

## ***Interactive comment on “Secondary maxima in ozone profiles” by R. Lemoine***

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Received and published: 28 May 2004

This text gives detailed comments to the comments by anonymous referee #1 on the article "Secondary maxima in ozone profiles" by R. Lemoine.

Several of the arguments used here were introduced in the Short Comments published on ACPD by the author on May 12, 2004.

Response to the general comments.

1. Introduction. Various phenomena like the influence of dynamical activity in the troposphere and the stratosphere on ozone, ozone transport through the tropopause, lamination and exchange of air at the boundary of the polar vortex and so on have been studied in the past and have been the subject of many detailed articles. These articles contain several case studies and are summarised in the Introduction section. This Introduction is voluntarily long in order to convince the reader that, although no definite answer has been presented, the state of knowledge of these phenomena is relatively high.

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Instead, the article discussed here tries to concentrate on work that has sparsely or never been presented before, like the climatology and global distribution of ozone secondary maxima and their relation to ozone trend. I was not aware of the work by Milch and Lastovicka [1996], reference to this work will be added.

2. Examples/ Fig. 1. The examples can be modified so that one more detailed example is given, with a short description of the meteorological situation and PV field. However, it is not the aim of this article to give case studies analysis.

An early version of this article contained two case studies of ozone secondary maxima, with PV maps and description of the formation of the secondary maximum through advection of air masses from different origins. These case studies turned out at the end to be almost carbon copies of the case studies presented by O'Connor et al [1999] and Varotsos et al [1994]. Pushing the analysis further as suggested by referee#1 would require an article dedicated to that aspect only.

The only new information that came out of the case studies is the apparent systematic association between ozone secondary maxima and Rossby wave breaking events. This result is presented in the present article, with more cases (17 cases instead of 2).

3. Fig. 1/ Fig. 2. The figures can be modified according to the comments. The confusion about start/end dates of trajectories will be corrected as well.

4. Secondary maxima and Rossby wave breaking. This section presents evidence using 17 cases of the association between ozone secondary maxima and Rossby wave breaking. The tool used here is kept as simple as possible. The use of trajectories can be sometimes problematic but the consistency of the examples shown should convince the reader of the relevance of the analysis. Trajectories give only a part of the information needed and it is true that an air mass that was over the arctic 5 days ago can be of tropical origin. However, if this air mass shows unusually high ozone concentration, the argument doesn't hold anymore.

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About the Dobson hypothesis, intrusions of tropospheric air can lead to the formation of low ozone layers in the lower stratosphere, but this phenomena was not found to be the origin of ozone secondary maxima in the cases analysed. The opinion of the author is that tropospheric intrusions cannot create ozone poor layers as high as the 100hPa level were the low ozone layer is generally observed when associated with a secondary maximum. This argument might not be clear in the text and the discussion in the article will be modified accordingly.

5. Trend in atmospheric circulation and ozone variation. About the regression section: an ozone profile contains more information than just ozone concentration levels at different altitudes. The shape of an ozone profile contains information about the air masses that were sampled by the sonde (or sensed by the satellite). The regression relating lower stratospheric/total ozone and aspects of secondary maxima should be understood this way: since secondary maxima are associated with atmospheric circulation and ozone transport, can we use the characteristics of secondary maxima as a proxy for the atmospheric circulation in the stratosphere instead of using classical quantities like the tropopause height or the QBO? The answer to that question is given by the results of the regression analysis. Evidence is presented that secondary maxima are linked with the exchange of air between the polar vortex and mid latitude air. Section 8 gives evidence that the frequency and amplitude of secondary maxima can be used to describe a large part of the ozone variability and trend. Hence, it is deduced that the frequency and amplitude of secondary maxima are representative of the component of atmospheric circulation that has a direct influence on ozone.

It is true that secondary maxima could be related to modelled quantities like a Rossby wave activity index or the EP flux, but this is another approach and can be the subject of a more model-oriented study.

Response to specific comments.

1. Abstract. The sentence can be changed to reflect the probable character of the

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correlation. However, the discussion in the article provides evidence that secondary maxima are related with specific patterns of the atmospheric circulation and that the occurrence and amplitude of secondary maxima accounts for a large part of the ozone variability.

2. Page 1793 (on-line pdf), line 4. This will be corrected.

3. Fig 1. Back trajectory analysis shown in the article suggests that the ozone-rich air mass in the secondary maximum is advected horizontally, without significant vertical motion (see Table 1). Since the air mass has its origin inside the polar vortex as suggested by the high PV values associated with the intrusion, the measured ozone concentrations in secondary maxima are (and should be) higher than the SAGE mean for 60-70degrees N but are typical for the lower polar vortex. No vertical displacement is needed here in order to explain the high ozone concentration. This fact is very important but might not appear clearly in the text and the article can be modified in order to make the text clearer.

4. Page 1799 (on-line pdf), lines 11 to 14. The sentence is wrongly split in two parts. The correct sentences are: It is important to note that Rossby wave breaking events have been identified as the likely origin of stratosphere-troposphere exchanges (Peters and Waugh, 1996) and play a role in the appearance of mini ozone holes (Hood et al., 1999). However, the results obtained here rule out the possibility that the ozone-poor air layer observed with ozone secondary maxima is air of tropospheric origin.

5. Page 1800 (on-line pdf), line 6. The height of the troposphere shows indeed a seasonal variation that is similar to the frequency of secondary maxima. Both phenomena are linked to the atmospheric circulation and seasonal appearance of the polar vortex. This will be mentioned in the text.

6. Zonal distribution. A comparison with the results obtained by Appenzeller et al will be added.

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7. Conclusions: page 1805, lines 9-11. The text will be changed accordingly.
8. Conclusions: page 1805, lines 21-22. The text will be changed accordingly.
9. Page 1805, line 23 to page 1806, line 5. The trend analysis is an important part of the article. The results presented in Section 8 and summarised in the Conclusions shed a new light on the link between atmospheric circulation and ozone variation. The atmospheric circulation information is derived here from secondary maxima analysis. This approach is relatively new and, to my knowledge, has never been published before. It is therefore difficult to simply remove this entire analysis and section without losing a large part of the original content of this article.

#### References

Weiss, A. K., Appenzeller, C., and Harris, N, Chemical and dynamical contribution to ozone profile trend of Payerne (Switzerland) balloon soundings, *J. Geophys. Res.*, 106, pp. 22.685-22.694, 2001.

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Interactive comment on *Atmos. Chem. Phys. Discuss.*, 4, 1791, 2004.

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