JAPAN

1. OBSERVATIONAL ACTIVITIES

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

Total column ozone and Umkehr measurements are carried out by the Japan Meteorological Agency (JMA) at four sites in Japan (Sapporo, Tsukuba, Naha, and Minamitorishima) and at Syowa Station in Antarctica (Table 1). A Brewer spectrophotometer is used for measurements at Minamitorishima, whereas Dobson spectrophotometers are used at the other observation sites.

Table 1. Locations of column ozone and Umkehr measurement sites operated by JMA

Observation site	Latitude	Longitude	Altitude (m)	WMO station number
Sapporo	43° 04′ N	141° 20′ E	26	47412
Tsukuba	36° 03′ N	140° 08′ E	31	47646
Naha	26° 12′ N	127° 41′ E	28	47936
Minamitorishima	24° 17′ N	153° 59′ E	9	47991
Syowa	69° 00′ S	39° 35’ E	22	89532

Concentrations of ozone-depleting substances and other atmospheric constituents are monitored by the Center for Global Environmental Research (CGER) of the National Institute for Environmental Studies (NIES) and by JMA. The monitoring sites are listed in Table 2. CGER/NIES monitors halocarbons (CFCs, CCl_4, CH_3CCl_3, and HCFCs), HFCs, surface ozone, CO_2, CH_4, CO, N_2O, SF_6, NO_x, H_2, the O_2/N_2 ratio, and aerosols at remote sites (Hateruma and Ochiishi). JMA measures surface concentrations of ozone-depleting substances (CFCs, CCl_4, and CH_3CCl_3) and other atmospheric constituents (surface ozone, CO_2, N_2O, CH_4, and CO) at Ryori, a Global Atmosphere Watch (GAW) Regional Station in northern Japan. Monitoring of concentrations of surface ozone, CO_2, CH_4, and CO is also carried out at Minamitorishima (a GAW Global Station) and Yonagunijima (a GAW Regional Station in the Ryukyu Islands).

The Japanese Ministry of the Environment (MOE) monitors concentrations of halocarbons (CFCs, CCl_4, CH_3CCl_3, halons, HCFCs, and CH_3Br) and HFCs at remote sites (around Wakkanai and Nemuro) and at an urban site (Kawasaki).

Table 2. Locations of monitoring sites for ozone-depleting substances and other minor atmospheric constituents

Monitoring site	Latitude	Longitude	Altitude (m)	Since	Organization
Ochiishi	43° 10′ N	145° 30′ E	45	Oct 1995	CGER/NIES
Hateruma	24° 03′ N	123° 49′ E	10	Oct 1993	CGER/NIES
Ryori	39° 02′ N	141° 49′ E	260	Jan 1976	JMA
Minamitorishima	24° 17′ N	153° 59′ E	8	Mar 1993	JMA
Yonagunijima	24° 28′ N	123° 01′ E	30	Jan 1997	JMA
Syowa	69° 00′ S	39° 35′ E	18	Jan 1997	JMA

JMA also monitors CFCs, CO_2, N_2O, and CH_4 concentrations in both the atmosphere and seawater of the western Pacific on board research vessels *Ryofu Maru* and *Keifu Maru*.

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

1.2.1 Ground-based and sonde measurements

From October 1990 to March 2011, CGER/NIES measured vertical profiles of stratospheric ozone at Tsukuba with an ozone laser radar (ozone lidar); these data were registered in the Network for the Detection of Atmospheric Composition Change (NDACC) database. CGER/NIES also measured vertical profiles of ozone with millimetre-wave radiometers from September 1995 to March 2011 at Tsukuba and from March 1999 to March 2011 at Rikubetsu.

JMA has been monitoring vertical ozone distributions weekly by ozone sonde at three sites in Japan (Naha, Sapporo, and Tsukuba) and at Syowa Station in Antarctica. The ECC type ozone sonde succeeded the KC type in October 2008 at Naha, in November 2009 at Sapporo and Tsukuba, and in March 2010 at Syowa. The KC sonde was developed by JMA and has been used in Japan since the 1960s.

