ABSTRACT

The present work is a mathematical study of the periodicities and climatic fluctuations of atmospheric ozone from 1957 through 1990. The study is based on revised total ozone Dobson data from 33 ground - based stations at geographical latitudes ranging from 74° 43′ N to 54° 30′ *S*. These data are the same as the data set used by NASA/WMO for the ozone layer assessment by the World Meteorological Organization (WMO) in Geneva (WMO Reports Nrs. 18 and 25, published in 1988 and 1991 respectively). The data used in the present paper were kindly made available by Dr. R. D. Bojkov of the WMO in Geneva. Previous studies showed several anomalies in interannual ozone variability which were still not fully accounted for by the most recent studies. (Zerefos et al., 1991). The aim of the present work is to contribute to a better understanding of these anomalies, and to express and describe total ozone variability adequately, with the help of simple algebraic equations. This mathematical model can be improved by using the whole spectrum of both defined and undefined fluctuations, at every time scale, from a few months up to many years.

The final mathematical model, representing the ozone variability and oscillation with an accuracy of nearly 99 %, is based on the sum of all the periodic, quasi - periodic and aperiodic parts of the total ozone time series at each Dobson Station.

The behavior of the fluctuation and the variability of total ozone, and the evolution of the yearly maxima and minima at each Station, are studied separately. The residuals of the monthly mean, deseasonalized and deperiodicized time show regular rhythms, at 3, 4, 6 and 12 months.

A STUDY OF THE PERIODICITIES AND CLIMATIC FLUCTUATIONS OF ATMOSPHERIC OZONE

1. INTRODUCTION

During the last 25 years, ozone, at first an atmospheric trace gas interesting only to a handful of scientific specialists, has grown into an issue of Global importance. This volte-face is due to the recent proof, by those same specialists, that the concentration of atmospheric total ozone is altering.

Ozone (O_3) is a form of oxygen which has three atoms instead of the usual two, in each molecule. It is produced in the stratosphere by the action of solar radiation on normal oxygen: the process called photolysis, whereby O_2 molecules are broken down, yielding atomic oxygen, which in turn combines with molecular oxygen to produce ozone. Ozone can also be destroyed naturally, through a series of catalytic cycles involving oxygen, nitrogen and hydrogen.

The atmosphere has a maximum partial pressure in the lower stratosphere at a level of 19 - 23 kms above the Earth's surface. The total atmospheric ozone at any specific location appears to be variable. If so, it is largely determined by large-scale atmospheric dynamics.

The stratosphere contains 90% of all the ozone in the atmosphere. If all the ozone molecules in the atmosphere were transferred to the Earth's surface, they would assume a thickness of only 2.5 - 3.5 mm at average surface temperature and pressure.

The maintenance of this thin layer is crucial for the preservation of the health of humans, animals and plants including phytoplankton, shielding them all from damaging ultraviolet radiation from the Sun. It also largely determines the thermal structure of the stratosphere, where temperature increases slowly with height.

Total ozone is defined as the amount of ozone contained in a vertical column of base 1 cm^2 at standard pressure and temperature. It is often expressed in *milli-atmosphere-centimeters* (m-at-cm), also known as Dobson Units, the terminology adopted in the present work. Typical amounts range from 230 to 500 D.U., with a world average of about 300 D.U., although total ozone is not equally distributed in the stratosphere.

There have been numerous studies of ozone variability on various time scales, mostly larger than one year. (see NASA/WMO Reports Nr. 18 (1988) and Nr. 25 (1991)).

Among the determining factors of total ozone interannual variability included are *quasi-biennial* oscillation e.g. Funk and Graham, (1982), Oltmans and London, (1982), Zerefos, (1983), Bowman, (1989) and Zerefos et al., (1991), and 11-year solar-related oscillation and the El Nino/Southern Oscillation (ENSO). (see NASA/WMO Nr. 18. 1988 and Zerefos et al., 1991). Many features of total ozone variability are therefore, analyzed in the revised ground-based Dobson total ozone data (Bojkov et al., 1990 and in NASA/WMO, 1988 report). These also show how revision procedures improved the total ozone data set. There are several anomalies in monthly departures, whose interannual and spatial variability is not fully understood.

The purpose of the present work is to study and test these unexplained anomalies against non-randomness, and to provide the mathematical expressions that best describe the overall phenomenon of variability and periodicity of the total ozone layer in the stratosphere.

The data set used in the present study consist of monthly values of total ozone (MVTOZ) at 33 Dobson Stations located at latitudes ranging from 74°43′N to 54°30′ S, mostly with records continuous from 1957 through 1990. These records have been revised by Dr. R. D. Bojkov (Bojkov et al., 1990), who kindly provided one of the authors, Prof. Dr. John Xanthakis, with the homogeneous data set.

The names and geographical coordinates of the Northern and the Southern Dobson Stations, and the time period of the data set used in this study, are listed in Table A.

Details of revision procedures can be found in the paper of Bojkov et al., (1990), and in NASA/WMO Report Nr. 18 (1988) and subsequent assessments by the Ozone Trends Panel (Stolarski et al., 1992).

TABLE A

STATIONS OF THE NORTHERN HEMISPHERE

No.	Station	φ	L	Record Length Monthly Observ.
1	Mexico City	19° 26′	99° 04′W	1976 - 1986
2	Mauna Loa	19° 32′	155° 35′W	1964 - 1986
3	Naha	26° 27′	127° 41′W	1974 - 1986
4	Quetta	30° 15′	66° 53′E	1957 - 1986
5	Tallahassee	30° 23′	84° 12′W	1965 - 1966
6	Kagoshima	31° 34′	130° 33′E	1958 - 1986
7	White Sands	32° 13′	100° 29′W	1972 - 1981
8	Tateno	36° 03′	140° 08′E	1957 - 1986
9	Nashville	36° 07′	86° 41′W	1963 - 1986
10	Wallops	37° 51′	75° 31′W	1970 - 1986
11	Mt. Louis	38° 45′	90° 23′W	1962 - 1979
12	Cagliari	39° 15′	09° 03′E	1957 - 1986
13	Boulder	40° 01′	105° 15′W	1964 - 1990
14	Rome	41° 54′	12° 29′E	1957 - 1990
15	Sapporo	43° 03′	141° 20′E	1957 - 1990
16	Toronto	43° 40′	79° 24′W	1960 - 1990
17	Arosa	46° 46′	09° 40′E	1957 - 1991
18	Bismarck	46° 46′	100° 45′W	1963 - 1990
19	Caribou	46° 52′	68° 01′W	1963 - 1990
20	Hohenpeissenberg	47° 48′	11° 01′E	1967 - 1991
21	Hradec Crálové	50° 11′	15° 50′E	1962 - 1990
22	Uccle	50° 48′	04° 21′E	1972 - 1991
23	Belsk	50° 50′	20° 47′E	1963 - 1990
24	Bracknell	51° 23′	00° 47′E	1969 - 1991
25	Goose Bay	53° 20′	60° 25′W	1962 - 1990
26	Edmonton	53° 34′	113° 31′W	1958 - 1990
27	Churchill	58° 47′	94° 11′W	1965 - 1990
28	Leningrad	59° 58′	30° 18′E	1969 - 1991
29	Lerwick	60° 08′	01° 11′W	1957 - 1989
30	Reykjavik	64° 08′	21° 54′W	1958 - 1990
31	Resolute	74° 43′	94° 59′W	1958 - 1990

STATIONS OF THE SOUTHERN HEMISPHERE

No.	Station	φ	L	Monthly Observ. Interval
1	Huancayo	12° 03′	75° 19′W	1964 - 1986
2	Aspendale	38° 02′	145° 06′E	1958 - 1986
3	Hobart	42° 50′	147° 30′E	1968 - 1986
4	Macquarrie	54° 30′	158° 57′E	1963 - 1986

2. THE MATHEMATICAL EQUATIONS FOR MONTHLY MEAN VALUES OF TOTAL OZONE (MMVTOZ)

Mean monthly values of total ozone (MMVTOZ) were calculated for each Station for the time interval in question.

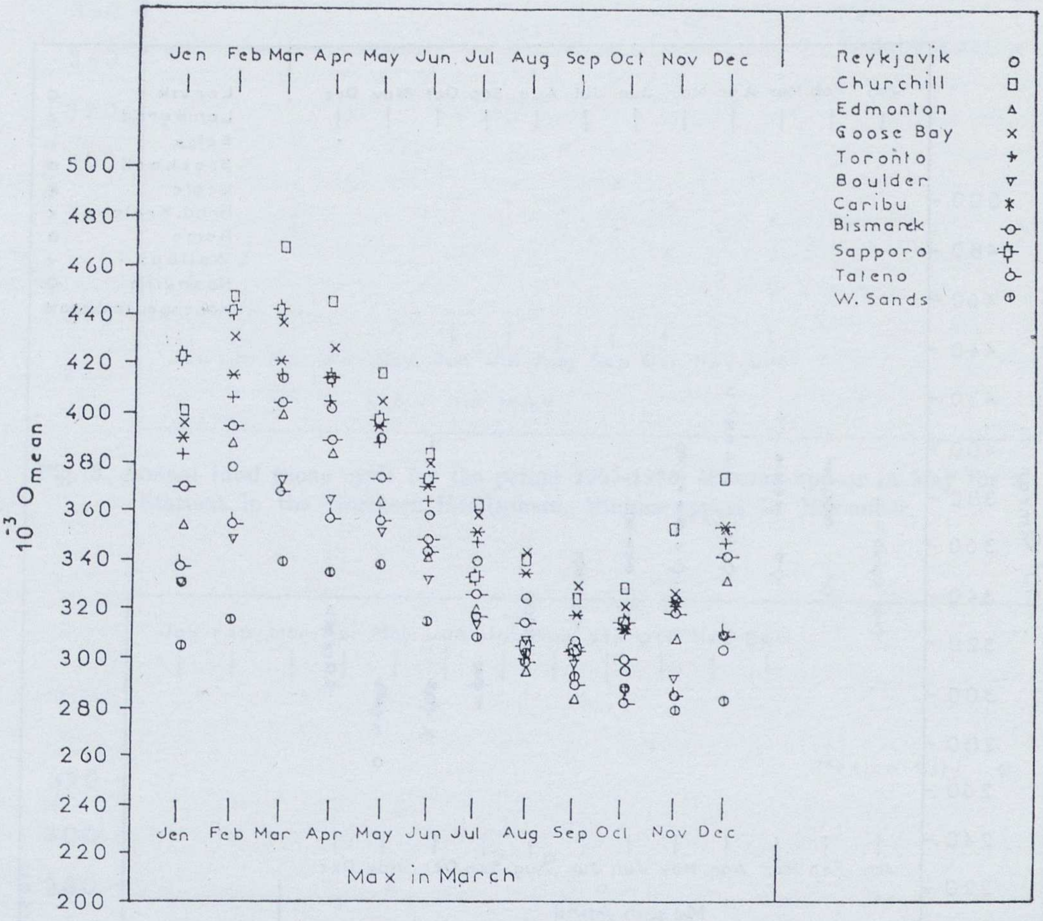

Fig. 1. Annual total ozone cycle for the period 1957-1986. Maxima appear in March for 11 Stations in the Northern Hemisphere. Minima appear in September.

According to the literature, ozone shows yearly variation, with a maximum in March and a minimum in September in the Northern Hemisphere (N.H.) and the reverse in the Southern Hemisphere (S.H.). Our work shows that there is indeed a yearly variation of total ozone, but that the maximum values occur during March, April, May and July, and minimum values occur during September, November and December. This is true for the N.H. while the inverse is true for the S.H. Figures, 1, 2, 3 and 4 show the annual cycle of total ozone in four group-

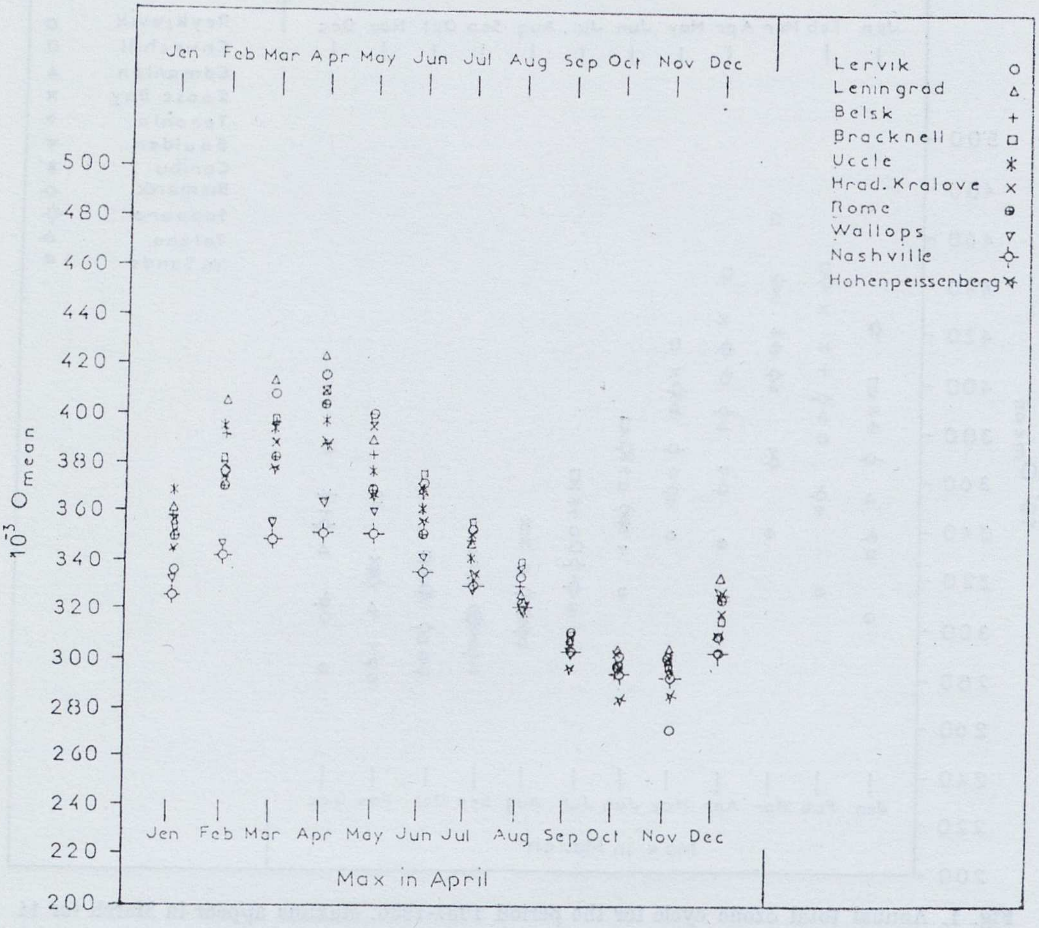

Fig. 2. Annual total ozone cycle for the period 1957-1986. Maxima appear in April for 10 Stations in the Northern Hemisphere. Minima appear in October.

ings of Stations with time of occurrence of maximum and minimum. As we move from Figure 1 to Figure 4, the time of maximum is shifted from March to May, or even to July (this occurs at Mexico Station, see Figure 4). Much the same can be said for the time of occurrence of minimum, which is shifted from September to December.

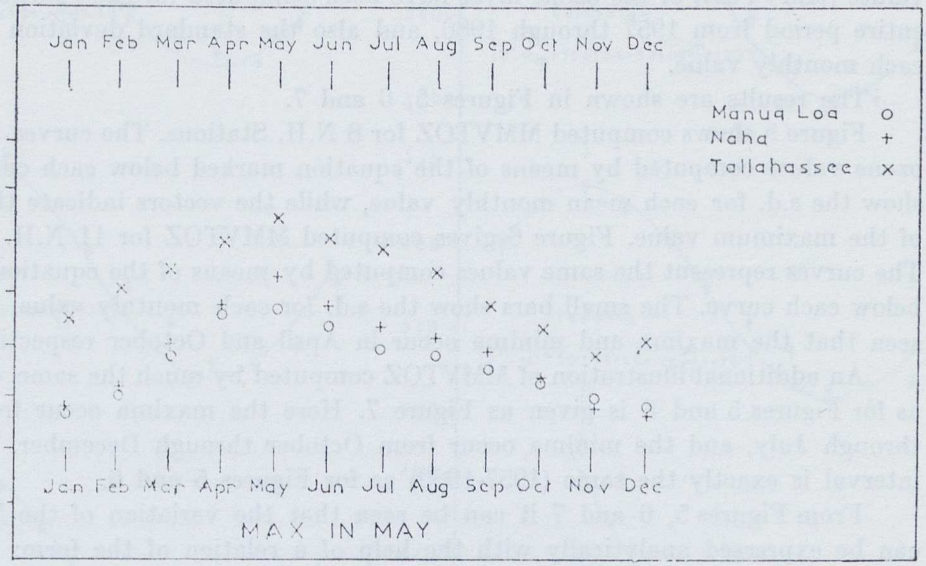

Fig. 3. Annual total ozone cycle for the period 1957-1986. Maxima appear in May for 3 Stations in the Northern Hemisphere. Minima appear in November.

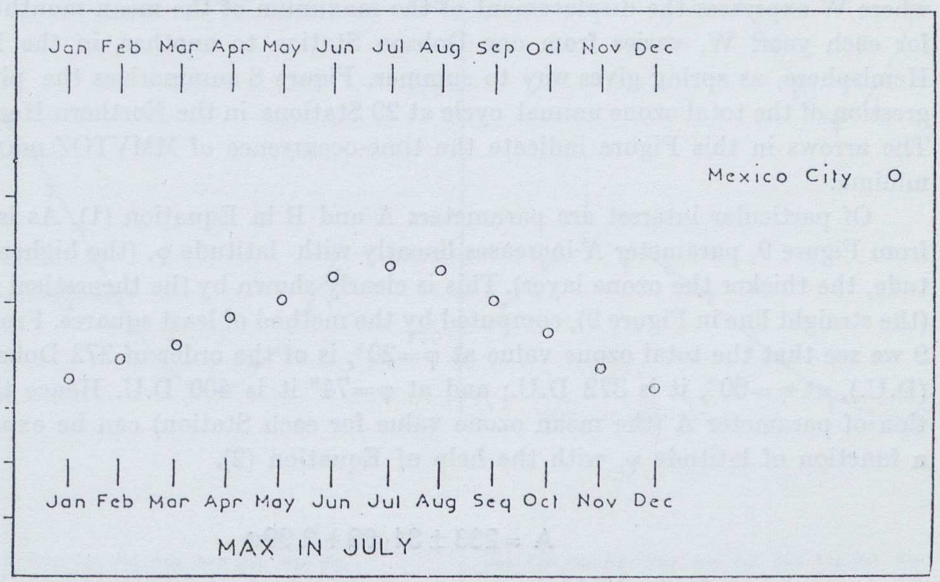

Fig. 4. Annual total ozone cycle for the Station Mexico City (N.H.). Maximum value appears in July and minimum value appears in December.

Inverse effects are observed in the Southern Hemisphere.

In order to arrive at a correct interpretation of the problem, the mean monthly values (MMVTOZ) of the ozone layer have been computed for each station for the entire period from 1957 through 1986, and also the standard deviation (s.d.) for each monthly value.

The results are shown in Figures 5, 6 and 7.

Figure 5 shows computed MMVTOZ for 8 N.H. Stations. The curves represent ozone values computed by means of the equation marked below each curve. Bars show the s.d. for each mean monthly value, while the vectors indicate the month of the maximum value. Figure 6 gives computed MMVTOZ for 11 N.H. Stations. The curves represent the same values computed by means of the equation marked below each curve. The small bars show the s.d. for each monthly value. It will be seen that the maxima and minima occur in April and October respectively.

An additional illustration of MMVTOZ computed by much the same equations as for Figures 5 and 6 is given as Figure 7. Here the maxima occur from April through July, and the minima occur from October through December. The time interval is exactly the same (1957-1986) as for Figures 5 and 6.

From Figures 5, 6 and 7 it can be seen that the variation of the MMVTOZ can be expressed analytically with the help of a relation of the form:

$$10^{-3} \cdot 0^{com}_{m} = A + B\left[\sin\left(\frac{2\pi}{12}t + W\right)\right] \quad (1)$$

where W expresses the displacement of the maximum of the mean monthly values for each year. W, varies from one Dobson Station to another, in the Northern Hemisphere, as spring gives way to summer. Figure 8 summarizes the phase progression of the total ozone annual cycle at 29 Stations in the Northern Hemisphere. The arrows in this Figure indicate the time-occurrence of MMVTOZ maxima and minima.

Of particular interest are parameters A and B in Equation (1). As is obvious from Figure 9, parameter A increases linearly with latitude φ. (the higher the latitude, the thicker the ozone layer). This is clearly shown by the theoretical variation (the straight line in Figure 9), computed by the method of least squares. From Figure 9 we see that the total ozone value at $\varphi=20°$, is of the order of 272 Dobson Units (D.U.), at $\varphi=60°$, it is 372 D.U.; and at $\varphi=74°$ it is 400 D.U. Hence the variation of parameter A (the mean ozone value for each Station) can be expressed as a function of latitude φ, with the help of Equation (2).

$$A = 233 \pm 31 \cdot 89 + 2.99\varphi \quad (2)$$

where the standard deviation (s.d.) σ, is $\sigma = \pm 31.89$ and the correlation coefficient, r, is equal to $r_{A,\varphi} = + 0.94$

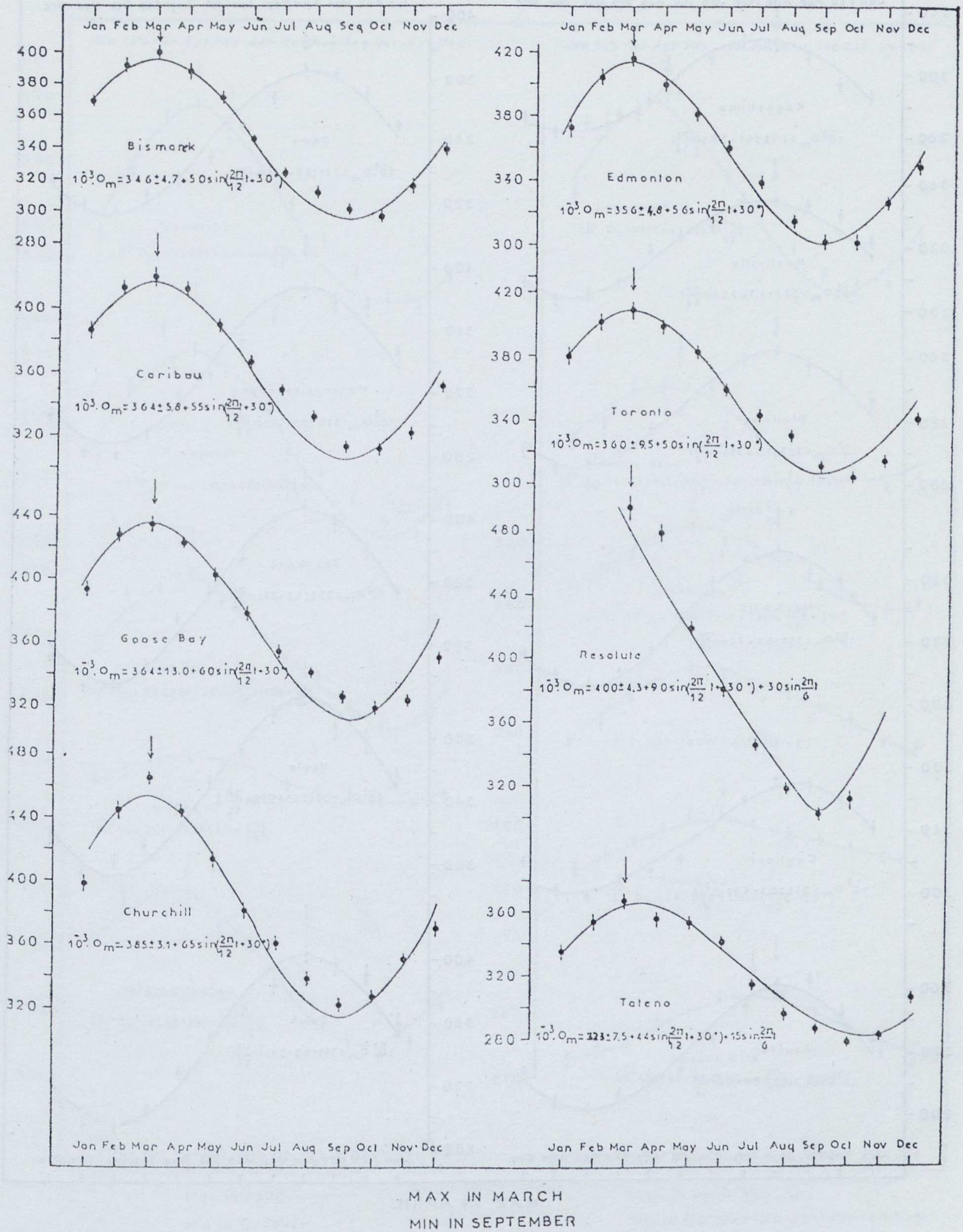

Fig. 5 Computed mean monthly values of total ozone (continuous curve) for the period 1957-1986. Maxima appear in March and minima in September. Each curve was computed by the equation shown below it. The small bars indicate computed s.d. for each mean monthly value, across the whole interval.

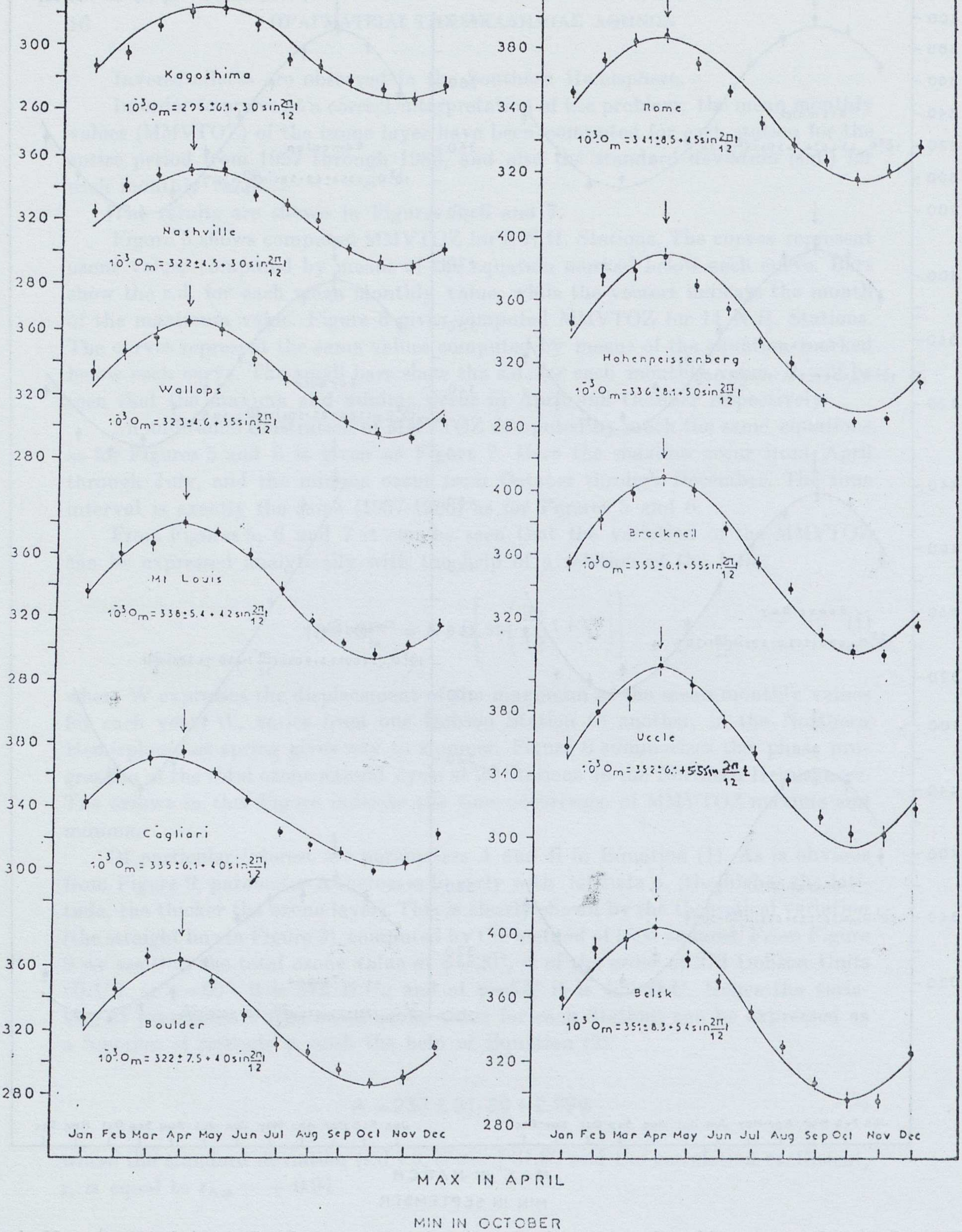

Fig. 6. Computed mean monthly values of total ozone (continuous curve) for the period 1957 - 1986. Maxima appear in April and minima in October. Each curve was computed by the equation shown below it. The small bars indicate computed s.d. for each mean monthly value, across the whole period.

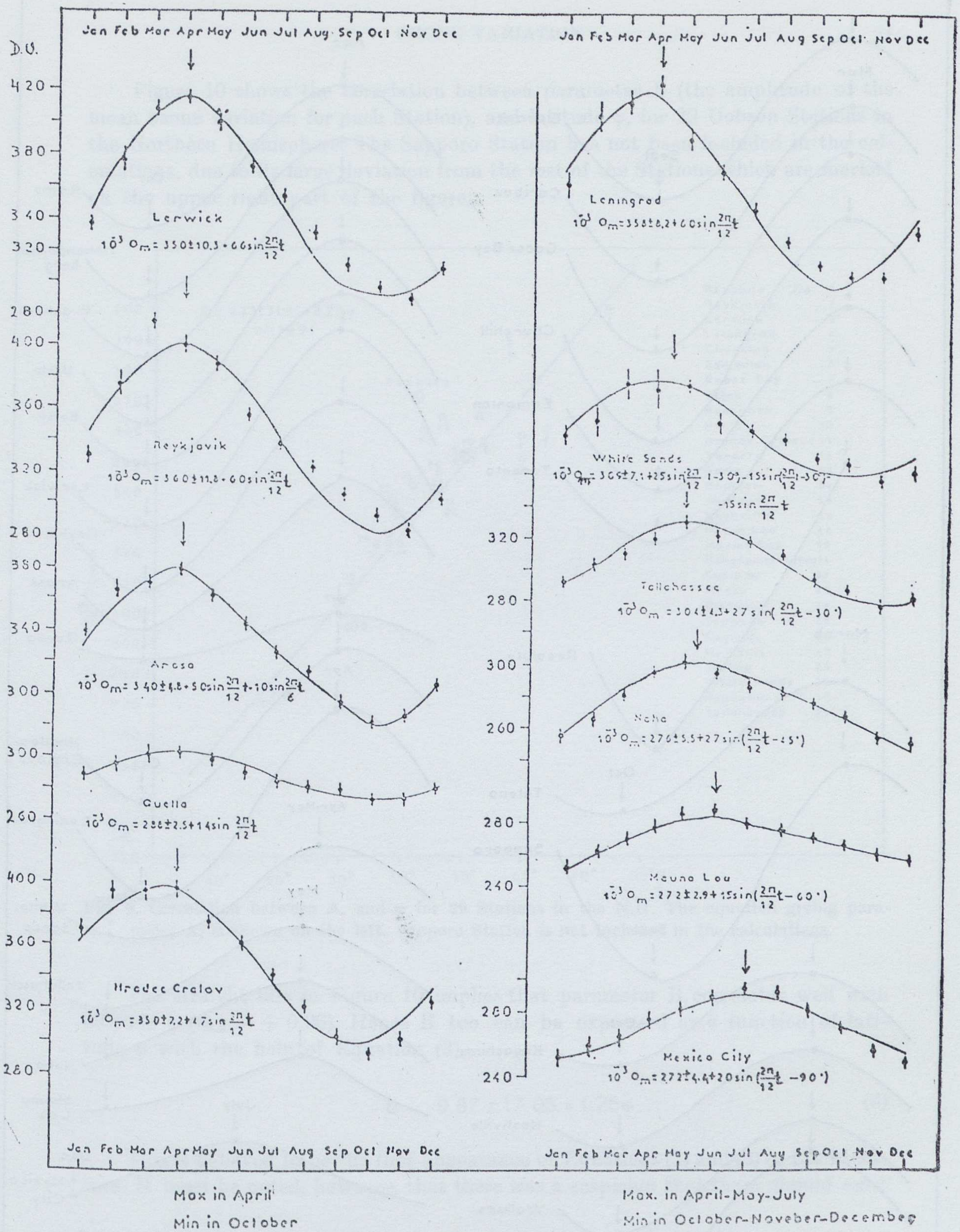

Fig. 7. Computed mean monthly values of total ozone (continuous curve). Maxima appear from April to July and minima from October till December. Each curve was computed by the equation shown below it. The small bars indicate computed s.d. for each mean monthly value across the whole period.

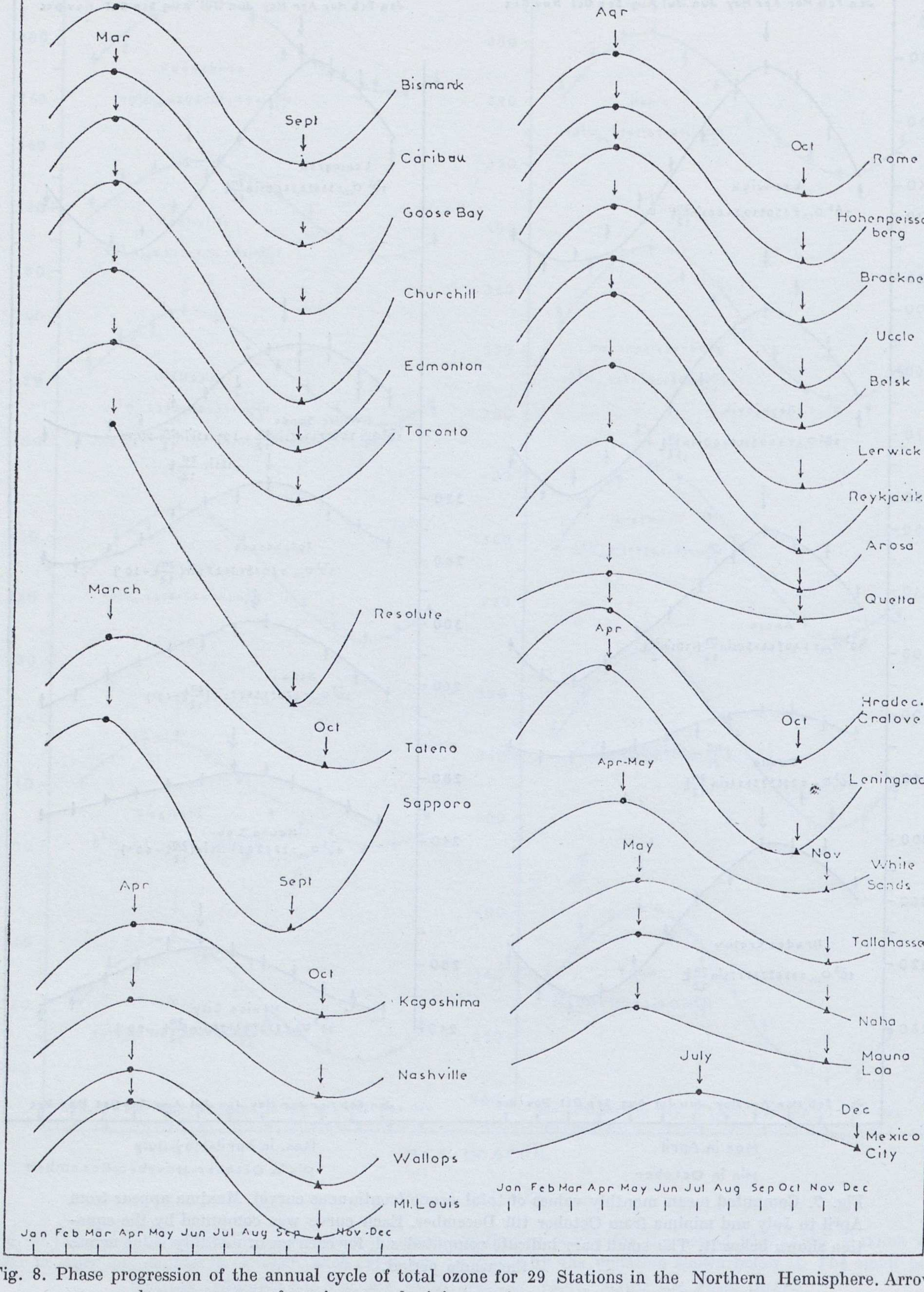

Fig. 8. Phase progression of the annual cycle of total ozone for 29 Stations in the Northern Hemisphere. Arrows show occurrence of maximum and minimum of mean monthly total ozone values.

Figure 10 shows the correlation between parameter B (the amplitude of the mean ozone variation for each Station), and latitude φ, for 29 Dobson Stations in the Northern Hemisphere. The Sapporo Station has not been included in the calculations, due to its large deviation from the rest of the Stations which are marked on the upper right part of the figure.

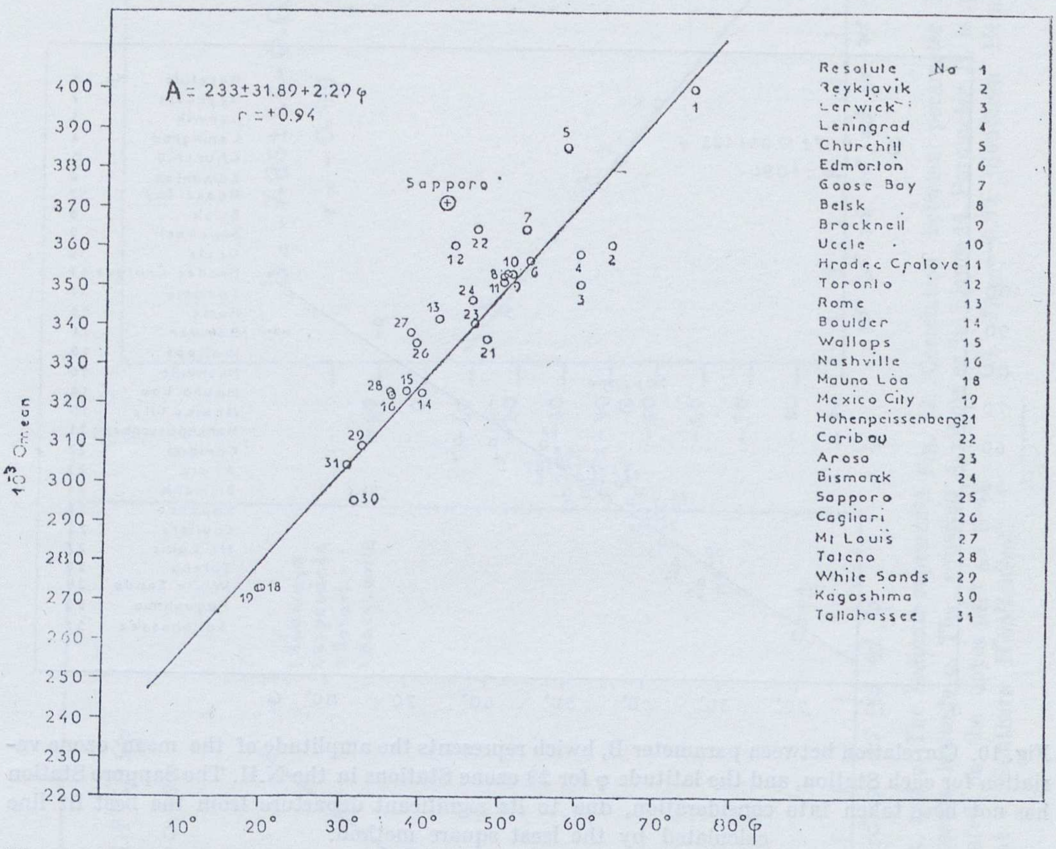

Fig. 9. Correlation between A, and φ for 29 Stations in the N.H. The equation giving parameter A, is shown on the left. Sapporo Station is not included in the calculations.

The straight line in Figure 10 implies that parameter B, correlates well with latitude φ ($r_{B,\varphi} = +0.96$). Hence B too can be expressed as a function of latitude φ with the help of Equation (3)

$$B = -9.87 \pm 17.05 + 1.25\varphi \tag{3}$$

This is believed to be the first appearance of Equations (3) and (2) in the literature. It must be noted, however, that there was a suspicion that there should exist a relationship between the mean variation of total ozone and latitude. A relationship between the mean variation of total ozone and latitude φ, had however been proposed by J. N. Xanthakis, C. Poulakos and C. Zerefos by means of Equations (2) and (3).

Figures 11 and 12 are analogous to Figures 9 and 10 and refer to the Southern Hemisphere. However, the results shown in them should be treated with caution,

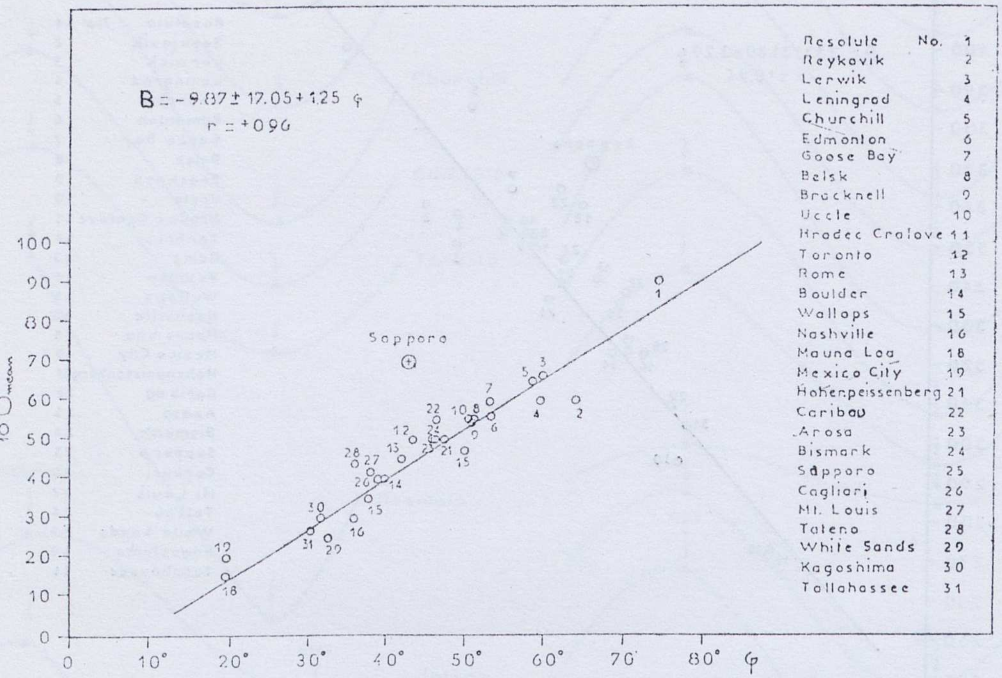

Fig. 10. Correlation between parameter B, hwich represents the amplitude of the mean ozone variation for each Station, and the latitude φ for 29 ozone Stations in the N.H. The Sapporo Station has not been taken into consideration, due to its significant departure from the best fit line calculated by the least square method.

because they are based on observational data from only 4 Stations in the Southern Hemisphere. Figures 11 and 12 show that parameters A and B can be analylically expressed as functions of latitude φ, in the same way as for the Northern Hemisphere with the help of Equations (4) and (5).

$$A = 270 \pm 1.7 + 1.31\varphi \quad (r_{A,\varphi} = +0.99) \tag{4}$$

$$B = -7.85 \pm 1.5 - 0.8\varphi \quad (r_{B,\varphi} = -0.99) \tag{5}$$

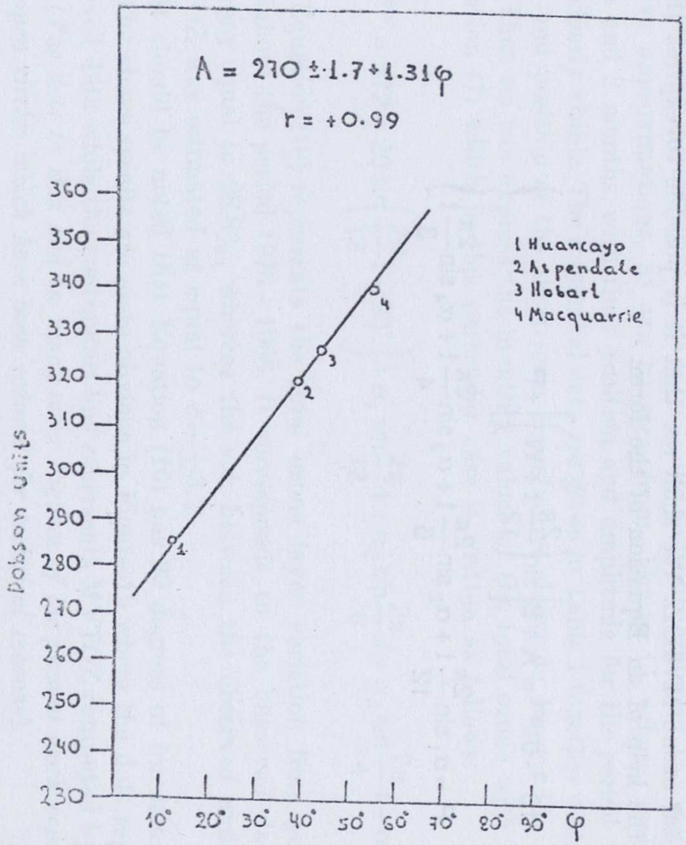

Fig. 11. Correlation between A, and φ. The ordinate represents D.U. and the abscissa represents latitude φ. The equation giving parameter A, is indicated on the upper part as well as the correlation coefficient **r** (Southern Hemisphere).

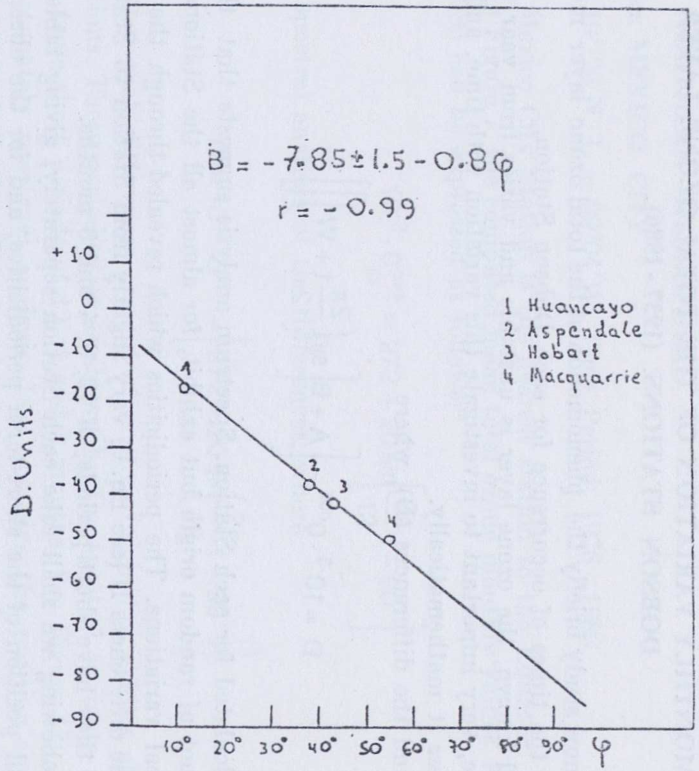

Fig. 12. Correlation between parameter B, and latitude φ. Symbols as in Figure 11. Parameter B, is given by Equation (5). $\mathbf{r}_{B,\varphi} = -0.99$. (Southern Hemisphere).

3. THE MONTHLY VARIATION OF THE TOTAL OZONE LAYER AT DOBSON STATIONS. (1957 - 1986).

We shall now study briefly the phenomenon of the total ozone layer mean variation giving the times of occurrence for each Dobson Station.

As is well known, the ozone layer is unstable and varies from year to year. It is, therefore, very important to investigate this variation with time, and if possible to express it mathematically.

To this end the differences (D), where

$$D = 10^{-3} \cdot 0^{obs} - \left[A + B \left[\sin\left(\frac{2\pi}{12} t + W \right) \right] \right] \tag{6}$$

have been calculated for each Station. Spectrum analysis suggests that these differences are not of random origin but exhibit, for almost all the Stations, short-term periodical variations. The periodicities which revealed through the spectral estimate of the differences D (see Eq. 6) vary slightly from Station to Station, but on the whole they have short periods, of 12, 6, 4 and 3 months.

In the following we shall take each Station separately, giving tables of the amplitude and position of the short-term periodicities, and for the observed and computed total ozone MVTOZ. We shall see that it is possible to express these values with the help of an Equation of the form:

$$\left.\begin{aligned} 10^{-3} \cdot 0^{com} &= A + B \left[\sin\left(\frac{2\pi}{12} t + W \right) \right] + P \\ P &= \alpha_1 \sin\frac{2\pi}{12} t + \alpha_2 \sin\frac{2\pi}{6} t + \alpha_3 \sin\frac{2\pi}{4} t + \alpha_4 \sin\frac{2\pi}{3} t \end{aligned}\right\} \tag{7}$$

4. THE NORTHERN HEMISPHERE

4.1 Station: MEXICO CITY

$\varphi = 19° 26'N$, $L = 99°04'W$, Time Period: 1976 - 1986.

The Mexico City Station is the nearest station to the Equator.

Using Figure 7, the computed mean total ozone monthly values for the period 1976 - 1986 can be expressed as follows:

$$10^{-3} \cdot O_m^{com} = 272 + 20 \sin\left[\frac{2\pi}{12} t - 90°\right] \tag{8}$$

The spectral analysis of the differences; where

$$D = 10^{-3} \cdot O^{obs} - \left[272 + 20 \sin\left(\frac{2\pi}{12} t - 90°\right)\right] \tag{9}$$

suggests that such differences are not of random origin but exhibit short periodical variations. These periodicities as shown by the spectral estimate of the differences (9) have short periods of 12, 4 and 3 months. See Figure 13.

Unfortunately spectrum analysis does not give the position and amplitude of short-term periodicities. This is achieved only by applying the method of successive approximations, as can be seen from Figure 14, where periodicities of 12, 4 and 3 months, with their position and amplitude for the period 1976 - 1986, are clearly visible. The numerical data are given in Table 1 together with the amplitude and position of the short-term periodicities shown in Figure 14.

Thus we can express the monthly values of the total ozone with the help of Equation (7) which in this particular case is written as follows:

$$10^{-3} \cdot O^{com} = 272 + 20 \sin\left(\frac{2\pi}{12} t - 90°\right) + \alpha_1 \sin\frac{2\pi}{12} t + \alpha_2 \sin\frac{2\pi}{6} t + \alpha_3 \sin\frac{2\pi}{4} t + \alpha_4 \sin\frac{2\pi}{3} t \tag{10}$$

Equation (10) represents the total ozone layer variation from year to year throughout the period 1976 - 1986. It corresponds to the observed data with an accuracy equal to 98.8%, whereas the s.d. between the observed and computed MVTOZ was estimated as equal to $\sigma = \pm 3.25$.

It should be noted that Equation (10) has 20 degrees of freedom.

The above results are more obvious in Figure 15 where the dots represent the observed data while the continuous line represents MVTOZ computed by Equation (10). (*The dots in this and in many other Figures of the present work represent original open circles which have been reduced for technical reasons*).

Table 1A summarizes the observed and computed total ozone monthly values for the Mexico City Station from 1976 through 1986.

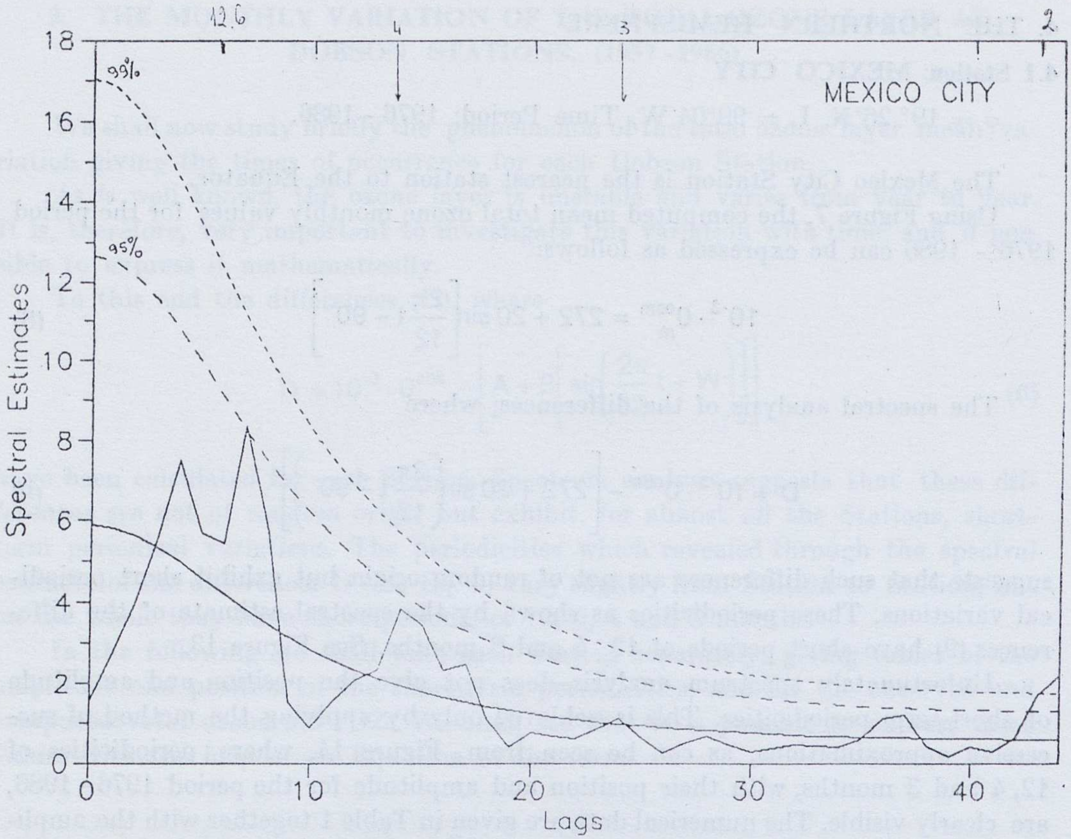

Fig. 13. Spectral estimate of the differences given by Equation (9), for the Mexico City Station. Periodicities of 12, 4 and 3 months are evident.

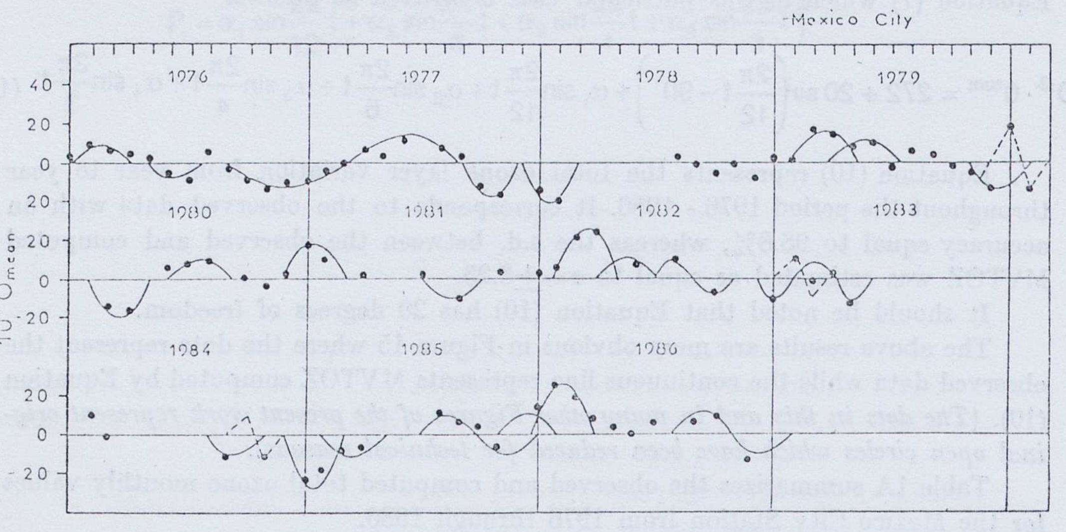

Fig. 14. Short-term periodicities of 12, 4 and 3 months are shown for the Mexico City Station. The time interval is from 1976 through 1986.

TABLE 1

Values of the parameters $\alpha_1 - \alpha_4$, and t (see Eq. 10).

α_1	t
+10	1976.1 - 1976.4, 1979.4 - 1979.7, 1980.6 - 1980.9, 1982.4 - 1982.7, 1984.9 - 1984.12, 1985.7 - 1985.10, 1985.11 - 1986.2, 1986.8 - 1987.2
α_2	t
—10	1976.5 - 1976.8, 1981.7 - 1981.10, 1984.8 - 1984.11, 1985.2 - 1985.5
—15	1977.9 - 1977.12, 1979.11 - 1980.2
—20	1977.12 - 1978.3, 1980.2 - 1980.5
+20	1979.2 - 1979.5
+25	1982.2 - 1982.5, 1986.1 - 1986.4
—25	1984.12 - 1985.3
α_3	t
+10	1982.7 - 1982.10
—10	1982.12 - 1983.6, 1984.1 - 1984.5
α_4	t
+15	1979.12 - 1980.3, 1980.12 - 1981.3
+10	1983.1 - 1983.4, 1984.9 - 1984.12

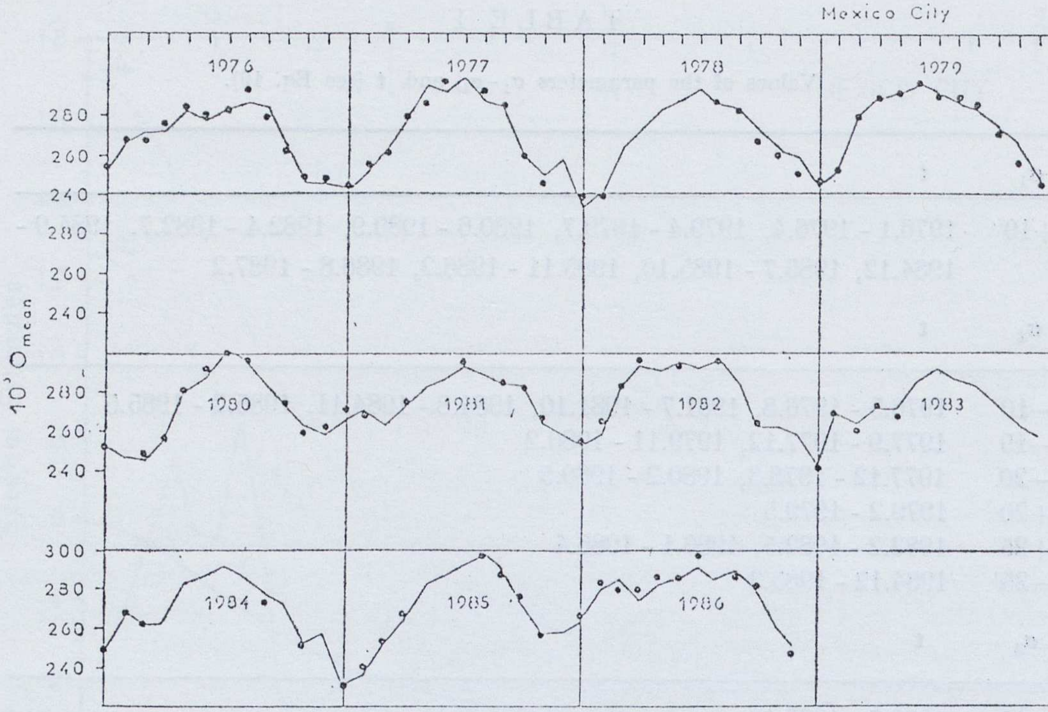

Fig. 15. Dots represent observed MVTOZ for the Mexico City Station. The time period is from 1976 - 1986. The solid line represents the MVTOZ computed by Equation (10).

TABLE 1A

Observed and computed MVTOZ for the Mexico City Station. Period is from 1976 through 1986.

Year/month	comp.	obs.	Year/month.	comp.	obs.
1976. 1	252	257	1979. 1	252	254
» 2	267	268	» 2	258	259
» 3	271	268	» 3	279	279
» 4	272	276	» 4	289	287
» 5	282	284	» 5	291	290
» 6	277	280	» 6	295	295
» 7	283	282	» 7	292	289
» 8	286	292	» 8	286	290
» 9	282	279	» 9	282	289
» 10	265	262	» 10	272	270
» 11	245	248	» 11	262	256
» 12	243	248	» 12	245	245
1977. 1	239	242	1980. 1	252	252
» 2	251	254	» 2	245	245
» 3	262	261	» 3	246	248
» 4	279	279	» 4	255	256
» 5	295	286	» 5	282	—
» 6	291	297	» 6	286	292
» 7	299	—	» 7	301	300
» 8	293	292	» 8	295	295
» 9	282	284	» 9	282	—
» 10	259	259	» 10	272	273
» 11	249	246	» 11	262	259
» 12	258	—	» 12	258	261
1978. 1	235	238	1981. 1	265	270
» 2	241	238	» 2	271	268
» 3	262	—	» 3	262	—
» 4	272	—	» 4	272	274
» 5	282	—	» 5	282	—
» 6	286	—	» 6	286	—
» 7	298	—	» 7	292	296
» 8	286	288	» 8	277	—
» 9	282	281	» 9	273	274
» 10	272	267	» 10	272	—
» 11	262	260	» 11	262	265
» 12	258	250	» 12	258	—

Year/month	comp.	obs.	Year/month	comp.	obs.
1982. 1	258	254	1985. 1	230	230
» 2	258	264	» 2	236	240
» 3	284	283	» 3	253	254
» 4	294	296	» 4	263	267
» 5	291	—	» 5	282	—
» 6	295	293	» 6	286	—
» 7	292	—	» 7	292	—
» 8	296	296	» 8	295	296
» 9	282	—	» 9	291	287
» 10	262	265	» 10	272	276
» 11	262	—	» 11	253	257
» 12	258	—	» 12	258	—
1983. 1	242	241	1986. 1	261	266
» 2	267	268	» 2	280	283
» 3	263	260	» 3	284	280
» 4	272	273	» 4	272	280
» 5	272	268	» 5	282	286
» 6	286	—	» 6	286	286
» 7	292	—	» 7	292	297
» 8	286	—	» 8	286	—
» 9	282	—	» 9	291	288
» 10	272	—	» 10	281	282
» 11	262	—	» 11	262	—
» 12	258	—	» 12	249	247
1984. 1	252	253			
» 2	268	268			
» 3	262	261			
» 4	262	—			
» 5	282	—			
» 6	286	—			
» 7	292	—			
» 8	286	—			
» 9	273	271			
» 10	272	—			
» 11	253	251			
» 12	258	—			

4.2 Station: MAUNA LOA

$\varphi = 19° 32'$N, L$=155° 35'$ W, Time Period: 1964 - 1986

Mauna Loa is the other Dobson Station near the Equator. As with Mexico City, the recorded period is not one of the longest in the present investigation. However both Stations give an indication of the variation of tropospheric total ozone near the equatorial zone.

Using Figure 7, the computed mean total ozone monthly values can be represented by Equation (11).

$$10^{-3} \cdot 0_m^{com} = 272 + 15 \sin\left[\frac{2\pi}{12} t - 60^\circ\right] \tag{11}$$

If we now analyse the differences

$$D \doteq 10^{-3} \cdot 0^{obs} - \left[272 + 15 \sin\left(\frac{2\pi}{12} t - 60^\circ\right)\right] \tag{12}$$

we find that they exhibit short-term periodicities, with periods equal to 36, 24, 12, 6, 4 and 3 months. The results of analysis are better shown in Figure 16, where there are significant periodicities of 36, 24, 12, 6, 4 and 3 months. The 4-month period in particular is even higher than the confidence level of 99%.

Figure 17 shows the above periodicities plotted according the method of successive approximations for the period 1964 - 1986. There are significant periodicities of 36, 24, 12, 6, 4 and 3 months some of which are very close to the confidence level of 99%. These periodicities can be expressed by the equation:

$$P = \alpha_1 \sin\frac{2\pi}{12} t + \alpha_2 \sin\frac{2\pi}{6} t + \alpha_3 \sin\frac{2\pi}{4} t + \alpha_4 \sin\frac{2\pi}{3} t \tag{13}$$

Table 2 tabulates the numerical data on which Figure 17 was based.

It is genuinely possible, therefore, to express the observed data as an Equation (7). For the Mauna Loa Station Equation (7) is written:
where the quantities and P are given by Equations (11) and (13) respectively.

$$10^{-3} \cdot 0^{com} = 10^{-3} \cdot 0_m^{com} + P \tag{14}$$

Equation (14) represents the observed data set with an accuracy equal to 98.8% while the s.d. between the observed and computed MVTOZ is found to be equal to $\sigma = \pm 3.16$. Equation (14) has 126 degrees of freedom.

These results are plotted in Figure 18, where the dots represent observed MV TOZ while the continuous line shows MVTOZ computed by Equations (11) and (13).

The numerical results are listed in Table 2A.

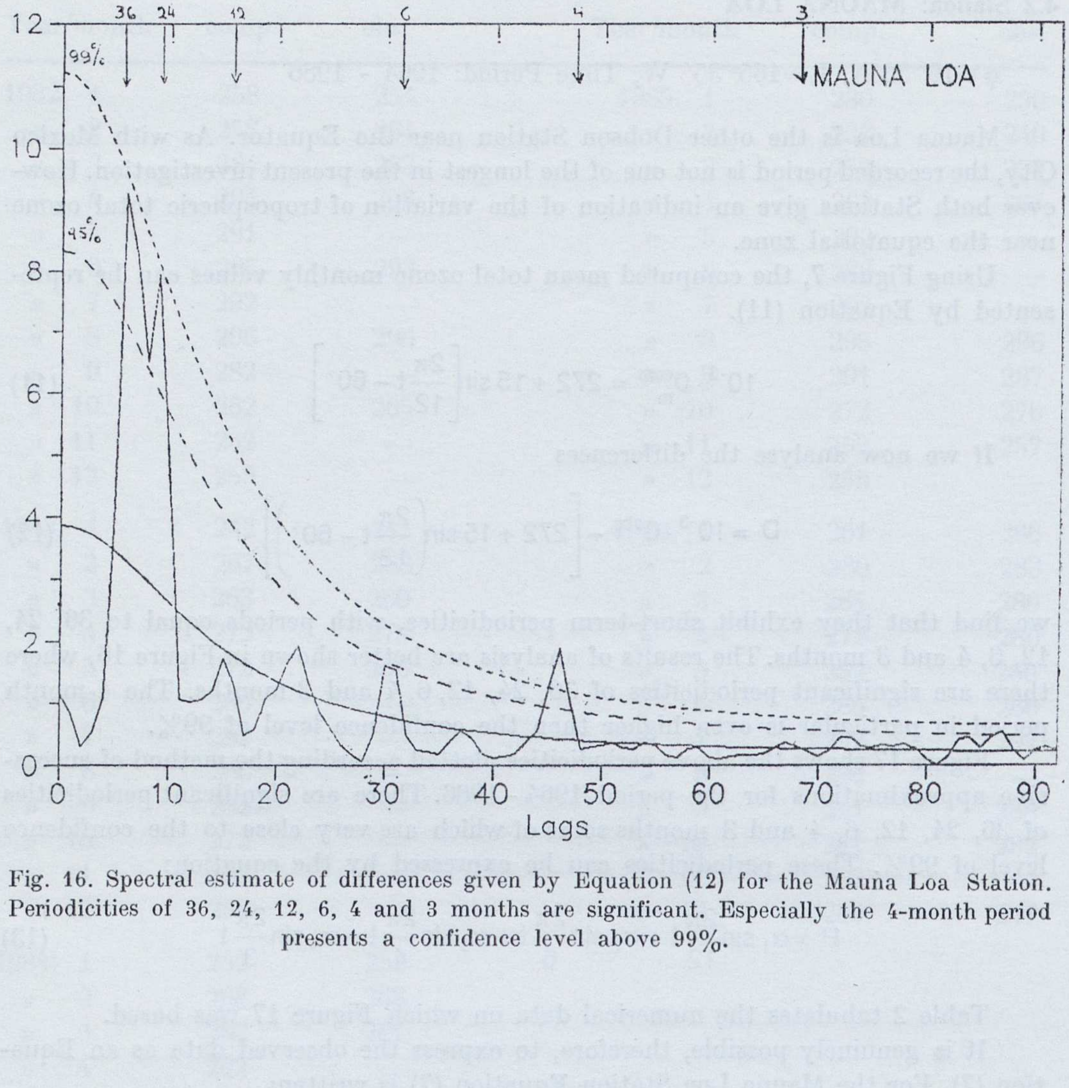

Fig. 16. Spectral estimate of differences given by Equation (12) for the Mauna Loa Station. Periodicities of 36, 24, 12, 6, 4 and 3 months are significant. Especially the 4-month period presents a confidence level above 99%.

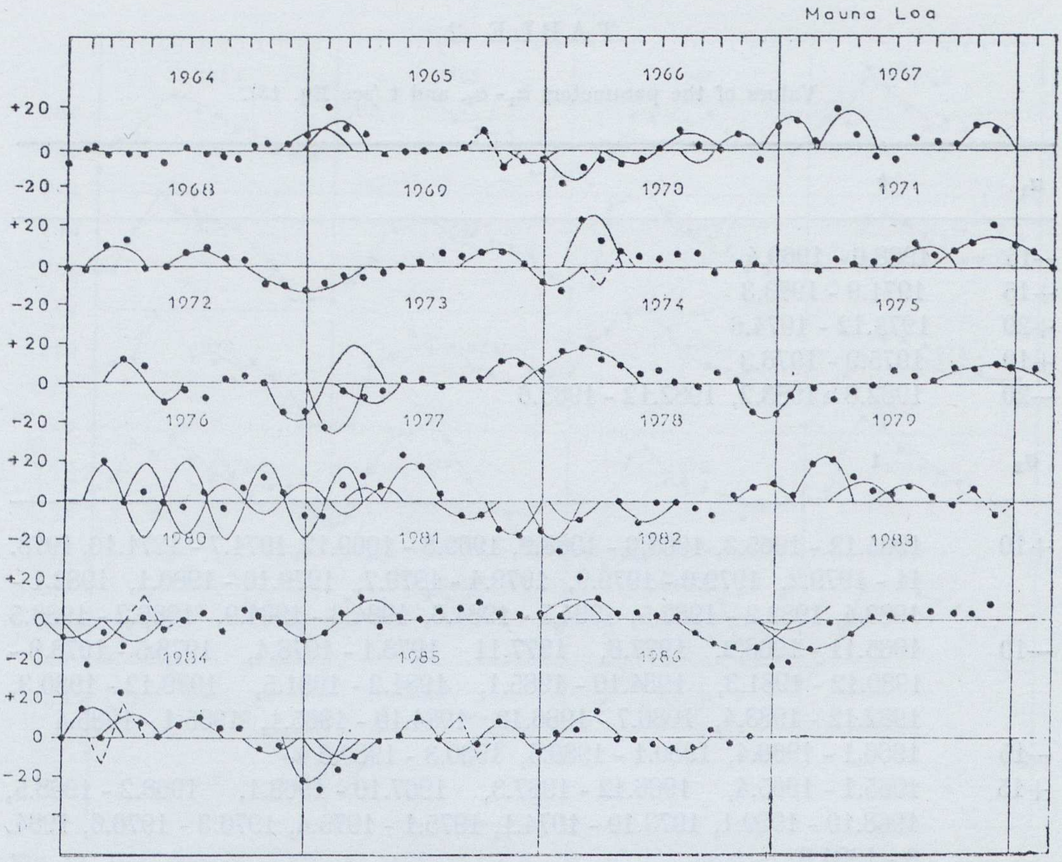

Fig. 17. Short - term periodicities with periods of 36, 24, 12, 6, 4 and 3 months are shown for the Mauna Loa Station. The periodicities appear as a network of periodicities and in some cases are overlapping with each other. The periodic terms were plotted on this figure by the successive approximation method. The amplitude and the position of the periodic terms are also shown. The period is from 1964 - 1986.

TABLE 2

Values of the parameters $\alpha_1 - \alpha_4$, and **t** (see Eq. 13).

α_1	t
—15	1968.6 - 1969.4
+15	1971.9 - 1973.3
+20	1973.12 - 1974.6
+10	1975.9 - 1976.3
—20	1982.8 - 1983.2, 1982.12 - 1983.6
α_2	**t**
+10	1964.12 - 1965.3, 1968.6 - 1968.9, 1969.8 - 1969.12, 1971.7 - 1971.10, 1978.11 - 1979.2, 1979.6 - 1979.9, 1979.4 - 1979.7, 1979.10 - 1980.1, 1982.1 - 1983.4, 1982.2 - 1982.5, 1984,3 - 1984.6, 1984.6 - 1984.9, 1986.2 - 1986.5
—10	1965.11 - 1966.2, 1977.8, 1977.11 1978.1 - 1978.4, 1978.5 - 1978.8 - 1980.12 - 1981.3, 1984.10 - 1985.1, 1981.2 - 1981.5, 1979.12 - 1980.3, 1982.12 - 1983.4, 1986.7 - 1986.10, 1984.10 - 1985.1, 1985.1 - 1985.4
—15	1966.1 - 1966.4, 1980.1 - 1980.4, 1980.3 - 1980.6
+15	1965.1 - 1965.4, 1966.12 - 1967.3, 1967.10 - 1968.1, 1968.2 - 1968.5, 1968.10 - 1969.1, 1973.10 - 1974.1, 1975.1 - 1975.4, 1976.3 - 1976.6, 1984.2 - 1984.8
+20	1970.2 - 1970.5, 1979,2 - 1979.5
—20	1973.11 - 1974.2, 1977.10 - 1978.1, 1977.12-1978.3, 1974.11 - 1975.2
—25	1973.1 - 1973.4, 1984.12 - 1985.3
α_3	**t**
—10	1966.8 - 1966.12, 1973.1 - 1973.5
+10	1976.3 - 1973.7, 1976.8 - 1976.12, 1985.6 - 1985.12
+20	1976.2 - 1976.6, 1976.4 - 1976.8
α_4	**t**
+10	1965.11 - 1966.2, 1973.3 - 1973.6, 1980.4 - 1980.7 1985.8 - 1985.11
—10	1970.3 - 1970.6
+15	1984.1 - 1984.4

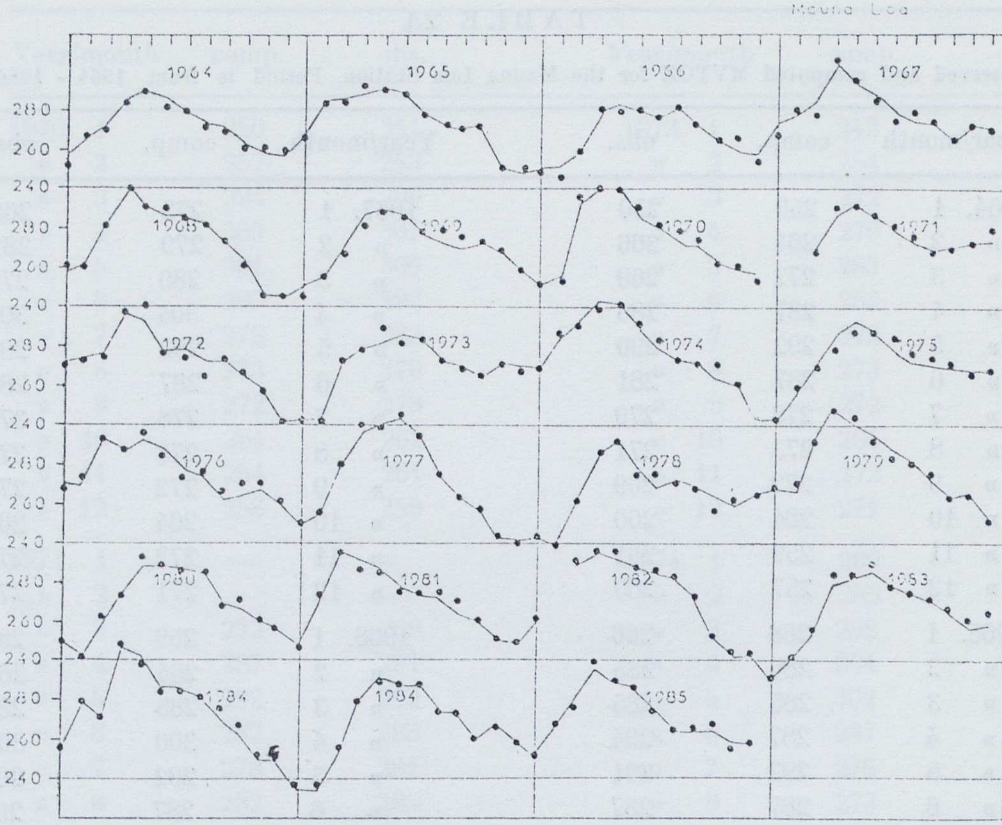

Fig. 18. Dots represent observed MVTOZ for the Mauna Loa Station. The solid line represents MVTOZ computed by Equation (14).

TABLE 2A

Observed and computed MVTOZ for the Mauna Loa Station. Period is from 1964 - 1986.

Year/month	comp.	obs.	Year/month	comp.	obs.
1964. 1	259	250	1967. 1	272	268
» 2	264	266	» 2	279	281
» 3	272	269	» 3	289	278
» 4	287	285	» 4	304	307
» 5	292	290	» 5	292	295
» 6	287	281	» 6	287	284
» 7	278	279	» 7	278	273
» 8	273	271	» 8	273	279
» 9	272	269	» 9	272	275
» 10	264	260	» 10	264	267
» 11	259	261	» 11	272	273
» 12	257	260	» 12	271	270
1965. 1	268	266	1968. 1	259	261
» 2	286	285	» 2	264	261
» 3	285	285	» 3	285	282
» 4	287	294	» 4	300	300
» 5	292	291	» 5	292	291
» 6	287	287	» 6	287	291
» 7	278	278	» 7	287	286
» 8	273	274	» 8	282	282
» 9	272	273	» 9	272	274
» 10	273	272	» 10	264	262
» 11	250	251	» 11	246	246
» 12	248	251	» 12	245	246
1966. 1	250	249	1969. 1	250	245
» 2	251	246	» 2	255	256
» 3	259	260	» 3	272	267
» 4	278	281	» 4	287	281
» 5	283	280	» 5	292	291
» 6	277	281	» 6	287	286
» 7	278	278	» 7	278	279
» 8	283	282	» 8	273	280
» 9	272	273	» 9	272	277
» 10	264	265	» 10	273	274
» 11	259	266	» 11	268	269
» 12	258	254	» 12	258	259

Year/month	comp.	obs.	Year/month	comp.	obs.
1970. 1	250	251	1973. 1	242	243
» 2	257	253	» 2	244	242
» 3	294	296	» 3	272	273
» 4	300	301	» 4	279	278
» 5	301	300	» 5	283	289
» 6	287	292	» 6	287	282
» 7	278	282	» 7	278	279
» 8	273	279	» 8	273	273
» 9	272	278	» 9	272	269
» 10	264	262	» 10	264	266
» 11	254	261	» 11	272	271
» 12	258	259	» 12	271	268
1971. 1	—	—	1974. 1	269	268
» 2	—	—	» 2	283	287
» 3	272	269	» 3	292	290
» 4	287	291	» 4	304	299
» 5	292	292	» 5	302	302
» 6	287	288	» 6	287	292
» 7	278	281	» 7	278	284
» 8	282	285	» 8	273	274
» 9	281	278	» 9	272	271
» 10	272	272	» 10	262	271
» 11	272	272	» 11	259	261
» 12	273	279	» 12	241	243
1972. 1	272	270	1975. 1	242	243
» 2	274	273	» 2	266	260
» 3	277	275	» 3	272	269
» 4	297	298	» 4	287	279
» 5	292	299	» 5	292	288
» 6	277	277	» 6	287	286
» 7	278	274	» 7	278	285
» 8	273	265	» 8	273	277
» 9	272	273	» 9	272	274
» 10	264	267	» 10	269	272
» 11	259	258	» 11	268	266
» 12	241	242	» 12	268	268

Year/month	comp.	obs.	Year/month	comp.	obs.
1976. 1	269	268	1979. 1	268	269
» 2	266	273	» 2	266	269
» 3	292	292	» 3	294	291
» 4	287	286	» 4	309	308
» 5	292	296	» 5	301	304
» 6	287	285	» 6	296	292
» 7	278	274	» 7	287	283
» 8	273	277	» 8	282	280
» 9	262	266	» 9	272	276
» 10	264	270	» 10	264	263
» 11	269	270	» 11	268	265
» 12	258	261	» 12	249	249
1977. 1	249	251	1980. 1	250	249
» 2	256	256	» 2	244	241
» 3	282	280	» 3	259	263
» 4	297	301	» 4	274	272
» 5	302	300	» 5	288	293
» 6	304	306	» 6	278	279
» 7	295	295	» 7	278	276
» 8	273	276	» 8	273	276
» 9	263	264	» 9	272	267
» 10	257	258	» 10	266	271
» 11	242	258	» 11	259	260
» 12	141	240	» 12	258	257
1978. 1	242	243	1981. 1	250	247
» 2	240	239	» 2	257	259
» 3	263	261	» 3	272	275
» 4	287	286	» 4	296	296
» 5	292	292	» 5	292	287
» 6	278	276	» 6	287	286
» 7	269	276	» 7	278	276
» 8	273	271	» 8	273	275
» 9	272	268	» 9	272	275
» 10	264	257	» 10	264	271
» 11	259	262	» 11	259	261
» 12	267	265	» 12	258	260

Year/month	comp.	obs.	Year/month	comp.	obs.
1982. 1	258	262	1985. 1	236	237
» 2	275	—	» 2	235	237
» 3	290	292	» 3	254	256
» 4	296	297	» 4	278	279
» 5	292	294	» 5	292	289
» 6	288	288	» 6	287	287
» 7	278	279	» 7	288	288
» 8	273	274	» 8	273	272
» 9	262	263	» 9	271	272
» 10	249	253	» 10	255	260
» 11	239	244	» 11	269	266
» 12	241	242	» 12	258	258
1983. 1	229	230	1986. 1	250	250
» 2	240	242	» 2	266	268
» 3	252	256	» 3	281	276
» 4	279	284	» 4	296	300
» 5	282	284	» 5	287	289
» 6	287	290	» 6	287	286
» 7	278	278	» 7	278	272
» 8	273	275	» 8	264	268
» 9	272	272	» 9	263	265
» 10	264	267	» 10	264	266
» 11	259	261	» 11	259	255
» 12	258	265	» 12	258	257
1984. 1	258	256			
» 2	279	279			
» 3	272	271			
» 4	309	309			
» 5	301	298			
» 6	267	284			
» 7	287	284			
» 8	282	281			
» 9	272	276			
» 10	264	267			
» 11	250	251			
» 12	249	251			

4.3 Station: NAHA

φ=26° 27′N, L = 127° 41′ W, Time Preriod: 1974 - 1986

Using Figure 7, the computed mean total ozone monthly values can be represented as:

$$10^{-3} \cdot 0_m^{com} = 276 + 27 \sin\left(\frac{2\pi}{12} t - 45^\circ\right) \tag{15}$$

The spectrum analysis of the differences, where

$$D = 10^{-3} \cdot 0^{obs} - \left[276 + 27 \sin\left(\frac{2\pi}{12} t - 45^\circ\right)\right] \tag{16}$$

shows short-term periodicities of 6, 4 and 3 months. The confidence level is for the first periodicity above the level of 99%, while for the other two it is above 95%. See Figure 19, and note that the 6-month periodicity is predominant.

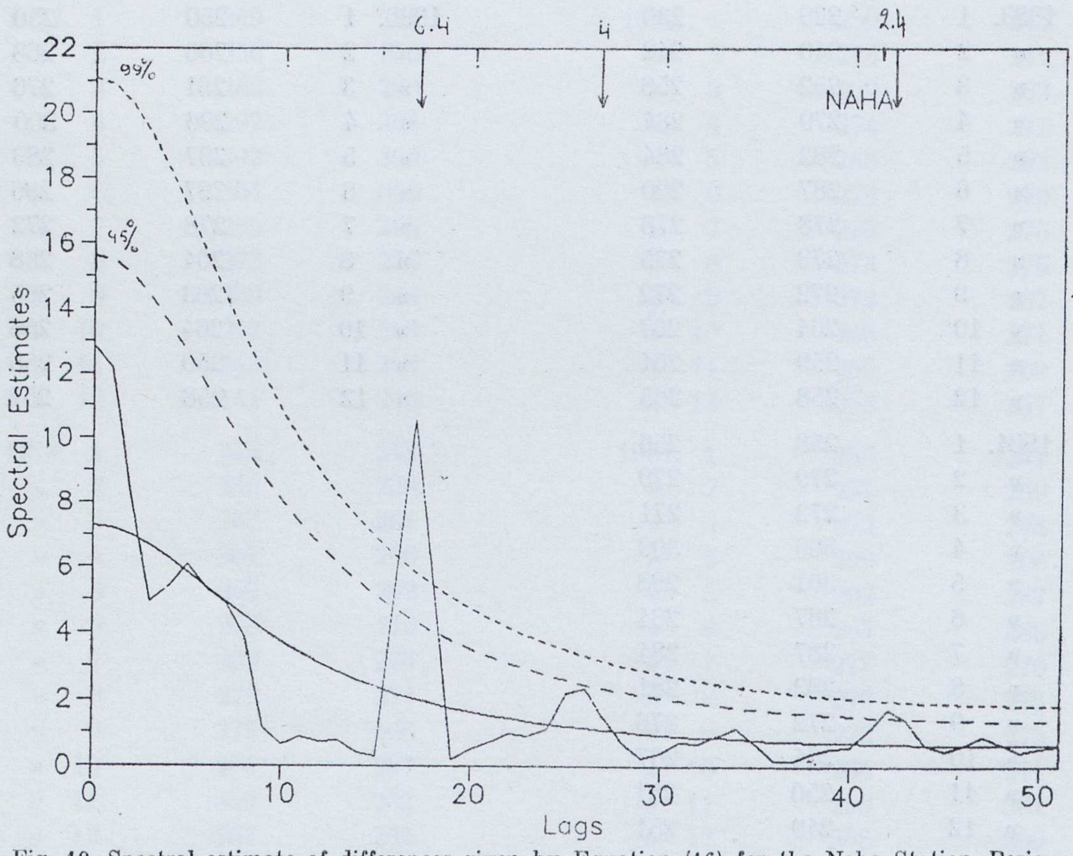

Fig. 19. Spectral estimate of differences given by Equation (16) for the Naha Station. Periodicities of 6, 4 and 3 months are significant. The 6-month period is predominant and has a confidence level above 99%. The 4 and 3-month periods are above the confidence level of 95%.

In Figure 20 the dots represent the differences given by Equation (16) while the dashed and solid lines represent periodic terms with periods equal to 6, 4 while and 3 months. These values can be expressed as follows:

$$P = \alpha_1 \sin\frac{2\pi}{12}t + \alpha_2 \sin\frac{2\pi}{6}t + \alpha_3 \sin\frac{2\pi}{4}t + \alpha_4 \sin\frac{2\pi}{3}t \tag{17}$$

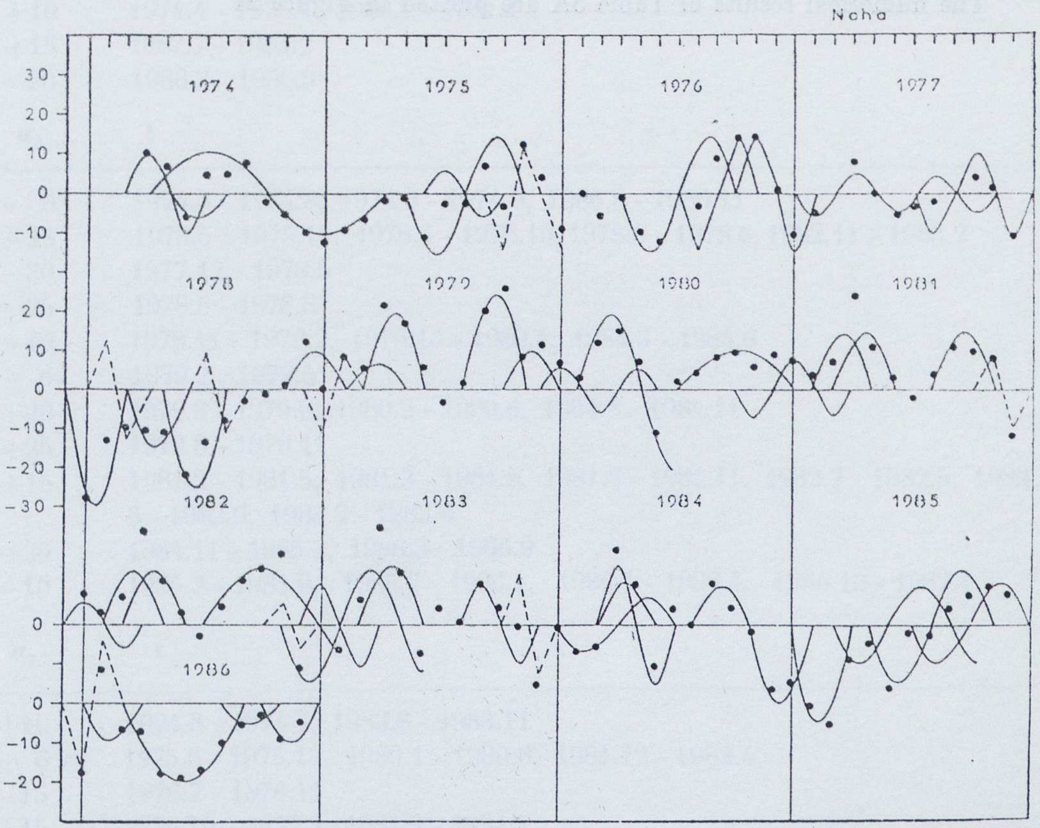

Fig. 20. Dots represent the differences, derived from Equation (16). The dashed and solid sinusoidal or semisinusoidal curves represent periodic terms of 6, 4 and 3 months. The periodic terms were plotted by the successive approximation method. The periodicities appear as a network with ocasional overlaps.

The position and amplitude of these periodic terms, as found by the method of successive approximations, are listed in Table 3 (see parameters α_1, α_2, α_3, α_4, and **t**).

Thus the variation and periodicity of total ozone monthly values can be represented with an accuracy of as great as 99.1% by the equation:

$$10^{-3} \cdot O^{com} = 10^{-3} \cdot O^{com}_{m} + P \tag{18}$$

where the quantities 10^{-3}. O_m^{com} and P are given by Equations (15) and (17) respectively.

Here MVTOZ (1974 - 1986) as observed are represented by dots (reduced open circles) and the same MVTOZ as computed by Equation (18) are represented by solid line.

Note the close agreement between the two.

The numerical results of Table 3A are plotted in Figure 21

TABLE 3

Values of the parameters $\alpha_1 - \alpha_4$ and **t** (see Eq. 17).

α_1	t
+10	1974.4 - 1975.4, 1980.7 - 1981.1
+15	1982.7 - 1983.2
—20	1986.3 - 1986.9
α_2	t
— 6	1974.5 - 1974.8, 1974.6 - 1974.9, 1986.8 - 1986.11
—15	1975.5 - 1975.11, 1976.4 - 1976.10, 1978.3 - 1978.6, 1982.11 - 1983,2
—30	1977.12 - 1978.5
—25	1978.5 - 1978.8
+10	1978.11 - 1979.2, 1979.10 - 1980.1, 1984.3 - 1984.6
+ 6	1979.2 - 1979.5
+20	1979.3 - 1979.6, 1980.2 - 1980.6, 1984.8 - 1984.11
+25	1979.8 - 1979.11
+15	1981.2 - 1981.5, 1981.3 - 1981.6, 1981.8 - 1981.11, 1982.2 - 1982.5, 1982.3 - 1982.6, 1983.3 - 1983.6
—20	1984.11 - 1985.2, 1986.3 - 1986.9
—10	1985.3 - 1985.9, 1985.7 - 1986.1, 1986.1 - 1986.4, 1986.10 - 1987.1
α_3	t
+10	1974.3 - 1974.7, 1983.8 - 1983.11
+ 6	1975.6 - 1975.10, 1980.1 - 1980.6, 1981.12 - 1982.4
—15	1976.7 - 1976.11
+15	1976.10 - 1977.2, 1984.3 - 1984.7
— 6	1977.1 - 1977.7, 1980.10 - 1981.2
α_4	t
—10	1977.7 - 1978.1
+15	1978.1 - 1978.4, 1983.10 - 1984.1
+10	1978.6 - 1978.9, 1981.10 - 1982.1
—10	1978.12 - 1979.3
— 6	1982.10 - 1983.1, 1984.1 - 1984.7
—20	1985.2 - 1986.3

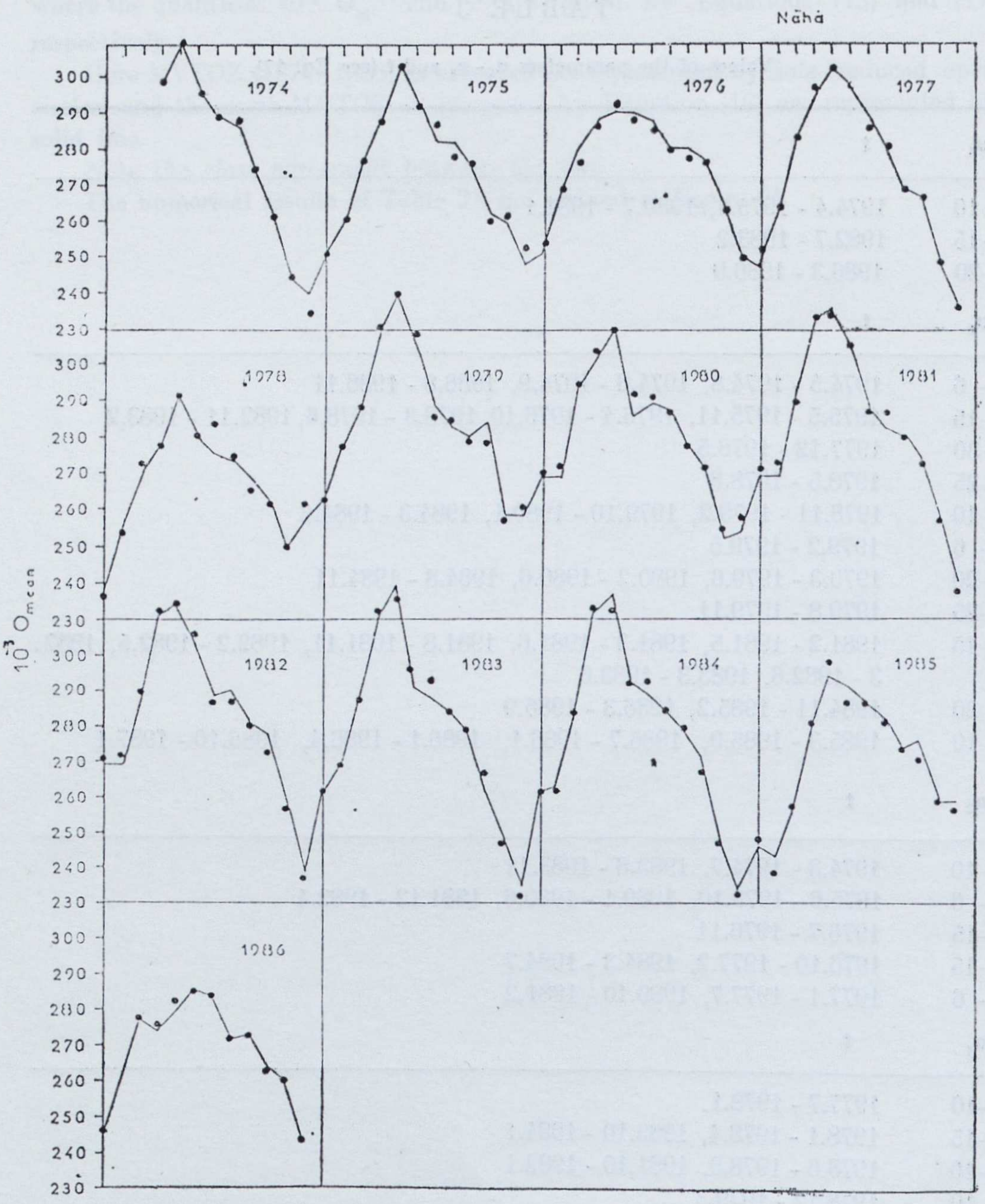

Fig. 21. Naha Station, 1974 - 1986. Observed MVTOZ is shown by dots. MVTOZ as found by Equation (18) is shown by a solid line. The s.d. is found to be equal to $\sigma = \pm 2.4$, while the accuracy is found to be equal to 99.1%. Note the close agreement between the two.

TABLE 3A

Naha Staton. Observed and computed MVTOZ.

Year/month	comp.	obs.	Year/month	comp.	obs.
1974. 1	—	—	1977. 1	248	253
» 2	—	—	» 2	263	264
» 3	—	—	» 3	283	283
» 4	299	299	» 4	295	297
» 5	308	310	» 5	303	303
» 6	297	296	» 6	297	298
» 7	289	289	» 7	289	286
» 8	287	288	» 8	279	281
» 9	274	276	» 9	269	269
» 10	263	261	» 10	267	267
» 11	244	244	» 11	247	249
» 12	240	235	» 12	237	236
1975. 1	253	251	1978. 1	238	236
» 2	260	260	» 2	256	254
» 3	278	277	» 3	271	273
» 4	289	288	» 4	277	278
» 5	303	303	» 5	291	292
» 6	291	292	» 6	281	281
» 7	283	287	» 7	276	284
» 8	283	278	» 8	274	275
» 9	275	276	» 9	269	266
» 10	263	260	» 10	263	262
» 11	261	262	» 11	249	250
» 12	249	253	» 12	258	262
1976. 1	254	254	1979. 1	263	263
» 2	269	269	» 2	278	278
» 3	283	277	» 3	288	289
» 4	289	287	» 4	311	311
» 5	291	293	» 5	320	320
» 6	291	289	» 6	303	309
» 7	289	286	» 7	289	286
» 8	280	280	» 8	283	285
» 9	281	278	» 9	291	289
» 10	278	277	» 10	285	279
» 11	264	263	» 11	258	257
» 12	249	250	» 12	258	261

Year/month	comp.	obs.	Year/month	comp.	obs.
1980. 1	269	270	1983. 1	261	262
» 2	269	272	» 2	269	269
» 3	294	295	» 3	285	283
» 4	302	304	» 4	313	313
» 5	309	310	»	320	316
» 6	286	292	» 6	291	296
» 7	289	291	» 7	289	293
» 8	288	287	» 8	283	284
» 9	278	278	» 9	279	277
» 10	273	272	» 10	263	267
» 11	252	255	» 11	249	247
» 12	254	258	» 12	235	232
1981. 1	269	271	1984. 1	263	262
» 2	269	273	» 2	264	262
» 3	295	290	» 3	288	289
» 4	313	313	» 4	313	313
» 5	315	314	» 5	317	313
» 6	303	306	» 6	293	292
» 7	289	287	» 7	289	293
» 8	283	287	» 8	283	284
» 9	281	280	» 9	278	279
» 10	275	273	» 10	272	267
» 11	258	257	» 11	249	247
» 12	240	237	» 12	232	232
1982. 1	269	271	1985. 1	246	248
» 2	269	272	» 2	243	238
»»» 3	289	290	3 3	257	257
» 4	313	313	» 4	280	280
» 5	315	314	» 5	294	298
» 6	303	306	» 6	291	287
» 7	289	287	»	286	287
» 8	290	287	» 8	283	280
» 9	281	286	» 9	272	273
» 10	278	277	» 10	275	270
» 11	256	257	» 11	258	258
» 12	239	237	» 12	258	256

Year/month	comp.	obs.
1986. 1	246	246
» 2	277	278
» 3	274	276
» 4	279	282
» 5	286	285
» 6	283	284
» 7	272	272
» 8	273	273
» 9	264	263
» 10	258	260
» 11	240	240
» 12	240	244

4.4 Sation QUETTA

$\varphi = 30°\ 15'N$, $L = 66°\ 53'\ E$, Time Period: 1957 - 1986

Using Figure 7, we see that the MMVTOZ can be adequately represented with the help of the relation:

$$10^{-3} \cdot O_m^{com} = 288 + 14 \sin\frac{2\pi}{12} t \tag{19}$$

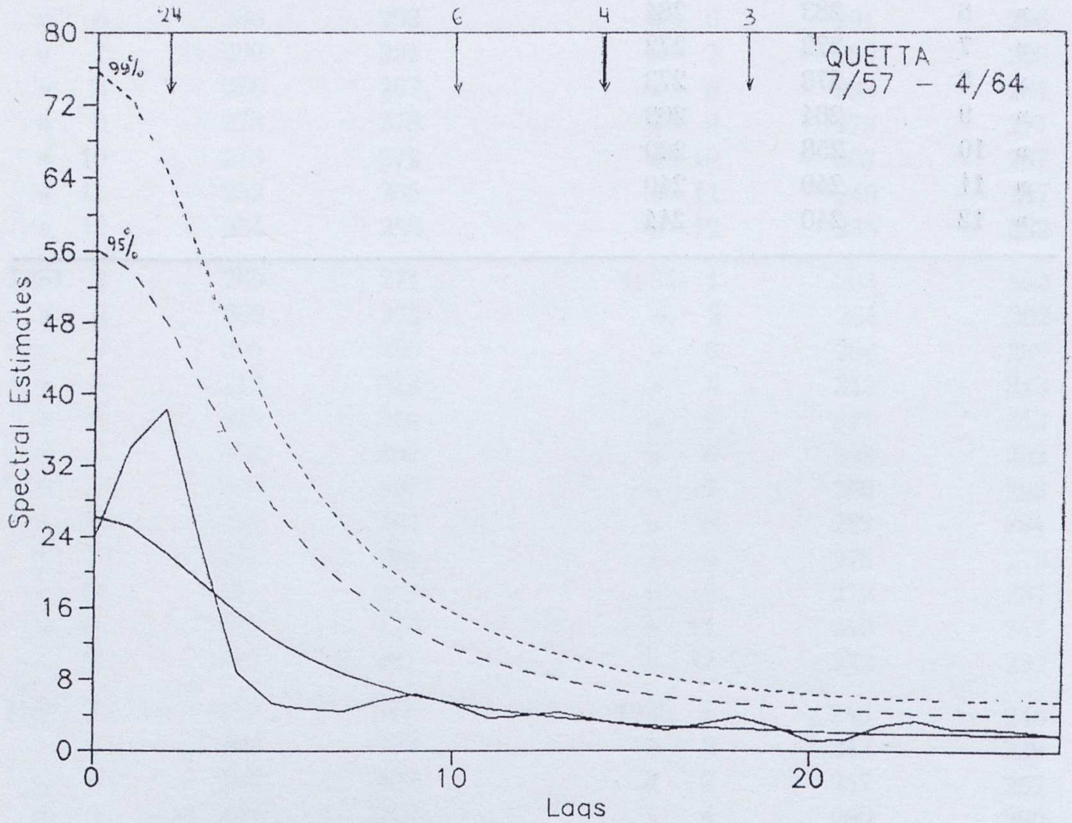

Fig. 22. Quetta Station, 1957 - 1986. Spectral estimate of the differences computed by Equation (20). Analysis shows periodicities of 24, 12, 6, 4 and 3 months. The confidence level is 99% and 95%.

If we now consider the differences:

$$D = 10^{-3} \cdot O^{obs} - \left(288 + 14 \sin\frac{2\pi}{12} t\right) \tag{20}$$

power-spetral estimate analysis shows that these differences can be represented by periodic and quasi-periodic terms of short periods; 24, 12, 6, 4 and 3 months. This is readily seen from Figures 22 and 23.

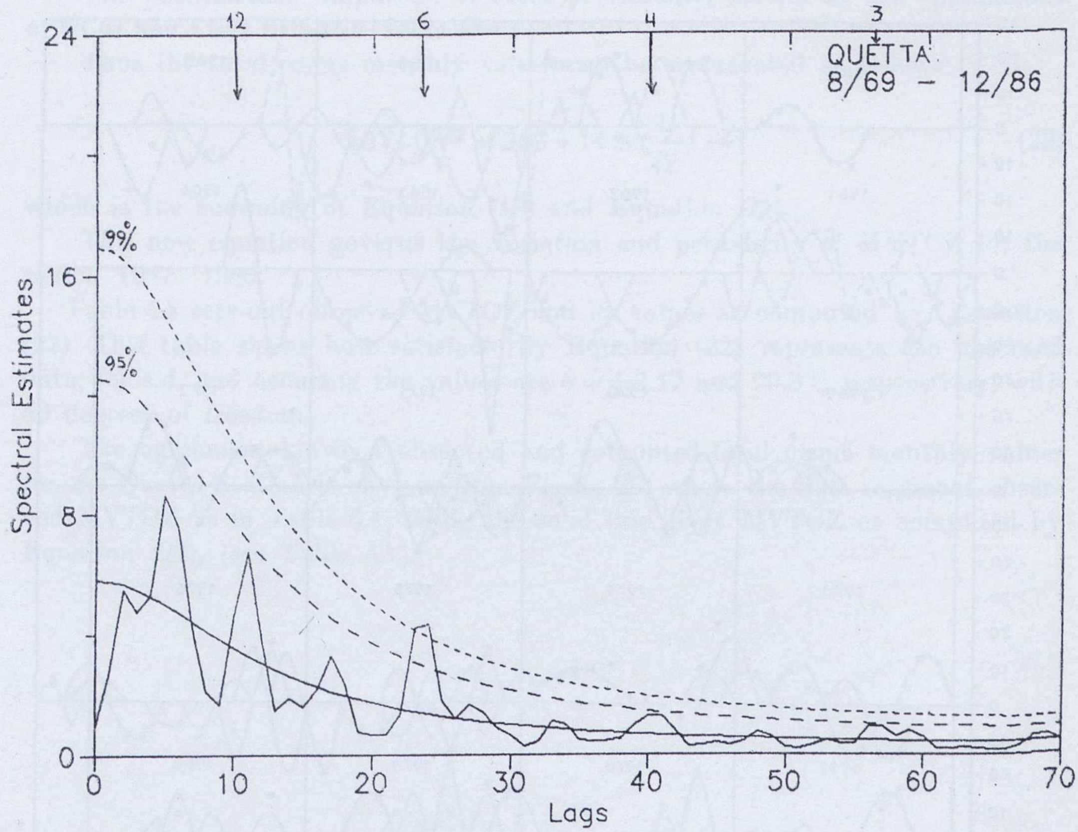

Fig. 23. Quetta Station, 8/1969-12/1986. Caption as for Figure 22, to which this Figure is complementary.

In Figure 24, the dots represent the differences $10^{-3}\,O^{obs} - 10^{-3}\,O_m^{com}$, while the dashed and solid lines represent periodic terms of 24, 12, 6, 4 and 3 months. These values can be expressed as:

$$P = \alpha_1 \sin\frac{2\pi}{12}t + \alpha_2 \sin\frac{2\pi}{6}t + \alpha_3 \sin\frac{2\pi}{4}t + \alpha_4 \sin\frac{2\pi}{3}t \qquad (21)$$

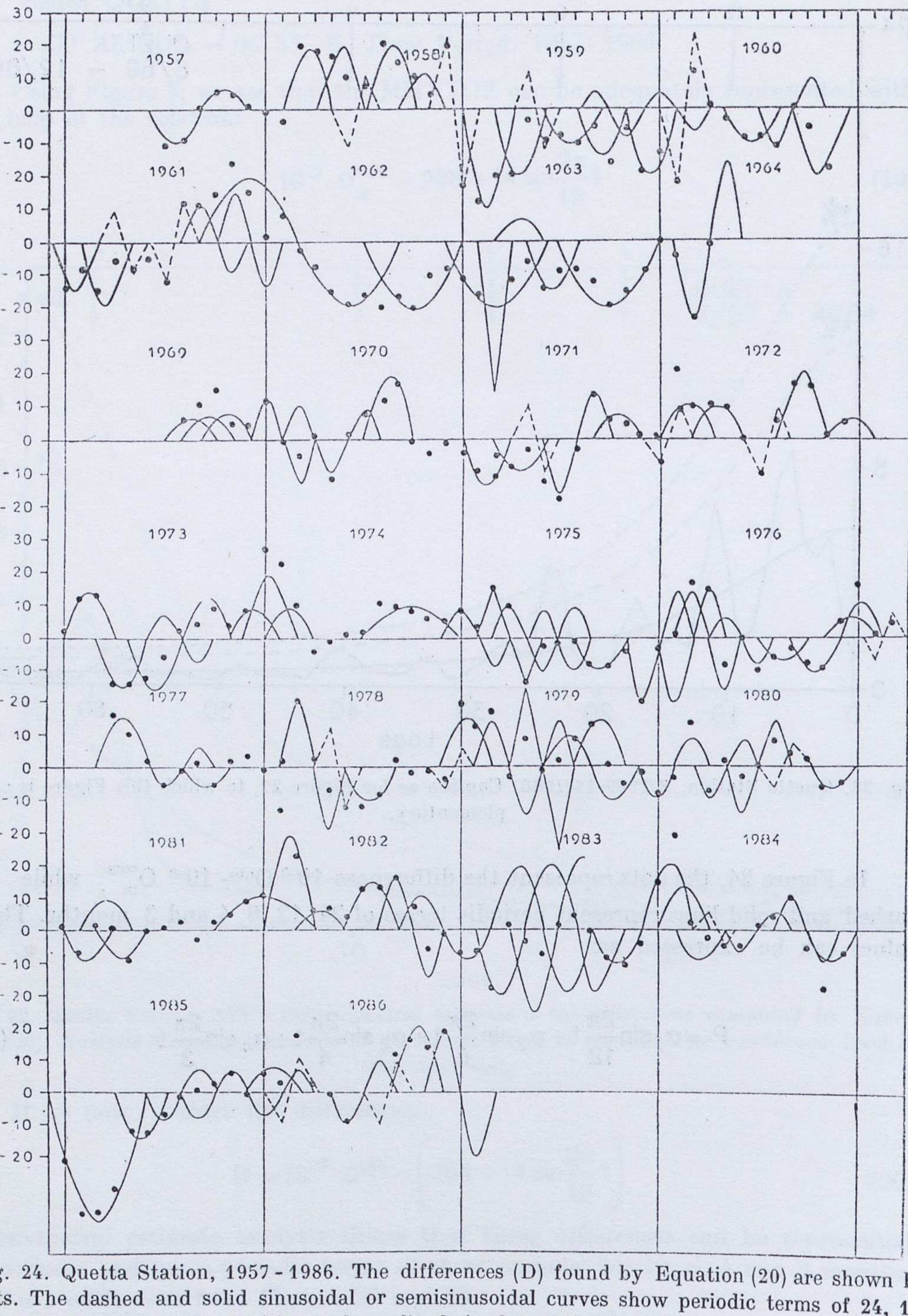

Fig. 24. Quetta Station, 1957 - 1986. The differences (D) found by Equation (20) are shown by dots. The dashed and solid sinusoidal or semisinusoidal curves show periodic terms of 24, 12, 6, 4 and 3 months, whose position and amplitude is also plotted by the successive approximation method.

