Interactive comment on Atmos. Chem. Phys. Discuss., 10, 9917, 2010.

Final Response : Interactive comment on "Global ozone monitoring by occultation of stars: an overview of GOMOS measurements on ENVISAT" by J. L. Bertaux et al.

15 September 2010

We thank both referees for their hard work to review such a long paper and their many useful comments, which helped to improve the paper. The referees comments are in blue, our answers are in black, and proposed modifications of text are in red.

We first answer on two general issues, raised by both referees: the quality of English, and the length of the paper.

1. Quality of English.

None of the initial authors is a native English speaker. Therefore, we will ask Gil Leppelmeier to re-polish the English. Though he is now retired, he accepted to do so. We request to the editor that he be put as an additional co-author. In view of his deep involvement in the preparation of GOMOS, calibration plan and participation in the algorithm developments, this is fully justified.

2. Length of the paper.

We apologize for the length of the paper, but it represent an overview of 22 years of work, by tens of individuals, with an approximate cost of more than 100 million euros.

Both referees suggest that the paper be shortened. We will try to cancel some redundant material; but we anticipate having problems to do significant cuttings. It is clear that we are talking of ozone and other species at two places: once, when we describe the scientific objectives existing in 1988 at the time of the proposal, and the corresponding instrument requirements, and another time when we summarize the results.

On the other hand, since ACP exists only in electronic form, the length of the paper will not consume any paper nor trees to make the paper. This is an attractive particularity of ACP that should be taken advantage of.

We note that the JGR paper of Yee et al., 2002, describing the results of stellar occultations MSX, is shorter only by a factor of 3; while the instrument was not done for that purpose, and acquired about 160 occultations, to be compared to the 600,000 of GOMOS.

Answers to the specific points and remarks:

Referee reports

Anonymous Referee #1

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The paper by Bertaux et al. is an elaborate overview of the GOMOS instrument, data analysis, and scientific achievements. It is notable that the various problems which occurred during the operation of the instrument are clearly stated. For such an overview paper it is justifiable that essentially no new scientific results are presented. Thus, publication in ACP is recommended. Still, I've two points to criticize: first, the length of the paper which could be reduced considerably by avoiding various repetitions in different chapters. Second, the quality of English varies significantly which makes reading not a pleasant task: proofreading by a native speaker could help.

Find below some specific remarks.

P9974L25: Can you explain, why both parameters are not fitted simultaneously?

In this new technique applied to NO_2 and NO_3 (a variant of DOAS method), the smoothly varying (with wavelength) part of the cross section is never set free in the fitting process,

because it could be coupled to the absorption of other constituents (like aerosols). Instead, it is forced to the NO_2 (or NO_3) quantity determined with the rapidly varying cross-section almost not coupled with other constituents. When the convergence is reached the two parameters (smoothly varying and fast varying absorptions) are equal. The total absorption of NO_2 and NO_3 is then well taken into account and there is no coupling with other species.

P9977L15: Can you give an explanation, why such a complicated way of different steps via line-densities is used and not a direct retrieval of altitude profiles?

All limb viewing measurements are integrating over some range of altitude varying along the line of sight, and therefore need a vertical inversion to retrieve local quantities. The vertical inversion of Abel's integral is inherently unstable, and some kind of smoothing is applied most of time. Here we use a rather classical Tikhonov method to avoid unphysical oscillations of the local densities versus altitude.
The first step of the retrieval (so-called spectral inversion) is to determine, from the observed atmospheric transmission, the integrated line densities of all absorbing species. This step is quite fast.
Alternate schemes have been thoroughly discussed among GOMOS specialists, and rejected for the time being.
In one scheme, the vertical inversion would be performed first, for each wavelength element. But since there are about 2200 spectral pixels, the vertical inversion would have to be made separately on each spectral pixel, needing smoothing etc…
In another proposed scheme, both vertical and spectral inversions are made simultaneously for one given occultation. However in this case, very large matrices (dimension ~100000 x 100000) have to be inverted, which is unpractical and computing expensive.

