Atmospheric ozone and Cyclogensies

A. K AL-Khalaf

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

ABSTRACT

The relationship between the total amount of ozone content with the development of a cyclonic system that occurred in the period 17 to 28 January 2005 has been studied. It was found that the total amount of ozone increases and decreases with the development and weakening of the cyclonic system respectively. There is also a good correlation between total amount of ozone with the thickness of height between 1000-500 hPa and tropopause pressure. This strong relationship between the total amount of ozone with these two parameters was used to deduce a linear regression equation relating them. The residual method has been used to evaluate linear regression equation relating the total amount of ozone with thickness of height and tropopause pressure. The total multiple correlations reached to 0.98 after using two predictors. These results were deduced only from the short data record and is to be taken as preliminary study pending further detailed examination.

1. Introduction

The correlation between total ozone and meteorological feature has been appreciated since the beginning of research on atmospheric ozone. The nature of day-to-day total ozone fluctuations has been of considerable for many years. Early studies based on a limited number of ground station reports (Dobson et al., 1946) helped to establish a firm meteorological basis for the observed daily variation. Reed (1950) pointed out the ozone variations are not only caused by chemical processes but also have dynamical origins, expressed by sudden increases in total ozone accompanying marked increase in tropopause pressure, such as found during the passage of a cold front or depression. This can be interpreted simply as an increase in the depth of ozone or as a combination of vertical and horizontal advection on ozone.

With the advent of satellite, instruments capable of measuring the global distribution of total ozone, therefore more detailed analyses of ozone variability have become possible, and the nature of this relationship could be examined more fully. For example, the study by Schoeber and Krueger (1983) successfully modeled observed total ozone changes in the Southern Hemisphere (SH) and further suggested that, in general, atmospheric disturbances which are vertically trapped near the tropopause and have little vertical phase shift will tend to produce the strongest correlation with total ozone. Recently the record of satellite observations of total ozone has become sufficiently long to allow, for the first time, nearly spatially complete estimates of the climatology of total ozone (Bowman and Krueger, 1985). In conjunction with the availability of global distributions of total ozone a number of studies have been reported of the close link between jet streams and gradients in total ozone (Shapiro et al., 1982; Reiter and Gao 1982) and of the marked signatures on total ozone maps of features such as tropopause folds and cut-off-lows (Uccellini et al., 1985; W.M.O 1985, Vaughan and Price 1988). However, comparatively little is understood about the extent to which horizontal variability in total ozone simply reflects variability in the pressure or structure of the tropopause, and the extent to which it reflects variability near the ozone maximum.

The purpose of the present study is to discuss and to analyze the relationship between ozone and cyclogenesis in the base of a cyclonic system that affected the Mediterranean area and KSA during the period from 17 to 28 January 2005.

2. Data and methodology

A) Data

The data used in this paper have been taken from the archives of the European Center for Medium-Range Weather Forecasts (ECMWF). It consists of the horizontal wind components (u- eastward, v-northward), the temperature (T) and the geopotential height (z) on regular latitude-longitude grid points resolution of 2.5o x 2.5o for the isobaric levels 1000, 850, 700, 500, 300, 200 and 100 hPa. The data used is only at 1200 GMT during the period 17 to 28 January 2005. The domain of study extends from 10oW to 60o E and from 10o N to 70o N. The inner domain which is used for the present study changes with time to enclose the cyclone during its life cycle Fig.(2).

Daily ozone data for the period 17 to 28 January 2005 were obtained from the Total Ozone Mapping Spectrometer (TOMS). Total Ozone Mapping Spectrometer (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.

For each day, average total amount of ozone was estimated by calculating the average gridded ozone values inside the domain of calculations (Fig. 2). This domain encloses the cyclone cell over the period of study, and so, our calculation of total amount of ozone average and meteorological parameters are made only over our domain to have a better view and investigation of total amount of ozone variations with meteorological parameters. Also the same procedure is applied to estimate the average daily mean tropopause pressure values that taken from NOAA – GAES climate diagnostics contour.

B- Residual method

The success of a statistical forecasting method does, of course, to some extent depend on the technique applied, but it depends even more on the selection of the predictors. After choosing a number of predictors from the physical point of view, the problem is how best to use them. One method of doing this is by using them one by one in successive correction manner. That we start with the best of these predictors, then improving the result by using the next and so on, the procedure of this method could be found in Eriksson, B. (1962).

Residual method has been applied to explore the possibility of forecasting total ozone average values by means of previous values of depth of height and tropopause pressure. The values of total ozone during the period of study (17 to 28 January 2005) have been taken as the dependent variable (predictand) and the corresponding values of depth of height and tropopause are the independent variables (predictors).

