Ozone variability over the Kingdom of Saudi Arabia

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ABSTRACT

The variability of ozone over the Kingdom of Saudi Arabia (KSA) has been studied in this paper. Higher values of coefficient of variation (COV) at all stations occurs at winter while lowest values occurs at autumn. The COV is function of latitude in annual, winter, spring and autumn values where it decreases gradually from the northern station to the southern station. The trend analysis of ozone over our stations indicates negative trends for both annual and seasonal time series with the greatest one at winter. Except at the year 1988, the long-term variability of the behavior of the annual ozone shows positive trend values in ozone are the dominant features during the period 1979-1993 at the most stations. Negative trend values in ozone are the dominant features during the period 1993- 2006 at all stations

1. Introduction

Despite its small proportion in terms of the total atmospheric composition, ozone plays an important role in global weather and climate as well as surface ecology. Ozone is an important trace gas which absorbs some of the biologically harmful ultraviolet radiation, therefore preventing them from reaching the earth's surface. An early paper by Molina and Rowland (1974) pointed out the potentially damaging effect that anthropogenic chlorofluorocarbon (CFC) emissions may have on the stratospheric ozone layer. Both satellite and surface data have documented a process of high stratospheric ozone depletion in the Antarctic environment during spring months (Farman *et al*., 1985; Stolarski *et al*., 1986). Although this effect cannot be expected to apply in other places to the same extent, more recent studies have indicated that ozone depletion is not confined to Antarctica, but that it has global features (Atkinson et al., 1989; Bojkov *et al*., 1990; Stolarski *et al*., 1991, 1992). There is some evidence showing that the decreased ozone levels have caused increases of ultraviolet radiation at the surface (Kerr and McElroy, 1993).

Analyses of total ozone have focused on trend analysis (Reinsel *et al.*, 1994; Bojkov and Fioletov, 1995) due to the increasing concern about dramatically decreasing stratospheric ozone. However, a full description of the variability of ozone should also include means, seasonal variation and extremes. This information should be more useful in understanding ozone dynamics. Evidence of global stratospheric ozone loss has been largely based on satellite observations. Over the northern hemisphere middle and high latitudes, data from Dobson stations have been used (Krzyscin, 1994). To measure long term trends in total ozone, an accurate instrument is required. The Brewer type spectrophotometer has proven to be one of the world's most accurate ozone-measuring devices (WMO, 1994). It should be remembered that ground-based instruments give point measurements, while satellite data cover a certain area. The objective of this work is to study the variability of ozone over the Kingdom of Saudi Arabia

2. Data

Total Ozone Mapping Spectrometer (TOMS) aboard Nimbus-7 and Meteor-3 provided global measurements of total column ozone on a daily basis and together provide a complete data set of daily ozone from November 1978 - December 1994. After an eighteen month period when the program had no on-orbit capability, ADEOS TOMS was launched on August 17, 1996 and provided data until June 29, 1997. Earth Probe TOMS was launched on July 2, 1996 to provide supplemental measurements, but was boosted to a higher orbit to replace the failed ADEOS. Earth Probe continues to provide near real-time data. Data resolution is 1º latitude by 1.25º longitude. The data are measured in Dobson Unite (DU) where 1000 DU are equivalent to 1 cm of ozone at 1000 hPa. The data set used in this study encompassed the period from 1978 to 2006. Occasionally, there are missing data (about 1% of the total data) which need to be dealt with in some fashion for calculation of the climatology. Linear interpolation is used to estimate missing values in order to complete the time series, which enables a computation of monthly and yearly means and a time series analysis of the daily data. Monthly and yearly means are calculated based on these daily values, assuming that they are representative of daily means.

The used data were obtained from the Total Ozone Mapping Spectrometer (TOMS) Ozone processing team NASA/GSFC code 613.3 from the web site http://toms.gsfc.nasa.gov/ozone/ozone_v8.html. The stations under study are distributed all over KSA, although their spatial density is low and uneven over some parts of the country. Table 1 illustrates the name, position and elevation of each of KSA meteorological stations.

Table 1: Name, position and elevation of KSA stations.

Name	Lat	Long	Elevation (m)	Name	Lat	Long	Elevation (m)
TURAIF	31.68	38.73	852	**WADI AWASER**	20.50	45.25	636
GURAIT	31.40	37.28	504	**SULAYEL**	20.46	45.617	10
ARAR	30.90	41.14	549	**MADINA**	24.54	39.69	4
ALJOUF	29.78	40.98	669	**YENBO**	24.14	38.06	1453
TABOUK	28.37	36.60	444	**JEDDAH**	21.71	39.18	240
HAIL	27.43	41.69	768	**MAKKAH**	21.43	39.79	701
WEJH	26.20	38.47	358	**TAIF**	21.48	40.55	614
RAFHA	29.62	43.49	413	**BAHA**	20.29	41.64	1652
ALQUSOMA	28.31	46.13	1002	**BISHA**	19.99	42.61	1162
HAFRBATEN	27.90	45.53	647	**ABHA**	18.23	42.66	2056
DHAHRAN	26.25	50.16	17	**KHAMIS MUSH**	18.29	42.80	2093
AHSA	25.29	49.48	24	**NAJRAN**	17.61	44.41	1212
GASSIM	26.30	43.76	178	**SHARURA**	17.46	47.10	725
RIYADH NEW	24.92	46.72	614	**GIZAN**	16.90	42.58	7
RYDOLD RY	24.71	46.73	620				