The position and amplitude of these periodicities as wel as the parameters α_1 to α_4 and **t** are listed in Table 4

Thus the total ozone monthly values can be represented as follows:

$$10^{-3} \cdot 0^{com} = 288 + 14 \sin\frac{2\pi}{12} t + P \tag{22}$$

which is the summing of Equation (19) and Equation (21).

This new equation governs the variation and periodicity of MVTOZ for the period 1957 - 1986.

Table 4A sets out observed MVTOZ and its values as computed by Equation (22). This table shows how satisfactorily Equation (22) represents the observed data; for s.d. and accuracy the values are $\sigma = \pm 2.17$ and 99.3% respectively, with 40 degrees of freedom.

The agreement between observed and computed total ozone monthly values for the Quetta Station is obvious from Figure 25, where the dots represent observed MVTOZ as in Table 4A, while the solid line gives MVTOZ as computed by Equation (22), (see Table 4A).

TABLE 4

Values of the parameters α_1 - α_4, and **t** (see Eq. 21)

α_1	t
+20	1961.3 - 1961.9
—20	1962.7 - 1963.1, 1862.12 - 1963.6, 1963.7 - 1964.1
+15	1974.7 - 1975.1
+10	1081.10 - 1982.4
—40	1983.12 - 1984.6

α_2	t
—10	1957.6 - 1957.12, 1959.6 - 1959.9, 1960.5 - 1960.8, 1963.5 - 1963.8, 1971.1 1971.4, 1971.3 - 1971.6, 1975.5 - 1975.11, 1976.9 - 1977.3, 1978.6 - 1978.9, 1981.1 - 1981.4, 1983.9 - 1983.12, 1984.2 - 1984.5
+20	1958.2 - 1958.5, 1958.4 - 1958.7, 1958.7 - 1958.10, 1972.8 - 1972.11, 1973. 12 - 1974.3, 1983.3 - 1983.6, 1983.12 - 1984.3, 1986.10 - 1987.1
+10	1958.9 - 1958.12, 1962.2 - 1962.5, 1971.8 - 1971.11, 1972.3 - 1972.6 1973. 11 - 1974.2, 1979.6 - 1979.9, 1982.9 - 1983.3, 1968.9 - 1968.12
—30	1959.1 - 1959,4
—20	1959.3 - 1959.6, 1959.11 - 1960.2, 1960.9 - 1960.12, 1983.2 - 1983.8
—15	1959.8 - 1959.11, 1960.11 - 1961.2, 1961.1 - 1961.4, 1971.5 - 1971.8
— 6	1961.3 - 1961.6, 1974.7 - 1974.10, 1977.8 - 1977.11, 1980.10 - 1981.1, 1984.9 - 1984.12, 1984.10 - 1985.1
+15	1961.6 - 1961.9, 1970.7 - 1970.10, 1972.1 - 1972.4, 1973.1 - 1973.4, 1977.3 -1977.6, 1978.12 - 1979.3
+ 6	1963.3 - 1963.6, 1969.7 - 1969.10, 1969.8 - 1969.11, 1972.11. - 1973.2 1976.11 - 1977.2, 1982.4 - 1982.7
+15	1979.8 - 1979.11, 1982.6 - 1982.9, 1984.1 - 1984.4, 1985.12 - 1986.3 1986.8 - 1986.11
+30	1982.1 - 1982.4
—25	1983.6 - 1983.9

α_3	t
+ 6	1959.8 - 1960.4, 1971.4 - 1971.10, 1971.4 - 1971.10, 1973.6 - 1973.10
—10	1960.7 - 1961.1, 1970.4 - 1970,8, 1979.12 - 1980.4, 1980.3 - 1980.7
+45	1963.2 - 1963.8, 1963.4 - 1963.8
—25	1964.2 - 1964.6
+10	1969.12 - 1970.4, 1974.12 - 1975.6, 1976.4 - 1976.8, 1981.2 - 1981.6 1984.8 - 1984.12

α_3	
+25	1975.2 - 1975.6, 1979.4 - 1979.8
—20	1975.11 - 1976.3, 1976.1 - 1976.5
— 6	1977.6 - 1977.10, 1984.5 - 1984.9, 1985.6 - 1985.10, 1985.8 - 1988.4
+20	1978.2 - 1978.6
—15	1980.5 - 1980.9

α_4	t
—10	1958.5 - 1958.8, 1961.12 - 1962.3, 1971.12 - 1972.3, 1971.6 - 1971.9, 1977.1 - 1977,4. 1986.5 - 1986.8
+25	1958.11 - 1959.2
+15	1959.4 - 1959.7, 1978.4 - 1978.7
—25	1960.1 - 1960.4
— 6	1978.11 - 1979.2, 1980.7 - 1980.10, 1982.2 - 1982.5
+ 6	1984.3 - 1984.6
+10	1985.4 - 1985.7
+15	1986.1 - 1986.4

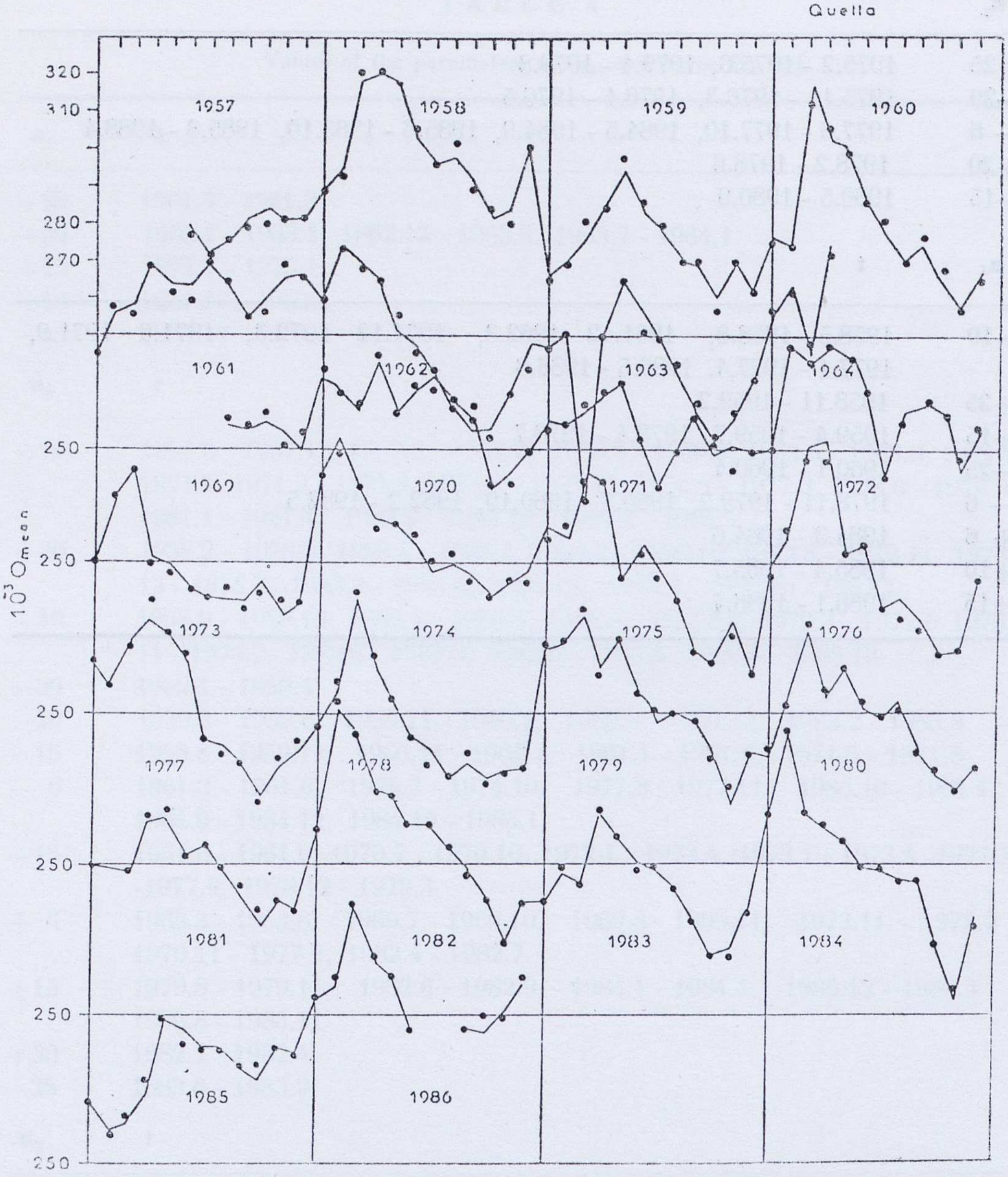

Fig. 25. Quetta Station, 1957 - 1986. Observed MVTOZ is shown by dots. MVTOZ as found by Equation (22) is shown by a solid line. The accuracy is 99.3%.

TABLE 4A

Quetta Station. 1957 - 1986. Observed and computed MVTOZ.

Year/month	comp.	obs.	Year/month.	comp.	obs.
1957. 1	—	—	1960. 1	277	275
» 2	—	—	» 2	274	274
» 3	—	—	» 3	317	313
» 4	—	—	» 4	303	306
» 5	—	—	» 5	301	299
» 6	—	—	» 6	286	286
» 7	279	277	» 7	279	282
» 8	272	272	» 8	271	270
» 9	275	276	» 9	275	277
» 10	282	279	» 10	266	268
» 11	284	280	» 11	258	257
» 12	280	282	» 12	268	265
1958. 1	288	288	1961. 1	276	274
» 2	296	293	» 2	284	288
» 3	318	321	» 3	289	286
» 4	320	321	» 4	298	298
» 5	318	318	» 5	296	293
» 6	303	306	» 6	295	290
» 7	297	296	» 7	300	301
» 8	298	302	» 8	293	294
» 9	292	289	» 9	285	286
» 10	282	284	» 10	290	287
» 11	284	280	» 11	295	299
» 12	302	301	» 12	297	296
1959. 1	266	265	1962. 1	289	290
» 2	270	269	» 2	305	304
» 3	275	281	» 3	300	298
» 4	286	284	» 4	295	296
» 5	296	298	» 5	281	286
» 6	283	286	» 6	278	276
» 7	279	280	» 7	268	271
» 8	272	270	» 8	264	261
» 9	269	270	» 9	255	258
» 10	261	257	» 10	254	253
» 11	269	270	» 11	265	265
» 12	263	262	» 12	272	272

Year/month	comp.	obs.	Year/month	comp.	obs.
1963. 1	278	277	1966. 1	—	—
» 2	279	280	» 2	—	—
» 3	236	236	» 3	—	—
» 4	291	292	» 4	—	—
» 5	296	295	» 5	—	—
» 6	286	281	» 6	—	—
» 7	279	279	» 7	—	—
» 8	271	273	» 8	—	—
» 9	258	263	» 9	—	—
» 10	253	254	» 10	—	—
» 11	258	260	» 11	—	—
» 12	270	271	» 12	—	—
1964. 1	288	288	1967. 1	—	—
» 2	296	293	» 2	—	—
» 3	276	278	» 3	—	—
» 4	303	302	» 4	—	—
» 5	—	—	» 5	—	—
» 6	—	—	» 6	—	—
» 7	—	—	» 7	—	—
» 8	—	—	» 8	—	—
» 9	—	—	» 9	—	—
» 10	—	—	» 10	—	—
» 11	—	—	» 11	—	—
» 12	—	—	» 12	—	—
1965. 1	—	—	1968. 1	—	—
» 2	—	—	» 2	—	—
» 3	—	—	» 3	—	—
» 4	—	—	» 4	—	—
» 5	—	—	» 5	—	—
» 6	—	—	» 6	—	—
» 7	—	—	» 7	—	—
» 8	—	—	» 8	—	—
» 9	—	—	» 9	—	—
» 10	—	—	» 10	282	—
» 11	—	—	» 11	284	284
» 12	—	—	» 12	280	281

Year/month	comp.	obs.	Year/month	comp.	obs.
1969. 1	—	—	1972. 1	279	280
» 2	—	—	» 2	317	317
» 3	—	—	» 3	313	311
» 4	—	—	» 4	312	313
» 5	—	—	» 5	310	310
» 6	—	—	» 6	295	295
» 7	—	—	» 7	276	276
» 8	286	288	» 8	290	287
» 9	285	286	» 9	292	293
» 10	287	289	» 10	290	289
» 11	284	281	» 11	275	277
» 12	280	285	» 12	285	286
1970. 1	298	300	1973 1.	293	291
» 2	296	295	» 2	308	308
» 3	291	293	» 3	313	314
» 4	303	305	» 4	291	289
» 5	291	289	» 5	289	287
» 6	295	297	» 6	283	283
» 7	298	296	» 7	282	281
» 8	293	293	» 8	281	284
» 9	287	291	» 9	281	278
» 10	273	273	» 10	285	282
» 11	275	271	» 11	275	280
» 12	280	279	» 12	289	289
1971. 1	288	285	1974. 1	314	314
» 2	287	287	» 2	322	319
» 3	292	290	» 3	310	310
» 4	294	295	» 4	303	299
» 5	298	298	» 5	301	300
» 6	283	283	» 6	295	297
» 7	270	270	» 7	288	290
» 8	281	279	» 8	289	292
» 9	290	289	» 9	287	285
» 10	282	280	» 10	283	281
» 11	275	281	» 11	282	281
» 12	280	282	» 12	288	285

Year/month	comp.	obs.	Year/month	comp.	obs.
1975. 1	298	296	1978. 1	288	287
» 2	296	299	» 2	296	298
» 3	316	316	» 3	321	322
» 4	313	313	» 4	303	305
» 5	286	286	» 5	293	294
» 6	295	292	» 6	283	283
» 7	288	286	» 7	279	276
» 8	281	280	» 8	272	273
» 9	266	267	» 9	275	278
» 10	264	264	» 10	273	271
» 11	275	271	» 11	275	274
» 12	260	260	» 12	275	276
1976. 1	288	286	1979. 1	305	308
» 2	296	298	» 2	308	309
» 3	321	318	» 3	316	318
» 4	323	318	» 4	303	300
» 5	291	292	» 5	311	310
» 6	295	294	» 6	295	294
» 7	278	278	» 7	287	291
» 8	281	276	» 8	290	290
» 9	275	272	» 9	287	288
» 10	264	265	» 10	276	273
» 11	266	266	» 11	266	270
» 12	285	285	» 12	280	278
1977. 1	302	304	1980. 1	278	280
» 2	296	297	» 2	296	292
» 3	310	308	» 3	311	314
» 4	315	320	» 4	293	295
» 5	313	312	» 5	301	303
» 6	295	297	» 6	290	292
» 7	282	283	» 7	288	288
» 8	281	279	» 8	291	289
» 9	276	276	» 9	280	279
» 10	268	267	» 10	273	275
» 11	275	277	» 11	270	269
» 12	280	283	» 12	275	275

Year/month	comp.	obs.	Year/month	comp.	obs.
1981. 1	288	290	1984. 1	305	303
» 2	287	289	» 2	325	325
» 3	302	303	» 3	304	303
» 4	303	304	» 4	299	300
» 5	291	292	» 5	296	296
» 6	295	295	» 6	289	290
» 7	288	289	» 7	288	289
» 8	281	284	» 8	287	285
» 9	275	278	» 9	285	285
» 10	273	276	» 10	268	268
» 11	280	280	» 11	255	257
» 12	289	289	» 12	275	273
1982. 1	298	299	1985. 1	268	267
» 2	331	333	» 2	261	258
» 3	327	324	» 3	261	263
» 4	308	309	» 4	268	273
» 5	306	308	» 5	290	289
» 6	300	299	» 6	286	282
» 7	300	301	» 7	282	281
» 8	293	294	» 8	281	280
» 9	290	291	» 9	275	276
» 10	282	280	» 10	273	276
» 11	269	269	» 11	281	281
» 12	280	279	» 12	280	279
1983. 1	279	280	1986. 1	294	294
» 2	287	289	» 2	296	299
» 3	284	283	» 3	319	319
» 4	303	304	» 4	303	305
» 5	296	297	» 5	301	300
» 6	290	288	» 6	286	286
» 7	288	289	» 7	—	—
» 8	286	285	» 8	—	—
» 9	275	274	» 9	287	287
» 10	264	265	» 10	285	289
» 11	266	264	» 11	292	289
» 12	280	276	» 12	297	299

4.5 Station KAGOSHIMA

$\varphi = 31^\circ\ 34'$ N, L $= 130^\circ\ 33'$ E, Time Period: 1958 - 1986

In Figure 6, mean total ozone monthly values are given by the equation:

$$10^{-3} \cdot 0^{com}_{m} = 295 + 30 \sin \frac{2\pi}{12} t \tag{23}$$

Difference analysis,

$$D = 10^{-3} \cdot 0^{obs} - \left(295 + 30 \sin \frac{2\pi}{12} t \right) \tag{24}$$

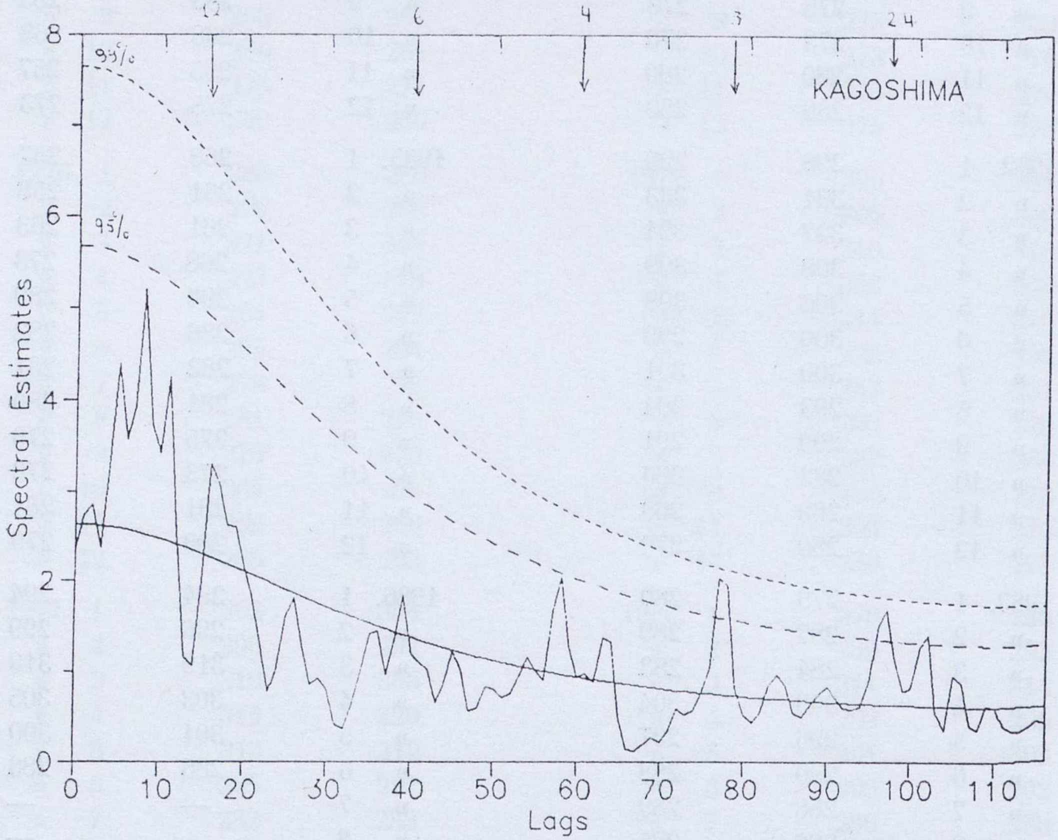

Fig. 26. Kagoshima Station, 1958 - 1986. Spectral estimate of the differences computed by Equation (24). Analysis shows periodicities of 12, 6, 4 and 3 months. The confidence level is above 95%.

reveals, as in the case of the previous stations, periodic variation with periods equal to 12, 6, 4 and 3 months. See Figure 26 which is the spectral estimate of the values of total ozone computed by Equation (24).

Applying the method of successive approximations to the results of Equation (24) we find the same periodicities as spectral analysis revealed. This also enable us to define the position and amplitude of their periodic terms, for which the equation is:

$$P = \alpha_1 \sin\frac{2\pi}{12}t + \alpha_2 \sin\frac{2\pi}{6}t + \alpha_3 \sin\frac{2\pi}{4}t + \alpha_4 \sin\frac{2\pi}{3}t \tag{25}$$

Table 5 summarizes the values for the parameters in Equation (25) and the position and amplitude of the periods found by the successive approximation method.

The short-term periodicities which were detected, and their position and amplitude, are shown in Figure 27. Here the dots represent the differences computed by Equation, (24) while the dashed and solid lines represent periodic terms of 12, 6, 4 and 3 months. As can be seen, these periodicities appear sporadically and form a periodic and quasi-periodic network. The time interval is from 1958 to 1986.

Using all the data from this station for the period 1958 - 1986, the variation of total ozone monthly values can be satisfactorily represented, in line with our present analysis as:

$$10^{-3} \cdot O^{com} = 295 + 30\sin\frac{2\pi}{12}t + P \tag{26}$$

which is the sum of Equation (23) and (25).

This new equation governs the variation and periodicity of MVTOZ of the Kagoshima Station.

The agreement is obvious from Figure 28, where the dots represent the observed data, while the solid line represents the total ozone monthly values for the period 1958 - 1986 as computed by Equation (26).

The numerical results of Figure 28 are presented by Table 5A.

Both Figure 28 and Table 5A show very close agreement between observed and computed MVTOZ. Standard deviation (s.d.) and accurary were estimated to be $\sigma = \pm 2.4$ and 99.2% respectively. Equation (26) has 44 degrees of freedom.

TABLE 5

Values of the parameters α_1 - α_4, and **t** (see Eq. 25).

α_1	t
—30	1961.3 - 1961.9
—15	1978.1 - 1978.7

α_2	t
+20	1958.4 - 1958.7, 1979.4 - 1979.7, 1983.10 - 1984.1, 1984.7 - 1984.10
—10	1958.6 - 1958.9, 1961.8 - 1961.11, 1962.3 - 1962.6, 1963.7 - 1963.10, 1963.11 - 1964.2, 1968.9 - 1968.12, 1968.10 - 1969.1, 1976.2 - 1976.5
—15	1959.5 - 1959.8, 1964.1 - 1964.4, 1964.3 - 1964.7, 1964.8 - 1964.11, 1968.6 - 1968.9, 1969.6 - 1969.9, 1969.10 - 1970.1, 1977.1 - 1977.4
—40	1960.1 - 1960.4, 1969.1 - 1969.4
+40	1961.12 - 1962.3, 1962.12 - 1963.3
—10	1962.10 - 1963.1, 1974.7 - 1975.1, 1979.7 - 1979.10, 1979.8 - 1979.11, 1980.9 - 1980.12, 1980.12 - 1981.3, 1981.4 - 1981.7, 1982.6 - 1982.9, 1982.8 - 1982.11, 1979.2 - 1979.5
—20	1964.6 - 1964.9, 1965.1 - 1965.4, 1965.6 - 1965.9, 1966.1 - 1966.4, 1967.3 - 1967.6
— 6	1964.10 - 1965.1, 1984.5 - 1984.8
—30	1966.12 - 1967.3, 1971.1 - 1971.4, 1977.11 - 1978.2
—25	1968.11 - 1969.2, 1973.1 - 1973.4, 1983.3 - 1983.6, 1984.11 - 1985.2
+50	1970.3 - 1970.6
+15	1972.9 - 1972.12, 1973.8 - 1973.11, 1980.7 - 1980.10, 1981.11 - 1982.2, 1984.8 - 1984.11, 1985.12 - 1986.3
+25	1973.11 - 1974.2
+30	1976.8 - 1976.11
+15	1978.5 - 1978.8, 1980.1 - 1980.4, 1982.11 - 1983.2, 1986.10 - 1987.1
—35	1985.1 - 1985.4
+ 6	1985.9 - 1986.1
—10	1983.12 - 1984.3, 1985.3 - 1985.6, 1985.5 - 1985.8, 1986.3 - 1986.6

α_3	t
— 6	1959.1 - 1959.7, 1971.12 - 1972.6, 1975.6 - 1975.10, 1984.10 - 1985.2
—25	1962.6 - 1962.10
+15	1963.3 - 1963.7, 1968.2 - 1968.6, 1971.3 - 1971.7, 1973.10- 1974.2, 1981.3 - 1981.7

α_3	t
−10	1965.3 - 1965.7, 1963.5 - 1963.9
+10	1965.7 - 1965.11, 1967.7 - 1968.1, 1971.4 - 1971.10, 1973.11 - 1974.2
−20	1966.10 - 1967.2, 1978.9 - 1979.1, 1978.11 - 1979.3, 1982.3 - 1982.7, 1986.8 - 1986.10
+40	1969.12 - 1970.4
−15	1970.4 - 1970.8, 1972.6 - 1972.10, 1974.11 - 1975.5, 1975.1 - 1976.7, 1978.7 - 1978.11
+ 6	1970.5 - 1971.1, 1974.1 - 1974.7, 1974.4 - 1974.8, 1983.8 - 1983.12

α_4	t
−10	1958.1 - 1958.4, 1958.10 - 1959.1, 1960.1 - 1960,4, 1866.6 - 1966.9, 1970.6 - 1970.9, 1972.11- 1973.2, 1976.9 - 1976.12, 1981.1 - 1981,4
+25	1958.3 - 1958.6
+15	1959.4 - 1959.8, 1967.11 - 1968.2, 1973.2 - 1973.6
−15	1962.1 - 1962.4, 1980.10 - 1981.1
−30	1962.8 - 1962.11, 1970.3 - 1970.6
−25	1963.1 - 1963.4
+10	1963.5 - 1963.8, 1967.1 - 1967.7, 1967.9 - 1967.12, 1969.3 - 1969.6, 1971.9 - 1971.12, 1977.5 - 1977.8
+20	1963.9 - 1963.12, 1965.9 - 1965.12
+30	1967.6 - 1967.9, 1969.2 - 1969.5, 1971.2 - 1971.5
+ 6	1969.7 - 1969.11, 1976.11 - 1977.2, 1982.7 - 1982.10
− 6	1972.5 - 1972.8, 1977.10 - 1978.1
−20	1986.8 - 1986.11

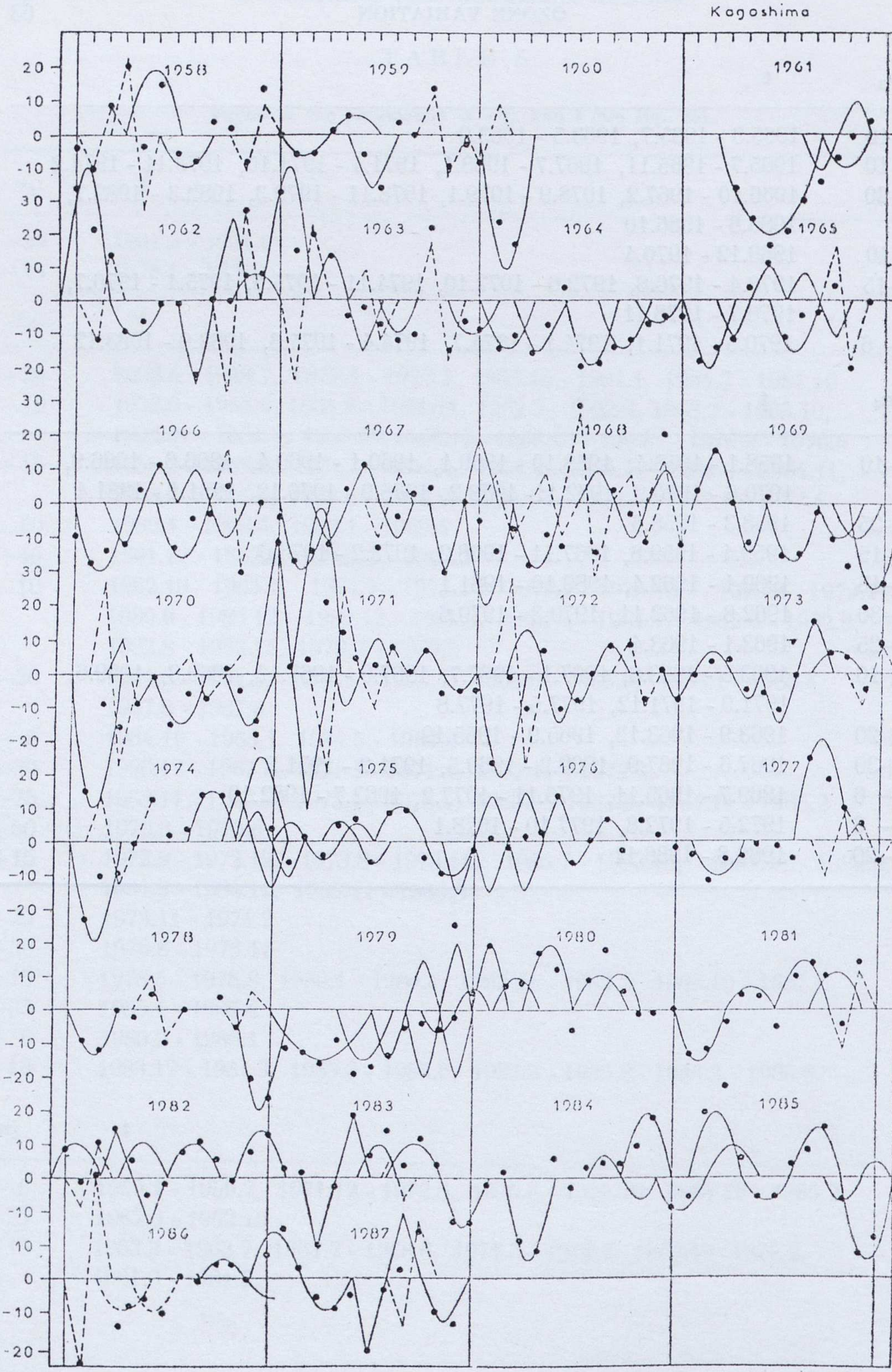

Fig. 27. Kagoshima Station, 1958-1986. The differences (D) found by Equation (24) are shown by dots. The dashed and solid sinusoidal or semisinusoidal curves show periodic terms of 12, 6, 4, and 3 months, whose position and amplitude is also plotted by the successive approximation method.

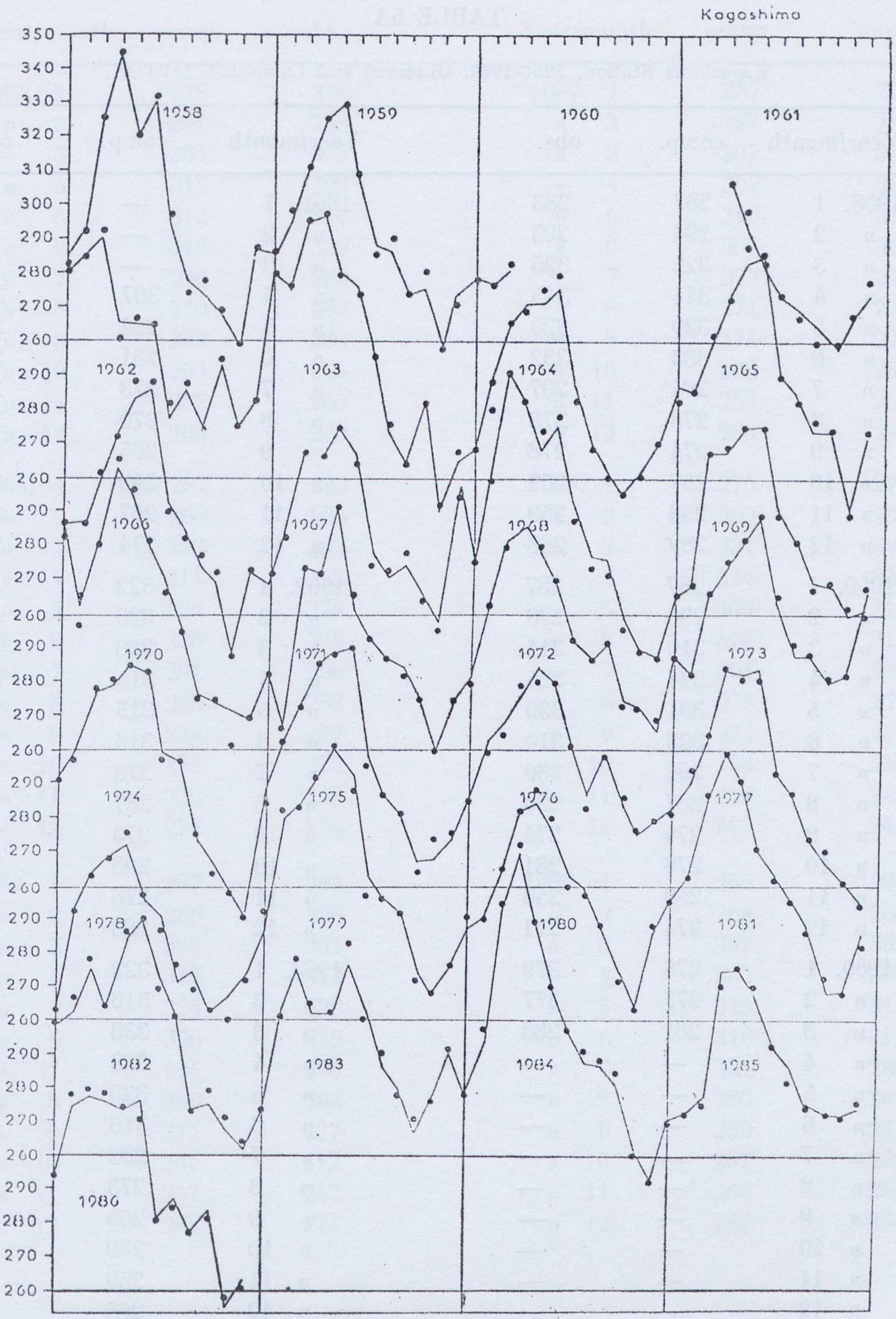

Fig. 28. Kagoshima Station, 1958-1986. Observed MVTOZ is shown by dots. MVTOZ as found by Equation (26) is shown by a solid line. The accuracy is equal to 99.2%.

TABLE 5A

Kagoshima Station, 1958-1986. Observed and Computed MVTOZ.

Year/month	comp.	obs.	Year/month	comp.	obs.
1958. 1	287	283	1961. 1	—	—
» 2	294	293	» 2	—	—
» 3	325	325	» 3	—	—
» 4	344	345	» 4	307	307
» 5	320	320	» 5	294	299
» 6	333	332	» 6	281	283
» 7	294	297	» 7	273	274
» 8	278	279	» 8	270	267
» 9	274	278	» 9	265	260
» 10	267	269	» 10	258	260
» 11	258	259	» 11	267	268
» 12	289	288	» 12	274	278
1959. 1	287	287	1962. 1	322	321
» 2	296	298	» 2	326	325
» 3	310	311	» 3	328	330
» 4	324	325	» 4	315	315
» 5	331	330	» 5	315	317
» 6	308	310	» 6	316	315
» 7	288	286	» 7	278	281
» 8	287	290	» 8	287	288
» 9	274	274	» 9	273	274
» 10	276	281	» 10	293	295
» 11	258	258	» 11	276	275
» 12	274	271	» 12	283	283
1960. 1	278	279	1963. 1	322	320
» 2	277	277	» 2	316	318
» 3	281	283	» 3	338	336
» 4	—	—	» 4	338	338
» 5	—	—	» 5	320	320
» 6	—	—	» 6	316	314
» 7	—	—	» 7	298	296
» 8	—	—	» 8	273	275
» 9	—	—	» 9	265	264
» 10	—	—	» 10	289	289
» 11	—	—	» 11	250	252
» 12	—	—	» 12	265	268

Year/month	comp.	obs.	Year/month	comp.	obs.
1964. 1	278	278	1967. 1	267	272
» 2	291	288	» 2	287	283
» 3	304	305	» 3	307	308
» 4	312	309	» 4	307	306
» 5	312	316	» 5	316	315
» 6	316	320	» 6	307	304
» 7	286	283	» 7	277	274
» 8	270	268	» 8	271	273
» 9	262	260	» 9	274	278
» 10	255	255	» 10	266	264
» 11	262	260	» 11	258	256
» 12	269	270	» 12	296	294
1965. 1	287	283	1968. 1	275	275
» 2	286	285	» 2	303	299
» 3	299	302	» 3	331	331
» 4	314	318	» 4	324	324
» 5	324	328	» 5	309	313
» 6	326	328	» 6	316	318
» 7	291	290	» 7	291	288
» 8	285	283	» 8	275	273
» 9	274	277	» 9	274	271
» 10	274	272	» 10	258	257
» 11	250	247	» 11	249	249
» 12	274	274	» 12	243	244
1966. 1	287	283	1969. 1	265	265
» 2	286	286	» 2	268	268
» 3	299	302	» 3	307	307
» 4	314	312	» 4	307	308
» 5	324	328	» 5	315	315
» 6	326	328	» 6	316	315
» 7	294	290	» 7	291	288
» 8	286	283	» 8	280	281
» 9	274	277	» 9	269	267
» 10	267	272	» 10	267	269
» 11	247	247	» 11	260	262
» 12	265	274	» 12	262	260

Year/month	comp.	obs.	Year/month	comp.	obs
1970. 1	327	326	1973. 1	296	296
» 2	303	305	» 2	281	283
» 3	321	320	» 3	306	306
» 4	343	345	» 4	312	315
» 5	335	336	» 5	324	324
» 6	316	321	» 6	328	329
» 7	309	306	» 7	303	305
» 8	296	295	» 8	287	291
» 9	274	275	» 9	286	288
» 10	273	274	» 10	279	281
» 11	267	261	» 11	282	282
» 12	268	269	» 12	306	307
1971. 1	287	283	1974. 1	294	291
» 2	277	276	» 2	299	297
» 3	316	315	» 3	316	318
» 4	313	314	» 4	318	320
» 5	334	331	» 5	330	329
» 6	301	305	» 6	322	332
» 7	293	295	» 7	297	297
» 8	287	287	» 8	296	296
» 9	284	282	» 9	283	285
» 10	276	276	» 10	267	263
» 11	258	259	» 11	258	258
» 12	274	275	» 12	252	250
1972. 1	281	279	1975. 1	287	284
» 2	303	302	» 2	303	302
» 3	322	320	» 3	316	314
» 4	324	328	» 4	324	326
» 5	318	320	» 5	330	328
» 6	311	310	» 6	331	331
» 7	293	292	» 7	297	296
» 8	287	285	» 8	287	287
» 9	289	290	» 9	280	281
» 10	272	273	» 10	267	264
» 11	272	272	» 1	267	274
» 12	265	269	» 12	274	276

Year/month		comp.	obs.	Year/month		comp.	obs.
1976.	1	287	285	1979.1	1	287	292
»	2	303	299	»	2	323	322
»	3	307	304	»	3	325	323
»	4	315	319	»	4	333	332
»	5	324	320	»	5	341	341
»	6	316	315	»	6	333	328
»	7	303	301	»	7	303	297
»	8	287	283	»	8	296	296
»	9	299	298	»	9	292	292
»	10	283	286	»	10	276	273
»	11	276	277	»	11	267	268
»	12	279	279	»	12	274	275
1977.	1	282	281	1980.	1	287	289
»	2	291	294	»	2	291	289
»	3	304	304	»	3	304	304
»	4	324	324	»	4	324	322
»	5	324	321	»	5	324	328
»	6	325	321	»	6	316	320
»	7	294	293	»	7	303	299
»	8	287	287	»	8	299	297
»	9	274	274	»	9	286	288
»	10	267	271	»	10	276	272
»	11	262	261	»	11	264	263
»	12	254	254	»	12	280	288
1978.	1	262	263	1981.	1	296	295
»	2	295	292	»	2	303	302
»	3	304	303	»	3	325	327
»	4	309	308	»	4	339	339
»	5	312	315	»	5	333	329
»	6	296	297	»	6	310	311
»	7	291	286	»	7	303	301
»	8	272	276	»	8	296	295
»	9	274	269	»	9	283	285
»	10	262	263	»	10	267	273
»	11	267	260	»	11	267	267
»	12	274	272	»	12	286	282

Year/month	comp.	obs.	Year/month	comp.	obs.
1982. 1	299	300	1985. 1	271	269
» 2	303	306	» 2	273	272
» 3	316	318	» 3	276	274
» 4	304	304	» 4	315	310
» 5	324	329	» 5	315	316
» 6	336	335	» 6	307	310
» 7	312	309	» 7	294	293
» 8	301	301	» 8	287	289
» 9	278	278	» 9	274	274
» 10	276	279	» 10	272	272
» 11	267	276	» 11	272	272
» 12	262	264	» 12	274	276
1983. 1	275	274	1986. 1	294	294
» 2	303	301	» 2	315	318
» 3	316	318	» 3	316	319
» 4	302	305	» 4	315	318
» 5	302	302	» 5	315	315
» 6	316	323	» 6	316	311
» 7	303	300	» 7	283	280
» 8	287	290	» 8	287	284
» 9	280	278	» 9	277	277
» 10	267	276	» 10	284	281
» 11	278	276	» 11	255	257
» 12	291	292	» 12	262	260
1984. 1	278	278			
» 2	294	297			
» 3	333	335			
» 4	350	351			
» 5	333	330			
» 6	311	310			
» 7	298	297			
» 8	287	291			
» 9	286	288			
» 10	279	282			
» 11	261	260			
» 12	252	252			

4.6 Station: WHITE SANDS

$\varphi = 32^0\ 13'$ N, L $= 100^0\ 29'$ W, Time Period: 1972 - 1981

Analysis of observed data shows that the mean monthly values of total ozone (MMVTOZ) can be analytically represented by the relation:

$$10^{-3}\,\bar{O}_m^{com.} = 309 + 30\sin\frac{2\pi}{12}t \tag{27}$$

Calculating the differences

$$D = 10^{-3}\cdot O^{obs} - \left(309 + 30\sin\frac{2\pi}{12}t\right) \tag{28}$$

we can compute the spectral estimate for the White Sands Station. The results are shown in Figure 29.

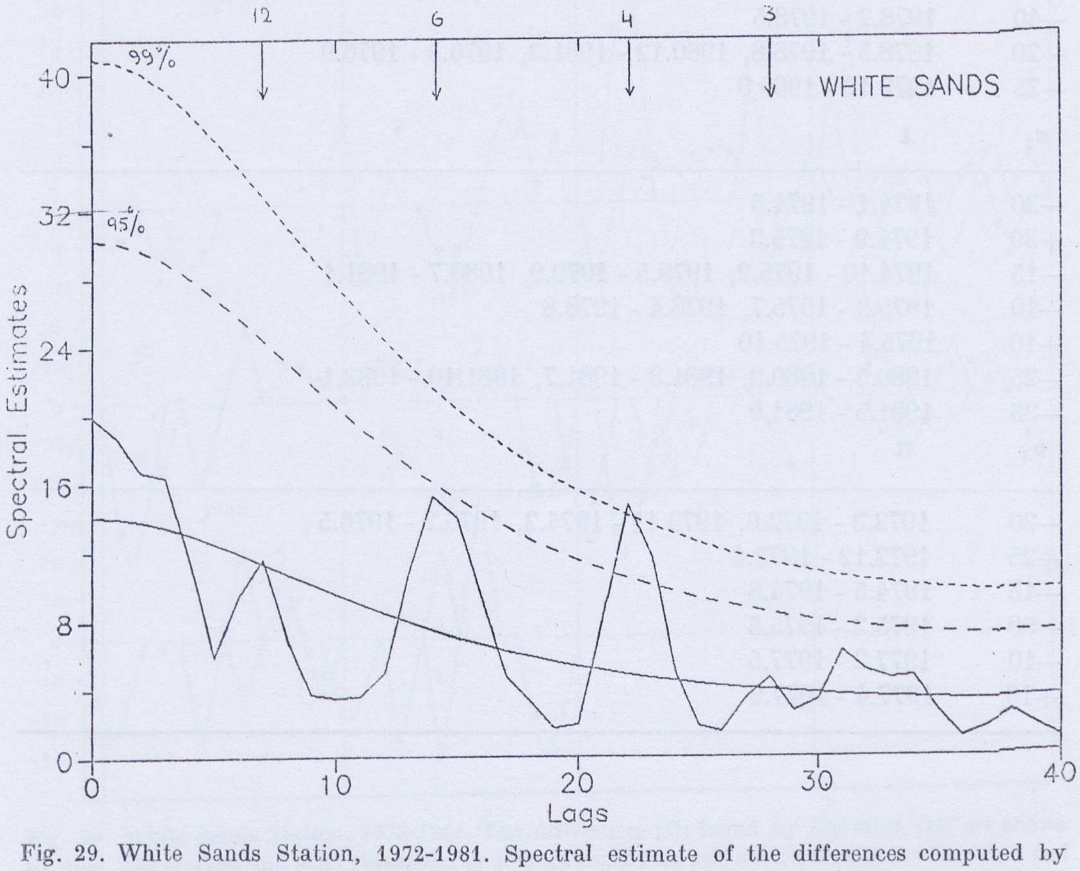

Fig. 29. White Sands Station, 1972-1981. Spectral estimate of the differences computed by Equation (28). Analysis shows short-term periodic terms of 6, 4 and 3 months. Note that the 4-month periodicity is predominant. The confidence level is above 99%.

TABLE 6

Values of the parameters α_1, α_2, α_3, and t (see Eq. 29).

α_1	t
—10	1971.12 - 1972.3
—15	1972.4 - 1972.7, 1973.5 - 1973.8, 1975.10 - 1976.1
+10	1973.1 - 1973.4, 1974.4 - 1974.7, 1976.9 - 1976.12, 1977.6 - 1977.9, 1978.7-1979.1, 1979.3 - 1979.9, 1979.8 - 1979.12
+25	1973.8 - 1973.11
+50	1974.2 - 1974.5
+15	1974.7 - 1974.10
—35	1976.1 - 1976.4
—30	1977. 12 - 1978.3
—40	1978.2 - 1978.5
—20	1978.5 - 1978.8, 1980.12 - 1981.3, 1976.5 - 1976.9
—25	1979.12 - 1980,3
α_2	**t**
—20	1974.1 - 1974.5
+30	1974.9 - 1975.3
—15	1974.10 - 1975.2, 1979.5 - 1979.9, 1980.7 - 1981.1
—10	1975.3 - 1975.7, 1978.4 - 1978.8
+10	1975.4 - 1975.10
—25	1980.5 - 1980.9, 1981.3 - 1981.7, 1981.10 - 1982.1
—35	1981.5 - 1981.9
α_3	**t**
—20	1972.3 - 1972.6, 1973.11 - 1974.2, 1976.2 - 1976.5
+25	1972.12 - 1973.4
—15	1974.5 - 1974.8
—50	1975.2 - 1975.5
—10	1977.2 - 1977.5
+10	1977.4 - 1977.9

As is fairly obvious from Figure 29, spectral analysis detects three short-term periodicities of 6, 4 and 3 months. These periodic terms can de represented as follows:

$$P = \alpha_1 \sin\frac{2\pi}{6}t + \alpha_2 \sin\frac{2\pi}{4}t + \alpha_3 \sin\frac{2\pi}{3}t \tag{29}$$

The values of parameters α_1, α_2, α_3 and t and the position and amplitude of the periodic terms found by the successive approximation method, are listed in Table 6 and represented in Figure 30, where the dots show the differences computed by Equation (28) while the dashed and solid lines show the position and amplitude of short-term periodicities.

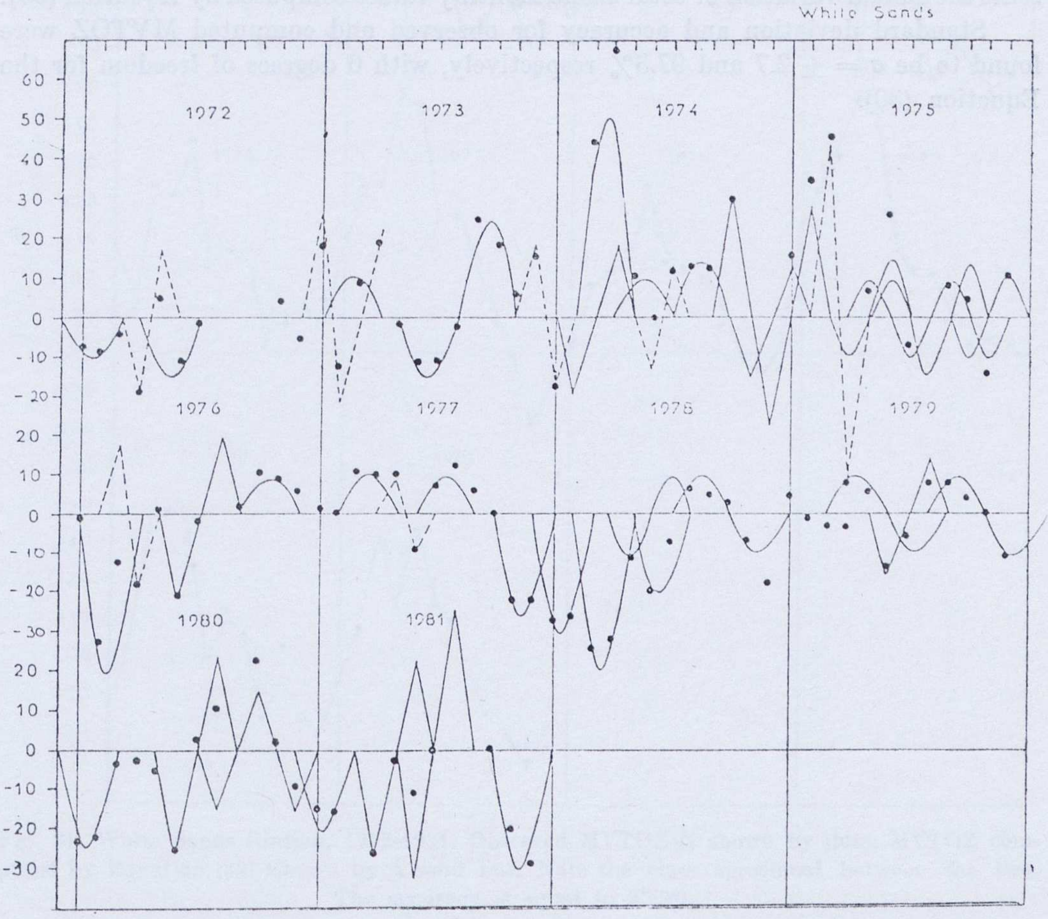

Fig. 30. White Sands Station, 1972-1981. The differences (D) found by Equation (28) are shown by dots. The dashed and solid sinusoidal or semisinusoidal curves, show periodic terms of 6, 4 and 3 months, whose position and amplitude is also plotted by the successive approximation method.

It follows that the observed MVTOZ can be written as the sum of Equations (27) and (29):

$$10^{-3} \cdot 0^{com} = 309 + 30 \sin\frac{2\pi}{12} t + \alpha_1 \sin\frac{2\pi}{6} t + \alpha_2 \sin\frac{2\pi}{4} t + \alpha_3 \sin\frac{2\pi}{3} t \qquad (30)$$

This new equation governs the variation and periodicity of MVTOZ for the White Sands Station (1972-1981).

Table 6A shows observed and computed MVTOZ for the White Sands Station for the time interval from 1972 through 1981. There is remarkably close agreement between observed and computed values of total ozone. This is even clearer from Figure 31. Here the dots represent the observed data while the solid line represents the annual variation of total ozone monthly values computed by Equation (30).

Standard deviation and accuracy for observed and computed MVTOZ were found to be $\sigma = \pm 2.7$ and 97.3% respectively, with 6 degrees of freedom for the Equation (30).

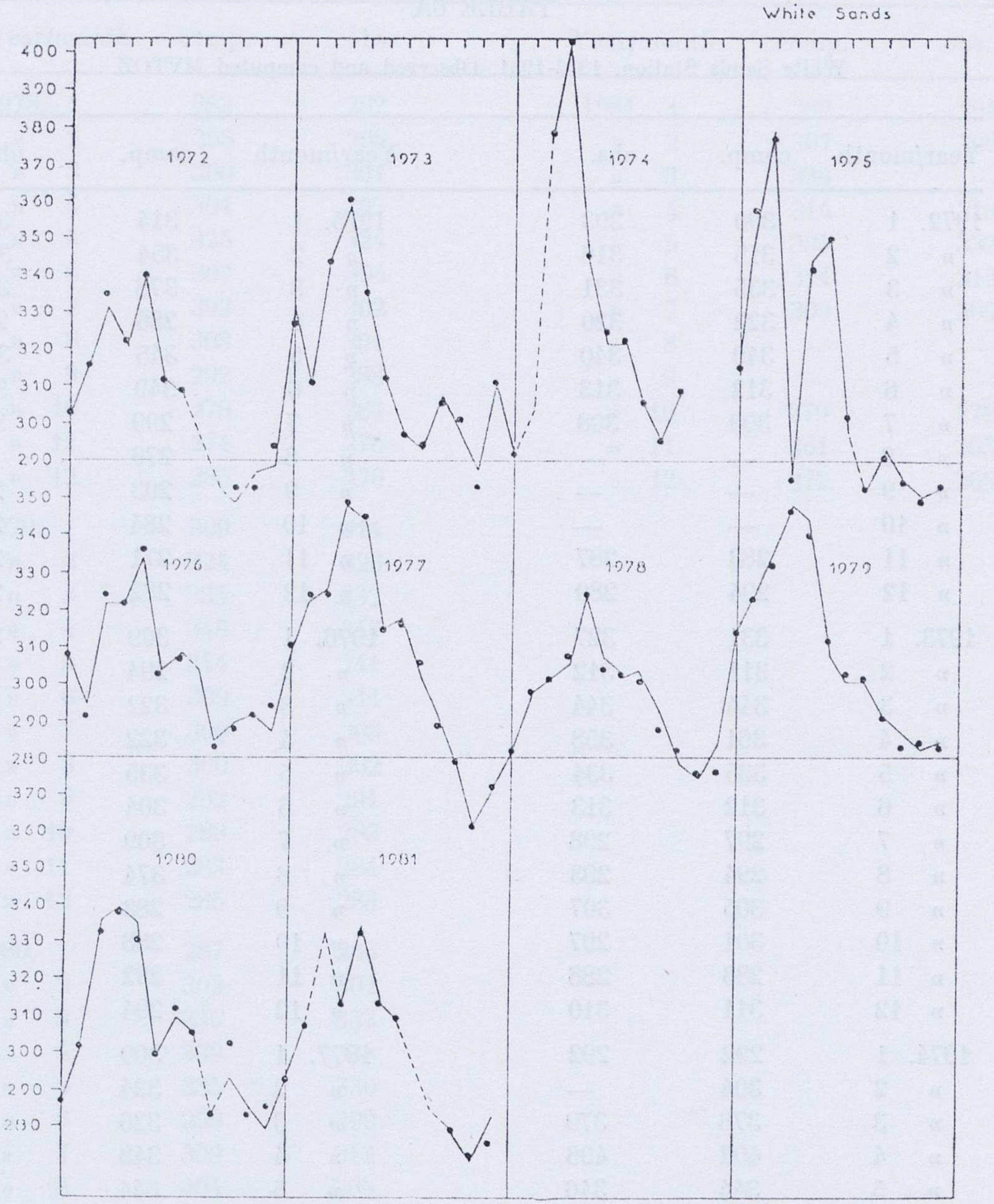

Fig. 31. White Sands Station, 1972-1981. Observed MVTOZ is shown by dots. MVTOZ computed by Equation (30) ishown by a solid line. Note the close agreement between the two. The accuracy is equal to 97.3%.

TABLE 6A

White Sands Station, 1972-1981. Observed and computed MVTOZ.

Year/month	comp.	obs.	Year/month	comp.	obs.
1972. 1	300	303	1975. 1	314	315
» 2	315	316	» 2	354	358
» 3	335	331	» 3	378	380
» 4	322	320	» 4	286	285
» 5	340	340	» 5	345	342
» 6	312	313	» 6	349	350
» 7	309	308	» 7	299	302
» 8	—	—	» 8	279	—
» 9	—	—	» 9	293	291
» 10	—	—	» 10	284	284
» 11	283	287	» 11	271	269
» 12	294	289	» 12	282	283
1973. 1	331	327	1976. 1	309	308
» 2	311	312	» 2	294	291
» 3	344	344	» 3	322	323
» 4	361	358	» 4	322	321
» 5	335	334	» 5	335	336
» 6	312	313	» 6	304	303
» 7	297	298	» 7	309	307
» 8	294	293	» 8	374	—
» 9	305	307	» 9	283	285
» 10	301	297	» 10	288	290
» 11	283	288	» 11	292	292
» 12	311	310	» 12	294	288
1974. 1	292	292	1977. 1	309	311
» 2	304	—	» 2	324	324
» 3	378	379	» 3	326	324
» 4	402	406	» 4	348	349
» 5	344	346	» 5	344	345
» 6	321	325	» 6	315	315
» 7	321	323	» 7	318	316
» 8	306	306	» 8	303	306
» 9	295	296	» 9	292	289
» 10	309	309	» 10	279	279
» 11	—	—	» 11	261	261
» 12	—	—	» 12	272	272

Year/month	comp.	obs.	Year/month	comp.	obs.
1978. 1	283	282	1981. 1	292	294
» 2	298	298	» 2	307	308
» 3	300	301	» 3	335	—
» 4	304	307	» 4	314	313
» 5	325	324	» 5	335	332
» 6	307	304	» 6	314	313
» 7	302	302	» 7	309	309
» 8	303	301	» 8	—	—
» 9	292	288	» 9	—	—
» 10	279	282	» 10	279	279
» 11	274	276	» 11	261	263
» 12	285	276	» 12	272	265
1979. 1	309	314			
» 2	324	323			
» 3	335	332			
» 4	348	347			
» 5	344	341			
» 6	309	311			
» 7	300	303			
» 8	300	302			
» 9	292	291			
» 10	288	283			
» 11	283	284			
» 12	285	283			
1980. 1	287	286			
» 2	302	302			
» 3	335	332			
» 4	339	338			
» 5	335	330			
» 6	299	299			
» 7	309	312			
» 8	304	305			
» 9	—	—			
» 10	294	302			
» 11	283	285			
» 12	279	285			

4.7 Station: TATENO

$\varphi = 36^0\ 03'$ N, L $= 140^0\ 08'$ E, Time Period: 1957 - 1986.

Using Figure 5, we can express the variation of the mean monthly values of total ozone at this Station as follows:

$$10^{-3} \cdot O_m^{com} = 323 + 44 \sin\left(\frac{2\pi}{12}t + 30^\circ\right) \tag{31}$$

If we proceed as in the case of the previous stations and consider the differences:

$$D = 10^{-3} \cdot O^{obs} - \left[323 + 44 \sin\left(\frac{2\pi}{12}t + 30^\circ\right)\right] \tag{32}$$

we see that they are not random but appear sporadically, as whole periods or quasi-periods shown in Figures 33 and 34 by dashed or sinusoidal curves. The pe-

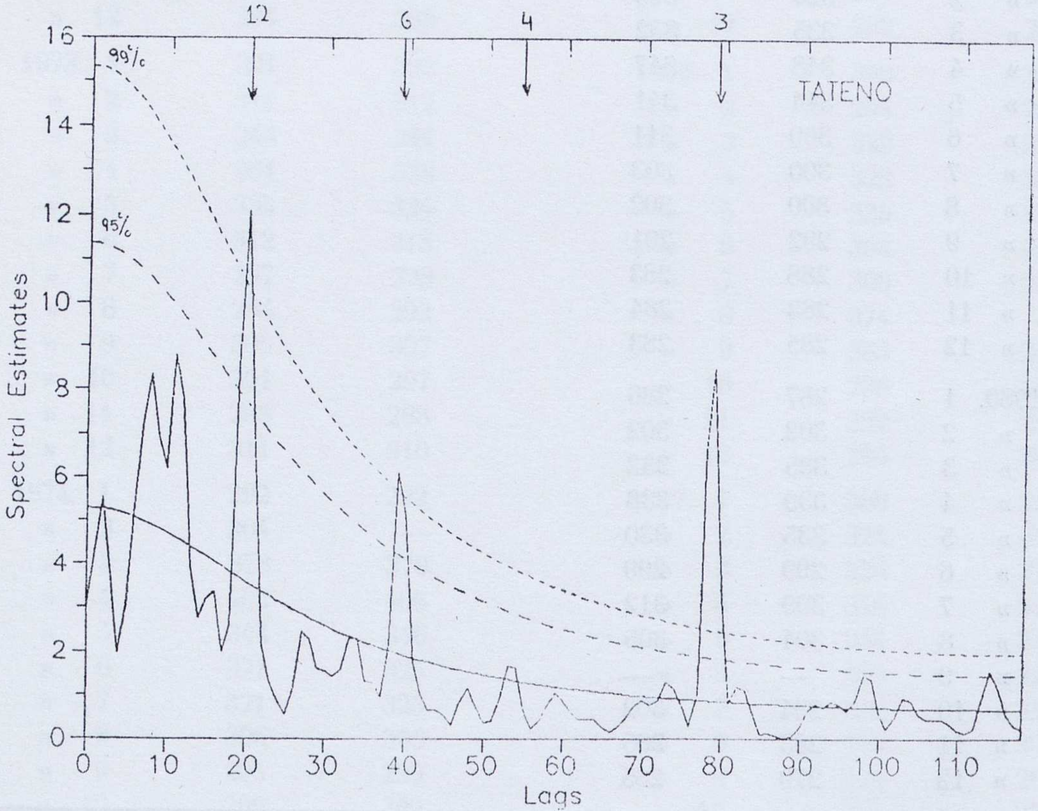

Fig. 32. Tateno Station, 1957-1986. Spectral estimate of the differences computed by Equation (32). Analysis shows periodicities of 12, 6, 4 and 3 months. Note that periodic terms of 12, 6 and 3 months are predominant with a confidence level above 99%.

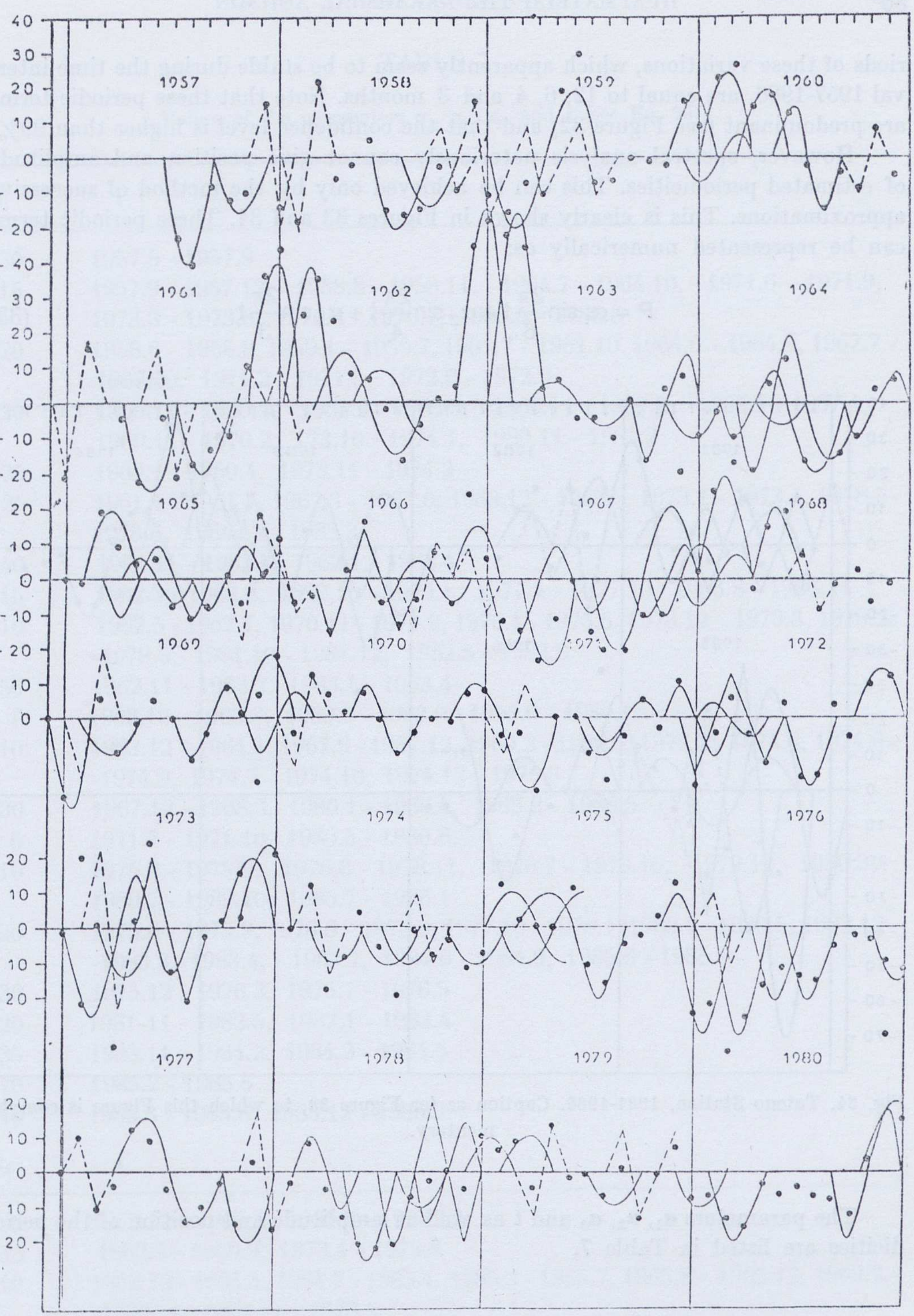

Fig. 33. Tateno Station, 1957-1980. The differences (D) computed by Equation (32) are shown by dots. The dashed and solid sinusoidal or semisinusoidal curves show periodic terms with periods of 12, 6, 4 and 3 months, whose position and amplitude is also plotted by the successive approximation method.

riods of these variations, which apparently seem to be stable during the time interval 1957-1986, are equal to 12, 6, 4 and 3 months. Note that these periodic terms are predominant (see Figure 32) and that the confidence level is higher than 99%.

However, spectral analysis notoriously cannot give position and amplitude of estimated periodicities. This can be achieved only by the method of successive approximations. This is clearly shown in Figures 33 and 34. These periodic terms can be represented numerically as:

$$P = \alpha_1 \sin\frac{2\pi}{6}t + \alpha_2 \sin\frac{2\pi}{4}t + \alpha_3 \sin\frac{2\pi}{3}t \tag{33}$$

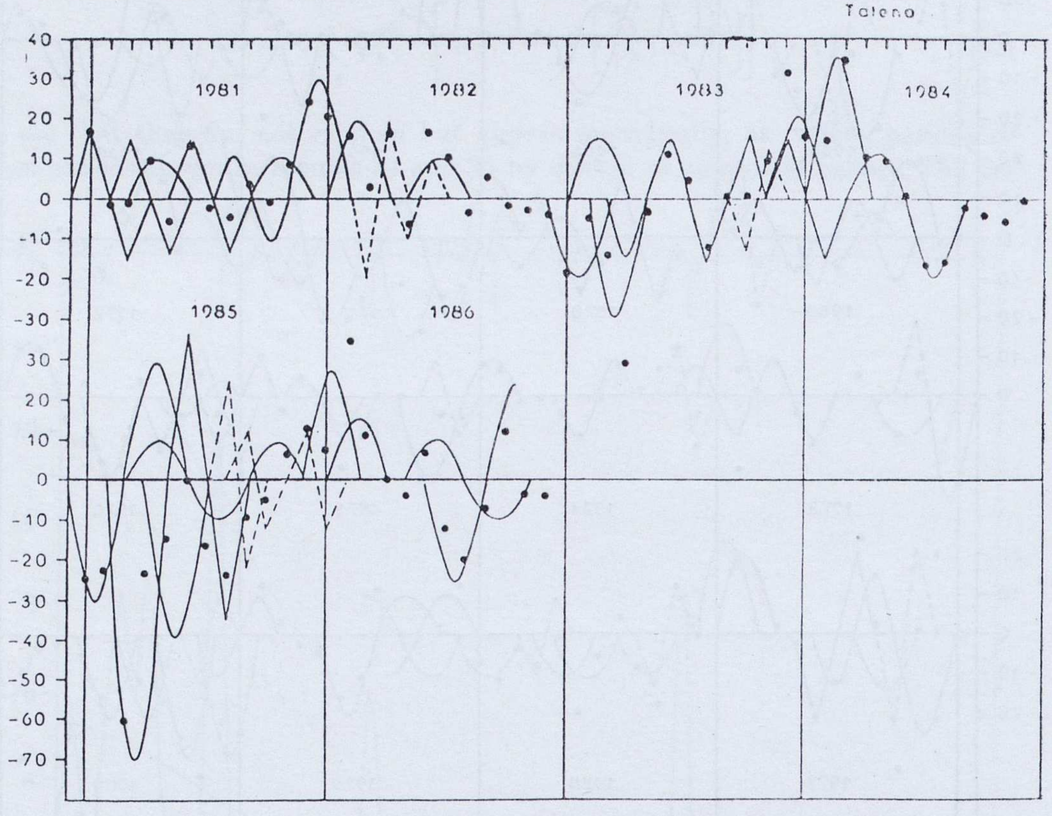

Fig. 34. Tateno Station, 1981-1986. Caption as for Figure 33, to which this Figure is complementary.

The parameters α_1, α_2, α_3 and **t** as well as amplitude and position of the periodicities are listed in Table 7.

TABLE 7

Values of the parameters α_1, α_2, α_3, and t (see Eq. 33).

α_1	t
—30	1957.5 - 1957.9
—15	1957.9 - 1957.12, 1958.8 - 1958.11, 1964.7 - 1964.10, 1971.6 – 1971.9, 1973.3 - 1973.6, 1976.4 - 1976.7, 1986.5 - 1986.8
—20	1958.6 - 1958.9, 1959.1 - 1959.7, 1961.7 - 1961.10, 1964.6 - 1964.9, 1967.7 - 1967.10, 1971.2 - 1971.5, 1972.6 - 1972.9
+20	1959.11 - 1960.2, 1965.2 - 1965.5, 1966.11 - 1967.2, 1967.1 - 1967.4, 1969.11 - 1970.2, 173.10 - 1974.1, 1980.11 - 1981.2
+25	1960.1 - 1960.4, 1973.11 - 1974.2
—25	1961.4 - 1961.7, 1967.3 - 1967.6, 1968.12 - 1969.3, 1973.1 - 1973.4, 1978.5-1978.8, 1984.12 - 1985.3
+40	1961.11 - 1962.2, 1962.1 - 1962.4
+15	1962.3 - 1962.6, 1972.10 - 1973.1, 1977.4 - 1977.10, 1986.8 - 1986.11
+10	1962.5 - 1962.7, 1970.11 - 1971.2, 1975.1 - 1975.5, 1978.12 - 1979.3, 1979.2--1979.5, 1981.10 - 1981.12, 1982.5 - 1982.8
—50	1962.11 - 1963.2, 1963.1 - 1963.4
+ 6	1962.12 - 1963.3, 1963.3 - 1963.9, 1980.9 - 1980.12
—10	1963.12 - 1964.1, 1967.9 - 1967.12, 1969.2 - 1969.5, 1974.3 - 1974.6, 1974.6--1974.9, 1974.7 - 1974.10, 1974.12 - 1975.6
+30	1967.12 - 1968.3, 1986.1 - 1986.4, 1968.2 - 1968.5
— 6	1971.7 - 1971.10, 1980.5 - 1980.8
—10	1975.2 - 1975.8, 1978.8 - 1978.11, 1979.7 - 1979.10, 1979.12 - 1980.3, 1980.7 - 1980.10, 1985.7 - 1986.1
—20	1975.6 - 1975.9, 1976.6 - 1976.9, 1977.10 - 1978.1, 1980.2 - 1980.5, 1982.12--1983.3, 1983.4, - 1983.7, 1984.6 - 1984.9, 1985.6 - 1985.9
—30	1975.12 - 1976.3, 1976.7 - 1976.5
+20	1981-11 - 1982.5, 1982.1 - 1982.4
+35	1983.11 - 1984.2, 1984.2 - 1984.5
—70	1985.2 - 1985.5
+10	1985.3 - 1985.6, 1985.12 - 1986.3

α_2	t
— 6	1959.12 - 1960,4, 1966.6 - 1966.12
+15	1960.5 - 1960.9, 1973.4 - 1973.8
—10	1963.12 - 1964.4, 1964.7 - 1965.1, 1965.3 - 1965.7, 1965.8 - 1965.12, 1969.7--1969.11, 1969.11 - 1970.5

α_2	t
−20	1964.3 - 1964.7, 1978.7 - 1979.1, 1980.9 - 1981.1
+ 6	1965.4 - 1965.8
−15	1966.3 - 1966.9, 1971.11 - 1972.6, 1978.9 - 1979.1, 1986.2 - 1986.6
+10	1967.4 - 1967.8, 1970.5 - 1970.9, 1970.11 - 1971.3, 1975.11 - 1976.3, 1978.2-1978.6
+20	1973.5 - 1973.9
−40	1983.3 - 1983.7

α_3	t
+20	1957.11 - 1958.2, 1958.11 - 1959.2, 1961.5 - 1961.8, 1977.11 - 1978.2
−25	1958.1 - 1958.4
+10	1958.9 - 1959.8, 1961.12 - 1962.4, 1965.12 - 1966.3, 1966.11 - 1967.2,1968.6–1968.9, 1974.2 - 1974.5, 1974.8 - 1974.11, 1976.1 - 1976.4
−10	1960.7 - 1960.12, 1961.9 - 1961.12, 1966.8 - 1966.11, 1971.1 - 1971.4, 1982.4 - 1982.7, 1983.8 - 1983.11, 1983.9 - 1983.12, 1984.3 - 1984.7
−20	1960.12 - 1961.3, 1963.9 - 1963.12, 1968.4 - 1968.7, 1969.1 - 1969.4, 1986.4–- 1986.7
+ 6	1964.4 - 1964.7, 1972.1 - 1972.4
+30	1967.11 - 1968.2, 1985.3 - 1985.6
−35	1968.3 - 1968.6
−15	1970.1 - 1970.4, 1979.3 - 1979.6, 1983.12 - 1984.4
− 6	1972.3 - 1972.6
+25	1973.2 - 1973.8
+10	1976.11 - 1977.2, 1981.3 - 1981.7, 1981.6 - 1981.9
+15	1977.1 - 1977.4, 1979.8 - 1979.12, 1981.5 - 1981.8, 1983.1 - 1983.9

This leads to the following equation:

$$10^{-3} \cdot 0^{com} = 323 + 44 \sin\left(\frac{2\pi}{12} t + 30^{\circ}\right) + P \tag{34}$$

where P is given by Equation (33). Equation (34) sums up the phenomenon of the variation and periodicities of monthly values of total ozone for the Tateno Station from 1957 to 1986.

The same results are presented in graphic form in Figures 35 and 36, where the dots represent the observed data, while the solid line represents the annual variation of computed monthly values of total ozone from 1957 through 1986. There is very satisfactory agreement between observed and computed MVTOZ with s.d. and accuracy of $\sigma = \pm 2.5$ and 99.2% respectively.

Table 7A tabulates observed and computed monthly values of total ozone for Tateno Station from 1957 through 1986.

It should be added that Equation (34) has 29 degrees of freedom.

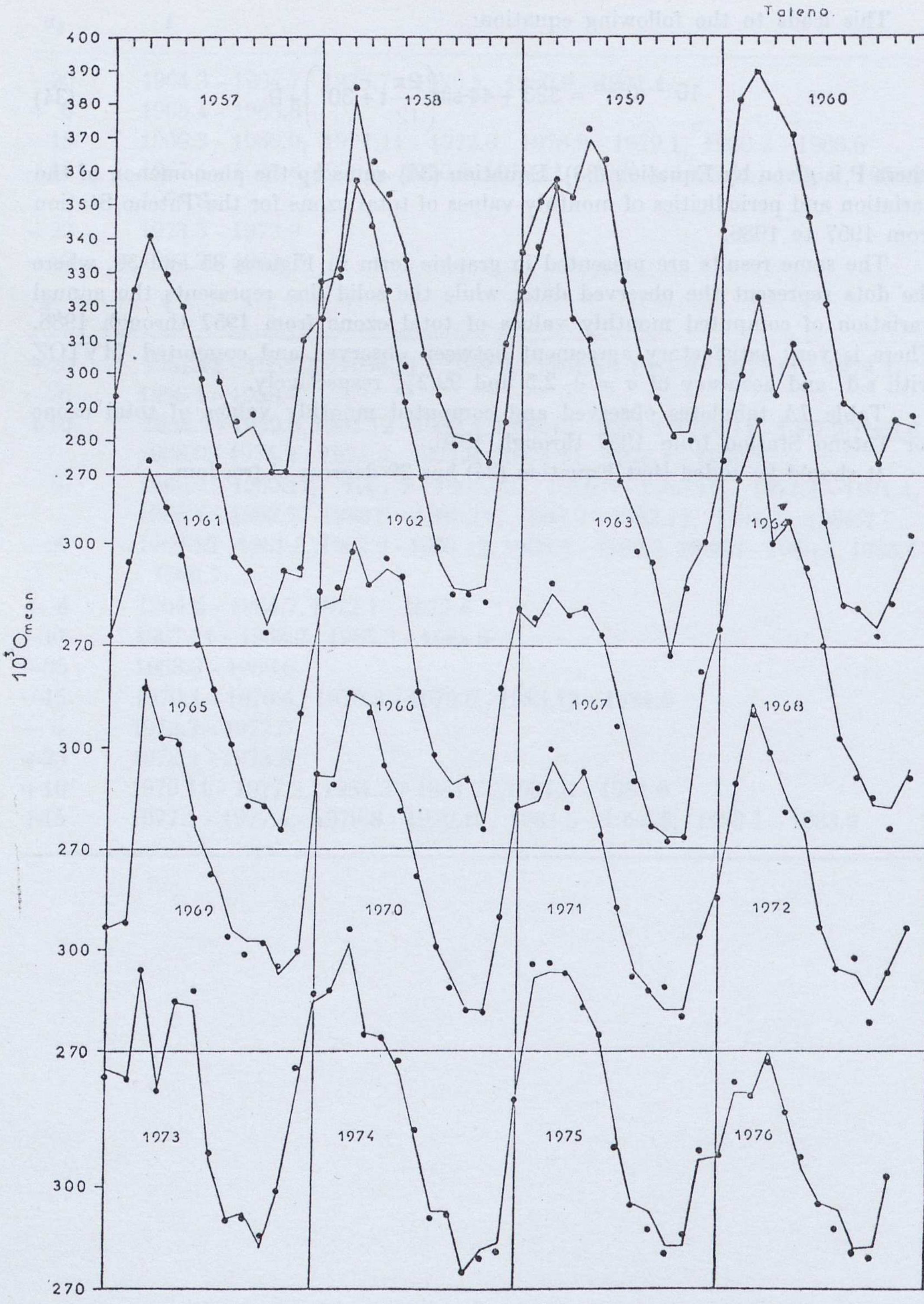

Fig. 35. Tateno Station, 1957-1976. Observed MVTOZ is shown by dots. MVTOZ computed by Equation (34) is shown by a solid line. The accuracy is equal to 99.2%.

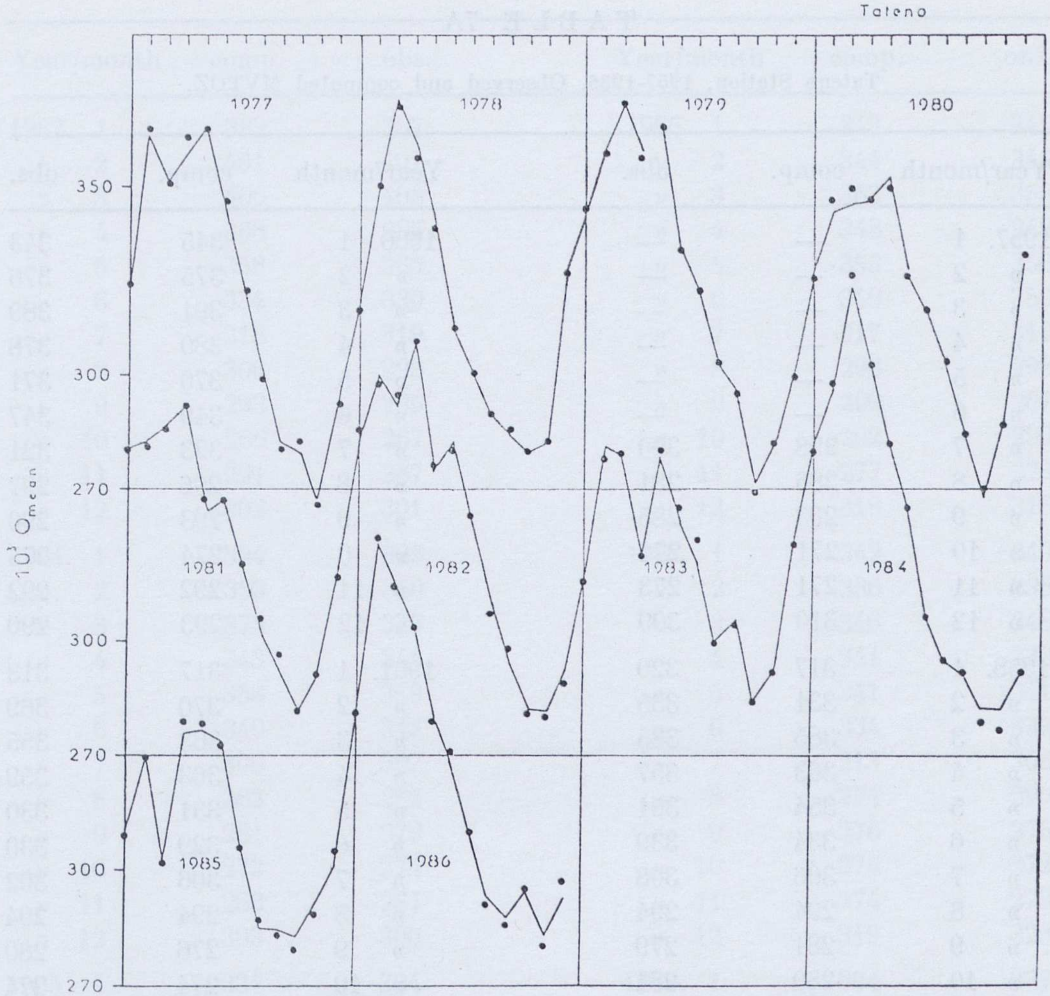

Fig. 36. Tateno Station, 1977-1986. Caption as for Figure 35, to which this Figure is complementary.

TABLE 7A

Tateno Station, 1957-1986. Observed and computed MVTOZ.

Year/month	comp.	obs.	Year/month	comp.	obs.
1957. 1	—	—	1960. 1	345	343
» 2	—	—	» 2	375	376
» 3	—	—	» 3	391	389
» 4	—	—	» 4	380	378
» 5	—	—	» 5	370	371
» 6	—	—	» 6	349	347
» 7	298	300	» 7	323	321
» 8	286	281	» 8	296	297
» 9	293	285	» 9	293	290
» 10	271	271	» 0	274	275
» 11	271	273	» 11	292	292
» 12	310	309	» 12	293	290
1958. 1	317	320	1961. 1	317	313
» 2	331	335	» 2	370	369
» 3	385	385	» 3	363	355
» 4	363	357	» 4	363	359
» 5	354	351	» 5	331	330
» 6	334	339	» 6	329	330
» 7	306	308	» 7	306	302
» 8	294	294	» 8	294	294
» 9	281	279	» 9	276	280
» 10	280	281	» 10	274	274
» 11	274	274	» 11	292	294
» 12	310	309	» 12	328	330
1959. 1	326	324	1962. 1	378	378
» 2	336	338	» 2	379	379
» 3	355	356	» 3	398	399
» 4	354	353	» 4	384	386
» 5	370	372	» 5	365	362
» 6	360	364	» 6	343	341
» 7	314	316	» 7	320	322
» 8	311	305	» 8	299	295
» 9	293	293	» 9	284	287
» 10	283	282	» 10	283	285
» 11	283	281	» 11	283	288
» 12	310	307	» 12	336	339

Year/month	comp.	obs.	Year/month	comp.	obs.
1963. 1	382	387	1966. 1	343	345
» 2	401	401	» 2	344	346
» 3	406	408	» 3	363	358
» 4	368	367	» 4	348	348
» 5	358	360	» 5	353	356
» 6	334	330	» 6	349	350
» 7	318	319	» 7	317	316
» 8	306	298	» 8	296	298
» 9	293	295	» 9	290	287
» 10	266	267	» 10	292	290
» 11	291	287	» 11	277	276
» 12	302	301	» 12	319	318
1964. 1	394	325	1967. 1	342	340
» 2	353	350	» 2	336	338
» 3	373	373	» 3	346	348
» 4	343	344	» 4	341	339
» 5	358	359	» 5	341	341
» 6	349	347	» 6	334	333
» 7	306	307	» 7	313	306
» 8	282	282	» 8	294	290
» 9	281	279	» 9	276	276
» 10	273	274	» 10	274	272
» 11	283	287	» 11	274	273
» 12	303	300	» 12	319	323
1965. 1	334	334	1968. 1	334	337
» 2	353	352	» 2	379	378
» 3	380	382	» 3	398	397
» 4	370	372	» 4	359	360
» 5	359	357	» 5	366	367
» 6	344	340	» 6	351	353
» 7	317	315	» 8	332	330
» 8	301	300	» 8	302	302
» 9	283	285	» 9	293	291
» 10	283	284	» 10	283	285
» 11	276	276	» 11	283	276
» 12	310	311	» 12	293	291

Year/month	comp.	obs.	Year/month	comp.	obs.
1969. 1	312	311	1972.	319	315
» 2	314	313	» 2	349	349
» 3	371	368	» 3	372	369
» 4	354	353	» 4	357	358
» 5	353	351	» 5	344	340
» 6	334	339	» 6	334	338
» 7	323	323	» 7	306	306
» 8	301	299	» 8	294	294
» 9	293	289	» 9	293	297
» 10	293	292	» 10	283	278
» 11	283	285	» 11	295	293
» 12	300	300	» 12	305	306
1970. 1	351	352	1973. 1	334	332
» 2	354	349	» 2	331	331
» 3	375	376	» 3	363	364
» 4	373	370	» 4	329	329
» 5	353	355	» 5	356	355
» 6	344	341	» 6	354	358
» 7	323	323	» 7	308	310
» 8	301	301	» 8	291	290
» 9	293	289	» 9	293	291
» 10	283	283	» 10	283	286
» 11	283	282	» 11	300	299
» 12	312	310	» 12	332	335
1971. 1	343	342	1974. 1	356	355
» 2	344	348	» 2	353	353
» 3	355	359	» 3	372	375
» 4	346	342	» 4	345	345
» 5	353	353	» 5	344	344
» 6	334	334	» 6	334	338
» 7	311	313	» 7	314	317
» 8	294	293	» 8	293	291
» 9	288	288	» 9	293	292
» 10	283	289	» 10	274	275
» 11	283	280	» 11	283	279
» 12	303	304	» 12	284	281

Year/month	comp.	obs.	Year/month	comp.	obs.
1975. 1	395	326	1978. 1	317	317
» 2	362	365	» 2	353	350
» 3	363	365	» 3	373	371
» 4	363	363	» 4	363	358
» 5	353	353	» 5	343	340
» 6	343	345	» 6	312	313
» 7	315	312	» 7	301	301
» 8	294	295	» 8	290	290
» 9	293	288	» 9	284	286
» 10	283	280	» 10	280	280
» 11	283	286	» 11	283	283
» 12	303	306	» 12	327	328
1976. 1	308	309	1979. 1	343	344
» 2	328	331	» 2	362	359
» 3	328	327	» 3	372	372
» 4	337	337	» 4	360	358
» 5	340	337	» 5	365	366
» 6	322	322	» 6	334	333
» 7	306	309	» 7	323	323
» 8	294	295	» 8	302	304
» 9	293	288	» 9	296	295
» 10	283	280	» 10	271	269
» 11	283	279	» 11	283	282
» 12	303	303	» 12	305	300
1977. 1	324	321	1980. 1	325	326
» 2	365	363	» 2	344	346
» 3	351	352	» 3	346	349
» 4	363	359	» 4	346	347
» 5	365	366	» 5	353	350
» 6	346	343	» 6	329	327
» 7	323	318	» 7	318	318
» 8	299	297	» 8	302	304
» 9	281	283	» 9	284	285
» 10	283	280	» 10	268	270
» 11	266	268	» 11	288	287
» 12	293	296	» 12	330	332

Year/month	comp.	obs.	Year/month	comp.	obs.
1981. 1	351	350	1984. 1	351	350
» 2	353	351	» 2	365	368
» 3	363	361	» 3	393	397
» 4	372	372	» 4	372	373
» 5	344	347	» 5	362	362
» 6	346	347	» 6	334	335
» 7	320	320	» 7	306	306
» 8	302	306	» 8	294	295
» 9	293	296	» 9	293	292
» 10	283	282	» 10	283	279
» 11	292	291	» 11	283	277
» 12	319	317	» 12	293	292
1982. 1	351	354	1985. 1	312	309
» 2	370	368	» 2	331	330
» 3	363	365	» 3	302	302
» 4	380	379	» 4	336	339
5 5	344	346	» 5	336	338
» 6	352	350	» 6	334	333
» 7	332	333	» 7	306	306
» 8	311	307	» 8	285	287
» 9	293	298	» 9	284	283
» 10	283	281	» 10	283	279
» 11	283	280	» 11	292	289
» 12	293	289	» 12	302	305
1983. 1	317	315	1986. 1	343	341
» 2	351	348	» 2	388	387
» 3	348	349	» 3	374	374
» 4	323	322	» 4	363	363
» 5	351	350	» 5	351	349
» 6	342	345	» 6	339	341
» 7	323	327	» 7	311	310
» 8	299	299	» 8	294	291
» 9	296	294	» 9	288	286
» 10	283	284	» 10	295	295
» 11	292	292	» 11	283	280
» 12	323	324	» 12	297	293

4.8 Station: NASHVILLE

$\varphi = 36^0\, 07'$ N, L $= 86^0\, 41'$ W, Time Period: 1963 - 1986.

Using Figure 6 the mean monthly values of total ozone can be expressed by a relation of the form:

$$10^{-3} \cdot O_m^{com} = 322 + 30 \sin \frac{2\pi}{12} t \tag{35}$$

The differences between observed monthly values of total ozone and the same values given by Equation (35), namely,

$$D = 10^{-3} \cdot 0^{obs} - 10^{-3} \cdot 0_m^{com} \tag{36}$$

are apparently not random and show periodicities with periods of 12, 6, 4 and 3 months, with a confidence level higher than 95%. This interpretation is supported by the spectrum analysis shown in Figure 37.

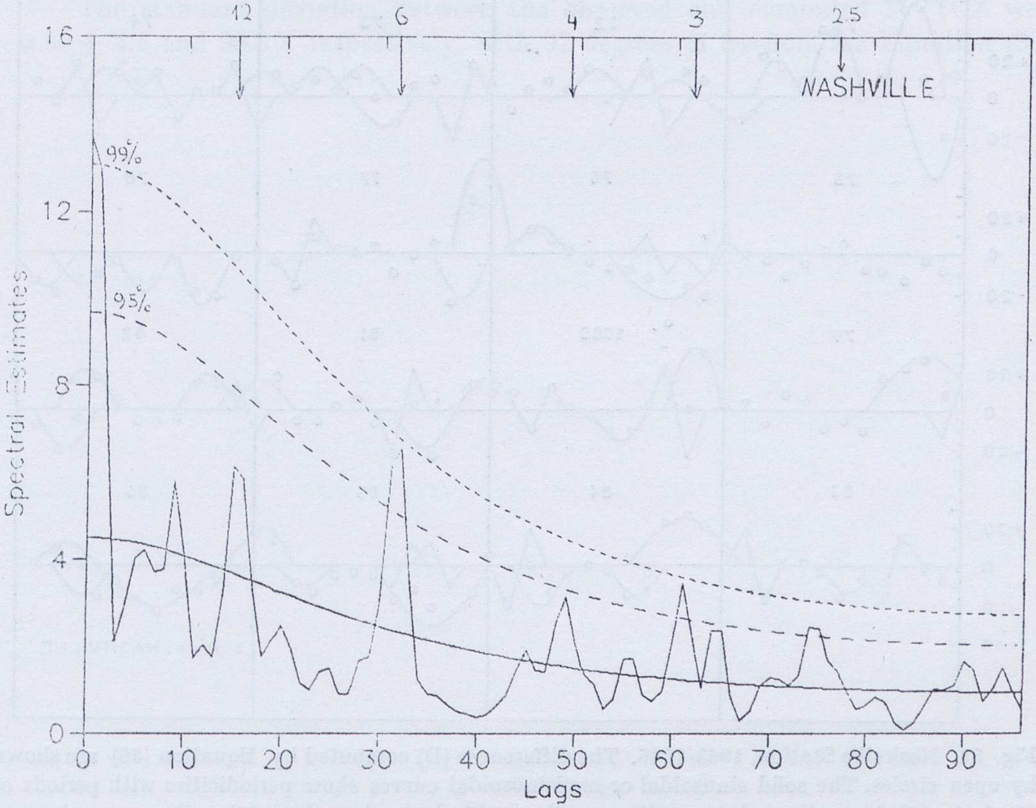

Fig. 37. Nashville Station, 1963 - 1986. Spectral estimate of the differences computed by Equation (36). Analysis shows periodicities with periods of 12, 6, 4 and 3 months significant at a confidence level of 99% and 95%.

The periodic variation of the just discussed differences can be written as:

$$P = \alpha_1 \sin\frac{2\pi}{12} t + \alpha_2 \sin\frac{2\pi}{6} t + \alpha_3 \sin\frac{2\pi}{3} t \tag{37}$$

The position and amplitude of these periodic terms, as plotted by means of the successive approximation method, are shown in Figure 38.

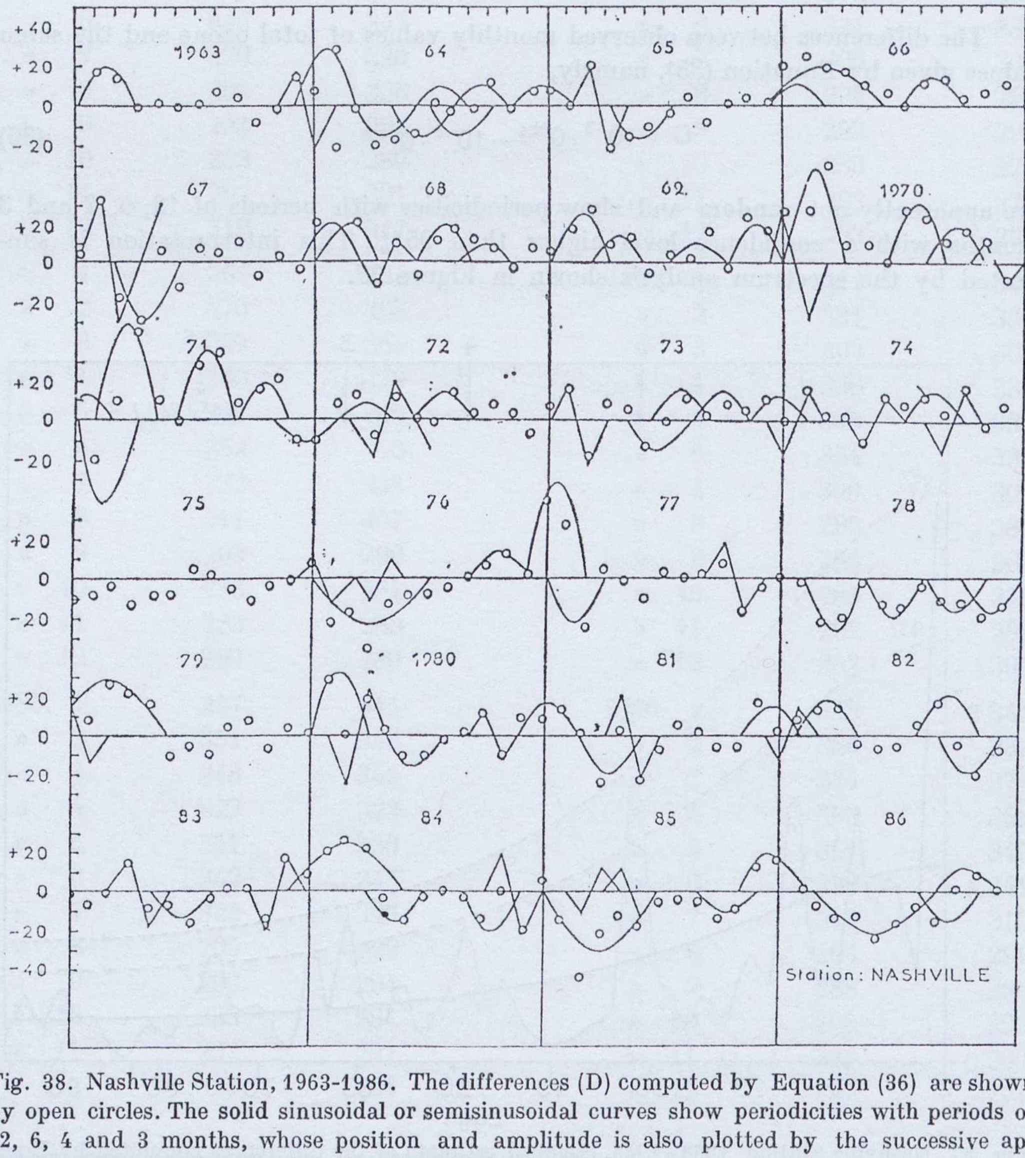

Fig. 38. Nashville Station, 1963-1986. The differences (D) computed by Equation (36) are shown by open circles. The solid sinusoidal or semisinusoidal curves show periodicities with periods of 12, 6, 4 and 3 months, whose position and amplitude is also plotted by the successive approximation method.

Here open circles represent the differences (D), found by Equation (36), and the solid sinusoidal or semisinusoidal curves represent periodic terms of 12, 6, 4 and 3 months, which appear as a network of periodicities with occasional «overlaps».

The values of the parameters $\boldsymbol{\alpha}_1$, $\boldsymbol{\alpha}_2$, $\boldsymbol{\alpha}_3$ and $\mathbf{t}$ are listed in Table 8.

Summing Equation (35) and Equation (37) we obtain

$$10^{-3} \cdot O^{com} = 10^{-3} \cdot O_m^{com} + P \tag{38}$$

This new equation governs the variation and periodicity of the monthly values of total ozone of the Nashville Station for the period 1963-1986.

Table 8A shows observed MVTOZ (open circles) and also its values as computed by Equation (38).

The agreement between the observed and computed values is obvious from Figure 39, where the open circles represent the observed data shown in Table 8A, while the solid line represents the monthly values of total ozone computed by Equation 38 (see also Table 8A).

The standard deviation between the observed and computed MVTOZ were $\sigma = \pm 4.4$ and 98.5% respectively, with 97 degrees of freedom for Equation (38).

TABLE 8

Values of the parameters α_1, α_2, α_3, and t (see Eq. 37).

α_1	t
+20	1965.12 - 1966.6
—20	1976.1 - 1976.7, 1986.3 - 1986.9
+25	1978.12 - 1979.6, 1983.12 - 1984.6
—30	1985.1 - 1985.7
α^2	t
+30	1962.11 - 1963.2, 1963.12 - 1964.3, 1980.1 - 1980.4
—20	1964.3 - 1964.9, 1978.10 - 1979.1, 1982.9 - 1982.12, 1984.4 - 1984.12
—15	1964.5 - 1964.11, 1964.7 - 1964.10, 1973.5 - 1973.11, 1978.5 - 1978.8. 1983.5 - 1983.8, 1984.4 - 1984.7, 1985.3 - 1985.6, 1986.8 - 1986.11
—10	1964.11 - 1965.2, 1965.12 - 1966.3, 1966.10 - 1967.1, 1966.12 - 1963.3, 1968.8 - 1968.11, 1973.11 - 1974.2
—20	1963.1 - 1963.4, 1971.9 - 1971.12, 1977.1 - 1977.4, 1982.8 - 1982.11, 1985.11 - 1986.2
+15	1966.7 - 1966.10, 1968.6 - 1968.9, 1969.3 - 1969.6, 1970.12 - 1971.3, 1972.6 - -1972.9, 1973.6 - 1973.9, 1974.7 - 1974.10, 1976.9 - 1972.12, 1980.12 - 1981.6, 1981.11 - 1982.2, 1982.2 - 1982.5
—30	1967.3 - 1967.6
+25	1967.12 - 1968.3, 1968.1 - 1968.4, 1969.1 - 1969.4, 1969.10 - 1970.1, 1970.9 - 1970.12
+60	1970.1 - 1970.4
+35	1970.6 - 1970.9, 1971.6 - 1971.9
—40	1971.1 - 1971.4
+55	1971.2 - 1971.5
—10	1971.11 - 1972.5, 1975.3 - 1975.6, 1978.8 - 1978.11, 1980.5 - 1980.8, 1988.9 - 1985.12
+50	1976.12 - 1977.3
—25	1978.2 - 1978.5
+15	1986.9 - 1986.12

a_3	t
+20	1963.11 - 1964.2, 1967.1 - 1967.5, 1969.7 - 1969.10, 1973.1 - 1973.4, 1981.4 - 1981.7
+25	1965.2 - 1965.5, 1984.10 - 1985.1
—15	1965.4 - 1965.7, 1972.3 - 1972.7, 1973.12 - 1974.3, 1974.8 - 1974.11, 1984.11 - 1985.2, 1985.2 - 1985.6
—10	1968.3 - 1968.6, 1974.4 - 1974.7, 1981.12 - 1982.3
+10	1975.12 - 1976.3, 1980.9 - 1980.12
+15	1977.9 - 1977.12, 1978.12 - 1979.3, 1983.3 - 1983.6
—25	1980.2 - 1980.5
—20	1983.10 - 1984.1

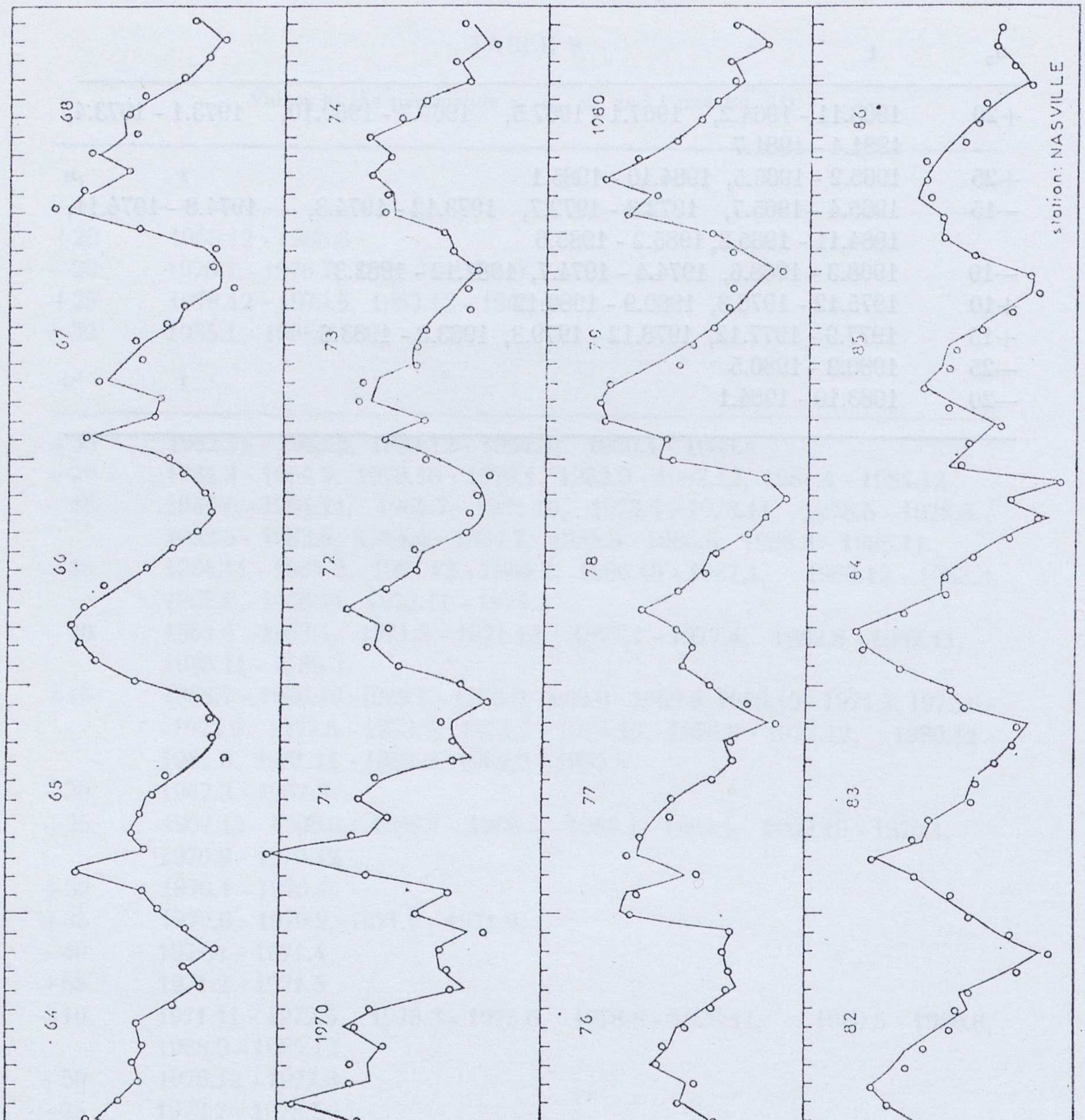

Fig. 39. Nashville Station, 1963-1986. Observed MVTOZ is shown by open circles. MVTOZ computed by Equation (38) is shown by a solid line. The accuracy is equal to 98.5%.

TABLE 8A

Nashville Station, 1963-1986. Observed and computed MVTOZ.

