

Appendix I: Dobson and Brewer Spectrophotometers

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The measurement of total column ozone with spectrometers has a long historical background, the first measurements with a Dobson Ozone Spectrophotometer having been made in the mid-1920's. A global network of Dobson instruments was established following the first International Geophysical Year in 1957. The modern Brewer Ozone Spectrophotometer was developed in the 1970's and introduced into the global network in 1982 with the delivery of instruments to Greece, Sweden, and Canada.

The basic measurement principle of both types of spectrometers is the same. The thickness of the ozone layer is determined by comparing the intensity of solar radiation that has passed through the atmosphere at ultraviolet wavelengths that are strongly and weakly absorbed by ozone. The Dobson utilizes an internal virtual 'ozone layer' (a variable 'optical wedge' attenuator) to measure the intensity ratio of two wavelengths, whereas the Brewer directly measures the intensity of light at a number of different ultraviolet wavelengths. The physical principles and instrumental characteristics of these methods are well documented and justify their designations as primary measurement techniques for the NDACC. It is, however, important, to characterize the individual instruments of both spectrometer types and to determine their specific calibration constants.

The following sections describe the methods used to certify the accuracy and precision of the instrument calibrations and the homogeneity and quality of their data records. As much special literature and manuals already exist, references to relevant publications and links to corresponding web pages will often replace detailed descriptions of the methods used.

Quality Criteria for the Evaluation of New Instruments and Instrument Teams

Independent Evaluation of Instrument Design, Observation Schedule, and Data Analysis

General:

As both the Dobson and Brewer spectrophotometers have been approved by the WMO as reliable high-quality instruments for more than 25 years, NDACC has selected them as tools to monitor the ozone layer. For a Dobson and/or Brewer station to be accepted into the NDACC, the observations must be made and verification tests performed according to the Standard Operating Procedures (SOP's) for the respective instruments. In addition, documentation is required showing that the instruments are in good calibration as a result of regular calibration exercises. The quality of the data records is to be certified by comparison with measurements by other instruments either directly or via

satellite transfer. The following sections detail the specific methods, documents and SOP's.

Dobson:

The manuals of G.M.B. Dobson (Dobson Ozone Spectrophotometer – III Observers' Handbook, Pergamon Press, 1957) and W. Komhyr (Operations Handbook – Ozone Observation with a Dobson Spectrophotometer, WMO Global Ozone Research and Monitoring Project Report No. 6, 1980) are still valid for describing the successful operation of Dobson instruments. The more recent revision of Komhyr's handbook (Robert Evans' WMO GAW Report No. 183, 2008) and other relevant information and publications are available at

<http://www.esrl.noaa.gov/gmd/ozwv/dobson> and
<http://www.o3soft.eu/dobsonweb/papers.html>

and give an update of the SOP's, taking into account the instrumental modifications (e.g. new electronics, other types of quartz for the prisms etc.) and the development of new test and observation methods. A special manual (Archie Asbridge, Dobson Spectrophotometer Calibration Notes. GAW/MOHP, 2000) was published primarily as an instruction sheet for Dobson experts at the World and Regional Dobson Calibration Centers (RDCC's) and contains information for Dobson network operators to gain a better understanding of the instrument performance.

Most of the stations with long-term records have written their own software for data analysis following the instructions in the manuals cited above. Software tools developed at the Solar and Ozone Observatory Hradec Kralove (Czech Republic) are offered as freeware on their homepage (<http://www.o3soft.eu/>) and are a valuable aid for new stations. The Japan Meteorological Agency (JMA) has also made analysis software available upon written request (<http://ds.data.jma.go.jp/wcc/dobson/windobson.html>). This free software is in use at Asian stations and is being evaluated for use at some US stations (Evans et al., 2017).

All Dobson stations currently have the necessary manuals/SOP's available and all observations and tests are carried out in accordance with these documents. If other software is in use, it should be compared with the recommended software from Hradec Kralove or JMA to confirm the accuracy of the analyzed ozone values.

