UK's National Report for the 12th WMO/UNEP Ozone Research Managers Meeting

Geneva, Switzerland, 24 - 26 April 2024

1. OBSERVATIONAL ACTIVITIES

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

Column ozone measurements are taken at three locations spanning the length of the UK: a Dobson instrument, operated by the Met Office, has been used at Lerwick in the Shetland Islands (North of Scotland) since 1957; a Mark III Brewer instrument, operated by the University of Manchester, has been used at Manchester in northern England since 2000; and a Mark IV Brewer has been operated by the University of Manchester at Reading in southern England since 2003. In addition, a SAOZ (Systeme D'Analyse par Observations Zenithale) instrument in Aberystwyth was in place from 1991 until 2019 with data reprocessed by the University of Manchester. The Manchester site itself was relocated in late 2023 due to infrastructure changes, but only moved by c. 800m. The Lerwick, Reading and Manchester operations are funded by the UK Government (Department for Environment, Food and Rural Affairs). In addition to ozone column measurements the SAOZ measured the nitrogen dioxide column. The site operation itself at Aberystwyth was supported by the Natural Environment Research Council (NERC) via the National Centre for Atmospheric Science (NCAS).

In the case of Reading, Manchester and Lerwick, the spectrophotometers operating in the UV band sample the ozone column at frequent intervals throughout the day to produce daily mean values, except when weather conditions prevent recording or during winter at Lerwick when the sun is too low. The data is submitted to the World Ozone and Ultraviolet Radiation Data Centre (WOUDC), WMO World Data Archive and University of Thessaloniki. The data from these measurements are available at: https://uk-air.defra.gov.uk/data/ozone-data.

Also, the Brewer Ozone Spectrophotometers at Manchester and Reading submit high frequency, near real time raw data to EuBrewNet for central processing and quality assurance. The processed data is available from the EuBrewNet servers, http://www.eubrewnet.org, and also via link from WOUDC.

It has also come to light that Kipp and Zonen will no longer manufacture Brewer spectrophotometers. In an effort to maintain the long-term ozone data series (two of the three UK Brewers are older single monochromator designs) and mitigate the difficulty posed by failed parts, alternatives have been sought. Therefore, currently under preliminary testing are, two recently purchased BTS-Solar instruments.

The instrument at Aberystwyth worked on a different methodology, operating in the Chappuis visible band (450nm to 570nm), acquiring slant columns during sunrise and sunset to produce two estimates per day. Normally data is submitted to WOUDC, the University of Thessaloniki WMO mapping centre and the Network for the Detection of Atmospheric Composition Change (NDACC). However, in May 2019 the SAOZ GPS ceased to provide the correct time. A new GPS unit was supplied and fitted in August 2019, but it has failed to resolve the issue. Discussions continue with LATMOS to try to find a solution, but these have proved unsuccessful. Therefore, we do not expect the SAOZ to come back into operation.

The UK also carries out ozone and nitrogen dioxide measurements at locations in Antarctica through the British Antarctic Survey (BAS). This includes a Dobson spectrophotometer, operated since 1956, and a SAOZ spectrometer, operated between 2013 and 2016 at the Halley station, and a SAOZ instrument at Rothera, operated since 1996, which was previously installed at Faraday from 1990 - 1995. Since the end of 2018, BAS have taken automatic readings from Halley during the Antarctic winter, with manual readings taken in the Antarctic summer between late November and early February. A Dobson instrument at Ukraine's Vernadsky/Faraday station, operated since 1957, is on long-term loan to Vernadsky from BAS. Radiosonde measurements are also taken at Halley and Rothera.

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

Brewer Umkehr profile measurements of ozone are made routinely at the Manchester and Reading sites, the raw data is routinely submitted to WOUDC.

The Met Office has conducted ozonesonde launches from Lerwick regularly since 1995, currently for model verification purposes. Data is sent the same day to the Norwegian Institute for Air Research (NILU) database. Data is sent monthly to the WOUDC. The UK Government Department for Energy Security and Net Zero (DESNZ) funds five stations in the UK and Ireland (UK DECC network) monitoring greenhouse gases, ozone-depleting substances (ODS) and related gases.

Two of these (Mace Head, a coastal station in the west of Ireland, operated since 1987, and Tacolneston, a Telecommunication mast in England, operated since 2012) make high frequency, real time, *in situ* measurements of a comprehensive suite of ODS including CFCs, HCFCs, halons, other halocarbons, and nitrous oxide (N_2O) as well as related radiatively active trace gases such as carbon dioxide (CO_2), methane (CH_4), PFCs, HFCs, sulphur hexafluoride (SF_6), nitrogen trifluoride (NF_3), carbon monoxide (CO), hydrogen (H_2) and ozone (O_3). Three further sites in the east and west of England and central Scotland (the latter now replaced by a site in northern England) measure CH_4, N_2O, CO_2 and SF_6.

The Mace Head site is well positioned to contrast clean westerly air entering Europe from the Atlantic with polluted air leaving Europe towards the Atlantic. The site is, therefore, ideally situated to record trace gas concentrations associated with both the Northern Hemisphere background levels and the more polluted air arising from Europe. The other sites in England provide spatial measurement distribution to help determine emissions estimates for the UK.

