Australian National Report
for the 10th WMO/UNEP Ozone Research Managers Meeting
Geneva, 28-30 March 2017

1. OBSERVATIONAL ACTIVITIES

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

The Australian Government's Bureau of Meteorology (BoM) has primary responsibility for monitoring total column ozone.

- The BoM Dobson network consists of stations located at Brisbane, Darwin, Macquarie Island, Melbourne, and Perth (Perth is operated in conjunction with NOAA). Brisbane, Macquarie Island and Melbourne have records stretching back to 1957.

A number of universities also undertake some total ozone monitoring:

- A Brewer spectrophotometer operated by the University of Tasmania (financially supported by the BoM).
- Remote sensing FTIR operated by the University of Wollongong - the measurements are made as part of the Network for the Detection of Atmospheric Composition Change, (NDACC).

The New Zealand National Institute of Water and Atmospheric Research (NIWA) operates a zenith viewing spectrometer at Macquarie Island for NO_2 column and profile information as part of NDACC.

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

Weekly ozonesonde measurements are taken by the BoM at:

- Broadmeadows (Melbourne)
- Macquarie Island
- Davis station, Antarctica, in conjunction with the Australian Antarctic Division (AAD) and the Chinese Academy of Meteorological Sciences (CAMS)

The ozonesonde program at Davis dates from 2003, Macquarie Island from 1994, and Broadmeadows continues the program originally located in Aspendale (1965-1982) and Laverton (1983-1998). Collaboration with CAMS includes information exchange and research associated with atmospheric chemistry measurements at China's Zhongshan station, near Davis.

- In conjunction with some of these ozonesonde flights, the AAD has operated a Rayleigh/Mie/Raman lidar at Davis to measure temperature and aerosol loading in the stratosphere (the lidar operated from 2001-2012 and is anticipated to collect further data from 2018).
- Coarse vertical resolution profiles from Dobson Umkehr measurements have been made at BoM Dobson network sites dating back to 1962. Umkehr observations are still made at Brisbane, Darwin and Perth (Stone et al., 2015).

1.3 UV measurements

1.3.1 Broadband ultraviolet

The Australian Radiation and Nuclear Safety Agency (ARPANSA) has maintained a network of UV detectors in capital cities around Australia since 1989. In 1996 the instruments were changed over to Solar Light UVB 501 broadband biometers. Kingston, Tasmania was added in 2007 Canberra was added in 2010, and more recently Alice Springs was added as a new site (2011). Biometers have also been collecting data at Macquarie Island since 2001 and the Australian Antarctic stations Mawson, since 2002, and both Davis and Casey since 1996. The biometers are intercompared at Yallambie before placement in the field.

1.3.2 Spectral ultraviolet

The BoM owns and operates two NIWA-designed spectroradiometers at Alice Springs and Melbourne.

ARPANSA currently uses a Bentham spectroradiometer based at the Melbourne site to simultaneously measure solar UVR and transfer a traceable calibration to the biometers before installation. This instrument commenced measurements in December 2008 and has been operating continuously since then. Spectral measurements with traceable calibrations at Antarctic mainland stations commenced in 2010 at Davis and Mawson. In 2011 a Bentham spectral system was installed at Davis for at least two summers with the aim of providing a longer duration series of calibrated spectral measurements and replaced in 2013 and is still recording UV spectral data. A Bentham spectral system was installed in Casey in December 2012 and removed in May 2014.

1.4 Calibration activities

The BoM holds the Region V Dobson standard and operates the Regional Dobson Calibration Centre (RDCC) for the south-west Pacific. The regional standard Dobson is inter-compared regularly with the world standard Dobson, most recently in Boulder in August 2013 and in Melbourne in February 2017. ARPANSA meets the WMO's instrument specifications and characterization as a health advisory agency that provides the daily UV levels. CSIRO/BoM ODS measurements employ calibration standards supplied by the Scripps Institution for Oceanography (USA) and the data are regular compared to data collected at Cape Grim by NOAA (USA), U. East Anglia (UK) and NIES (Japan).

In Melbourne in 2013 APRANSA was involved with an international intercomparison of solar UVR spectral measurements involving the ARPANSA Bentham spectroradiometer intercompared with the BoM owned NIWA-designed spectroradiometer and solar UVR spectroradiometer from Public Health England (PHE).

A Regional Dobson Intercomparison campaign is being held in Melbourne in February 2017, including participation from the Philippines supported by the Vienna Convention Trust Fund for Research and Systematic Observations.

