6 Years of Ozone and UV Measurements with Brewer #199 at Marambio, Antarctica

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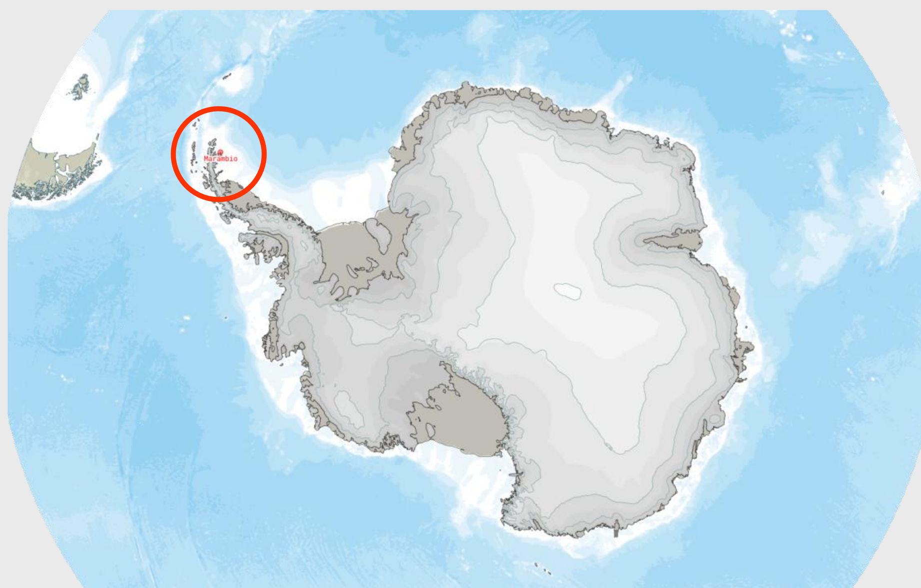
HISTORY

Brewer #199, MKIII, has been bought in 2009. After necessary tests at Solar and Ozone Observatory (SOO) of the Czech Hydrometeorological Institute (CHMI) at Hradec Kralove, it was moved to Marambio Base (Seymour Island, 64.233 S, 56.623 W, 198 msl) and put into operation on February 14, 2010. The operation is funded by the State Environmental Fund of the Czech Republic (SFŽP ČR) under the project No. 03461022 *„Monitoring of the State of the Earth Ozone Layer and UV-radiation in Antarctica“*.



With exception of enhanced heating and insulation, the instrument has not been specially modified for operation in hard Antarctic environment. Measured data are sent daily to SOO Hradec Kralove via Inmarsat BGAN network. It allows not only regular supervision of the instrument and the data transmissions but also remote control of both Brewer and connected notebook. Regular operation of the instrument is safeguarded by the cooperation with the staff of Dirección Nacional del Antártico, Instituto Antártico Argentino (DNA/IAA), Argentina.

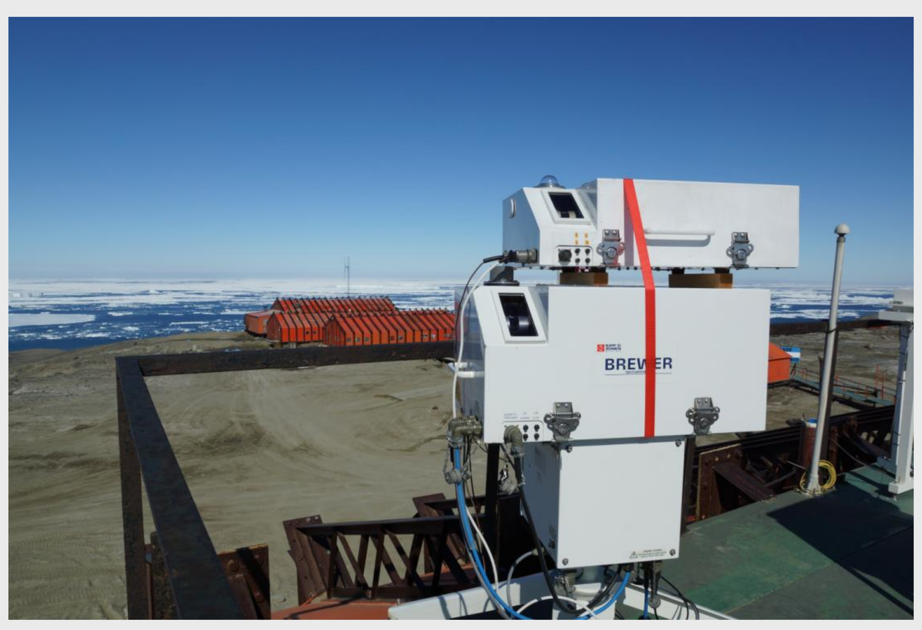
Total ozone (TOZ) measurements are possible in the period from cca August 8 to cca April 30, when the Sun rises at least 10 degrees above horizon at noon. In remaining part of the year, Sun elevation is too low for reliable ozone measurements.

