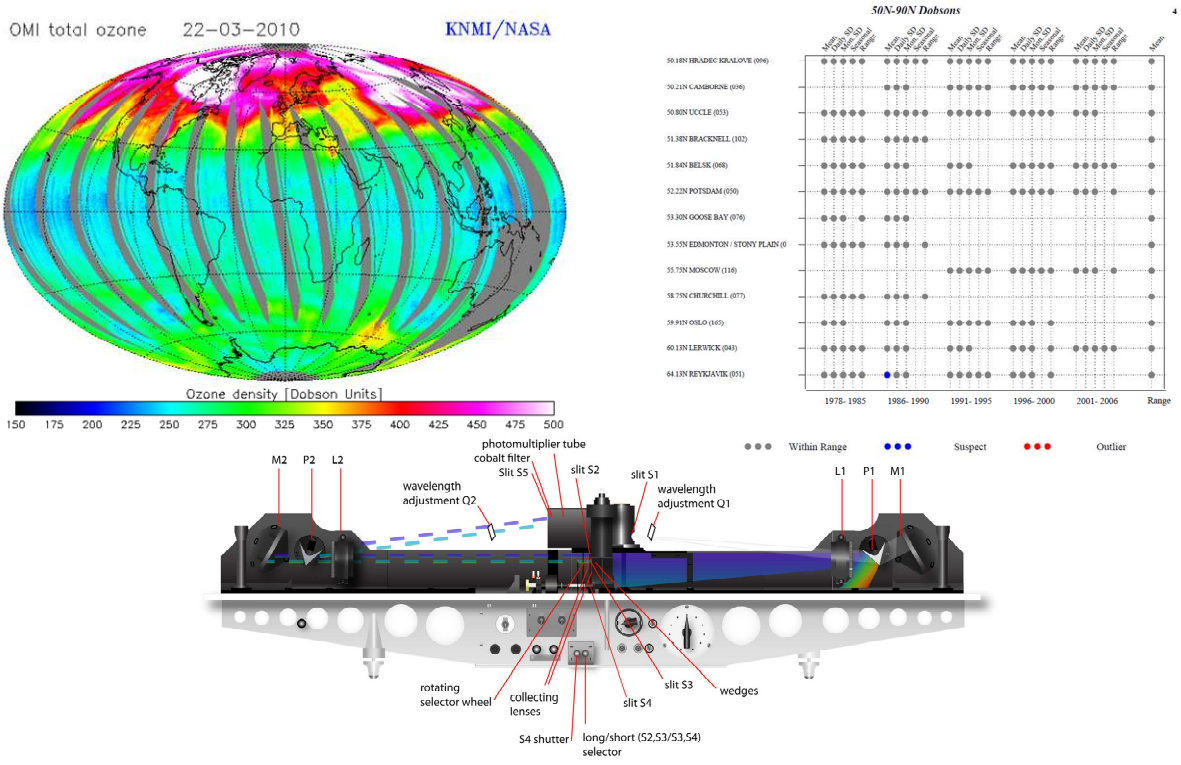
defra Department for Environment Food and Rural Affairs

Review of the Monitoring Programme: Baseline Measurement and Analysis of UK Ozone and UV

(Contract Reference AQ0925)



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Centre for Ecology & Hydrology
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University of Leicester

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The image on the front cover is a montage based on figures used in the report: Total Column Ozone data from NASA-AURA OMI, Dobson spectrophotometer [WMO-GAW (2008)] and the comparison of the ground-based and satellite measurements [Taken from the supplementary material of Fioletov *et al.* (2008)].

Executive Summary

The Department for Environment, Food and Rural Affairs (Defra) and the Devolved Administrations (DA) continue to fund a long-running programme *Baseline Measurement and Analysis of UK Ozone and UV* to monitor column (effectively stratospheric) ozone and surface UV.

The main driver for the monitoring programme is the 1985 Vienna Convention on the **Protection of the Ozone Layer**. The Convention obliges parties (including the UK) to undertake *inter alia* monitoring, data dissemination and information exchange activities.

The current monitoring programme comprises:

- measurements of column ozone at two sites in the UK (Lerwick and Reading)
- spectrally-resolved UV measurements at one site (Reading)

The ozone element of the monitoring programme was reviewed in 2002. Defra has commissioned this review of the programme to ensure that it continues to meet current and future policy and scientific requirements as well as international obligations.

The Review

The review was structured in terms of 7 questions, which addressed a range of strategic, technical and organisational aspects of the monitoring programme.

1. *How does the monitoring programme help to meet the UK obligations under the Vienna Convention on the Protection of the Ozone Layer?*
2. *Are the data currently collected in the monitoring programme fit for purpose?*

   If not, what measures could be employed to make the data fit for purpose? Are there any activities in the current monitoring programme which are no longer needed?
3. *Are the current measurement techniques viable into the future (over a 5-20 year timescale), and what other techniques/instruments are available?*
4. *Are current methodologies for disseminating information sufficient?*

   If other techniques/instruments are preferable, how (or indeed could) they be introduced whilst maintaining the continuity of the results?
5. *Is the current monitoring programme cost effective?*
6. *Is the current monitoring programme structured for optimum delivery?*
7. *Should all or part of the programme be competitively tendered, or indeed should it be competitively tendered at all?*

The review was undertaken between January and March and involved face-to-face meetings or telephone calls with key stakeholders and organisations. These and other users drawn from the policy, scientific and international communities were invited to participate in a short consultation exercise. Significant replies (or any clarification of the responses) were followed up by telephone or e-mail.

Summary of Findings

The key findings are

1. The current monitoring programme is working well but it has a low profile and impact
2. There are options to evolve the programme but these require further, more detailed evaluation.

The monitoring programme helps fulfil UK obligations under the Vienna Convention. The number of sites and the measurement programme is considered to be appropriate and proportionate. The UK has played an active role in stratospheric ozone research and in the international assessment and

policy arenas. Any reduction of the UK programme (real or apparent) will be perceived as a lack of UK commitment and could affect support for future UK-led initiatives in this area.

There is evidence that the measurements (O_3 and UV) are being used in the international assessments and for the validation of satellite measurements. The value of the datasets increases with its length. From that perspective, we would rank the measurements in the current programme in the order:

1. Ozone at Lerwick (Dobson spectrophotometer)
2. Spectral UV at Reading (Bentham DM150)
3. Ozone at Reading (Brewer spectrophotometer)

The current monitoring programme follows the guidance and standard operating procedures produced internationally for the different instruments. The quality and reliability of the measurements have been established through participation in international instrument comparisons. There are no obvious data quality issues with the current measurements, although some historic datasets still need to be reprocessed. We note the current drive to harmonise the measurements from satellite and ground-based instruments. There is likely to be a requirement to reprocess all the data (both current and historic) following the adoption of new ozone absorption cross-sections.

The main dissemination routes are to the World Ozone and UV Data Centre (which also fulfils the UK obligations under the Vienna Convention) and a project website. We suggest that the website or the measurements, at least, could be made integrated into the National Air Quality Archive, as this would enhance their visibility. A low ozone alert service is operated as part of the monitoring programme. The alerts are currently sent to the project team and Defra, but neither to the HPA nor the Met Office (who are involved in UV monitoring and forecasting activities). It is worth considering the purpose and effectiveness of this service and whether it represents best use of the resources.

A number of papers have been published in the open literature. Despite this, the monitoring programme is seen to have a low profile and impact. The National Ozone seminar held in 2007 is a good example of raising the profile of the programme and engaging with the research community. It is also suggested that the programme could offer a forum for a UK assessment of stratospheric ozone and UV, similar to those prepared for the Department by the Stratospheric Ozone Review Group and the Ultraviolet Measurements and Impacts Review Group. There will be an ongoing requirement to increase the science and policy impact of these measurements.

From information provided on the resources used in the Swiss and German monitoring programmes, the manpower resources deployed in the Defra-funded programme are similar to those of the Swiss programme. More resources are used in the German programme at Hohenpeissenberg, but this is to be expected given the more extensive range of measurements made there and its role internationally as a regional Dobson calibration centre.

Looking to the future, no activities have been undertaken within the World Meteorological Organisation to evaluate potential alternative ground-based measurement systems, as far as we are aware. It is unlikely therefore that a new instrument could be developed, operated in a network context and with sufficient overlap to ensure continuity of existing records, within the next 10 years. The Brewer and Dobson spectrophotometer will remain the instruments used to make column ozone measurements, certainly over this period and perhaps longer.

Although the current programme appears to meet the contract objectives, there are areas in the present programme that could be restructured (a) to improve the robustness of the UK measurements; and (b) to raise the profile and impact of the programme. We also identified a number of options for the future shape of this programme and indicated some of the benefits, disadvantages and risks associated with each option. In addition to the business-as-usual option, alternative options include:

- Introduction of a Brewer (or other) instrument at Lerwick
- Replacement of the Lerwick Dobson with the Manchester Brewer measurements
- Use the Reading Brewer instrument to make spectral UV measurements
- Integration with the HPA programme

Any changes need to be carefully planned, managed and communicated. It is therefore recommended that a forward-looking strategy is developed and owned by Defra and the project team. In addition to the changes outlined above, we also recommend that the contract period should be extended from the present three years to provide stability and time to make the changes.

Recommendations

Recommendation 1. **As a minimum, the monitoring programme should be maintained at its current level of 2 ozone sites and one UV site [Question 1].**

Recommendation 2. Defra continues to support (a) the participation of the UK monitoring teams in international instrument comparisons as this establishes the quality and reliability of the measurements, and (b) any reprocessing of data arising from intercomparison [Question 2].

Recommendation 3. With the adoption of new ozone absorption cross sections, Defra makes provision for the reprocessing of the UK ozone datasets and the submission of the revised data to the international databases [Question 2].

Recommendation 4. **Defra should engage the Department of Health and Health Protection Agency to identify opportunities to align their respective monitoring activities. A joint study should be undertaken to compare the spectrally-resolved UV measurements made at Reading and Chilton [Question 3].**

Recommendation 5. Defra and the contractor(s) should look for opportunities to share experience and expertise with the British Antarctic Survey, not only in terms of the Dobson measurements but also in terms of profile raising and the experience of BAS with other ozone measurement methods [Question 3].

Recommendation 6. **The contractor(s) for the monitoring programme should develop a monitoring strategy to address the future requirements of the programme in terms of aims, sites, instrumentation, implementation, communication, etc. The strategy should be periodically updated and tested externally [Question 3].**

Recommendation 7. **As part of the strategy, the feasibility, practicality and costs of the following options should be investigated: (i) to replace the Dobson instrument at Lerwick and (ii) to make spectral UV measurements at Reading using a Brewer instrument [Question 3].**

Recommendation 8. Data on the project website should encompass the entire Lerwick dataset. The presentation of the trend plot on the website should be made consistent [Question 4].

Recommendation 9. Defra should review whether the Low Ozone Service is a cost effective use of resource. If it is retained, the information should be disseminated more widely [Question 4].

Recommendation 10. Defra should consider whether this programme could provide a function and outputs similar to that of the Stratospheric Ozone Review Group [Question 4].

Recommendation 11. The contractor(s) should be required develop a proactive communication strategy to raise the profile of the programme. This could include events such as the National Ozone seminar, publication of briefing notes, etc. The scientific impact should be increased with more peer reviewed papers on topics other than measurement methods, QA/QC, etc. . . [Question 4]

Recommendation 12. A single organisation should have overall responsibility for the quality of the UK measurements [Question 6].

Recommendation 13. **The contract period should be extended from the present three years to provide stability and time to make the changes. Because of the potentially significant changes to the monitoring programme, we recommend that the next phase of the monitoring programme should be competitively tendered [Question 7].**

Recommendation 14. There should be an appropriate handover period if new (or inexperienced) organisations become involved in the monitoring programme [Question 7].

Contents

1 Introduction and Background

The Department for Environment, Food and Rural Affairs (Defra) and the Devolved Administrations (DA) continue to fund a long-running programme *Baseline Measurement and Analysis of UK Ozone and UV* to monitor the total column ozone and surface ultra violet (UV) radiation.

The current monitoring programme comprises:

- 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 1.1, taken from the website for the monitoring programme[1].

Figure 1.1: Location of Defra and Other Ozone and UV Monitoring Sites.

The contract is held by a project team led by AEA Technology. The project team also includes the Met Office, the University of Manchester 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.

The ozone monitoring component of the programme[2] was reviewed by Harris, Farman and Pasteur in 2002. Defra has commissioned this review of the programme to ensure that it continues to meet current and future policy and scientific requirements, as well as international obligations.

This report is structured as follows

Section:	**Contents:**
Section 2 Background	Background information on stratospheric ozone, the policy drivers, instrumentation and the Defra monitoring programme
Section 3 – Approach	Questions to be considered; approach to the review
Section 4 – The Review	Response to the questions
Section 5 - Summary	Summary of findings and recommendations
Section 6 - References	Literature cited
Section 7 - Acknowledgements	

A number of appendices have been included to provide background or relevant material for the Review.

[1] This has been updated to http://ozone-uv.defra.gov.uk/ (previously http://www.ozone-uv.co.uk/).
[2] The programme then consisted of Dobson ozone measurements at Lerwick and Camborne.

2 Background

2.1 Stratospheric Ozone and UV

Ozone forms a pronounced layer - the Ozone Layer - in the lower stratosphere at altitudes between 15 and 40 km above the ground. The protective role of the ozone layer, its depletion on a global scale by a range of halogen-containing compounds arising from human activities and the action taken to address the depletion are well known. The latest available assessment prepared by the World Meteorological Organisation [WMO, 2007] contains a Question and Answer section, which provides accessible information on these topics [WMO-QA, 2007].

The ozone layer acts as a protective shield since it absorbs the high-energy ultraviolet (UV) radiation emitted by the sun, reducing the amount reaching the earth's surface. Exposure to such UV radiation has been linked [UMIRG, 1996] to

(a) human health impacts (skin cancer, immune suppression, eye disorders);
(b) impacts on aquatic ecosystems, soils and vegetation; and,
(c) accelerated wear of natural and synthetic materials.

Ozone is continuously being created and removed in the atmosphere by photochemical processes. It is now well established that ozone concentrations are controlled by catalytic cycles involving trace constituents containing chlorine, bromine, nitrogen or hydrogen [See, for example, Wayne, 2000].

The column ozone measurements made over Antarctica by Farman *et al.* [1985] provided the first direct evidence of ozone depletion. Ozone depletion has now occurred on a global scale, with seasonal depletions also occurring in the Arctic and a small but measurable depletion globally (~4% lower than 1980 levels) [WMO-QA, 2007]. The measurements of ozone and of other species made since the discovery of the Ozone Holes over Antarctica, supported by laboratory studies and numerical model calculations of the atmosphere, have demonstrated unequivocally that the reactive fragments produced when chlorofluorocarbons (CFCs), halons and other halogenated compounds breakdown in the stratosphere were responsible for the ozone loss [WMO-QA, 2007].

There is a complex two-way interaction between ozone and climate. Ozone in the stratosphere has a direct impact on climate through its radiative properties; ozone is a greenhouse gas (as are the CFCs and many of the replacement compounds). Ozone depletion has had a net cooling effect (*i.e.*, negative radiative forcing) [IPCC-TEAP, 2005; WMO, 2007]. The temperature of the lower stratosphere will also cool as a result of climate change. This will increase the frequency of polar stratospheric cloud formation, an important element in the activation of chlorine and bromine compounds, which subsequently leads to ozone depletion [WMO-QA, 2007] and hence delay the recovery. On the other hand, lower temperatures elsewhere might lead to greater ozone production ('super-recovery') as the destruction reactions removing ozone become slower as the temperature is reduced [Shepherd, 2008; Li *et al.*, 2009].

Solar UV irradiance at the Earth's surface exhibits pronounced variations. The observed irradiance depends on the ozone column, tropospheric and boundary air pollution, aerosol loadings, altitude, albedo and clouds. All of these effects depend on solar zenith angle, which defines the path length through the atmosphere. All other factors being equal, the decline in stratospheric ozone concentrations should lead to increases in UV-B levels at high and mid-latitudes. Kerr and McElroy [1993] reported such an increase in Canada. However, the expected anti-correlation has been masked by variations or changes in cloud cover, tropospheric pollution and most especially the aerosol content of the atmosphere. These factors have complicated the assessment of trends and illustrate the need for high quality UV observations at a variety of locations [WMO, 2007].

