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Research Article

Spatial and temporal variation of total column ozone over Turkey with MERRA-2

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Abstract

Ozone has important impact on climate change, the radiative balance and atmospheric chemistry. The main aim of this study is to analyses spatial and temporal variation of total column ozone as well as the trend over Turkey with MERRA-2 Reanalysis for the period 1980-2019. First of all, MERRA-2 total column ozone is compared with ground-based Brewer Spectrophotometer located in Ankara. It is found that MERRA-2 total column ozone agrees quite well (R2=0.9781) with that from the Brewer Spectrophotometer. Secondly, analysis are carried out with MERRA-2 total column ozone. The trend analysis over Turkey indicates statistically significant decreasing trend in the 1980-1999 period, non-significant decreasing trend in the 2000-2009 period and non-significant increasing trend in the 2010-2019 period. The highest annual average total column ozone are found in Istanbul, Canakkale and Samsun cities with the values of 326.3±6.9 DU, 324.0±6.7 DU and 322.2±6.6 DU, respectively. Total column ozone are the highest in spring, followed by winter, and the lowest in summer and autumn seasons over Turkey.

Keywords: Total ozone, Spatial and temporal variation, Brewer spectrophotometer, MERRA-2 reanalysis

Introduction

Total ozone is the total amount of ozone molecules distributed vertically in the atmosphere from the ground to the upper level of the atmosphere. Especially, the amount of ozone molecules in the troposphere and stratosphere plays a determining role on the total ozone thickness. Ozone distribution is generally controlled by large-scale transport from the tropics to the Polar Regions. Tropical low level stratospheric air moves upward and carries total ozone to stratospheric Polar Regions (Crutzen, 1971; Salawitch et al., 2019). Total ozone amount has the lowest average on the equator belt with 240 Dobson Unit (DU) and increases up to 400 DU as it goes from the equator to the poles. The global average of total ozone is about 300 DU, it varies geographically between 230 and 500 DU (Demirhan Bari and Topcu, 2011). Average total ozone values in 2006-2009 have remained at the same level for the past decade, about 3.5% and 2.5% below the 1964-1980 averages respectively for 90°S-90°N and 60°S-60°N. Northern Hemisphere midlatitude (35°N-60°N) annual mean total column ozone (TCO) amounts over the period 2006-2009 have remained at the same level as observed during 1998-2005, approximately 3.5% below the 1964-1980 average (WMO, 2010).

Air masses affected a region have important impact on ozone variability. The ozone-rich air masses are of polar origin, while the ozone-poor air masses are of tropical origin (Lemoine, 2004). The air masses affecting Turkey are mainly polar origin such as continental polar (cP) and maritime polar (mP), and tropical origin such as maritime tropical (mT) and continental tropical (cT). Figure 1 shows air masses that influence Turkey. cP air mass, which has cold and dry characteristic, is originated from Siberian. It affects Turkey all year round, but this effect is more in winter-spring period. mP air mass originated from Atlantic Ocean and passes over Europe through Turkey. It also affects Turkey May-August period and December months, but its effects on Turkey in the winter-spring period are higher. mT air mass, which has warm and humid characteristic, is originated from Azores Islands, while cT air mass, which has hot and dry characteristic, is originated from North African Desert. Polar air masses have an increasing effect on ozone due to bringing cold and ozone rich air to Turkey, while tropical air masses have a decreasing effect because they bring hot and ozone-poor air (Sensoy, 2004; Açar et al., 2013).

TCO is a measure of the total amount of atmospheric ozone vertically from the earth's surface to the top of the atmosphere in a column. It is measured by ground-based stations and satellites. Ground-based stations have provided ozone level data for years, but only for a small area. Besides, satellite measurements provide global coverage dataset of ozone level, but their spatial resolution is coarse. In recent years, the usage of atmospheric reanalysis models in ozone studies has become widespread. They provide global high spatial and temporal resolution of ozone level dataset by utilizing the data assimilation methodology (Cohn, 1997; Kalnay, 2003), whereby satellite and ground-based observations are combined with general circulation model simulations in a statistically optimal way (Wargan et al., 2017).

The spatial and temporal distributions and validation of atmospheric reanalysis ozone has been investigated worldwide in several studies. Dragani (2011) assessed the quality of the ERA-Interim ozone analyses and found ERA-Interim production show a good level of agreement with observations. Madhu and Gangadharan (2016) validated ECMWF Reanalysis of TCO data and investigated distribution of TCO over Cochin/India for the period 1981-2014. As a result of the study, they found that ECMWF TCO values are positively correlated and increase during monsoon season. Andersson et al. (2017) investigated reanalyses of near-surface ozone for Sweden for the period 1990–2013. They found that high near-surface ozone concentrations in Sweden are decreasing and low ozone concentrations are increasing. Shangguan et al. (2019) analysed variability of ozone in the upper troposphere and lower stratosphere from observations and reanalysis data for the period 2002–2017. They found asymmetric trends of ozone in the midlatitudes of two hemispheres in the middle stratosphere and significant ozone decrease in the Northern Hemisphere and increase in ozone in the Southern Hemisphere. Resmi et al. (2021) analysed TCO variations and tropospheric ozone variations over different locations in the Indian sub-continent. They realized that TCO was found to decrease throughout the north Indian region and higher concentration of tropospheric ozone in the summer season.

The main aim of this study is to analyse the spatial and temporal distribution of TCO over Turkey with MERRA-2. For this purpose, we have examined validation of MERRA-2 TCO with ground-based station in Ankara-Turkey. The trend analysis and distribution and spatial variation of MERRA-2 TCO have been investigated for Turkey and several cities for the period 1980-2019.

