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THE INFLUENCE OF DYNAMIC STRATOSPHERE ON THE TOTAL OZONE – CASE STUDY

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Abstract. The analysis of the short and medium term variations (daily and monthly variations), of the total ozone measured during the period (1980–2009) emphasized a particular situation that occurred during February 2008, namely a pronounced decrease in the total ozone quantity. In order to identify the causes of this phenomenon, a complex analysis of temperature and ozone distribution fields was performed, both on hemispherical and local scale. The ozone depletion process through the activation of the troposphere/stratosphere exchange mechanism was highlighted.

Key words: stratosphere, total ozone, atmosphere circulation, SST, radio soundings, latitudinal distribution, ozone depleting, polar vortex, Brewer-Dobson circulation, multiple tropopause.

1. INTRODUCTION

Since the 1970's, the fact that some atmospheric components resulted from the human activities contribute to the ozone layer depletion has been recognized. The scientists' efforts in identifying and assessing those chemical components, as well as the results that these had on the ozone layer, lead to the adoption of some important international regulations. These regulations are represented by The Montreal Protocol on the ozone depleting substances with the subsequent Amendments. According to Article 6 of the Protocol, the panel nominated by this agreement (TEAP – Technology and Economic Assessment Panel, SAP – Scientific Assessment Panel and EEAP – Environmental Effects Assessment Panel), elaborates regular assessments of the scientific aspects of ozone depletion, the effects of ozone depletion on the environment, substances and alternative technologies status, as well as their economic implications. The results are published under auspices of UNEP (United Nations Environment Programmer) and WMO (World Meteorological Organization). The last report "Scientific Assessment of Ozone Depletion 2010" gives new information about the climate change effects on the ozone layer, and also the impact of ozone variations on Earth's climate.

Also, the Report concludes that the highest scientific challenge that should be solved is the projection of future increase of ozone by assessing the complex relations between ozone and climate change. It is believed that the climate changes will have an increased influence on the stratospheric ozone in the next decades, these changes deriving mainly from long-lived greenhouse gases emissions, especially carbon dioxide, associated with human activities. Over 300 scientists contributed to this Report which was launched with the occasion of World Day for Ozone Layer Conservation, on September 16th, 2010. Besides issues such as analysis of long-lived compounds, short-lived halogenated compounds, ultraviolet radiation, troposphere ozone (trend, precursors and emissions) and ozone-climate interaction, within the research studies on atmospheric ozone, a special place is taken by the total and stratosphere ozone variations, as well as the polar ozone, closely related to the variations of meteorological factors, that contribute to global but also local ozone distribution. In this direction, the present article aims to investigate some significant variations of total ozone in context of its regular variations, determined only by dynamic changes of atmosphere circulation.

Beside ozone layer's researches, important studies are made based on many others atmospheric components (Georgescu şi Ştefan, 2010; Rusu-Zagar *et al.*, 2011; Ungureanu *et al.*, 2010, [2, 3, 5]) whose influences on humans activities are also very important.

2. DATA

The following data sets were analyzed in the case study: the ozone data measured at Bucharest station, the air temperature and wind data measured during the radio soundings performed at Bucharest, the latitudinal distribution of monthly averages of ozone concentrations in the northern hemisphere and the distribution of mean monthly temperature at 30 hPa in stereographical polar projection.

The total ozone measurements have been performed at Bucharest station (Lat. 44º48', Long. 26º13'), with Dobson spectrophotometer, since 1980; calibration is provided by the WMO Regional Center, from Hohenpeissenberg, Germany, every four years by comparison with the regional standard. Observations are performed 4–5 times a day, on clear or cloudy sky, excepting the rainfall situations. Daily values are sent in real time to the two collecting centers: the Regional Center in Greece and the World Center in Canada, in order to draw daily maps of total ozone distribution.

The series of temperature data obtained from the radio sounding measurements performed in Bucharest for over 50 years provide a high level of confidence for determining the trends of variation.

Latitudinal distribution of ozone based on the altitude, analyzed for the whole northern hemisphere, and the temperature field distribution were obtained from the European Centre for Medium Range Weather Forecast (ECMWF) based in England.