2.2 Policy Driver

The Vienna Convention on the **Protection of the Ozone Layer** was agreed in 1985, as the international response to the concern about the fate and impact of compounds such as chlorofluorocarbons (CFCs) and related compounds, first raised by Molina and Rowland [1974]. The severe depletion of the ozone layer in Antarctica accelerated the negotiation and subsequent implementation of a protocol to the Convention, the Montreal Protocol on **Substances that Deplete the Ozone Layer**. The Montreal Protocol, which was adopted in September 1987, together with its

subsequent amendments and adjustments, has defined schedules for the reduction and ultimate phase-out of a number of ozone-depleting substances (ODS), such as chlorofluorocarbons, methyl chloroform, etc. The Montreal Protocol is seen as a "success story" to address a global environmental issue.

Under Article 6 of the Montreal Protocol, there is a requirement to assess and review the control measures on a periodic basis. The assessments cover scientific, environmental, technical and economic aspects. A number of scientific assessments on the ozone layer have been produced [WMO, 1990, 1992, 1995, 1999, 2003 and 2007]. The then Department of the Environment supported two expert review groups – the Stratospheric Ozone Review Group (SORG) and the Ultraviolet Measurements and Impacts Review Group (UMIRG), which produced a series of reports between 1987 and 1999 [SORG, 1987, 1988, 1990 1991, 1993, 1996, 1999; UMIRG, 1996].

The measures taken under the Montreal Protocol have reduced the emissions of many ODS to the atmosphere to zero. The atmospheric concentrations of many of the compounds are declining and the total halogen loading in the troposphere has now peaked [WMO, 2007]. We are now in the recovery phase where column ozone abundances should increase as the total halogen loading falls. It is accepted that the recovery will take many decades given the long residence times of many of the ODS in the atmosphere.

As well as the coupling between climate change and stratospheric ozone layer depletion, there is also a policy linkage between these topics. Replacement CFCs such as hydrofluorocarbons (HFCs), which are less harmful for the ozone layer in the sense that they deliver no chlorine or bromine to the stratosphere, are however significant greenhouse gases. Thus the Montreal Protocol on *Substances that Deplete the Ozone Layer* and the Kyoto Protocol to limit greenhouse gas emissions have common and possibly conflicting issues of interest. A scientific assessment of these issues was prepared jointly by the Intergovernmental Panel on Climate Change and the Technology and Economic Assessment Panel of the Montreal Protocol [IPCC-TEAP, 2005]. Similarly, the scientific links between UV radiation changes and biodiversity could indicate common areas of interest under the UN convention on Biological Diversity.

The Vienna Convention provides the main policy driver for the monitoring programme. Articles of the Vienna Convention oblige 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 (see Appendix 1 for the relevant Articles).

2.3 Instrumentation

2.3.1 Ground-based Measurements

There are a number of ground-based instruments that are used to measure the total ozone column. The three most widely used are:

- the Dobson ozone spectrophotometer, which was developed by Dobson in the 1920's [Dobson and Harrison, 1926; Dobson, 1931]. Measurements were made from a number of sites around the world, as described in the review paper by Brönnimann *et al.* [2003a]. In 1957, as part of the first International Geophysical Year, a global network was established with improved instrumentation. This provides the effective start date for many of the sites in the WMO World Ozone and UV Data Centre (WOUDC)[3], as many of the early measurements are of insufficient quality [Brönnimann *et al.*, 2003b].
- the Brewer spectrophotometer, developed at Environment Canada in the 1970's. It is an automated instrument, which is commercially available [Kipp and Zonen[4]] and capable of other measurements: sulphur dioxide columns, aerosol optical depth, spectral UV and depending on the model, nitrogen dioxide columns. There are a number of different models. The double-monochromator optical system used in the Mk III instrument has much improved stray light performance compared to the single-monochromator employed in the Mk II and Mk IV models[5].

3 See http://www.woudc.org/
4 See http://www.kippzonen.com/?productgroup/26142/Brewer+Spectrophotometer.aspx.
5 The operational and spare Brewer instruments used at Reading are Mark IV and Mark II models, respectively. These are no longer manufactured. The Mark III model is recommended.

- the Système d'Analyse par Observation Zenithale (SAOZ) spectrometer [Pommereau and Goutail, 1988, see also Sarkissian *et al.*, 1995]. This is also an automated instrument, developed initially for stratospheric measurements of ozone and nitrogen dioxide at high latitudes. The instrument is widely used in France and elsewhere and is accepted within the Network for the Detection of Atmospheric Composition Change (NDACC)[6].

All three instruments use the same measurement principle of differential optical absorption spectroscopy. The Brewer and Dobson instruments determine the ozone column by comparing the intensity of solar radiation that has passed through the atmosphere at wavelengths in the ultraviolet region, which are strongly and weakly absorbed by ozone. The Dobson spectrophotometer uses a quartz wedge as a variable attenuator to mimic the differential absorption of the ozone column. The Brewer instrument makes direct measurements of the intensity of light at a number of discrete wavelengths in the ultraviolet. Appendix 2 provides further information on the instruments.

The SAOZ spectrometer uses the visible region between 450 and 560 nm where there are 4 broad absorption features in the Chappuis band of the ozone absorption spectrum. SAOZ is designed to measure column totals of ozone and nitrogen dioxide twice a day at twilight (sunrise and sunset). Spectra are recorded throughout the day: at 5 minutes intervals during twilight up to 94° solar zenith angle (SZA) and every hour at SZA < 85°. The spectra are analysed by differential absorption spectroscopy relative to a reference spectrum taken at low SZA.

All three instruments require experienced operators, regular maintenance and calibration. Standard operating procedures have been prepared [WMO-GAW, 2008; EC, 2008; SAOZ, 2008] and comparison of the instrument against international reference instruments, at least for the Dobson and Brewer instruments, is a key element in demonstrating the quality and reliability of the measurements. Data processing and subsequent interpretation again require experienced users.

For completeness, filter ozonometers have also been used, especially at sites in the former Soviet Union.

2.3.2 Satellite Measurements

Remote sounding of the atmosphere from satellites yields measurements of atmospheric composition, which give regional and global views on spatial and temporal scales not available from any other observing system. Total column ozone measurements from space go back as far as the late 60's and early 70s. TOMS (Total Ozone Monitoring Spectrometer) and its predecessor, the Nimbus-4 Backscatter Ultraviolet (BUV) instrument were some of the first satellites to measure column ozone from space. From the launch of the first TOMS until late 1994, the NASA TOMS program provided daily global views of ozone along with a number of other US instruments. The current NASA instrument is the Ozone Monitoring Instrument (OMI) on the Aura satellite[7] (see Figure 2.1).

With the advent of the Global Ozone Monitoring Experiment (GOME) in 1995, the European Space Agency (ESA) entered into the measurement of global distributions of atmospheric constituents including total column ozone. GOME-2 on MetOP is the current operational instrument that makes daily ozone column measurements from space.

All these instruments and more have relied on calibration and validation from ground-based remote sensing. Figure 2.2 shows a typical plot taken from the EUMETSAT O_3 satellite applications facility. The ground-based remote sensing data is taken from the WOUDC and therefore uses in particular the Lerwick observations. The relationship between the satellite measurements and the ground-based total column ozone measurements are synergistic rather than exclusive. The calibration and validation function of the ground-based network has assured the long-term quality of the satellite measurements that provide the global and temporal view.

The satellite measurements on their own are not robust enough to be used independently of the ground-based measurements.

6 See http://www.ndacc.org/.
7 See http://aura.gsfc.nasa.gov/instruments/omi.html.

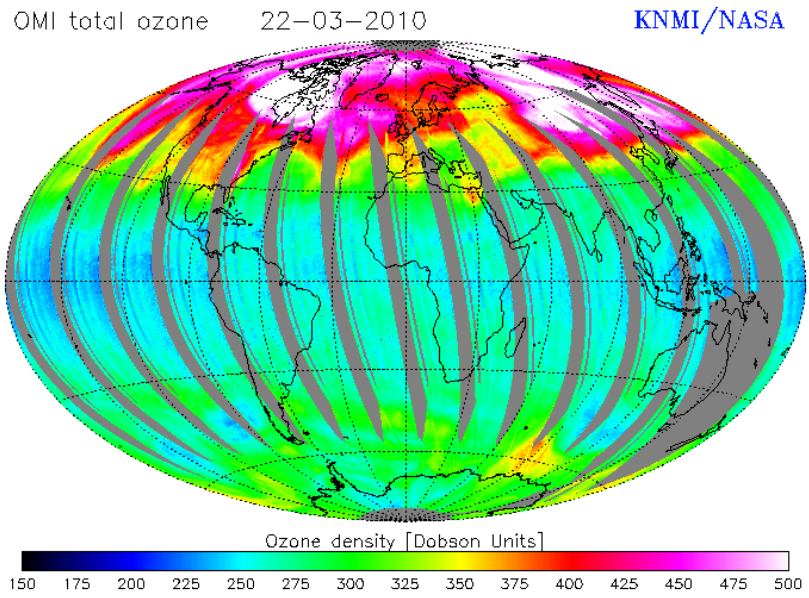

Figure 2.1: Total column ozone data (NRT) from NASA-AURA OMI for the 22nd March 2010.

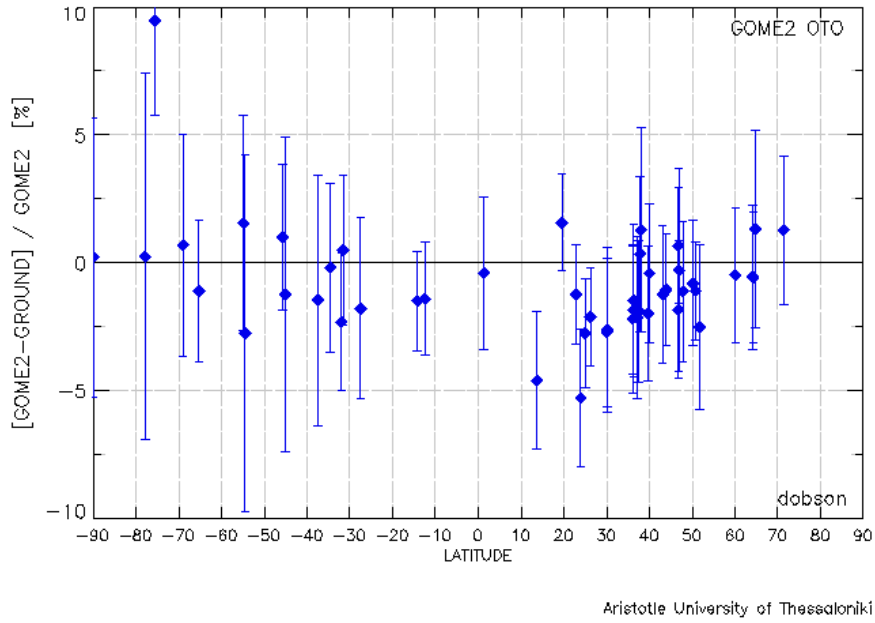

Figure 2.2: Mean differences between satellite and ground based observations for each station for GOME-2 (http://lap.physics.auth.gr/eumetsat/totalozone/). One of the data points in this plot is from the UK Lerwick measurements

2.4 The Defra Monitoring Programme

Defra has supported the monitoring of total column ozone and surface UV since the early 1990's. Prior to 2003, the total column ozone measurements were made using the manual Dobson ozone spectrophotometers at 2 sites (Lerwick and Camborne). In 2003, Defra terminated its support for the Camborne measurements and established ozone monitoring at Reading using an automated Brewer instrument (although measurements appear to date back to 2000). Spectrally-resolved UV measurements have been made at Reading since 1993.

The Dobson and Brewer ozone spectrophotometers used are loaned to the monitoring programme by the Met Office.

The rationale for the sites can be considered to be:

- Lerwick (Northern site), close to the Arctic polar vortex, for monitoring ozone depletion and recovery
- Reading (Southern site) for population exposure

The ozone monitoring contract was originally held by the Met Office. Following a competitive tendering exercise in 2000, AEA Technology and Imperial College became responsible for the processing, analysis and dissemination of the ozone measurements. The Met Office retained the ozone measurement elements under a separate contract. The issues arising from these changes, in part, prompted the previous review [Harris, Farman and Pasteur, 2002]. The UV monitoring programme has always been led by Ann Webb (the contract was initially held by the University of Reading and then by the University of Manchester following her move to Manchester). In the tendering exercise of 2003, the ozone and UV monitoring programmes were merged and a single contract was let to a project team involving AEA Technology, the Met Office, the University of Manchester and Imperial College. The contract was subsequently re-let in 2006 under single tender action. Box 1 lists the requirements of the current contract and the individual objectives.

The monitoring of ozone and UV formed part of the research programme of the Global Atmosphere Division (later renamed to Climate, Energy and Ozone Science and Analysis). In 2008, the programme was transferred to the then Air and Environmental Quality (AEQ) Division within Defra when the Department for Energy and Climate Change was formed. AEQ - now known as Atmosphere and Local Environment - is responsible for the national monitoring of air pollution.

There has been a frequent turnover in the staff responsible for the project within Defra. As a consequence, the monitoring programme has largely continued in *maintenance* mode and there has been a lack of strategic direction.

Box 1 - Requirements of the Contract

The overall aim of the proposed project is to monitor and analyse stratospheric ozone and ground-level UVB over the UK, in the context of policy measures introduced to control ozone-depleting substances and protect human and environmental health.

The objectives of the contract, adapted from those given in the specification, are:

Objective/Tasks		Achieved
Objective 1:	**Continuation of the Existing Long-term Monitoring Programmes –** The Department wishes to maintain the existing long-term, high quality data records, especially for ozone, and thus continue to honour the UK commitments under the Vienna Convention. The specific tasks are:	
	a. To measure total ozone and ground-level UVB at Lerwick (Column Ozone) and Reading (Column Ozone and UV) using the instruments currently employed at the sites.	**Yes, on-going**
	b. To process data to provide daily total ozone values and hourly UV values.	**Yes, on-going**
	c. To ensure that the ozone and UV measurements are consistent and to use the datasets to inform analysis of one other.	**Unable to assess**
	d. To conduct regular comparisons of data with other UK measurements and satellite data (intercomparisons should be at least annual for the UV measurements), and represent the UK at international intercomparisons of instruments.	**Yes, on-going**
Objective 2:	**Data analysis** - Full analysis of all data will be performed to provide quantitative information on the changing state of the ozone layer over the UK since measurements began. The specific tasks are:	
	e. To preserve and maintain the existing measurement records.	**Yes, website**
	f. To provide long term trends in ozone concentration, seasonal variations in long-term ozone trends, assessment of natural variability and explanations of observed anomalies in the ozone record.	**Yes, used for low ozone events**
	g. To provide comparison of UK results with trends in ozone observed in northern mid-latitudes.	**Yes, on-going**
	h. To provide comparison with satellite derived ozone and other information as appropriate.	**Yes, as part of QA**
Objective 3:	**Data Dissemination:** Daily mean column ozone Dobson observations will be submitted by to the World Ozone and UV Data Centre in Canada, the EDUCE and other World Meteorological Organisation (WMO) affiliated organisations. In addition, the occurrence of low ozone events has wider public interest and it is therefore important that the measurement data and possible explanations are provided in a timely fashion. The specific tasks are:	
	i. To ensure information is provided and regularly updated on a public website describing, in an easy-to-understand format, the state of the ozone layer above the UK, and to ensure low ozone episodes are reported.	**Yes**
	j. To ensure information is provided on a regular basis to the WOUDC and University of Thessaloniki, the EDUCE European UV database at the Finnish Meteorological Institute.	**Yes, monthly**
	k. To contribute to relevant international UV and stratospheric ozone research programmes.	**Yes, see text**

The original contract specification also included a further objective on the **Measurements of Atmospheric Species** as an option, but this was not taken up.

3 Approach

3.1 Questions for the Review

In discussion with members of the Atmosphere and Local Environment team in Defra, the following questions were identified for the review [see Box 2]. These aimed to cover a range of strategic, technical and organisational aspects of the monitoring programme.

