CANADA

OBSERVATIONAL ACTIVITIES

The Meteorological Service of Canada (MSC), part of Environment Canada, is the Canadian government department responsible for atmospheric ozone research. Its column ozone and UV monitoring programme is based on Brewer spectrophotometer measurements made at nine sites. Ozonesondes are flown at least weekly from six of these sites and from four new, recently established stations. Column abundances of other molecules important to understanding ozone chemistry and climate change are measured by Fourier Transform Spectroscopy (FTS) at two locations. The World Ozone and UltraViolet radiation Data Centre is operated by the MSC on behalf of the World Meteorological Organization WMO.

Although intense resource pressures and a protracted re-organization are taking place within Environment Canada, the MSC continues to support an extensive range of activities in the fields of ozone and ultraviolet radiation research and monitoring.

Column Measurements of Ozone and Other Gases

Brewer spectrophotometers are currently being operated at 9 stations in Canada (Saturna Island, British Columbia; Stoney Plain, Alberta; Bratt's Lake, Saskatchewan; Churchill, Manitoba; Resolute Bay, North West Territories; Alert and Eureka, Nunavut; Toronto, Ontario; Goose Bay, Labrador). This reflects the closing of three relatively recently established observing sites (Winnipeg, Manitoba; Montreal, Quebec; and Halifax, Nova Scotia) as a result of resource pressures. The instruments are programmed to make total ozone measurements on the sun, moon and zenith sky. Near-real time total ozone data is used with the Canadian Weather Prediction model to generate public forecasts of the UV-index; real time UV scan data are used for public information and validation of the UV forecasts. The raw data from the Brewers are processed in the Brewer Data Management Centre, which is also used to process data from several Brewer instruments operated in other countries. The Canadian sonde data as well as ozone and UV data from the Brewers are archived and made available to all users through the World Ozone and UV Radiation Data Centre (WOUDC).

Profile Measurements of Ozone

Ozonesondes are flown at 6 of the column ozone measuring stations (Stoney Plain, Churchill, Resolute Bay, Alert, Eureka, and Goose Bay, Labrador) and at four new stations (Kelowna, British Columbia; Bratt's Lake, Saskatchewan; Egbert, Ontario; Yarmouth, Nova Scotia) where the primary goal is the measurement of ozone in the troposphere. The Brewer Spectrophotometers also make Umkehr measurements of the vertical profile of ozone.

UV Measurements

Broadband measurements

Narrowband filter instruments

Environment Canada does not support these measurement types.

Spectroradiometers

The Brewer Spectrophotometers at all Canadian column ozone stations also make spectral scans of the horizontal UV irradiance. The data are reported in the WOUDC data base. Some stations are now equipped with double monochromator versions of the Brewer (Mark III). The instruments are re-calibrated on a two-year refurbishment and re-calibration cycle and an active life

cycle management programme is underway to replace the present network instruments with MK III Brewers at the rate of one per year

Calibration Activities

Toronto is the WMO/GAW Brewer Spectrophotometer Ozone Calibration Centre. The ozone calibration reference is a group of three single monochromator Brewers, the Brewer 'Triad', that are characterized regularly and taken approximately every two years to a high altitude, low-latitude station (Mauna Loa) in order to track their extra-terrestrial readings; except for these trips they remain in Toronto. Figure 1 demonstrates that the Triad is maintaining a long-term reference accuracy better than 1 %. Most field Brewer calibrations are done on site by bringing another Brewer (a 'Travelling Standard') to the station and making simultaneous measurements there. The Travelling Standard will normally be one of three instruments that are compared at least twice per year against the reference Triad in Toronto. Besides maintaining the reference and travelling instruments and a Dobson spectrophotometer, the Calibration Centre continues work on ozone metrology such as the relationships between ozone measurements made at different wavelengths and with different viewing geometries from the ground or space and the effects of temperature on ozone measurements. A double as well as a single Brewer are operated permanently by the MSC at the NDSC Mauna Loa station for research purposes as well as to provide a comparison for instruments being transported to Mauna Loa for absolute calibration.

