The Brewer Triad and Calibrations; the Canadian Brewer Spectrophotometer Network

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14th WMO-GAW BREWER USERS GROUP MEETING

State Meteorological Agency of Spain, Tenerife, Spain
24th – 28th March 2014
Network Integration

- Brewer network (7 sites with 2+ instruments and 3 sites with one instrument, 42 instruments including 10 Double Brewers) and 2 sites outside Canada
- AEROCAN sunphotometer network (20 sites)
- Ozonesondes network (8 sites)
- (new) Pandora (2 instruments)
- The Canadian Air and Precipitation Monitoring Network (CAPMoN) – operated by EC
  - Particles and Related Trace Gases, 24 hour integrated filter samples. particulate Cl-, NO3-, SO4=, NH4+, Na+, K+, Ca++, Mg++, gaseous HNO3 and SO2
  - Ground level Ozone Measurements, hourly averages.
  - Nitrogen Measurements, gaseous NO, NO2, and NOy hourly averages.
  - Size Selective Particulate Matter, 24 hour integrated samples PM2.5, PM10 and coarse fraction mass
  - Precipitation Chemistry, 24 hour integrated samples. Cl-, NO3-, SO4=, NH4+, Na+, K+, Ca++, Mg++, pH
  - ...

- National Air Pollution Surveillance (NAPS)
  - SO2, NO2, O3, PM2.5, PM10 - continuously monitored
Team members & support

• Stoyka Netcheva: network management
• Vitali Fioletov: science, algorithms, data analysis, QA/QC
• Tom Grajnar: network operation, calibrations, instrument maintenance
• Michael Brohart: instrument maintenance, repairs, upgrades and calibrations
• Akira Oguy: computer support, web, BPS, data processing, QA/QC
• Other ARQM staff providing support as needed
• Volodya Savastiouk - regular contracts for calibrations, instrument repairs, upgrade and maintenance of software for Brewer operation, calibrations, and diagnostics …

Support from other branches of EC (infrastructure, instrument operations, basic maintenance, and inspections) at 7 stations

CANDAC occasional support at Eureka Pearl Observatory

NOAA at Mauna Loa Observatory
NOAA at South Pole Observatory
Network

New developments 2012-2014:

• Double Brewers at Churchill, Goose Bay, and Stony Plain: no more data gaps in winter
• Calibration of 4+2 Brewers at Mauna Loa in October 2013
• The new triad of double Brewers (#145, #187, #191) established in October 2013
• Two new Brewer instruments (#223 and #224) purchased in 2014
Deseasonalized, area-weighted total ozone deviations for 90°S–90°N, adjusted for solar, volcanic, and QBO effects. The yellow line represents the component of ozone variability due to changes in the equivalent effective stratospheric chlorine (EESC) based on a fit to data from 1964–2012 (updated from WMO (2007))
Brewers applications: Brewers and others

Ground-Based total ozone data available from the World Ozone and UV Data Centre (WOUDC). In the most recent 5-year interval, the number of Brewer sites is almost equal to the number of Dobson sites.

The total number of sites reported data to the WOUDC. Stations submitted less than 100 DS observations per bin are not included.

Relative number (in % of the total number) of sites with "no issues" in the record in 6 bins for Dobson, Brewer, and filter instrument sites located between 60ºS and 60ºN

Updated in 2013 from Fioletov et al., JGR, 2008
EC Brewer at NOAA at SPO vs. other instruments

Figure 56: Total ozone above the South Pole as measured by a Brewer spectrophotometer, which belongs to Environment Canada, ozonesondes (orange circles) launched by NOAA, a Dobson spectrophotometer operated by NOAA and by the OMI instrument on board the AURA satellite. Due to the late sunrise at the South Pole after the polar night, the satellite retrievals start only on 24 September, the Dobson measurements start on 7 October and the Brewer measurements start on 10 October. The grey curve shows the 1992-2012 median as derived from MSR and TM3 data based on satellite overpasses. The light grey shaded area shows the range of values during the 1992-2012 time period.

WMO Antarctic Ozone Bulletin No 6/2013
Seasonal variation of the noontime UV Index at Eureka. The top (first) panel compares noontime UVI measurements performed in 2011 (red dots) with the average noontime UVI (blue line), the range between the 10th and 90th percentile (dark shading), and the range of historical minima and maxima (light shading). The second panel shows the 2011 UVI anomaly in absolute terms, calculated as the difference between measurements and the average. The third panel shows the relative UVI anomaly calculated as the percentage departure from the climatological mean. The fourth panel shows a similar anomaly analysis for total ozone derived from satellite measurements. Vertical broken lines indicate the times of the vernal equinox, summer solstice, and autumnal equinox, respectively.

Brewer UV from 3 Arctic Brewer sites (Resolute, Eureka, Alert) are used in NOAA Arctic Report Card, BAMS State of Climate report, and other publications.

In the spring of 2011, they reported UV levels that are 60% higher than normal.