Analysis of the atmospheric observation data identifies sources of and trends in ODS and related gas emissions from different areas, including comparison of observed data with expected trends from inventories. Work is in progress to identify new substances with ozone depleting or radiative forcing properties, and a significant number of these have been identified, including "new" CFCs, HFCs, HCFCs and PFCs. Some of these measurements form a key part of the international Advanced Global Atmospheric Gases Experiment (AGAGE) measurement programme. Measurements at Ridge Hill and Weybourne are part of the Integrated Carbon Observing System (http://www.icos-uk.org/icos-and-uk). More information, including links to the data is available at: UK DECC Network | School of Chemistry | University of Bristol and http://agage.mit.edu/

Table 1:

Summary of UK stations monitoring ozone-depleting substances (ODS) and related gases

Station	Surface or tall tower	Date ODS-related measurements started	ODS and related measurements	Network affiliated	Responsible organisation

Mace Head, Ireland	Surface	1987	CFCs, HCFCs, HFCs, HFCs PFCs and other halocarbons, O_3, N_2O, CH_4, SF_6, CO_2, CO, H_2	UK DECC & AGAGE	UBristol
Tacolneston, England	Telecom mast	2012	CFCs, HCFCs, HFCs, HFCs PFCs and Halocarbons, N_2O, CH_4, SF_6, CO_2, CO	UK DECC & AGAGE	UBristol
Weybourne, England	Surface	2013	N_2O, CH_4, SF_6, CO_2	ICOS	UEA
Angus, Scotland (no longer monitoring since 2015)	Telecom mast	2007	CH_4,CO_2,	UK DECC	UBristol
Bilsdale, England (replaced Angus). Currently unavailable due to fire damage.	Telecom mast	2014	N_2O, CH_4, SF_6, CO_2, CO	UK DECC	UBristol
Ridge Hill, England	Telecom mast	2012	N_2O, CH_4, SF_6, CO_2	UK DECC & ICOS	UBristol
Heathfield, England	Telecom mast	2013	N_2O, CH_4, SF_6, CO_2	UK DECC	NPL & UBristol

The NCAS supports various long-term halocarbon measurement programmes at the University of East Anglia (http://weybourne.uea.ac.uk/data.php). These include the Cape Grim air archive measurements from Tasmania (dating back to 1978) and the CARIBIC flying observatory (www.caribic-atmospheric.com) which provide regular data from the upper troposphere/lower stratosphere (UTLS) region. UEA also have numerous other ODS-related projects which include surface measurements in East and SE Asia, aircraft measurements and measurements in air trapped in firn and ice. For many years UEA have pioneered the detection and identification of new ODS in the atmosphere and are currently developing a unique low-cost “AirCore” sampling programme for halocarbons in the stratosphere, which will provide data over the 30-40 km altitude range.

<u>1.2.1 Expansion of ODS measurement network</u>

Under the UK Research and Innovation (UKRI) funded Greenhouse gas Measurement and Modelling Advancement (GEMMA) project, two new in situ ODS and GHG measurement sites are being constructed to begin operation in 2024, one in Scotland and the other in North-West England. These instruments are under development at the University of Bristol.

The University of Bristol has received funding from the European Union, via UNEP, to examine potential new locations for global monitoring stations. Flask sampling campaigns are ongoing in the Maldives and Bangladesh. These new measurements will also be augmented by exploratory sampling in Vietnam and Taiwan by UEA, funded through the Natural Environment Research Council (NERC) InHALE (Investigating Halocarbon impacts on the global Environment) project.

1.3 UV measurements

1.3.1 Broadband measurements

Solar radiation is measured at nine sites (from 50 to 60° N) across the UK by the UK Health Security Agency (UKHSA). UKHSA also operates sites in Gibraltar, Cyprus and Malin Head in the Republic of Ireland. Each site includes three detectors measuring erythema weighted UV and UV-A irradiances, and illuminance. These monitoring sites provide Global Solar UV Index information to the public (https://uk-air.defra.gov.uk/data/uv-index-graphs).

UKHSA also operates a Kipp and Zonen Solys 2 Sun tracker with two Kipp and Zonen UV-S-E-T broadband radiometers measuring global and diffuse components of erythema weighted UV radiation and two ULS2048L-EVO spectroradiometers from Avantes for measurements of UV-A and visible radiation at Chilton in Oxfordshire.

The University of Manchester operates a Kipp and Zonen UV-S-AE-T broadband radiometer which measures erythemal UV radiation in central Manchester.

1.3.2 Narrowband filter instruments

The University of Manchester operates a Biospherical GUV-541 multifilter instrument, located in central Manchester, which has been in operation since 1997. It has 5 channels of bandwidth ~ 10 nm, centred at 305, 313, 320, 340 and 380 nm. From this the erythemal / UV index is calculated every minute and is available on https://uk-air.defra.gov.uk/data/uv-index-graphs

1.3.3 Spectroradiometers

The UK Government funds measurements from a Bentham DM150 spectroradiometer which is co-located with the Brewer spectrophotometer at Reading in southern England. The data series is one of the longest in the World and extends back to 1991 with regular operation since 1993. The current instrument takes calibrated (NIST-traceable) measurements from 290nm to 500nm at 0.5nm resolution at half-hour periods during daylight hours, every day of the year. Data is submitted monthly to WOUDC.

The University of Manchester uses a Mark III Brewer (double monochromator) to measure spectral UV irradiance (290nm to 363 nm) in Manchester. This instrument has been in operation since 2000 and forms the basis for studies requiring long term spectral data in the north of England.