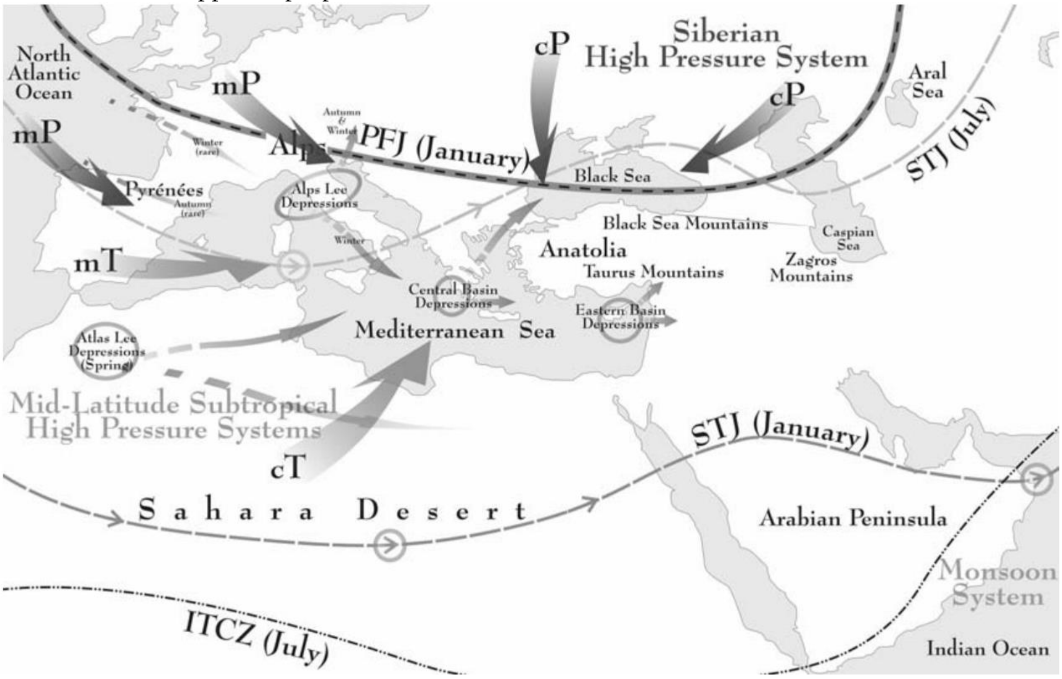

Fig. 1. Air masses that influence Turkey (Akçar and Schlüchter, 2005).

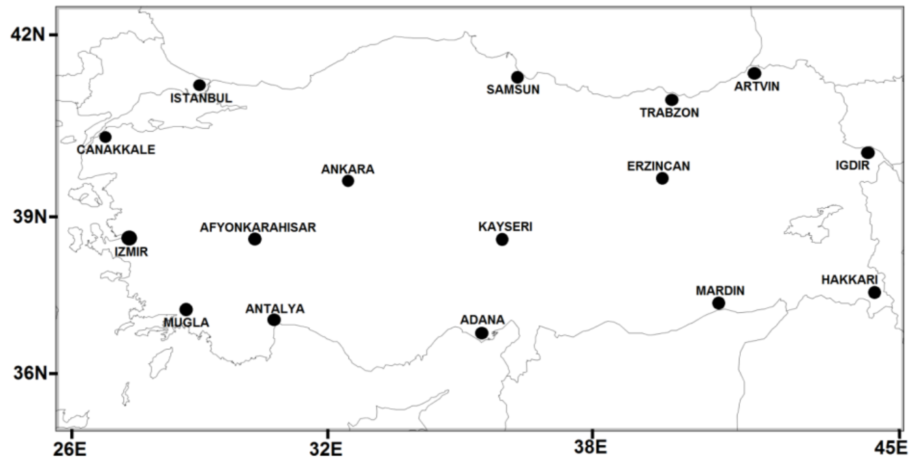

Fig. 2. Study area and locations selected over Turkey.

Materials and Methods

Study Area and Selected Locations

The study focuses on Turkey, which is located in Southeastern Europe and Southwestern Asia along the Black, Aegean, and Mediterranean Seas. Turkey is a link between Europe and Asia lying between 36°-42° North latitude and 26°-45° East longitude (Figure 2). Turkey's topography has a varied characteristic that is formed with a high central plateau, a narrow coastal plain and several large mountain ranges (Briney, 2019). This study also includes the analysis of 16 selected locations shown in Figure 2. These locations were selected to be homogeneously dispersed over Turkey.

Brewer Spectrophotometer

Brewer Spectrophotometer, first developed in Canada by Dr. Brewer in the 1970s, is one of the Spectrophotometers widely used in the world for ozone measurement. It is an automated instrument that provides near-simultaneous observations of the ultraviolet radiation, TCO and sulphur dioxide between the instrument and the upper atmosphere. Brewer Spectrophotometer divides the atmosphere into 10 layers up to 50 km from the ground with the Umkehr inversion algorithm, and measures the ozone density and TCO of each layer separately (Mateer and Diitsch, 1964; Stone, 2015). It consists of three separate models below:

a. MK-II Model: Measures the ultraviolet radiation, TCO and sulphur dioxide in the range of 290 - 325 nm,
b. MK-III Model: Measures the ultraviolet radiation, TCO and sulphur dioxide in the range of 286.5 - 325 nm,
c. MK-IV Model: Measures the ultraviolet radiation, TCO, nitrogen dioxide and sulphur dioxide in the range of 290 - 320 nm.

Fig. 3. An illustration of the Brewer spectrometer in Ankara.

Brewer spectrophotometer is installed on a solar azimuth rotate that provides instant on a daily basis measurements of total ozone, zenith sky and direct sun in Ankara station which is a part of WMO-Global Atmosphere Watch Programme. Figure 3 shows an illustration of the Brewer spectrophotometer in Ankara. It provides measurements from September, 2006 to the present at the location of 39° 57' N latitude and 32° 53' E longitude. Some information about the station can be seen in Table 1. Obtained data by Brewer MK-III Spectrophotometer are stored in the database of Turkish State Meteorological Service (TSMS) and are also sent to the World Ozone and UV radiation Data Center (WOUDC) in Toronto, Canada to store in there. And the data has started to share with EUBrewnet Project that is the supported by WMO and GAW as a COST Project (UNEP, 2011).

Table 1. Information about Brewer spectrophotometer in Ankara.

Station	Instrument	Institution	Latitude	Longitude	Start date of observation
Ankara	Brewer MKIII-188	TSMS	39° 57' (N)	32° 53' (E)	Sept.,2006 to present

MERRA-2 Atmospheric Reanalysis Model

Modern-Era Retrospective Analysis for Research and Applications, version 2 (MERRA-2), is an atmospheric reanalysis model developed by NASA's Global Modeling and Assimilation Office. MERRA-2 (Bosilovich et al., 2015) is designed to provide aspects of the climate system including trace gas constituents (stratospheric ozone), and improved land surface representation, and cryospheric processes (Bosilovich et al., 2019). It provides global dataset at a resolution of 0.5° latitude and 0.625° longitude at 72 hybrid sigma/pressure levels up to 0.01 hPa from 1980 to the present with 3-hourly temporal resolution. For ozone data asimilation, MERRA-2 uses dataset from several ground-based ozonesondes and satellite sources such as SBUV Nimbus-7, SBUV/2 NOAA, OMI EOS Aura and MLS EOS Aura instruments. In the studies by Wargan et al. (2015) and Davis et al. (2017), they concluded that global distributions of MERRA-2 ozone in the stratosphere and upper troposphere show well representation. Wargan et al. (2017) analysed validation of the MERRA-2 ozone with Total Ozone Monitoring Spectrometer and concluded that the column ozone values show good similarity with the values of 1.83% in the midlatitudes and the tropics and 1.45% in the northern higher latitudes.

