RELATIONSHIPS BETWEEN OZONE AND METEOROLOGICAL PARAMETERS IN THE LOWER STRATOSPHERE

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ABSTRACT

Relationships between atmospheric ozone and meteorological parameters in the lower stratosphere over Europe are studied. Correlation coefficients between total ozone amount and temperature, geopotential height, and north-south wind component at 100 mb are presented. The distribution of ozone amounts in relation to stratospheric troughs and ridges is shown.

High ozone amounts are found to be associated with high temperatures, low geopotential heights, southerly winds, and cyclonic-contour curvatures in the lower stratosphere. The results are discussed qualitatively in terms of stratospheric motions and the distribution of ozone.

1. Introduction

A knowledge of the interrelationships between ozone and meteorological processes in the atmosphere is of primary importance in explaining the observed distribution and variability of atmospheric ozone. In the present paper, we shall be concerned mainly with the day-to-day variability of ozone and its relationship to meteorological elements. Most of our information on ozone variability is based upon measurements of the total amount of ozone in a vertical column of the atmosphere because, at the present time, this is the only type of ozone measurement routinely made. There is only a small number of stations which take ozone observations, and most studies, including the present one, on ozone-meteorology interrelationships are of a statistical nature.

There has been a number of investigations in which ozone was correlated with various meteorological parameters in the upper troposphere and lower stratosphere. (See, for example, Meetham, 1937; Fritz and Stevens, 1950; Miyake and Kawamura, 1956; Johansen, 1958.) These studies show that ozone is fairly well correlated with the geopotential height, the temperature, and the tropopause height. The ozone-geopotential height correlation is negative for both troposphere and stratosphere, the ozone-temperature correlation is negative in the troposphere and positive in the stratosphere, and the ozone-tropopause height correlation is negative. For the most part, these studies have been confined to single stations with limited amounts of data. Relatively few papers have dealt with the seasonal variation of the correlation coefficients, and none has explored the latitudinal dependence of the coefficients. The present investigation is an attempt to define, from a larger sample of data for a number of stations, the correlations between ozone and meteorological parameters in the stratosphere, and to determine the seasonal and latitudinal variability, if any, of the correlation coefficients.

Several articles (Normand, 1953; Gowan *et al.*, 1956; Kawamura, 1957; and others) on ozone amounts in relation to the long-wave trough-ridge pattern at upper tropospheric levels indicate that, in general, relatively high ozone amounts are associated with troughs and relatively low ozone amounts are associated with ridges. Since there is more ozone in the lower stratosphere than in the upper troposphere, a change in stratospheric ozone content presumably has a greater effect upon the total ozone change than does a change in tropospheric ozone content. Therefore, a synoptic-statistical investigation of ozone in relation to stratospheric contour patterns is included in the present paper.

2. Computations of correlation coefficients

The ozone data consist of observations of the total amount taken by the European ozone network during 1956 and 1957. These data were kindly made available to us by Dr. C. W. B. Normand of the International Ozone Commission. Radiosonde data for the ozone-observing stations were obtained from the Northern Hemisphere Data Tabulations of the U.S. Weather Bureau. Several of the ozone-observing sites were in locations which do not take upper-air observations, and in these cases the nearest radiosonde reports were used. Table 1 presents a listing of the locations of the ozone-measuring sites and the corresponding radiosonde stations. The available meteorological data are for 03Z through March 1957 and 00Z thereafter; the ozone observations were taken during daylight which, for the European network, consists of the time period between about 06Z and 18Z.

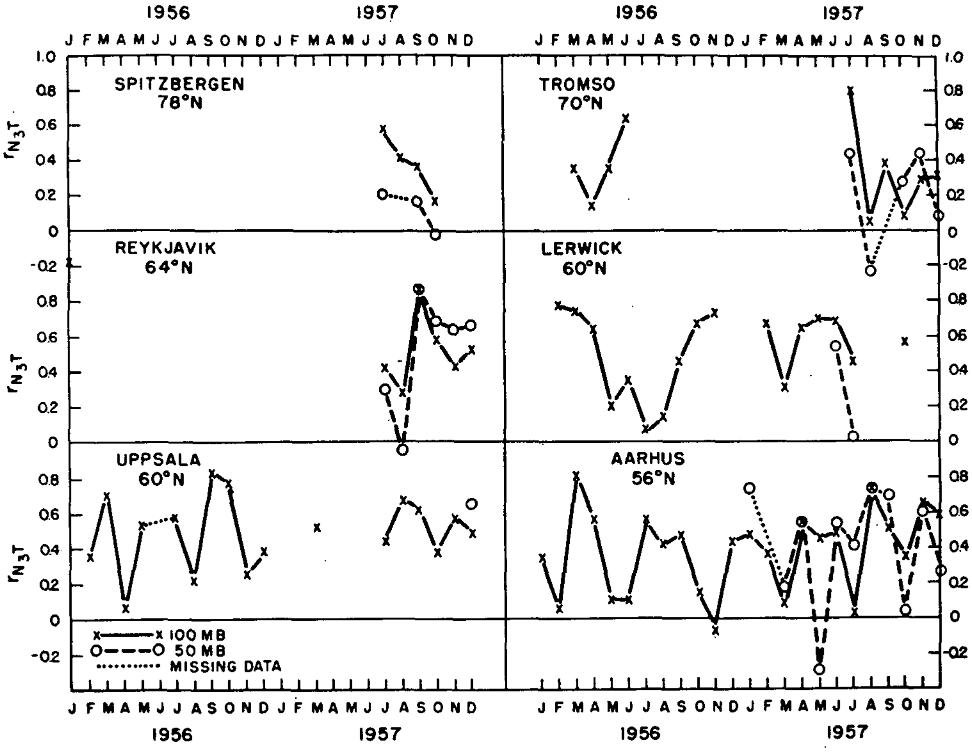

FIG. 1. Monthly values of total ozone — 100-mb-temperature correlation and total ozone — 50-mb-temperature correlation at several European stations.

