Ozone estimation over Kingdom of Saudi Arabia

A. K AL-Khalaf and H. Abdel Basset

Department of Meteorology, Faculty of Meteorology, Environment, and Arid Land Agriculture, King Abdulaziz University, Jeddah, Saudi Arabia.

ABSTRACT

In this paper the relationships between total ozone amount and meteorological variables have been deduced for each station of the Kingdom of Saudi Arabia (KSA). Residual method has been applied to estimate total ozone values using the meteorological variables. An emperical equations relating the total ozone amount with these variables have been deduced for KSA stations. Residual method has been applied also to deduced emperical equations relating the total ozone with tropopause pressure, tropopause temperature and the thickness of atmospheric layers. Very good correlation coefficient (0.8) between the actual and estimated values of ozone for the middle and southern stations of KSA have been found. It is found that the results at southern stations are better than those at the middle and north of KSA. The obtained good relations make us able to estimate and forecast ozone amount whether there are meteorological stations or not, by using numerical weather prediction models outputs.

1. Introduction

It is known that the daily total ozone amount (O_3) is linked with meteorological elements (e.g., Dobson et al., 1929). The nature of day-to-day total ozone fluctuations has been of considerable interest for many years. Significant statistical relations between O_3 and a number of meteorological variables have long been known (Reed, 1950; Normand, 1953; Vaughan and Price, 1991; Abdel Basset and Gahein, 2000, 2003). These relationships have recently been used in short-term O_3 forecasting in middle and high latitudes (Burrows et al., 1993, 1994; Poulin and Evans, 1994; Austin et al., 1994; Vogel et al., 1995). These statistical relations are, however, regionally and seasonally independent (e.g., Ohring and Muench, 1960; Schubert and Munteanu, 1988; Mote et al., 1991; Petzoldt et al., 1994).

Early studies based on a limited number of ground station reports (e.g., Dobson et al., 1929) helped to establish a firm meteorological basis for the observed daily ozone variation. Reed (1950) pointed out that ozone variations are not only caused by chemical processes but also have dynamical origins. For example sudden increases in total ozone generally accompany marked increase in tropopause pressure occurred during the passage of a cold front or depression. This can be interpreted simply as an increase in the depth of ozone and the ozone-rich stratosphere or as a combination of vertical and horizontal advection of ozone. Ozone absorbs most of the harmful ultraviolet radiation emitted by the sun before it reaches the earth's surface. This absorption creates a heat source that leads to temperature increases with height (stratosphere). The laboratory of atmospheric physics, University of Thessalonike, provides an approach for regional ozone forecasting (Vogel .et.al., 1995). This approach is based on results from detailed statistical calculations showing strong correlation between O_3 and meteorological parameters in the lower stratosphere and higher troposphere. Thus the thermal structure of the atmosphere can be used to forecast ozone. Ozone is found in two different height regions in the atmosphere at heights between about 10 and 50 km in the stratosphere while the remaining ozone is found closer to the surface in the troposphere. The aim of this paper is to estimate total ozone amount using some meteorological variables such as pressure, temperature, relative humidity, rainfall amount, tropopause pressure, tropopause temperature and the thickness of atmospheric layers.

2. Data and methodology

A) Data

Monthly means of sea level pressure, surface temperatures, maximum temperature, minimum temperature, surface relative humidity, maximum relative humidity, minimum relative humidity and rainfall are used for the 28 stations of the Presidency of Meteorology and Environment (PME). 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 name, position, elevation and avaliable period of each station. Another meteorological data used in this paper have been taken from the archives of the European Center for Medium-Range Weather Forecasts (ECMWF). It consists of tropopouse perssure and temperature, the horizontal wind components (u, v), the temperature (T) and the geopotential height (z). The data is avilable on regular latitude-longitude grid points resolution of 2.5^o x 2.5^o for the isobaric levels 1000, 850, 700, 500, 300, 200 and 100 hPa.

The ozone data were obtained from the Total Ozone Mapping Spectrometer (TOMS). TOMS provided global measurements of total column ozone on a daily basis 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.

B) Methodology

Residual method has been applied to explore the possibility of forecasting total ozone average values by means of the values of pressure, temperature, relative humidity, and rainfall amount at each station. The monthly values of total ozone during the period 1979 to 2006 have been taken as the dependent variable (predicted) and the corresponding values of pressure, temperature, relative humidity, and rainfall are the independent variables (predictors).

First step, the correlation coefficient (C.C) between the values of total ozone and each predictor (pressure, temperature, relative humidity, and rainfall) has been determined. The predictor which has the strongest C.C with the predicted (total ozone) has been used to be the first predictor, and then the regression line and the regression coefficients are determined. The error between the actual and estimated value of total ozone was taken as a predicted.

Second step, the mentioned above error was subjected to the process performed in the first step. The second step has been repeated with new predictors until the additional predictors have no significant effect on the predicted and there is no need for any further steps (i.e. the improvement cannot be expected to be very great with adding new predictors). In tables 2 to 5 the meteorological variables pressure, temperature, maximum temperature, minimum temperature, relative humidity, maximum ralative humidity, minimum relative humidity and rainfall are denoted by P, Tm, Tmx, Tmn, RHm, RHmx, RHmn and RF respectively.

Also, the relation between total ozone with tropopause pressure, tropopause temperature and depth of height is investigated. Depth of height represented by the thickness of four layers, the first layer is the thickness 1000 – 500 hPa, the second is the thickness 300 – 500 hPa, the third is the thickness 100 – 1000 hPa, and the last layer is the thickness 200 – 300 hPa. The same procedure (Residual method) is applied for tropopause pressure, tropopause temperature and geopotential differences of the above mentioned layers.

3. Results

3.1. Estimation of ozone from measured meteorological variables

In this section, the relation between total ozone amount and meteorological variables (pressure, temperature, relative humidity, and rainfal amount) have been investigated. Emperical equations relating the total ozone with these variables have been deduced by applying the residual method for each station of the Kingdom of Saudi Arabia.

Tables 2 to 5 show the number of steps, the predictor, the regression coefficients (Ai, Bi) the root mean square error (RMSE) and mean absolute error (MAE) arising from the error between the actual and estimated data after each step, and multiple correlation coefficient (C.C) from a stepwise regression analysis for each stations of KSA. Figures 1 and 2 illustrate actual (solid line) and estimated (dashed line) total values of ozone from 1979 to 2006 for 16 stations of KSA. The results of residual method shown in tables 2 to 5 and figures 1 to 2 can be summarized as follows.

- Weak agreement between the actual and estimated values of ozone for the northern stations of KSA that lies between 31.68^{o}N to 27.90^{o}N (Turaif, Guriat, Arar, Aljouf, Rafha, Tabouk, Alqaisomah, Hafr-Albaten, Hail and Alwejh), where the total multiple correlation coefficient ranges between 0.25 to 0.56 after using five predictors. The low values of total multiple correlation coefficients have been appeared clear in Figure 1 where a weak agreement between the actual and estimated time series of ozone is observed.

- Good agreement between the actual and estimated values of ozone for the middle stations of KSA that lies between 26.30^{o}N to 24.14^{o}N (Dhahran, Gassim, Al

Ahsa, Madinah, Riyadh new, Riyadh old and Yanbo), where the total multiple correlation coefficient ranges between 0.47 to 0.65 after using five predictors. The reasonable values of total multiple correlation coefficients have been appeared clear in Figure 2 where a good agreement between the actual and estimated time series of ozone is observed.

