Brewer spectrometer total ozone column measurements in Sodankylä

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Abstract. The Brewer total ozone column measurements started in Sodankylä in May 1988, 9 months after the agreement of The Montreal Protocol. The Brewer instrument has been well maintained and frequently calibrated since to produce a high quality ozone time series now spanning over 26 years. The data has now been uniformly reprocessed between 1988 and 2014. The quality

5 of the data has been assured by automatic data rejection rules as well as by manual checking. The daily mean values calculated from highest quality direct sun measurements are available 77 % of time with up to 75 measurements per day on a clear day. Zenith sky measurements fill another 14 % of the time series and winter months are sparsely covered by moon measurements. The time series provides information to survey the evolution of Arctic ozone layer and can be used as a reference

10 point for assessing other total ozone column measurement practises.

1 Introduction

Ozone is a molecule consisting of three oxygen atoms (O_3). It is produced from oxygen atoms and molecules by photochemistry in the equatorial stratosphere, where the UV radiation is at its strongest. It is then transported to higher latitudes by atmospheric circulation pattern (e.g. Müller,

15 2012). Ozone is a strong absorber of ultra violet (UV) radiation and thus an important constituent of atmosphere enabling life on earth as we know it. Extensive amount of UV radiation is known to have harmful biological effects. It is known to cause diseases on eyes and skin for example(Lucas et al., 2006) as well as having bad influence on vegetation (Teramura and Ziska, 1996).

In 1984 it was found out that total ozone above Antarctica diminishes during antarctic spring

20 (Farman et al., 1985) and the discovery was later confirmed by analysing satellite data (Bhartia et al., 1985). This showed how significant effect the chlorofluorocarbons (CFC) had in reality for the total amount of ozone - in theory this concept had been suggested already by Molina and Rowland (1974). These findings caused a reaction in decision makers and led to The Vienna Convention for the Protection of the Ozone Layer in 1985 and to The Monreal Protocol in 1987, both aiming to

25 decrease the amount of CFCs used widely as refrigerants and blowing agents at that time. The de-

velopement of total ozone amounts have been under close scrutiny since and the state of the ozone layer is revised regularly (WMO, 1985, 1988, 1989, 1991, 1995, 1998, 2003, 2007, 2011, 2014).

In the wake of The Montreal Protocol ozone measurements were introduced at the Finnish Meteorologial Institute Arctic Research Center (FMI-ARC) in Sodankylä as both the Brewer measurements and the regular ozone soundings started in 1988. Even though the ozone depletion is more pronounced and regular in the Antarctis the Arctic has witnessed some really low total ozone amounts in the cold winters and springs of 1990's and 2000's (Rex et al., 1997, 2002; Manney et al., 2011). The location of FMI-ARC (67.368°N, 26.633°E) is well suited for Arctic ozone studies as it often lies within or on the edge of the polar vortex during the time of ozone depletion in the spring.

Sodankylä is one of only seven Brewer stations north of the Arctic Circle (Kipp & Zonen, 2015). As the Arctic ozone is highly variable these few measurement sites are extremely valuable for monitoring the developement of ozone layer. Also the measurement techniques face challenges at high latitudes where the solar elevation angle is very low for long periods. The FMI-ARC has been active in evaluating the effects of low solar elevation angle and Brewer #037 has been serving as a reference instument for satellite validation as well as validation for other ground based measurement methods.

As a manned station north of the Arctic circle, FMI-ARC is a rarity, and can produce data of high quality and with infrequent data gaps. In this paper the uniformly processed Brewer dataset from 1988 to 2014 is presented. In section 2 the instrument itself is described and the measurement procedure is explained. The means of maintaining the quality and continuity of the measurements are presented. In section 3 the data flow is shortly described and the data processing algorithm is presented with the rules applied to disregard inaccurate or erroneus data. In section 4 the dataset obtained is demonstrated and some features are highlighted. Some useful diagnostics and statistics of the availability of the data are presented.

2   Instrument operation

2.1   Instruments

Total ozone column over Sodankylä has been measured with Brewer spectrophotometer, serial number 037, since May 1988. In September 2012 a new Brewer, serial number 214, was acquired but is still in comparison phase rather than in operational use.

The Brewer instrument stands on a tripod which can be leveled by adjusting the height of all three legs separately. On top of the tripod sits a tracker which maintains the azimuthal orientation of the entrance optics towards the Sun. Accurate tracking of the Sun requires the rotational axis of the tracker to be exactly vertical. The spectrometer itself is mounted on top of the tracker.

