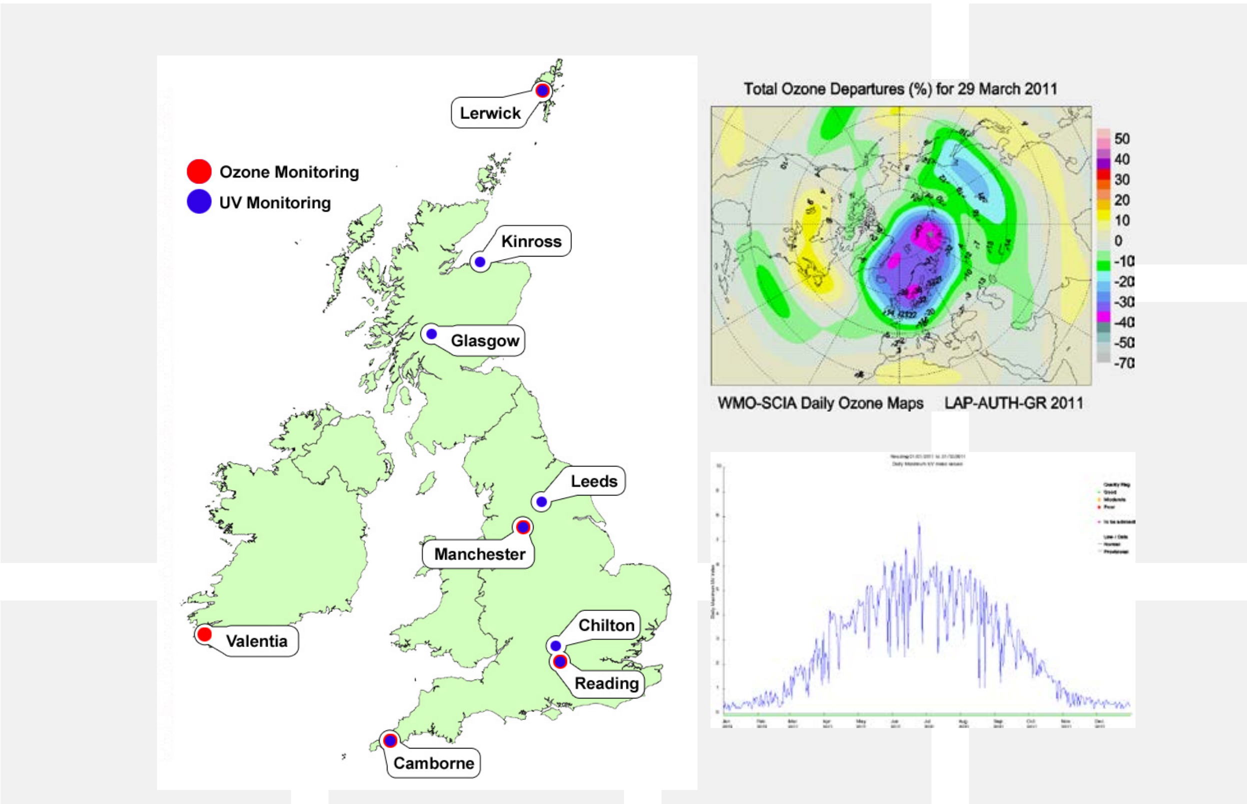
RICARDO-AEA

Baseline Measurement and Analysis of UK Ozone and UV

Annual 2012 Report



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30 September 2015

Signed:

Executive summary

As part of the UK commitment to the Vienna Convention to Protect the Ozone Layer, the Department for Environment, Food and Rural Affairs (Defra) has supported the ground-based monitoring of column ozone at two UK sites over many years. Ozone measurements are made on a daily basis at Lerwick by the Met Office using Dobson ozone spectrophotometers, with an historical record going back to 1957 at this location. The Department has also supported the University of Manchester in making automated Brewer ozone measurements at Reading since 2003, and spectrally resolved UV measurements at Reading since 1993. The UV radiation measurements are primarily made to assess human exposure and are more local in their relevance given the sensitivity to factors such as tropospheric air pollution, cloud cover, etc.

In the present contract, awarded to a project team led by Ricardo-AEA, the Ozone and UV monitoring activities are combined under one programme with the following commitments in place:

- **Continuation of the Dobson Ozone Monitoring Programme at Lerwick:** There is an overwhelming case to continue the ozone measurements made at Lerwick because of the proximity of this station to the Arctic polar vortex region where significant ozone depletion has been observed, and its long data record. It provides one of the key worldwide data sets.
- **Continuation of UV Measurements at Reading:** The Reading dataset, which started in 1993, provides the longest time series of such measurements in the UK. The Reading measurements are considered to be an essential part of any future UK monitoring programme.
- **Brewer Ozone monitoring at Reading:** The state-of-the-art ozone monitoring at Reading using a Brewer spectrophotometer is co-located with the existing UV spectrometer. This allows high frequency automated measurements, which, when combined with the UV data, provide additional insight into the factors controlling column ozone and surface UV levels. Reading acts as the southern UK monitoring site, providing representative data for an area of high population density.

The current contract commenced on 16th October 2010 and will be completed on 15th October 2015. The project team comprises Ricardo-AEA, the University of Manchester, Imperial College and the Met Office. This annual report covers the project activities for the period 1st October 2011 – 30th September 2012 and describes the work carried on the data processing, reporting and analysis of the measurements made.

The key activities and results during the reporting period were:

- **The Reading and Lerwick sites remained fully operational.** High quality, reliable results were made with a Dobson spectrophotometer at Lerwick, and with the automated Brewer ozone spectrometer and UV spectrometer at Reading. Staff at the Met Office Lerwick Observatory and the University of Manchester respectively carried out initial data checks, ensuring conformance with WMO best practice. Data transfer systems have been developed to enable Ricardo-AEA to carry out the quality assurance and reporting of ozone data from Lerwick and both ozone and UV data from Reading.
- **The on-going reporting** of the daily-averaged ozone values determined at the Reading and Lerwick sites, and the Reading Spectral UV data, continued to a number of different organisations, including world data centres. The reporting of the ozone measurements fulfils part of the UK commitments under the Vienna Convention.

- **Trend Analysis of the Measurements** suggests that the long-term decline in column ozone over the UK has not yet been reversed. The long-term (since 1978) autumn decline reported previously is no longer significant for the multiple regression. This is more in line with our understanding of chemical ozone depletion as it was always difficult to explain enhanced ozone loss prior to the cold season of polar stratospheric cloud formation. Trend analysis of the short Reading time series shows an annual mean increase which is however not significant

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1 Introduction

The Department for Environment, Food and Rural Affairs (Defra) has let a contract for the Baseline Measurement and Analysis of UK Ozone and UV to a project team led by Ricardo-AEA. The other members of the project team are the Met Office, the University of Manchester, the University of Reading and Imperial College. Each has specific individual responsibilities for the monitoring, reporting or analysis of stratospheric ozone and UV as illustrated in Figure 1below.

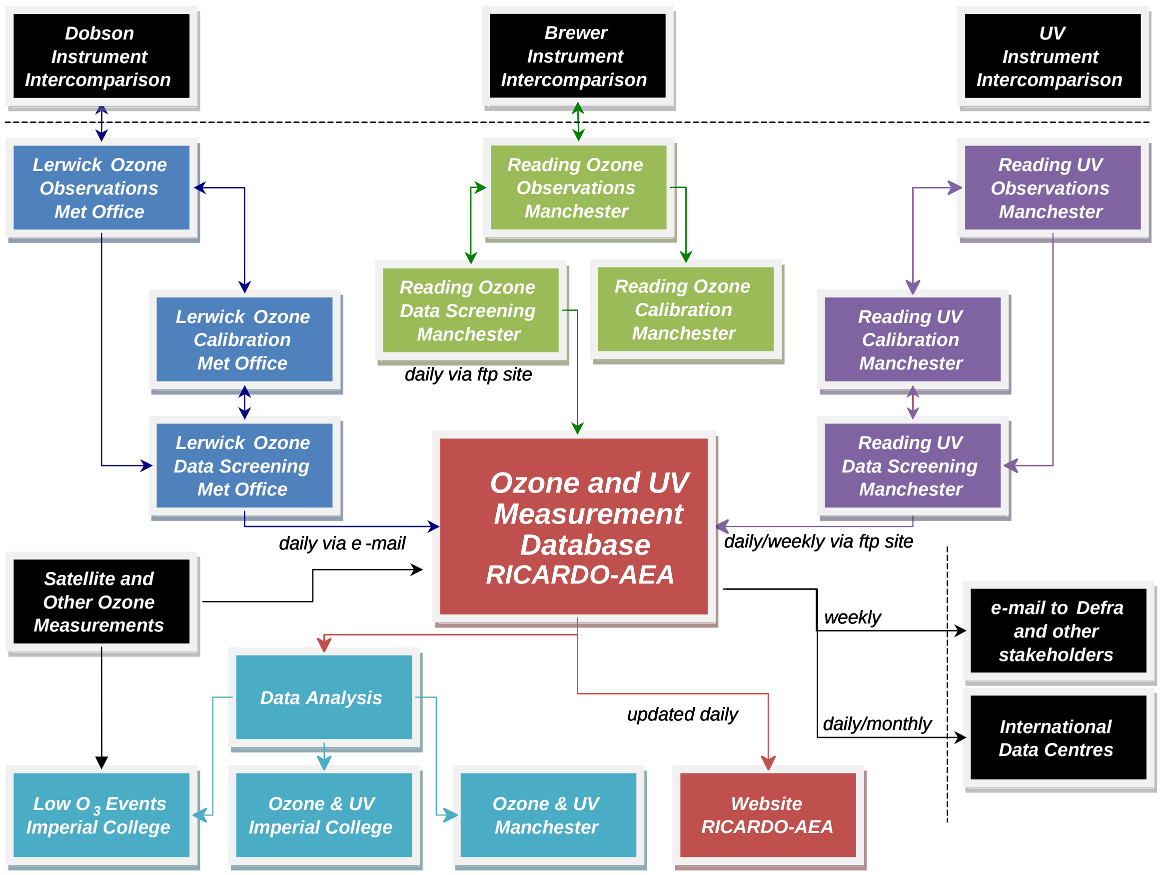

Figure 1 Project team roles

The current contract runs from the 16th October 2010 to 30th September 2015. This annual report covers the period 1st October 2011 to 30th September 2012

2 Project Aims and Objectives

2.1 Background

The current monitoring programme runs from the 16th October 2010 to 30th September 2015. It has recently been independently reviewed[1] and continues operation with:

- Daily measurements of total column ozone at Lerwick using Dobson spectrophotometers (1957-present)
- Automated measurements of total column ozone at Reading using a Brewer instrument (2003-present)
- Spectral UV measurements at Reading (1993-present, co-located with the Brewer instrument).

The locations of these and the other measurement sites for ozone and UV in the UK and the Republic of Ireland are shown in **Figure 2**, taken from the website for the monitoring programme[2].

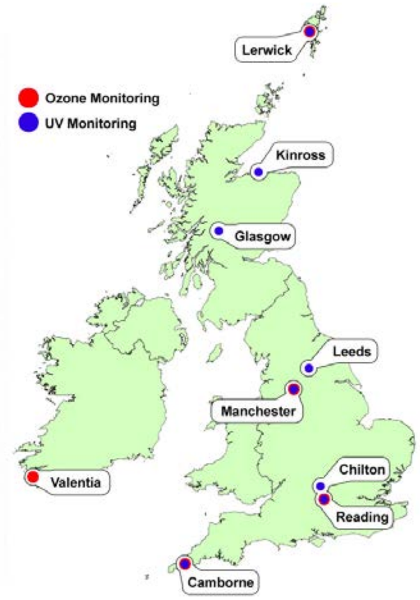

Figure 2 Location of Defra and Other Ozone and UV Monitoring Sites.

The contract is held by a project team led by Ricardo-AEA. The project team also includes the Met Office, the University of Manchester, the University of Reading and Imperial College.

