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# CONSTRUCTING A COHERENT LONG-TERM GLOBAL TOTAL OZONE CLIMATOLOGY FROM THE BUV, MFR, AND SBUV/TOMS DATA SETS

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## 1. INTRODUCTION

The backscatter ultraviolet spectrometer (BUV) aboard the NIMBUS 4 satellite provided global ozone data until mid-1977. The Total Ozone Mapping Spectrometer (TOMS) and Solar Backscattered Ultraviolet (SBUV) instrument aboard the NIMBUS 7 satellite began providing global ozone in November 1978. The only satellite derived global total ozone data available between the termination of the BUV data and the startup of the SBUV/TOMS data is that from the Multichannel Filter Radiometer (MFR) instrument aboard the Defense Meteorological Satellite Program (DMSP) series of satellites.

The MFR was a cross track scanning instrument that measured radiance from channels in the 9.6-$\mu$m ozone bands, 15-$\mu$m carbon dioxide bands, 18- to 30-$\mu$m rotational water vapor band, and from the atmospheric "window" near 12-$\mu$m. MFR data began in March 1977 and continued until mid-February 1980. Four MFR instruments provided total ozone data over this period. The data from the F1 and F2 instruments span March 25, 1977 through July 10, 1977 and July 10, 1977 through February 16, 1980, respectively. Data from the other two MFR instruments began and terminated within the time period of the MFR F2 data record and are not considered in this study.

In this paper we intercompare the MFR and the SBUV/TOMS data during the data overlap period in order to determine how well the MFR data might be used to represent the SBUV/TOMS and BUV data during the data gap period.

## 2. THE COMPARISON TECHNIQUE

The DMSP satellite carrying the MFR F2 instrument was in a near polar, sun-sychronous orbit with local daytime overpass time between 8 and 10 AM at the equator on the ascending portion of its orbit. The NIMBUS satellites are also in near polar, sun-synchronous orbits but with a local noon ascending time. The MFR scans cross track so that it produces total ozone measurements at 40 to 120 km resolution (Nichols, 1975). The TOMS also scans cross track to produce total ozone measurements at 50 to 150 km resolution, whereas the SBUV measures ozone in the nadir only at a 200 km resolution (Heath et al., 1978).

We have intercompared TOMS and SBUV ozone data that are within 6 hours of an MFR ozone sample, thus eliminating the MFR ozone data measured during the nighttime descending portion of the orbit from the comparison. We experimented with various limiting distances between the MFR and the other data sample locations extending from 20 km to 400 km and found no improvement in the RMS differences at distances less than 100 km. Our testing was done over various latitude zones and over hundreds of thousands of data points. This point is demonstrated in Fig. 1 for the latitude zone 35N–45N on January 1, 1979. Intercomparison is made between the MFR and the TOMS total ozone measurements at distances of 0-50 km, 50-100 km, 100-200 km, 200-300 km, and 300-400 km. We also compared the MFR data with itself, and the TOMS data with itself at various separation distances beginning with 50-100 km separation in order to see how the data vary with distance for each sensor. Contributions to the RMS difference in these latter two cases come from random error in the measurements, possible systematic error with cross track scan angle, and variation of ozone. Both curves have similar slopes, increasing as separation distance increases, and they each show significantly less RMS difference than the MFR-TOMS intercomparison.

Fig. 2 shows the scatter of the 1103 MFR and TOMS ozone values at the 100 km-or-less separation distance. A wide range of values occurs within this zonal band. The correlation coefficient is 0.88 for the MFR and TOMS data. In Fig. 3 the average of the ozone values in 10 degree latitude-longitude bins for this same latitude zone shows no obvious phase differences at the larger scale or bias between the two data sets. Therefore we selected the 100 km-or-less separation distance for all intercomparisons.

## 3. THE MFR OZONE RETRIEVAL MODEL

The theory and total ozone retrieval algorithm development for the MFR are discussed in Lovill el al. (1978) and updated in Luther and Weichel (1981). The retrieval algorithms were statistically derived using the method of multiple linear regression. The dependent data used in the statistical regression technique were vertically integrated total ozone from historical ozonesondes (calibrated against the Dobson spectrophotometer), and simulated MFR radiances calculated with a line-by-line radiation code as applied to the atmospheric vertical temperature, ozone, water vapor, cloud, and $CO_2$ profiles. Retrieval algorithms were developed for each of 11 latitude bands and for each calendar month (132 different algorithms in total) by employing dependent data that were geographically located within each band and that spanned a two month period centered on the month of interest.