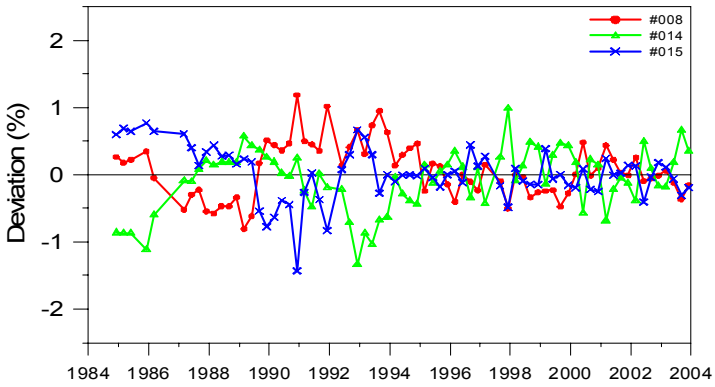

Figure 1: Deviations of ozone values of individual triad Brewers from the mean of the three instruments. Each point on the graph represents a 3-month average.

MSC participated in the first use of the European Brewer Reference Standard from Izana, Spain in September, 2005. The new reference which consists of a Triad of double monochromator Brewers maintained at Izana, Tennerife in the Canary Islands will provide a redundant, independent reference for Brewer calibration in Europe. It is intended that the Toronto Triad and the Izana Triad will be maintained in agreement to high precision through comparisons like the one held in Mazagon, Spain in September.

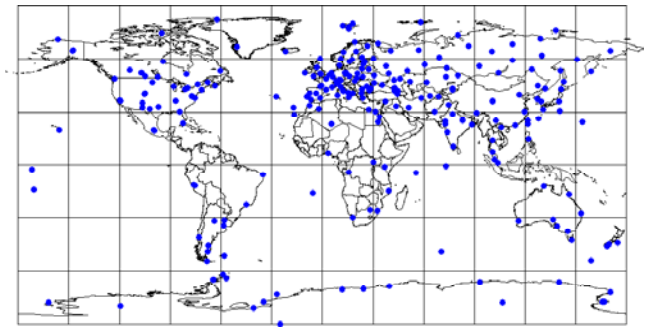

Figure 2: Stations reporting total column ozone data to the WOUDC. August, 2005.

Figure 3: Stations reporting Umkehr observations to the WOUDC. August, 2005.

RESULTS FROM OBSERVATIONS AND ANALYSIS

The MSC operates the WOUDC on behalf of the WMO. The availability of all types of data from the WOUDC and their value depends to a considerable extent on the prompt submission of data from those agencies throughout the world that make ozone and UV measurements. Generally the submission of data is highly satisfactory.
There are minor exceptions such as the lack of some ozonesonde data sets and spectral

