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UPPER WINDS OVER THE WORLD

PART III

Standard Vector Deviation of
Wind up to the 100-Millibar Level over the World

BY

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UPPER WINDS OVER THE WORLD

PART III—STANDARD VECTOR DEVIATION OF WIND UP TO THE 100-MILLIBAR LEVEL OVER THE WORLD

§ 1—INTRODUCTION

Geophysical Memoirs No. 85,^{1*} published in 1950, included seasonal charts of the standard vector deviation of wind at the standard pressure levels 700, 500, 300, 200 and 130 millibars. These charts were based on extremely scanty data and also on the assumption that the product of the standard vector deviation σ and the air density ρ is constant for any one place and season. This assumption is an oversimplification and using it in a quantitative analysis must involve quite large inaccuracies. The necessary revision of the charts of standard vector deviation is made possible by the amount of upper air data now available.

The charts in *Geophysical Memoirs No. 85* apply to the four seasons, each of three months. In the present study the charts are restricted to the mid-season months January, April, July and October over the five-year period 1949–53; these were chosen to conform to the complementary revision of the contour height charts and the associated streamline—isotach charts published in *Geophysical Memoirs No. 103*.² However, in order to obtain five years' data, recourse was often made to years outside this range, particularly to the 1951–55 period. For a few stations data were restricted to a shorter period than five years and in some cases observations up to December 1957 were used. Finally it was decided to include the 100-millibar level and to substitute the 150-millibar for 130-millibar level.

§ 2—DATA

The data used were mainly radio or radar-wind observations but some pilot-balloon observations were also analysed to help construct the lower-level charts. Sources of data are listed on page 20.

The standard vector deviation of wind was based on the values calculated directly from daily values for all stations for which these standard vector deviations were available in the Climatological Division of the Meteorological Office. (For a few of these stations, seasonal values were used instead of values for mid-season months which were not available.) Observations from some other stations were available in the form of mean vector wind speed V_R and mean scalar wind speed V_S . For these stations the standard vector deviation σ was calculated from a method derived by Brooks, Durst and Carruthers³ and modified by Knighting.⁴ This assumes a normal circular distribution of individual wind vectors about the mean vector, whence the ratio σ/V_R is uniquely determined by the "constancy" q , where $q = 100 V_R/V_S$, except where V_R approached zero in which case σ approximates to $1.13 V_S$.

For the majority of stations no observations were immediately available in analysed form. Daily observations were extracted from the various publications and entered in frequency tables constructed for each level. Direction was in 30-degree ranges and speed in 10-knot ranges.

* The index numbers refer to the bibliography on p. 19.

From these tables the resultant (mean vector) wind \mathbf{V}_R was calculated and also the mean square velocity \overline{V}^2 . The standard vector deviation is then given by

$$\sigma^2 = \overline{V}^2 - V_R^2$$

The final network of observations consists of radar-wind or radio-wind stations and 44 pilot-balloon stations. These are plotted on Figures 4 and 5 (pages 28 and 29) and are classified so as to give an idea of the degree of confidence attached to the values at each station. There are five groups :

A. Radar-wind or radio-wind stations with a sufficient number of observations at all levels for the computed standard vector deviation to be considered reliable.

B. Radar-wind or radio-wind stations with a sufficient number of observations up to only the 300-millibar level for the computed standard vector deviation to be considered reliable.

C. Radar-wind or radio-wind stations with infrequent observations, but estimates of the standard vector deviation up to differing levels were obtained by combining observations during all three months in each season.

D. Pilot-balloon winds with heterogeneous periods of observation. This group also includes radar-wind or radio-wind stations where observations were very infrequent. These stations were used to provide an estimate of the standard vector deviation at the 700-millibar level only.

E. Stations for which data published by Crutcher⁵ (see page 13) became available late in the preparation of the charts. These data extend upwards to 200 millibars and mean values of standard vector deviation are given for each season from data extending over varying periods between 1949 and 1955.

No correction has been attempted for any possible selectivity in favour of light wind by radar-wind or radio-wind soundings. For this reason the values of standard vector deviation of wind at the highest levels will probably tend to be too low rather than too high.

The number of observations required for a value of standard vector deviation to be considered "reliable" varied according as the station was in a region of low or high standard vector deviation. At most stations where observations were reported only once a day, provided they were fairly evenly distributed over each month, the minimum number of observations acceptable was 50 at each level. Generally however, the number of observations at all stations plotted on Figures 4 and 5 was well above this minimum figure at the levels concerned.

§ 3—METHOD OF CONSTRUCTING THE CHARTS

Over much of the world data were sparse and values were occasionally based on relatively few observations. Accordingly, indirect methods were adopted to supplement wind observations.

700-, 500- and 300-millibar charts, north of 30°N.—Jenkinson⁶ and Buell⁷ have investigated the relation between standard vector deviation of wind σ and standard deviation of contour height s ; both arrive at results suggesting a linear relation. Jenkinson derived the formula

$$\sigma = ks \operatorname{cosec} \phi \quad \dots\dots (1)$$

where k is a "universal" constant (constant in space and time) and ϕ is the latitude. Values of standard deviation of contour height have not been computed on a global scale and this would involve much time and labour. However, using statistical relations, Jenkinson⁸ also developed

an equation between s and certain other parameters which have already been computed and mapped:

$$s^2 = 0.72(s'')^2 + 0.60s''s_0 + s_0^2 \quad \dots\dots (2)$$

where $s'' = \frac{R}{g} \ln\left(\frac{1000}{p}\right) \sigma_T'$ and $s_0 = \frac{R}{g} T_0 \frac{\sigma_p}{1000}$.

R is the gas constant; p the pressure surface considered; σ_T' the root mean square of standard deviation of temperature σ_T at fixed pressure levels between 1000 millibars and p ; T_0 the average temperature at 1000 millibars; and σ_p the standard deviation of surface pressure in millibars.

Combining equations (1) and (2)

$$\sigma = \{0.72(s'')^2 + 0.60s''s_0 + s_0^2\}^{\frac{1}{2}} k \operatorname{cosec} \phi \quad \dots\dots (3)$$

or $\sigma = \xi k$.

ξ is called the Jenkinson parameter. The three variables involved in the computation of ξ are σ_T' , T_0 and σ_p . T_0 was obtained from unpublished charts in the World Climatology Branch of the Meteorological Office. Values of σ_p for the northern hemisphere north of 10°N have been calculated by Schumann and van Rooy,⁹ and for the southern hemisphere between 15°S and 55°S by Jenkinson.⁸ Values of σ_T' were computed from published charts of σ_T at various standard pressure levels¹⁰ and from values of σ_T at the surface. The latter were obtained in the following ways:

(i) Charts of the standard deviation of monthly mean temperature at the surface over most of the continental areas and part of the oceans in the northern hemisphere have been prepared for each month by Anderson.¹¹

If σ_m represents the standard deviation of monthly mean temperature and σ_d that of daily mean temperature, then it can be shown¹² that

$$\sigma_m = \sigma_d n^{-1} [n + 2\{(n-1)r_1 + (n-2)r_2 + \dots + r_{n-1}\}]^{\frac{1}{2}}, \quad \dots\dots (4)$$

where n is the number of days in the month and r_i is the serial correlation of daily temperatures with a lag of i days.

Craddock¹² has calculated values of r_i , i varying from one to seven, for Kew for each month of the year using a very long series of temperatures covering 51 years. He showed that although these serial correlations decreased rapidly with increasing values of i they were not independent of the time of year. Using Craddock's values for the first seven values of r_i in equation (4), the ratios σ_d/σ_m are: January, 2.23; April, 2.30; July, 2.36; October, 2.32. Since r_i for higher values of i tends to oscillate within small limits about zero, the first seven values were considered enough to determine the ratio σ_d/σ_m with sufficient accuracy.

These values for Kew were assumed to be representative of world-wide values so that the relation

$$\sigma_d = 2.3 \sigma_m \quad \dots\dots (5)$$

could be used to determine values of σ_d for each mid-season month over the whole area covered by Anderson's charts of σ_m .

(ii) σ_d over the oceans of the northern and southern hemispheres was obtained from charts of the five-percentile range R_a of surface air temperature over the oceans.¹³ The frequency distribution of temperature is sufficiently close to normal for the relation

$$\sigma_d = R_a/3.3 \quad \dots\dots (6)$$

to be used.

Charts of σ_d north of 20°N and between 20°S and 50°S were constructed for each mid-season month and values for a 20-degree longitude, 10-degree latitude grid were tabulated. These were combined with grid values of σ_p , \bar{T}_0 and σ_T at the appropriate levels to obtain values of ξ at the 700-, 500- and 300-millibar levels. Charts of ξ at these levels were then drawn.

The relation between σ and ξ was investigated at each level for each mid-season month using all stations for which σ had been calculated from more than 100 wind observations. The correlation coefficient r and the standard deviation e of σ about the regression line of σ on ξ were computed and are given in Table I together with the number of stations.

TABLE I—THE RELATION BETWEEN THE OBSERVED STANDARD VECTOR DEVIATION σ AND THE DERIVED PARAMETERS ξ AND ξ'

Month				No. of stations	Pressure level	$\sigma: \xi$		$\sigma: \xi'$	
						r	e	r	e
					<i>mb</i>		<i>kt</i>		<i>kt</i>
January	..	..	..	75	{ 700	+0.68	4.6	+0.69	4.5
					{ 500	+0.62	4.7	+0.72	3.9
					{ 300	+0.39	7.1	+0.62	6.4
April	..	..	..	76	{ 700	+0.71	3.7	+0.76	2.9
					{ 500	+0.64	4.6	+0.70	4.2
					{ 300	+0.45	7.0	+0.49	6.8
July	..	..	..	56	{ 700	+0.61	3.2	+0.64	3.0
					{ 500	+0.65	3.8	+0.66	3.6
					{ 300	+0.35	7.3	+0.38	7.0
October	..	..	..	69	{ 700	+0.60	3.6	+0.61	3.8
					{ 500	+0.60	5.6	+0.62	5.8
					{ 300	+0.48	7.6	+0.33	7.8

An examination of these results suggested that for some areas too much weight was being given to surface values by using σ_T' . Accordingly a modified form of the Jenkinson parameter ξ' was computed for each level. This modified parameter was obtained by replacing σ_T' in the expression for s'' on page 5 by $\frac{1}{2}\{\sigma_T \text{ (surface)} + \sigma_T \text{ (700 mb)}\}$ at 700 millibars, σ_T (700 mb) at 500 millibars and σ_T (500 mb) at 300 millibars. Values of r and e for the relation $\sigma: \xi'$ are given in Table I.

The largest improvements in the values of e are in January at 500 millibars and in April at 700 millibars, the two months with the highest values of the standard deviation of surface temperature. In January the standard deviation of daily temperature exceeds 11°C at the surface over much of Asia and Canada but this high value is probably confined to a relatively shallow layer close to the surface. Over Canada and the U.S.S.R. in January the deviations of σ from the regression line of σ on ξ' were much greater at 700 millibars than at 500 millibars. The 500-millibar relation for this month therefore has the additional advantage of giving a derived pattern of σ equally consistent everywhere with observed values.

The parameter method of supplementing wind observations was considered most applicable for each month at the level with the lowest value of e . In the absence of a better and more convenient method the 500-millibar chart for January and the 700-millibar charts for the other months were constructed for the northern hemisphere north of 25°N. The regression equations used are given in Table II. Isopleths of σ were always drawn to fit reliable observations, and the parameter method was used only to provide a pattern for shaping the isopleths where no observations existed or where they were of doubtful significance.

TABLE II—REGRESSION EQUATIONS USED IN CONSTRUCTING THE INITIAL CHARTS

Month				Regression equation
January	..	..	..	$\sigma_{500} = 0.046 \xi'_{500} + 3.1$
April	..	..	..	$\sigma_{700} = 0.068 \xi'_{700} - 3.0$
July	..	..	..	$\sigma_{700} = 0.067 \xi'_{700} + 1.4$
October	..	..	..	$\sigma_{700} = 0.048 \xi'_{700} + 4.3$

These charts of σ were regarded as the best estimates possible because they fitted all reliable observational values and employed statistical methods only to fill in the pattern between observation points. Using these charts, a regression technique was used to help derive the 700-millibar and 300-millibar charts for January and the 500-millibar charts for the other months. The correlation between observed values of σ at these levels and derived values obtained by regression on the values of σ on the initial charts is much higher than that given by the direct regression on ξ or ξ' .

Charts of σ for April, July and October contained many more reliable observational values than the charts for 300 millibars. It was therefore considered appropriate to fill in the spaces between reliable 300-millibar values by a regression technique based on σ_{500} .

Values of r , e and the regression equations relating the standard vector deviation of wind at adjacent levels are given in Table III.

TABLE III—VALUES OF r , e AND THE REGRESSION EQUATIONS RELATING THE VALUES OF σ AT ADJACENT LEVELS

Month			No. of stations	r	e	$\sigma_{700} : \sigma_{500}$ Regression equation	r	e	$\sigma_{300} : \sigma_{500}$ Regression equation
					<i>kt</i>			<i>kt</i>	
January	..	..	75	+0.86	2.5	$\sigma_{700} = 0.69 \sigma_{500} + 2.2$	+0.82	5.6	$\sigma_{300} = 1.15 \sigma_{500} + 4.2$
April	..	..	78	+0.88	3.0	$\sigma_{500} = 1.21 \sigma_{700} + 3.2$	+0.85	3.4	$\sigma_{300} = 1.08 \sigma_{500} + 7.9$
July	..	..	56	+0.84	2.3	$\sigma_{500} = 1.24 \sigma_{700} + 1.6$	+0.84	3.3	$\sigma_{300} = 1.33 \sigma_{500} + 2.5$
October	..	..	69	+0.87	3.3	$\sigma_{500} = 1.33 \sigma_{700} + 0.1$	+0.84	4.5	$\sigma_{300} = 1.37 \sigma_{500} + 0.5$

700-, 500- and 300-millibar charts, south of 30°S.—Reliable radar-wind or radio-wind data were obtained for only seven stations south of 30°S.* The following method of constructing charts of σ was therefore adopted.

The southern hemisphere stations south of 30°S were grouped with northern hemisphere oceanic and coastal stations between 30°N and 60°N. Regression equations of σ_{700} on ξ'_{700} were computed for each month: the southern hemisphere values were combined with the opposite season values in the northern hemisphere. These equations together with the number of stations, r and e are given in Table IV. As before, these equations were then used in the construction of charts of σ south of 30°S. However, the grid values of ξ'_{700} over the southern hemisphere were based on very scanty temperature and surface-pressure data. Therefore a second method was devised to supplement this one.

The relation between the standard vector deviation of wind at the surface, σ_s , and at 700 millibars, σ_{700} , was investigated over the oceans between 30°N and 60°N. σ_s was obtained

* After the charts were completed, more Australian data were published.¹⁴ Isopleths over Australia were modified slightly to take account of these.

from unpublished charts in the World Climatology Branch of the Meteorological Office and σ_{700} from the northern hemisphere charts described above. Values were extracted at the intersection of ten-degree lines of latitude and twenty-degree lines of longitude where these intersections occur over the oceans. Thirty-nine points were considered, and the corresponding regression equations and values of r and e appear in Table IV (second row for each month).

When this second method was used to draw charts of σ_{700} , the grid-point values were very similar to those of the first method and the root mean square difference over the 72 grid points for all four seasons was 2.8 knots. The values of e for the corresponding equations in Table IV are also similar and one method cannot definitely be preferred to the other especially since the observations upon which both methods were based were very sparse. The final chart of σ_{700} south of 30°S was drawn by considering both methods, giving more weight to the σ_s method where surface observations were frequent and more weight to the ξ'_{700} method where they were sparse.

The 500-millibar and 300-millibar charts of σ were constructed by using the northern hemisphere oceanic and coastal stations and the southern hemisphere stations to obtain regression equations of σ_{500} on σ_{700} (see Table IV). These equations were used at grid points to draw the σ_{500} chart from the σ_{700} chart and this was then modified to fit the plotted wind observations. Similarly the σ_{300} chart was constructed from the σ_{500} chart and modified to fit the wind observations.

TABLE IV—RELATIONSHIPS USED IN THE CONSTRUCTION OF CHARTS OF σ_{700} , σ_{500} AND σ_{300} , SOUTH OF 30° S

Month	Parameters	No. of stations	r	e	Regression equation
<i>kt</i>					
January*	$\sigma_{700} : \xi'_{700}$	35	+0.85	2.5	$\sigma_{700} = 0.038 \xi'_{700} + 7.8$
	$\sigma_{700} : \sigma_s$	39	+0.94	2.3	$\sigma_{700} = 1.59\sigma_s - 2.4$
	$\sigma_{500} : \sigma_{700}$	34	+0.80	3.2	$\sigma_{500} = 1.09\sigma_{700} + 5.6$
	$\sigma_{300} : \sigma_{500}$	34	+0.78	4.6	$\sigma_{300} = 0.97\sigma_{500} + 11.9$
April*	$\sigma_{700} : \xi'_{700}$	35	+0.65	2.6	$\sigma_{700} = 0.063 \xi'_{700} - 2.2$
	$\sigma_{700} : \sigma_s$	39	+0.92	2.4	$\sigma_{700} = 1.63\sigma_s - 2.8$
	$\sigma_{500} : \sigma_{700}$	34	+0.80	3.1	$\sigma_{500} = 1.12\sigma_{700} + 5.5$
	$\sigma_{300} : \sigma_{500}$	34	+0.85	4.3	$\sigma_{300} = 1.23\sigma_{500} + 3.4$
July*	$\sigma_{700} : \xi'_{700}$	34	+0.75	2.4	$\sigma_{700} = 0.092 \xi'_{700} - 4.8$
	$\sigma_{700} : \sigma_s$	39	+0.96	2.0	$\sigma_{700} = 1.75\sigma_s - 2.7$
	$\sigma_{500} : \sigma_{700}$	34	+0.85	2.9	$\sigma_{500} = 1.26\sigma_{700} + 0.5$
	$\sigma_{300} : \sigma_{500}$	34	+0.90	3.6	$\sigma_{300} = 1.33\sigma_{500} + 3.0$
October*	$\sigma_{700} : \xi'_{700}$	33	+0.59	2.8	$\sigma_{700} = 0.053 \xi'_{700} + 3.3$
	$\sigma_{700} : \sigma_s$	39	+0.94	2.2	$\sigma_{700} = 1.59\sigma_s - 2.4$
	$\sigma_{500} : \sigma_{700}$	33	+0.90	2.8	$\sigma_{500} = 1.35\sigma_{700} - 0.7$
	$\sigma_{300} : \sigma_{500}$	32	+0.90	3.5	$\sigma_{300} = 1.07\sigma_{500} + 11.3$

700-, 500- and 300-millibar charts, 30°N–30°S.—The method involving the Jenkinson parameter is based on the geostrophic assumption and therefore cannot be used in the tropics. Instead, the relations $\sigma_s : \sigma_{700}$, $\sigma_{700} : \sigma_{500}$, $\sigma_{500} : \sigma_{300}$ determined for 36 tropical stations were used. Values of r and e and the regression equations are given in Table V.

* The months apply to southern hemisphere stations; opposite months were used for northern hemisphere stations in these groups.

TABLE V—RELATIONSHIPS USED IN THE CONSTRUCTION OF CHARTS OF σ_{700} , σ_{500} AND σ_{300} BETWEEN 30° N AND 30° S

Month	Parameters	r	e	Regression equation
January	$\left\{ \begin{array}{l} \sigma_S : \sigma_{700} \\ \sigma_{700} : \sigma_{500} \\ \sigma_{500} : \sigma_{300} \end{array} \right.$	$\begin{array}{c} +0.80 \\ +0.91 \\ +0.90 \end{array}$	$\begin{array}{c} 2.4 \\ 2.7 \\ 3.7 \end{array}$	$\begin{array}{l} \sigma_{700} = 1.35\sigma_S + 2.0 \\ \sigma_{500} = 1.23\sigma_{700} + 0.4 \\ \sigma_{300} = 1.33\sigma_{500} \end{array}$
April	$\left\{ \begin{array}{l} \sigma_S : \sigma_{700} \\ \sigma_{700} : \sigma_{500} \\ \sigma_{500} : \sigma_{300} \end{array} \right.$	$\begin{array}{c} +0.67 \\ +0.83 \\ +0.83 \end{array}$	$\begin{array}{c} 2.0 \\ 2.1 \\ 3.8 \end{array}$	$\begin{array}{l} \sigma_{700} = 0.86\sigma_S + 4.5 \\ \sigma_{500} = 1.16\sigma_{700} + 1.5 \\ \sigma_{300} = 1.53\sigma_{500} - 0.4 \end{array}$
July	$\left\{ \begin{array}{l} \sigma_S : \sigma_{700} \\ \sigma_{700} : \sigma_{500} \\ \sigma_{500} : \sigma_{300} \end{array} \right.$	$\begin{array}{c} +0.75 \\ +0.72 \\ +0.84 \end{array}$	$\begin{array}{c} 1.7 \\ 2.8 \\ 3.3 \end{array}$	$\begin{array}{l} \sigma_{700} = 0.83\sigma_S + 3.7 \\ \sigma_{500} = 1.20\sigma_{700} - 0.7 \\ \sigma_{300} = 1.50\sigma_{500} - 3.0 \end{array}$
October	$\left\{ \begin{array}{l} \sigma_S : \sigma_{700} \\ \sigma_{700} : \sigma_{500} \\ \sigma_{500} : \sigma_{300} \end{array} \right.$	$\begin{array}{c} +0.62 \\ +0.56 \\ +0.71 \end{array}$	$\begin{array}{c} 2.0 \\ 2.3 \\ 3.6 \end{array}$	$\begin{array}{l} \sigma_{700} = 1.15\sigma_S + 3.5 \\ \sigma_{500} = 0.73\sigma_{700} + 4.9 \\ \sigma_{300} = 1.29\sigma_{500} + 1.0 \end{array}$

200 millibar charts.—In view of the change of stability between the troposphere and the stratosphere, and the effect this has in damping the effect of tropospheric disturbances in the lower stratosphere, the tropopause may be expected to affect the vertical variation of σ . Since the tropopause usually occurs between 300 millibars and 200 millibars, its height must be taken into consideration in any statistical treatment of the relation $\sigma_{300} : \sigma_{200}$. Therefore, using charts of the mean tropopause height¹⁰, the data were divided into three groups:

- (i) polar tropopause—average pressure ≥ 250 millibars,
- (ii) polar tropopause (on more than 50 per cent of occasions)
—average pressure < 250 millibars,
- (iii) tropical tropopause (on more than 50 per cent of occasions).

The corresponding values of r and e , the number of stations and the regression equations for the relation $\sigma_{300} : \sigma_{200}$ are given in Table VI. Only stations with more than 50 observations at both levels were used. These regression equations were used in conjunction with the σ_{300} charts to obtain grid-point values and these were in turn used to supplement observations in the construction of the σ_{200} charts.

100-millibar charts.—Wind observations at 150 millibars for many stations were not published for the years 1949–53. It was therefore decided to draw up the 100-millibar charts first and then to use these and the 200-millibar charts as aids in constructing charts of σ_{150} at the middle level.

When constructing the charts of σ_{100} , the data were divided into two groups—stations with a polar tropopause (on more than 50 per cent of occasions) and those with a tropical tropopause.

Polar tropopause region: The 100-millibar level is in the lower stratosphere, and all the stations used in the following analysis had more than 50 observations at both the 200-millibar and 100-millibar levels. The root mean square differences between observed and computed values of σ_{100} using the regression technique are given in Table VII. A better relationship was found by taking into account the mean geostrophic wind speed V_g ; the geostrophic wind was chosen

TABLE VI—RELATIONSHIPS IN TROPOPAUSE PRESSURE GROUPS USED IN THE CONSTRUCTION OF CHARTS OF σ_{200}

Month	Tropopause pressure group	No. of stations	r	e	Regression equation
January*	(i)	21	+0.91	2.8	$\sigma_{200} = 0.71 \sigma_{300} + 3.1$
	(ii)	19	+0.66	4.0	$\sigma_{200} = 0.58 \sigma_{300} + 13.4$
	(iii)	45	+0.92	3.4	$\sigma_{200} = 0.81 \sigma_{300} + 7.4$
April*	(i)	26	+0.88	3.3	$\sigma_{200} = 0.86 \sigma_{300} - 6.7$
	(ii)	18	+0.77	3.7	$\sigma_{200} = 0.65 \sigma_{300} + 7.1$
	(iii)	47	+0.96	3.6	$\sigma_{200} = 1.03 \sigma_{300} + 3.5$
July*	(i)	7	+0.77	3.9	$\sigma_{200} = 1.03 \sigma_{300} - 14.5$
	(ii)	32	+0.70	4.4	$\sigma_{200} = 0.89 \sigma_{300} - 0.8$
	(iii)	52	+0.86	3.2	$\sigma_{200} = 0.80 \sigma_{300} + 8.8$
October*	(i)	16	+0.92	3.2	$\sigma_{200} = 1.05 \sigma_{300} - 10.7$
	(ii)	26	+0.83	3.6	$\sigma_{200} = 0.84 \sigma_{300} + 0.4$
	(iii)	54	+0.95	3.2	$\sigma_{200} = 0.97 \sigma_{300} + 5.3$

because world-wide charts of contour height over the period of analysis have already been published.²

A parameter C is defined as $C = \sigma/V_g$. It has been shown⁴ that given a normal circular distribution, the constancy, $100 V_R/V_s$, is uniquely determined by the value σ/V_R . V_s is the scalar mean speed and V_R the resultant wind speed. V_R is approximately equal to V_g ; C can therefore be considered as related to the constancy. The ratio of C between the 100-millibar and 200-millibar levels, $P = C_{100}/C_{200}$, was calculated for each station for which wind data up to 100 millibars were available and plotted as a function of latitude ϕ (Figure 1). The curves show that in the stratosphere the constancy decreases with height at high latitudes but increases with height at lower latitudes. All stations poleward of 20 degrees of latitude were considered, with the exception of five low-latitude stations in July (Brownsville, Bahrain, Clark Field, Khartoum and Miami) whose soundings sample the belt of strong easterlies which occur at 100 millibars in July. The relation appears to break down here and these areas have been grouped with the 20°N–20°S region; the method used is described below.

Using the values of P given by the curves in Figure 1 and calculating the ratio V_{g100}/V_{g200} from average contour charts², values of σ_{100} at 10-degree latitude–20-degree longitude grid points were obtained from the relation

$$\sigma_{100} = \sigma_{200} P(\phi) \frac{V_{g100}}{V_{g200}}.$$

The root mean square differences between observed and computed values of σ_{100} using this technique and the regression technique are given in Table VII.

Tropical tropopause region: The method used to supplement observations in the polar tropopause region was used down to latitude 20° (except in July). The differences between observed and calculated values tended to be largest in the lowest latitudes, and the method cannot be used equatorward of 20° latitude.

* The months apply to northern hemisphere stations; opposite months were used for southern hemisphere stations in these groups.

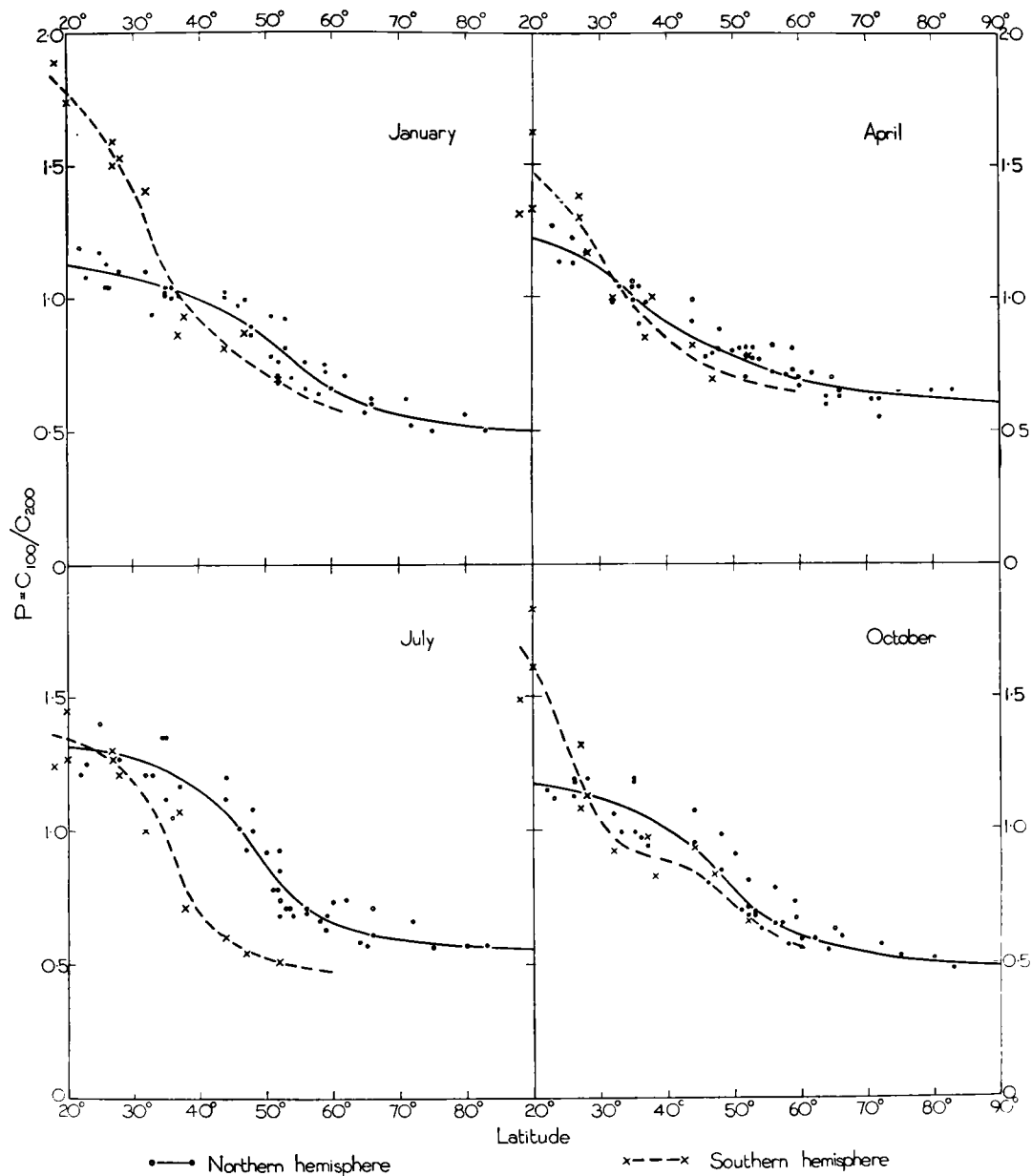
FIGURE 1—CURVES OF P AS A FUNCTION OF LATITUDE

TABLE VII—ROOT MEAN SQUARE DIFFERENCES BETWEEN OBSERVED AND CALCULATED VALUES OF σ_{100}

Month	Method		No. of observations
	Regression on σ_{200}	$P(\phi)$ technique	
	kt	kt	
January	4.6	2.9	42
April	4.0	3.1	45
July	4.8	3.8	43
October	4.1	3.8	42

Correlation coefficients were computed between σ_{200} and σ_{100} at all stations between 20°N and 20°S with more than 50 observations at both levels for each of the four months. These were very low and the standard deviation of σ_{100} values from the regression line were large. This is because in some areas, particularly where strong easterlies exist at 100 millibars (notably in July), the standard vector deviation decreases more slowly between 200 millibars and 100 millibars, and in some cases it increases, for example at Khartoum, Bahrain and Aden in July.

No analytical method could be devised which was reasonably applicable to the whole of the tropics for each season. Consequently the tropical areas linking the higher latitudes, already constructed, were drawn in by eye, taking account of the following two points:

(i) In areas where easterly winds at 200 millibars were maintained or increased at 100 millibars there is a tendency for the standard vector deviation to be maintained or to increase.

(ii) Rough estimates of the standard vector deviation of wind can be obtained from detailed studies of the wind field over the Marshall Islands.¹⁴ These suggest that at 100 millibars the standard vector deviation decreases southwards to a minimum of about 15 to 20 knots at about latitude 10°N and begins to rise again in the vicinity of the equator. Although these studies only deal with March, April, May, October and November, the three trans-equator sets of observations that exist (in Africa, South-East Asia–Australia, and the Central Pacific) suggest that a pattern involving a secondary maximum zone in the vicinity of the equator with a belt of lower standard vector deviation to the north and/or south is sometimes a feature of other longitudes.

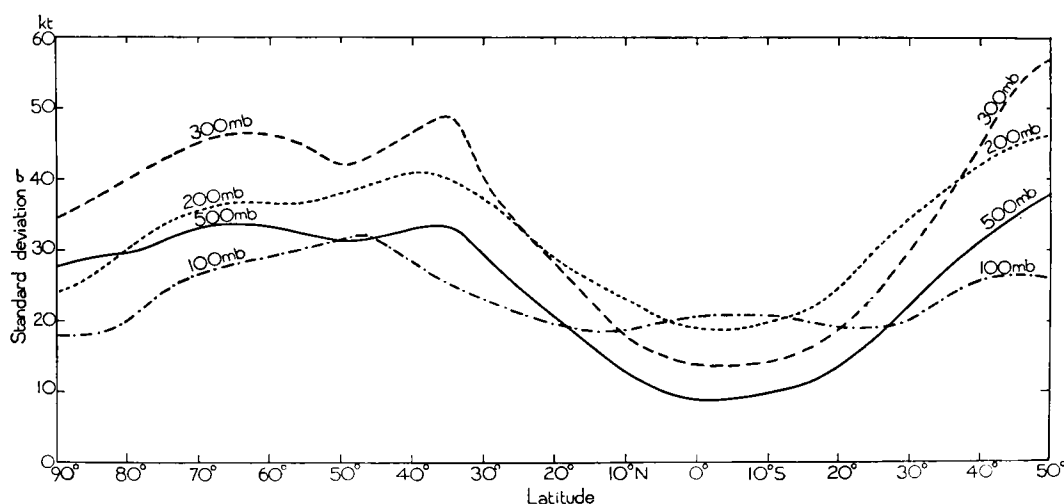
150-millibar charts.—Values of σ_{200} , σ_{150} and σ_{100} at all stations in each month with more than 50 observations at each level were considered. The regression equations of σ_{150} on σ_{100} and σ_{200} were computed. The equations and the standard deviation of σ_{150} about the regression line are given in Table VIII. The equations were then used, together with values of σ_{200} and σ_{100} taken off the appropriate charts, to obtain grid values of σ_{150} to supplement the observations when constructing the chart of σ_{150} .

Final adjustments to the charts.—After the initial drawing of all the charts for each month was completed, the method of mutual adjustment used in *Geophysical Memoirs No. 85*¹ (§ 14, page 30) was applied. Plots of σ against latitude were made for each of twelve different longitudes, the curves for each level being plotted on the same diagram. Typical of these is the variation of σ along longitude 30°E in January (Figure 2). Mutual adjustments between one level and another within the framework of wind observations were made in the light of these diagrams to ensure that the charts were reasonably consistent.

TABLE VIII—THE RELATION BETWEEN σ_{150} , σ_{100} AND σ_{200}

Month	No. of stations	Regression equation	Root mean square deviation of σ_{150} from regression line
			kt
January	40	$\sigma_{150} = 0.61 \sigma_{100} + 0.37 \sigma_{200}$	3.5
April	46	$\sigma_{150} = 0.87 \sigma_{100} + 0.35 \sigma_{200}$	3.4
July	38	$\sigma_{150} = 0.84 \sigma_{100} + 0.37 \sigma_{200}$	3.5
October	47	$\sigma_{150} = 0.54 \sigma_{100} + 0.40 \sigma_{200}$	4.1

The sample curves shown in Figure 2 were chosen for reproduction because the longitude and the season coincide with those published in *Geophysical Memoirs No. 85* (reproduced here in Figure 3). Since the charts presented here are a revision of those in *Geophysical Memoirs No. 85*, a detailed and comprehensive comparison is unnecessary. However, the two diagrams Figures 2 and 3 illustrate the major difference between the original and the revised charts. The original charts depict high values at the highest level (130 millibars) in the tropics; this is in direct contrast with the low values at 150 millibars and 100 millibars given in the revised charts which are based on reliable sets of wind observations at many tropical stations.

FIGURE 2—CROSS-SECTIONS OF σ ALONG 30°E LONGITUDE (REVISED VALUES)

Late in the preparation of the charts further data became available from two main sources:

(i) Australian upper wind summaries¹⁵ were obtained and some minor alterations were necessary in the light of these.

(ii) Crutcher⁵ has published detailed statistical summaries of upper wind parameters on a seasonal basis at standard pressure levels up to 200 millibars for numerous stations in the northern hemisphere. In general, the differences between these values of standard vector deviation and the charts presented here are small and within the differences to be expected since both sets of data are necessarily heterogeneous; also, Crutcher's values are seasonal whereas the charts refer to mid-season months. However, minor alterations were made to the charts in the Alaska-Canada area where Crutcher had data from more stations than were available in England.

The final charts appear on pages 30 to 101.

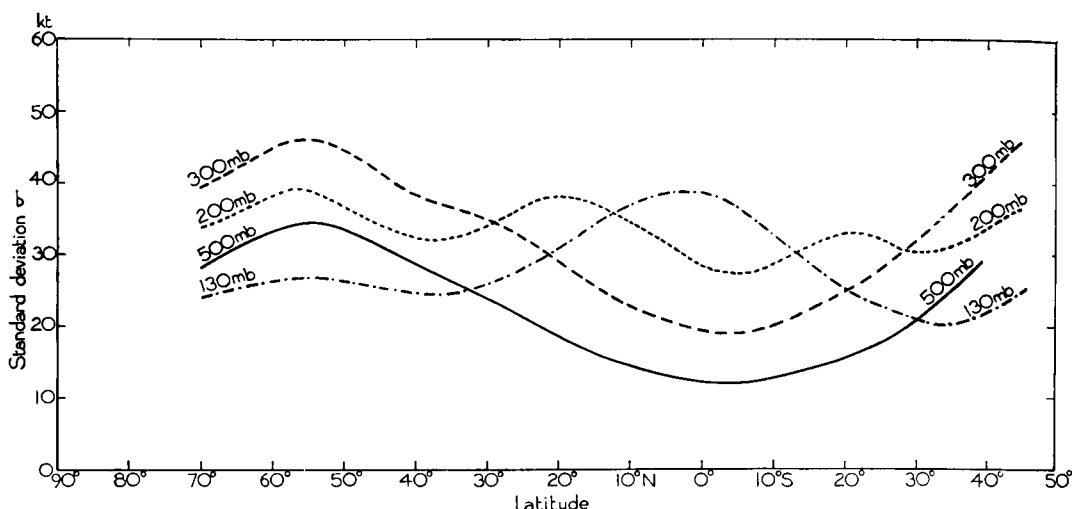


FIGURE 3—CROSS-SECTIONS OF σ ALONG 30°E LONGITUDE
(GEOPHYSICAL MEMOIRS No. 85¹ VALUES)

§ 4—CONSTRUCTION OF A WIND ROSE

If the upper winds are distributed about the vector mean wind in accordance with the normal law of errors (that is if there is a normal circular distribution of winds), it is possible to represent any wind distribution by only two parameters, the vector mean wind \mathbf{V}_R and the standard vector deviation σ . Conversely, given these two parameters it is possible to construct the wind rose. Revised charts of the vector mean wind speed and direction have already been published³ and revised charts of the standard vector deviation of wind are published here. The methods of constructing a wind rose from \mathbf{V}_R and σ is described fully in *Geophysical Memoirs No. 85¹* and elsewhere; it is repeated below only in outline. The requisite tables are also reproduced with corrections and checks incorporated as suggested by Knighting.⁴

The relation between V_R , V_S and σ .— σ is first converted into the constancy q , defined as $100V_R/V_S$ where V_S is the scalar mean wind. The constancy q is uniquely determined by σ/V_R except when V_R approaches zero when q also approaches zero; σ/V_R becomes large and σ is approximately given by $1.13V_S$.

The relation between V_R , V_S and σ is

$$V_S = \frac{1}{2}\sqrt{\pi\sigma} {}_1F_1\left(\frac{1}{2}, 1, -V_R^2/\sigma^2\right)$$

where ${}_1F_1$ is the confluent hypergeometric function which is tabulated.¹⁶ The table relating σ/V_R to q (Table II in *Geophysical Memoirs No. 85*) has been modified and is given here as Table IX.

A series of tables for different values of q are reprinted from *Geophysical Memoirs No. 85* in Appendix I. They give frequencies calculated for steps of 20 degrees of ϕ , the angle which an individual wind vector makes with the resultant direction, and for suitable steps of V/V_R . To construct a wind rose it is therefore only necessary to express the required direction ranges and speed ranges in terms of ϕ and V/V_R . If the ranges of V/V_R required do not coincide with those given in the Appendix tables, combination and/or subdivision of the range-groups in these tables will be necessary, that is interpolation within the table will be necessary. If the derived value of

TABLE IX—CONVERSION OF σ/V_R TO q

Range of σ/V_R	q	Range of σ/V_R	q	Range of σ/V_R	q
Over 45.5	0	2.45–2.83	40	0.87–1.01	80
14.9–45.5	5	2.14–2.45	45	0.72–0.87	85
8.9–14.9	10	1.88–2.14	50	0.55–0.72	90
6.4–8.9	15	1.67–1.88	55	0.40–0.55	95
4.9–6.4	20	1.49–1.67	60	0.25–0.32	98
3.97–4.9	25	1.32–1.49	65	0.25–0.32	98
3.32–3.97	30	1.15–1.32	70	0.14–0.25	99
2.83–3.32	35	1.01–1.15	75		

q falls between those for which tables are published, interpolation between two tables will be necessary. It should be noted that in using Table 13 for $q = 0$ speeds are to be expressed in terms of σ and not V_R ; further, since there is no distinction as to direction, the totals for “all directions” can be used divided by the number of directions required. Frequencies for 20° limits are given for comparison with Tables 1 to 12. For general purposes, especially in view of the probable error in the estimate of q or σ , it seems sufficient to calculate q to the nearest 5 per cent (1–2½ per cent between 90 and 100 per cent) and to use the frequency table applicable to this approximate value or interpolate between the frequency tables on either side. Finally combination and/or subdivision of the frequencies for different ranges of ϕ will probably be necessary. (The frequency distributions derived will be symmetric about the line of the vector mean wind.) A sample calculation from *Geophysical Memoirs No. 85* is reproduced below.

Independent checks.—Knighting⁴ has pointed out that since much interpolation is probably necessary in constructing a wind rose by this method, an independent check is desirable. The checks suggested by Knighting were carried out for each of the q -tables. These showed an agreement which was never worse than three per mille and except in three cases was better than one per mille. Accordingly the q -tables have been reproduced without alteration in Appendix I.

An example of the calculation.—As an example, the frequency distribution of winds at the 500-millibar level over Larkhill was calculated from March to May using 536 observations for the years 1940–45. The “observed” frequencies (Table XI) gave a vector mean of 16.5 knots from 283° east of north and a scalar mean of 33.0 knots, so that $q = 50$ and the theoretical frequencies were calculated from Table 8.

The first step is to combine or subdivide the speed groups of Table 8. This is shown in Table XII. The first column gives the divisions between the speed ranges required for the complete summary (in this case those of Table XI). The second column gives the ratio of the “dividing” speeds to V_R (in this case 16.5 knots), so that the speeds are reduced to the units given in the Appendix table. Since in Table 8 the ranges of V/V_R are 0.4 in width, V/V_R in computing the theoretical summary is expressed to the nearest 0.04 (a tenth of the width of the range). The body of Table XII shows the splitting up and combining of the per mille frequencies of Table 8. For example, for the division at $V/V_R = 0.20$, the first line of Table 8 is divided in half, 0.5 being included in the “calms” (0–3 knots) and 0.5 in the speed range 3–14 knots; for the division at $V/V_R = 0.84$, 0.1 of the line for V/V_R between 0.8 and 1.2 is included in the range 3–14 knots and the remaining 0.9 in the range 14–27 knots. The total “all directions” is expressed to the nearest 0.2 and the sum of the figures along each line, adjusted if necessary, should be exactly half the right-hand total. The central line (in Table XII) of each speed group is compounded of the frequencies of the speed ranges between the divisions for the group. In the group 3–14 knots, for example, the middle line is the line 0.4–0.8 of Table 8.

Totals of the cells are given in italics at the right-hand side of each column in Table XII (stage 2 of the computations). Each of the horizontal lines of italic figures should add up to half the corresponding frequency (also italic) in the "all directions" column and the total of this column should be $1000\cdot0$.

In the example chosen $q = 50$ so that only one table of the Appendix has been used. If, for example, q had a value between 43 and 47, stages 1 and 2 would be repeated using Table 9. For this table, V/V_R (at the divisions between the speed groups) would be expressed to the nearest $0\cdot06$ to facilitate computation, namely:

V	=	3	14	27	41	54	. . .
V/V_R	=	0.18	0.84	1.62	2.46	3.30	. . .

A new table would then be formed such that the frequency in each cell was the mean of the corresponding italic frequencies (stage 2) for $q = 50$ and $q = 40$. "All directions" frequencies should still be given to the nearest $0\cdot2$ and should total $1000\cdot0$, and the "throwing" of the means should be arranged so that each "all directions" frequency is exactly twice the sum of the line at the end of which it stands. Up to this stage we are dealing with only half the summary, from $\phi = 0^\circ$ to $\phi = 180^\circ$, because it is symmetrical about $\phi = 0$.

The next step, shown in Table XIII, is the splitting up and combining of the frequencies for different ranges of ϕ to give the larger direction grouping of (in this case) an eight-point summary. It is sufficient to work to the nearest $2\frac{1}{2}^\circ$ in direction, that is to one-eighth of the range given in each column of Table XII. Thus the direction of the vector mean wind (283° east of north) is taken to be $282\frac{1}{2}^\circ$, distant $77\frac{1}{2}^\circ$ from the centre of the direction group, N, and the frequencies for N are therefore those lying between $\phi = 55^\circ$ and $\phi = 100^\circ$. Similarly those for NE lie between $\phi = 100^\circ$ and $\phi = 145^\circ$. Divisions are made at $55^\circ, 100^\circ, 145^\circ, \dots$ in much the same way as for the speeds in stage 1 (Table XII). The division at 55° , for example, is made by throwing one-quarter of the column $40\text{--}60^\circ$ of Table XII into the group for N and the remaining three-quarters into the group for NW. It is useful to sum the two portions of each column divided in this way and check that they are in the correct ratio. For the division at 55° the sum, $19\cdot7$, is nearly one-third of the other sum, $59\cdot3$. For an eight- or sixteen-point summary, it is preferable to work in eighths, since the range for each direction point is a multiple of $2\frac{1}{2}^\circ$; otherwise however, as for example for units of ten degrees of direction, tenths are simpler.