The main driver for the monitoring programme is the 1985 Vienna Convention on the Protection of the Ozone Layer. The Vienna Convention obliges parties (including the UK) to undertake various activities, including *inter alia* monitoring, data dissemination and information exchange, in accordance with their capabilities and the means at their disposal.

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[1] Hayman G.D. & Monks P. Review of the monitoring programme: Baseline Measurement and Analysis of UK Ozone and UV. Available from the Defra website, at http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=433&FromSearch=Y&Publisher=1&SearchText=review of the monitoring&SortString=ProjectCode&SortOrder=Asc&Paging=10#Description

[2] http://ozone-uv.defra.gov.uk/

3 Data Measurement, Processing & Reporting

The Met Office determines column ozone amounts at Lerwick using a Dobson ozone spectrophotometer. The University of Manchester makes ozone measurements at Reading using a Brewer spectrophotometer, together with spectral UV measurements using a Bentham spectroradiometer. The University of Reading provides local support for the Reading monitoring activities. In accordance with WMO recommended best practise, the instrument operators carry out the initial data processing and quality checks, before forwarding the results to Ricardo-AEA for collation, analysis and final reporting.

3.1 Dobson Ozone Measurements

3.1.1 Site Operations at Lerwick

Bi-annual visits have been made to Lerwick to inspect the instruments, perform maintenance tasks, update ISO9000 documentation, train staff and if possible conduct intercomparisons.

During the April 2012 inspection visit by D Moore to Lerwick, a faulty EHT switch on Dobson 32 was identified, dismantled, cleaned and fixed. Lamp tests have not been affected by the fault nor have ozone readings been affected as far as we are aware, as the fault would not change the calibration of the instrument.

During the September visit a noisy motor drive was rectified on Dobson 32. Also the Q1 lever on the spare instrument Dobson 41 was found to sag in the A wavelength position by 0.3 º. Any errors introduced would be insignificant and this fault has therefore been scheduled to be fixed at the next visit due to the amount of work already planned during the September trip.

3.1.1.1 Standard and Mercury Lamp Tests

Standard and Mercury lamp tests have continued throughout the period with both instruments performing satisfactorily.

One of Dobson 32's three standard lamps burnt out and a replacement has been kindly provided by the Dobson Calibration Centre at Hohenpeissenberg. It was used as a check on the main lamps optical clarity so its demise was not important once the replacement was operational.

3.1.1.2 Mu Measurements

A series of high Mu measurements were made in the winter to determine how the cloudy polynomials performed outside their normal range. The results confirmed previous work that ozone values increase with increasing Mu and that this characteristic varied between different days. This effect was also noted within the normal Mu range used operationally. The results were sent to Ricardo-AEA and other members of the ozone consortium.

3.1.1.3 Dobson 35 Operational availability

Information has been received regarding the status of the loan of Dobson 35 to the South African Weather Service. It was recalibrated in 2009 and ad hoc lamp tests have been made on the instrument. It was originally intended for deployment at Marion Island, but this didn't take place and it is now intended for use at Cape Point GAW laboratory, for which a certain amount of structural work is required and which is being completed. Various unexpected permissions are also required.

At the time of writing Dobson35 is operating on an ad hoc basis from Stellenbosch and should be installed permanently in December at the Cape Point GAW laboratory.

No data from Dobson 35 have yet been reported to the WOUDC during its time in South Africa.

3.1.2 Polynomial Reassessment Measurements

A new Dobson schedule has been written to supplement the existing measurements so that, in due course, the existing cloudy polynomials can be updated, after enough data has been gathered. The Met Office reports that this has necessitated focussed sun measurements being reintroduced to the UK after a gap of several decades. These are basically direct sun measurements with the ground quartz plate diffuser removed which provides a smaller but brighter image of the sun inside the instrument enabling the instrument to be used at lower sun angles. This should enable more time coincident direct sun and zenith measurements to be made as direct sun measurements cannot be made at such a low sun angle as zenith measurements.

The focussed sun measurements are not as easy to make as direct sun since more light enters the instrument more care is required to not overload the photomultiplier. They also are also noisier than direct sun measurements and will not be used to provide the ozone value for the day.

3.1.3 Informal Intercomparisons conducted at Lerwick

During 2012 there were several limited intercomparisons conducted during the Lerwick site visits by David Moore (Met Office). The results were excellent and are illustrated in Table 1

Date	Dobson (41-32) DSAD (%)	Dobson (41-32) DSCD (%)	Dobson 41 DSAD Ozone values (DU)
23rd Apr 2012	0.0%	-	395
27th Sept 2012	-0.2%	-	286
28th Sept 2012	-0.3%	+0.6%	284

Table 1 Intercomparison results at Lerwick between instruments #041 and #032

3.1.4 Measurement Summary

Figure 3 and Figure 4 shows the comparison of daily Lerwick column ozone values with measurements from the OMI satellite-based instrument during this reporting period. There appears to be generally good agreement between ground-based measurements at Lerwick and the OMI satellite data.

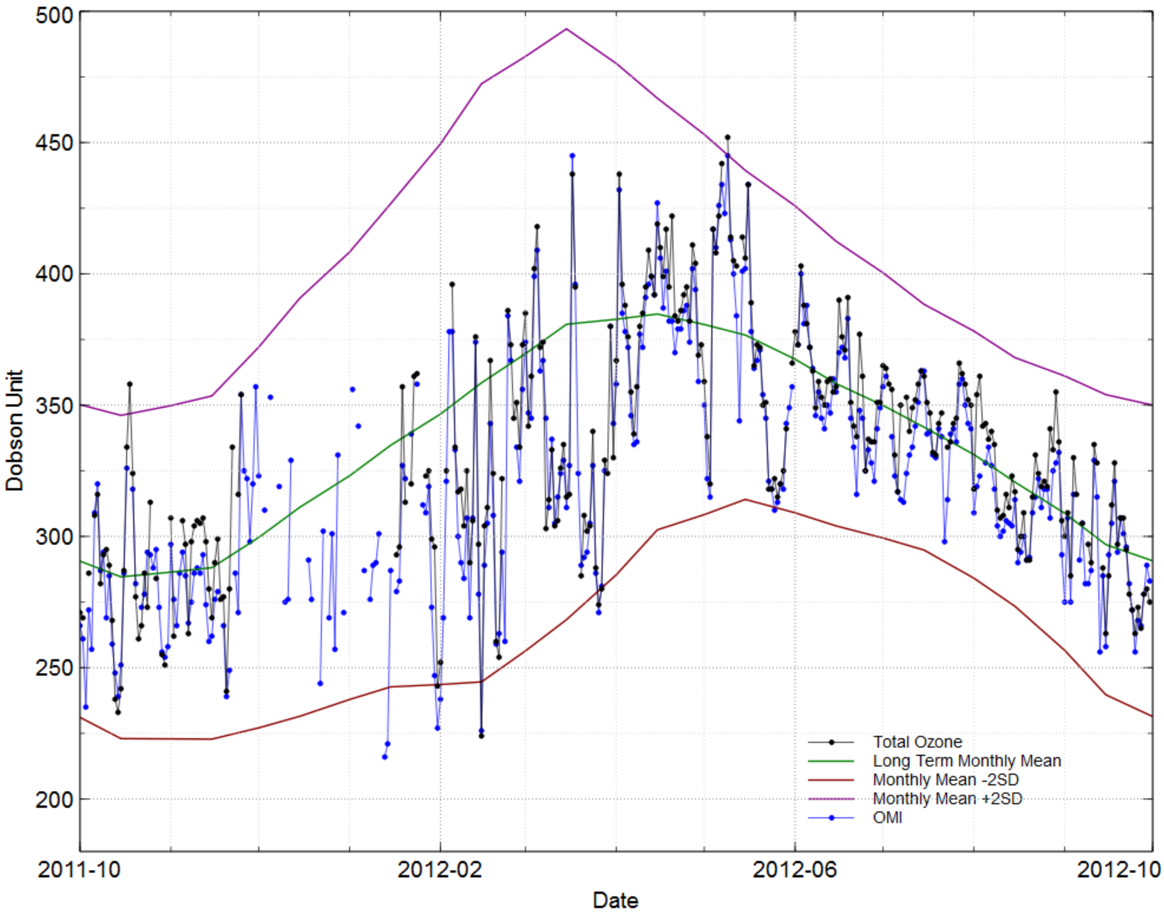


Figure 3 - Lerwick vs OMI October 2011 to September 2012

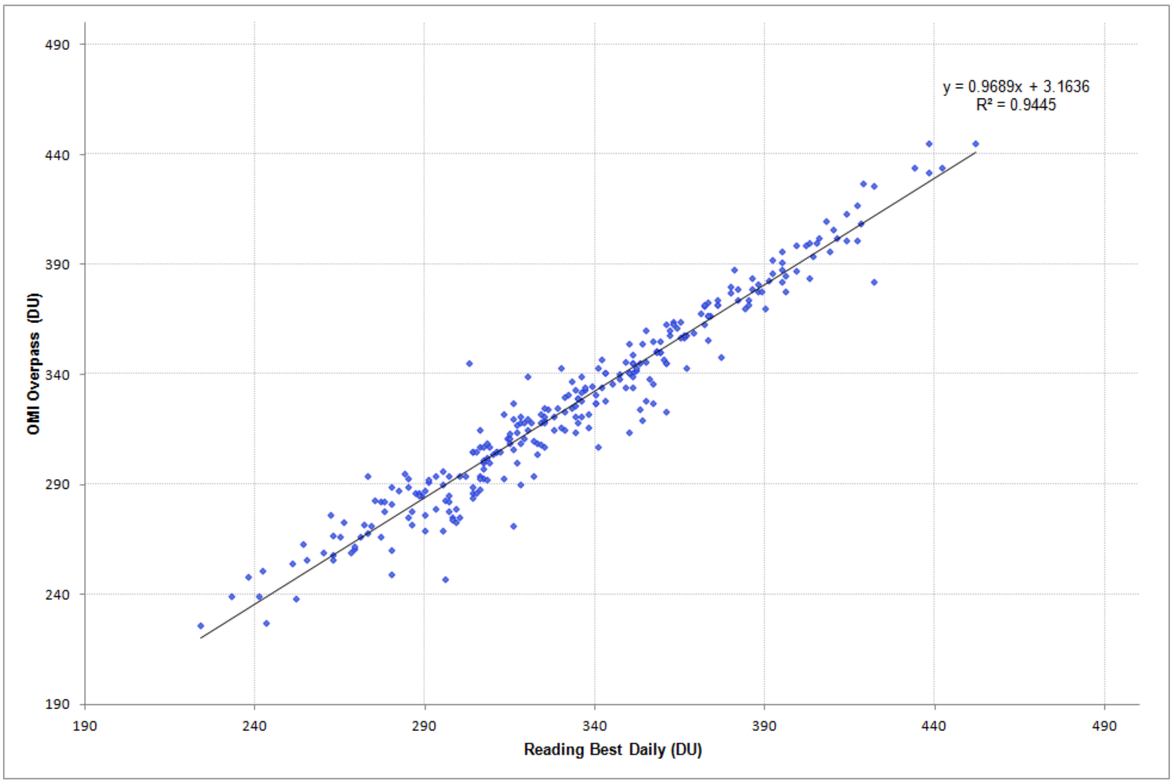


Figure 4 - Lerwick Best Daily vs OMI Overpass 01/10/2011 - 30/09/2012

3.2 Reading Ozone and UV Measurements

3.2.1 Ozone Measurements Brewer

At the end of the period covered by the previous annual report Brewers #075 and #126 underwent their biennial calibration at the Regional Brewer Calibration Centre (RBCC-E) site at El Arenosillo, Spain. On their return Brewer #075 was relocated to Reading, with Brewer #126 returning to Manchester for lab monitoring. Prior to calibration the Reading ozone record was maintained by Brewer #126, courtesy of the UKMO. During the last quarter of 2011, we received the final calibration report and instrument constants from IOS, and these were then applied to the 2009 to 2011 inter-calibration period.