3. Methodology

Bartlett test con be used to examine the homogeneity of the data when Gaussian distribution of values is considered. The method is simply accomplished by dividing the concidered time series into K equal subperiod (k ≥2). The sample variance, S_k^2 is calculated using the following relation (Mitchell *et al.* ,1966):

$$S_k^2 = \frac{1}{n}\left(\sum x_i^2 - \frac{1}{n}\left(\sum x_i\right)^2\right) \qquad (1)$$

Where the summations range over the n values of the Series, Σi in the subperiod K. The estimated ratio between the maximum and minimum values $\left(S_{\max}^{2} / S_{\min}^{2}\right)$ is compared with the values given in table 31 of Pearson and Hartley (1958) to determine the percentage value of significance.

A coefficient of variation (COV) for each individual station has been determined as follows:

$$COV = 100 * SD / \mu \tag{2}$$

Where, SD is the standard deviation and μ is the temporal mean for N years.

Different methods have been applied to study the trend and fluctuations of ozone over the studied area. These methods are; (a) Linear regression by using Least Square method (Panofsky and Brier ,1963), (b) Gaussian low-pass filter (Mitchell *et al* 1966), (c) Binomial low-pass filter (Mitchell *et al.* ,1966 and Tyson *et al.*,1975). Also the non-parametric Mann-Kendall (M-K) rank correlation test (Sneyers, 1990; Schonwiese and Rapp, 1997; Hasanean, 2004) has been used to detect any possible trend in ozone series, and to test whether or not such trends are statistically significant.

To visualize the decadal and inter-decadal fluctuations or "persistence" in the behavior of the KSA ozone, cumulative seasonal means method is used (Pavia and Graef 2002). The advantage of this is to reveal time varying structures in time series. The cumulative seasonal means time series can be defined as;

$$y_j = \frac{1}{j}\sum_{i=1}^{j} x_i \ , \qquad j = 1,2,..............,N. \tag{3}$$

Where, x_i is the total amount of ozone and N is the number of years of data used. Of course, $y_{j=N} = \overline{x}(N)$.

4. Results

4.1 Homogenity of the data

Studies on data homogeneity is essential in climatology. Homogeneity is manifested differently in different climatic elements. The values of climatic elements could be the method of estimating daily and monthly averages. Artificial lakes and reservoirs and other man-made changes of local environment produce sources of inhomogeneity in historical record of climatic data.

Homogeneity of the ozone time series over the cities of KSA has been examined by means of Bartlet test (described in section 3). Table 2 shows Bartlet test (short-cut) result for annual ozone. The mean annual ozone seems to be homogeneous at all stations regarding the ratio (S^2_{max} / S^2_{min}) Bartlet test with 95% significance point (3.28) as shown in (Mitchell *et al*., 1966).

Table 2 : Bartlet test (short- cut) result for the KSA stations (n=14 is the number of terms in each subperiod k, and k=2 is the number of the subperiod).

Name	Annual	Name	Annual
TURAIF	1.08	WADI AWASER	1.49
GURAIT	1.08	SULAYEL	1.63
ARAR	1.02	MADINA	1.81
ALJOUF	1.17	YENBO	1.7
TABOUK	1.32	JEDDAH	1.79
HAIL	1.22	MAKKAH	1.71
WEJH	1.49	TAIF	1.7
RAFHA	1.44	BAHA	1.73
ALQUSOMA	1.3	BISHA	1.76
HAFRBATEN	1.27	ABHA	1.99
DHAHRAN	1.64	KHAMIS MUSH	2.0
AHSA	1.5	NAJRAN	1.57
GASSIM	1.5	SHARURA	1.71
RIYADH NEW	1.46	GIZAN	1.79
RYDOLD RY	1.48		

4.2 Coefficient of variation

The COV of annual, winter, spring, summer and autumn ozone is displayed in figure 1. The higher values of COV at all stations occur at winter while the lowest values of COV occur at autumn. The COV of spring at all stations are greater than those in summer and annual values. The COV in annual and winter decreases gradually from the northen stations to the southern station. So it can be said that the COV is a function of latitude in winter and annual values. The maximum value of COV in spring and autumn occurs at Turaif. It reaches 4.28 and 3.09 in spring and autumn respectively. Also as in winter, the values of COV in spring and autumn decrease gradually from the northern station to the southern station. In summer season the behaviour of COV at our stations is different from that in winter, spring and autumn seasons. The lowest values of COV in summer appear at the southern three stations (Najran, Sharorah and Gizan).

