CANADA

OBSERVATIONAL ACTIVITIES

Since the last Country Report, Environment Canada has undergone an organizational change that has separated the monitoring of column ozone and UV radiation from the scientific research and the ozonesonde launches with which it has historically been associated. Today, the Canadian Brewer Network is part of the Meteorological Service of Canada (MSC), while the scientific research, the World Meteorological Organization components (World Ozone and Ultraviolet Data Centre (WOUDC), Brewer Reference Triad) and the vertical profiling of ozone by ozonesondes and LIDAR observations are part of a newly created Science and Technology Branch. These administrative changes, however, are not reflected in daily operations, nor have they had any adverse affects on the personnel involved in the observational activities. A second key factor in Canadian Brewer network observations that has occurred over the last 2 years is the Meteorological Service of Canada has undergone certification under the International Standards Organization (ISO) and the network observations are now certified under ISO 9002. It is anticipated that the greater degree of accountability found under ISO 9002 will be reflected in the overall improvement in the quality of the operating procedures used throughout the Canadian networks.

Column Measurements of Ozone and Other Gases

The MSC operates a network of 8 Brewer Spectrophotometers across Canada (see map). Significant effort over the last several years has seen the duplication of instrumentation at all of the northern stations as a means of improving the overall number and quality of the observations, while reducing the need and costs of providing emergency service to instrumentation at remote locations. Two years ago a new life-cycle management plan was established for this network under an overall MSC initiative to improve and maintain the overall quality of observations used within the weather program of Environment Canada. As part of this program two new Mk III Brewers were purchased in each of 2006 – 07 and 2007 – 08 to replace older Mk II and Mk IV versions. Another two will be purchased in fiscal 2008 – 09.

An updated version of the Brewer operating software has been installed for all network and research Brewer Spectrophotometers over the last year and aerosol optical depth (AOD) measurement capability is currently being added into the network as part of an on-going process to provide more real-time forecast capabilities to the network.

As part of ISO 9002, quality metrics are being developed for the network and as part of this activity new software is under development that will allow for the monitoring of instrument warning and error messages along with diagnostic and measurement summary information as a means of improving data quality assurance and the monitoring of the newly developed process metrics.

During 2008, a Brewer spectrophotometer will be installed at Environment Canada's Centre for Atmospheric Research Experiments (CARE), Egbert, Ontario. Over the last three years this facility has expanded its ozone monitoring capabilities with the addition of weekly ozonesonde launches and the completion of a tropospheric ozone LIDAR system. New funding beginning in 2008 – 09 has been budgeted for the development of a new stratospheric LIDAR system with the intention of being able to observe the complete ozone profile from the surface to 40 km as part of a 'one atmosphere' research initiative within the Air Quality Research Division of the Science and Technology Branch of Environment Canada.

