Journal of Atmospheric and Solar-Terrestrial Physics 120 (2014) 88–95

Contents lists available at ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

journal homepage: www.elsevier.com/locate/jastp

Long-term trends in the northern extratropical ozone laminae with focus on European stations

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ARTICLE INFO

Article history:
Received 6 August 2013
Received in revised form
3 September 2014
Accepted 5 September 2014
Available online 16 September 2014

Keywords:
Ozone laminae
Long-term trends
Atmospheric dynamics

ABSTRACT

Narrow layers of substantially enhanced ozone concentration in ozonesonde-observed ozone profiles, called positive ozone laminae, reveal much stronger trend than the stratospheric and total ozone itself. They seem to be sensitive to both the ozone concentration and even more to changes in the stratospheric dynamics. We are studying long-term trends of strong positive laminae based on balloon-borne ozone sounding in Europe, Japan, North America and Arctic over 1970–2011 with focus on European stations due to their highest frequency of ozone sounding. Laminae characteristics exhibit strong negative trend till the mid-1990s (decrease by 50% or more). In more recent years this negative trend reverses to a positive trend. According to regression analysis, several factors play a role in the trend in laminae in Europe, namely NAO, EESC and the behavior of the winter polar stratospheric vortex represented here by the 10 hPa polar temperature. On the other hand, several factors are found not to play a significant role in the long-term trend in laminae.

1. Introduction

The ozone profiles measured by ozonesondes often do not display “textbook”-type smooth ozone profiles. Particularly in late winter and early spring these profiles tend to display relatively narrow layers of substantially increased or depleted ozone concentration. These narrow layers are called laminae, positive for the increased ozone concentration and negative for depleted ozone concentration. The laminar structure of ozone profiles was first observed by Dobson (1973) based on ozonesonde data. Laminae have been detected also in satellite and lidar ozone profiles (e.g., Olsen et al., 2010; Reid and Vaughan, 1993) but with poorer height resolution (which is critical for lamina determination) and with shorter data series, even though satellites provide global coverage and more frequent measurements than ozonesondes (2–3 times per week at best). Since we are interested in long-term trends in laminae, we have been using laminae derived from ozonesonde-measured ozone profiles.

The ozone laminae are a sensitive detector of long-term changes and trends in the stratosphere. Their evolution is affected by changes of both the ozone concentration and particularly the atmospheric transport and dynamics. Lastovicka (2002) estimated the contribution of the trends in laminae to the total ozone trends at European midlatitudes to be as much as one third of the overall trend in late winter/early spring but negligible in early autumn.

We determine laminae in terms of the absolute values of ozone concentration, not in terms of changes in the ozone mixing ratio. Our experience shows that positive laminae are better determined than negative laminae. Strong positive laminae are very predominantly released by polar vortex near its edge as filaments (e.g., Reid et al., 1998). Then they are transported to middle latitudes and tilted by height-dependent circulation. Balloon-borne measurements confirm well-resolved laminations near the vortex edge (Orsolini et al., 1998). High-resolution modeling confirms that that tilted ozone sheets, peeled off near the vortex edge in the ozone profile result in the formation of laminae (Orsolini et al., 1997). Weak laminae may be of various origin being caused, e.g., by propagating gravity waves (e.g. Pierce and Grant, 1998). Therefore only strong positive laminae with the ozone concentration increase by more than 40 nbar with respect to background are studied in this paper but negative laminae reveal similar trend results as positive laminae as shown, e.g., by Krizan and Lastovicka (2005). Such laminae occur between the tropopause and the ozone profile maximum, not above, as experience shows (e.g., Krizan and Lastovicka, 2005 and references herein).

Laminae are observed most frequently during the winter and spring in extratropics (Reid and Vaughan, 1991). Laminae occur more than five times more often in late winter and early spring than in early autumn at European middle latitudes (Mlch and Lastovicka, 1996). Therefore here we study laminae only for the first half of the year (January–June). Two basic lamina parameters

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http://dx.doi.org/10.1016/j.jastp.2014.09.006
1364-6826/

are studied, the number of laminae per profile and the overall ozone content in laminae per profile. The method of lamina determination, which we use, is very similar to that described by Krizan and Lastovicka (2005). There are various methods of lamina determination/definition. Fortunately, even though the values of ozone content in laminae (and thus the number of large laminae) are significantly affected by the applied method of lamina determination, trends themselves are essentially independent on the method of lamina determination (e.g., Krizan and Lastovicka, 2005).

Krizan and Lastovicka (2005, 2006) investigated long-term trends in the Northern Hemisphere (hereafter NH) high and middle latitudes and the Southern Hemisphere (hereafter SH) high latitudes using all available long ozone profile data series from ozonosonde measurements. Their main results are as follows:

1. There was a strong trend of reduction of the overall ozone content in positive laminae, as well as the overall ozone deficit in negative laminae per ozone profile and in the number of both positive and negative laminae per profile from 1970 to the mid-1990s in all four regions (Europe, Northern America, Japan, Arctic). The reduction reached more than 50% for the overall ozone content in positive laminae. The trends have been observed down to latitudes ~35°N (Japan).
2. After the mid-1990s the trend in both positive and negative laminae reversed from negative to positive in all four regions. However, data series was short (end in 2003) and the increase was unexpectedly large.
3. The trends in the number of laminae are very similar to those in the overall ozone content (or deficit) in positive (negative) laminae.
4. The overall ozone content (deficit) in positive (negative) laminae per profile is much larger in the NH than SH. Laminae are much more frequent in the NH as the NH vortex is much less stable than the SH vortex.

