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UV and total ozone climatology at the South Pole based on Version 2 NSF network data

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ABSTRACT

Spectral ultraviolet (UV) and visible irradiance has been monitored at the South Pole with a SUV-100 spectro-radiometer since 1991. A new data version labeled "Version 2" has recently been produced, which has a higher accuracy than the original released "Version 0". We have established a UV climatology for the South Pole based on the new data set, focusing on the effects of cloudiness, total column ozone, and volcanic aerosols. In addition, total column ozone was calculated from the spectral UV measurements for solar zenith angles (SZA) up to 87° using a recently developed algorithm. This new total ozone data set can complement Dobson ozone observations to validate satellite total ozone data. At the South Pole, NASA/TOMS Version 7 overpass data exceed SUV-100 total ozone measurements by 5-8%. In contrast, TOMS Version 8 data agree on average to within 2% with SUV-100 measurements, and the ratio of the two data sets shows virtually no dependence on SZA and the ozone amount. The good agreement confirms that the well-documented bias of TOMS Version 7 data at high austral latitudes was successfully reduced with the release of Version 8. A similar comparison between SUV-100, Dobson, and TOMS ozone measurements was performed for the NSF/OPP network site at Arrival Heights (78°S), and results are discussed.

Keywords: Solar ultraviolet radiation, Antarctica, climatology, total ozone.

1. INTRODUCTION

The National Science Foundation Office of Polar Programs (NSF/OPP) Ultraviolet Radiation Monitoring Network was established in 1987 in response to severe ozone depletion reported in Antarctica. The network currently consists of six stations that are equipped with high-resolution SUV-100 spectroradiometers measuring global spectral irradiance between 280 and 600 nm. An overview of the network including locations, instrumentation, measurement protocols, data analysis methods, quality control procedures, and data dissemination can be found in *Booth et al.*[1], Network Operations Reports[2], and at the website www.biospherical.com/nsf.

Currently published NSF/OPP network data have not been corrected for deviations of the angular response of SUV-100 spectroradiometers from the ideal cosine response. Furthermore, slight modifications to instrumentation and data analysis methods have occurred over the years of operation, causing discontinuities in data time series. To improve accuracy, a new data version, named "Version 2", has recently been produced. The new data set will be introduced in a paper submitted to *Journal of Geophysical Research* (JGR). This paper will also include a climatology of UV radiation at the South Pole (SPO). As there is no need to duplicate all results here, we will only summarize the most important findings.

Clouds at SPO are predominantly optically thin and attenuate UV irradiance on average by less than 5%; attenuation by more than 23% was not observed. Largest radiation levels occur in late November and early December when low stratospheric ozone amounts coincide with relatively small SZAs. Due to the large effect of the "ozone hole", short and long-term variability of UV during the austral spring is very high. When the ozone hole breaks down, DNA-damaging irradiance can decrease by more than a factor of two within two days. Summer UV Index values range between 2 and 3.5, which is small compared to typical mid-latitude values, however, daily UV doses at the South Pole are comparable

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with mid-latitude levels due to 24 hours of daylight. Aerosols from the Mt. Hudson eruption of 1991 reduced UV radiation by about 5-10%.

As an example of the new data set, Figure 1 shows monthly average erythemal daily dose at SPO. There are large changes between different years due to large differences in total ozone. This high year-to-year variability prevents the calculation of statistically significant trends in erythemal UV during the monitoring period. As the NSF/OPP UV monitoring network was established only after the ozone hole had been discovered, no data is available to directly compare current UV measurements with data from the pre-ozone hole era. Measurements between the years 1991–2002 therefore document variability on an elevated level.

