Monitoring and prediction of UV radiation in Australia

M.J. Manton
Bureau of Meteorology Research Centre, Melbourne, Australia

Because of its damaging impact on living matter, the flux of UV radiation at the earth’s surface needs to be monitored and predicted. This requirement has been highlighted in recent years by the measurable reduction in global stratospheric ozone, which attenuates the flux of solar UV radiation. However, over the last decade there has been substantial progress in identifying the nature of stratospheric ozone depletion and in establishing international policies to respond to the problems associated with the emission of ozone-depleting substances into the atmosphere.

Notwithstanding the scientific and political progress, the international community recognises the need to develop much more robust research and operational programs to ensure that the state of the stratospheric ozone layer and the flux of UV radiation to the surface can be effectively monitored and predicted. Because the meteorology of the southern hemisphere is quite different from that of the northern hemisphere, these programs cannot be ignored in our region. Australia is the most developed country in the southern hemisphere which is affected by the annual Antarctic ozone ‘hole’, and so we should play a leading role in these activities. In this paper, the current status of research and operational programs is reviewed, and the prospects for future developments are considered.

Introduction

In 1989 the Menzies Foundation organised a symposium on the health consequences of depletion of the stratospheric ozone layer. At that time there was still some uncertainty about the relative roles of atmospheric dynamics and chemistry in the creation and maintenance of the annual ozone ‘hole’ over Antarctica. Moreover, the role of polar stratospheric clouds (PSCs) in providing a pathway for the destruction of ozone in the springtime polar vortex was only just becoming clear (Plumb 1989). Thus the Montreal Protocol at that time was based on the assumption that ozone depletion was due to homogeneous chemistry, which grossly underestimated the rate of depletion (Fraser 1989).

The last decade has seen remarkable progress in the science and politics of stratospheric ozone depletion. Based on advances in understanding of heterogeneous chemistry and on knowledge gained from a series of airborne expeditions to the Antarctic and Arctic, the nature of the Antarctic ozone hole is much better understood. The advances in the science have sustained the political will to strengthen the Montreal Protocol so that the concentrations of the main ozone-depleting substances in the atmosphere are all expected to be decreasing by the end of the decade (e.g. Montzka et al. 1996).

While there has been valuable progress on the acute problem of ozone depletion, there remain substantial strategic issues on the long-term monitoring and prediction of ozone and UV radiation across Australia. In this paper, we consider the need for sustained programs of
research and monitoring to protect the health of the Australian community. These activities would complement the systems being developed in other countries around the world.

Need for action

It is well known that UV radiation is damaging to living matter, and that the ozone layer in the lower stratosphere absorbs a substantial fraction of the UV-B radiation from the sun. There is complete absorption of the shorter-wavelength UV-C radiation by oxygen, nitrogen and ozone molecules in the atmosphere, so that no UV-C radiation reaches the surface. Thus the shielding effect of the stratospheric ozone layer is necessary for life on earth in its present form. This layer is quite tenous, in the sense that if the ozone in the stratosphere were reduced to standard temperature and pressure then the layer would be only about 3 mm deep (corresponding to 300 Dobson Units of total column ozone).

The ozone layer is important not only for the maintenance of life but also for its impact on the dynamics of the atmosphere. The absorption of UV radiation in the ozone layer leads to heating, which largely determines the thermodynamic structure of the stratosphere. Horizontal gradients in the heating in turn cause pressure gradients which drive the large-scale circulation in the stratosphere.

In the early 1970s, it was recognised that human activity may be leading to the injection of ozone-depleting substances into the stratosphere. The initial concern was aimed at the output of oxides of nitrogen from supersonic transport aircraft flying in the lower stratosphere. However, Molina and Rowland (1974) noted that chlorofluorocarbons (CFCs), used in an increasing range of industries, could cause long-term destruction of ozone in the stratosphere. The chemical stability of CFCs at the surface is a reason for their use in industrial applications, such as solvents. Thus CFCs can be carried from the surface to the stratosphere, where they can be finally broken down to release chlorine atoms that catalytically destroy ozone. This early research, including the role of nitrogen oxides on ozone destruction, by Drs P. Crutzen, M. Molina and S. Rowland was the basis of their jointly receiving the 1995 Nobel Prize for chemistry.