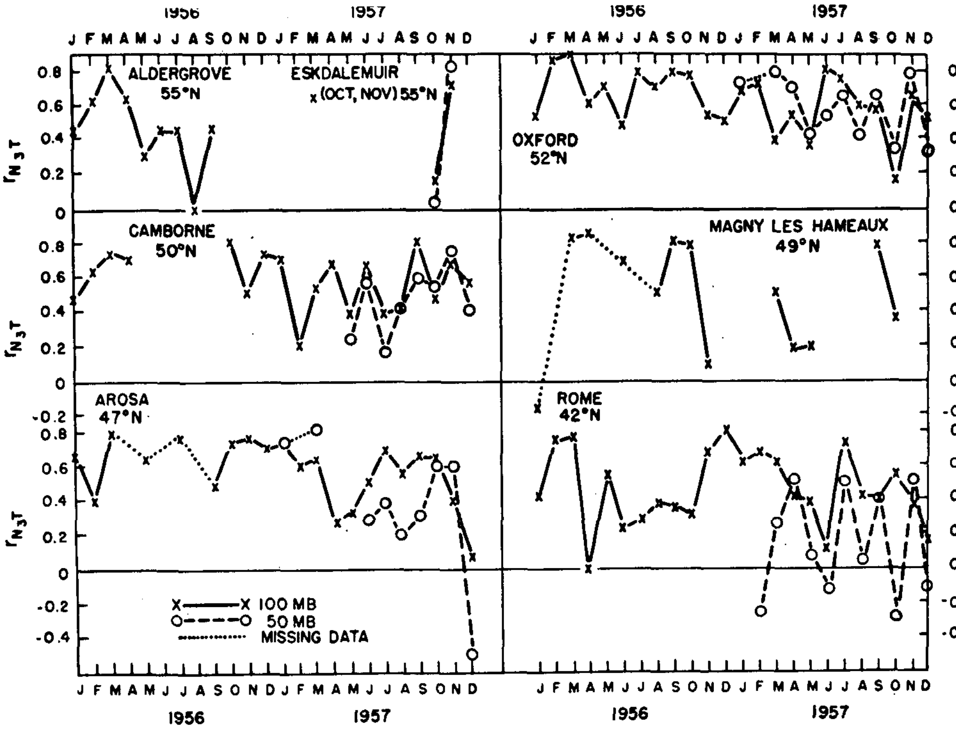

FIG. 2. Same as fig. 1.

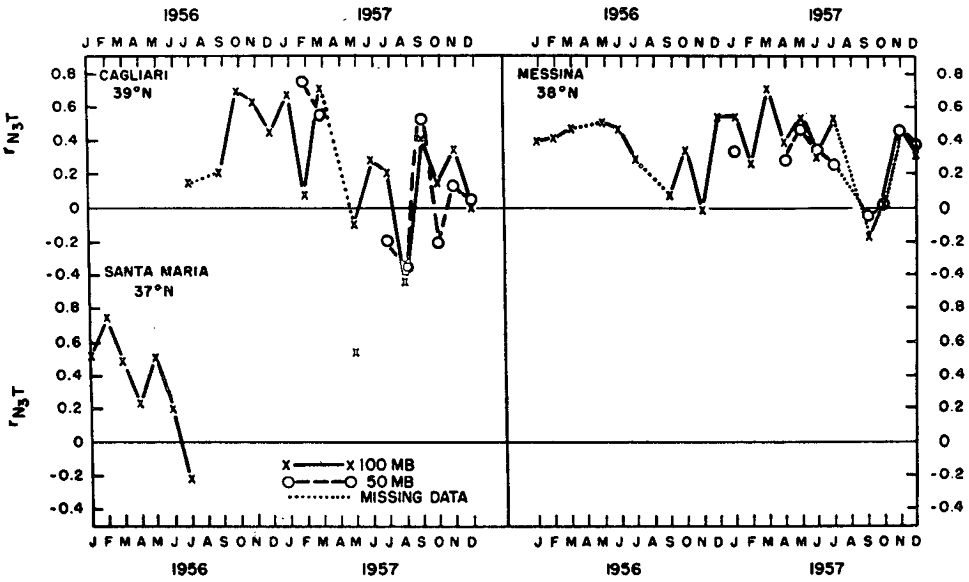

Fig. 3. Same as fig. 1.

Correlation coefficients for each month of the two-year period were computed between the daily values of ozone amount and the daily values of temperature, geopotential height, and north-south component of the wind at 100 mb. Correlations between ozone and temperature at 50 mb were computed for each month of the year 1957. Only for those months in which the number of pairs of daily observations exceeded nine were the correlations computed. It was assumed that the seasonal trends of ozone and the meteorological parameters do not significantly affect the correlation coefficients computed for a particular month. Therefore, these correlations are representative of the short-term variability of the elements.

3. Ozone-correlation coefficients

Figs. 1, 2, and 3 indicate the seasonal variations of the monthly ozone-temperature correlations for the European ozone network. The solid lines refer to 100-mb temperatures and the dashed lines to 50-mb temperatures. At both levels, the correlations are quite variable and almost always positive. In most cases, the 50-mb correlations are somewhat lower than the 100-mb correlations. There appears to be no consistent seasonal variation at any of the stations, and there is little agreement between the correlation values for the same month in the two successive years. These computed correlations are probably somewhat lower than the true correlation values because of the following effects, all of which tend to reduce the computed values of the correlations. These are the inherent random observational errors for both ozone and temperature measurements, the difference in location between the ozone-observation site and the radiosonde site for some of the stations, and the difference in times of observation between the ozone and temperature measurements.

Table 1. Locations of ozone and radiosonde stations.

Ozone station	Latitude (°)	Longitude (°)	Radiosonde station	Latitude (°)	Longitude (°)
Spitzbergen	78.1	E13.6	Bjornoya	74.5	E19.0
Tromso	69.7	E19.0	Tromso		
Reykjavik	64.1	W21.9	Keflavik	64.0	W22.6
Lerwick	60.1	W 1.2	Lerwick		
Uppsala	59.9	E17.6	Stockholm	59.4	E18.0
Aarhus	56.1	E10.2	Kobenhaven	55.6	E12.7
Eskdalemuir	55.3	W 3.2	Leuchars	56.4	W 2.9
Aldergrove	54.6	W 6.2	Aldergrove		
Oxford	51.7	W 1.2	Crawley	51.1	E 0.2
Uccle	50.8	W 4.4	Uccle		
Camborne	50.2	W 5.3	Camborne		
Magny les Hameaux	48.7	E 2.0	Trappes	48.8	E 2.0
Arosa	46.8	E 9.7	Milano	45.5	E 9.3
Rome	41.8	E12.6	Rome		
Cagliari	39.2	E 9.0	Cagliari		
Messina	38.2	E15.5	Messina		
Santa Maria	36.9	W25.2	Lages	38.8	W27.1

For an explanation of the positive relationship between ozone and stratospheric temperature, one can turn to the following two physical processes: (1) advection and (2) vertical motion. If the temperature increases polewards, as is usually the case for these latitudes in the lower stratosphere, motion from the north would bring warm air and motion from the south cold air. Since the total amount of ozone also usually increases polewards, advection from the north would presumably be associated with air that is not only warm but rich in ozone while advection from the south would be associated with cool, ozone-poor air. Hence, a positive relationship would exist between ozone and temperature. However, as we shall see later, more often than not, high ozone amounts are associated with southerly (from the south) winds rather than northerly

