UNITED KINGDOM

1. OBSERVATIONAL ACTIVITIES

1.1. Column measurements of ozone and other gases/variables relevant to ozone loss

The UK Government Department for Environment, Food and Rural Affairs (Defra) funds an on-going monitoring programme that records total values of stratospheric ozone at two UK locations. Measurements with a Dobson instrument are taken at the Lerwick Observatory in the Shetland Islands (N of Scotland) and a Brewer spectrophotometer is used at the Reading site in Berkshire (S England).The latter site replaced the Camborne Observatory site in Cornwall at the end of 2003, where a Dobson instrument had been used for ozone measurements. The spectrophotometers sample the ozone column at frequent intervals throughout the day to produce daily mean values, except for when weather conditions prevent values from being recorded and during the winter at Lerwick when the sun is too low in the sky.

Column ozone measurements are also made at the University of Manchester (N England) using a Brewer instrument. These are also made available to the above monitoring programme (but are separately funded) and similarly submitted to the WOUDC. Measurements using a SAOZ instrument are made in Aberystwyth, and are submitted to the NDACC network.

The British Antarctic Survey continues total column ozone measurements at Halley with a Dobson spectrophotometer, and supports those made at Vernadsky (Ukraine). BAS also continues total ozone and NO_2 column measurements at Rothera with a SAOZ spectrometer. A radiosonde programme continues at both Halley and Rothera, supported by the UK Met Office.

The UK Met Office has lent Dobson #35 to the South African Weather Service. It is not yet in active use, but has been intercompared.

1.2. Profile measurements of ozone and other gases/variables relevant to ozone loss

High frequency, real time *in situ* measurements of the principal halocarbons and radiatively active trace gases have been made at Mace Head on the West coast of Ireland since 1987, as part of the Global Atmospheric Gases Experiment (GAGE) there. For about 70% of the time the measurement station, which is situated on the Atlantic coast, monitors clean westerly air that has travelled across the North Atlantic Ocean. For about 30% of the time, Mace Head receives substantial regional scale pollution in air that has travelled from the industrial regions of Europe. The site is therefore ideally situated to record trace gas concentrations associated with both the Northern Hemisphere background levels and with the more polluted air arising from Europe.

Using the Mace Head data with a Lagrangian dispersion model that determines the origin of the air arriving at Mace Head at the time of each observation, estimates of the Northern

hemisphere baseline concentrations are made for each trace gas. By removing the underlying baseline trends from the observations and by modelling where the air originated from on a regional scale, an iterative best-fit technique then searches a set of random emission maps to determine the one that most accurately mimics the Mace Head observations.

The UK Department for Energy and Climate Change is intending to expand the Atmospheric Observation Network to include three additional sites in the UK, to be located at Edinburgh, Tacolneston, and Ridge Hill. These sites will result in significant increases in spatial and temporal resolution for the interpretation work, enabling UK Devolved Administration emission estimates from atmospheric observations as well as decreasing the uncertainties associated with all the analytical outputs of this project.

Analysis of the atmospheric observation data also identifies sources of and trends in ozone formation from different areas, including comparison of observed data with expected trends, to identify any new substances with ozone depleting or radiative forcing properties. The possible use and analysis of any data coming from other sites that could be of policy relevance is currently under consideration.

1.3. UV measurements

1.3.1. Broadband measurements

The solar UV index is measured at six sites at approximately 2 degrees of latitude increments (from 50 to 60° N) across the UK by the Centre for Radiation, Chemical and Environmental Hazards of the Health Protection Agency (HPA). A seventh site on Mount Snowdon in Wales has been temporarily removed while the site is developed. In addition, spectral UV measurements are carried out at the HPA site at Chilton. A portable spectral measurement system is currently under development for temporary deployment during extreme weather or atmospheric events or at locations where large numbers of people gather outside. The Department of Health provides support for this UV monitoring work, which provides information for the Global Solar UV Index in association with WHO, WMO, UNEP and the International Commission on Non-Ionizing Radiation Protection.

1.3.2. Narrowband filter instruments

No instruments of this type are currently being used in the UK.

1.3.3. Spectroradiometers

A spectroradiometer is co-located with the Brewer spectrophotometer in Reading, funded as part of the Defra monitoring programme. The Bentham DM150 UV spectroradiometer has been in place since 1993, and is regularly calibrated in situ. The instrument takes spectra from 290nm to 500nm at 0.5nm resolution at half-hour periods during daylight hours, every day of the year.

A spectroradiometer is also co-located with the Brewer spectrophotometer at the University of Manchester, which provides five minute averages in each of the five narrow wavebands (305, 313, 320, 340, 380nm). Apart from calibration periods, the Manchester instrument has

been in continuous operation since 1997, and provides a southern site in the Nordic network of GUV radiometers. Data are submitted to WOUDC alongside the ozone data series.

