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STUDIES OF STRATOSPHERIC EDDY TRANSPORT

I. The Observed Ozone Flux by the Transient Eddies, 0-30 km

[redacted]

II. Eddy Diffusion Coefficients and Wind Statistics, 30-60 km

(10) G. D. Nastrom, [redacted] D. E. Brown
R. W. Wilcox

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In Part I, ozonesonde data ~~have been~~ were matched with concomittant rawinsonde data to provide a direct determination of meridional flux of ozone by ~~the~~ transient eddies. Data are from about 25 stations in ~~the four regions~~: eastern and western North America, western Europe, and Japan. Results generally confirm the existence of significant northward flux, 10-18 km, in winter/spring; ~~as shown by previous investigators.~~ However, areas of significant equatorward flux have been found at high mid-latitudes, 10-16 km, over North America in winter/spring and at all latitudes, 10-18 km, over Japan in spring. Fluxes are typically small in summer, as well as throughout the troposphere, and throughout most of the middle stratosphere. ~~Additional,~~ qualitative, statements are made concerning the relative importance of mean meridional and standing eddy fluxes.

Rocketsonde data, 30-60 km, 1961-1976, are the data base used for the three components of the eddy diffusion matrix and circulation statistics. ~~presented in Part II.~~ Horizontal diffusivities, Kyy, are obtained from the variance of the meridional wind and the meridional wind's integral time scale. The present results are generally smaller than past estimates, presumably because temporal variations longer than a month were ~~have been~~ filtered out in this work. Estimates of K_{yz} are based on the tentative assumption that the diffusivity is proportional to the slope of the isentropic surfaces. Vertical diffusivities, K_{zz}, are based on a method proposed by Hines, and the present results agree well with past work. For the first time, means, variances, and covariances of wind and temperature ~~have~~ been prepared using the same data handling and analysis methods and the same data base for all components.

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PART I

THE OBSERVED OZONE FLUX BY TRANSIENT EDDIES, SURFACE TO 30 KM

A. INTRODUCTION

Although constituting less than one-millionth part of the atmosphere by volume, ozone is of vital importance to the biosphere through its absorption of certain harmful ultraviolet wavelengths and its regulation of the thermal structure of the stratosphere. It has long been known that photochemical theory, by itself, fails to account for the observed ozone distribution, and atmospheric motions are largely responsible for the distribution in the lower and middle stratosphere. A basic disagreement, however, concerns the relative importance of mean motions and turbulent motions (the "eddies") in accomplishing this distribution. It has been maintained by some (e.g., Brewer, 1949; Dobson, 1973) that a mean meridional circulation transports ozone-rich air directly from the tropical middle stratosphere to the high latitude lower stratosphere. The other school of thought is that the eddies are primarily responsible for the poleward flux of ozone, at least in middle latitudes, and this view is much more dynamically reasonable. That eddies play an important role in the poleward ozone flux has been argued by Martin (1956), Godson (1960), and Newell (1961, 1964), among others.

If χ represents the instantaneous concentration of ozone and v represents the instantaneous northward wind, then the total northward flux of χ past any particular point is given by

$$\overline{v\chi} = \bar{v}\,\bar{\chi} + \overline{v'\chi'}. \qquad (1)$$

Here the overbar signifies a time average and a prime the deviation therefrom. The first term on the right of (1) is the flux due to the mean northward wind past a single point and is thus composed of a contribution by a) the zonally averaged, time averaged, northward wind (the "mean meridional circulation") and b) the deviation from the mean meridional circulation of $\bar{v}$ at the point (the "standing eddies"). With the present network of ozone and rawin stations, it is not possible to distinguish between contributions a) and b) at single stations. The second term on the right of (1) is the flux due to the "transient eddies", and this term we are able to evaluate at stations where both v and χ are observed.

It should be emphasized that, in addition to the horizontal mean and eddy fluxes, there are eddy and mean vertical fluxes which are certainly an important part of the global flux picture. Since vertical wind is not measured, it is not possible to directly compute vertical fluxes, even if one had much better station coverage.

Several investigators have carried out the transient eddy flux computation for ozonesondes at individual stations: Hering (1966) for Seattle, Fort Collins, and Bedford; Pittock (1968) for Aspendale, Australia; Dütsch and Favarger (1969) for Boulder; Hutchings and Farkas (1971) for Christchurch, New Zealand, and DeMuer (1976) for Uccle. Although these results varied from station to station, they generally showed a large horizontal transient eddy flux of ozone at about 12 - 16 km over mid-latitudes in winter and spring, with small, or even negative, fluxes in other seasons and at other heights. All these studies were for mid-latitude stations.

The present study uses similar methods as the previous studies, but encompasses more stations and regions. Specifically, these regions are Japan (3 stations), western North America (6 stations), eastern North America (12 stations), and western Europe (6 stations). Presented are seasonal height-latitude tables and cross sections for each region.

B. DATA AND COMPUTATIONAL METHOD

1. Data

The data used in this study are described in Table 1 and in Figures 1-3. The North American ozone data were primarily from the Air Force Cambridge Research Laboratories' (AFCRL) 1963-1965 sounding network (and the extension until 1969 at a few stations). These data were obtained from World Data Center-A (Asheville). Most of the remaining data were obtained through the World Data Center for Ozone, Downsview, Ontario, Canada. Data for Boulder and Thalwil were extracted from Dütsch (1966) and Dütsch, et al. (1970).

Nastrom (1978) has shown that ozone and northward wind are nearly 90° out of phase in the extratropical lower stratosphere, with the v maximum lying to the east of the ozone maximum. Typical X,v correlations are quite small,

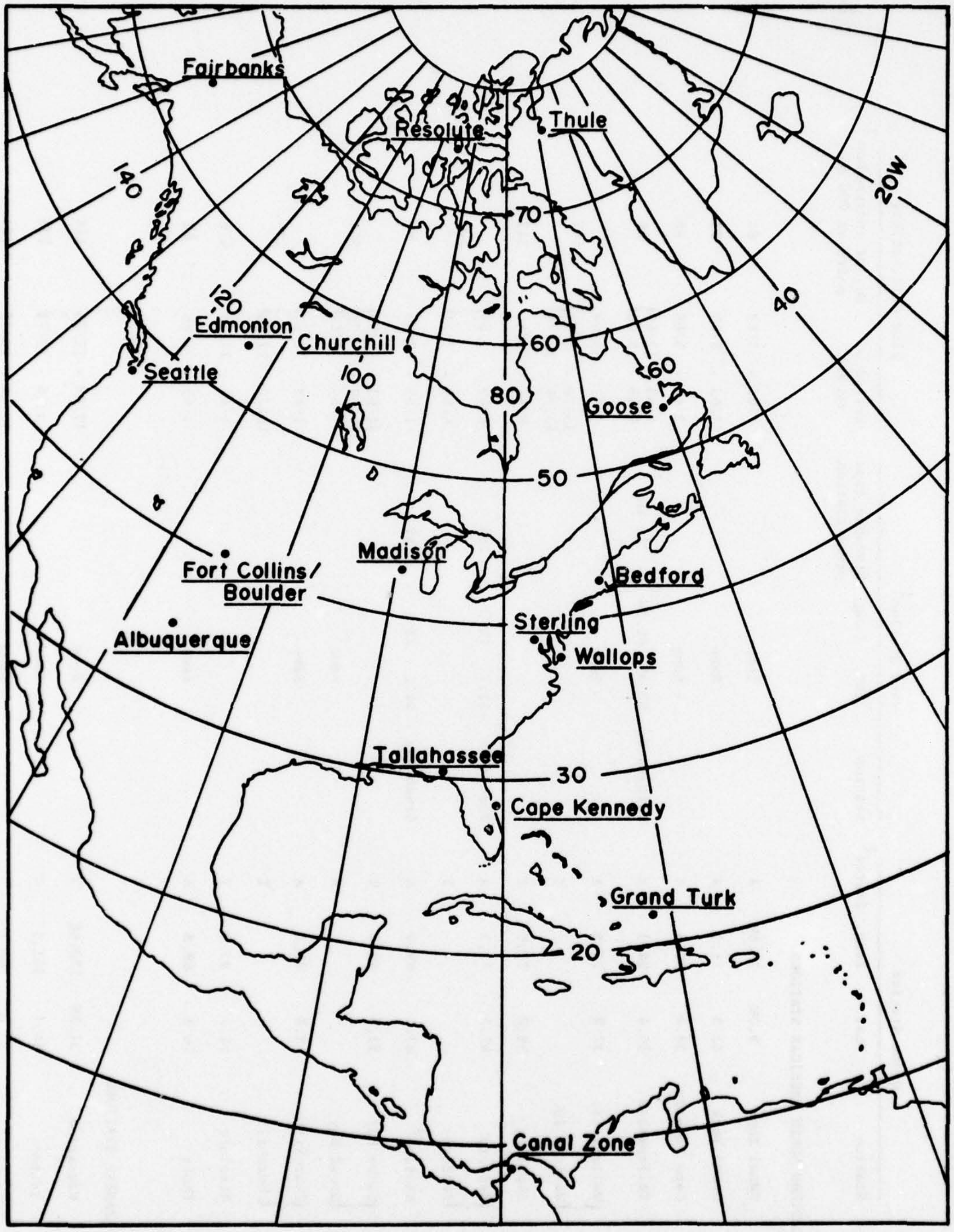

FIGURE 1. North American ozonesonde stations. 100°W divides "western" and "eastern" North America.

TABLE 1. Ozone and wind data.

Ozone Station				Wind Station[1]				Flux Calculations	
Station	Lat.	Long.	Source[2]	Station	Lat.	Long.	Distance from ozone station	Period of record	No. of independent pairs at 200 mb[3]
EASTERN NORTH AMERICAN STATIONS									
Canal Zone	9.0N	79.6W	A		Same			1/63 - 5/69	81
Grand Turk	21.5	71.1	A		Same			12/63 - 5/69	68
Cape Kennedy	28.4	80.5	A		Same			2/66 - 5/69	85
Tallahassee	30.4	84.3	A	Valparaiso	30.5N	86.5W	211 km	1/63 - 12/65 4/68 - 5/68	60
Wallops Is.	37.8	75.5	A		Same			2/67 - 5/69	195
Wallops Is.			T					5/70 - 4/75 3/76 - 12/76	
Sterling	39.0	77.5	T					8/62 - 6/66	143
Bedford	42.5	71.3	A	Portland	43.7	70.3	156	9/63 - 5/69	321
Bedford			T					6/69 - 3/71	
Madison[6]	43.1	89.4	A	Green Bay	44.5	88.1	187	1/63 - 12/65	63
Goose Bay	53.3	60.4	T					1/63 - 12/63 6/69 - 12/76	504
Goose Bay			A		Same			1/64 - 5/69	
Churchill	58.8	94.1	A		Same			1/63 - 12/65	194
Churchill			T					10/73 - 12/76	
Resolute	74.7	95.0	T					1/66 - 12/76	476
Thule	76.5	68.8	A		Same			1/63 - 1/66	68
JAPANESE STATIONS									
Kagoshima	31.6N	130.6E	T		Same			12/68 - 12/75	178
Tateno	36.1	141.3	T		Same			3/68 - 12/75	178
Sapporo	43.0	140.1	T		Same			12/68 - 12/75	205

WESTERN NORTH AMERICAN STATIONS

Albuquerque	35.0N	106.6W	A		Same			1/63 - 12/65	136
Boulder[4]	40.0	105.2	D1,D2	Denver	39.8N	104.9W	44 km	8/63 - 7/66	342
Fort Collins	40.6	105.1	A	Denver	39.8	104.9	92	1/63 - 6/67	160
Seattle	47.4	122.3	A	Salem[5]	44.9	123.0	283	1/63 - 12/65	78
Edmonton	53.6	114.1	T					10/70 - 9/77	247
Fairbanks	64.8	147.9	A		Same			9/63 - 9/64	83
Fairbanks			T					11/64 - 12/65	

WESTERN EUROPEAN STATIONS

Lisbon	38.8N	9.2W	T					6/73 - 12/75	80
Cagliari	39.2	9.0E	T					7/68 - 7/70 1/73 - 8/76	206
Payerne[4,7]	46.8	6.9	T		Same			8/68 - 6/72	606
Thalwil	47.3	8.6	D2	Payerne	46.8N	6.9E	132	9/66 - 7/68	
Hohenpeissenberg	47.8	11.0	T					3/65 - 12/76	571
Uccle	50.8	4.3	T					12/65 - 8/67	88
Berlin[7]	52.5	13.4	T					11/66 - 1/73	439
Lindenberg[7]	52.2	14.1	T					1/75 - 12/76	

NOTES

1 If all columns under this heading are blank, wind and ozone are from the same sounding. If the word "Same" appears, soundings are at the same station but at different hours.

2 Sources: T = World Data Center for Ozone, Downsview, Ontario; A - World Data Center-A, Asheville, NC; D1 = Dütsch (1966); D2 = Dütsch, et al. (1970).

3 Observations are judged independent if they are separated by at least 42 hours. See text.

4 These ozonesonde data were not accompanied by temperature, so concentrations have been calculated using temperature data at the wind station.

5 For the period 9/63 - 12/63 Olympia (47.0N, 122.9W) wind data was used.

6 The observations were actually moved to Green Bay in October 1964.

7 Thalwil and Payerne have been merged into single time series for this report, as have Berlin and Lindenberg.

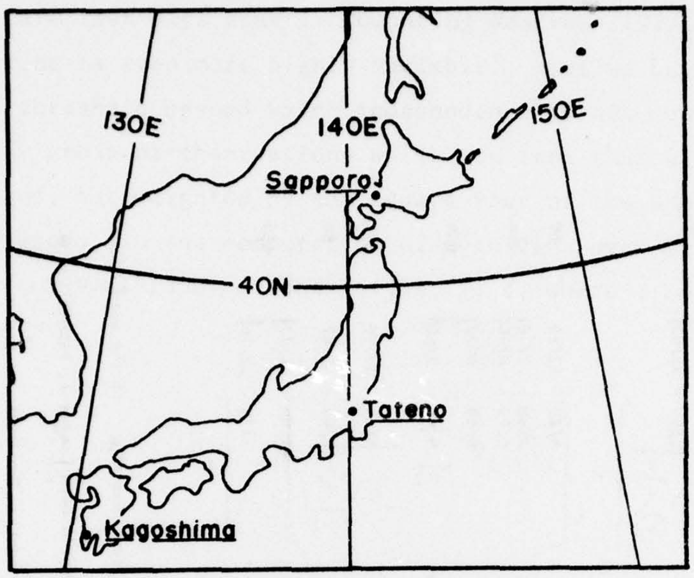

FIGURE 2. Japanese ozonesonde stations.

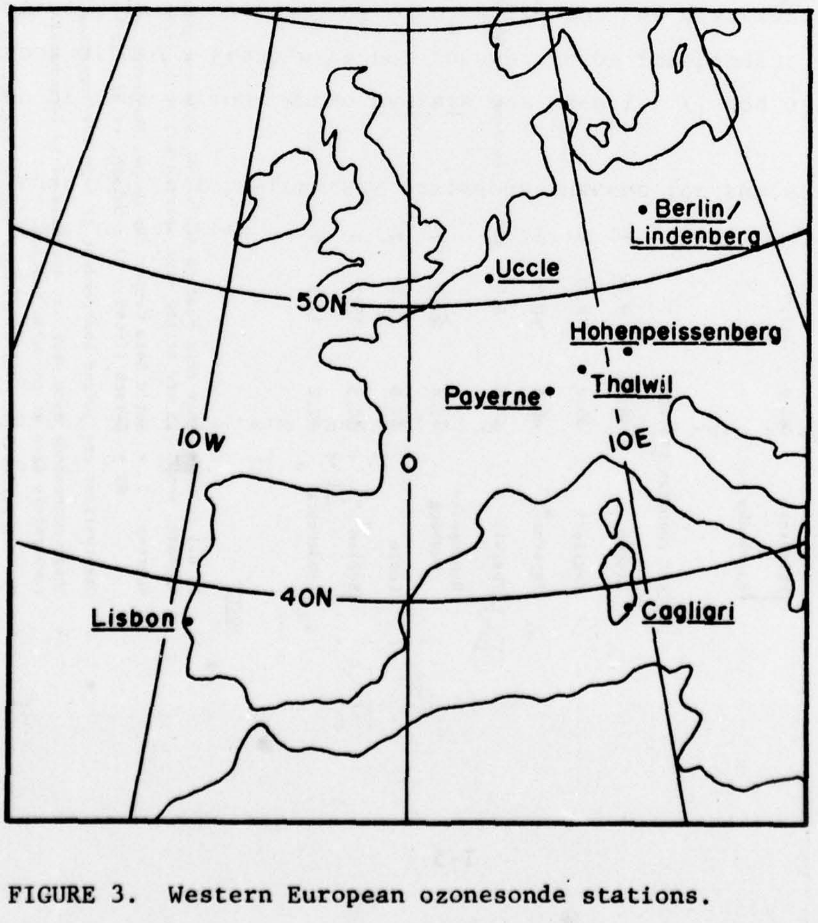

FIGURE 3. Western European ozonesonde stations.

and sensitive to space and time lags of the individual observations. It is therefore unfortunate that wind data accompanying the AFCRL soundings were discarded (Hering, personal communication, 1977) and that, at a few other stations, wind data were not routinely reported. When concomitant wind was not available, data within ±8 hours from a nearby rawin station were used. Such rawinsonde data were obtained from World Data Center-A. For the few ozone stations which did not report temperature (needed for determination of concentration), temperature was also taken from this rawinsonde report.

The choosing of a rawin station to pair with an ozone station was usually based simply on separation distance, but consideration was also given to the fact that v is about twice as highly autocorrelated in the north-south direction as in the east-west direction in the upper troposphere (Buell, 1973), and probably in the lower stratosphere as well. Therefore, Seattle is paired with Salem (283 km south) rather than with Tatoosh Is. (210 km west).

All wind data were objectively checked using a vertical wind shear criterion proposed by Essenwanger (1967). Temperature was also required to pass certain vertical consistency checks (details available on request). The computation of flux was carried out for the levels 1000, 850, 700, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 20, 10, and 7 mb. Values at 2.5 km height increments were subsequently read off the analyses, according to seasonal mean height-pressure relationships in the standard atmospheres of various latitudes (U.S. Standard Atmosphere Supplements, 1966).

There have been occasional periods at a few ozone stations when ascents were made only a few hours apart. This often led to the pairing of two or even three ozonesondes with a single rawinsonde. When this happened, the ozone data were averaged and henceforth treated as one observation.

2. Flux Computation

In computing seasonal mean fluxes, care was taken not to give undue weight to observation series whose temporal density indicated the individual observations were not independent in the statistical sense. Wilcox (1978) determined that total ozone observations (at middle latitudes) may be considered independent if they are four days apart. Comparing Nastrom (1977, Figure 2), it seems that local ozone is even more highly variable. Here we have arbitrarily set 42 hours as the threshold beyond which independence is assumed, and averages are taken over any group of observations which are less than 42 hours apart. This average is used, but weighted by the square root of the number of such observations in the group, in the computation of mean flux over a single season. $\overline{F}_j$, the flux for individual season j (j=1,...,J, where J is the number of years used) is

$$\overline{F}_j = \left[\frac{1}{\sum_{i=1}^{I}\sqrt{n_i}}\sum_{i=1}^{I} v_i\chi_i\sqrt{n_i}\right]_j - \left[\frac{1}{\sum_{i=1}^{I}\sqrt{n_i}}\sum_{i=1}^{I} v_i\sqrt{n_i}\right]_j \bullet \left[\frac{1}{\sum_{i=1}^{I}\sqrt{n_i}}\sum_{i=1}^{I}\chi_i\sqrt{n_i}\right]_j \qquad (2)$$

in which n_i is the number of observations in the ith observation group, and I is the number of groups in the season. Usually, there was only one observation per group, in which case, $n_i = \sqrt{n_i} = 1$. But, as described above, when observations within a group were not thought to be independent, n_i is equal to the number of observations whose <u>average</u> was used for χ_i and v_i.

Note that (2) is term-for-term analagous, except for the weighting, with the more concise notation

$$\overline{F}_j = \overline{v\chi} - \overline{v}\,\overline{\chi}. \qquad (2a)$$

In forming the long-term seasonal flux, $\overline{F}$, the $\overline{F}_j$s were weighted by the square root of N_j, where $N_j = \sum_{i=1}^{I}\sqrt{n_{ij}}$, i.e.,

$$\overline{F} = \frac{1}{\sum_{j=1}^{J}\sqrt{N_j}}\sum_{j=1}^{J}\overline{F}_j\sqrt{N_j} \qquad (3)$$

It will be noted that this computational method does not take into account the positive correlation of seasonal changes in χ and v in the mid-latitude lower stratosphere. This correlation, when positive, makes an algebraically positive contribution to the flux (see Nastrom, 1977). However, the effect is not thought to be serious over the three-month averaging periods, and efforts to account for the variability would, in any case, be inaccurate due to dearth of data.

3. Standard Errors

Standard errors, $\sigma_{\overline{F}}$, of the long-term seasonal mean fluxes, were estimated by

$$\sigma_{\overline{F}} = \frac{\sigma_\chi \sigma_v}{\left[\left(\sum_{j=1}^{J} N_j\right) - 4\right]^{\frac{1}{2}}} \qquad (4)$$

where σ_χ and σ_v are the standard deviations of ozone and northward wind, respectively (Panofsky and Brier, 1958, p.93). Standard errors helped to guide the analysis in areas where individual fluxes were spatially inconsistent.

C. ANALYSIS AND RESULTS

Fluxes were statistically insignificant, typically, over most of the altitude range considered. Usually, it is only just above the tropopause that the magnitudes of individual fluxes surpass twice the standard error (i.e., 95% confidence in the sign). These regions, usually in mid-latitudes, from 10 to 18 km, show significant winter and spring fluxes which are generally poleward, except equatorward over Japan and at high mid-latitudes over North America. Above and below these regions, and at all altitudes of low latitudes, the fluxes are generally small, but usually, through consideration of fluxes at several levels and/or stations, a good guess at the proper sign can be made.

1. Eastern North America (Figure 4 and Table 2)

During winter and spring, there is a region of very significant northward (positive) flux near 40N from about 10 to 16 km. This is in qualitative and

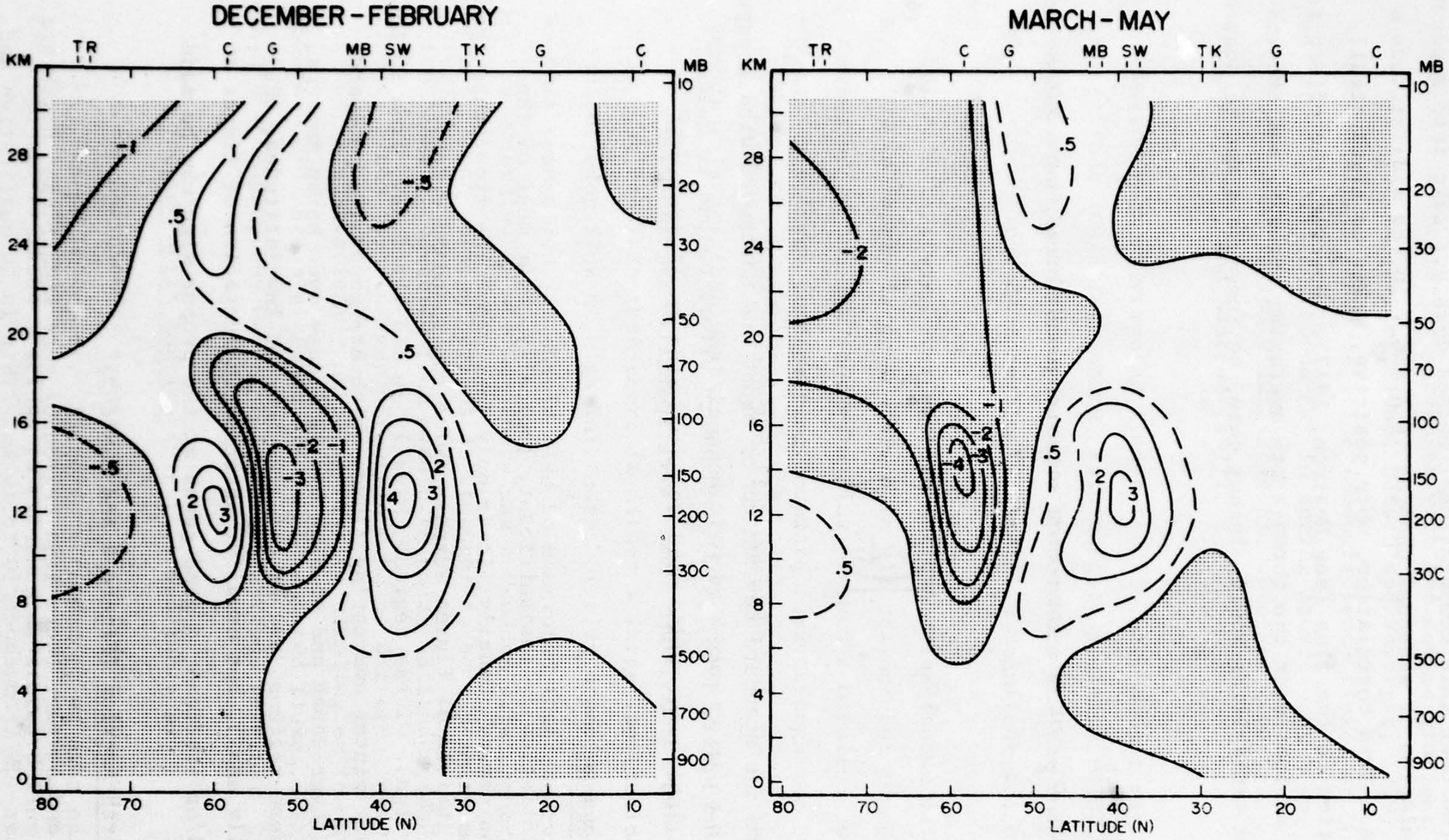

FIGURE 4. Northward ozone flux by the transient eddies over eastern North America. Units are 10^{18} molecules m^{-2} sec^{-1}. Letters at the top refer to stations (Table 1). Southward regions shaded.

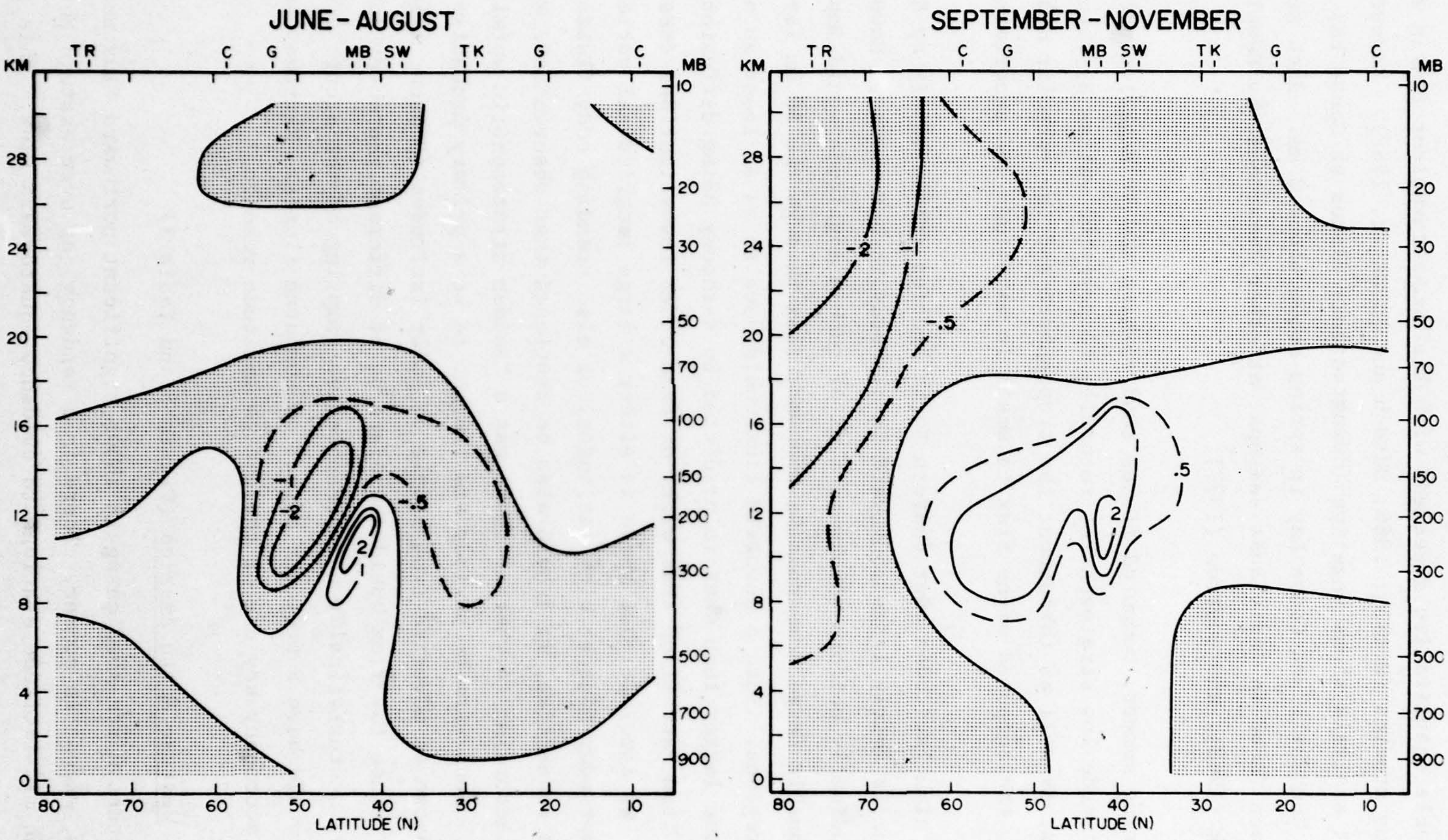

FIGURE 4. (Continued).

reasonable quantitative agreement with the countergradient fluxes found in previous studies (Hering, 1966; Dütsch and Favarger, 1969). However, the present analysis shows negative (downgradient) fluxes at Goose Bay in winter and at Churchill and Goose Bay in spring above about 8 km. Such negative fluxes have been found in individual seasons, at other locations, by Newell (1964), Pittock (1968), and Nastrom (1977).

During summer, computed fluxes tend to have modest negative values in the mid-latitude low stratosphere, returning to positive values by autumn. In the tropics, as well as throughout the troposphere and the subpolar middle stratosphere, the computed ozone flux is small in magnitude and uncertain in sign.

At high latitudes over eastern North America (shown mainly by Resolute), the flux is fairly large southward in all seasons but summer. However, a longitudinally uniform southward flux of such a magnitude would imply an unreasonably large compensating downward flux through the 30 km level over polar regions. Such a downward flux would have to be at least an order of magnitude larger than what is predicted by K-theory using diffusion coefficients from Part II of this work, or from other investigations (see CIAP, 1975). We conclude that there is either a large longitudinal variability in the transient eddy flux at high latitudes, or else standing eddy fluxes compensate. In this connection, it should also be mentioned that observations were not sorted according to whether there was a "sudden stratospheric warming" occurring or not. Such warming periods are thought to be a primary mechanism through which ozone is advected from middle to polar latitudes (Godson, 1960; Clark, 1970). Since the flux would therefore be of different character during these periods, a statistically unrepresentative sampling of the arctic winter stratosphere would have a profound affect on computed fluxes. Extreme caution should accompany any use of these high latitude results.

2. Western North America (Figure 5 and Table 3)

Western North America again shows significant northward flux near 40N, 8-16 km, except in summer. There is a tendency, as over eastern North America, for high mid-latitude stations to evidence equatorward flux. This is particularly true at Seattle, which has relatively few observations and whose "concomitant" winds came from a fairly distant station, but the more reliable Edmonton data suggests negative fluxes also.

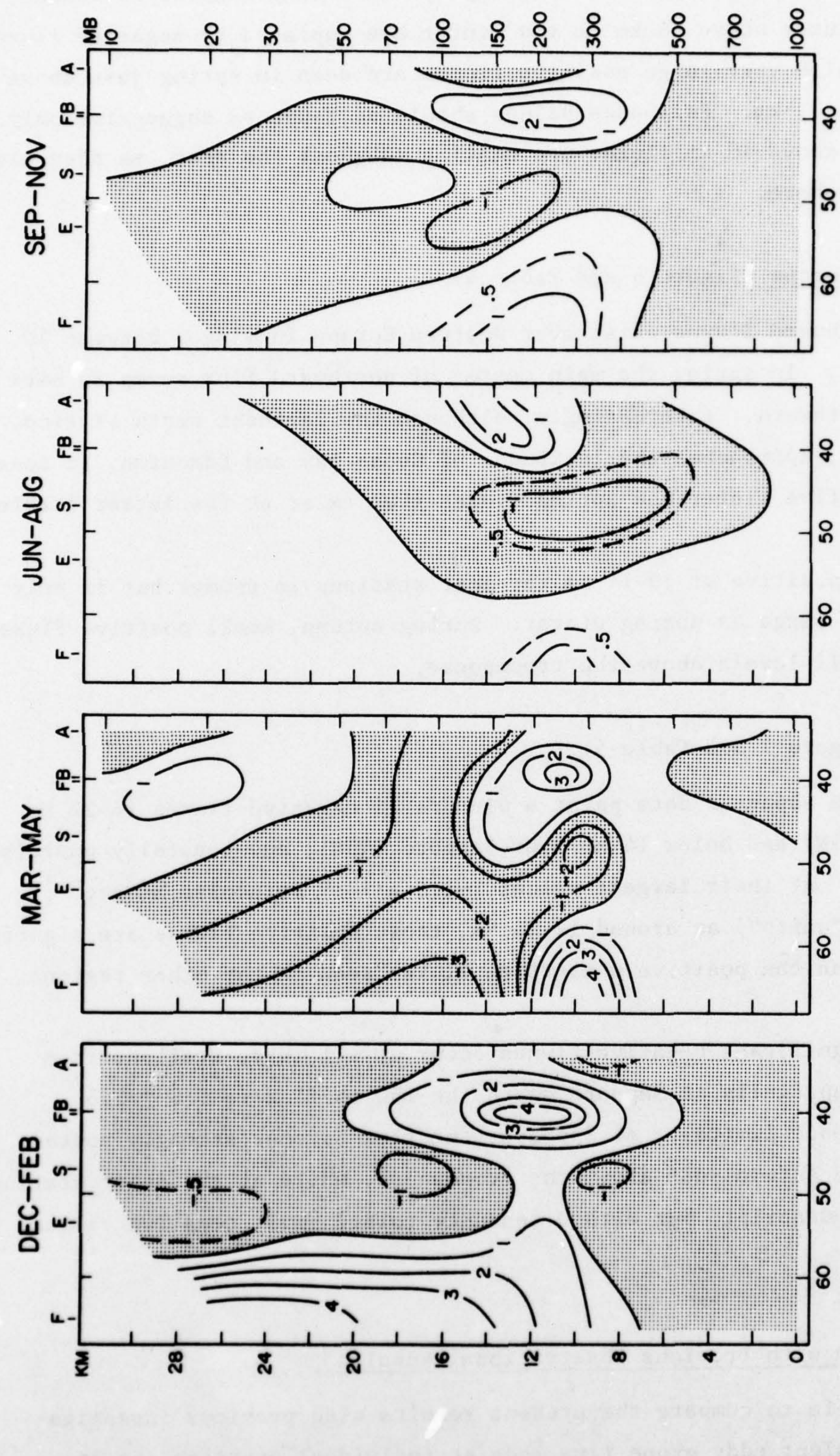

FIGURE 5. Northward ozone flux by the transient eddies over western North America. Units are 10^{18} molecules $m^{-2}sec^{-1}$. Letters at top refer to stations (Table 1). Southward regions shaded.