1.2.2 Airborne measurements

In February 2011, JMA began taking monthly (approx.) airborne in situ measurements (flask sampling) of CO_2, CH_4, CO and N_2O concentrations at an altitude of about 6 km along the flight path from mainland Japan to Minamitorishima.

1.2.3 Satellite measurements

The Superconducting Submillimeter-Wave Limb-Emission Sounder (SMILES) was developed for deployment in the Japanese Experiment Module (JEM) on the International Space Station (ISS) through cooperation of the Japan Aerospace Exploration Agency (JAXA) and the Japanese National Institute of Information and Communications Technology. On 11 September 2009 (all dates are JST), SMILES was successfully transported to the ISS in the H-II Transfer Vehicle, launched by an H-IIB rocket. It was attached to the JEM on 25 September and began atmospheric observations on 12 October. The mission objectives are (1) to demonstrate the viability in the outer space environment of a 4-K mechanical cooler and superconducting mixers for submillimetre-wave limb-emission sounding in frequency bands 624.32–626.32 GHz and 649.12–650.32 GHz and (2) to take global measurements of atmospheric concentrations of minor constituents (e.g., O_3, HCl, ClO, HO_2, HOCl, BrO, O_3 isotopes, HNO_3, and CH_3CN) in the middle atmosphere to gain a better understanding of the factors and processes, including climate change, that control the amounts of stratospheric ozone.

Unfortunately, SMILES observations have been suspended since 21 April 2010 owing to the failure of a critical component in the submillimetre local oscillator. Until operations were suspended, SMILES measured concentrations of minor species in the stratosphere and mesosphere for about six months from October 2009 to April 2010. Processing of SMILES data provides global and vertical distributions of about 10 minor atmospheric constituents related to ozone chemistry; these data are now distributed by ISAS/JAXA from DARTS (Data ARchives and Transmission System; http://darts.isas.jaxa.jp/iss/smiles/) for use by the scientific community. An important outcome of the SMILES observations is that they have revealed the global pattern of diurnal ozone variations throughout the stratosphere. The peak-to-peak difference of the stratospheric ozone mixing ratio reaches 8% over the course of a day, suggesting the need for care when merging ozone data from satellite measurements made at different local time (Sakazaki et al., 2013).

1.3 UV measurements

1.3.1 Broadband measurements

CGER/NIES has used broadband radiometers to monitor surface UV-A and UV-B radiation at five observation sites in Japan since 2000. CGER/NIES calculates the UV Index from the observed data and makes it available to the public hourly via the Internet.

1.3.2 Spectroradiometers

JMA monitors surface UV-B radiation with Brewer spectrophotometers at Sapporo, Tsukuba, and Naha in Japan and at Syowa Station in Antarctica. Observations commenced in 1990 at Tsukuba and in 1991 at the other sites.

1.4 Calibration activities

JMA has operated the Quality Assurance/Science Activity Centre (QA/SAC) and the Regional Dobson Calibration Centre (RDCC) under the GAW programme of the World Meteorological Organization (WMO) to contribute to improving the quality of ozone observations in WMO Regional Associations II (Asia) and V (South-west Pacific). The Regional Standard Dobson instrument (D116) is calibrated against the World Standard instrument (D083) every three years. The most recent calibration was in 2013 at Boulder, Colorado, USA. Through the QA/SAC, a JMA expert visited the ozone observatory in Manila in April 2010 to calibrate the Dobson spectrophotometer there and provide training in measurement and maintenance of the instruments used there to monitor the ozone layer. JMA supported installation of automated observation systems for Dobson instruments at NOAA/ESRL, Boulder, Colorado (May 2009); Mauna Loa, Hawaii (June 2010); the Bureau of Meteorology, Melbourne, Australia (August 2010); the National Meteorological Service, Buenos Aires, Argentina (November 2010); and NIWA, Lauder, New Zealand (January 2012).