1.5 Ozone Depleting Substances

Australian activities in ODS research are focused on *in situ* ODS observations at the WMO Baseline Station at Cape Grim, Tasmania (funded and managed by the Australian Bureau of Meteorology, with the science program jointly undertaken with CSIRO) and at the CSIRO Oceans and Atmosphere laboratory at Aspendale, Victoria, analysing air samples from the Cape Grim Air Archive, from the CSIRO Australian and global flask sampling networks and from firn air samples

from Antarctica. Australian activities also include ODS modelling, and all ODS observational and modelling research involve collaborations with AGAGE (Advanced Global Atmospheric Gases Experiment) and other colleagues in the USA, Europe and Japan.

ODSs monitored and modelled in the Australian program include species from all the major ODS groups – CFCs (chlorofluorocarbons), HCFCs (hydrochlorofluorocarbons), halons, chlorocarbons, bromocarbons and nitrous oxide. HFCs (hydrofluorocarbons), which are regulated under the Montreal Protocol following the Kigali Amendment (2016), are also monitored and modelled.

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

2.1 Ozone Depleting Substances

Australian research on ozone depleting substances (ODSs) made major contributions (Carpenter, Reimann *et al*., 2014; Liang, Newman, Reimann *et al*,, 2016) to the WMO/UNEP *Scientific Assessment of Ozone Depletion: 2014* and the 2016 *SPARC Report on the Mystery of Carbon Tetrachloride.*

ODS contributions to Equivalent Effective Stratospheric Chlorine (EESC) and global radiative forcing (RF) have been derived from Cape Grim data and data from other global AGAGE stations, from the Cape Grim Air Archive and from Antarctic firn air (Fraser *et a*l., 2014a; Rigby *et al*., 2014; Klekociuk *et al*., 2014a,b, 2015).

Global and Australian regional estimates of carbon tetrachloride (CCl_4) emissions and a revised global atmospheric CCl_4 lifetime have been derived for this important ODS from Cape Grim, global AGAGE and NOAA data. The previously report gap between so-called 'top-down' and 'bottom-up' estimates of global CCl_4 emissions has been reduced significantly (Fraser *et al*., 2014b; Chipperfield *et al*., 2016; Liang *et al*., 2016).

Global emissions of the three major halons (H-1211, H-1301, H-2402) in the atmosphere have been derived from Cape Grim Air Archive and global AGAGE halon data (Vollmer *et al*., 2016).

Several new ODSs, minor chlorofluorocarbons (CFCs-112, -112a, -113a, -114a, 216ba, 216ca) and minor hydrochlorofluorocarbons (HCFCs: -31, -133a, -225), some of which are growing in the background atmosphere, have been identified in the Cape Grim Air Archive and their emissions and lifetimes have been estimated (Laube *et al*., 2014, 2016; Kloss *et al*., 2014; Schoenenberger *et al*. 2015; Vollmer *et al*., 2015).

The chlorine isotopic composition of the major CFCs (-11, 12, -113) are consistent with the finding that these CFCs are entirely anthropogenic in origin (Allin *et al*., 2015).

Global HCFC emissions have remained approximately constant over the past 5 years despite a global cap on production and consumption since 2013. This is due to growing emissions in developing countries and declining emissions in developed countries (Simmonds *et al*., 2016).

Cape Grim and AGAGE global *in situ* nitrous oxide (N_2O) concentration and isotopic data from the CSIRO global monitoring network have been used to further advance the understanding of the sources and sinks of this important ODS, confirming that the major source of growing N_2O in the atmosphere is agricultural soils (Saikawa *et al*., 2014; Wells *et al*., 2015; Prokopiou *et al*., 2016)

2.2 Ozone and UV

Gies et al 2013 studied a low ozone event observed over southern Australia in August 2011, which led to anomalously high UV exposure for this time of year.

The Melbourne Dobson record from 1978-2012 was analysed in Tully et al. (2013) who found total ozone has been closely tracking mid-latitude EESC over this period.

Analyses of ozonesonde data from Davis station (Antarctica) are used in the following areas;

- Investigation of polar ozone loss processes and ozone variability through projects 737, 4012 and 4293 of the Australian Antarctic program (e.g. Alexander et al., 2013a; Klekociuk et al., 2015a, 2015b, 2016; Hope et al., 2015; Stone et al., 2016; see also https://secure3.aad.gov.au/proms/public/projects/report_project_public.cfm?season=1112&project_no=737 https://secure3.aad.gov.au/public/projects/report_project_public.cfm?season=1516&project_no=4012, and https://secure3.aad.gov.au/public/projects/report_project_public.cfm?season=1516&project_no=4293)
- Near real-time analyses of ozone in the Southern Hemisphere winter (WMO Antarctic Ozone Bulletins; see http://www.wmo.ch/pages/prog/arep/gaw/ozone/index.html)
- Satellite and instrument validation (e.g. Sofieva 2017).
- Assimilation into global atmospheric composition reanalysis (e.g. Benedictow et al., 2013).

