# Merged monthly zonal mean ozone profiles

Data description and user manual

20 June 2013
V. Sofieva and Ozone-CCI Limb Team

## 1 Introduction

The creation of the merged monthly zonal mean ozone profiles using Envisat limb instruments (GOMOS, MIPAS, SCIAMACHY) and ESA Third Party Mission instruments (OSIRIS, SMR, and ACE-FTS) is targeted mainly for climate modeling and climate research. The merged monthly zonal mean data (MMZM hereafter) include merged ozone profiles in 10° latitude zones for each month in years 2007-2008, at ozone-CCI pressure grid from 250 hPa to 1 hPa, and the parameters, which characterize the uncertainty of the merged profiles.

This Technical Note describes the details of computing the MMZM data (Section 2) and the parameters of the created netcdf files (Section 3), as well as the preliminary evaluation of the merged ozone zonal mean profiles (Section 4).

## 2 Data processing and parameters

First, monthly average profiles and their uncertainties $\sigma_{mean}$ in 10° latitudinal bins are created for each instrument, as described in [*Sofieva et al*., 2013a]. Then the weighted mean will constitute the "merged" climatologic-resolution dataset.

The vertical coordinate is the ozone-CCI pressure grid [*Sofieva et al*., 20013b; *Rahpoe and Lloyd*, 2013]. The merged dataset is created in the altitude range from ~10 km up to ~ 50 km (250 hPa – 1 hPa), in order to avoid significant diurnal variations at upper altitudes. Since ozone measurements by six satellite instruments participating in ozone-CCI project do not provide uniform sampling in local time, the merged dataset does not represent exactly "day and night mean".

Satellite measurements sample a continuous ozone field at some locations and times. For each instrument, the uncertainty of monthly mean values is:

$$\sigma^2 = \sigma_{mean}^2 + \sigma_{sampling}^2 \quad (1)$$

The first term, $\sigma_{mean}^2$, is the standard error of the mean, which is discussed in [*Sofieva et al.*, 2013a, Eq.(2)]. The second term, $\sigma_{sampling}^2$, is the sampling uncertainty, which is related to potentially non-uniform sampling by measurements in space and in time. In has been shown in [Sofieva et al., 2012] that the sampling error allows a simple parameterization

$$\sigma_{sampling} = \frac{1}{2}\left(H_{lat} + H_{time}\right)\cdot\sigma_{nat}, \quad (2)$$

where $H_{lat}$ and $H_{time}$ are inhomogeneity measures in latitude and in time, respectively, and $\sigma_{nat}$ is the profile of natural variability taken from LLM climatology [*McPeters et al.*, 2007], for each month and each latitude bin. Uncertainty of the mean values $\sigma_{mean}$, sam-

pling error $\sigma_{sampling}$ and total error $\sigma$ (Eq.(1)) of the instrument-based zonal mean data in January 2008 are shown in Figure 1.