The light source is selected with a rotating prism inside the spectrometer. The input can be global radiation through the diffuser on top of the instrument, direct radiation from a point source or radi-

60   ation from any of two inner calibration lamps. Direct radiation viewing angle is approximately 2 -
2.7 degrees (Kazadzis et al., 2005).

The input light is dispersed in a monochromator, consisting of a spherical mirror and a grating. Grating can be rotated by a motorized micrometer to select the measured wavelength. In the more recent Brewer, serial number 214, there is a double monochromator with two sets of mirrors and

65   gratings working synchronously. Double monochromator has significantly less light coming outside the wanted wavelength band.

In place of an exit slit there is a slit mask with 8 different positions. The mask can be rotated fast to go through a set of predefined wavelengths without moving the grating. One of the positions has the exit slit completely shut for determining the dark current of the photomultiplier and one position

70   allows light from two slits to enter the photomultiplier for characterisation purposes. The wavelength resolution for the Brewers is roughly 0.6 nm (FWHM of the instrument function), slightly depending on the individual instrument. The wavelength range is 290 to 325 nm for the Brewer #037 and 286.5 to 365 nm for the Brewer #214.

The photons are counted by a photomultiplier and the counts are recorded. Due to high variability

75   in the intensity along the day there is a filter wheel with set of wavelength neutral filters with different attenuations to choose from depending on the initial intensity check. Another filter wheel is deployed to choose a diffuser, a polarizer or a clear slit depending on the measurement procedure.

2.2   Measurement procedure

There are four measurement procedures to measure ozone with Brewer instrument each to suit dif-

80   ferent conditions. Direct sun (ds) measurement suits clear sky conditions with solar elevation angle higher than 15 degrees. Focused sun (fz) measurements are used for direct sunlight when the elevation angle is below 15 degrees. Zenith sky (zs) measurements are used when the direct sunlight is blocked due to cloudy weather. During the polar winter when the sun elevation stays low for a long period focused moon (fm) measurements are possible when the phase is close to full moon.

85   In direct sun measurement the azimuth tracker rotates towards the Sun and the zenith prism turns so that the direct light from the Sun is guided to the entrance slit. A diffuser is used to smooth the input light so there is less problems due to slight misalignment. A further attenuation filter might be selected depending on the intensity in a pretest. The grating is kept stationary at a predefined ozone measurement position and the slit mask is rotated to rapidly to select the output wavelengths.

90   The wavelengths are roughly 306.3, 310.1, 313.5, 316.8 and 320.1 nanometers. The wavelengths are more accurately defined for each individual instrument in the yearly or biennial calibration.

For low solar elevation angles the procedure called focused sun is performed. To enhance the input light intensity the diffuser is omitted but a neutral density filter may be applied to protect the photomultiplier. The forward scattered sky light entering the photomultiplier is estimated, by

95   measuring the intensity just beside the Sun, and subtracted form the intensities measured from the direct sunlight.

When the direct sunlight is blocked by clouds the total ozone column is estimated by measuring scattered light from the zenith. The prism is directed at the zenith angle of 0 degrees and the same wavelengths are measured as in the direct sun measurements. No diffuser is applied but neutral filters

100   are applied when needed. To be less affected by the clouds light goes through a film polarizer that is fixed so that the polarizing axis is parallel with respect to the reference horizontal plane of the instrument (Muthama et al., 1995).

For high latitudes there is a time when the Sun does not rise high enough for any of above mentioned measurement procedures. For that time of the year the only possibility is to measure from the

105   moon. The routine is called focused moon (fm). There is no diffuser used. The intensities are rather low and usually no neutral density filter is needed.

The instrument operation is fully automated. The commands can be given manually but normally the instrument operates on a schedule written by the operator. The schedule consists of command strings set to start when a certain solar zenith angle is reached. In addition to the ozone measurement

110   modes mentioned above, there are several commands to check the status of the motors and follow the changes of instrument characteristics as well as measurement mode for measuring global UV -radiation.

2.3   Calibration

The instruments need to be calibrated regularly to keep track of possible changes in their charac-

115   teristics and the effect of these changes in the ozone measurements. Calibration can be done at the instruments home institute against a well calibrated reference instrument or the instrument can be moved to take part in calibration campaign where the instrument can be calibrated against a reference instrument or by using a Langley extrapolation method. The calibration history of the Brewer #037 is presented in table 1. The main characteristics to be redefined are the extraterrestrial constant

120   (ETC), the ratio of measurements from the internal calibration lamp at ozone measurement wavelengths, the wavelength setting in ozone measurements, the instrument function and the absorption coefficient (α).