North of 60N, an area represented solely by the scanty data of Fairbanks, large positive fluxes above 16 km in the winter are replaced by negative fluxes in the spring, while very large positive fluxes are seen in spring just above the tropopause, 8-11 km. Fairbanks values should be taken as suggestive only. South of 60N and above 18 km fluxes are small throughout the year, as they also are in the troposphere.

D. Western Europe (Figure 6 and Table 4)

Sizeable northward fluxes exist over western Europe in winter between 40 and 50N, 10-14 km. In spring the main center of northward flux seems to have moved farther northward. Interestingly, although the farthest north station, Berlin/Lindenberg, approaches the latitudes of Goose Bay and Edmonton, it does not show the negative winter and spring fluxes that exist at the latter stations.

Flux remains positive at 10-14 km for most stations in summer but is only less than half as large as during winter. During autumn, small positive fluxes exist at almost all levels above the tropopause.

4. Japan (Figure 7 and Table 5)

In winter, the Japanese data paint a picture of negative fluxes 16-22 km over Kagoshima (32N) and below 14 km over Sapporo (43N), and generally positive fluxes elsewhere. At their largest values ($\sim 1.5 \times 10^{18}$ molecules $m^{-2} sec^{-1}$, hereafter called "units") at around 14-16 km, these positive fluxes are significantly smaller than the positive wintertime fluxes seen in the other regions.

In spring, significant negative fluxes occur at all three stations from about 10-16 km, especially at Sapporo where the 150 mb flux is 5.8 ± 2.5 units (95% confidence limits). At Sapporo, the flux becomes strongly northward in summer and autumn just above the tropopause, while at the other stations the pattern is nondescript, but with a tendency toward small negative values.

D. DISCUSSION

1. Comparison with Previous Observational Results

It is worthwhile to compare the present results with previous investigations of the transient eddy ozone flux made at individual stations, or at

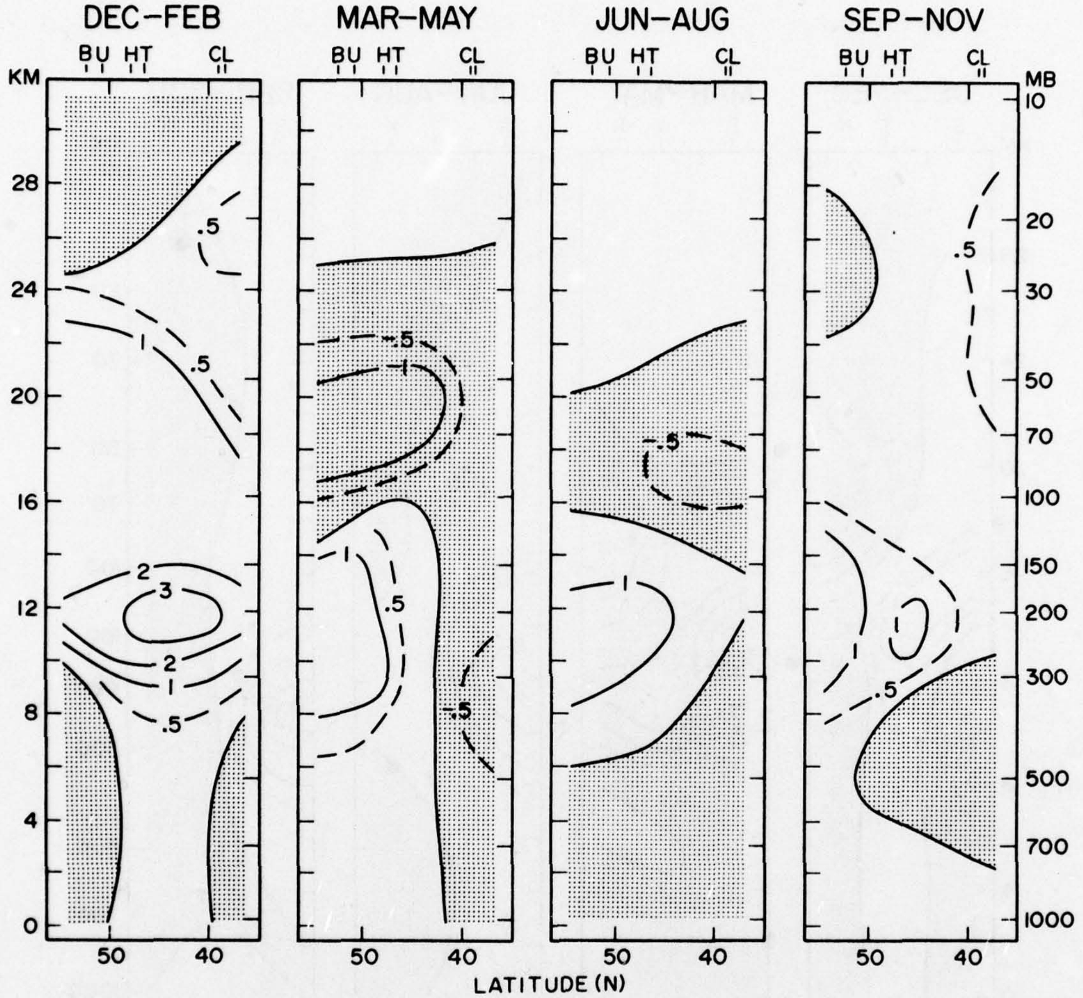

FIGURE 6. Northward ozone flux by the transient eddies over western Europe. Units are 10^{18} molecules $m^{-2}sec^{-1}$. Letters at the top refer to stations (Table 1). Southward regions shaded.

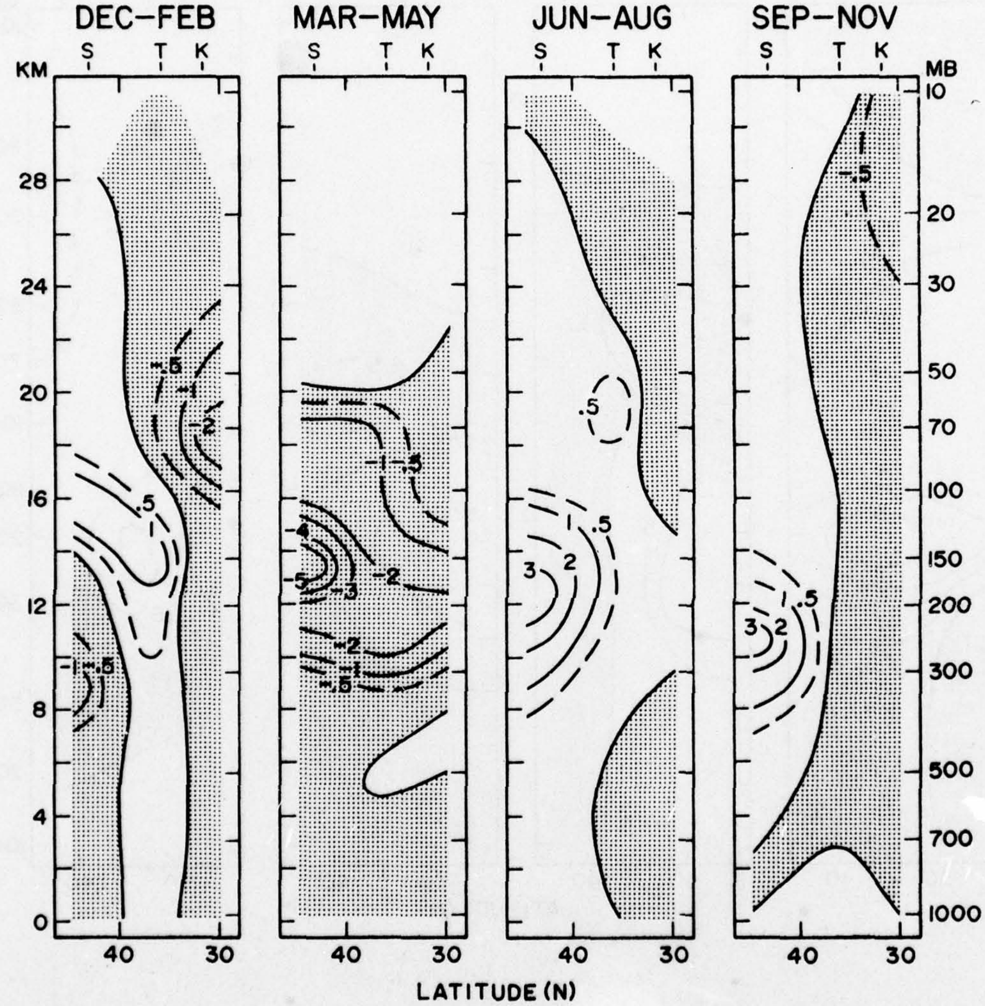

FIGURE 7. Northward ozone flux by the transient eddies over Japan. Units are 10^{18} molecules $m^{-2}sec^{-1}$. Letters at the top refer to stations. Southward regions shaded.

groups of a few stations (as in the case of Hering, 1966). However, although the present study includes the stations used in several of these previous investigations, differences in period of record, availability of wind data, and computational technique make differences in results inevitable.

All previous investigations of the ozone flux which used ozonesondes have been for mid-latitude stations. They have all shown positive winter and spring fluxes from about 10-18 km, with maxima at about 12 km. Dütsch and Favarger (1969) have computed this maximum to be 3.8 units in winter and 2.7 units in spring for two years at Boulder, while Hering puts it at 5.0 units for an average of two years' December-May fluxes at Seattle, Fort Collins and Bedford. (It is not clear whether or not Hering removed the flux due to the correlations between the annual waves of v and χ. While we did not remove this correlation either (see Section B), Hering's longer averaging period (six months) would have more serious consequences (Nastrom, 1977).)

At Aspendale, Pittock (1968) found 200 mb poleward fluxes of 2.6 units in some winters or springs, but equatorward fluxes (of up to 4.0 units) in others. Hutchings and Farkas (1971), from a very small data sample at Christchurch, determined an annual average flux at the 12 km level of about 3.1 units. Not included in the present report are several recent years of soundings at Uccle, from which DeMuer (1976) has computed fluxes. His annual mean value at 200 mb is 1.5 units which compares well with our annual mean at nearby (in latitude) Berlin (1.4 units).

Nastrom (1977) has computed fluxes between 11 and 12 km, 10-60N, from one year of simultaneous wind and ozone measurements aboard commercial aircraft. Again, his fluxes are in reasonable agreement with the present values, especially considering the very different sampling characteristics.

Of course, comparisons of results could be made for every level and season, but the main point can now be stated very simply: The present results are consistent, in the main, with previous results, despite differences in data and computational method. This fact should lend confidence to the new results presented here, most notably the negative fluxes over Japan and North America, and, in general, the large latitudinal variability of the fluxes. It is also clear from the regional differences in the present results that there is a large longitudinal and/or interannual variability in the transient eddy flux of ozone. This comes as no surprise, as Nastrom (1977) has also provided such a picture at 11-12 km, 40-50N. In particular, for one March in the longitude sector 120E-180 (i.e., mostly north and east of Japan), Nastrom found a negative flux of 6 units, while most other longitude sectors showed positive fluxes of varying magnitudes. The negative spring Japan flux agrees well with the values deduced from ozonesondes. It is also evident from the aircraft data that equatorward fluxes occur in other longitude sectors, sometimes at latitudes as far south as 40N, but that there is considerable interannual variability in this latitude, as can also be inferred from the results of Newell (1964) and Pittock (1968). Interestingly, spring is the only season in which Newell (1964), in his correlations of v with total ozone, did not infer a negative transient eddy flux in the lower stratosphere over Japan. It is for these reasons of significant longitudinal and interannual variability that we have chosen not to try to combine our regional fluxes.

2. Qualitative Remarks on the Ozone Flux Budget

Similarities between patterns of the zonal mean observed isentropes and ozone concentrations imply that the countergradient ozone flux is effected by the same process that effects the countergradient heat flux. The spatial relationship of temperature and height fields in the mid-latitude lower stratosphere indicates the subsidence of air in the troughs and the ascent of air in the ridges. Wallace (1978) has explained that air must move through a lower stratospheric trough at a subgeostrophic speed and that, conversely, air moving through a ridge must do so at a supergeostrophic speed; that is, there is a poleward acceleration in the troughs and an equatorward acceleration in the ridges. Combined with the fact that potential temperature increases with height, this process leads to the observed downward, poleward (countergradient) heat flux. Ozone, since its concentration also increases with height, is transported downward and poleward by the same process.

This explanation predicts only poleward flux throughout mid-latitudes, as is observed in the case of both standing and transient eddy heat flux (Oort and Rasmusson, 1971, pp.286-289). However, the present results for ozone indicate an equatorward transient eddy flux in winter and especially spring at high mid-latitudes. Newell (1964) has suggested that the negative fluxes he found over Japan may be associated with stratosphere-troposphere exchange processes. This association is appealing, since the large convergence of ozone between the positive and negative fluxes would have to be in large part balanced by downward removal into the troposphere. However, association does not necessarily imply cause, and we cannot at present offer a dynamical explanation of the high mid-latitude equatorward fluxes. We can, however, note a strong association with the mean potential temperature field. Climatology (Labitzke, 1972; U.S. Weather Bureau, 1966) shows that areas near Japan and eastern North America have 200 mb potential temperature maxima which are both relatively stronger and located more equatorward than those over western North America and, especially, Europe. These features correlate well with our analyzed patterns of the locations and strengths of the equatorward ozone flux.

It is desirable to make some qualitative assessment of the relative importance of standing and transient eddy ozone fluxes, and we do this via comparison of the present transient eddy results with a three-dimensional model's predictions of total eddy fluxes (steady plus transient). Prinn, et al. (1978), have shown total eddy fluxes, integrated throughout the depth of the model atmosphere, for an annual cycle of their three-dimensional dynamical-chemical model. To compare our results, we have also integrated from the surface to 30 km for the eastern North America sector only (Figure 8). The model's total eddy flux at its wintertime maximum (50N) is one and a half times as large as our transient eddy flux at our maximum location of 37N. The model's winter eddy flux decreases rapidly toward pole and equator, but does not become negative, as ours does from 45-55N and again poleward of 65N. However, even if its transient and standing eddy fluxes were shown separately, it is likely that the model would fail to portray the southward transient eddy flux in winter north of 50N. As indicated previously, this feature can be associated with the existence of a potential temperature maximum at mid-latitudes, which this model fails to predict (Cunnold, et al., 1975; Prinn, et al., 1978).

There are clearly large differences between this model's (and other models') results and the present observational results which cannot be dismissed simply by noting that the models fail to reproduce the mid-latitude temperature

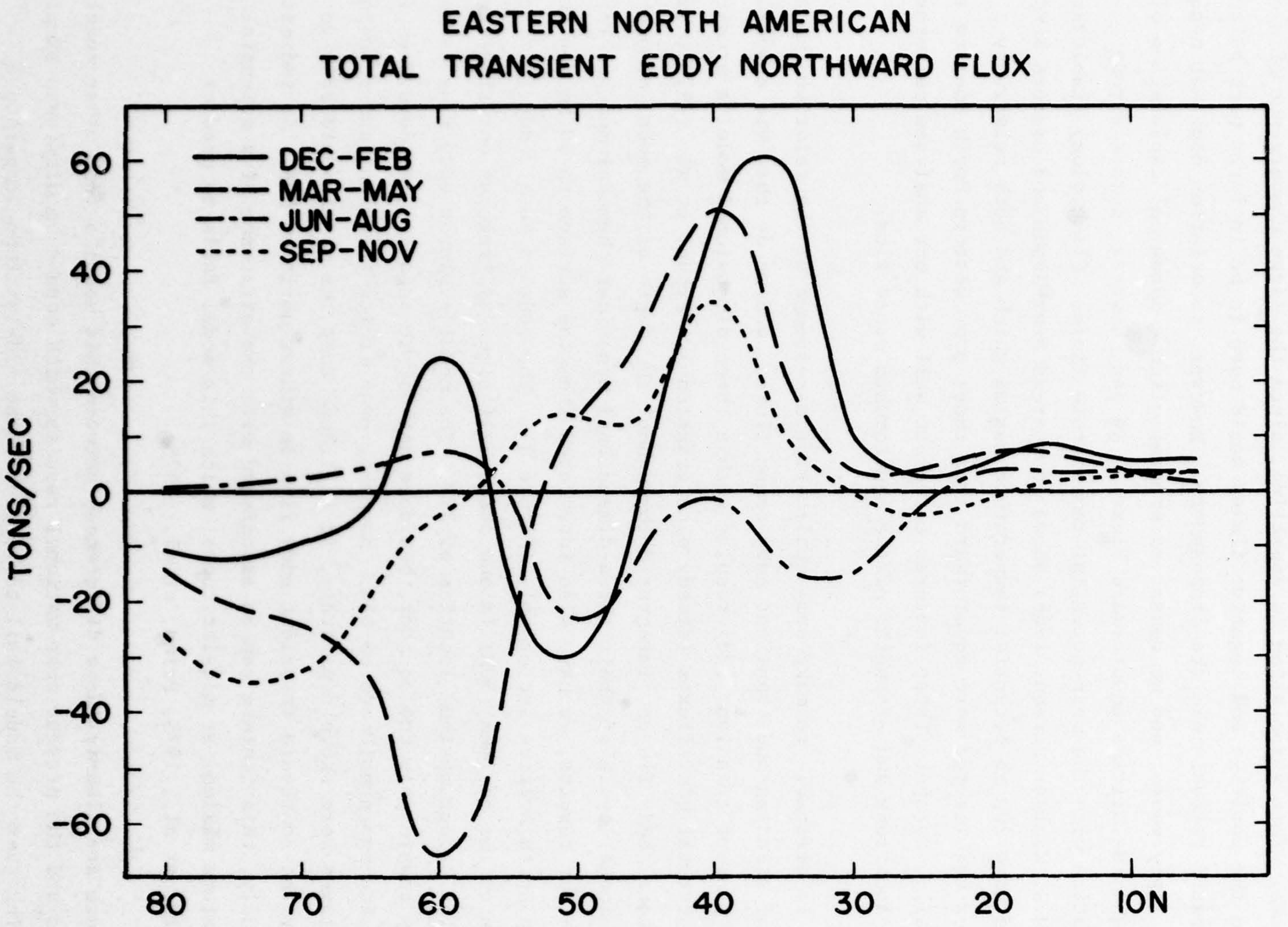

FIGURE 8. Northward transient eddy ozone flux, integrated from the surface to 30 km and around the latitude circle, using eastern North American fluxes only.

maximum. A major difference must be in the model's inclusion of standing eddies, which must make a large contribution to the total eddy ozone flux poleward of about 45N in all seasons except summer, when our results agree with the model's results fairly well. Since transient eddies are damped in the stratosphere, only the ultra-long, quasi-stationary waves are evident in the middle stratosphere, and those only in non-summer months. It is therefore reasonable to surmise that the standing eddy ozone flux is much larger than the transient eddy ozone flux above 18 km or so, and that it is basically the standing eddy flux which accounts for the rapid buildup of ozone near the level of the maximum concentration (about 20 km) at high latitudes in winter and early spring (see, e.g., Wilcox, et al., 1977). This suggestion has also been made by Dütsch and Favarger (1969). It might also be noted that the standing eddy heat flux (Oort and Rasmusson, 1971, pp.288-289) is comparable to the transient eddy heat flux (pp.286-287) in the mid-latitude lower stratosphere. We are led to infer that the standing eddy and transient eddy ozone fluxes are probably of comparable magnitude even in the lower stratosphere (i.e., tropopause to about 18 km).

The tropical mean meridional circulation (Hadley Cell) appears capable of transporting large amounts of ozone from its primary source region in the tropical middle stratosphere downward and poleward to the sub-tropics, and it is probably the major mechanism in so doing (Hunt and Manabe, 1968; Cunnold, et al., 1975). The mean meridional flux in mid-latitudes is almost certainly equatorward, but its magnitude is relatively uncertain. Model results range from portraying it as a minor effect (Cunnold, et al., 1975; Prinn, et al., 1978) to almost balancing the eddy flux (Hunt and Manabe, 1968; Mahlman and Moxim, 1978).

In conclusion, both the direct computations reported here and the results of other investigations imply that the transient eddy flux of ozone appears to be of at least equal importance to the standing eddy and mean meridional fluxes in the mid- and high-latitude lower stratosphere. Above about 18 km, the standing eddy flux is probably more important, and, in the tropics, the mean meridional flux is the primary agent of transport. Direct quantitative estimates of these horizontal fluxes, as well as indirect estimates of vertical fluxes, must necessarily await more spatially extensive observations.

REFERENCES

Brewer, A. W., 1949: Evidence for a world circulation provided by the measurements of helium and water vapor distribution in the stratosphere. Quart. J. Roy. Met. Soc., 75, 351-363.

Buell, C. E., 1973: Correlation functions for wind and geopotential on isobaric surfaces. J. Appl. Meteor., 11, 51-59.

CIAP, 1975: The natural stratosphere of 1974, CIAP Monograph 1, DOT-TST-75-51.

Clark, J. H., 1970: A quasi-geostrophic model of the winter stratospheric circulation. Mon. Wea. Rev., 98, 443-461.

Cunnold, D., F. Alyea, N. Phillips, and R. Prinn, 1975: A three-dimensional dynamical-chemical model of atmospheric ozone. J. Atmos. Sci., 32, 170-194.

DeMuer, D., 1977: The vertical ozone distribution over Uccle (Belgium) in relation to simultaneous observations of wind and temperature. Proceedings of the Joint Symposium on Atmospheric Ozone, Dresden, 9-17 August 1976, Volume I, 261-276.

Dobson, G. M. B., 1973: Atmospheric ozone and the movement of air in the stratosphere. Pure and Appl. Geophys., 106-108, 1520-1530.

Dütsch, H. U., 1966: Two years of regular ozone soundings over Boulder, Colorado. NCAR Technical Note 10, Boulder, 441pp.

Dütsch, H., and D. Favarger, 1969: Meridional ozone transport by transient eddies over Boulder, Colorado. Ann. Geophys., 25, 279-281.

Dütsch, H. U., W. Züllig, and Ch. Ling, 1970: Regular ozone observation at Thalwil, Switzerland, and at Boulder, Colorado. LAPETH-1, Zurich, 279pp.

Essenwanger, O., 1967: Comments on "Mesoscale structure of 11-20 km winds". J. Appl. Meteor., 6, 591-592.

Godson, W. L., 1960: Total ozone and the middle stratosphere over arctic and sub-arctic areas in winter and spring. Quart. J. Roy. Met. Soc., 86, 301-317.

Hering, W. S., 1966: Ozone and atmospheric transport processes. Tellus, 18, 329-336.

Hunt, B., and S. Manabe, 1968: Experiments with a stratospheric general circulation model. II. Large-scale diffusion of tracers in the stratosphere. Mon. Wea. Rev., 96, 503-539.

Hutchings, J. W., and E. Farkas, 1971: The vertical distribution of atmospheric ozone over Christchurch, New Zealand. Quart. J. Roy. Met. Soc., 97, 249-254.

Labitzke, K., and collaborators, 1972: Climatology of the stratosphere in the Northern Hemisphere, Part I, Meteorologische Abhandlungen, 100, 4. Institute for Meteorology, Free University of Berlin.

Mahlman, J., and W. Moxim, 1978: Tracer simulation using a global general circulation model: Results from a midlatitude instantaneous source experiment. J. Atmos. Sci., 35, 1340-1374.

Martin, D. W., 1956: Contributions to the study of atmospheric ozone. Scientific Rpt. No. 6, General Circulation Project, Department of Meteorology, Massachusetts Institute of Technology.

Nastrom, G. D., 1977: Vertical and horizontal fluxes of ozone at the tropopause from the first year of GASP data. J. Appl. Meteor., 16, 740-744.

Nastrom, G. D., 1978: Variability of ozone near the tropopause from GASP data. Research Report No. 1, Contract NAS3-20618, Control Data Corporation, Minneapolis.

Newell, R. E., 1964: Further ozone transport calculations and the spring maximum in ozone amount. Pure and Appl. Geophys., 59, 191-206.

Newell, R. E., 1961: The transport of trace substances in the atmosphere and their implications for the general circulation of the stratosphere. Pure and Appl. Geophys., 49, 137-158.

Oort, A. H., and E. M. Rasmusson, 1971: Atmospheric Circulation Statistics. NOAA Prof. Paper No. 5, U.S. Department of Commerce.

Panofsky, H., and G. Brier, 1958: Some Applications of Statistics to Meteorology, University Park: Mineral Industries Extension Services, The Pennsylvania State University, 224pp.

Prinn, R. G., F. N. Alyea, and D. M. Cunnold, 1978: Photochemistry and dynamics of the ozone layer. Ann. Rev. Earth and Planetary Sci., 1978.6, 43-74.

Pittock, A. B., 1968: Seasonal and year-to-year ozone variations from soundings over south eastern Australia. Quart. J. Roy. Met. Soc., 94, 563-575.

U. S. Standard Atmosphere Supplements, 1966. ESSA, NASA, USAF; Washington DC, 289pp.

U. S. Weather Bureau, 1966: Selected Level Temperatures and Dew Points for the Northern Hemisphere. NAVAIR 50-1C-52, U.S. Government Printing Office.

Wallace, J. M., 1978: Trajectory slopes, countergradient heat fluxes and mixing by lower stratospheric waves. J. Atmos. Sci., 35, 554-558.

Wilcox, R. W., 1978: Total ozone trend significance from space and time variability of daily Dobson data. J. Appl. Meteor., 17, 405-409.

Wilcox, R. W., G. D. Nastrom, and A. D. Belmont, 1977: Periodic analysis of total ozone and of its vertical distribution. J. Appl. Meteor., 16, 290-298.

TABLE 2. Transient eddy ozone flux over eastern North America. Positive denotes northward. Units: 10^{18} molecules $m^{-2} sec^{-1}$.

SEASON: December - February

km	80N	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5
30.0	-1.6	-1.4	-1.2	-1.0	-.4	.5	.8	.2	-.7	-.7	-.4	.1	.3	.0	-.6	-.7
27.5	-1.4	-1.2	-.6	.0	1.0	.8	.3	-.2	-.6	-.5	.0	.2	.2	.0	-.3	-.5
25.0	-1.2	-.6	-.1	.5	1.2	.5	.2	.0	-.5	-.4	.0	.2	.2	.1	.0	.0
22.5	-.5	-.3	.0	.4	1.0	.7	.4	.2	-.2	-.4	-.3	-.1	.1	.2	.4	.4
20.0	-.1	.0	.1	.1	.0	.5	.7	.6	.6	.0	-.3	-.3	-.1	.1	.3	.4
17.5	.0	.0	.1	.1	-1.0	-2.0	-1.0	.5	.8	.8	.0	-.2	-.2	.0	.2	.3
15.0	-.6	-.5	.0	.1	.1	-2.0	-2.5	-1.0	2.0	2.4	.5	.0	.0	.1	.2	.2
12.5	-.7	-.6	-.5	-.5	3.0	-1.0	-3.0	-1.0	3.0	3.4	.8	.2	.1	.2	.2	.3
10.0	-.7	-.6	-.5	.0	1.8	-1.0	-2.0	.5	2.2	2.4	.8	.3	.2	.3	.3	.3
7.5	-.3	-.3	-.3	-.2	-.1	-.2	.0	.6	1.2	1.2	.4	.2	.1	.1	.1	.1
5.0	-.1	-.1	-.2	-.2	-.2	.0	.2	.2	.2	.4	.1	.0	.0	.0	.0	.0
2.5	.0	.0	-.1	-.2	-.2	.0	.2	.3	.2	.2	-.2	-.2	-.1	.0	.0	.0

SEASON: March - May

km	80N	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5
30.0	-1.6	-1.6	-1.4	-1.2	-1.2	.3	.7	.4	.1	.0	-.1	-.1	-.1	-.1	-.2	-.3
27.5	-2.2	-1.8	-1.6	-1.4	-1.2	.0	.6	.5	.1	-.1	-.1	-.1	-.1	-.1	-.1	-.2
25.0	-2.8	-2.6	-1.8	-1.6	-1.2	.2	.5	.4	.0	-.1	-.1	-.1	-.1	-.1	-.1	-.1
22.0	-2.8	-2.6	-2.0	-1.6	-1.2	-.6	.0	.1	.1	.1	.1	.1	.0	.0	-.1	-.1
20.0	-1.8	-1.8	-1.6	-1.4	-1.2	-.8	-.3	-.1	.1	.4	.4	.3	.2	.1	.0	.0
17.5	-.8	-1.0	-1.2	-1.6	-1.8	-1.0	-.2	.3	.5	.5	.4	.4	.3	.2	.1	.1
15.0	-.3	-.5	-.6	-1.0	-3.5	-1.6	.0	1.0	2.4	1.0	.4	.2	.2	.2	.2	.2
12.5	.5	.3	.2	-.5	-3.0	-2.4	.1	.8	3.4	1.4	.4	.2	.2	.2	.2	.2
10.0	.7	.6	.4	.0	-2.0	-1.2	.5	1.4	2.0	.8	.0	.2	.2	.2	.2	.2
7.5	.5	.5	.4	.1	-.6	-.2	.6	.6	.3	-.1	-.4	-.1	.2	.2	.1	.1
5.0	.3	.3	.3	.2	.0	.2	.2	-.1	-.4	-.5	-.3	-.2	.1	.1	.1	.1
2.5	.2	.2	.2	.2	.2	.1	.1	.1	-.1	-.2	-.3	-.2	-.1	.0	.0	.0

TABLE 2. (Continued).

SEASON: June - August

km	80N	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5
30.0	.1	.1	.1	.1	.1	.0	-.1	-.1	-.1	.0	.2	.1	.1	.0	.0	-.1
27.5	.1	.1	.1	.0	.0	-.1	-.1	-.1	-.1	.0	.1	.1	.1	.0	.0	.0
25.0	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
22.5	.2	.2	.2	.2	.2	.2	.2	.2	.2	.2	.1	.1	.1	.1	.1	.1
20.0	.2	.2	.2	.2	.1	.1	.1	.1	.1	.1	.1	.2	.2	.2	.2	.2
17.5	.2	.1	.0	.0	-.1	-.2	-.4	-.4	-.4	-.3	.0	.1	.2	.2	.2	.2
15.0	-.2	-.2	-.2	-.1	.0	-.4	-1.0	-2.0	-.8	-.8	-.5	.1	.1	.1	.1	.1
12.5	-.1	-.1	.0	.2	.6	-.5	-2.0	-2.0	.0	-.5	-.7	-.2	.1	.1	.1	.0
10.0	.2	.3	.4	.5	.5	.8	-2.0	1.4	.5	-.4	-.8	-.4	-.1	-.1	-.1	-.1
7.5	.0	.1	.2	.2	.2	-.4	.0	.6	.3	-.2	-.4	-.2	-.1	-.1	-.1	-.1
5.0	-.2	-.2	.1	.1	.2	.3	.3	.3	.1	-.1	-.1	-.1	-.1	-.1	-.1	.0
2.5	-.1	-.1	-.1	-.1	.0	.2	.3	.3	.0	-.1	-.1	-.1	-.1	.0	.0	.0

SEASON: September - November

km	80N	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5
30.0	-2.6	-2.4	-2.0	-1.4	-.5	-.3	-.2	-.2	-.2	-.2	-.2	-.1	.1	.3	.4	.4
27.5	-2.6	-2.4	-2.2	-1.2	-.8	-.6	-.3	-.2	-.1	-.1	-.1	-.1	.0	.2	.2	.3
25.0	-2.6	-2.4	-2.0	-1.0	-.6	-.6	-.4	-.2	-.1	-.1	-.1	-.1	.0	.0	.0	.0
22.5	-2.4	-2.2	-1.6	-.8	-.6	-.5	-.3	-.2	-.2	-.2	-.2	-.1	-.1	-.3	-.4	-.4
20.0	-2.0	-1.8	-1.4	-.7	-.4	-.3	-.2	-.1	-.1	-.1	-.1	-.1	-.1	-.1	-.2	-.2
17.5	-1.6	-1.4	-.9	-.4	.0	.1	.1	.1	.2	.2	.1	.1	.1	.1	.1	.1
15.0	-1.4	-1.0	-.4	.1	.3	.4	.5	1.0	1.8	.7	.4	.1	.1	.1	.1	.1
12.5	-1.0	-.6	-.2	.2	.7	1.0	1.4	1.2	2.0	.7	.4	.1	.1	.1	.1	.1
10.0	-.8	-.6	-.2	.2	1.0	1.8	1.6	.4	1.6	.3	.1	.1	.1	.1	.1	.1
7.5	-.7	-.6	-.4	-.2	.3	.6	.5	.4	.4	.1	-.1	-.1	-.1	.0	.0	.0
5.0	-.5	-.4	-.3	-.2	-.1	.0	.1	.2	.3	.1	-.1	-.2	-.1	-.1	.0	.0
2.5	-.3	-.3	-.2	-.2	-.2	-.1	.0	.1	.2	.1	-.2	-.2	-.2	-.1	.0	.0

TABLE 2. (Continued).

SEASON: June - August

km	80N	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5
30.0	.1	.1	.1	.1	.1	.0	-.1	-.1	-.1	.0	.2	.1	.1	.0	.0	-.1
27.5	.1	.1	.1	.0	.0	-.1	-.1	-.1	-.1	.0	.1	.1	.1	.0	.0	.0
25.0	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
22.5	.2	.2	.2	.2	.2	.2	.2	.2	.2	.2	.1	.1	.1	.1	.1	.1
20.0	.2	.2	.2	.2	.1	.1	.1	.1	.1	.1	.1	.2	.2	.2	.2	.2
17.5	.2	.1	.0	.0	-.1	-.2	-.4	-.4	-.4	-.3	.0	.1	.2	.2	.2	.2
15.0	-.2	-.2	-.2	-.1	.0	-.4	-1.0	-2.0	-.8	-.8	-.5	.1	.1	.1	.1	.1
12.5	-.1	-.1	.0	.2	.6	-.5	-2.0	-2.0	.0	-.5	-.7	-.2	.1	.1	.1	.0
10.0	.2	.3	.4	.5	.5	.8	-2.0	1.4	.5	-.4	-.8	-.4	-.1	-.1	-.1	-.1
7.5	.0	.1	.2	.2	.2	-.4	.0	.6	.3	-.2	-.4	-.2	-.1	-.1	-.1	-.1
5.0	-.2	-.2	.1	.1	.2	.3	.3	.3	.1	-.1	-.1	-.1	-.1	-.1	-.1	.0
2.5	-.1	-.1	-.1	-.1	.0	.2	.3	.3	.0	-.1	-.1	-.1	-.1	.0	.0	.0

SEASON: September - November

km	80N	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5
30.0	-2.6	-2.4	-2.0	-1.4	-.5	-.3	-.2	-.2	-.2	-.2	-.2	-.1	.1	.3	.4	.4
27.5	-2.6	-2.4	-2.2	-1.2	-.8	-.6	-.3	-.2	-.1	-.1	-.1	-.1	.0	.2	.2	.3
25.0	-2.6	-2.4	-2.0	-1.0	-.6	-.6	-.4	-.2	-.1	-.1	-.1	-.1	.0	.0	.0	.0
22.5	-2.4	-2.2	-1.6	-.8	-.6	-.5	-.3	-.2	-.2	-.2	-.2	-.1	-.1	-.3	-.4	-.4
20.0	-2.0	-1.8	-1.4	-.7	-.4	-.3	-.2	-.1	-.1	-.1	-.1	-.1	-.1	-.1	-.2	-.2
17.5	-1.6	-1.4	-.9	-.4	.0	.1	.1	.1	.2	.2	.1	.1	.1	.1	.1	.1
15.0	-1.4	-1.0	-.4	.1	.3	.4	.5	1.0	1.8	.7	.4	.1	.1	.1	.1	.1
12.5	-1.0	-.6	-.2	.2	.7	1.0	1.4	1.2	2.0	.7	.4	.1	.1	.1	.1	.1
10.0	-.8	-.6	-.2	.2	1.0	1.8	1.6	.4	1.6	.3	.1	.1	.1	.1	.1	.1
7.5	-.7	-.6	-.4	-.2	.3	.6	.5	.4	.4	.1	-.1	-.1	-.1	.0	.0	.0
5.0	-.5	-.4	-.3	-.2	-.1	.0	.1	.2	.3	.1	-.1	-.2	-.1	-.1	.0	.0
2.5	-.3	-.3	-.2	-.2	-.2	-.1	.0	.1	.2	.1	-.2	-.2	-.2	-.1	.0	.0

TABLE 3. Transient eddy ozone flux over western North America. Positive denotes northward. Units: 10^{18} molecules $m^{-2}sec^{-1}$.