3. RESULTS AND DISCUSSIONS

Monthly variation of total ozone is very well defined, especial in middle and high latitudes, and is caused by the large-scale atmospheric circulation, which causes the ozone transport from maximum genesis regions (the stratosphere regions between the two tropics). From those areas, the ozone is carried on descending surfaces to middle and high latitudes (Brewer-Dobson circulation), and depending on the circulation character – zonal or southern, the ozone is stored at high latitudes or transferred from those latitudes towards middle ones.

In the global distribution of the total ozone, the transfers that take place between the stratosphere and the troposphere, through the tropopause have a particular role especially in decreasing the ozone from the low stratosphere and increasing the one in the troposphere. The stratosphere-troposphere exchange (SST) has also impact on the distribution of emissions from aircrafts as well as the vertical structure of the aerosols and greenhouse effect gases. SST also refers to the entering and exit of the air masses into and out of the stratosphere.

The transport of anthropogenic substances, such as chlorofluorocarbons from the troposphere in stratosphere, has an effect on the chemical balance in both regions and provides catalysts involved in the destruction of stratospheric ozone. The troposphere-stratosphere exchange also controls the transport rate between the production area of products which destroy the ozone and the area in which the ozone depletion occurs. A consequence of this fact is the long interval of time between the release of those products and the stratospheric ozone reduction.

The representation of multiannual monthly distribution of total ozone values from Bucharest station (Fig. 1) shows a sinusoidal distribution, specific to middle latitudes. In Table 1, are represented the deviations of monthly mean values (%), towards the multiannual monthly mean, for February, since 1980 to 2009. In general, the deviations vary within the range (–5.5 ÷ 7.6) %.

Table 1

Deviations of monthly mean values (%) for total ozone in February, towards the multiannual monthly mean

1980	3.0	1986	0.9	1992	1.0	1998	-1.1	2004	-1.5
1981	0.0	1897	2.6	1993	2.2	1999	-4.6	2005	4.6
1982	0.5	1988	-1.6	1994	-0.6	2000	0.6	2006	2.8
1983	0.0	1989	2.1	1995	3.0	2001	0.6	2007	-5.5
1984	0.9	1990	1.3	1996	1.8	2002	-0.6	2008	**-10.1**
1985	1.2	1991	-1.4	1997	0.4	2003	-2.7	2009	7.6

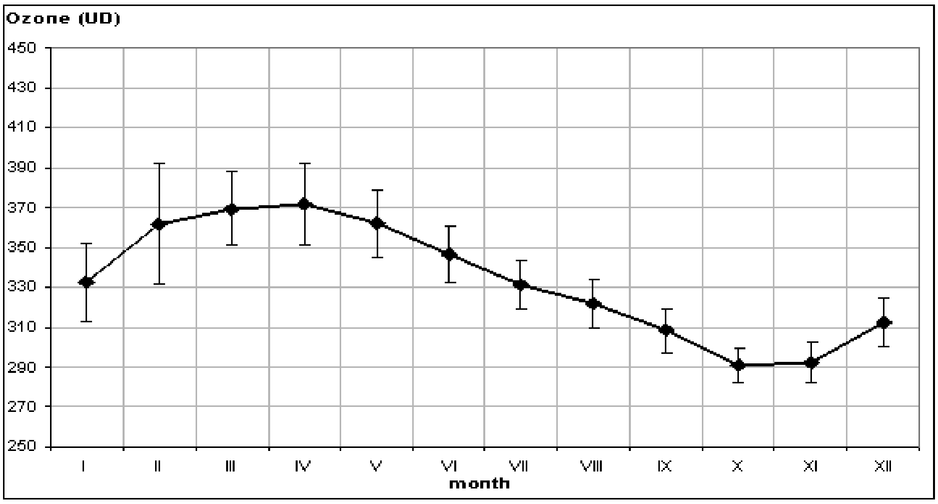

Fig. 1 – Multiannual monthly mean values of total ozone for Bucharest station (1980–2010).