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

Trend analyses for total ozone concentrations at three sites (Sapporo, Tsukuba, and Naha), eliminating solar activity and QBO, have shown an overall decrease of total ozone during the 1980s, but, in spite of large year-to-year variations, these analyses indicate either no significant change or slight increasing trends since the mid-1990s. Vertical ozone profiles from Umkehr and sonde measurements in 2012 show reduced ozone levels at altitudes of about 25 km at all three sites, above 35 km at Sapporo and Tsukuba, at about 45 km at Naha, and between 10 and 20 km at Sapporo compared with those in 1979. In contrast, increasing trends of ozone levels from 1998 to 2012 have been identified at altitudes of 13 km, and between 20 and 27 km at Sapporo, and below 24 km altitude at Tsukuba and Naha.

Erythemal UV measurements have been observed at three sites in Japan (Tsukuba, Naha, and Sapporo) since the early 1990s. At Sapporo and Tsukuba, the increasing trends in erythemal irradiance have been observed since the early 1990s. Especially, the yearly sums of erythemal irradiance at Tsukuba during the last three years of observation (2011–2013) are higher than those measured during the period of 1990-2010. On the other hand, no change of erythemal radiation was observed at Naha after the 2000s. Since the decline of total ozone at Sapporo and Tsukuba ceased around the mid-1990s, the increase of erythemal UV radiation since 1990 cannot be attributed to a reduction of ozone levels.

The duration of solar exposure required for vitamin D_3 synthesis in the human body has been estimated by numerical simulation using observed UV data at JMA's three UV monitoring sites

(Sapporo, Tsukuba, and Naha). The numerical simulation for Tsukuba at noon in July under a cloudless sky indicated that 3.5 min of solar exposure is required to produce 5.5 μg of vitamin D_3 per 600 cm^2 skin, which is the minimum requirement for human health. In contrast, the simulation for Sapporo in December at noon under a cloudless sky showed that it took 76 min to produce the same quantity of vitamin D_3.

3. THEORY, MODELLING, AND OTHER RESEARCH

The Center for Climate System Research (CCSR, now the Division of Climate System Research within the Atmosphere and Ocean Research Institute), the University of Tokyo and NIES developed a chemistry–climate model (CCSR/NIES CCM). JMA's Meteorological Research Institute (MRI) independently developed another chemistry–climate model (MRI-CCM). Both the CCSR/NIES and MRI groups participated in the second round of the Chemistry–Climate Model Validation Activity (CCMVal-2) of the Stratospheric Processes and their Role in Climate (SPARC) programme, and contributed to comparisons between and improvement of CCMs, leading to a better understanding of the individual strengths of these models. The CCSR/NIES and MRI CCMs were used to simulate the recent past and future evolution and global distribution of the stratospheric ozone layer by using concentrations of greenhouse gases and ozone depletion substances as recommended by CCMVal-2. The results of the simulations were published in the SPARC-CCMVal Report (2010). Scientific papers based on the outcome of the simulations were published in a special issue of CHEMCLIM1-Modeling of chemistry and climate (Mc2) in the *Journal of Geophysical Research* in 2010 and in the WMO Ozone Assessment Report in 2010.

NIES is developing a new version of its CCM with T42 horizontal resolution, constructed on the MIROC 3.2 AGCM, which was used for future projections of climate for the IPCC Fourth Assessment Report. This model has a new radiation code that greatly reduces the problem in the previous model of cold bias in the tropical upper troposphere/lower stratosphere. The new CCM incorporates more stratospheric water vapour than the previous version and better represents observed data. The new CCM is also used as a three-dimensional chemical transport model (CTM) in which temperature and wind velocity data are assimilated into the calculated fields in the model by using a nudging method. The model simulates the global distribution of chemical species observed by SMILES, global patterns of diurnal ozone variation throughout the stratosphere, longitude-dependent ozone concentrations, and ozone chemical forcing at times of sudden stratospheric warming. The CCM and CTM are used for simulations recommended by the Chemistry Climate Model Initiative (CCMI), which is superseding the CCMVal, in order to investigate the individual and combined effects of changes in ozone depletion substances and greenhouse gases on past and future ozone changes. For these simulations, NIES focuses on chemical processes in the stratosphere and their effects on stratospheric and tropospheric climate. The CTM was also used to simulate a low-ozone event in southern South America in November 2009.

