Referee 1.

EuBrewNet - A European Brewer network (COST action ES1207), an overview by J. Rimmer et al. The manuscript describes the progress made during the Cost action in establishing a quality assessed and quallity controlled network of Brewer instruments in Europe, with the focus on total ozone column (TOC) measurements. This is important and relevant for a broad audience interested in high quality ozone measurements (eg. for trend analysis or validation of satellite observations). Therefore it would be worth publishng in ACP. There are however some points that need improvement before acceptance which I list hereafter.

The introduction should make more references to relevant papers. Some examples:

p2 near line 15: give a reference for the involvement of ozone in radiative processes

A reference has been added as suggested

p2 near line 22: give reference about representativity of satellite measurements

A reference has been added as suggested

p2 near line 24: refer also to the Brewer manual

The Brewer manual has been referred to and listed in the reference section.

The description of the procedures for calculation of TOC and corrections could be better clarified. This would help the non Brewer specialist.

p4 line 17: The description should be corrected: actually the Brewer instrument makes 5 consecutive measurement (direct sun observations). Each of these consists of a number of cycles (standard 20) of quasi simultanious measurements of the different wavelengths by fast switching the entrence slit mask.

The authors take note of the correction suggested, however the measurements are taken by fast switching of the _exit_ slit mask. The manuscript has been revised as follows:

"Each observation consists of 20 cycles of quasi-simultaneous measurements of intensity at five UV-wavelengths by fast switching of the spectrometer exit slit mask."

p4 line 23: it should be clear which double ratio is used. Maybe it is better to write down explicitly in a general notation (eg see De Backer and De Muer, JGR 96, D11, p20711-20719, 20 Nov 1991) what is meant actually. MS9 is a naming of an internal variable of the Brewer software and it is the log of the measured intensity ratio.

The authors appreciate that the description of the algorithm does not go into any great depth. However, this paper is an overview aimed at the Brewer data user rather than the Brewer operator and as such the objective was to keep it simple. We have added references pointing to more in depth descriptions of the standard algorithm and have changed the notation of the double ratio to be more consistent with the internal standard lamp equation. The idea is to make it easier to see how the added data enhancements work.

p5 line 6: if the notation above is adopted it becomes clear that R6 is the same measurement but on the internal standard lamp

See above.

on p5 line 19: is this formula correct? what is the meaning of the multiplication factor O3 on the right hand side of eq (5)? please clarify.

This error is typographic. The O3 is not a factor, it was intended as a label for the delta. The equation has been corrected to:

$$O_3 = O_{30} + \Delta O_{3_{SL}} - \Delta O_{3_{Filter}} - \Delta O_{3_{StrayLight}}$$

on p6 line 1-2: it is more accurate to mention this as 5 consecutive measurements (see also comment above p4 line 17)

Point taken. Quasi-simultaneous has been replaced by consecutive.

on p 8 line 11 there is reference to a figure 2 that mentions filter correction, but there is no figure about the filter correction; please correct

The reference to figure 2 has been removed.

Referee 2.

General Comments The manuscript provides an overview of the achievements made (and those still promised) of the "EuBrewNet" network as funded by a specific COST action. The project has been very important for improving the quality, consistency and transparency of Brewer data in Europe and beyond. This is of great interest to users of high quality total ozone data and lies within the scope of ACP. My general comment is that in some places the manuscript currently reads more like a project proposal than a scientific paper. There are a number of places where I feel the details could be tightened up or the marketing talk toned down.

Once this has been done I believe it will be suitable for publication in ACP.

Specific Comments

Page 1 Lines 8-20 I think the whole abstract should be rewritten to be more specific about the contents of the paper and less polemical.

The abstract has been re-written.

Lines 11-13 This list of relevant international bodies sounds like a project proposal or funding pitch and I think should be deleted.

Have been deleted.

Page 2 Lines 2-17 These statements should be better referenced. I suggest the UNEP/WMO Ozone Assessments as authoritative references for many of these claims. Hossiaini et al. 2015 seems a random choice to choose for this topic.

Reference to the WMO/UNEP ozone assessments has been added.

Line 8-10 You can't say the 2011 Arctic depletion showed a lack of understanding, because CTMs were able to reproduce the event forced with the actual meteorology, but it did illustrate that low ozone and high UV can still be a big issue in Europe despite the success of the Montreal Protocol. You could refer to recent work on ozone trends (eg Chipperfield et al. 2017, Weber et al. 2018).

The sentence has been re-written including the suggested references:

"The unprecedented depletion of the arctic ozone layer in spring 2011 (Manney et al, 2011) served as a stark reminder that, 24 years after the Montreal Protocol, our understanding of trends in stratospheric ozone (Chipperfield et al. 2017, Weber et al. 2018) is still important ."

Lines 17-23 Again I think these statements should be referenced.

Included in corrections for referee 1.

Line 24 "TOC" has not previously been defined.

*TOC is defined in the sentence "*Spectral UV irradiance products derived from satellite instruments are entirely estimated, based on radiative transfer models and the retrieved **total ozone column (TOC),** and they are far from representing the actual radiation field at a specific ground location (Zempila et al., 2016), particularly under cloudy conditions or at heavily polluted environments."

Line 25 For the information of readers not as familiar with the subject, you should also mention the Dobson which is slowly being supplanted by Brewers. I am not sure "most" is correct globally but no doubt it is true in Europe these days.

The Dobson has now been mentioned and 'most' limited to Europe.

Line 30 "was being" - before what?

'was being' changed to 'was previously being'

Page 3 Line 2 "any disparity" – disparity in what? (I assume you mean disparity in technique).

'disparity' changed to 'operational disparity'

Line 2 – 6 This statement is too hyperbolic for a scientific paper – again it sounds like a proposal.