Stage 3 is reasonably simple, but care must be taken to see that the components of any division are thrown into the correct direction groups especially near $\phi = 0^\circ$ and $\phi = 180^\circ$. In group N, the column commencing with $12\cdot9$ is the sum of columns $60\text{--}80^\circ$ and $80\text{--}100^\circ$ of Table XII; no splitting up is required at 100° (in this example). The column, starting $10\cdot7$, of NE is composed of the columns $100\text{--}120^\circ$ and $120\text{--}140^\circ$, and then a division must be made at 145° throwing one-quarter to NE and three-quarters to E. The next division occurs at 170° , but, although this is in the column $160\text{--}180^\circ$, the whole of the column ($160\text{--}180^\circ$) also must be inserted in E to make up the 45 degrees of direction:

15 degrees from column $140\text{--}160^\circ$
 20 degrees from column $160\text{--}180^\circ$ and a further
 10 degrees from column $160\text{--}180^\circ$.

Since each direction group (for an eight-point summary) is composed of 45 degrees, the columns of stage 2 (Table XII) each occur twice (whole or divided) in stage 3 (Table XIII), and so when the components of the frequency cells have been totalled as in stage 4 (Table XIV) the sums of the lines will equal the totals ("all directions") at the ends.

Table XIV gives the theoretical frequencies per mille according to the cell divisions required. The particular arrangement of cells adopted in this example is for comparison with the given

summary of observations in Table XI. The frequencies, however, are not correct to 0.1 per mille as given in the table. The reason for retaining all the digits is solely for ease in checking. Percentage frequencies (derived from Table XIV) are given in Table XV with the "observed" values (derived from Table XI) for comparison. These have been adjusted slightly so that the "rounded off" figures agree with the totals.

TABLE XI—WINDS AT 500 MILLIBARS AT LARKHILL, MARCH-MAY 1940-45
536 observations, $V_R = 16.5$ knots, $q = 50$

Speed	N	NE	E	SE	S	SW	W	NW	All directions
<i>kt</i>	<i>No. of observations</i>								
0-3	..	..	..	..	..	..	..	..	6
3-14	7	8	6	6	7	15	13	7	69
14-27	29	12	11	10	26	29	30	27	174
27-41	20	5	7	4	16	32	43	26	153
41-54	11	5	2	..	2	14	21	19	74
54-68	4	..	..	1	3	3	14	8	33
68-81	4	..	..	..	1	2	4	7	18
81-95	1	..	..	..	..	..	4	4	9
All speeds	76	30	26	21	55	95	129	98	536

TABLE XII—COMPUTATION OF THEORETICAL WIND SUMMARY, STAGES 1 AND 2
 $V_R = 16.5$ knots, $q = 50$

V	V/V_R^*	Ratio of division	Angle between resultant wind direction and individual wind vector (ϕ)																	All directions			
			0-20°	20-40°			40-60°		60-80°		80-100°		100-120°		120-140°		140-160°		160-180°				
kt			<i>per mille</i>																				
3	0.20	0.5																				15.0	15.0
		0.5	0.9	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.7						15.0		
		0.1	6.2	8.1	5.9	7.8	5.6	7.4	5.1	6.8	4.6	6.1	4.2	5.6	3.8	5.1	3.6	4.8	3.5	4.6	85.0	112.6	
14	0.84		1.0	1.0	0.9		0.9		0.8		0.7		0.6	0.5	0.4		0.4		0.4		12.6		
		0.9	9.6		9.0		8.1		7.0		5.9		5.0		4.3		4.0		3.7		113.2		
		0.1	14.3	25.6	13.2	23.7	11.3	20.6	9.2	17.1	7.4	14.0	5.8	11.3	4.7	9.4	4.1	8.4	3.8	7.8	147.6	275.8	
27	1.64		1.7		1.5		1.2		0.9		0.7		0.5		0.4		0.3		0.3		15.0		
		0.9	14.6		13.2		10.9		8.4		6.2		4.6		3.6		3.0		2.6		134.2		
		0.2	16.3	33.8	14.4	30.1	11.4	24.2	8.3	18.0	5.8	12.9	4.0	9.2	2.9	6.9	2.3	5.6	2.0	4.8	134.8	291.0	
41	2.48		2.9		2.5		1.9		1.3		0.9		0.6		0.4		0.3		0.2		22.0		
		0.8	11.8		10.2		7.7		5.3		3.4		2.2		1.5		1.1		1.0		88.4		
		0.2	12.0	25.6	10.1	21.8	7.3	16.0	4.7	10.6	2.9	6.7	1.8	4.2	1.1	2.7	0.8	2.0	0.7	1.7	82.8	182.6	
54	3.28		1.8		1.5		1.0		0.6		0.4		0.2		0.1		0.1		0.1		11.4		
		0.8	7.0		5.8		4.0		2.5		1.4		0.8		0.5		0.3		0.4		45.4		
		0.3	6.0	14.1	4.8	11.5	3.2	7.8	1.8	4.6	1.0	2.5	0.5	1.4	0.3	0.8	0.2	0.5	0.2	0.6	36.0	87.6	
68	4.12		1.1		0.9		0.6		0.3		0.1		0.1								6.2		
		0.7	2.6		2.0		1.2		0.7		0.4		0.1		0.1		0.1		0.1		14.6		
		0.3	2.1	5.0	1.6	3.9	1.0	2.3	0.5	1.3	0.2	0.6	0.1	0.2	0.1	0.2	0.1	0.1	0.1	0.1	11.2	27.4	
81	4.92		0.3		0.3		0.1		0.1												1.6		
		0.7	0.8		0.5		0.4		0.1		0.1		0.1		0.1						4.0		
		0.5	1.4		0.4		1.0		0.2		0.6		0.1		0.2		0.1				2.6	7.0	
95	5.76		0.1		0.1				0.1		0.2		0.1		0.2		0.1				0.4		
		0.6	0.1		0.1		0.1		0.1												0.6		
		0.1	0.2		0.1		0.2		0.1												0.4	1.0	

* To nearest 0.04.

1000.0

TABLE XIII—COMPUTATION OF THEORETICAL SUMMARY, STAGE 3
Resultant direction = 283° east of north (taken as 282½°)

	N		NE		E		SE		S		SW		W		NW					
	Angle between resultant wind direction and individual wind vector (ϕ)																			
V	55°	100°	145° - 180° - 170°		125°		80°		35° - 0° - 10°		55°									
	$\frac{1}{4}$		$\frac{1}{4}$	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{3}{4}$	$\frac{1}{4}$		$\frac{1}{4}$	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{3}{4}$							
kt	per mille																			
3-14	1.9	12.9	10.7	1.2	3.6	4.6	2.3	2.3	4.8	3.8	1.3	11.7	14.2	1.9	5.9	8.1	4.1	4.0	7.8	5.5
14-27	5.1	31.1	20.7	2.1	6.3	7.8	3.9	3.9	8.4	7.1	2.3	25.3	37.7	5.9	17.8	25.6	12.8	12.8	23.7	15.5
27-41	6.1	30.9	16.1	1.4	4.2	4.8	2.4	2.4	5.6	5.2	1.7	22.1	42.2	7.5	22.6	33.8	16.9	16.9	30.1	18.1
41-54	4.0	17.3	6.9	0.5	1.5	1.7	0.9	0.8	2.0	2.0	0.7	10.9	26.6	5.5	16.3	25.6	12.8	12.8	21.8	12.0
54-68	1.9	7.1	2.2	0.1	0.4	0.6	0.3	0.3	0.5	0.6	0.2	3.9	12.4	2.9	8.6	14.1	7.1	7.0	11.5	5.9
68-81	0.6	1.9	0.4	..	0.1	0.1	0.1	..	0.1	0.1	0.1	0.8	3.6	1.0	2.9	5.0	2.5	2.5	3.9	1.7
81-95	0.1	0.4	0.1	..	..	..	..	..	..	..	..	0.3	0.8	0.3	0.7	1.4	0.7	0.7	1.0	0.5
Over 95	..	..	..	..	..	..	..	..	..	..	..	0.1	0.1	0.1	0.2	0.1	0.1	0.2	0.1	..
All speeds	19.7			5.3	16.1				18.8	6.3		25.1	74.9						59.3	

TABLE XIV—COMPUTATION OF THEORETICAL SUMMARY, STAGE 4

V	N	NE	E	SE	S	SW	W	NW	All directions
<i>kt</i>	<i>per mille</i>								
0-3	..	..	..	..	..	..	..	..	15.0
3-14	14.8	11.9	10.5	10.9	13.0	16.1	18.1	17.3	112.6
14-27	36.2	22.8	18.0	19.4	27.6	43.6	56.2	52.0	275.8
27-41	37.0	17.5	11.4	13.2	23.8	49.7	73.3	65.1	291.0
41-54	21.3	7.4	4.1	4.8	11.6	32.1	54.7	46.6	182.6
54-68	9.0	2.3	1.3	1.4	4.1	15.3	29.8	24.4	87.6
68-81	2.5	0.4	0.3	0.2	0.9	4.6	10.4	8.1	27.4
81-95	0.5	0.1	..	..	0.3	1.1	2.8	2.2	7.0
Over 95	..	..	..	..	..	0.2	0.4	0.4	1.0
All speeds	121.3	62.4	45.6	49.9	81.3	162.7	245.7	216.1	1000.0

TABLE XV—COMPARISON OF COMPUTED FREQUENCIES WITH OBSERVED FREQUENCIES, LARKHILL,
MARCH-MAY 1940-45

536 observations. Vector mean wind: resultant direction = 283°, speed = 16.5 knots; constancy (*q*) = 50
The observed frequencies are given in brackets

V	N	NE	E	SE	S	SW	W	NW	All directions
<i>kt</i>	<i>per cent</i>								
0-3	..	..	..	..	..	..	..	..	1.5 (1.1)
3-14	1.5 (1.3)	1.2 (1.5)	1.1 (1.1)	1.1 (1.1)	1.3 (1.3)	1.6 (3)	1.8 (2)	1.7 (1.3)	11 (13)
14-27	4 (5)	2 (2)	1.8 (2)	1.9 (1.9)	3 (5)	4 (5)	6 (6)	5 (5)	28 (32)
27-41	4 (4)	2 (0.9)	1.1 (1.3)	1.3 (0.7)	2 (3)	5 (6)	7 (8)	6 (5)	29 (29)
41-54	2 (2)	0.7 (0.9)	0.4 (0.4)	0.5 (0.0)	1.2 (0.4)	3 (3)	5 (4)	5 (3)	18 (14)
54-68	0.9 (0.7)	0.2	0.1	0.1 (0.2)	0.4 (0.6)	1.5 (0.6)	3 (2)	3 (1.5)	9 (6)
68-81	0.3 (0.7)	..	..	..	0.1 (0.2)	0.5 (0.4)	1.0 (0.8)	0.8 (1.3)	3 (3)
81-95	0.1 (0.2)	..	..	..	..	0.1	0.3 (0.8)	0.2 (0.7)	0.7 (1.7)
All speeds	13 (14)	6 (5)	5 (5)	5 (4)	8 (11)	16 (18)	24 (24)	22 (18)	100 (100)

The magnitude of variations about the vector mean wind.—It is often important to know the percentage of winds that lie within a circle of given radius centred on the end point of the vector mean wind. These percentages, with radii in terms of σ are given in Table XVI.

TABLE XVI—PERCENTAGE FREQUENCY OF END POINTS OF INDIVIDUAL VECTOR WINDS WHICH OCCUR WITHIN CIRCLES OF A GIVEN RADIUS CENTRED ON THE END POINT OF THE VECTOR WIND

Percentage frequency (γ) ..	25	50	62.5	75	80	85	90	95
Radius/ σ	0.54	0.83	1.00	1.18	1.27	1.38	1.52	1.73

Values of radius/ σ are computed from the expression

$$\left\{ \log_e \left(1 - \frac{\gamma}{100} \right)^{-1} \right\}^{\frac{1}{2}}.$$

The mean vector departure from the end point of the vector mean is

$$\frac{\sigma}{2} \sqrt{\pi} = 0.89 \sigma.$$

BIBLIOGRAPHY

1. BROOKS, C. E. P., DURST, C. S., CARRUTHERS, N., DEWAR, D. and SAWYER, J. S. ; Upper winds over the world. *Geophys. Mem., London*, **10**, No. 85, 1950.
2. HEASTIE, H. and STEPHENSON, P. M. ; Upper winds over the world, Parts I and II. *Geophys. Mem., London*, **13**, No. 103, 1960.
3. BROOKS, C. E. P., DURST, C. S. and CARRUTHERS, N. ; Upper winds over the world, Part I. The frequency distribution of winds at a point in the free air. *Quart. J. R. met. Soc., London*, **72**, 1946, p. 55.
4. KNIGHTING, E. ; Correspondence. Upper winds over the world. *Quart. J. R. met. Soc., London*, **80**, 1954, p. 239.
5. CRUTCHER, H. L. ; Upper wind distribution statistical parameter estimates. *Tech. Pap. U.S. Weath. Bur., Washington, D.C.*, No. 34, 1958.
6. JENKINSON, A. F. ; The relation between standard deviation of contour height and standard vector deviation of wind. *Quart. J. R. met. Soc., London*, **82**, 1956, p. 198.
7. BUELL, C. E. ; An approximate relation between the variability of wind and the variability of pressure or height in the atmosphere. *Bull. Amer. met. Soc., Lancaster, Pa.*, **38**, 1957, p. 47.
8. JENKINSON, A. F. ; The relationship between standard deviation of contour height and standard vector deviation of wind, with practical applications. *Met. Res. Pap., London*, No. 869, 1954.
9. SCHUMANN, T. E. W. and VAN ROOY, M. P. ; Analysis of the standard deviation of atmospheric pressure over the northern hemisphere. South African Weather Bureau, Department of Transport, W. B. 16, Pretoria, 1951.
10. GOLDIE, N., MOORE, J. G. and AUSTIN, E. E. ; Upper air temperature over the world. *Geophys. Mem., London*, **13**, No. 101, 1958.
11. ANDERSON, L. C. ; The standard deviation as a measure of variability of monthly mean temperature in the northern hemisphere. Office of the Quartermaster-General, Research and Development Center, Environmental Protection Division. *Tech. Rep., Washington, D.C.*, No. EP-16, 1955.
12. CRADDOCK, J. M. ; The serial correlation of daily mean temperatures at Kew Observatory. *Met. Res. Pap., London*, No. 1023, 1956.
13. London, Meteorological Office ; Monthly meteorological charts for the oceans. London, 1947–1950.
14. KORSHOVER, J. ; Mean winds over the Marshall Islands, March 1951, October 1952, November 1952, April 1951 and May 1951. *Sci. Rep. Inst. Geophys., Oahu Research Center, University of California, Los Angeles*. Nos. 1, 4, 6, 8, 10. Contract No. AF 19 (604)–546, 1954–55.

15. LAMOND, M. ; Tabulated upper wind data for Australia. *Proj. Rep. Bur. Met., Melbourne*, No. 55/688, 1959.
16. London, British Association for the Advancement of Science ; Report 1927. *Rep. Brit. Ass., London*, 1928.

APPENDIX I—SOURCES OF DATA

GENERAL

1. CRUTCHER, H. L. ; Upper wind distribution statistical parameter estimates. *Tech. Pap. U.S. Weath. Bur., Washington, D.C.*, No. 34, 1958.
2. London, Meteorological Office ; Upper wind summaries. Unpublished.
3. Washington, United States Weather Bureau ; *Daily Series Synoptic Weather Maps*. Washington, D.C.

AFRICA

4. Pretoria, South African Weather Bureau, Department of Transport ; Reports for the year. Pretoria.

AMERICA

5. Buenos Aires, Ministerio de Asuntos Tecnicos ; Upper air wind summaries. Unpublished.
6. HENRY, T. J. G., NURKLIK, A. and THORN, W. A. ; Vector mean winds and standard vector deviations for selected rawin stations in Canada. *Circ. met. Div. Dep. Transp., Toronto*, No. 2507, 1954.
7. Toronto, Department of Transport, Meteorological Division ; Climatological Summaries, Toronto, 1955-58.

ASIA

8. Poona, India Meteorological Department ; Upper air data. Poona.
9. SCHMIDT, F. H. ; Upper winds over Indonesia and Western New Guinea. *Djawatan Meteorologi dan Geofisik, Verhandelingen* No. 45, Djakarta, 1952.
10. SCOTT, J. R. ; Wind statistics at Singapore ; *Quart. J. R. met. Soc., London*, **83**, 1957, p. 381.
11. Tokyo, Central Meteorological Observatory ; *Aerol. Data Japan, Tokyo*.

AUSTRALASIA

12. FARKAS, E. ; Upper winds over Canton Island and Tarawa. *Tech. Notes, N.Z. met. Serv., Wellington*, No. 115, 1954.
13. FARKAS, E. ; Upper winds over Invercargill. *Tech. Notes, N.Z. met. Serv., Wellington*, No. 121, 1955.
14. Melbourne, Commonwealth Bureau of Meteorology ; Upper wind manuscript data. Unpublished.
15. PORTER, E. M. ; Upper winds over Nandi and Auckland. *Tech. Notes, N.Z. met. Serv., Wellington*, No. 92, 1952.
16. PORTER, E. M. ; Upper winds over Invercargill. *Tech. Notes, N.Z. met. Serv., Wellington*, No. 94, 1952.
17. Wellington, New Zealand Meteorological Service ; *Daily Weather Bulletins*, Wellington.

APPENDIX II—LIST OF SYMBOLS

C	=	σ/V_g
e	=	standard deviation of σ about the regression line
g	=	acceleration due to gravity
k	=	" universal " constant (constant in space and time)
n	=	number of days in the month
p	=	pressure
P	=	C_{100}/C_{200}
q	=	$100 V_R/V_S$
r	=	correlation coefficient

R	=	gas constant
r_i	=	serial correlation of daily temperatures with a lag of i days
R_a	=	five-percentile range of surface air temperature
s	=	standard deviation of contour height
s^*	=	$\frac{R}{g} \ln \left(\frac{1000}{p} \right) \sigma'_T$
s_o	=	$\frac{R}{g} \bar{T}_o \frac{\sigma_p}{1000}$
\bar{T}_o	=	average temperature at 1000 millibars
V	=	instantaneous wind speed
V_g	=	mean geostrophic wind speed
V_R	=	mean vector wind speed
\mathbf{V}_R	=	mean vector wind
V_s	=	mean scalar wind
γ	=	percentage frequency
ξ	=	Jenkinson parameter
ξ'	=	modified Jenkinson parameter
σ	=	standard vector deviation of wind
σ_d	=	standard deviation of daily mean temperatures
σ_m	=	standard deviation of monthly mean temperatures
σ_p	=	standard deviation of surface pressure
σ_T	=	standard deviation of temperature
σ'_T	=	the root mean square of values of σ_T at fixed pressure levels
ϕ	=	latitude

APPENDIX III—TABLES FOR THE CONSTRUCTION OF WIND ROSES; FREQUENCY DISTRIBUTION

TABLE 1
 $q = 98, \sigma/V_R = 0.28$

V/V_R	ϕ			All directions
	0-20°	20-40°	40-60°	
	<i>per mille</i>			
0.0-0.1	—	—	—	—
0.1-0.2	—	—	—	—
0.2-0.3	—	—	—	—
0.3-0.4	0.2	0.1	—	0.6
0.4-0.5	1.1	0.3	—	2.8
0.5-0.6	4.8	0.9	—	11.4
0.6-0.7	15.1	2.1	0.1	34.6
0.7-0.8	36.0	3.7	0.1	79.6
0.8-0.9	65.5	5.0	—	141.0
0.9-1.0	90.9	5.1	—	192.0
1.0-1.1	96.6	4.0	—	201.2
1.1-1.2	78.8	2.4	—	162.4
1.2-1.3	49.5	1.1	—	101.2
1.3-1.4	23.9	0.4	—	48.6
1.4-1.5	8.9	0.1	—	18.0
1.5-1.6	2.6	—	—	5.2
1.6-1.7	0.6	—	—	1.2
1.7-1.8	0.1	—	—	0.2
All speeds	474.6	25.2	0.2	1000.0

TABLE 2

$$q = 97, \sigma/V_R = 0.37$$

V/V_R	ϕ				All directions
	0-20°	20-40°	40-60°	60-80°	
	<i>per mille</i>				
0.0-0.1	—	—	—	—	—
0.1-0.2	0.1	—	—	—	0.2
0.2-0.3	0.3	0.2	0.1	—	1.2
0.3-0.4	1.2	0.7	0.2	—	4.2
0.4-0.5	3.6	1.7	0.4	0.1	11.6
0.5-0.6	9.0	3.5	0.6	0.1	26.4
0.6-0.7	18.7	6.1	0.7	—	51.0
0.7-0.8	32.7	8.9	0.8	—	84.8
0.8-0.9	48.5	11.1	0.7	—	120.6
0.9-1.0	61.3	11.8	0.5	—	147.2
1.0-1.1	66.3	10.7	0.4	—	154.8
1.1-1.2	61.4	8.3	0.2	—	139.8
1.2-1.3	48.7	5.6	0.1	—	108.8
1.3-1.4	33.2	3.2	—	—	72.8
1.4-1.5	19.5	1.6	—	—	42.2
1.5-1.6	9.8	0.7	—	—	21.0
1.6-1.7	4.2	0.2	—	—	8.8
1.7-1.8	1.6	0.1	—	—	3.4
1.8-1.9	0.5	—	—	—	1.0
1.9-2.0	0.1	—	—	—	0.2
2.0-2.1	—	—	—	—	—
All speeds	420.7	74.4	4.7	0.2	1000.0

TABLE 3

$$q = 95, \sigma/V_R = 0.47$$

V/V_R	ϕ									All directions
	0-20°	20-40°	40-60°	60-80°	80-100°	100-120°	120-140°	140-160°	160-180°	
	<i>per mille</i>									
0.0-0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	—	2.2
0.2-0.4	3.1	2.3	1.2	0.5	0.2	0.1	—	—	—	14.8
0.4-0.6	15.1	8.8	3.2	0.8	0.2	—	—	—	—	56.2
0.6-0.8	42.9	20.0	4.8	0.7	0.1	—	—	—	—	137.0
0.8-1.0	77.4	28.9	4.6	0.4	—	—	—	—	—	222.6
1.0-1.2	91.8	27.6	3.0	0.1	—	—	—	—	—	245.0
1.2-1.4	73.1	17.7	1.3	—	—	—	—	—	—	184.2
1.4-1.6	39.3	7.7	0.3	—	—	—	—	—	—	94.6
1.6-1.8	14.4	2.3	0.1	—	—	—	—	—	—	33.6
1.8-2.0	3.6	0.5	—	—	—	—	—	—	—	8.2
2.0-2.2	0.6	0.1	—	—	—	—	—	—	—	1.4
2.2-2.4	0.1	—	—	—	—	—	—	—	—	0.2
All speeds	361.6	116.1	18.7	2.6	0.6	0.2	0.1	0.1	—	1000.0

TABLE 4
 $q = 90, \sigma/V_R = 0.64$

V/V_R	ϕ									All directions
	0-20°	20-40°	40-60°	60-80°	80-100°	100-120°	120-140°	140-160°	160-180°	
	<i>per mille</i>									
0.0-0.2	0.7	0.7	0.6	0.5	0.4	0.4	0.3	0.3	0.3	8.4
0.2-0.4	4.8	4.0	2.9	1.9	1.1	0.7	0.4	0.3	0.3	32.8
0.4-0.6	14.2	10.6	6.1	2.9	1.3	0.6	0.3	0.2	0.1	72.6
0.6-0.8	29.2	19.3	8.9	3.2	1.0	0.3	0.1	0.1	0.1	124.4
0.8-1.0	45.0	26.5	9.9	2.6	0.5	0.1	0.1	—	—	169.4
1.0-1.2	54.2	28.4	8.4	1.6	0.3	0.1	—	—	—	186.0
1.2-1.4	51.8	24.1	5.8	0.8	0.1	—	—	—	—	165.2
1.4-1.6	39.6	16.5	3.1	0.3	0.1	—	—	—	—	119.2
1.6-1.8	24.4	9.1	1.4	0.1	—	—	—	—	—	70.0
1.8-2.0	12.2	4.0	0.5	0.1	—	—	—	—	—	33.6
2.0-2.2	4.9	1.4	0.2	—	—	—	—	—	—	13.0
2.2-2.4	1.6	0.4	0.1	—	—	—	—	—	—	4.2
2.4-2.6	0.4	0.1	—	—	—	—	—	—	—	1.0
2.6-2.8	0.1	—	—	—	—	—	—	—	—	0.2
All speeds	283.1	145.1	47.9	14.0	4.8	2.2	1.2	0.9	0.8	1000.0

TABLE 5
 $q = 80, \sigma/V_R = 0.93$

V/V_R	ϕ									All directions
	0-20°	20-40°	40-60°	60-80°	80-100°	100-120°	120-140°	140-160°	160-180°	
	<i>per mille</i>									
0.0-0.2	1.0	1.0	0.9	0.9	0.8	0.7	0.7	0.7	0.6	14.6
0.2-0.4	4.3	4.0	3.4	2.8	2.2	1.7	1.4	1.2	1.1	44.2
0.4-0.6	9.4	8.2	6.4	4.5	3.0	2.0	1.5	1.1	1.0	74.2
0.6-0.8	15.7	13.0	9.0	5.6	3.2	1.9	1.1	0.8	0.7	102.0
0.8-1.0	21.9	17.2	10.8	5.8	2.9	1.4	0.8	0.5	0.4	123.4
1.0-1.2	26.7	19.8	11.2	5.3	2.2	0.9	0.4	0.2	0.2	133.8
1.2-1.4	28.6	20.0	10.3	4.2	1.5	0.5	0.2	0.1	0.1	131.0
1.4-1.6	27.2	18.1	8.4	3.0	0.9	0.3	0.1	—	—	116.0
1.6-1.8	23.3	14.6	6.1	1.9	0.5	0.1	0.1	—	—	93.2
1.8-2.0	17.9	10.7	4.0	1.1	0.2	0.1	—	—	—	68.0
2.0-2.2	12.4	7.0	2.4	0.5	0.1	—	—	—	—	44.8
2.2-2.4	7.8	4.2	1.3	0.3	—	—	—	—	—	27.2
2.4-2.6	4.4	2.2	0.6	0.1	—	—	—	—	—	14.6
2.6-2.8	2.3	1.1	0.3	—	—	—	—	—	—	7.4
2.8-3.0	1.1	0.5	0.1	—	—	—	—	—	—	3.4
3.0-3.2	0.5	0.2	—	—	—	—	—	—	—	1.4
3.2-3.4	0.2	0.1	—	—	—	—	—	—	—	0.6
3.4-3.6	0.1	—	—	—	—	—	—	—	—	0.2
All speeds	204.8	141.9	75.2	36.0	17.5	9.6	6.3	4.6	4.1	1000.0

TABLE 6

 $q = 70, \sigma/V_R = 1.24$

V/V_R	ϕ									All directions
	0-20°	20-40°	40-60°	60-80°	80-100°	100-120°	120-140°	140-160°	160-180°	
	<i>per mille</i>									
0.0-0.2	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	13.2
0.2-0.4	3.1	3.0	2.8	2.4	2.1	1.9	1.7	1.5	1.4	39.8
0.4-0.6	6.0	5.6	4.8	4.0	3.2	2.6	2.1	1.8	1.7	63.6
0.6-0.8	9.3	8.5	6.9	5.2	3.8	2.8	2.1	1.8	1.6	84.0
0.8-1.0	12.5	11.0	8.5	6.0	4.0	2.7	1.9	1.5	1.3	98.8
1.0-1.2	15.4	12.9	9.4	6.1	3.8	2.3	1.5	1.1	0.9	106.8
1.2-1.4	17.1	14.1	9.6	5.8	3.3	1.8	1.1	0.8	0.6	108.4
1.4-1.6	17.8	14.1	9.2	5.1	2.6	1.3	0.7	0.5	0.4	103.4
1.6-1.8	17.2	13.3	8.2	4.2	2.0	0.9	0.5	0.3	0.2	93.6
1.8-2.0	15.6	11.6	6.7	3.2	1.4	0.6	0.3	0.2	0.1	79.4
2.0-2.2	13.5	9.6	5.2	2.3	0.9	0.3	0.1	0.1	—	64.0
2.2-2.4	10.6	7.4	3.8	1.6	0.6	0.2	0.1	—	—	48.6
2.4-2.6	8.0	5.5	2.7	1.0	0.3	0.1	—	—	—	35.2
2.6-2.8	5.7	3.7	1.7	0.6	0.2	0.1	—	—	—	24.0
2.8-3.0	3.8	2.5	1.1	0.3	0.1	—	—	—	—	15.6
3.0-3.2	2.5	1.5	0.6	0.2	—	—	—	—	—	9.6
3.2-3.4	1.5	0.9	0.5	0.1	—	—	—	—	—	6.0
3.4-3.6	0.8	0.5	0.2	—	—	—	—	—	—	3.0
3.6-3.8	0.4	0.3	0.1	—	—	—	—	—	—	1.6
3.8-4.0	0.3	0.1	—	—	—	—	—	—	—	0.8
4.0-4.2	0.1	0.1	—	—	—	—	—	—	—	0.4
Over 4.2	0.1	—	—	—	—	—	—	—	—	0.2
All speeds	162.1	127.0	82.8	48.9	29.0	18.3	12.8	10.3	8.8	1000.0

TABLE 7

 $q = 60, \sigma/V_R = 1.60$

V/V_R	ϕ									All directions
	0-20°	20-40°	40-60°	60-80°	80-100°	100-120°	120-140°	140-160°	160-180°	
	<i>per mille</i>									
0.0-0.4	2.7	2.6	2.6	2.4	2.3	2.2	2.1	2.0	2.0	41.8
0.4-0.8	9.7	9.2	8.3	7.2	6.1	5.2	4.5	4.0	3.9	116.2
0.8-1.2	17.2	15.6	13.1	10.4	7.9	6.0	4.8	4.0	3.6	165.2
1.2-1.6	22.4	19.6	15.4	11.1	7.6	5.2	3.8	3.0	2.6	181.4
1.6-2.0	23.8	20.1	14.7	9.6	5.9	3.7	2.4	1.7	1.5	166.8
2.0-2.4	21.1	17.3	11.7	7.0	3.9	2.1	1.3	0.9	0.7	132.0
2.4-2.8	16.1	12.6	8.0	4.3	2.2	1.1	0.6	0.4	0.2	91.0
2.8-3.2	10.5	8.0	4.7	2.3	1.0	0.5	0.2	0.1	0.1	54.8
3.2-3.6	5.9	4.3	2.4	1.1	0.4	0.2	0.1	0.1	—	29.0
3.6-4.0	2.9	2.0	1.1	0.4	0.2	0.1	—	—	—	13.4
4.0-4.4	1.3	0.8	0.4	0.2	0.1	—	—	—	—	5.6
4.4-4.8	0.5	0.3	0.1	0.1	—	—	—	—	—	2.0
4.8-5.2	0.2	0.1	—	—	—	—	—	—	—	0.6
5.2-5.6	0.1	—	—	—	—	—	—	—	—	0.2
All speeds	134.4	112.5	82.5	56.1	37.6	26.3	19.8	16.2	14.6	1000.0

TABLE 8
 $q = 50, \sigma/V_R = 2.04$

V/V_R	ϕ									All directions
	0-20°	20-40°	40-60°	60-80°	80-100°	100-120°	120-140°	140-160°	160-180°	
	<i>per mille</i>									
0.0-0.4	1.8	1.8	1.8	1.7	1.7	1.6	1.6	1.5	1.5	30.0
0.4-0.8	6.2	5.9	5.6	5.1	4.6	4.2	3.8	3.6	3.5	85.0
0.8-1.2	10.6	10.0	9.0	7.8	6.6	5.6	4.8	4.4	4.1	125.8
1.2-1.6	14.3	13.2	11.3	9.2	7.4	5.8	4.7	4.1	3.8	147.6
1.6-2.0	16.3	14.7	12.1	9.3	6.9	5.1	4.0	3.3	2.9	149.2
2.0-2.4	16.3	14.4	11.4	8.3	5.8	4.0	2.9	2.3	2.0	134.8
2.4-2.8	14.7	12.7	9.6	6.6	4.3	2.8	1.9	1.4	1.2	110.4
2.8-3.2	12.0	10.1	7.3	4.7	2.9	1.8	1.1	0.8	0.7	82.8
3.2-3.6	8.8	7.3	5.0	3.1	1.8	1.0	0.6	0.4	0.4	56.8
3.6-4.0	6.0	4.8	3.2	1.8	1.0	0.5	0.3	0.2	0.2	36.0
4.0-4.4	3.7	2.9	1.8	1.0	0.5	0.2	0.1	0.1	0.1	20.8
4.4-4.8	2.1	1.6	1.0	0.5	0.2	0.1	0.1	—	—	11.2
4.8-5.2	1.1	0.8	0.5	0.2	0.1	0.1	—	—	—	5.6
5.2-5.6	0.5	0.4	0.2	0.1	0.1	—	—	—	—	2.6
5.6-6.0	0.2	0.2	0.1	—	—	—	—	—	—	1.0
6.0-6.4	0.1	0.1	—	—	—	—	—	—	—	0.4
All speeds	114.7	100.9	79.9	59.4	43.9	32.8	25.9	22.1	20.4	1000.0

TABLE 9
 $q = 40, \sigma/V_R = 2.64$

V/V_R	ϕ									All directions
	0-20°	20-40°	40-60°	60-80°	80-100°	100-120°	120-140°	140-160°	160-180°	
	<i>per mille</i>									
0.0-0.6	2.7	2.6	2.6	2.5	2.4	2.4	2.3	2.3	2.2	44.0
0.6-1.2	8.5	8.4	7.8	7.2	6.6	6.0	5.6	5.3	5.1	121.0
1.2-1.8	13.6	13.0	11.8	10.4	8.9	7.7	6.8	6.2	5.9	168.6
1.8-2.4	16.6	15.5	13.5	11.3	9.2	7.5	6.3	5.5	5.1	181.0
2.4-3.0	16.8	15.3	12.9	10.2	7.8	6.0	4.8	4.0	3.7	163.0
3.0-3.6	14.5	13.0	10.5	7.9	5.7	4.1	3.1	2.5	2.3	127.2
3.6-4.2	10.9	9.6	7.5	5.4	3.6	2.5	1.8	1.4	1.2	87.8
4.2-4.8	7.3	6.2	4.7	3.2	2.0	1.3	0.9	0.7	0.6	53.8
4.8-5.4	4.3	3.6	2.6	1.7	1.0	0.6	0.4	0.3	0.2	29.4
5.4-6.0	2.2	1.9	1.3	0.8	0.4	0.2	0.2	0.1	0.1	14.4
6.0-6.6	1.1	0.8	0.6	0.3	0.2	0.1	0.1	—	—	6.4
6.6-7.2	0.4	0.4	0.2	0.1	0.1	—	—	—	—	2.4
7.2-7.8	0.2	0.1	0.1	—	—	—	—	—	—	0.8
7.8-8.4	0.1	—	—	—	—	—	—	—	—	0.2
All speeds	99.2	90.4	76.1	61.0	47.9	38.4	32.3	28.3	26.4	1000.0

TABLE 10
 $q = 30, \sigma/V_R = 3.68$

V/V_R	ϕ									All directions
	0-20°	20-40°	40-60°	60-80°	80-100°	100-120°	120-140°	140-160°	160-180°	
	<i>per mille</i>									
0.0-0.6	1.5	1.4	1.4	1.4	1.4	1.3	1.3	1.3	1.3	24.6
0.6-1.2	4.4	4.3	4.2	4.1	3.9	3.7	3.6	3.4	3.4	70.0
1.2-1.8	7.2	7.1	6.7	6.3	5.8	5.4	5.0	4.8	4.7	106.0
1.8-2.4	9.4	9.1	8.5	7.7	6.9	6.2	5.7	5.3	5.1	127.8
2.4-3.0	10.6	10.2	9.3	8.3	7.2	6.3	5.6	5.1	4.9	135.0
3.0-3.6	10.9	10.3	9.2	8.0	6.7	5.7	4.9	4.4	4.2	128.6
3.6-4.2	10.2	9.5	8.4	7.1	5.8	4.7	4.0	3.5	3.3	113.0
4.2-4.8	8.9	8.2	7.0	5.8	4.6	3.6	3.0	2.5	2.4	92.0
4.8-5.4	7.2	6.6	5.5	4.4	3.4	2.6	2.1	1.8	1.6	70.4
5.4-6.0	5.4	4.9	4.1	3.1	2.4	1.8	1.4	1.1	1.0	50.4
6.0-6.6	3.8	3.4	2.8	2.1	1.5	1.1	0.9	0.7	0.6	33.8
6.6-7.2	2.5	2.3	1.8	1.3	0.9	0.7	0.5	0.4	0.3	21.4
7.2-7.8	1.6	1.4	1.1	0.8	0.5	0.4	0.2	0.2	0.2	12.8
7.8-8.4	1.0	0.8	0.6	0.4	0.3	0.2	0.1	0.1	0.1	7.2
8.4-9.0	0.5	0.5	0.3	0.2	0.2	0.1	0.1	—	—	3.8
9.0-9.6	0.3	0.2	0.2	0.1	0.1	—	—	—	—	1.8
9.6-10.2	0.1	0.1	0.1	0.1	—	—	—	—	—	0.8
10.2-10.8	0.1	0.1	—	—	—	—	—	—	—	0.4
Over 10.8	0.1	—	—	—	—	—	—	—	—	0.2
All speeds	85.7	80.4	71.2	61.2	51.6	43.8	38.4	34.6	33.1	1000.0

TABLE 11
 $q = 20, \sigma/V_R = 5.62$

V/V_R	ϕ									All directions
	0-20°	20-40°	40-60°	60-80°	80-100°	100-120°	120-140°	140-160°	160-180°	
	<i>per mille</i>									
0-1	1.7	1.7	1.7	1.7	1.7	1.7	1.6	1.6	1.6	30.0
1-2	5.2	5.1	5.0	4.9	4.7	4.6	4.4	4.4	4.3	85.2
2-3	8.1	8.0	7.7	7.3	6.9	6.6	6.3	6.0	6.0	125.8
3-4	10.0	9.8	9.3	8.7	8.1	7.5	7.0	6.7	6.5	147.2
4-5	10.7	10.3	9.7	8.8	8.0	7.3	6.7	6.3	6.1	147.8
5-6	10.1	9.7	9.0	8.1	7.1	6.4	5.7	5.3	5.1	133.0
6-7	8.7	8.3	7.6	6.7	5.8	5.0	4.5	4.1	3.9	109.2
7-8	6.9	6.5	5.8	5.1	4.3	3.6	3.2	2.9	2.7	82.0
8-9	5.0	4.7	4.2	3.5	2.9	2.4	2.1	1.9	1.7	56.8
9-10	3.4	3.1	2.8	2.3	1.9	1.5	1.3	1.1	1.0	36.8
10-11	2.2	1.9	1.7	1.4	1.1	0.9	0.7	0.6	0.6	22.2
11-12	1.2	1.1	0.9	0.8	0.6	0.5	0.4	0.3	0.3	12.2
12-13	0.7	0.6	0.5	0.4	0.3	0.2	0.2	0.2	0.2	6.6
13-14	0.3	0.3	0.3	0.2	0.1	0.1	0.1	0.1	0.1	3.2
14-15	0.2	0.1	0.1	0.1	0.1	0.1	—	—	—	1.4
15-16	0.1	0.1	0.1	—	—	—	—	—	—	0.6
All speeds	74.5	71.3	66.4	60.0	53.6	48.4	44.2	41.5	40.1	1000.0

TABLE 12
 $q = 10, \sigma/V_R = 11.3$

V/V_R	ϕ									All directions
	0-20°	20-40°	40-60°	60-80°	80-100°	100-120°	120-140°	140-160°	160-180°	
	<i>per mille</i>									
0-2	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	30.6
2-4	5.0	5.0	4.9	4.9	4.8	4.7	4.7	4.6	4.6	86.4
4-6	7.6	7.6	7.4	7.2	7.1	6.9	6.7	6.6	6.6	127.4
6-8	9.2	9.0	8.8	8.5	8.2	7.9	7.6	7.5	7.4	148.2
8-10	9.4	9.3	9.0	8.6	8.2	7.8	7.5	7.3	7.2	148.6
10-12	8.7	8.5	8.2	7.8	7.4	6.9	6.6	6.3	6.2	133.2
12-14	7.3	7.1	6.8	6.4	5.9	5.5	5.3	5.0	4.9	108.4
14-16	5.6	5.5	5.2	4.8	4.4	4.1	3.8	3.6	3.5	81.0
16-18	4.0	3.8	3.6	3.4	3.1	2.8	2.6	2.4	2.3	56.0
18-20	2.6	2.5	2.3	2.2	1.9	1.8	1.6	1.5	1.5	35.8
20-22	1.6	1.5	1.4	1.3	1.2	1.0	0.9	0.9	0.8	21.2
22-24	0.9	0.9	0.8	0.7	0.6	0.5	0.5	0.5	0.5	11.8
24-26	0.5	0.5	0.4	0.4	0.3	0.3	0.3	0.2	0.2	6.2
26-28	0.3	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	3.2
28-30	0.1	0.1	0.1	0.1	0.1	0.1	0.1	—	—	1.4
Over 30	0.1	0.1	0.1	—	—	—	—	—	—	0.6
All speeds	64.6	63.3	60.9	58.2	55.1	52.2	50.0	48.2	47.5	1000.0

TABLE 13
 $q = 0$

V/σ	Frequency for 20° range	All directions	V/σ	Frequency for 20° range	All directions
	<i>per mille</i>			<i>per mille</i>	
0.0-0.2	2.2	39	1.8-2.0	1.1	20
0.2-0.4	6.1	109	2.0-2.2	0.6	10
0.4-0.6	8.6	155	2.2-2.4	0.3	5
0.6-0.8	9.5	171	2.4-2.6	0.1	1.8
0.8-1.0	8.9	160	2.6-2.8	—	0.7
1.0-1.2	7.2	131	2.8-3.0	—	0.2
1.2-1.4	5.3	96			
1.4-1.6	3.5	63	All speeds	55.5	1000.0
1.6-1.8	2.1	38			

