Canadian National Report
for the 9th WMO/UNEP Ozone Research Managers' Meeting
14 – 16 May 2014, Geneva, Switzerland

1. Observation activities

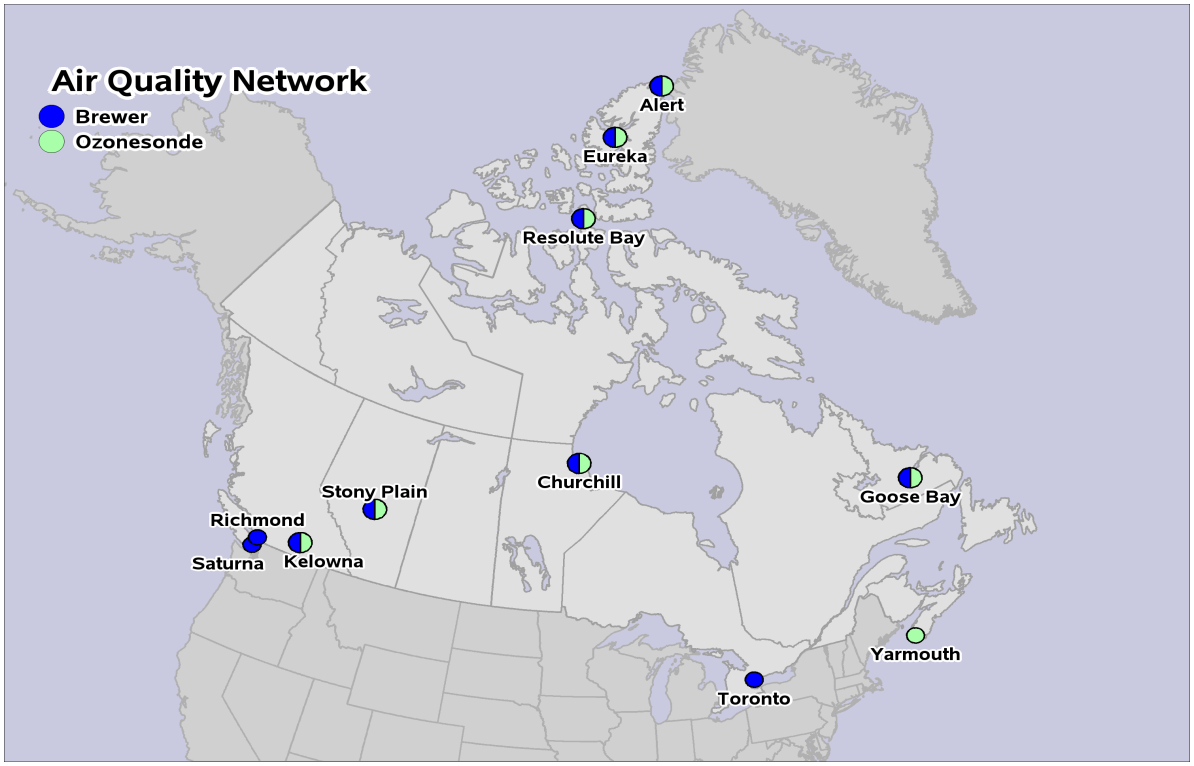

Figure 1 Canadian Ozone Monitoring stations

1.1 Column measurements of ozone

As reported at the 2011 ORM meeting, the Canadian Brewer Ozone Spectrophotometer network consists of 10 main observing sites (Figure 1). The network southern stations (Saturna Island, Edmonton, Churchill, Toronto, Goose Bay, Kelowna, Richmond) operates two Brewer Spectrophotometers and the Arctic stations (Resolute, Eureka, Alert) have three instruments on site. The additional instruments provide redundancy; reduce likelihood of long gaps in the data due to difficult logistics (transportation and travel time) associated with monitoring in the Canadian Arctic; provide means of optimizing the observations of both column ozone and UV spectral irradiance; and quality assurance purposes. Over the last several years Environment Canada, initiated the replacement of single monochromator spectrophotometers with new

double monochromator instruments through network life cycle management. One double monochromator Brewer spectrophotometer is currently operating per station. The advantage of using double monochromator Brewers is the expansion of the daily hours to collect data by including low sun conditions which are particularly important for the Winter, Spring and Autumn observations from the Canadian Arctic. All Canadian stations have been visited for service, upgrade and calibration purposes in the 2011-2014 period and a two year cycle is targeted. Two new double MARK III Brewers were acquired in 2013 in order to replace aging MKIV instruments and their performance is currently under evaluation.

