Answer to the referee #1 comments on the paper "Ozone zonal asymmetry and planetary waves characterization during Antarctic spring" by I. Ialongo et al.

The authors are thankful to the referee for the useful and constructive comments. The referee's comments are shown in italics.

The authors examine the structure and temporal behaviour of zonally asymmetric ozone in the southern hemisphere during spring, based on different recent satellite data (OMI, GOMOS, Aura-MLS). From my point of view the paper gives new and important aspects for understanding the southern hemispheric ozone variability and, in agreement with the authors, for future climate studies. Overall the paper is well-written and worthwhile to be published in ACP. However, I have some few specific questions, and I recommend some few minor improvements before final publication.

Specific comments: 1) P. 32338, l. 10: Relative amplitudes (here: 50%) can lead to misleading interpretations if absolute values are not provided. I suggest specifying the absolute amplitudes, for example in DU as done in Section 4.2. Please check this point throughout the text. In particular, some absolute values should be given in Section 4.3 when discussing the relative amplitudes in the ozone profiles (see specific comment 6 below).

Thanks for your comment. The ozone number density and mixing ratio depend on altitude, so do the wave amplitudes presented in absolute values. Please look at the reply on comment #6 below.

2) P. 32343, ll. 16-22., Fig. 2: I see a pronounced interannual variability with stronger amplitude during 2005, 2007 and 2009, and weaker amplitude during 2006, 2008 and 2010. This variation might be related to the Quasi-Biennal Oscillation (as far as I know the years 2005 and 2007 are characterized by easterly phase of OBO, but the years 2006 and 2008 by the westerly phase). Could you give some comments or discussion on a possible modulating influence of the QBO, here and/or at some other places (e.g., in the discussions at P. 32344, ll. 10-16, or P. 32345, ll. 13-19, or P. 32347, ll. 3-4).

Thank you for your suggestion. The following sentence has been added in the revised manuscript: "The observed year-to-year fluctuations in Antarctic total ozone may be partly influenced by the Quasi-Biennal Oscillation (QBO), leading to relatively low (high) ozone values occurring during the westerly (easterly) phase (see e.g. Garcia and Solomon, 1987)."

Garcia, R. R., and S. Solomon (1987), A possible relationship between interannual variability in Antarctic ozone and the quasi-biennial oscillation, Geophys. Res. Lett., 14(8), 848–851, doi:10.1029/GL014i008p00848.

3) P. 32344, l. 16-17: The weakening of the amplitude in early November before increasing again is an interesting point (also mentioned at P. 32347, ll. 19-20, and at P. 32348, ll. 26-27). Do you have an explanation for this feature? One could assume

some kind of reinforcement of the polar vortex due to the photo-chemical ozone depletions and associated radiative cooling potentially, at least leading to a delayed polar vortex break-up. However, perhaps it is just unclear and further research is needed to clarify the involved processes.

The mechanism you propose can potentially exist. However, enhancements of winds in polar night jet or in vortex size are not observed during these periods (e.g., http://www.cpc.ncep.noaa.gov/products/stratosphere/, http://acd-ext.gsfc.nasa.gov/Data_services/met/ann_data.html). These reductions of wave 1 amplitude can be of dynamic origin related to planetary wave propagation. Note that decreased wave 1 amplitude is often accompanied with increased wave 2 amplitude, as noticed in our manuscript.
These features might be related to interactions of waves and the background flow, which is characterized by beginning of transition from "winter wind system" to "summer wind system" in the beginning of November. However, this requires a deep investigation, which is beyond the scope of our paper; therefore this hypothesis is not presented in our manuscript.

4) P. 32345, ll. 9-11: I do not really understand what you want to say with this sentence. Do you mean that strong local maximum ozone values are correlated with strong zonal mean values and that therefore strong local minimum ozone values are also correlated with strong zonal mean ozone values? Please reformulate this sentence.

P. 32345, LL 9-11 What we mean here is that the distribution of high and low values at a given latitude circle affects the amplitude value. But this is already said in the previous sentence, thus this part has been removed as unnecessary.

5) P. 32345, ll. 21-23: The effect of photo-chemical processes on zonally asymmetric ozone is indeed important, but this requires, as a prerequisite, planetary wave patterns in temperature or in other trace gas constituents. Therefore, if I understand you right, it would be more precisely to say that zonally asymmetric ozone is defined not only by transport due to planetary waves, but also by zonal asymmetries in photochemical processes due to planetary waves.

P 32345, LL 21-23 We mean here an introductory sentence as: "The distribution of ozone is defined by chemical and dynamical processes, so is the vertical extent of the ozone asymmetry." The text is rephrased in the revised text.

6) P. 32346, ll. 1-12, Figure 6: The pictures show only relative amplitudes without a relation to absolute values. Therefore large amplitudes in % could be not significant in regions of very weak ozone concentrations, for example those of ozone number density in regions above the stratopause. This problem holds also for Fig. 7 and Fig. 8. Therefore some absolute values of zonally asymmetric ozone have to be provided, or some information for the reader where these absolute values can be found. I also suggest providing some absolute values for zonally asymmetric temperature. For example, a very easy way would be just including two additional sub-figures in Fig. 6,

one for the absolute values in ozone number density and one for those of ozone mixing ratio. Then Fig. 6 but also Figures 7 and 8 become more understandable. However, some more specifications in the text might be sufficient.