In addition to TOZ measurements, B#199 also takes UV spectral measurements (286.5 to 363 nm, each 30 minutes) and Umkehr measurements.

MAINTENANCE AND CALIBRATIONS

Every year, in January or February, the instrument is serviced by specialists from CHMI and International Ozone Services, Inc., Canada (IOS). In 2012 and 2016 these service trips were connected with calibration of B#199 with the help of traveling standard B#017, directly at Marambio Base (the first ever calibrations of Brewer spectrophotometers in Antarctica).

The instrument appeared to be very stable and reliable. “Daily representative values” of TOZ are available for 98% of the days with sufficient Sun elevation.



SUMMARY OF MEASUREMENT TYPES

Annually, about 10900 individual measurements are taken on average. Table below summarizes the proportion of individual measurement types, according to WOUDC ObsCode (period 2010-2015):

WOUDC ObsCode	DS	ZS	GI	FZ
Perc. of obs.	18 %	40 %	40 %	2 %

Due to low Sun elevations in some parts of the year, measurements at high MU values are very important at this high-latitude station. The table below indicates minimal MU values during the measurements in individual months in period 2010-2015:

MONTH	JAN	FEB	MAR	APR	...	AUG	SEP	OCT	NOV	DEC
MIN. MU	1.32	1.46	1.80	2.70	...	3.24	2.05	1.54	1.35	1.32

For example, all April measurements were taken at MU≥2.7 and all August measurements at MU≥3.24.

As for “daily representative values”, most of them (73%) could be calculated from DS measurements, 24% from ZS measurements and only 3% were calculated from GI measurements.

It is clear that ZS measurements, even at high MU values, are very important at Marambio Base, as this type of measurement significantly contributes to "daily representative value" calculations. For this reason, accuracy of ZS measurements becomes very important question.

