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The Trends of Biologically Active Ultraviolet Radiation Exposure in Taipei, Taiwan

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ABSTRACT

The decreasing trend of total ozone in Taipei is presened, analyzed and discussed. Seasonal trends of the total column ozone show that winter has the sharpest decreasing trend in the past. Summer shows the slightly increasing trend from the TOMS data. The result from trend analysis of total ozone levels provides the information for the estimation of UV-B reached the surface in Taipei. The UV-B model predicts that the future increasing exposure of UV-B due to the decreasing ozone level varies dependent upon the legislation enacted in Taiwan.

(Key words: Total column ozone, UV-B radiation, TOMS data, Trend anaysis, Taipei, Future UV-B scenarios)

1. INTRODUCTION

Ozone depletion is one of the major concerns in earth history. Many researchers have documented the discovery of a decreasing trend of ozone concentrations in Antarctic regions (Michaels and Stookskury, 1992; Hamill and Toon, 1991). Ozone, serving as the shield for the Earth from the overreaching of UV radiation, has declined as much as 8% over the past decade in between 40° and 50° (WMO, 1992). Several researchers have noted the negative trend of total ozone measurements based on monthly data (Niu *et al.*, 1992). At low latitude, the changes in total ozone levels were found to be near zero but and negative at middle and high latitudes in both hemispheres (Stolarski *et al.*, 1991). Researchers also analyzed the seasonal trend of total ozone. It was found that in the summer time there was about a 2% decrease per decade over middle latitudes, but an even greater decrease in winter.

The decrease in total ozone causes the intrusion of more UV light, which leads to several potential effects such as cataracts , skin cancer, and damage to immune systems as well as to the DNA structure (Elmer-Desitt, 1992). Abnormal UV radiation would also alter the routine mechanism of marine life (Carmichael, 1992).

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Because of recent urbanization in some dense areas, surface ozone levels in large cities have been steadily increasing. Based on the finding of a 20-record of ozone ballon soundings in Switzerland, Staehelin and Schmid (1991) reported the rising tropospheric ozone since 1969. Since then Ozone in urban areas has been considered to be one of the major source of pollution (Girgzdiene, 1991).

Due to the complication of a decrease in total ozone and an increase in tropospheric ozone, the study of solar radiation reaching the earth's surface has become interesting and somewhat intriguing. In this case study, Taipei, Taiwan has been selected as the study area because of its location and population. In recent years, Taipei has developed into a highly commercialized urban area and its population has increased from 1 to 3 million within the past 15 years. Trends of total ozone measurements are discussed and a prediction of future concentrations based on past data serves here as the evidence for the UV-B prediction models.

2. METHODOLOGY

2.1 Source of Data

Since November 1978, total ozone has been measured on a nearly global basis by the Total Ozone Mapping Spectrometer (TOMS) from the Nimbus 7 satellite. The TOMS measures the earth's ultraviolet albedo at several wavelengths near 300 nm. The main problem with maintaining a long-term ozone record with the TOMS has been the degradation of the diffuser plate used to make the solar observation for the determination of albedo. Ozone data from the TOMS before 1983 included a correction for diffuser plate darkening (Fleig *et al.*, 1986). Recent measurements of ozone data, however, have been corrected through an improved method. Thus, a precision of 1.3 percent is the final estimation of ozone data relative to the beginning of the record.

Satellite measurements of the vertical profile of stratospheric ozone have been made by the Stratospheric Aerosol and Gas Experiment (SAGE). SAGE I data began in February 1979 and extended through November 1981. SAGE II was the instrument of experiment on the Earth Radiation Budget Satellite (ERBS). and it has been continuously operated since October 1984. The technique employed in SAGE is solar occultation, and profile measurements are obtained at sunrise and sunset on each orbit. This measurement technique is insensitive to drift in instrumental calibration, but there may be systematic differences between the data from SAGE I and SAGE II. Since the data used in this study were derived from SAGE II only, such differences do not pose a problem in final representation of the data. Data from the SAGE II contain the vertical profile of ozone, temperature, and pressure data plus other measurements such as NO_2, aerosols and water vapor. Spatial coverage of the SAGE II ranges from 80°N to 80°S (for 5 km above or cloud tops). Resolution is 250 km by 250 km horizontally and 1 km below 25 km and 5 km above 25 km vertically. The SAGE II provides an ozone concentration profile of the stratosphere and troposphere (above 5 km), as derived from solar occultation radiometric measurements.

2.2 The UV-B Calculation Model

The prediction of UV irradiances and photolysis prototype was based on the model developed by Bruhl and Crutzen (1989). However, a modified model was performed to obtain the estimates of UV-B exposures for Taipei. This section outlines the fundamental theories behind this computer model.

(a) Spectral Diffuse: spectral diffuse downward and upward irradiance Y^u, Y_d and the direct irradiance S are

$$\frac{dY^u}{du} = k_1 Y^u - k_2 Y_d - \frac{k_3 S}{\cos q}$$

$$\frac{dY_d}{du} = k_2 Y^u - k_1 Y_d - \frac{k_4 S}{\cos q}$$

$$\frac{dS}{du} = \frac{-(1 - Yg^2)S}{\cos q}$$

where

u: optical depth, counted from the top of the atmosphere,
g: the asymmetry factor which accounts for anisotropic scattering by aerosol and cloud particles,
q: solar zenith angle, and
w: single scattering albedo,

and

$$k_1 = 2(1 - w(1 - b)) \qquad k_3 = (1 - g^2)wb(q)$$

$$k_2 = 2wb \qquad k_4 = (1 - g^2)w(1 - b(q))$$

where
b: backscatter coefficients= $\frac{3}{8}(1 - g)$, and
$b(q)$: diffuse and direct radiation=$\frac{1}{2} - \frac{3}{4}\frac{g}{1+g}$ cos$q$.

In order to compute the photolysis rates, the required actinic fluxes are derived from the irradiances (Madronich, 1987):

$$\int_0^{2x}\int_0^{x} L(\theta', \Theta') \, sin\, \theta' d\theta' d\Theta' = \frac{S}{\cos\theta} + 2(\Psi_d + \Psi^u),$$

where $L(\theta', \Theta')$ is the radiance from zenith angleθ' and azimuthΘ'.
The above outline of the configuration of computer models is used for calculating the UV-B and other related parameters.

3. RESULTS AND DISCUSSION

3.1 Trend Analysis

Niu *et al.* have researched the trend of total ozone measurements based on TOMS data (Niu *et al.*, 1992). In this study, the variation of ozone levels in different categories such as month, latitude and longitude were discussed and presented. A twenty-nine percent decrease in the total ozone per decade was found in the region of 70°S and 20°W-100°W. A maximum decrease in total ozone was found to be seven percent in the northern hemisphere. They also proposed a specific time series model to estimate the seasonal variation of total ozone levels.

One of the major purposes of the present study is to find the ozone trend in one specific location, Taipei, and to predict the UV-B that reaches the surface in this area. Taiwan is an island located at 24°N and 121°E of the Pacific Rim (Figure 1). With a population of 20 million people living in a 36,000 square-kilometer area, this country has gone through a rapid industrialization process over the past ten to twenty years. Recent studies have shown the surface ozone problem in Taipei with higher surface ozone levels during the summer season (Liu *et al.*, 1990). To understand the existing trend, the authors start from the global visual image of total ozone, then focus on ozone trends in Taipei and finally predict solar radiation change in the future.