The British Antarctic Survey makes spectral measurements of UV using a Bentham spectro-radiometer at Rothera.

1.4. Calibration activities

Regular calibrations have been carried out on both Met Office Dobson instruments and the Reading Brewer spectrophotometer. The current recommendation is to re-calibrate every two years.

Dobson #32 and the Brewer #075 were taken to Spain in September 2007 for international inter-comparison at El Arenosillo. The Brewer results were good, but the Dobson calibration identified a problem with the CD measurements, which required re-evaluation of historical data. This was carried out and it was demonstrated that the new calibration provided a much more accurate dataset.

Dobson #41 was taken to Hohenpeissenberg for international inter-comparison in June 2009 and was found to be performing well. A further calibration is scheduled for September 2011.

Brewer instrument #075 was taken to El Arenosillo during September 2009. The change in instrument response for measuring ozone over the two year period was found to be 0.3%, well within the acceptable limits. Following technical problems and subsequent repairs, Brewer #075 was calibrated at the RBCC-E home site at Izana, Tenerife, where a new calibration was determined and verified against the European triad of Brewer instruments. During the intervening period, the instrument was temporarily replaced with Brewer #126 courtesy of the UK Met Office in order to maintain the time series.

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

The long-term annual mean trend in ozone for the Lerwick site, and a combined southern England trend from the Camborne (up to 2003) and Reading (2003 onwards) are given below.

A recent trends analysis paper in the International Journal of Climatology (Smedley *et al.*, 2011), analysed the trend data from these sites. This paper demonstrated that the year at which total ozone stopped decreasing over the UK was 1993, by which time statistically significant reductions of 4.8% per decade for Southern England and 5.8% per decade for Lerwick were observed. These rates of decrease are at the upper end of the range in comparison with other European ozone trends before the mid-1990s.

From 1993 to the present the data did not show any significant trend, although small average increases were noted. That there is no trend over this time period is in contrast with Europe as a whole, where a significant increase has been noted.

