Atmos. Chem. Phys. Discuss., doi:10.5194/acp-2017-383, 2017
Manuscript under review for journal Atmos. Chem. Phys.
Discussion started: 8 May 2017

The US Dobson Station Network Data Record Prior to 2015, Re-evaluation of NDACC and WOUDC archived records with WinDobson processing software

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Abstract. The United States government has operated Dobson Ozone Spectrophotometers at various sites, starting during the International Geophysical Year (July 1, 1957 to December 31, 1958). A network of stations for long-term monitoring of the total column content (thickness of the ozone layer) of the atmosphere was established in the early 1960s, and eventually grew to sixteen stations, fourteen of which are still operational and submit data to the United States of America's National Oceanic and Atmospheric Administration (NOAA). Seven of these sites are also part of the Network for the Detection of Atmospheric Composition Change (NDACC), an organization that maintains its own data archive. Due to recent changes in data processing software the entire data set was re-evaluated for possible changes. To evaluate and minimize potential changes caused by the new processing software, the reprocessed data record was compared to the original data record archived in the World Ozone and UV Data Center (WOUDC) in Toronto, Canada. The history of the observations at the individual stations, the instruments used for the NOAA network monitoring at the station, the method for reducing zenith sky observations to total ozone, and calibration procedures were re-evaluated using data quality control tools built into the new software. At the completion of the evaluation, the new data sets are to be published as an update to the WOUDC and NDACC archives, and the entire data set is to be made available to the scientific community. The procedure for reprocessing Dobson data and the results of the re-analysis on the archived record is presented in this paper. A summary of historical changes to fourteen station records is also provided.

Background

The Dobson ozone spectrophotometer was designed in the 1920s, and is still in use today. The instrument is fully described elsewhere (Dobson, 1931, 1968), but briefly, it measures the relative difference of intensity between selected wavelength pairs in the range 300-350 nanometers. These pairs are named A (305.5 and 325.4 nanometers (nm)), C (311.5 and 334.4 nm), C' (334.4 and 453.6 nm) and D (317.5 and 339.8 nm); and are combined in the measurement process either as A and D (AD); C and C' (CC'); and C and D (CD). The optical arrangement of the instrument is presented in Figure 1. Measurements on either direct solar light or scattered from the zenith can be used to calculate the amount of ozone between the instrument and the top of the atmosphere (total ozone column or TOC). Approximately 90% of this TOC resides in the region between 15 and 30 KM above the Earth's surface that is defined as the ozone layer. The importance of the Dobson Spectrophotometer and its measurements are demonstrated by use of **Dobson Units (DU)** to reference the thickness of the ozone layer. One DU is equivalent to a layer 0.01mm of pure ozone at standard temperature and pressure.

Data reduction is fully discussed in the Section 7 of the Operations Handbook – Ozone Observations with a Dobson Spectrophotometer available from the World Meteorological Organization Global Atmosphere Watch. (http://www.wmo.int/pages/prog/arep/gaw/documents/GAW183-Dobson-WEB.pdf)

The instrument's readings (R-values) are converted to an indicator of the relative intensity difference caused by its passage through the ozone layer (N-value), including the instrument's extra-terrestrial constant using a set of RtoN tables. These tables change during the instruments' lifespan due to repairs, updates and aging, thus each set has a limited period of application. The usefulness of the RtoN table is monitored by means of intercomparisons with standard Dobson instruments, and with the use of instrument specific reference lamps. The calculation of ozone from observations made on the direct sun (DS) light (or reflected light from the moon) is with a defined algorithm based on Beer's law. The resolution of the measurement is 1 DU, and the precision is considered to be ±1%, based on repeatability. Accuracy is another issue. The accuracy is dependent on knowledge of the ozone and temperature profile at the time of the measurement to correctly calculate the ozone absorption cross section. The accepted method is to use a static value for the station based on a standard northern mid-latitude ozone and temperature profile in the algorithm. The accuracy is also dependent on the knowledge of the ozone cross-section datasets used to determine the absorption coefficients in the reduction algorithm (Redondas, et al, 2014). The reduction of measurements on the zenith sky (ZS) is more complicated, as it is based on statistical analysis of direct sun and zenith sky observations close in time. The precision of ZS is considered to be 2-5%, and is dependent on the wavelength pairs used and the sky conditions. The actual method of statistical analysis is not defined in the standard operating procedures. Different organizations using the instrument employ different methods. The Dobson instrument has limitations in the accuracy of measurements at certain observing conditions (Basher, 1982). Internal stray light is one such limitation. Moreover, each Dobson instrument has unique optical components that result in an instrument specific level of the stray light. The quality and aging stability of the individual wedge construction has improved over time; especially for instruments within the NOAA network, which had optical components replaced with those of a more robust design during instrument rebuilding in the 1980s.

Station History

There are measurements of TOC in the USA prior to 1960 made by University and Federal organizations (Brönnimann, S., 2003), but the development of a coherent network of observing sites within the US Weather Service was started in the 1960s under the guidance of Walter Komhyr. The network was transferred to NOAA's Global Monitoring for Climate Change (GMCC) in the early 1970s, and is currently operated by NOAA's Earth System Research Laboratory's Global Monitoring Division (ESRL/GMD). As many as 16 stations comprised the network since its establishment. Two stations have been either closed or been transferred to another parent authority. Table 1 displays the stations reporting at end of 2015. Originally, observations using the Dobson instruments were recorded with pen or pencil on forms designed to assist manual calculations (https://youtu.be/w1rV_96UChk). As computer power increased, the data was transcribed to punched cards for processing, then to direct entry by keyboard. By the mid-1990s, the NOAA instruments were equipped with computers and encoders, and the data was recorded in a "dayfile" at the time of the measurement. Six stations were equipped with fully automated instruments in the 1980s.

Data Processing

TOC is normally archived as a single representative value selected for each day. In this publication, the term "select" value means the daily value produced in the NOAA processing stream. An earlier reprocessing of the stations' data was done in the 1990s (Komhyr, et al, 1995); the report also details much of the early history of measurements in the US system of stations.

To convert measurements to TOC values, calibration (RtoN) tables and information (reference lamp adjustment – RLA value) from monthly instrument tests using reference lamps are required. The RtoN tables are defined by comparison of the station instrument to a reference standard. These referencing are normally done on four to six year schedule. The calibration of the wedge is normally measured at the same time. The reference lamp tests are an indication of the instrument's aging, but are only a single point test in the instrument measurement range. The comparison process measures instrument performance over a wide range. The calibration tables are changed when the difference between the station and reference instrument is greater than the equivalent of 1% in TOC. When the calibration tables are changed due to a drift, the existing data set from the last calibration change to the new calibration is to be reprocessed and re-published in the archives.
The set of computer programs used for the NOAA processing were written in the FORTRAN language, and by the 2010s were difficult to use and maintain due to changes in computer hardware and personnel. The decision was made to convert the NOAA processing to processing using the WinDobson software package, as the fully automated instruments were updated to a modern system based on this software:
(http://ds.data.jma.go.jp/wcc/dobson/windobson/windobson.pdf)

Developed by personnel of the Japan Meteorological Agency, WinDobson is a software package for operations, data analysis and quality assurance of Dobson spectrophotometer observations. For the NOAA application, new components were developed. These new components are available from NOAA to other users of WinDobson. It is applicable for both TOC and Umkehr (ozone vertical profile) measurements. As this software has a different statistical method for the reduction of the zenith measurements, and set of rules for determining the representative value, the entire data record of each operational station was reprocessed in the WinDobson system to minimize the effect of the change.

Data Format Conversion and Initial Comparison of Data Sets.

The NOAA processed data were converted to "long line format" (LLF) files. These files are actually the image of the information sent to printers in the 1990s version of the data stream. The select values for the WOUDC and NDACC archives were originally produced from these files, using a process of both machine and personnel inspection. Programs were developed to convert the LLF and dayfiles into formats compatible with the WinDobson data stream. Files with instrument, station and calibration information (parafiles) were also developed to complete the structure of the WinDobson system. Connections to other sources of TOC information (satellite data records, for example) were developed so that comparisons with these values could be performed using tools internal to WinDobson. Reference lamp values were extracted from the LLF records for time periods prior to 1995 and from the dayfiles afterwards. By the end of 2015, all operational stations' data were being processed in WinDobson.

Initially, the data sets of only ADDS (fundamental wavelength pairs) observations from the two processing streams were compared with the expectation that the results should agree within ±1DU. Time periods with differences greater than this were investigated to determine the source of the problem, and correct any differences. When the differences were reconciled, the ZS observations were compared to the DS observations to define a polynomial method for converting the ZS observations to TOC. Separate polynomials were defined for various time periods related to instrument repairs and calibration changes. The change in the methods of reduction of ZS measurements often produced large changes in reported TOC values. The improvement in the ZS results with respect to the ADDS results is displayed in Figure 3 and in Table 3. The new method has resulted in ~91% of zenith sky derived total ozone (ADZB) within 2% of the coincident direct sun ozone column (ADDS). This is an improvement over the 78% value reported in the 2006 Operations Handbook. Results of observations made on the direct sun using the CD wavelength pairs differ from those made on AD pairs. The differences come primarily from imperfect knowledge of the ozone cross-sections used to determine the absorption coefficients used in the algorithm, and of the optical characteristics of the instrument (Redondas, et al, 2014.). The differences in observational results within a specific solar zenith angle range were analyzed, and a multiplying factor was established to bring the average of the CD results to that of the AD results.

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Comparison of WinDobson Representative Values with Archived Daily Values

The individual station records are archived as daily values in the World Ozone and Ultraviolet Radiation Data Centre (WOUDC) in Canada. (http://woudc.org/home.php). The format of reporting is a single value for the local day, but in UTC time with a resolution of an hour. The NDACC (http://www.ndsc.ncep.noaa.gov/data/) archive has the same TOC values for a subset of the WOUDC stations, but in a different format. The reprocessed data sets will be archived in WOUDC and NDACC. For each station, tools in WinDobson were used to make a data set of daily representative TOC values. These data sets were compared to the data sets of select values downloaded from the WOUDC and NDACC, and the differences were investigated. The history of the instrument calibrations was again reviewed, and some adjustments were made in the WinDobson process for some stations.

The differences stem from a number of reasons.

- There are data in the WOUDC data set for some stations that was reported by earlier organizations. The processing and selection rules for this data are unknown.
- The older processing included time periods of special processing to attempt to account for specific problems in the older optics of specific instruments:
    - So-called Mu-dependency (Komhyr et al, 1995), where DS results are lower at low sun angles. As this effect is dependent on the intensity of the input solar beam, and thus on the TOC; no attempt was made to account for this effect in WinDobson processing.
    - Drifts in the “wedge” calibration. It is unclear how this was actually performed in earlier processing; no attempt was made to account for this effect in WinDobson processing.
    - Drifts in the “extra-terrestrial constant” as part of the calibration. This was done in the (2016) processing, but with a different scheme. The older processing modified the reference lamp correction, and this was passed into the WinDobson processing as WinDobson used the same values.
- There was a weakness in the NOAA processing in choosing a select value for each day. During the original review of observations, certain observations were rejected for selection; this rejection was not recorded in the LLF files, and thus rejected observations appeared in the WinDobson data set. We scrutinized the record for these discrepancies and amended the results.
- The results of the zenith measurements changed due to updates to the reduction method, and these type of changes affect all stations.
- For some stations, it’s common for observations to be made throughout the local day, but on the next consecutive UTC day. This occurs at Lauder (LDR), Samoa (SMO) and South Pole (SPO), where UTC date changes during normal observing period. For SPO, observations on a local day can differ by 22 hours; thus choice of the selected/representative ozone in the NOAA/WinDobson may differ by 22 hours. At certain times of the year, the TOC can change appreciatively during this time.

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- Data archives sometimes failed to be updated after a calibration drift was detected during an intercomparison with a standard. This is not necessarily a failure of the internal WOUDC archiving process. NDACC appears to capture these periods more correctly.
- The rules for choosing the NOAA selected value were not consistent throughout the record, and the record of these rules is incomplete.