- Very good agreement between the actual and estimated values of ozone for the south west and southern stations of KSA that lies between 21.71^{o}N to 16.90^{o}N (Jeddah, Makkah, Taif, Baha, Wadi Aldwaser, Sulayel, Bisha, Abha, Khamis, Najran, Sharorah and Gizan), where the total multiple correlation coefficient ranges between 0.57 to 0.87 (which is quite high) after using five predictors. The high values of total multiple correlation coefficients have been appeared clear in Figure 2 where a very good agreement between the actual and estimated time series of ozone is observed.

3.2The multiple regression equations

The multiple regression equations for the predicting values of the total ozone over KSA stations from the known predicting values temperature, maximum temperature, minimum temperature, relative humidity, maximum ralative humidity, minimum relative humidity and rainfall can be written (for the stations Guriat, Riyadh old and Sharorah as an example) in the following forms:

$$\text{Ozone (Guriat)} = 1202.03 - 0.477 * Tmn - 0.57 * RHmn - 0.247 * RHmx - 0.448 * Tmx - 907 * P$$

$$\text{Ozone (Riyadh old)} = 1017.226 - 1.853 * P + 0.122 * RF - 0.332 * RHmn + 0.055 * RHmx - 0.066 * RHm$$

$$\text{Ozone (Sharorah)} = 198.402 + 2.273 * Tm - 0.01 * RHmn$$

3.3 Estimation of ozone from global data

In this section, the relation between total ozone with tropopause pressure, tropopause temperature and depth of height will be investigated. Depth of height represented by the thickness of four layers, the first layer is the thickness between 1000 – 500 hPa, the second is the thickness between 300 – 500 hPa, the third is the thickness between 100 – 1000 hPa, and the last layer is the thickness between 200 – 300 hPa. Emperical equations relating the total ozone with these variables have been deduced. This will be done also using the residual method at each station of KSA. In tables 6-8 the meteorological variables tropopause pressure, , the thickness between 1000 – 500 hPa, the thickness between 300 – 500 hPa, the thickness between 100 – 1000 hPa and the thickness between 200 – 300 hPa are denoted by P-Trop, T-Trop, Z(1000-500), Z(300-500), Z(100-1000) and Z(200-300) respectively.

Tables 6 to 8 show the number of steps, the predictor used in each step, the regression coefficients arising in each step (Ai, Bi) the root mean square error (RMSE) and mean absolute error (MAE) arising from the error between the actual and estimated data after each step, and multiple correlation coefficient (r) from a stepwise regression analysis for each stations of KSA. Figures 3 to 4 illustrate actual (solid line) and estimated (dashed line) total values of ozone from 1979 to 2006 for the stations of KSA. The results of residual method shown in tables 6 to 8 and figures 3 to 4 can be summarized as follows.

- Weak agreement between the actual and estimated values of ozone for the northern stations of KSA that lies between 31.68^{o}N to 27.90^{o}N (Turaif, Guriat, Arar, Aljouf, Rafha, Tabouk, Alqaisomah, Hafr-Albaten, Hail and Alwajh), where the total multiple correlation coefficient ranges between 0.31 to 0.5 after using four predictors. The low values of total multiple correlation coefficients have been appeared clear in Figures 3 and 4 where a weak agreement between the actual and estimated time series of ozone is observed.

- Good agreement between the actual and estimated values of ozone for the middle stations of KSA that lies between 26.30^{o}N to 24.14^{o}N (Dhahran, Gassim, Al Ahsa, Madinah, Riyadh new, Riyadh old and Yanbo), where the total multiple correlation coefficient ranges between 0.44 to 0.59 after using five predictors (except at Gassim where the total multiple correlation coefficient reached to 0.82). The reasonable values of total multiple correlation coefficients have been appeared clear in Figures 3 and 4 where a good agreement between the actual and estimated time series of ozone is observed.

- Very good agreement between the actual and estimated values of ozone for the south west and southern stations of KSA that lies between 21.71^{o}N to 16.90^{o}N (Jeddah, Makkah, Taif, Baha, Wadi Aldwaser, Sulayel, Bisha, Abha, Khamis, Najran, Sharorah and Gizan), where the total multiple correlation coefficient ranges between 0.7 to 0.85 (which is quite high) after using five predictors. The high values of total multiple correlation coefficients have been appeared clear in Figure 4 where a very good agreement between the actual and estimated time series of ozone is observed.

3.4 The multiple regression equations

The multiple regression equations for the predicting values of the total ozone over KSA stations from the known predicting values of tropopause pressure, tropopause temperature , the thickness between 1000 – 500 hPa, the thickness between 300 – 500 hPa, the thickness between 100 – 1000 hPa and the thickness between 200 – 300 hPa can be written (for the stations Guriat, Riyadh old and Sharorah as an example) in the following forms:

Ozone (Guriat) = 251.497 + 2.5 * T-Trop + 0.017 * Z(1000-500) – 0.02 * Z(300-500) +0.006 * Z(100-1000)

Ozone (Riyadh old) = -84.186 + 0.082 * Z(500-1000) - 0.242 * P-Trop
– 0.04 * Z(300-500) + 0.007 * Z(100-1000) + 0.752 * T-Trop

Ozone (Sharorah) = -1002.85 + 0.245 * Z(500-1000) + 0.156 * P-Trop
- 0.043 * Z(300-500)

4. Summary and Conclusion

This work aimed to estimate the total amount of ozone from the meteorological variables (pressure, temperature, relative humidity, and rainfall amount). Residual method has been applied to explore the possibility of forecasting total ozone average values by means of the values of these meteorological variables for each station of KSA. The monthly values of total ozone during the period 1979 to 2006 have been taken as the dependent variable (predictand) and the corresponding values of the meteorological variables are the independent variables (predictors). Empirical equations relating the total ozone with these variables have been deduced at each station of KSA. Very good agreement between the actual and estimated values of ozone for the south west and southern stations of KSA have been found, where the total multiple correlation coefficient ranges reached to greater than 0.8 (which is quite high) at some stations. In this work also, the relation between total ozone with tropopause pressure, tropopause temperature and depth of height represented by the thickness of four layers have been invistigated. And we used also the residual method to deduce empirical equations relating the total ozone with tropopause pressure, tropopause temperature and depth of height at each station of KSA. Good agreement between the actual and estimated values of ozone for the middle and southern stations of KSA have been found. Generally the results at southern stations are better than those at the middle and north of KSA for the two sets of equation. The obtained good relations make us able to estimate and forecast of ozone whether there are meteorological stations or not, by using numerical weather prediction models outputs.

Referrances

Abdel Basset. H and A. Gahein, (2000) On the relationship between ozone and cyclogenesis: case study. *AL-Azhar Bull*. Sci. Vol. 11, No. **1** (June): pp. 35-50.

Abdel Basset. H and A. Gahein, (2003) Diagnostic study on the relation between ozone and potential vorticity. *Atmosfera*. **16**, 67- 82.

Austin, J., B. R. Barwell, S. J. Cox, P. A. Hughes, J. R. Knight, G. Ross, P. Sinclair, and A. R. Webb, (1994) The diagnosis and forecast of clear-sky ultraviolet levels of the Earth's surface, *Meteorol. Appl.*, **1,** 321-336.