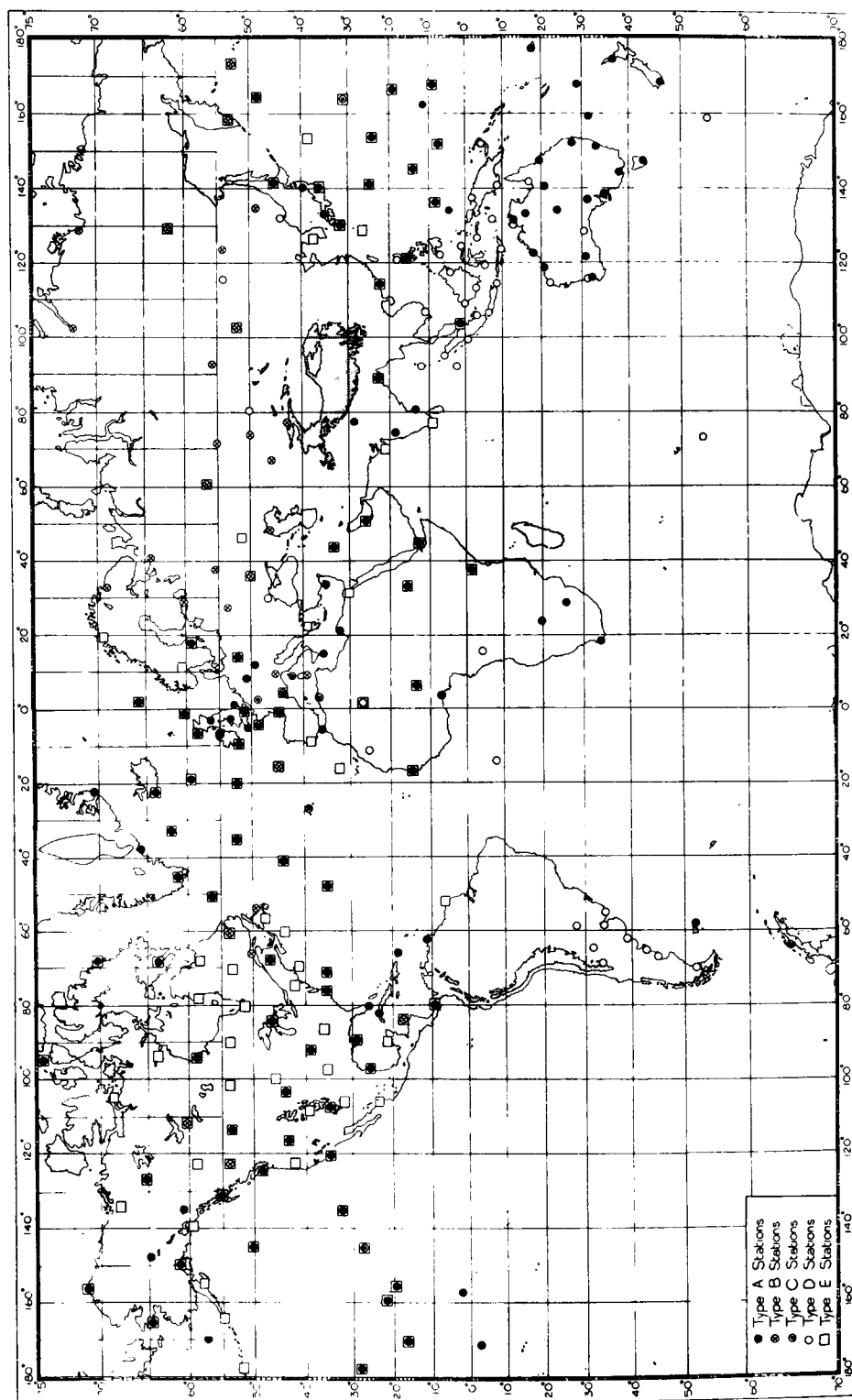


FIGURE 4—STATIONS FOR WHICH WIND DATA WERE AVAILABLE FOR CONSTRUCTING THE
MERCATOR CHARTS

For an explanation of Types A–E see page 4

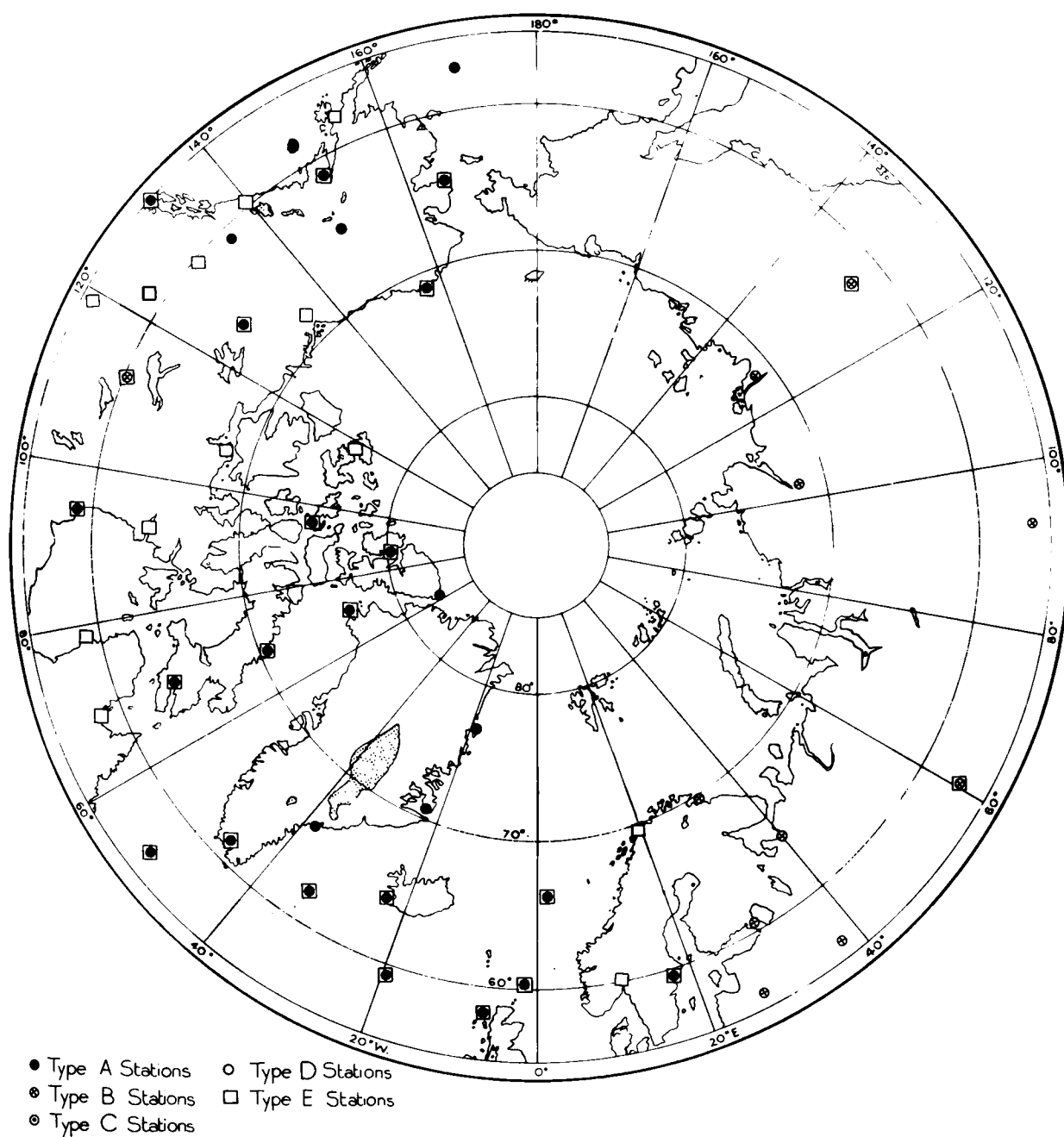


FIGURE 5—STATIONS FOR WHICH WIND DATA WERE AVAILABLE FOR CONSTRUCTING THE CIRCUMPOLAR CHARTS

For an explanation of Types A-E see page 4

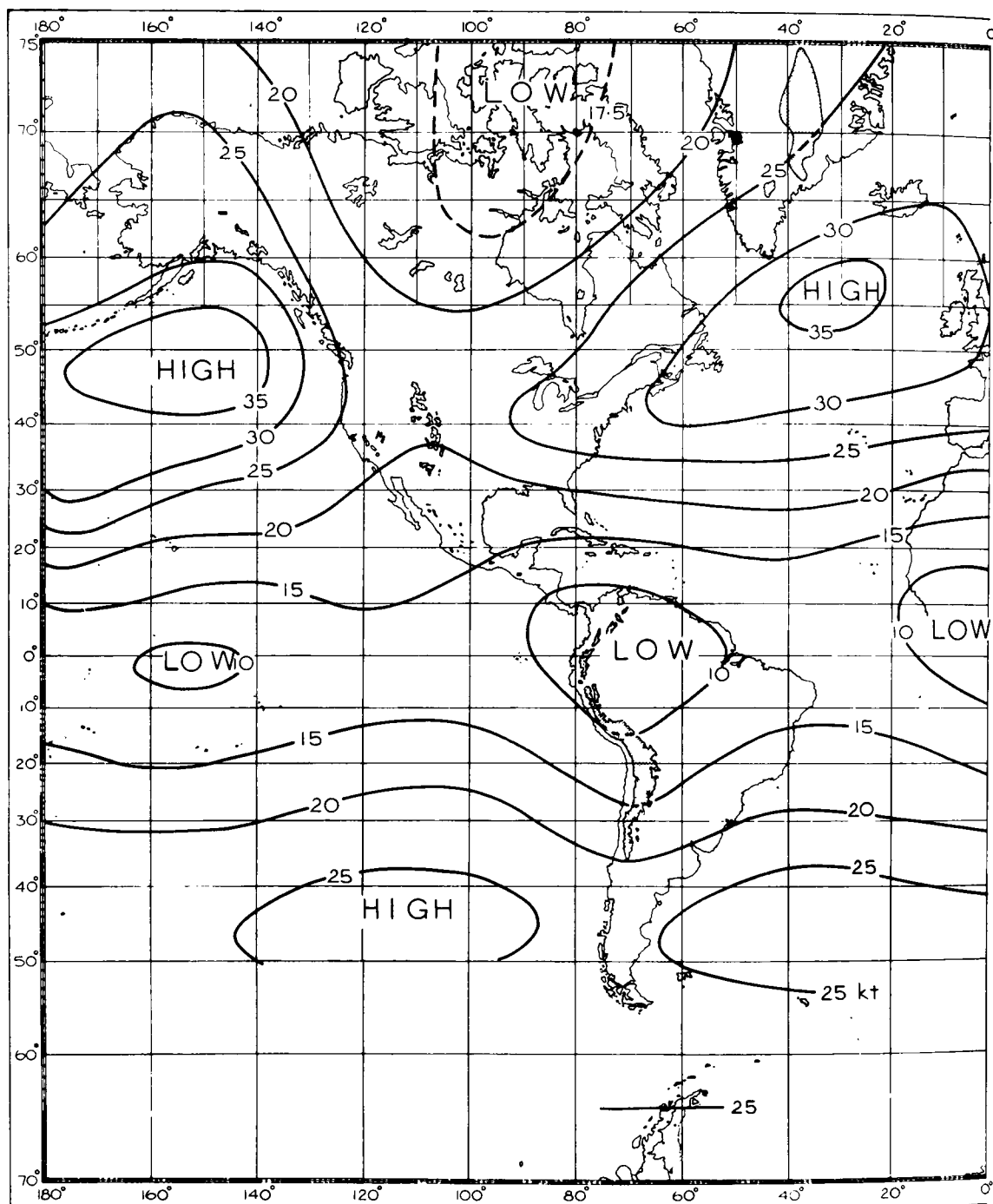


FIGURE 6—STANDARD VECTOR DEVIATION OF WIND AT 700 MB, JANUARY 1949-53

ICAO height = 9,882 ft = 3,012 m

Shaded areas represent land over 3,000 m

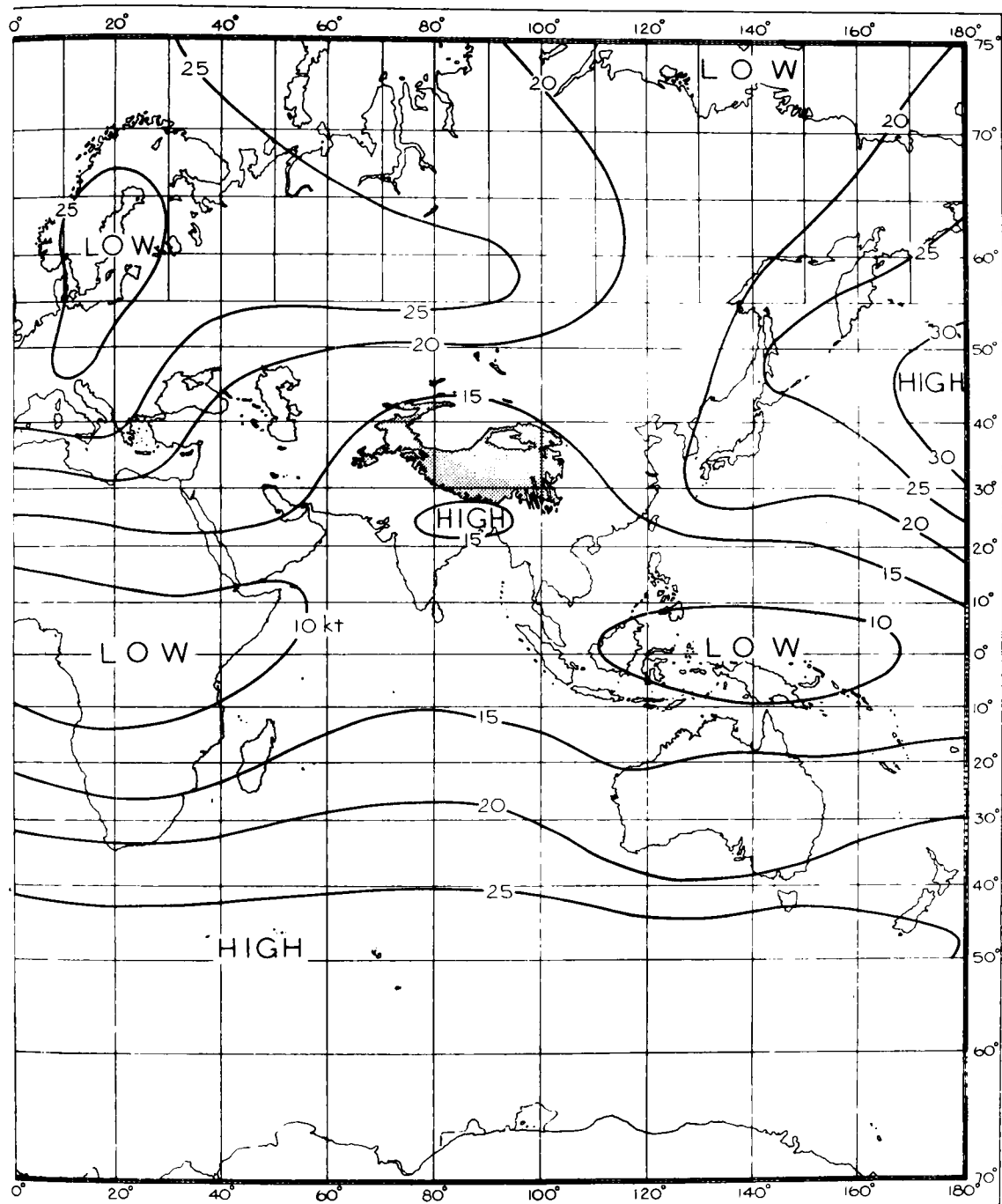


FIGURE 6—CONTINUED

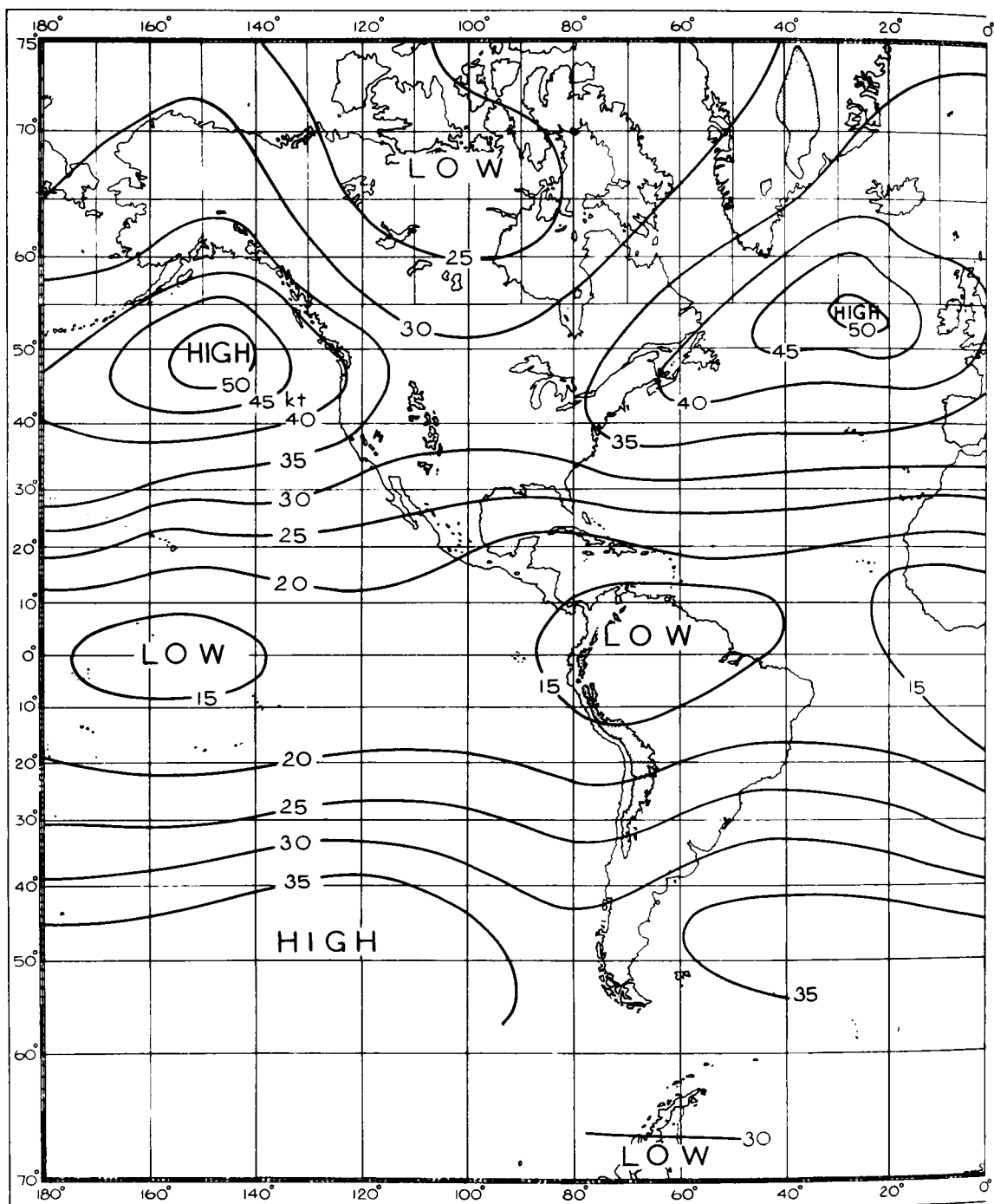


FIGURE 7—STANDARD VECTOR DEVIATION OF WIND AT 500 MB, JANUARY 1949-53

ICAO height = 18,289 ft = 5,574 m
 Shaded areas represent land over 3,000 m

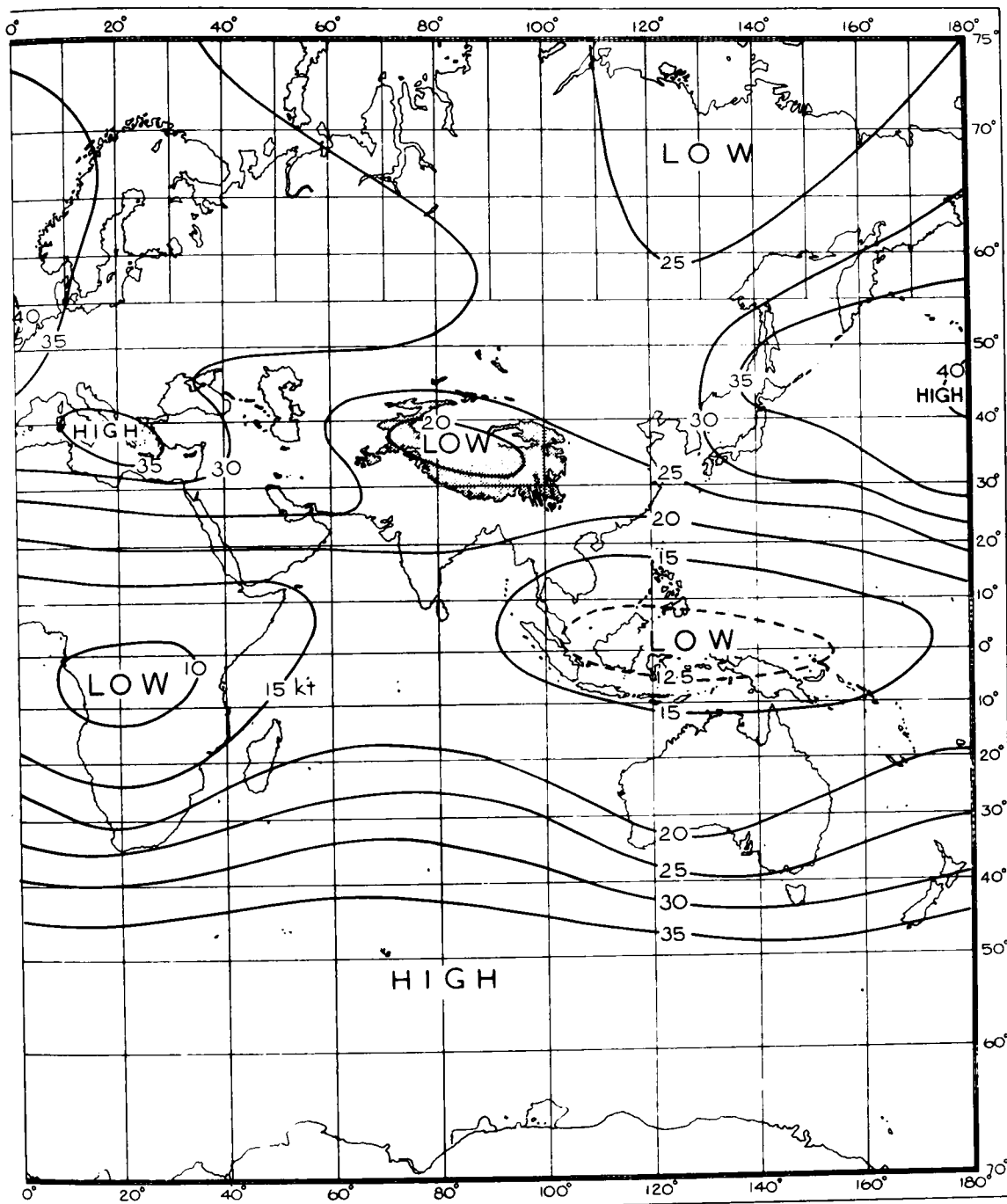


FIGURE 7—CONTINUED

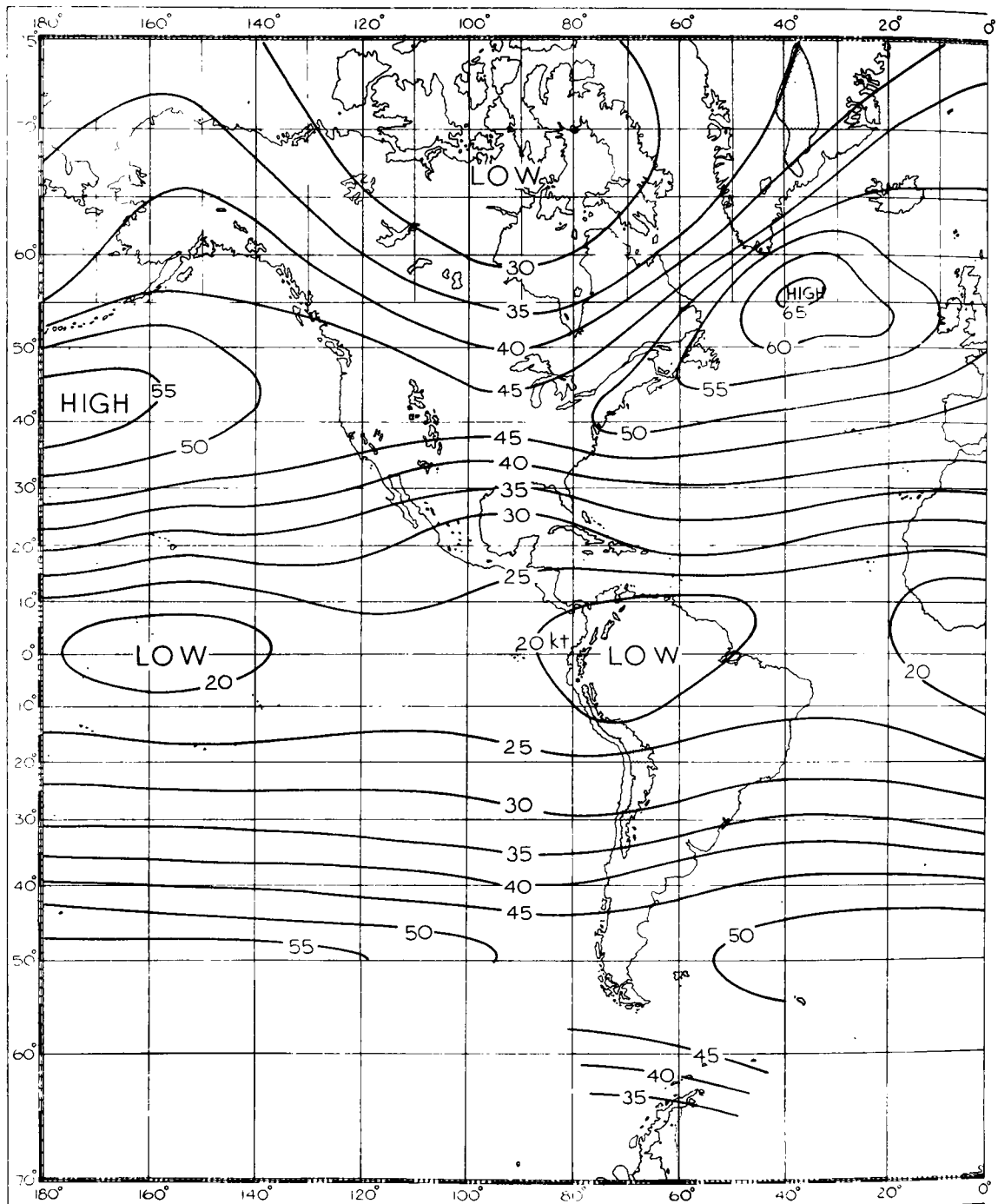


FIGURE 8—STANDARD VECTOR DEVIATION OF WIND AT 300 MB, JANUARY 1949-53

ICAO height = 30,065 ft = 9,164 m
 Shaded areas represent land over 3,000 m

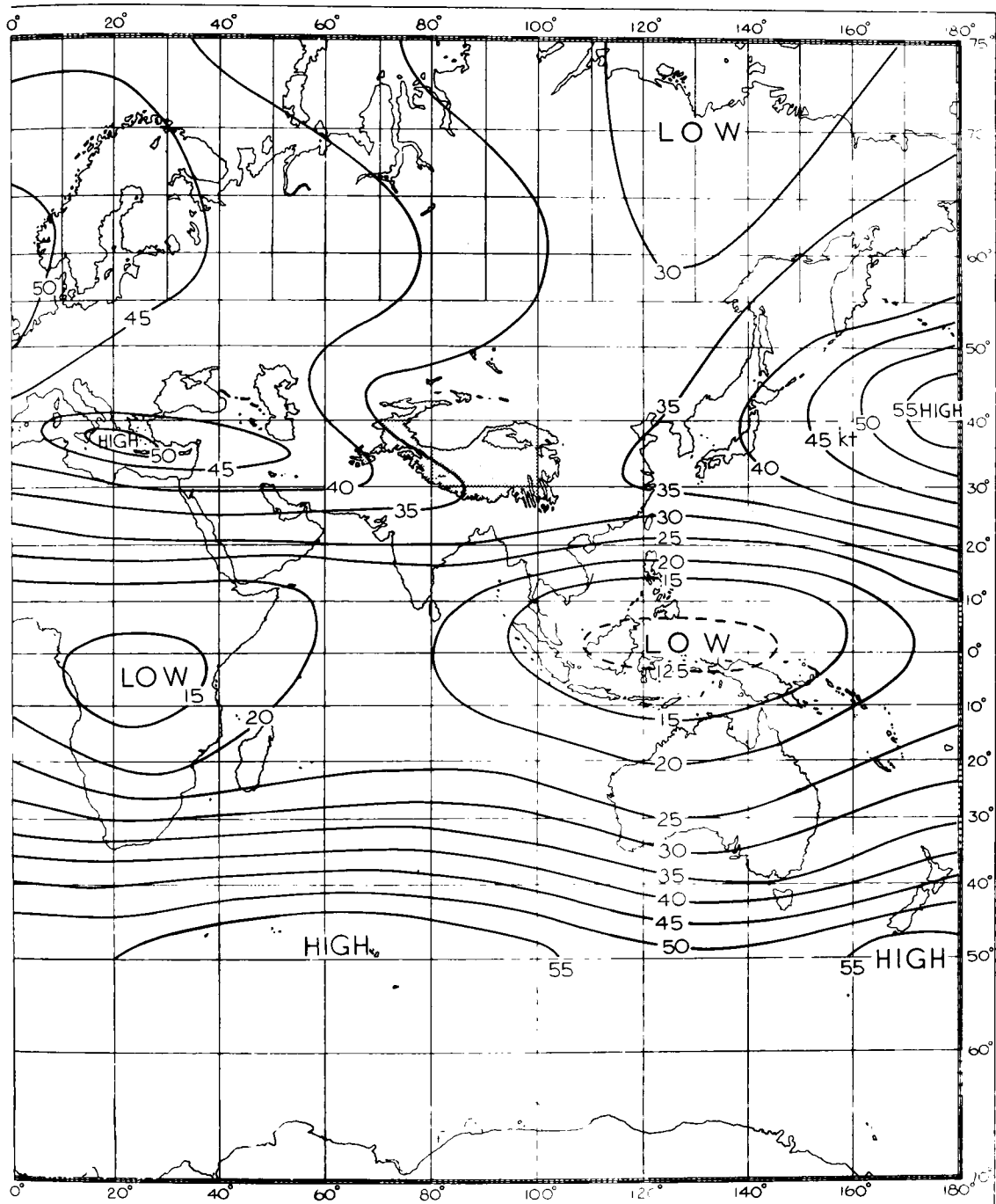


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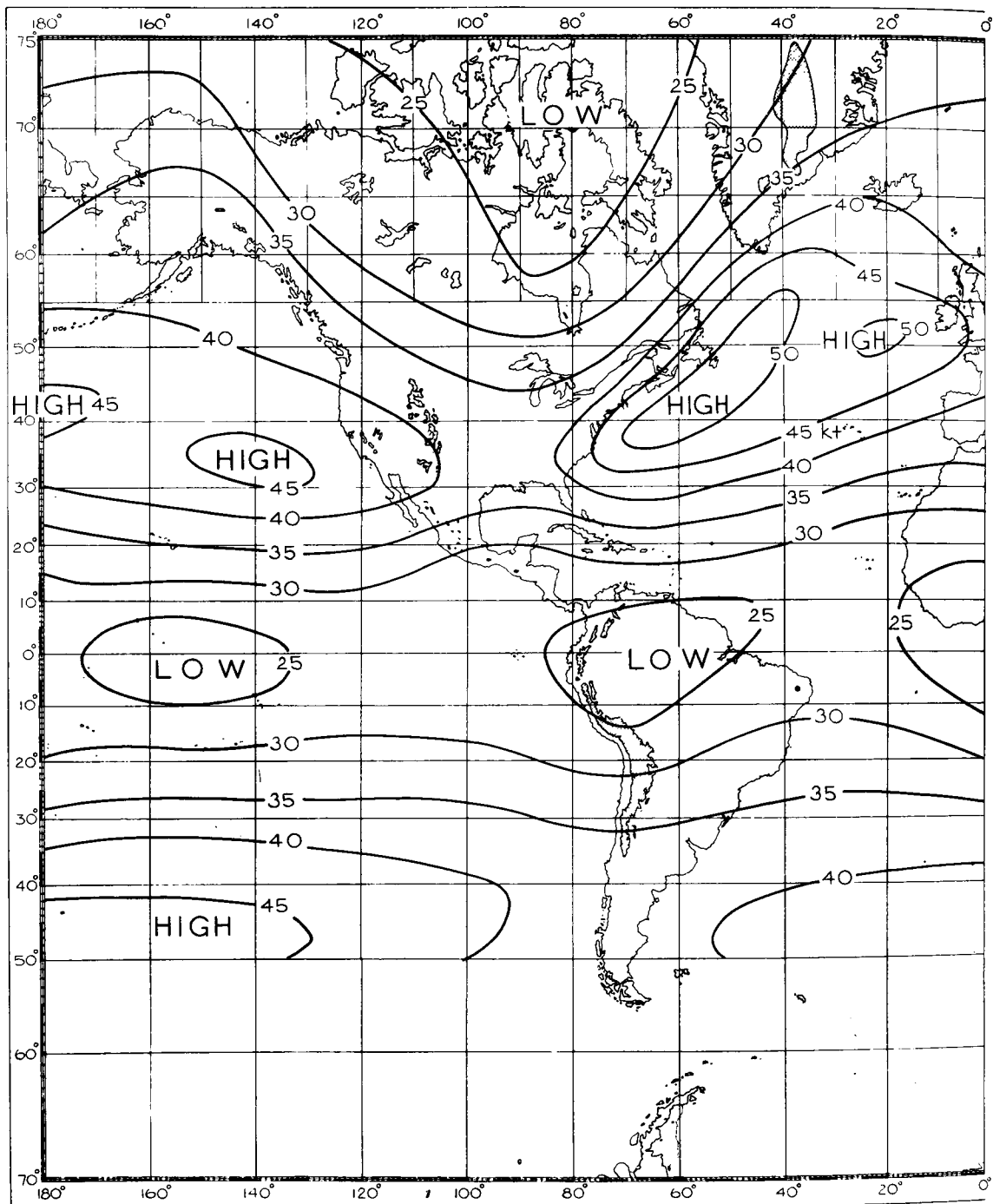


