Association of the Laminated Vertical Ozone Structure with the Lower-Stratospheric Circulation

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ABSTRACT

In this study the examination of the role of the atmospheric circulation in the lower stratosphere in relation to the laminated structure of ozone in the subtropical atmosphere is attempted. This analysis is based on the vertical ozone profile data collected by balloon-borne sondes released at Athens, Greece (38°N, 24°E). From the 29 ozone soundings performed during the winter 1991/92 in the framework of both the European Arctic Stratospheric Ozone Experiment (EASOE) and the Tropospheric Ozone Research (TOR), it is shown that the lamination phenomenon in ozone profiles, especially in the lower stratosphere, was very frequently present. Furthermore, a characteristic minimum of ozone partial pressure at the height region of 14–17 km has also been detected. The occurrence of the laminated ozone structure as well as the appearance of the characteristic ozone minimum, correlated with the general circulation, leads to the following results: (a) The laminated ozone profiles are associated with the north-northwest circulation in the lower stratosphere; and (b) the characteristic ozone minimum is related to the influence of the subtropical jet stream circulation.

1. Introduction

During the last 30 years many researchers have reported the existence of layers with enhanced and depleted ozone amounts (laminar structure) in the vertical ozone profiles (Hering 1964; Hering and Borden 1964; Reid and Vaughan 1991; Varotsos et al. 1992). In particular, Dobson (1973) made a systematic analysis of the laminated ozone structure in the stratosphere over a wide latitudinal and longitudinal range. In Dobson's analysis the criterion for the detection of laminae was the change of ozone partial pressure in a certain height interval to be greater than 3 mPa. Also, in the same study the ozone profiles were separated into three groups: group 0, with profiles containing almost no laminae, group 1, with profiles exhibiting moderate laminar layer, and group 2, with profiles extensively laminated. Among the findings of Dobson's work is that the features of the laminated structure vary with latitude and season. In particular, between January and April the lamination phenomenon is most frequently present. Also, at latitudes below about 20°N during spring and below about 30°N during autumn a laminar structure of the ozone is very seldom found. In more detail, about 35% of all profiles were classified at group 1 at high latitudes in spring, while group 2 during summer, while group 1 was found in polar regions throughout the year. In Dobson's paper no explanation was given for both the incidence of the minima at a preferred height region of 14–17 km and its constancy with latitude. It has been stated though that there is a strong correlation between the existence of the characteristic ozone minimum at 14–17 km and the occurrence of the double tropopause, especially at latitudes around 40°N. Finally, it should be stressed that Dobson made the assumption that the laminated structure and the characteristic ozone minimum are of the same origin, since the variations in the appearance frequency with both season and latitude are very similar.

Reid and Vaughan (1991) in a recent study examined the ozone laminar structure in the altitude range of 9.5–21.5 km. Laminae were classified according to their vertical extent (depth), as well as the difference in ozone partial pressure (magnitude). They also used some criteria to separate genuine laminar features from instrumental noise or large-scale features in the ozone profile. The acceptable depth for laminae was chosen to be between 200 m and 2.5 km while the minimum magnitude was set to 2 mPa. They also showed that laminae are mostly found below 18 km at high latitudes during winter and spring, which is in agreement with the findings of Dobson's study. But Reid and Vaughan (1991) disagree with Dobson about the origin of laminae. Based on the observation that their magnitude is greatest and their depth least during winter and spring, they ruled out the suggestion of Dobson that they all originate near the subtropical jet.

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stream, although the possibility remains that a small number of laminae may be generated by stratosphere-troposphere exchange according to Begum (1989). Reid and Vaughan (1991) suggested that laminae may represent evidence for a process that can cause exchange of air in and out of the polar vortex. This argument is supported by recent polar ozone campaigns, where particularly sharp and deep laminae near the winter polar vortex have been detected (Mc Kenna et al. 1989).

Given the ozone destruction that is known to take place within the vortex (Stolarski et al. 1991), the possibility that such exchange can spread ozone depletion to lower latitudes is examined in the present paper.

2. Results and discussion

Twenty-nine ozone soundings in the period between December 1991 and April 1992 (six in December, seven in February, eight in March, eight in April) have been performed at Athens. The ozonesondes used for the vertical soundings were the Electrochemical Concentration Cells (ECC, Scientific Pump) after Komhyr (1969). For the measurement of temperature and humidity as well as the data transmission we have used RS-80 radiosondes (Vaisala). The interface cards for the digitization of the signals and the receiving system, were also from Vaisala. The data were taken during the ascent of the balloon (TOTEX, 1200 g). The ozone soundings were performed at 1000 UTC.

The 29 vertical ozone profiles measured at the Athens station were classified into four groups according to their specific features. The first group (12 experimental days) consists of profiles in cyclonic flow at 200 hPa, generally on the western or southern side of an elongated trough. The main characteristics of the profiles of the first group are (a) high tropopause; (b) small secondary maximum in ozone (<7 mPa); and (c) ozone minimum at 100 hPa.

The second group (six experimental days) is similar meteorologically to the first group but consists of profiles with a rather larger secondary layer in the lower stratosphere, and again, an ozone minimum at 100 hPa.

The third group (eight experimental days) is mainly characterized by many thin layers in the lower strato-
should be noted that the data of Cagliari were collected between 1972 and 1975, while the Athens data were collected later (1991–92). It is reasonable, however, to assume that the same regime at the lower stratosphere applied over Cagliari and Athens during the time period 1972–75. This fact, in combination with the observation that the laminar events are much more pronounced at the edge of the polar vortex, can be explained by the observation that the vortex expanded in 1992 due to the Pinatubo eruption (Angell 1992; Angell and Korshover 1985). It should be stressed here that the nearest ozone sounding station to Athens (Hohenpeissenberg, Germany, 47.5°N) is too distant to obtain more information about the situation over our region.

Inspection of the weather maps, provided by the German Weather Service, shows that there is a significant correlation between the appearance of laminar events and the establishment of a north-northwest circulation in the lower stratosphere over our site (Fig. 2). In this case, it is clearly seen that the experimental

sphere (laminated structure). The profiles of the third group were observed during fairly cyclonic flow or on the eastern side of the trough.

Finally the fourth group (three experimental days) contains profiles with one thick layer in the lower stratosphere and an ozone minimum at 14–17 km. The profiles of the fourth group were usually observed during cutoff low events.

For the identification of laminar structures, the same criteria (laminar depths less than 2.5 km and magnitudes higher than 2 mPa) as in the work of Reid and Vaughan (1991) have been used. Features having depths higher than 2.5 km are considered ozone maxima and minima.

The first important finding of the present study is that the lamination phenomenon has been observed very frequently over our region, in contradiction with previous measurements in our latitudes (Reid and Vaughan 1991). This difference becomes much more pronounced in February and March, where the lamination frequency over Athens is about twice that observed over Cagliari, Italy (39.1°N) (see Fig. 1). It
By examining the weather maps of the experimental days with the characteristic ozone minima, it is evident that during these days Athens was influenced by the subtropical jet stream. One characteristic example is observed in Fig. 4. This is in agreement with the observations made by Dobson (1973) that the 15-km minimum is associated with air coming from the subtropical region. Finally, in Fig. 5 a case where our site was influenced by both types of circulation of air masses in the lower stratosphere is presented. The distinct minimum around 17-km height as well as the laminar structures are clearly shown.

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REFERENCES