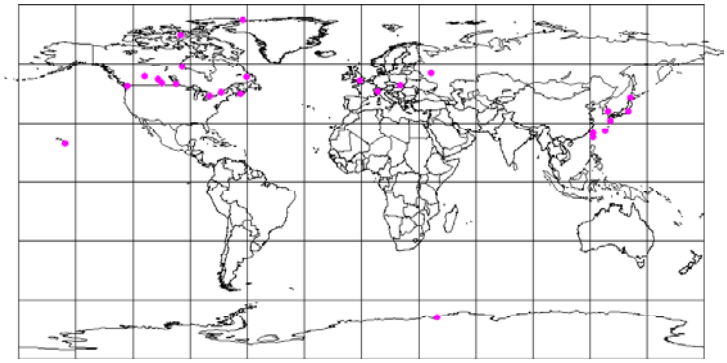

Figure 4: Stations reporting spectral UV data to the WOUDC. August, 2005

UV data from some countries in Europe. However, the current volume of spectrally- resolved UV data in the WOUDC is approximately 400 station-years, which may be more than 75% of what could be made available. Figures 2 through 5 indicate the kinds of data and numbers of stations reporting to the WOUDC. During the past six years the WOUDC has moved towards making products that assist the originators and users of UV and ozone data with quality control. The centre now accepts ozone and UV data in near real time and posts current maps of column ozone obtained from current ground-based and satellite instruments. Daily hemispheric and global maps (Figures 6 and 7) are available for all periods during the past forty years. Also various forecasts maps of ozone (at present KNMI, NCEP and MSC) are posted on the site. Data from the new OMI satellite instrument will soon be included to replace the now unreliable EP-TOMS data. The Centre is still struggling to increase the amount of 'raw' Brewer data (so-called B-files) that are submitted.

Analyses from the data centre are contributed to the Ozone Assessment process and for the preparation of the WMO Ozone Bulletins.

THEORY, MODELLING, AND OTHER RESEARCH

The Canadian Middle Atmosphere Model (CMAM), collaboratively developed over the last decade by scientists from Canadian universities and Environment Canada, is a middle atmospheric climate general circulation model (GCM) stretching from the ground to ~95 km, or ~0.001 hPa. This model incorporates complex, online gas-phase and heterogeneous chemistry for the middle atmosphere. The CMAM was involved in the last WMO intercomparison aimed at assessing current middle atmospheric GCMs capabilities for describing the current and future states of the stratosphere and the impact of greenhouse gases and chlorine loading upon the ozone layer in particular. A new WMO scenario experiment is currently underway involving similar work with newer model versions intended to continue this task. The currently running simulation using CMAM covers 1960-2050+ as part of the latest SPARC/WMO assessment.

Stratospheric chemistry has also been coupled to a version of the Canadian Global Environmental Multiscale Model (GEM) for weather forecasting extended to 0.1 hPa. This has been done for the ESA-funded project 'Coupled Chemical-Dynamical Data Assimilation'. This project, led by Environment Canada in collaboration with The Belgian Institute for Space Aeronomy (BIRA) and York University, is a study of ozone chemistry, dynamics, and their interactions in a data assimilation context.

Figure 5: Stations reporting ozonesonde profile data to the WOUDC. August, 2005.

Both of these models, CMAM and GEM, are being employed in data assimilation mode using the Environment Canada 3-D variational system (3DVar). 3DVar has been adapted to allow the assimilation of species observations. To support this, the preparation of a database of ozone-related observations from various sources has been undertaken. Short-term preliminary assimilations of ozone observations have been performed using data from the OSIRIS, SBUV/2, TOMS, and GOME-2 instruments.

The Canadian Space Agency and Environment Canada are supporting the CMAM Facility for Data Assimilation and Modelling (CMAM-FDAM). Its principal objective is to provide support to the Canadian atmospheric measurement community. In that context, species products relying on assimilated dynamics are being provided for sites and periods of interest. This is to eventually incorporate products from species assimilation.

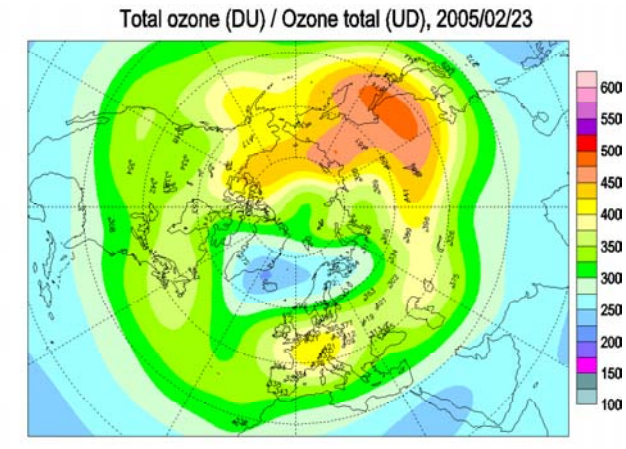

Figure 6:Total ozone map from the WOUDC for February 23, 2005 showing low ozone off the coast of Greenland.

