



Supplement of

The world Brewer reference triad – updated performance assessment and new double triad

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A. Brewer Single and Double Triad Instrument Repair and Upgrade Review: 1999 – 2019

Brewer #008

Single monochromator, multi-board electronics Brewer c/w pushrod micrometer design.

- 5 • May 2000: Zenith positioning issues were noted. Some zenith sky measurements, due to poor zenith pointing, may be incorrect, and depending on the filter criteria and other factors, the incorrect data may or may not be omitted. For example, incorrect data may be uniform enough to clear filters and be considered a good measurement. The zenith drive bearing was replaced.
- 10 • August 2001: Degrading Run/Stop tests noted. Some data, due to intermittent shutter movement quality, may be incorrect and be omitted. Shutter motor replaced Aug. 22 – 24. Testing after the motor replacement resulted in a dead time change from 49 ns to 45 ns.
- 15 • January 2002: Secondary power supply failure and replacement. Board replaced and board settings adjusted to replicate the original voltage settings. Measurement failures occurred until deficiency was addressed.
- 20 • March 2002: Dead Time tests poor and Standard Lamp (SL) voltage too low. Not able to set to historic values - replaced faulty Secondary Power Supply (SPS).
- 25 • January 2004: Intermittent power issues – cable replaced. Intermittent power issues - power switch faulty. Some zenith sky measurements, due to poor azimuth tracking, may be incorrect and depending on the filter criteria and other factors, the incorrect data may or may not be omitted. For example, incorrect data may be uniform enough to clear filters and be considered a good measurement.
- 30 • January 2005: New heater system. Original design attached to instrument structure and had potential to affect data by producing temperature gradients through the spectrometer frame.
- 35 • March 2005: Power issues caused by a faulty power harness. Harness replaced. Measurements missed or failed during intermittent problems.
- 40 • July 2007: Grating arm “pin flag” replaced with a Delrin flag. The flag change necessitated a micrometer offset change equal to the change in flag position on the grating arm, leaving the optical reference to mercury emission line distance unchanged. Occurrences of the flag being missed by the optical sensor and jamming were eliminated.
- 45 • March 2008: Jumps seen within scan measurements were attributed to binding between the pushrod and the pointed grating arm cones during micrometer movement. The pointed grating arm cone was replaced with a ball ended grating arm cone to ensure uniform movement.
- April 2008: Installed a viewing window cover. Visible light entering the viewing ports could be adding to the stray light measured by single monochromator Brewers. Adding the cover eliminated this possibility.
- January 2009: Replaced braided line driven iris drive with a worm motor driven iris drive. Poor data caused by periodic breakage in the braided line resolved.
- January 2010: Proportional heater control and humidity sensor installed. Environmental stability reduced the necessity of diagnostics tests. More time for atmospheric measurements.
- March 2011: Installed a rotary connector into Brewer #008’s tracker. Data lost due to cable damage and azimuth tracker failures resolved.
- October 2012: Replaced A/D (Analog-to-Digital) board. Diagnostics returned to normal. Measurements not affected.
- May 2015: Adjusted shutter motor height; increased SL voltage and lowered dead time during instrument review in preparation for the calibration at Mauna Loa Observatory (MLO).
- March 2016: Zenith motor failure. Some zenith sky measurements, due to poor zenith pointing may be incorrect, and depending on the filter criteria and other factors, the incorrect data may or may not be omitted. For example, incorrect data may be uniform enough to clear filters and be considered a good measurement. The zenith motor was replaced.

