VALIDATION OF GOME-2 OZONE PROFILES USING BALLOON SOUNDING DATA

Andy Delcloo and Olaf Tuinder

Royal Meteorological Institute of Belgium, Ringlaan 3, B-1180 Ukkel, Belgium
Royal Netherlands Meteorological Institute, De Bilt, The Netherlands

Abstract

A validation of the GOME-2 vertical ozone profiles has been carried out. This has been done by using balloon ozone-sounding data, which have a vertical resolution of about 100 m and is measuring ozone from the surface up to about 30 km.
GOME-2 vertical ozone profiles are given as partial ozone columns [in DU per layer] between varying pressure levels (40 levels between surface and 0.1 hPa). To validate the satellite derived ozone layers with the balloon ozone sounding data, we integrate the ozone measured by the balloon ozone soundings between the corresponding GOME-2 pressure levels.
GOME-2 ozone data was made available by KNMI at pre-selected sites. The reference data includes in a first validation phase the European mid-latitudes and the European Nordic region.
The results show that the mean relative difference between GOME-2 and mid-latitude ozone sondes is within ±10 % in the troposphere and the stratosphere. The high latitude stations give poorer results: the mean relative difference between GOME-2 and ozone sondes is within ±15 % in the troposphere and the stratosphere. The bias is larger in the UTLS region, especially at high latitudes. The standard deviation on the mean difference is of the order of 30% in the troposphere and 10 to 15% in the stratosphere at mid-latitudes. In the UTLS region, the standard deviation on the mean is considerably larger.
We take into account the GOME-2 averaging kernels in our analysis in order to smooth the ozone sounding data towards the resolution of the satellite data.
Data from the SHADOZ network, the Antarctic region and some other stations is also included in the analysis in order to have a more global view on the performance of GOME-2 on the retrieval of ozone profiles.

INTRODUCTION

EUMETSAT's Satellite Application Facility on Ozone and Atmospheric Chemistry Monitoring (O3M SAF) is producing near real-time and offline products based on Metop satellite data from measurements of the Global Ozone Monitoring Experiment-2 (GOME-2) instrument. GOME-2, launched in October 2006, is a nadir scanning UV/VIS spectrometer designed for ozone and trace gas retrieval.
Ozone profiles are retrieved from GOME-2 spectra by KNMI using optimal estimation. This involves the use of an a-priori ozone profile and error covariances to complement the profile information in the measured spectra. The GOME-2 ozone profile product is currently pre-operational and is available in NRT (3 hours from sensing) via the SAF-Europe channel of EUMETCast. The archived offline products can be ordered via UMARF.
This study shows validation results for GOME-2 ozone profiles, reprocessed with **algorithm version PPF 4.0**, for the O3M SAF using ozone-sounding data for the time period January 2007 – August 2009.

Ozone sondes are lightweight balloon-borne instruments capable of making ozone measurements from the surface up to about 30 km, with much better vertical resolution than satellite data. In general also the precision and accuracy will be better, at least in the lower stratosphere and the troposphere. Another advantage is that ozone soundings can be performed at any time and at any meteorological condition.

The precision of ozone sondes varies with altitudes and depends on the type of sonde used. Table 1 below shows indicative precision (in percent) of the Electrochemical Concentration Cell (ECC) and the Brewer-Mast (B-M) ozone sondes, at different pressure levels of the sounding (taken from the O3MSAF Science Plan).

Pressure level (hPa)	ECC	B-M
10	2	10
40	2	4
100	4	6
400	6	16
900	7	14

Table 1: Precision of different types of ozonesondes at different pressure levels in %.

We see that the profiles from ozonesondes are most reliable around the 40 hPa level, which is around the ozone maximum. The error bar of profiles from ozonesondes increases rapidly at levels above the 10 hPa level, which is around 31 km altitude. For this validation paper, only the station of Hohenpeissenberg is using B-M sondes, all the other 21 stations under consideration (Figure 1) use ECC sondes, while for the stations of Tateno-Tsukuba, Sapporo and Naha, KC-79 sondes have been used.