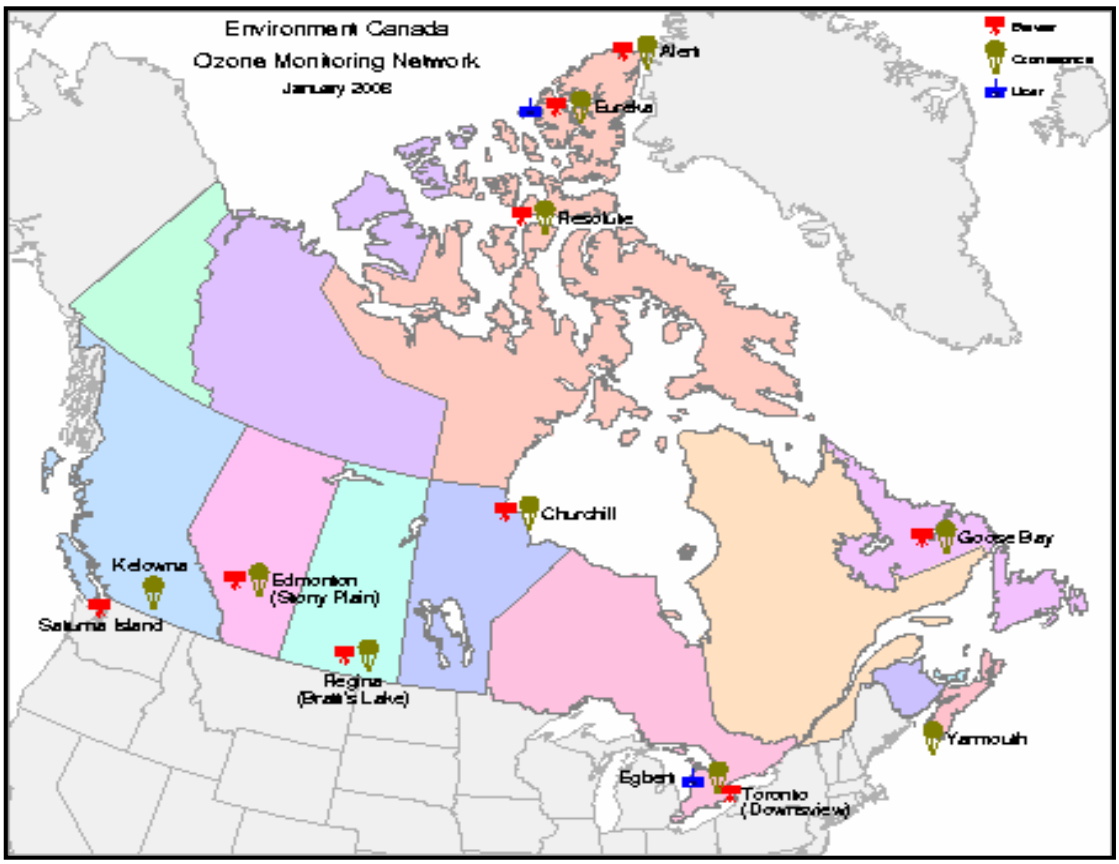

Figure 1: Canadian Stratospheric Ozone Observation Networks.

Fourier Transform Infrared Spectrometer observations using a Bomem DA8 have been ongoing over the last 12 years at Eureka, Nunavut and Egbert, Ontario. Resource and manpower limitations have kept the Eureka observations primarily to periods immediately following Arctic sunrise. With the launch of the Atmospheric Chemistry Experiment in 2004 (see below), these observations have increased in number and importance. The Egbert, Ontario instrument operated more frequently during this timeframe and is now in the process of being automated in order to provide continuous operation throughout the year (weather permitting).

Profile Measurements of Ozone and other gases/variables relevant to ozone loss

Environment Canada now operates 10 ozonesonde stations across the country (Figure 1). In 2004, four southern Canadian stations were added to the original network of northern stations as a means of studying trans-boundary pollution and the affect of stratospheric intrusions on lower tropospheric ozone concentrations. Although originally designed as a short-term (3-year) project to understand ozone dynamics and trans-boundary flow, the operation of these stations has provided significant scientific information and has been given an extended life of at least another 3 years.

Originally operated as part of Environment Canada, the Arctic observing site at Eureka, Nunavut now operates through a university consortium CANDAC (Canadian Detection of Atmospheric Change). As part of this effort, the stratospheric ozone DIAL LIDAR system operates during the period about polar sunrise for the purposes of monitoring stratospheric ozone concentrations during this critical period when ozone destruction may be at its peak, depending on the location and temperature of the Arctic vortex, and to provide validation data for the ACE satellite mission. Figure 2 provides a comparison of ozone and temperature profiles for the 2008 spring season showing the change in ozone concentration as the vortex moves over the Eureka location. Spring 2008 was exceptionally clear at Eureka providing some of the best LIDAR retrievals since the start of operation in the early 1990's.