A further concern arises with CFCs because they are very effective greenhouse gases; in particular, a unit mass of the common CFCs can be several thousand times more effective in warming the earth's surface than the same mass of carbon dioxide. The CFCs in the atmosphere at present directly contribute about 10 per cent of the total change in greenhouse radiative forcing since pre-industrial times. However, because they have also destroyed stratospheric ozone (which is itself a natural greenhouse gas), the net contribution of CFCs to the enhanced greenhouse effect is about five per cent of the total radiative forcing (Houghton et al. 1996).

It is clear that stratospheric ozone is a key constituent of our atmosphere. It naturally controls the flux of UV radiation to the surface, as well as influencing the general circulation of the atmosphere. Moreover, human activities over the last three decades have caused changes in the radiative balance that have led to a suggestion of 'a discernible human influence on global climate' (Houghton et al. 1996) and that could also have changed the overall UV flux to the surface. For example, local observations at Mauna Loa Observatory (Hofmann et al. 1996) show a strong correlation between total ozone and the clear-air UV flux at the surface. Because of the sensitivity of living matter to UV radiation, these changes in UV and ozone must be monitored, understood and (if possible) predicted.

The required nature and extent of any monitoring of a parameter is determined by the variability of that parameter. The flux of UV to the surface clearly has a dominant diurnal cycle, and the surface flux will be greatly moderated by the presence of clouds and aerosols in the atmosphere. However, the large-scale determinant of surface UV is the vertical distribution of stratospheric ozone above the surface location. Because the local production of ozone is controlled by solar insolation, there are diurnal variations in stratospheric ozone. Its distribution has a large seasonal cycle, and it also responds to the changes in incoming radiation with the solar cycle.

The geographical variations in UV and ozone are substantial, owing to meridional variations in solar zenith angle and to the meridional transport of ozone by the general circulation of the atmosphere. Zonal variations are caused by synoptic features of the weather moderating the ozone distribution and by smaller scale features, such as clouds. The vertical distribution of ozone is determined by the local balance of the chemical creation and destruction of ozone molecules, as well as by transport processes. Thus stratospheric ozone is spread vertically between about 15 and 50 km altitude, with a peak in the concentration (specific volume) at about 35 km.

The addition of CFCs and other human-made chemicals has led to changes in the geographical distribution of ozone. The major impact has been on the development of the Antarctic ozone hole in the austral spring (Farman et al. 1985). The impact of ozone-depleting substances has not been as great in high latitudes of the northern hemisphere because the polar vortex in the Arctic is less stable than that in Antarctica, and so it does not act as an effective 'container' as the southern polar vortex. It is also found that the total ozone has
been reduced over the last decades at mid-latitudes. Thus there are measurable long-term trends in the meridional variation of ozone and UV that need to be monitored. To ensure that the science is fully understood it is also necessary to monitor the concentrations of ozone-depleting substances in the atmosphere.

Careful observations over the last few years have demonstrated that the unpredictable eruptions of volcanoes can affect the stratosphere. The sulphate aerosol emitted by the eruption of Mt Pinatubo in 1991 led to short-term changes in the thermodynamics and chemistry of the lower stratosphere. In particular, the temperature and ozone levels were reduced for about three years, but the stratosphere has now recovered from that transitory disturbance (WMO 1995).

There are many natural and anthropogenic causes of variation in the distribution of stratospheric ozone, which in turn lead to changes in the surface flux of UV radiation. A substantial program of observations is needed to monitor all these changes, which occur on a range of space and time-scales.

A further incentive for the maintenance and enhancement of a global system to provide sustained and careful monitoring of ozone and UV radiation is the observed trend of increasing occurrence of malignant melanoma in different populations around the world (e.g. Elwood 1989). Because of the time lag between sun exposure and the occurrence of melanoma, these trends commenced before the recent reductions in stratospheric ozone became clear. It is likely that the increasing impacts of UV radiation on human health are largely due to changes in personal behaviour. This result means (a) that any reduction in stratospheric ozone could exacerbate the health problem, and (b) that, independent of ozone depletion, there is a continuing need to monitor and predict ozone and UV radiation as important components of our environment that will always impact on human health.