DATASET DESCRIPTION

GOME-2 ozone data used in this validation paper is from the beginning of January 2007 up to the end of August 2009. GOME-2 ozone data was made available by KNMI at pre-selected sites. These sites correspond to sites where ozone soundings are performed on a regular basis. In order to have a more global view on the performance of the ozone profile product, we used about 25 stations, introducing the SHADOZ-network (Thompson *et al., 2003a,* Thompson *et al., 2003b,* http://croc.gsfc.nasa.gov/shadoz/) for the Tropical stations. For the other stations, data was made available by the World Ozone and Ultraviolet Data Center (WOUDC). (http://www.woudc.org) and the NILU's Atmospheric Database for Interactive Retrieval (NADIR) at Norsk Institutt for Luftforskning (NILU) (http://www.nilu.no/nadir/).

Latitude belts from North to South:

1. **Polar stations North:** green (67N – 90 N)
2. **Mid-Latitude stations North:** black (30 N – 67 N)
3. **Tropical stations:** Red (30 N – 30 S)
4. **Mid-Latitude stations South:** grey (30 S – 70 S)
5. **Polar stations South:** orange (70 S – 90 S)

Latitude band	Nr of coincidences 2007-2008	% of converged profiles	Nr of coincidences 01/2009 – 08/2009	% of converged profiles
Polar North (90-67)	18437	71.7	2529	74.5
Mid-Latitudes North (30-67)	15068	92.2	4247	90.3
Tropics (+30 – 30)	4317	99.7	-	-
Mid-Latitudes South (–30 –70)	2593	97.5	-	-
Polar South (–70 –90)	2124	64.7	284	88.4

Table 2: Overview of number of coincidences and soundings at different station locations for the two different time periods under consideration