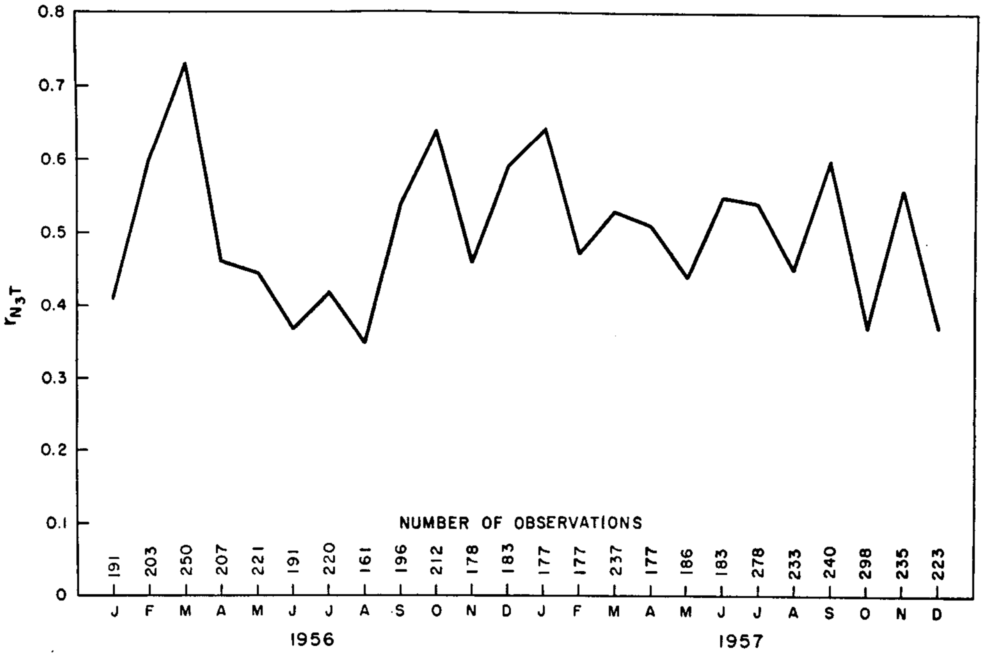

FIG. 4. Average values of total ozone — 100-mb-temperature correlation ($r_{\mathrm{N}_3\mathrm{T}}$) as a function of month of the year.

winds at 100 mb. Thus, the simple advection theory is not supported by the ozone-wind correlations. Therefore, although advection may be important in individual cases, it cannot be used as a general explanation of the ozone-temperature correlation.

The vertical-motion theory is based upon the fact that the ozone mixing ratio increases rapidly with height in the lower stratosphere. Thus, descending motion associated with convergence aloft would increase the total amount in a vertical column, while ascending motion associated with divergence aloft would decrease the total amount of ozone. Furthermore, downward motion would be accompanied by adiabatic heating and upward motion by adiabatic cooling. Hence, the effect of vertical motions on ozone and temperature is such as to produce a positive relationship between the two. The vertical-motion effect has been investigated quantitatively by Reed (1950) who computed ozone changes associated with sample ozone and vertical-velocity profiles.

If, for each month, all the correlations are averaged, mean monthly correlation coefficients can be obtained. Fig. 4 indicates the seasonal variation of the mean monthly ozone — 100-mb-temperature correlation coefficients obtained for the European stations. The monthly mean correlations were computed with the aid of Fisher's z' transformation. (See, for example, Brooks and Carruthers, 1953.) Several investigators (Johansen, 1958; Valovcin, 1958) have found evidence of a seasonal variation of the correlation coefficients. At Tromso, Johansen found maximum values during April-May. Our results for Tromso (see fig. 1) and for the other northern stations (Lerwick, Reykjavik, and Uppsala) do not show this seasonal variation. Valovcin working with United States data, found evidence of minimum correlations during the summer. Although fig. 4 indicates a tendency for a summer minimum in 1956, there is no such tendency in 1957, and thus a regular seasonal variation, which has the same form from year to year, does not seem to occur. For the most part, the monthly correlations range between +0.4 and +0.6 with a grand average close to +0.5.

In order to see if there were any regular latitudinal variations, the monthly correlations for each station were averaged for each year of the two-year period.

TABLE 2. Average ozone — 100-mb-temperature correlations as a function of latitude (each coefficient is an average of at least three monthly correlations, and n is total number of pairs of observations).

Ozone station	Latitude (°)	1956		1957	
		$r_{\mathrm{N}_3\mathrm{T}}$	n	$r_{\mathrm{N}_3\mathrm{T}}$	n
Spitzbergen	78			0.43	77
Tromso	70	0.34	76	0.40	124
Reykjavik	64			0.57	144
Lerwick	60	0.42	249	0.59	176
Uppsala	60	0.51	198	0.53	123
Aarhus	56	0.38	288	0.46	302
Aldergrove	55	0.48	168		
Oxford	52	0.69	314	0.60	324
Camborne	50	0.67	153	0.57	303
Magny les Hameaux	49	0.65	102	0.44	73
Arosa	47	0.70	137	0.55	233
Rome	42	0.52	239	0.49	276
Cagliari	39	0.46	91	0.32	219
Messina	38	0.38	168	0.38	236
Santa Maria	37	0.38	205		

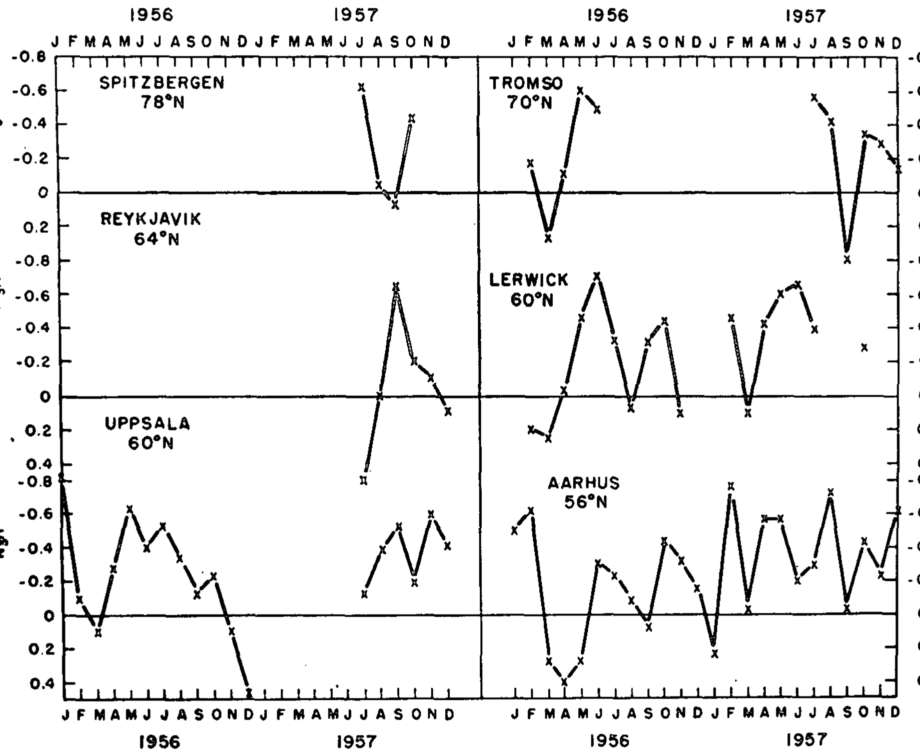

Fig. 5. Monthly values of total ozone — 100-mb-height correlation at several European stations.