Due to its deteriorating nickel sulphate filter, it was not possible to deploy Brewer #075 at Reading between the 2010 Izana calibration until after its filter replacement at the 2011 calibration. However the new 2011 calibration constants are now in use and are being applied to all post-calibration data. It should be noted that the Extra-Terrestrial Constants (ETCs) determined for Brewer #075 at the RBCC-E in 2011 are now close to the 2009 values, and moreover the difference between ETCs and standard lamp datums in 2010 and 2011 are identical – therefore the reprocessing with the new calibration values had no net effect on the ozone column values determined. This then lends further weight to the method of standard lamp correction, as well as showing the high quality of the calibrations.

As part of the calibration report, it was also recommended that it would be better to use a more highly attenuating neutral density filter during a standard lamp check on Brewer #075, and also to adjust the step number (fine tuning of the mercury calibration point) by 2 points. As the 2011 standard lamp datums were determined without these changes being operational, they were taken into account when the new calibration constants were applied. Consequently there was a corresponding small change in the standard lamp datums on day 336 of 2011 which has been applied to all data since that date.

Brewer #126 on the other hand showed a slight change in its instrument response between 2009 and 2011. Applying interpolated ETCs and standard lamp datums to the relevant periods when Brewer #126 was located in Reading, results in an increase of up to 1.4%. In 2009 the calculated ozone column has increased by 0.1% to 0.2%, while for the section of the time series attributable to Brewer in #126 in 2010 to 2011, reprocessed column ozone values are 0.4% to 1.4% higher. Overall the mean change is +0.66%.

Since the return of Brewer #075 from calibration, ozone measurements at Reading have continued largely unperturbed. There have been two instances where the schedule was interrupted due to the azimuthal tracking related issues. The first during the second quarter of 2012 was due to the tether on the azimuth kill switch being slightly too tight, whilst the second during mid-August 2012 was traced to degraded cabling. Otherwise measurements have continued according to schedule.

For both Reading and Manchester instruments, the reprocessed data is now marked at v4.1 for WOUDC purposes, indicating that the new calibration has been applied, but that there have been no major changes in reprocessing or analysis method.

The raw bfiles for both instruments during the period that each is sited in Reading have been submitted as is usual to the WOUDC by the University of Manchester team.

At the last project meeting on 28th November 2011, it was recognised that Brewer vertical profile umkehr measurements would be an important addition to the monitoring program. John Rimmer presented three options to include these measurements and it was left that Peter Coleman and Will Cook would discuss and agree on which of these options to adopt before changes to the measurement schedule were made. In early November 2012 since there had not yet been any communication from Defra so umkehr measurements are still not being made at Reading.

Figure 5 and Figure 6 shows the comparison of the daily Reading column ozone values with measurements from the OMI satellite instrument. The four sets of measurements are generally in good qualitative and quantitative agreement.

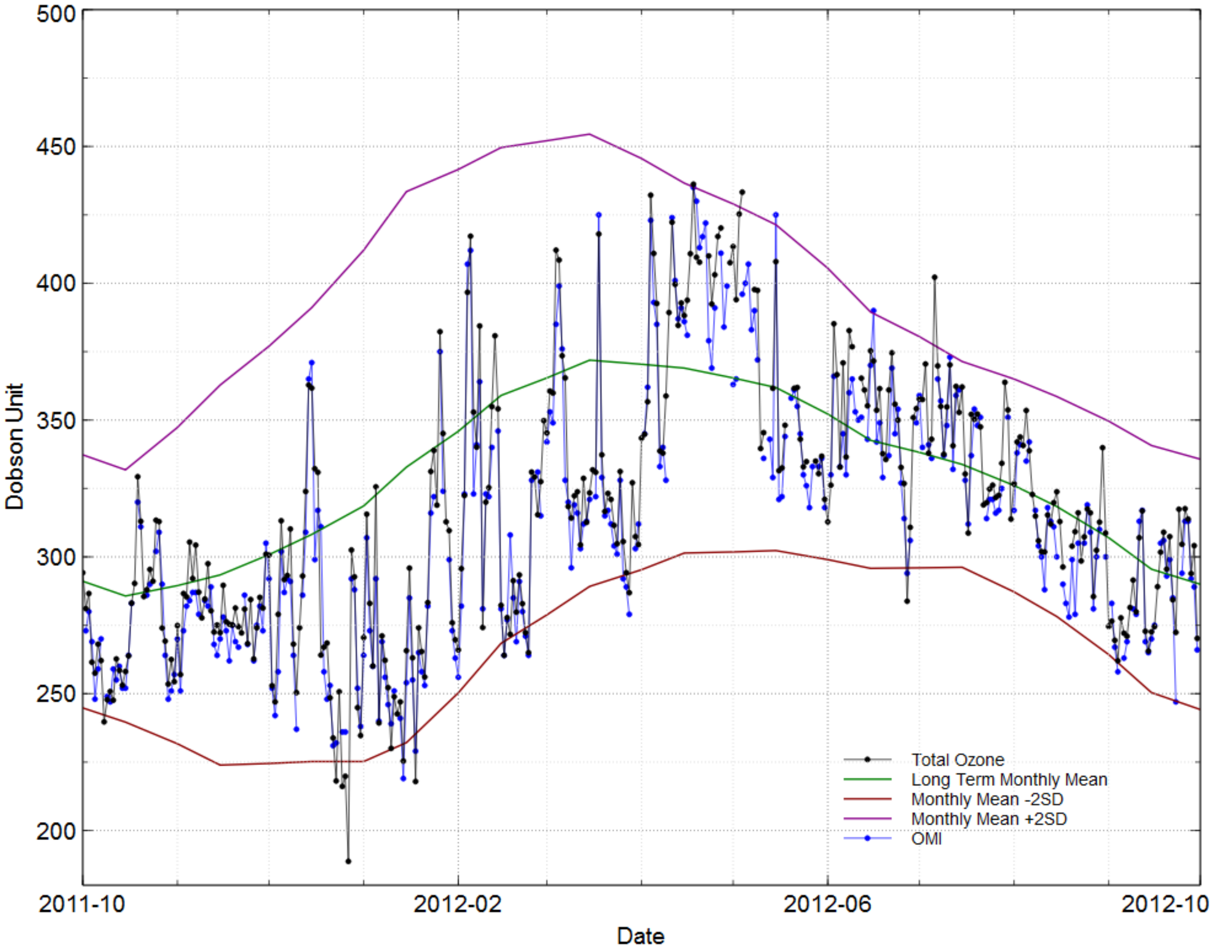


Figure 5 - Reading vs. OMI, October2011 to September 2012.

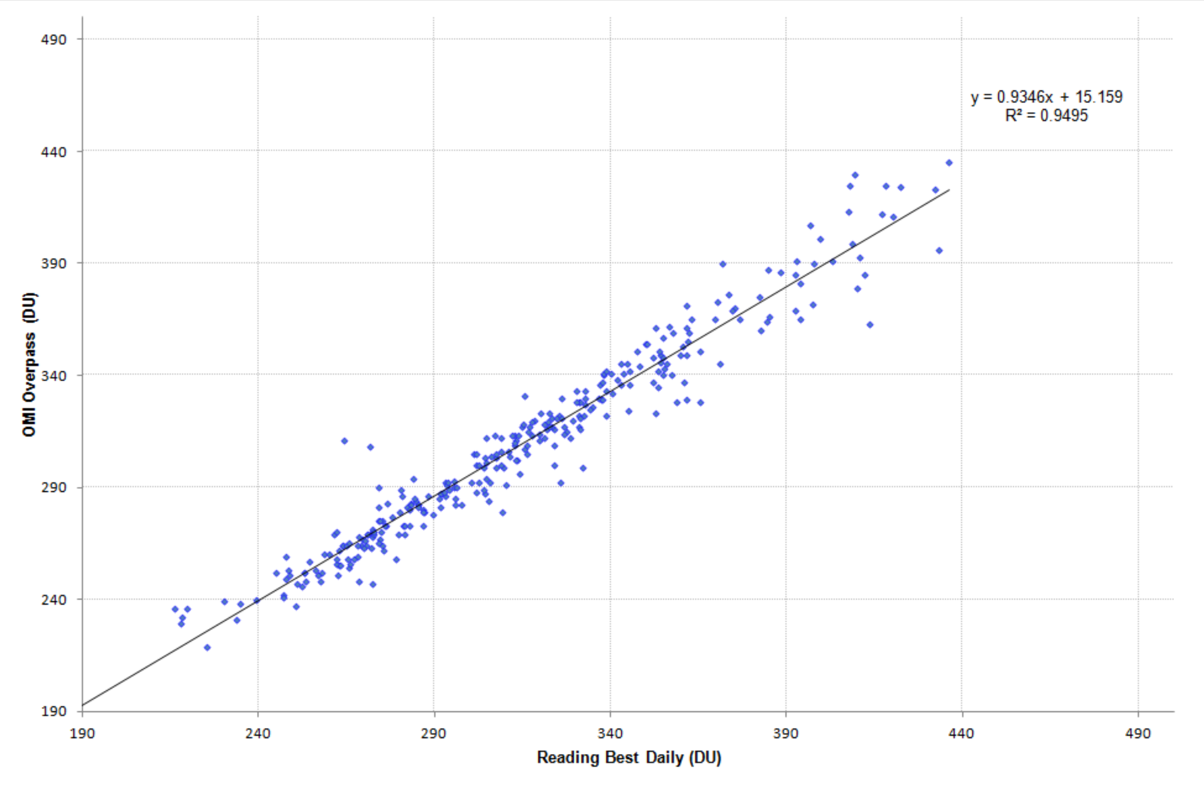


Figure 6 - Lerwick Best Daily vs OMI Overpass 01/10/2011 - 30/09/2012

3.2.2 Reading UV

Spectral UV measurements have continued during the last 12 months with more interruptions than is usual. The majority of these are associated with the construction of the new Reading Atmospheric Observatory during summer 2012. This was originally scheduled to begin during April, but the start date was later moved to 8th May 2012 with a temporary instrument shelter being installed before this date. At the end of September the University of Manchester was informed that the new observatory building was ready for the relocation of the Bentham DM150 spectroradiometer. During the continued construction work the instrument experienced a number of minor power outages and intermittent issues with the on-site ethernet that, in turn, impacted upon data acquisition and data transfers. The long-standing data transfer system was monitored during office hours on an hourly basis from Manchester to provide early warning of any such issues, minimise downtime and ensure data processing was brought back up to date as soon as possible.

During summer 2012, whilst the instrument was housed in its temporary accommodation, an issue with the temperature control of the envirobox was observed. Efforts were made to resolve this, with the instrument being removed to the manufacturers, Bentham Instruments, for a period of several days for diagnosis. As part of the tests carried out the set-point was adjusted to 22ºC, but the symptoms could not be replicated in their laboratories. One possible cause was the quality of the temporary power supply to the instrument, and mitigating steps were taken in this regard, with the air temperature of the shelter also being closely monitored. However a noticeable improvement was seen after contractors left the site with the instrument envirobox temperature being within its expected limits since that time.

A number of additional maintenance tasks have arisen during the period: in November 2011 the pump that circulates air through the desiccant trap began to overheat and thus required replacement. A small number of spectra were affected by the resulting condensation in the input optics and therefore were removed from the data record. Further, a new data acquisition PC was required in May 2012.

A visit from the world travelling standard spectroradiometer instrument, QASUME, was planned at the end of June 2012, arranged in conjunction with HPA to reduce costs for both parties. QASUME visited the HPA Chilton site first, followed by Reading, the latter portion scheduled for 28th June 2012 to 2nd July 2012. Initial results indicate that our measurements have been stable w.r.t. to QASUME at the 2% level since the last intercomparison in 2003. Much of the time during the intercomparison was spent recording data that was assimilated into our normal time series, so that, save for a short gap during installation, the campaign spectra have now been processed and included into our time series. During the campaign in addition to a direct comparison of both instruments, the cosine response of our global irradiance optics was measured, and a new slit function was determined using a 325nm HeCd laser. At the time of writing we are still awaiting a draft report and full results from the World Radiation Centre.