COMPARISON OF DS AND ZS MEASUREMENTS OF TOZ - METHOD

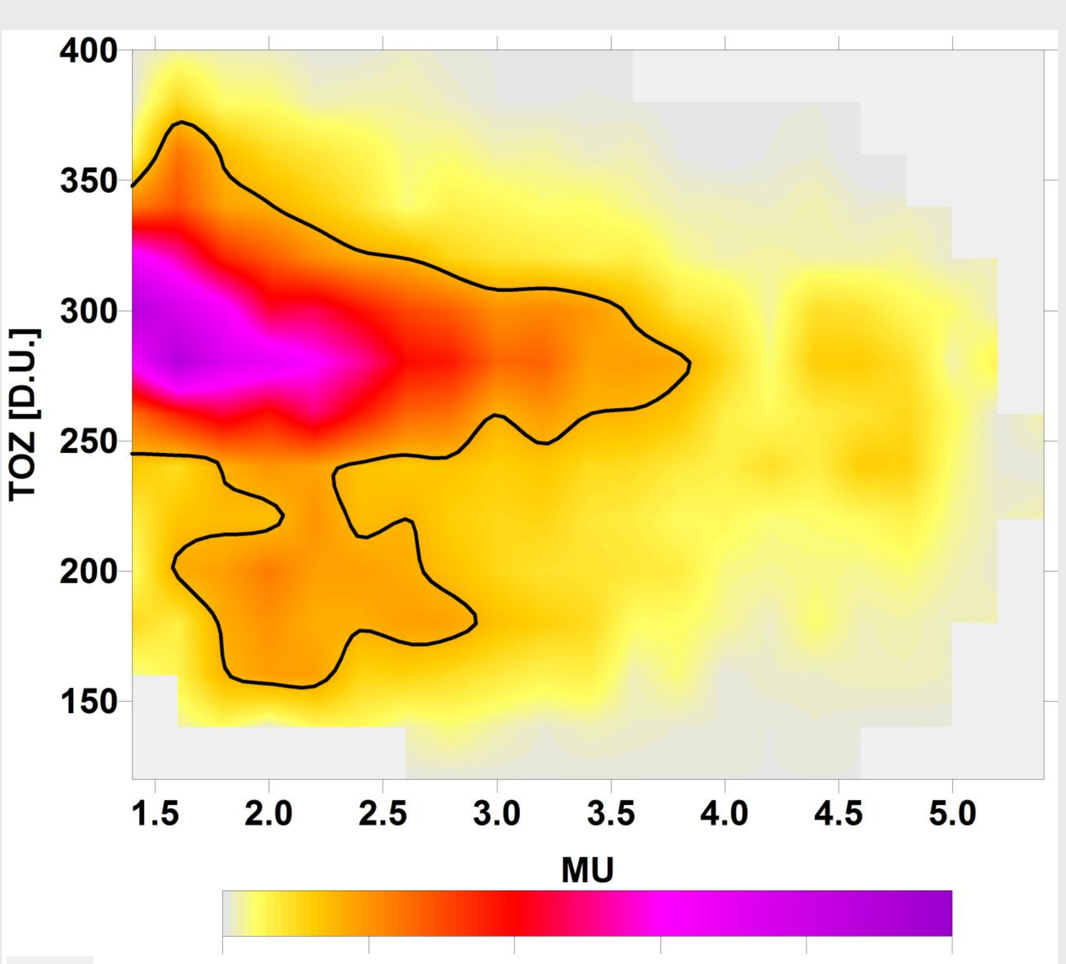


Fig.1

From the period August 2010 - April 2015 (5 whole “measurement seasons”), pairs of almost concurrent DS and ZS measurements of TOZ were selected, with maximal 10 minutes time difference between them. In this way, 7624 pairs were found. These pairs of TOZ data, one of them DS (= TOZ_{DS}), the other ZS (= TOZ_{ZS}), were categorized to the “bins” according to solar MU (at the moment of DS measurement) and TOZ_{DS} value. The step between bins was 0.2 in MU values and 20 D.U. in TOZ_{DS} values. Totally, 246 bins were defined in this way. Then mean values of both TOZ_{DS} and TOZ_{ZS} were calculated for each bin and compared.

Figure 1 indicates the number of TOZ pairs in individual bins. Black line marks the region with above-average (=39) number of pairs in individual bins. Strong concentration of TOZ pairs at MU values below 2.5 and TOZ around 300 is clearly visible. On the other hand, pairs at very high and very low TOZ values as well as at high MU values are obviously less frequent.

COMPARISON OF DS AND ZS MEASUREMENTS OF TOZ - RESULTS

Differences between “concurrent” TOZ_{ZS} and TOZ_{DS} values (TOZ_{ZS}-TOZ_{DS} differences) were also categorized to the bins defined above. Mean differences for bins with at least 10 members (TOZ_{ZS}-TOZ_{DS} pairs) are shown at Fig 2.

Slight systematic ZS overestimation is present for MU<3 (blue color), but it does not exceed 5 D.U. and it manifests itself mainly at TOZ<250 D.U. and at TOZ ca 350 D.U. At the region of the most frequent observations (MU<2.5, TOZ ca 300 D.U.), systematic differences are very low.

On the other hand, for MU>3, ZS measurements systematically underestimate (red color). For MU>4, the underestimation may exceed 10 D.U. and for MU>4.5 even 20 D.U.