*The statement has been revised to "*The aim of COST Action ES1207 was to facilitate the harmonization of procedures and therefore provide spatially consistent data."

Line 7 I would drop or re-work this sentence. The separate funding is not the issue from a scientific point of view, the real issue is the different schedules, processing etc which you then go on to describe.

Dropped!

Lines 8-10 I would prefer more detail here. How does a different schedule affect the measurements? Were the results of different processing significantly different from each other? How big an effect do the instrument characteristics make?

Examples of the effects of schedules, different processing and characterisations have been given.

Line 13 – Explain what you mean by "first generation".

Explanation included in parenthesis.

Lines 18-22 Now the writing has changed to future tense. This again makes the manuscript sound like a proposal.

This last sentence of the paragraph has been deleted

Lines 23-28 This paragraph is excellent because it lists the specific issues and gives references for each. However I don’t like the "etc" because either EuBrewNet characterises these properties or does not. You could give a reference for slit functions too.

‘etc’ deleted. The slit function is determined by in situ measurement, this has been added in parenthesis.

Page 4 Line 9-10 "the National Metrology Institutes" – which ones?

Explanations have been added

Line 12 "developed with" should be just "developed" unless there was going to be something else in the sentence.

Corrected

Line 18 Personally I think "roughly" is too informal for a journal paper and would prefer "approximately".

Agreed but have substituted ‘nominally’

Line 23 I think it would be better to express these quantities (such as MS9 and O30) in more general notation (in fact as it normally appears in Brewer papers) and then give their equivalent in Brewer-specific terminology.

This has been addressed by Referee 1.

Page 5 Line 1 ETC_0 hasn't been defined yet.

Now defined in the second line of the paragraph.

Line 2 This is perhaps a philosophical discussion but I am surprised the first derivation of ozone is considered level 0 data. Level 0 would normally be the raw intensities. To calculate ozone you need to have an algorithm for mu and alpha and these have previously changed, and will continue to change, for example with new cross-sections.

In fact the Brewer does produce and store a raw value for ozone based on some constants hard-coded in the software but in reality this would never be submitted to any data centres for scientific use. In any case, this is the classification in EuBrewNet and this paper can only report it as it is.

Line 7 How are the filters characterised for non-linearities?

The explanation has been added.

Line 11 "stray light correction" should be "a stray light correction"

Corrected

Line 15 It should be explained more clearly when these iterations are performed. By the notation it appears O3_0 -> O3_1 -> O3_2 etc going up in the processing levels.

An explanation has been included.

Line 19 O3 is not meant to be on both sides of the equation, is it?

This has been addressed by referee 1.

Page 6 Line 1 "Finally the data is filtered to select only valid measurements" – this makes it sound as if your filters are 100% accurate in removing all bad data but no good data. Maybe re-word to something like "to try to select only valid measurements".

*The sentence has been revised to "*Finally the data is filtered to select only those measurements which conform as follows:"

Lines 10-18 The arrangement of the paper seems wrong here because we have already read about the central processing in detail in the previous section but now we are being introduced to it again in general terms. (I suspect there has been cutting & pasting from different co-authors' contributions). Please ensure the different sections are unified and flow together properly.

Section 4 has been edited so that details of the processing are not re-introduced.

Page 7 Line 17 It's not really correct to say the "WMO SAG Ozone has recently ruled...", in fact the International Ozone Commission wrote to the SAG directing them to implement the new cross sections (and to take stratospheric temperature into account too).

This statement has been corrected as suggested

Page 8 Line 11 Figure 2 is nothing to do with the filter correction. The filter correction was previously alluded to but has remained somewhat mysterious to the reader.

Dealt with by referee 1.

Line 12-14 This is important. It is good to see the effect of all your work quantified like this. I would have liked to see more quantitative detail like this throughout the rest of the manuscript.

Technical comments

Page 2 Line 4 and Line 6 - It is unusual for "Ozone Layer" to be in capitals.

Capitals removed.

Throughout, "et al" should be "et al. "

Done.

The spellings of words are inconsistent, both "characterise" and "charcaterize" are used in different places, presumably by different co-authors.

Done.

References

Chipperfield, M. P., Bekki, S., Dhomse, S., Harris, N. R. P., Hassler, B., Hossaini, R., Steinbrecht, W., Thiéblemont, R. & Weber, M. (2017). Detecting recovery of the stratospheric ozone layer. Nature, 549(7671), 211–218. https://doi.org/10.1038/nature23681

Weber, M., Coldewey-Egbers, M., Fioletov, V. E., Frith, S. M., Wild, J. D., Burrows, J. P., Long, C. S., and Loyola, D.: Total ozone trends from 1979 to 2016 derived from five merged observational datasets – the emergence into ozone recovery, Atmos. Chem. Phys., 18, 2097-2117, https://doi.org/10.5194/acp-18-2097-2018, 2018.

Referee 3

This paper provides a concise overview of the motivation for and implementation of the EuBrewNet activity. However, it falls short in summarizing the breadth of specific early achievements and in discussing EuBrewNet progress in developing improved linkages to other agencies and networks. This project is, indeed, a major step towards achieving a quality-assured uniform international database for ozone, spectral UV, and aerosol optical depth from Brewer measurements. However, consideration should be given to revising the manuscript so as to acknowledge already existing efforts that this action builds upon and to provide an indication of the road forward beyond EuBrewNet. As written, a reader without extensive knowledge of existing measurement activities (either isolated or coordinated within established networks) could get the impression that such measurements have been in such disarray as to be useless for scientific trends and process studies. Further, while I am a strong supporter of EuBrewNet. I do not think that it will solve every problem (as seems to be indicated) but rather will point to the next steps that must be taken.