Burrows, W. R., L. J. Wilson, and M. Vallee, (1993) A statistical forecast procedure for daily total ozone based on TOMS data, paper presented at 13 th Conference on Weather Analysis and Forecasting Including Symposium on Flash Floods, Am. *Meteorol*. Soc., Vienna, Va., Aug. 2-6.

Burrows, W. R., M. Vallee, D. I. Wardle, J. B Kerr, L. J Wilson, and D. W Tarasick, (1994) The Canadian operational procedure for forecasting total ozone and UV radiation. *Meteor. Apps*., **1**, 247-265.

Dobson, G. M. B., Harrison, D. N., and Lawrence, J.1929: Measurements of the amount of ozone in the earth's atmosphere and its relation to other geophysical conditions, iii, Proc. Royal Society London A, 122, 456–486.

Mote, P. W., J. R. Holton, and J. M. Wallace, (1991) Variability in total ozone associated with baroclinic waves, *J. Atmos* Sci., **48**. 1900-1903.

Normand, C., (1953) Atmospheric ozone and upper air conditions, Q. J. R.*Meteorol.* Soc**., 79**, 39-50.

Ohring, G., and H. S. Muench, (1960) Relationships between ozone and meteorological parameters in the lower stratosphere, *J. Meteorol*., **17**, 195-206.

Petzoldt, K., B. Naujokat, and K. Neugebohren, (1994) Correlation between stratospheric temperature, total ozone, and tropospheric weather systems, *Geophys.* Res. Lett., **21**, 1203-1206.

Poulin, I., and W. F. J. Evans, (1994) Total ozone from meteorological parameters, Atmos. *Ocean*, **32**, 285-297.

Reed. R.J., 1950: The role of vertical motion in ozone-weather relationships.*J. Meteorol.*, **7,** 263-267.

Schubert, S.D., Munteanu, M. J., (1988) An analysis of tropopose pressure and total ozone correlation. *Monthly Weather Review* **116**, 569-582.

Vaughan, G., and D. J. Price, (1991) On the relation between total ozone and meteorology, Q. *J. R. Meteorol.* Soc., **117**, 1281-1298.

Vogel G., D. Spankuch, E. Schultz, U. Feister, and W. Dohler, (1995) Regional short-term forecast of total column ozone, *Atmospheric Environment*, **29**,10,1155-1163.

No	Name	Lat	Long	Elevation	Available Data
1	TURAIF	31.68	38.73	852.44	1978 --- 2006
2	GURAIT	31.40	37.28	503.90	1985 --- 2006
3	ARAR	30.90	41.14	548.88	1979 --- 2006
4	ALJOUF	29.78	40.98	668.74	1978 --- 2006
5	TABOUK	28.37	36.60	444.10	1978 --- 2006
6	HAIL	27.43	41.69	768.11	1970 --- 2006
7	ALWEJH	26.20	38.47	357.60	1978 --- 2006
8	RAFHA	29.62	43.49	413.00	1978 --- 2006
9	ALQUSOMA	28.31	46.13	1001.52	1978 --- 2006
10	HAFR-ALBATEN	27.90	45.53	646.71	1985 --- 2006
11	DHAHRAN	26.25	50.16	16.77	1970 --- 2006
12	AHSA	25.29	49.48	23.73	1985 --- 2006
13	GASSIM	26.30	43.76	178.17	1978 --- 2006
14	RIYADH NEW	24.92	46.72	613.55	1985 --- 2006
15	RYDOLD RY	24.71	46.73	619.63	1970 --- 2006
16	WADI AWASER	20.50	45.25	635.60	1978 --- 2006
17	SULAYEL	20.46	45.617	10.40	1985 --- 2006
18	MADINA	24.54	39.69	3.58	1970 --- 2006
19	YENBO	24.14	38.06	1452.75	1978 --- 2006
20	JEDDAH	21.71	39.18	240.35	1970 --- 2006
21	MAKKAH	21.43	39.79	701.02	1985 --- 2006
22	TAIF	21.48	40.55	614.39	1970 --- 2006
23	BAHA	20.29	41.64	1651.88	1985 --- 2006
24	BISHA	19.99	42.61	1161.97	1970 --- 2006
25	ABHA	18.23	42.66	2055.93	1978 --- 2006
26	KHAMIS MUSH	18.29	42.80	2093.35	1970 --- 2006
27	NAJRAN	17.61	44.41	1212.33	1978 --- 2006
28	SHARURA	17.46	47.10	724.65	1985 --- 2006
29	GIZAN	16.90	42.58	7.24	1970 --- 2006

Table 1: The name, position, elevation and the avaliable data period for each KSA station.

Table 2: The predictor used in each step, the regression coefficients arising in each step (A_i, B_i), MAE and RMSE arising from the error between the actual and estimated data after each step, and multiple correlation coefficient (C.C) from a stepwise regression analysis for the stations Turaif, Guriat, Arar, Aljouf, Rafha, Tabouk and Alqaisoma.

Stations	Step No.	Predictors	Regression coefficients		MAE	RMSE	C.C
			A_i	B_i			
Turaif	1	Tmx	304.613	-0.509	14.465	18.098	0.242
	2	RHmn	5.478	-0.442	14.215	17.736	0.352
	3	Tmn	3.739	-0.318	14.027	17.594	0.361
	4	P	382.928	-0.417	14.013	17.516	0.368
	5	RF	-0.966	0.126	13.915	17.419	0.378
	6	RHm	3.525	-0.085	13.882	17.362	0.399
Guriat	1	Tmn	295.387	-0.477	14.404	17.882	0.174
	2	RHmn	6.025	-0.57	13.95	17.244	0.332
	3	RHmx	21.541	-0.247	13.758	17.049	0.384
	4	Tmx	12.777	-0.448	13.094	16.623	0.446
	5	P	866.3	-0.907	13.072	16.242	0.537
Arar	1	Tmx	296.434	-0.261	13.627	17.286	0.144
	2	RHmn	3.585	-0.279	13.526	17.113	0.224
	3	Tmn	2.607	-0.178	13.425	17.053	0.231
	4	P	102.09	-0.107	13.347	16.96	0.248
	5	RF	-0.527	0.107	13.315	16.934	0.252
	6	RHm	2.862	-0.079	13.315	16.875	0.275
Aljouf	1	P	1008.716	-0.774	12.774	16.289	0.179
	2	Tmn	5.962	-0.436	12.208	15.946	0.443
	3	RHmn	4.091	-0.438	11.977	15.662	0.463
	4	Tmx	5.156	-0.179	11.842	15.579	0.403
	5	RHm	2.501	-0.079	11.815	15.527	0.425
Rafha	1	P	757.551	-0.492	12.316	15.943	0.159
	2	RHmx	-8.585	0.108	11.903	15.673	0.317
	3	RHmn	3.412	-0.244	11.726	15.514	0.351
	4	RF	-0.712	0.09	11.645	15.457	0.372
	5	RHm	2.272	-0.061	11.652	15.419	0.391
	6	Tmx	4.861	-0.157	11.561	15.344	0.401
Tabouk	1	RHm	297.833	-0.538	11.164	14.738	0.388
	2	Tmx	10.06	-0.338	10.814	14.505	0.472
	3	P	617.755	-0.667	10.746	14.322	0.487
	4	Tmn	3.443	-0.239	10.57	14.224	0.503
	5	RHmn	2.281	-0.247	10.548	14.134	0.534
	6	RF	-0.395	0.155	10.538	14.095	0.549
	7	RHmx	4.472	-0.06	10.489	14.059	0.560
Alqaisoma	1	RHmn	283.972	-0.455	11.009	14.773	0.221
	2	RF	-0.495	0.046	11.003	14.748	0.234
	3	Tm	-2.777	0.11	10.942	14.713	0.240
	4	P	31.762	-0.033	10.932	14.701	0.244

Table 3: As in table 2 but for the satations Hafr, Hail, Qassim, Dhahran, Alwajh, Alahsa and Riyadh new.