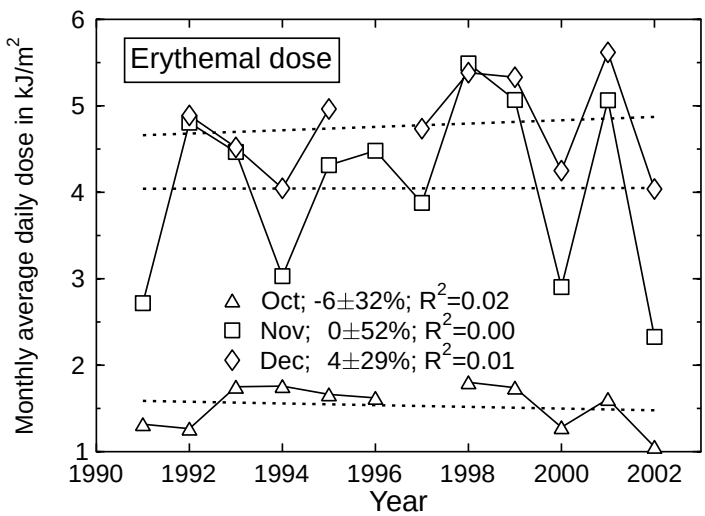

Figure 1. Monthly average erythemal daily dose for October, November, and December at the South Pole. Dashed lines are trend lines determined by linear regression. Trend per decade, uncertainty of trend, and regression coefficient R^2 are indicated in the legend.

The remainder of this manuscript will focus on total column ozone values retrieved from spectral UV measurements at SPO and Arrival Heights. Both data sets are part of the Version 2 data release, but are not discussed in the JGR publication mentioned previously.

2. TOTAL OZONE MEASUREMENTS BY SUV-100, TOMS, AND DOBSON

Total column ozone was calculated from SUV-100 UV spectra using the inversion algorithm described by *Bernhard et al.*[3] and the *Bass and Paur*[4] ozone absorption cross section. In brief, measured spectra were compared with several modeled spectra that had been calculated with different settings of the model total ozone value. The ozone value returned by the method is the model ozone value that leads to the best agreement between measurement and model. To obtain most accurate results, ozone profiles used in model calculations were taken from balloon soundings performed in close spatial and temporal proximity with UV measurements. At the South Pole, ozone profiles measured by NOAA's Climate Monitoring and Diagnostics Laboratory (CMDL) were used. Soundings were performed approximately every 3rd day during the austral summer. Ozone profiles for Arrival Heights were measured at McMurdo and are part of the data set maintained by the Network for the Detection of Stratospheric Change (NDSC).

2.1 Comparison of total ozone measurements at South Pole

Figure 2 shows a comparison of SUV-100 total ozone values measured at the South Pole with observations from the collocated NOAA/CMDL Dobson spectrophotometer, as well as TOMS Version 7 and 8 total ozone data. In Panels

A-C of Figure 2, ratios of the three data sets are plotted versus SZA. Panels D-F depict the same data sets but plotted versus total ozone. Statistics of the comparison are provided in Table 1. Only SUV-100 spectra measured to within ±30 minutes of the TOMS overpass were used; SUV-100 and Dobson observations were separated by less than ±60 minutes.

The following conclusions can be drawn from the comparison:

- For SZAs smaller than 80°, Dobson ozone values are on average 1.6% smaller than SUV-100 values. The difference of both instruments increases at larger SZAs. A closer inspection revealed that differences between the two instruments at large SZAs may in fact be caused by dependence on total ozone. The agreement of the two data sets is better if the comparison is restricted to Dobson "AD" measurements (Figure 2D). The reasons for the larger differences for other Dobson observation modes is still under investigation.
- TOMS Version 7 ozone values are biased high by 5-8%. The offset is somewhat dependent on SZA and total ozone. For example, Figure 2E shows that the bias is larger during the ozone hole period when total ozone is below 220 DU. The bias in Version 7 TOMS data at high southern latitudes has been noted previously[5], and is one of the reasons why Version 8 TOMS data were recently produced by NASA.
- Version 8 TOMS data at the South Pole are on average 1.7% lower than SUV-100 data. The ratio of the two data sets depends only little on SZA (Figure 2C) and total ozone (Figure 2F).