Spectral UV measurements have been carried out at the UKHSAsite at Chilton since 1993 using scanning spectroradiometers; in 2018 the capability was upgraded to a Bentham DTMc300 (Bentham Instruments, Reading, UK). This instrument takes measurements from 280 nm to 800 nm at 30-minute intervals. Two portable spectral measurement systems (APSUS) have been developed for field deployment outside Chilton. A customised Bentham DMc150 double Monochromator for 280nm to600 nm spectral range housed in an environmental housing has been operated around the world.

1.4 Calibration activities

The Dobson #32 machine at Lerwick was last calibrated in 2023. The next calibration will take place in 2029 at the Regional Dobson Calibration Centre at Hohenpeissenberg, Germany. Dobson #41 at Lerwick was calibrated at Hohenpeissenberg in 2020 and the next calibration is due in 2026.

Brewers #075, #126, Reading and #172, Manchester are calibrated biennially at El Arenosillo in Spain against the Regional Brewer Calibratoin Centre - Europe triad. The last calibration was September 2023. The next calibration is due in 2025. The instruments are now also characterised for filter non-linearities and stray light errors for input into the EuBrewNet processing algorithms. This calibration includes both ozone and spectral UV irradiance measured by the Brewer.

The Bentham DM150 UV spectroradiometer in Reading is calibrated monthly in situ with reference to the NIST traceable irradiance standards held at the University of Manchester calibration laboratory. In addition, in May 2022 the QASUME instrument (WMO World Calibration Reference) operated by PMOD/WRC was brought to the site for a calibration intercomparison. The next visit is due in 2025. The Biospherical GUV-541 and the Kipp and Zonen UV-S-E-T are periodically sent to PMOD/WRC when regional or global intercomparisons are offered there. Otherwise calibrations are checked *in situ* between instruments and with the calibration facilities available at University of Manchester.

At least one of the BAS Dobson instruments in Antarctica was last recalibrated at Hohenpeissenberg in 2017. It may be possible to exchange this with the Dobson currently at the Vernadsky station in future years and discussions about this are ongoing.

UKHSA’s solar network (12 sites) and spectral systems at Chilton are regularly calibrated in situ.

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

2.1 UV exposures

UKHSA has carried out an analysis into a 25-year dataset of erythema effective UV at Chilton, Oxfordshire. An increase in annual erythema effective radiant exposure of 4.4% per year was found between 1991 and 1995 and explained by decreasing ozone and increasing sunshine hours; a small decrease of 0.8% per year was found from 1995-2015. Sunshine hours data were from the Radcliffe Meteorological Station, University of Oxford.

This analysis can be found here: Hooke, R.J., Higlett, M.P., Hunter, N. and O'Hagan, J.B., 2017. Long term variations in erythema effective solar UV at Chilton, UK, from 1991 to 2015. *Photochemical & Photobiological Sciences*, *16*(11), pp.1596-1603.
Comparison of erythema effective exposure with ozone and cloud cover showed that between 1991 and 2004 there was a significant increasing trend of 1.01% per year, largely explained by cloud cover. Between 2004 and 2015 there was a significant decreasing trend of 1.35% per year, with ozone having the greater effect.

This analysis can be found here: Hunter, N., Rendell, R.J., Higlett, M.P., O'Hagan, J.B. and Haylock, R.G., 2019. Relationship between erythema effective UV radiant exposure, total ozone, cloud cover and aerosols in southern England, UK. *Atmospheric Chemistry and Physics*, *19*(1), pp.683-699

2.2 Column ozone

Data from the ozone column measurements at Lerwick, Manchester and Reading are published by the UK Government here: https://uk-air.defra.gov.uk/data/ozone-data.

UV data is viewable from the UKHSA solar network and from Manchester and Reading here: https://uk-air.defra.gov.uk/data/uv-index-graphs. Data is also available on request from UKHSA (solar@UKHSA.gov.uk), while Reading and Manchester data is available here: https://uk-air.defra.gov.uk/data/uv-data.

Trends analysis of the measurements suggests that as of the start of 2024, the long-term decline in column ozone over the UK has not yet been reversed. A long-term (since 1978) autumn decline is significant for single and multiple regression. It is difficult to explain enhanced ozone loss prior to the cold season of polar stratospheric cloud formation. However, the principal component analysis confirms that the most likely cause of the autumn trend is tropospheric circulation changes. In Smedley et al (2010) (Int. J. Climatol., doi:10.1002/joc.2275) the Reading ozone series was homogenised with older records to create a southern UK time series extending back to 1979.

Table 2: Trend analyses

Site (ordered south to north)	1979-1994 annual linear trend [DU/yr]	Significance of 1979-1994 annual linear trend [%]	Post-1994 annual linear trend [DU/yr]	Significance of post-1994 annual linear trend [%]	Recent decadal trend [DU/yr]
Southern UK / Reading	**-1.29**	**99.86**	+0.27	45.59	-1.1
Manchester	N/A	N/A	-0.06	29.02	-1.19
Lerwick	**-1.77**	**98.30**	+0.48	78.76	-0.88

Notes:

These trend analyses are updated versions of those described in Smedley et al (2010), Int. J. Clim.

Annual mean residuals used to calculate the trends are the annual de-seasonalised values i.e. annual mean of ozone minus the observed climatology.