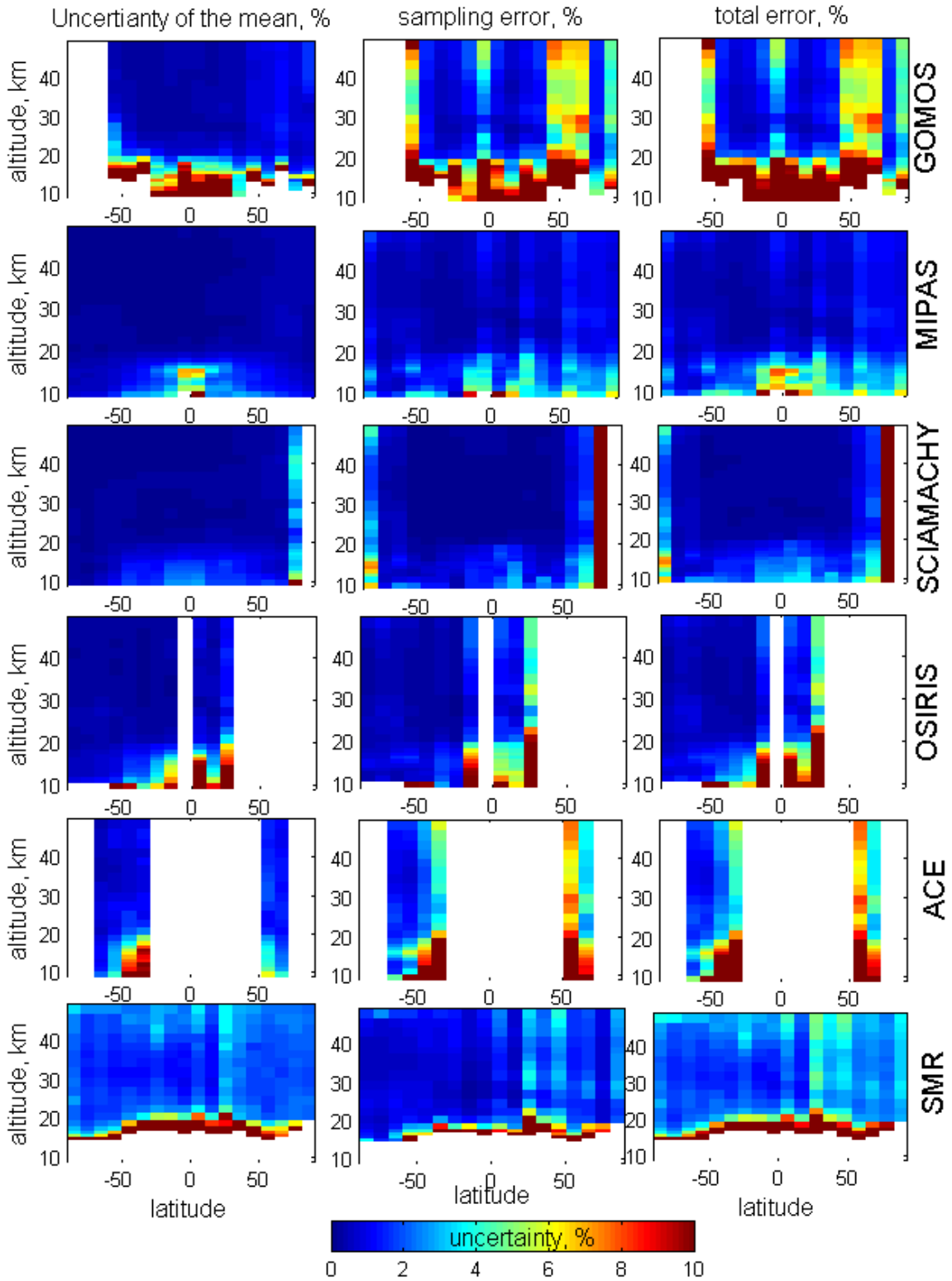


Figure 1 Uncertainty of the mean values, sampling error $\sigma_{sampling}$ and total error of the instrument-based zonal mean data in January 2008. All uncertainties are presented in %.

The merged monthly zonal mean is computed as the weighted mean of the zonal mean datasets from individual instruments, with the weights $\alpha_i$ that are inversely proportional to uncertainties $\sigma_i^2$ (Eq.(1)):

$$\rho_{merged} = \sum_{i=1}^{N_{instru}} \alpha_i \rho_i$$
$$\alpha_i = \frac{1/\sigma_i^2}{\sum 1/\sigma_i^2} \qquad (3)$$

The merged zonal mean ozone data for January 2008 is shown in Figure 2.
The associated uncertainty of the merged dataset will be defined by:

$$\sigma^2_{merged} = \frac{1}{\sum_{i=1}^{N_{instru}} 1/\sigma_i^2} \cdot \frac{1}{(N_{insru}-1)} \sum_{i=1}^{N_{instru}} \frac{(\rho_i - \rho_{merged})^2}{\sigma_i^2} . \qquad (4)$$

The first factor in (4), $\frac{1}{\sum_{i=1}^{N_{instru}} 1/\sigma_i^2} = \sigma^2_{wmean}$ , is the uncertainty of the weighted mean provided the uncertainties $\sigma_i$ are the only source of variations in ozone. The second factor in Eq. (4) takes into account variability between the datasets. The uncertainties $\sigma_{wmean}$ and $\sigma_{merged}$ are shown in Figure 3. As observed in Figure 3, the variability between the datasets has a dominating contribution into uncertainty $\sigma_{merged}$ of the merged zonal mean data.