Mann-Kendall trend test and Sen's slope estimate

Mann-Kendall trend test (Mann, 1945; Kendall, 1975) is widely used to detect the significance of trends in a time series. The test is calculated as below:

$$S \quad \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(Xj - Xi) \qquad \text{(Eq.1)}$$

$$sgn(Xj - Xi) = \begin{cases} If \quad (Xj - Xi) > 0, & = +1 \\ If \quad (Xj - Xi) = 0, & = 0 \\ If \quad (Xj - Xi) < 0, & = -1 \end{cases} \quad \text{(Eq.2)}$$

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p (t_p - 1)(2t+5) \right] \quad \text{(Eq.3)}$$

$$Z = \begin{cases} If \quad S > 0, & = \frac{S-1}{\sqrt{VAR(S}} \\ If \quad S = 0, & = 0 \\ If \quad S < 0, & = \frac{S+1}{\sqrt{VAR(S)}} \end{cases} \quad \text{(Eq. 4)}$$

where, n: is the length of the dataset, Xi and Xj: are observations of time series in chronological order, tp: is the number of data values in the pth group, q: is the number of tied values. Positive determined Z values indicate an increasing trend, negative determined Z values indicate a decreasing trend. If $|Z|>Z1-\alpha/2$, H0 hypothesis is invalid and a statistically significant trend exists in the time series. Otherwise, the H0 hypothesis is accepted and there is not statistically significant trend (Kisi and Ay, 2014; Ahmad et al., 2015; Abdalla et al., 2021).

Sen's slope estimate test is a non-parametric method. It is used to demonstrate the slope of the trend in a time series (Sen, 1968). The method assumes a linear trend in time series. The slope (Qi) of all data value pairs is calculated by below formula:

$$Qi = \frac{Xj - Xk}{j - k}, here\ j > k \quad (5)$$

In the formulation, Xj and Xk are the values at x and y time steps. Sen's Slope estimate is the median value of N values obtained from the formula Qi. The N values of the Qi are sorted from small to large, using the following formula to estimate Sen's Slope:

$$If\ N\ is\ odd\ number,\ Q = Q_{[(N+1)/2]} \quad (6)$$

$$If\ N\ is\ even\ number,\ Q = \left(Q_{[N/2]} + Q_{[(N+2)/2} \right) \quad (7)$$

Two-tailed test is carried out in the 100% (1-α) confidence interval to obtain the real slope of the nonparametric test in the series. Positive or negative Qi refers to the increasing or decreasing trend (Srıdhar and Ravıraj, 2017).

Results

Comparison of MERRA-2 TCO and Brewer Spectrophotometer TCO

Comparison is important part of the study to specify representation of MERRA-2 TCO for studied region. This section presents comparisons of Brewer Spectrophotometer and MERRA-2 TCO for Ankara city. Comparison period covers only 2007-2017, since that is measurement period of Brewer Spectrophotometer. Scatter plot of Brewer Spectrophotometer and MERRA-2 TCO as well as monthly distributions are shown in Figure 4. First of all, it is seen that the small difference exist in TCO between Brewer Spectrophotometer and MERRA-2. Besides fluctuations are very similar between 2007-2017.

It is clear from the scatter plot that MERRA-2 TCO agrees quite well with that from the Brewer Spectrophotometer. The linear equation is y = 1.0095x + 2.4688 with the slope of R2=0.9781. This indicates that the TCO obtained from MERRA-2 have well correlation with the ground-based observations.

TCO Trend

This section includes analysis of TCO trends of several cities and Turkey. Table 2 shows Mann-Kendall trend test ve Sen's slope estimate results of TCO. The study period was investigated in 3 seperate part (1980-1999, 2000-2009 ve 2010-2019). For 1980-1999 period, all cities and Turkey indicate statistically significant decreasing trends. These decreasing trends are found to be 90% significance level in Afyonkarahisar, Izmir and Mugla cities and 99% significance level in Artvin and Igdir cities. All other cities and Turkey have decreasing trends at 95% significance level. The highest decreasing trends exist in Samsun and Istanbul cities with the values of Q=-0,67 DU/year and Q=-0,64 DU/year. The lowest decreasing trends exist in Antalya city with the value of Q=-0,41 DU/year. For 2000-2009 period, all cities and Turkey indicate non-significant decreasing trends. For the last period covering 2010-2019, Turkey and all other cities except Samsun city indicate non-significant increasing trend.

As summary of this section, the TCO trend results show that statistically significant decreasing trends dominate in the first part covering 1980-1999 periods. In the next part covering 2000-2009 periods, results show still decreasing trends, even non-significant. However, for the last part covering 2010-2019 period, the trends in almost all cities and Turkey turn increasing trend, even non-significant.