**Brief history of actions**

The speed of the international policy response to the issue of stratospheric ozone depletion is a clear example of the value of long-term strategic research in establishing the foundation for rapid action when an acute problem arises. As part of a curiosity-driven research program, G.M.B. Dobson commenced observations of total column ozone in 1924 at Oxford. The standard instrument for such surface-based measurements remains the Dobson spectrophotometer (Komhyr 1980), and it is used routinely at about 100 sites around the world.

As with many significant observation programs, systematic world-wide ozone measurements were initiated by the International Geophysical Year (IGY). In 1957 the World Meteorological Organization (WMO) took responsibility for the network developed for the IGY, and thus the Global Ozone Observing System (GO3OS) was established.

Australian observations of stratospheric ozone were begun in 1956 by CSIRO as a contribution to the IGY. Over the next decade, a network of six stations was established in collaboration with the Bureau of Meteorology. In 1965 the CSIRO also commenced weekly flights of an ozone sonde at Melbourne which measured the vertical distribution of ozone, complementing the total column ozone measurements from the spectrophotometers.

In 1982 the ozone monitoring network in Australia was formally transferred from CSIRO to the Bureau of Meteorology. There are now routine Dobson measurements at five sites (Darwin, Brisbane, Perth, Melbourne and Macquarie Island), giving an appropriate meridional distribution of observations. There is also a weekly ozone sonde release in Melbourne.

At present, the Bureau has a research project with Wollongong University to monitor UV radiation at its Baseline Air Pollution Station at Cape Grim in north-western Tasmania. At that site, regular observations are collected with a spectral radiometer and with a broadband erythemal UV-B detector (Wilson and Forgan 1996). The Australian Radiation Laboratory (ARL) has routinely been measuring integrated UV dosage at 18 sites in Australia and Antarctica since the 1980s (Roy et al. 1997). This network follows earlier observations by CSIRO in the 1970s using Robertson-Berger meters.

While surface-based instruments should provide accurate and consistent measurements, they cannot give the full global picture of the variations of ozone and UV radiation. Global coverage of environmental variables is most effectively obtained through satellite-based instruments. Such instruments have been flown since the 1960s, and routine observations of stratospheric ozone are now available from the TOVS, TOMS and SBUV instruments on operational meteorological satellites. In particular, the extended record from TOMS instruments provides direct information on the trends in global ozone (e.g. McPeters et al. 1996). The TOMS data can also be used to estimate the surface flux of UV (e.g. Eck et al. 1995). More detailed information is also collected from research satellites such as UARS, SAGE II and GOME.

The background provided by the strategic research and monitoring of stratospheric ozone meant that the international community was able to respond in a considered manner to the concerns raised in the early 1970s about the potential damage by the emission of ozone-depleting substances. In 1977 the United Nations Environment Programme (UNEP) established the World Plan of Action on the Ozone Layer, with WMO as the
lead agency for monitoring and research on modification to the ozone layer. As part of the WMO Global Ozone Research and Monitoring Project, regular assessments of the state of the ozone layer have been carried out, with the first report in 1981.

The monitoring of the chemical constituents of the atmosphere began in the 1960s, and WMO now coordinates the Background Air Pollution Monitoring Network (BAPMoN) as part of its Global Atmosphere Watch (GAW) program. The Bureau of Meteorology operates a Baseline Air Pollution Station at Cape Grim at which the physical properties and chemical composition of the atmosphere are monitored. The research program at Cape Grim is jointly managed by the Bureau and CSIRO, and the quality and scope of the observation program is internationally recognised. The observations from the station show almost the entire history of CFCs and other human-made chemicals from when they were first released into the atmosphere (Francey et al. 1996).