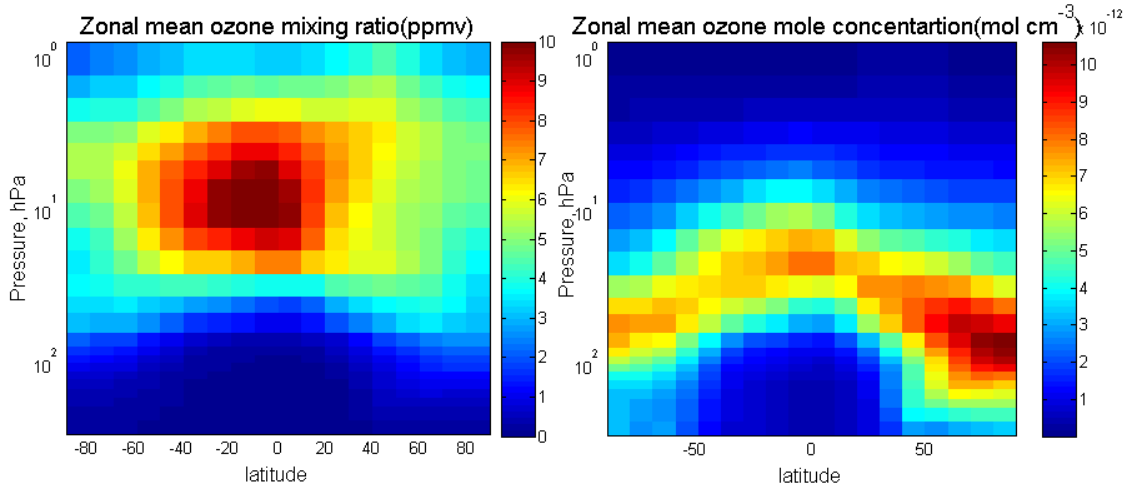

Figure 2. Merged ozone-CCI profiles of mixing ratio (left) and mole concentration (right), for January 2008.

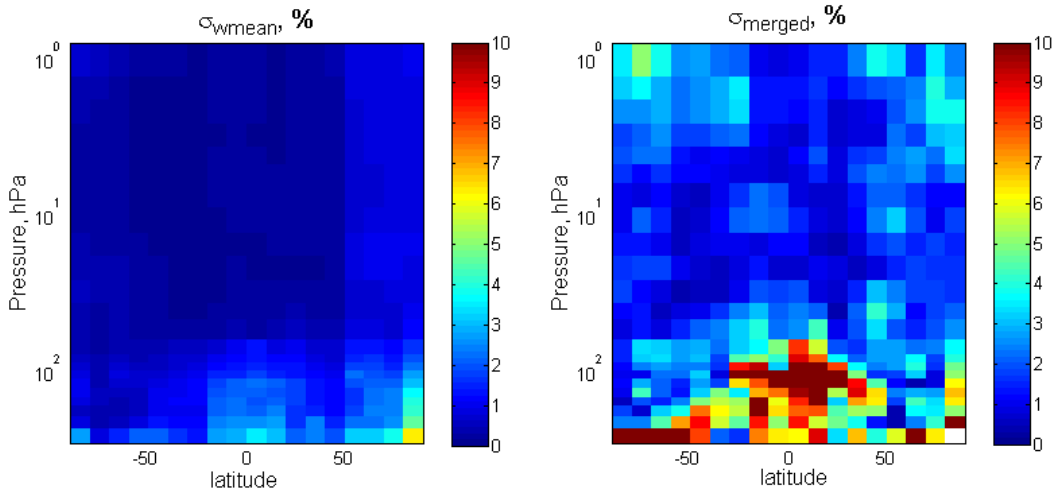

Figure 3 Uncertainties associated with the merged monthly mean profile.