Form Bernhard et al., ACP, 2013
Brewers application: UV Index forecast validation

Scatterplots and linear regression fits of EC and NOAA forecast methods (FM) plotted against collocated Brewer measurements. Blue open circles show EC forecasts, and red plus signs show NOAA forecasts. A small amount of random noise is added to the UV index data for better visualization. Four major weather types are represented: cloud-free sky (type 1), light clouds (type 2), heavy clouds (type 3), and rain (type 4). The correlation coefficients $R$ between the measured and forecast values are also shown.

From He et al., JAMC, 2013
The Brewer Triads and Calibrations

Toronto Brewers in March 2014
The triad update: long-term record

The main challenge in maintaining the triad’s instruments is their stability.

Calibrations and service every 2 years are necessary.

Deviations of ozone values of individual triad Brewers from the mean of the three instruments. Each point on the graph represents a 3-month average. Plots for ozone values from b-files (top) and after re-processing (bottom) are shown. The vertical line indicates the end of the period used in the original triad paper.

Updated from Fioletov et al., GRL, 2005 (the triad paper)
Toronto triad record vs. satellites
Difference between triad data (available from the WOUDC) and various satellite instruments

Seasonal mean differences between triad Brewer DS measurements and Nimbus 7 TOMS, Meteor 3 TOMS, EP TOMS, OMI, GOME, GOME-2, SCIAMACHY satellite total ozone data.

The whiskers represent 95% confidence limits for seasonal mean differences.

Table of the difference statistics.
Note that the standard deviation of monthly mean differences is 0.7% in the most recent 5-year bin.

updated from Fioletov et al., JGR, 2008.
Pandora Spectrometer

- Sun and sky spectrometer – measures solar spectra
- Can also work in ZS and MAX-DOAS modes
- Under development since 2006 (Jay Herman et al., NASA)
- Designed for satellite validation and pollution monitoring
- Operation and software design are similar to these for the Brewer spectrophotometer (commands, schedules)
- Automated, established algorithms, data available in real time
- Specifications:
  - Czerny-Turner spectrometer with backthinned CCD detector (Avantes)
  - 270-530 nm at 0.6 nm spectral resolution, 4 pixels oversampling
  - Wavelength independent FOV of 1.5° (FWHM)
  - S/N of 400 at 400 nm
  - T stabilized spectrometer (enclose insulation under improvement)
  - High temporal resolution (<30 seconds per measurement)
  - Simultaneous measurements of various trace gases incl. O₃, NO₂, SO₂, BrO, HCHO, water vapour
  - Small size and portability (20 kg)
  - Cost: ~$40k
- Two instruments were deployed in 2013 (McKay and Toronto)
- Continue comparison with Triad instruments in Toronto.

The Pandora-Brewer difference

There is a 0% to 4% systematic difference between Brewer and Pandora total ozone caused likely by the difference in ozone absorption coefficients and their temperature dependence.
The triad update - 2013

The old and new triads agree within 1%, but there are some systematic differences likely due to stray light. The long-term instrument stability is a challenge.

Brewers 014, 015, 191 returned from Mauna Loa

Old Triad

New Triad

Hg bulb was replaced in Brewer 008

5-day Statistics, mu<3

01OCT13 01NOV13 01DEC13 01JAN14 01FEB14 01MAR14 01APR14

Brewer measurements with 1.5 minute frequency were used to account for the difference in ozone due to difference in observation time between individual Brewer measurements.

Stray light causes an underestimation of ozone values by the single Brewer. Pandora measurements adjusted for the bias were used as a reference.

The biases between individual Brewer triad instruments and the “baseline.” The baseline was established using high-frequency Pandora measurements adjusted for the Pandora-Brewer bias.: The biases between Pandora and the new triad due to different ozone cross-sections were removed on a daily basis.

The error bars represent 95% confidence limits for 5-day mean differences.

The whiskers represent 5th and 95th percentiles, the box edges represent the 25th and 75th percentiles, the centre is drawn at the median value.
Brewer UV measurements were normalized to modeled UV at 324 nm for sea level clear sky, no aerosol conditions. Noon values were calculated as averages between 11:30 and 12:30. The whiskers represent 1st and 99th percentiles, the box edges represent the 25th and 75th percentiles, the centre is drawn at the median value.

Based on cloud cover information, June and September are the best months for calibration, while March, April, and November are the worst ones.

EC operates 2 Brewers at the NOAA Mauna Loa Observatory. Brewers 009 and 119 were installed in 1997.

The most recent calibration of both instruments was in October 2013.

Brewer 009 data for 1997-2012 and Brewer 119 data for 2003-2012 were used for this slide.
MLO Brewer observations: Volcanic SO2

The activity of Kilauea volcano near Mauna Loa has increased after 2007

This may affect ozone calibration activities, particularly for Dobsons. SO2 values as high as 50 DU under clear sky and as high as 400 DU under cloudy conditions (with the multiple scattering effect) were seen.

Note that the Observatory (3400 m) is located above the volcano (1222 m) otherwise column SO2 would be even larger.