P9977L18: Relative errors are given here. Could you state whether/which of the original error sources lead more to relative or absolute errors.

We propose to add the following sentence at the beginning of section 5.8:

"With GOMOS we measure atmospheric transmissions, from which are derived optical thicknesses from Beer-Lambert law. Optical thicknesses are absolute quantities, and all errors affecting the measurements translate into absolute errors on line densities, then on local densities after vertical inversion. Relative errors are then computed by the ratio of absolute errors to retrieved absolute quantities (line densities, or local densities as shown on Fig. 14 and 22). The absolute error estimate is based…."

Could you also show the absolute profiles in Fig. 22 to which the relative data refer to?

The typical absolute profiles values to which the relative error data refer to may be found either in Fig.14, where NO_2, NO_3, and O_3 are shown; or on fig 22, where there are several ozone median profiles for various latitudes, in both log and linear coordinates. Both figures are now quoted in the above paragraph.

P9979L24 'Another ozone profiles interesting comparison was made in the': 1. strange sentence, 2: what have been the results of this comparison.

We propose the following modified sentence:

"Another ozone profiles comparison was made in the tropics with SAOZ long duration balloon measurements (doing solar occultation measurements) in 2003 and 2004 (Borchi and Pommereau, 2007), together with other instruments. A good agreement was found between 22 and 26 km showing a small negative bias (-1 to -2.5%) and 6% dispersion on individual profiles."

P9979L27: For such an overview paper it is in my opinion not appropriate to show examples of only two profiles in the validation section: either a paper should be quoted where this has been analysed in detail or a statistical analysis should be given here.

The validation of GOMOS by comparison with other sources is discussed briefly in the second paragraph of this section 6: Validation of GOMOS products. The remark of the reviewer refers rather to the second paragraph, where we discuss the internal consistency of GOMOS data. We show one example where the same region was sampled twice by GOMOS on two successive orbits, with two different stars, Fig.23. Such a situation is rare and we were not able to make a statistical analysis of many similar cases.
Another way to check the internal consistency is to examine a series of profiles in a region where natural variability is small. This is the case for low latitudes.

We propose to add one figure Figure 23b, showing (left) a series of 10 profiles obtained with the same star, gathered within a day (therefore, at a constant latitude of 9° N, and sampling all longitudes). While above 30 km, all measurements are almost identical, below 30 km there are longitude variations of the detailed vertical structure; daily mean profiles may be constructed, and overplotted together as on Fig 23b (right) showing 19 of such daily mean profiles. During this span time, the point of star occultation varied from 0 to 15° N, which may be a factor for the small internal dispersion of the profiles.

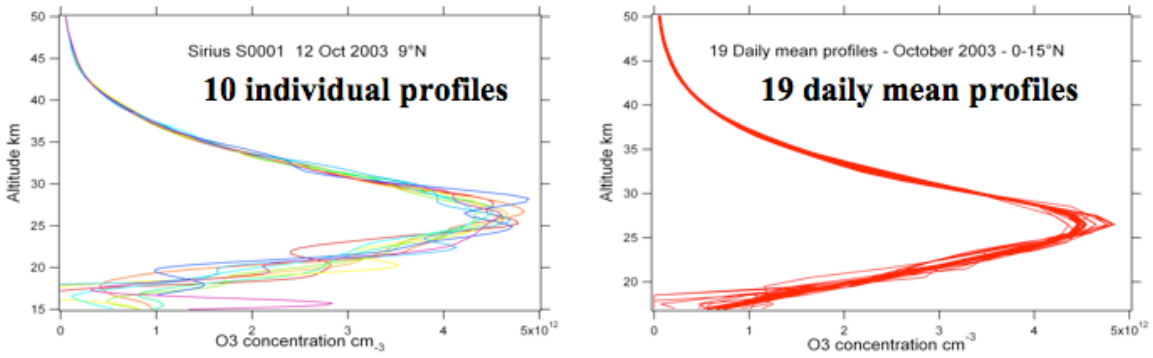

Fig.23b. Left: ozone vertical profiles obtained with the occultation of Sirius at 9°N and 10 different longitudes, obtained in a single day (9 October 2003). Right: 19 daily mean profiles obtained with Sirius during the month of October, 2003.