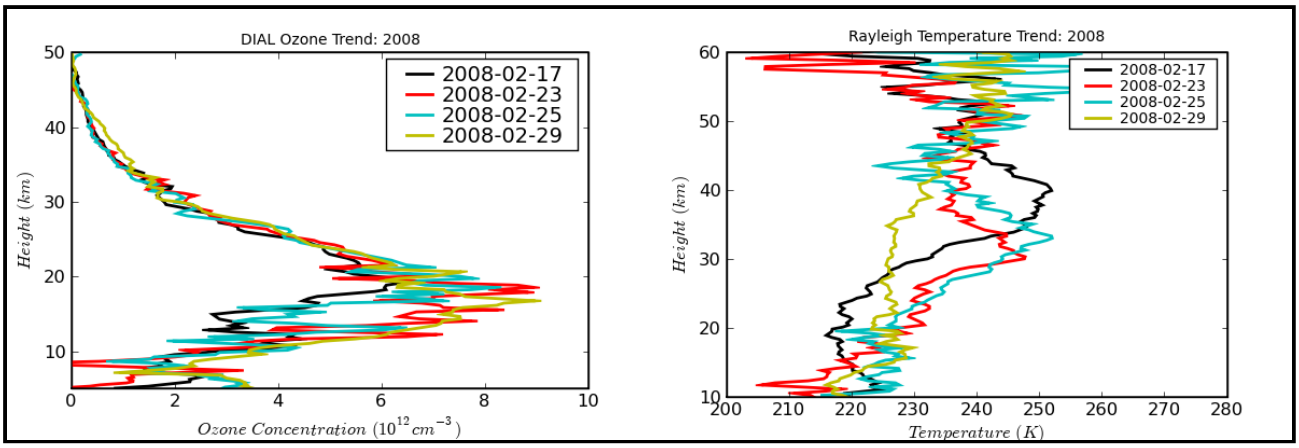

Figure 2: **LIDAR profiles showing changes in stratospheric ozone concentration as the Arctic Vortex moves over Eureka, Nunavut.**

UV Measurements

Broadband Measurements

Environment Canada does not collect broadband data.

Narrowband filter instruments

Although Environment Canada does not collect data from narrowband filter instruments, it does provide logistical support for the United States Department of Agriculture (USDA) UV-B Monitoring and Research Program at two Canadian stations; Toronto, Ontario and Bratt's Lake, Saskatchewan, as part of a data sharing and scientific research agreement.

Spectroradiometers

The Brewer spectrophotometer obtains spectral scans between 290 and 325 nm or 286 nm and 363 nm depending on the instrument type, as part of its normal operation. Spectral scans are obtained approximately once every 20 minutes during daylight hours. The instruments are calibrated on site once every two years using a set of NIST standard quartz halogen bulbs and a specially designed travelling calibration unit. In order to monitor the overall quality of the scans between calibrations the spectrophotometer obtains internal standard lamp and mercury lamp scans with each spectral UV scan. The results of these scans are monitored for internal consistency and to ensure the spectral wavelength accuracy of each scan. Along with these scans each Brewer is equipped with an internal sky imager to provide information on cloud cover during the scan period.

Calibration Activities

The World Meteorological Organization Global Atmosphere Watch Brewer Spectrophotometer Ozone Calibration Centre is housed within the Environment Canada research laboratory in Toronto, Ontario. The Brewer 'triad' of single monochromator instruments acts as the ozone calibration reference group of instruments. These instruments are regularly characterized and approximately once every two years one of the three instruments is taken to Mauna Loa Observatory (MLO) as a means of tracking their extraterrestrial readings. Further, a Brewer instrument is permanently maintained at MLO to further facilitate maintaining the quality of the Brewer 'triad'. Within the network a travelling standard instrument is used to compare the network instruments to the reference 'triad'. A second travelling standard is on permanent loan to the WMO as a means of linking the global Brewer network to the 'triad'.

Over the last several years, EC has participated in comparisons affiliated with the European Brewer Reference Standard at Izania, Spain and NASA. In all cases, the quality of the observations indicates that excellent agreement is being maintained within the various 'standard' groups of instruments.

Over the last 18 months, EC has further enhanced its calibration efforts with the purchase of new NIST traceable standard lamps and re-established ties with the NOAA Central UV Calibration Facility (CUVCF) as part of a continuing effort of improving the UV component of the Canadian network.

RESULTS FROM OBSERVATIONS AND ANALYSIS

Ground-based / In-situ Observations

Environment Canada maintains the WMO World Ozone and UV Data Centre as part of its on-going commitment to the WMO. Data obtained from the Brewer network and the 10-station ozonesonde network, once quality assured, is permanently archived in the WOUDC.

The WOUDC continues to expend significant effort to improve its overall effectiveness as a WMO data centre. Details can be found at the WOUDC website: www.woudc.org. Overall, 131 Agencies from 75 Countries representing 406 platforms (stations) have contributed or continue to contribute data to the WOUDC.