Box 2 – Review Questions

1. *How does the monitoring programme help to meet the UK obligations under the Vienna Convention on the Protection of the Ozone Layer?*
2. *Are the data currently collected in the monitoring programme fit for purpose?*

   If not, what measures could be employed to make the data fit for purpose? Are there any activities in the current monitoring programme which are no longer needed?
3. *Are the current measurement techniques viable into the future (over a 5-20 year timescale), and what other techniques/instruments are available?*
4. *Are current methodologies for disseminating information sufficient?*

   If other techniques/instruments are preferable, how (or indeed could) they be introduced whilst maintaining the continuity of the results?
5. *Is the current monitoring programme cost effective?*
6. *Is the current monitoring programme structured for optimum delivery?*
7. *Should all or part of the programme be competitively tendered, or indeed should it be competitively tendered at all?*

In addition, a number of specific topics were also highlighted:

- The low profile and impact of the programme
- The role and purpose of the spectral UV measurement programme, given the broadband UV monitoring activities supported by the Department for Health

3.2 Activities Undertaken for the Review

The review was undertaken between January and March. The review team undertook a number of activities to gather the information to address the questions outlined in Box 2:

- A meeting was held with the staff in Defra responsible for this policy area and for the monitoring programme
- Meetings or telephone interviews were held with the members of the current project team
- The chief scientist at the Met Office (Prof Julia Slingo) was contacted about ozone monitoring activities in the World Meteorological Organisation (WMO)[8]
- Telephone interviews were held with leading UK experts in the field (*e.g.*, Dr Neil Harris, European Ozone Research Co-ordinating Unit, EORCU)
- Contact was made with key organizations involved in related UK monitoring activities (British Antarctic Survey [BAS] [9] and the Health Protection Agency [HPA][10])

8 The UK Met Office represents the UK within the World Meteorological Organisation.
9 BAS operates both Dobson and SAOZ spectrometers in Antarctica (see See http://www.antarctica.ac.uk/met/jds/ozone/).
10 HPA operates a broad-band UV monitoring programme on behalf of the Department of Health (see http://www.hpa.org.uk/webw/HPAweb&HPAwebStandard/HPAweb_C/1195733761671?p=1158934607746).

These and other users drawn from the policy, scientific and international communities were invited to participate in a short consultation exercise, based on a questionnaire circulated by e-mail (see Appendix 3 for the questionnaire and the recipients). As time and resources were limited, we aimed to draw upon a representative cross-section of the UK and international users. Significant replies (or any clarification of the responses) were followed up by telephone or e-mail.

We were provided with documentation on the project (contract[11], example reports) and also drew on available published reports and scientific papers.

3.3 Key points from the stakeholder consultations

15 completed questionnaires were received (Defra science and policy – 3; UK research community – 9; International – 3), representing individual or collective views. The key points from the completed questionnaires, the meetings and telephone interviews were:

- The measurements are seen as an important and valuable contribution to the Vienna Convention and to international activities
- Any reduction in the number of sites/measurements could lead to loss of influence
- There were no 'obvious' data quality issues
- The measurements are being used in the international assessment process and for the validation of satellite instruments
- The Dobson and Brewer instruments will remain the preferred instruments for total column ozone measurements for the foreseeable future.
- Satellite measurements are not sufficiently reliable and require the ground-based measurements for verification/validation
- The low profile and impact of the monitoring programme

3.4 Recommendations from the 2002 Review: Status

Harris, Farman and Pasteur made a number of recommendations as part of the 2002 review of the ozone monitoring programme. We provide a status report on the implementation of the recommendations in Appendix 3.

We observe that many of the recommendations on operational aspects of the programme have been implemented (*e.g.*, local data processing) or have been superseded by changes to the monitoring programme. As far as we can tell from contact with the UK Met Office, no progress was made on the more strategic recommendations concerning future ozone monitoring methods and the roles of Defra and the UK Met Office with respect to the WMO.

11 Subject to a Confidentiality Agreement.

4 The Review

4.1 UK Obligations under Vienna Convention

Question 1: How does the monitoring programme help to meet the UK obligations under the Vienna Convention on the Protection of the Ozone Layer?

Response:

The Vienna Convention requires signatory states to make systematic observations of the ozone layer (Article 2) and to exchange data and information (Article 3) [see Appendix 2]. The observations include *inter alia* measurements of the total ozone column and of ultraviolet radiation at the surface. The measurements made in the current Defra-funded monitoring programme (Lerwick Ozone; Reading Ozone and UV) help to fulfil the UK obligations under the Convention.

The measurements are seen as a valuable contribution to the international programme for the following reasons:

1. Lerwick Ozone
   - Close to Arctic polar vortex
   - Measurements started in 1952, predating the depletion of the ozone layer
   - Measurements made using the same instrumentation (Dobson spectrophotometers)
   - Measurements of known quality as the instruments are regularly calibrated and compared to international reference instruments
   - Measurements used in WMO assessments and for evaluation of satellite instruments
2. Reading spectral UV
   - Measurements started in 1993
   - One of the longest spectrally-resolved UV records available
   - Measurements of known quality as the instruments are regularly calibrated
3. Reading Ozone
   - Measurements started in 2002
   - Measurements of known quality as instrument regularly calibrated and compared to international reference instruments
   - Measurements are compared satellite instruments
   - Recently established as WMO-GAW station

The British Antarctic Survey makes ground-based column ozone measurements in Antarctica using both Dobson and SAOZ instruments; the measurements made at Halley were pivotal in identifying polar ozone depletion [Farman et al., 1985]. The Health Protection Agency operates a broadband UV monitoring programme at 7 sites across the UK, on behalf of the Department of Health. These and the other UK ozone and UV measurement sites (current and historic) are summarised in Table 4.1. The table provides additional information on the different sites and indicates if the measurements are available on the WOUDC website[12]. At the time of writing, the measurements from the Defra-funded programme were available up to January 2010.

The UK has played an active role and has made significant contributions to stratospheric ozone research over the years. For example, the UK hosted and co-funded the European Ozone Research Co-ordinating Unit (EORCU) at the University of Cambridge. The UK continues to contribute to the international ozone assessments (scientific and technical); Defra is supporting the participation of Profs John Pyle (University of Cambridge), Mary Norval (University of Edinburgh) and Nigel Paul (University of Lancaster) in the WMO ozone assessment that is currently in preparation. UK researchers (including members of the current project team) are involved in measurement groups of the WMO

Thus the UK would appear to fulfil its commitments under the Vienna Convention.

12 See http://www.woudc.org/

Table 4.1: Information on operational (in bold) and historic sites used for measurements of total ozone and surface UV in the UK.

Total Ozone

Operator	Site	Instrument	Period of Operation	Data in WOUDC
Met Office	**Lerwick**	**Dobson** Sonde	**1957-present** 1992-2005	**Yes (to 2010)** Yes
	Camborne	Dobson Brewer	1957-1967 and 1989-2003 1991-1993	Yes Yes
	Aldergrove Bracknell Eskdalemuir Hemsby	Dobson	1952-1957 1967-1989 1957-1963 1952-1955	Yes Yes Yes Yes
University of Manchester	**Reading**	**Brewer**	**2002-present**	**Yes (to 2010)**
	Manchester (note 1)	**Brewer**	**2000-present**	**Yes (to 2010)**
	Aberystwyth	**SAOZ**	**1991-present**	**No (note 2)**
British Antarctic Survey	**Halley (Antarctica)**	**Dobson**	**1957-present**	**Yes (to 2007, note 3)**
	Rothera (Antarctica)	**SAOZ**	**1996-present**	**No**
	Faraday/Vernadsky (note 3)	**Dobson** SAOZ	**1957-present** 1990-1995	**Yes (to 2007, note 3)**
University of Oxford	Oxford	Dobson	1924-1975 (not continuous)	Yes
University of Cambridge	Cambridge	SAOZ	-	-

Surface UV

Operator	Site	Instrument	Period of Operation	Data in WOUDC
University of Manchester	**Reading**	**Bentham (spectral, 0.5 nm)**	**1993-present**	**Yes**
Health Protection Agency	**Chilton**	**Broadband** **Jobin-Yvon (spectral, 1 nm)**	**1988-present** **1988-present**	**No** **No**
	Glasgow, Leeds	**Broadband**	**1988-present**	**No**
HPA/Met Office	**Lerwick, Camborne, Kinross**	**Broadband**	**1993-present**	**No**
University of Oxford	**Oxford**	**Broadband**	**1993-present**	**No**
British Antarctic Survey	**Rothera (Antarctica**	**Bentham (spectral)**	**1997-present**	**-**

Notes (1) This Brewer spectrophotometer is supported by the NERC National Centre for Atmospheric Science's Facility for Ground-based Atmospheric Measurement (FGAM), see http://www.cas.manchester.ac.uk/restools/instruments/radiation/brewer/index.html; (2) This site is in the Network for the Detection of Atmospheric Composition Change (NDACC), see http://www.ndsc.ncep.noaa.gov/sites/stat_reps/abery/; (3) This site is now operated by the National Antarctic Scientific Centre of Ukraine, (4) British Antarctic Survey submit datasets on an irregular basis to the WOUDC, once the dataset has been finalised and taking account of instrument intercomparisons.

Table 4.2: Comparison of UK and International Ozone monitoring activities as represented by information in the WOUDC.

Country	Number of Sites Operational (Closed)	Sites (Instrument)	Comment
UK	6 (8)	Lerwick (D) Reading (B, UV-s) Manchester (B) Halley (D) Rothera (SAOZ, UV-s) Faraday/Vernadsky (D)	Operated by UK Met Office Operated by University of Manchester (note 2) Operated by BAS Supported by BAS
Germany	2 (7)	Hohenpeissenberg (D, B) Lindenberg (B)	Hosts the Regional Dobson Calibration Centre
France	-	-	Uses the SAOZ instrument (Note 1)
Belgium	1	Uccle (B)	Previously used a Dobson
The Netherlands	1	De Bilt (B)	Used for comparison purposes in the Defra programme
Ireland	1	Valentia (B)	Used for comparison purposes in the Defra programme
Switzerland	2	Arosa (D,B) Payerne (Sonde)	
Spain	5	El Arenosillo (D, B) La Coruña (B) Madrid (B) Murcia (B) Zaragoza (B)	Hosts a calibration centre for Brewer spectrophotometers at El Arenosillo
Norway	3 (4)	Oslo (B) Ny Alesund (B) Andoya (B)	Used for comparison purposes in the Defra programme
Iceland	1	Reykjavik (B)	
Canada	12		

Notes: (1) Information and data from the French sites can be found at http://saoz.obs.uvsq.fr/index.html; (2) Also operate the SAOZ spectrometer at Aberystwyth.

Unlike the European Directives for Air Quality, there is no 'mandatory' requirement to monitor and also no requirement *per se* on the number of sites. Point 2 under Article 2 of the Convention (see Appendix 1) uses the phrase "*To this end the Parties shall, in accordance with the means at their disposal and their capabilities"*. The obligation is similar to those under the United Nations Convention on Long Range Transport of Air Pollution.

The question then becomes whether the UK contribution is proportionate. In Table 4.2, we compare the UK activities with those in Canada and other European countries. Germany has several sites and hosts the Regional Dobson Calibration centre at Hohenpeissenberg. There is one site in Holland, Belgium and Ireland. According to the WOUDC, there is no active site in France. However, the SAOZ technique, which was developed in France, is used and the measurements are available at http://saoz.obs.uvsq.fr/index.html.

This again suggests that the current Defra contribution is proportionate and, with the BAS activities, comparable to other countries. Comment was made in several of the completed questionnaires that any reductions in the programme (real or apparent) would be seen as a lack of commitment by the UK and could affect support for future UK-led initiatives, not only within the scientific activities but also within the Montreal Protocol process itself.

Summary

The Defra-funded monitoring programme helps the UK fulfil its obligations under the Vienna Convention. The information in Table 4.2 and the general view of the community suggest that the number of sites and measurement programme are appropriate. The UK has played an active role in stratospheric science and in the international assessment and policy arenas. Any reduction of the programme would be seen as a lack of commitment by the UK.

Recommendations

Recommendation 1. As a minimum, the monitoring programme should be maintained at its current level of 2 ozone sites and one UV site.

4.2 Is current monitoring programme fit for purpose?

Question 2: Are the data currently collected in the monitoring programme fit for purpose?

If not, what measures could be employed to make the data fit for purpose? Are there any activities in the current monitoring programme which are no longer needed?

Response:

We consider the response to this question under three headings:

- Do the measurements meet the agreed data quality objectives?
- Do the data meet the scientific needs?
- Do the data meet policy needs?

Ozone

1. Data Quality Objectives

   The World Meteorological Organisation has produced guidance and standard operating procedures for the operation of both the Dobson and Brewer spectrophotometers [EC, 2008; WMO-GAW, 2008]. These procedures require regular checks and calibration of the instrument at the monitoring site. Coupled with this, on a longer cycle, the instrument is taken out of service and taken to a calibration centre for comparison against an international reference instrument. These are seen as crucial activities to establish the quality and hence reliability of the measurements. The project team undertake regular instrument calibrations and Defra has supported the participation of the team in the international activities.

A number of recommendations in the 2002 Review sought to improve the Defra-funded programme by adopting best practice in ozone monitoring. Thus, the observers at Lerwick now undertake the initial processing of the Dobson ozone measurements. This should allow 'suspect' measurements to be identified and removed.

The importance of these calibration and intercomparison activities is clearly illustrated in the performance of the Brewer spectrophotometer at Reading after its initial installation. The instrument had not been calibrated and there were defective parts. After the defective parts had been replaced and the instrument had been calibrated, its reliability was much improved. This no doubt contributed to the measurements being flagged as 'outliers' in the assessment of the ground-based measurements using satellite data by Fioletov *et al.* [2008], as discussed in point 2 below.

Depending on the outcome of the instrument comparison, datasets may need to be reprocessed. Although most of the Dobson datasets have been processed where required, there are still several measurements periods that need to be reprocessed. Reprocessing of these datasets was a recommendation in the 2002 Review and this is still outstanding [See Appendix 3].

In the annual project prepared in 2009 [AEAT, 2009], the intercomparison of one of the Dobson spectrophotometers used at Lerwick (spectrophotometer #41) revealed contamination of the quartz wedge. Subsequent measurements at Lerwick revealed differences of up to 10% on the different wavelength pairs, with the largest discrepancy on the CD wavelength pairs. The acceptance criteria in the international comparisons are for the measurements made to be within ±1% of the reference instrument. We have investigated this further with the project team and also Ulf Köhler at the Regional Dobson calibration centre to see if this could have been identified earlier (or avoided). Although the team at AEA Technology had noted an increasing frequency of low O_3 measurements, this was masked to some extent over the summer period by the availability of other measurements. AEA Technology took the lead to reprocess the Lerwick data affected [AEAT, 2009]. As a consequence, the monthly QA/QC review has been made more stringent and data from other European stations (De Bilt, Oslo) are now used for comparison purposes. We note the actions taken but we are concerned that this was not noticed sooner.

Several of the responses referred to the international activities to harmonise the ground-based and satellite measurement systems[13]. As part of this, there is likely to be a recommendation to adopt new absorption cross sections for ozone and this will affect both the Dobson and Brewer measurements (current and historic). The WMO is currently discussing how and when these new parameters will be introduced into the measurement programme. A major consequence of this will be the need to reprocess all the ozone data using the new coefficients.

2. Meeting Scientific User Requirements

The value of the ozone datasets increases with its length. Thus, the Lerwick dataset will have been more often used. We see an application of the measurements in the international scientific assessments [e.g., WMO, 1988; 2006] and an increasing use in the evaluation of satellite measurements. For example, the Lerwick data were used in the validation of the total ozone retrieval algorithm for TOMS (McPeters and Labow, 1996) and GOME (Weber *et al*., 2005) and are being used for the validation of the Ozone Mapping Instrument (OMI). In his response, Johannes Stähelin (ETH Zürich) included the following remarks from Gordon Labow (NASA):

> *"The Lerwick data look fine (and we routinely use these data for OMI comparisons). The data have a drift that occurs in early 2005 and it appears to have been corrected in late 2005 and the rest of the dataset (2006-present) looks good". Thus, the data are used and of high quality and therefore no demand to improve the running measurements.*

[13] See for example page 7 of the WMO IGACO-Ozone and UV Radiation Implementation Plan, available as WMO-GAW Report 182 from: http://www.wmo.ch/pages/prog/arep/gaw/documents/TD_No1465_GAW182_web.pdf.