SEASON: December - February

km	65N	60	55	50	45	40	35
30.0	4.5	2.0	-.5	-.5	-.2	-.1	-.1
27.5	4.5	1.6	-.6	-.5	-.2	-.1	-.1
25.0	4.8	2.2	-.5	-.5	-.3	-.2	-.2
22.5	4.5	2.2	.0	-.3	-.3	-.2	-.3
20.0	4.0	2.2	.0	-.5	-.4	.2	-.5
17.5	3.5	2.2	-.1	-1.0	-.8	1.2	-.5
15.0	3.1	2.1	.0	-.6	.2	2.2	.7
12.5	2.3	1.8	1.0	.1	.9	4.1	.8
10.0	1.3	1.1	.2	-.8	.8	3.0	-.4
7.5	.1	-.2	-.2	-.7	-.2	.8	-.8
5.0	-.4	-.3	-.2	-.2	-.2	.0	-.1
2.5	-.1	-.1	-.1	-.1	-.1	-.1	-.1

SEASON: March - May

km	65N	60	55	50	45	40	35
30.0	-1.7	-1.0	-.2	.3	1.0	.5	-.5
27.5	-2.0	-1.1	-.5	.1	.8	1.1	-.1
25.0	-2.0	-1.4	-.8	-.3	.4	1.0	.2
22.5	-2.3	-1.8	-1.2	-.7	-.1	.4	.2
20.0	-2.8	-2.2	-1.6	-.9	-.4	.0	.0
17.5	-3.2	-2.7	-2.2	-1.5	-1.2	-1.2	-1.0
15.0	-3.2	-2.7	-2.0	-1.2	-.3	-1.0	-1.3
12.5	-1.0	-1.1	-1.3	.4	1.4	1.9	.0
10.0	4.2	2.3	-.4	-2.1	-.7	3.0	.8
7.5	1.3	.8	.3	.2	.2	.2	.2
5.0	.3	.3	.3	.4	.3	-.1	.1
2.5	.1	.1	.1	.1	.0	-.1	.0

SEASON: June - August

km	65N	60	55	50	45	40	35
30.0	.4	.3	.2	.2	.2	.1	.1
27.5	.4	.3	.2	.2	.2	.1	.1
25.0	.3	.3	.3	.2	.1	.1	.0
22.5	.3	.3	.3	.2	.1	.0	-.1
20.0	.2	.3	.3	.2	.0	-.1	.0
17.5	.2	.2	.1	-.1	-.2	-.4	.2
15.0	.3	.1	-.2	-.4	-.4	.0	2.0
12.5	.7	.2	-.2	-1.0	-.8	1.8	1.0
10.0	1.2	.7	-.2	-1.1	-1.0	.0	.0
7.5	.4	.3	.1	-.6	-1.2	-.4	-.2
5.0	.2	.2	.1	-.2	-.5	-.4	-.0
2.5	.1	.1	.1	.0	-.1	.0	.1

SEASON: September - November

km	65N	60	55	50	45	40	35
30.0	-.2	-.1	-.1	.0	.0	.1	.1
27.5	-.1	-.2	-.3	-.3	.0	.1	.2
25.0	.0	-.2	-.3	-.5	-.5	.1	.4
22.5	.0	-.1	-.2	-.3	-.3	-.2	.3
20.0	.1	.0	-.3	.0	.0	-.1	.1
17.5	.4	.0	-.7	.0	.0	.0	.2
15.0	.8	.2	-1.0	-1.0	-.2	1.2	-.2
12.5	1.8	.7	.1	-1.2	-.5	2.1	-.2
10.0	1.1	.8	.4	-.2	-.2	2.1	.2
7.5	.0	.2	.2	-.2	-.2	.5	.3
5.0	-.3	-.2	-.2	-.2	-.2	-.2	-.1
2.5	-.3	-.2	-.1	-.3	-.3	-.1	-.1

TABLE 4. Transient eddy ozone flux over western Europe. Positive denotes northward. Units: 10^{18} molecules $m^{-2}sec^{-1}$.

SEASON: December - February

km	55N	50	45	40	35
30.0	-.4	-.3	-.2	-.2	.0
27.5	-.3	-.2	-.1	.2	.5
25.0	-.1	.0	.2	.5	.4
22.5	1.0	1.0	.5	.3	.3
20.0	1.2	1.2	1.1	.7	.3
17.5	1.2	1.2	1.2	1.2	.8
15.0	1.3	1.3	1.4	1.6	1.5
12.5	1.9	2.2	3.0	2.8	2.0
10.0	.5	2.0	2.2	1.7	.9
7.5	-.2	.0	.2	.2	-.1
5.0	-.5	.0	.1	.0	-.2
2.5	-.3	.0	.1	.0	-.2

SEASON: March - May

km	55N	50	45	40	35
30.0	.4	.3	.2	.2	.2
27.5	.2	.2	.2	.2	.2
25.0	.0	.0	.0	-.1	-.1
22.5	-.4	-.4	-.4	-.3	-.2
20.0	-1.0	-1.2	-1.3	-.5	-.3
17.5	-1.2	-1.1	-.8	-.3	-.2
15.0	-.2	.2	.2	-.2	-.2
12.5	1.6	1.2	.3	-.2	-.3
10.0	1.6	1.6	.4	-.3	-.6
7.5	.8	.7	.2	-.2	-.6
5.0	.3	.3	.2	-.2	-.4
2.5	.1	.1	.1	-.1	-.2

SEASON: June - August

km	55N	50	45	40	35
30.0	.1	.1	.1	.1	.1
27.5	.2	.2	.1	.1	.1
25.0	.3	.2	.1	.1	.1
22.5	.2	.1	.1	.0	.0
20.0	.0	-.1	-.2	-.2	-.2
17.5	-.2	-.3	-.6	-.7	-.4
15.0	.1	.1	-.1	-.2	-.3
12.5	1.0	1.2	1.0	.2	.0
10.0	1.8	1.3	.8	.0	-.3
7.5	.5	.5	.1	-.3	-.4
5.0	-.1	-.1	-.1	-.3	-.3
2.5	-.1	-.1	-.1	-.2	-.2

SEASON: September - November

km	55N	50	45	40	35
30.0	.3	.3	.2	.1	.1
27.5	-.1	.1	.2	.4	.7
25.0	-.4	-.2	.2	.5	.7
22.5	-.1	.0	.2	.5	.7
20.0	.2	.2	.3	.5	.6
17.5	.4	.3	.3	.4	.5
15.0	1.0	.5	.3	.3	.3
12.5	1.2	1.0	.8	.4	.3
10.0	1.2	.9	.8	.3	.0
7.5	.5	.2	-.1	-.2	-.2
5.0	.2	.0	-.1	-.2	-.2
2.5	.1	.1	.1	.0	.0

TABLE 5. Transient eddy ozone flux over Japan. Positive denotes northward. Units: 10^{18} molecules $m^{-2}sec^{-1}$.

SEASON: December - February

km	45N	40	35	30
30.0	.0	-.2	-.4	-.4
27.5	.1	.0	-.3	-.3
25.0	.2	.0	-.2	-.3
22.5	.2	.0	-.3	-.7
20.0	.2	.0	-.5	-1.6
17.5	.6	.3	-.5	-2.0
15.0	.7	1.5	.5	-.4
12.5	-.2	.4	.7	-.5
10.0	-1.0	-.2	.4	-.7
7.5	-.5	.0	.2	-.5
5.0	-.2	.0	.2	-.2
2.5	-.2	.0	.2	-.2

SEASON: March - May

km	45N	40	35	30
30.0	.2	.2	.1	.1
27.5	.2	.2	.2	.1
25.0	.2	.2	.2	.1
22.5	.1	.1	.1	.0
20.0	.0	.0	.0	-.2
17.5	-1.4	-1.3	-.7	-.2
15.0	-3.2	-1.8	-.9	-.5
12.5	-4.0	-2.8	-2.2	-1.8
10.0	-1.0	-1.5	-2.0	-1.0
7.5	-.4	-.4	-.1	.1
5.0	-.1	-.1	.2	-.1
2.5	-.1	-.1	-.1	-.2

SEASON: June - August

km	45N	40	35	30
30.0	.1	.1	.1	.1
27.5	.1	.1	.1	.1
25.0	.2	.1	-.1	-.1
22.5	.1	.1	.0	-.1
20.0	.1	.3	.3	-.3
17.5	.3	.3	.2	-.3
15.0	1.6	1.0	.3	.0
12.5	3.6	2.2	.3	.3
10.0	1.8	.8	.2	.0
7.5	.5	.3	.0	-.1
5.0	.3	.1	-.2	-.2
2.5	.2	.1	-.3	-.3

SEASON: September - November

km	45N	40	35	30
30.0	.3	.2	.0	-.8
27.5	.3	.1	-.3	-.8
25.0	.2	-.1	-.3	-.5
22.5	.0	-.1	-.2	-.1
20.0	.3	.0	-.4	-.4
17.5	.3	.2	-.2	-.3
25.0	.3	.2	-.1	-.3
12.5	1.2	.5	-.2	-.3
10.0	3.0	1.2	-.2	-.1
7.5	.7	.3	-.2	-.1
5.0	.2	.0	-.1	-.1
2.5	.0	.0	.0	-.2

PART II

EDDY DIFFUSION COEFFICIENTS AND WIND STATISTICS, 30-60 KM

A. INTRODUCTION

The transport of trace substances in the atmosphere is effected by motion systems of widely varying space and time scales. In two-dimensional (height and latitude) atmospheric models, the transport by zonal mean meridional circulations is explicitly computed, while the transport by all other scales of motion is parameterized by eddy diffusion coefficients. Also, all models are calibrated and verified by comparing their output statistics with the observed atmospheric statistics. As models become more complex, statistics other than just the mean fields will be used for this purpose. For example, Cunnold, et al. (1975), found it useful to discuss the standard deviation of total ozone values, and future model results might be compared with other circulation statistics. The purpose of this report is to present seasonal estimates of all three components of the eddy diffusion matrix (K_{yy}, K_{yz}, K_{zz}) and of the means, variances, and covariances of wind and temperature at 30 to 60 km by latitude.

Previous efforts to estimate the individual components of the eddy diffusion matrix or the circulation statistics will be discussed as each set of results is presented. It will be noted here only that data above 30 km are limited to rocketsonde wind and temperature measurements and, recently, satellite measurements of radiance. Although the radiance data are useful for qualitative purposes, they cannot be directly interpreted as temperature measurements, and there are serious theoretical and practical problems in retrieving temperature profiles from them. Some authors (e.g., Hartman, 1977) have attempted to find temperature and wind fields from a relatively short period of radiance data, but there seems to be no widely accepted climatology of such data at this time. Thus, the rocket data are presently the only suitable base for estimating diffusion coefficients or circulation statistics above 30 km. Table 1 lists the rocket stations used in this study. Although the complete period of record used here was 1961-1976, the maximum number of years of suitable data for a given season at any station was 14 years and a typical number of years was about 11. These results are thus based on at least twice as many years of data as those of Kao, et al. (1978) (six years), Louis (1974) (four years), or Justus (1973) (six years).

Circulation statistics such as means and variances have been presented by many authors in the past. However, those results are scattered among different publications, have differing methods of data treatment and analysis, or use differing stations and periods of record. The circulation statistics presented here are the first results for both wind and temperature based on the same period of record and analyzed with the same technique for all results.

All rocketsonde data were obtained from WDC-A, Asheville, except for the stations near 70E during 1972-1976. The latter data were extracted from tabulations of rocket soundings along the Eastern Meridian Network obtained from NASA Wallops Space Flight Center. Throughout this report, three month seasons will be used with winter defined as December, January, and February.

B. DIFFUSION COEFFICIENTS

1. K_{yy}

a. Method

From G. I. Taylor's theorem, the diffusion coefficient is equal to the product of the wind variance and the integral time scale. Murgatroyd (1969) used this theorem to obtain the meridional diffusion coefficient K_{yy} by modeling the autocorrelation function as an exponentially damped cosine function of the time lag τ. The model is given by

$$R(\tau) = e^{-\nu\tau} \cos \omega\tau, \qquad (1)$$

with the parameters ν and ω obtained from wind trajectory data. The method of this report uses Murgatroyd's model with the parameters obtained by a least-squares fit to the calculated autocorrelation function for the meridional wind.

For each station and for each two kilometers from 30 km to 60 km, the sequence of daily wind values was high-pass filtered to remove seasonal trends and other very long-period variations associated with scales of motion not of interest. A 61 point Gaussian filter with a 50% response point at 28 days was used. The wind data are intermittent, and therefore to obtain an effective filter at least five points were required to be under the filter and the sum of filter weights was required to be at least .15. The filtered wind values were then divided into individual seasons for which the autocorrelation function was calculated out to a lag of 21 days. For larger lags, noise and insufficient data render meaningless the calculation of an autocorrelation function.

From the derived parameters, the Eulerian integral time scales were obtained and transformed to Lagrangian values by multiplying by .64, the value given by Murgatroyd for a height of 30 mb. The resulting integral time scales were multiplied by the meridional wind variances to give the meridional diffusion coefficients for each individual season. Finally, for each station and height, the values were averaged over all years to produce mean seasonal diffusion coefficients, K_{yy}. A standard error of estimate was calculated for each K_{yy}.

Because of the essential non-linearity of the model and the poor time distribution of some of the data, the least-squares routine failed to find parameter values for some of the individual seasons. This problem was very severe for stations along the Eastern Meridian Network. For these stations, observations are often taken only once a week making the calculation of an autocorrelation coefficient impossible. Only at Heiss Island during winter was the data sufficient to calculate K_{yy} values.

b. Errors

An estimate of the relative error in K_{yy} is given by the ratio of the standard error of K_{yy} to its mean value. This ratio varied considerably with station, season, and height, e.g., at Thule in winter from .5 at 30 km to 4.8 at 60 km, and at White Sands in winter from .4 at 30 km to .5 at 60 km. In summer, the corresponding ratios were .8 and 2.8 for Thule, and .4 and .5 for White Sands. In general, the relative error in K_{yy} was about 50% at low and middle latitudes and about 100% at high latitudes.

c. Results

An example of an autocorrelation function is given in Figure 1. The exponential damping is clearly present. However, a number of autocorrelation functions show an increase for lags of 10 to 15 days before damping toward zero, so in all cases the fitting was done only to lag 10.

The K_{yy} values are given in Figure 2 and Table 2 for cross sections along 80W, 150W, and the average of the two meridians. Stations along 150W are more limited in latitudinal distribution than those stations along 80W. As a result, the mean cross section at very high and low latitudes is not an average but a repetition of the 80W K_{yy} values for those latitudes. Figure 3 compares the winter K_{yy} profile for Thule with that for Heiss Island. Though K_{yy} values at Heiss Island are larger than those at Thule, the similarity of the profiles is obvious.

In winter, K_{yy} values increase with latitude and generally with height (Figure 2). Largest values of K_{yy} are found above 50 km along both 80W and 150W. Along 80W, a secondary maximum is located at about 35 km and 65N. A ridge of large values projects from high to middle latitudes with its axis between 50 and 52.5 km. During spring, K_{yy} again generally increases with height and latitude. However, along 80W, a region of large values occurs over the equator at 60 km. K_{yy} decreases in middle latitudes but increases again at high latitudes. The pattern of values tends to be more horizontal in summer. Along 80W, a wave-like pattern is present in the values with ridges around 15N and 45N. These ridges extend from 30 km to 60 km. However, they are not present in the 150W cross section. The autumn K_{yy} pattern is similar to the spring pattern. Higher values of K_{yy} occur at high latitudes and above 50 km, while a secondary maximum is present at 60 km over the equator.

d. Discussion

Previous work on diffusion coefficients by Murgatroyd (1969) and others is nearly all limited to levels below 30 km and is not comparable to results in this report. However, Kao, et al., (1978) and Louis (1974) computed diffusion coefficients for a comparable region of the atmosphere. Though Kao, et al., did remove means and linear trends from the winds, neither they nor Louis removed seasonal and other long-period wind variations such as were removed by our high-pass filter. The emphasis in this study on the smaller scale diffusion process may account for much of the difference between present results and early work. Furthermore, because the wind variance in Kao, et al., is similar to our values, differences in K_{yy} between the results of Kao, et al., and this report may be due to differences in the integral time scales.

In winter, the K_{yy} values of Kao, et al., agree well with our values at low latitudes, but they are larger at high latitudes. Their maximum occurs at 45N near 30 km where it exceeds our value by about an order of magnitude. They do not show the maximum near 60 km where our values are larger by a factor of 4. On the other hand, Louis finds the maximum K_{yy} at high latitudes near 50 km and low values near 30 km at all latitudes which agrees well with our results. In spring, our K_{yy} pattern and that of Kao, et al., agree at low latitudes and heights. The values of Louis are much smaller and his results do not show a maximum at high latitudes. The summer wave-like pattern in K_{yy} values is present in both our results and those of Kao, et al. However, our values near 55 km are about one-half of those of Kao. Louis does not show the wave-like pattern and his summer values are smaller by a factor of 3. The autumn pattern of K_{yy} differs the most among the three results. We find maxima near 60 km at high latitudes and over the equator. Kao, et al., find no maxima in these regions but rather near 60N at 30-35 km. Louis' pattern consists of a horizontal band of large values stretching from the equator to the pole at 50 km. His K_{yy} values are smaller than our results by a factor of 5.

2. K_{yz}

a. Method

The method employed to calculate K_{yz} is based on that of Reed and German (1965). The diffusion coefficient K_{yz} is set proportional to the meridional diffusion coefficient K_{yy}, and the proportionality factor, α, is the slope of the mixing path. In the middle troposphere, α is about one-half of the slope, β, of the isentropic surfaces. Wilcox (1976) computed the seasonal values of α and β for tropospheric levels using heat flux data. Because the relationship between α and β is not known for stratospheric levels, the method of this report uses the ratio of α to β as computed by Wilcox for the approximately 26 km level at all levels.

The vertical and northward gradients of the isentropic surfaces were computed on a seasonal basis for each longitude. From these results, the ratio of the horizontal to the vertical potential temperature gradient was computed for each station, level, and season. The negative of this ratio was set equal to β, which was then multiplied by the ratio of α/β, given by Wilcox, to give α. The resulting α values were multiplied by the corresponding K_{yy} values to give K_{yz}.

b. Errors

Because K_{yz} depends directly upon K_{yy}, errors in K_{yy} generate errors in K_{yz}. In addition, the ratio of α/β given by Wilcox was derived for conditions at about 26 km, but the ratio is used for all heights from 30 km to 60 km. Therefore, considerable uncertainty, especially with regard to the sign of K_{yz}, is introduced at high altitudes. As a result, the error in K_{yz} is at least as great as the error in K_{yy}, and could be larger.

c. Results

The values of K_{yz} for 80W, 150W, and mean cross sections are given in Figure 4 and Table 3. As a reminder, the 150W cross section is limited in latitude and the mean cross section at high and low latitudes is not an average but a repetition of the 80W cross section. Also, no K_{yz} are available for the Eastern Meridian Network because the data there were inadequate.

The K_{yz} pattern for winter shows the largest positive values at 55 km and 40N with the largest negative values below and slightly poleward. This pattern of large positive values over large negative values is present at both 80W and 150W. In addition, there are a number of vertical bands of K_{yz} alternating in sign which are located at lower latitudes. These vertical bands are probably due to the use of a constant α/β ratio at all heights. The largest values of K_{yz} in these bands tend to be located near 60 km.

For the spring pattern, a large negative center is located near 60 km at 60N. This negative center projects downward and toward middle latitudes. In the lower latitudes, the alternating vertical bands of K_{yz} are again present on the 80W and mean cross sections. For the 150W cross section, negative values dominate the middle and low latitudes. In summer, the pattern is simplified as poleward of 40N there are negative values at all heights, while equatorward the values are positive, except for a band of negative K_{yz} values at 20N. The K_{yz}

pattern in autumn shows large positive values above 50 km at high latitudes and between 5N and 10N. Negative values are located at low levels in middle latitudes, at all heights south of the equator and above 45 km at 20N.

d. Discussion

Previous estimates of K_{yz} above 30 km have been given by Louis, but extended to only 50 km. In winter, there is good agreement at high latitudes between our results and those of Louis. At middle and low latitudes, Louis found a larger area of weak positive values of K_{yz}, while our results produce a more detailed K_{yz} structure with a large negative center at 50N and 50 km and negative regions scattered throughout the tropics.

In spring, there is good agreement between our results and those of Louis, except near 20N where we have a large negative area from 30 km to 60 km and Louis has weak positive values. At high and middle latitudes, we have a band of positive values extending from 45 km at 75N to 30 km at 50N, while Louis has weak negative values throughout the region. The summer patterns are very similar except at 20N where we have negative K_{yz} values compared to Louis' positive values. Our autumn pattern is very dissimilar to that of Louis. We find large positive values above 50 km at high latitudes and sharply alternating regions above 45 km at low latitudes. In contrast, Louis has weak and uniform negative values at high latitudes and weak negative values at low latitudes.

General features for all seasons are the negative values at high latitudes and a region of large K_{yz} values of contrasting sign from 15-20N at heights above 50 km. If the sign changes of K_{yz} are real in this second region, these changes would indicate that significant eddy diffusion is occurring in this subtropical area.

3. Vertical Eddy Diffusion Coefficients (K_{zz})

In the stratosphere, the vertical dispersion of material proceeds much slower than does the horizontal dispersion, and this will be reflected in the relative smallness of the K_{zz} values presented below compared with the K_{yy} or K_{yz} values. Due to the high static stability of the stratosphere, convective overturning is suppressed and mechanical turbulence is confined to regions of very high wind shear. The shears associated with planetary scale waves or the mean circulation are not large enough to produce local instabilities. However, the relatively short vertical wavelengths of gravity waves can lead to unstable shears when the amplitude of the wave is sufficiently great. Hines (1970, 1974) has argued that the normal growth of wave amplitude with height arising from decreasing density will be offset by energy lost to turbulence, so the wave amplitude is constant with altitude. Based on this premise, Hines has developed a formalism to compute vertical diffusion coefficients.

According to Hines (1970), the vertical eddy diffusion coefficient is given by

$$K_D = 0.014\,\tau_g^{-1} H^{-1} \lambda_x^{4} \lambda_z^{4} (\lambda_x^{2} + \lambda_z^{2})^{-5/2} \tag{2}$$

where τ_g is the Brunt-Vaisala period, H is the atmospheric density scale height, and λ_x and λ_z are the horizontal and vertical wavelengths of upward propograting gravity waves. In the case $\lambda_z \ll \lambda_x$ then equation (2) can be simplified (Justus, 1973) as

$$K_D = 0.014\lambda_z^{4} (\tau_g H \lambda_x)^{-1} \tag{3}$$

Zimmerman (1974) has argued that no amplitude growth is a poor approximation in the lower atmosphere. By balancing the vertical gradient of the specific wave energy with an effective turbulent viscosity he derived an alternate expression for the vertical component of K, which will be called K_{zz} here:

$$K_{zz} = (\lambda_z^{3}/4\pi^{2}T)\,\{1/H - 1/Z \ln V^{2}/V_o^{2}\} \tag{4}$$

where T is the period of the gravity wave, V_o is the perturbation velocity at the reference level, and V is that at level Z.

If the kinetic energy of the gravity wave is decreasing according to

$$E = E_o \exp(-Z/h) \tag{5}$$

then it can easily be shown that (4) is a modification to (3) as follows:

$$K_{zz} = (H/h)K_D \tag{6}$$

aside from the constant numerical factor. But Hines (1970) states that his numerical factor (0.014) was designed to give a predetermined result. Thus, the difference between 0.014 and the numerical factor in (4) ($1/4\pi^2 = 0.025$) is probably not important. In deriving (6) from (4), use is made of equation (34) of Hines (1974, paper 7), and the relations $E = 1/2\ \rho U^2$ and $\rho = \rho_o \exp(-Z/H)$.

In the case of no amplitude growth with height, then (6) shows that $K_{zz} = K_D$ because then H = h. In general, however, $K_{zz} < K_D$ because there is some aplitude growth with height. This is illustrated in Figure 5, where the growth of V^2 below 50 km causes the kinetic energy to fall off less rapidly than density ($H<h$), while above 50 km there is no amplitude growth so H = h.

Estimates of K_{zz} given below were made using (4) after applying equation (34) of Hines (1974, paper 7). All available temperature and density data at each station were used to estimate τ_g and H for each season at 5 km height intervals. Estimates of λ_z were made using the daily difference method described below. The ratios of λ_x to λ_z from the data given by Justus (1973) were used at all stations (Table 1) because the present data did not permit new estimates of λ_x. The error introduced by using constant values of λ_x/λ_z should be very small, however, as K_{zz} varies with the fourth power of λ_z but only inversely with λ_x.

In the daily difference method, zonal and meridional wind data for soundings separated by 24 hours (± 15 minutes) in time are differenced on a level-by-level basis to resolve the gravity wave component of the data. As detailed in Justus and Woodrum (1972), this approach eliminates the seasonal, synoptic period, and tidal components of the winds. The vertical structure function, D(Z), of the differenced values was made for each sounding pair through 12 km intervals in height, centered 5 km apart, from 26 to 61 km. In each layer, a sounding pair was used only if all levels were present in the layer. The number of profiles (sounding pairs) available at 36-48 km is given in Table 1. Ideally, D(Z) should resemble a cycloid with wavelength λ_z. In practice, small-scale noise and a mixing of wavelengths combine to permit detection of only the average first maximum in D(Z), as illustrated in Figure 5. The half-wavelength was estimated from D(Z) by the location of the minimum of the second derivative with height.

Values of K_{zz} for the stations along 80W, along about 150W, and for their mean are given in Figure 6 and Table 4. In general, K_{zz} increases steadily from 30 km to the upper stratosphere, and usually increases very rapidly in the lower mesosphere, (note that the contours in Figure 6 are at non-uniform intervals). Although there are differences between the 80W and 150W sections, some persistent features emerge in the mean sections. For example, the trough of relatively small values with latitude near 25N in the upper stratosphere during winter is found near 60N in spring, 40N in summer, and 40N in autumn. In the mean sections, largest values are found in the tropical mesosphere during all seasons, and exceed 200 m^2s^{-1} during winter and summer.

Statistical errors of K_{zz} range from 15 to 55%, and average about 30% of the value of K_{zz}. Errors were estimated by a Monte Carlo simulation of D(Z), randomly allowing each point along D(Z) to be anywhere within one standard error of the mean value of D(Z). For each simulation a λ_z was computed, and the standard error of the mean of the sample of λ_z's was used in the differential form of equation (4) to estimate the error in K_{zz}.

At 55 km the present results are about three-fourths as large as the seasonal-latitudinal average value given by Justus (1973). His data are from all seasons and apparently represent the average of Ascension Island, Cape Kennedy, and Fort Greely for the period 1964-1969 (Justus and Woodrum, 1972). At 35 km the seasonal-latitudinal average of the present results is about 4 m^2sec^{-1} while Justus gives about 20 m^2sec^{-1}. The present results are smaller than those of Justus because the adjustment factor presented in equation 6 is less than one at all levels on the average, and is smaller at 35 than at 55 km.

A new feature of the present results is the very rapid increase of K_{zz} above the stratopause. Past workers have suggested a sudden decrease of K_{zz} at the tropopause followed by a steady increase up to the mesopause. It now appears that there is a sudden increase at the stratopause.

C. CIRCULATION STATISTICS

All mean values presented here were computed by arithmetically averaging all available observations for a given season and level at each station. Variances and covariances were computed using data high-pass filtered with the filter described in Section B.

1. Seasonal Means and Variances

a. Temperature

Temperature data for all stations listed in Table 1 were used to prepare the results presented in Figures 7-8 and Tables 5-6. Data at stations near 60E were ignored above 50 km because they are not compatible with other data at high altitudes (Finger, et al., 1975). Corrections for solar radiation errors were applied to observations flagged as not already corrected, as described in Nastrom and Belmont (1974).

During all seasons, the mean stratopause slopes upward toward the pole (Figure 7), but has mean temperatures above 270K at all latitudes only during spring. Variance of temperature (Figure 8) is largest during winter near 60N. During spring, largest variances are found at highest latitudes below 45 km, while during autumn the maximum variance is near 60 km at 60N. Largest variance during summer occurs in the lower mesosphere near 30N.

b. Zonal wind speed

The winter jet in mean zonal wind speed (Figure 9 and Table 7) is found above 55 km near 40N, in agreement with past results (Belmont, et al., 1975; Taresenko, et al., 1976). Other features of the mean zonal flow are also well-known and serve to verify past results. One interesting feature which cannot be shown in seasonal mean sections is the quasi-biennial oscillation (QBO), which is largest below about 30 km equatorward of about 20° latitude (Belmont, et al., 1975). Due to the QBO, mean values in the tropical mid-stratosphere depend strongly on the period of record chosen for averaging. Finally, it should be noted that no attempt has been made to reconcile the mean zonal winds and the mean temperatures via the thermal wind relation. The available stations (Table 1) do not permit making true zonal means, and even along given longitudes the stations do not lie along a straight north-south line and only approximate a meridional section. Also, stations don't all take their observations at the same time. Station distribution, observational incongruities, and other sampling problems can lead to model dynamic instability, such as found by Schoeberl and Zalesak (1976) for the CIRA (1972) zonal wind model despite the care taken to make it obey the thermal wind relation.

The variances of zonal wind speed (Figure 10 and Table 8) generally follow the same pattern as the variances of temperature. It should be noted that the present results represent wind variability due only to high frequency variations and do not include interannual or other long-period changes.

c. Meridional wind speed along 80W

The seasonal mean values of meridional wind speed given in Figure 11 and Table 9 verify the patterns previously published for mid-seasonal months (Nastrom, et al., 1975). As stressed in the latter paper, the mean meridional winds at a given location are largely due to standing planetary waves. Thus, the mean value is a strong function of longitude so that a dense network of stations would be required to resolve the zonal mean value.

The variances of meridional wind speed, which were used in Section B for estimating K_{yy}, are given in Figure 12 and Table 10. Largest variances are found near the polar stratopause during all seasons except summer, when the largest values are in the tropical mesosphere. These results should not be compared with previous values (e.g., Newell, et al., 1966) which failed to remove the interannual component of the variance. As shown in Nastrom, et al. (1975, Table 2), the variance due to interannual variations is about the same magnitude as the high-frequency component presented here.

2. Seasonal Covariances

The covariances of the (high-pass filtered) meridional wind with zonal wind and temperature are presented in Figure 13 and 14 and Tables 11 and 12.

These represent the poleward fluxes of westerly momentum and temperature (sensible heat) by the transient eddies. In preparing these results, data for all stations were plotted, but stations nearest 80W were favored during the analysis if longitudinal differences were found. For example, during winter at 40 km the covariance of wind and temperature at Heiss is large positive while at Thule it is large negative, and so the final analysis shows negative values. Also, these results do not represent the fluxes by standing waves. Although there have been efforts (e.g., Stanford and Dunkerton, 1978) to estimate winds and temperatures from satellite data on a global basis, a useful climatology of such data is not yet available to compute standing eddy fluxes. Thus, there is no way to measure the relative importance of transient and standing eddy fluxes.

D. SUMMARY

In view of the differing analysis techniques or differing data samples, the eddy diffusivities presented here agree remarkably well with past estimates. However, in the application of K-values to two-dimensional models the actual magnitude of the diffusivities is no more important than their spatial patterns, i.e., their gradients with height and latitude. As the present patterns are often much different from those of past results (and from each other, depending on longitude), these diffusivities are expected to influence future model results.

The circulation statistics presented here confirm and expand on the numerous past results given, usually, for each parameter separately or for a relatively short period of record. It seems that these covariances of meridional wind with temperature and zonal wind are the first complete set of such results to be presented.

REFERENCES

Belmont, A. D., D. G. Dartt, and G. D. Nastrom, 1975: Variations of stratospheric zonal winds, 20-65 km, 1961-1971. J. Appl. Meteor., 14, 585-594.

Cunnold, D., F. Alyea, N. Phillips, and R. Prinn, 1975: A three-dimensional dynamical-chemical model of atmospheric ozone. J. Atmos. Sci., 32, 170-194.

Finger, F. G., M. E. Gelman, F. J. Schmidlin, R. Leviton, and B. Kennedy, 1975: Compatibility of meteorological rocketsonde data as indicated by international comparison tests. J. Atmos. Sci., 32, 1710-1714.

Hartman, D. L., 1977: Stationary planetary waves in the Southern Hemisphere. J. Geophys. Res., 82, 4930-4934.

Hines, C. O., 1970: Eddy diffusion coefficients due to instabilities in internal gravity waves. J. Geophys. Res., 75, 3937-3939.

Hines, C. O., 1974: The Upper Atmosphere in Motion, American Geophysical Union, Washington, Paper 12.

Justus, C. G., and A. Woodrum, 1972: Atmospheric pressure, density, temperature and wind variations between 50 and 200 km. NASA-CR-2062, 77pp.

Justus, C. G., 1973: Upper atmospheric mixing by gravity waves. Presented at Conference on Environmental Impact of Aerospace Operations in the High Atmosphere, June, 1973, Denver.

Kao, S. K., R. J. Okrasinski, and N. J. Lordi, 1978: Horizontal eddy diffusivities in the Northern Hemispheric stratosphere and lower mesosphere. NASA-CR-3006, 75pp.

Louis, J., 1974: A two-dimensional transport model of the atmosphere. Ph.D. Thesis, University of Colorado, 150pp.

Murgatroyd, R. J., 1969: Estimations from geostrophic trajectories of horizontal diffusivity in the mid-latitude troposphere and lower stratosphere. Quart. J. Roy. Met. Soc., 95, 40-62.

Nastrom, G. D., and A. D. Belmont, 1975: Periodic variations in stratospheric-mesospheric temperature from 20-60 km at 80°N to 30°S. J. Atmos. Sci., 32, 1715-1722.

Nastrom, G. D., A. D. Belmont, and D. G. Dartt, 1975: Periodic variations in stratospheric meridional wind from 20 to 65 km: 80°N to 70°S. Quart. J. Roy. Met. Soc., 101, 583-596.

Newell, R. E., J. M. Wallace, and J. R. Mahoney, 1966: The general circulation of the atmosphere and its effect on the movement of trace substances, Part 2. Tellus, 18, 363-380.

Reed, R. J., and K. E. German, 1965: A contribution to the problem of stratospheric diffusion by large-scale mixing. Mon. Wea. Rev., 93, 313-321.

Schoeberl, M. R., and S. T. Zalesak, 1976: A critical analysis of climatological wind data used in the forecast of radioactive debris cloud movement. NRL-Memo-Rpt 3366, 13pp.

Stanford, J. L., and T. J. Dunkerton, 1978: The character of ultra-long stratospheric temperature waves during the 1973 austral winter. Beitr. Phys. Atmos., 51, 174-188.

Tarasenko, D. A., I. A. Scherba, and R. A. Britvina, 1976: Periodic temperature and wind fluctuations in the stratosphere and mesosphere. Metro. Gidro., 25-30.

Wilcox, R. W., 1976: Ten-year set of K_{yy} and K_{yz}. Letter report to NASA-Ames Research Center; Control Data Corporation, Minneapolis.

Zimmerman, S. P., 1974: The effective vertical turbulent viscosity as measured from radio meteor trails. J. Geophys Res., 79, 1095-1098.

TABLE 1. Rocketsonde data used, 1961-1976 (at 50 km).