In advance of both the observatory rebuild and the QASUME intercomparison, the daily maintenance logs completed by the on-site staff for both Bentham DM150 and Brewer #075 were upgraded to an electronic format. These were designed to diagnose and track any instrument problems, and contain a full instrument history including calibrations, any significant changes to the hardware or software, alongside the maintenance record.

Although there have been some short breaks in the time series due to the rebuilding of the observatory and associated issues, the fraction of yellow (fair) level_1 quality flags continues to be very low, as shown in Figure 7 and Figure 8, with green flags being produced almost all of the time during the period, showing that the resulting data series is of the highest quality. As normal where changes over the 2% threshold have been noted during recent calibration checks, corrections have been made to the instrument response before spectral measurements were resumed (Figure 9).

The University of Manchester continues to produce WOUDC and EUVDB format files during the nightly processing routines, from the level_1 spectral UV dataset, filtering these for quality flags. These files reside on the o3uvdata.seaes.manchester.ac.uk ftp database. At the end of each month these files are sent to the World Ozone and UV Data Centre (WOUDC) and European Ultraviolet Database (EUVDB) for use by the wider scientific community. This processing is still considered as state of the art, although WMO have now approved the inclusion of UV-index into WOUDC files. University of Manchester staff are currently waiting on details of the specified format from WOUDC. However due to ongoing developments at Environment Canada who host the WOUDC we expect there to be a delay before this task can be completed. When possible the change will also be applied to the historic data series, before resubmission.

The Finnish Meteorological Institute who host EUVDB are have yet to resolve their technical difficulties with part of submission process, which incurs a slight delay before data is manually added into the database. The processing of data by the Manchester team ensures that the dataset is identical to that submitted to the WOUDC as EUVDB format files are produced during the nightly processing routines from the same underlying files.

The University of Manchester has also been approached this year by Prof. Joanna Haigh's group at Imperial College, London regarding using the Reading UV and ozone datasets. The aim of their work is to try and extract a solar signal from ground-based observations of UV radiation to determine top-of-atmosphere irradiance variability. Their work will incorporate our co-located ozone measurements and other ancillary meteorological measurements from the Reading Atmospheric Observatory.

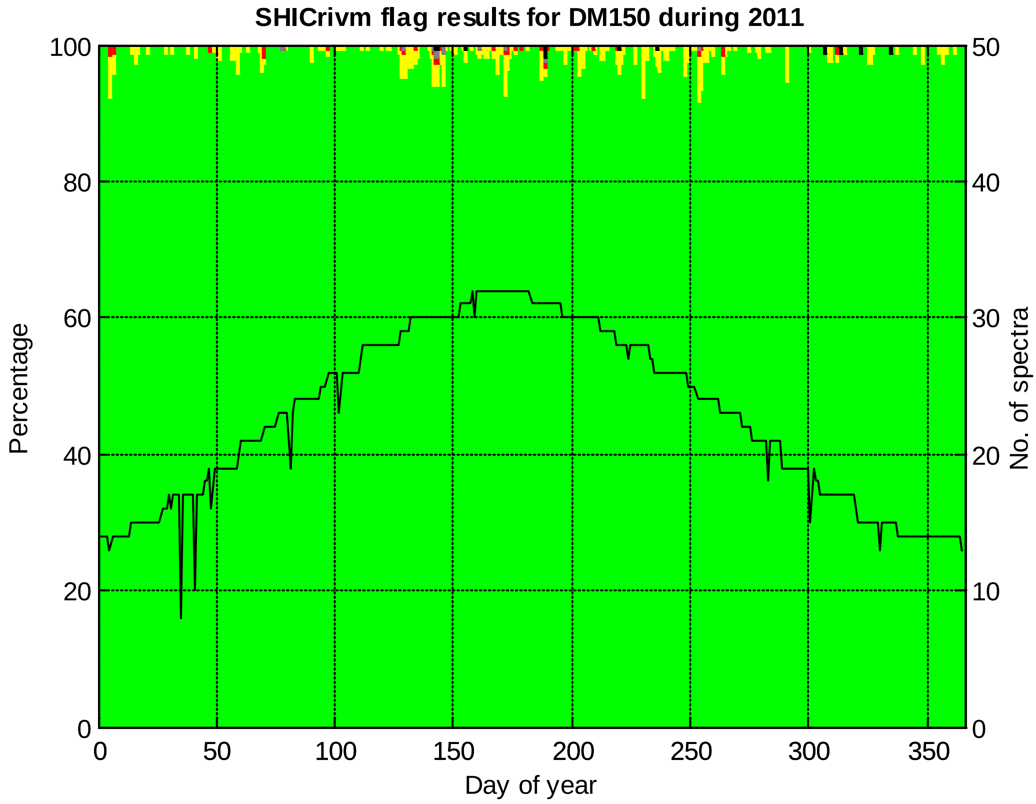


Figure 7 **- 2011 level_1 quality flags produced by the ShicRIVM processing software.**

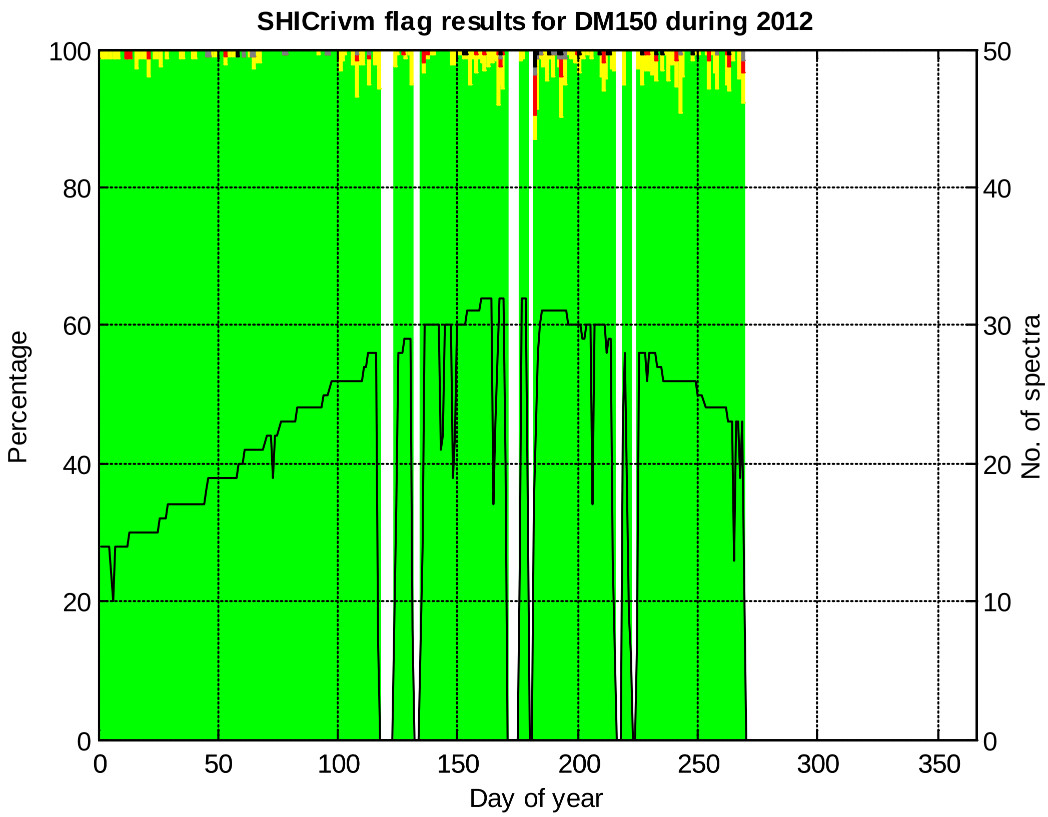


Figure 8 **- 2012 level_1 quality flags produced by the ShicRIVM processing software.**

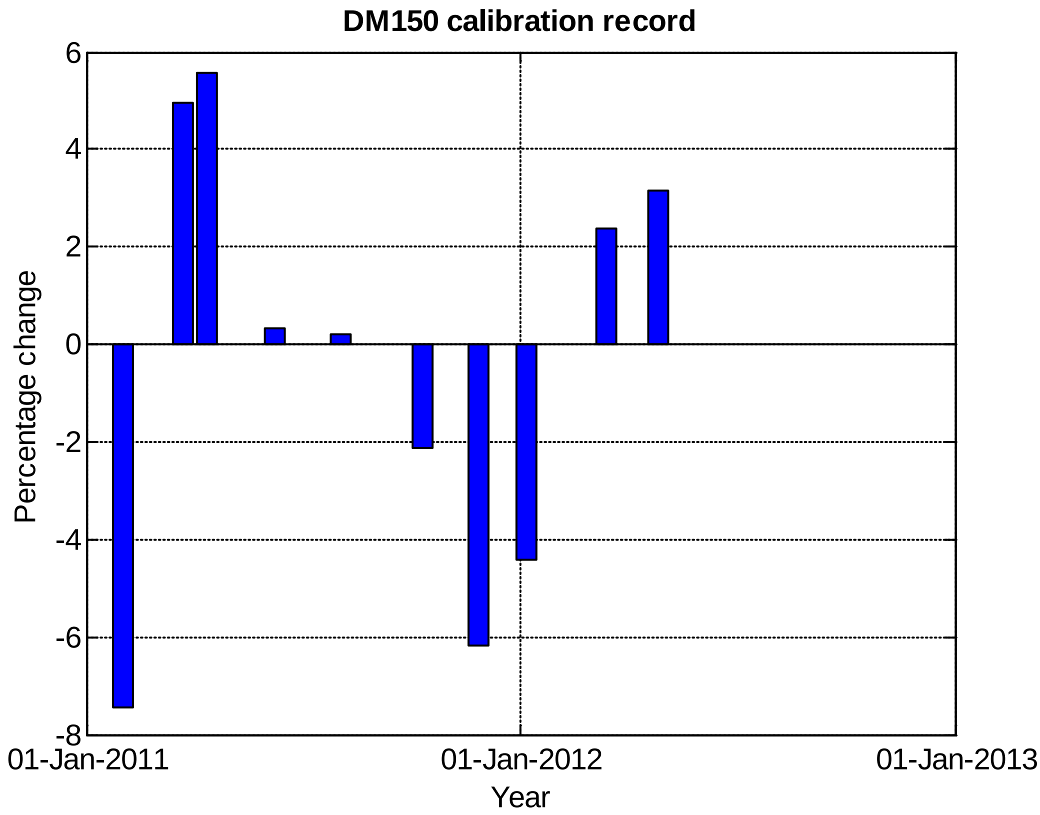


Figure 9 DM150 irradiance calibration record.

3.2.3 UV Index

Software developed by Ricardo-AEA automatically processes the spectral data from the DM150 UV instrument at Reading and converts them to a simple UV index comparable with the results from the HPA broadband UV monitoring network. The measurement data and plots of the daily UV index and of the maximum daily UV index throughout the year are available on the website one day in arrears for public information.

The daily maximum UV index values are plotted with quality flags, as an ongoing annual graph. The daily maximum UV index graphs for Reading for 2011 can be found here http://ozone-uv.defra.gov.uk/uv/data_search.php

3.3 Manchester Measurements

The University of Manchester also makes column ozone measurements at Manchester using a Brewer instrument (#172), in parallel with the reading measurements with Brewer #075. The analysis contains individual measurements made at air masses up to 6.0, as well as the usual standard lamp corrections. The version 4.1 reprocessed data, including checks against the satellite record, from Brewer #172 is being submitted to WOUDC on a monthly basis together with the raw bfiles, i.e. on the same basis as both the single monochromator instruments, Brewers #075 and #126.

