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Interactive comment on "An unusual stratospheric ozone decrease linked to isentropic air-mass transport as observed over Irene (25.5° S, 28.1° E) in mid-May 2002" *by* N. Semane et al.

N. Semane et al.

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We thank Referee #2 for his kind words concerning our paper. We will quote his remarks and provide our reply below.

-"To avoid irritations, it should be somehow clarified or strengthened in the title and in the abstract that this study focuses on SH only!"

>> Following the referee's recommendation, the title and abstract have been completed in order to emphasize that this study focuses on SH only.

The title is now: <An unusual stratospheric ozone decrease in the Southern Hemi-

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sphere subtropics linked to isentropic air-mass transport as observed over Irene (25.5° S, 28.1° E) in mid-May 2002>.

-"strong planetary wave activity: strong is relative? Just for this time of the season or?"

>> The following sentence (P2, L25-L28): <Indeed, the perturbed vortex was typically predisposed for easy erosion by dynamical transport processes, which have been driven by strong planetary wave activity and have eventually resulted in a very large latitudinal advection of polar air masses towards the subtropics.>, has been completed as follows:

Indeed, the perturbed vortex was typically predisposed for easy erosion by dynamical transport processes, which have been driven by pulses in planetary-wave activity that occurred as early as May 2002 and resulted in a minor warming by mid-May (Newman and Nash, 2005). This was followed by a very large latitudinal advection of polar air masses of low ozone content towards the subtropics in the middle stratosphere.

- "The Referee suggests to include some others references in the introduction which are more valuable for our study, which investigated the simultaneously occurrence of polar vortex and tropical extrusions into the extratropics/subtropics e.g.: Calisei et al. 2001, Koch et al. 2002, Riese et al. 2002, Krüger et al. 2005."

>> We agree with the Referee, and have added the aforementioned references through the following sentences:

- Calisesi et al. (2001) reported on large episodic perturbations of the mid-stratospheric ozone values and showed that they were linked to deformations and southward excursions of the polar vortex in association with strong planetary-wave activity.

- Using ozone soundings over Payerne (Switzerland) during 1970-2001, Koch et al. (2002) showed that negative/positive ozone deviations generally coincide with transport from regions with climatologically low/high ozone values.

- Riese et al. (2002) used Cryogenic Infrared Spectrometers and Telescopes for the

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Atmosphere (CRISTA) observations of N2O in the Southern Hemispheric stratosphere, which were performed in early November 1994, in order to highlight a strong interaction of the South polar vortex with the subtropical transport barrier, which led to transport of tropical air towards higher latitudes.

- This major warming, which is the first of its kind ever observed before over the Southern Hemisphere since regular monitoring began in the 1940s (Krüger et al., 2005).

- "among the best: why? Not obvious, too strong"

>> The following sentence (P3, L7-L8): <the tropical Southern Hemisphere latitudes are among the best locations for detecting a possible recovery of the ozone layer.>, has been modified as follows:

the southern tropical and subtropical latitudes are among locations where a possible recovery of the ozone layer may be detected.

- "starting in the early winter 2002 (Scaife et al): when? Early winter can be long"

>> The following sentence (P5, L7-L8): <This was associated with distinctive persistent stratospheric vacillations starting in the early winter 2002 (Scaife et al).>, has been completed and is now:

This was associated with distinctive persistent stratospheric vacillations starting around 20 June 2002 (Scaife et al., 2005).

- "Which instrument was used for the ozone measurements?"

>> We have added one sentence in the paragraph on the description of the ozone measurements used in this study - see P6, L8-L12:

The ozonesonde used is of Science Pump ECC6A type with 1% KI buffered solution, and the meteorological sonde is of Väisälä RS80-15GE type. For the present study, 178 profiles measured fortnightly between November 1998 and May 2005 were used. More precisely, in order to examine the early winter state of stratospheric ozone over

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Irene, we focused our analysis on the May ozone concentration profiles measured during the period from 1999 to 2005.

- "TOMS?"

>> This abbreviation has been written out once in the abstract. We have also added some information about the TOMS data we have used - see the sentence on P6, L12-L13, which has been completed as follows:

total ozone columns over Irene for the same period were taken from the TOMS experiment on board the Earth Probe satellite (Earth Probe TOMS V.8 overpass data).

- "The use of Epv, PV, APV is misleading! Why not using the standard abbreviations?"