We have selected four days of the MFR and TOMS total ozone data (one day from each season) to evaluate how well the algorithms met their designed capability (Table 1). The linear correlation coefficient as applied to the dependent data set, which gives a measure of the design capability of the algorithm and is the square root of the fractional variance explained by the algorithm, is represented by r' for each month within each of the 11 latitude bands. Linear correlations (r') vary from as low as 0.28 in the tropics, where total ozone has only small temporal and spatial variation (small signal to noise ratio), to as high as 0.90 in the higher latitudes, where total ozone generally shows large temporal and spatial variation (large signal to noise ratio). The percent standard deviation (s) of one day of TOMS total ozone data within each latitude band depicts the spatial variation of total ozone with latitude and with season.

In latitude zones 15S-25S and 50S-70S there are no r' values except in the zone 50S-70S during the month of July. This indicates that the algorithm used within that zone was interpolated from the algorithm in adjacent bands north and south. Interpolation was required when there were insufficient ozonesonde data available in a latitude band for constructing an ozone retrieval algorithm.

Also shown in Table 1 is the linear correlation coefficient (r) between the MFR and the TOMS total ozone data for each of the four days. For the most part the r' and the r values agree quite well. However, there are cases where the r' values are much larger than the r values. If the TOMS total ozone data are taken as a reference standard by which to measure the MFR total ozone algorithm accuracy, then the algorithms in the latitude bands marked with a star are performing below their design capability. Since the objective of this work is to determine how well the MFR total ozone data might perform as a surrogate data set in place of the TOMS/SBUV data during the period between the BUV and SBUV/TOMS data, then using the TOMS data as a reference standard is appropriate. The correlation coefficient is not an absolute measure of how well the MFR and TOMS data sets agree since two data sets can show high correlation yet show large average difference and RMS difference due to biases and differences in wave amplitudes or scaling, respectively. In the next section we examine these latter two differences.

## 4. INTERCOMPARISON OF THE MFR AND THE SBUV/TOMS OZONE DATA

We have selected data for one month out of each season during the data overlap period of the MFR and SBUV/TOMS ozone data to demonstrate how well they intercompare. Average differences (d) and the standard deviation of the differences (sd), both in percent, for 5 months of data in 10 degree latitude bands (except at the poles where they are 5 degree bands) are shown in Table 2. There are more than 10,000 intercomparisons for each entry in the table except at the northernmost and southernmost entries, which can be as small as 600 intercomparisons. The majority of the differences are negative in sign indicating that the TOMS average ozone is less than the MFR average. The reverse is true only in the northern middle latitudes in January 1979 and 1980 and in the southern tropical to middle latitudes in July and November 1979. The fact that the average difference varies with latitude is undoubtedly partially caused by differences in the 11 MFR ozone retrieval algorithms.

It is surprising that differences are not more nearly equivalent between the two January cases, since the same MFR retrieval algorithms have been used. In fact the differences in January 1980 are more positive by 3% in the southern high latitudes, by 1% in the southern tropics, and by more than 7% in the northern high latitudes than they are in corresponding latitudes in January 1979. The TOMS data increased by a larger amount in the Southern Hemisphere from January 1979 to January 1980 than did the MFR data. In the northern high latitudes the MFR data actually decreased between the two Januaries, whereas the TOMS data increased. Bhartia et al. (1984) found that the TOMS data increased by 0.34 ±0.17% with respect to the Dobson data from the first to the second year of data, which would account for less than 0.5% of the difference.

The standard deviation of the differences (% sd in Table 2) varies by less than 3% at the equator to greater than 9% in the January northern high latitudes. These numbers are about 1.5 times greater than those Bhartia et al. (1984) observed between the TOMS and the Dobson spectrophotometer data.

We have also compared the MFR data with the SBUV total ozone data and the TOMS data with the SBUV total ozone data using the same SBUV data points in both cases. The number of intercomparisons are 10 to 20 times fewer than in the MFR-TOMS intercomparison because of the smaller number of measurements from the non-scanning, nadir looking SBUV instrument. We have elected to show the percent difference of the TOMS minus the SBUV total ozone (Table 3) and use the TOMS data as a transfer standard between the MFR and the SBUV data. The differences in Table 3 vary from 0.4% in the northern tropical latitudes in April to 3% or less in the higher latitudes for all months. Taken together, these numbers do not disagree with the overall 1.7% difference that Bhartia et al. (1984) found. However, there is some indication from Table 3 that this difference is getting larger with time.

