Homogenization of the total ozone amount series derived from NOAA/TOVS data

B.Lapeta\textsuperscript{1}, I.Dyras\textsuperscript{1}, Z.Ustrnul\textsuperscript{2}

\textsuperscript{1}Institute of Meteorology and Water Management, ul. Borowego 14, 30-215 Krakow, Poland
e-mail: Bozena.Lapeta@imgw.pl;
\textsuperscript{2}University of Silesia, ul. Bedzinska 60, 41-200 Sosnowiec, Poland.

ABSTRACT

Total ozone amount has been operationally derived from NOAA/TOVS data in the Satellite Research Department of Institute of Meteorology and Water Management since 1993, and has been daily calculated for the area covering Central Europe. Such a relatively long series is extremely valuable for the trend analysis. However, such an application requires a series to be fully homogenous and of good quality. Meanwhile, during a 13 year period of the ozone retrieval from the satellite data, both software and instruments have been changed several times. Simultaneously, there are some gaps in the series caused by the lack of satellite data. The total ozone amount series is presented as well as the steps undertaken for its homogenization. The analysis was performed for monthly mean values using the ground total ozone measurements from Belsk, Hradec-Kralove, and Hohenpeissenberg. The well known in climatology Standard Normal Homogeneity Test (SNHT) by Alexandersson was applied. The obtained results are presented and discussed.

INTRODUCTION

Large worldwide total ozone depletion observed during the last two decades (Bojkov, 1999; Solomon, 1999) as well as the results of the EU research programmes on stratospheric ozone depletion in the Arctic and mid-latitudes (Knudsen et al., 1998; Rex et al., 1997a, 1999b), have clearly shown the importance of ozone monitoring. The satellite data are the irreplaceable source of information related to the global ozone distribution. The existing data series is long enough to allow searching for ozone trends. However, the data has to be homogenised to start with and this paper presents the results of the method used.

In the first part of this paper, the applied method for ozone data retrieval from NOAA/TOVS satellite data is described together with the results of the comparative analysis for total ozone amount derived from satellite data and ground measurements.

In the second part of the paper is devoted to the satellite total ozone series the homogenization method using the Standard Normal Homogeneity Test (SNHT) created by Alexandersson.

DATA

Total Ozone Amount from NOAA/TOVS Data

NOAA/TOVS series of satellites are meteorological, orbiting satellites measuring radiances within visible, infrared and microwave spectral channels. Ozone retrievals are performed on the base of measurements made in the 9.6\textmu m ozone absorption band by TIROS Operational Vertical Sounder (TOVS).

To retrieve the total ozone amount from 9.6 \textmu m ozone band, a physical model (Xia-Lin Ma et.al 1984) has been applied. It includes an iterative scheme, in which the first guess of the ozone profile is constructed using regression relation between the ozone concentration and...
the brightness temperatures observed in HIRS carbon dioxide channels. Additionally, in order to make the first guess of the ozone profile sufficiently accurate, the ozone mixing ratio profile is moved up or down by $\delta N$ levels calculated from the following relationships (Xia-Lin Ma et.al 1984):

$$\delta N = 0.5 + 1.4 (T_{\text{cal}} - T_{\text{obs}}) \quad \text{for low latitudes, and}$$

$$\delta N = -0.2 + 1.8 (T_{\text{cal}} - T_{\text{obs}}) \quad \text{for middle latitudes,} \quad (1)$$

where $T_{\text{cal}}$ and $T_{\text{obs}}$ are the brightness temperatures calculated from the ozone guess profile and observed in the ozone 9.6 $\mu$m.

Calculations are carried out for each 3x3 individual instrument’s field of view, what gives the ozone distribution maps with the spatial resolution of around 75 km.

The total ozone amount has been operationally derived from NOAA/TOVS satellite data since 1993. Since then the following algorithms were used:

– 1993-1999 an iterative scheme based on the physical model (Xia-Lin Ma et.al 1984) as described above;

– 2000-2006 PC-TOVS software package based on the ITPP from Wisconsin University; the first guess ozone profile from TIGR database. Calculations for 3x3 individual HIRS field of view.

**Total Ozone Amount from Ground Measurements**

Ground total ozone measurements have been obtained from the World Ozone Data and Ultraviolet Data Centre in Toronto for the period 1994-2005. For the analysis, the following three stations were selected: Belsk (52.0N, 21.0E), Hradec-Kralove (50.85N, 15.83E) and Hohenpeissenberg (47.8N, 11.02E). Only the measurements made with Dobson spectroradiometer were used.

**COMPARISON WITH GROUND DATA**

The total ozone amount operationally calculated from NOAA/TOVS was compared with the ground measurements taken at these selected stations. In order to select satellite ozone value for the particular localization, the ozone distribution maps have been converted into a regular grid with 1° step resolution by the kriging spatialisation algorithm. The use of other spatialisation algorithms gave rather poor results.

Then, the total ozone amount for given geographical co-ordinates has been calculated as the inverted distance weighted mean value estimated from four nearest grids. The example of the distribution of total ozone amount over Europe is presented on the Figure 1.
On the Figure 2, the monthly means for satellite-derived and ground measured total ozone amount are presented for Belsk, for the period of 1993-2005. The same comparison with the ground measurements has been carried out for the other two sites: Hradec-Kralove and Hohenpeissenberg.

The annual variability of both curves is almost the same; however, the variations’ amplitude is higher for ground data. The best agreement has been obtained for the springtime, when the satellite-derived ozone amount is often smaller than the measured one. The biggest discrepancies are observed for autumn. For this period, the differences between satellite-
derived total ozone and ground measurements are bigger than the standard deviation calculated for the ground monthly means.