Stations	Step No.	Predictors	Regression coefficients		MAE	RMSE	C.C
			A_i	B_i			
Hafr-Albaten	1	P	1106.344	-0.859	11.722	16.134	0.284
	2	RHmn	-4.456	0.345	11.639	15.927	0.339
	3	RHm	1.39	-0.043	11.544	15.905	0.341
	4	RHmx	-1.683	0.024	11.456	15.889	0.349
Hail	1	P	1042.186	-0.85	10.702	14.533	0.289
	2	RHm	4.416	-0.118	10.628	14.407	0.317
	3	RF	-1.017	0.1	10.545	14.248	0.344
	4	RHmn	1.514	-0.143	10.476	14.220	0.349
	5	RHmx	-2.892	0.041	10.394	14.177	0.356
	6	Tm	-2.477	0.111	10.351	14.149	0.361
	7	Tmx	0.799	-0.027	10.310	14.127	0.368
Gassim	1	Tmn	259.384	0.855	9.976	13.487	0.412
	2	RF	-1.303	0.102	9.715	13.280	0.445
	3	RHmn	2.309	-0.255	9.622	13.143	0.461
	4	RHmx	-2.475	0.038	9.588	13.091	0.470
	5	RHm	1.723	-0.058	9.561	13.054	0.472
Dhahran	1	RHm	304.478	-0.547	9.292	12.992	0.496
	2	RF	-0.817	0.102	9.210	12.797	0.522
	3	RHmn	4.484	-0.278	8.926	12.560	0.544
	4	RHmx	-7.165	0.077	8.898	12.536	0.546
	5	Tmx	1.535	-0.046	8.892	12.530	0.547
	6	P	96.312	-0.096	8.871	12.510	0.549
Alwajh	1	P	1028.146	-0.748	10.715	14.396	0.298
	2	RHmn	5.657	-0.263	10.463	14.048	0.365
	3	RF	0.443	-0.202	10.293	13.911	0.385
	4	Tmn	-4.5	0.226	10.220	13.878	0.392
	5	RHmx	-5.305	0.057	10.208	13.872	0.394
	6	Tmx	4.162	-0.139	10.174	13.863	0.398
	7	Tm	-1.824	0.073	10.101	13.851	0.412
Alahsa	1	P	1521.796	-1.264	8.656	12.556	0.570
	2	RHm	4.117	-0.098	8.605	12.478	0.580
	3	RF	-0.527	0.072	8.524	12.408	0.584
	4	RHmn	1.448	-0.107	8.51	12.383	0.588
	5	Tmx	3.795	-0.109	8.453	12.346	0.601
	6	Tm	-0.717	0.026	8.450	12.344	0.613
Riyadh new	1	Tmn	247.797	1.257	8.921	12.552	0.572
	2	RF	-0.903	0.091	8.741	12.392	0.588
	3	RHmn	2.038	-0.251	8.603	12.248	0.599
	4	RHmx	-2.033	0.032	8.595	12.216	0.603
	5	P	136.973	-0.145	8.553	12.188	0.605

Table 4: As in table 2 but for the satations, Riyadh Old, Madinah, Yanbo, Jeddah Taif, Makkah, Albaha and Bisha.

Stations	Step No.	Predictors	Regression coefficients		MAE	RMSE	C.C
			A_i	B_i			
Riyadh Old	1	P	2016.561	-1.853	8.387	11.973	0.609
	2	RF	-0.357	0.122	8.340	11.769	0.626
	3	RHmn	2.736	-0.332	8.109	11.564	0.644
	4	RHmx	-3.439	0.055	8.026	11.459	0.651
	5	RHm	1.725	-0.066	7.980	11.418	0.654
Madinah	1	P	2422.154	-2.295	8.539	12.291	0.597
	2	RHmn	5.381	-0.469	8.435	11.897	0.615
	3	RF	-0.988	0.178	8.368	11.710	0.630
	4	RHm	2.388	-0.101	8.358	11.661	0.636
	5	Tmn	5.609	-0.263	8.208	11.536	0.645
Yanbo	1	Tm	228.366	1.567	10.061	13.380	0.479
	2	RHm	40.069	-0.73	9.375	12.706	0.552
	3	RF	0.546	-0.223	9.261	12.581	0.567
	4	Tmx	8.151	-0.235	9.202	12.529	0.570
	5	P	217.514	-0.216	9.180	12.466	0.576
Jeddah	1	P	3377.078	-3.088	7.450	10.314	0.736
	2	RHm	32.592	-0.515	7.145	9.790	0.765
	3	Tmn	10.746	-0.474	7.106	9.662	0.768
	4	RF	0.166	-0.037	7.062	9.638	0.769
	5	RHmn	0.843	-0.044	7.048	9.629	0.775
Taif	1	Tmn	232.441	2.046	7.407	10.160	0.737
	2	RF	-0.81	0.055	7.358	10.039	0.745
	3	P	480.24	-0.561	7.338	9.991	0.749
	4	RHmx	-5.681	0.068	7.315	9.923	0.751
	5	RHm	2.463	-0.056	7.273	9.892	0.754
Makkah	1	RHm	321.256	-1.185	7.236	9.828	0.766
	2	Tmx	-14.47	0.382	7.042	9.642	0.781
	3	RHmx	-12.976	0.161	6.820	9.441	0.786
	4	Tmn	-6.573	0.268	6.721	9.378	0.791
Albaha	1	Tmn	221.343	2.475	6.840	9.730	0.777
	2	RF	-0.982	0.078	6.772	9.580	0.785
	3	P	260.839	-0.312	6.763	9.565	0.786
	4	RHmx	-2.539	0.032	6.757	9.549	0.791
Bisha	1	Tm	205.668	2.258	6.661	9.106	0.799
	2	RF	-0.804	0.103	6.511	8.922	0.808
	3	RHmn	1.554	-0.213	6.448	8.847	0.812
	4	RHmx	-2.073	0.029	6.442	8.827	0.813
	5	P	112.968	-0.128	6.443	8.821	0.819

Table 5: As in table 2 but for the satations Khamis Moshet, Abha, Najran, Sharorah and Gizan.