OMI mean total column SO2 over Hawaii in 2005-2007 and 2008-2010

Mauna Loa UV spectra, April 26, 2008, 22:53 UTC (12:33 LST), Brewer #009, SO2=400 DU due to multiple scattering within the cloud.
MLO Brewer and Dobson observations

Brewer ozone retrievals are not sensitive to SO₂, while Dobson overestimates ozone in presence of SO₂

The last day of the calibration trip

Total column SO₂ measured by Brewers 009 and 119 measured on November 20, 2013.

Dobson and Brewer ozone measurements in October-December 2013.

Dobson measurement was at 13:00 HAST

The whiskers represent 10th and 90th percentiles, the box edges represent the 25th and 75th percentiles, the centre is drawn at the median value. Dobson measurements (direct sun or blue zenith) are taken once a day near local noon. Dobson data were provided by NOAA.
New Brewer ZS algorithm:
The same parameterization, but only 2 parameters instead of 9 are estimated from measurements

The Brewer ZS algorithm does really not work when $\mu>4$ and ozone>300: the Brewer wavelengths and weighting coefficients produce values that are not sensitive to ozone.

The plot shows weighted sums of logarithms of zenith irradiance intensities ($G$) as a function of total ozone for various values of slant path ($\mu$) for high latitudes. The model calculations were done for albedo = 0.80. $G$ shows little sensitivity to total ozone when $\mu>4$ and total ozone is greater than 400.

The shape of the vertical ozone profile affect the ZS retrievals when when $\mu>3$.

Difference between DS ozone daily means and ZS ozone means for different $\mu$ values for Churchill (59°N). ZS data were processed using models based on midlatitudinal (black) and high-latitudinal (gray) ozone profiles. Calculations were done using 0.8 albedo for December–April and 0.05 for the rest of the year. The mean values (horizontal lines) with 2 standard errors of the mean (vertical bars) are shown.
UV calibration: comparison between 40 and 50 cm calibration systems (4 identical UV lamps and data logger on both systems)
March 17, 2014

The combined effect of polar ozone depletion and high tropopause is seen below for March 17, with a large ozone anomaly (30-35% below normal) centered over the most populated areas of Europe.
Work with Kipp and Zonen to facilitate service and maintenance and improve instrument reliability

- Replace NFS80 with NFS110 power supply - more current on 24V line for more reliable micrometer motor movement

- Higher power level applied to standard lamp - improves stability of dead time and run stop test results

- Ball-end grating arm and micrometer points - eliminates potential source of hysteresis in micrometer movement

- Rotary connector installed in trackers along with heater system - cables do not rotate with tracker during day, eliminates data and power cable movement stress and breakage, internal shut off switch not required, no accidental breakage of shut-off string due to accidental over-rotation during drive plate cleaning, tracker heater helps to ensure better tracker movement in cold environments

- Use 296.728 nm hg single peak line for hg test instead of 302.1 nm doublet peak line - reduce hg lamp warm-up to 2 minutes from 5 and reduce micrometer positioning changes since doublet line peak can change with lamp age, reduces hg lamp aging, saves time for more ds, uv, etc.

- Neutral density filters with tighter tolerances on specified attenuation values - prevents artificial spikes in ozone measurements when successive neutral density filters are introduced into the optical path

- Magnetic window in back tracker cover with chain link to tracker cover bolt - facilitates visual inspection and tool-free cleaning of the drive plate edge, eliminates tracker seal issues due to cover bolt spacer positioning errors

- 1/8” Hole in center of blocked filter - to determine and confirm the UV focusing of the Brewer

- Micrometer movement referenced to spectrometer LEDs - allows for reproducible micrometer reset even after reinstallation/replacement of the micrometer and/or pushrod replacement

- Power and data cables rated to -70 C - More reliable in colder environments
Brewer operational issues that still need to be addressed

- Long-term stability for micrometer motor movement—mostly resolved by new NFS110 power supply but still have instances of poor micrometer movement and jamming

- Standard lamp power—needs to be adjustable as it was in single board Brewers so that standard lamp intensity can be optimized for each lamp as required in order for stable and acceptable diagnostic test results

- Sensitivity to power issues—single board Brewers appear to be sensitive to power failures or brownouts and sometimes require config and/or firmware to be re-installed

- PMT sensitivity decline over time-- Brewer PMT’s have been originally set with a relatively low high voltage setting and the NFS80 power supply may not have been providing the necessary current at 24V

- PMT acceptance testing prior to installation into Brewers--one of our PMTs recovers slowly after being exposed to light and residual signal can bleed over into the next measurement

- Noisy negative voltages—understand the cause of the variability to confirm no effect on the instrument
Strategy

• Maintain smaller network but with assured stream of high quality data with 2+ Brewers at each site plus other instruments
• Let the Brewer do what it can do best, i.e., to produce high quality and stable over time total ozone and UV data and use other instruments for other tasks
• Focus on implementing what has been developed by other, rather than developing everything ourselves
• Strongly support unification and standardization of measurements and data processing
• Open to suggestions