WORLD METEOROLOGICAL ORGANIZATION

GLOBAL ATMOSPHERE WATCH

WORLD DATA CENTRE FOR GREENHOUSE GASES

WMO WDCGG DATA SUMMARY

WDCGG No. 38

GAW DATA
Volume IV-Greenhouse Gases and Other Atmospheric Gases

PUBLISHED BY
JAPAN METEOROLOGICAL AGENCY
IN CO-OPERATION WITH
WORLD METEOROLOGICAL ORGANIZATION

MARCH 2014

Acknowledgements

This issue of *Data Summary* reports the latest status of greenhouse and some reactive gases in the global atmosphere. This *Data Summary* has been prepared by the World Data Centre for Greenhouse Gases (WDCGG), established under the Global Atmosphere Watch (GAW) Programme of the World Meteorological Organization (WMO) and operated by the Japan Meteorological Agency (JMA). This *Data Summary* is based on the data submitted by many contributors worldwide (Appendix: LIST OF CONTRIBUTORS). These contributors include both organizations and individuals involved in observations and research of greenhouse and some reactive gases at stations and laboratories operating within the framework of GAW and some other monitoring and research programmes. The WDCGG thanks all of these organizations and individuals, including those from the global air sampling network of the National Oceanic and Atmospheric Administration (NOAA), for their efforts in maintaining the observation programme and continuous provision of observational data. Not all of the contributors may be explicitly acknowledged in this publication, owing to lack of space, but all the organizations and individuals that have submitted data to the WDCGG are nevertheless here acknowledged as invaluable contributors to this latest issue of *Data Summary*.

CONTENTS

SUMMARY

This *Data Summary* reports the results of basic analyses of greenhouse and some reactive gas data submitted to the WMO World Data Centre for Greenhouse Gases (WDCGG) by contributing organizations and individuals. This issue covers observations from 1968 through 2012, based on data reported to the WDCGG by November 2013. The *Data Summary* includes analyses of global, hemispheric and latitudinal monthly mean mole fractions of greenhouse and some reactive gases calculated on the basis of observations at marine and continental surface-based stations, and provides current information on the state of mole fractions of these gases.

Although only monthly mean mole fractions were used for the analyses, the WDCGG greatly appreciates those stations that submit daily and hourly mean mole fractions, which are important for analysis of variations on shorter time scales. All data submitted to the WDCGG are available on its website, http://ds.data.jma.go.jp/gmd/wdcgg/. In this *Data Summary,* data are reported as dry air mole fractions defined as the number of molecules of a target gas species divided by the number of all molecules in the air including the target itself, but excluding water vapor. Mole fractions are expressed as parts per million (ppm), parts per billion (ppb), and parts per trillion (ppt), which correspond to the SI units of µmol/mol, nmol/mol and pmol/mol, respectively.

Variations in the mole fractions of some gases are presented as combinations of seasonal cycles and deseasonalized long-term trends. Growth rates are presented as time derivatives of the long-term trends. Global average mole fractions are presented with accompanying uncertainty. The analytical results are summarized below for each greenhouse and reactive gas.

Carbon Dioxide (CO_2)

The level of carbon dioxide (CO_2), which contributes the most to increases in anthropogenic induced radiative forcing, has been increasing since the beginning of the industrial era. The global average mole fraction of CO_2 reached a new high of 393.1±0.1 ppm in 2012, which constitutes 141% of the pre-industrial level (in 1750). The annual average increase of 2.2 ppm from 2011 to 2012 was greater than the average growth rate for the 1990s (about 1.5 ppm/year) and the average growth rate for the past decade (about 2.0 ppm/year).

The global growth rate of CO_2 has a significant interannual variability driven by natural processes. Interannual changes higher than 2 ppm/year in 1987/1988, 1997/1998, 2002/2003 and 2009/2010 resulted from warmer conditions caused by El Niño-Southern Oscillation (ENSO) events. The anomalously strong El Niño event in 1997/1998 resulted in greater annual increases in CO_2 worldwide in 1998 than during any other one-year period. The high growth rate in 2006 may have been related to the global high temperature during the same year. The exceptionally low growth rate in 1992, including negative values in northern high latitudes, may have been due to low global temperatures following the eruption of Mount Pinatubo in 1991. Variations in CO_2 mole fraction can be seen both on seasonal and long-term scales. The seasonal amplitudes are large in northern high and mid-latitudes and small in the Southern Hemisphere. In southern low latitudes, there is no clear annual cycle, but a semiannual cycle can be determined.

Methane (CH_4)

Methane (CH_4) is the second most significant greenhouse gas which is largely influenced by anthropogenic activity and whose level has been increasing since the beginning of the industrial era. The annual average mole fraction was 1819±1 ppb in 2012, an increase of 6 ppb since 2011. The mole fraction is now 260% of that in the pre-industrial period. This is the sixth year of marked methane increases since levelling-off at the beginning of this century.

The latitudinal gradient of CH_4 mole fraction is large from the northern mid-latitudes to the tropics, suggesting that the major sources of CH_4 are located in the Northern Hemisphere.

CH_4 growth rates decreased significantly in some years, including 1992, when negative values were recorded in northern high and mid-latitudes. However, both hemispheres experienced high growth rates in 1998, caused by higher than average global mean temperature. The global growth rates were generally low from 1999 to 2006, except during the El Niño event of 2002/2003. The global growth rate averaged over the period 1984-1990 was 11.5 ppb/year, but decreased markedly in the 1990s. The mean annual absolute increase during last 10 years was 3.7 ppb/year, but in the last six years through 2012, the global mole fraction increased by a total of 35 ppb.

CH_4 mole fractions vary seasonally, being relatively high in winter and low in summer. Unlike CO_2, the seasonal amplitudes of CH_4 are large, not only in the Northern Hemisphere but also in southern high and mid-latitudes which are associated with methane sinks. In southern low latitudes, a distinct secondary maximum in boreal winter overlies the annual cycle.

Nitrous Oxide (N_2O)

Nitrous oxide (N_2O) is an important greenhouse gas whose level is increasing globally. N_2O data submitted to the WDCGG show that mole fractions are increasing in both hemispheres. The global mean mole fraction reached a new high of 325.1±0.1 ppb in 2012, which is 0.9 ppb higher than that in the previous year. This mole fraction corresponds to 120% of that in the pre-industrial period. The mean annual absolute increase during last 10 years was 0.80 ppb/year and the inter-hemispheric gradient in N_2O is 1.1 ppb (averaged over the years 1980 to 2012), indicating that the majority of N_2O sources are situated in the Northern Hemisphere.