FIGURE 9—STANDARD VECTOR DEVIATION OF WIND AT 200 MB, JANUARY 1949-53

ICAO height = 38,663 ft = 11,784 m

Shaded areas represent land over 3,000 m

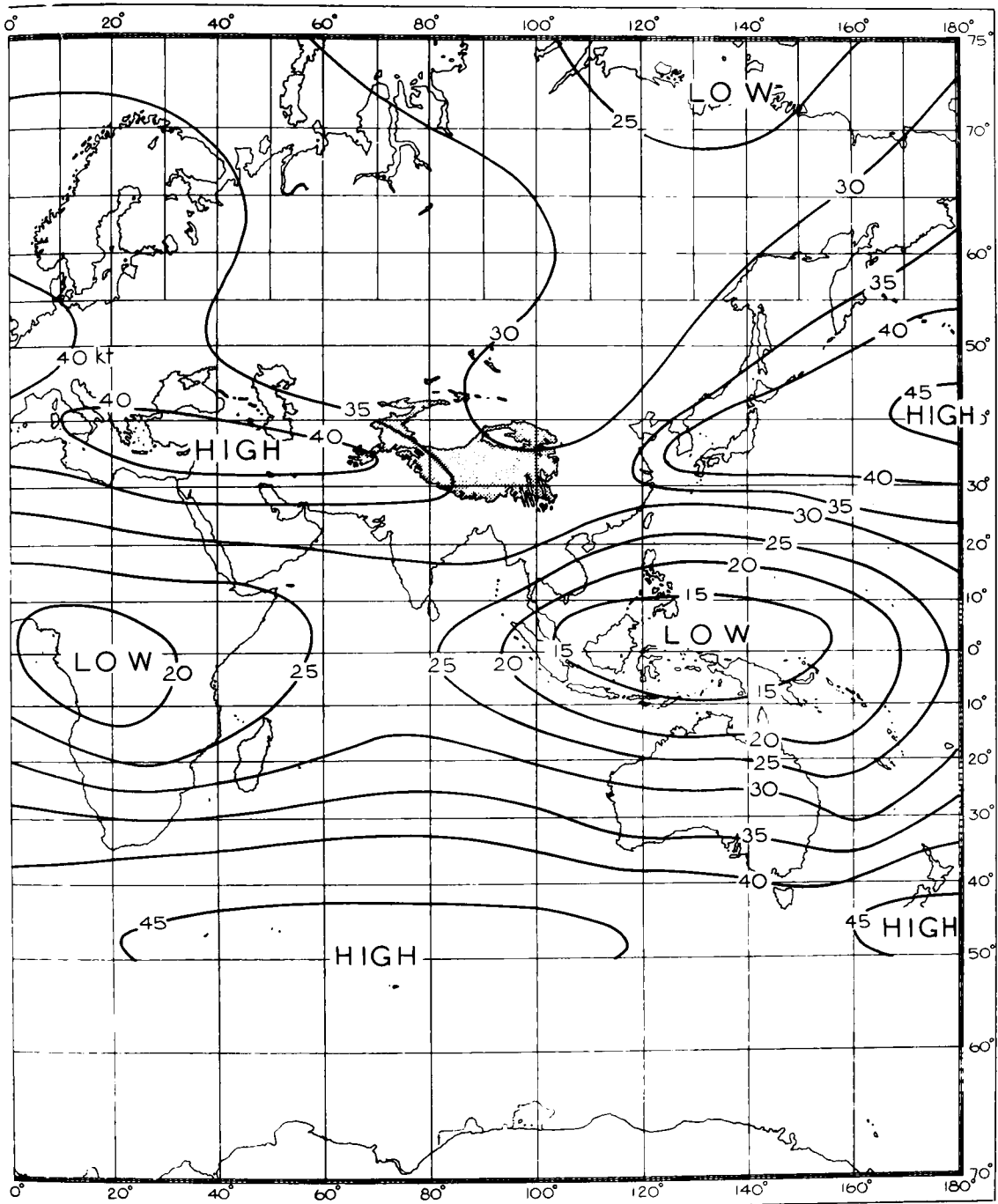


FIGURE 9—CONTINUED

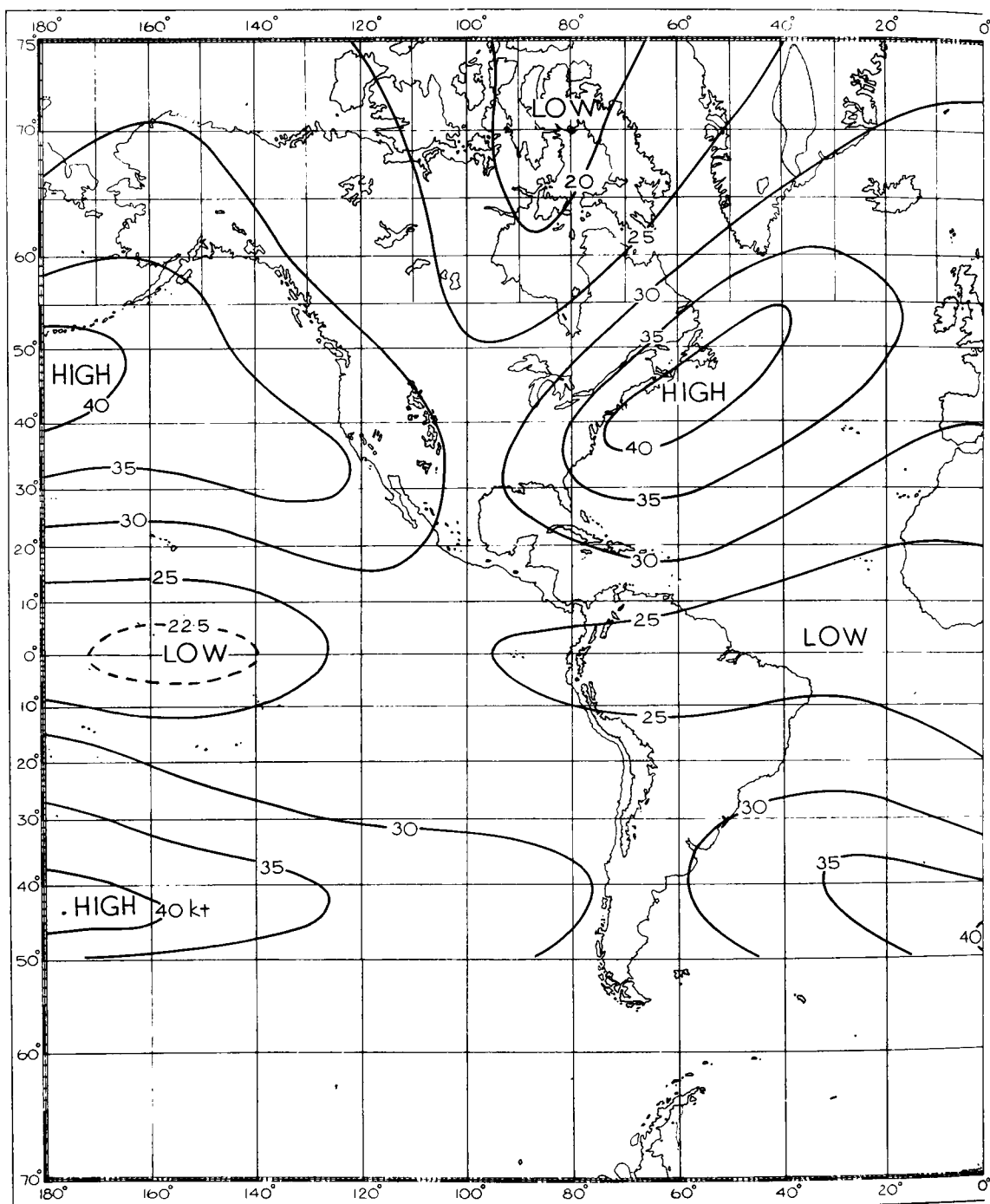


FIGURE 10—STANDARD VECTOR DEVIATION OF WIND AT 150 MB, JANUARY 1949-53

ICAO height = 44,647 ft = 13,608 m
 Shaded areas represent land over 3,000 m

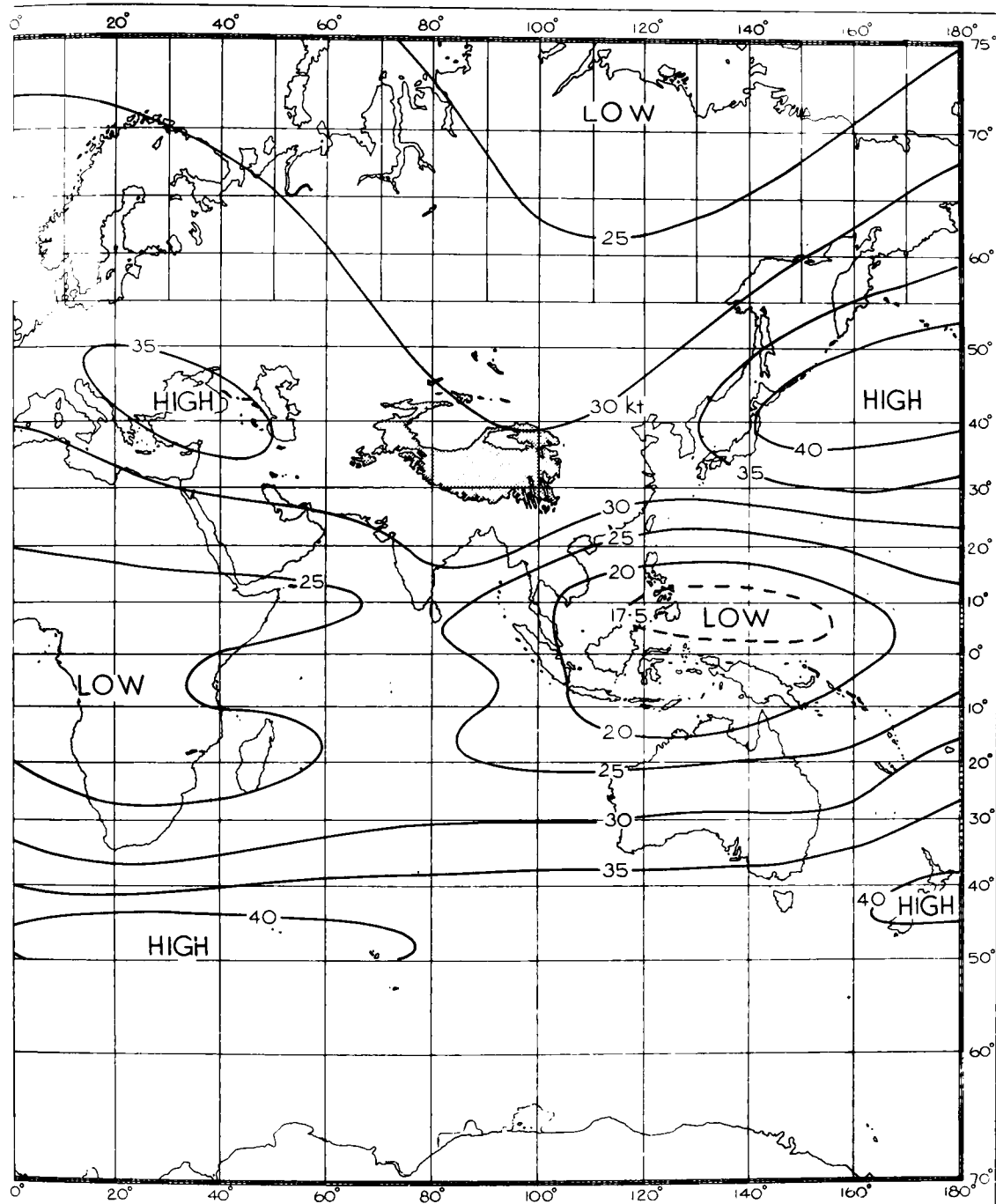


FIGURE 10—CONTINUED

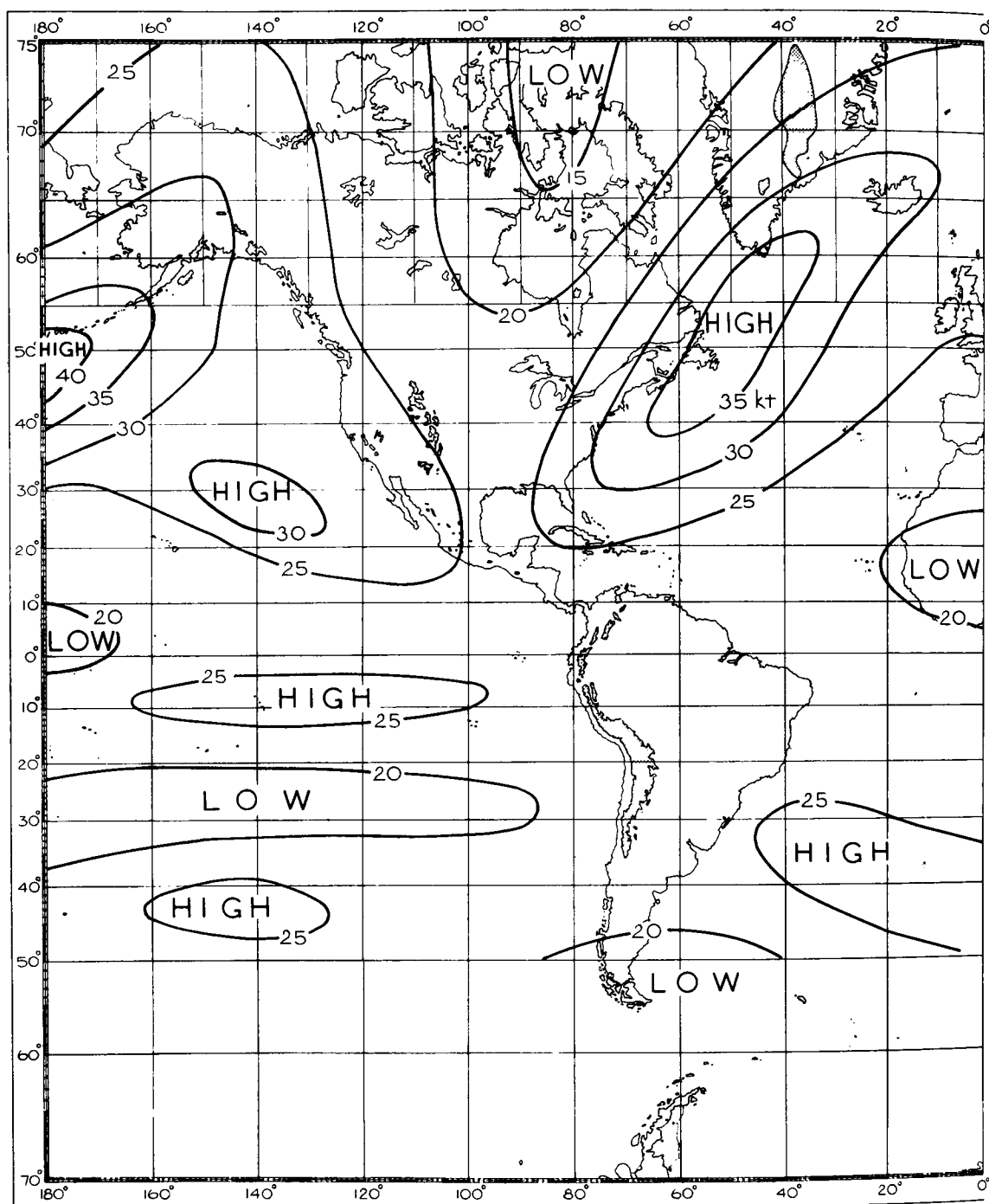


FIGURE 11—STANDARD VECTOR DEVIATION OF WIND AT 100 MB, JANUARY 1949-53

ICAO height = 53,083 ft = 16,180 m
 Shaded areas represent land over 3,000 m

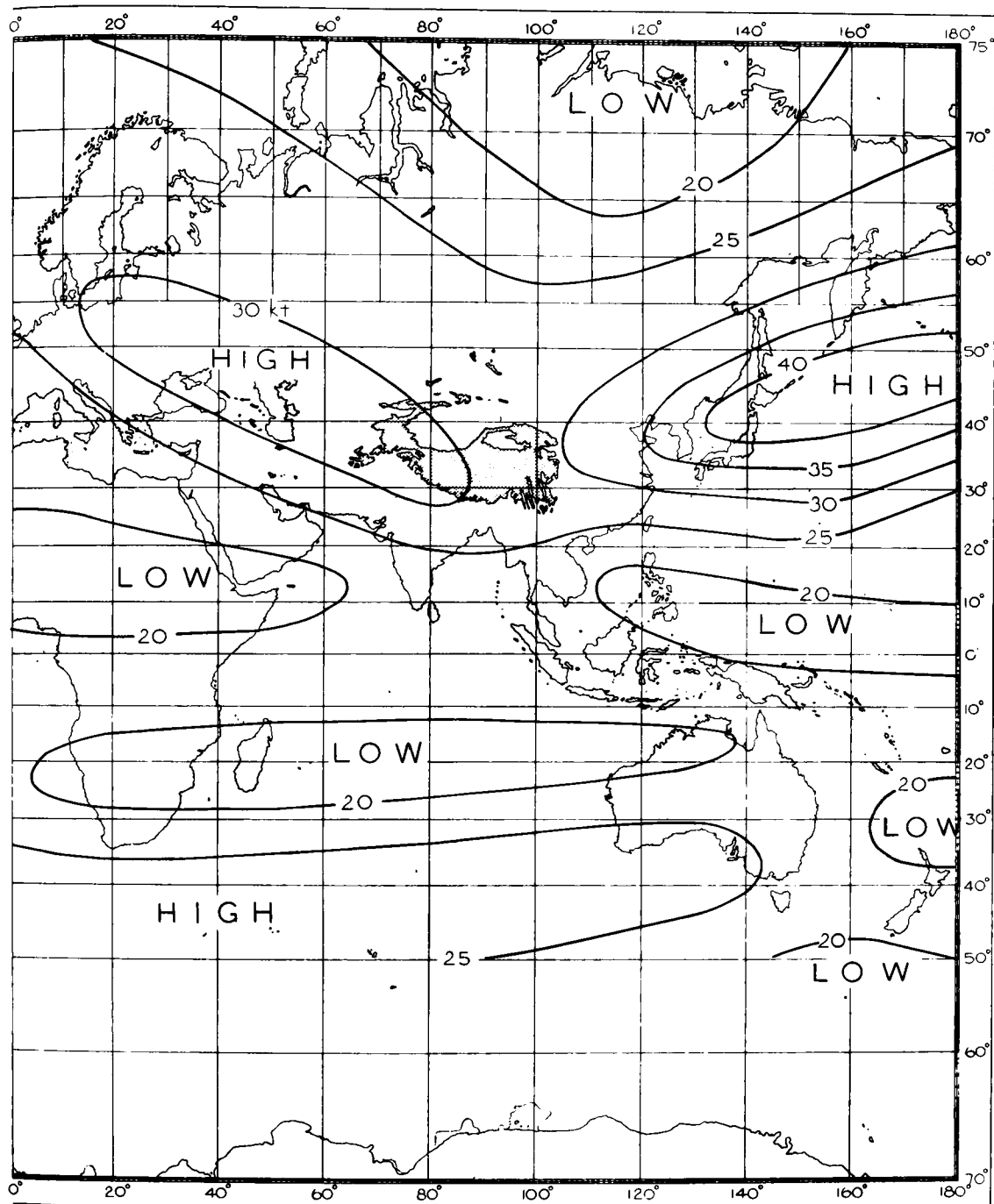


FIGURE 11—CONTINUED

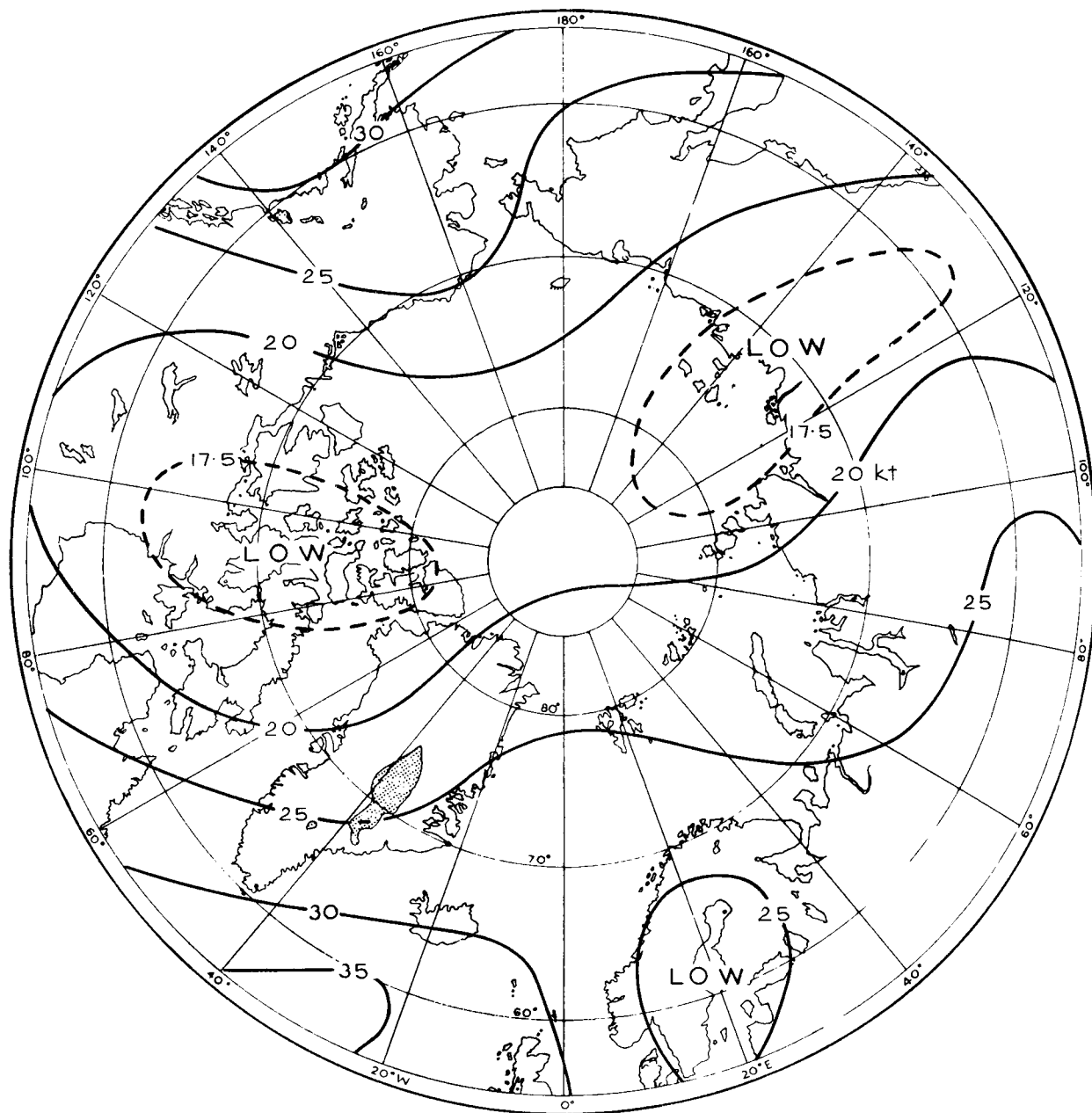


FIGURE 12—STANDARD VECTOR DEVIATION OF WIND AT 700 MB, JANUARY 1949-53

ICAO height = 9,882 ft = 3,012 m

Shaded areas represent land over 3,000 m

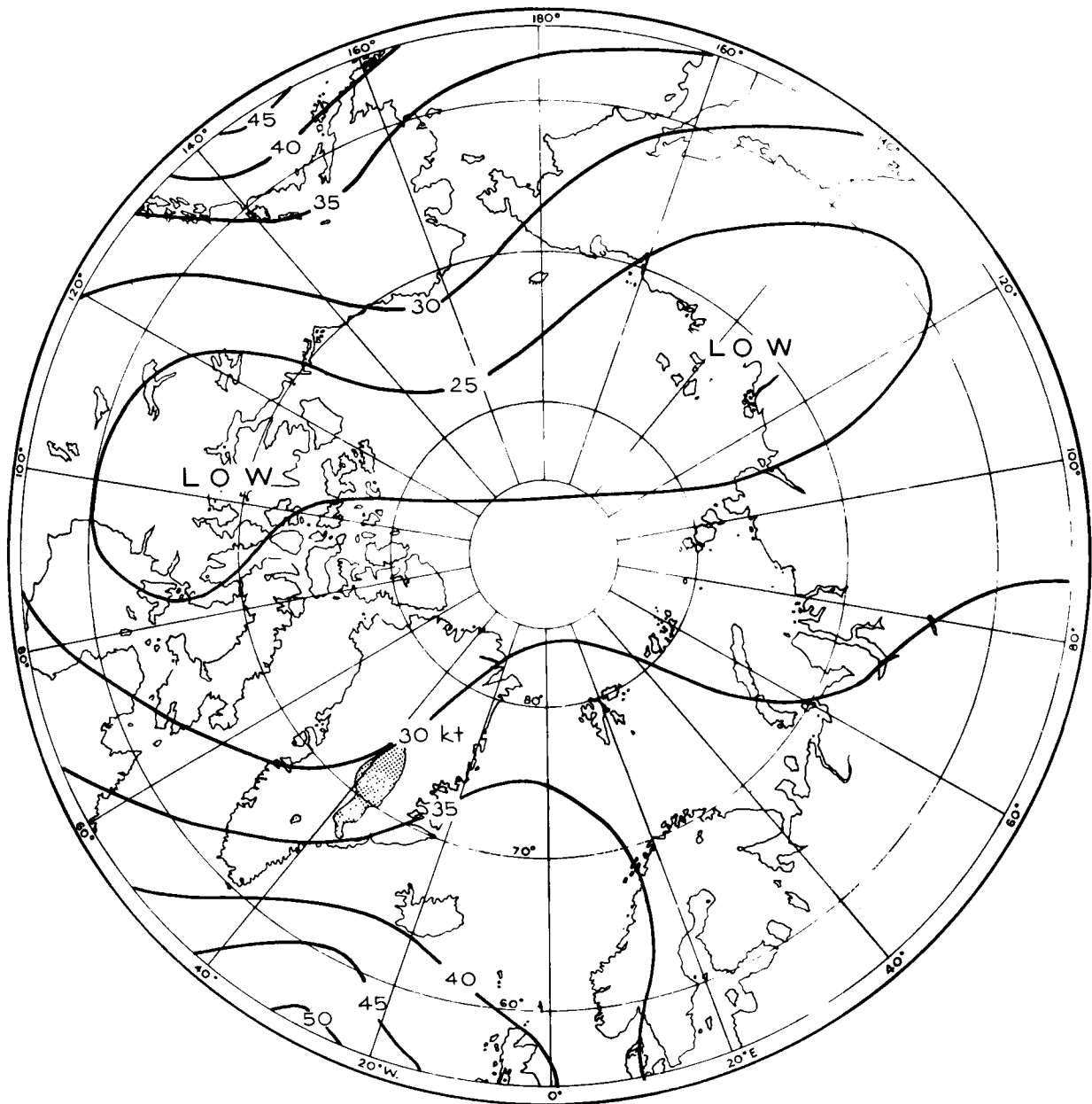


FIGURE 13—STANDARD VECTOR DEVIATION OF WIND AT 500 MB, JANUARY 1949-53

ICAO height = 18,289 ft = 5,574 m

Shaded areas represent land over 3,000 m

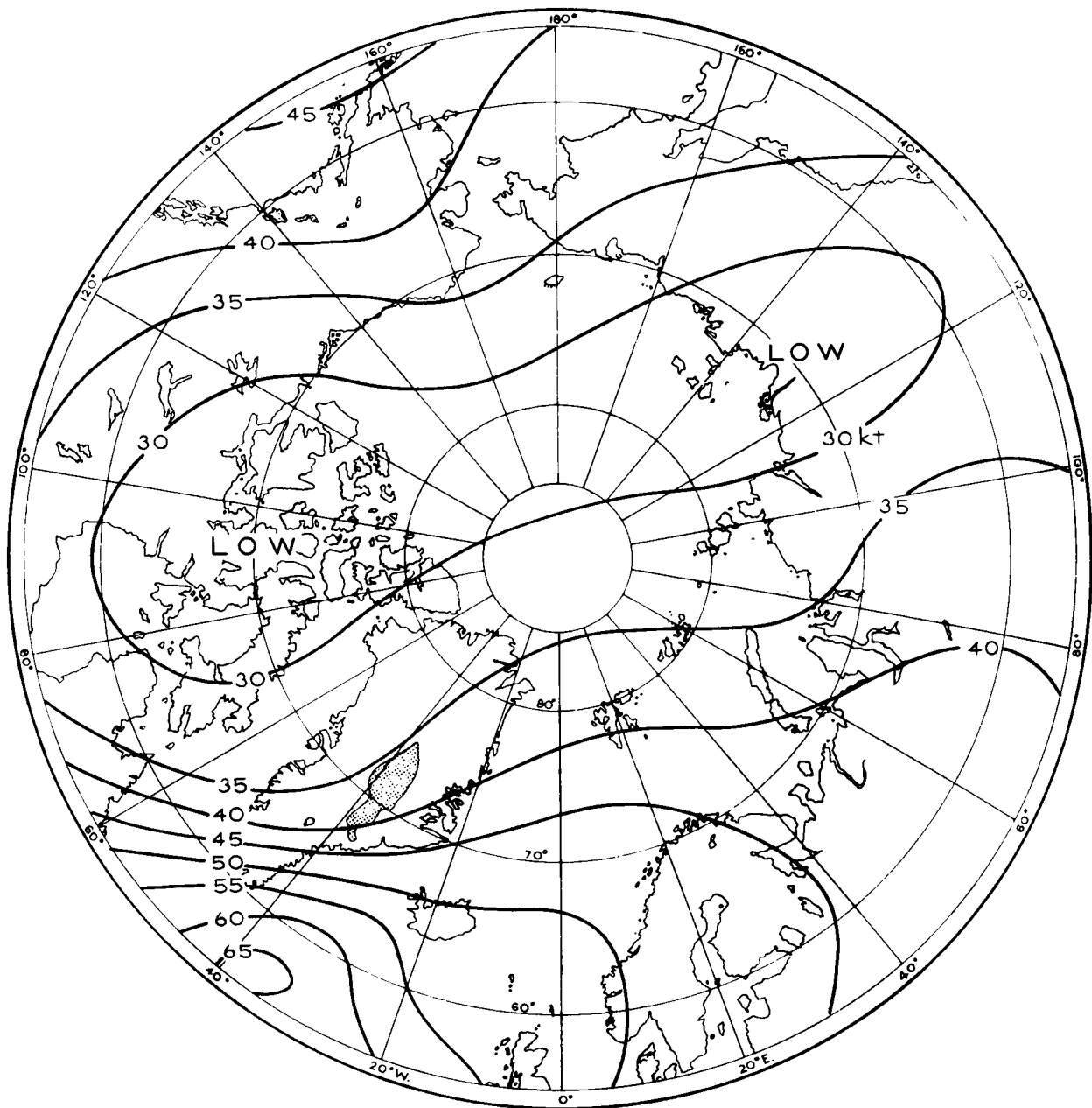


FIGURE 14—STANDARD VECTOR DEVIATION OF WIND AT 300 MB, JANUARY 1949-53

ICAO height = 30,065 ft = 9,164 m
Shaded areas represent land over 3,000 m

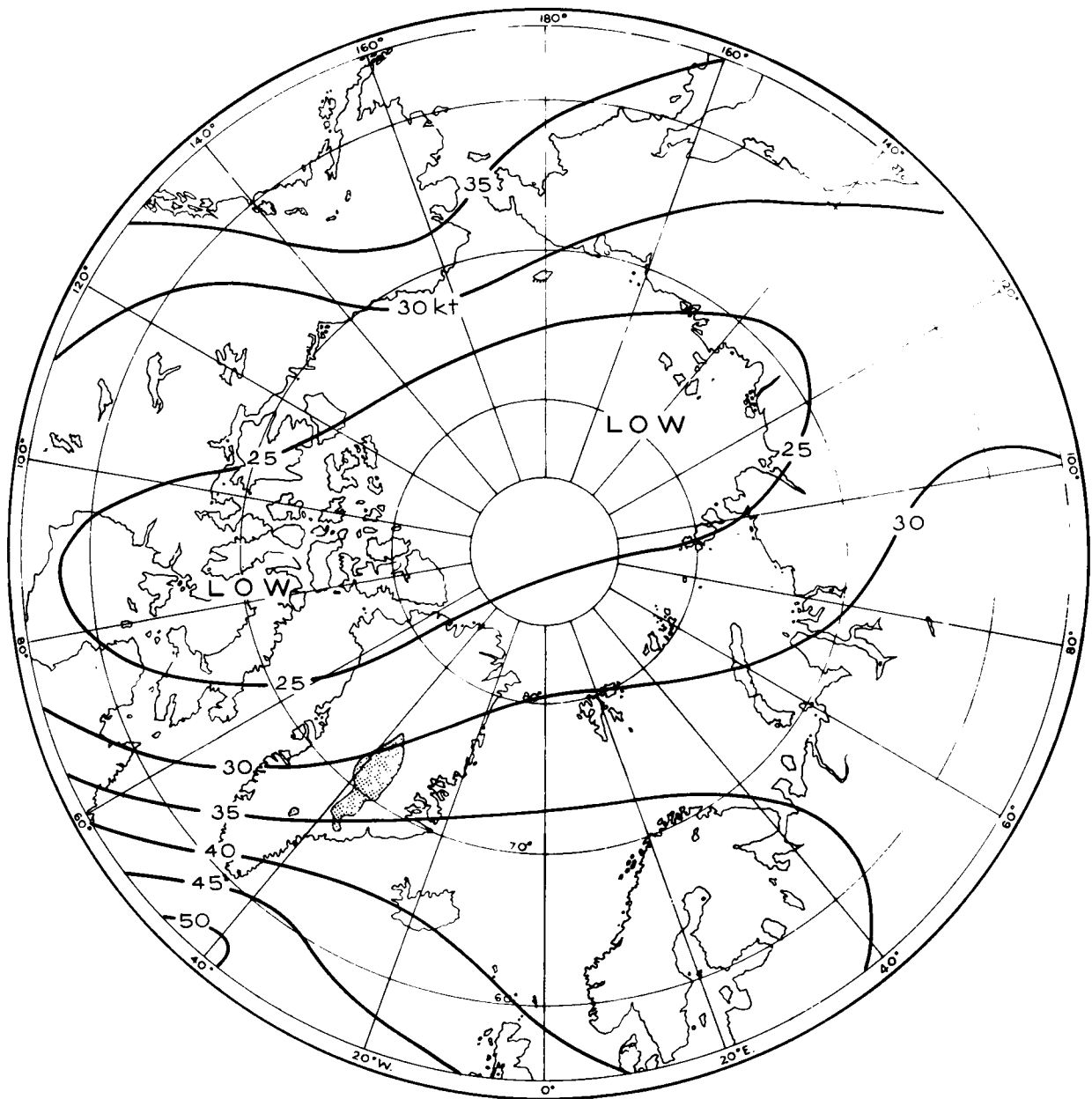


FIGURE 15—STANDARD VECTOR DEVIATION OF WIND AT 200 MB, JANUARY 1949-53

ICAO height = 38,663 ft = 11,784 m
Shaded areas represent land over 3,000 m

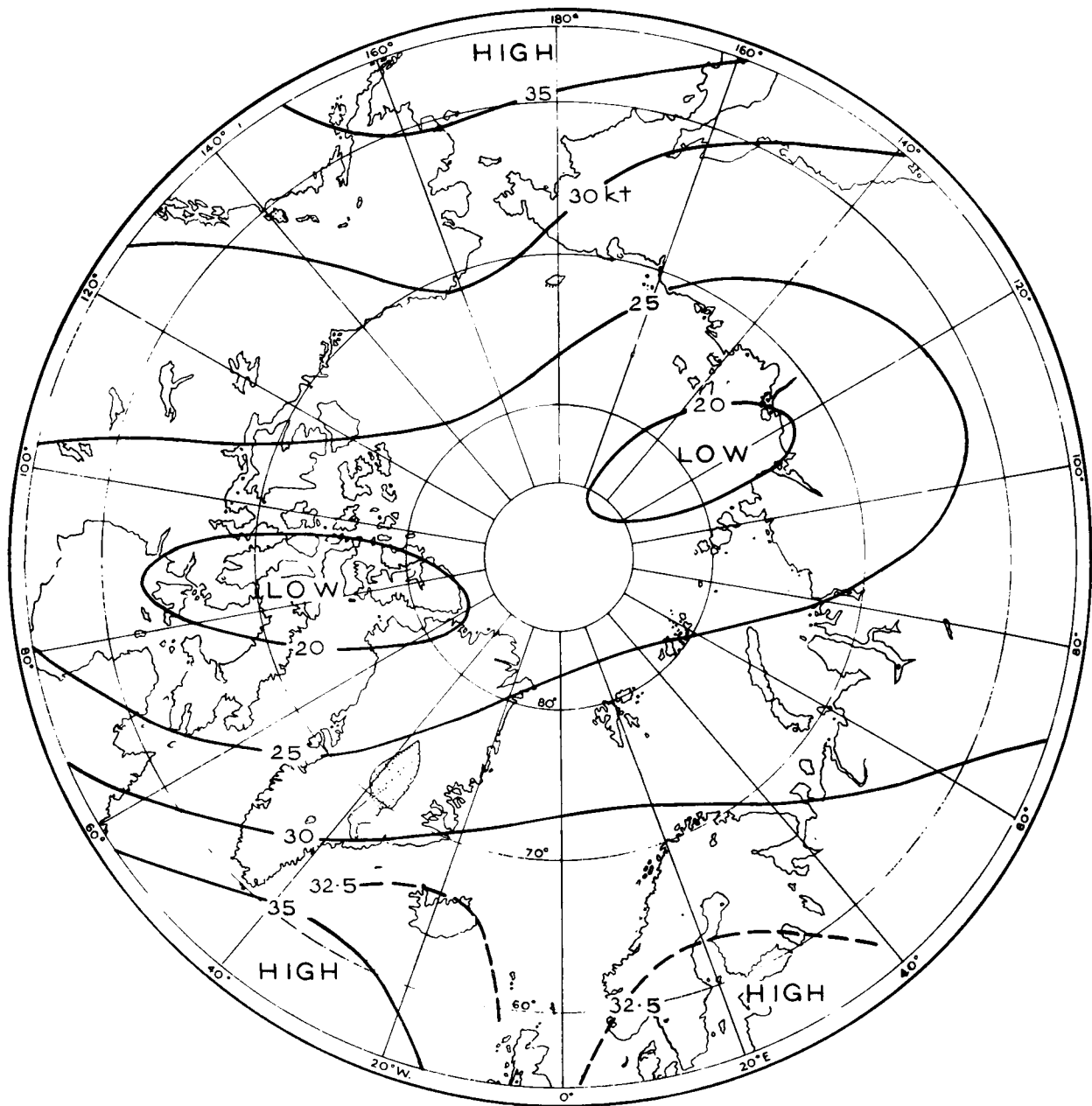


FIGURE 16—STANDARD VECTOR DEVIATION OF WIND AT 150 MB, JANUARY 1949-53

ICAO height = 44,647 ft = 13,608 m
 Shaded areas represent land over 3,000 m

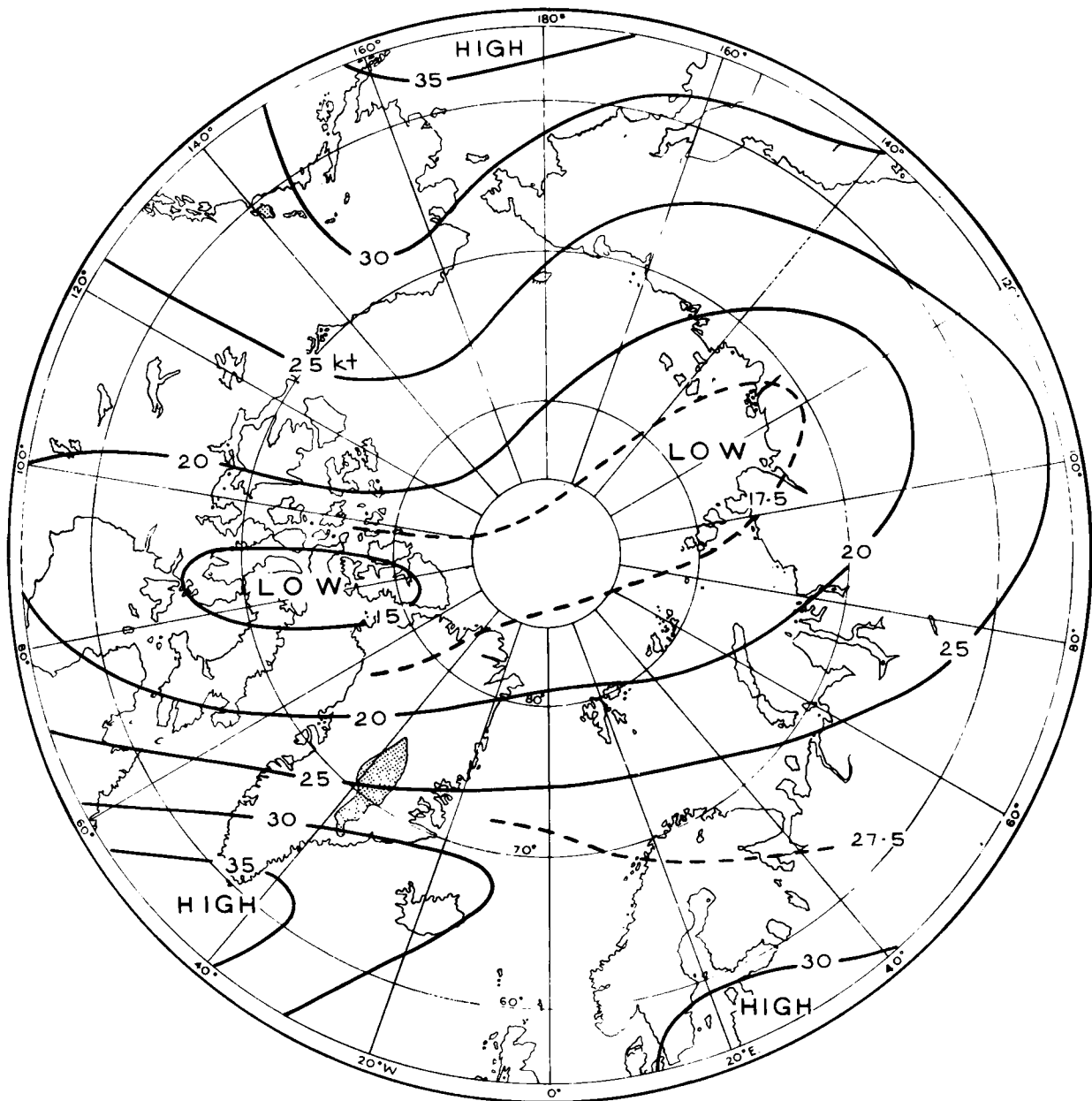


FIGURE 17—STANDARD VECTOR DEVIATION OF WIND AT 100 MB, JANUARY 1949-53

ICAO height = 53,083 ft = 16,180 m
 Shaded areas represent land over 3,000 m

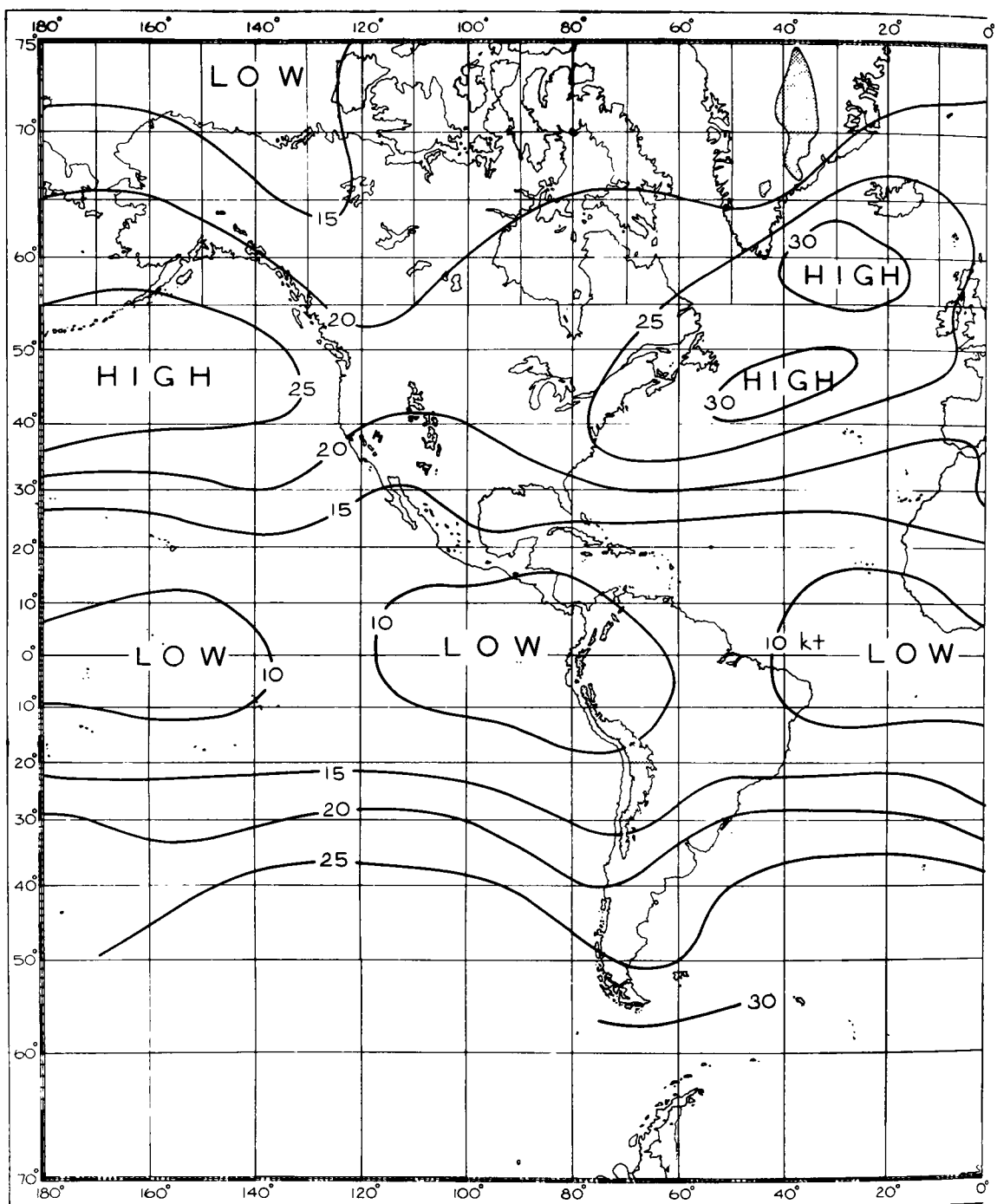


FIGURE 18—STANDARD VECTOR DEVIATION OF WIND AT 700 MB, APRIL 1949-53

ICAO height = 9,882 ft = 3,012 m

Shaded areas represent land over 3,000 m

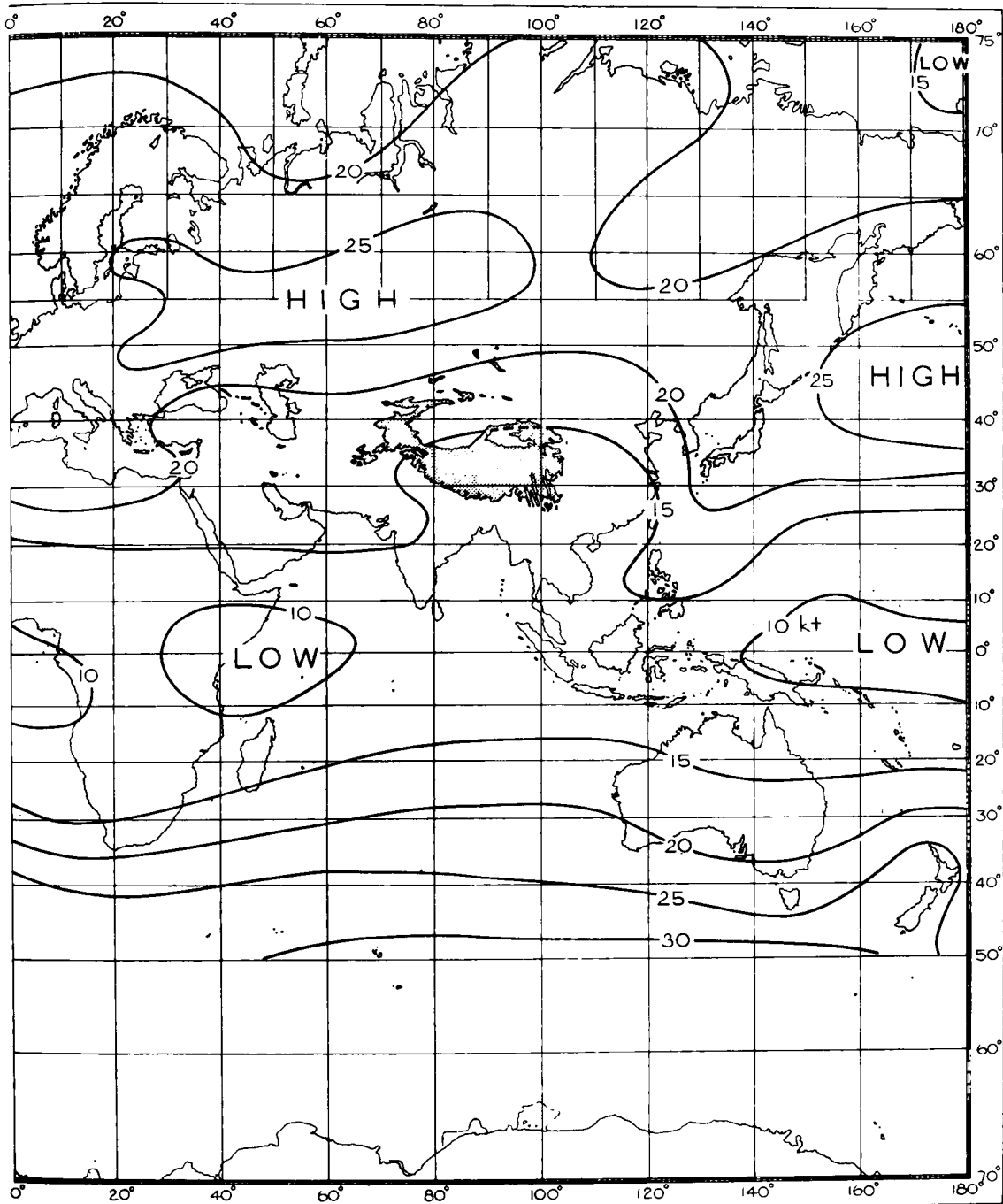


FIGURE 18—CONTINUED

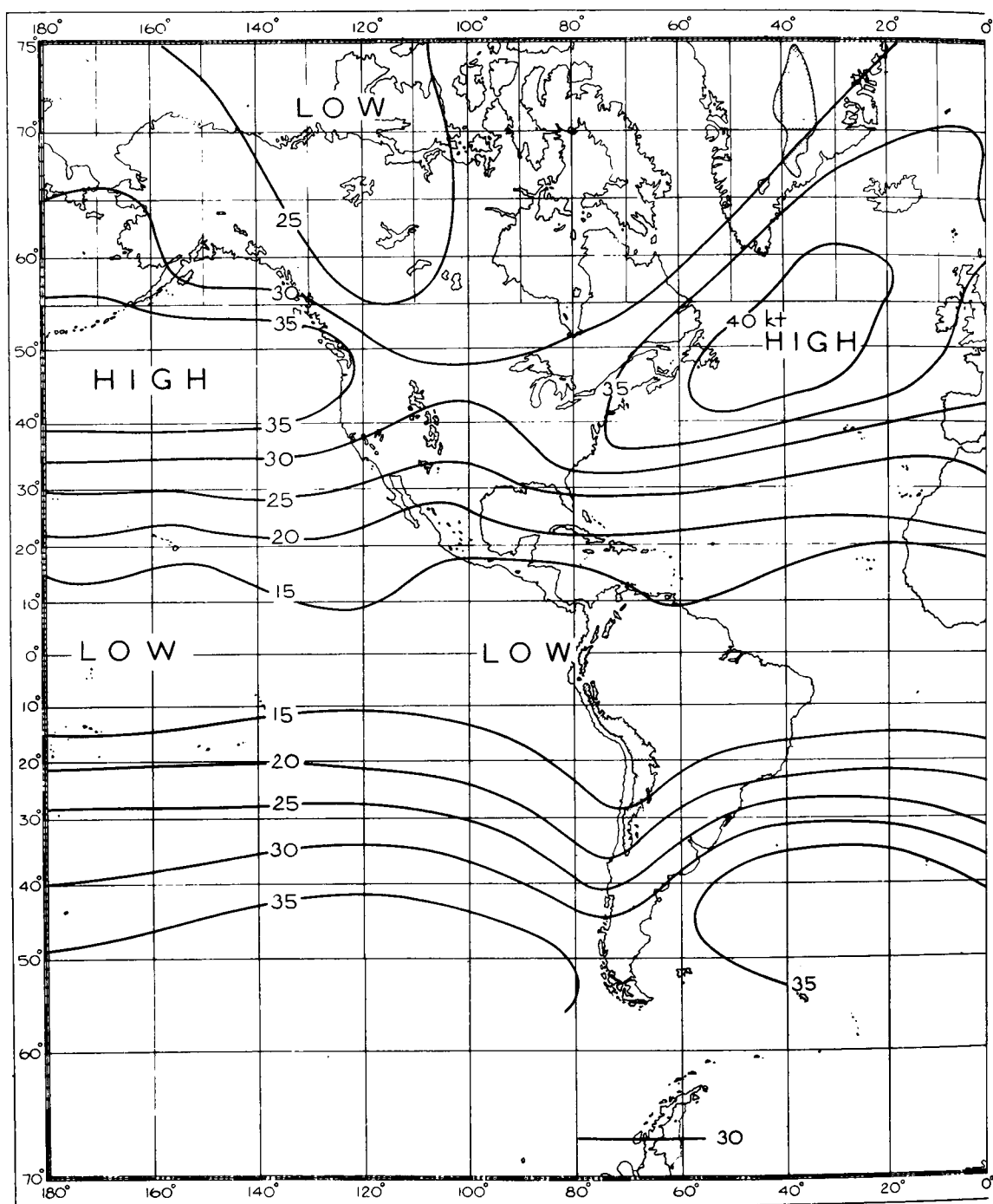


FIGURE 19—STANDARD VECTOR DEVIATION OF WIND AT 500 MB, APRIL 1949-53
 ICAO height = 18,289 ft = 5,574 m
 Shaded areas represent land over 3,000 m

