GOMOS LIMB SCATTERING OZONE PROFILE RETRIEVAL

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ABSTRACT

We analyzed a set of GOMOS bright limb measurements with solar zenith angles less than 80^o, and within 150 km of SAGE II measurements. In order to perform any species retrieval, GOMOS measurements were first corrected for stray light contamination. Ozone profile retrievals were performed using GOMOS data in the OMPS limb profiler algorithm in order to evaluate code functionality under different atmospheric conditions, assess the accuracy of the pointing algorithm, and identify potential improvements. The OMPS algorithm performs a simultaneous optimal estimation inversion of both Hartley-Huggins and Chappuis band radiances. GOMOS ozone retrievals are restricted to 25-53 km because of signal saturation and residual stray light. The retrieved ozone profiles agree with collocated SAGE II measurements on average to within 10%, and with a standard deviation of 10%. Retrieval results were consistent for both upper and lower GOMOS detector bands.

1. INTRODUCTION

The Global Ozone Monitoring by Occultation of Stars (GOMOS) onboard ENVISAT performs stellar occultation at wavelengths from the near UV through the visible region and produces profile of ozone, NO_2, NO_3, OCLO, and aerosol as standard products [1] In order to distinguish stellar light from the sky background, the detector is split into central (star), upper and lower bands (limb). If properly calibrated, backscattered radiances measured by GOMOS could be used to retrieve various gaseous species as well as aerosol extinction. The information content is similar to that obtained by other limb scatter sensors, such as the Scanning Imaging Absorption Spectrometer for Atmospheric Cartography (SCIAMACHY/ENVISAT) [2], and Optical Spectrograph and InfraRed Imager System (OSIRIS/ODIN) [3], with one important difference; each GOMOS image contains a stellar signal. Sensor pointing, and hence the vertical profile registration of atmospheric species, should be superior to other limb sensors.

The main objective of this ongoing work is to assess the retrieval algorithm of the Ozone Mapping and Profiler Suite (OMPS) Limb Profiler (LP), on board the National Polar Orbiting Operational Environment Satellite System (NPOESS) and the NPOESS Preparatory Project (NPP) satellite to be launched in 2013 and 2009 respectively. A second objective is to investigate the ability of GOMOS limb measurement to retrieve ozone profiles. The instrument measures the stellar occultation in 3 different conditions: dark, twilight and bright limb. Bright limb species retrieval, where the solar zenith angle (SZA) is less than 80^o, is very difficult mainly because of the strong solar light interference, and often produce a poor quality ozone profile [4]. On the other hand, background limb measurements for the same bright conditions, are ideal for ozone retrieval, and therefore, can supplement the original GOMOS planned global coverage.

In this paper, a set of 98 GOMOS events during 2003, in which there were two background measurements each, upper and lower bands, were selected. Measurements were within 150km, on the same day as SAGE II measurements. In order to perform ozone retrieval, GOMOS radiances had to be analyzed and corrected for stray light contamination. Results of the inverted ozone profiles are presented and compared to SAGE II ozone measurements.

2. MEASUREMENTS QUALITY

GOMOS L1b geolocated limb spectra are calibrated and corrected for offset as described in [5]. Figure 1 is a sample GOMOS calibrated limb radiances profile at selected wavelengths that are relevant to ozone retrieval. The radiances are coloured for different wavelengths, from black (280 nm) to red (755 nm). Radiances at each wavelength are for upper (dotted) and lower (continuous) bands. Notice the good agreement between the two profiles. Close investigation of the sample radiances reveal several features that persist in all data sets used in this work. Limb measurements never extend below 20km, often ending at ~22km. Measurements at ~280 nm are very noisy. Also radiances suffer from saturation at lower altitudes, usually below 25km, mostly for wavelength 400-500 nm. The most

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challenging problem is stray light contamination. Stray light usually originate from photons within the passband but outside the optical path. The contamination appears to be well behaved and minimal at shorter wavelength, but increases as both wavelength and altitude increase. Therefore, it was assumed that stray light is mostly in-band.