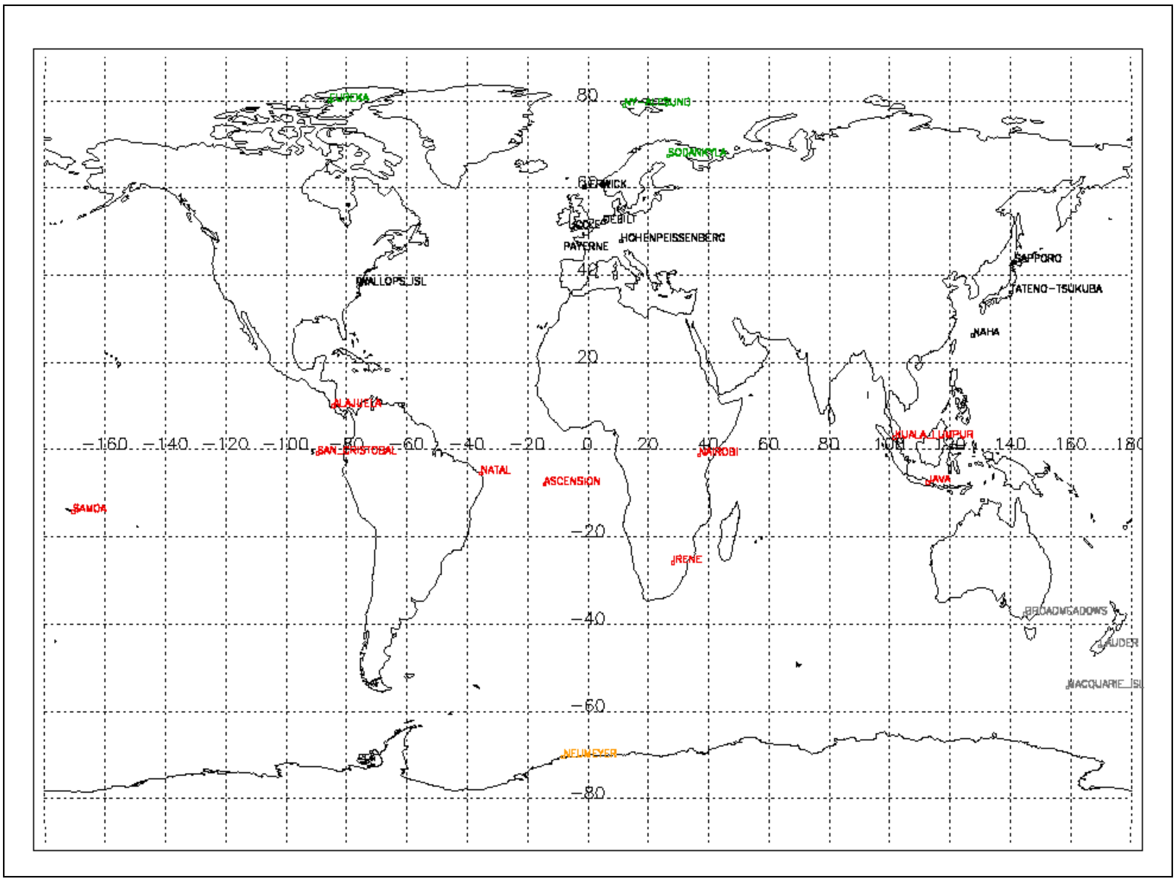


Figure 1: Overview of different station locations used in the analysis.

METHODOLOGY

Co-location criteria

The selection criteria, taken into account are two folded:
The geographic distance between the GOME-2 pixel center and the sounding station location is taken into account and the criterion is fixed at a distance of 300 KM.
The time difference between the pixel sensing time and the sounding launch time is the second criterion and is fixed at about ten hours of time difference. Each sounding that is correlated with a GOME-2 over-pass is generally correlated with several GOME-2 pixels if the orbit falls within the 300 km circle around

the sounding station. This means that a single ozone profile is compared to more than one GOME-2 measurement.

Ozone sounding pre-processing

GOME-2 ozone profiles are given as partial ozone columns on varying pressure levels (40 levels between surface and 0.1 hPa). Ozone partial columns are expressed in Dobson Units.
Ozonesondes measure the ozone concentration along the ascent with a much higher vertical resolution (100 m) than GOME-2, until 30 km.
The integration requires interpolation, as GOME-2 levels never match exactly ozonesonde layers. This interpolation causes negligible errors given the high vertical resolution of ozonesonde profiles.

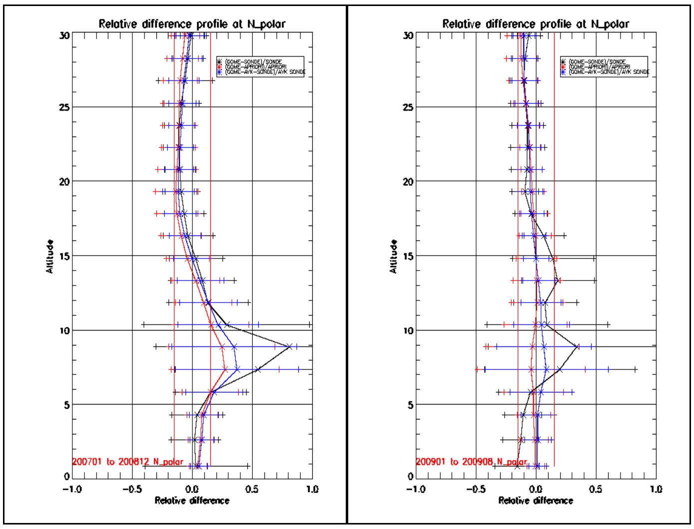
The validation of the GOME-2 profiles is calculated by using the averaging kernels (AVK) of the GOME-2 profile. The motivation to apply the AVK is to “smooth” the ozone soundings towards the resolution of the satellite, to look at the GOME-2 profiles with “the eyes” from the satellite. Equation (1) shows how the kernels have been applied.

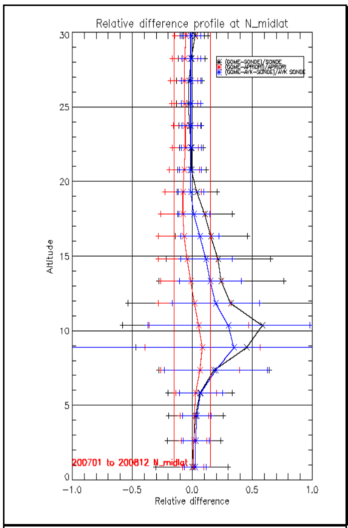
$$X_{avk\_sonde} = X_{apriori} + A\,(X_{raw\ sonde} - X_{apriori}) + \epsilon \qquad (1)$$

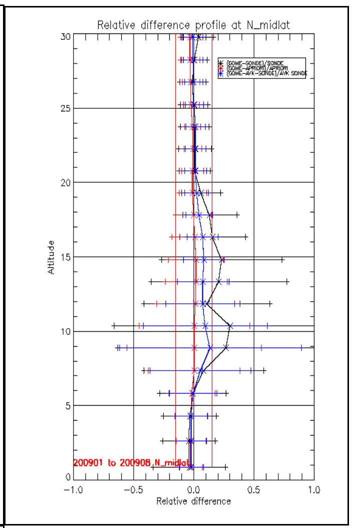
Where A represents the averaging kernel, X_{avk_sonde} is the retrieved ozonesonde profile, X_{sonde} is the ozonesonde profile and $X_{apriori}$ is the apriori profile.