Brewer #014

50 Single monochomator, multi-board electronics Brewer c/w pushrod micrometer design.

- September 2000: Replaced braided line driven iris drive with a worm motor driven iris drive. Poor data caused by periodic breakage in the braided line resolved.
- September 2000: Replaced micrometer ribbon cable, I/O board. Removed, cleaned, lubricated and repositioned micrometer. Intermittent positioning errors would affect data quality.
- 55 Deficiency addressed.
- October 2002: Azimuth tracker failure. Reference flag missed. Cables unwound and azimuth reference re-established. All measurements stopped until deficiency was addressed.
- March 2004: HG (mercury-line wavelength calibration) lamp failure traced to SPS board failure. Board replaced and board settings adjusted to replicate the original voltage settings.
- 60 Measurement failures occurred until deficiency was addressed.
- July 2004: Primary power supply failure. Power supply replaced and the 5 volt setting adjusted to replicate the original voltage setting. All measurements stopped until deficiency was addressed.
- February 2008: New heater system. Original design attached to instrument structure and had potential to affect data by producing temperature gradients through the spectrometer frame.
- 65 • April 2008: Installed a viewing window cover. Visible light entering the viewing ports could be adding to the stray light measured by single monochromator Brewers. Adding the cover eliminated this possibility.
- November 2008: Replaced braided line driven iris drive with a worm motor driven iris drive. Poor data caused by periodic breakage in the braided line resolved.
- 70 • November 2008: Fore-optics lenses optimized for focus and alignment. Adjustment improved intensity and tracking, improving measurements.
- June 2009: The iris constant was found set to 75 steps and should have been set to 250 steps for new iris that was installed. Field of view on the sun and sky would have been reduced, affecting the measurements and likely reducing the attenuation needed from the neutral density filters during the measurements.
- 75 • March 2010: Proportional heater control and humidity sensor installed. Environmental stability reduced the necessity of diagnostics tests. More time for atmospheric measurements.
- September 2010: Frequent sighting changes, suggesting tracking issues. Early morning or late afternoon tracking may have been affected. Re-levelled instrument.
- 80 • February 2011: Azimuth tracker failure. Reference flag missed. Cables unwound and azimuth reference re-established. All measurements stopped until deficiency was addressed.
- January 2012: Standard Lamp burnt out. Lamp replaced. Standard lamp test data interpolation needed over this time period.
- 85 • May 2011: Frequent sighting changes, suggesting tracking issues. Zenith prism alignment performed and instrument re-levelled.
- August 2013: Standard Lamp burnt out. Lamp replaced. Standard lamp test data interpolation needed over this time period.
- October 2013: Installed a rotary connector into Brewer #014's tracker. Data lost due to cable damage and azimuth tracker failures resolved.
- 90 • October 2013: Installed longer zenith window. Now able to measure closer to the horizon.

Brewer #015

Single monochomator, multi-board electronics Brewer c/w pushrod micrometer design.

- August 2000: Azimuth tracker failure. Reference flag missed. Cables unwound and azimuth reference re-established. All measurements stopped until deficiency was addressed.
- 95

- December 2000: Micrometer jam. Removed, cleaned, lubricated and repositioned micrometer. Intermittent positioning errors would affect data quality. Deficiency addressed.
- December 2000: Blown tracker fuse. Fuse replaced. Measurements ceased until deficiency addressed.
- 100 • April 2001: Intermittent azimuth and micrometer failures persisted. BA-E501A I/O board replaced. Board replacement addressed intermittent errors. Measurements missed or fail until deficiency was addressed.
- June 2001: Frequent sighting changes, suggesting tracking issues. Early morning or late afternoon tracking may have been affected. Re-levelled instrument.
- 105 • October 2001: Multi-step corrections between observations noted. Suspected the cause to be micrometer wear. New micrometer installed.
- 2002: Multiple Azimuth tracker failures throughout the year. Reference flag missed. Cables unwound and azimuth reference re-established. All measurements stopped until deficiency was addressed.
- 110 • January 2003: Micrometer positioning discrepancies. Micrometer removed, cleaned and re-installed. Intermittent positioning errors would affect data quality. Deficiency addressed.
- April 2003: Zenith positioning errors. Zenith gear worn and binding, replaced Brass gear c/w shaft and split gear. Intermittent positioning errors would affect data quality. Deficiency addressed.
- 115 • March 2004: Secondary power supply board failure. Board replaced and board settings adjusted to replicate the original voltage settings. Measurement failures occurred until deficiency was addressed.
- July 2004: Primary power supply failure. Power supply replaced and the 5 volt setting adjusted to replicate the original voltage setting. All measurements stopped until deficiency was addressed.
- 120 • January 2005: New heater system. Original design attached to instrument structure and had potential to affect data by producing temperature gradients through the spectrometer frame.
- April 2008: Installed a viewing window cover. Visible light entering the viewing ports could be adding to the stray light measured by single monochromator Brewers. Adding the cover eliminated this possibility.
- 125 • January 2009: Secondary power supply board failure. Board replaced and board settings adjusted to replicate the original voltage settings. Measurement failures occurred until deficiency was addressed. Pointed grating arm cone replaced with ball ended grating arm cone to ensure uniform movement. Jumps seen within scan measurements attributed to binding on the pointed cones. Replaced braided line driven iris drive with a worm motor driven iris drive. Poor data caused by periodic breakage in the braided line resolved.
- 130 • March 2010: Proportional heater control and humidity sensor installed. Environmental stability reduced the necessity of diagnostics tests. More time for atmospheric measurements.
- June 2011: Major failure. Replaced BA-E501A I/O board; microprocessor board; clock board and the shutter motor. All measurements suspended during failure and repair.
- 135 • October 2011: Measurement discrepancy traced to a damaged NiSO₄/UG11 combo filter. Filter replaced. Measurements would be drifting as the filter degraded.
- March 2012: Installed a rotary connector into Brewer #015's tracker. Data lost due to cable damage and azimuth tracker failures resolved.
- 140 • September 2012: Thermister 1 and humidity getting intermittent erroneous readings. Erroneous temperature affects and causes erroneous ozone readings. Not investigated, as the problem seemed to be solved by reseating the instrument electronics boards in the card cage.
- August 2013: Thermister 1 and humidity getting erroneous readings. Not investigated, as the problem seemed to be solved by reseating the instrument electronics boards in the card cage.
- 145 • September 2013: Filter Wheel #2 Assembly (FW2) replacement - non-uniform spacing between filters corrected; Packed up for shipping to MLO.