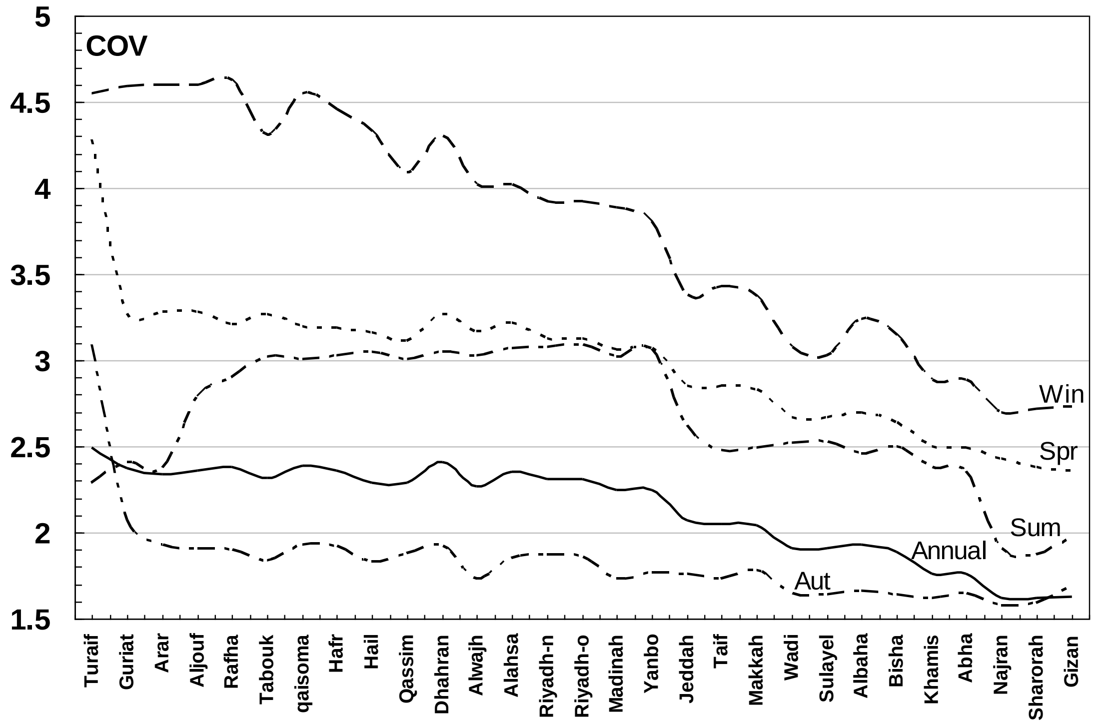

Fig. 1: The coefficient of variation of annual, winter, spring, summer and autumn ozone for KSA stations.

4.3 Trend analysis

The annual ozone time series for the KSA stations under study have been investigated to determine their trends. The studies of trends have been performed by means of both a simple and a sophisticated tools. These methods are: 1) Least square method of first order (linear regression), 2) Moving filters by using Gaussian low- pass filter and binomial low- pass filter and 3) Mann-Kendall rank statistical test. Discussion of the important aspects of the long-term variations and trends are given below for annual ozone time series.

4.3.1 Trend by least square method

Figure 2 shows the values of trend by least square method for the annual ozone of

KSA stations. It illustrates that there is a a negative trend of annual ozone at all KSA stations. It is interesting to note that the negative trend values decrease from north to south where we found the maximum negative value occuring at Turaif (-0.05 DU/year) while the minimum value at Najran (-0.017 DU/year).

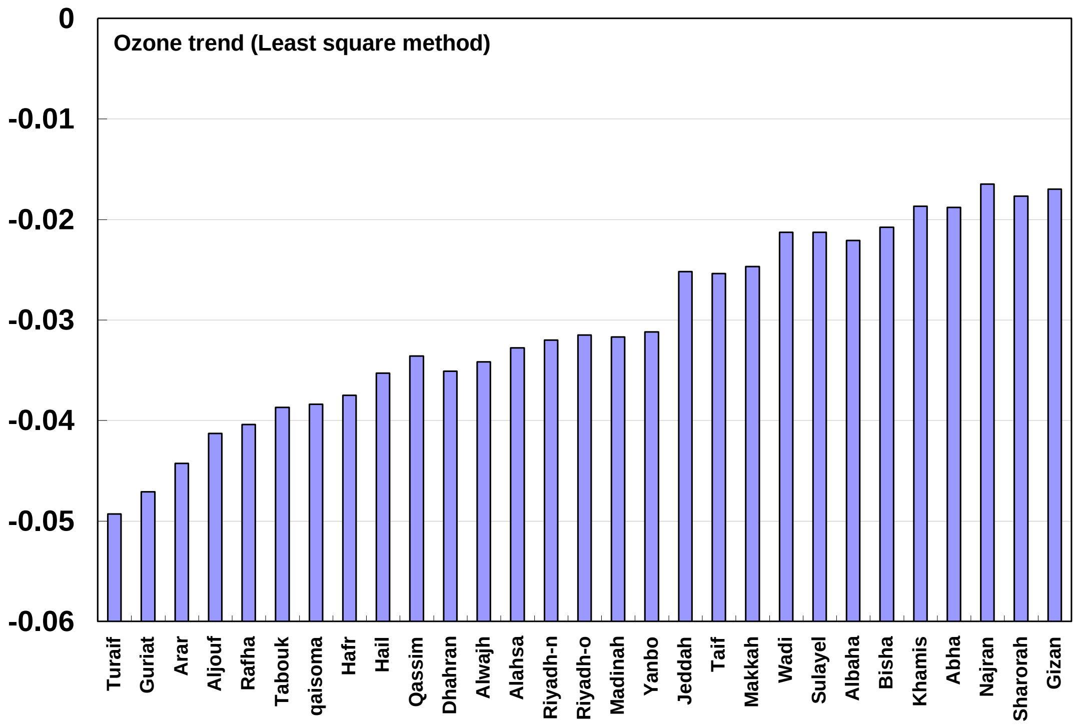

Fig. 2 : The trend values of the annual ozone of KSA stations by least square method.