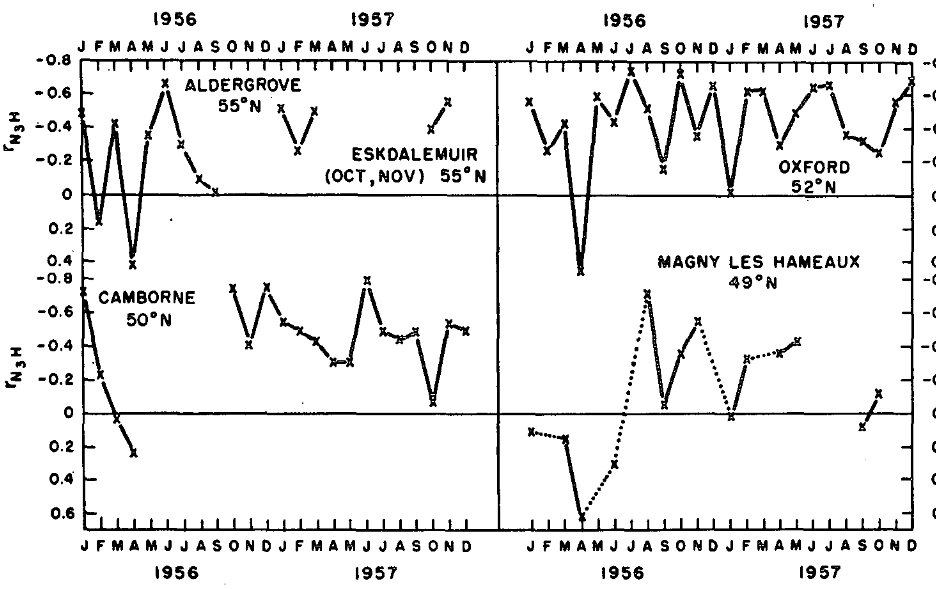

Fig. 6. Same as fig. 5.

These station means for both 1956 and 1957 are shown in table 2 where the stations are listed according to latitude. Although the variations with latitude are quite small, there is evidence, especially in 1956, of a maximum at about 50N with decreasing coefficients to the north and south. It should be realized that since these stations are not all on the same meridian the variations shown in table 2 could be partly due to longitudinal variations. If this latitudinal variation of the correlation coefficient is indeed real, it would indicate that the influence of meteorological processes at 100 mb upon changes in the total amount of ozone is greatest at about 50N.

In order to investigate the relationship between total ozone and geopotential height, we computed correlation coefficients between ozone and the height of

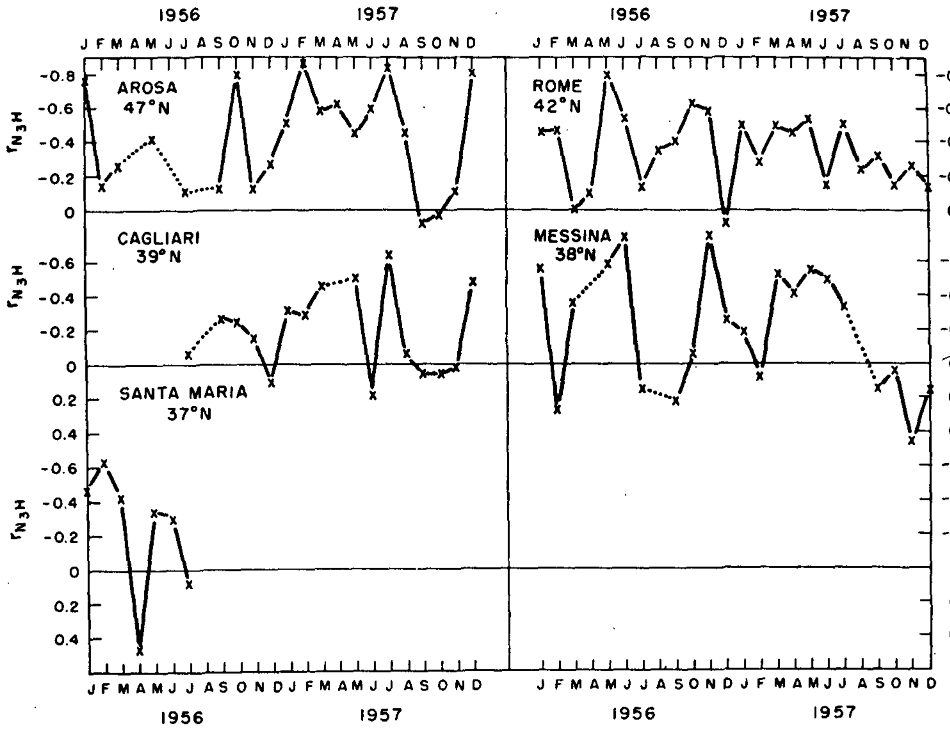

FIG. 7. Same as fig. 5.

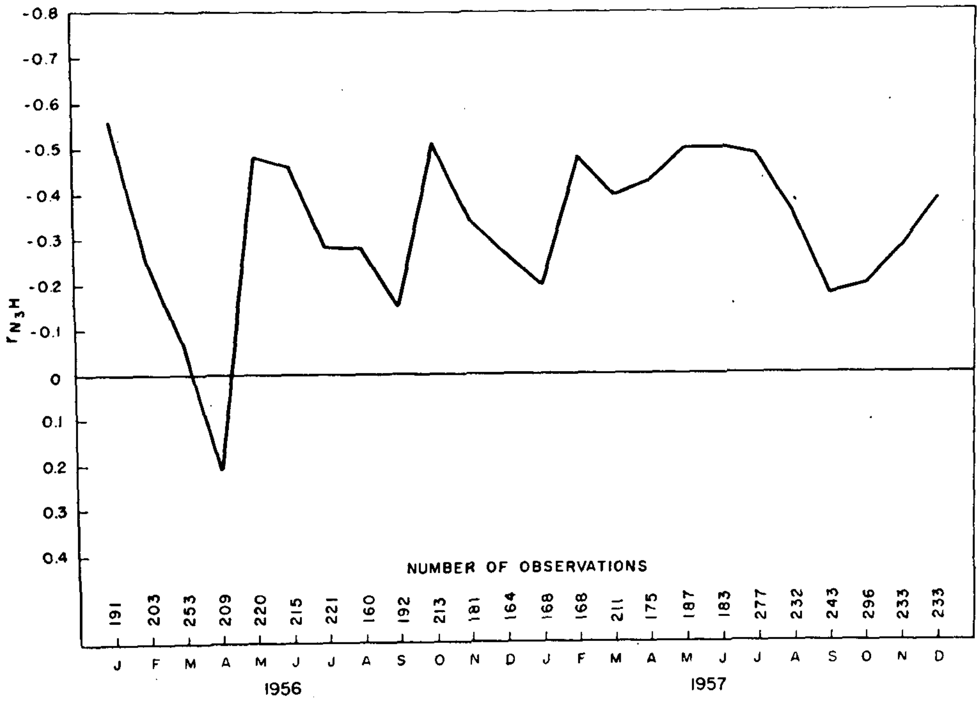

FIG. 8. Average values of total ozone — 100-mb-height correlation (r_{N_3H}) as a function of month of the year.

the 100-mb surface. The seasonal variations of the ozone — 100-mb-height correlations are shown in figs. 5, 6, and 7. In general, the correlations are negative, indicating that high ozone amounts are associated with low 100-mb heights. Such a relationship is presumably due to a systematic pattern of vertical motions with descending motion downstream into the troughs and ascending motion upstream into the ridges. The seasonal variations are irregular, and no orderly oscillation is apparent.