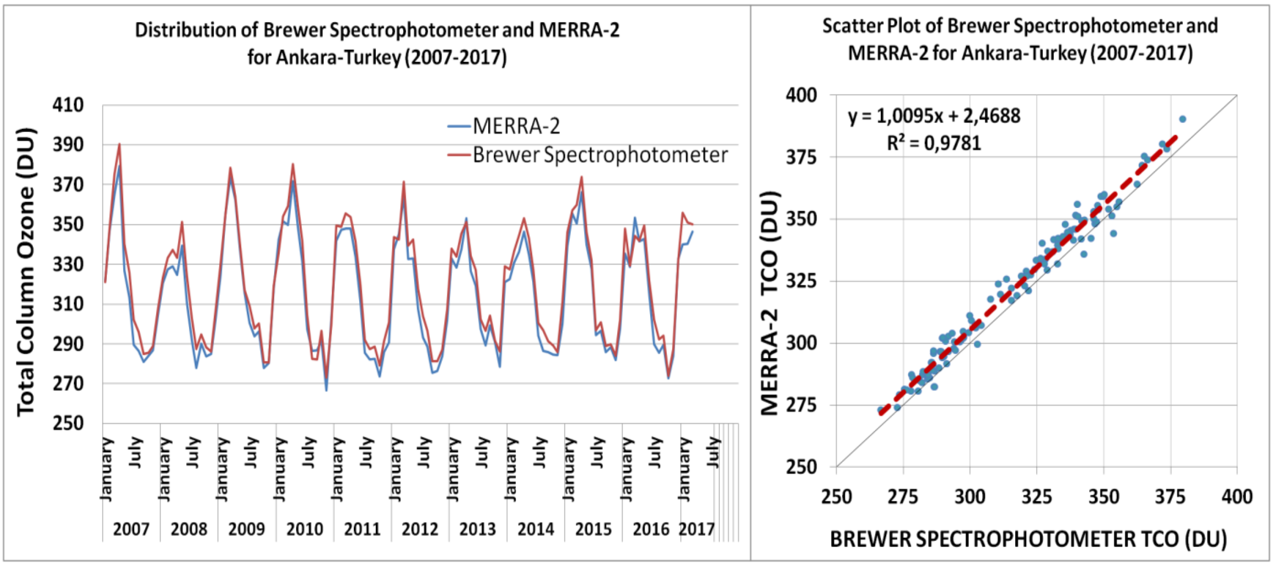

Fig. 4. Monthly distribution and scatter plot of MERRA-2 TCO and Brewer Spectrophotometer TCO for Ankara city (2007-2017).

Table 2. Mann-Kendall trend test and Sen's slope estimate results of TCO.

Location	1980-1999			2000-2009			2010-2019		
	MK trend		Sen's slope estimate	MK trend		Sen's slope estimate	MK trend		Sen's slope estimate
	Test Z	**Sig.**	**Q**	**Test Z**	**Sig.**	**Q**	**Test Z**	**Sig.**	**Q**
Adana	-1.98	*	-0.44	-1.25	no	-0.55	0.89	no	0.34
Afyonkarahisar	-1.91	+	-0.51	-0.54	no	-0.17	1.43	no	0.56
Ankara	-2.04	*	-0.54	-0.72	no	-0.20	0.89	no	0.32
Antalya	-2.04	*	-0.41	-1.61	no	-0.19	0.72	no	0.40
Artvin	-2.69	**	-0.50	-0.36	no	-0.57	0.00	no	0.10
Canakkale	-2.04	*	-0.61	-0.18	no	-0.15	1.25	no	0.69
Erzincan	-2.24	*	-0.50	-0.54	no	-0.54	0.00	no	0.00
Hakkari	-1.98	*	-0.51	-0.89	no	-0.32	1.25	no	0.34
Igdir	-2.69	**	-0.47	-0.36	no	-0.47	0.36	no	0.06
Istanbul	-2.11	*	-0.64	-0.36	no	-0.13	0.54	no	0.62
Izmir	-1.85	+	-0.48	-0.54	no	-0.19	1.25	no	0.64
Kayseri	-2.24	*	-0.48	-0.72	no	-0.49	1.07	no	0.22
Mardin	-2.17	*	-0.47	-1.25	no	-0.37	1.07	no	0.24
Mugla	-1.85	+	-0.44	-1.43	no	-0.31	1.25	no	0.44
Samsun	-2.56	*	-0.67	-0.54	no	-0.39	0.00	no	-0.05
Trabzon	-2.56	*	-0.54	-0.54	no	-0.58	0.00	no	0.11
TURKEY	-2.23	*	-0.52	-0.54	no	-0.37	1.43	no	0.45

*Trend significance levels: ***p<0.001, **p<0.01, *p<0.05, +p<0.1*

Distribution and Spatial Variations of TCO

The TCO trend and distribution were analyzed at 16 cities in Turkey for the period 1980-2019. Based on the same period, spatial variation of long-term and seasonal average TCO were also presented for Turkey in the study. Table 3 shows average TCO as well as the annual average maximum and minimum values from 1980 to 2019 in several cities and Turkey. The highest annual average TCO were found in Istanbul, Canakkale ve Samsun cities with the values of Aver.TCO= 326.3±6.9 DU, 324.0±6.7 DU and 322.2±6.6 DU, respectively. These cities are located in the North sides of Turkey. The lowest annual average TCO were found in Hakkari, Mardin and Igdir cities with the values of Aver.TCO= 303.5±5.6 DU, 310.1±5.9 DU and 311.4±6.0 DU, respectively. These cities are located in the South and Southeast sides of Turkey.

Table 3. Annual average, annual average maximum and minimum TCO values from 1980 to 2019.

Locations	Aver.TCO ± 1σ	Annual Aver. Maximum TCO	Annual Aver. Minimum TCO
Adana	312.9 ± 6.1	329.5 (1982)	300.6 (1993)
Afyon	317.1 ± 6.4	331.5 (1982)	303.3 (1993)
Ankara	318.1 ± 6.4	332.9 (1982)	303.9 (1993)
Antalya	312.6 ± 6.1	328.4 (1982)	300.4 (1993)
Artvin	317.0 ± 6.4	331.2 (1982)	303.6 (1993)
Canakkale	324.0 ± 6.7	337.5 (1981)	308.7 (1993)
Erzincan	311.8 ± 6.2	327.4 (1982)	299.0 (1993)
Hakkari	303.5 ± 5.6	318.8 (1982)	292.3 (1993)
Igdir	311.4 ± 6.0	325.4 (1982)	299.1 (1993)
Istanbul	326.3 ± 6.9	340.4 (1981)	310.2 (1993)
Izmir	320.5 ± 6.3	334.3 (1982)	306.8 (1993)
Kayseri	312.4 ± 6.3	328.5 (1982)	299.3 (1993)
Mardin	310.1 ± 5.9	325.8 (1982)	298.3 (1993)
Mugla	316.4 ± 6.1	331.2 (1982)	303.6 (1993)
Samsun	322.2 ± 6.6	336.6 (1982)	307.4 (1993)
Trabzon	317.1 ± 6.4	332.0 (1982)	303.5 (1993)
TURKIYE	315.1 ± 6.2	330.0 (1982)	301.8 (1993)

The highest annual average maximum TCO were found in Istanbul, Canakkale and Samsun cities with the values of TCO= 340.4 DU, 337.5 DU and 336.6 DU. The lowest annual average minimum TCO were found in Erzincan, Mardin and Hakkari cities with the values of TCO=299.0 DU, 298.3 DU and 292.3 DU. For Turkey, annual average TCO value was found as 315.1±6.2 DU, the highest value of annual average TCO was found as 330.0 DU and the lowest value of annual average TCO was found as 301.8 DU.

Annual average TCO distributions of several cities from 1980 to 2019 are shown in Figure 5 (cities located in northern half of Turkey) and Figure 6 (cities located in southern half of Turkey). Besides, annual average TCO distributions of Turkey are shown in Figure 7, seperately. It stand out that annual average TCO fluctuates from year to year. The highest annual average TCO in all cities and Turkey are evident in the years 1980-1982, 1987, 1991 and 2003. It is obvious from NCEP/NCAR plots that negative temperature anomalies were observed over Turkey in these years (Figure 8).