Stations	**Step No.**	**Predictors**	**Regression coefficients**		**MAE**	**RMSE**	**C.C**
			A_i	**B_i**			
Khamis Moshet	1	Tm	199.943	3.19	6.722	9.034	0.797
	2	RF	-1.089	0.066	6.583	8.862	0.806
	3	RHmn	2.87	-0.189	6.473	8.725	0.813
	4	Tmn	3.639	-0.284	6.438	8.658	0.816
	5	P	170.943	-0.214	6.430	8.651	0.827
Abha	1	Tm	200.74	3.322	6.107	8.447	0.826
	2	RF	-0.818	0.041	6.021	8.308	0.832
	3	P	637.726	-0.803	5.979	8.248	0.835
Najran	1	Tm	204.368	2.257	5.992	7.767	0.848
	2	RHmn	1.835	-0.193	5.852	7.665	0.853
	3	P	-299.524	0.341	5.777	7.587	0.856
	4	RHmx	1.888	-0.028	5.749	7.560	0.859
	5	Tmn	-0.626	0.037	5.746	7.557	0.866
Sharorah	1	Tm	198.254	2.273	5.577	7.482	0.868
	2	RHmn	0.148	-0.01	5.548	7.457	0.869
Gizan	1	Tm	131.331	4.4	6.091	7.888	0.841
	2	RHmn	3.949	-0.098	6.019	7.821	0.845
	3	Tmn	5.178	-0.199	6.001	7.798	0.846
	4	P	242.357	-0.241	5.949	7.745	0.849

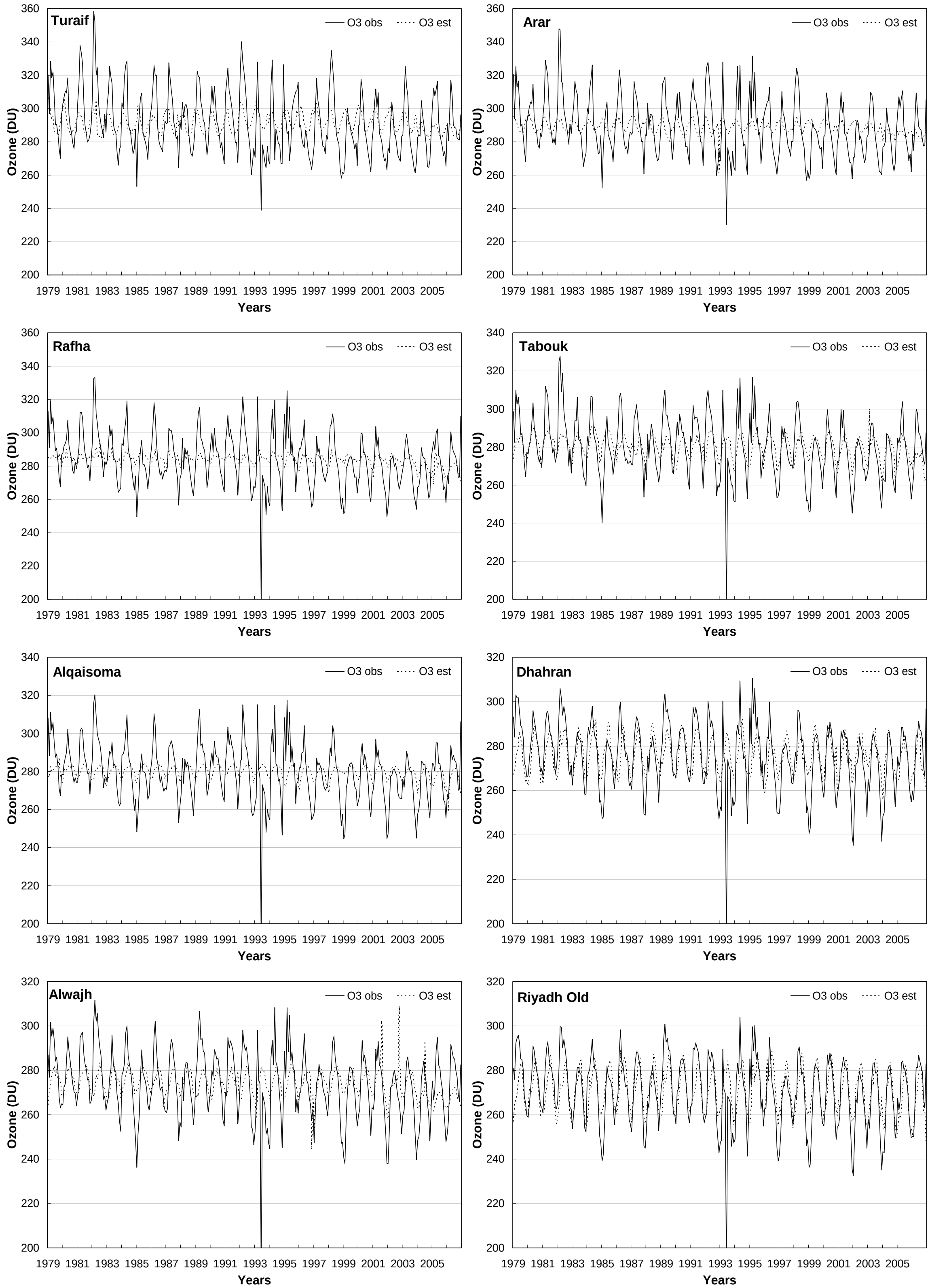

Fig. 1: Actual (solid line) and estimated (dashed line) total ozone amount from 1989 to 2006 for the stations stations Turaif, Arar, Rafha, Tabouk, Qaisoma, Dhahran, Alwjha and Riyadh old.