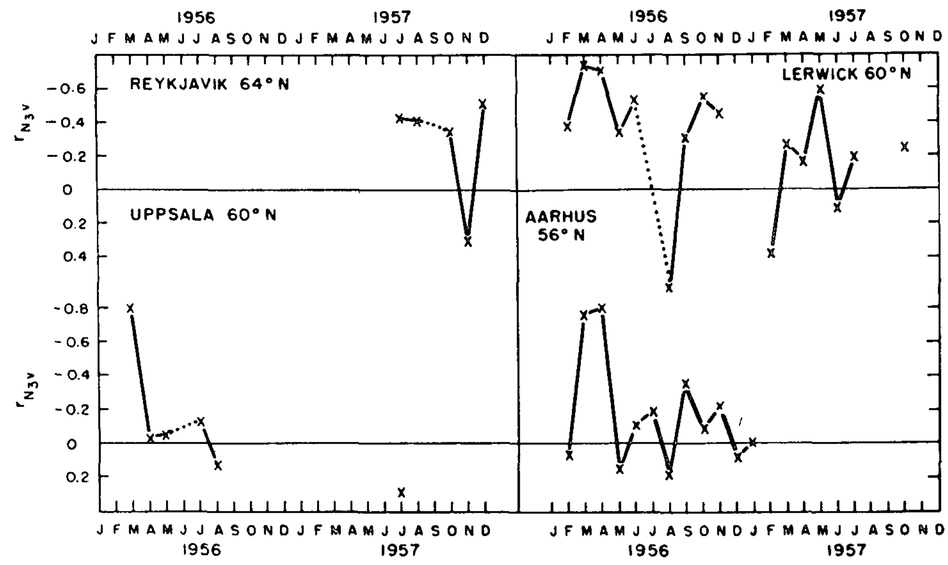

FIG. 9. Monthly values of total ozone — 100-mb north-south wind correlation at several European stations.

The individual station correlations were averaged for each month and plotted against time of year (fig. 8). Except for April 1956, each month of the two-year period has a negative ozone — 100-mb-height correlation. Although it varies quite irregularly from month to month, the correlation generally lies between −0.1 and −0.5. The overall average value of the ozone — 100-mb-height correlation is close to −0.3, which is less than the average ozone — 100-mb-temperature correlation. One month of one year may be quite different from the same month of another year as can be seen by inspecting the January, April, and October values of both years.

The variations of these ozone — 100-mb-height correlations with latitude are presented in table 3 where the station means are listed according to latitude.

TABLE 3. Average ozone — 100-mb-height correlations as a function of latitude (each coefficient is an average of at least three monthly correlations, and *n* is total number of pairs of observations).

Ozone station	Latitude (°)	1956		1957	
		r_{N_3H}	*n*	r_{N_3H}	*n*
Spitzbergen	78			−0.36	58
Tromso	70	−0.25	88	−0.27	125
Reykjavik	64			−0.16	144
Lerwick	60	−0.22	253	−0.42	172
Uppsala	60	−0.31	230	−0.35	111
Aarhus	56	−0.16	289	−0.39	300
Aldergrove	55	−0.18	168	−0.45	39
Oxford	52	−0.47	310	−0.48	318
Camborne	50	−0.47	155	−0.47	302
Magny les Hameaux	49	−0.07	102	−0.19	83
Arosa	47	−0.38	135	−0.50	235
Rome	42	−0.37	241	−0.35	269
Cagliari	39	−0.11	87	−0.24	198
Messina	38	−0.33	159	−0.19	215
Santa Maria	37	−0.25	205		

As in the case of the ozone-temperature correlation (and presumably due to the same cause), there are indications of a maximum correlation at about 50N. The correlations at Magny les Hameaux are distinctly lower than the correlations at the stations immediately north and south of it, but this may be due to larger random observational errors, especially in the ozone measurements.

According to the advection theory, one should find relatively high ozone amounts with flow from the north and relatively low ozone amounts with flow from the south. In order to test this hypothesis, correlations were computed between ozone and the north-south component of the wind at 100 mb. A wind from the north was considered positive and a wind from the south negative. Figs. 9, 10, and 11 show the results of these computations. In general, but not always, there is a negative correlation, indicating that there is a tendency for high ozone amounts to be associated with southerly flow rather than with northerly flow in the lower stratosphere. This is in contradiction to previous thought and work on this subject. For example, Miyake and Kawamura (1956) find a correlation of about +0.5 between ozone and the north-south component of the 14-km and 16-km wind at Tokyo. However, in a synoptic-statistical study of the European ozone data, Martin (1956) finds that the ozone amounts are generally higher with trajectories from the south at 100 mb. Thus, the simple advection theory does not seem to hold up, at least for the European data. If the negative correlations found in the present study are indeed real, as appears to be the case, then we must look for possible explanations. It may be that, at 100 mb, ozone concentrations increase equatorwards — opposite to the normal gradient of total

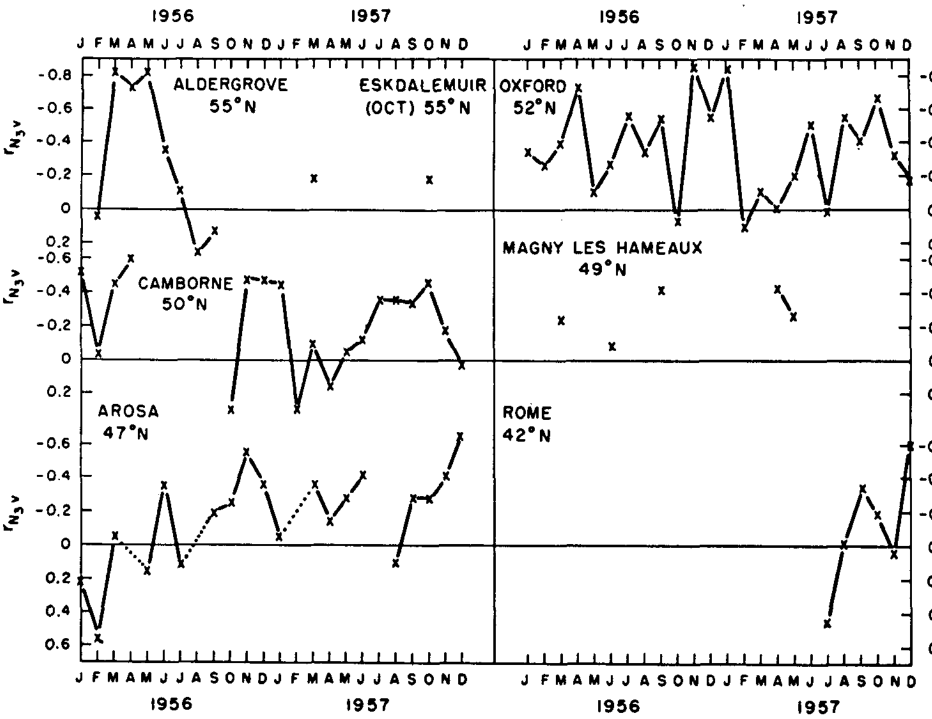

FIG. 10. Same as fig. 9.