We propose to add the following paragraph , supported by Fig.23b:

"Another way to check the GOMOS internal consistency is to examine a series of profiles in a region where natural variability is in principle small. This is the case for low latitudes, as illustrated in Fig. 23b, showing (left) a series of 10 profiles obtained with the star Sirius, gathered within a day (therefore, at a constant latitude of 9° N, and sampling all longitudes). While above 30 km, all measurements are almost identical, below 30 km there are longitude variations of the detailed vertical structure; daily mean profiles may be constructed, and overplotted together as on Fig 23b showing 19 of such daily mean profiles. During this span

time, the point of star occultation varied from 0 to 15° N, which may be a factor for the small internal dispersion of the daily profiles."

P9980L14, 'Before GOMOS on ENVISAT, the best ozone climatology (based on measurements)
was produced by': the wording 'best' is not very informative: can you explain
why it is the 'best' or use some clearer statement here
We agree that the word "best" is not appropriate, and we propose to change to:
"…the most commonly used ozone climatology with vertical profiles…"

P9981L25: Can you give references for your claim that these are the two most important causes for the differences?

It is a common knowledge that it exists a hemispheric asymmetry in the stratospheric circulation and in the ozone distribution (see for instance Tie et al., 1999). The planetary wave activity is stronger in the North due to the contrast between oceans and continents, leading to a faster Brewer-Dobson circulation and enhanced transport of ozone from equatorial region to mid- and high-latitudes .
The second reason is the result of air masses motions, with more ozone depletion in the South, migrating from polar vortex toward lower latitudes in spring (Fioletov and Shepherd, 1995, and WMO report: Scientific Assessment of Ozone Depletion: 2006, published in 2007)

We propose to modify our paragraph as follows:
"We believe that the main reason is the greater activity of planetary waves in the northern hemisphere (due to the contrast between oceans and continents), leading to a faster Brewer-Dobson circulation and enhanced transport of ozone from equatorial region to mid- and High-latitudes (see for instance Tie et al., 1999). The second reason is the more severe man-made depletion in the Southern hemisphere (-5.5 %) than in the North (-3 %) , as a result of air masses migrating from polar vortex toward lower latitudes in spring (Fioletov and Shepherd, 2005; WMO, Scientific Assessment of Ozone Depletion, 2007); but this accounts for only 6 Dobson difference between North and South mid-latitudes, out of 28."

Tie, X., G. Brasseur, P. Hess, and M. Riese, Hemispheric asymmetry of chemical species and its effect on stratospheric ozone: emphasis on halogen loading, Adv. Space Res., 24, 1631-1636, 1999.
Fioletov, V.E., and T.G., Shepherd : Summertime total ozone variations over middle and polar latitudes, Geophys. Res. Lett., 32, L04807, doi : 10.1029/2004GL022080, 2005.

P9996L14 'According to this first GOMOS climatology of PMCs, they seem to be more frequent in the Northern Hemisphere than in the Southern Hemisphere.': could you justify a bit more this observation? Are the number of available stars for PMC detection similar in the north and south? How much more in the north?

The distribution in latitude of star occultations is quite different in the NH and in the SH during the PMC season. But the same effect (more PMC at NH than SH) has been observed by other methods.

We propose to re-phrase the sentence as follows:

"According to this first GOMOS climatology of PMCs, they seem to be more frequent in the Northern Hemisphere than in the Southern Hemisphere, confirming other observations. The number of stars for GOMOS available during the PMC season is about twice greater in the North than in the South in the latitude band 65°-75°. The frequency of PMC occurrence, normalized by the number of observations, is 50% in the South and 80% in the North at the peak season (Pérot et al. 2010, Figure 7)"

P9996L28, 'The scattering efficiency as a function of wavelength will allow to determine the characteristics (at least the size distribution) of these icy particles.': can you specify which/how many independent parameters of the size distribution should be able to be retrieved.