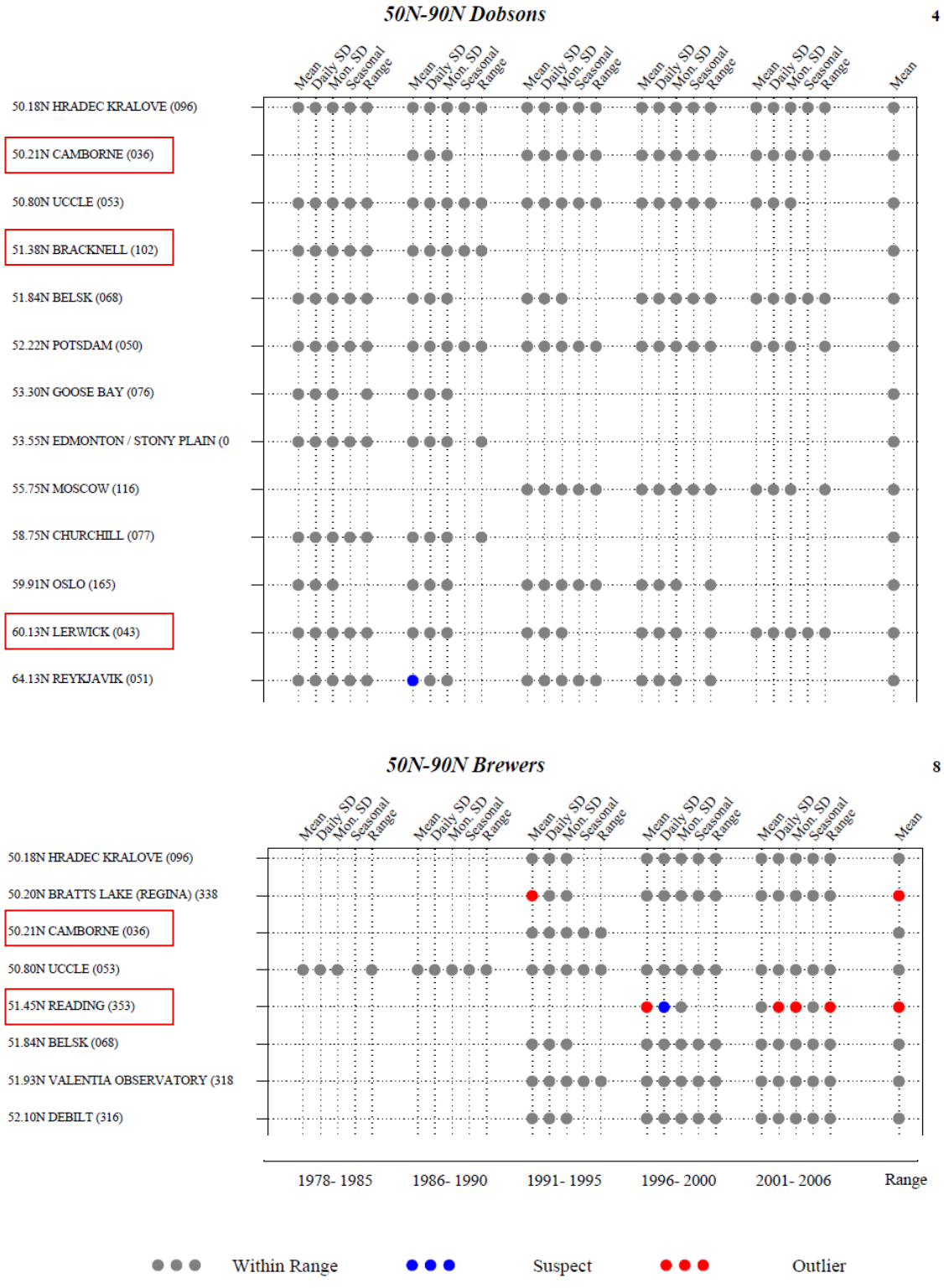

Figure 4.1: Evaluation of ground-based column ozone stations from a comparison with a gridded merged dataset of satellite measurements. The figure is taken from the supplementary material provided with the paper of Fioletov *et al.* [2008]. The supplementary material is available on the WOUDC website at: ftp://ftp.tor.ec.gc.ca/Projects-Campaigns/Ground-Sat_Plots/

Fioletov *et al*. (2008) reprocessed the measurements made from a series of various satellite-based instruments using a common retrieval algorithm to create a single gridded global dataset for the period 1973-2007[14]. This satellite dataset was then used to assess the ground-based measurements, which were described as 'within range', 'suspect' or 'outlier' for a number of statistical parameters. Figure 4.1, extracted from the supporting material to the paper, shows the results for the UK ozone measurements (current and historic). Apart from the Reading Brewer measurements (which are probably influenced by the poor quality of the early measurements), the comparison shows that the UK measurements compare agree well with the satellite measurements.

Thus, the measurements are being used and there are no obvious data quality concerns. In his response, Johannes Stähelin included the following remarks from Vitali Fioletov (Environment Canada), who has been analysing the column ozone measurements for the assessment report that is in preparation:

Dobson Measurements

- Camborne and Lerwick: *Data are fine*.

Brewer Measurements

- Camborne: *Good data, but a very short record (1991-1993).* Note the Met Office has put all its ozone data on the WOUDC and this is effectively an evaluation of the Brewer instrument.
- Reading: *Good data after the calibration in late 2005. Not so good between 2000-2002*
- Manchester: *Data are fine*.

3. Meeting Policy User Requirements

As indicated in Section 2.2, the main policy actions have largely been taken. The Montreal Protocol and the subsequent amendments and adjustments to the Protocol have led to the phase out of various Ozone depleting-substances (ODS). These measures have reduced the emissions to zero and the atmospheric concentrations of many of the compounds are declining.

Even when the Montreal Protocol was being actively negotiated, it is unlikely that the UK-based measurements alone had a direct effect on policy development. Their main contribution to policy development was indirect, *i.e.*, through their use in international assessments such as the WMO ozone assessments (see point 2 above).

Within the UK, the measurements are also used in various publications as part of the sustainability agenda. For example:

- The environment in your pocket[15]
- e-Digest Statistics about: Ozone Depletion[16]
- The State of the Environment report for Scotland[17]

UV

1. Data Quality Objectives

UV radiation at the Earth's surface is a function of wavelength, solar zenith angle, ozone (and some other trace gases, NO_2, SO_2), cloud, aerosol, albedo, altitude and Earth-Sun distance. Monitoring of UV radiation has been a challenging task because of the great difficulties in conducting accurate measurements and proper quality control, and because UV is highly

14 There appears to be some circularity here as the ground-based measurements are used to validate the satellite data.
15 See http://www.defra.gov.uk/evidence/statistics/environment/eiyp/pdf/eiyp2009.pdf
16 See http://www.defra.gov.uk/evidence/statistics/environment/ozone/ozkf04.htm
17 See http://www.sepa.org.uk/science_and_research/data_and_reports/state_of_the_environment.aspx

variable both in time and space as a result of changes in any or several of the influencing atmospheric variables. There has been a significant effort over the past 20 years to develop a measurement infrastructure across Europe and thus to derive a consistent European UV climatology. Ann Webb and her team at the University of Manchester have played a leading role in many of the activities and she is currently chair of the WMO UV Science Advisory Group[18]. Ed Hare (WOUDC) noted that the Reading UV measurements are the only stable UV spectrally-resolved data from this part of Europe.

2. Meeting Scientific User Needs

The main policy application of the spectrally-resolved UV measurements is through their application in international assessments. We see evidence that the Reading measurements are being used (or at least reference is made) in the international assessments (see Chapter 7 of the 2006 WMO assessment [WMO, 2007]).

The low scientific impact was made in several of the responses. Ann Webb provided a list of publications based from the University of Manchester team (see Appendix 5). We note that many of the publications are concerned with measurement methods, intercomparisons, etc rather than the advancement of scientific understanding. We acknowledge that this has, in part, reflected the need for high quality surface UV measurements.

The Defra measurements have been used over the years for evaluation of the UK UV forecasting model, operated by the Met Office (see point 3 below).

3. Meeting Policy User Needs

Exposure to elevated UV radiation has been linked [UMIRG, 1996] to

(a) human health impacts;

(b) impacts on aquatic ecosystems, soils and vegetation; and,

(c) accelerated wear of natural and synthetic materials.

The Department of Health has the policy lead for the impact on human health, at least for the exposure to solar radiation. Through the Health Protection Agency, DoH supports a monitoring programme of broadband measurements at 7 locations across the UK[19] (see also Table 4.1). Information on the UV index is provided. The DoH also supports a forecasting service operated by the Met Office[20]. We note that neither the HPA nor Met Office websites have a link to the Defra website.

As noted in the response to Question 1, Defra's interests, at least within ALE, largely consist of supporting the participation of UK experts in the international assessment process.

Summary

The UK programme follows the guidance and standard operating procedures. The quality and reliability of the measurements are established through participation in the international instrument comparisons. There are no obvious data quality issues with the current measurements.

There is clear evidence that the measurements are being used in the international ozone assessment and for the validation of satellite measurements. The value of the datasets increases with its length. From that perspective, we would rank the measurements in the current programme in the order: (1) Lerwick ozone; (2) Reading UV and (3) Reading Brewer.

We note the current drive to harmonise the measurements from satellite and ground-based instruments. There is likely to be a requirement to reprocess all the data (both current and historic) following the adoption of new ozone absorption cross-sections.

18 See http://uv.colorado.edu/ssc.html.
19 See http://www.hpa.org.uk/webw/HPAweb&HPAwebStandard/HPAweb_C/1195733761671?p=1158934607746.
20 See http://www.metoffice.gov.uk/weather/uk/uk_forecast_uv.html

Recommendations

Recommendation 2. Defra continues to support (a) the participation of the UK monitoring teams in international instrument comparisons as this establishes the quality and reliability of the measurements, and (b) any reprocessing of data arising from intercomparison.

Recommendation 3. With the adoption of new ozone absorption cross sections, Defra makes provision for the reprocessing of the UK ozone datasets and the submission of the revised data to the international data centres.

4.3 Sustainability

Question 3: Are the current measurement techniques viable into the future (over a 5-20 year timescale), and what other techniques/instruments are available?

If other techniques/instruments are preferable, how (or indeed could) they be introduced whilst maintaining the continuity of the results?

Response:

In this section, we look to the future and again consider the ozone and UV monitoring components separately. The 2002 Review only considered the ozone monitoring element.

Ozone

Concerns were identified in the 2002 review about the viability of the Defra Dobson ozone measurement programme (instrument no longer manufactured and the expertise at the Met Office largely resided with the Ozone Technical Manager). Despite this, the Dobson spectrophotometer was nonetheless regarded as the preferred instrument over the short to medium term. Since 2002, there have been a number of changes, which have helped to secure the future of both the overall Defra-funded programme and of the Dobson measurements, in the short to medium-term at least:

- The Dobson ozone programme at Camborne was terminated and replaced by the Reading Brewer measurements
- The Regional Dobson Calibration Centre at Hohenpeissenberg (Germany) has facilities to manufacture parts for the Dobson spectrophotometers
- The initial data processing is now undertaken by Met Office staff at Lerwick

The Brewer instruments now seem to be much more accepted and appear to have a number of benefits compared to the Dobson instruments (automated, better data coverage as less affected by the weather, capability to make other measurements: vertical ozone profiles, NO_2 columns, SO_2 columns, aerosol optical depth and spectral UV). Indeed, the report of the 7th meeting of Ozone Research Managers (ORM, 2008) contains the following statement (3rd bullet point on page 29 of the report):

> *Brewers are the preferred instrument for all expansion efforts around the globe where a new Ozone and UV monitoring programme is to be established. Unused Dobson instruments are a more economical way to expand these networks and to introduce observations into new sites or programmes.*

The current global networks currently comprise 69 Dobson and 60 Brewer instruments. This is based on the number of stations reported as having updated the WOUDC since 1st January 2007. The evaluation of the ground-based stations by Fiotetov *et al.* (2008) suggests that there were 75 Dobson and 68 Brewer instruments operational between 2001 and 2006.

In the 1990s, the Met Office explored the option to replace the Dobson instruments at the Lerwick and Camborne sites with Brewer instruments (Mark II and Mark IV instruments). According to David Moore (Met Office), significant effort was needed to make the Brewer instrument operational. Other countries have replaced Dobson instruments with Brewer instruments (e.g., at Uccle in Belgium, De Bilt in the Netherlands and Oslo) or operate both Dobson and Brewer instruments (e.g., Arosa in Switzerland and Hohenpeissenberg in Germany). Current guidance suggests that at least 3 years

side-by-side operation is required to determine seasonal dependences of the transfer function [WMO-GAW, 2003][21]. If a Brewer instrument were to be operated at Lerwick, a double monochromator instrument (Brewer Mark III) would be required. Even then, experience in Germany and Switzerland cautions whether a continuous dataset could be derived.

As noted in Section 2.3.1, the SAOZ instruments are used in France, in the UK (Aberystwyth) and within the Network for the Detection of Atmospheric Composition Change (NDACC). The British Antarctic Survey operates a SAOZ instrument at Rothera in Antarctica. According to Johannes Stähelin (ETH Zürich), the SAOZ instruments provide high quality measurements, especially when using the algorithm recently developed within the NDACC.

There have been a number of satellite-based measurements of the total ozone column (see Section 2.3.2). However, these satellite measurements are not sufficiently reliable to meet the precision and accuracy requirements to identify decadal changes at the percent level. There is still a need for ground-based measurements for validation or verification of the satellite measurements.

One of the recommendations of the 2002 Review was that Defra and the UK Met Office ask the WMO to conduct an international expert study of the options that exist to ensure high quality monitoring of ozone over the next 25 years [see Appendix 3]. From information received from the Met Office International Team, no activities have been undertaken within WMO to evaluate potential alternative ground-based measurement systems. It is unlikely, therefore, that a new instrument could be developed, operated in a network context and with sufficient overlap to ensure continuity of existing records, within the next 10 years. The Dobson and Brewer spectrophotometers are still and will likely remain the preferred instruments for total column ozone measurements.

Spectral UV

There is a continuing scientific requirement for spectral UV measurements (and an implied policy requirement through their use in international assessments). The WMO Commission on Atmospheric Sciences stated in its fifteenth report [WMO-CAS, 2009] in the section on *Ozone Depletion, Ultraviolet Radiation and the Vienna Convention*:

> *5.3.2.12 The impact of total ozone on UV irradiance has been studied quite extensively in the past. While there has been progress in recent years, the influence of other factors determining UV irradiance such as clouds, aerosols and albedo, are less well understood. The importance of such studies is highlighted by the fact that these other factors will very likely be affected by climate change. These changes may have a higher impact on UV than changes in ozone. Noting the current interest in vitamin D and UV and also the importance of UV in atmospheric chemistry, the Commission recognized that it is imperative to monitor and study UV in its own right and not only as connected to ozone depletion. Further analysis might include statistical investigations on UV irradiance changes, with time and location dependency. CAS recommended that new process studies on the impact of clouds, aerosols and albedo be undertaken. In addition one should also analyse existing data series to study the UV variability due to changes in clouds, aerosols and albedo.*

The UV measurements in the Defra programme are made with a double monochromator scanning spectroradiometer. Broadband radiometers (as used by the HPA) and multi-filter radiometers are also available, but they do not provide the spectral detail, nor have the accuracy, of the double monochromator systems.

A number of CCD/diode array spectrometers have become available at low cost in recent years. These have the advantage that they can measure the whole spectrum at the same time. Their disadvantages are that the diode arrays are far less sensitive than the photomultiplier tubes used in the scanning instruments; only a single monochromator is used, leading to straylight problems when measuring the solar spectrum, particularly in the UV-B region where the signal is weakest; the dark current has to be very carefully characterised. While there are clear advantages to these instruments for some applications, they fail to accurately represent the solar spectrum in the UV-B, the region of most interest for ozone research, many UV effects and atmospheric chemistry. For reliable, high

21 The temperature dependence of the ozone absorption cross sections for the different wavelengths used by the Dobson and Brewer instruments gives rise to small but significant seasonal differences.

quality data, particularly at the critical short wavelengths, the scanning spectroradiometer will remain the instrument of choice for the foreseeable future.

We note that the Brewer instrument is capable *inter alia* of making spectrally-resolved UV measurements. The Canadian network of 12 stations, for example, is making measurements of column ozone and spectral UV from the same Brewer instrument. The UV range is limited (286.5-325/400 nm depending on the Brewer model) compared to the Reading measurements (290-500 nm). There could be some savings in terms of purchases, calibration and data processing if the Brewer instrument could be used. However, we would need to establish that the continuity of the Reading data record would be maintained.

One of the supplementary issues for this Review was the respective roles of the Defra and DoH/HPA UV monitoring programmes. The HPA has made spectrally-resolved measurements at its Chilton site since 1988 and these are used to reference its broadband measurements. Although attempts have been made to establish formal links between the Defra and HPA/DoH programmes through options in recent Invitations to Tender, these have not been taken up. Any interactions that have occurred have been informal and of a technical nature.

The Chilton and Reading sites are ~25-30 miles apart. John O'Hagan (HPA), who is responsible for the UV programme, characterised Reading as *an urban site under the Heathrow flight path* while Chilton was *a rural site*, suggesting that these sites, despite their proximity, would have different characteristics. Although there was some comparison of the datasets in the early 1990's, there have been no published comparisons of the longer datasets now available, to our knowledge.

Over the next 5 years, the HPA is looking to introduce spectrally-resolved UV measurements into its programme. Clearly, there is scope for a greater degree of interaction and co-operation between these centrally-funded UV monitoring activities. A necessary first step is to confirm the QA/QC processes used at both sites and to undertake a comparison of the Chilton and Reading datasets.