Data Category	Number of Platforms	Number of Files	Representative Years
Lidar	2	675	1991-1998
Ozonesonde	124	55,826	1962-2008
Total column ozone	280	58, 718 (monthly)	1924-2008
Umkehr	64	10,000 monthly records, >50,000 retrievals	1951-2008

Data stored within the WOUDC is subjected to various forms of quality assurance and data submitters are informed if their data does not pass quality control procedures. The overall data policy for the WOUDC does not permit the WOUDC to alter data, but only request data submitters to either reprocess and resubmit data or provide an explanation as to why the data does not conform to the standard quality assurance procedures.

While the primary purpose of the archive is the storage, quality assurance and re-transmission of data to the global user community, several on-line products are available such as the daily global distribution of ozone.

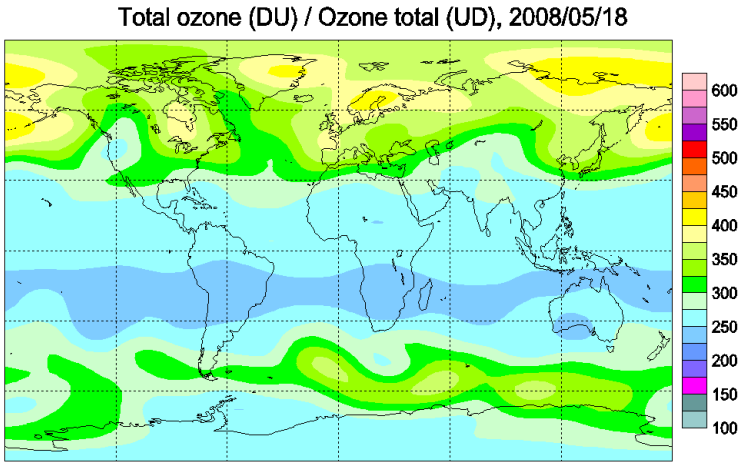

Figure 3: Daily global ozone map: product of the WOUDC.

Space-based Observations

Through the Canadian Space Agency, Canada has three instruments aboard 2 satellites (one Canadian) that are observing ozone and ozone-related variables.

OSIRIS Instrument on the Odin Satellite

The Canadian instrument OSIRIS, onboard the Swedish satellite Odin, has been fully operational since November 2001 and continues to deliver global profiles of ozone from the upper troposphere to the lower mesosphere, 7 km to 60 km. The instrument, measures limb radiance profiles of scattered sunlight from 270 nm to 810 nm. The profiles, which are constrained to the sunlit section of the orbit, have a height resolution varying between 1 and 2 km and are spaced between 3 and 8 degrees along the satellite track, depending upon the mode of operation.

The OSIRIS ozone results have been validated against both ACE-FTS and SAGE II coincident, solar occultation profiles. The agreement with both ACE-FTS and SAGE II is, on average, better than 3% over the entire altitude range from 18 km to 53 km.

The OSIRIS Level 1 radiance measurements as well as the OSIRIS level 2 ozone and aerosol products have been in algorithm development associated with the OMPS instrument on the NPOESS Preparatory Project. The OSIRIS and OMPS team members have worked closely together over the past year, sharing data and retrieval techniques, to ensure the success of this mission.

The OSIRIS Level 2 ozone product has also been found to be a valuable resource for studying Upper Troposphere Lower Stratosphere (UTLS) transport, and in particular, the flux of ozone across the tropopause. Unlike many other limb profiling instruments, OSIRIS has both sufficient sensitivity and spatial-temporal coverage to measure global ozone transport across the tropopause on a weekly or even daily basis. Collaborative studies between researchers at McGill, University of Saskatchewan, University of Toronto and Cairo are underway.

The Odin mission is an international collaboration between Sweden, Canada, Finland and France and was officially designated an ESA Third Party Mission in 2007. The OSIRIS data are freely available through an ESA portal at http://eopi.esa.int/esa/esa. The OSIRIS team is led by principal investigators from the University of Saskatchewan.

Atmospheric Chemistry Experiment (ACE) aboard SciSat1

The Atmospheric Chemistry Experiment (ACE), is a Canadian Space Agency small satellite mission for remote sensing of the Earth's atmosphere using solar occultation (Bernath et al. 2005). The primary mission goal is to improve our understanding of the chemical and dynamical processes that control the distribution of ozone in the stratosphere and upper troposphere, particularly in the Arctic. The high precision and accuracy of solar occultation makes SCISAT useful for monitoring changes in atmospheric composition and the validation of other satellite instruments including MIPAS, HIRDLS and MLS.