Halocarbons and Other Halogenated Species

Halocarbons, most of which are anthropogenic and generated since the 20th century, are potent greenhouse gases, with some also acting as ozone-depleting compounds. Levels of some halocarbons (*e.g.* CFCs) increased in the 1970s and 1980s, but this increase has almost ceased by now, due to the production and consumption control of halocarbons under the Montreal Protocol on Substances that Deplete the Ozone Layer and its subsequent Adjustments and Amendments. However, some substances targeted by the Kyoto Protocol but not regulated by the Montreal Protocol, such as HFCs and SF_6, are increasing.

The mole fraction of CFC-11 peaked around 1992 and then started decreasing. The mole fraction of CFC-12 increased until around 2005 and then started decreasing gradually. The mole fraction of CFC-113 stopped increasing in the 1990s, followed by a slight decrease over about twenty years. The mole fractions of HCFCs, used mainly as substitutes for CFCs, have increased significantly during the last decade, but the growth of HCFC-141b decelerated rapidly in the last decade. The mole fraction of Halon-1211 has not increased since 2005, whereas the mole fraction of Halon-1301 is increasing. The mole fraction of CCl_4 was maximal around 1991 and has since decreased slowly. The mole fraction of CH_3CCl_3 peaked around 1992 and decreased thereafter. The mole fractions of HFC-134a, HFC-152a and SF_6 are increasing, but the growth of HFC-152a decelerated in the second half of the decade.

Surface Ozone (O_3)

Ozone (O_3) plays important roles in the atmospheric environment through radiative and chemical processes. It absorbs solar UV radiation in the stratosphere, influencing the vertical temperature profile as well as terrestrial IR radiation, and contributing to the greenhouse effect as a greenhouse gas. Ozone is also involved in the chemical transformations of the primary air pollutants, as its mole fraction in the boundary layer serves as an indicator of air quality.

The mole fraction of O_3 near the surface, so-called surface ozone, reflects various processes. While some of the O_3 in the troposphere comes from the stratosphere, the rest is chemically produced in the troposphere through oxidation of CO or hydrocarbons in the presence of NO_x.

The mole fraction of surface ozone is measured at many locations in various environments. Continuous ozone observations are reported mostly as wet mole fraction. Due to uneven geographic distribution of surface ozone, it is difficult to identify its global long-term trend (WMO, 2011b).

Carbon Monoxide (CO)

Carbon monoxide (CO) is not a greenhouse gas itself but influences the mole fractions of greenhouse gases by affecting hydroxyl radicals (OH). Beginning in 1950, the CO mole fraction increased at a rate of 1% per year but started to decrease in the late 1980s (WMO, 1999). In 2012, the global mean mole fraction of CO was about 92±2 ppb. The mole fraction is high in the Northern Hemisphere and low in the Southern Hemisphere, suggesting substantial anthropogenic emissions in the Northern Hemisphere.

There is a large interannual variability of CO growth rates. The growth rate increases are usually attributed to biomass burning emissions during El Niño conditions.

The monthly mean mole fractions show seasonal variations, with large amplitudes in the Northern Hemisphere and small amplitudes in the Southern Hemisphere with opposite phase.

Nitrogen Monoxide (NO) and Nitrogen Dioxide (NO_2)

Nitrogen oxides (NO_x, *i.e.*, NO and NO_2) are not greenhouse gases, but they are involved in the photochemical production of ozone in the troposphere. In the presence of NO_x, CO and hydrocarbons are oxidized to produce ozone (O_3), which affects the Earth's radiative balance as a greenhouse gas and the oxidization capacity of the atmosphere by reproducing OH.

Most of the stations that have so far reported NO_x data to the WDCGG are located in Europe. NO_x has a large temporal and spatial variability, and it is difficult to identify its long-term global trend based on a spatially limited dataset.

Sulphur Dioxide (SO_2)

Sulphur dioxide (SO_2) is not a greenhouse gas but a precursor of atmospheric sulphate aerosols. Sulphate aerosols are produced by SO_2 oxidation through photochemical gas-to-particle conversion. SO_2 has also been a major source of acid rain and deposition throughout the industrial era.

Most of the stations reporting SO_2 data to the

WDCGG are located in Europe, and it is difficult to identify its long-term global trend based on a spatially limited dataset.

Volatile Organic Compounds (VOCs)

Volatile organic compounds (VOCs) are organic chemicals that easily evaporate or sublimate at ordinary atmospheric temperatures (vapor pressure ≧ 0.01 kPa at 20℃). Many are in the form of non-methane hydrocarbons (NMHCs) of different complexity including aliphatics and aromatics which dominate anthropogenic emissions, and unsaturated molecules including terpenes which dominate natural emissions. They also exist as oxygenated hydrocarbons such as acetone and methanol, and sulphur-containing molecules such as dimethyl sulphide.

Although they are not important greenhouse gases in themselves, they are of interest to Global Atmosphere Watch (GAW) because of their environmental impacts, including ozone production and precursors to aerosols. Their main interest to GAW is as tracers of processes which either produce or destroy other major species in the atmosphere measured by GAW. An example is given in chapter 11 of how ethane measurements increase understanding of the behavior of methane.

In its function of the World Data Centre for reactive gases and GHGs, as of November 2013, WDCGG records 53 individual species of VOCs from which a subset, widespread throughout the global atmosphere has been selected as a focus for the GAW VOC Programme. Temporal coverage of VOC measurements has grown extensively over the last decade, since a global flask network came into operation in 2005, supplementing the longer series of measurements made at a few continental sites.

In this 38th edition of the WDCGG *Data Summary*, global analyses are performed for ethane and propane with their relatively long lifetime and wide measurement network. Ethane mole fractions are relatively high in winter and low in summer. The seasonal amplitudes are large in northern high and mid-latitudes but very small in the southern latitudes. Observed seasonal differences are connected with photochemical processes, whereas hemispheric differences indicate the majority of ethane sources in northern latitudes. The propane distribution shows basically similar general features as for ethane with stronger seasonality and more pronounced latitudinal gradients in the Northern Hemisphere (NH) during winter. The stronger seasonality is mainly because of its higher reactivity. Also, due to its shorter atmospheric lifetime compared to ethane, the NH seasonal cycle of propane shows a maximum close to mid-winter.

1. INTRODUCTION

Human activities have had major impacts on the global environment. Since the beginning of the industrial era, mankind has increasingly made use of land, water, minerals and other natural resources, and continuous growth of the world human population and economies may further increase our impact on the environment. As the climate, biogeochemical processes and natural ecosystems are closely interlinked, changes in any one of these may affect the others and be detrimental to humans and other organisms. Emissions of man-made gaseous species and particulate matter alter the energy balance of the atmosphere, which in turn has implications for the multiple interactions within the complex Earth's system. These interactions are not fully understood, partly due to the lack of high quality observations.