Canada, in collaboration with the U.S. National Oceanic and Atmospheric Administration (NOAA), maintains 2 Brewer spectrophotometers at the Mauna Loa Observatory, Hawaii and one instrument at South Pole Station, Antarctica. Data from the South Pole Brewer are submitted to the WMO and are used in the WMO Antarctic Ozone Bulletins. There are a number of other Brewers operated by Canadian universities in collaboration with Environment Canada for research purposes for which the data are not reported on a regular basis.

In 2013, Environment Canada acquired two Pandora spectral sunphotometers. While the instrument is primarily used for NO_2 and SO_2 observations, it is also capable of producing high quality total column ozone data. One of the instruments is under evaluation in Toronto co-located with the Brewer Triads in order to study its suitability for long-term ozone monitoring.

1.2 Ozone Profiles

Environment Canada launches ozonesondes at 8 locations across Canada (Kelowna, Edmonton, Churchill, Goose Bay, Yarmouth, Resolute, Eureka, Alert) once per week using Electro-chemical Concentration Cell and Vaisala Radiosonde. A limited number of higher frequency launches are carried out every year during Match (in collaboration with the Alfred Wagner Institute, Bremerhaven, Germany) and Atmospheric Chemistry Experiment campaigns.

1.3 UV

Broadband measurements and Narrowband filter instruments

At present, broadband observations are not made by Environment Canada, however commercial forecasting companies have developed their own broadband UV network for observing erythemal-weighted UV at major Canadian cities. The United States Department of Agriculture (USDA) UV-B Monitoring and Research Program network is collocated with the Canadian Brewer Spectrophotometers monitoring site in Toronto. As part of their measurement program they obtain erythemal-weighted UV-B irradiance using a Yankee Environmental Systems UVB-1 Pyranometer. Further information can be found at: http://uvb.nrel.colostate.edu/UVB/index.jsf

Environment Canada is conducting a pilot project associated with the 2015 PanAm games to be held in Toronto. As part of this pilot project, two Kipp and Zonen broadband instruments that measure erythemal UV are being evaluated in Toronto to report UV index in real time.

Spectroradiometers

Observations of spectral UV-Irradiance are made using Brewer Spectrophotometers. Approximately 5 UV spectra are obtained each hour. All 8 Brewer sites are equipped with double Brewer spectrophotometers that measure UV in the 286-363 nm spectral range (the older MKII Brewer instruments take measurements in the 290-325 nm range). Collected data are used for UV Index forecast validation purposes and are also available to the public in near-real time at: http://exp-studies.tor.ec.gc.ca.

1.4 Calibrations

As part of the World Brewer Calibration Centre activities, three Brewer instruments were absolutely calibrated at Mauna Loa Observatory in October 2013. As a result, a new triad of absolutely calibrated double monochromator Brewer instruments (#145, #187, #191) was established in addition to the existing triad of single monochromator Brewer spectrophotometers (#008, #014. #015).

Following the WMO Ozone SAG recommendation, Toronto Brewer #145 was sent to Izana, Spain to compare the Toronto Triad with the Triad of the European Calibration Centre, Spain at the end of March 2014. The inter-comparison between the reference instruments of the two Calibration Centers is in progress and will be completed by the end of May 2014.

An analysis had been undertaken between NOAA's Dobson reference instrument in Mauna Loa and Environment Canada's instruments stationed at that location to evaluate the potential impact of the Kilauea volcano near Mauna Loa due to its activity increase after 2007. Ozone and SO_2 data collected by Brewer instruments and OMI SO_2 data were cross referenced with Dobson data during dates used to carry out absolute calibrations. Preliminary results suggest that the operation of the primary Dobson standard instrument calibrations were not affected by this increase of the volcanic activity. A report with findings is expected by the end of 2014.

Environment Canada's Brewer spectrophotometer #017 is recognized by WMO as the global traveling standard instrument. It has been used for more than 30 years and is directly linked to the global stratospheric monitoring program coordinated by WMO. Ozone calibrations have been transferred from the Brewer Triad in Toronto to 115 instruments in 43 countries during the past 3 years through WMO.

NOAA's Brewer spectrophotometer #109 was calibrated against the Brewer Triad in Toronto in May 2013 and was used as traveling standard to transfer ozone calibration to the rest of

NOAA's instruments. #109 was compared back to the reference standard after the calibration of the Brewer instruments at US stations in June 2013.

Scientists from Japan Meteorological Agency visited the Calibration Centre in Toronto in March 2014. Two Japanese Brewer spectrophotometers were inter-compared with Environment Canada's Brewer Triad.