- October 2013: Installed longer zenith window. Now able to measure closer to the horizon.
- October 2013: It was noted that the aluminum optical frame was expanding 90-100 parts per million per degree Celsius faster than the aluminum pushrod was expanding. The spectrum was drifting with temperature faster than is compensated for by the mercury (Hg) bulb tests. This instrument characteristic will cause the measurements to have greater than normal variability.
- November 2014: Zenith motor failure. Some zenith sky measurements, due to poor zenith pointing may be incorrect, and depending on the filter criteria and other factors, the incorrect data may or may not be omitted. For example, incorrect data may be uniform enough to clear filters and be considered a good measurement. The zenith motor was replaced.
- December 2016: Micrometer positioning discrepancies. Micrometer motor replaced. Intermittent positioning errors would affect data quality. Deficiency addressed.
- October 2017: Replaced optical frame to address the temperature dependence and replaced the main wire harness to address the unknown source of the voltage spikes. Changes made increased the dependability of the measurements.

Brewer #145

Double monochromator, multi-board electronics Brewer c/w wire connected micrometer design.

- November 2013: Change in FW2 position from position 1 to 0 to increase standard lamp intensity. The increased counts had no effect on SL ratios or atmospheric measurements but did improve diagnostics test results.
- November 2014: Top micrometer jammed. Top micrometer shaft replaced, micrometer spindle serviced all micrometer wire attachments unchanged. Intermittent micrometer positioning issues causing inaccurate wavelength selection addressed, with minimal disruption to the instrument.
- August 2015: Installed a rotary connector into Brewer #145's tracker. Data lost due to cable damage and azimuth tracker failures resolved.
- April 2016: Mistakenly, it was thought that the Cal Step was accidentally left at 962 at October 2015 calibration at MLO. Sun scans seen in April indicated that the Cal Step should have been 969, as did the processed MLO data. The 969 Cal step was applied. Later it was discovered that the slit mask was manufactured such that the offset in Cal step was both intentional and necessary. Adjustments were made to the calibration for processing data collected in this configuration.
- August 2017: Mercury bulb test repeats were increasing. Counts were too high at 1M. Changed FW2 to Pos1 in the configuration file for HG measurements, to reduce the counts. Now about 300K counts at the peak. This reduced test failures, increased the bulb life and allowed more time for atmospheric measurements.
- September 2017 Micrometer 1 jammed, and found to be stiff. Top micrometer replaced. Wire connections left undisturbed. Intermittent micrometer positioning issues causing inaccurate wavelength selection addressed, with minimal disruption to the instrument.
- September 2018: Instrument moved temporarily to Egbert, Canada (44.230° N, -79.780° W) in preparation for construction work proposed on the building in Toronto.
- August 2019: Fully replaced the top and bottom micrometers including all the connecting wires of the wire micrometer system. This preventative maintenance work was done in preparation of the absolute calibration in October and to ensure reliable micrometer movement in both micrometers in future measurements.