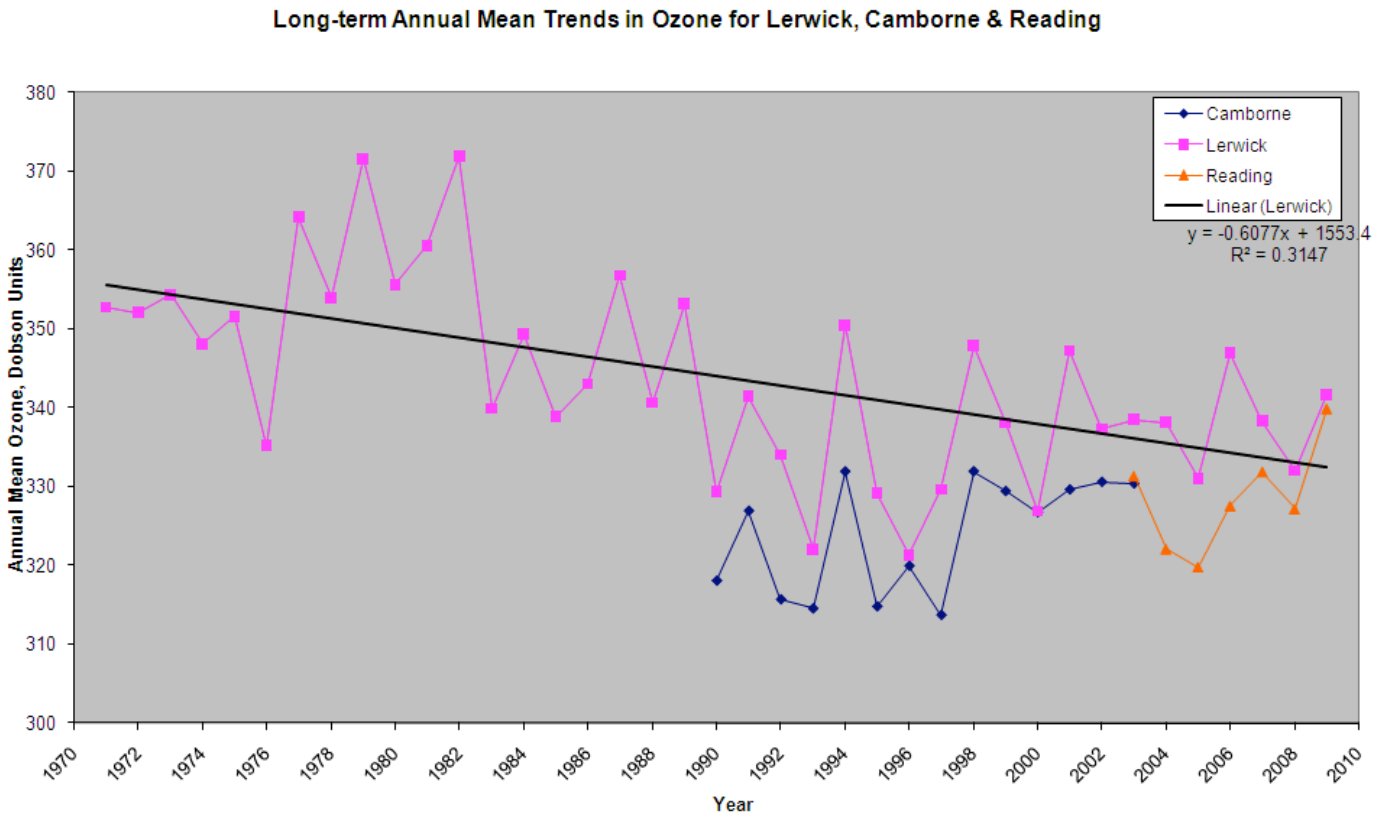

Figure 1 – total ozone trends for Lerwick and combined Southern England.

The data from the monitoring programme have also been analysed seasonally. Table 1 shows that a significant decline at Lerwick since 1978 is seen in the annual mean, Spring and Autumn for both single and multiple regression analysis. There are no significant changes at Reading since 2003. Multiple regression has a large impact on seasonal trends at Reading because of the shorter record.

	Annual	Winter (DJF)	Spring (MAM)	Summer (JJA)	Autumn (SON)
Lerwick -SR	**-0.62** +/- 0.20	-0.12+/- 0.58	**-0.85** +/- 0.30	-0.24 +/-0.17	**-0.61** +/- 0.21
Lerwick- MR	**-0.50**+/- 0.21	-0.08+/-0.60	**-0.69**/- 0.26	-0.22/-0.14	**-0.40+/-**0.18
Reading -SR	+2.97+/-1.19	+2.86+/-2.69	+2.18+/-1.70	+1.76+/-0.74	+2.19+/-1.70
Reading -MR	+2.02+/-1.65	**+**0.07+/-1.79	+2.10+/-1.87	+1.66+/-0.89	+0.49+/-1.15

Table 1 Column ozone trend in DU per year with standard errors. Numbers in bold are significant at the 95% confidence level (P<0.05) SR: single regression; MR: multiple regression. Lerwick since 1978 and Reading since 2003 both to December 2010.

Low ozone events observed by the Defra monitoring programme are reported in near real-time. Two events were reported in 2008, two in 2009 and none in 2010. The frequency of these events has been found to exhibit little historical pattern, but there are two features to note. Firstly, an anomalous decade at Lerwick (1977-1987) when there were very few low ozone events reported. Secondly, high ozone events of the southern UK may be increasing – perhaps in line with a northwards displacement of the Atlantic storm track suggested by climate change predictions.

The UV monitoring results from the Defra programme were also assessed in the Smedley *et al*. paper, which found no significant trend between 1993 and 2008 in the daily totals of UV, but an increase of 6% per decade was seen in the mid-day values of the UV index. This, combined with a lack of correlation between ozone and UV anomalies suggests that changes in cloud cover were the cause.

It should be noted that despite the long-term data produced by the UK total ozone and spectral UV records, in order to clearly observe significant trends since the mid-1990s several more years of high quality data are necessary.

3. THEORY, MODELLING AND OTHER RESEARCH

No activities to report.

4. DISSEMINATION OF RESULTS

4.1. Data reporting

The ozone monitoring data from Lerwick and Reading are processed daily by local operators prior to being quality checked and disseminated. A number of checks are performed to ensure the integrity of these data, including comparison of daily results with OMI satellite measurements and the nearest ground-based measurements.

Results are disseminated by uploading to a dedicated website (http://ozone-uv.defra.gov.uk/) and issuing results to the WOUDC Real-time Mapping Centre. Monthly data are submitted to the WOUDC for inclusion on their archive.

Both total ozone and spectral UV data from the Manchester site are submitted regularly to the WOUDC.

Level 0 and Level 1 ozone data from Halley and Rothera were submitted to the WOUDC by the British Antarctic Survey. Near real-time ozone observations are submitted by BAS to the WMO on a weekly basis. Near real-time reporting using CREX code on the GTS will commence in the near future.

4.2. Information to the public

Ozone monitoring results from the Lerwick, Reading and Camborne sites are publically available on the website (http://ozone-uv.defra.gov.uk/), along with relevant reports.