2. Scientific Results

2.1 Ozonesonde records re-evaluation

The impact of individual and combined effect of various changes on ozone sonde types and engineering parameters at the Canadian ozonesonde network over 5 decades has been investigated by laboratory and chamber based experiments to estimate potential impact on existing trend analysis and other research. Correction factors had been developed to reflect different contributions and station data records are being re-evaluated and homogenized as part of the SPARC/IGACO/IOC/NDAAC (SI^2N) initiative on "Past Changes in the Vertical Distribution of Ozone". While some of those parameters continue to be the subject of evaluation (e.g. pump flow, radiosonde changes), the scatter and the drift of the existing data have been reduced and there are no impacts on trends.

2.2 Ozone climatology

A new ozonesonde-based climatology has been developed. The global three-dimensional (i.e. latitude, longitude, altitude) climatology of tropospheric and stratospheric ozone was derived from the ozone sounding record by trajectory mapping. Approximately 52 000 ozonesonde profiles from more than 100 stations worldwide since 1962 were used. The small number of stations worldwide causes a spacity of geographical information. Forward and backward trajectory calculations were performed for each sounding to map ozone measurements to a number of other locations to fill in the spatial domain. The resulting three-dimensional global ozone climatology facilitates visualization and comparison of different years, decades, and seasons, and offers some insights into the global variation of tropospheric and stratospheric ozone (Liu, et al, 2013).

2.3 Ground-based global/zonal total ozone data set

The WOUDC continues to produce a summary ground-based global/zonal total ozone data set that is used in scientific reports, Ozone Assessments and scientific papers. A recent comparison with the latest satellite data (SBUV v 8.6 and GOME-type) demonstrated a good agreement

(within 1 %.) between zonal mean ground-based and satellite data (Chiou et al., AMT, 2014, in press).

2.4 EC/NOAA UV index forecast validation

A study "Validation of Environment Canada and NOAA UV Index Forecasts with Brewer Measurements from Canada" led by Environment Canada scientists, was published (He et al.) in 2013. The study shows that for most conditions, only modest differences are found between the two forecasting systems; that is, UV index forecasts reported in the United States and Canada for Canadian sites are compatible. In general, the physically based NOAA system, which started operation in 2005, performs better than the semi-empirical Environment Canada model, developed in the mid-1990s. The difference in model performance is not large under clear-sky and light-cloud conditions, but the EC model underperforms relative to the NOAA model under heavy-cloud and rainy conditions.

2.5 Canadian Network for the Detection of Atmospheric Change (CANDAC)

Polar Environment Atmospheric Research Laboratory **(**PEARL) continues to carry out research on large range of atmospheric constitutes including the partial and total column measurements of trace gases, trends in halogen containing species and other atmospheric constituents and parameters controlling the ozone budget with complex suite of instrumentation. These measurements will be used to quantify the contributions from dynamics, chemistry, and climate change to stratospheric ozone depletion and recovery. PEARL based observations have been used to validate SCISAT/ACE Atmospheric Chemistry Experiment and Odin data. In addition, measurements of tropospheric ozone and BrO collected from that location will be used to investigate the origin and occurrence of bromine explosions and their impact on the surface ozone budget at Eureka. The ultimate goal of such comprehensive measurement and atmospheric models will be to facilitate both improved modelling of the atmosphere and the interpretation of the measurements. Fourier transform infrared (FTIR) measurements are conducted over Toronto to identify mid-latitude polar vortex intrusions and establish a dynamical cause for some of the winter/spring variability of stratospheric trace gases observed at this mid-latitude site (K. Strong, K. Walker private communications, Adams et al. 2012, Adams et al. 2013, Adams et al. 2014, Bourassa et al. 2014, Whaley et al. 2013).

2.6 Satellites (space based monitoring and research)

The SCISAT/ACE (Atmospheric Chemistry Experiment) satellite was launched in 2003. SCISAT/ACE measures more than 40 different trace gases in the upper stratosphere and lower troposphere, several of which are currently only being measured by this particular satellite, thus filling a gap in the global observing system. The validation of ozone profiles, primarily from the ACE-FTS and OSIRIS satellite instruments using PEARL stationed measurements. The length of the SCISAT/ACE data record, now exceeding ten years, makes it very relevant for climate and

climate trend studies Adams et al. 2013, Adams et al. 2014, Bourassa et al. 2014). The SCISAT/ACE data are also widely used by the WMO/UNEP Ozone Assessments to track changes in vertical profiles of ozone and ozone depleting substances. The extension for a further three years of the satellite's operations and data processing is currently under review at the Canadian Space Agency. Environment Canada plans to continue making use of SCISAT/ACE measurements to assess the quality of stratospheric ozone model predictions, which is a central component of the next version of the UV forecasting system.