Brewer #187

Double monochromator, multi-board electronics Brewer c/w pushrod micrometer design.

- 195 • April 2013: Multiple mercury test failures even though bulb counts were good; service micrometers with no improvement. Intermittent positioning errors would affect data quality.
- April 2013: Increased the voltage from the primary power supply to aid power to the micrometer motors. Intermittent positioning errors would affect data quality.
- July 2013: Changed the mercury bulb in an attempt to minimize data loss due to mercury test failures. Failures reduce the amount of data collected.
- 200 • November 2013: Reporting micrometer#2 jammed at maximum end - cycled power with no change - checked micrometer, not jammed. Suspected main board; board configuration or power problems.
- November 2013: Micrometer #2 issues still persisted even after firmware and configuration file was reloaded - new 110W PS installed. Data collection interrupted while problems persisted.
- 205 • November 2013: Micrometer #2 grating arm position adjusted at grating mount to allow Micro#2 to follow Micrometer #1 without crashing at the high wavelength end of the travel. Adjusted minimum motor position in configuration file for Micrometer #2 motor. The original instrument setup reached physical ends during some measurements. Adjustments made to avoid physical limitations of the instrument.
- January 2014: Changed Micrometer #2 minimum boundary from -9546 to -9808. The configuration needed adjustment to reflect the physical changes made to the instrument.
- 210 • February: Testing for instrument dark count improvement done. Returned discriminator value back to 6.7 mV and HV (High Voltage) back to 1132 V. #187 Photomultiplier (PMT) noisy - DC presently at 2200. The signal to noise ratio is acceptable but this PMT is poor when compared with others within the network.
- 215 • March 2014: Micrometer jammed. Measurements interrupted until operator intervention.
- September 2014: Brewer indoors for PMT replacement.
- November 2014: Top micrometer having trouble moving - Replaced main board - bottom micrometer appeared to be moving well but some inconsistencies showing up. Intermittent positioning errors would affect data quality.
- 220 • December 2014: Micrometers continuing to fail. Converting to multi-board electronics to decipher if the problems originated from board control or from motor quality.
- January 2015: Brewer #187 optics now running with Brewer #020 electronics.
- January 2015: Found PMT Shield Ground wire broken - replaced wire.
- 225 • January 2015: Micrometer #1 jammed at the minimum end, caused by building power outages and poor recovery by the instrument. Measurements interrupted until micrometer was repositioned by hand and the schedule restarted.
- January 2015: Testing with #020 PMT installed.
- March 2015: Found uneven torsion of vertical support wires on bottom grating - released stress reassembled and established new slope and intercept values.
- 230 • August 2015: Replaced all pins on photon counter DB - found 2 broken but held in place by silicone. Changed the SL filter position from 1 to 0 and the HG position from 2 to 1. Packed up for MLO.
- February 2017: SL Bulb replacement required. All offsets affected by the change in SL reference position were addressed. Zenith offset from 20 to 32, and changed horizon correction from -5 to 7 and UV offset from 2226 to 2238.
- 235 • September 2018: Instrument moved temporarily to Egbert, Canada in preparation for construction work proposed on the building in Toronto.
- November 2019: During UV Data review, a noted intensity drop was seen after the instrument transport to Egbert, Canada. The most likely cause is the bottom mirror positioning screw is

240 loose and the mirror tilted out of position during transport. Relative measurements (Ozone) will not be affected, but absolute measurements (UV) will be affected. Yet to be addressed.

Brewer #191

Double monochromator, single-board electronics Brewer c/w pushrod micrometer design.