A discussion of the individual station records and the changes is presented in the following section.

The station discussions are accompanied by a referenced graphic of the time dependent differences, consisting of either three panels (all stations) or five panels (NDACC) Stations. First panel: The time record of total ozone measured at the station from the start of observations through 2015 (or until station was converted to WinDobson processing. Second Panel: percent difference between daily WinDobson total ozone records compared to the WOUDC record, (WinDobson-WOUDC). The red line is a linear fit. Third panel: the same as the second but for monthly and yearly averages (based on all the values in the month in each data set). The small white circles are averages made from DS observations only; the red symbols represent averages using all Dobson total ozone records; the large black open circles are yearly averages of all observations, based on monthly averages. Large + (plus) symbols indicate major calibration or instrument changes that lead to creating the new R-N tables; however, not all calibrations checks of the station record are shown. For NDACC Stations only: The fourth panel is the same as the second panel but for comparisons with the data archived at NDACC center (WinDobson-NDACC). The black line is a linear fit. The fifth panel is the same as the third panel for comparisons with the NDACC archived monthly and yearly averages. NDACC values are not recorded as observation type. Table 2 displays standard statistics of the differences between WinDobson and WOUDC , and WinDobson and NDACC records.

Assessment of changes in the WinDobson representative dataset relative to WOUDC record is analyzed in the form of probability distributions, where percent differences in TOC are plotted (Figure 2) as function of likely change when the archive is updated. The datasets analyses are separated into ADDS and other type of measurements.   The ADDS curves are symmetric, and indicate that the vast majority of ADDS values will be unchanged. The “other” curves are less symmetric, and are driven by the updated ZS reduction polynomials. As the overall record average offsets are small (<1.0%), this is an indication of the number of ADDS observations versus other observation types.

Mauna Loa Observatory, Hawai’i, USA (19°N, 156°W, NDACC Station)

Observations at MLO were started in December 1957. The instrument was damaged in 1961, and thus the calibration is unknown prior to 1963. Before 1984, the primary instrument was D063, with short periods with other instruments. The data in the archive prior to 1984 was not processed in the standard method in an attempt to account for instrument calibration drifts, which causes larger variation in reprocessed data, compared to WinDobson record. The automated instrument D076 was installed at the station in 1984 after rebuilding in Boulder. A mirror deteriorated, so the calibration in the period 1990-1995 is based on comparisons with World Standard Dobson D083 while it was on station for Langley plot campaigns (The Langley plot method is used to establish an Extra-terrestrial constant for an instrument (Langley, 1884).) This new calibration is not reflected in the WOUDC or NDACC archives. The instrument was rebuilt and the WinDobson automation installed in June, 2010. Data from 2010 through 2014 was processed in the NOAA system. All of 2015 is missing from the WOUDC archive. The NDACC archive appears to have updates not reflected in the WOUDC Archive. The difference between the WOUDC and NDACC archives records processed in the NOAA system and WinDobson system are presented graphically in Figure 4.

South Pole, Antarctica (90°S, 59°E, NDACC Station)

South Pole Station was established in 1957. The first Dobson instrument failed due to the extreme cold. Observations started again in 1961 and these results are in the archive, but the calibration record dates from 1963. The normal routine is to change the instrument every four years for calibration checks. This station has the possibility of large changes in reported daily values, primarily due to the extended daily observation period, and high variation in total ozone during certain periods of the year. The station local day is the same as that of Christchurch, New Zealand for ease of logistics, but the Dobson observations are reported in the WOUDC in UTC date and hour. There is evidence of incorrect UTC hour calculation for a number of dates in the years prior to 1992. The calculation of the astronomical parameters used in the algorithm for reducing reflected moon observations was incorrect in the NOAA program. Changes in the method of deriving total ozone from zenith observations improved the average with respect to direct sun averages. There are several periods missing from the archive, including all of 2015. The exclusion of early October values in the archived data (small white circles are outside of the plot range) in some years also produces differences in the averages (see large deviations in open circles seen in some years in the panel c and e). Differing methods for choosing a "Select" value versus a "Representative" value are the primary reason for differences. The difference between the WOUDC and NDACC archives records processed in the NOAA system and WinDobson system are presented graphically in Figure 5.

Bismarck, North Dakota, USA (47°n, 101°W)

The instrument is operated by the National Weather Service office at Bismarck Airport. There are observations in the archive from the late 1950s, but the documented record starts in December 1962. The difference between the WOUDC and NDACC archives records processed in the NOAA system and WinDobson system are presented graphically in Figure 6.

Caribou, Maine, USA (47°N, 68°W)

The instrument is operated at the National Weather Service office at the Caribou Airport. There are observations in the archive from the late 1950s, but the documented record starts in August 1962. The Weather service office was rebuilt in the early 2000s, with data gaps during that period of the record. The difference between the WOUDC and NDACC archives records processed in the NOAA system and WinDobson system are presented graphically in Figure 7.

Nashville, Tennessee, USA (36°N, 87°W)

The instrument is operated at the National Weather Service office near Old Hickory, Tennessee. There are observations in the archive from the late 1950s, but the documented record starts in July 1962. This station record shows a larger offset (+0.6%) between the WOUDC and WinDobson data sets, due to the change to the zenith observations results. . The difference between the WOUDC and NDACC archives records processed in the NOAA system and WinDobson system are presented graphically in Figure 8.

Fairbanks, Alaska, USA (65°N, 148°W)

Observations were started at the Fairbanks airport in 1964 using instrument D076, but ceased in 1972. Observations were restarted at the Poker Flat Research Range (65°N, 147°W) in 1985. The mission of the Range changed in 1993 and the Dobson shelter was moved to the roof of the Geophysical Institute at University of Fairbanks. Operations restarted in April 1994. This station is at 65 degrees north, with observations on low sun with high ozone amounts common, especially in March and April. The instrument shows patterns in the comparison with other instrumentation that imply an under estimation of ozone on the ADDS wavelength under conditions of low sun and high ozone. The selection of observations should be changed for this station to favor the CDDS observations during those conditions. The difference between the WOUDC and NDACC archives records processed in the NOAA system and WinDobson system are presented graphically in Figure 9.

Boulder, Colorado, USA (40°N, 105°W, NDACC station)

Dobson observations were started at the University of Colorado east campus in 1966. Earlier observations were made either at the National Center for Atmospheric Research or at the Table mountain facility north of Boulder. The station was moved to the David Skaggs Research Center in 1999. Multiple instruments have been used here in the record, especially prior to the automation of Dobson instrument D061 in 1980. The observations made after 1980 automation do not include CC' zenith observations. The instrument was rebuilt with the WinDobson automation, but the data was processed in the NOAA system until the beginning of 2015. There is data in the archive prior to 1966, but it is not connected to a calibration. The data for July 2013 to July 2014 is missing from the Archive. The periods 1992-1996, and 1998-2005 were not processed or archived using the correct calibration information. The difference between the WOUDC and NDACC archives records processed in the NOAA system and WinDobson system are presented graphically in Figure 10.

Wallops Island Flight Center, Virginia, USA (38°N, 76°W, NDACC Station)

Dobson observations were started at WIFC in 1967 as support for balloon and rocket borne experiments. The station has moved several times to different sites within the facility. Since 1995, only ADDS observations are made, to support ozonesonde flights. There are periods in the WOUDC and NDACC archives with either missing data, or archived with incorrect calibration information applied. The difference between the WOUDC and NDACC archives records processed in the NOAA system and WinDobson system are presented graphically in Figure 11.

NOAA/ESRL/GMD Observatory, Barrow, Alaska (71°N, 157°W)

Dobson observations at the NOAA observatory began in 1973. The instrument was out of operation between1983-1986, due to lack of funding. The station's weather is far cloudier than at other stations; this means there are more zenith observations than at other stations. The difference between the WOUDC and NDACC archives processed in the NOAA system and WinDobson system are presented graphically in Figure 12.

NOAA/ESRL/GMD Observatory, American Samoa (14°S, 171°W, NDACC Station)

Dobson observations were started at the NOAA observatory in 1976. The station is in a warm, humid marine environment which caused instrument degradation in the early part of the record. The original processing pre-1995 was not standard and not repeatable. Inspection of the record of calibrations revealed that the results were incorrectly applied in the period 1997 to 2001. An earthquake and tsunami on the 29 September 2009 damaged the station and instrument observations were interrupted for several years. The difference between the WOUDC and NDACC archives records processed in the NOAA system and WinDobson system are presented graphically in Figure 13.

Fresno and Hanford, California, USA (36°N, 120°W)

Dobson observations were started at the Fresno Weather Service Office, California, (37°N, 120°W) in 1982, with observations starting the next year. The Weather Service Office was moved to Hanford in March of 1995. The difference between the WOUDC and NDACC archives records processed in the NOAA system and WinDobson system are presented graphically in Figure 14.

Observatoire de Haute-Provence, France (44°N, 6°E, NDACC Station)

Dobson observations were started at the Observatoire de Haute-Provence (Station Géophysique Gérard Mégie) in 1983. The station and instrument are operated by the Centre National de la Recherché Scientifique, CNRS. The period of 1990 to 1999 was reprocessed to account for calibration drift, but has not yet been updated in WOUDC and NDACC. The difference between the WOUDC and NDACC archives records processed in the NOAA system and WinDobson system are presented graphically in Figure 15.

Perth Airport, Western Australia, Australia (32°S, 116°E)

Dobson observations were started originally in 1969 at Perth Airport weather radar, Perth Western Australia, then the NOAA automated instrument D081 was installed in 1984. In the late 1990s, the station was moved to the newly constructed Weather Station. There are periods of missing data in the WOUDC archive. The period after 2012 in the WOUDC archive does not have correct calibration information. The difference between the WOUDC and NDACC archives records processed in the NOAA system and WinDobson system are presented graphically in Figure 16.

Lauder, Central Otago, New Zealand (45°S, 170°E, NDACC Station)

Dobson observations began in early 1987 at the Research station in Central Otago, South Island, New Zealand. The station's time zone is UTC + 12, which means the UTC day changes at Local Standard Time 12 noon. The calculation of the UTC day for reporting the selected value was incorrect prior to 1992. Also, a selected value could be from the afternoon of one local day, and the representative value from the morning of the following local day while still being in the same UTC day. When inspected during the WinDobson processing, the instrument record between 2006 through 2011 revealed rain damage following reinstallation shortly after the 2006 intercomparison in Melbourne. The 2012 calibration information determined before the rebuilding of the instrument was used to process the data in WinDobson. The WOUDC and NDACC records are not yet updated. The instrument was rebuilt at the beginning of 2012, and has been operated with the data reduction in WinDobson since that time. The difference between the WOUDC and NDACC archives records processed in the NOAA system and WinDobson system are presented graphically in Figure 17.

Conclusions

The new data records in the WOUDC and NDACC archives will be more correct and complete, and the history of calibrations of the instruments networks has been homogenized. The overall changes are small (~0.1% offset), but several individual stations have a larger offset (Maximum 0.7%) driven by the changes in the ZC reduction polynomials. The average difference expressed as trends is also small. The ADDS observations are mostly unchanged from the early values. Larger differences exists within time periods for the individual stations Station (SPO for example), especially on shorter time scales.

Atmos. Chem. Phys. Discuss., doi:10.5194/acp-2017-383, 2017
Manuscript under review for journal Atmos. Chem. Phys.
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Acknowledgements.

The authors would like to acknowledge the work done by such people as Walter Komhyr, Robert Grass, Kent Leonard and others in establishing the US network.