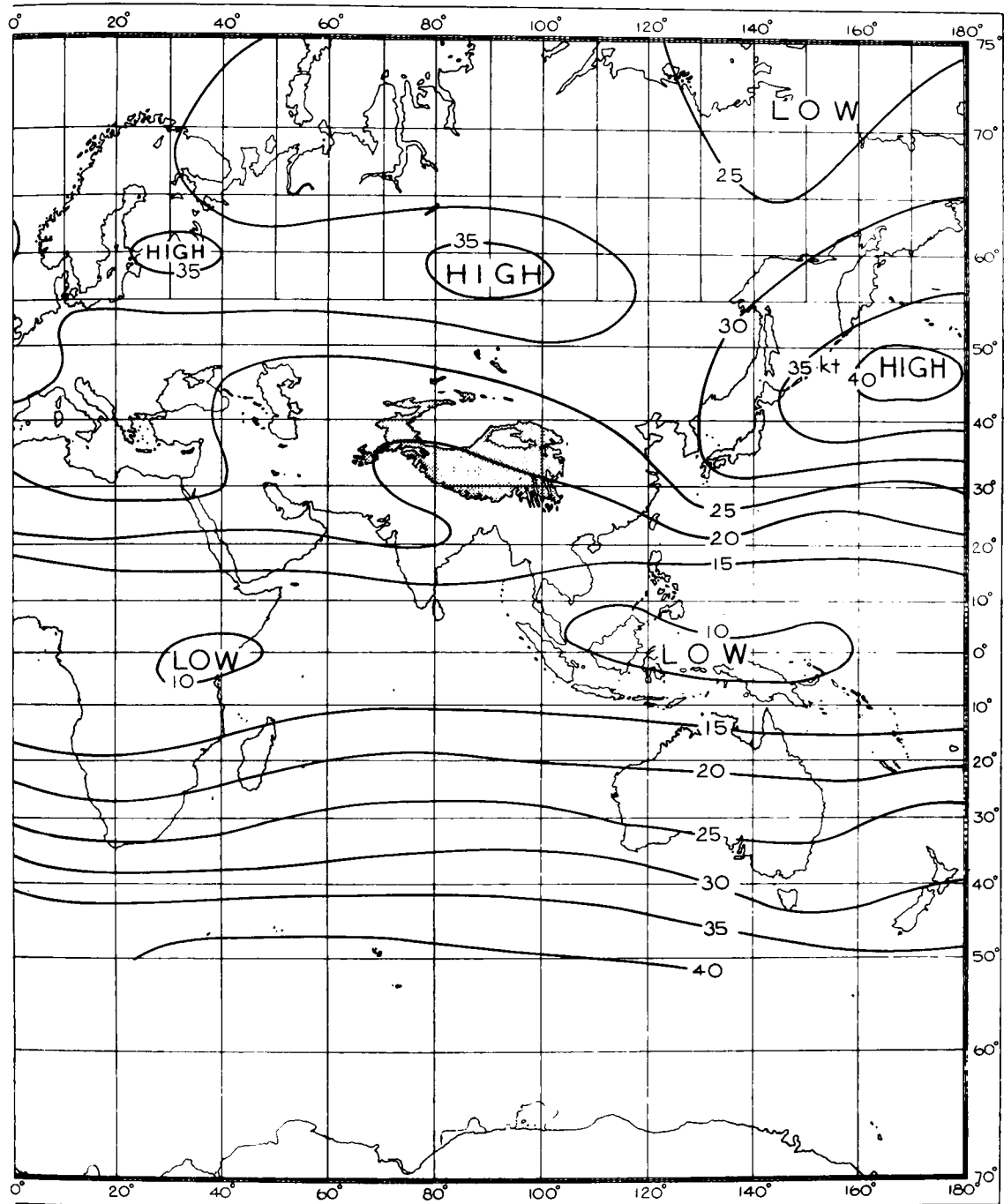


FIGURE 19—CONTINUED

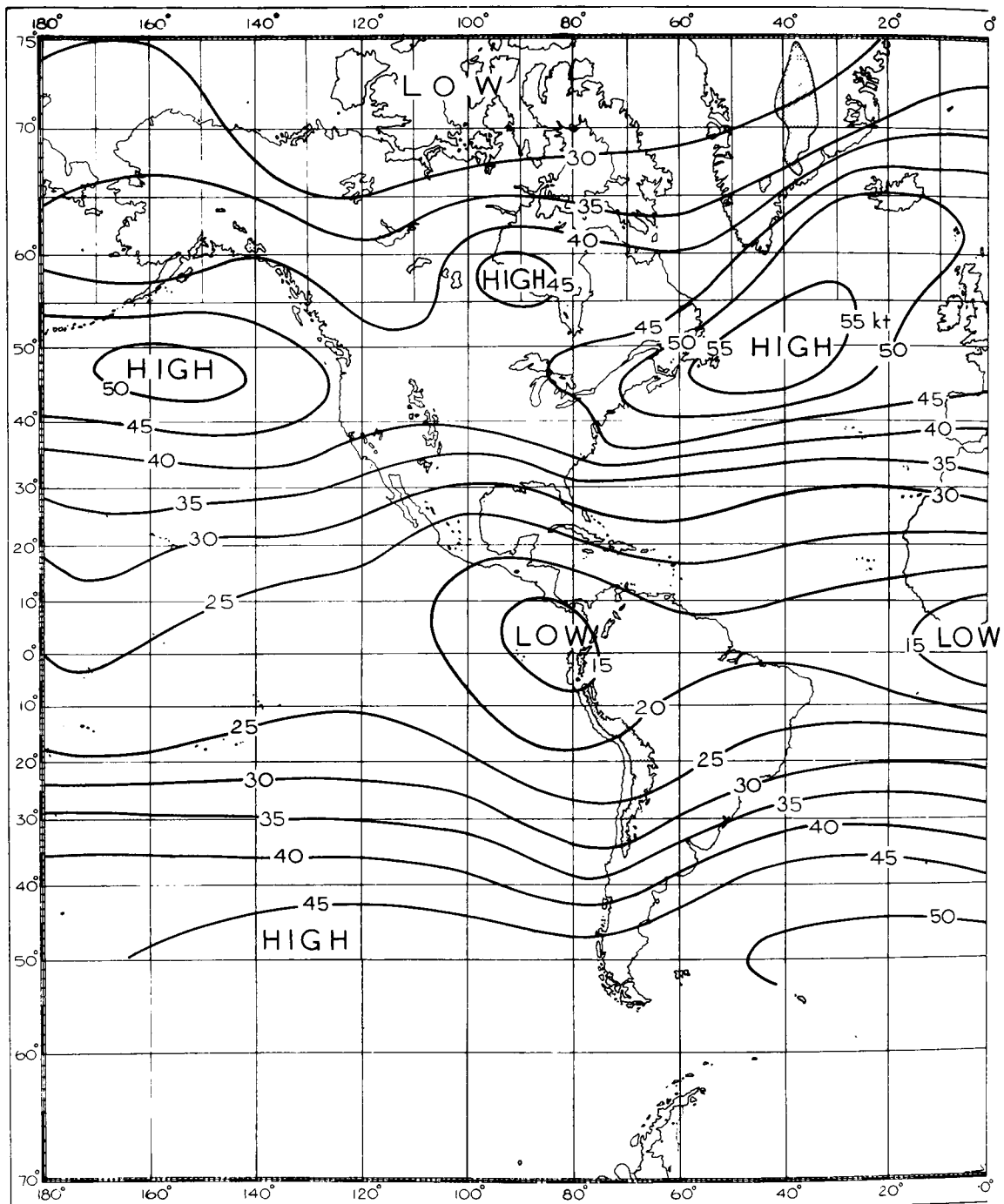


FIGURE 20—STANDARD VECTOR DEVIATION OF WIND AT 300 MB, APRIL 1949-53

ICAO height = 30,065 ft = 9,164 m

Shaded areas represent land over 3,000 m

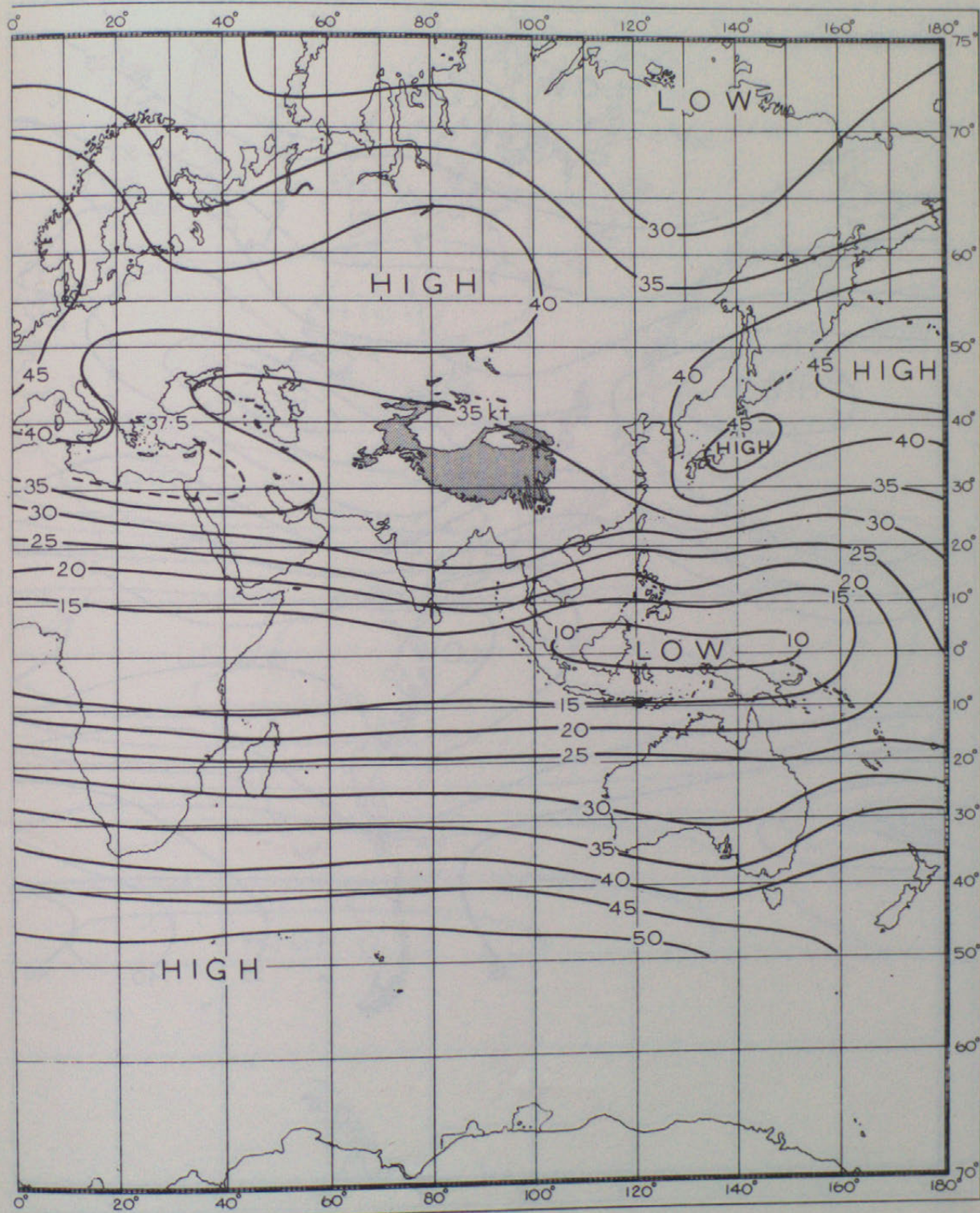


FIGURE 20—CONTINUED

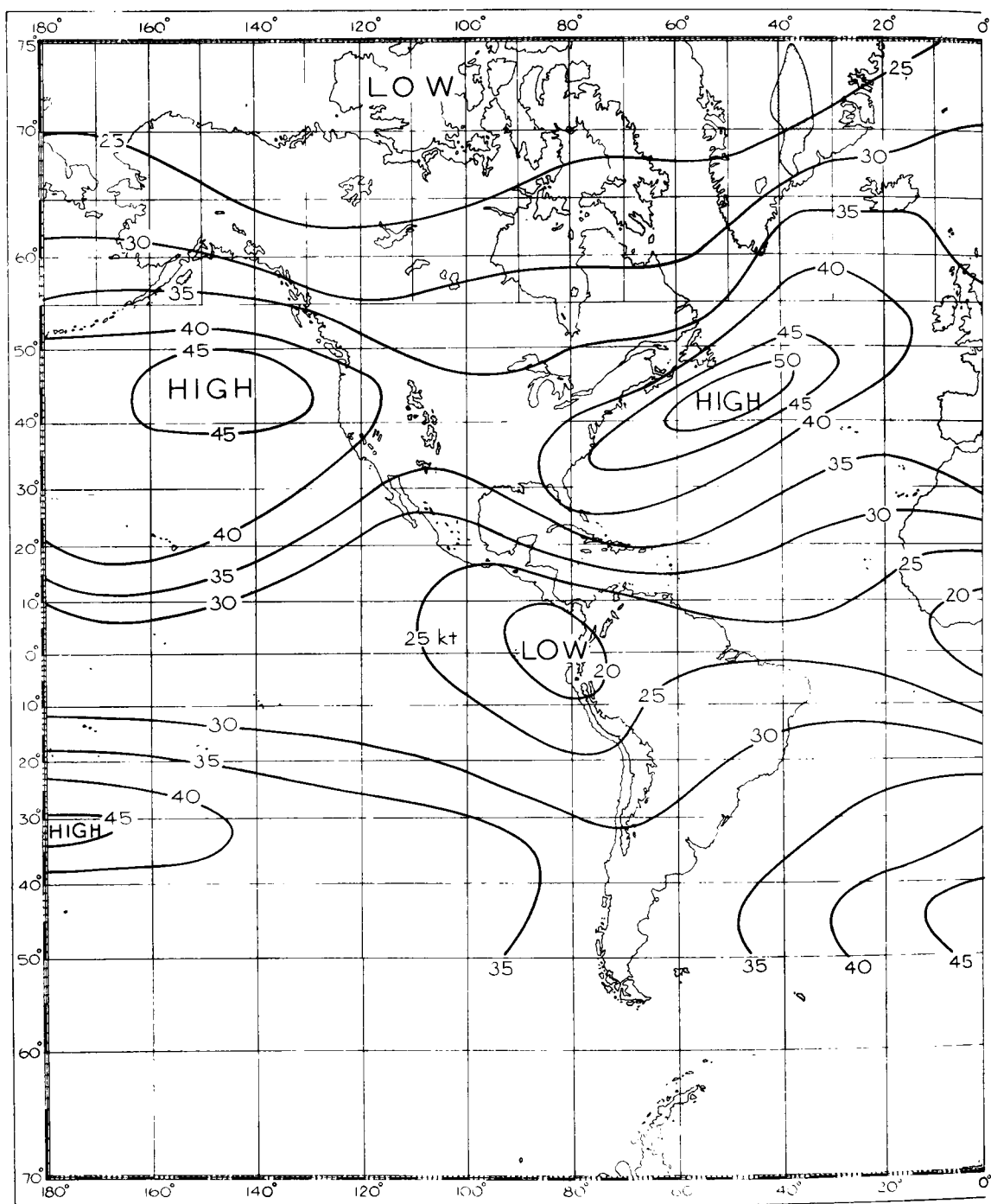


FIGURE 21—STANDARD VECTOR DEVIATION OF WIND AT 200 MB, APRIL 1949-53

ICAO height = 38,663 ft = 11,784 m

Shaded areas represent land over 3,000 m

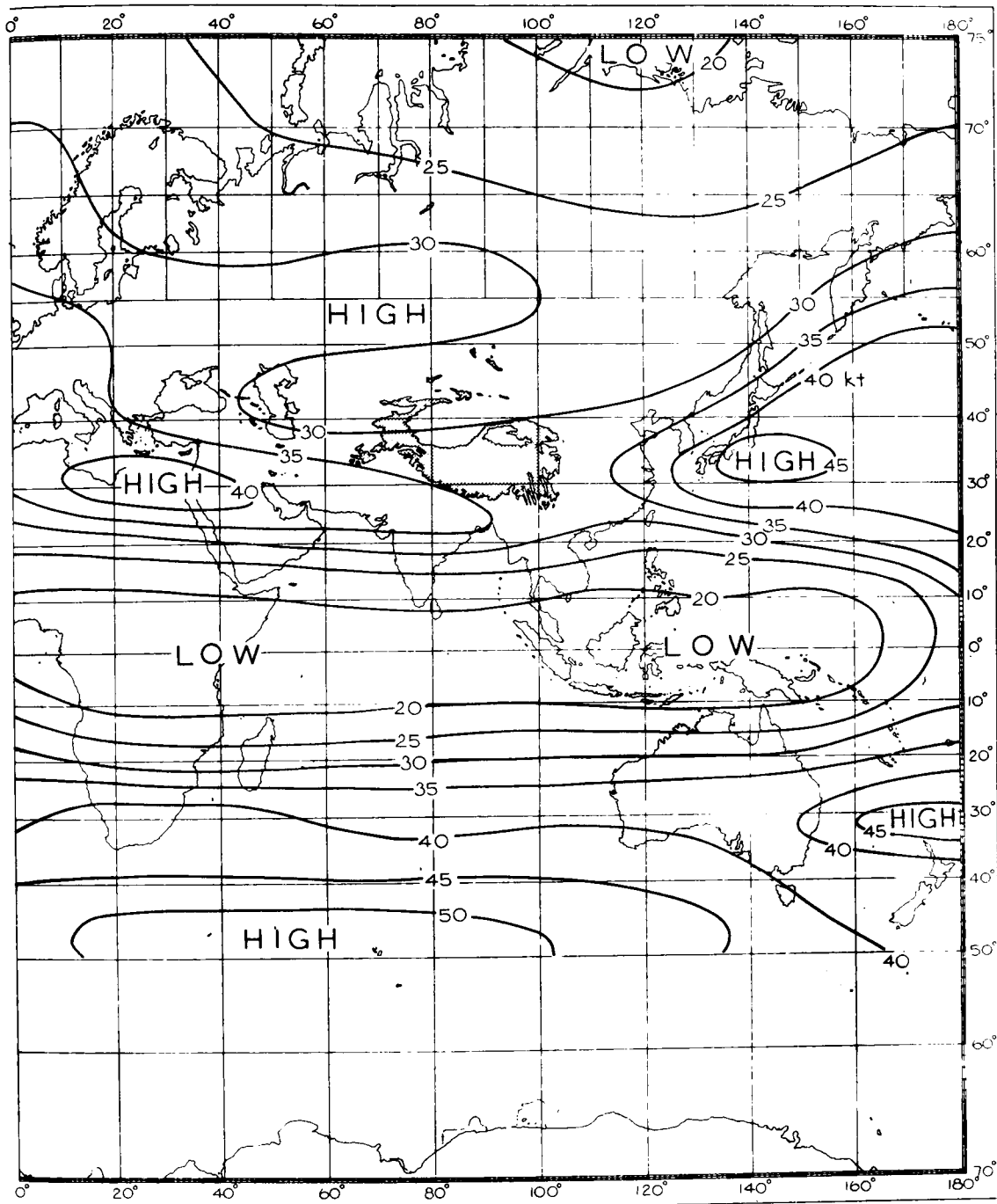


FIGURE 21—CONTINUED

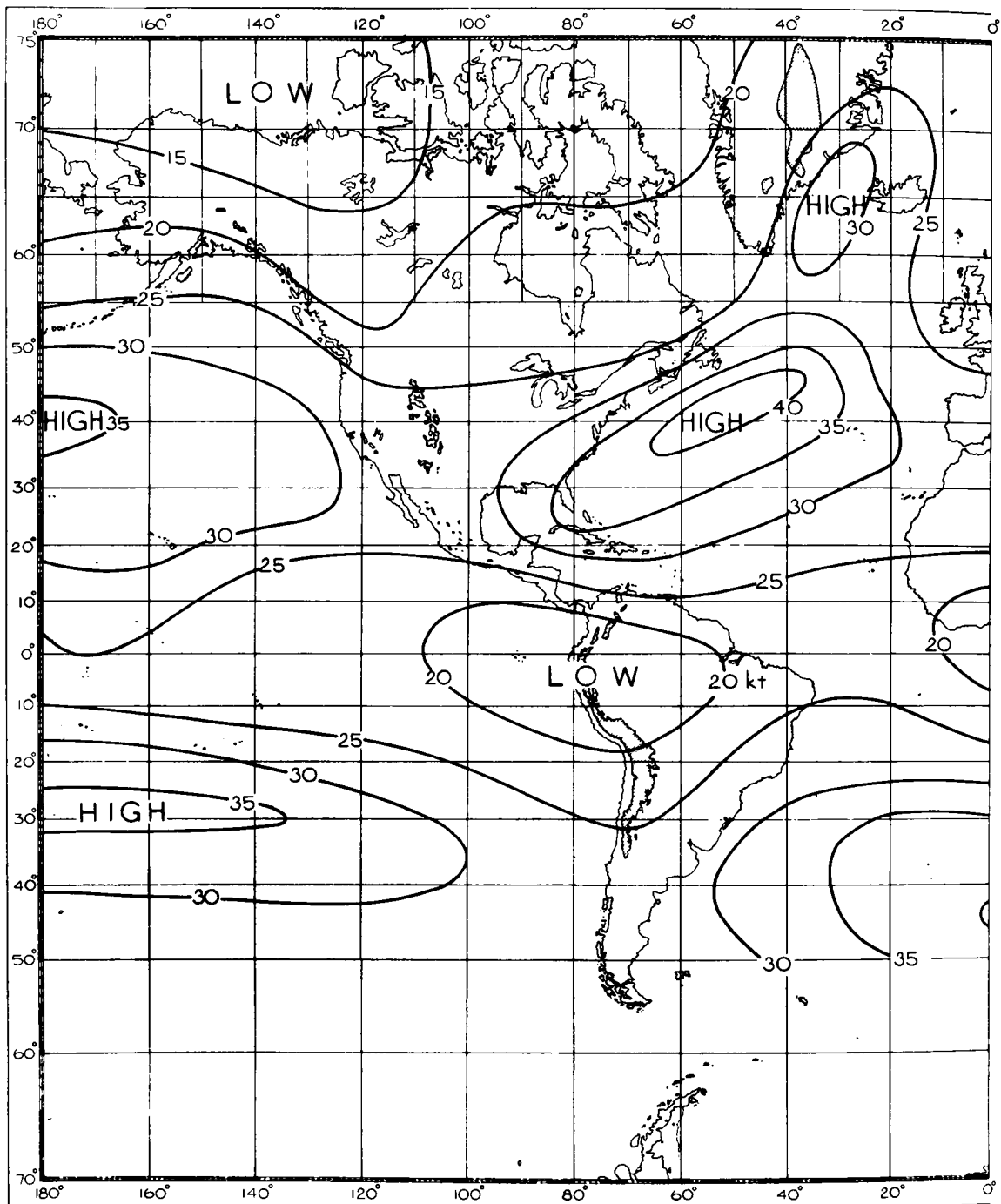


FIGURE 22—STANDARD VECTOR DEVIATION OF WIND AT 150 MB, APRIL 1949-53

ICAO height = 44,647 ft = 13,608 m

Shaded areas represent land over 3,000 m

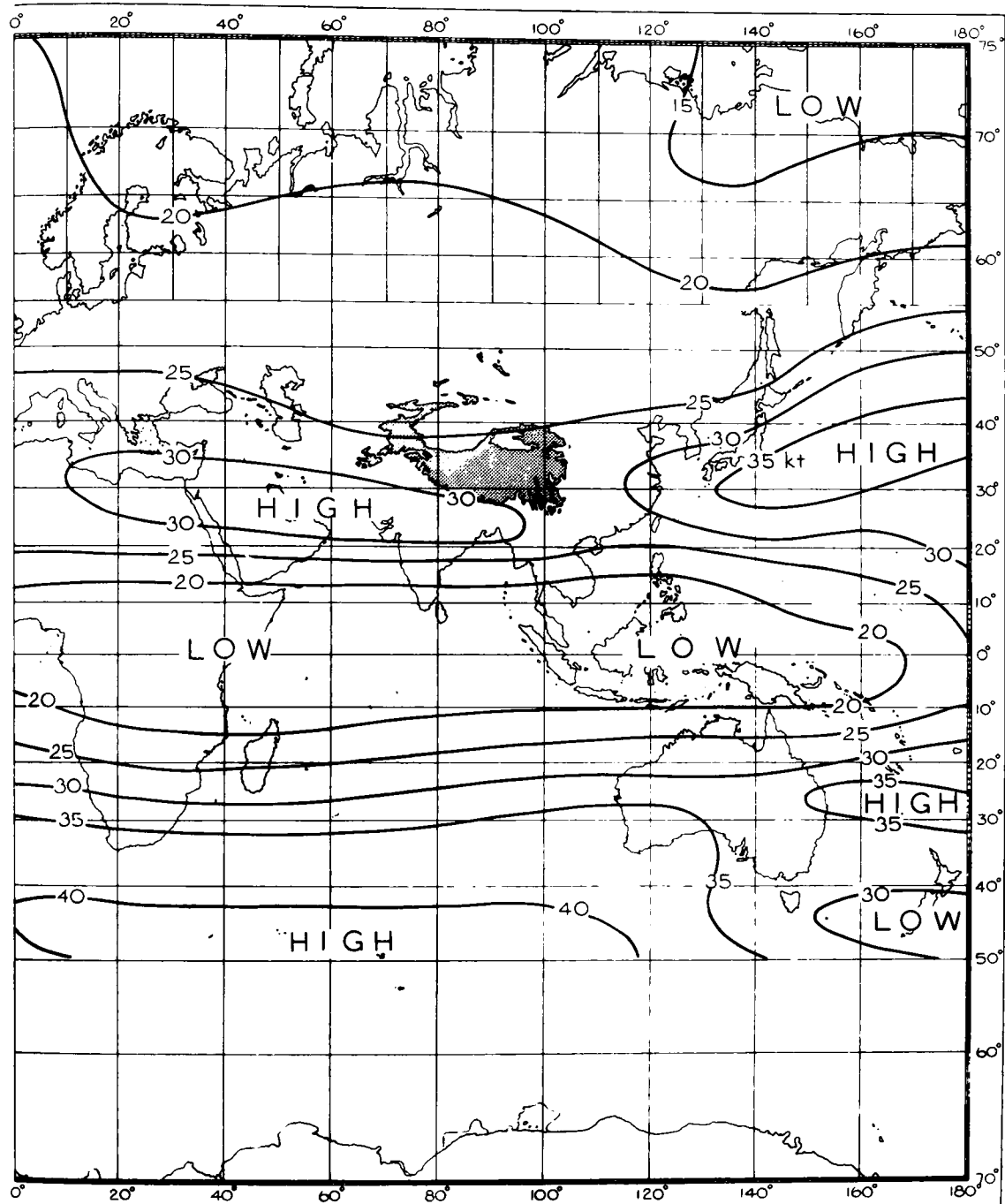


FIGURE 22—CONTINUED

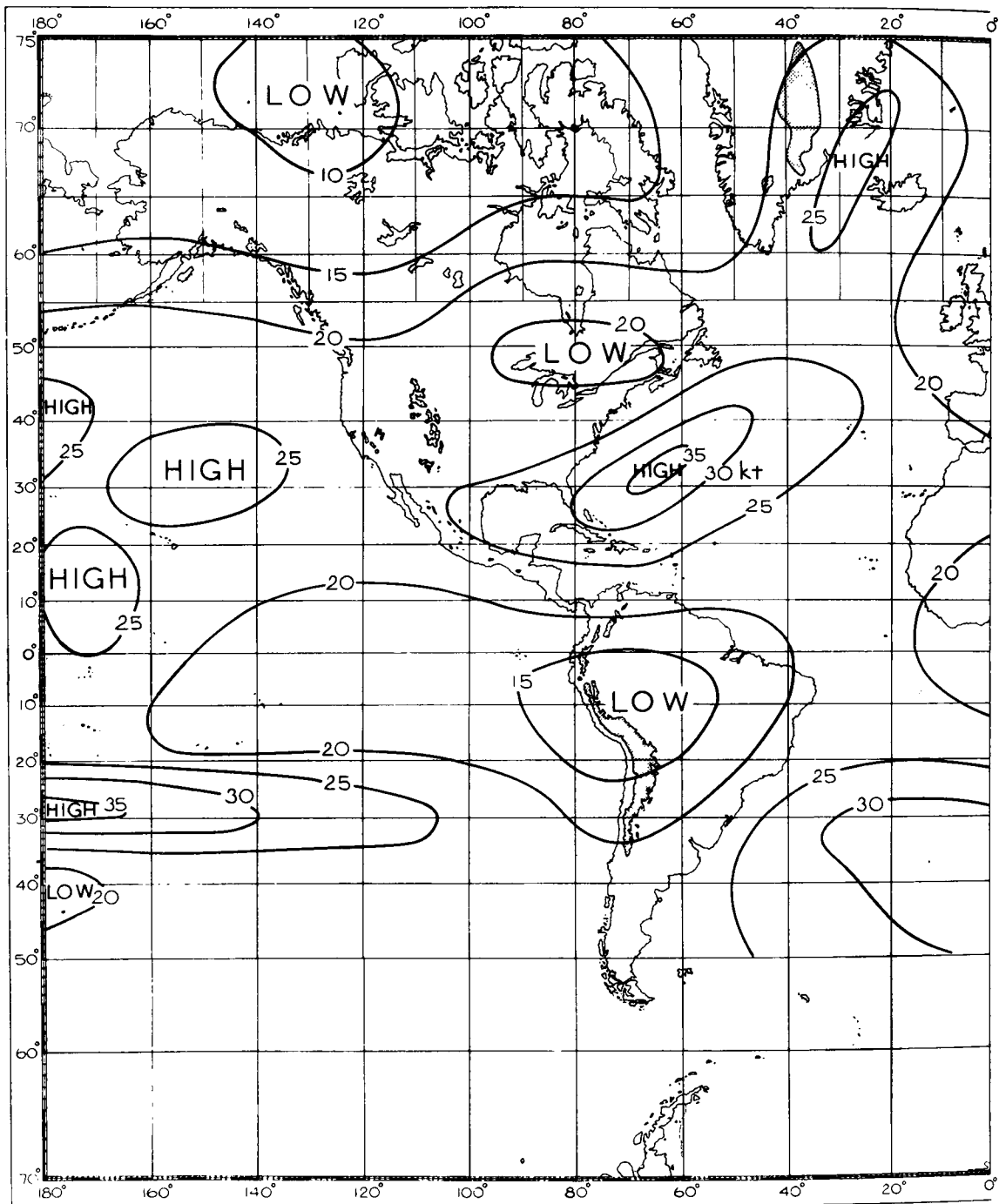


FIGURE 23—STANDARD VECTOR DEVIATION OF WIND AT 100 MB, APRIL 1949-53

ICAO height = 53,083 ft = 16,180 m

Shaded areas represent land over 3,000 m

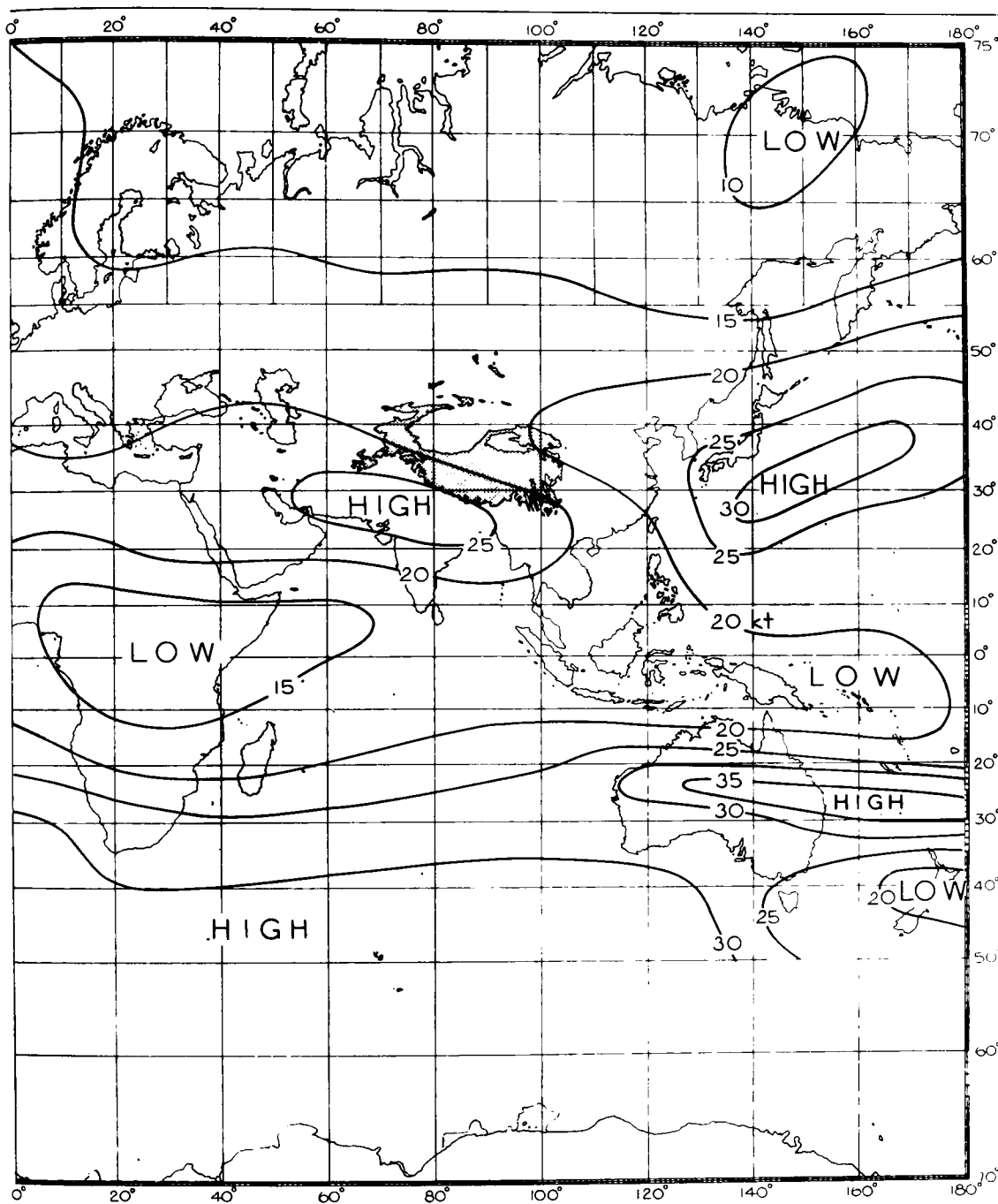


FIGURE 23—CONTINUED

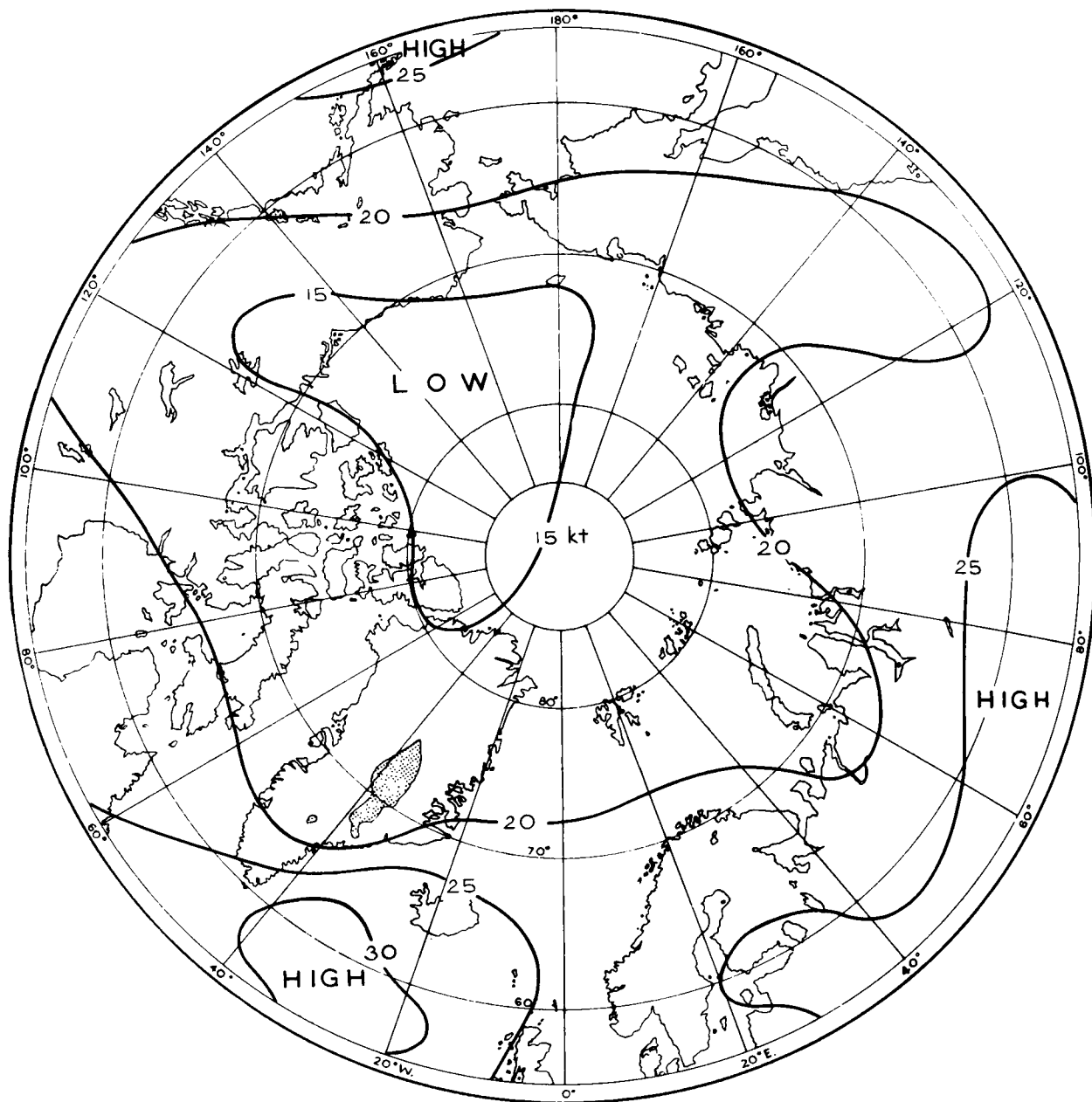


FIGURE 24—STANDARD VECTOR DEVIATION OF WIND AT 700 MB, APRIL 1949-53
ICAO height = 9,882 ft = 3,012 m
Shaded areas represent land over 3,000 m

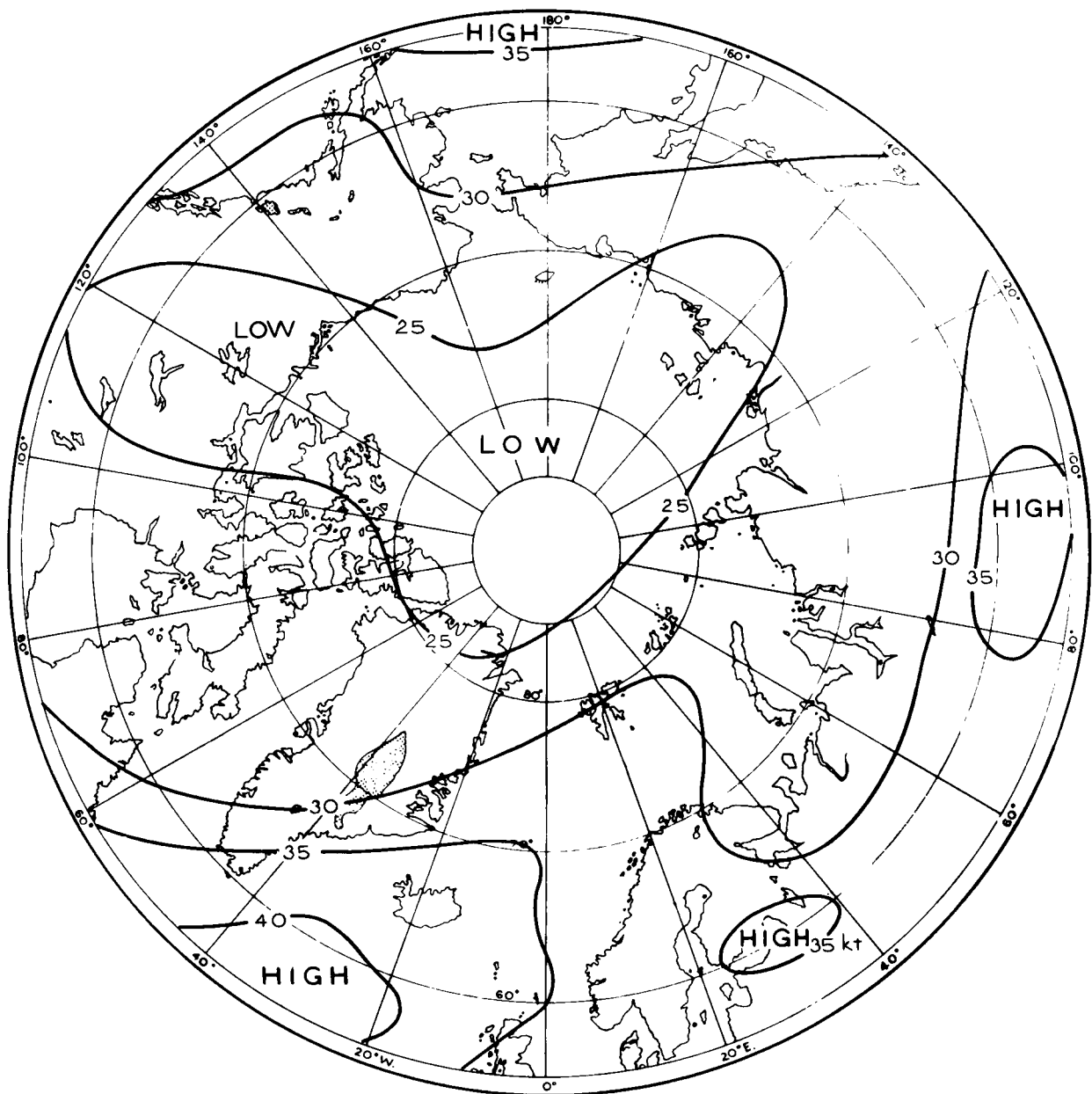


FIGURE 25—STANDARD VECTOR DEVIATION OF WIND AT 500 MB, APRIL 1949-53
ICAO height = 18,289 ft = 5,574 m
Shaded areas represent land over 3,000 m.

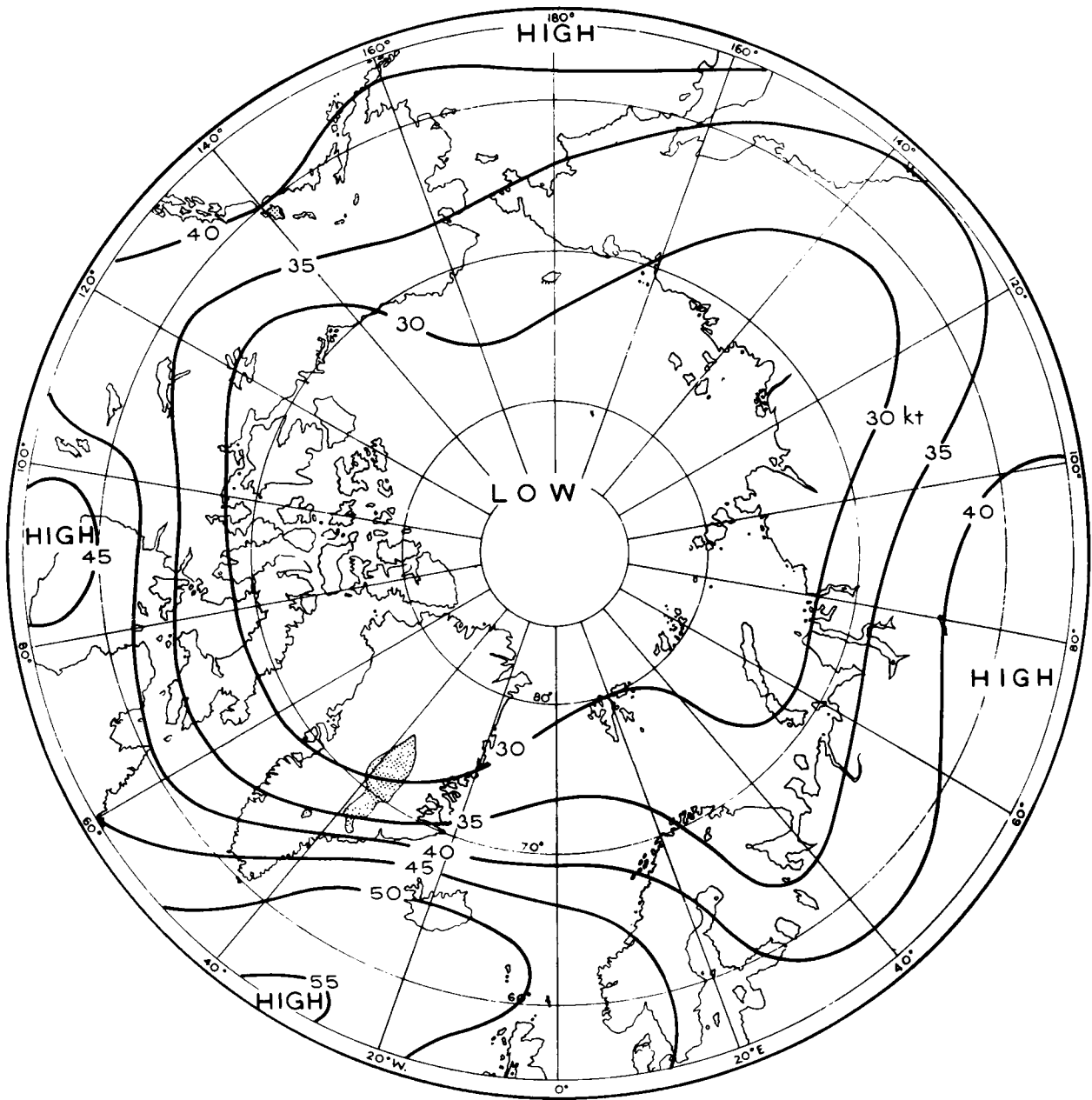


FIGURE 26—STANDARD VECTOR DEVIATION OF WIND AT 300 MB, APRIL 1949-53
ICAO height = 30,065 ft = 9,164 m
Shaded areas represent land over 3,000 m

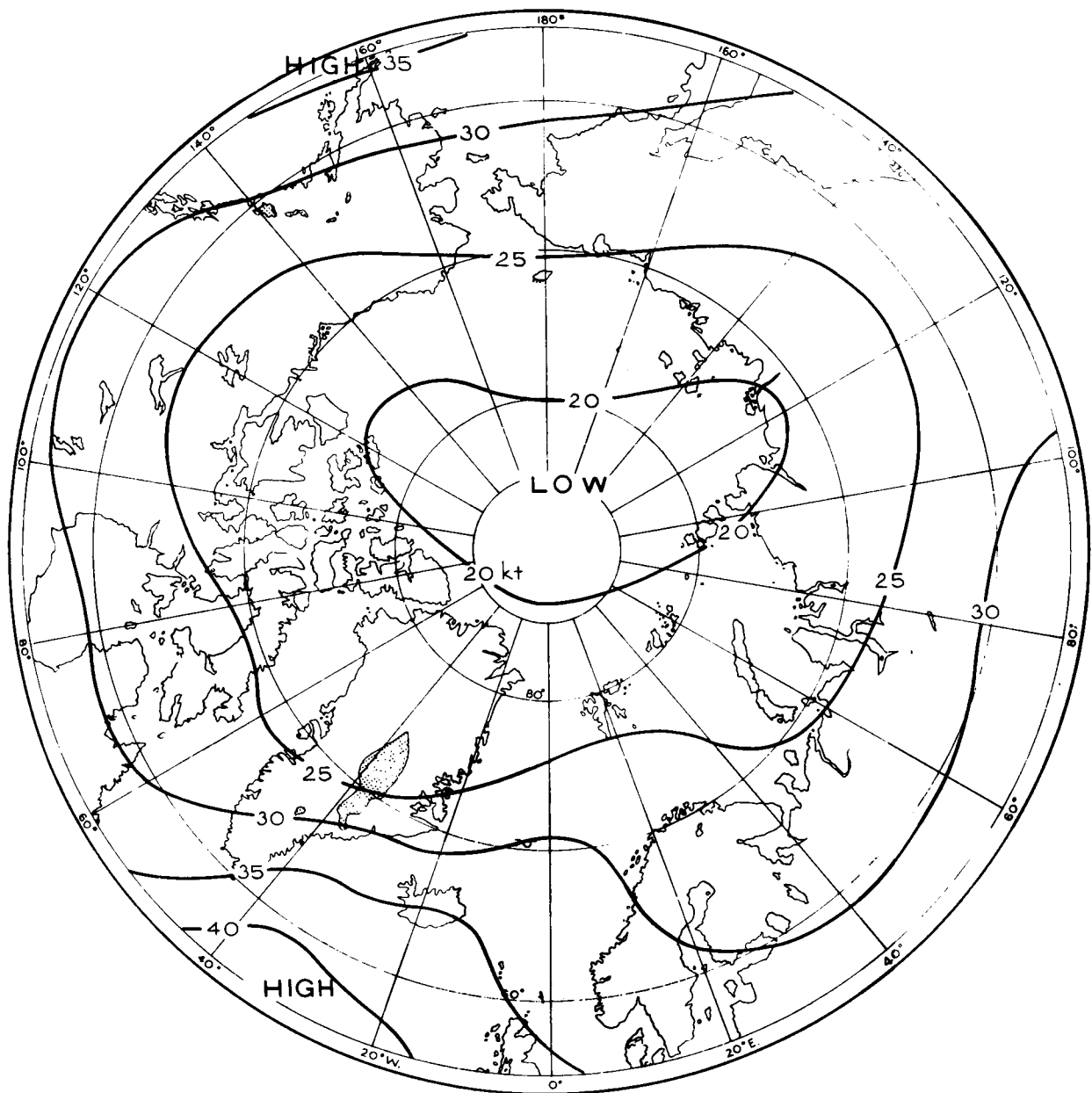


FIGURE 27—STANDARD VECTOR DEVIATION OF WIND AT 200 MB, APRIL 1949-53
ICAO height = 38,663 ft = 11,784 m
Shaded areas represent land over 3,000 m

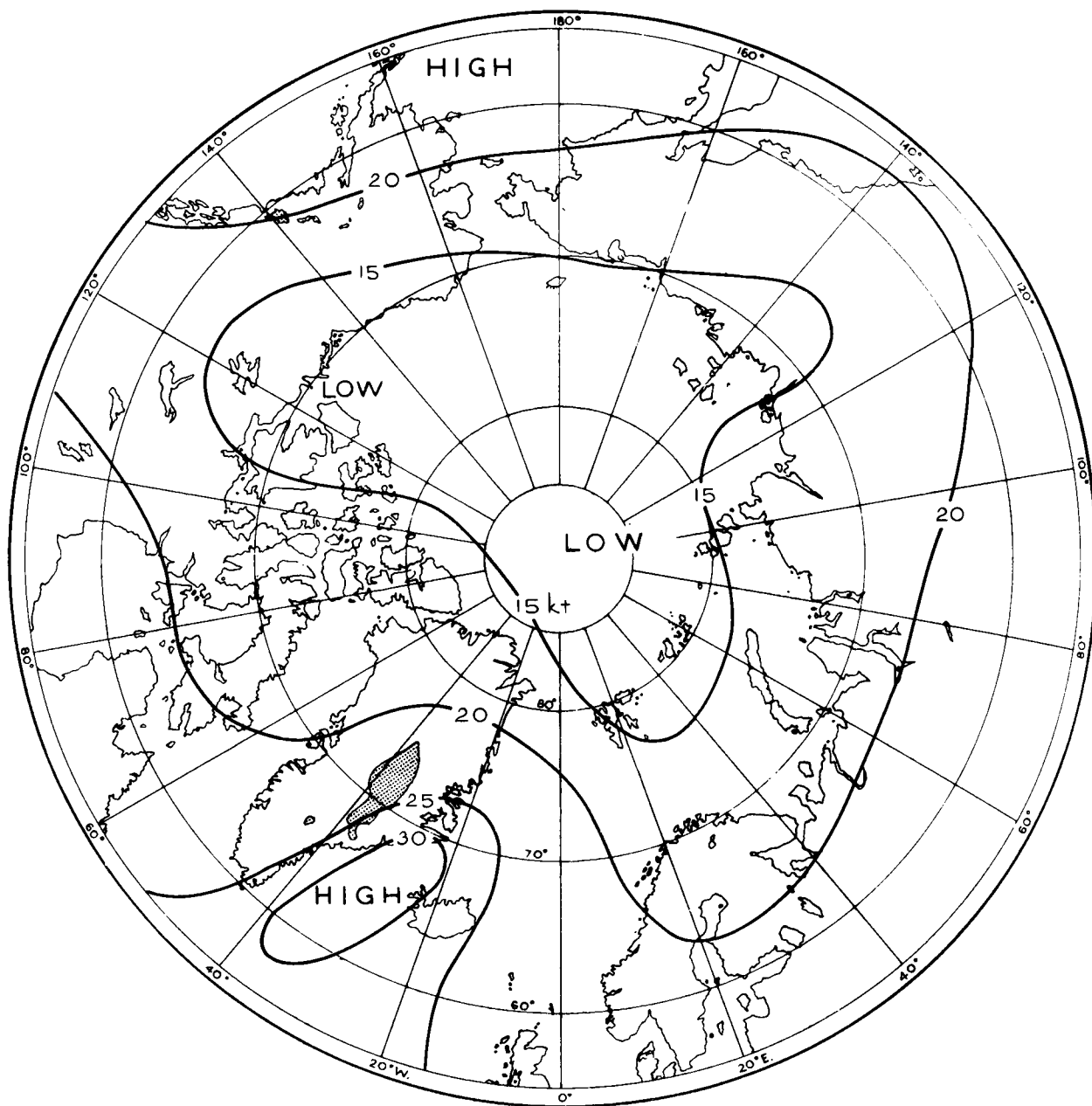


FIGURE 28—STANDARD VECTOR DEVIATION OF WIND AT 150 MB, APRIL 1949-53
ICAO height = 44,647 ft = 13,608 m
Shaded areas represent land over 3,000 m

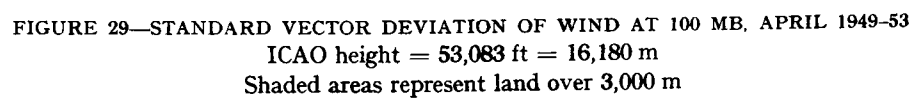


FIGURE 29—STANDARD VECTOR DEVIATION OF WIND AT 100 MB, APRIL 1949-53
ICAO height = 53,083 ft = 16,180 m
Shaded areas represent land over 3,000 m