>> We agree with the referee that the standard abbreviation of the Ertel's potential vorticity is Epv. Nevertheless, the quantity advected by the MIMOSA model is not the true dynamical Epv but < a quasi-passive Epv>, which correlates well with the concentration of ozone or others long-lived trace species in the lower stratosphere. In particular, the true Epv is probably poorly conserved in small-scale filaments due to radiative and dynamical processes. In order to avoid confusion, the quantity advected by MIMOSA is called <advected potential vorticity> (APV) in the paper.

- "ECMWF?"

>> Following the referee's suggestion, we have added a new subsection in order to give a detailed description of the meteorological data used in our study:

Information about the dynamical evolution of the atmosphere in the early southern winter 2002 is provided by the ERA-40 re-analyses archived on the ECMWF web site (http://data.ecmwf.int/data/d/era40_daily/). In this study, ECMWF horizontal winds and temperature were extracted on a 2.5°X2.5° grid from 1000 to 1 hPa (23 levels) at 00:00, 06:00, 12:00 and 18:00 UT, for the period extending from April 1 to May 31, 2002.

- "How about showing a vertical a cross section over Irene with Mimosa?"

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>> Following the Referee's suggestion, a new figure has been added in order to show the time evolution of APV as a function of potential temperature over Irene during May 2002. As expected, during the mid-May period, the Irene site is under the influence of polar air masses in the middle stratosphere and of tropical ones in the lower stratosphere.

The new figure has been included in Fig.3 of our paper as <Plate (c)> and has the following caption:

Plate (c) Top panel: temporal evolution of advected potential vorticity (APV) as a function of potential temperature obtained from the high-resolution MIMOSA model at Irene in May 2002. Bottom panel: same as top panel but zoomed in on the vertical range from 380 to 520 K.

The description and analysis of the new figure have been included in our paper as follows - see P9, L19-23:

Nearly the same transport situations are obtained from MIMOSA outputs for selected isentropic surfaces in the 625-800K (middle stratosphere) range (not shown). Furthermore, Plate (c) of Fig. 3 shows the time evolution of APV as a function of potential temperature over Irene during May 2002 in the stratosphere. During the mid-May period, the Irene site is under the influence of polar air masses in the middle stratosphere (top panel) and of tropical ones in the lower stratosphere (bottom panel). This is in agreement with the vertical extension of the negative deviation observed on the ozone concentration profile recorded on May 15 for isentropic levels higher than 625K and for those between 400K and 450K (see Fig. 2).

- "In the lower and upper stratosphere: should be the lowermost and middle stratosphere. Upper stratospheric levels include pressure levels from 5 hPa upward"

>> Following the referee's comment, the sentence has been reworded - see on P10, L5-L8:

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Thus, the unusual reduction of total ozone observed over Irene by mid-May 2002 seems to be related to isentropic transport of air masses simultaneously in the lowermost and middle stratosphere, respectively from the tropics to the mid-latitudes and from the pole to the subtropics.

- "As for the low concentrations of ozone in the upper part of the profile (above 625K), they can be attributed to air-mass advection from pole to tropics due to the fact that there is less ozone in the polar region. This is not shown by your paper and is also not cited and proofed with others papers. For this time of the year the chemical ozone loss usually has not started. This point is very important for your main conclusions and has to be clarified either with maps or with references!!! See also in the abstract and in the discussion"

>> We agree with the Referee and have then added some references in our argumentation - see on P10, L12-L14:

As for the low concentrations of ozone in the upper part of the profile (above 625K), they can be attributed to air-mass advection from pole to tropics due to the fact that there is less ozone in the polar mid-stratospheric region (Koch et al., 2002; Godin et al., 2002).

- "The transport of polar air toward low latitudes can occur in the form of a polar filament. There can be also other ways add "

>> The following sentence (P10, L20-L21): <The transport of polar air toward low latitudes occurs in the form of a polar filament.>, has been completed as:

According to Marchand et al. (2003), the transport of polar air toward midlatitudes can occur through the extension of filament toward lower latitudes and through vortex intrusions.

- "Fig. 4a: you have not described the enhanced PW activity at the surface for May 3-8 which seems to be somehow connected to the increased PW activity later on in the

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upper stratosphere."

>> We have added the following sentence (P11, L5):

Fig. 4a shows enhanced wave activity in the troposphere for May 3-8, which has led to the increase of wave activity later in the stratosphere.

- "a large region of convergence: wave-mean flow interactions? ie. How does the zonal wind react on it!"