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Atmos. Chem. Phys. Discuss., doi:10.5194/acp-2017-383, 2017
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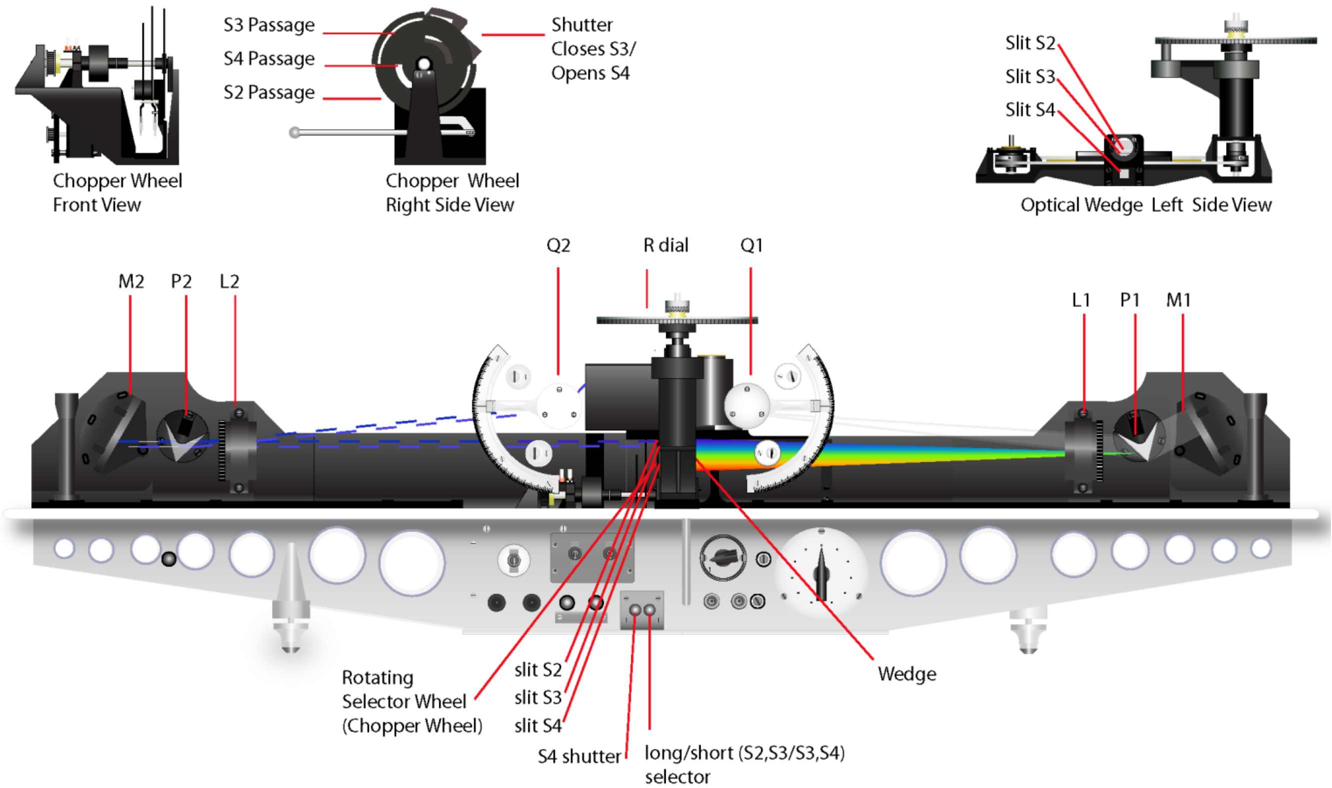

315 **Figure 1**: Diagram of Dobson Instrument, with cover omitted from view (some components shown are actually mounted in the cover.)

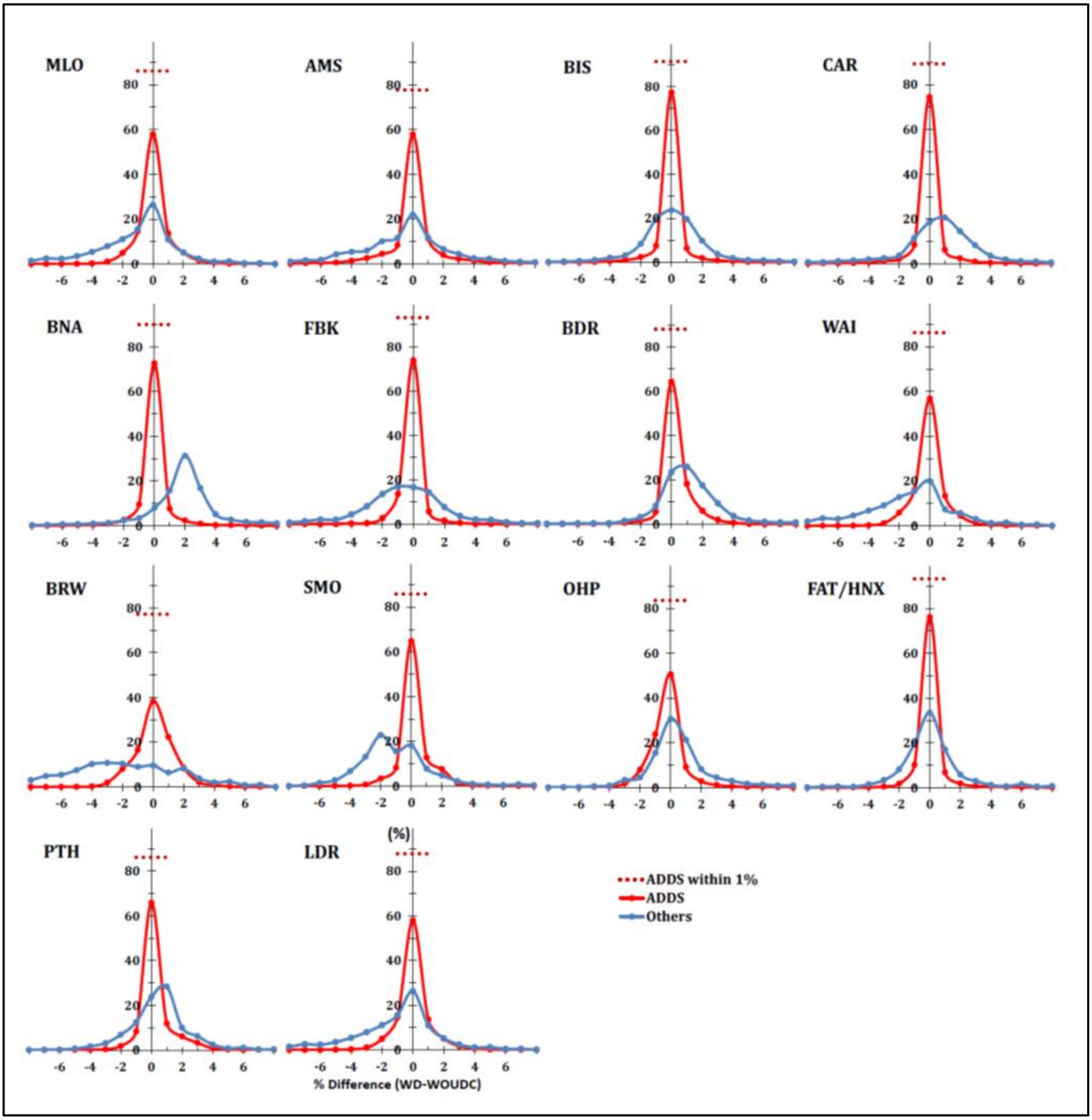

Figure 2. The Probability of a daily value changing by a particular percentage for each station. The red line is for ADDS type observations; the blue for all other types**;** the horizontal line is the percent of ADDS in the range **±1%** differences.

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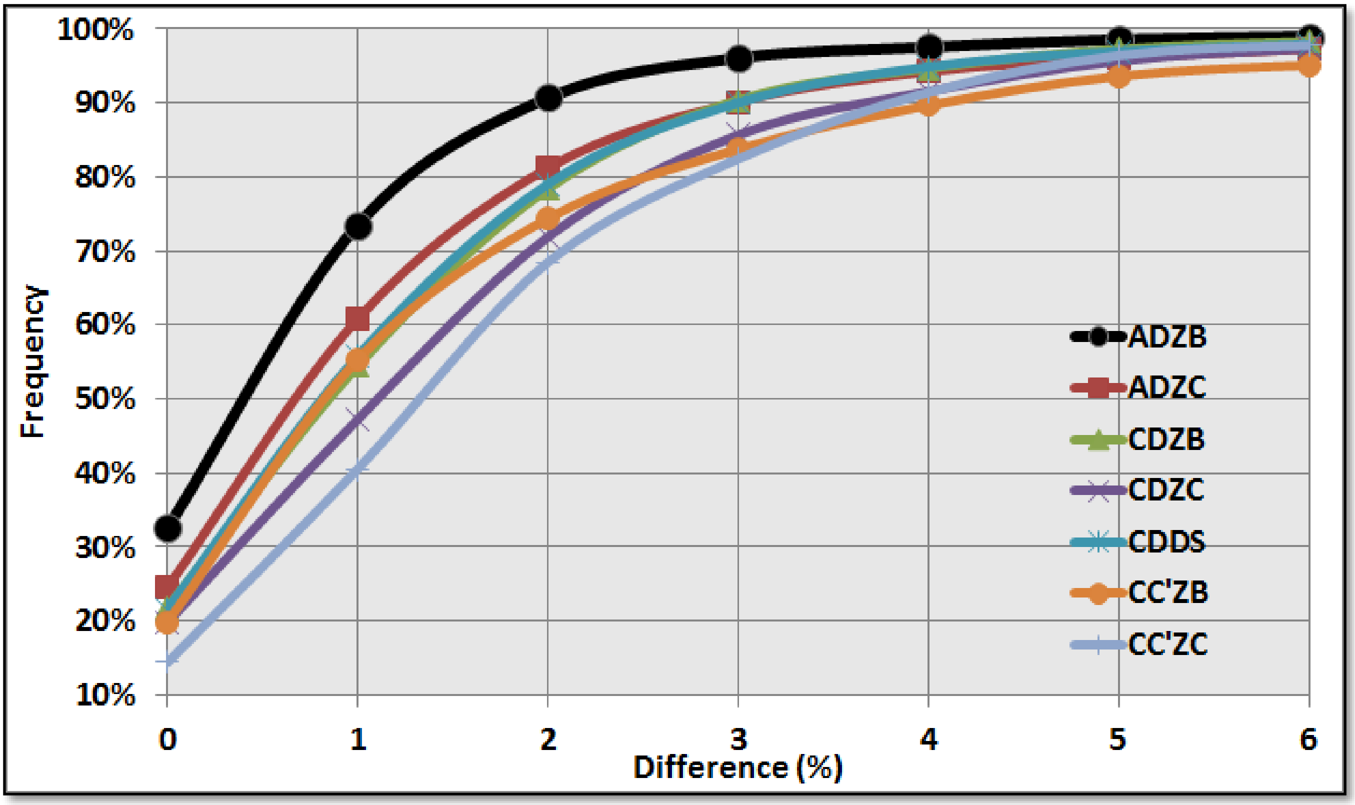

Figure 3. Distribution of differences between results from direct sun (ADDS) compared to zenith measurements on the same day. The frequency of compared zenith and ADDS total ozone (y-axes) is accumulated between 0 to 6 % (X-axes). Results are shown for other types of zenith sky measurements denoted by colors in the legend. Results are the average of 12 stations in the US network except for the CC' results, which is based on the SPO data record.

