerical values below each station.

In the troposphere, wind shears are greatest during the winter season and least during summer. In the lower stratosphere greatest shears occur in the spring and least in the fall, and in the highest layers considered in this study, largest values are again observed in winter and smallest in the summer.

The largest shear values of the entire column considered in this study occur in the layer 100-80 mb. during all seasons, while the smallest are in the 250-150-mb. layer. Shear throughout the entire column can be described as being rather large through most of the troposphere, where winds are generally high at both boundaries of the considered layer (usually 250 to 200 mb.), with resultant small values of shear. Wind speeds start decreasing rapidly in the lower stratosphere creating the large shear values indicated for the 150-100-mb. and especially the 100 to 80-mb. layers.

Winter

Winter shear values of 3 to almost 8 knots per kilometer prevail in the 700-500 and 400-300-mb. layers (charts 27 and 31). These are all from westerly directions, indicating winds with westerly components, increasing rather rapidly with height. The largest shear values are in the mid-eastern portion of the country in the general area of the maximum vector wind speeds. In the layer 300-250 mb. (chart 35) shear values are smaller throughout the United States but westerly components persist. These increase southward, with the greatest values in the southeastern part of the United States, where the tropopause has not yet been reached. The maximum of 7 knots per kilometer is at Miami. In the 250-200-mb. layer (chart 39), westerly components in the south have decreased, while in the north they have given way to easterly components as the result of westerly winds decreasing with height.

Easterly wind shear occurs at all stations in the 200-150-mb. stratum (chart 43), caused by decreasing westerly winds in the layer, with largest shears of 4 to 5 knots per kilometer occurring in an area centered roughly over Indiana.

Winds continue decreasing with height in the 150-100, 100-80, and the 80-50 mb. strata, as demonstrated by the uniformity of shears with easterly components on charts 47, 51, and 55. The largest shears (11 knots per kilometer) are for the 100-80-mb. layer. Maximum values occur in the southeastern portion of the country in each of these layers.

Spring

During spring shear values in the 700-500 and the 400-300-mb. layers (charts 28 and 32) are smaller than during winter, with maximum values slightly above 6 knots per kilometer occuring in the southwestern and south-central areas, respectively. The chart for the 300-250-mb. layer (chart 36) is quite similar to its counterpart for winter, with shear speeds increasing toward the south. The small easterly components of shear at extreme northerly stations in the 250-200-mb. stratum (chart 40) indicate that the westerly winds have begun to decrease with height in this region while still increasing over the rest of the United States. However, in the next higher layer, 200-150 mb. (chart 44), westerly winds are on the decrease throughout, and the resultant shears have easterly components over the entire country. Maximum shears of around 5 knots per kilometer are centered in an area roughly over Pennsylvania. The largest shears for the entire column are again in the 100-80-mb.

layer. (chart 52). These vary from 3 knots per kilometer in the northwest to 10 knots per kilometer in the extreme southeast. Shears decrease in the 80-50-mb. stratum (chart 56) and range from 2 knots per kilometer in the northwest to 6 knots per kilometer in the southeast.

Summer

Charts 29, 33, and 37 indicate that the area of greatest shear moves to the northwest in the three lowest layers in summer, with a secondary maximum in the northeast in the 300-250-mb. stratum. Largest values are just above 4 knots per kilometer. Shears increase northward in contrast to the other seasons when shears rather generally increase southward. Easterly shears are shown at Miami on charts 33 and 37, due to easterly winds increasing with height. Shear values are extremely small in the 250-200-mb. layer (chart 41), with maxima only slightly above 2 knots per kilometer. The vector mean shear at International Falls has an easterly component in this stratum, indicating that westerly winds in this area have begun to decrease in speed. The four highest charts (45, 49, 53, 57) are composed entirely of vector wind shears with easterly components. Maximum shears are in the north on charts 45 and 49, due to decreasing westerly winds. On chart 53, the area of maximum shear has moved southward to about the 40th parallel. The easterly components in this layer (100-80 mb.) are still due to decreasing westerly winds in northern United States, while those in lower latitudes are due to westerly winds shifting to easterly with height, or easterly winds increasing with height. In the 80-50-mb. layer, winds shift from westerlies to easterlies in the north, and the easterlies increase with height in the south, again resulting in shears with easterly components throughout. Maximum shears occur in the 150-100-mb. layer during the summer, with extreme values exceeding 8 knots per kilometer.

Fall

During fall the average shear value of about 4 knots per kilometer in the north decreases to only about 3 knots per kilometer in the south in the 700-500-mb. layer (chart 30). In the next higher stratum (chart 34) the picture reverses with smaller values in the north and west, and shears becoming greater than 5 knots per kilometer in the southeast. These become slightly smaller in the 300-250-mb. layer (chart 38). As in other seasons, easterly shears are first evident in the 250-200-mb. stratum (chart 42), but, as in summer, barely reach the United States border in the neighborhood of International Falls. Shears decrease generally in the 200-150-mb. layer (chart 48) and practically all have easterly components. Shears are greatest in the 150-100 and 100-80-mb. strata and decrease considerably in the 80-50-mb. layer (chart 58).

STANDARD VECTOR DEVIATIONS OF THE VERTICAL SHEAR

Numerical values of standard deviation from the mean vector shear (knots per kilometer) are shown by each station arrow on charts 27 to 58. The range of these values is quite small in all seasons and at all surfaces.

In winter, the mean of the standard deviations of wind shear is about 8 knots per kilometer for the layer between 700 and 500 mb., with individual values ranging between 6 and 10 knots per kilometer. These increase to an average of about 17 knots per kilometer between 300 and 200 mb. where the total range is 8 knots per kilometer. In the 80-50-mb. stratum, the mean value is down to about 5 knots per kilometer, and all values throughout the country are between 4 and 7 knots per kilometer.

Summer values follow a similar pattern and are about 3 knots per kilometer smaller than those at comparable surfaces in winter, except at the three highest layers, where the differences are even less.

ACKNOWLEDGMENTS

Grateful acknowledgment is made to the Sandia Corporation for machine analysis of the large amount of data from which this paper was prepared; to Dr. Helmut E. Landsberg for guidance throughout the project; to Mr. Milton L. Blanc for valuable editorial comments; and to Messrs. Albert A. Karpovich, Joseph S. Barry, and George W. Cry for preparation of the numerous charts contained herein. Further thanks are given to Miss Vivian M. Campbell of the Weather Bureau Drafting Section for work entailed in drafting the charts. Support of the Office of Civil and Defense Mobilization for compilation of the wind values used for this presentation is also gratefully acknowledged.

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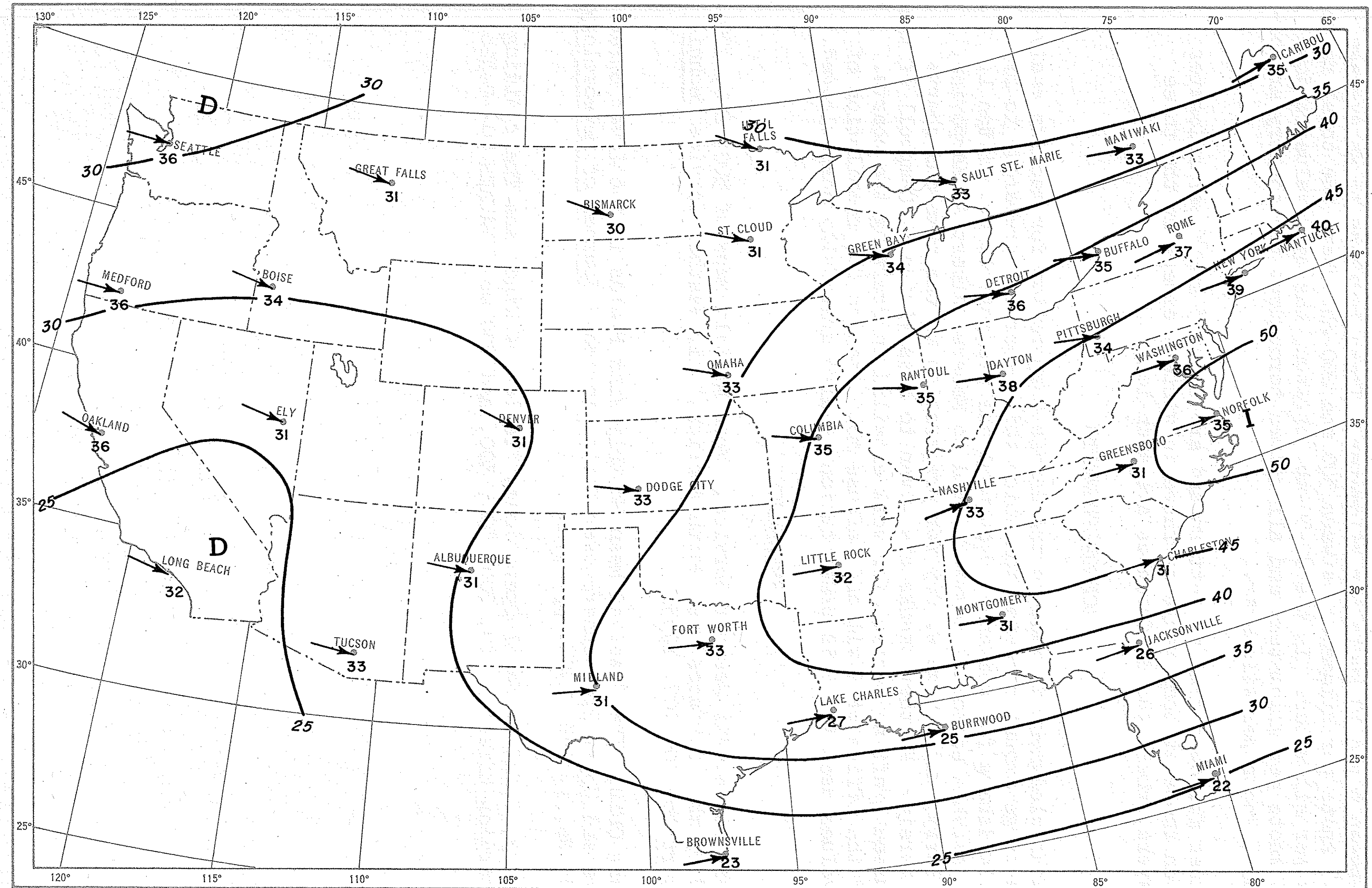

Chart 1. - 500 mb. Winter. Mean vector winds (speed in knots shown by isotachs, direction by arrows) and standard vector deviations (knots).

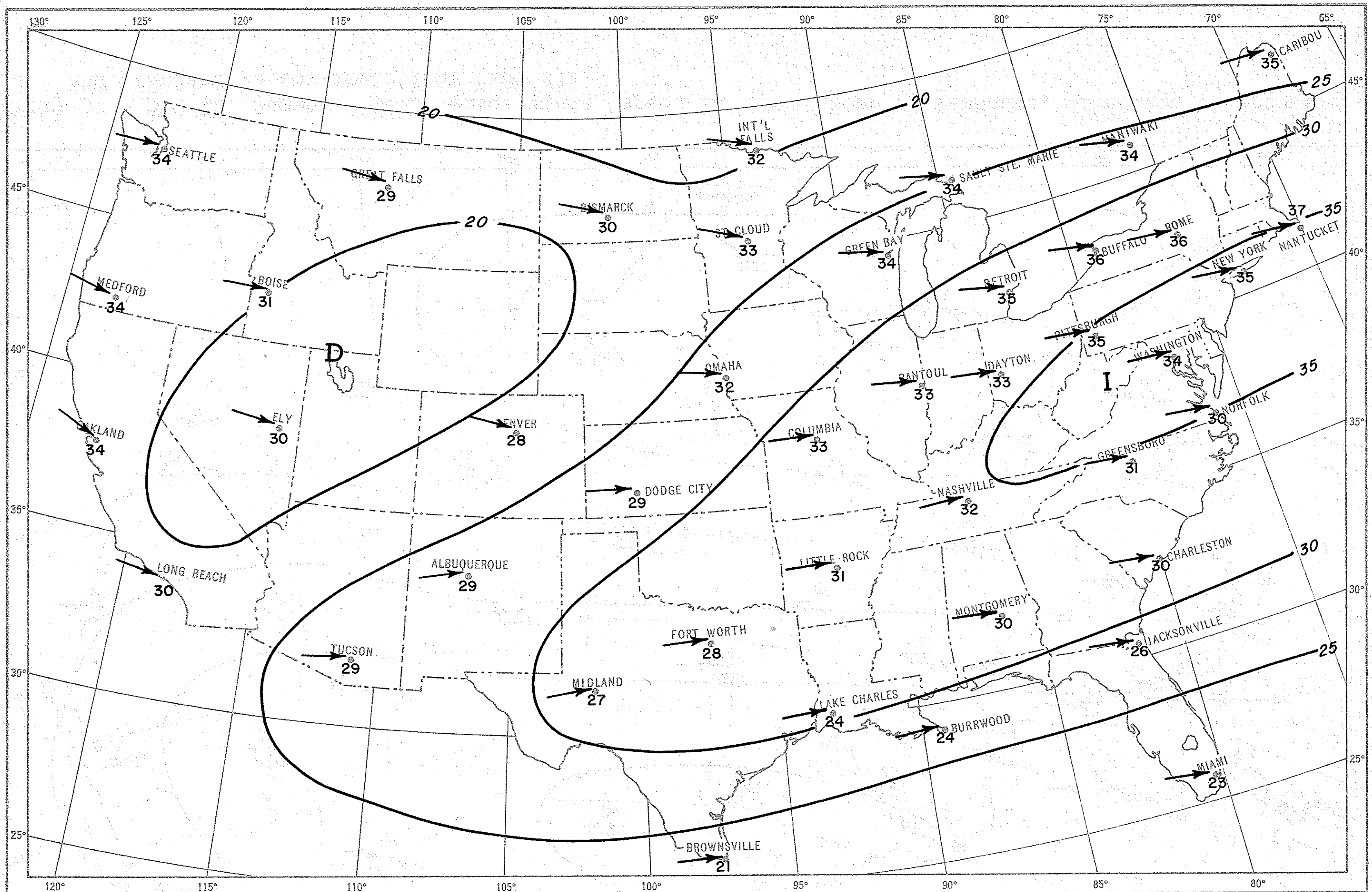

Chart 2. - 500 mb. Spring. Mean vector winds (speed in knots shown by isotachs, direction by arrows) and standard vector deviations (knots).

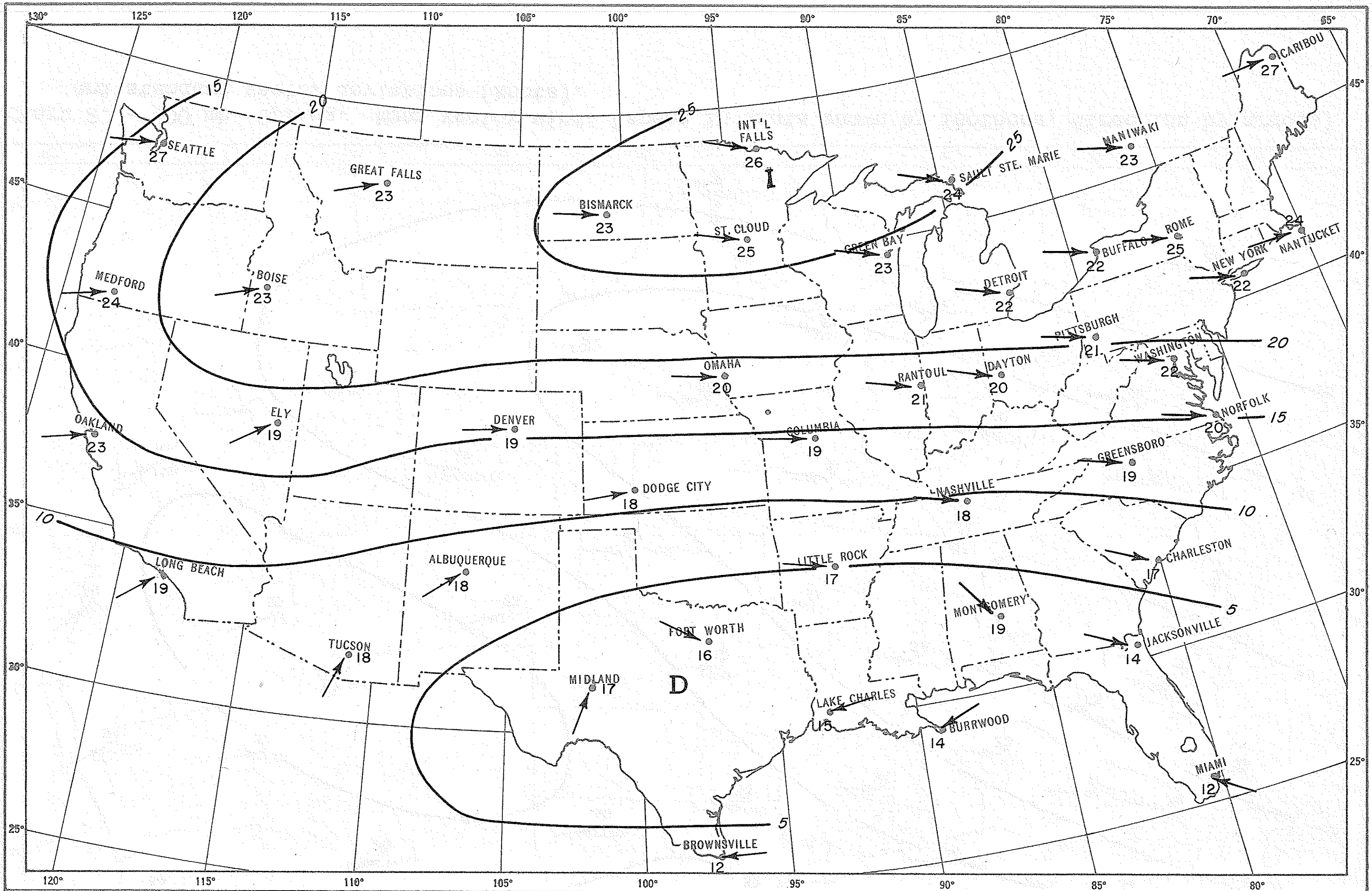

Chart 3. - 500 mb. Summer. Mean vector winds (speed in knots shown by isotachs, direction by arrows) and standard vector deviations (knots).

49303 O - 59 - 3

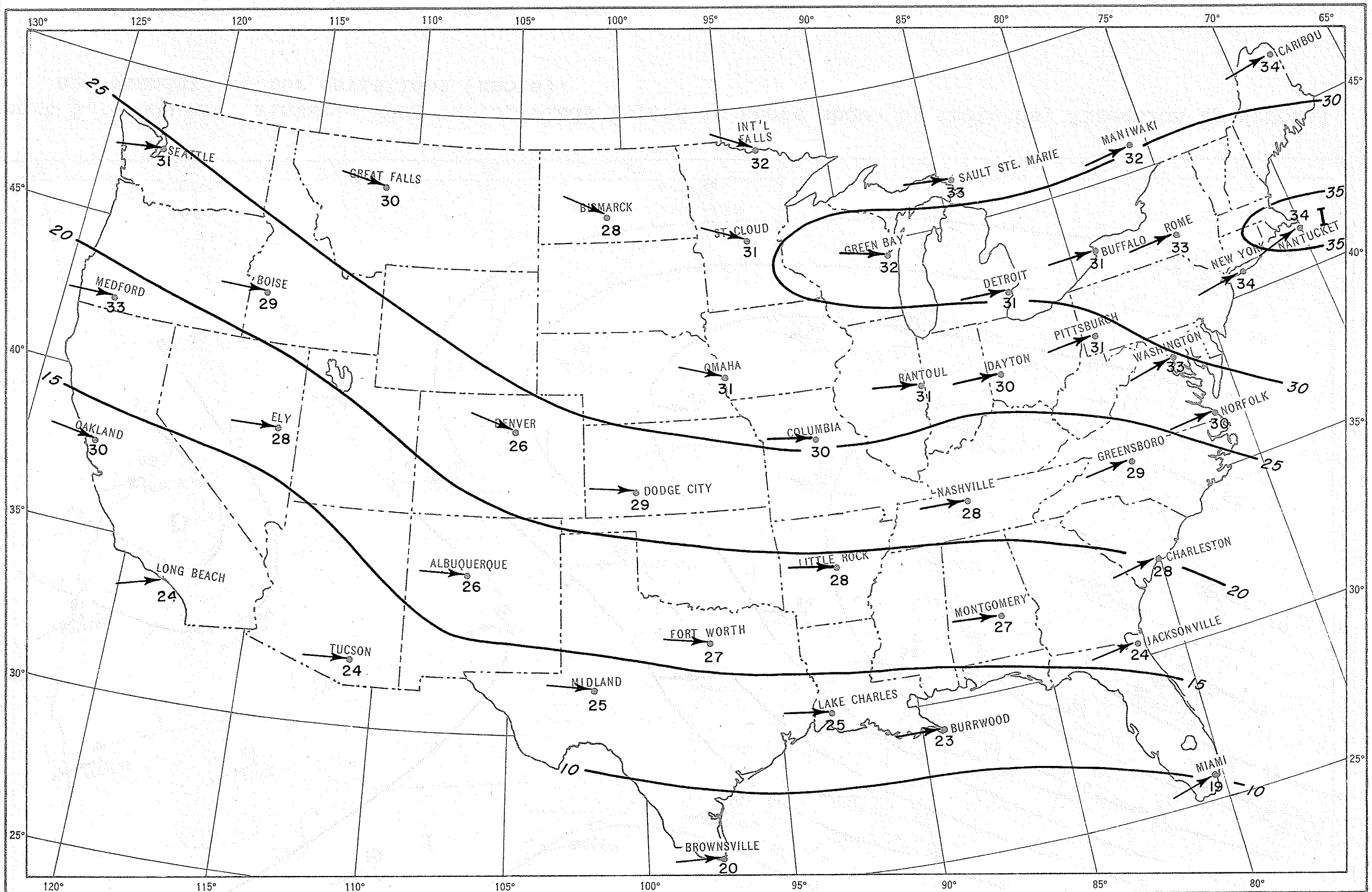

Chart 4. - 500 mb. Fall. Mean vector winds (speed in knots shown by isotachs, direction by arrows) and standard vector deviations (knots).

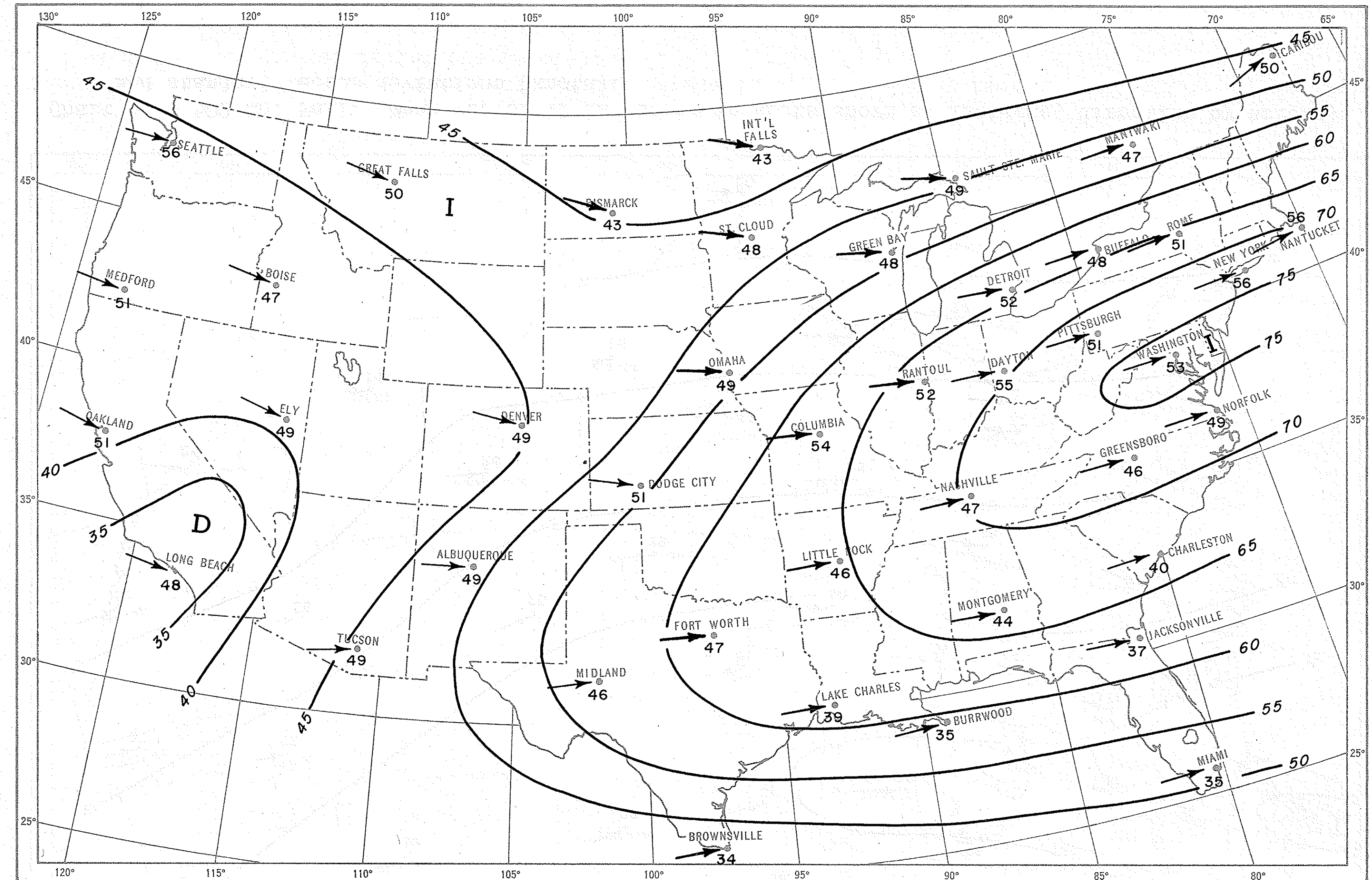

Chart 5. - 300 mb. Winter. Mean vector winds (speed in knots shown by isotachs, direction by arrows) and standard vector deviations (knots).

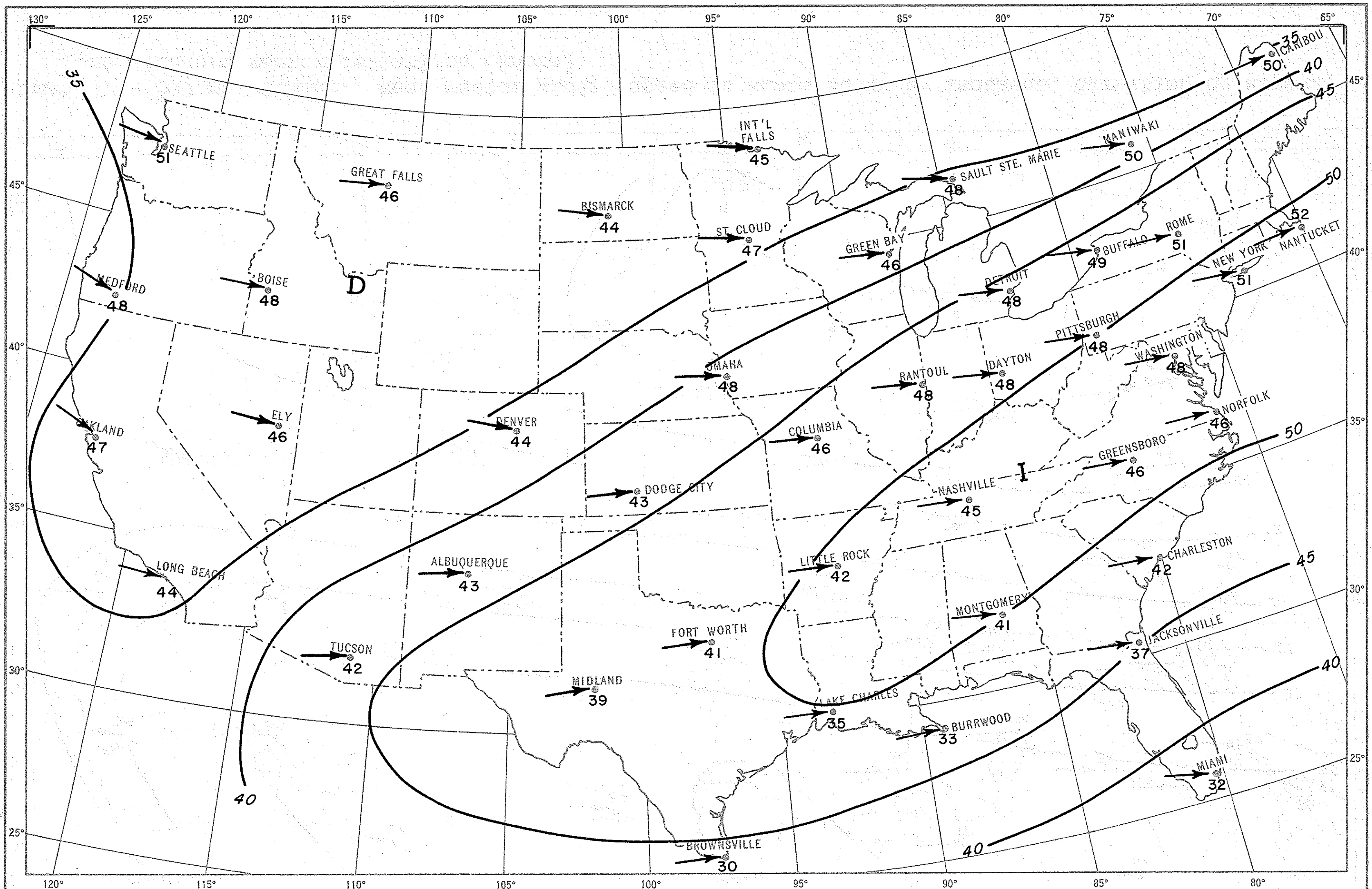

Chart 6. - 300 mb. Spring. Mean vector winds (speed in knots shown by isotachs, direction by arrows) and standard vector deviations (knots).