It can be observed (Table 1) that the value recorded in February, 2008 (–10.1%), was atypical. The measured values from Bucharest were not unique; the same situation was met at almost all stations from middle latitudes in Europe. The winter 2007–2008 was characterized, at hemispherical scale, by positive values of the total ozone anomalies, particularly at high latitudes. The positives anomalies of total ozone have been associated with positive anomalies of the low and middle stratosphere temperature field. The arctic temperatures were not low enough for polar stratospheric cloud formation, and consequently, the rate of ozone depletion by chemical mechanisms, in the polar vortex was not significant.

In the absence of other factors (for example a volcanic eruption), that could affect this much the ozone quantity, the only possible explanation would be the dynamic origin. In this sense, the temperature and wind fields have been analyzed, at hemispherical and local level, in direct correlation with the ozone field at the same scale of time and space.

Since the transport of chemical species in the stratosphere is made by Brewer-Dobson circulation (maximum in winter), to which a Pole-oriented mass flow is associated, the effects of this type of circulation on the chemical species is completed by mixing processes (mainly quasi-horizontal) that contribute to both Pole and equator-oriented air mass transport.

In February, 2008, the intense western circulation, (stratospheric jet – Draghici, I., 1998 [1]), in the middle and high stratosphere from middle latitudes and over 15 km altitudes with maximum effect between 20 and 30 km (Fig. 6), blocked the ascending propagation of planetary waves from the troposphere and their interaction with stratospheric circulation, resulting in a weak transport of ozone concentrations from the genesis area (Fig. 2).

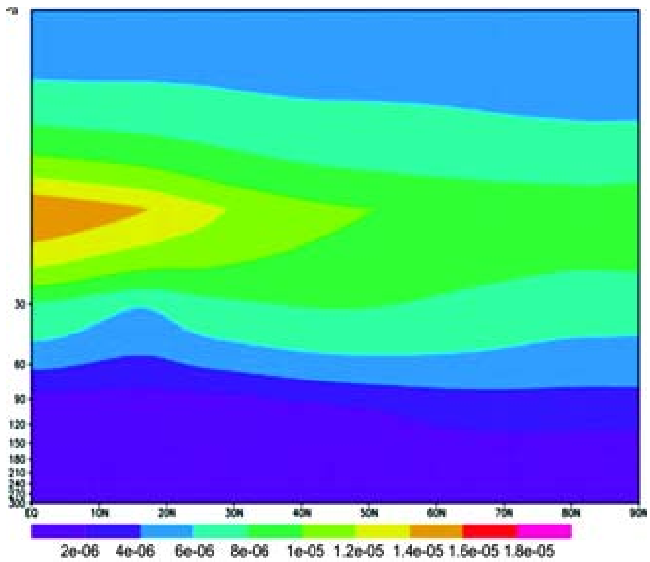

Fig. 2 – Latitudinal distribution of monthly mean ozone concentrations in the northern hemisphere (ECMWF analysis) – February, 2008.

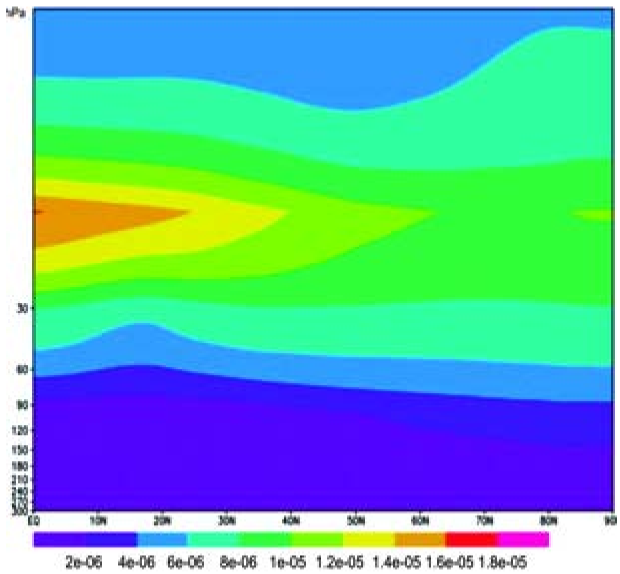

Fig. 3 – Latitudinal distribution of monthly mean ozone concentrations in the northern hemisphere (ECMWF analysis) – March, 2008.