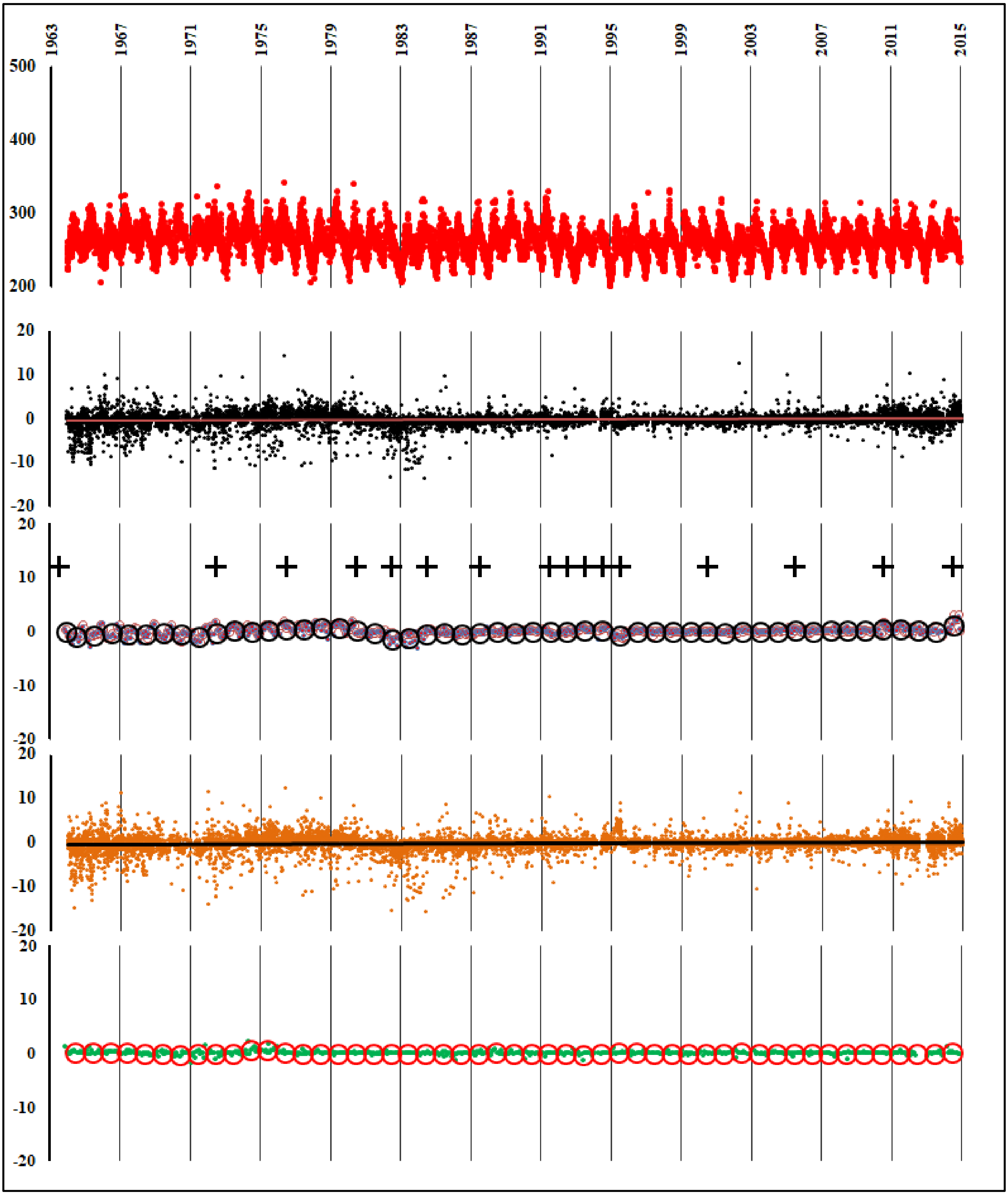
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Figure 4: Graphic representation of the changes in the MLO record after the conversion into WinDobson processing. First panel: The time record of total ozone measured at the station from the start of observations through 2015 (or until station was converted to WinDobson processing. Second Panel: percent difference between daily WinDobson total ozone records compared to the WOUDC record, (WinDobson-WOUDC). The red line is a linear fit. Third panel: the same as the second but for monthly and yearly averages (based on all the values in the month in each data set). The small white circles are averages made from DS observations only; the red symbols represent averages using all Dobson total ozone records; the large black open circles are yearly averages of all observations, based on monthly averages. Large + (plus) symbols indicate major calibration or instrument changes that lead to creating the new R-N tables; however, not all calibrations checks of the station record are shown. For NDACC Stations only: The fourth panel is the same as the second panel but for comparisons with the data archived at NDACC center (WinDobson-NDACC). The black line is a linear fit. The fifth panel is the same as the third panel for comparisons with the NDACC archived monthly and yearly averages. NDACC values are not recorded as observation type.

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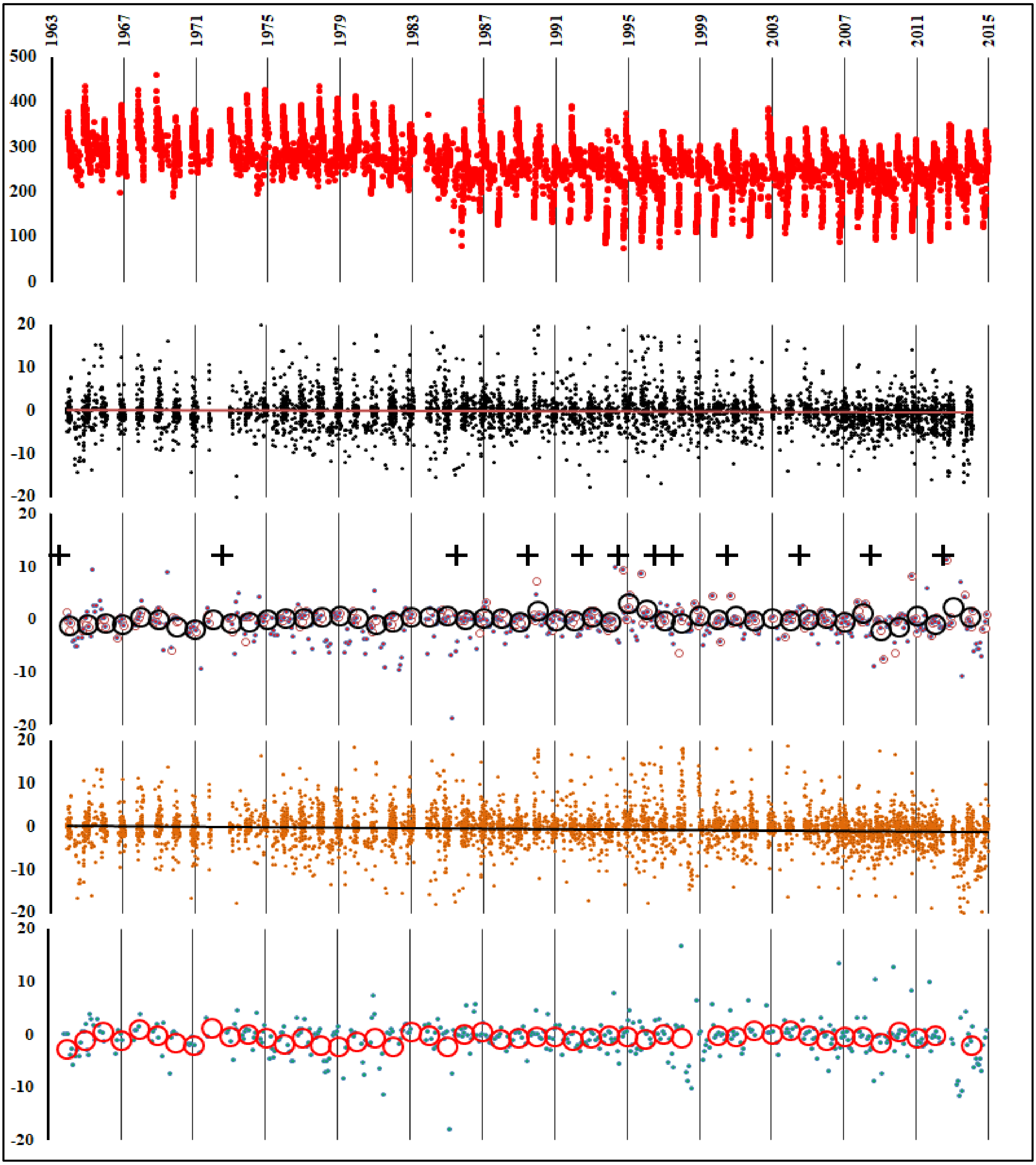

340 **Figure 5.** Graphic representation of the changes in the SPO record with the conversion into WinDobson processing.

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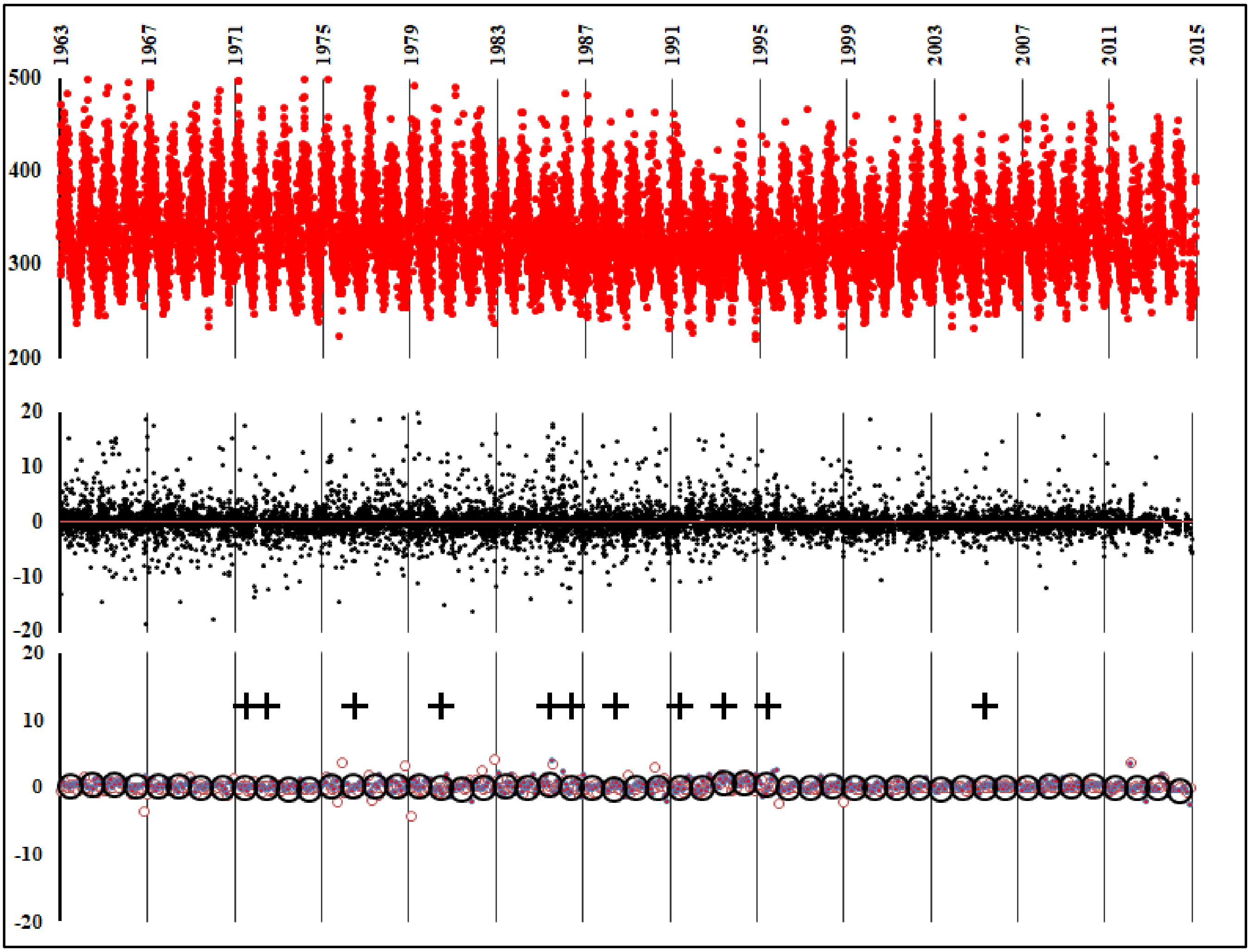

Figure 6. Graphic representation of the changes in the BIS record with the conversion into WinDobson processing.