4.3.2 Fluctuation of annual Ozone

Trends of annual ozone of the concerned stations by means of Gaussian and binomal low- pass filter (dotted curve, thin curve) has been inviestigated. Figures 3 and 4 illustrate the results of the two methods for 16 stations. Results for all stations confirm that ozone values are greater than the normal at our stations from the beginning of measurments (1979) to the year 1985 with maximum values at 1982. However, the lowest value of 1985 is less than the mean value at each station except at Turaif station. Binomaial low- pass filter (thin curve) revealed that there are different regular fluctuations (waves) with different periods and different amplitude. Gradual increase of ozone from 1985 up to 1991 are found followed by decrease but above normal up to 1992. An other considerable decrease of ozone can be noticed during the period from 1992 up to 1995 with the lowest one at 1993. The amount of this decrease in annual ozone reaches about 4 DU but is not uniform at all stations.

An insight to results achived by means of Gaussian low- pass filter is shown in figure 3 (dotted curve). An important increase occurs at all stations around the year 1982, where the annual increase of ozone at this year reaches about 9 DU at most stations. Also another considerable increase of about 4 DU is found around year 1990 at all stations. An other small increase of annual ozone is detected in 1995 at the northern stations, it reaches about 2 DU. A long period of ozone decreasing starts from the beginning of 1996 till now has been detected. The lowest decrease during this period occurs at year 2003 at all stations. A pronounced flactuation (wave) appears during the period 1997 to 2003 at the middle and southern stations (from Riyadh new to Gizan).