The ETC tells what the instrument would measure if there was no atmosphere between the instrument and the Sun. It is dependent on the spectral response of the instrument and the change in

125   ETC is monitored by measuring the intensities at the same wavelengths from an internal calibration lamp. In the calibration campaign the ETC and lamp reference value ($R6_{sl,ref}$) are determined. If these values behave the same as in the last calibration any change in the lamp intensity ratios are considered as a change in the instrument response and not a change in the lamp and thus the time series between calibrations must be corrected for ETC changes as indicated by the changes in the

130   lamp value.

Table 1. Brewer #037 calibration history (partly adopted from IOS, 2015)

Year	Month	Location
1988	April	Sodankylä
1989	June	Sodankylä
1990	June	Sodankylä
1993	November	Izaña
1994	September	Jokioinen
1995	June	Sodankylä
1996	October	Izaña
1997	July	Sodankylä
1998	June	Jokioinen
1999	June	Jokioinen
2000	June	Tylosand
2001	June	Jokioinen
2002	June	Sodankylä
2003	June	Sodankylä
2004	June	Jokioinen
2005	June	Sodankylä
2006	June	Jokioinen
2007	May	Sodankylä
2008	June	Jokioinen
2009	June	Sodankylä
2009	December	Izaña
2011	November	Izaña
2013	November	Izaña

The optimal grating position for ozone measurements is searched by measuring ozone with several positions close to the expected one. The wavelength scale for the micrometer positions is determined by measuring a set of known emission lines from different discharge lamps, for example mercury and cadmium lamps. From these lamp measurements the instrument function is also retrieved. Absorption coefficient is calculated for the exact operational wavelengths as a convolution between the instrument function and the ozone absorption cross section.

In addition to these annual or biennial checks the dead time of the photomultiplier is constantly monitored. The temperature dependence has been characterized already at the factory by the manufacturer. The neutral filter wavelength dependence has also been measured more frequently lately but no corrections have been applied this far.

2.3.1 Quality control

Quality control includes procedures to ensure the instrument is measuring in the ideal manner, the measurements are not stopped or obstructed and all the changes in the instrument are recorded.

To ensure the view is not obstructed and the sunlight is transmitted ideally inside the instrument the window is regularly manually cleaned using isopropyl alcohol. For the snow and rain a blower has been istalled that keeps the window clear except for the heaviest snowfalls. After heavy snowfall a manual cleaning is required and the situation can be checked from a webcam installed to see the Brewer at all times.

Inside the instrument there are two calibration lamps, a mercury discharge lamp and a quartz-halogen lamp, called standard lamp, with continuous spectrum. The emission lines of the mercury lamp are used for frequent checks of the wavelength selection for accurate measurements and for ensuring the correct behavior of the step motors moving the grating. In Sodankylä the measurements are usually made before each spectral scan where the step motors make numerous small steps to scan a big wavelength range with 0.5 nanometer interval. This ensures the measurements are always made at the exact wavelengts that are expected.

Standard lamp is measured daily for the same wavelengths that are used in ozone measurements. This assures all the changes in the instrument response are recorded. Assuming the lamp does not change the value measured from the lamp corresponds a change in the solar measurements. In a calibration campaign the lamp measurements are reviewed to check if the lamp measurement changes are due to change in the lamp or due to change in the instrument. Ozone measurements are corrected respectively.

Because the Brewer is also used for spectral UV measurements the changes in the response are followed very carefully by measuring 1000 W calibration lamp in a dark room every 6 weeks. After each calibration before the instrument returns to the measurement site the tracker is opened and the friction wheel rotating the tracker is cleaned to allow the maximum friction and to ensure there is no slipping and losing steps which would result in poor azimuthal pointing accuracy.

To ensure the maximum intensity and thus the maximum contrast in the measurements the orientation of the tracker and the zenith prism need to be checked regularly. This procedure is called sighting. The instrument is oriented towards the Sun and the entrance slit is viewed from a view port on top of the instrument. If the instrument orientation is perfect the picture of the Sun is centered around the entrance slit. If this is not the case the azimuth tracker and zenith prism motors are commanded from buttons on the side of the instrument casing to turn the instrument to achieve perfect orientation.

For an accurate orientation check a human eye is needed but for a rough check an automatic routine measurement has been developed. In this routine the intensity of the light through the entrance slit is measured in the original position and in positions few motor steps away from the original

one. The maximum intensity is regarded as the optimum orientation and changes are suggested if necessary by the operating software.