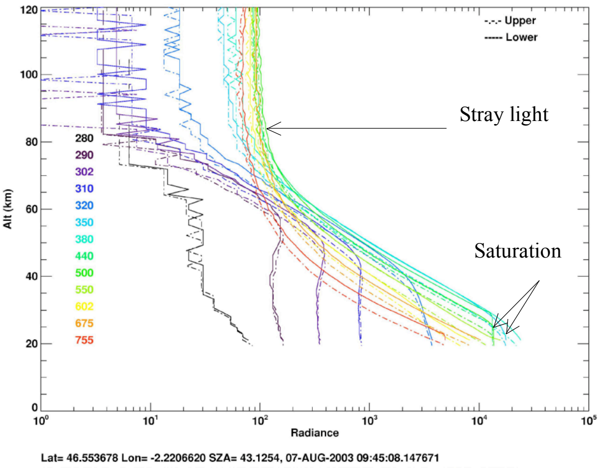

Figure 1: Sample of GOMOS calibrated radiances at wavelength 280 to 755nm.

3. STRAY LIGHT ANALYSIS AND REMOVAL

The first and most significant step required in order to perform species retrieval using GOMOS limb measurements is to model and remove the stray light signal. Rault, [6] successfully estimated and corrected stray light contamination that was affecting SAGE limb measurements and subsequently retrieved a good quality ozone profile.

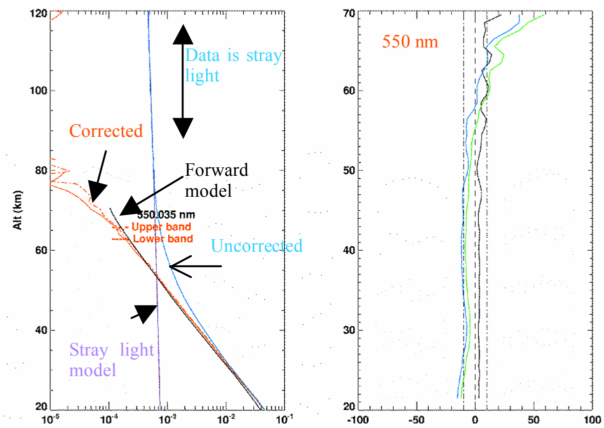

Figure 2: Example of radiance level of contamination by stray light and effectiveness of modeled corrections.

A radiative transfer model [7] is used to calculate simulated limb radiances, with inputs from nearby SAGE II [8] ozone, aerosol, and NO_2 profiles, as well as NCEP temperature and pressure that accompany the SAGE files, so as to accurately model limb scattering radiances at the GOMOS measurement location, and characterize stray light signals. Radiance profiles were constructed at selected pixels relevant to the retrieval algorithm and compared to GOMOS measurements. Figure 2 is an example of a comparison that illustrates the extent of the stray light contamination at wavelength 550 nm. The left panel is a plot of uncorrected (blue) and modeled (black) radiance. Notice that the model output is only up to 70 km, while the measurement extends to 120 km. The disagreement is gradually increasing at altitudes above 30 km. To model the stray light signal, first we have to assume that measurements between 80 and 120 km are all stray light and are greater than noise. A simple linear fit is used to model that signal, then it was extended to lower altitudes (violet), figure 2. The Modeled signal is subtracted from the upper (red-continuous) and lower (red-dotted) measurement. The right panel is the percent difference between the corrected upper and lower bands (black). The difference is mainly less than 5% below 50 km but slightly increases to ~10% up to 70 km. This is mainly a consistency test to verify that corrections are consistent for both bands. Also shown is the difference between the calculated radiance and upper (blue) and lower (green) bands. Both show a similar and constant difference of ~10% at an altitude range of 20-60km. This verifies that the model is accurately accounting for the entire stray light signal in both bands, up to 60 km.

Similar results were obtained for other wavelengths. Herein, we use the same procedure to estimate and correct for the stray light signal at each wavelength independently. Notice that only measured radiances are used to model the stray light signal and subsequent corrections. The calculated radiances generated by the forward model and described above are only used to validate these corrections.