In order to obtain some quantitative information, the values of mean difference, mean square difference, and standard deviation of difference have been calculated. The results are presented in the Table 1. The differences were calculated by subtracting the ground-measured values from the satellite-derived ones.

Table 1. Results of the comparative analysis for the both total ozone data sources at the selected stations (1993-2005) (difference = satellite – ground)

<table>
<thead>
<tr>
<th></th>
<th>Belsk</th>
<th>Hradec-Kralove</th>
<th>Hohenpeissenberg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean difference</td>
<td>9.4 D</td>
<td>11.8 D</td>
<td>11.6 D</td>
</tr>
<tr>
<td>Mean square difference</td>
<td>18.7 D</td>
<td>23.0 D</td>
<td>22.8 D</td>
</tr>
<tr>
<td>Standard deviation for difference</td>
<td>20.2 D</td>
<td>19.8 D</td>
<td>19.7 D</td>
</tr>
<tr>
<td>Correlation coefficient</td>
<td>0.83</td>
<td>0.8</td>
<td>0.78</td>
</tr>
<tr>
<td>RMSE</td>
<td>5.7 %</td>
<td>7.4 %</td>
<td>7.2 %</td>
</tr>
</tbody>
</table>

The results obtained for all stations were very similar and showed quite good conformity between satellite-derived and ground ozone data. The values of the mean difference, which is the measure of the systematic error, indicate that the total ozone amount derived from NOAA/TOVS data is slightly overestimated. However, the behaviour of the monthly mean values of the total ozone amount showed on the Figure 3 indicates that in spring the TOVS derived ozone data is underestimated while in other seasons it is overestimated. This suggests that the analysis should be also performed for different seasons separately.

On the figure 4 the values of RMSE obtained for different seasons are shown. The smallest values are observed for spring and the biggest values were obtained for autumn. The explanation for those differences is neither straightforward nor unambiguous. However, poor results for autumn may be partially explained by the difficulties in surface temperature
estimation as well as the influence of mid-stratospheric dynamics, which is particularly strong in autumn and spring (Neuendorffer, 1996). This manifests in too high TOVS ozone values in autumn and too low values in spring.

![Graph showing RMSE values for different seasons and stations](image)

**Fig. 4** RMSE values obtained for different seasons and different stations on the base of data from 1993-2005 period.

**HOMEGENEITY TEST**

– The SNHT test was applied to the series of ozone data separately for each month with the ground measurements being the reference data despite the difficulties originated from the gaps in the satellite data. The figure 5 illustrates the SNHT test values obtained for Belsk, for the chosen months. The inhomogeneity in the series can be detected subjectively, on the base of SNHT values (Ti). The change points usually correspond to the well defined maximum of Ti values. The obvious inhomogeneity can be noticed for August and December (Fig.5). For all selected stations, the inhomogeneity of the satellite derived total ozone series was found for the most of the autumn and winter months in the years 2002 – 2003. It may be caused by the change in satellite pass (noon NOAA-11 to morning NOAA-14) and the processing algorithm that occurred in that time.

![SNHT values for 'satellite' total ozone series for Belsk and for selected months](image)

**Fig. 5** SNHT values for ‘satellite’ total ozone series for Belsk and for selected months.
On the base of the SNHT procedure, the inhomogeneous ‘satellite’ ozone series can be adjusted in order to remove the change points. On the figure 6, the example of the SNHT values after adjustments are presented for December.

![SNHT values for 'satellite' total ozone series for Belsk and for December after adjustment.](image)

The adjustment procedure was applied for each month whenever felt necessary in order to obtain the homogenous satellite-derived total ozone series. The result is presented on the figure 7.

![Monthly mean total ozone amount derived from NOAA/TOVS data (blue) and adjusted according the SNHT test values, and measured by Dobson spectroradiometer in Belsk (red) for the 1993-2005 period](image)

**CONCLUSIONS**

From the presented above experiment the following initial conclusions can be drawn:
- The application of NOAA/TOVS satellite data leads to the overestimation of total ozone amount.
- Strong seasonal variability in quality of the total ozone amount derived from NOAA/TOVS data has been observed, therefore, the analysis of homogeneity was performed for each month separately.
Standard Normal Homogeneity Test (Alexandersson test) that is widely used in homogeneity analysis of the climatological series proved to be very useful in analysis of the satellite derived total ozone series.

For all selected stations, the inhomogeneity of the satellite derived total ozone series was found for the most of the autumn and winter months in the years 2002 – 2003. It may be caused by the change in satellite pass (noon NOAA-11 to morning NOAA-14) and the processing algorithm that occurred in that time.

After adjusting the homogenous ‘satellite-derived’ total ozone series was obtained, however, big gaps in data in 1995 and 1999-2000 lessened the climatological value of the series.

ACKNOWLEDGMENTS

The work was partly funded by grant of the Polish Ministry of Science SPUB-M 618/E-217/SPB/COST/KN/DWM 50/2005-2006 and Polish Chief Inspectorate for Environmental Protection. Ground total ozone data (monthly means) originated from WMO World Ozone and Ultraviolet Data Centre. The homogeneity analysis was performed with the usage of the freeware version of the AnClim software (Stepanek, P. (2006): AnClim - software for time series analysis. Dept. of Geography, Fac. of Natural Sciences, MU, Brno)

LITERATURE

Proceedings of the
Fifteenth International
TOVS Study Conference

Maratea, Italy
4 October - 10 October 2006