First step, the correlation coefficient (r) between the values of total ozone and each of depth of height and tropopause pressure (predictors) has been determined. The predictor which has the strongest r with the predictand has been used to be the first predictor, then the regression line and the regression coefficients is determined. The error between the actual and estimated value of total ozone was taken as a predictand.

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 (if we have many predictors) until the additional predictor has no significant effect on the predictand and there is no need for any further steps (i.e the improvement can not be expected to be very great with adding new predictors).

3. Synoptic discussion

A common case of winter cyclogenesis over the Mediterranean is considered in the present study. Its period extended from 18 to 26 January 2005. Based on 1000 hPa and 500 hPa charts the life cycle of this cyclone can be divided into two periods. The first period (growth period) is from 18 to 23 January while the second period (decay period) is from 24 to 26 January. 1000 hPa and 500 hPa charts at 1200 GMT on each day are shown in Figurs 1 and 2 respectively. 1000 hPa charts depict contours of height with 20 geopotential meter (GPM) increament while upper air charts (500 hPa) contain contours of height with 40 GPM increment. The isotherms in the charts of the two levels are analyzed with 5^{o}C increament. The cyclone of special interest first appeared as an extension of the traveling depression north west of Europe at 18 January. A cut-off low is formed at 19 January and a well-defined cyclonic depression become clear over south west of Italy. At 19 January a strong thermal gradient lies along the northern Italy and middle of Europe. In this highly baroclinic zone the surface storm undergoes strong intensification.

The evolution of the lee cyclogenesis was consistent at least in the second and third days, with the schematic processes outlined in Buzzi and Tibalidi (1978). The interaction of the cold front with the Alps produced the initial disturbances which then grow as a baroclinic disturbances.