The World Meteorological Organization (WMO) established the Global Atmosphere Watch (GAW) Programme in 1989 to promote systematic and reliable observations of the global environment, including but not limited to greenhouse gases (*e.g.*, CO_2, CH_4, CFCs, and N_2O) and some reactive gases (*e.g.*, O_3, CO, VOCs, NO_x, and SO_2) in the atmosphere. In October 1990, WMO designated the Japan Meteorological Agency (JMA) in Tokyo to serve as the World Data Centre for Greenhouse Gases (WDCGG). The WDCGG is responsible for collecting, archiving and providing data on greenhouse and reactive gases in the atmosphere and oceans from a number of observational sites throughout the world that participate in GAW and other scientific monitoring programmes (Appendix: LIST OF OBSERVATIONAL STATIONS). In August 2002, the WDCGG took over the role of the World Data Centre for Surface Ozone from the Norwegian Institute for Air Research (NILU).

With regard to the issue of climate change the Kyoto Protocol to the United Nations Framework Convention on Climate Change came into force in February 2005. In March 2006, WMO commenced annual publication of the WMO Greenhouse Gas Bulletin, which summarizes the state of greenhouse gases in the atmosphere. The ninth issue of the Bulletin was published in November 2013. The WDCGG contributes to the production of the Bulletin through timely and adequate collection and analysis of data in cooperation with the contributors of the data.

Since its establishment, the WDCGG has provided its users with data and other information through its regular publications, including the *Data Summary* and *DVD* (Appendix: LIST OF WMO WDCGG PUBLICATIONS). In accordance with the GAW Strategic Plan: (2008–2015) and its Addendum, all data and information have been made available on the WDCGG web site, improving the accessibility of data, information and products (WMO, 2007a; WMO, 2011a). The WDCGG published the Data Submission and Dissemination Guide in 2007 (WMO, 2007b), which, with its revision in 2009 (WMO, 2009b), is designed to facilitate submission of observational data and provide access to archived data in the WDCGG. Clear guidelines for data submission are included in the measurement guidelines published by GAW for the variables, which are under responsibility of WDCGG.

The GAW Strategic Plan requests that World Data Centres assist data users by providing the data and analysis related to atmospheric observations. To this end, the WDCGG provides global and integrated diagnostics on the state of greenhouse and some reactive gases as analytical information in the *Data Summary*. The WDCGG global analysis method has been described in a GAW technical report (WMO, 2009a). The content of the *Data Summary* is revised and improved based on comments from data contributors and scientists. We hope the diagnostic information presented here will promote the use of data on greenhouse and reactive gases and will enhance appreciation of the value of the GAW Programme.

All users are required to accept the following statement endorsed by the Commission for Atmospheric Sciences (CAS) at its thirteenth session: "For scientific purposes, access to these data is unlimited and provided without charge. By their use you accept that an offer of co-authorship will be made through personal contact with the data providers or owners whenever substantial use is made of their data. In all cases, an acknowledgement must be made to the data providers or owners and to the data centre when these data are used within a publication." The WDCGG requests data users to make appropriate acknowledgements. The principal investigators and other contacts can be obtained from the WDCGG website, as well as from the GAW Station Information System (GAWSIS) website, http://gaw.empa.ch/gawsis/. Information on these websites is updated in cooperation with the data contributors and the WMO Secretariat.

Finally, the WDCGG would like to thank all data contributors worldwide, including those involved in on-site measurements, for their efforts in maintaining the observational programmes and for continuous data provision.

Mailing address:
WMO World Data Centre for Greenhouse Gases (WDCGG)
c/o Japan Meteorological Agency
1-3-4, Otemachi, Chiyoda-ku, Tokyo 100-8122, Japan
E-mail: wdcgg@met.kishou.go.jp
Telephone: +81-3-3287-3439
Facsimile: +81-3-3211-4640
Web Site: http://ds.data.jma.go.jp/gmd/wdcgg/

2. ANALYSIS

The WDCGG reposits, archives and provides observational data on the mole fractions of greenhouse and some reactive gases, and publishes diagnostic information on these gases based on the reported data.

The long-term trends and seasonal variations in the mole fractions of CO_2, CH_4, N_2O and CO are calculated for the whole globe (global means) and for latitudinal belts (zonal means). Global long-term trends in the surface O_3, are not analyzed due to its substantial spatial gradients, and its uneven geographic distribution which is poorly covered by observational sites. Zonal mean time series for selected VOCs (ethane and propane) are newly introduced. For halocarbons, NO_x and SO_2, only monthly mean mole fractions over time are presented without global, hemispheric or zonal averaging, due to insufficient number of reporting sites for each compound.

Mole fractions are expressed as parts per million (ppm), parts per billion (ppb), and parts per trillion (ppt), which correspond to the SI units of µmol/mol, nmol/mol and pmol/mol, respectively.

The method of analysis for CO_2, CH_4, N_2O and CO is summarized below. The details of the global analysis method are provided in the *Technical Report of Global Analysis Method for Major Greenhouse Gases by the World Data Centre for Greenhouse Gases*, published as a GAW technical report (WMO, 2009a). Additional uncertainty can be expected in the result of CO global analysis due to diversity of scales. When assessing long-term trends for CO_2, CH_4 and N_2O, the growth rates at both ends of the period were assumed to be simple linear extensions of the adjacent year, thus avoiding end effects. For simplicity, the rates for the rest of the period were approximated by linear functions.

(1) Site selection

For CO_2, CH_4 and N_2O, the diagnostic analyses, including global, hemispheric and zonal means, were based on data from sites that have adopted a standard scale traceable to the Primary Standard designated by WMO. These analyses also utilize data on other standard scales that are convertible to the WMO scale through a proven equation. Letters informing data submitters of the most recent WMO scales are sent out regularly by the WDCGG as well as discussed at the regular expert meetings (WMO, 2012).

Selection of observational sites is also based on whether they provide data representing a reasonably large geographical area, considering the fact that some sites may be susceptible to local sources and sinks. Sites are selected objectively using data submitted to the WDCGG. For CO_2, CH_4 and CO, only those sites that provide annual mean mole fractions falling within a range of ±3σ from a curve fitted to the LOESS model curve (Cleveland and Devlin, 1988) have been selected, with outliers rejected in an iterative manner. This procedure does not affect the datasets residing in the WDCGG, and these data may be useful for purposes other than global analysis, such as identification of sources and sinks.

The sites selected according to the above criteria are marked with asterisks in Plate 3.1 for CO_2, Plate 4.1 for CH_4, Plate 5.1 for N_2O and Plate 8.1 for CO, which represent 136 (72%), 127 (78%), 56 (70%) and 118 (87%) of the submitted datasets respectively (detailed in 'LIST OF OBSERVATIONAL STATIONS' in this issue).