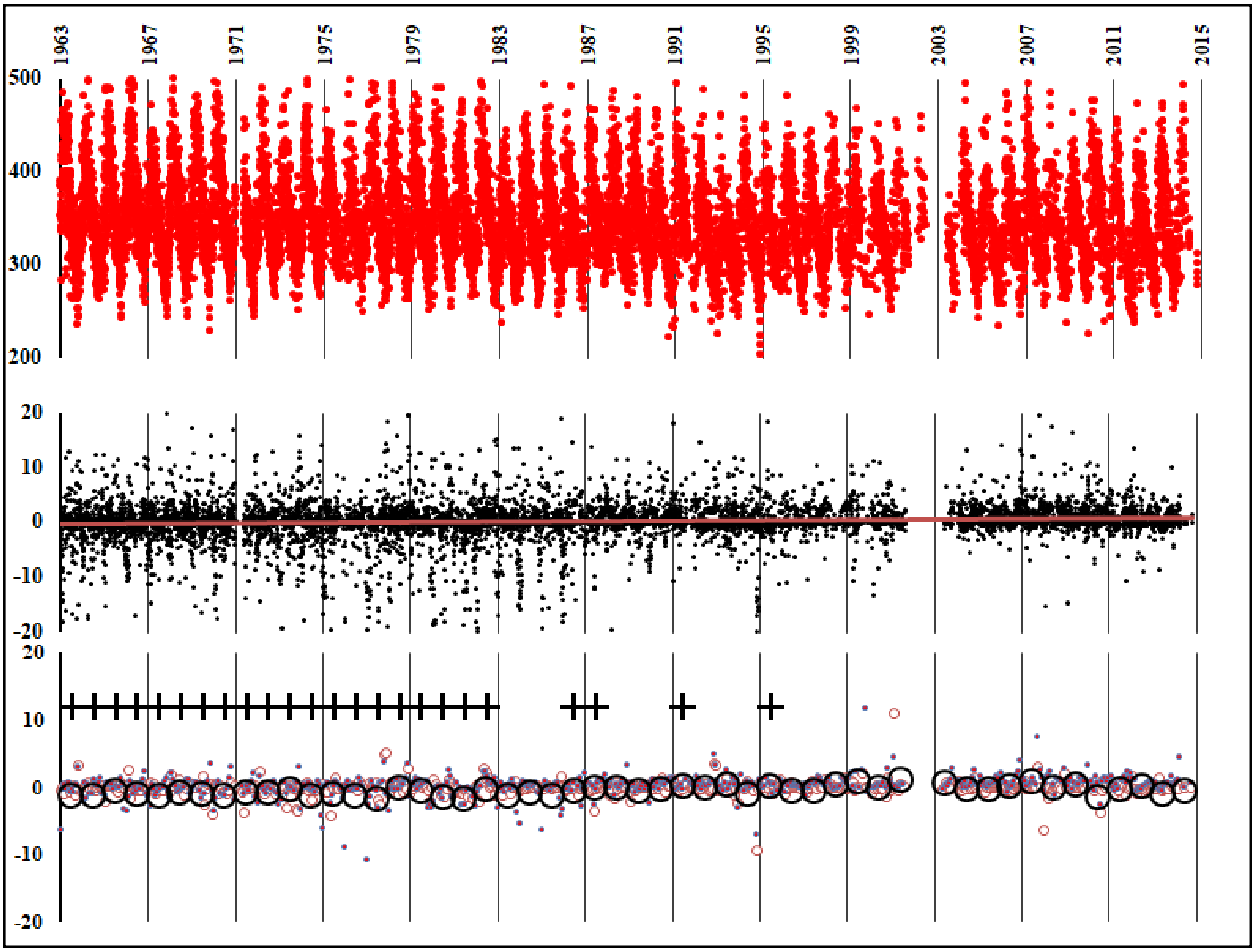

Figure 7. Graphic representation of the changes in the CAR record with the conversion into WinDobson processing.

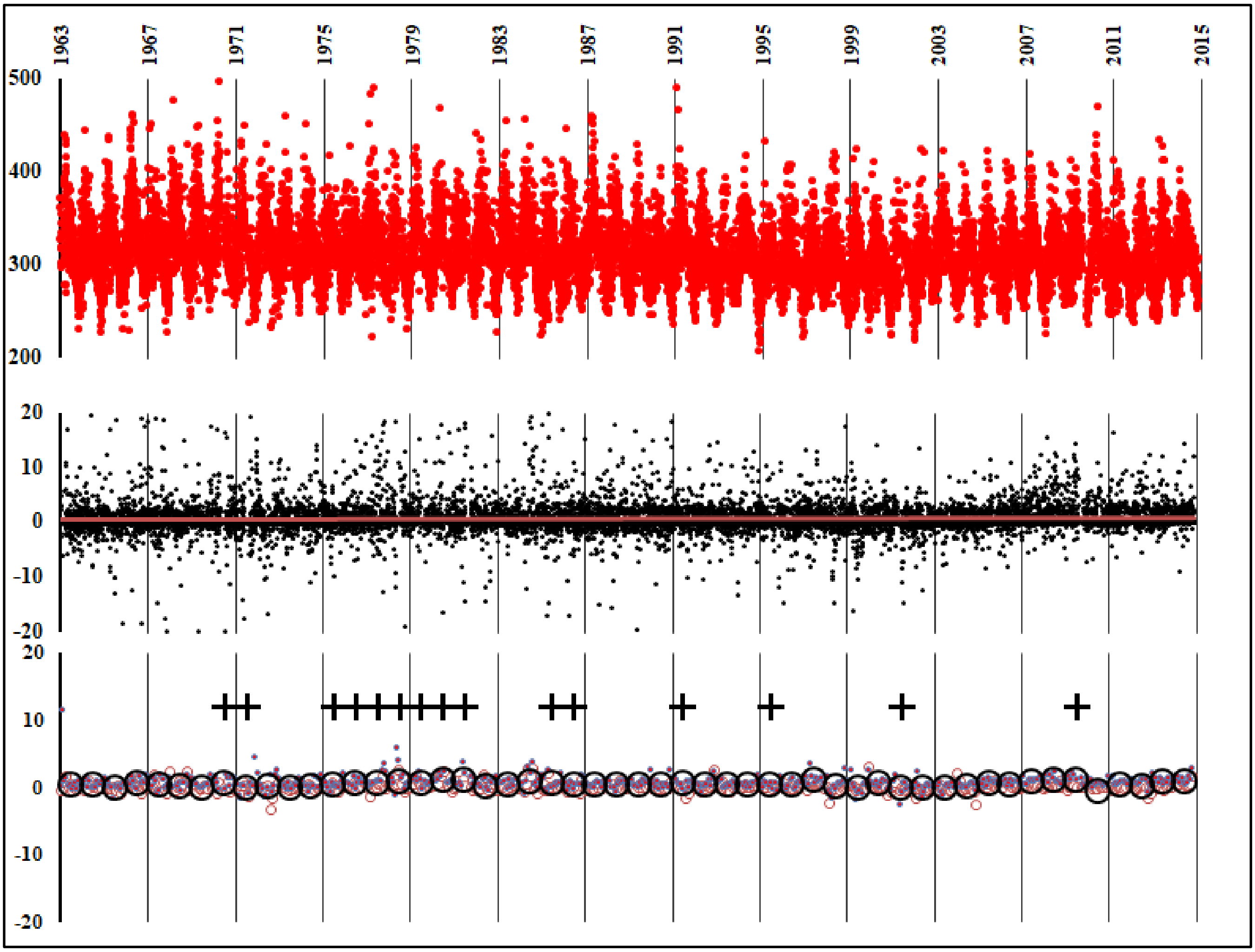

Figure 8. Graphic representation of the changes in the BNA record with the conversion into WinDobson processing.

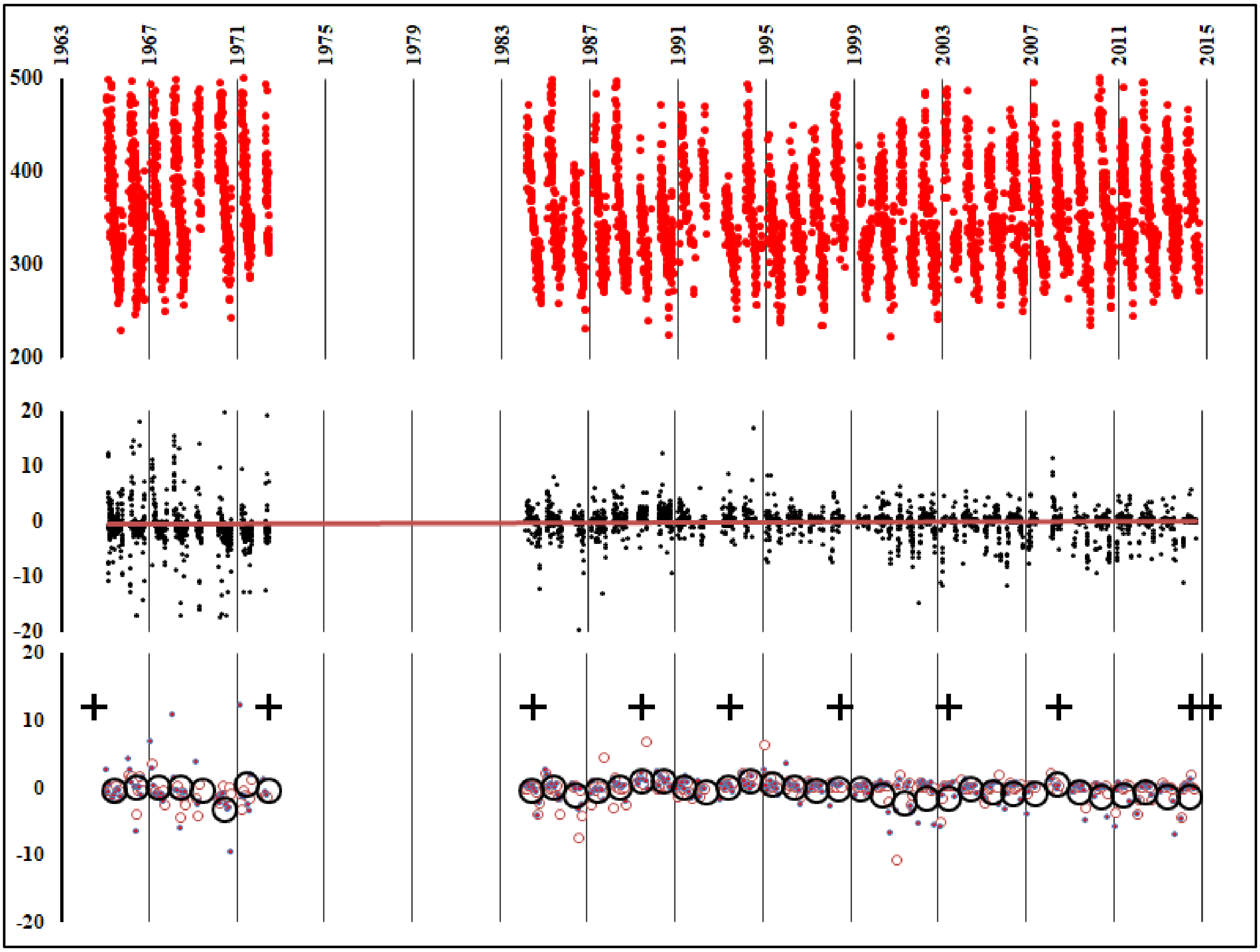

Figure 9. Graphic representation of the changes in the FBK record with the conversion into WinDobson processing.