Ozone-rich polar cold air masses were effective over Turkey, which caused high TCO, especially in 1980-1982 period and 1987 year. It is also seen that annual average TCO dropped rapidly in 1993 year. All cities and Turkey had the lowest annual average TCO in 1993 year. Lower stratospheric ozone and TCO were strongly affected by the Mt. Pinatubo Volcano eruption, which caused emissions of millions tons of aerosols into the atmosphere, between 1992 and 1996 years (Douglass et al., 2010). The low values observed in 1993 year were due to the effects of the Mt. Pinatubo Volcano eruption. In 1994, annual average TCO values increased again due to the decrease of effects of the volcano eruption.

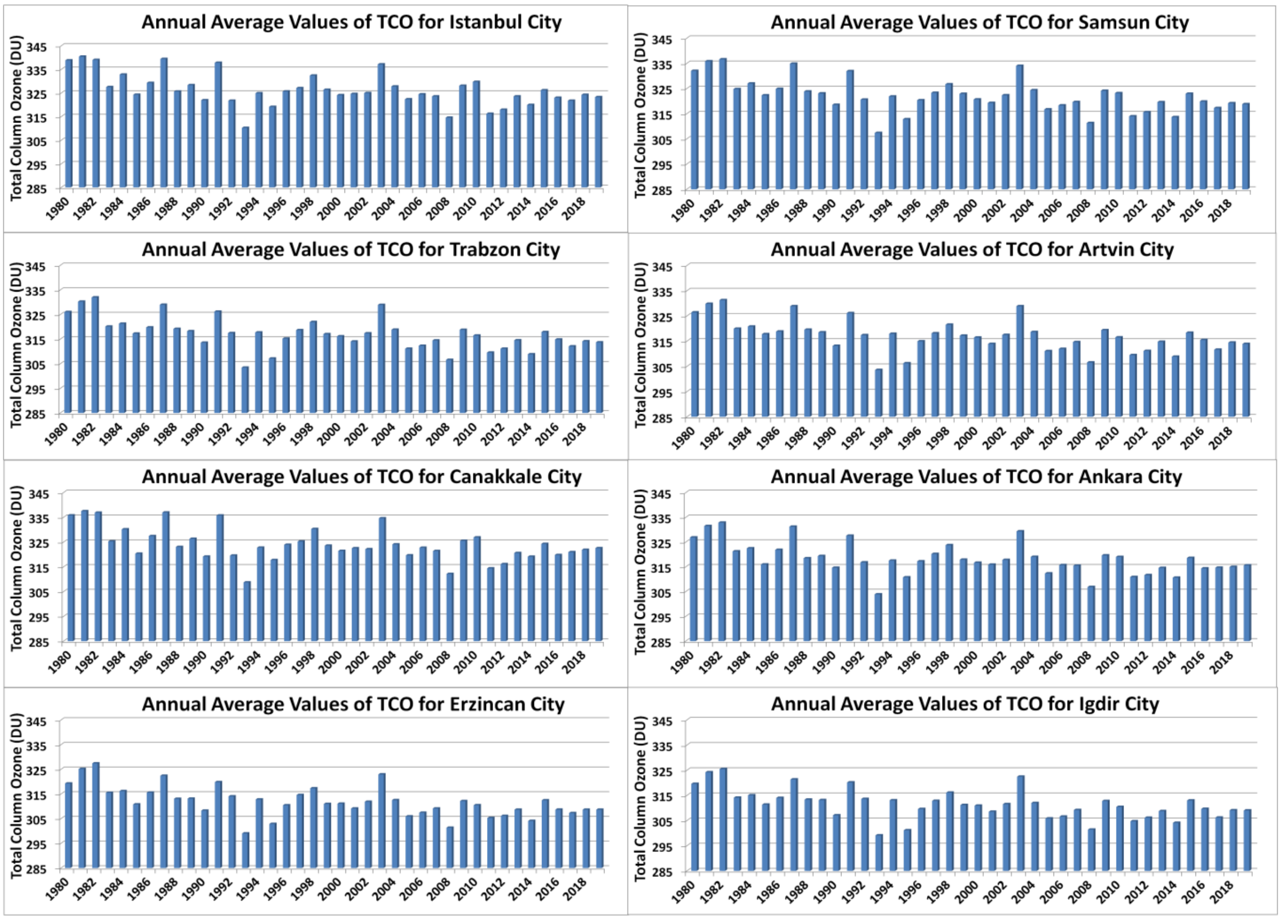

Fig. 5. Annual average TCO distributions of MERRA-2 from 1980 to 2019 for cities located in northern half of Turkey.