The follow-on instrument to OSIRIS is named CATS (Canadian Atmospheric and Tomography System). It will provide enhanced measurements of ozone, aerosols, nitrogen dioxide and bromine monoxide concentrations by extending to lower altitudes in the atmosphere and with greater vertical resolution. The CATS observations, by continuing the OSIRIS time series, will allow for trend analysis to look for signatures of changes in the Brewer-Dobson circulation on the distribution of ozone. Some additional applications include studies of transport and mixing processes in the upper troposphere and lower stratosphere and observations of nitrogen dioxide for constraining emissions from lightning. There are currently two feasibility studies for CATS, one where the instrument would fly on a microsatellite under the Canadian Space Agency microsatellite program and the other where CATS would be part of a multi-instrument small satellite platform named ALISS (Atmospheric Limb Sounding Satellite). The latter study is in collaboration with Sweden who would provide an instrument to measure atmospheric water vapor.

3. Theory, modelling and other research

3.1 Stratospheric ozone related modelling

The Canadian Middle Atmosphere Model (CMAM) is a chemistry-climate model that has been developed jointly by Environment Canada and university-based collaborators over the past 15 years. CMAM was one of four models that provided input to the 2014 WMO Ozone Science Assessment on the effects of revised ODS scenarios on ozone recovery. All four models consistently show that the effect of the revision in the ODS scenarios on ozone is relatively small. Recent work with CMAM has focused on constraining the evolution of the atmospheric dynamics in the model, to follow meteorological reanalysis datasets. Constraining the atmospheric circulation to follow the observed evolution of the atmospheric winds and temperature allows for a more direct comparison of the model chemical fields, such as total column ozone, with observations, and for improved attribution of observed ozone changes to changes in ozone depleting substances and other factors. The addition of background tropospheric chemistry has also greatly improved the response of ozone in the troposphere to changes in the stratosphere-to-troposphere flux of ozone. Future work will focus on contributing to the follow-on to the Chemistry-Climate Model Validation (CCMVal) project, the Chemistry-Climate Model Initiative (CCMI). The CCMI is a similar international model

intercomparison of chemistry-climate models, with a focus on simulating changes in both tropospheric and stratospheric ozone.

The inclusion of tropospheric chemistry and the ability to constrain the model atmospheric dynamics to follow the observed evolution of the atmosphere has opened up new avenues in the use of chemistry climate models to understand past changes. Shepherd et al. (2014) use the CMAM nudged reanalysis to interpret the observed evolution of total column ozone since the mid-1960s. Previous comparisons of CCMs projections with the satellite record of total column ozone from 1980 onwards (WMO, 2010) has shown discrepancies, with CCMs showing statistically significant declines while observations show no change. Unlike them, the reanalysis-driven simulation of CMAM shows good agreement for total column ozone compared with the ground-based observations, which is the result of decreases in the stratospheric column and a long-running increase in the troposphere. Compensation of stratospheric decreases by increases in the troposphere has been suggested by satellite observations of total column and stratospheric partial columns, but uncertainties in the satellite record have precluded a definitive answer. These model results provide further evidence to support the idea of a compensating increase of ozone in the tropical troposphere. Although not discussed here, these simulations also provide further evidence that anomalies in atmospheric circulation explain the apparent lack of a similar decrease in Southern Hemisphere total column ozone to that observed in the Northern Hemispheres after the Mount Pinatubo eruption in 1992. These simulations, by removing the effects of dynamical variability on total column ozone, also suggest that the chemical destruction of ozone by ozone depleting substances has decreased by 10% since the peak perturbation in the late 1990s (Shepherd et al., 2014).

3.2 Chemical data assimilation

Chemical data assimilation consists of improving chemical model forecasts by incorporation information from constituent observations, including ozone measurements. Global stratospheric and column ozone data assimilation is being conducted at Environment Canada as a means of investigation different aspects for improving and or inquiring insight in chemical data assimilation, of investigating feedback effects on weather, and toward providing lateral boundary conditions for regional chemical data assimilation and improving ultraviolet (UV) index forecasts. Some of these activities involve international collaborations such as undergoing activities with the Belgium Institute for Space Aeronomy (BIRA; e.g., completed comparison of ensemble Kalman filter and 4D Var methods) and the completed Observation System Simulation Experiments (OSSEs) study which was part of the ESTEC/ESA-funded project on “Quantification of Atmospheric Pollution and Climate Aspects” led by the Jülich Research Centre, Germany. These efforts are to contribute to a recently initiated development of a comprehensive system for assimilating air quality measurements (including stratospheric ozone) into Environment Canada’s air quality model prediction systems.