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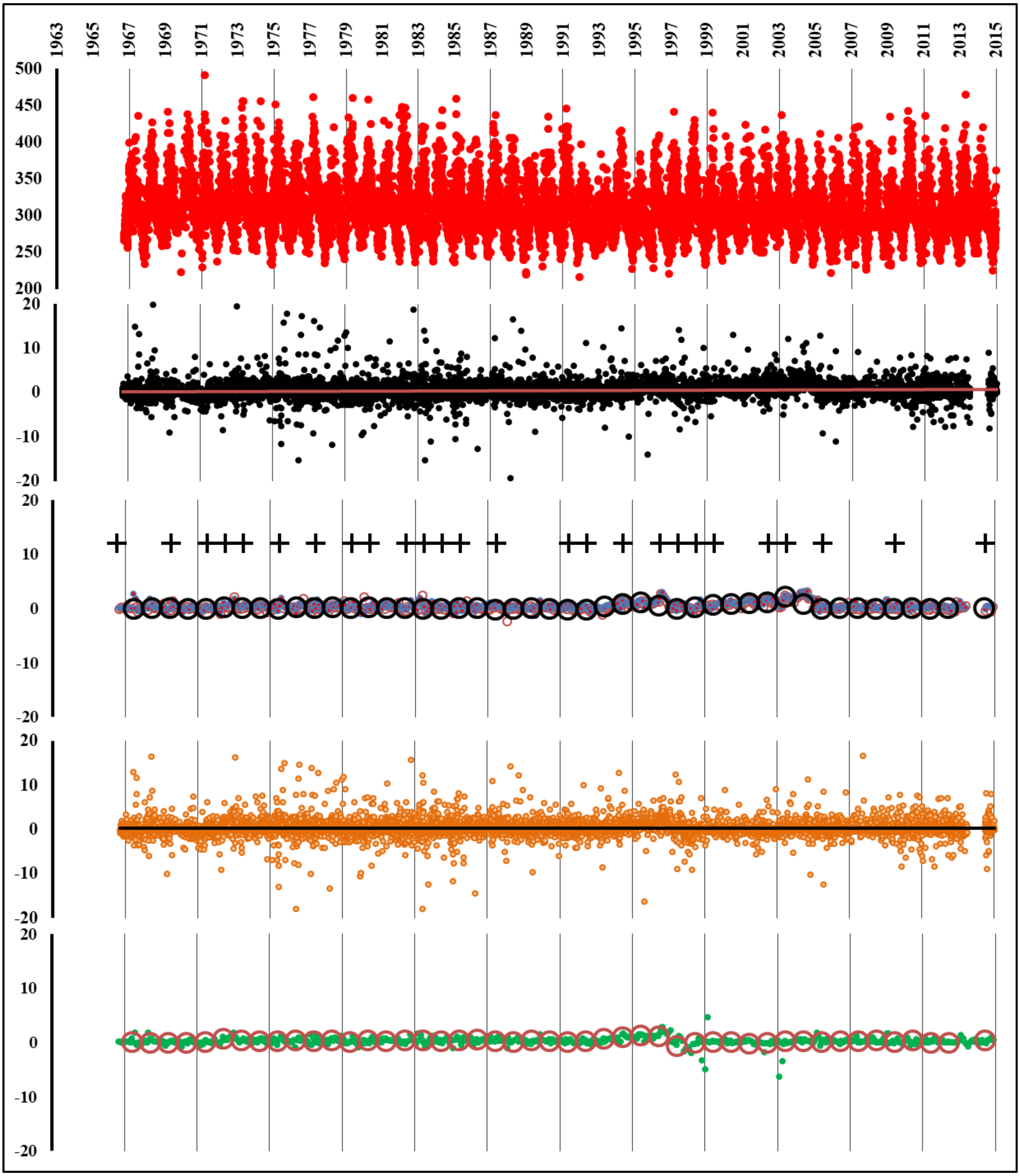

350 **Figure 10.** Graphic representation of the changes in the BDR record with the conversion into WinDobson processing.

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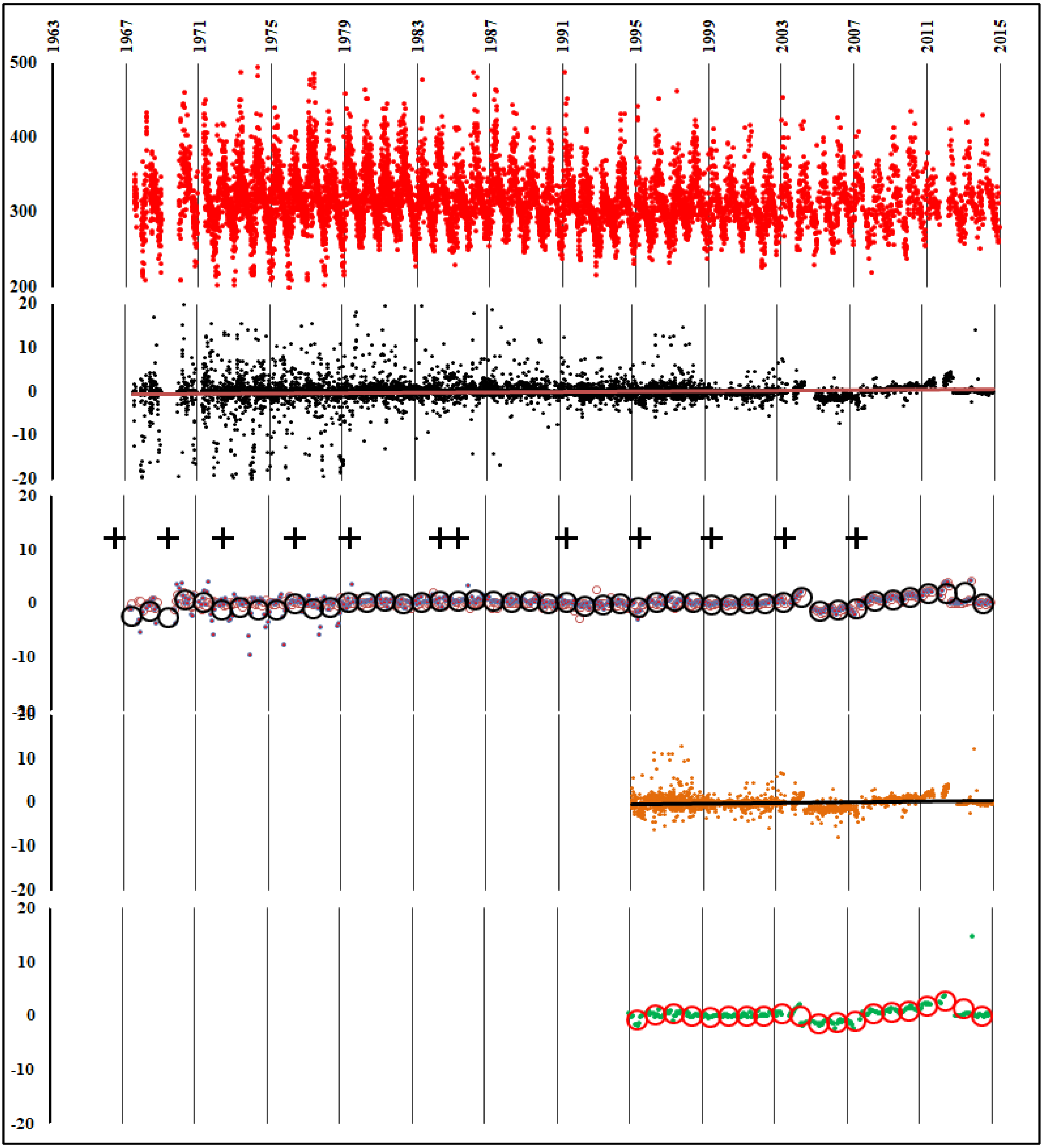

Figure 11. Graphic representation of the changes in the WAI record with the conversion into WinDobson processing.

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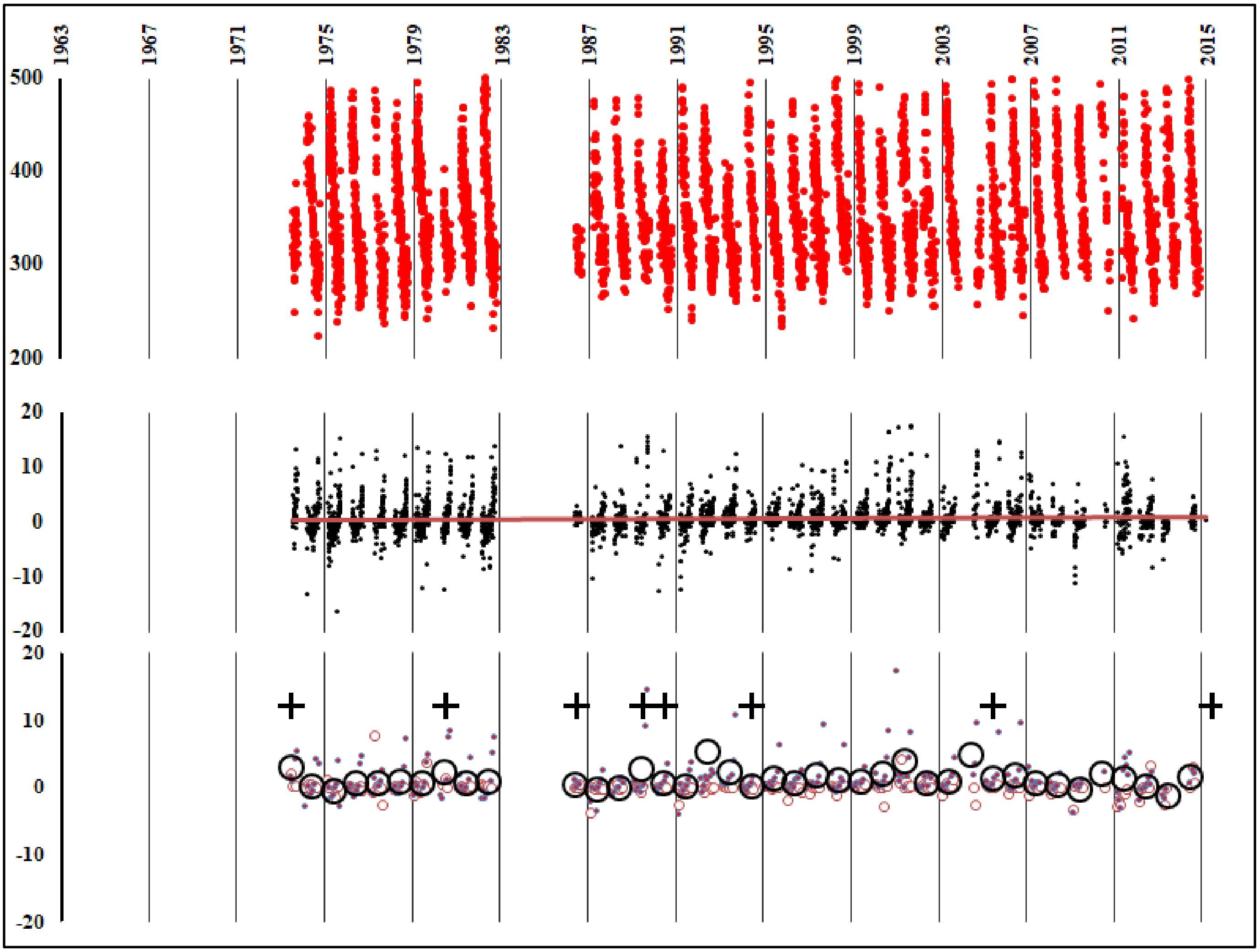

355 **Figure 12.** Graphic representation of the changes in the BRW record with the conversion into WinDobson processing.