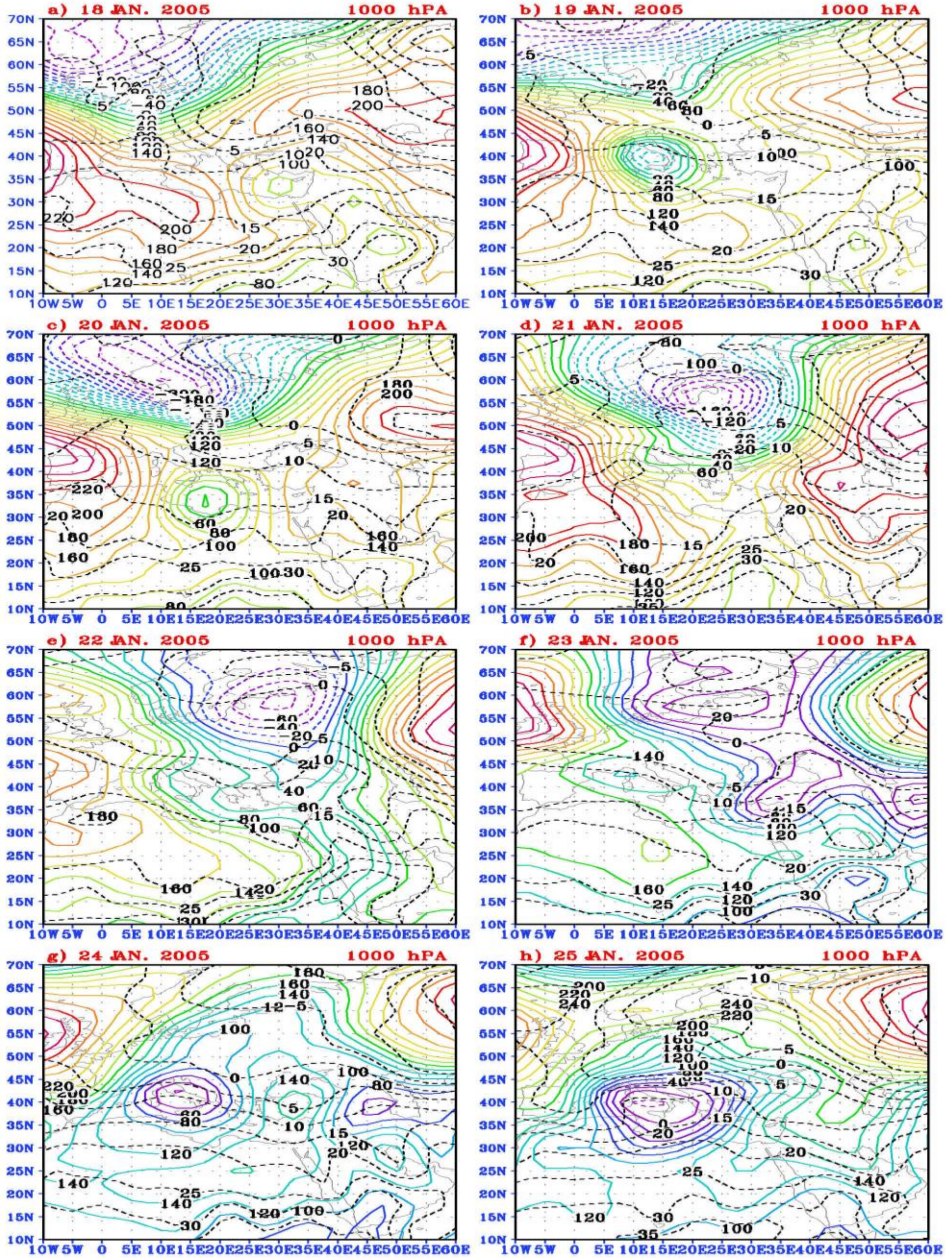

Fig. 1: 1000 hPa geopotential contour every 20 m intervals (solid) and temperature (dashed) every 5o C for 1200 UTC 18-25 January 2005.

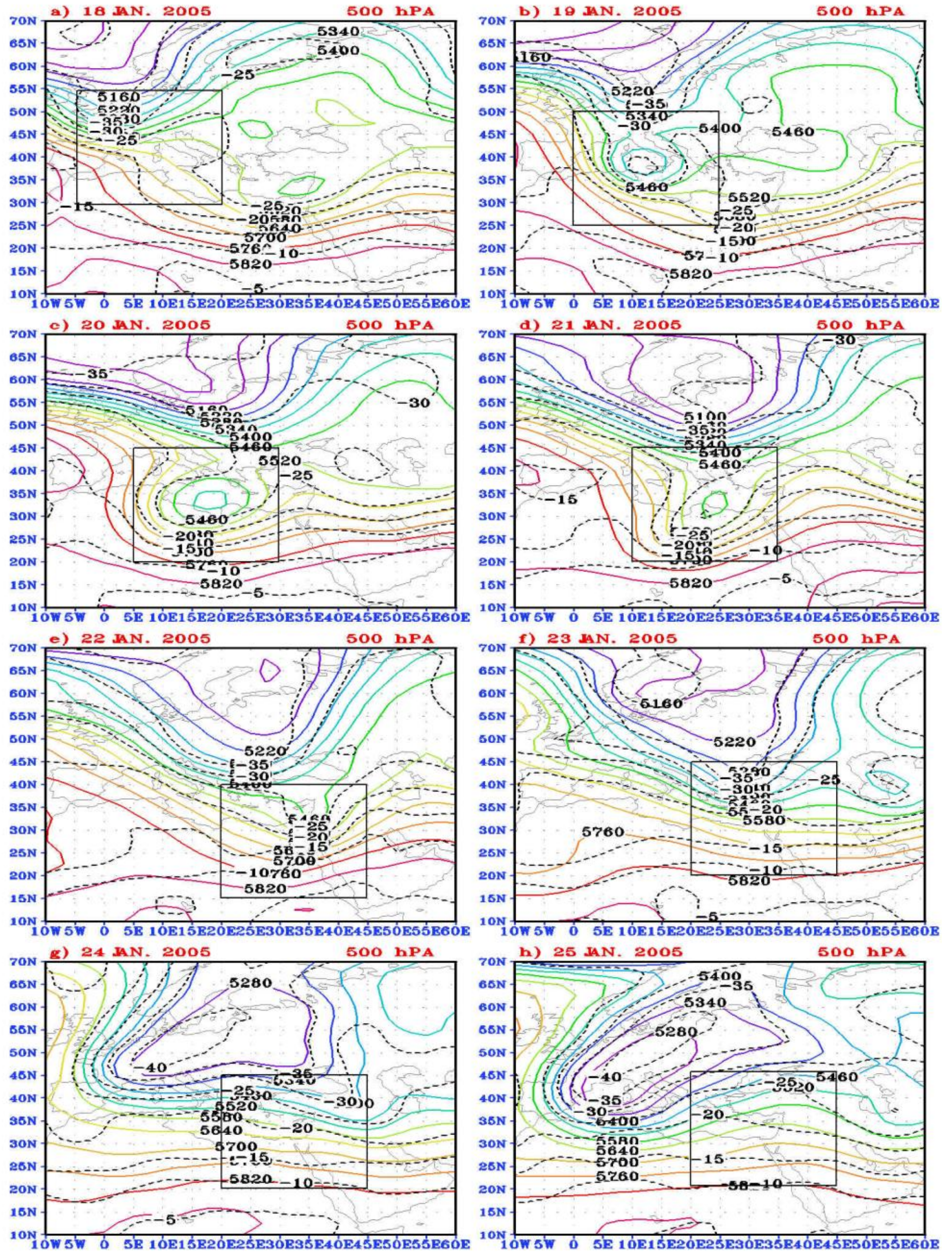

Fig. 2: 500 hPa geopotential contours every 40 m intervals (solid) and isotherms (dashed) every 5o C for 1200 UTC 18-25 January 2005.