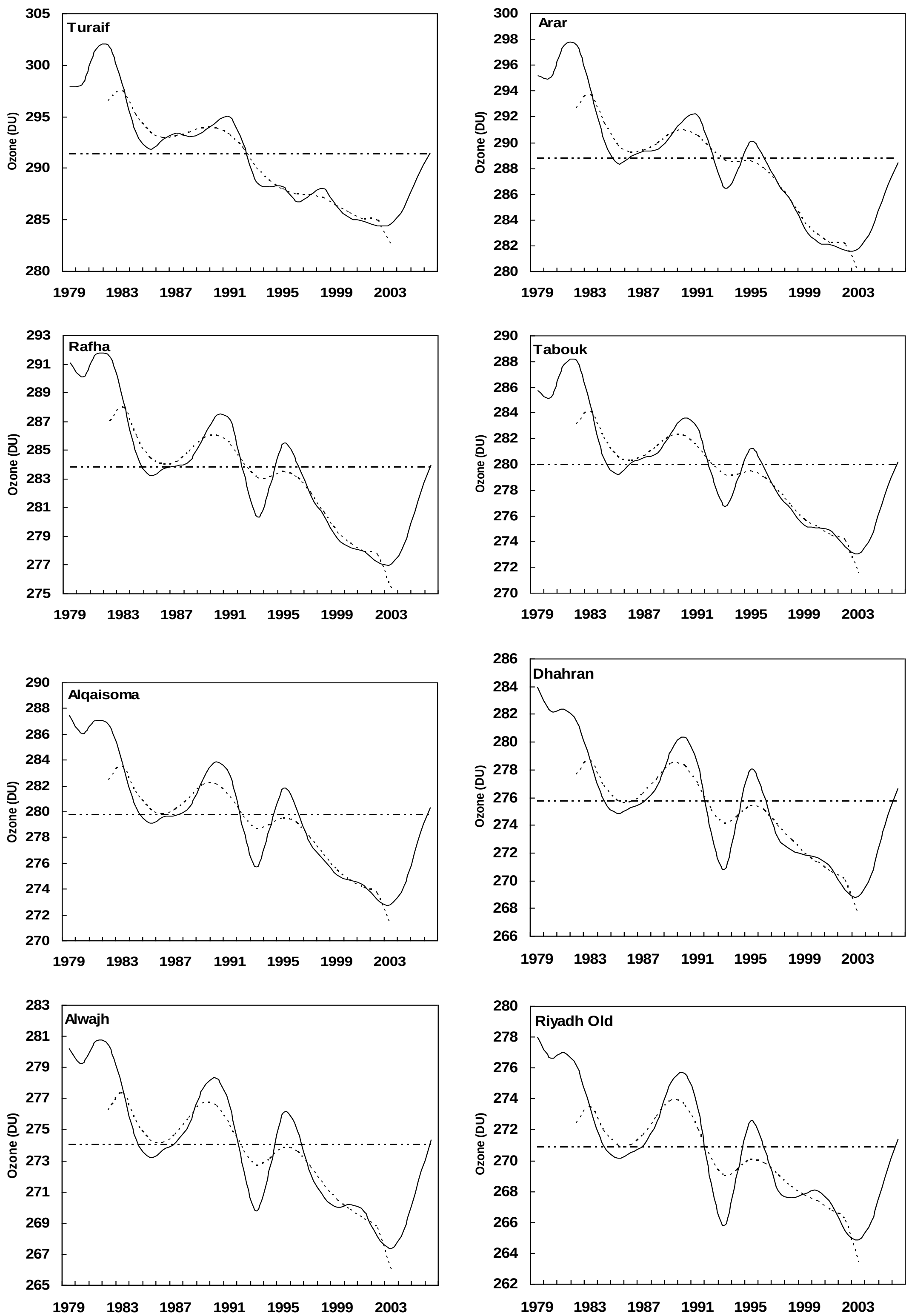

Fig. 3: The fluctuations of the annual ozone of the stations Turaif, Arar, Rafha, Tabouk, Qaisoma, Dhahran, Alwjh and Riyadh old. -·-·-·- means annual ozone, ——— Binomial low-pass filter, …… Gaussian low-pass filter.

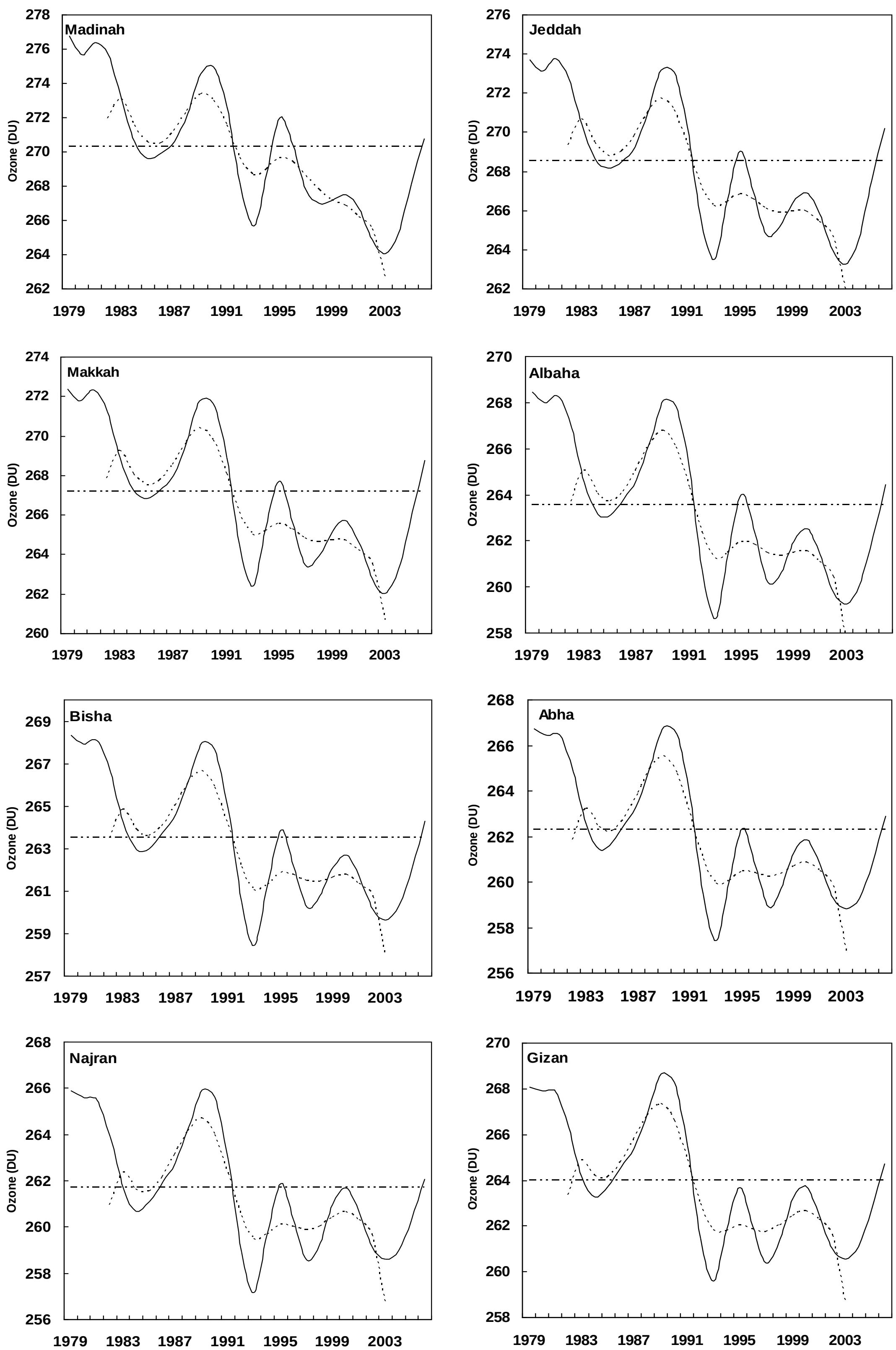

Fig. 4: As in Fig. 3 but for the stations Madinah, Jeddah, Makkah, Albaha, Bisha, Abha, Najran and Gizan.