During summer 2011 Brewer #172 took part in the RBCC-E calibration at El Arenosillo, and as expected was found to be operating well and in a stable manner. It subsequently returned to Manchester to continue the ozone time series using its standard measurement schedule

(UV scans, direct sun and zenith sky ozone measurements, plus Umkehr profiles during the morning and evening) and the new calibration constants were assessed and applied to the inter-calibration period (2009 to 2011) and all subsequent data. There was a small change in instrument response and consequently calculated ozone column values at the end of the inter-calibration period are up to 0.5% higher than before reprocessing. The new calibration constants are still in place for Brewer #172 at the time of writing, and reprocessed data has been marked as v4.1 for WOUDC purposes, in line with both other instruments.

Umkehr ozone profiling measurements have been run by Brewer #172 as part of the daily schedule of measurements since 2008 (except during calibrations and when running pre-calibration schedules). During the period we have continued to process these profiles on a monthly basis using a third party application, filter for good ozone profiles, and upload the resulting data files onto the Manchester-hosted database.

Following the loss of expert scientific support from Environment Canada, the Manchester monitoring team was approached by Kipp and Zonen in late 2011, the sole manufacturers of Brewer instruments, and requested to assist with pre-production testing and de-bugging of the latest version of the electronics hardware. The current prototype electronics board has been re-designed with modern components, but otherwise is required to be totally transparent in terms of existing cable connections and command set. The new board was fitted to Brewer #172 for a short period of lab testing in early December, but due to configuration problems was returned to the rooftop site, with the original board re-fitted. In January 2012 the prototype board was reinstalled into Brewer #172 and testing of the prototype board resumed. During the following weeks, some issues were noted with the diagnostic outputs, and particularly the operation of the micrometers at high instrument temperatures which required manual editing of the data series to remove anomalous results. However the original board was reinstalled on 30 May and Brewer #172 has operated without fault or interruption since that date.

3.4 Manchester FTP

The FTP server has continued to be reliable providing data to the project team.

3.5 Ozone Data Reporting

A summary of daily Dobson and Brewer ozone data is reported on a weekly basis by email to the project partners and a number of other interested organisations and individuals.

The data are also delivered daily to the University of Thessaloniki for the World Ozone and Ultraviolet Radiation Data Centre (WOUDC) near real-time ozone mapping programme. Interpolated maps are disseminated by return to all the participants. The mapped results can also be viewed from the web page: http://exp-studies.tor.ec.gc.ca/e/ozone/Curr_allmap.htm.

Final data are reported monthly (after Ricardo-AEA's monthly QC checks and any follow-up actions) to the WOUDC data archive. The QC checks involve:

- Comparison of all relevant datasets against each other for consistency.
- Follow-up with data providers any data points which are apparent outliers.
- Regression analysis between ground-based and satellite data to determine whether the relationship is improving or deteriorating.
- Comparison with climatology to assess whether levels are normal for the time of year.

Climatology updated by Ricardo-AEA now includes 2011 data. The Reading site now uses its own climatology rather than that transferred from the closed Camborne site.

All reports were delivered successfully during this period of the contract.

4 Data Analysis

4.1 Summary

During the period of the contract the ozone columns at Reading and Lerwick followed their normal seasonal progression. The 2011 annual means at both sites were similar to values recorded in the last 20 years.

4.2 A new statistical model

On daily time scales the column ozone is strongly influenced by troposphere weather systems. The long term role of weather changes on ozone trends is only now beginning to be examined. We have examined the role of the geopotential height at 500 hPa proxy. On a daily basis this dynamical proxy is known to be anti-correlated with column ozone i.e. large heights or anti-cyclones also tend to depress the ozone column by lifting the tropopause. This is a well understood physical connection and the ozone column by itself should have negligible impact on the height. In previous work we have shown that other proxies such as the geopotential height at 200 hPa, the solar cycle (10.7 cm solar flux time series) and the Quasi Biennial Oscillation (QBO) signal do not materially improve the statistical model. This year we have further studied the role of the 500 hPa proxy by performing an empirical orthogonal function (EOF) analysis of only the 500 hPa geopotential height.

Since the introduction of EOF analysis in atmospheric science by Lorenz, this simple yet effective method has been used extensively in atmospheric, oceanic, and climatic research (e.g. Hannachi et al. 2007). The essence of EOF analysis is to identify and extract the spatiotemporal modes that are ordered in terms of their representations of data variance. Because a small number of leading modes usually account for most of the total variance, EOF analysis enables one to pick out the dominant and sometimes physically meaningful modes of variability while greatly reducing the data space. By construction, the spatial patterns (EOFs) and the temporal coefficients [principal components (PCs)] of these modes are both orthogonal. Such orthogonality has the advantage of isolating uncorrelated modes, but sometimes it also leads to complexity of spatial structures and difficulty in physical interpretations; thus, it may cause misunderstanding and confusion.

Figure 10, Figure 11, Figure 12 and Figure 13 show the first and second EOFs of the seasonal mean 500 hPa field. Together these two components account for 72 % (DJF), 62 % (MAM), 61% (JJA), and 61% (SON). It can be seen that the basic spatial pattern is very similar between the seasons. The first principal pattern is a single lobe whose centre shifts seasonally south into the winter. The second pattern is of a dipole nature splitting northern and southern Europe. The second component in the summer is anomalous with a rotated dipole pattern.

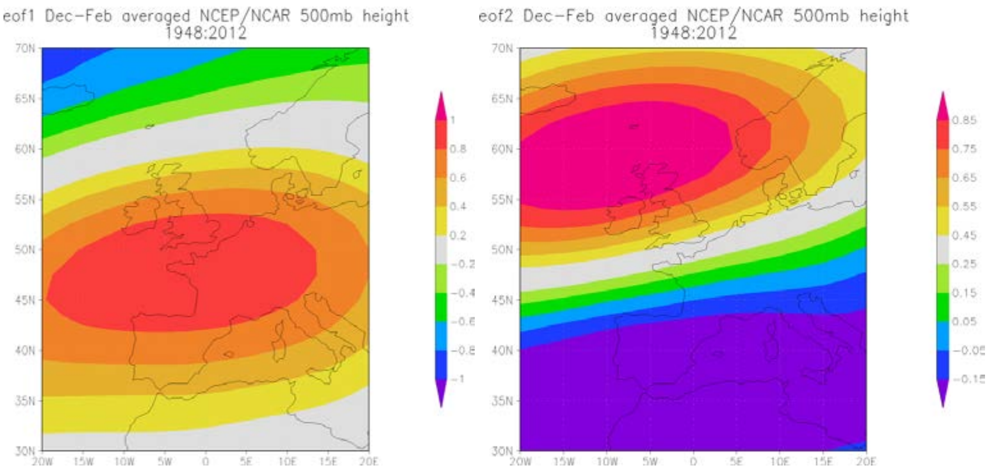


Figure 10 - Winter (DJF) principal components 1 and 2 from the NCEP re-analysis (1948-2012).

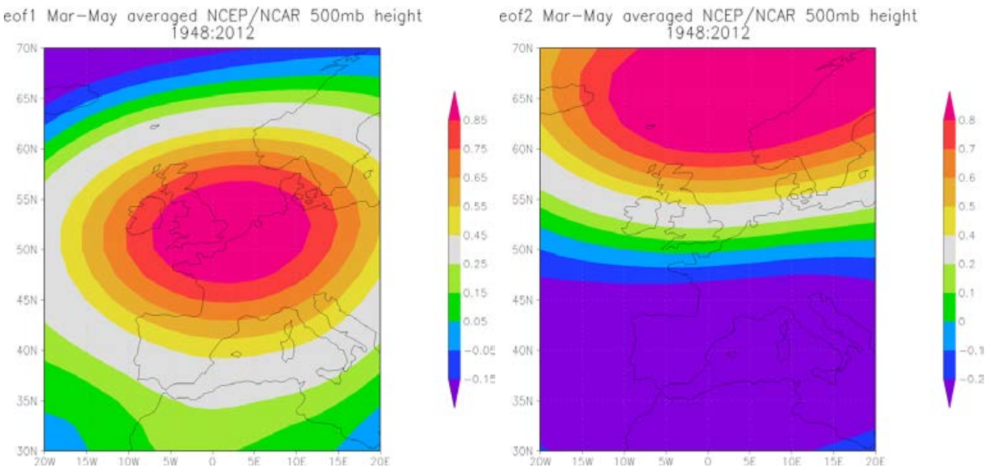


Figure 11 - Spring (MAM) principal components 1 and 2 from the NCEP re-analysis (1948-2012).

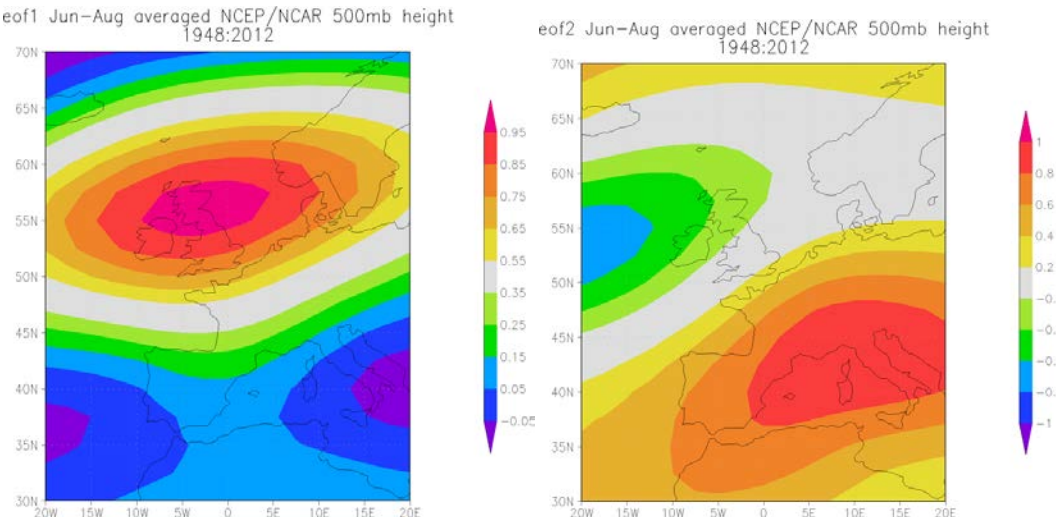


Figure 12 - Summer (JJA) principal components 1 and 2 from the NCEP re-analysis (1948-2012).

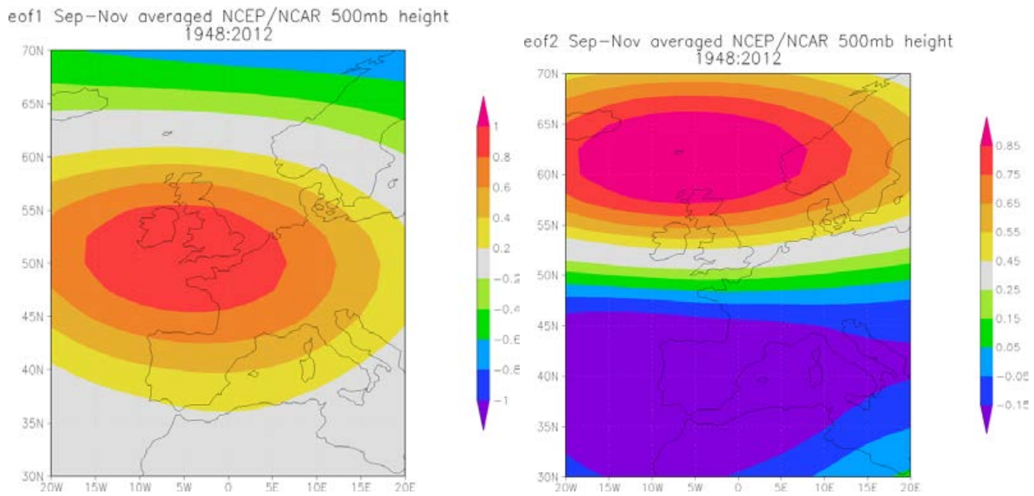


Figure 13 - Autumn (SON) principal components 1 and 2 from the NCEP re-analysis (1948-2012).