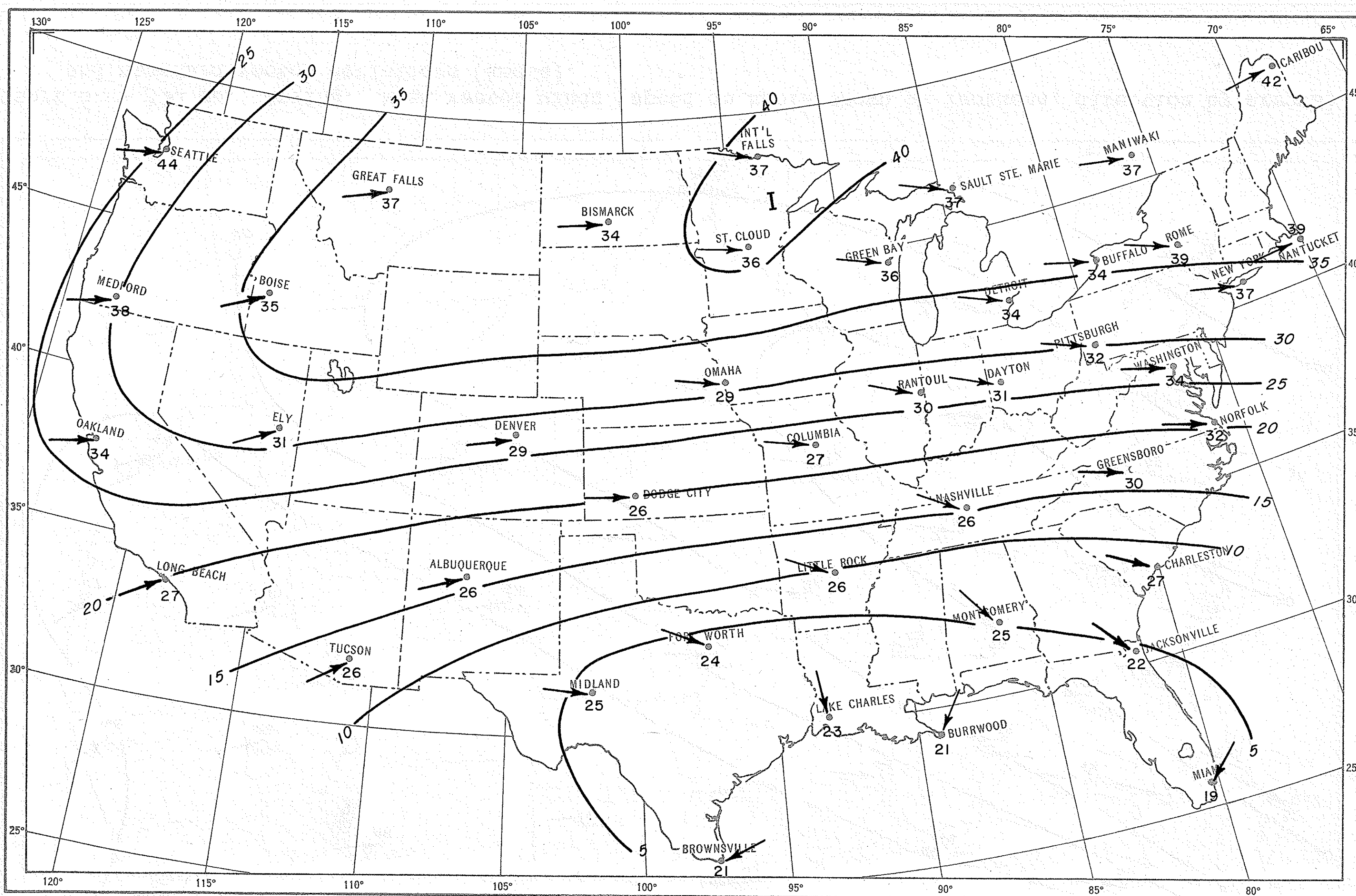

Chart 7. - 300 mb. Summer. Mean vector winds (speed in knots shown by isotachs, direction by arrows) and standard vector deviations (knots).

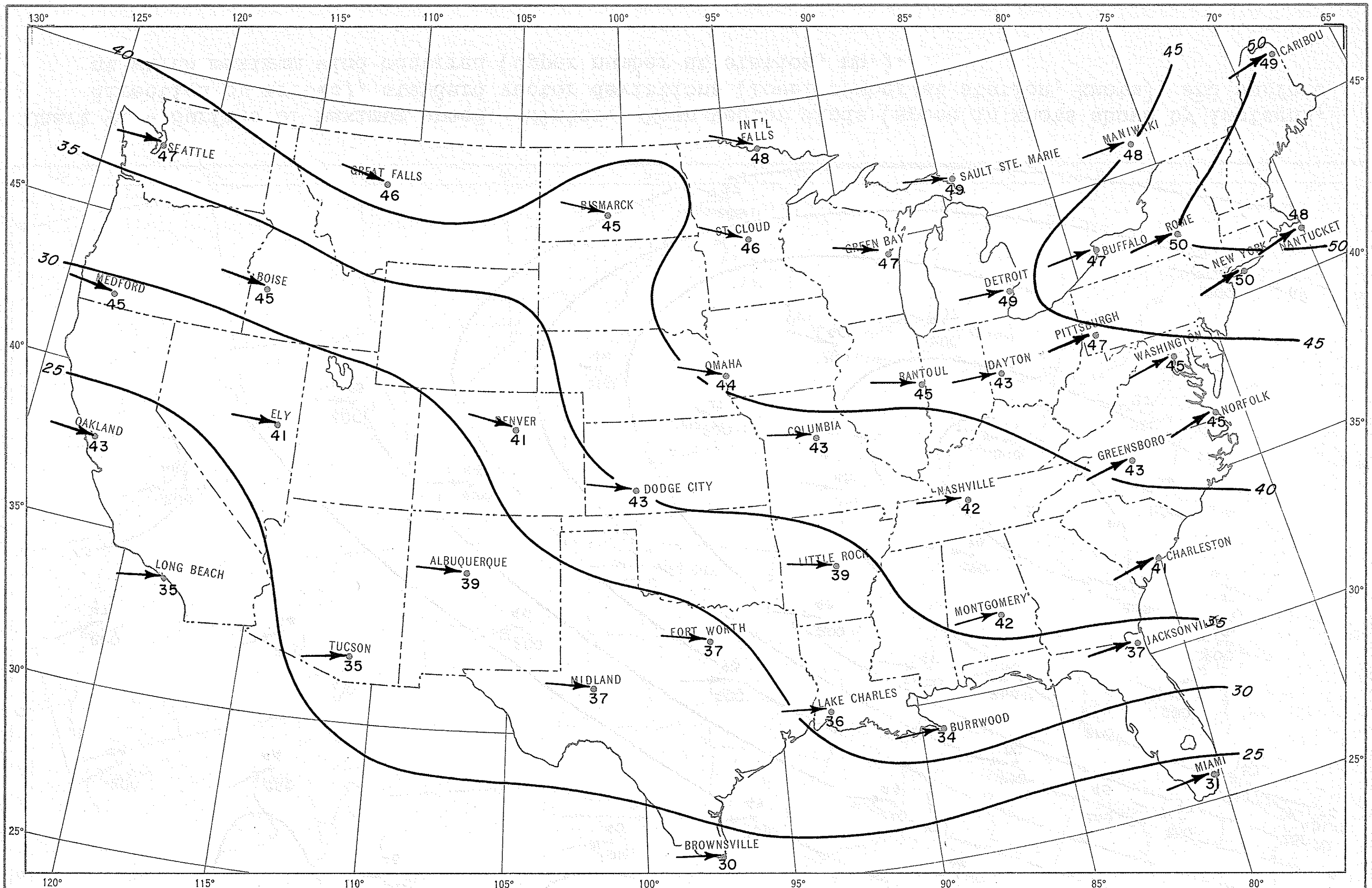

Chart 8. - 300 mb. Fall. Mean vector winds (speed in knots shown by isotachs, direction by arrows) and standard vector deviations (knots).

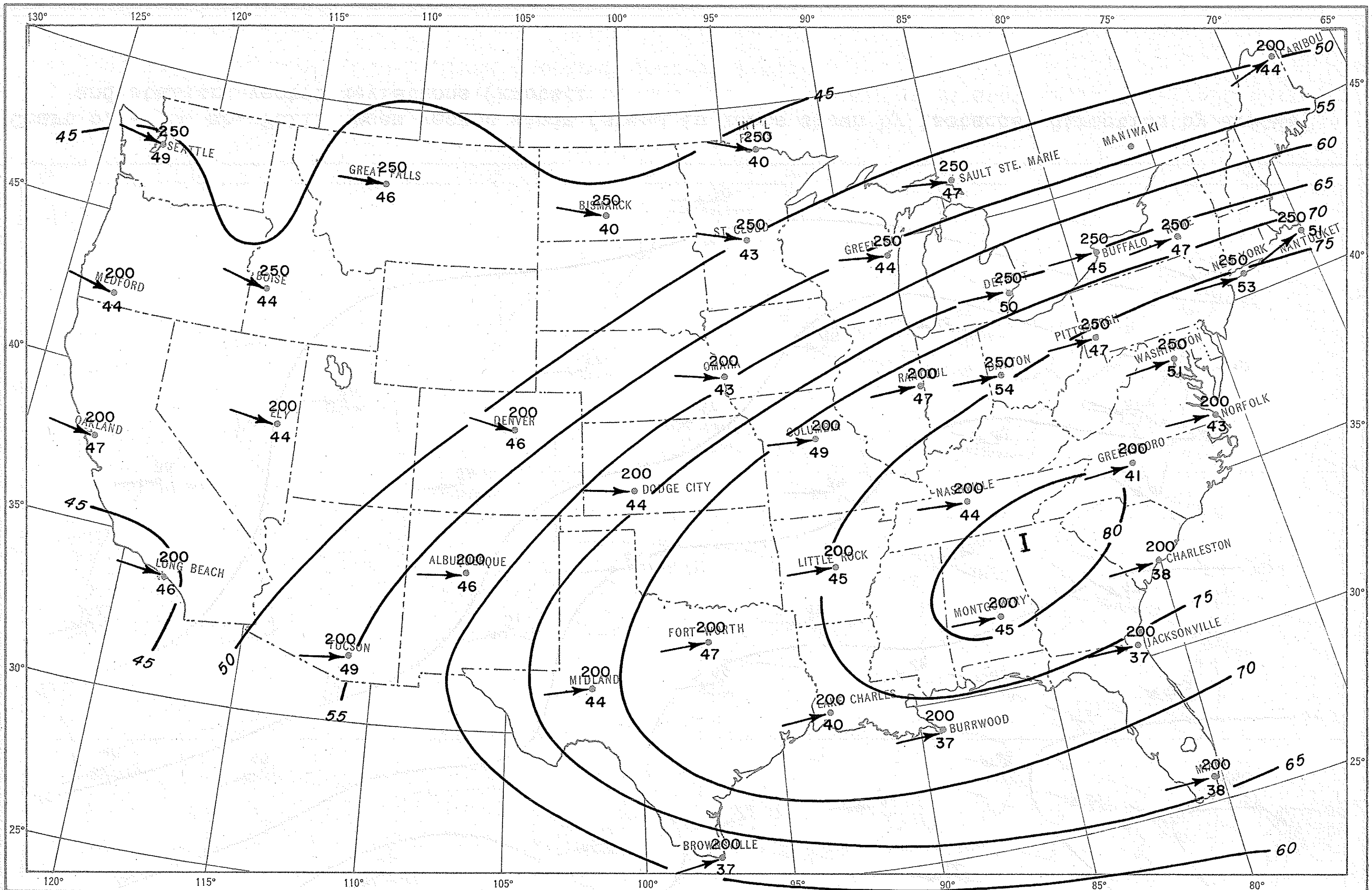

Chart 9. - Surface of maximum speed. Winter. Mean vector winds (speed in knots shown by isotachs, direction by arrows), standard vector deviations (lower number at station, knots), and surface at which maximum wind occurred (upper number at station, mb.).

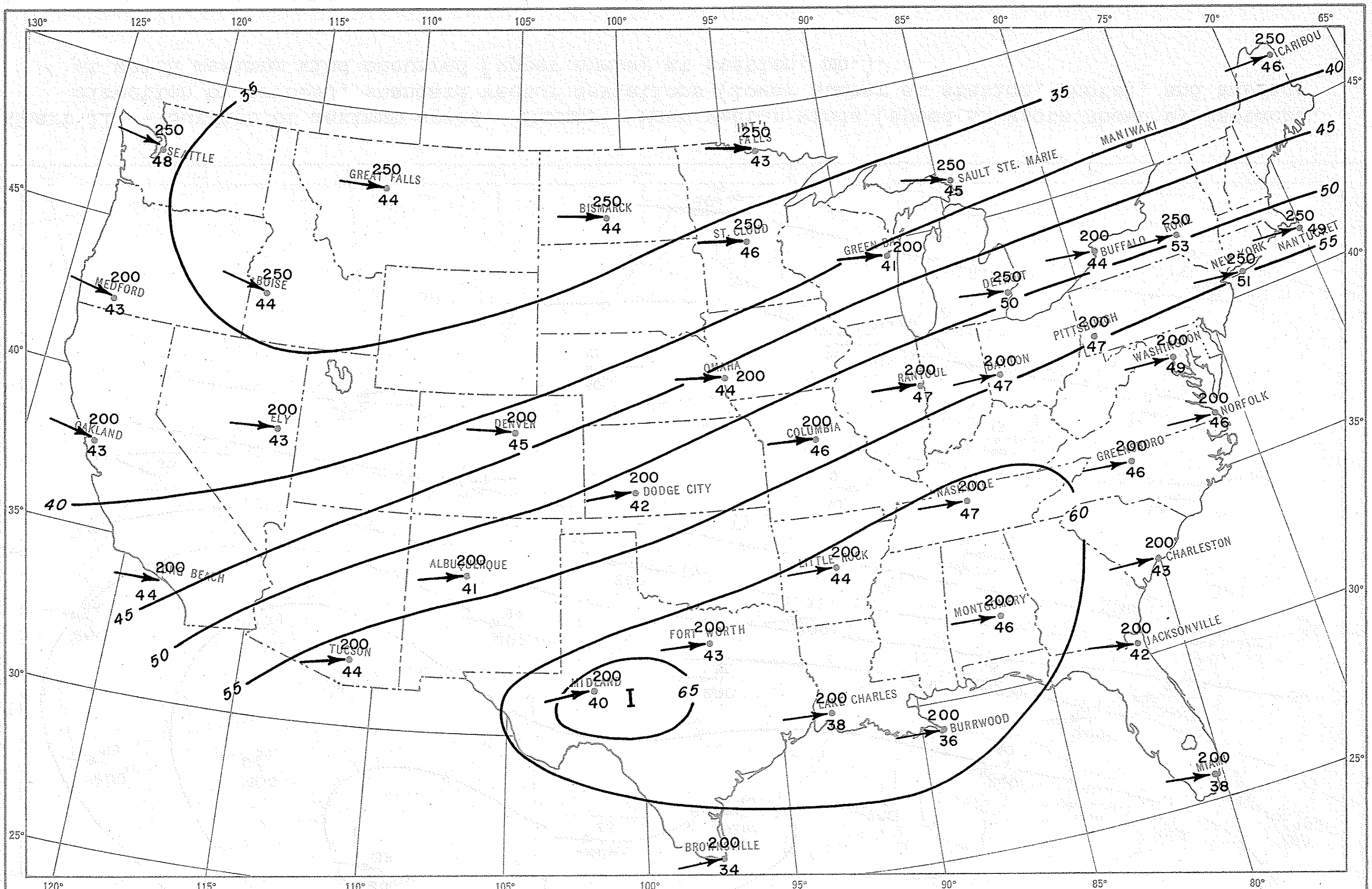

Chart 10. - Surface of maximum speed. Spring. Mean vector winds (speed in knots shown by isotachs, direction by arrows), standard vector deviations (lower number at station, knots), and surface at which maximum wind occurred (upper number at station, mb.).

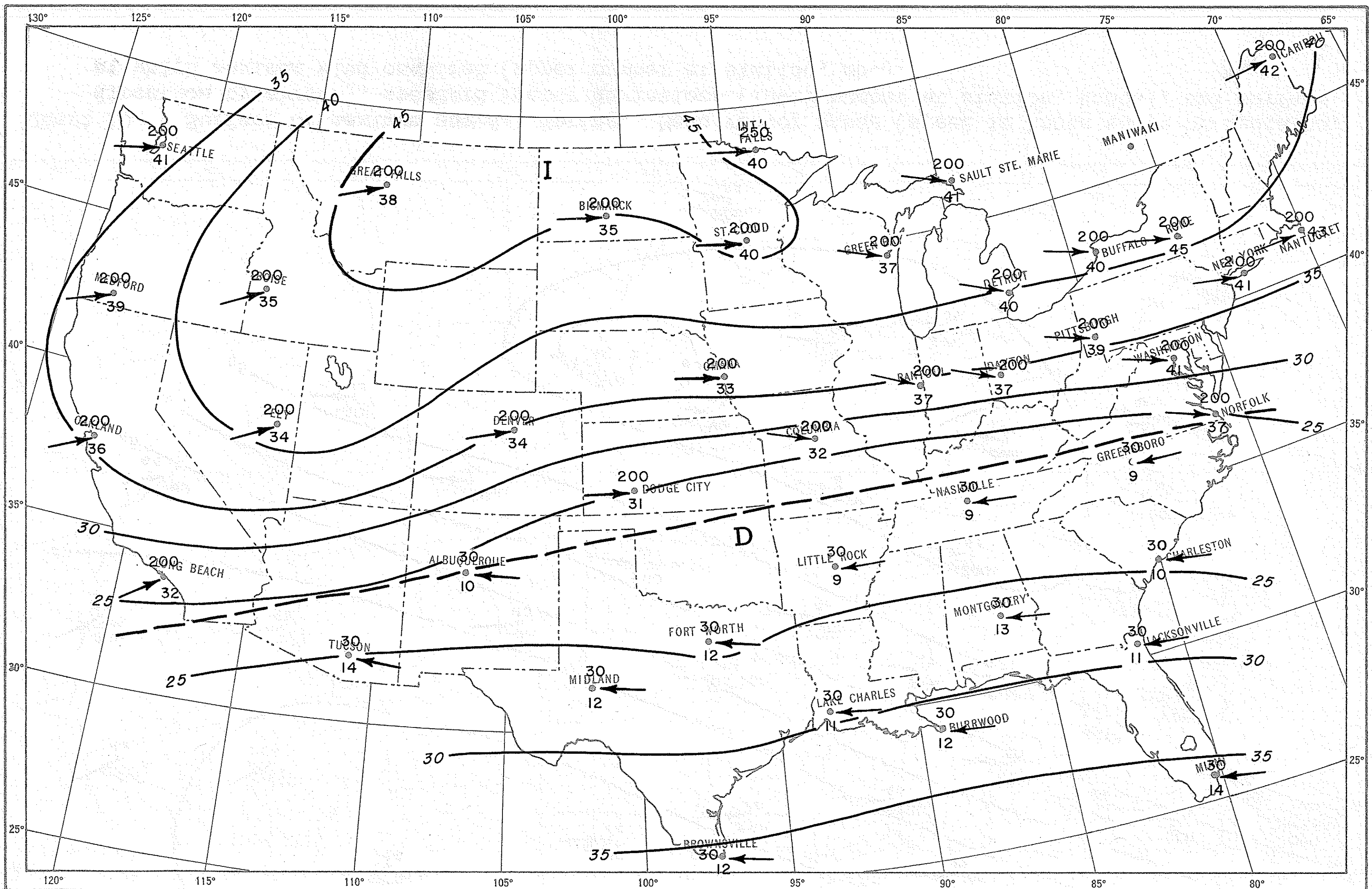

Chart 11. - Surface of maximum speed. Summer. Mean vector winds (speed in knots shown by isotachs, direction by arrows), standard vector deviations (lower number at station, knots), and surface at which maximum wind occurred (upper number at station, mb.).

495303 O - 59 - 4

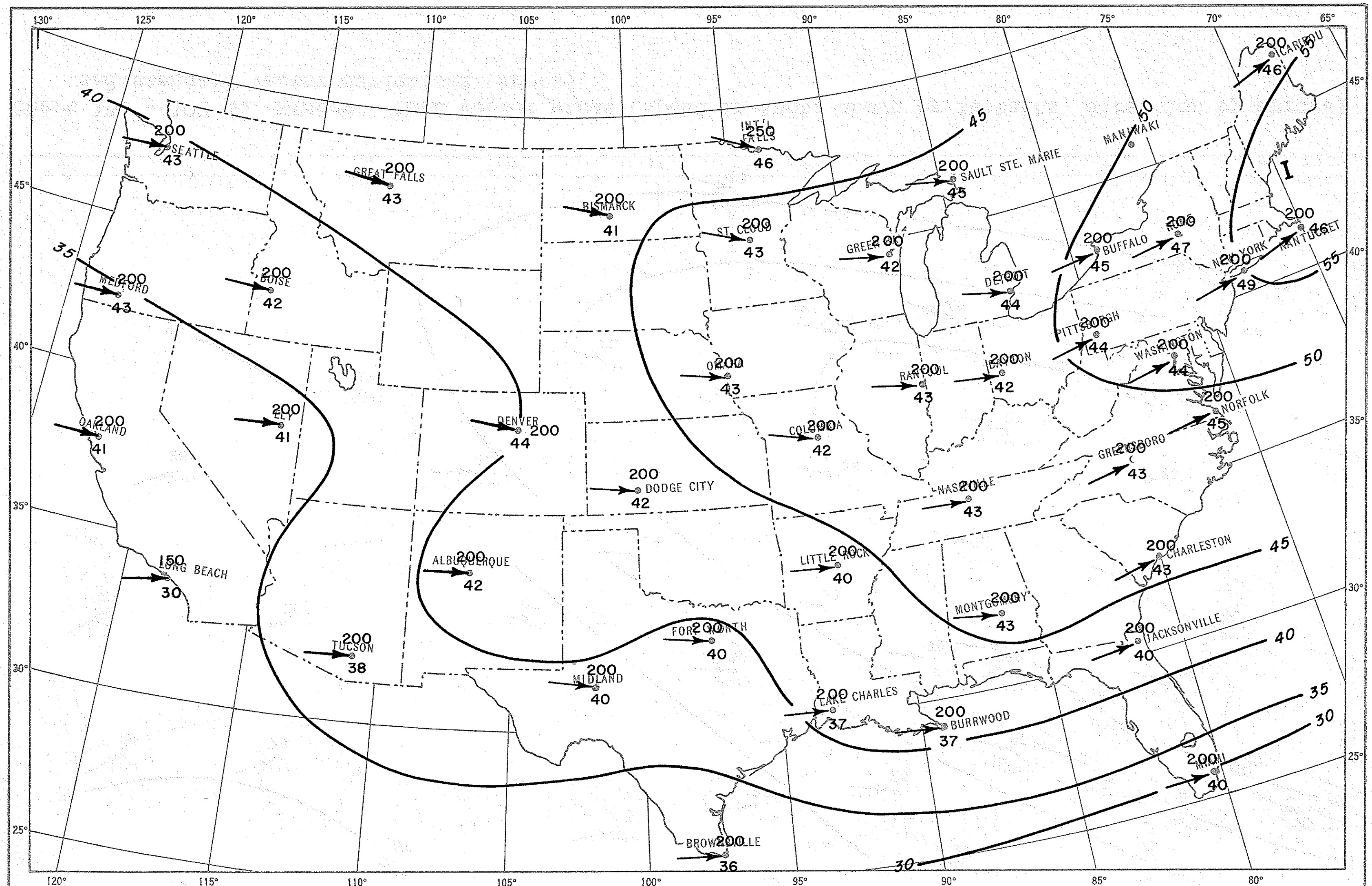

Chart 12. - Surface of maximum speed. Fall. Mean vector winds (speed in knots shown by isotachs, direction by arrows), standard vector deviations (lower number at station, knots), and surface at which maximum wind occurred (upper number at station, mb.).

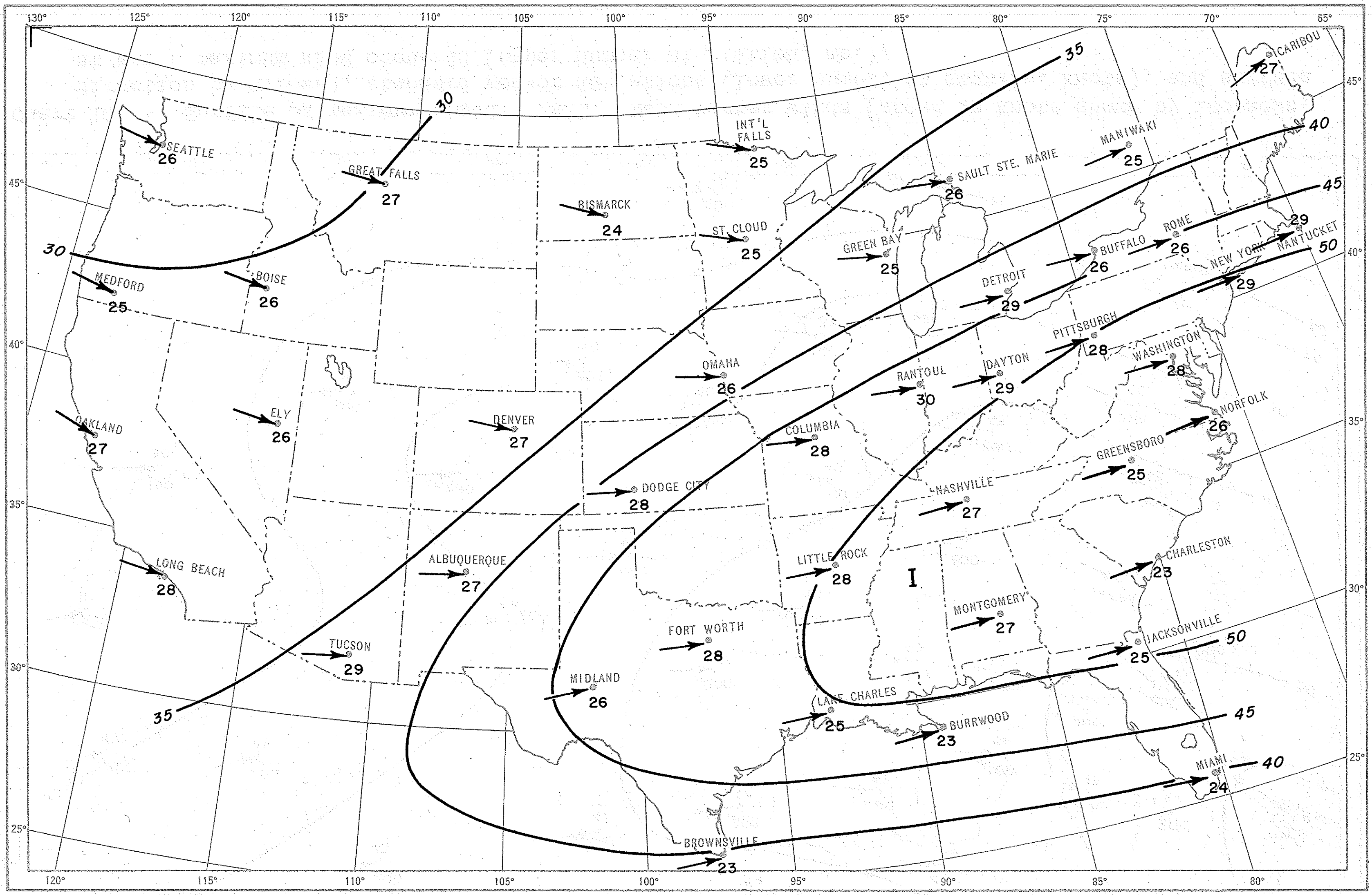

Chart 13. - 100 mb. Winter. Mean vector winds (speed in knots shown by isotachs, direction by arrows) and standard vector deviations (knots).