(2) Analysis of long-term trends

The mole fractions of greenhouse and reactive gases over time, measured under unpolluted conditions, exhibit variations on different time scales. The two major components are seasonal variations and long-term trends. Several attempts have been made to separate these various scales from the measured data, including objective curve fitting (Keeling *et al.*, 1989), digital filtering (Thoning *et al.*, 1989; Nakazawa *et al.*, 1991), or both (Conway *et al.*, 1994; Dlugokencky *et al.*, 1994).

In this report, seasonal variations derived from components of Fourier harmonics and long-term trends are extracted by low-pass filtering with a cut-off frequency of 0.48 $year^{-1}$ for each selected site. Details are described in WDCGG *Data Summary* No. 22 (WMO, 2000).

(3) Estimation for missing periods and gaps

The number and distribution of sites used to assess trends during the analysis period should be kept as invariable as possible to avoid the effects of changes in the availability of data over time. However, only a small number of sites provided data throughout the entire analysis period; others may have covered shorter periods or had gaps in measurements due to different reasons. To use as many sites as possible, data for missing values are constructed using interpolation and extrapolation in the calculation of zonal means as described below.

Gaps in some data were filled by linear interpolation based on available data, by subtracting the seasonal variation calculated from the longest consecutive period of data with Lanczos filters (Duchon, 1979). The subtracted variation was added back to the data to obtain estimated mole fractions in a single sequence.

In the case of extrapolation, long-term trends from the existing or interpolated series of data were extrapolated based on zonal mean growth rates calculated from other sites in the same latitudinal zone. The seasonal variation was added to the extrapolated long-term trend to obtain estimated mole fractions for the entire period of analysis.

Using these statistical procedures, the future addition of new stations should not affect the consistency in global estimates over time.

Nevertheless, while adding new sites in the analysis WDCGG performs calculations both with and without the new information to ensure the consistency of the global average calculations.

(4) Calculation of global, hemispheric and zonal means

Zonal means were calculated by determining the arithmetic average of the mole fractions in each latitudinal zone, based on consistent datasets derived as above.

Global and hemispheric means were calculated as the weighted averages of the zonal means taking account of the area of each latitudinal zone.

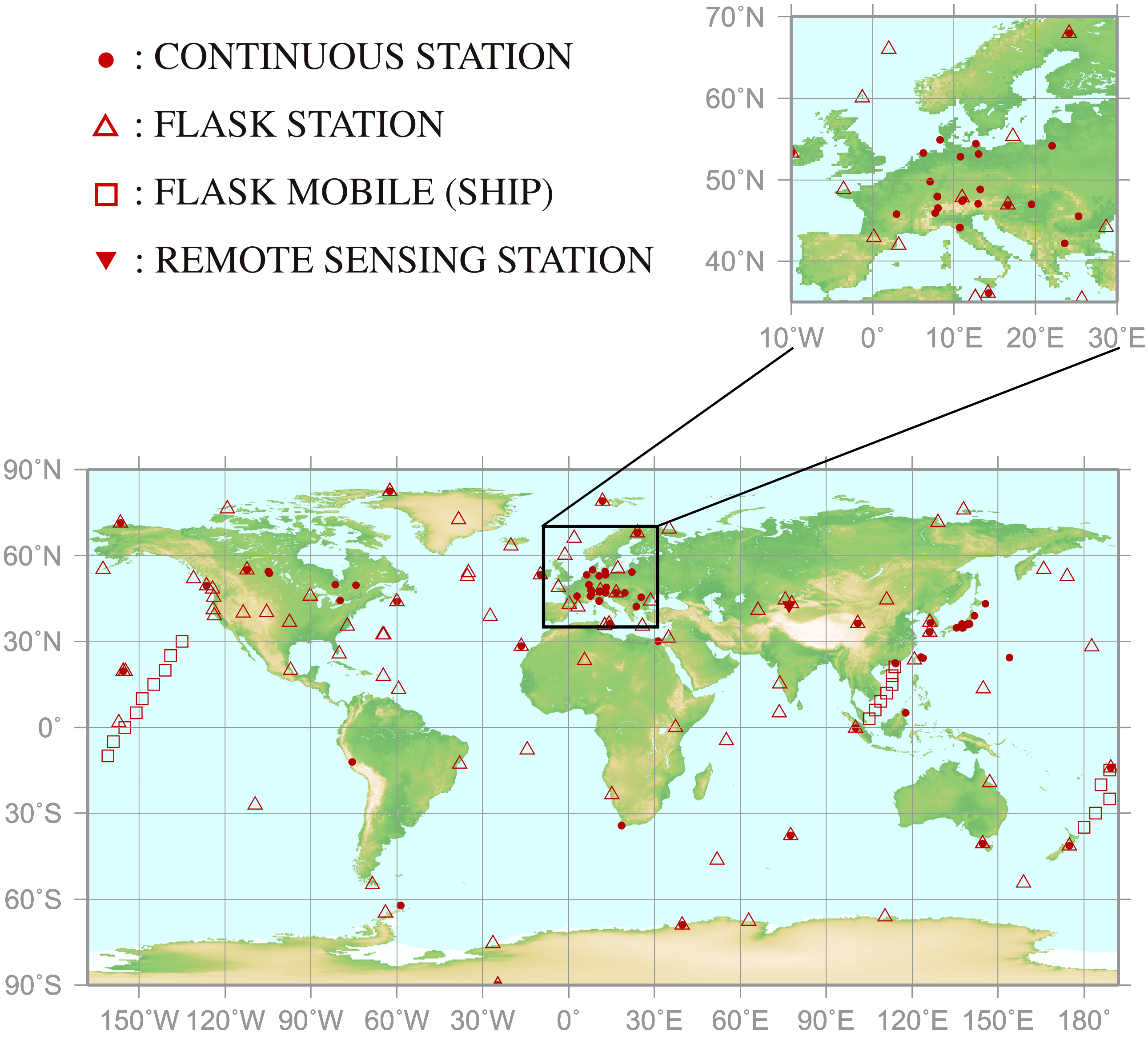
Deseasonalized long-term trends and growth rates for the globe, each hemisphere and each latitudinal zone were calculated from the global, hemispheric and zonal means, respectively, using the low-pass filter mentioned above and the time derivatives after filtering.

Error ranges estimated by a bootstrap method (Conway *et al.*, 1994) are included with the global means of major GHGs (CO_2, CH_4, N_2O and CO), where uncertainty is estimated as the standard deviation of many global means calculated by each bootstrap network.

3.