There has also been an assessment of stratospheric incursion events bringing ozone from the stratosphere into the troposphere (Greenslade, 2017). This has used ozone sonde data from Davis, Macquarie Island and Melbourne (Broadmeadows).

An assessment of long-term trends in the vertical distribution (Harris et al., 2015) has included data from ozone sondes, Umkehr and FTIR measurements made in Australia and Antarctica.

Measurements at Cape Grim, Tasmania (2000 – 2005) of the UV-B driven photolysis of ozone producing reactive oxygen atoms have been analysed to quantify the impact of the key drivers (ozone, solar zenith angle and cloud) (Wilson 2015)

A study of HCl loading in the stratosphere has been carried out using both ground and satellite based instruments. The work found increases in stratospheric HCl in the northern hemisphere despite reductions in the anthropogenic sources. This increase is believed to be due to changes in stratospheric circulation that are important for predicting changes in the ozone layer (Mahieu et al., 2014).

Kay et al. (2015) looked at internal model variability using improved ozone forcing for the simulations, ensuring the Antarctic ozone hole was simulated in a more realistic manner than previous simulations had done.

3. THEORY, MODELLING, AND OTHER OZONE RELATED RESEARCH

Using the UK Chemistry and Aerosols (UKCA) model within the Australian Community Climate and Earth-Simulation System (ACCESS) framework, researchers at the University of Melbourne and CSIRO, along with collaborators at the New Zealand National Institute of Water and Atmospheric Research (NIWA) and the Australian Antarctic Division (AAD) are developing the capability of a fully coupled atmosphere-chemistry (and eventually ocean) model. The model is being used to simulate the stratospheric ozone layer chemistry and dynamics with the goal of a better understanding of the impacts of the development and recovery of the Antarctic Ozone Hole on the climate of the Southern Hemisphere (see Stone et al., 2016). Specific simulations are being performed for the 1st Chemistry-Climate Model Initiative (CCMI-1). This work operates under project q90 of the National Computational Infrastructure, and Project 4012 of the Australian Antarctic Science (AAS) scheme:

https://secure3.aad.gov.au/proms/public/projects/report_project_public.cfm?season=1213&project_no=4012.

AAS Project 4012 (Polar Feedbacks of Ozone Recovery on Climate in the Southern Hemisphere) is using the model output to investigate the influence of ozone zonal asymmetries on Antarctic surface climate.

Siddaway et al. (2013) examined the timing of the return to pre-ozone hole conditions in spring and summer ozone recovery using model simulations from the 2nd Chemistry-Climate Model Validation activity (CCMVal-2), finding that recovery is slower in the later months.

CSIRO is planning to develop a new coupled-chemistry model based on the latest version of ACCESS with a fully coupled ocean in 2017-18 in collaboration with the University of Melbourne.

4. DISSEMINATION OF RESULTS

4.1 Data reporting

Ozonesonde and Dobson data from all Bureau of Meteorology stations are archived at the World Ozone and UV Data Centre (WOUDC) and widely used in the literature, including for satellite validation and model comparisons.

Measurements of column amounts from the FTIR system at Wollongong are reported via the Network for Detection of Atmospheric Composition Change (NDACC) database (see http://www.ndsc.ncep.noaa.gov/data/), as are spectral UV data from Alice Springs.

Cape Grim and AGAGE global ODS data, and N_2O data from the CSIRO global flask monitoring network are regularly archived at the WMO World Data Center for Greenhouse Gases (WDCGG) in Japan: http://ds.data.jma.go.jp/gmd/wdcgg/

ARPANSA provides UVR data from its Solar Light UVB 501 broadband biometers in Casey, Davis, Mawson and Macquarie Island to the Australian Antarctic Division Data Centre.

4.2 Information to the public

A UV forecast is issued daily by the Bureau of Meteorology, and provided to the media as part of the weather report (Deschamps et al., 2006). It is also available at:

http://www.bom.gov.au/uv/index.shtml, and it is extensively used in Australia's SunSmart promotional and educational campaigns.