Table 1. The variables in MMZM netcdf files

| | *Parameter and unit* | *Dimensions* | *Description* |
|---|---|---|---|
| General parameters | air pressure (hPa) | $N_{alt}\times 1$ | The vertical coordinate |
| | approximate_altitude (km) | $N_{alt}\times 1$ | Approximate altitude at pressure levels computed as $z = 16\ \log_{10}(1013/P)$, $P$ is pressure in hPa |
| | latitude_centers (degrees_north) | $N_{lat}\times 1$ | Centers of latitude bins: -85°: 10°:85° |
| | instruments | $N_{instru}\times 1$ | A dimension for individual datasets, instrument order 1-GOMOS, 2-MIPAS, 3-SCIAMACHY, 4-OSIRIS, 5-ACE-FTS , 6-SMR |
| Merged data | merged_ozone_vmr | $N_{lat}\times N_{alt}$ | Merged monthly zonal mean ozone mixing ratio vertical profiles |
| | merged_ozone_concentration (mol/cm$^3$) | $N_{lat}\times N_{alt}$ | Vertical profiles of merged monthly zonal mean ozone mole concentration. Number density (cm$^{-3}$) is acquired by multiplying the variable with Avogadro constant $N_A$=6.02214e23 mol$^{-1}$ |
| | uncertainty_of_ merged_ozone (%) | $N_{lat}\times N_{alt}$ | Uncertainty $\sigma_{merged}$ of the merged data, Eq.(4) |
| Individual datasets | ozone_vmr | $N_{lat}\times N_{alt}\times N_{instru}$ | Monthly zonal mean ozone mixing ratio vertical profiles for individual instruments |
| | ozone_mole_concentration (mol/cm$^3$) | $N_{lat}\times N_{alt}\times N_{instru}$ | Monthly zonal mean ozone mole concentration vertical profiles for individual instruments. |
| | standard_error_of_the _mean (%) | $N_{lat}\times N_{alt}\times N_{instru}$ | Uncertainty of the monthly zonal mean for individual datasets, $\sigma_{mean}$, Eq. (2) in [Sofieva et al., 2013a] |
| | sampling_error (%) | $N_{lat}\times N_{alt}\times N_{instru}$ | Sampling error $\sigma_{sampling}$ for individual datasets characterized using (2). |
| | total_ error (%) | $N_{lat}\times N_{alt}\times N_{instru}$ | Total uncertainty of monthly zonal mean data from individual instruments, see Eq.(1) |

## 3 The data format

The merged monthly zonal mean data are structured into monthly netcdf files with self-explanatory names. For example, the file "ESACCI-OZONE-L3-LP-MERGED-MZM-200801-fv0002.nc" contains merged monthly zonal mean data for January 2008. In addition to the variables of the merged data, the profiles from individual instruments with

their uncertainty parameters are also included (for the altitude range 250-1 hPa used in data merging). The variables included into netcdf files are collected in Table 1. An example of the full structure of the netcdf file is presented in Appendix A.

# 4 Preliminary evaluation of the MMZM dataset

## *4.1 Strange features of individual zonal mean data*

During the data analysis, it was found that GOMOS monthly zonal mean (MZM) data have sometimes strange features (like shown in Figure 4 left, where the values for 10N-20N are lower than those at adjacent latitudes). Further investigation of this particular case has shown that GOMOS monthly mean data in this latitude zones are based on only 39 occultations of dim star #134. Since such data are accompanied with very large uncertainty (large sampling and total error), this strange feature is not observed in merged data (Figure 4, right)