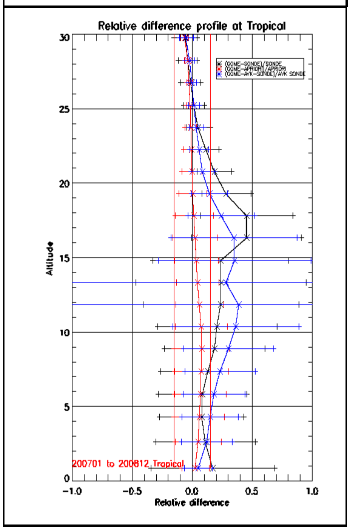
VALIDATION RESULTS

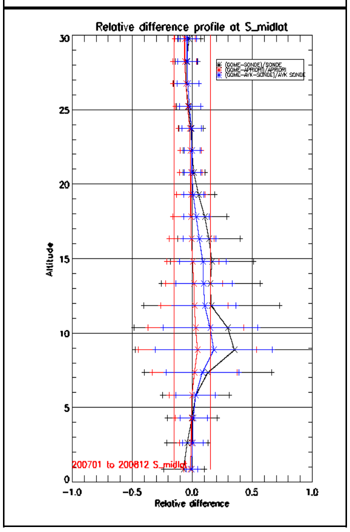
Figures 3 shows relative difference profiles between GOME-2 ozone profiles at the one hand and on the other hand ozonesonde-, apriori- and AVK ozonesonde profiles for the latitude belts, listed in Table 2 for respectively the time periods 2007-2008 and January 2009 – August 2009. The error bars represent one standard deviation on the mean error. It should be notified that for the second time period for the Southern Mid-Latitude stations and the tropical stations not enough ground truth data was available to include them already in this paper.




Relative difference profile at N_midlat
(GOME-SONDE)/SONDE
(GOME-APRIORI)/APRIORI
(GOME-AVK-SONDE)/AVK SONDE
Altitude
Relative difference
200701 to 200812 N_midlat


Relative difference profile at N_midlat
(GOME-SONDE)/SONDE
(GOME-APRIORI)/APRIORI
(GOME-AVK-SONDE)/AVK SONDE
Altitude
Relative difference
200901 to 200908 N_midlat


Relative difference profile at Tropical
(GOME-SONDE)/SONDE
(GOME-APRIORI)/APRIORI
(GOME-AVK-SONDE)/AVK SONDE
Altitude
Relative difference
200701 to 200812 Tropical


Relative difference profile at S_midlat
(GOME-SONDE)/SONDE
(GOME-APRIORI)/APRIORI
(GOME-AVK-SONDE)/AVK SONDE
Altitude
Relative difference
200701 to 200812 S_midlat

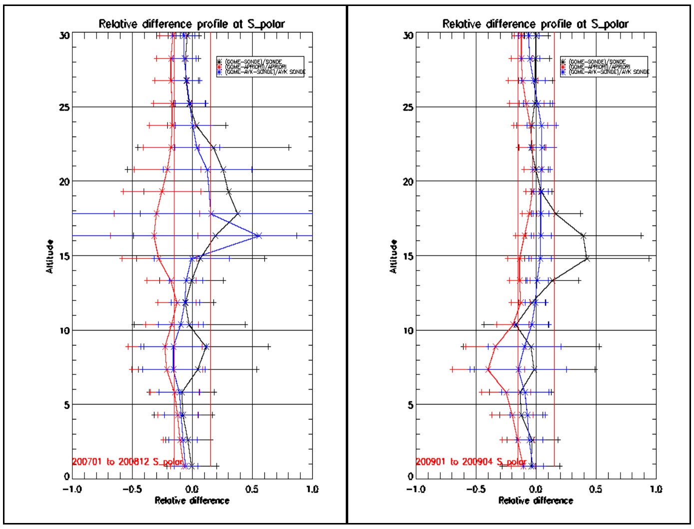


Figure 3:Relative difference profiles) between GOME-2 profiles and ozonesondes (black), apriori profile (red) and smoothed ozonesondes (blue), according to equations 2,3 and 4 for different latitude belts for the time period 2007-2008 (left) and the time period 01/2009 – 08/2009 (right)