Year/month	comp.	obs.	Year/month	comp.	obs.
1963. 1	341	342	1966. 1	333	337
» 2	348	348	» 2	356	356
» 3	361	360	» 3	364	365
» 4	352	351	» 4	369	370
» 5	352	353	»	362	363
» 6	344	344	» 6	344	352
» 7	330	331	» 7	331	331
» 8	315	323	» 8	329	327
» 9	300	306	» 9	314	314
» 10	294	285	» 10	294	297
» 11	294	294	» 11	302	301
» 12	318	317	» 12	309	312
1964. 1	323	324	1967. 1	323	320
» 2	356	361	» 2	356	363
» 3	344	343	» 3	326	326
» 4	334	332	» 4	326	323
» 5	334	335	» 5	356	358
» 6	331	331	» 6	344	332
» 7	335	333	» 7	330	338
» 8	319	312	» 8	314	322
» 9	300	300	» 9	300	313
» 10	307	309	» 10	294	288
» 11	294	293	» 11	294	297
» 12	309	309	» 12	300	297
1965. 1	323	322	1968. 1	336	336
» 2	330	330	» 2	374	380
» 3	365	366	» 3	365	366
» 4	330	330	» 4	343	342
» 5	339	337	» 5	360	363
» 6	331	333	» 6	344	339
» 7	330	327	» 7	343	342
» 8	315	319	» 8	328	334
» 9	300	291	» 9	309	314
» 10	294	295	» 10	301	300
» 11	294	297	» 11	294	299
» 12	300	303	» 12	303	309

Year/month	comp.	obs.	Year/month	comp.	obs.
1969. 1	315	320	1972. 1	306	305
» 2	352	348	» 2	336	339
» 3	365	372	» 3	353	356
» 4	365	361	» 4	347	344
» 5	365	364	» 5	365	365
» 6	344	339	» 6	344	345
» 7	330	335	» 7	330	330
» 8	332	335	» 8	328	331
» 9	318	316	» 9	300	304
» 10	294	291	» 10	294	302
» 11	315	317	» 11	294	298
» 12	321	319	» 12	300	293
1970. 1	341	342	1973. 1	315	324
» 2	356	348	» 2	348	347
» 3	396	393	» 3	326	326
» 4	352	361	» 4	352	361
» 5	352	361	» 5	352	358
» 6	344	343	» 6	331	331
» 7	361	354	» 7	330	330
» 8	346	344	» 8	328	326
» 9	300	304	» 9	313	302
» 10	315	311	» 10	307	302
» 11	315	316	» 11	294	299
» 12	300	292	» 12	309	312
1971. 1	328	326	1974. 1	311	316
» 2	310	311	» 2	343	348
» 3	357	354	» 3	344	345
» 4	399	405	» 4	352	353
» 5	352	361	» 5	343	344
» 6	344	343	» 6	352	356
» 7	361	359	» 7	330	338
» 8	345	349	» 8	328	326
» 9	300	309	» 9	300	304
» 10	311	311	» 10	307	310
» 11	311	316	» 11	294	291
» 12	292	292	» 12	300	308

Year/month	comp.	obs.	Year/month	comp.	obs.
1975. 1	314	306	1978. 1	315	314
» 2	330	325	» 2	330	329
» 3	344	341	» 3	322	322
» 4	343	339	» 4	330	331
» 5	343	344	» 5	352	351
» 6	344	336	» 6	331	330
» 7	330	336	» 7	317	316
» 8	314	318	» 8	315	311
» 9	300	297	» 9	292	293
» 10	294	285	» 0	285	286
» 11	294	291	» 11	276	274
» 12	300	299	» 12	283	286
1976. 1	323	324	1979. 1	340	335
» 2	312	309	» 2	340	338
» 3	326	328	» 3	360	371
» 4	323	319	» 4	373	374
» 5	343	332	» 5	364	368
» 6	334	337	» 6	344	331
» 7	336	325	» 7	334	325
» 8	315	317	» 8	314	314
» 9	300	303	» 9	300	305
» 10	307	302	» 10	294	302
» 11	307	306	» 11	300	304
» 12	300	302	» 12	300	304
1977. 1	358	355	1980. 1	315	316
» 2	356	359	» 2	356	360
» 3	326	319	» 3	348	343
» 4	352	357	» 4	373	372
» 5	352	352	» 5	352	355
» 6	344	334	» 6	335	335
» 7	330	334	» 7	322	320
» 8	315	313	» 8	315	313
» 9	300	302	» 9	300	303
» 10	307	302	» 10	302	306
» 11	281	277	» 11	285	286
» 12	300	294	» 12	300	313

Year/month		comp.	obs.	Year/month		comp.	obs.
1981.	1	328	323	1984.	1	328	325
»	2	343	344	»	2	352	352
»	3	344	346	»	3	369	371
»	4	339	329	»	4	373	374
»	5	356	356	»	5	351	349
»	6	326	322	»	6	331	328
»	7	330	324	»	7	330	328
»	8	315	321	»	8	315	314
»	9	300	303	»	9	300	314
»	10	294	287	»	10	276	280
»	11	294	288	»	11	298	296
»	12	313	318	»	12	266	268
1982.	1	319	318	1985.	1	328	321
»	2	339	339	»	2	315	317
»	3	357	357	»	3	305	300
»	4	365	365	»	4	322	327
»	5	357	347	»	5	338	340
»	6	348	338	»	6	331	326
»	7	330	325	»	7	330	325
»	8	315	321	»	8	315	311
»	9	318	315	»	9	300	295
»	10	294	289	»	10	285	280
»	11	276	273	»	11	285	285
»	12	300	293	»	12	318	315
1983	1	315	315	1986	1	332	332
»	2	330	324	»	2	330	331
»	3	344	343	»	3	344	337
»	4	365	366	»	4	342	340
»	5	339	343	»	5	334	339
»	6	331	336	»	6	324	320
»	7	317	315	»	7	313	314
»	8	315	312	»	8	305	310
»	9	300	302	»	9	287	287
»	10	294	294	»	10	294	295
»	11	276	280	»	11	307	304
»	12	318	319	»	12	300	302

4.9 Station: WALLOPS

$\varphi = 37° 51'$ N, L $= 75° 31'$ W, Time Period: 1970 - 1986.

As can be seen from Figure 6, the mean monthly values of total ozone for the Wallops Station can be expressed as:

$$10^{-3} \cdot O_m^{com} = 323 + 35 \sin \frac{2\pi}{12} t \tag{39}$$

Calculating the differences

$$D = 10^{-3} \cdot 0^{obs} - 10^{-3} \cdot 0_m^{com} \tag{40}$$

we can compute the spectral estimate for the Wallops Station and we can arrive at Figure 40, which shows short term periodicities of 24, 12, 6, 4 and 3 months.

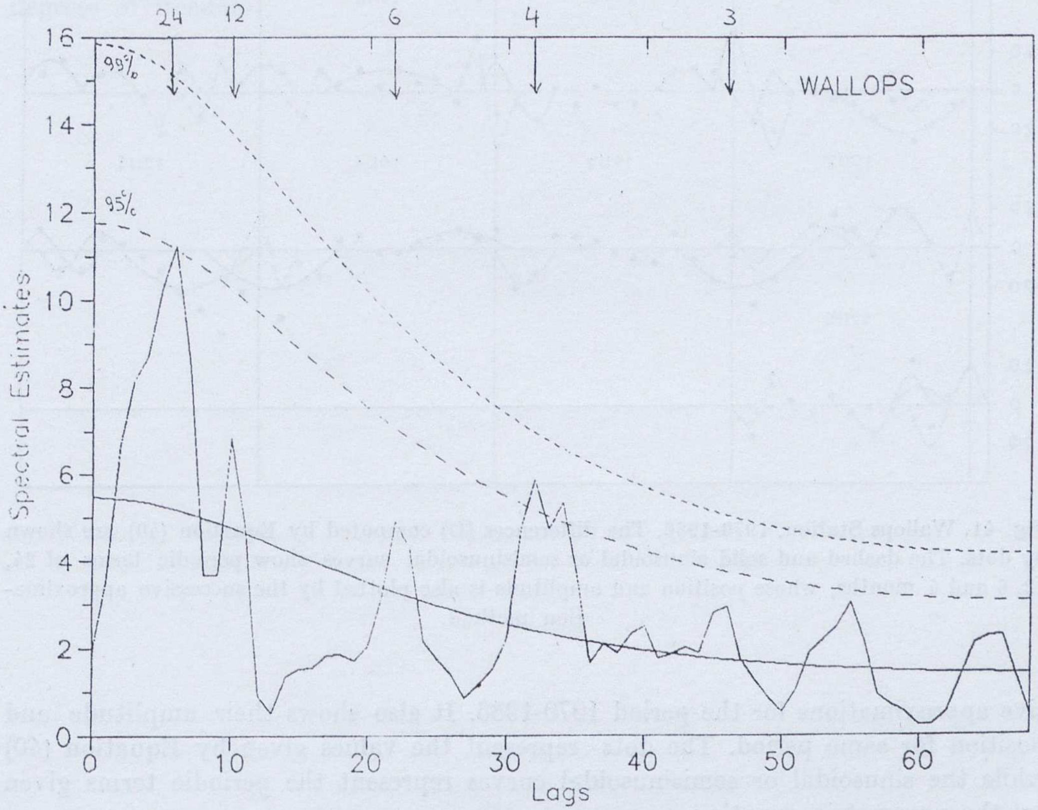

Fig. 40. Wallops Station, 1970-1986. Spectral estimate of the differences computed by Equation (40). Analysis shows periodic terms with periods of 24, 12, 6, 4 and 3 months.

As is fairly obvious from Figure 40, spectral estimate detects five short-term periodicities of 24, 12, 6, 4 and 3 months.

Figure 41 shows the same periodicities plotted according the method of succes-

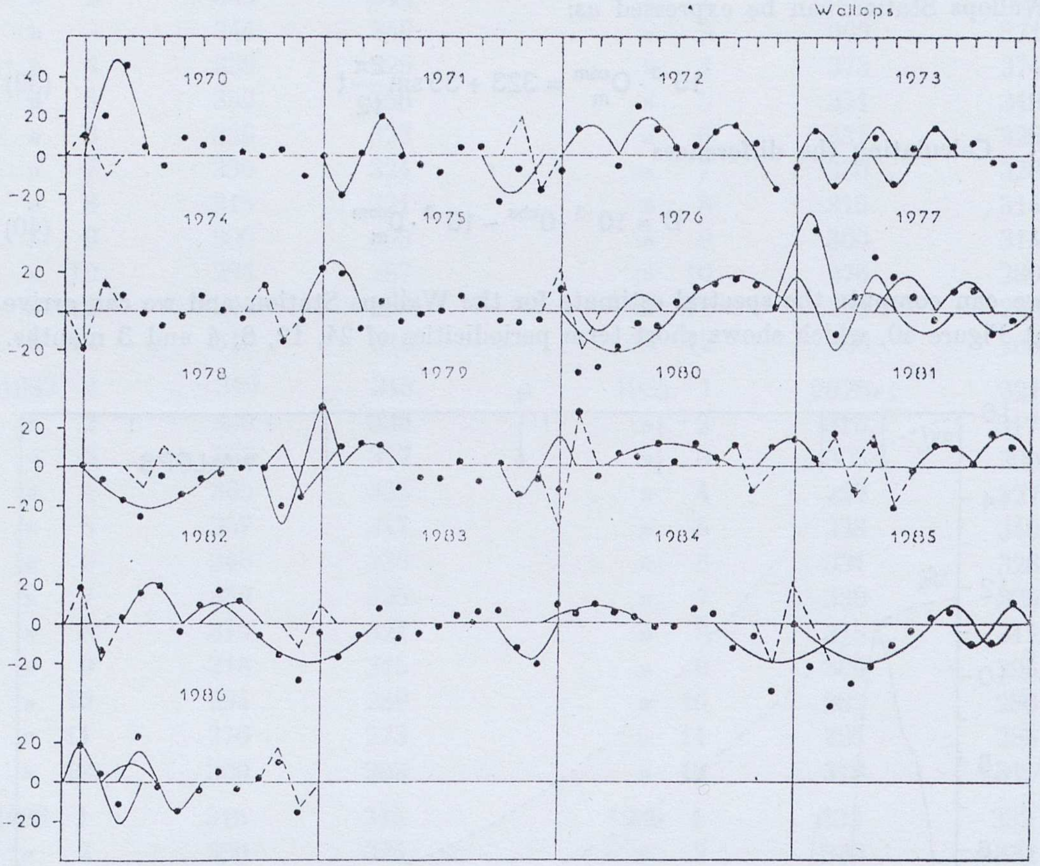

Fig. 41. Wallops Station, 1970-1986. The differences (D) computed by Equation (40) are shown by dots. The dashed and solid sinusoidal or semisinusoidal curves show periodic terms of 24, 12, 6 and 4 months, whose position and amplitude is also plotted by the successive approximation method.

sive approximations for the period 1970-1986. It also shows their amplitude and position for same period. The dots represent the values given by Equation (40) while the sinusoidal or semisinusoidal curves represent the periodic terms given by the parametric equation:

$$P = \alpha_1 \sin\frac{2\pi}{24}t + \alpha_2 \sin\frac{2\pi}{12}t + \alpha_3 \sin\frac{2\pi}{6}t + \alpha_4 \sin\frac{2\pi}{4}t + \alpha_5 \sin\frac{2\pi}{3}t \qquad (41)$$

Table 9 summarizes the numerical values on which Figure 41 was based (parameters α_1 through α_5 and $\mathbf{t}$).

Summing Equation (39) and Equation (41), we obtain a new equation of the form:

$$10^{-3} \cdot 0^{com} = 10^{-3} \cdot O_m^{com} + P \tag{42}$$

which governs the variation and periodicity of MVTOZ of the Wallops Station.

The above results are again obvious from Figure 42. Here the dots represent observed MVTOZ, while the continuous line represents variation in MVTOZ computed by Equation (42).

The numerical results shown graphically in Figure 42 are listed in Table 9A. The standard deviation between the observed and computed MVTOZ as well as the accuracy are $\sigma = \pm 4.2$ and 98.7% respectively. Equation 42, which sums up the phenomenon of variation and periodicity for the Wallops Station has 84 degrees of freedom.

TABLE 9

Values of the parameters α_1-α_5, and **t** (see Eq. 41).

α_1	**t**
—20	1978.1 - 1978.8, 1985.1 - 1985.8, 1982.9 - 1983.4
+10	1980.3 - 1980.10
α_2	**t**
—20	1976.1 - 1977.1
+10	1983.12 - 1984.6
α_3	**t**
+50	1970.1 - 1970.4, 1976.12 - 1977.3
—20	1971.9 - 1971.12, 1983.10 - 1984.1
+15	1972.1 - 1972.4, 1973.7 - 1973.11, 1979.2 - 1979.5, 1980.11 - 1981.2, 1981.2- - 1981.5, 1981.10 - 1982.1
+20	1972.4 - 1972.7, 1977.5 - 1977.8, 1982.3 - 1982.6
+25	1974.12 - 1975.3
+10	1977.3 - 1977.7, 1981.7 - 1981.10, 1982.5 - 1982.9, 1982.7 - 1982.10, 1986.2-1986.5
—10	1977.10 - 1978.1
α_4	**t**
—20	1971.1 - 1971.5
—15	1972.11 - 1973.3, 1973.2 - 1973.6, 1973.5 - 1973.9, 1979.10 - 1980.2
—10	1974.4 - 1974.8, 1974.2 - 1974.6
+20	1972.12 - 1973.6, 1985.12 - 1986.4
+10	1985.8 - 1985.12
α_5	**t**
+10	1969.12 - 1970.3, 1978.10 - 1979.2
+20	1971.10 - 1972.1
—20	1973.12 - 1974.3, 1975.12 - 1976.3, 1984.11 - 1985.3
+15	1974.9 - 1974.12, 1980.9 - 1980.12, 1981.2 - 1981.5, 1981.4 - 1981.7, 1986.10 - 1987.1
—10	1978.3 - 1978.6, 1982.11 - 1983.2
—30	1979.12 - 1980.3
+20	1981.12 - 1982.3

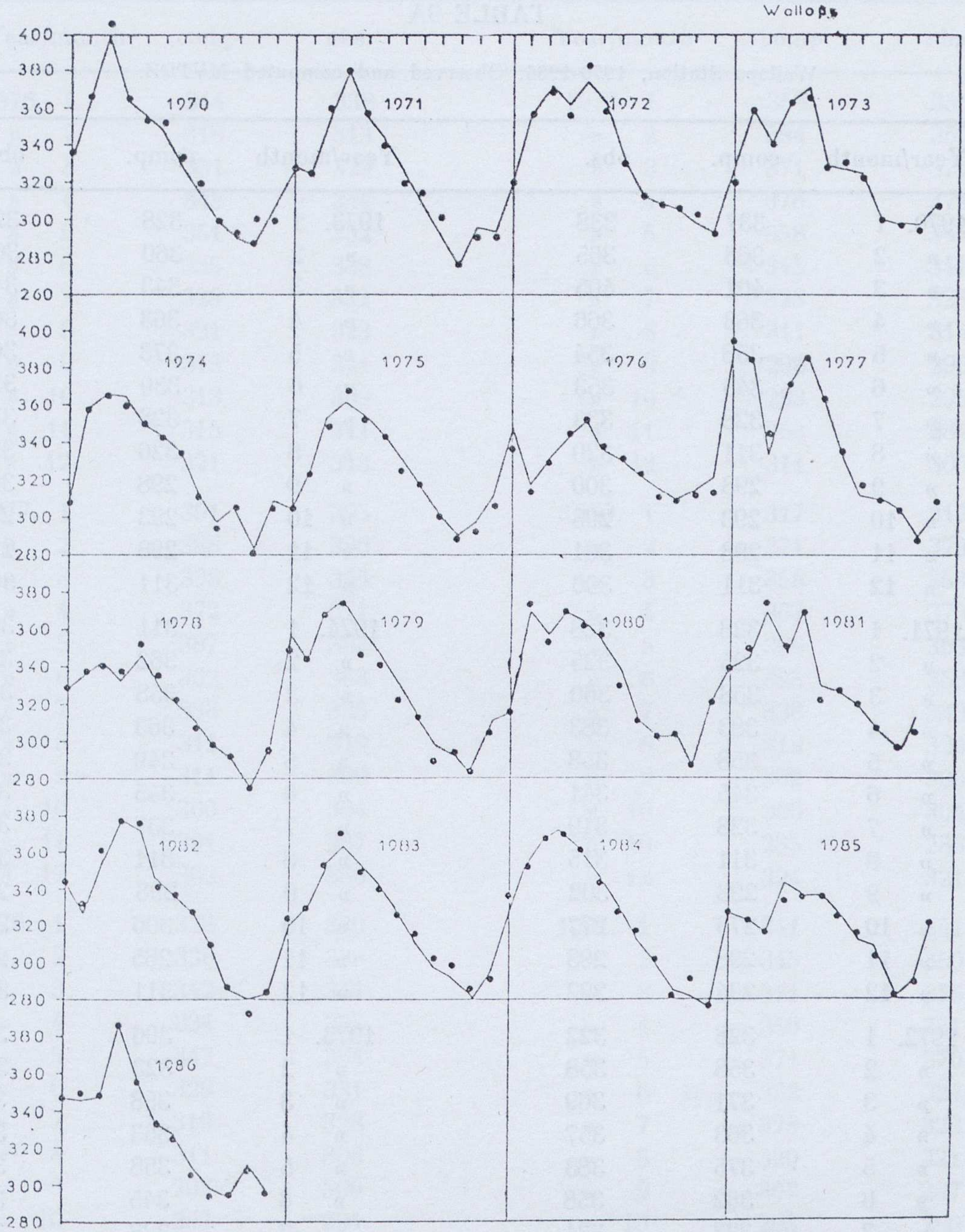

Fig. 42. Wallops Station, 1970-1986. Observed MVTOZ is shown by dots. MVTOZ computed by Equation (42) is shown by a solid line. The accuracy is equal to 98.7%.

TABLE 9A

Wallops Station, 1970-1986. Observed and computed MVTOZ.

Year/month	comp.	obs.	Year/month	comp.	obs.
1970. 1	337	338	1973. 1	328	321
» 2	368	365	» 2	360	360
» 3	401	405	» 3	343	341
» 4	363	366	» 4	363	363
» 5	358	354	» 5	373	366
» 6	345	353	» 6	330	329
» 7	328	333	» 7	328	332
» 8	311	320	» 8	326	324
» 9	298	300	» 9	298	302
» 10	293	293	» 10	293	298
» 11	298	301	» 11	298	296
» 12	311	300	» 12	311	308
1971. 1	328	328	1974. 1	311	309
» 2	325	325	» 2	362	359
» 3	358	360	» 3	358	366
» 4	383	383	» 4	363	361
» 5	358	358	» 5	349	351
» 6	345	341	» 6	345	343
» 7	328	319	» 7	337	336
» 8	311	315	» 8	311	312
» 9	298	302	» 9	298	295
» 10	276	277	» 10	306	306
» 11	298	293	» 11	285	282
» 12	294	292	» 12	311	307
1972. 1	328	322	1975. 1	306	306
» 2	358	358	» 2	323	323
» 3	371	369	» 3	358	349
» 4	363	357	» 4	363	368
» 5	375	383	» 5	358	353
» 6	362	358	» 6	345	343
» 7	328	331	» 7	328	327
» 8	311	315	» 8	311	319
» 9	311	309	» 9	298	301
» 10	306	307	» 10	293	289
» 11	298	304	» 11	298	293
» 12	296	293	» 12	311	307

Year/month	comp.	obs.	Year/month	comp.	obs.
1976. 1	344	338	1979. 1	358	350
» 2	318	313	» 2	354	355
» 3	331	329	» 3	371	370
» 4	343	344	» 4	376	374
» 5	351	352	» 5	358	347
» 6	335	338	» 6	345	341
» 7	328	332	» 7	328	323
» 8	321	323	» 8	311	314
» 9	315	311	» 9	298	290
» 10	313	309	» 10	293	295
» 11	315	311	» 11	283	284
» 12	321	313	» 12	311	305
1977. 1	391	395	1980. 1	317	317
» 2	388	386	» 2	371	373
» 3	338	345	» 3	358	353
» 4	372	371	» 4	367	370
» 5	387	387	» 5	366	363
» 6	362	363	» 6	355	358
» 7	336	336	» 7	338	330
» 8	311	319	» 8	319	322
» 9	311	309	» 9	302	303
» 10	306	304	» 10	306	304
» 11	291	287	» 10	285	286
» 12	302	308	» 12	324	321
1978. 1	328	330	1981. 1	341	341
» 2	336	338	» 2	345	350
» 3	342	341	» 3	371	375
» 4	334	338	» 4	350	351
» 5	347	354	» 5	371	370
» 6	329	331	» 6	332	324
» 7	319	328	» 7	328	328
» 8	311	308	» 8	320	321
» 9	298	300	» 9	307	307
» 10	293	294	» 10	293	296
» 11	277	277	» 11	311	305
» 12	302	295	» 12	324	322

Year/month	comp.	obs.	Year/month	comp.	obs.
1982. 1	345	346	1985. 1	325	328
» 2	328	332	» 2	321	323
» 3	358	361	» 3	317	316
» 4	380	378	» 4	343	333
» 5	375	377	» 5	338	336
» 6	345	341	» 6	331	335
» 7	337	337	» 7	328	325
» 8	329	328	» 8	311	315
» 9	307	310	» 9	308	304
» 10	285	287	» 10	283	282
» 11	282	272	» 11	288	288
» 12	282	283	» 12	321	321
1983. 1	317	324	1986. 1	348	347
» 2	329	329	» 2	345	349
» 3	350	353	» 3	347	348
» 4	363	370	» 4	387	386
» 5	358	350	» 5	358	356
» 6	345	340	» 6	330	331
» 7	328	326	» 7	328	325
» 8	311	315	» 8	311	316
» 9	298	303	» 9	298	295
» 10	293	299	» 10	293	295
» 11	281	286	» 11	311	308
» 12	294	290	» 12	298	295
1984. 1	331	337			
» 2	354	350			
» 3	368	367			
» 4	372	369			
» 5	361	361			
» 6	345	343			
» 7	328	327			
» 8	311	318			
» 9	298	302			
» 10	285	281			
» 11	282	291			
» 12	274	277			

4.10 Station: MT. LOUIS

$\varphi = 38^0\ 45'$ N, L = $90^0\ 23'$ W, Time Period: 1962 - 1979.

Using Figure 6, the mean monthly values of total ozone can be expressed by means of the relation:

$$10^{-3} \cdot O_m^{com} = 338 + 42 \sin\frac{2\pi}{12} t \tag{43}$$

Power spectrum analysis of the differences (D) between MVTOZ as observed and as derived from Equation (43), where

$$D = 10^{-3} \cdot 0^{obs} - 10^{-3} \cdot 0_m^{com} \tag{44}$$

reveals short-term periodicities of 12, 6, 4 and 3 months. Of these only the 6-month periodicity reaches a confidence level higher than 99%. The rest can be considered interesting but their confidence level is lower than 95% (See Figure 43).

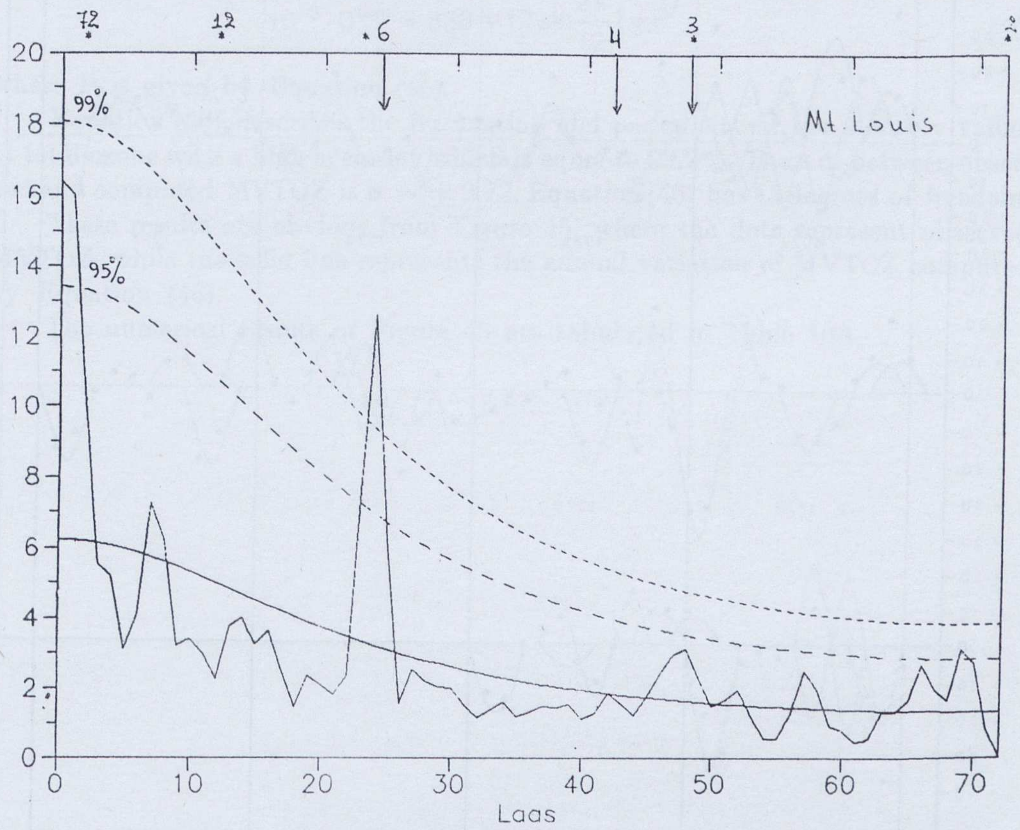

Fig. 43. Mt. Louis Station, 1962-1979. Spectral estimate of the differences computed by Equation (44). Analysis shows periodicities of 12, 6, 4 and 3 months. The 6-month periodicity is predominant, with a confidence level above 99%.

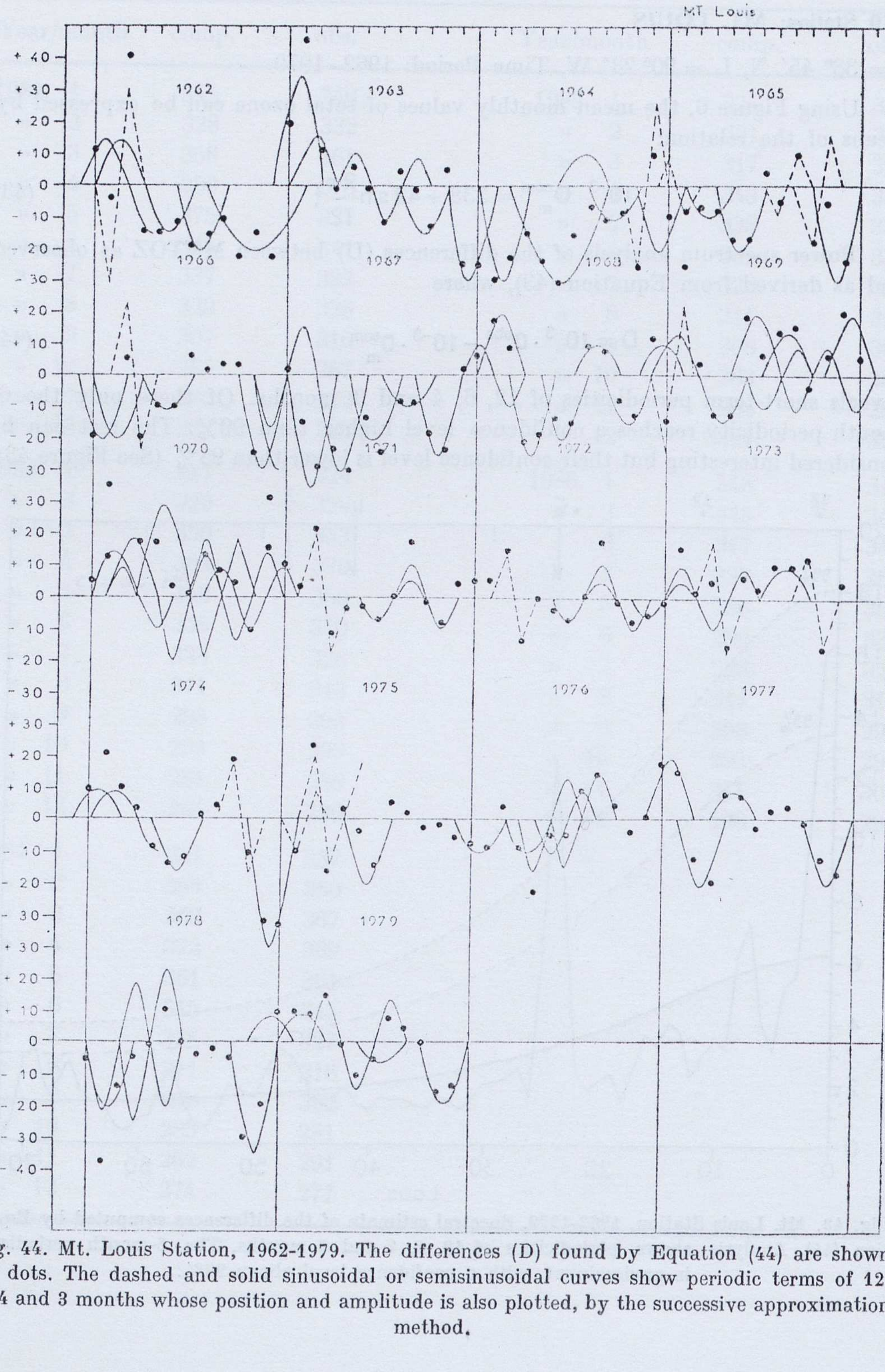

Fig. 44. Mt. Louis Station, 1962-1979. The differences (D) found by Equation (44) are shown by dots. The dashed and solid sinusoidal or semisinusoidal curves show periodic terms of 12, 6, 4 and 3 months whose position and amplitude is also plotted, by the successive approximation method.

As is well known, spectrum analysis cannot show the position and amplitude of the short-term periods. This can be only achieved by using the successive approximation method. Figure 44 shows the same periodicities computed by means of the cuccessive approximation method using equation:

$$P = \alpha_1 \sin\frac{2\pi}{12}t + \alpha_2 \sin\frac{2\pi}{6}t + \alpha_3 \sin\frac{2\pi}{4}t + \alpha_4 \sin\frac{2\pi}{3}t \tag{45}$$

which defines their position and amplitude. In Figure 44 dots represent the differences (D), found by Equation (44), and dashed or solid sinusoidal or semisinusoidal curves represent periodicities, which appear as a network with occasional overlaps.

Table 10 gives the values of the parameters α_1, α_2, α_3, α_4 and **t**.

Thus it is valid to represent the observed data for Mt. Louis Station through the observing period, in a equation of the form:

$$10^{-3} \cdot 0^{com} = 338 + 12 \sin\frac{2\pi}{12}t + P \tag{46}$$

where P is given by Equation (45).

Equation (46) describes the fluctuation and periodicity of the monthly values of total ozone with a high accuracy which is equal to 99.2%. The s.d. between observed and computed MVTOZ is $\sigma = \pm 2.72$. Equation (46) has 13 degrees of freedom.

These results are obvious from Figure 45, where the dots represent observed MVTOZ, while the solid line represents the annual variation of MVTOZ computed by Equation (46).

The numerical results of Figure 45 are tabulated in Table 10A.

TABLE 10

Values of the parameters α_1-α_4 and t (see Eq. 45).

α_1	t
—20	1962.8 - 1963.2
—30	1964.3 - 1964.9

α_2	t
+15	1961.12 - 1962.3, 1962.1 - 1962.7, 1963.1 - 1963.4, 1963.8 - 1963.11, 1969.7 - 1969,10, 1970.1 - 1970.4
—20	1962.6 - 1962.9, 1964.11 - 1965.2, 1965.4 - 1965.7, 1965.12 - 1966.3, 1966.1-1966.4, 1967.5 - 1967.8, 1968.5 - 1968.8
+35	1962.12 - 1963.3
—30	1963.11 - 1964.2, 1965.10 - 1966.1, 1966.10 - 1967.1, 1967.3 - 1967.6
—15	1963.8 - 1963.11, 1974.5 - 1974.8
—35	1964.1 - 1964.4, 1967.1 - 1967.4, 1978.10 - 1979.1
+10	1964.6 - 1964.9, 1968.7 - 1968.10, 1968.11 - 1969.2, 1973.1 - 1973.4, 1973.7--1973.10, 1973.12 - 1974.3, 1974.1 - 1974.5, 1977.5 - 1977.7, 1978.11 - 1979.2, 1979.1 - 1979.4
—10	1964.8 - 1964.11, 1966.4 - 1966.7, 1967.7 - 1967.10, 1975.12 - 1976.3, 1976.3 - 1976.6
—25	1967.9 - 1967.12, 1968.3 - 1968.6, 1968.9 - 1969.6
+25	1968.1 - 1968.4
+20	1969.5 - 1969.8, 1969.11 - 1970.2, 1970.2 - 1970.5, 1976.12 - 1977.3
+30	1970.4 - 1970.7
+ 6	1974.10 - 1975.1
—40	1974.11 - 1975.2
—20	1975.5 - 1975.8, 1977.2 - 1977.5, 1977.10 - 1978.1, 1978.1 - 1978.4, 1979.10 - 1980.1
— 6	1979.6 - 1979.9

α_3	t
+10	1963.4 - 1963.10, 1967.12 - 1968.4, 1970.8 - 1971.2, 1971.8 - 1971.12, 1972.8 - 1972.12
—15	1966.11 - 1967.3, 1976.4 - 1976.8, 1976.6 - 1976.10
—10	1969.7 - 1970.1, 1976.6 - 1976.10
—20	1970.5 - 1970.9, 1970.7 - 1970.11, 1978.1 - 1978.7
+15	1970.7 - 1971.1

α_3	t
— 6	1971.6 - 1971.10, 1972.8 - 1972.12, 1972.11 - 1973.3
—25	1978.3 - 1978.7

α_4	t
—35	1962.1 - 1962.4
—30	1964.10 - 1965.1, 1968.12 - 1969.3
+10	1964.12 - 1965.3
—10	1965.2 - 1965.5, 1965.7 - 1965.10, 1975.1 - 1975.4
—20	1965.9 - 1965.12
+25	1966.2 - 1966.5
+20	1971.2 - 1971.5
+15	1972.2 - 1972.5, 1973.9 - 1973.12
+20	1973.3 - 1973.6, 1974.9 - 1974.12, 1975.2 - 1975.6

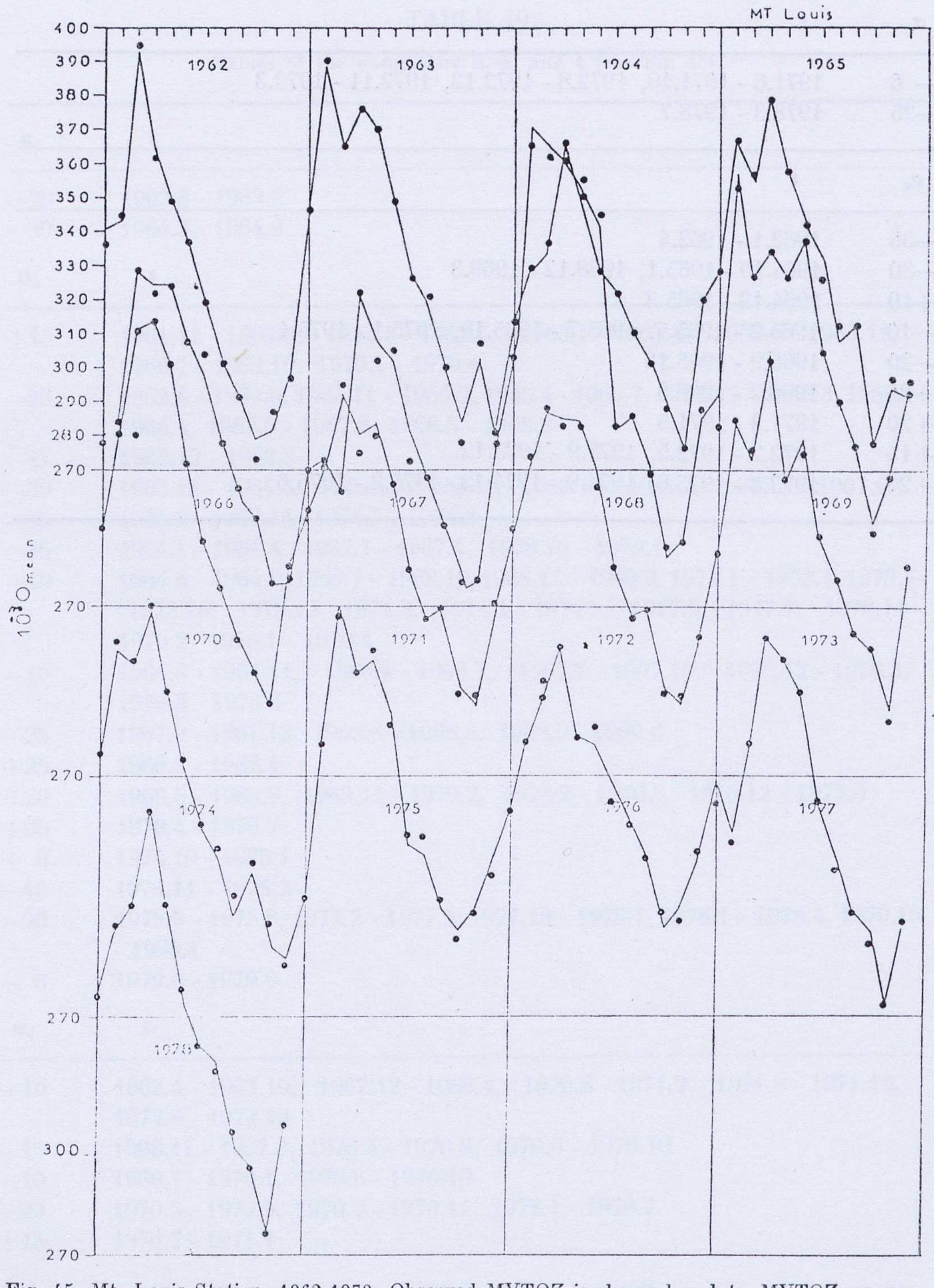

Fig. 45. Mt. Louis Station, 1962-1979. Observed MVTOZ is shown by dots. MVTOZ as computed by Equation (46) is shown by a solid line. The accuracy is equal to 99.2%. Note the very close agreement between the two.

TABLE 10A

Mt. Louis Station, 1962 - 1979. Observed and computed MVTOZ.

Year/month	comp.	obs.	Year/month	comp.	obs.
1962. 1	350	347	1965. 1	330	328
» 2	353	355	» 2	368	367
» 3	406	405	» 3	355	357
» 4	375	372	» 4	378	379
» 5	362	359	» 5	357	358
» 6	347	347	» 6	342	342
» 7	321	319	» 7	338	326
» 8	300	301	» 8	308	312
» 9	292	291	» 9	313	312
» 10	279	273	» 10	279	278
» 11	282	287	» 11	293	297
» 12	300	299	» 12	291	293
1963. 1	358	357	1966. 1	321	318
» 2	401	405	» 2	325	324
» 3	376	375	» 3	369	369
» 4	387	386	» 4	365	362
» 5	384	380	» 5	365	364
» 6	359	359	» 6	350	348
» 7	328	326	» 7	338	344
» 8	317	321	» 8	317	318
» 9	300	300	» 9	302	305
» 10	284	278	» 10	296	294
» 11	302	307	» 11	276	277
» 12	281	281	» 12	276	278
1964. 1	312	313	1967. 1	338	340
» 2	329	329	» 2	344	343
» 3	334	336	» 3	334	334
» 4	372	372	» 4	361	363
» 5	348	350	» 5	348	342
» 6	329	328	« 6	342	345
» 7	321	322	» 7	321	313
» 8	311	310	» 8	308	308
» 9	293	291	» 9	293	294
» 10	289	288	» 10	274	277
» 11	276	276	» 11	280	278
» 12	319	320	» 12	317	318

Year/month	comp.	obs.	Year/month	comp.	obs.
1968. 1	348	344	1971. 1	348	348
» 2	381	376	» 2	359	362
» 3	376	372	» 3	381	385
» 4	365	365	» 4	370	365
» 5	352	355	» 5	374	370
» 6	342	345	» 6	359	356
» 7	321	323	» 7	332	331
» 8	326	326	» 8	317	317
» 9	311	309	» 9	318	319
» 10	284	288	» 10	296	294
» 11	290	289	» 11	292	294
» 12	326	328	» 12	317	321
1969. 1	333	323	1972. 1	338	343
» 2	397	393	» 2	359	364
» 3	364	367	» 3	376	378
» 4	375	374	» 4	375	373
» 5	362	361	» 5	374	373
» 6	376	377	» 6	359	355
» 7	345	344	» 7	332	331
» 8	329	330	» 8	317	317
» 9	314	317	» 9	318	319
» 10	296	292	» 10	296	294
» 11	312	308	» 11	292	294
» 12	334	336	» 12	311	321
1970. 1	345	343	1973. 1	338	336
» 2	371	371	» 2	375	375
» 3	403	401	» 3	364	366
» 4	404	404	» 4	394	392
» 5	390	391	» 5	357	358
» 6	365	362	» 6	369	365
» 7	338	339	» 7	338	341
» 8	332	330	» 8	326	328
» 9	312	310	» 9	311	312
» 10	301	300	» 10	308	308
» 11	292	291	» 11	290	286
» 12	332	332	» 12	317	322

Year/month	comp.	obs.	Year/month	comp.	obs.
1974. 1	347	347	1977. 1	355	356
» 2	377	380	» 2	376	374
» 3	373	374	» 3	347	351
» 4	387	390	» 4	370	367
» 5	365	365	» 5	383	382
» 6	342	345	» 6	368	366
» 7	326	326	» 7	338	335
» 8	317	319	» 8	317	320
» 9	302	306	» 9	302	306
» 10	313	315	» 10	296	295
» 11	290	297	» 11	285	289
» 12	287	285	» 12	300	299
1975. 1	303	305	1978. 1	338	332
» 2	350	349	» 2	322	321
» 3	390	387	» 3	347	350
» 4	370	370	» 4	382	382
» 5	374	377	» 5	374	373
» 6	359	355	» 6	364	365
» 7	321	323	» 7	338	338
» 8	317	322	» 8	317	313
» 9	302	304	» 9	302	300
» 10	296	293	» 10	296	291
» 11	302	300	» 11	272	272
» 12	317	311	» 12	296	292
1976. 1	329	330	1979. 1	347	347
» 2	350	350	» 2	368	367
» 3	364	368	» 3	373	373
» 4	378	378	» 4	402	401
» 5	350	351	» 5	374	373
» 6	349	354	» 6	344	348
» 7	338	333	» 7	333	332
» 8	327	326	» 8	327	324
» 9	317	316	» 9	302	306
» 10	296	300	» 10	296	296
» 11	302	298	» 11	277	276
» 12	317	318	» 12	302	302

4.11 Station: CAGLIARI

$\varphi = 39^0\ 15'$ N, L $= 09^0\ 03'$ E, Time Period: 1957 - 1986.

Using Figure 6, the mean monthly values of total ozone for this station can be expressed analytically as:

$$10^{-3} \cdot 0_m^{com} = 335 + 40 \sin \frac{2\pi}{12} t \tag{47}$$

The spectral analysis of the differences (D) between the observed and computed MMVTOZ as derived from Equation (47), where

$$D = 10^{-3} \cdot 0^{obs} - 10^{-3} \cdot 0_m^{com} \tag{48}$$

shows four periodicities, of 12, 6, 4 and 3 months. The predominant term is of 3 months, with a confidence level higher than 99%.

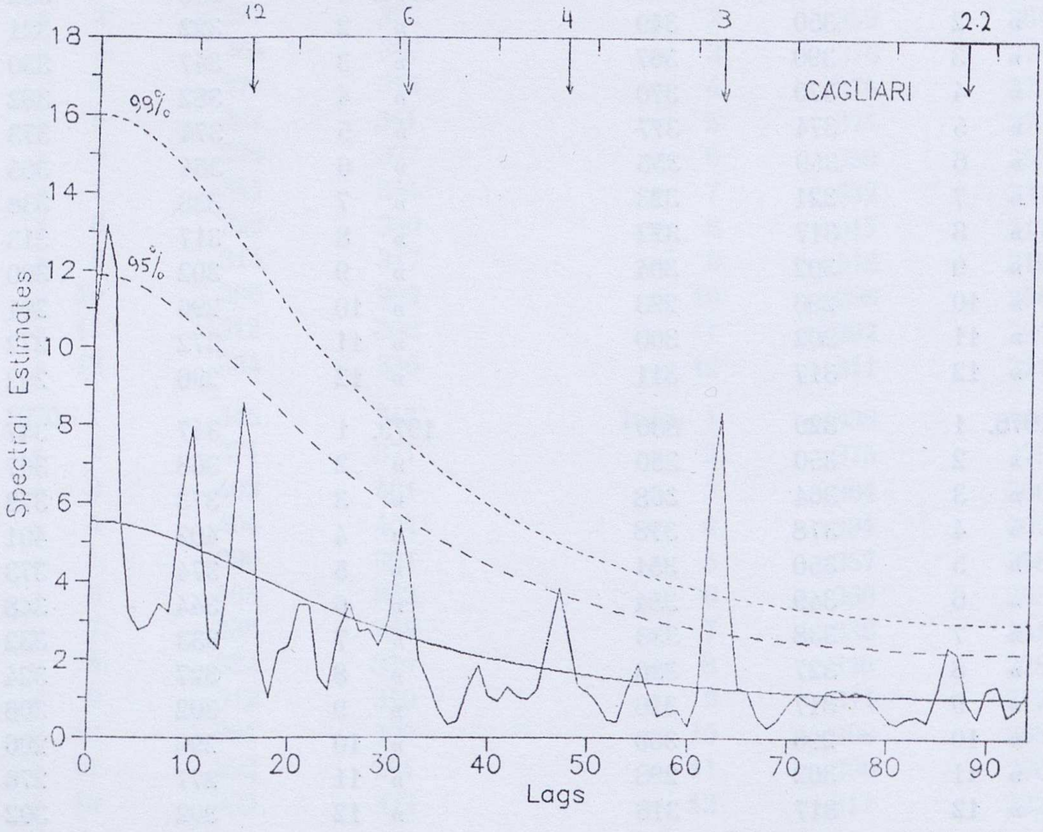

Fig. 46. Cagliari Station, 1957-1986. Spectral estimate of the differences computed by Equation (48). Analysis shows periodicities of 12, 6, 4 and 3 months, all with a confidence level close to 95%. Only the 3-month period has a confidence level higher than 99%.

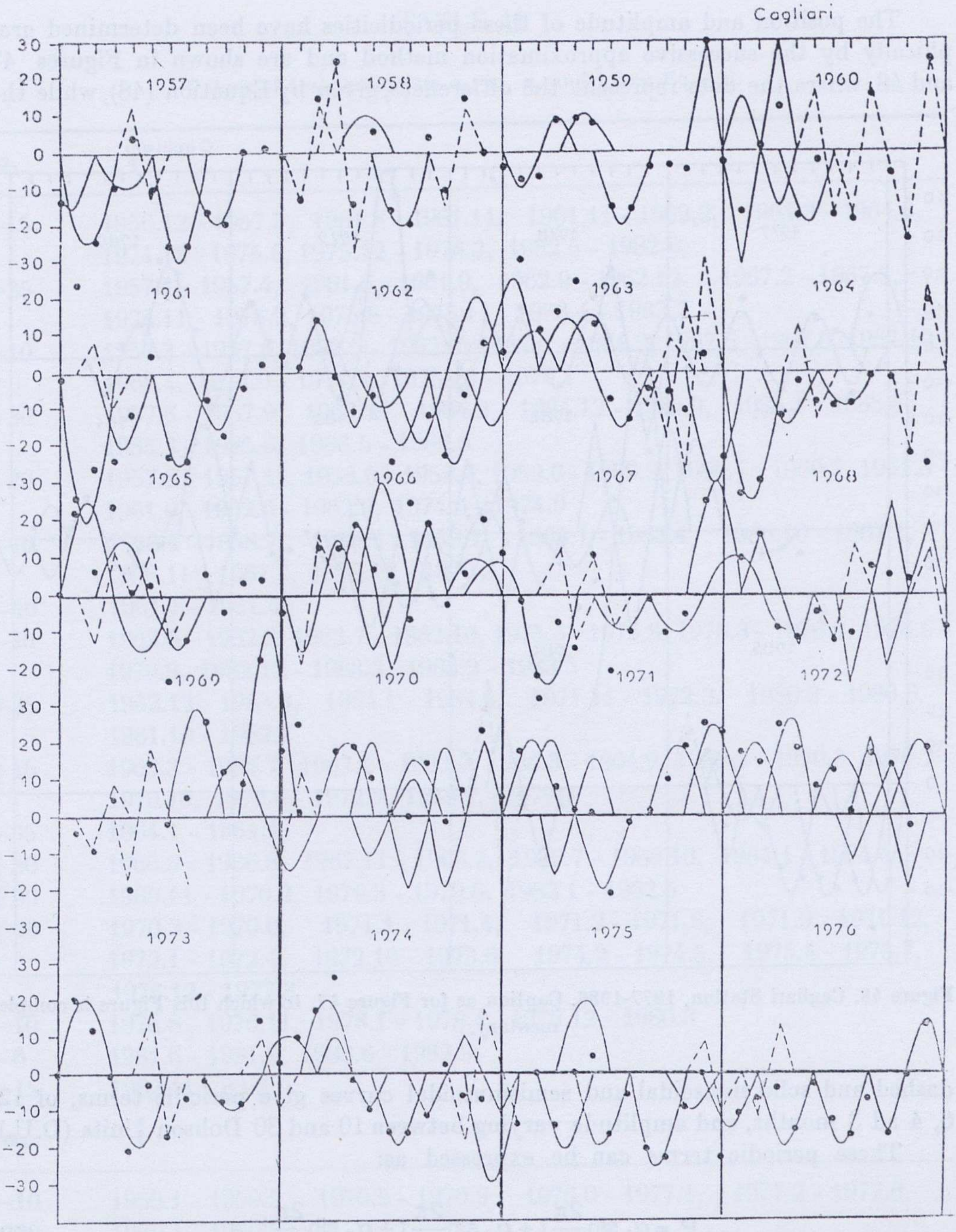

Fig. 47. Cagliari Station, 1957-1976. The differences (D) found by Equation (48) are shown by dots. The dashed and solid sinusoidal and semisinusoidal curves show periodic terms of 12, 6, 4 and 3 months, whose position and amplitude is also plotted, by the successive approximation method.

The position and amplitude of these periodicities have been determined graphically by the successive approximation method and are shown in Figures 47 and 48, where the dots represent the differences, given by Equation (48), while the

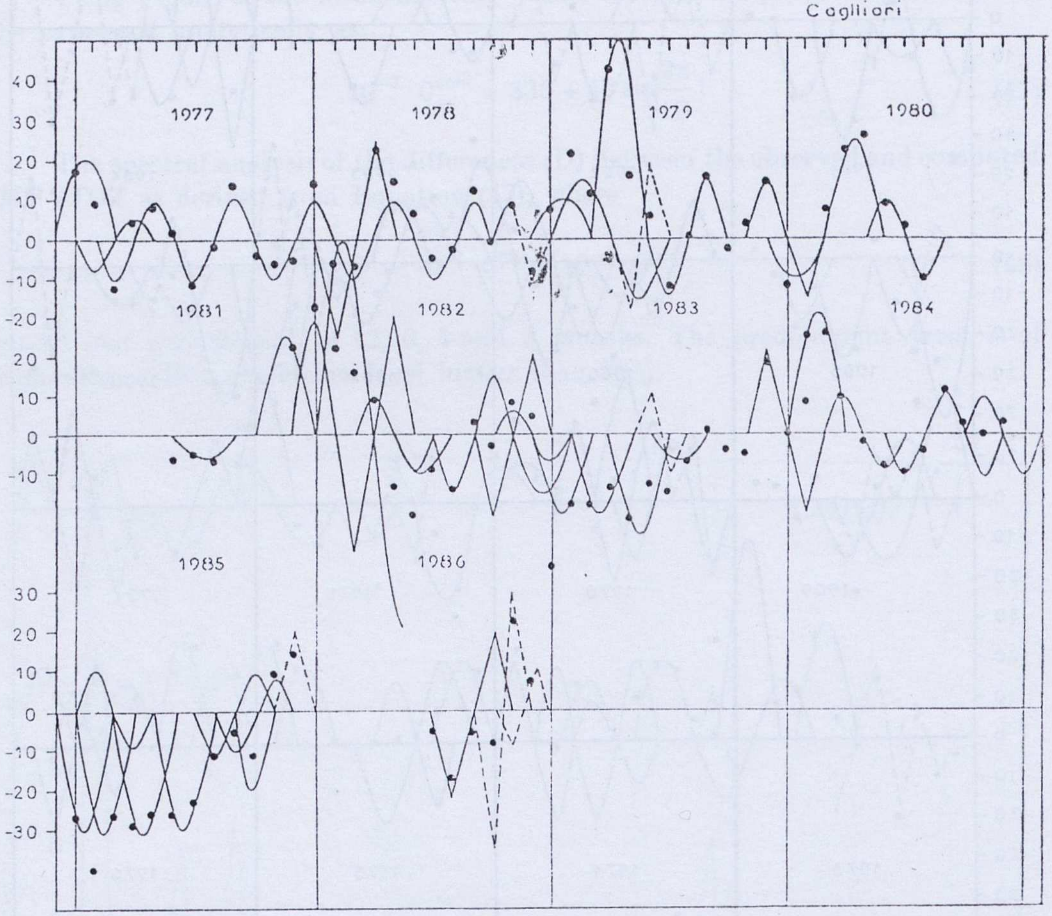

Figure 48. Cagliari Station, 1977-1986. Caption as for Figure 47, to which this Figure is complementary.

dashed and solid sinusoidal and semisinusoidal curves give periodic terms, of 12, 6, 4 ad 3 months, and amplitude varying between 10 and 30 Dobson Units (D.U.).

These periodic terms can be expressed as:

$$P = \alpha_1 \sin\frac{2\pi}{6}t + \alpha_2 \sin\frac{2\pi}{4}t + \alpha_3 \sin\frac{2\pi}{3}t \tag{49}$$

where the values (coefficients) of α_1, α_2 and α_3 and the time interval **t**, are taken from Table 11.

TABLE 11

Values of the parameters α_1, α_2, α_3 and t (see Eq. 49).

α_1	t
—15	1956.12 - 1957.3, 1961.8 - 1961.11, 1961.11 - 1962,2, 1964.3 - 1964.6, 1974.12 - 1975.6, 1975.12 - 1976.3, 1982.5 - 1982.8,
—25	1957.1 - 1957.4, 1961.6 - 1961.9, 1962.9 - 1962.12, 1967.2 - 1967.5, 1974.11 - 1975.2, 1975.8 - 1975.11, 1983.4 - 1983.7
—10	1957.3 - 1957.6, 1962.5 - 1962.8, 1964.6 - 1964.9, 1967.6 - 1967.9, 1967.10 - 1968.4, 1973.9 - 1974.3, 1975.10 - 1976.1
—30	1957.6 - 1957.9, 1963.11 - 1964.2, 1984.12 - 1985.3, 1985.1 - 1985.4, 1985.3 - 1985.6, 1986.5 - 1986.8
—20	1957.8 - 1957.11, 1958.6 - 1958.9, 1959.6 - 1959.9, 1960.4 - 1960.7, 1961.3 - 1961.6, 1962.6 - 1962.9, 1974.6 - 1974.9
+10	1958.4 - 1958.7, 1959.4 - 1959.7, 1963.1 - 1963.4, 1966.10 - 1967.1, 1966.11 - 1967.2, 1978.12 - 1979.3
—40	1961.1 - 1961.4
—20	1962.6 - 1962.9, 1962.7 - 1962.10, 1975.5 - 1975.8, 1976.3 - 1976.6, 1976.6 - 1976.9, 1982.12 - 1983.3, 1983.2 - 1983.5
+25	1962.12 - 1963.3, 1964.1 - 1964.4, 1971.11 - 1972.3, 1980.3 - 1980.6, 1981.10 - 1982.1
+15	1963.3 - 1963.7, 1963.4 - 1963.7, 1964.3 - 1964.9, 1969.9 - 1970.3, 1970.7 - 1970.10, 1972.6 - 1972.9, 1979.1 - 1979.7
—35	1964.1 - 1964.4
+30	1966.5 - 1966.8, 1967.11 - 1968.2, 1969.7 - 1969.10, 1984.1 - 1984.4
+50	1969.11 - 1970.2, 1979.3 - 1979.6, 1982.1 - 1982.5
+20	1970.3 - 1970.6, 1971.1 - 1971.4, 1971.2 - 1971,8, 1971.9 - 1971.12, 1972.1 - 1972.4, 1972.10 - 1973.6, 1974.2 - 1974.5, 1975.4 - 1975.7, 1976.12 - 1977.3
—10	1976.8 - 1976.11, 1978.1 - 1978.4, 1979.12 - 1980.3
—6	1981.6 - 1981.9, 1983.6 - 1983.9
—15	1982.11 - 83.2

α_2	t
—10	1959.1 - 1959.5, 1970.5 - 1970.9, 1976.9 - 1977.1, 1977.2 - 1977.6,
—30	1960.1 - 1960.5
+15	1960.1 - 1960.5, 1962.2 - 1962.6, 1968.2 - 1968.6, 1979.11 - 1980.3
—15	1966.1 - 1966.7, 1971.3 - 1971.7, 1972.7 - 1972.11, 1979.6 - 1979.10

α_2	t
+20	1966.4 - 1966.10, 1970.5 - 1970.11, 1972.8 - 1972.12, 1982.7 - 1982.11, 1983.11 - 1984.5, 1985.9 - 1986.1
—25	1968.7 - 1968.11, 1968.9 - 1969.1, 1970.9 - 1971.1
+10	1974.6 - 1974.12, 1978.4 - 1978.8, 1978.8 - 1978.12, 1980.5 - 1980.9, 1982.3 - 1982.7, 1984.3 - 1984.9, 1985.1 - 1985.5
—6	1977.1 - 1977.5
—20	1978.1 - 1978.5, 1982.9 - 1983.1, 1986.7 - 1986.11
+30	1981.12 - 1982.4
+6	1982.10 - 1983.2

α_3	t
+15	1957.4 - 1957.7, 1964.4 - 1964.7, 1965.5 - 1965.8, 1967.3 - 1967.6, 1967.5 - 1967.8, 1968.11 - 1969.2
—15	1958.1 - 1958.4, 1958.9 - 1958.12, 1965.2 - 1965.5, 1968.6 - 1968.9, 1969.12 - 1970.3, 1976.2 - 1976.5
+30	1958.3 - 1958.6
+20	1960.5 - 1960.8
—20	1960.7 - 1960.10, 1963.9 - 1963.12, 1969.4 - 1969.8, 1973.5 - 1973.8, 1974.10- 1975.1, 1979.4 - 1979.7
—30	1960.10 - 1961.1, 1986.9 - 1986.12
+10	1961.2 - 1961.5, 1973.11 - 1974.2, 1975.11 - 1976.2, 1978.10 - 1979.1, 1983.5 - 1983.8
—10	1963.8 - 1963.11, 1969.2 - 1969.5, 1986.10 - 1987.1
—25	1964.10 - 1965.1
—20	1966.1 - 1966.4

From the above analysis it is concluded that the monthly values of total ozone at Cagliari Station can be expressed analytically by the relationship:

$$10^{-3} \cdot 0^{com} = 335 + 40 \sin \frac{2\pi}{12} t + P \tag{50}$$

where P is given by Equation (49).

In Figures 49 and 50 the dots represent the observed data for the Cagliari Station (1957-1986). The solid line represents the variation of monthly values of total ozone, computed by Equation (50).

In Figures 49 and 50, there are very few cases where the differences between observed MVTOZ and computed values of MVTOZ exceed $\pm$ 3 D.U. This is further evidence for a close correlation between these two sets of values.

Table 11A shows observed and computed MVTOZ. The s.d. and accuracy were estimated to be equal to $\sigma = \pm 2.56$ and 99.3% respectively, with 13 degrees of freedom for Equation (50).

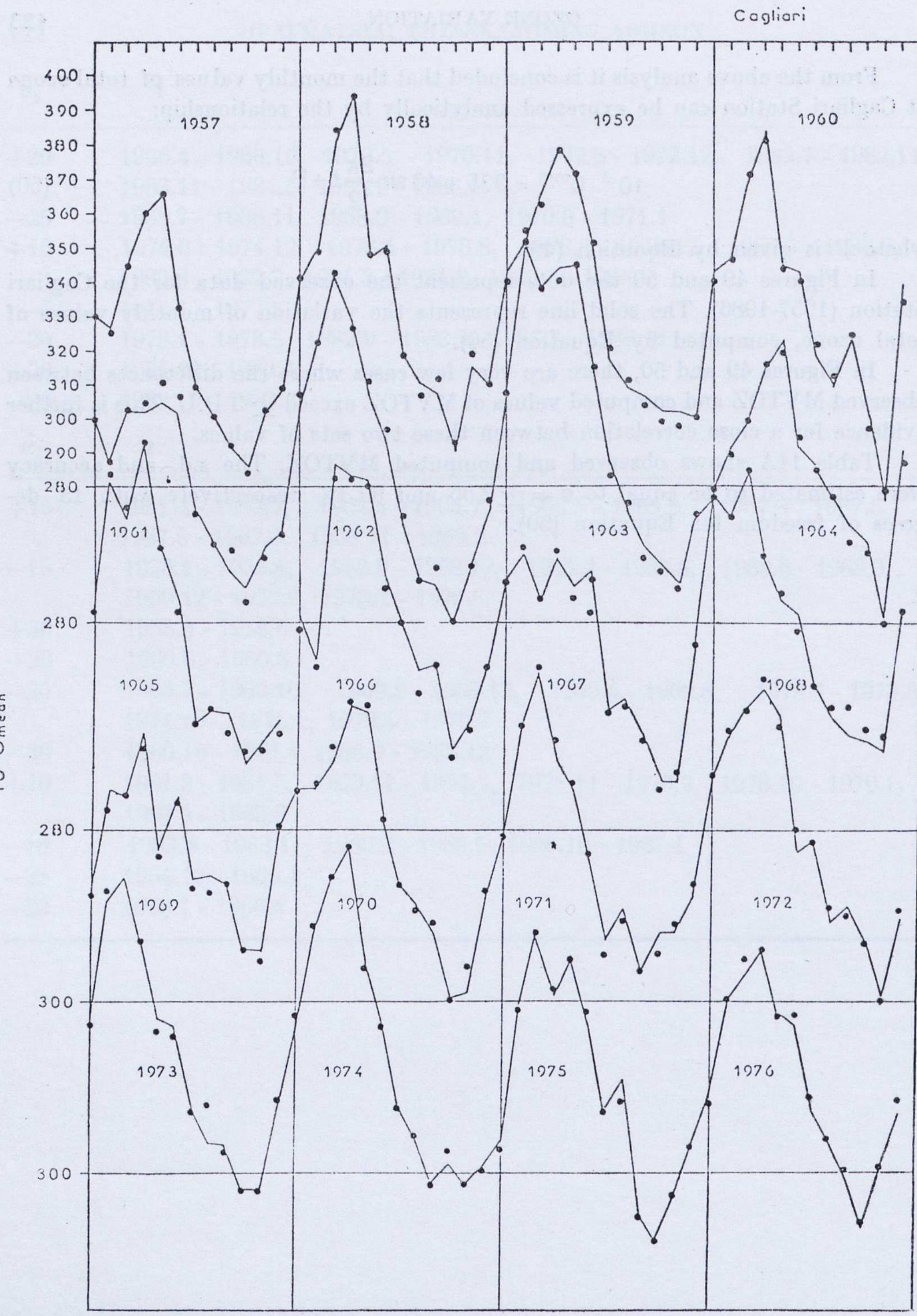

Fig. 49. Cagliari Station, 1957-1976. Observed MVTOZ is shown by dots. MVTOZ computed by Equation (50) is shown by a solid line. Accurary is equal to 99.3%.

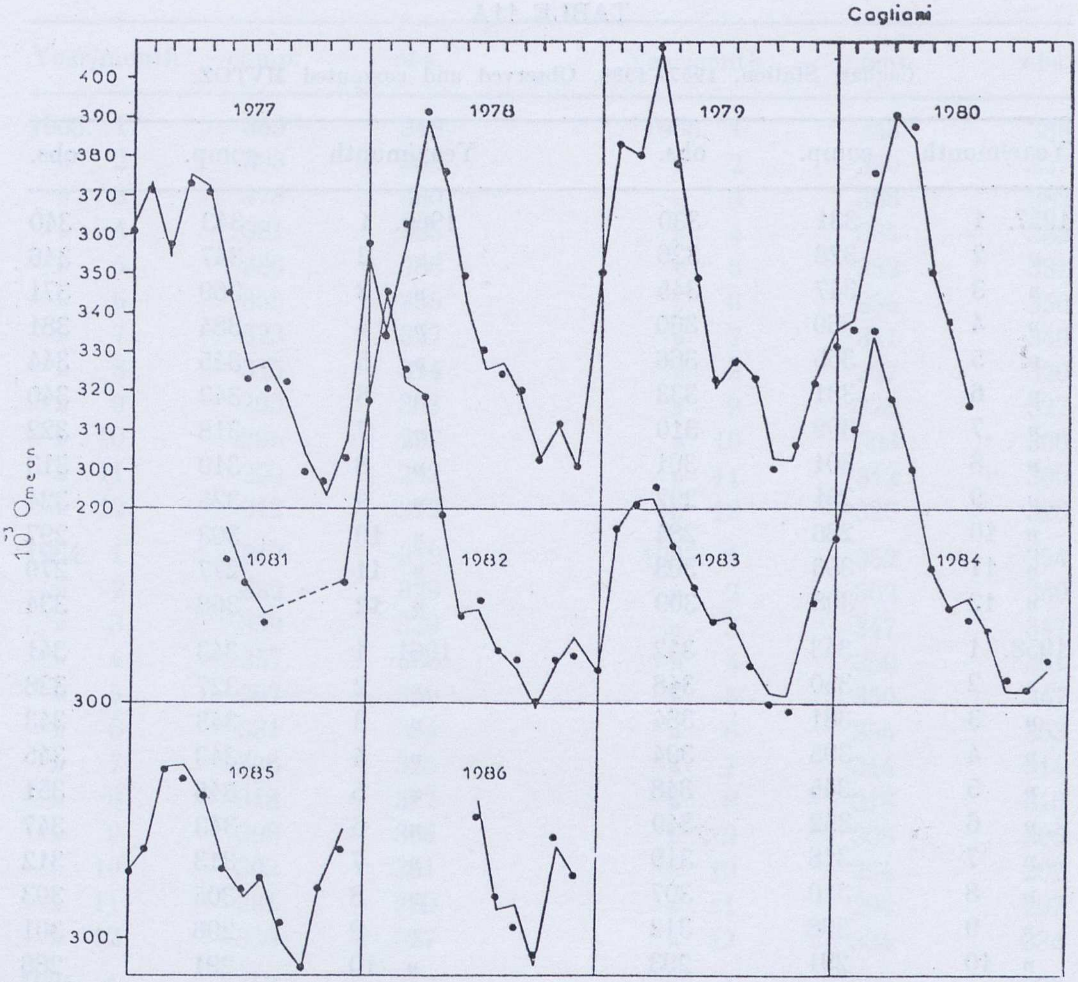

Fig. 50. Cagliari Station, 1977-1986. Caption as for Figure 49, to which this Figure is complementary.

TABLE 11A

Cagliari Station, 1957 - 1986. Observed and computed MVTOZ.

Year/month	comp.	obs.	Year/month	comp.	obs.
1957. 1	331	330	1960. 1	343	340
» 2	328	326	» 2	347	346
» 3	347	345	» 3	369	371
» 4	360	360	» 4	384	381
» 5	365	366	» 5	345	344
» 6	331	333	» 6	343	340
» 7	309	310	» 7	318	322
» 8	301	301	» 8	310	313
» 9	291	292	» 9	325	324
» 10	286	284	» 10	303	297
» 11	303	303	» 11	277	279
» 12	308	309	» 12	308	334
1958. 1	343	342	1961. 1	343	341
» 2	350	348	» 2	327	328
» 3	381	384	» 3	343	343
» 4	395	394	» 4	343	345
» 5	345	348	» 5	345	351
» 6	352	349	» 6	343	347
» 7	318	319	» 7	313	312
» 8	310	307	» 8	305	303
» 9	308	312	» 9	296	301
» 10	291	293	» 10	291	286
» 11	315	319	» 11	303	299
» 12	308	308	» 12	308	306
1959. 1	343	340	1962. 1	343	347
» 2	352	355	» 2	362	363
» 3	369	363	» 3	384	383
» 4	379	378	» 4	369	367
» 5	371	371	» 5	347	351
» 6	352	351	» 6	334	337
» 7	318	321	» 7	309	311
» 8	310	312	» 8	293	292
» 9	308	304	» 9	291	296
» 10	303	299	» 10	281	280
» 11	303	298	» 11	298	297
» 12	338	338	» 12	313	316

Year/month	comp.	obs.	Year/conth	comp.	obs.
1963. 1	359	348	1966. 1	343	338
» 2	393	393	» 2	330	327
» 3	378	380	» 3	386	382
» 4	381	385	» 4	384	382
» 5	386	386	» 5	382	381
» 6	355	355	» 6	354	350
» 7	323	327	» 7	341	340
» 8	315	314	» 8	327	320
» 9	299	303	» 9	328	327
» 10	295	297	» 10	303	300
» 11	290	292	» 11	312	309
» 12	312	312	» 12	326	328
1964. 1	317	319	1967. 1	352	354
» 2	332	329	» 2	362	360
» 3	339	339	» 3	347	347
» 4	357	356	» 4	359	361
» 5	362	359	» 5	350	347
» 6	331	334	» 6	355	353
» 7	326	325	» 7	314	314
» 8	318	317	» 8	318	316
» 9	308	304	» 9	308	306
» 10	303	301	» 10	294	292
» 11	281	280	» 11	294	297
» 12	330	327	» 12	334	334
1965. 1	343	343	1968. 1	378	379
» 2	384	385	» 2	371	371
» 3	374	371	» 3	384	385
» 4	393	394	» 4	360	360
» 5	362	364	» 5	347	349
» 6	343	346	» 6	343	338
» 7	311	312	» 7	323	322
» 8	315	315	» 8	314	316
» 9	308	314	» 9	308	316
» 10	303	299	» 10	306	309
» 11	303	306	» 12	303	307
» 12	308	312	» 12	345	344

Year/month	comp.	obs.	Year/month	comp.	obs.
1969. 1	331	334	1972. 1	365	366
» 2	362	356	» 2	379	379
» 3	360	360	» 3	386	385
» 4	378	374	» 4	391	394
» 5	345	342	» 5	384	380
» 6	360	358	» 6	343	350
» 7	335	333	» 7	347	347
» 8	336	332	» 8	324	328
» 9	334	334	» 9	328	325
» 10	315	315	» 10	318	317
» 11	315	312	» 11	300	300
» 12	351	351	» 12	325	327
1970. 1	362	361	1973. 1	343	343
» 2	362	363	» 2	379	382
» 3	369	374	» 3	386	381
» 4	386	387	» 4	369	368
» 5	379	381	» 5	345	341
» 6	353	353	» 6	343	340
» 7	335	334	» 7	318	318
» 8	329	327	» 8	327	320
» 9	320	323	» 9	308	306
» 10	301	301	» 10	294	295
» 11	303	310	» 11	294	295
» 12	330	332	» 12	317	323
1971. 1	343	348	1974. 1	343	346
» 2	379	380	» 2	371	372
» 3	403	401	» 3	386	386
» 4	371	376	» 4	396	395
» 5	362	364	» 5	362	360
» 6	341	343	» 6	333	333
» 7	318	314	» 7	318	319
» 8	327	324	» 8	310	311
» 9	308	309	» 9	298	297
» 10	320	313	» 10	303	306
» 11	320	323	» 11	296	297
» 12	330	334	» 12	303	301

Year/month	comp.	obs.	Year/month	comp.	obs.
1975. 1	309	307	1978. 1	353	357
» 2	350	348	» 2	333	334
» 3	369	370	» 3	360	362
» 4	352	354	» 4	389	391
» 5	362	362	» 5	372	376
» 6	343	347	» 6	343	349
» 7	318	318	» 7	325	330
» 8	327	321	» 8	327	324
» 9	286	287	» 9	318	320
» 10	281	280	» 10	303	302
» 11	294	294	» 11	312	311
» 12	308	308	» 12	299	300
1976. 1	322	320	1979. 1	352	350
» 2	350	351	» 2	383	383
» 3	357	362	» 3	381	380
» 4	364	365	» 4	412	412
» 5	345	346	» 5	376	378
» 6	343	346	» 6	348	349
» 7	318	322	» 7	320	323
» 8	310	310	» 8	327	327
» 9	299	301	» 9	323	323
» 10	284	286	» 10	303	300
» 11	303	302	» 11	303	306
» 12	318	321	» 12	323	322
1977. 1	360	360	1980. 1	334	331
» 2	373	371	» 2	338	336
» 3	354	357	» 3	369	376
» 4	375	373	» 4	391	391
» 5	372	370	» 5	384	388
» 6	343	345	» 6	353	351
» 7	325	323	» 7	335	338
» 8	327	325	» 8	317	317
» 9	318	322	» 9	—	—
» 10	303	299	» 10	—	—
» 11	293	297	» 11	—	—
» 12	308	303	» 12	—	—

Year/month	comp.	obs.	Year/month	comp.	obs.
1981. 1	—	—	1984. 1	343	344
» 2	—	—	» 2	367	370
» 3	—	—	» 3	394	395
» 4	—	—	» 4	379	378
» 5	—	—	» 5	362	360
» 6	343	337	» 6	333	335
» 7	330	330	» 7	325	325
» 8	322	320	» 8	327	323
» 9	—	—	» 9	318	319
» 10	—	—	» 10	303	306
» 11	—	—	» 11	303	303
» 12	330	331	» 12	308	311
1982. 1	373	376	1985. 1	318	316
» 2	405	406	» 2	322	322
» 3	382	385	» 3	344	343
» 4	379	378	» 4	344	340
» 5	349	348	» 5	337	336
» 6	321	322	» 6	318	317
» 7	323	326	» 7	310	312
» 8	312	313	» 8	317	315
» 9	308	311	» 9	298	303
» 10	298	300	» 10	293	292
» 11	309	311	» 11	313	312
» 12	316	312	» 12	328	322
1983. 1	308	309	1986. 1	—	—
» 2	345	344	» 2	—	—
» 3	352	351	» 3	—	—
» 4	352	355	» 4	—	—
» 5	340	340	» 5	—	—
» 6	330	330	» 6	—	—
» 7	321	321	» 7	325	330
» 8	322	320	» 8	307	310
» 9	308	309	» 9	308	302
» 10	303	299	» 10	293	295
» 11	303	298	» 11	324	325
» 12	328	326	» 12	317	315

4.12 Station: BOULDER

$\varphi = 40^0\ 01'$ N, L $= 105^0\ 15'$ W, Time Period: 1964 - 1986.

Analysis of the observed data (see Figure 6) shows that the mean monthly values of total ozone (MMVTOZ) can be represented analytically with the help of a simple algebraic equation:

$$10^{-3} \cdot 0_m^{obs} = 322 + 40 \sin\frac{2\pi}{12} t \tag{51}$$

Calculating the differences (D) between the observed and computed values as derived from Equation (51), where

$$D = 10^{-3} \cdot 0^{obs} - 10^{-3} \cdot 0_m^{com} \tag{52}$$

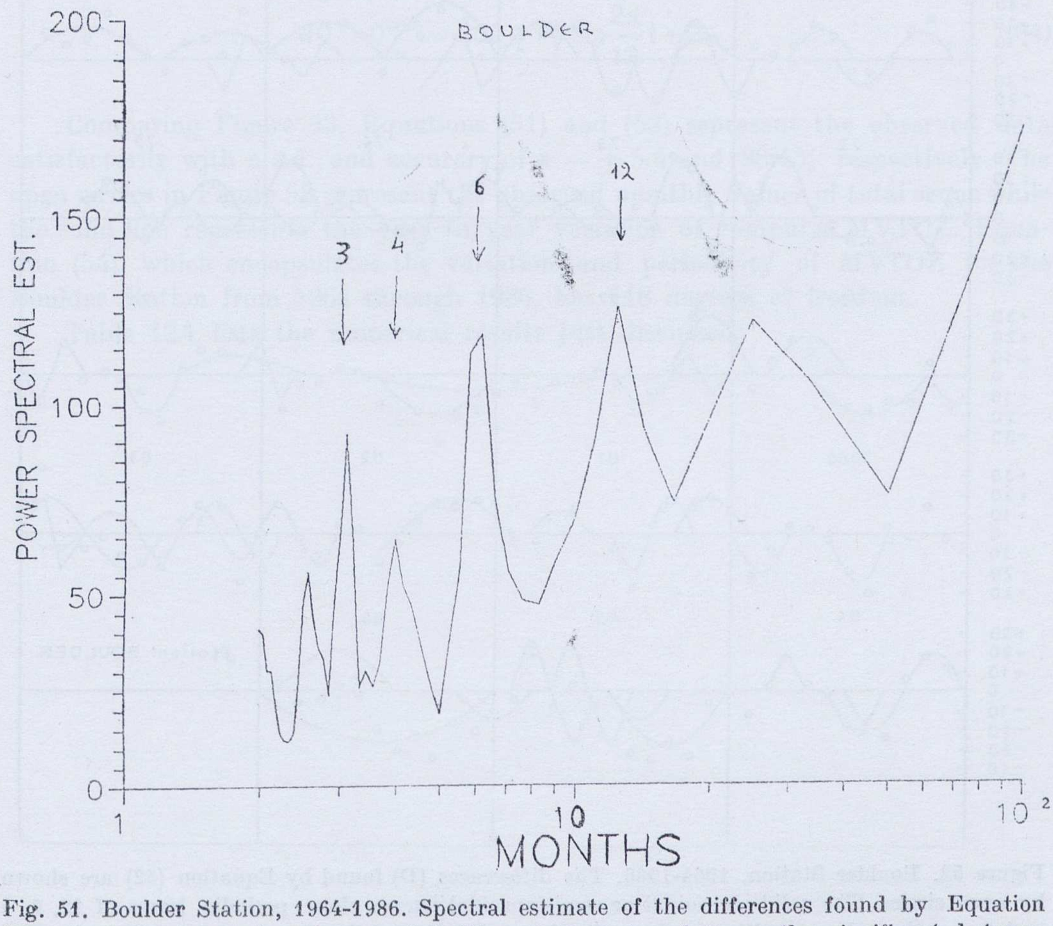

Fig. 51. Boulder Station, 1964-1986. Spectral estimate of the differences found by Equation (52). Analysis shows short-term periodicities of 12, 6, 4 and 3 months, significant between the confidence levels of 95% and 99%.

as for previous Dobson Stations, power spectrum analysis shows short-term periodicities of 12, 6, 4 and 3 months, significant between the confidence levels of 95% and 99%.

As it has been already cited in the preceding stations, power spectrum analysis is unable to define the position and amplitude of the revealed periodicities. Only the method of successive approximations can do this. Figure 52 is a graphic sta-

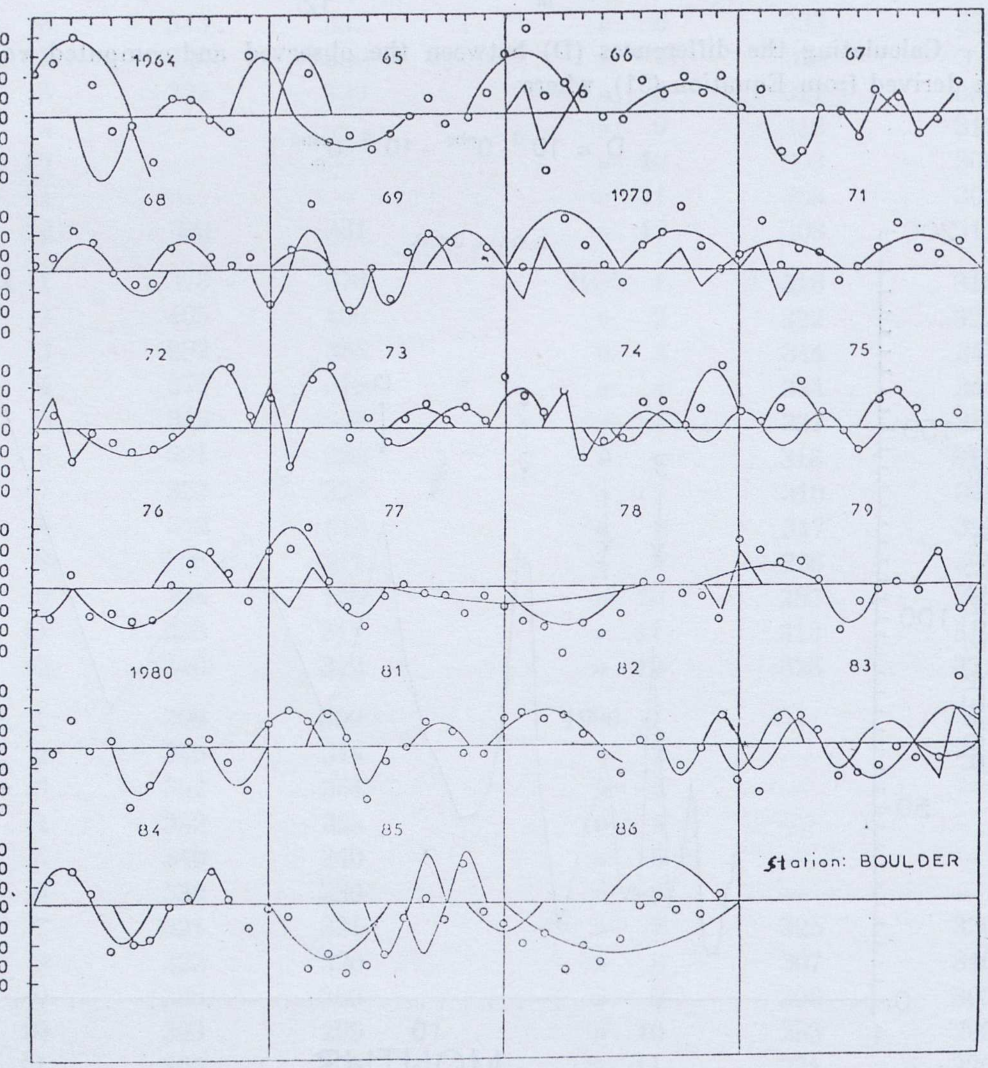

Figure 52. Boulder Station, 1964-1986. The differences (D) found by Equation (52) are shown by open circles. The solid sinusoidal or semisinusoidal curves show periodic terms of 12, 6, 4 and 3 months, whose position and amplitude is also plotted, by the successive approximation method. In some cases the periodic terms appear more or less stable overlapping each other.

tement of the periodicities detected, and of their position and amplitude for the Boulder Station (1964-1986). Here open circles represent the differences (D) found by Equation (52), and solid sinusoidal or semisinusoidal curves represent periodic terms of 12, 6, 4 and 3 months, which appear as a network with occasional overlaps.

The above periodic terms can be expressed as:

$$P = \alpha_1 \sin\frac{2\pi}{24}t + \alpha_2 \sin\frac{2\pi}{12}t + \alpha_3 \sin\frac{2\pi}{6}t + \alpha_4 \sin\frac{2\pi}{4}t + \alpha_5 \sin\frac{2\pi}{3}t \qquad (53)$$

The coefficients α_1, α_2, α_3, α_4 and α_5 as well as the parameter **t**, of Equation (53) are listed in Table 12.

We are now in a position to express analytically the MVTOZ as the sum of Equation (51) and Equation (53) as follows:

$$10^{-3} \cdot 0^{com} = 332 + 40 \sin\frac{2\pi}{12}t + P \qquad (54)$$

Comparing Figure 53, Equations (51) and (53) represent the observed data satisfactorily with a s.d., and accurary of $\sigma = \pm 5.4$ and 98.4% respectively. The open circles in Figure 53 represent the observed monthly values of total ozone while the solid line represents the year to year variation of computed MVTOZ. Equation (54), which encapsulates the variation and periodicity of MVTOZ for the Boulder Station from 1964 through 1986, has 118 degrees of freedom.

Table 12A lists the numerical results just discussed.

TABLE 12

Values of the parameters $\alpha_1 - \alpha_5$, and **t** (see Eq. 53).

α_1	t
—10	1977.6 - 1978.6
—40	1985.1 - 1985.10, 1985.12 - 1986.12

α_2	t
+40	1963.12 - 1964.6
+30	1970.1 - 1970.7
—15	1965.2 - 1965.8, 1972.3 - 1972.9
+20	1965.11 - 1966.5, 1970.12 - 1971.6, 1981.12 - 1982.12
+15	1966.7 - 1967.1, 1970.12 - 1971.6, 1971.7 - 1972.1, 1978.11 - 1979.5
—20	1976.3 - 1976.9
—30	1978.1 - 1978.7
+25	1985.6 - 1985.12, 1986.6 - 1986.12

α_3	t
+20	1969.9 - 1970.1, 1980.12 - 1981.4, 1983.10. - 1984.2
+15	1976.8 - 1976.12
+30	1976.12 - 1977.4

α_4	t
—30	1964.3 - 1964.6, 1980.5 - 1980.8
+10	1964.7 - 1964.11, 1966.3 - 1966.6, 1973.7 - 1973.10, 1974.11 - 1975.2, 1969.1 - 1969.4, 1974.11 - 1975.2
+25	1964.10 - 1965.2, 1965.1 - 1965.4
—10	1967.6 - 1967.9, 1970.4 - 1970.7, 1973.6 - 1973.12, 1974.5 - 1974.9, 1974.7 - 1974.11
—25	1967.1 - 1967.5, 1969.1 - 1969.7
+15	1968.2 - 1968.8, 1968.7 - 1968.10, 1981.8 - 1981.11, 1980.3 - 1980.6
—15	1977.4 - 1977.7, 1975.12 - 1976.3, 1984.10 - 1985.1
—20	1979.5 - 1979.8, 1980.10 - 1981.1, 1983.5 - 1983.8, 1984.6 - 1984.12
+30	1972.9 - 1972.12, 1973.2 - 1973.5, 1974.12 - 1975.1
+20	1973.12 - 1974.3, 1975.7 - 1975.10, 1981.3 - 1981.6, 1982.7 - 1982.11, 1984.1 - 1984.7

α_5	t
—10	1967.5 - 1967.8, 1977.1 - 1977.4
+10	1967.8 - 1967.12, 1970.9 - 1970.12, 1966.1 - 1966.4, 1971.1 - 1971.4, 1972.1 - 1972.4
+15	1969.5 - 1969.9, 1979.10 - 1980.1
—15	1970.1 - 1970.5, 1978.11 - 1979.2
+20	1972.12 - 1973.3, 1969.5 - 1969.8, 1974.3 - 1974.6, 1982.11 - 1983.2
—20	1983.10 - 1984.1, 1983.10 - 1984.1
—30	1983.1 - 1983.4

TABLE 12A

Boulder Station, 1964 - 1986. Observed and computed MVTOZ.

Year/month	comp.	obs.	Year/month	comp.	obs.
1964. 1	342	345	1967. 1	322	324
» 2	376	370	» 2	342	354
» 3	407	399	» 3	345	335
» 4	376	380	» 4	340	342
» 5	360	352	» 5	357	353
» 6	342	338	» 6	342	343
» 7	302	299	» 7	313	311
» 8	311	312	» 8	311	315
» 9	296	294	» 9	296	295
» 10	282	281	» 10	273	272
» 11	278	279	» 11	287	283
» 12	324	335	» 12	311	319
1965. 1	344	—	1968. 1	322	324
» 2	362	—	» 2	342	347
» 3	387	382	» 3	370	377
» 4	359	350	» 4	375	376
» 5	342	347	» 5	357	355
» 6	322	325	» 6	329	333
» 7	315	312	» 7	309	314
» 8	302	302	» 8	315	313
» 9	294	295	» 9	308	304
» 10	272	278	» 10	282	288
» 11	287	285	» 11	287	291
» 12	317	313	» 12	302	308
1966. 1	349	354	1969. 1	300	304
» 2	381	385	» 2	351	352
» 3	371	366	» 3	388	392
» 4	379	378	» 4	362	362
» 5	366	367	» 5	335	336
» 6	342	340	» 6	337	346
» 7	322	318	» 7	305	306
» 8	310	319	» 8	302	310
» 9	300	297	» 9	307	305
» 10	297	301	» 10	296	296
» 11	300	296	» 11	307	—
» 12	310	321	» 12	316	312

Year/month	comp.	obs.	Year/month	comp.	obs.
1970. 1	—	—	1973. 1	339	335
» 2	348	342	» 2	325	320
» 3	392	398	» 3	383	380
» 4	392	387	» 4	388	390
» 5	374	368	» 5	357	350
» 6	348	345	» 6	342	345
» 7	322	315	» 7	313	315
» 8	312	314	» 8	302	305
» 9	304	305	» 9	296	300
» 10	310	313	» 10	291	285
» 11	295	298	» 11	296	300
» 12	312	302	» 12	302	305
1971. 1	330	329	1974. 1	339	346
» 2	364	366	» 2	359	357
» 3	363	359	» 3	357	364
» 4	375	372	» 4	379	380
» 5	365	365	» 5	340	340
» 6	342	335	» 6	339	334
» 7	322	322	» 7	313	315
» 8	310	314	» 8	312	313
» 9	300	310	» 9	296	299
» 10	297	292	» 10	282	281
» 11	300	295	» 11	304	296
» 12	310	317	» 12	337	332
1972. 1	322	318	1975. 1	331	328
» 2	351	347	» 2	342	344
» 3	348	339	» 3	364	365
» 4	354	359	» 4	379	384
» 5	344	348	» 5	367	364
» 6	327	329	» 6	342	338
» 7	309	311	» 7	312	310
» 8	294	296	» 8	319	315
» 9	287	290	» 9	304	308
» 10	—	—	» 10	282	290
» 11	313	316	» 11	287	288
» 12	302	305	» 12	302	308

Year/month	comp.	obs.	Year/month	comp.	obs.
1976. 1	309	310	1979. 1	348	347
» 2	329	326	» 2	357	361
» 3	357	364	» 3	370	369
» 4	352	349	» 4	370	372
» 5	340	344	» 5	357	358
» 6	322	325	» 6	325	319
» 7	305	304	» 7	305	314
» 8	292	303	» 8	302	301
» 9	298	300	» 9	287	289
» 10	297	300	» 10	282	280
» 11	298	294	» 11	300	305
» 12	302	295	» 12	289	290
1977. 1	341	341	1980. 1	322	314
» 2	363	361	» 2	342	340
» 3	387	387	» 3	357	372
» 4	362	364	» 4	362	361
» 5	344	347	» 5	357	360
» 6	329	324	» 6	316	312
» 7	322	318	» 7	296	303
» 8	299	305	» 8	302	300
» 9	282	284	» 9	287	290
» 10	275	278	» 10	282	286
» 11	278	274	» 11	270	279
» 12	292	298	» 12	285	281
1978. 1	319	312	1981. 1	336	336
» 2	314	315	» 2	362	361
» 3	335	331	» 3	371	370
» 4	332	328	» 4	382	379
» 5	335	339	» 5	363	361
» 6	327	319	» 6	322	315
» 7	322	309	» 7	306	307
» 8	302	304	» 8	302	301
» 9	287	291	» 9	300	299
» 10	282	278	» 10	295	287
» 11	287	282	» 11	287	289
» 12	294	286	» 12	302	298

Year/month	comp.	obs.	Year/month	comp.	obs.
1982. 1	332	336	1985. 1	322	319
» 2	359	361	» 2	331	335
» 3	370	370	» 3	337	323
» 4	379	379	» 4	334	336
» 5	367	361	» 5	322	322
» 6	342	339	» 6	316	313
» 7	312	308	» 7	294	295
» 8	302	304	» 8	288	293
» 9	284	290	» 9	277	289
» 10	265	270	» 10	276	272
» 11	277	284	» 11	299	308
» 12	319	316	» 12	292	295
1983. 1	305	302	1986. 1	312	311
» 2	316	316	» 2	313	314
» 3	370	370	» 3	342	340
» 4	375	376	» 4	330	328
» 5	357	364	» 5	334	334
» 6	325	324	» 6	302	311
» 7	305	306	» 7	298	302
» 8	302	289	» 8	290	300
» 9	287	285	» 9	284	288
» 10	282	273	» 10	284	278
» 11	283	277	» 11	288	280
» 12	339	334	» 12	302	305
1984. 1	336	336			
» 2	359	353			
» 3	374	374			
» 4	362	368			
» 5	340	333			
» 6	325	321			
» 7	305	303			
» 8	305	300			
» 9	287	289			
» 10	299	299			
» 11	297	289			
» 12	289	289			

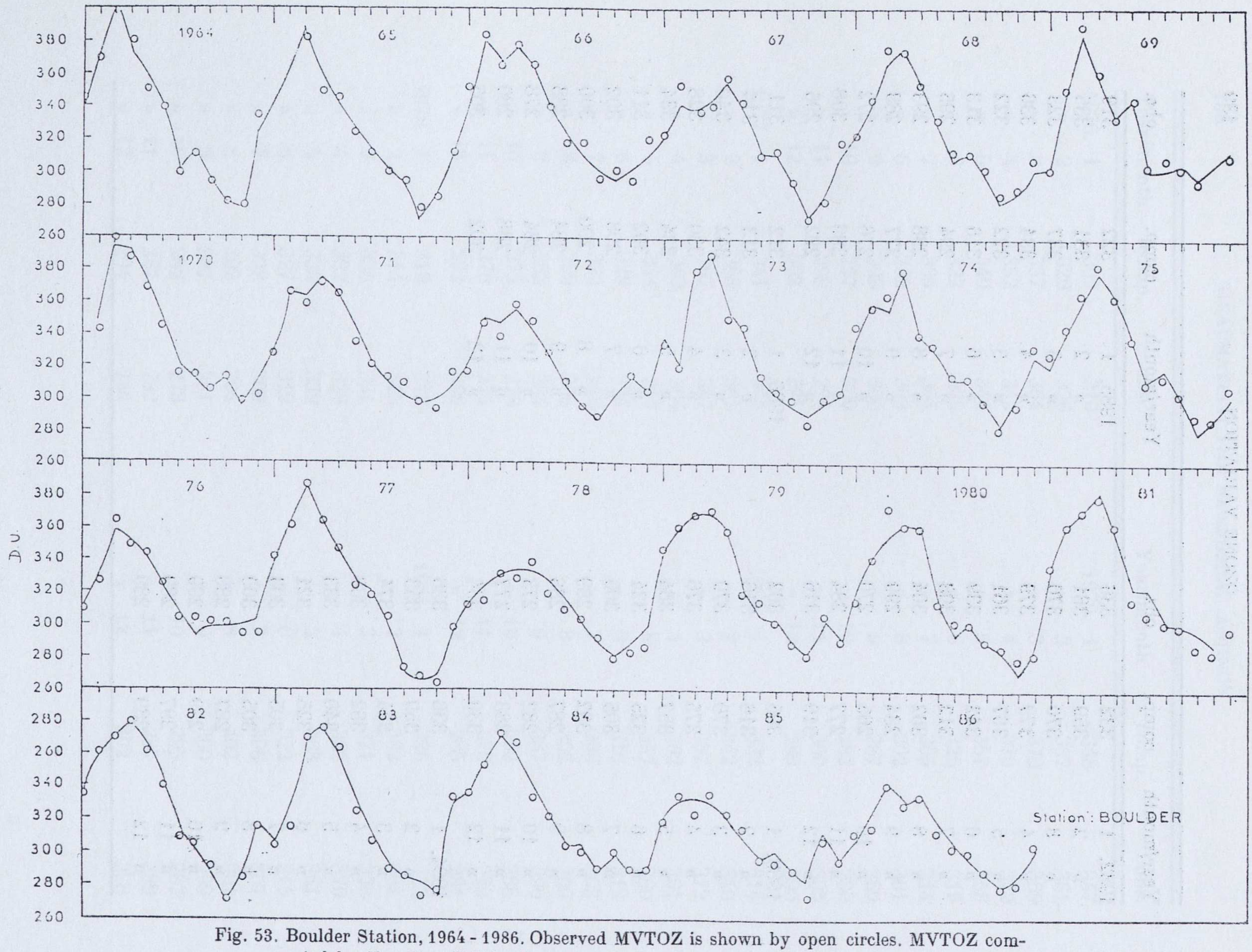

Fig. 53. Boulder Station, 1964 - 1986. Observed MVTOZ is shown by open circles. MVTOZ computed by Equation (54) is shown by a solid line. Accuracy is equal to 98.4%.

4.13 Station: ROME

$\varphi = 41^0\ 54'$ N, L $= 12^0\ 29'$ E, Time Period: 1957 - 1986.

Using Figure 6, MMVTOZ (Rome) can be expressed as:

$$10^{-3} \cdot 0_m^{com} = 341 + 45 \sin\frac{2\pi}{12} t \tag{55}$$

If we now analyze the differences (D) between the observed and computed MMVTOZ as derived from Equation (55), where

$$D = 10^{-3} \cdot 0^{obs} - 10^{-3} \cdot 0_m^{com} \tag{56}$$

power spectrum analysis shows four short-term periodicities of 12, 6, 4 and 3 months, significant at the confidence level above 99% and 95%. See Figure 54, where there are three predominant short-term periodicities of 12, 6 and 4 months.

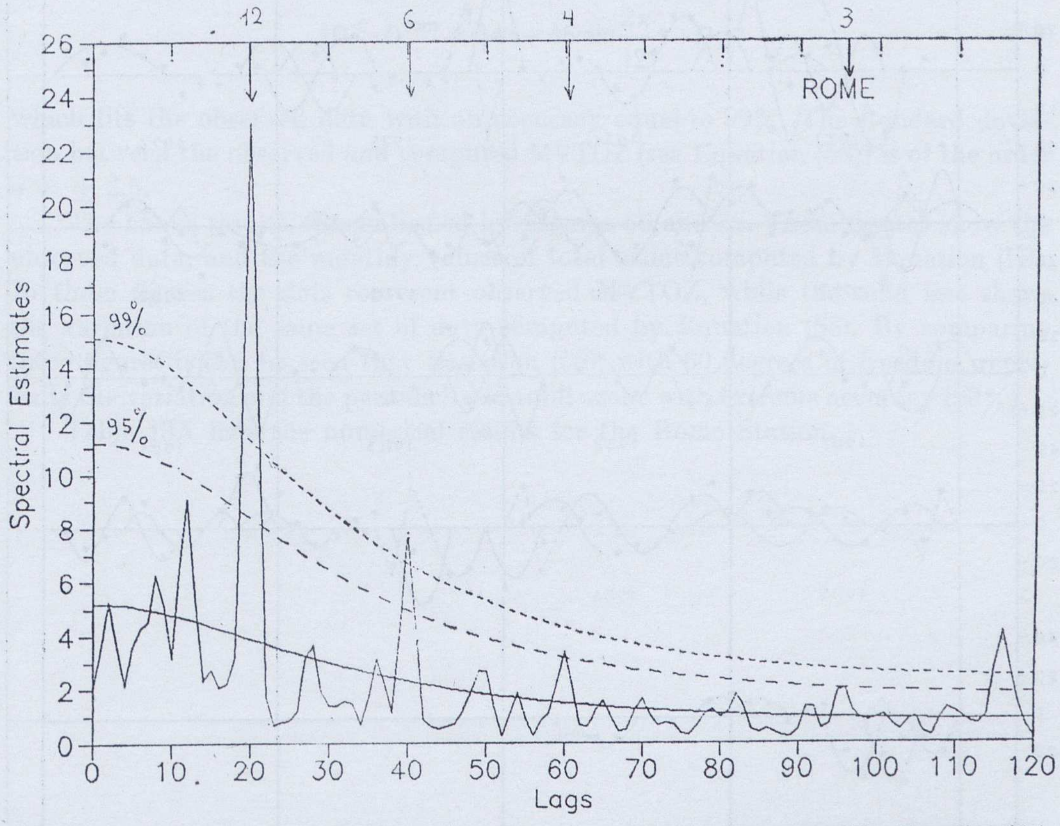

Fig. 54. Rome Station, 1957 - 1986. Spectral estimate of the differences found by Equation (56). Analysis shows short-term periodicities of 12, 6, 4 and 3 months, all with a confidence level above 95%. Note the 12-month and the 6-month term which are at a confidence level above 99%.

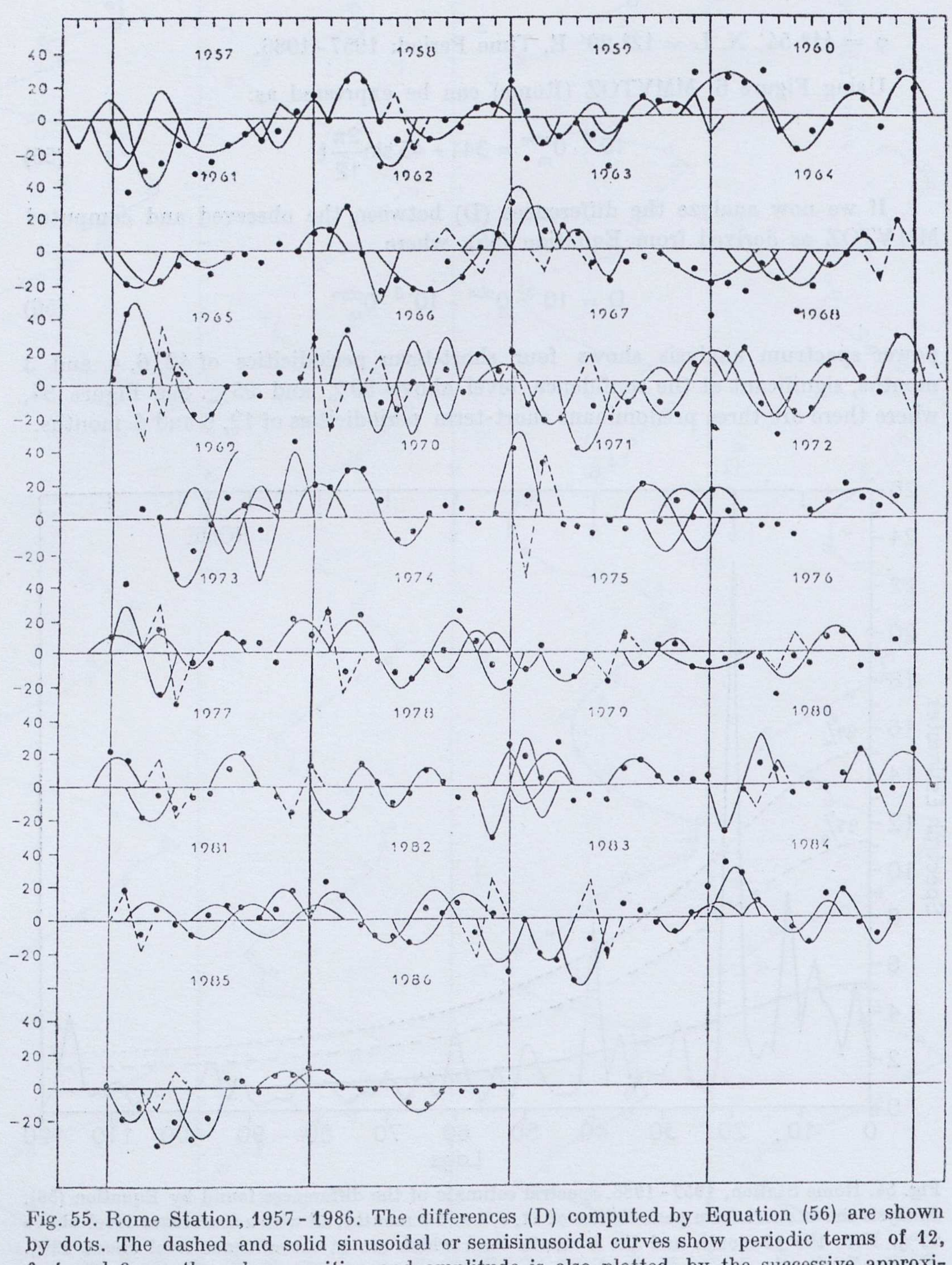

Fig. 55. Rome Station, 1957 - 1986. The differences (D) computed by Equation (56) are shown by dots. The dashed and solid sinusoidal or semisinusoidal curves show periodic terms of 12, 6, 4 and 3 months, whose position and amplitude is also plotted, by the successive approximation method.

The position and amplitude of the above cited periods are represented graphically in Figure 55, where the dots represent the differences (D), derived from Equation (56) and dashed or solid sinusoidal or semisinusoidal curves represent periodic terms of 12, 6, 4 and 3 months, which appear as a network of periodicities. The amplitude fluctuates between 10 and 30 Dobson Units (D.U.). Sometimes the revealed periodicities, found by means of the successive approximation method, overlapping one another. These short-terms can be expressed as:

$$P = \alpha_1 \sin\frac{2\pi}{12}t + \alpha_2 \sin\frac{2\pi}{6}t + \alpha_3 \sin\frac{2\pi}{4}t + \alpha_4 \sin\frac{2\pi}{3}t \qquad (57)$$

where the values for the parameters (coefficients) $\boldsymbol{\alpha}_1$ to $\boldsymbol{\alpha}_4$ and **t**, are taken from Table 13.

Equations (55) and (57) can be summed; giving an equation of the form:

$$10^{-3} \cdot 0^{com} = 341 + 45 \sin\frac{2\pi}{12}t + P \qquad (58)$$

which fits the observed data with an accuracy equal to 99%. The standard deviation between the observed and computed MVTOZ (see Equation (58)) is of the order $\sigma = \pm 3.5$.

The above results are confirmed by Figures 56 and 57. These figures show the observed data, and the monthly values of total ozone computed by Equation (58). In these figures the dots represent observed MVTOZ, while the solid line shows the variation of the same set of data computed by Equation (58). By comparing these figures it can be seen that Equation (58), with 60 degrees of freedom, represents the variation and the periodicity of total ozone with extreme accuracy (99%).

Table 13A lists the numerical results for the Rome Station.

TABLE 13

Values of the parameters $\alpha_1 - \alpha_4$, and **t** (see Eq. 57).

α_1	t
—20	1957.4 - 1957.8, 1963.10 - 1964.4
+30	1959.11 - 1960.5
—25	1962.5 - 1962.11
+15	1972.7 - 1973.1
—10	1975.10 - 1976.4

α_2	t
—30	1956.12 - 1957.3, 1958.4 - 1958.7, 1983.2 - 1983.5
—40	1957.2 - 1957.5, 1967.4 - 1967.7, 1969.5 - 1969.8, 1983.4 - 1983.7, 1985.3 - 1985.6
+30	1958.2 - 1958.5, 1963.1 - 1963.4, 1968.11 - 1969.2, 1969.12 - 1970.3, 1970.2 1970.5, 1971.8 - 1971.11, 1984.1 - 1984.4
—10	1958.7 - 1959.1, 1961.5 - 1961.8, 1963.6 - 1963.10, 1986.6 - 1986.9
—20	1959.5 - 1959.8, 1960.5 - 1960.11, 1961.1 - 1961.4, 1961.2 - 1961.5, 1964.4 - 1964.7
+10	1959.9 - 1959.12, 1966.11 - 1967.2, 1969.8 - 1969.11, 1969.10 - 1970.1, 1972.12 - 1973.3, 1981.2 - 1981.11
+25	1960.11 - 1961.2
+15	1961.12 - 1962.3, 1962.10 - 1963.1, 1975.7 - 1975.10, 1979.7 - 1979.10, 1982.1 - 1982.8
+40	1962.12 - 1963.3
—15	1964.2 - 1964.5, 1968.3 - 1968.6, 1982.6 - 1982.12
+50	1965.1 - 1965.3, 1970.12 - 1971.3
—25	1967.2 - 1967.5, 1967.9 - 1968.3, 1982.11 - 1983.2
+20	1967.11 - 1968.2, 1973.11 - 1974.2, 1974.2 - 1975.2, 1976.12 - 1977.3, 1977.7 - 1977.10, 1979.2 - 1979.5
—20	1975.4 - 1975.7, 1977.2 - 1977.5, 1978.1 - 1978.4, 1985.1 - 1985.4, 1985.5 - 1985.8
+10	1981.6 - 1982.3, 1983.12 - 1984.3, 1985.10 - 1986.1, 1985.12 - 1986.3
+20	1981.10 - 1982.1

α_3	t
—15	1957.1 - 1957.8, 1957.10 - 1958.2, 1974.8 - 1974.12, 1984.6 - 1984.12
+20	1958.12 - 1959.4, 1967.11 - 1968.2, 1968.2 - 1968.6, 1969.5 - 1969.11, 1979.2 - 1979.4

α_3	t
−10	1954.3 - 1954.7, 1959.6 - 1959.10, 1961.5 - 1961.9, 1964.7 - 1964.11, 1967.7 - 1967.11, 1971.10 - 1972.2
+30	1962.2 - 1962.6, 1966.2 - 1966.8, 1973.1 - 1973.5
+15	1962.8 - 1962.12, 1963.4 - 1963.6
−30	1966.6 - 1966.10, 1978.11 - 1979.3
−20	1966.8 - 1966.12
−40	1969.10 - 1970.1
+10	1973.3 - 1973.9, 1974.11 - 1975.3, 1978.3 - 1978.9, 1983.7, 1983.11, 1984.3-1984.9, 1959.11 - 1960.2
−30	1980.1 - 1980.5
+20	1980.4 - 1981.1

α_4	t
−10	1957.9 - 1957.12, 1972.5 - 1972.9, 1976.4 - 1976.7, 1979.1 - 1979.4
+15	1958.5 - 1958.8, 1966.12 - 1967.3, 1970.4 - 1970.7, 1977.3 - 1977.6, 1985.4-1985.7
+10	1960.3 - 1960.8, 1979.3 - 1979.6, 1983.4 - 1983.12
−15	1963.2 - 1963.5, 1964.10 - 1965.1, 1965.3 - 1965.6, 1975.6 - 1975.9, 1980.3-1980.6
−40	1965.2 - 1965.5, 1971.1 - 1971.4
+30	1965.12 - 1966.3, 1973.3 - 1973.6, 1974.1 - 1974.4
+20	1966.4 - 1966.7, 1980.11 - 1981.2, 1981.1 - 1981.4
+25	1967.5 - 1967.8, 1983.5 - 1983.8
−20	1968.12 - 1969.3, 1977.11 - 1978.2
−25	1971.9 - 1971.12, 1982.10 - 1983.1

TABLE 13A

Rome Station, 1957 - 1986. Observed and computed MVTOZ.