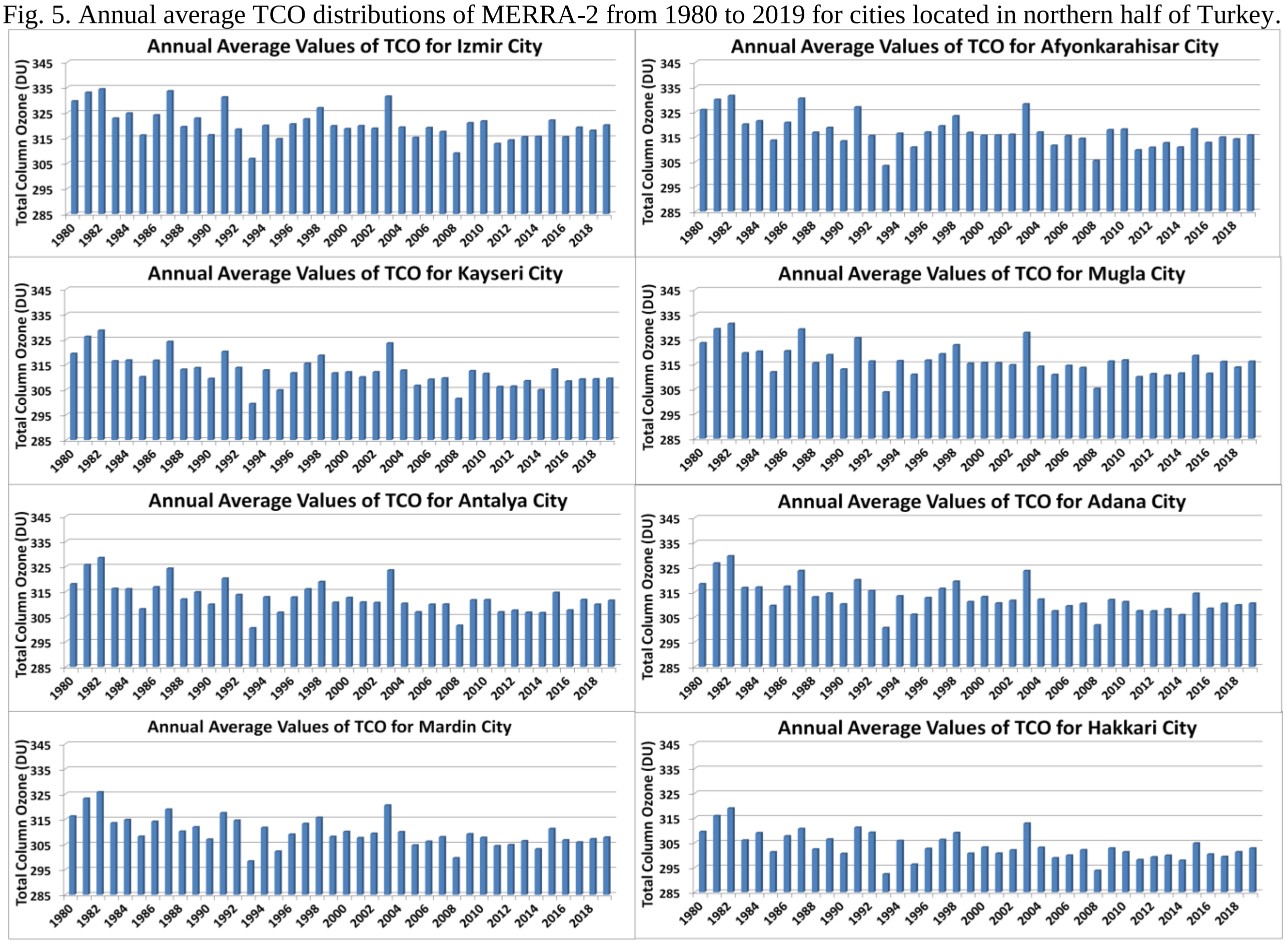

Fig. 6. Annual average TCO distributions of MERRA-2 from 1980 to 2019 for cities located in southern half of Turkey.

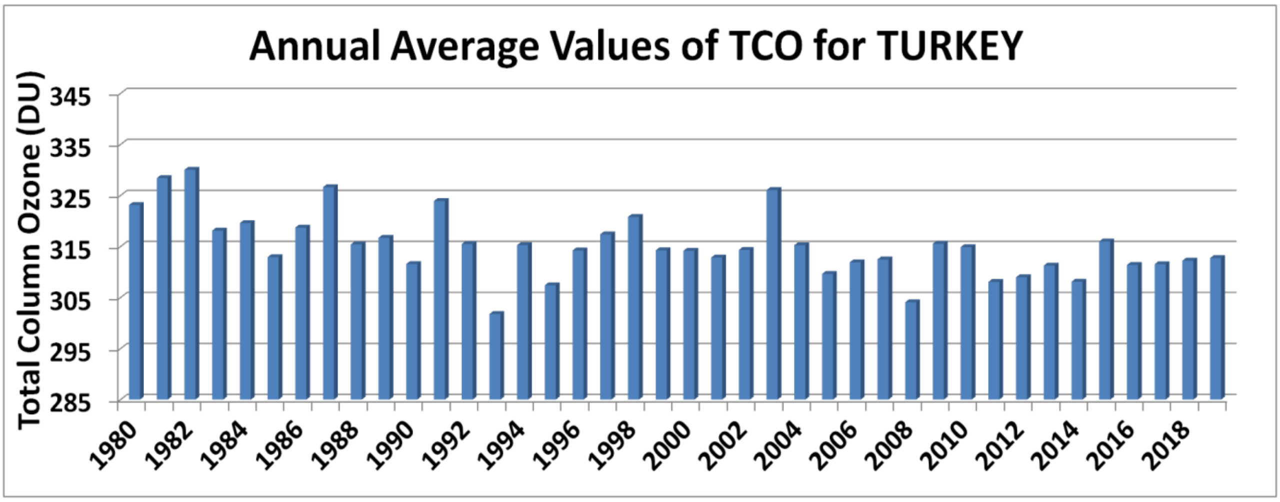

Fig. 7. Annual average values of MERRA-2 TCO from 1980 to 2019 for Turkey.