For the Northern polar stations, the difference plots show an underestimation until –15 % in the stratosphere and an overestimation until +80 % in the upper troposphere, lower stratosphere zone, further referred as the UTLS-zone in this paper. For the lower troposphere, the relative difference is within 15 %. Applying the averaging kernels improves the comparison significantly (+30 % in the UTLS-zone). For the current year, the relative differences at the Northern polar stations improved. Relative differences are within the target values when validated against the $X_{AVK\text{-}sonde}$. An overestimation of about +30 % is present in the UTLS-zone and the lower stratosphere shows an overestimation until 15 % compared to ozonesondes.

For the Northern Mid-Latitude stations, GOME-2 performs excellent for altitudes between 20 km and 30 km. There is an overestimation present in the UTLS-zone until +60 % for the first time period and +30 % for the second time period when validated against the ozonesondes. With the $X_{AVK\text{-}sonde}$, the overestimation is considerably lower and shows only in the UTLS-zone an overestimation up to +30 % for the first time period and within target values (+15 %) for the second time period.

For the Tropical stations, the SHADOZ-network has been taken into consideration to validate the GOME-2 retrieved ozone profiles. In the troposphere, it is observed that the collocated GOME-2 ozone profiles are overestimating the X_{sonde} profiles. The relative differences are within 30 % for heights between 0 km and 15 km. The UTLS-zone is overestimated by +45 %. Higher than 20 km the relative differences are close to zero (3.4 %) with an averaged standard deviation of about 7 %.

For the Southern Mid-Latitudes, GOME-2 performs well. Relative differences are within the 15 % for stratosphere and troposphere. The UTLS-zone shows an overestimation until +40 % in the UTLS-zone. With the $X_{AVK\text{-}sonde}$ the relative difference is reduced to +15 %.

The most temptative results are obtained at the station of Neumayer in the Southern polar belt. The relative difference is within 15 % for the troposphere for both time periods. There is an overestimation present for altitudes between 15 and 23 km and around the UTLS zone (up to +15 %). For the second time period this overestimation in the stratosphere is also present between 13 km and 18 km height. The individual comparisons show that GOME-2 is able to retrieve these particular ozone profiles, but still overestimates the amount of ozone. Figure 4 is an example of an ozone profile retrieval at Neumayer station on the 3rd of December 2008. It is also shown that the apriori profile for the South Pole is higher than the retrieved and measured ozone profile.