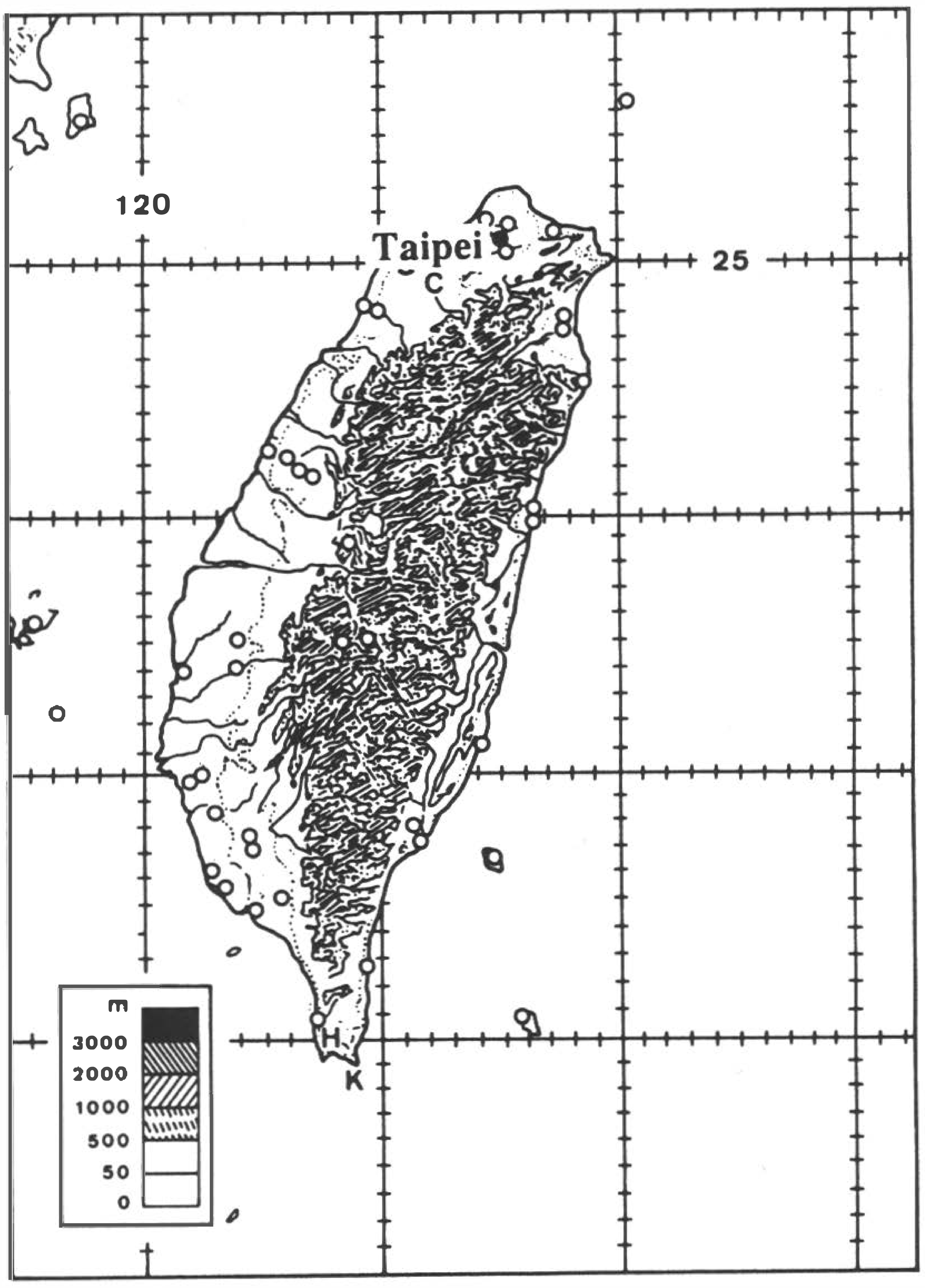

Fig. 1. Taiwan.

Figure 2 presents the minimum total ozone concentration on the latitude band of 20°N to 30°N globally. This presentation also shows the time serial decreasing trend during the past decade.

Figure 3 shows the thirteen-year daily data of total ozone over Taipei from the TOMS. A total of 4,834 daily records is shown in this figure. The all time low total ozone level is found in the winter of 1984/85, but this is not found in Figure 2, indicating that the detailed analysis is necessary to obtain the information of ozone trend in a specific location.

3.2 Statistical Analysis of Total Ozone Levels

A total of thirteen-years of data is available from the TOMS as mentioned above. Starting from daily data, the total ozone level trend shows a slightly decreasing trend over the past decade. Figure 3 presents all the data points collected from the TOMS. A 5.63

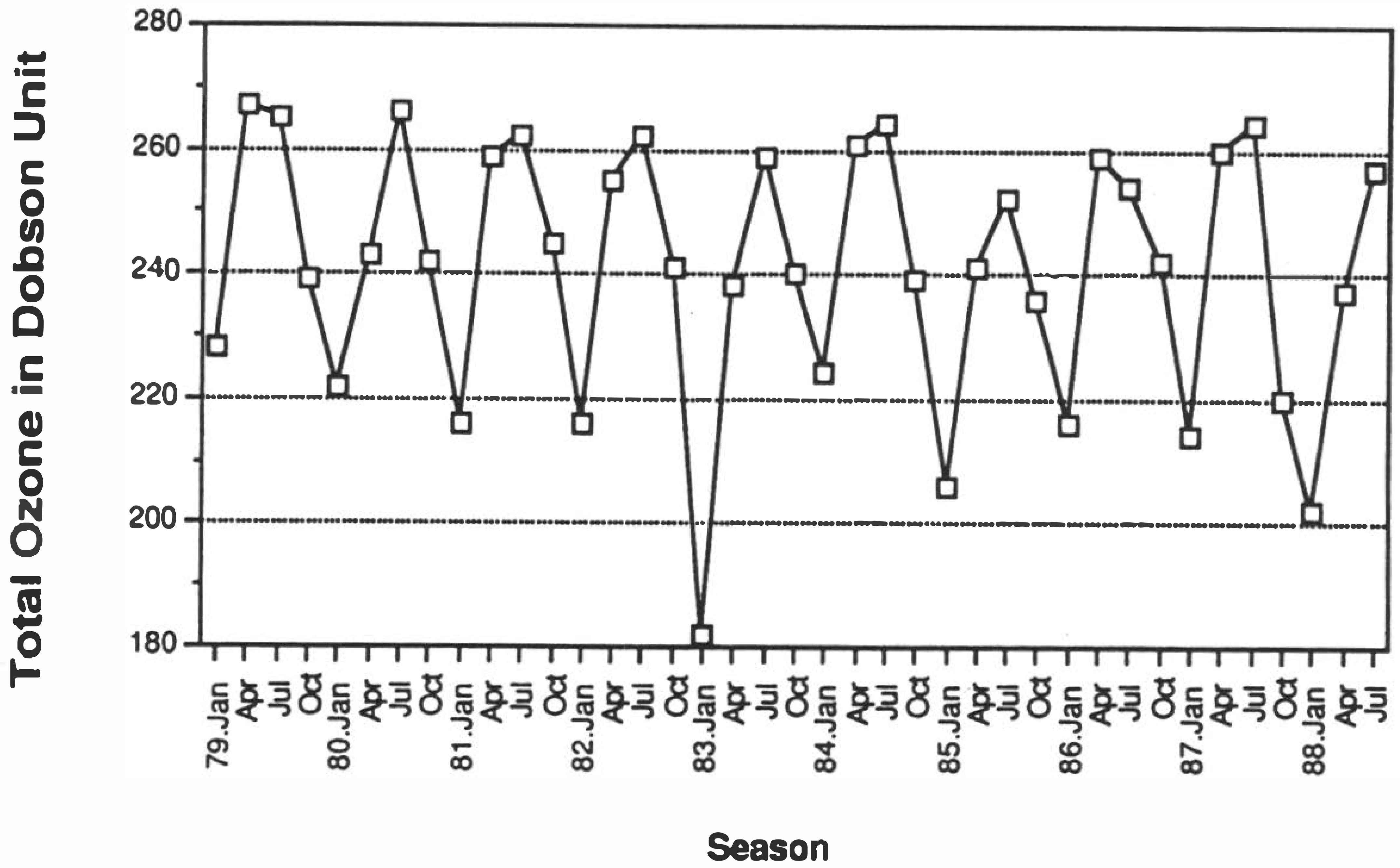

Fig. 2. Ozone trends on the 20N-30N latitude band, 1979-1988.