Each pattern has a principle component time series which can be correlated with the column ozone measurements at Lerwick and Reading. Table 2 shows this correlation for the components and for comparison the correlation with the local geopotential height. It can be seen that for Reading the principal component analysis outperforms the local geopotential in all seasons. It is thus a very promising substitute proxy in future multiple regression analysis. The analysis for the longer Lerwick time series also shows mostly good correlation; however, for autumn and winter it is the second component that most closely correlates with ozone. In winter for Lerwick and summer in Reading the correlations are low (and not significant) for both proxies. The cause for this could be data gaps in winter at Lerwick and dominance of horizontal advection as an explanation for ozone variability in the summer at Reading. For Lerwick the principal component time series shows some promise to replace the local geopotential height measure, but more work needs to be done. However, it is encouraging that both Lerwick and Reading data sets can now be explained by a single analysis (time series). The patterns physical significance will need to be established in the next year. This is a promising route to replace the current geopotential proxy.

	Lerwick		Reading	
	PC (1 or 2)	GP	PC (1 or 2)	GP
DJF	0.02 (2)	0.01	0.70 (1)	0.59
MAM	0.32 (1)	0.35	0.25 (1)	0.22
JJA	0.25 (1)	0.31	0.04 (1)	0.01
SON (to 2011)	0.36 (2)	0.38	0.84 (1)	0.77

Table 2 Correlation coefficient, R^2, between the column ozone at Lerwick (1978-2012) and Reading (2003-2012) and the first and second principal component time series (1 and 2) as well as the local 500 hPa geopotential height (GP).

4.3 Trends

In trend analysis to date we have chosen only the 500 hPa rather than the sometimes used 200 hPa to make sure that the proxy is truly tropospheric and not partly influenced by stratospheric temperatures which are influenced by stratospheric ozone. We have performed two types of trend analysis for Lerwick and Reading over the reporting year:

1. A simple regression of the column ozone from the start of record for Reading in 2003 and since the start of the satellite observations for Lerwick in 1978.

2. A multiple regression where we include the monthly 500 hPa geopotential height over the site from NCEP re-analysis as a tropospheric dynamical proxy.

These analyses have now been automated using the "R" statistical software so that they can be performed as simply as possible from the ozone and meteorological databases. We are of course aware that long-term trends will not vary greatly from quarter-to-quarter (e.g. the changes in the Lerwick seasonal trends from 2011 to 2012 in Table 3) but this analysis quickly highlights any interesting anomalies or features in the data such as the change in significance of the autumn trend for Lerwick from multiple regression.

4.3.1 Lerwick

Analysis by simple linear regression of annual means shows that since the early 1980s ozone has been decreasing ~2% per decade over Lerwick (Table 3, Figure 14). This long-term trend is declining as ozone has stabilised since the 1990s. Trends are sensitive to the chosen time frame and we have chosen the beginning of the global 30 year satellite period as suitable starting year. There is as yet no evidence of significant ozone recovery. The long-term (since 1978) autumn decline reported previously is no longer significant for the multiple regression. This is more in line with our understanding of chemical ozone depletion as it was always difficult to explain enhanced ozone loss prior to the cold season of polar stratospheric cloud formation. Since 1990 the Lerwick annual mean trend has been upward but this is not significant (at the 95% confidence interval). The seasonal evolution is shown in Figure 14. There is an apparent turn-around in the spring (March/April/May) ozone column over this location. From the 1970's until around 1990 there was a very strong downward trend, which has now levelled off. However, there is no statistically significant recovery since the late 1990s, when stratospheric chlorine loading is thought to have peaked.

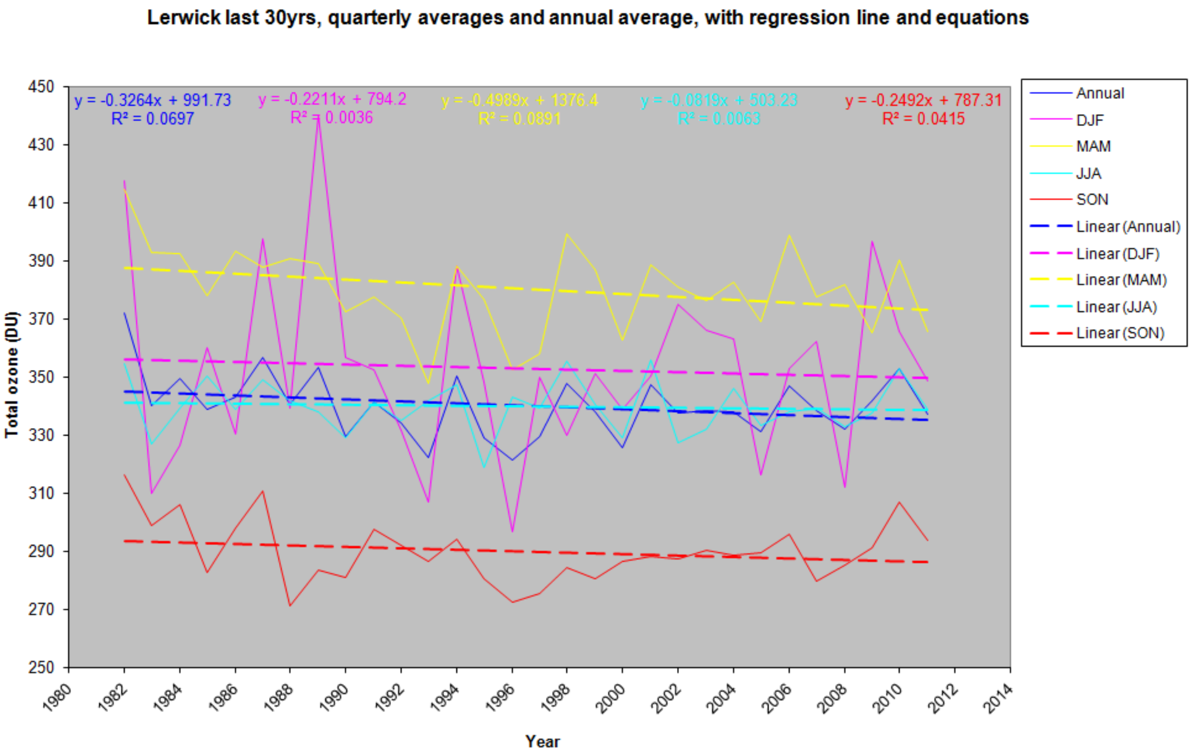


Figure 14 Long-term trends since 1982 in annual and seasonal ozone column over Lerwick

4.3.2 Reading

At Reading there is an annual increase of ozone since 2003 but this is not significant. Seasonal trends are also not significantly different from zero at the 95% confidence interval. The data record is relatively short so that trends are very sensitive to record length and possibly tropospheric circulation trends.

4.3.3 Trends including 2011, single and multiple regression

Table 3 shows the results of the analysis to date including quarterly updates from the year 2012 where available (winter, spring and summer trends have been updated), as well as the trends as they stood at the end of the year 2011 for comparison. The trends as they stood in 2011 have been italicised to distinguish them clearly from the current values for the trend.

	Annual **(to 2011);** ***(to 2010)***	**Autumn (SON)** **(to 2011);** ***(to 2010)***	**Winter[3] (DJF)** **(2011-2012);** ***(2010-2011)***	**Spring (MAM)** **(to 2012);** ***(to 2011)***	**Summer (JJA)** **(to 2012);** ***(to 2011)***
Lerwick -SR	**-0.60** +/**-** 0.19; ***-0.62*** *+/- 0.20*	**-0.55** +/**-** 0.20; ***-0.61*** *+/- 0.21*	**-**0.28+/**-** 0.52; *-0.13+/- 0.55*	**-0.88** +/**-** 0.27; ***-0.87*** *+/- 0.28*	**-**0.19 +/**-**0.15; *-0.23 +/-0.16*
Lerwick- MR	**-0.49**+/**-** 0.20; ***-0.52***+/- 0.21	-0.33**+/-**0.18; ***-0.40+/-****0.18*	**-**0.25+/**-**0.54; *-0.09+/-0.56*	**-0.66+/-** 0.24; ***-0.67***+/- 0.25	-0.22+/-0.12; -0.23+/-0.13
Reading -SR	+1.43+/-1.32; *+2.97+/-1.19*	+0.99+/**-**1.58; *+2.19+/-1.70*	+0.34+/**-**2.57; *+3.55+/-2.12*	-0.30+/**-**1.44; *-0.10+/-1.87*	+1.00+/**-**0.65; *+0.75+/-0.81*
Reading -MR	+0.29+/-1.24; *+2.10+/-1.94*	+0.50+/**-**0.83; *+0.49+/-1.15*	**-**1.14+/**-**1.76; *+1.38+/-1.58*	**+**0.19+/**-**1.41; *+0.48+/-1.80*	+1.06+/**-**0.91; *+0.80+/-1.07*

Table 3 Column ozone trend in DU per year with standard errors. Numbers in bold are significant at the 95% confidence level (P<0.05) SR: single regression; MR: multiple regression. Lerwick since 1978 and Reading since 2003 and both to August 2012.

4.3.4 Camborne / Reading

In this contract we attempted to create a simple synthetic Camborne/Reading time series. Creating synthetic time series is fraught with difficulties and results should be regarded with caution. According to satellite observations the inter-annual correlation of the annual mean ozone at Camborne and Reading should be very high (correlation coefficient greater than 0.95). The annual mean ozone of the two stations should therefore track each other very well. In 2003 both sites were run simultaneously for a complete year and it was found that Reading column ozone was 0.7% larger than the column ozone at Camborne. This is within the uncertainty of both instruments. However to be conservative Reading annual means were scaled down by 0.7% for the synthetic time series. The synthetic annual mean Camborne/Reading (1990-2009) upward trend of 0.7 DU/yr is significant (at 95%). For 2011 the annual mean ozone at Reading and at Lerwick were similar to values recorded in the last 20 years and can been seen in Figure 15.

[3] Winter (DJF) season includes December of preceding year e.g. Winter 2012 is December 2011 to February 2012.