			Number of data pairs at lag zero (for K_{yy} & K_{yz})				Number of sounding pairs (for K_{zz})			
Station	LAT	LON	SPR	SUM	AUT	WIN	SPR	SUM	AUT	WIN
a. Stations near 80°W (Atlantic zone)										
Thule	77	69	137	188	122	61	21	30	25	17
Churchill	59	94	316	235	229	357	43	17	74	113
Wallops	38	75	399	460	277	301	27	29	40	33
White Sands	32	106	748	672	574	598	97	72	91	118
Canaveral	28	81	518	623	478	438	141	102	93	160
Antigua	17	62	183	92	124	160	2	3	2	5
Sherman	8	80	276	271	201	207	51	37	25	36
Ascension	-8	14	437	438	477	283	72	51	35	57
b. Stations near 150°W (Pacific zone)										
Poker Flats	64	146	147	202	158	144	72	78	54	59
Primrose	55	110	172	58	194	94	6	4	8	10
Point Mugu	34	119	593	542	548	557	61	52	62	59
Barking Sands	22	160	557	445	441	355	141	131	112	102
Kwajalein	9	-168	161	175	150	230	5	6	6	7
c. Stations near 60°E										
Heiss Island	81	-58	7	23	0	58	6	11	1	9
Volgograd	49	-44	6	0	8	11	3	1	0	1
Thumba	8	-77	20	0	0	0	0	0	0	0

TABLE 2. Seasonal values of K_{yy} (10^4 $m^2 sec^{-1}$).

SEASON:WINTER HORIZONTAL DIFFUSION COEFFICIENTS (K-YY) IN 10^4 METERS SQUARED PER SECOND

```
LATITUDE        75    70    65    60    55    50    45    40    35    30    25    20    15    10     5     0    -5

LONGITUDE: 80W

  60.0 KM      884   741   592   430   259   119   121   123   258   168   120   127   114   103   100   105   115
  57.5         759   681   592   480   344   219   183   183   269   166   116   117    97   106   116   117   112
  55.0         634   622   593   531   429   320   244   243   281   163   113   108    81   109   131   129   110
  52.5         500   515   514   480   405   316   248   236   253   141    90    91    83    93   101    98    89
  50.0         365   409   436   430   381   312   252   229   224   120    68    75    86    78    70    68    68
  47.5         312   360   391   388   344   278   222   205   210   119    57    49    63    61    56    54    54
  45.0         258   310   346   347   306   244   192   181   195   118    46    23    41    44    41    40    41
  42.5         360   399   420   407   350   271   198   160   156   109    62    37    35    36    36    35    33
  40.0         462   487   494   467   395   297   203   138   117   101    78    50    29    28    30    29    25
  37.5         415   475   509   493   412   295   180   107    92    77    53    35    32    29    26    23    20
  35.0         367   462   524   520   430   293   157    75    66    54    29    19    35    30    22    17    15
  32.5         258   346   408   415   352   247   138    65    48    45    31    21    28    20    13    10    10
  30.0         149   230   291   310   273   201   119    55    30    37    33    24    20    10     4     2     5

LONGITUDE: 150W

  60.0 KM                  541   461   386   322   267   223   188   162   145   135   133   135
  57.5                     533   494   447   386   319   255   204   174   159   153   149   146
  55.0                     524   527   507   450   370   286   219   185   174   171   165   156
  52.5                     513   546   547   494   403   300   213   161   139   136   141   149
  50.0                     502   566   588   538   436   315   206   137   104   101   116   143
  47.5                     516   504   475   416   337   254   183   135   108    96    95    99
  45.0                     531   443   362   294   239   194   159   133   111    92    74    56
  42.5                     519   409   311   237   184   147   122   104    90    77    61    44
  40.0                     507   374   260   179   128    99    84    76    70    62    49    33
  37.5                     429   313   214   144   101    77    64    57    52    46    38    28
  35.0                     352   252   167   109    74    55    45    39    34    30    27    23
  32.5                     270   183   111    66    44    36    34    31    27    24    21    20
  30.0                     188   113    54    22    13    17    22    23    20    17    16    17

LONGITUDE: MEAN

  60.0 KM      884   741   566   445   327   220   194   173   223   165   132   131   123   119   100   105   115
  57.5         759   681   562   487   395   302   251   219   236   170   137   135   123   126   116   117   112
  55.0         634   622   558   529   468   385   307   264   250   174   143   139   123   132   131   129   110
  52.5         500   515   513   513   476   405   325   268   233   151   114   113   112   121   101    98    89
  50.0         365   409   469   498   484   425   344   272   215   128    86    88   101   110    70    68    68
  47.5         312   360   453   446   409   347   279   229   196   127    82    72    79    80    56    54    54
  45.0         258   310   438   395   334   269   215   187   177   125    78    57    57    50    41    40    41
  42.5         360   399   469   408   330   254   191   153   139   106    76    57    48    40    36    35    33
  40.0         462   487   500   420   327   238   165   118   100    88    74    56    39    30    30    29    25
  37.5         415   475   469   403   313   219   140    92    78    67    52    40    35    28    26    23    20
  35.0         367   462   438   386   298   201   115    65    55    46    31    24    31    26    22    17    15
  32.5         258   346   339   299   231   156    91    50    41    38    29    22    24    20    13    10    10
  30.0         149   230   239   211   163   111    66    36    26    30    26    20    18    13     4     2     5
```

TABLE 2. Seasonal values of K_{yy} (10^4 $m^2 sec^{-1}$).

SEASON:SPRING HORIZONTAL DIFFUSION COEFFICIENTS (K-YY) IN 10^4 METERS SQUARED PER SECOND

LONGITUDE: 80W

LATITUDE	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0	-5
60.0 KM	270	223	175	125	74	36	27	63	113	54	53	89	107	151	174	167	140
57.5	296	231	168	113	69	42	38	65	97	52	40	66	95	112	115	106	91
55.0	322	238	162	102	64	47	49	66	81	50	27	42	83	73	56	46	42
52.5	235	199	163	128	96	69	55	58	70	49	38	45	59	58	52	46	41
50.0	148	160	164	155	127	91	61	51	59	49	49	48	35	42	48	47	41
47.5	131	135	134	124	101	74	53	48	57	50	52	51	35	37	41	40	36
45.0	113	110	104	93	76	58	45	46	55	50	55	54	34	31	33	33	31
42.5	109	103	96	84	67	50	39	38	46	46	52	49	27	24	26	26	25
40.0	104	96	87	75	59	43	32	30	36	41	48	43	20	17	19	20	20
37.5	100	95	87	76	61	44	31	26	30	32	32	28	19	20	22	21	19
35.0	96	93	87	77	62	44	30	22	23	24	16	12	18	24	25	23	19
32.5	72	81	86	82	67	46	27	18	19	18	15	13	13	18	20	19	16
30.0	48	70	85	87	72	48	25	13	15	12	13	14	8	12	15	15	12

LONGITUDE: 150W

LATITUDE	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0	-5
60.0 KM			243	194	158	143	143	147	144	127	105	91	93	104			
57.5			190	169	150	136	125	115	106	95	85	77	74	74			
55.0			137	144	143	129	107	84	67	63	64	64	56	44			
52.5			126	113	99	86	73	63	58	57	58	58	53	46			
50.0			115	82	56	42	39	43	48	51	52	52	50	48			
47.5			130	93	64	49	45	47	51	51	48	45	42	39			
45.0			144	104	72	56	51	52	53	50	44	37	33	30			
42.5			116	86	62	48	42	41	42	42	40	36	31	26			
40.0			89	69	52	40	33	31	31	34	36	35	30	22			
37.5			72	58	46	37	31	28	26	27	27	27	23	17			
35.0			55	48	41	35	29	24	21	20	19	18	16	13			
32.5			55	46	39	31	25	20	17	15	15	14	13	11			
30.0			54	45	36	28	21	16	13	11	11	10	10	9			

LONGITUDE: MEAN

LATITUDE	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0	-5
60.0 KM	270	223	209	159	116	89	85	105	128	90	79	90	100	127	174	167	140
57.5	296	231	179	141	109	89	81	90	101	73	62	71	84	93	115	106	91
55.0	322	238	149	123	103	88	78	75	74	56	45	53	69	58	56	46	42
52.5	235	199	144	120	97	77	64	60	64	53	48	51	56	52	52	46	41
50.0	148	160	139	118	91	66	50	47	53	50	50	50	42	45	48	47	41
47.5	131	135	132	108	82	61	49	47	54	50	50	48	38	38	41	40	36
45.0	113	110	124	98	74	57	48	49	54	50	49	45	33	30	33	33	31
42.5	109	103	106	85	64	49	40	39	44	44	46	42	29	25	26	26	25
40.0	104	96	88	72	55	41	32	30	33	37	42	39	25	19	19	20	20
37.5	100	95	79	67	53	40	31	27	28	29	29	27	21	18	22	21	19
35.0	96	93	71	62	51	39	29	23	22	22	17	15	17	18	25	23	19
32.5	72	81	70	64	53	38	26	19	18	16	15	13	13	14	20	19	16
30.0	48	70	69	66	54	38	23	14	14	11	12	12	9	10	15	15	12

TABLE 2. Seasonal values of K_{yy} (10^4 $m^2 sec^{-1}$).

SEASON:SUMMER HORIZONTAL DIFFUSION COEFFICIENTS (K-YY) IN 10^4 METERS SQUARED PER SECOND

LATITUDE	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0	-5
LONGITUDE: 80W																	
60.0 KM	193	137	91	64	61	75	94	105	103	106	120	129	140	210	246	232	185
57.5	118	93	72	57	51	54	65	83	99	93	93	91	91	138	165	160	133
55.0	43	49	53	50	40	32	35	60	95	80	65	54	43	67	85	88	81
52.5	35	40	43	42	36	30	32	47	70	62	51	44	45	64	76	77	70
50.0	26	30	33	33	31	28	28	35	45	44	36	35	47	62	68	66	59
47.5	22	24	26	26	23	20	20	25	36	42	37	32	38	48	53	54	52
45.0	18	19	19	18	15	12	12	16	27	40	38	30	28	33	39	42	44
42.5	15	16	16	14	10	7	7	13	25	31	31	27	22	27	33	37	39
40.0	12	13	12	10	5	1	2	10	23	23	24	24	16	21	28	32	34
37.5	12	13	12	10	6	1	1	8	19	18	19	18	14	20	26	28	28
35.0	12	13	12	10	6	2	0	5	14	14	13	13	12	19	23	24	21
32.5	11	10	10	8	5	2	1	4	11	11	12	12	10	17	22	22	20
30.0	9	8	7	5	3	1	1	3	8	9	12	11	7	14	20	21	18
LONGITUDE: 150W																	
60.0 KM			67	59	57	66	81	94	97	87	72	61	65	77			
57.5			59	62	67	73	79	83	81	73	63	57	58	65			
55.0			50	66	77	80	78	72	65	59	54	52	52	53			
52.5			40	50	58	60	58	54	49	46	44	43	42	42			
50.0			29	35	39	40	39	36	34	34	34	34	32	30			
47.5			23	27	29	30	30	29	29	31	33	35	36	36			
45.0			17	18	19	20	21	22	25	28	32	36	39	42			
42.5			13	15	17	18	19	19	20	22	24	26	27	28			
40.0			8	12	15	16	16	16	15	16	17	17	16	14			
37.5			7	11	14	15	14	13	12	12	12	12	12	12			
35.0			6	10	12	13	12	10	8	7	7	8	9	10			
32.5			5	7	8	8	8	8	7	6	6	6	7	8			
30.0			5	4	3	3	4	5	6	6	5	5	5	5			
LONGITUDE: MEAN																	
60.0 KM	193	137	79	61	59	70	87	99	100	96	96	95	102	143	246	232	185
57.5	118	93	65	59	59	63	72	83	90	83	78	74	74	101	165	160	133
55.0	43	49	51	58	58	56	56	66	80	69	59	53	47	60	85	88	81
52.5	35	40	41	46	47	45	45	50	59	54	47	43	43	53	76	77	70
50.0	26	30	31	34	35	34	33	35	39	39	35	34	39	46	68	66	59
47.5	22	24	24	26	26	25	25	27	32	36	35	33	37	42	53	54	52
45.0	18	19	18	18	17	16	16	19	26	34	35	33	33	37	39	42	44
42.5	15	16	14	14	13	12	13	16	22	26	27	26	24	27	33	37	39
40.0	12	13	10	11	10	8	9	13	19	19	20	20	16	17	28	32	34
37.5	12	13	9	10	10	8	7	10	15	15	15	15	13	16	26	28	28
35.0	12	13	9	10	9	7	6	7	11	10	10	10	10	14	23	24	21
32.5	11	10	7	7	6	5	4	6	9	8	9	9	8	12	22	22	20
30.0	9	8	6	4	3	2	2	4	7	7	8	8	6	9	20	21	18

THIS PAGE IS BEST QUALITY PRACTICABLE
FROM COPY FURNISHED TO DDC

TABLE 2. Seasonal values of K_{yy} (10^4 $m^2 sec^{-1}$).

SEASON:AUTUMN HORIZONTAL DIFFUSION COEFFICIENTS (K-YY) IN 10^4 METERS SQUARED PER SECOND

LATITUDE	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0	-5
LONGITUDE: 80W																	
60.0 KM	792	628	472	333	221	145	116	144	199	160	144	127	111	269	359	332	229
57.5	635	528	423	323	231	161	126	139	177	137	125	125	115	186	222	202	144
55.0	479	428	374	312	242	177	135	133	154	113	106	123	119	103	86	71	58
52.5	393	374	344	290	210	130	84	104	166	109	86	96	88	68	54	46	44
50.0	307	320	313	269	179	83	32	76	177	104	65	69	57	33	21	21	30
47.5	300	293	275	238	176	111	71	83	131	94	62	51	44	32	25	25	29
45.0	292	265	238	207	173	140	111	91	84	83	59	33	30	30	29	28	28
42.5	258	252	239	215	175	130	91	71	74	74	55	34	27	26	25	25	25
40.0	224	236	241	222	177	121	72	51	63	64	52	35	24	21	21	22	22
37.5	196	217	226	211	167	110	61	41	53	47	39	30	20	18	19	19	19
35.0	168	195	210	200	157	100	50	31	44	29	25	25	15	15	17	16	15
32.5	140	162	174	166	132	86	45	27	33	25	20	18	12	12	13	14	14
30.0	111	128	137	131	107	72	40	22	23	21	15	10	9	10	10	11	12
LONGITUDE: 150W																	
60.0 KM			530	335	183	104	83	94	110	110	98	80	64	50			
57.5			462	307	185	121	103	109	118	112	96	77	62	49			
55.0			394	278	187	139	124	125	126	114	94	74	60	49			
52.5			366	262	179	134	118	117	115	103	83	63	48	37			
50.0			338	245	171	129	113	109	105	91	72	52	37	25			
47.5			320	235	165	123	103	96	92	85	73	59	43	27			
45.0			302	225	160	117	93	82	79	78	74	66	50	29			
42.5			249	183	128	91	72	63	61	59	56	49	38	25			
40.0			195	141	95	66	51	44	42	40	37	33	27	20			
37.5			184	126	78	49	36	33	33	31	28	23	19	15			
35.0			173	111	61	32	22	21	23	22	18	14	11	9			
32.5			148	96	53	28	18	17	18	17	15	12	10	9			
30.0			124	80	45	24	15	13	13	13	11	9	9	8			
LONGITUDE: MEAN																	
60.0 KM	792	628	501	334	202	124	99	119	154	135	121	103	87	159	359	332	229
57.5	635	528	442	315	208	141	114	124	147	124	110	101	88	117	222	202	144
55.0	479	428	384	295	214	158	129	129	140	113	100	98	89	76	86	71	58
52.5	393	374	355	276	194	132	101	110	140	106	84	79	68	52	54	46	44
50.0	307	320	325	257	175	106	72	92	141	97	68	60	47	29	21	21	30
47.5	300	293	297	236	170	117	87	89	111	89	67	55	43	29	25	25	29
45.0	292	265	270	216	166	128	102	86	81	80	66	49	40	29	29	28	28
42.5	258	252	244	199	151	110	81	67	67	66	55	41	32	25	25	25	25
40.0	224	238	218	181	136	93	61	47	52	52	44	34	25	20	21	22	22
37.5	196	217	205	168	122	79	48	37	43	39	33	26	19	16	19	19	19
35.0	168	195	191	155	109	66	36	26	33	25	21	19	13	12	17	16	15
32.5	140	162	161	131	92	57	31	22	25	21	17	15	11	10	13	14	14
30.0	111	128	130	105	76	48	27	17	18	17	13	9	9	9	10	11	12

TABLE 3. Seasonal values of K_{yz} ($10^1\ m^2 sec^{-1}$).

SEASON:WINTER HORIZONTAL DIFFUSION COEFFICIENTS (K-YZ) IN 10 METERS SQUARED PER SECOND

LONGITUDE: 80W

LATITUDE	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0	-5
60.0 KM	-188	-165	-135	-53	273	307	12	261	398	-308	-426	624	281	-211	-31	3	-32
57.5	-225	-188	-135	-49	268	391	18	518	427	-314	-432	406	189	-164	-24	4	-28
55.0	-261	-211	-134	-46	262	475	605	775	456	-320	-338	188	97	-116	-17	4	-23
52.5	-218	-181	-112	-35	193	344	443	563	388	-211	-238	131	74	-85	-10	3	-17
50.0	-174	-152	-89	-25	123	214	280	351	320	-101	-137	74	52	-54	-4	2	-12
47.5	-168	-145	-76	-15	43	56	107	260	225	-83	-71	48	37	-31	-3	0	-6
45.0	-162	-139	-63	-5	-36	-101	-66	169	130	-65	-4	23	22	-8	-2	0	0
42.5	-239	-193	-79	-4	-69	-160	-112	117	106	-55	-22	26	16	-6	-1	0	0
40.0	-317	-246	-96	-2	-101	-219	-159	65	82	-45	-41	29	11	-4	0	0	0
37.5	-259	-215	-86	0	-103	-203	-127	54	51	-38	-23	18	6	-5	0	0	0
35.0	-201	-184	-76	0	-104	-187	-95	42	20	-30	-4	7	0	-5	0	0	0
32.5	-129	-125	-54	0	-75	-133	-59	49	3	-40	-3	2	2	0	0	0	0
30.0	-56	-66	-31	0	-46	-78	-22	56	-13	-50	-1	-2	4	3	0	0	0

LONGITUDE: 150W

LATITUDE	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0	-5
60.0 KM			18	-1	103	372	621	687	365	130	50	66	84	67			
57.5			24	0	101	403	683	726	346	90	4	19	46	39			
55.0			30	2	98	433	745	764	326	49	-41	-26	8	10			
52.5			48	10	32	283	551	593	264	55	-17	-23	-12	-10			
50.0			66	19	-34	134	358	422	202	60	5	-20	-32	-32			
47.5			77	20	-65	-7	100	151	84	37	17	3	-8	-12			
45.0			88	22	-97	-149	-157	-118	-33	14	30	26	15	6			
42.5			83	19	-84	-129	-136	-108	-39	1	17	18	11	5			
40.0			78	17	-71	-108	-115	-98	-46	-11	5	10	7	4			
37.5			44	10	-50	-83	-91	-77	-34	-6	4	5	3	1			
35.0			11	3	-28	-57	-66	-56	-22	-2	3	1	-1	-1			
32.5			0	0	-13	-30	-35	-33	-17	-6	-1	0	0	0			
30.0			-12	-1	1	-2	-4	-10	-13	-11	-6	-1	1	1			

LONGITUDE: MEAN

LATITUDE	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0	-5
60.0 KM	-188	-165	-58	-27	188	340	317	474	381	-88	-238	345	182	-71	-31	3	-32
57.5	-225	-188	-55	-24	184	397	351	622	386	-112	-214	213	117	-62	-24	4	-28
55.0	-261	-211	-52	-21	180	454	675	770	391	-135	-189	80	52	-52	-17	4	-23
52.5	-218	-181	-31	-12	112	314	497	578	326	-78	-128	54	31	-48	-10	3	-17
50.0	-174	-152	-11	-3	44	174	319	386	261	-20	-66	27	9	-43	-4	2	-12
47.5	-168	-145	0	2	-11	24	103	206	154	-22	-26	26	14	-21	-3	0	-6
45.0	-162	-139	12	8	-67	-125	-111	25	48	-25	12	24	18	0	-2	0	0
42.5	-239	-193	1	7	-76	-144	-124	4	33	-27	-2	22	14	0	-1	0	0
40.0	-317	-246	-9	7	-86	-164	-137	-16	18	-28	-17	20	9	0	0	0	0
37.5	-259	-215	-21	4	-76	-143	-109	-11	8	-22	-9	12	4	-1	0	0	0
35.0	-201	-184	-32	2	-66	-122	-81	-7	-1	-16	0	4	0	-3	0	0	0
32.5	-129	-125	-27	0	-44	-81	-47	7	-7	-23	-2	1	1	0	0	0	0
30.0	-56	-66	-22	0	-22	-40	-13	22	-13	-30	-3	-1	2	2	0	0	0

TABLE 3. Seasonal values of K_{yz} (10^1 $m^2 sec^{-1}$).

SEASON:SPRING HORIZONTAL DIFFUSION COEFFICIENTS (K-YZ) IN 10 METERS SQUARED PER SECOND

LONGITUDE: 80W

LATITUDE	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0	-5
60.0 KM	67	-1	-208	-479	-375	-162	-124	-98	-135	243	382	-1172	-1008	1249	350	-103	-230
57.5	-97	-136	-244	-379	-277	-137	-131	-137	-151	213	283	-755	-723	776	196	-70	-144
55.0	-262	-272	-280	-278	-178	-112	-139	-176	-167	182	185	-337	-438	303	43	-36	-57
52.5	-139	-153	-186	-237	-186	-120	-125	-137	-143	134	194	-253	-271	198	30	-30	-46
50.0	-16	-35	-93	-196	-193	-128	-110	-99	-118	85	202	-170	-103	93	18	-23	-34
47.5	8	0	-35	-104	-113	-79	-72	-70	-116	42	179	-125	-64	79	18	-15	-25
45.0	32	36	22	-12	-33	-30	-34	-41	-114	0	157	-80	-26	64	18	-7	-16
42.5	-12	-10	-1	11	10	0	-11	-35	-90	5	129	-61	-13	49	15	-4	-11
40.0	-57	-57	-26	34	54	31	11	-28	-66	11	101	-42	-1	33	12	-1	-6
37.5	-98	-105	-68	17	61	40	21	-15	-44	22	73	-36	-14	36	11	-2	-6
35.0	-139	-154	-110	0	67	50	31	-2	-22	33	45	-29	-28	38	11	-3	-6
32.5	-114	-155	-140	-36	51	44	26	0	-6	28	34	-23	-22	16	5	0	-1
30.0	-89	-155	-169	-72	35	37	21	2	8	24	23	-18	-16	-5	0	3	3

LONGITUDE: 150W

LATITUDE	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0	-5
60.0 KM			220	134	-35	-123	-247	-382	-415	-365	-260	-148	-64	-40			
57.5			114	51	-84	-150	-235	-294	-273	-221	-154	-89	-41	-25			
55.0			9	-31	-133	-176	-223	-207	-130	-77	-47	-30	-17	-10			
52.5			11	-17	-80	-105	-137	-139	-101	-66	-39	-14	3	8			
50.0			14	-3	-27	-34	-52	-72	-71	-56	-31	1	24	26			
47.5			62	36	-6	-23	-42	-63	-66	-51	-23	12	34	34			
45.0			109	77	14	-13	-33	-55	-60	-47	-15	24	44	41			
42.5			103	78	23	-2	-18	-34	-42	-36	-9	32	52	42			
40.0			96	79	32	8	-2	-13	-23	-25	-3	40	60	43			
37.5			52	45	25	12	8	1	-8	-12	-3	19	30	22			
35.0			8	12	17	17	20	16	7	0	-2	-1	0	0			
32.5			-5	-1	8	11	14	14	9	5	1	0	-2	-2			
30.0			-19	-14	-1	4	9	12	11	10	6	0	-5	-5			

LONGITUDE: MEAN

LATITUDE	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0	-5
60.0 KM	67	-1	5	-172	-205	-143	-185	-240	-275	-61	60	-660	-536	604	350	-103	-230
57.5	-97	-136	-64	-163	-180	-143	-183	-215	-212	-4	64	-422	-382	375	196	-70	-144
55.0	-262	-272	-135	-155	-156	-144	-181	-191	-148	52	68	-184	-228	146	43	-36	-57
52.5	-139	-153	-87	-127	-133	-112	-131	-138	-122	33	77	-134	-133	103	30	-30	-46
50.0	-16	-35	-39	-99	-110	-81	-81	-85	-95	14	85	-84	-39	60	18	-23	-34
47.5	8	0	13	-33	-60	-51	-57	-66	-91	-4	78	-56	-15	56	18	-15	-25
45.0	32	36	66	32	-9	-21	-34	-48	-87	-23	70	-28	9	53	18	-7	-16
42.5	-12	-10	50	44	17	0	-14	-34	-66	-15	59	-14	19	45	15	-4	-11
40.0	-57	-57	34	56	43	19	4	-21	-45	-6	48	0	29	38	12	-1	-6
37.5	-98	-105	-8	31	43	26	15	-7	-26	4	35	-8	7	29	11	-2	-6
35.0	-139	-154	-50	6	42	33	25	7	-7	16	21	-15	-13	19	11	-3	-6
32.5	-114	-155	-72	-18	29	27	20	7	1	17	18	-12	-12	7	5	0	-1
30.0	-89	-155	-94	-43	16	21	15	7	10	17	15	-9	-11	-5	0	3	3

TABLE 3. Seasonal values of K_{yz} (10^1 $m^2 sec^{-1}$).

SEASON:SUMMER HORIZONTAL DIFFUSION COEFFICIENTS (K-YZ) IN 10 METERS SQUARED PER SECOND

LONGITUDE: 80W

LATITUDE	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0	-5
60.0 KM	0	0	-7	-20	-34	-45	-14	84	80	14	8	-66	224	312	27	17	137
57.5	0	0	-6	-16	-24	-28	-9	51	46	24	43	-46	122	189	17	10	88
55.0	0	0	-5	-12	-14	-11	-4	18	11	33	78	-27	21	67	8	4	39
52.5	0	0	-3	-7	-8	-6	-2	8	0	25	62	-31	10	63	8	2	29
50.0	0	0	-2	-3	-2	-2	-1	0	-13	18	47	-36	0	59	8	1	19
47.5	0	0	-1	-1	-1	-1	0	0	-13	12	47	-31	-1	44	6	1	15
45.0	0	0	0	0	0	0	0	0	-12	5	47	-25	-4	28	4	0	11
42.5	0	0	0	0	0	0	0	0	-7	3	27	-14	-1	17	2	0	6
40.0	0	0	0	0	0	0	0	0	-2	1	7	-2	1	5	1	0	2
37.5	0	0	0	0	0	0	0	0	-1	2	5	-2	0	3	0	0	0
35.0	0	0	0	0	0	0	0	0	0	3	3	-1	-1	1	0	0	-1
32.5	0	0	0	0	0	0	0	0	0	2	5	-1	-1	1	0	0	0
30.0	0	0	0	0	0	0	0	0	0	1	7	-1	-1	1	0	0	0

LONGITUDE: 150W

LATITUDE	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0	-5
60.0 KM			0	0	-1	-4	-5	-2	6	15	15	9	3	1			
57.5			0	-1	-4	-8	-9	-4	4	13	14	11	5	3			
55.0			0	-2	-7	-12	-12	-7	1	10	14	13	7	4			
52.5			0	-2	-4	-7	-7	-4	0	4	9	13	11	7			
50.0			0	-1	-1	-2	-2	-2	-2	-1	3	13	16	11			
47.5			0	-1	-1	-1	-1	-1	-1	0	3	12	15	11			
45.0			0	0	0	0	0	0	0	0	3	11	15	12			
42.5			0	0	0	0	0	0	0	0	2	7	9	7			
40.0			0	0	0	0	-1	-1	-1	0	1	4	4	2			
37.5			0	0	0	0	0	0	0	0	0	2	2	1			
35.0			0	0	0	0	0	0	0	0	0	0	0	0			
32.5			0	0	0	0	0	0	0	0	0	0	0	0			
30.0			0	0	0	0	0	0	0	0	0	0	0	0			

LONGITUDE: MEAN

LATITUDE	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0	-5
60.0 KM	0	0	-3	-10	-18	-24	-9	41	43	15	11	-28	114	156	27	17	137
57.5	0	0	-3	-8	-14	-18	-9	23	25	18	29	-17	64	96	17	10	88
55.0	0	0	-3	-7	-10	-11	-8	5	6	22	46	-6	14	36	8	4	39
52.5	0	0	-2	-4	-6	-6	-5	2	0	15	36	-9	11	35	8	2	29
50.0	0	0	-1	-2	-2	-2	-1	-1	-7	8	25	-11	8	35	8	1	19
47.5	0	0	0	-1	-1	-1	0	0	-7	5	25	-9	6	27	6	1	15
45.0	0	0	0	0	0	0	0	0	-6	2	25	-6	5	20	4	0	11
42.5	0	0	0	0	0	0	0	0	-4	1	14	-3	4	12	2	0	6
40.0	0	0	0	0	0	0	0	0	-1	0	4	0	3	4	1	0	2
37.5	0	0	0	0	0	0	0	0	-1	0	2	0	1	2	0	0	0
35.0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	-1
32.5	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0
30.0	0	0	0	0	0	0	0	0	0	0	3	-1	0	0	0	0	0

TABLE 3. Seasonal values of K_{yz} (10^1 $m^2 sec^{-1}$).

SEASON:AUTUMN HORIZONTAL DIFFUSION COEFFICIENTS (K-YZ) IN 10 METERS SQUARED PER SECOND

LATITUDE	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0	-5
LONGITUDE: 80W																	
60.0 KM	10	296	517	490	314	223	142	138	106	-1	88	-154	-233	596	186	-351	-641
57.5	8	245	463	459	289	199	124	117	77	0	64	-119	-167	356	100	-207	-377
55.0	5	194	409	428	265	176	107	95	49	0	39	-84	-100	115	13	-64	-114
52.5	4	140	305	315	178	104	59	61	37	0	22	-53	-53	70	8	-36	-71
50.0	2	86	200	202	92	33	10	28	24	0	4	-21	-7	25	4	-8	-29
47.5	1	61	132	115	33	-1	2	23	14	0	5	-15	-1	31	9	-10	-32
45.0	1	36	63	28	-26	-36	-4	18	5	0	6	-9	4	38	13	-12	-35
42.5	0	30	51	10	-43	-46	-9	11	2	0	6	-2	5	24	9	-6	-20
40.0	0	23	38	-6	-60	-56	-13	5	0	0	5	3	6	10	5	0	-4
37.5	0	19	33	-4	-51	-48	-12	2	-1	0	4	1	4	11	5	0	-6
35.0	0	16	28	-2	-41	-41	-12	0	-2	0	4	-1	2	11	5	-2	-8
32.5	0	10	18	-1	-28	-30	-11	-2	-2	0	2	0	1	8	3	-1	-6
30.0	0	4	8	0	-14	-20	-11	-4	-2	0	1	0	1	4	1	0	-3
LONGITUDE: 150W																	
60.0 KM			-117	-68	51	102	82	61	29	0	-15	-26	-36	-40			
57.5			-80	-44	54	109	89	59	25	0	-10	-19	-28	-32			
55.0			-44	-20	57	116	95	58	20	0	-5	-11	-20	-25			
52.5			-37	-20	40	86	71	42	14	0	-2	-6	-12	-15			
50.0			-30	-20	22	56	46	26	7	0	0	-1	-5	-6			
47.5			-26	-22	4	24	21	12	2	0	1	1	-1	-2			
45.0			-22	-24	-14	-6	-2	-2	-2	0	3	4	2	1			
42.5			-13	-15	-13	-10	-6	-3	-2	0	2	5	7	8			
40.0			-3	-7	-12	-15	-9	-5	-1	0	2	7	13	14			
37.5			3	0	-8	-12	-7	-4	-1	0	1	5	8	10			
35.0			10	6	-5	-9	-5	-3	-1	0	0	2	4	5			
32.5			10	7	-2	-6	-4	-2	-1	0	0	1	2	3			
30.0			10	8	0	-3	-2	-1	-1	0	0	1	1	1			
LONGITUDE: MEAN																	
60.0 KM	10	296	200	210	182	162	112	99	67	0	36	-90	-135	278	186	-351	-641
57.5	8	245	191	207	172	154	106	88	51	0	26	-69	-97	161	100	-207	-377
55.0	5	194	182	204	161	146	101	76	35	0	17	-48	-60	45	13	-64	-114
52.5	4	140	133	147	109	95	65	52	25	0	9	-29	-33	27	8	-36	-71
50.0	2	86	85	91	57	44	28	27	16	0	2	-11	-6	9	4	-8	-29
47.5	1	61	52	46	18	11	12	17	8	0	3	-7	-1	14	9	-10	-32
45.0	1	36	20	1	-20	-21	-3	8	1	0	5	-2	3	19	13	-12	-35
42.5	0	30	18	-2	-28	-28	-7	4	0	0	4	1	6	16	9	-6	-20
40.0	0	23	17	-7	-36	-35	-11	0	0	0	3	5	9	12	5	0	-4
37.5	0	19	18	-2	-29	-30	-10	-1	-1	0	3	3	6	10	5	0	-6
35.0	0	16	19	1	-23	-25	-8	-2	-1	0	2	0	3	8	5	-2	-8
32.5	0	10	14	2	-15	-18	-7	-2	-1	0	1	0	2	5	3	-1	-6
30.0	0	4	9	3	-7	-11	-6	-3	-1	0	1	0	1	2	1	0	-3

TABLE 4. Seasonal values of K_{zz} ($10^3 \mathrm{cm}^2 \mathrm{sec}^{-1}$).

SEASON:WINTER VERTICAL DIFFUSION COEFFICIENTS (K-ZZ) IN CM SQUARED PER SECOND TIMES 10^3

LONGITUDE: 80W

LATITUDE	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0	-5
60.0 KM	1050	1000	1000	1150	1200	1300	1350	1250	1150	1100	1050	1200	1600	2000	2100	2300	2450
57.5	800	760	770	875	975	1115	1185	1125	1025	950	900	975	1200	1490	1575	1750	1875
55.0	550	520	540	600	750	930	1020	1000	900	800	750	750	800	980	1050	1200	1300
52.5	450	415	420	500	600	715	775	750	655	585	585	605	615	710	755	850	950
50.0	350	310	300	400	450	500	530	500	410	370	420	460	430	440	460	500	600
47.5	310	280	275	330	345	375	390	355	280	270	315	350	345	355	375	390	425
45.0	270	250	250	260	240	250	250	210	150	170	210	240	260	270	290	280	250
42.5	210	190	180	180	165	160	150	125	90	100	140	175	195	195	195	185	165
40.0	150	130	110	100	90	70	50	40	30	20	70	110	130	120	100	90	80
37.5	110	96	80	71	61	49	36	28	23	24	47	70	81	75	65	60	57
35.0	70	62	50	41	31	28	22	16	15	18	23	30	31	29	30	30	33
32.5	51	45	37	31	24	22	18	14	14	18	20	21	21	19	20	22	26
30.0	32	28	23	20	17	15	13	12	13	17	16	12	11	8	10	14	18

LONGITUDE: 150W

LATITUDE	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0	-5
60.0			2100	2000	2000	1800	1600	1500	1150	1100	1050	1050	1150	1250			
57.5			1800	1750	1850	1550	1375	1275	1075	1000	925	950	1050	1125			
55.0			1500	1500	1700	1300	1150	1050	1000	900	800	850	950	1000			
52.5			1000	1025	1150	975	875	795	760	700	625	625	710	765			
50.0			500	550	600	650	600	540	520	500	450	400	470	530			
47.5			350	425	475	520	455	410	370	350	315	305	345	390			
45.0			200	300	350	390	310	280	220	200	180	210	220	250			
42.5			115	230	285	290	210	175	135	130	130	150	155	165			
40.0			30	160	220	190	110	70	50	60	80	90	90	80			
37.5			18	95	146	118	68	45	30	38	54	63	81	83			
35.0			6	30	71	45	25	20	10	15	28	36	71	86			
32.5			14	25	44	30	19	19	16	18	22	26	50	61			
30.0			21	19	17	14	12	18	21	20	15	16	28	36			

MEAN

LATITUDE	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0	-5
60.0	1050	1000	1419	1575	1600	1550	1475	1375	1150	1100	1050	1125	1375	1681	2100	2300	2450
57.5	800	760	1161	1313	1413	1333	1280	1200	1050	975	913	963	1125	1329	1575	1750	1875
55.0	550	520	903	1050	1225	1115	1085	1025	950	850	775	800	875	976	1050	1200	1300
52.5	450	415	650	763	875	845	825	773	708	643	605	615	663	724	755	850	950
50.0	350	310	396	475	525	575	565	520	465	435	435	430	450	470	460	500	600
47.5	310	280	321	378	410	448	423	383	325	310	315	328	345	367	375	390	425
45.0	270	250	245	280	295	320	280	245	185	185	195	225	240	263	290	280	250
42.5	210	190	173	205	225	225	180	150	113	115	135	163	175	183	195	185	165
40.0	150	130	100	130	155	130	80	55	40	45	75	100	110	103	100	90	80
37.5	110	96	69	83	104	84	52	37	27	31	61	67	81	76	65	60	57
35.0	70	62	39	36	51	37	24	18	13	17	26	33	51	49	30	30	33
32.5	51	45	31	28	34	26	19	17	15	19	21	24	36	34	20	22	26
30.0	32	28	23	20	17	15	13	15	17	19	16	14	20	19	10	14	18

TABLE 4. Seasonal values of K_{zz} ($10^3 cm^2 sec^{-1}$).