NDACC requires that the documents referenced, the name of the software used, the observation schedules, and any other pertinent information be published by the Principal Investigators in a metadata file to document station performance.

Brewer:

Brewer operations are largely automatic with the instrument running unattended according to predetermined schedules. Thus, much of the detail with which the Dobson operator's manuals are concerned is taken care of by the Brewer operating software. Technical and operational details are provided by the Brewer

manufacturer in the form of published manuals, including the operator's manual and the service manual at

<http://www.kippzonen.com/?news/78232/New+Brewer+Spectrophotometer+for+Korean+Meteorological+Administration.aspx>

A Standard Operating Procedures manual for the Brewer Spectrometer is available at

http://www.io3.ca/Download/Brewer_SOP_DRAFT.pdf

WMO Consultation on Brewer Ozone and UV Spectrophotometer Operation, Calibration and Data Reporting reports are issued approximately every two years. They document the activities of the Brewer User's workshops, provide detailed information about the operation and the use of the Brewer ozone spectrophotometer, and are available at

<https://community.wmo.int/en/gaw-reports>.

General background information on making ozone measurements can be found in the 2014 edition of the WMO Guide to Meteorological Instruments and Guide to Observations available at

https://community.wmo.int/en/activity-areas/imop/wmo-no_8

Instrument and Data Analysis Intercomparison

General:

A considerable number of intra- and inter-instrumental comparisons have been carried out and published in the past. The results of these comparisons were presented and discussed at meetings of the WMO Scientific Advisory Group on Ozone (SAG) and are used to determine the quality (in particular, homogeneity) of long-term records and to detect possible problems. Assistance in dealing with these data issues can be obtained through this SAG.

Quality Criteria for the Evaluation of Continuing Instruments and Instrument Teams

General:

Four different methods can be applied to verify continuing high data quality, which is a basic requirement for NDACC stations.

1. Regular performance of daily and monthly tests according to the SOP's and application of the results.
2. Regular comparison of Dobson and Brewer data at the station, if both instrument types are operated simultaneously or with data from instruments at near-by stations.
3. Comparison of the ground-based spectrophotometer data with satellite overpass data provided by NASA
https://avdc.gsfc.nasa.gov/pub/data/satellite/SBUV2/OVP_INT for older data before 2005 and <https://www.earthdata.nasa.gov/learn/find-data/near-real-time/omi> for the latest OMI-data). In addition, detailed

intercomparisons between satellite data and several ground stations have been performed by Gordon Labow from NASA and Vitali Fioletov from WOUDC. Their results (Labow et al., 2013 and Fioletov et al., 1999) are very helpful in the assessment of the homogeneity of long-term records. Results of comparisons are publicly available at WOUDC directory: http://www.woudc.org/archive/Projects-Campaigns/Ground-Sat_Plots/.

4. Regular participation in international intercomparison and calibration services.

Dobson:

The main goals of the global Dobson calibration system consisting of one World Dobson Calibration Center (WDCC, NOAA, Boulder, USA) and five Regional Dobson Calibration Centres (RDCC) that exist as part of the WMO GAW infrastructure are:

- To transfer the calibration scale defined by the World Primary Dobson Spectrophotometer D083 (WPDS) into the Dobson part of the GAW ozone monitoring network through regional intercomparisons of spectrophotometers
- To assist in regular maintenance of Dobson instruments in the regions by technical services, spare parts or expert missions
- To implement new technologies and GAW rules, e.g., QA procedures, software and IT tools for processing of observations and data transfer

Within this framework, regular Dobson Intercomparisons and Services are offered (every four or five years for each instrument according to WMO recommendations). A majority of the Dobsons employed in the global network take part in these campaigns. These activities enable the assessment and evaluation of the active Dobsons and guarantee the quality of the obtained data records.