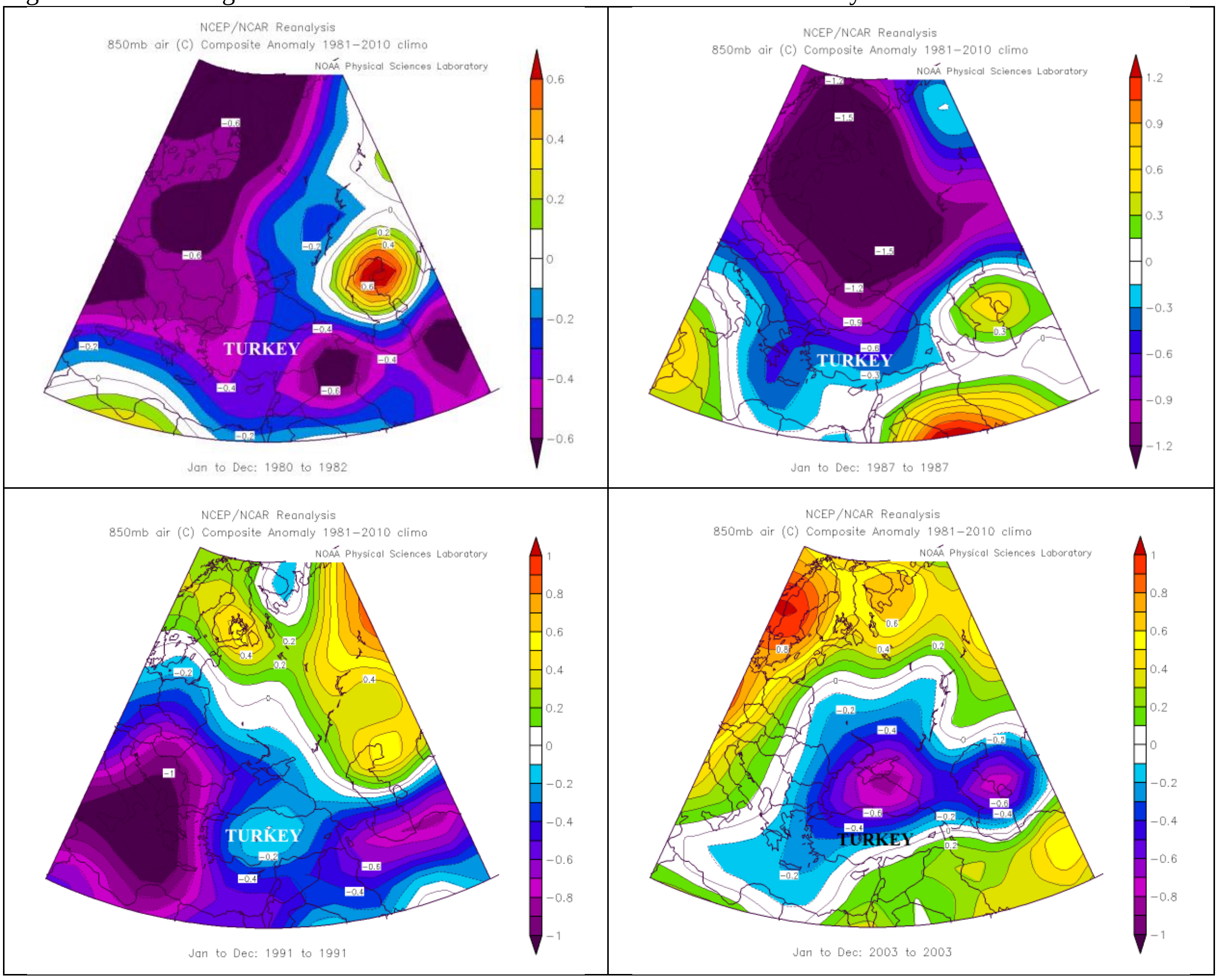

Fig. 8. Temperature anomaly maps of NCEP/NCAR Reanalysis from 850 mb for the period 1980-1982 (top left) and years 1987 (top right), 1991 (bottom left), 2003 (bottom right).

The spatial variation of long-term average TCO over Turkey for the period 1980-2019 is shown in Figure 9. The highest values of TCO are distributed over North and Northwest regions of Turkey. It can be seen that there is a gradual decrease in TCO from Northwest to Southeast. The lowest values of TCO appear over South, especially Southeast regions of Turkey. These findings note that TCO decreases with decreasing latitude. This decrease is due to the fact that the ozone-rich polar air masses affect Turkey from the northern directions, and ozone-poor tropical air masses affect Turkey from the southern directions as we explain below in detail.

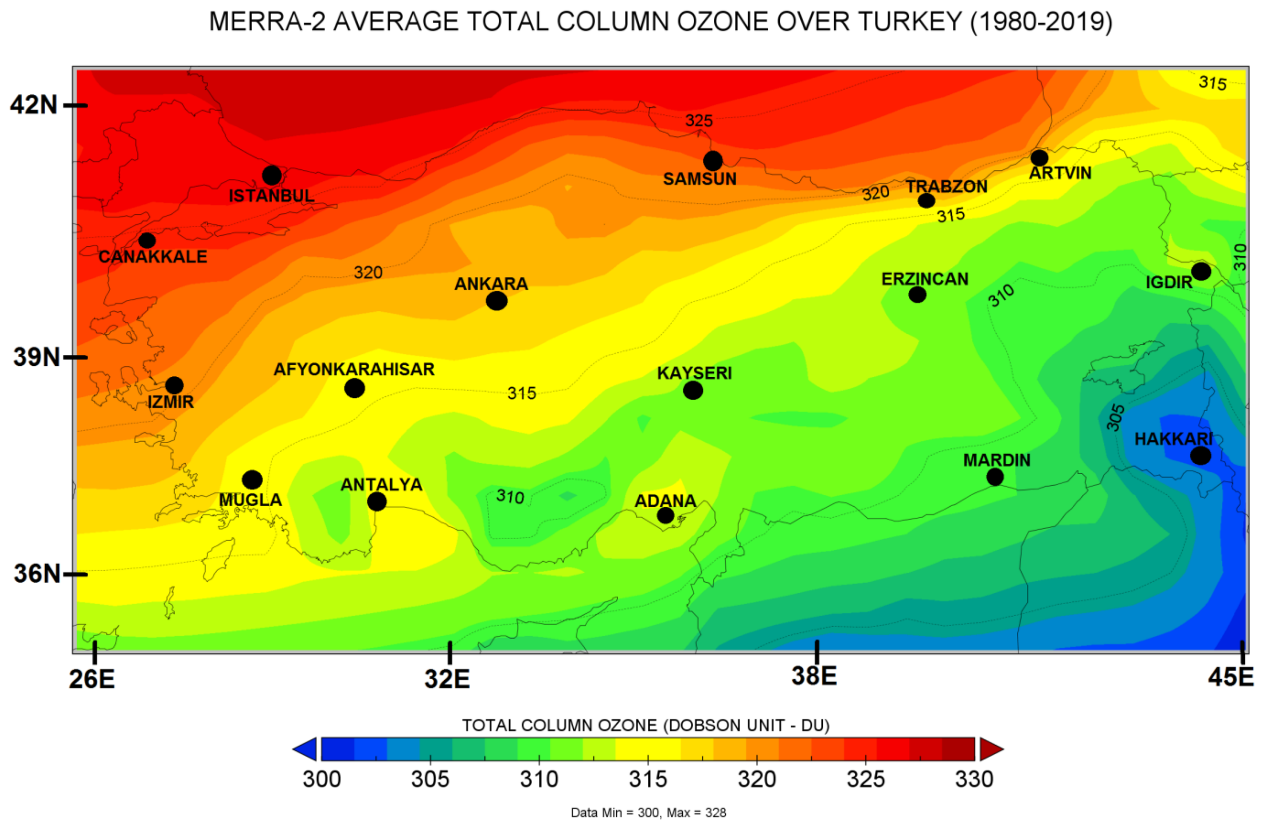

Fig.9. Spatial variation of long-term average TCO over Turkey for the period 1980-2019.

The spatial variation of seasonal average TCO over Turkey for the period 1980-2019 is shown in Figure 10. The highest values of TCO are distributed over North and Northwest regions of Turkey in all seasons, similar to the long-term average TCO. It decreases gradually from Northwest to Southeast in all seasons except winter. For winter season, the decrease from North to South is evident dominantly. The decrease from North to South in winter season is due to the influence of the ozone-rich polar air masses from Northern direction. In the spring and summer seasons, the decrease is from Northwest to Southeast due to the fact that air masses affect Turkey mostly from Northwest and West directions.