The substantial political progress on the control of ozone-depleting substances has been supported by a sustained program of research and monitoring. Our understanding of the potential impact of ozone-depleting substances led to the signing in 1985 of the Vienna Convention for the Protection of the Ozone Layer, which committed nations to ‘appropriate measures’ to protect human health and the environment from adverse effects of modification of the ozone layer. In that same year, the growing magnitude of the annual Antarctic ozone ‘hole’ was highlighted (Farman et al. 1985). This led to the more specific Montreal Protocol on Substances that Deplete the Ozone Layer, which committed signatories to the gradual phasing out of CFCs and halons.

The strategy for the phasing out of ozone-depleting substances under the Montreal Protocol was based on a limited understanding of the physics and chemistry of the processes occurring in the stratosphere, and the potential rate of depletion of stratospheric ozone was grossly underestimated. A series of research campaigns was initiated by the US National Aeronautics and Space Administration (NASA), in which a high-altitude (ER-2) aircraft flew into the polar vortices of the Antarctic and Arctic during the springtime. Observations from the Antarctic Airborne Ozone Experiment in 1987 provided the ‘smoking gun’ linking the build-up of chlorine in the stratosphere to the subsequent depletion of ozone in the polar vortex (Tuck et al. 1989). The first Airborne Arctic Stratospheric Experiment in 1989 showed that the same processes occur in the northern springtime polar vortex, although to a reduced extent (Turco et al. 1990). Further studies in the Arctic (e.g. Anderson and Toon 1993) and the Antarctic (e.g. Tuck et al. 1997) have confirmed the basic chemistry of the ozone-depletion process and increased our understanding of the role of transport mechanisms on the distribution of stratospheric ozone.

The knowledge gained from such experiments and from the development of a better understanding of the heterogeneous chemistry associated with ozone depletion demonstrated that the implementation strategy in the Montreal Protocol in 1987 was inadequate. However, the Amendments to the Protocol agreed in London in 1990 and in Copenhagen in 1992, followed by the 1995 Vienna Adjustments, have ensured that the production of the major ozone-depleting substances will be phased out before the end of the decade, so that the ozone layer should return to its natural state by the middle of the next century (WMO 1995). The long time-lag between the phasing out of CFCs and other chemicals and the response of the stratosphere is due to the long lifetime of these chemicals in the atmosphere.

Future international activities

The political progress on the phase-out of ozone-depleting substances has been possible only because of the long-term research and monitoring programs that provided the scientific understanding of processes involved. These programs must clearly be sustained into the future. One reason for continuation of these activities is to monitor progress and ensure that nations comply with the obligations under the Montreal Protocol and its Amendments. A second reason is that the health and environmental impacts of ozone and UV radiation are a continuing concern, independent of any depletion of the ozone layer. A third and vital reason is the need to support scientific studies that improve our general understanding of our environment, so that when an unexpected event (such as the Antarctic ozone ‘hole’) occurs we have a sound base for immediate and considered action.

Under the WMO GAW program, there is now a network of surface-based observations to monitor stratospheric ozone, UV radiation and ozone-depleting substances. The network is not dense, especially in the southern hemisphere, and much vigilance is needed to ensure that the quality and consistency of measurements are maintained at high standards. It is hoped that the GAW network to measure stratospheric ozone can be greatly expanded in the future, so that reliable and consistent long-term observations of ozone variability can be obtained. These observations also provide calibration information for satellite-based systems, which will continue to be deployed.

The development of the network to measure UV radiation at the surface is still in its early stages. Following a meeting of experts in July 1994 in Switzerland, a Scientific Steering Committee has been appointed with the responsibility to oversee the observation program, to coordinate studies to calibrate and intercompare instruments, to develop a system for the archive and distribu-
tion of UV data, and to ensure the quality control of the measurements.