A breakpoint is assumed to occur in 1994, and two-part linear trends are calculated on this basis for the Southern UK / Reading and Lerwick data series. The Manchester data series starts in 2000.

Significant trends at the 5% level are highlighted in bold. Only trends during ozone depletion are significant and none of the three sites yet shows statistical significant signs of recovery, with a weakening of any recovery since c. 2014.

Figure 1:

Annual deseasonalised mean total column ozone for three UK sites (dark grey) 1979-2023. Data smoothed with a 10-year window is shown in red.

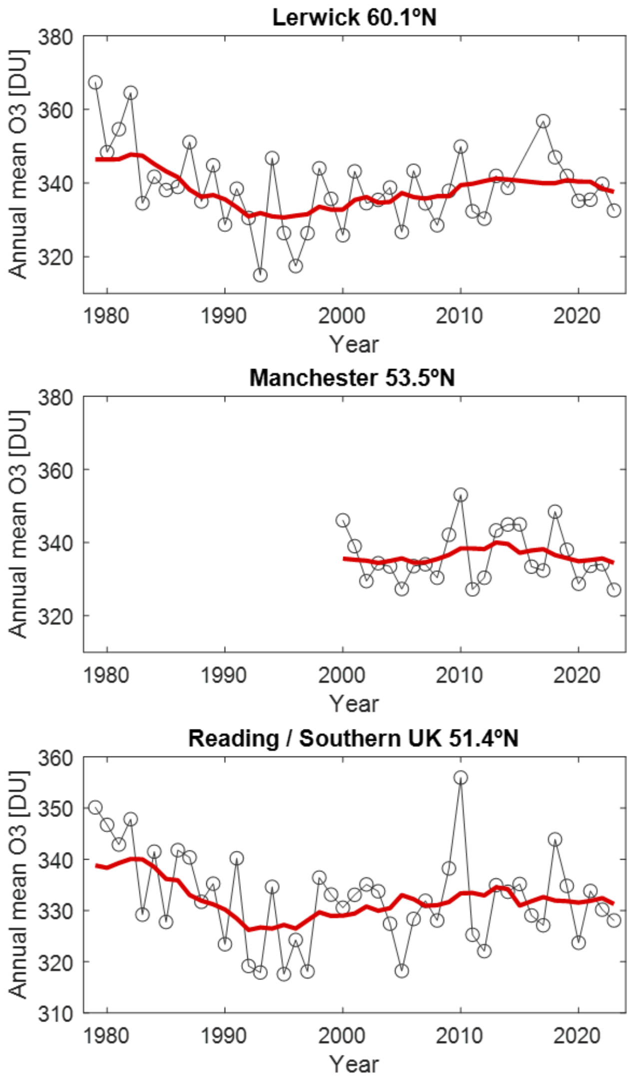


Table 3: Days that meet the Low Ozone Event criteria since Jan 2014

Lerwick	Manchester	Reading
5-Sep-23	23-Dec-23	
4-Sep-23	21-Dec-23	

20-Apr-23		07-Oct-23
14-Feb-23		20-Aug-23
13-Feb-23	24-Jun-23	24-Jun-23
12-Feb-23	12-Feb-23	12-Feb-23
11-Feb-23	11-Feb-23	11-Feb-23
26-Oct-21		10-Feb-23
24-Oct-21	09-Jun-22	
23-Oct-21	27-Oct-21	
24-Sep-21	06-Sep-21	06-Sep-21
15-Jul-21	17-Jul-21	
30-Jun-21	18-Nov-20	
26-Jun-21	10-Apr-20	
16-Jun-21	06-Apr-20	
15-Aug-20		
15-Jun-20		
17-Apr-20		
10-Apr-20		
9-Apr-20		
5-Apr-20		
4-Apr-20		
25-Jan-20		
	03-Dec-19	03-Dec-19
		26-Nov-19
23-Oct-19		
	05-Oct-19	05-Oct-19
	15Sep-19	
25-Jul19		
28-Jun-19		
27-Jun-19		
	20-Mar-19	20-Mar-19
	26-Sep-18	
	25-Sep-18	
9-Jul-18		
4-Jun-18		

2.3 Ozone depleting substances

Research by the University of Bristol and the Met Office, in collaboration with AGAGE and NOAA colleagues, has led to several notable findings relevant to the Montreal Protocol. Scientific results related to ODSs for the period 2016 – 2020 were summarised in Chapter 1 and Chapter 2 of the 2022 WMO Scientific Assessment of Ozone Depletion, for which University of Bristol researchers participated as lead and contributing authors (Liang and Rigby, 2022; Laube and Teigtmeier, 2022) . Recent notable scientific publications by this team have included quantification of global emissions of CFCs and HCFCs that are primarily thought to be used as chemical feedstocks or are formed as by-products during the manufacture of other species (Western, et al., 2023, Figure 1) and the quantification of emissions from ODSs from China (An et al., 2023).