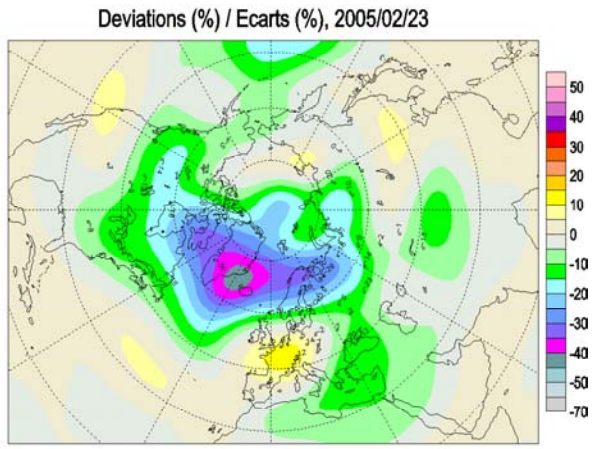

Figure 7: The same data as in Figure expressed as a departure from historically normal levels. Note that depletions reached more than 40%.

DISSEMINATION OF RESULTS

Data Reporting

Canadian column ozone measurements, ultraviolet radiation measurements and ozonesonde profiles are all submitted to the WOUDC on a regular basis by the MSC.

Information to the Public

Canada developed a UV Index in April, 1992. Since then Canadian public weather forecasts and reports have included the UV Index. Surveys indicate that there is a widespread public awareness of the Index and the data suggest that the majority of the public have modified their behaviour in response to the information provided. Six years ago MSC and Health Canada cooperated to develop a special programme to educate school children about UV exposure. It is called the “Children’s UV-Index Sun Awareness Programme” and was initially directed toward primary school children but now includes high school students as well. Part of the programme is World Wide Web (WWW) based and involves the students making and reporting measurements.

Addresses:

World Ozone and UV Data Centre	http://www.woudc.org/
Maps and real time measurements	http://exp-studies.tor.ec.gc.ca
Children’s UV-Index Sun Awareness Programme	http://www.msc-smc.ec.gc.ca/uvindex

Information on the state of the ozone layer is released on the WWW each week. It includes a comparison of the current two-week average ozone values over Canadian stations with estimates of un-depleted ozone data based on an analysis of historical records.

Ozone maps that are prepared for scientific use as indicated in Section 2, are also freely available to the general public on the WWW (Figures 6 and 7). Figures 8 and 9 compare satellite based estimated of UV irradiance to Brewer network measurements.

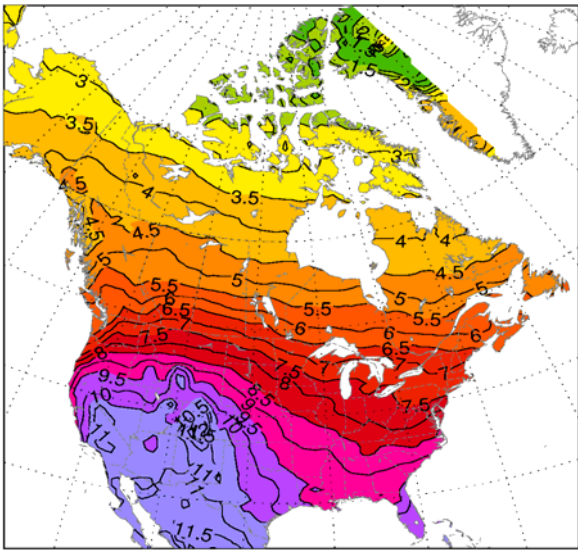

Figure 8: Map of mean noon (11 am-1 pm) UV index values for July estimated from TOMS.