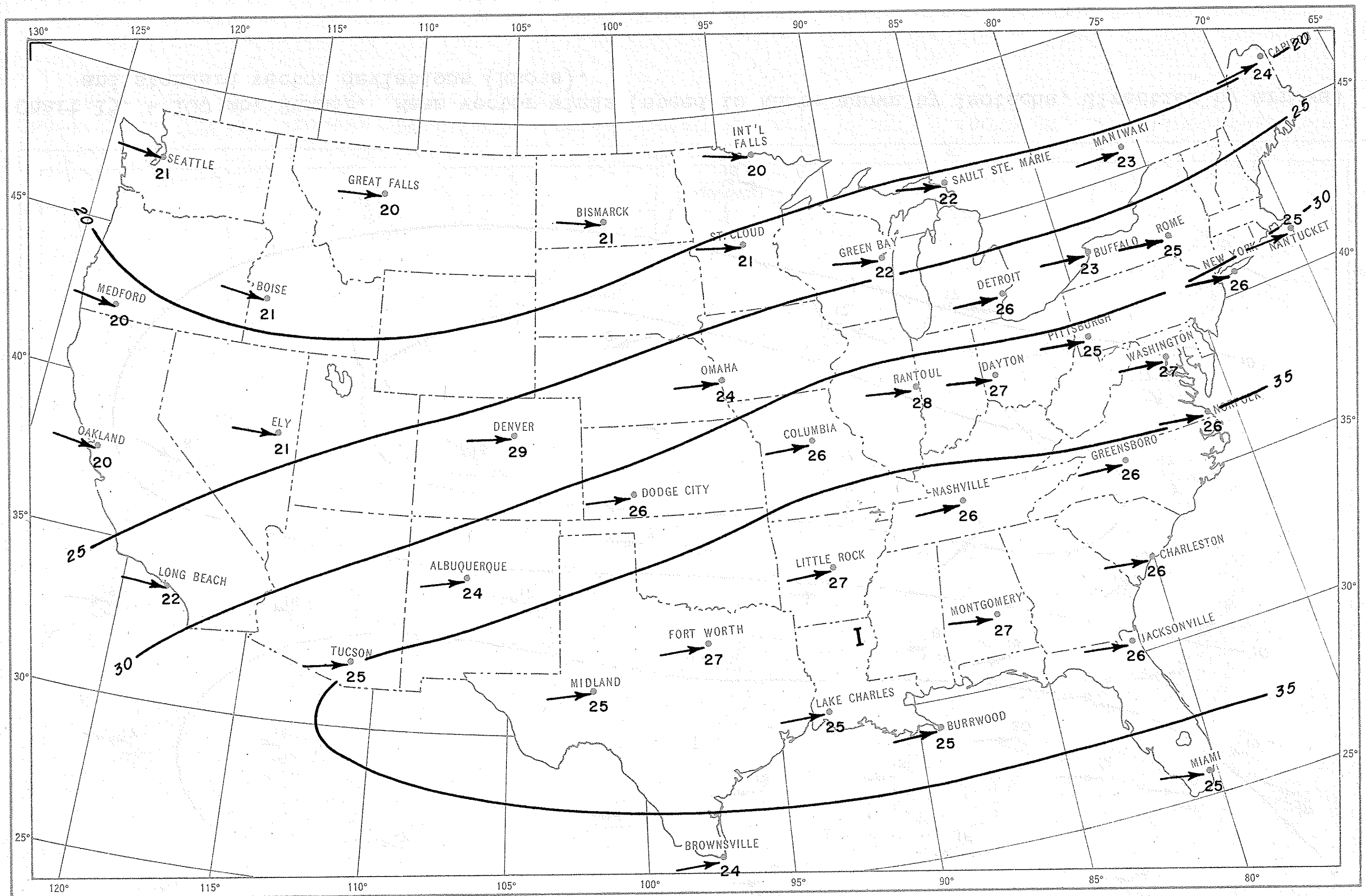

Chart 14. - 100 mb. Spring. Mean vector winds (speed in knots shown by isotachs, direction by arrows) and standard vector deviations (knots).

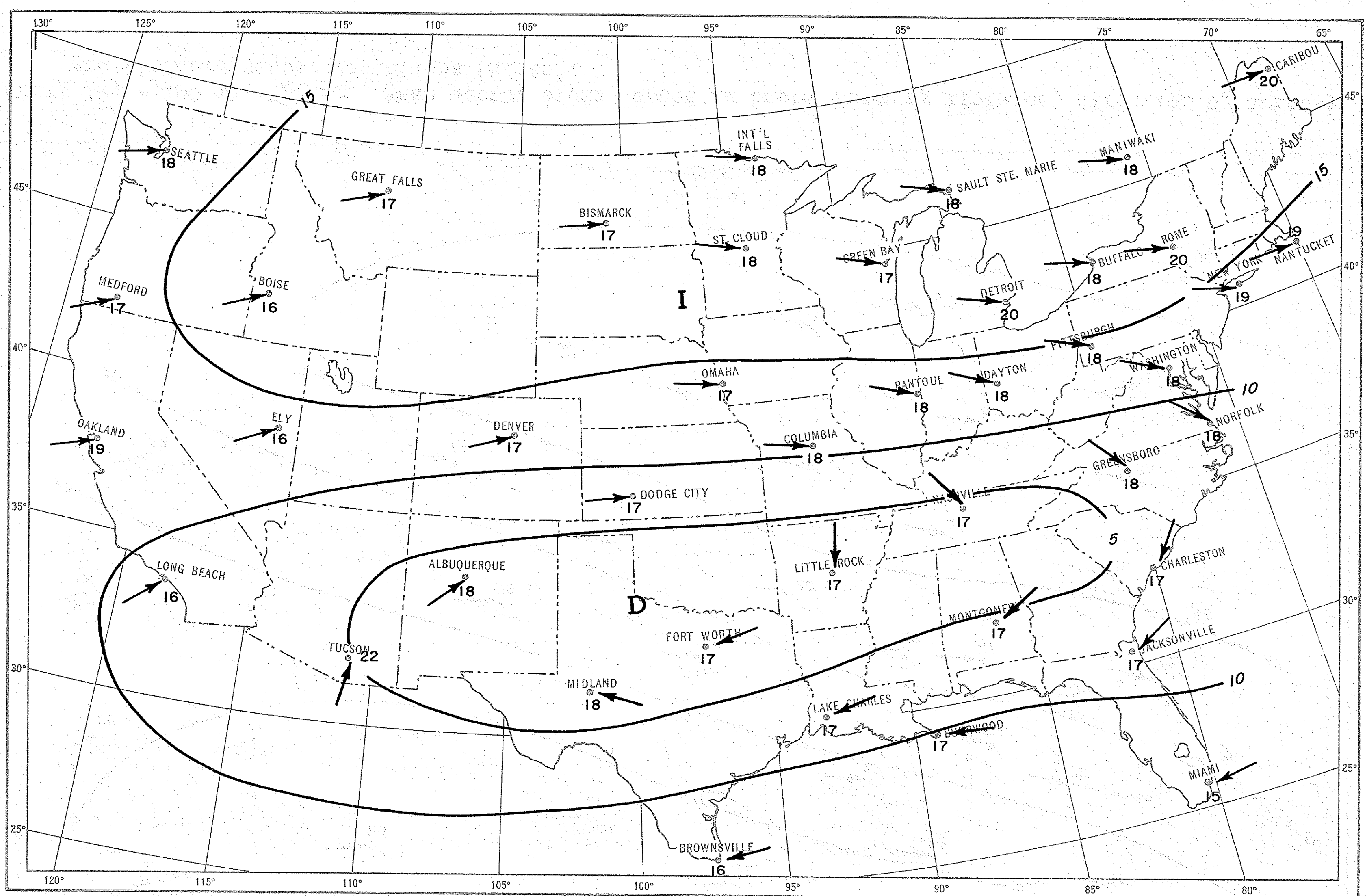

Chart 15. - 100 mb. Summer. Mean vector winds (speed in knots shown by isotachs, direction by arrows) and standard vector deviations (knots).

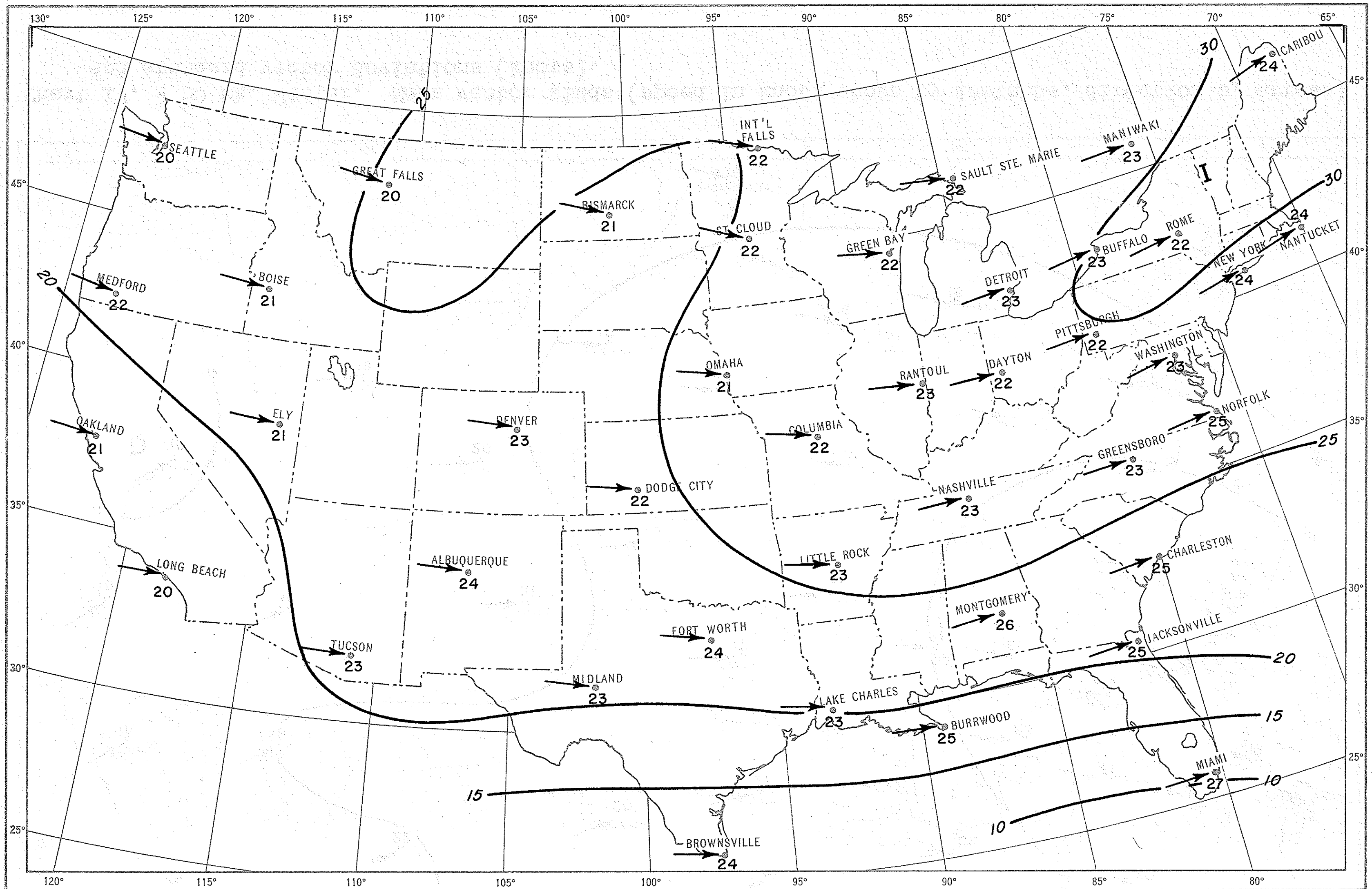

Chart 16. - 100 mb. Fall. Mean vector winds (speed in knots shown by isotachs, direction by arrows) and standard vector deviations (knots).

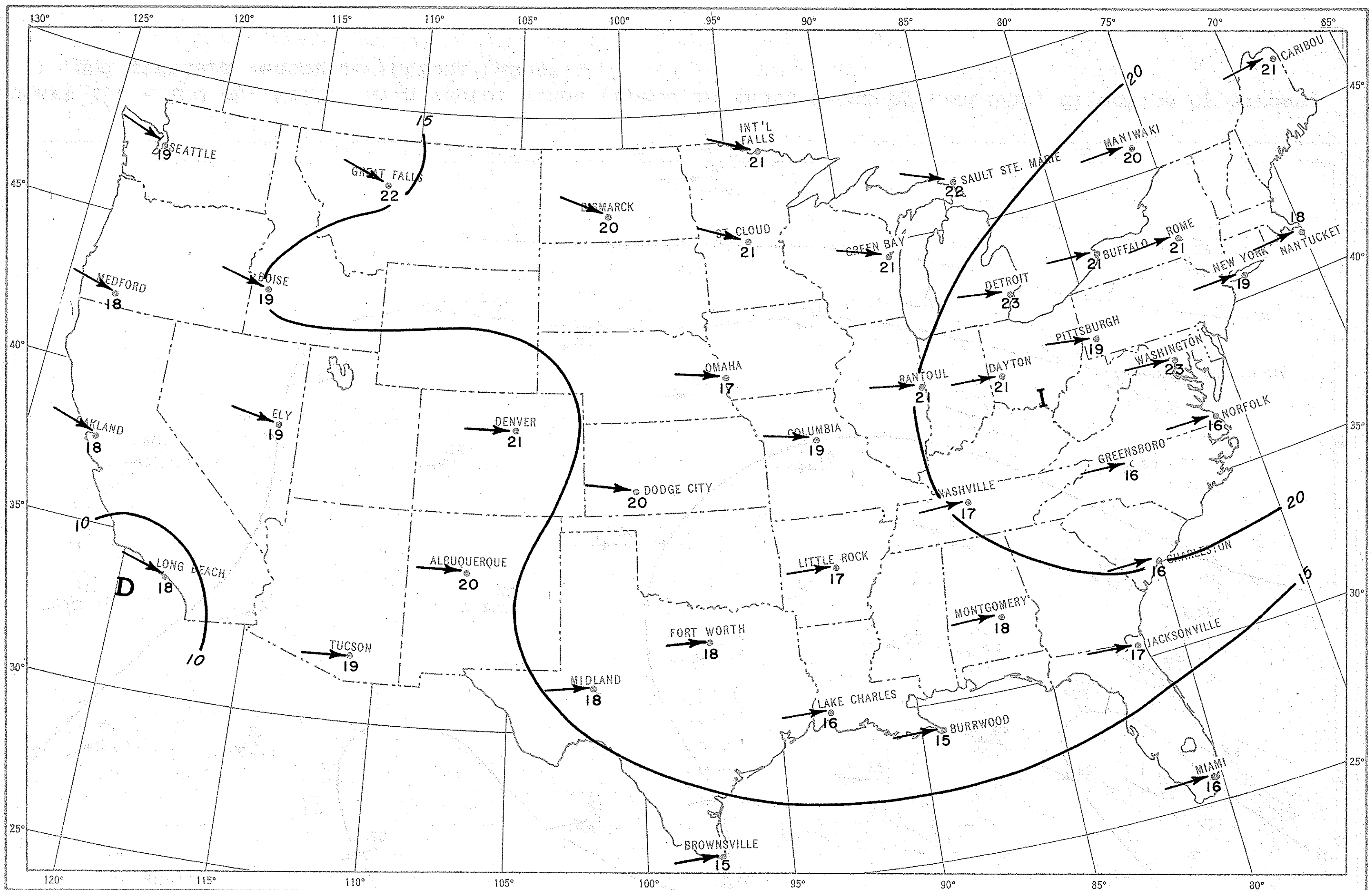

Chart 17. - 50 mb. Winter. Mean vector winds (speed in knots shown by isotachs, direction by arrows) and standard vector deviations (knots).

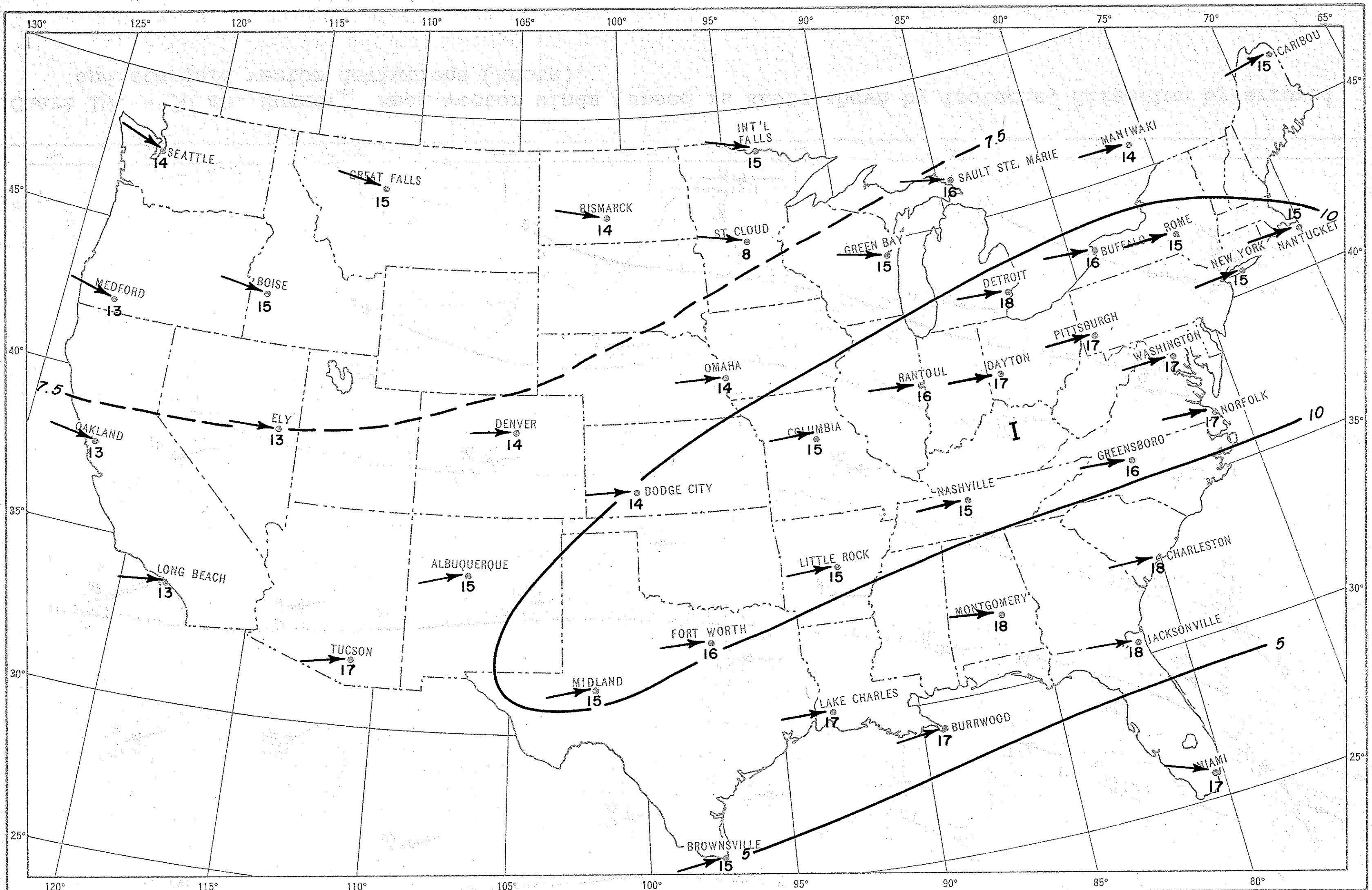

Chart 18. - 50 mb. Spring. Mean vector winds (speed in knots shown by isotachs, direction by arrows) and standard vector deviations (knots).

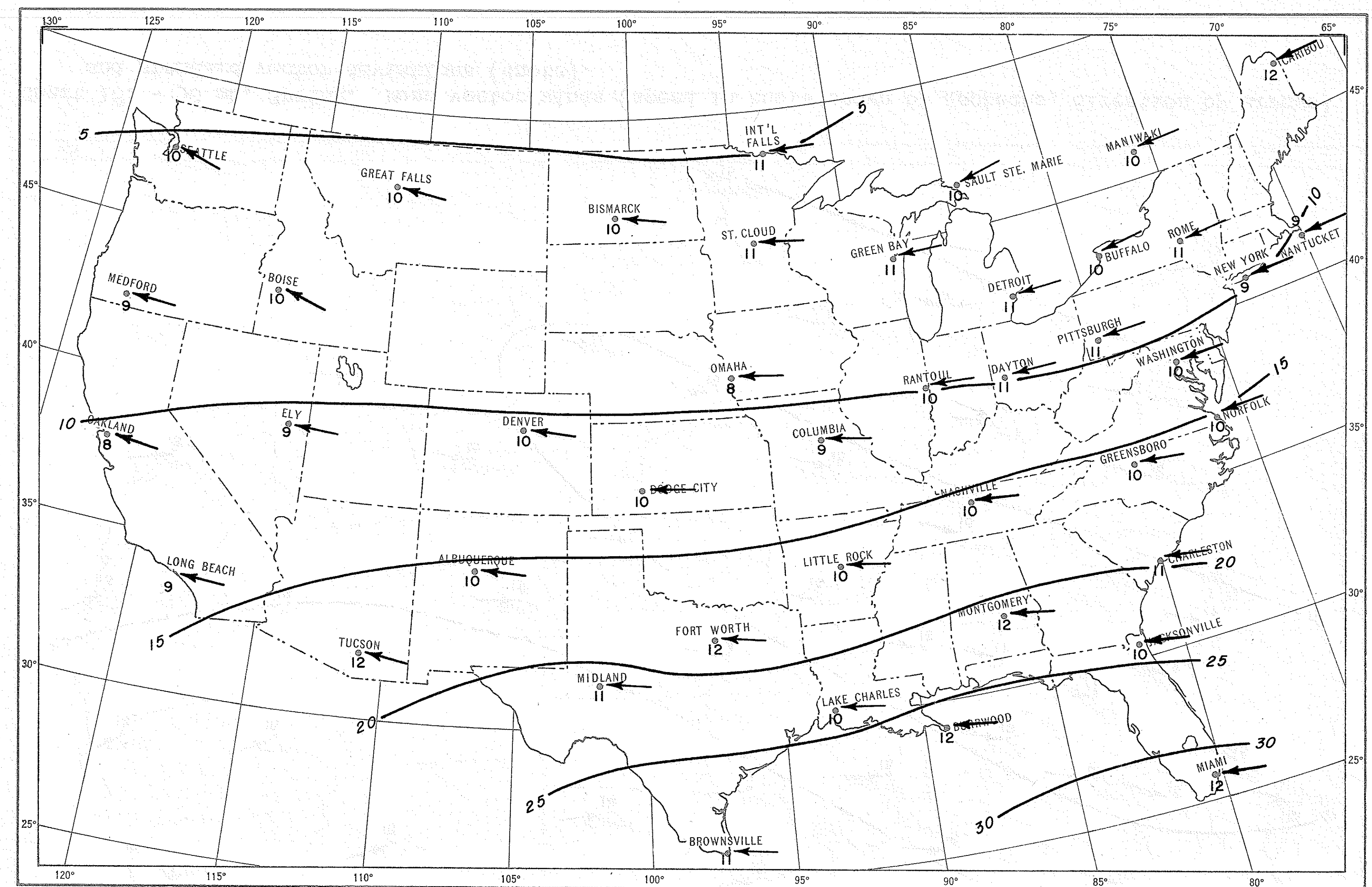

Chart 19. - 50 mb. Summer. Mean vector winds (speed in knots shown by isotachs, direction by arrows) and standard vector deviations (knots).

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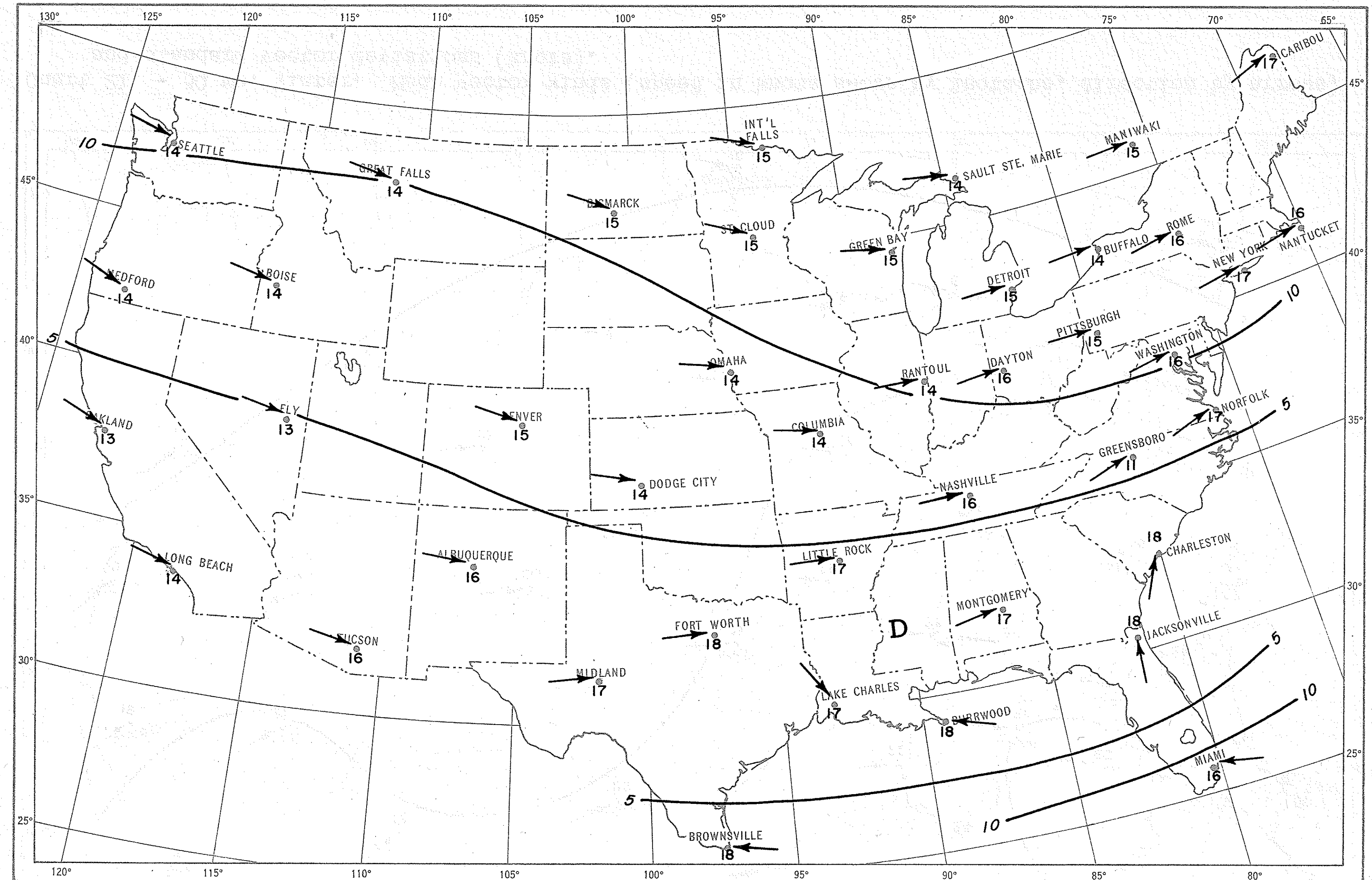

Chart 20. - 50 mb. Fall. Mean vector winds (speed in knots shown by isotachs, direction by arrows) and standard vector deviations (knots).

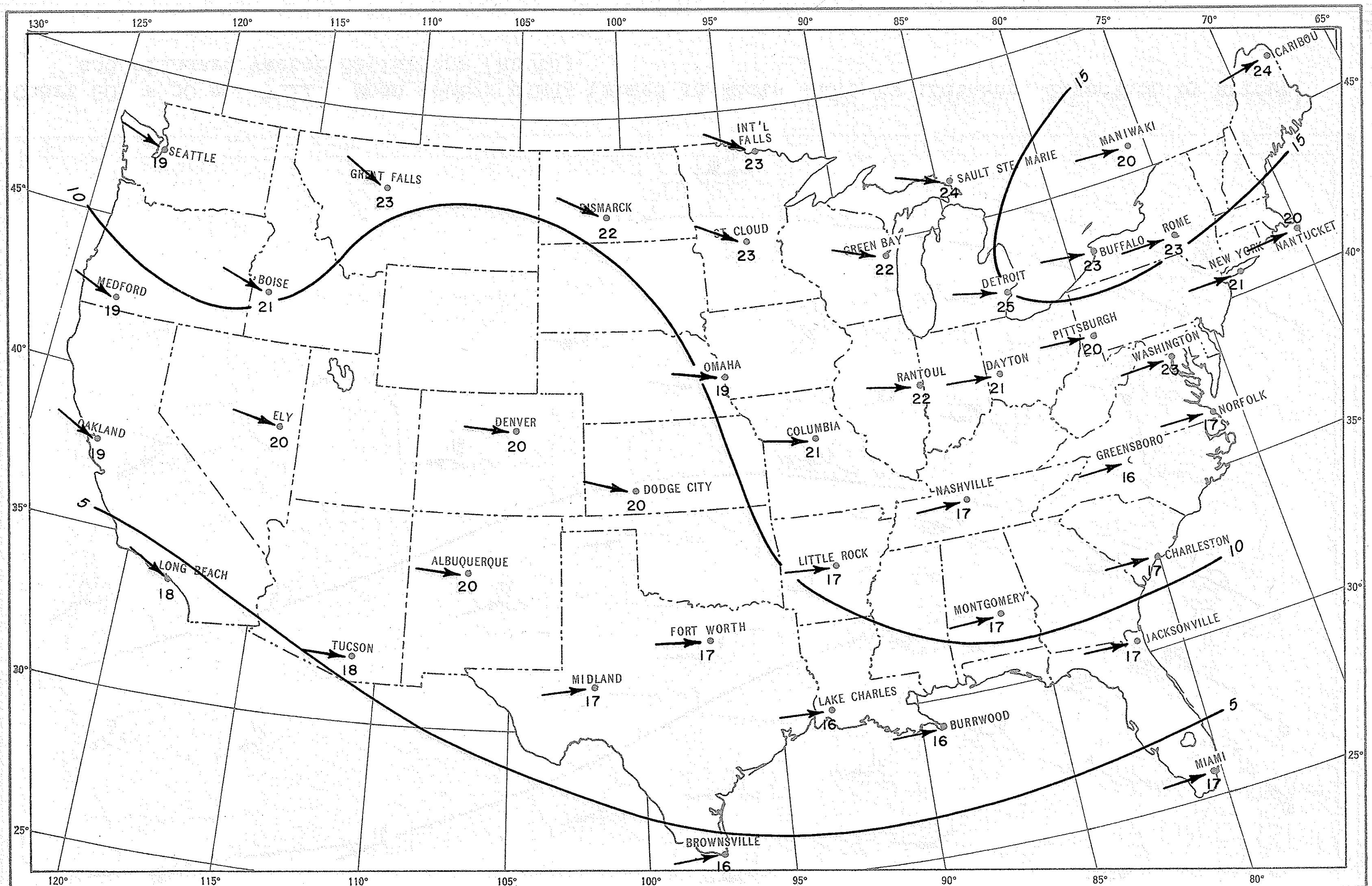

Chart 21. - 30 mb. Winter. Mean vector winds (speed in knots shown by isotachs, direction by arrows) and standard vector deviations (knots).

