A Preliminary Comparison between TOVS and GOME Level 2 Ozone Data

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Abstract

A preliminary comparison between total column ozone concentration values derived from TIROS Operational Vertical Sounder (TOVS) and Global Ozone Monitoring Experiment (GOME) has been carried out. Two comparisons of ozone datasets have been made : a) TOVS ozone analysis maps vs. GOME level 2 data; b) TOVS data located at Northern Hemisphere Ground Ozone Stations (NHGOS) vs. GOME data. Both analyses consistently showed an offset in the value of the total column ozone between the datasets [for analyses a) 35 Dobson Units (DU); and for analyses b) 10 DU], despite a good correlation between the spatial and temporal features of the datasets. A noticeably poor correlation in the latitudinal bands 10 / 20 North and 10 / 20 South was observed - the reasons for which are discussed. The smallest region which was statistically representative of the ozone value correlation dataset of TOVS data at NHGOS and GOME level-2 data was determined to be a region that was enclosed by effective radius of 0.75 arc-degrees.

Introduction

The remote monitoring of the Earth's ozone layer has found great importance in many scientific areas. From 1979 to 1993, a NASA series of satellites carried sensors (TOMS - Total Ozone Mapping Spectrometer) capable of determining the total column ozone concentrations from space-borne platforms. Work has been performed in an attempt to tie this extensive archive of data with new data derived from the NOAA based TOVS series of instruments1

GOME is a new UV-visible sensor and is part of the core payload of the second Earth Research Satellite (ERS-2) which was launched by ESA on the 21^{st} April 1995. GOME, which was originally proposed as SCIA-mini, is a small scale version of SCIAMACHY, which will fly on ENVISAT in 19992,3. The measurement objective of both SCIAMACHY and GOME is the accurate determination of the back scattered, reflected and transmitted radiance from the Earth's atmosphere and the extra-terrestrial irradiance4,5,6. Division of these two quantities yields the effective atmospheric absorbance and enables the amounts of atmospheric constituents which either absorb (e.g. trace gases), emit (e.g. trace gases) or scatter light (e.g. aerosols) to be determined.

The GOME instrument contains a double monochromator having four spectral channels and measures simultaneously light between 240 and 790 nm. Each channel comprises a grating, transmissive optics and a silicon diode array detector having 1024 elements. Between 240 and 400 nm the spectral resolution is approximately 0.2 nm. For the measurement of ozone, the spectral window between 325 and 335 nm has been selected. The algorithm used to retrieve the total column ozone amount uses a Differential Optical Absorption Spectroscopy (DOAS) approach.

The DOAS method relies on the determination of the slant column absorption of ozone in this spectral window, where some relatively strong Huggins bands of ozone are observed, and resultant derivation of the slant column amount. The division of the latter by the air mass factor (AMF) yields the total column amount of ozone. AMF factors are determined by use of a radiative transfer forward model and appropriate climatological ozone profiles. The data used in this study represents the first provisional set of data from the GOME Data Processor Level 2.0. it is anticipated that the GDP data products will improve in accuracy as its validation continues.

Measurement of the total column ozone values derived from TOVS radiances are made via channel 9 on the HIRS-2 instrument. There are four main ways to derive the total ozone value from the radiances7-9 :

A physical method - using the assumption that the total ozone value is linearly correlated with the mean pressure of the ozone layer.
A regression method - iteratively solving the radiative transfer equation (see Equation 1) and thus determining the amount of ozone present.
A statistical method - using past known ozone concentrations and climatologies to derive current values.
Use of multi-band information in an attempt to reduce error propagation.

However, the use of a thermal channel has the disadvantage that it can be confused by certain ground / climatic conditions which causes the amount of ozone, determined by the above methods, to be subject to significant errors.

As there is no time at which GOME and TOMS have made concurrent observations, a comparison has been made between ozone data values derived from GOME and TOVS observations. The aim of this preliminary investigation is to perform a quantitative evaluation of the ozone data derived from GOME and TOVS. A quantitative spatial and temporal evaluation has been undertaken to examine the correlation between the two ozone datasets; and to identify significant spatial aspects10,11 and to isolate temporal aspects of the two datasets.