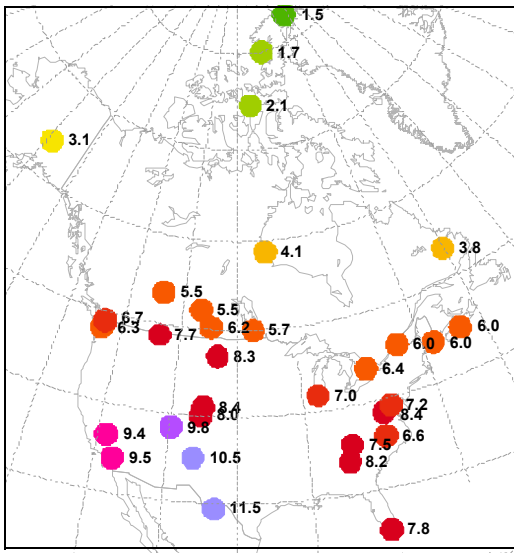

Figure 9: The same as Figure 8 but estimated from Brewer measurements.

PROJECTS AND COLLABORATION

WMO/GAW Biennial Brewer Users' Workshops

Canada supports the Global Ozone Observing System through organizing and Chairing the Brewer Users' Workshops. These are held in different host countries every two years and are intended to improve the consistency and quality of ozone observations through the sharing of knowledge concerning the operation and maintenance of the Brewer instrument. They also provide a mechanism for the propagation of scientific information to encourage a wider range of measurements to be made and to provide feedback on a scientific level to improve operations. Canada hosted the Seventh Brewer users' meeting in Toronto in September, 2002. The most recent meeting was hosted by the Brewer Spectrophotometer's manufacturer, Kipp & Zonen B.V., in Delft, the Netherlands, in June, 2005. Between 4 and 6 MSC staff organize and participate in these meetings.

Figure 10: The PEARL observatory. The Eureka research facility is undergoing a full-scale upgrade, including the installation of a 128 kbs^{-1} satellite communications link.

Arctic Ozone Research

The Arctic Stratospheric Ozone Observatory (ASTRO) at Eureka, Nunavut (80°N) was established in 1992 as a contribution from Canada to the WMO/GAW Network for the Detection of Stratospheric Change (NDSC). The observatory instrument complement included Raman (added in 1996) and Rayleigh lidars for the measurement of ozone, water vapour, density and aerosols; FTIR spectrometers both for atmospheric thermal emission and for solar and lunar occultation; and various UV/Vis spectrometers, including modified Brewer spectrometers. However, since the 2002 Ozone Assessment, which led policy-makers to the conclusion that the ozone depletion issue was solved based on the observed decline in regulated, ozone-depleting chemicals, resourcing of the stratospheric science programme has decreased significantly, resulting in the Eureka observatory being at first moth-balled and then ceded to the university community in 2004.

Figure 11: Two sea containers were insulated and equipped in Toronto and airlifted to Eureka a by C-130 Hercules. They are situated near sea level at the site of the Eureka weather station.

In 2005, the university consortium - the Canadian Network for the Detection of Atmospheric Change (CANDAC) - was successful in gaining 5-year funding to re-establish an atmospheric research facility at Eureka. The new laboratory is called the Polar Environment Atmospheric Research Laboratory (PEARL) and is operated by that consortium. It includes partners from a number of Canadian Universities and from other countries. Within Canada it is supported by funding from nine different federal and provincial organizations. The major contributors are: the Canadian Foundation for Innovation (CFI), the Canadian Foundation for Climate and Atmospheric Science (CFCAS) and the Natural Sciences and Engineering Research Council (NSERC). There are also contributions in kind from the MSC. It is hoped that some research involvement from the MSC can be maintained.