SEASON:SPRING VERTICAL DIFFUSION COEFFICIENTS (K-ZZ) IN CM SQUARED PER SECOND TIMES 10^3

LONGITUDE: 80W

LATITUDE	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0	-5
60.0 KM	650	600	600	550	530	550	700	850	1000	1100	1000	900	750	600	700	900	1050
57.5	550	485	450	405	405	450	575	700	850	950	875	750	625	510	585	750	950
55.0	450	370	300	260	280	350	450	550	700	800	750	600	500	420	470	600	850
52.5	380	325	285	255	270	315	370	435	560	650	605	485	425	410	450	540	685
50.0	310	280	270	250	260	280	290	320	420	500	460	370	350	400	430	480	520
47.5	285	255	230	210	210	225	240	265	340	390	370	305	305	345	365	385	410
45.0	260	230	190	170	160	170	190	210	260	280	280	240	260	290	300	290	300
42.5	200	180	160	145	140	145	150	160	180	185	200	185	185	160	165	185	205
40.0	140	130	130	120	120	120	110	110	100	90	120	130	110	30	30	80	110
37.5	91	87	88	83	87	90	83	74	65	61	88	96	70	25	25	51	70
35.0	41	43	45	46	53	60	56	38	30	32	56	62	30	20	20	22	30
32.5	31	30	30	29	34	38	35	24	19	22	39	42	25	20	20	21	28
30.0	20	17	15	12	14	15	13	10	8	12	21	21	20	20	19	20	25

LONGITUDE: 150W

LATITUDE	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0	-5
60.0			230	240	250	270	290	310	400	530	1000	1050	800	600			
57.5			210	230	255	275	310	355	425	565	910	900	675	510			
55.0			190	220	260	280	330	400	450	600	820	750	550	420			
52.5			180	210	240	280	340	400	445	540	660	600	450	360			
50.0			170	200	220	280	350	400	440	460	500	450	350	300			
47.5			160	180	200	240	300	350	375	395	400	360	275	245			
45.0			150	160	180	200	250	300	310	310	300	270	200	190			
42.5			135	135	140	150	180	210	225	225	225	205	170	160			
40.0			120	110	100	100	110	120	140	140	150	140	140	130			
37.5			97	70	55	60	68	75	86	90	98	94	95	91			
35.0			74	30	10	19	26	29	32	40	45	48	50	52			
32.5			56	21	8	12	17	23	29	34	36	37	37	36			
30.0			37	12	6	5	7	16	26	27	27	25	23	20			

MEAN

LATITUDE	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0	-5
60.0	650	600	456	395	390	410	495	580	700	815	1000	975	775	669	700	900	1050
57.5	550	485	366	318	330	363	443	528	638	758	893	825	650	564	585	750	950
55.0	450	370	275	240	270	315	390	475	575	700	785	675	525	459	470	600	850
52.5	380	325	256	233	255	298	355	418	503	595	633	543	438	415	450	540	685
50.0	310	280	236	225	240	280	320	360	430	490	480	410	350	370	430	480	520
47.5	285	255	210	195	205	233	270	308	358	393	385	333	290	311	365	385	410
45.0	260	230	184	165	170	185	220	255	285	295	290	255	230	253	300	290	300
42.5	200	180	154	140	140	148	165	185	203	205	213	195	178	166	165	185	205
40.0	140	130	124	115	110	110	110	115	120	115	135	135	125	79	30	80	110
37.5	91	87	88	77	71	75	76	75	76	76	93	95	83	56	25	51	70
35.0	41	43	50	38	32	40	41	34	31	36	51	55	40	33	20	22	30
32.5	31	30	35	25	21	25	26	24	24	28	38	40	31	27	20	21	28
30.0	20	17	20	12	10	10	10	13	17	20	24	23	22	20	19	20	25

TABLE 4. Seasonal values of K_{zz} ($10^3 cm^2 sec^{-1}$).

SEASON:SUMMER VERTICAL DIFFUSION COEFFICIENTS (K-ZZ) IN CM SQUARED PER SECOND TIMES 10^3

LONGITUDE: 80W

LATITUDE	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0	-5
60.0 KM	550	480	470	450	450	430	480	550	1050	1800	2100	2250	2000	1450	1300	2000	2150
57.5	485	440	440	440	415	375	390	420	690	1150	1675	1700	1500	1000	975	1550	1975
55.0	420	400	410	430	380	320	300	290	330	500	1050	1150	1000	550	650	1100	1800
52.5	385	365	370	370	335	290	260	260	295	345	735	860	725	420	475	800	1350
50.0	350	330	330	310	290	260	220	230	260	290	420	570	450	290	300	500	900
47.5	285	295	300	280	245	200	170	180	230	255	340	430	280	190	200	335	625
45.0	220	260	270	250	200	140	120	130	200	220	260	290	110	90	100	170	350
42.5	165	190	195	180	150	110	90	100	150	175	185	185	80	65	75	125	225
40.0	110	120	120	110	100	80	60	70	100	130	110	80	50	40	50	80	100
37.5	71	78	79	75	76	71	60	62	72	84	71	53	36	31	37	54	67
35.0	31	35	38	40	51	62	60	54	43	38	31	26	22	21	24	28	33
32.5	25	28	30	28	33	37	35	31	29	28	26	24	23	23	23	23	23
30.0	19	20	21	16	15	12	10	8	14	14	20	22	23	25	21	17	13

LONGITUDE: 150W

LATITUDE	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0	-5
60.0			350	400	500	600	480	360	320	440	560	800	1000	1100			
57.5			265	350	440	485	390	310	285	360	645	640	825	1050			
55.0			180	300	380	370	300	260	250	280	330	480	650	1000			
52.5			145	250	325	315	250	190	220	260	300	390	515	720			
50.0			110	200	270	260	200	120	190	240	270	300	380	440			
47.5			100	150	230	210	135	75	135	215	240	255	320	370			
45.0			90	100	190	160	70	30	80	140	210	210	260	300			
42.5			80	90	140	115	50	55	105	150	155	150	185	220			
40.0			70	80	90	70	30	80	130	110	100	90	110	140			
37.5			60	70	73	50	28	60	84	70	63	60	78	100			
35.0			50	60	55	30	25	40	38	30	26	29	45	60			
32.5			38	45	43	25	19	29	32	26	23	26	35	44			
30.0			25	29	30	20	12	18	26	21	20	23	25	28			

MEAN

LATITUDE	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0	-5
60.0	550	480	431	425	475	515	480	455	685	1120	1330	1525	1500	1338	1300	2000	2150
57.5	485	440	385	395	428	430	390	365	488	755	1010	1170	1163	1047	975	1550	1975
55.0	420	400	339	365	380	345	300	275	290	390	690	815	825	756	650	1100	1800
52.5	385	365	298	310	330	303	255	225	256	328	518	625	620	559	475	800	1350
50.0	350	330	256	255	280	260	210	175	225	265	345	435	415	361	300	500	900
47.5	285	295	228	215	238	205	153	128	183	235	290	343	300	265	200	335	625
45.0	220	260	199	175	195	150	95	80	140	205	235	250	185	169	100	170	350
42.5	165	190	150	135	145	113	70	78	128	163	170	168	133	124	75	125	225
40.0	110	120	101	95	95	75	45	75	115	120	105	85	80	78	50	80	100
37.5	71	78	73	73	75	61	44	61	78	77	67	57	57	57	37	54	67
35.0	31	35	43	50	53	46	43	47	41	34	29	28	34	35	24	28	33
32.5	25	28	33	37	38	31	27	30	31	27	25	25	29	30	23	23	23
30.0	19	20	22	23	23	16	11	13	20	20	20	23	24	25	21	17	13

TABLE 4. Seasonal values of K_{zz} ($10^3 cm^2 sec^{-1}$).

SEASON:AUTUMN VERTICAL DIFFUSION COEFFICIENTS (K-ZZ) IN CM SQUARED PER SECOND TIMES 10^3

LONGITUDE: 80W

LATITUDE	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0	-5
60.0 KM	570	590	640	620	580	530	520	600	750	1000	1600	2000	2200	2300	2100	1800	1450
57.5	535	540	555	540	510	475	470	515	615	825	1425	1725	2000	2100	1900	1650	1250
55.0	500	490	470	460	440	420	420	430	480	650	1050	1450	1800	1900	1700	1500	1050
52.5	410	410	410	430	425	415	420	425	435	525	775	1150	1425	1500	1350	1175	825
50.0	320	330	350	400	410	410	420	420	390	400	500	850	1050	1100	1000	850	600
47.5	250	265	295	335	350	360	380	375	330	330	390	590	765	805	750	645	465
45.0	180	200	240	270	290	310	340	330	270	260	280	330	480	510	500	440	330
42.5	150	160	175	190	205	225	260	250	200	190	210	255	350	375	350	300	230
40.0	120	120	110	110	120	140	180	170	130	120	140	180	220	240	200	160	130
37.5	105	95	85	81	90	103	120	110	86	78	98	130	153	158	132	107	88
35.0	90	70	60	52	68	65	60	50	41	35	55	80	85	75	64	53	45
32.5	58	47	40	34	38	40	38	34	30	28	40	55	58	54	46	38	31
30.0	25	24	20	16	15	15	16	17	19	21	24	29	30	32	28	22	17

LONGITUDE: 150W

LATITUDE	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0	-5
60.0			1500	1600	1500	1300	1150	1050	1100	1150	1150	1050	400	300			
57.5			1350	1350	1250	1125	975	800	775	825	950	875	385	315			
55.0			1200	1100	1000	950	800	550	450	500	750	700	370	330			
52.5			925	825	750	725	600	450	410	450	605	600	395	335			
50.0			650	550	500	500	400	350	370	400	460	500	420	340			
47.5			385	320	290	300	280	275	300	335	380	410	375	320			
45.0			120	90	80	100	160	200	230	270	300	320	330	300			
42.5			95	65	50	65	120	150	170	190	210	230	240	235			
40.0			70	40	20	30	80	100	110	110	120	140	150	170			
37.5			61	34	22	28	56	73	86	81	82	90	98	115			
35.0			52	27	23	26	31	45	62	52	43	40	45	59			
32.5			44	25	22	21	25	34	44	39	32	29	32	40			
30.0			35	22	20	16	18	23	26	25	20	17	19	21			

MEAN

LATITUDE	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0	-5
60.0	570	590	960	1110	1040	915	835	825	925	1075	1375	1525	1300	1500	2100	1800	1450
57.5	535	540	848	945	880	800	723	658	695	825	1138	1300	1193	1377	1900	1650	1250
55.0	500	490	735	780	720	685	610	490	465	575	900	1075	1085	1254	1700	1500	1050
52.5	410	410	594	628	588	570	510	438	423	488	690	875	910	1024	1350	1175	825
50.0	320	330	451	475	455	455	410	385	380	400	480	675	735	794	1000	850	600
47.5	250	265	318	328	320	330	330	325	315	333	385	500	570	612	750	645	465
45.0	180	200	185	180	185	205	250	265	250	265	290	325	405	429	500	440	330
42.5	150	160	140	128	128	145	190	200	185	190	210	243	295	314	350	300	230
40.0	120	120	94	75	70	85	130	135	120	115	130	160	185	199	200	160	130
37.5	105	95	75	58	56	66	88	92	86	80	90	110	126	133	132	107	88
35.0	90	70	56	40	42	46	46	48	52	44	49	60	65	66	64	53	45
32.5	58	47	40	30	30	31	32	34	37	34	35	42	45	46	46	38	31
30.0	25	24	25	19	18	16	17	20	23	23	22	23	25	27	28	22	17

TABLE 5. Seasonal mean temperatures (^{o}K).

SEASON:WINTER MEAN T

LATITUDE	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0	-5
60.0 KM	258	258	259	260	260	259	257	255	256	256	258	259	260	260	261	261	260
57.5	257	258	259	260	261	261	260	258	258	258	261	264	265	265	266	266	265
55.0	256	257	258	260	261	262	262	261	260	260	264	268	270	270	270	270	270
52.5	254	254	254	257	260	262	262	263	263	264	267	270	271	272	272	271	271
50.0	251	250	250	253	258	261	262	264	266	268	269	271	272	273	273	272	272
47.5	248	246	246	249	254	259	261	263	266	269	270	271	271	271	271	271	271
45.0	244	242	241	244	250	256	260	262	265	270	270	270	269	269	269	270	270
42.5	238	237	236	239	245	253	256	257	260	263	263	264	263	263	263	264	264
40.0	232	231	230	233	240	250	252	252	254	255	256	257	257	257	257	257	257
37.5	228	227	227	229	235	245	247	247	247	248	248	249	249	249	249	249	249
35.0	223	223	223	225	229	239	241	241	240	240	240	241	241	240	240	240	241
32.5	220	220	221	222	226	233	234	234	235	235	235	235	235	235	235	235	236
30.0	216	217	218	219	222	226	226	227	229	230	230	229	229	229	229	230	231
SEASON:SPRING																	
60.0 KM	268	266	265	264	262	260	259	257	257	258	257	256	257	257	258	258	259
57.5	270	269	268	267	266	264	263	261	261	262	261	260	261	261	262	262	263
55.0	271	271	270	270	270	268	266	265	265	265	265	264	265	265	265	266	266
52.5	271	272	271	271	271	270	269	268	268	268	268	268	269	268	268	269	268
50.0	271	272	272	272	271	271	271	271	271	270	271	271	272	271	271	271	270
47.5	268	268	269	269	270	270	270	271	270	269	270	270	271	271	271	271	271
45.0	264	264	265	266	268	269	269	270	269	266	268	269	270	270	271	271	271
42.5	258	258	258	258	260	262	263	264	264	263	263	264	265	265	266	266	266
40.0	251	251	250	250	252	255	256	257	258	258	258	259	260	260	260	260	261
37.5	246	246	245	245	246	249	250	251	252	252	252	252	253	252	252	252	253
35.0	240	240	239	239	240	243	244	245	245	245	245	245	245	244	244	244	244
32.5	236	235	235	234	235	237	237	239	239	239	239	239	239	239	239	239	239
30.0	231	230	230	229	229	230	230	232	232	233	233	233	232	233	233	233	233
SEASON:SUMMER																	
60.0 KM	276	274	271	268	262	259	257	253	253	253	253	254	256	256	256	255	255
57.5	279	277	275	272	267	264	262	258	258	258	257	258	260	260	260	260	260
55.0	281	280	278	275	271	269	266	263	262	262	261	262	264	264	264	264	265
52.5	283	281	279	277	273	271	269	267	266	266	264	264	265	266	266	267	268
50.0	284	282	280	278	275	272	271	271	270	269	267	266	266	267	268	269	270
47.5	281	280	278	276	274	272	271	271	269	268	266	265	266	266	267	268	268
45.0	277	277	275	274	273	272	271	270	268	266	264	264	265	265	265	266	266
42.5	271	271	269	267	267	266	265	264	262	261	260	260	260	260	260	261	261
40.0	265	264	262	260	260	260	259	257	256	256	255	255	254	254	255	256	256
37.5	259	257	256	255	255	254	253	252	251	250	249	249	248	248	248	249	250
35.0	252	250	250	249	249	248	247	246	245	243	243	242	241	241	241	242	243
32.5	246	245	245	244	243	242	240	239	239	237	237	237	236	236	236	236	237
30.0	240	239	239	238	237	235	233	232	232	231	231	231	230	230	230	230	230
SEASON:AUTUMN																	
60.0 KM	261	261	261	260	260	260	259	257	257	256	256	256	256	257	257	257	256
57.5	261	262	262	261	261	262	261	260	260	260	261	261	261	261	261	261	261
55.0	261	262	262	262	262	263	263	263	263	264	265	265	265	265	265	265	265
52.5	259	260	261	261	261	262	263	264	265	266	267	268	268	268	268	269	269
50.0	256	257	259	260	260	261	263	265	267	268	269	270	271	271	271	272	272
47.5	251	253	255	256	257	259	262	264	266	267	268	269	270	271	271	271	272
45.0	245	248	250	252	254	257	260	263	264	265	266	268	269	270	270	270	271
42.5	238	241	243	246	248	251	254	256	257	259	260	262	263	264	265	265	266
40.0	231	233	236	239	241	244	247	249	250	252	254	256	257	258	259	259	260
37.5	227	229	231	234	236	239	242	244	245	246	247	249	250	251	252	252	253
35.0	222	224	226	228	230	233	236	238	239	240	240	241	242	243	244	245	246
32.5	219	221	223	225	227	229	232	234	235	235	236	236	237	238	238	238	239
30.0	216	218	220	221	223	225	228	229	230	230	231	231	232	232	231	231	232

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TABLE 6. Variance of temperature ($^oK^2$).

SEASON:WINTER VAR T

LATITUDE	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0	-5
60.0 KM	72	74	76	73	70	54	35	27	31	33	26	17	14	14	13	14	15
57.5	68	74	74	73	68	52	33	26	29	30	24	17	14	13	13	14	15
55.0	64	73	72	72	66	50	30	25	26	26	22	16	14	12	12	13	15
52.5	68	73	74	73	66	51	31	25	25	24	20	16	14	12	12	13	15
50.0	72	73	75	73	66	52	31	25	24	21	18	15	14	12	12	13	14
47.5	71	74	78	78	71	59	41	33	28	25	19	15	13	13	13	13	13
45.0	70	75	80	83	76	65	50	40	32	28	20	15	12	13	13	12	11
42.5	64	71	79	82	67	58	48	42	35	29	19	15	12	13	13	13	13
40.0	58	66	78	81	58	50	45	43	37	30	18	14	11	12	12	13	14
37.5	49	57	66	66	48	40	36	34	31	25	17	13	11	12	11	12	12
35.0	40	48	54	50	38	29	27	24	24	20	15	12	11	11	10	10	10
32.5	37	41	42	39	31	25	22	20	19	16	13	11	10	9	8	9	9
30.0	34	33	30	28	23	20	17	15	14	11	10	9	8	6	6	7	8

SEASON:SPRING

60.0 KM	18	16	15	17	17	14	13	15	16	17	13	11	12	12	13	14	14
57.5	20	17	15	16	16	14	13	14	16	16	13	10	12	12	13	14	13
55.0	21	17	14	15	14	13	12	12	15	15	12	9	11	12	12	13	12
52.5	22	19	15	15	14	13	13	13	14	14	12	9	11	12	13	13	12
50.0	22	20	16	14	13	13	13	13	12	12	11	9	10	12	13	12	11
47.5	24	20	17	15	14	14	13	13	12	12	11	9	10	13	14	13	11
45.0	26	20	17	16	14	14	13	13	12	12	11	9	9	13	15	14	11
42.5	28	20	18	16	15	14	13	13	13	13	11	9	9	12	15	15	14
40.0	30	20	18	16	15	13	13	12	14	14	10	9	9	11	15	16	16
37.5	30	20	17	15	15	13	13	12	13	12	10	9	9	11	13	14	14
35.0	30	19	15	14	14	13	12	11	11	10	9	8	9	10	11	11	12
32.5	29	17	14	13	13	12	11	10	9	9	8	7	8	8	9	9	10
30.0	27	14	13	12	11	10	9	9	7	7	6	6	6	5	6	7	8

SEASON:SUMMER

60.0 KM	11	9	8	8	8	9	13	20	22	23	22	22	21	19	17	15	15
57.5	10	9	8	8	8	9	12	17	21	23	22	19	18	16	15	14	14
55.0	9	8	7	7	7	8	10	13	19	22	21	16	14	12	12	12	13
52.5	10	9	8	7	7	8	10	13	17	21	17	14	13	12	12	12	12
50.0	11	10	9	7	7	8	10	12	14	19	13	11	11	12	12	11	11
47.5	14	12	10	8	7	8	10	12	14	17	13	13	13	12	12	11	10
45.0	17	13	11	9	7	7	9	11	13	15	12	15	15	11	11	10	9
42.5	17	14	11	9	7	7	8	10	12	15	12	14	14	11	10	9	9
40.0	16	15	11	8	7	7	7	8	11	14	12	13	13	10	9	8	8
37.5	15	15	12	9	7	7	7	7	9	11	10	11	10	9	8	8	8
35.0	13	14	12	8	7	6	6	6	7	8	8	8	7	7	7	8	8
32.5	12	12	9	6	6	5	5	6	7	7	7	7	6	6	6	7	7
30.0	11	10	6	4	4	4	4	5	6	6	6	6	5	5	5	6	6

SEASON:AUTUMN

60.0 KM	33	34	38	41	30	26	22	19	19	30	21	18	16	15	15	15	14
57.5	33	34	38	40	30	26	21	19	19	26	19	16	15	14	14	14	13
55.0	32	34	37	39	30	25	20	18	18	22	17	14	13	13	12	12	11
52.5	34	35	37	36	30	25	20	18	18	19	16	13	12	13	12	12	10
50.0	35	35	36	32	30	24	20	17	17	16	14	11	11	12	12	11	9
47.5	35	35	35	32	29	24	20	18	17	16	14	12	12	12	12	11	10
45.0	35	35	33	31	27	23	19	18	16	16	14	13	13	12	12	11	10
42.5	30	31	29	25	22	19	17	16	15	17	15	13	13	14	14	13	11
40.0	25	26	24	19	17	14	14	13	14	17	15	12	13	16	16	14	11
37.5	20	21	20	17	15	13	12	11	12	15	15	12	12	13	13	12	11
35.0	14	16	16	14	13	11	10	9	10	12	14	11	11	10	10	10	11
32.5	12	14	14	12	11	10	9	8	9	11	12	10	10	9	9	9	10
30.0	10	11	12	10	9	8	7	7	7	10	10	9	8	7	7	8	8

TABLE 7. Seasonal mean zonal wind speed (10^1 m $\sec^{-1}$).

SEASON:WINTER MEAN U

LATITUDE	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0	-5
60.0 KM	150	175	190	430	480	540	600	715	700	580	470	400	300	210	200	160	80
57.5	113	150	190	425	475	535	605	713	653	525	410	325	215	140	103	55	-39
55.0	75	125	190	420	470	530	610	710	605	470	350	250	130	70	5	-50	-160
52.5	73	128	195	410	465	535	605	680	578	435	320	175	30	-14	-82	-134	-229
50.0	70	130	200	400	460	540	600	650	550	400	290	100	-70	-100	-170	-220	-300
47.5	65	140	205	365	433	515	590	628	518	390	250	48	-72	-124	-184	-262	-359
45.0	60	150	210	330	405	490	580	605	485	380	210	-5	-75	-150	-200	-305	-420
42.5	68	150	215	300	378	445	500	518	428	335	205	-12	-67	-129	-199	-292	-384
40.0	75	150	220	270	350	400	420	430	370	290	200	-20	-60	-110	-200	-280	-350
37.5	88	155	220	265	310	340	370	390	335	260	185	-9	-44	-117	-187	-249	-324
35.0	100	160	220	260	270	280	320	350	300	230	170	0	-30	-125	-175	-220	-300
32.5	110	165	215	240	245	253	268	275	248	185	130	3	-24	-82	-142	-199	-257
30.0	120	170	210	220	220	225	215	200	195	140	90	5	-20	-40	-110	-180	-215
SEASON:SPRING																	
60.0 KM	-50	-35	-10	10	20	40	45	45	30	30	60	95	120	150	180	250	300
57.5	-54	-34	-12	20	40	58	65	63	45	45	63	83	103	128	160	220	265
55.0	-60	-35	-15	30	60	75	85	80	60	60	65	70	85	105	140	190	230
52.5	-64	-37	-17	25	55	88	103	103	78	70	60	53	58	83	120	160	200
50.0	-70	-40	-20	20	50	100	120	125	95	80	55	35	30	60	100	130	170
47.5	-59	-34	-14	20	55	103	125	138	103	80	35	3	3	35	70	100	133
45.0	-50	-30	-10	20	60	105	130	150	110	80	15	-30	-25	10	40	70	95
42.5	-42	-29	-14	10	53	103	125	153	125	85	8	-64	-72	-44	-14	20	35
40.0	-35	-30	-20	0	45	100	120	155	140	90	0	-100	-120	-100	-70	-30	-25
37.5	-27	-24	-19	-2	33	85	113	148	133	90	0	-102	-124	-137	-114	-89	-87
35.0	-20	-20	-20	-5	20	70	105	140	125	90	0	-105	-130	-175	-160	-150	-150
32.5	-14	-14	-14	-7	8	48	73	105	88	60	-9	-92	-127	-162	-154	-154	-159
30.0	-10	-10	-10	-10	-5	5	40	70	50	30	-20	-80	-125	-150	-150	-160	-170
SEASON:SUMMER																	
60.0 KM	-230	-270	-310	-340	-375	-405	-460	-505	-500	-400	-300	-190	-95	-60	-30	0	25
57.5	-207	-239	-279	-314	-347	-392	-434	-467	-484	-419	-349	-234	-142	-84	-54	-24	3
55.0	-185	-210	-250	-290	-320	-380	-410	-430	-470	-440	-400	-280	-190	-110	-80	-50	-20
52.5	-172	-192	-224	-257	-297	-342	-384	-414	-444	-432	-404	-314	-232	-162	-124	-84	-59
50.0	-160	-175	-200	-225	-275	-305	-360	-400	-420	-425	-410	-350	-275	-215	-170	-120	-100
47.5	-144	-157	-179	-202	-237	-277	-329	-364	-394	-412	-409	-362	-292	-234	-184	-139	-104
45.0	-130	-140	-160	-180	-200	-250	-300	-330	-370	-400	-410	-375	-310	-255	-200	-160	-110
42.5	-109	-119	-137	-157	-177	-219	-252	-289	-324	-349	-364	-352	-312	-262	-204	-159	-104
40.0	-90	-100	-115	-135	-155	-190	-205	-250	-280	-300	-320	-330	-315	-270	-210	-160	-100
37.5	-74	-87	-104	-119	-137	-167	-187	-219	-242	-262	-289	-309	-304	-262	-209	-159	-102
35.0	-60	-75	-95	-105	-120	-145	-170	-190	-205	-225	-260	-290	-295	-255	-210	-160	-105
32.5	-57	-69	-82	-92	-104	-122	-142	-162	-187	-207	-239	-274	-274	-242	-204	-159	-109
30.0	-55	-65	-70	-80	-90	-100	-115	-135	-170	-190	-220	-260	-255	-230	-200	-160	-115
SEASON:AUTUMN																	
60.0 KM	220	250	280	320	350	380	420	500	470	410	350	290	195	180	175	165	145
57.5	215	248	280	323	358	390	448	498	440	393	340	295	193	173	158	140	120
55.0	210	245	280	325	365	400	475	495	410	375	330	300	190	165	140	115	95
52.5	153	185	233	328	358	395	443	450	390	353	315	260	180	158	133	108	83
50.0	95	125	185	330	350	390	410	405	370	330	300	220	170	150	125	100	70
47.5	135	178	230	320	338	360	370	360	330	290	255	203	155	128	108	75	50
45.0	175	230	275	310	325	330	330	315	290	250	210	185	140	105	90	50	30
42.5	165	213	248	275	288	295	290	275	245	210	170	130	75	48	35	13	5
40.0	155	195	220	240	250	260	250	235	200	170	130	75	10	-10	-20	-25	-20
37.5	148	178	200	213	218	225	215	203	170	140	90	30	-34	-54	-57	-52	-39
35.0	140	160	180	185	185	190	180	170	140	110	50	-15	-80	-100	-95	-80	-60
32.5	135	148	160	158	150	145	138	125	95	63	5	-59	-99	-119	-117	-104	-84
30.0	130	135	140	130	115	100	95	80	50	15	-40	-105	-120	-140	-140	-130	-110

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TABLE 8. Variance of zonal wind speed ($m^2 sec^{-2}$).

SEASON:WINTER VAR U

LATITUDE	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0	-5
60.0 KM	630	600	560	520	495	390	300	280	310	315	275	250	220	190	170	160	150
57.5	620	555	530	535	563	443	340	310	338	320	273	240	205	175	160	150	140
55.0	610	510	500	550	630	495	380	340	365	325	270	230	190	160	150	140	130
52.5	510	445	440	515	615	548	403	345	398	323	265	220	180	155	145	138	133
50.0	410	380	380	480	600	600	425	350	430	320	260	210	170	150	140	135	135
47.5	355	328	333	413	510	550	413	340	413	310	243	195	150	125	118	113	110
45.0	300	275	285	345	420	500	400	330	395	300	225	180	130	100	95	90	85
42.5	280	258	253	280	328	373	340	305	330	250	183	138	105	88	83	76	70
40.0	260	240	220	215	235	245	280	280	265	200	140	95	80	75	70	62	55
37.5	245	218	183	183	195	195	228	248	238	178	118	83	65	62	59	54	50
35.0	230	195	145	150	155	145	175	215	210	155	95	70	50	48	48	46	45
32.5	210	178	140	140	143	135	145	160	153	115	73	55	40	38	37	36	35
30.0	190	160	135	130	130	125	115	105	95	75	50	40	30	28	26	25	24

SEASON:SPRING

60.0 KM	180	175	160	155	155	160	140	125	120	115	120	120	120	125	120	110	105
57.5	160	150	135	130	135	145	130	118	110	105	106	108	110	115	109	100	92
55.0	140	125	110	105	115	130	120	110	100	95	92	95	100	105	98	90	78
52.5	135	113	100	98	110	123	110	100	83	80	79	80	88	90	84	80	74
50.0	130	100	90	90	105	115	100	90	65	65	65	65	75	75	70	70	70
47.5	120	98	90	88	103	110	95	88	65	65	63	65	68	65	63	64	65
45.0	110	95	90	85	100	105	90	85	65	65	60	65	60	55	55	58	60
42.5	108	83	73	70	80	85	75	73	60	59	55	57	53	50	51	52	53
40.0	105	70	55	55	60	65	60	60	55	53	50	48	45	45	46	46	45
37.5	95	58	48	50	55	58	55	55	50	47	41	40	39	38	38	39	40
35.0	85	45	40	45	50	50	50	50	45	40	32	32	32	30	30	32	34
32.5	68	40	35	40	43	41	41	40	36	32	27	26	26	25	25	26	27
30.0	50	35	30	35	35	32	32	30	26	23	21	20	20	20	20	20	20

SEASON:SUMMER

60.0 KM	60	60	55	55	60	70	90	110	160	170	175	180	190	210	215	200	180
57.5	53	50	45	48	58	65	78	90	118	135	138	143	150	168	178	170	150
55.0	45	40	35	40	55	60	65	70	75	100	100	105	110	125	140	140	120
52.5	38	33	29	33	48	58	60	63	65	78	77	80	90	100	113	118	111
50.0	30	26	22	25	40	55	55	55	55	55	53	55	70	75	85	95	102
47.5	28	23	21	23	34	44	47	48	48	49	49	52	61	69	77	85	91
45.0	25	20	20	21	28	32	38	40	40	42	44	48	52	62	68	75	80
42.5	21	16	15	15	21	29	32	31	30	36	40	42	46	56	62	66	71
40.0	16	12	10	8	14	25	25	22	20	30	35	35	40	50	55	57	62
37.5	14	11	9	8	11	18	18	17	17	24	27	26	30	48	48	50	55
35.0	12	10	8	8	8	10	10	12	14	18	18	16	20	30	40	43	48
32.5	11	9	7	7	7	9	9	10	12	15	15	14	18	28	34	35	36
30.0	9	7	6	6	6	7	7	7	9	11	11	11	15	25	27	26	23

SEASON:AUTUMN

60.0 KM	360	330	305	280	260	240	225	195	190	185	170	150	140	130	125	105	95
57.5	325	285	255	243	243	220	198	173	165	163	150	135	125	115	110	98	90
55.0	290	240	205	205	225	200	170	150	140	140	130	120	110	100	95	90	85
52.5	245	205	183	190	183	155	133	120	118	123	110	103	98	90	88	83	80
50.0	200	170	160	175	140	110	95	90	95	105	90	85	85	80	80	75	75
47.5	165	138	128	145	118	100	90	85	83	85	78	73	70	68	70	68	68
45.0	130	105	95	115	95	90	65	60	70	65	65	60	55	55	60	60	60
42.5	105	83	73	93	80	78	78	75	68	60	57	51	49	48	50	51	52
40.0	80	60	50	70	65	65	70	70	65	55	48	42	42	40	40	42	44
37.5	65	50	45	64	60	60	64	64	59	51	43	37	36	34	34	37	41
35.0	50	40	40	57	55	55	57	58	53	47	37	32	30	28	28	32	38
32.5	44	35	35	49	45	45	46	49	44	39	30	25	24	24	25	28	31
30.0	38	30	30	40	35	35	35	40	35	30	23	18	18	20	22	24	24

TABLE 9. Seasonal mean meridional wind speed (10^1 m sec^{-1}) along 80°W.