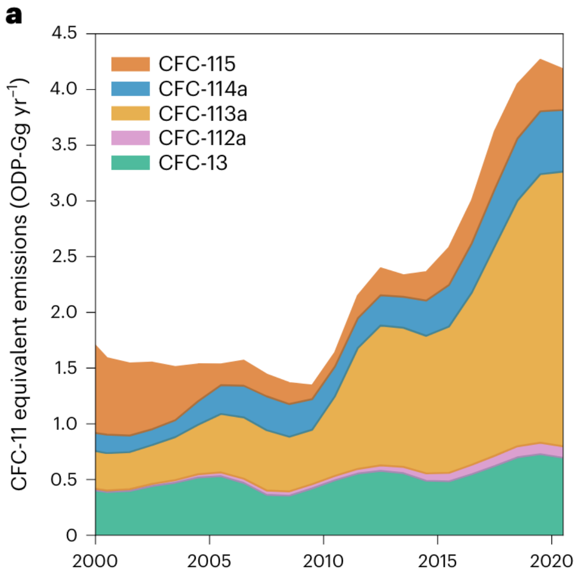


Figure 2. CFC-11 equivalent emissions of CFCs 13, 112a, 113a, 114a and 115 (Western et al., 2023)

Global atmospheric trends together with UK and North-west European emissions of a wide range of ODS are reported to DESNZ each year (Monitoring and verification of long term UK atmosUKHSAric measurement of greenhouse gas emissions - GOV.UK (www.gov.uk)). These regional estimates have been made using the atmospheric observations from Mace Head, Tacolneston and 4 other European stations: Jungfraujoch, Monte Cimone, Zeppelin and Taunus.

For example, the estimated UK emissions of HCFC-22 are shown in Figure 2.

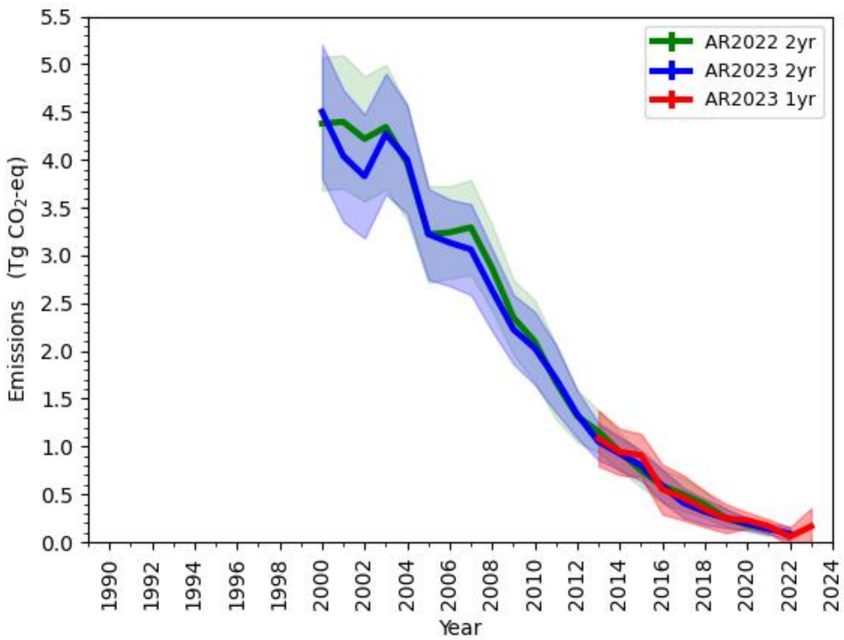
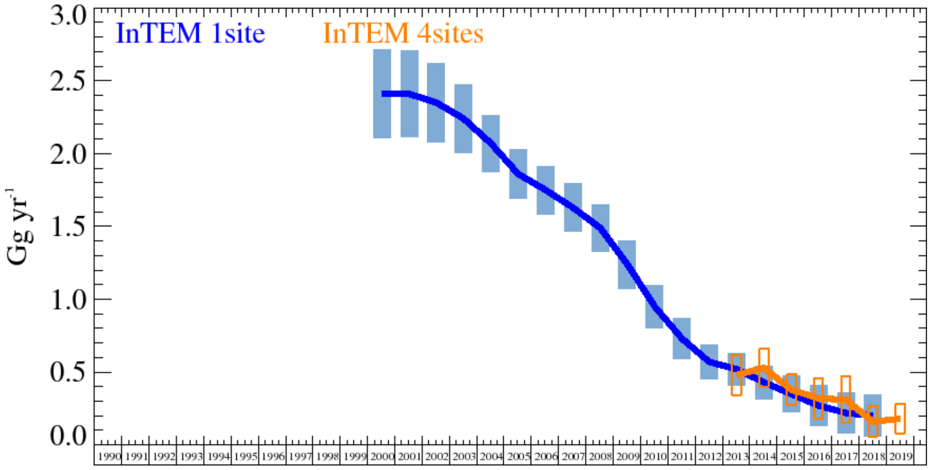


Figure 2. UK emission estimates (Tg CO2-eq yr-1) of HCFC-22 using InTEM (annually averaged): (a) 2yr inversion from previous annual report (green), (b) 2-yr inversion from

current annual report (blue) and (c) 1-yr inversion from current annual report (orange). The uncertainty bars represent 1 std.



3. THEORY, MODELLING, AND OTHER OZONE RELATED RESEARCH

Since the last report for the 10th Ozone Research Manager's meeting, the University of Manchester has undertaken a range of research on ozone and UV. Details are included in section 4.3 below.

Since the last report, Public Health England has undertaken a range of research on UV exposures. Details are included in sections 4.3 and 5.