Even though the number of intercomparisons in each entry of Table 2 differs by an order of magnitude from the number used in each entry in Table 3, the differences between the MFR and TOMS ozone are essentially the same using either the MFR-TOMS or the MFR-SBUV data (not shown). Therefore, the entries in Table 3 can be subtracted from the entries in Table 2 to show approximately how the MFR and SBUV differ. The differences become smaller for all positive entries and larger for all negative entries in Table 2. Since most of the entries in Table 2 are negative, the MFR-SBUV differences are generally greater than the MFR-TOMS differences.

## 5. CONCLUSIONS

From the sample of five months studied, we see that the differences between the MFR total ozone and the TOMS or SBUV total ozone are latitudinally and monthly dependent. The average differences between the TOMS and the MFR ozone vary from -12.4 to +13.3% with differences in the tropical to middle latitudes generally between ±4%. The standard deviation of the differences for the same intercomparison set vary from 2.5 to 10%, the largest values being in the high latitudes.

There are latitude zones in which biases occur between the data sets which can be removed by operating on the MFR ozone data with an appropriate algorithm. The latitude zones in which the standard deviation of the differences are large are more difficult to reconcile with the TOMS data. One possibility for correcting this type of difference is to reconstruct the MFR statistical retrieval algorithms by regressing the MFR radiance data on the TOMS or SBUV total ozone data.

## ACKNOWLEDGEMENTS

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## REFERENCES

Bhartia, P. K., K. F. Klenk, C. K. Wong, and D. Gordon, (1984) "Intercomparison of the NIMBUS 7 SBUV/TOMS Total Ozone Data Sets With Dobson and M83 Results," *J. Geophys. Res.*, *89*, 5239–5247.

Heath, D., A. J. Krueger, and H. Park, (1978) "The Solar Backscatter Ultraviolet (SBUV) and Total Ozone Mapping Spectrometer (TOMS) experiment, in the NIMBUS 7 User's Guide," edited by C.R. Madrid, NASA Goddard Space Flight Center, Greenbelt, Md., 175-211.

Lovill, J. E., T. J. Sullivan, R. L. Weichel, J. S. Ellis, J. G. Huebel, J. A, Korver, P. P. Weidhaas, and F. A. Phelps, (1978) "Total Ozone Retrieval From Satellite Multichannel Filter Radiometer Measurements," Lawrence Livermore National Laboratory, UCRL-52473, 97 pp.

Luther, F. M. and R. L. Weichel, (1981) "Determination of total ozone from DMSP multichannel filter radiometer measurements," Proceedings of the Quadrennial International Ozone Symposium, Boulder, Colorado.

Nichols, D. A., (1975) "DMSP block 5D special meteorological sensor H, optical subsystem," *Opt. Engr.*, *14*, 284-288.

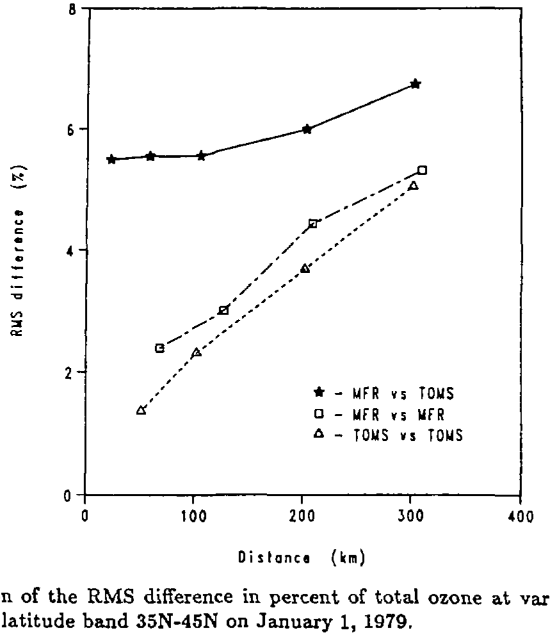

Fig. 1. Variation of the RMS difference in percent of total ozone at various separation distances in the latitude band 35N-45N on January 1, 1979.