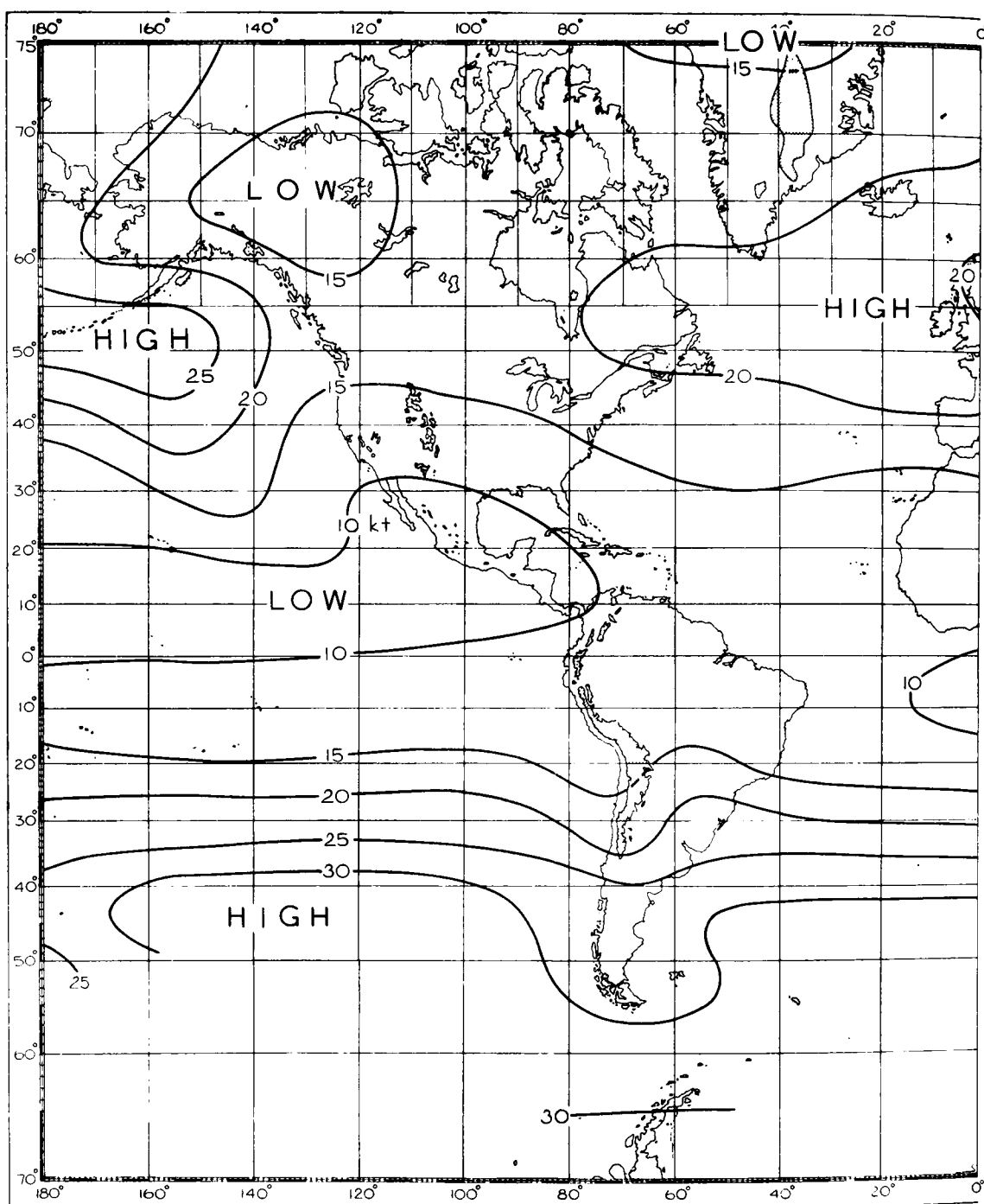


FIGURE 30—STANDARD VECTOR DEVIATION OF WIND AT 700 MB, JULY 1949-53

ICAO height = 9,882 ft = 3,012 m

Shaded areas represent land over 3,000 m

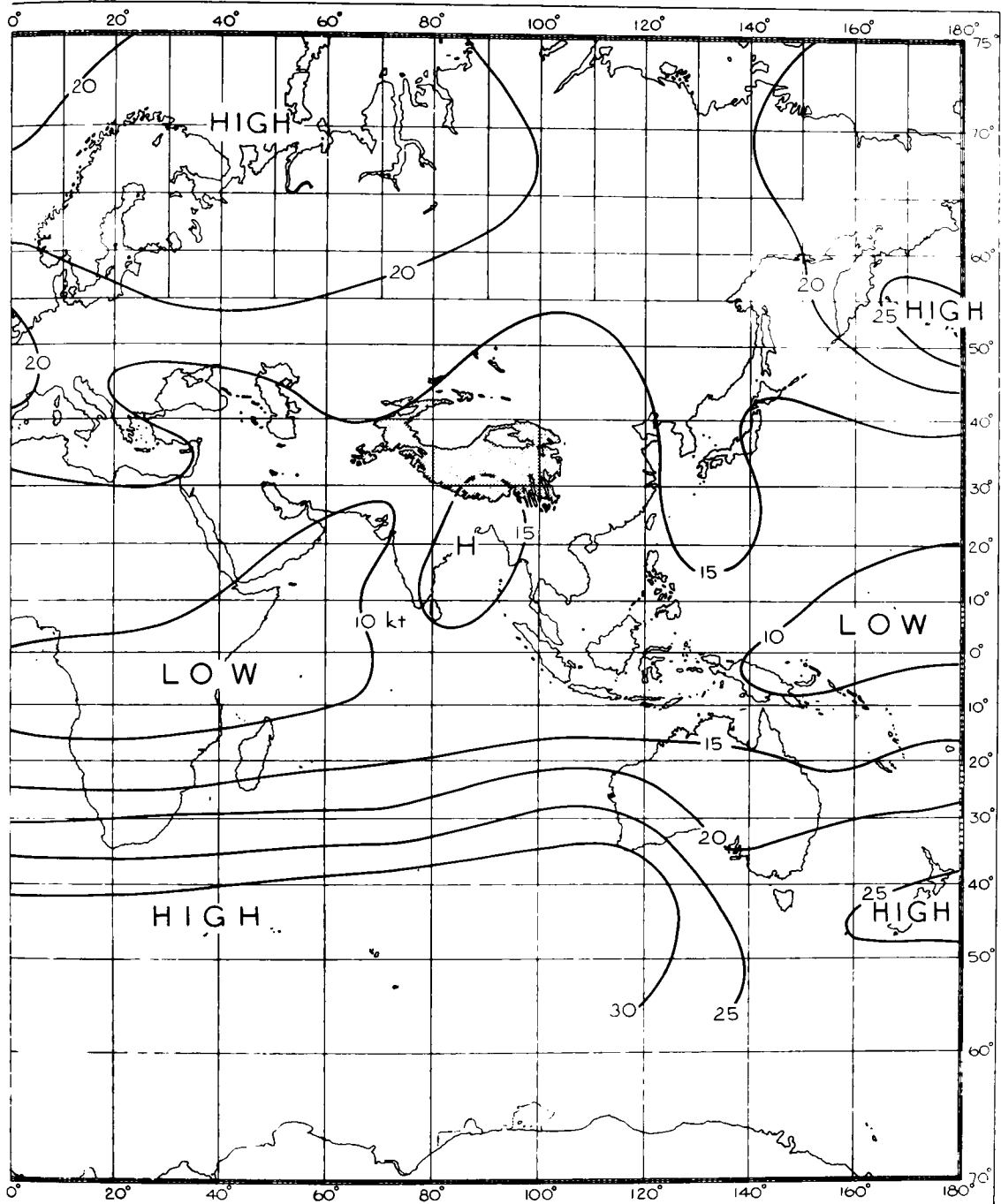


FIGURE 30—CONTINUED

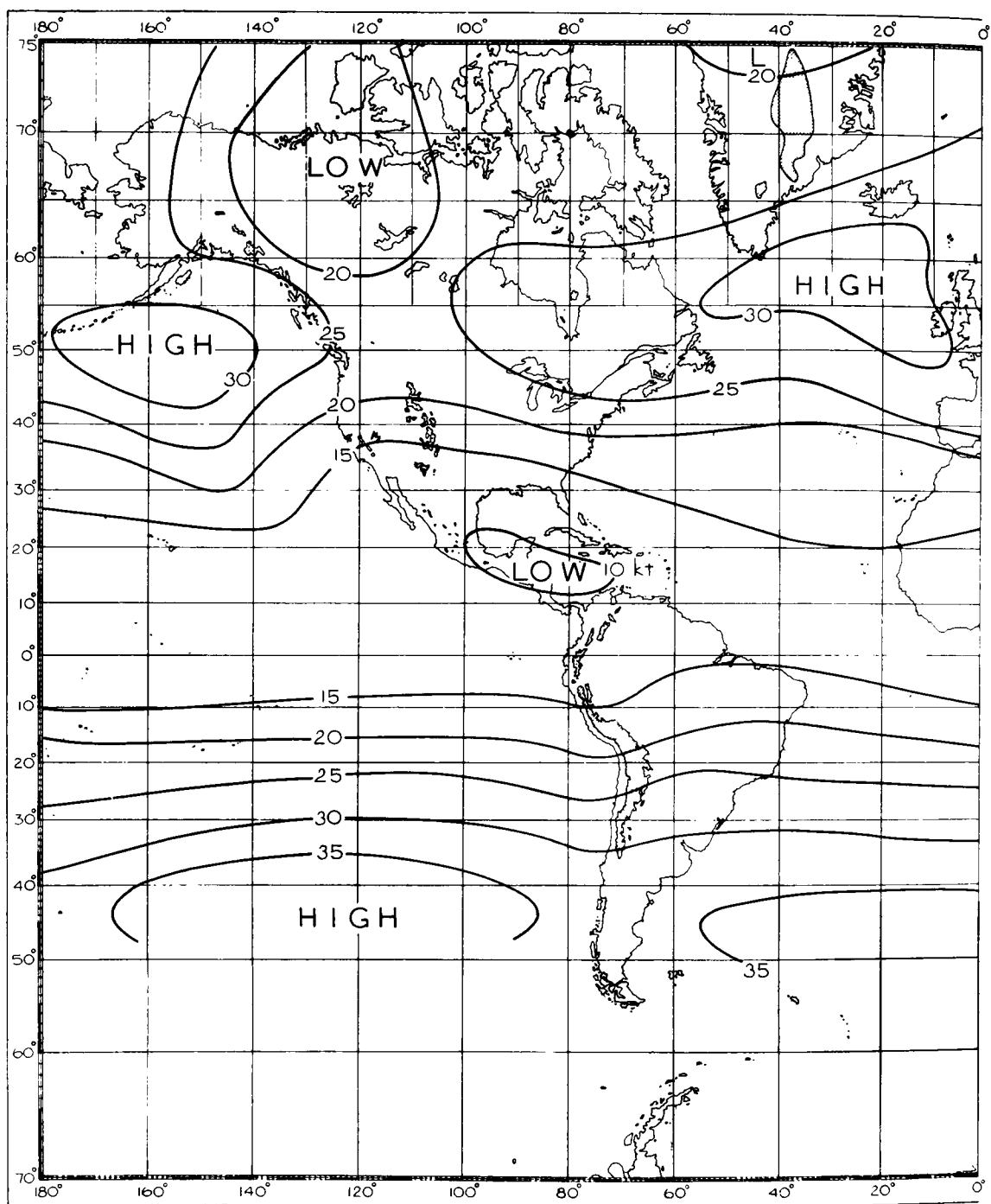


FIGURE 31—STANDARD VECTOR DEVIATION OF WIND AT 500 MB, JULY 1949-53

ICAO height = 18,289 ft = 5,574 m

Shaded areas represent land over 3,000 m

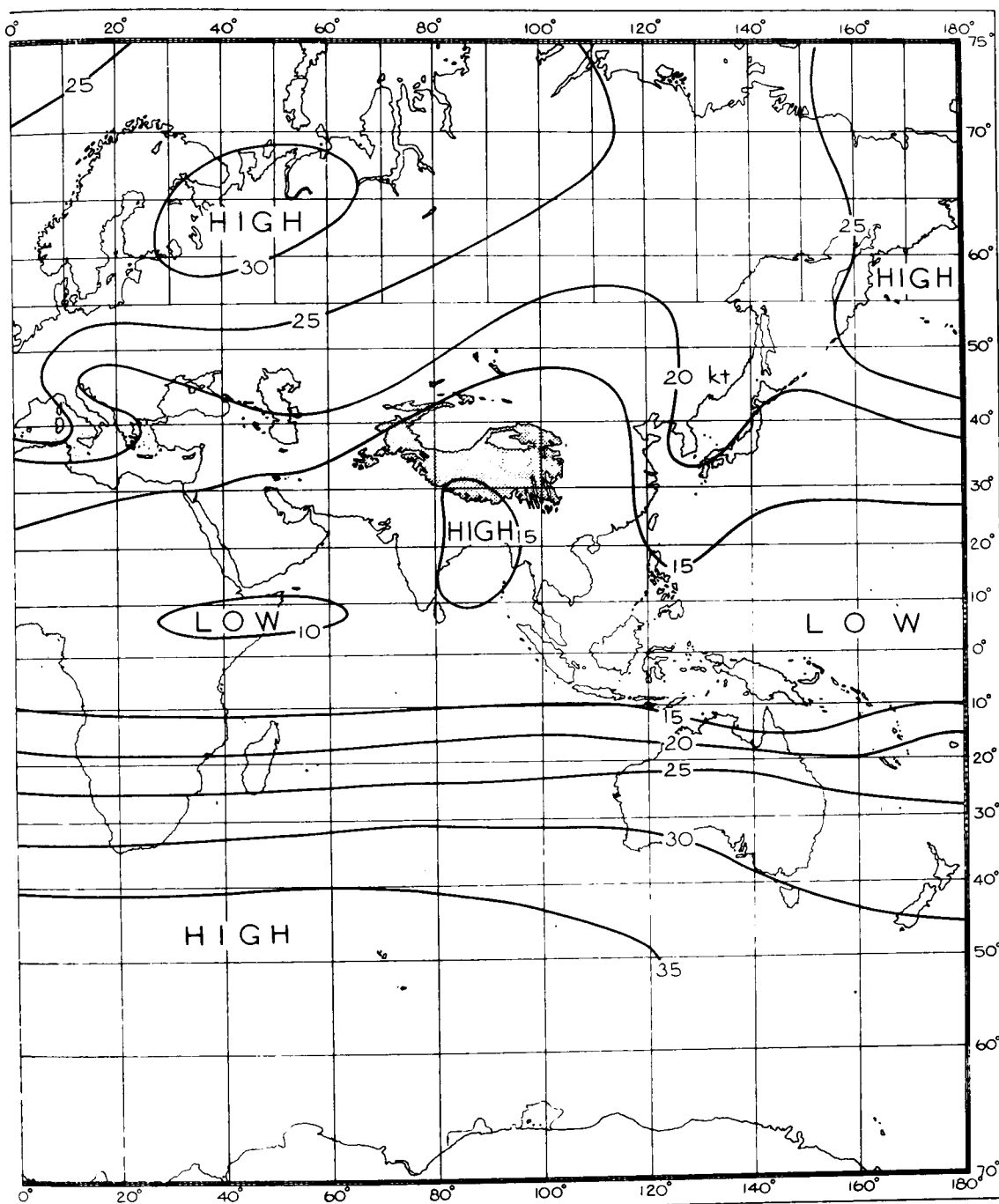


FIGURE 31—CONTINUED

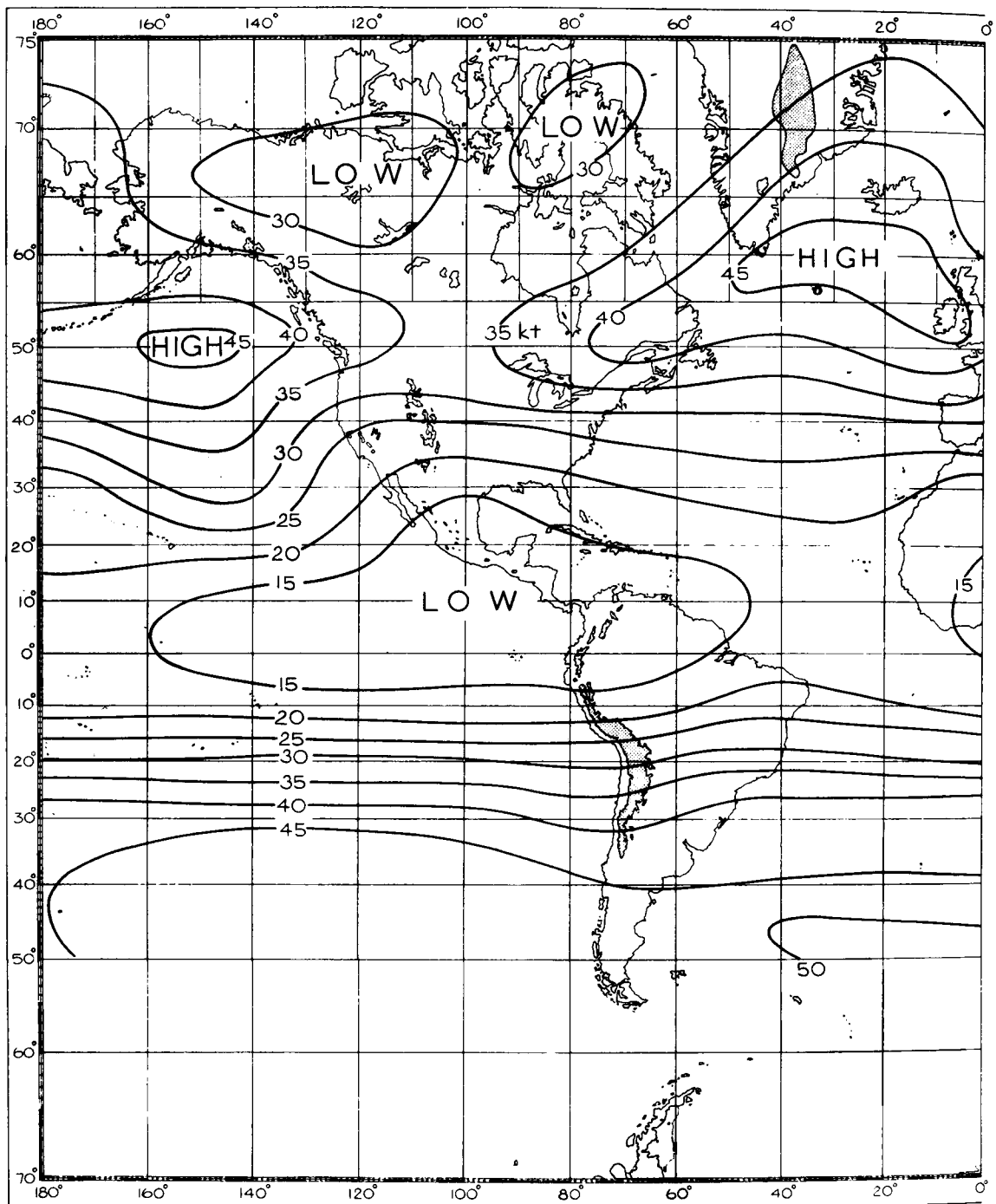


FIGURE 32—STANDARD VECTOR DEVIATION OF WIND AT 300 MB, JULY 1949-53

ICAO height = 30,065 ft = 9,164 m

Shaded areas represent land over 3,000 m

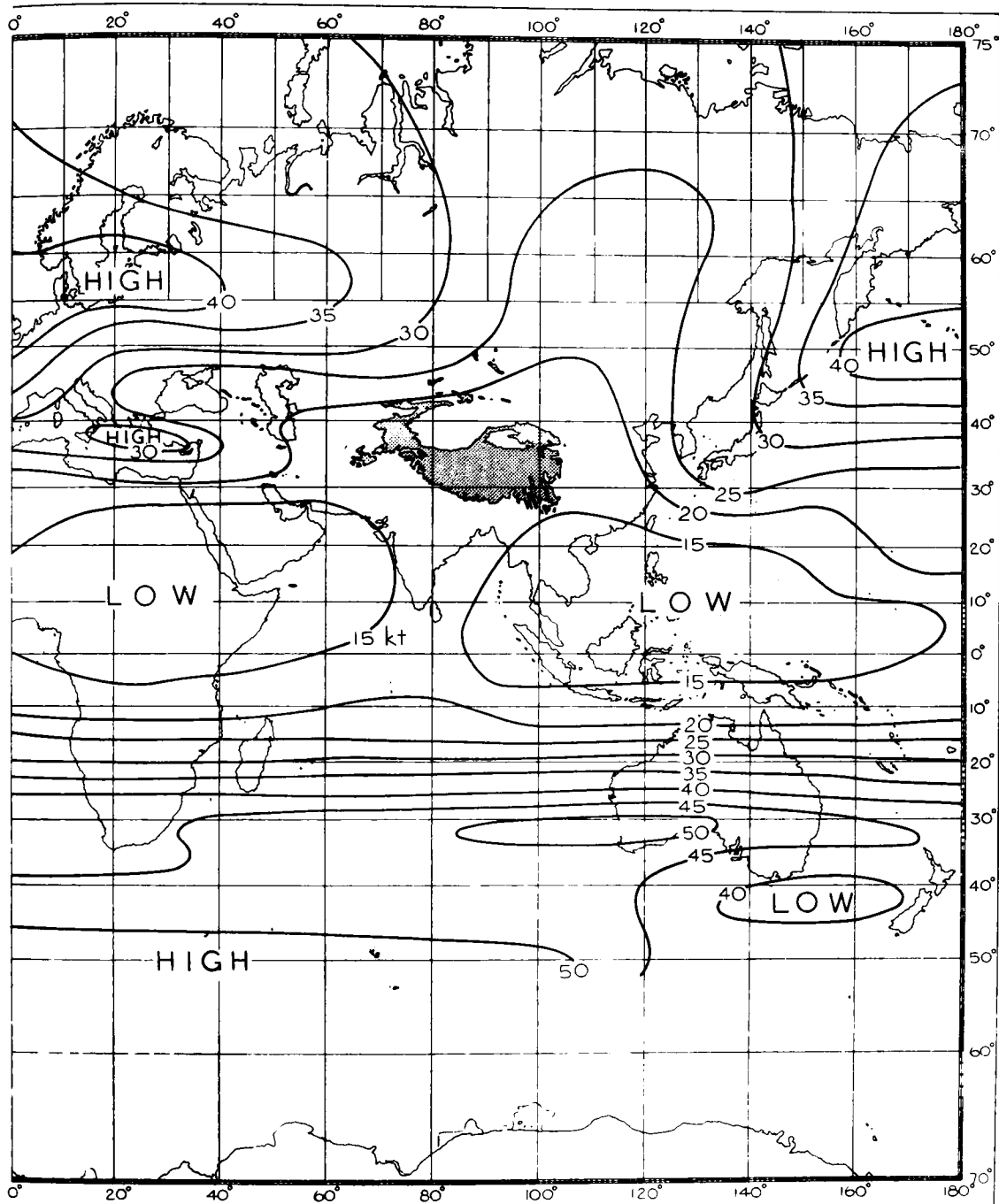


FIGURE 32—CONTINUED

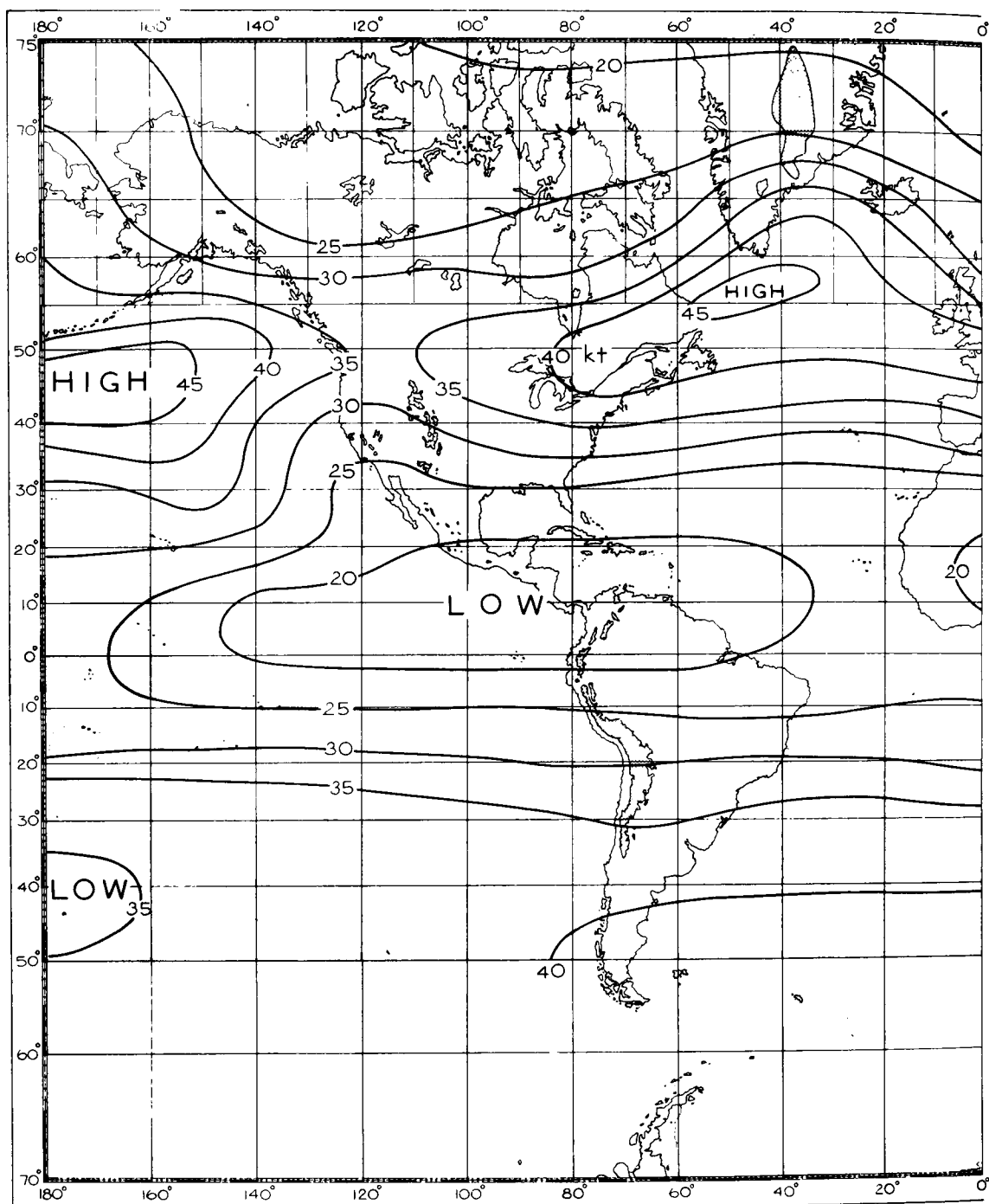


FIGURE 33—STANDARD VECTOR DEVIATION OF WIND AT 200 MB, JULY 1949-53

ICAO height = 38,663 ft = 11,784 m

Shaded areas represent land over 3,000 m

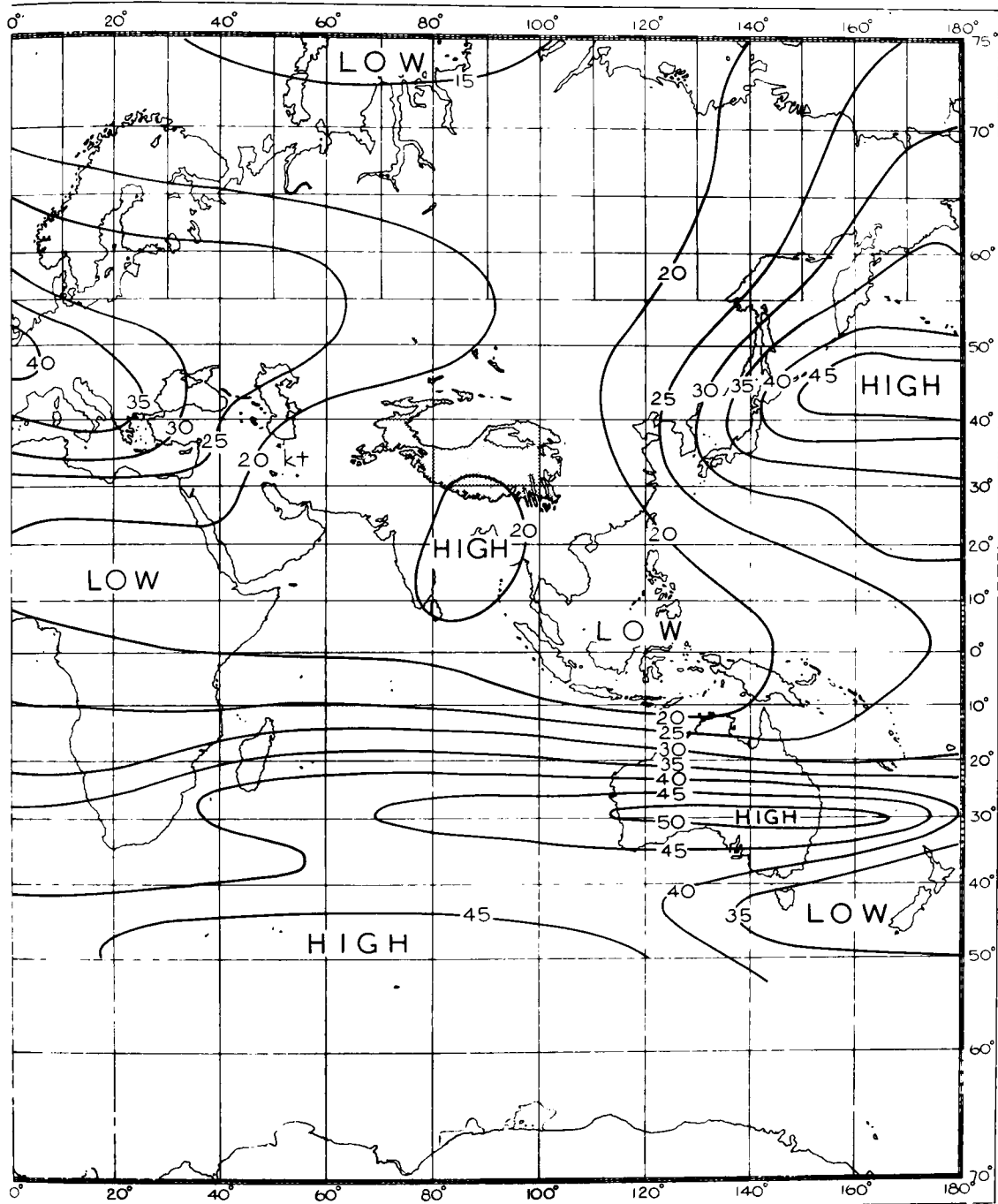


FIGURE 33—CONTINUED

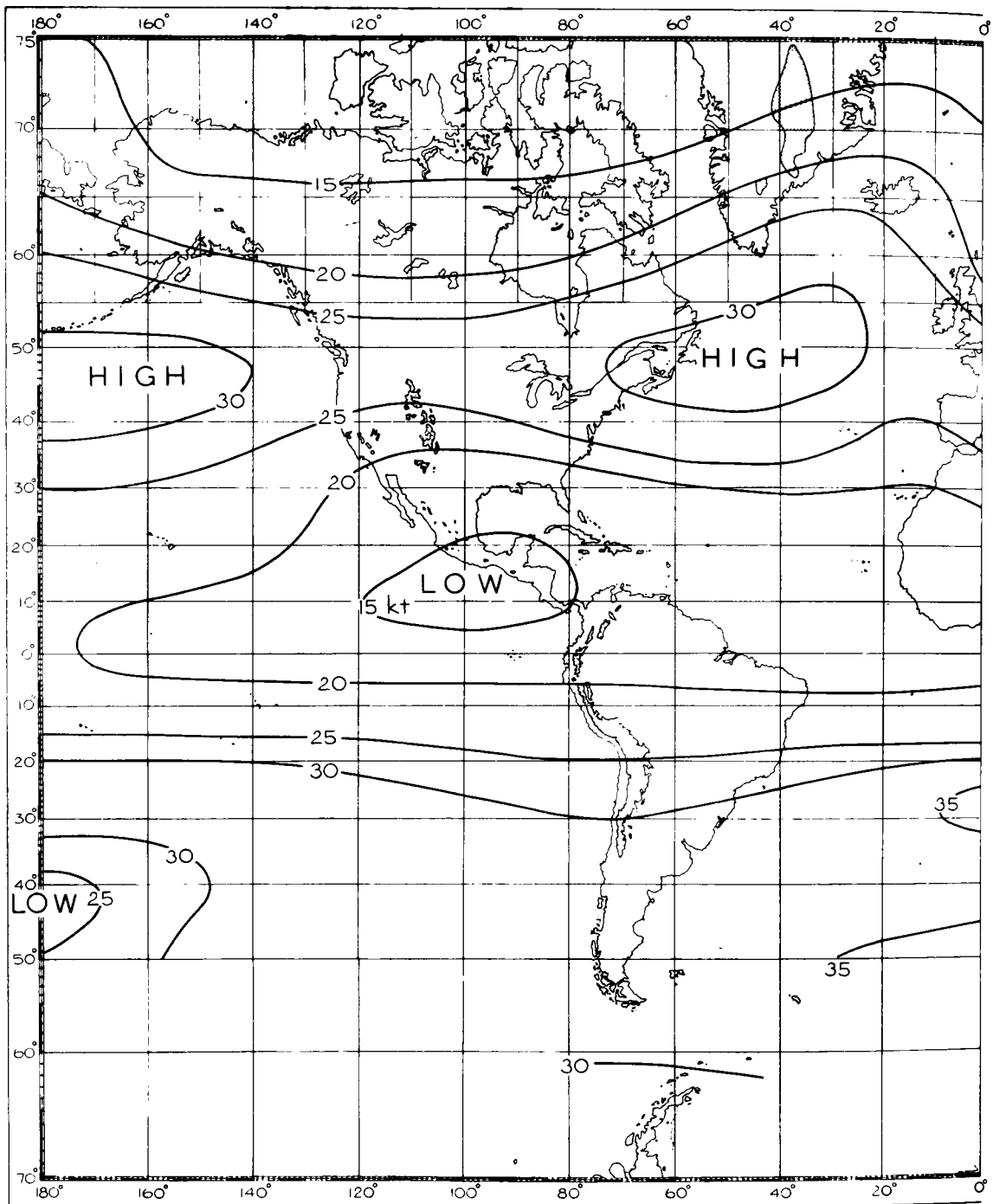


FIGURE 34—STANDARD VECTOR DEVIATION OF WIND AT 150 MB, JULY 1949-53

ICAO height = 44,647 ft = 13,608 m

Shaded areas represent land over 3,000 m

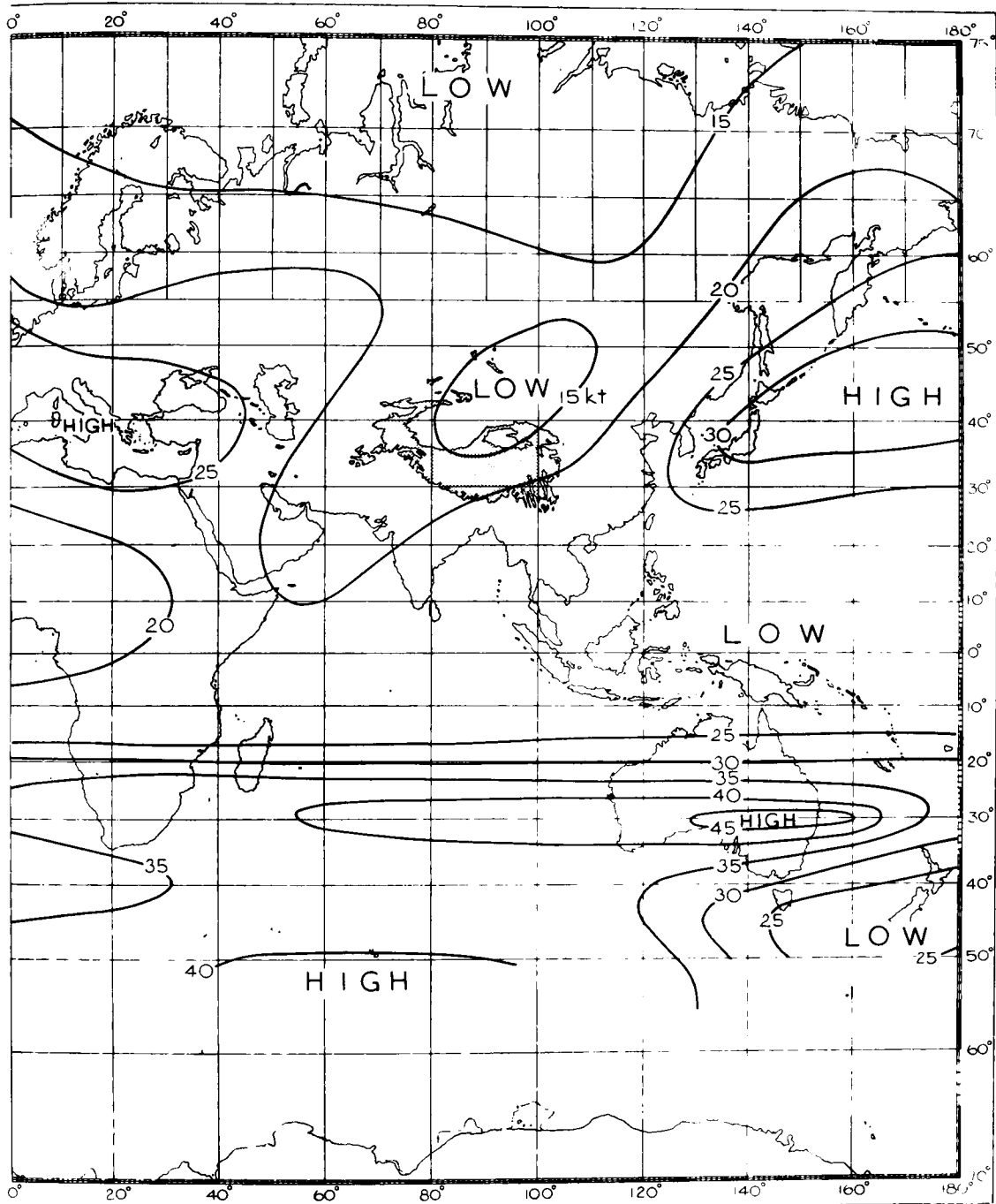


FIGURE 34—CONTINUED

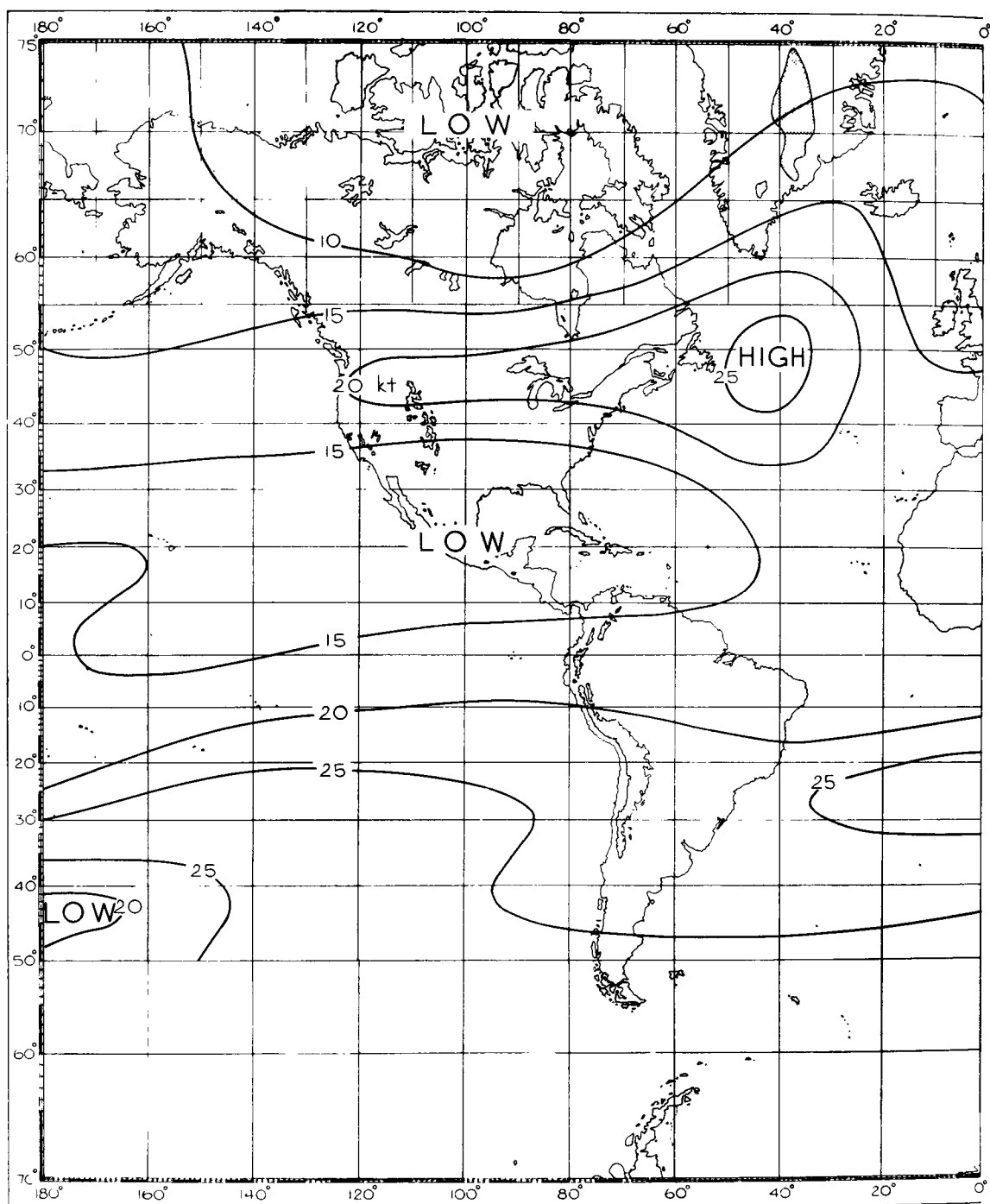


FIGURE 35—STANDARD VECTOR DEVIATION OF WIND AT 100 MB, JULY 1949-53

ICAO height = 53,083 ft = 16,180 m

Shaded areas represent land over 3,000 m

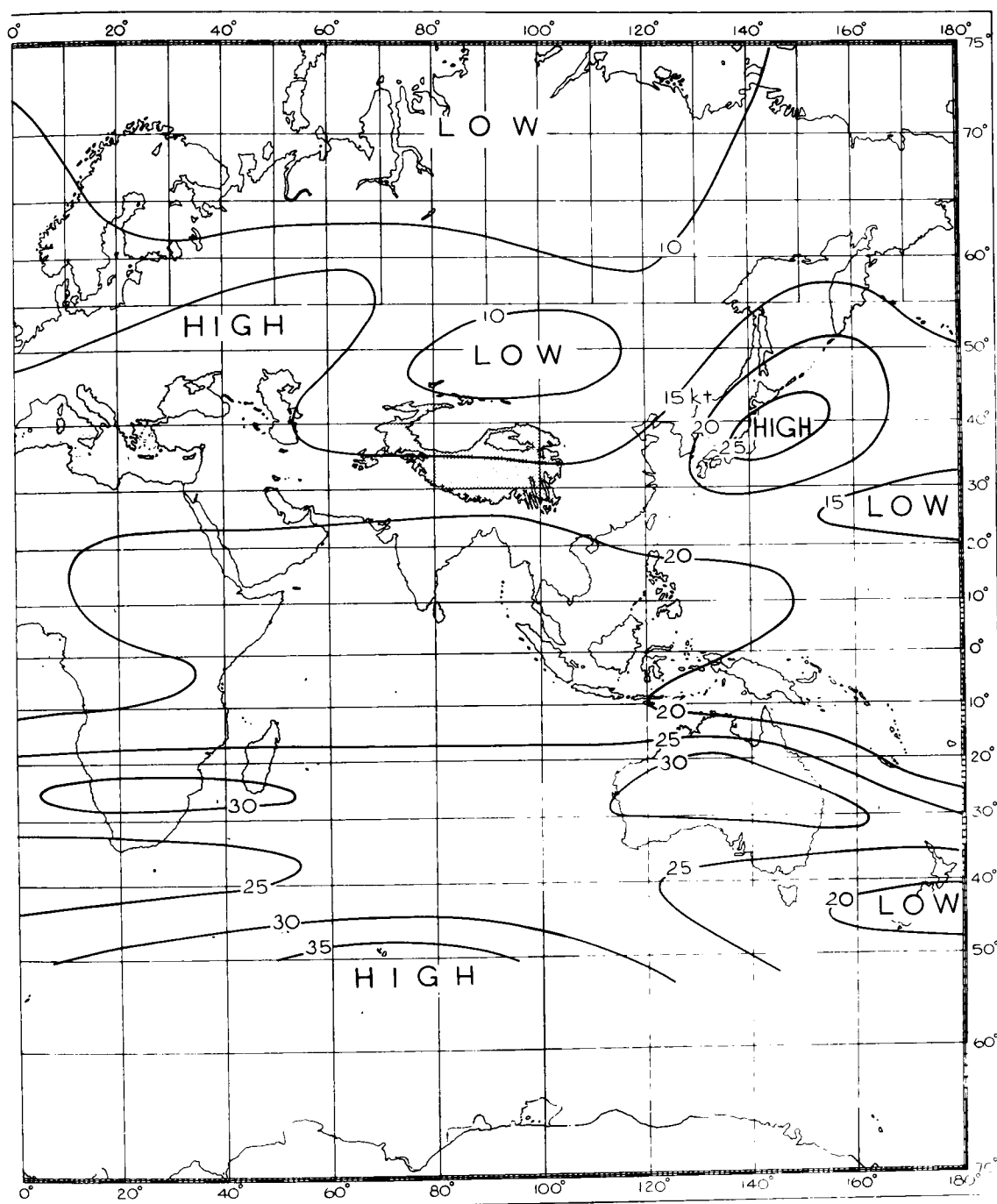


FIGURE 35—CONTINUED

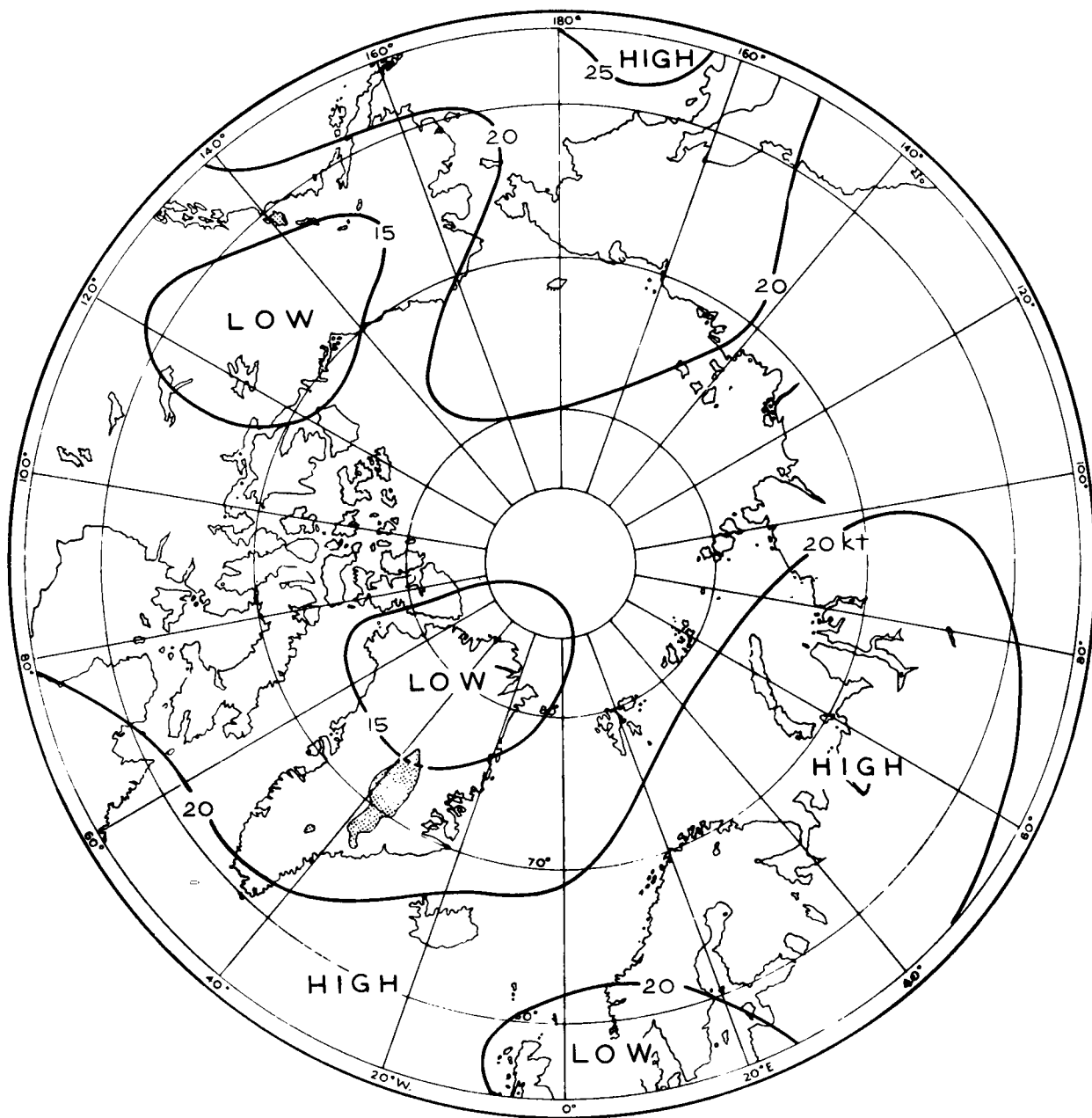


FIGURE 36—STANDARD VECTOR DEVIATION OF WIND AT 700 MB, JULY 1949-53
ICAO height = 9,882 ft = 3,012 m
Shaded areas represent land over 3,000 m