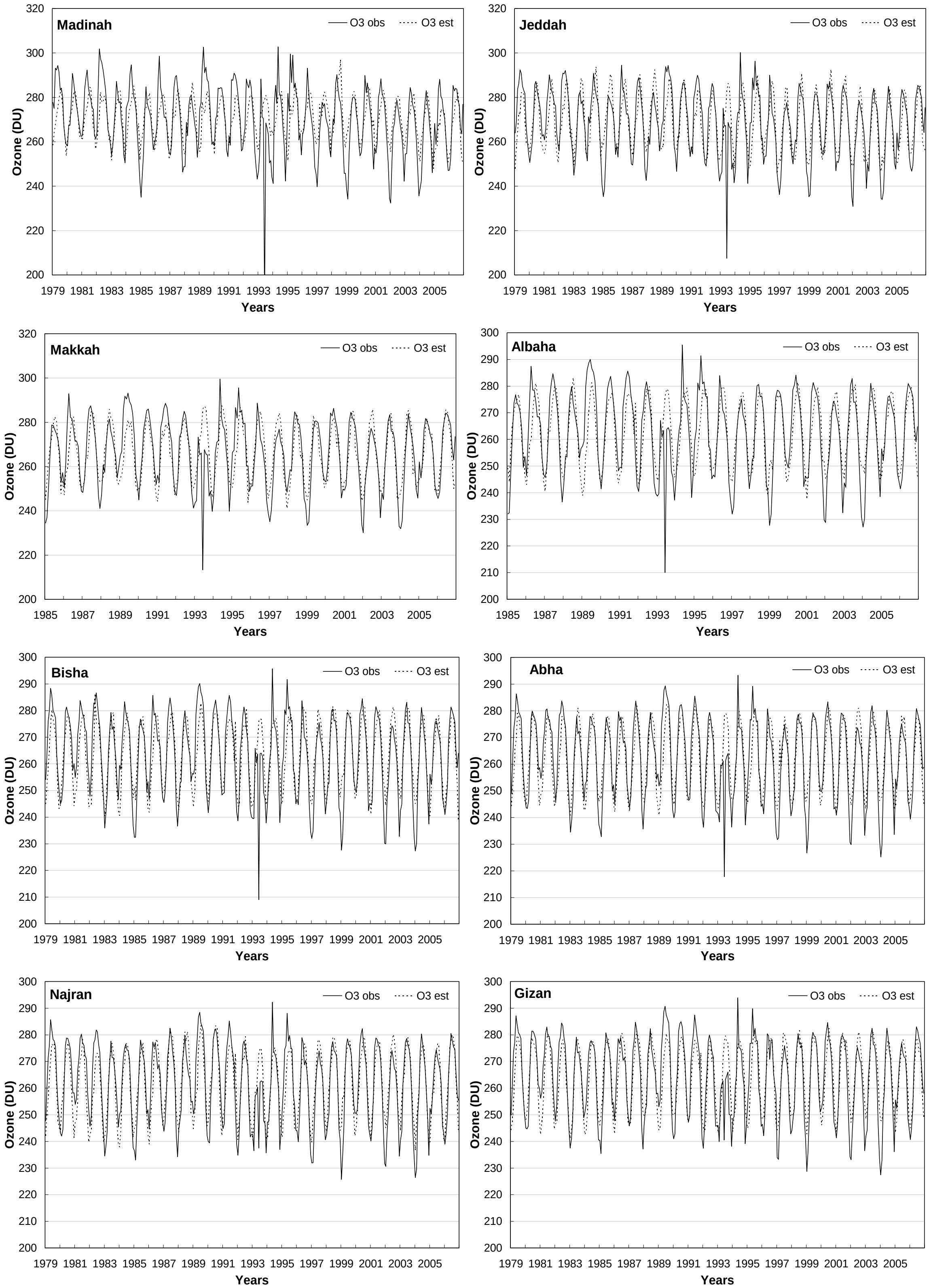

Fig. 2: As in Fig. 1 but for the stationas Madinah, Jeddah, Makkah, Albaha, Bisha, Abha, Najran and Gizan.

Table 6: The predictor used in each step, the regression coefficients arising in each step (A_i, B_i), MAE and RMSE arising from the error between the actual and estimated data after each step, and multiple correlation coefficient (C.C) from a stepwise regression analysis for the stations Turaif, Guriat, Arar, Aljouf, Rafha, Tabouk, Alqaisoma, Hafr and Hail.

Stations	**Step No.**	**Predictors**	**Regression Coefficients**		**MAE**	**RMSE**	**C.C**
			A_i	**B_i**			
Turaif	1	T-Trop	440.9	2.37	13.286	16.926	0.449
	2	Z(100-500)	-162.936	0.015	12.955	16.801	0.470
	3	Z(300-500)	72.176	-0.019	12.921	16.700	0.472
	4	Z(100-1000)	-74.31	0.005	12.886	16.660	0.481
Guriat	1	T-Trop	450.052	2.5	13.116	16.966	0.464
	2	Z(100-500)	-183.59	0.017	12.743	16.813	0.488
	3	Z(300-500)	75.752	-0.02	12.701	16.706	0.490
	4	Z(100-1000)	-90.717	0.006	12.629	16.650	0.502
Arar	1	T-Trop	410.844	1.918	12.685	16.270	0.399
	2	Z(100-500)	-178.619	0.017	12.308	16.119	0.431
	3	Z(300-500)	71.671	-0.019	12.286	16.021	0.434
	4	Z(100-1000)	-93.541	0.006	12.194	15.955	0.452
Aljouf	1	T-Trop	366.021	1.269	12.521	16.149	0.279
	2	Z(100-500)	-211.121	0.02	12.031	15.959	0.340
	3	Z(300-500)	75.981	-0.02	12.001	15.861	0.349
	4	Z(100-1000)	-108.158	0.007	11.888	15.782	0.379
Rafha	1	T-Trop	349.301	1.011	12.324	15.939	0.227
	2	Z(100-500)	-208.263	0.019	11.838	15.753	0.302
	3	Z(300-500)	76.811	-0.021	11.708	15.653	0.314
	4	Z(100-1000)	-105.632	0.006	11.682	15.572	0.354
Tabouk	1	T-Trop	324.238	0.674	12.355	16.039	0.139
	2	Z(100-500)	-308.099	0.029	11.731	15.713	0.268
	3	Z(300-500)	86.523	-0.023	11.713	15.612	0.338
	4	Z(100-1000)	-133.488	0.008	11.514	15.519	0.341
	5	Z(300-500)	80.773	-0.022	11.500	15.430	0.403
Alqaisoma	1	Z(100-500)	80.485	0.019	11.322	15.233	0.145
	2	T-Trop	42.835	0.647	11.193	15.080	0.230
	3	Z(100-1000)	-103.777	0.006	11.030	15.006	0.236
	4	Z(300-500)	75.698	-0.02	11.010	14.921	0.308
Hafr-Albaten	1	Z(100-500)	18.271	0.024	11.161	15.048	0.185
	2	T-Trop	36.893	0.558	11.010	14.937	0.239
	3	Z(500-1000)	-68.976	0.012	10.935	14.867	0.241
	4	Z(300-500)	83.314	-0.022	10.927	14.767	0.340
Hail	1	Z(100-1000)	27.7	0.015	11.323	15.050	0.205
	2	T-Trop	43.288	0.648	11.199	14.911	0.281
	3	P-Trop	12.648	-0.097	11.085	14.831	0.277
	4	Z(300-500)	76.828	-0.02	11.115	14.755	0.411

Table 7: As in table 6 but for the satations Qassim, Dhahran, Alwajh, Alahsa, Riyadh new, Riyadh Old, Madinah and Yanbo.

Stations	Step No.	Predictors	Regression coefficients		MAE	RMSE	C.C
			A_i	B_i			
Qassim	1	Z(500-1000)	-415.156	0.118	6.581	9.042	0.803
	2	T-Trop	29.042	0.426	6.512	8.966	0.809
	3	P-Trop	11.621	-0.094	6.412	8.898	0.810
	4	Z(300-500)	62.926	-0.017	6.401	8.826	0.817
Dhahran	1	Z(100-1000)	-178.665	0.028	10.142	13.970	0.392
	2	Z(300-500)	80.328	-0.021	10.103	13.894	0.421
	3	Z(500-1000)	-79.011	0.014	9.997	13.810	0.429
	4	Z(200-300)	66.224	-0.01	9.732	13.761	0.436
Alwajh	1	Z(100-1000)	-165.855	0.027	10.715	14.438	0.325
	2	Z(300-500)	104.509	-0.028	10.666	14.323	0.387
	3	P-Trop	21.367	-0.171	10.458	14.177	0.394
	4	T-Trop	48.827	0.717	10.353	14.042	0.445
Alahsa	1	Z(500-1000)	-122.79	0.069	9.690	13.361	0.475
	2	P-Trop	22.162	-0.191	9.506	13.263	0.489
	3	Z(300-500)	127.49	-0.034	9.446	13.089	0.517
	4	Z(100-500)	-137.776	0.013	9.263	13.021	0.525
	5	T-Trop	46.026	0.66	9.230	12.927	0.537
Riyadh new	1	Z(500-1000)	-189.938	0.08	9.464	13.102	0.507
	2	P-Trop	30.629	-0.266	9.169	12.928	0.529
	3	Z(300-500)	156.06	-0.041	9.019	12.692	0.562
	4	Z(100-1000)	-121.105	0.007	8.873	12.618	0.579
	5	T-Trop	55.204	0.787	8.781	12.488	0.584
Riyadh Old	1	Z(500-1000)	-198.904	0.082	9.396	13.041	0.523
	2	P-Trop	27.943	-0.242	9.134	12.886	0.542
	3	Z(300-500)	150.541	-0.04	8.984	12.657	0.573
	4	Z(100-1000)	-116.405	0.007	8.849	12.586	0.569
	5	T-Trop	52.639	0.752	8.754	12.462	0.593
Madinah	1	Z(500-1000)	-230.773	0.087	9.868	13.407	0.478
	2	P-Trop	35.038	-0.299	9.622	13.154	0.512
	3	Z(300-500)	175.114	-0.046	9.462	12.905	0.543
	4	Z(100-500)	-210.231	0.02	9.247	12.793	0.546
	5	T-Trop	52.967	0.759	9.085	12.667	0.570
Yanbo	1	Z(100-1000)	-526.027	0.048	9.661	13.380	0.499
	2	P-Trop	39.39	-0.335	9.387	13.084	0.534
	3	Z(300-500)	203.83	-0.054	9.126	12.780	0.577
	4	Z(500-1000)	-108.817	0.019	9.026	12.686	0.571
	5	T-Trop	46.029	0.658	8.900	12.596	0.591