Year/month	comp.	obs.	Year/month	comp.	obs.
1957. 1	330	332	1960.1	357	352
» 2	321	322	» 2	394	390
» 3	345	350	» 3	406	401
» 4	366	362	» 4	411	414
» 5	370	366	» 5	370	373
» 6	332	332	» 6	347	345
» 7	321	318	» 7	334	333
» 8	301	304	» 8	318	314
» 9	302	296	» 9	319	320
» 10	287	286	» 10	313	307
» 11	296	297	» 11	302	296
» 12	318	325	» 12	340	346
1958. 1	356	358	1961. 1	363	359
» 2	364	365	» 2	347	345
» 3	406	405	» 3	346	345
» 4	412	410	» 4	369	370
» 5	354	352	» 5	380	373
» 6	351	351	» 6	355	358
» 7	328	325	» 7	332	329
» 8	309	307	» 8	318	315
» 9	293	302	» 9	302	303
» 10	296	293	» 10	296	291
» 11	311	310	» 11	302	309
» 12	327	327	» 12	318	319
1959. 1	361	365	1962. 1	354	354
» 2	364	368	» 2	377	379
» 3	360	365	» 3	410	409
» 4	376	376	» 4	386	384
» 5	380	377	» 5	350	357
» 6	357	356	» 6	351	347
» 7	314	313	» 7	319	320
» 8	318	317	» 8	293	296
» 9	312	314	» 9	295	297
» 10	305	305	» 10	283	279
» 11	311	308	» 11	300	303
» 12	343	345	» 12	331	329

Year/month	comp.	obs.	Year/month	comp.	obs.
1963. 1	376	371	1966. 1	367	369
» 2	425	423	» 2	338	338
» 3	393	392	» 3	410	413
» 4	399	401	» 4	386	383
» 5	395	391	» 5	367	369
» 6	364	355	» 6	347	349
» 7	326	323	» 7	346	343
» 8	309	309	» 8	318	315
» 9	293	295	» 9	312	311
» 10	296	291	» 10	296	291
» 11	292	291	» 11	322	320
» 12	301	305	» 12	327	326
1964. 1	321	323	1967. 1	363	361
» 2	347	344	» 2	351	352
» 3	357	354	» 3	358	358
» 4	373	378	» 4	364	365
» 5	363	364	» 5	345	342
» 6	330	327	» 6	351	350
» 7	324	319	» 7	319	319
» 8	308	309	» 8	308	307
» 9	302	301	» 9	302	299
» 10	306	305	» 10	284	281
» 11	289	287	» 11	280	282
» 12	331	332	» 12	335	330
1965. 1	341	345	1968. 1	380	387
» 2	407	409	» 2	386	381
» 3	388	389	» 3	400	400
» 4	408	406	» 4	373	374
» 5	393	387	» 5	347	350
» 6	347	347	» 6	347	348
» 7	324	324	» 7	324	327
» 8	318	318	» 8	335	331
» 9	302	309	» 9	319	318
» 10	296	291	» 10	296	299
» 11	302	309	» 11	302	298
» 12	318	322	» 12	344	346

Year/month	comp.	obs.	Year/month	comp.	obs.
1969. 1	350	350	1972. 1	351	358
» 2	381	386	» 2	364	368
» 3	380	384	» 3	380	384
» 4	386	385	» 4	381	381
» 5	345	345	» 5	380	375
» 6	349	343	» 6	355	353
» 7	341	338	» 7	350	346
» 8	333	329	» 8	326	327
» 9	311	310	» 9	315	323
» 10	385	389	» 10	311	311
» 11	311	312	» 11	315	309
» 12	367	365	» 12	326	331
1970. 1	363	361	1973. 1	350	350
» 2	386	385	» 2	403	406
» 3	406	408	» 3	380	384
» 4	412	417	» 4	396	401
» 5	393	392	» 5	350	349
» 6	351	350	» 6	354	357
» 7	341	332	» 7	341	335
» 8	318	318	» 8	328	330
» 9	302	307	» 9	302	308
» 10	296	299	» 10	296	302
» 11	302	297	» 11	302	295
» 12	318	320	» 12	335	339
1971. 1	384	384	1974. 1	368	354
» 2	372	375	» 2	390	388
» 3	415	413	» 3	371	368
» 4	386	382	» 4	403	409
» 5	380	375	» 5	380	376
» 6	364	358	» 6	347	350
» 7	341	339	» 7	324	325
» 8	318	312	» 8	318	315
» 9	324	323	» 9	304	303
» 10	296	294	» 10	313	320
» 11	314	313	» 11	317	309
» 12	318	318	» 12	309	311

Year/month	comp.	obs.	Yrear/month	comp.	obs.
1975. 1	324	321	1978. 1	358	355
» 2	354	353	» 2	347	349
» 3	380	384	» 3	363	365
» 4	373	374	» 4	396	400
» 5	367	365	» 5	380	382
» 6	364	361	» 6	354	354
» 7	328	325	» 7	341	337
» 8	331	326	» 8	328	328
» 9	302	296	» 9	302	305
» 10	296	299	» 10	296	290
» 11	307	305	» 11	302	298
» 12	320	308	» 12	288	288
1976. 1	331	334	1979. 1	361	366
» 2	356	361	» 2	384	382
» 3	375	372	» 3	387	385
» 4	386	383	» 4	412	413
» 5	358	356	» 5	371	370
» 6	360	361	» 6	364	362
» 7	341	334	» 7	341	335
» 8	331	327	» 8	331	329
» 9	315	314	» 9	315	317
» 10	296	289	» 10	296	299
» 11	302	301	» 11	302	304
» 12	318	324	» 12	318	319
1977. 1	358	362	1980. 1	341	347
» 2	381	380	» 2	334	336
» 3	363	361	» 3	380	377
» 4	382	382	» 4	403	399
» 5	367	370	» 5	393	390
» 6	364	358	» 6	364	359
» 7	341	338	» 7	341	341
» 8	335	330	» 8	318	317
» 9	319	322	» 9	302	309
» 10	296	298	» 10	316	317
» 11	302	297	» 11	302	299
» 12	301	302	» 12	315	316

Year/month	comp.	obs.	Year/month	comp.	obs.
1981. 1	358	363	1984. 1	360	359
» 2	381	383	» 2	399	398
» 3	372	373	» 3	406	407
» 4	395	392	» 4	396	396
» 5	380	378	» 5	380	379
» 6	355	356	» 6	354	359
» 7	341	343	» 7	326	327
» 8	327	325	» 8	328	333
» 9	311	310	» 9	317	319
» 10	296	297	» 10	296	294
» 11	310	309	» 11	297	292
» 12	335	337	» 12	318	317
1982. 1	350	347	1985. 1	341	342
» 2	386	389	» 2	347	345
» 3	393	394	» 3	363	369
» 4	385	381	» 4	351	352
» 5	367	370	» 5	358	360
» 6	351	354	» 6	334	334
» 7	328	326	» 7	326	322
» 8	318	325	» 8	318	321
» 9	302	306	» 9	302	303
» 10	309	306	» 10	296	292
» 11	293	294	» 11	311	309
» 12	318	321	» 12	327	324
1983. 1	319	310	1986. 1	350	353
» 2	364	362	» 2	373	373
» 3	354	359	» 3	—	—
» 4	360	361	» 4	—	—
» 5	345	342	» 5	—	—
» 6	351	352	» 6	—	—
» 7	319	321	» 7	332	333
» 8	328	325	» 8	309	309
» 9	302	306	» 9	302	300
» 10	295	293	» 10	296	294
» 11	293	292	» 11	302	304
» 12	318	321	» 12	318	319

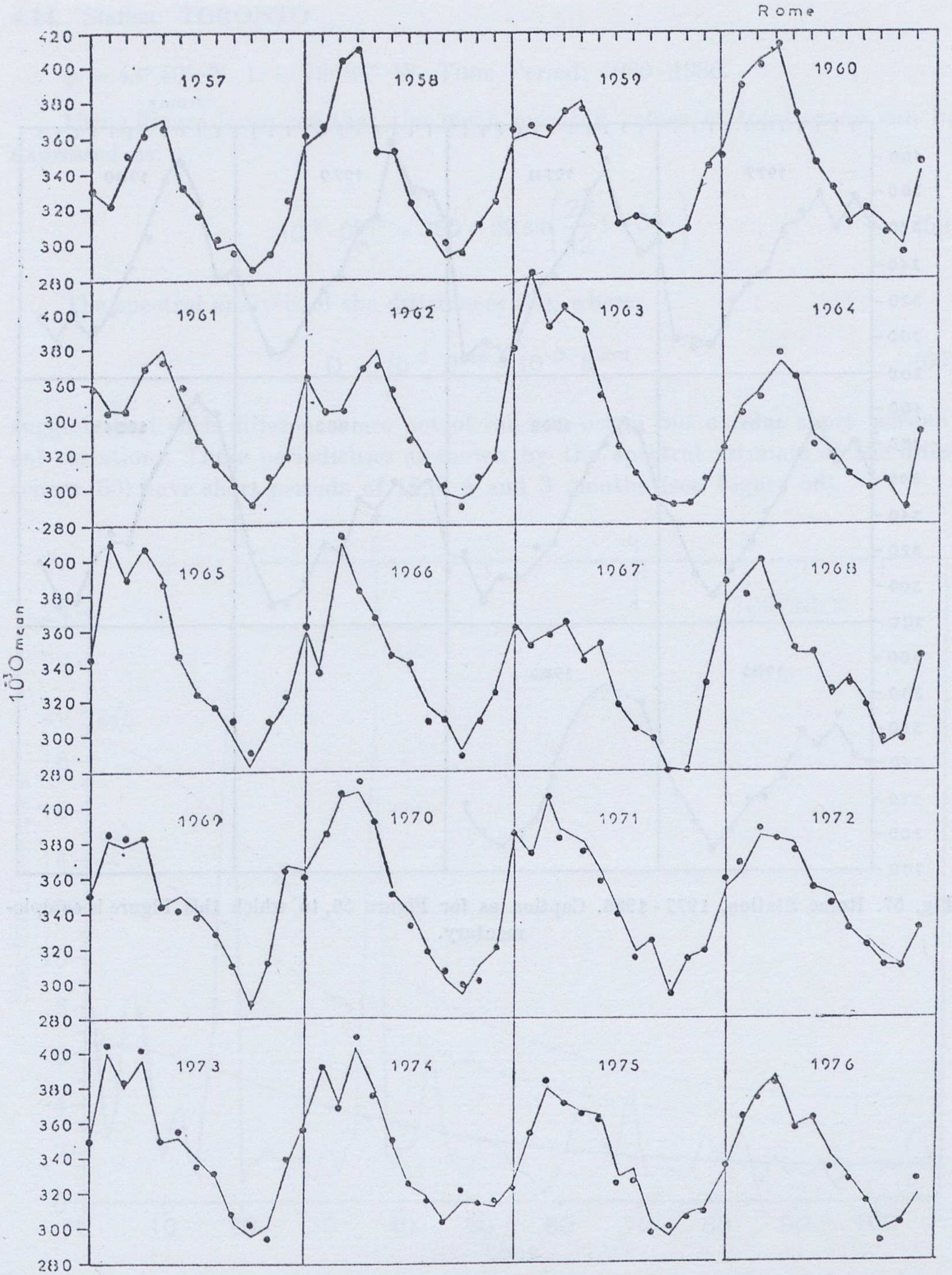

Fig. 56. Rome Station, 1957 - 1976. Observed MVTOZ is shown by dots. MVTOZ as found by Equation (58) is shown by a solid line. Accuracy is equal to 99%. Note the very close agreement between the two.

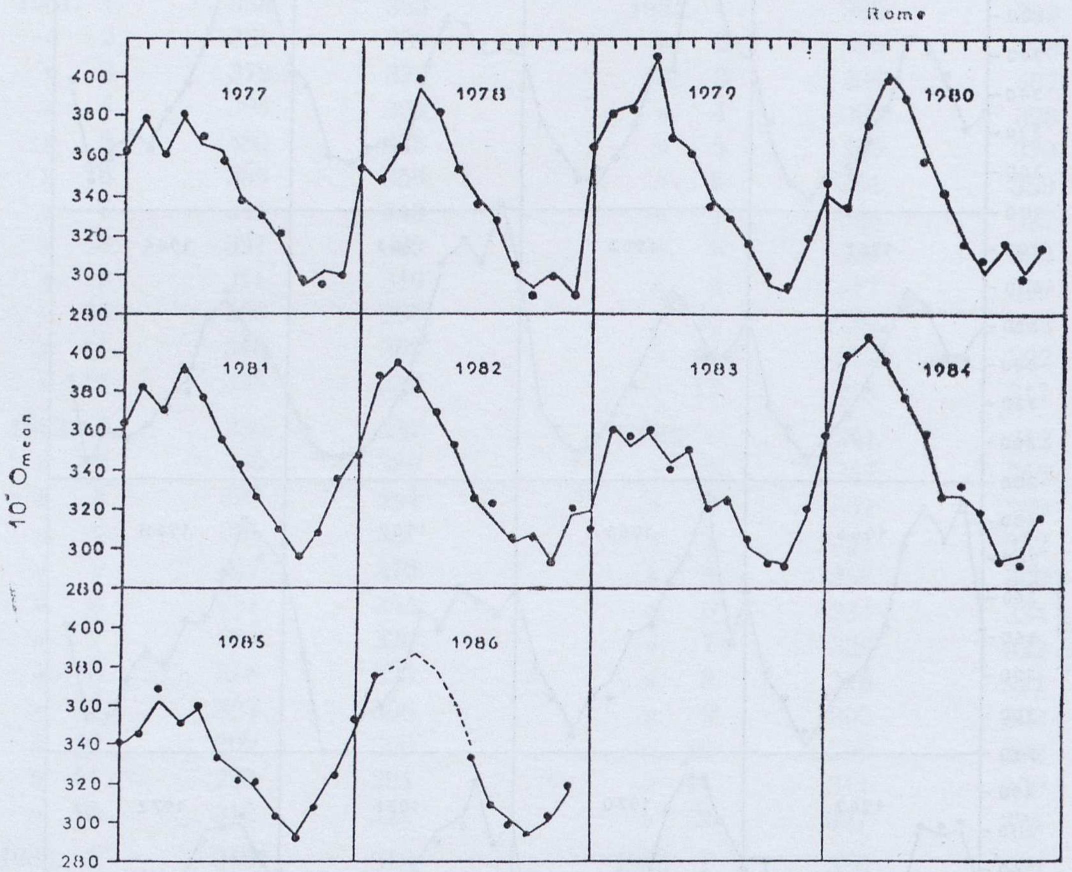

Fig. 57. Rome Station, 1977 - 1986. Caption as for Figure 56, to which this Figure is complementary.

4.14. Station: TORONTO

$\varphi = 43^0\,40'$ N, L $= 79^0\,24'$ W, Time Period: 1960 - 1986.

Using Figure 5, we see that the mean monthly values of total ozone can be expressed as:

$$10^{-3} \cdot 0_m^{com} = 360 + 50 \sin\left(\frac{2\pi}{12} t + 30^\circ\right) \tag{59}$$

The spectral analysis of the differences (D); where

$$D = 10^{-3} \cdot 0^{obs} - 10^{-3} \cdot 0_m^{com} \tag{60}$$

suggests that such differences are not of random origin but exhibit short periodical variations. These periodicities as shown by the spectral estimate of the differences (60) have short periods of 12, 6 4 and 3 months (see Figure 58).

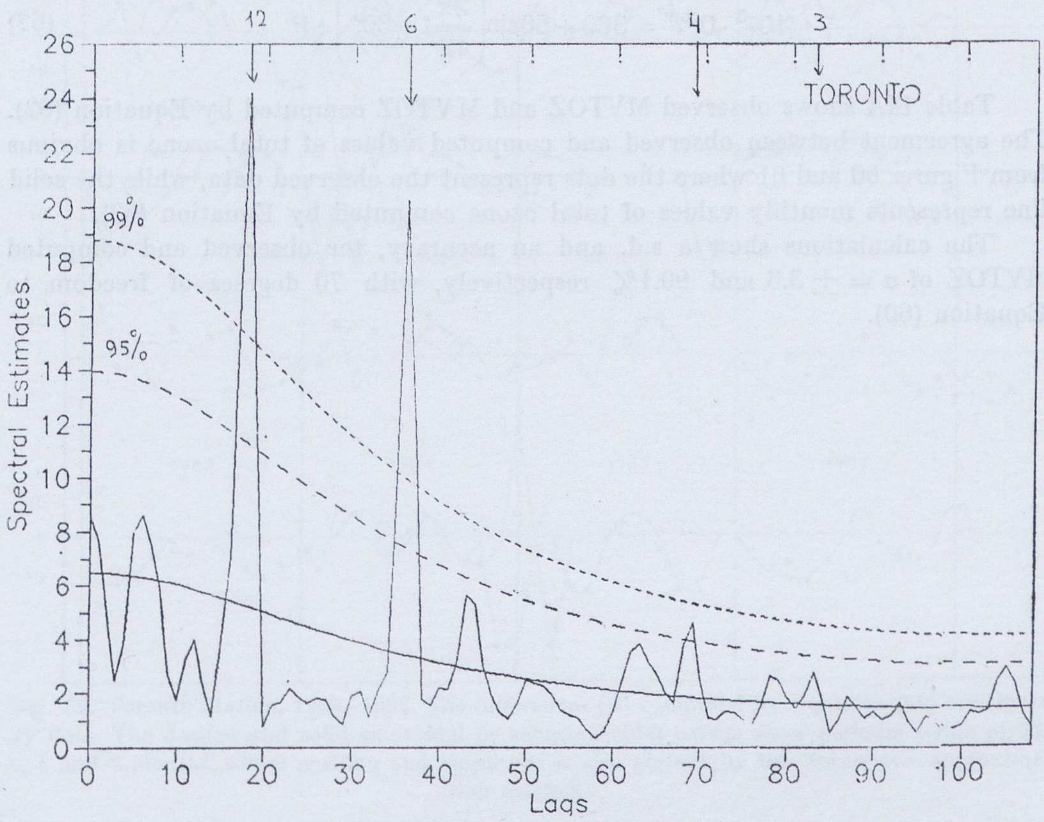

Fig. 58. Toronto Station, 1960 - 1986. Spectral estimate of the differences computed by Equation (60). Analysis shows periodicities with periods of 12, 6, 4 and 3 months. Note that the 12 and 6-month periods are predominant, with a confidence level above 99%.

Terms of 12 and 6 months predominate with a confidence level above 99%.

The amplitude and position of the short-term periods, as plotted by the successive approximation method are shown in Figure 59, where the dots represent the differences (D) given by Equation (60), while the dashed and solid sinusoidal and semisinusoidal curves represent periods of 12, 6, 4 and 3 months. These periodic terms can be expressed as:

$$P = \alpha_1 \sin\frac{2\pi}{12}t + \alpha_2 \sin\frac{2\pi}{6}t + \alpha_3 \sin\frac{2\pi}{4}t + \alpha_4 \sin\frac{2\pi}{3}t \tag{61}$$

The values of the parameters α_1 to α_4 and t in Equation (61) are listed in Table 14.

Thus the MVTOZ for Toronto Station from year to year and for the period 1960-1986 can be expressed as a simple algebraic equation (which is the sum of Equation (59) and Equation (61)) as follows:

$$10^{-3} \cdot 0^{com} = 360 + 50\sin\left(\frac{2\pi}{12}t + 30^\circ\right) + P \tag{62}$$

Table 14A shows observed MVTOZ and MVTOZ computed by Equation (62). The agreement between observed and computed values of total ozone is obvious from Figures 60 and 61 where the dots represent the observed data, while the solid line represents monthly values of total ozone computed by Equation (62).

The calculations show a s.d. and an accuracy, for observed and computed MVTOZ of $\sigma = \pm 3.3$ and 99.1% respectively, with 70 degrees of freedom to Equation (60).

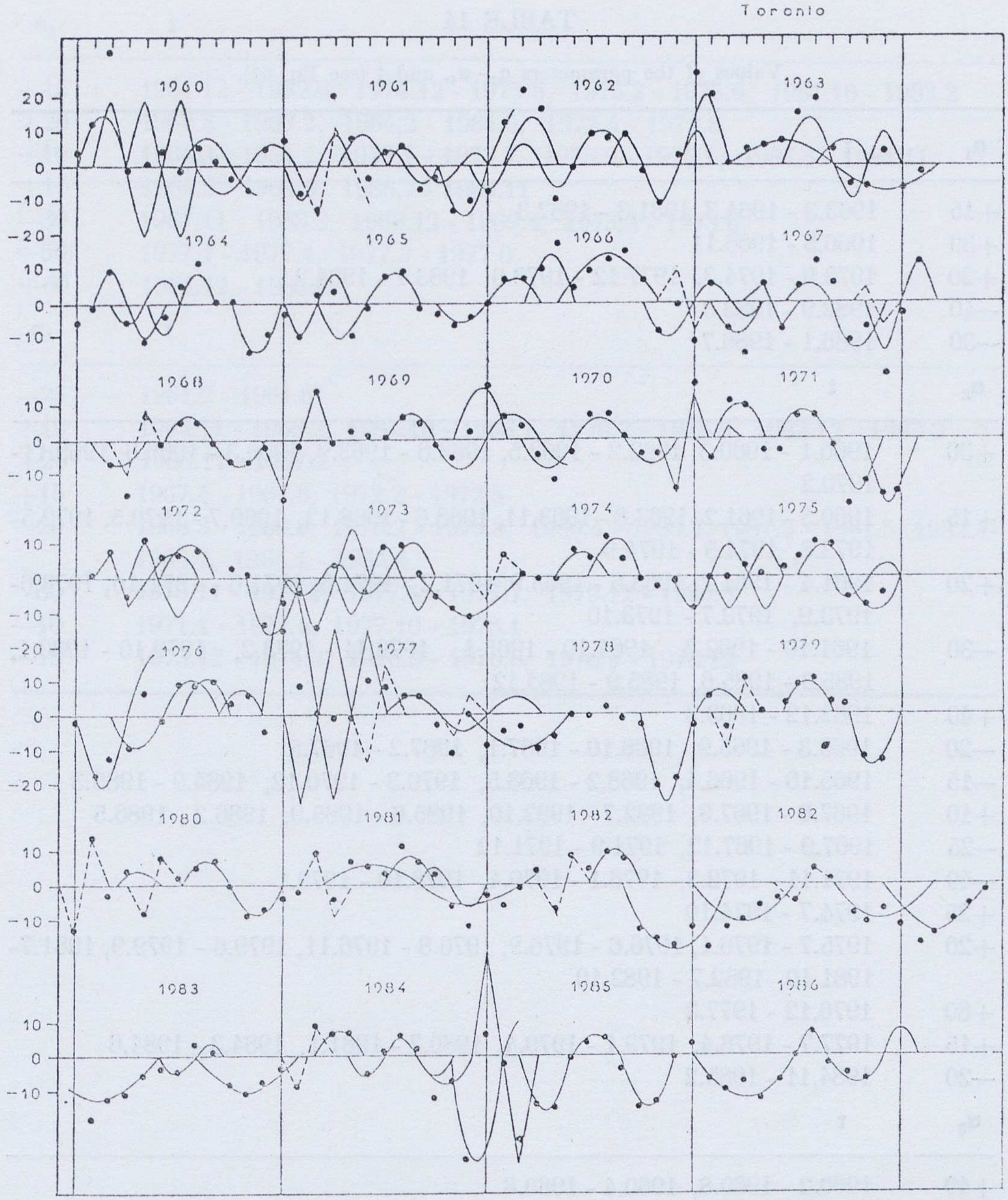

Fig. 59. Toronto Station, 1960 - 1986. The differences (D) computed by Equation (60) are shown by dots. The dashed and solid sinusoidal or semisinusoidal curves show periodic terms of 12, 6, 4 and 3 months, whose position and amplitude is also plotted, by the successive approximation method.

TABLE 14

Values of the parameters α_1 - α_4, and **t** (see Eq. 61).

α_1	t
+15	1963.3 - 1964.3, 1981.3 - 1982.3
+30	1966.5 - 1966.11
+20	1973.9 - 1974.3, 1977.12 - 1978.6, 1983.1 - 1984.2
—40	1982.9 - 1983.3
—30	1986.1 - 1986.7
α_2	**t**
+30	1960.1 - 1960.3, 1962.2 - 1962.5, 1963.6 - 1963.9, 1966.3 - 1966.6, 1969.11-1970.2
+15	1960.5 - 1961.2, 1963.8 - 1963.11, 1968.6 - 1968.12, 1969.7 - 1970.5, 1972.5-1972.8, 1974.5 - 1974.9
+20	1961.4 - 1961.7, 1963.6 - 1963.9, 1971.2 - 1971.5, 1971.6 - 1971.10, 1973.6-1973.9, 1973.7 - 1973.10
—30	1961.10 - 1962.2, 1964.10 - 1965.1, 1972.11 - 1973.2, 1979.10 - 1980.1, 1985.3 - 1985.6, 1985.9 - 1985.12
+40	1962.12 - 1963.3
—20	1965.3 - 1965.9, 1966.10 - 1967.1, 1967.2 - 1967.5
—15	1965.10 - 1966.4, 1968.2 - 1968.5, 1970.3 - 1970.12, 1984.9 - 1985.3
+10	1967.6 - 1967.9, 1982.7 - 1982.10, 1985.6 - 1985.9, 1986.2 - 1986.5
—25	1967.9 - 1967.12, 1971.9 - 1971.12
—40	1971.11 - 1972.2, 1976.1 - 1976.4, 1978.10 - 1979.1
+25	1974.7 - 1974.10
+20	1975.7 - 1976.1, 1976.6 - 1976.9, 1976.8 - 1976.11, 1979.6 - 1979.9, 1981.7-1981.10, 1982.7 - 1982.10
+80	1976.12 - 1977.3
+15	1977.7 - 1978.4, 1979.1 - 1979.4, 1980.7 - 1981.1, 1984.3 - 1984.6
—20	1984.11 - 1985.2
α_3	**t**
+40	1960.2 - 1960.8, 1960.4 - 1960.8
—20	1961.1 - 1961.5, 1963.9 - 1964.1, 1966.1 - 1966.5, 1973.4 - 1973.10
+10	1961.6 - 1961.10, 1961.7 - 1962.1, 1967.1 - 1967.5, 1981.9 - 1982.2

a_3	t
—15	1961.12 - 1962.6, 1974.12 - 1975.8, 1975.2 - 1975.6, 1981.10 - 1982.2
+20	1962.8 - 1963.2, 1964.2 - 1964.6, 1972.4 - 1972.8
—10	1964.3 - 1964.7, 1973.1 - 1973.7, 1975.9 - 1976.1, 1984.5 - 1984.11
+15	1964.5 - 1964.9, 1986.7 - 1986.11
—30	1967.11 - 1968.3, 1968.12 - 1969.4, 1973.2 - 1973.6
—50	1977.1 - 1977.4, 1977.3 - 1977.6
+60	1984.12 - 1985.4

a_4	t
—25	1961.2 - 1961.6
+10	1964.11 - 1965.2, 1967.10 - 1968.1, 1976.2 - 1976.5, 1982.12 - 1983.3
+20	1966.11 - 1967.2
+15	1967.4 - 1967.8, 1972.2 - 1972.5
—20	1968.3 - 1968.6, 1979.2 - 1979.8, 1980.4 - 1980.7, 1981.2 - 1981.5, 1982.4-1982.7, 1984.1 - 1984.4
—30	1970.11 - 1971.8, 1977.4 - 1977.7, 1979.12 - 1980.3
—10	1971.1 - 1971.4, 1977.10 - 1978.1
—15	1973.12 - 1974.3, 1976.3 - 1976.6, 1976.9 - 1976.12

TABLE 14A

Toronto Station, 1960 - 1986. Observed and computed MVTOZ.

Year/month	comp.	obs.	Year/month	comp.	obs.
1960. 1	385	393	1963. 1	440	440
» 2	429	428	» 2	438	444
» 3	476	477	» 3	410	411
» 4	403	401	» 4	411	413
» 5	388	390	» 5	401	400
» 6	373	369	» 6	375	375
» 7	348	351	» 7	374	367
» 8	330	328	» 8	351	357
» 9	310	313	» 9	322	320
» 10	304	310	» 10	309	307
» 11	323	320	» 11	323	325
» 12	373	371	» 12	365	369
1961. 1	398	402	1964. 1	372	372
» 2	383	386	» 2	395	399
» 3	388	386	» 3	430	429
» 4	445	445	» 4	393	392
» 5	405	404	» 5	368	365
» 6	355	353	» 6	355	354
» 7	345	344	» 7	365	343
» 8	327	329	» 8	332	333
» 9	300	296	» 9	310	309
» 10	307	311	» 10	317	317
» 11	310	310	» 11	310	308
» 12	344	340	» 12	343	341
1962. 1	370	372	1965. 1	376	378
» 2	429	429	» 2	383	383
» 3	451	453	» 3	410	415
» 4	429	437	» 4	406	409
» 5	373	369	» 5	371	369
» 6	360	360	» 6	360	357
» 7	352	354	» 7	352	351
» 8	334	334	» 8	334	336
» 9	330	328	» 9	310	306
» 10	317	315	» 10	317	311
» 11	316	315	» 11	323	322
» 12	360	365	» 12	347	351

Year/month	comp.	obs.	Year/month	comp.	obs.
1966. 1	385	386	1969. 1	355	350
» 2	416	417	» 2	403	402
» 3	423	424	» 3	440	439
» 4	429	422	» 4	403	402
» 5	414	421	» 5	388	394
» 6	375	368	» 6	360	364
» 7	361	353	» 7	335	337
» 8	347	340	» 8	330	330
» 9	336	340	» 9	323	319
» 10	332	330	» 10	317	316
» 11	319	319	» 11	323	326
» 12	360	358	» 12	373	365
1967. 1	368	362	1970. 1	411	416
» 2	413	415	» 2	416	417
» 3	393	395	» 3	423	418
» 4	376	373	» 4	390	394
» 5	398	399	» 5	362	365
» 6	347	345	» 6	360	353
» 7	344	346	» 7	348	350
» 8	339	340	» 8	330	331
» 9	312	322	» 9	310	312
» 10	295	295	» 10	304	308
» 11	323	323	» 11	323	327
» 12	321	319	» 12	334	333
1968. 1	385	381	1971. 1	411	419
» 2	433	430	» 2	394	392
» 3	397	397	» 3	436	430
» 4	373	371	» 4	420	420
» 5	405	403	» 5	388	382
» 6	360	359	» 6	360	353
» 7	348	346	» 7	352	351
» 8	330	328	» 8	334	333
» 9	310	309	» 9	311	307
» 10	304	305	» 10	280	279
» 11	323	323	» 11	314	312
» 12	360	364	» 12	325	325

Year/month	comp.	obs.	Year/month	comp.	obs.
1972. 1	350	356	1975. 1	370	368
» 2	403	406	» 2	403	403
» 3	423	426	» 3	410	411
» 4	390	392	» 4	403	409
» 5	408	410	» 5	388	390
» 6	373	372	» 6	360	366
» 7	345	348	» 7	350	347
» 8	334	333	» 8	334	337
» 9	310	303	» 9	328	329
» 10	317	322	» 10	307	306
» 11	336	339	» 11	319	320
» 12	334	333	» 12	353	351
1973. 1	359	356	1976. 1	385	382
» 2	393	394	» 2	368	368
» 3	380	381	» 3	384	386
» 4	413	411	» 4	381	384
» 5	398	400	» 5	401	402
» 6	350	353	» 6	360	358
» 7	355	353	» 7	352	353
» 8	334	336	» 8	334	335
» 9	307	313	» 9	327	330
» 10	307	307	» 10	321	324
» 11	319	318	» 11	349	350
» 12	340	338	» 12	360	350
1974. 1	355	358	1977. 1	454	452
» 2	406	417	» 2	422	420
» 3	410	414	» 3	410	410
» 4	403	402	» 4	403	402
» 5	388	388	» 5	388	387
» 6	373	376	» 6	384	381
» 7	348	347	» 7	361	351
» 8	347	340	» 8	330	328
» 9	319	321	» 9	323	321
» 10	317	316	» 10	317	311
» 11	336	311	» 11	314	314
» 12	360	363	» 12	356	360

Year/month	comp.	obs.	Year/month	comp.	obs.
1978. 1	375	366	1981. 1	385	378
» 2	399	394	» 2	403	399
» 3	403	403	» 3	427	429
» 4	386	383	» 4	393	395
» 5	378	375	» 5	400	402
» 6	360	360	» 6	375	370
» 7	335	335	» 7	347	342
» 8	317	322	» 8	341	340
» 9	310	308	» 9	317	324
» 10	317	310	» 10	320	323
» 11	301	295	» 11	324	324
» 12	325	325	» 12	335	336
1979. 1	385	380	1982. 1	383	379
» 2	416	413	» 2	396	391
» 3	406	402	» 3	410	408
» 4	420	423	» 4	410	412
» 5	388	389	» 5	371	374
» 6	360	367	» 6	377	378
» 7	352	352	» 7	344	344
» 8	334	337	» 8	334	336
» 9	310	317	» 9	327	326
» 10	317	322	» 10	297	291
» 11	310	312	» 11	301	305
» 12	334	334	» 12	320	325
1980. 1	359	361	1983. 1	359	361
» 2	429	432	» 2	364	367
» 3	410	406	» 3	393	386
» 4	403	412	» 4	383	382
» 5	371	373	» 5	381	376
» 6	377	377	» 6	350	354
» 7	335	340	» 7	335	327
» 8	330	327	» 8	326	325
» 9	323	323	» 9	309	313
» 10	317	317	» 10	300	300
» 11	323	319	» 11	316	315
» 12	347	346	» 12	343	345

Year/month		comp.	obs.
1984.	1	375	378
»	2	386	385
»	3	427	429
»	4	416	416
»	5	401	402
»	6	350	350
»	7	335	338
»	8	327	329
»	9	310	316
»	10	291	293
»	11	323	321
»	12	299	300
1985.	1	397	399
»	2	394	399
»	3	362	362
»	4	377	377
»	5	362	361
»	6	360	359
»	7	344	342
»	8	326	329
»	9	310	304
»	10	291	288
»	11	310	311
»	12	360	360
1986.	1	385	393
»	2	388	390
»	3	393	391
»	4	382	387
»	5	362	363
»	6	345	345
»	7	335	335
»	8	332	331
»	9	310	305
»	10	302	307
»	1	321	323
»	12	—	—

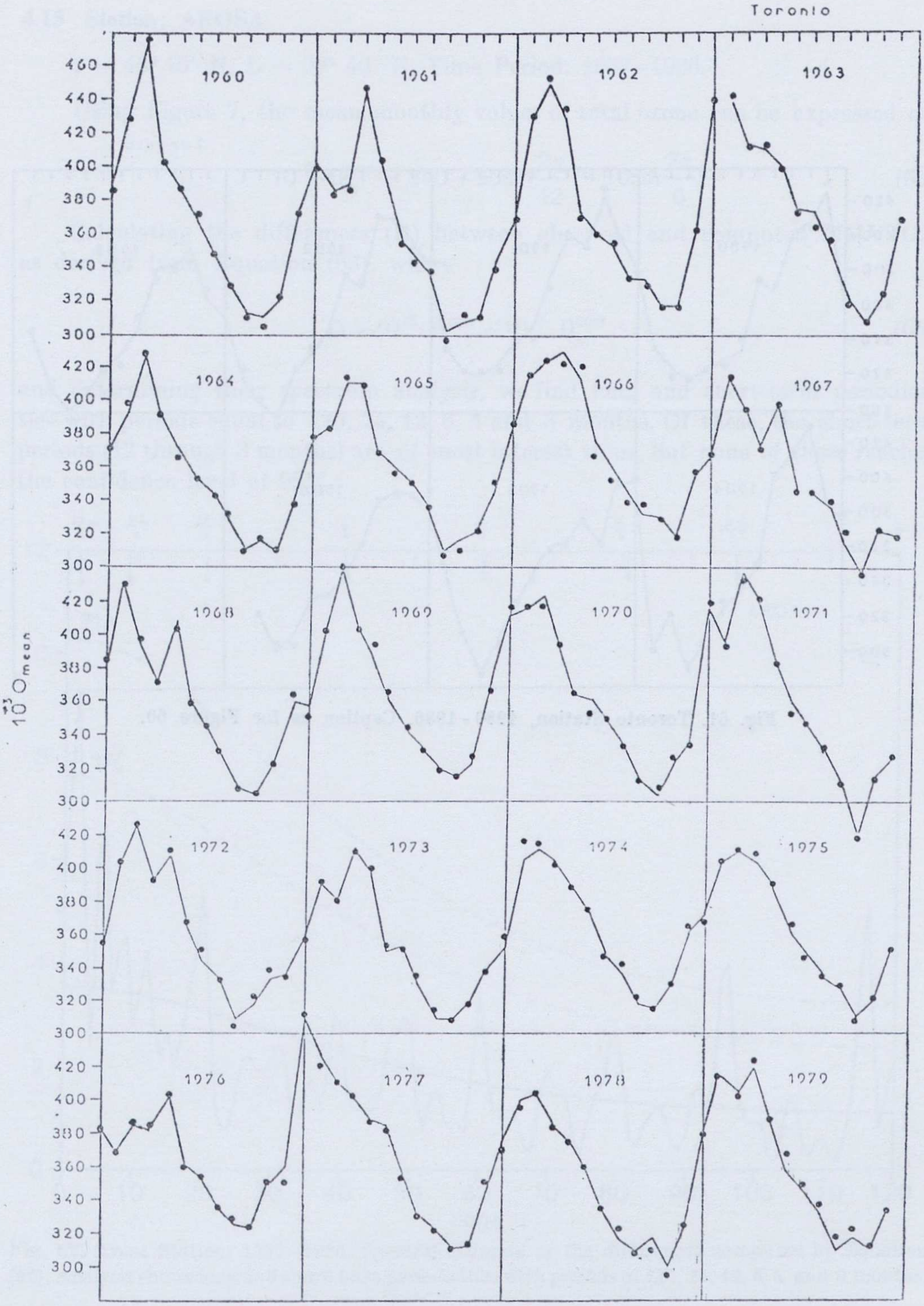

Fig. 60. Toronto Station, 1960 - 1979, Observed MVTOZ is shown by dots. MVTOZ as found by Equation (62) is shown by a solid line. Accuracy is equal to 99.1%.

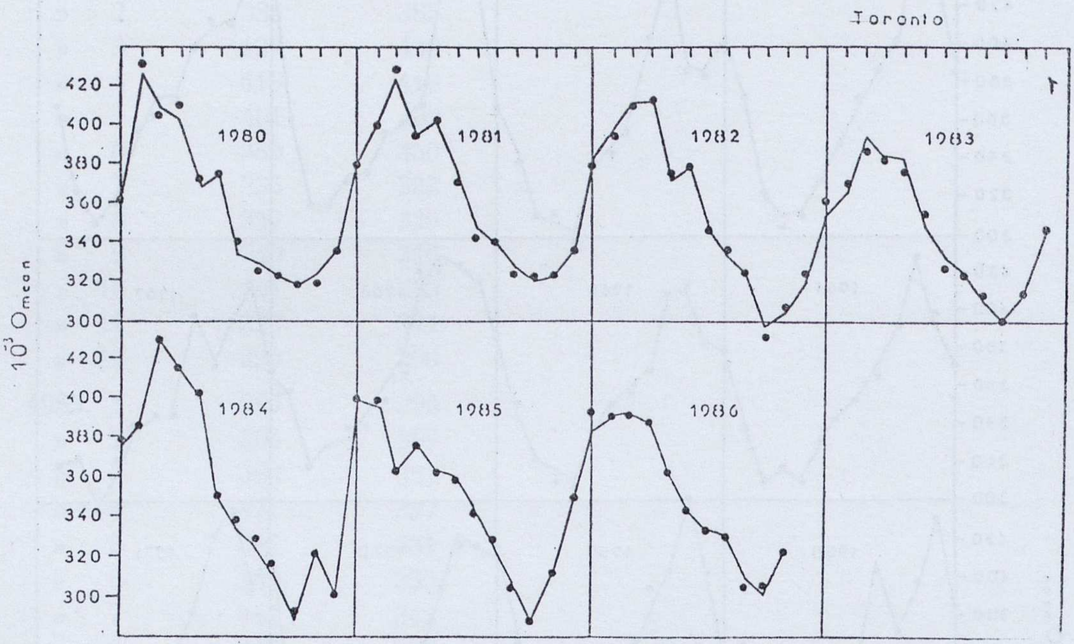

Fig. 61. Toronto Station, 1980 - 1986. Caption as for Figure 60.

4.15 Station: AROSA

$\varphi = 46^0\,46'$ N, L = $09^0\,40'$ E, Time Period: 1957 - 1986.

Using Figure 7, the mean monthly volues of total ozone can be expressed as:

$$10^{-3} \cdot 0_m^{com} = 340 + 50\sin\frac{2\pi}{12}t + 10\sin\frac{2\pi}{6}t \tag{63}$$

Calculating the differences (D) between observed and computed MMVTOZ as derived from Equation (63), where

$$D = 10^{-3} \cdot 0^{obs} - 10^{-3} \cdot 0_m^{com} \tag{64}$$

and determining their spectrum analysis, we find long and short-term periodicities with periods equal to 120, 24, 12, 6, 4 and 3 months. Of these, the short-term periods (12 through 3 months) are of most interest to us, but none of these reaches the confidence level of 95%.

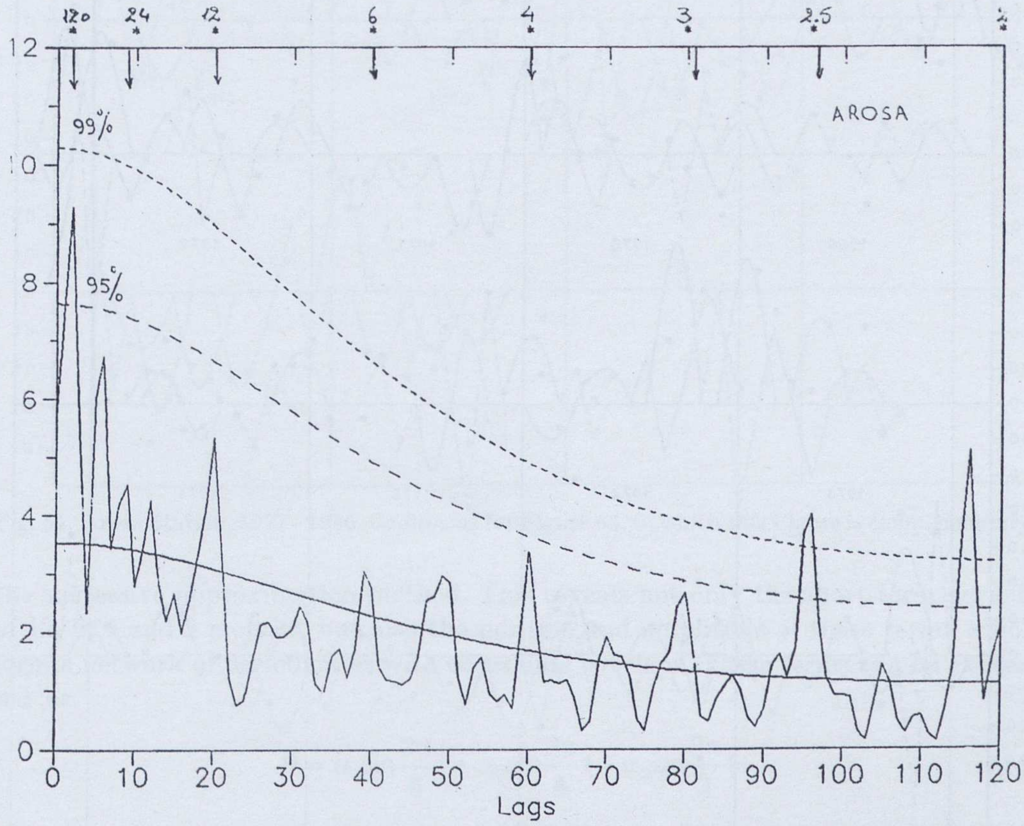

Fig. 62. Arosa Station, 1957 - 1986. Spectral estimate of the differences computed by Equation (63). Analysis shows long and short-term periodicities with periods of 120, 24, 12, 6, 4 and 3 months.

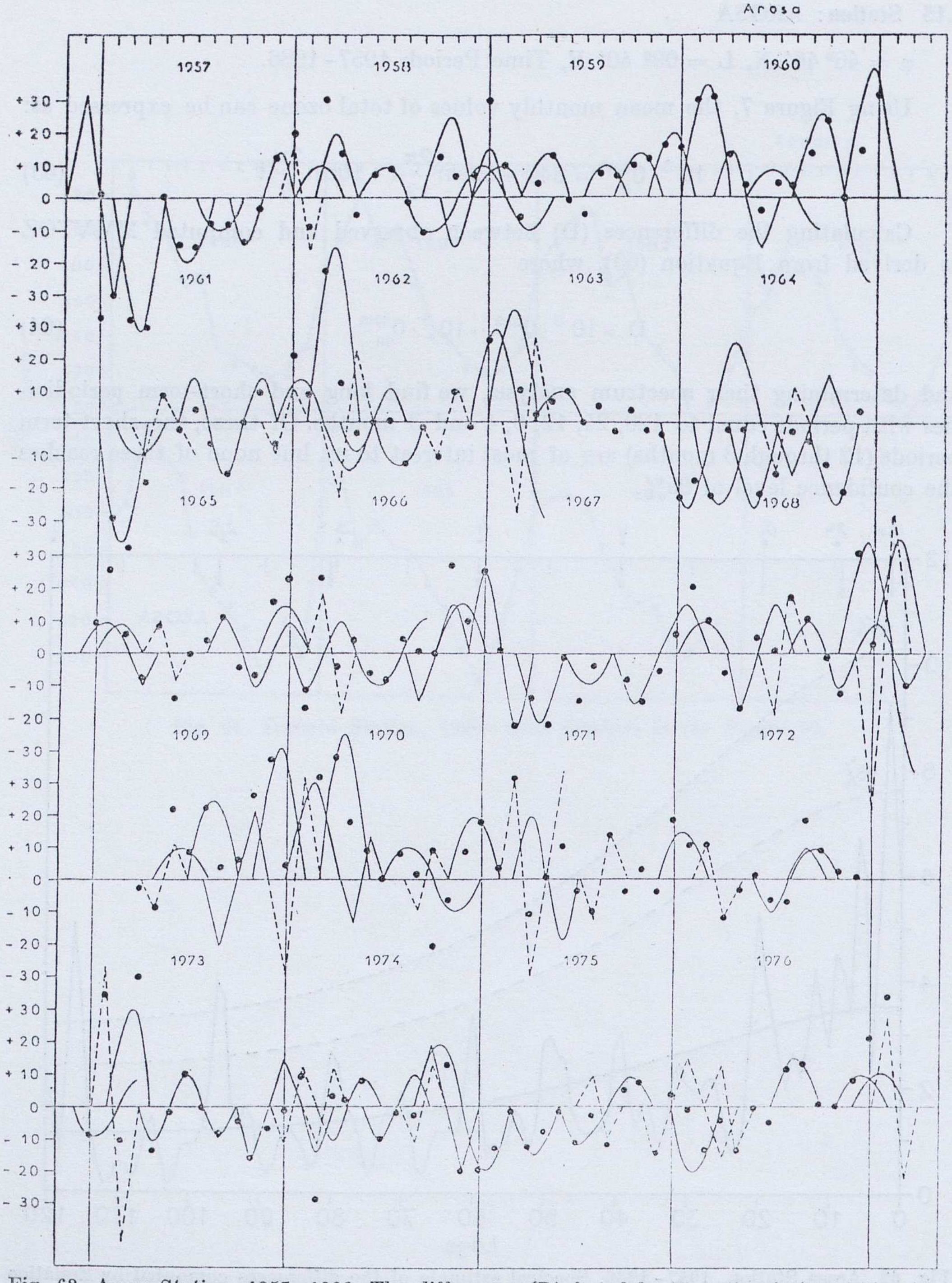

Fig. 63. Arosa Station, 1957-1986. The differences (D) found by Equation (64) are shown by dots. The dashed and solid sinusoidal or semisinusoidal curves show periodic terms of 12, 6, 4 and 3 months, whose position and amplitude is also plotted, by the successive approximation method.

In Figures 63 and 64 the dots or open circles represent the differences (D) found by Equation (64), while the sinusoidal and semisinusoidal curves are plotted by

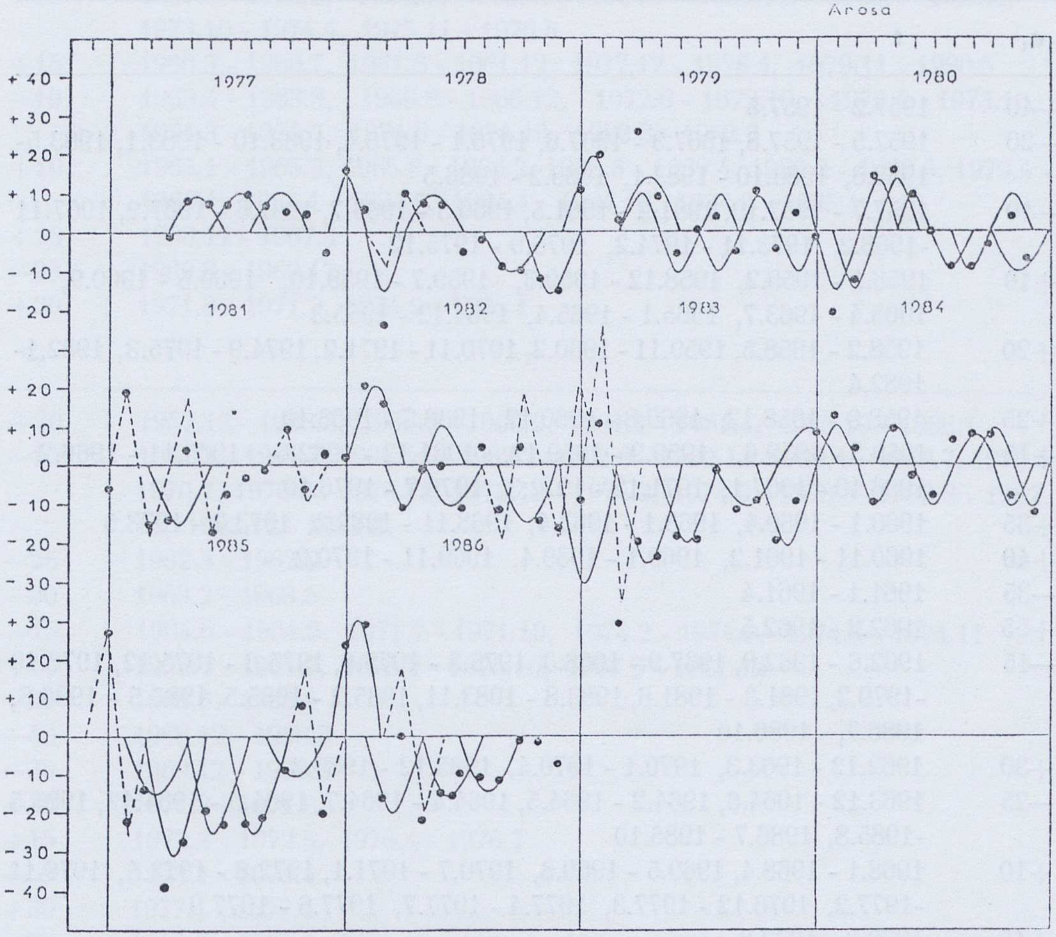

Fig. 64. Arosa Station, 1977 - 1986. Caption as for Figure 63, to which this Figure is complementary.

the successive approximation method. This reveals not only the short-term periods of 12, 6, 4 and 3 months, but also the position and amplitude of these terms which form a network of periodicities with occasional overlaps. These terms can be expressed as:

$$P = \alpha_1 \sin\frac{2\pi}{6}t + \alpha_2 \sin\frac{2\pi}{4}t + \alpha_3 \sin\frac{2\pi}{3}t \tag{65}$$

The numerical values of the parameters α_1, α_2 and α_3 as well as of **t**, in Equation (65) are listed in Table 15.

TABLE 15

Values of the parameters α_1, α_2, α_3, and **t** (see Eq. 65).

α_1	t
—40	1957.2 - 1957.5
—20	1957.5 - 1957.8, 1967.3 - 1967.6, 1976.1 - 1976.4, 1983.10 - 1983.1, 1983.5-1983.8, 1983.10 - 1983.1, 1986.2 - 1986.5
—10	1957.7 - 1957.10, 1961.2 - 1961.5, 1966.5 - 1966.7, 1967.6 - 1967.9, 1967.11 -1968.2, 1973.11 - 1974.2, 1975.9 - 1975.12
+10	1958.1 - 1959.2, 1958.12 - 1959.3, 1959.7 - 1959.10, 1960.5 - 1960.9, 1963.4 - 1963.7, 1965.1 - 1965.4, 1964.12 - 1965.3
+20	1958.2 - 1958.5, 1959.11 - 1960.2, 1970.11 - 1971.2, 1974.9 - 1975.3, 1982.1-1982.4
+25	1958.9 - 1958.12, 1960.8 - 1960.12, 1968.7 - 1968.10
+15	1959.3 - 1959.6, 1959.9 - 1959.12, 1961.12 - 1962.6, 1965.11 - 1966.2 1966.10 - 1967.1, 1971.12 - 1972.3, 1976.7 - 1976.10
+35	1960.1 - 1960.4, 1963.1 - 1963.4, 1968.11 - 1969.2, 1973.2 - 1973.5
+40	1960.11 - 1961.2, 1969.1 - 1969.4, 1969.11 - 1970.2
—35	1961.1 - 1961.4
+55	1962.2 - 1962.5
—15	1962.6 - 1962.9, 1967.9 - 1968.3, 1975.3 - 1975.6, 1975.6 - 1975.12, 1978.10 -1979.2, 1981.3 - 1981.6, 1983.8 - 1983.11, 1985.2 - 1985.5, 1986.5 - 1986.8, 1986.7, - 1986.10
+30	1962.12 - 1963.3, 1970.1 - 1970.4, 1985.12 - 1986.3
—25	1963.12 - 1964.6, 1964.2 - 1964.5, 1964.4 - 1964.7, 1964.9 - 1964.12, 1985.5 -1985.8, 1986.7 - 1986.10
+10	1968.1 - 1968.4, 1969.5 - 1969.8, 1970.7 - 1971.1, 1972.8 - 1973.4, 1976.11 -1977.2, 1976.12 - 1977.3, 1977.4 - 1977.7, 1977.6 - 1977.9
+45	1970.3 - 1970.6
+10	1978.4 - 1978.7, 1978.12 - 1979.3, 1983.11 - 1984.2
—10	1978.8 - 1978.11, 1980.1 - 1980.3, 1980.11 - 1981.2, 1982.5 - 1982.8, 1985.9 -1985.12
+15	1979.3 - 1979.6, 1980.4 - 1980.10
—45	1983.2 - 1983.5
—30	1985.3 - 1985.6

α_2	t
+30	1956.12 - 1957.3
–15	1957.9 - 1958.1, 1958.10 - 1959.2, 1964.7 - 1964.11, 1968.4 - 1968.8, 1973.10 - 1974.4, 1975.11 - 1976.5
+15	1960.3 - 1960.7, 1961.6 - 1961.12, 1977.12 - 1978.4, 1979.11 - 1980.5
–10	1963.4 - 1963.8, 1966.8 - 1966.12, 1972.6 - 1972.10, 1973.4 - 1973.10, 1974.3 - 1974.7, 1974.6 - 1974.10, 1982.3 - 1982.7
+10	1965.1 - 1965.5, 1965.8 - 1966.2, 1968.8 - 1969.4, 1970.2 - 1970.6, 1979.4 - 1980.1, 1984.1 - 1984.5, 1984.4 - 1984.12, 1984.9 - 1985.1
+25	1966.12 - 1967.4
–20	1969.8 - 1969.12
+20	1971.3 - 1971.7, 1974.9 - 1975.1

α_3	t
+20	1957.12 - 1958.3, 1966.2 - 1966.5, 1981.1 - 1981.4, 1985.10 - 1986.1
–10	1961.3 - 1961.7, 1961.11 - 1962.2, 1962.9 - 1962.12, 1969.4 - 1969.7, 1970.4 1970.7, 1970.8 - 1970.11, 1973.12 - 1974.3, 1978.2 - 1978.5, 1982.8 - 1982. 11, 1982.12 - 1983.3
–25	1962.3 - 1962.6
–30	1963.2 - 1963.5
–15	1964.6 - 1964.9, 1971.7 - 1971.10, 1974.2 - 1974.8, 1974.8 - 1974.11
+10	1965.4 - 1965.7, 1975.7 - 1975.10, 1981.9 - 1981.12
–20	1968.6 - 1968.9
–40	1968.12 - 1969.3
–35	1969.12 - 1970.3
+35	1971.2 - 1971.6
+15	1972.2 - 1972.5, 1976.4 - 1976.7
–50	1973.1 - 1973.4
+30	1977.1 - 1977.4
+25	1983.3 - 1983.6, 1984.12 - 1985.3, 1986.3 - 1986.6

Summing Equation (63) and Equation (65), we obtain:

$$10^{-3} \cdot 0^{com} = 10^{-3} \cdot 0^{com}_{m} + P \tag{66}$$

This new equation governs the variation and periodicity of the MVTOZ and represents the observed data of total ozone with an accuracy equal to 99.1%. The s.d. between observed and computed monthly values of total ozone is $\sigma = \pm 2.6$ and Equation (66) has 32 degrees of freedom. These results are confirmed by Figures 65 and 66, where the dots represent observed MVTOZ while the solid line gives the year to year variation of MVTOZ, computed by Equation 66 from 1957 through 1986. The agreement between the observed and computed monthly values of total ozone is remarkably close.

Table 15A lists the numerical values plotted in Figures 65 and 66.

TABLE 15A

Arosa Station, 1957 - 1986. Observed and computed MVTOZ.

Year/month	comp.	obs.
1957. 1	330	332
» 2	325	325
» 3	334	335
» 4	341	340
» 5	364	365
» 6	329	332
» 7	313	315
» 8	305	306
» 9	287	288
» 10	265	266
» 11	287	284
» 12	320	318
1958. 1	347	350
» 2	347	347
» 3	399	405
» 4	397	394
» 5	364	359
» 6	355	354
» 7	339	339
» 8	314	313
» 9	287	286
» 10	293	293
» 11	294	294
» 12	312	312
1959. 1	363	360
» 2	364	365
» 3	364	367
» 4	383	384
» 5	376	378
» 6	346	345
» 7	330	326
» 8	323	322
» 9	305	303
» 10	292	290
» 11	299	299
» 12	322	322

Year/month	comp.	obs.
1960. 1	347	346
» 2	386	385
» 3	403	404
» 4	395	393
» 5	364	368
» 6	340	342
» 7	339	335
» 8	314	318
» 9	309	310
» 10	302	303
» 11	287	288
» 12	318	320
1961. 1	365	363
» 2	325	326
» 3	334	335
» 4	362	362
» 5	373	373
» 6	346	344
» 7	336	334
» 8	314	309
»	281	281
» 10	280	280
» 11	302	296
» 12	296	298
1962. 1	354	351
» 2	367	364
» 3	421	421
» 4	394	392
» 5	364	361
» 6	346	347
» 7	328	331
» 8	302	302
» 9	296	295
» 10	271	270
» 11	296	297
» 12	305	304

Year/month	comp.	obs.	Year/month	comp.	obs.
1963. 1	356	356	1966. 1	352	353
» 2	411	414	» 2	345	344
» 3	377	383	» 3	390	396
» 4	380	383	» 4	373	376
» 5	373	371	» 5	364	368
» 6	355	356	» 6	337	340
» 7	330	330	» 7	321	322
» 8	314	319	» 8	314	318
» 9	296	294	» 9	295	297
» 10	280	284	» 10	280	280
» 11	287	285	» 11	309	314
» 12	305	302	» 12	317	315
1964. 1	308	308	1967. 1	355	355
» 2	333	338	» 2	355	356
» 3	351	351	» 3	348	351
» 4	380	379	» 4	363	367
» 5	364	363	» 5	347	342
» 6	324	325	» 6	346	345
» 7	318	315	» 7	321	316
» 8	311	312	» 8	305	310
» 9	296	292	» 9	296	292
» 10	273	268	» 10	269	272
» 11	265	267	» 11	275	273
» 12	305	309	» 12	296	300
1965. 1	339	339	1968. 1	333	334
» 2	383	381	» 2	376	376
» 3	382	379	» 3	382	383
» 4	370	372	» 4	280	374
» 5	373	372	» 5	349	348
» 6	337	332	» 6	346	350
» 7	330	330	» 7	328	331
» 8	314	318	» 8	331	332
» 9	306	307	» 9	306	307
» 10	280	276	» 10	280	278
» 11	277	280	» 11	277	275
» 12	317	321	» 12	335	335

Year/month		comp.	obs.	Year/month		comp.	obs.
1969.	1	331	333	1972.	1	342	348
»	2	429	427	»	2	367	366
»	3	368	363	»	3	385	384
»	4	380	377	»	4	368	367
»	5	355	355	»	5	364	361
»	6	364	368	»	6	346	348
»	7	339	338	»	7	320	325
»	8	336	336	»	8	314	307
»	9	298	299	»	9	315	314
»	10	289	286	»	10	289	289
»	11	316	313	»	11	287	289
»	12	340	342	»	12	305	305
1970.	1	335	334	1973.	1	321	321
»	2	410	409	»	2	391	389
»	3	408	405	»	3	358	362
»	4	419	418	»	4	419	420
»	5	384	382	»	5	354	350
»	6	355	355	»	6	346	344
»	7	330	330	»	7	340	340
»	8	323	322	»	8	314	313
»	9	296	297	»	9	286	288
»	10	289	289	»	10	280	285
»	11	278	280	»	11	272	271
»	12	313	313	»	12	296	298
1971.	1	347	347	1974.	1	327	329
»	2	355	357	»	2	364	364
»	3	403	404	»	3	346	344
»	4	370	369	»	4	382	383
»	5	364	365	»	5	364	366
»	6	356	356	»	6	356	354
»	7	330	326	»	7	320	320
»	8	302	304	»	8	314	312
»	9	308	311	»	9	294	293
»	10	280	276	»	10	329	329
»	11	287	290	»	11	304	300
»	12	305	301	»	12	285	285

Year/month	comp.	obs.	Year/month	comp.	obs.
1975. 1	313	310	1978. 1	345	346
» 2	338	342	» 2	355	361
» 3	373	371	» 3	349	349
» 4	368	367	» 4	389	390
» 5	352	356	» 5	373	371
» 6	346	344	» 6	355	353
» 7	318	318	» 7	330	325
» 8	311	310	» 8	314	312
» 9	287	284	» 9	287	287
» 10	283	285	» 10	271	270
» 11	290	294	» 11	275	275
» 12	290	290	» 12	293	290
1976. 1	330	334	1979. 1	339	341
» 2	353	353	» 2	376	375
» 3	356	359	» 3	373	376
» 4	377	375	» 4	402	406
» 5	352	350	» 5	376	372
» 6	346	345	» 6	336	341
» 7	330	324	» 7	330	331
» 8	326	325	» 8	314	318
» 9	308	309	» 9	296	291
» 10	280	280	» 10	290	291
» 11	287	287	» 11	287	283
» 12	314	312	» 12	310	310
1977. 1	348	350	1980. 1	330	329
» 2	389	388	» 2	331	334
» 3	348	349	» 3	364	360
» 4	380	379	» 4	395	394
» 5	373	372	» 5	376	380
» 6	356	353	» 6	358	355
» 7	339	337	» 7	330	330
» 8	323	323	» 8	302	305
» 9	296	303	» 9	284	287
» 10	280	274	» 10	280	277
» 11	287	281	» 11	287	291
» 12	305	299	» 12	296	298

Year/month	comp.	obs.	Year/month	comp.	obs.
1981. 1	321	324	1984. 1	339	338
» 2	372	374	» 2	365	367
» 3	356	358	» 3	373	377
» 4	368	366	» 4	370	370
» 5	369	368	» 5	374	373
» 6	329	328	» 6	346	344
» 7	330	323	» 7	320	322
» 8	314	311	» 8	314	320
» 9	296	295	» 9	306	303
» 10	289	290	» 10	290	287
» 11	278	281	» 11	277	279
» 12	305	308	» 12	295	292
1982. 1	330	332	1985. 1	355	357
» 2	372	376	» 2	330	333
» 3	390	389	» 3	361	359
» 4	370	369	» 4	343	341
» 5	364	363	» 5	339	337
» 6	347	346	» 6	324	327
» 7	321	319	» 7	308	307
» 8	314	319	» 8	292	291
» 9	287	285	» 9	274	275
» 10	289	286	» 10	271	272
» 11	270	273	» 11	290	295
» 12	288	289	» 12	288	285
1983. 1	291	292	1986. 1	355	354
» 2	364	366	» 2	380	384
» 3	334	332	» 3	356	356
» 4	363	361	» 4	385	380
» 5	342	341	» 5	342	342
» 6	329	329	» 6	334	331
» 7	313	311	» 7	318	320
» 8	314	313	» 8	302	303
» 9	284	284	» 9	284	285
» 10	268	271	» 10	280	279
» 11	270	268	» 11	287	286
» 12	297	296	» 12	305	289

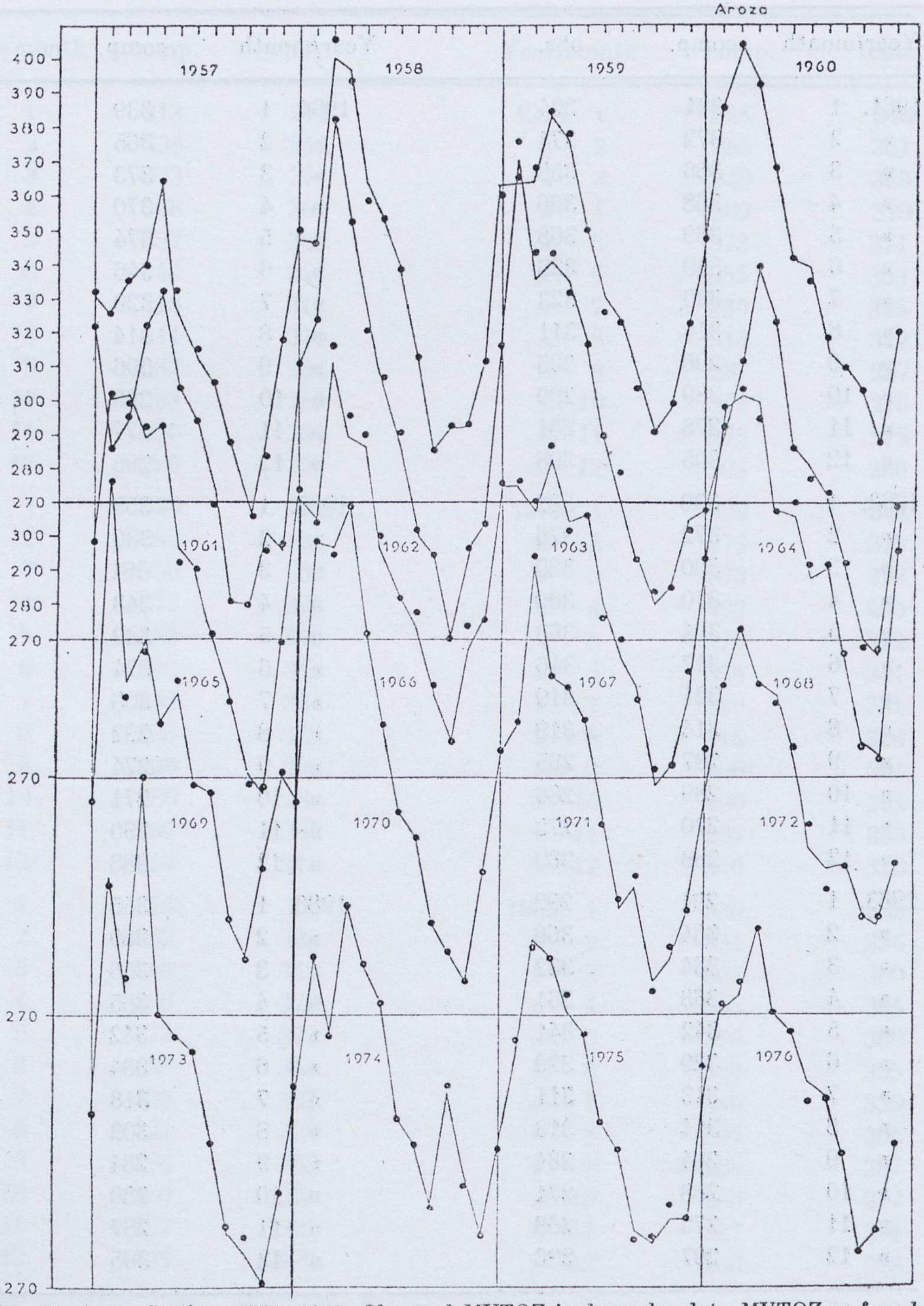

Fig. 65. Arosa Station, 1957 - 1976. Observed MVTOZ is shown by dots. MVTOZ as found by Equation (66) is shown by a solid line. Accuracy is equal to 99.1%.

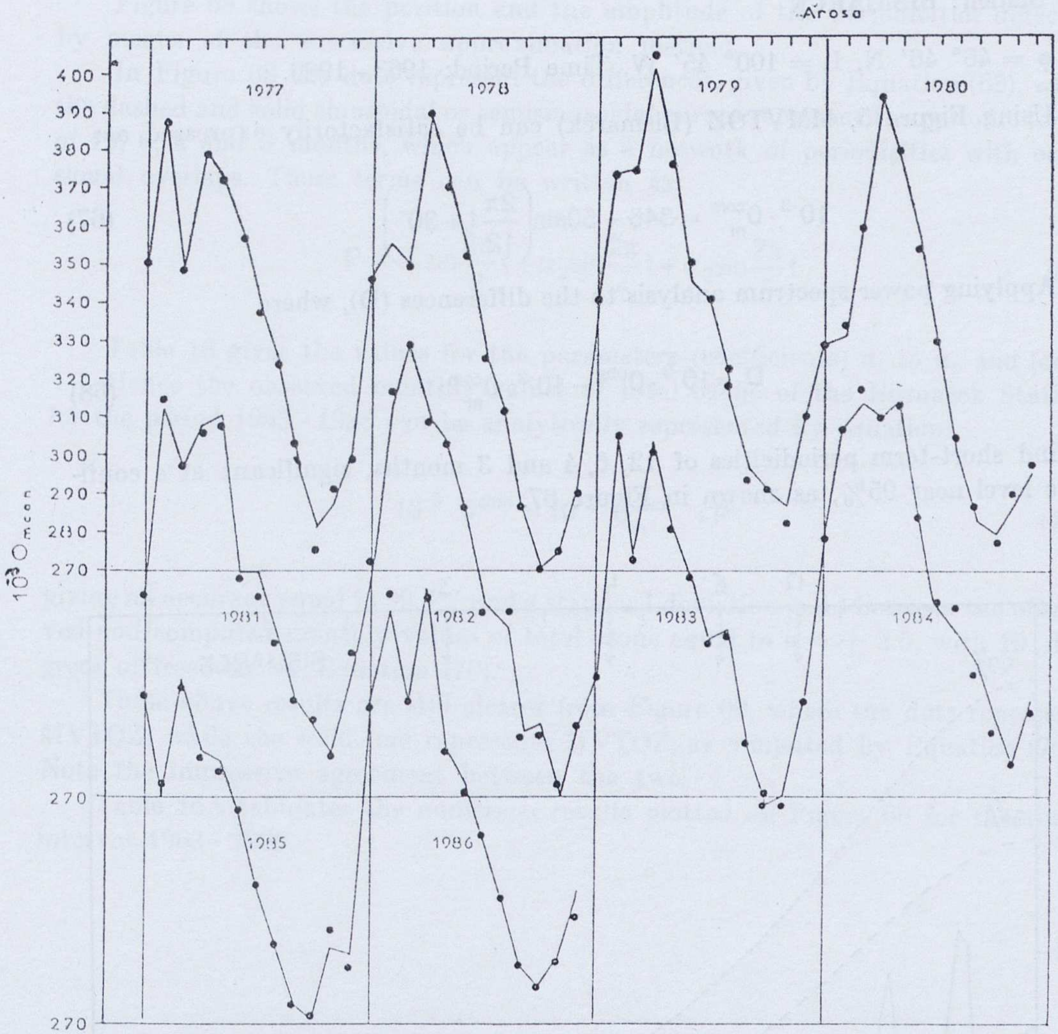

Fig. 66. Arosa Station, 1977 - 1986. Caption as for Figure 65, to which this Figure is complementary.

4.16 Station: BISMARCK

$\varphi = 46° \ 46'$ N, L = $100° \ 45'$ W, Time Period: 1963 - 1986.

Using Figure 5, MMVTOZ (Bismarck) can be satisfactorily expressed as:

$$10^{-3} \cdot 0^{com}_{m} = 346 + 50 \sin\left(\frac{2\pi}{12} t + 30°\right) \tag{67}$$

Applying power spectrum analysis to the differences (D), where

$$D = 10^{-3} \cdot 0^{obs} - 10^{-3} \cdot 0^{com}_{m} \tag{68}$$

we find short-term periodicities of 12, 6, 4 and 3 months, significant at a confidence level near 95%, as shown in Figure 67.

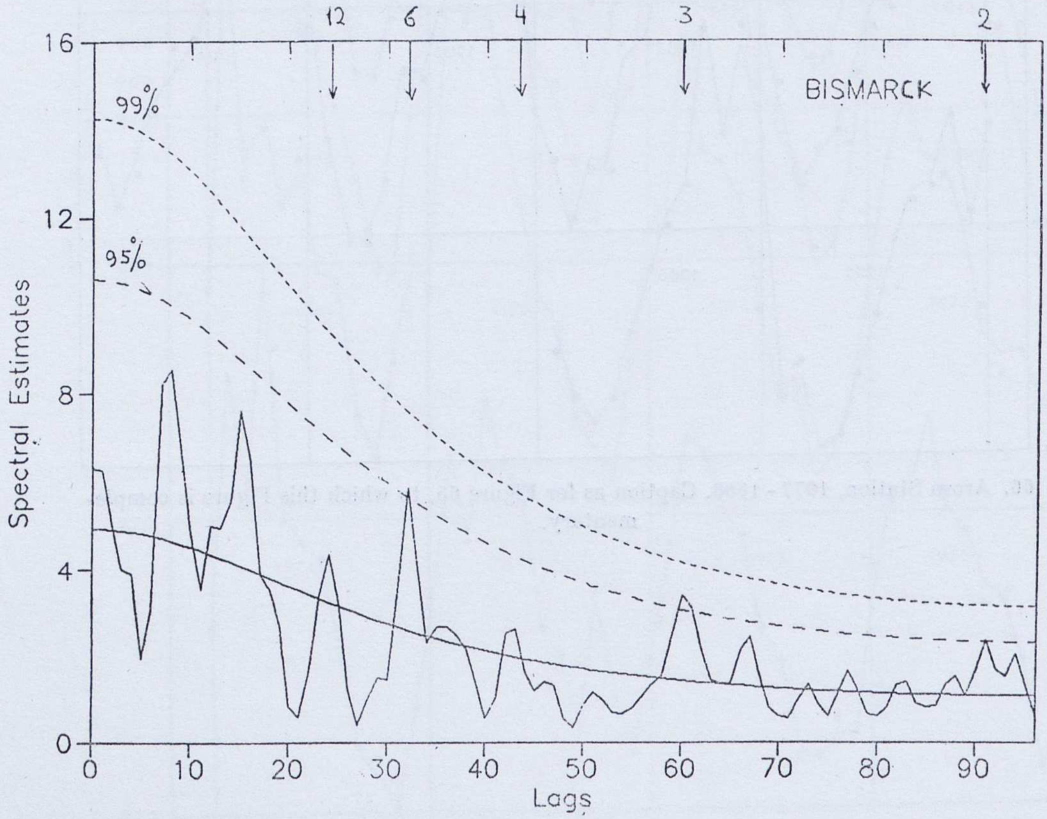

Fig. 67. Bismarck Station, 1963 - 1986. Spectral estimate of the differences computed by Equation (68). Analysis shows short-term periodicities with periods of 12, 6, 4 and 3 months.

Figure 68 shows the position and the amplitude of the periodicities detected by means of the successive approximation method.

In Figure 68 the dots represent the differences, given by Equation (68), while the dashed and solid sinusoidal or semisinusoidal curves represent the periodic terms of 12, 6, 4 and 3 months, which appear as a netwotk of periodicities with occasional overlaps. These terms can be written as:

$$P = \alpha_1 \sin\frac{2\pi}{6} t + \alpha_2 \sin\frac{2\pi}{4} t + \alpha_3 \sin\frac{2\pi}{3} t \tag{69}$$

Table 16 gives the values for the parameters (coefficients) $\boldsymbol{\alpha}_1$ to $\boldsymbol{\alpha}_3$ and for **t**.

Hence the observed monthly values of total ozone of the Bismarck Station for the period 1963 - 1986 can be analytically represented by equation:

$$10^{-3} \cdot 0^{com} = 10^{-3} \cdot 0^{com}_{m} + P \tag{70}$$

giving an accuracy equal to 99.3% and a standard deviation (s.d.) between the observed and computed monthly values of total ozone equal to $\sigma = \pm 2.5$, with 10 degrees of freedom for Equation (70).

These above results are still clearer from Figure 69, where the dots represent MVTOZ, while the solid line rapresents MVTOZ, as computed by Equation (70). Note the impressive agreement between the two.

Table 16A tabulates the numerical results plotted on Figure 69 for the time interval 1963 - 1986.

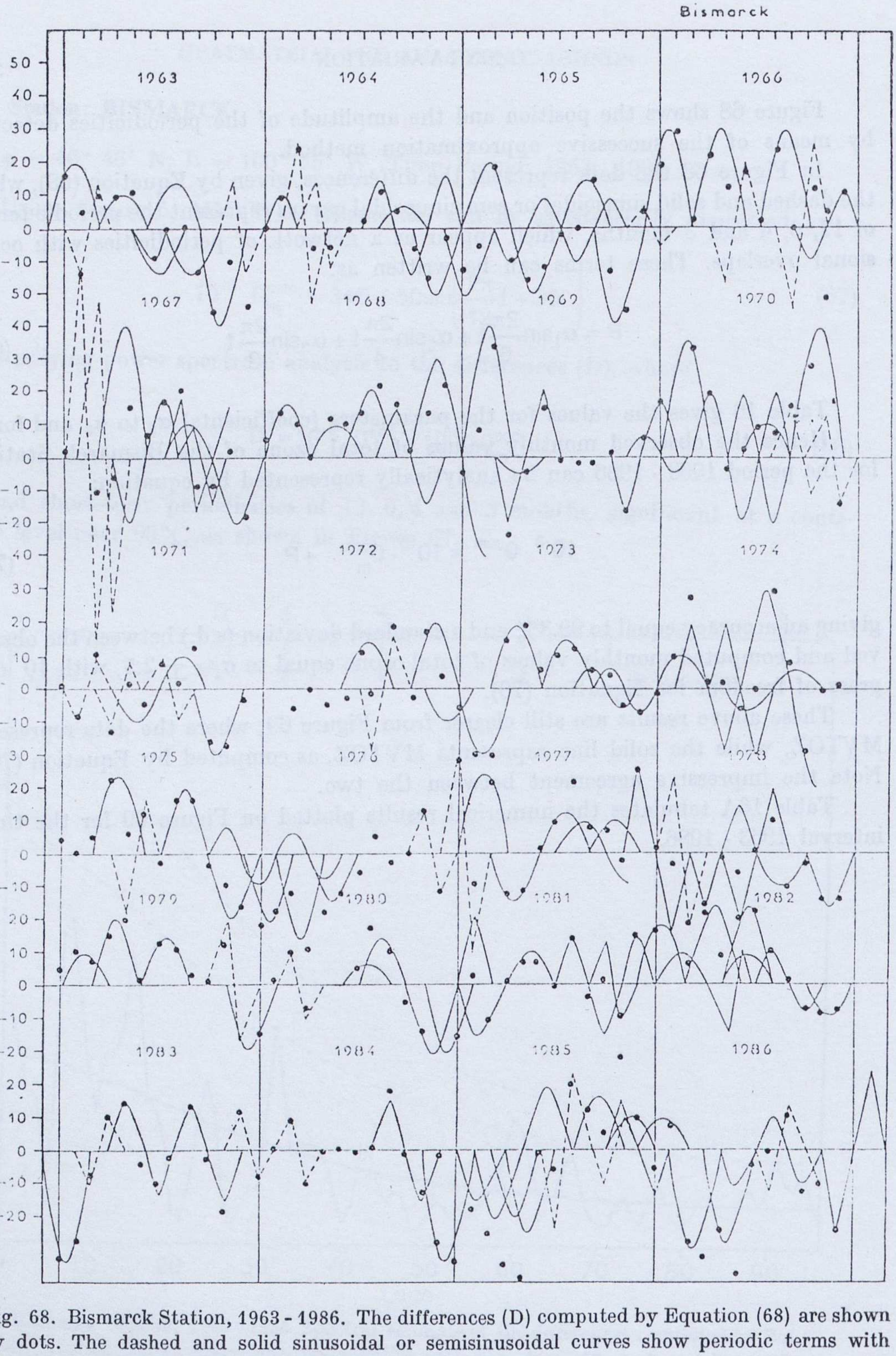

Fig. 68. Bismarck Station, 1963 - 1986. The differences (D) computed by Equation (68) are shown by dots. The dashed and solid sinusoidal or semisinusoidal curves show periodic terms with periods of 12, 6, 4 and 3 months, whose position and amplitude is also plotted, by the successive approximation method. The amplitude of the short-term periods vary from 10 to 50 D.U.

TABLE 16

Values of the parameters α_1, α_2, α_3, and **t** (see Eq. 69).

α_1	t
+20	1962.12, - 1963.3, 1968.6 - 1968.9, 1970.7 - 1970.10, 1972.10 - 1973.1, 1973.3 - 1973.6, 1975.7 - 1975.10, 1979.3 - 1979.6
+10	1963.3 - 1963.6, 1970.6 - 1970.10, 1974.4 - 1974.8, 1977.7 - 1977.11, 1977.7 - 1977.12, 1979.1 - 1979.4
—10	1972.11 - 1973.2, 1982.9 - 1982.12, 1982.11 - 1983.2, 1985.2 - 1985.6
—15	1963.5 - 1963.8, 1963.7 - 1963.10, 1975.10 - 1976.1, 1975.2 - 1975.5, 1975.5 -1975.8, 1977.3 - 1977.9, 1978.10 - 1979.1, 1980.11 - 1981.2, 1985.4 - 1985.7, 1986.10 - 1987.1, 1986.11 - 1987.2
+15	1963.6 - 1963.9, 1968.1 - 1968.4, 1968.4 - 1968.7, 1971.7 - 1971.10, 1972.6-1972.9 , 1973.6 - 1973.9, 1979.6 - 1979.9, 1980.7 - 1980.10, 1982.6 - 1982.9, 1985.7 - 1985.10, 1985.10 - 1986.1
—30	1963.9 - 1963.12, 1965.9 - 1965.12, 1982.12 - 1983.3, 1985.3 - 1985.6
+ 6	1964.8 - 1964.11, 1976.6 - 1976.9
—20	1964.10 - 1965.7, 1964.12 - 1965.3, 1967.10 - 1968.1, 1971.9 - 1971.12, 1973.1 - 1973.4, 1975.12 - 1976.3, 1980.10 - 1981.1
+30	1966.3 - 1966.6, 1966.7 - 1966.10, 1974.6 - 1974.10
+40	1967.3 - 1967.6, 1969.1 - 1969.4, 1970.1 - 1970.4, 1970.9 - 1970.12
+25	1968.10 - 1969.3, 1975.3 - 1975.6, 1977.1 - 1977.4, 1982.3 - 1982.6
— 6	1969.4 - 1969.7, 1971.4 - 1971.7, 1974.5 - 1974.11, 1980.3 - 1980.9, 1986.5-1986.8
—25	1979.11 - 1980.2
—20	1981.1 - 1981.4, 1985.1 - 1985.4
+10	1981.4 - 1981.7, 1982.1 - 1982.4, 1982.5 - 1982.8, 1985.11 - 1986.2
+20	1981.12 - 1982.3
—35	1984.11 - 1985.2, 1986.2 - 1986.5, 1986.4 - 1986.7

α_2	t
—10	1963.11 - 1964.2, 1965.3 - 1965.11
+15	1964.7 - 1965.1, 1968.8 - 1968.12, 1978.7 - 1978.11, 1981.7 - 1982.1, 1983.4-1983.12, 1984.8 - 1984.12, 1985.10 - 1986.2
—15	1966.9 - 1967.1, 1969.10 - 1970.2, 1969.10 - 1970.2
—20	1967.4 - 1967.8, 1969.3 - 1969.7, 1980.11 - 1981.3
+ 6	1969.11 - 1970.3, 1973.8 - 1973.12, 1973.9 - 1974.1

α_2	t
+20	1970.4 - 1970.7, 1970.5 - 1970.9, 1974.4 - 1974.8
+25	1977.11 - 1978.8

α_3	t
—15	1963.1 - 1963.4, 1975.4 - 1975.7, 1982.4 - 1982.7
+15	1963.10 - 1964.1, 1970.10 - 1970.12, 1976.10 - 1976.12, 1979.10 - 1980.1, 1981.7 - 1981.12, 1983.11 - 1984.5, 1986.8 - 1986.11
+25	1964.2 - 1964.5
+20	1964.3 - 1964.6, 1967.7 - 1967.11
+ 6	1965.11 - 1966.2
—20	1966.4 - 1966.7, 1972.7 - 1972.10
—30	1966.8 - 1966.11
+65	1967.1 - 1967.4
+45	1967.2 - 1967.5
+10	1967.8 - 1967.11, 1971.6 - 1971.9, 1980.2 - 1980.5
—10	1971.1 - 1971.4, 1971.3 - 1971.6, 1983.2 - 1983.8, 1985.6 - 1985.9
+30	1976.12 - 1977.3

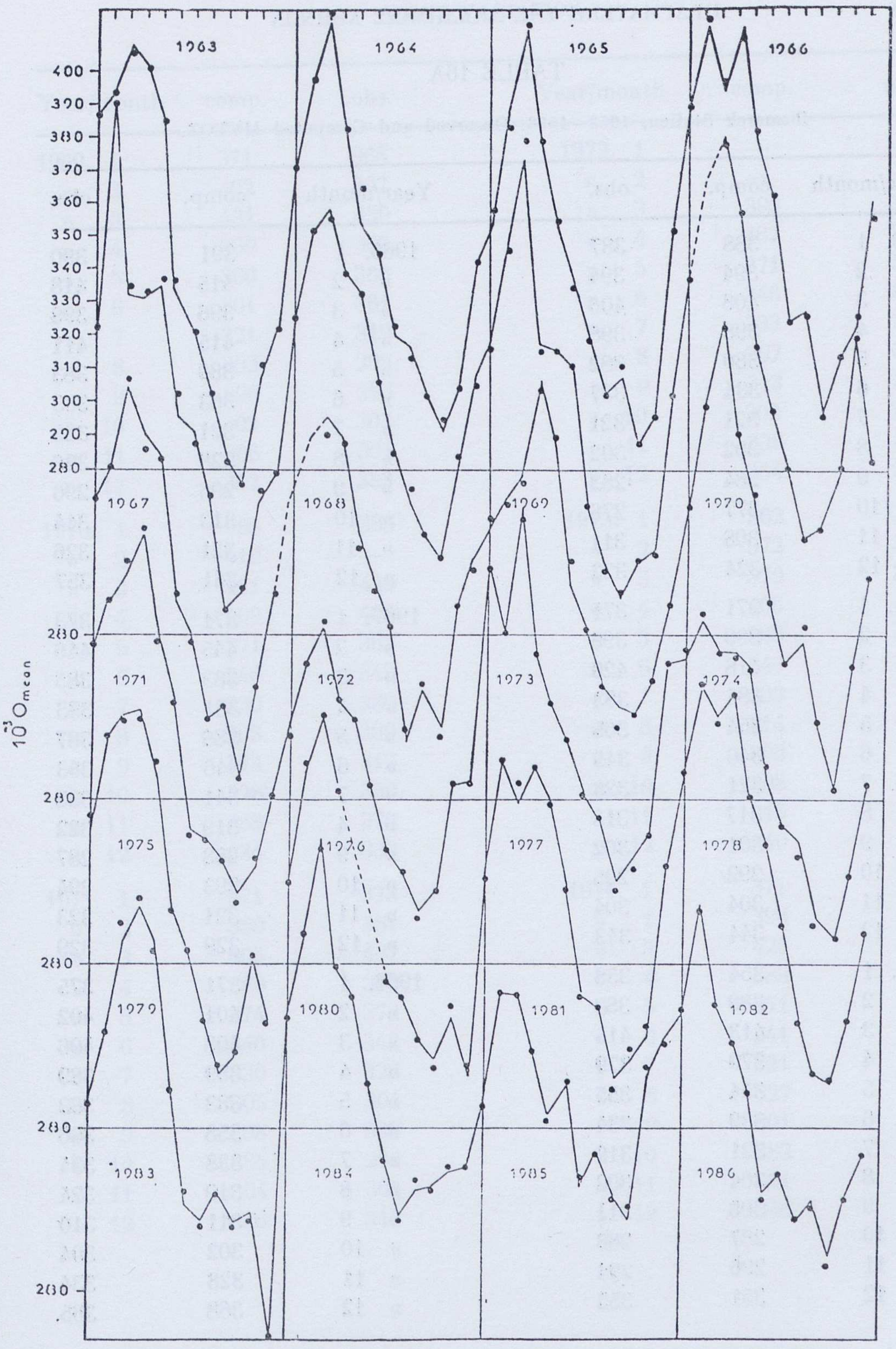

Fig. 69. Bismarck Station, 1963 - 1986. Observed MVTOZ is shown by dots. MVTOZ computed by Equation (70) is shown by a solid line. Accuracy is equal to 99.3%. Note the extremely agreement between the two.

TABLE 16A

Bismarck Station, 1963 - 1986. Observed and Computed MVTOZ.

Year/month	comp.	obs.	Year/month	comp.	obs.
1963. 1	388	387	1966. 1	391	390
» 2	394	394	» 2	415	418
» 3	408	406	» 3	396	398
» 4	398	398	» 4	415	411
» 5	380	382	» 5	380	383
» 6	334	337	» 6	363	363
» 7	321	321	» 7	321	323
» 8	302	302	» 8	328	326
» 9	284	282	» 9	296	296
» 10	277	276	» 10	313	314
» 11	308	311	» 11	321	326
» 12	324	322	» 12	361	357
1964. 1	371	371	1967. 1	371	373
» 2	399	398	» 2	445	446
» 3	418	420	» 3	383	385
» 4	384	383	» 4	381	383
» 5	354	365	» 5	386	387
» 6	346	345	» 6	346	353
» 7	321	323	» 7	341	338
» 8	317	313	» 4	319	322
» 9	301	302	» 9	288	287
» 10	292	295	» 10	293	294
» 11	304	304	» 11	321	323
» 12	344	343	» 12	329	329
1965. 1	354	358	1968. 1	371	375
» 2	389	383	» 2	401	402
» 3	413	415	» 3	408	406
» 4	379	379	» 4	389	389
» 5	354	355	» 5	383	383
» 6	339	334	» 6	358	356
» 7	321	319	» 7	338	334
» 8	304	302	» 8	319	324
» 9	308	311	» 9	311	310
» 10	287	288	» 10	302	304
» 11	296	296	» 11	328	334
» 12	351	352	» 12	368	365

Year/month	comp.	obs.	Year/month	comp.	obs.
1969. 1	371	366	1972. 1	—	—
» 2	402	397	» 2	—	—
» 3	431	430	» 3	396	390
» 4	369	365	» 4	387	387
» 5	366	366	» 5	371	366
» 6	361	361	» 6	346	343
» 7	321	319	» 7	333	332
» 8	302	299	» 8	297	301
» 9	296	293	» 9	313	315
» 10	302	303	» 10	302	299
» 11	306	304	» 11	338	339
» 12	352	353	» 12	354	350
1970. 1	386	388	1973. 1	362	365
» 2	419	—	» 2	372	369
» 3	431	429	» 3	379	376
» 4	409	408	» 4	406	404
» 5	371	367	» 5	388	390
» 6	346	348	» 6	346	352
» 7	330	330	» 7	333	331
» 8	308	309	» 8	314	314
» 9	313	312	» 9	302	302
» 10	328	330	» 10	308	306
» 11	368	370	» 11	315	316
» 12	334	333	» 12	340	339
1971. 1	371	373	1974. 1	371	369
» 2	380	381	» 1	398	399
» 3	405	407	» 3	425	423
» 4	380	376	» 4	389	391
» 5	374	373	» 5	371	373
» 6	340	342	» 6	341	340
» 7	330	328	» 7	321	321
» 8	305	304	» 8	327	332
» 9	308	308	» 9	301	304
» 10	285	286	» 10	282	283
» 11	304	304	» 11	321	321
» 12	346	343	» 12	346	348

Year/month	comp.	obs.	Year/month	comp.	obs.
1975. 1	371	377	1978. 1	371	374
» 2	389	390	» 2	386	386
» 3	396	402	» 3	374	374
» 4	411	412	» 4	374	373
» 5	381	378	» 5	371	370
» 6	358	359	» 6	336	340
» 7	321	319	» 7	321	322
» 8	319	318	» 8	317	313
» 9	313	312	» 9	296	292
» 10	302	299	» 10	287	288
» 11	309	312	» 11	309	307
» 12	334	331	» 12	334	334
1976. 1	354	349	1979. 1	371	376
» 2	372	371	» 2	398	399
» 3	384	384	» 3	405	403
» 4	360	360	» 4	406	404
» 5	354	354	» 5	388	391
» 6	334	334	» 6	346	347
» 7	314	315	» 7	333	334
» 8	307	308	» 8	314	313
» 9	296	294	» 9	296	299
» 10	302	302	» 10	302	303
» 11	333	335	» 11	333	333
» 12	334	334	» 12	312	312
1977. 1	401	400	1980. 1	349	356
» 2	381	380	» 2	389	391
» 3	418	418	» 3	405	406
» 4	377	376	» 4	384	382
» 5	359	359	» 5	365	—
» 6	346	348	» 6	—	—
» 7	333	331	» 7	326	326
» 8	323	324	» 8	319	320
» 9	305	304	» 9	308	307
» 10	311	309	» 10	302	298
» 11	321	319	» 11	304	307
» 12	371	372	» 12	294	294

Year/month	comp.	obs.	Year/month	comp.	obs.
1981. 1	359	355	1984. 1	359	363
» 2	392	392	» 2	389	389
» 3	379	385	» 3	408	405
» 4	389	390	» 4	377	379
» 5	380	378	» 5	371	370
» 6	355	353	» 6	346	346
» 7	321	320	» 7	321	320
» 8	317	317	» 8	302	302
» 9	296	292	» 9	311	314
» 10	300	304	» 10	302	301
» 11	309	311	» 11	306	308
» 12	361	360	» 12	316	318
1982. 1	388	388	1985. 1	341	336
» 2	415	414	» 2	372	371
» 3	405	403	» 3	370	370
» 4	411	412	» 4	355	354
» 5	379	380	» 5	334	332
» 6	367	366	» 6	343	345
» 7	342	343	» 7	312	315
» 8	314	312	» 8	323	322
» 9	296	297	» 9	308	308
» 10	293	295	» 10	302	306
» 11	312	313	» 11	348	349
» 12	337	339	» 12	358	355
1983. 1	337	338	1986. 1	365	366
» 2	364	361	» 2	398	396
» 3	387	393	» 3	366	368
» 4	398	400	» 4	359	356
» 5	386	385	» 5	341	341
» 6	346	342	» 6	311	308
» 7	306	311	» 7	316	316
» 8	302	300	» 8	302	302
» 9	311	310	» 9	308	306
» 10	302	300	» 10	290	287
» 11	306	302	» 11	309	308
» 12	358	358	» 12	322	322

4.17 Station: CARIBOU

$\varphi = 46° \ 52'$ N, L $= 68° \ 01'$ W, Time Period: 1963 - 1986.

Using Figure 5, the observed data of the mean monthly values of total ozone can be expressed very satisfactorily by the equation:

$$10^{-3} \cdot 0_m^{com} = 364 + 55 \sin\left(\frac{2\pi}{12} t + 30°\right) \quad (71)$$

Power spectrum analysis of the differences (D) between the observed and computed MMVTOZ as derived by Equation (71), where

$$D = 10^{-3} \cdot 0^{obs} - 10^{-3} \cdot 0_m^{com} \quad (72)$$

shows that these periodicities are not of random origin but excibit more or less stable periodic terms of 12, 6, 4 and 3 months. (see Figure 70).

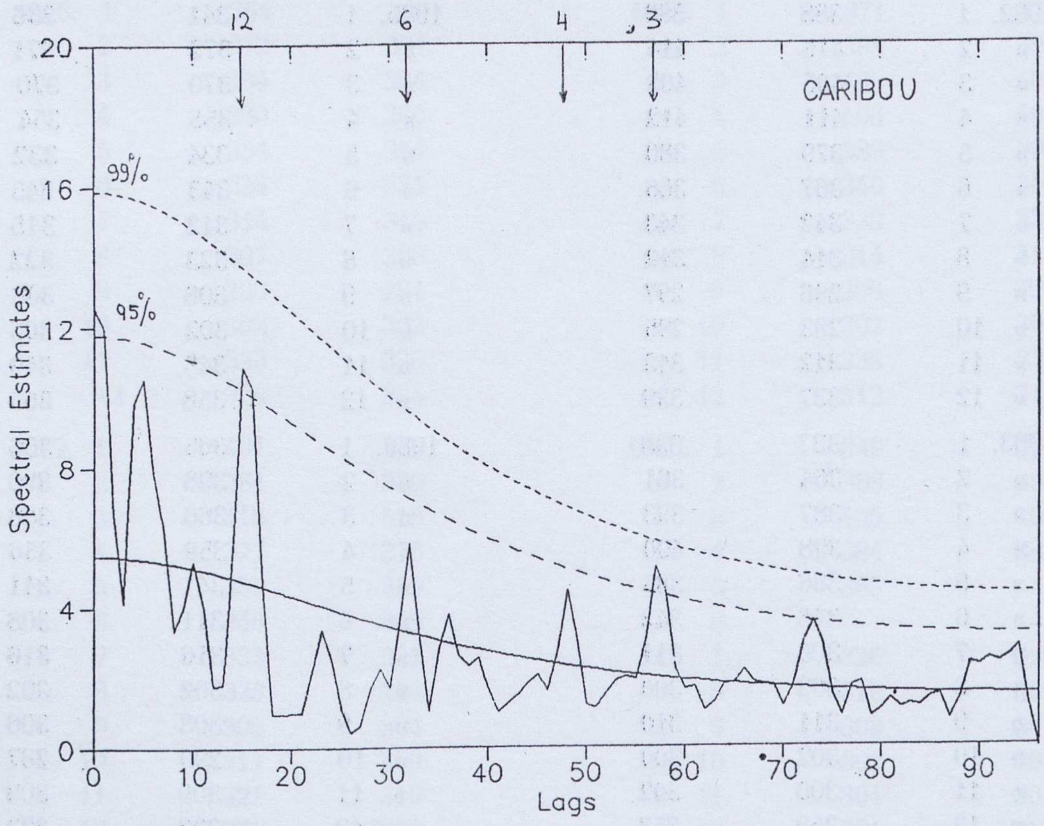

Fig. 70. Caribou Station, 1963 - 1986. Spectral esrtimate of the differences computed by Equation (72). Analysis shows short-term periodicities with periods of 12, 6, 4 and 3 months significant at a confidence level above 95%.

Figures 71 and 72 are graphically determined by means of the successive approximation method which only this gives the position and amplitude of the short-term periodic terms detected by the spectrum analysis.

The dots in each Figure (71, 72) represent differences, given by Equation (72), while the dashed and solid sinusoidal and semisinusoidal curves give the terms of 12, 6, 4 and 3 months, position and amplitude for the Caribou Station. Generally, the amplitude does not exceed 10 to 30 D.U. in width. Exceptionally, it fluctuates between 10 and 80 D.U.

The periodic terms can be satisfactorily written as:

$$P = \alpha_1 \sin\frac{2\pi}{6}t + \alpha_2 \sin\frac{2\pi}{4}t + \alpha_3 \sin\frac{2\pi}{3}t \tag{73}$$

Table 17 lists values of the parameters (coefficients) α_1. α_2, α_3 and of the parameter **t** in Equation (73).

Summing Equations (71) and (73), we obtain

$$10^{-3} \cdot 0^{com} = 10^{-3} \cdot 0^{com}_{m} + P \tag{74}$$

This new equation represents the whole phenomenon of the variation and periodicity of the monthly values of total ozone and represents the observed data with an accuracy of 99%, while the s.d. between MVTOZ as observed and as computed by Equation (74) was found to be equal to $\sigma = \pm 2.83$, with 26 degrees of freedom for Equation (74). These results are obvious from Figures 73 and 74 where the dots represent observed MVTOZ, while the dashed and solid line represent the same MVTOZ computed by Equation (74). Note the extremely close agreement between the two.

The results are shown numerically in Table 17A which gives the observed and computed monthly values of total ozone for the Caribou Station.

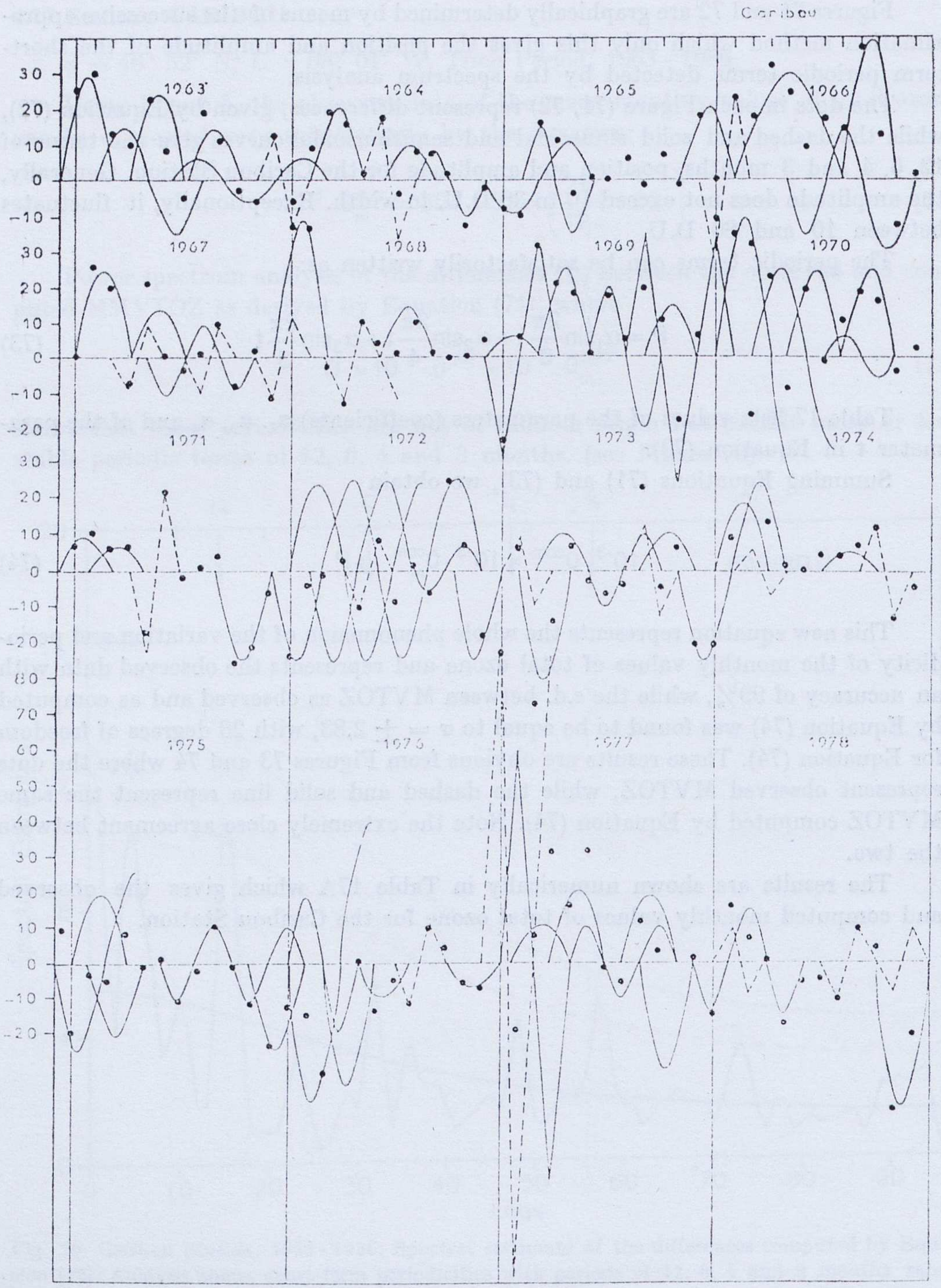

Fig. 71. Caribou Station, 1963 - 1978. The differences (D) computed by Equation (72) are shown by dots. The dashed and solid sinusoidal or semisinusoidal curves show periodic terms with periods of 12, 6, 4 and 3 months, whose position and amplitude is also plotted, by the successive approximation method.

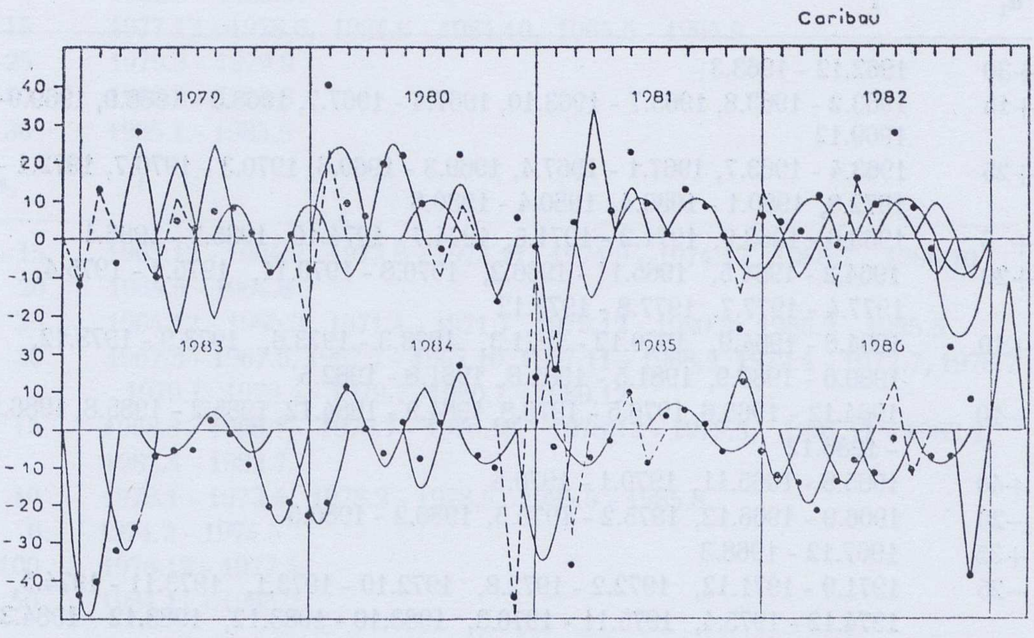

Fig. 72. Caribou Station, 1979 - 1986. Caption as for Figure 72, to which this Figure is complementary.

TABLE 17

Values of the parameters α_1, α_2, α_3, and **t** (see Eq. 73).