The satellite carries two instruments: (1) A high resolution (0.02 cm 1) infrared Fourier transform spectrometer (FTS) operating from 2 to 13 microns (750-4400 cm-1) is measuring the vertical distribution of trace gases, particles and temperature with a vertical resolution of about 3-4 km from the cloud tops up to about 150 km. P. Bernath of the University of Waterloo is the principal investigator. (2) A dual optical spectrograph called MAESTRO (Measurement of Aerosol Extinction in the Stratosphere and Troposphere Retrieved by Occultation) covers the 400-1030 nm spectral region and measures primarily ozone, nitrogen dioxide and aerosol/cloud extinction. It has a vertical resolution of about 1-2 km. T. McElroy of Environment Canada is the principal investigator.

SCISAT is able to monitor all of the main components involved in activated polar chlorine chemistry: O3, HCl, ClONO2, ClO, HNO3, H2O and polar stratospheric clouds (PSCs). Nassar et al. (2005) determined a global inventory of atmospheric chlorine for 2004 and included in the Scientific Assessment of Ozone Depletion: 2006. The average total stratospheric chlorine concentration measured by ACE was 3.65 ppb, which is significantly higher than the accepted value derived from HALOE observations of HCl. The HCl concentrations from SCISAT and MLS are in good agreement, suggesting that the HALOE values are about 10-15% low. The newer, higher values for the total stratospheric chlorine concentrations suggest that the recovery of the ozone layer is somewhat delayed, compared to previous estimates. Although the total chlorine in

the atmosphere is declining, the total fluorine is increasing. Fluorine-containing molecules such as CFC substitutes are potent greenhouse gases and cause global warming.

THEORY, MODELLING AND OTHER RESEARCH

Complementary chemical weather projects relying on coupled Global Circulation and Chemistry modelling (GCCM) and data assimilation systems (DAS) have been initiated in Canada. Meteorological data assimilation provides analyses of dynamics and temperatures impacting species chemistry and transport. The chemical (and meteorological) state can be further improved by also assimilating observations of constituents such as ozone.

The first successful integration of chemical data assimilation and forecasting into an operational Numerical Weather Prediction (NWP) system was accomplished in 2006 through an ESA-funded project on Coupled Chemical-Dynamical Data Assimilation (CCDDA) that produced the model GEM-BACH (Global Environmental Multiscale model with Belgium Atmospheric CHemistry) as part of a collaborative effort between EC and the Belgian Institute for Space Aeronomy (BIRA-IASB), which provided online calculation of detailed stratospheric chemistry integrated into an operational NWP model. The CCDDA project focused on the stratosphere and the use of ENVISAT observations. The study investigated the interactions between atmospheric dynamics, radiation and chemistry from analyses relying on chemical and meteorological observations using a GCCM-DAS. The project final report was delivered in December 2007. The overall success of the effort is seen in the number of important results produced on topics such as ozone-radiation interaction, the dependence of photochemistry on temperature, the wind-tracer relationship, and the impact of multi-species assimilation on ozone.

DISSEMINATION OF RESULTS

Data Reporting

Canadian observations of ozone and UV radiation are reported in near-real-time to the Canadian Meteorological Centre (CMC) as part of the forecast validation system. These data are quality assured before being archived in the WOUDC. Data from the 10 ozonesonde stations are generally processed within days of the weekly flights with the objective of being archived in the WOUDC on a quarterly basis.

Information to the Public

Environment Canada continues to provide UV-index forecasts to the general public. These standard forecasts are distributed through normal media outlets and through the Environment Canada website:
http://weatheroffice.gc.ca/forecast/textforecast_e.html?Bulletin=fpcn48.cwao

A spring / summer seasonal forecast is normally placed on the EC website in late April or early May.

The EC website displays information on the UV Index, year-to-date ozone values and plots of global ozone concentrations; http://exp-studies.tor.ec.gc.ca/e/ozone/Curr_map.htm.

Figure 4 illustrates one of the types of data that can be publicly accessed. Maps of total ozone are updated automatically each daylight hour.