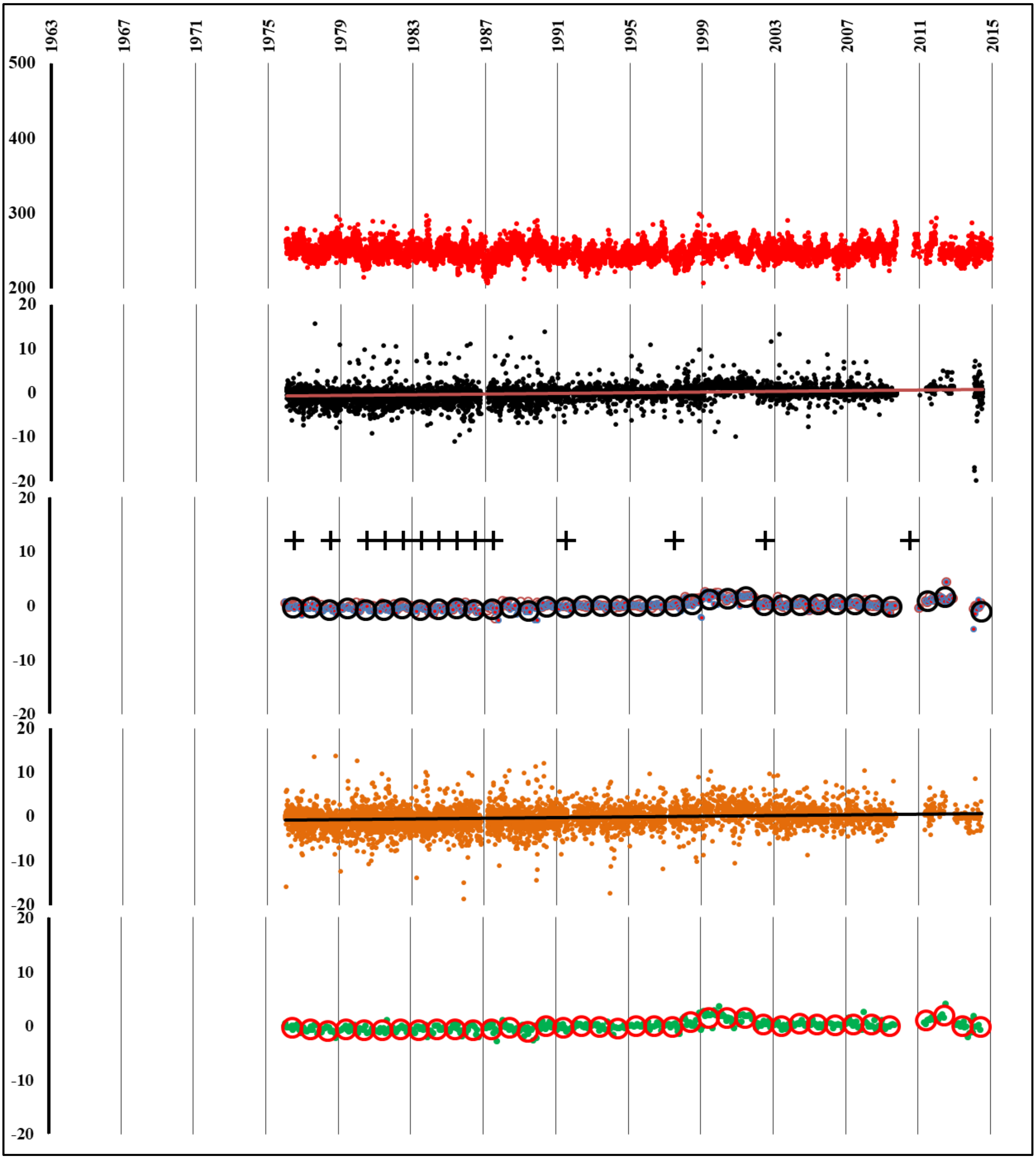

Figure 13. Graphic representation of the changes in the SMO record with the conversion into WinDobson processing.

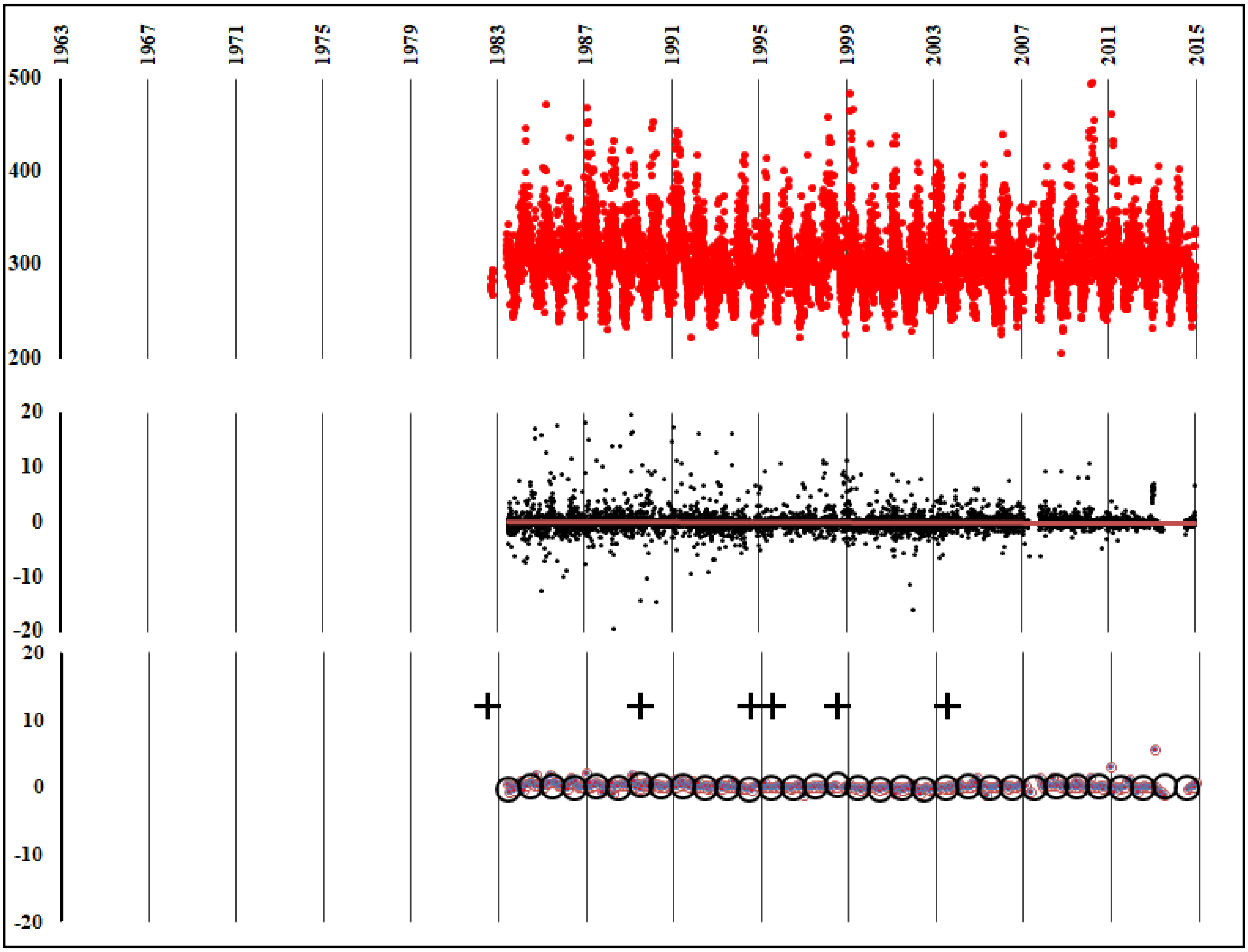

Figure 14. Graphic representation of the changes in the FAT/HNX record with the conversion into WinDobson processing.

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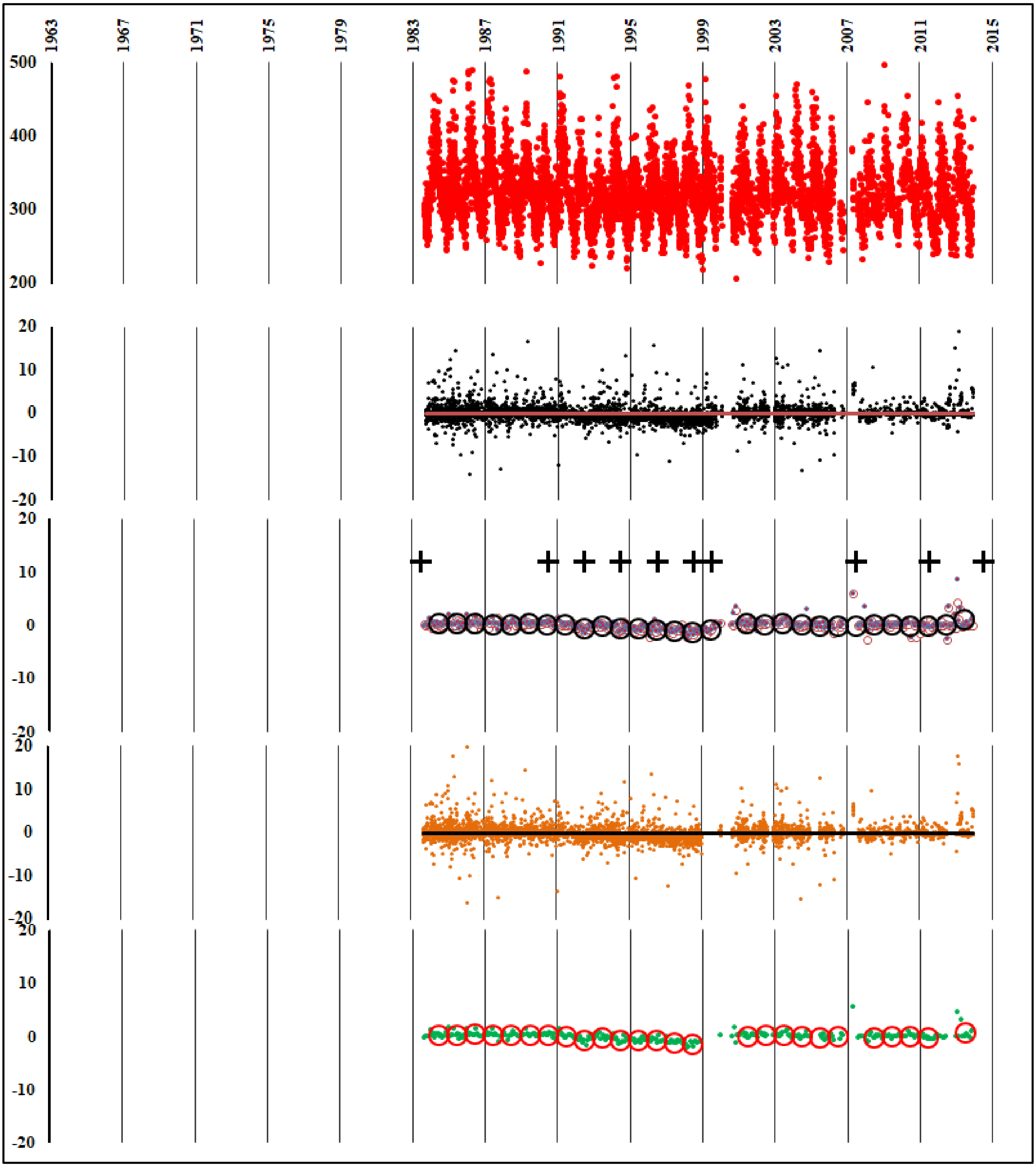

Figure 15. Graphic representation of the changes in the OHP record with the conversion into WinDobson processing.