We aim here to characterize the ozone perturbations at different altitudes. As the ozone number density and mixing ratio depend on altitude, we used the relative amplitudes to take into account relatively large ozone variations at different altitudes. Furthermore, the presentation in relative units allows comparison on wave amplitudes in different years, which are characterized by different ozone abundances.
For completeness and as suggested, in the revised paper we include two subplots into the Fig.6 (upper panels) including the distribution of ozone number density and mixing ratio.

7) P. 32346, ll. 7-10: Based on the pictures I conclude that the perturbations in zonally asymmetric ozone number density and in air density are in phase only above a height of about 25 km. Here it is somewhat difficult to follow your argumentation. Do you want to say that the wave pattern in ozone number density is related to that in air density (indicating the polar low and high anomalies)? However, both of these wave patterns are related to that of temperature. I think it would be advisable to reformulate or to extend this sentence to make your argumentation somewhat clearer.

The text will be clarified in the revised manuscript as follows:

"The distribution of ozone is defined by both chemical and dynamical processes, so is the vertical extent of the ozone asymmetry. At high latitudes in winter and spring, the ozone distribution is affected by the polar vortex disturbed by planetary waves. Therefore, the amplitude of ozone deviations from the zonal mean will depend on vertical coordinate (geometric altitude or pressure) and on quantity (number density or mixing ratio) used. This is illustrated in Fig. 6 …"
"… As seen in Fig. 6, perturbations on ozone number density, which are of nearly constant amplitude up to 45 km, are in phase with perturbations in air density above 25 km, therefore the analogous perturbations on mixing ratio decrease more rapidly with altitude. It can be noticed the positive correlation of ozone and temperature perturbations below 35 km and their anti-correlation above 35-50 km. This change in correlation is typical for transition from dynamically controlled lower stratosphere to the upper altitudes where chemical processes play a significant role in shaping the ozone distribution (Brasseur and Solomon, 2005; Rood and Douglass, 1985; Smith, 1995}."

Brasseur, G. P. and Solomon, S.: Aeronomy of the Middle Atmosphere, 3rd ed., Springer, Dordrecht., 2005.

Rood, R. and Douglass, A. R.: Interpretation of Ozone Temperature Correlations 1. Theory, J. Geophys. Res., 90(D3), 5733-5743, 1985.

Smith, A. K.: Numerical simulation of global variations of temperature, ozone, and trace species in the stratosphere, J. Geophys. Res., 100(D1), 1253-1269, doi:10.1029/94JD02395, 1995.

8) P. 32346, ll. 19-26: In the context of specific comment 6, it would be more precisely to use here the terminus "relative" wave amplitudes.

P. 32346, l. 14: In the revised version, we define the relative wave amplitude: "Being presented in percents of a zonal mean value, the relative amplitudes of wave number 1 and 2…"

9) P. 32347, ll. 22-23: Where exactly is this visible? Do you mean the disturbed line of downward propagating dark blue area located approximately 5-10 km above the red area?

Yes, exactly. The sentence will be modified as suggested: "Local minima observed in GOMOS are also visible in MLS data at 35–40 km (see the downward propagating dark blue area located about 5-10 km above the red area in Fig. 8)."

10) P. 32347, ll. 23-25: In contrast to this statement, but in agreement with the discussion in Sect. 4.2, I see a significant year-to-year variability also for September and October.

P. 32347, ll. 23-25 This sentence is removed

11) P. 32348, ll. 10-11: The link to the maximum in polar vortex jet stream intensity occurs somewhat abrupt. Could you give some more explanation on this link?

Please see the revised manuscript. The sentence was removed when reorganizing the text.

12) P. 32348, ll. 17-18: Based on the results it is not really evident why the decrease in altitude location of greatest amplitude in time is related to the effect of vertical transport in the polar region. Could you give some more explanation or a reference?

The sentence is modified as follows: "The altitude location of the largest amplitude decreases with time, as also the area of the strongest ozone depletion decreases in altitude. This happens when the ozone hole recovery starts (usually in October) and ozone-rich air masses appear and descend from 50 hPa to 100 hPa and below, replacing part of the ozone depleted air (van Peet et al, 2009)."

van Peet, J. C. A., R. J. van der A, A. T. J. de Laat, O. N. E. Tuinder, G. König-Langlo, and J. Wittig (2009), Height resolved ozone hole structure as observed by the Global Ozone Monitoring Experiment-2, Geophys. Res. Lett., 36, L11816, doi:10.1029/2009GL038603.

Technical corrections:

1) P. 32339, ll. 27: A relation is missed, I suggest "... in a warmer Antarctic stratosphere in comparison to three-dimentional ozone field."

Corrected

2) P. 32344, l. 3: The related pre-ozone hole values are not given. Can you specify these values?

In the revised version, we specified these low ozone values which we want to emphasize. The sentence is modified also according to referee 2 comment as follows:

"During the last 6 yr, the zonal minimum remained below 250 DU, showing the largest values during 2009 and 2010."

3) P. 32348, l. 15: It extends up to altitudes 60-65 km only for the relative amplitude in ozone number density.

This is modified in the Discussion and summary of the revised manuscript. Please check the answer 7 to referee #2.

4) Figures: In the print-version provided by ACPD, Figures 2, 4 and 8 are too small. I suggest enlarging the figures as given in the manuscript I got for the initial review

We will make sure that in the final version of the manuscript all the figures have a proper presentation.