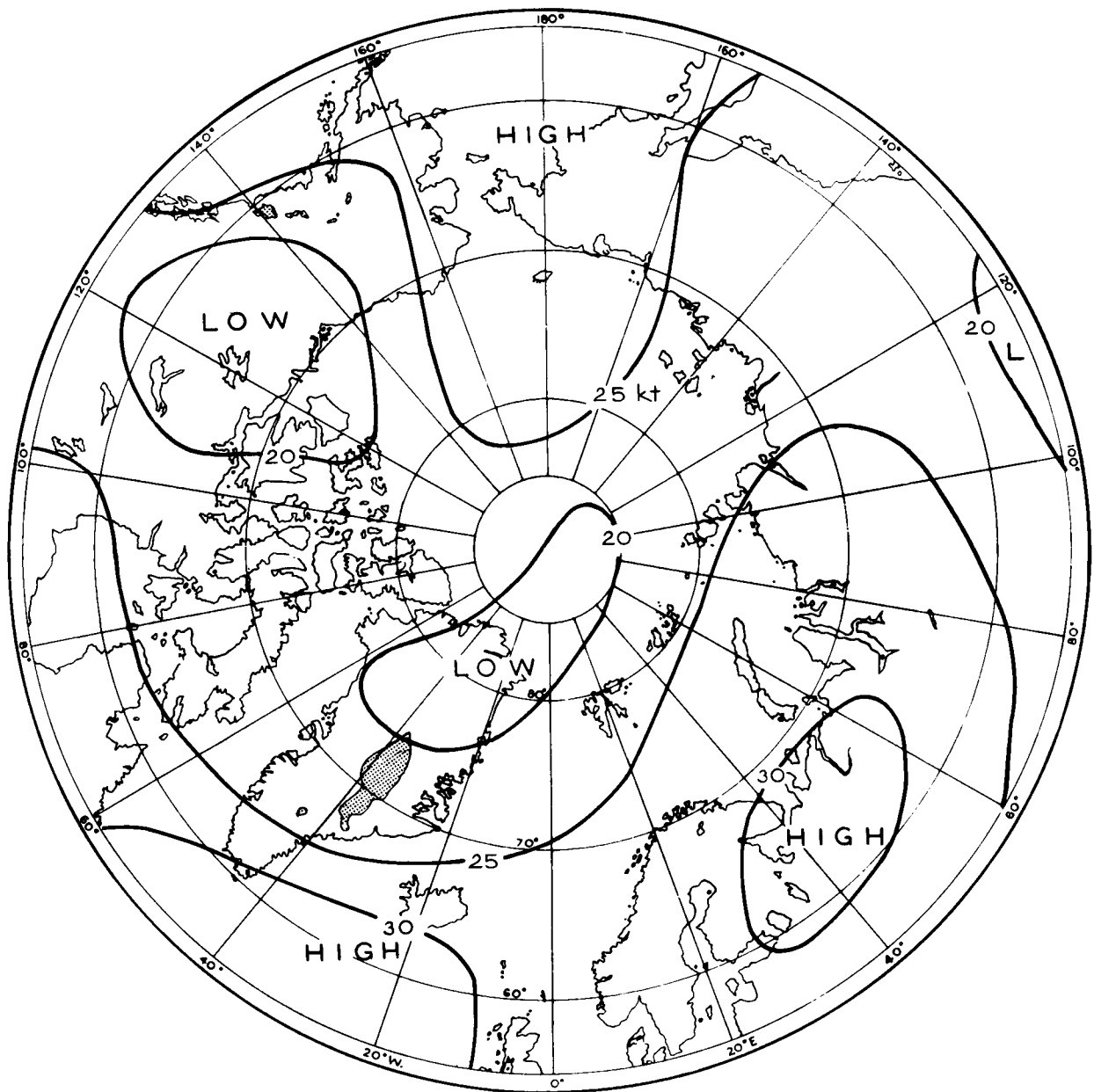


FIGURE 37—STANDARD VECTOR DEVIATION OF WIND AT 500 MB, JULY 1949-53

ICAO height = 18,289 ft = 5,574 m

Shaded areas represent land over 3,000 m

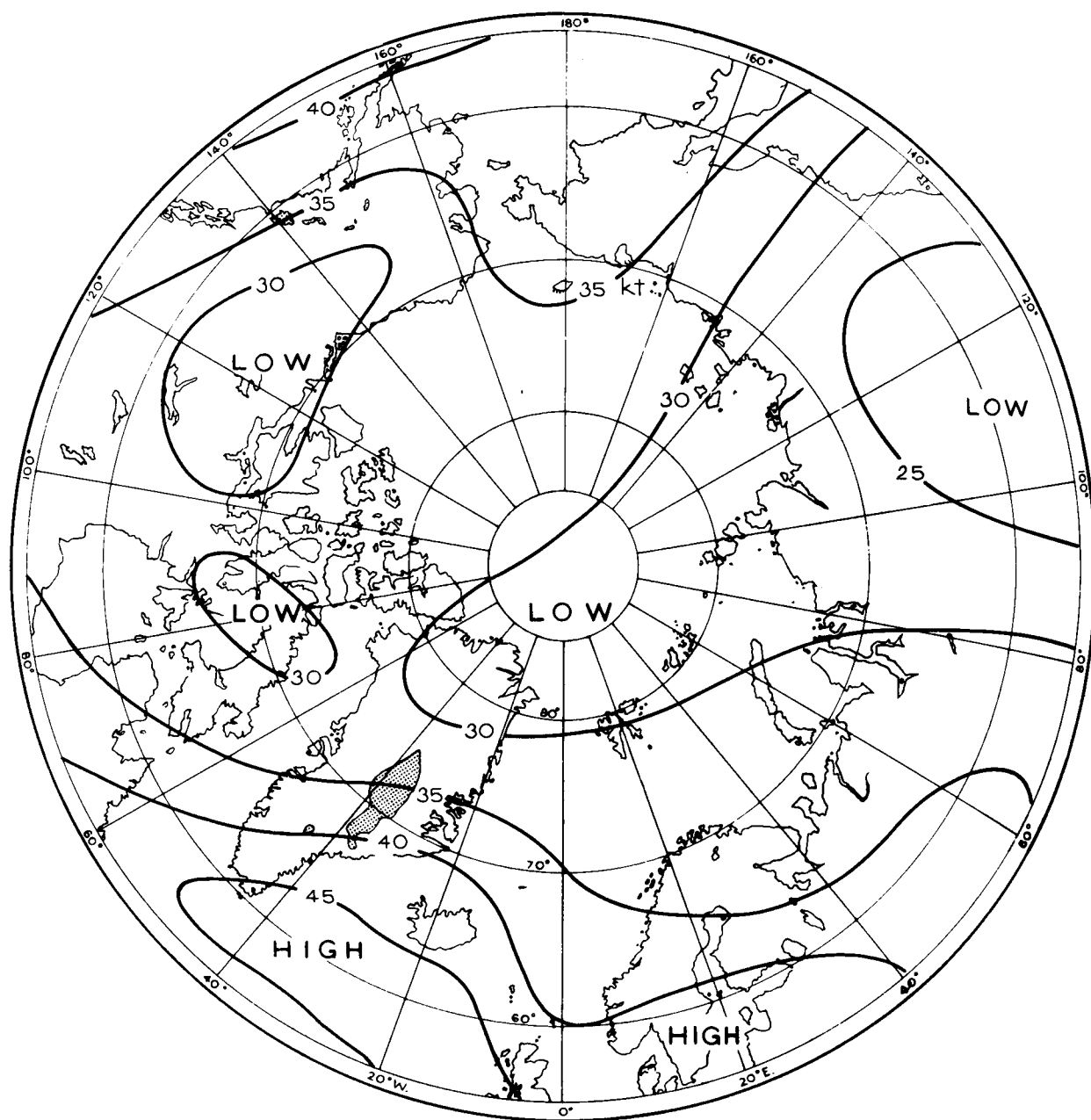


FIGURE 38—STANDARD VECTOR DEVIATION OF WIND AT 300 MB, JULY 1949-53

ICAO height = 30,065 ft = 9,164 m

Shaded areas represent land over 3,000 m

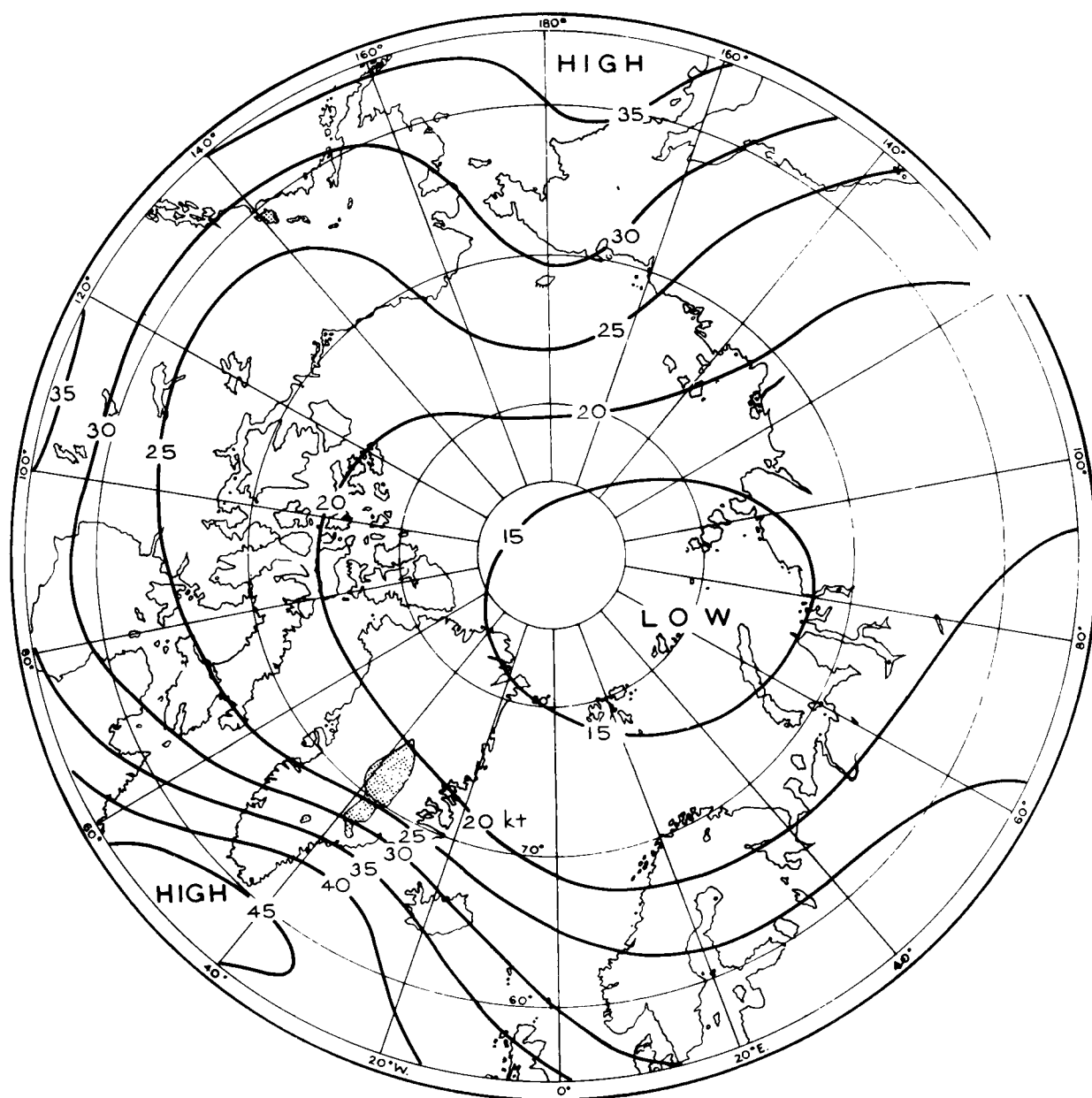


FIGURE 39—STANDARD VECTOR DEVIATION OF WIND AT 200 MB, JULY 1949-53

ICAO height = 38,663 ft = 11,784 m

Shaded areas represent land over 3,000 m

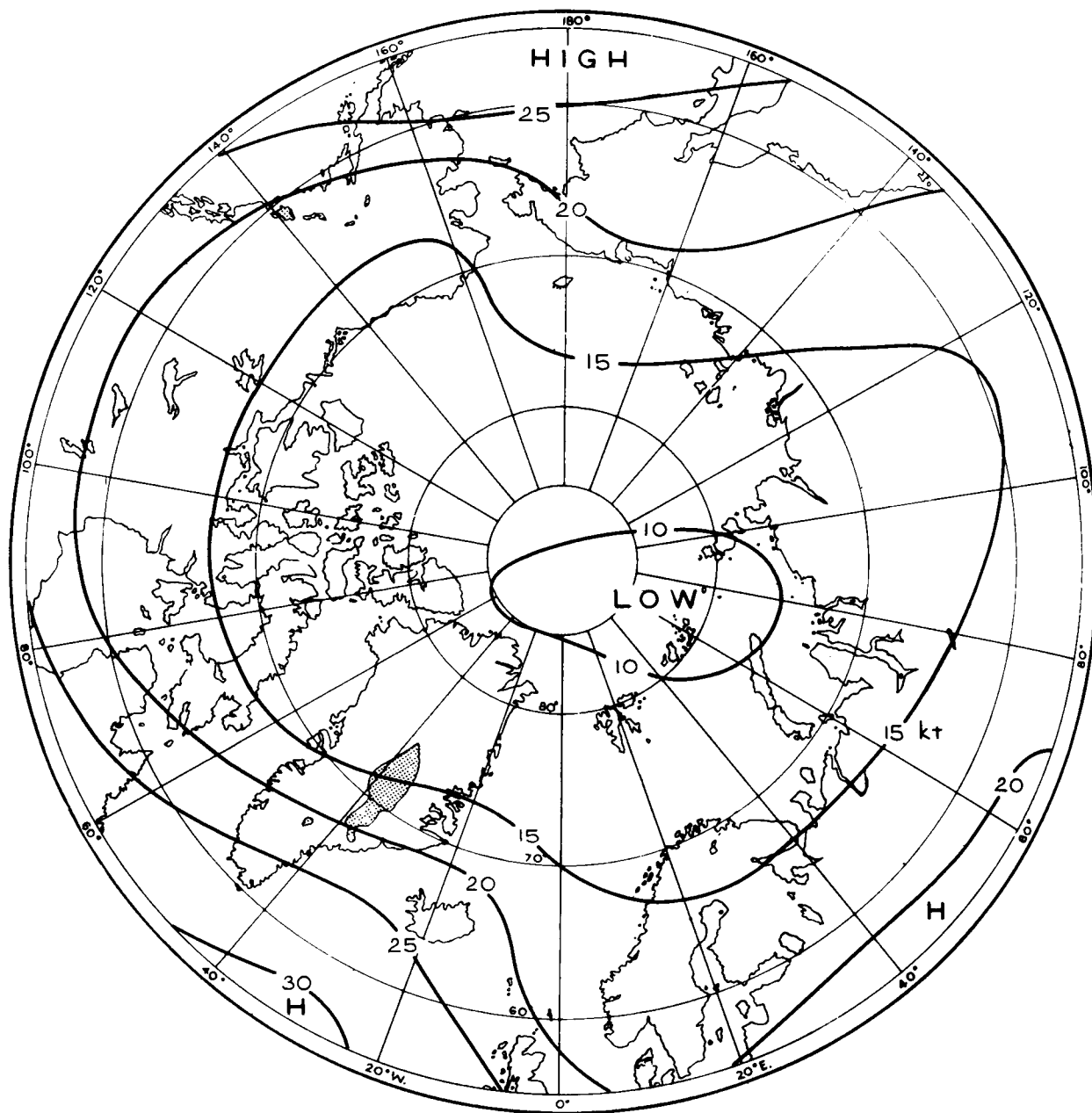


FIGURE 40—STANDARD VECTOR DEVIATION OF WIND AT 150 MB, JULY 1949-53
ICAO height = 44,647 ft = 13,608 m
Shaded areas represent land over 3,000 m