CARBON DIOXIDE

(CO_2)



This map shows locations of the stations that have submitted data for monthly mean mole fraction.

CO$_2$ Monthly Data

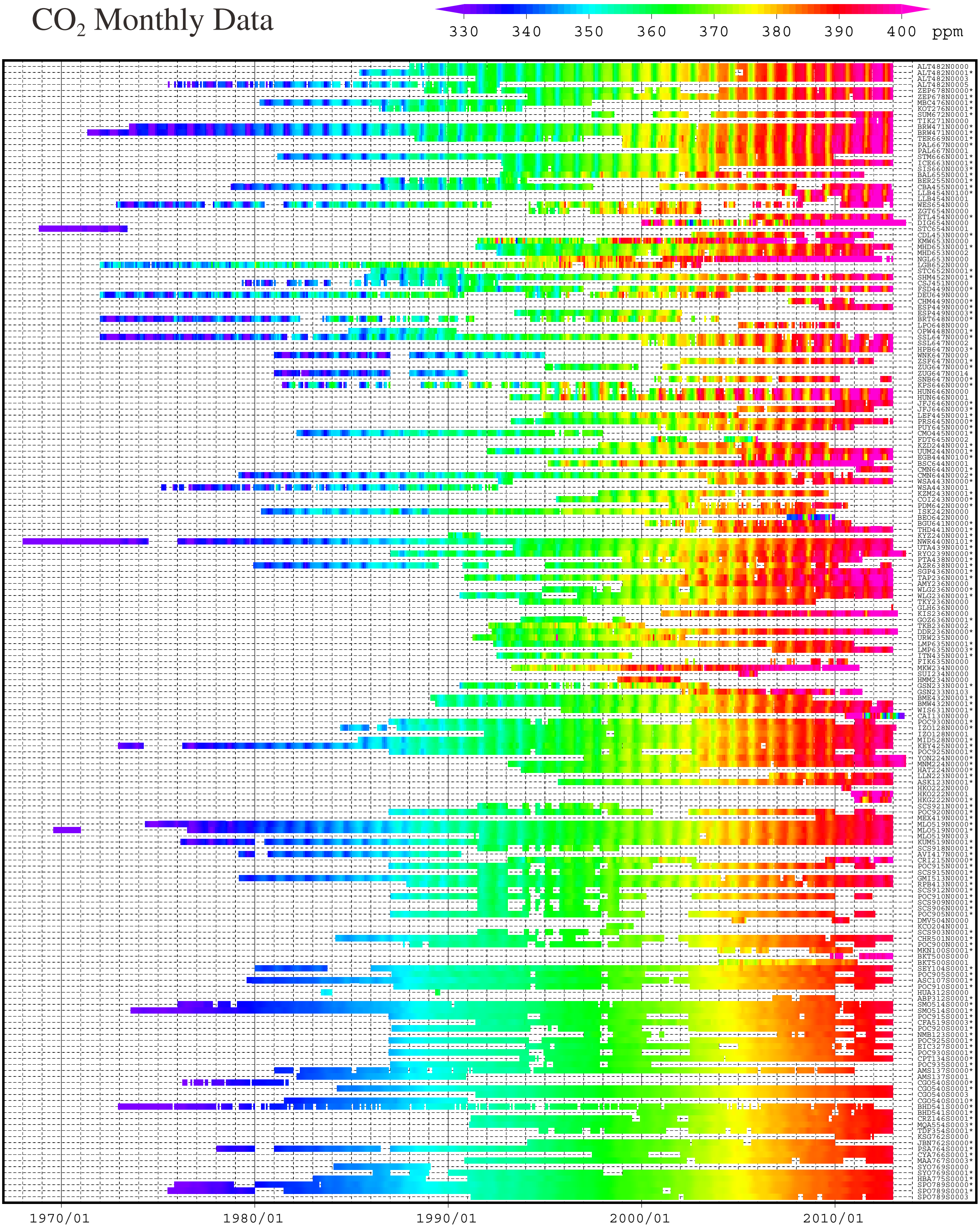


Plate 3.1 Monthly mean CO$_2$ mole fractions that have been reported to the WDCGG. The mole fractions are illustrated in different colours. The sites are listed in order from north to south. In the case where data are reported for two or three different altitudes, only the data at the highest altitudes are illustrated. In the case where monthly means are not reported, the WDCGG calculates them from hourly or other mole fractions reported to the WDCGG by simple arithmetic mean. The data from the sites with an asterisk at the end of the station index are used for the analysis shown in Plate 3.2. (see Chapter 2)