α_1	t
+30	1962.12 - 1963.3
+15	1963.2 - 1963.8, 1963.7 - 1963.10, 1967.4 - 1967.7, 1968.6 - 1968.9, 1969.9-1969.12
+25	1963.4 - 1963.7, 1967.1 - 1967.4, 1969.3 - 1969.6, 1970.3 - 1970.7, 1972.1 - 1972.8, 1980.1 - 1980.4, 1980.4 - 1980.8
+ 6	1963.6 - 1963.9, 1971.2 - 1971.5, 1974.7 - 1974.10, 1985.7 - 1986.1
+20	1964.2 - 1964.5, 1965.11 - 1966.2, 1970.8 - 1970.11, 1975.1 - 1975.4, 1977.4 - 1977.7, 1977.8 - 1977.12
+10	1964.6 - 1964.9, 1970.12 - 1971.3, 1973.3 - 1973.6, 1973.9 - 1973.12, 1980.6 - 1980.9, 1981.5 - 1981.8, 1981.8 - 1982.5
—10	1964.12 - 1965.6, 1976.5 - 1976.8, 1984.9 - 1984.12, 1985.2 - 1985.8, 1986.9 - 1986.12
+40	1965.8 - 1965.11, 1970.1 - 1970.5
—20	1966.9 - 1966.12, 1975.2 - 1975.5, 1986.2 - 1986.5
+35	1967.12 - 1968.3
—25	1971.9 - 1971.12, 1972.2 - 1972.8, 1972.10 - 1973.1, 1973.11 - 1974.5, 1974.12 - 1975.4, 1975.11 - 1976.3, 1983.10 - 1983.12, 1983.12 - 1984.3
—30	1973.2 - 1973.5, 1977.9 - 1977.12, 1983.2 - 1983.5,
—40	1976.1 - 1976.5
— 6	1976.10 - 1977.1
—35	1978.10 - 1979.1, 1984.12 - 1985.3
+10	1982.6 - 1982.9, 1982.7 - 1983.1, 1977.2 - 1977.5
—25	1982.10 - 1983.1
—45	1982.12 - 1983.3
—15	1986.4 - 1986.7

α_2	t
+ 6	1964.8 - 1964.12, 1970.7 - 1970.11, 1983.7 - 1983.11
+15	1965.2 - 1965.6, 1980.8 - 1980.12, 1985.11 - 1986.3
—10	1967.5 - 1967.11, 1973.6 - 1973.10, 1975.6 - 1976.2
—30	1968.12 - 1969.4
+20	1969.6 - 1969.10, 1976.1 - 1976.5, 1979.5, - 1979.9
+35	1969.8 - 1970.2
— 6	1972.8 - 1972.12

α_2	t
+65	1977.1 - 1977.5
+10	1977.4 - 1977.12, 1979.8 - 1980.4, 1982.7 - 1982.11, 1984.2 - 1984.8, 1982.9 - 1983.1
—15	1977.12 - 1978.6, 1984.6 - 1984.10, 1965.5 - 1965.9
+25	1979.3 - 1979.9
—10	1982.2 - 1982.6
+30	1985.1 - 1985.5

α_3	t
+ 15	1963.12 - 1964.2, 1973.8 - 1973.11, 1974.9 - 1974.12, 1986.7 - 1986.10
+ 20	1964.5 - 1964.8
— 25	1964.12 - 1965.3, 1971.4 - 1971.7, 1979.12 - 1980.3, 1985.2 - 1985.5
— 10	1967.3 - 1967.6, 1967.7 - 1967.10, 1967.11 - 1968.2, 1972.4 - 1972.7, 1978.7 - 1979.1, 1979.4 - 1979.7, 1980.7 - 1980.12
— 15	1968.3 - 1968.7, 1976.7 - 1976.10, 1978.12 - 1979.3, 1981.11 - 1982.2, 1982.4 - 1982.7
+ 10	1973.1 - 1973.4, 1978.2 - 1978.5, 1985.5 - 1985.8
+ 6	1974.2 - 1974.5
+100	1976.12 - 1977.4
— 50	1984.11 - 1985.2

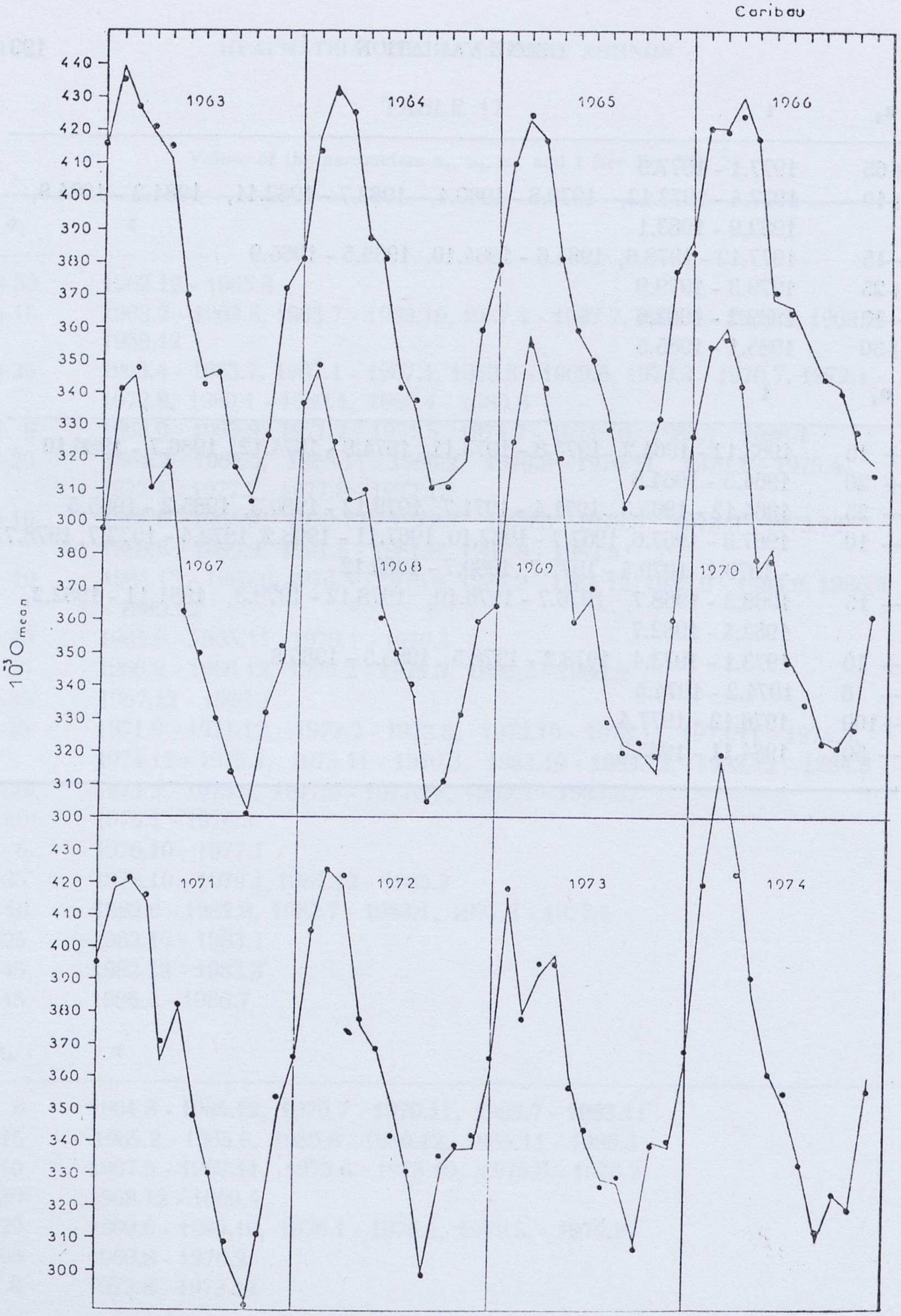

Fig. 73. Caribou Station, 1963 - 1974. Observed MVTOZ is shown by dots. MVTOZ as found by Equation (74) is shown by a solid line. Accuracy is equal to 99%. Note the strikingly close agreement between the two.

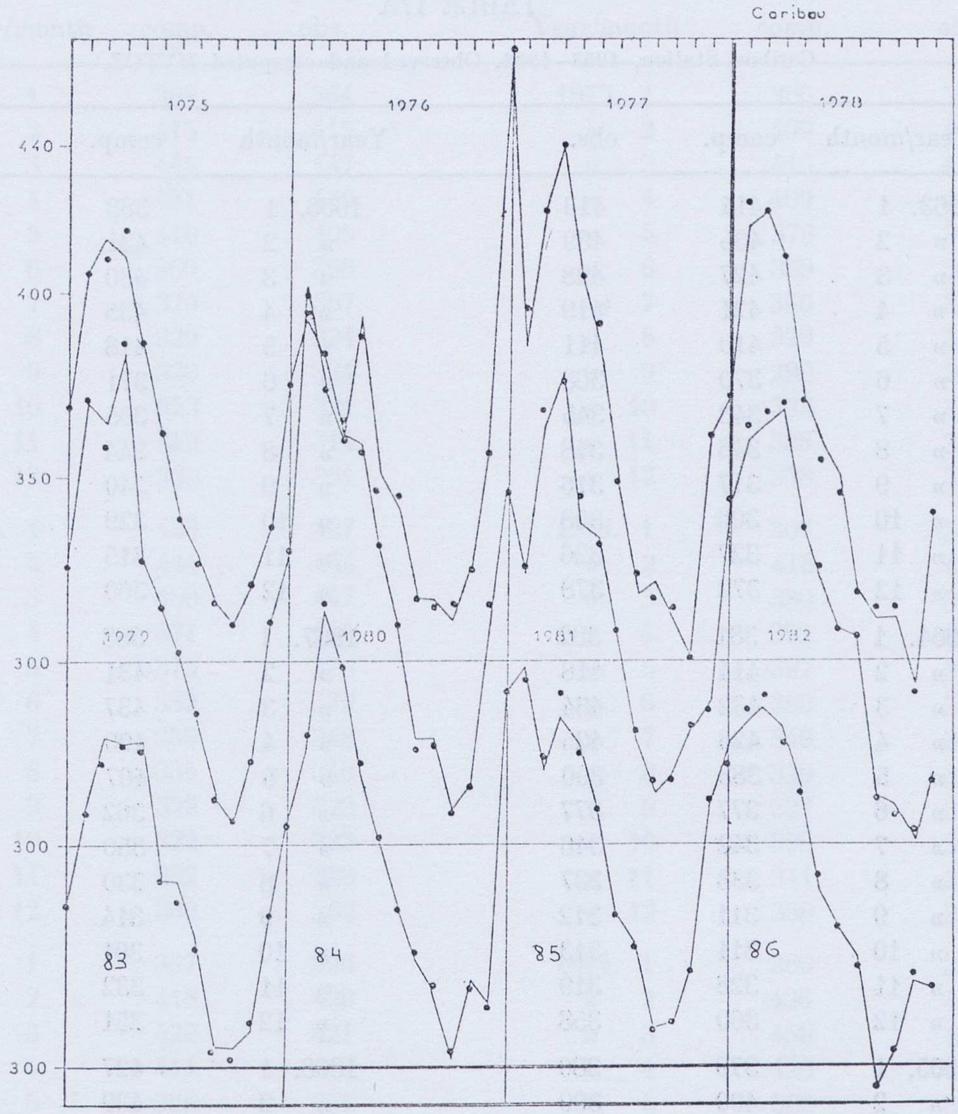

Fig. 74. Caribou Station, 1975 - 1986. Caption as for Figure 73, to which this Figure is complementary.

TABLE 17A

Caribou Station, 1963 - 1986. Observed and computed MVTOZ.

Year/month	comp.	obs.	Year/month	comp.	obs.
1963. 1	414	413	1966. 1	383	388
» 2	435	439	» 2	431	432
» 3	427	428	» 3	430	432
» 4	421	419	» 4	435	441
» 5	410	411	» 5	418	417
» 6	370	368	» 6	371	369
» 7	343	345	» 7	365	367
» 8	346	348	» 8	344	344
» 9	317	316	» 9	340	342
» 10	306	308	» 10	329	324
» 11	327	326	» 11	315	319
» 12	372	378	» 12	360	363
1964. 1	381	382	1967. 1	388	388
» 2	414	418	» 2	431	430
» 3	432	434	» 3	437	435
» 4	426	425	» 4	400	401
» 5	388	390	» 5	407	409
» 6	377	377	» 6	362	361
» 7	342	346	» 7	350	347
» 8	338	337	» 8	330	330
» 9	311	312	» 9	314	314
» 10	311	313	» 10	301	303
» 11	326	319	» 11	332	334
» 12	360	358	» 12	351	348
1965. 1	379	380	1968. 1	427	426
» 2	400	399	» 2	439	440
» 3	430	431	» 3	415	412
» 4	418	420	» 4	397	396
» 5	382	384	» 5	400	398
» 6	360	361	» 6	360	364
» 7	350	350	» 7	350	351
» 8	329	335	» 8	341	339
» 9	305	304	» 9	305	306
» 10	311	318	» 10	311	311
» 11	332	331	» 11	332	332
» 12	377	378	» 12	360	365

Year/month	comp.	obs.	Year/month	comp.	obs.
1969. 1	365	364	1972. 1	366	364
» 2	415	415	» 2	409	405
» 3	445	447	» 3	415	414
» 4	431	430	» 4	409	412
» 5	410	405	» 5	379	378
» 6	360	360	» 6	369	369
» 7	370	367	» 7	350	342
» 8	329	334	» 8	329	331
» 9	320	324	» 9	299	299
» 10	323	321	» 10	333	336
» 11	319	314	» 11	338	339
» 12	360	361	» 12	338	342
1970. 1	423	427	1973. 1	366	364
» 2	444	444	» 2	418	415
» 3	450	447	» 3	380	378
» 4	431	432	» 4	392	395
» 5	375	379	» 5	397	395
» 6	382	379	» 6	360	357
» 7	350	348	» 7	340	344
» 8	335	340	» 8	329	326
» 9	322	323	» 9	327	329
» 10	322	322	» 10	308	307
» 11	332	328	» 11	341	339
» 12	360	362	» 12	338	340
1971. 1	397	396	1974. 1	366	368
» 2	418	420	» 2	426	419
» 3	420	421	» 3	459	459
» 4	414	416	» 4	426	423
» 5	366	371	» 5	388	391
» 6	382	382	» 6	360	361
» 7	350	348	» 7	350	355
» 8	330	330	» 8	334	334
» 9	305	309	» 9	310	313
» 10	289	286	» 10	323	324
» 11	310	311	» 11	320	319
» 12	350	354	» 12	360	356

Year/month	comp.	obs.	Year/month	comp.	obs.
1975. 1	366	369	1978.1	373	373
» 2	404	406	» 2	418	425
» 3	415	410	» 3	421	422
» 4	414	418	» 4	409	410
» 5	388	387	» 5	373	371
» 6	360	362	» 6	360	355
» 7	340	339	» 7	350	346
» 8	329	327	» 8	320	319
» 9	315	316	» 9	314	315
» 10	311	310	» 10	311	315
» 11	322	321	» 11	293	291
» 12	338	337	» 12	339	340
1976. 1	376	376	1979. 1	376	376
» 2	394	395	» 2	421	422
» 3	380	384	» 3	415	409
» 4	359	360	» 4	434	437
» 5	393	389	» 5	379	378
» 6	351	347	» 6	364	365
» 7	341	346	» 7	350	353
» 8	317	318	» 8	334	336
» 9	317	315	» 9	315	313
» 10	311	316	» 10	311	312
» 11	327	326	» 11	322	323
» 12	355	353	» 12	360	361
1977. 1	475	475	1980. 1	376	380
» 2	387	396	» 2	453	449
» 3	424	423	» 3	427	424
» 4	440	441	» 4	409	415
» 5	405	405	» 5	410	438
» 6	387	392	» 6	382	382
» 7	349	349	» 7	359	360
» 8	319	324	» 8	329	326
» 9	322	318	» 9	329	327
» 10	312	315	» 10	311	309
» 11	306	302	» 11	317	316
» 12	360	362	» 12	360	366

Year/month	comp.	obs.	Year/month	comp.	obs.
1981. 1	388	386	1984. 1	366	366
» 2	374	374	» 2	387	390
» 3	415	419	» 3	425	427
» 4	429	427	» 4	409	409
» 5	388	395	» 5	378	382
» 6	384	382	» 6	360	362
» 7	359	359	» 7	345	343
» 8	329	331	» 8	329	331
» 9	314	318	» 9	320	322
» 10	320	318	» 10	302	304
» 11	332	333	» 11	323	322
» 12	339	337	» 12	317	316
1982. 1	391	394	1985. 1	401	402
» 2	409	414	» 2	409	405
» 3	414	417	» 3	381	384
» 4	418	420	» 4	395	402
» 5	386	386	» 5	388	385
» 6	372	376	» 6	369	370
» 7	359	359	» 7	341	341
» 8	357	357	» 8	334	333
» 9	314	313	» 9	310	310
» 10	311	308	» 10	311	312
» 11	301	304	» 11	327	326
» 12	319	318	» 12	370	373
1983. 1	345	344	1986. 1	388	382
» 2	366	369	» 2	394	397
» 3	389	383	» 3	398	401
» 4	383	383	» 4	392	388
» 5	383	381	» 5	376	374
» 6	355	355	» 6	348	352
» 7	350	345	» 7	338	338
» 8	335	332	» 8	329	327
» 9	305	304	» 9	293	294
» 10	305	302	» 10	302	304
» 11	310	312	» 11	323	325
» 12	338	341	» 12	320	321

4.18 Station : HOHENPEISSENBERG

$\varphi = 47^{0}\ 48'N$, $L = 11^{0}\ 01'E$, Time Period: 1967 - 1986.

Using Figure 6, MMVTOZ (Hohenpeissenberg) can be written as:

$$10^{-3} \cdot 0_{m}^{com} = 336 + 50 \sin\frac{2\pi}{12} t \qquad (75)$$

Calculating the differences (D) where

$$D = 10^{-3} \cdot 0^{obs} - 10^{-3} \cdot 0_{m}^{com} \qquad (76)$$

and analyzing these values by means of power spectrum method we find four short-term periodicities of 12, 6, 4 and 3 months as shown in Figure 75

In Figure 76 the dots (or open small circles) represent the differences given by Equation (76), while the dashed and solid sinusoidal and semisinusoidal curves represent periodic terms determined graphically by the successive approximation method. Periods of 12, 6, 4 and 3 months are clearly visible, The revealed periodicities appear as a network of short-term periods, overlapping in some cases. The position and the amplitude of the periodic terms are also shown in Figure 76. These short-terms can be expressed analytically as:

$$P = \alpha_1 \sin\frac{2\pi}{6} t + \alpha_2 \sin\frac{2\pi}{4} t + \alpha_3 \sin\frac{2\pi}{3} t \qquad (77)$$

where the values of the parameters (coefficients) $\boldsymbol{\alpha}_1$ to $\boldsymbol{\alpha}_3$ and **t**, are given in Table 18.

Thus the observed data of the Hohenpeissenberg Station for the time interval from 1967 through 1986 can be expressed by an algebraic equation as follows:

$$10^{-3} \cdot 0^{com} = 336 + 50 \sin\frac{2\pi}{12} t + P \qquad (78)$$

Equation (78) represents the observed data with an accuracy equal to 99.2% while the s.d. between observed-computed MVTOZ was found to be $\boldsymbol{\sigma} = \pm 2.8$. Equation (78), which completely describes the behavior of the variation of the monthly values of total ozone from year to year for a relatively long period of time, has 7 degrees of freedom. These results can be clearly seen in Figure 77 where the dots represent observed MVTOZ while the solid line gives MVTOZ computed by Equation (78). It is noteworthy that only in exceptional cases is the disagreement between the observed and computed values of total ozone greater than 6 D.U.

Table 18A lists observed and computed MVTOZ for the Hohenpeissenberg Station for the period 1967-1986.

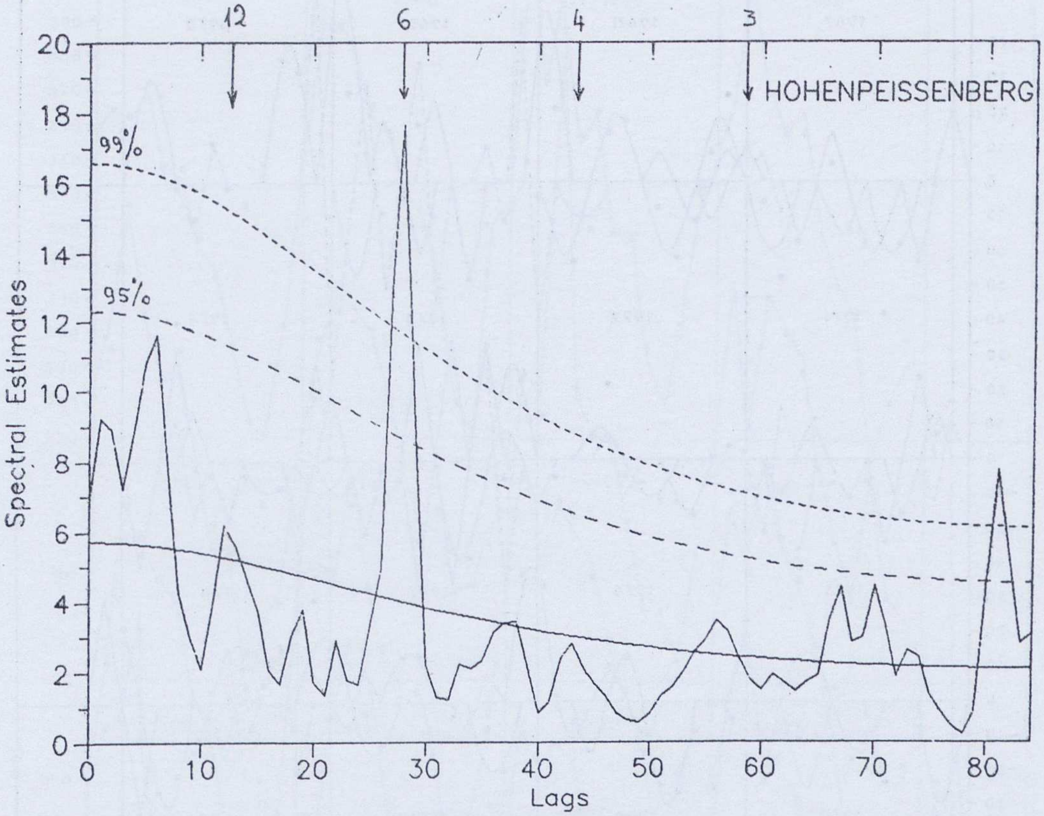

Fig. 75. Hohenpeissenberg Station, 1967 - 1986. Spectral estimate of the differences computed by Equation (76). Analysis shows periodicities with periods 12, 6, 4 and 3 months. Note that the 6-month periodicity is predominant, with a confidence level above 99%.

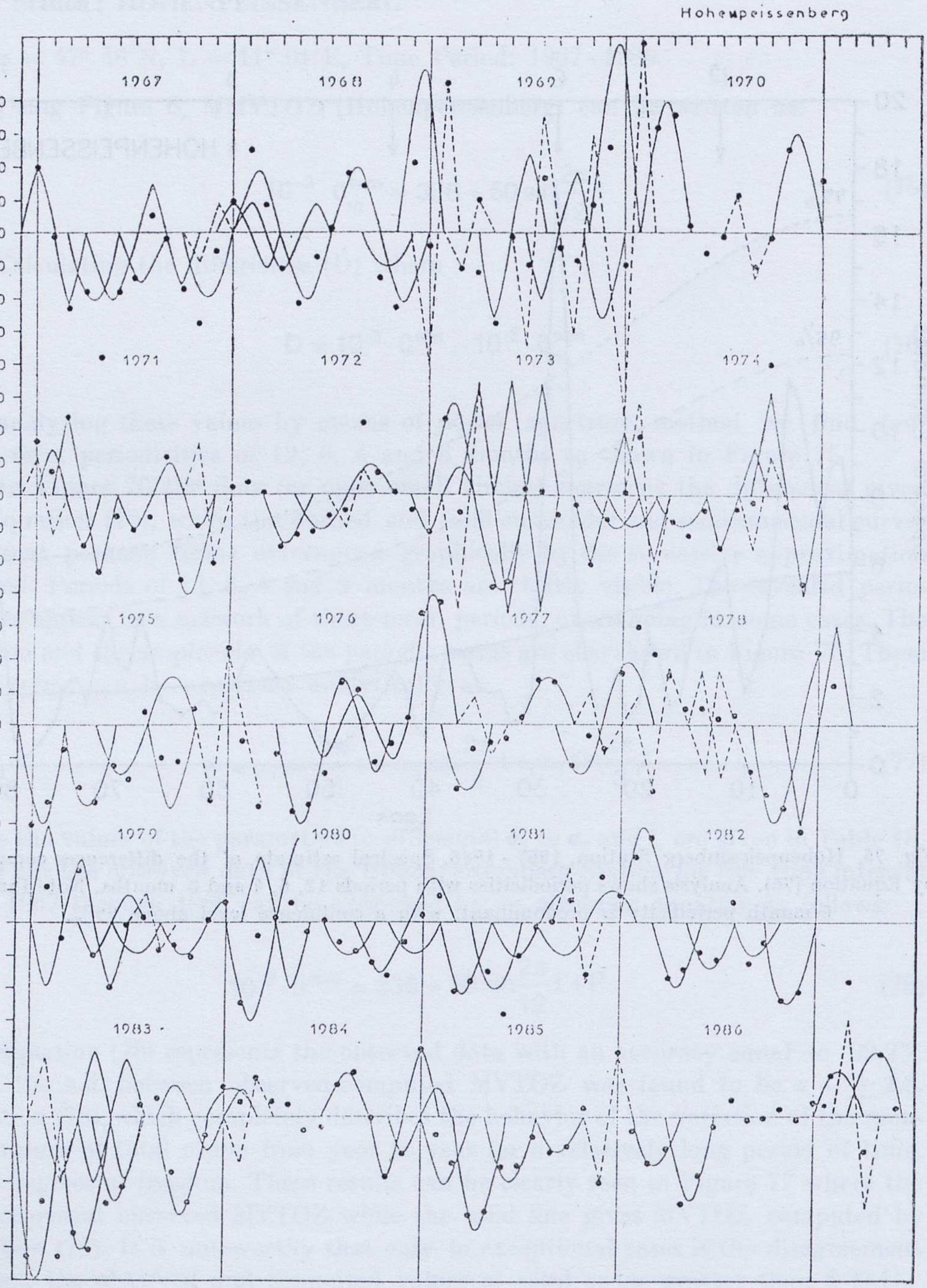

Fig. 76. Hohenpeissenberg Station, 1967 - 1986. The differences (D) found by Equation (76) are shown by dots. The dashed and solid sinusoidal or semisinusoidal curves show periodic terms of 12, 6, 4 and 3 months, whose position and amplitude is plotted graphically by the successive approximation method.

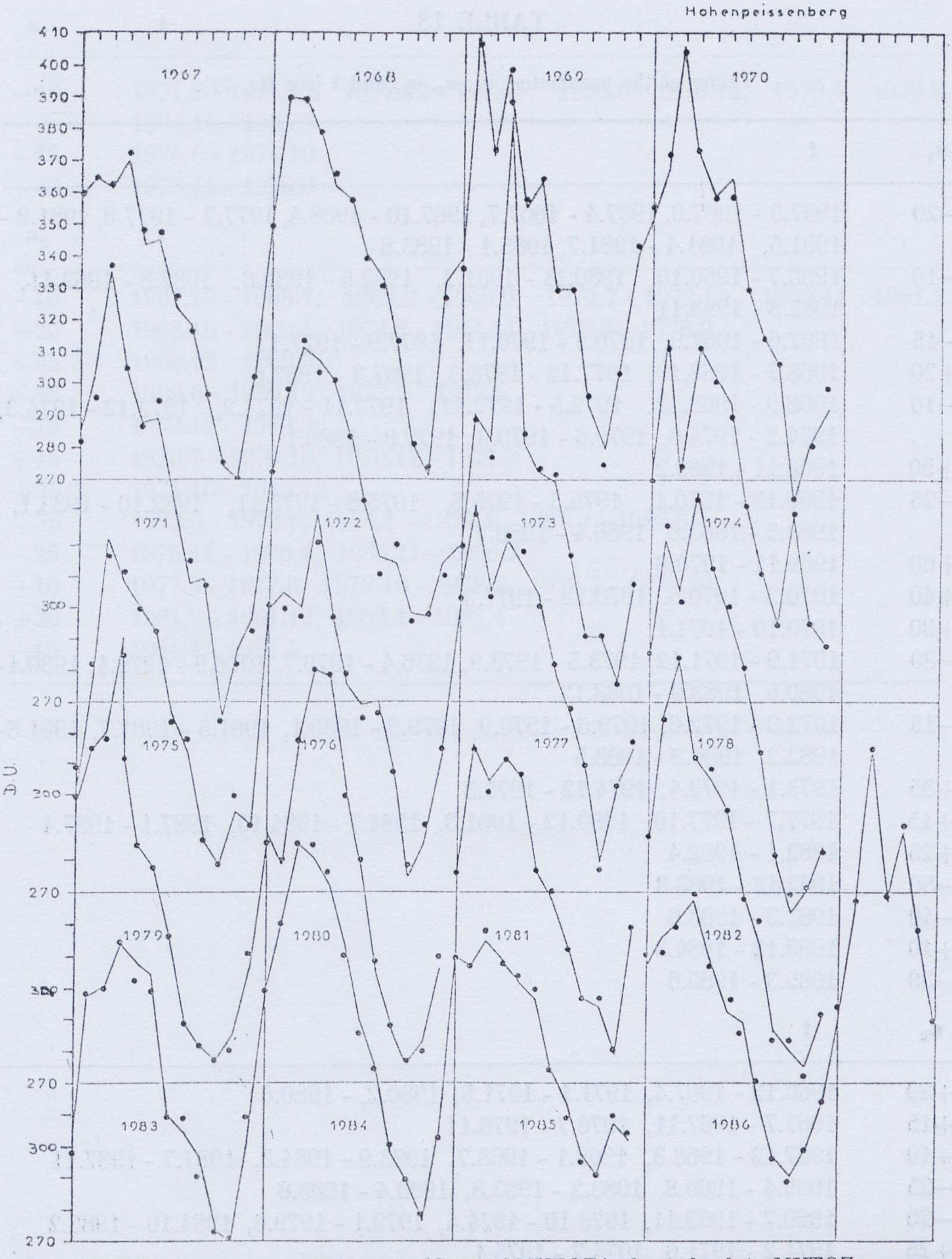

Fig. 77. Hohenpeissenberg, 1967 - 1986. Observed MVTOZ is shown by dots. MVTOZ computed by Equation (78) is shown by a solid line. Accuracy is equal to 99.2%. The close agreement between observed-computed MVTOZ is evident.

TABLE 18

Values of the parameters α_1, α_2, α_3, and **t** (see Eq. 77).

α_1	**t**
—20	1967.3 - 1967.6, 1967.4 - 1967.7, 1967.10 - 1968.4, 1977.2 - 1977.8, 1981.2 - 1981.5, 1981.4 - 1981.7, 1985.1 - 1985.8
—10	1980.7 - 1980.10, 1980.11 - 1981.2, 1982.5 - 1982.8, 1982.8 - 1982.11, 1985.8 - 1985.11
—15	1967.6 - 1967.9, 1976.5 - 1976.11, 1977.9 - 1977.12
+20	1968.7 - 1968.10, 1977.12 - 1978.3, 1987.3 - 1987.6
—10	1968.9 - 1968.12, 1972.5 - 1972.11, 1973.11 - 1974.2, 1973.12 - 1974.3, 1974.2 - 1974.6, 1979.6 - 1979.9, 1979.9 - 1980.1
+50	1968.11 - 1969.2
—25	1969.10 - 1970.1, 1975.3 - 1975.6, 1975.8 - 1975.11, 1982.10 - 1983.1, 1983.5 - 1983.8, 1986.4 - 1986.7
+60	1969.11 - 1970.8
+40	1970.2 - 1970.5, 1976.12 - 1977.3
+30	1970.10 - 1971.1
—30	1971.9 - 1971.12, 1973.5 - 1973.9, 1976.4 - 1976.7, 1978.9 - 1979.1, 1980.1-1980.5, 1983.9 - 1983.12
—15	1972.3 - 1972.6, 1979.6 - 1979.9, 1979.9 - 1980.1, 1981.5 - 1981.7, 1981.8-1982.2, 1986.2 - 1986.5
+35	1973.1 - 1973.4, 1974.12 - 1975.3
+15	1977.7 - 1977.10, 1980.12 - 1981.3, 1984.7 - 1984.10, 1987.1 - 1987.4
+25	1982.1 - 1982.4
—50	1982.12 - 1983.3
—40	1983.3 - 1983.6
+10	1983.12 - 1984.3
—39	1985.3 - 1985.6

α_2	**t**
+20	1966.12 - 1967.4, 1971.1 - 1971.5, 1980.2, - 1980.6
+15	1967.7 - 1967.11, 1976.7 - 1976.11
+10	1967.12 - 1968.3, 1968.1 - 1968.7, 1983.9 - 1984.3, 1987.7 - 1987.11
—25	1969.4 - 1969.8, 1983.2 - 1983.8, 1983.4 - 1983.8
—20	1969.7 - 1969.11, 1973.10 - 1974.4, 1979.1 - 1979.6, 1984.10 - 1985.2
+25	1971.2 - 1971.6, 1974.7 - 1975.1

α_2	t
−10	1971.6 - 1971.12, 1972.12 - 1973.4, 1976.6 - 1976.12, 1979.4 - 1979.8, 1984.11 - 1985.3
−15	1974.6 - 1974.10
−30	1978.11 - 1979.3

α_3	t
+10	1967.10 - 1968.1, 1969.2 - 1969.6, 1972.7 - 1972.10, 1980.11 - 1981.3
+20	1968.10 - 1969.1, 1974.8 - 1974.11, 1978.3 - 1978.9
+45	1968.12 - 1969.3
−40	1969.6 - 1969.12, 1973.2 - 1973.5
−70	1969.12 - 1970.3
+15	1970.7 - 1970.10, 1970.12 - 1971.3
+25	1971.10 - 1972.12
+35	1973.3 - 1973.6, 1974.1 - 1974.4, 1987.2 - 1987.5
−25	1975.11 - 1976.4, 1985.11 - 1986.2
+10	1977.3 - 1977.6, 1977.10 - 1978.2, 1979.7 - 1979.10
+20	1981.9 - 1981.12, 1983.1 - 1983.4
−15	1984.1 - 1984.4

TABLE 18A

Hohenpeissenberg Station, 1967 - 1986. Observed and computed MVTOZ.

Year/month	comp.	obs.	Year/month	comp.	obs.
1967. 1	360	360	1970. 1	331	330
» 2	365	364	» 2	426	426
» 3	363	360	» 3	418	415
» 4	373	372	» 4	425	426
» 5	349	345	» 5	383	385
» 6	348	347	» 6	365	359
» 7	328	326	» 7	340	339
» 8	318	320	» 8	327	327
» 9	297	296	» 9	285	287
» 10	275	274	» 10	290	291
» 11	271	269	» 11	323	323
» 12	307	310	» 12	336	—
1968. 1	350	350	1971. 1	352	356
» 2	392	390	» 2	368	373
» 3	390	392	» 3	408	407
» 4	380	380	» 4	375	374
» 5	366	362	» 5	358	359
» 6	358	358	» 6	365	359
» 7	340	342	» 7	330	329
» 8	332	334	» 8	315	308
» 9	314	312	» 9	307	309
» 10	281	277	» 10	264	263
» 11	271	275	» 11	283	288
» 12	332	337	» 12	293	294
1969. 1	340	337	1972. 1	340	343
» 2	408	412	» 2	365	369
» 3	374	373	» 3	383	384
» 4	399	400	» 4	378	374
» 5	358	356	» 5	371	371
» 6	365	365	» 6	356	354
» 7	330	331	» 7	331	334
» 8	330	332	» 8	306	311
» 9	297	293	» 9	315	320
» 10	275	282	» 10	299	297
» 11	304	306	» 11	297	298
» 12	345	341	» 12	315	311

Year/month	comp.	obs.	Year/month	comp.	obs.
1973. 1	330	329	1976. 1	362	363
» 2	391	389	» 2	365	360
» 3	384	378	» 3	361	358
» 4	455	459	» 4	390	381
» 5	353	355	» 5	357	357
» 6	343	344	» 6	339	341
» 7	340	343	» 7	330	326
» 8	317	317	» 8	330	328
» 9	294	292	» 9	307	308
» 10	290	292	» 10	275	279
» 11	277	276	» 11	287	292
» 12	306	308	» 12	315	317
1974. 1	342	341	1977. 1	375	374
» 2	386	383	» 2	400	403
» 3	333	335	» 3	366	364
» 4	381	382	» 4	282	283
» 5	374	371	» 5	374	378
» 6	365	361	» 6	365	361
» 7	325	324	» 7	340	343
» 8	315	311	» 8	328	329
» 9	295	295	» 9	309	310
» 10	332	330	» 10	278	278
» 11	297	295	» 11	294	294
» 12	290	288	» 12	306	308
1975. 1	304	310	1978. 1	357	356
» 2	339	342	» 2	391	395
» 3	383	376	» 3	365	363
» 4	368	371	» 4	407	405
» 5	361	360	» 5	383	388
» 6	353	353	» 6	365	370
» 7	328	324	» 7	340	341
» 8	315	319	» 8	315	318
» 9	287	287	» 9	280	283
» 10	280	279	» 10	264	269
» 11	297	302	» 11	271	272
» 12	293	292	» 12	285	283

Year/month	comp.	obs.	Year/month	comp.	obs.
1979. 1	366	363	1982. 1	352	348
» 2	375	376	» 2	387	385
» 3	383	378	» 3	405	404
» 4	410	406	» 4	373	373
» 5	373	373	» 5	366	369
» 6	345	345	» 6	356	356
» 7	341	339	» 7	331	328
» 8	315	317	» 8	315	321
» 9	288	289	» 9	288	284
» 10	281	283	» 10	281	284
» 11	298	286	» 11	275	273
» 12	315	316	» 12	293	293
1980. 1	349	346	1983. 1	297	298
» 2	339	340	» 2	339	339
» 3	377	379	» 3	341	340
» 4	390	391	» 4	355	355
» 5	289	289	» 6	348	343
» 6	365	362	» 6	343	339
» 7	340	341	» 7	318	319
» 8	306	309	» 8	315	319
» 9	288	289	» 9	297	291
» 10	278	278	» 10	274	273
» 11	285	281	» 11	271	271
» 12	306	311	» 12	305	310
1981. 1	343	337	1984. 1	349	349
» 2	377	374	» 2	372	370
» 3	366	362	» 3	395	396
» 4	373	372	» 4	390	395
» 5	366	368	» 5	283	387
» 6	338	337	» 6	365	361
» 7	328	330	» 7	340	337
» 8	315	313	» 8	327	325
» 9	297	297	» 9	309	311
» 10	295	297	» 10	290	290
» 11	280	281	» 11	277	279
» 12	327	329	» 12	305	304

Year/month	comp.	obs.
1985. 1	360	361
» 2	358	359
» 3	366	369
» 4	360	360
» 5	353	354
» 6	348	350
» 7	323	325
» 8	315	309
» 9	288	286
» 10	281	281
» 11	297	300
» 12	293	295
1986. 1	358	360
» 2	365	361
» 3	371	369
» 4	378	380
» 5	361	357
» 6	343	347
» 7	340	337
» 8	315	320
» 9	297	296
» 10	290	289
» 11	297	299
» 12	315	314
1987. 1	340	344
» 2	377	377
» 3	425	426
» 4	377	379
» 5	400	402
» 6	365	368
» 7	340	340
» 8	325	328
» 9	297	300
» 10	280	285
» 11	—	—
» 12	—	—

4.19 Station: HRADEC CRÁLOVÉ

$\varphi = 50° \ 11'$ N, L = 15° 50′ E, Time Period: 1962-1985.

Using Figure 7, we see that the mean monthly values of total ozone can be very satisfactorily expressed as:

$$10^{-3} \cdot 0_m^{com} = 350 + 47 \sin\frac{2\pi}{12} t \tag{79}$$

Power spectrum analysis of the differences (D), where

$$D = 10^{-3} \cdot 0^{obs} - 10^{-3} \cdot 0_m^{com} \tag{80}$$

shown in Figure 78, shows periodicities (short-term) with periods equal to 12, 6, 4 and 3 months. The differences given with the help of the relation (80) are apparently not random but show periodicities of 12, 6, 4 and 3 months. This is confirmed by the successive approximation method as shown in Figure 79. These periodicities appear as a network of periodic terms, most of which overlap each other. The position and amplitude of these periodic terms can be represented as:

$$P = \alpha_1 \sin\frac{2\pi}{12} t + \alpha_2 \sin\frac{2\pi}{6} t + \alpha_3 \sin\frac{2\pi}{4} t + \alpha_4 \sin\frac{2\pi}{3} t \tag{81}$$

Table 19 lists the values of the parameters (coefficients) of Equation (81).

Summing Equation (79) and Equation (81), we obtain:

$$10^{-3} \cdot 0^{com} = 10^{-3} \cdot 0_m^{com} + P \tag{82}$$

This new equation represents the variation and periodicity of MVTOZ for the Hradec Crálové Station. It represents the observed data with an accuracy of 99.9% and s.d. of $\sigma = \pm 3.72$ with 30 degrees of freedom for Equation (82).

Table 19A summarizes observed and computed monthly values of total ozone for Hradec Crálové Station from 1967 through 1986.

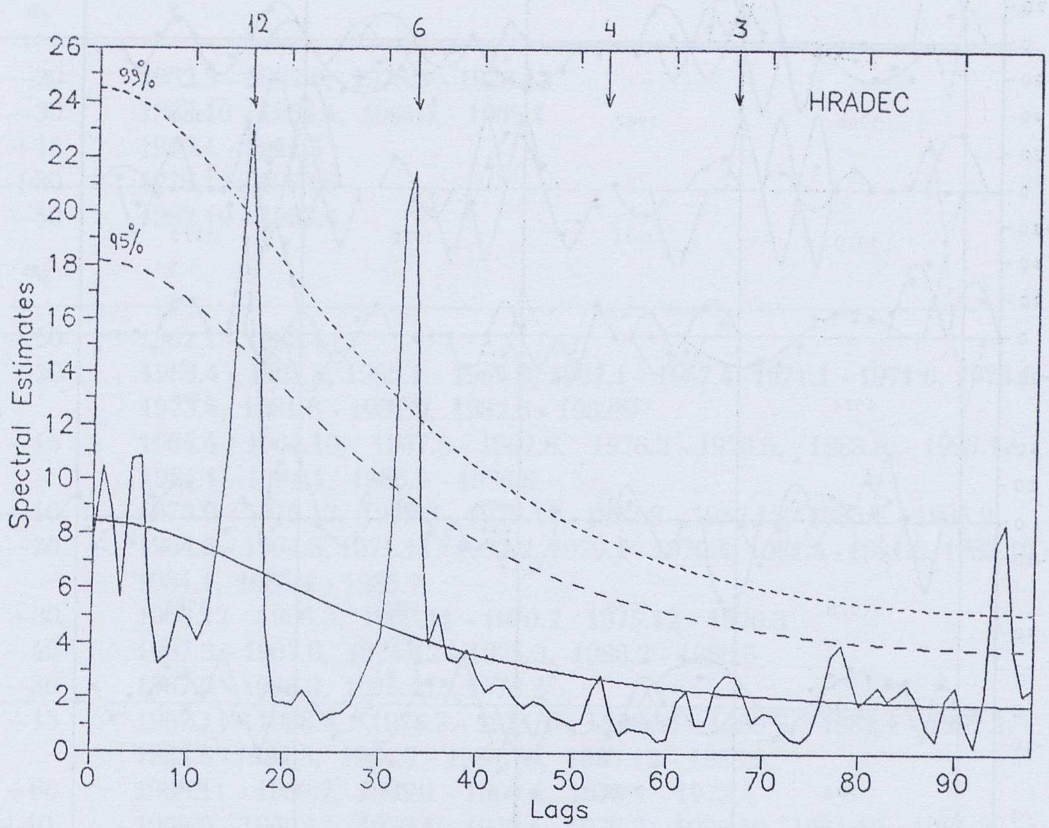

Fig. 78. Hradec Crálové Station, 1962 - 1985. Spectral estimate of the differences computed by Equation (80) shows short-term periodicities of 12, 6, 4 and 3 months. Of these the 12 and 6-month periods are predominant, with a confidence level above 99%.

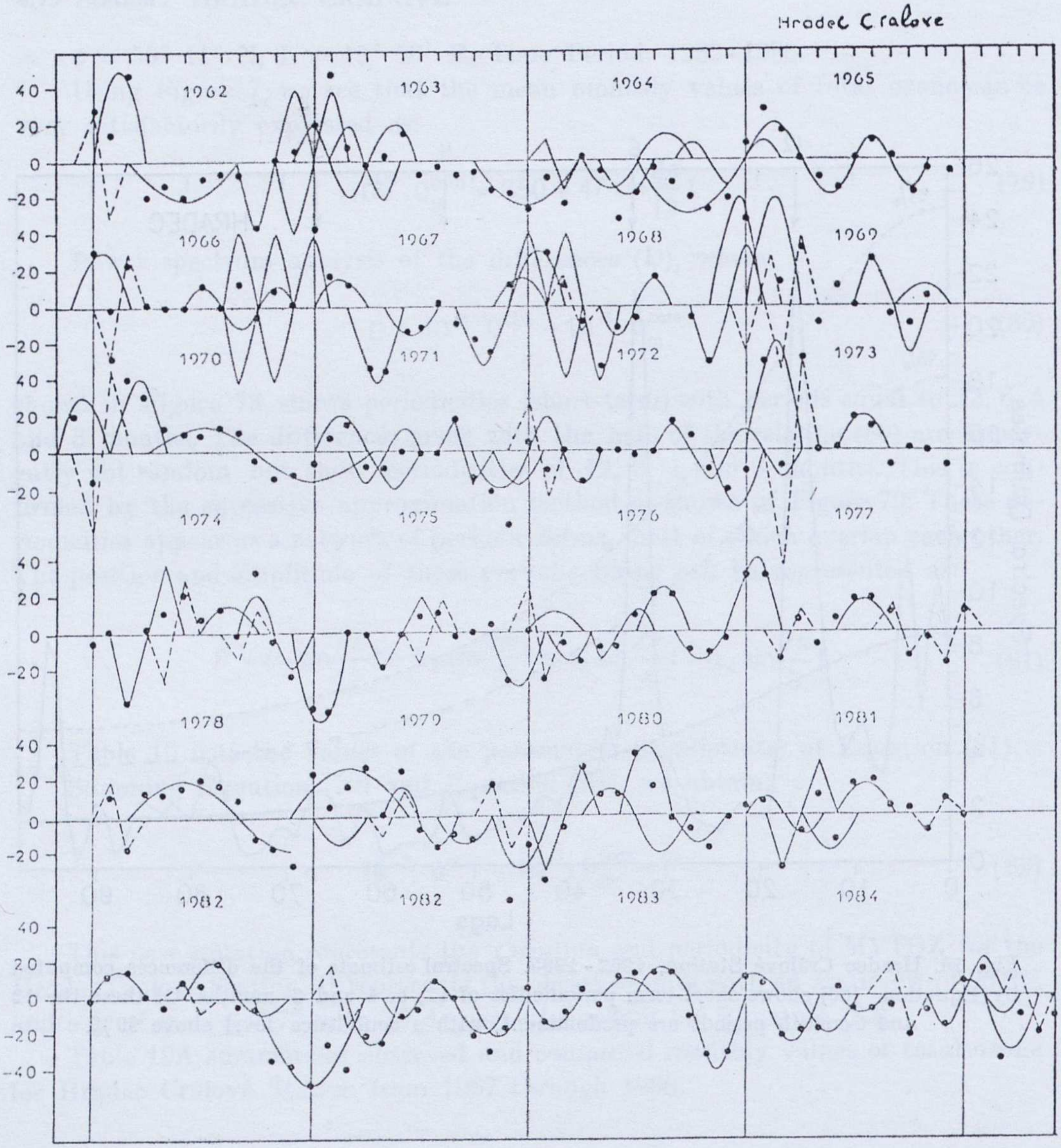

Fig. 79. Hradec Crálové Station, 1962-1985. The differences (D) found by Equation (80) are shown by dots. The dashed and solid sinusoidal or semisinusoidal curves show periodic terms of 12, 6, 4 and 3 months, whose position and amplitude is also plotted, by the successive approximation method. The appearance of these periodic terms appears as a network of periodicities with occasional overlaps.

TABLE 19

Values of the parameters α_1-α_4, and **t** (see Eq. 81).

α_1	t
—20	1962.3 - 1962.9, 1978.3 - 1978.12
—30	1963.10 - 1964.4, 1964.7 - 1965.1
+15	1970.4 - 1971.3
+30	1978.12 - 1979.6
—50	1982.10 - 1983.4

α_2	t
+50	1962.1 - 1962.4
+20	1963.4 - 1963.8, 1965.1 - 1965.6, 1967.1 - 1967.4, 1971.1 - 1971.6, 1973.1 - 1973.4, 1981.6 - 1981.9, 1982.6 - 1982.9
—15	1964.4 - 1964.10, 1967.5 - 1967.8, 1976.2 - 1976.5, 1983.9, - 1983.12, 1984.1 - 1984.4, 1986.5 - 1986.8
—10	1976.9 - 1976.12, 1979.8 - 1979.11, 1982.9 - 1982.12, 1985.6 - 1985.9
—20	1964.5 - 1964.8, 1971.11 - 1972.2, 1979.1 - 1979.4, 1981.4 - 1981.6, 1983.10 - 1984.1, 1985.4 - 1985.7
+30	1965.12 - 1966.3, 1969.11 - 1970.2, 1975.12 - 1976.3
—40	1967.3 - 1967.6, 1974.12 - 1975.3, 1986.2 - 1986.5
—30	1967.9 - 1968.3, 1975.11 - 1976.2
+15	1967.11 - 1968.2, 1974.7 - 1974.10, 1980.4 - 1980.7, 1982.1 - 1982.4, 1984.5 - 1984.8, 1984.7 - 1984.10, 1985.12 - 1986.3
+60	1968.11 - 1969.2, 1969.1 - 1969.4, 1973.1 - 1973.4
+10	1969.9 - 1969.12, 1976.1 - 1976.4, 1978.7 - 1978.10, 1984.12 - 1985.3
+40	1970.2 - 1970.5, 1980.6 - 1980.9
—30	1971.10 - 1972.1, 1972.11 - 1973.2, 1980.9 - 1980.12, 1983.3 - 1983.6
+25	1976.7 - 1976.10, 1977.6 - 1977.9
—35	1979.11 - 1980.2, 1984.10 - 1985.2
—25	1986.2 - 1986.8, 1985.9 - 1985.12

α_3	t
—35	1962.9 - 1963.1, 1962.11 - 1963.3
+20	1962.12 - 1963.4, 1963.2 - 1963.6, 1974.9 - 1975.1
+10	1964.9 - 1965.3, 1981.1 - 1981.4
+15	1965.7 - 1965.11, 1972.1 - 1972.5, 1972.8 - 1973.4, 1979.5 - 1979.9
—40	1966.8 - 1966.12, 1974.2 - 1974.6

α_3	t
+40	1966.8 - 1967.2, 1967.12 - 1968.4, 1968.2 - 1968.6
—30	1968.10 - 1969.2, 1981.3 - 1981.6
—25	1969.7 - 1969.11
—15	1971.3 - 1971.7
—20	1975.4 - 1975.8, 1980.1 - 1980.4, 1980.7 - 1980.11
—10	1983.5 - 1983.11

α_4	t
+30	1961.12 - 1962.2, 1975.12 - 1976.3
+15	1964.1 - 1964.4, 1977.8 - 1977.11, 1978.1 - 1978.4, 1979.12 - 1980.3
—30	1966.1 - 1966.4, 1968.12 - 1969.3, 1974.4 - 1974.7
—10	1967.8 - 1967.11, 1969.5 - 1969.7, 1976.5 - 1976.8, 1981.10 - 1982.1
+10	1968.2 - 1968.8, 1968.4 - 1968.8, 1982.5 - 1982.8
—40	1969.3 - 1969.5
—60	1969.12 - 1970.3
+20	1971.8 - 1971.11, 1979.10 - 1980.1, 1983.1 - 1983.4, 1985.10 - 1986.1
+25	1971.12 - 1972.3, 1986.3 - 1986.6
—50	1973.2 - 1973.8
—15	1974.8 - 1974.11, 1975.6 - 1975.9, 1977.2 - 1977.8, 1979.4 - 1979.7
—20	1977.11 - 1978.2

TABLE 19A

Hradec Crálové Station, 1962 - 1986. Observed and computed MVTOZ.

Year/month		comp.	obs.	Year/month		comp.	obs.
1962.	1	388	389	1965.	1	362	373
»	2	401	399	»	2	411	413
»	3	440	446	»	3	414	414
»	4	387	377	»	4	396	399
»	5	367	369	»	5	367	375
»	6	342	342	»	6	345	347
»	7	319	326	»	7	336	336
»	8	304	308	»	8	329	324
»	9	301	294	»	9	301	303
»	10	266	266	»	10	286	283
»	11	314	316	»	11	314	311
»	12	336	342	»	12	336	330
1963.	1	382	384	1966.	1	384	392
»	2	419	431	»	2	384	383
»	3	397	404	»	3	423	420
»	4	397	395	»	4	397	398
»	5	381	386	»	5	384	382
»	6	379	377	»	6	362	360
»	7	336	330	»	7	336	347
»	8	314	311	»	8	314	315
»	9	301	293	»	9	301	313
»	10	301	295	»	10	301	296
»	11	299	299	»	11	314	324
»	12	310	318	»	12	336	338
1964.	1	332	333	1967.	1	402	404
»	2	371	374	»	2	401	401
»	3	369	374	»	3	414	411
»	4	397	399	»	4	362	364
»	5	371	377	»	5	349	348
»	6	332	331	»	6	349	349
»	7	319	318	»	7	323	327
»	8	312	310	»	8	314	316
»	9	288	289	»	9	292	293
»	10	281	282	»	10	284	282
»	11	288	288	»	11	288	289
»	12	311	315	»	12	349	347

Year/month	comp.	obs.	Year/month	comp.	obs.
1968. 1	441	441	1971. 1	347	356
» 2	410	414	» 2	389	392
» 3	406	411	» 3	408	413
» 4	388	390	» 4	382	389
» 5	353	351	» 5	367	374
» 6	353	350	» 6	360	363
» 7	336	330	» 7	336	336
» 8	323	330	» 8	314	314
» 9	301	305	» 9	318	320
» 10	301	296	» 10	284	287
» 11	284	283	» 11	292	292
» 12	288	295	» 12	297	295
1969. 1	408	410	1972. 1	367	368
» 2	462	464	» 2	377	374
» 3	414	411	» 3	397	395
» 4	432	428	» 4	382	380
» 5	375	375	» 5	384	382
» 6	371	373	» 6	362	362
» 7	336	338	» 7	336	334
» 8	339	330	» 8	314	314
» 9	301	297	» 9	316	318
» 10	285	291	» 10	301	309
» 11	323	319	» 11	299	302
» 12	358	358	» 12	310	315
1970. 1	332	345	1973. 1	351	352
» 2	436	436	» 2	436	441
» 3	432	438	» 3	391	391
» 4	422	427	» 4	440	448
» 5	392	396	» 5	384	382
» 6	374	372	» 6	362	364
» 7	351	345	» 7	353	354
» 8	326	327	» 8	331	328
» 9	309	310	» 9	301	293
» 10	301	296	» 10	301	301
» 11	306	299	» 11	314	314
» 12	324	322	» 12	336	329

Year/month	comp.	obs.	Year/month	comp.	obs
1974. 1	362	359	1977. 1	388	390
» 2	384	386	» 2	410	411
» 3	357	359	» 3	384	383
» 4	397	400	» 4	410	406
» 5	398	396	» 5	384	378
» 6	388	382	» 6	362	369
» 7	336	345	» 7	358	356
» 8	327	327	» 8	336	336
» 9	298	299	» 9	314	312
» 10	334	337	» 10	288	287
» 11	314	309	» 11	314	307
» 12	316	313	» 12	319	317
1975. 1	327	330	1978. 1	379	373
» 2	349	351	» 2	397	393
» 3	397	396	» 3	384	379
» 4	397	395	» 4	407	409
» 5	364	365	» 5	401	396
» 6	362	360	» 6	382	377
» 7	343	344	» 7	353	356
» 8	327	326	» 8	333	331
» 9	301	298	» 9	310	310
» 10	301	300	» 10	291	288
» 11	314	317	» 11	297	295
» 12	310	309	» 12	316	309
1976. 1	362	362	1979. 1	377	385
» 2	369	369	» 2	396	389
» 3	393	392	» 3	410	412
» 4	384	386	» 4	423	423
» 5	384	378	» 5	386	384
» 6	353	355	» 6	390	386
» 7	345	345	» 7	336	330
» 8	336	337	» 8	299	299
» 9	323	323	» 9	292	294
» 10	292	292	» 10	292	290
» 11	305	303	» 11	331	331
» 12	336	331	» 12	289	289

Year/month	comp.	obs.	Year/month	comp.	obs.
1980. 1	345	347	1983. 1	312	312
» 2	351	350	» 2	358	359
» 3	387	392	» 3	355	357
» 4	417	422	» 4	375	375
» 5	397	397	» 5	362	359
» 6	375	375	» 6	352	352
» 7	371	370	» 7	336	330
» 8	329	330	» 8	324	328
» 9	301	299	» 9	301	301
» 10	299	292	» 10	278	279
» 11	292	296	» 11	284	285
» 12	336	334	» 12	319	319
1981. 1	362	366	1984. 1	362	365
» 2	394	391	» 2	371	371
» 3	367	370	» 3	384	388
» 4	387	388	» 4	397	401
» 5	397	395	» 5	384	380
» 6	345	349	» 6	375	373
» 7	353	353	» 7	349	350
» 8	331	332	» 8	327	328
» 9	301	306	» 9	314	316
» 10	301	304	» 10	301	297
» 11	305	306	» 11	294	283
» 12	345	344	» 12	306	306
1982. 1	362	362	1985. 1	371	373
» 2	397	396	» 2	393	391
» 3	410	412	» 3	375	376
» 4	397	398	» 4	375	373
» 5	384	379	» 5	367	365
» 6	371	370	» 6	367	366
» 7	344	343	» 7	327	330
» 8	331	333	» 8	305	308
» 9	301	296	» 9	301	296
» 10	292	295	» 10	279	280
» 11	280	279	» 11	309	307
» 12	293	298	» 12	319	318

Year/month	comp.	obs.
1986. 1	375	371
» 2	397	400
» 3	362	362
» 4	384	386
» 5	362	364
» 6	349	350
» 7	—	—
» 8	—	—
» 9	—	—
» 10	—	—
» 11	—	—
» 12	—	—

4.20 Station: UCCLE

$\varphi = 50^0\ 48'$ N, L $= 04^0\ 21'$ E, Time Period: 1972-1986.

Using Figure 6, we see that the mean monthly values of total ozone can be analytically written as:

$$10^{-3} \cdot 0_m^{com} = 352 + 55 \sin\frac{2\pi}{12}t \tag{83}$$

According to the spectrum analysis, the differences (D), where

$$D = 10^{-3} \cdot 0^{obs} - 10^{-3} \cdot 0_m^{com} \tag{84}$$

are apparently not of random origin but show short-term periodic variations, of 12, 6, 4 and 3 months. These are shown in Figure 80.

The above detected periodicities are also shown in Figure 81 where both position and amplitude are plotted on Figure 81 by means of the successive approximation method. The dots in this figure represent the differences found by Equation (84), while the dashed and solid curves represent periodic terms of 12, 6, 4 and 3 months. These terms are tabulated in Table 20 and can be expressed as:

$$P = \alpha_1 \sin\frac{2\pi}{12}t + \alpha_2 \sin\frac{2\pi}{6}t + \alpha_3 \sin\frac{2\pi}{4}t + \alpha_4 \sin\frac{2\pi}{3}t \tag{85}$$

Table 20 lists the values of the parameters of Equation (85).

Summing Equations (83) and (85) we see that we can obtain Equation (86)

$$10^{-3} \cdot 0^{com} = 352 + 55 \sin\frac{2\pi}{12}t + P \tag{86}$$

which represents the observed monthly values of total ozone with an accuracy of 99% and a s.d. between observed-computed MVTOZ equal to $\sigma = \pm 3.46$. The degrees of freedom of Equation (86) are equal to 32.

These results are listed in Table 20A, which gives observed and computed MVTOZ for the Uccle Station for the period 1972-1986.

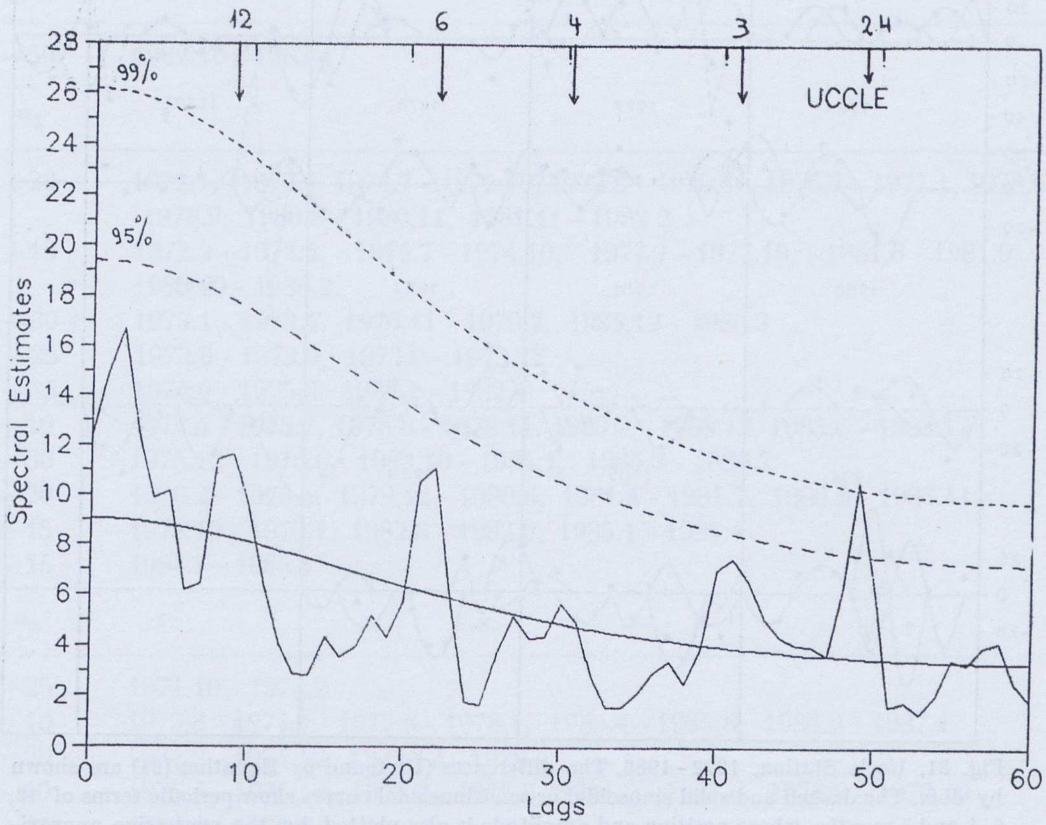

Fig. 80. Uccle Station, 1972 - 1986. Spectral estimate of the differences computed by Equation (84). Analysis shows short-term periodicities with periods of 12, 6, 4 and 3 months.

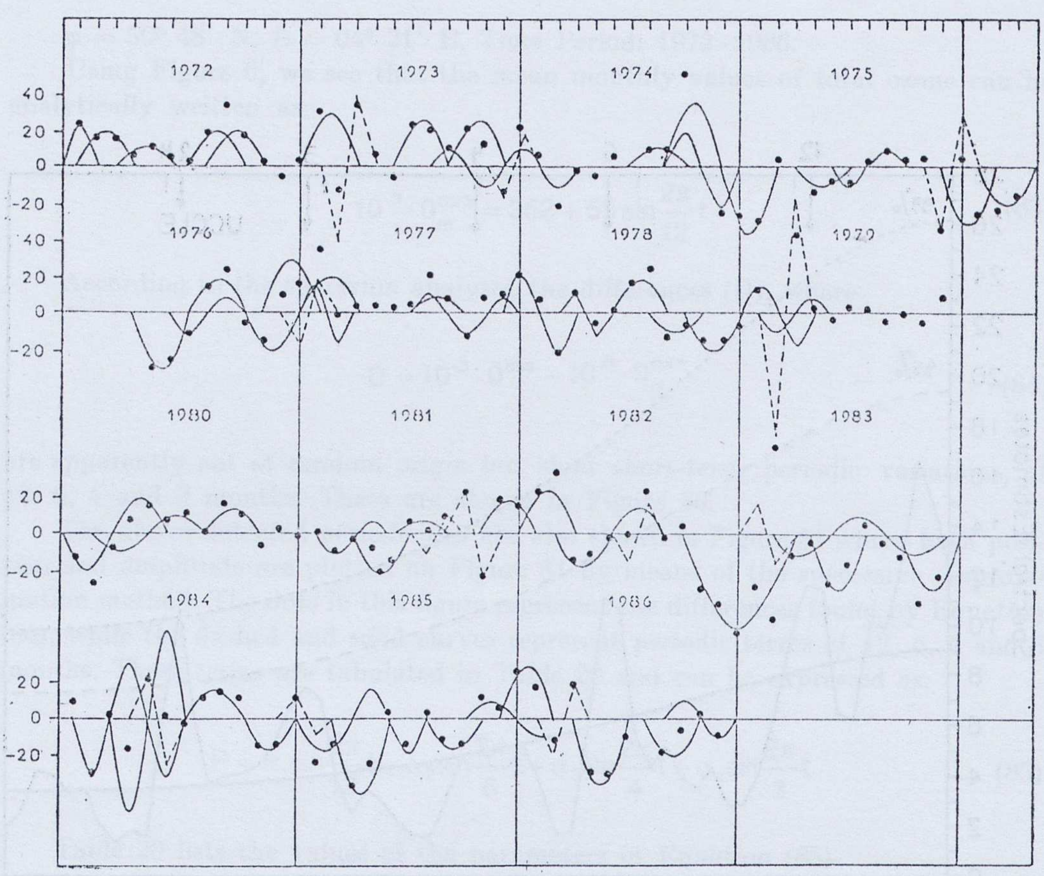

Fig. 81. Uccle Station, 1972 - 1986. The differences (D) found by Equation (84) are shown by dots. The dashed and solid sinusoidal or semisinusoidal curves show periodic terms of 12, 6, 4 and 3 months, whose position and amplitude is also plotted, by the successive approximation method. The amplitude of these periodic terms varies between 10 and 20 D.U., but in exceptional cases (such as the year 1979), it is as high as 60 D.U. or even higher.

TABLE 20

Values of the parameters α_1, - α_4 and **t** (see Eq. 85)

α_1	t
—50	1982.10 - 1983.4

α_2	t
+20	1972.1 - 1972.4, 1972.7 - 1972.10, 1972.8 - 1972.11, 1976.7 - 1977.1, 1978.6 -1978.9, 1980.8 - 1980,11, 1981.11 - 1982.2
+10	1972.2 - 1972.5, 1974.7 - 1974.10, 1977.7 - 1977.10, 1981.6 - 1981.9, 1985.10 - 1986.2
+30	1973.1 - 1973.4, 1976.11 - 1976.2, 1985.12 - 1986.3
+25	1973.6 - 1973.9, 1973.9 - 1973.12
+35	1974.9 - 1975.3, 1982.1 - 1982.4
—10	1975.4 - 1975.7, 1978.8 - 1978.11, 1980.9 - 1980.12, 1983.6 - 1983.12
—30	1975.12 - 1976.6, 1983.10 - 1984.1, 1986.3 - 1986.7
—20	1976.2 - 1976.5, 1979.12 - 1980.6, 1981.4 - 1981.7, 1986.8 - 1986.11
—15	1978.10 - 1979.1, 1982.3 - 1982.9, 1985.1 - 1985.4
+15	1984.7 - 1985.1

α_3	t
+25	1971.10 - 1972.2
+10	1973.8 - 1974.4, 1977.6 - 1978.1, 1985.4 - 1985.8, 1986.9 - 1987.1
+20	1974.9 - 1974.12, 1977.12 - 1978.4
—10	1975.6 - 1975.10, 1979.2 - 1979.6, 1981.2 - 1981.6, 1976.6 - 1976.10
+15	1979.1 - 1979.5
—30	1984.1 - 1984.7
—50	1984.3 - 1984.7

α_4	t	α_4	t
—40	1973.2 - 1973.5, 1975.11 - 1976.2	—70	1979.2 - 1979.5,
—15	1973.11 - 1974.3, 1982.6 - 1982.9	+25	1981.9 - 1981.12
—10	1976.12 - 1977.3, 1980.3 - 1980.9, 1980.5 - 1980.8, 1981.6 - 1981.9		
+10	1978.3 - 1978.6, 1984.12 - 1985.3		
+20	1983.1 - 1983.4		

TABLE 20A

Uccle Station, 1972 - 1986. Observed and computed MVTOZ.

Year/month	comp.	obs.	Year/month	comp.	obs.
1972. 1	376	376	1975. 1	322	325
» 2	396	397	» 2	349	350
» 3	417	418	» 3	400	405
» 4	416	414	» 4	407	406
» 5	409	411	» 5	391	387
» 6	379	385	» 6	370	372
» 7	352	355	» 7	342	344
» 8	342	344	» 8	325	328
» 9	338	338	» 9	314	314
» 10	314	315	» 10	297	300
» 11	304	306	» 11	304	310
» 12	325	321	» 12	290	291
1973. 1	352	361	1976. 1	361	357
» 2	405	410	» 2	353	354
» 3	391	388	» 3	383	376
» 4	442	442	» 4	390	392
» 5	400	407	» 5	374	372
» 6	379	373	» 6	353	354
» 7	374	376	» 7	342	341
» 8	347	345	» 8	342	340
» 9	314	315	» 9	331	327
» 10	319	319	» 10	297	291
» 11	316	319	» 11	287	289
» 12	312	311	» 12	334	335
1974. 1	375	374	1977. 1	369	368
» 2	379	386	» 2	405	415
» 3	377	378	» 3	400	399
» 4	407	404	» 4	407	411
» 5	400	395	» 5	400	403
» 6	379	384	» 6	379	381
» 7	352	354	» 7	352	356
» 8	334	335	» 8	344	346
» 9	313	314	» 9	313	312
» 10	347	348	» 10	287	285
» 11	334	335	» 11	304	313
» 12	305	301	» 12	325	336

Year/month		comp.	obs.	Year/month		comp.	obs.
1978.	1	372	373	1981.	1	352	350
»	2	379	387	»	2	379	380
»	3	380	378	»	3	390	391
»	4	416	419	»	4	407	405
»	5	391	395	»	5	393	392
»	6	379	380	»	6	362	365
»	7	369	369	»	7	361	359
»	8	342	349	»	8	325	326
»	9	295	291	»	9	313	314
»	10	288	291	»	10	319	320
»	11	291	290	»	11	282	280
»	12	312	310	»	12	342	344
1979.	1	352	359	1982.	1	369	370
»	2	394	392	»	2	409	402
»	3	324	327	»	3	430	433
»	4	453	450	»	4	394	393
»	5	410	403	»	5	387	389
»	6	379	377	»	6	379	376
»	7	352	356	»	7	352	351
»	8	325	328	»	8	351	348
»	9	304	301	»	9	304	302
»	10	297	297	»	10	297	301
»	11	304	300	»	11	279	275
»	12	325	334	»	12	282	288
1980.	1	335	340	1983.	1	302	300
»	2	362	353	»	2	353	351
»	3	391	393	»	3	358	355
»	4	416	415	»	4	398	396
»	5	417	416	»	5	391	396
»	6	387	386	»	6	353	352
»	7	361	363	»	7	335	336
»	8	325	324	»	8	334	332
»	9	320	320	»	9	304	301
»	10	305	307	»	10	288	286
»	11	295	297	»	11	269	268
»	12	325	327	»	12	299	304

Year/month		comp.	obs.
1984.	1	352	362
»	2	349	350
»	3	400	403
»	4	387	391
»	5	422	421
»	6	377	380
»	7	352	350
»	8	338	336
»	9	317	319
»	10	297	308
»	11	291	289
»	12	312	312
1985.	1	361	364
»	2	357	355
»	3	387	386
»	4	372	371
»	5	375	375
»	6	379	383
»	7	342	338
»	8	325	328
»	9	291	293
»	10	284	284
»	11	313	316
»	12	334	331
1986.	1	378	378
»	2	396	396
»	3	383	388
»	4	424	427
»	5	370	371
»	6	349	349
»	7	343	343
»	8	—	—
»	9	287	286
»	10	290	292
»	11	304	307
»	12	315	316

4.21 Station: BELSK

$\varphi = 50° \ 50'$ N, L = $20° \ 47'$ E, Time Period: 1963 - 1986.

Using Figure 6, the mean monthly values of total ozone for the Belsk Station for the period 1963 - 1986 can be written as:

$$10^{-3} \cdot 0_m^{com} = 351 + 54 \sin\frac{2\pi}{12} t \tag{87}$$

Spectrum analysis of the differences (D), where

$$D = 10^{-3} \cdot 0^{obs} - 10^{-3} \cdot 0_m^{com} \tag{88}$$

(see Figure 82) shows a predominant 6-month period at a confidence level higher than 99%, and three secondary short-term periods of 12, 4 and 3 months.

The position and amplitude of the detected periodicities were determined graphically by means of the successive approximation method. This showed the same periodic terms as in Figure 82. These terms are again shown in Figure 83, where the dots represent the differences computed by Equation 88, while the dashed and solid sinusoidal or semisinusoidal curves, represent short periodic terms with periods equal to 12, 6, 4 and 3 months. These periodic terms can be expressed as:

$$P = \alpha_1 \sin\frac{2\pi}{12} t + \alpha_2 \sin\frac{2\pi}{6} t + \alpha_3 \sin\frac{2\pi}{4} t + \alpha_4 \sin\frac{2\pi}{3} t \tag{89}$$

Table 21 lists the values of the parameters of Equation (89)

By adding Equations (87) and (89) we obtain the new Equation (90). This equation expresses the observed data of total ozone (MVTOZ) with very high accuracy, i.e. 99%,

$$10^{-3} \cdot 0^{com} = 351 + 54 \sin\frac{2\pi}{12} t + P \tag{90}$$

The s.d. between observed-computed MVTOZ was estimated to be $\sigma = \pm 3.4$.

Figure 84 confirms the MVTOZ analysis for the Belsk Station.

The dots (or small open circles) represent observed MVTOZ while the solid line represents MVTOZ computed with the help of Equation (90), which has 13 degrees of freedom.

The numerical results of figure 84 are listed in Table 21A which gives observed and computed monthly values of total ozone from 1963 through 1986.

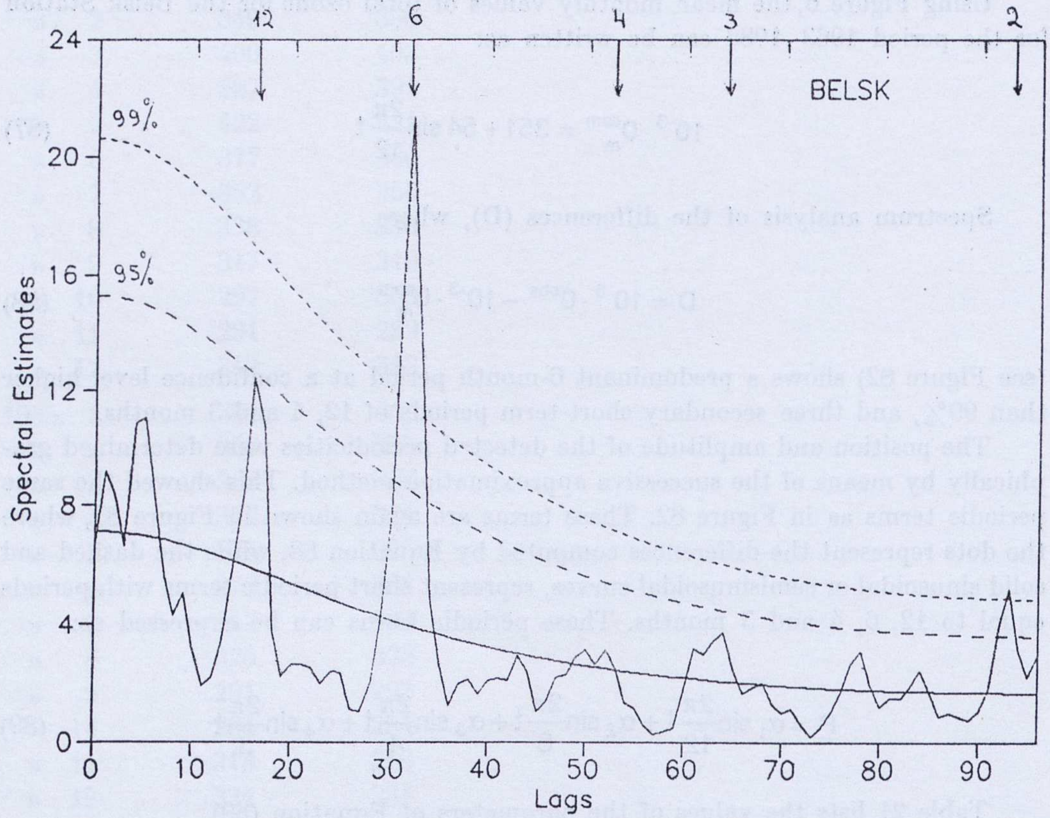

Fig. 82. Belsk Station, 1963 - 1986. Spectral estimate of the differences computed by Equation (88). Analysis shows short-term periodicities with periods of 12, 6, 4 and 3 months. The 12 and 6-month periods are predominant.

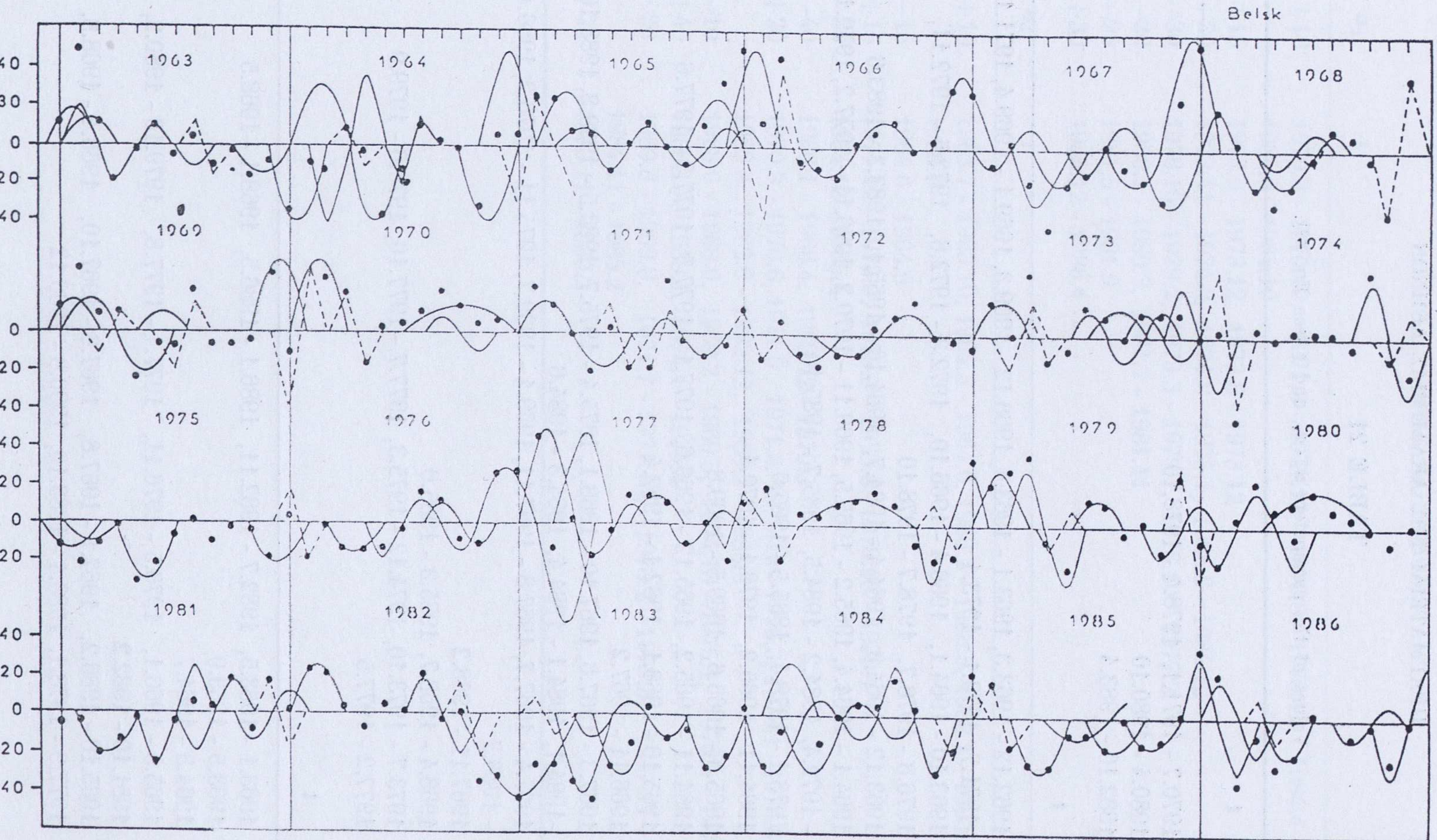

Fig. 83. Belsk Station, 1963 - 1986. The differences (D) computed by Equation (88) are shown by dots. The dashed and solid sinusoidal or semisinusoidal curves show periodic terms of 12, 6, 4 and 3 months, whose position and amplitude is also plotted, by the successive approximation method. These periodicities appear as a network with occasional overlaps.

TABLE 21

Values of the parameters $\alpha_1 - \alpha_4$, and **t** (see Eq. 89).

α_1	t
+15	1970.7 - 1971.1, 1978.4 - 1978.10
+20	1980.4 - 1980.10
—40	1982.10 - 1983.4
α_2	t
+20	1962.12 - 1963.3, 1963.1 - 1963.4, 1968.12 - 1969.3, 1969.1 - 1969.4, 1971.1 -1971.7, 1973.1 - 1973.4
—15	1963.10 - 1964.1, 1966.4 - 1966.10, 1972.3 - 1972.6, 1972.5 - 1972.11, 1976.3 - 1976.7, 1978.7 - 1978.10
—40	1963.12 - 1964.3, 1964.4 - 1964.7, 1964.10 - 1965.1, 1983.3 - 1983.6
+30	1964.1 - 1964.4, 1965.2 - 1965.5, 1969.11 - 1970.2, 1976.11 - 1977.2, 1979.1 - 1979.4, 1984.2 - 1984.5, 1985.7 - 1985.10
—10	1978.1 - 1978.4, 1985.5 - 1985.9
+40	1964.11 - 1965.2, 1970.1 - 1970.4
+10	1965.3 - 1965.6, 1969.5 - 1969.8
+50	1964.11 - 1965.2, 1965.12 - 1966.6, 1977.1 - 1977.5, 1977.3 - 1977.6
+25	1965.10 - 1966.1, 1982.1 - 1982.4
+35	1966.11 - 1967.2
—30	1967.3 - 1967.6, 1967.10 - 1968.1, 1975.4 - 1975.7, 1983.5 - 1983.8, 1983.10 -1984.1, 1984.1 - 1984.4, 1984.3 - 1984.6
—20	1967.4 - 1967.7, 1967.8 - 1967.11, 1969.4 - 1969.7, 1975.11 - 1976.2, 1986.4 - 1986.7
+60	1967.11 - 1968.2
—25	1968.4 - 1968.7, 1985.3 - 1985.6
+15	1973.7 - 1973.10, 1974.12 - 1975.3, 1977.7 - 1977.10, 1979.6 - 1979.9
—50	1977.2 - 1977.5
α_3	t
+20	1963.1 - 1963.5, 1982.7 - 1982.11, 1986.1 - 1986.5, 1968.1 - 1968.5
+10	1963.5 - 1963.9
—40	1964.3 - 1964.7
—15	1965.5 - 1966.1, 1976.5 - 1976.11, 1977.4 - 1977.8, 1979.10 - 1980.2, 1981.10 - 1982.2
—10	1965.10 - 1966.2, 1967.1 - 1967.8, 1967.6 - 1967.10, 1968.4 - 1968.8, 1977.9 - 1978.1, 1983.4 - 1983.10, 1986.8 - 1986.12

α_3	t
+10	1970.8 - 1970.12, 1971.8 - 1971.12, 1976.8 - 1976.12, 1984.4 - 1984.8, 1984.6 - 1984.10
+15	1973.6 - 1973.12, 1973.8 - 1973.12
+30	1973.11 - 1974.2, 1974.9 - 1975.1, 1984.8 - 1984.12
—30	1978.10 - 1979.2, 1979.3 - 1979.7, 1976.10 - 1977.2
—20	1980.1 - 1980.7, 1981.7 - 1981.11
—25	1981.5 - 1981.9
+35	1985.12 - 1986.4

α_4	t
+10	1963.7 - 1963.10, 1964.3 - 1964.6, 1966.2 - 1966.5, 1983.1 - 1983.4, 1986.3-1986.6
—15	1964.6 - 1964.9
+15	1971.12 - 1972.3, 1973.3 - 1973.6, 1978.10 - 1979.1
—30	1964.12 - 1965.4
—40	1966.1 - 1966.4, 1969.12 - 1970.3
+20	1970.3 - 1970.6, 1971.5 - 1971.8, 1975.12 - 1976.3, 1978.1 - 1978.4, 1981.11-1982.2, 1982.9 - 1982.12, 1985.1 - 1985.4
—10	1968.6 - 1968.9, 1969.2 - 1969.5, 1974.10 - 1975.1, 1979.4 - 1979.7
+40	1968.10 - 1969.1, 1974.1 - 1974.4
—20	1969.6 - 1969.9, 1971.7 - 1971.10, 1973.2 - 1973.5, 1977.11 - 1978.1, 1984.11 - 1985.2
+25	1979.11 - 1980.2

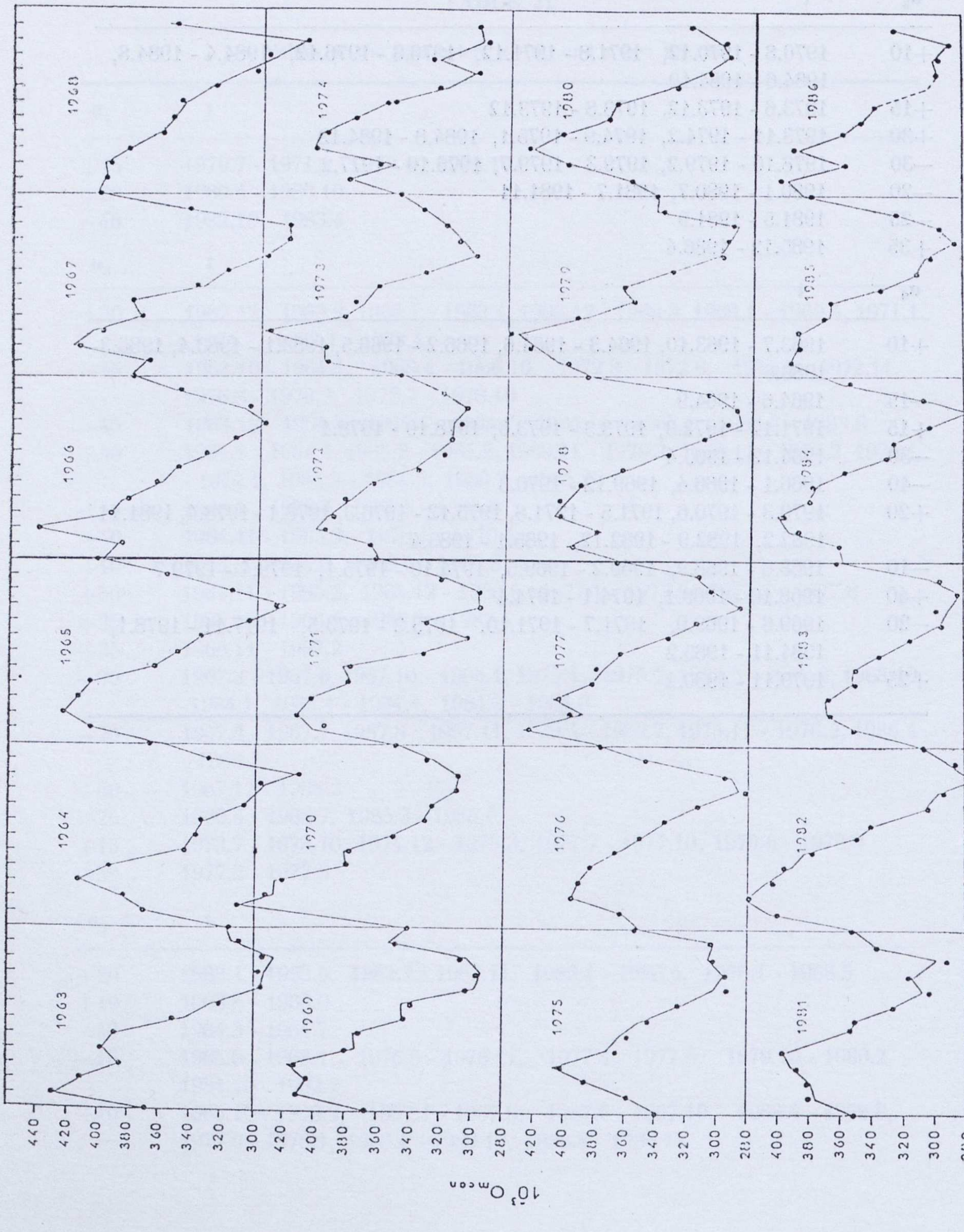

Fig. 84. Belsk Station, 1963 - 1986. Observed MVTOZ is shown by dots. MVTOZ as computed by Equation (90) is shown by a solid line. Accuracy is equal to 99%.

TABLE 21A

Belsk Station, 1963 - 1986. Observed and computed MVTOZ.

Year/month	comp.	obs.	Year/month	comp.	obs.
1963. 1	368	370	1966. 1	404	402
» 2	430	430	» 2	388	393
» 3	411	410	» 3	442	445
» 4	385	386	» 4	396	397
» 5	398	395	» 5	385	388
» 6	390	391	» 6	367	363
» 7	351	347	» 7	351	354
» 8	321	327	» 8	335	330
» 9	295	295	» 9	317	316
» 10	297	293	» 10	297	296
» 11	294	288	» 11	307	311
» 12	309	314	» 12	352	353
1964. 1	316	318	1967. 1	381	380
» 2	371	371	» 2	370	371
» 3	384	386	» 3	398	401
» 4	414	414	» 4	389	383
» 5	394	395	» 5	355	356
» 6	345	344	» 6	363	362
» 7	338	339	» 7	341	338
» 8	335	334	» 8	322	323
» 9	307	307	» 9	297	296
» 10	297	295	» 10	280	282
» 11	272	275	» 11	281	280
» 12	330	328	» 12	348	347
1965. 1	367	358	1968. 1	403	406
» 2	407	407	» 2	400	400
» 3	425	423	» 3	398	401
» 4	414	413	» 4	385	385
» 5	407	405	» 5	366	368
» 6	365	367	» 6	358	355
» 7	351	352	» 7	352	347
» 8	337	335	» 8	331	333
» 9	304	304	» 9	304	310
» 10	282	289	» 10	297	291
» 11	318	319	» 11	272	273
» 12	359	354	» 12	357	361

Year/month	comp.	obs.	Year/month	comp.	obs.
1969. 1	368	366	1972. 1	364	365
» 2	414	415	» 2	367	365
» 3	406	408	» 3	398	404
» 4	414	417	» 4	392	395
» 5	381	375	» 5	385	381
» 6	372	375	» 6	367	370
» 7	343	344	» 7	338	340
» 8	339	345	» 8	322	327
» 9	304	298	» 9	317	315
» 10	297	291	» 10	310	315
» 11	307	303	» 11	307	307
» 12	348	353	» 12	327	321
1970. 1	342	340	1973. 1	351	345
» 2	450	452	» 2	397	399
» 3	433	428	» 3	398	399
» 4	422	427	» 4	435	438
» 5	381	381	» 5	385	385
» 6	380	383	» 6	380	374
» 7	351	356	» 7	366	367
» 8	331	334	» 8	335	333
» 9	327	327	» 9	302	304
» 10	312	313	» 10	312	311
» 11	310	312	» 11	322	320
» 12	330	328	» 12	337	335
1971. 1	351	352	1974. 1	351	351
» 2	397	406	» 2	385	383
» 3	415	415	» 3	363	355
» 4	405	406	» 4	405	405
» 5	381	379	» 5	398	403
» 6	380	384	» 6	380	380
» 7	334	333	» 7	351	355
» 8	305	304	» 8	322	326
» 9	331	334	» 9	304	300
» 10	297	296	» 10	327	331
» 11	297	298	» 11	298	296
» 12	322	317	» 12	301	302

Year/month	comp.	obs.	Year/month	comp.	obs.
1975. 1	338	340	1978. 1	368	364
» 2	358	358	» 2	397	400
» 3	390	387	» 3	381	379
» 4	405	402	» 4	405	410
» 5	372	367	» 5	406	400
» 6	354	359	» 6	393	390
» 7	351	346	» 7	366	364
» 8	322	324	» 8	335	340
» 9	304	294	» 9	312	315
» 10	297	295	» 10	297	288
» 11	307	303	» 11	290	290
» 12	305	302	» 12	309	306
1976. 1	351	354	1979. 1	381	386
» 2	363	363	» 2	406	401
» 3	398	397	» 3	424	427
» 4	392	392	» 4	435	438
» 5	385	384	» 5	389	395
» 6	365	368	» 6	359	359
» 7	351	348	» 7	368	366
» 8	337	338	» 8	335	333
» 9	314	316	» 9	304	300
» 10	282	288	» 10	297	298
» 11	297	297	» 11	292	294
» 12	348	349	» 12	344	339
1977. 1	377	380	1980. 1	344	343
» 2	423	427	» 2	360	360
» 3	398	388	» 3	398	402
» 4	405	408	» 4	425	428
» 5	383	383	» 5	408	406
» 6	380	376	» 6	377	376
» 7	366	367	» 7	371	370
» 8	335	337	» 8	337	332
» 9	316	316	» 9	314	310
» 10	287	287	» 10	297	297
» 11	307	307	» 11	307	300
» 12	315	316	» 12	322	323

Year/month	comp.	obs.	Year/month	comp.	obs.
1981. 1	351	347	1984. 1	351	356
» 2	380	376	» 2	354	354
» 3	381	378	» 3	398	391
» 4	388	392	» 4	405	400
» 5	398	396	» 5	382	384
» 6	355	356	» 6	380	382
» 7	351	347	» 7	351	358
» 8	327	329	» 8	322	328
» 9	304	308	» 9	324	324
» 10	317	316	» 10	297	301
» 11	292	298	» 11	277	277
» 12	339	340	» 12	305	305
1982. 1	353	352	1985. 1	368	375
» 2	402	404	» 2	397	398
» 3	420	421	» 3	381	383
» 4	405	410	» 4	383	382
» 5	398	392	» 5	376	372
» 6	380	385	» 6	371	371
» 7	351	352	» 7	342	343
» 8	342	342	» 8	309	307
» 9	304	301	» 9	300	303
» 10	294	298	» 10	284	283
» 11	270	273	» 11	294	295
» 12	287	291	» 12	322	323
1983. 1	311	309	1986. 1	386	388
» 2	354	355	» 2	400	404
» 3	369	371	» 3	363	363
» 4	370	372	» 4	394	396
» 5	353	355	» 5	372	374
» 6	354	355	» 6	363	361
» 7	335	337	» 7	351	354
» 8	322	326	» 8	—	—
» 9	294	293	» 9	294	295
» 10	297	290	» 10	297	294
» 11	281	281	» 11	287	285
» 12	296	301	» 12	322	321

4.22 Station: BRACKNELL

$\varphi = 51° \, 23'$ N, L $= 00° \, 47'$ E, Time Period: 1969-1986.

Again using Figure 6, as for the other stations of the Northern Hemisphere, we see that the mean monthly values of total ozone can be represented with the help of the relation:

$$10^{-3} \cdot 0_m^{com} = 353 + 55 \sin\frac{2\pi}{12}t \tag{91}$$

Spectral analysis of the differences (D), where

$$D = 10^{-3} \cdot 0^{obs} - 10^{-3} \cdot 0_m^{com} \tag{92}$$

shows only three significant short-term periods, of 12, 6 and 4 months. See Figure 85.

Position and amplitude of periodic terms of MVTOZ cannot be defined by spectral analysis. This can be achieved only by using the method of successive approximations. This is obvious from Figure 86, where the dots represent the differences computed by Equation (92), while the dashed and solid sinusoidal or semi-sinusoidal curves represent the periodic terms determined graphically. As can be seen from Figure 86, the graphic method reveals four periodicities of 12, 6, 4 and 3 months i.e. four periodic terms. (This does not agree with the spectral analysis result). These periodic terms can be expressed as:

$$P = \alpha_1 \sin\frac{2\pi}{6}t + \alpha_2 \sin\frac{2\pi}{4}t + \alpha_3 \sin\frac{2\pi}{3}t \tag{93}$$

The values of the parameters (coefficients) $\boldsymbol{\alpha_1}$, $\boldsymbol{\alpha_2}$, $\boldsymbol{\alpha_3}$ and **t**, are listed in Table 22. Thus, summing Equations (91) and (93) we obtain

$$10^{-3} \cdot 0^{com} = 353 + 55 \sin\frac{2\pi}{12}t + P \tag{94}$$

i.e. a new equation which represents the observed data with an accuracy equal to 99%. The s.d. between observed-computed MVTOZ is $\boldsymbol{\sigma} = \pm 3.4$. Equation (94) has 46 degrees of freedom.

The above results are shown graphically in Figure 87 which demonstrates the close correlation (agreement) between observed monthly values of total ozone (dots) and the corresponding MVTOZ computed by Equation (94), for the period from 1969 through 1986 (solid line).

Table 22A tabulates observed and computed MVTOZ for the Bracknell Station (1969-1986).

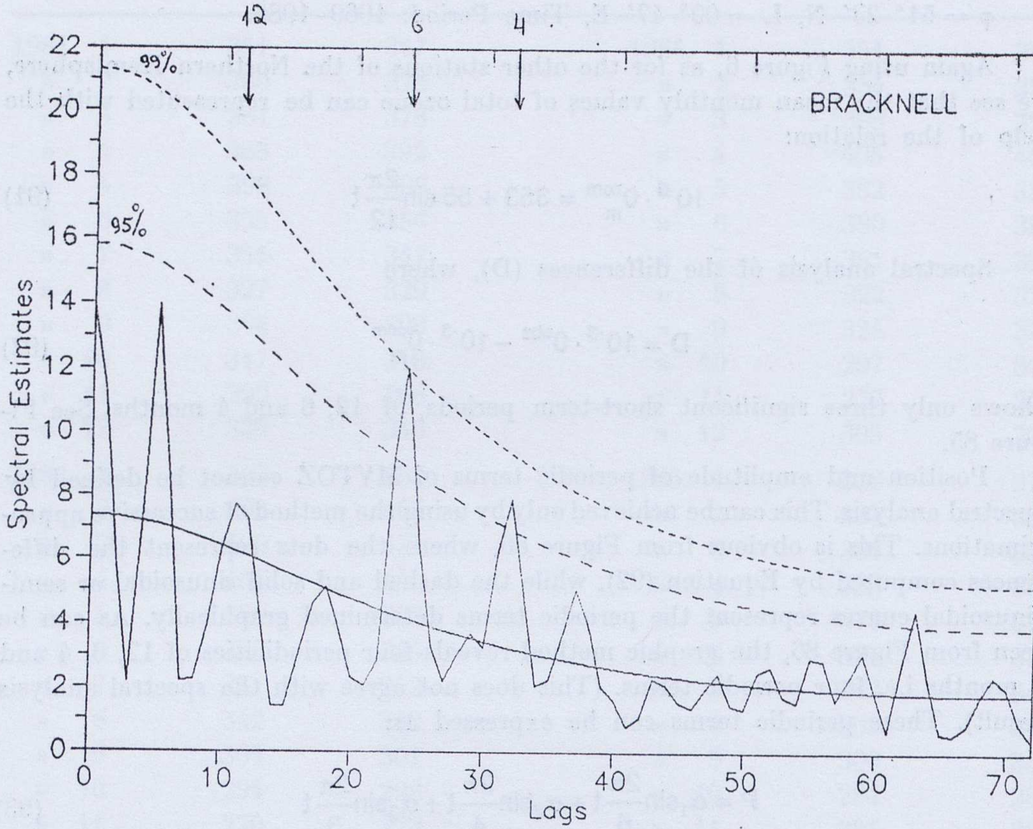

Fig. 85. Bracknell Station, 1969 - 1986. Spectral estimate of the differences computed by Equation (92). Analysis shows short-term periods of 12, 6, and 4 months. The first of these periods is below the confidence level of 95% while the second and third are above the confidence levels of 95% and 99%.

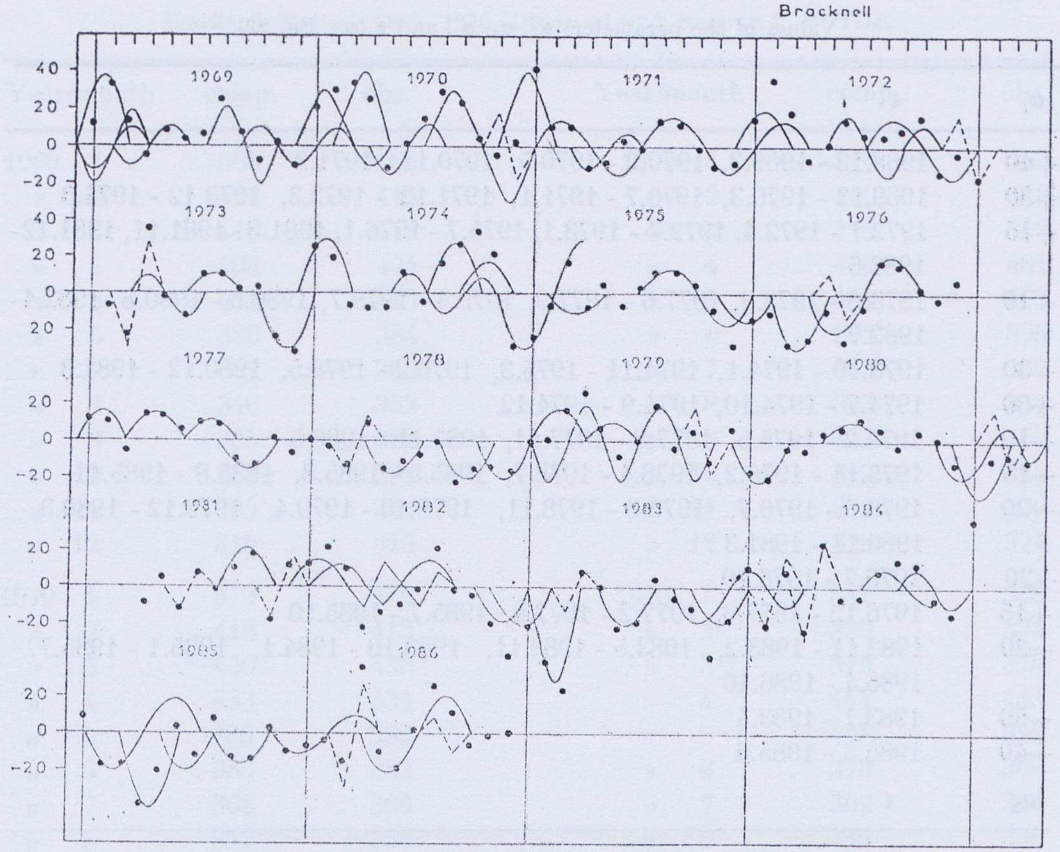

Fig. 86. Bracknell Station 1969 - 1986. The differences (D) found by Equation (92) are shown by dots. The dashed and solid sinusoidal or semisinusoidal curves show periodic terms of 12, 6 and 4 months, whose position and amplitude is also plotted, by the successive approximation method.

TABLE 22

Values of the parameters α_1, α_2, α_3, and **t** (see Eq. 93).

α_1	t
+40	1968.12 - 1969.3, 1970.2 - 1970.5, 1970.11 - 1971.2
+30	1969.12 - 1970.3, 1970.7 - 1971.1, 1971.12 - 1972.3, 1973.12 - 1974.3
+15	1972.1 - 1972.4, 1972.7 - 1973.1, 1975.7 - 1976.1, 1981.8 - 1981.11, 1981.12-1982.6
+10	1973.6 - 1973.9, 1977.6 - 1977.9, 1979.4 - 1979.7, 1980.5 - 1980.8, 1982.1-1982.7
—30	1973.10 - 1974.1, 1974.11 - 1975.3, 1976.2 - 1976.5, 1980.12 - 1981.3
+30	1974.7 - 1974.10, 1974.9 - 1974.12
—10	1975.2 - 1975.5, 1977.8 - 1977.11, 1985.11 - 1986.5
—15	1975.11 - 1976.2, 1978.4 - 1978.7, 1985.5 - 1985.8, 1985.8 - 1985.11
—20	1976.4 - 1976.7, 1978.8 - 1978.11, 1978.10 - 1979.4, 1979.12 - 1980.3, 1980.11 - 1981.3
+20	1976.7 - 1976.10
+15	1976.12 - 1977.3, 1977.2 - 1977.6, 1985.7 - 1985.10
—20	1982.11 - 1983.2, 1983.5 - 1983.11, 1983.10 - 1984.1, 1985.1 - 1985.7, 1986.4 - 1986.10
—50	1983.1 - 1983.4
—40	1985.3 - 1985.6
α_2	**t**
—20	1968.12 - 1969.3, 1979.1 - 1979.7
—10	1969.3 - 1969.6, 1971.3 - 1971.6
+20	1969.7 - 1969.10
+10	1969.9 - 1970.1, 1970.1 - 1970.5, 1973.3 - 1973.6, 1974.5 - 1974.11, 1983.12-1984.4
—15	1970.4 - 1970.8
+15	1972.5 - 1972.11, 1984.9 - 1985.1
α_3	**t**
+20	1970.10 - 1971.1, 1981.1 - 1981.4
+15	1972.11 - 1973.2
—30	1973.2 - 1973.5, 1984.3 - 1984.6, 1986.2 - 1986.5
+10	1976.4 - 1976.7, 1979.8 - 1979.12, 1981.2 - 1981.5
—20	1978.2 - 1978.5, 1981.10 - 1982.1, 1984.1 - 1984.4
—10	1981.5 - 1981.8, 1982.3 - 1982.9, 1983.2 - 1983.5
+10	1986.7 - 1986.10

TABLE 22A

Bracknell Station, 1969 - 1986. Observed and computed MVTOZ.