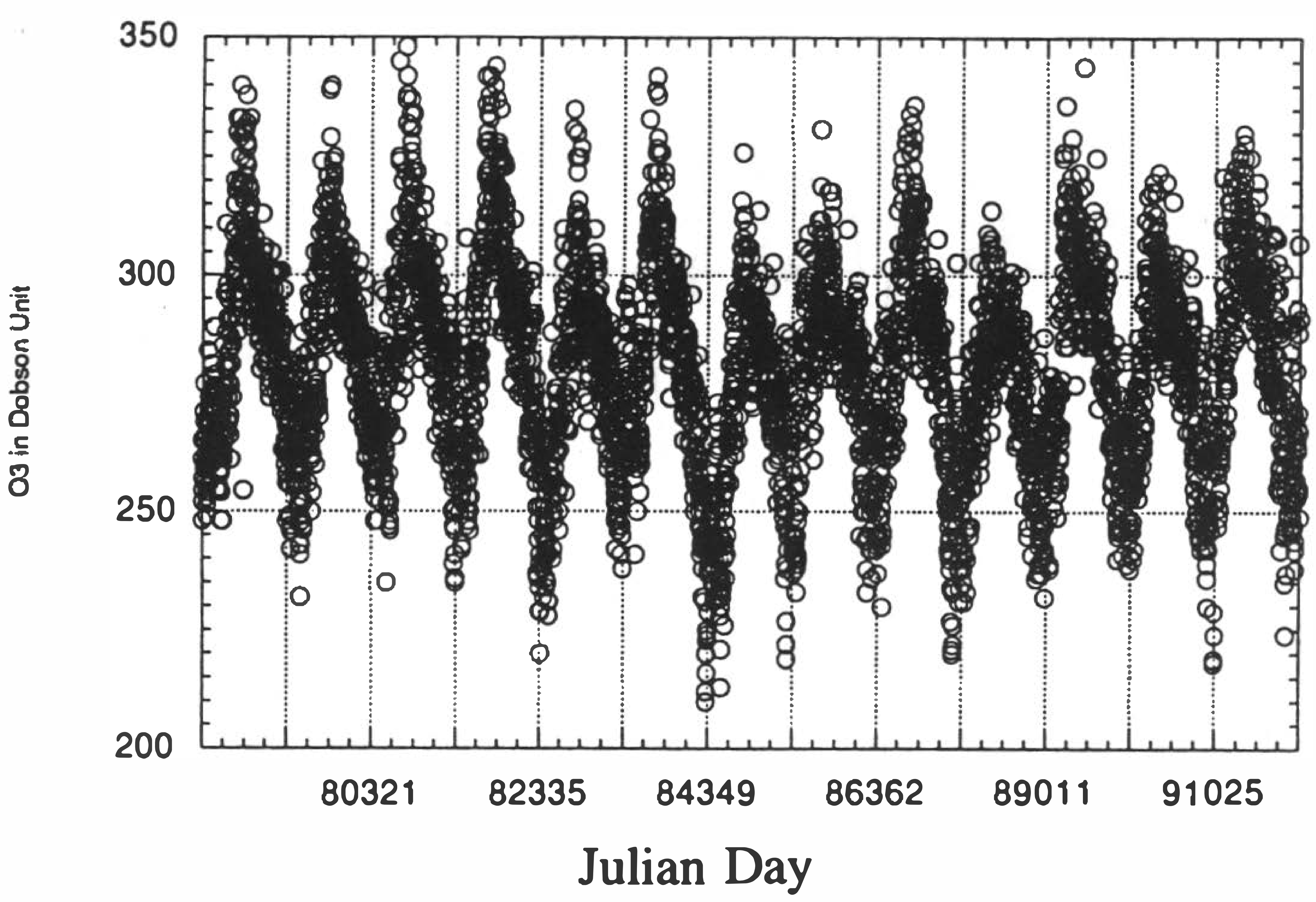

Fig. 3. Daily measurements of total ozone over Taipei, 1978-1992.

Dobson unit decrease in total ozone was noticed during this period, a decrease equal to a 1.99% decrease over the 13.25-year span. Thus, a 1.5% decrease per decade was shown in this figure.

Figure 3 presents the daily variation of total ozone measurements over the 13-year period. Overall, the decreasing trend was determined to be 1.5% in the past decade. This type of data isn't useful in analysis; , thus, further integration of data is needed and provided here. A monthly pattern of ozone variation is shown in Figure 4. The comparatively low ozone level in winter as shown in Figure 4 suggests that the study of the integrated data of seasonal change would be more useful. The integrated data in Figure 5 presents the seasonal variation over the past decades for ozone measurements. Winter is defined as the season from December through February, Spring as the season from March through May, Summer as the season from June through August and Fall as the season from September through November. Again, the specific pattern of low winter ozone is seen evident. As indicated

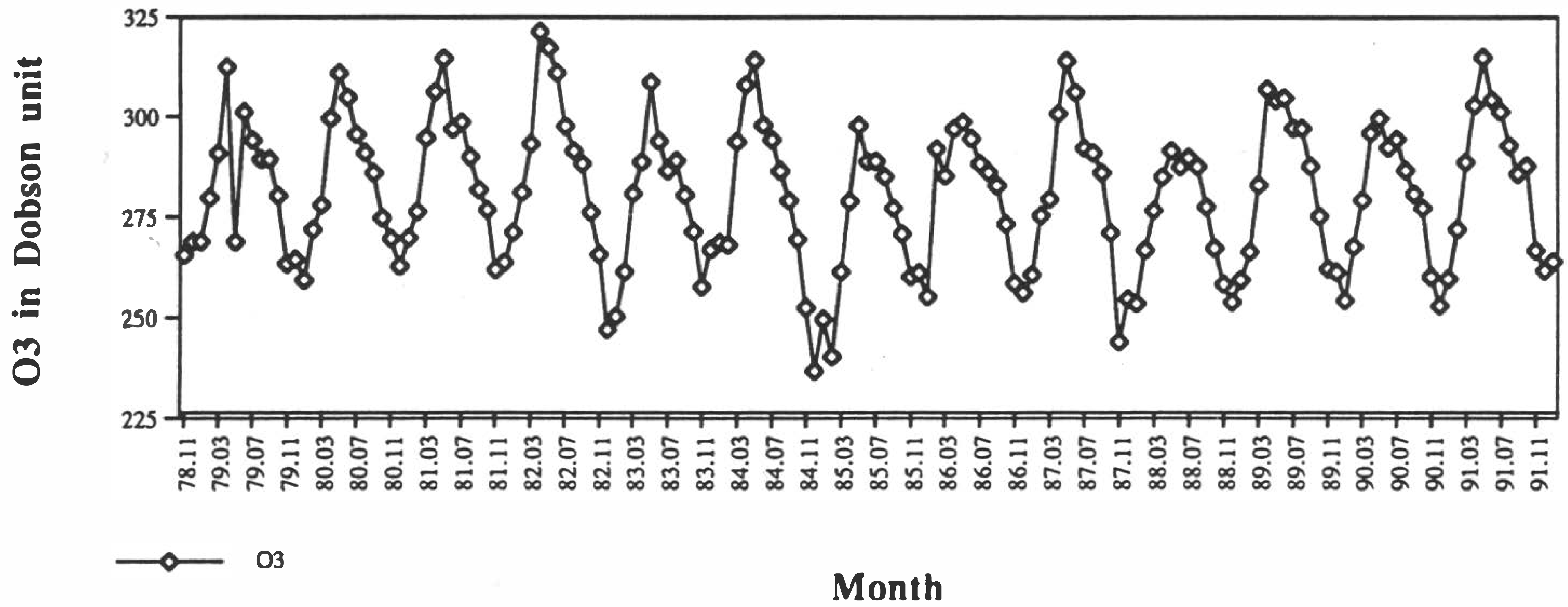

Fig. 4. Monthly ozone over Taipei from 1978-1992.