<u>Future Programme</u>

The current programme is working well and could be continued in its present form, in the short-term at least. Looking to the future, we note the following:

- A continuing obligation to make measurements of column ozone and surface UV
- Pressure on budgets and the need for efficiency gains
- The Defra-funded programme currently uses three different instrument types, each with its own operating regime, calibration requirements and data processing activities.
- The consensus view that the Brewer and Dobson spectrophotometers will remain the instruments used to make column ozone measurements, certainly over the next 5-10 years and perhaps longer (although other instruments such as the SAOZ instrument are now becoming established and accepted).
- A reduction in UK expertise of Dobson instruments as key personnel will be retiring over the next 5 years
- An implied shift from Dobson to Brewer instruments
- Potential opportunities to rationalise the UK UV measurements

Taking account of the above and our first recommendation (see Section 4.1), we present possible options for a future Defra-funded programme:

- Ozone:
  - Option 1a – Business as usual
  - Option 1b – Replace the Dobson spectrophotometer at Lerwick with an automated instrument (such as a Brewer or SAOZ spectrophotometer). While the Brewer option has some attraction, we need further information to demonstrate the overall benefit of a change. The SAOZ spectrometer is also a possible candidate.
  - Option 1c – Replace the Lerwick ozone measurements with those made at Manchester (also operated by the University of Manchester). This option builds on one respondent's view that the Lerwick ozone programme could be terminated on cost grounds (and availability of other sites at this latitude) but maintains the number of sites.

- UV
  - Option 2a – Business as usual
  - Option 2b – Use the current (or a new) Brewer instrument at Reading to make spectral UV measurements
  - Option 2c – Co-operation with HPA

We identify some of the advantages and disadvantages of these options in Table 4.3.

Table 4.3 Options for a future Defra-funded monitoring programme.

1) Options for Ozone	Benefits	Disadvantages/Risks
a) Business as Usual • Lerwick: Dobson • Reading: Brewer	• Ensure continuity of existing records	• While the Dobson instrument is viable, there will be an inevitable reduction in UK technical expertise as key personnel will retire over the next 5 years. • 2 different instruments used.
b) Install a Brewer, SAOZ (or other) instrument at Lerwick • Lerwick: Brewer (other) • Reading: Brewer	• Introduction of automated instrument, capable of other measurements • Overcome issues with loss of expertise of Dobson instruments • Efficiency gains from use of one instrument type (for Brewer)	• Double monochromator Brewer needed (Note: these are the only type now manufacturered) • Need for at least 3 years side-by-side operation (at least for a Brewer instrument) • No guarantee that a single continuous dataset can be realised
c) Replace Lerwick programme • Reading: Brewer • Manchester: Brewer	• Maintains 2 UK ozone sites • Introduction of automated instrument, capable of other measurements • Overcomes issues with loss of expertise of Dobson instruments • Efficiency gains from use of one instrument type	• Loss of important Lerwick dataset • International reaction (see text) • Increased reliance on University of Manchester • Reduced or no role for Met Office (which owns the Brewer instruments used at Reading)
2) Options for UV	**Advantages**	**Disadvantages/Risks**
a) Business as Usual • Reading: Bentham, spectral UV	• Ensure continuity of existing records	
b) Use Brewer at Reading • Reading: Brewer, spectral UV	• Potential cost savings • Alignment of technology	• Potential loss of data continuity • Need for a period of side-by-side operation
c) Co-operation with HPA programme	• Cost saving • Multiple use of outputs • May ensure long-term continuity of UV measurements	• Transparency of HPA QA/QC and data processing • Loss of control • Data reporting to WOUDC

Option 1c would need to be carefully managed. The reviewer of this report noted that

> *Option 1c would in my view be a major risk with respect to the international community and would need very thorough consultation if it was to be proposed.*

The programme has suffered from a lack of strategic direction and cannot be changed overnight. Any changes need to be carefully planned and managed. The separation of the ozone contract in 2000 caused concern both within the UK and internationally and, in part, prompted the 2002 review. The closure of the Camborne Dobson ozone measurement programme in 2003 resulted in questions being raised in parliament[22].

22 See http://www.publications.parliament.uk/pa/cm200405/cmhansrd/vo050118/text/50118w07.htm.

To overcome this, a monitoring strategy needs to be developed and updated periodically to move from the current to a different future programme. The strategy needs to cover sites, instrument selection, side-by-side operation, data continuity and a proactive approach to consulting/informing the UK and international community.

Summary

No activities have been undertaken within WMO to evaluate potential alternative ground-based measurement systems. It is unlikely therefore that a new instrument could be developed, operated in a network context and with sufficient overlap to ensure continuity of existing records, within the next 10 years. The Brewer and Dobson spectrophotometer will remain the instruments used to make column ozone measurements, certainly over this period and perhaps longer.

We identified a number of options for the future shape of this programme and indicated some of the benefits, disadvantages and risks associated with each option. In addition to the business-as-usual option, alternative options include:

- Introduction of a Brewer at Lerwick
- Replacement of the Lerwick Dobson with the Manchester Brewer measurements
- Use the Reading Brewer instrument to make spectral UV measurements
- Integration with the HPA programme

Any changes need to be carefully planned, managed and communicated. To that end, there is a clear need for a strategy to be developed and owned by Defra and the project team.

Recommendations

Recommendation 4. Defra should engage the Department of Health and Health Protection Agency to identify opportunities to align their respective monitoring activities. A joint study should be undertaken to compare the spectrally-resolved UV measurements made at Reading and Chilton.

Recommendation 5. Defra and the contractor(s) should look for opportunities to share experience and expertise with the British Antarctic Survey, not only in terms of the Dobson measurements but also in terms of profile raising and the experience of BAS with other ozone measurement methods.

Recommendation 6. The contractor(s) for the monitoring programme should develop a monitoring strategy to address the future requirements of the programme in terms of aims, sites, instrumentation, implementation, communication, etc. The strategy should be periodically updated and tested externally.

Recommendation 7. As part of the strategy, the feasibility, practicality and costs of the following options should be investigated: (i) to replace the Dobson instrument at Lerwick and (ii) to make spectral UV measurements at Reading using a Brewer instrument.

4.4 Data Dissemination

Question 4: Are current methodologies for disseminating information sufficient?

Response:

The measurements made in the monitoring programme are currently disseminated

- to the WOUDC on a monthly basis, which is part of the UK obligations under Article 3 of the Vienna Convention
- to a publically-accessible project website on a daily basis
- to the WMO Ozone Mapping Centre, which is operated and hosted by the Aristotle University of Thessaloniki, Greece[23], on a daily basis (working week)

23 See http://lap.physics.auth.gr/ozonemaps2/index.php. The site provides maps of ozone over the Northern Hemisphere.

- to the project team, Defra, Valentia Observatory in Ireland and the Health Protection Agency on a weekly basis with a summary of the best daily average O_3 measurements for the previous week

Project Website

Although a recommendation from the 2002 Review [see Appendix 3], the project website has never been officially launched. Despite this, usage has gradually increased. In 2009, there were 2,000 hits from 400 distinct users. Users include researchers from the science community, the media, consultancies, *etc* …. This does not include school users. As part of a UK Government e-initiative, the Defra website (and those operated on its behalf externally) will be reorganised to a consistent format. The project website has been amended and the address changed[24].

When the programme was managed by Defra's Climate, Science, Ozone Science and Analysis team, it was understandable that the website for the monitoring programme should be separate and distinct to the Air Quality Archive. However, now that the programme has been transferred to the same division responsible for the UK's national air quality monitoring programme, there is a strong case to incorporate the column ozone and UV measurements into the Air Quality Archive. This would provide an opportunity to promote the programme and to link it directly to air pollution measurements (such as those of particulate matter), which can affect surface UV measurements. We also note that Defra has recently initiated a review of the Air Quality website.

Several of the respondents made specific comments about the project website:

- to make the entire Lerwick dataset available (currently from 1979-present)
- to use a common format for the time series
- the HPA noted that the map of the UK ozone and UV monitoring sites did not differentiate the sites operated by Defra, the HPA and other organisations.

Low Ozone Alert Service

There is an alert service provided to Defra related to low ozone events. A low ozone event occurs when the daily average value is more than two standard deviations from the long-term monthly mean value at that site (the monthly mean is updated). The service involves an initial e-mail message to Defra and the project team to advise of a low ozone event, which is followed up within 1-2 days by a second message providing information on the event (origin, spatial extent, duration). Table 4.4 gives a breakdown of the frequency of these events.

Table 4.4: Occurrence of low ozone events over the UK between 2000 and 2009.

Year	Number	Year	Number
2000	1 (September)	2005	3 (March, May, October)
2001	1 (May)	2006	5 (January, March, June, October, November)
2002	2 (June, September)	2007	3 (April, October, November)
2003	0	2008	2 (February, November)
2004	3 (July, September, October)	2009	3 (July, August and October)

A 1% decrease in the ozone column corresponds to a 1.2% increase in the erythemally-weighted surface UV radiation[25]. Further, events in the winter months are generally of less significance as surface UV levels are lower at this time (shorter days and lower sun angles). There does not appear to have been any attempt in the documents provided to link the column ozone and UV measurements to see if these events resulted in higher UV exposure (Other factors such as cloud cover and aerosol/particulate matter loading may however confound the analysis).

The Department of Health supports (i) the HPA to operate a network of surface UV measurements and (ii) the Met Office to operate a UV forecasting service. We note that the alert service is neither

24 The new address is http://ozone-uv.defra.gov.uk/, although the old address still works and links to the new site.
25 See http://woudc.ec.gc.ca/e/ozone/uv_index_definition.htm.

sent to the HPA nor the Met Office. Although information on these events can also be found on the project website[26], it is not clear how widely known this is, given that the website was not formally launched (see Appendix 3). As noted earlier, neither the Met Office nor HPA websites have a link to Defra's column ozone and UV website. It is worth considering the purpose and effectiveness of this service and whether it represents best use of the resources.

Profile and Impact

Many of those who completed the questionnaire made comment on the low profile and impact of the programme. A number of scientific publications have been prepared using the measurements made in the monitoring programme, mostly from the University of Manchester team (see Appendix 5). These papers are not available from the project website and also not well known to the wider UK community.

As part of the current contract, a National Ozone seminar was held in 2007 at the University of Manchester[27]. The theme was "Understanding Ozone-Climate Links" and the seminar was attended by about 30 participants from the UK research community. Although this is good example of raising the profile of the programme, it seems to have been a one-off event with no obvious follow-up activity.

As noted in Section 2.2, the then Department of the Environment supported two expert groups – the Stratospheric Ozone Review Group (SORG) and the Ultraviolet Measurements and Impacts Review Group (UMIRG). These groups produced a series of highly-regarded reports between 1987 and 1999 [see the Reference section (Section 6) for a list of the reports]. There has been no such forum since then. The reconstitution of a group such as SORG through this programme, with the production of an updated report, would certainly help to raise the profile of the monitoring programme and establish links to the UK research community.

As indicated in the response to Question 2, the measurements are also used as part of the sustainability agenda in:

- The environment in your pocket[28]
- e-Digest Statistics about: Ozone Depletion[29]
- The State of the Environment report for Scotland[30]

Summary

The main dissemination routes are to the WOUDC (which fulfils the UK obligations under the Vienna Convention) and a project website. We have suggested that the website or the measurements, at least, could be made integrated into the National Air Quality Archive, as this would enhance their visibility.

A low ozone alert service is operated as part of the monitoring programme. The alerts are currently sent to the project team and Defra but neither to the HPA nor the Met Office, who are involved in UV monitoring and forecasting activities. It is worth considering the purpose and effectiveness of this service and whether it represents best use of the resources.

Although there have been a number of papers published in the open literature, the monitoring programme is seen to have a low profile and impact. The National Ozone seminar held in 2007 is a good example of raising the profile of the programme. It is also suggested that the programme could offer a forum for a UK assessment of stratospheric ozone and UV, similar to those prepared for the Department by the Stratospheric Ozone Review Group and the Ultraviolet Measurements and Impacts Review Group.

26 See http://www.ozone-uv.defra.gov.uk/ozone/events.php
27 The seminar was held during the 10th International Brewer Users Meeting hosted by the University of Manchester.
28 See http://www.defra.gov.uk/evidence/statistics/environment/eiyp/pdf/eiyp2009.pdf
29 See http://www.defra.gov.uk/evidence/statistics/environment/ozone/ozkf04.htm
30 See http://www.sepa.org.uk/science_and_research/data_and_reports/state_of_the_environment.aspx

Recommendations

Recommendation 8. Data on the project website should encompass the entire Lerwick dataset. The presentation of the trend plot on the website should be made consistent.

Recommendation 9. Defra should review whether the Low Ozone Service is a cost effective use of resources. If it is retained, the information should be disseminated more widely.

Recommendation 10. Defra should consider whether this programme could provide a function and outputs similar to that of the Stratospheric Ozone Review Group.

Recommendation 11. The contractor(s) should be required develop a proactive communication strategy to raise the profile of the programme. This could include events such as the National Ozone seminar, publication of briefing notes, etc. The scientific impact should be increased with more peer reviewed papers on topics other than measurement methods, QA/QC, etc.

4.5 Cost Effectiveness

Question 5: Is the current monitoring programme cost effective?

Response:

The Atmosphere and Local Environment team within Defra is responsible not only for this monitoring programme but also for a number of national air quality monitoring networks. In this response, we start by comparing the annual cost of this monitoring programme with those of other monitoring contracts in ALE (see Table 4.5).

Table 4.5: Comparison of annual costs of the Ozone and UV monitoring programme with those of ALE's air quality monitoring programmes, based on information available from the Air Quality Information Archive[31].

Monitoring Programme	Annual Cost (£k)	Policy Driver
Black Smoke Monitoring Network (2006-9) [RMP 2591]	93 (FY 08/09)	-
Operation and Management of the EMEP Supersite at Auchencorth Moss [CPEA 33]	126 (FY 08/09)	UN ECE/EMEP
Heavy Metal deposition Mapping [CPEA 32]	180 (FY 08/09)	UN ECE/EMEP
Baseline Measurements and Analysis of UK Ozone and UV	**317 (FY 09/10)**	**Vienna Convention**
Monitoring airborne particulate concentrations & numbers in the UK - Phase II [CPEA 28]	331 (FY 08/09)	UK Policy
Acid Deposition Monitoring Programme [RMP 2901]	338 (FY 07/08)	UN ECE/EMEP
Heavy Metals Monitoring Network [RMP 2443]	470 (FY 08/09)	EU Air Quality Directive UK Air Quality Strategy
PAH Monitoring in the UK [RMP 2334]	493 (FY 08/09)	EU Air Quality Directive UK Air Quality Strategy
QA/QC Services for the Automatic Urban Rural Monitoring Network [RMP 1883]	942 (FY 07/08)	EU Air Quality Directive UK Air Quality Strategy
CMCU of the Automatic Urban Rural Monitoring Network [EPG 1/3/191]	2,210 (FY 07/08)	EU Air Quality Directive UK Air Quality Strategy

The costs for this monitoring programme are of the order of £317k per annum. It is neither the cheapest nor the most expensive programme. It is however difficult to draw any firm conclusions on value for money without additional information on the number of sites, pollutants monitored, sampling

31 See http://www.airquality.co.uk/contracts/index.php

methods and frequencies. The costs of this programme are however elevated by the participation in international instrument comparisons, which form a necessary part of the QA/QC activities.

The majority of the effort (and hence funding) is allocated either to making the actual measurements or the subsequent data processing (~3.0 man years). We have obtained information on the resources deployed on ozone monitoring in Germany and Switzerland (see Table 4.6). The man power levels appear similar to those of the Swiss programme (although more instruments are operated there). The manpower deployed in the German programme is larger, presumably because Hohenpeissenberg is also a Regional Dobson Calibration Centre.

Table 4.6: Comparison of staff resource allocated to the Defra, Swiss and German ozone monitoring activities.