SEASON:WINTER MEAN V

LATITUDE	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0	-5
60.0 KM	-40	-30	-20	-8	5	45	85	125	135	120	90	65	25	-5	-15	-25	-35
57.5	-74	-52	-32	-18	-4	33	90	140	145	120	90	68	39	13	-6	-19	-34
55.0	-110	-75	-45	-30	-15	20	95	155	155	120	90	70	53	30	1	-15	-35
52.5	-139	-107	-72	-42	-27	9	98	158	155	115	85	68	52	30	8	-7	-37
50.0	-170	-140	-100	-55	-40	-3	100	160	155	110	80	65	50	30	15	0	-40
47.5	-172	-149	-124	-79	-47	-8	76	155	145	100	68	55	45	30	18	5	-24
45.0	-175	-160	-150	-105	-55	-15	52	150	135	90	55	45	40	30	20	10	-10
42.5	-189	-174	-162	-129	-74	-32	39	108	98	68	43	30	25	23	20	13	-2
40.0	-205	-190	-175	-155	-95	-50	25	65	60	45	30	15	10	15	20	15	5
37.5	-202	-199	-189	-164	-109	-52	15	50	48	33	18	2	0	7	12	12	7
35.0	-200	-210	-205	-175	-125	-55	5	35	35	20	5	-12	-10	-2	3	8	8
32.5	-179	-189	-192	-169	-127	-54	3	25	28	20	10	-3	-2	0	0	3	3
30.0	-160	-170	-180	-165	-130	-55	0	15	20	20	15	5	5	0	-3	-3	-2

SEASON:SPRING

60.0 KM	30	45	50	60	70	65	65	65	65	70	78	74	45	30	20	15	5
57.5	10	28	35	48	60	63	68	70	68	68	72	72	50	35	25	13	0
55.0	-10	10	20	35	50	60	70	75	70	65	65	70	55	40	30	10	-5
52.5	-19	-4	8	20	38	51	61	68	68	63	60	60	50	40	25	8	-9
50.0	-30	-20	-5	5	25	42	52	60	65	60	55	50	45	40	20	5	-15
47.5	-39	-29	-14	-4	10	24	39	51	57	53	48	43	36	30	18	8	-4
45.0	-50	-40	-25	-15	-5	5	25	42	49	45	40	35	30	20	15	10	5
42.5	-62	-50	-37	-22	-12	0	17	29	32	28	25	22	21	18	15	11	10
40.0	-75	-62	-50	-30	-20	-5	8	15	15	10	10	8	12	15	14	12	15
37.5	-77	-65	-52	-32	-22	-7	4	10	13	10	11	10	10	12	10	10	13
35.0	-80	-70	-55	-35	-25	-10	0	5	10	10	12	12	8	8	6	8	10
32.5	-72	-59	-47	-32	-22	-9	0	8	10	11	12	12	9	8	7	7	7
30.0	-65	-50	-40	-30	-20	-10	0	10	10	12	12	12	10	8	8	6	4

SEASON:SUMMER

60.0 KM	53	55	50	45	40	35	35	30	35	40	43	50	48	45	38	32	25
57.5	48	52	52	50	46	42	41	38	41	46	52	60	57	53	44	19	8
55.0	42	48	53	55	52	49	47	45	46	52	60	70	65	60	50	5	-10
52.5	39	42	47	52	53	52	51	50	51	56	58	62	59	56	50	18	-9
50.0	35	35	40	48	53	55	55	55	55	60	55	53	52	51	50	30	-10
47.5	30	29	30	34	38	41	45	50	48	50	44	39	38	38	39	30	8
45.0	25	22	20	20	23	26	35	45	40	40	33	25	23	25	28	30	26
42.5	22	20	18	18	19	22	25	29	25	23	19	13	11	15	20	23	22
40.0	18	18	16	15	15	18	15	12	10	6	4	0	-1	4	12	16	18
37.5	17	17	17	17	16	16	13	11	9	7	5	3	0	0	4	8	9
35.0	16	16	18	16	16	14	11	9	7	7	6	6	0	-4	-4	-1	0
32.5	13	13	14	13	12	11	10	9	8	8	8	7	2	0	-1	0	-1
30.0	10	10	9	7	7	8	8	8	9	9	9	7	4	2	0	-1	-3

SEASON:AUTUMN

60.0 KM	-65	-60	-60	-55	-50	-15	20	55	60	60	55	53	50	25	15	4	-8
57.5	-72	-64	-62	-52	-39	-4	35	68	70	69	63	52	45	28	18	2	-13
55.0	-80	-70	-65	-50	-30	5	50	80	80	78	70	50	40	30	20	0	-20
52.5	-92	-82	-69	-49	-27	13	58	85	85	82	68	46	37	29	18	3	-14
50.0	-105	-95	-75	-50	-25	20	65	90	90	85	65	42	33	28	15	5	-10
47.5	-114	-99	-82	-52	-29	10	53	80	85	78	55	36	29	22	15	8	-2
45.0	-125	-105	-90	-55	-35	0	40	70	80	70	45	30	25	15	15	10	5
42.5	-124	-102	-84	-57	-39	-2	30	50	55	45	30	23	18	12	12	9	6
40.0	-125	-100	-80	-60	-45	-5	20	30	30	20	15	15	10	8	8	7	7
37.5	-117	-94	-72	-57	-44	-7	15	25	27	19	14	11	5	4	5	6	7
35.0	-110	-90	-65	-55	-45	-10	10	20	23	17	12	7	0	0	2	4	6
32.5	-89	-72	-54	-47	-37	-9	8	16	19	17	13	7	1	0	0	0	-1
30.0	-70	-55	-45	-40	-30	-10	5	12	14	16	14	7	2	0	-3	-6	-9

TABLE 10. Variance of meridional wind speed ($m^2 sec^{-2}$).

SEASON:WINTER VAR V

LATITUDE	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0	-5
60.0 KM	650	600	475	410	360	290	200	165	200	200	170	160	130	125	115	110	105
57.5	750	640	525	435	388	288	190	165	205	188	165	145	123	115	108	100	90
55.0	850	680	575	460	415	285	180	165	210	175	160	130	115	105	100	90	75
52.5	800	680	568	445	420	343	215	188	205	168	143	115	105	93	85	75	65
50.0	750	680	560	430	425	400	250	210	200	160	125	100	95	80	70	60	55
47.5	675	608	500	405	443	455	275	203	175	133	108	88	78	65	58	50	48
45.0	600	535	440	380	460	510	300	195	150	105	90	75	60	50	45	40	40
42.5	515	450	380	345	383	380	238	158	123	88	73	60	48	40	38	38	38
40.0	430	365	320	310	305	250	175	120	95	70	55	45	35	30	30	35	35
37.5	378	323	285	275	253	195	135	98	75	55	44	36	29	25	26	29	31
35.0	325	280	250	240	200	140	95	75	55	40	32	26	22	20	21	22	26
32.5	265	233	205	195	150	110	78	62	44	33	26	21	17	15	16	19	23
30.0	205	185	160	150	100	80	60	48	32	25	20	15	12	10	10	15	20

SEASON:SPRING

60.0 KM	150	135	130	120	125	130	120	100	105	100	105	100	105	105	100	95	90
57.5	155	138	125	105	105	115	108	88	85	75	75	73	77	80	80	74	69
55.0	160	140	120	90	85	100	95	75	65	50	45	45	48	55	60	52	47
52.5	138	125	110	88	75	83	75	63	57	48	40	40	44	49	51	45	41
50.0	115	110	100	85	65	65	55	50	48	45	35	35	40	43	42	37	35
47.5	115	103	93	78	65	61	53	44	44	43	34	31	33	35	35	32	31
45.0	115	95	85	70	65	57	50	38	40	40	32	27	26	26	27	27	26
42.5	98	83	75	68	63	55	45	37	35	35	29	24	23	23	24	24	23
40.0	80	70	65	65	60	52	40	35	30	30	25	21	20	20	21	21	20
37.5	78	70	64	59	55	39	32	28	25	26	22	18	18	18	16	17	16
35.0	75	70	63	53	50	25	23	20	20	21	18	15	15	15	15	12	12
32.5	70	60	52	42	35	20	19	16	16	17	14	12	13	13	12	11	11
30.0	65	50	40	30	20	15	15	12	12	12	9	9	10	10	9	9	9

SEASON:SUMMER

60.0 KM	50	52	55	60	60	65	85	100	110	120	125	130	130	125	125	115	105
57.5	38	39	43	46	48	53	64	74	80	93	100	105	108	110	110	100	83
55.0	25	26	30	32	35	40	43	47	50	65	75	80	85	95	95	85	60
52.5	20	21	25	29	32	35	38	40	44	55	62	65	68	72	70	63	49
50.0	15	16	20	26	28	30	32	32	37	44	48	50	50	48	45	41	38
47.5	14	15	18	22	25	27	28	28	31	38	39	39	40	42	39	37	35
45.0	12	14	16	18	21	24	24	24	25	31	30	28	30	35	32	32	31
42.5	11	12	12	13	16	17	18	20	22	26	27	26	26	29	28	28	27
40.0	9	9	8	8	10	10	12	16	18	21	23	23	22	22	23	23	22
37.5	8	8	7	7	8	8	10	12	13	16	19	20	19	19	20	19	19
35.0	7	7	6	6	6	6	7	8	8	10	14	18	16	16	16	15	15
32.5	7	7	6	6	6	5	6	6	7	9	11	12	13	13	13	12	12
30.0	6	6	5	5	5	4	4	4	5	7	7	7	9	9	9	8	8

SEASON:AUTUMN

60.0 KM	330	320	305	225	190	150	130	115	115	105	95	80	75	65	65	62	62
57.5	315	308	288	228	185	135	110	98	98	95	88	73	70	63	60	56	54
55.0	300	295	270	230	180	120	90	80	80	85	80	65	65	60	55	50	45
52.5	245	245	233	208	153	108	80	68	68	75	65	53	50	48	43	40	40
50.0	190	195	195	185	125	95	70	55	55	65	50	40	35	35	30	30	35
47.5	160	165	163	145	105	78	59	50	51	56	44	37	34	35	30	29	30
45.0	130	135	130	105	85	60	48	45	47	47	37	33	32	35	30	28	25
42.5	110	113	110	90	70	53	42	38	40	42	33	29	27	27	25	25	24
40.0	90	90	90	75	55	45	35	30	33	38	28	24	21	19	20	21	22
37.5	88	88	83	66	49	38	30	25	27	29	23	21	19	18	19	21	22
35.0	85	85	75	57	43	31	24	20	20	22	18	17	16	16	18	20	21
32.5	75	73	64	52	40	28	23	19	18	19	15	13	13	13	15	16	18
30.0	65	60	52	46	37	25	21	18	15	15	12	9	9	10	11	12	14

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TABLE 11. Covariance of zonal and meridional wind speed ($10^1\ m^2 sec^{-2}$).

SEASON:WINTER COV U-V

LATITUDE	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0	-5
60.0 KM	-35	-20	-10	10	15	20	20	20	15	10	5	5	4	3	1	-2	-5
57.5	208	203	208	205	195	173	165	175	333	285	203	123	-12	-33	-9	4	10
55.0	450	425	425	400	375	325	310	330	650	560	400	240	-30	-70	-20	10	25
52.5	1100	1013	913	775	638	413	355	403	700	510	325	170	-37	-74	-44	-2	18
50.0	1750	1600	1400	1150	900	500	400	475	750	460	250	100	-45	-80	-70	-15	10
47.5	1925	1875	1650	1355	1090	750	475	538	675	455	215	105	5	-54	-64	-39	-17
45.0	2100	2150	1900	1560	1280	1000	550	600	1000	450	180	110	55	-30	-60	-65	-45
42.5	1390	1575	1625	1430	1265	1100	825	825	1025	475	190	135	83	18	-32	-49	-57
40.0	680	1000	1350	1300	1250	1200	1100	1050	1050	500	200	160	110	65	-5	-35	-70
37.5	315	550	888	1100	1185	1200	1150	1025	850	425	205	155	125	78	8	-24	-64
35.0	-50	100	425	900	1120	1200	1200	1000	650	350	210	150	140	90	20	-15	-60
32.5	-174	-59	143	600	810	925	950	820	560	300	203	145	118	65	15	-12	-62
30.0	-300	-220	-140	300	500	650	700	640	470	250	195	140	95	40	10	-10	-65
SEASON:SPRING																	
60.0 KM	-260	-260	-175	-80	110	320	400	350	250	170	80	25	25	20	5	-30	-80
57.5	-204	-207	-149	-92	50	220	285	290	275	133	65	18	3	-29	-27	-34	-52
55.0	-150	-155	-125	-105	-10	120	170	230	300	95	50	10	-20	-80	-60	-40	-25
52.5	-179	-172	-129	-77	53	130	160	173	195	83	48	18	-7	-54	-54	-34	-27
50.0	-210	-190	-135	-50	115	140	150	115	90	70	45	25	5	-30	-50	-30	-30
47.5	-192	-152	-67	45	143	150	135	105	83	68	53	43	23	-9	-32	-27	-29
45.0	-175	-115	0	140	170	160	120	95	75	65	60	60	40	10	-15	-25	-30
42.5	-82	23	103	190	190	168	130	100	85	58	60	58	43	15	-2	-12	-17
40.0	10	160	205	240	210	175	140	105	95	50	60	55	45	20	10	0	-5
37.5	143	210	210	208	168	140	125	108	90	45	53	45	38	20	13	8	3
35.0	275	260	215	175	125	105	110	110	85	40	45	35	30	20	15	15	10
32.5	238	215	165	83	48	33	58	75	78	45	43	35	30	18	15	13	8
30.0	200	170	115	-10	-30	-40	5	40	70	50	40	35	30	15	15	10	5
SEASON:SUMMER																	
60.0 KM	120	40	-20	-25	-25	-20	-5	20	35	35	25	20	15	15	10	5	5
57.5	75	23	-12	-22	-29	-29	-24	-17	-14	-17	-24	-24	-22	-17	-14	-12	-7
55.0	30	5	-5	-20	-35	-40	-45	-55	-65	-70	-75	-70	-60	-50	-40	-30	-20
52.5	28	8	-3	-14	-29	-34	-39	-47	-47	-44	-47	-49	-39	-32	-22	-14	0
50.0	25	10	-2	-10	-25	-30	-35	-40	-30	-20	-20	-30	-20	-15	-5	0	20
47.5	23	13	2	-4	-13	-17	-19	-20	-13	-7	-9	-19	-19	-19	-6	3	25
45.0	20	15	5	0	-3	-5	-5	-1	2	4	0	-10	-20	-25	-8	5	30
42.5	20	18	10	5	1	0	5	10	11	10	1	-8	-17	-27	-18	-4	10
40.0	20	20	15	10	5	5	15	20	20	15	2	-8	-15	-30	-30	-15	-10
37.5	13	14	13	10	7	5	8	8	13	13	4	-8	-17	-22	-22	-12	-4
35.0	5	8	10	10	8	5	0	-5	5	10	5	-10	-20	-15	-15	-10	0
32.5	3	6	8	8	4	0	-3	-5	4	6	4	-6	-12	-7	-5	1	10
30.0	1	3	5	5	0	-5	-8	-7	2	6	3	-3	-5	-1	3	12	20
SEASON:AUTUMN																	
60.0 KM	-7	-5	-3	-7	-8	-4	2	8	15	15	5	5	10	15	15	5	0
57.5	172	168	156	142	136	128	114	109	98	18	-7	-17	-34	-37	-32	-22	-9
55.0	350	340	315	290	280	260	225	210	180	20	-20	-40	-80	-90	-80	-50	-20
52.5	333	333	318	300	285	265	238	220	190	80	5	-34	-64	-74	-64	-39	-17
50.0	315	325	320	310	290	270	250	230	200	140	30	-30	-50	-60	-50	-30	-15
47.5	288	303	310	308	295	273	245	223	188	133	48	-19	-37	-42	-34	-24	-19
45.0	260	280	300	305	300	275	240	215	175	125	65	-10	-25	-25	-20	-20	-25
42.5	225	240	263	273	270	248	223	193	135	90	43	-7	-19	-22	-22	-22	-27
40.0	190	200	225	240	240	220	205	170	95	55	20	-5	-15	-20	-25	-25	-30
37.5	158	170	188	203	200	170	153	135	103	45	5	-14	-19	-19	-17	-12	-14
35.0	125	140	150	165	160	120	100	100	110	35	-10	-25	-25	-20	-10	0	0
32.5	103	115	125	138	135	105	85	93	108	43	-12	-22	-22	-14	-2	8	15
30.0	80	90	100	110	110	90	70	65	105	50	-15	-20	-20	-10	5	15	30

TABLE 12. Covariance of temperature and meridional wind speed (10^1 m °K sec^{-1}).

SEASON:WINTER COV V-T

LATITUDE	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0	-5
60.0 KM	70	60	70	75	80	70	60	65	70	50	10	-5	-10	-5	5	10	25
57.5	-49	-49	-29	-17	-9	10	25	83	95	50	0	-12	-24	-17	-12	-7	-2
55.0	-170	-160	-130	-110	-100	-50	-10	100	120	50	-10	-20	-40	-30	-30	-25	-30
52.5	-142	-129	-84	-42	0	30	60	115	100	55	20	-9	-27	-22	-24	-22	-22
50.0	-115	-100	-40	25	100	110	130	130	80	60	50	0	-15	-15	-20	-20	-15
47.5	45	53	80	103	138	145	155	140	65	25	30	20	8	3	-2	-4	-9
45.0	205	205	200	180	175	180	180	150	50	-10	10	40	30	20	15	10	-5
42.5	178	210	215	210	213	220	220	195	88	-9	-2	13	13	10	8	0	-9
40.0	150	215	230	240	250	260	260	240	125	-10	-15	-15	-5	0	0	-10	-15
37.5	25	143	175	195	208	230	283	278	110	-4	-12	-7	0	3	3	-4	-7
35.0	-100	70	120	150	165	200	305	315	95	0	-10	0	5	5	5	0	0
32.5	-49	50	90	110	130	150	205	203	78	5	-12	-4	5	8	8	3	3
30.0	0	30	60	70	95	100	105	90	60	10	-15	-10	5	10	10	5	5

SEASON:SPRING

60.0 KM	60	50	45	45	50	40	40	35	20	5	-5	-5	-3	2	4	5	5
57.5	53	45	40	40	40	35	38	40	48	30	-2	-12	-1	2	-2	-7	-12
55.0	45	40	35	35	30	30	35	45	75	55.	0	-20	0	2	-10	-20	-30
52.5	65	58	48	46	43	40	38	40	60	53	0	-2	10	11	-2	-12	-22
50.0	85	75	60	60	55	50	40	35	45	50	0	15	20	20	5	-5	-15
47.5	130	100	80	70	63	60	50	43	45	45	13	18	20	20	10	0	-9
45.0	175	125	100	80	70	70	60	50	45	40	25	20	20	20	15	5	-5
42.5	168	140	115	98	85	75	60	51	45	40	23	20	18	18	14	6	-1
40.0	160	155	130	115	100	80	60	52	45	40	20	20	15	15	12	7	2
37.5	80	103	100	105	95	73	56	49	35	30	13	13	13	13	8	4	1
35.0	0	50	70	95	90	65	52	45	25	20	5	5	10	10	4	1	-1
32.5	-17	25	53	75	75	57	46	35	20	18	3	1	7	7	2	0	-1
30.0	-35	0	35	55	60	48	40	25	15	15	0	-3	3	4	0	-1	-2

SEASON:SUMMER

60.0 KM	-40	-15	5	15	15	12	10	7	7	5	5	2	-2	-2	0	1	1
57.5	18	25	33	35	35	39	43	44	51	53	33	21	4	0	0	-6	-14
55.0	75	65	60	55	55	65	75	80	95	100	60	40	10	0	0	-15	-30
52.5	58	48	43	40	45	55	63	68	78	63	23	0	-12	0	3	-4	-14
50.0	40	30	25	25	35	45	50	55	60	25	-15	-40	-35	0	5	5	0
47.5	33	28	23	23	28	35	43	48	53	25	-7	-22	-19	-2	-2	-4	-9
45.0	25	25	20	20	20	25	35	40	45	25	0	-5	-5	-5	-10	-15	-20
42.5	20	20	18	18	18	23	28	33	35	30	15	10	8	5	-2	-7	-14
40.0	15	15	15	15	15	20	20	25	25	35	30	25	20	15	5	0	-10
37.5	13	13	13	13	13	16	17	20	21	28	25	22	17	13	5	2	-3
35.0	10	10	10	10	11	12	13	14	16	20	20	18	14	10	5	3	2
32.5	9	9	8	8	9	10	11	12	14	16	16	14	11	9	6	5	4
30.0	7	7	6	6	7	7	8	9	11	11	12	10	8	8	6	6	5

SEASON:AUTUMN

60.0 KM	4	4	5	6	6	6	6	6	8	8	6	3	0	-2	0	1	2
57.5	-52	-57	-67	-76	-61	-36	8	18	7	4	4	-10	-14	-15	-14	-16	-16
55.0	-110	-120	-140	-160	-130	-80	10	30	5	0	1	-25	-30	-30	-30	-35	-35
52.5	-87	-84	-89	-134	-122	-69	15	33	18	-2	1	-7	-11	-12	-16	-21	-23
50.0	-65	-50	-40	-110	-115	-60	20	35	30	-5	0	10	7	4	-3	-8	-13
47.5	-49	-24	20	-54	-109	-64	18	28	33	-3	-2	4	3	2	-1	-5	-8
45.0	-35	0	80	0	-105	-70	15	20	35	-2	-5	-2	-1	0	-1	-3	-5
42.5	-49	10	83	33	-59	-37	13	18	28	-1	2	3	0	-2	-3	-4	-4
40.0	-65	20	85	65	-15	-5	10	15	20	-2	8	8	-1	-5	-6	-6	-4
37.5	-42	5	68	55	15	18	20	18	10	-10	0	2	0	-1	0	0	0
35.0	-20	-10	50	45	45	40	30	20	0	-20	-8	-5	0	1	4	5	4
32.5	-24	-14	25	30	33	33	25	18	8	-10	0	4	7	8	6	4	2
30.0	-30	-20	0	15	20	25	20	15	15	-2	8	12	14	14	8	3	-1

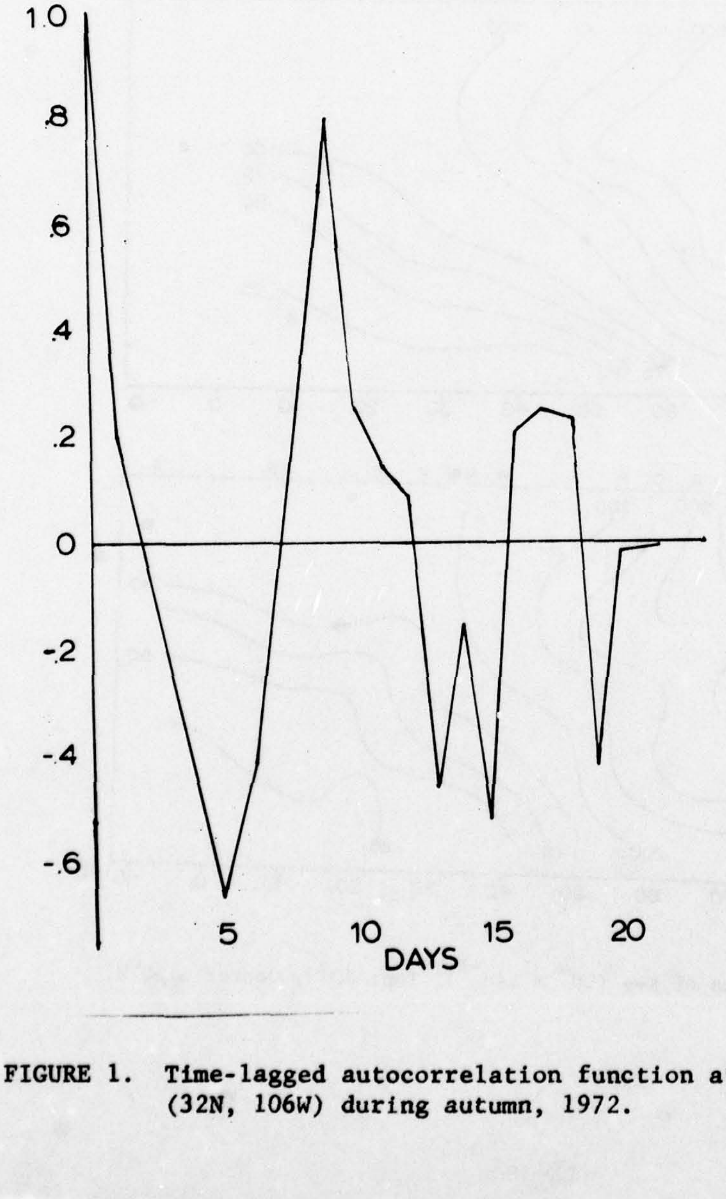
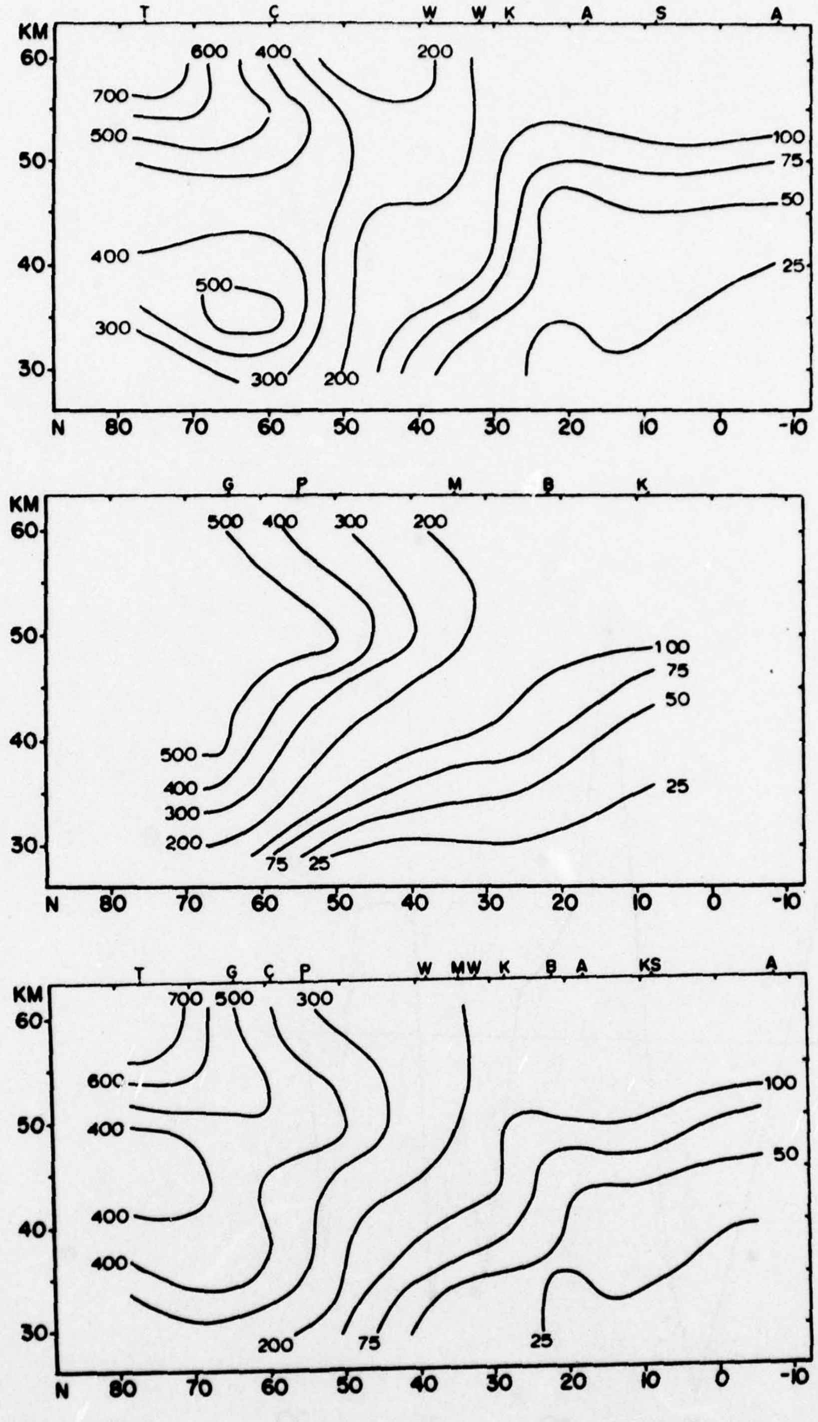
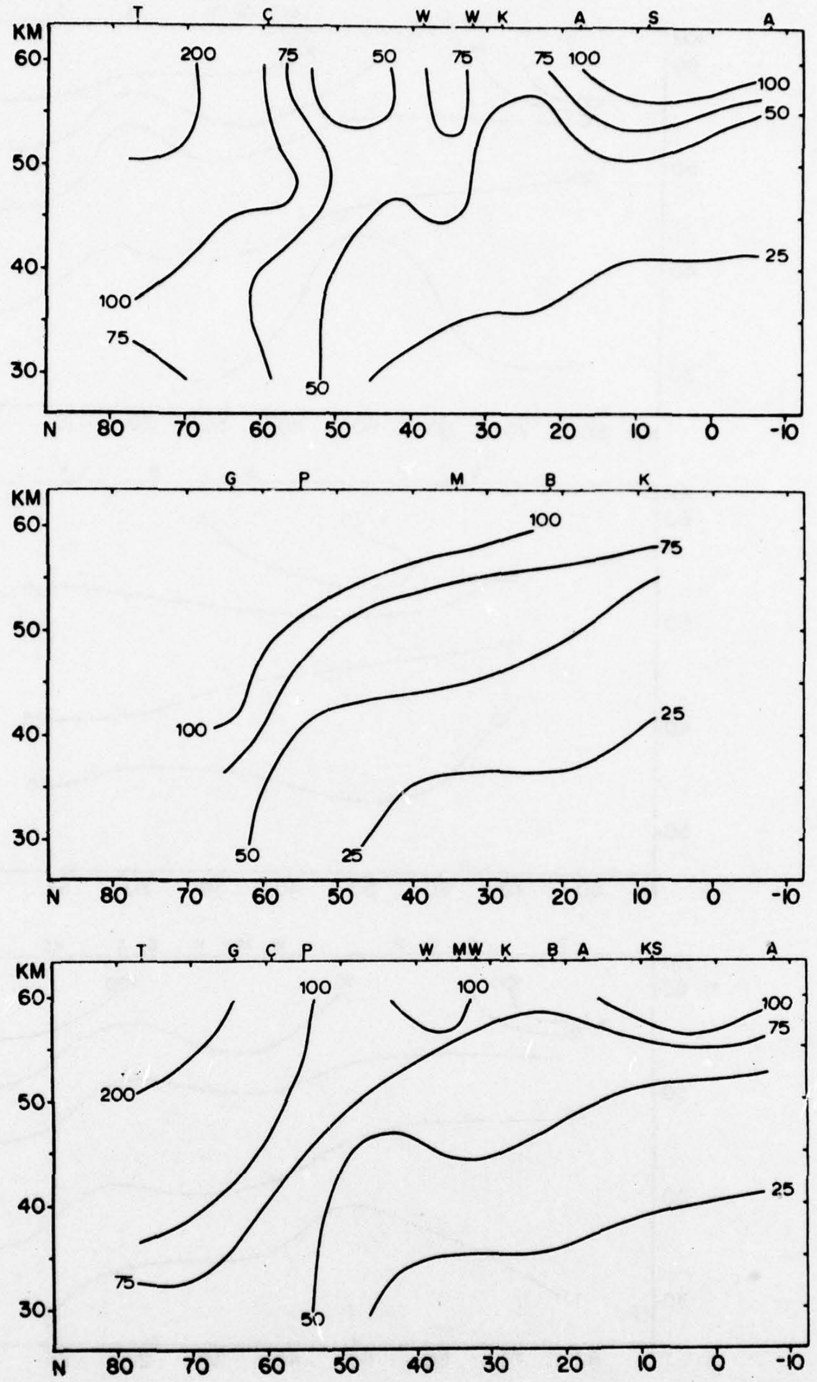


FIGURE 1. Time-lagged autocorrelation function at 30 km at White Sands (32N, 106W) during autumn, 1972.



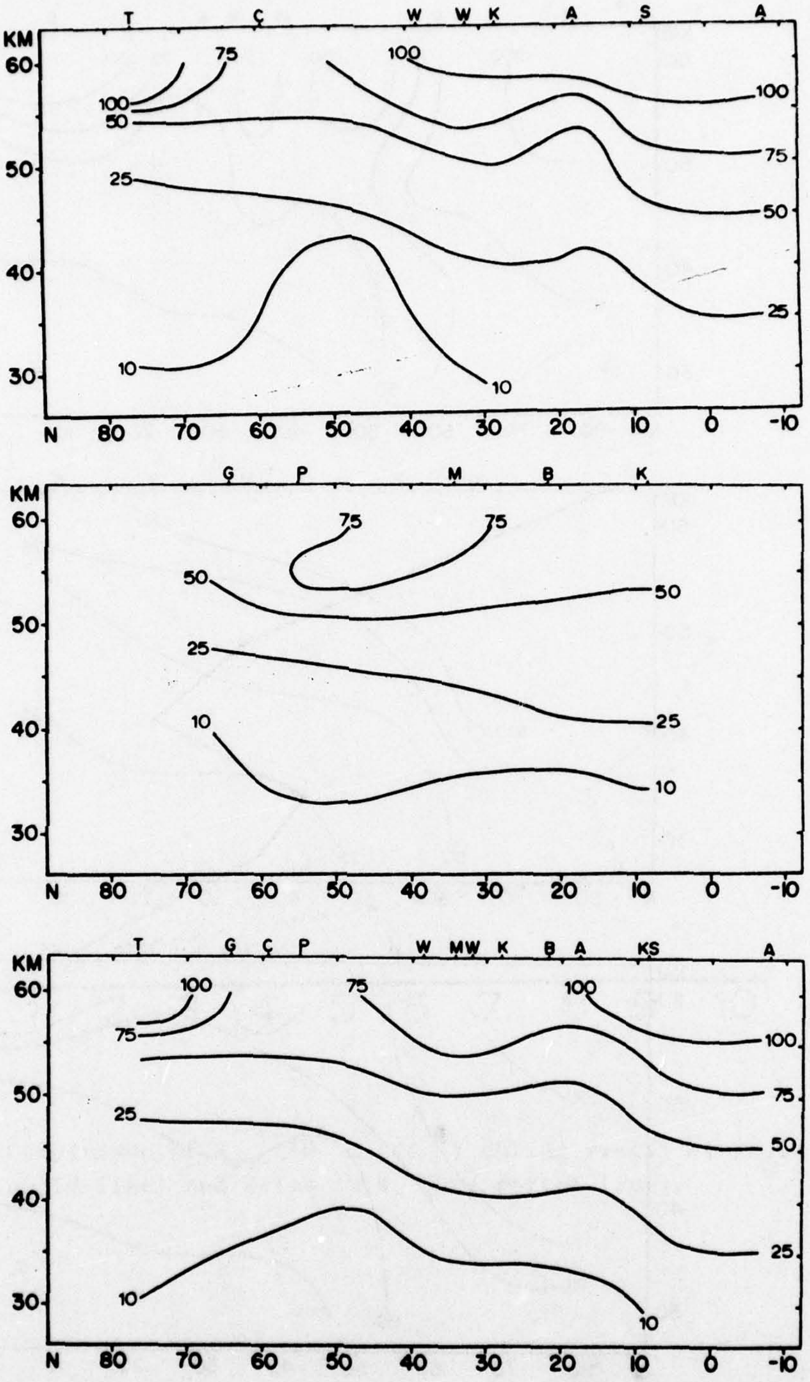
(a) WINTER

FIGURE 2. Seasonal values of Kyy ($10^4\ m^2 sec^{-1}$). Top: 80°W, Center: 150°W, Bottom: mean.



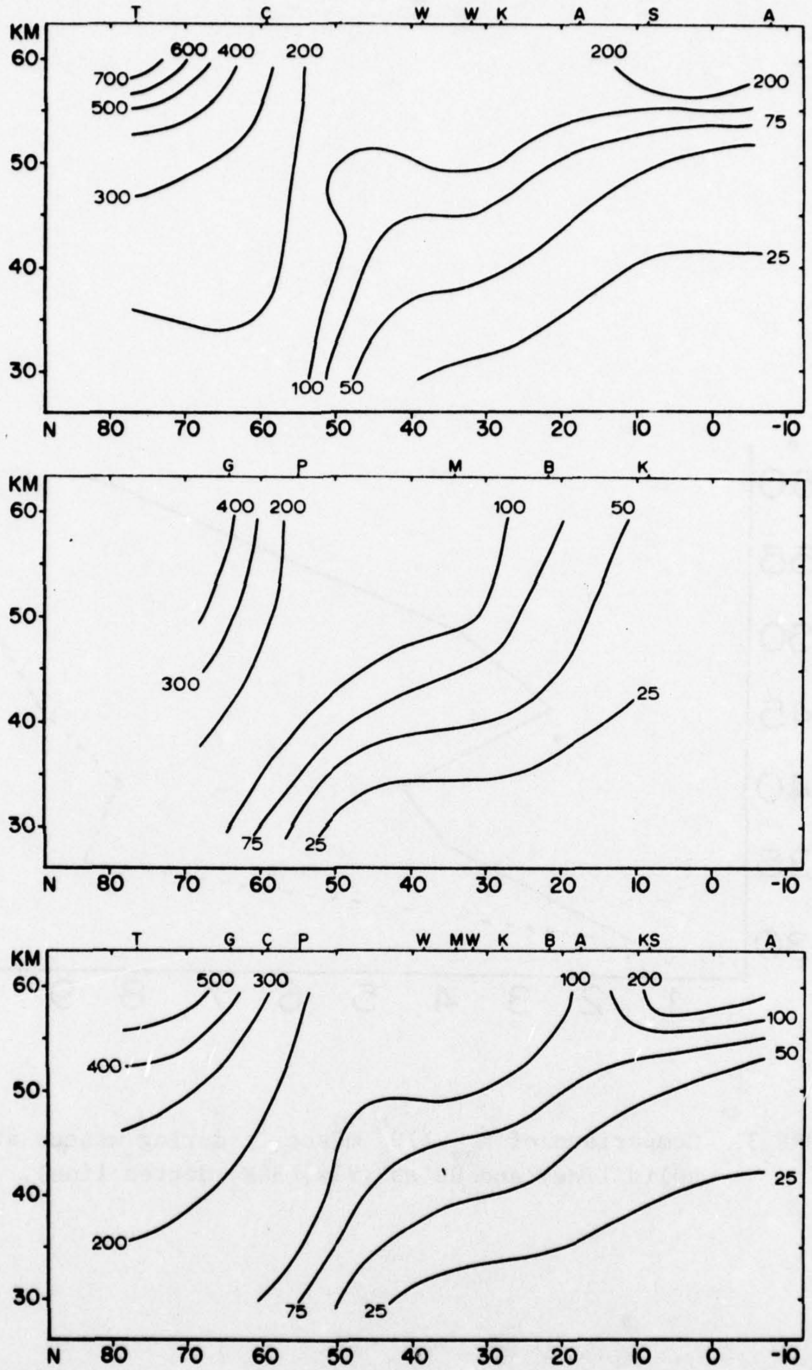
(b) SPRING

FIGURE 2. Continued.