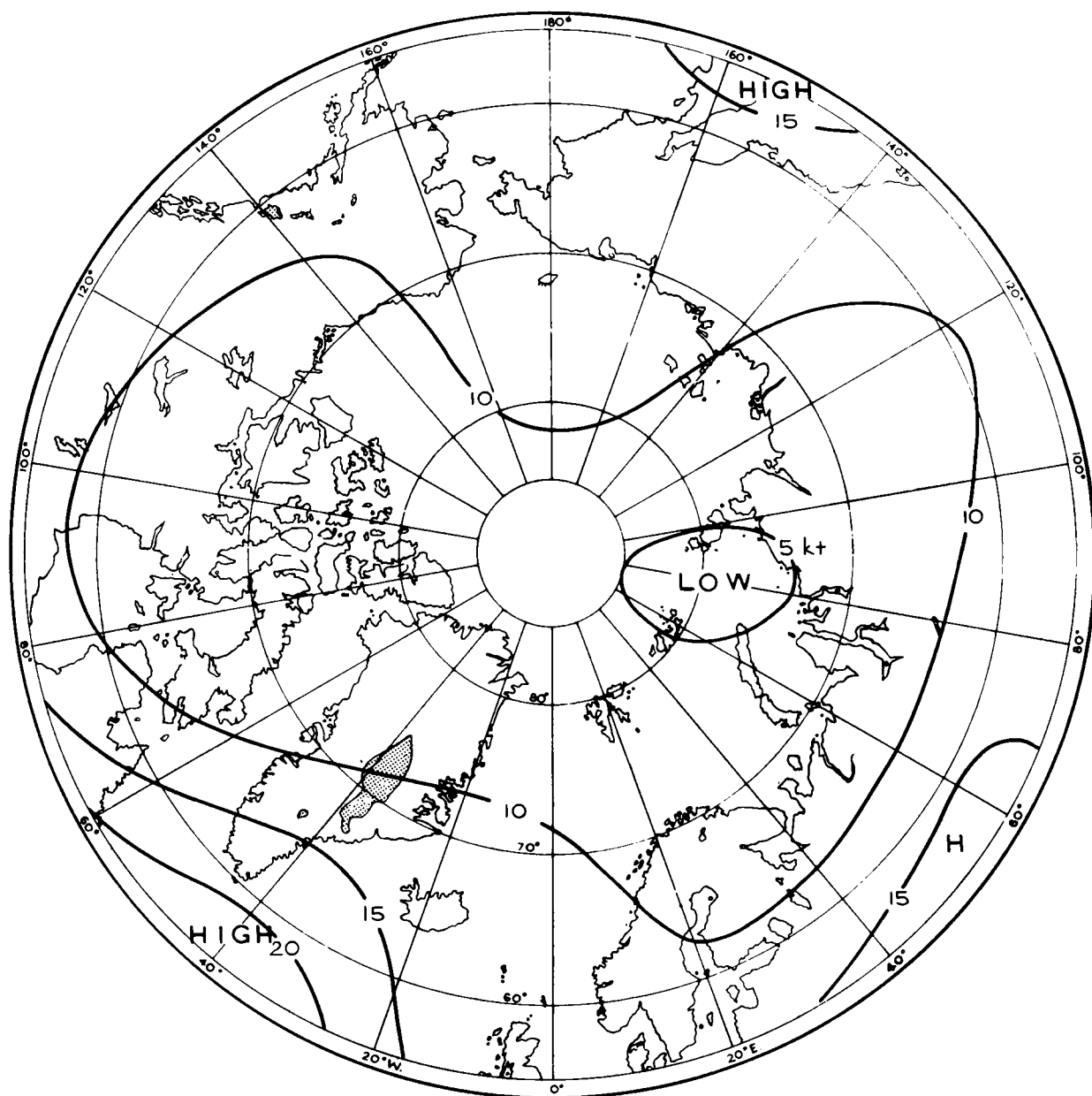


FIGURE 41—STANDARD VECTOR DEVIATION OF WIND AT 100 MB, JULY 1949-53

ICAO height = 53,083 ft = 16,180 m

Shaded areas represent land over 3,000 m

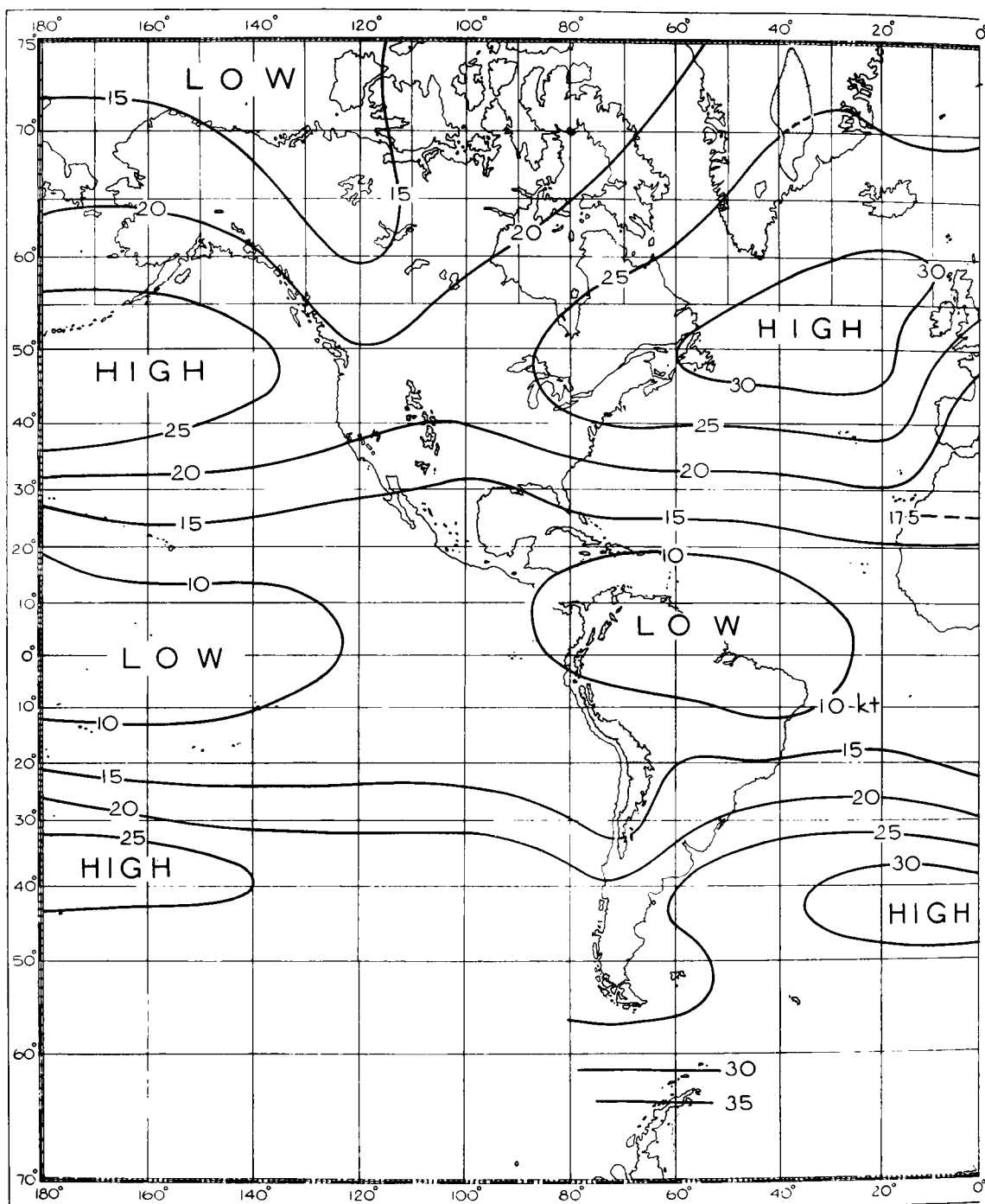


FIGURE 42—STANDARD VECTOR DEVIATION OF WIND AT 700 MB, OCTOBER 1949-53

ICAO height = 9,882 ft = 3,012 m

Shaded areas represent land over 3,000 m

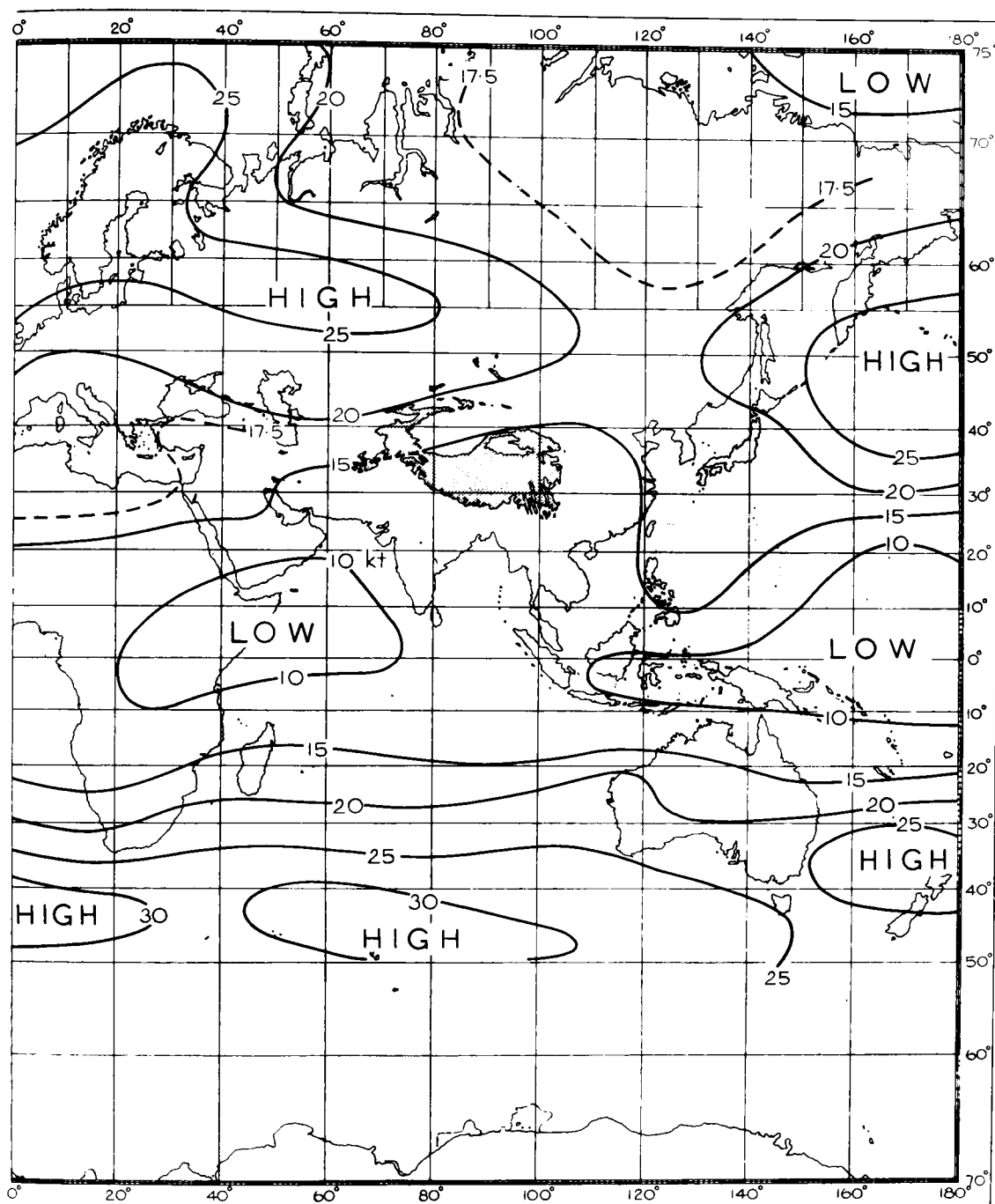


FIGURE 42—CONTINUED

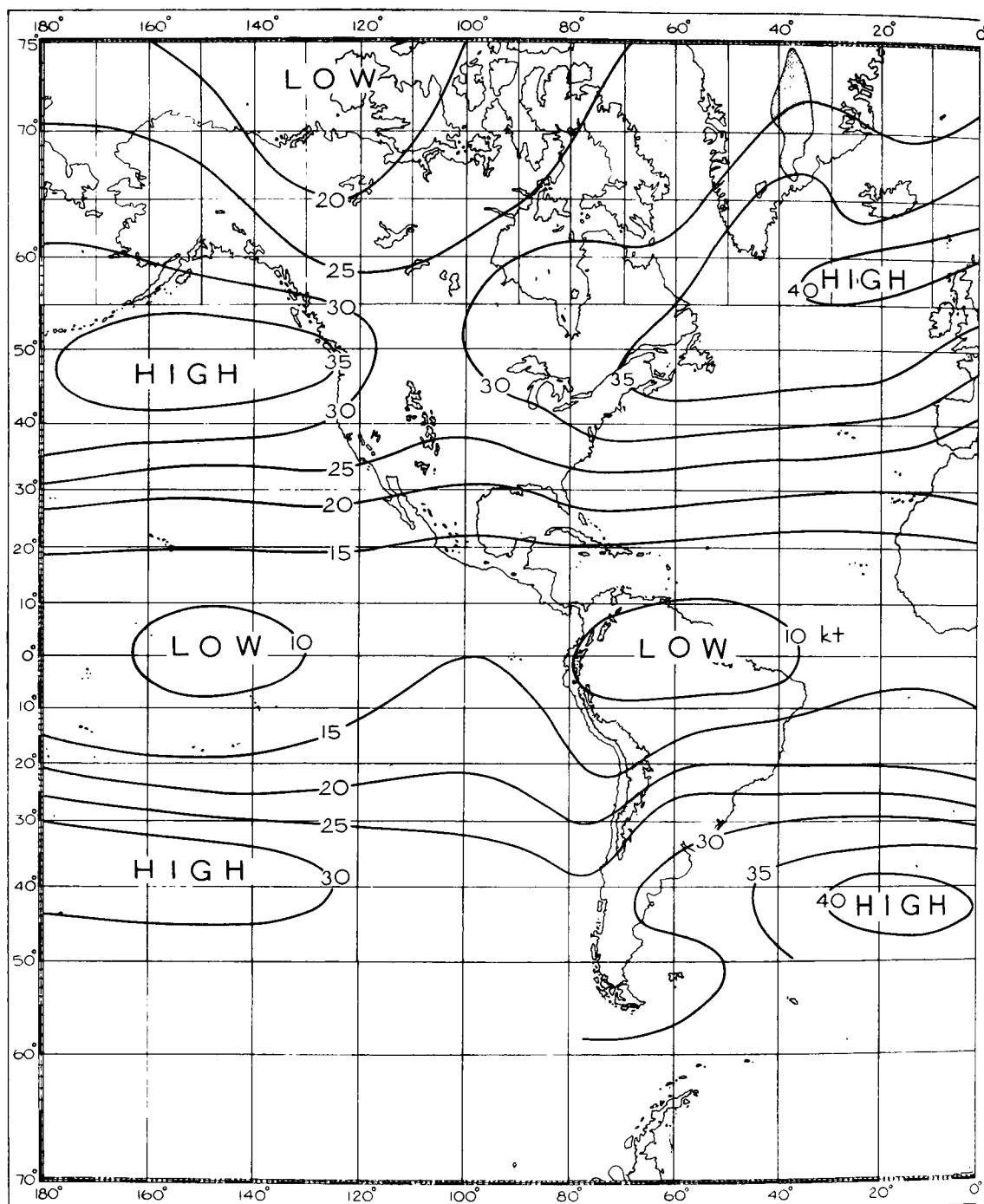


FIGURE 43—STANDARD VECTOR DEVIATION OF WIND AT 500 MB, OCTOBER 1949-53

ICAO height = 18,289 ft = 5,574 m

Shaded areas represent land over 3,000 m

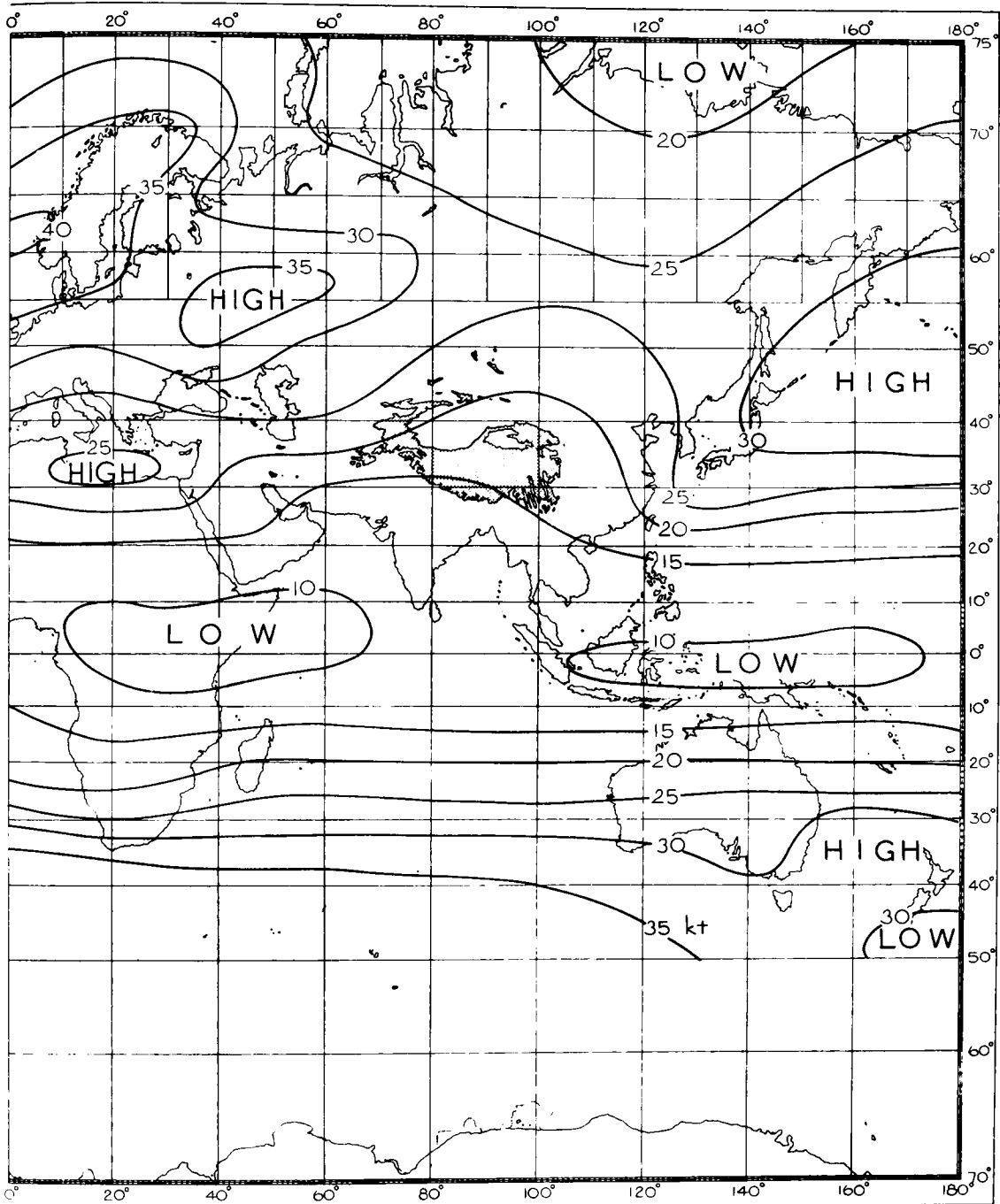


FIGURE 43—CONTINUED

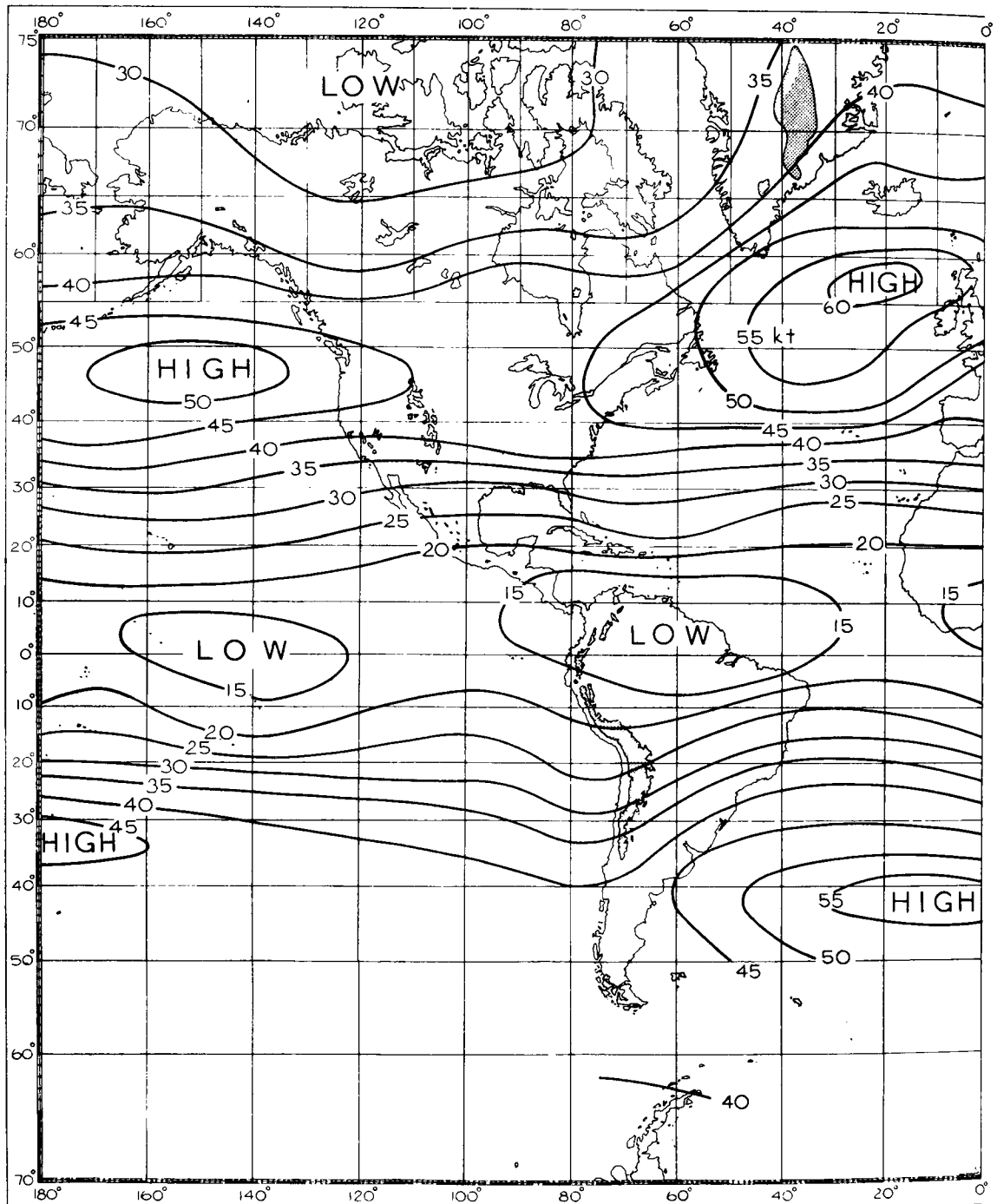


FIGURE 44—STANDARD VECTOR DEVIATION OF WIND AT 300 MB, OCTOBER 1949-53

ICAO height = 30,065 ft = 9,164 m

Shaded areas represent land over 3,000 m

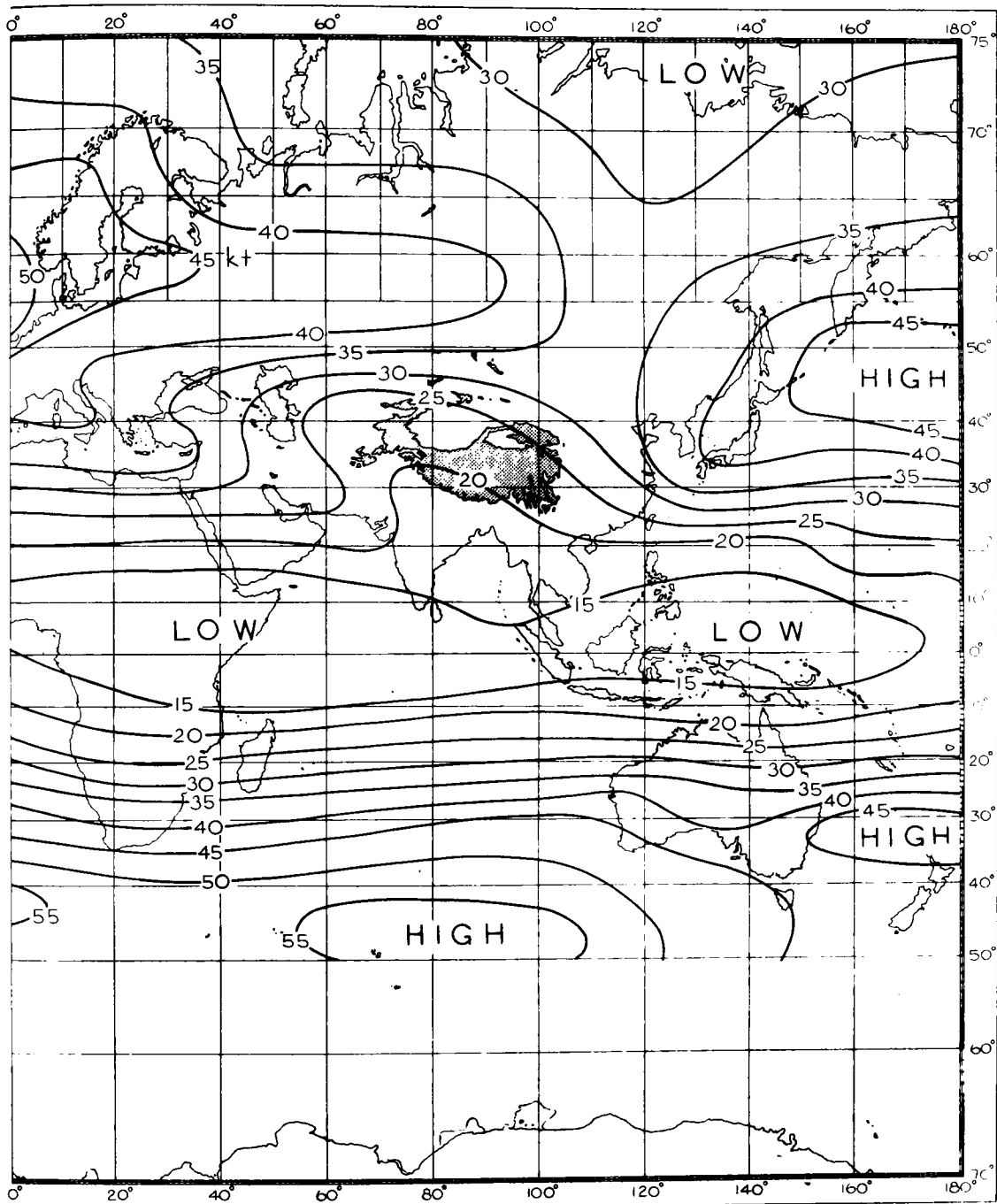


FIGURE 44—CONTINUED

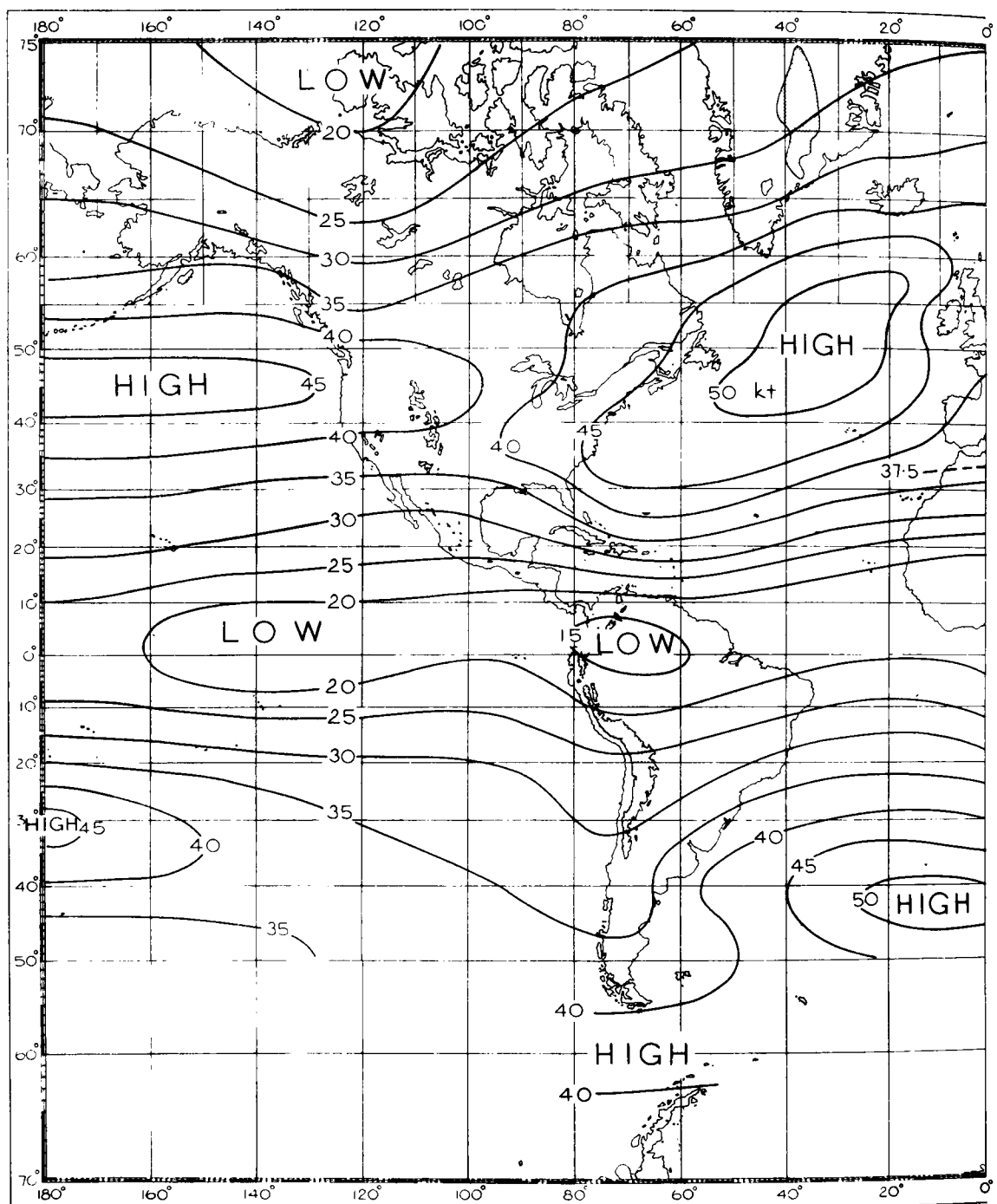


FIGURE 45—STANDARD VECTOR DEVIATION OF WIND AT 200 MB, OCTOBER 1949-53

ICAO height = 38,663 ft = 11,784 m

Shaded areas represent land over 3,000 m

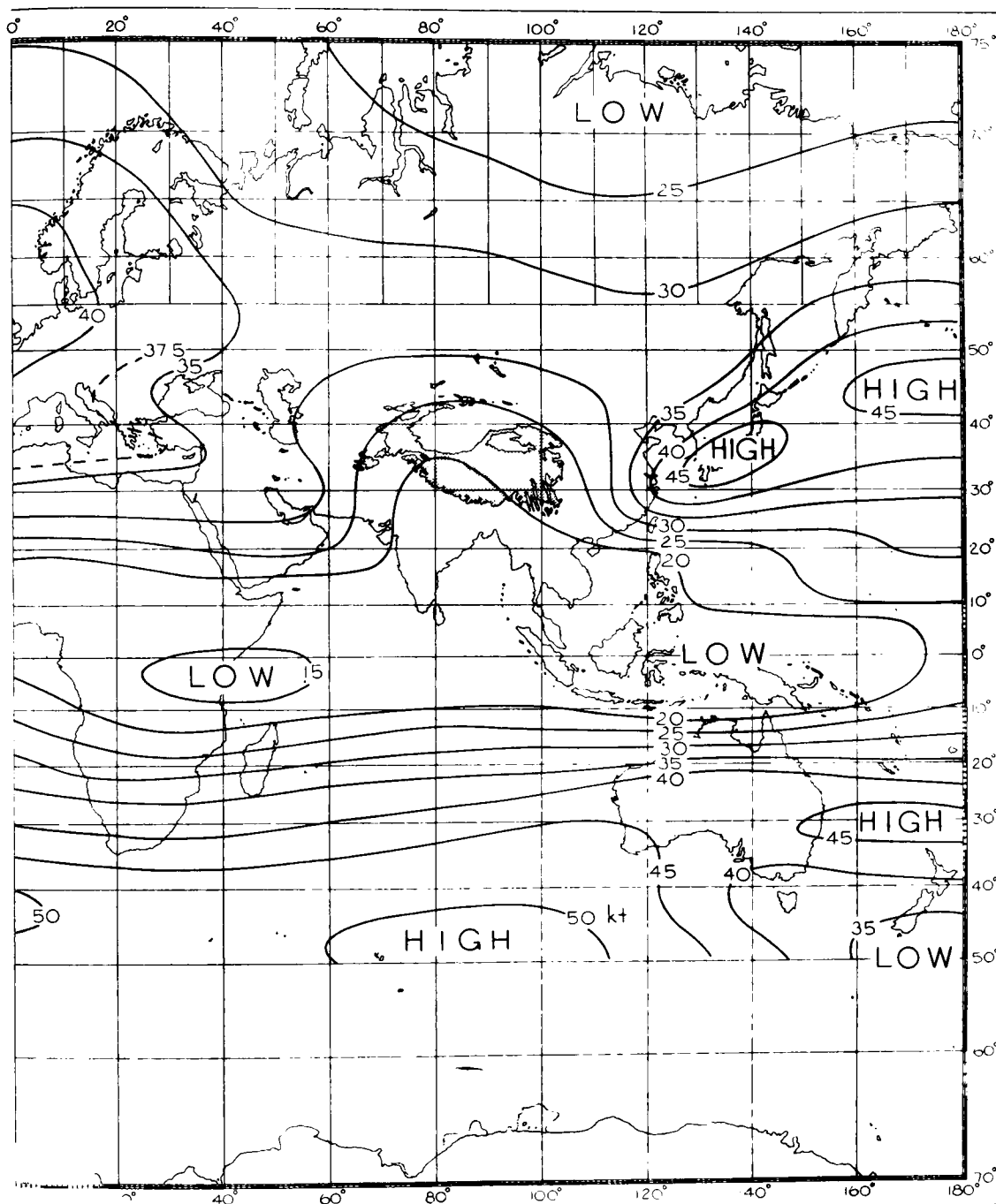


FIGURE 45---CONTINUED

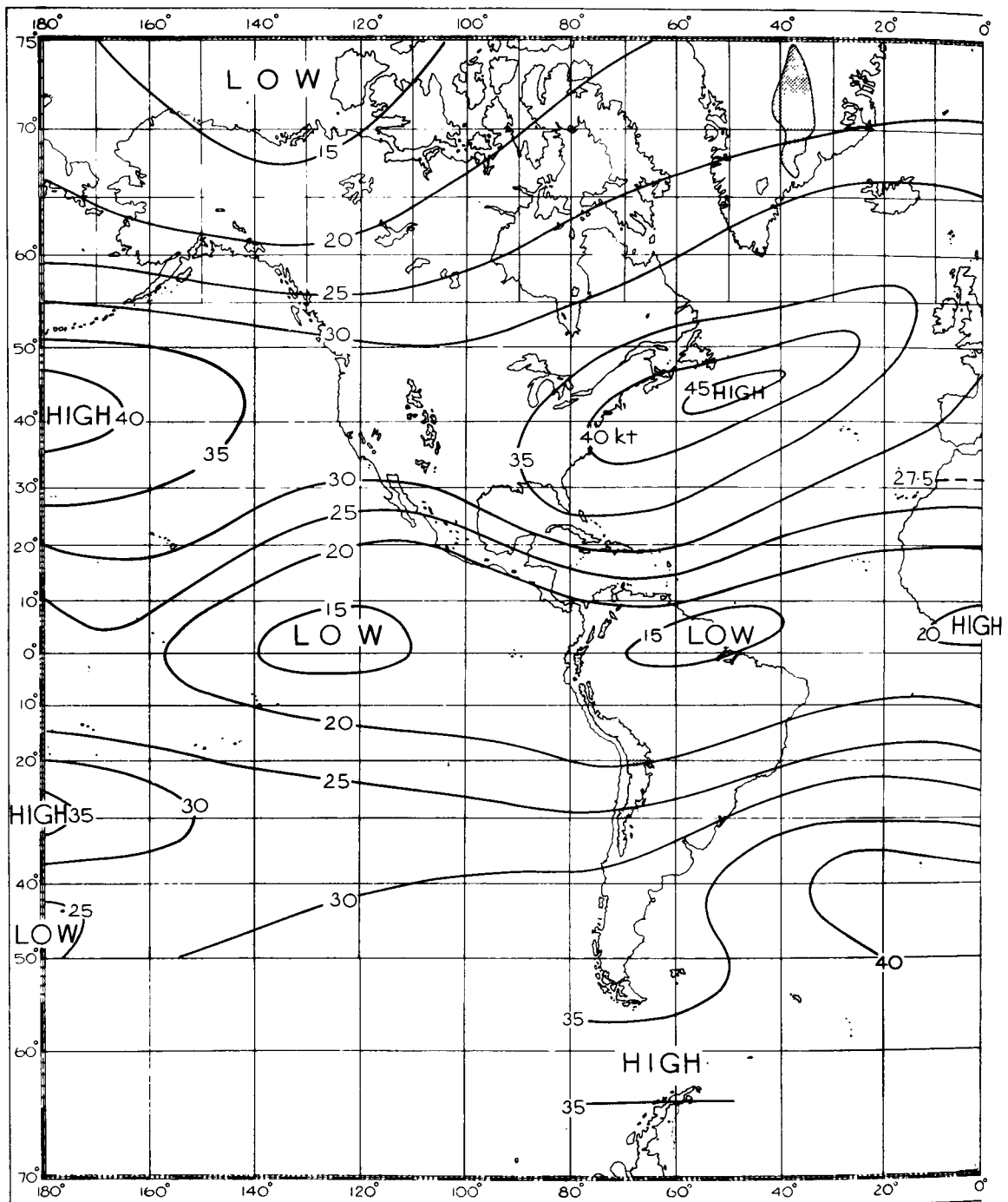


FIGURE 46—STANDARD VECTOR DEVIATION OF WIND AT 150 MB, OCTOBER 1949-53

ICAO height = 44,647 ft = 13,608 m

Shaded areas represent land over 3,000 m

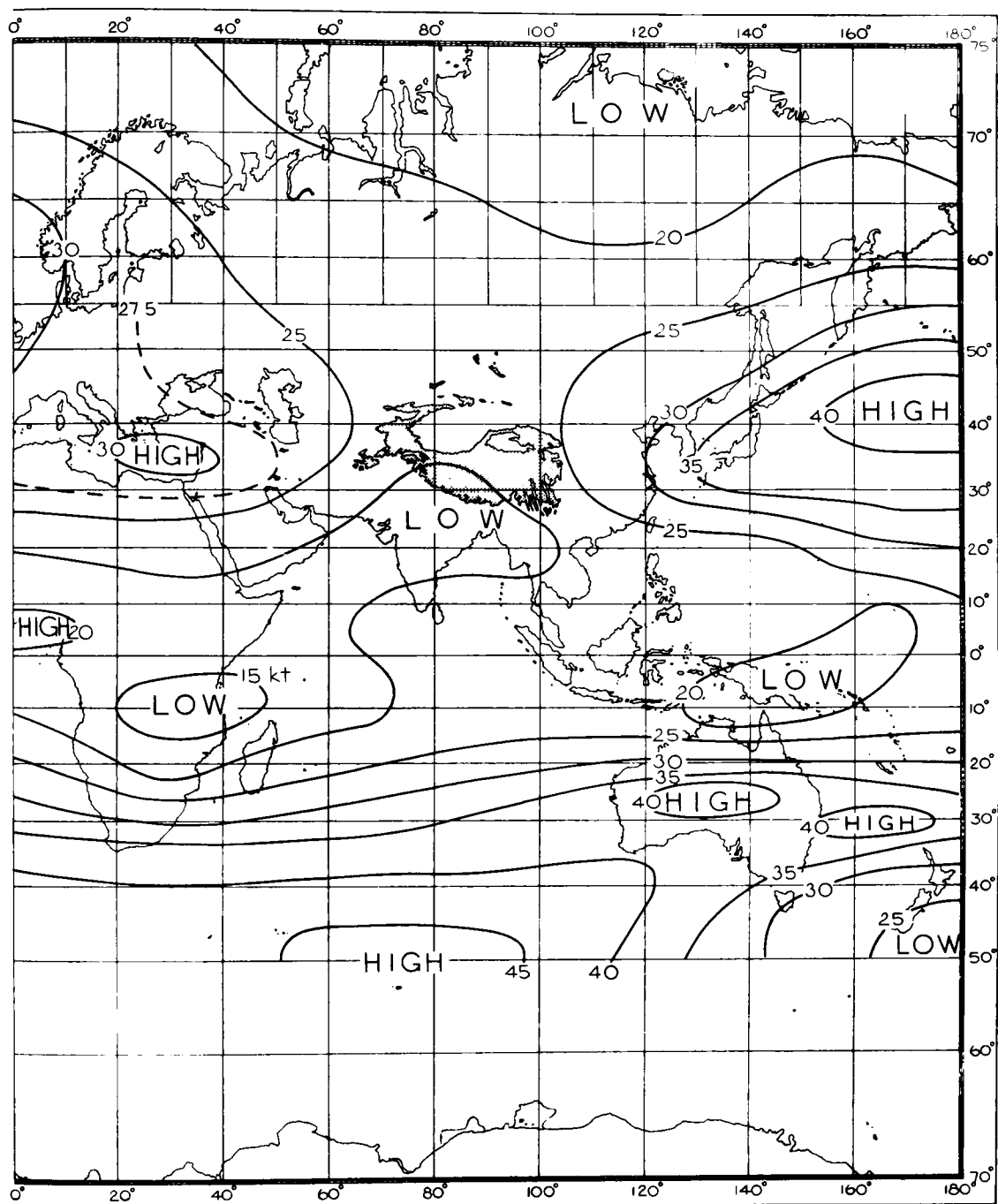


FIGURE 46—CONTINUED

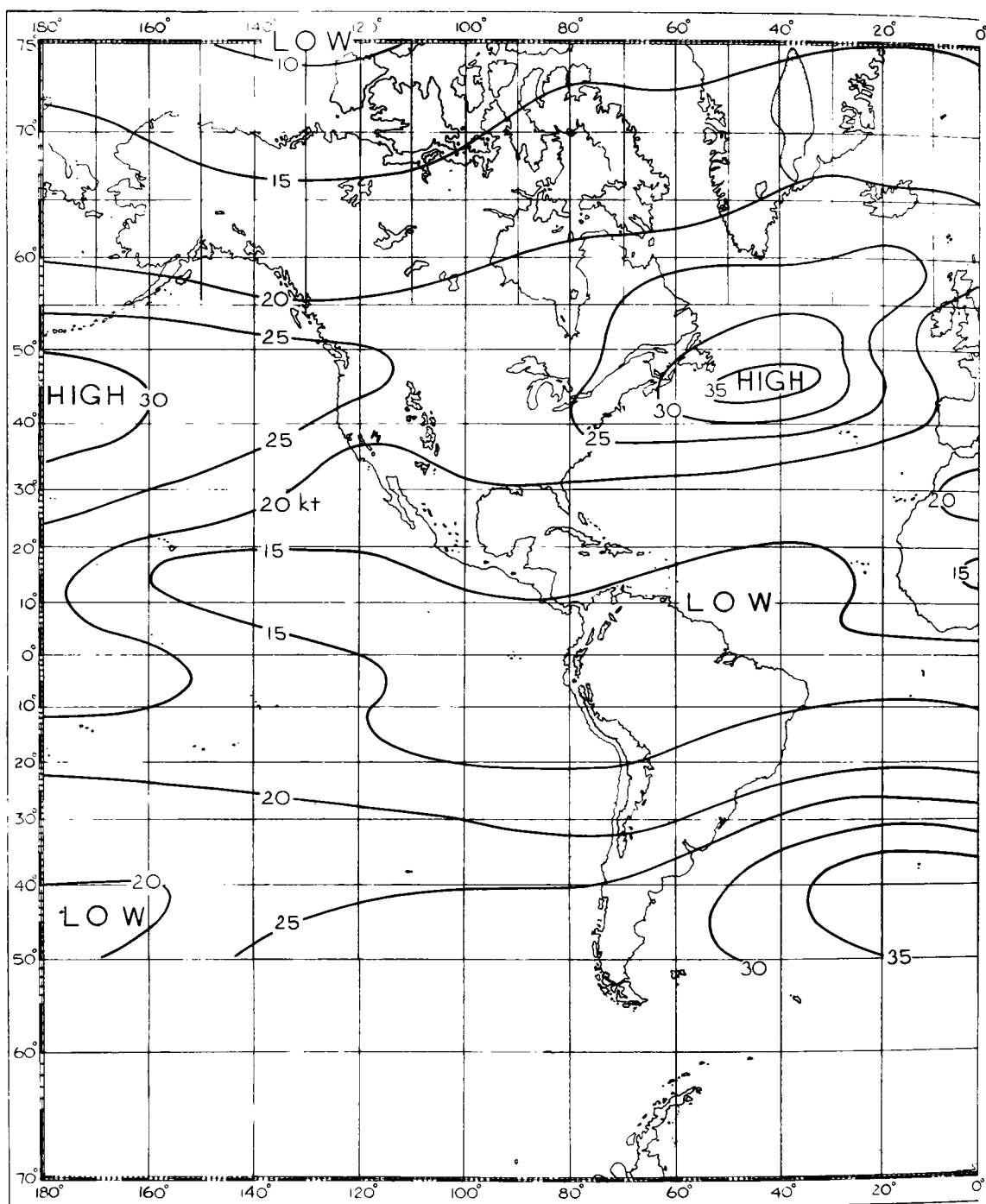


FIGURE 47—STANDARD VECTOR DEVIATION OF WIND AT 100 MB, OCTOBER 1949-53
 ICAO height = 53,083 ft = 16,180 m
 Shaded areas represent land over 3,000 m

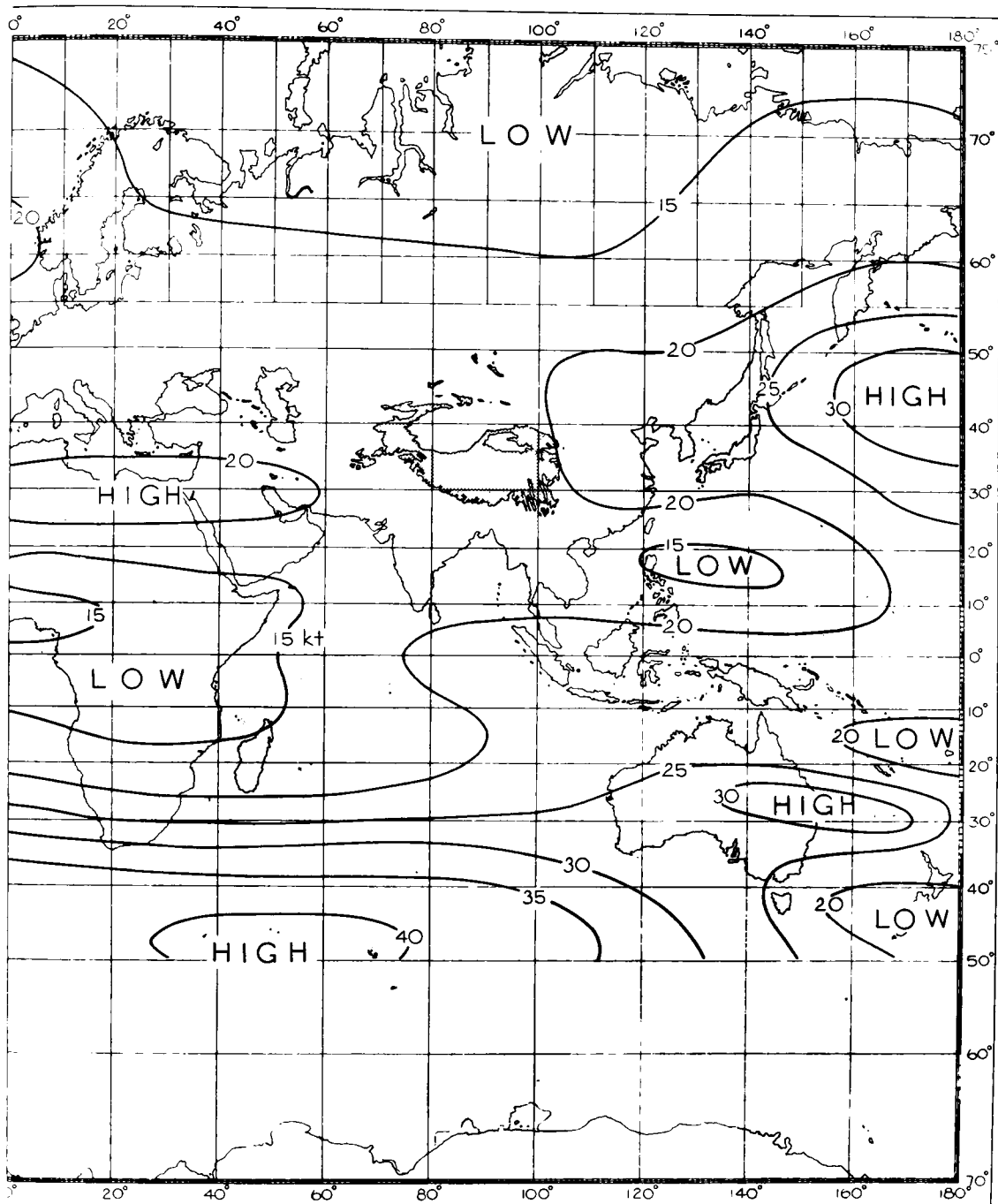


FIGURE 47—CONTINUED

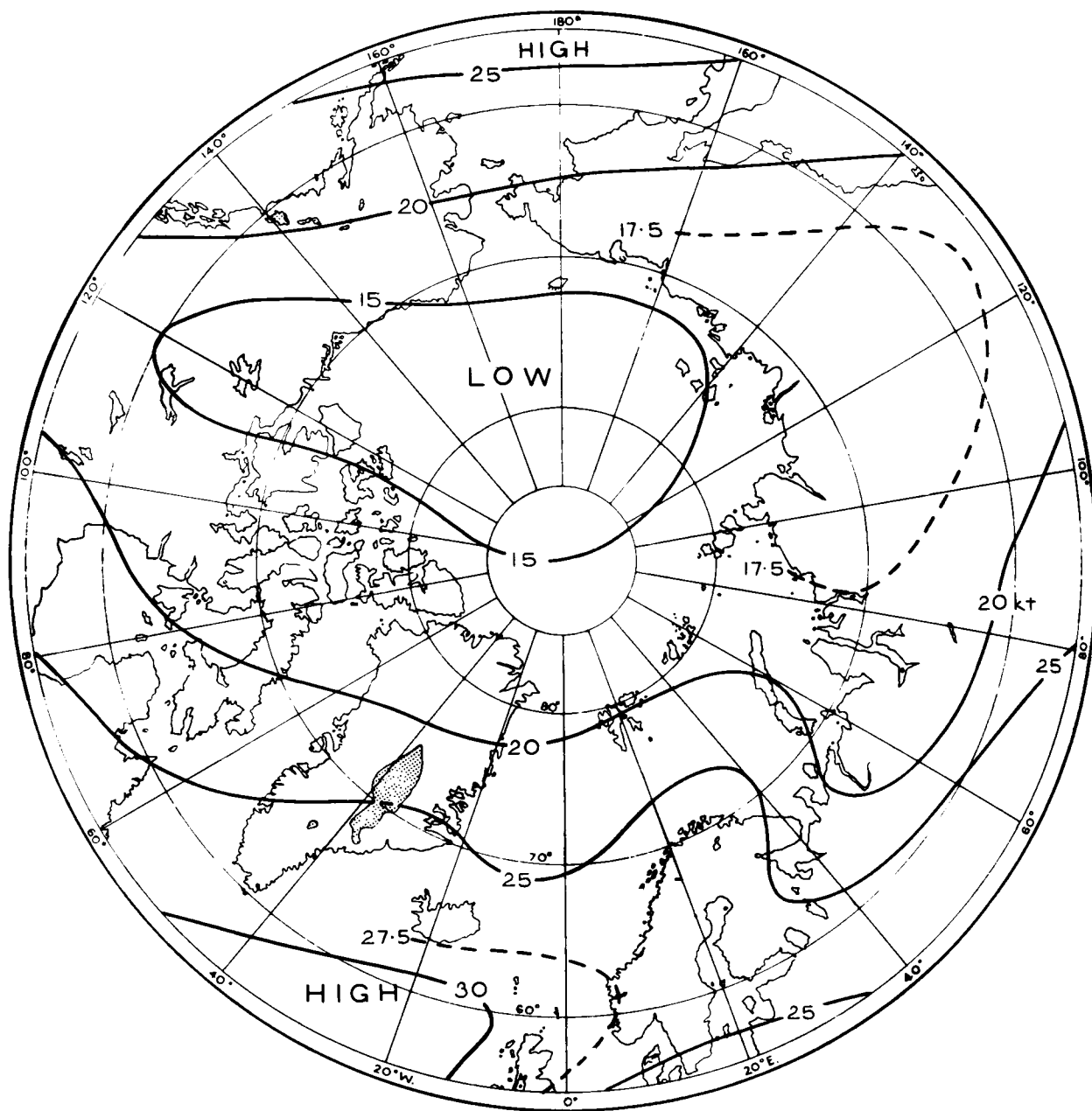


FIGURE 48—STANDARD VECTOR DEVIATION OF WIND AT 700 MB, OCTOBER 1949-53
ICAO height = 9,882 ft = 3,012 m
Shaded areas represent land over 3,000 m

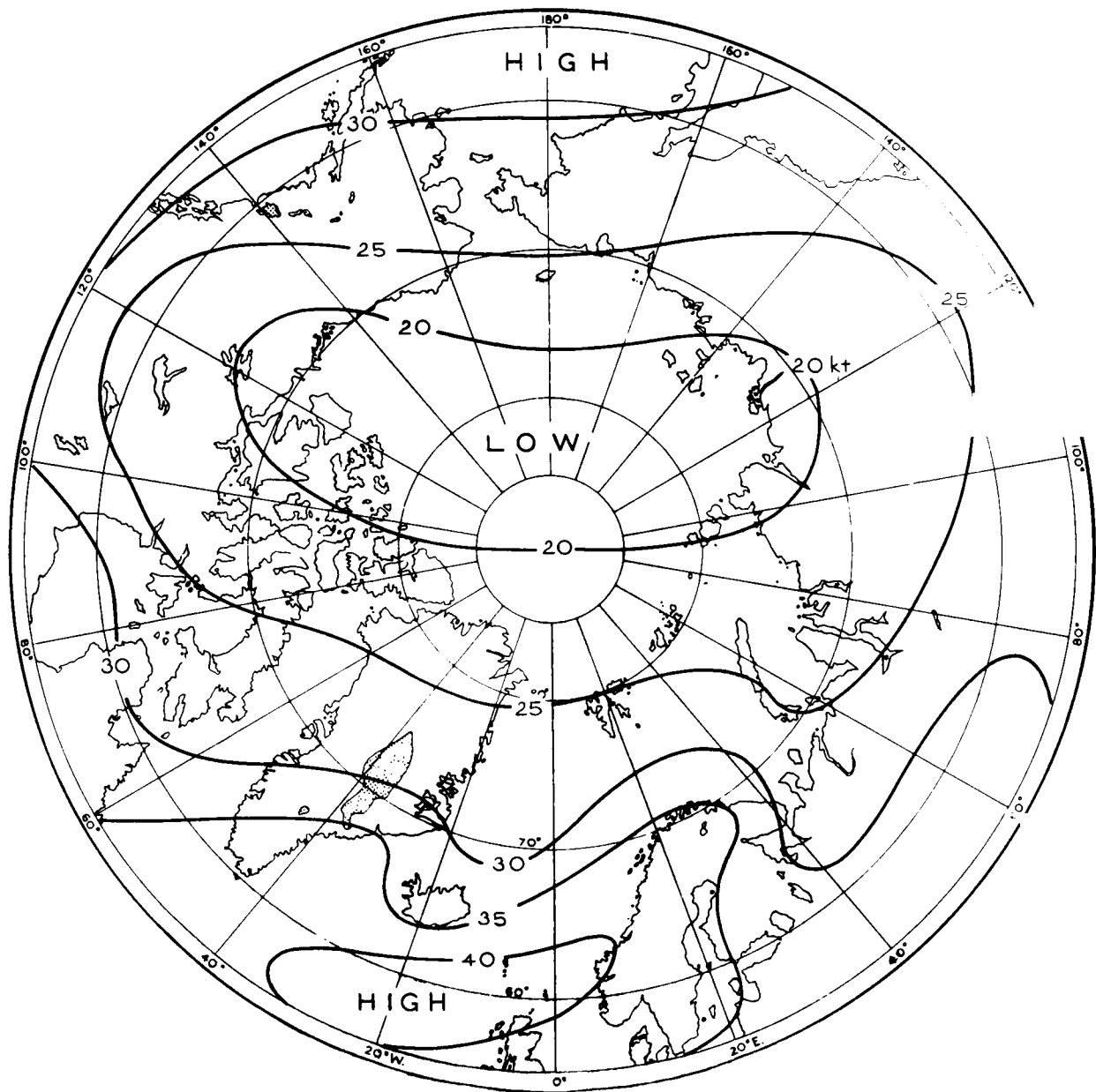


FIGURE 49—STANDARD VECTOR DEVIATION OF WIND AT 500 MB, OCTOBER 1949-53

ICAO height = 18,289 ft = 5,574 m
Shaded areas represent land over 3,000 m

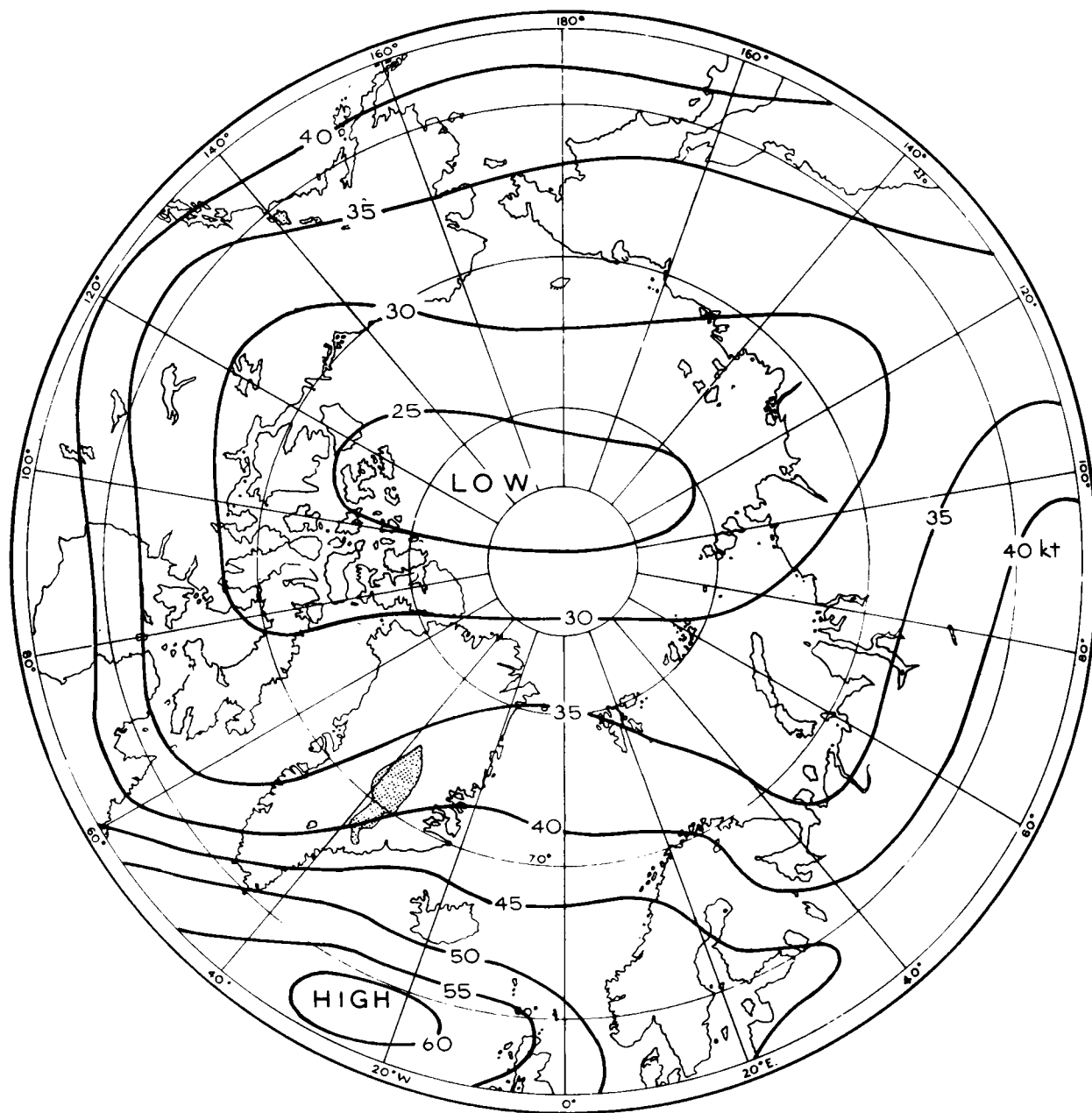


FIGURE 50—STANDARD VECTOR DEVIATION OF WIND AT 300 MB, OCTOBER 1949-53

ICAO height = 30,065 ft = 9,164 m
Shaded areas represent land over 3,000 m

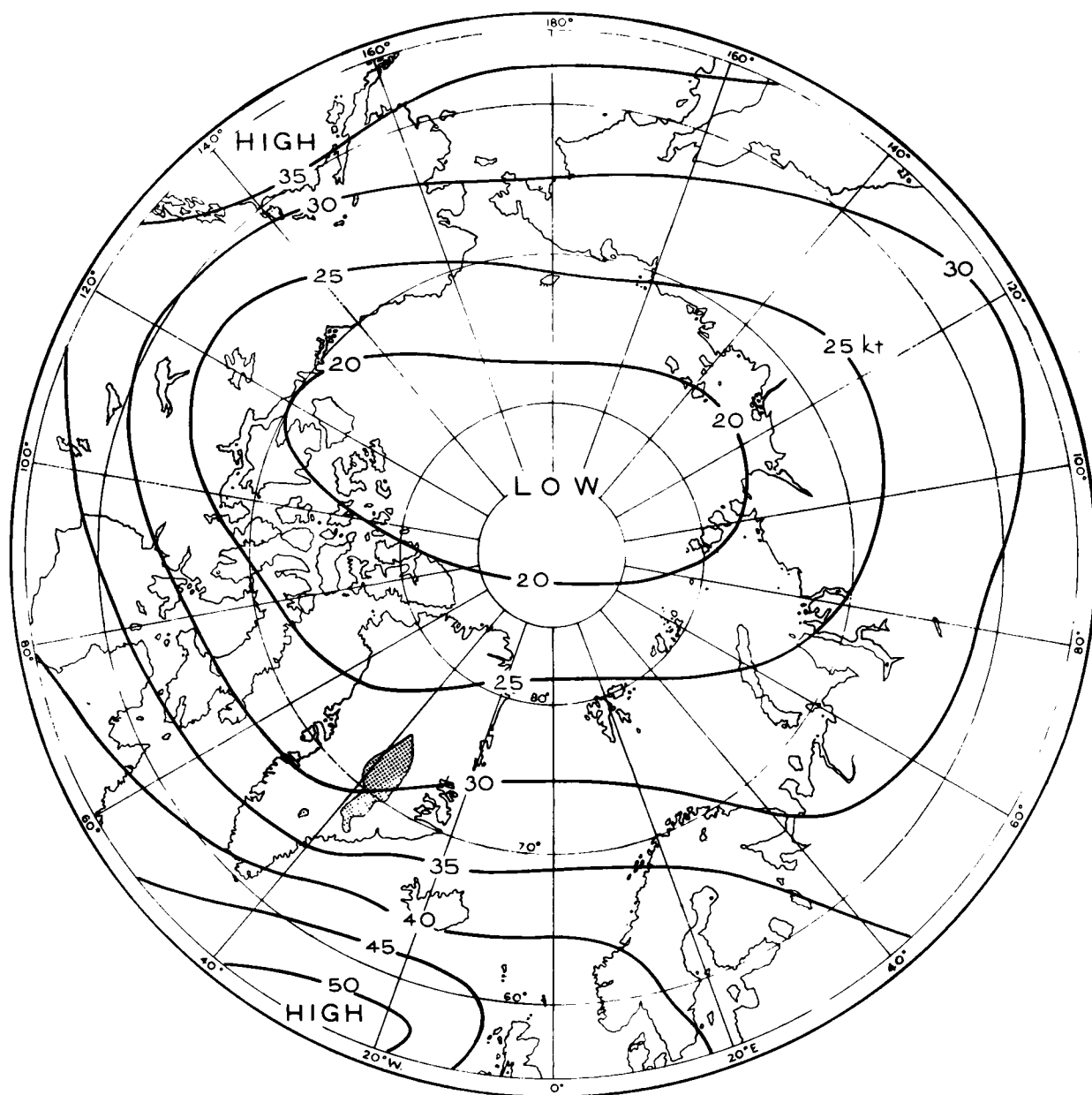


FIGURE 51—STANDARD VECTOR DEVIATION OF WIND AT 200 MB, OCTOBER 1949-53

ICAO height = 38,663 ft = 11,784 m
Shaded areas represent land over 3,000 m

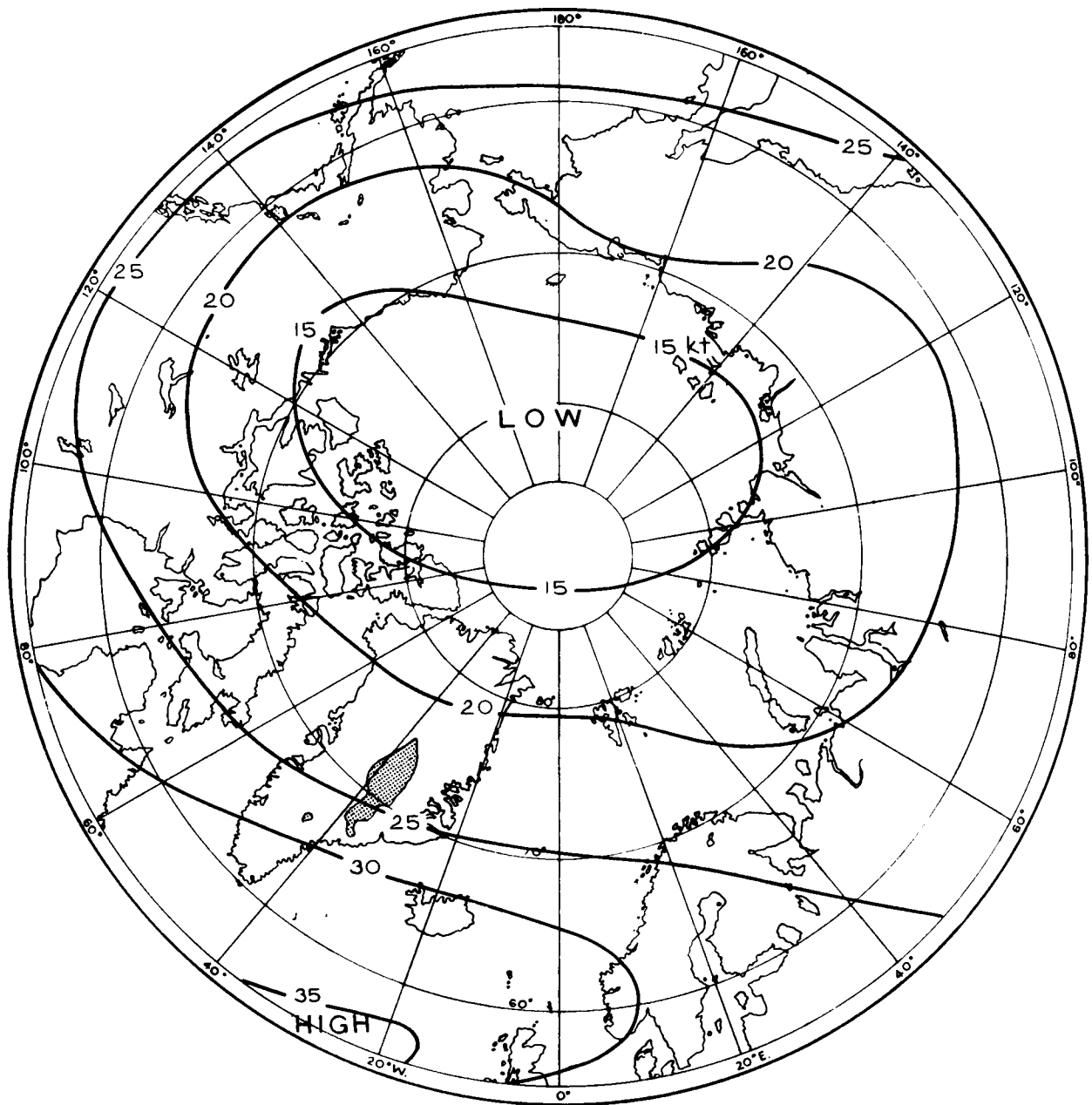


FIGURE 52—STANDARD VECTOR DEVIATION OF WIND AT 150 MB, OCTOBER 1949-53

ICAO height = 44,647 = 13,608 m
Shaded areas represent land over 3,000 m

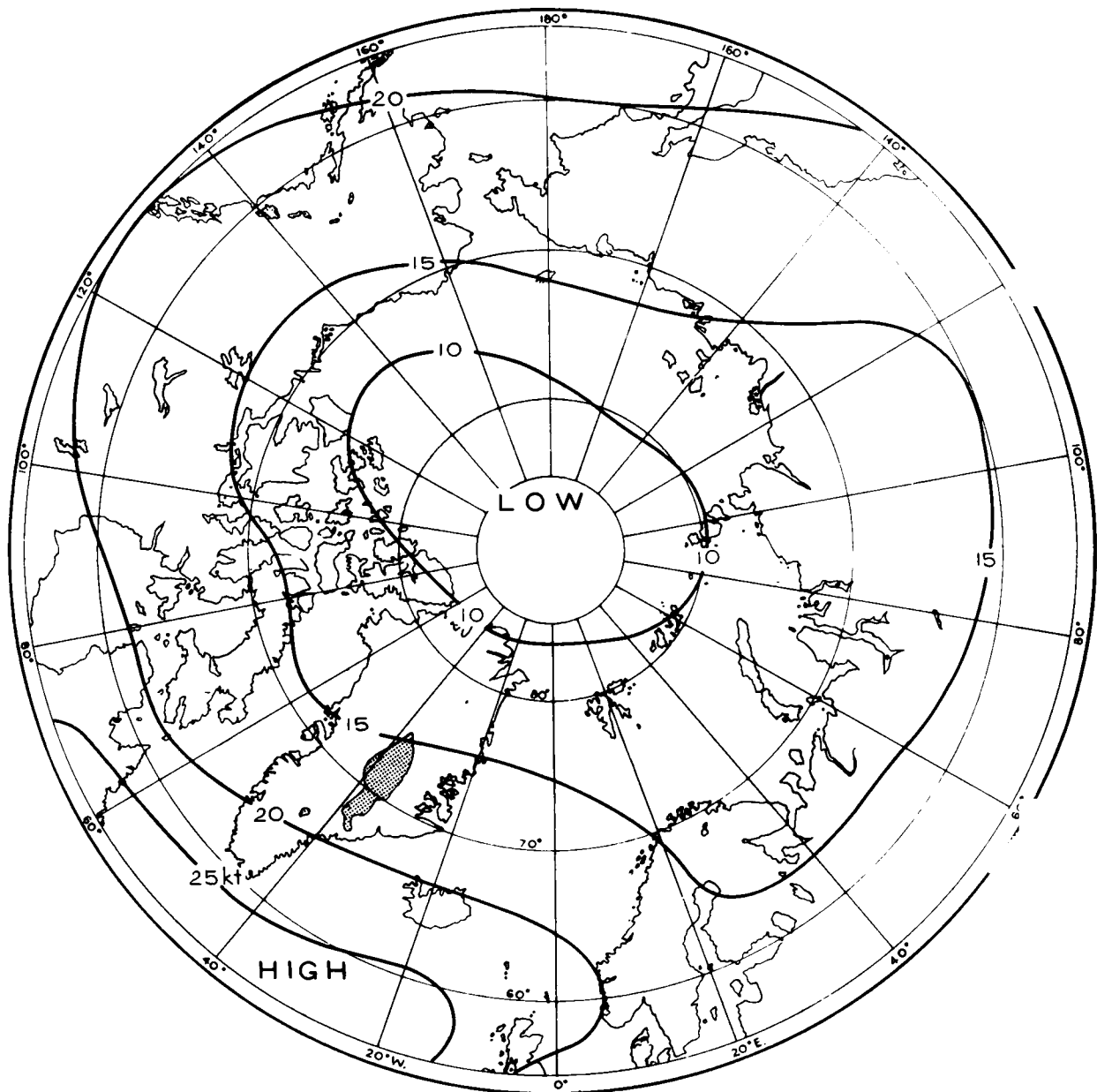


FIGURE 53—STANDARD VECTOR DEVIATION OF WIND AT 100 MB, OCTOBER 1949-53

ICAO height = 53,083 ft = 16,180 m
Shaded areas represent land over 3,000 m