Country	Monitoring Activities	Total Manpower (man years)
UK	Lerwick - Total ozone by one Dobson instrument (manual data acquisition with automated data transfer) [daily] Reading - Total ozone measurements with 1 Brewer instruments (completely automated) - Spectral UV measurements with 1 scanning spectrometer (completely automated)	~4.0 (Note 1)
Switzerland	Arosa: - Total ozone by two Dobson instruments (manual data acquisition with automated data transfer) [daily] - Total ozone and UV-B measurements with 3 Brewer instruments (completely automated) - Umkehr measurements by an additional Dobson instrument (completely automated) and the 3 Brewer instruments. (Twice a month, manual Dobson Umkehr for comparison) - Spectral UV scan with the Brewer instruments - Surface ozone measurement close to Arosa site (~100 m higher) Payerne: - Ozone profile measurements by ECC ozone sondes (3 times per week) - Ozone profile measurements by microwave instrument (automated, 30 minutes mean profiles)	~3.7 (Notes 2, 3)
Germany	Hohenpeissenberg: - Total ozone amount with Dobson (since 1968) - Total ozone amount with Brewer (since 1983) - Total ozone amount with Microtops (since 1996) - Ozone vertical profile with Brewer/Mast sonde (since 1967) - Ozone vertical profile with Lidar (since 1987/88) - Surface ozone (since 1971) under the responsibility of the GAW group - WMO Regional Dobson Calibration Centre	8.0 (3 scientists, 1 engineer and 4 technicians) Notes (4, 5)

Notes: (1) Based on the total mandays given in the 6-month contract extension and assuming 1 man year = 220 mandays; (2) From information provided by J. Stähelin; (3) It should also be noted that MeteoSwiss supports PhD positions at ETH Zürich (through the program GAW-CH) in order to study some research aspects in more depth. (4) From information provided by U Köhler; (5) Ozone measurements also made at Lindenberg.

A WMO-GAW guide on measurements (WMO, 2001) contains the following statements on resource requirements:

Total Ozone (Page 17)

- *Personnel: Operator - 1 hour per day.* ***Note: this seems low for the current ozone measurement schedules and does not include data processing, QA/QC, instrument comparisons.***
- *Training: Dobson/Brewer for global observations -2 weeks*
- *Brewer maintenance requires high technical abilities.*

UV (Page 69)

- *Personnel: 1 full-time radiation expert and 1 half-time data processor assistant*
- *Training for low-resolution instrument – 1 month, for high-resolution instrument – 1 year*

Across the three measurements, the Defra monitoring programme seems to conform to the WMO guide.

Summary

The manpower resources deployed in the Defra-funded programme are similar to those of the Swiss programme and in total appear to conform to WMO guidelines. More resources are used in the German programme at Hohenpeissenberg, but this is to be expected given the more extensive range of measurements and its role internationally as a regional Dobson calibration centre.

Recommendations

We have not made any specific recommendations here as many of our recommendations regarding the future shape of the Defra-funded monitoring programme will have implications for the overall cost and the cost-effectiveness of the programme.

4.6 Structure

Question 6: Is the current monitoring programme structured for optimum delivery?

Response:

The monitoring programme has three main objectives or tasks: (i) measurements, (ii) dissemination and (iii) analysis. Box 1 in Section 2.4 listed the requirements of the contract and the individual objectives. As far as we can tell, these objectives are largely being achieved.

The current monitoring programme involves a project team led by AEA Technology and comprising the Met Office, the University of Manchester and Imperial College. Table 4.7 summarises the roles and responsibilities of the different project team members. Figure 4.2 provides a schematic of the data flows and interactions in the contract. Figure 4.2 also shows the organisation responsible for the specific elements of the three main activities. As currently configured, the project partners generally have distinct roles. There is little overlap or duplication, although Imperial College and the University of Manchester both contribute to the 'data analysis' tasks.

Communication between AEA Technology and the Met Office was a source of concern at the time of the 2002 Review. This has improved significantly and there now seems to be good communication and working relationships between all the current project partners.

As can be seen in Figure 4.2 and from Table 4.7, no one partner has overall responsibility for quality assurance. AEA Technology has overall responsibility for the QA of the Dobson ozone measurements but a more limited role in the Brewer ozone measurements. The University of Manchester has overall responsibility for the QA of the UV measurements and their subsequent dissemination to the international data centres. This reflects the evolution of the different measurements (the UV monitoring was let under a separate contract to the University of Manchester until 2003) and the relative expertise of the different organisations.

Table 4.7: Allocation of activities within the monitoring programme to the project partners.

Organisation	Lerwick Ozone	Reading Ozone	Reading UV	Other
Met Office (Lerwick Ozone) University of Manchester (Reading Ozone and UV)	• Make the measurements according to the agreed schedule • Ensure that the instrument(s) are maintained and calibrated according to the agreed schedule • Participate in international instrument intercomparison • Process the measurements to derive the ozone column amount and the best daily average • Transfer the raw and processed data to AEA Technology	• Make the measurements according to the agreed schedule • Ensure that the instrument(s) are maintained and calibrated according to the agreed schedule • Participate in international instrument intercomparison • Process the measurements to derive the ozone column amount and the best daily average • Transfer the processed data to AEA Technology	• Make the measurements according to the agreed schedule • Ensure that the instrument is maintained and calibrated according to the agreed schedule • Participate in international instrument calibration activities • Process the measurements • Undertake the required QA/QC activities • Transfer the processed data to AEA Technology for uploading on the website • Dissemination to WOUDC and other repositories • Undertake analysis of measurements • Determination of trends	• Participate in project meetings • Participate in WMO UV technical and Brewer User groups (University of Manchester)
AEA Technology	• Review and QA of measurements on a monthly basis • Clarification of measurement with Met Office as needed • Updating of website with new measurements • Dissemination to WOUDC and other repositories	• Review of measurements on a monthly basis • Clarification of measurement with University of Manchester as needed • Updating of website with new measurements • Dissemination to WOUDC and other repositories	• Updating of website with new measurements	• Project Management • Maintenance and updating of the website
Imperial College	• Analysis of measurements • Determination of trends • Analysis and interpretation of low ozone events	• Analysis of measurements • Determination of trends • Analysis and interpretation of low ozone events		• Response to questions on stratospheric ozone science and policy

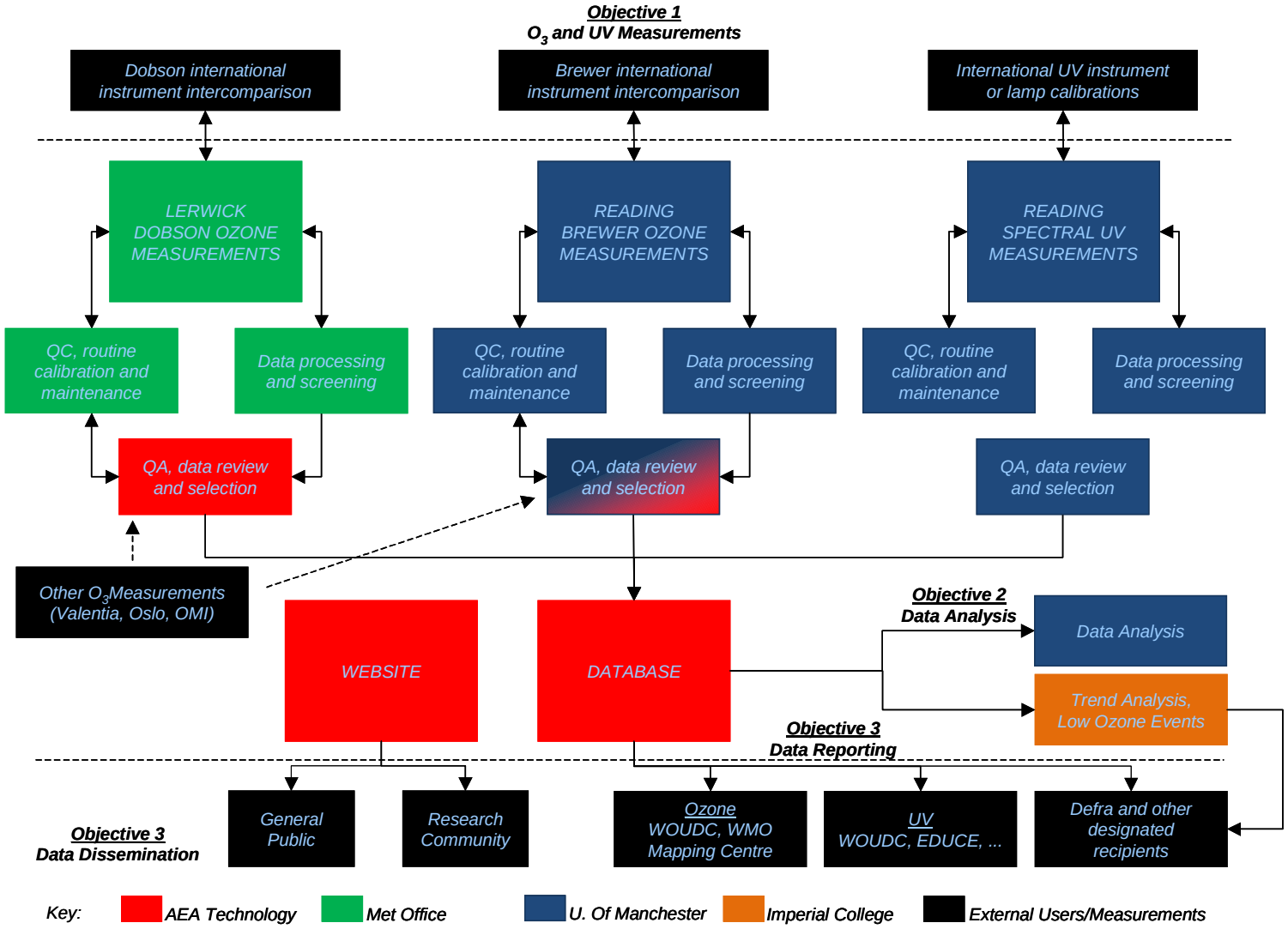

Figure 4.2: Schematic of the data flows in the current monitoring programme, colour-coded to show the project partner responsible.

A number of respondents made comment that the organisation making the measurements should be responsible for the data processing. For example, WOUDC are generally taking a more active role in the QA/QC of the measurements and this is leading to more direct interaction with the organizations making the measurements. However, as noted in the 2002 Review, there is no *a priori* reason why split responsibilities should not succeed and indeed there could be significant benefits in an independent scrutiny of the measurements.

Both Imperial College and the University of Manchester undertake 'data analysis' tasks. These cover for example the determination of long term trends in ozone concentrations and surface UV radiation, seasonal variations in the long-term trends, assessment of natural variability and explanations of observed anomalies in the ozone record. There is an informal arrangement that Imperial College focuses on ozone and Manchester on UV. It is largely left to the project team to identify potential data analysis tasks.

Ralf Toumi (Imperial College) made a clear distinction between the 'data analysis' tasks in the current contract and 'research' projects that advance scientific understanding and lead to high profile publications. Unless unusual events occur, analyses of trends in themselves excite little general interest and are difficult to publish on a regular basis. We addressed the profile and impact of the programme under the response to Question 4 (see Section 4.4).

In the response to Question 3 (see Section 4.3), we have suggested a number of options for a future UK monitoring programme. These will have significant implications for the structure of such a programme.

Summary

Although the current programme appears to meet the contract objectives, there are areas in the present programme that could be restructured to address concerns raised during this review:

- To improve the robustness of the UK measurements: We see benefit in one organisation, independent of the measurement groups, having overall responsibility for quality assurance. This is the model adopted in many of the national air quality monitoring networks.
- To raise the profile and impact: A future programme needs to engage more actively with the research community and other stakeholders. We have also suggested that the project could for example provide a function similar to that of the Stratospheric Ozone Review Group. Resource would need to be re-allocated within the programme to cover such activities.

In the response to Question 3, we have suggested a number of options for a future UK monitoring programme. These will have significant implications for the structure of such a programme.

Recommendations

We re-iterate recommendations 9 and 10 in Section 4.4.

Recommendation 12. A single organisation should have overall responsibility for the quality of the UK measurements.

4.7 Procurement Options

Question 7: Should all or part of the programme be competitively tendered, or indeed should it be competitively tendered at all?

Response:

Over the years, the monitoring programme has been commissioned by competitive tendering and single tender action:

- 2000: Competitive tendering of the ozone monitoring programme
- 2003: Competitive tendering of the merged ozone and UV monitoring programme
- 2006: Contract let by single-tender action

This is a highly technical area requiring specialist knowledge and expertise. No-one UK organisation is currently capable of undertaking the whole programme and there are a limited number of UK organisations with the capability to undertake specific elements of the programme. Apart from the organisations involved in the current programme (AEA Technology, Met Office, University of Manchester and Imperial College), only the British Antarctic Survey (for Ozone) and the Health Protection Agency (for UV) have relevant operational or network experience. There is potentially a wider pool of organisations with expertise in either stratospheric ozone science/measurements or advanced instrumentation. These include Defra contractors as well as groups in the UK research community.

In our response to Question 3 (see Section 4.3), we identified a number of options for the future shape of this programme and indicated some of the benefits, disadvantages and risks associated with each option. In addition to the business-as-usual option, alternative options included:

- Introduction of a Brewer, SAOZ or other automated instrument at Lerwick
- Effective replacement of the Lerwick Dobson with the Manchester Brewer measurements
- Use of the Reading Brewer instrument to make spectral UV measurements
- Integration of the Defra UV programme with the HPA programme

These need further evaluation to confirm their feasibility. Ideally, this should be completed prior to the issue of an Invitation to Tender. Otherwise, it will be difficult for bidders to make a credible response.

The monitoring programme cannot be changed overnight. If changes are to be made, a forward-looking strategy needs to be developed to move from the current to the new programme. The strategy needs to cover instrument selection, side-by-side operation, data continuity and a proactive approach to consulting/informing the UK and international community. We suggest that this is prepared in the initial phase of the next contract.

The 2002 Review also made the case for longer duration contracts to provide stability and security. The latter is a particular issue for the academic partners in the present contract (e.g., University of Manchester). There are other monitoring contracts within Defra's Atmosphere and Local Environment programme of longer duration. For example, the contracts for (a) the Central Management and Co-ordination Unit (CMCU) and (b) the Quality Assurance and Quality Control (QA/QC) were let for 5 years with an option to extend by 2 years. Ann Webb (University of Manchester) pointed to the Austrian ozone monitoring programme, where a contract for 10 years was recently awarded. We see a longer duration contract as important in providing sufficient time to develop, plan and implement any changes to the measurement programme.

Depending on the shape of the programme, possible procurement options are then:

1. Competitive tendering of the entire programme

   The Met Office and University of Manchester are likely to be common partners to all bids if the current Lerwick and Reading measurements are retained. In this option, each bidding team agrees the contribution from and associated costs with the Met Office and University of Manchester. Although providing flexibility, it is likely that a common service and costs will be offered.

2. Competitive tendering of the entire programme with specified roles

   This is similar to 1 above except that the Met Office and/or the University of Manchester would have minimum defined roles, responsibilities and costs (if the current Lerwick and Reading measurements are retained). This would ensure that all consortia bid on a common basis but Defra will need to come to an agreement with the Met Office and the University of Manchester on the services and associated costs prior to the tendering process. In principle, the Met Office or the University of Manchester would be free to undertake other aspects of the project.

3. Split programme with measurement element commissioned by single tender action and the other elements by competitive tendering.

   The largest components of the present programme are making the measurements and these are largely tied to the Met Office and University of Manchester. However, we see little benefit in splitting the programme. It will increase the programme management effort required at

Defra as well as requiring additional project management or co-ordination effort within the individual contracts to ensure effective communication. As noted elsewhere, it was the split of the ozone monitoring programme in 2000 that prompted the previous review.

4. Single tender action

   The case for single tender action would be strong if we were proposing a continuation of the existing programme as it is likely that the present project team would be the only bidder. We have however identified a number of major changes to the shape of a future programme and also proposed a longer contract period. We have also recommended changes to the 'data analysis' activities to raise the profile and impact of the programme. If these are adopted, this would represent a significant change of scope and single tender action would not be appropriate.

The preference should be for competitive tendering to allow for changing requirements, innovation, introduction of new partners, etc.

We also endorse the recommendation from the 2002 Review that there is a sufficient handover period if a new contractor is to be introduced into the programme.

Summary

We have made a number of recommendations regarding the shape of a future programme and recommend that the contract period should be extended from the present three years to provide stability and time to make the changes. We have also recommended restructuring the 'data analysis' activities to raise the profile and impact of the programme. If these are adopted, this would represent a significant change of scope to the programme and the preference should be for competitive tendering of the contract to cover these changing requirements, to demonstrate value for money and to allow for innovation, introduction of new partners.

Recommendations

Recommendation 13. The contract period should be extended from the present three years to provide stability and time to make the changes. Because of the potentially significant changes to the monitoring programme, we recommend that the next phase of the monitoring programme should be competitively tendered.

Recommendation 14. There should be an appropriate handover period if new (or inexperienced) organisations become involved in the monitoring programme.

5 Summary and Recommendations

A review has been undertaken of the monitoring programme *Baseline Measurements and Analysis of UK Ozone and UV*. The review was structured in terms of 7 questions, which addressed a range of strategic, technical and organisational aspects of the monitoring programme. In this section, we bring together the summaries and recommendations made at the end of the responses to the questions (see Sections 4.1-4.7).