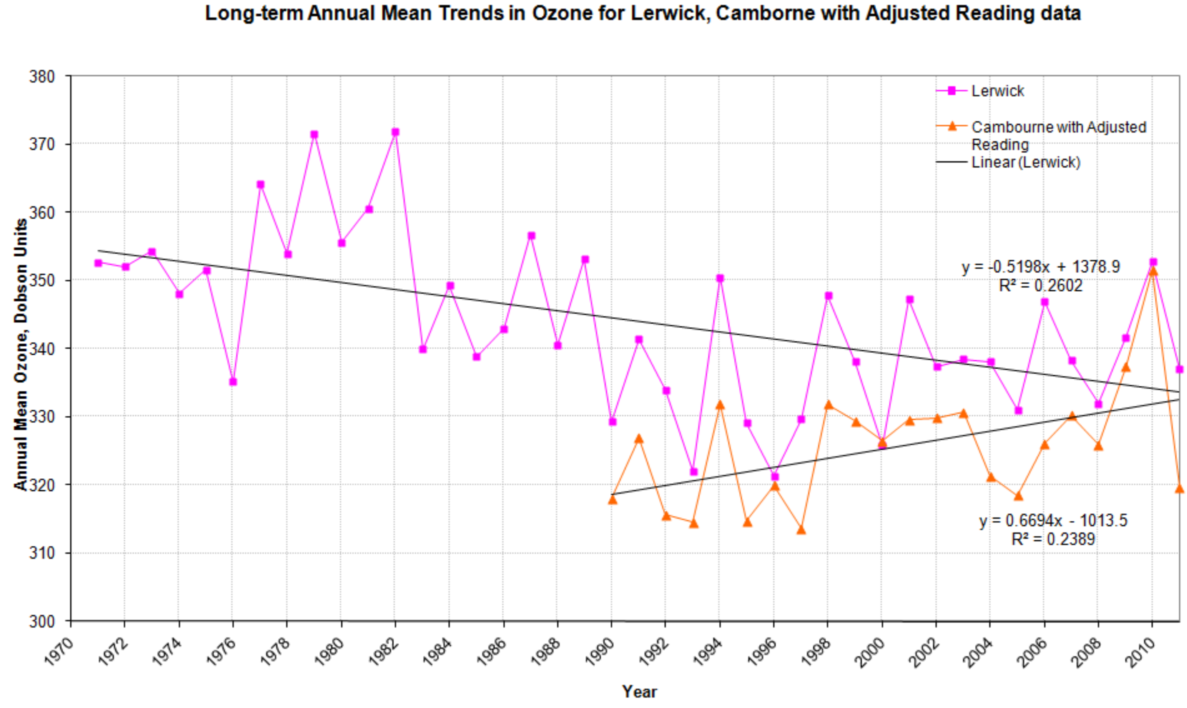
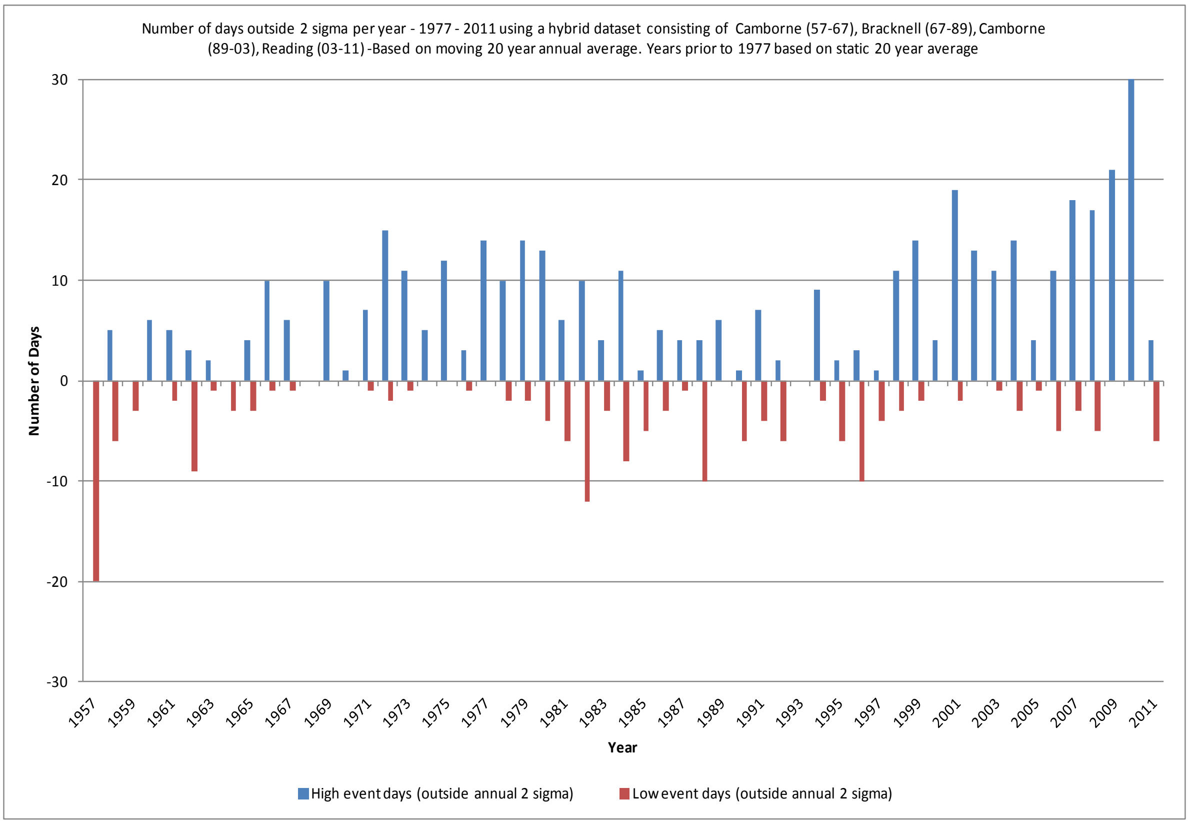


Figure 15 The annual mean of daily ozone column over the UK (Lerwick includes incomplete winter days).

4.4 High and Low Ozone Events

High and low ozone events have been determined as 2 standard deviation anomalies relative to a 20 year moving average. **Figure 16** shows the long-term evolution of high and low events at Reading and Lerwick. There appear to be long-term decadal cycles of high and low ozone events (Figure 17). We have not identified a cause for this but it is consistent with shifting patterns of tropospheric indicators, such as the North Atlantic Oscillation (NAO), which also remain unexplained. The cycles are out of phase. In the current phase we are experiencing more high events in Reading and Lerwick. 2011 was a year of relatively few high and low events.



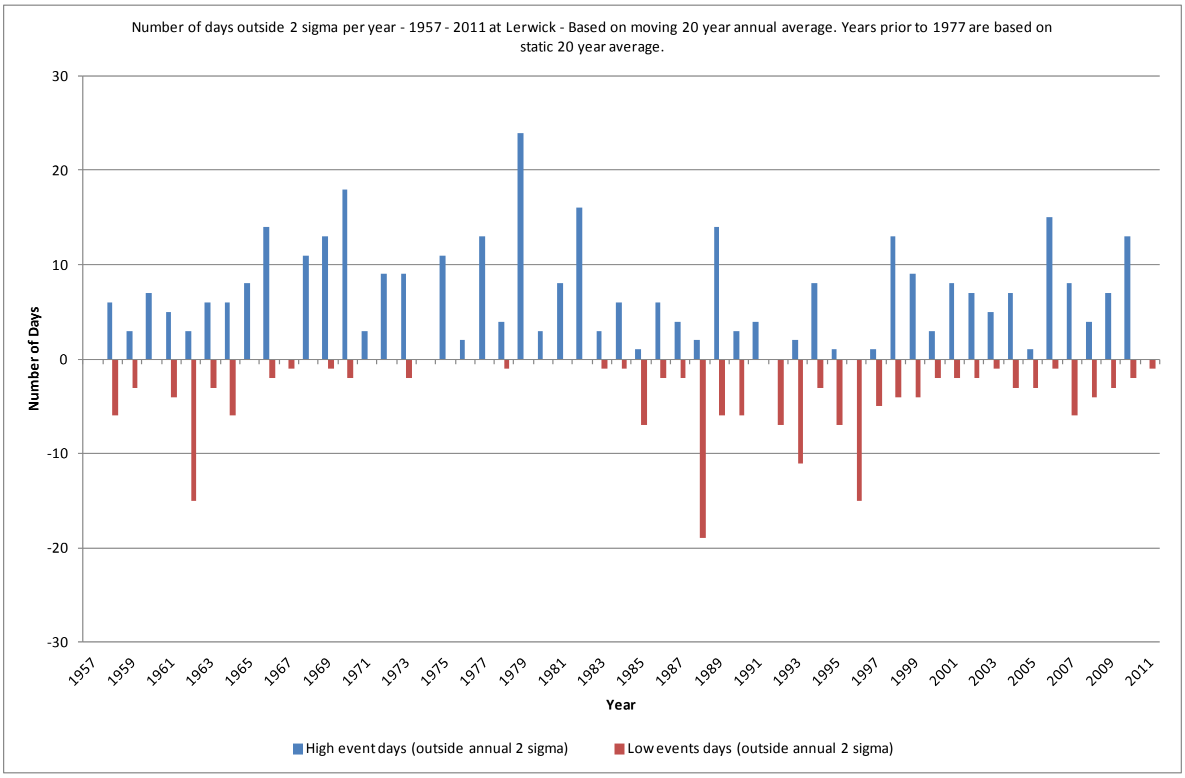


Figure 16 -Time series of high and low ozone events at Reading (top) and Lerwick (bottom). The Reading data is synthesis including other nearby stations.

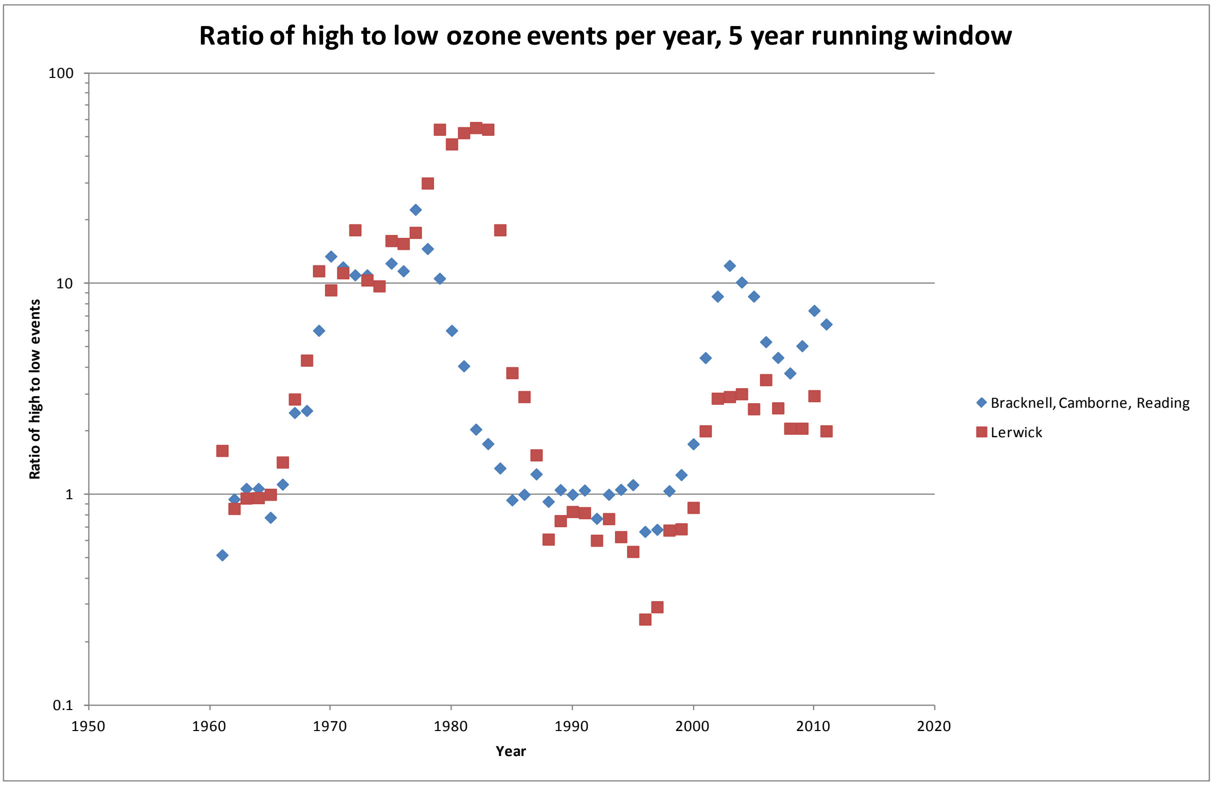


Figure 17 The ratio of the number of high and low ozone events per year when applying a 5 year moving average.

4.5 Conclusion and Future work

We have identified principle component (PC) analysis as a promising route to improve the geopotential analysis. This appears more promising than the two alternatives identified in the last annual report. It is not attractive to use QBO solely for summer regression because the physical basis is not identified. Equivalent latitude may be still be an attractive proxy; it however has some ambiguities in the choice of potential temperature and availability of data in time for the quarterly analysis. The attraction of the PCs is that they give a plausible way to identify the major modes of variability and not be concerned with the high frequency noise which can distort relationships and trends. In the next year it is proposed to identify the physical basis of the principle components. This will give more confidence if they are to replace the current multiple regression methodology.

4.6 References:

Hannachi, A., Jolliffe, I. T., and Stephenson, D. B. Empirical orthogonal functions and related techniques in atmospheric science: A review. INTERNATIONAL JOURNAL OF CLIMATOLOGY, Vol: 27, Iss: 9, 1119-1152, 2007. DOI: 10.1002/joc.1499.