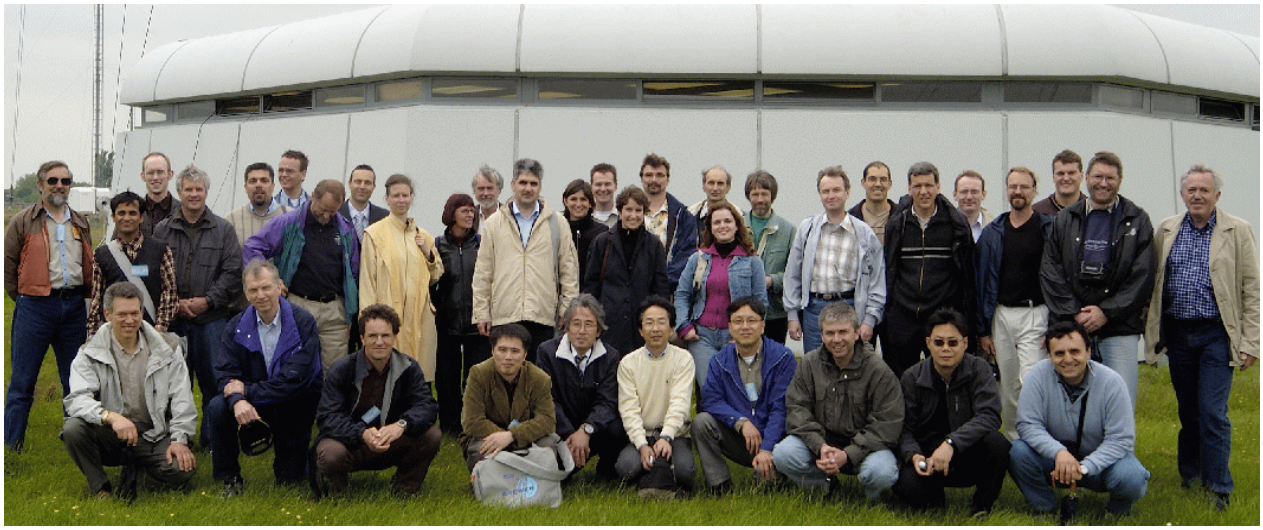

Figure 12: Attendees at the 2005 Brewer User's Workshop in Delft. The photo was taken at the bottom of the Netherlands' 200 m flux tower. Photo courtesy of Ben Dieterink, Kipp & Zonen B.V.

The overall objective of the new PEARL laboratory encompasses air quality, climate change and ozone studies. The laboratory will be fully functional by 2007 in time to participate in the International Polar Year (IPY). The instrumentation of the former laboratory has been maintained and upgraded to enable the continuation of previous datasets and new observations are planned for the study radiation, clouds and aerosols in the lower atmosphere, and composition and waves in the upper atmosphere.