Well-maintained Dobsons should agree within $\pm 1\%$ (initial calibration). If not, data re-processing is recommended and supported on request. The reports can be provided through the RDCC's and it is recommended to include them in the metadata sets for each instrument. All affiliated NDACC Dobson stations should permit publication of the reports on their instruments' calibration services (see also next section). This permission can be considered as crucial to fulfilling the NDACC quality criteria in the long term.

Brewer:

The calibration of Brewer instruments is traceable to a Triad of MkIII Brewers at the Environment Canada facility in Toronto, Canada. The reference instruments in Toronto are independently and absolutely calibrated every few years at the Mauna Loa Observatory in Hawaii. Some instruments are brought to Toronto for calibration but most are calibrated by comparison with a traveling Standard Brewer either at the observing station or at another location during intercomparison campaigns. There is also a secondary reference site Regional Brewer Calibration Centre – Europe (RBCC-e) at Izaña in Spain hosted by the

Spanish Meteorological office (AEMET). The reference maintained by the three double monochromator Brewers (Brewer MkIII) in Spain is monitored with respect to the calibration reference in Toronto through frequent visits to Spain by Canadian instruments that have been calibrated against the Toronto triad. Reports of the outcome of these calibration intercomparisons are posted for general access on the International Ozone Services (IOS) website and the World Ozone and Ultraviolet radiation Data Centre (WOUDC) website.

Changes in Instruments and Data Analysis

General:

All instrumental changes, which are generally performed during calibration campaigns, should be reported in metadata files deposited in the corresponding data centers (NDACC DHF as well as the co-operating WOUDC in Toronto).

General changes in the data analysis, such as the application of new ozone cross-sections, are normally decided upon and initiated by the official WMO GAW bodies. The NDACC Dobson/Brewer Instrument Working Group (IWG) Representatives act as intermediaries between those bodies and the individual station PI's or the managers of the RDCCs / RBCCs to ensure that the new coefficients will be introduced into the data processing algorithms.

Planned instrument changes, such as replacing a Dobson with a Brewer, should be carefully prepared and carried out following the detailed instructions and recommendations described in the WMO GAW Report No. 149, "Comparison of Total Ozone Measurements of Dobson and Brewer Spectrophotometers and Recommended Transfer Functions" (by Staehelin, Kerr, Evans and Vanicek; https://library.wmo.int/viewer/41204?medianame=wmo-td_1147).

Dobson:

The easiest way for the Dobson Principal Investigators to record the calibration history of their instruments is to give permission to the responsible RDCC's to submit detailed calibration reports to the data centers. All necessary information about the performance of the Dobsons at the station and during the calibration campaign is documented in these reports. The list of main intercomparisons performed by the WDCC and RDCCs as WMO/GAW missions since the seventies and links to the reports are available at <http://www.o3soft.eu/dobsonweb/calibrations.html>. New data processing algorithms and especially new calibration coefficients normally result in reprocessed data (partial or complete records), which is submitted to the databases and identified with an updated version number. A description of the various versions in the metadata files is mandatory.

Brewer:

Most Brewers are re-calibrated by International Ozone Services. When a calibration takes place, the instrument PI is given a report on the outcome of the comparison. These reports should be submitted to the data center to be archived and made available to the data users. The results from comparisons

carried out by other means should be similarly documented. The IOS reports serve as a useful guide for the content of the report.

References

Evans, R.D., Petropavlovskikh, I., McClure-Begley, McConville, A.G., Quincy, D., Miyagawa, K., The US Dobson Station Network Data Record Prior to 2015: Re-evaluation of NDACC and WOUDC archived records with WinDobson processing software.”

Fioletov, V.E., J.B. Kerr, E.W. Hare, G.J. Labow, and R.D. McPeters, An assessment of the world ground-based total ozone network performance from the comparison with satellite data, 104, n. D1, 1737-1747, 1999.

Labow, G.J., R.D. McPeters, P.K. Bhartia, and N. Kramarova, A comparison of 40 years of SBUV measurements of column ozone with data from the Dobson/Brewer network, 118, n. 13, 7370-7378, 2013. DOI: 10.1002/jgrd.50503

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