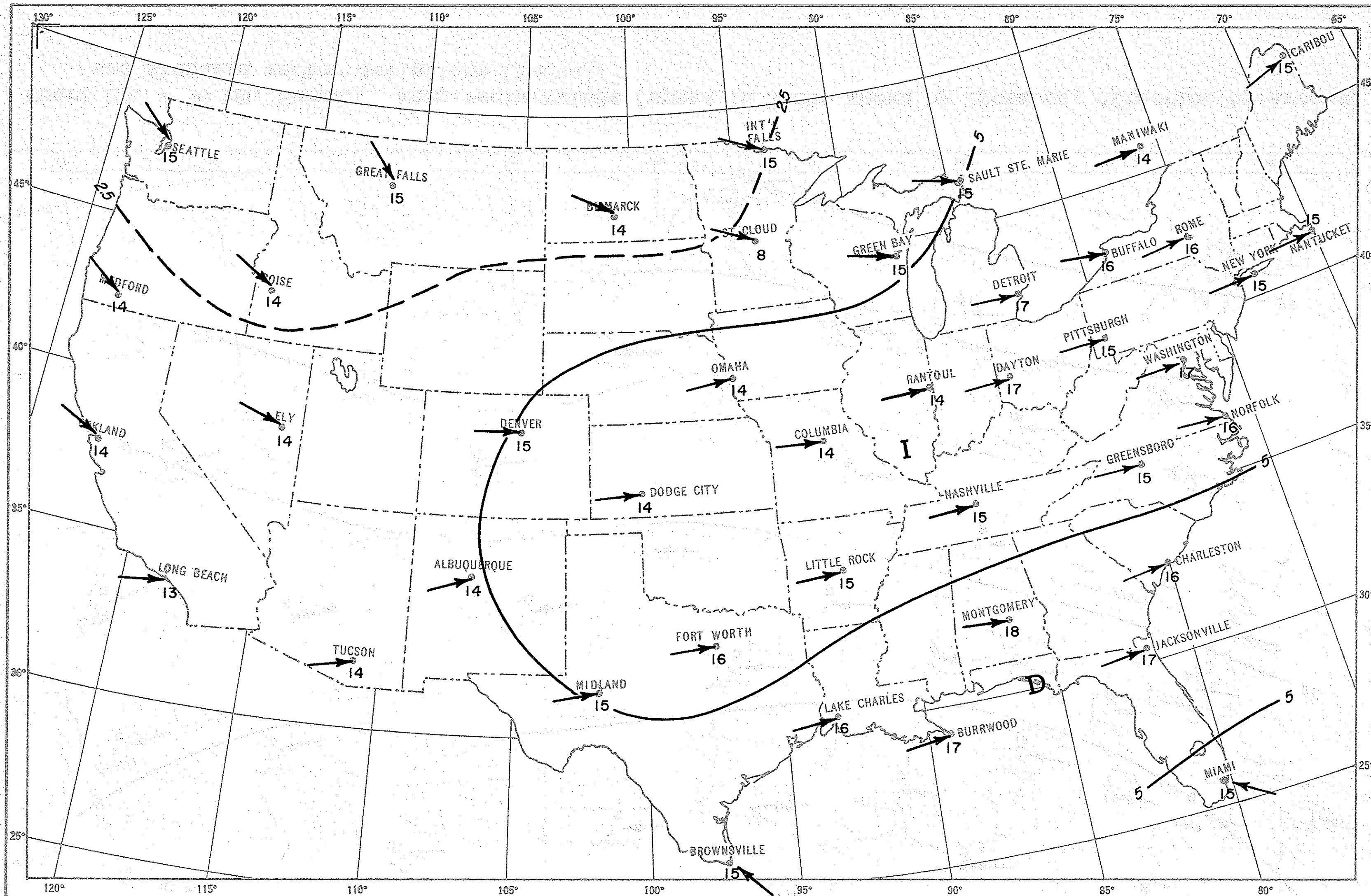

Chart 22. - 30 mb. Spring. Mean vector winds (speed in knots shown by isotachs, direction by arrows) and standard vector deviations (knots).

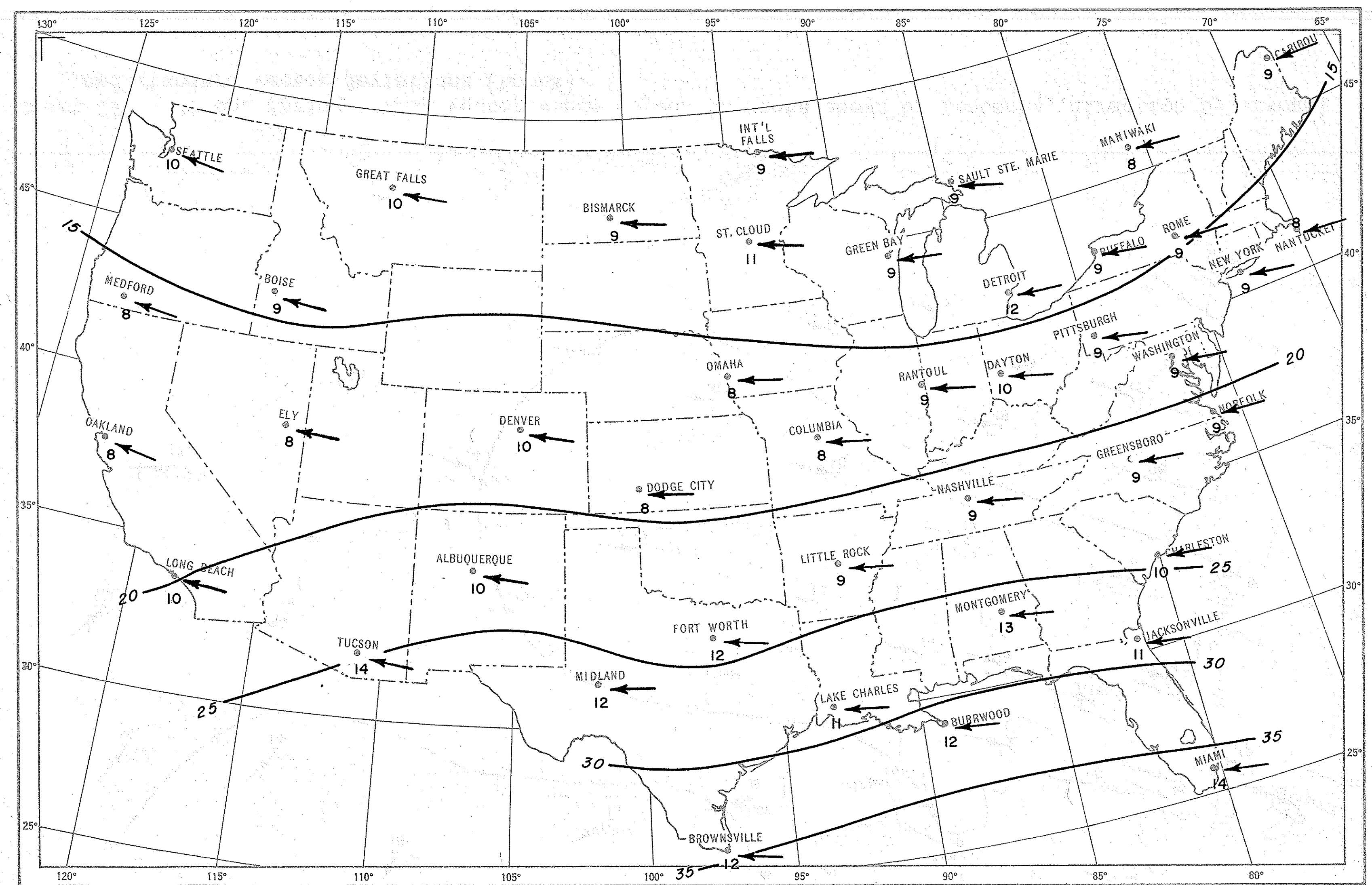

Chart 23. - 30 mb. Summer. Mean vector winds (speed in knots shown by isotachs, direction by arrows) and standard vector deviations (knots).

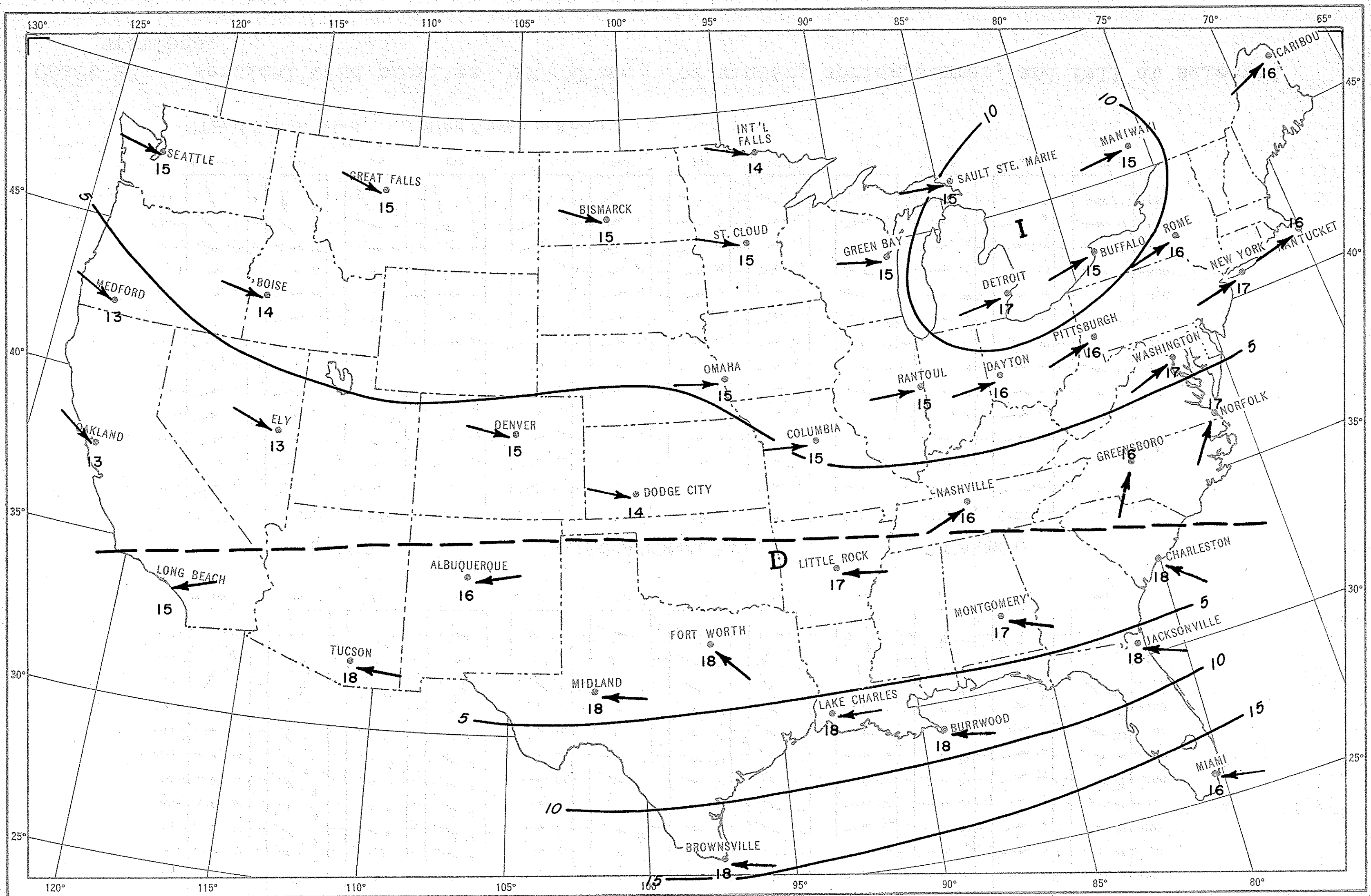

Chart 24. - 30 mb. Fall. Mean vector winds (speed in knots shown by isotachs, direction by arrows) and standard vector deviations (knots).

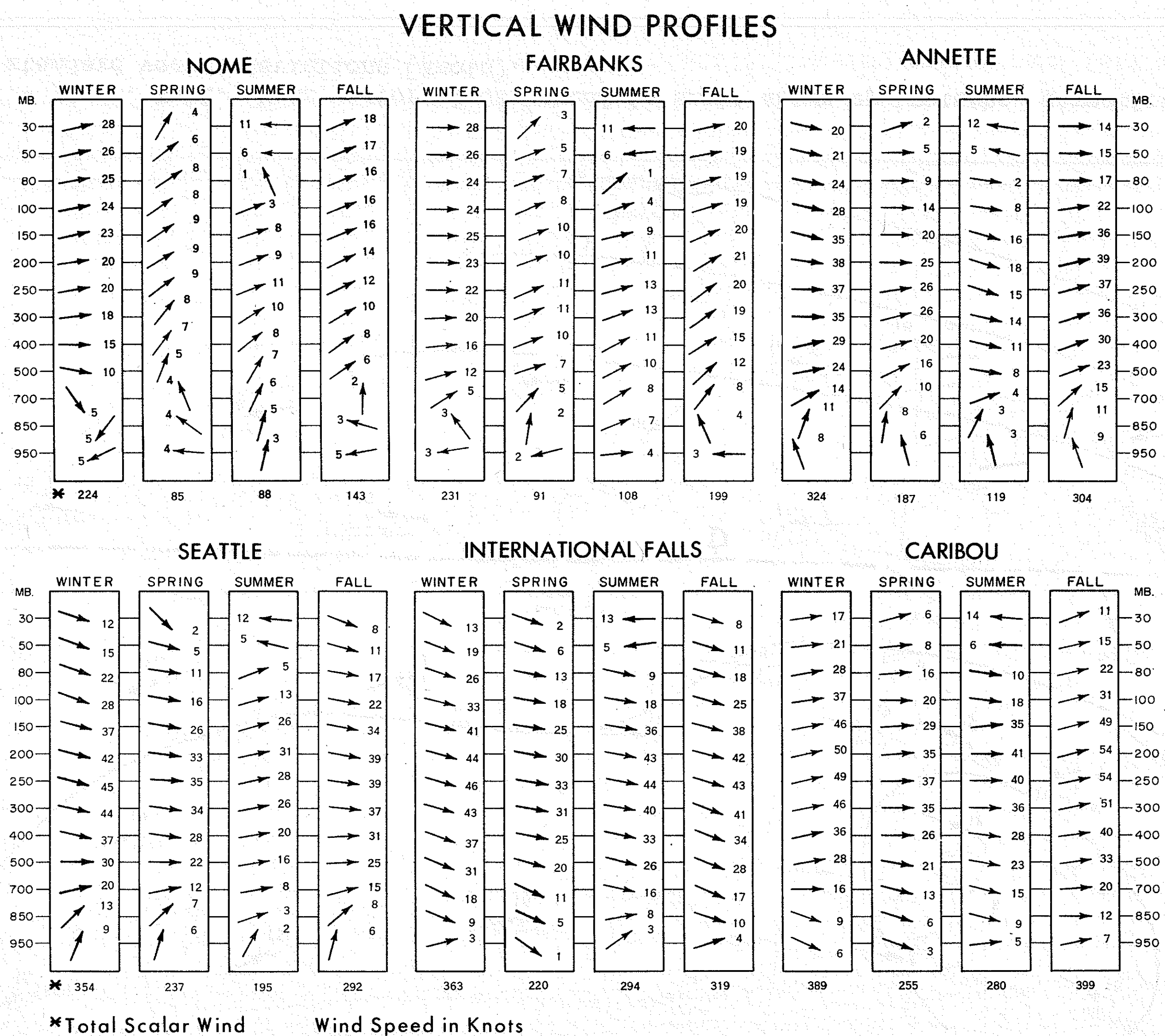

Chart 25. - Vertical wind profiles, 950-30 mb., for winter, spring, summer, and fall at **selected** stations.

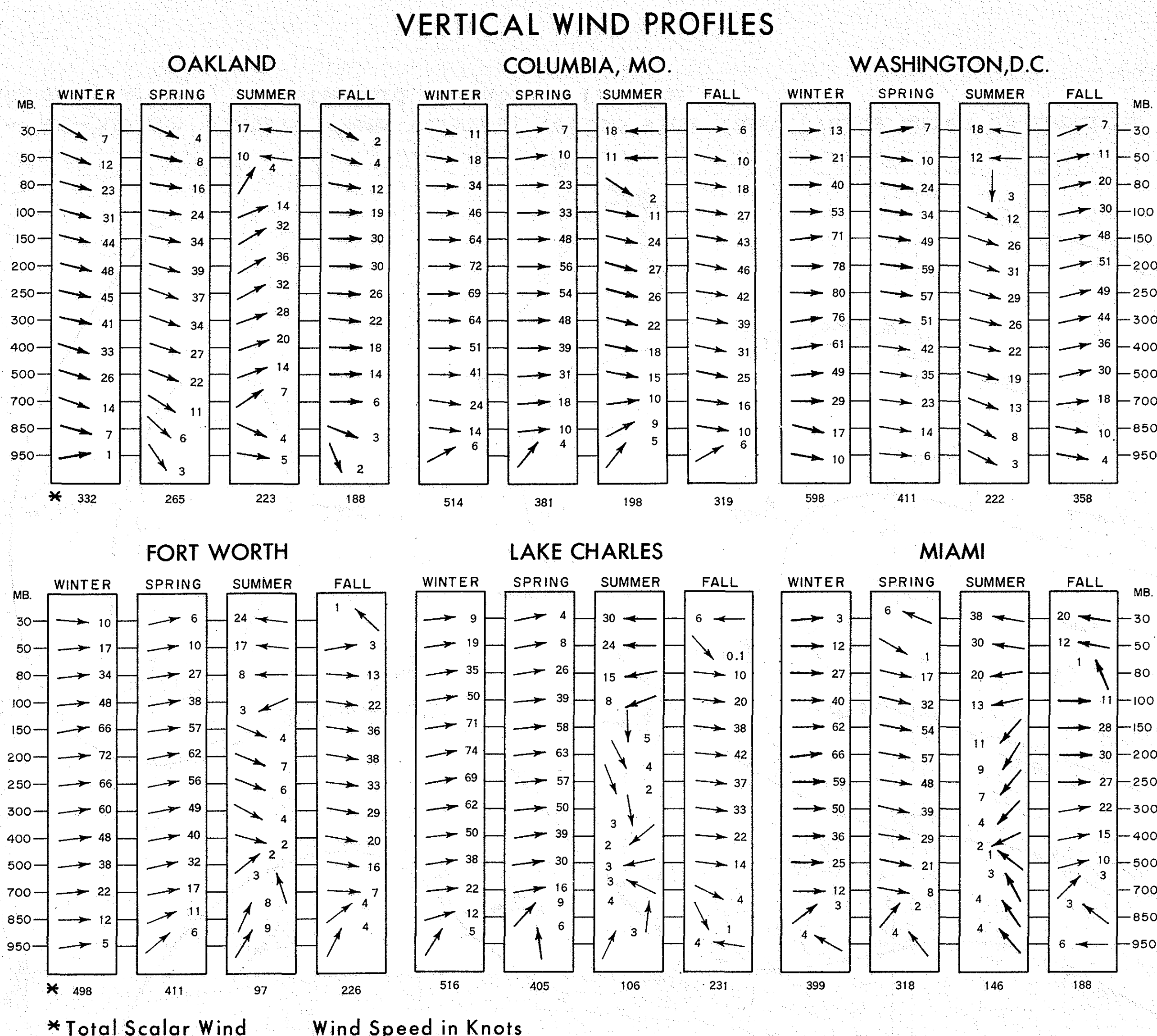

Chart 26. - Vertical wind profiles, 950-30 mb., for winter, spring, summer, and fall at selected stations.

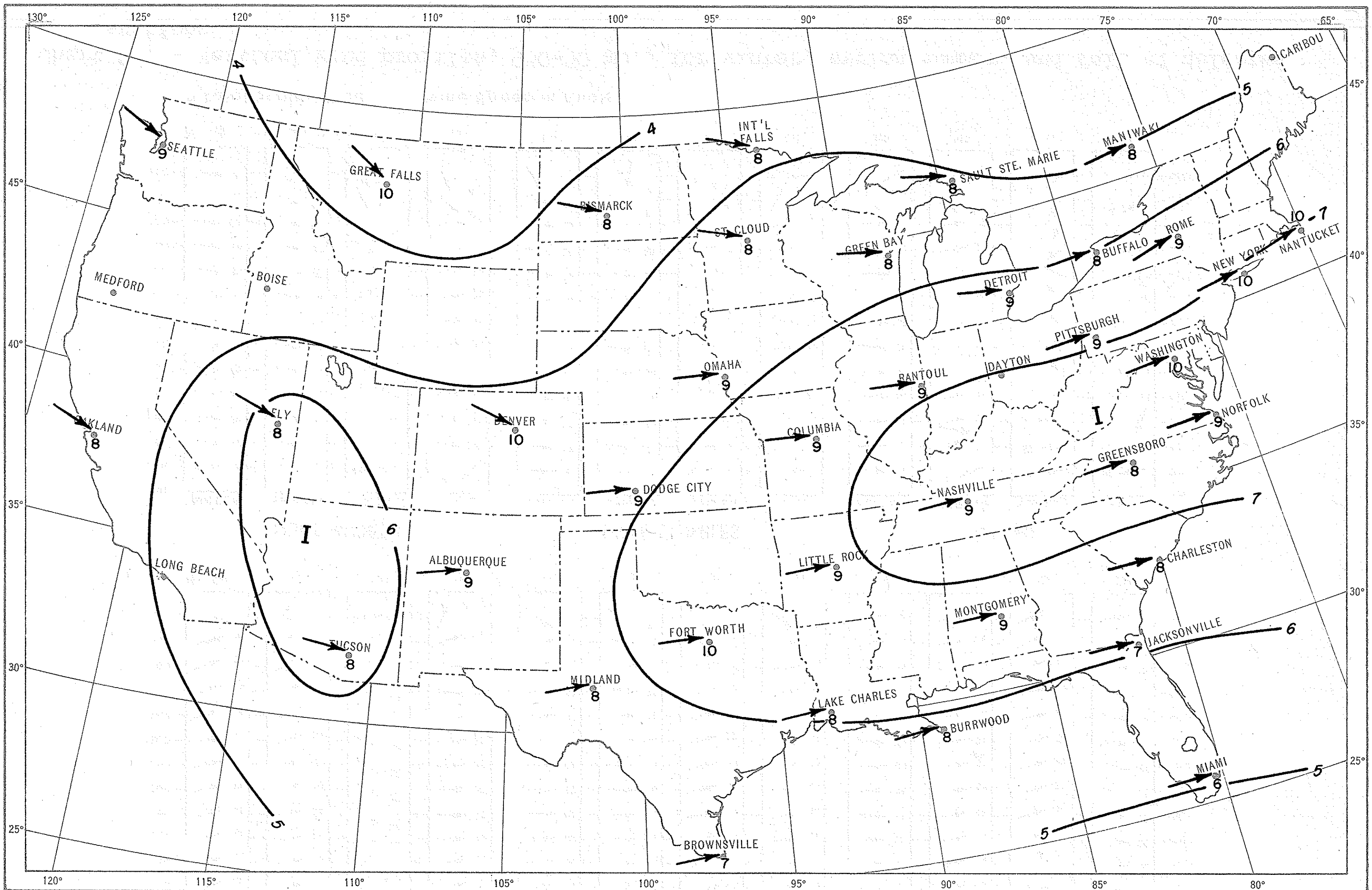

Chart 27. - 700-500 mb. Winter. Mean vertical vector wind shear (value shown by isolines in kt./km., direction by arrows) and standard deviations (kt./km.).

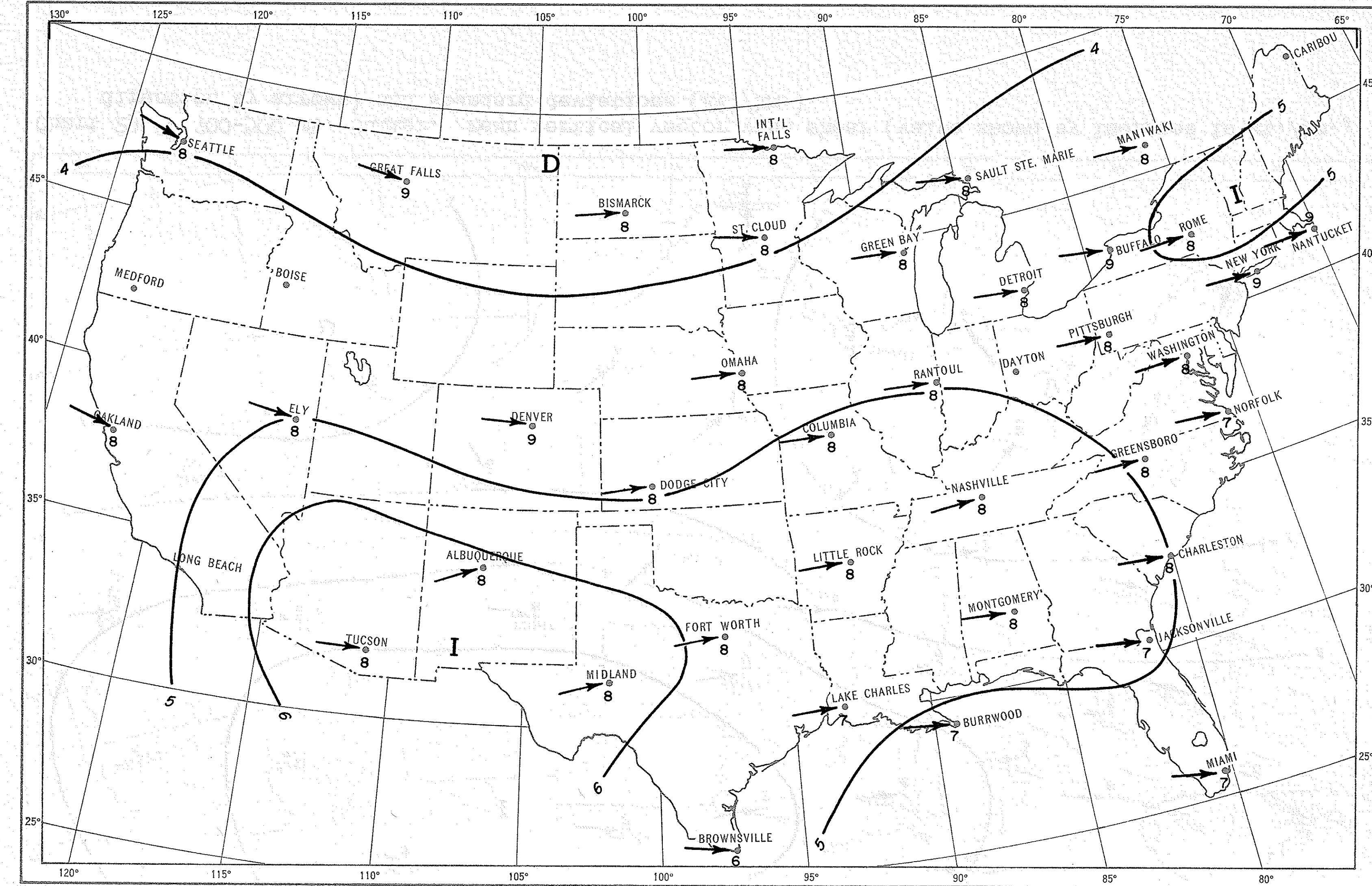

Chart 28. - 700-500 mb. Spring. Mean vertical vector wind shear (value shown by isolines in kt./km., direction by arrows) and standard deviations (kt./km.).