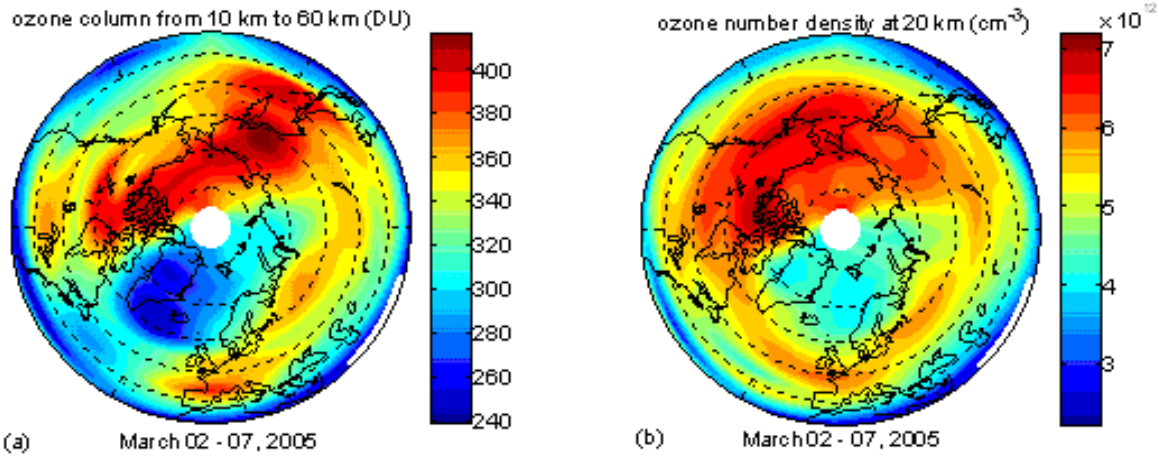

Figure 13: The total ozone column from 10 to 60 km and the ozone number density at 20 km as measured by OSIRIS. The structures seen in these plots indicate a minor northern hemisphere ozone depletion event in spring 2005.

OSIRIS Instrument on the ODIN Satellite

The OSIRIS instrument team is led by a principal investigator from the University of Saskatchewan in Saskatoon. OSIRIS was launched in March, 2001 on the Swedish satellite ODIN in an international collaboration that also involves French researchers. The OSIRIS spectrometer has been producing limb radiance spectra since it was commissioned in August, 2001. Ozone and NO_2 vertical profiles are available from these measurements. These have exceptionally high vertical and spatial resolution. The Canadian Space Agency renewed funding for the OSIRIS project in the spring of 2005, so data will continue to be available for at least two more years.

Atmospheric Chemistry Experiment (ACE)

The Canadian Space Agency funded the development of the Atmospheric Chemistry Experiment (ACE) satellite, also called SCISAT, to make atmospheric measurements relevant to ozone depletion, primarily focussed on the Arctic wintertime and early springtime stratosphere. This satellite mission is based on a proposal submitted by a mission scientist from the University of Waterloo. SCISAT was launched on August 12, 2003 and is currently making valuable occultation measurements with an infrared Fourier transform spectrometer (FTIR) and an MSC-developed diode-array spectrometer operating in the UV/visible/NIR wavelength range. The data will provide concentration profiles of more than ten trace gases as well as information about the

Figure 14: SciSat undergoing final assembly at the David Florida Laboratories in Ottawa. The satellite was subsequently shipped to Vandenberg AFB to be launched on a Pegasus launch vehicle.

characteristics and occurrence of polar stratospheric clouds. The science team of ACE reflects substantial collaboration with teams in Belgium, France and the USA.

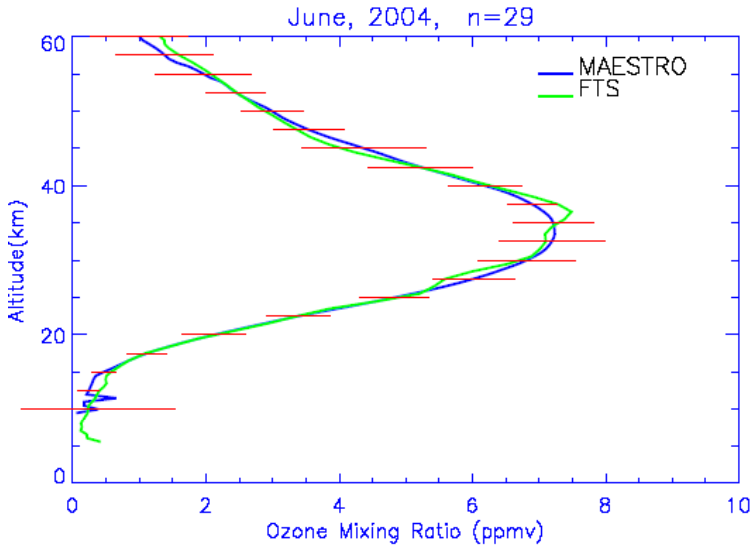

Figure 15: The mean of 29 ozone profiles taken with ACE-FTS (Green) and MAESTRO (Blue). The 'error bars' indicate the standard deviation of the 29 profiles. (Courtesy of J. Kar, U. Toronto).