Since the beginning of 2015 a database system called IDEAS has been in use to enhance the con-
180   tinuity and quality of the data. The system parses the raw data files and updates in approximately 10 minute intervals. Warnings are raised and sent by e-mail if there are signs in the data for misbehavior of the instrument, for example if the wavelength calibration is too much off of the reference value. This warning system ensures the erroneus behavior of the instrument is noticed as soon as possible and corrective action can be taken.

185   **3   Data handling**

3.1   Data flow and data storage

Data is collected by the operating computer controlling the Brewer. At this point the data consists of raw counts and preliminary data reduction including not only the measurements of ozone but also the wavelength calibration and stability check information. This data is retrieved to a local server
190   once every 5 minutes. Another server hosting a database system, IDEAS, collects the data from the primary local server every 5 minutes. IDEAS parses the data and is able to send out warning messages by e-mail in case of suspected malfunction of the instrument. This way the any problems in the measurements or in the instrument are noticed within 10 minutes of the start of the problem.

The processing of the final products that are sent to World Ozone and UV Data Center (WOUDC)
195   and to the FMI-ARC database litdb.fmi.fi still require human interaction. The data is collected from the primary local server to a personal computer and processed with a software described in section 3.2. There are rules to assure the quality of the data (section 3.3) but some erroneus measurements must still be filtered out by human eye. At the moment the data is available in WOUDC database until May 2010 and the update for Sodankylä data will be made when the quality assurance is finished.

200   Finland is participating in Eubrewnet COST action (COST-ES1207, www.eubrewnet.org) and the Brewer data is sent from primary local server to Eubrewnet database every 20 minutes. The database is under developement and not fully operational at this moment. When operational the database will receive Brewer raw data from all the participating countries and the final products will be processed by a central computer. This way way the data will be coherent through the whole network.

205   **3.2   Algorithm**

For all ozone measurement procedures the raw data includes total counts from the photomultiplier for seven positions of the slit mask, F0 to F6. To retrieve vertical ozone column O3Brewer -software, written in Delphi language by Martin Stanek, is used (Stanek, 2015). The retrieval process is de-
scribed below.

210 Before the physical modeling of the absorption itself the raw counts are first turned into count rates C (counts/second) (SCI-TEC Instruments Inc., 1999). First the dark counts are removed and the integration time for each slit exposure is taken into account in term $2/IT$ and CY is the number of slit exposure cycles. Dark counts, F_1, are measured at slit mask position 1, where the exit slit is closed. The count rate, C_i, for slit mask position i, becomes

215
$$C_i = \frac{2 \times (F_i - F_1)}{IT \times CY}, \text{ for position } i = 2..6. \tag{1}$$

The photomultiplier has a dead time (DT) , a time it takes it to recover from a hit by a photon to be able to count another photon. The effect is assumed to follow the Poisson statistics and hence the equation

$$C_{i,m} = C_{i,t} \times e^{-C_{i,t} \times DT}, \tag{2}$$

220 where $C_{i,m}$ is the measured count rate and $C_{i,t}$ is the true count rate. The first estimate for the true count rate is given by

$$C_{i,t,1} = C_{i,m} \times e^{C_{i,m} \times DT}. \tag{3}$$

After this a better estimate is calculated by plugging the first estimate in the original equation

$$C_{i,t,2} = C_{i,m} \times e^{C_{i,t,1} \times DT}. \tag{4}$$

225 This is repeated 8 times and the result is expected to converge until then, making $C_{i,t,9}$ the final estimate for $C_{i,t}$.

Later will be shown that, when calculating ozone we are dealing with logarithms of irradiance ratios. For this reason the count rates are converted to logarithmic scale, $C_{i,l}$

$$C_{i,l} = 10^4 \times log_{10}(C_{i,t}) \tag{5}$$

230 The response of the instrument may change according to the change in temperature inside the instrument. The effect is assumed linear and has been characterized at the factory. Corrected count rate, $C_{i,tc}$, will be

$$C_{i,tc} = C_{i,l} + (TC_i) \times T, \tag{6}$$

where T is temperature and TC_i is the wavelength dependent temperature correction coefficient.

235 The final instrumental correction will be neutral density correction. This actually does not affect the ozone calculation as the attenuation is assumed to be wavelength independent. The effect of filter non-neutrality has been found very small in recent calibrations. The final count, rate $C_{i,f}$, will be

$$C_{i,f} = C_{i,tc} + NF, \tag{7}$$

where *NF* is the 10000 times the ten based logarithm of attenuation ratio of the filter.