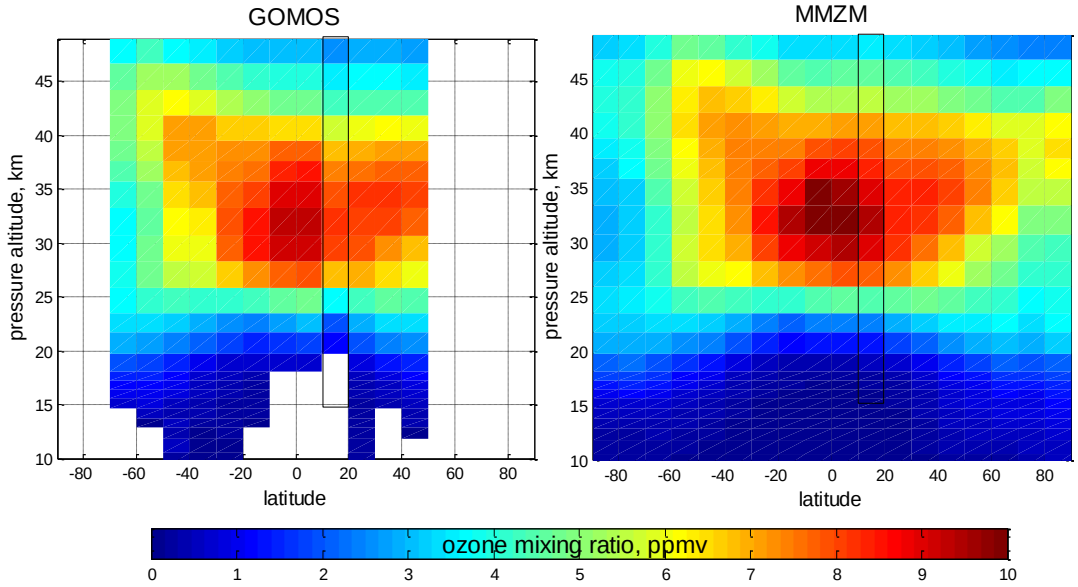


Figure 4 Left: GOMOS zonal mean ozone for May 2008. Right: merged zonal mean ozone profiles for May 2008.

## *4.2 Upper troposphere and the lower stratosphere (UTLS).*

Nearly all limb data participating in ozone-CCI are biased in UTLS. Figure 5 shows mean deviations from the ML climatology [*McPeters and Labow*, 2012] in year 2008 as a functions of latitude and altitude (averaging has been performed over all months). In this climatology, ozone in the UTLS is derived using ozonesondes and MLS/AURA measurements. The MMZM data have the smallest average deviation in UTLS, compared to those of individual instruments, as illustrated in Figure 6. Interestingly, local enhancements of deviations in the equatorial troposphere are very similar for MIPAS, SCIAMACHY, OSIRIS and ACE-FTS.