Differences between TOMS Version 7 and 8 data at high latitude are the result of a combination of several effects including: hemisphere- and month-dependent tropospheric ozone and temperature climatology, improved cloud model for snowy scenes, and a new correction for profile shape errors[6].

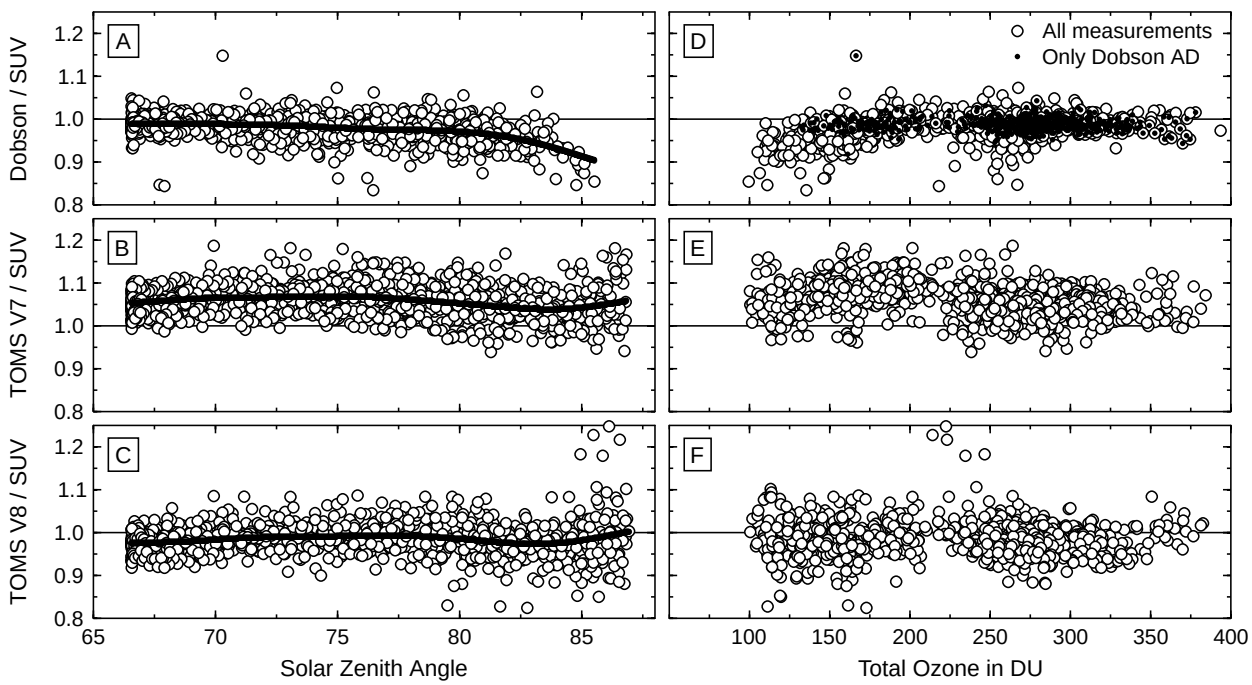

Figure 2. Ratios of total column ozone measured by Dobson and TOMS relative to SUV-100 total ozone observations at the South Pole. In Panels A-C, the data sets are plotted versus solar zenith angle. In Panels D-F, the same data sets are plotted versus total ozone. Panel A and D: Ratio Dobson / SUV-100. Panel B and E: Ratio TOMS Version 7 / SUV-100. Panel C and F: Ratio TOMS Version 8 / SUV-100 The thick lines in Panels A-C are trend lines fitted to the data.

Table 1: Statistics of comparison of SUV-100, Dobson, TOMS Version 7, and Version 8 total ozone observations at South Pole.