The physical model of retrieval from final count rates to total ozone column, well described by Savastiouk (2006), is based on Beer-Lambert -law considering Rayleigh scattering and scattering by aerosols as well as absorption by sulphur dioxide and ozone. The data from slit mask position 0 is not taken into account so using the other five (positions 2 to 6) wavelength a set of wavelength dependent weighting coefficients are found such that the ozone calculus is in theory not affected by sulphur dioxide or aerosols. The final count rates are corrected for Rayleigh scattering according to equation

$$Ci = C_{i,f} + \frac{BE_i \times \mu_r \times P}{1013}, \tag{8}$$

where BE_i is Rayleigh correction coefficient for slit mask position i. The BE_i used are the original ones calculated by the instrument designer (citation). P is the pressure of the instrument location, set to 1000 mbar for Sodankylä. μ_r is the air mass factor for Rayleigh scattering, calculated from

$$\mu_r = \sec\{\arcsin[(6370/6375) \times \sin(A)]\}, \tag{9}$$

where A is the solar zenith angle at the time of the measurement. The ratio, *R6*, affected only by ozone is calculated from Rayleigh corrected count rates, Ci, as

$$R6 = -C3 + 0.5 \times C4 + 2.2 \times C5 - 1.7 \times C6. \tag{10}$$

Total ozone column, X_{O3}, is retrieved from the ratio as

$$X_{O3} = (R6 - ETC + SL)/(\mu_{O3} \times \alpha), \tag{11}$$

where extraterrestrial constant, *ETC*, and absorption coefficient, α, are constants determined in calibration. *SL* is the change in *R6* value measured from a calibration lamp. For this a reference value $R6_{sl,ref}$ is determined during calibration campaign and the changes are followed by measuring this ratio, $R6_{sl}$, several times per day. The lamp is assumed not to change and so the changes should reflect changes in the ETC. The assumption is then checked at the next calibration when also the new reference value is determined. The correction factor, SL, is based on daily mean value $\overline{R6_{sl}}$ as

$$SL = R6_{sl,ref} - \overline{R6_{sl}}. \tag{12}$$

Ozone airmass factor, μ_{O3}, describes the path length that the light has to travel compared to a thickness of the ozone layer right above us. For the calculation ozone is considered to lie in a thin layer at the altitude of 22 km. This makes the air mass factor

$$\mu_{O3} = \sec\{\arcsin[(6370/6392) \times \sin(A)]\}, \tag{13}$$

where A is the solar zenith angle.

For the focused sun measurements, fz, the algorithm is the same. Before calculating the R6 how-
ever, the count rate measured 0.5 degrees off of the Sun is deducted from the count rate measured
from the direct sun. This is made to counter the effect of multiply scattered light reaching the instru-
ment from the same direction than the direct light (Josefsson, 1992). For moon measurements the
algorithm is identical to direct sun algorithm.

The processing of the zenith sky measurements is based on the comparison of zenith sky (zs) and
direct sun measurements (ds) (Muthama et al., 1995). A polynomial will be fitted between a number
of near simultaneous zs and ds measurements so that using the X_{O3} from ds measurements a best
possible set of coefficients a to i are found for relation

$$R6_{zs} - ETC = a + b \times \mu + c \times \mu^2 + d \times X + e \times X\mu + f \times X\mu^2 + g \times X^2 + h \times X^2\mu + i \times X^2\mu^2. \quad (14)$$

These coefficients depend on the instrument and on the measurement location. For Brewer #037 the
fitting of the coefficients, the so called sky chart, has been done by Karhu (1995).

The daily value is calculated as an average of measurements that meet the filtering criteria (see
3.3). Only one type of measurement is used for one daily value. The measurement types are ranked
by their expected quality so that the order is ds, fz, zs, fm. The measurements of lower rank are only
used if there is no measurements at the higher level. The ranking is justified by the assumptions that
focused sun and moon measurements are more prone to errors due to small deviations in pointing
accuracy and zs is more prone to errors due to retrieval algorithm based on a non physical model.

3.3 Quality assurance

To assure the quality of the data some automatic data filtering rules have been obeyed. The mea-
surement routine for one ozone value has five consecutive measurements. The standard deviation
among these five measurements is not allowed to be more than 3 Dobson units (DU) in ds-, zs- or
fz-measurements. For moon measurements the deviation is allowed to be 5 Dobson units. The air
mass factor has been limited to 3.8 for ds- and to 3.0 for zs-measurements to avoid the effects of
stray light but to allow measurements to start as early as possible in the spring. For focused sun mea-
surements the air mass limit is set to 6 and for moon measurements to 3.5. Before submitting the data
to database it is also inspected by eye for obvious spikes or other suspicious behavior. The random
errors of individual observations are within $\pm 1\%$ in about 90% of all measurements (Fioletov et al.,
2005).