4. Dissemination of results

Near real-time observations are provided to the public at: http://exp-studies.tor.ec.gc.ca. These include both ozone and UV-Index based on Brewer observations. This website also displays maps of ozone concentrations and deviations of these concentrations from mid-1980 levels.

Each year, based on springtime ozone levels, a summer seasonal forecast is provided to the public through the Meteorological Service of Canada website: http://www.ec.gc.ca/uv/default.asp?lang=En&n=C28590EA-1. The forecast normally comes out before Canada's May 24 (Victoria Day) long weekend as this is the 'first' long weekend of summer in Canada and many individuals are prone to extended hours outdoors for the first time since winter.

Canada provides daily UV-Index forecasts for values greater that 2 through the Meteorological Service of Canada regular forecasts: http://www.weatheroffice.gc.ca/canada_e.html

Private sector forecasts of the UV-Index are also provided by such organizations as the Weather Network: http://www.theweathernetwork.com/uvreport/canuv_en/?ref=topnav_homepage_uvrepo

5. World Ozone and Ultraviolet radiation Data Centre (WOUDC)

World Ozone and Ultraviolet radiation Data Centre (woudc.org) is being renewed to create a new foundation to meet growing requirements. The ultimate goal of this undertaking is to enhance the data submission mechanism and infrastructure; to provide effective and efficient data management; to modernize data access mechanisms and improve accessibility and usability of the website. While a temporary freeze was put on the processing of submitted data so that progress could be made on the renewal all correctly submitted data has been processed and being made available at the beginning of May 2014. A Beta version of the renewed website will be available in the spring to get the user feedback.

6. Environment Canada Scientists involved in 2014 WMO/UNEP Ozone Assessment

Nathan Gillett: Lead Author of Chapter 4 'Stratospheric ozone changes and climate'

Vitali FIoletov: Chapter Editor: Chapter 2, 'Update on global ozone: Past, present and futurer'

David Plummer, Chris McLinden: Contributors, Chapter 2, 'Update on global ozone: Past, present and futurer'

Michael Sigmond, Neil Swart: Contributors, Chapter 4 'Stratospheric ozone changes and climate'

7. Publications

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8. Ozone and UV-related reports and work

(Coordinating Lead Authors) A. Douglass, V. Fioletov, (Lead Authors) S. Godin-Beekmann, R. Müller, R. Stolarski, A. Webb, (Authors) A. Arola, J. Burkholder, J. Burrows, M. Chipperfield, J. V. Canossa, R. Cordero, C, David, P. den Outer, S. Diaz, L. Flynn, M. Hegglin, J. Herman, P. Huck, S.

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McKenzie, R., Blumthaler, M., Diaz, S. , Fioletov, V., Herman, J.,Seckmeyer, G., Smedley, A., Webb, A., RATIONALIZING NOMENCLATURE FOR UV DOSES AND EFFECTS ON HUMANS, Joint publication of CIE and WMO, WMO/GAW Report No. 211, World Meteorol. Organ., Geneva, 2014.

SPARC/IGACO/IOC/NDAAC (SI^2N) initiative on "Past Changes in the Vertical Distribution of Ozone"

Canadian Centre for Climate Modelling and Analysis is currently carrying out chemistry-climate model simulations (using the Canadian Middle Atmosphere Model, CMAM) in support of the IGAG/SPARC Chemistry-Climate Model Initiative (CCMI) - http://www.met.reading.ac.uk/ccmi/

NOAA Arctic Report Cards

BAMS State of Climate reports

9. Selected collaborative projects:

CAFTON - the Canadian FTIR Observing Network, a Canadian Space Agency-funded project (2012-2015)

National Science Research Council of Canada -funded project PAHA (Probing the Atmosphere of the High Arctic) project with three themes, one of which is Composition Measurements (CM), which includes a project on Ozone and Related Species (CM-O3)

Collaboration in the development of the 4DVar/EnsKF systems at the Belgium Institute for Space Aeronomy (BIRA, Belgium; on-going).

Contribution to a "Study group on the added-value of chemical data assimilation in the stratosphere and upper-troposphere" in collaboration with BIRA and other institutions. This is a two-year study (currently on-going) supported by the International Space Science Institute, Switzerland, through the International Teams in Space and Earth Sciences program.