JMA's MRI has developed both a CTM and CCM to study stratospheric ozone. A prominent feature of the MRI-CCM is that QBO, which plays a crucial role in inter-annual variations in the stratosphere, is spontaneously reproduced for wind and ozone in the tropical stratosphere by a T42L68 version that has about 300 km of horizontal resolution and 500 m of vertical resolution in the stratosphere. The MRI-CCM has been used at JMA to simulate ozone distributions by incorporating total ozone data from Ozone Monitoring Instruments (OMI) and has produced ozone forecasts for several days. At present, JMA is investigating the incorporation of ozone data from the Ozone Mapping & Profiler Suite (OMPS) of instruments. The ozone distributions so calculated can be used to monitor variations in total and stratospheric ozone, and to provide a UV forecast service. The MRI-CCM is also used to investigate the effect of the ozone layer on climate and for predictions of the future state of the ozone layer.

A new version of the model developed in 2011, MRI-CCM Version 2 (MRI-CCM2), includes detailed tropospheric ozone chemistry. The chemistry module of MRI-CCM2 is also an important component of the MRI earth-system model (MRI-ESM1), which participated in the fifth phase of the Coupled Model Intercomparison Project. MRI-ESM1 has been developed as an extension of the atmosphere–ocean coupled general circulation model, MRI-CGCM3, by adding chemical and biogeochemical processes. This model is also used to perform some of the CCMI-recommended simulations.

University of Tokyo, NIES, and the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) developed a CCM in 2011 (Watanabe et al., 2011). The CCM was developed by extending the upper boundary of the CHASER model from the lower stratosphere to the mesosphere and includes stratospheric chemistry and PSC processes. This model, known as MIROC-ESM-CHEM, also performs some of the CCMI-recommended simulations, focusing on chemistry–climate processes in the troposphere.

4. DISSEMINATION OF RESULTS

4.1 Data reporting

NIES and the Solar-Terrestrial Environment Laboratory (STEL) of Nagoya University have established stations at Tsukuba and Rikubetsu equipped with NDACC instruments, including lidars, millimetre-wave radiometers, and FTIR spectrometers. Some of the activities of these organizations have been incorporated in NDACC measurements in Japan.

Observational data acquired at JMA's stations are submitted monthly to the World Ozone and UV Data Centre (WOUDC) in Toronto, Canada. Provisional total ozone data are also delivered daily on the Character Form for the Representation and Exchange of Data (CREX) through the WMO Global Telecommunication System (GTS), and used at the WMO Ozone Mapping Centre in Thessaloniki, Greece, to map the total ozone distribution over the Northern Hemisphere. Total ozone and ozone sonde data acquired at Syowa Station during the Antarctic winter and spring are submitted weekly to the WMO Secretariat for incorporation in Antarctic Ozone Bulletins.

4.2 Information provided to the general public

An annual report on the state of the ozone layer, surface UV-B radiation, and atmospheric concentrations of ozone-depleting substances is published by the Japanese MOE.

Data summaries of JMA's total ozone, ozone sonde, and UV-B measurements are published monthly on the Internet. An annual report that includes detailed trend analyses of ozone over Japan and the globe is also published for both government and public use. Since 2005, JMA has been providing an Internet-based UV forecast service (in the form of an hourly UV-index map) based on UV-B observations and ozone forecast modelling techniques. Analytical UV maps and quasi-real-time UV observations are also posted hourly on the website. MRI-CCM UV forecasts will be replaced by MRI-CCM2 forecasts in the near future.

The MOE supports research on preservation of the environment in Japan and around the world (including ozone layer depletion) through the Environment Research and Technology Development Fund (ERTDF); their results are published in Annual Summary Reports.