4 Demonstration of the dataset

The daily values of total ozone column over Sodankylä are presented as a time series in figure 1.
The yearly highest and lowest total ozone values of March and April are highlighted. Contrary to
Antarctica the minimum values do not coincide with yearly minimum as the annual minima of ozone
in the Arctic do not occur in spring but later in autumn because of strong modulation of ozone layer

thicknes by the Brewer-Dobson circulation. Ozone is build up at high latitudes during the winter time and even after the ozone loss inside the polar vortex the total amount of ozone will be high after the vortex is broken up and the ozone rich air is transported to polar areas. During the summer the circulation of ozone rich air from the equatorial region is weaker and the ozone is destructed by natural photochemistry as the solar elevation is higher. As a result the ozone reaches its minimum during late autumn before a new build up begins. However the spring minimum is still the best indicator for the extent of chemical destruction of the ozone layer. The high values of February 1989 stand out from the time series but the data from the same date from TOMS instrument aboard the Nimbus-7 satellite confirms the total amount of ozone was very high.

Monthly mean values have been presented in figure 2. In the figure is also presented the number of daily values available for a particular monthly value. Overall the direct sun measurements are available during about 77 % of the days zenith sky covering 14 %. Winter months are sporadically covered by focused moon measurements. While no significant trend is observed in the monthly mean values the March monthly mean plot (figure 3) suggests that in the beginning of the 1990's there was a period of strong spring ozone depletion and after 1997 there has been huge variability between cold and warm winters. Monthly mean of March is affected by the intensity of the chemical depletion but also the persistence of the polar vortex giving a bit more insight on the extent of the depletion than just the minimum total ozone column measured.

More in depth trend and regression analysis is a matter for further study and some earlier work has been done. Kivi et al. (1999) analyzed Brewer total ozone time series. They found a trend of (-1.0 ± 0.1) % per year corresponding to the time period 1989 until 1997. At Sodankylä vertically resolved ozone sounding have been performed since late 1980s. Based on the ozonesonde data, Kivi et al. (2007) found that negative trends prior to 1997 can be attributed to a combined effect of dynamical changes, winters of relatively large chemical ozone depletion and the impact of aerosols from Mt. Pinatubo eruption in 1991. The regression model used by Kivi et al. (2007) included a number of proxies accounting for the dynamical and chemical variability. They found that total ozone amounts in the stratosphere correlate highly with proxies for the stratospheric circulation, polar ozone depletion and tropopause height.

The daily ozone climatology is depicted in figure 4. The main features are the accumulation of ozone during the winter and early spring and the decline during the summer owing to the atmospheric circulation patterns and their seasonal changes (Weatherhead et al., 2005). The variability is very large in spring as the location, timing and persistence of the polar vortex hugely affect the transportation and chemical loss of ozone. The uncertainties are larger for the deep winter months as the only measurement mode available is the focused moon procedure.

Figure 5 shows mean and maximum daily amounts of different types of measurements and gives another view on measurement availability. From the dashed lines depicting maximum amounts it can be seen that direct sun measurements are more frequent than zenith sky measurements when
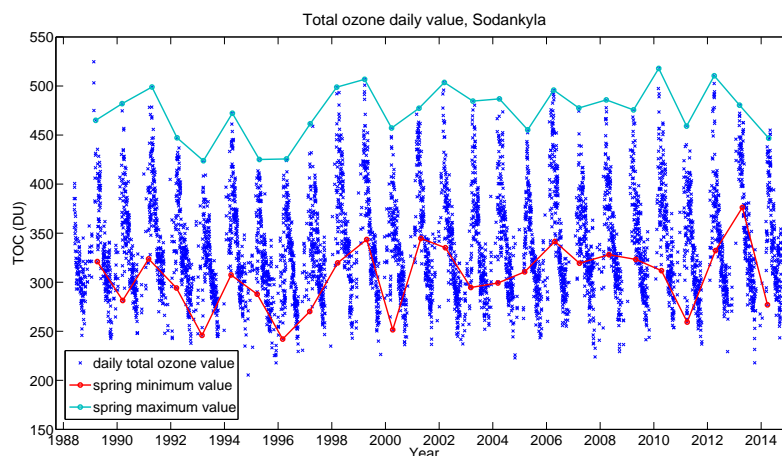
Figure 1. Total ozone column daily average time series with spring time extreme values highlighted for each year. For the spring minima and maxima measurements from March and April are considered.