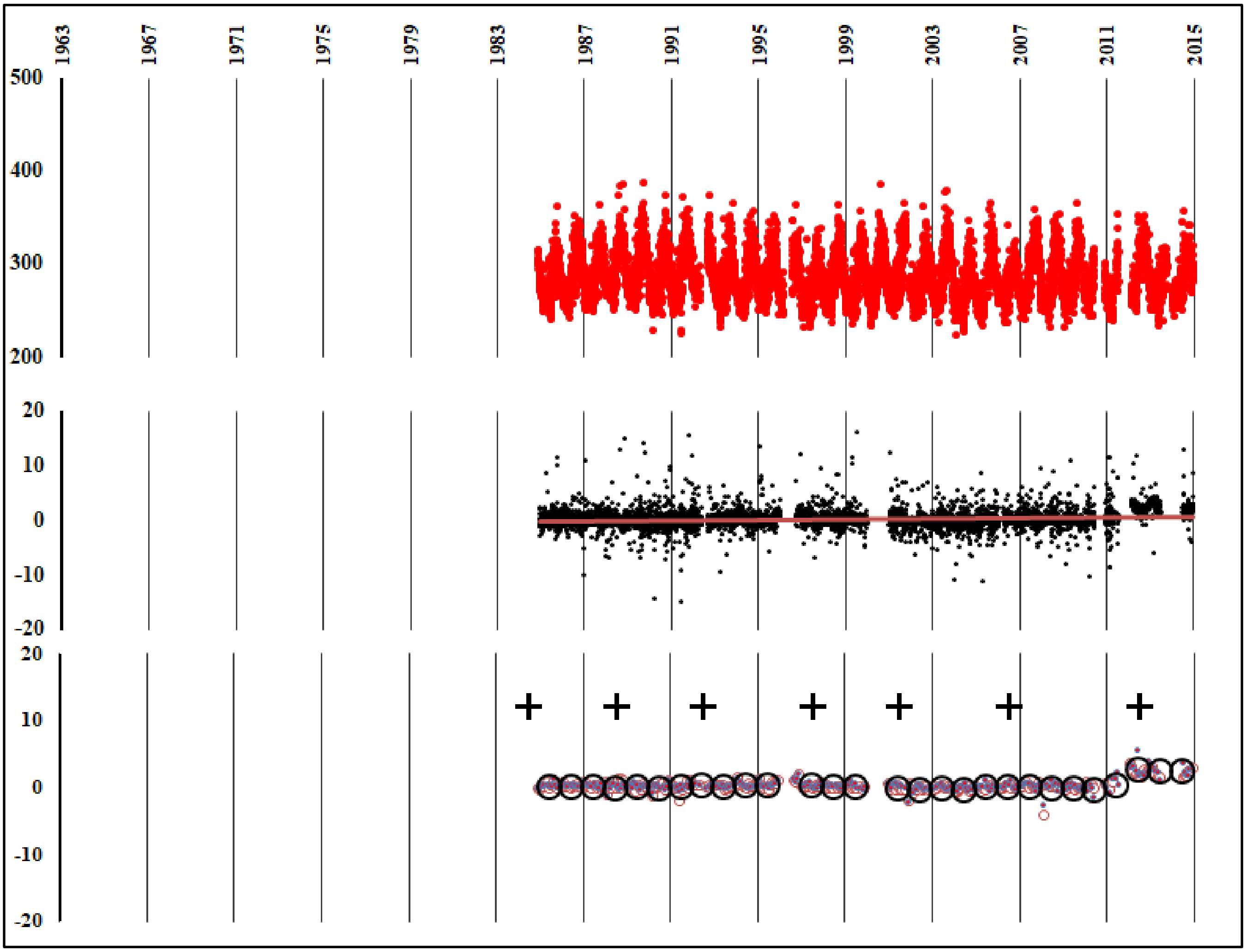

Figure 16. Graphic representation of the changes in the PTH record with the conversion into WinDobson processing.

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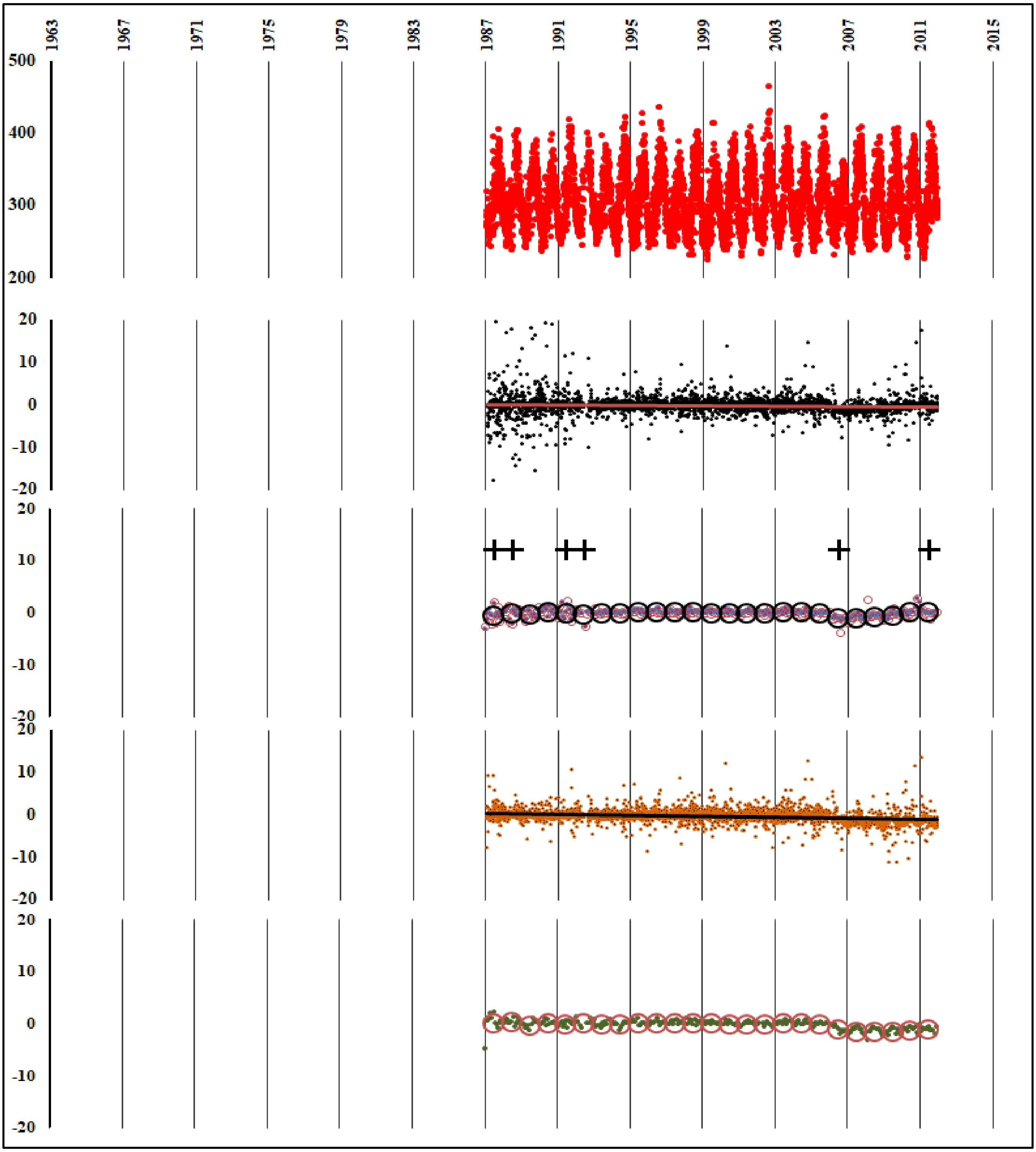

Figure 17. Graphic representation of the changes in the LDR record with the conversion into WinDobson processing.

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Station Name	Station Code	Station Dobson Record Started	Responsible Organizations (Archives)	Current Automation Status
Mauna Loa GMD Observatory	MLO	1963	NOAA (NDACC and WOUDC)	WinDobson Full
South Pole	SPO	1963	NOAA (NDACC and WOUDC)	NOAA Semi-Auto
Bismarck, North Dakota	BIS	1962	NOAA	NOAA Semi-Auto
Caribou, Maine	CAR	1962	NOAA	NOAA Semi-Auto
Nashville, Tennessee	BNA	1962	NOAA	NOAA Semi-Auto
Fairbanks, Alaska	FBK; POK	1965	NOAA; University of Alaska	WinDobson Full
Boulder, Colorado	BDR	1966	NOAA (NDACC and WOUDC)	WinDobson Full
Wallops Is., Virginia	WAI	1967	NOAA; NASA (NDACC and WOUDC)	NOAA Semi-Auto
Barrow GMD Observatory	BRW	1973	NOAA	NOAA Semi-Auto
American Samoa, GMD Observatory	SMO	1976	NOAA (NDACC and WOUDC)	NOAA Semi-Auto
Haute Provence, France	OHP	1983	NOAA; Centre National de la Recherche Scientifique, (NDACC and WOUDC)	WinDobson Full
Fresno and Hanford, California	FAT; HNX	1983	NOAA	NOAA Semi-Auto
Perth, Australia	PTH	1984	NOAA; Australian Bureau Meteorology	NOAA Full
Lauder, New Zealand	LDR	1987	NOAA; National Institute for Water and Atmosphere (NDACC and WOUDC)	WinDobson Full

Table 1. Current Stations in the NOAA Network using Dobson Ozone Spectrophotometers

Station Code	Offset WinDobson-WOUDC	Linear Trend WinDobson-WOUDC Per Year	Offset WinDobson-NDACC	Linear Trend WinDobson-NDACC Per year
MLO	-0.1% ± 1.6%	+0.014 ± 0.001%	-0.1% ± 1.8%	+0.015 ± 0.001%
SPO	-0.0% ± 4.0%	-0.016 ± 0.003%	-0.5% ± 6.9%	-0.026 ± 0.006%
BIS	+0.1% ± 2.2%	-0.004 ± 0.001%	N/A	N/A
CAR	+0.2% ± 3.2%	+0.022 ± 0.002%	N/A	N/A
BNA	+0.6% ± 2.7%	+0.002 ± 0.001%	N/A	N/A
FBK	-0.4% ± 2.8%	+0.033 ± 0.003%	N/A	N/A
BDR	+0.3% ± 1.7%	+0.007 ± 0.001%	+0.3% ± 1.5%	-0.001 ± 0.001%
WAI	-0.1% ± 3.3%	+0.024 ± 0.003%	+0.0% ± 1.6%	+0.032 ± 0.006%
BRW	+0.7% ± 2.8%	+0.011 ± 0.004%	N/A	N/A
SMO	-0.1% ± 1.7%	+0.042 ± 0.002%	-0.1% ±2.3%	+0.042 ± 0.002%
OHP	-0.1% ± 1.8%	-0.002 ± 0.003%	-0.1% ± 1.7%	-0.004 ± 0.003%
FAT/HNX	+0.0% ± 1.5%	-0.003 ± 0.002%	N/A	N/A
PTH	+0.3% ± 1.6%	+0.022 ± 0.002%	N/A	N/A
LDR	-0.1% ± 1.8%	-0.022 ± 0.003%	-0.3% ± 1.3%	-0.066 ± 0.002%

Table 2. Statistics of the overall differences between WOUDC and NDACC records and WinDobson record (WinDobson-WOUDC, NDACC).

Difference	ADZB	ADZC	CDZB	CDZC	CDDS	CC'ZB	CC'ZC
0	33%	25%	21%	17%	22%	19%	11%
1	74%	61%	53%	44%	56%	49%	32%
2	91%	81%	76%	67%	79%	69%	61%
3	96%	90%	89%	81%	90%	81%	75%
4	98%	94%	94%	89%	95%	89%	85%
5	99%	96%	97%	93%	97%	94%	91%
6	99%	97%	98%	95%	98%	96%	95%
7	99%	98%	99%	97%	98%	98%	97%
8	100%	99%	99%	97%	99%	98%	97%
Frequency	**ADZB**	**ADZC**	**CDZB**	**CDZC**	**CDDS**	**CC'ZB**	**CC'ZC**
85%	1.5%	2.3%	2.5%	3.0%	2.5%	3.3%	3.3%
90%	1.9%	3.0%	3.0%	3.6%	3.0%	4.0%	3.8%

Table 3.

Table 3. Results are the average of 12 stations in the NOAA network (Barrow, Fairbanks, Caribou, Bismarck, Haute Provence, Boulder, Wallops Island, Mauna Loa, Tutuila, Perth, Lauder and South Pole).