During the next 24 hours, the center of the low propagates slowly to the southeastward and the geopotential height at the center reaches to 20GPM (Figure 2c). A corresponding cut off low at 500 hPa becomes over north libya with center of 5400 GPM. On 21 January a strong development occurs at the surface and at the upper air, where the surface cyclone moved east ward and becomes continued (joints) with the main cyclone (its center at 55^{o}N, 25^{o}E). Also the inverted v-shap trough of the sudan low oscillate north ward to the north of the red sea, and in the upper air (500 hPa) the cut of low also moved east ward to a point just north east of Egypt. At 1200 GMT 22 January (the rainy day), a strong interaction occurs between the trough that extended from the tropical region and that extended from middle latitude region, and the two cyclones becomes joints with other. The most interesting features is that there is north ward strong warm advection from the tropical region associated with the air flow around the sudan low and a south wad strong cold advection. The interaction between these two air masses causing a strong instability over the east of Mediterranean and at the west of saudia arabia. By 1200 GMT January, the trough of sudan low moved south west ward with the trough of the midllatitude low moved east ward to centerd over Iran. During the next two days (25 and 26 January) the depression started filling and its central pressure increased gradually. On the other hand the high pressure over Atlantic is extended with a major ridge that joints the Siberian high on 22 January, Figure 2d. In other wards no more cold advection is permitted from the to the cyclone. While the Siberian high pressure propagate westward, the horizontal extension of the cyclone decrease and moved slowly eastward, and it become stationary vortex rotating above the north east of Mediterranean. Finally the cyclone was drifted slowly north-eastward and was out of the computational domain by 27 January.

4. Relationship between ozone and cyclogensies

It has been known that the total ozone content is linked with synoptic scale meteorological phenomena. In this section the relation between total ozone and both the depth of height and tropopause pressure will be investigated. This will be made during the period of my case study (17 to 28 January 2005).

4.1 Ozone and depth of height

Figure 3 shows the horizontal distribution of the total ozone values during the period 18 to 25 January, while figure 2 illustrate the 500 hPa charts of the life cycle of our cyclone during the same period. It is clear that the maximum values of total ozone are associated with maximum deepening, while the minimum values of total ozone are associated with the minimum deepening. It is interesting to note that the maximum values of total ozone and minimum values of height are occurred during the period of maximum cyclogenesis. And so we can say that there exists a very direct connection between the spatial distribution of ozone and spatial distribution of the 500 hPa height. To investigate the relation between total ozone and depth of height (Δz), where Δz is the difference between 500 hPa geopotential height and 1000 hpa geopotential height, the total amount of ozone and depth of height are calculated by averaging all the gridded points values inside the fixed domain that include the cyclone cell over all period of study. Figure 4 illustrate the daily variation in total ozone average and depth of height. It is shown that, the anti-correlation between total ozone and depth of height is very strong and significant over all the period. Figure 4 shows that the greater values of total ozone are associated with low values of ΔZ and vise verse. Also, the life cycle of our case of study is apparent in the values of total ozone and ΔZ. The maximum values of total ozone (and the corresponding minimum values of ΔZ) occurred during the period of maximum cyclogenesis, while the inverse is satisfied during the period of minimum cyclogenesis. The largest value of total ozone average throughout the period of study (17 to 28 January 2005) is about 510 DU and exists at 18 January. Finally, it is clear that the variations of the daily values of total ozone average and the corresponding depth of height (ΔZ) represent a close visual correspondence between these two parameters, which is striking and suggests a strong link between synoptic weather, as expressed depth of height, and total ozone. The correlation coefficient (r) between the two time series of total ozone and the corresponding of ΔZ (during the period of study) is equal -0.94. This strong relationship between these two parameters is used to deduce a linear regression equation relating these two parameters. The correlation between total ozone and depth of height is strongly negative and significant not only between the depth of height between 500 hPa and 1000 hPa, but also for the depth of height between 200, 300 hPa and 1000 hPa.