5 Project Information & Dissemination

5.1 Web Site

The project homepage is illustrated in Figure 18 below and accessible via the following address http://ozone-uv.defra.gov.uk/ .

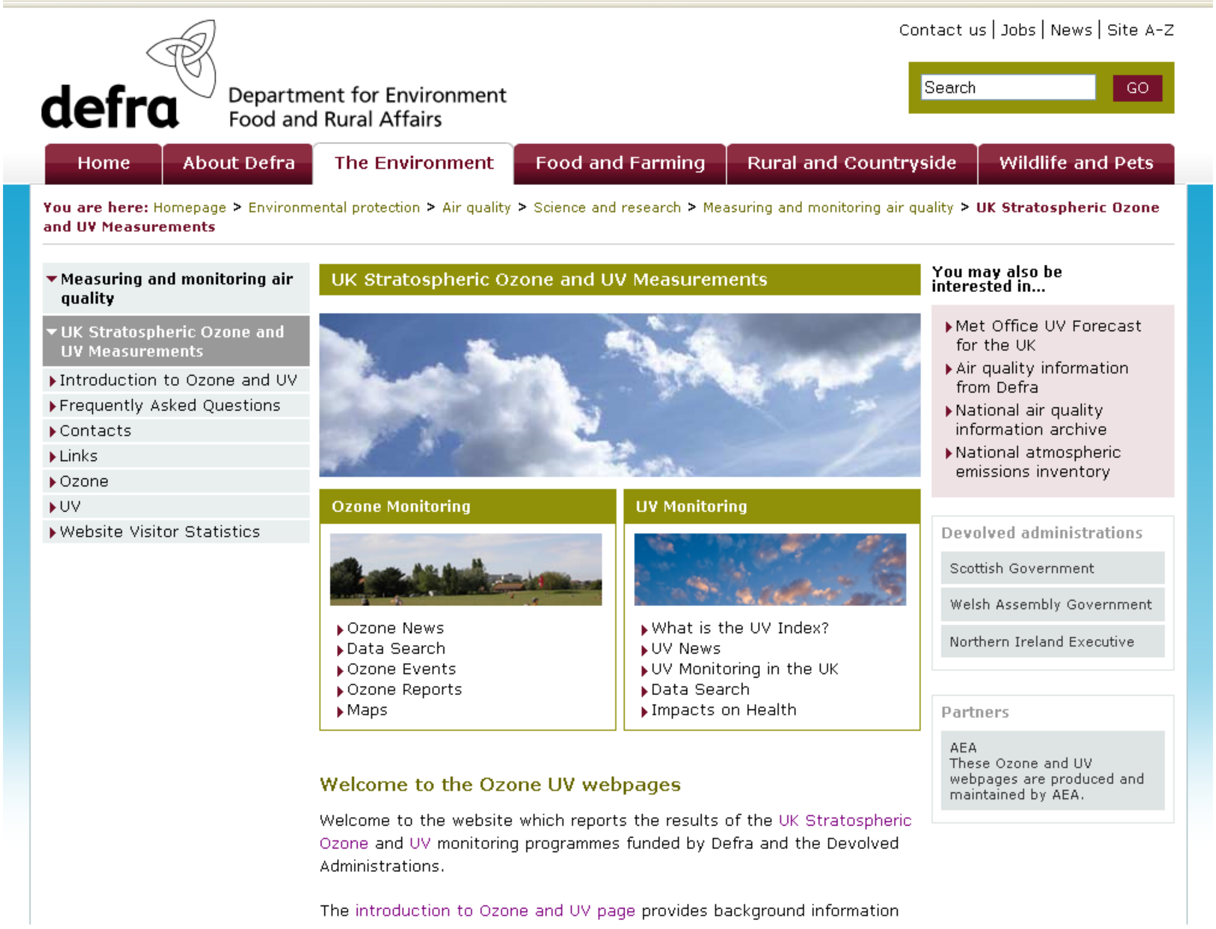


Figure 18 - The project website homepage.

Traffic continues to be redirected from the old project web url (http://www.ozone-uv.co.uk/). The live statistics can be accessed from the link section off the main project page and can be viewed directly at http://ozone-uv.defra.gov.uk/cgi-bin/usage.pl.

The following data are currently updated daily during normal working hours and made available for download from the website:

- **Dobson ozone data from Lerwick (plus historic data from Camborne)**
- **Brewer ozone data from Reading.**
- **Graphs of Manchester Brewer ozone data.**
- **Spectral UV data from Reading.**

The news section continues to be periodically updated as and when suitable articles are identified. Recent articles added include the following:

- Arctic ozone loss at record level
- Measurements at Lerwick ceased for 2011
- Measurements at Lerwick recommenced for 2012
- Ozone pioneer Rowland dies at 84

Further publicity for the website may still be helpful in order to increase its usage and it was discussed at the last project team meeting the possibility of providing links from the Met Office website to increase project exposure.

5.1.1 Website Cookies

On the 26th May 2012 a new EU law came into effect requiring consent for some cookies on UK websites.

More information about cookies can be found http://www.aboutcookies.org/ but they are essentially small bits of information the website puts a user's computer to help the user get around.

The UK Stratospheric Ozone and UV Measurements website (http://ozone-uv.defra.gov.uk/) uses cookies in some ways, such as recording visitor numbers. Therefore to ensure that the project website was compliant, RICARDO-AEA has added an information page about these cookies to ensure the user is informed via a link accessible in the page footer. Our approach was discussed with the Defra webmaster however in light of no official policy at this time the approach taken is to show compliance with the new law, and there could be some further tweaks needed but we will await to see if this is needed.

The additional page can be accessed directly here http://ozone-uv.defra.gov.uk/cookies.php.

5.1.2 Website Usage Overview

Under the new contract a brief summary of the website usage was requested to be included in the quarterly reports. Table 4 data has been taken from the AWSTATS software which monitors the site usage, and is broken down on a month by month basis (See footnotes for any clarification of what each data represents).

Year	Month	Unique visitors[4]	Number of visits[5]	Pages[6]	Hits[7]	Bandwidth[8]
2011	September	226	406	3264	7177	263.66 MB
2011	October	361	576	3483	9405	266.87 MB
2011	November	399	755	4000	12589	372.87 MB
2011	December	356	633	2661	7186	272.06 MB
2012	January	416	744	3613	10701	373.13 MB
2012	February	477	677	2893	8915	420.14 MB
2012	March	544	850	5168	16004	607.79 MB

[4] **Unique Visitor:** A unique visitor is a person or computer (host) that has made at least 1 hit on 1 page of your web site during the current period shown by the report. If this user makes several visits during this period, it is counted only once.
[5] **Visits:** Number of visits made by all visitors. Think "session" here, say a unique IP accesses a page, and then requests three other pages within an hour. All of the "pages" are included in the visit, therefore you should expect multiple pages per visit and multiple visits per unique visitor
[6] **Pages:** The number of "pages" viewed by visitors. Pages are usually HTML, PHP or ASP files, not images or other files requested as a result of loading a "Page".
[7] **Hits**: Any files requested from the server (including files that are "Pages").
[8] **Bandwidth:** Total number of bytes for pages, images and files downloaded by web browsing.

2012	April	424	789	4094	11814	472.11 MB
2012	May	419	943	4534	13281	432.61 MB
2012	June	370	766	3772	9318	282.75 MB
2012	July	410	995	4709	10128	394.22 MB
2012	August	438	990	3804	9724	351.24 MB
2012	September	566	974	4688	11788	527.24MB
Summary		5,406	10,098	50,683	138,030	4,509.45MB

Table 4 AWSTATS data for http://ozone-uv.defra.gov.uk/ Ozone AWSTATS

5.2 Literature Review

During the period of the project Defra requested a review on papers focusing on column ozone or UV measurements and a short non-technical summary to be provided on each paper together with its policy significance. During this period eleven relevant papers were reviewed and their findings are summarised in the project quarterly reports

- Balis, D., et al. (2011), Observed and modelled record ozone decline over the Arctic during winter/spring 2011, Geophys. Res. Lett., 38, L23801, doi: 10.1029/2011GL049259.
- Krzyścin, J. W. (2012), Onset of the total ozone increase based on statistical analyses of global ground-based data for the period 1964–2008. Int. J. Climatol., 32: 240–246. doi: 10.1002/joc.2264
- Anderson, James G.; Wilmouth, David M.; Smith, Jessica B.; et al. UV Dosage Levels in Summer: Increased Risk of Ozone Loss from Convectively Injected Water Vapor . SCIENCE Volume: 337 Issue: 6096 Pages: 835-839 DOI: 10.1126/science.1222978

6 Other Project Activities

6.1.1.1 Project Meetings

The annual Project Review meeting was held on the 28th November 2011

6.1.1.2 Other Meetings

There have been a number of international conferences and meetings over the project duration which have helped to raise the profile of UK Ozone and UV monitoring activities. Selected synopses and a list of posters presented, follow:

6.1.1.3 European Brewer Spectrophotometers COST action

In January 2012, John Rimmer launched an initiative to bring all the European Brewer Spectrophotometers together into a formal network through the COST mechanism. The full proposal has now been reviewed by the external expert panel and achieved the highest score with 70/75. The proposal was presented by John Rimmer, by invitation, at the COST offices in Brussels last month and was ranked first by the ESSEM Domain Committee. This is a very important step for the monitoring of ozone, UV and aerosol optical depth in Europe and will lead to more accurate, higher quality data, better capacity, scientific exchange and knowledge transfer. This UK led initiative will go a long way to filling the void in global leadership following the recent re-structuring of Environment Canada.

6.1.1.4 SPARC/IGACO/IO3C/NDACC

In April 2012, John Rimmer was invited to attend the SPARC/IGACO/IO3C/NDACC follow on meeting in Columbia for the ‘Past ozone profiles’ initiative. John Rimmer is a member of the working party on Umkehr profiles which will prepare a number of publications, in particular regarding the European profiles, for a special edition of APC which will be used in the compilation of the next Ozone Assessment Report.

6.1.1.5 International Radiation Symposium

During August 2012 Drs Ann Webb and Andrew Smedley attended the International Radiation Symposium, held in Berlin, Germany. During this conference there were a number of sessions focussing on UV with a particular emphasis on the instrument development being carried out as part of the European Metrology Research Project ENV03: "Traceability for surface spectral solar ultraviolet radiation". The aim of this project is to significantly enhance the reliability of spectral solar UV radiation measured at the Earth surface by developing improved techniques and new instruments that can provide traceable irradiance measurements with an uncertainty approaching 1%. The project has partners from across Europe from metrology institutes, instrument manufacturers and from the solar UV community. As such, Dr Andrew Smedley is the holder of a Researcher Excellence Grant within the ENV03 project alongside his DEFRA commitments, the specific aim of his work being to upgrade the University of Manchester spectral array instruments and deploy one of them in a monitoring scenario at the Manchester rooftop surface radiation site.

6.1.1.6 Quadrennial Ozone Symposium

Also in August 2012, the Quadrennial Ozone Symposium was held in Toronto and was attended by Dr John Rimmer, who had a joint presentation with RBCC-E. The opening topic dealt with the arctic ozone hole observed in Spring 2011. A chemical depletion of ~40% was confirmed with the cause attributed to extreme cold and unprecedented de-nitrification extending into late spring. As yet there are no explanations and, in fact, an EU call has gone out under FP7 to investigate the reasons. Although there is no clear periodicity to low arctic winter stratosphere temperatures, a pattern is evident that each cold year, when it occurs, is colder than the last. Since a 1deg. temperature change is equivalent to a 10% increase in ODS, it may be that we will see further depletions in the arctic. Of further importance is the emergence of a new set of ozone cross sections from Bremen. The final ACSO report was not released because of this and it may now be necessary to hold another ACSO meeting next year to discuss the situation. The new cross sections cover a wide wavelength range from UV to NIR and have been measured at many temperatures.

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