5. PROJECTS AND COLLABORATION

A project named *Studies on the Variability of Stratospheric Processes and Uncertainties in the Future Projection of Stratospheric Ozone* was jointly undertaken as a ERTDF project by NIES, CCSR, Hokkaido University, and Miyagi University of Education. This project used soundings of vertical water vapour profiles in the tropical western Pacific to show that lower stratospheric water vapour at 19–21 km altitude was high and increasing in the 1990s, low between 2000 and 2003, and then increased to return to the level of the late 1990s in the mid-2000s. High-quality measurements were also made of O_2, N_2 isotopes, CO_2, and SF_6 that for the first time allowed identification of gravitational separation in the stratosphere. The results suggested that there has been little change in the age of air in the middle stratosphere of the Northern Hemisphere mid-latitudes since 1975. As part of the project, numerical experiments were also conducted using the CCSR/NIES CCM to investigate the stratospheric response to future increases of greenhouse gases and the impact of long-term variations of the size of the ozone hole.

NIES has started a new ERTDF project named *Effects of Additional CFC Regulation on Fragility of*

Ozone Layer under Future Global Warming. This project investigates the possibility of large-scale ozone depletion in the Arctic, as observed in 2011, by using 100-year CCM simulations in which the concentrations of ozone-depleting substances and greenhouse gases are fixed to past or near-future concentrations. Because the Arctic ozone exhibits large year-to-year variability, 100-year simulations employing different combinations of ozone-depleting substances and greenhouse gases will lead to a better understanding of the fragility of the ozone layer under the influence of future global warming.

JMA's Aerological Observatory has developed an automated Dobson measuring system (described at the JMA web site; http://gaw.kishou.go.jp/wcc/dobson/windobson.html) that reduces the burden on equipment operators and improves data quality. JMA has provided technical support to some foreign organizations interested in using this system.

6. FUTURE PLANS

Ongoing monitoring of levels of ozone, water vapour, and other species near the tropical tropopause will continue to improve our understanding of the role of the tropical transition layer in chemistry–climate interactions. Precise measurements of the concentrations of trace gases in the stratosphere will continue to provide key information on physical, chemical, and dynamic processes in the stratosphere. For example, precise monitoring of trace gases in the middle atmosphere enables identification of variability in the mean age of air and evaluation of the ability of current models to reproduce changes in dynamic atmospheric processes.

Development and improvement of CCM and CTM numerical models will continue, which will allow better prediction of future changes to the ozone layer and improve our understanding of the mechanisms of chemistry–climate interactions. A regular CCM update based on the newest global circulation model will be necessary for ongoing research on chemistry-climate interactions. For example, a new CCM is being constructed based on the MIROC 5 GCM that was used for future climate projections for the IPCC Fifth Assessment Report. Because MIROC 5 GCM simulates sea-surface temperature distributions better than MIROC3.2 GCM, it provides better climate simulations than those of MIROC 3.2 GCM; thus, the new CCM might provide better chemistry-climate projections using the same chemical module as that of MIROC 3.2 CCM.

7. NEEDS AND RECOMMENDATIONS

Processing and reporting to WOUDC of a long record of unprocessed Brewer Umkehr data from Minamitorishima are needed. For Brewer instruments, a method for selection of cloud-free “good” data from unattended observations is needed, as are side-by-side comparisons with Dobson instruments.

Systematic observations to evaluate the changing state of the ozone layer, including detection of ozone layer recovery, should be continued in cooperation with international monitoring networks such as NDACC and the WMO/GAW programme.

Because of the strong connection between the stratosphere and the mesosphere, much more knowledge about chemical, dynamical and radiative processes in the upper middle atmosphere is needed. For example, reliable observation data for ozone and other chemicals in the upper middle atmosphere are needed, especially for HOx-related species such as OH and HO_2. The depletion and recovery of stratospheric ozone is dependent on climate change and changes of air quality, which, in turn, are dependent on levels of stratospheric ozone; these interdependencies need to be assessed. For example, there is a need to study the influence of super-recovery of the ozone layer in response to continuous increases of greenhouse gases on both climate and air quality in the troposphere. Re-evaluation of chemical reaction data, including photochemical data for use in stratospheric modelling, is urgently required to resolve discrepancies between observations and model calculations. CCMs need to be improved to more accurately simulate the effect on the atmosphere of variations of solar flux. Modelling of dynamical and chemical processes in the mesosphere and lower thermosphere is also necessary.

Finally, a systematic calibration program and well-coordinated monitoring network should be established to detect variations and long-term trends in ground-level UV radiation.

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