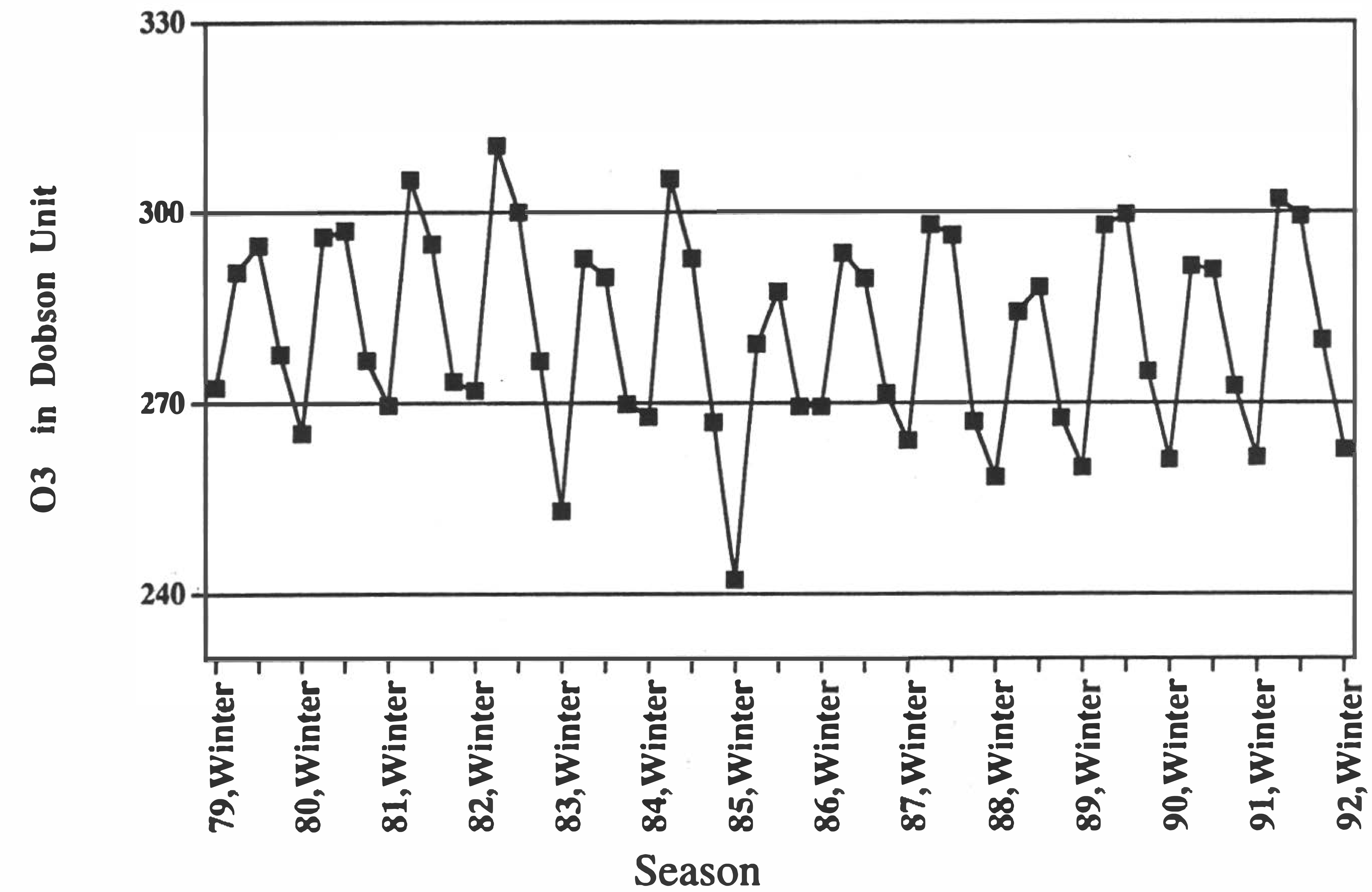

Fig. 5. Seasonal ozone variations over Taipei from 1979-1992.

in Figure 5, each season shows the particular trend that can not be discussed in terms of yearly trends. Figures 6, 7, 8, and 9 display the variation in ozone measurements over the past decade for four seasons. Winter has the largest decreasing trend as shown in Figure 6. A total 4.7% decrease was found in this study, which is equal to 12.5 Dobson Units (D.U.) of ozone depletion. In 1985, the total ozone level was observed at an average of 242 D.U. which is the record low of the past decade. Recently, from 1988 up to 1992, a slightly decreasing trend was measured, but still, the overall ozone level during this period has been decreasing accordingly. A pattern of random walk was recognized in observing the ozone level of Spring. This season presented a slightly decreasing trend in terms of the overall level (Table 1). Summer has had a very steady ozone level over the past decade as shown in Figure 8. A low ozone level span was found from 1983 through 1986. From 1983 to 1988, ozone was found at lower levels in Fall. In general, Winter and Spring had larger decreasing trend compared to those of Summer and Fall.