4.3.3 Mann-Kendall rank statistical test

The values of M–K trend test (*u*) were computed according to Sneyers (1990). Table 7 shows the M–K statistics for the annual, winter, spring, summer and autumn time series of the KSA stations. Negative trends are observed over all stations for the annual and seasonal time series. The behavior of negative trends of the annual time series of all stations is very consistent with the corresponding values from the least square method. Table 7 also illustrats that the negative trend values of winter season is greater than those in the other seasons. The lowest negative trend values occur at the summer season. The negative trend values of the annual and seasonal seasons decreasing gradually from north to south of KSA. At Turaif the trend values are -0.83, -0.81, -0.33, -0.31 and -0.55 for winter, spring, summer, autumn and annual time series respectively, while the crossponding values at Gizan are -0.41, -0.18, -0.13, -0.23 and -0.22.

4.4 Cumulative annual means

In this section, the long- term variability of the behavior of the annual ozone is analyzed with regard to the time variations of annual ozone. To visualize the decadal and inter-decadal fluctuations in the behavior of the annual ozone, cumulative annual means are used, because they advantageously reveal time varying structures in time-series, which are not readily recognizable in raw data. Moreover, the cumulative means have a smoothing effect, similar to low-pass filters (Lozowski *et al*., 1989). Persistent phases of alternating increase or decrease of the ozone, which vary in length, are recognizable in the time series of the annual ozone.

Figures 5 and 6 illustrate the behavior of ozone during the available data period of 16 stations. In this section, the long-term variability of the behavior of the annual ozone is analyzed with regard to the time variations of annual ozone. It is clear that positive trend values in ozone are the domaniant features during the period 1979- 1993 at the stations Turaif and Guriat (not shown). Also, except at the year 1988, the positive trend values are the dominant features at the other stations of KSA. Negative trend values in ozone are the dominant features during the period 1993- 2006 at the all stations

Table 7: The trend values of the annual, winter, spring, summer and autumn ozone of KSA stations by Mann-Kendall rank correlation test.

Station	Win	Spr	Sum	Aut	Annual
Turaif	-0.83	-0.81	-0.33	-0.31	-0.55
Guriat	-0.80	-0.65	-0.34	-0.36	-0.52
Arar	-0.80	-0.65	-0.30	-0.33	-0.49
Aljouf	-0.77	-0.61	-0.28	-0.32	-0.46
Rafha	-0.80	-0.60	-0.26	-0.29	-0.45
Tabouk	-0.68	-0.57	-0.27	-0.32	-0.43
Alqaisoma	-0.82	-0.58	-0.23	-0.27	-0.43
Hafr Albaten	-0.80	-0.57	-0.23	-0.27	-0.42
Hail	-0.73	-0.52	-0.23	-0.26	-0.39
Qassim	-0.72	-0.50	-0.20	-0.25	-0.38
Dhahran	-0.80	-0.55	-0.18	-0.25	-0.40
Alwajh	-0.68	-0.52	-0.23	-0.26	-0.39
Alahsa	-0.73	-0.52	-0.18	-0.24	-0.38
Riyadh new	-0.69	-0.50	-0.18	-0.25	-0.37
Riyadh Old	-0.68	-0.50	-0.17	-0.25	-0.37
Madinah	-0.66	-0.47	-0.19	-0.25	-0.37
Yanbo	-0.64	-0.47	-0.21	-0.25	-0.36
Jeddah	-0.52	-0.39	-0.17	-0.22	-0.30
Taif	-0.53	-0.38	-0.17	-0.24	-0.30
Makkah	-0.51	-0.38	-0.16	-0.22	-0.29
Wadi Aldwaser	-0.46	-0.31	-0.14	-0.22	-0.26
Sulayel	-0.46	-0.31	-0.14	-0.22	-0.26
Albaha	-0.48	-0.32	-0.14	-0.22	-0.26
Bisha	-0.46	-0.28	-0.13	-0.22	-0.25
Khamis Moshet	-0.42	-0.22	-0.12	-0.22	-0.23
Abha	-0.42	-0.22	-0.12	-0.22	-0.23
Najran	-0.38	-0.18	-0.12	-0.19	-0.20
Sharorah	-0.39	-0.19	-0.14	-0.21	-0.22
Gizan	-0.41	-0.18	-0.13	-0.23	-0.22