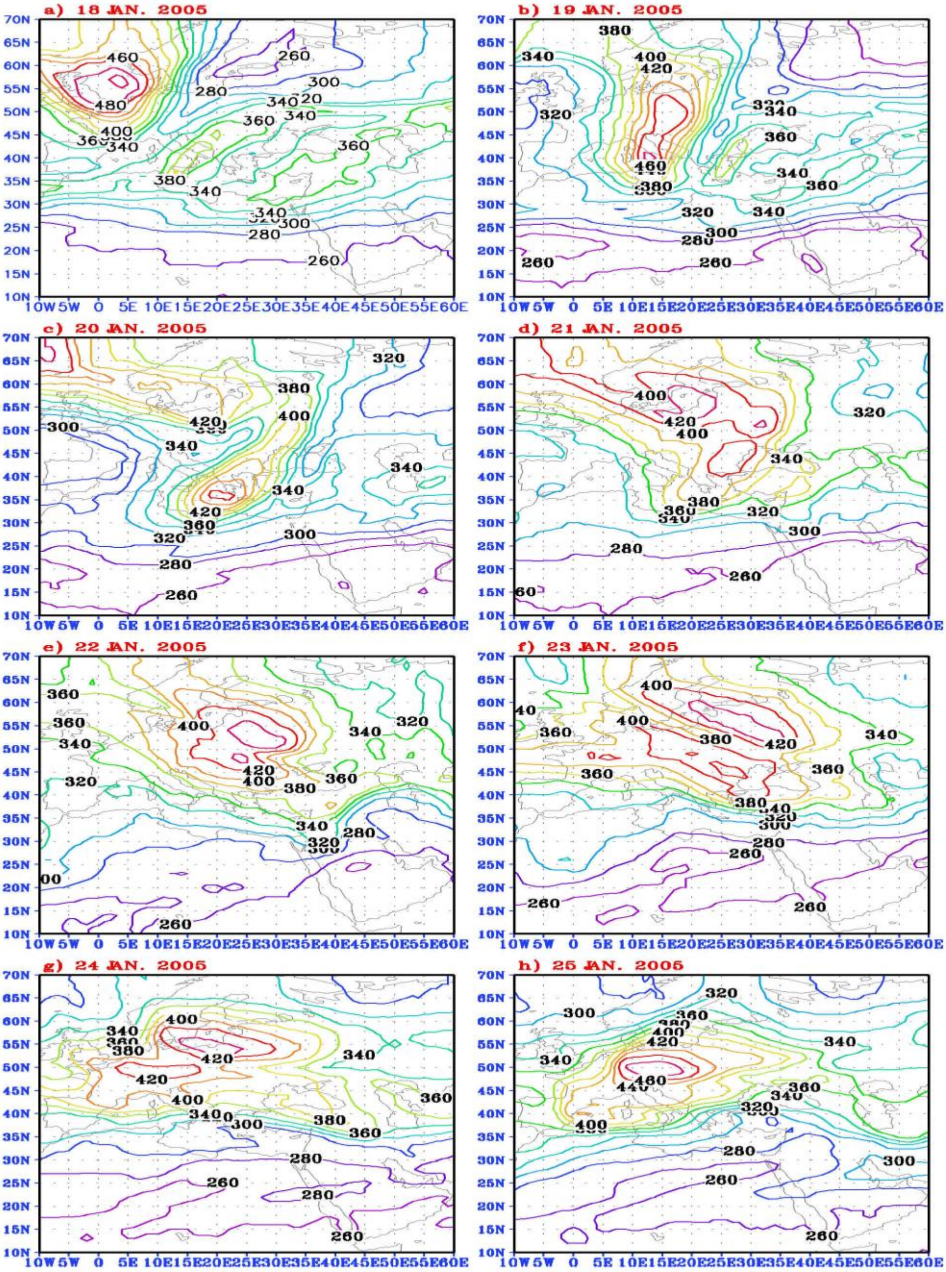

Fig. 3: Vertically integrated values of total ozone during the period 18-25 January 2005.

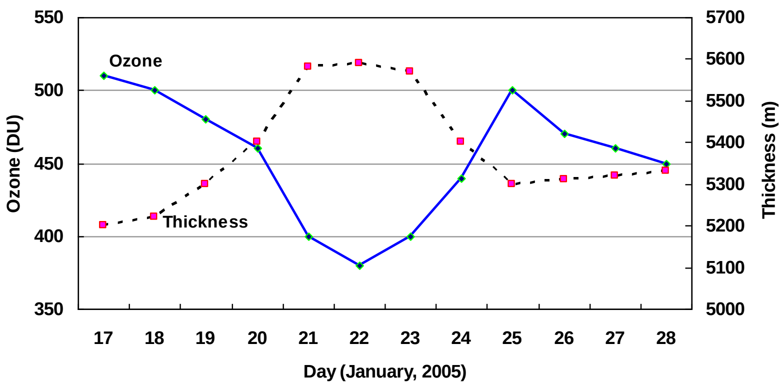

Fig. 4: The area average values of total ozone with the crossponding thickness (500- 1000 hPa) over the area containing the cyclone during the period 17 to 28 January 2005.