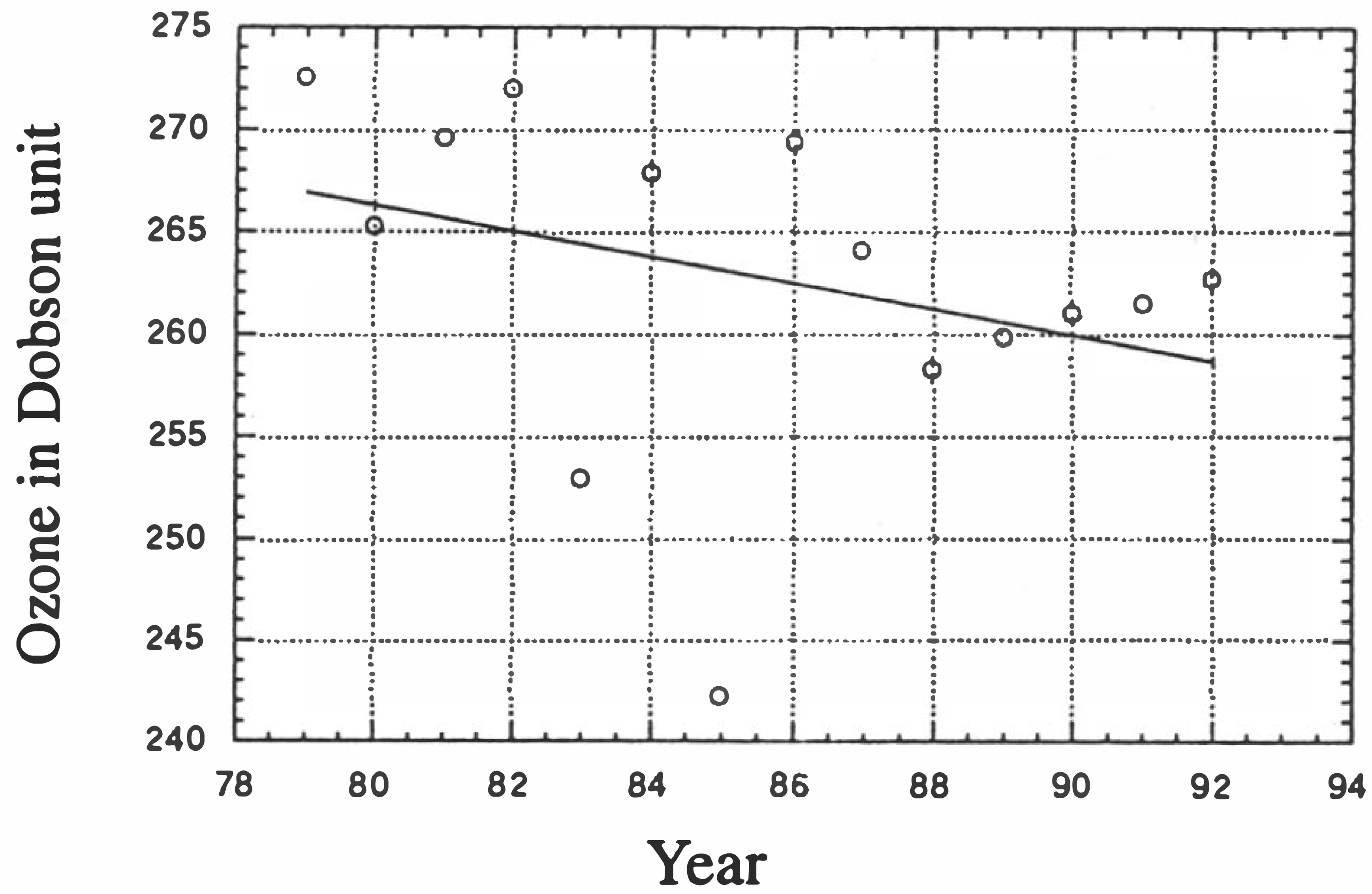

Fig. 6. Seasonal ozone variations for Winter.

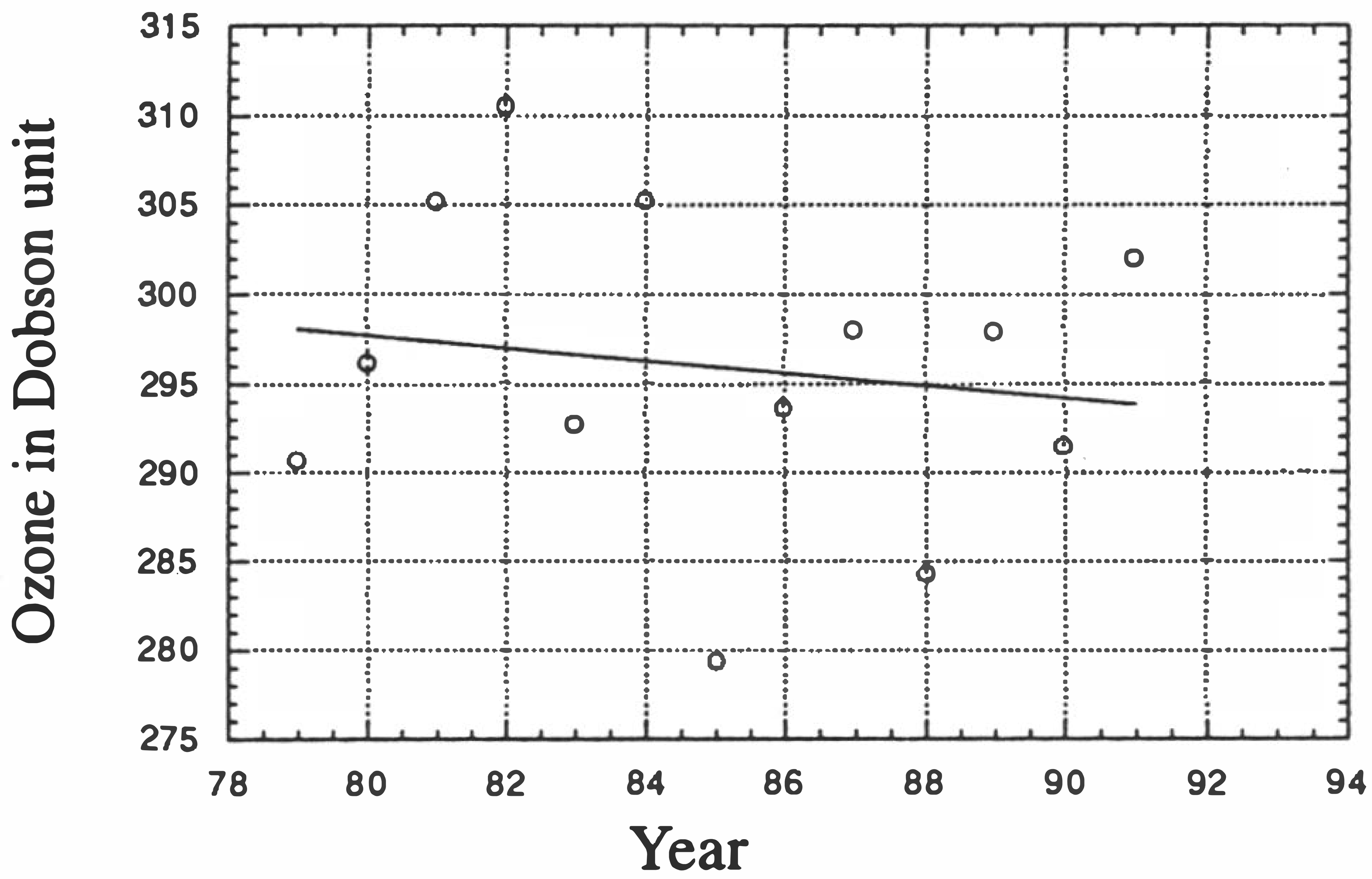

Fig. 7. Seasonal ozone variations for Spring.