(c) SUMMER

FIGURE 2. Continued.



(d) AUTUMN

FIGURE 2. Continued.

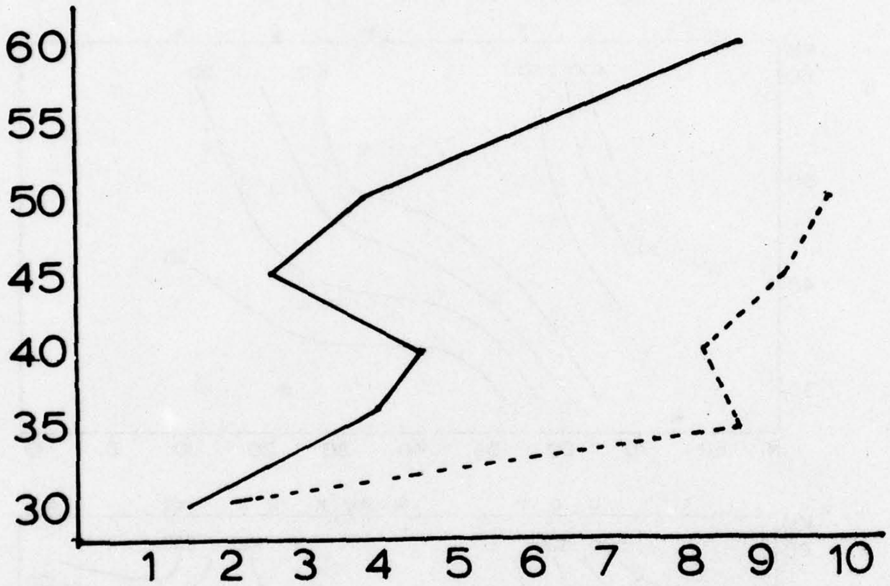
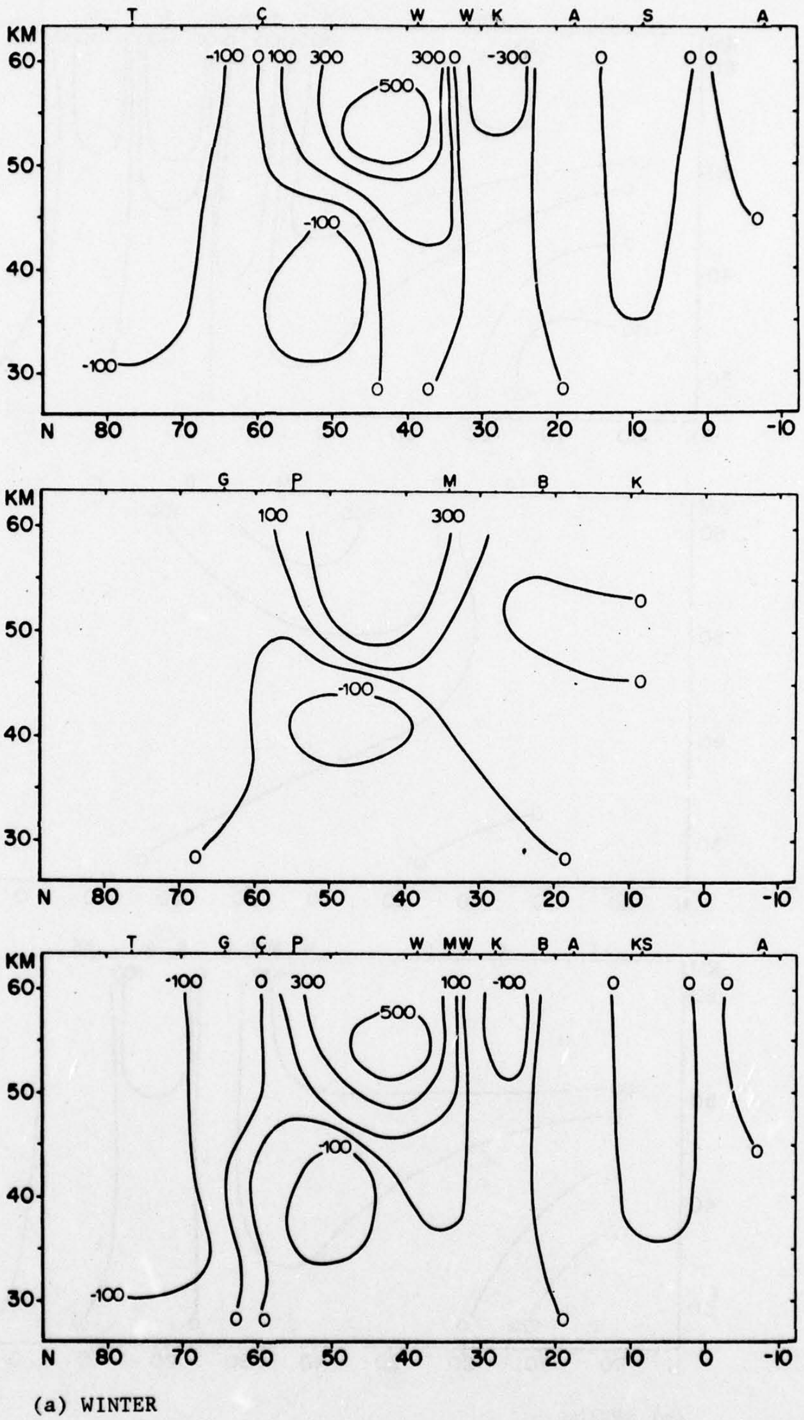
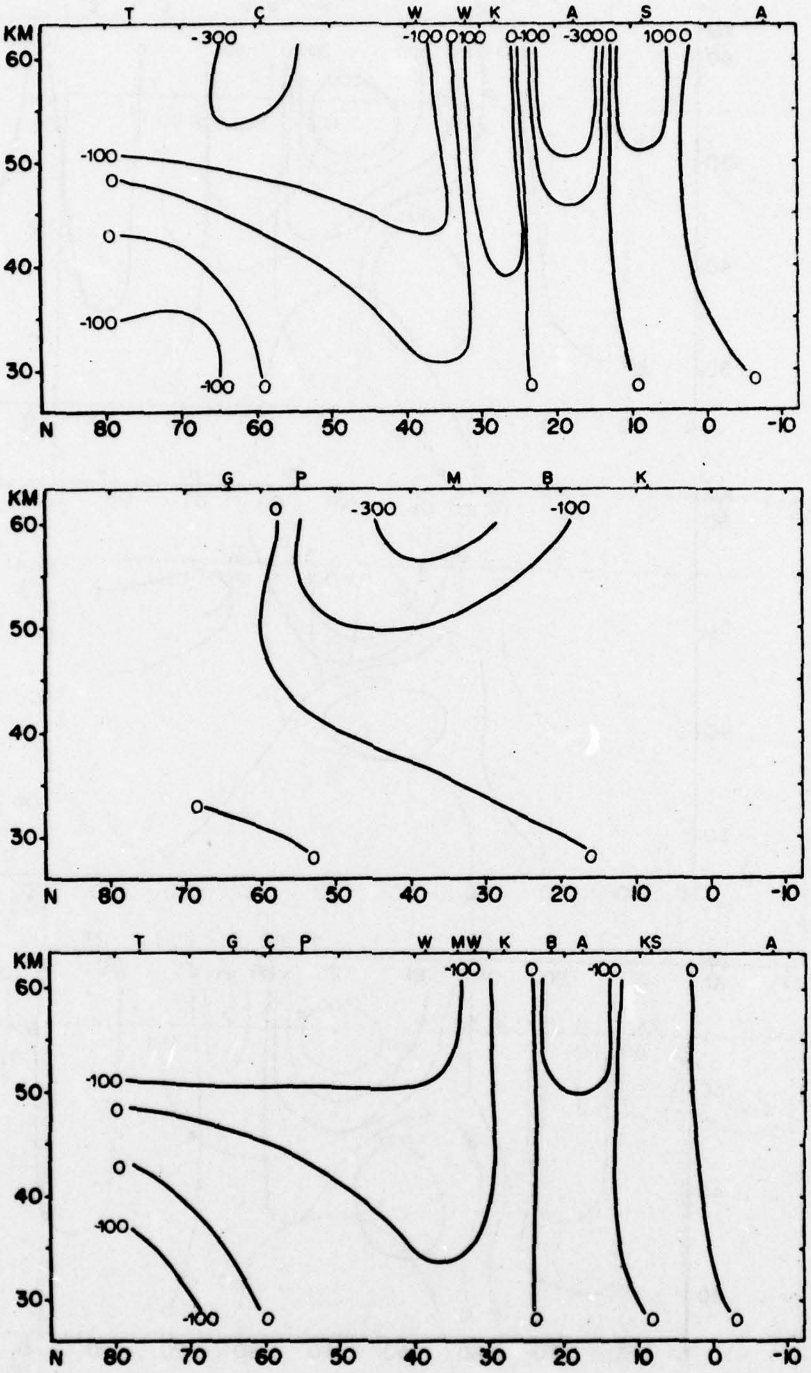


FIGURE 3. Comparison of K_{yy} ($10^4\ m^2 sec^{-1}$) during winter at Thule (77N, 69W, solid line) and Heiss (91N, 58E, dotted line).



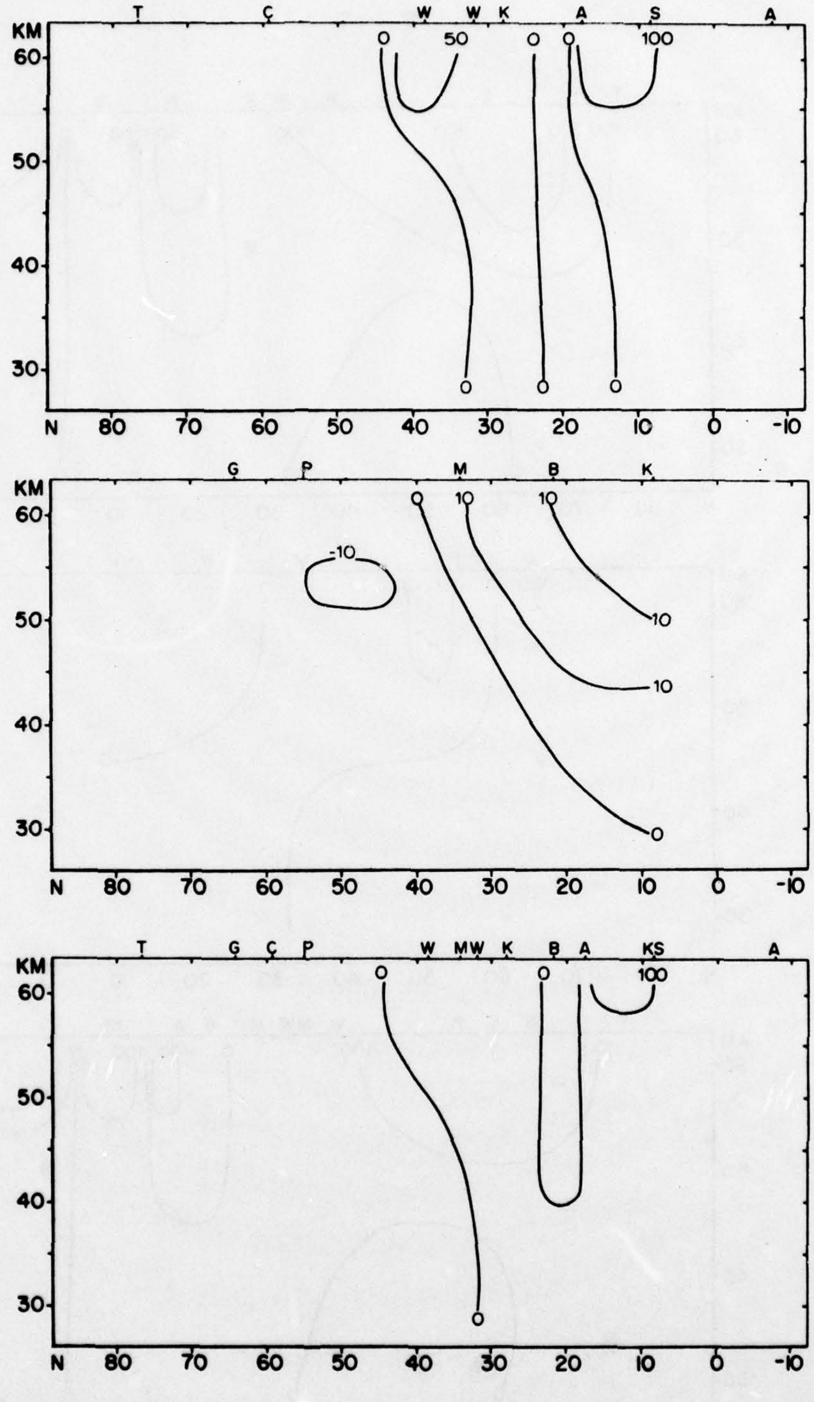
(a) WINTER

FIGURE 4. Seasonal values of K_{yz} (10^1 $m^2 sec^{-1}$). Top: 80°W, Center: 150°W, Bottom: mean.



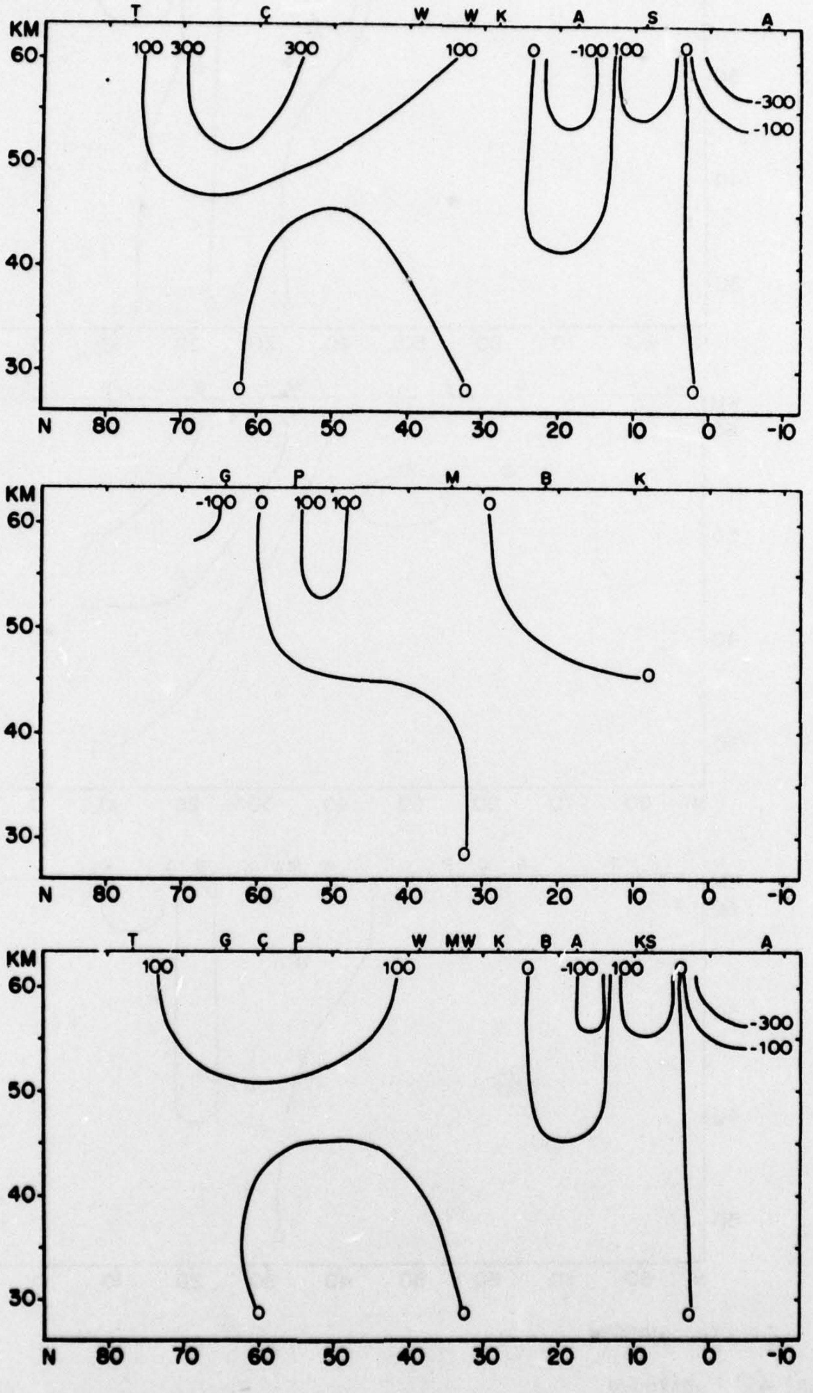
(b) SPRING

FIGURE 4. Continued.



(c) SUMMER

FIGURE 4. Continued.



(d) AUTUMN

FIGURE 4. Continued.

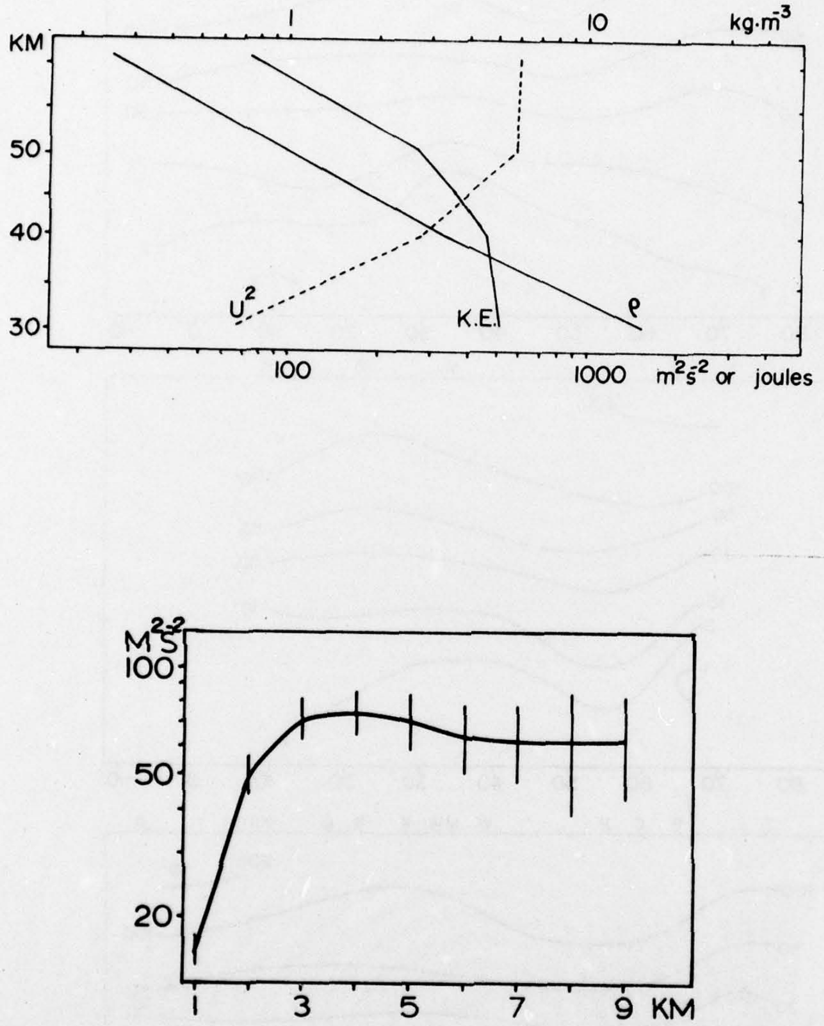
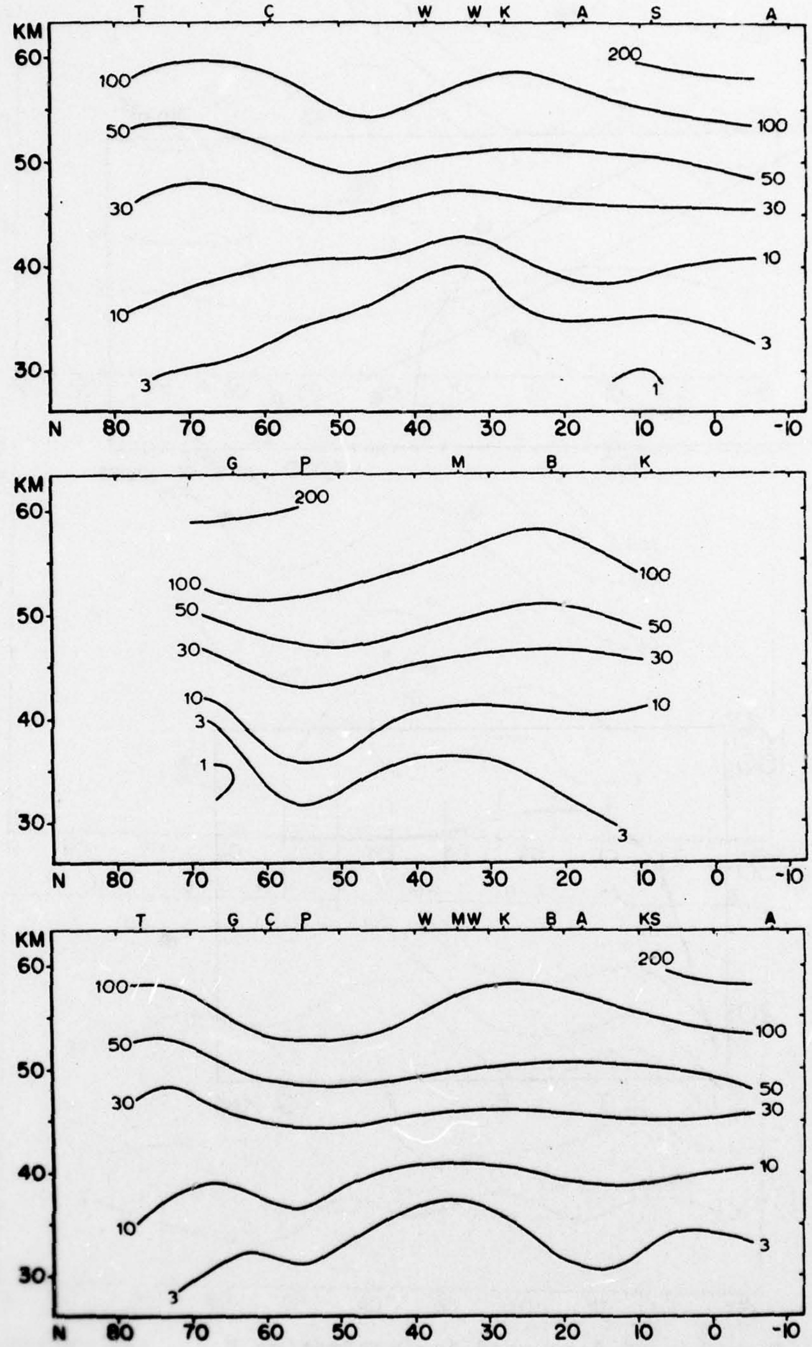
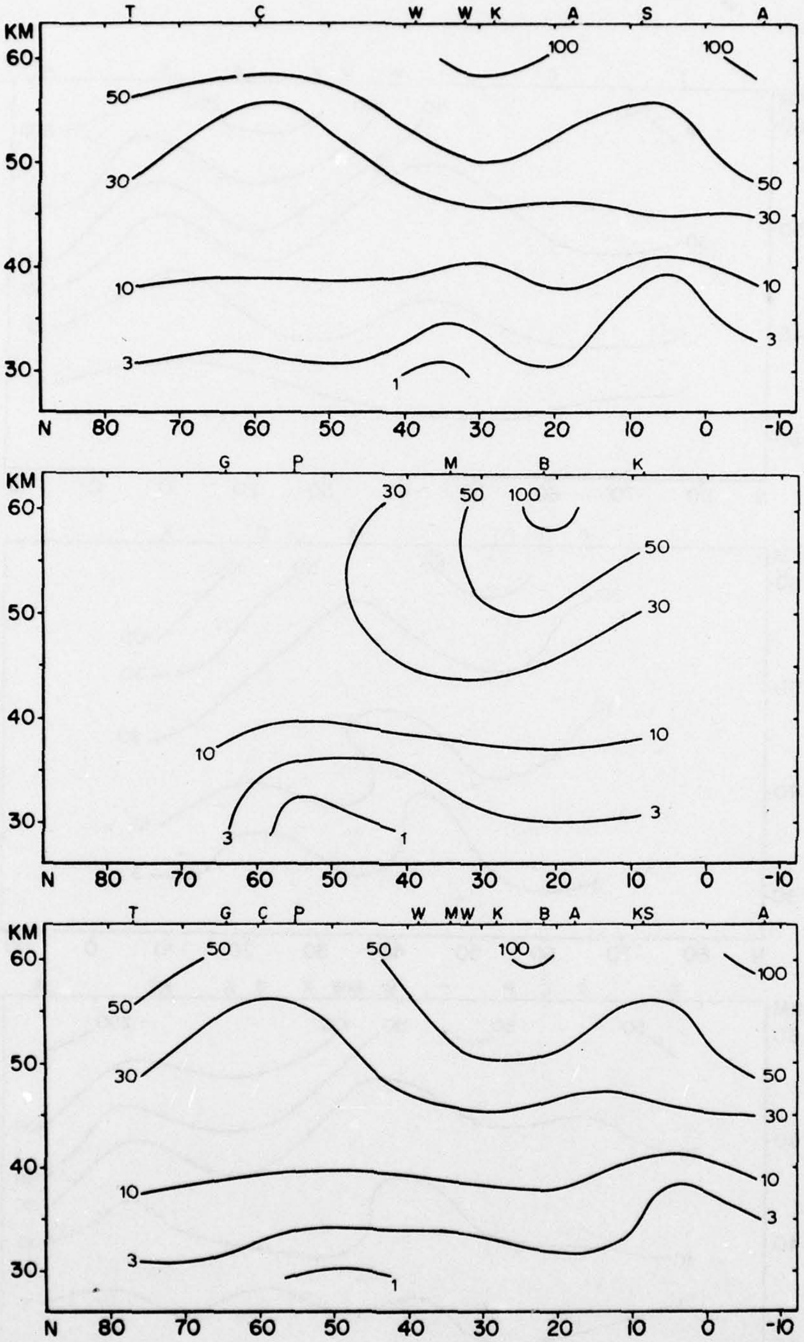


FIGURE 5. Examples of data used for estimating K_{ZZ}. (a) Vertical profiles of specific kinetic energy, density, and the square of the perturbation wind speed at Point Mugu during winter. (b) Magnitude of the vertical structure function (D(Z)) as a function of separation distance for the altitude range 52-64 km at Canaveral during autumn.



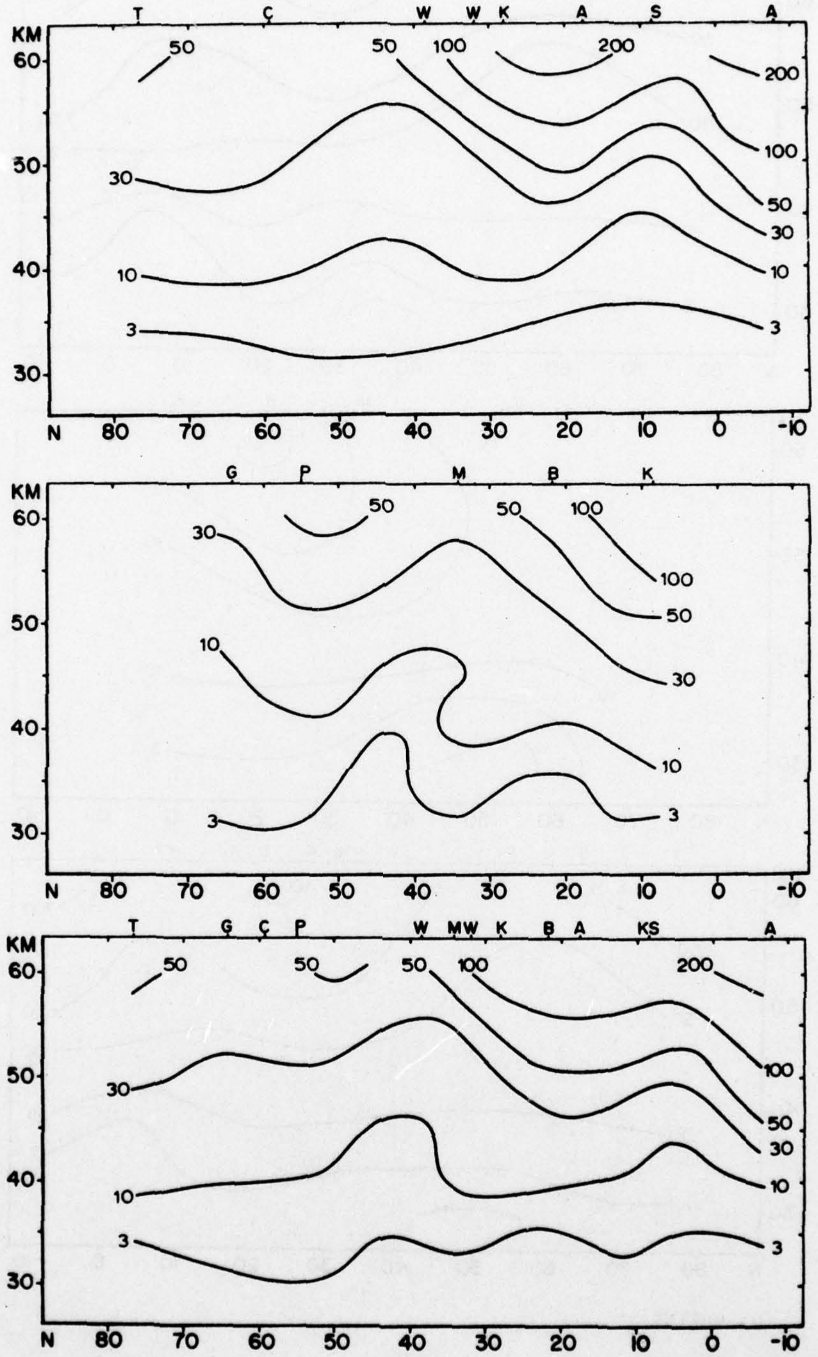
(a) WINTER

FIGURE 6. Seasonal values of K_{zz} ($m^2 sec^{-1}$). Top: 80°W, Center: 150°W, Bottom: mean.



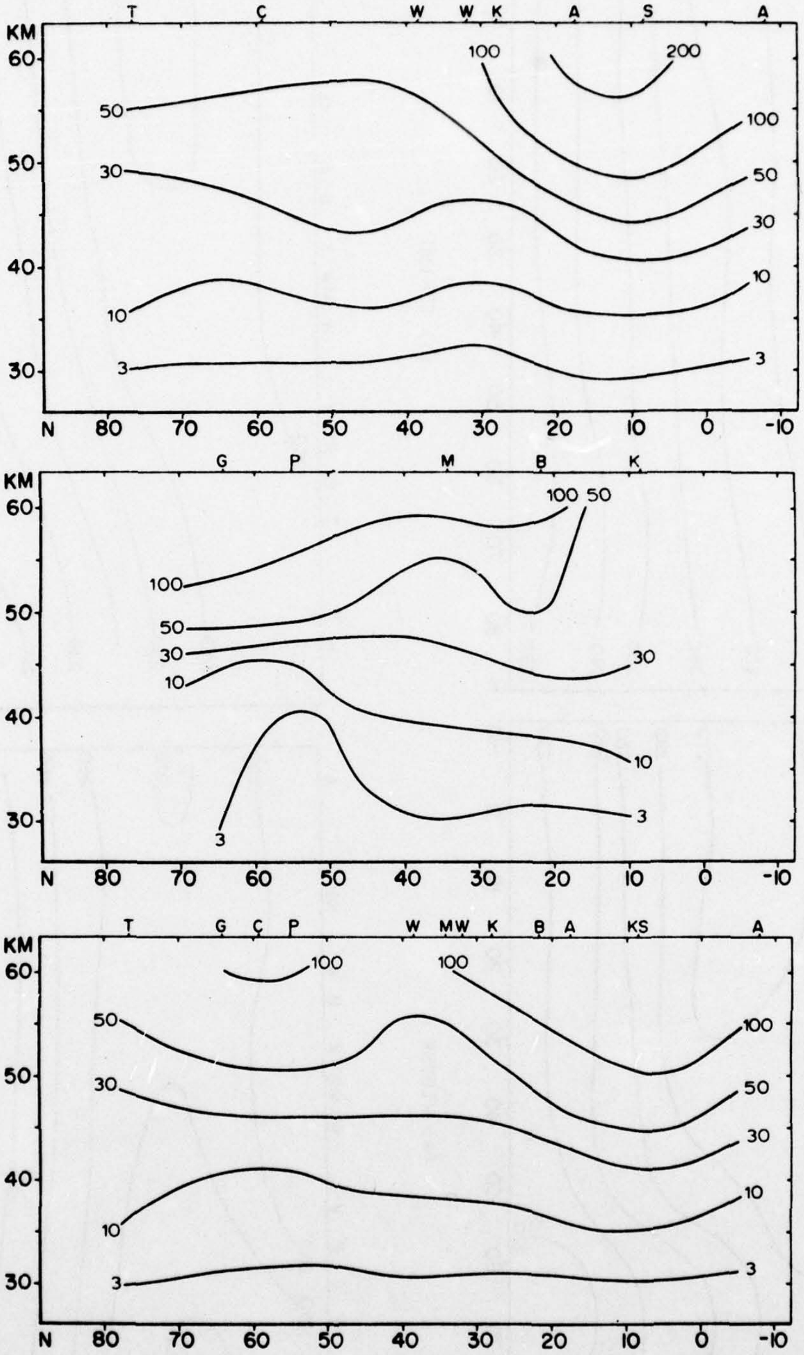
(b) SPRING

FIGURE 6. Continued.