5.1 Summary

The key findings are

1. The current monitoring programme is working well but it has a low profile and impact
2. There are options to evolve the programme but these require further, more detailed evaluation.

The Defra-funded monitoring programme helps fulfil UK obligations under the Vienna Convention. The number of sites and the measurement programme is considered to be appropriate and proportionate. The UK has played an active role in stratospheric ozone research and in the international assessment and policy arenas. Any reduction of the UK programme (real or apparent) will be perceived as a lack of UK commitment and could affect support for future UK-led initiatives in this area.

There is evidence that the measurements (O_3 and UV) are being used in the international assessments and for the validation of satellite measurements. The value of the datasets increases with its length. From that perspective, we would rank the measurements in the current programme in the order:

1. Ozone at Lerwick
2. Spectral UV at Reading
3. Ozone at Reading

The current monitoring programme follows the guidance and standard operating procedures produced internationally for the different instruments. The quality and reliability of the measurements have been established through participation in international instrument comparisons. There are no obvious data quality issues with the current measurements, although some historic datasets still need to be reprocessed. We note the current drive to harmonise the measurements from satellite and ground-based instruments. There is likely to be a requirement to reprocess all the data (both current and historic) following the adoption of new ozone absorption cross-sections.

The main dissemination routes are to the World Ozone and UV Data Centre (which also fulfils the UK obligations under the Vienna Convention) and a project website. We suggest that the website or the measurements, at least, could be made integrated into the National Air Quality Archive, as this would enhance their visibility. A low ozone alert service is operated as part of the monitoring programme. The alerts are currently sent to the project team and Defra, but neither to the HPA nor the Met Office (who are involved in UV monitoring and forecasting activities). It is worth considering the purpose and effectiveness of this service and whether it represents best use of the resources.

A number of papers have been published in the open literature. Despite this, the monitoring programme is seen to have a low profile and impact. The National Ozone seminar held in 2007 is a good example of raising the profile of the programme. It is also suggested that the programme could offer a forum for a UK assessment of stratospheric ozone and UV, similar to those prepared for the Department by the Stratospheric Ozone Review Group and the Ultraviolet Measurements and Impacts Review Group. There is a requirement to increase the science and policy impact of these measurements.

From information provided on the resources used in the Swiss and German monitoring programmes, the manpower resources deployed in the Defra-funded programme are similar to those of the Swiss programme. More resources are used in the German programme at Hohenpeissenberg, but this is to be expected given the more extensive range of measurements made there and its role internationally as a regional Dobson calibration centre.

Looking to the future, no activities have been undertaken within the World Meteorological Organisation to evaluate potential alternative ground-based measurement systems, as far as we are aware. It is unlikely therefore that a new instrument could be developed, operated in a network context and with sufficient overlap to ensure continuity of existing records, within the next 10 years. The Brewer and Dobson spectrophotometer will remain the instruments used to make column ozone measurements, certainly over this period and perhaps longer.

Although the current programme appears to meet the contract objectives, there are areas in the present programme that could be restructured (a) to improve the robustness of the UK measurements; and (b) to raise the profile and impact of the programme. We identified a number of options for the future shape of this programme and indicated some of the benefits, disadvantages and risks associated with each option. In addition to the business-as-usual option, alternative options include:

- Introduction of a Brewer (or other) instrument at Lerwick
- Replacement of the Lerwick Dobson with the Manchester Brewer measurements
- Use the Reading Brewer instrument to make spectral UV measurements
- Integration with the HPA programme

Any changes need to be carefully planned, managed and communicated. To that end, there is a clear need for a strategy to be developed and owned by Defra and the project team.

In addition to the changes outlined above, we also recommend that the contract period should be extended from the present three years to provide stability and time to make the changes. If these changes are adopted, they would represent a significant change of scope to the programme and the preference should be for competitive tendering of the contract to cover these changing requirements, to demonstrate value for money and to allow for innovation, introduction of new partners.

We also endorse the recommendation from the 2002 Review that there is a sufficient handover period if a new contractor is to be introduced into the programme.

5.2 Recommendations

Question 1

Recommendation 1. As a minimum, the monitoring programme should be maintained at its current level of 2 ozone sites and one UV site.

Question 2

Recommendation 2. Defra continues to support (a) the participation of the UK monitoring teams in international instrument comparisons as this establishes the quality and reliability of the measurements, and (b) any reprocessing of data arising from intercomparison.

Recommendation 3. With the adoption of new ozone absorption cross sections, Defra makes provision for the reprocessing of the UK ozone datasets and the submission of the revised data to the international databases.

Question 3

Recommendation 4. Defra should engage the Department of Health and Health Protection Agency to identify opportunities to align their respective monitoring activities. A joint study should be undertaken to compare the spectrally-resolved UV measurements made at Reading and Chilton.

Recommendation 5. Defra and the contractor(s) should look for opportunities to share experience and expertise with the British Antarctic Survey, not only in terms of the Dobson measurements but also in terms of profile raising and the experience of BAS with other ozone measurement methods.

Recommendation 6. The contractor(s) for the monitoring programme should develop a monitoring strategy to address the future requirements of the programme in terms of aims, sites, instrumentation, implementation, communication, etc. The strategy should be periodically updated and tested externally.

Recommendation 7. As part of the strategy, the feasibility, practicality and costs of the following options should be investigated: (i) to replace the Dobson instrument at Lerwick and (ii) to make spectral UV measurements at Reading using a Brewer instrument.

Question 4

Recommendation 8. Data on the project website should encompass the entire Lerwick dataset. The presentation of the trend plot on the website should be made consistent.

Recommendation 9. Defra should review whether the Low Ozone Service is a cost effective use of resource. If it is retained, the information should be disseminated more widely.

Recommendation 10. Defra should consider whether this programme could provide a function and outputs similar to that of the Stratospheric Ozone Review Group.

Recommendation 11. The contractor(s) should be required develop a proactive communication strategy to raise the profile of the programme. This could include events such as the National Ozone seminar, publication of briefing notes, etc. The scientific impact should be increased with more peer reviewed papers on topics other than measurement methods, QA/QC, etc.

Question 5

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Question 6

Recommendation 12. A single organisation should have overall responsibility for the quality of the UK measurements.

Question 7

Recommendation 13. The contract period should be extended from the present three years to provide stability and time to make the changes. Because of the potentially significant changes to the monitoring programme, we recommend that the next phase of the monitoring programme should be competitively tendered.

Recommendation 14. There should be an appropriate handover period if new (or inexperienced) organisations become involved in the monitoring programme.

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Appendices

Appendix 1 – Vienna Convention

Appendix 2 – Ozone Instruments

Appendix 3 – Recommendations from the 2002 Review

Appendix 4 – User Consultation Questionnaire

Appendix 5 – Published papers arising from the Monitoring Programme between 2001 and 2010.

Appendix 1 – Vienna Convention

The Vienna Convention for The Protection of the Ozone Layer was agreed in 1985. Articles 2 and 3 and Annex 1 of the Convention

Article 2: General obligations

1. The Parties shall take appropriate measures in accordance with the provisions of this Convention and of those protocols in force to which they are party to protect human health and the environment against adverse effects resulting or likely to result from human activities which modify or are likely to modify the ozone layer.
2. **To this end the Parties shall, in accordance with the means at their disposal and their capabilities:**
   (a) **Co-operate by means of systematic observations, research and information exchange in order to better understand and assess the effects of human activities on the ozone layer and the effects on human health and the environment from modification of the ozone layer;**
   (b) Adopt appropriate legislative or administrative measures and co-operate in harmonizing appropriate policies to control, limit, reduce or prevent human activities under their jurisdiction or control should it be found that these activities have or are likely to have adverse effects resulting from modification or likely modification of the ozone layer;
   (c) Co-operate in the formulation of agreed measures, procedures and standards for the implementation of this Convention, with a view to the adoption of protocols and annexes;
   (d) Co-operate with competent international bodies to implement effectively this Convention and protocols to which they are party.
3. The provisions of this Convention shall in no way affect the right of Parties to adopt, in accordance with international law, domestic measures additional to those referred to in paragraphs 1 and 2 above, nor shall they affect additional domestic measures already taken by a Party, provided that these measures are not incompatible with their obligations under this Convention.
4. The application of this article shall be based on relevant scientific and technical considerations.

Article 3: Research and systematic observations

1. The Parties undertake, as appropriate, to initiate and co-operate in, directly or through competent international bodies, the conduct of research and scientific assessments on:
   (a) **The physical and chemical processes that may affect the ozone layer;**
   (b) **The human health and other biological effects deriving from any modifications of the ozone layer, particularly those resulting from changes in ultra-violet solar radiation having biological effects (UV-B);**
   (c) **Climatic effects deriving from any modifications of the ozone layer;**
   (d) **Effects deriving from any modifications of the ozone layer and any consequent change in UV-B radiation on natural and synthetic materials useful to mankind;**
   (e) **Substances, practices, processes and activities that may affect the ozone layer, and their cumulative effects;**
   (f) **Alternative substances and technologies;**
   (g) Related socio-economic matters;

   and as further elaborated in annexes I and II.

2. The Parties undertake to promote or establish, as appropriate, directly or through competent international bodies and taking fully into account national legislation and

relevant ongoing activities at both the national and international levels, joint or complementary programmes for systematic observation of the state of the ozone layer and other relevant parameters, as elaborated in annex I.

3. **The Parties undertake to co-operate, directly or through competent international bodies, in ensuring the collection, validation and transmission of research and observational data through appropriate world data centres in a regular and timely fashion.**

Appendix 2 – Ozone Instruments

A2.2.1 Dobson ozone spectrophotometer

The material in this section has been extracted from the operation handbook for ozone observations by the Dobson spectrophotometer [WMO-GAW, 2008].

Observations are made by measuring the relative intensities of ultraviolet radiation emanating from the sun, moon or zenith sky at selected pairs of wavelengths, called the A, B*[33], C, C', and D wavelength pairs. The A wavelength pair consists of the 305.5 nm wavelength that is highly absorbed by ozone, and the more intense 325.4 nm wavelength that is relatively unaffected by ozone. Outside the earth's atmosphere the relative intensity of these two wavelengths remains essentially fixed. As the UV radiation passes through the atmosphere to the instrument, however, both wavelengths lose intensity because of scattering of the light by air molecules and dust particles; additionally, the 305.5 nm wavelength is strongly attenuated while passing through the ozone layer whereas the 325.4 nm wavelength is little affected. The relative intensity of the A wavelength pair as seen by the instrument, therefore, varies with the amount of ozone present in the atmosphere since as the ozone amount increases the observed intensity of the 305.5 nm wavelength decreases, whereas the intensity of the 325.4 nm wavelength remains practically unaltered. Thus, by measuring the relative intensities of suitably selected pair wavelengths with the Dobson instrument, it is possible to determine how much ozone is present in a vertical column of air extending from ground level to the top of the atmosphere in the neighbourhood of the instrument. The result is expressed in terms of a thickness of a layer of pure ozone at standard temperature and pressure. Detailed information concerning derivation of the mathematical equations used in reducing total ozone measurement data obtained from observations on direct sun or moon are given elsewhere (Dobson, 1957a).

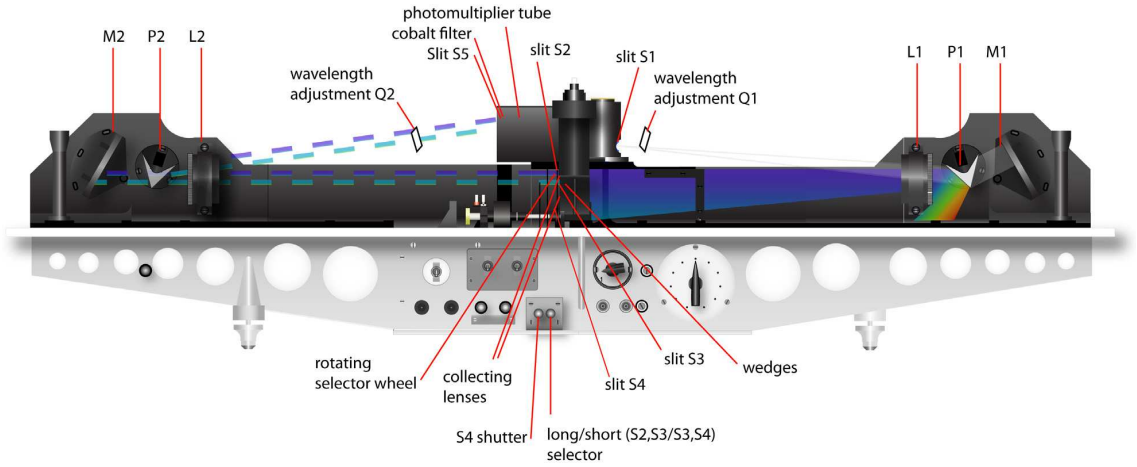

Figure A2.1: Optical system of the Dobson spectrophotometer (L1 and L2 are lenses; M1 and M2 are mirrors and P1 and P2 are prisms). Taken from WMO-GAW, 2008.

The schematic of the spectrophotometer is given in Figure A2.1. Light enters the instrument through a window in the top of the instrument and, after reflection in a right-angled prism, falls on slit S1 of a spectroscope. This spectroscope consists of a quartz lens which renders the light parallel, a prism which breaks up the lights into its spectral colours, and a mirror which reflects the light back through the prism and lens to form a spectrum in the focal plane of the instrument. The required wavelengths are isolated by means of slits S2, S3, and S4 located at the instrument's focal plane. Two shutter rods are mounted in the base of the spectrophotometer. The left-hand S4 shutter rod is used only when spectrophotometer tests

[33] Observations on the B wavelength pair are not needed for determinations of total ozone, but they are useful for research into the accuracy of ozone measurements. The B wavelength pair is also affected by other absorbing atmospheric pollutants, and this pair is not used in the global Dobson network.

are conducted. The right-hand wavelength selector rod blocks out light passing either through slit S2 or S4. When this rod is set to position labels SHORT, only slits S2 and S3 are open so that observations can be made on the A, B, C, or D wavelength pairs. With the wavelength selector rod in the LONG position, only slits S3 and S4 are open and observations can be made on the C' wavelengths.

Four wavelength pairs have been established by the International Ozone Commission, and recommended for universal use by the WMO (see Table A2.1). To correct for absorption by other atmospheric trace gases or scattering by aerosols, a combination of wavelength pairs is used. The most widely used combination, recommended as the international standard, is the pair of wavelength pairs listed as A and D. The reported ozone content is obtained from the combined result. As the sun falls in the sky, the slant path becomes longer and it becomes more difficult and inaccurate to make observations using the A pair. In this case, the CD double wavelength pairs are used.

Table A2.1: Wavelength Pairs Established by the International Ozone Commission

Designation	Shorter Wavelength (nm)	Longer Wavelength (nm)	O_3 Absorption Coefficient
A	305.5	325.4	1.748
B	308.8	329.1	1.140
C	311.45	332.4	0.800
D	317.6	339.8	0.360
C’	332.4	453.6	

Calibration

A2.2.1 Brewer ozone spectrophotometer

The Brewer ozone spectrophotometer also makes measurements of the total ozone column (and other components) using the principle of differential optical absorption spectroscopy. The following is adapted from the Operator’s Manual for the Mark III Brewer [Kipp and Zonen, 2008].

Incoming light is directed through the foreoptics by the director prism (see Figure A2.2), which may be rotated to select light from either the zenith sky, the direct sun, or one of the two calibration lamps. A mercury lamp provides a line source for wavelength calibration of the spectrometer, while a quartz halogen lamp provides a well regulated light source so that the relative spectral response of the spectrometer may be monitored. Elements in the foreoptics provide adjustment for field-of-view, neutral-density attenuation, ground-quartz diffusion, and selection of film polarizers.

Light then passes into the spectrometer’s optical assembly through an entrance slit and is disperse into a high-quality spectrum along the exit-slit focal plane. The spectrometer is a modified Ebert type with focal length 16 cm, and aperture ratio f/6. Six exit slits are positioned along the exit focal plane at the Ozone operating wavelengths - 303.2 nm (302.1 nm for mercury-wavelength calibration), 306.3 nm, 310.1 nm, 313.5 nm, 316.8 nm and 320.1 nm with 0.6 nm resolution. The wavelength is adjusted by rotating the gratings with stepper motors which drive micrometers acting on lever arms. The wavelength-calibration procedure is capable of measuring the wavelength setting with a precision of 0.0001 nm, and of controlling the wavelength setting to 0.006 nm. Between the spectrometer is a cylindrical mask which exposes only one wavelength slit at a time. The mask is positioned by a stepper motor which cycles through all five operating wavelengths, approximately once per second.

The instrument is automated and produces a variety of output and diagnostic files.