4. RETRIEVAL ALGORITHM

The OMPS algorithm performs a simultaneous optimal estimation inversion of both Hartley-Huggins and Chappuis band radiances, as outlined by Flittner et al. [9] describing the ozone retrieval algorithm used for the Shuttle Ozone Limb Scattering Experiment/Limb Ozone Retrieval experiment (SOLSE/LORE) and further applied to OSIRIS data by von Savigny et al. [10]. In order to minimize the effect of aerosol scattering, the retrieval uses the ratio of two spectral channels in the UV range, a strong and a weak O_3 absorption, and a triplet for the visible wavelength, one strong divided by the average of two weaker ozone absorbing channels. It also uses radiance normalization at a reference altitude, typically in the range 60-45 km depending on sensitivity to O_3 absorption and radiances quality, mainly to eliminate the need to account for the unattenuated solar radiation, usually used for self-calibration in limb occultation. It also reduces the effect of surface reflectance and clouds [9].

In the UV range, pixels at wavelengths 299, 302, 310, and 320 nm were paired with either 347 or 353, and normalized at ~53 km. Radiances only used for altitude range from 38-55 km. For the visible, pixels at wavelength 575, 602, and 616 nm were paired with 514 nm and 675 nm, normalized at ~45km, for an altitude range from 22-38 km. The code in its current version is flexible enough to change the wavelength selection and normalization altitude. Ideally, the code should utilize the signal to noise ratio for each channel to select the best wavelength pairing and normalization altitude in order to optimize the retrieval result. Unfortunately, the reported error budget of GOMOS limb measurements doesn't accurately reflect on the quality of the measurements. Furthermore, there are no saturation flags, nor did we attempt to incorporate information about the accuracy of stray light correction. Both saturation and stray light are the main sources of error for GOMOS limb measurements and their extent vary with altitude, wavelength, as well as for each measurement.

Optimal estimation retrieval requires the use of an *apriori* ozone profile [11]. In this work, we use the same single ozone profile as *apriori* for all retrievals, to ensure minimum influence on the solution.

5. RESULTS

A subset of GOMOS measurements were selected during year 2003, in which there are two background measurements each, upper and lower bands and SZA less than 80°. The data set is evenly distributed around the globe and with time in order to study the effect of seasonal/geographical variations on the ozone retrieval. Furthermore, measurements were selected to coincide with SAGE II, within 150km and same day measurements. SAGE II has been the benchmark for satellite ozone profile measurements in the stratosphere, and widely known for its highly accurate and precise measurements [12, 13]. Figure 3 is the measurements' location map. The lower panel is a scatter plot of the measurements latitude vs. time.

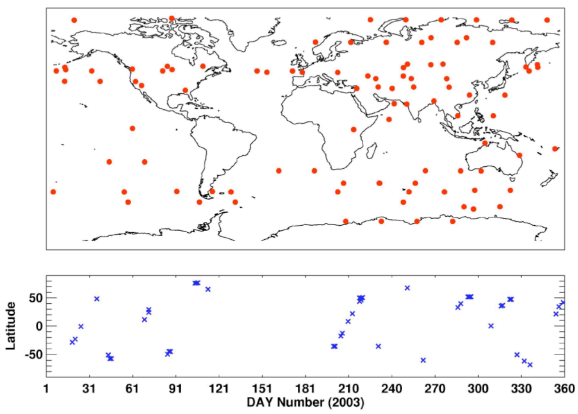

Figure 3 Location of GOMOS measurements subset, (upper panel) and latitude vs. time (lower panel).

Figure 4 shows typical ozone profile retrieval for a single event, on August 7, 2003. The left panel is the retrieved ozone profile for upper (red) and lower (green) bands. Black is the SAGE II ozone profile, while blue is the *apriori* profile. The right panel is the percent difference between the retrieved ozone profiles for upper / lower bands and SAGE II. The dotted line is the same but for the *apriori*. The figure shows a consistent retrieval for both upper and lower bands. Although upper and lower measurements are made separately, they are expected to agree with each other since they are very close in location. The difference between retrieved ozone and SAGE II is within 5-10% in the altitude range of 25-50 km. below 25 km, the retrieval is unrealistic, caused by signal saturation. The percent difference at altitude range 34–43 km is relatively greater, but within 10%. The altitude range where the transition of both UV and Visible channels retrieval occurs, and therefore, the accuracy of both start decreasing. Above 50 km, the retrieval is also unrealistic, mainly because of decreased signal sensitivity and the increase of stray light contamination. Notice that there is a better agreement between the retrieval and SAGE II than that with *apriori*.