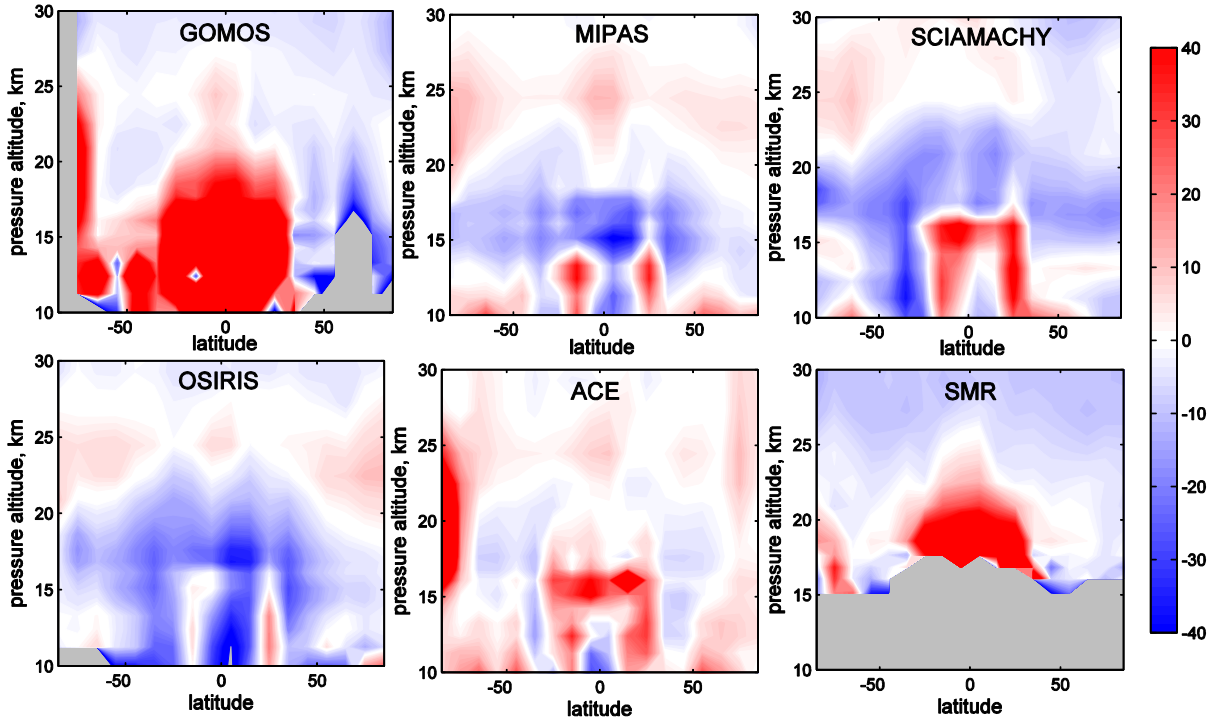


Figure 5 Mean deviations from ML climatology (expressed in %) for year 2008, for individual monthly zonal mean datasets.

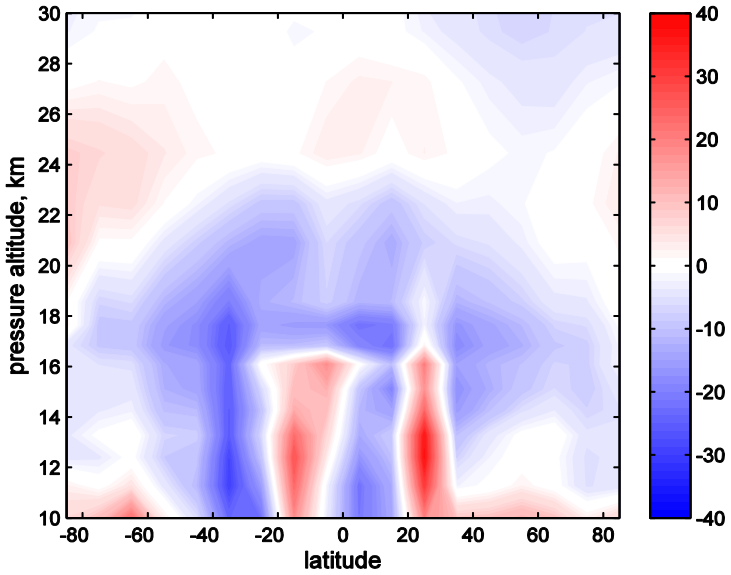


Figure 6 As Figure 2, but for merged monthly zonal mean data

## *4.3 Improved data characterization*

Figure 7 shows time series in years 2007-2008 of monthly zonal mean ozone from individual instruments, as well as merged data, at altitude ~30 km. Evident discrepancy between datasets are observed. Since large number of measurements contributes to MZM data, the standard error of the mean is usually very small. Errorbars on lines corresponding to individual datasets correspond to the total error, which includes the standard error of the mean and sampling error. Errorbars often intersect, thus indicating that some discrepancy in the MZM value can be attributed to non-uniform sampling patterns. In addi-

tion, some exceptional values (e.g. in Feb 2007 for OSIRIS, in Sep 2008 for GOMOS) are accompanied with large error bars, which are associated with highly non-uniform spatio-temporal sampling. The grey shaded areas indicate 1σ uncertainty of the merged data, which takes into account also variability between individual data.