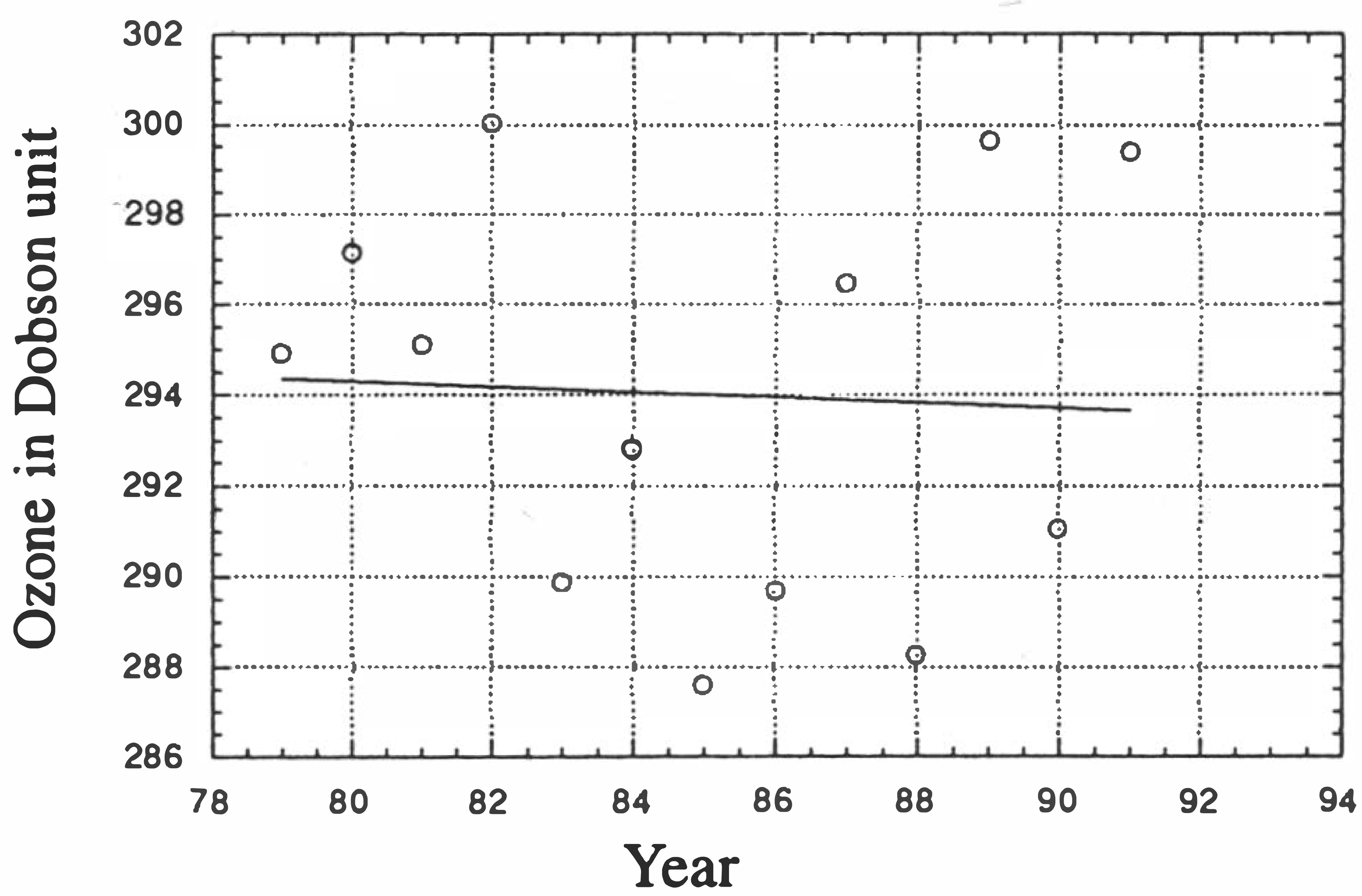

Fig. 8. Seasonal ozone variations for Summer.

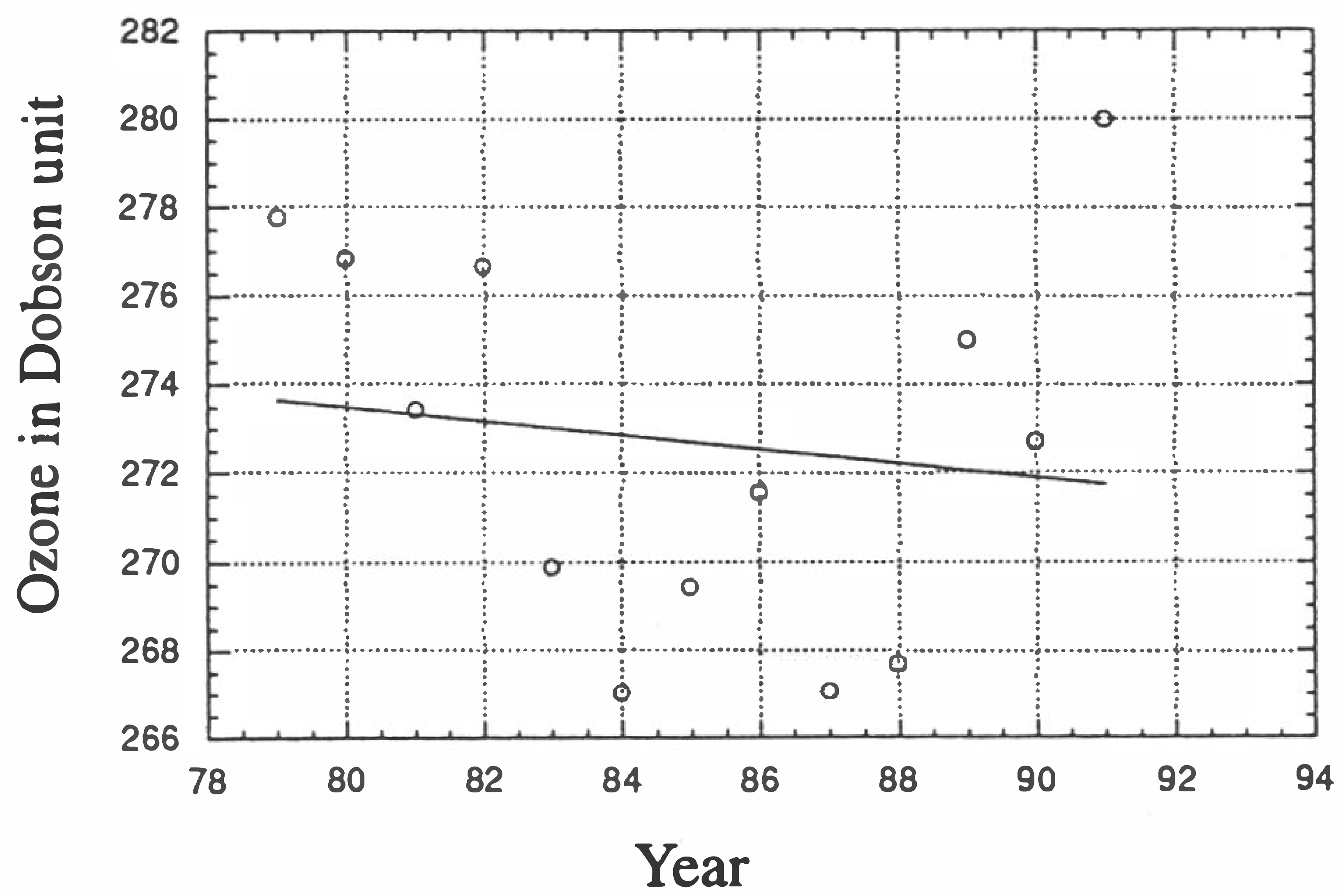

Fig. 9. Seasonal ozone variations for Fall.

Table 1. Seasonal variation of ozone measurement and their linear equation for past trends.

Season	Linear Equation	Change/ Decade	% Change/ Decade
Winter	Ozone = 317.20 - 0.636 * Year	- 12.5 D.U.	- 4.68
Spring	Ozone = 326.02 - 0.353 * Year	- 6.25 D.U.	- 2.34
Summer	Ozone = 299.15 - 0.060 * Year	- 0.60 D.U.	- 0.20
Fall	Ozone = 286.00 - 0.160 * Year	- 1.60 D.U.	- 0.60

Year: 78-92 for Winter; otherwise, 78-91.

3.3 Solar Radiation Change

An increase in tropospheric ozone due to the greenhouse effect in the industrialized northern hemisphere can overcompensate for increased UV-B radiation resulting from ozone depletion due to chlorine-catalyzed reactions in the stratosphere. Such a phenomenon is common, especially in urban areas. Taipei is one such city where a decreasing trend in total ozone and an increasing ozone concentration at the troposphere are shown.