This paper focuses on updating the above results by prolonging the data series of strong positive laminae from 2003 to 2011, and on possible explanation of trends in ozone laminae at middle and high latitudes of the Northern Hemisphere. It is not feasible to study very scarce laminae at the Southern Hemisphere. Section 2 deals with updating the results by laminae data until 2011. Section 3 investigates possible factors, which could affect trends in ozone laminae. Section 4 contains brief conclusions.

2. Updated trends in ozone laminae

Data in four regions, each with ozone sounding stations with reasonably long data series, namely Europe, Japan, Arctic and the midlatitude North America, are used for the lamina trend analysis. These stations are Hohenpeissenberg ((47.8°N, 11.0°E), Payerne (46.5°N, 6.6°E), Uccle ((50.8°N, 4.3°E), Lindenberg (52.2°N, 14.1°E) and Legionovo (52.4°N, 21.0°E) for Europe; Sapporo (43.1°N, 141.3°E) and Tateno (36.1°N, 140.1°E) for Japan; Alert (82.5°N, 62.3°W), Resolute Bay (74.7°N, 95.0°W) and Sodankylä (67.4°N, 26.6°E) for Arctic; Goose Bay (53.3°N, 60.3°W), Churchill (58.8°N, 94.1°W), Edmonton (53.6°N, 114.0°W) and Wallops Island (37.9°N, 75.5°W) for America. Ozone profiles are taken from the World Ozone and Ultraviolet radiation Data Center (WOUDC) in Toronto, www.woudc.org. Hereafter only strong positive laminae (>40 nbar, Krizan and Lastovicka, 2005) are studied for January–June of each year. Focus is on European stations as they have highest and most homogeneous frequency of ozone sounding.

Fig. 1 reveals for Europe a decrease until the mid-1990s in both the number of laminae per profile and the overall ozone content in laminae per profile followed by a rapid increase until 2002–2003, which after a drop turns to a more moderate increase in recent

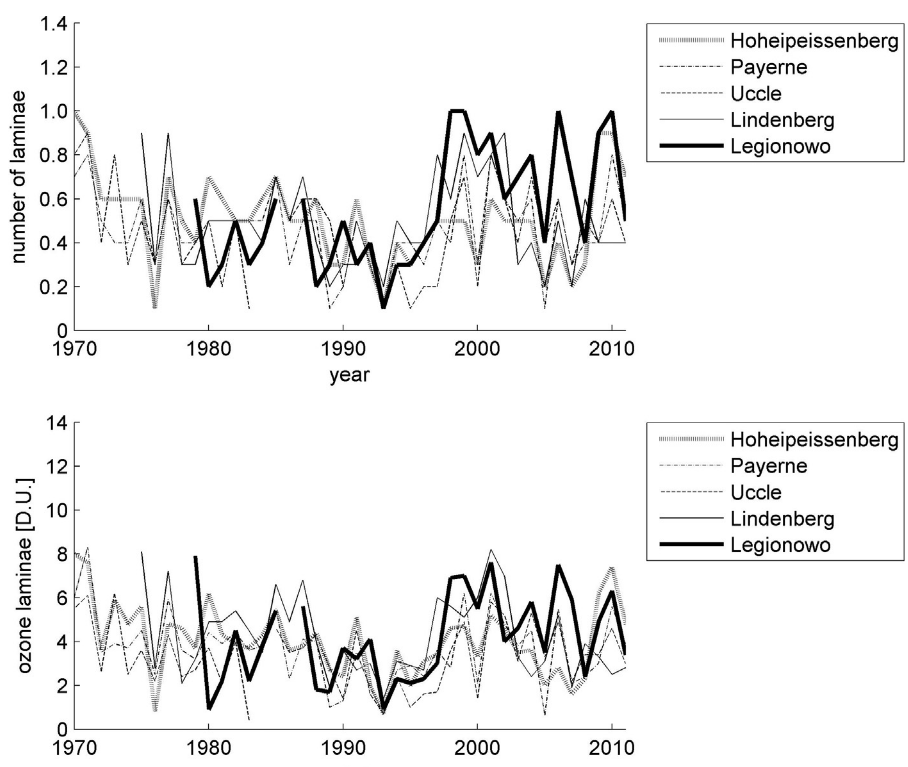

Fig. 1. Long-term evolution of ozone laminae over Europe, 1970–2011. Top panel – number of laminae per profile. Bottom panel – the overall ozone content in laminae per profile. Stations Hohenpeissenberg, Payerne, Uccle, Lindenberg and Legionowo.