Specific page-by-page comments follow.

Page 1, lines 15-20: The inclusion of more details on the specific achievements to date in these areas would make this a much-improved paper.

This has been done in the re-write of the abstract suggested by referee 2

Page 2, lines 3-4: It is incorrect to state that there are uncertainties regarding the effects of ozone protection policy measures. The efficiency of the Montreal Protocol with respect to protecting the ozone layer from depletion by halocarbons is well understood and documented. The combined effects of the declining influence of chemical depletion and the increasing influence of climate change complicate the prediction of future ozone trends. Indeed, this is mentioned. However, the way it's presented makes it sound like we don't have a handle on the chlorofluorocarbon issue.

This has been addressed by referee 2

Page 2, lin6 6: Suggest changing the wording to “will influence the evolution of the ozone layer”.

Done.

Page 2, lines 8-9: This statement is simply not true! The possibility of severe Arctic ozone depletion, such as occurred in spring 2011, was stated following the results obtained from airborne campaigns conducted during 1989-1992. Substantial ozone loss was projected to occur in years when low vortex temperatures persisted into late February and beyond. Our understanding of the chemical depletion processes is quite robust.

This has been addressed by referee 2.

Page 3, lines 4-5: The COST action is a great mechanism for facilitating harmonization and quality assurance in Brewer measurement. However, to state that it is the only mechanism is somewhat of an overstatement. There are efforts in existing networks to achieve similar results. For example, the Dobson/Brewer Working Group of the Network for the Detection of Atmospheric Composition Change has developed specific protocols for such work and the investigators are involved in EuBrewNet.

This paragraph has already been re-written following comments from previous referees.

Page 3, lines 7-21: Admittedly there has been a lack of uniformity and standardization in Brewer measurements. However, are there no examples of stations at which experienced investigators have been conducting measurements and analyses “properly”? If so, would it not be appropriate to cite some examples and then discuss how EuBrewNet will amplify such procedures throughout Europe. As presented, the reader is given the impression that previous data from Brewer sites should be viewed with great skepticism.

This paragraph has been modified following comments from previous referees, however a further sentence has been added to address this referees concerns over the impression of viewing previous data with scepticism. The authors do not fell it would be right to pick out investigators who are doing it ‘properly’ as this would be tantamount to denigrating the rest.

Section 2:

There is no mention in this section of the possible effects of using different ozone cross-sections.

Choice of cross sections is not mentioned here as it cannot be decided by EuBrewNet. The use of different cross sections is discussed in section 4 in relation to the database and a reference is given on the effects on the data.

In addition, while the ATMOZ project is mentioned, none of the initial results are summarized. Admittedly, there is a reference to (Redondas, 2017). However, the references include two such papers, both of which were submitted very recently. My understanding is that there were some wavelength calibrations issues discovered. Some mention of the results and the path forward would improve this manuscript.

The authors did not intend to discuss the ATMOZ project here. It was mentioned simply to point out that the result was obtained from that experiment and was not part of a EuBrewNet campaign. However, further information has been added.

In addition, I would have expected a section on characterization and calibration to address how possible comparisons with data obtained using other co-located instrument types might be used for establishing measurement accuracy.

Finally, there is no mention of how long-term instrument stability will be verified.

These points are addressed in sections 4 and 5. Instrument stability is assessed by the interpolations necessary to produce Level 2 data and the comparison with satellite overpass data and neighbouring instruments can be used to assist with this process.

Section 3:

While details are provided on the retrieval of TOC, the section does not specifically address how central data processing will actually be implemented throughout the network.

The authors are puzzled by this comment. Central data processing will be implemented centrally, not throughout the network. A description is given in section 4.

The need for valid mercury lamp wavelength calibration is stated; however, specific details or recommendations for such calibrations are not provided.

The detail has been added.

Section4:

The implementation of a near real time data base will be an important aspect of EuBrewNet. However, unless provisions are made for some preliminary scientific analyses of the results by someone (i.e., to ascertain whether the data make sense from a geophysical point of view) there is a risk that erroneous data could be posted.

This is a valid point but individual stations have already been making comparisons with overpass data as a check on data validity. It is hoped that further, more in depth investigations can be made as the database matures.

Having two versions of the level 2.0 data corresponding to the use of two different sets of cross sections can be quite valuable when trying to intercompare with data obtained outside of the network or when attempting to generate a merged data set. Are there no results that can be shown on the effect of using one or the other set of cross sections?

A reference has been added in section 4.

Section 5: Is there a path forward suggested by the results from the recent intercomparison campaign. There is a reference given; but the paper has just been submitted.

The current work has focussed mainly on TOC. We have added a sentence indicating that the work is not yet complete and we would like to see similar achievements with UV and AOD-UV.

Section 6:

This manuscript could be improved considerably if it included more specific details to support the achievements listed in this section.

A link has been included to the EuBrewNet WiKi which contains more specific technical information.

EuBrewNet – A European Brewer network (COST Action ES1207), an overview.

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Abstract.

COST Action ES1207, EuBrewNet, was proposed to coordinate Brewer Spectrophotometer measurements of ozone, spectral UV and aerosol optical depth (AOD-UV) in the UV within Europe, and unite the ozone, UV and AOD communities, through a formally managed European Brewer Network capable of delivering a consistent, spatially homogeneous European data resource. With emphasis on the ozone measurements, an overview is given of new calibration and instrument characterisation procedures which are then incorporated into new algorithms for the determination of total column ozone taking account of non-linearities and stray light effects within the spectrometer. A new near real time database is described where all raw data is processed centrally and subjected to the same quality control criteria. Data products are produced in levels which reflect the stages of quality control applied from initial near real time to final archive quality for trend analysis. Work is ongoing to complete similar procedures for the UV and AOD-UV data products. Governance of the new network, which has already expanded beyond the boundaries of Europe, will be overseen directly by the WMO Scientific Advisory Groups.