With the growing community concern in the northern hemisphere about the impacts of ozone depletion, a number of national meteorological services have commenced operational procedures to predict UV radiation at the surface. For example, the Canadian Atmospheric Environment Service has been disseminating UV-B forecasts since 1992 and the US National Weather Service commenced a similar service in 1994 (Long et al. 1996). These forecasting systems generally are based upon statistical relationships between ozone, UV and primary meteorological variables, such as the vertical temperature profile. A considerable amount of research and development is needed to progress these procedures to the stage where they become an integral part of the well-developed numerical weather prediction systems that are the backbone of modern weather-forecasting operations. The systems to analyse and predict UV radiation also require comprehensive and reliable observational programs to validate the forecasts. Thus the quality control of these new UV forecasting systems is very dependent upon the global networks to measure ozone and UV radiation.

Over the last few years, the World Climate Research Programme (WCRP) has established a program to enhance and coordinate the international research on stratospheric ozone and UV radiation. The Stratospheric Processes and their Role in Climate (SPARC) project has set up a number of projects that depend upon international cooperation. These activities include the development of an improved climatology of the structure of the stratosphere, an assessment of trends in stratospheric temperatures with an emphasis on separating the impacts of carbon dioxide and ozone, the development of a climatology of water vapour in the lower stratosphere, and observational studies to improve our understanding of ozone trends. These research activities are important in ensuring that we continue to increase our understanding of the processes affecting UV radiation at the surface, and in supporting the increasing number of routine operational functions that are being implemented by national meteorological services to forecast UV and ozone.

Future national activities

As in much atmospheric science, Australia has made significant contributions to the international activities related to stratospheric ozone and UV. This work is needed because we are somewhat isolated in the southern hemisphere from other industrialised countries and because the meteorology of our hemisphere is different from that of the northern hemisphere. The Australian meteorological community is well connected to the international groups involved in these issues, so that there is invariably a large return from our research and monitoring investments in international cooperative projects. For example, we obtain free access to data for research and operational use from satellite programs developed for hundreds of millions of dollars by other nations. It is therefore vital for us to continue to participate in appropriate international programs related to stratospheric ozone and UV radiation.

The Baseline Station at Cape Grim is internationally recognised, and it plays a vital role in monitoring the background concentrations of CFCs and other ozone-depleting substances. We need to continue to monitor these substances and their chemical replacements into the future.

The Bureau of Meteorology monitors total column ozone at sites extending from Darwin to Macquarie Island, and these observations are expected to be continued as part of the Bureau's public-good responsibilities. It is also expected that funds will continue to be available to maintain the weekly ozone sondes at Melbourne, which yields information on the vertical profile of ozone. The Melbourne site is only one of three conducting routine sonde flights in the southern hemisphere outside Antarctica. In the northern hemisphere there are currently twenty-four sonde stations, and so the network in our hemisphere is seen to be inadequate to delineate the three-dimensional variations of ozone.

There is a proposal for the Bureau to establish a weekly ozone sonde site at Alice Springs. That site is preferred because it is representative of much of the continent and because it is at a latitude where studies of meridional transport between the tropics and mid-latitudes could be carried out. It is also near the subtropical jetstream, which means that the stratosphere-troposphere exchange of ozone at the tropopause break could be monitored.

There is great interest in establishing a routine ozone sonde program at Macquarie Island, but logistical constraints mean that such a long-term commitment is not currently feasible. On the other hand, a collaborative research program is being put in place to allow a limited number (about 25) of sonde flights from Macquarie Island over the next few years. The project is led by the Cooperative Research Centre for Southern Hemisphere Meteorology (CRC-SHM), with support from the Bureau of Meteorology and the Australian Antarctic Division and with some funding from the Antarctic Science Advisory Committee (ASAC) and the Antarctic Cooperative Research Centre at the University of Tasmania.

Because of the human-health impacts of UV radiation, the Australian Radiation Laboratory (ARL) has a substantial network across Australia and Antarctica to
measure the erythemal flux of UV radiation (Roy et al. 1997). The operation of this network, in cooperation with the Bureau of Meteorology and others, is expected to continue and to evolve with the needs of ARL. To complement those observations, the Bureau plans to implement a limited network of spectro-radiometers and Robertson-Berger meters as part of its overall radiation measurement program. These observations would be quality-controlled, archived and distributed with the other solar and infrared radiation measurements obtained in the Bureau program.