In March 2008, an increase in the ozone transport to the North Pole (Fig. 3), a wakening in the thermal gradient in temperature field from 30 hPa (Fig. 5) were noticed, and in the western circulation, a relaxation appeared (Fig. 7), allowing a release of the troposphere-stratosphere coupling, thus favoring the upward propagation of planetary waves in the stratosphere and their interaction with low and high stratosphere. There have been powerful upwards, with rapid cooling alternating with stronger subsidence, that produce a rapid increases in temperature allowing, like in March, a stratospheric warming (Fig. 5) and the disintegration of the Polar vortex, culminating with its collapse in April 2008 (Fig. 8).

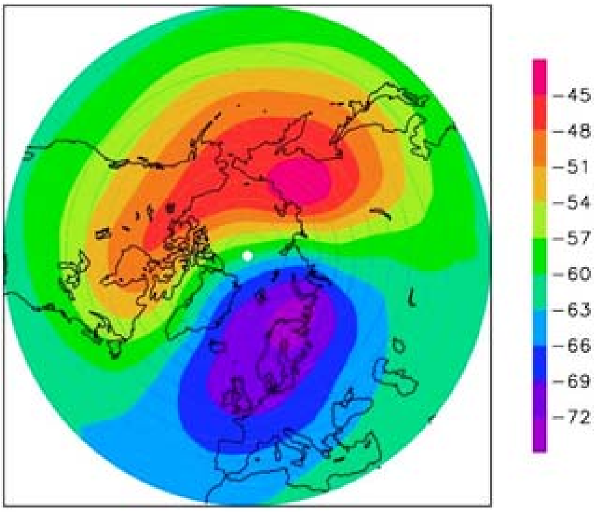

Fig. 4 – Distribution of monthly mean temperature field at 30 hPa in polar stereo projection (ECMWF analysis) – February, 2008.

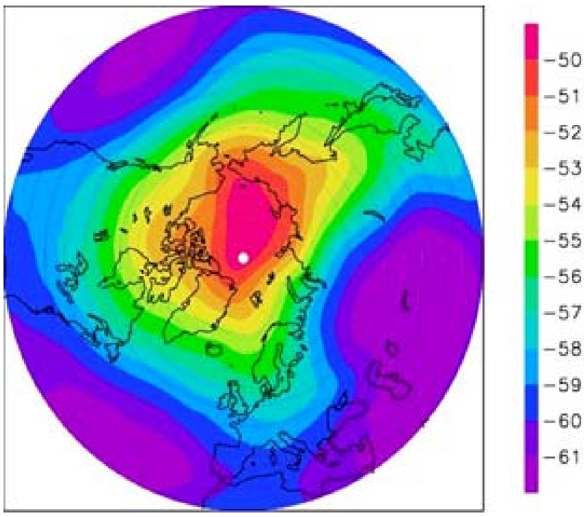

Fig. 5 – Distribution of monthly mean temperature field at 30 hPa in polar stereo distribution (ECMWF analysis) – March, 2008.

Another possible mechanism that can produce the total ozone decrease, recorded in February 2008, was based on recent research on the ozone profile, obtained from surveys and satellite measurements. William J. *et al.* (2006) [8] showed a decrease in the ozone concentration between 10 and 25 km, at middle and high latitudes, when multiple tropopause phenomenon occurred. Upalla *et al.* (2005) [6] revealed from the ECMWF analysis of ERA 40 data over the interval 1957–2002, an increase in the climatological frequency of double tropopause in the latitude band (30N-60N), for the interval December-February.