Due to the positive effects of decreased ozone in total ozone levels and negative effects from the increase in surface ozone, the research of UV-B radiation is interesting and complex. Bruhl and Crutzen[11] showed the counter-effectiveness of these two phenomena by using estimated and observed data. The results from their study showed that, based on data from 1966 to 1986, a 0.5% decrease in the UV-B was observed . Other researchers also presented the seasonal UV-B flux variation and radiation models (Chou, 1992; Prasad *et al.*, 1992). Due to the lack of information on cloud amount and sunshine duration, the factors influencing the UV-B flux reaching the surface of Taipei, this paper only discusses the change of UV-B flux due to ozone concentrations.

A 1.5 percent decrease in total ozone per decade is confirmed for the urban area of Taipei (Figure 3). Data from the SAGE II and simulated models provide the ozone profiles for the analysis of past trends, from which the authors selected the years 1978/79 and 1988/89 for the starting and ending points of the past decade. Figure 10 shows the estimated seasonal changes of the UV-B in the past decade based on the total ozone data from the TOMS. In order to simulate future scenarios, the models used parameters modified from urban areas in the Eastern United States. The estimated UV-B (280 to 320 nm) flux based on the ozone trend in Taipei shows the decreasing trend over the last decade. The high percentage change shown in the summer is due to the assumption that there was much higher surface ozone in 1989 than in 1979. A significant decrease in the UV-B (10%) was found in summer (Figure 11). Winter had the largest decrease in the total ozone compared to other seasons (Figure 11), but it did not show the influence of ozone depletion. This result matches the observations reported by Scotto, *et al.* (1988). An average 7.75% decrease in UV-B flux reaching the surface of Taipei is shown in Figures 10 and 11. There are two scenarios studied in this case. The polluted scenario assumes that the current pollution trend extends into the future, but, on the other hand if clean air legeslation is enacted in Taiwan, an unpolluted scenario make for the future prediction. The two scenarios were defined to compare the polluted and unpolluted scenarios in the Spring of 2010. For the polluted scenario, a 10% increase in tropospheric ozone and 1.5% decrease in total ozone per decade was assumed and, for the unpolluted scenario, an unchanged tropospheric ozone level was assumed. Final simulation showed that a fourteen percent increase in the UV-B was expected in the unpolluted scenario compared to a near zero percent change on the UV-B due to the polluted source and ozone depletion (Figure 12).

4. SUMMARY AND CONCLUSIONS

In this research, major findings regarding the ozone trends on the Taipei area are presented, discussed and analyzed statistically. Satellite measured data were analyzed and a UV-B prediction model was used. The regional trends of ozone levels in Taipei are presented and discussed, and the results from ultraviolet radiation models are discussed. The major conclusions are outlined as follows:

- For the 20° to 30°N latitude band area, total ozone is plotted and discussed. A decreasing trend was observed while outliers show the extreme cases of ozone levels.
- Total ozone level data obtained from the TOMS show a decreasing trend in the Taipei area.
- Infonnation integration processes used in analyzing data present the differences in ozone in the past decade.
- Monthly percentage changes per decade indicate the seasonal trends in ozone. More than a 4% decrease per decade in ozone is observed in winter, while summer shows a very slightly increasing trend in the data.
- Daily, monthly, yearly, and seasonal variation of total ozone measurements are presented, compared and analyzed.
- UV-B model shows the decrease of UV-B flux over the last decade. Ten percent decrease of UV-B in Summer per decade is shown under certain assumptions. Winter has the least UV-B decrease with a 5 percent per decade during the last 10 years. For the year 2010, two scenarios are assumed to project the future UV-B radiation. The results show that unchanged UV-B is expected due to the interaction of polluted environment and total ozone depletion and a fourteen percent increase of UV-B due to only total ozone decrease, if the Clean-Air-Act legislation is enacted in Taiwan.

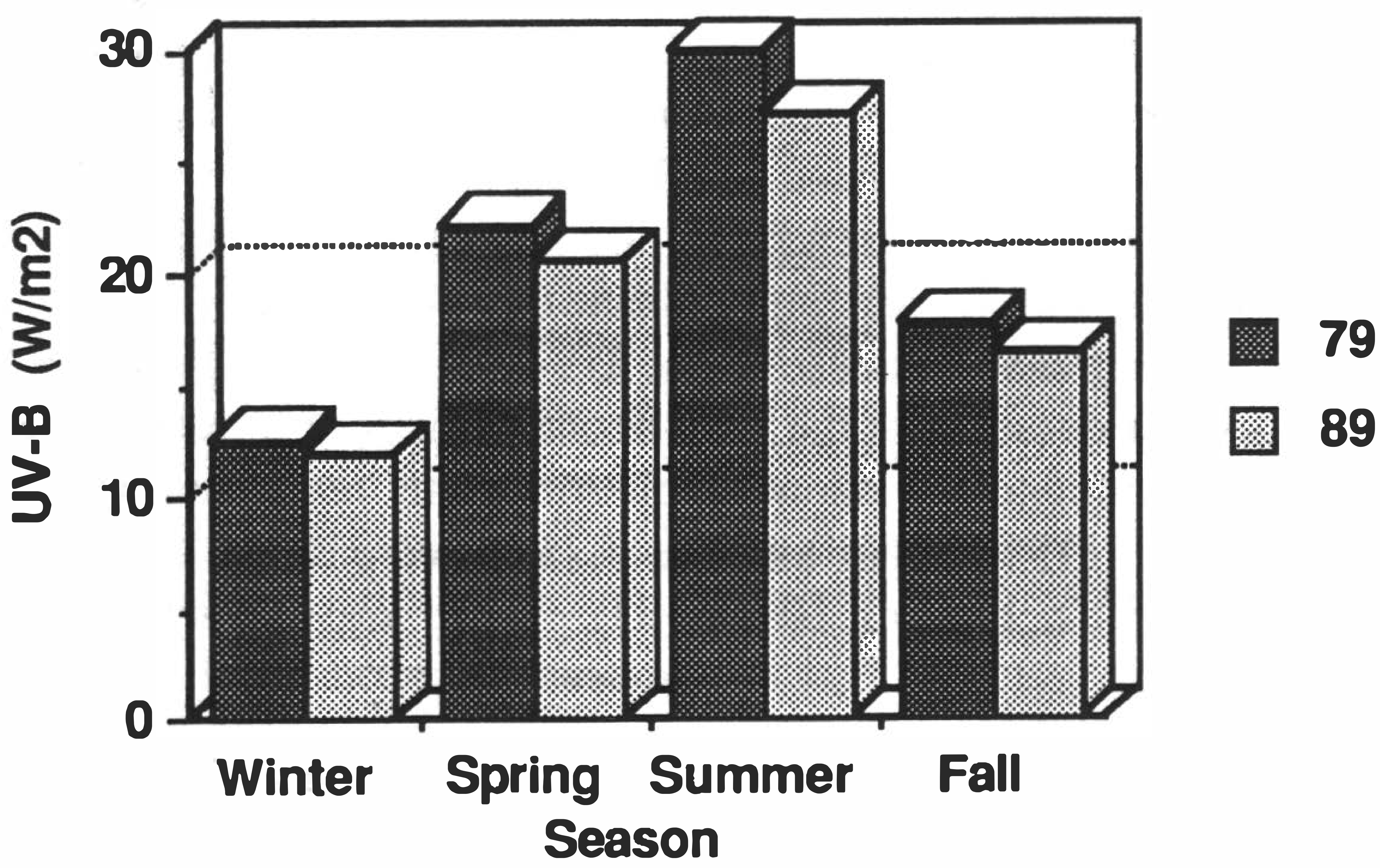

Fig. 10. Integrated UV-B estimated for Taipei.