Table 8: As in table 6 but for the satations Jeddah, Taif, Makkah, Albaha, Bisha, Khamis Moshet, Abha, Najran, Sharorah and Gizan.

Stations	Step No.	Predictors	Regression coefficients		MAE	RMSE	C.C
			A_i	B_i			
Jeddah	1	Z(500-1000)	-642.745	0.158	8.273	11.268	0.670
	2	P-Trop	37.176	-0.336	8.037	11.029	0.687
	3	T-Trop	52.603	0.731	7.830	10.927	0.696
	4	Z(300-500)	61.531	-0.016	7.806	10.908	0.701
Taif	1	Z(500-1000)	-718.079	0.17	8.067	10.963	0.695
	2	P-Trop	34.335	-0.314	7.902	10.762	0.708
	3	T-Trop	49.074	0.679	7.704	10.675	0.715
	4	Z(300-500)	85.209	-0.022	7.620	10.641	0.722
Makkah	1	Z(500-1000)	-711.011	0.169	8.096	10.988	0.690
	2	P-Trop	34.923	-0.316	7.914	10.780	0.704
	3	T-Trop	49.639	0.687	7.714	10.691	0.711
	4	Z(300-500)	71.206	-0.019	7.705	10.666	0.717
Albaha	1	Z(500-1000)	-937.835	0.208	7.337	10.149	0.749
	2	Z(300-500)	137.95	-0.036	7.307	10.077	0.757
	3	Z(100-500)	-209.561	0.019	7.204	10.004	0.758
	4	P-Trop	16.84	-0.157	7.127	9.954	0.761
Bisha	1	Z(500-1000)	-995.74	0.218	7.059	9.862	0.766
	2	Z(300-500)	141.574	-0.037	7.048	9.788	0.774
	3	Z(100-1000)	-168.933	0.01	6.952	9.725	0.778
	4	Z(200-300)	90.526	-0.014	6.948	9.694	0.780
Khamis Moshet	1	Z(500-1000)	-1256.7	0.263	6.540	9.010	0.804
	2	Z(300-500)	141.169	-0.037	6.521	8.962	0.808
	3	T-Trop	35.791	0.482	6.452	8.910	0.812
Abha	1	Z(500-1000)	-1278.04	0.266	6.554	8.979	0.806
	2	T-Trop	34.499	0.467	6.481	8.929	0.809
	3	Z(300-500)	148.038	-0.039	6.458	8.873	0.814
Najran	1	Z(500-1000)	-1277.75	0.266	6.216	8.248	0.831
	2	P-Trop	-16.47	0.155	6.200	8.195	0.833
	3	Z(300-500)	183.327	-0.048	6.141	8.112	0.838
	4	Z(100-1000)	-105.819	0.006	6.123	8.088	0.848
Sharorah	1	Z(500-1000)	-1150.8	0.245	6.303	8.285	0.833
	2	P-Trop	-15.781	0.156	6.288	8.222	0.836
	3	Z(300-500)	163.731	-0.043	6.227	8.152	0.840
Gizan	1	Z(500-1000)	-1480.44	0.302	6.237	8.242	0.832
	2	T-Trop	59.293	0.792	6.100	8.083	0.839
	3	Z(300-500)	138.038	-0.036	6.078	8.047	0.842