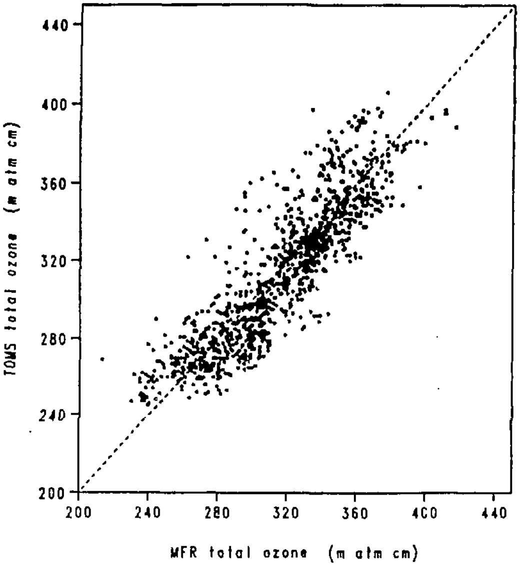

Fig. 2. Scatter plot of the MFR and TOMS total ozone (1103 points at 100 km separation distance) in latitude band 35N-45N on January 1, 1979.

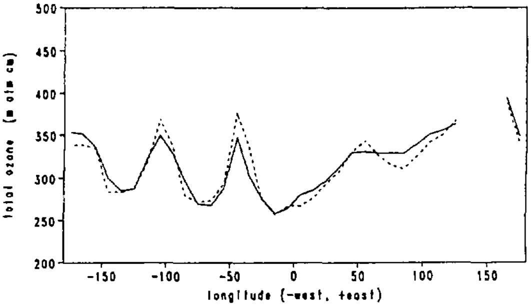

Fig. 3. The 1-by-10 degree latitude-longitude average of the 1103 MFR (solid) and the TOMS (dashed) total ozone data at 100 km separation distance inthe 35N-45N latitude zone on January 1, 1979.

Table 1. The linear correlation coefficient within latitude zones between MFR and TOMS total ozone on selected days (r), between the historical ozonesonde data and model calculations (r'), and the percent standard deviation of the TOMS total ozone within the latitude zones (s).

| Latitude | Jan. 13, 1979 | | | Apr. 15, 1979 | | | July 14, 1979 | | | Nov. 15, 1979 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | r | r' | s (%) | r | r' | s (%) | r | r' | s (%) | r | r' | s (%) |
| 90N-70N | | | | * 0.39 | 0.76 | 5 | 0.83 | 0.89 | 7 | | | |
| 70N-55N | 0.89 | 0.79 | 17 | 0.77 | 0.84 | 9 | 0.73 | 0.79 | 6 | 0.81 | 0.85 | 13 |
| 55N-45N | 0.93 | 0.90 | 15 | 0.78 | 0.86 | 8 | 0.71 | 0.90 | 6 | 0.84 | 0.89 | 12 |
| 45N-35N | 0.86 | 0.87 | 10 | 0.80 | 0.89 | 12 | * 0.52 | 0.82 | 7 | 0.82 | 0.92 | 10 |
| 35N-25N | 0.78 | 0.78 | 9 | * 0.60 | 0.82 | 8 | * 0.32 | 0.69 | 5 | * 0.34 | 0.83 | 5 |
| 25N-15N | 0.55 | 0.51 | 5 | * 0.36 | 0.62 | 6 | * 0.32 | 0.56 | 3 | * 0.06 | 0.63 | 3 |
| 15N-15S | 0.44 | 0.39 | 3 | 0.40 | 0.28 | 3 | 0.72 | 0.28 | 5 | 0.41 | 0.42 | 4 |
| 15S-25S | 0.48 | -- | 3 | 0.27 | -- | 3 | 0.58 | -- | 4 | 0.65 | -- | 4 |
| 25S-50S | 0.90 | 0.83 | 8 | 0.78 | 0.84 | 7 | 0.88 | 0.89 | 13 | 0.87 | 0.90 | 8 |
| 50S-70S | 0.71 | -- | 6 | 0.55 | -- | 7 | 0.79 | 0.86 | 12 | 0.87 | -- | 13 |
| 70S-90S | 0.65 | 0.76 | 4 | * 0.55 | 0.87 | 4 | | | | 0.84 | 0.75 | 14 |

Table 2. The average difference (d) and the standard deviation (sd) of the differences of the TOMS minus the MFR total ozone, both in percent of the MFR total ozone, for selected months.