~~COST Action ES1207, EuBrewNet, was proposed to coordinate Brewer Spectrophotometer measurements of ozone, spectral UV and aerosol optical depth (AOD-UV) in the UV within Europe, and unite the ozone, UV and AOD communities, through a formally managed European Brewer Network capable of delivering a consistent, spatially homogeneous European data resource, significant for the World Meteorological Organisation (WMO), the World Ozone and UV Data Centre (WOUDC), the International Ozone Commission (IO3C), the Intergovernmental Panel on Climate Change (IPCC), Global Monitoring for Environment and Security (GMES) and the ozone trend assessment panels. Around 50 Brewer Spectrophotometers are deployed in Europe, independently funded by national agencies, each were duplicating effort to achieve separately best practice and accuracy. EuBrewNet was established to remove this disparity, establish knowledge exchange and training, and open up a route to links with international agencies and other networks globally. New instrument characterisation, calibration and consistent data processing algorithms have been developed and applied with a new near real time database providing a range of data products resulting from centralised processing algorithms and quality control methods. Governance of the new network, which has already expanded beyond the boundaries of Europe, will be overseen directly by the WMO Scientific Advisory Groups.~~

1 Introduction

Although our knowledge and understanding of the processes and reactions that affect ozone concentrations in the stratosphere have grown significantly in recent years, there are still uncertainties in the predictions of future trends and the quantification of the effects of policy measures to protect the ~~Ozone~~ ozone l~~L~~ayer. There is also a growing recognition that the issues of stratospheric ozone depletion and of climate change are closely linked (Hossaini ~~et al~~at al., 2015; McKenzie ~~et al~~at al., 2011) and that climate change ~~may affect~~will influence the recovery of the o~~O~~zone l~~L~~ayer (see also WMO/UNEP Scientific Assessments of Ozone, https://www.esrl.noaa.gov/csd/assessments/ozone/). Therefore, long-term monitoring continues to be essential to provide the necessary feedback into predictions on the recovery of the stratosphere.

The unprecedented depletion of the arctic ozone layer in spring 2011 (Manney ~~et al~~at al., 2011) served as a stark reminder that, 24 years after the Montreal Protocol, our understanding of global and local trends in stratospheric ozone (Chipperfield at al... 2017, Weber at al... 2018) is still important~~is still far from clear cut~~. The corresponding significant increases in UV radiation over large areas of northern Europe were clearly cause for concern. In addition to ozone, aerosols and clouds affect the UV radiation and usefully accurate forecasts also must take account of these factors. The challenge remains to improve the accuracy and understanding of the relationships between UV radiation, ozone, clouds and aerosols. Furthermore, although the ozone variations have been considered mainly for their effect on the ultraviolet radiation, it should be kept in mind that ozone, even if in a small abundance in the atmosphere, plays a key role in the energy balance of the planet through its involvement in radiative processes. Ozone changes may have lasting consequences within the climate system.

While satellites are routinely used to retrieve atmospheric data products, their accuracy is underpinned by ground station measurements. Once launched, drifts in calibration or errors due to snow or cloud albedo, can only be detected by comparison with ground station data. Spectral UV irradiance products derived from satellite instruments are entirely estimated, based on radiative transfer models and the retrieved total ozone column (TOC), and they are far from representing the actual radiation field at a specific ground location (Zempila at al.., 2016), particularly under cloudy conditions or at heavily polluted environments. As is particularly true whenever long-term trends are of interest, the fundamental responsibility to define the limits of accuracy therefore rests with the ground station instruments.

The fully automated Brewer Spectrophotometer (Kerr ~~et al~~at al., 1985, Brewer MKIII Operator's Manual) is slowly supplanting its predecessor, the Dobson ozone spectrophotometer, and has provided high quality TOC data for more than 30 years and is now deployed at most of the ground based TOC monitoring stations in Europe. It is also capable of measurements of ozone vertical profiles (Umkehr method), spectral UV radiation and aerosol optical depth in the UV (AOD-UV), as well as columns of other trace constituents such as sulphur dioxide and nitrogen dioxide. There are over two hundred Brewers deployed throughout the world, independently operated by national agencies, of which around fifty are located within Europe (some already since the early 1980s). This represents not only a significant proportion of the total global monitoring effort, but also an extremely valuable resource of co-located TOC, UV and AOD-UV measurements which was previously being considerably underused due to the lack of coordination and harmonisation between the respective agencies. The co-location of these measurements is crucial for providing consistent data for research into radiative transfer and forecasting models, however any operational disparity serves to severely restrict the overall utility. The aim of COST Action ES1207 was to facilitate the harmonization of procedures and therefore provide spatially consistent data.