Year/month	comp.	obs.	Year/month	comp.	obs.
1969. 1	368	365	1972. 1	370	369
» 2	415	415	» 2	409	418
» 3	410	413	» 3	413	419
» 4	408	404	» 4	408	401
» 5	411	410	» 5	401	403
» 6	380	384	» 6	395	395
» 7	353	360	» 7	353	359
» 8	346	352	» 8	323	331
» 9	305	312	» 9	317	313
» 10	288	291	» 10	313	315
» 11	305	306	» 11	293	290
» 12	316	313	» 12	326	324
1970. 1	379	375	1973. 1	341	338
» 2	416	412	» 2	380	374
» 3	436	436	» 3	375	379
» 4	433	434	» 4	444	445
» 5	386	389	» 5	401	399
» 6	380	382	» 6	370	369
» 7	368	368	» 7	362	364
» 8	352	358	» 8	335	336
» 9	331	329	» 9	305	308
» 10	298	302	» 10	298	302
» 11	296	301	» 11	279	282
» 12	318	327	» 12	300	294
1971. 1	388	394	1974. 1	379	378
» 2	392	391	» 2	406	400
» 3	413	412	» 3	401	396
» 4	398	397	» 4	408	401
» 5	389	393	» 5	401	394
» 6	378	384	» 6	390	392
» 7	353	352	» 7	353	350
» 8	338	341	» 8	342	343
» 9	317	316	» 9	331	332
» 10	298	296	» 10	334	332
» 11	293	295	» 11	331	327
» 12	314	318	» 12	300	298

Year/month	comp.	obs.	Year/month	comp.	obs.
1975. 1	327	330	1978. 1	353	353
» 2	380	374	» 2	380	379
» 3	418	419	» 3	384	382
» 4	399	401	» 4	425	420
» 5	401	406	» 5	389	386
» 6	380	375	» 6	368	369
» 7	353	357	» 7	353	345
» 8	338	338	» 8	326	326
» 9	317	318	» 9	288	283
» 10	298	304	» 10	281	283
» 11	293	297	» 11	288	292
» 12	302	299	» 12	309	310
1976. 1	341	339	1979. 1	353	353
» 2	380	369	» 2	377	381
» 3	375	374	» 3	418	418
» 4	382	384	» 4	428	435
» 5	393	393	» 5	410	408
» 6	359	355	» 6	369	372
» 7	353	348	» 7	353	353
» 8	343	344	» 8	346	346
» 9	322	321	» 9	305	302
» 10	298	301	» 10	307	304
» 11	305	303	» 11	296	295
» 12	326	333	» 12	326	332
1977. 1	365	365	1980. 1	336	336
» 2	392	390	» 2	363	360
» 3	401	396	» 3	401	398
» 4	420	422	» 4	408	403
» 5	413	414	» 5	401	406
» 6	380	386	» 6	389	387
» 7	362	363	» 7	362	365
» 8	335	335	» 8	326	333
» 9	296	295	» 9	305	303
» 10	289	286	» 10	298	303
» 11	305	306	» 1	305	306
» 12	326	320	» 12	309	312

Year/month	comp.	obs.	Year/month	comp.	obs.
1981. 1	310	310	1984. 1	363	363
» 2	371	371	» 2	363	360
» 3	393	393	» 3	408	410
» 4	399	399	» 4	382	384
» 5	401	405	» 5	427	426
» 6	371	368	» 6	380	374
» 7	362	361	» 7	353	348
» 8	326	326	» 8	338	335
» 9	322	317	» 9	317	320
» 10	315	316	» 10	313	311
» 11	288	287	» 11	305	299
» 12	343	337	» 12	311	312
1982. 1	365	366	1985. 1	353	360
» 2	401	402	» 2	363	363
» 3	410	411	» 3	384	384
» 4	387	386	» 4	373	370
» 5	389	388	» 5	383	381
» 6	371	371	» 6	384	384
» 7	356	352	» 7	340	341
» 8	347	347	» 8	326	335
» 9	305	304	» 9	292	292
» 10	298	294	» 10	285	284
» 11	288	287	» 11	305	308
» 12	292	289	» 12	316	317
1983. 1	336	332	1986. 1	343	347
» 2	337	340	» 2	380	376
» 3	349	346	» 3	385	386
» 4	417	417	» 4	444	445
» 5	401	401	» 5	384	391
» 6	363	358	» 6	363	361
» 7	336	334	» 7	353	356
» 8	325	331	» 8	352	352
» 9	305	298	» 9	313	316
» 10	281	287	» 10	298	292
» 11	271	267	» 11	305	304
» 12	309	309	» 12	326	327

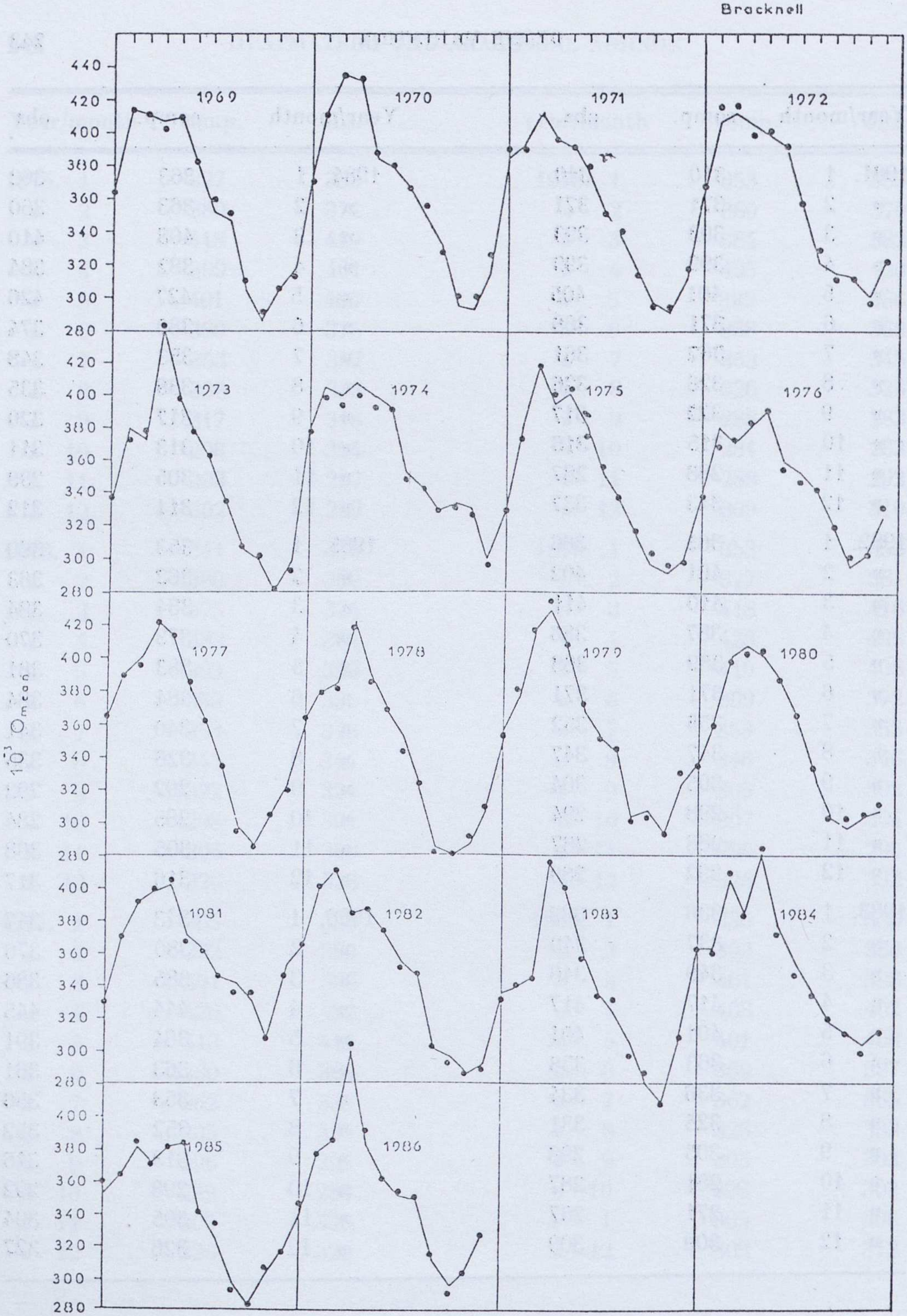

Fig. 87. Bracknell Station, 1969 - 1986. Observed MVTOZ is shown by dots. MVTOZ as computed by Equation (94) is shown by a solid line. Accuracy is equal to 99%. Note the extremely close agreement between the two.

4.23 Station: GOOSE BAY

$\varphi = 53^0\ 20'$ N, L $= 60^0\ 25'$ W, Time Period: 1962-1986.

Using Figure 5, MMVTOZ (Goose Bay) can be expressed as:

$$10^{-3} \cdot 0_m^{com} = 364 + 60 \sin\left(\frac{2\pi}{12}t + 30^\circ\right) \tag{95}$$

Power spectrum analysis of the differences (D), where

$$D = 10^{-3} \cdot 0^{obs} - 10^{-3} \cdot 0_m^{com} \tag{96}$$

reveals four short periodic terms of 12, 6, 4 and 3 months. (see Figure 88), with a confidence level higher than 95% and, in the case of the 4-month period, higher than 99%.

In Figure 89 the dots represent the values of the differences computed by Equation (96) while the dashed and solid sinusoidal and semisinusoidal curves represent the periodic or quasi-periodic terms of 12, 6, 4 and 3 months, as determined by the successive approximation method. These periodicities (or periodic terms) can be expressed as:

$$P = \alpha_1 \sin\frac{2\pi}{12}t + \alpha_2 \sin\frac{2\pi}{6}t + \alpha_3 \sin\frac{2\pi}{4}t + \alpha_4 \sin\frac{2\pi}{3}t \tag{97}$$

Table 23 summarizes the values of the parameters of Equation (97).

By summing Equations (95) and (97) we obtain a new equation

$$10^{-3} \cdot 0^{com} = 364 + 60 \sin\left(\frac{2\pi}{12}t + 30^\circ\right) + P \tag{98}$$

whereby the observed data of the monthly values of total ozone can be expressed with very high accuracy (99%). The s.d. between MVTOZ as observed and as computed by Equation (98), was found equal to $\sigma = \pm 3.6$, with 61 degrees of freedom for Equation (98).

The above results can be clearly seen in Figures 90 and 91 where the dots represent observed monthly values of total ozone, while the solid line represents the MVTOZ computed by Equation (98).

Table 23 A tabulates the numerical results plotted on Figures 90. and 91.

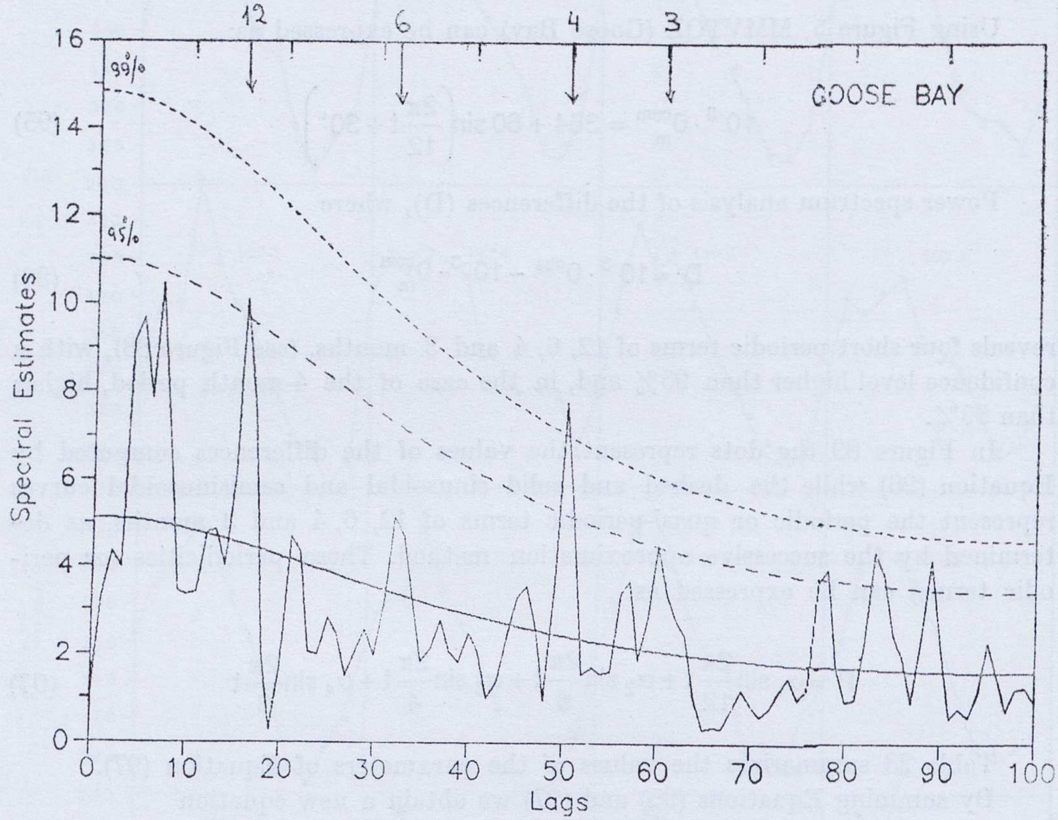

Fig. 88. Goose Bay Station, 1962-1986. Spectral estimate of the differences computed by Equation (96) shows periodicities of 12, 6, 4 and 3 months. Note that the 4-month period is above the confidence level of 99%.

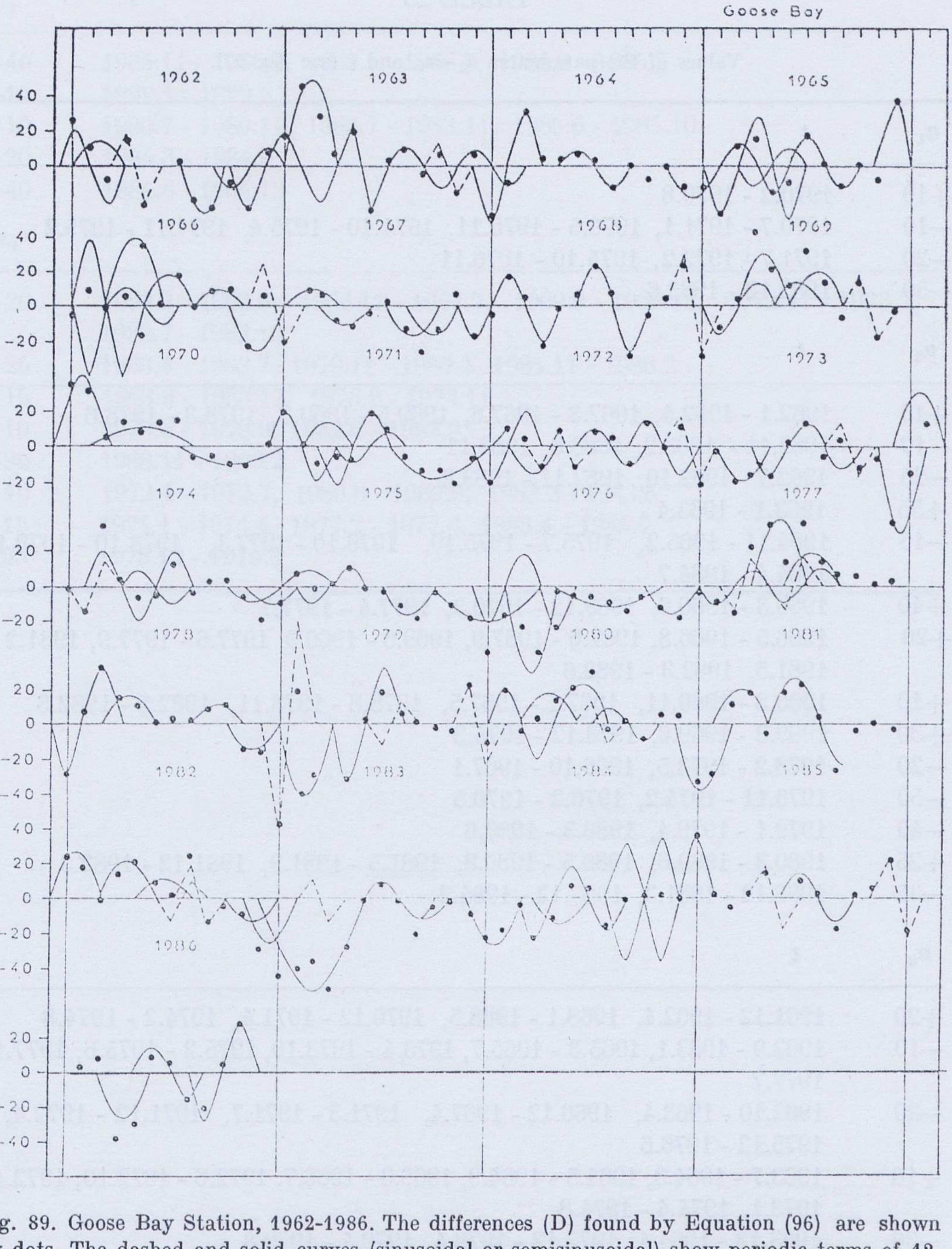

Fig. 89. Goose Bay Station, 1962-1986. The differences (D) found by Equation (96) are shown by dots. The dashed and solid curves (sinusoidal or semisinusoidal) show periodic terms of 12, 6, 4 and 3 months, whose position and amplitude is also plotted, by the successive approximation method.

TABLE 23

Values of the parameters $\alpha_1 - \alpha_4$, and t (see Eq. 97).

α_1	t
+10	1970.2 - 1970.8
—10	1970.7 - 1971.1, 1976.5 - 1976.11, 1974.10 - 1975.4, 1974.11 - 1975.2
—20	1971.7 - 1972.2, 1975.10 - 1976.11
—50	1982.12 - 1983.6

α_2	t
+15	1962.1 - 1962.4, 1967.3 - 1967.6, 1969.5 - 1969.8, 1978.3 - 1978.6
—10	1982.11 - 1983.2, 1983.8, 1983.11
—25	1962.7 - 1962.10, 1982.11 - 1983.2
+55	1963.1 - 1963.4
—15	1964.11 - 1965.2, 1975.7 - 1975.10, 1976.10 - 1977.1, 1978.10 - 1979.1, 1984.4 - 1984.7
+40	1966.3 - 1966.6, 1969.12 - 1970.3, 1977.4 - 1977.7
+20	1966.5 - 1966.8, 1967.6 - 1967.9, 1969.6 - 1969.9, 1977.6 - 1977.9, 1981.2 - 1981.5, 1982.3 - 1982.6
+10	1966.8 - 1966.11, 1967.1 - 1967.5, 1978.8 - 1978.11, 1982.5 - 1982.8
+30	1969.3 - 1969.6, 1973.12 - 1974.3
—20	1973.2 - 1973.5, 1966,10 - 1967.1
—50	1973.11 - 1974.2, 1976.2 - 1976.5
—40	1979.1 - 1979.4, 1986.3 - 1986.6
+25	1980.3 - 1980.6, 1980.5 - 1980.8, 1981.5 - 1981.9, 1981.12 - 1982.3
—35	1980.12 - 1981.3, 1983.12 - 1984.3

α_3	t
+20	1961.12 - 1962.4, 1968.1 - 1968.5, 1970.12 - 1971.4, 1974.2 - 1974.8
—10	1962.9 - 1963.1, 1965.3 - 1965.7, 1973.4 - 1973.10, 1975.2 - 1975.6, 1977.1-1977.7
—20	1962.10 - 1963.4, 1966.12 - 1967.4, 1971.3 - 1971.7, 1971.12 - 1972.4, 1975.12 - 1976.6
+10	1963.7 - 1964.3, 1964.5 - 1964.9, 1966.3 - 1966.7, 1972.6 - 1972.10, 1972.4-1973.1, 1974.4 - 1974.8
—30	1963.12 - 1964.4, 1977.12 - 1978.4, 1979.4 - 1979.8
+25	1965.1 - 1965.7, 1968.6 - 1968.10, 1979.11 - 1980.2
+15	1965.7 - 1965.10, 1986.5 - 1986.9

α_3	t
+40	1965.11 - 1966.3, 1966.1 - 1966.5, 1984.8 - 1985.2
−15	1969.1 - 1969.5
+10	1980.7 - 1980.11, 1983.7 - 1983.11, 1985.6 - 1985.10
−20	1984.3 - 1984.9
−40	1984.8 - 1984.12

α_4	t
+20	1962.3 - 1962.6, 1966.11 - 1967.2, 1969.9 - 1969.12, 1972.11 - 1973.2, 1982.7 - 1982.10
+25	1963.4 - 1963.7, 1979.11 - 1980.2, 1985.11 - 1986.2
+15	1963.9 - 1963.12, 1973.8 - 1973.11
−10	1979.6 - 1979.9, 1982.6 - 1982.9
+30	1968.11 - 1969.2
+10	1972.4 - 1972.7, 1980.6 - 1980.9, 1983.2 - 1983.5
−15	1974.1 - 1974.4, 1977.2 - 1977.8, 1985.4 - 1985.7
−65	1978.12 - 1979.3

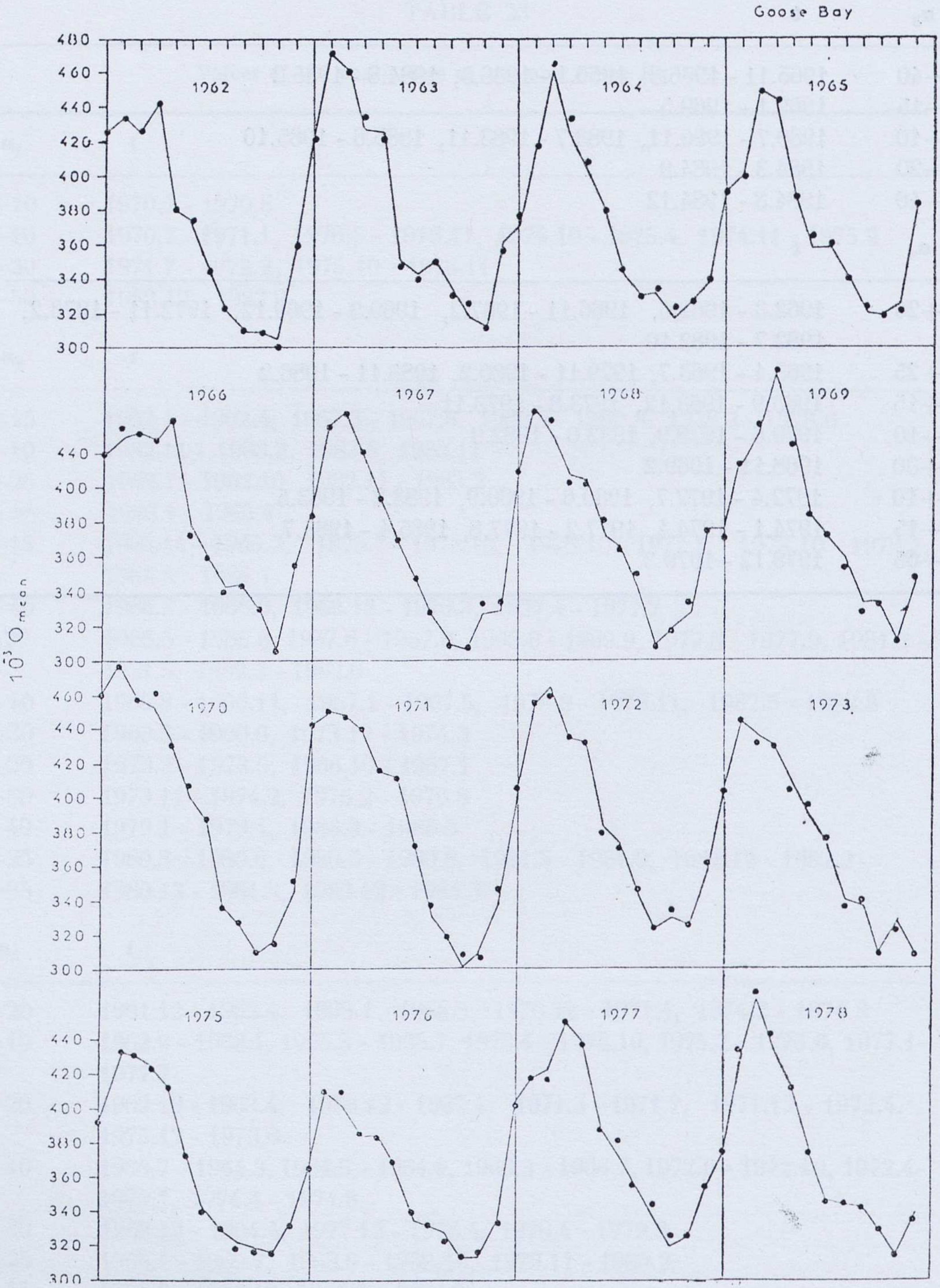

Fig. 90. Goose Bay Station, 1962 - 1978. Observed MVTOZ is shown by dots. MVTOZ as computed by Equation (98) is shown by a solid line. Accuracy is equal to 99%.

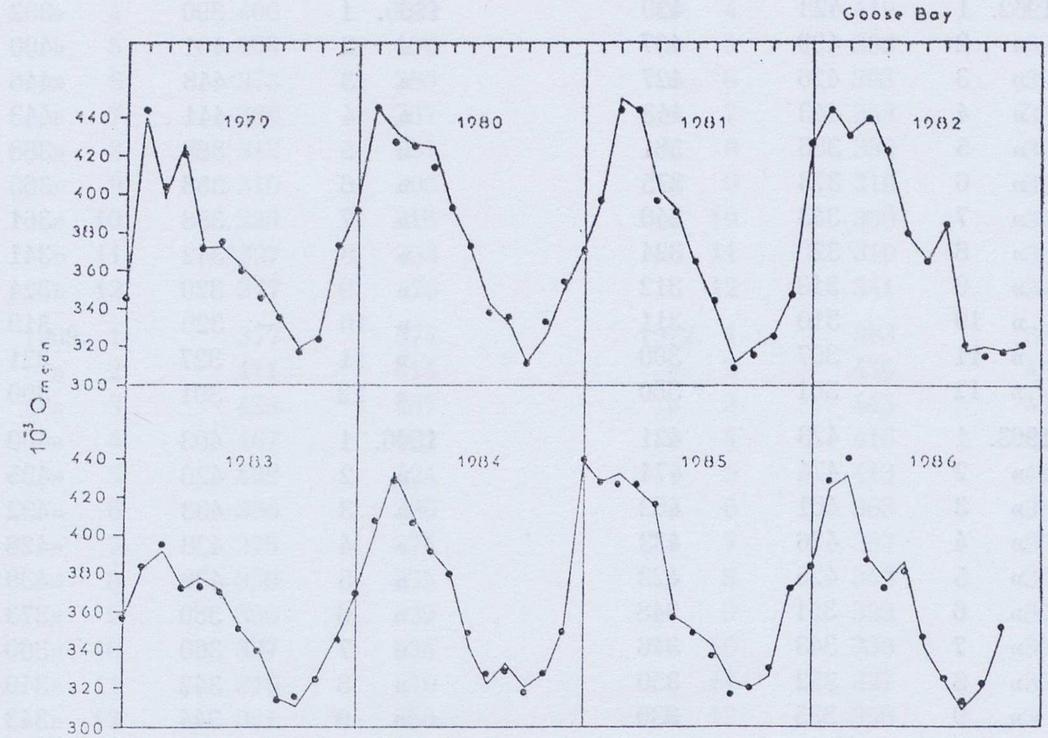

Fig. 91. Goose Bay Station, 1979-1986. Caption as for Figure 90, to which this Figure is complementary.

TABLE 23A

Goose Bay Station, 1962 - 1986. Observed and Computed MVTOZ.

Year/month	comp.	obs.	Year/month	comp.	obs.
1962. 1	423	429	1965. 1	390	392
» 2	439	437	» 2	401	400
» 3	426	427	» 3	448	446
» 4	443	443	» 4	441	443
» 5	386	381	» 5	388	388
» 6	373	375	» 6	358	365
» 7	343	346	» 7	358	361
» 8	320	324	» 8	342	341
» 9	313	312	» 9	320	324
» 10	310	311	» 10	320	319
» 11	307	300	» 11	327	321
» 12	361	360	» 12	391	390
1963. 1	423	421	1966. 1	403	400
» 2	474	474	» 2	426	435
» 3	461	462	» 3	433	432
» 4	426	433	» 4	428	428
» 5	425	423	» 5	438	439
» 6	351	348	» 6	380	373
» 7	343	346	» 7	360	360
» 8	352	350	» 8	342	340
» 9	335	330	» 9	344	343
» 10	320	326	» 10	329	330
» 11	314	313	» 11	302	305
» 12	361	357	» 12	351	356
1964. 1	373	377	1967. 1	386	383
» 2	416	418	» 2	435	436
» 3	463	465	» 3	442	440
» 4	426	432	» 4	417	420
» 5	403	408	» 5	394	393
» 6	383	380	» 6	373	370
» 7	343	346	» 7	343	346
» 8	332	330	» 8	329	328
» 9	335	335	» 9	309	310
» 10	320	314	» 10	307	307
» 11	327	327	» 11	327	334
» 12	338	340	» 12	331	334

Year/month		comp.	obs.	Year/month		comp.	obs.
1968.	1	403	408	1971.	1	423	423
»	2	446	444	»	2	426	428
»	3	433	439	»	3	426	425
»	4	406	404	»	4	419	420
»	5	403	402	»	5	393	396
»	6	373	380	»	6	393	392
»	7	368	367	»	7	353	352
»	8	342	351	»	8	332	336
»	9	310	306	»	9	318	320
»	10	320	316	»	10	300	306
»	11	327	333	»	11	310	307
»	12	377	376	»	12	341	345
1969.	1	377	374	1972.	1	383	382
»	2	411	414	»	2	436	436
»	3	433	437	»	3	443	438
»	4	467	469	»	4	416	415
»	5	429	424	»	5	413	412
»	6	386	386	»	6	363	361
»	7	373	374	»	7	353	351
»	8	359	355	»	8	342	347
»	9	335	329	»	9	325	325
»	10	337	334	»	10	330	334
»	11	310	310	»	11	327	326
»	12	351	350	»	12	358	362
1970.	1	438	440	1973.	1	386	382
»	2	461	458	»	2	426	424
»	3	438	438	»	3	416	413
»	4	435	441	»	4	409	410
»	5	413	412	»	5	393	386
»	6	382	388	»	6	373	377
»	7	358	358	»	7	353	357
»	8	337	337	»	8	342	336
»	9	326	329	»	9	338	340
»	10	310	310	»	10	307	308
»	11	318	315	»	11	327	322
»	12	346	352	»	12	308	307

Year/month	comp.	obs.	Year/month	comp.	obs.
1974. 1	376	376	1977. 1	403	401
» 2	439	440	» 2	416	417
» 3	466	468	» 3	420	417
» 4	426	430	» 4	449	449
» 5	393	397	» 5	438	437
» 6	373	367	» 6	385	387
» 7	353	356	» 7	373	380
» 8	342	341	» 8	359	355
» 9	335	331	» 9	335	343
» 10	320	322	» 10	320	326
» 11	318	320	» 11	327	328
» 12	333	331	» 12	351	356
1975. 1	394	395	1978. 1	373	374
» 2	435	433	» 2	426	433
» 3	432	431	» 3	463	466
» 4	426	423	» 4	439	442
» 5	413	413	» 5	416	411
» 6	373	372	» 6	373	374
» 7	343	340	» 7	343	345
» 8	329	331	» 8	342	344
» 9	322	319	» 9	344	342
» 10	320	317	» 10	329	329
» 11	317	316	» 11	314	313
» 12	334	332	» 12	338	335
1976. 1	363	365	1979. 1	346	345
» 2	409	409	» 2	448	445
» 3	400	409	» 3	398	405
» 4	383	386	» 4	426	421
» 6	383	381	» 5	373	372
» 6	368	369	» 6	373	376
» 7	335	339	» 7	364	360
» 8	332	332	» 8	352	346
» 9	327	321	» 9	335	339
» 10	315	314	» 10	320	318
» 11	314	316	» 11	327	323
» 12	338	333	» 12	373	375

Year/month	comp.	obs.	Year/month	comp.	obs.
1980. 1	394	392	1983. 1	356	358
» 2	446	446	» 2	383	385
» 3	433	429	» 3	392	396
» 4	428	428	» 4	374	374
» 5	425	416	» 5	378	375
» 6	395	394	» 6	373	371
» 7	374	374	» 7	353	351
» 8	343	339	» 8	342	340
» 9	335	337	» 9	316	314
» 10	310	312	» 10	311	316
» 11	327	333	» 11	327	325
» 12	351	356	» 12	351	346
1981. 1	373	371	1984. 1	371	370
» 2	396	398	» 2	404	408
» 3	450	445	» 3	433	429
» 4	443	445	» 4	406	402
» 5	403	398	» 5	390	391
» 6	395	392	» 6	380	380
» 7	365	366	» 7	343	349
» 8	342	345	» 8	322	328
» 9	313	309	» 9	335	330
» 10	320	317	» 10	320	319
» 11	327	326	» 11	327	329
» 12	351	348	» 12	351	351
1982. 1	425	427	1985. 1	438	440
» 2	448	444	» 2	426	428
» 3	433	431	» 3	433	428
» 4	443	441	» 4	426	427
» 5	420	424	» 5	416	417
» 6	382	381	» 6	360	358
» 7	343	345	» 7	353	350
» 8	368	367	» 8	342	338
» 9	318	321	» 9	325	317
» 10	320	316	» 10	320	321
» 11	318	318	» 11	327	332
» 12	320	321	» 12	373	373

Year/month	comp.	obs.
1986. 1	381	384
» 2	426	429
» 3	433	441
» 4	391	388
» 5	378	373
» 6	388	382
» 7	343	348
» 8	327	326
» 9	310	314
» 10	320	323
» 11	352	355
» 12	—	—

4.24 Station: EDMONTON

$\varphi = 53^0\ 34'$ N, L $= 113^0\ 31'$ W, Time Period: 1958 - 1986.

Following the same procedure as for other Northern Hemisphere Stations MMVTOZ (Edmonton) can be written as:

$$10^{-3} \cdot 0_m^{com} = 356 + 56 \sin\left(\frac{2\pi}{12} t + 30^\circ\right) \tag{99}$$

Spectrum analysis of computed differences (D), where

$$D = 10^{-3} \cdot 0^{obs} - 10^{-3} \cdot 0_m^{com} \tag{100}$$

reveals periodicities with periods equal to 12, 6, 4 and 3 months, significant at a confidence level close to 99% and 95% shown in Figure 92.

Figure 93 shows, in graphic form, the periodic terms of 12, 6, 4 and 3 months as plotted by means of the successive approximation method which gives their position and amplitude. The dots represent the differences computed by Equation (100), while the dashed and solid sinusoidal or semisinusoidal curves represent periodic or quasi-periodic terms. These terms can be expressed with a relation of the form:

$$P = \alpha_1 \sin\frac{2\pi}{12} t + \alpha_2 \sin\frac{2\pi}{6} t + \alpha_3 \sin\frac{2\pi}{4} t + \alpha_4 \sin\frac{2\pi}{3} t \tag{101}$$

The values of the parameters of Equation (101) are listed in Table 24.

Summing Equations (99) and (101), we obtain Equation (102),

$$10^{-3} \cdot 0^{com} = 356 + 56 \sin\left(\frac{2\pi}{12} t + 30^\circ\right) + P \tag{102}$$

which represents the observed data of the Edmonton Station for the period from 1958 through 1986 with an accuracy equal to 98.9%, the s.d. between observed-computed MVTOZ is $\sigma = \pm 3.48$ with 44 degrees of freedom for Equation (102).

These results are demonstrated by Figures 94 and 95, where the dots (or small open circles redused for technical reasons) represent observed MVTOZ, while the solid line represents MVTOZ as computed by Equation (102). The close agreement between observed and computed monthly values of total ozone is noteworthy.

Table 24A lists the observed and computed values of total ozone from 1958 through 1986.

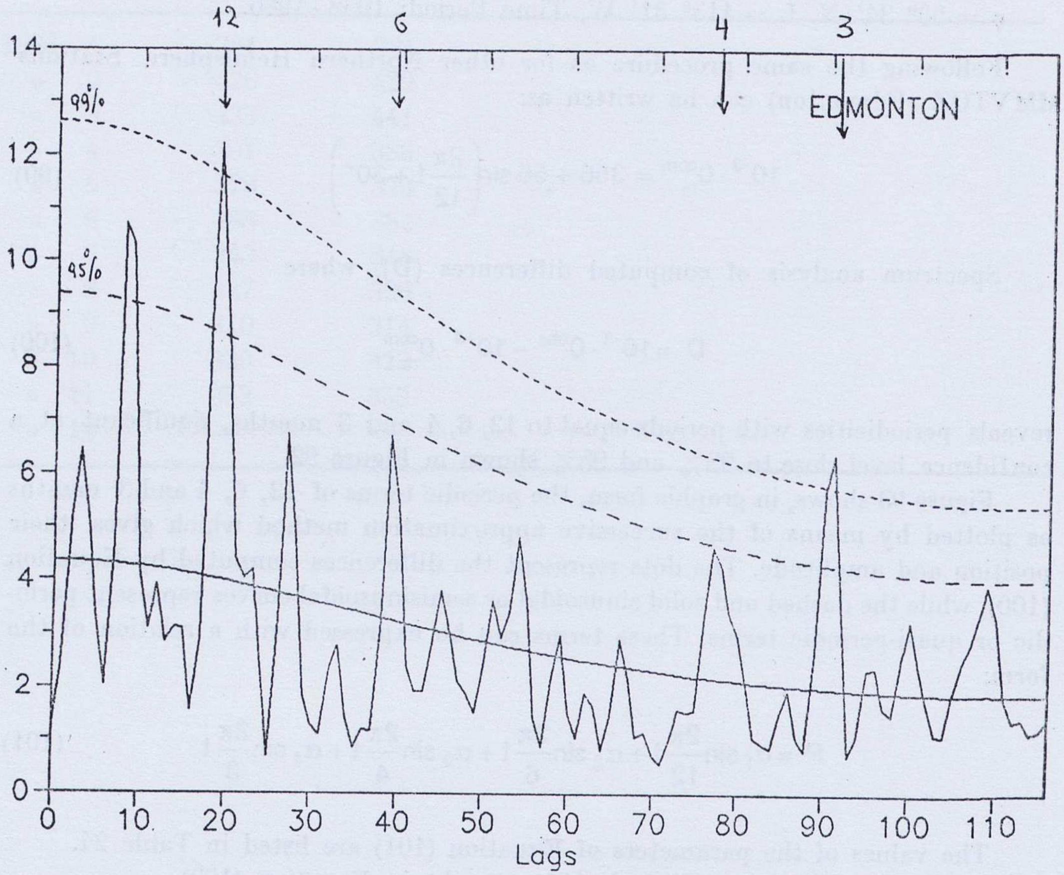

Fig. 92: Edmonton Station, 1958 - 1986. Spectral estimate of the differences computed by Equation (100). Analysis shows short-term periods of 12, 6, 4 and 3 months. Note that the 12 and 3-month periods are predominant, with a confidence level of 99%.

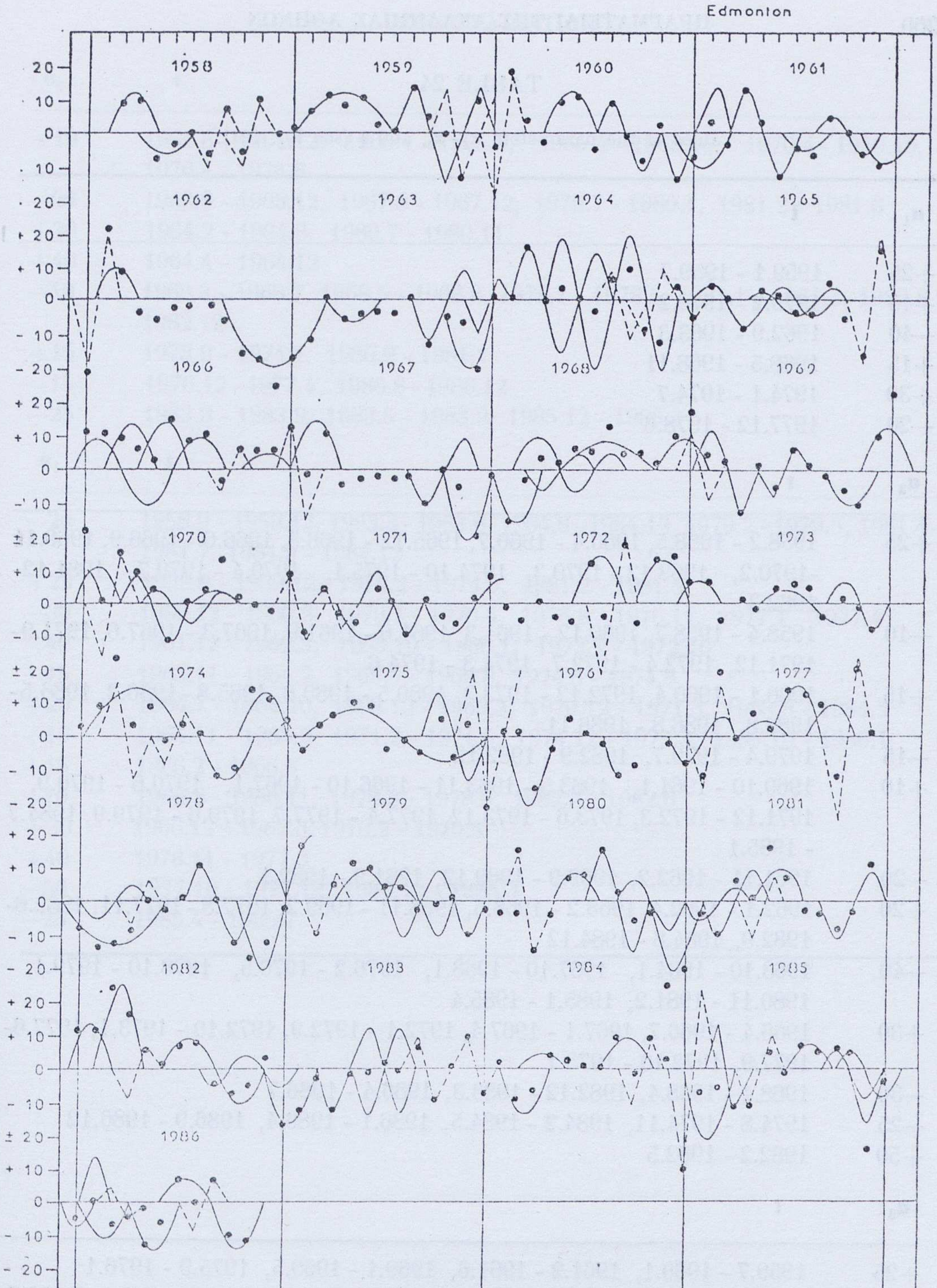

Fig. 93. Edmonton Station, 1958-1986. The differences (D) found by Equation (100) are shown by dots (or open circles). The dashed and solid sinusoidal or semisinusoidal curves show periodic terms of 12, 6, 4 and 3 months, whose position and amplitude is also plotted, by the successive approximation method.

TABLE 24

Values of the parameters α_1 - α_4, and **t** (see Eq. 101).

α_1	t
+25	1959.1 - 1959.7
+15	1975.2 - 1976.2
—40	1962.9 - 1963.3
+15	1968.5 - 1968.11
+30	1974.1 - 1974.7
—20	1977.12 - 1978.6

α_2	t
+25	1958.2 - 1958.5, 1960.4 - 1960.7, 1965.12 - 1966.3, 1966.6 - 1966.9, 1969.11 -1970.2, 1969.12 - 1970.3, 1974.10 - 1975.1, 1979.4 - 1979.7, 1981.12-1982.3
—10	1958.4 - 1958.7, 1960.12 - 1961.3, 1961.6 - 1961.9, 1967.3 - 1967.6, 1971.9-1971.12, 1972.4 - 1972.7, 1974.3 - 1974.6
+15	1960.1 - 1960.4, 1972.12 - 1973.3, 1980.5 - 1980.8, 1985.8 - 1986.2, 1986.5-1986.8, 1986.8 - 1986.11
—15	1979.4 - 1979.7, 1982.9 - 1982.12
+10	1960.10 - 1961.1, 1963.5 - 1963.11 - 1966.10 - 1967.1, 1970.6 - 1970.9, 1971.12 - 1972.3, 1973.6 - 1973.12, 1977.4 - 1977.7, 1979.6 - 1979.9, 1984.7 - 1985.1
—20	1961.11 - 1962.2, 1969.9 - 1969.12, 1981.9 - 1982.1
+20	1962.1 - 1962.4, 1968.2 - 1968.5, 1968.11 - 1969.2, 1977.8 - 1977.11, 1982.6-1982.9, 1984.8 - 1984.12
—40	1963.10 - 1964.1, 1967.10 - 1968.1, 1976.2 - 1976.5, 1978.10 - 1979.1, 1980.11 - 1981.2, 1985.1 - 1985.4
+30	1966.4 - 1966.7, 1967.1 - 1967.4, 1972.1 - 1972.9, 1972.10 - 1973.1, 1977.6-1977.9, 1972.10 - 1973.1
—30	1968.1 - 1968.4, 1982.12 - 1983.3, 1986.4 - 1986.7
—25	1974.8 - 1974.11, 1984.2 - 1984.5, 1986.1 - 1986.4, 1986.9 - 1986.12
+50	1982.2 - 1982.5

α_3	t
+25	1959.7 - 1960.1, 1961.2 - 1961.6, 1969.1 - 1969.5, 1975.9 - 1976.1
+20	1960.7 - 1961.1, 1970.3 - 1970.7, 1971.5 - 1971.9, 1978.7 - 1979.1, 1979.7-1979.11

a_3	t
+10	1961.8 - 1961.12, 1965.1 - 1965.5, 1965.4 - 1965.10, 1970.4 - 1970.10, 1976.4 - 1976.8
—20	1963.8 - 1963.12, 1967.8 - 1967.12, 1979.7 - 1980.1, 1981.2 - 1981.6
+30	1964.2 - 1964.8, 1980.7 - 1980.11
+40	1964.4 - 1964.12
—10	1968.3 - 1968.7, 1968.5 - 1968.8, 1978.1 - 1978.5, 1981.1 - 1981.5, 1982.8 - 1982.12
+15	1973.9 - 1974.1, 1980.9 - 1981.1
—15	1976.12 - 1977.4, 1986.8 - 1986.12
—25	1983.3 - 1983.9, 1983.5 - 1983.9, 1985.12 - 1986.3

a_4	t
—20	1958.9 - 1959.12, 1963.3 - 1963.6, 1964.9 - 1964.12, 1979.2 - 1979.5, 1981.4 - 1981.7, 1984.9 - 1984.12
+25	1959.9 - 1959.12, 1974.2 - 1974.5, 1981.2 - 1981.5
—30	1959.12 - 1960.3, 1970.1 - 1970.4, 1976.8 - 1976.11, 1977.1 - 1977.4
—40	1961.12 - 1962.3, 1965.10 - 1966.1, 1972.7 - 1972.10
—15	1963.11 - 1964.2, 1969.5 - 1969.8, 1974.5 - 1974.8
+20	1964.7 - 1964.10, 1968.12 - 1969.3, 1970.12 - 1971.3, 1983.8 - 1984.2
+10	1964.11 - 1965.2, 1971.2 - 1971.5, 1974.12 - 1975.3, 1985.10 - 1986.1
+15	1966.2 - 1966.5
—10	1966.8 - 1966.11, 1978.3 - 1978.6, 1982.3 - 1982.6
+30	1966.12 - 1967.3, 1970.2 - 1970.5
+40	1976.11 - 1977.3
—50	1977.10 - 1977.12, 1984.12 - 1985.3
—25	1985.4 - 1985.7

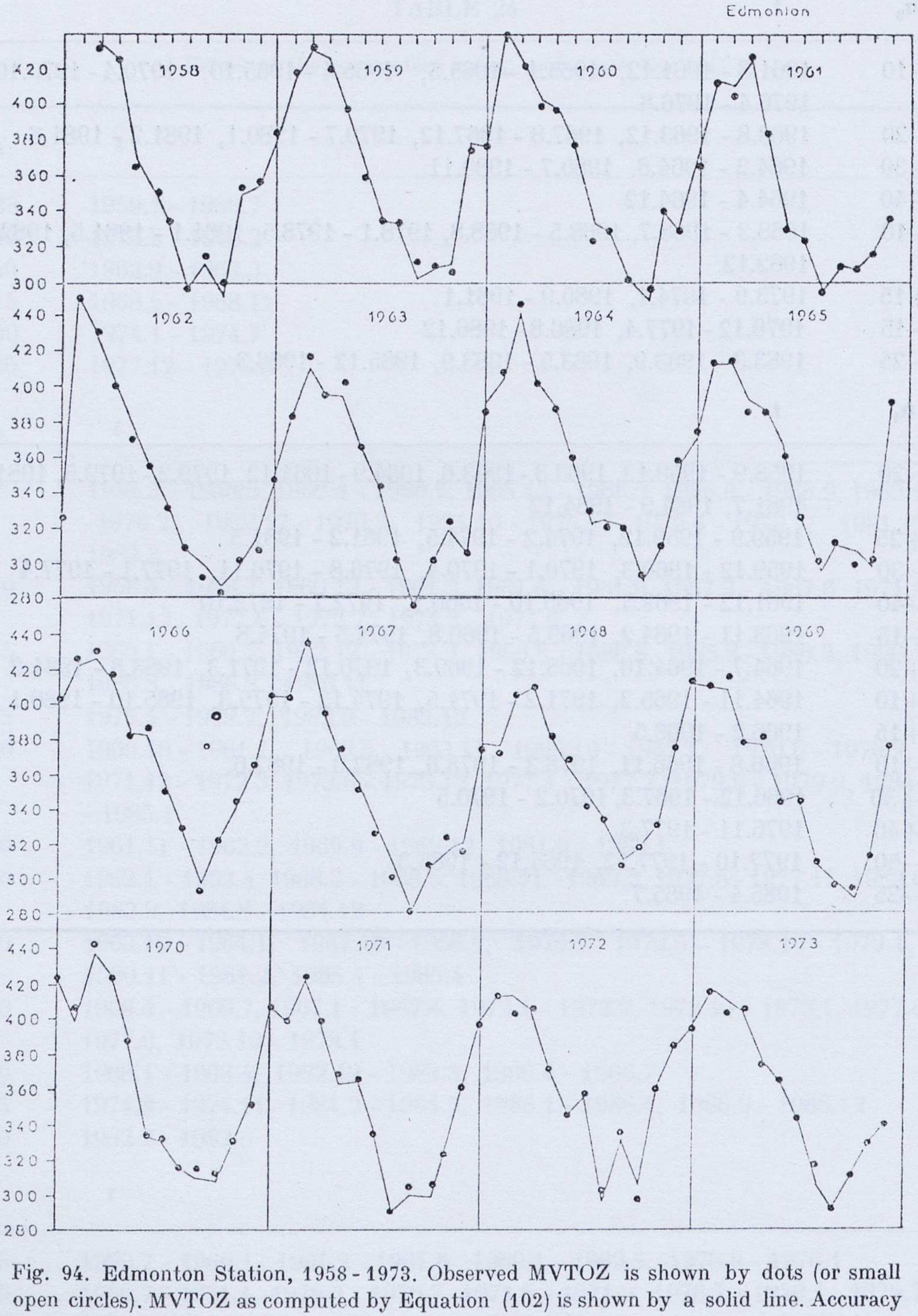

Fig. 94. Edmonton Station, 1958 - 1973. Observed MVTOZ is shown by dots (or small open circles). MVTOZ as computed by Equation (102) is shown by a solid line. Accuracy is equale to 98%.

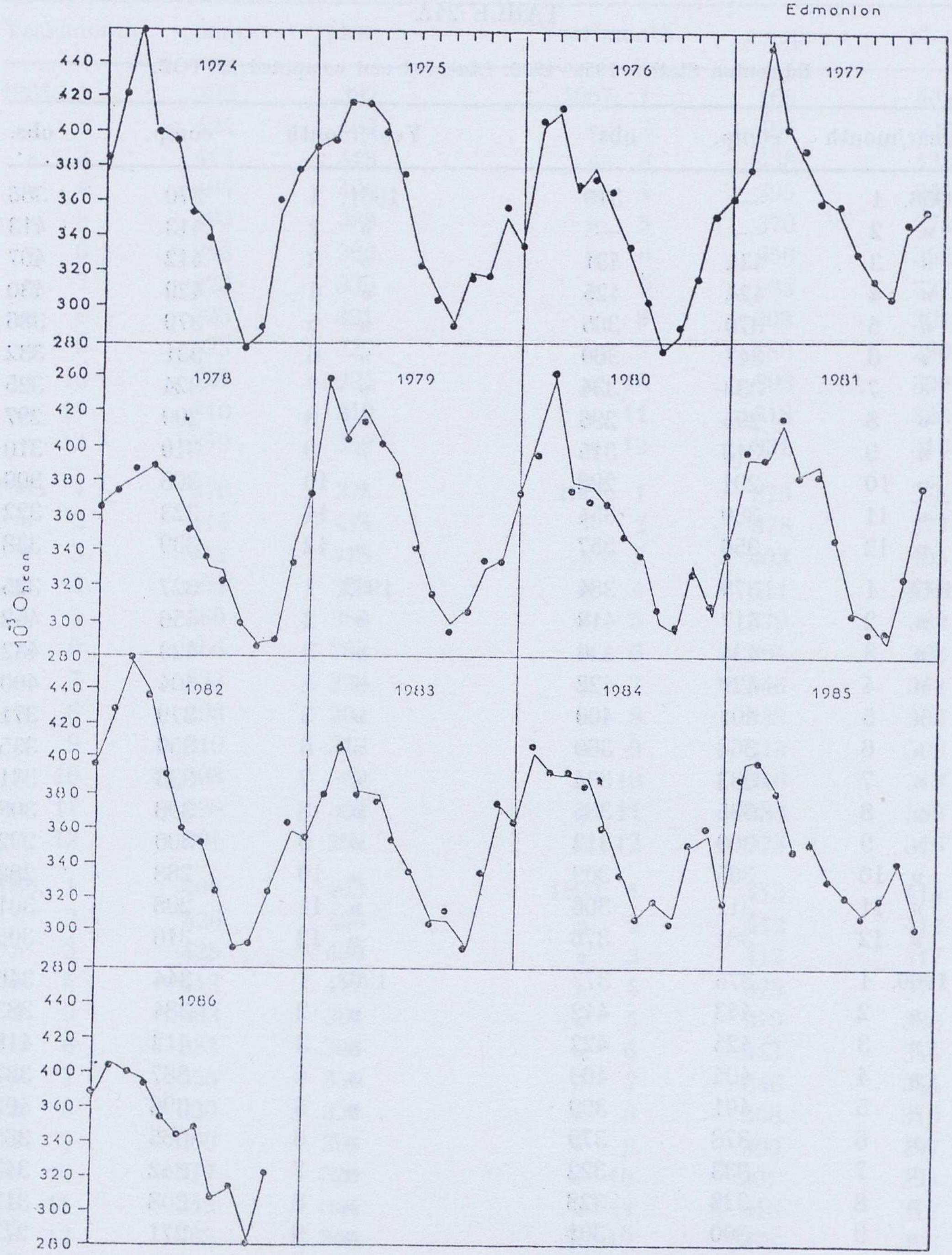

Fig. 95. Edmonton Station 1974 - 1986. Caption as for Figure 94, to which this Figure is complementary.

TABLE 24A

Edmonton Station 1958 - 1986. Observed and computed MVTOZ.

Year/month	comp.	obs.	Year/month	comp.	obs.
1958. 1	—	319	1961. 1	370	366
» 2	—	—	» 2	413	413
» 3	434	431	» 3	412	407
» 4	424	425	» 4	429	430
» 5	370	365	» 5	379	386
» 6	347	360	» 6	331	332
» 7	333	334	» 7	324	325
» 8	295	296	» 8	299	297
» 9	313	315	» 9	310	310
» 10	291	298	» 10	308	309
» 11	350	354	» 11	323	322
» 12	356	357	» 12	339	338
1959. 1	379	384	1962. 1	327	325
» 2	417	419	» 2	456	452
» 3	434	436	» 3	429	432
» 4	429	422	» 4	404	400
» 5	401	400	» 5	379	371
» 6	368	360	» 6	356	355
» 7	333	334	» 7	333	331
» 8	335	335	» 8	308	308
» 9	300	312	» 9	300	292
» 10	305	309	» 10	288	282
» 11	311	306	» 11	298	301
» 12	381	376	» 12	316	305
1960. 1	375	377	1963. 1	344	346
» 2	443	442	» 2	384	383
» 3	425	422	» 3	412	418
» 4	404	400	» 4	387	387
» 5	401	399	» 5	396	402
» 6	378	379	» 6	365	365
» 7	333	322	» 7	342	343
» 8	328	328	» 8	308	312
» 9	300	301	» 9	271	277
» 10	288	296	» 10	299	301
» 11	342	341	» 11	318	323
» 12	327	329	» 12	308	306

Year/month	comp.	obs.	Year/month	comp.	obs.
1964. 1	392	387	1967. 1	405	405
» 2	404	409	» 2	404	403
» 3	442	448	» 3	438	433
» 4	404	404	» 4	395	394
» 5	389	388	» 5	370	374
» 6	356	360	» 6	356	352
» 7	323	330	» 7	333	327
» 8	325	321	» 8	308	301
» 9	323	320	» 9	280	280
» 10	291	294	» 10	308	309
» 11	310	310	» 11	318	323
» 12	359	359	» 12	321	316
1965 1	370	374	1968. 1	379	376
» 2	414	414	» 2	378	377
» 3	412	415	» 3	403	405
» 4	394	388	» 4	411	410
» 5	389	388	» 5	379	382
» 6	366	362	» 6	364	368
» 7	323	328	» 7	346	342
» 8	298	302	» 8	333	333
» 9	310	313	» 9	313	309
» 10	308	300	» 10	316	318
» 11	298	302	» 11	333	336
» 12	291	292	» 12	373	376
1966. 1	401	403	1969. 1	413	414
» 2	426	426	» 2	412	412
» 3	425	430	» 3	412	417
» 4	413	417	» 4	379	379
» 5	383	381	» 5	379	382
» 6	382	386	» 6	343	344
» 7	355	350	» 7	346	344
» 8	330	329	» 8	308	310
» 9	300	293	» 9	300	297
» 10	317	320	» 10	291	295
» 11	342	344	» 11	316	312
» 12	365	366	» 12	378	376

Year/month	comp.	obs.	Year/month	comp.	obs.
1970. 1	423	423	1973. 1	392	391
» 2	410	406	» 2	417	415
» 3	438	442	» 3	412	402
» 4	424	422	» 4	404	406
» 5	389	387	» 5	379	376
» 6	336	334	» 6	365	364
» 7	332	333	» 7	342	344
» 8	317	316	» 8	318	318
» 9	310	316	» 9	291	292
» 10	308	312	» 10	314	311
» 11	333	331	» 11	333	330
» 12	356	351	» 12	341	340
1971. 1	396	397	1974. 1	379	386
» 2	387	389	» 2	419	423
» 3	421	423	» 3	460	460
» 4	395	398	» 4	403	401
» 5	366	368	» 5	396	396
» 6	363	365	» 6	358	354
» 7	333	334	» 7	346	340
» 8	288	290	» 8	308	311
» 9	300	303	» 9	278	277
» 10	299	305	» 10	286	289
» 11	324	322	» 11	355	361
» 12	356	360	» 12	378	379
1972. 1	397	397	1975. 1	388	391
» 2	413	412	» 2	395	396
» 3	412	402	» 3	420	419
» 4	404	405	» 4	417	417
» 5	370	371	» 5	404	400
» 6	347	345	» 6	369	374
» 7	359	357	» 7	331	324
» 8	299	301	» 8	308	305
» 9	335	335	» 9	292	290
» 10	308	297	» 10	320	318
» 11	359	359	» 11	318	319
» 12	382	384	» 12	352	358

Year/month		comp.	obs.	Year/month		comp.	obs.
1976.	1	336	337	1979.	1	379	374
»	2	404	408	»	2	439	439
»	3	412	415	»	3	395	394
»	4	369	372	»	4	421	415
»	5	379	374	»	5	401	402
»	6	356	367	»	6	378	376
»	7	333	336	»	7	342	342
»	8	308	304	»	8	317	317
»	9	274	277	»	9	300	295
»	10	285	289	»	10	308	306
»	11	320	318	»	11	333	336
»	12	356	354	»	12	336	336
1977.	1	364	363	1980.	1	379	375
»	2	378	380	»	2	404	397
»	3	453	451	»	3	438	443
»	4	404	404	»	4	378	377
»	5	388	393	»	5	379	373
»	6	365	362	»	6	369	369
»	7	359	361	»	7	346	349
»	8	334	333	»	8	338	339
»	9	317	318	»	9	300	306
»	10	307	309	»	10	293	297
»	11	351	350	»	11	333	328
»	12	356	359	»	12	306	309
1978.	1	369	366	1981.	1	344	339
»	2	377	375	»	2	394	397
»	3	392	388	»	3	392	393
»	4	387	388	»	4	414	418
»	5	379	381	»	5	382	382
»	6	356	352	»	6	386	383
»	7	333	337	»	7	346	347
»	8	328	329	»	8	308	304
»	9	300	299	»	9	300	294
»	10	288	285	»	10	288	294
»	11	298	299	»	11	333	327
»	12	341	335	»	12	376	378

Year/month	comp.	obs.	Year/month	comp.	obs.
1982. 1	401	398	1985. 1	319	318
» 2	426	428	» 2	396	390
» 3	455	460	» 3	399	399
» 4	438	437	» 4	382	381
» 5	388	391	» 5	357	358
» 6	356	360	» 6	363	361
» 7	350	352	» 7	333	330
» 8	325	324	» 8	323	322
» 9	290	291	» 9	313	310
» 10	295	294	» 10	321	320
» 11	330	323	» 11	342	342
» 12	356	363	» 12	303	303
1983. 1	343	347	1986. 1	366	373
» 2	378	380	» 2	407	405
» 3	412	407	» 3	399	400
» 4	379	380	» 4	395	394
» 5	379	376	» 5	353	353
» 6	356	354	» 6	343	344
» 7	333	336	» 7	346	348
» 8	308	306	» 8	308	309
» 9	317	313	» 9	313	314
» 10	291	290	» 10	282	280
» 11	333	335	» 11	320	321
» 12	373	376	» 12	—	—
1984. 1	362	364			
» 2	404	409			
» 3	390	393			
» 4	391	393			
» 5	388	387			
» 6	356	361			
» 7	333	334			
» 8	308	309			
» 9	317	319			
» 10	308	305			
» 11	350	351			
» 12	356	361			

4.25 Station: CHURCHILL

$\varphi = 58^0\ 47'$ N, L $= 94^0\ 11'$ W, Time Period: 1965-1986.

Using Figure 5, we see that the MMVTOZ for the Churchill Station can be expressed as:

$$10^{-3} \cdot 0_m^{com} = 385 + 65 \sin\left(\frac{2\pi}{12} t + 30^\circ\right) \tag{103}$$

Power spectrum analysis of the differences (D), where

$$D = 10^{-3} \cdot 0^{obs} - 10^{-3} \cdot 0_m^{com} \tag{104}$$

reveals four periodic terms of 12, 6, 4 and 3 months. The confidence level of these terms is higher than 95%, and in two cases (6-month and 4-month) is higher than 99%. See Figure 96.

In Figure 97 the small open circles represent the differences (104), while the solid sinusoidal or semisinusoidal curves represent the periodic or quasi-periodic terms of 12, 6, 4 and 3 months, determined by the successive approximation method. These terms can be written as:

$$P = \alpha_1 \sin\frac{2\pi}{12} t + \alpha_2 \sin\frac{2\pi}{4} t + \alpha_3 \sin\frac{2\pi}{3} t \tag{105}$$

The values of the parameters of Equation (105) are listed in Table 25.

Thus, the observed MVTOZ for the Churchill Station can be simply expressed as:

$$10^{-3} \cdot 0^{com} = 385 + 65 \sin\left(\frac{2\pi}{12} t + 30^\circ\right) + P \tag{106}$$

where P is derived from Equation (105).

The above results are shown graphically in Figures 98 and 99, where the open circles represent observed MVTOZ while the solid line represents computed MVTOZ. Equation (106) has 80 degrees of freedom and expresses the observational data with an accuracy of 98.6%. The s.d. between observed-computed MVTOZ is $\sigma = \pm 5.3$.

Table 25A lists the numerical data plotted on Figures 98 and 99.

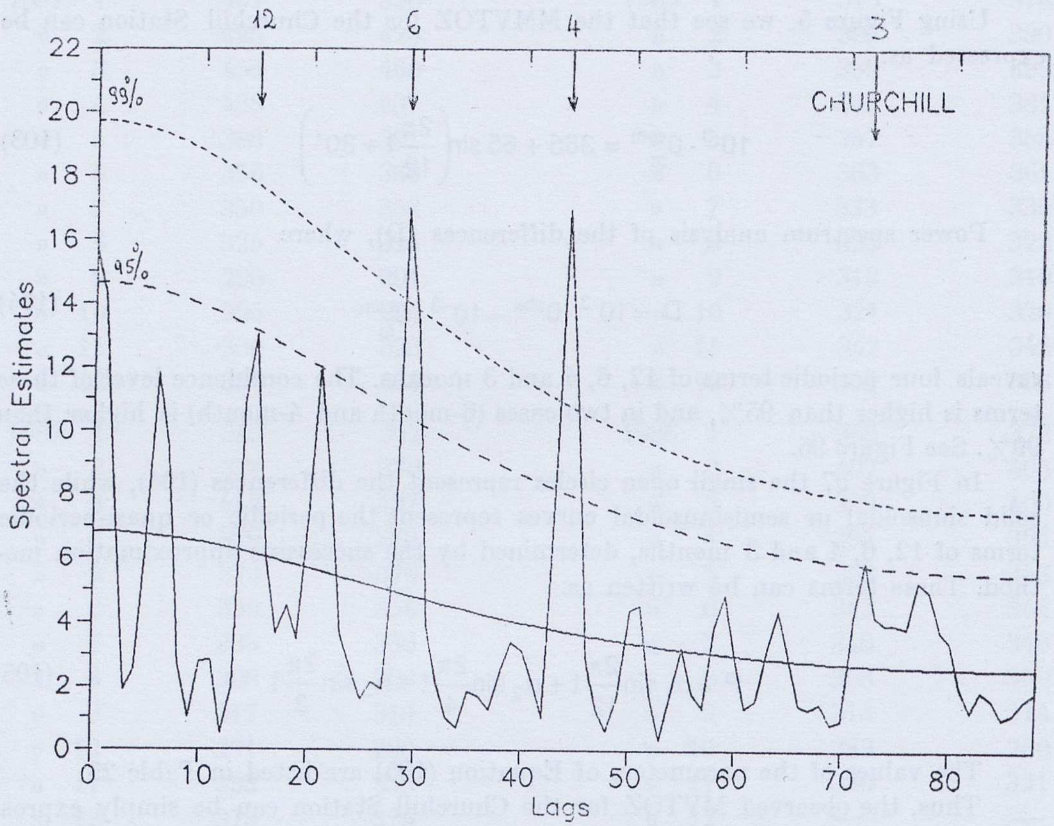

Fig. 96. Churchill Station, 1965 - 1986. Spectral estimate of the differences computed by Equation (104). Analysis shows short-term periodicities with periods of 12, 6, 4 and 3 months. Note that all the periodic terms are significant. Especially the 6 and the 4-month period is above the confidence level of 99%.

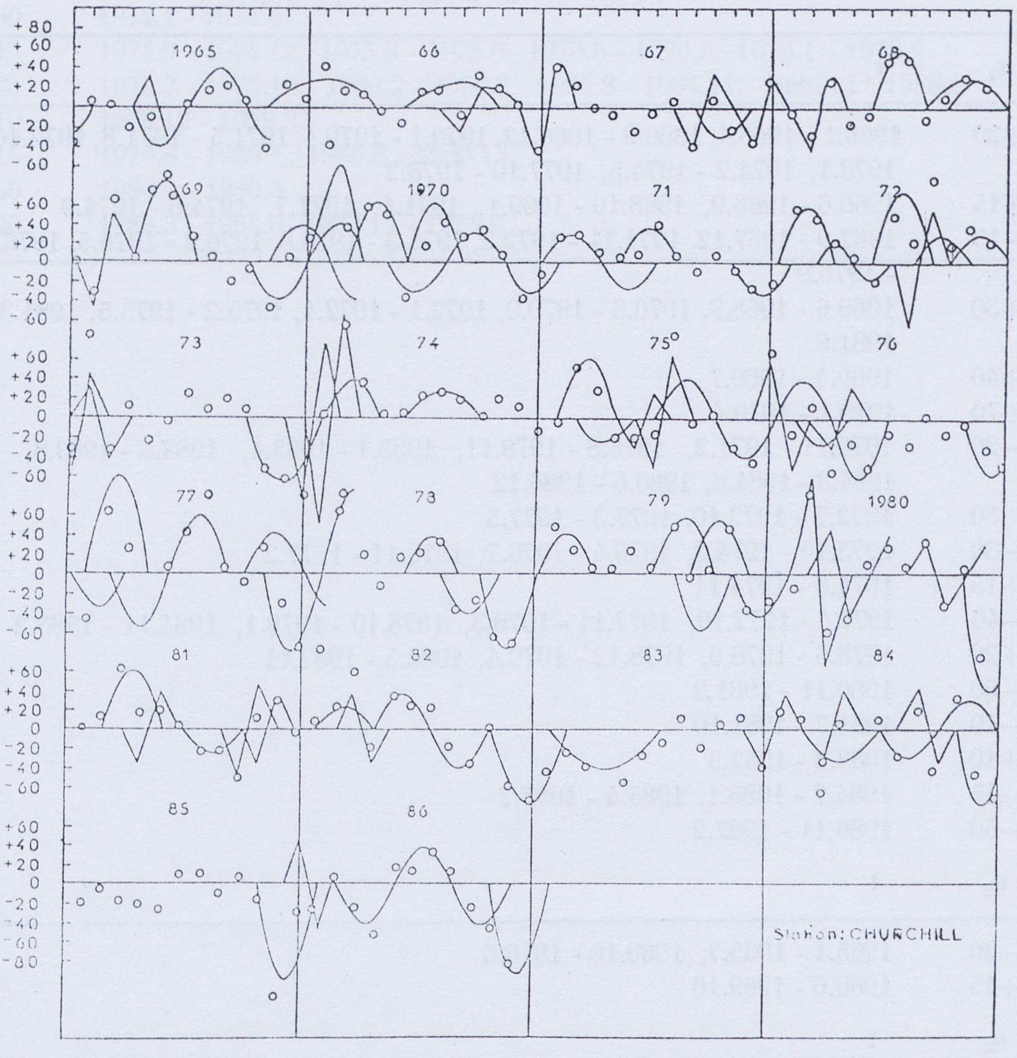

Fig. 97. Churchill Station, 1965 - 1986. The differences (D) found by Equation (104) are shown by open circles. The solid sinusoidal or semisinusoidal curves show periodic terms of 12, 6, 4 and 3 months, whose position and amplitude is also plotted, by the successive approximation method.

TABLE 25

Values of the parameters α_1, α_2, α_3, and **t** (see Eq. 105).

α_1	t
+20	1966.1 - 1966.4, 1966.9 - 1966.12, 1970.1 - 1970.4, 1971.5 - 1971.8, 1972.10-1973.1, 1974.2 - 1974.5, 1977.10 - 1978.2
+15	1966.6 - 1966.9, 1968.10 - 1969.1, 1971.1 - 1971.7, 1974.6 - 1974.9
—15	1967.9 - 1967.12, 1971.11 - 1972.2, 1975.3 - 1975.8, 1976.2 - 1976.5, 1976.6 - 1976.9
+30	1968.6 - 1968.9, 1970.6 - 1970.9, 1972.1 - 1972.4, 1975.2 - 1975.5, 1981.3 - 1981.6
+40	1969.4 - 1969.7
+70	1970.1 - 1970.4
—20	1970.11 - 1971.2, 1978.8 - 1978.11, 1983.1 - 1983.4, 1983.5 - 1983.8, 1984.3 - 1984.6, 1986.6 - 1986.12
+50	1972.7 - 1972.10, 1977.3 - 1977.5
—30	1973.10 - 1974.2, 1976.4 - 1976.7, 1976.11 - 1977.2
+15	1974.8 - 1974.11
—40	1977.4 - 1977.10, 1977.11 - 1978.3, 1978.10 - 1979.1, 1984.11 - 1985.2
+20	1978.6 - 1978.9, 1978.12 - 1979.4, 1982.5 - 1982.11
—60	1980.11 - 1981.2
—10	1981.7 - 1981.10
+10	1982.2 - 1982.5
—15	1984.7 - 1985.1, 1985.4 - 1985.7
—50	1986.11 - 1987.2

α_2	t
—20	1965.1 - 1965.7, 1969.10 - 1970.6
+15	1969.6 - 1969.10

α_3	t
—20	1965.1 - 1965.5, 1965.10 - 1966.1, 1967.8 - 1968.2, 1981.3 - 1981.7, 1981.10 - 1982.1, 1982.2 - 1982.6
—25	1966.12 - 1967.3, 1969.1 - 1969.4, 1972.12 - 1973.3, 1981.9 - 1981.12
+30	1972.6 - 1972.9, 1975.12 - 1976.3, 1979.7 - 1980.1
+20	1973.1 - 1973.4
—40	1973.12 - 1974.3

a_1	t
—60	1974.1 - 1974.4
—15	1974.9 - 1974.12, 1975.3 - 1975.8, 1976.6 - 1976.9, 1978.1 - 1978.4
+25	1975.7 - 1975.10, 1980.2 - 1980.7, 1984.8 - 1984.11, 1985.12 - 1986.3
—10	1978.12 - 1979.3
+15	1979.8 - 1980.1, 1980.8 - 1980.12
+50	1980.2 - 1980.5
—20	1983.3 - 1983.6, 1983.12 - 1984.6

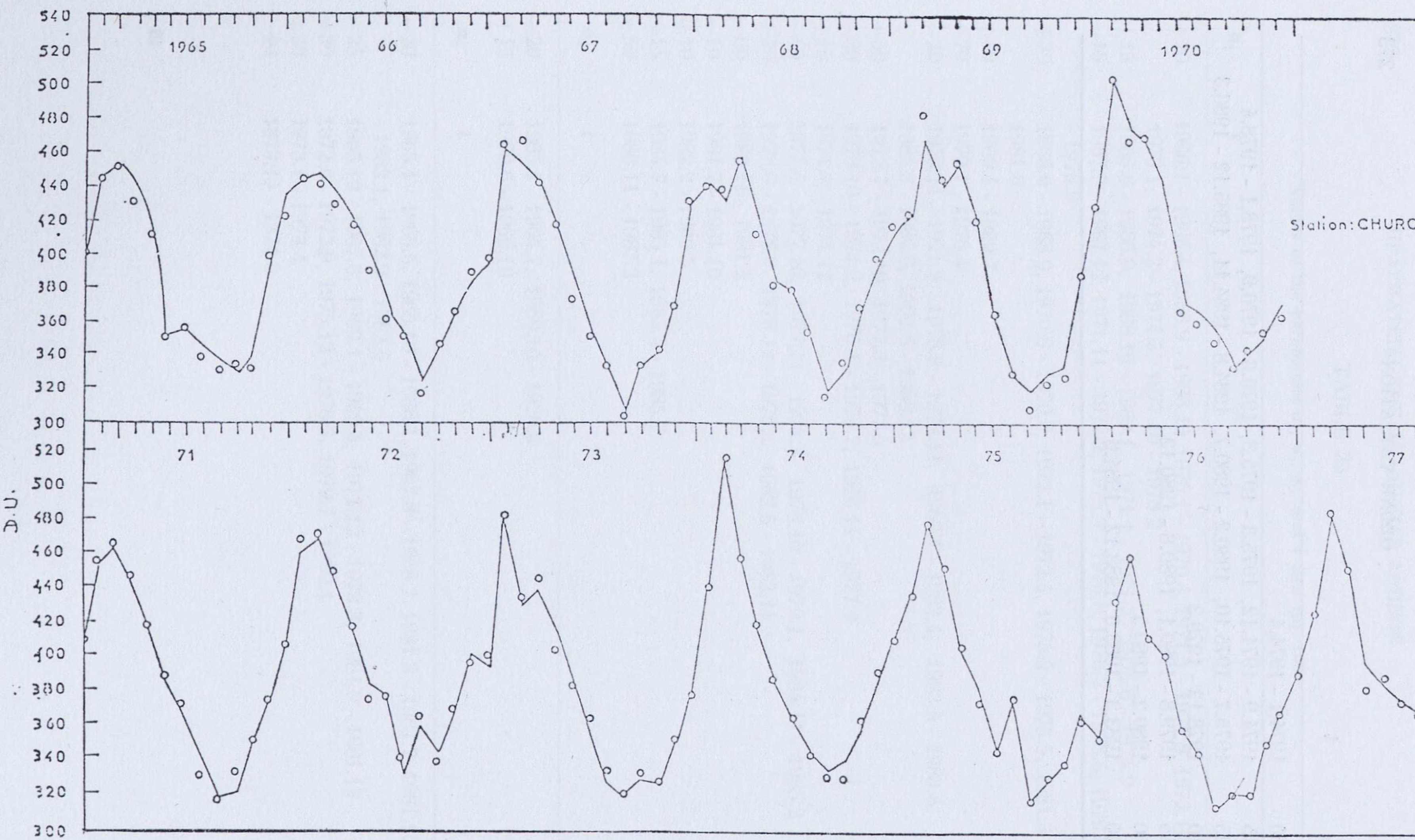

Fig. 98. Churchill Station, 1965 - 1977. Observed MVTOZ is shown by open circles. MVTOZ as found by Equation (106) is shown by a solid line. Accuracy is equal to 98.6%.

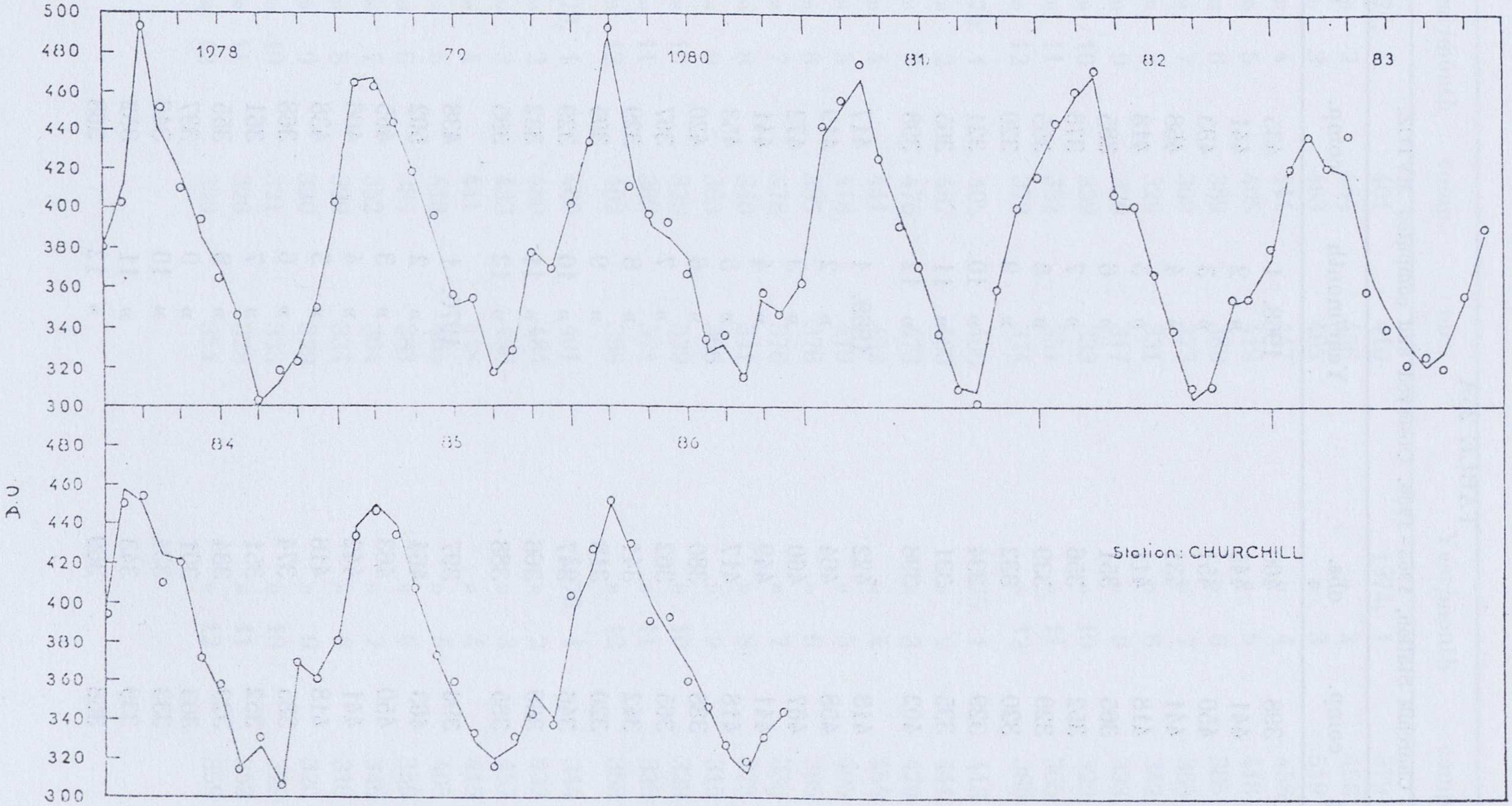

Fig. 99. Churchill Station, 1978 - 1986. Caption as for Figure 98, to wchich this Figure is complementary.

TABLE 25A

Churchill Station, 1965 - 1986. Observed and computed MVTOZ.

Year/month	comp.	obs.	Year/month	comp.	obs.
1965. 1	398	400	1968. 1	435	433
» 2	441	445	» 2	441	440
» 3	450	451	» 3	433	438
» 4	441	431	» 4	458	456
» 5	418	411	» 5	418	412
» 6	365	351	» 6	385	382
» 7	352	356	» 7	378	379
» 8	329	339	» 8	355	355
» 9	320	332	» 9	320	315
» 10	329	334	» 10	321	336
» 11	335	331	» 11	365	370
» 12	402	398	» 12	398	398
1966. 1	418	422	1969. 1	417	417
» 2	458	464	» 2	419	424
» 3	467	460	» 3	472	482
» 4	441	449	» 4	441	443
» 5	418	417	» 5	453	455
» 6	388	380	» 6	420	420
» 7	365	362	» 7	367	366
» 8	342	341	» 8	329	331
» 9	320	318	» 9	305	309
» 10	346	347	» 10	329	325
» 11	369	366	» 11	332	329
» 12	385	388	» 12	385	389
1967. 1	396	397	1970. 1	438	430
» 2	463	464	» 2	502	503
» 3	450	463	» 3	465	469
» 4	441	442	» 4	466	470
» 5	418	416	» 5	438	443
» 6	385	374	» 6	368	367
» 7	352	351	» 7	361	362
» 8	329	334	» 8	355	350
» 9	303	301	» 9	337	334
» 10	333	334	» 10	346	346
» 11	339	343	» 11	352	356
» 12	368	369	» 12	368	365

Year/month		comp.	obs.	Year/month		comp.	obs.
1971.	1	401	410	1974.	1	379	379
»	2	454	456	»	2	450	442
»	3	463	465	»	3	519	518
»	4	441	447	»	4	458	459
»	5	405	419	»	5	418	420
»	6	389	389	»	6	385	388
»	7	369	373	»	7	365	365
»	8	329	331	»	8	342	343
»	9	320	317	»	9	333	331
»	10	329	333	»	10	329	329
»	11	352	351	»	11	365	363
»	12	372	374	»	12	385	391
1972.	1	405	406	1975.	1	413	411
»	2	467	469	»	2	441	438
»	3	476	473	»	3	479	479
»	4	441	452	»	4	454	454
»	5	418	419	»	5	405	407
»	6	385	376	»	6	385	375
»	7	378	378	»	7	339	345
»	8	346	341	»	8	378	372
»	9	363	366	»	9	315	317
»	10	329	339	»	10	329	330
»	11	369	371	»	11	335	337
»	12	402	398	»	12	368	362
1973.	1	400	401	1976.	1	344	351
»	2	480	484	»	2	432	432
»	3	433	436	»	3	457	459
»	4	441	448	»	4	415	412
»	5	418	405	»	5	405	404
»	6	385	383	»	6	359	359
»	7	352	364	»	7	340	345
»	8	329	334	»	8	316	314
»	9	320	329	»	9	320	320
»	10	321	333	»	10	329	320
»	11	326	328	»	11	352	349
»	12	359	354	»	12	359	368

Year/month	comp.	obs.	Year/month	comp.	obs.
1977. 1	392	390	1980. 1	405	403
» 2	424	428	» 2	441	436
» 3	479	486	» 3	493	494
» 4	450	453	» 4	420	412
» 5	383	382	» 5	396	397
» 6	385	389	» 6	385	392
» 7	387	375	» 7	374	367
» 8	364	370	» 8	329	336
» 9	325	322	» 9	333	338
» 10	324	326	» 10	316	316
» 11	369	366	» 11	352	358
» 12	367	370	» 12	346	345
1978. 1	383	380	1981. 1	365	360
» 2	411	403	» 2	441	442
» 3	498	493	» 3	450	457
» 4	441	452	» 4	467	475
» 5	418	411	» 5	427	426
» 6	385	394	» 6	402	392
» 7	370	365	» 7	353	351
» 8	346	346	» 8	320	318
» 9	303	303	» 9	311	310
» 10	312	318	» 10	307	303
» 11	317	322	» 11	357	360
» 12	350	349	» 12	402	400
1979. 1	409	404	1982. 1	417	416
» 2	467	466	» 2	441	444
» 3	467	464	» 3	459	460
» 4	441	444	» 4	467	471
» 5	418	420	» 5	401	408
» 6	385	396	» 6	402	402
» 7	352	357	» 7	369	367
» 8	355	355	» 8	329	339
» 9	307	319	» 9	303	311
» 10	316	330	» 10	312	310
» 11	378	378	» 11	352	355
» 12	372	370	» 12	351	356

Year/month	comp.	obs.	Year/month	comp.	obs.
1983. 1	384	379	1986. 1	397	404
» 2	414	420	» 2	419	428
» 3	433	438	» 3	450	454
» 4	424	422	» 4	424	430
» 5	435	437	» 5	401	391
» 6	370	359	» 6	385	393
» 7	346	340	» 7	369	360
» 8	324	322	» 8	346	345
» 9	320	327	» 9	320	327
» 10	329	319	» 10	312	318
» 11	352	356	» 11	335	331
» 12	385	390	» 12	342	344
1984. 1	401	396			
» 2	458	451			
» 3	450	454			
» 4	407	410			
» 5	418	420			
» 6	376	371			
» 7	361	358			
» 8	316	314			
» 9	329	330			
» 10	307	306			
» 11	365	370			
» 12	383	381			
1985. 1	383	380			
» 2	441	434			
» 3	450	448			
» 4	441	436			
» 5	405	407			
» 6	372	373			
» 7	352	359			
» 8	329	334			
» 9	320	316			
» 10	329	332			
» 11	352	342			
» 12	342	327			

4.26 Station: Leningrad

$\varphi = 59^0\ 58'$ N, L $= 30^0\ 18'$ E, Time Period: 1969 - 1985.

Using Figure 7, the mean monthly values of total ozone for Leningrad Station can be written as:

$$10^{-3} \cdot 0_m^{com} = 358 + 60 \sin\frac{2\pi}{12} t \tag{107}$$

Power spectrum analysis of the differences (D), where

$$D = 10^{-3} \cdot 0^{obs} - 10^{-3} \cdot 0_m^{com} \tag{108}$$

reveals four short-term periodic terms of 12, 6, 4 and 3 months, significant at a confidence level above 95% and 99%. See Figure 100.

Figure 101 represents the same results as that shown in Figure 100, but this figure determines graphically the position and amplitude which varies between 20 and 60 D.U. The dashed and solid sinusoidal or semisinusoidal curves represent the periodic or quasi-periodic terms given by Equation (109), while the dots-open circles - represent values of the differences (108).

The periodic or quasi-periodic terms can be expressed as:

$$P = \alpha_1 \sin\frac{2\pi}{12} t + \alpha_2 \sin\frac{2\pi}{6} t + \alpha_3 \sin\frac{2\pi}{4} t + \alpha_4 \sin\frac{2\pi}{3} t \tag{109}$$

Table 26 gives the values of the parameters of Equation (109).

Summing Equations (107) and (109) we obtain Equation (110) which governs the variation and the periodicity of the monthly values of total ozone and expresses the observed data with an accuracy of 97.1%. The s.d. between observed-computed MVTOZ is $\sigma = \pm 4.6$, with 45 degrees of freedom for Equation (110).

These results are more obvious from Figure 102.

In Figure 102 the dots represent the observed MVTOZ while the solid line represnts the same MVTOZ computed by Equation (110).

$$10^{-3} \cdot 0^{com} = 358 + 60 \sin\frac{2\pi}{12} t + P \tag{110}$$

Table 26 A lists the numerical values plotted in Figure 102. There is a notably close agreement between observed and computed monthly values of total ozone.

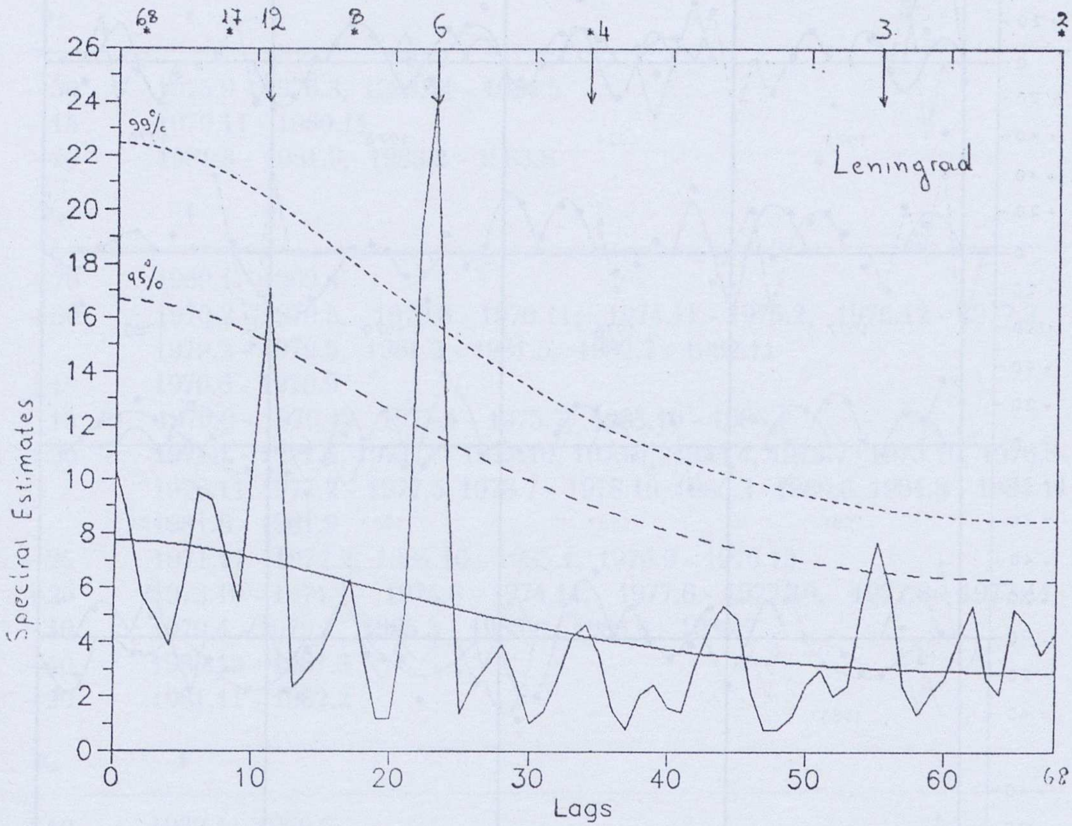

Fig. 100. Leningrad Station 1969 - 1985. Spectral estimate of the differences computed by Equation (108). Analysis shows periodic terms of 12, 6, 4 and 3 months. The 12, 6 and 3-month periods are above the confidence level of 95% and 99% (Especially the 6-month period is the most predominant).

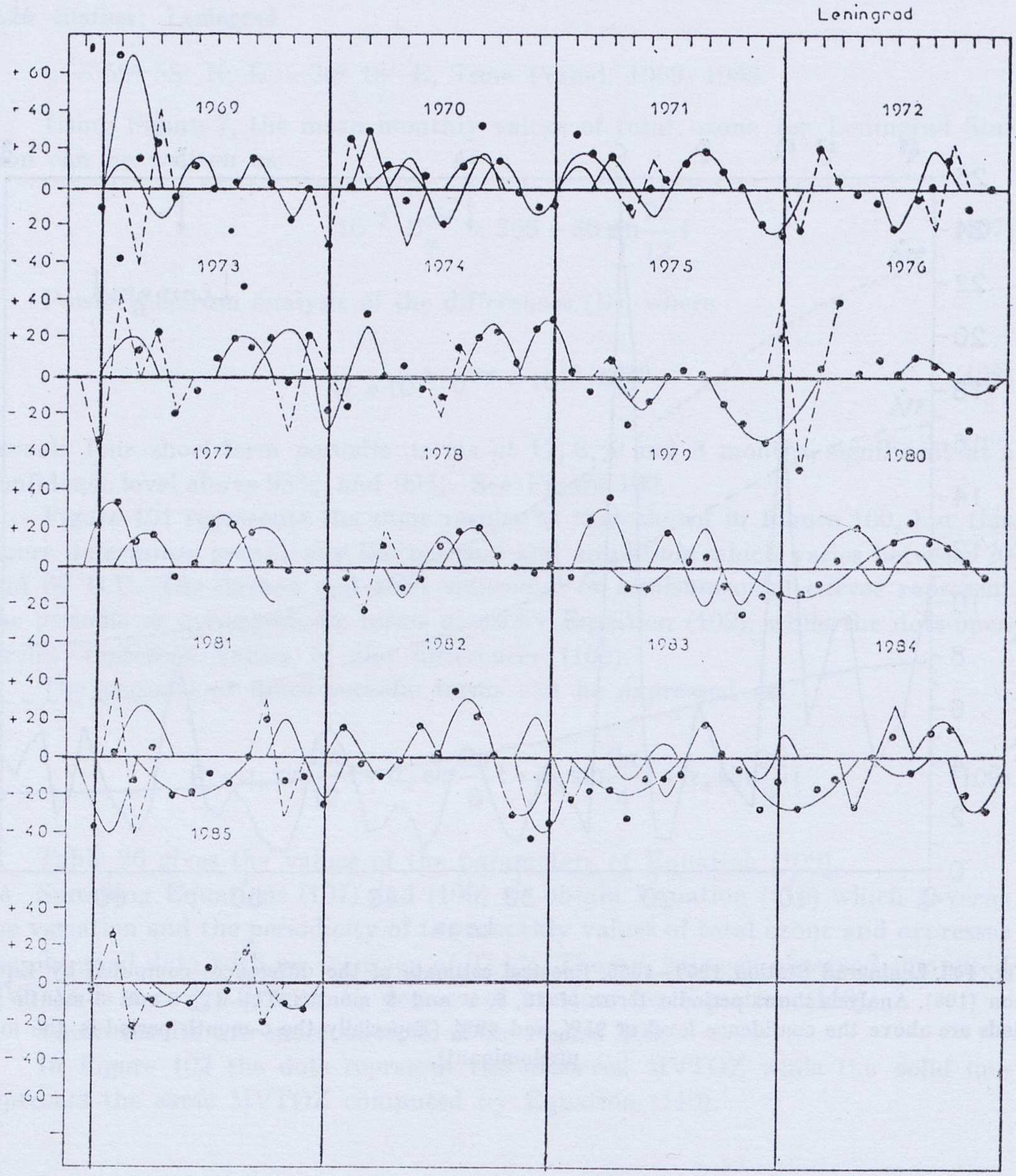

Fig. 101. Leningrad Station, 1969 - 1985. The defferences (D) found by Equation (108) are shown by dots. The dashed and solid sinusoidal or semisinusoidal curves show periodic terms of 12, 6, 4 and 3 months, whose position and amplitude is also plotted, by the successive approximation method.

TABLE 26

Values of the parameters α_1 - α_4 and t (see Eq. 109).

α_1	t
—30	1975.9 - 1976.3, 1983.11 - 1984.5
—15	1979.11 - 1980.11
—20	1981.3 - 1981.9, 1983.2 - 1983.8
α_2	t
+70	1969.1 - 1969.4
+30	1970.2 - 1970.5, 1970.8 - 1970.11, 1974.11 - 1975.2, 1976.12 - 1977.3, 1979.2 - 1979.5, 1981.2 - 1981.5, 1982.7 - 1982.11
+15	1970.6 - 1970.9
—15	1970.9 - 1970.12, 1975.4 - 1975.7, 1985.10 - 1986.1
+20	1971.1 - 1971.4, 1971.7 - 1971.10, 1973.1 - 1973.4, 1973.7 - 1973.10, 1976.8- 1976.11, 1977.2 - 1977.5, 1978.7 - 1978.10, 1980.3 - 1980.6, 1984.8 - 1984.11 1981.6 - 1981.9
—25	1971.11 - 1972.2, 1984.10 - 1985.1, 1976.9 - 1976.12
+25	1973.10 - 1974.1, 1974.8 - 1974.11, 1977.6 - 1977.10, 1977.8 - 1977.11
—10	1979.4 - 1979.7, 1985.3 - 1985.6, 1985.4 - 1985.7
—40	1980.12 - 1981.3
—20	1981.11 - 1982.2
α_3	t
+10	1969.1 - 1969.5
+15	1971.3 - 1971.7
—20	1972.6 - 1972.10
—15	1978.4 - 1978.8, 1983.6 - 1983.10
+20	1974.7 - 1974.11, 1979.9 - 1980.1, 1982.11 - 1983.3
+15	1982.1 - 1982.7, 1969.8 - 1969.11
—10	1983.4 - 1983.8
—25	1984.4 - 1984.8
α_4	t
—30	1969.2 - 1969.8, 1969.12 - 1970.3
—10	1969.2 - 1969.6, 1983.11 - 1984.1, 1984.6 - 1984.9
+10	1970.3 - 1970.6, 1975.3 - 1975.6, 1976.9 - 1976.12, 1981.11 - 1982.2
—20	1972.1 - 1972.4, 1972.8 - 1972.11, 1978.2 - 1978.5

α_4	t
—40	1972.12 - 1973.3, 1982.11 - 1983.2
+25	1973.3 - 1973.6
—25	1973.10 - 1974.1
—15	1974.6 - 1974.9
+40	1975.12 - 1976.4, 1981.1 - 1981.4
+20	1981.9 - 1981.12

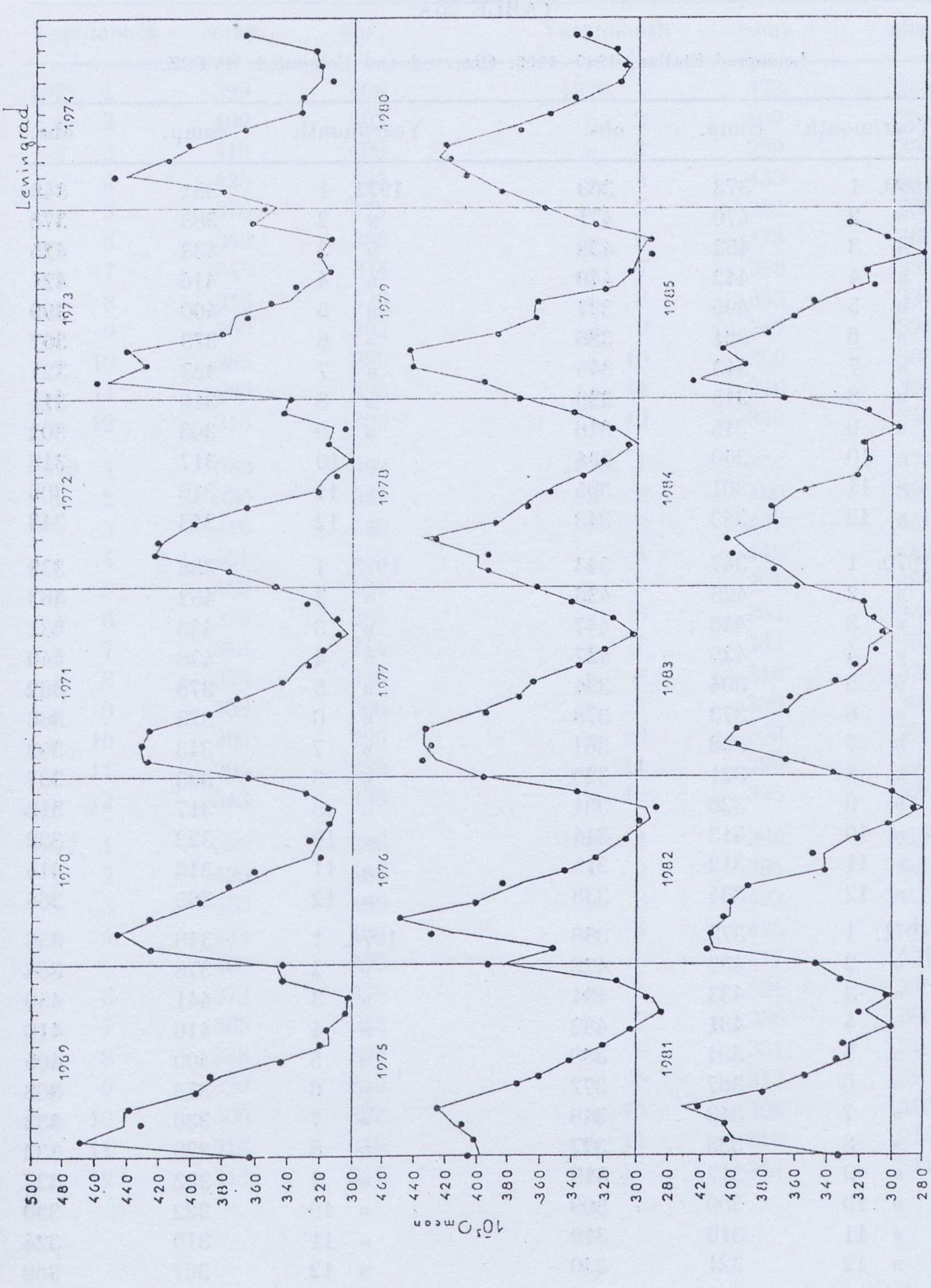

Fig. 102. Leningrad Station, 1969 - 1985. Observed MVTOZ is shown by dots (or small open circles). MVTOZ as computed by Equation (110) is shown by a solid line. Accuracy is equal to 97.1%.

TABLE 26A

Leningrad Station, 1969 - 1985. Observed and Computed MVTOZ.

Year/month	comp.	obs.	Year/month	comp.	obs.
1969. 1	373	363	1972. 1	351	349
» 2	470	471	» 2	383	378
» 3	452	433	» 3	433	425
» 4	442	440	» 4	416	421
» 5	400	397	» 5	400	399
» 6	381	386	» 6	373	367
» 7	343	345	» 7	323	321
» 8	315	320	» 8	316	311
» 9	315	316	» 9	303	302
» 10	300	304	» 10	317	316
» 11	301	305	» 11	316	305
» 12	343	343	» 12	343	343
1970. 1	347	343	1973. 1	338	339
» 2	426	426	» 2	452	463
» 3	446	447	» 3	433	431
» 4	425	427	» 4	438	440
» 5	394	394	» 5	378	382
» 6	373	378	» 6	373	366
» 7	358	361	» 7	343	352
» 8	321	320	» 8	333	337
» 9	326	331	» 9	317	316
» 10	313	314	» 10	322	322
» 11	312	315	» 11	316	315
» 12	334	333	» 12	365	364
1971. 1	373	366	1974. 1	348	356
» 2	432	428	» 2	378	384
» 3	433	434	» 3	441	450
» 4	431	432	» 4	416	416
» 5	391	389	» 5	400	405
» 6	367	372	» 6	373	368
» 7	343	346	» 7	330	333
» 8	333	327	» 8	329	332
» 9	317	319	» 9	322	322
» 10	300	309	» 10	322	320
» 11	316	319	» 11	316	324
» 12	321	330	» 12	367	369

Year/month		comp.	obs.	Year/month		comp.	obs.
1975.	1	399	406	1978.	1	373	362
»	2	400	402	»	2	400	394
»	3	416	409	»	3	399	393
»	4	425	425	»	4	433	427
»	5	378	375	»	5	385	388
»	6	360	360	»	6	373	368
»	7	343	344	»	7	358	355
»	8	316	320	»	8	333	334
»	9	300	302	»	9	317	321
»	10	285	285	»	10	300	305
»	11	290	293	»	11	316	316
»	12	313	309	»	12	343	340
1976.	1	382	393	1979.	1	373	374
»	2	350	351	»	2	400	396
»	3	416	429	»	3	442	441
»	4	451	449	»	4	442	443
»	5	400	401	»	5	391	388
»	6	373	384	»	6	364	363
»	7	343	344	»	7	363	362
»	8	325	326	»	8	316	320
»	9	308	306	»	9	300	305
»	10	295	299	»	10	300	292
»	11	294	289	»	11	296	292
»	12	343	338	»	12	335	328
1977.	1	399	396	1980.	1	360	358
»	2	426	434	»	2	385	386
»	3	433	430	»	3	403	408
»	4	433	433	»	4	425	419
»	5	400	396	»	5	417	421
»	6	373	375	»	6	381	375
»	7	365	365	»	7	356	356
»	8	338	337	»	8	331	340
»	9	320	320	»	9	313	313
»	10	300	302	»	10	308	310
»	11	316	316	»	11	316	314
»	12	343	341	»	12	343	331

Year/month	comp.	obs.	Year/month	comp.	obs.
1981. 1	338	336	1984. 1	356	360
» 2	400	404	» 2	370	372
» 3	406	404	» 3	390	400
» 4	432	421	» 4	401	404
» 5	383	380	» 5	375	374
» 6	353	354	» 6	373	376
» 7	343	335	» 7	359	355
» 8	326	330	» 8	325	322
» 9	300	300	» 9	317	315
» 10	317	320	» 10	317	318
» 11	299	303	» 11	294	296
» 12	335	333	» 12	321	315
1982. 1	347	347	1985. 1	373	369
» 2	415	416	» 2	422	426
» 3	416	415	» 3	394	393
» 4	401	405	» 4	407	407
» 5	400	401	» 5	382	379
» 6	388	390	» 6	364	363
» 7	343	347	» 7	343	352
» 8	342	351	» 8	316	312
» 9	326	321	» 9	317	317
» 10	300	302	» 10	283	280
» 11	280	286	» 11	303	305
» 12	302	300	» 12	330	328
1983. 1	338	337			
» 2	380	377			
» 3	406	397			
» 4	399	398			
» 5	370	367			
» 6	356	364			
» 7	328	334			
» 8	316	323			
» 9	315	310			
» 10	300	306			
» 11	316	312			
» 12	319	318			

4.27 Station: LERWICK

$\varphi = 60^{0}\,08'$ N, L $= 01^{0}\,11'$ W, Time Period: 1957-1986.

Using Figure 7, we see that the mean monthly values of total ozone can be written as:

$$10^{-3} \cdot 0_m^{com} = 350 + 66 \sin\frac{2\pi}{12} t \tag{111}$$

Power spectrum analysis to (D), where

$$D = 10^{-3} \cdot 0^{obs} - 10^{-3} \cdot 0_m^{com} \tag{112}$$

we find four short-term periodic terms of 12, 6, 4 and 3 months. See Figure 103.

Figure 104 shows the same periodicities determined graphically by means of the successive approximation method. Their amplitude and position are also shown. The dots represent values of the differences derived from Equation (112), while the dashed and solid sinusoidal or semisinusoidal curves represent the periodic or in some cases quasi-periodic terms. These terms are expressed as:

$$P = \alpha_1 \sin\frac{2\pi}{12} t + \alpha_2 \sin\frac{2\pi}{6} t + \alpha_3 \sin\frac{2\pi}{4} t + \alpha_4 \sin\frac{2\pi}{3} t \tag{113}$$

Table 27 lists the values of the parameters of Equation (113) (parameters $\boldsymbol{\alpha}_1$ to $\boldsymbol{\alpha}_4$ and **t**).

By summing Equations (111) and (113) the observational data of the Lerwick Station for the period 1957-1986 can be represented simply as:

$$10^{-3} \cdot 0^{com} = 350 + 66 \sin\frac{2\pi}{12} t + P \tag{114}$$

where P is derived from Equation (113).

Equation (114) represents the observed MVTOZ at Lerwick Station with an accuracy of 98.7%. The s.d. between observed-computed MVTOZ is $\boldsymbol{\sigma} = \pm 4.5$, with an estimated 93 degrees of freedom for Equation (114).

These results are clearly shown in Figures 105 and 106, where the dots (or small open circles) represent observed MVTOZ while the solid line represents the variation of the computed values of MVTOZ for the Lerwick Station.

The numerical values plotted in Figures (105) and (106) are listed in Table 27A.

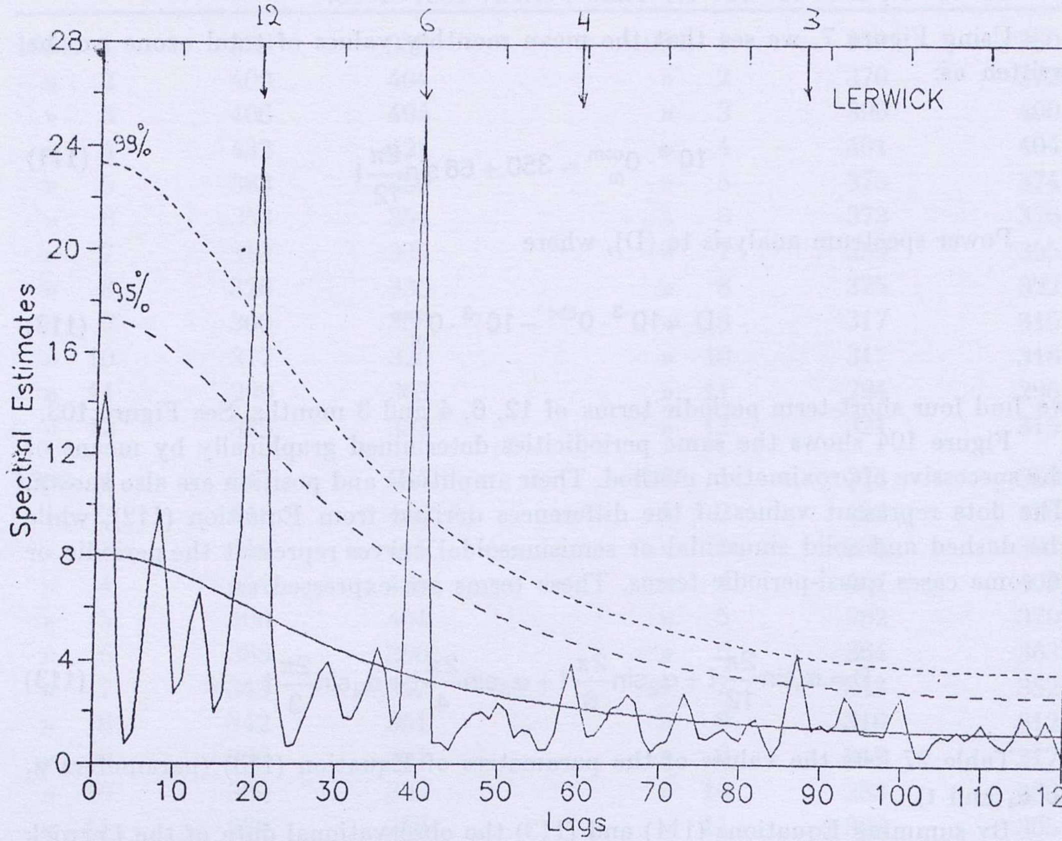

Fig. 103. Lerwick Station 1957 - 1986. Spectral estimate of the differences computed by Equation (112). Analysis shows periodic terms of 12, 6, 4 and 3 months, The 12, 6 and 3-month periods are predominant with a confidence level above 99%.