| Latitude | Jan. 79 | | Apr. 79 | | Jul. 79 | | Nov. 79 | | Jan. 80 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | d | sd | d | sd | d | sd | d | sd | d | sd |
| 90N-85N | | | -4.1 | 7.6 | -4.2 | 4.2 | | | | |
| 85N-75N | | | -3.6 | 8.0 | -4.9 | 4.5 | | | | |
| 75N-65N | 2.8 | 9.2 | 0.2 | 6.6 | -7.3 | 5.0 | -0.3 | 8.7 | 13.3 | 10.1 |
| 65N-55N | 4.1 | 9.3 | -1.0 | 5.8 | -5.9 | 4.6 | 0.5 | 8.2 | 10.7 | 9.2 |
| 55N-45N | -0.8 | 7.4 | 0.1 | 6.3 | -2.1 | 4.8 | -1.2 | 6.3 | 0.8 | 7.8 |
| 45N-35N | 0.8 | 6.5 | -2.5 | 7.0 | -3.8 | 6.5 | -0.4 | 5.6 | -1.1 | 7.0 |
| 35N-25N | 0.0 | 5.8 | -2.2 | 7.2 | -5.4 | 6.6 | -3.1 | 5.7 | -3.6 | 6.3 |
| 25N-15N | -6.3 | 5.8 | -2.3 | 6.2 | -2.2 | 5.2 | -4.1 | 6.1 | -9.4 | 5.1 |
| 15N- 5N | -5.5 | 3.5 | -0.6 | 3.8 | 1.8 | 2.9 | -0.6 | 3.8 | -5.9 | 3.5 |
| 5N- 5S | -4.9 | 2.6 | -2.4 | 3.7 | -2.6 | 3.0 | 1.2 | 3.4 | -0.8 | 2.9 |
| 5S-15S | -1.2 | 3.2 | -3.5 | 3.3 | -2.8 | 2.5 | 3.6 | 3.1 | 2.0 | 3.2 |
| 15S-25S | -0.6 | 4.0 | -4.0 | 3.6 | -1.3 | 3.8 | 2.6 | 4.9 | 2.5 | 4.4 |
| 25S-35S | 0.7 | 3.4 | -1.3 | 4.1 | 0.0 | 5.4 | 2.6 | 3.6 | 2.2 | 3.6 |
| 35S-45S | -1.2 | 3.4 | -2.3 | 3.8 | 0.3 | 5.7 | 0.6 | 4.1 | 0.2 | 4.0 |
| 45S-55S | -1.1 | 4.1 | -2.7 | 5.5 | 1.7 | 7.4 | 2.9 | 5.7 | 0.6 | 4.7 |
| 55S-65S | -3.7 | 4.6 | -0.5 | 8.3 | 4.1 | 8.3 | 3.7 | 7.4 | -1.5 | 4.7 |
| 65S-75S | -7.2 | 4.0 | 0.0 | 7.0 | 9.9 | 5.7 | -1.6 | 8.6 | -4.9 | 4.7 |
| 75S-85S | -8.9 | 3.2 | -4.7 | 6.0 | | | -8.2 | 7.0 | -6.4 | 3.8 |
| 85S-90S | -10.6 | 2.8 | | | | | -12.4 | 6.7 | -7.4 | 4.0 |

Table 3. The average difference of the TOMS minus the SBUV total ozone as a percent of the MFR total ozone for selected months.

| Latitude | Jan. 79 | Apr. 79 | Jul. 79 | Nov. 79 | Jan. 80 |
|---|---|---|---|---|---|
| 90N-85N | | | | | |
| 85N-75N | | 2.6 | 1.7 | | |
| 75N-65N | | 1.6 | 1.8 | 0.4 | |
| 65N-55N | 2.6 | 1.6 | 1.4 | 2.2 | 2.8 |
| 55N-45N | 1.8 | 1.7 | 1.8 | 2.4 | 2.4 |
| 45N-35N | 2.1 | 1.7 | 1.4 | 2.2 | 2.1 |
| 35N-25N | 1.8 | 0.9 | 0.8 | 2.0 | 2.0 |
| 25N-15N | 1.3 | 0.4 | 0.5 | 2.1 | 2.3 |
| 15N- 5N | 1.0 | 0.4 | 1.4 | 2.5 | 2.0 |
| 5N- 5S | 1.2 | 1.4 | 1.6 | 2.3 | 2.2 |
| 5S-15S | 1.2 | 1.2 | 1.4 | 2.4 | 2.6 |
| 15S-25S | 1.0 | 1.2 | 1.5 | 2.1 | 1.9 |
| 25S-35S | 1.1 | 1.5 | 1.8 | 2.2 | 2.0 |
| 35S-45S | 1.6 | 1.8 | 1.7 | 2.6 | 2.7 |
| 45S-55S | 2.2 | 1.5 | 1.7 | 3.0 | 3.0 |
| 55S-65S | 1.8 | 1.5 | 2.2 | 3.0 | 2.8 |
| 65S-75S | 2.0 | 1.4 | 4.2 | 3.3 | 2.8 |
| 75S-85S | 1.1 | 1.7 | | 1.7 | 1.6 |
| 85S-90S | | | | | |

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