~~Since Brewer measurements constitute a long term monitoring operation and the data provides the foundation for end users including forecasting agencies, policy decision makers, general public, academic personnel and other researchers, COST Action ES1207 was the ideal, if not the only mechanism to facilitate the harmonization of procedures and therefore spatially consistent data, through networking and capacity building.~~

~~Currently, each monitoring agency is funded nationally to comply with the terms of the Vienna Convention. However, the d~~Disparity arises since each station may pursue differing measurement schedules which may not contribute to a coordinated outcome. Furthermore, data processing methods vary such that different agencies may arrive at different results from the same raw data file which in some cases may exceed the 1% level of accuracy which is currently sought. Effects of instrument characteristics on the derived products may be handled differently if, indeed, they are handled at all and quality control methods also vary from site to site. For example, any slowly varying change in the instrument spectral response would lead to a 'false' trend in the data over time or stray light effects in single spectrometer Brewers would cause highly significant errors in daily mean values unless measurements were restricted to low air mass factors. In addition, there have been no protocols to govern updates to software or experimentally determined physical constants. Although the Regional Brewer Calibration Centre – Europe (RBCC-E) has been in place providing support for a first generation (derived from stable atmosphere Langley plots rather than transfer) calibrated Brewer reference triad on TOC for several years, there are no mandatory and clear protocols for frequency and retro-application of calibration data. The well-reputed services of the World Ultra-Violet Calibration Centre (WUVCC) have also been underused with too few stations participating to guarantee the homogeneity of time series on spectral UV. In short, there has been no formal European Brewer Network and related regional data base capable of providing spatially consistent data to a high degree of accuracy with a common scale of quality assurance. This is not to say that previous Brewer data cannot be trusted for serious scientific study. In fact, the majority of measurement stations have been providing high quality data for many years and the more experienced operatives have been quick to offer assistance to the less well versed or newly set up observatories, particularly in the developing world (e.g. the WMO/GAW Brewer Users Group workshops organised by Environment Canada). EuBrewNet is a first step in trying to bring everything into alignment as more exacting demands are placed on our data analysis.

~~**We therefore need to present the European Brewer stations globally as a formal network with clear operational and data protocols, encompassing the RBCC-E reference triad (one of only two in the world, the other supported by Environment Canada), which will be a keystone in global monitoring activities and a major step towards a true global network for ozone UV and AOD-UV.**~~.

2 Characterisation and calibrations

A first step in ensuring consistency is to set standards for observational quality. Individual instruments must therefore be characterised to establish how component characteristics, e.g. slit function (measured directly using Hg and Cd sources), wavelength calibration (Redondas ~~et al~~at al., 2014, Redondas ~~et al~~at al. 2017) , Photomultiplier tube (PMT) linearity (Fountoulakis ~~et al~~at al., 2016), spectral responsivity, temperature dependence (Berjón ~~et al~~at al., 2017; Fountoulakis 2017), stray light (Karppinen ~~et al~~at al., 2015, Puli ~~et al~~at al. 2016, Redondas ~~et al~~at al. 2017), field of view, angular response, polarisation (Carreño ~~et al~~at al., 2016)~~ etc.~~, uniquely affect measurement outcomes and how potential errors may be avoided or corrected for.

In addition, measurement accuracy is ultimately dependent on regular and accurate calibration. Methodologies which ensure the best transfer of calibration constants and traceability to the reference laboratories, these being the RBCC-E triad for total ozone, the World Ultra-Violet Calibration Centre (WUVCC) and the Quality Assurance of solar Spectral Ultraviolet irradiance Measurements carried out in Europe (QASUME; Gröbner and Sperfeld, 2005) for the UV measurements, either have been or are being developed. Regular comparison with the Canadian Brewer Triad is also maintained to ensure global compatibility of TOC measurements (León ~~et al~~at al. 2017). In order to ensure a traceable laboratory ~~characterization~~characterisation of the reference Brewer instruments, the reference RBCC-E (Regional Brewer Calibration Center for Europe) Brewer from the calibration triad from the Spanish Meteorological Agency at Izaña and the travelling reference Brewer #158 from the manufacturer Kipp & Zonen were thoroughly ~~characterize~~characterised for temperature dependency, wavelength bandwidth and stray light in 2016 and 2017 respectively on the frame of the ENV59 Traceability for atmospheric total column ozone (ATMOZ) project. The instruments were ~~characterize~~characterised using a dedicated climate chamber and tunable laser facilities at the National Metrology Institutes. . In the ATMOZ project, participants included the metrology institutes of Finland, Czech Republic, Germany, Netherlands and Switzerland. The temperature experiment was performed by Physikalisch-Technische Bundesanstalt, PTB (Germany) and Netherlands (VSL) National Metrology Institute and the wavelength calibration was performed at PTB. Filter and Stray Light characterisation were performed by Aalto (Finland) (Pulli at al..).

The results confirmed the existing understanding and correction of the temperature dependence of Brewer instruments to properly estimate and to reduce the uncertainty of ozone retrieval with Brewers (Redondas 2017, Berjon et alat al. 2017). Also a preliminary error estimation was developed with (Egli 2016) with the objective to implement on the Eubrewnet database.

3 Central data processing

For each ozone value five quasi-simultaneous observations are made. Each observation consists of 20 cycles of quasi-simultaneous measurements of intensity at five UV-wavelengths by fast switching of the spectrometer exit slit maskEach observation consists of simultaneous measurement of intensity at five UV-wavelengths. Wavelengths are instrument specific but roughly nominally 306.3, 310.1, 313.5, 316.8, and 320.1 nm. Intensities are written to a raw file for further processing. Raw data is transferred automatically every half hour from each Brewer on the network to the new EuBrewNet database, hosted by the Agencia Estatal Meteorologia (AEMET).

The algorithm to retrieve TOC from individual observations is based on differential absorption of ozone at the measured wavelengths and has been described several times (De Backer and De Muer, 1991; Savastiouk and McElroy, 2005). A simplified description is given here in order to illustrate the improvements implemented through EuBrewNet.