We propose to change the text to:

' The scattering efficiency as a function of wavelength will allow to determine the characteristics (at least the mean radius, and possibly the standard deviation of the size distribution width, assuming for instance a Gaussian distribution) of these icy particles.':

Technical:

Abstract: OCLO should read OClO, like in the text: done
P9920L3, '8.2 tons': not necessary for the description of GOMOS. We think that the general reader may be interested by this information on ENVISAT, and particularly the European tax payer.
P9920L11, 'necessary: to answer the following questions': : : : beside others done
P9920L26, 'Local Time, and period 100 mn.': This is not a sentence.
It is a sentence: Local time refers to 10:00 am, while the period is in the suite of the characteristics of the orbit.
We propose to re-write the sentence in this way:

"ENVISAT was launched from French Guiana (Kourou) on 28 February 2002, and placed on a circular orbit at 800 km altitude, with a period of 100 mn. The orbit is almost polar (98.55° inclination) and helio-synchronous with a descending node (equator crossing) at 10:00 a.m. Local Time."

P9921L2, 'ozone, NO2, NO3, H2O, air, aerosols, O2, temperature and turbulence parameters':
could you be more specific here, i.e. air-density, aerosol-extinction ... done
P9924L13, '0.5.' : delete 2nd dot. done
P9925L16, 'emission-looking instruments (like MIPAS and SCIAMACHY, for example).':
SCIAMACHY does not look at the atmospheric emission but detects the scattered radiation.

Agreed. The sentence has been changed to:
'limb-looking or nadir-looking instruments (like MIPAS and SCIAMACHY, for example).':

P9926L19 'for NO2 and NO3': this appears two times in the sentence, skip one. Done
P9927L14: delete dot before '(' Done
P9930L20, 'In Sect. 7 is presented a short overview of': change to 'In Sect. 7 a short overview of : : : is presented' Done

P9932L7 ‘For instance, the influence of Quasi Biennal Oscillation (QBO) on ozone depends on altitude.’: This is not a sentence.
We propose to rewrite the sentence as:

"For instance, the influence of Quasi Biennal Oscillation (QBO) on ozone was shown to depend on altitude: Hauchecorne et al. (2010) found three different regions with different influences."

P9932L24: check the sentence. Done.
The new sentence reads:
"ESA is delivering GOMOS ozone data within 3 h of collection through the Ground Segment system."
P9934L7, ‘discrepancy’: -> discrepancies done
P9934L10, ‘It is clear’: : : :.make this sentence easier readable.

We propose to rephrase in this way:
" …help to improve the modeling. At the time of the GOMOS proposal (1988) we thought that, if we would not be able to reproduce mesospheric ozone through modeling of the mesosphere where the ozone balance is relatively simple, it would cast serious doubts about the modeling of ozone in lower regions of the atmosphere, where the same reactions (among others) do occur also when oxygen and hydrogen radicals are present. One powerful diagnostic to validate models is the time variations of mesospheric ozone, and in particular the day-to-night variation, and variations connected to solar activity. It turns out that there are still discrepancies between model and observations (section 7.2), and the mesospheric ozone balance is certainly not as simple as once believed, probably for atmospheric dynamic factors rather than chemical factors.

P9940L14, ‘we do not felt’: -> we do not feel Done
P9941L25, ’It is a thin layer (~2 km) of small ice particles (r <0.1 μm) at 83–85 km’:
really only there or more extended but not visible?

There are now evidence from radar measurements that ice particles extend from 80 to 90 km; however, they are too small at highest altitudes to scatter visible light. Evidence of smaller particles at higher altitudes comes from radar measurements, as reviewed by Rapp and Lübken, found at:

http://www.atmos-chem-phys.net/4/2601/2004/acp-4-2601-2004.html

We propose to modify the text as follows:

" The polar summer mesosphere is characterized by extremely low temperatures (below 150 K, the coldest region of the entire planet), due to a strong upward motion and subsequent adiabatic cooling of air. In the altitude range between ~80 and 90 km, water vapor abundance becomes higher than the local saturation vapor pressure, and icy particles condensate around condensation nuclei, which could be either meteoritic dust particles or large water cluster ions. Very small ice particles are electrically charged and lead to measurable signatures in the form of strong radar echoes, called Polar Mesosphere Summer Echoes (PMSE). Under favorable conditions, these small icy particles grow and sediment. They sublimate when they reach warmer layers

below the cloud. Therefore, smaller particles are found at the top and larger particle in the bottom part. The largest of them can be observed by optical techniques, and are then called Polar Mesospheric Clouds (PMC) when observed from space, or Noctilucent Clouds (NLC) when observed from the ground at twilight. This part of the mesospheric ice layer is a thin layer (~2 km) of small ice particles (r<0.1 μm) at 83-85 km of altitude, which vertical optical thickness is $\tau_v = 10^{-4}$, and tangential optical thickness around $\tau_h = 10^{-2}$.

These ice particles produce scattered sunlight which are detected by the GOMOS spectrometers and photometers (Fig. 45). "

P9942L4, 'In emission': you mean when looking at scattered sunlight; i.e. not a direct emission of the PMCs.

Agreed: We propose to change the sentence :
"They produce scattered sunlight which are detected…"

P9942L20, 'possibly in relation with less leakage from russian gas pipelines': this is only one possible explanation beside many others; better to skip it or give evidence.
We will skip the sentence.

P9943L3 'limb emission': this term is usually used in the mid-IR for real emission of the atmosphere; please change to limb scattering; done

P9955L16, 'It should be noted the high degree of resemblance between the data and the model,': this is not the case for the water absorption, but only mentioned in the Figure caption of Fig. 16. It should be stated in the text.
We propose to rephrase as follows:

It should be noted the high degree of resemblance between the data and the model for O_2, demonstrating the high spectral quality of the data, considering the weakness of the stellar source. For H_2O, all absorption features predicted by the model are present in the observed spectra. However there are also other features in the measured spectra that do not come from H_2O absorption, but rather from an imperfect correction of the severe Pixel-to-pixel-non-Uniformity affecting the CCD of spectrometer B2 in the range 940 nm.

P9961L21, 'In addition is needed an atmospheric vertical profile, in order to account for atmospheric refraction': an atmospheric profile of air density is needed. Done
P9963L18, 'Data form the SATU (Star Acquisition Tracking Unit).': This is not a sentence.
Sorry, a piece of sentence is missing;
The correct wording is:
'Data from the SATU (Star Acquisition Tracking Unit) are used to correct the wavelength of each pixel by a small amount, since the image of the star is much smaller than the width of the entrance slit of the spectrometer.'

P9967L8: ozone 'and' other gases done

P9968L11, 'the corrected star signal Sobs is corrected as': 2xcorrected?
The sentence should read:
Once the star signal is corrected as described above to obtain S_{obs},….

P9970L14, 'the line density data are noisier than the line densities': should read 'the local density data: : :' yes !

P9974L9, MSISE: -> MSIS:

No. The full name of the model is actually MSISE-90. E stands for Extended in altitude (Hedin, 1991).

Hedin, A. E.: Extension of the MSIS thermosphere model into the middle and lower atmosphere, Journal of Geophysical Research, 96, 1159-1162, 1991.

P9974L9, 'After all, ECMWF are based on actual measurements made all over the planet, updated every 6 h.': What should this sentence mean?

We meant that ECMWF is not a only model prediction but is assimilates also actual data, therefore providing a good representation of reality.
We propose the following re-phrasing:

" It could be emphasized that ECMWF outputs are based on actual measurements made all over the planet, updated every 6 h through data assimilation, therefore providing a good representation of reality."

P9981L29: reference missing: Three references have been added, see our modified text for page 9981.

P9989L8: This paragraph is a very general statement which should be moved to the conclusions and be extended by definite examples/plans.

Unfortunately we have no definite plan on this subject at the time being. We hope that other scientists will pursue this suggested line of thinking.

P9992L20, 'In Fig. 40 are represented the line densities for 6 occultation : : :': In Fig. 40 the line densities for 6 occultations : : :. are presented done

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