340   the sky is clear. However because of clouds the mean amounts of zenith sky measurements are a bit higher during the summer. The peak in the maximum amounts at midsummer is from the calibration campaign 2003. During the calibration direct sun measurements are priorised and UV-scans are omitted. This permits over 100 direct sun measurements to be made during one day. Normally a clear day with regular UV-scans can have up to 75 direct sun measurements. Even though the clouds seem

345   to obstruct on average one third of the possible ds-measurements a high portion of the daily values is based on them as there usually is a possibility during the day to get some succesful direct sun measurements. The availability of ds- and zs-measurements in the spring and in the fall are affected by the air mass factor limits of 3.8 and 3.0 respectively. The focused sun and moon measurements are in average very rare but some days can give up to 20 good quality measurements during the time

350   when direct sun or zenith sky measurements are impossible or too unreliable.

    In figure 6 is the comparison of Brewer #037 and Ozone Monitoring Instrument on board the NASA EOS-AURA satellite between the years 2004 and 2014 showing a systematic difference of about 1.9 percent. Sodankylä Brewer data has been used in several satellite comparisons (e.g. Kyrö, 1993; Balis et al., 2007; Damiani et al., 2012) and in comparison to other ground based instruments

355   (e.g. Vigouroux et al., 2008). Sodankylä also hosted two total ozone column intercomparison campaigns in springs 2006 and 2007 aiming to characterise and tackle the measurement challenges caused by low solar elevation angles (McPeters et al., 2006). A follow-up CEOS intercal Nordic campaign was arranged consisting of measurement periods at Sodankylä, for low solar elevation measurements, and at Izaña for high solar elevation measurements and laboratory characterisation

360   (Karppinen et al., 2015).
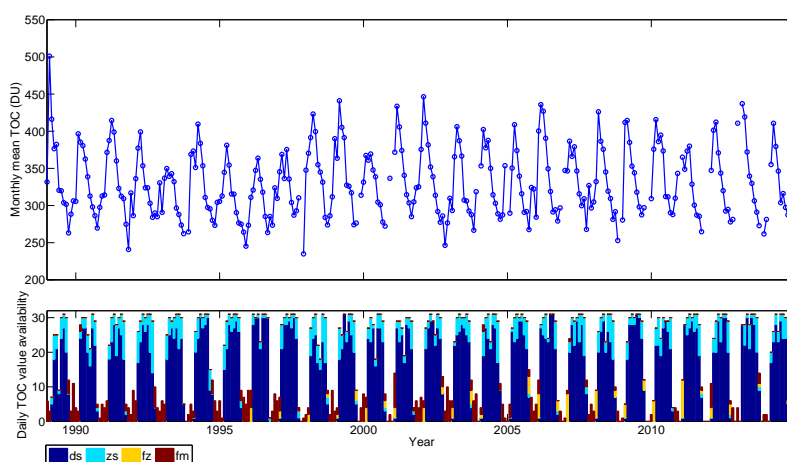
Figure 2. Upper panel shows the monthly mean ozone calculated from daily values. The amount of daily values available for each month is shown in the lower panel. Different measurement styles have been color coded to show which type of measurements have been used for monthly mean value.
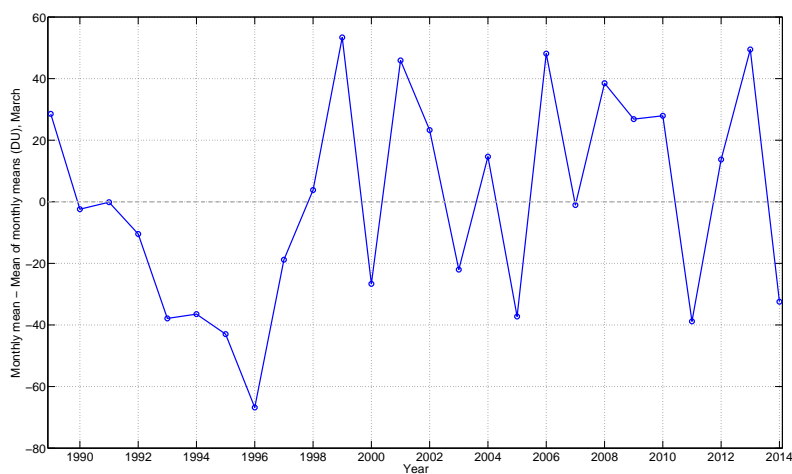
Figure 3. The difference of March monthly mean each year to the all time March mean.