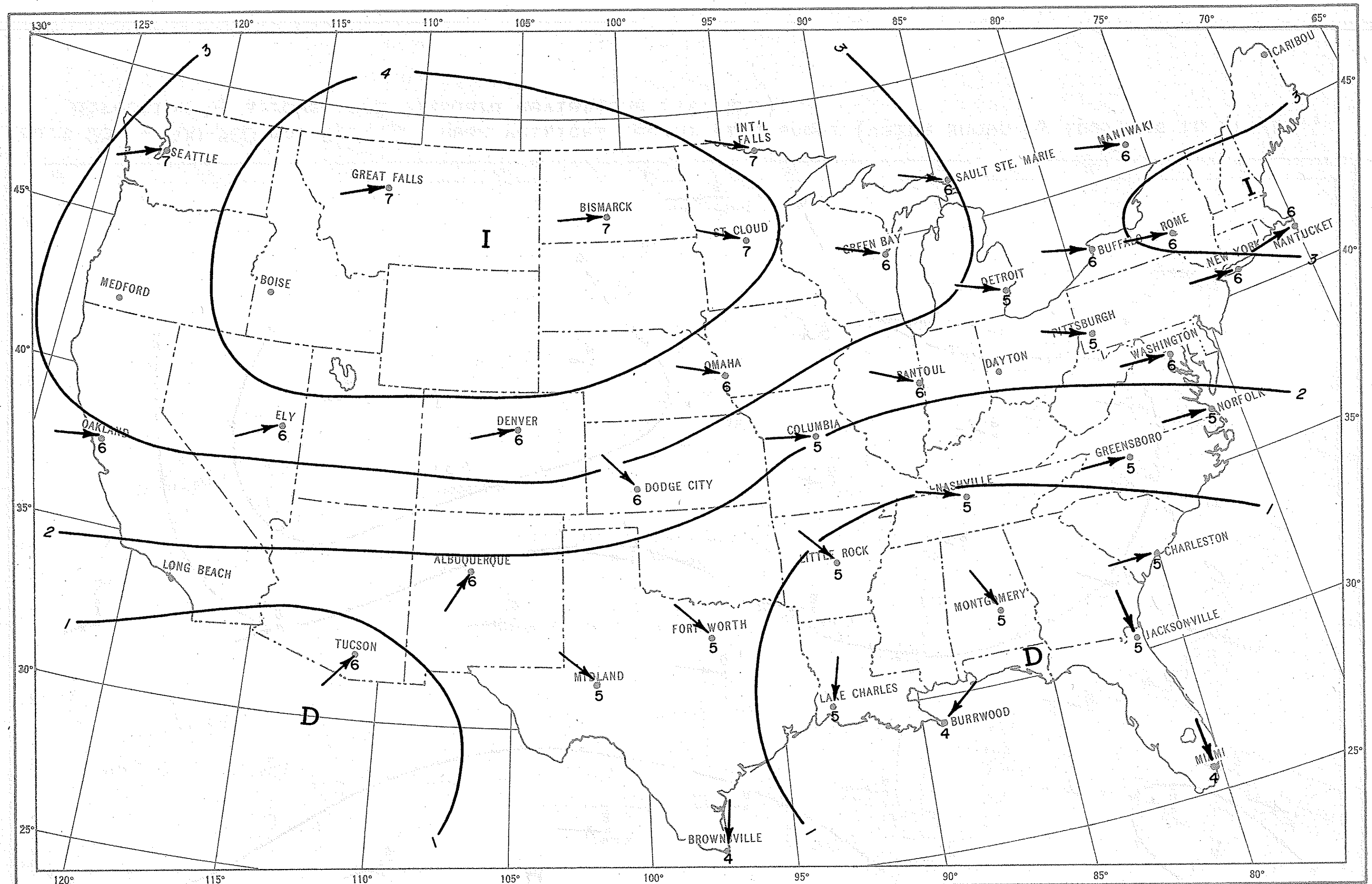

Chart 29. - 700-500 mb. Summer. Mean vertical vector wind shear (value shown by isolines in kt./km., direction by arrows) and standard deviations (kt./km.).

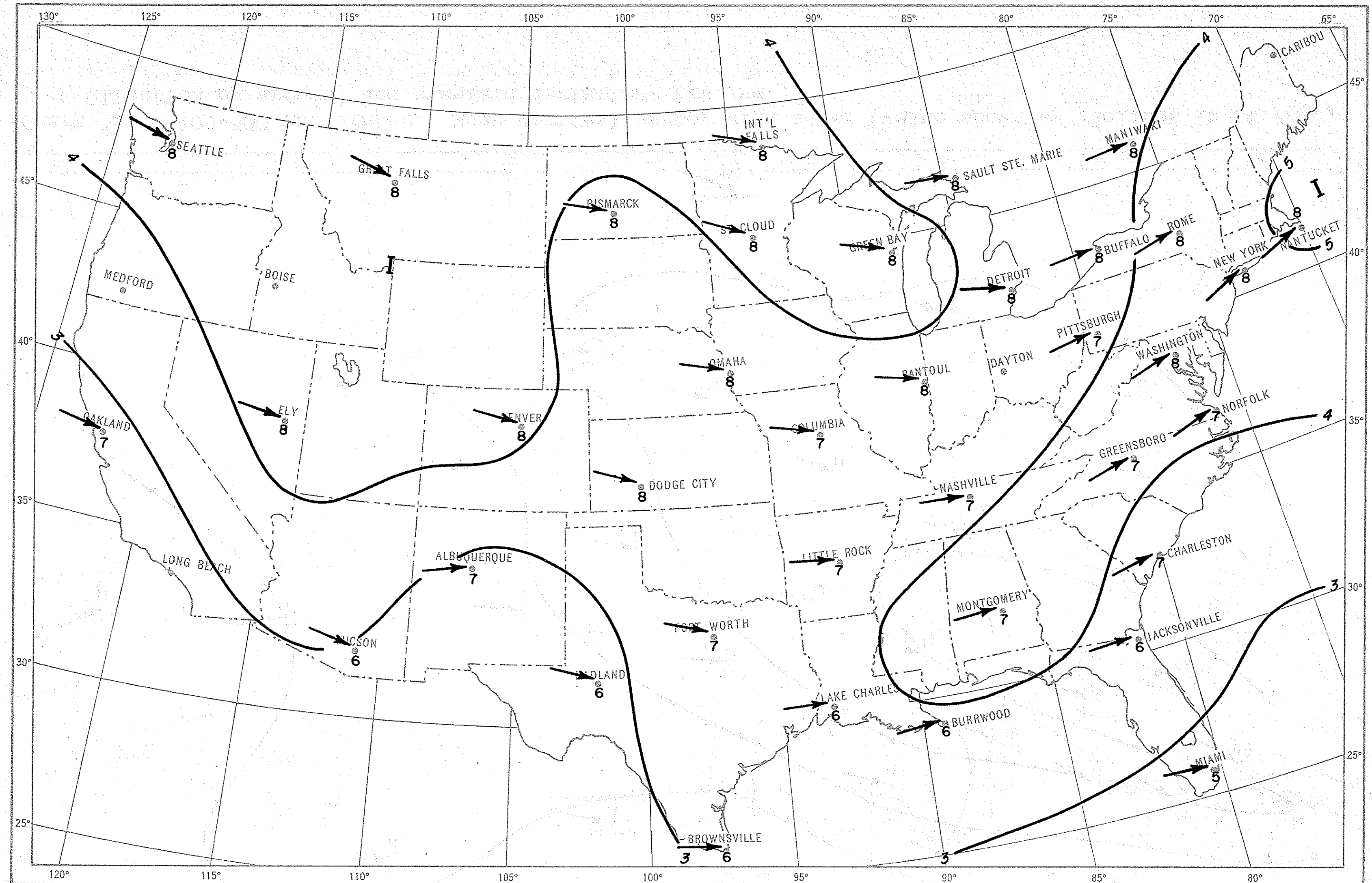

Chart 30. - 700-500 mb. Fall. Mean vertical vector wind shear (value shown by isolines in kt./km., direction by arrows) and standard deviations (kt./km.).

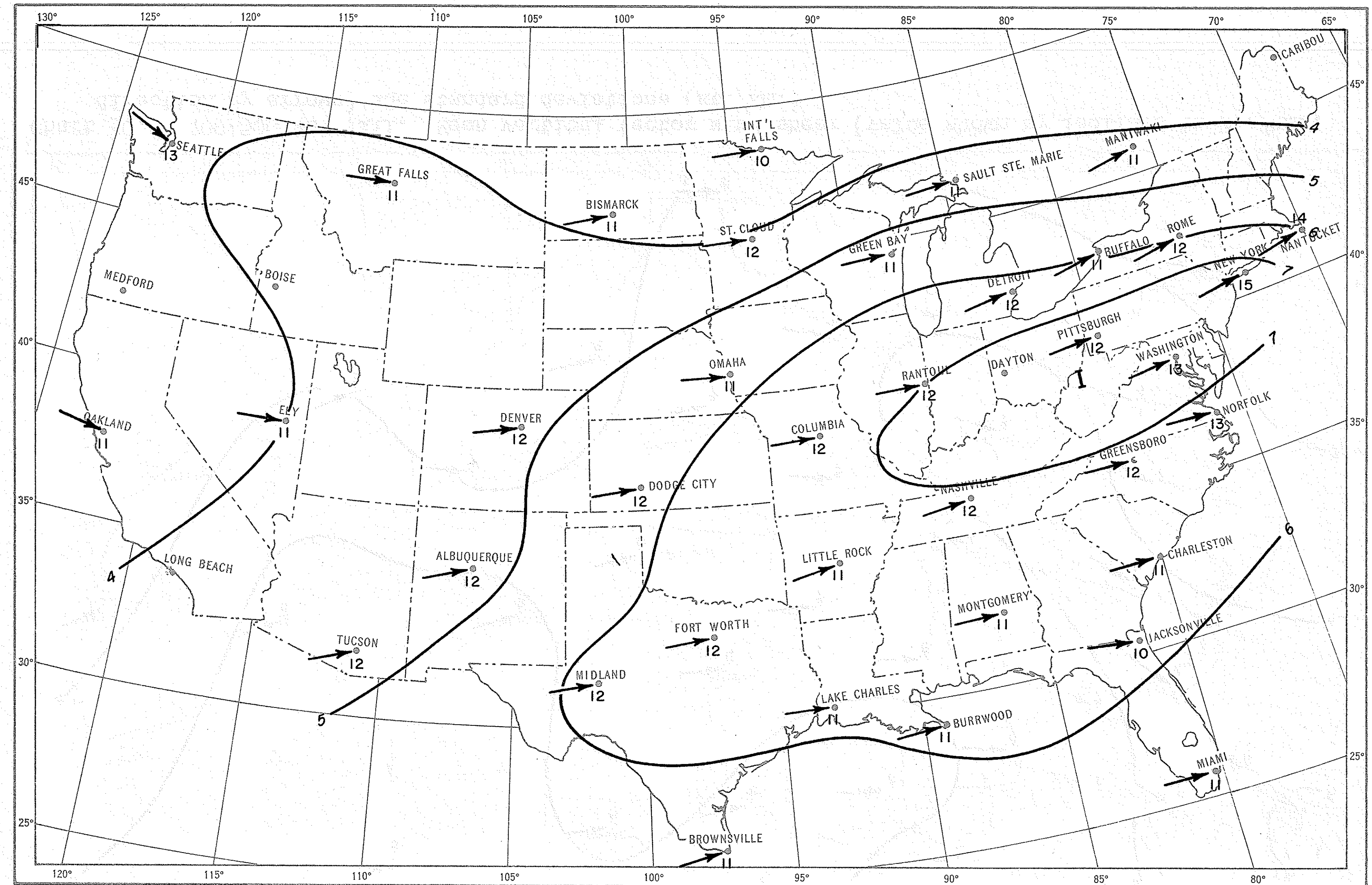

Chart 31. - 400-300 mb. Winter. Mean vertical vector wind shear (value shown by isolines in kt./km., direction by arrows) and standard deviations (kt./km.).

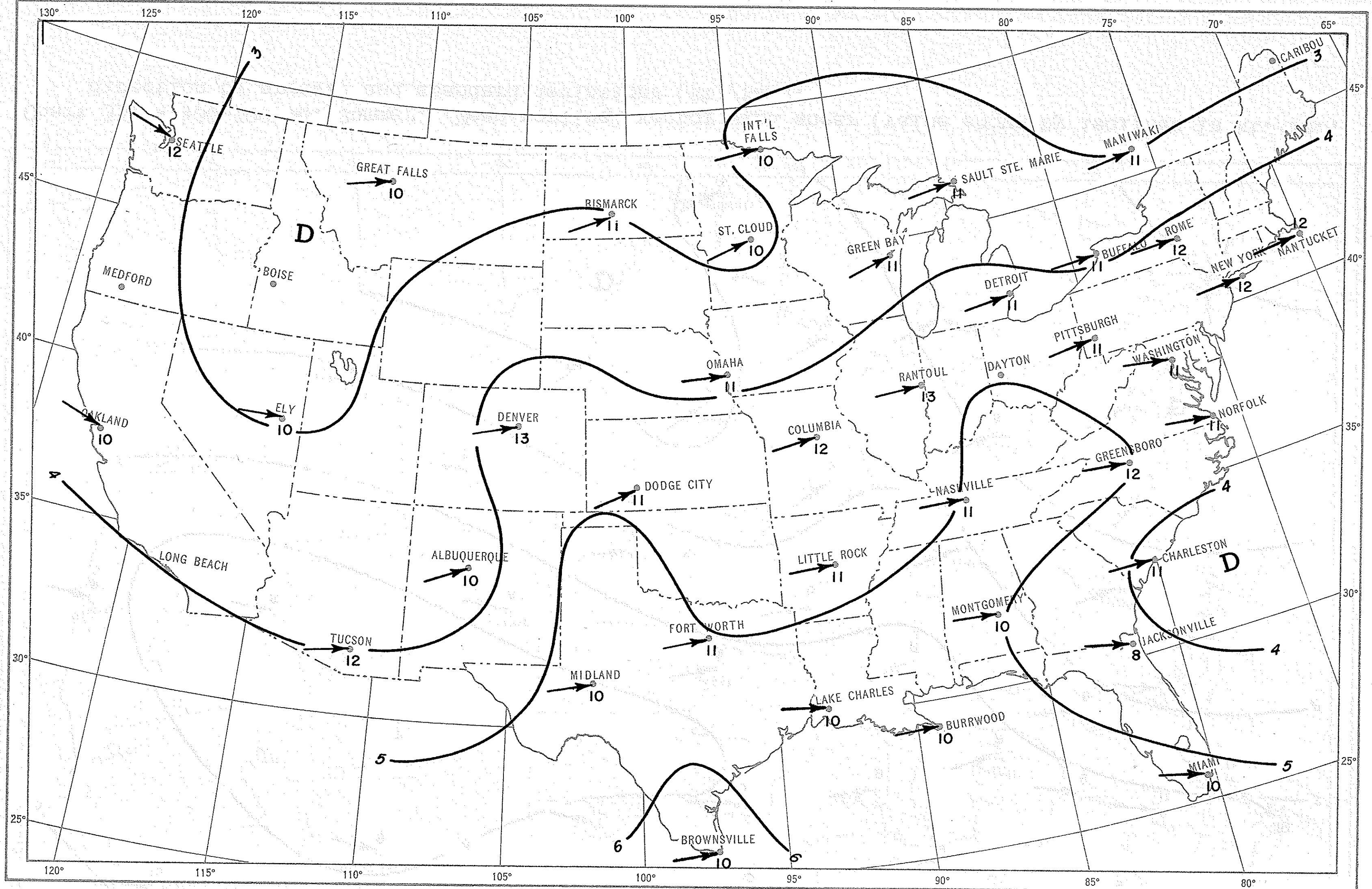

Chart 32. - 400-300 mb. Spring. Mean vertical vector wind shear (value shown by isolines in kt./km., direction by arrows) and standard deviations (kt./km.).

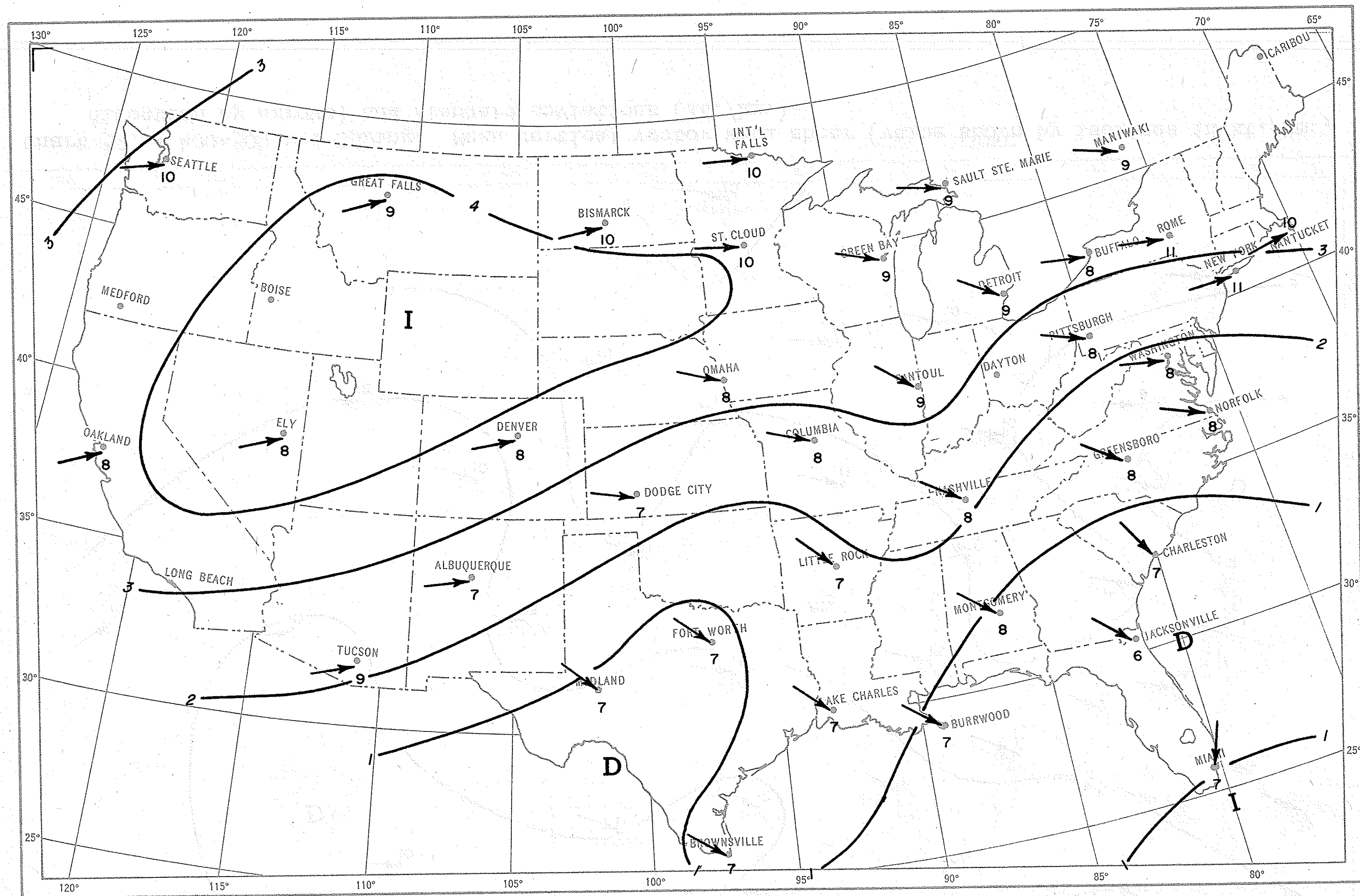

Chart 33. - 400-300 mb. Summer. Mean vertical vector wind shear (value shown by isolines in kt./km., direction by arrows) and standard deviations (kt./km.).

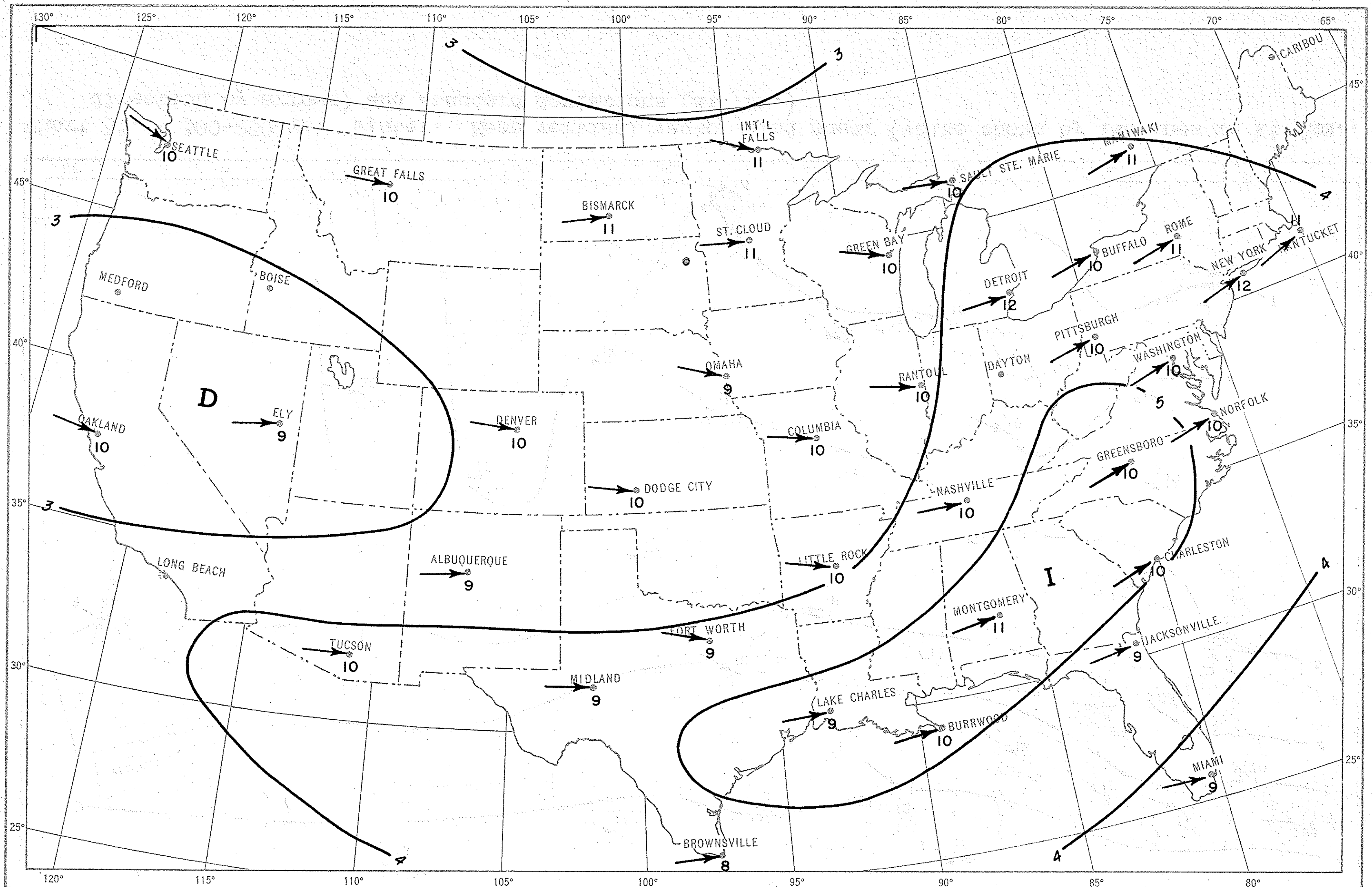

Chart 34. - 400-300 mb. Fall. Mean vertical vector wind shear (value shown by isolines in kt./km., direction by arrows) and standard deviations (kt./km.).

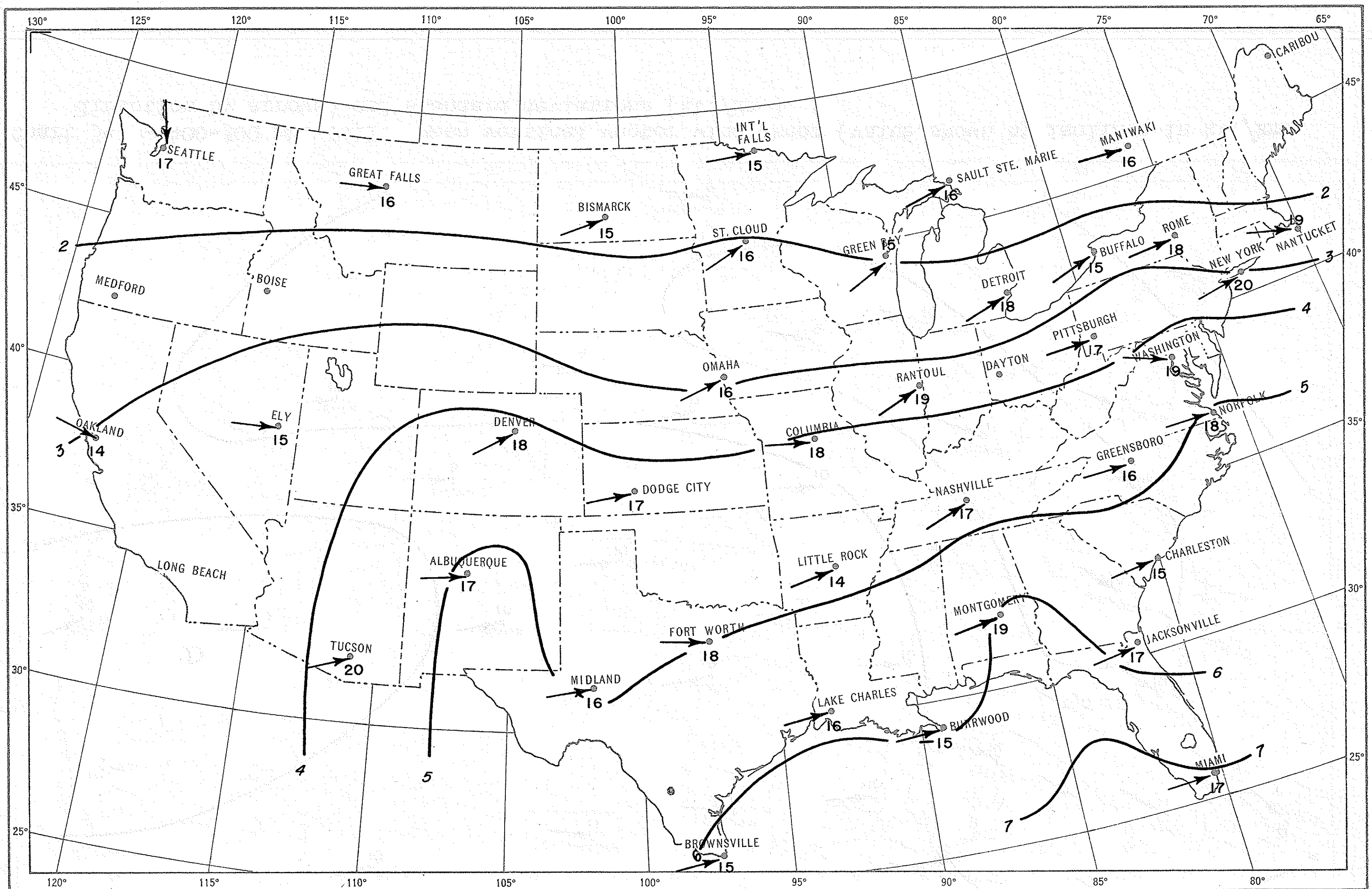

Chart 35. - 300-250 mb. Winter. Mean vertical vector wind shear (value shown by isolines in kt./km., direction by arrows) and standard deviations (kt./km.).

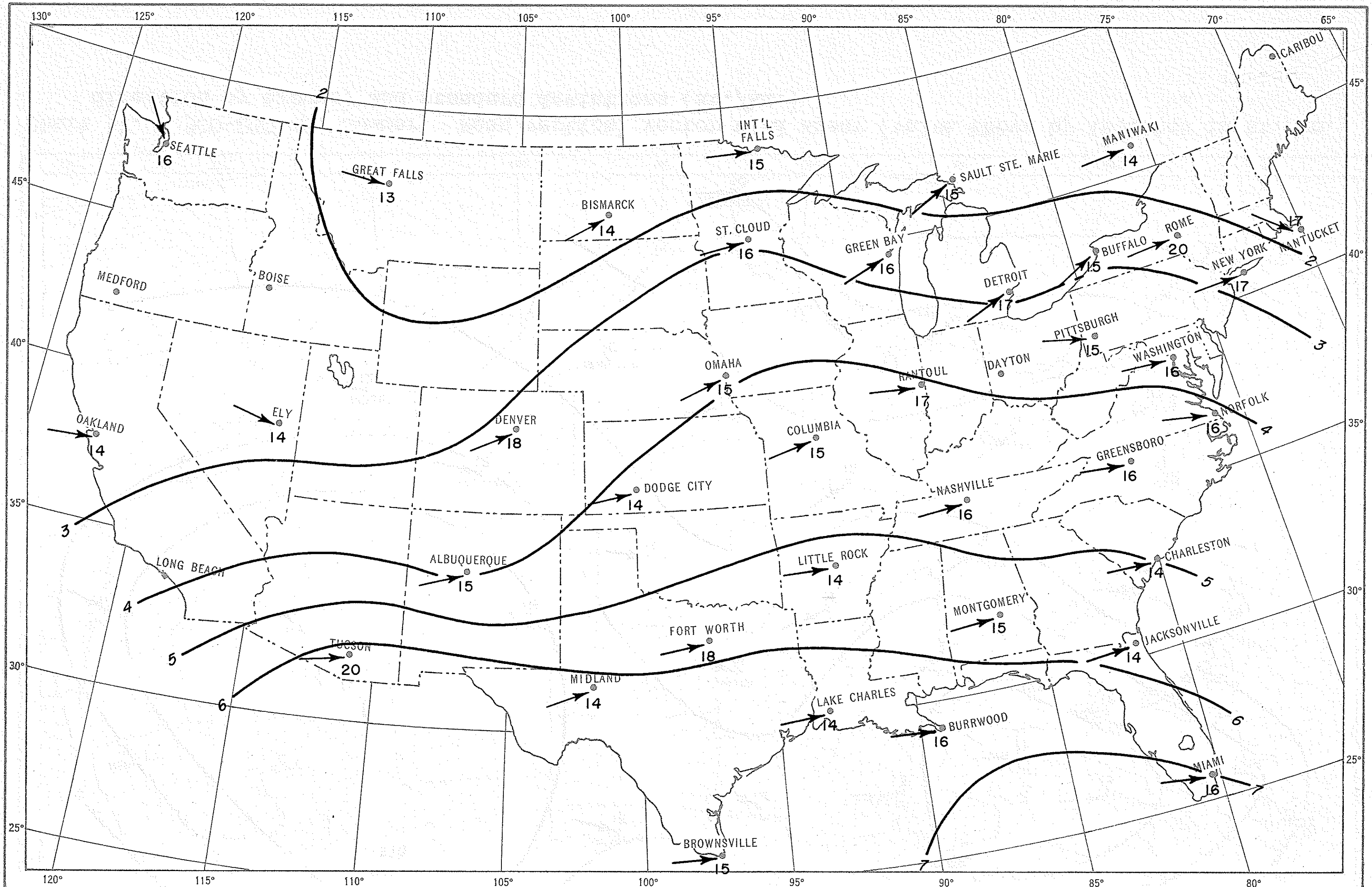

Chart 36. - 300-250 mb. Spring. Mean vertical vector wind shear (value shown by isolines in kt./km., direction by arrows) and standard deviations (kt./km.).