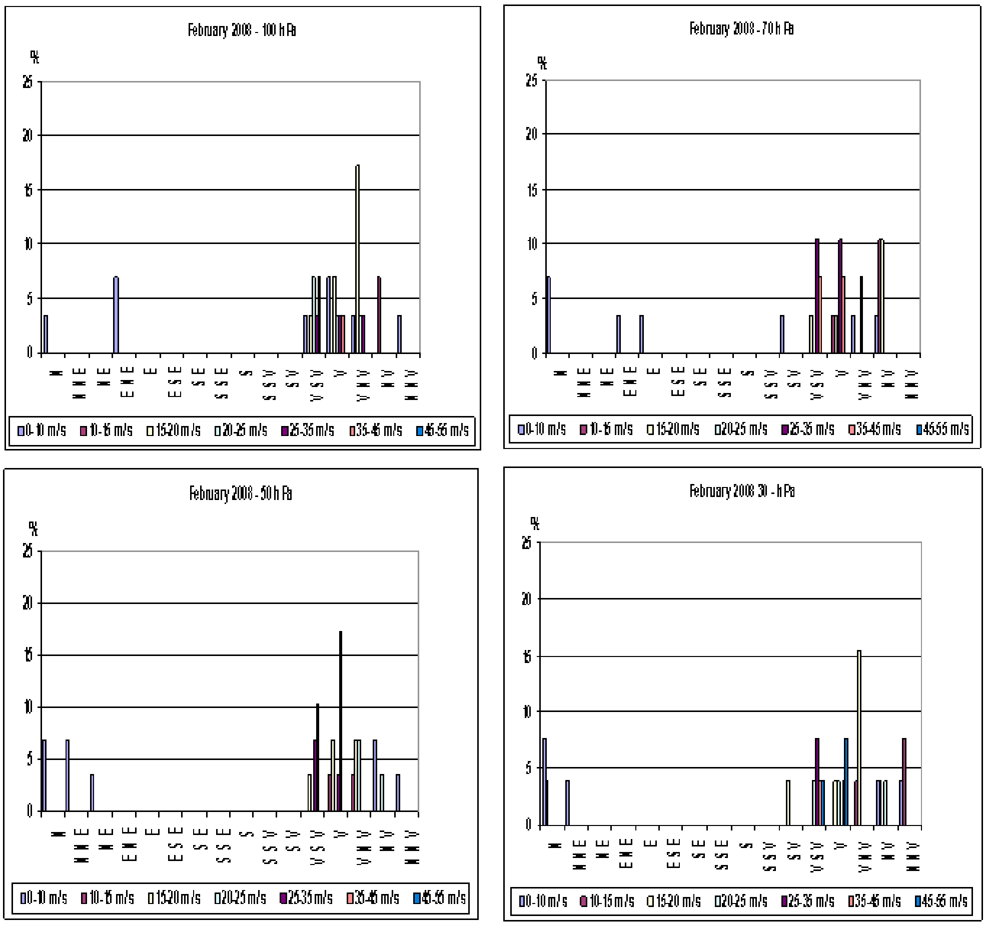

Fig. 6 – Wind Class Frequency Distribution– February, 2008.