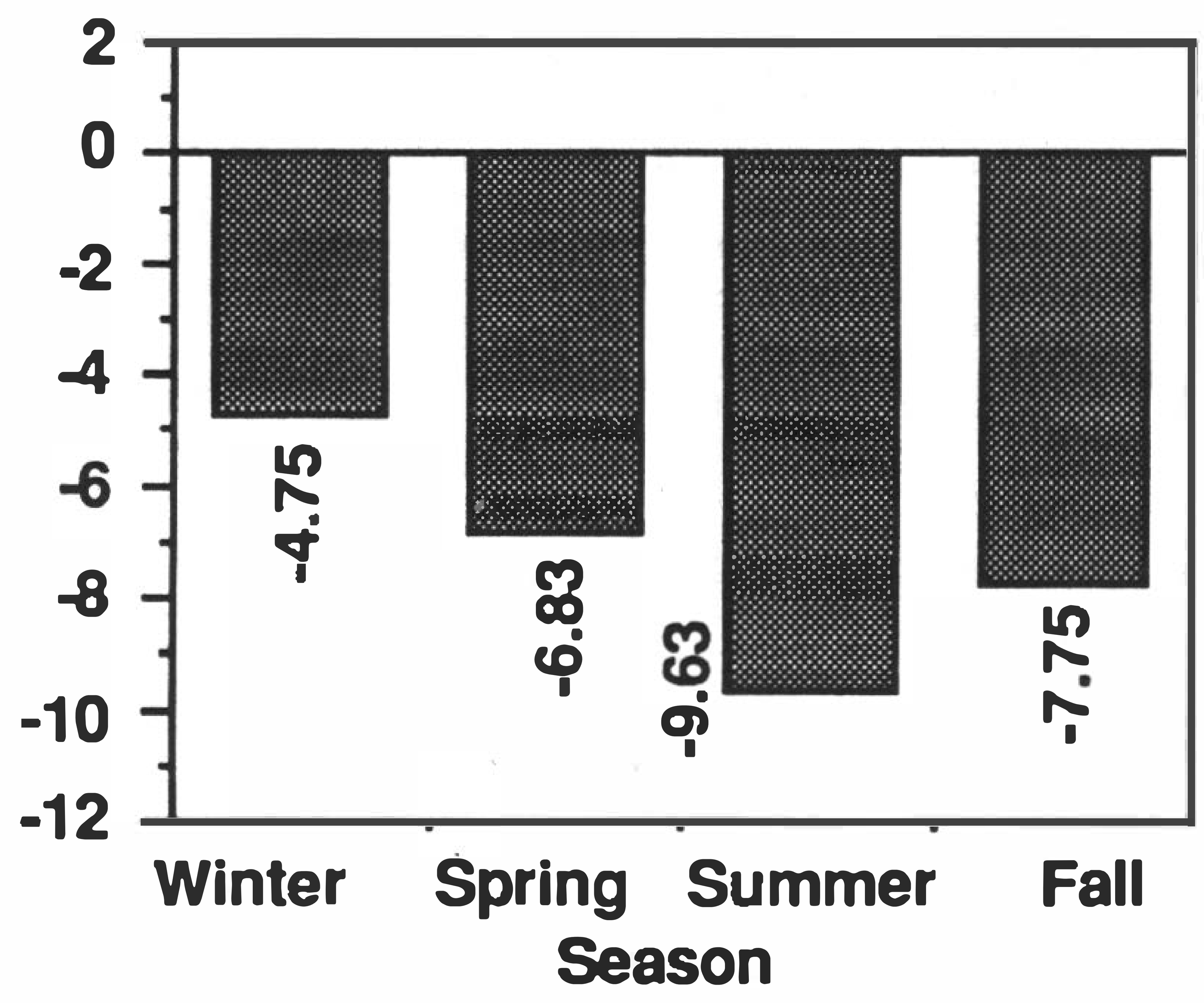

Fig. 11. Estimated percent change of UV-B over the past decade.

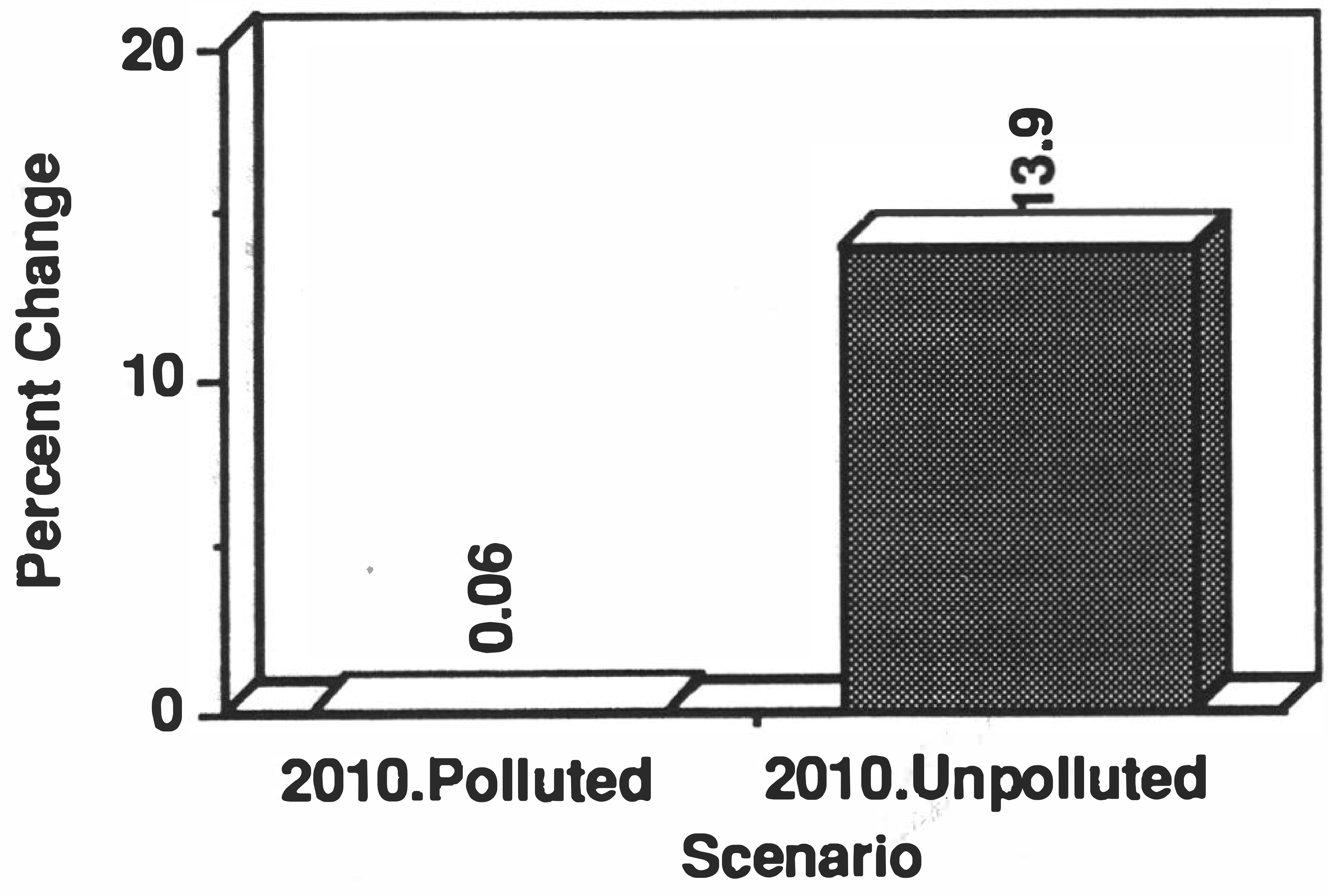

Fig. 12. predicted UV-B for scenarios of polluted and unpolluted Spring in year 2010.

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