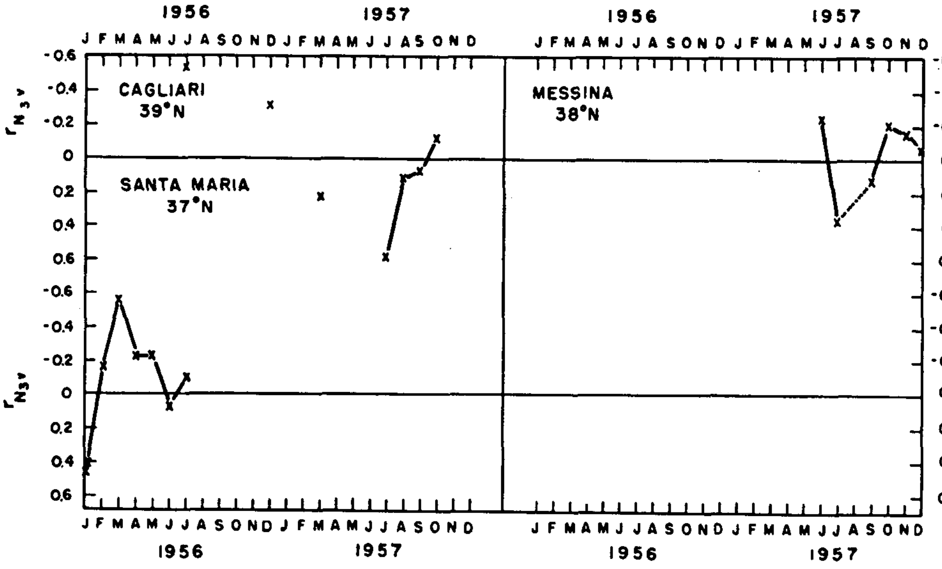

FIG. 11. Same as fig. 9.

ozone. Most probably, in the photochemical region, above 25 to 30 km, there is more ozone at low latitudes than at high latitudes. Such a distribution of ozone concentration at 100 mb would cause a higher amount of ozone to be associated with southerly flow at 100 mb and a lower amount with northerly flow. However, such a latitudinal variation at 100 mb is highly unlikely.

A second possibility is that there is descending motion from a point somewhat ahead of the ridge to a point somewhat ahead of the trough. The parcels which had descended the furthest (those which ended up ahead of the trough) would have the highest ozone content, and thus the ozone maximum would occur slightly ahead of the trough. Conversely, if there is ascending motion from ahead of the trough to ahead of the ridge, the ozone minimum would be ahead of the ridge. With the ozone maximum displaced to a point ahead of the trough, the overall area between trough and ridge would have a small ozone surplus and the

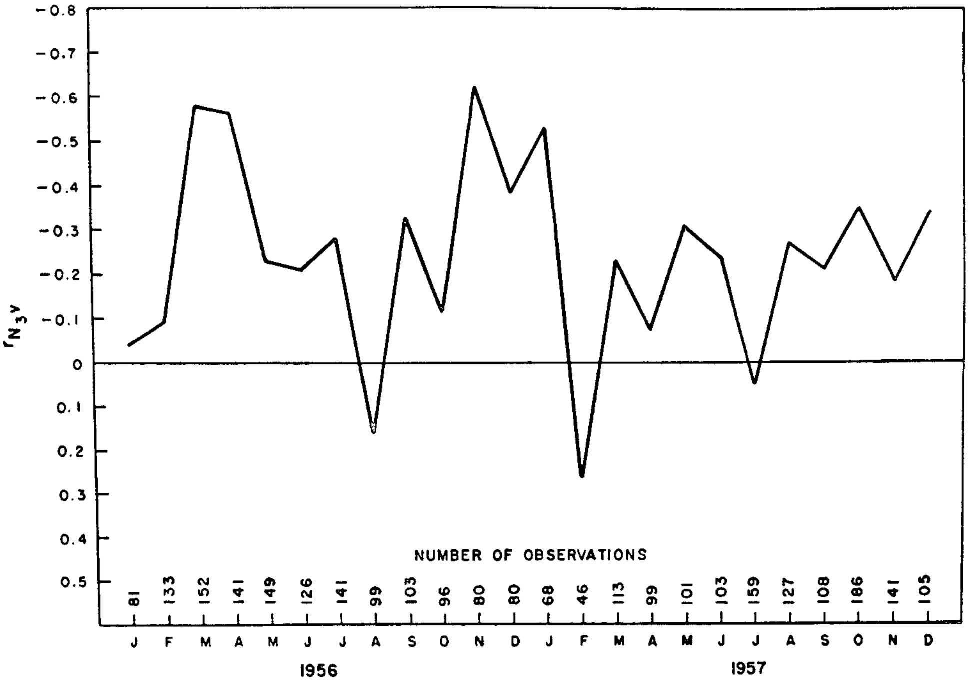

Fig. 12. Average values of total ozone — 100-mb north-south wind correlation (r_{N_3v}) as a function of month of the year.

area from ridge to trough a deficit. Thus, southerly winds would be associated with high ozone amounts and northerly winds with low ozone amounts, because of vertical motions.

If there is such a distribution of vertical motion with respect to 100-mb troughs and ridges, one should also find a negative correlation between temperature and north-south wind component — *i.e.*, higher temperatures with southerly winds. In sample calculations, this was indeed found to be generally true. Since the 100-mb temperature increases polewards throughout most of the year at these latitudes, a negative correlation between temperature and meridional wind cannot be the result of advection.

Obviously, to explain the correlation of total ozone with the north-south wind component, we shall have to have more detailed information on the distribution of ozone and vertical velocities in the lower stratosphere over Europe. Until such information is available, these suggested explanations for the computed correlations should be considered as speculative only.

The average seasonal changes of the ozone — 100-mb north-south wind-component correlations for the European stations are shown in fig. 12. The variations, with no apparent seasonal trends, are similar to those of the other ozone correlations. Although generally negative, the correlations are low; in August 1956 and February and July 1957, the correlations were positive. The average monthly correlations between ozone and the north-south wind component at 100 mb are close to -0.2.