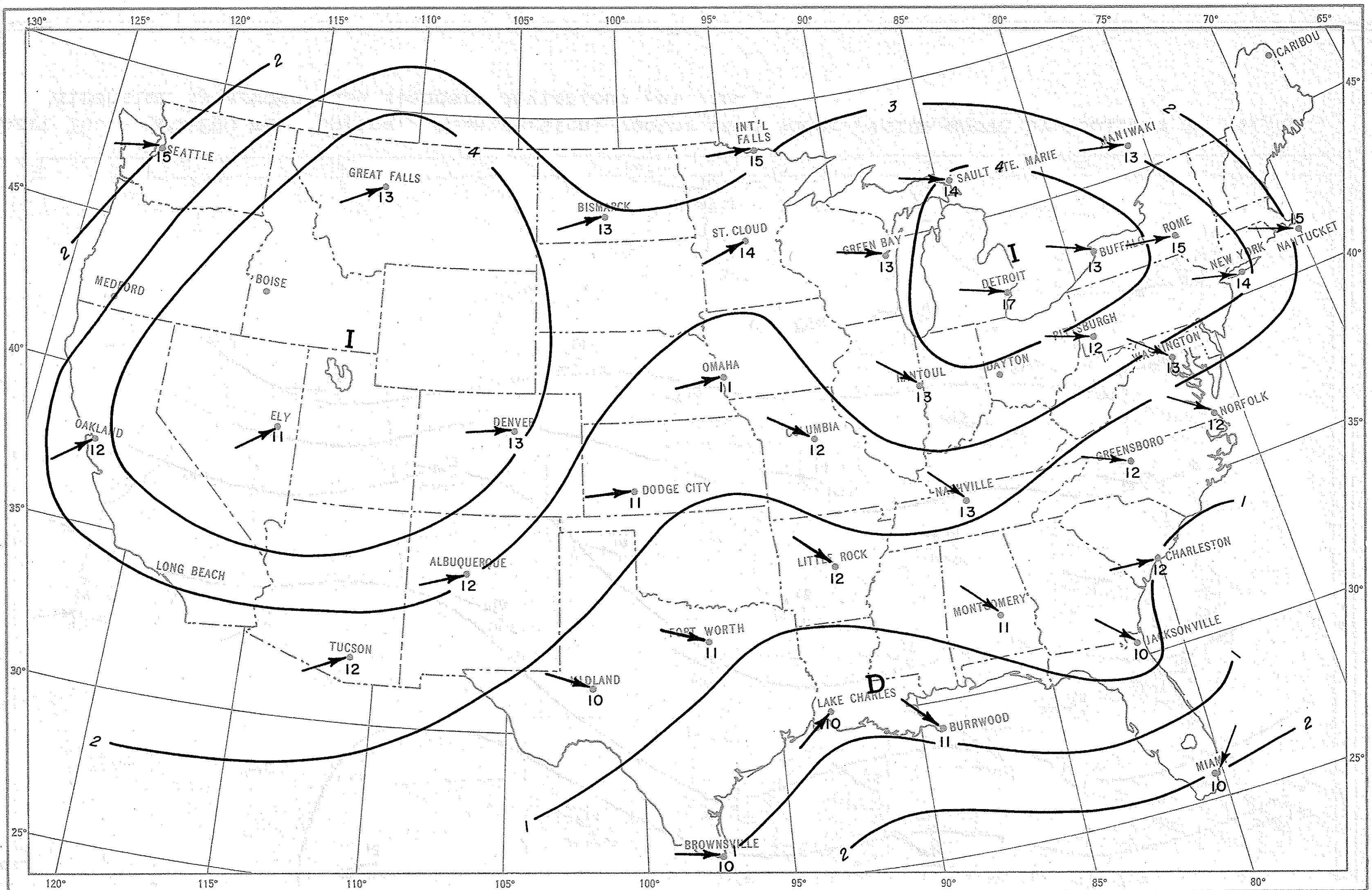

Chart 37. - 300-250 mb. Summer. Mean vertical vector wind shear (value shown by isolines in kt./km., direction by arrows) and standard deviations (kt./km.).

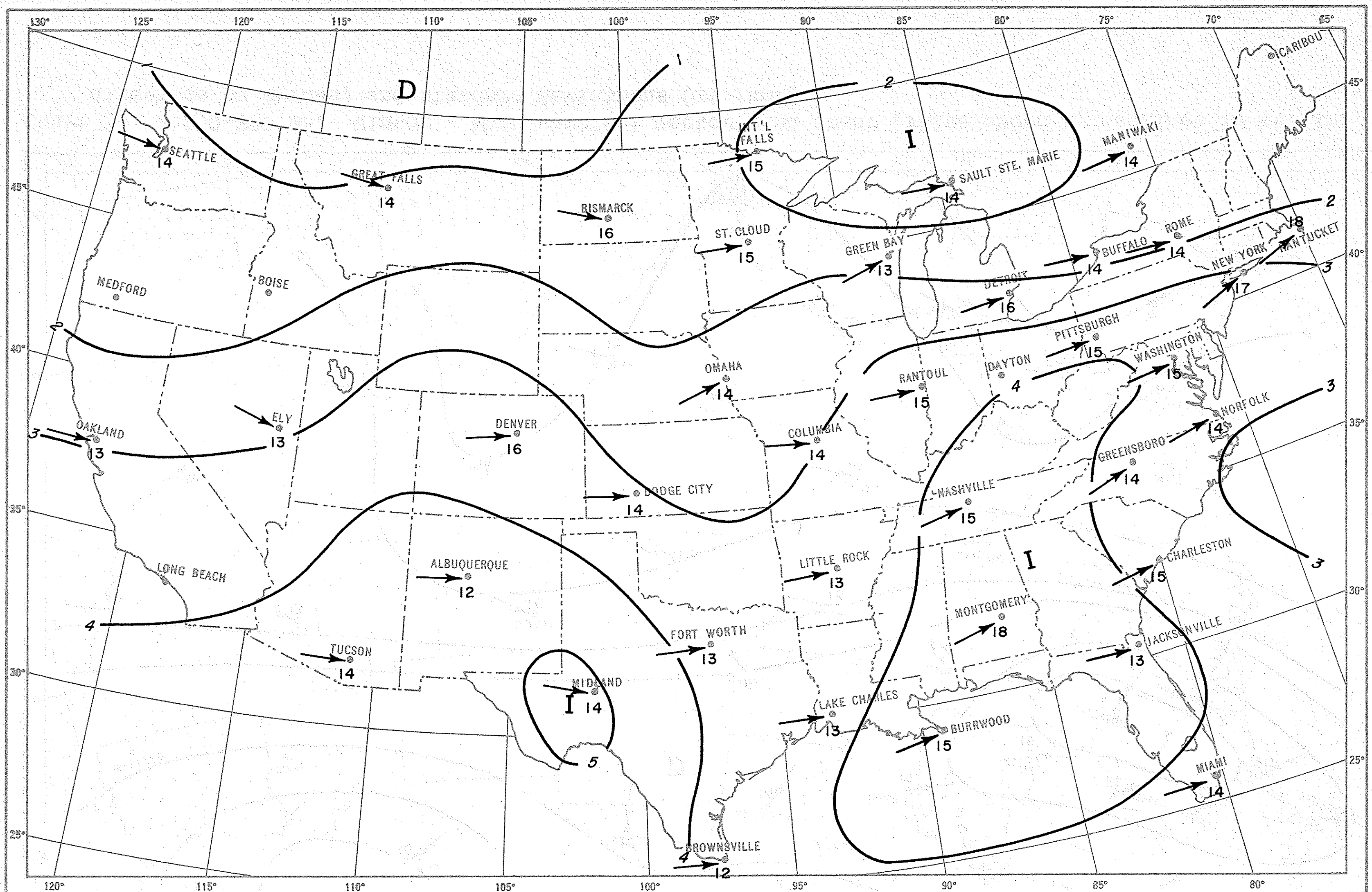

Chart 38. - 300-250 mb. Fall. Mean vertical vector wind shear (value shown by isolines in kt./km., direction by arrows) and standard deviations (kt./km.).

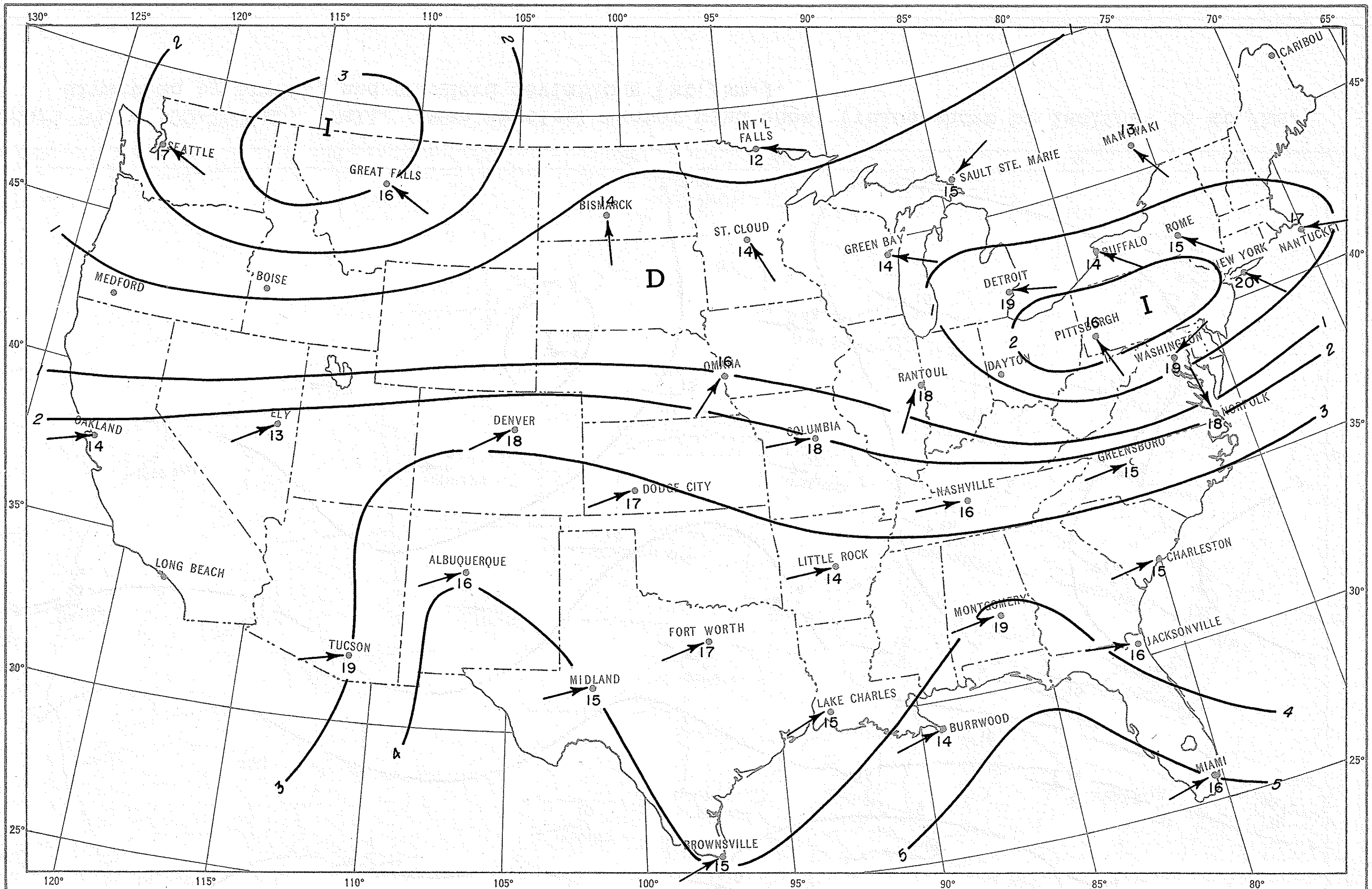

Chart 39. - 250-200 mb. Winter. Mean vertical vector wind shear (value shown by isolines in kt./km., direction by arrows) and standard deviations (kt./km.).

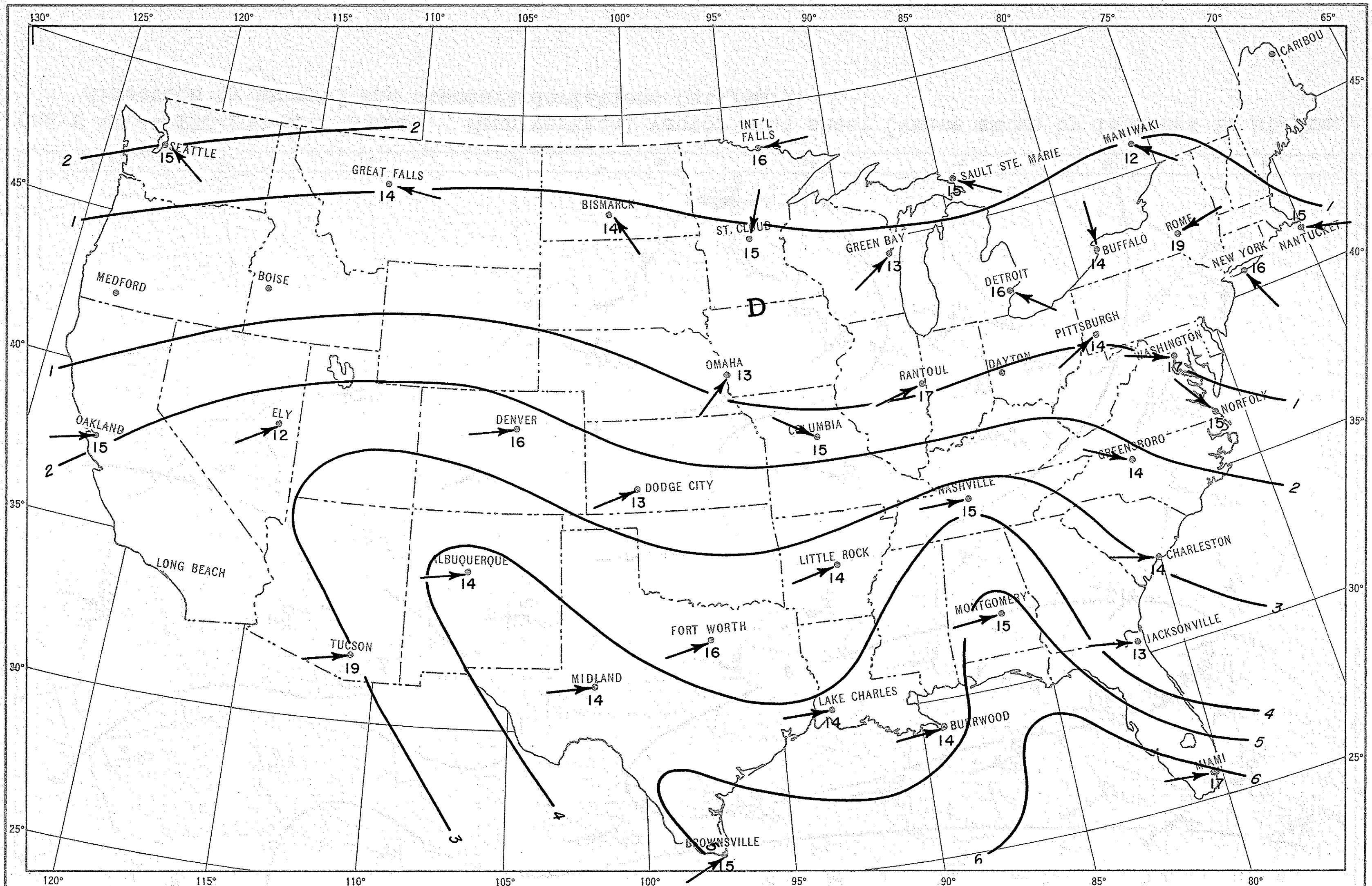

Chart 40. - 250-200 mb. Spring. Mean vertical vector wind shear (value shown by isolines in kt./km., direction by arrows) and standard deviations (kt./km.).

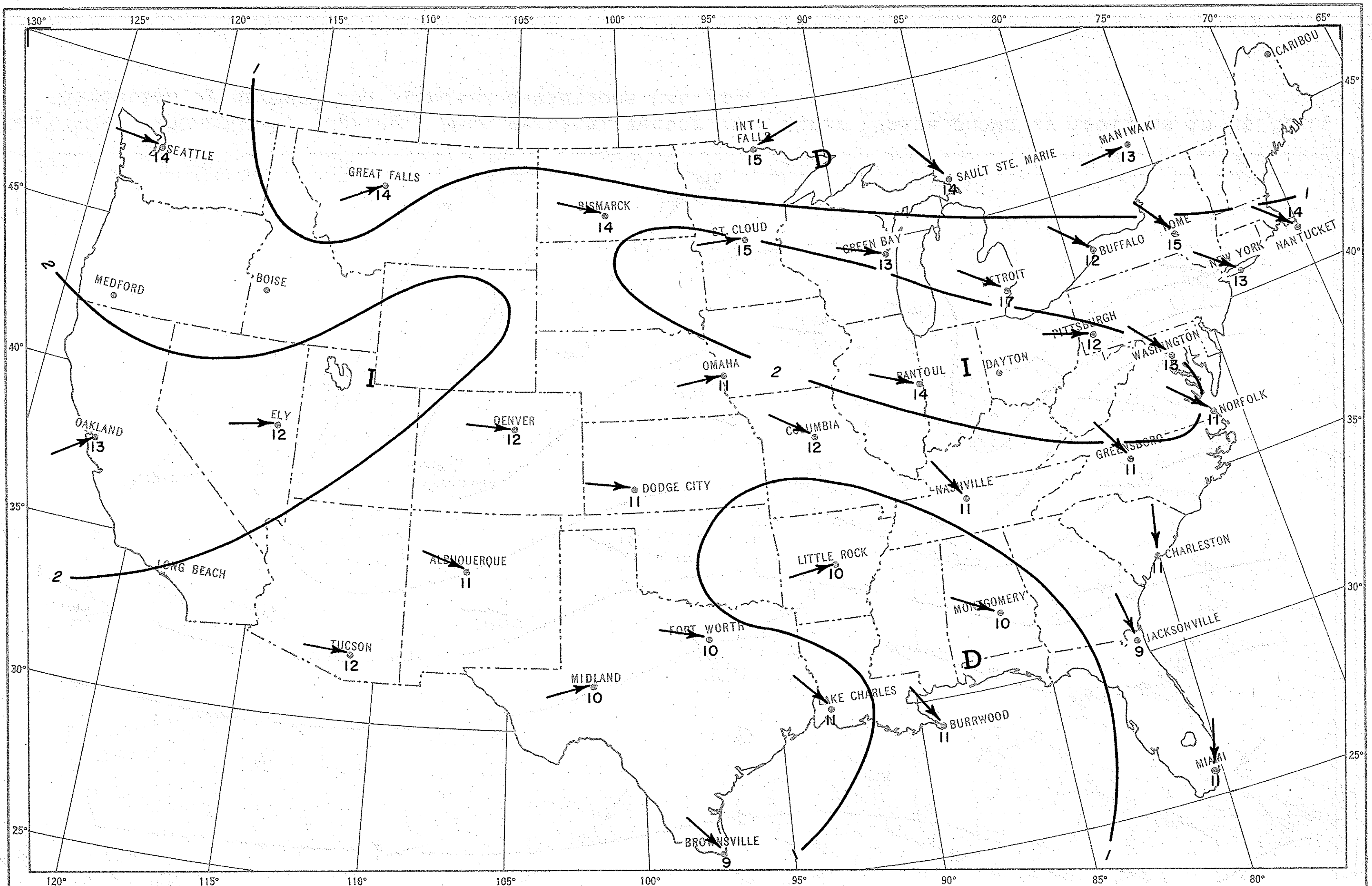

Chart 41. - 250-200 mb. Summer. Mean vertical vector wind shear (value shown by isolines in kt./km., direction by arrows) and standard deviations (kt./km.).

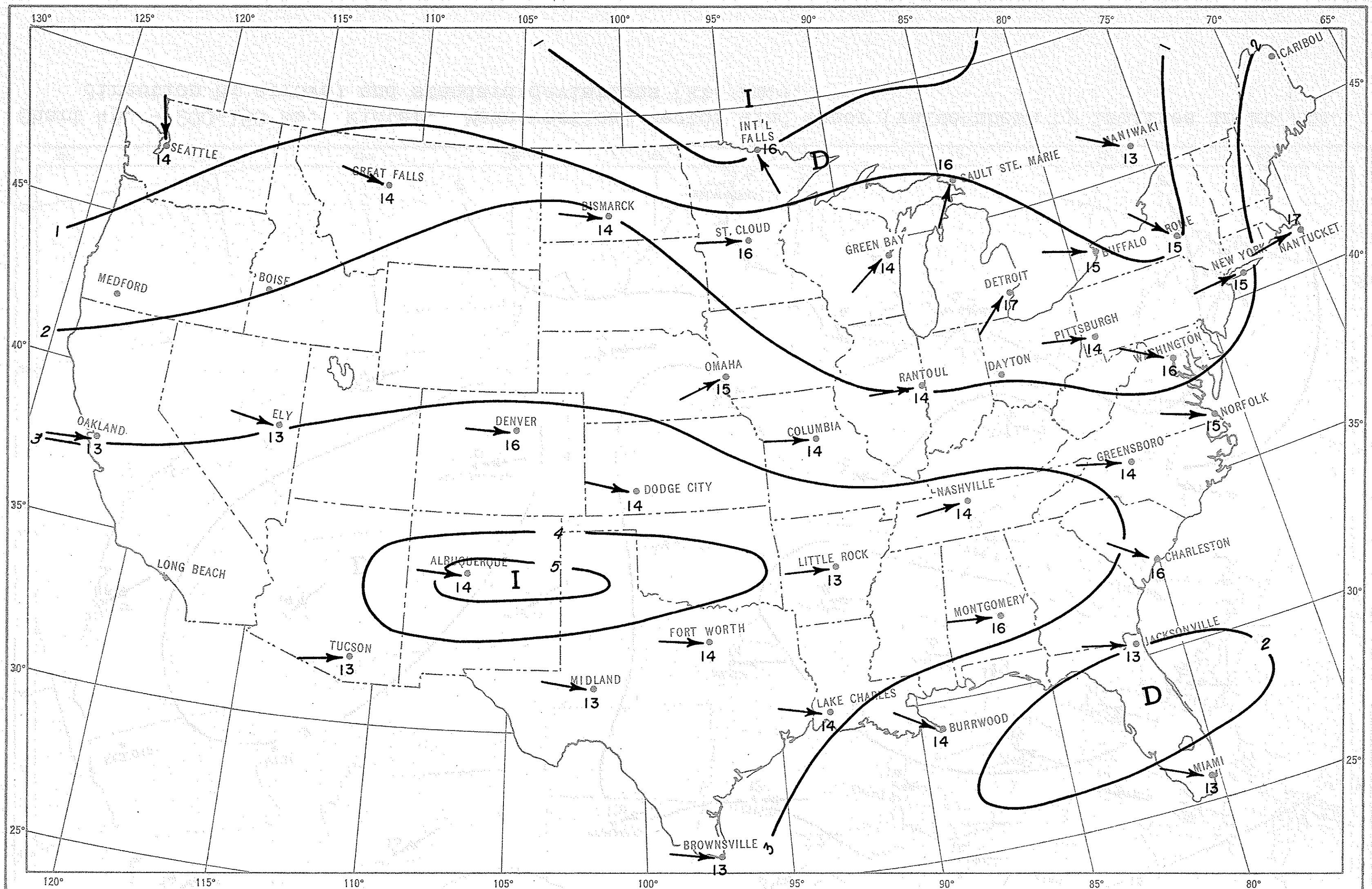

Chart 42. - 250-200 mb. Fall. Mean vertical vector wind shear (value shown by isolines in kt./km., direction by arrows) and standard deviations (kt./km.).

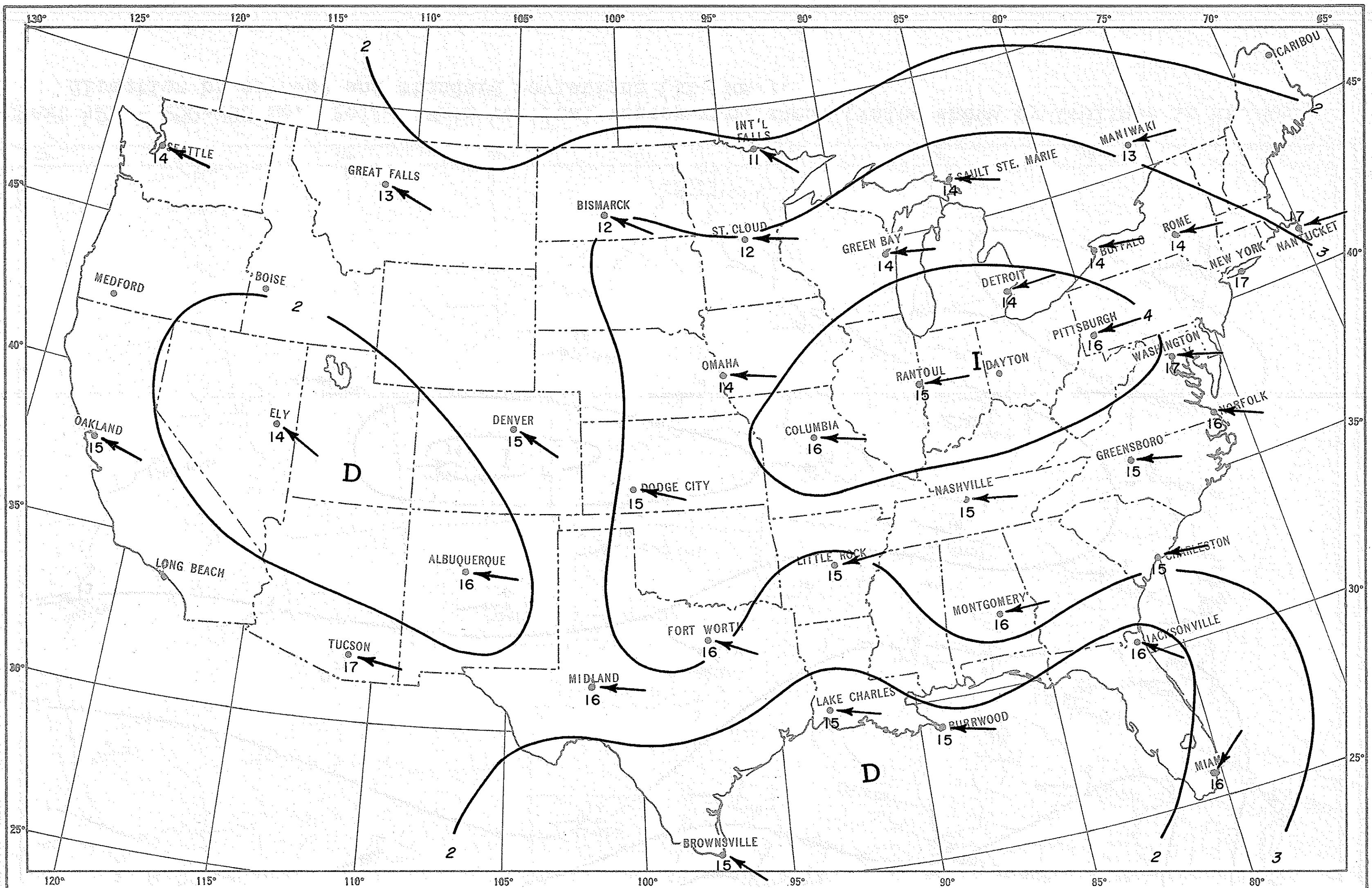

Chart 43. - 200-150 mb. Winter. Mean vertical vector wind shear (value shown by isolines in kt./km., direction by arrows) and standard deviations (kt./km.).