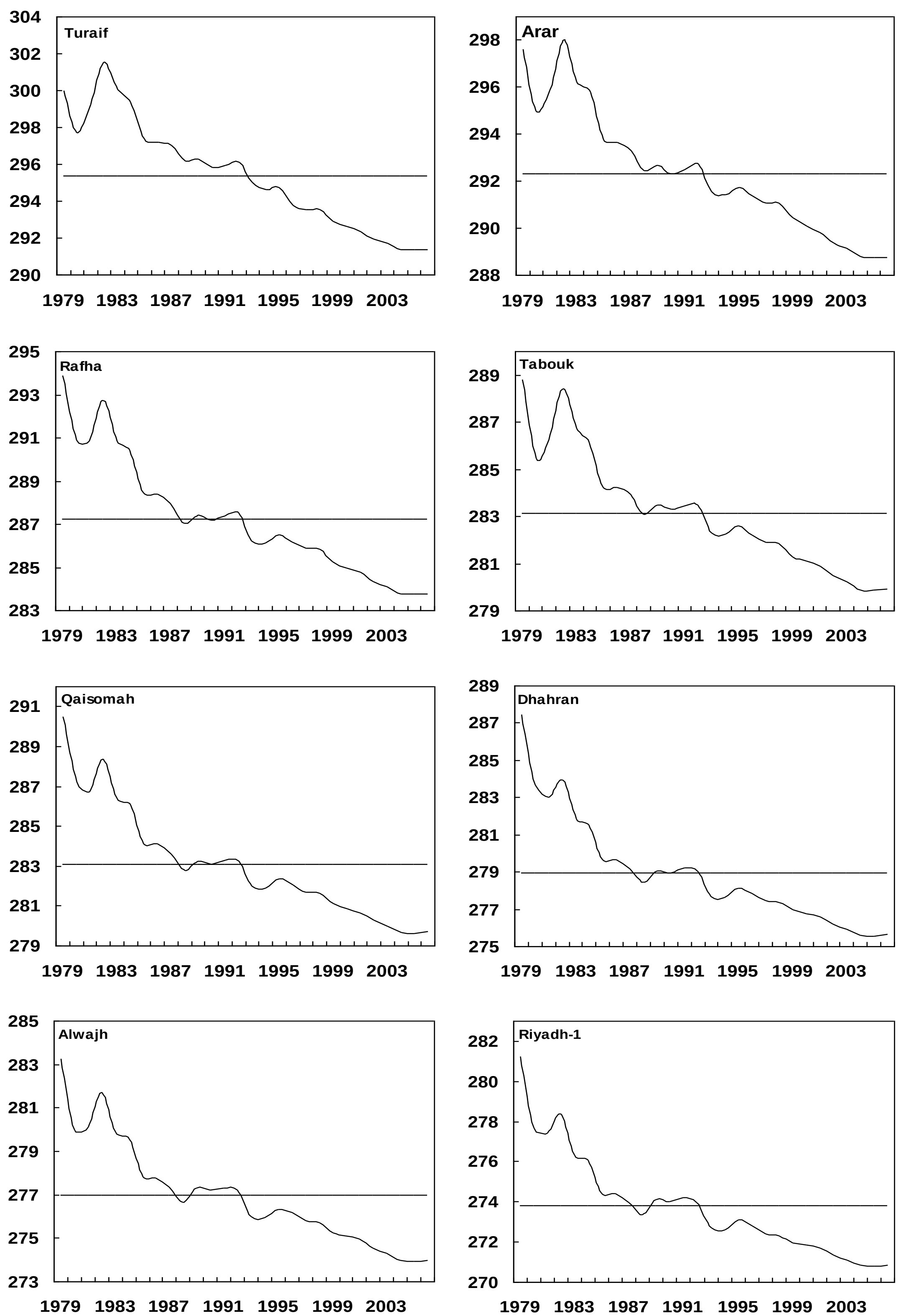

Fig. 5: The comulative annual mean (CAM) time series and the averaged CAM of the stations Turaif, Arar, Rafha, Tabouk, Qaisoma, Dhahran, Alwjh and Riyadh old.