Method

Three datasets were used in the investigation : TOVS ozone analysis maps (obtained re-binned into 30 DU bins), TOVS data geo-located at the northern hemisphere ground ozone monitoring stations (NHGOS) (original accuracy) and the extracted12-14 GOME level-2 data (original accuracy). For the purposes of comparison, (and owing to the ongoing generation of the GOME level 2 data at DLR, Germany), a range of only 23 days were used for the investigation - 25^{th} Aug. 1995 to 09^{th} Sept. 1995, and 11^{th} Jan 1996. to 17^{th} Jan 1996. It is worth noting that the range of days represent both a summer and a winter period; this can adjudged as seasonally representative. A standard array of 1024 512 cells representing a global coverage was designed. Zero degrees longitude and latitude was arbitrarily assigned as (512,256) - other values being obtained by a simple bilinear mapping. (This ensured a single entry from the GOME level 2 data would be represented by an area at least one entry wide.) All three datasets were then transformed onto the array.

Two sets of correlation analyses of the ozone data were performed:

TOVS ozone analysis maps vs. GOME level 2 data,
TOVS data at NHGOS vs. GOME level 2 data.

The reference ellipsoids for the datasets were unavailable. It was necessary to devise suitable methods to reduce induced transformation errors. For TOVS ozone analysis maps vs. GOME level-2 data, a regional scanning method was used to test all cells covered by a GOME pixel, with the corresponding TOVS data values. Only if all the TOVS values were identical would the GOME value be designated 'valid. The limitation of this process, imposed by computational time restrictions, was that only values latitudes below 59.2 were acceptable. The accepted data values (averaging 5445 per day) were ordered in two distinct ways. a) Correlation and Regression Analyses by Latitudinal Bands: where each of the 23 daily accepted data values were subjected to a global regression analysis, and twelve individual latitudinal regression analyses (as indicated in Table 1), b) Correlation and Regression Analyses by TOVS Total Ozone Bands: where the 23 daily accepted data files were then subjected to a global regression analysis (to check the invariance of the data analysis techniques to data order), and six ozone band correlation analyses (as indicated in Table 2).

For the comparison of TOVS data at NHGOS vs. GOME level-2 ozone data, the average distance in degrees of arc between the stated location of the NHGOS and the five geolocation records for a GOME pixel were calculated. Only if this average was within 1.00 of arc would the GOME pixel be designated 'valid'. The accepted data values (limited to a maximum of 184 per orbit - the number of NHGOS) were then ordered by increasing average arc length difference (r), and four 'regions' were defined with r = 0.25, 0.50, 0.75 and 1.00. A set of correlation analyses were performed upon the data values contained within each of these regions (i.e. the larger regions completely contain all smaller regions).

Results and Discussion

TOVS ozone analysis maps vs. GOME level 2 data.

The temporal variation of the global correlation coefficient for the total column ozone derived from the TOVS and GOME observations is shown in Figure 1. There is a substantial variation in the values - a feature emphasised in the large variation produced within single band over the temporal range. A residual analysis on the variation of the daily means about the temporal means of the TOVS and GOME total ozone data was performed. A correlation analysis produced a correlation coefficient of 0.954, with a least squares restricted linear fit producing :

$$(\text{mean GOME}) = (\text{mean TOVS}) +35.1 \text{ DU}$$

The results of the correlation analyses clearly show that there is a large difference between the temporal means of the TOVS and GOME ozone data - an apparent time-independent value of 35 DU. Despite the differences in the absolute measurements of the ozone values within each dataset, both sets of ozone data are isolating similar temporal and spatial variations of the ozone field. Figure 2 shows the variation of the temporally averaged correlation coefficients for the twelve latitudinal bands. The two hemispheres show similar profiles.

From this form of analysis, several preliminary observations can be made:

- there is a greater fall off in the temporally averaged correlation level, between the ozone values derived from GOME and TOVS observations, towards higher latitudes in the northern hemisphere
- the prominent 10 / 20 drop in correlation level is sharper in the northern hemisphere, but broader in effect in the southern hemisphere - having an effect on the neighbouring bands.
- there is significant variations of correlation levels within some latitudinal bands over the entire temporal range (e.g. 30 / 40 South - range of 0.457 to 0.857; 50 / 60 North - range of 0.010 to 0.785).
- nowhere is the temporally averaged correlation level at 0.70 or above, despite numerous single entries being above this level - further emphasising the wide variation in correlation coefficients within a single band over the temporal range.