The University of Bristol has developed global modelling capability for all major ODSs and related gases. These modelling techniques are used to provide global emissions estimates to the Parties via the WMO Scientific Assessments of Ozone Depletion (e.g. Engel and Rigby, 2018). The Met Office has developed an atmospheric chemical transport model, NAME, which is widely used to study regional ODS dispersion. Met Office and University of Bristol researchers use NAME model output and Bayesian inverse methods to infer regional ODS emissions from atmospheric observations (e.g. Rigby, et al., 2019; Fang, et al., 2018; Lunt, et al., 2018).

4. DISSEMINATION OF RESULTS

4.1 Data reporting

The ozone monitoring data from Lerwick, Reading, and Manchester is processed daily and quality checked by comparison with Ozone Monitoring Instrument (OMI) satellite measurements, the nearest ground-based measurements and previous ozone climatology. Results are supplied to the WOUDC Real-time mapping centre and University of Thessaloniki. The Brewer data from Manchester and Reading is also automatically transferred to the new EuBrewNet NRT database. The data is also published on the internet at http://uk-air.defra.gov.uk/research/ozone-uv for the wider research community.

Both total ozone, multi-filter UV data from the Manchester site and spectral UV data from Reading are submitted regularly to the WOUDC.

Level 0 and level 1 Dobson ozone data from the Halley and Vernadsky stations in Antarctica are submitted to the WOUDC by the BAS. Observations are reported in real-time using CREX (Character form for the Representation and EXchange of data) on the Global

Telecommunications System (GTS) from Halley, Rothera and Vernadsky. Quality controlled ozone observations are submitted by BAS to the WMO on a regular basis.

AGAGE data are reported to ESS-DIVE bi-annually (https://data.ess dive.lbl.gov/view/doi:10.3334/CDIAC/ATG.DB1001).
UK DECC network data are reported to CEDA (http://data.ceda.ac.uk/badc/uk-decc-network/data) on a regular basis.

4.2 Information to the public

Ozone monitoring results from the Lerwick, Reading, Manchester and (no longer operational) Camborne sites are publicly available at http://uk-air.defra.gov.uk/research/ozone-uv/. Real time UV Index graphs are also published on that site at this address: https://uk-air.defra.gov.uk/data/uv-index-graphs. Public health messages continue to be issued in collaboration with Defra, the UK Met Office and UKHSA at times of higher than expected levels of UV Index. Data from the Antarctic stations, and assessments about the ozone hole are available at
https://legacy.bas.ac.uk/met/jds/ozone/index.html

4.3 Relevant scientific papers

Below is a list of scientific papers led by or involving UK organisations, published since the last Ozone Research Managers meeting in 2017.

An, M., Western, L. M., Hu, J., Yao, B., Mühle, J., Ganesan, A. L., Prinn, R. G., Krummel, P. B., Hossaini, R., Fang, X., O'Doherty, S., Weiss, R. F., Young, D., and Rigby, M.: Anthropogenic Chloroform Emissions from China Drive Changes in Global Emissions, Environ. Sci. Technol., 57, 13925–13936, https://doi.org/10.1021/acs.est.3c01898, 2023.

Elliott TM, Gordon LG, Webb A, Kift R, Foeglein A and Neale RE. (2023) Making the sunshine vitamin – How much sun exposure is needed to maintain 25-hydroxy vitamin D concentration? *Photochem Photobiol.* **00**, 1–10. doi:10.1111/php.13854

Petkov, BH, Vitale V, Di Carlo P, Drofa O, Mastrangelo D, Smedley ARD et al. (2023) An unprecedented Arctic ozone depletion event during spring 2020 and its impacts across Europe. *Journal of Geophysical Research: Atmospheres* **128**, e2022JD037581. doi: 10.1029/2022JD037581

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Walker HL, Heal MR, Braban CF, Leeson SR, Simmons I, Jones MR, Kift R, Marsden N and Twigg MM. (2022), The importance of capturing local measurement-driven adjustment of modelled j(NO2). *Atmosphere* **13**, 1065.

Webb AR, Van Der Zande BMI, Kift RC, O'Neil H, Lin NX and Wright D. (2022) Ultra-low ultraviolet radiation in office lighting can moderate seasonal vitamin D cycle: a pilot study. *Anticancer Res.* **42**(10), 5101–5106. doi: 10.21873/anticanres.16020

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Webb AR, Alghamdi R, Kift R and Rhodes LE. (2021) Dose–response for change in 25-hydroxyvitamin D after UV exposure: outcome of a systematic review. *Endocrine Connections* **10**, R248–R266.

Kosmopoulos PG et al. (31 authors inc. Webb AR) (2021) Real-time UV-Index retrieval in Europe using earth-observation based techniques and validation against ground-based measurements. *Atmos. Meas. Tech.* **14**, 5657–5699. doi: 10.5194/amt-14-5657-2021

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Felton S, Shih B, Watson R, Kift R, Webb A and Rhodes L. (2020) Photoprotection conferred by low level summer sunlight exposures against pro-inflammatory UVR insult. *Photochem. Photobiol. Sci.* **19**, 810–818.

Fountoulakis I, Diémoz H, Siani A-M, Laschewski G, Filippa G, Arola A, Bais AF, De Backer H, Lakkala K, Webb AR, De Bock V, Karppinen T, Garane K, Kapsomenakis J, Koukouli M-E and Zerefos CS. (2020) Solar UV irradiance in a changing climate: trends in Europe and the significance of spectral monitoring in Italy. *Environments* **7**(1), 1–31.