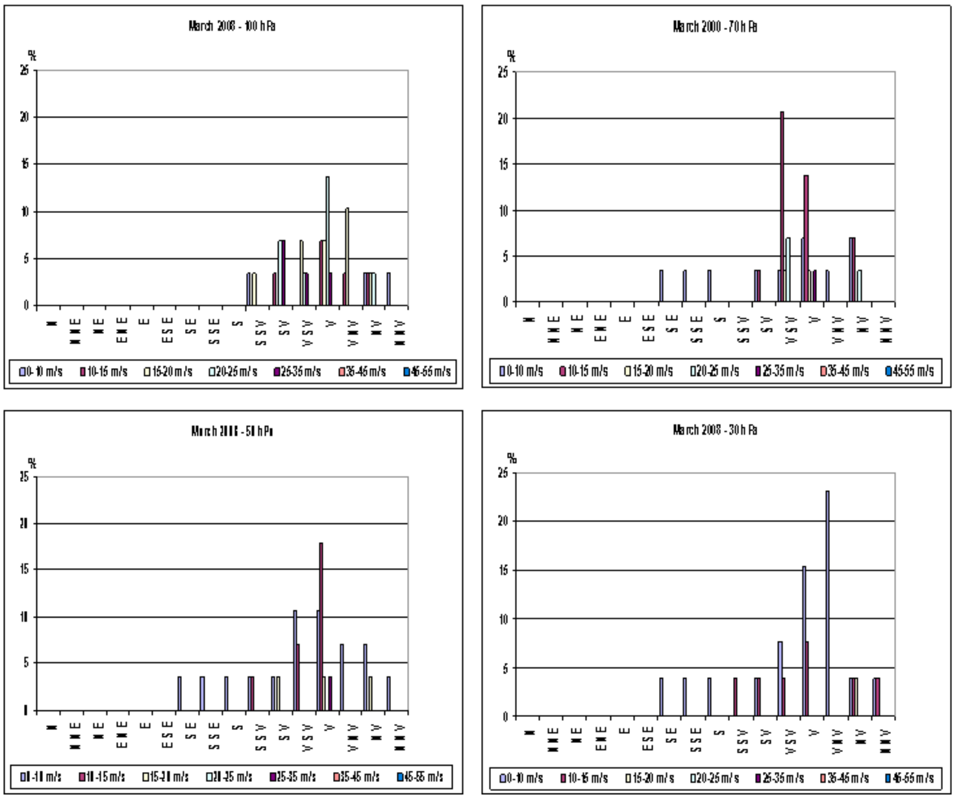

Fig. 7 – Wind Class Frequency Distribution– March, 2008.

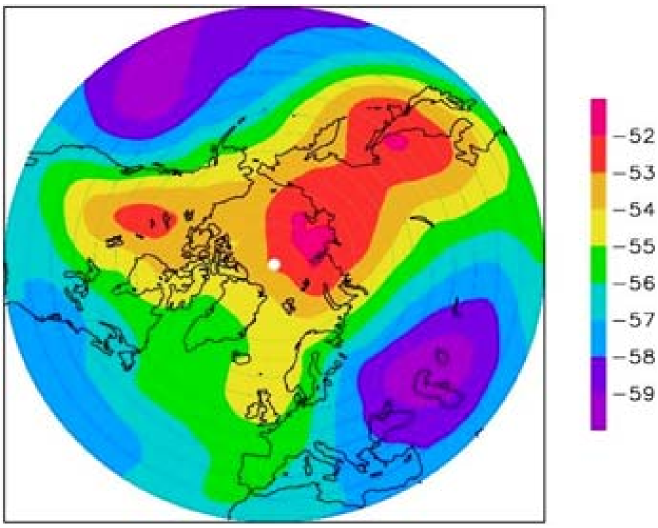

Fig. 8 – Monthly mean temperature at 30 hPa – April, 2008.

Taking these considerations, had been extracted from the radio sounding (at 00 UTC and 12 UTC), days with double tropopause recorded at Bucharest over the period 01.01.2008–31.03.2008 (Figs. 9 and 10). It can be noticed the increased frequency in the analyzed double tropopause days and the high enough frequency of occurrence of the second tropopause in the 100 hPa–50 hPa area, where the ozone concentration is high. This is the way in which, the ozone depletion processes are initiated through the activation of the troposphere-stratosphere exchange mechanism, when the ozone is transported into the lower stratosphere where it is photo chemically destroyed (Steinbrecht *et al.*, 1998; Varotsos, 2004) [4,7].

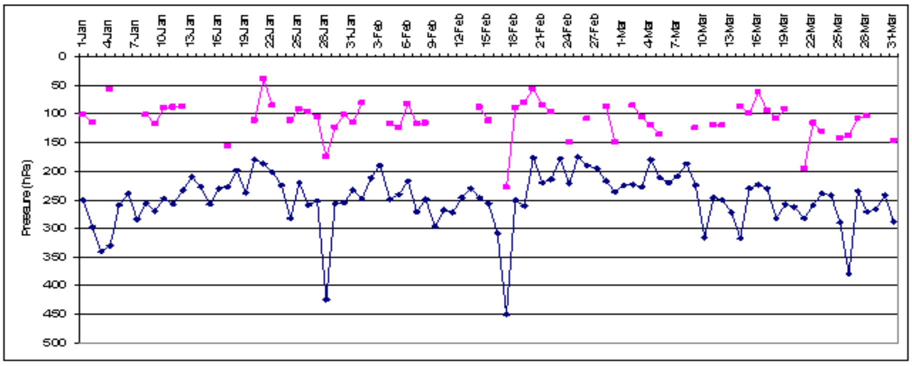

Fig. 9 – Days with double tropopause from January to March, 2008, at 00 UTC, Bucharest.