Data set	Ratio ± 1σ
South Pole	
Dobson / SUV-100 at South Pole	
All data	0.981 ± 0.028
SZA < 80°	0.984 ± 0.025
Dobson AD pair	0.988 ± 0.016
Dobson CD pair, Ozone > 220 DU	0.984 ± 0.030
Dobson CD pair, Ozone < 220 DU	0.960 ± 0.034
TOMS Version 7 / SUV-100 at South Pole	
All data	1.057 ± 0.035
SZA < 80°	1.061 ± 0.031
Nimbus 7 (Feb 91 – Feb 93)	1.070 ± 0.033
Meteor (Oct 93 – Nov 94)	1.063 ± 0.034
Earth Probe (Oct 96 – Jan 03)	1.052 ± 0.035
Total ozone < 130 DU	1.053 ± 0.036
130 DU < total ozone < 220 DU	1.080 ± 0.035
Total ozone > 220 DU	1.047 ± 0.031
TOMS Version 8 / SUV-100 at South Pole	
All data	0.983 ± 0.038
SZA < 80°	0.984 ± 0.029
Nimbus 7 (Feb 91 – Mar 93)	0.992 ± 0.035
Earth Probe (Oct 96 – Jan 03)	0.980 ± 0.038
Arrival Heights	
Dobson / SUV-100 at Arrival Heights	
All data (Jan 94 – Jan 03)	1.002 ± 0.041
SZA < 80°	1.003 ± 0.037
Earth Probe TOMS Version 7 / SUV-100 at Arrival Heights	
All data (Aug 96 – Jan 03)	1.045 ± 0.053
SZA < 80°	1.045 ± 0.041
Earth Probe TOMS Version 8 / SUV-100 at Arrival Heights	
All data (Aug 96 – Jan 03)	0.978 ± 0.054
SZA < 80°	0.973 ± 0.044

2.2 Comparison of total ozone measurements at Arrival Heights

Figure 3 shows a comparison of SUV-100, Earth Probe TOMS, and Dobson total ozone observations at Arrival Heights (77°50'S, 166°40'E, altitude 183 m). Arrival Heights is located on Ross Island, Antarctica, close the U.S. research base McMurdo. Dobson data from the period 1/22/94–1/22/03 were measured by New Zealand's National Institute of Water & Atmospheric Research (NIWA). Only Earth Probe TOMS data from the period 8/30/96 – 1/22/03 were used. Statistics of the comparison are also included in Table 1.

The following conclusions can be drawn:

- There is no bias between SUV-100 and Dobson data. The ratio of the two data sets is independent of SZA (Figure 3A) and total ozone (Figure 3D).
- TOMS Version 7 data exceed SUV-100 measurements on average by 3-5.5%. The scatter between the two data sets is somewhat larger as for the Dobson/SUV-100 comparison. This may partly be caused by the variation of total ozone over the footprint of TOMS and uncertainties introduced by clouds.
- TOMS Version 8 total ozone observations are on average lower by 0-3% than SUV-100 measurements. The ratio TOMS/SUV-100 increases slightly with SZA. The scatter between TOMS Version 8 and SUV-100 data is similar to the scatter observed for the TOMS Version 7 / SUV-100 comparison.