Rendell R, Higlett MP, Khazova M and O'Hagan J. (2020) Public health implications of solar UV exposure during extreme cold and hot weather episodes in 2018 in Chilton, South East England. *Journal of Environmental and Public Health*, art. no.: 2589601. doi: 10.1155/2020/2589601

Stanley KM, Say D, Mühle J, Harth CM, Krummel PB, Young D, O'Doherty SJ, Salameh PK, Simmonds PG, Weiss RF, Prinn RG, Fraser PJ and Rigby M. (2020) Increase in global emissions of HFC-23 despite near-total expected reductions. *Nat. Commun.* **11**(1), 397. doi: 10.1038/s41467-019-13899-4

Yu D, Yao B, Lin W, Vollmer MK, Ge B, Zhang G, Li Y, Xu H, O'Doherty S, Chen L and Reimann S. (2020) Atmospheric CH_3CCl_3 observations in China: historical trends and implications. *Atmos. Res.* **231**, art. no.: 104658. doi:10.1016/j.atmosres.2019.104658

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Baczynska KA, Khazova M and O'Hagan JB. (2019) Sun exposure of indoor workers in the UK–survey on the time spent outdoors. *Photochemical and Photobiological Sciences* **18**(1), 120–128.

Corradi E, Baczynska KA, Morelli M, Giulietti D and Khazova M. (2019) Method for measurements of terrestrial ultraviolet radiation on inclined surfaces in personal dosimetry field studies. *Photochemistry and Photobiology* **95**(6), 1454–1460.

Hossaini R, Atlas E, Dhomse SS, Chipperfield MP, Bernath PF, Fernando AM, Mühle J, Leeson AA, Montzka SA, Feng W, Harrison JJ, Krummel P, Vollmer MK, Reimann S, O'Doherty S, Young D, Maione M, Arduini J and Lunder CR. (2019) Recent trends in stratospheric chlorine from very short-lived substances. *J. Geophys. Res. Atmos.* **124**(4), 2318–2335. doi:10.1029/2018JD029400

Hunter N, Rendell R, Higlett M, O'Hagan J and Haylock R. (2019) Relationship between erythema effective UV radiant exposure, total ozone and cloud cover in southern England UK: 1991-2015. *Atmospheric Chemistry and Physics* **19**, 683–699.

Isner J-C, Olteanu V-A, Hetherington AJ, Coupel-Ledru A, Sun P, Pridgeon AJ, Jones GS, Oates M, Williams TA, Maathuis FJM, Kift R, Webb A, Gough J, Franklin KA and Hetherington AM. (2019) Short and long-term effects of UV-A on Arabidopsis are mediated by a novel cGMP phosphodiesterase. *Current Biology* **29**(15), 2580–2585.

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5. PROJECTS, COLLABORATION, TWINNING AND CAPACITY BUILDING

Since the 11th ORM, the following additional activities have taken place.

5.1 University of Manchester

Chairing the EUBREWNET project, originally funded by the European COST Office, to bring all the European Brewer Ozone Spectrophotometer stations together in a formal network. The project integrates, automates and improves the consistency of Brewer ozone, UV and aerosol optical depth measurements by employing central data processing and QA/QC in a new NRT database, which adds significantly to the scientific value of the data. EUBREWNET has expanded from its original scope of European sites and now includes stations in South America, Australia, Africa, USA, Scandinavia, Middle East, Malaysia, Russian Federation, Singapore and Antarctica. This is leading to a fully functioning global network which is helping to restore the capacity required for authentic satellite validations. More information is available at: http://www.eubrewnet.org

Helped with the initial discussions relating to the recent Brewer intercomparison held in Brazil.

5.2 Public Health England

UKHSA is a WHO Collaborating Centre for Radiation Protection participating in WHO activities on health effects of optical radiation and in WHO's INTERSUN Programme.

UKHSA current research covers sun exposures of NHS patients undergoing daylight Photodynamic Therapy (dPDT), UV exposures of Xeroderma Pigmentosum (XP) patients, UV exposures of office workers and commercial pilots, input into epidemiology of non-melanoma skin cancers (NMSC), development of methods and instrumentation for assessment of personal exposures. Results of the study on in-flight exposures of commercial pilots was submitted as evidence to the UK Industrial Injuries Advisory Council and to WHO Department of Public Health, Environmental and Social Determinants of Health. UKHSA also carried out research into the impact of solar UV exposure during extreme hot and cold weather events in 2018. UKHSA organised and hosted the Nordic Ozone Group workshop in 2019.

5.3 University of Bristol

Measurement of a comprehensive suite of ODS and related gases at a tall tower in the south of England (UK DECC Network) as part of a UK inventory validation activity.

Measurement of a comprehensive suite of ODS and related gases at Mace Head, Ireland and Ragged Point, Barbados as part of the international AGAGE program.

University of Bristol investigators were lead authors of and contributors to the 2018 WMO Scientific Assessment of Ozone Depletion.

Dr Matt Rigby of the University of Bristol is a scientific consultant for the TEAP report "VOLUME 1: DECISION XXX/3 TEAP TASK FORCE REPORT ON UNEXPECTED EMISSIONS OF TRICHLOROFLUOROMETHANE (CFC-11)", September 2019 and lead author for the upcoming Scientific Assessment Panel (SAP) report on CFC-11.