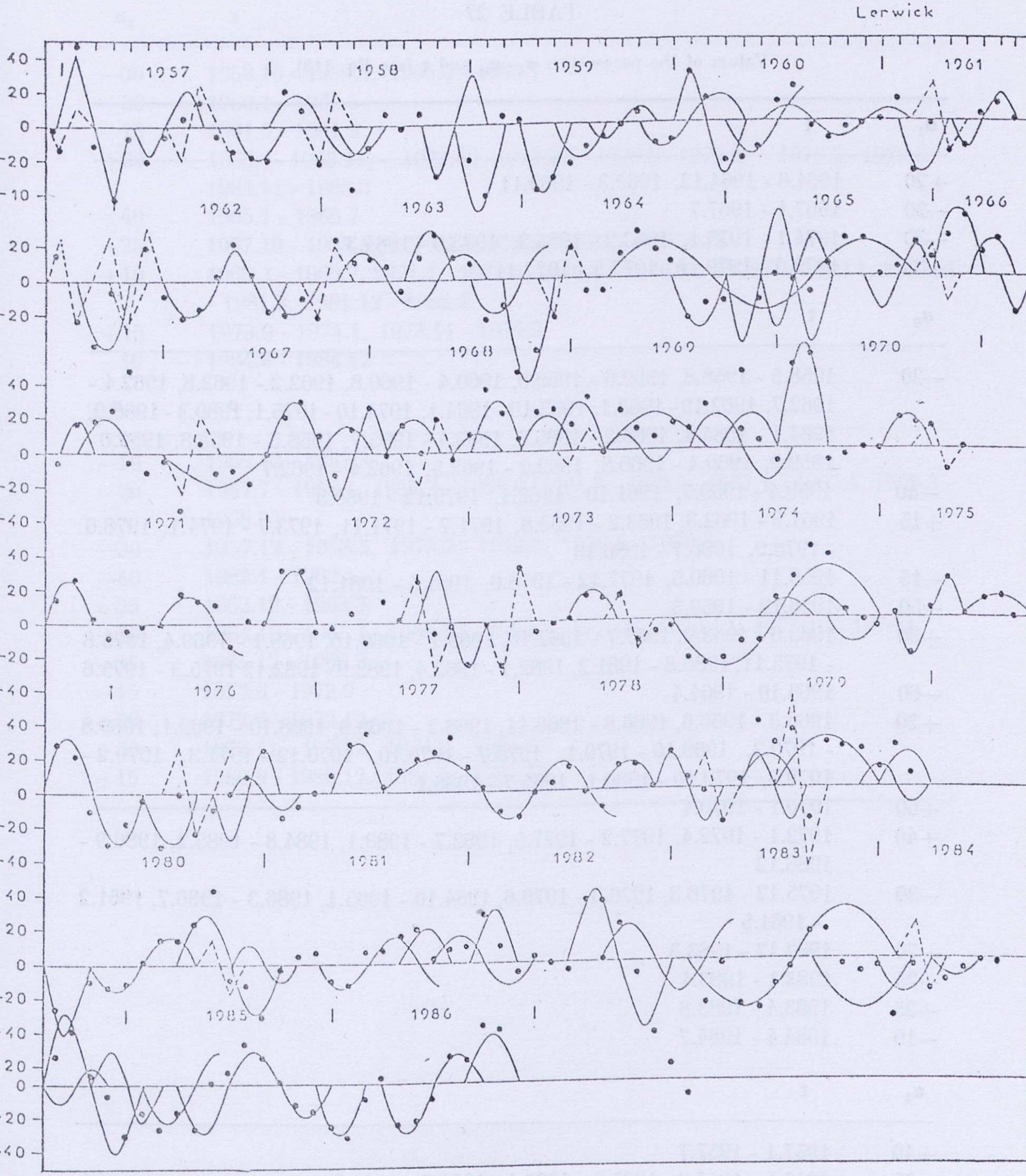

Fig. 104. Lerwick Station, 1957 - 1986. The differences (D) computed by Equation (112) are shown by dots (or small open circles). The dashed and solid sinusoidal or semisinusoidal curves show periodic terms of 12, 6, 4 and 3 months, whose position and amplitude is also plotted, by the successive approximation method.

TABLE 27

Values of the parameters α_1 - α_4, and t (see Eq. 113).

α_1	t
+20	1964.6 - 1964.12, 1969.3 - 1969.11
—20	1967.1 - 1967.7
—30	1974.1 - 1975.1, 1983.2 - 1984.2, 1983.9 - 1984.3
+30	1979.6 - 1979.10, 1977.5 - 1977.11
α_2	t
—20	1958.5 - 1958.8, 1959.6 - 1959.9, 1960.4 - 1960.8, 1962.2 - 1962.8, 1962.4 - 1962.7, 1962.10 - 1963.1, 1963.10 - 1964.1, 1974.10 - 1975.1, 1980.3 - 1980.9, 1984.1 - 1984.4, 1985.2 - 1985.6, 1985.4 - 1985.7, 1958.5 - 1958.8, 1959.6 - 1959.9, 1960.4 - 1960.8, 1962.2 - 1962.5, 1962.4 - 1962.7
—40	1959.4 - 1959.7, 1961.10 - 1962.1, 1979.12 - 1980.3
+15	1961.9 - 1962.3, 1963.2 - 1963.8, 1971.7 - 1971.11, 1973.7 - 1974.1, 1978.6 - 1978.9, 1986.7 - 1986.10
—15	1959.11 - 1960.5, 1977.12 - 1978.6, 1981.4 - 1981.12
—50	1958.12 - 1959.3
+30	1963.6 - 1963.9, 1967.7 - 1967.10, 1968.7 - 1968.10, 1969.1 - 1969.4, 1975.8 - 1975.11, 1980.8 - 1981.2, 1982.1 - 1982.4, 1982.9 - 1982.12 1975.3 - 1975.6
—60	1963.10 - 1964.4
+20	1966.3 - 1966.6, 1966.8 - 1966.11, 1968.2 - 1968.8, 1968.10 - 1969.1, 1969.8 - 1970.2, 1969.10 - 1970.1, 1970.7 - 1970.10, 1970.12 - 1971.3, 1979.2 - 1979.5, 1979.10 - 1980.1, 1985.7 - 1986.1
+60	1970.1 - 1970.4
+40	1972.1 - 1972.4, 1977.2 - 1977.5, 1982.7 - 1983.1, 1984.8 - 1985.2, 1986.9 - 1986.12
—30	1975.12 - 1976.3, 1976.3 - 1976.6, 1964.10 - 1965.1, 1986.3 - 1986.7, 1961.2 - 1961.5
—70	1982.12 - 1983.3
—25	1983.1 - 1983.4
+25	1983.4 - 1983.8
—10	1984.4 - 1984.7
α_3	t
+40	1957.1 - 1957.7
—20	1957.5 - 1957.8, 1965.9 - 1966.1, 1966.5 - 1966.9

a_3	t
—30	1958.10 - 1959.2, 1965.3 - 1965.7
+30	1960.1 - 1960.5
—15	1961.5 - 1961.9
+20	1968.7 - 1968.11, 1972.10 - 1973.2, 1978.9 - 1979.2, 1979.2 - 1979.6, 1984.11 - 1985.3
—40	1965.1 - 1965.7
—25	1967.10 - 1968.1, 1975.2 - 1975.6, 1976.7 - 1976.11
+10	1969.3 - 1969.7, 1971.1 - 1971.5, 1976.8 - 1976.12, 1979.9 - 1980.1, 1980.11 - 1981.3, 1981.12 - 1982.4
+15	1973.9 - 1974.1, 1973.11 - 1974.3
—10	1984.8 - 1984.12

a_4	t
—10	1956.12 - 1957.3
—20	1957.7 - 1958.1, 1958.3 - 1958.6, 1964.2 - 1964.5, 1967.1 - 1967.4, 1968.3 - 1968.6
—30	1957.12 - 1958.3, 1973.2 - 1973.5, 1976.4 - 1976.8
—40	1962.1 - 1962.4
—25	1962.12 - 1963.3
+10	1964.10 - 1965.1, 1968.12 - 1969.3, 1970.9 - 1970.12, 1975.10 - 1976.1
+15	1965.12 - 1966.3
—15	1972.6 - 1972.9
+30	1972.9 - 1972.12
+20	1978.11 - 1979.2, 1984.2 - 1984.5
+15	1980.9 - 1980.12, 1981.9 - 1981.12

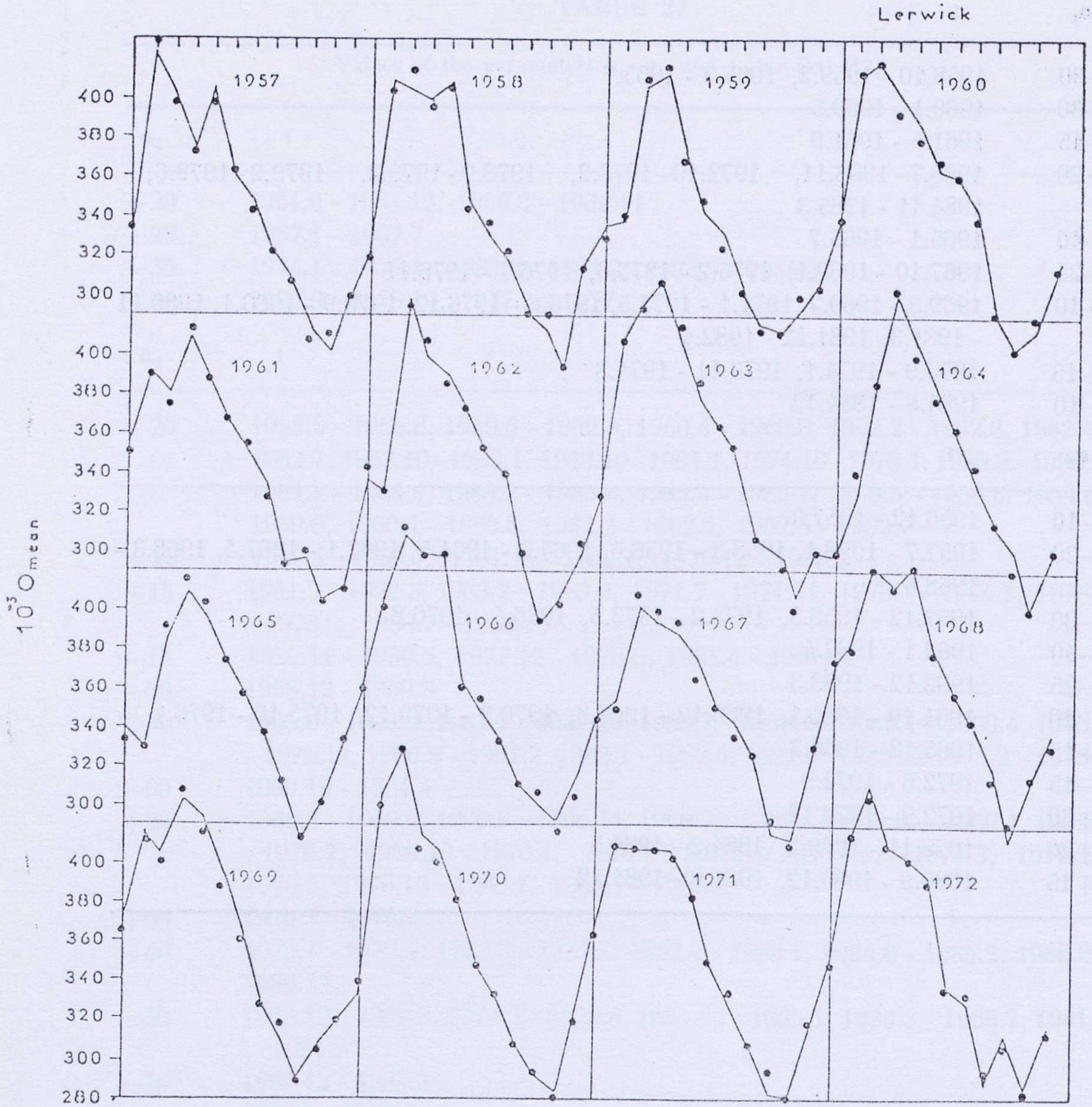

Fig. 105. Lerwick Station 1957 - 1972. Observed MVTOZ is shown by dots (or open circles). MVTOZ as found by Equation (114) is shown by a solid line. Accuracy is equal to 98.7%.

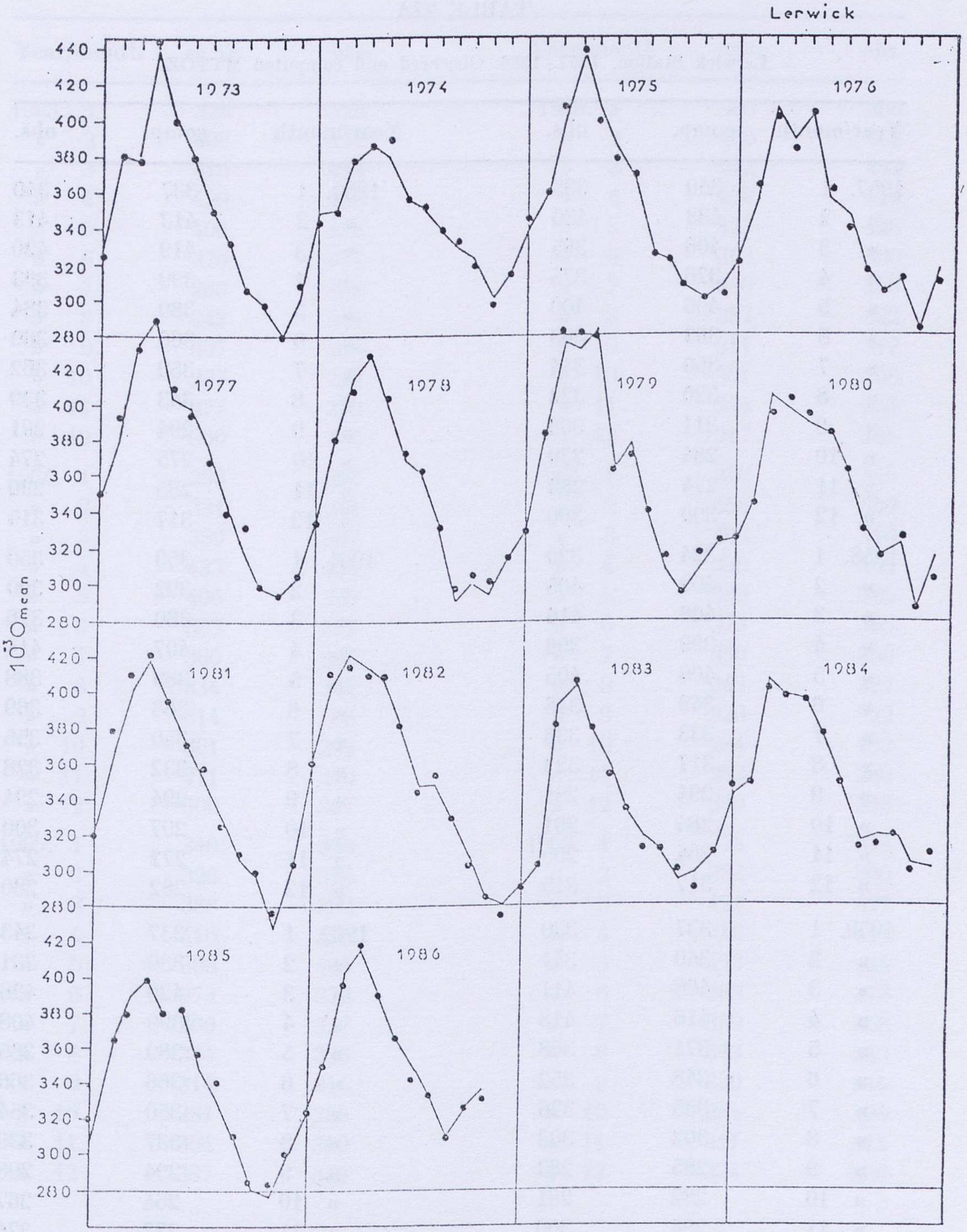

Fig. 106. Lerwick Station 1973 - 1986. Caption as for Figure (105), to which this Figure is complementary.

TABLE 27A

Lerwick Station, 1957 - 1986. Observed and computed MVTOZ.

Year/month	comp.	obs.	Year/month	comp.	obs.
1957. 1	340	335	1960. 1	337	340
» 2	433	430	» 2	413	413
» 3	406	395	» 3	419	420
» 4	376	375	» 4	399	393
» 5	406	400	» 5	389	384
» 6	363	363	» 6	366	369
» 7	350	344	» 7	359	362
» 8	320	322	» 8	343	339
» 9	311	308	» 9	294	291
» 10	284	279	» 10	275	274
» 11	274	280	» 11	285	290
» 12	300	300	» 12	317	315
1958. 1	324	320	1961. 1	359	350
» 2	409	405	» 2	392	390
» 3	406	416	» 3	380	376
» 4	399	396	» 4	407	414
» 5	406	405	» 5	389	388
» 6	349	346	» 6	368	369
» 7	333	338	» 7	350	355
» 8	317	323	» 8	332	328
» 9	294	291	» 9	294	294
» 10	284	291	» 10	297	300
» 11	264	265	» 11	272	274
» 12	317	315	» 12	282	280
1959. 1	337	330	1962. 1	337	343
» 2	340	341	» 2	330	331
» 3	406	411	» 3	429	426
» 4	416	418	» 4	399	408
» 5	371	368	» 5	389	385
» 6	348	352	» 6	366	366
» 7	335	326	» 7	350	354
» 8	302	303	» 8	337	339
» 9	285	283	» 9	294	298
» 10	282	281	» 10	264	267
» 11	294	300	» 11	277	274
» 12	307	305	» 12	300	305

Year/month	comp.	obs.	Year/month	comp.	obs.
1963. 1	328	328	1966. 1	363	360
» 2	405	407	» 2	406	402
» 3	419	416	» 3	442	442
» 4	429	428	» 4	433	429
» 5	406	414	» 5	423	428
» 6	370	377	» 6	363	360
» 7	363	364	» 7	350	355
» 8	343	344	» 8	337	332
» 9	307	308	» 9	311	312
» 10	297	292	» 10	301	308
» 11	277	270	» 11	294	287
» 12	300	301	» 12	317	305
1964. 1	298	297	1967. 1	350	345
» 2	331	341	» 2	356	350
» 3	389	387	» 3	406	410
» 4	433	434	» 4	396	405
» 5	406	398	» 5	389	395
» 6	383	377	» 6	373	365
» 7	360	364	» 7	350	350
» 8	334	344	» 8	343	337
» 9	314	308	» 9	320	322
» 10	301	292	» 10	284	292
» 11	271	270	» 11	282	280
» 12	300	301	» 12	330	330
1965. 1	340	335	1968. 1	375	375
» 2	326	326	» 2	383	380
» 3	386	392	» 3	423	422
» 4	410	416	» 4	416	415
» 5	396	405	» 5	423	424
» 6	373	372	» 6	383	378
» 7	360	357	» 7	359	358
» 8	334	338	» 8	343	343
» 9	314	314	» 9	320	315
» 10	281	285	» 10	284	290
» 11	304	300	» 11	311	315
» 12	337	335	» 12	334	330

Year/month	comp.	obs.	Year/month	comp.	obs.
1969. 1	367	365	1972. 1	350	350
» 2	418	413	» 2	417	415
» 3	406	402	» 3	440	436
» 4	436	438	» 4	416	412
» 5	423	416	» 5	406	405
» 6	393	388	» 6	392	390
» 7	367	364	» 7	337	338
» 8	327	329	» 8	330	334
» 9	311	319	» 9	294	297
» 10	291	288	» 10	310	308
» 11	311	304	» 11	288	287
» 12	317	320	» 12	317	315
1970. 1	333	340	1973. 1	330	325
» 2	435	430	» 2	383	381
» 3	458	459	» 3	380	379
» 4	416	407	» 4	442	447
» 5	406	402	» 5	406	401
» 6	383	381	» 6	383	380
» 7	350	349	» 7	350	351
» 8	334	335	» 8	330	332
» 9	311	308	» 9	307	306
» 10	293	295	» 10	297	298
» 11	285	280	» 11	281	280
» 12	326	320	» 12	304	310
1971. 1	367	365	1974. 1	350	345
» 2	409	409	» 2	353	350
» 3	406	408	» 3	380	379
» 4	407	407	» 4	386	391
» 5	406	402	» 5	380	391
» 6	383	381	» 6	368	368
» 7	350	349	» 7	359	362
» 8	330	335	» 8	341	340
» 9	307	308	» 9	329	334
» 10	284	295	» 10	323	320
» 11	281	280	» 11	303	297
» 12	317	320	» 12	315	315

Year/month	comp.	obs.	Year/month	comp.	obs.
1975. 1	350	345	1978. 1	337	335
» 2	361	360	» 2	383	382
» 3	406	409	» 3	419	410
» 4	438	439	» 4	429	428
» 5	406	400	» 5	406	405
» 6	383	379	» 6	370	373
» 7	359	359	» 7	363	365
» 8	326	325	» 8	330	332
» 9	323	323	» 9	294	298
» 10	310	309	» 10	304	306
» 11	303	300	» 11	294	301
» 12	308	305	» 12	317	315
1976. 1	324	320	1979. 1	330	330
» 2	357	365	» 2	383	385
» 3	406	402	» 3	438	445
» 4	390	385	» 4	433	442
» 5	406	406	» 5	444	440
» 6	357	361	» 6	366	364
» 7	350	341	» 7	380	371
» 8	317	317	» 8	343	341
» 9	304	305	» 9	309	315
» 10	309	309	» 10	294	296
» 11	284	279	» 11	311	318
» 12	317	310	» 12	324	325
1977. 1	350	350	1980. 1	325	325
» 2	383	394	» 2	348	345
» 3	438	434	» 3	406	396
» 4	448	451	» 4	399	403
» 5	406	411	» 5	389	395
» 6	397	396	» 6	383	385
» 7	376	369	» 7	367	365
» 8	347	340	» 8	334	331
» 9	320	331	» 9	320	317
» 10	299	299	» 10	323	327
» 11	294	295	» 11	281	285
» 12	304	305	» 12	317	305

Year/month	comp.	obs.	Year/month	comp.	obs.
1981. 1	324	320	1984. 1	340	346
» 2	373	380	» 2	351	351
» 3	406	410	» 3	406	402
» 4	416	422	» 4	399	397
» 5	393	396	» 5	397	396
» 6	370	371	» 6	374	377
» 7	350	357	» 7	350	348
» 8	330	325	» 8	317	314
» 9	307	310	» 9	319	312
» 10	297	303	» 10	319	320
» 11	268	277	» 11	304	300
» 12	317	315	» 12	302	310
1982. 1	359	360	1985. 1	315	320
» 2	409	412	» 2	363	366
» 3	423	415	» 3	389	380
» 4	416	411	» 4	399	400
» 5	406	410	» 5	389	380
» 6	383	383	» 6	383	384
» 7	350	345	» 7	350	357
» 8	352	354	» 8	334	341
» 9	329	330	» 9	311	310
» 10	310	305	» 10	284	284
» 11	285	285	» 11	277	282
» 12	282	275	» 12	300	300
1983. 1	290	290	1986. 1	324	325
» 2	300	303	» 2	357	351
» 3	391	381	» 3	406	397
» 4	412	415	» 4	416	420
» 5	376	380	» 5	380	381
» 6	357	352	» 6	357	360
» 7	335	335	» 7	350	341
» 8	317	313	» 8	330	333
» 9	309	311	» 9	307	308
» 10	295	300	» 10	319	318
» 11	298	290	» 11	329	325
» 12	313	310	» 12	—	—

4.28 Station: REYKJAVIK

$\varphi = 64^0\ 08'$ N, L $= 21^0\ 54'$ W, Time Period: 1958-1986.

This station is one of the Dobson Stations located near the Arctic Circle and therefore the available observational data are incomplete.

Using Figure 7, the mean monthly values of total ozone for the period 1958-1986 can be written as:

$$10^{-3} \cdot 0_m^{com} = 360 + 60 \sin\frac{2\pi}{12} t \tag{115}$$

Power spectrum analysis of the differences (D), where

$$D = 10^{-3} \cdot 0^{obs} - 10^{-3} \cdot 0_m^{com} \tag{116}$$

reveals only two significant periodic terms with periods of 6 and 3 months. See Figures 107 and 108. The apparent anomaly is probably due to the lack of enough available observational data.

Figure 109, however, which represents the periodicity of the MVTOZ for the period 1958-1986, as determined by the successive approximation method, implies a different result: four periodic terms, of 12, 6, 4 and 3 months. The dots represent the differences derived from Equation (116) while the dashed and solid sinusoidal or semisinusoidal curves represent the periodic or quasi-periodic terms, which appear as a network of periodicities overlapping in some cases each other. These terms can be expressed as:

$$P = \alpha_1 \sin\frac{2\pi}{12} t + \alpha_2 \sin\frac{2\pi}{6} t + \alpha_3 \sin\frac{2\pi}{4} t + \alpha_4 \sin\frac{2\pi}{3} t \tag{117}$$

Table 28 tabulates the values of the parameters (coefficients) of Equation (117).

By adding Equations (115) and (117), we obtain the Equation (118),

$$10^{-3} \cdot 0^{com} = 360 + 60 \sin\frac{2\pi}{12} t + P \tag{118}$$

which represents the observed data of MVTOZ with an accuracy of 98.8%. The s.d. between observed-computed MVTOZ is $\sigma = \pm 4.12$, with 70 degrees of freedom for Equation (118). This is obvious from Figures 110 and 111 where the dots represent observed MVTOZ, while the solid line represents MVTOZ computed by Equation (118).

Table 28A summarizes the values with which Figures 110 and 111 were plotted.

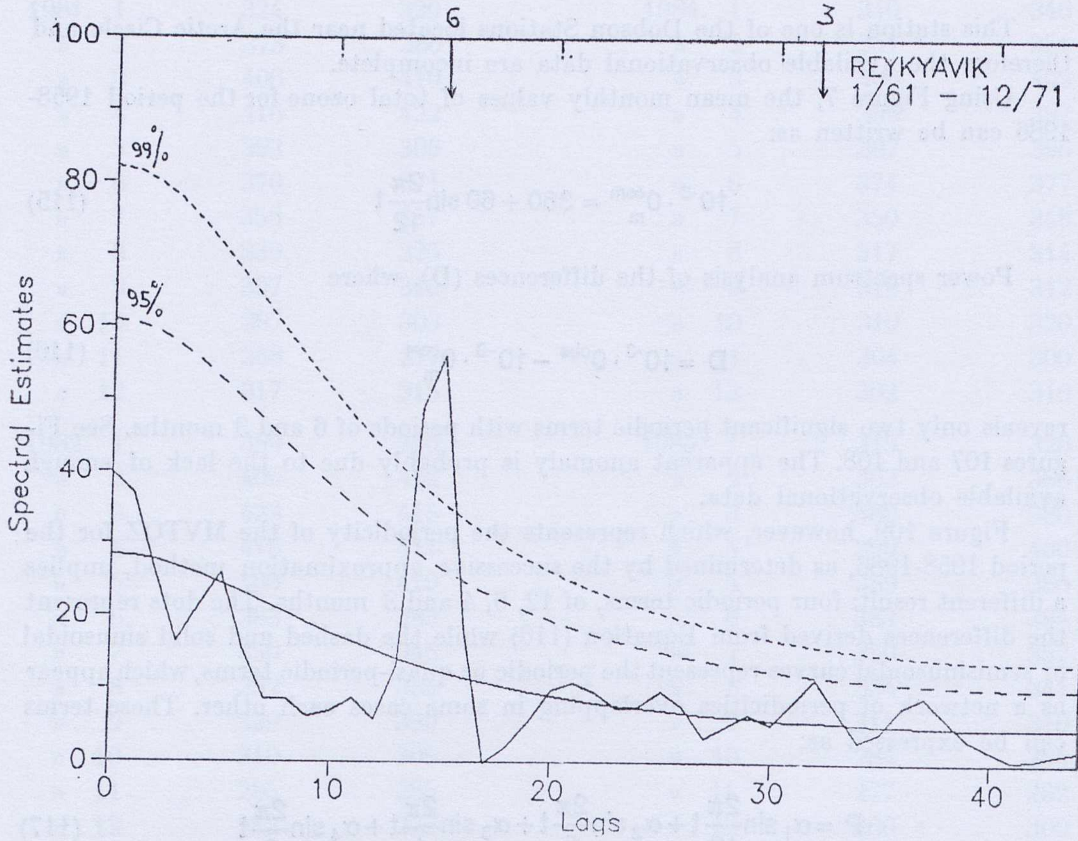

Fig. 107. Reykjavik Station, 1961 - 1971. Spectral estimate of the differences computed by Equation (116). Analysis shows short-term periodic terms with periods of 6 and 3 months. Note that the 6-month term is predominant with a confidence level above 99%.

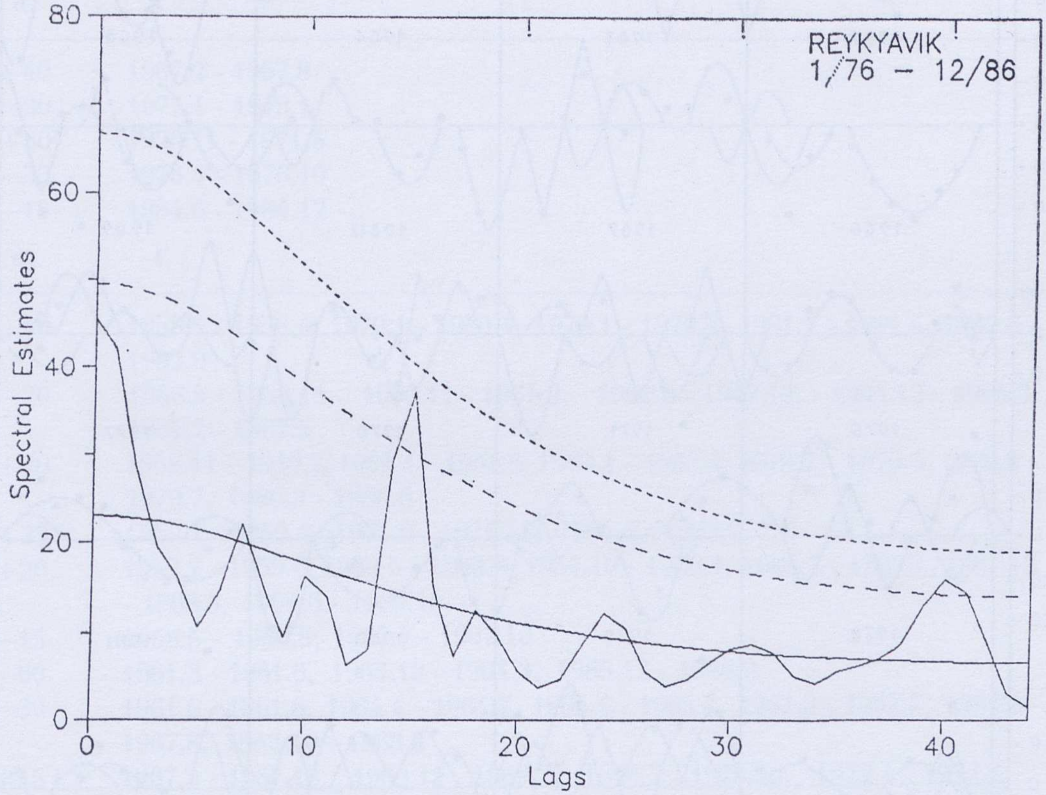

Fig. 108. Reykjavik Station, 1976 - 1986. Caption as for Figure 107, to which this Figure is complementary.

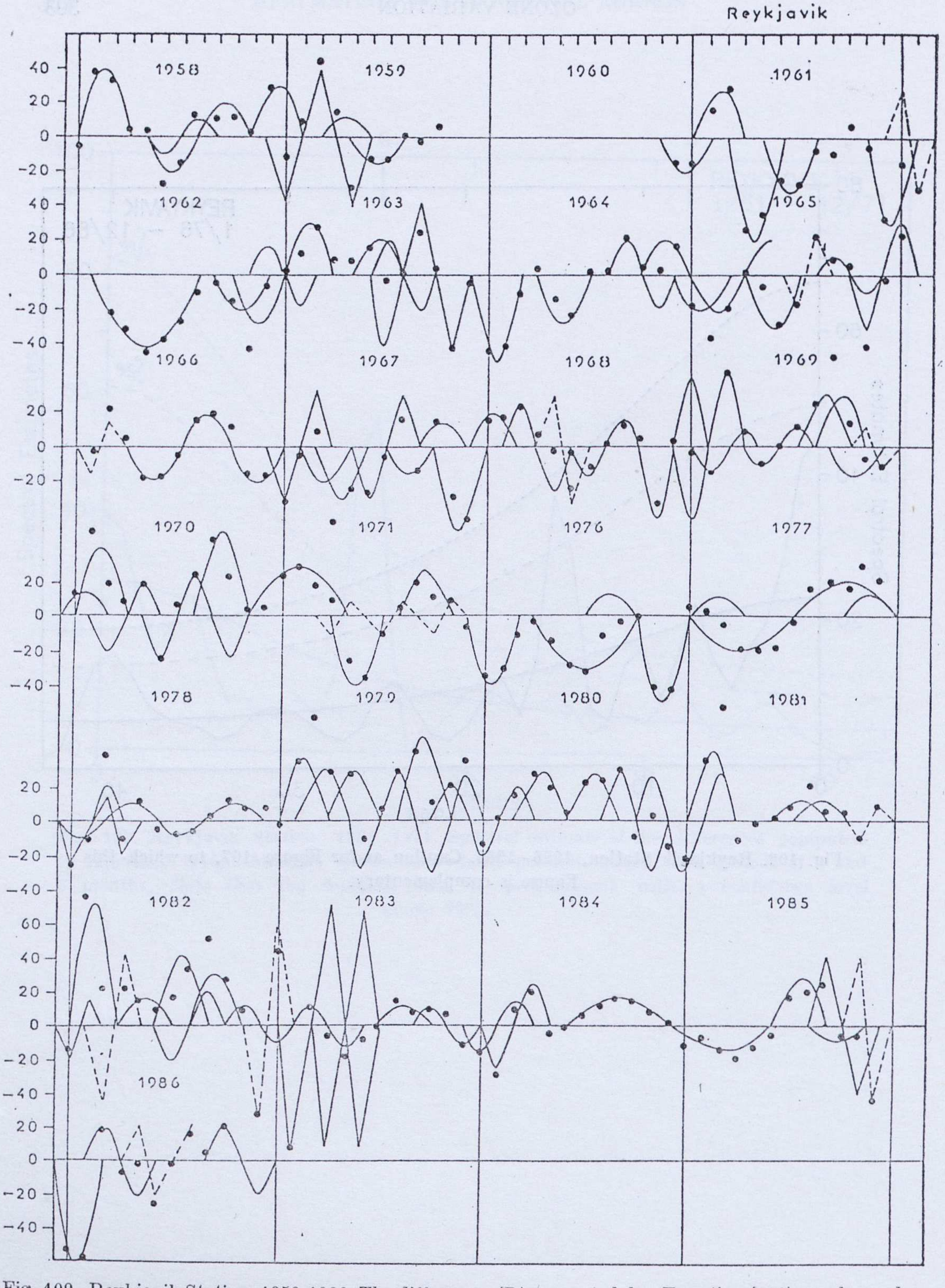

Fig. 109. Reykjavik Station, 1958-1986. The differences (D) computed by Equation (116) are shown by dots. The dashed and solid sinusoidal or semisinusoidal curves show periodic terms, of 12, 6, 4 and 3 months. These periodic terms were graphically determined by means of the successive approximation method. The position and amplitude of the periodic terms are shown in this Figure.

TABLE 28

Values of the parameters α_1 - α_4, and t (see Eq. 117).

α_1	t
—40	1967.2 - 1967.8
—20	1977.1 - 1978.1
+30	1970.11 - 1971.5
—30	1976.4 - 1976.10
—15	1984.6 - 1984.12

α_2	t
+40	1958.1 - 1958.4, 1970.1 - 1970.4, 1979.1 - 1979.4, 1981.1 - 1981.4, 1982.6 - 1982.9
—20	1958.5 - 1958.11, 1960.11 - 1961.2, 1962.9 - 1962.12, 1964.12 - 1965.3, 1967.2 - 1967.5
+30	1958.11 - 1959.2, 1961.1 - 1961.4, 1963.1 - 1963.4, 1979.2 - 1979.5, 1979.4 - 1979.7, 1980.3 - 1980.6
+25	1959.1 - 1959.4, 1971.8 - 1971.11, 1985.6 - 1985.9
+20	1959.2 - 1959.6, 1963.5 - 1963.8, 1964.10 - 1965.1, 1966.7 - 1967.1, 1967.12 - 1968.3, 1969.6 - 1969.10
—15	1959.5 - 1959.8, 1967.7 - 1967.10
—60	1961.3 - 1961.6, 1963.12 - 1964.3, 1985.12 - 1986.3
—30	1961.5 - 1961.8, 1964.4 - 1964.7, 1965.4 - 1965.7, 1967.3 - 1967.7, 1967.5- 1967.8, 1962.10 - 1963.1
+15	1967.9 - 1967.12, 1969.12 - 1969.3, 1976.7 - 1976.10, 1972.1 - 1972.4, 1982.4 - 1982.7
—50	1967.10 - 1968.1, 1976.10 - 1977.1, 1982.11 - 1983.2
+60	1969.8 - 1969.11
—25	1969.9 - 1969.12
+50	1970.8 - 1970.11, 1979.8 - 1979.11
—40	1971.4 - 1971.7, 1971.12 - 1972.3, 1975.12 - 1976.3
—10	1977.12 - 1978.12
+30	1980.6 - 1980.9, 1982.8 - 1982.11
+10	1981.6 - 1981.9, 1981.7 - 1981.10, 1983.7 - 1983.10

α_3	t
—10	1958.5 - 1958.9
—40	1958.12 - 1959.6, 1963.6 - 1963.12, 1968.10 - 1969.2, 1968.12 - 1969.4
+20	1962.11 - 1963.3, 1963.6 - 1963.10, 1964.8 - 1964.11

α_3	t
+10	1964.2 - 1964.6, 1965.6 - 1965.12, 1977.7 - 1977.11, 1980.9 - 1981.1, 1983.2 - 1983.6, 1983.9 - 1984.1
—30	1965.10 - 1966.2, 1966.12 - 1967.4, 1967.5 - 1967.9, 1979.10 - 1980.1
+25	1968.2 - 1968.6
—15	1968.6 - 1968.10, 1969.1 - 1969.5, 1969.4 - 1969.8
—20	1970.2 - 1970.6, 1980.12 - 1981.4
—25	1970.7 - 1970.11, 1978.6 - 1978.10, 1984.1 - 1984.5
+30	1980.8 - 1980.12
—70	1983.1 - 1983.7, 1983.3 - 1983.7
+40	1985.8 - 1985.12
+20	1986.2 - 1986.6, 1986.9 - 1987.1

α_4	t
+30	1961.12 - 1962.3
+10	1962.3 - 1962.6
—25	1965.6 - 1965.9
—15	1966.1 - 1966.4, 1981.12 - 1982.4
—20	1966.9 - 1967.1
+15	1969.10 - 1970.4
—10	1971.8 - 1971.12, 1981.10 - 1982.1, 1983.4 - 1983.7
+20	1978.2 - 1978.5, 1986.4 - 1986.8
—40	1982.2 - 1982.5
—50	1982.11 - 1983.2
+40	1985.10 - 1986.1

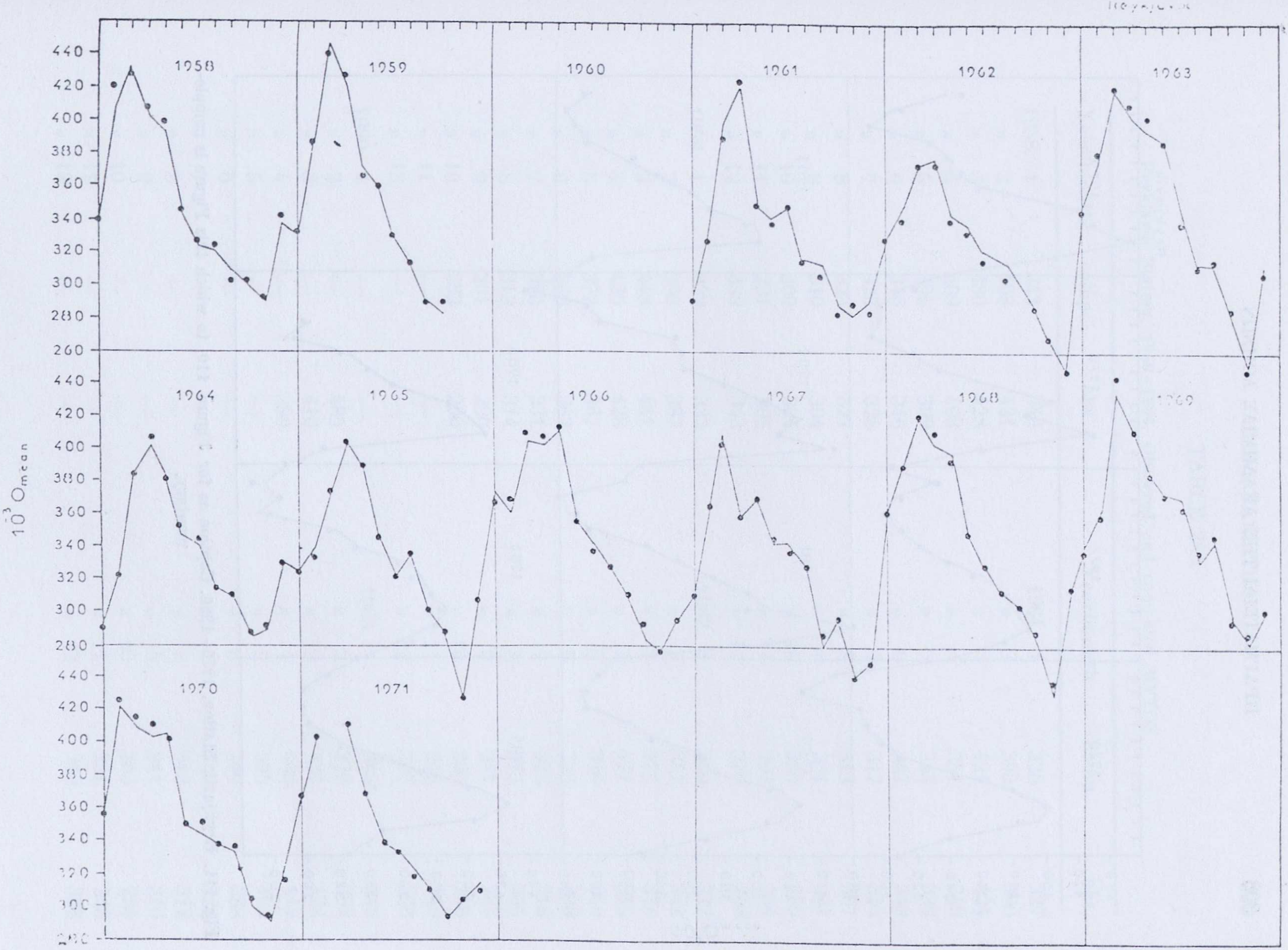

Fig. 110. Reykjavik Station, 1958 - 1971. Observed MVTOZ is shown by dots. MVTOZ as computed by Equation (118) is shown by a solid line. Accuracy is equal to 98. 8%.

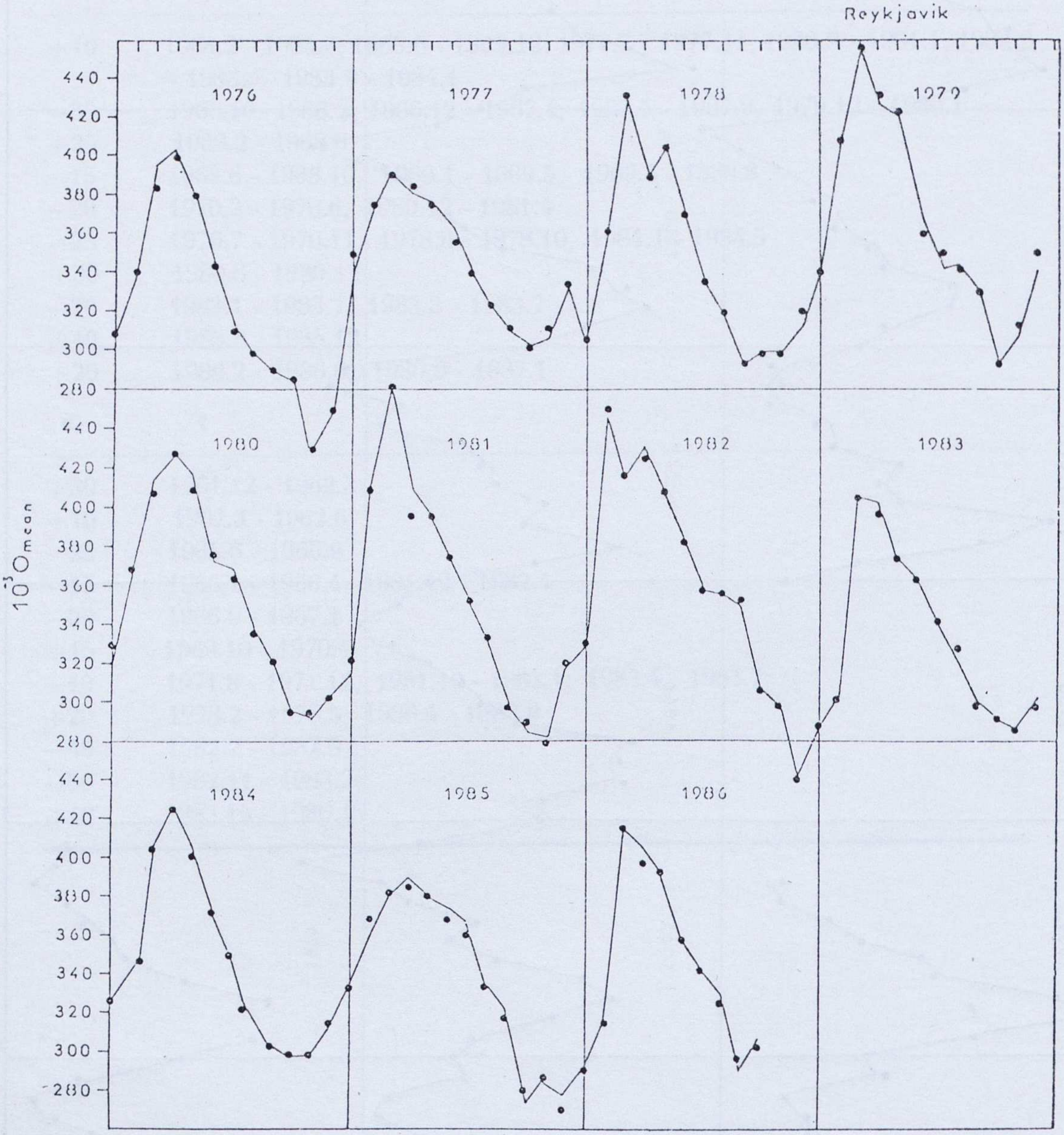

Fig. 111. Reykjavik Station, 1976 - 1986. Caption as for Figure 110, to which this Figure is complementary.

TABLE 28A

Reykjavik Station, 1958 - 1986. Observed and computed MVTOZ.

Year/month	comp.	obs.	Year/month	comp.	obs.
1958. 1	343	340	1961. 1	326	327
» 2	408	421	» 2	399	390
» 3	430	428	» 3	421	424
» 4	409	408	» 4	351	349
» 5	395	399	» 5	343	339
» 6	346	346	» 6	347	349
» 7	326	328	» 7	317	315
» 8	323	327	» 8	313	307
» 9	310	304	» 9	291	281
» 10	300	304	» 10	283	290
» 11	291	295	» 11	291	284
» 12	339	343	» 12	270	268
1959. 1	329	332	1962. 1	326	327
» 2	386	387	» 2	347	341
» 3	448	441	» 3	375	374
» 4	420	428	» 4	377	375
» 5	372	367	» 5	346	340
» 6	360	362	» 6	338	336
» 7	330	331	» 7	323	316
» 8	313	314	» 8	313	305
» 9	291	290	» 9	291	287
» 10	283	290	» 10	266	268
» 11	—	—	» 11	248	248
» 12	—	—	» 12	307	308
1960. 1	—	—	1963. 1	343	345
» 2	—	485	» 2	379	382
» 3	—	410	» 3	421	422
» 4	—	390	» 4	403	411
» 5	—	—	» 5	395	403
» 6	—	—	» 6	390	388
» 7	—	—	» 7	340	339
» 8	—	—	» 8	313	312
» 9	—	—	» 9	311	316
» 10	—	—	» 10	283	286
» 11	—	—	» 11	251	248
» 12	—	—	» 12	313	308

Year/month	comp.	obs.	Year/month	comp.	obs.
1964. 1	291	289	1967. 1	310	310
» 2	321	321	» 2	373	366
» 3	385	383	» 3	408	404
» 4	403	407	» 4	360	359
» 5	379	381	» 5	369	370
» 6	347	353	» 6	343	346
» 7	343	345	» 7	343	337
» 8	313	315	» 8	330	329
» 9	311	312	» 9	278	287
» 10	283	281	» 10	296	298
» 11	288	292	» 11	262	260
» 12	330	330	» 12	271	270
1965. 1	326	325	1968. 1	360	360
» 2	339	334	» 2	390	390
» 3	378	374	» 3	420	420
» 4	403	404	» 4	403	410
» 5	386	389	» 5	396	393
» 6	347	345	» 6	347	349
» 7	321	321	» 7	328	329
» 8	335	336	» 8	313	315
» 9	301	301	» 9	306	305
» 10	283	287	» 10	283	288
» 11	251	248	» 11	251	258
» 12	313	308	» 12	313	317
1966. 1	373	367	1969. 1	343	338
» 2	360	369	» 2	363	359
» 3	408	414	» 3	435	444
» 4	403	408	» 4	413	412
» 5	412	413	» 5	385	385
» 6	356	356	» 6	373	372
» 7	343	338	» 7	370	365
» 8	330	329	» 8	330	338
» 9	308	311	» 9	343	347
» 10	283	294	» 10	296	296
» 11	278	277	» 11	282	289
» 12	296	296	» 12	300	301

Year/month	comp.	obs.	Year/month	obs.	obs.
1970. 1	356	357	1973. 1	—	—
» 2	421	423	» 2	—	—
» 3	410	415	» 3	—	—
» 4	403	410	» 4	—	—
» 5	415	412	» 5	—	—
» 6	348	348	» 6	—	—
» 7	343	350	» 7	—	—
» 8	338	338	» 8	—	—
» 9	334	337	» 9	—	—
» 10	301	306	» 10	—	—
» 11	291	294	» 11	—	—
» 12	328	316	» 12	—	—
1971. 1	369	367	1974. 1	—	—
» 2	403	403	» 2	—	—
» 3	—	—	» 3	—	—
» 4	409	411	» 4	—	—
» 5	369	369	» 5	—	—
» 6	338	338	» 6	—	—
» 7	334	333	» 7	—	—
» 8	322	318	» 8	—	—
» 9	311	312	» 9	—	—
» 10	296	294	» 10	—	—
» 11	300	301	» 11	—	—
» 12	313	309	» 12	—	—
1972. 1	—	340	1975. 1	—	—
» 2	—	370	» 2	—	—
» 3	—	420	» 3	—	—
» 4	—	—	» 4	—	—
» 5	—	—	» 5	—	—
» 6	—	—	» 6	—	—
» 7	—	—	» 7	—	—
» 8	—	—	» 8	—	—
» 9	—	—	» 9	—	—
» 10	—	—	» 10	—	—
» 11	—	—	» 11	—	—
» 12	—	—	» 12	—	—

Year/month	comp.	obs.	Year/month	comp.	obs.
1976. 1	308	309	1979. 1	349	340
» 2	338	343	» 2	408	408
» 3	395	384	» 3	456	457
» 4	403	400	» 4	429	432
» 5	380	380	» 5	421	423
» 6	347	345	» 6	369	360
» 7	313	310	» 7	343	350
» 8	300	300	» 8	343	341
» 9	289	290	» 9	334	330
» 10	283	286	» 10	296	293
» 11	248	250	» 11	311	313
» 12	270	270	» 12	343	350
1977. 1	343	348	1980. 1	323	330
» 2	376	375	» 2	373	373
» 3	391	390	» 3	415	411
» 4	383	385	» 4	429	430
» 5	378	375	» 5	421	413
» 6	363	356	» 6	373	376
» 7	343	340	» 7	369	363
» 8	323	330	» 8	339	336
» 9	308	311	» 9	321	320
» 10	303	301	» 10	293	292
» 11	321	324	» 11	291	294
» 12	336	335	» 12	303	300
1978. 1	314	316	1981. 1	313	320
» 2	364	361	» 2	408	409
» 3	432	435	» 3	460	462
» 4	395	392	» 4	403	392
» 5	404	406	» 5	395	394
» 6	373	368	» 6	373	375
» 7	334	335	» 7	352	352
» 8	304	307	» 8	331	333
» 9	291	293	» 9	300	297
» 10	292	293	» 10	283	288
» 11	300	298	» 11	282	278
» 12	313	320	» 12	322	320

Year/month	comp.	obs.	Year/month	comp.	obs.
1982. 1	330	330	1985. 1	336	332
» 2	447	450	» 2	360	367
» 3	416	417	» 3	380	380
» 4	430	424	» 4	390	383
» 5	408	410	» 5	387	382
» 6	386	382	» 6	373	368
» 7	358	359	» 7	365	360
» 8	348	347	» 8	335	334
» 9	337	343	» 9	322	317
» 10	309	307	» 10	274	279
» 11	300	299	» 11	286	286
» 12	261	260	» 12	278	270
1983. 1	286	285	1986. 1	291	290
» 2	303	301	» 2	321	314
» 3	405	406	» 3	404	414
» 4	403	397	» 4	403	396
» 5	376	375	» 5	392	392
» 6	364	364	» 6	356	357
» 7	343	342	» 7	343	341
» 8	322	328	» 8	330	325
» 9	300	298	» 9	291	295
» 10	293	292	» 10	303	305
» 11	291	286	» 11	291	—
» 12	303	298	» 12	293	—
1984. 1	328	326			
» 2	348	346			
» 3	410	404			
» 4	428	423			
» 5	395	390			
» 6	373	372			
» 7	350	348			
» 8	326	322			
» 9	306	306			
» 10	296	298			
» 11	298	298			
» 12	313	315			

4.29 Station : RESOLUTE

$\varphi = 74^0\,43'$ N, L $= 94^0\,59'$ W, Time Period: 1958-1986.

This Station is the Northernmost Dobson Station in the Northern Hemisphere. Due to its location, the series of available observational data has many gaps.

Using Figure 5, the mean monthly values of total ozone can be expressed as:

$$10^{-3}\cdot 0_m^{com} = 400 + 90\sin\left(\frac{2\pi}{12}t + 30^\circ\right) + 30\sin\frac{2\pi}{6}t \tag{119}$$

Calculating the differences (D), where

$$D = 10^{-3}\cdot 0^{obs} - 10^{-3}\cdot 0_m^{com} \tag{120}$$

and applying the successive approximation method, we obtain Figure 112 where the dots represent differences derived from Equation (120), while the dashed and solid sinusoidal and semisinusoidal curves represent periodic or quasi-periodic terms of 12, 6, 4 and 3 months. This finding cannot be confirmed by the power spectrum analysis, because of the gaps in the records. In this case, it is the graphic method which reveals the position and amplitude of the periodic terms. See Figure 112. The terms can be expressed analytically as:

$$P = \alpha_1\sin\frac{2\pi}{12}t + \alpha_2\sin\frac{2\pi}{6}t + \alpha_3\sin\frac{2\pi}{4}t + \alpha_4\sin\frac{2\pi}{3}t \tag{121}$$

The values of the coefficients $\boldsymbol{\alpha}_1$ to $\boldsymbol{\alpha}_4$ and **t**, are listed in Table 29.

Thus the observed MVTOZ can be expressed, with an accuracy of 99.9% by means of Equation (122),

$$10^{-3}\cdot 0^{com} = 10^{-3}\cdot 0_m^{com} + P \tag{122}$$

where P is derived from Equation (121).

The s.d. between observed-computed MVTOZ is $\boldsymbol{\sigma} = \pm 4.3$, with 8 degrees of freedom for Equation (122). This is confirmed by Figures 113 and 114 where the dots-small open circles represent observed MVTOZ, while the solid line represents same MVTOZ computed by Equation (122). The estimated accuracy (99.9%) is clearly implied in this pair of Figures. Observed and computed MVTOZ are almost identical.

Table 29A lists the values plotted on Figures 113 and 114.

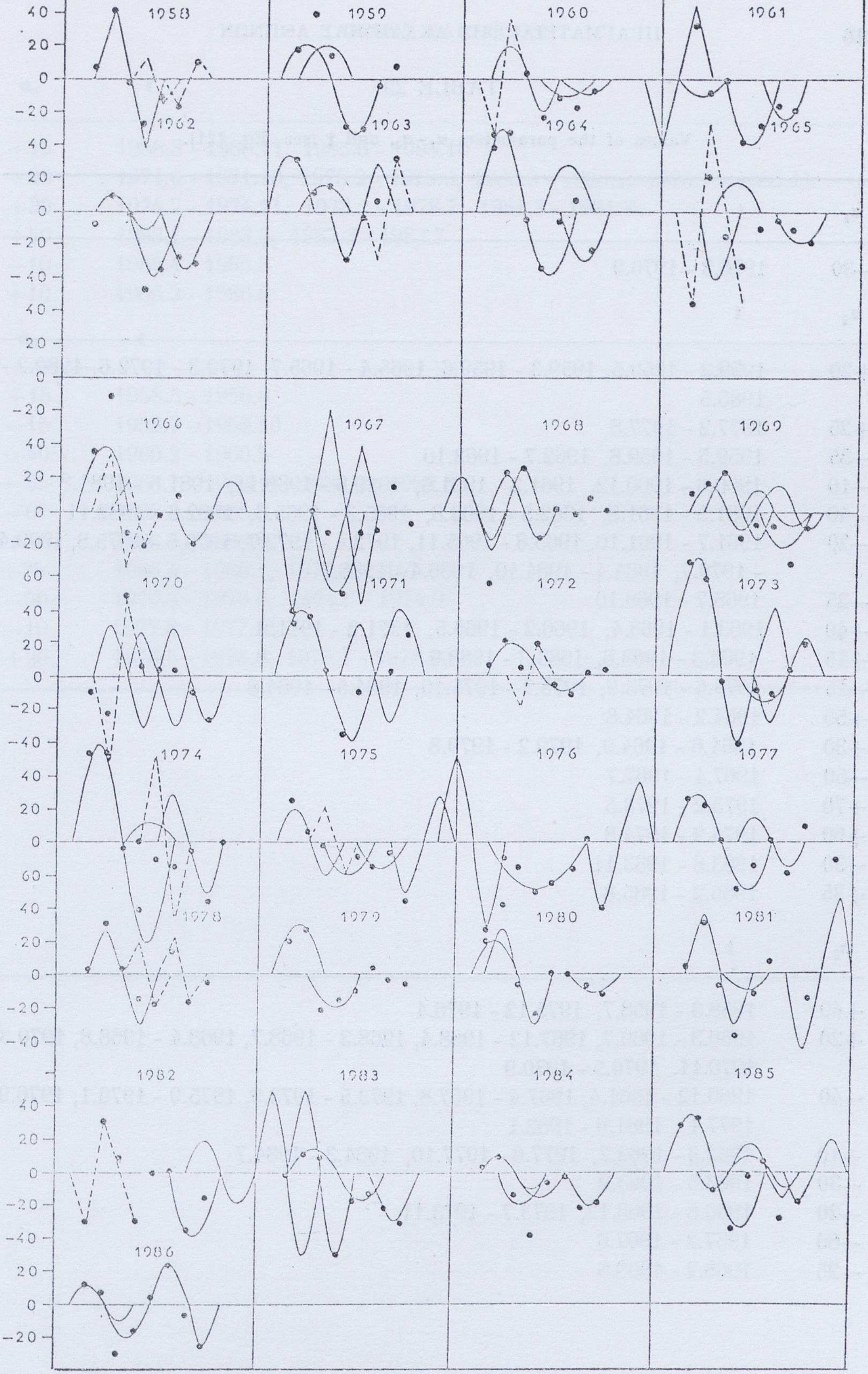

Fig. 112. Resolute Station, 1958 - 1986. The differences computed by Equation (120) are shown by dots. The dashed and solid sinusoidal or semisinusoidal curves show periodic terms of 12, 6, 4 and 3 months. These periodicities are graphically determined by applying the successive approximation method.

TABLE 29

Values of the parameters $\alpha_1 - \alpha_4$, and **t** (see Eq. 121).

α_1	t
—30	1976.3 - 1976.9
α_2	t
+20	1959.2 - 1959.5, 1959.3 - 1959.6, 1965.4 - 1965.7, 1972.3 - 1972.6, 1980.2 - 1980.5
+25	1977.2 - 1977.8
—35	1959.5 - 1959.8, 1962.7 - 1962.10
—10	1960.6 - 1960.12, 1961.2 - 1961.5, 1980.8 - 1980.11, 1981.5 - 1981.8
—40	1961.5 - 1961.8, 1962.5 - 1962.8, 1965.3 - 1965.6, 1982.8 - 1982.11
—20	1961.7 - 1961.10, 1965.8 - 1965.11, 1972.4 - 1972.7, 1975.5 - 1975.8, 1979.4 - 1979.7, 1984.4 - 1984.10, 1986.4 - 1986.7
—25	1968.7 - 1968.10
+40	1963.1 - 1963.4, 1966.2 - 1966.5, 1971.2 - 1971.8
+15	1963.3 - 1963.6, 1983.3 - 1983.9
—15	1973.6 - 1973.9, 1975.7 - 1975.10, 1984.5 - 1984.8
+50	1964.2 - 1964.8
+30	1964.6 - 1964.9, 1979.2 - 1979.8
—50	1967.4 - 1967.7
+70	1973.2 - 1973.5
+60	1974.2 - 1974.8
—30	1983.8 - 1983.11
+35	1985.2 - 1985.8
α_3	t
+40	1958.3 - 1958.7, 1975.12 - 1976.4
+20	1960.3 - 1960.7, 1967.12 - 1968.4, 1968.3 - 1968.7, 1968.4 - 1968.8, 1970.3-1970.11, 1970.5 - 1970.9
—40	1960.12 - 1961.4, 1967.4 - 1967.8, 1973.5 - 1973.9, 1975.9 - 1976.1, 1976.9-1977.1 , 1981.9 - 1982.1
+10	1962.3 - 1962.7, 1977.6 - 1977.10, 1984.3 - 1984.7
—30	1963.5 - 1963.9
—20	1966.8 - 1966.12, 1973.7 - 1973.11
—60	1967.2 - 1967.6
—25	1968.2 - 1968.6

α_3	t
+15	1968.3 - 1968.11, 1985.6 - 1985.10
+25	1971.6 - 1971.10, 1975.2 - 1975.6, 1980.3 - 1980.7, 1986.7 - 1986.11
+30	1974.7 - 1974.11, 1978.3 - 1978.7, 1981.3 - 1981.7
+50	1983.1 - 1983.5, 1983.3 - 1983.7
—10	1985.4 - 1985.8
+10	1986.2 - 1986.6

α_4	t
+15	1958.5 - 1958.8
—15	1958.7 - 1958.10
—40	1960.2 - 1960.5
—35	1963.7 - 1963.10, 1982.2 - 1982.6
—60	1965.2 - 1965.6
+40	1966.3 - 1966.6
+25	1966.4 - 1966.7, 1975.4 - 1975.7
—50	1970.3 - 1970.6, 1974.6 - 1974.9
—10	1977.8 - 1977.11
+20	1978.5 - 1978.8, 1978.7 - 1978.10

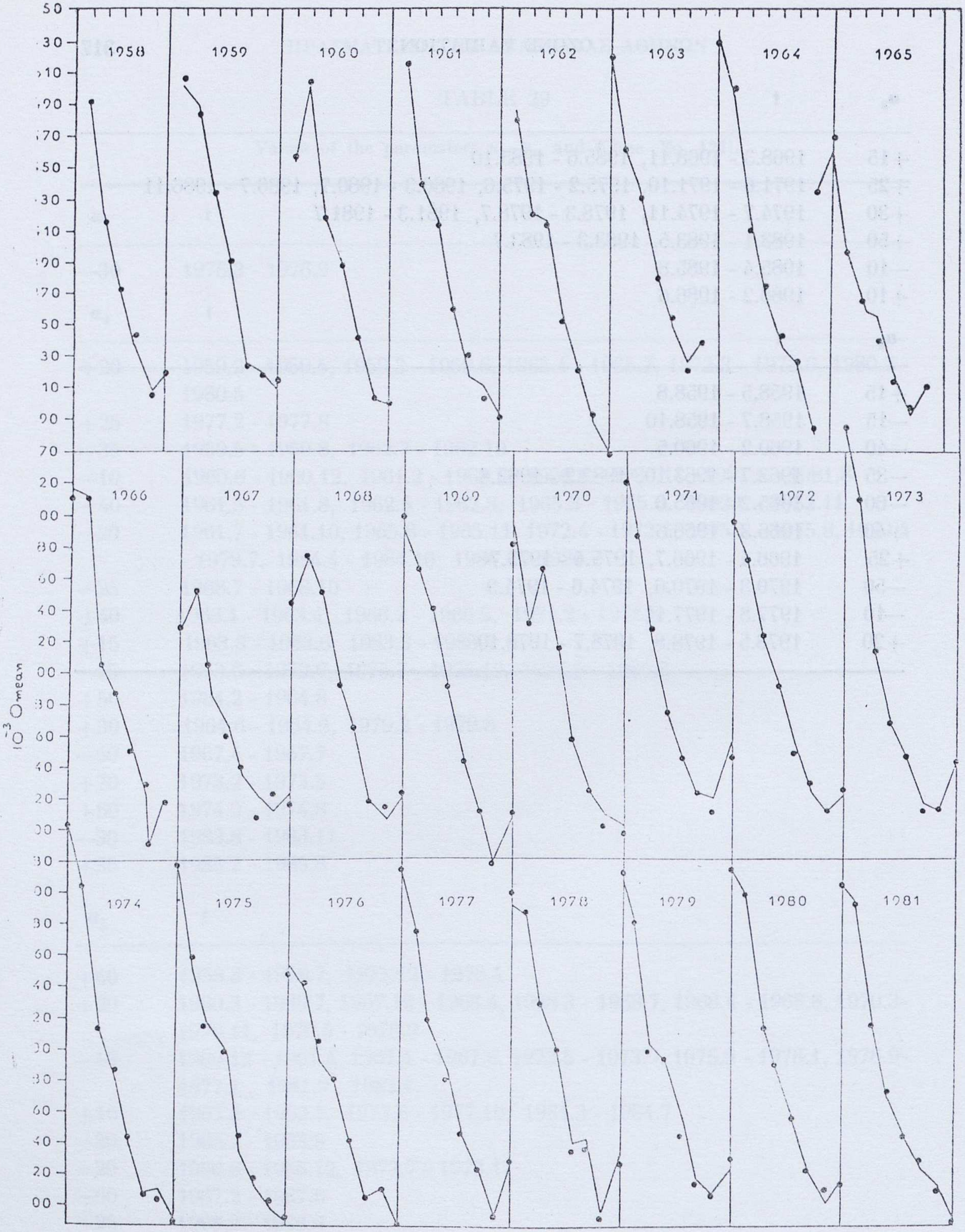

Fig. 113. Resolute Station, 1958 - 1981. Observed MVTOZ is shown by dots. MVTOZ as computed by Equation (122) is shown by a solid line. Accuracy is equal to 99.9%. Note the extremely close agreement between the two.

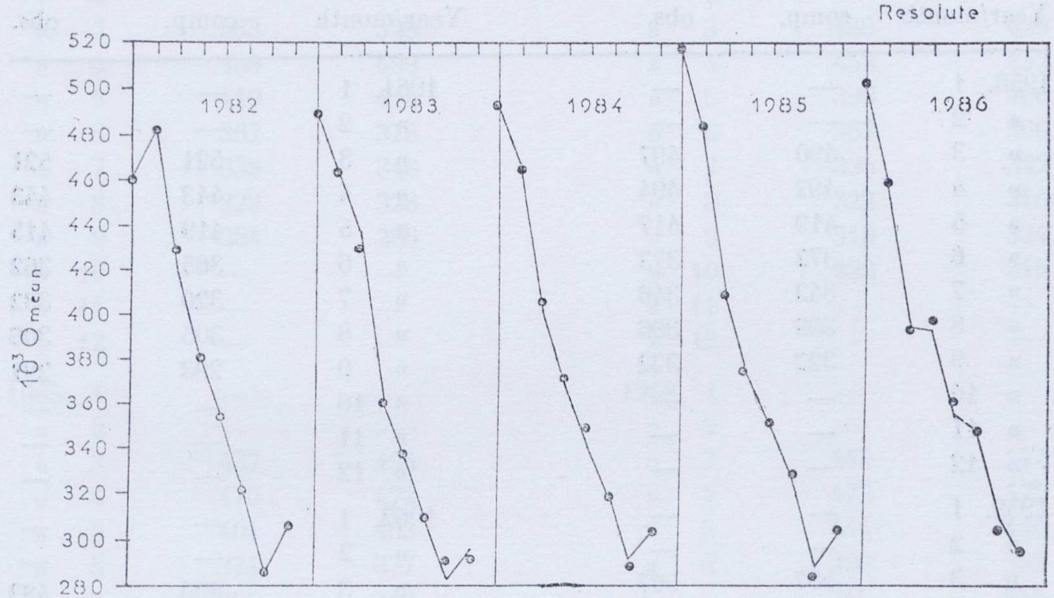

Fig. 114. Resolute Station, 1982-1986. Caption as for Figure 113, to which this Figure is complementary.

TABLE 29A

Resolute Station, 1958 - 1986. Observed and computed MVTOZ.

Year/month	comp.	obs.	Year/month	comp.	obs.
1958. 1	—	—	1961. 1	—	—
» 2	—	—	» 2	—	—
» 3	490	497	» 3	521	521
» 4	492	494	» 4	443	443
» 5	419	417	» 5	419	415
» 6	373	373	» 6	365	362
» 7	342	346	» 7	320	332
» 8	309	306	» 8	305	306
» 9	323	322	» 9	293	291
» 10	—	—	» 10	—	—
» 11	—	—	» 11	—	—
» 12	—	—	» 12	—	—
1959. 1	—	—	1962. 1	—	—
» 2	—	—	» 2	—	—
» 3	507	507	» 3	490	483
» 4	486	491	» 4	422	422
» 5	436	433	» 5	419	417
» 6	370	371	» 6	355	353
» 7	325	325	» 7	320	321
» 8	322	319	» 8	292	294
» 9	310	317	» 9	280	279
» 10	—	—	» 10	—	—
» 11	—	—	» 11	—	—
» 12	—	—	» 12	—	—
1960. 1	—	—	1963. 1	—	—
» 2	—	—	» 2	—	—
» 3	455	457	» 3	525	521
» 4	507	507	» 4	465	463
» 5	419	421	» 5	432	434
» 6	380	377	» 6	380	380
» 7	346	343	» 7	355	351
» 8	304	304	» 8	322	328
» 9	301	302	» 9	340	340
» 10	—	—	» 10	—	—
» 11	—	—	» 11	—	—
» 12	—	—	» 12	—	—

Year/month	comp.	obs.	Year/month	comp.	obs.
1964. 1	—	—	1967. 1	—	—
» 2	—	—	» 2	—	—
» 3	533	528	» 3	430	429
» 4	495	499	» 4	452	452
» 5	419	413	» 5	396	406
» 6	367	376	» 6	367	360
» 7	338	346	» 7	335	342
» 8	322	328	» 8	322	310
» 9	284	286	» 9	310	324
» 10	—	—	» 10	322	315
» 11	—	—	» 11	—	—
» 12	—	—	» 12	—	—
1965. 1	—	—	1968. 1	—	—
» 2	—	—	» 2	—	—
» 3	437	434	» 3	445	447
» 4	470	472	» 4	472	475
» 5	401	403	» 5	444	445
» 6	374	377	» 6	390	392
» 7	355	343	» 7	355	355
» 8	322	315	» 8	322	319
» 9	293	298	» 9	310	316
» 10	305	302	» 10	322	323
» 11	—	—	» 11	—	—
» 12	—	—	» 12	—	—
1966. 1	—	—	1969. 1	—	—
» 2	—	—	» 2	—	—
» 3	525	522	» 3	490	499
» 4	522	521	» 4	467	467
» 5	406	405	» 5	439	441
» 6	388	389	» 6	395	392
» 7	355	352	» 7	345	344
» 8	322	330	» 8	315	311
» 9	290	290	» 9	278	278
» 10	322	318	» 10	307	310
» 11	—	—	» 11	—	—
» 12	—	—	» 12	—	—

Year/month	comp.	obs.	Year/month	comp.	obs.
1970. 1	—	—	1973. 1	—	—
» 2	—	—	» 2	—	—
» 3	490	482	» 3	551	556
» 4	529	530	» 4	513	510
» 5	462	467	» 5	419	415
» 6	410	416	» 6	370	369
» 7	355	358	» 7	342	346
» 8	322	325	» 8	315	311
» 9	310	301	» 9	310	314
» 10	302	296	» 10	342	341
» 11	—	—	» 11	—	—
» 12	—	—	» 12	—	—
1971. 1	—	—	1974. 1	—	—
» 2	—	—	» 2	—	—
» 3	525	520	» 3	542	544
» 4	487	488	» 4	504	507
» 5	419	429	» 5	419	416
» 6	375	375	» 6	358	369
» 7	345	345	» 7	346	345
» 8	322	323	» 8	309	308
» 9	320	312	» 9	310	304
» 10	357	346	» 10	292	286
» 11	—	—	» 11	—	—
» 12	—	—	» 12	—	—
1972. 1	—	—	1975. 1	—	—
» 2	—	—	» 2	—	—
» 3	490	495	» 3	515	517
» 4	469	472	» 4	452	458
» 5	419	423	» 5	416	416
» 6	393	392	» 6	371	369
» 7	355	348	» 7	338	345
» 8	322	329	» 8	305	308
» 9	310	310	» 9	297	304
» 10	322	324	» 10	287	286
» 11	—	—	» 11	—	—
» 12	—	—	» 12	—	—

Year/month	comp.	obs.	Year/month	comp.	obs
1976. 1	—	—	1979. 1	—	—
» 2	—	—	» 2	—	—
» 3	450	447	» 3	516	514
» 4	437	443	» 4	478	480
» 5	393	404	» 5	402	398
» 6	380	381	» 6	393	393
» 7	329	331	» 7	355	345
» 8	307	306	» 8	322	325
» 9	310	312	» 9	310	306
» 10	282	282	» 10	322	328
» 11	—	—	» 11	—	—
» 12	—	—	» 12	—	—
1977. 1	—	—	1980. 1	—	—
» 2	—	—	» 2	—	—
» 3	512	515	» 3	507	510
» 4	474	473	» 4	494	495
» 5	419	419	» 5	419	414
» 6	388	381	» 6	385	386
» 7	343	341	» 7	355	356
» 8	322	323	» 8	322	322
» 9	291	291	» 9	301	303
» 10	331	332	» 10	313	310
» 11	—	—	» 11	—	—
» 12	—	—	» 12	—	—
1978. 1	—	—	1981. 1	—	—
» 2	—	—	» 2	—	—
» 3	490	493	» 3	490	493
» 4	482	485	» 4	482	481
» 5	419	419	» 5	419	413
» 6	397	396	» 6	371	372
» 7	338	335	» 7	346	344
» 8	339	335	» 8	322	328
» 9	293	291	» 9	310	306
» 10	322	314	» 10	282	280
» 11	—	—	» 11	—	—
» 12	—	—	» 12	—	—

Year/month	comp.	obs.	Year/month	comp.	obs.
1982. 1	—	—	1985. 1	—	—
» 2	—	—	» 2	—	—
» 3	460	460	» 3	520	519
» 4	482	483	» 4	482	484
» 5	419	428	» 5	409	408
» 6	380	380	» 6	380	375
» 7	355	353	» 7	350	351
» 8	322	322	» 8	322	328
» 9	285	286	» 9	285	281
» 10	307	306	» 10	302	304
» 11	—	—	» 11	—	—
» 12	—	—	» 12	—	—
1983. 1	—	—	1986. 1	—	—
» 2	—	—	» 2	—	—
» 3	490	488	» 3	500	502
» 4	465	463	» 4	452	459
» 5	432	428	» 5	392	391
» 6	360	360	» 6	393	396
» 7	342	338	» 7	355	360
» 8	309	309	» 8	347	346
» 9	284	289	» 9	310	304
» 10	296	291	» 10	297	296
» 11	—	—	» 11	—	—
» 12	—	—	» 12	—	—
1984. 1	—	—			
» 2	—	—			
» 3	490	493			
» 4	465	466			
» 5	402	406			
» 6	370	371			
» 7	342	349			
» 8	322	319			
» 9	293	288			
» 10	305	304			
» 11	—	—			
» 12	—	—			

5. THE SOUTHERN HEMISPHERE

In addition to the 29 Northern Hemisphere Dobson Stations, we have also taken into consideration the four Stations which at present exist in the Southern Hemisphere. It is unfortunate that these are not located very close to the Antarctic Region. The satellite data were unsuitable for our investigation of the Southern Hemisphere, since they do not cover enough period of observation.

In the following we shall now study in detail the behaviour of total ozone in this very vulnerable zone, from latitude 12^0 S through 54^0 S.

5.1 Station: HUANCAYO

$\varphi = 12^0\ 03'$ S, L $= 75^0\ 19'$ W, Time Period: 1964-1986.

The analysis of the monthly values of total ozone for the Huancayo Station shows that the MMVTOZ, can be represented by Equation (123),

$$10^{-3} \cdot 0_m^{com} = 258 - 5 \sin\frac{2\pi}{8} t \qquad (123)$$

where t = 0 corresponds in April and t = 8 corresponds in December.

Subtracting the values computed by (123) from the observed values of total ozone we get:

$$D = 10^{-3} \cdot 0^{obs} - 10^{-3} \cdot 0_m^{com} \qquad (124)$$

Power spectrum analysis of the differences given by Equation (124) revealed three significant periodic terms of 12, 6 and 3 months. Note that the 12-month and 6-month periods are above the confidence level of 99% and 95% respectively. See Figure 115.

Unfortunately the spetral analysis cannot give the position and amplitude of the periodic terms. This can be achieved only by the graphic method of successive approximations, which in this case reveals short-term periodic terms with periods of 12, 6, 4 and 3 months. See Figure 116b (lower part of Firure 116).

Here the dots represent the differences computed by Equation (124) while the dashed and solid sinusoidal or semisinusoidal curves represent periodic or quasiperiodic terms, which appear as a network of periodicities with occasional overlaps. These terms can be expressed analytically as:

$$P = \alpha_1 \sin\frac{2\pi}{12} t + \alpha_2 \sin\frac{2\pi}{6} t + \alpha_3 \sin\frac{2\pi}{4} t + \alpha_4 \sin\frac{2\pi}{3} t \qquad (125)$$

The values of the parameters of Equation (125) are listed in Table 30.

By summing Equations (123) and (125), we can express the variation of observed monthly values of total ozone, with respect to the periodic terms of Equation (125) as:

$$10^{-3} \cdot 0^{com} = 258 - 5\sin\frac{2\pi}{8}t + P \tag{126}$$

This Equation represents the observational data with a very high accuracy (99.5%). The s.d. between observed-computed values of MVTOZ is $\sigma = \pm 1.65$, with 146 degrees of freedom for Equation (126). This is confirmed in the upper section of Figure 116, where the dots (or small open circles) represent observed MVTOZ, while the solid line represents MVTOZ computed by Equation (126).

Table 30A lists the values used for plotting Figure 116.

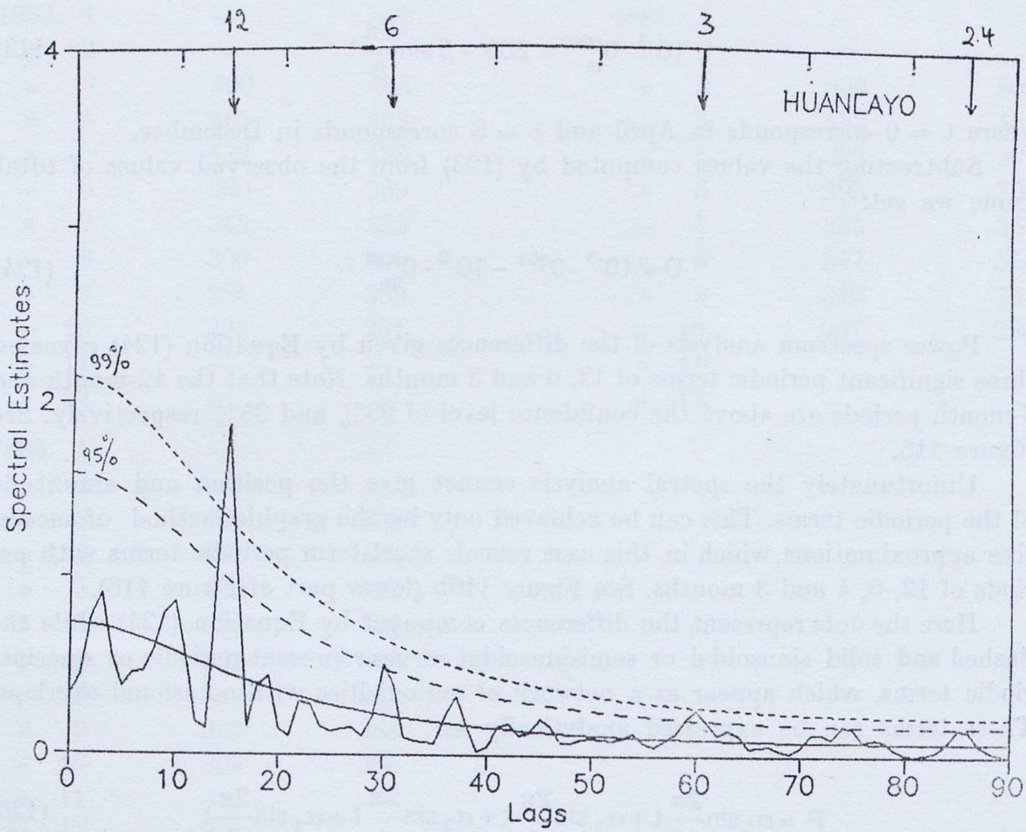

Fig. 115. Huancayo Station, 1964 - 1986. Spectral estimate of the differences computed by Equation (124). Analysis shows periodic terms of 12, 6, and 3 moths. Note that the 12 and 6-month periods are above the confidence level of 99% respectively.

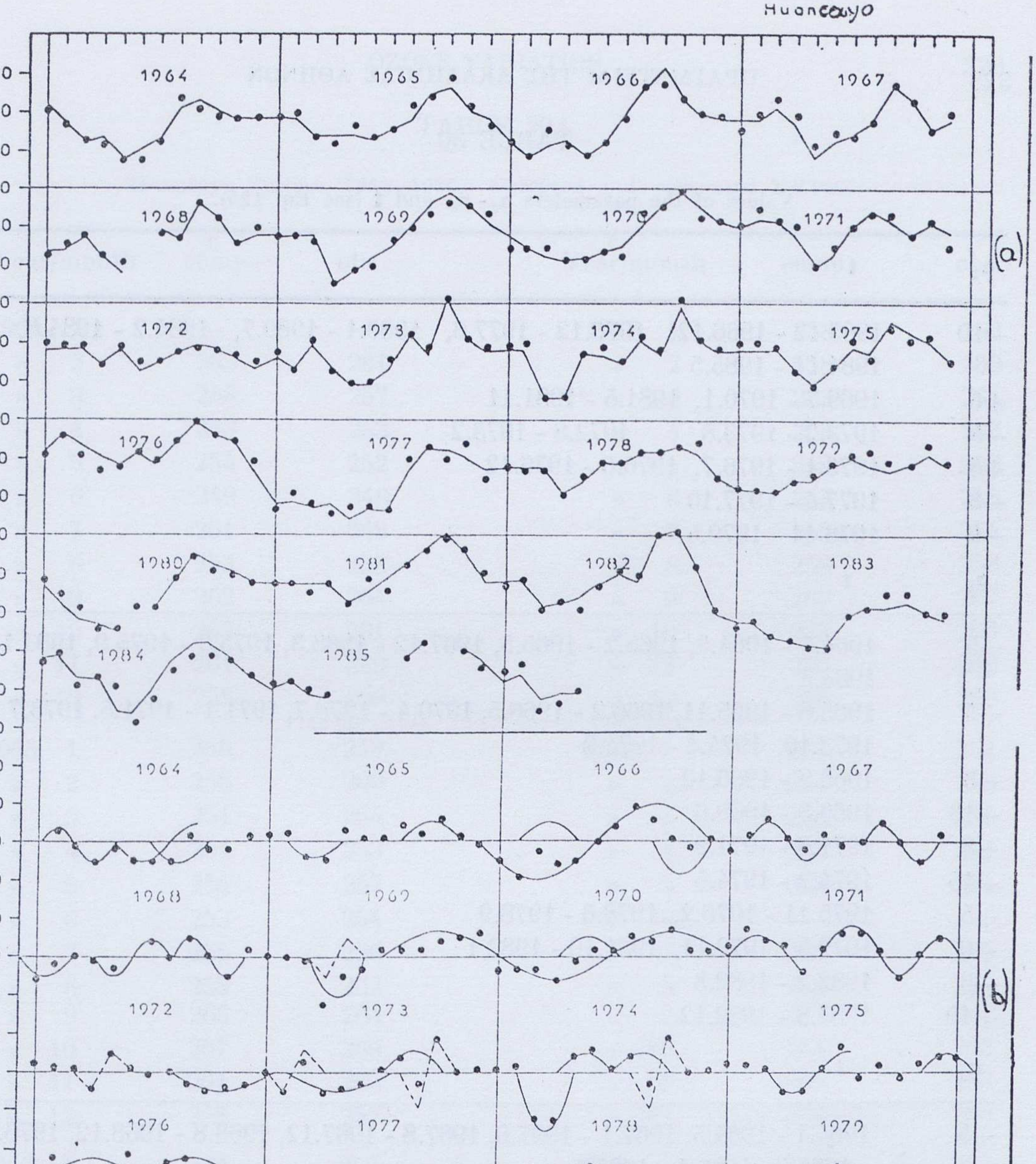

Fig. 116. Huancayo Station, 1964 - 1986. *Lower part of the Figure*: The differences (D) computed by Equation (124) are shown by dots. The dashed and solid sinusoidal or semisinusoidal curves show periodic terms of 12, 6, 4 and 3 months, whose position and amplitude is also plotted by the successive approximation method. *Upper part*: The variation of the observed-computed MVTOZ. Accuracy is equal to 95.5%.

TABLE 30

Values of the parameters $\alpha_1 - \alpha_4$, and **t** (see Eq. 125).

α_1	t
—10	1965.12 - 1966.12, 1976.12 - 1977.6, 1980.1 - 1980.7, 1984.2 - 1984.8, 1984.11 - 1985.5
+6	1969.7 - 1970.1, 1981.5 - 1981.11
—5	1973.2 - 1973.8 1972.8 - 1973.2
+8	1976.1 - 1976.7, 1976.6 - 1976.12
—8	1977.4 - 1977.10
—6	1978.11 - 1979.5
α_2	t
—5	1964.5 - 1964.9, 1965.2 - 1965.5, 1967.12 - 1968.3, 1975.3 - 1975.9, 1983.1-1983.5
+5	1965.8 - 1965.11, 1966.2 - 1966.5, 1970.4 - 1970.7, 1971.1 - 1971.5, 1973.7 - 1973.10, 1974.4 - 1974.7
—8	1966.9 - 1966.12
—10	1969.3 - 1969.6
+8	1971.6 - 1971.9
—15	1974.2 - 1974.5
+5	1975.11 - 1976.2, 1978.6 - 1978.9
+6	1979.5 - 1979.11, 1981.10 - 1982.1
—6	1982.2 - 1982.8
+10	1982.8 - 1982.12
α_3	t
+5	1964.1 - 1964.5, 1967.1 - 1967.6, 1967.8 - 1967.12, 1968.8 - 1968.12, 1976.1 - 1976.7, 1985.1 - 1985.5
—5	1968.4 - 1968.8, 1971.9 - 1972.1, 1968.3 - 1968.7
—6	1978.3 - 1978.7
α_4	t
—5	1964.7 - 1964.10, 1969.3 - 1969.6, 1972.3 - 1972.6, 1973.1 - 1973.4, 1975.7-1975.10, 1980.5 - 1980.9
—8	1973.8 - 1973.11
—10	1974.8 - 1974.11

TABLE 30A

Huancayo Station, 1964 - 1986. Observed and computed MVTOZ.

Year/month	comp.	obs	Year/month	comp.	obs.
1964. 1	—	—	1967. 1	258	256
» 2	263	261	» 2	258	260
» 3	258	257	» 3	263	264
» 4	253	253	» 4	258	259
» 5	254	252	» 5	249	252
» 6	249	248	» 6	253	255
» 7	251	248	» 7	255	254
» 8	253	253	» 8	258	258
» 9	262	264	» 9	267	267
» 10	263	261	» 10	263	263
» 11	261	259	» 11	256	256
» 12	258	259	» 12	258	260
1965. 1	258	259	1968. 1	254	252
» 2	258	260	» 2	254	256
» 3	254	254	» 3	258	258
» 4	254	253	» 4	253	259
» 5	254	257	» 5	249	251
» 6	253	254	» 6	—	—
» 7	255	256	» 7	260	259
» 8	258	262	» 8	258	258
» 9	266	264	» 9	267	267
» 10	267	269	» 10	263	263
» 11	261	262	» 11	255	256
» 12	258	257	» 12	258	260
1966. 1	253	253	1969. 1	258	258
» 2	249	249	» 2	258	258
» 3	252	256	» 3	258	257
» 4	253	252	» 4	245	246
» 5	249	249	» 5	249	249
» 6	253	253	» 6	253	250
» 7	260	259	» 7	255	257
» 8	267	267	» 8	261	260
» 9	272	268	» 9	267	264
» 10	265	264	» 10	269	267
» 11	259	260	» 11	266	266
» 12	258	259	» 12	261	264

Year/month	comp.	obs.	Year/month	comp.	obs.
1970. 1	258	255	1973. 1	256	258
» 2	255	255	» 2	254	253
» 3	253	255	» 3	260	261
» 4	252	252	» 4	254	253
» 5	253	252	» 5	249	250
» 6	254	254	» 6	249	250
» 7	255	253	» 7	253	256
» 8	261	264	» 8	262	262
» 9	267	266	» 9	257	259
» 10	269	270	» 10	272	272
» 11	266	263	» 11	261	261
» 12	261	262	» 12	258	259
1971. 1	258	261	1974. 1	258	259
» 2	262	265	» 2	258	260
» 3	262	262	» 3	246	246
» 4	258	261	» 4	246	246
» 5	250	250	» 5	258	258
» 6	253	255	» 6	257	259
» 7	262	261	» 7	255	256
» 8	265	264	» 8	262	262
» 9	261	264	» 9	257	259
» 10	258	258	» 10	272	272
» 11	261	262	» 11	261	261
» 12	263	263	» 12	258	259
1972. 1	258	260	1975. 1	258	260
» 2	258	259	» 2	258	260
» 3	258	259	» 3	258	259
» 4	254	254	» 4	254	253
» 5	258	259	» 5	250	249
» 6	253	255	» 6	253	254
» 7	255	255	» 7	259	261
» 8	258	258	» 8	258	256
» 9	260	259	» 9	266	264
» 10	259	258	» 10	263	261
» 11	256	257	» 11	261	263
» 12	254	255	» 12	262	262

Year/month	comp.	obs.	Year/month	comp.	obs.
1976. 1	262	261	1979. 1	253	253
» 2	267	266	» 2	252	252
» 3	264	262	» 3	253	252
» 4	261	257	» 4	255	254
» 5	259	258	» 5	254	256
» 6	262	262	» 6	258	258
» 7	259	260	» 7	260	261
» 8	264	265	» 8	258	262
» 9	270	270	» 9	257	259
» 10	267	267	» 10	258	258
» 11	265	265	» 11	261	263
» 12	258	259	» 12	258	259
1977. 1	249	247	1980. 1	258	259
» 2	249	251	» 2	253	255
» 3	248	249	» 3	249	252
» 4	249	246	» 4	248	246
» 5	245	248	» 5	245	246
» 6	247	248	» 6	249	252
» 7	247	247	» 7	251	252
» 8	252	255	» 8	258	259
» 9	258	258	» 9	266	265
» 10	269	260	» 10	263	261
» 11	261	264	» 11	261	260
» 12	258	255	» 12	257	258
1978. 1	258	258	1981. 1	258	258
» 2	258	257	» 2	258	258
» 3	258	257	» 3	258	256
» 4	252	251	» 4	258	258
» 5	254	256	» 5	254	253
» 6	259	259	» 6	256	259
» 7	259	259	» 7	260	256
» 8	262	262	» 8	264	263
» 9	262	262	» 9	267	266
» 10	263	263	» 10	271	269
» 11	261	264	» 11	266	267
» 12	255	255	» 12	258	261

Year/month	comp.	obs.	Year/month	comp.	obs.
1982. 1	258	257	1985. 1	249	252
» 2	258	259	» 2	253	252
» 3	253	251	» 3	249	250
» 4	253	253	» 4	248	249
» 5	254	251	» 5	—	—
» 6	258	257	» 6	—	—
» 7	260	261	» 7	—	—
» 8	258	260	» 8	258	258
» 9	271	271	» 9	262	262
» 10	272	272	» 10	—	—
» 11	261	262	» 11	261	260
» 12	249	259	» 12	258	256
1983. 1	258	256	1986. 1	253	255
» 2	258	258	» 2	249	252
» 3	254	254	» 3	248	244
» 4	254	253	» 4	249	246
» 5	254	251	» 5	249	250
» 6	253	251	» 6	—	—
» 7	259	259	» 7	—	—
» 8	262	261	» 8	—	—
» 9	262	265	» 9	—	—
» 10	263	265	» 10	—	—
» 11	261	260	» 11	—	—
» 12	258	260	« 12	—	—
1984. 1	258	259			
» 2	258	259			
» 3	253	250			
» 4	249	252			
» 5	244	249			
» 6	244	242			
» 7	250	248			
» 8	258	255			
» 9	262	259			
» 10	263	259			
» 11	261	258			
» 12	253	254			

5.2 Station: ASPENDALE

$\varphi = 38^0\ 02'$ S, L $= 145^0\ 06'$ E, Time Period: 1958-1986.

The mean monthly values of total ozone for the period from 1958 through 1986 can be represented with the help of the relation:

$$10^{-3} \cdot 0_m^{com} = 322 - 40\sin\left(\frac{2\pi}{12}t - 30^\circ\right) \tag{127}$$

Power spectrum analysis of the differences (D), where

$$D = 10^{-3} \cdot 0^{obs} - 10^{-3} \cdot 0_m^{com} \tag{128}$$

reveals short-term periodicities of 24, 12, 6, 4 and 3 months, at a confidence level higher than 99%. See Figure 117.

Unfortunately spectrum analysis is unable to define the position and amplitude of the periodic terms. This is only possible by using the method of successive aproximations. See Figures 118 and 119 where the dots represent the differences (D) derived from Equation (128), while the dashed and solid sinusoidal and semi-sinusoidal curves represent periodic or quasi-periodic terms of 24, 12, 6, 4 and 3 months and appear as a network with occasional overlaps. These terms can be expressed as:

$$P = \alpha_1 \sin\frac{2\pi}{12}t + \alpha_2 \sin\frac{2\pi}{6}t + \alpha_3 \sin\frac{2\pi}{4}t + \alpha_4 \sin\frac{2\pi}{3}t \tag{129}$$

The values of the parameters of Equation (129) are listed in Table 31.

Thus the observed MVTOZ for Aspendale Station can be represented by Equation (130) as follows:

$$10^{-3} \cdot 0^{com} = 322 - 40\sin\left(\frac{2\pi}{12}t - 30^\circ\right) + P \tag{130}$$

where P is derived from Equation (129).

Equation (130) represents the currently available observational data with an accuracy of 99.2%. The s.d. between observed-computed MVTOZ is $\sigma = \pm 2.66$, with 92 degrees of freedom for Equation (130).

The above results are graphically shown in Figure 120, where the dots represent observed MVTOZ for the period 1958-1987, while the solid line represents the same MVTOZ computed by Equation (130). Note that Figure 120 shows no differences higher than 3 D.U.

Table 31A lists the numerical results plotted in Figure 120.

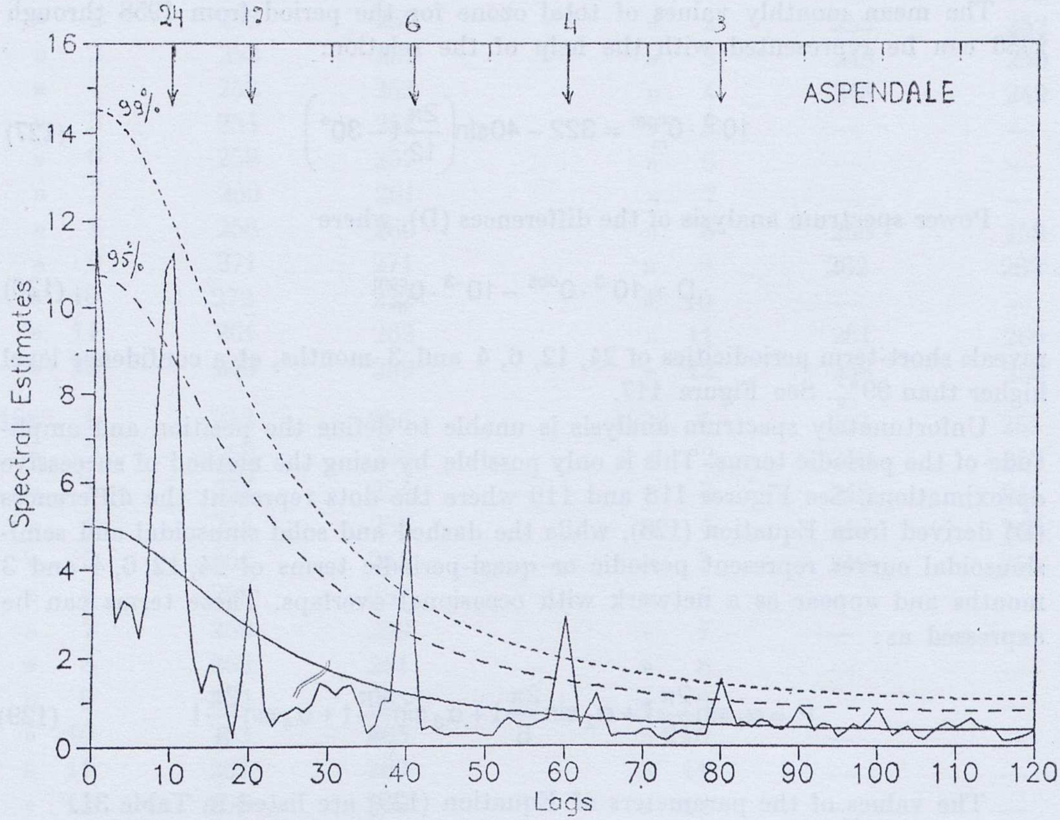

Fig. 117. Aspendale Station, 1958 - 1986. Spectral estimate of the differences computed by Equation (128). Analysis shows periodic terms of 24, 12, 6, 4 and 3 months significant at a confidence level around 99%-95%.

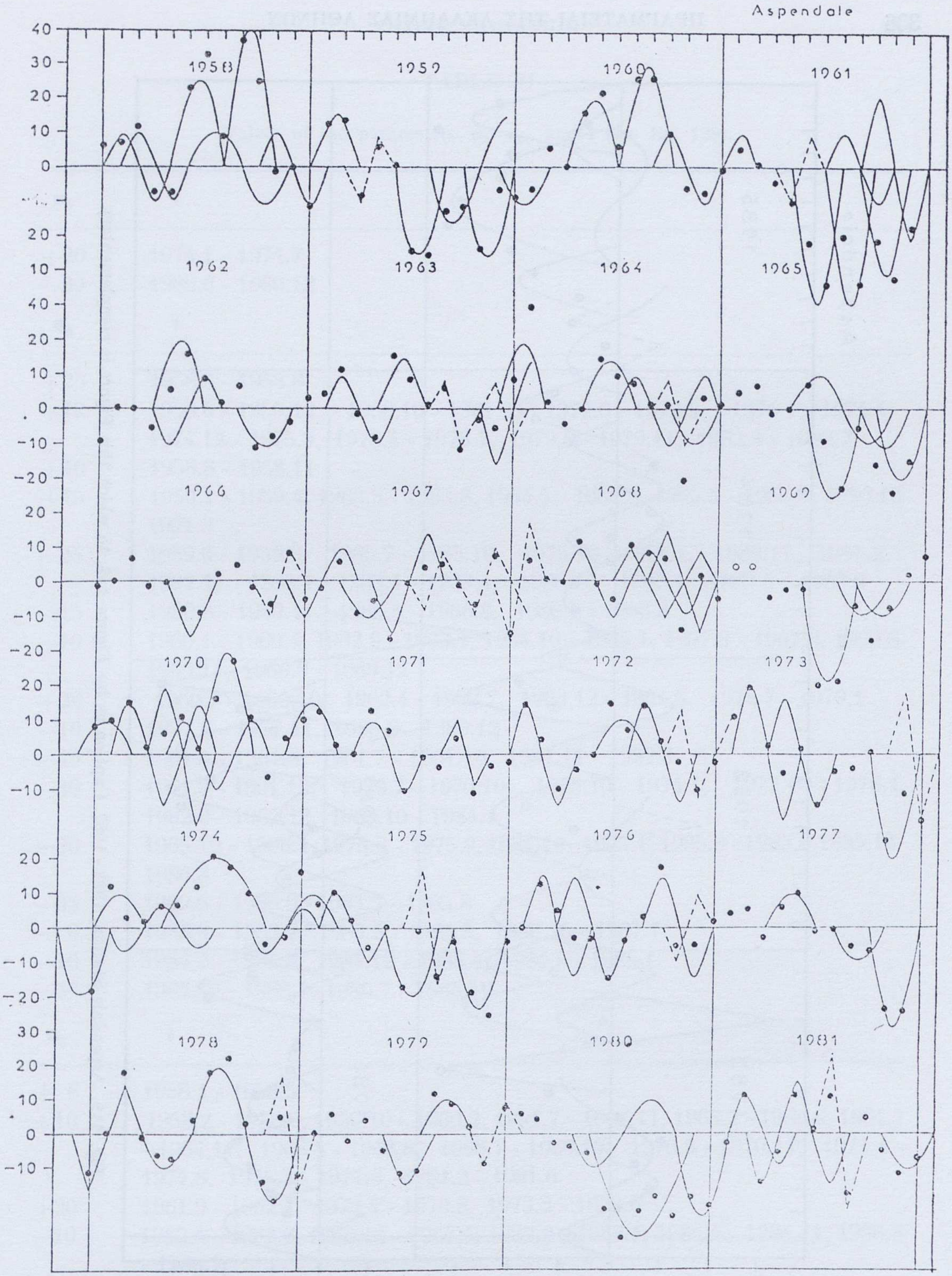

Fig. 118. Aspendale Station, 1958 - 1981. The differences (D) computed by Equation (128) are shown by dots. The dashed and solid sinusoidal or semisinusoidal curves show periodic terms of 24, 12, 6,4. and 3 months, whose position and amplitude is also plotted, by the successive approximation method.

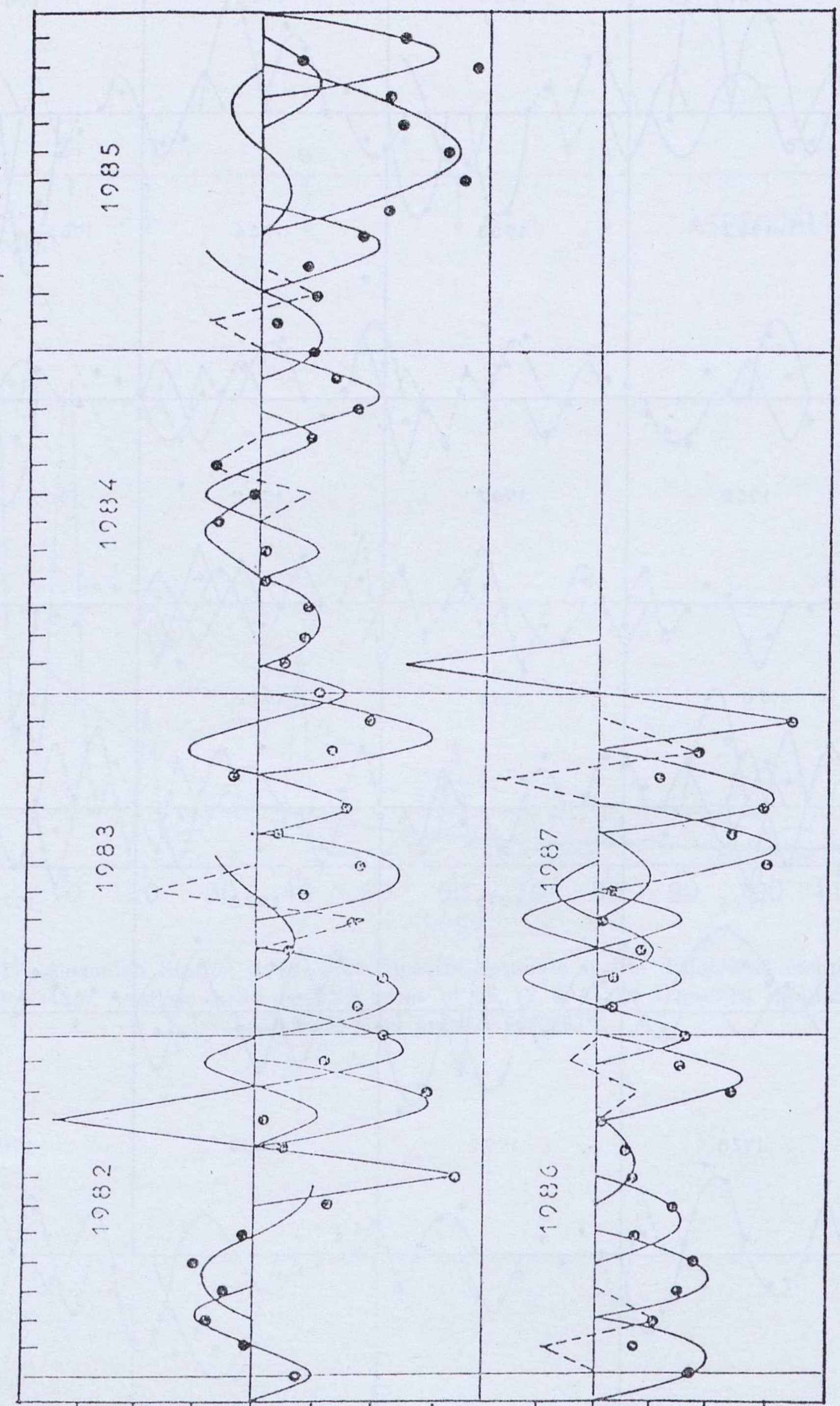

Fig. 119. Aspendale Station, 1982 - 1987. Caption as for Figure 118, to which this Figure is complementary.

TABLE 31

Values of the parameters α_1 - α_4, and **t** (see Eq. 129).