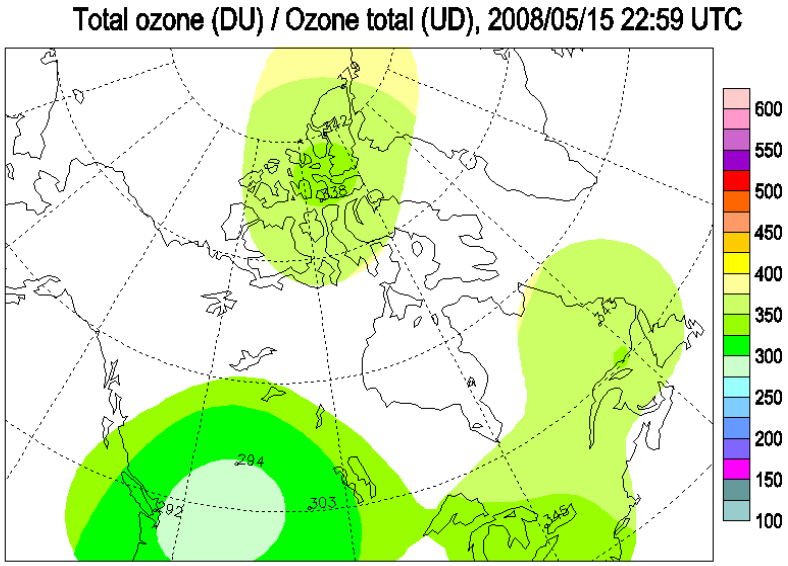

Figure 4: Daily total ozone map automatically generated from Canada Brewer Network observations.

The 20th Anniversary celebrations associated with the Montreal Protocol meeting held during 2007 provided Canadian researchers an unparalleled opportunity to provide scientific information to politicians, policy-makers and the public. In honour of the Montreal Protocol, Canadian scientists from both government and academia published a peer reviewed scientific ozone assessment in the Canadian journal Atmosphere-Ocean (references below) and provided participants of the Montreal meeting an executive summary of the document. This summary document is accessible at http://www.msc-smc.ec.gc.ca/saib/ozone/ozone_e.html. Along with these science and policy documents, scientists developed a display available to both the public and policy-makers on the ozone history of Canada that included a combination of historic instruments and modern interactive data displays. The EC Communications Department developed a special issue of the EC online magazine *Envirozine* to enhance further the department's public outreach on ozone and UV radiation during the period surrounding the Montreal Protocol meeting, http://www.ec.gc.ca/EnviroZine/english/issues/75/home_e.cfm

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PROJECTS AND COLLABORATION

- During the 20th Anniversary Year of the Montreal Protocol, EC gave 2 Brewer User Group Workshops, Manchester, UK (June 2007) and Seoul, Korea (October 2007) as part of an on-going WMO collaborative activity.

- The Canadian university consortium CANDAC (Canadian Network for the Detection of Atmospheric Change) continues to successfully operate the former EC ASTRO laboratory, renamed PEARL (Polar Environment Atmospheric Research Laboratory) at Eureka, Nunavut. EC continues to play an important logistical and scientific role at the laboratory. One continuing project is the overhaul of the DIAL LIDAR system at Eureka. Over the last two years over $500K has been allotted to upgrading this system. This summer work will commence on installing a new laser, provided through funding to CANDAC and new electronics components by EC.

- NOAA and EC have teamed up to install a new EC MK III Brewer at South Pole. First observations from the Brewer were taken February 12, 2008. The objective of this collaboration is to provide improved columnar ozone amounts at high low solar elevations and to observe columnar ozone throughout the Antarctic winter by using lunar observations. Several cold weather enhancements necessary for this system to function in the Antarctic climate regime have shown significant improvements in maintaining the Brewer internal temperature and reducing the overall power consumption of the system that they will now be installed in systems in the Canadian Arctic.

- A new four-year research and development project called BACCHUS (Belgium And Canada for CHemical weather User-oriented Services) has also been undertaken as a spin-off of the CCDDA project (under modelling). It is a bilateral collaboration of the Belgian and Canadian governments involving EC and BIRA-IASB. The main objective of BACCHUS is to develop an

integrated assimilation/forecasting system for chemical weather applications on global and continental scales. Its focus is Air Quality in the troposphere (global and continental scale) and ozone depletion in the stratosphere (global scale).