Broadband UV Index graphs produced by the UK Health Protection Agency are also available on their website at:

http://www.hpa.org.uk/Topics/Radiation/UnderstandingRadiation/UnderstandingRadiationTopics/UltravioletRadiation/uv_Index/

5. PROJECTS AND COLLABORATION

The UK Met Office

The UK Met Office has applied its ozone data assimilation scheme to infer chemical polar ozone loss and to examine phenomena such as low ozone events in the southern summer stratosphere. Studies on the impact of the representation of stratospheric ozone on extended range tropospheric forecasts are also being carried out. The above work is being carried out in collaboration with Imperial College London and European partners. In addition, a Met Office representative co-leads the WCRP SPARC Data Assimilation Working Group.

The UK Met Office Hadley Centre (MOHC) is working on the modelling of stratospheric and tropospheric ozone and their relationship to climate change, as part of its joint DECC/Defra funded MOHC Programme. The MOHC is represented on the coordinating/planning committees of two of the WCRP's SPARC modelling initiatives: CCMVal-2 (Chemistry-Climate Model Validation-2) and DynVar (Modelling the Dynamics and Variability of the Stratosphere-Troposphere System).

The MOHC has further developed its whole atmosphere chemistry model UKCA (United Kingdom Chemistry and Aerosols), in collaboration with Cambridge, Leeds and Oxford universities. These developments are making the UKCA model more self-consistent so that, for example, changes to aerosol concentrations change the chemistry through the photolysis rates. The improvements will also ensure that responses to climate change are well modelled.

Further developments of a full Earth-System Model, in which the UKCA is combined with the MOHC's climate and ecosystem models, have been made. This is enabling the prediction of feedbacks involving tropospheric and stratospheric ozone between climate, chemistry and ecosystems. This links in strongly with the NERC QUEST programme, its earth-system modelling (QUESM), the atmospheric chemistry component (QUAAC) and the land surface component (JULES).

The Natural Environment research Council

The UK Natural Environment Research Council (NERC) funds a number of research programmes relating to stratospheric ozone. The CLEARFOGG (Checking Layers of the Earth's Atmosphere For halogenated Ozone-depleting and Greenhouse Gases) project, due to complete in 2011, is performing a systematic screening of various layers in the Earth's atmosphere for unknown halocarbons, and will determine the influence of these halocarbons on stratospheric ozone depletion.

The Southern hemisphere climate change in an era of ozone recovery project, due to complete in 2011, will use state of the art climate modelling to derive a range of predictions of future climate change which take account of our uncertainty in future ozone change, particularly focussing on the southern hemisphere and the Antarctic ozone hole.

The SOLCLI consortium are running a 4-year coordinated study which began in 2007, on the influences of solar variability on atmospheric composition and climate. The consortium is led by Imperial College, with partners at the Universities of Cambridge, Leeds and Reading and the British Antarctic Survey and with collaborators in Germany, Japan, the USA and the UK

Met Office. Study topics include: variability over the past 150 years in solar spectral irradiance; detection of solar signals throughout the lower and middle atmosphere; response of stratospheric composition, specifically ozone, to varying UV; mechanisms for stratosphere-troposphere dynamical coupling; and better representation of solar effects in climate models.

Further NERC-funded research projects relating to stratospheric ozone include: the impact of the representation of ozone on tropospheric weather forecasts; multi-scale modelling of mesospheric metals, and the impact of the mesosphere on stratospheric ozone and climate; interactions of the lower stratosphere with the tropospheric chemistry/climate system (including recovery scenarios for stratospheric ozone); producing a century-long record of trace gases in the northern hemisphere from the NEEM ice core drilling project in Greenland.

The University of Manchester

The University of Manchester is represented on the WMO Brewer sub-committee, and has been active in discussions on the effective changeover of ozone absorption coefficients and the need for a reliable historical dataset on ozone profiles, required for trend analysis in the presence of climate and circulation changes.

The British Antarctic Survey

An opinion piece by Jonathan Shanklin was published in Nature, and a celebratory meeting held in Cambridge in 2010, to mark the 25th anniversary of the discovery of the ozone hole. Work is in progress on re-evaluating BAS ozone data collected since 1972.

6. FUTURE PLANS

Defra does not have any plans at present to provide direct government funding for any additional ozone, UV or ODS monitoring sites in the UK. The current basic levels of monitoring will, however, be continued.

Defra is keeping future research needs for policy development on stratospheric ozone under review.

NERC is continuing to provide some funding support for new research projects on ozone.

7. NEEDS AND RECOMMENDATIONS

International agreement needs to be reached on the form of zenith polynomial for use in Dobson zenith sky measurements.

Maintenance of long time-series remains essential, especially for trend analysis and ground-truthing of satellite data.

Further work to model emissions of trace gases and ODS will be beneficial for assessing emissions inventories.