In winter and spring seasons, TCO have higher values than that in other seasons over Turkey. For spring season, which have highest seasonal values, TCO reaches to about 360 DU over Northwest regions of Turkey. The lowest TCO value is about 330 DU over Southeast regions of Turkey in spring season. Winter season follows spring season with the highest value of 335 DU and the lowest value of 320 DU over Turkey. The highest values of TCO in spring and winter seasons are associated with the movement of ozone from tropical regions to Polar Regions as well as polar air masses affected Turkey. Ozone amount increases in middle latitudes and Polar Regions especially in winter and spring seasons, and decreases in tropics according to global annual changes of total ozone in the atmosphere. This is the result of ozone being carried by large-scale planetary waves from the tropics to the poles (Dobson et al., 1946). This movement causes TCO increase in the winter and spring seasons over Turkey located in the middle latitudes. Besides, cP and mP air masses bring cold and ozone-rich air through Turkey, especially in winter and spring seasons. This contributes to significant increase at TCO in Turkey.

It can be also seen that TCO decreases in summer and autumn seasons with the highest values of 320 DU and 295 DU over Northwest regions of Turkey, and the lowest values of 285 and 278 DU over Southeast regions of Turkey, respectively. The lowest values of TCO in autumn season is related to effects of ozone-poor mT and cT tropical air masses and Basra Low Center over Turkey in this season. The polar cold air, which is effective throughout the winter, begins to pull towards the northern latitudes from May and Turkey is under the influence of tropical air mass (Koçman, 1993). Therefore, TCO begins to decrease as of the summer months. Besides, the ozone-poor Basra Low Pressure center affects Turkey, especially in autumn, by entering from the South and Southwest directions. In this case, it leads to significant TCO decrease in Turkey. The difference between the highest and lowest values of TCO over Turkey for spring season is about 30 DU. It can be also seen that the differences between the highest and lowest values of TCO for summer, autumn and winter seasons are about 35, 17 and 15 DU, respectively.

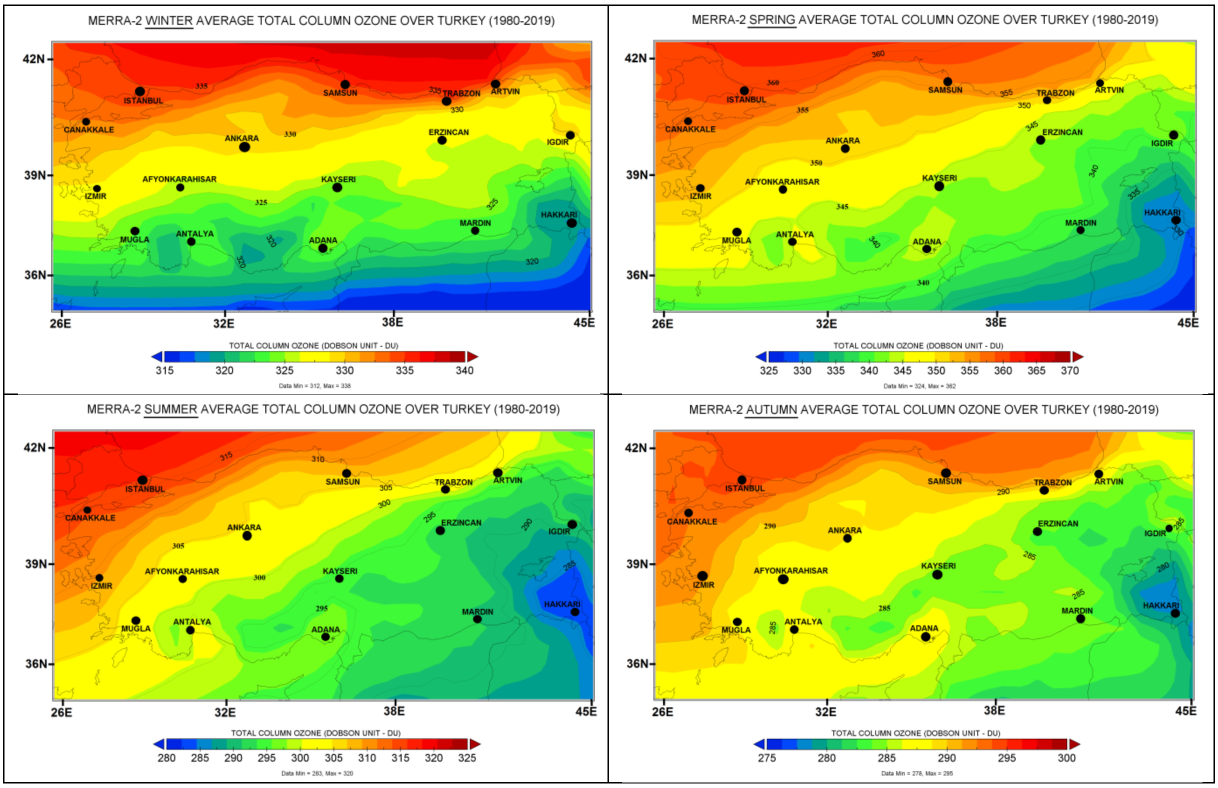

Fig. 10. Spatial variation of seasonal average TCO over Turkey for the period 1980-2019.

Discussion and Conclusion

In this study, we studied trend, spatial and temporal variation of TCO with MERRA-2 dataset from 1980 to 2019 over Turkey. MERRA-2 TCO dataset for Ankara city showed very well agreement with ground based observation. The trend analysis indicated that TCO shows statistically significant decreasing trend in 1980-1999 period, non-significant decreasing trend in 2000-2009 period and non-significant increasing trend in 2010-2019 period over Turkey. The highest annual average TCO were found in Istanbul, Canakkale ve Samsun cities located in the North sides of Turkey. The lowest annual average TCO were found in Hakkari, Mardin and Igdir cities located in the South and Southeast sides of Turkey. It was concluded that the highest annual average TCO were found in the years 1980-1982, 1987, 1991 and 2003 over Turkey. The lowest annual average TCO were found in 1993 year due to the effects of the Mt. Pinatubo Volcano eruption. The spatial variation of long-term (1980-2019) average TCO showed that the highest values are distributed over North and Northwest regions of Turkey, while the lowest values distributed over South, especially Southeast regions of Turkey. It was also shown that TCO values are the highest in spring, followed by winter, and the lowest in summer and autumn seasons over Turkey. These are associated with effect of ozone-rich polar air masses from northern directions especially in winter and spring seasons and ozone-poor tropical air masses from southern directions especially in autumn season.

In future study the relationship between TCO and global atmospheric oscillations for Turkey may be conducted in detail. This work would be helpful for better evaluation of TCO changes caused by global atmospheric oscillations.

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