By utilising the re-binning into 30 DU bands of the TOVS ozone analysis maps, and performing analyses by these ozone bands (as detailed in Table 2), the following preliminary observations can be drawn:-

- the daily means for the ozone values derived from TOVS observations are consistently higher than the corresponding values derived from GOME observations (this is as expected, proving the invariance of the datasets to the data processing techniques employed)
- the higher TOVS bands (4, 5 and 6 - representing ozone values of 300 - 390 DU) show good delineation in the GOME ozone dataset; there are three distinct corresponding bands, albeit of different absolute values.
- the lower TOVS bands (1, 2 and 3 - representing ozone values of 210 - 300 DU) have poor delineation in the GOME ozone dataset; a single broad GOME band encompasses all three TOVS bands, yielding non-resolvability of the lower ozone values derived from TOVS observations within the GOME dataset.

TOVS data at NHGOS vs. GOME level 2 data.

These analyses were used to determine the smallest statistically representative region that maintains the properties of the region, whilst eliminating any anomalous spatial perturbations. Table 3 shows the main statistical results from the analyses. Region r = 0.75 and r = 1.00 have similar properties. Extension of the regional boundary caused the correlation values to fall further, with no significant reduction of the standard error. For this reason, it was concluded that the most representative region for comparison between the two datasets was that bounded by r = 0.75.

Figure 3 demonstrates the consistent difference between the daily global averages of the two ozone datasets (10 DU). This value, although still significant, was less than corresponding value obtained from the analyses of the ozone data derived from TOVS ozone analysis map data and GOME level 2 data. This signifies that the processing of the data has a large impact on the final correlation levels. Significant flaws can develop - the re-binning of the ozone data derived from TOVS data into 30 DU bins (as in the TOVS total ozone analysis maps) is an example - the magnification of the associated errors with each data value, thus yielding poorer absolute ozone concentration level correlations. Figure 3 also shows the seasonal features associated with the northern hemisphere ozone field. The northern hemisphere winter days have slightly higher average ozone values than the summer days, as is expected.

Conclusions

A preliminary comparison between the TOVS and GOME total column ozone datasets has been performed; two sets of analyses were used to interpret the data enabling the following conclusions to be drawn.

TOVS ozone analysis maps vs. GOME level 2 data.

A fall in the correlation values at 10 / 20 (North and South) is observed throughout the observational period. The effect is sharper in the northern hemisphere, but broader in effect in the southern hemisphere - having an effect on the neighbouring bands. The contributing factors for this poor correlation levels at 10 / 20 North and South include near-permanent cloud cover, and the presence of large areas of tropical ocean, semi-desert and desert regions. There is a greater fall off of correlation between the two datasets towards higher latitudes in the northern hemisphere - suggesting the possible effect of the differing fields of view of the TOVS and GOME systems. There is significant variation in the correlation levels within the latitudinal bands; thus nowhere is the temporally averaged correlation level at 0.70 or above, despite numerous single entries being above this level. The higher ozone bands from the TOVS data are comparable to similar distinct bands within the ozone data derived from GOME level-2 data; the lower ozone bands from the TOVS data proved non-resolvable; indicating a possible non-linear relationship between the two ozone datasets. The main conclusions from these correlation analyses are that the two ozone datasets showed good spatial and temporal correlation; but poor absolute ozone concentration level correlation.

TOVS data at NHGOS vs. GOME level 2 data.

The most statistically representative region was determined to be such that it was bounded by r=0.75°, implying that when considering cross-dataset calibration/validation, care must be taken to eliminate small scale anomalous spatial effects. Good correlation was evident between the ozone data values derived from the TOVS data located at NHGOS and GOME level-2 data; however, the absolute ozone concentration level correlation was still subject to a significant offset.

Undoubtedly, TOVS and GOME offer a complimentary way of measuring ozone in the Earth's atmosphere, they have distinct advantages and disadvantages :

TOVS : advantage - 24 hour measurement; disadvantage - empirical returns for lower altitudes

GOME : advantage - measure to cloud top (or 'surface' if cloud absent); disadvantage - 12 hour measurements only.