A weighted double ratio, R6(O3), MS9, of the measured intensities is calculated and compared to the similar extra-terrestrial double ratio, ETC_o,one, ETC, determined by transfer from a travelling reference instrument. The weighting coefficients are designed to minimize the effects of aerosols and SO_2 spectral absorption. A differential absorption coefficient, α, corresponding to this ratio is calculated from ozone absorption cross sections convoluted with the slit functions at the measurement wavelengths and, is used to transform this difference into total ozone on the light path or slant column. To get the vertical total ozone column, $O_{30,}$ the value is further divided by air mass factor μ (Eq 1).

$$O_{30} = \frac{R6(O3)-ETC_0}{\mu\alpha} \; O_{30} = \frac{MS9-ETC_0}{\mu\alpha} \qquad (1)$$

The next step is to apply corrections to the level 0 data, O_{30}, based on the instrument characterisation where available. A current controlled halogen lamp located inside the Brewer is used to track instrument response stability. Measurements of the lamp to produce a similar weighted double ratio, R6(SL)this lamp, R6, are compared to a reference, $R6_{ref}$, taken at the time of calibration and used to apply a correction Δ_{SL} to the measured ozone data (Eq 2).

$$\Delta_{SL} = \frac{R6_{ref}-R6(SL)}{\mu\alpha} \; \Delta_{SL} = \frac{R6_{ref}-R6}{\mu\alpha} \qquad (2)$$

A series of neutral density filters are present in the input optics of the Brewer and these are characterised for non-linearities, ETC_N, by observing changes in instrument response via the calculated ratio, R6(SL) as filters are changed, so that a filter dependent correction, Δ_{Filter}, can also be applied (Eq 3).

$$\Delta_{Filter} = \frac{ETC_N}{\mu\alpha} \qquad \textbf{(3)}$$

Finally, a stray light correction is applied to the single Brewers where this has been characterised. The characterisation is based on an exponential fit between single and double Brewer measurements (Karppinen et alat al., 2015). The correction is an iterative process resulting in bringing the single Brewer values into agreement with the double Brewers, as shown in the example of Figure 1, even at low solar elevation angles (Eq 4). N in Eq 4 is the iteration index where the first iteration is performed on the uncorrected ozone value and the corrected value is then inserted back into the equation N times until the result converges.

$$\Delta_{StrayLight,N} = \frac{A*(\mu O_{3,N-1})^B}{\mu\alpha} \qquad \textbf{(4)}$$

The constants A and B are determined during the characterisation process. The resulting ozone value is given by combining Eqs 1-4.

$$O_3 = O_{30} + \Delta O_{3_{SL}} - \Delta O_{3_{Filter}} - \Delta O_{3_{StrayLight}} \quad O_3 = O_{30} + \Delta_{SL} O_3 - \Delta_{Filter} O_3 - \Delta_{StrayLight} O_3 \qquad (5)$$

Finally the data is filtered to select only those measurements which conform as follows: ~~valid measurements.~~ For the ozone product, the standard deviation of the 5 quasi-simultaneous ozone measurements must be less than 2.5 Dobson units (DU), the air mass factor must be less than 3.5 (this can be set higher for MKIII double Brewers or where stray light correction has been applied), there must be a valid mercury lamp wavelength calibration before and after the measurement such that the difference between the two does not exceed three steps of the spectrometer micrometer drive (~0.02nm) and the measured ozone value must be between 100 DU and 500DU (although this may be edited by the data provider if necessary, e.g. 600 DU may sometimes be observed in Sodankylä). The AOD-UV data product is described elsewhere (López-Solano ~~et al~~at al., 2017) and will be implemented within EuBrewNet in the coming months. Similarly work is underway to develop the calibration protocols and processing for the UV data (Lakkala ~~et al~~at al., 2016).

4 The EuBrewNet near real time database

Figure 2 is a recent snapshot of the EuBrewNet network which is constantly growing. A real time updated version can be found here http://webciai2new.aemet.es/eubrewnet . The core of EuBrewNet is a data storage and scientific information processing system for the Brewer spectrophotometers (http://rbcce.aemet.es/eubrewnet/brewer/index) to which the Brewer raw data is automatically transferred on a half hourly basis. The data is then processed in near real time (NRT) as described above in section 3~~The data is processed, subjected to quality filters, and corrections are applied all at the database in near real time. In this way, all Brewer data from all stations are processed and quality assured the same way, removing all associated inconsistencies that may otherwise apply across the network. EuBrewNet is closely associated with the Regional Brewer Calibration Centre for Europe (RBCC-E) and this allows the characterisation of instrument specific non-linearities or other sources of error that can be corrected for in the centralised processing~~. A schematic of the data stream and processing is shown in figure 3.

The calibration and characterisation data for each instrument must also be stored in the database which will then allow the raw data to be converted into data products in near real time (NRT). The raw data is also uploaded to WOUDC for long term data archiving and back up. The output of ozone products is now operational and these are accessible from the EuBrewNet database. A similar methodology is being developed for the Brewer UV and aerosol optical depth products which should be available in the near future.

The data products are produced as different levels:

Level 0: Raw data from the Brewer. This is the unprocessed data which is only available to the providing operator so that appropriate diagnostic checks can be made to check data on a regular basis.

Level 1.0: Basic values from calibration data calculated using Eq 1. This is the most basic ozone product without any QA or corrections applied, equivalent to the calculation made by the Brewer control software on site. This enables a comparison to be made to check that the correct calibration data is being used

Level 1.5: NRT data changeable over the first week. Calibration and characteristic corrections applied as in Eqs 2-5. This is the first data product available to the registered users. The data is passed through a series of filters, and corrections are applied based on the instrument characterisation and the stability checks by the internal standard lamp. The standard lamp correction is applied using a triangular weighted smoothing 3 days before and after the day of the measurement. This means that L1.5 data can change as more QA information becomes available. This NRT data is most useful for assimilation into forecast models.