Table 4 indicates the latitudinal variations of the ozone-wind correlations. Although the evidence is rather poor, a tendency for a maximum correlation at about 50N is once again indicated.

4. Ozone in relation to stratospheric troughs and ridges

The ozone correlations indicate that high ozone amounts are associated with low geopotential heights and also with southerly winds. This would suggest that higher-than-normal ozone amounts are most apt to occur immediately preceding stratospheric troughs.

Table 4. Average ozone — 100-mb meridional-wind correlations as a function of latitude (each coefficient is an average of at least three monthly correlations, and n is total number of pairs of observations).

Ozone station	Latitude (°)	1956		1957	
		r_{N_3v}	n	r_{N_3v}	n
Reykjavik	64			−0.28	112
Lerwick	60	−0.37	186	−0.20	154
Uppsala	60	−0.19	86		
Aarhus	56	−0.22	150		
Aldergrove	55	−0.35	137		
Oxford	52	−0.43	304	−0.36	287
Camborne	50	−0.33	134	−0.18	267
Magny les Hameaux	49	−0.23	34		
Arosa	47	−0.10	139	−0.28	178
Rome	42			−0.06	91
Cagliari	39			0.16	68
Messina	38			−0.01	86
Santa Maria	37	−0.12	204		

In order to see if this was true and to determine the ozone distribution relative to stratospheric troughs and ridges, a sample study was made relating ozone departures from monthly means to trough-ridge systems at 100 mb and 50 mb over Europe.

Stratospheric flow patterns were obtained from a series of Geophysics Research Directorate 100-mb and 50-mb analyzed maps. These charts were drawn daily from December 1956 to April 1957 and every third day from May 1957 to November 1957. The maps are for 15Z through March 1957 and 12Z thereafter. At 100 mb, data coverage was adequate to about 20E long; at 50 mb, however, data were scarce, and there is some question as to the accuracy of the analyses. For lack of better data, the 100-mb and 50-mb maps were used as drawn.

Two parameters were chosen to indicate qualitatively where an ozone deviation was located with respect to the trough-ridge system. Wind direction, or contour orientation, was used to indicate whether the report was in front of or behind a trough; curvature was used to specify whether a report was close to a ridge line, close to a trough line, or near the inflection point. Wind direction was determined to the nearest ten degrees; radius of curvature was estimated with a small plastic overlay and placed into one of the five categories listed in table 5.

TABLE 5. Radius-of-curvature categories (cylonic +; anticylonic −).

Radius of curvature (n mi)	<250	250–500	500–1000	1000–3000	3000–∞
Curvature category	4	3	2	1	0

Category four is indicative of extremely high curvature, whereas category zero is indicative of no curvature.

According to its position in the trough-ridge pattern, each ozone departure from a monthly mean was placed into one of the curvature categories, and average ozone departures for each curvature category at 100 mb and 50 mb were then obtained. Fig. 13 illustrates the dependence of ozone deviation on the curvature of the 100-mb and 50-mb contours for the winter months (November, 1957; December, 1956; January, February, and March, 1957); fig. 14 indicates the ozone-curvature relationship for the summer months (May to September, 1957). These graphs show that positive ozone deviations are associated with cyclonic (positive) curvature and negative ozone deviations with anticyclonic (negative) curvature at 100 mb and at 50 mb. In general, the greater the curvature, the larger is the ozone deviation. It is also evident from the diagrams that the ozone deviations in the summer are smaller than those during winter.

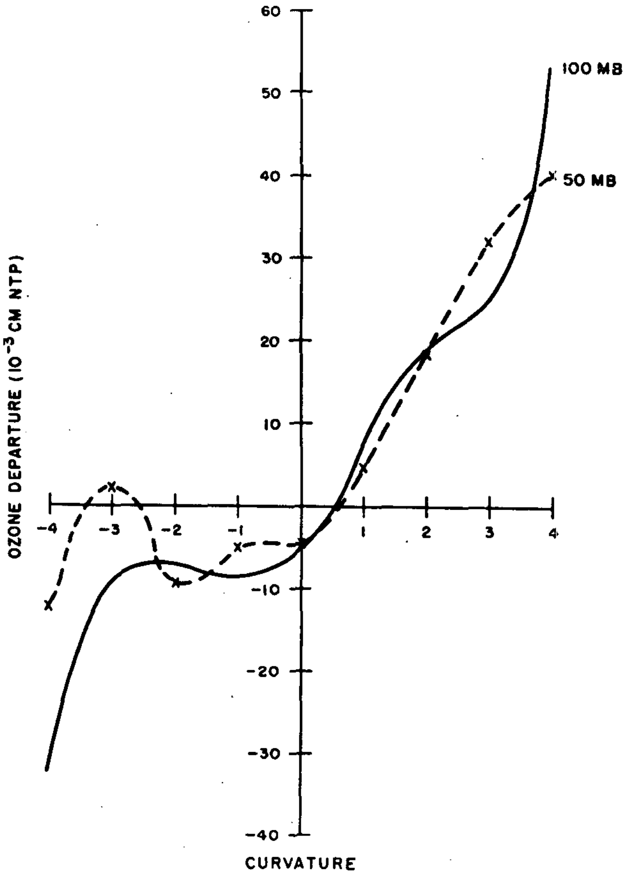

FIG. 13. Departure of total ozone from monthly mean *versus* curvature. Winter (Nov. 1957, Dec. 1956–March 1957).

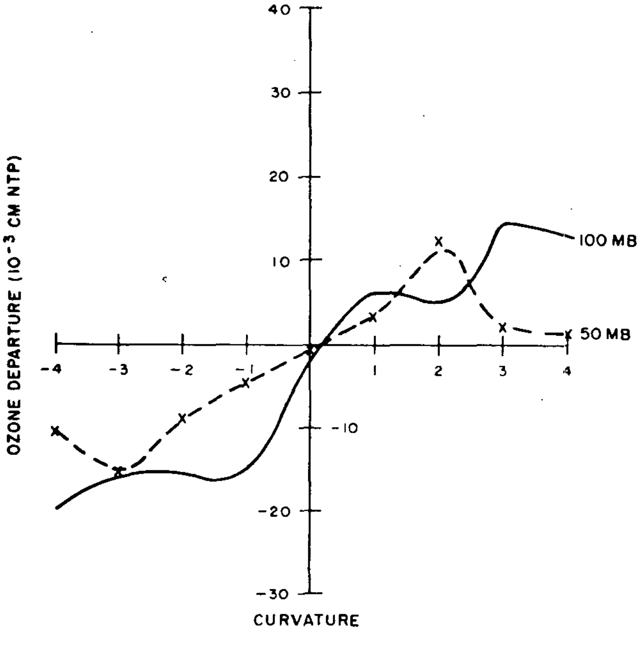

FIG. 14. Departure of total ozone from monthly mean *versus* curvature. Summer (May–Sept. 1957).