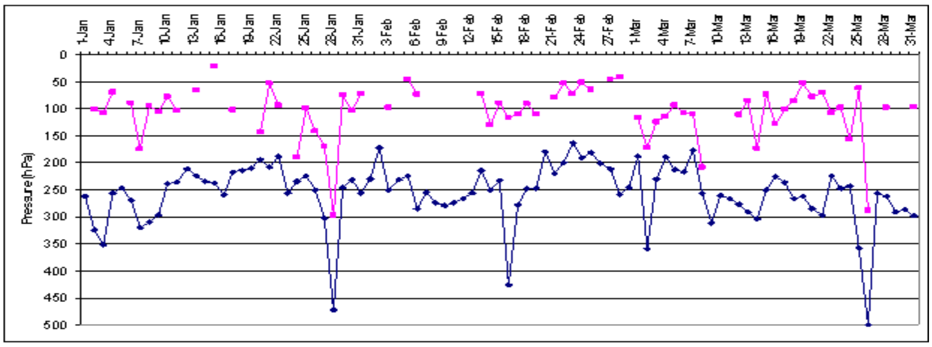

Fig. 10 – Days with double tropopause, from January to March, 2008 – 12 UTC, Bucharest.

Steinbrecht *et al.* (1998) [4] were the first who pointed out the ozone dependence on the variation of first tropopause altitudes, which increased by 150±70 m/decade, between 1967 and 1997, at Hohenpeissenberg. According to their investigations, the increase of the tropopause explains about 25% of the ozone decreasing trends in the analyzed period. This increase in tropopause height is regionally restricted, with great effect over Europe. The ozone trends, in lower stratosphere, during the winter, are strongly affected by the pressure variations at the tropopause, because the correlation between these two variables (ozone and tropopause), is extremely strong at the tropopause. Some recent modeling studies, suggested that stratosphere cooling, due to ozone depletion, acting together with the troposphere warming, caused by greenhouse gases, could contribute to tropopause height variations, but, in this case, the tropopause high variations can not be regarded as fully responsible for the ozone variations. A source of uncertainty in these models is that the most climate models can not solve the recorded variations of tropopause height, so that it is only inferred by interpolation; another source could be that the observed variations of total ozone are not well quantified in comparison with the tropopause.

4. CONCLUSIONS

The great deviation of the total ozone in February 2008 (–10.1%), emphasized through measurements performed at Bucharest with Dobson 121 spectrophotometer, is due to the meteorological context (at the level of lower and middle stratosphere) during the winter 2007/2008. Two possible mechanisms that led to decreasing of total ozone quantity, in February 2008, were proposed:

– enhanced circulation from the western sector (stratospheric jet), led to the upward propagation blocking of the planetary waves in the stratosphere, with consequences on the ozone transport from the genesis area to middle and high latitudes;

– increase of frequency of double tropopause occurrence in Bucharest, a phenomenon associated with increased troposphere-stratosphere exchange processes, which led to the transport of ozone in the lower stratosphere and its photochemical destruction.

The transport and mixture of the air masses coming from different latitudes and altitudes can influence the budget of stratospheric ozone and the tendencies in middle latitudes of the Northern Hemisphere. The transport processes are also controlled by dynamic processes specific to the stratosphere-troposphere exchange, which can be produced, both horizontally and vertically. Therefore, establishing a weight regarding the ozone transport variation towards the Pole, during the winter, due to the stratospheric circulation (hemispherical character), and the changes of photochemical processes that affect the budget of stratospheric ozone in middle latitudes areas, is difficult to quantify.

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