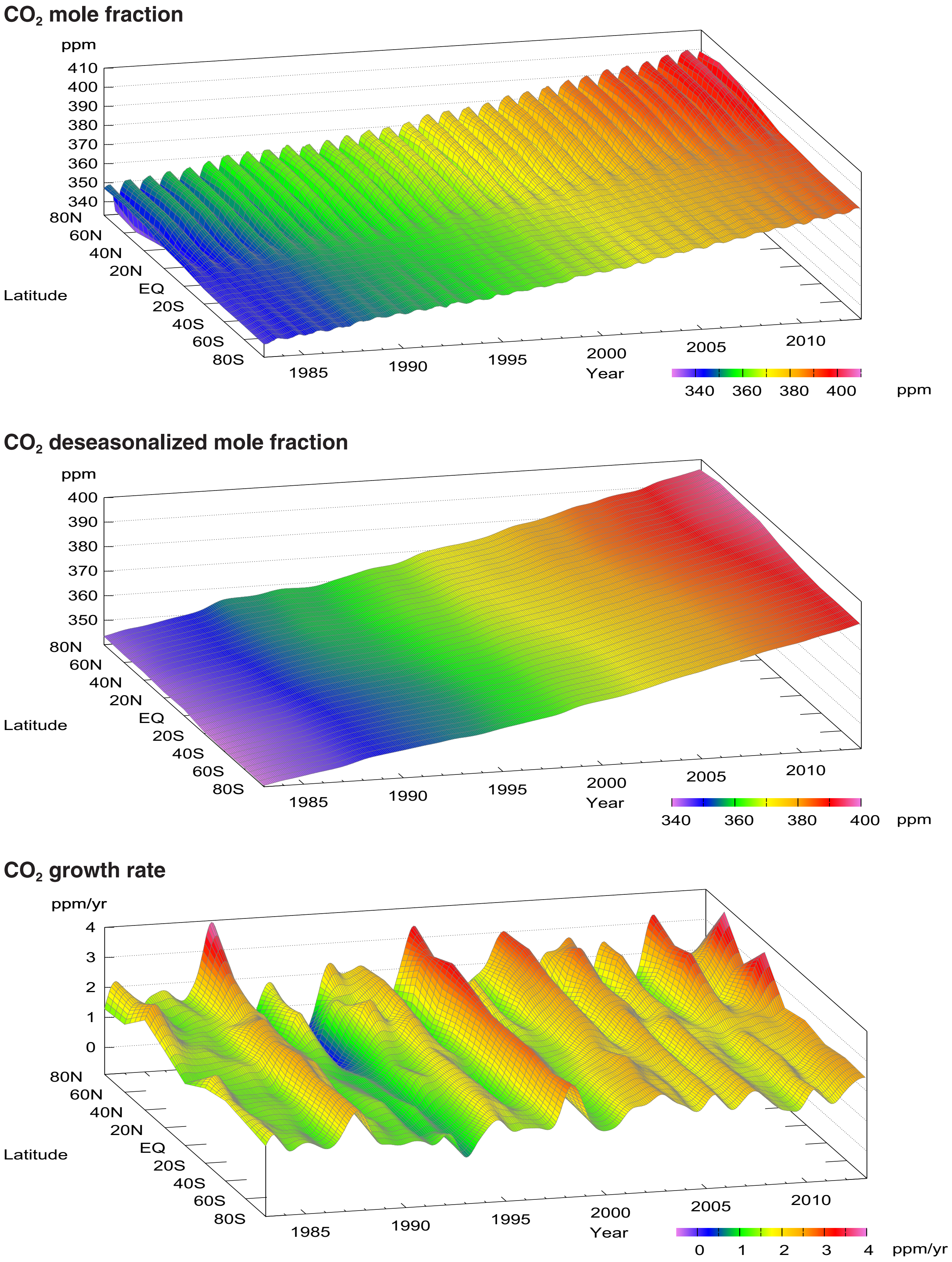


Plate 3.2 Variation of zonally averaged monthly mean CO_2 mole fractions (top), deseasonalized long-term trends (middle), and growth rates (bottom). The zonally averaged mole fractions are calculated for each 20° zone. The deseasonalized trends and growth rates are derived as described in Chapter 2.

3. CARBON DIOXIDE (CO_2)

Basic information on CO_2 with regard to environmental issues

Carbon dioxide (CO_2) has strong absorption bands in the infrared region and is the biggest anthropogenic contributor to the man-made greenhouse effect. CO_2 accounts for about 64% of total increase in the radiative forcing (since 1750) due to long-lived greenhouse gases in the atmosphere (WMO, 2013). It is responsible for 84% of the increase in radiative forcing over the past decade and 82% over the past five years.

The balance of the fluxes between the atmosphere, the oceans and the biosphere determines the mole fraction of CO_2 in the atmosphere. An amount of 515 [445 to 585] PgC was emitted between 1870 to 2011 (IPCC, 2013) and annual anthropogenic emissions mainly due to fossil fuel combustion reached 9.5±0.5 gigatonnes in 2011 (http://www.globalcarbonproject.org/). Carbon in the atmosphere is exchanged with two other large reservoirs, the terrestrial biosphere and the oceans. CO_2 exchanges between the atmosphere and terrestrial biosphere occur mainly through absorption by photosynthesis and emission from the respiration of plants and the decomposition of organic soils. These biogenic activities vary seasonally, resulting in large seasonal variations in the level of CO_2. The direction of CO_2 exchange between the atmosphere and oceans is determined by the gradient of CO_2 mole fraction, and varies in time and space.

The current mole fractions of atmospheric CO_2 far exceed historic records, dating back at least the 2.1 million years (Tans, 2009). Based on the results of ice core studies, the mole fraction of atmospheric CO_2 in pre-industrial times was about 278 ppm (IPCC, 2013). The emission of CO_2 due to human activities has increased dramatically since the beginning of the industrial era, impacting CO_2 exchange rates between different reservoirs and CO_2 levels not only in the atmosphere but in the oceans and terrestrial biosphere. The global carbon cycle, which is comprised mainly of CO_2, is not fully understood. About half of anthropogenic CO_2 emissions has remained in the atmosphere, with the remainder removed by sinks, including the terrestrial biosphere and oceans. However, the amount of CO_2 removed from the atmosphere varies significantly over time (Figure 3.1) without confirmed trend (Levin, 2012).

Carbon isotopic studies have shown the importance of the terrestrial biosphere and oceans as sources and sinks of CO_2 (Francey *et al.*, 1995; Keeling *et al.*, 1995; and Nakazawa *et al.*, 1993, 1997). In contrast, the atmospheric content of O_2 depends primarily on its removal by the burning of fossil fuels and on its release from the terrestrial biosphere. Therefore, the uptake of carbon by the terrestrial biosphere and oceans can be estimated from the combination of measurements of O_2 (O_2/N_2) and CO_2 (Manning and Keeling, 2006). A quasi-equilibrium amount of CO_2 is expected to be retained in the atmosphere by the end of the millennium that is surprisingly large: typically 40% of the peak concentration enhancement over pre-industrial values (278 ppm) (Solomon *et al.*, 2009).

Large amounts of CO_2 are exchanged among the reservoirs in nature, and the global carbon cycle is coupled with the climate system on seasonal, yearly and decadal time scales. Complete understanding of the global carbon cycle is essential for estimating future CO_2 mole fractions in the atmosphere.

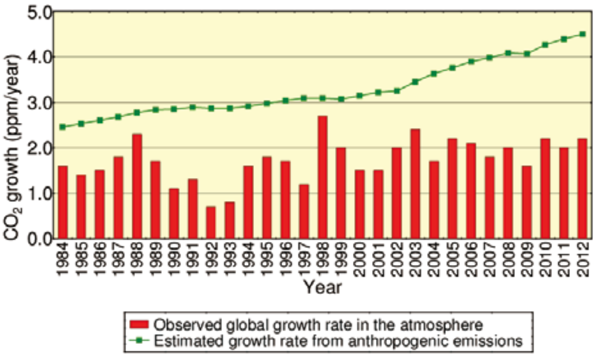


Fig. 3.1 Annual mean growth rates of CO_2 in the atmosphere, calculated from observational data (red columns) and from data for anthropogenic emissions (green curve). The estimated growth rates were calculated using CO_2 emissions as a proxy (from CDIAC, Boden et al., 2013). The values from 2011 to 2012 are estimations of Carbon Dioxide Information Analysis Center (CDIAC), expressed as moles divided by the total mass of gas in the atmosphere (5.2 petatonnes) converted to moles based on the mean molar mass of dry air (about 29.0 g/mol). The observed growth rates were calculated by the WDCGG. The observed CO_2 abundance is expressed as mole fraction with respect to dry air, while the CO_2 amount calculated from anthropogenic emissions is based on the atmosphere, including water vapor, usually in a fraction less than 1%.