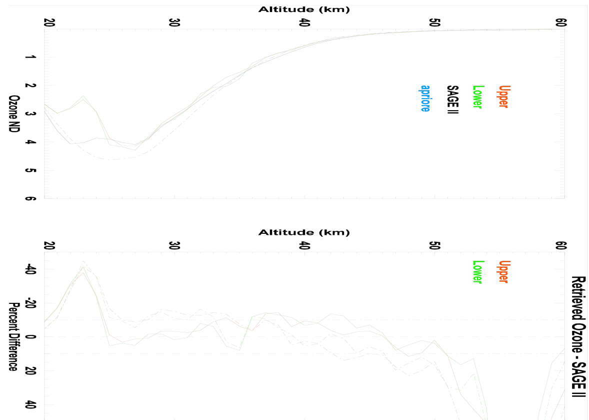

Figure 4: Left panel is the retrieved ozone profile for upper (red) and lower (green) bands for August 7, 2003. Black is SAGE II ozone profile, while blue is the apriori profile. The right panel is the percent difference between the retrieved ozone profiles for upper / lower bands and SAGE II. The dotted line is the same but with the apriori.

Figure 5 is a summary plot of all the comparison for retrieved GOMOS ozone profile number density. The figure is the same as figure 4, but for the average of all comparisons (98 events). The dotted line in the right panel is the standard deviation. Numbers on the right side are the number of each valid measurement included in the average calculations. The dots in the background of the right panel are the entire measurement points of all profiles. The average difference and standard deviation is calculated using only measurements within 30% of SAGE II. This filter was necessary to exclude corrupted and unrealistic outliers, since the algorithm in its current version doesn't flag for those erroneous measurement points. Most of the excluded measurements are below 27 km and their number increase by decreasing altitude. They are mostly contaminated by saturation. Few points were also removed around 38km, the level where the transition between UV and visible channels take place.

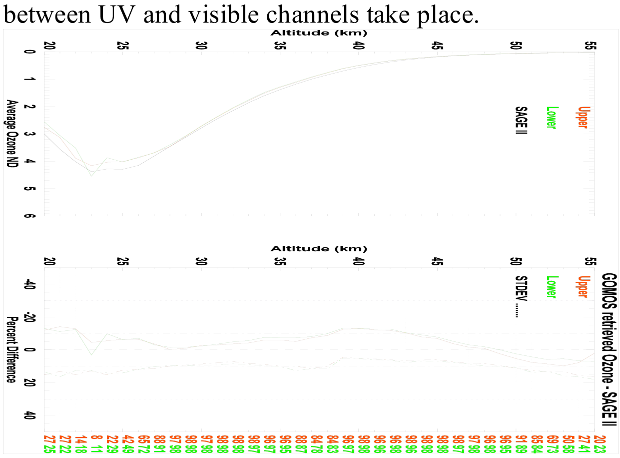

Figure 5: Same as figure 4, but for the average of all comparison. The dotted line is the standard deviation. Numbers on the right side are the number of each valid measurement included in the average.

In general, the mean percent difference is within 10% over the altitude range 24-53km, with the difference ~12% around 39-40km. Agreement is better below 35 km, where the strongly absorbing Chappuis band radiances are used. The standard deviation is almost unchanged for all altitudes, ~7-10%. Both upper and lower band retrieved ozone profile show very similar behavior.

6. SUMMARY AND CONCLUSION

GOMOS limb scattering measurements were analysed and compared to radiances calculated using a forward model, with inputs from a nearby SAGE II measurement. Results show that GOMOS limb measurements suffer from signal saturation and stray light contamination. A model to estimate the stray light signal was applied and shown to be effective up to ~60 km tangent altitude. The corrected radiances were used to retrieve ozone profiles, which were compared to SAGE II. Ozone retrievals were restricted to ~25-53 km because of signal saturation and residual stray light. The retrieved ozone profiles agree with collocated SAGE II measurements on average to within 10% and a standard deviation of ~10%, and were consistent for both upper and lower bands. In general, the GOMOS upper and lower band measurements, if properly correct for stray light signal, contain very useful information of the ozone number density profile, and can supplement the stellar occultation routine production to provide near global coverage.

It is recommended that an accurate error estimate of the GOMOS radiances that also accounts for saturation and stray light contamination would be very useful in controlling which channel, normalization level, and altitude range is picked to perform the retrieval.

7. ACKNOWLEDGMENT

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