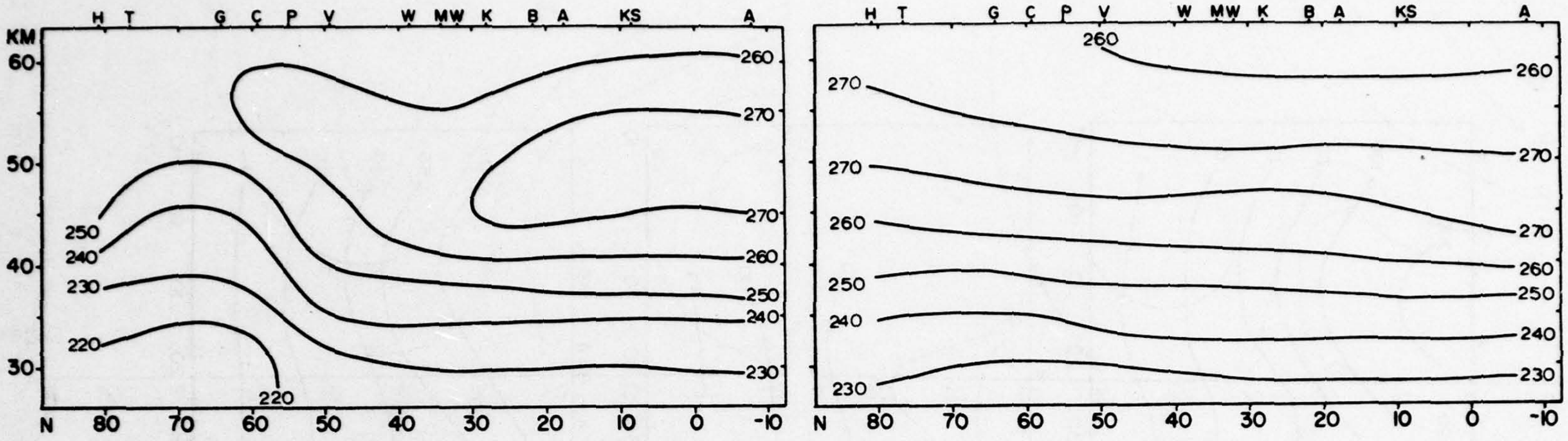
(c) SUMMER

FIGURE 6. Continued.

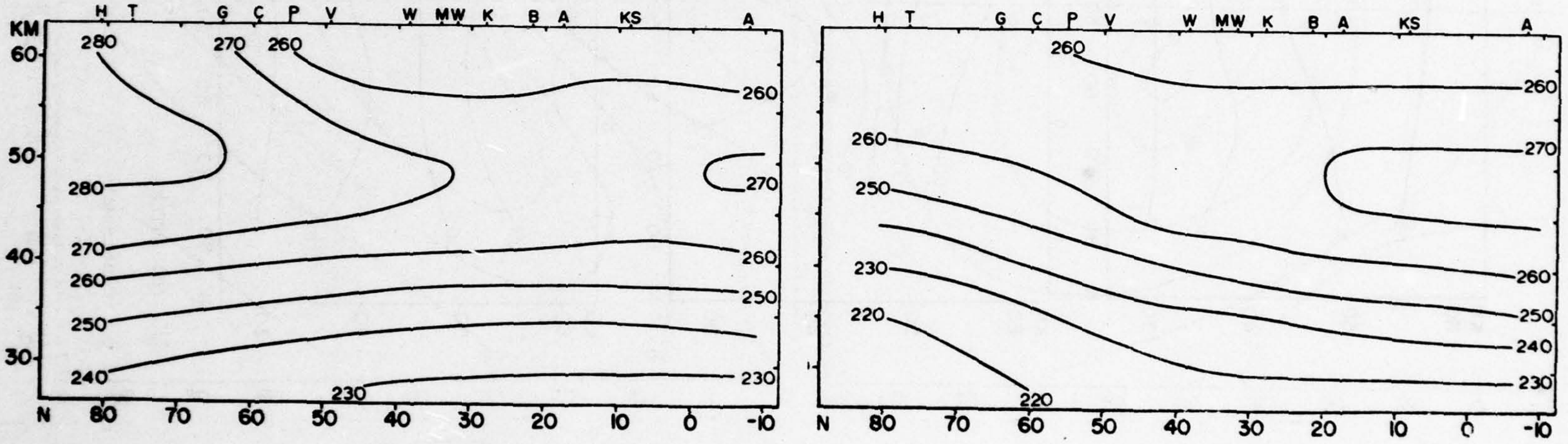


(d) AUTUMN

FIGURE 6. Continued.

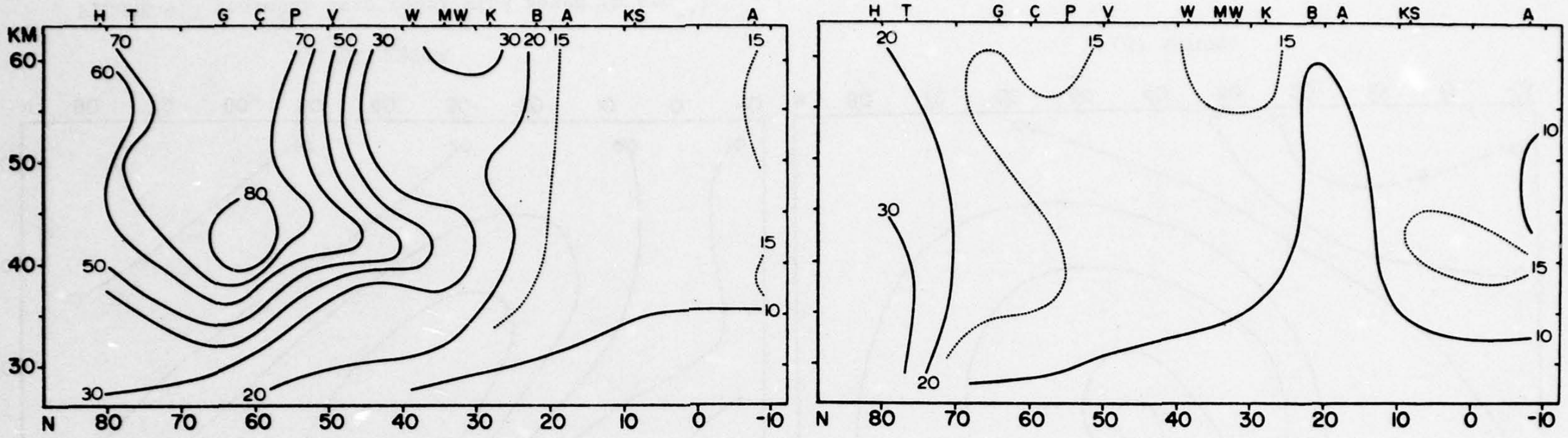


(a) WINTER (b) SPRING



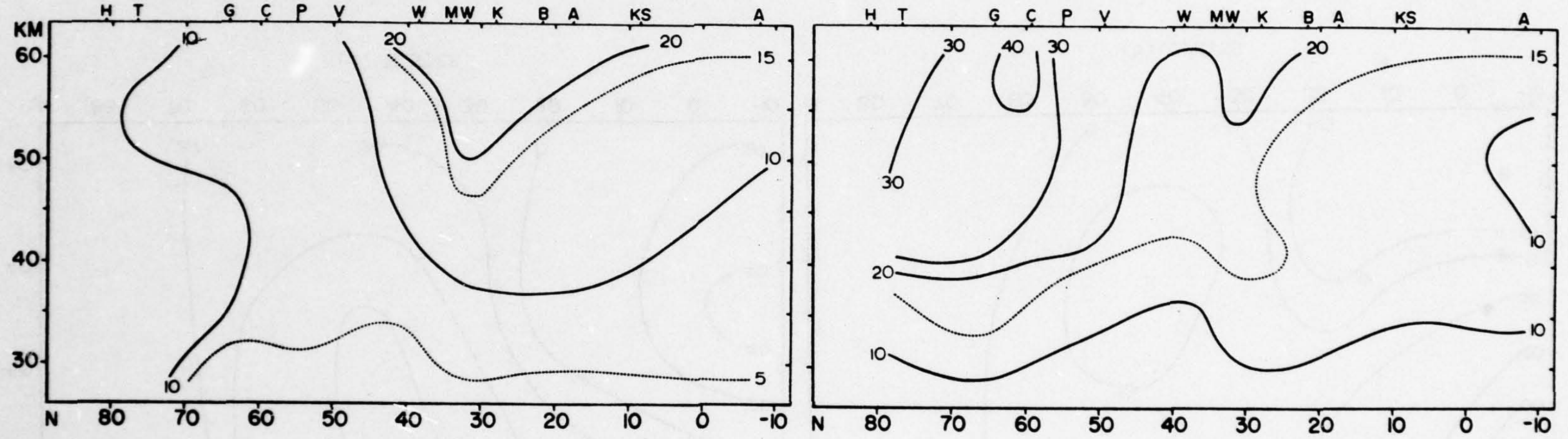
(c) SUMMER (d) AUTUMN

FIGURE 7. Seasonal mean temperatures (^{o}K).



(a) WINTER

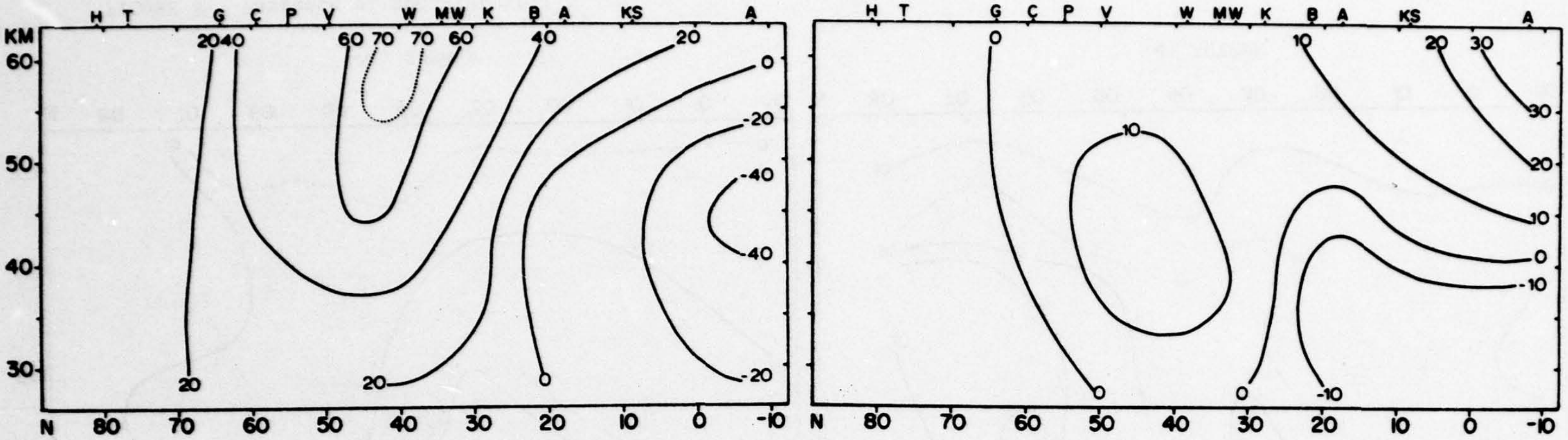
(b) SPRING



(c) SUMMER

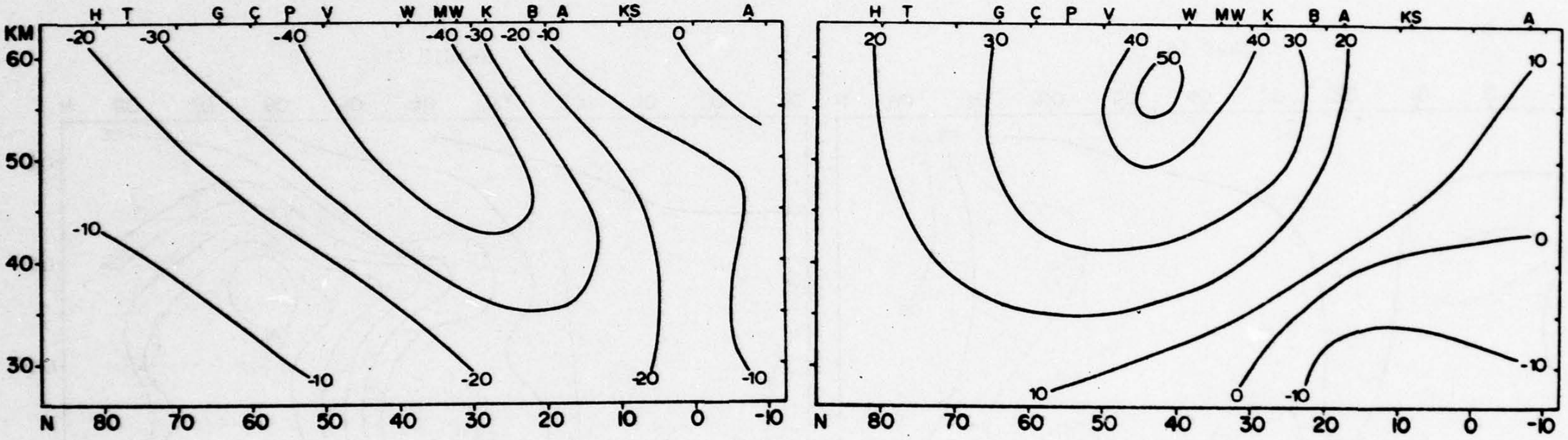
(d) AUTUMN

FIGURE 8. Variance of temperature ($^{o}K^{2}$).



(a) WINTER

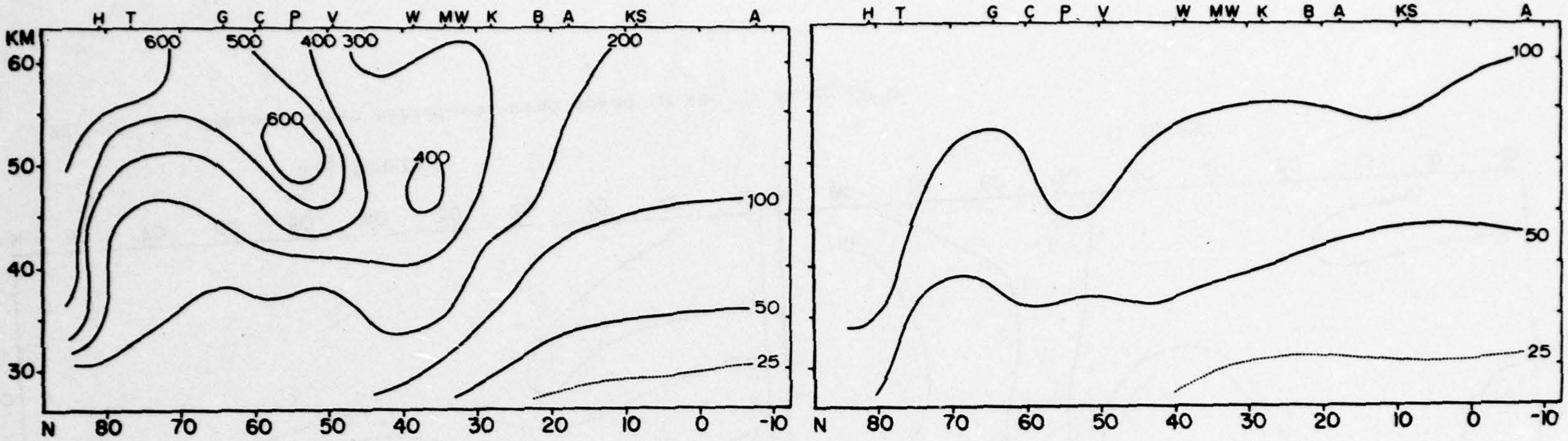
(b) SPRING



(c) SUMMER

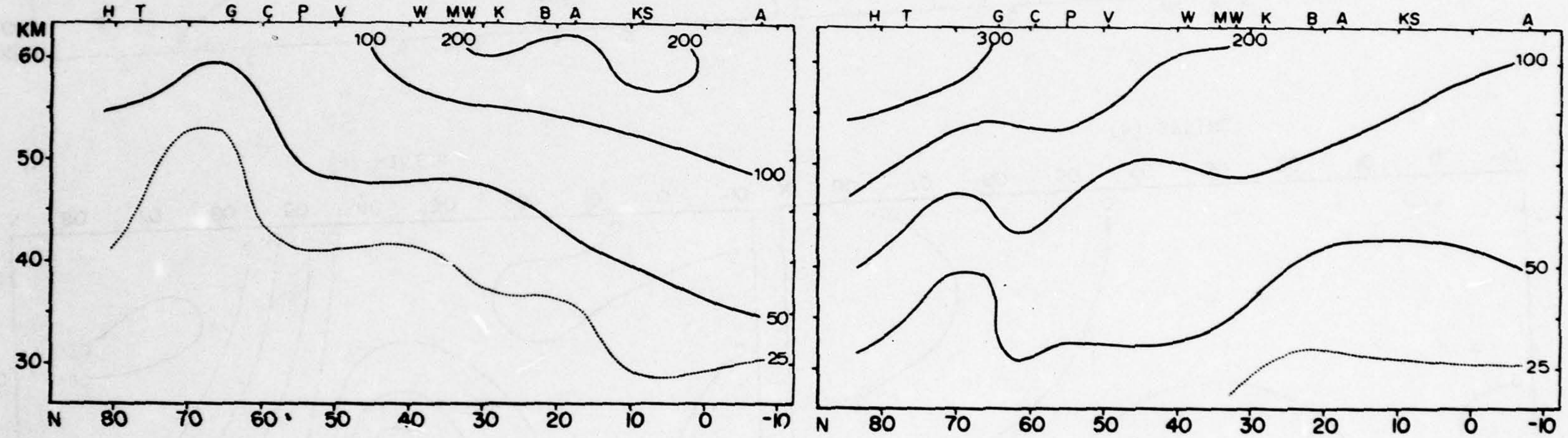
(d) AUTUMN

FIGURE 9. Seasonal mean zonal wind speed (m sec^{-1}).



(a) WINTER

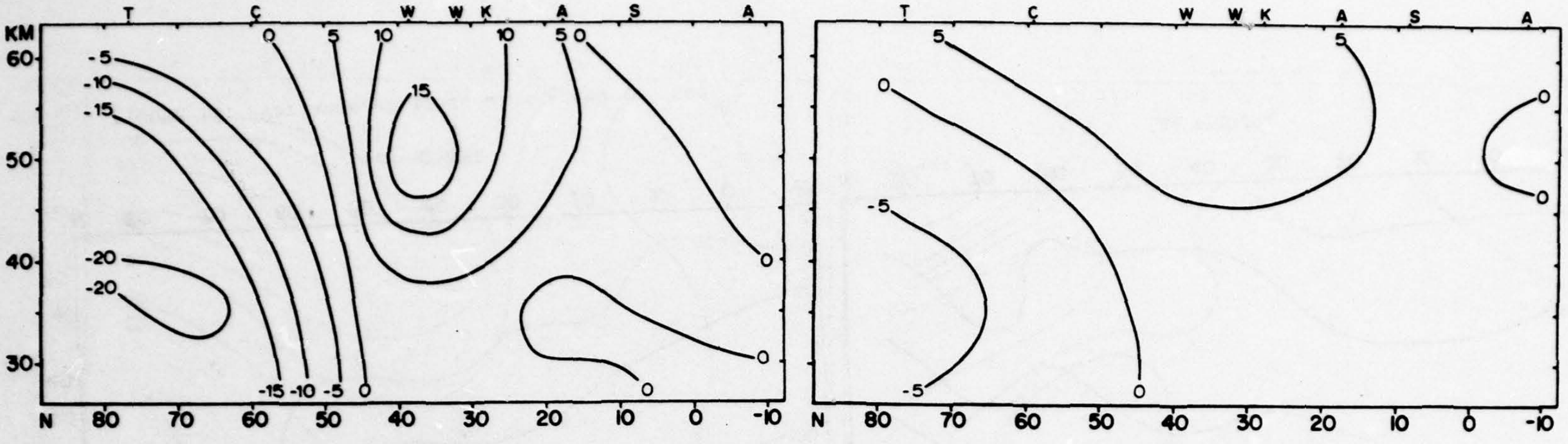
(b) SPRING



(c) SUMMER

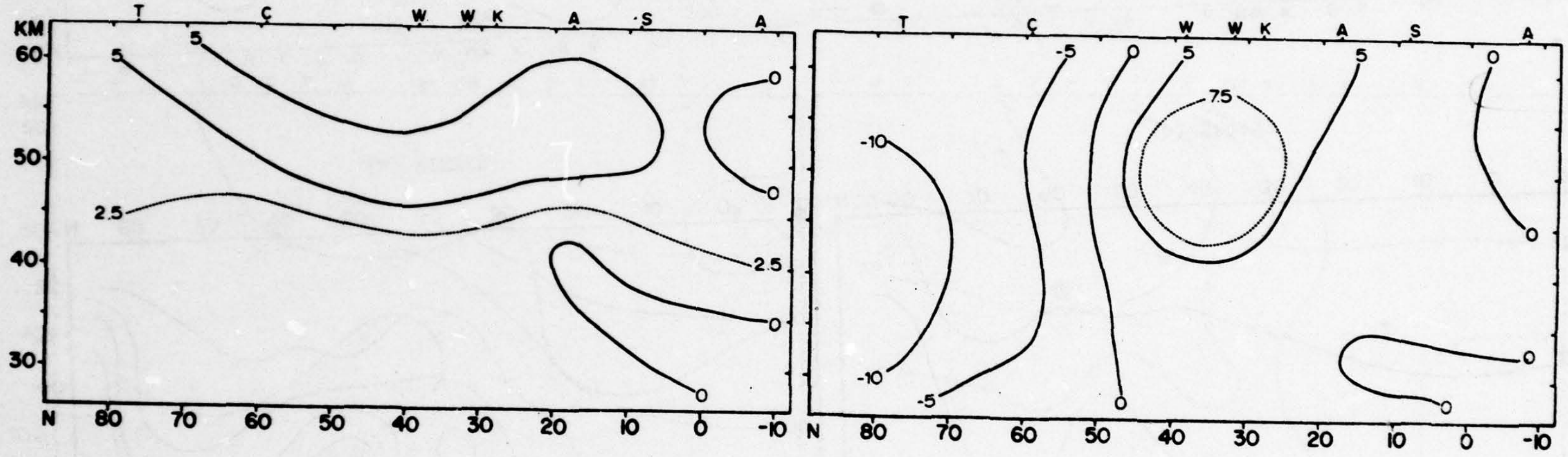
(d) AUTUMN

FIGURE 10. Variance of zonal wind speed (m^2 sec^{-2}).



(a) WINTER

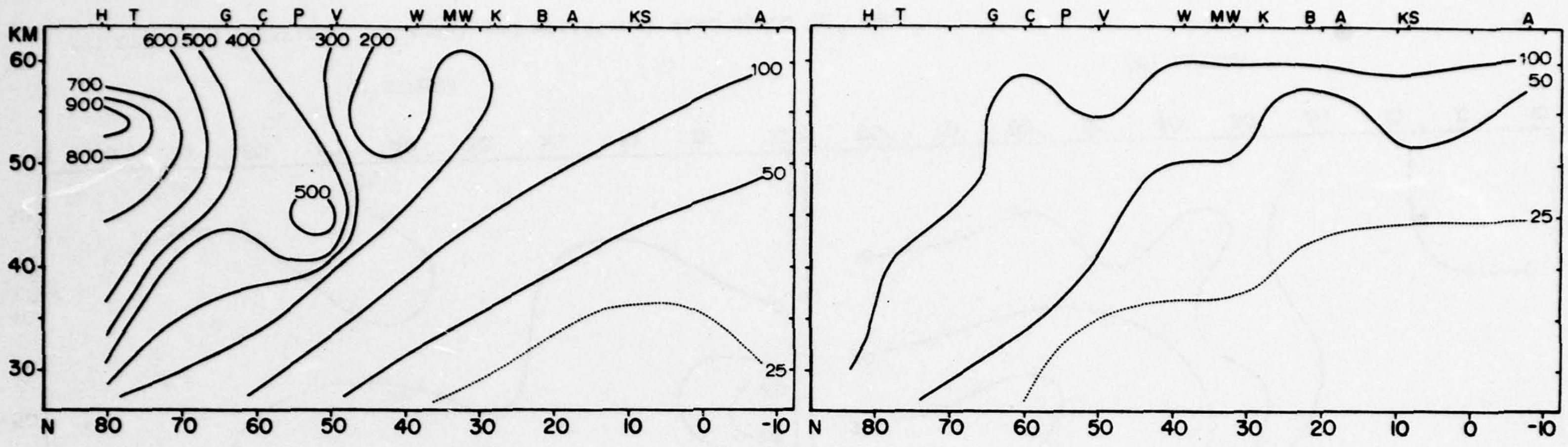
(b) SPRING



(c) SUMMER

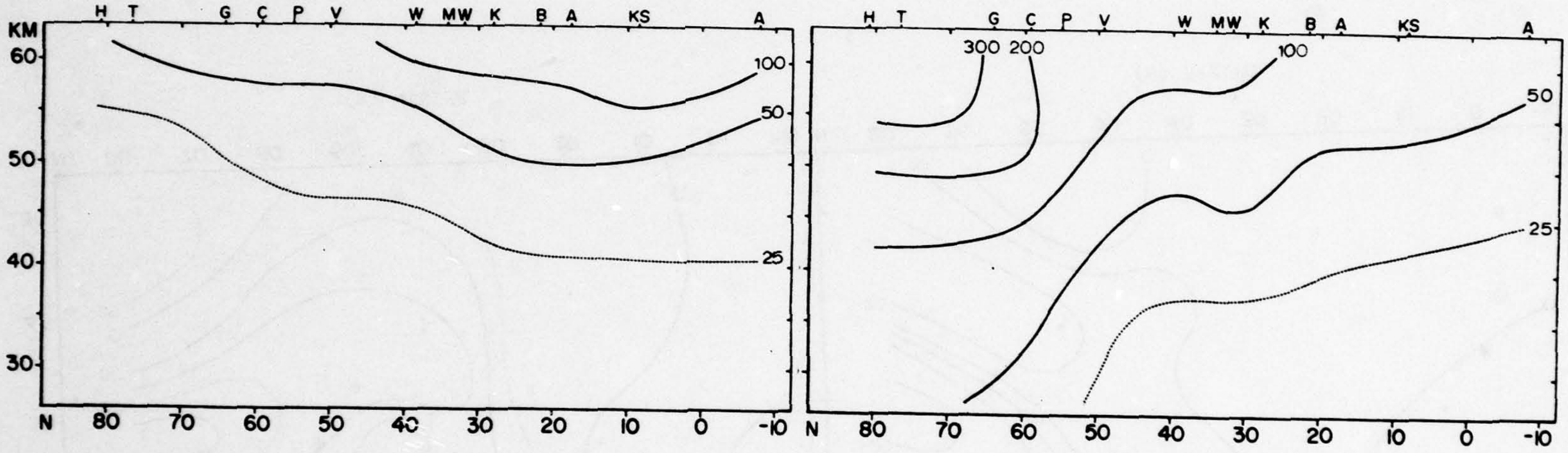
(d) AUTUMN

FIGURE 11. Seasonal mean meridional wind speed (m sec^{-1}) along 80^{o}W.



(a) WINTER

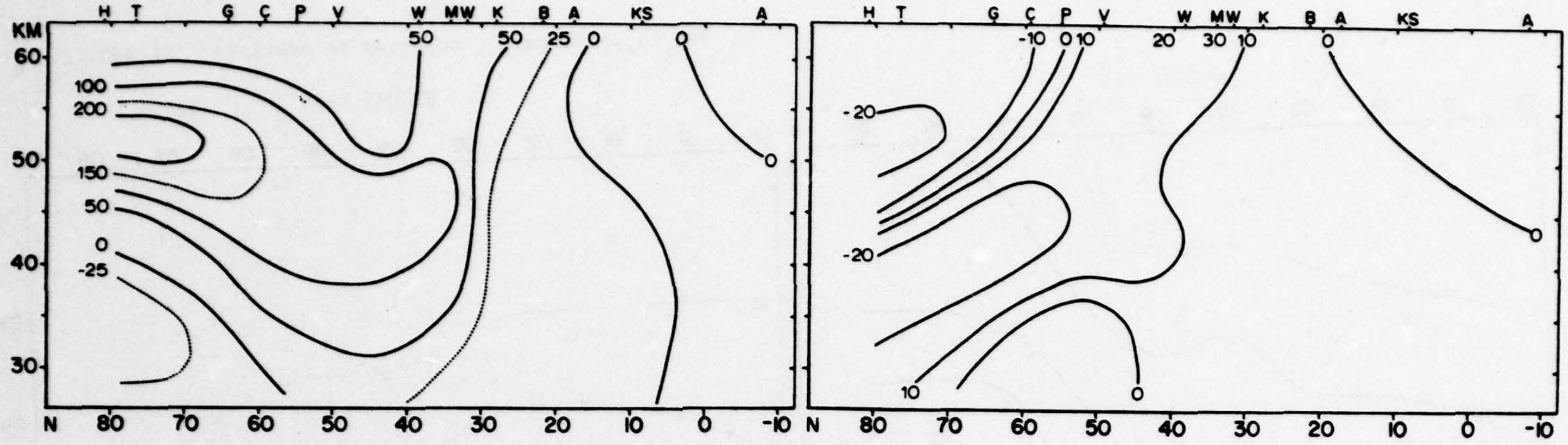
(b) SPRING



(c) SUMMER

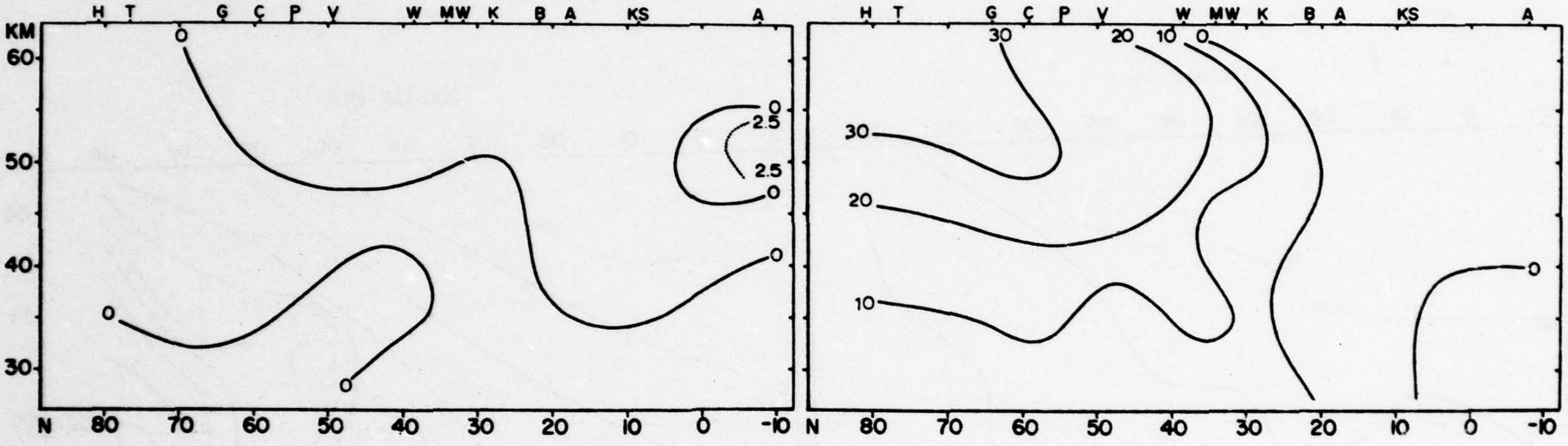
(d) AUTUMN

FIGURE 12. Variance of meridional wind speed (m^2sec^{-2}).



(a) WINTER

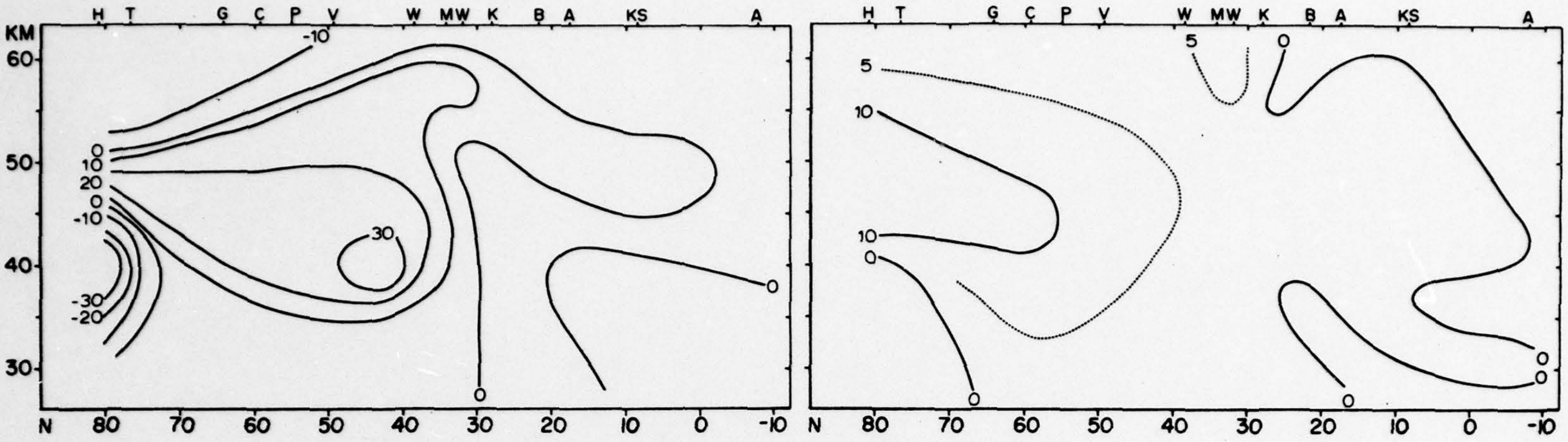
(b) SPRING



(c) SUMMER

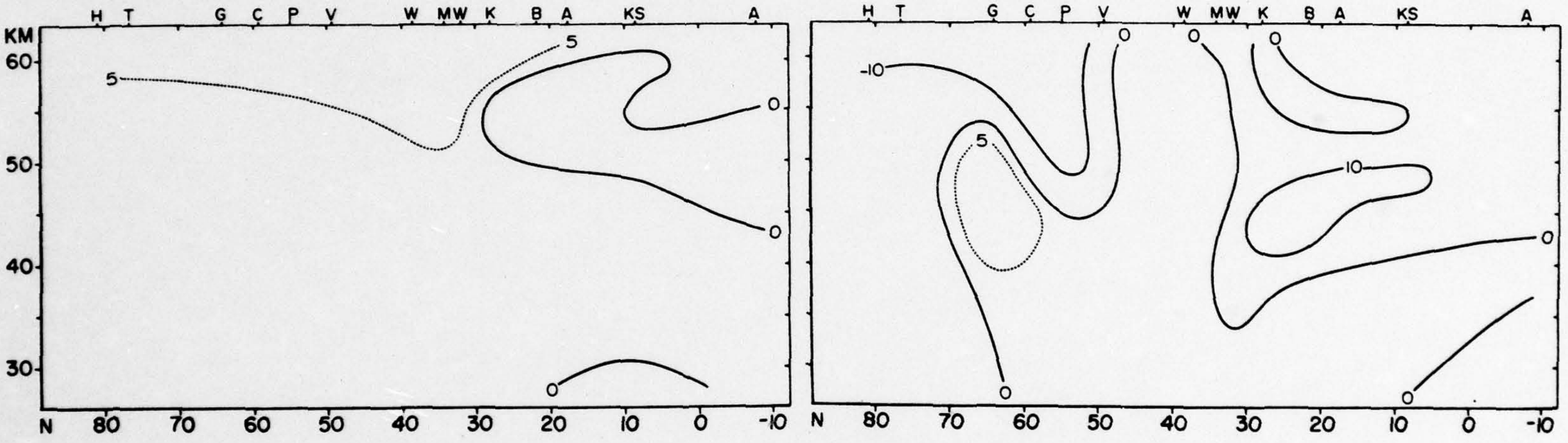
(d) AUTUMN

FIGURE 13. Covariance of zonal and meridional wind speed (m^2 sec^{-2}).



(a) WINTER

(b) SPRING



(c) SUMMER

(d) AUTUMN

FIGURE 14. Covariance of temperature and meridional wind speed (m K $\sec^{-1}$).