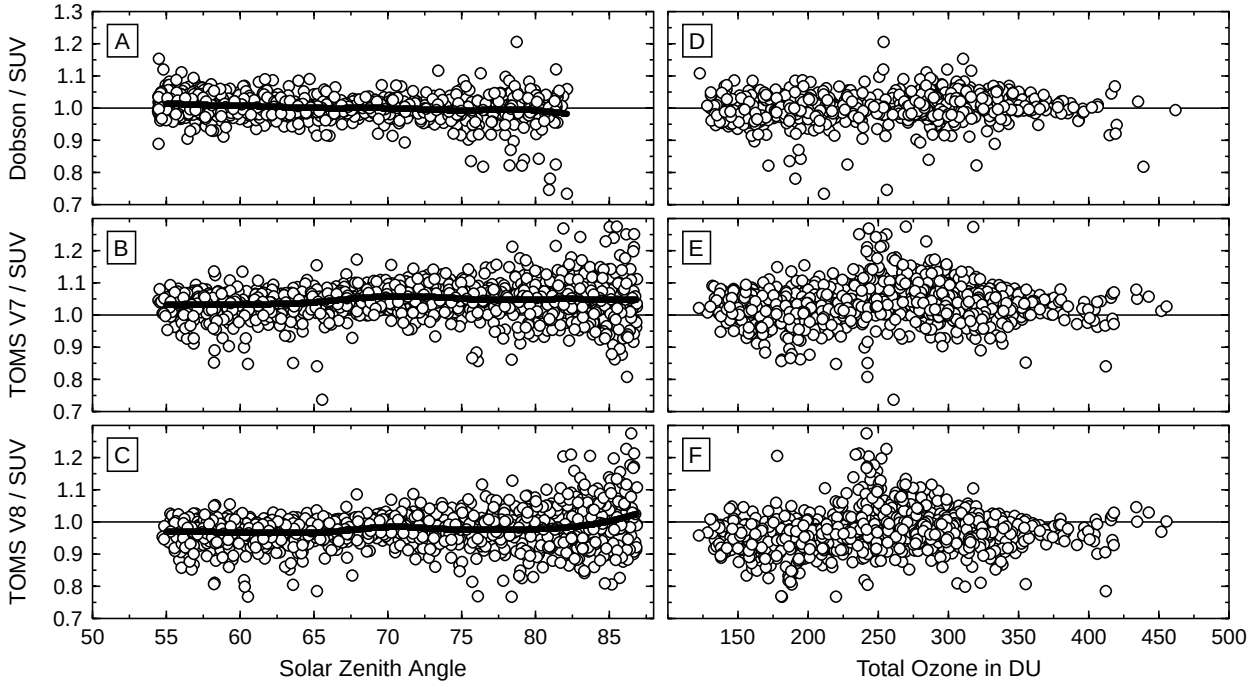

Figure 3. Ratios of total column ozone measured by Dobson and TOMS relative to SUV-100 total ozone observations at Arrival Heights. In Panels A-C, the data sets are plotted versus solar zenith angle. In Panels D-F, the same data sets are plotted versus total ozone. Panel A and D: Ratio Dobson / SUV-100. Panel B and E: Ratio TOMS Version 7 / SUV-100. Panel C and F: Ratio TOMS Version 8 / SUV-100 The thick lines in Panels A-C are trend lines fitted to the data.

3. CONCLUSIONS

A new version of UV data of the NSF/OPP network is currently being produced. Version 2 data for SPO are now available and a paper introducing the new data set has been submitted to *Journal of Geophysical Research.* Version 2 data for Arrival Heights will become available shortly. A climatology of UV radiation at the South Pole has been prepared, focusing on the effects of clouds, total ozone, and aerosols on UV. Version 2 also includes new data products such as total ozone. We have compared the new ozone data set with Dobson and TOMS measurements at SPO and Arrival Heights. This comparison confirmed the well established bias of TOMS Version 7 data at high southern latitudes. Recently released TOMS Version 8 ozone data agree very well with SUV-100 ozone values at the South Pole, but are a few percent lower at Arrival Heights. There is excellent agreement between Dobson and SUV-100 measurements at Arrival Heights. Dobson and SUV-100 ozone data at SPO agree on average to within ±2%, but show larger differences at low ozone values and large SZAs. The reason for these discrepancies is still under investigation. SUV-100 ozone values are available at high temporal resolution, allowing to investigate changes in total ozone during the course of one day.

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sonde data from McMurdo available. Dobson ozone measurements at Arrival Heights were performed by New Zealand's National Institute of Water & Atmospheric Research (NIWA) and were obtained from the World Ozone and Ultraviolet Radiation Data Centre.

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