Level 1.6: Interim data with calibration and characteristic corrections applied. Available to users, this is simply L1.5 data once the standard lamp correction has been fully applied and the value is now stable. This data is most useful for the interim values normally used for day to day reporting.

Level 2.0: This is the final processed data for archiving, interpolated over a calibration cycle and also available to users. To comply with WMO best practice, Brewers should be calibrated every two years. The procedure is to first check the status of the calibration, second do any maintenance and lastly set the final calibration. If the initial status of the calibration does not agree with the final calibration of the previous intercomparison, this indicates instrument drift and the ozone values must be re-calculated based on the interpolation between the two points. The resulting L2 data is the highest quality which can then be archived and used for trend analysis.

In addition to levels, the database also stores multiple versions, each containing its own levels as described above. For example, Version 1 contains ozone data using Bass and Paur ozone cross sections. However, the International Ozone Commission recently wrote to the WMO SAG-Ozone directing them to implement the new Bremen cross sections, and also to take stratospheric temperature into account.~~However, the WMO SAG Ozone has recently ruled that the new Bremen cross sections should be used~~. EuBrewNet makes this easy by re-processing all the data in the data base using the new cross sections and storing it as Version 2, also retaining Version 1, in parallel, for the historical record. A study on the effects of using different ozone cross sections has been carried out previously (Redondas at al.., 2014).

The idea is that all these data products will be available directly via a link with the WOUDC so that users do not need to go to a different data base. However, this link is still under construction under the supervision of a sub-group of the WMO SAG-Ozone. For the moment, users may register to access data at http://rbcce.aemet.es/eubrewnet/brewer/index , which includes a wiki which contains information about the system and user support, and further information including instructions on how to contribute to the network can be found at www.eubrewnet.org .

5 Regional Calibration Centre for Europe (RBCC-E)

The RBCC-E campaigns and regular calibration play an important role on the final data (Level 2), as is indicated in equation 2 , the operative ozone is corrected by the Standard Lamp, the standard lamp reference value is provided during the calibration and examined during the intercomparison campaign (Redondas 2017). The previous calibration and new calibration are compared with and without the Standard Lamp correction to assure that the internal standard lamp is tracking the changes on calibration.

As a result of the calibration the validity of the current calibration is examined during the campaign and if a new calibration is provided, the history of the instrument is studied to determine from when the observations have to be reprocessed using a step function or if the changes are continuous and linear evolution of the instrument calibration are implemented between calibrations. In both cases comparison with external instruments, neighbouring Brewer or satellite overpass measurements, will help to evaluate the application of these functions.

The campaigns also help on the ~~characterization~~characterisation of the instruments, the comparison with a well maintained and ~~characterize~~characterised instrument reveals instrumental characteristics that are difficult to detect at the station without a reference. In particular the filter correction ~~(Figure 2)~~ and the Stray light (Figure 1)

The introduction of the instrumental ~~characterization~~characterisation greatly improves the results of the TOC intercomparison (Redondas and Rodriguez, 2012), in particular the Stray light correction application at the final calibration brings all the instrument to ~~the~~ within -+/- 0.5 % ~~range~~ (Redondas 2017) on the full range. In the future it is hoped that similar achievements can be made for the UV and AOD-UV products.

6 Conclusions

COST Action ES1207, “EuBrewNet – A European Brewer Network”, was awarded to allow the harmonisation and coordination of Brewer ozone spectrophotometer measurements of TOC, spectral UV and AOD-UV. New instrument characterisation methodologies have been implemented and calibration campaigns have been carried out which use these new methodologies to greatly improve the accuracy of the results. Common data processing and quality assurance also now ensure consistency of measurements throughout the network.

A major part of EuBrewNet is the new NRT database which automatically collects raw data from the instruments and applies the new data processing and quality assurance centrally, thereby ensuring the consistency of the resulting data products across the network. Currently, the TOC processing is in operation and NRT data is available to registered users. The AOD-UV processing algorithms have been developed but are yet to be implemented. Similarly the UV processing is still under development but should be implemented in the early part of 2018.

A link to the WOUDC is currently under construction so that data will be available through a portal at the WOUDC web site. The Brewer raw data is also transferred to the WOUDC for long term archiving. Governance of the EuBrewNet is to be overseen by the WMO SAG Ozone.

Further details of EuBrewNet and registration for data are available at the web site www.eubrewnet.org and more specific technical details are available from the EuBrewNet WiKi at http://rbcce.aemet.es/dokuwiki/doku.php

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Acknowledgements

The authors would like to acknowledge networking support by the COST Action ES1207, and contributions from the Regional Brewer Calibration Centre for Europe and the World Radiation Centre. The authors also acknowledge the considerable support from all the working group members of COST Action ES1207 who contributed significantly to the project.