Mole fractions of CO_2 can be analyzed utilizing data submitted to the WDCGG from fixed stations and some ships. The observational sites from which data were used for the analysis are shown on the map at the beginning of this chapter. They include fixed stations performing continuous measurements as well as flask-sampling stations, including those in the NOAA/ESRL cooperative air sampling network. In addition, mobile platforms such as ships and aircrafts and other stations observing on an event basis report their data to the WDCGG (see Appendix: LIST OF OBSERVATIONAL STATIONS), which are not used for global analysis.

Annual variation of CO_2 mole fraction in the atmosphere

The monthly mean mole fractions of CO_2 used in the analysis are shown in Plate 3.1, with mole fraction levels illustrated in different colours. Global, hemispheric and zonal mean mole fractions were analyzed based on data from selected stations under unpolluted conditions (see the caption on Plate 3.1). Zonally averaged mole fractions of atmospheric CO_2, together with their deseasonalized components and growth rates, are shown as three-dimensional representations in Plate 3.2. These plots show that the seasonal variations in mole fraction are large in northern high and mid-latitudes, but are indistinct in the Southern Hemisphere. The increases in the Northern Hemisphere precede those in the Southern Hemisphere by one or two years, and the interannual variations in growth rate are larger in the Northern Hemisphere.

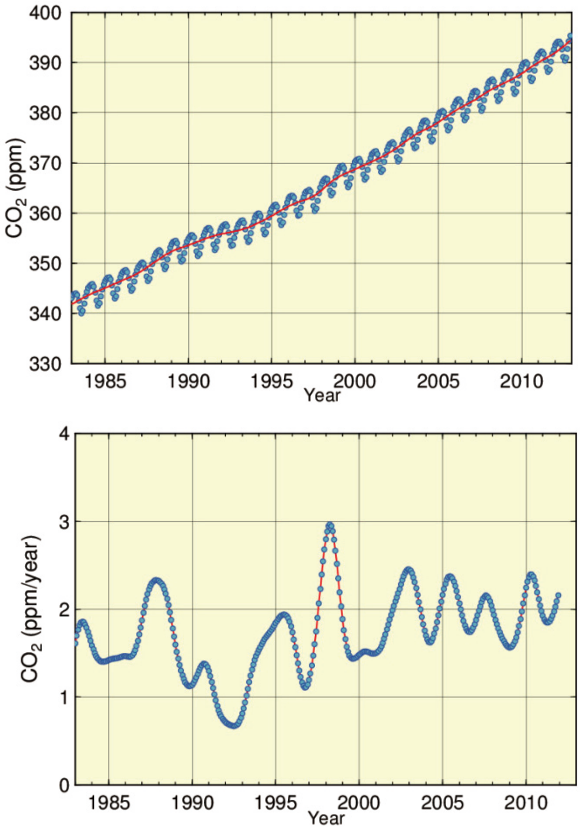


Fig. 3.2 Global monthly mean mole fraction of CO_2 from 1983 to 2012, including deseasonalized long-term trend shown as a red line (top) and annual growth rate (bottom).

Figure 3.2 shows global monthly mean CO_2 mole fractions and their growth rates from 1983 to 2012. The global average mole fraction reached a new high of 393.1±0.1 ppm in 2012, which is 141% of the pre-industrial level of 278 ppm. The 2.2 ppm annual increase in 2011-2012 was greater than the average growth rate for the 1990s (about 1.5 ppm/year) and that of the past decade (about 2.0 ppm/year).

The global growth rate shows large interannual variations, with an instantaneous maximum of about 3 ppm/year in 1998 and a minimum below 1 ppm/year in 1992. There were short periods of high rates in 1987/1988, 1997/1998, 2002/2003, 2005/2006, 2007 and 2009/2010.

Figure 3.3 shows monthly mean mole fractions and long-term trends from 1983 to 2012 for each 30° latitudinal zone, indicating that there were clear long-term increases in both hemispheres and seasonal variations in the Northern Hemisphere.

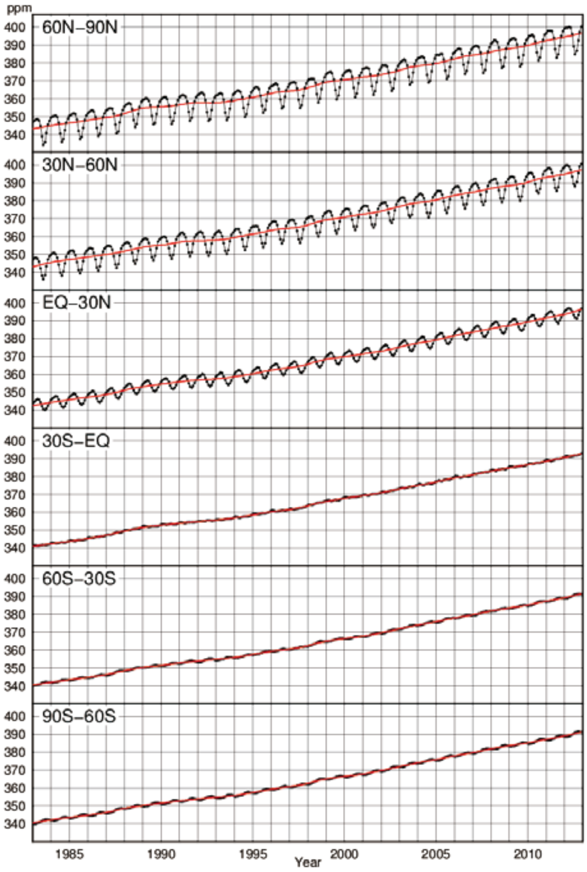


Fig. 3.3 Monthly mean mole fractions of CO_2 from 1983 to 2012 for each 30° latitudinal zone (dots) and their deseasonalized long-term trends (red lines).

As shown in Figure 3.4, the growth rates for each 30° latitudinal zone fluctuated between –0.3 and 3.6 ppm/year, with the largest interannual variability in northern high latitudes. High growth rates for all 30°

latitudinal zones were observed in 1987/1988, 1997/1998, 2002/2003, 2005, 2007, and 2010, with negative rates recorded in northern high latitudes in 1992.

Changes in growth rate are partly associated with ENSO. The El Niño events in 1982/1983, 1986–1988, 1991/1992, 1997/1998 and 2002/2003 coincided with high growth rates of CO_2, with an exception in 1992. The growth rates of CO_2 observed by aircraft at high altitudes (8–13 km) over the Pacific Ocean were also associated with ENSO (Matsueda *et al.*, 2002). The latest El Niño event occurred in 2009/2010.