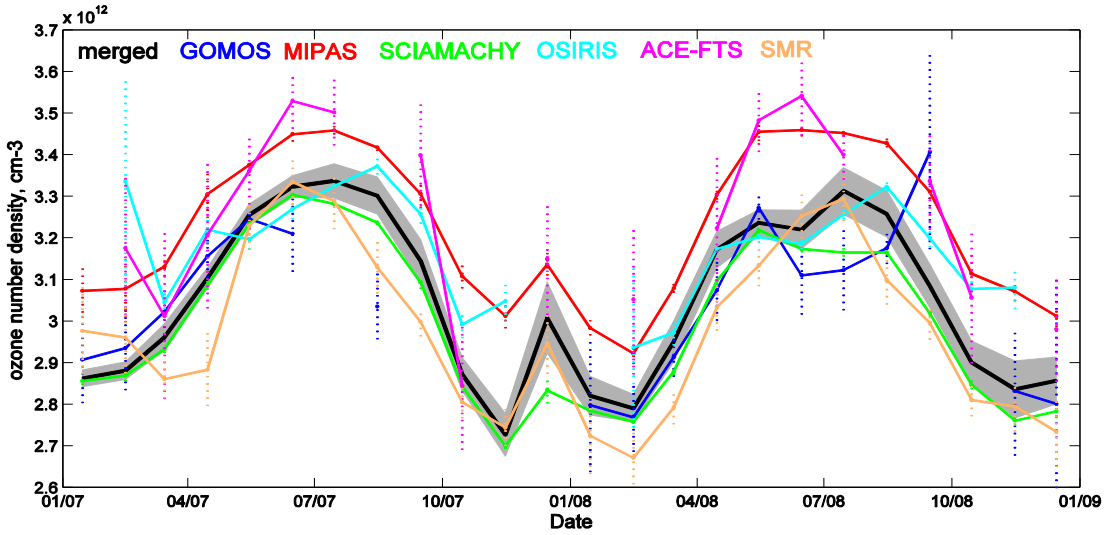


Figure 7 Ozone MZM number density at 15 hPa (~30 km) at latitudes 40°N-50°N in 2007-2008 for individual datasets and the MMZM dataset. Errorbars for individual datasets show the total error (which includes sampling error). Grey shaded area show 1σ uncertainty of the merged data.

## References


McPeters, R. D., and G. J. Labow (2012), Climatology 2011: An MLS and sonde derived ozone climatology for satellite retrieval algorithms, *J. Geophys. Res.*, *117*(D10), D10303, doi:10.1029/2011JD017006. [online] Available from: http://dx.doi.org/10.1029/2011JD017006

McPeters, R. D., G. J. Labow, and J. A. Logan (2007), Ozone climatological profiles for satellite retrieval algorithms, *J. Geophys. Res.*, *112*(D5), D05308, doi:10.1029/2005JD006823.

Rahpoe, N., and N. D. Lloyd (2013), *Ozone Limb Level 2 Harmonized Single Instrument Document*

Sofieva V.F., Kalakoski N., and Päivärinta S.-M. (2012): Sampling error of satellite instruments, Technical Note.

Sofieva et al., (2013a): Instrument-based monthly zonal mean ozone profiles, Technical Note, 15 Apr 2013.

Sofieva et al., (2013b): Harmonized dataset of ozone profiles from ESA Envisat and Third Party Missions limb measurements, Technical Note.