6. IMPLEMENTATION OF THE RECOMMENDATIONS OF THE 10th OZONE RESEARCH MANAGERS MEETING

Relevant actions undertaken by UK organisations are listed below.

6.1 Research Needs

6.1.1 Factors affecting UV

See UKHSA publications 1 and 5 in Section 4.3.

6.1.2 UV change impacts

Public health impacts of solar UV exposure, both positive and negative, during extreme hot and cold weather in England in 2018 were addressed in UKHSA publication 11 in Section 4.3. UKHSA also carried out studies on UV exposure of British office workers (publication 10), vitamin D and sun exposure at holidays in high UV index destinations (publications 13-15). UKHSA is also working with the NHS to develop new treatments for actinic keratosis using sunlight, (publications 2, 6 and 7)

6.2 Systematic observations

6.2.1 Ground based stations

The University of Manchester operates a Bentham DM150 spectroradiometer, sited in Reading, which takes half hourly measurements of spectral UV from 290nm to 500nm. Dating back to 1993, this is now one of the longest spectral UV records in the world.

The University of Manchester also operates a Brewer Ozone Spectrophotometer measuring total column ozone (TCO), collocated with the Bentham UV instrument, since 2003 plus another at Manchester since 2000. The Reading data has been homogenised with the Camborne and Bracknell Dobson data to give a long term record for the Southern UK since 1967. Dobson TOC data from Lerwick, operated by UKMO also dates back to 1952.

The Brewers operated by the University of Manchester at Reading and Manchester also take daily umkehr ozone profile measurements. All instruments are calibrated and data is quality assured according to WMO guidelines.

The Public Health England solar network includes ground-based UV detectors. It consists of twelve sites, five of which have >25y of solar UV data (Camborne, Chilton, Glasgow, Leeds, Lerwick), see UKHSA publications 1, 3 and 4 in Section 4.3.

6.2.2 New and cost effective instruments

The University of Manchester using funding provided by DEFRA has purchased a suite of 3

Gigahertz-Optik instruments. Two BTS-Solar UV Spectroradiometer's on suntrackers for direct solar irradiance measurements and TOC determination and a BTS2048-VL-TEC-WP outdoor UV spectroradiometer. As noted earlier the Gigahertz instruments were chosen due to the end of Brewer manufacturing by Kipp and Zonen. These are in the process of characterisation and will be deployed later this year for testing outside with the intention of setting up next to the existing instruments at Manchester and Reading to allow for a period of collocated running. This will enable the inter-instrument calibrations to be checked with an aim of providing backup in case of equipment failure due to age and to ensure the continuity of the time series of high-quality measurements.

6.2.3 Mechanisms to give recognition to data providers, exchange findings and feedback on data quality

EuBrewNet data will be assigned DOI's to help with appropriate recognition.

6.3 Data Archiving and Stewardship

6.3.1 Developing robust automated data submission

EUBrewNet data submission complies with the automation, QA, NRT, calibration, reprocessing and submission requirements and now has scientific oversight. Tools are also available to the data user.

6.3.2 Encourage data providers to submit to established databases

EuBrewNet provides for this, all that is needed is client software and an internet connection. Archived data is also submitted to WOUDC.

6.4 Capacity building

Helped with the initial discussions relating to the recent Brewer intercomparison and operator course held in Brazil.

7. FUTURE PLANS

The University of Manchester will continue with the Brewer and UV monitoring and will also assess the new BTS instruments for consideration as replacement instruments. Research into UV exposure and vitamin D will also continue.

Under the UK Research and Innovation (UKRI) funded Greenhouse gas Measurement and Modelling Advancement (GEMMA) project, two new in situ ODS and GHG measurement sites are being constructed to begin operation in 2024, one in Scotland and the other in North-West England. These instruments are under development at the University of Bristol.

The University of Bristol has received funding from the European Union, via UNEP, to examine potential new locations for global monitoring stations. Flask sampling campaigns are ongoing in the Maldives and Bangladesh. These new measurements will also be augmented by exploratory sampling in Vietnam and Taiwan by UEA, funded through the Natural Environment Research Council (NERC) InHALE (Investigating Halocarbon impacts on the global Environment) project.

8. NEEDS AND RECOMMENDATIONS

Extending the current monitoring of the main ODS gases to more areas of the world should be a priority.

As climate change continues to intensify, long-term measurement of both spectral UV and ozone, ideally co-located, is essential to track changes near population centres. The coincident measurements are essential for disaggregation of factors that affect UV with a prioritisation to stations where populations might be affected either negatively or beneficially. Recent studies have shown that high quality spectral UV data is required to separately calculate the available UV for Vitamin D production, DNA damage and erythema risk, which is not possible with broadband measurements.

The worldwide reduction in ozone and UV monitoring has still not been fully reversed, risking further damage to our monitoring capabilities. In particular it is essential to ensure that there continues to be sufficient high quality, geographically distributed ground station data submitted to the world data centres in order to ensure adequate validation of satellite data. Equally important is the maintenance of technical and scientific expertise which is often lost as staff are lost because of station closures, or funding does not allow for succession as staff retire.

The impact and future projected emissions of chlorinated ‘very short-lived substances’ should be investigated further to enable Montreal Protocol Parties to consider whether further action needs to be taken. In addition, it is now especially important to consider the effectiveness of monitoring networks in the wake of the recently detected rogue emissions of CFC-11 from North East Asia.”