>> The point has been clarified by modifying our argumentation in P11, from L20 to L26 as follows:

From the superimposed contours on Fig. 5 illustrating ECMWF ERA-40 zonal winds as a function of equivalent latitude, it can be seen that the southern stratospheric zonal circulation changed from easterlies to westerlies, allowing the planetary waves to spread and bend equatorward nearby the subtropics (as shown by EP-flux on Fig. 4). According to Newman and Nash (2005), the subtropical zonal wind in the upper stratosphere in April 2002 (prior to any wave events) was anomalously easterly. Subtropical easterlies were also observed in April 2002 in the middle stratosphere (as shown on Fig. 5). Therefore, the anomalous easterlies in the mid-to-upper stratosphere in April corroborated by a particular reversal to westerlies in early May, suggests that wave propagation was highly anomalous during the early winter of 2002. The mechanism for this appears to be the dependence of planetary wave propagation and breaking on the structure of the mean zonal wind (Brasseur et al., 1999). In fact, when the subtropical wind is westerly, waves can propagate as far as toward the equator, and the surf zone is shifted to lower latitudes. Thus, the two anomalous features both in the zonal wind and in the planetary-wave activity contribute to the increase in isentropic mixing over the subtropics by mid-May 2002. This is a result of mixing by planetary waves breaking in the surf zone. Indeed, one notices that mixing (Keff) has increased in the 20-30° S equivalent latitude range by mid-May as underlined by the dotted circle, which also denotes the region of wave breaking.

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- "The wave activity is particularly strong on May 15, 2002 (Fig.4c) and is associated with a greater wave penetration and an enhanced wave driving in the subtropical middle stratosphere where the wave driving reaches a minimum lower than -10 m.s-1 per day. Where is the middle stratosphere for you? It is around 10hPa!"

>> Following the referee's comment, the sentence has been rewritten as:

The wave activity is particularly strong on May 15, 2002 (Fig.4c) and is associated with a greater wave penetration and an enhanced wave driving in the subtropical upper stratosphere where the wave driving reaches a minimum lower than -10 m.s-1 per day.

- "This analysis demonstrates that, by early-winter 2002, planetary-wave activity has significantly increased during the mid-May period. It shows upward and equatorward planetary-wave trajectories. What are PW trajectories? I would not mix up trajectories and PWs nomenclature!"

>> Following the referee's comment, the sentence has been modified as follows:

This analysis demonstrates that, by early-winter 2002, planetary-wave activity has significantly increased during the mid-May period. It shows upward and equatorward planetary-wave propagation.

- "This gave rise to large-scale transport of polar air toward the subtropics and contributed to the development of the low ozone episode over Irene in mid-May 2002. Mid-stratospheric ozone does not contribute much for chemical ozone loss? Second also for this time of the year?"

>> Indeed, the polar vortex in the early winter of 2002 was unusually disturbed so that enhanced planetary-wave activity easily eroded it into filaments. This gave rise to large-scale transport of polar air toward the subtropics in the middle stratosphere and contributed to the development of the low ozone episode of a purely dynamical origin over Irene in mid-May 2002. This is due to the fact that the climatological ozone gradient points to the south in the middle stratosphere of both hemispheres (Godin et

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al., 2002).

- "From planetary-wave trajectories illustrated by EP-flux in Fig. 4, the large-scale transport polar air-masses was driven by an unusual increase of planetary-wave activity due to the early reversal of the zonal circulation followed by an increase of mixing near the subtropics (Fig. 5)."

>> As some elements here were not clear, we have changed the argumentation:

The reversal to westerlies in the subtropics allows the planetary waves (PWs) to propagate further to the equator, so that they can break at the subtropical barrier. The propagation of the PWs can be seen in APV-maps in the middle stratosphere (polar tongue), whereas the breaking of PWs (see div (F) in Fig. 4) leads to tropical erosion. This was followed by an increase of mixing near the subtropics (Fig. 5).

- "To summarize, a 8-12% decrease in total column of ozone, concomitant with low-ozone concentrations in the middle stratosphere at isentropic levels above 625K and in the lower stratosphere (400-450K) observed over Irene in mid-May 2002, can be attributed respectively to ozone-poor air originally from the polar vortex and to ozone-poor air coming from tropics. Distinguish between natural and chemical ozone losses."

>> This point has been clarified as follows:

To summarize, a 8-12% decrease in total column of ozone, concomitant with low-ozone concentrations in the middle stratosphere at isentropic levels above 625K and in the lower stratosphere (400-450K) observed over Irene in mid-May 2002, is of purely dynamical origin. Indeed, it can be attributed respectively to ozone-poor air originally from the polar vortex and to ozone-poor air coming from tropics.

- "Figure 5: units of effective diffusivity"

>> The Fig. 5 shows time-versus-equivalent latitude logarithm of keff (m2.s-1) normalized by the local diffusivity k: <ln(keff/k)>.

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