4.2 Tropopause pressure (TP) and total ozone correlation

Figures 3 and 5 show day-to-day variations in the values of total ozone and those corresponding of tropopause pressure during the period of study (17 to 28 January 2005). Figures 3 and 5 illustrate a very good correlation between total ozone and tropopause pressure. It is clear that the maximum values of total ozone are associated with maximum values of tropopause pressure, while the minimum values of total ozone are associated with the minimum values of tropopause pressure. It is interesting to note that the maximum values of total ozone and maximum values of tropopause pressure are occurred during the period of maximum cyclogenesis with the largest values during the first three days.

From the previous we can conclude that when the tropopause descends (i.e. its pressure increase), the fraction of stratospheric air above the location increases, there by increasing total ozone, on the other hand when the tropopause ascends (i.e its pressure decrease), there is a corresponding decrease in total ozone. And so we can say that there exists a very direct connection between the spatial distribution of ozone and spatial structure of the tropopause.

Two important features from figures 3 and 5 can be shown. First, the total ozone at northern mid-latitudes (during the life cycle of a cyclone) is highly variable, as changes of 100 DU can occur with in a few days. Second, high total ozone is strongly correlated with high tropopause pressure in the previous day and vice versa. Figure 6 shows that the values of total ozone are associated with tropopause pressure over the area containing the cyclone during the period 17 to 28 January 2005. The correlation coefficient between total ozone and tropopause pressure is equal to 0.92. This high correlation coefficient indicates that these two quantities are connected very closely. In the case of day-to-day fluctuations, it is generally accepted that synoptic scale weather patterns in the troposphere are the predominant cause for the observed ozone changes (Tung and Yang, 1988; Salby, 1996).

4.3. Empirical formula for estimating ozone from ΔZ and TP

The relation between depth of height (ΔZ) and changes in tropopause pressure (TP) with total ozone was discussed previously. A very good correlation is apparent between both meteorological parameters and total ozone. The topic of this section is the estimation of total ozone average by using an empirical formula relating it to the depth of height and tropopause pressure. The strong correlation coefficient (-0.94) between total ozone and the depth of height between 500 hPa and 1000 hPa make us able to establish a linear regression equation relating these two parameters. This equation was made by using the data of total ozone and the depth of height that represented in figure 3 and it represented as follows.

$$\text{Total Ozone} = 2078.791 - 0.30216 \times \Delta Z \quad (1)$$

By the aid of empirical equation, the average total amount of ozone can be estimated by knowing the depth of height value. This empirical equation is valid and gives a good results for the most cases of cyclogenesis specially in the cases of deep cyclogenesis. Residual method has been applied to explore the possibility of forecasting total ozone average values by means of previous values of depth of height and tropopause pressure. Table 2 shows 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)