5   Conclusions

There is a dataset of 26 years of uniformly processed Brewer ozone data from Sodankylä and the processing algorithm with the data acceptance rules have been described in this paper. The instrument has been well maintained and regularly calibrated during its time of operation. An automatic
365   warning system has been built to allow fast response to any unexpected stops in the measurements
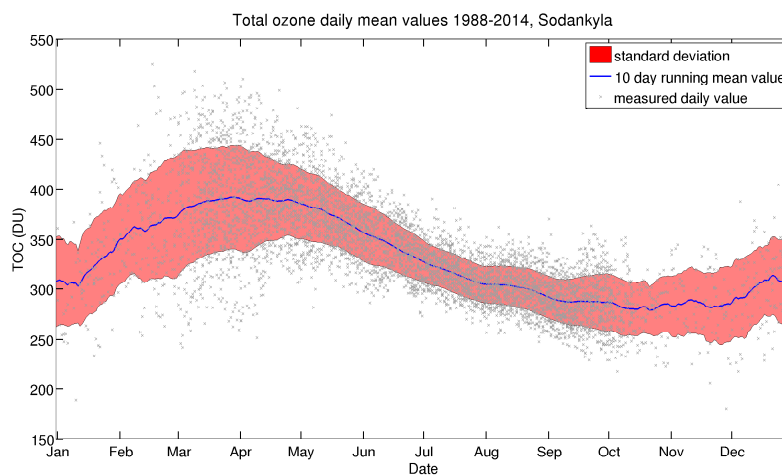
Figure 4. Ten days running average of daily values 1988 to 2014 for each day of the year.
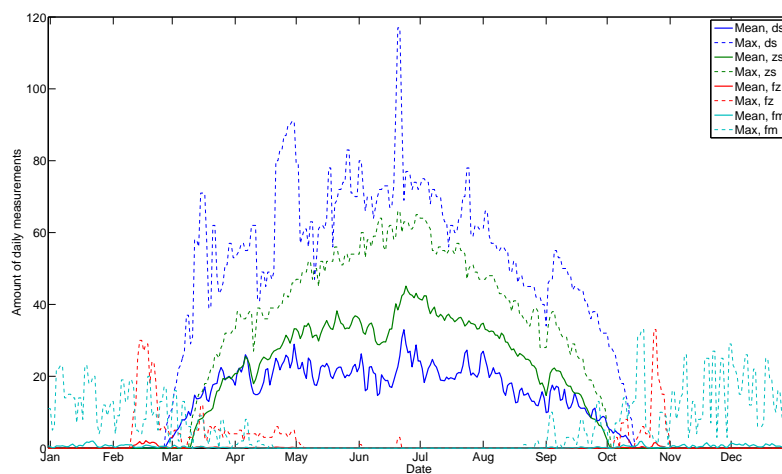
Figure 5. The seasonal variability of the amount of measurements. In solid lines are presented the mean amount of measurements of each type for each day of the year. The maximum amount for any year for this certain day of year has been plotted in dashed line in the color presenting the measurement type.

and to follow that the instrument is operating in an ideal way. The quality assured data will be available in WOUDC database as well as in litdb.fmi.fi. Data is also sent to Eubrewnet database where the Brewer community will set up best possible data processing algorithm to achieve coherent total ozone data across the Eubrewnet network. Sodankylä data is valuable for Arctic ozone studies and for validating other ozone measurements at high latitudes.
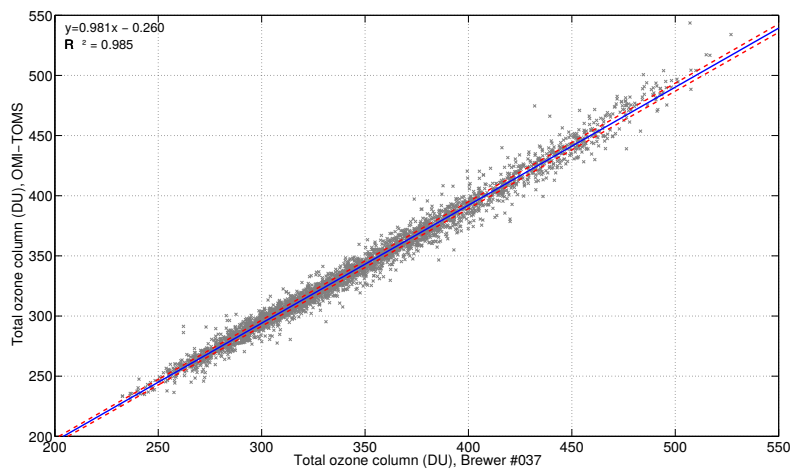
Figure 6. Comparison of Brewer #037 direct sun measurements and OMI satellite data using TOMS retrieval algorithm. The Brewer reference value was the closest direct sun measurement with a limit of maximum of one hour difference in the measurement times.

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