- 245 • August 2013: Brought inside for pre-MLO check-up. SL burned out, replaced. Standard lamp test data interpolation needed over this time period.
- September 2013: Brought in for FW2 replacement - non-uniform spacing between filters corrected. Packed for MLO. Uniform spacing between optical densities will reduce oscillations between filters and increase time for measurements.
- 250 • January 2014: Stuck in the loop while running the RL (prints the firmware error log) command - log full - restarted schedule - working with K&Z too find a solution. Received code to clear the Brewer internal log. Developed code to read, record then delete the internal Brewer logs. The development of log handling reduced the possibility of interruption caused by the log features within the single board electronics.
- 255 • February 2015: SL bulb failure - bulb changed, now using long life (2000-hour rating) bulbs. Modified configuration file to change zenith offset from 4 to 11, changed horizon correction from -32 to -38 and UV position from 2221 to 2214. Adjusted to ensure offsets reflect the standard lamp reference position change caused by the bulb replacement.
- March 2017: HG failed, b1 (turns on the HG lamp) no light, changed Hg bulb still no light. Continued to troubleshoot to find the lamp board Hg potentiometer too high. Adjusted HG 260 voltage from ~15V to ~10. Brewer mercury tests now working normally.
- August 2017: Instrument review and maintenance in preparation of calibration at MLO. Bulbs changed. Changed zenith origin from 4 to 11, and changed horizon correction from -31 to -24 and UV offset from 2214 to 2207. Adjusted to ensure offsets reflect the standard lamp reference position change caused by the bulb replacement.
- 265 • September 2018: Instrument moved temporarily to Egbert, Canada in preparation for construction work proposed on the building in Toronto.

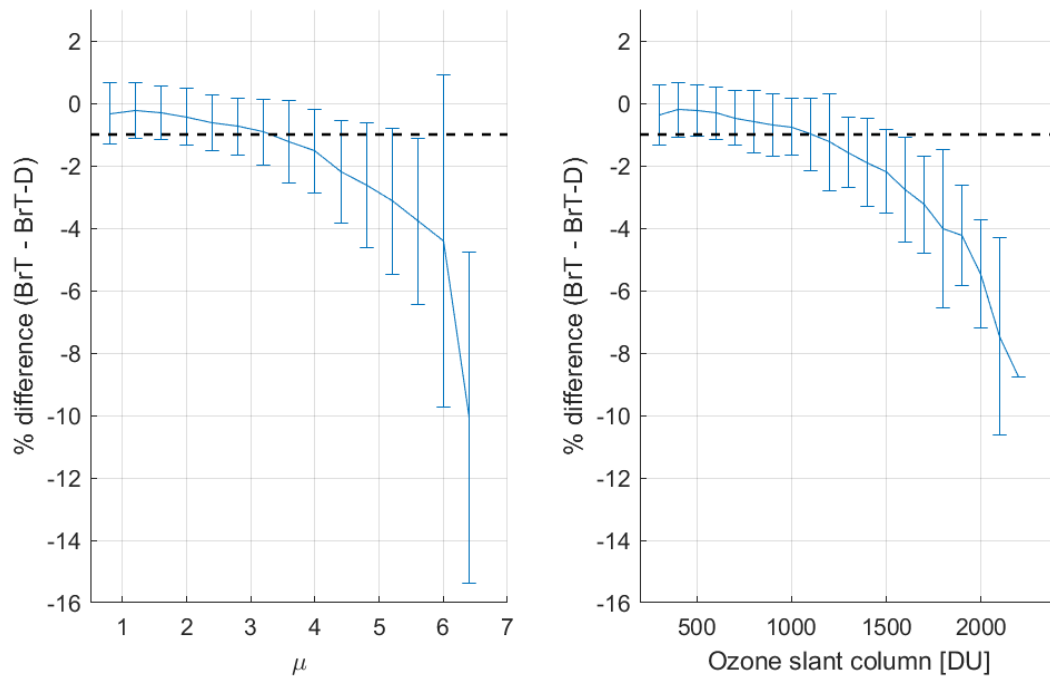


Figure S1. The relative difference between BrT and BrT-D, in terms of air mass factor (μ) and slant column ozone. The error bars represent 1 σ of the relative difference values. The black dash lines show the -1 % relative difference.