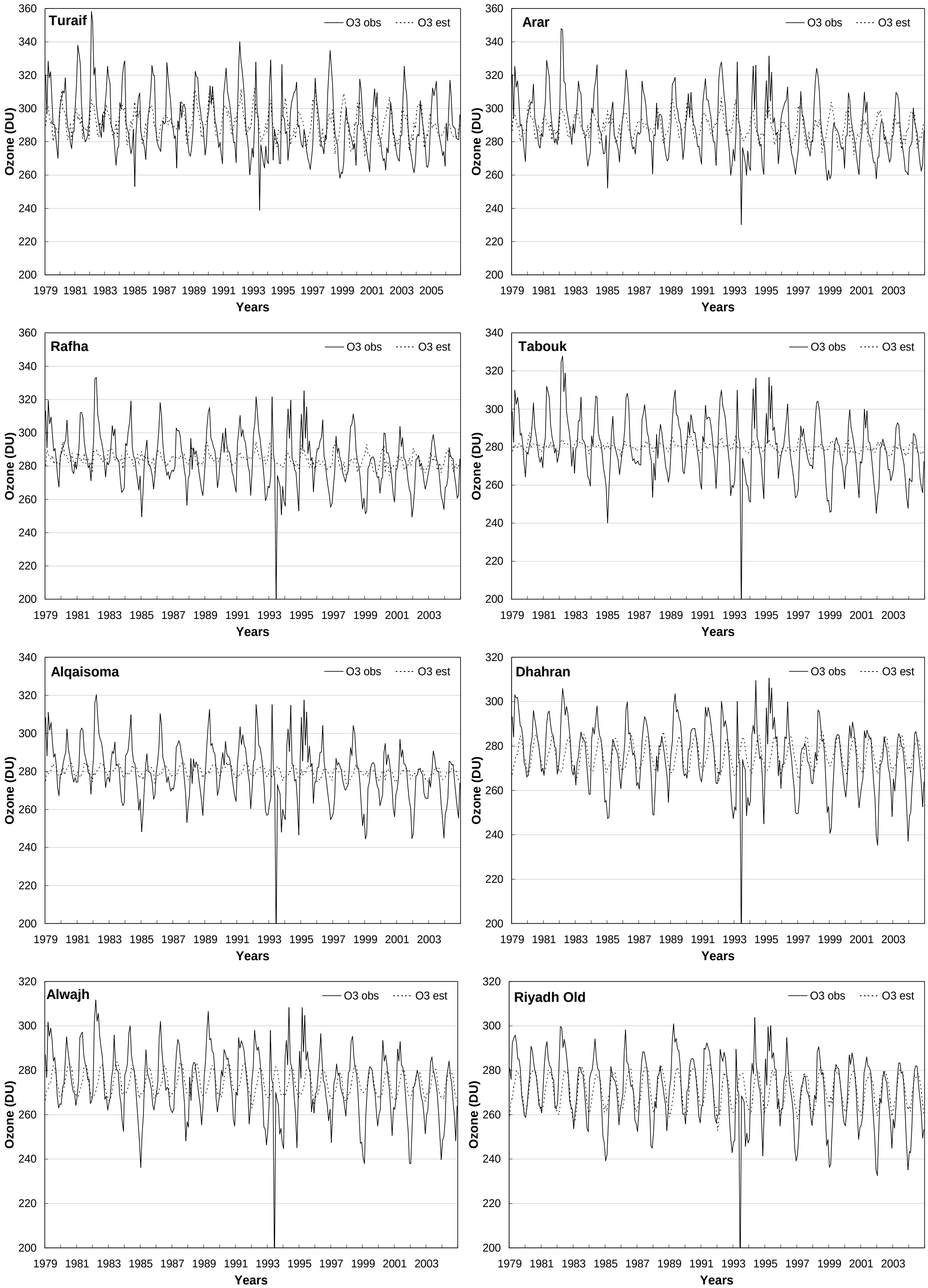

Fig. 3: Actual (solid line) and estimated (dashed line) total ozone amount from 1979 to 2006 for the stations Turaif, Arar, Rafha, Tabouk, Qaisoma, Dhahran, Alwajh and Riyadh old

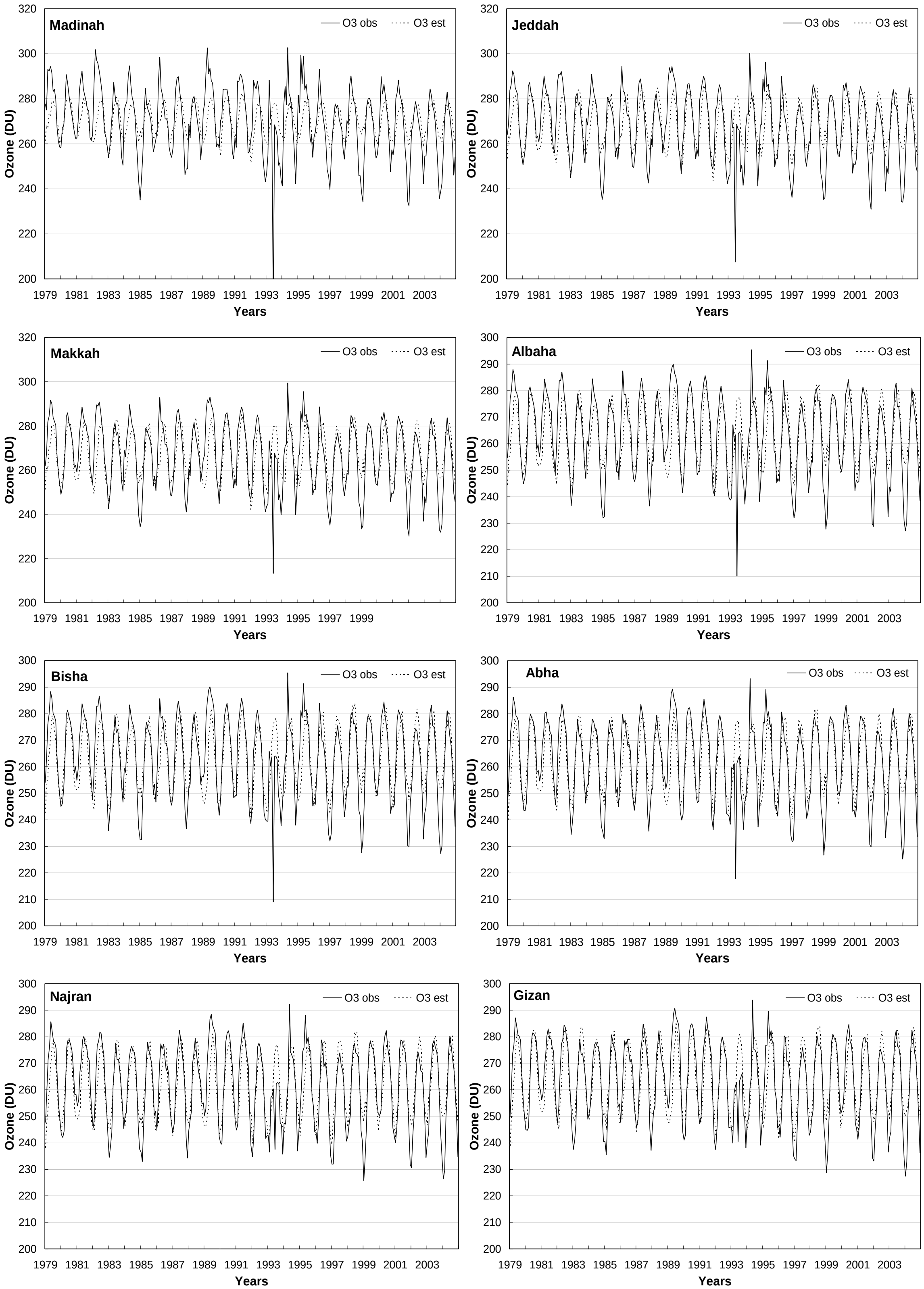

Fig. 4: As in Fig. 3 but for the stations Madinah, Jeddah, Makkah, Albaha, Bisha, Abha, Najran and Gizan.

تقدير الاوزون فوق المملكة العربية السعودية

عبد الرحمن خلف الخلف و حشمت عبدالباسط محمد

كلية الأرصاد والبيئة وزراعة المناطق الجافة - جامعة الملك عبد العزيز- جدة – المملكة العربية السعودية

الملخص

فى هذا البحث تم دراسة العلاقة بين القيم الكلية للاوزون وعناصر الطقس عند كل محطة من محطات المملكة العربية السعودية. وتم تطبيق طريقة الباقى لتقدير قيم الاوزون الكلية من خلال عناصر الارصاد الجوية. وعلى ذلك تم استنتاج معادلات تجريبية تربط قيمة الاوزون الكلية بهذه العناصر عند كل محطة من محطات المملكة. وتم تطبيق نظرية الباقى أيضا فى استنتاج معادلات تجريبية تربط بين قيم الاوزون الكلية مع الضغط ودرجة الحرارة عند مستوى التروبوبوزوكذلك سمك طبقات الغلاف الجوى. وتم التوصل الى معامل ارتباط جيد جدا (٠,٨) بين قيم الاوزون المقاسة والقيم المستنتجة خاصة فوق وسط وجنوب المملكة. ووجد ان النتائج عند محطات المنطقة الجنوبية احسن بكثير عن المنطقة الوسطى والشمالية للمملكة. وسوف تمكننا هذه العلاقات والمعادلات الجيدة التى تم التوصل اليها من استنتاج والتنبؤ بقيم الاوزون الكلى سواء ما إذا كانت هناك محطات للأرصاد الجوية أم لا وذلك باستخدام نتائج النماذج العددية للتنبؤ بالطقس.