Comprehensive routine observations of ozone and UV radiation are critical components for the development of an operational UV forecasting system. The Bureau has developed a UV forecasting system in cooperation with CRCSHM. The initial system, which was implemented operationally by the Bureau in September 1996, is based on an analysis of total column ozone from TOVS data on the NOAA polar-orbiting operational satellite. A simple advection scheme, incorporating results from the Bureau’s global numerical weather prediction (NWP) system, is used to predict the evolution of stratospheric ozone over the next 24 hours. Based on the predicted distribution of ozone, the UV flux to the surface is calculated for midday clear-air conditions by numerically solving the radiative transfer equation. The UV Index (UVI) is then computed by an erythemal weighting of the spectral flux across the UV-B spectrum. Validation of the system is provided first by comparing the satellite-based ozone analysis and the predicted ozone distribution with the Dobson ozone observations around Australia, and secondly by comparing the UVI analyses and predictions with the surface observations from the ARL network across the country.

While the initial UVI forecast system of the Bureau is comparable with those operated by other national meteorological services, it can be considerably extended in the future. Using output from the Bureau’s global NWP systems, it is possible to predict the evolution of cloud and so it will be feasible to include the effects of cloud in the UV flux calculations. Considerable research is needed to develop a comprehensive assimilation system so that ozone can be formally included in the Bureau’s operational NWP system. An ozone assimilation system would allow stratospheric ozone to be treated directly within the NWP system, so that its predictions would be entirely consistent with the predictions of the other forecast variables, such as wind and temperature.

Strategic research on stratospheric ozone is being carried out in Australia through the CRCSHM, which involves Monash University, the Bureau of Meteorology, CSIRO Division of Atmospheric Research, and CSIRO Division of Telecommunications and Industrial Physics, and Cray Research (Australia). A major program of the CRCSHM is on ozone, with the aim of providing a strong scientific basis in Australia for the provision of advice on stratospheric ozone. The program has projects on mechanisms of ozone variability and transport, stratospheric dynamics and modelling, and radiative transfer modelling and remote sensing. The CRCSHM is substantially involved with the international research community; for example it co-hosted the first general assembly of the SPARC project of the WCRP in December 1996. The establishment of the CRCSHM provides a national resource for strategic research that can complement the research and development needed to implement operational systems to analyse and predict stratospheric ozone and UV radiation at the surface.

Conclusions

By filtering out most of the UV-B radiation from the sun, stratospheric ozone plays a critical role in the maintenance of life on earth. For Australia there is a continuing human-health issue on the variability of ozone and its impact on the UV radiation at the earth’s surface. This issue has been highlighted over the last few decades by the effects of ozone-depleting substances in the atmosphere.

In order to understand and manage the ozone issue, it is necessary for Australia to have an appropriate capability to monitor and predict the distribution of stratospheric ozone and surface UV radiation across the country. There are significant advantages in these activities being carried out in cooperation with international programs. In particular, collaboration allows us to share data and knowledge on the global variations in relevant parameters, and especially to obtain access to satellite data. The extremely sparse network of surface observations in the southern hemisphere means that Australia achieves substantial benefits from collaboration in international programs that involve the sharing of satellite data.

Satellite data require in situ observations to calibrate and validate remotely sensed observations. It is therefore necessary for Australia to maintain and enhance its capability to monitor stratospheric ozone and UV radiation at the earth’s surface. The measurement of UV radiation needs to be extended to include spectral observations at a number of baseline stations, to allow detailed comparison with the results of model-based systems. The real-time analysis and prediction of UV at the surface needs to be developed such that it is incorporated with the data assimilation and prediction system used by the Bureau of Meteorology for operational weather forecasting.

Australia operates a world-class facility at Cape Grim, which routinely measures the background con-
centrations of ozone-depleting substances. These observations, along with other research and monitoring activities, allow Australia to maintain a significant role in the international research and policy forums on stratospheric ozone and UV radiation. It is therefore important for these measurement programs to be continued.

The rapid response of the international community to the issue of the depletion of stratospheric ozone was possible because of the long-term strategic research programs that were established in the earlier decades of this century.

References