## Appendix A: The structure of the MMZM netcdf file

The example of the structure of netcdf file is presented January 2008.

```
Global Attributes:
        title                 = 'ESA CCI ozone  merged monthly zonal mean data '
        summary               = 'merged monthly zonal mean ozone profiles(MMZM) in 10-deg latitude
                                 zones and data uncertainty characterization'
        comment               = 'Monthly zonal mean from individual sensors are also presented. Definitions
                                 of parameters and data processing are described in the dedicated Technical
                                 Note'
        year                  = '2008'
        month                 = '01'
        number_of_pressure_levels = '23'
        number_of_latitude_bins   = '18'
        geospatial_lat_resolution = '10 deg '
        geospatial_lat_min        = '-90 deg'
        geospatial_lat_max        = '90 deg'
        geospatial_vertical_min   = ' 250 hPa'
        geospatial_vertical_max   = '1 hPa'
        value_for_nodata          = 'NaN'
        date_created              = '20130317T160310'
        creator_name              = 'Viktoria Sofieva'
        creator_email             = 'viktoria.sofieva@fmi.fi'
        address                   = 'P.O.Box 503, 00101 Helsinki, Finland'
        naming_authority          = 'FMI - Finnish Meteorological Institute'
        Conventions               = 'CF-1.5'
        standard_name_vocabulary  = 'NetCDF Climate and Forecast(CF) Metadata Convention version 18'
        license                   = 'ozone_cci guidelines'
        restriction               = 'Restricted under the use of ozone cci guidelines'
        file_version              = 'fv0001'
Dimensions:
        air_pressure     = 23
        latitude_centers = 18
        instruments      = 6
Variables:
   air_pressure
        Size:       23x1
        Dimensions: air_pressure
        Datatype:   single
        Attributes:
                units         = 'hPa'
                standard_name = 'air_pressure'
   latitude_centers
        Size:       18x1
        Dimensions: latitude_centers
        Datatype:   single
        Attributes:
                units         = 'degrees_north'
                standard_name = 'latitude'
                long_name     = 'centers of latitude bins'
   approximate_altitude
        Size:       23x1
        Dimensions: air_pressure
        Datatype:   single
        Attributes:
                units         = 'km'
```

```
            standard_name = 'altitude'
            long_name     = 'approximate altitude corresponding to pressure levels'
instruments
    Size:       6x1
    Dimensions: instruments
    Datatype:   int16
    Attributes:
            units     = '1'
            long_name = 'index of instruments: 1-GOMOS, 2-MIPAS, 3-SCIAMACHY, 4-OSIRIS, 5-
                        SMR, 6-ACE-FTS'
merged_ozone_vmr
    Size:       18x23
    Dimensions: latitude_centers,air_pressure
    Datatype:   double
    Attributes:
            units         = '1'
            standard_name = 'mole_fraction_of_ozone_in_air'
            long_name     = 'merged monthly zonal mean ozone mixing ratio'
merged_ozone_concentration
    Size:       18x23
    Dimensions: latitude_centers,air_pressure
    Datatype:   double
    Attributes:
            units         = 'mol cm-3'
            standard_name = 'mole_concentration_of_ozone_in_air'
            long_name     = 'merged monthy zonal mean ozone mole concentration'
uncertainty_of_merged_ozone
    Size:       18x23
    Dimensions: latitude_centers,air_pressure
    Datatype:   double
    Attributes:
            units     = '%'
            long_name = 'total uncertainty of merged ozone profiles'
ozone_mole_concentration
    Size:       18x23x6
    Dimensions: latitude_centers,air_pressure,instruments
    Datatype:   double
    Attributes:
            units         = 'mol cm-3'
            standard_name = 'mole_concentration_of_ozone_in_air'
            long_name     = 'monthly zonal mean concentrations from individual instruments'
ozone_vmr
    Size:       18x23x6
    Dimensions: latitude_centers,air_pressure,instruments
    Datatype:   double
    Attributes:
            units         = '1'
            standard_name = 'mole_fraction_of_ozone_in_air'
            long_name     = ' monthly zonal mean vmr from individual instruments'
standard_error_of_the_mean
    Size:       18x23x6
    Dimensions: latitude_centers,air_pressure,instruments
    Datatype:   single
    Attributes:
            units     = '%'
            long_name = 'standard error of the mean  for individual instruments'
sampling_error
    Size:       18x23x6
    Dimensions: latitude_centers,air_pressure,instruments
    Datatype:   single
```

Attributes:
units = '%'
long_name = 'sampling error for individual instruments'

total_error
Size: 18x23x6
Dimensions: latitude_centers,air_pressure,instruments
Datatype: single
Attributes:
units = '%'
long_name = 'total uncertainty of zonal monthly mean data for individual instruments'

## Acronyms

| | |
|---|---|
| ESA | European Space Agency |
| ozone-CCI | Ozone Climate Change Initiative |
| GOMOS | Global Ozone Monitoring by Occultation of Stars |
| MIPAS | Michelson Interferometer for Passive Atmospheric Sounding |
| SCIAMACHY | Scanning Imaging Spectrometer for Atmospheric Chartography |
| OSIRIS | Optical Spectrograph and InfraRed Imaging System |
| SMR | Sub-Millimeter Radiometer |
| ACE-FTS | Atmospheric Chemistry Experiment – Fourier Transform Spectrometer |
| MZM | Monthly Zonal Mean |
| MMZM | Merged Monthly Zonal Mean |