ARPANSA provide measured real-time UV levels which are updated every minute. A plot of the UV levels for Australian sites is available on the ARPANSA web site at: http://www.arpansa.gov.au/uvindex/realtime/index.cfm. Historical UV index data since 2004 is also available on the ARPANSA web site at http://www.arpansa.gov.au/uvindex/monthly/ausmonthlyindex.htm

The University of Melbourne Earth Sciences' website provides five-minute UV index updates for Melbourne:

http://earthsci.unimelb.edu.au/engage/dynamic-earth-updates/weather-station

Ozone analyses and forecasts are used by a number of groups to issue statements on the development of the ozone hole each year.

During spring of each year, CSIRO provides a weekly update on the status of the ozone hole, based primarily on satellite data from OMPS, OMI and TOMS, which is posted on the Department of Environment and Energy website and publicly available.

4.3 Relevant scientific papers

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5. PROJECTS, COLLABORATION, TWINNING AND CAPACITY BUILDING

Information on Australian activities related to ozone and UV is shared through the *Australian Ozone Science Group,* co-ordinated by the Australian Government Department of Environment & Energy, which has led to greatly increased co-operation and co-ordination between agencies and institutions in both Australia and New Zealand, and is appreciated by all.

A number of Australian scientists contributed as lead-authors, co-authors, contributors or reviewers of the 2014 Scientific Assessment of Ozone Depletion, supported by the Department of Environment & Energy, and a similar number are also expected to take part in preparing the 2018 Assessment. Professor David Karoly is a member of the Scientific Steering committee for the 2018 Scientific Assessment of Ozone Depletion, as he was for 2014, again supported by the Department of Environment & Energy.

Similarly, the assessment of the Environmental Effects of Ozone Depletion has a significant number of Australian scientists involved. This includes involvement in the environmental assessment of trifluoroacetic acid, a product of the decomposition of a number of the HFCs introduced under the Montreal Protocol (Solomon et al, 2016).

The Bureau of Meteorology has ongoing collaboration projects with the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) on UV Index validation against surface measurements and with SunSmart (Cancer Council Australia) on the use of the UV Index to promote sun protection.

The BoM/AAD ozonesonde and AAD lidar measurements at Davis station in Antarctica have contributed to the International Polar Year cluster project ORACLE-O3, and the CONCORDIASI and MATCH campaigns.

ARPANSA has an ongoing collaborative project with the Australian Antarctic Division entitled Determination of the ultraviolet radiation environment at the Australian Antarctic Stations using broadband and spectral instrumentation (AAS 4115).

The Australian Research Council has funded a 5 year project looking at a number of atmospheric "grand challenges" in the southern hemisphere involving the University of Wollongong, the University of Melbourne and several overseas collaborators. (2016 – 2020, DP160101598)

Other projects and collaborations are also discussed in Section 3.

6. IMPLEMENTATION OF THE RECOMMENDATIONS OF THE 9th OZONE RESEARCH MANAGERS MEETING

Progress towards implementing the specific recommendations of the 9th ORM include the following actions:

- Research work has continued regarding the development and validation of Chemistry-Climate models in Australia, recognising the interactions between ozone and climate.
- The BoM has nominated 5 candidate sites for participation in the GCOS Reference Upper Air Network (GRUAN) to maintain reference quality measurements of temperature in the upper troposphere and stratosphere
- Long-term ozone monitoring sites have continued, in particular total ozone and ozonesonde programs at Macquarie Island
- High quality baseline measurements of emerging ODS substitutes such as HFCs are being made by CSIRO at Cape Grim
- The BoM is conducting intercomparisons of modern instrumentation for ozone measurement such as the "Pandora".
- Digitisation of historic (1960s and 1970s) Dobson umkehr observations has now been completed (University of Melbourne and BoM).
- A Region V Dobson intercomparison is being held in Melbourne (February 2017), including participants from the Philippines.
- An Asia/Pacific Brewer Workshop is to be held in Sydney in September 2017, hosted by the BoM.

7. FUTURE PLANS

Further chemistry-climate simulations using the ACCESS model will be archived for the CCMI-1 project.

The historic Umkehr Dobson record is to be reanalysed for the Australian region (BoM – University of Melbourne). The Dobson total ozone record is also being progressively reprocessed as is the ozonesonde dataset according to the international O3S-DQA homogenisation project.

8. NEEDS AND RECOMMENDATIONS

It is recommended that the ORM urge the Parties to continue long-term ozone observations, and request the Parties remind responsible agencies and institutions in their own countries of the importance of continuing long time-series.

Continued financial support for the Vienna Convention Trust Fund for Research & Systematic Observations is important to continue the work of building capacity and improving the global ozone observing system.

Space agencies are requested to make more effort to explicitly support the ground-based measurements required for calibration and validation, either by making a financial contribution to their operation or simply by directly communicating with the relevant agencies.