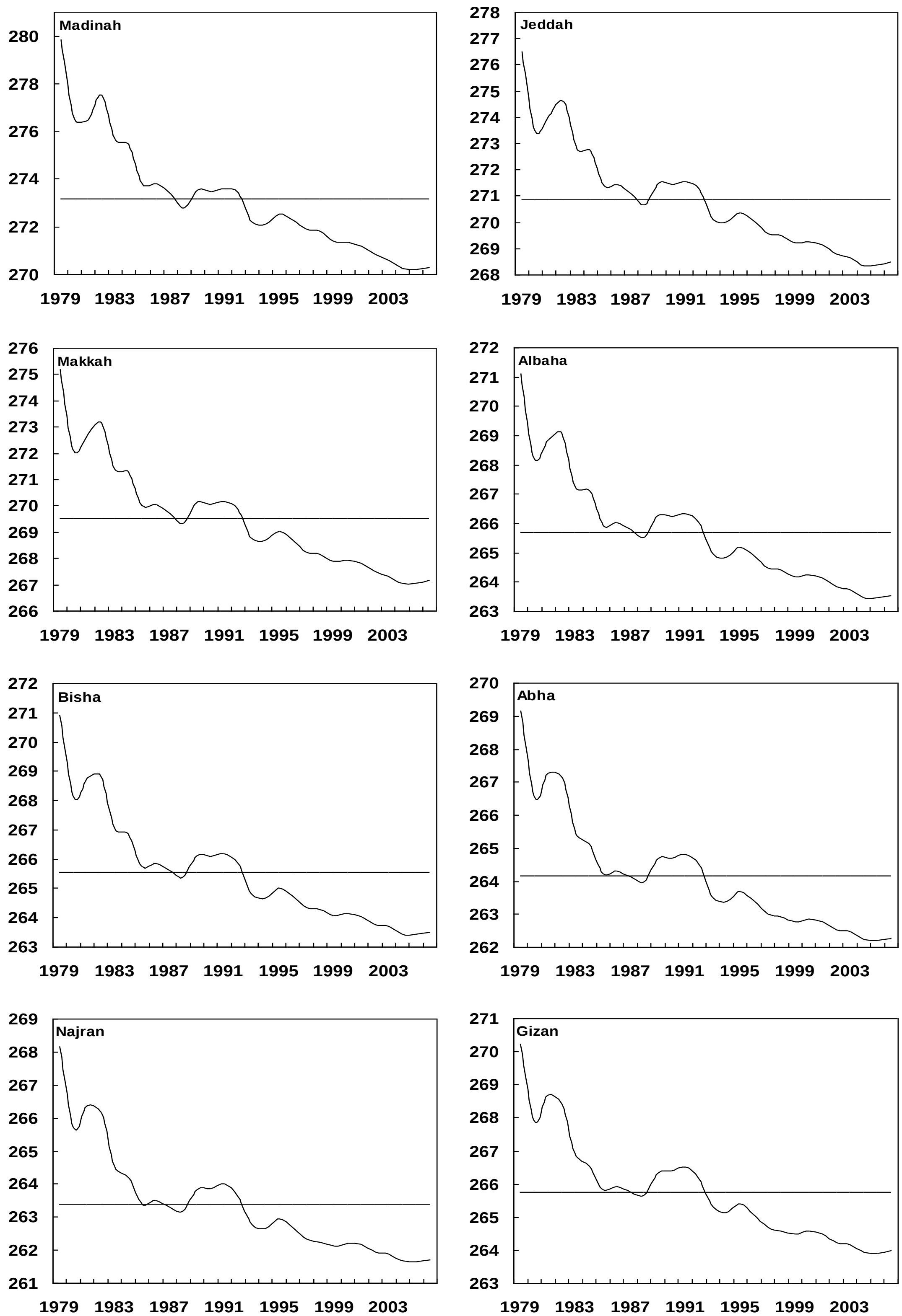

Fig. 6: As in Fig. 5 but for the stations Madinah, Jeddah, Makkah, Albaha, Bisha, Abha, Najran and Gizan.

4. Summary and conclusions

In this work ozone variability over the Kingdom of Saudi Arabia has been studied. Results of studying the COV of annual, winter, spring, summer and autumn ozone show that the higher values of COV at all stations occur at winter while the lowest values of COV occur at autumn. The COV values of spring at all stations are greater than those in summer and annual values. The COV is function of latitude in winter, annual, spring and autumn values where, it decreases gradually from the northern station to the southern station. The behaviour of COV in summer season at our stations is different from that in winter, spring and autumn seasons. The trend analysis by least square method and Mann-kendall test for the seasonal and annual values of ozone over our stations were made. The most siginficant finding is that all stations have negative trends for the annual and seasonal time series. The negative trend values of winter season is greater than those in the other seasons. The lowest negative trend values occur at the summer season. The negative trend values of the annual and seasonal seasons increase gradually from north to south of KSA. Careful examination of the trends of annual ozone of the concerned stations by means of Gaussian and binomal low- pass filter has been made. It is found that, ozone values are greater than the normal at our stations from the beginning of measurements (1979) to the year 1985 with maximum values at 1982. Gradual increase of ozone from 1985 up to 1991 followed by a considerable decrease of ozone during the period from 1992 up to 1995 with lowest one at 1993 was found. A long period of ozone decrease starting from the beginning of 1996 up till now is detected. The lowest decrease during this period occurs at year 2003 at all stations.

The long-term variability of the behavior of the annual ozone was analyzed with regard to the time variations of annual ozone. It is found that positive trend values in ozone are the dominant features during the period 1979- 1993 at the stations Turaif and Guriat. Also, except at the year 1988, the positive trend values are the dominant features at the other stations of KSA. Negative trend values in ozone are the dominant features during the period 1993- 2006 at all stations

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التغير فى الاوزون فوق المملكة العربية السعودية

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الملخص

فى هذا البحث تم دراسة التغير فى الأوزون فوق المملكة العربية السعودية. وقد وجد أن أعلى قيم لمعامل التغير فى الأوزون تظهر فى الشتاء على جميع محطات المملكة بينما اقل قيم لمعامل التغير فى الاوزون تظهر فى الخريف، وان معامل التغير دالة فى خطوط العرض وذلك لقيم الاوزون السنوية والفصلية، حيث وجد أنه يقل تدريجيا من المحطات الشمالية الى المحطات الجنوبية. وتم حساب مسلك وميل الاوزون لمحطات المملكة وتبين أن قيم الميل سالبة لمتسلسلات قيم الأوزون الفصلية والسنوية وأن أعلى قيم كانت فى الشتاء. وقد أظهرت دراسة التغير طويل المدى لمسلك الاوزون لقيم الاوزون السنوية وجود قيم موجبة للميل مسيطرة خلال الفترة من ١٩٧٩ حتى ١٩٩٣ عند معظم محطات المملكة ماعدا عند عام ١٩٨٨ فقط . كما أظهرت وجود قيم موجبة للميل مسيطرة خلال الفترة من ١٩٩٣ حتى ٢٠٠٦ عند كل المحطات.