In order to determine whether the ozone deviations were indeed more positive ahead of, rather than behind, the trough line and more negative ahead of, rather than behind, the ridge line, as indicated by the correlation coefficients, cases of curvature and wind direction were selected that conformed best to a "typical" sinusoidal trough-ridge system imbedded in the westerlies. As shown in fig. 15, this model trough-ridge pattern has four sectors. Ozone departures were placed into a sector if they were associated with the curvatures and wind directions representative of that sector. Since the circulation over Europe is often characterized by closed highs and lows, the "typical" pattern is not so typical, and the categories may represent sectors of closed circulations rather than sectors of a continuous trough-ridge sequence.

The results of this analysis are shown in tables 6 and 7. Since a number of ozone observations did not fit into any of the sectors, the average deviation for a particular month is not necessarily zero in these tables. At 100 mb, during December, January, and April, maximum ozone amounts do occur immediately ahead of the trough lines (Sector C), and minimum ozone amounts do occur immediately ahead of the ridge lines (Sector A); however, during the remainder of the year, the maximum positive and negative departures are behind the trough (B) and ridge (D) lines, respectively. At 50 mb, the maximum ozone amounts in all months except January and April are located ahead of the trough line, and the minimum amounts, except for February and March, are immediately ahead of the ridge lines. The overall averages for the year at 100 mb indicate that, although the troughs are ozone rich, there is no generally preferred area of maximum ozone within the trough. This result is somewhat contradictory to the previously stated negative correlation with the north-south wind component, at 100 mb. A distinct possibility is that in fitting our "typical" pattern we have discarded a fair number of cases that just didn't fit this "typical" pattern, and the ozone amounts of these "misfit" cases may have been moderately correlated (negatively) with north-south wind component.

Table 6. Average ozone departures in the four sectors of a trough-ridge system at 100 mb (number of observations in parentheses).

Months	Sectors A	B	C	D
Dec. 1956	−11.8(14)	−3.8(10)	25.9(15)	−3.0(18)
Jan. 1957	−13.9(23)	6.2(34)	31.4(14)	13.0(6)
Feb. 1957	−22.1(19)	19.0(42)	−5.9(2)	−22.5(22)
Mar. 1957	7.2(39)	10.1(33)	−6.9(14)	−9.9(22)
Apr. 1957	−8.7(7)	3.4(21)	11.4(19)	−2.5(15)
May–Aug. 1957	−5.8(10)	9.9(26)	1.9(41)	−17.4(31)
Sept.–Nov. 1957	−8.5(18)	5.2(37)	3.2(31)	−11.6(18)
Mean departure	−6.9(130)	9.0(203)	8.2(136)	−11.2(132)

Table 7. Average ozone departures in the four sectors of a trough-ridge system at 50 mb (number of observations in parentheses).

Months	Sectors A	B	C	D
Dec. 1956	−3.5(12)	14.3(2)	27.3(9)	0.4(7)
Jan. 1957	−16.5(19)	2.6(21)	13.3(5)	35.6(5)
Feb. 1957	−19.1(17)	0.3(16)	23.3(1)	−35.6(16)
Mar. 1957	14.4(23)	2.9(44)	15.2(3)	2.9(12)
Apr. 1957	−3.1(8)	10.5(21)	6.0(17)	0.0(1)
May–Sept. 1957		Few cases		
Oct., Nov. 1957	−7.0(13)	−1.7(31)	10.2(32)	−4.5(14)
Mean departure	−5.1(92)	2.8(135)	12.1(67)	−7.6(55)

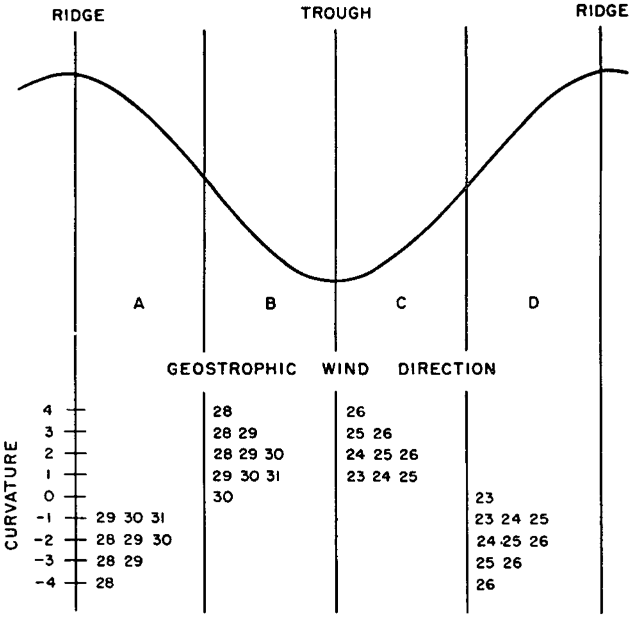

Fig. 15. Sectors of "typical" trough-ridge pattern and curvature and direction criteria.

5. Conclusions

Based upon the correlation and trough-ridge analyses, we reach the following conclusions on the synoptic variability of ozone and its relationship to meteorological processes in the stratosphere:

(1) There is a positive correlation, averaging about +0.5, between the total amount of ozone and stratospheric temperatures, which is probably due to the effects of vertical motions on both of these parameters.

(2) There is an average negative correlation of −0.3 between ozone and geopotential-height which is related to a systematic pattern of vertical motions in the stratospheric trough-ridge pattern.

(3) There is a small negative correlation between ozone and the north-south component of the wind. This suggests that the distribution of vertical velocities in the troughs and ridges is such as to produce ozone

maximums ahead of the troughs and ozone minimums ahead of the ridges.

(4) There is no regular seasonal variation of the correlation coefficients.

(5) There is evidence of a small latitudinal variation of the 100-mb correlation coefficients with the maximum correlations located at about 50N. This suggests that the influence of meteorological processes at 100 mb upon changes in the total amount of ozone is greater at mid-latitudes than at high or low latitudes.

(6) Lower stratospheric troughs are regions of relatively high amounts of total ozone; lower stratospheric ridges are regions of relatively low total amounts. Although the evidence is somewhat contradictory, we suspect there is more total ozone immediately ahead of lower stratosphere troughs than immediately behind. Further study is needed to verify this point.

One should consider that these results are for a relatively small geographical area — the European continent. Synoptically, the tropospheric disturbances over Europe are usually in a different stage of development than disturbances in the eastern United States, for instance, and one would expect that the fields of temperature and vertical motion in the European disturbance would differ somewhat from temperature and vertical-motion fields of disturbances elsewhere. And, for this reason, correlations of total ozone with meteorological parameters in the lower stratosphere might well differ in magnitude from one geographical region to another.

The conclusions are based upon relations between meteorological elements at essentially one level in the atmosphere and the total amount of ozone in the entire atmosphere. Obviously, it is much more desirable to have observational data on the vertical distribution of ozone for a study on the relationships between ozone variability and meteorological processes. Only when such data become available will it be possible to attack more directly the entire ozone problem.

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