α_1	t
+20	1974.1 - 1974.7
—30	1980.6 - 1980.12
α_2	t
+25	1958.5 - 1958.8
+10	1958.6 - 1958.12, 1960.10 - 1961.2, 1972.6 - 1972.9, 1974.1 - 1974.4, 1974.12 - 1975.3, 1978.4 - 1978.7, 1979.8 - 1979.11, 1982.3 - 1982.7
+40	1958.8 - 1958.11
+15	1959.1 - 1959.4, 1963.5 - 1963.8, 1964.5 - 1964.8, 1965.5 - 1965.8, 1970.12-1971.3
—25	1959.6 - 1959.9, 1965.7 - 1965.10, 1975.10 - 1976.1, 1980.11 - 1981.2, 1982.11 - 1983.1, 1983.1 - 1983.4, 1986.10 - 1987.1, 1983.5 - 1983.8
—15	1959.8 - 1959.11, 1966.5 - 1966.8, 1986.5 - 1986.8
—10	1960.1 - 1960.4, 1962.9 - 1963.1, 1964.10 - 1965.1, 1967.3 - 1967.6, 1969.8-1969.11, 1969.9 - 1969.12
+20	1960.7 - 1960.10, 1962.4 - 1962.7, 1963.12 - 1964.6, 1978.7 - 1979.1
—10	1977.8 - 1977.11, 1980.6 - 1980.12
—40	1961.5 - 1961.8, 1961.7 - 1961.10, 1981.11 - 1982.3
—30	1961.9 - 1961.12, 1970.7 - 1970.10, 1973.10 - 1974.1, 1977.10 - 1978.1, 1982.9 - 1982.12, 1983.10 - 1984.1
—20	1965.10 - 1966.1, 1975.6 - 1975.9, 1984.10 - 1985.1, 1985.3 - 1985.6,1985.12-1986.3
—35	1969.6 - 1969.9, 1985.5 - 1985.8
— 6	1983.3 - 1983.7, 1985.5 - 1985.8, 1986.10 - 1987.1
—10	1984.2 - 1984.8, 1984.12 - 1985.4, 1984.9 - 1985.1
—30	1985.10 - 1986.1, 1985.7 - 1985.10
α_3	t
+ 6	1958.1 - 1958.5
+10	1958.2 - 1958.6, 1959.10 - 1960.2, 1961.7 - 1961.11, 1963.2 - 1963.6, 1964.7 - 1964.11, 1968.4 - 1968.8, 1968.7 - 1968.10, 1970.5 - 1970.11, 1971.4 - 1971.8, 1975.2 - 1975.6, 1981.2 - 1981.6
+20	1961.9 - 1962.1, 1970.4 - 1970.8, 1973.2 - 1973.6
—10	1962.4 - 1962.8, 1966.12 - 1967.4, 1982.9 - 1983.1, 1984.5 - 1984.11, 1986.3 - 1986.7

α_3	t
—15	1963.11 - 1964.3, 1967.5 - 1967.9, 1977.12 - 1978.4, 1981.3 - 1981.9, 1983.8 - 1983.12, 1985.12 - 1986.6
+15	1968.9 - 1969.1, 1970.2 - 1970.8, 1972.1 - 1972.5, 1972.8 - 1972.12, 1976.2 - 1976.6, 1976.4 - 1976.8, 1976.9 - 1977.1
— 6	1974.2 - 1974.8, 1974.10 - 1975.2
—35	1982.7 - 1982.11, 1985.11 - 1986.3

α_4	t
+10	1958.10 - 1959.2, 1963.8 - 1964.2, 1971.9 - 1971.12, 1985.1 - 1985.4, 1986.1 - 1986.4
—10	1961.4 - 1961.7, 1966.10 - 1967.1, 1967.7 - 1968.1, 1976.10 - 1977.1, 1977.4 - 1977.7, 1979.11 - 1980.2, 1984.7 - 1984.10
+20	1965.8 - 1965.11, 1973.11 - 1974.2 1978.11 - 1979.2, 1985.9 - 1985.12
—20	1967.12 - 1968.3
+15	1972.10 - 1973.1
—15	1979.6 - 1979.9, 1983.4 - 1983.7
— 6	1980.10 - 1981.1, 1986.10 - 1987.1
+25	1981.7 - 1981.10

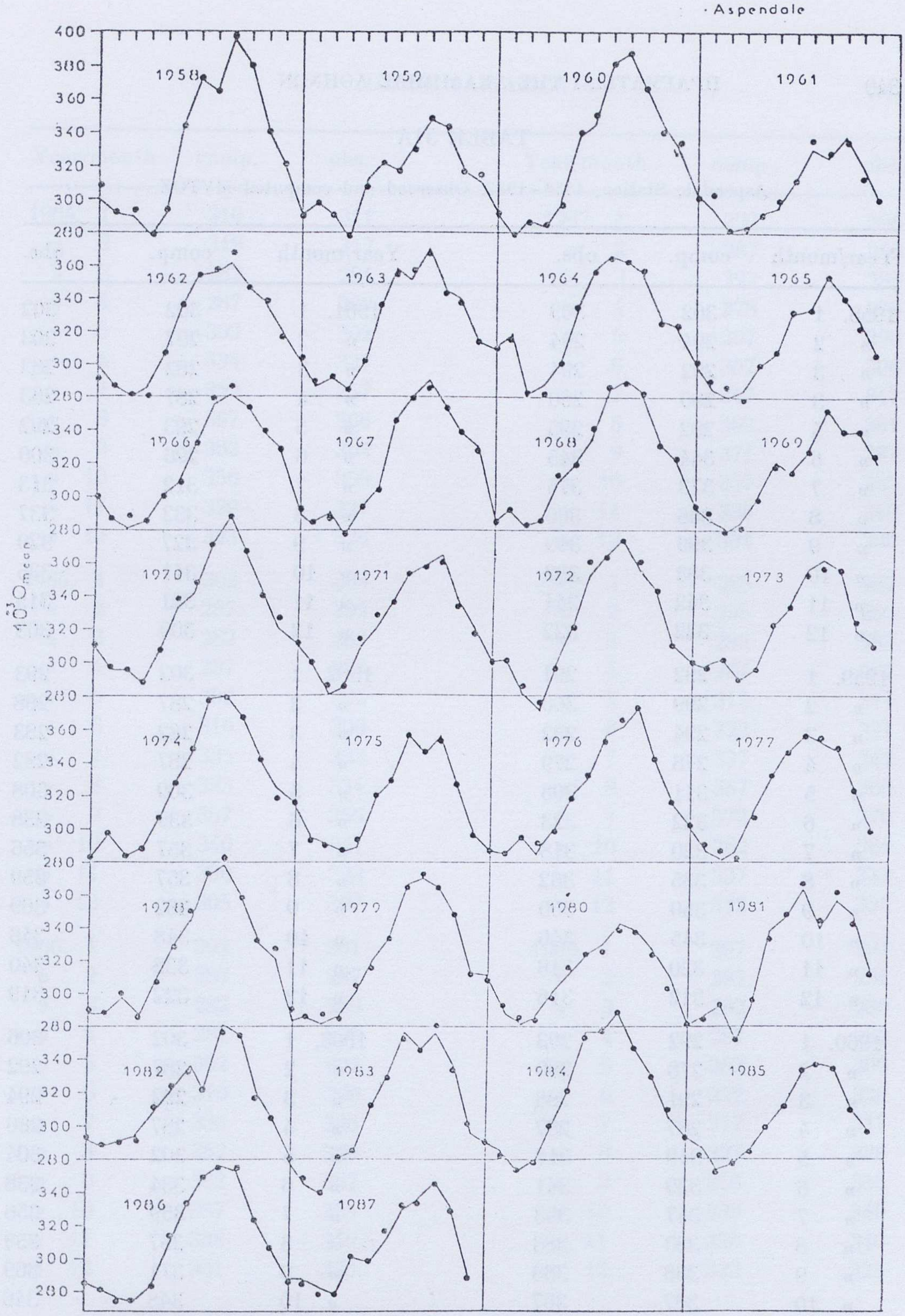

Fig. 120. Aspendale Station, 1958 - 1987. Observed MVTOZ is shown by dots. MVTOZ as computed by Equation (130) is shown by a solid line. Accuracy is equal to 99.2%. Note the close agreement between the two.

TABLE 31A

Aspendale Station, 1958 - 1987. Observed and computed MVTOZ.

Year/month	comp.	obs.	Year/month	comp.	obs.
1958. 1	302	309	1961. 1	302	302
» 2	294	294	» 2	297	303
» 3	292	294	» 3	282	283
» 3	280	280	» 4	287	283
» 5	292	295	» 5	293	292
» 6	344	345	» 6	296	300
» 7	373	375	» 7	312	313
» 8	366	366	» 8	332	337
» 9	399	399	» 9	327	329
» 10	383	382	» 10	341	335
» 11	342	341	» 11	321	315
» 12	322	322	» 12	300	303
1959. 1	292	291	1962. 1	302	293
» 2	299	300	» 2	287	288
» 3	294	292	» 3	282	283
» 4	278	279	» 4	287	282
» 5	311	308	» 5	309	308
» 6	322	323	» 6	339	338
» 7	320	318	» 7	357	356
» 8	335	332	» 8	357	359
» 9	350	350	» 9	362	369
» 10	345	346	» 10	348	346
» 11	320	318	» 11	338	340
» 12	312	316	» 12	322	319
1960. 1	292	293	1963. 1	302	306
» 2	278	280	» 2	287	292
» 3	291	288	» 3	292	294
» 4	287	287	» 4	287	286
» 5	319	318	» 5	302	304
» 6	339	341	» 6	334	338
» 7	347	353	» 7	359	356
» 8	383	383	» 8	357	359
» 9	388	388	» 9	371	369
» 10	367	367	» 10	348	346
» 11	347	341	» 11	342	340
» 12	312	315	» 12	316	317

Year/month		comp.	obs.	Year/month		comp.	obs.
1964.	1	310	311	1967.	1	292	296
»	2	319	317	»	2	287	286
»	3	282	284	»	3	292	288
»	4	287	289	»	4	278	278
»	5	302	302	»	5	297	296
»	6	334	337	»	6	307	306
»	7	359	357	»	7	347	347
»	8	367	366	»	8	363	361
»	9	362	364	»	9	371	367
»	10	356	359	»	10	357	355
»	11	329	327	»	11	338	340
»	12	323	326	»	12	331	330
1965.	1	302	304	1968.	1	285	287
»	2	287	292	»	2	295	293
»	3	282	289	»	3	282	283
»	4	287	286	»	4	287	287
»	5	302	302	»	5	312	314
»	6	310	309	»	6	322	321
»	7	335	333	»	7	337	342
»	8	335	334	»	8	367	368
»	9	357	356	»	9	372	370
»	10	340	341	»	10	362	364
»	11	330	323	»	11	337	333
»	12	305	307	»	12	322	324
1966.	1	302	301	1969.	1	297	297
»	2	287	287	»	2	287	291
»	3	282	289	»	3	282	280
»	4	287	286	»	4	287	282
»	5	302	302	»	5	302	300
»	6	310	309	»	6	322	320
»	7	335	333	»	7	317	317
»	8	357	360	»	8	327	328
»	9	362	367	»	9	353	355
»	10	357	355	»	10	339	340
»	11	338	340	»	11	338	340
»	12	331	330	»	12	322	325

Year/month	comp.	obs.	Year/month	comp.	obs.
1970. 1	311	310	1973. 1	302	300
» 2	296	297	» 2	299	297
» 3	297	297	» 3	302	301
» 4	287	289	» 4	287	289
» 5	307	308	» 5	297	296
» 6	332	333	» 6	322	323
» 7	342	341	» 7	332	332
» 8	373	373	» 8	357	351
» 9	388	389	» 9	362	358
» 10	367	368	» 10	357	357
» 11	347	341	» 11	321	325
» 12	322	327	» 12	313	310
1971. 1	314	312	1974. 1	286	283
» 2	299	300	» 2	296	298
» 3	282	285	» 3	285	285
» 4	287	287	» 4	287	289
» 5	312	315	» 5	308	308
» 6	322	329	» 6	332	329
» 7	337	337	» 7	358	359
» 8	357	356	» 8	377	378
» 9	362	359	» 9	379	380
» 10	366	362	» 10	367	367
» 11	338	336	» 11	341	342
» 12	322	319	» 12	322	319
1972. 1	302	300	1975. 1	317	318
» 2	302	301	» 2	296	294
» 3	282	286	» 3	292	292
» 4	272	277	» 4	287	289
» 5	302	297	» 5	292	296
» 6	322	322	» 6	322	322
» 7	356	362	» 7	330	330
» 8	366	364	» 8	357	357
» 9	377	376	» 9	345	348
» 10	357	361	» 10	357	354
» 11	344	345	» 11	325	328
» 12	310	312	» 12	300	298

Year/month	comp.	obs.	Year/month	comp.	obs.
1976. 1	284	288	1979. 1	285	290
» 2	287	287	» 2	287	287
» 3	297	295	» 3	282	288
» 4	287	292	» 4	287	285
» 5	302	299	» 5	302	306
» 6	322	319	» 6	322	317
» 7	332	333	» 7	335	335
» 8	357	353	» 8	369	366
» 9	362	365	» 9	371	374
» 10	372	374	» 10	366	366
» 11	338	342	» 11	347	349
» 12	316	317	» 12	313	313
1977. 1	302	303	1980. 1	311	309
» 2	287	291	» 2	287	293
» 3	282	287	» 3	282	286
» 4	287	284	» 4	287	284
» 5	311	307	» 5	302	298
» 6	331	331	» 6	313	316
» 7	347	346	» 7	323	325
» 8	357	356	» 8	331	326
» 9	353	356	» 9	341	339
» 10	348	350	» 10	340	338
» 11	321	323	» 11	327	323
» 12	296	298	» 12	305	303
1978. 1	287	290	1981. 1	280	281
» 2	287	288	» 2	287	284
» 3	297	300	» 3	292	293
» 4	287	286	» 4	272	272
» 5	311	308	» 5	292	296
» 6	331	329	» 6	337	333
» 7	347	351	» 7	347	348
» 8	375	375	» 8	364	367
» 9	379	384	» 9	340	344
» 10	357	360	» 10	357	361
» 11	330	333	» 11	347	342
» 12	322	327	» 12	313	310

Year/month	comp.	obs.	Year/month	comp.	obs.
1982. 1	293	294	1985. 1	293	292
» 2	287	289	» 2	287	284
» 3	291	290	» 3	273	272
» 4	296	292	» 4	279	279
» 5	311	312	» 5	285	284
» 6	322	324	» 6	299	299
» 7	338	334	» 7	312	311
» 8	322	322	» 8	332	334
» 9	362	357	» 9	337	337
» 10	356	356	» 10	335	335
» 11	321	317	» 11	312	309
» 12	310	310	» 12	298	297
1983. 1	280	280	1986. 1	285	285
» 2	265	270	» 2	279	280
» 3	260	260	» 3	273	271
» 4	282	281	» 4	270	272
» 5	285	286	» 5	285	284
» 6	312	314	» 6	310	315
» 7	330	329	» 7	335	333
» 8	357	353	» 8	352	350
» 9	345	346	» 9	357	356
» 10	357	361	» 10	357	356
» 11	337	334	» 11	322	323
» 12	297	302	» 12	307	307
1984. 1	287	291	1987. 1	287	286
» 2	287	283	» 2	287	285
» 3	273	274	» 3	282	279
» 4	278	278	» 4	277	279
» 5	302	301	» 5	302	301
» 6	321	321	» 6	296	299
» 7	356	354	» 7	311	317
» 8	358	358	» 8	331	333
» 9	371	370	» 9	336	333
» 10	347	348	» 10	348	346
» 11	330	330	» 11	330	329
» 12	305	309	» 12	287	288

5.3 Station: HOBART

$\varphi = 42^0\ 50'$ S, L $= 147^0\ 30'$ E, Time Period: 1968 - 1986

The mean monthly values of total ozone for the Hobart Station can be represented with the help of the relation:

$$10^{-3} \cdot 0_m^{com} = 327 - 42\sin\left(\frac{2\pi}{12}t + 30^\circ\right) \tag{131}$$

Power spectrum analysis of the differences (D), where

$$D = 10^{-3} \cdot 0^{obs} - 10^{-3} \cdot 0_m^{com} \tag{132}$$

reveals 3 short-term periods of 12, 4 and 3 months. See Figures 121 and 122.

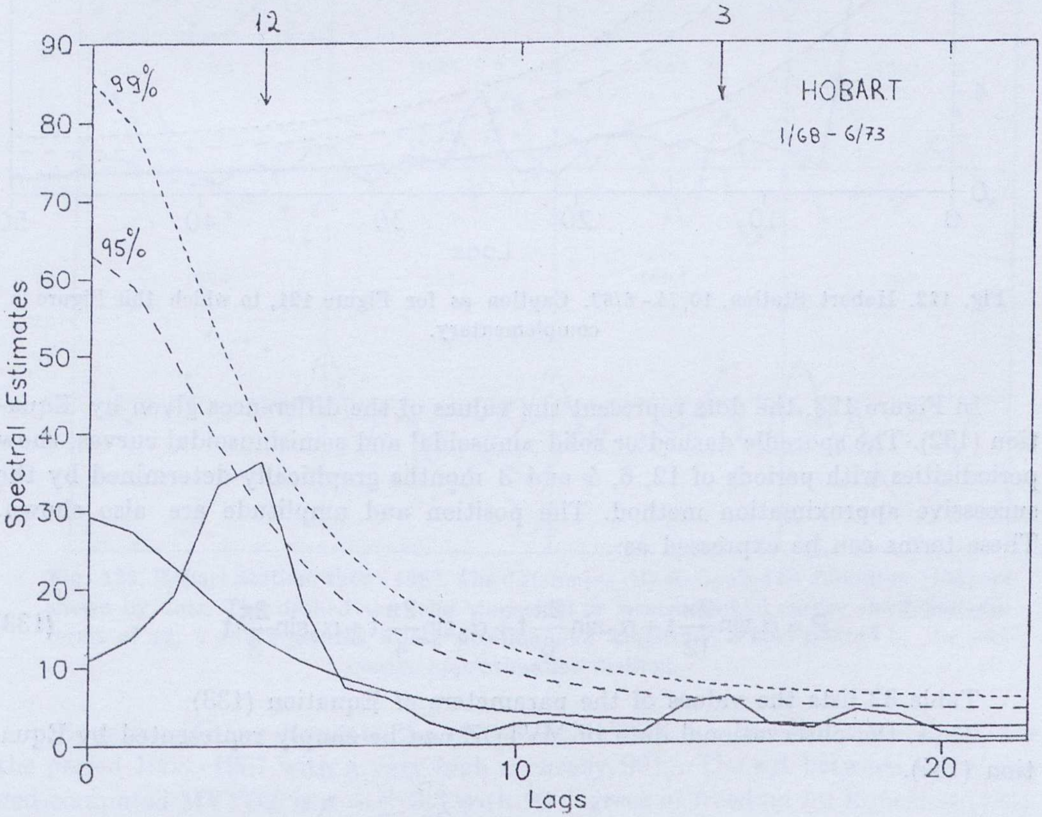

Fig. 121. Hobart Station 1/1968 - 6/1973. Spectral estimate of the differences computed by Equation (132). Analysis shows periodic terms of 12, 4 and 3 months

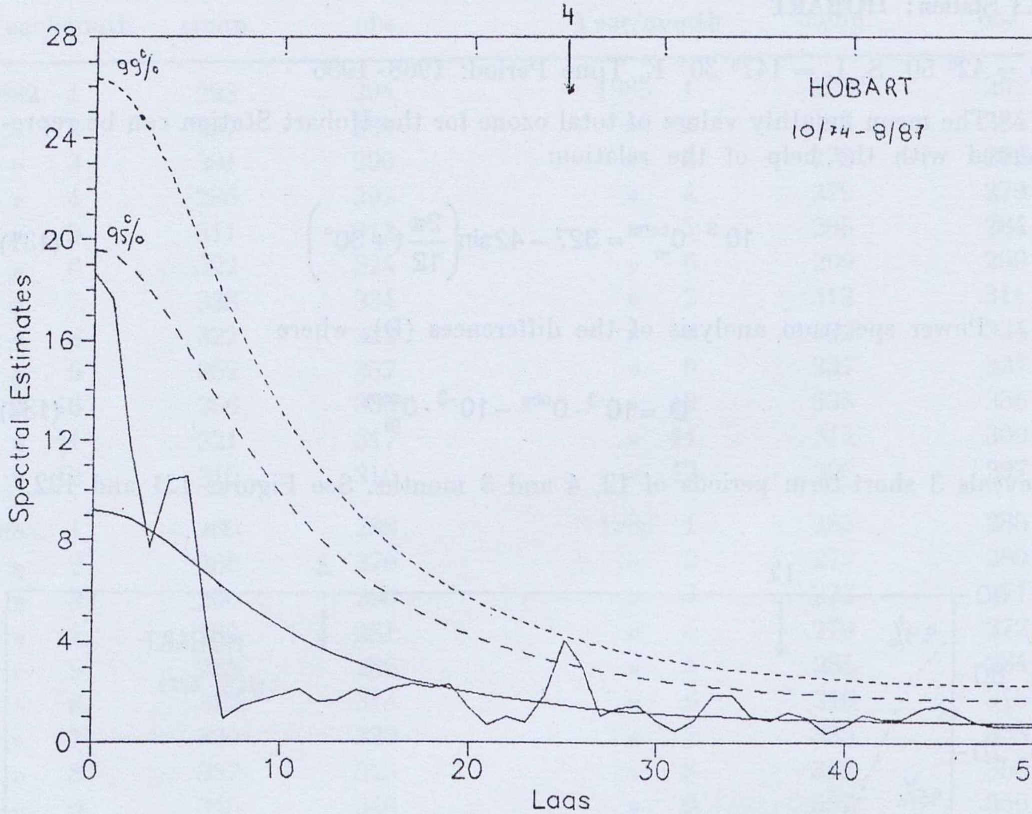

Fig. 122. Hobart Station, 10/74 - 8/87. Caption as for Figure 121, to which this Figure is complementary.

In Figure 123, the dots represent the values of the differences given by Equation (132). The sporadic dashed or solid sinusoidal and semisinusoidal curves, show periodicities with periods of 12, 6, 4 and 3 months graphically determined by the successive approximation method. The position and amplitude are also shown. These terms can be expressed as:

$$P = \alpha_1 \sin\frac{2\pi}{12}t + \alpha_2 \sin\frac{2\pi}{6}t + \alpha_3 \sin\frac{2\pi}{4}t + \alpha_4 \sin\frac{2\pi}{3}t \tag{133}$$

Table 32 lists the values of the parameters of Equation (133).

Thus, the observational data of MVTOZ can be simply represented by Equation (134).

$$10^{-3} \cdot 0^{com} = 327 - 42\sin\left(\frac{2\pi}{12}t + 30^\circ\right) + P \tag{134}$$

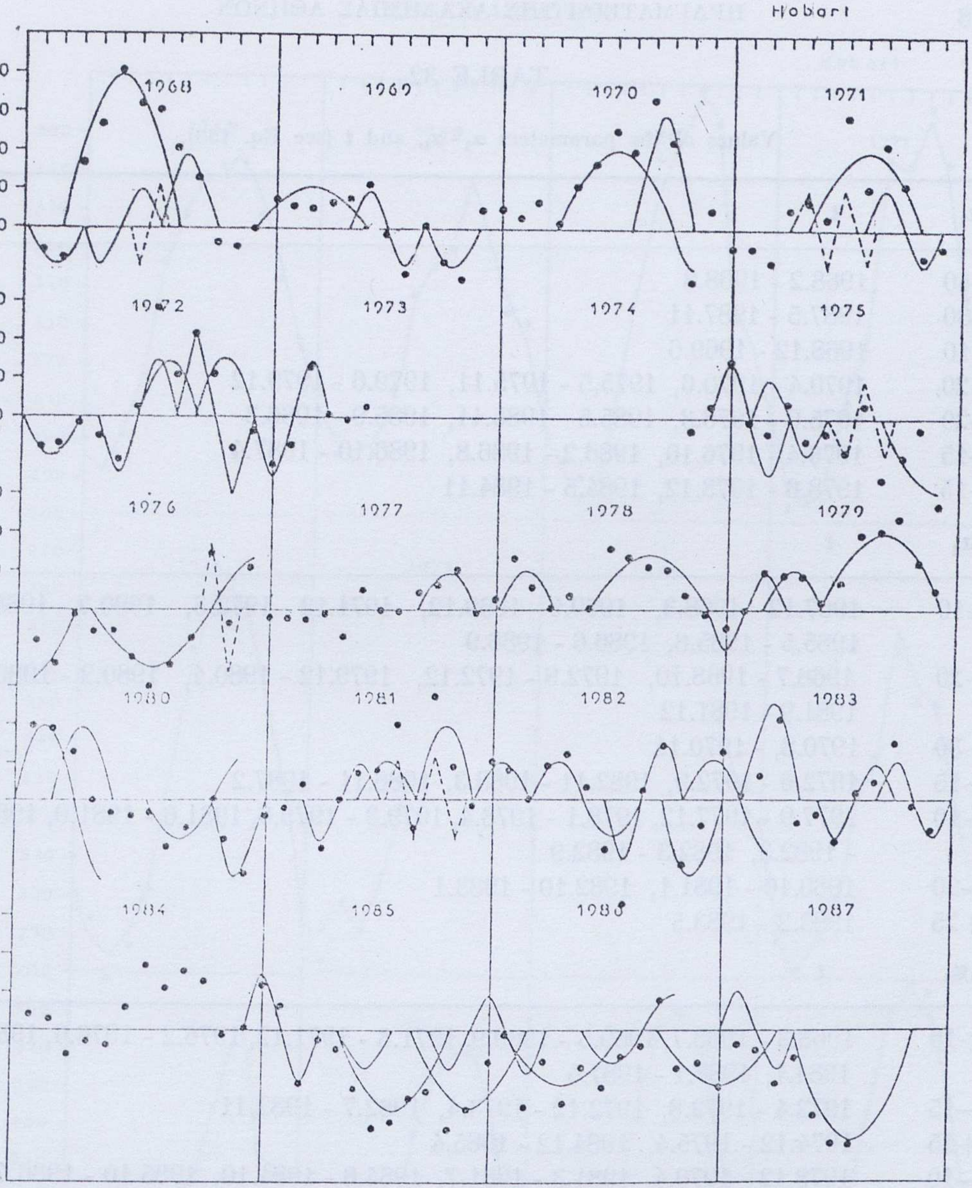

Fig. 123. Hobart Station, 1968 - 1987. The differences (D) computed by Equation (133) are shown by dots. The dashed and solid sinusoidal or semisinusoidal curves show periodic terms of 12, 4 and 3 months whose position and amplitude is also plotted by the successive approximation method.

Equation (134) represents the observed MVTOZ for the Hobart Station, for the period 1968 - 1987 with a very high accuracy, 99%. The s.d. between the observed-computed MVTOZ is $\sigma = \pm 3.3$ with 90 degrees of freedom for Equation (134). See Figures 124 and 125, where the dots and the solid line represent observed and computed MVTOZ respectively.

Table 32A lists the observed and computed MVTOZ for the Hobart Station for the period 1968-1987.

TABLE 32

Values of the parameters $\alpha_1 - \alpha_4$, and **t** (see Eq. 133).

α_1	t
+40	1968.2 - 1968.8
–30	1987.5 - 1987.11
+10	1968.12 - 1969.6
+20	1970.4 - 1970.6, 1975.5 - 1975.11, 1979.6 - 1979.12
–20	1975.9 - 1976.3, 1985.5 - 1985.11, 1985.9 - 1986.3
–15	1976.4 - 1976.10, 1986.2 - 1986.8, 1986.10 - 1987.4
+15	1978.6 - 1978.12, 1984.5 - 1984.11
α_2	**t**
–10	1967.12 - 1968.3, 1969.9 - 1969.12, 1971.12 - 1972.3, 1980.7 - 1980.11, 1985.5 - 1985.8, 1986.6 - 1986.9
+20	1968.7 - 1968.10, 1972.9 - 1972.12, 1979.12 - 1980.4, 1980.2 - 1980.5, 1981.9 - 1981.12
+30	1970.8, - 1970.11
+15	1972.6 - 1972.9, 1982.11 - 1983.3, 1986.11 - 1987.2
+10	1977.9 - 1977.12, 1978.1 - 1978.4, 1979.3 - 1979.6, 1981.6 - 1981.9, 1981.12 - 1982.3, 1982.3 - 1982.9
–20	1980.10 - 1981.1, 1982.10 - 1983.1
+25	1983.2 - 1983.5
α_3	**t**
+10	1968.3 - 1968.7, 1969.5 - 1969.9, 1971.8 - 1971.12, 1976.2 - 1976.6, 1983.9 - 1984.1, 1987.1 - 1987.5
–15	1972.4 - 1972.8, 1972.12 - 1973.4, 1982.7 - 1982.11
+15	1974.12 - 1975.4, 1984.12 - 1985.4
–10	1978.12 - 1979.4, 1981.3 - 1981.7, 1984.6 - 1984.10, 1985.10 - 1986.4
+20	1972.8 - 1972.12
α_4	**t**
–10	1968.6 - 1968.12, 1975.7 - 1975.10
+10	1971.4 - 1971.8, 1981.8 - 1981.11
+20	1976.10 - 1977.4

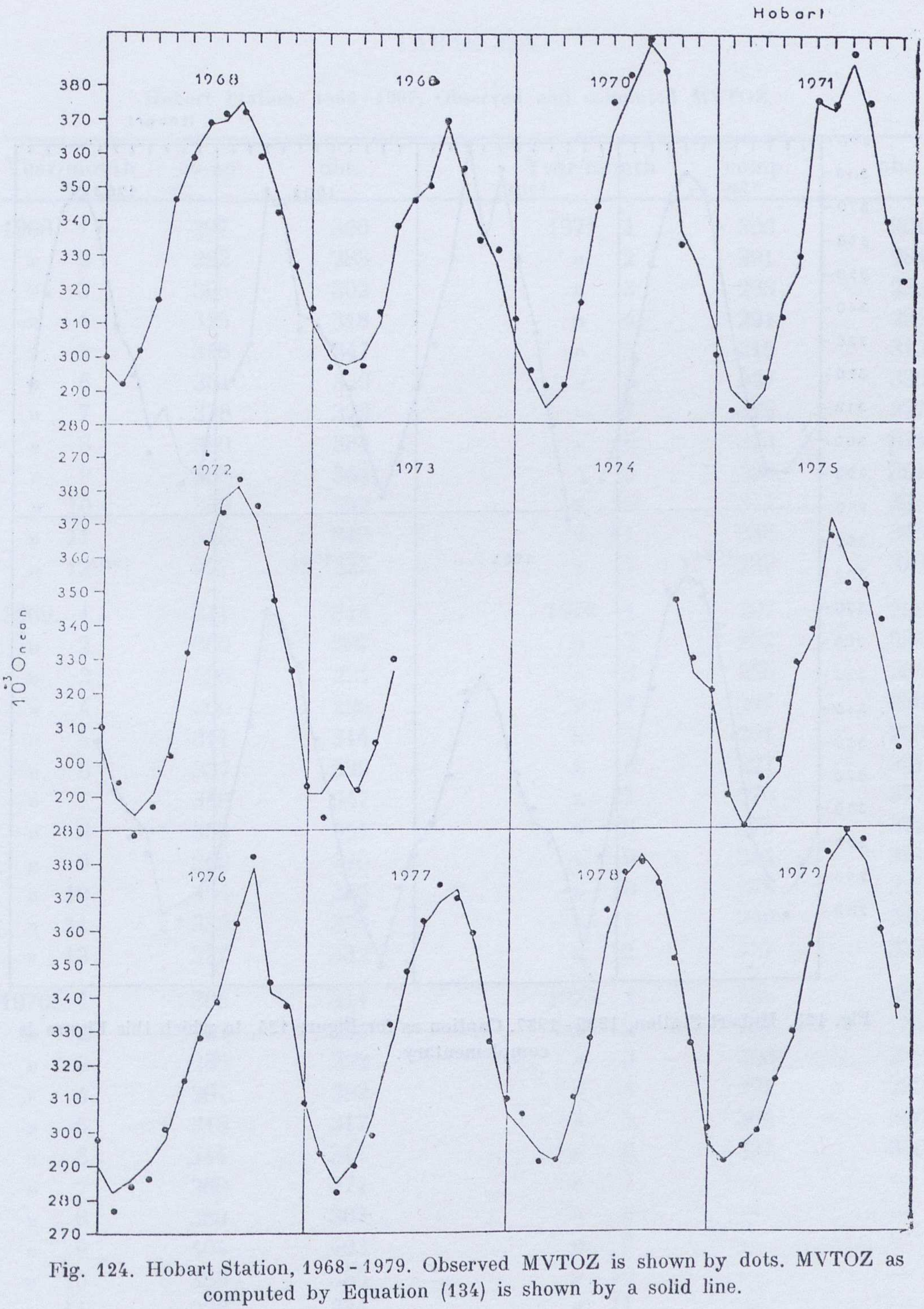

Fig. 124. Hobart Station, 1968 - 1979. Observed MVTOZ is shown by dots. MVTOZ as computed by Equation (134) is shown by a solid line.

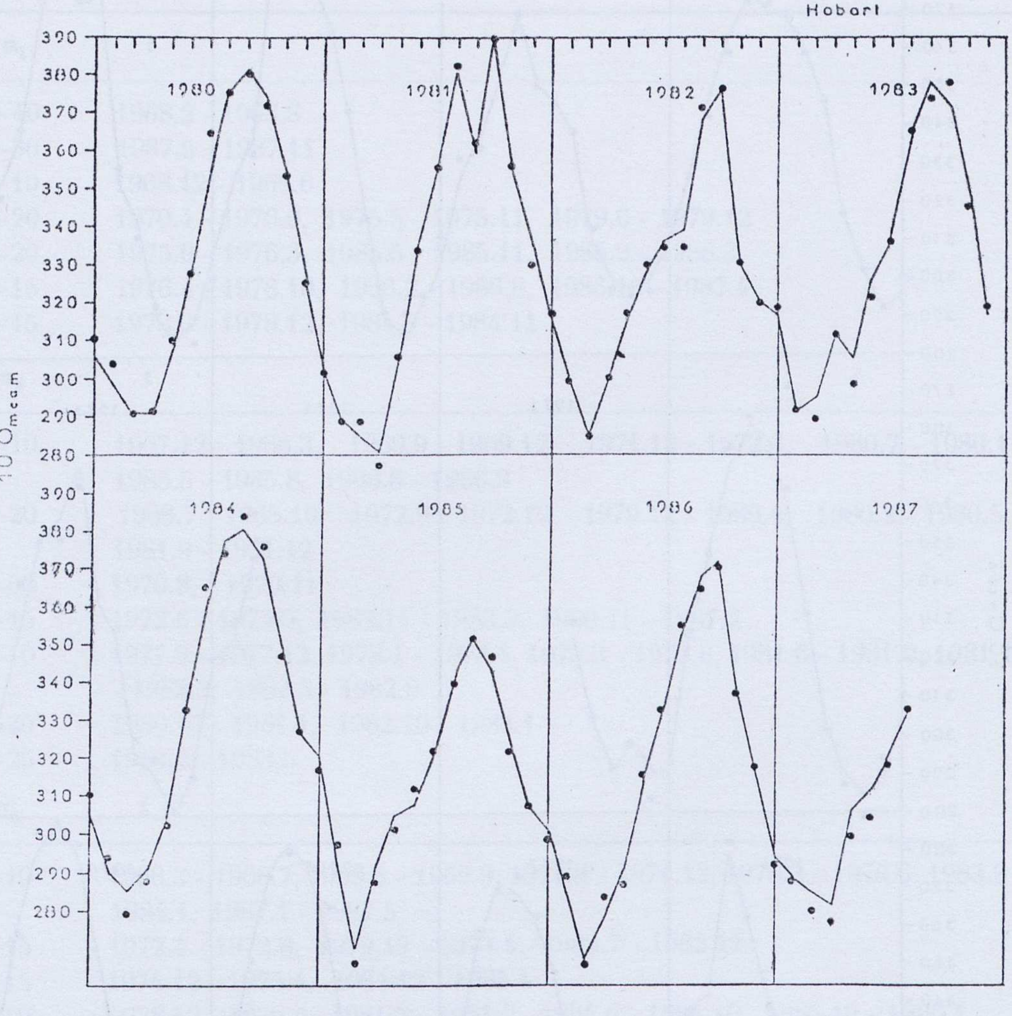

Fig. 125. Hobart Station, 1980 - 1987. Caption as for Figure 124, to which this Figure is complementary.

TABΛE 32A

Hobart Station, 1968 - 1987. Observed and computed MVTOZ.

Year/month	comp.	obs.	Year/month	comp.	obs.
1968. 1	297	300	1971. 1	306	301
» 2	282	283	» 2	291	284
» 3	305	302	» 3	285	285
» 4	315	318	» 4	291	294
» 5	346	347	» 5	315	313
» 6	361	359	» 6	327	330
» 7	378	379	» 7	375	377
» 8	380	384	» 8	373	374
» 9	386	382	» 9	388	391
» 10	363	352	» 10	373	375
» 11	348	343	» 11	338	340
» 12	327	327	» 12	327	323
1969. 1	311	314	1972. 1	297	298
» 2	300	297	» 2	282	284
» 3	295	291	» 3	285	284
» 4	300	298	» 4	291	286
» 5	311	314	» 5	291	295
» 6	337	339	» 6	327	331
» 7	348	347	» 7	375	377
» 8	353	351	» 8	375	374
» 9	369	370	» 9	384	391
» 10	354	356	» 10	375	375
» 11	339	335	» 11	340	340
» 12	327	332	» 12	327	323
1970. 1	306	311	1973. 1	291	294
» 2	291	294	» 2	291	284
» 3	285	292	» 3	300	299
» 4	291	292	» 4	291	292
» 5	316	317	» 5	306	306
» 6	344	344	» 6	327	330
» 7	368	374	» 7	—	—
» 8	380	383	» 8	—	—
» 9	404	403	» 9	—	—
» 10	389	385	» 10	—	—
» 11	338	334	» 11	—	—
» 12	337	332	» 12	—	—

Year/month	comp.	obs.	Year/month	comp.	obs.
1974. 1	—	—	1977. 1	306	304
» 2	—	—	» 2	291	289
» 3	—	—	» 3	285	283
» 4	—	—	» 4	291	290
» 5	—	—	» 5	306	299
» 6	—	—	» 6	327	332
» 7	—	—	» 7	348	348
» 8	—	—	» 8	363	363
» 9	—	—	» 9	369	374
» 10	—	—	» 10	372	370
» 11	348	348	» 11	357	359
» 12	327	331	» 12	327	326
1975. 1	321	321	1978. 1	306	309
» 2	291	290	» 2	300	305
» 3	280	281	» 3	294	291
» 4	291	295	» 4	291	292
» 5	296	300	» 5	306	310
» 6	327	323	» 6	327	328
» 7	337	339	» 7	356	365
» 8	373	367	» 8	375	377
» 9	359	353	» 9	384	381
» 10	353	353	» 10	375	374
» 11	331	342	» 11	356	352
» 12	307	304	» 12	327	326
1976. 1	289	298	1979. 1	296	301
» 2	281	277	» 2	291	291
» 3	285	284	» 3	295	295
» 4	291	286	» 4	300	300
» 5	299	301	» 5	315	315
» 6	315	315	» 6	327	329
» 7	333	328	» 7	358	355
» 8	351	349	» 8	380	383
» 9	362	362	» 9	389	390
» 10	380	383	» 10	380	387
» 11	343	345	» 11	358	360
» 12	339	338	» 12	327	332

Year/month	comp.	obs.	Year/month	comp.	obs.
1980. 1	323	326	1983. 1	318	319
» 2	308	310	» 2	291	292
» 3	302	298	» 3	295	290
» 4	291	291	» 4	313	312
» 5	306	303	» 5	306	299
» 6	327	323	» 6	327	323
» 7	348	345	» 7	338	337
» 8	354	351	» 8	363	365
» 9	360	362	» 9	374	374
» 10	363	364	» 10	373	378
» 11	340	338	» 11	348	346
» 12	310	308	» 12	317	319
1981. 1	306	302	1984. 1	306	310
» 2	291	289	» 2	291	294
» 3	285	289	» 3	285	279
» 4	281	278	» 4	291	288
» 5	306	306	» 5	306	302
» 6	337	334	» 6	335	333
» 7	357	356	» 7	360	365
» 8	381	383	» 8	378	374
» 9	360	362	» 9	381	384
» 10	390	390	» 10	371	376
» 11	355	356	» 11	348	347
» 12	317	326	» 12	327	327
1982. 1	315	316	1985. 1	321	317
» 2	300	299	» 2	291	297
» 3	285	285	» 3	270	266
» 4	300	300	» 4	291	288
» 5	315	318	» 5	306	301
» 6	327	330	» 6	308	312
» 7	337	335	» 7	322	322
» 8	339	336	» 8	343	339
» 9	369	372	» 9	352	352
» 10	378	377	» 10	343	347
» 11	331	331	» 11	321	322
» 12	322	320	» 12	307	308

Year/month	comp.	obs.
1986. 1	299	298
» 2	281	289
» 3	267	266
» 4	279	284
» 5	291	287
» 6	315	317
» 7	331	333
» 8	354	356
» 9	369	365
» 10	373	371
» 11	340	337
» 12	315	318
1987. 1	291	292
» 2	289	288
» 3	275	280
» 4	281	277
» 5	306	299
» 6	312	304
» 7	322	318
» 8	333	333
» 9	—	—
» 10	—	—
» 11	—	—
» 12	—	—

5.4 Station: MACQUARRIE

$\varphi = 54^0\ 30'$ S, L $= 158^0\ 57'$ E, Time Period: 1963-1980.

Macquarrie is the Dobson Station nearest to the Antarctic Circle. It would be desirable to have a larger data set for this Station than the available record (1963-1980). Nevertheless, in the same way as for the previous Stations in both the Northern and Southern Hemispheres the MMVTOZ can be written as:

$$10^{-3} \cdot 0_m^{com} = 340 - 50\sin\frac{2\pi}{12}t + 20\sin\frac{2\pi}{6}t \tag{135}$$

Power spectrum analysis of the differences (D), where

$$D = 10^{-3} \cdot 0^{obs} - 10^{-3} \cdot 0_m^{com} \tag{136}$$

shows two significant periods, of 12 and 4 months. See Figure 126.

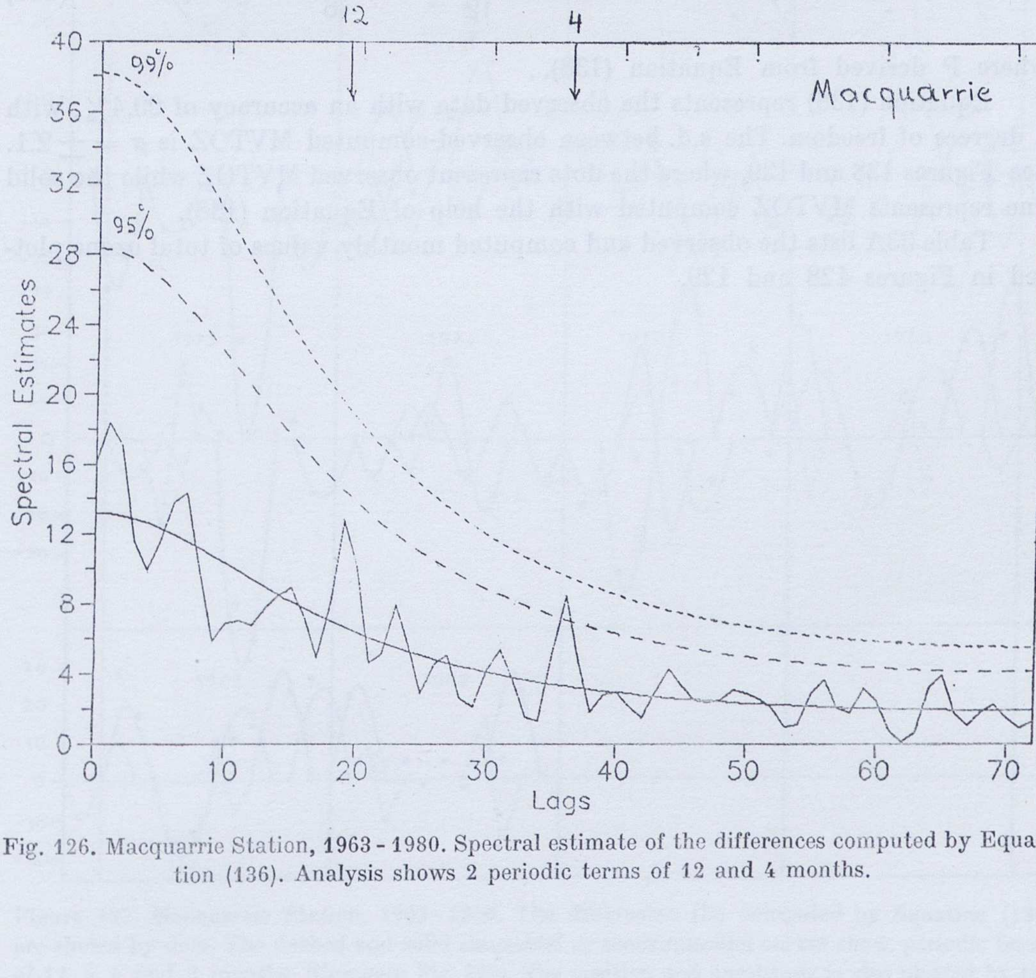

Fig. 126. Macquarrie Station, 1963 - 1980. Spectral estimate of the differences computed by Equation (136). Analysis shows 2 periodic terms of 12 and 4 months.

Successive approximations analysis of the differences computed by Equation (136), however, reveals four periods, of 12, 6, 4 and 3 months. See Figure 127, where the dots represent differences computed by Equation (136), while the dashed and solid sinusoidal or semisinusoidal curves represent periodic terms which appear as a network of periodicities with occasional overlaps. Figure 127 also reveals position and amplitude of the periodic or quasi-periodic terms. These periodic terms can be expressed as:

$$P = \alpha_1 \sin\frac{2\pi}{12}t + \alpha_2 \sin\frac{2\pi}{6}t + \alpha_3 \sin\frac{2\pi}{4}t + \alpha_4 \sin\frac{2\pi}{3}t \qquad (137)$$

The numerical values of the parameters of Equation (137) are listed in Table 33.

From the above analysis it is deduced that the MVTOZ for the Macquarrie Station and for the period 1963-1980 can be expressed as:

$$10^{-3} \cdot 0^{com} = 340 - 50\sin\frac{2\pi}{12}t + 20\sin\frac{2\pi}{6}t + P \qquad (138)$$

where P derived from Equation (138).

Equation (138) represents the observed data with an accuracy of 99.4%, with 4 degrees of freedom. The s.d. between observed-computed MVTOZ is $\sigma = \pm 2.1$. See Figures 128 and 129, where the dots represent observed MVTOZ while the solid line represents MVTOZ computed with the help of Equation (138).

Table 33A lists the observed and computed monthly values of total ozone plotted in Figures 128 and 129.

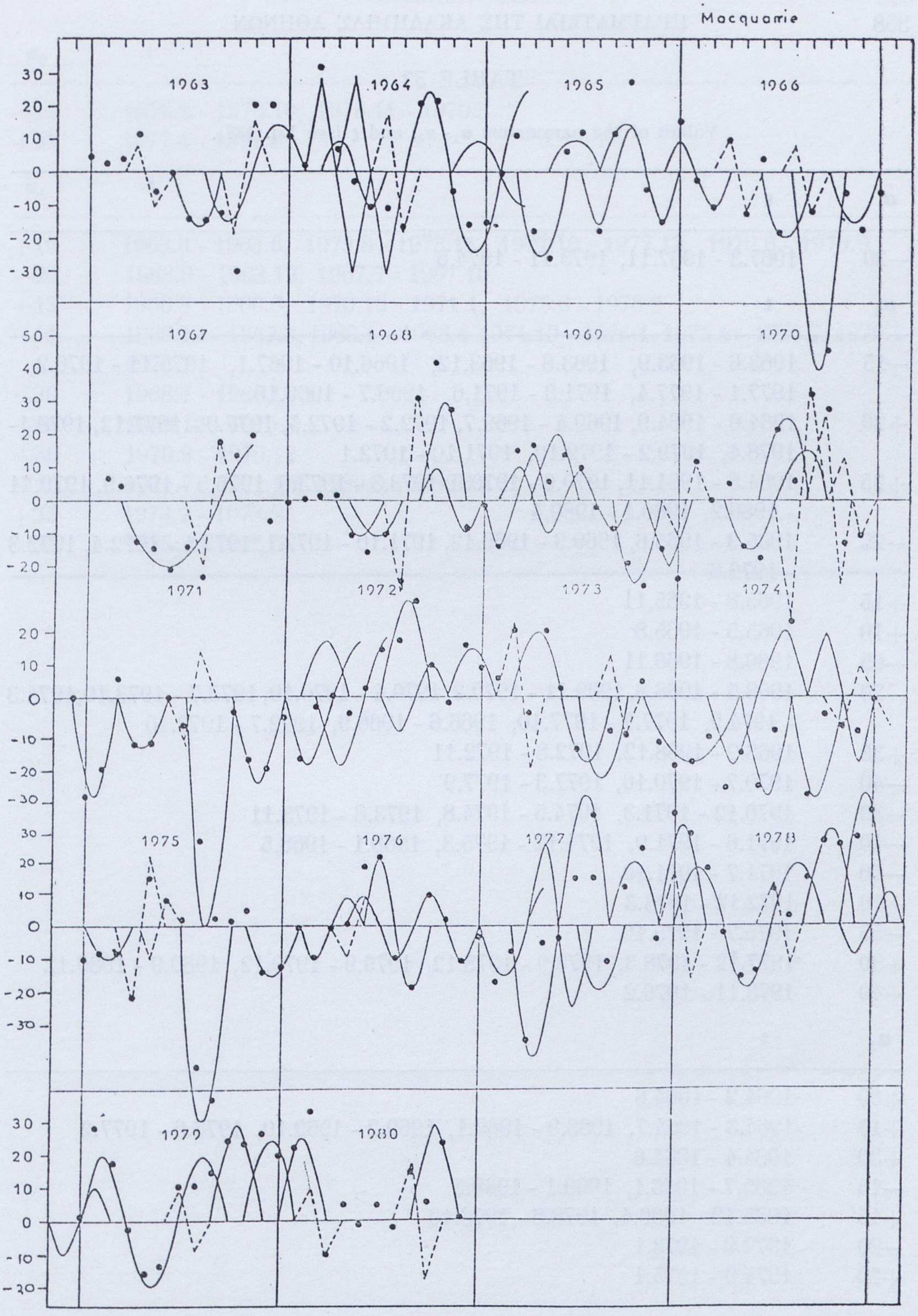

Figure 127. Macquarrie Station, 1963 - 1980. The differences (D) computed by Equation (13C) are shown by dots. The dashed and solid sinusoidal or semisinusoidal curves show periodic terms of 12, 6, 4 and 3 months. (Compare Fig. 126). The position and amplitude is also plotted by the successive approximation method.

TABLE 33

Values of the parameters α_1 - α_4, and **t** (see Eq. 137).

α_1	t
—20	1967.3 - 1967.11, 1973.11 - 1974.5
α_2	t
—15	1963.6 - 1963.9, 1963.8 - 1963.12, 1966.10 - 1967.1, 1975.11 - 1976.2, 1977.1 - 1977.4, 1971.3 - 1971.6, 1966.7 - 1966.10
+20	1964.6 - 1964.9, 1969.4 - 1969.7, 1972.2 - 1972.5, 1977.9 - 1977.12, 1978.1-1978.4, 1979.2 - 1979.10, 1971.10 - 1972.1
+25	1964.8 - 1964.11, 1970.6 - 1970.9, 1973.3 - 1973.9, 1976.5 - 1976.9, 1979.11 - 1980.2, 1980.1 - 1980.4
—25	1965.3 - 1965.6, 1969.9 - 1969.12, 1971.10 - 1972.1, 1972.1 - 1972.4, 1972.3 - 1972.6
+15	1965.8 - 1965.11
+10	1965.5 - 1965.8
—65	1966.8 - 1966.11
—20	1968.5 - 1968.8, 1969.11 - 1970.2, 1970.4 - 1970.10, 1973.7 - 1973.10,1974.3 - 1974.9, 1977.7 - 1977.10, 1966.6 - 1966.9, 1972.7 - 1972.10
+35	1968.9 - 1968.12, 1972.8 - 1972.11
—40	1970.7 - 1970.10, 1977.3 - 1977.9
—30	1970.12 - 1971.3, 1974.5 - 1974.8, 1973.8 - 1973.11
—10	1971.6 - 1971.9, 1974.12 - 1975.3, 1968.1 - 1968.5
—60	1971.7 - 1971.10
+10	1972.12 - 1973.3
—55	1975.7 - 1975.10
+30	1977.12 - 1978.3, 1978.9 - 1978.12, 1979.9 - 1979.12, 1980.9 - 1980.12
+40	1978.11 - 1979.2
α_3	t
+30	1964.2 - 1964.6
+10	1964.3 - 1964.7, 1968.9 - 1969.1, 1969.2 - 1969.10, 1976.6 - 1977.2
+30	1964.4 - 1964.8
—15	1965.7 - 1966.1, 1969.1 - 1969.5
+15	1965.12 - 1966.4, 1978.6 - 1978.10
—20	1972.9 - 1973.1
+20	1974.9 - 1975.1

α_3	t
—10	1976.2 - 1976.10, 1978.11 - 1979.3
+25	1977.4 - 1977.8

α_4	t
+10	1963.3 - 1963.6, 1973.8 - 1973.11, 1977.10 - 1977.12, 1979.6 - 1979.9
—20	1963.9 - 1963.12, 1967.7 - 1967.10
+15	1966.3 - 1966.6, 1970.10 - 1971.1, 1978.6 - 1978.9
—10	1966.12 - 1967.3, 1968.1 - 1968.4 1974.10 - 1975.1, 1975.4 - 1975.7, 1976.4-1976.7
—30	1968.7 - 1968.10
—15	1969.12 - 1970.3
+30	1970.9 - 1970.12
+20	1971.7 - 1971.10, 1980.9 - 1980.12
+25	1973.2 - 1973.5
—25	1975.3 - 1975.6

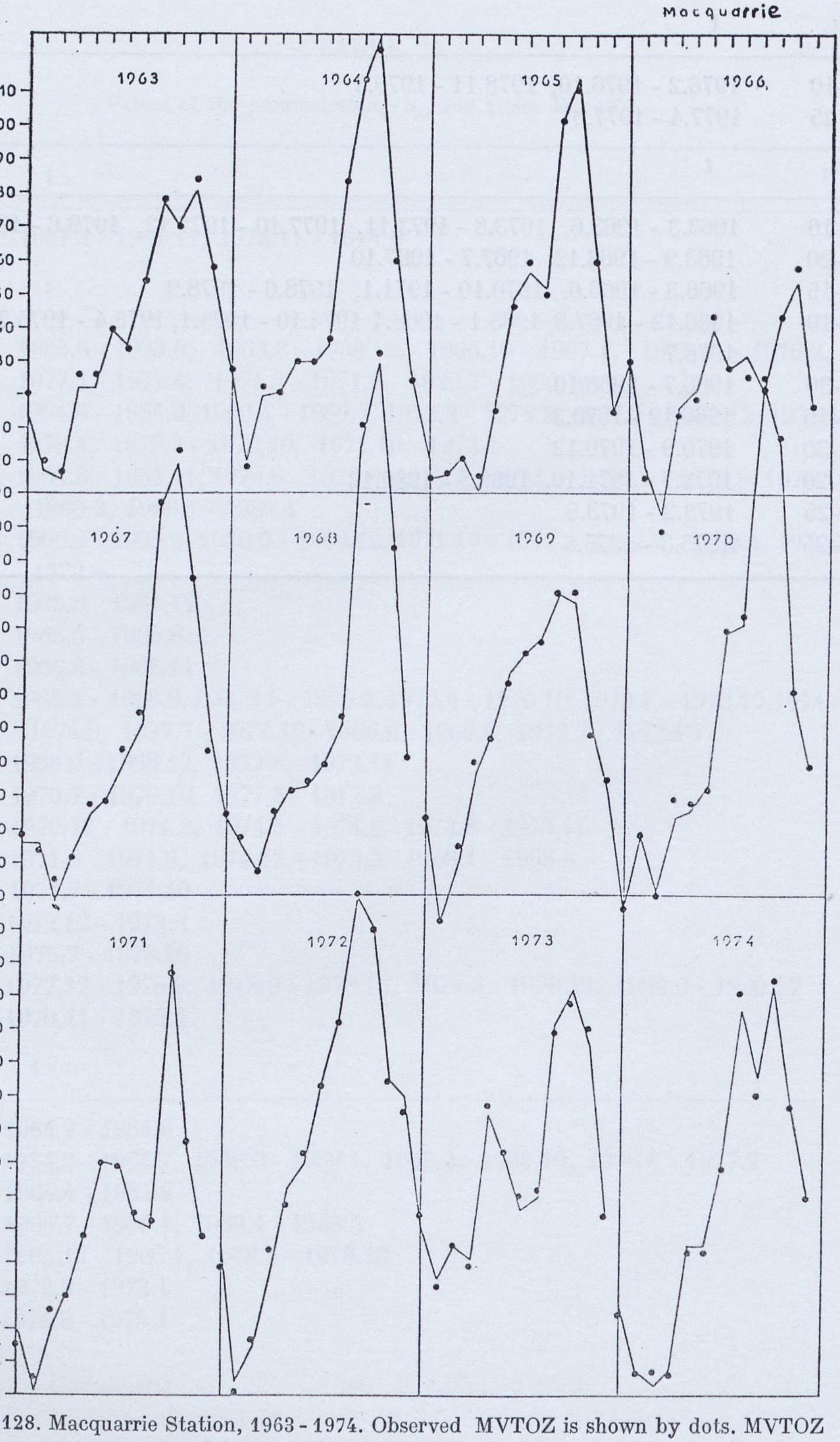

Fig. 128. Macquarrie Station, 1963 - 1974. Observed MVTOZ is shown by dots. MVTOZ as computed by Equation (138) is shown by a solid line.

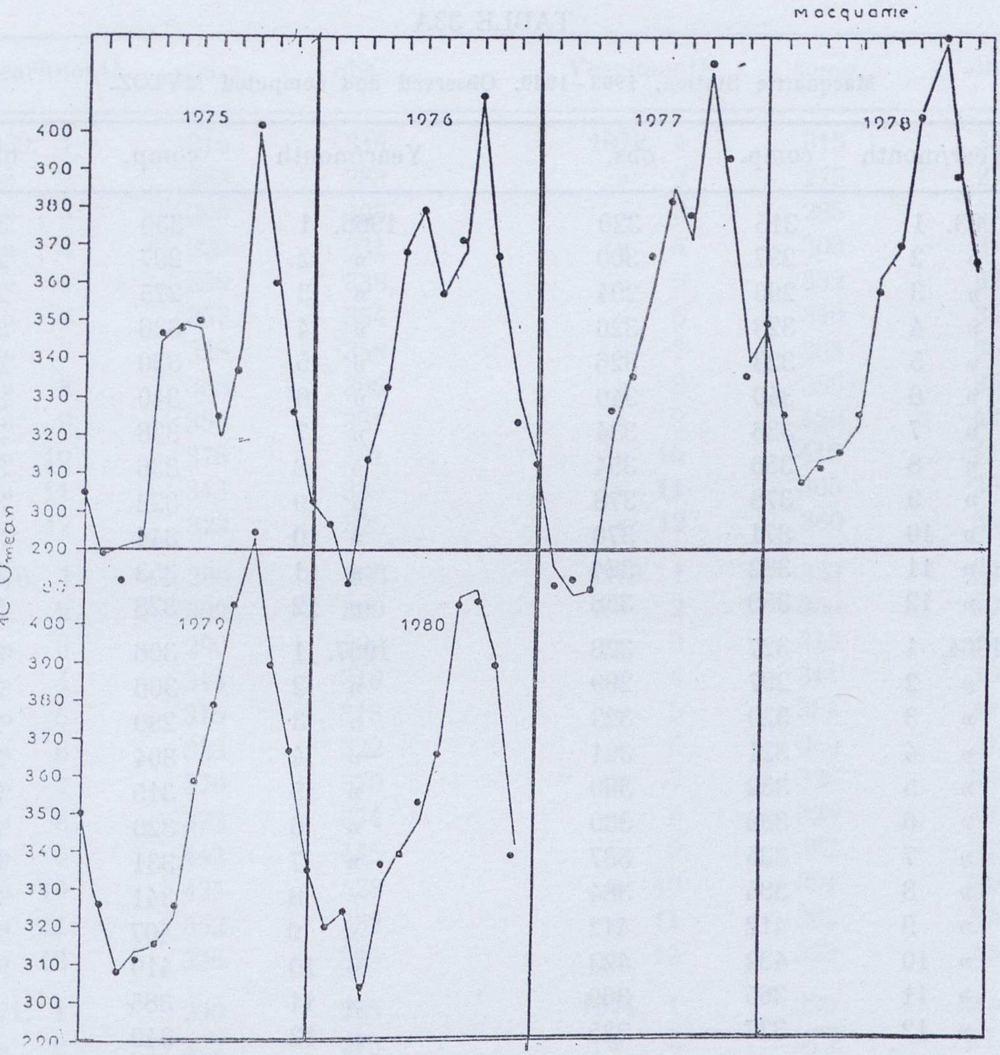

Fig. 129. Macquarrie Station, 1975 - 1980. Caption as for Figure 128, to which this Figure is complementary.

TABLE 33A

Macquarrie Station, 1963 - 1980. Observed and computed MVTOZ.

Year/month	comp.	obs.	Year/month	comp.	obs.
1963. 1	315	320	1966. 1	330	331
» 2	297	300	» 2	297	295
» 3	290	294	» 3	275	279
» 4	323	326	» 4	326	324
» 5	323	326	» 5	330	329
» 6	340	340	» 6	340	344
» 7	336	334	» 7	328	329
» 8	356	354	» 8	336	326
» 9	378	378	» 9	322	322
» 10	371	370	» 10	344	344
» 11	382	384	» 11	353	359
» 12	358	358	» 12	328	327
1964. 1	327	328	1967. 1	306	309
» 2	297	299	» 2	306	304
» 3	320	323	» 3	290	295
» 4	321	321	» 4	304	302
» 5	332	330	» 5	315	318
» 6	330	330	» 6	320	319
» 7	335	337	» 7	331	334
» 8	385	384	» 8	341	345
» 9	412	412	» 9	407	408
» 10	422	423	» 10	410	414
» 11	365	360	» 11	385	385
» 12	327	325	» 12	340	334
1965. 1	302	295	1968. 1	315	315
» 2	297	297	» 2	306	308
» 3	303	302	» 3	299	298
» 4	292	296	» 4	314	316
» 5	320	316	» 5	323	322
» 6	349	347	» 6	323	325
» 7	357	360	» 7	331	330
» 8	353	350	» 8	342	344
» 9	402	402	» 9	416	422
» 10	427	423	» 10	440	443
» 11	365	360	» 11	395	394
» 12	325	325	» 12	330	332

Year/month		comp.	obs.	Year/month		comp.	obs.
1969.	1	315	314	1972.	1	315	309
»	2	282	283	»	2	275	271
»	3	300	305	»	3	285	287
»	4	329	331	»	4	309	314
»	5	339	338	»	5	332	327
»	6	357	354	»	6	340	343
»	7	358	358	»	7	365	363
»	8	368	366	»	8	385	382
»	9	380	381	»	9	420	421
»	10	378	381	»	10	410	410
»	11	343	339	»	11	365	364
»	12	323	325	»	12	360	356
1970.	1	286	286	1973.	1	322	324
»	2	309	309	»	2	306	303
»	3	290	290	»	3	315	315
»	4	314	319	»	4	311	309
»	5	315	318	»	5	354	357
»	6	323	322	»	6	340	343
»	7	370	370	»	7	326	330
»	8	372	374	»	8	329	332
»	9	442	445	»	9	382	379
»	10	425	428	»	10	391	388
»	11	352	352	»	11	365	370
»	12	328	329	»	12	323	324
1971.	1	290	285	1974.	1	298	294
»	2	272	275	»	2	277	277
»	3	290	296	»	3	273	277
»	4	302	300	»	4	277	276
»	5	320	318	»	5	315	313
»	6	340	340	»	6	315	313
»	7	339	339	»	7	340	338
»	8	323	325	»	8	385	391
»	9	320	323	»	9	365	360
»	10	400	397	»	10	395	395
»	11	343	346	»	11	356	356
»	12	318	318	»	12	329	329

Year/month	comp.	obs.	Year/month	comp.	obs
1975. 1	306	305	1978. 1	348	350
» 2	288	289	» 2	322	326
» 3	290	282	» 3	307	308
» 4	292	294	» 4	314	312
» 5	345	347	» 5	315	316
» 6	349	348	» 6	323	326
» 7	348	350	» 7	363	359
» 8	320	325	» 8	370	371
» 9	342	337	» 9	407	405
» 10	400	402	» 10	426	425
» 11	365	360	» 11	391	389
» 12	328	326	» 12	365	367
1976. 1	303	303	1979. 1	350	350
» 2	297	297	» 2	324	326
» 3	280	281	» 3	307	308
» 4	314	314	» 4	314	312
» 5	333	333	» 5	315	316
» 6	371	369	» 6	323	326
» 7	380	380	» 7	357	359
» 8	359	358	» 8	376	379
» 9	368	372	» 9	407	405
» 10	410	410	» 10	426	425
» 11	365	368	» 11	391	389
» 12	330	324	» 12	362	367
1977. 1	315	312	1980. 1	337	335
» 2	285	280	» 2	319	320
» 3	278	282	» 3	324	324
» 4	279	279	» 4	302	304
» 5	322	327	» 5	332	337
» 6	340	336	» 6	340	339
» 7	358	368	» 7	348	353
» 8	386	383	» 8	368	366
» 9	373	379	» 9	407	405
» 10	408	412	» 10	409	406
» 11	391	394	» 11	391	389
» 12	340	336	» 12	340	339

6. THE MINIMA AND MAXIMA OF THE MONTHLY VALUES OF TOTAL OZONE OBSERVED FROM 1957 THROUGH 1990

If we look closely at the Figures illustrating the variation of observed monthly values of total ozone from year to year for the thirty three Dobson Stations studied in Sections 4 and 5 above, we shall see that the existence of a more or less stable «ozone hole» is implausible. This is so at least for the time period investigated, which covers the years 1957 through 1990, for the majority of the Dobson Stations.

Worthwhile is the fact, that the present investigation is based *on monthly values of total ozone.*

We shall now consider the lowest and the highest monthly values for each year and for each Dobson Station in both Hemispheres.

Figure 130 illustrates the monthly minima per year of the total ozone values for the time interval 1957 through 1990. As is obvious these monthly minima per year for the recorded period do not fall below a lower limit of 240m-atm-cm, which does not mean an ozone «hole» of any sort.

Figure 131 illustrates the monthly maxima per year of total ozone values (TOZV) for three Dobson Stations (D.S.), Resolute, Reykjavik and Arosa. The variation of the maximum values of total ozone for these Stations is close to normal, fluctuating around an average value of 490m-atm-cm for the Resolute Station and 420 and 390 D.U. (m-atm-cm) for the Reykjavik and Arosa Stations respectively.

Figure 132 plots the monthly maxima per year of the total ozone values (TOZV) for Mt. Louis, Boulder, Cagliari, Wallops and Rome Stations. Note that the record period is different for each Station. As is obvious from figure 132 the variation of the monthly maxima at these Stations is smoothed. The maximum fluctuates slightly around an average value indicated by the thick straight line plotted on each part of the Figure. However, no Station shows a systematic decrease of the total ozone values with time.

Figure 133 is similar to Figure 132 and represents the interannual monthly maxima of TOZV for Tateno, Kagoshima, White Sands, Tallahassee, Cairo and Quetta Stations. As in the previous two Figures, the variation of the maximum TOZV shows smooth variation with time, fluctuating around an average value indicated by the thick straight line characteristic of each Station. No Station of Figure 133 shows a decrease in the ozone layer with the exception of Cairo, which contrary to the other Stations shows a very slight increase of the maximum total ozone values.

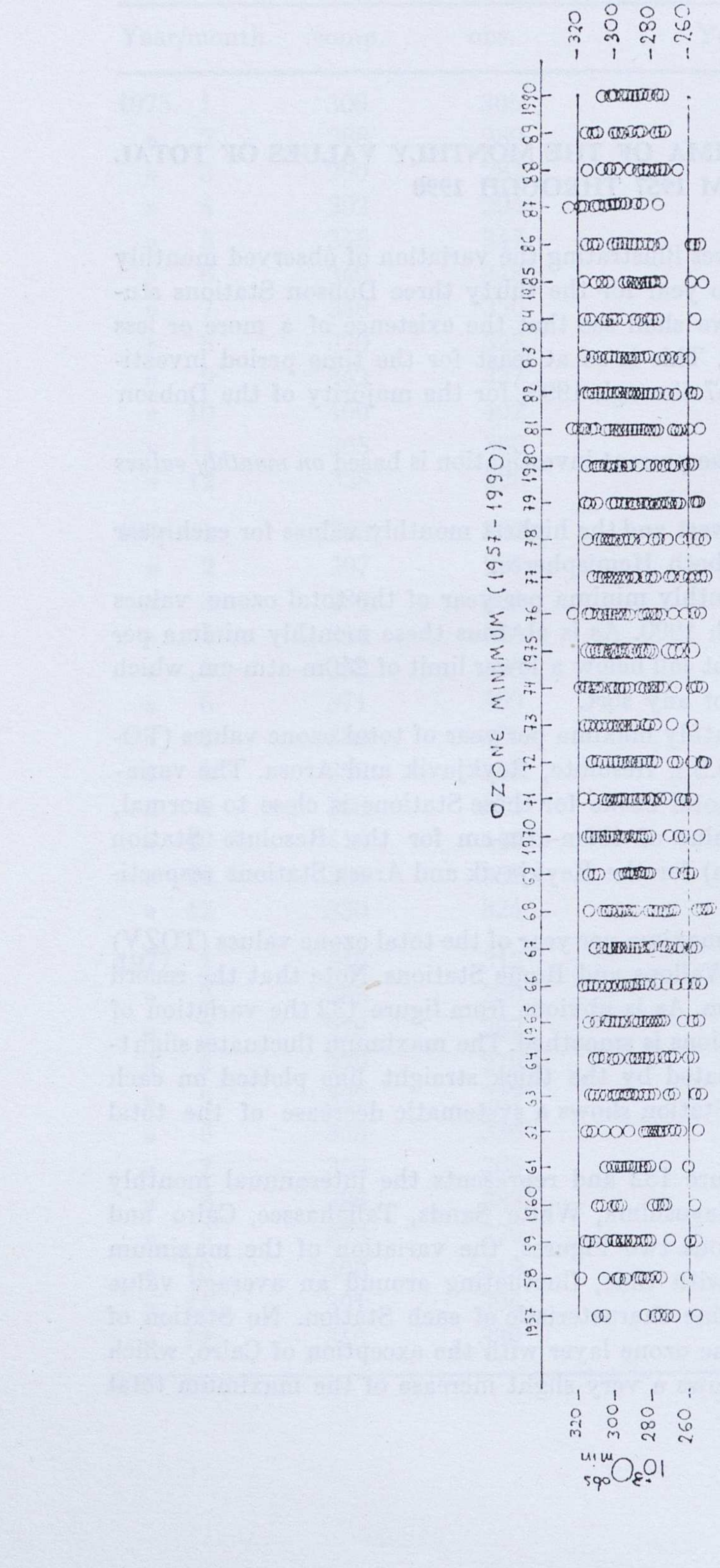

Fig. 130. The small circles represent the monthly minima per year for the period 1957-1990. As it is seen the monthly minima of the total ozone do not fall below the limit of 240 D.U. Abscissa denotes years.

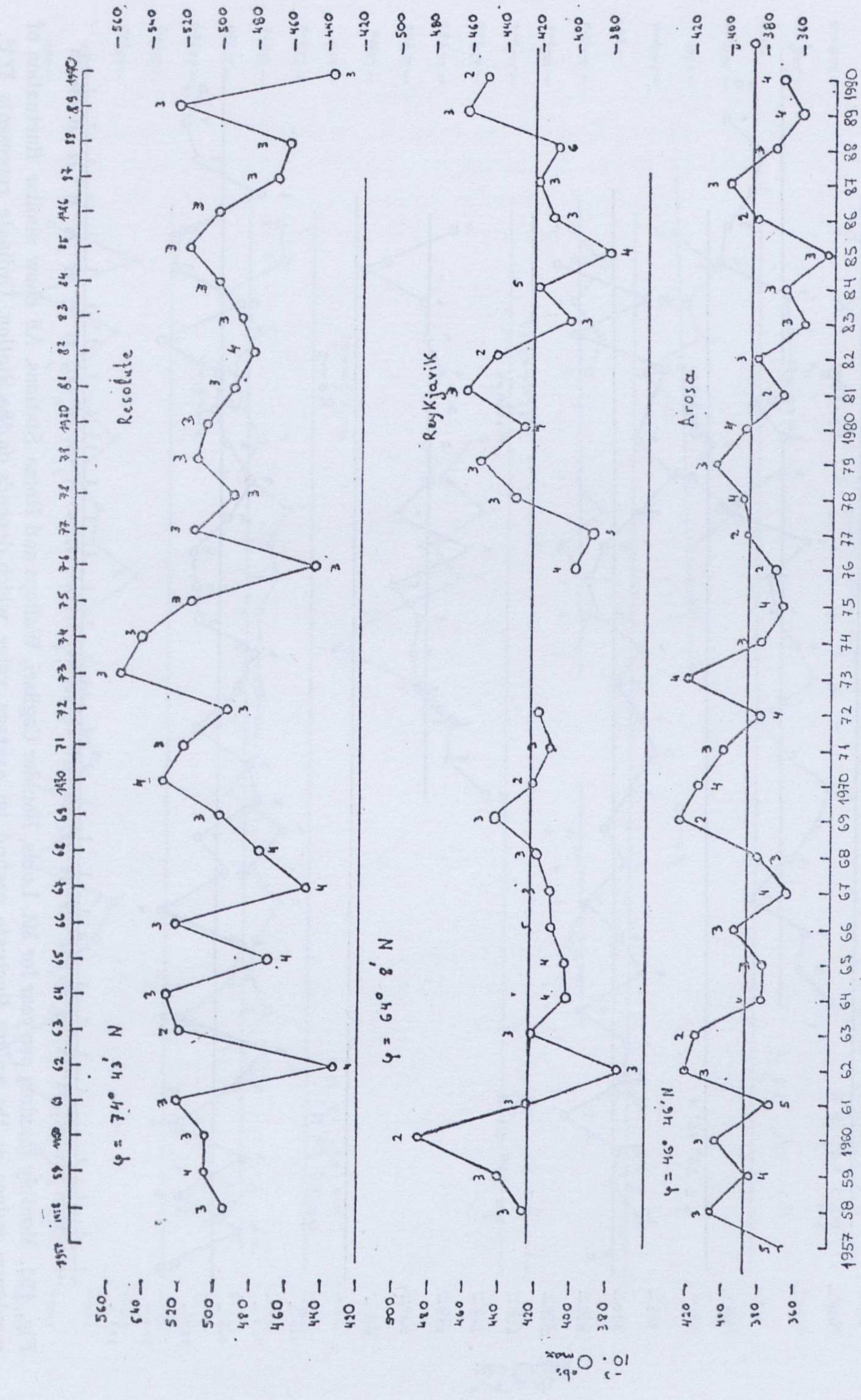

Fig. 131. Monthly maxima per year for Resolute, Reykjavik and Arosa Stations. Ordinate denotes D.U.Abscissa denotes years. Numbers above the small circles denote the month of the observed max TOZV during each year. (This remark refers to the figures 131 - 138).

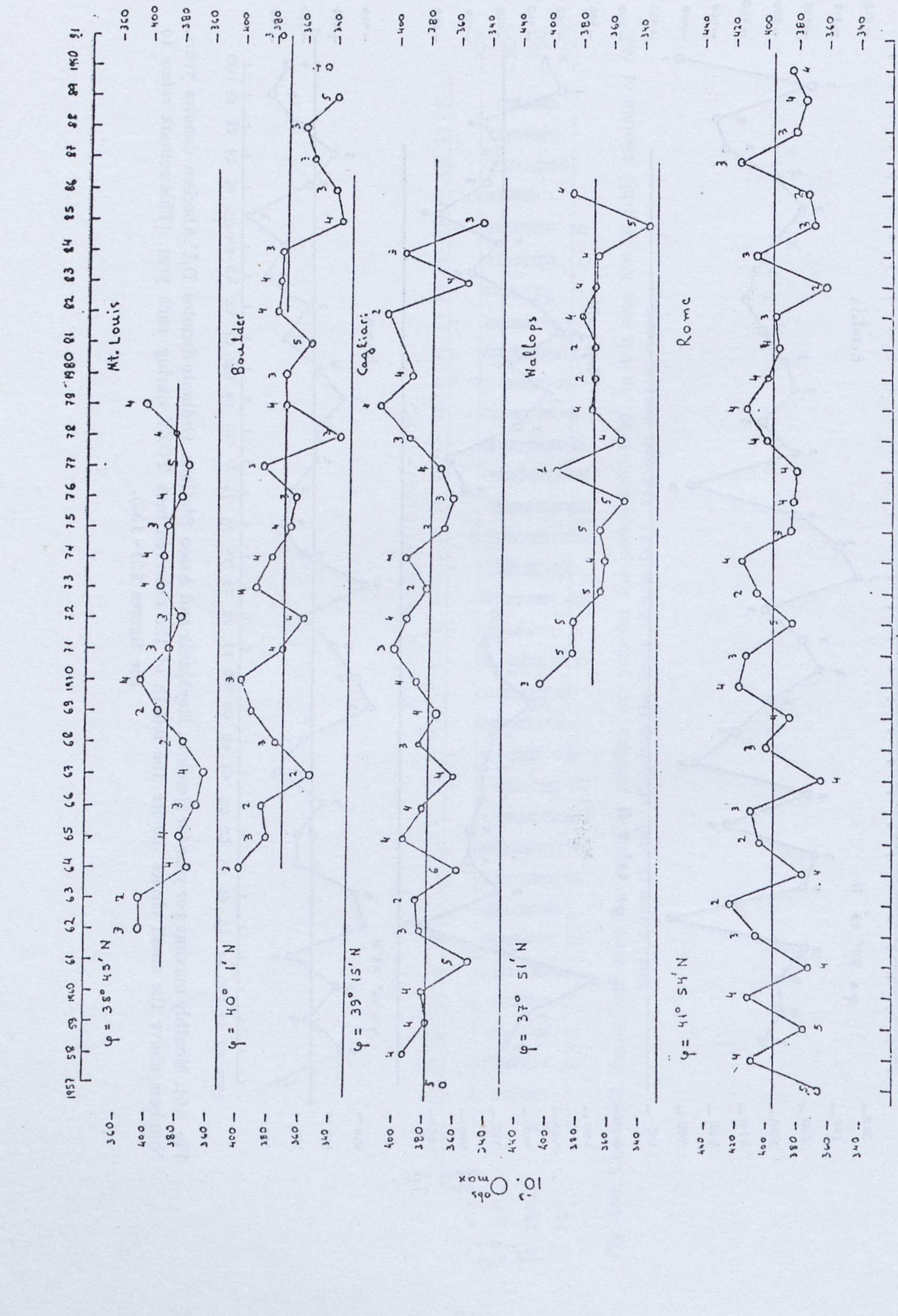

Fig. 132. Monthly maxima per year for Mt. Louis, Boulder Cagliari, Wallops and Rome Stations. All show similar fluctuation of maximum values as the values fluctuate around an average value which depends on the Station. Ordinate represents D.U. Abscissa denotes years.

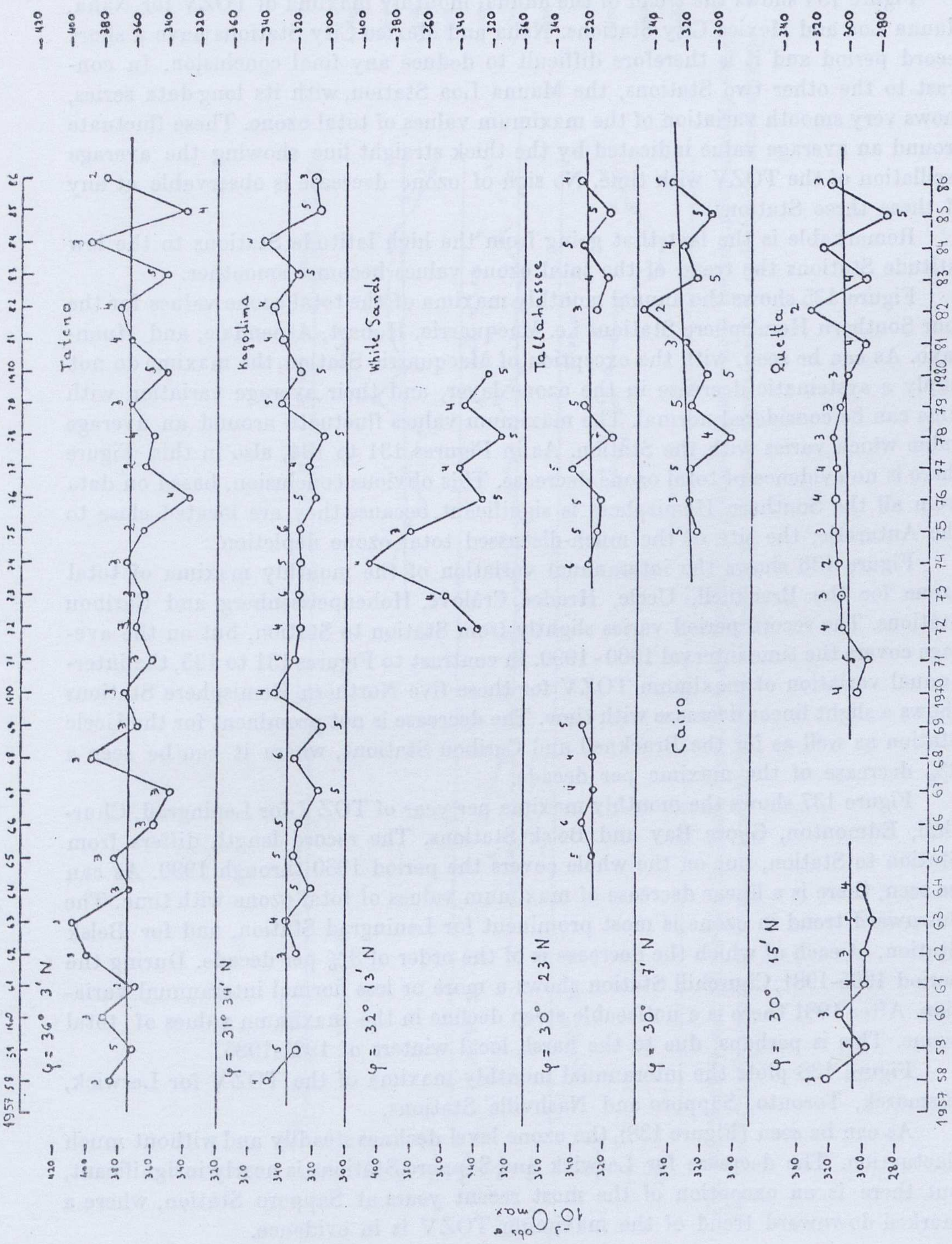

Fig. 133. Monthly maxima per year for Tateno, Kagoshima, White Sands, Tallahasses, Cairo and Quetta Stations. As is fairly obvious the average variation of the maximum values of all these Stations is normal, and no Station shows systematic decrease with time during the period 1957 - 1990. Ordinate represents D.U. Abscissa denotes years.

Figure 134 shows the trend of the annual monthly maxima of TOZV for Naha, Mauna Loa and Mexico City Stations. Naha and Mexico City Stations have a short record period and it is therefore difficult to deduce any final conclusion. In contrast to the other two Stations, the Mauna Loa Station, with its long data series, shows very smooth variation of the maximum values of total ozone. These fluctuate around an average value indicated by the thick straight line showing the average oscillation of the TOZV with time. No sign of ozone decrease is observable at any of these three Stations.

Remarkable is the fact that going from the high latitude Stations to the low latitude Stations the trend of the total ozone values becomes smoother.

Figure 135 shows the annual monthly maxima of the total ozone values for the four Southern Hemisphere Stations i.e. Macquarrie, Hobart, Aspendale, and Huancayo. As can be seen, with the exception of Macquarrie Station, the maxima do not imply a systematic decrease in the ozone layer, and their average variation with time can be considered normal. The maximum values fluctuate around an average value which varies with the Station. As in Figures 131 to 134, also in this Figure there is no evidence of total ozone decrease. This obvious conclusion, based on data from all the Southern Hemisphere is significant, because they are located close to the Antarctic; the site of the much-discussed total ozone depletion.

Figure 136 shows the interannual variation of the monthly maxima of total ozone for the Bracknell, Uccle, Hradec Crálové, Hohenpeissenberg and Caribou Stations. The record period varies slightly from Station to Station, but on the average covers the time interval 1960 - 1990. In contrast to Figures 131 to 135, the interannual variation of maximum TOZV for these five Northern Hemisphere Stations shows a slight linear decrease with time. The decrease is not prominent for the Uccle Station as well as for the Bracknell and Caribou Stations, where it can be seen a 2% decrease of the maxima per decade.

Figure 137 shows the monthly maxima per year of TOZV for Leningrad, Churchill, Edmonton, Goose Bay and Belsk Stations. The record length differs from Station to Station, but on the whole covers the period 1960 through 1990. As can be seen, there is a linear decrease of maximum values of total ozone with time. The downward trend in ozone is most prominent for Leningrad Station, and for Belsk Station, at each of which the decrease is of the order of 3% per decade. During the period 1965-1981, Churchill Station shows a more or less normal interannual variation. After 1981 there is a noticeable steep decline in the maximum values of total ozone. This is perhaps, due to the harsh local winters of 1981-1985.

Figure 138 plots the interannual monthly maxima of the TOZV for Lerwick, Bismarck, Toronto, Sapporo and Nashville Stations.

As can be seen (Figure 138), the ozone level declines steadily and without much fluctuation. The decrease for Lerwick and Sapporo Stations is nearly insignificant, but there is an exception of the most recent years at Sapporo Station, where a marked downward trend of the maximum TOZV is in evidence.

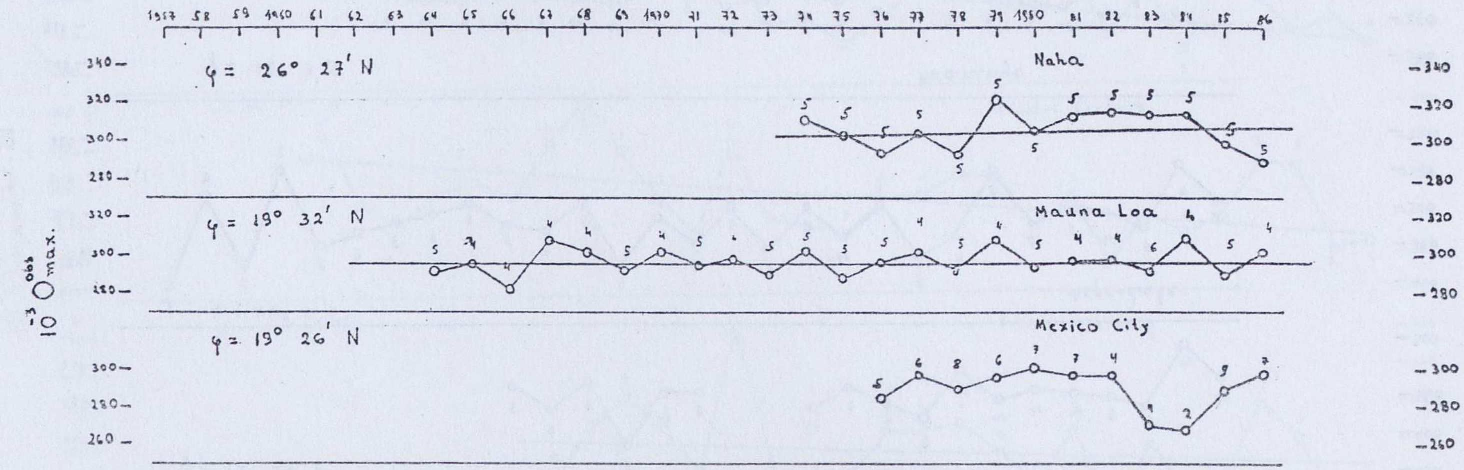

Fig. 134. Monthly maxima per year for Naha, Mauna Loa, and Mexico City Stations. As is obvious the maximum monthly values fluctuate normally around an average value which depends on the Station. Ordinate represents D.U. and abscissa denotes years.

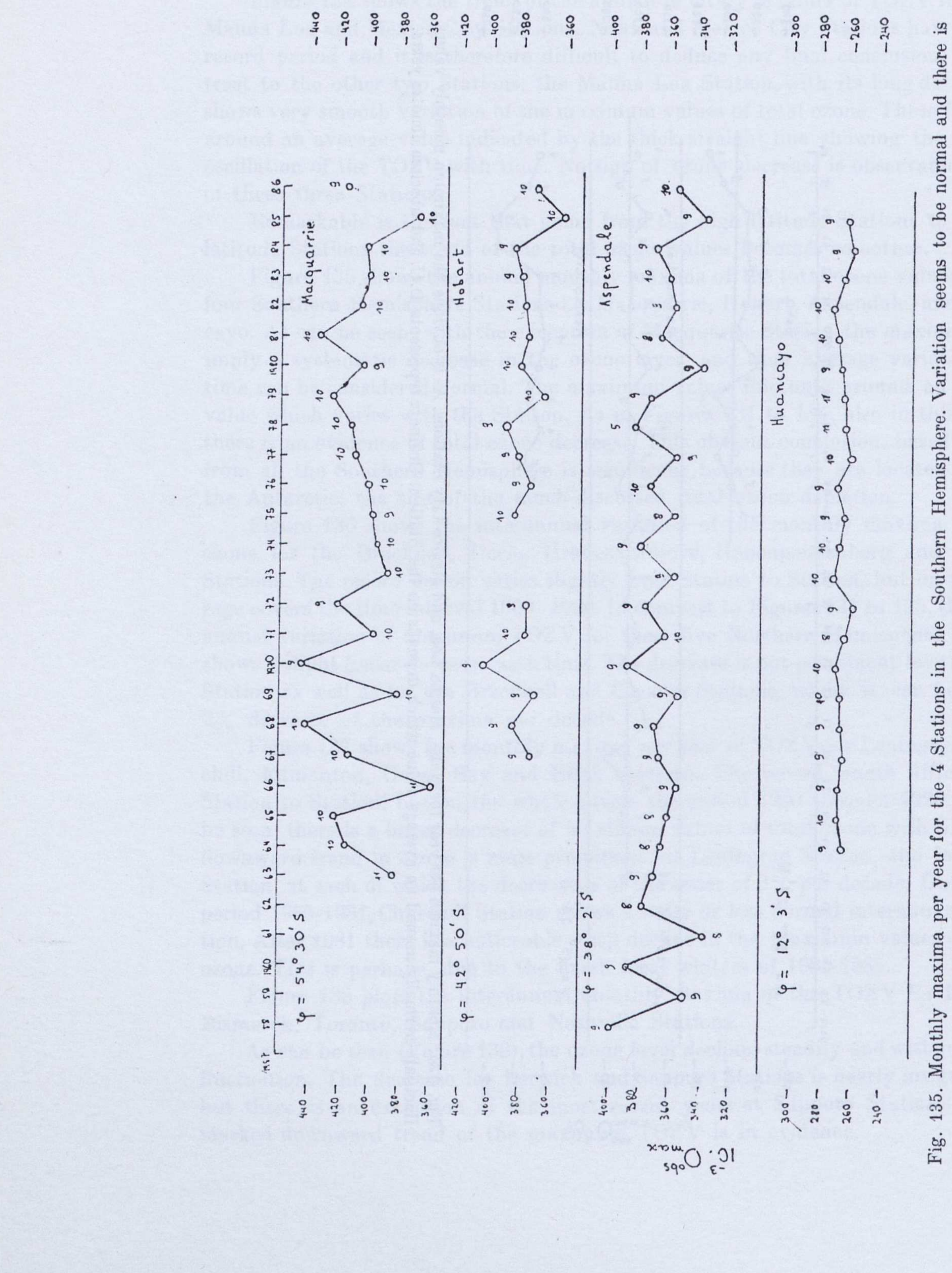

Fig. 135. Monthly maxima per year for the 4 Stations in the Southern Hemisphere. Variation seems to be normal and there is no decrease in the average maxima. Ordinate represents D.U and abscissa denotes years.

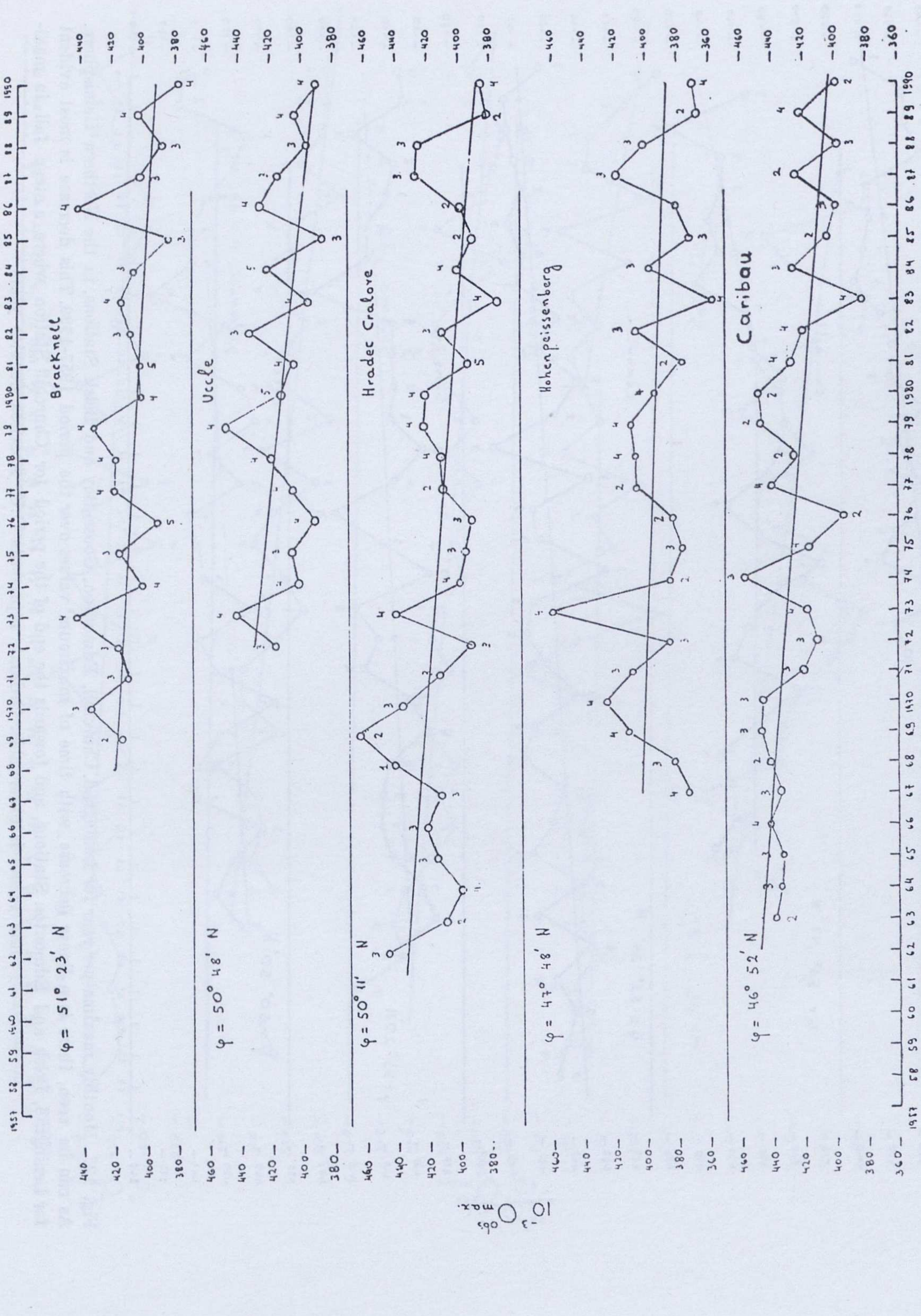

Fig. 136. Monthly maxima per year for Bracknell, Uccle, Hradec Crálové, Hohenpeissenberg and Caribou Stations. In this Figure can be seen a slight linear decrease of maximum values of total ozone during the period 1960-1990. Ordinate represents D.U. and abscissa denotes years.

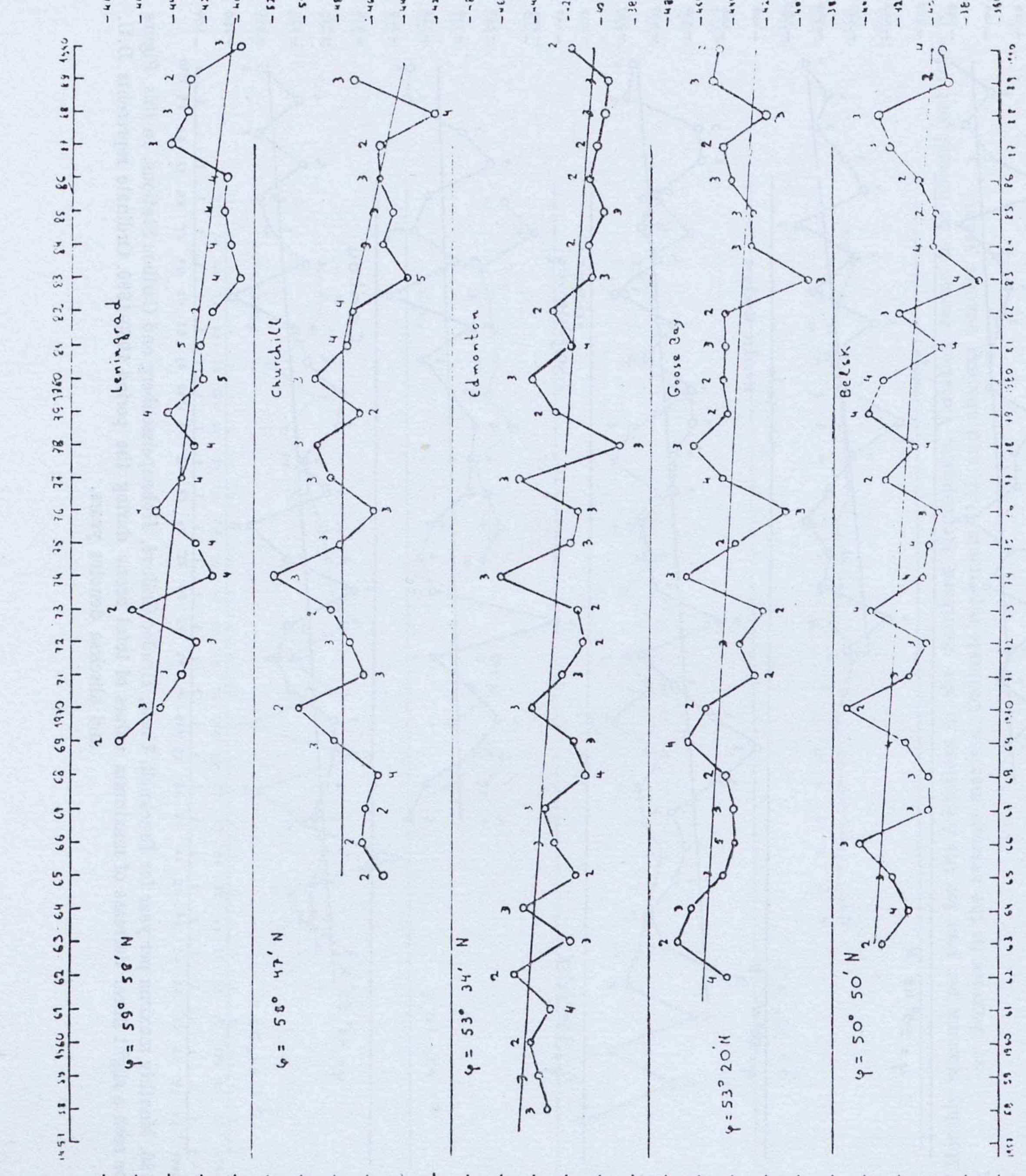

Fig. 137. Monthly maxima per year for Leningrad, Churchill, Edmonton, Goose Bay and Belsk Stations, in the Northern Hemisphere. As can be seen, there is a linear decrease with time of maximum values over the period 1957-1990. This decrease is most evident for Leningrad, Belsk and Edmonton Stations, and towards the end of the period for Churchill Station where a steep fall in maximum values is observable. Ordinate represents D.U. Abscissa denotes years.

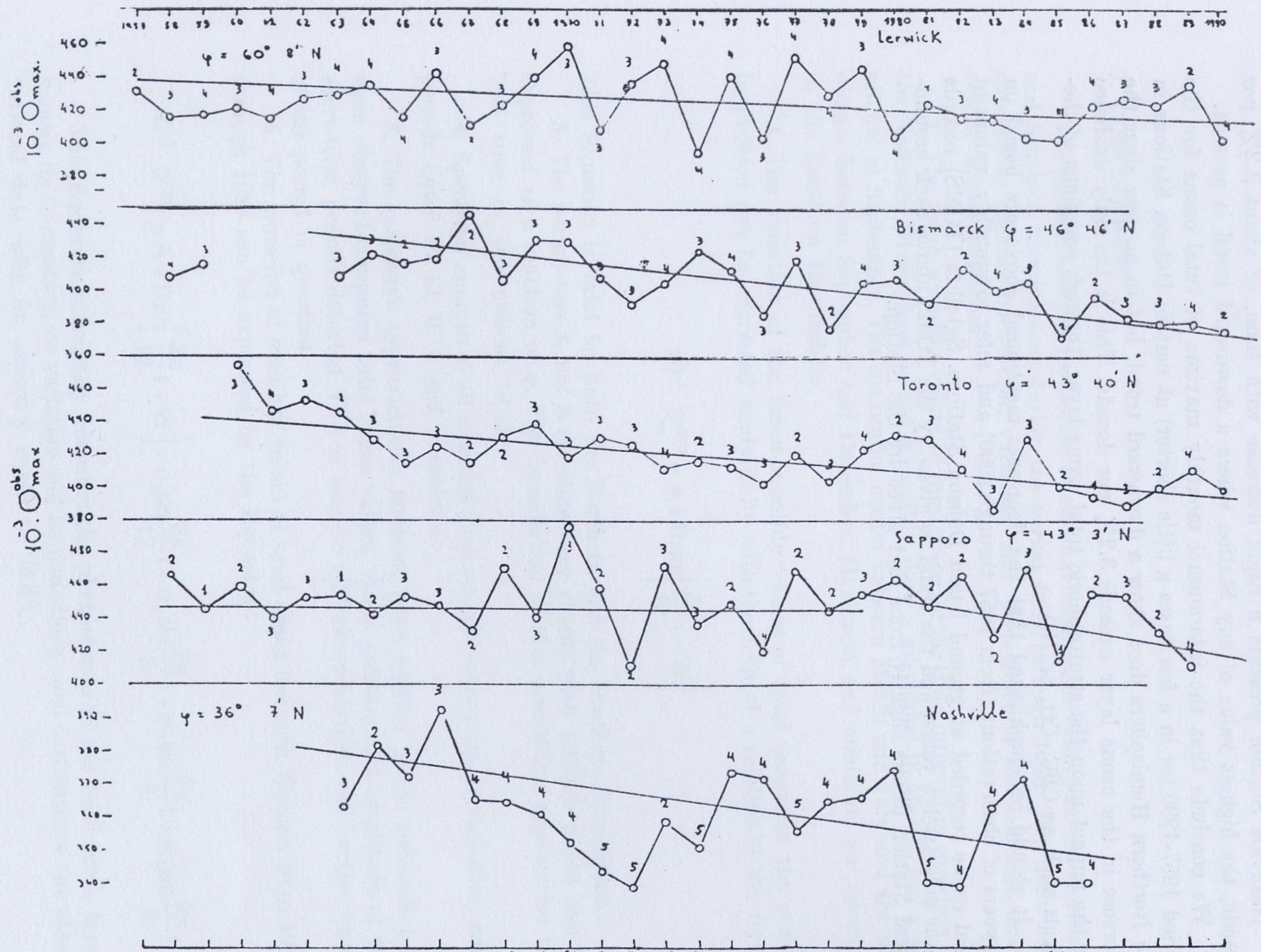

Fig. 138. Monthly maxima per year for Lerwick, Bismarck, Toronto, Sapporo and Nashville Stations, in the Northern Hemisphere. A linear decrease of the maximum values of total ozone with time can be clearly seen. This decrease is most pronounced for Bismarck, Toronto, and Nashville Stations. Ordinate represents D.U. Abscissa denotes years.

Nashville Station presents a rapid decrease with time, of about 3.2% per decade, the highest value of any Station where a downward trend is present.

We conclude that the interannual monthly maxima of total ozone for the period 1957-1990 (or in a few cases a little shorter) at certain Dobson Stations in the Northern Hemisphere does show a downward trend, but in no case does the decrease in the ozone layer exceeds 3.2% per decade. This is the only evidence for the impact upon the stratospheric total ozone layer, through emissions of chemicals such as CFC, CO, or NO.

It should be emphasized that the decreases mentioned above are based on 34 years of observations (from 1957 through 1990) and refer to monthly values of total ozone recorded at ground based Dobson Stations. Satellite (TOMS) records cover only twelve years, and the trend as given by the TOMS above each ground-based Station differs slightly from that given by the Station.

7. CONCLUSIONS

The present analysis makes use of all total ozone observations in the Northern and Southern Hemispheres during the period 1957 through 1990. The main conclusions as regards fluctuation, variation and periodicity of stratospheric ozone can be stated as follows:

1. The mean monthly values of total ozone for the time interval in question, in the Northern Hemisphere do not invariably show a maximum in March and a minimum in September. The maximum occurs between March and July and the minimum between September and December. Maximum and minimum are inverted in the Southern Hemisphere.

2. The variation of the mean monthly values of total ozone for the period in question can be expressed analytically with the help of a relation of the form:

$$10^{-3} \cdot 0_{m}^{com} = A + B\sin\left[\frac{2\pi}{12}t + W\right]$$

This Equation is valid for both the Northern and the Southern Hemisphere.

3. The parameters **A** and **B** correlate very closely with lattiude **φ** and can be expressed as a function of **φ**. The formulation of this correlation appears for the first time in the present Study.

4. Spectrum analysis of all avalable data reveals short-term periodicities, with periods aqual to 12, 6, 4 and 3 months.

5. The successive approximation method, when applied to the residuals between observed-computed total ozone values, shows position and amplitude of the short-term periods detected. This is true for all Dobson Stations and for the whole of the period in question.

6. The variation of monthly values of total ozone for each Station from 1957 through 1986 can be expressed by the Equation:

$$10^{-3} \cdot 0^{com} = A + B\sin\left(\frac{2\pi}{12}t + W\right) + \alpha_1\sin\frac{2\pi}{12}t + \alpha_2\sin\frac{2\pi}{6}t + \alpha_3\sin\frac{2\pi}{4}t + \alpha_4\sin\frac{2\pi}{3}t$$

This Equation completely describes the phenomenon of the total ozone layer, namely its fluctuation, its variation and its periodicity, and furthermore the observational data with an accuracy equal to 98.8%.

7. The per year monthly minima of total ozone for the period 1957-1990 do not fall below 240 D.U.

8. The per year monthly maxima of total ozone for the period 1957-1990 show a slight linear decrease with time for nearly half the Stations in the Northern Hemisphere (15 out of 33 Stations).

In no case does the decrease exceeds 3.2% in any ten year-period.

ACKNOWLEDGMENTS

The authors wish to express their gratitude to Dr. R.D. Bojkov for providing all the corrected ozone data used in the present work.

They are particularly deeply indebted to the Research Committee of the Academy of Athens for providing financial support through a grant which made possible the carrying out of the present research work.

Thanks are also due to Dr. R. C. H. Witt for his valued assistance in the structuring of the text.

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ΠΕΡΙΛΗΨΗ

Το όζον είναι ένα αέριον εκ των συστατικών της ατμοσφαίρας και ευρίσκεται συγκεντρωμένον εις ύψος μεταξύ 15 km και 35 km από της επιφανείας της θαλάσσης. Όπως είναι γνωστόν η περιοχή αυτή της στρατοσφαίρας είναι μία πολύ ευάλωτη περιοχή της γήινης ατμοσφαίρας και υφίσταται την επίδρασιν τόσον των φυσικών όσον και των ανθρωπίνων επιδράσεων. Φυσικά φαινόμενα επιδρώντα επί του όζοντος μπορεί να είναι περιοδικά ή παροδικά. Διακυμαντικού τύπου φαινόμενα περιλαμβάνουν την οιονεί—διετή διακύμανσιν των ανέμων εις την περιοχήν της τροπικής στρατοσφαίρας καθώς και άλλους παράγοντες και παραμέτρους που σχετίζονται στενά με 11 - ετή ηλιακό κύκλο.

Παροδικά φαινόμενα περιλαμβάνουν, π.χ. ηφαιστιακές εκρήξεις, πυρηνικές εκρήξεις κλπ. Διά τα ανωτέρω είδη επιδράσεων επί του όζοντος υπάρχει πλούσια βιβλιογραφική αναφορά.

Εις την παρούσαν έρευναν παρουσιάζονται εντελώς νέα αποτελέσματα, ευρήματα και συμπεράσματα σχετικώς με την διακύμανσιν, την μεταβολήν και την περιοδικότητα την οποία εμφανίζει το στρώμα του ολικού όζοντος (εφεξής αναφερομένου ως ΣΟΟΖ) τα οποία σημειωτέον βασίζονται εις τα πλέον ποιοτικώς ηλεγμένα δεδομένα τα οποία διαθέτει ο επιστημονικός κόσμος σήμερον και τα οποία παρεχωρήθησαν κατ' αποκλειστικότητα εις το Κέντρον Ερευνών Αστρονομίας και Εφηρμοσμένων Μαθηματικών (Ακαδημαϊκόν Ι. Ξανθάκην) υπό του Dr. R. Bojkov, Διευθυντού του Τμήματος Περιβάλλοντος του Διεθνούς Μετεορολογικού Οργανισμού (εφεξής WMO) δια του Καθηγητού κ. Χρ. Ζερεφού) αφού προηγουμένως ηλέγχθησαν από ειδικούς επιστήμονες της NASA και του WMO.

ΥΛΙΚΟΝ ΤΩΝ ΠΑΡΑΤΗΡΗΣΕΩΝ

Το υλικόν των παρατηρήσεων περιλαμβάνει μηνιαίες τιμές του ολικού όζοντος προερχόμενον από 33 επιγείους σταθμούς παρατηρήσεων του Βορείου και Νοτίου Ημισφαιρίου και καλύπτει την χρονικήν περίοδον 1957-1990. Το υλικόν αυτό παρεχωρήθη ευγενώς υπό του WMO της Γενεύης και δη, υπό του Dr. R. Bojkov, διευθυντού του Τμήματος Περιβάλλοντος του εν λόγω Οργανισμού και τον οποίον ευχαριστούμεν και από της θέσεως αυτής.

Αι μηνιαίαι τιμαί του όζοντος εχρησιμοποιήθησαν δια την μελέτην της διακυμάνσεως, της μεταβλητότητος και της πιθανής περιοδικότητος που εμφανίζεται να υπάρχει εις το ΣΟΟΖ. Οι σταθμοί παρατηρήσεως καλύπτουν όλο το πλάτος από 74^0 N έως 54^0 S.