- The human health aspects of increased UV radiation reaching the Earth's surface has brought about a number of collaborations between the Canadian health community; both government and non-governmental agencies, and EC. These collaborative arrangements have produced a number of algorithms that use various surface and satellite observations to obtain spatial distributions of UV Index, erythemal and vitamin D uptake over Canada to match with public health products and surveys.

FUTURE PLANS

Observations of ozone will not likely change in the near future. While EC is presently undergoing two reviews concerning its mandate and notional funding levels, it is not anticipated that ozone and UV radiation monitoring will be reduced from their current levels.

Over the last several years, EC has moved away from monitoring stratospheric ozone as a means of assessing the success of the Montreal Protocol and become more concerned with human and environmental health as they more directly relate to the overall direction of present government mandates. This new direction has nevertheless included UV radiation and tropospheric ozone and provided increased funding for monitoring ozone levels in southern Canada. Furthermore, increased interest in air quality modelling and assessing the effectiveness of new government regulations on emission has increased Canadian interest in the UTLS and how stratospheric intrusions affect near-surface ozone concentrations (note Canadian involvement in IONS and ARCTAS programs and follow-on studies). This same change in mandate has also increased the interest in tropospheric ozone profiling using LIDARS. Therefore, it is anticipated that over the next 5 years their will be increased development in these systems with the intention of developing a national network of aerosol and ozone LIDARs for assimilation into a next-generation air quality model.

Results from the recently completed ESA contract on data assimilation has shown that ozone profiles can improve upper atmospheric forecasts and may, in fact, improve surface forecasts under certain conditions by up to one full day. Based on this, it is anticipated that increased efforts on data assimilation of vertical ozone profiles will continue. ECMWF has approached EC to operationalize and increase the number of ozonesonde stations across Canada as a means of improving its forecast, however, funding for such increased activities has yet to be acquired.

Although SCISAT has been in orbit for 4.5 years, the performance remains nominal; indeed the FTS spectra are now better than just after launch because the rate of contamination of the detectors by ice is now very low. To maintain the long-term data record of solar occultation measurements needed to monitor changes in atmospheric composition, a SCISAT follow-on mission is needed. A small proposal for a feasibility study for a mission called SOAR (Solar Occultation for Atmospheric Research) has been submitted to the Canadian Space Agency.

With the effects of climate change being seen more frequently in the Arctic, Canada has become acutely aware of its responsibility to northern Canadians and the need to protect Arctic sovereignty. In a recent Speech from the Thrown, the present Canadian government has recognized the need to enhance Arctic research. Therefore, it is anticipated that over the next 7 – 10 years there will be a significant shift toward the Arctic research, including increased monitoring and process studies associated with atmospheric chemistry.

NEEDS AND RECOMMENDATIONS

In a recent meeting of a Senior Scientific Advisory Committee instituted by the Space Science Directorate of the Canadian Space Agency concerns were raised on the lack of quality profession technical staff, young scientists and the capacity within Canada to develop new scientific instrumentation. While these comments were primarily directed toward the development of Earth

Observation instruments, the same concerns have been raised within universities and science-based federal government departments. For Canada to continue as a provider of quality space-based scientific instruments and a developer of ground-based instrumentation, new ways must be found to increase the ability of scientists to train highly qualified personnel and sustain working technical laboratories.

Canada over the last decade has played a significant role in the development of scientific instrumentation to measure ozone and other chemicals, both from the surface and from space. The recognition by the global scientific community for these efforts has been overwhelming. Nevertheless, this global support has not been fully utilized in moving Canadian research into the future. Canadian scientific community must find an effective means of using the respect of the global community to obtain national support (funding) if we are to continue to play a role in understanding our environment.

The scientific community is awash in data, but within the Canadian context, the overall capacity to effectively archive and then utilize this data is lacking. This includes the ability to use effectively the internet and web to manipulate and transfer this data. While data archival is an important scientific issue, obtaining the significant amounts of funding needed to properly archive and use this data is difficult to obtain. Therefore, is it crucial for the global scientific community to recommend strongly the need for governments to protect the investment made in making these observations through the adequate funding of data archival.

The apparent lack of limb scanning instruments needed to obtain ozone vertical profiles is a grave concern. The Ozone Research Managers need to recommend that national space agencies re-assess and correct this situation in a timely manner.

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