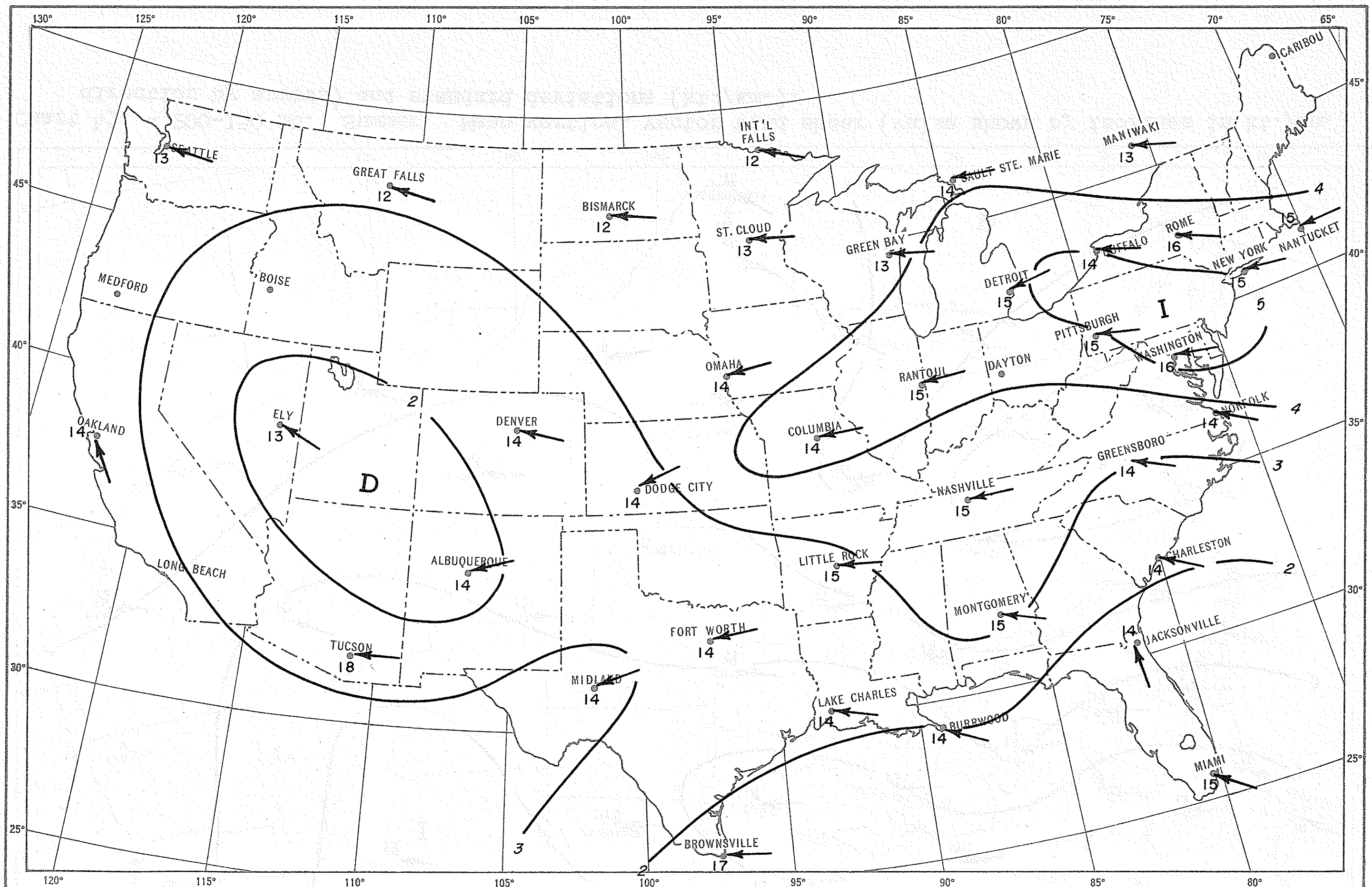

Chart 44. - 200-150 mb. Spring. Mean vertical vector wind shear (value shown by isolines in kt./km., direction by arrows) and standard deviations (kt./km.).

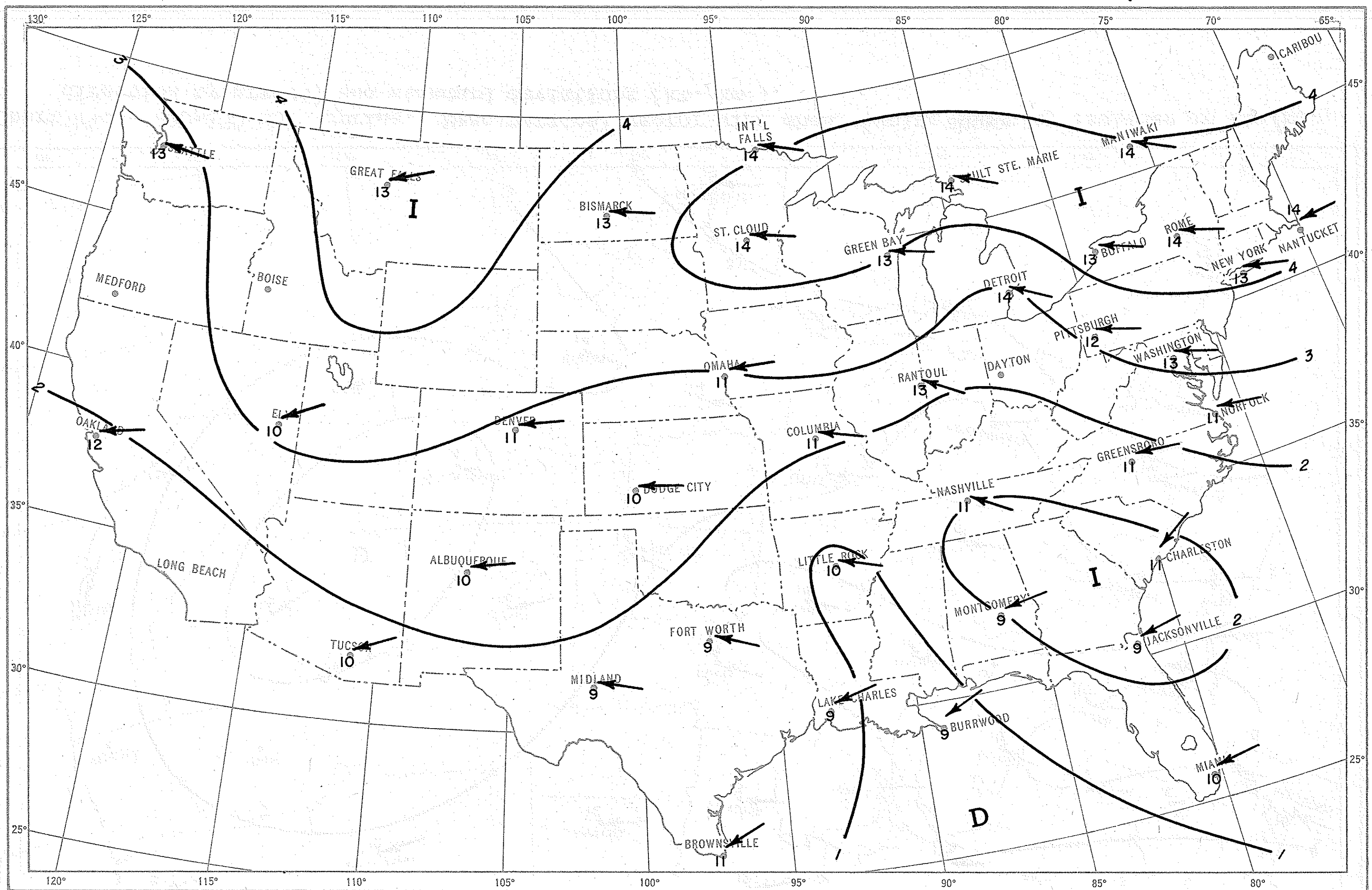

Chart 45. - 200-150 mb. Summer. Mean vertical vector wind shear (value shown by isolines in kt./km., direction by arrows) and standard deviations (kt./km.).

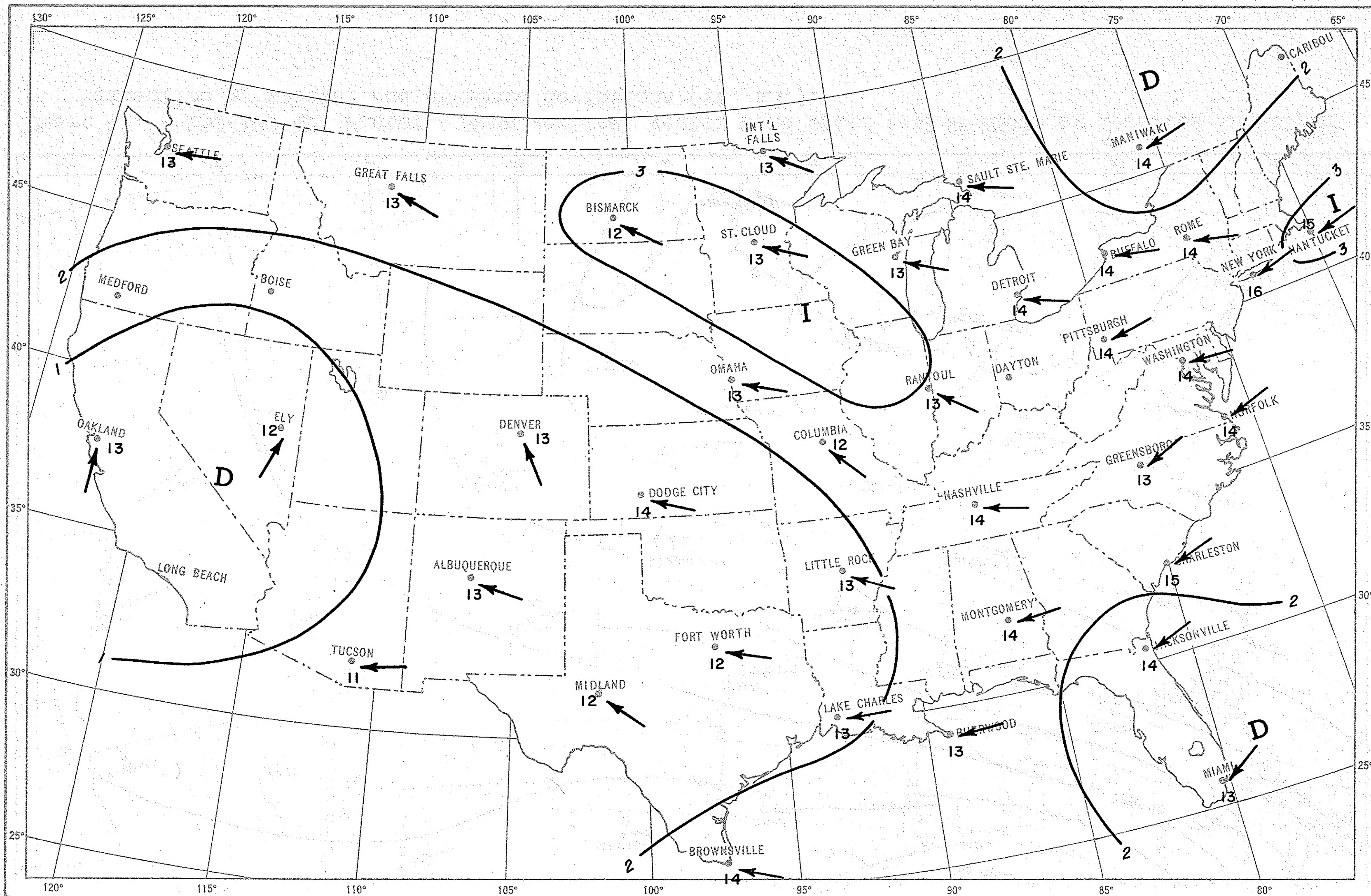

Chart 46. - 200-150 mb. Fall. Mean vertical vector wind shear (value shown by isolines in kt./km., direction by arrows) and standard deviations (kt./km.).

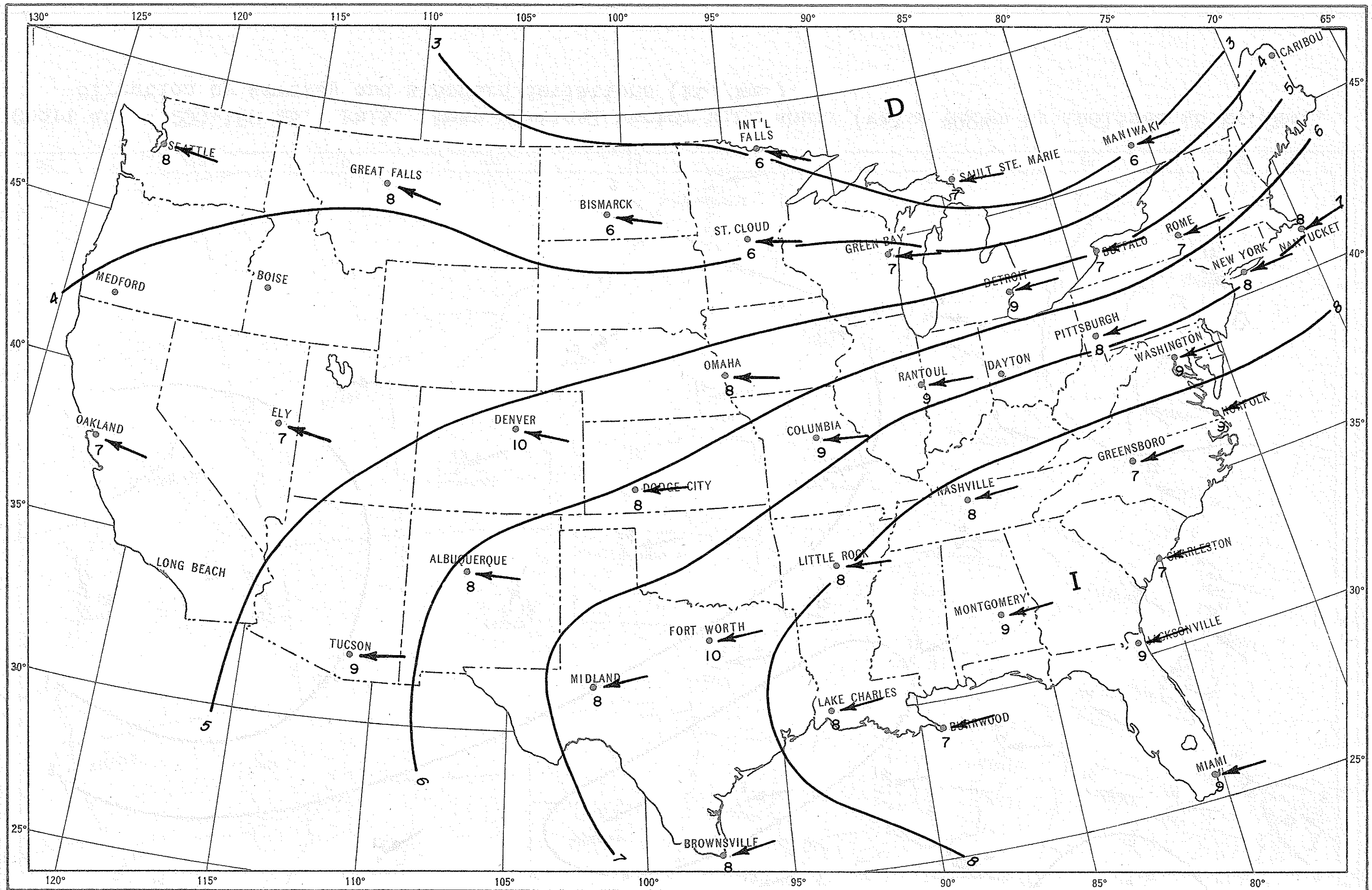

Chart 47. - 150-100 mb. Winter. Mean vertical vector wind shear (value shown by isolines in kt./km., direction by arrows) and standard deviations (kt./km.).

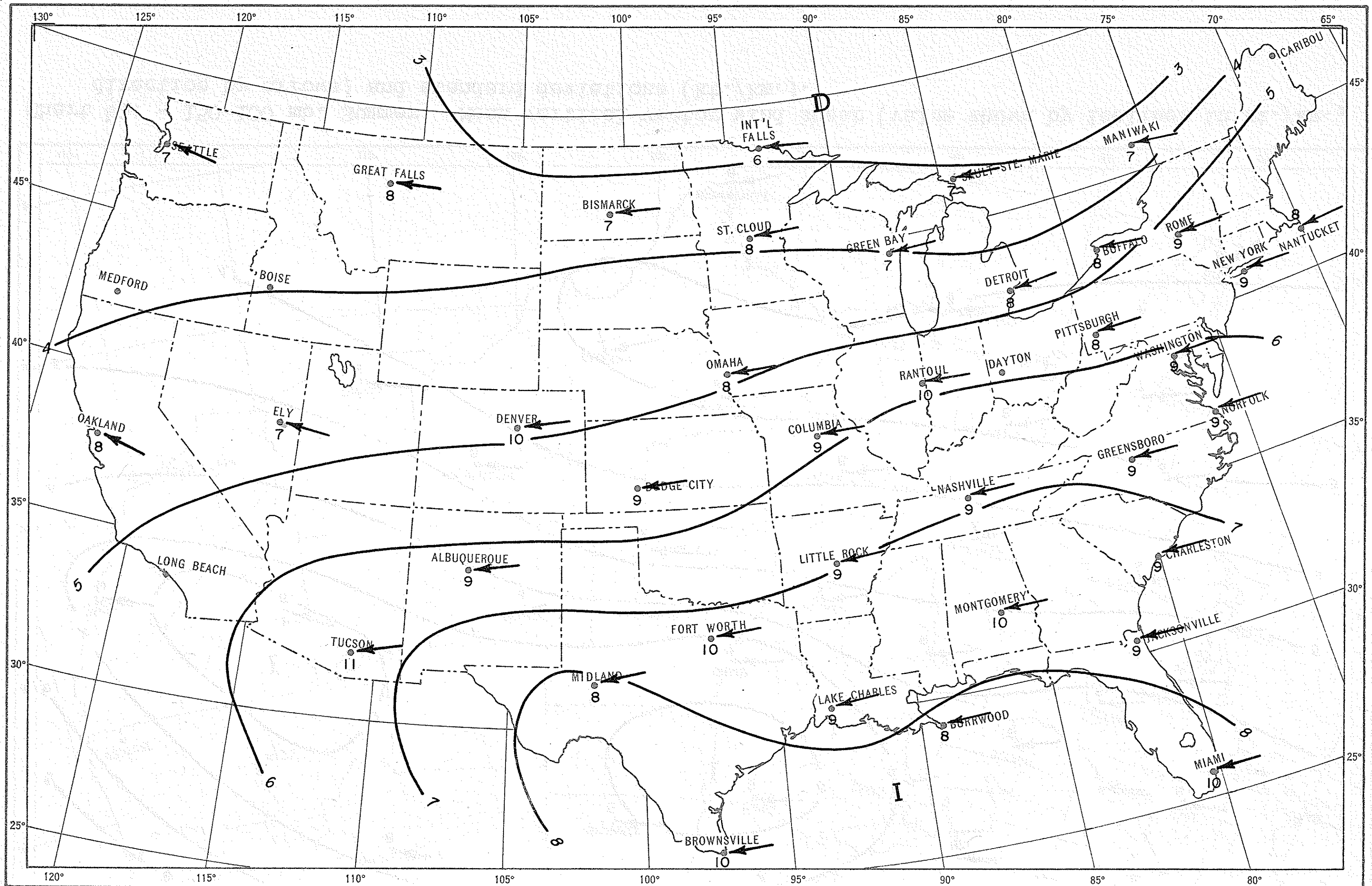

Chart 48. - 150-100 mb. Spring. Mean vertical vector wind shear (value shown by isolines in kt./km., direction by arrows) and standard deviations (kt./km.).

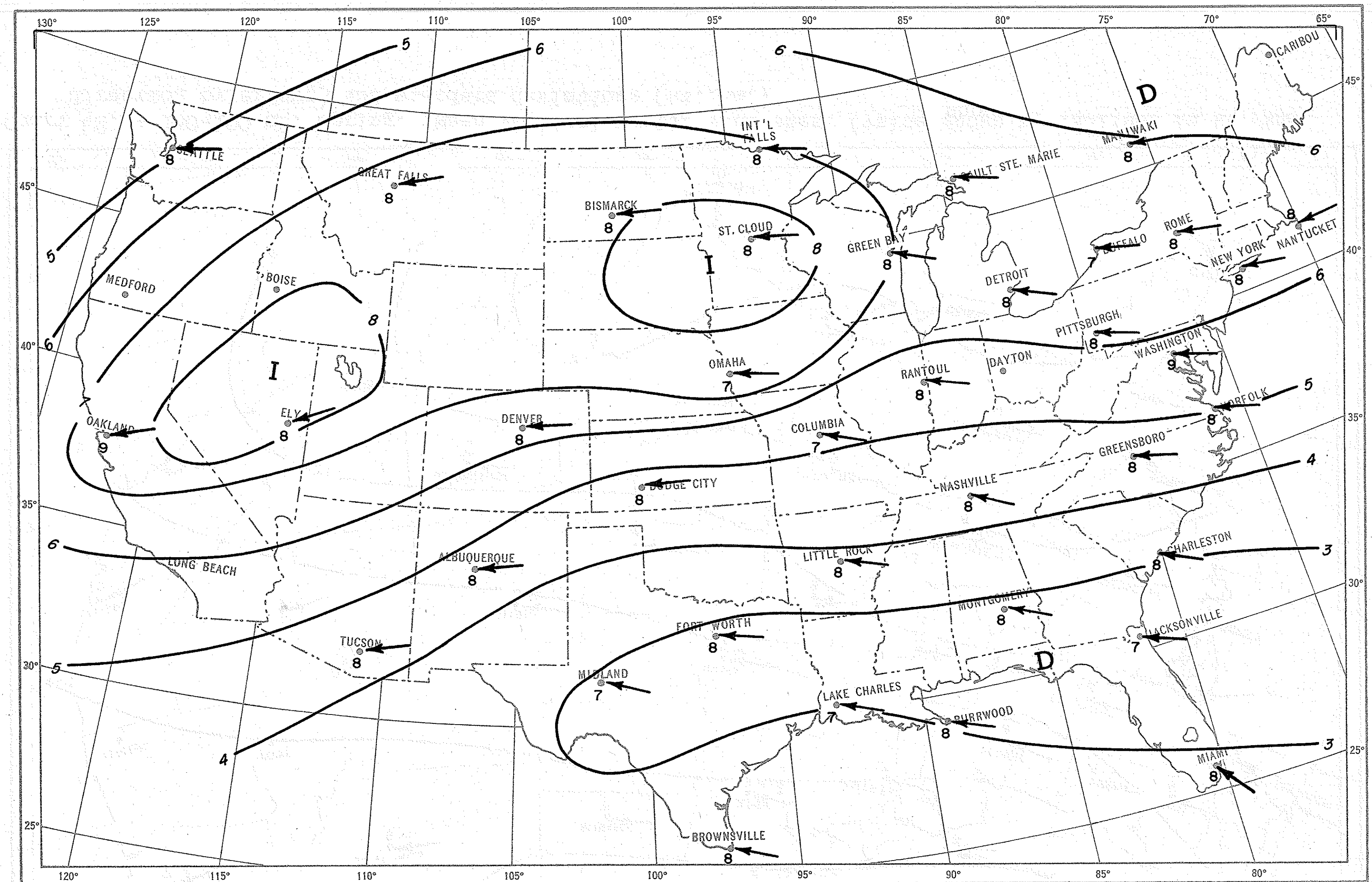

Chart 49. - 150-100 mb. Summer. Mean vertical vector wind shear (value shown by isolines in kt./km., direction by arrows) and standard deviations (kt./km.).

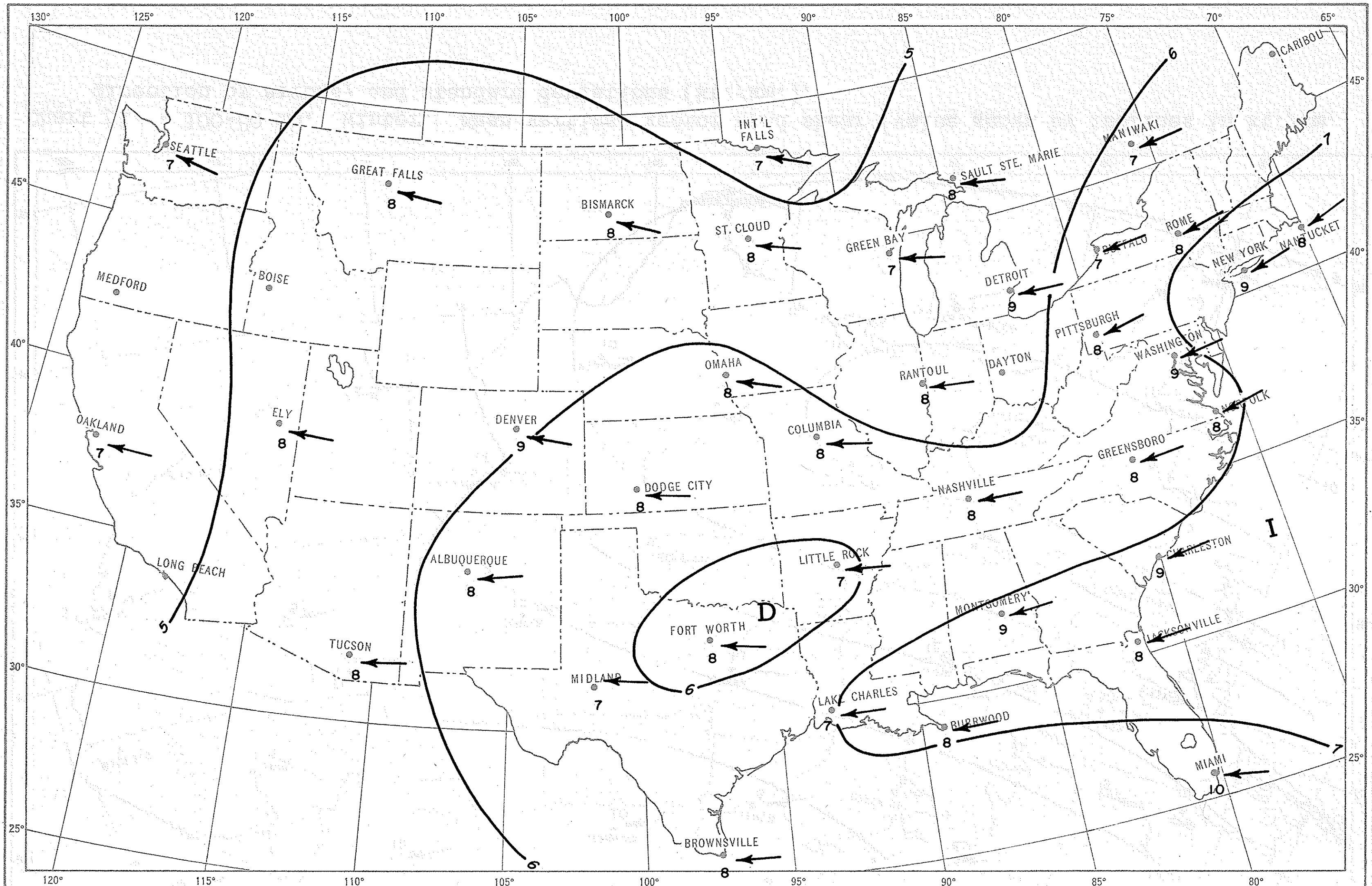

Chart 50. - 150-100 mb. Fall. Mean vertical vector wind shear (value shown by isolines in kt./km., direction by arrows) and standard deviations (kt./km.).

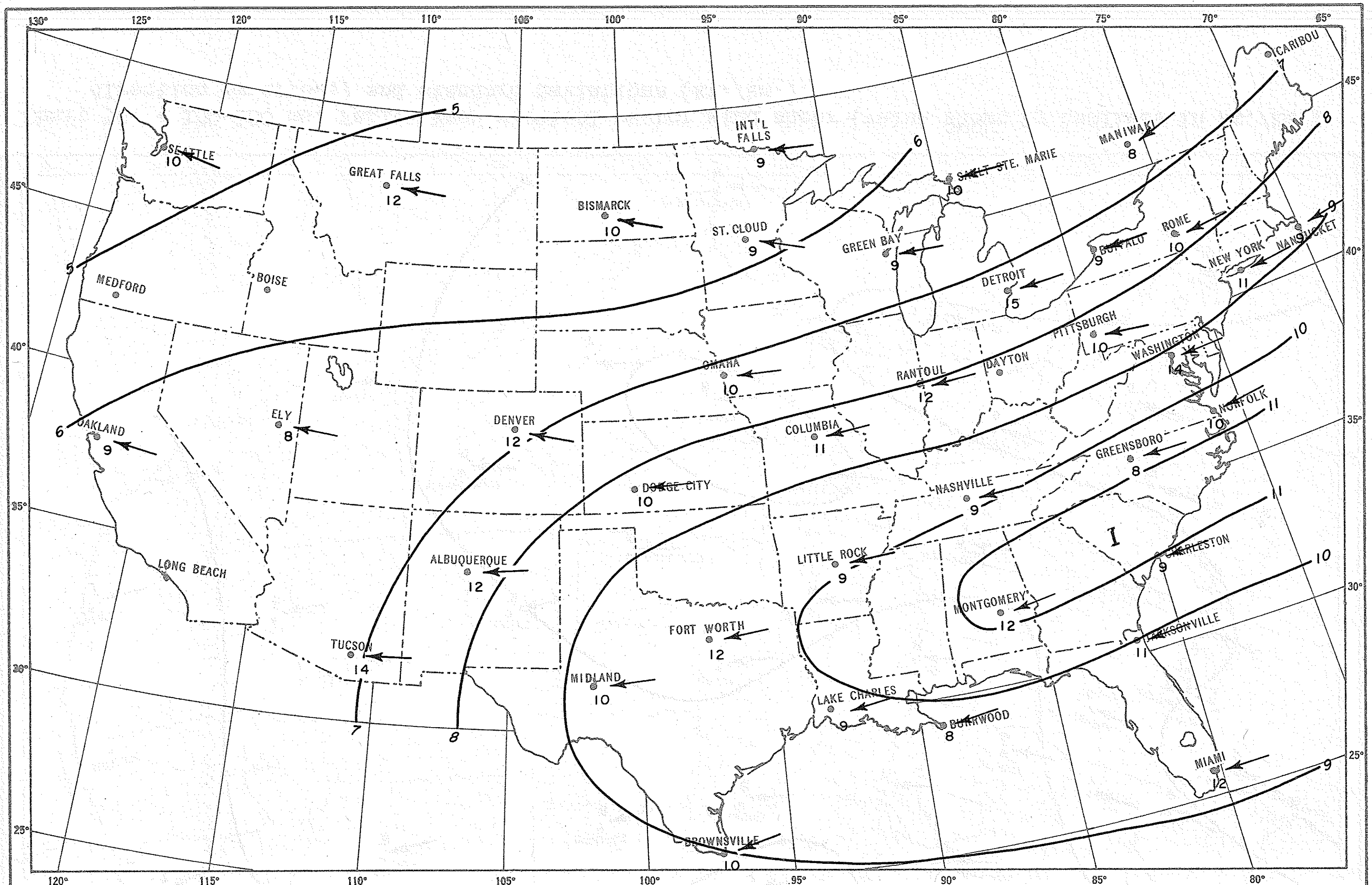

Chart 51. - 100-80 mb. Winter. Mean vertical vector wind shear (value shown by isolines in kt./km., direction by arrows) and standard deviations (kt./km.).