In conclusion, although ozone values derived from TOVS and GOME data show the same spatial and temporal features, there is a repeatable, distinct, offset between the absolute data values over the period studied. This warrants further investigation into the characteristics of the two observation systems.

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Table 1 The twelve latitudinal bands and their bounding parallels.

Latitudinal Band	Bounding Parallels	Latitudinal Band	Bounding Parallels
1	60N† - 50N	7	0NS - 10S
2	50N - 40N	8	10S - 20S
3	40N - 30N	9	20S - 30S
4	30N - 20N	10	30S - 40S
5	20N - 10N	11	40S - 50S
6	10N - 0NS	12	50S - 60S†

† Actual latitude 59.2

Table 2 The six TOVS total ozone analysis bands.			
TOVS ozone band	**TOVS lower limit**	**TOVS upper limit**	**Accepted Value**
1	**210**	**240**	**225 ± 15**
2	**240**	**270**	**255 ± 15**
3	**270**	**300**	**285 ± 15**
4	**300**	**330**	**315 ± 15**
5	**330**	**360**	**345 ± 15**
6	**360**	**390**	**375 ± 15**

Table 3 A summary of the temporally averaged statistics for the correlations between the TOVS NHGOS data and GOME data.					
Bounding arc length	**Average correlation coefficient**	**Correlation Coefficient**	**Standard Error (DU)**	**Average of TOVS daily means (DU)**	**Average of GOME daily means (DU)**
r = 0.25	**0.657**	**0.917**	**7.407**	**300.46**	**289.64**
r = 0.50	**0.679**	**0.968**	**3.098**	**299.39**	**288.60**
r = 0.75	**0.687**	**0.974**	**2.589**	**300.33**	**288.70**
r = 1.00	**0.676**	**0.972**	**2.545**	**300.89**	**288.78**

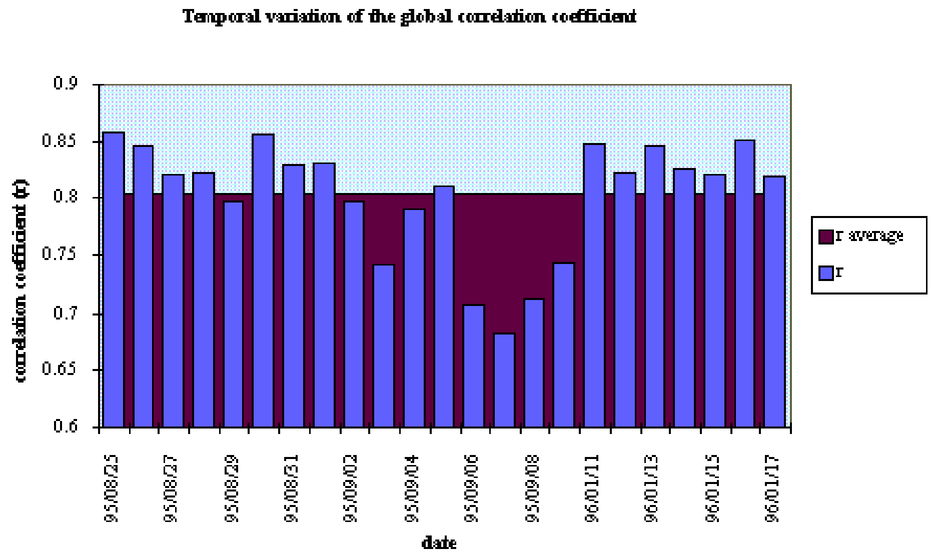

Figure 1. *The temporal variance of the global correlation coefficient (r) between ozone values derived from TOVS and GOME observations.*