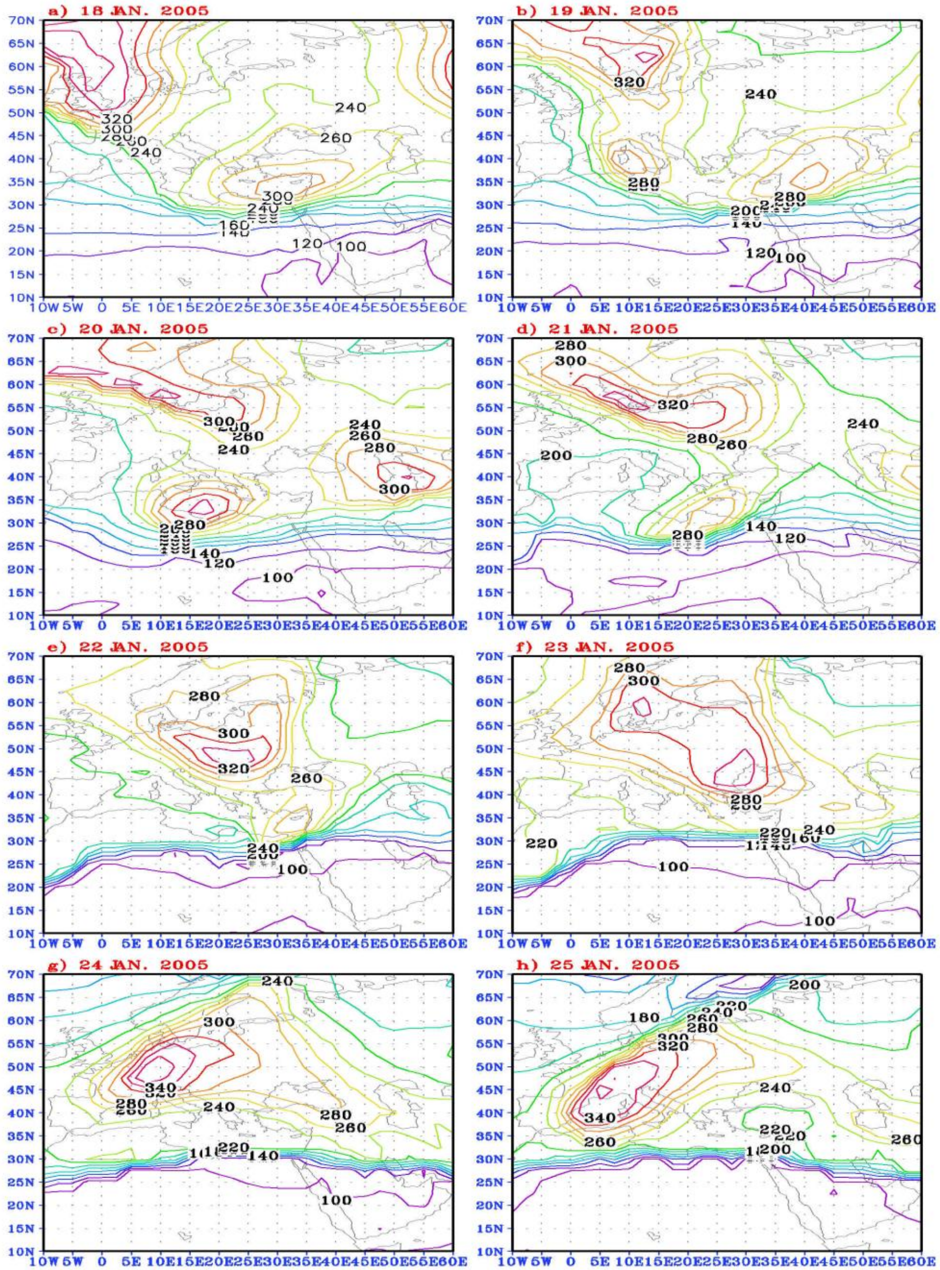

Fig. 5: The horizontal distribution of tropopause pressure during the period 18- 25 Jaunary 2005.

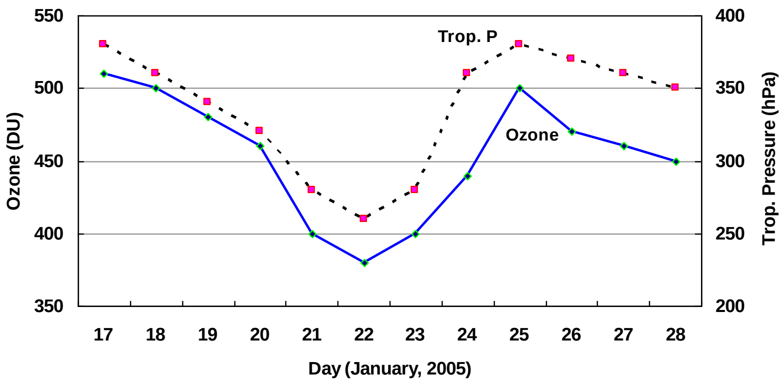

Fig. 6: The area average values of total ozone with the crossponding Tropopause pressure over the area containing the cyclone during the period 17 to 28 January 2005.

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. Figure 6 illustrate the daily variation in total ozone average and tropopause pressure. From table 1, it can be shown that the total multiple correlations reached to 0.98 after using two predictors. This increasing of r is associated with a decreasing of RMSE and MAE. The multiple regression equation for the predicting values of total ozone from the known preceding values of depth of height and tropopause pressure can be written as follows:

$$\text{Total Ozone} = 2076.65 - 0.30216 \times \Delta Z + 0.0063 \times TP \qquad (2)$$

This equation estimate the total ozone amount by knowing both the depth of height and tropopause pressure values, and give a valid values for total ozone estimation specially in the cases of deep cyclogenesis. The present study is based on 12 values (represent the period of the case of study) and is to be taken as preliminary study pending further detailed examination. This results must be tempered by the short data record. To obtain more statistically reliable results, long data series (large numbers of cases of cyclogenesis) are required.

Table 1: Regression coefficient (A_i, B_i), root mean square error, mean absolute error, and multiple correlation coefficient (R) from a stepwise regression analysis.