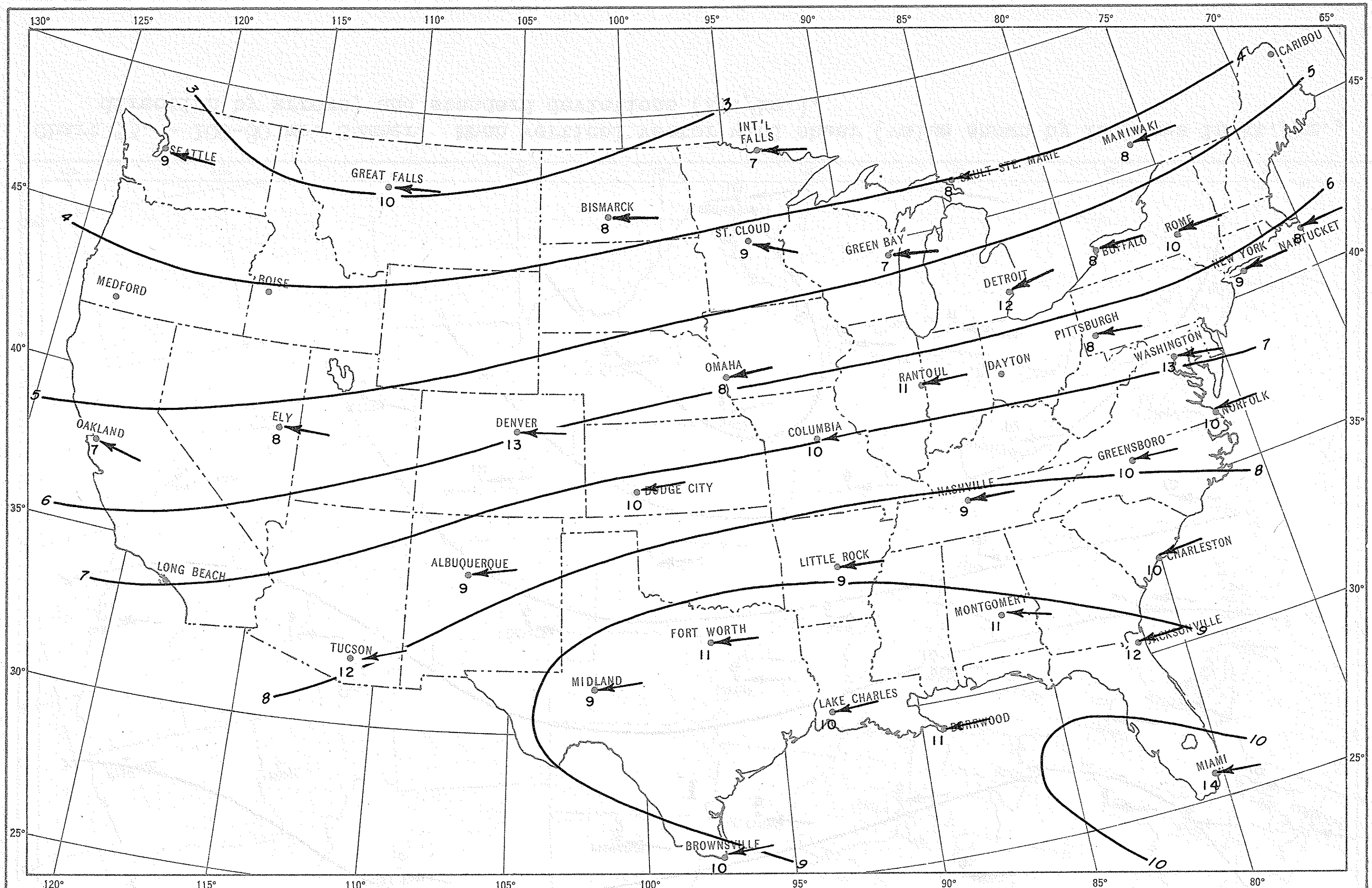

Chart 52. - 100-80 mb. Spring. Mean vertical vector wind shear (value shown by isolines in kt./km., direction by arrows) and standard deviations (kt./km.).

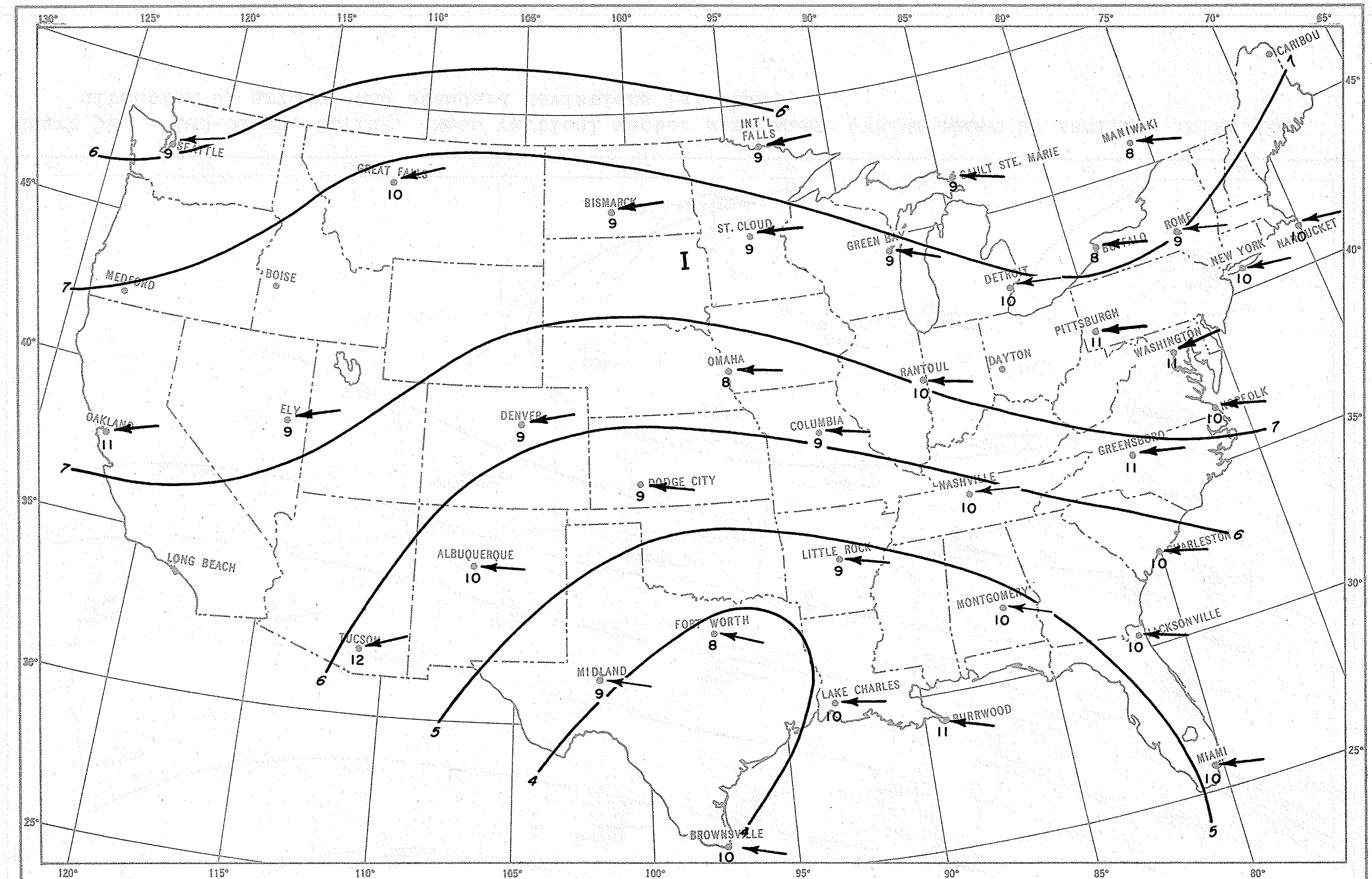

Chart 53. - 100-80 mb. Summer. Mean vertical vector wind shear (value shown by isolines in kt./km., direction by arrows) and standard deviations (kt./km.).

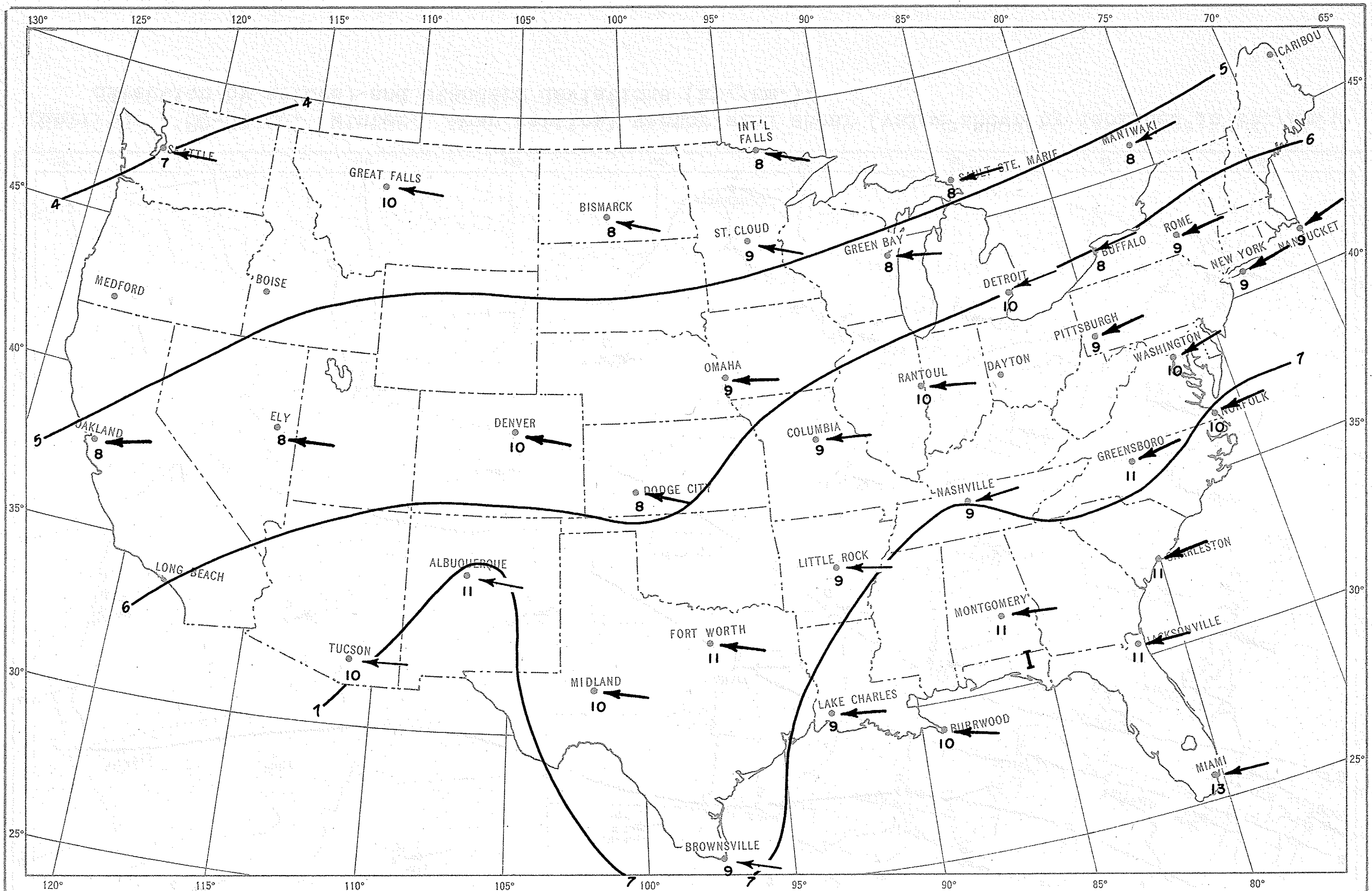

Chart 54. - 100-80 mb. Fall. Mean vertical vector wind shear (value shown by isolines in kt./km., direction by arrows) and standard deviations (kt./km.).

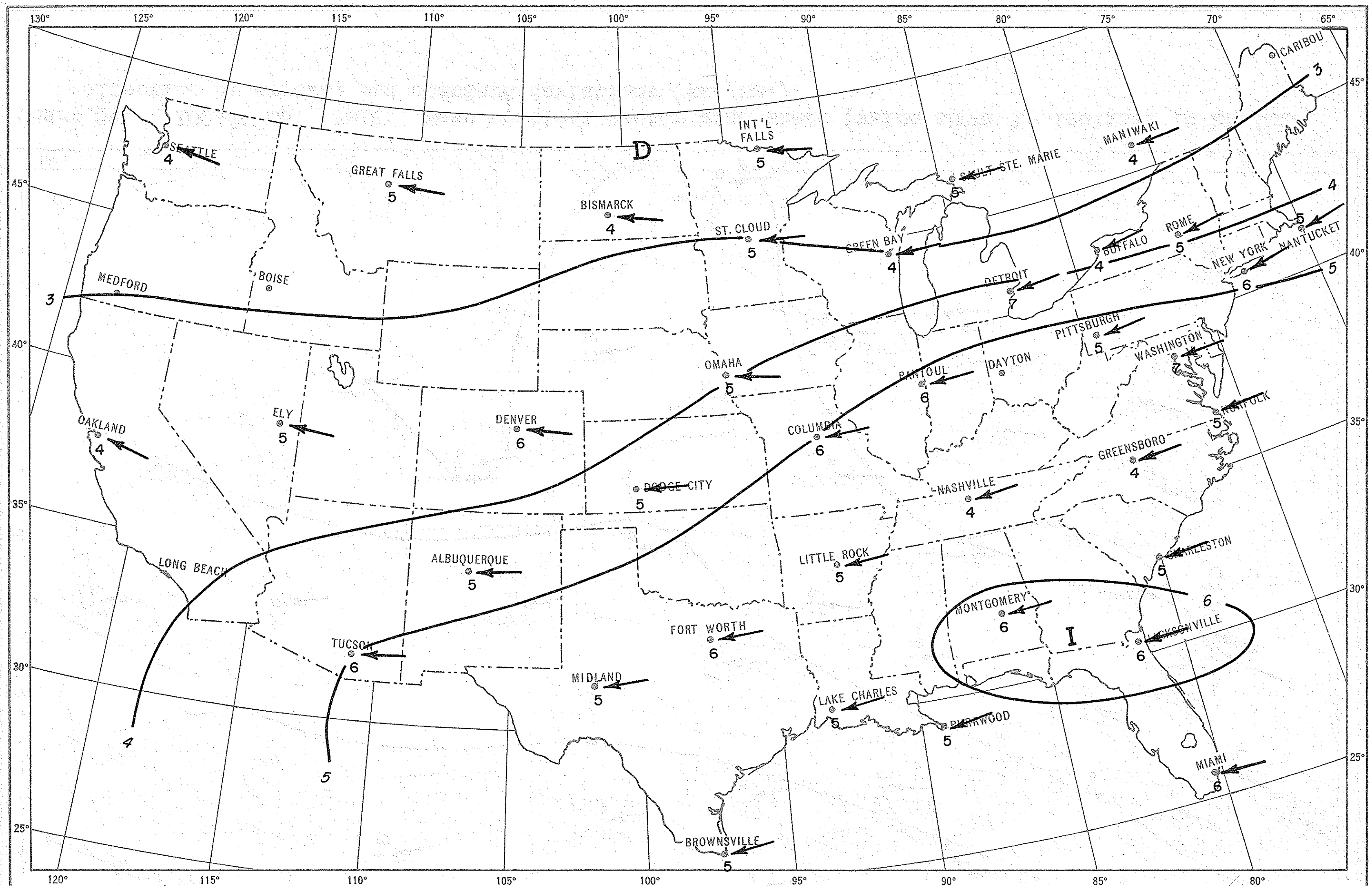

Chart 55. - 80-50 mb. Winter. Mean vertical vector wind shear (value shown by isolines in kt./km., direction by arrows) and standard deviations (kt./km.).

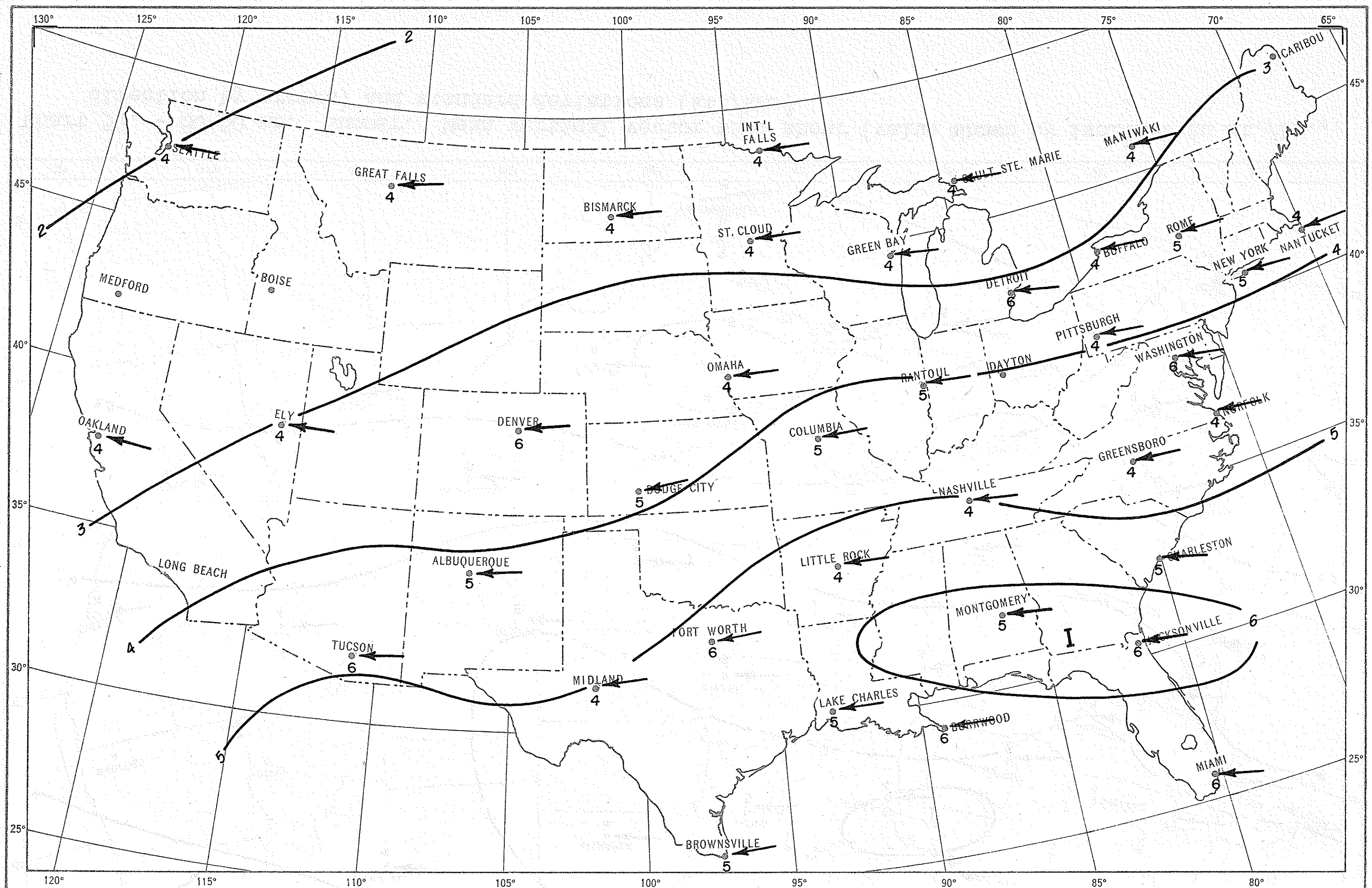

Chart 56. - 80-50 mb. Spring. Mean vertical vector wind shear (value shown by isolines in kt./km., direction by arrows) and standard deviations (kt./km.).

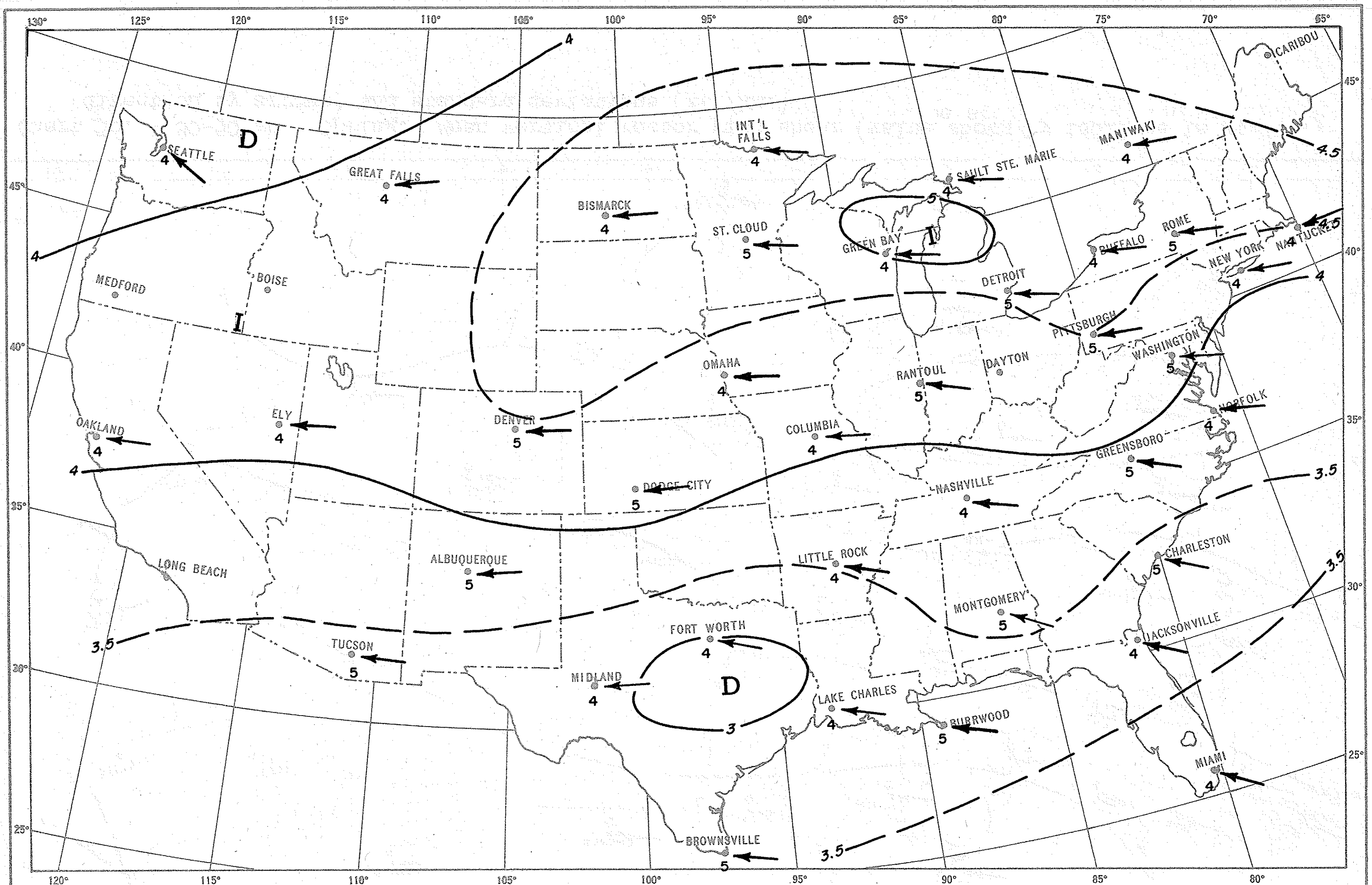

Chart 57. - 80-50 mb. Summer. Mean vertical vector wind shear (value shown by isolines in kt./km., direction by arrows) and standard deviations (kt./km.).

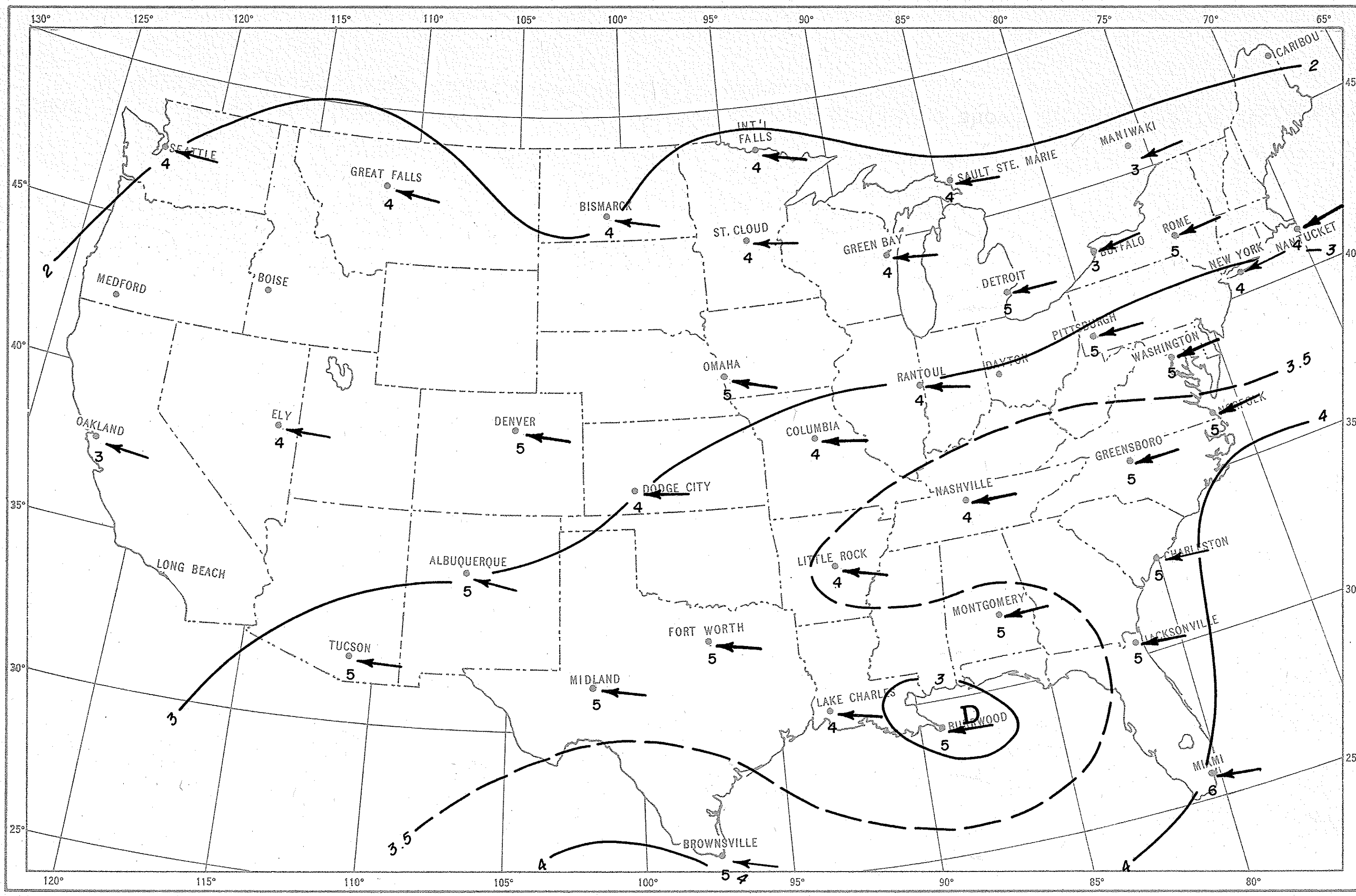

Chart 58. - 80-50 mb. Fall. Mean vertical vector wind shear (value shown by isolines in kt./km. direction by arrows) and standard deviations (kt./km.).

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