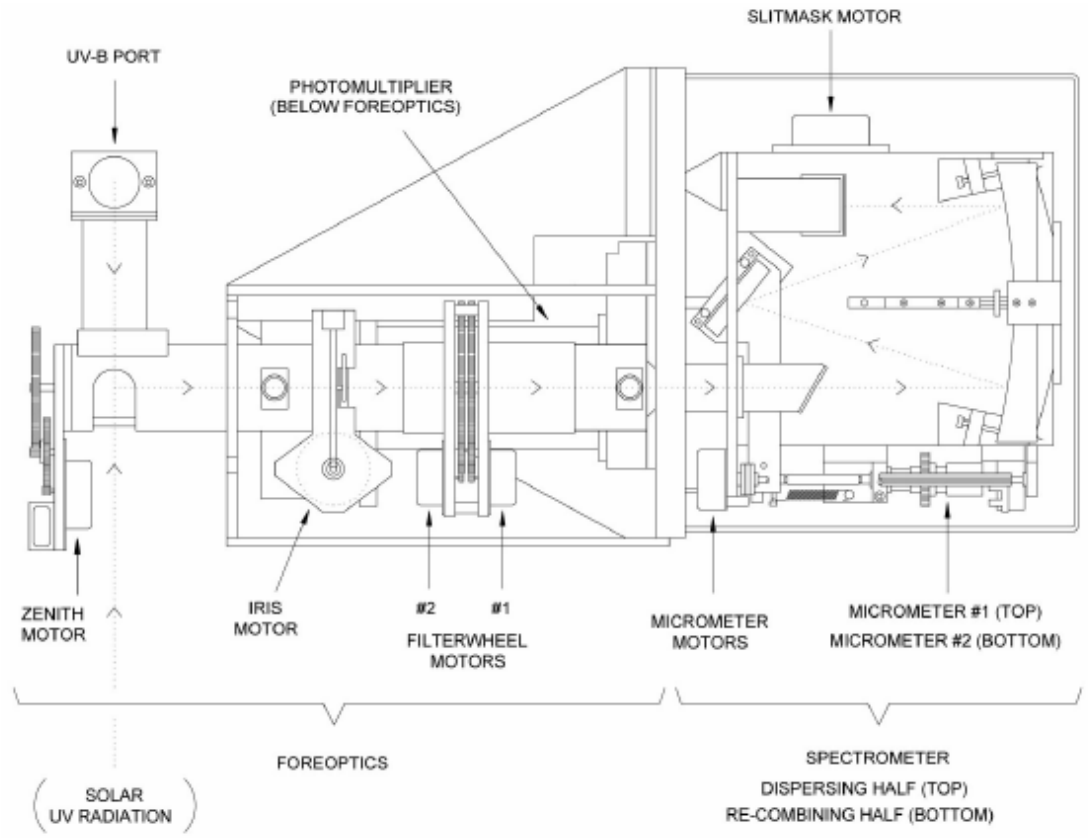

Figure A2.2: Schematic of the Mark III Brewer Spectrophotometer (Figure 2.5 in the Operator's Manual for the Mark III Brewer).

Appendix 3 – Recommendations from the 2002 Review

At the time of the 2002 review, there were separate contracts for the monitoring of ozone and surface UV radiation. The monitoring programmes were combined in 2003. Some of the recommendations on the measurements and data processing for ozone do however have relevance to the UV element of the monitoring programme.

A number of recommendations were made, covering both the short and long-terms. A brief update is given after each recommendation.

Recommendations in the shorter term

1. Defra and the UK Met Office (UKMO) should come to some agreement on support for the Ozone Technical Manager at UKMO, in the event of serious damage to any of the spectrophotometers, or if other excessive demands are made on his time (or illness). ***Status*: This was overtaken by the changes made to the monitoring programme in 2003, when the ozone measurement programme at Camborne (using manual Dobson spectrophotometers) was replaced by measurements from an automated Brewer instrument. Of the three Dobson instruments at the Met Office, two are deployed at Lerwick (one operational and one as a spare) and the third has been loaned to the South African Meteorological Service. Other recommendations on data processing (see below) have helped to spread the expertise within the Met Office. A successor to the Ozone Technical Manager is currently being trained.**

2. UKMO should investigate the possibility of processing raw data at the measurement stations. Two options should be considered: (a) processing after a short time delay (say a day) so that erroneous measurements can be identified and excluded; and (b) processing in real-time to allow additional measurements to be made when required. Proper costings are required, but we think that option (a) should be viable. Such a procedure would be in line with WMO recommended practices. ***Status*: Data processing software was installed at Lerwick to enable processing of the Dobson ozone measurements.**

3. We recommend that the two organisations openly discuss their methodologies for data processing and agree on one preferred method to be used by both groups. Furthermore, the two contractors need to establish a better mechanism for communication and should consider organising regular review meetings to deal with issues such as revising and submitting recent data. ***Status*: The data processing systems at AEAT and the Met Office now give the 'same' results. Communication is much improved as all the activities are covered by a single contract. Regular meetings held to review progress and issues.**

4. A second tier of data quality checks should be made routinely to improve confidence in the data quality. Comparisons should also be made using the best quality measurements rather than the whole data set. Comparisons with nearby stations should also be performed using difference plots with satellite overpasses (AEAT). Consideration should be given toward developing some ground-based measurements to be used explicitly for satellite comparisons (UKMO). This will be important in the coming years when several satellite instruments (e.g. ENVISAT and EUMETSAT) will be making total ozone measurements. ***Status*: As part of the current QA/QC processes, AEA Technology compares the UK measurements with those from satellites (TOMS initially and now OMI) and ground-based stations (Valentia). Recently, measurements from other ground-based stations have been used (De Bilt in Holland and Oslo in Norway).**

5. A clear plan for revising old data needs to be developed and implemented. This was unfortunately not included in the current contracts. ***Status*: Some historic datasets from Lerwick still need reprocessing. This activity has been included as options in recent Invitations to Tender, but these have not been taken up.**

6. The web site should be made freely and easily accessible. ***Status*: The website is up and running, although it was never formally launched by Defra. Usage appears to be increasing over time.**

7. Greater clarity about the roles of Defra and UKMO in relation to the Montreal Protocol and WMO is required to provide an improved long-term security for the UK ozone monitoring programme. ***Status*: No progress.**

Recommendations in the longer term

1. There is no a priori reason why a split contract should not work. However any such arrangements need to ensure stability and critical mass in the measurement programme, and to involve better collaboration than has occurred to date between UKMO and AEAT. ***Status*: The current programme has expanded to include UV measurements and changes to the ozone monitoring programme. The University of Manchester has joined the project consortium and is responsible for the ozone and UV measurements at Reading. There appears to be effective collaboration between the members of the expanded project team and no obvious evidence of a deterioration in data quality.**
2. We recommend that if there continues to be a split in the contract for the monitoring of ozone in the UK, the organisation responsible for making the measurements should also process the raw data to produce daily ozone values. ***Status*: This has been implemented (see Short-term Recommendation 2).**
3. A much clearer Invitation To Tender should be written for the next round of contracts, which should include a clear delineation of responsibilities if more that one contractor is to be involved. This clarity should be carried on into the contracts. ***Status*: The changes made to the monitoring programme in 2003 and the implementation of the recommendation on data processing have generally introduced greater clarity into the roles and responsibilities of the different project partners.**
4. Further, the stability which is essential for long-term monitoring is not provided in the current set-up. Longer contracts (possibly with staged reviews) or automatic extensions if performance is good are strongly recommended. A successful long-term total ozone monitoring programme requires a high level commitment from funding bodies in order to give flexibility and allow for difficulties in the programme. ***Status*: The current contract was originally let for three years. Other monitoring contracts let by the Atmosphere and Local Environment Division in Defra have provision for extensions and there are examples of longer contract periods (e.g., 5 years with an option for a 2-year extension for the CMCU and QA/QC contracts for the automatic urban and rural air pollution monitoring networks). In principle, future contracts for this monitoring programme could be of similar duration.**
5. If Defra unfortunately do have to involve a new, inexperienced contractor in the measurement programme, a longer hand-over period is absolutely necessary in order to maintain the quality of the data. ***Status*: This has not occurred since 2000. We would strongly support this recommendation.**
6. The Dobson Spectrophotometer is the recommended instrument for the measurement of total ozone over at least the next 3-5 year period. ***Status*: This is still the case for the short-term and for the foreseeable future.**
7. We strongly recommend that Defra and UKMO ask WMO to conduct an international expert study of the options that exist to ensure high quality monitoring of ozone over the next 25 years. EUMETNET may also be willing to conduct such a study. The study should be wide-ranging, and consider technical, practical and economic issues. The viability of all possible instruments should be considered with the aim of identifying options that can lead to a transition in the next ten years or so (to allow time for development, proving and side-by-side station comparisons) into a network that is viable in the long term. ***Status*: No progress.**

Appendix 4 – User Consultation

Review of the Monitoring Programme: Baseline Measurement and Analysis of UK Ozone and UV

Preamble

The UK Department for Environment, Food and Rural Affairs (Defra) and the UK Devolved Administrations (DA) continue to fund a long-running programme *Baseline Measurement and Analysis of UK Ozone and UV* to monitor column (effectively stratospheric) ozone and surface ultraviolet radiation. Defra has commissioned a review of the programme to ensure that it continues to meet current and future policy and scientific requirements as well as international obligations.

The current monitoring programme comprises:

- daily measurements of column ozone at **Lerwick** using a Dobson spectrophotometer (1957-present)
- automated measurements of ozone at **Reading** using a Brewer instrument (2003-present)
- spectrally-resolved 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 1.

The contract is led by AEA Technology and also involves the UK Met Office, the University of Manchester and Imperial College.

A website for the monitoring programme can be found at http://www.ozone-uv.co.uk/.

Figure 1 – Location of Defra and Other Ozone and UV Monitoring Sites [taken from http://www.ozone-uv.co.uk/].

The measurements form part of the UK obligations under the 1985 Vienna Convention on the **Protection of the Ozone Layer** to make systematic observations of the ozone layer and surface UV radiation and hence to investigate long-term trends and variability in total ozone levels.

We have prepared a brief questionnaire to inform the review. We have structured the questionnaire under the following headings:

- the contribution the UK measurements make to national or international policy actions
- the scientific and technical importance of the UK measurement programme
- dissemination/access to the UK measurements
- other information

We invite you to complete the questionnaire. You do not need to answer every section/question, only those that you feel able to. We would be pleased to discuss or follow-up the questionnaire with you.

Yours sincerely

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User Questionnaire

Name:	
Institute:	
Contact Details:	

1. Please provide a brief description of your interest in column ozone and/or surface UV radiation.

Policy Significance

2a. In your opinion, how do the UK measurements of column ozone and/or surface ultraviolet contribute to international actions taken to protect the ozone layer?

2b. Are there actions that could be taken to enhance the policy impact or usefulness of the measurements?

Technical

3a Please give your views on the scientific importance of these measurements?

3b. What actions could be taken to enhance the scientific impact or usefulness of the measurements?

3c. In your opinion, are there any areas where the UK monitoring programme could be improved?

3d. We would welcome your views on the viability of the current measurement techniques (e.g., over (a) a 3-5 year and (b) 5-20 year timescales). What other techniques/instruments are available and how could these be introduced?

Dissemination

4. The measurements are submitted to the World Ozone and UV Data Centre (WOUDC, http://www.woudc.org/), are available through the project website (http://www.ozone-uv.co.uk/), and sent by e-mail to selected recipients. Is this sufficient or are there ways in which this could be improved?

Other

5. Please provide any additional information that you consider relevant to this review.

Thank you.

Please return completed questionnaire by 22nd February to:

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Circulation List for Questionnaire

Policy	• Will Cook [Sarah Honour, Elizabeth Chrominska] (Defra) • David Warrilow [Andy Chalmers, Helen Champion] (DECC) • Bob Watson, Defra Chief Scientific Adviser • Department of Health/Health Protection Agency • Scottish Executive • Welsh Assembly Government • Northern Ireland Department of Environment
Scientific	• John Pyle (EORCU/University of Cambridge) • Neil Harris (EORCU/University of Cambridge) • Joe Farman (EORCU, via Neil Harris) • John Shanklin, John King and Howard Roscoe (British Antarctic Survey) • Julia Slingo (Met Office, Chief Scientist) • Bill Collins (Met Office) • Keith Shine, Janet Barlow, Richard Inwood (University of Reading) • Geraint Vaughan (University of Manchester) • John Burrows (CEH) • Ken Carslaw (University of Leeds) • Don Grainger (University of Oxford) • Martyn Chipperfield (University of Leeds) • Rod Jones (University of Cambridge) • Mary Norval (University of Edinburgh) • Nigel Paul (University of Lancaster) • Peter Woods and Tom Gardiner (National Physical Laboratory) • John O'Hagan (Health Protection Agency)
International	• Geir Braathen (WMO) • Ed Hare (World Ozone and UV Data Centre) • Vitali Fioletov (Environment Canada) • Ulf Köhler (Hohenpeissenberg Obs./RDCC) • Johannes Stähli n (ETH Zürich) • Gordon Labow (NASA)
Project	• Paul Willis (AEA Technology) • David Moore and Helen Bye (UK Met Office) • Ann Webb and John Rimmer (University of Manchester) • Ralf Toumi (Imperial College)

Appendix 5 – Published papers arising from the Monitoring Programme between 2001 and 2010.

Imperial College

R. Toumi, J. Syroka, C. Barnes and P. Lewis (2001) **Robust non-gaussian statistics and long-range correlation of total ozone**. Atmospheric Science Letters, **2**, 94-103, doi 10.1006/asle.2001.0045.

University of Manchester

R. Kift, A.R. Webb, J. Page, J. Rimmer and S. Janjai (2006) **A Web Based Tool for UV Irradiance Data: Predictions for European and South-East Asian Sites**. Photochemistry and Photobiology, 82(2), 579–586. doi: 10.1562/2005-04-20-RA-494.

J. Grobner, M. Blumthaler, S. Kazadzis, A. Bais, A. Webb, J. Schroder, G. Seckmeyer and D. Rembges (2006) **Quality assurance of spectral solar UV measurements: results from 25 UV monitoring sites in Europe, 2002 to 2004**. Metrologia 43, S66-S71

G. Seckmeyer, D. Pissulla, M. Glandorf, D. Henriques, B. Johnsen, A. Webb, A.-M. Siani, A. Bais, B. Kjeldstad, C. Brogniez, J. Lenoble, B. Gardiner, P. Kirsch, T. Koskela, J. Kaurola, B. Uhlmann, H. Slaper, P. den Outer, M. Janouch, P. Werle, J. Gröbner, B. Mayer, A. de la Casiniere, S. Simic, F. Carvalho (2008) **Variability of UV Irradiance in Europe**. Photochemistry and Photobiology, 84(1), 172–179.

G. Seckmeyer, M. Glandorf, C. Wichers, R. McKenzie, D. Henriques, F. Carvalho, A. Webb, A.-M. Siani, A. Bais, B. Kjeldstad, C. Brogniez, P. Werle, T. Koskela, K. Lakkala, J. Gröbner, H. Slaper, P. den Outer, U. Feister (2008) **Europe's darker atmosphere in the UVB**. Photochemistry and Photobiology Sciences 7, 925–930, doi: 10.1039/b804109a

A. Malkki, G. Braathen, J. Staehlin and A. Webb (2009) **IGACO-Ozone and UV Radiation Implementation Plan report**. GAW Report No. 182., WMO.

A. Arola, S. Kazadzis, A. Lindfors, N. Krotkov, J. Kujanpaa, J.Tamminen, A. Bais, A. di Sarra, J. M. Villaplana, C. Brogniez, A. M.Siani, M. Janouch, P. Weihs, A. Webb, T. Koskela, N. Kouremeti, D.Meloni, V. Buchard, F. Auriol, I. Ialongo, M. Staneck, S. Simic, A.Smedley, and S. Kinne. (2009) **A new approach to correct for absorbing aerosols in OMI UV: a preliminary evaluation**. Geophysical Research Letters, 36(22), L22805, doi: 10.1029/2009GL041137.

A. Lindfors, A. Tanskanen, A. Arola, R. van der A, A. Bais, U. Feister, M. Janouch, W. Josefsson, T. Koskela, K. Lakkala, P. N. den Outer, A.R.D. Smedley, H. Slaper, and A.R. Webb (2009) **The Promote UV Record: a global satellite-based climatology of ultraviolet irradiance**. JSTARS special issue (on Fostering Applications of Earth Observations of the Atmosphere) 2(3), 207–212.

S. Buntoung and A.R. Webb (2010) **Comparison of erythemal UV irradiances from OMI and ground-based data at four Thai stations**. J. Geophys. Res. (in review)

With 4 other papers in preparation.