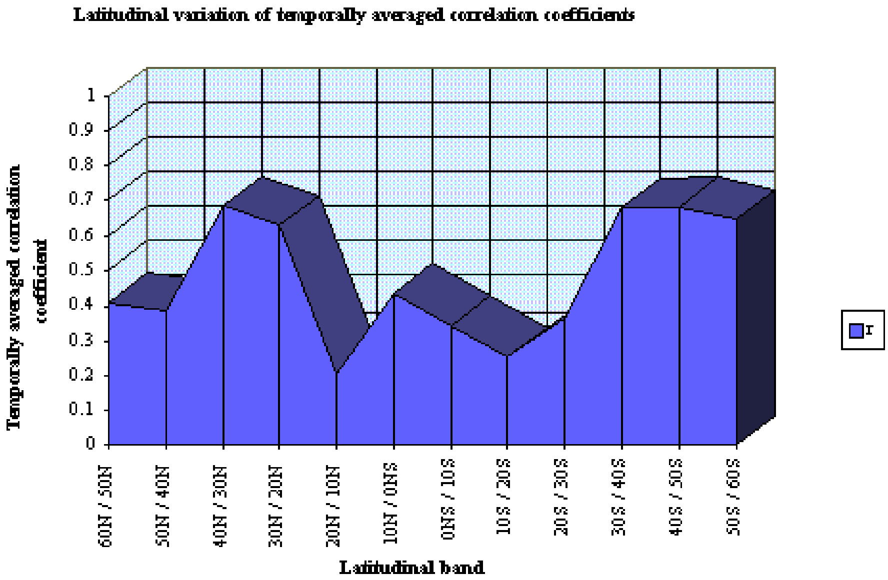

Figure 2. *The variation of the temporally averaged correlation coefficients (r) between the ozone values derived from TOVS and GOME observations for the twelve latitudinal bands detailed in Table 1.*

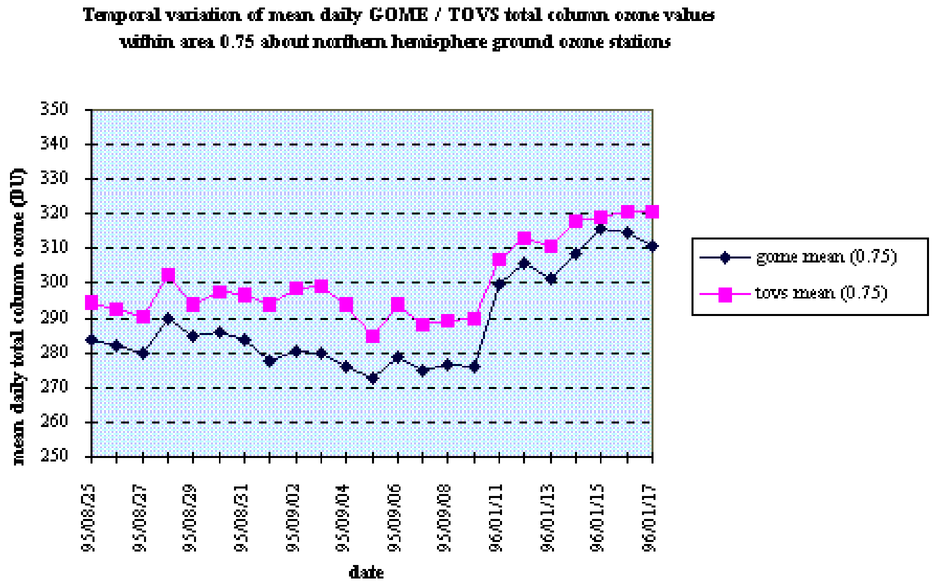

Figure 3. *The temporal variation of the mean daily ozone values derived from TOVS data at NHGOS and GOME level 2 data, within the region r=0.75.*

$$I_i = \int_{n_1}^{n_2} F_i(n) \left[B_n\left(T(p_s)\right) . t_n(p_s) + \int_{p_s}^{0} B_n\left(T(p)\right) \frac{\partial t_v(p)}{\partial p} dp \right] dn$$

m

Equation 1 *Radiative Transfer Equation, I_i is the radiance received at the i^{th} channel of the HIRS-2 sensor. ($_I$() is the transmittance function of the filter of the i^{th} channel, B(T(p)) is the Planck function at wavenumber and temperature T(p) at an altitude of atmospheric pressure of p, (p) is the transmittance at wavenumber from the altitude p to the top of the atmosphere where p = 0. The subscript s denotes the surface or cloud top.)*