Step No.	Predictors	Regression Coefficients		MAE	RMSE	R
		A_i	B_i			
1	ΔZ	2078.791	-0.3022	8.699	10.765	-0.94
2	trop. Pressure	-2.14196	0.00633	8.541	10.624	0.98

5. Summary and conclusion

A common case of winter cyclogenesis over the Mediterranean is considered in the present study extended from 17 to 28 January 2005. Since, the total ozone content is linked with synoptic scale meteorological phenomena, the relationship between total ozone content and thickness of height of the atmosphere and tropopause pressure have been investigated for a middle latitude cyclonic system. Strong correlation between ozone and the thickness of atmospheric height and also with tropopause pressure have been found especially during the periods of maximum development of the cyclonic system. The correlation coefficient (r) between the two time series of total ozone and the corresponding of ΔZ (during the period of study) is equal -0.94. This strong relationship between these two parameters is used in deducing a linear regression equation relating these two parameters. The residual method has been used to evaluate linear regression equations relating the total amount of ozone with thickness of height and tropopause pressure. The total multiple correlations reached to 0.98 after using two predictors. These results were deduced only from the short data record where the present study is based on 12 values (represent the period of our case study) and is to be taken as preliminary study pending further detailed examination.

References

Bowman, K. P. and A. J. Krueger, 1985: A Global Climatology of Total Ozone form the Nimbus 7 Total Ozone Mapping Spectrometer. *J. Geophys*. Res., **90**, 7967- 7976.

Buzzi, A. and Tibaldi, A. 1978: Cyclogenesis in the lee of the Alps: A case study, Quart. J. Roy. 25 *Meteorol*. Soc., **104**, 271–287.

Dobson, G.M.B., A.W. Brewer and B.M. Cwilong, 1946: Meterorolgy of the lower atmosphere. Proc. Roy. Soc. *London*, A **185**, 144-175.

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

Reiter, E. R. and Gao, Deng- Yi., 1982: Heating of the Tibet plateau and movement of the south Asian high during Spring. Mon. Weather Rev**.,110**, 1694-1711.

Salby, M.L., 1996: Fungamentals of Atmospheric Physics, Academic Press.

Schoeberl, M.R., and A.J. Krueger, 1983: Medium scale disturbance in total amount of ozone during southern hemisphere summer. *Bull. Amer. Meteor.* Soc., **64,** 1358-1365.pp.

Shapiro, M.A., A.J. Krueger, and P.J. Kennedy, 1982: Nowcasting the position and intensity of jet streams using a satelite-borne Total amount of ozone Mapping Spectrometer, in Nowcasting ed. K. A. Browning. Academic Press, London.

Uccellini, L. W., D. Keyser, K. F. Brill and C. H. Wash, 1985: The Presidents Day Cyclone of 18-19 February 1979: Influence of upstream trough amplification and associated tropopause folding

Vaughan, G., 1988: Stratosphere}troposphere exchange of ozone. In: Bojkov, R.D., Fabian, P., Ozone in the Atmosphere. A. Deepak Publishing, Hampton, USA, pp. 125-135.

WMO. 1985: The global climate system: a critical review of the climate system during 1982–1984. World Climate Data Programme.

الاوزون فى الغلاف الجوى وتكون وتطور المنخفضات

د. عبد الرحمن خلف الخلف

كلية الأرصاد والبيئة وزراعة المناطق الجافة - جامعة الملك عبد العزيز

جدة – المملكة العربية السعودية

المستخلص. تم دراسة العلاقة بين كمية الاوزون الكلية مع تكون وتطور منخفض جوى والذى ظهر فى الفترة من ١٧ الى ٢٨ يناير ٢٠٠٥ م. وقد وجد ان كمية الاوزون تزيد مع تطور وتعمق المنخفض وتقل مع ضعف المنخفض. كما وجدت علاقة قوية بين كمية الاوزون الكلية مع سمك طبقة الهواء بين مستويى الضغط ١٠٠٠ و ٥٠٠ هيكتوباسكال وكذلك مع ضغط التروبوبوز. وقد تم استخدام هذه العلاقة القوية بين كمية الاوزون من ناحية وسمك طبقة الهواء وضغط التربوبوز من ناحية اخرى فى استنتاج معادلة خطية تربط بينهم. وقد تم استخدام طريقة الباقى لاستنتاج هذه المعادلة الخطية بين الاوزون وضغط التربوبوز وسمك طبقة الهواء. وقد وصل معامل الارتباط بين البيانات الاصلية والناتجة من المعادلة الى ٠,٩٨ . وهذه النتائج تم استنتاجها من استخدام متسلسلة قصيرة من البيانات ومن ثم تم اخذها واعتبارها دراسة اولية انتظارا لدراسات مستقبلية مستفيضه فى هذه الجزئية.