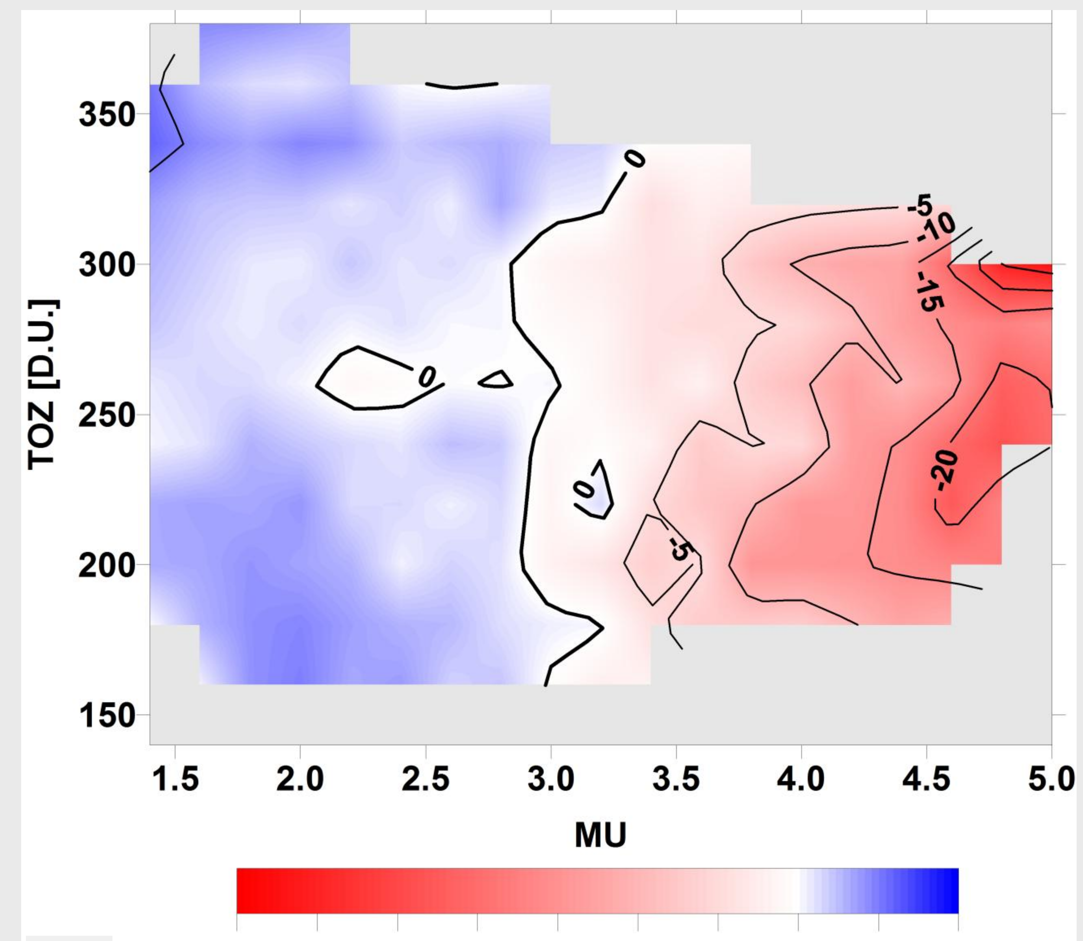


Fig.2

To assess the statistical significance of the differences, standard deviations (STDs) of categorized differences and consecutively standardized differences were calculated for each bin (i.e. mean difference for pairs in the bin divided by STD of differences within that bin). For bins with MU<3, the magnitude of standardized differences is mostly less than 1, which indicates that the mean difference itself is lower than the standard deviation of individual differences within the bin and these differences are of low statistical significance.