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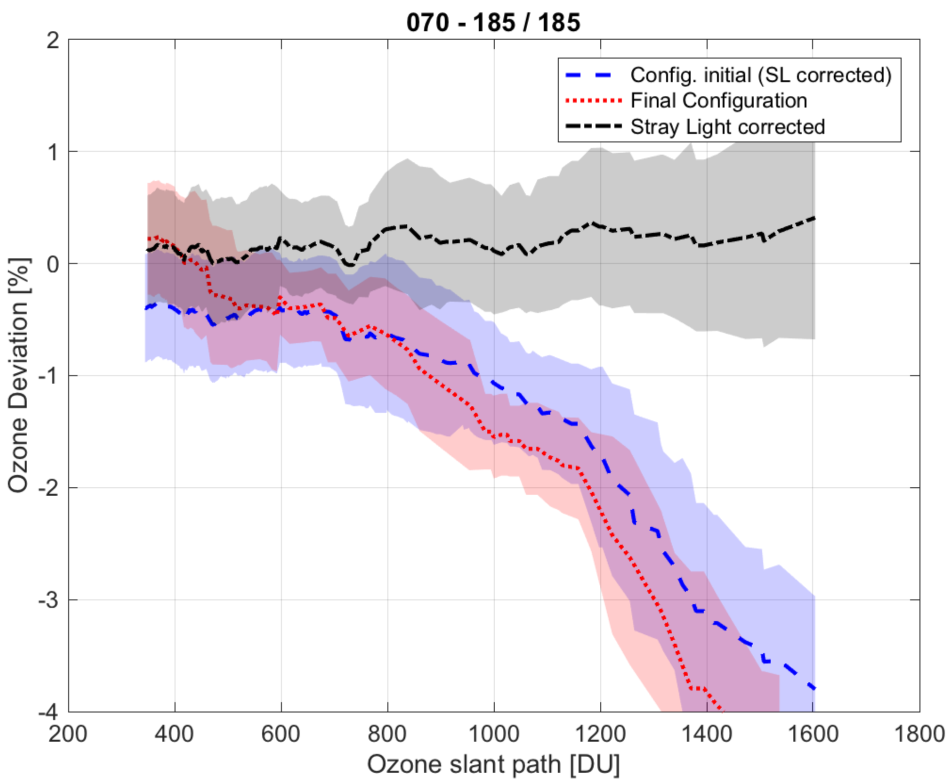

Figure 1: A comparison of a single Brewer, #070, with the RBCC-E reference Brewer, #185, showing stray light correction. The blue and red lines are the initial ozone deviation of #070 from the reference before and after calibration. The black line shows the stray light corrected values.

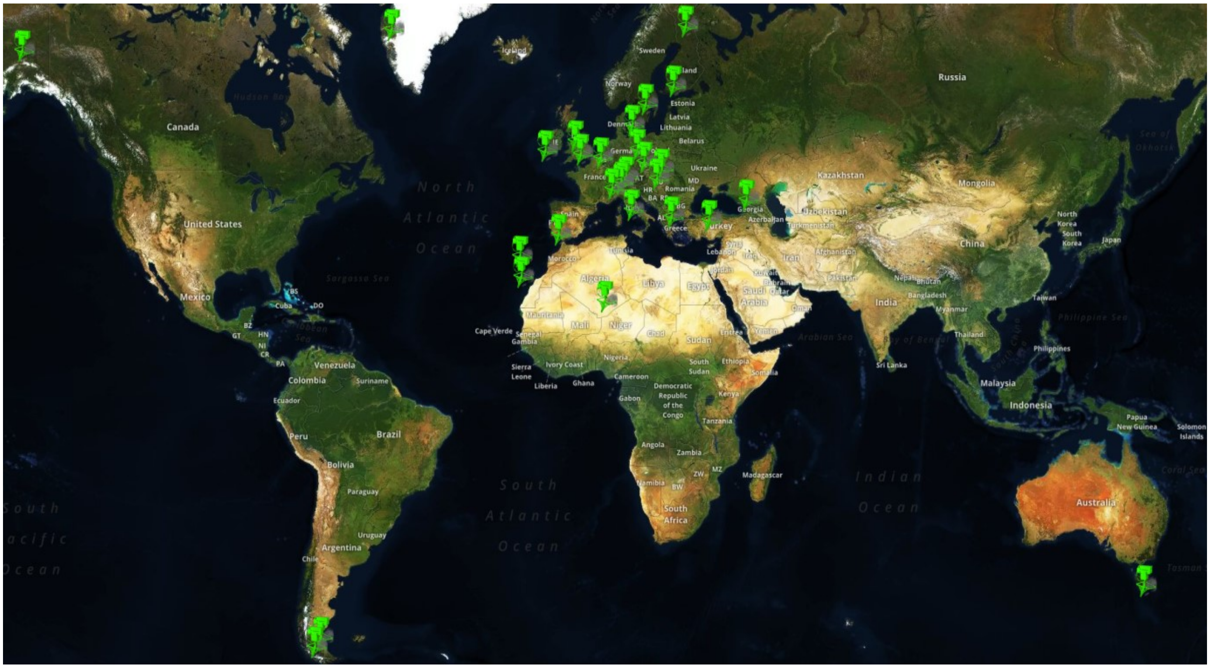

Figure 2: A snapshot of the Brewer stations contributing to EuBrewNet.

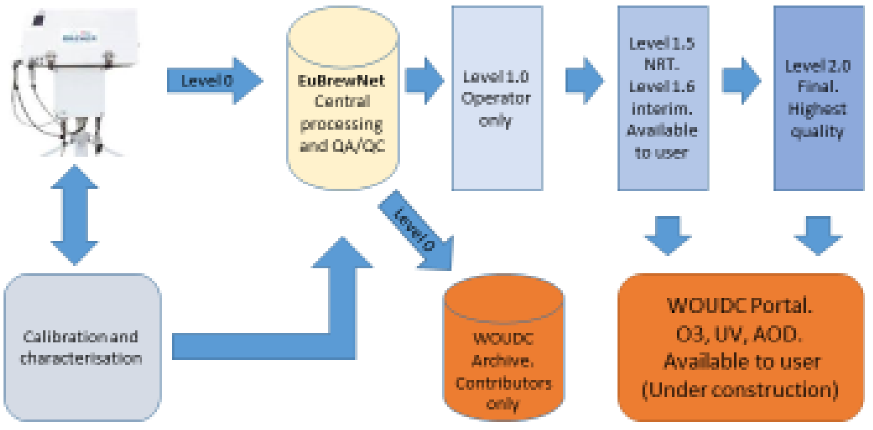

Figure 3: Schematic of the EuBrewNet near real time database.