TOMS3F

MSC participated in a NASA-led project in spring, 2001 to improve our understanding of the relationship between satellite-based (TOMS) measurements of ozone and measurements made by ground-based instruments at high latitudes. The TOMS3F campaign provided measurements from the Fairbanks Dobson instrument, one double monochromator Brewer owned by NASA/Goddard, and one single and one double Brewer provided and operated by MSC as well as ozonesonde and Microtops data. The data have not yet been published, but preliminary assessment has indicated that the agreement between double Brewer instruments and TOMS observations is very good while systematic errors in Dobson and single Brewer measurements contribute a significant discrepancy in comparison with the satellite results. MSC is attempting to arrange participation in a follow-on campaign in Sodankyla, Finland in the Winter of 2005 - 2006.

Brewer Spectrophotometer Manufacture and Maintenance

After a period of uncertainty, that the supply of Brewers for the global ozone observing network has been assured by the demonstrated, continuing interest of Kipp & Zonen, B.V. of Delft, the Netherlands, the Brewer manufacturer, and the signing of a multi-year license agreement between Environment Canada and Kipp & Zonen. Maintenance and calibration services for the Brewers is also available, with both the manufacturer and International Ozone Services of Toronto supporting instruments in service at Brewer observing locations around the world. Environment Canada is actively participating in this process through the Brewer workshops as well as by providing consulting services and calibration support to both companies.

Figure 16: The Canadian contingent present at Vandenberg AFB for the launch of SciSat on August 12, 2003. Left to right: Peter Bernath (Mission Scientist, U. Waterloo), Randy Shelly (Bus Manager, CSA), Roger Colley (Director General, Space Science, CSA), Tom McElroy (MAESTRO Principal Investigator, MSC), Wally Eliuk (Bristol Aerospace), Reg Colin (Université Libre de Bruxelles, Belgium). The white cylinder with 'Canada' marked on it is the Pegasus rocket that carried the satellite into space after being dropped over the Pacific Ocean from the L-1011 aircraft on which it is mounted as shown in this photograph.

FUTURE PLANS

MSC is continuing, within resource constraints, to work on improving the basic scientific foundation for spectroscopic measurements of ozone and solar radiation. The scope of this work ranges from technical issues related to instrument performance as well as scientific studies related to optimizing the analysis of data collected in the Brewer observing network. The development of new instruments with superior performance for atmospheric remote sounding is also being addressed. For example, the MAESTRO spectrophotometer on SCISAT was developed and the flight model constructed at the MSC. MSC is attempting to arrange participation in a TOMS3F follow-on campaign in Sodankyla, Finland in the Winter of 2005 - 2006.

NEEDS AND RECOMMENDATIONS

(a) It is imperative to improve the ground-based network to a capability of detecting a 1% per decade trend in the ozone recovery rate so that a turnaround comprising a recovery in the ozone layer may be detected in less than several decades. With the failure of the TOMS instrument and its replacement by new systems such as OMI, a high quality surface network is crucial to maintain a consistency of observations both between satellites and over the life-time of an individual instrument. The development and maintenance of such a crucial network cannot be accomplished with the reduction in resources being experienced by many of the meteorological agencies within the WMO.

(b) Those responsible for decisions concerning the implementation of the Montreal Protocol and Vienna Convention on Ozone Depleting Substances within national governments must be made aware of the need for long-term consistent high-quality observations. The present belief among many policy analysts is that network observations can be easily reconfigured as a short-term cost-saving measure. They must be convinced of the importance of long-term monitoring of atmospheric trends and the enormous damage inflicted in the determination of such trends when observing sites are decommissioned.

(c) Heads of meteorological agencies within the WMO should be apprized of the potential of assimilating ozone observations, made both from the surface and from space, as a means of significantly improving weather and air quality forecasts.

Relevant Scientific Papers

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Fioletov, V.E, J.B. Kerr, C.T. McElroy, D.I. Wardle, V. Savastiouk, and T.S. Grajnar, The Brewer Reference Triad, Geophys. Res. Lett., in press, 2005.

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