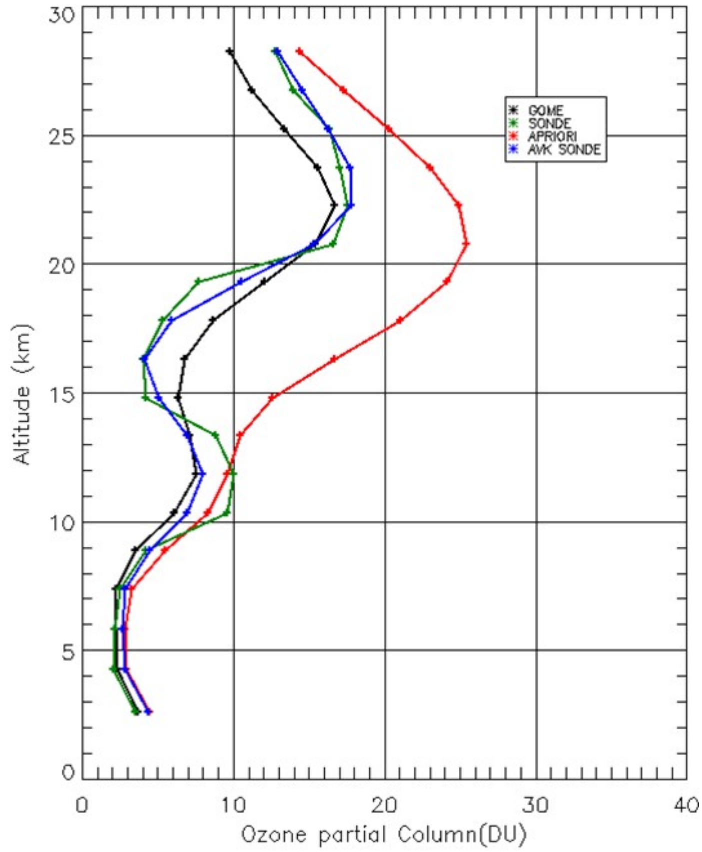


Figure 4: Ozone profile retrieval at Neymayer station during low ozone event (20081203)

CONCLUSIONS

This study contains global validation results of about three year of GOME-2 retrieved ozone profile data.

The *threshold* accuracies for the GOME-2 ozone profiles are 30% for the stratosphere and 70% for the troposphere. These targets are met for all the stations used in the analysis, except for Neumayer.

The *target* accuracies for the ozone profiles are respectively 30% in the troposphere and 15% in the stratosphere. This accuracy is reached at least partially in the stratosphere.

GOME-2 ozone profiles give sensibly better results at Mid-Latitude stations than at the other latitude belts. The mean relative difference between GOME-2 and $X_{AVK\text{-}sonde}$ is in general within ± 15 % in the troposphere (for heights below 7 km) and the stratosphere (for heights between 15 and 30 km when compared against the $X_{AVK\text{-}sonde}$). For the Mid-Latitude belts there is an overestimation of about +15 % for the complete time period for heights between 10 km and 15 km. For heights between 20 km and 30 km the relative difference is stable with a standard deviation of about 10 %.

For the Northern polar stations GOME-2 underestimates until –15 % in the stratosphere and overestimates until +40 % in the UTLS-zone. For the lower troposphere, the relative difference is within 10 %. The relative difference between GOME-2 and the smoothed ozone profiles shows a better comparison in the UTLS-zone with an overestimation of about 30 %. After correction for polarisation, it is shown that the retrieved profiles have significantly improved.

The standard deviation on the mean difference is of the order of 14 % in the troposphere and 10 to 15 % in the higher stratosphere (20 km – 30 km). For the UTLS-zone the standard error is considerably larger.

The information content is lower in the troposphere, UTLS-zone and around the ozone maximum.

Also low ozone profiles have been successfully retrieved at Neumayer station. The algorithm has problems with the UTLS-zone and tends to overestimate the ozone in the lower stratosphere during winter- and early spring season.

ACKNOWLEDGEMENT

The ozonesonde data was made available by WOUDC (http://www.woudc.org), the SHADOZ network (http://croc.gsfc.nasa.gov/shadoz/) and the NILU's Atmospheric Database for Interactive Retrieval (NADIR) at Norsk Institutt for Luftforskning (NILU) (http://www.nilu.no/nadir/).

REFERENCES

Thompson, A.M., J.C. Witte, R.D. McPeters, S.J. Oltmans, F.J. Schmidlin, J.A. Logan, M.Fujiwara, V.W.J.H. Kirchhoff, F. Posny, G.J.R. Coetzee, B. Hoegger, S. Kawakami, T. Ogawa, B.J. Johnson, H. Vömel and G. Labow, Southern Hemisphere Additional Ozonesondes (SHADOZ) 1998-2000 Tropical ozone climatology 1. Comparison with Total Ozone Mapping Spectrometer (TOMS) and ground-based measurements, *J. Geophys. Res.*, **Vol.** 108 No. D2, 8238, doi: 10.1029/2001JD000967, 30 January 2003.

Thompson, A.M., J.C. Witte, S.J. Oltmans, F.J. Schmidlin, J.A. Logan, M. Fujiwara, V.W.J.H. Kirchhoff, F. Posny, G.J.R. Coetzee, B. Hoegger, S. Kawakami, T. Ogawa, J.P.F. Fortuin, and H.M. Kelder, Southern Hemisphere Additional Ozonesondes (SHADOZ) 1998-2000 Tropical ozone climatology 2. Tropospheric variability and the zonal wave-one, *J. Geophys. Res.*, **Vol.** 108 No. D2,8241, doi: 10.1029/2002JD002241, 31 January 2003.