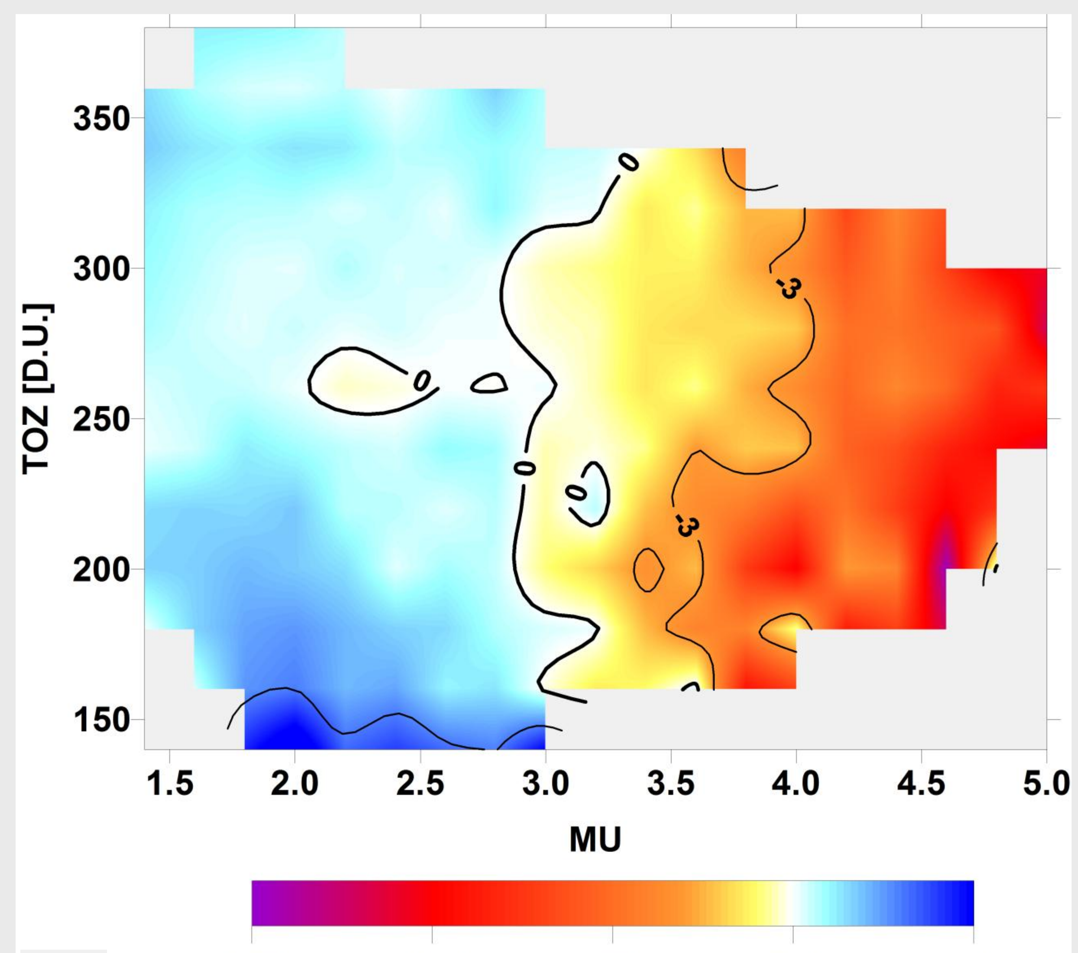


Fig.3

On the other hand, for bins with MU>4, the magnitude of standardized differences often exceeds 2. At these bins, the mean differences are more than twice as large as standard deviation of individual differences within the bin and for this reason these differences are of higher statistical significance (not shown).

In relative values (Fig.3), the maximal overestimation of TOZ_{ZS} measurements (as compared with “concurrent” TOZ_{DS} measurements) reaches about 3% for TOZ<150 D.U. 3% relative difference is similar to TOZ_{ZS} measurement uncertainty. Maximal underestimation is at MU>4 and may reach 10-15%, which highly exceeds the uncertainty of TOZ_{ZS} measurement. Relative differences of ±3%, comparable to the accuracy of TOZ_{ZS} measurements, are indicated by thin lines and zero difference by thick lines in Fig.3.

It clearly demonstrates bias of TOZ_{ZS} measurements at high MU values.

DISCUSSION AND CONCLUSIONS

ZS values of TOZ are calculated with the help of zenith polynomial (empirical mixed quadratic polynomial function of MU and TOZ). From this equation, TOZ may be calculated by solving quadratic equation for known MU and ZS ratio (F) values, if parameters of zenith polynomial are known. These parameters are usually calculated from the set of measured values (near-simultaneous TOZ_{DS} and F measurements at known MU) by minimizing of RSS (Residual Sum of Squares).

There are several possible reasons of TOZ_{ZS} underestimation at high MU values:

- Zenith polynomial does not cover well the whole span of MU and TOZ values. RSS method of parameters estimation prefers low residual sum of squares in the region (bins) with high number of observations (high observations density) at the expense of regions with low observations density. For this reason, regions with low observations density (high MU values) may suffer from some systematic error.
- For MU>3, some influences connected with Umkehr effect may be present, which are not contained in zenith polynomial.
- As the zenith polynomial independent variables (“predictors”) are not mutually independent (e.g. MU and MU^2, TOZ and TOZ^2, etc.), the zenith polynomial suffers from multicolinearity. In such cases, the estimates of zenith polynomial parameters may change erratically in response to small changes in the data, parameters do not converge well with increasing number of observations and the reliability of parameters is lower.

Possible solutions:

- Application of more general empirical non-linear model instead of 2D quadratic zenith polynomial, that would be valid across the whole span of predictors. Neural networks (Multilayer Perceptron) were tested for this purpose. Results were good, neural networks do not exhibit TOZ_{ZS} underestimation at high MU values but they are inconvenient in regular operation.
- Application of the table, similarly to GI measurements.
- Re-definition of the “best representative value” so that TOZ_{ZS} measurement at high MU values are not used. Instead of ZS measurements, GI measurements of TOZ should be used for high MU values (MU > about 3.5).

Underestimation of TOZ_{ZS} measurements at high MU values may be present at more stations. It may be an issue especially at high-latitude stations with big cloud coverage in the period of low solar elevations. In some cases, GI measurements may be more accurate than ZS measurements at very high MU values.

ACKNOWLEDGEMENT

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