During El Niño events, the up-welling of CO_2-rich ocean water in the eastern equatorial Pacific is suppressed, resulting in reduced CO_2 emissions from this area. El Niño events induce high temperature anomalies in many areas, particularly in the tropics, resulting in increased CO_2 emissions from the terrestrial biosphere due to the enhanced respiration of plants and activated decomposition of organic matter in soil (Keeling *et al.*, 1995). This effect is enhanced by the suppression of plant photosynthesis in areas of anomalously low precipitation, particularly in the tropics. These oceanic and terrestrial processes during El Niño events have opposing effects, but Heimann and Reichstein (2008) suggested that the latter was the main cause of the variation in the CO_2 growth rate.

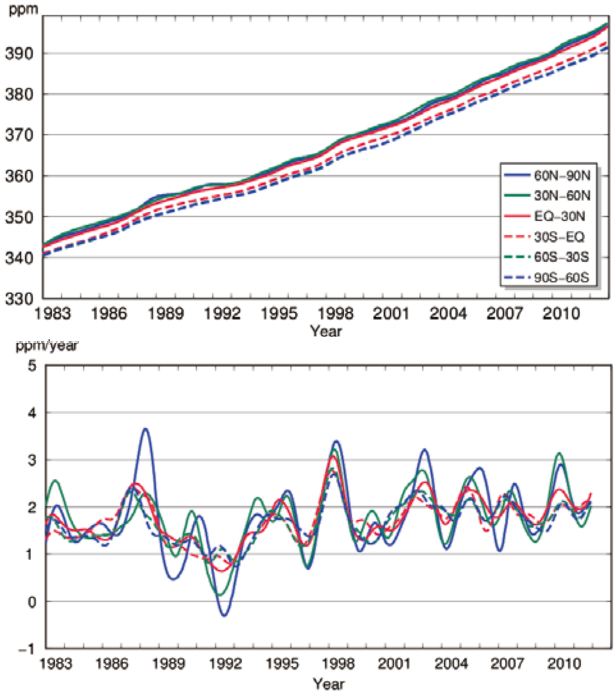


Fig. 3.4 Long-term trends in the mole fraction of CO_2 for each 30° latitudinal zone (top) and their growth rates (bottom) .

However, an exceptionally low CO_2 growth rate occurred during the El Niño event in 1991/1992. The injection of 14 - 20 megatonnes (Mt) of SO_2 aerosols into the stratosphere by the Mount Pinatubo eruption in June 1991 affected the radiation budget and atmospheric circulation (Hansen *et al.*, 1992; Stenchikov *et al.*, 2002), resulting in a drop in global temperature. Angert *et al.* (2004) suggested that the low CO_2 growth rate observed during this El Niño event was due to reduced CO_2 emissions caused by consequent changes in the respiration of terrestrial vegetation and the decomposition of organic matter (Conway *et al.*, 1994; Lambert *et al.*, 1995; Rayner *et al.*, 1999), and by enhanced CO_2 absorption due to intensive photosynthesis caused by an increase in diffuse radiation (Gu *et al.*, 2003).

Seasonal cycle of CO_2 mole fraction in the atmosphere

Figure 3.5 shows average seasonal cycles in the mole fraction of CO_2 for each 30° latitudinal zone. The seasonal cycles are clearly large in amplitude in northern high and mid-latitudes and small in the Southern Hemisphere. The seasonal cycle in the Northern Hemisphere is mainly dominated by the land biosphere (Nevison *et al.*, 2008), and it is characterized by rapid decreases from June to August and large returns from September to December.

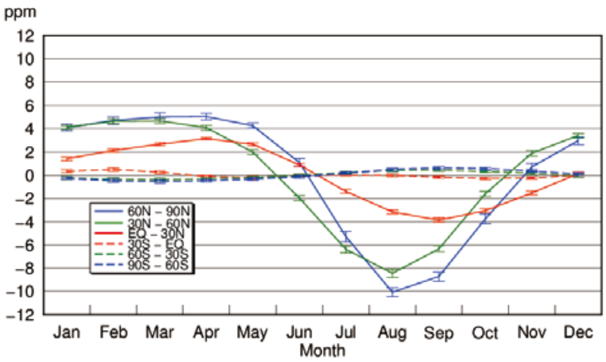


Fig. 3.5 Average seasonal cycles in the mole fraction of CO_2 for each 30° latitudinal zone obtained by subtracting long-term trends from the zonal mean time series. Vertical error bars represent the range of ±1σ which is calculated for each month. (Average from 1983 to 2012)

The mole fractions of CO_2 in northern low latitudes lagged behind that in high latitudes by one or two months. Minimum values appeared in August in northern high and mid-latitudes and in September in northern low latitudes.

In the Southern Hemisphere, seasonal variations showed small amplitudes with a half-year delay due to small amounts of net emission and absorption by the terrestrial biosphere. Seasonal variations in both northern and southern mid-latitudes were apparently superimposed in southern low latitudes (0–30°S). The direct influence of sources and sinks in the Southern Hemisphere may be partially cancelled by the propagation of an antiphase variation from the Northern Hemisphere.

Figure 3.6 shows latitudinal distributions of the mole fractions of CO_2 in January, April, July and October 2012, from sites marked with an asterisk in Plate 3.1. In latitudes north of 30°N, the mole fractions increased towards higher latitudes in January and April, and decreased towards higher latitudes in July, corresponding to the large seasonal variations in northern high and mid-latitudes, variations associated with activities of the terrestrial biosphere.

It can be noticed that during seasonal maximum many stations of the Northern Hemisphere observed monthly mean CO_2 mole fractions above the “symbolic” threshold of 400 ppm.

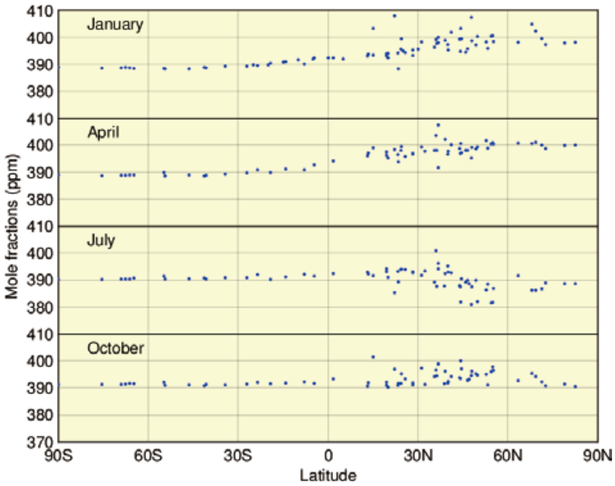


Fig. 3.6 Latitudinal distributions of the monthly mean mole fractions of CO_2 in January, April, July and October 2012.

4.

METHANE

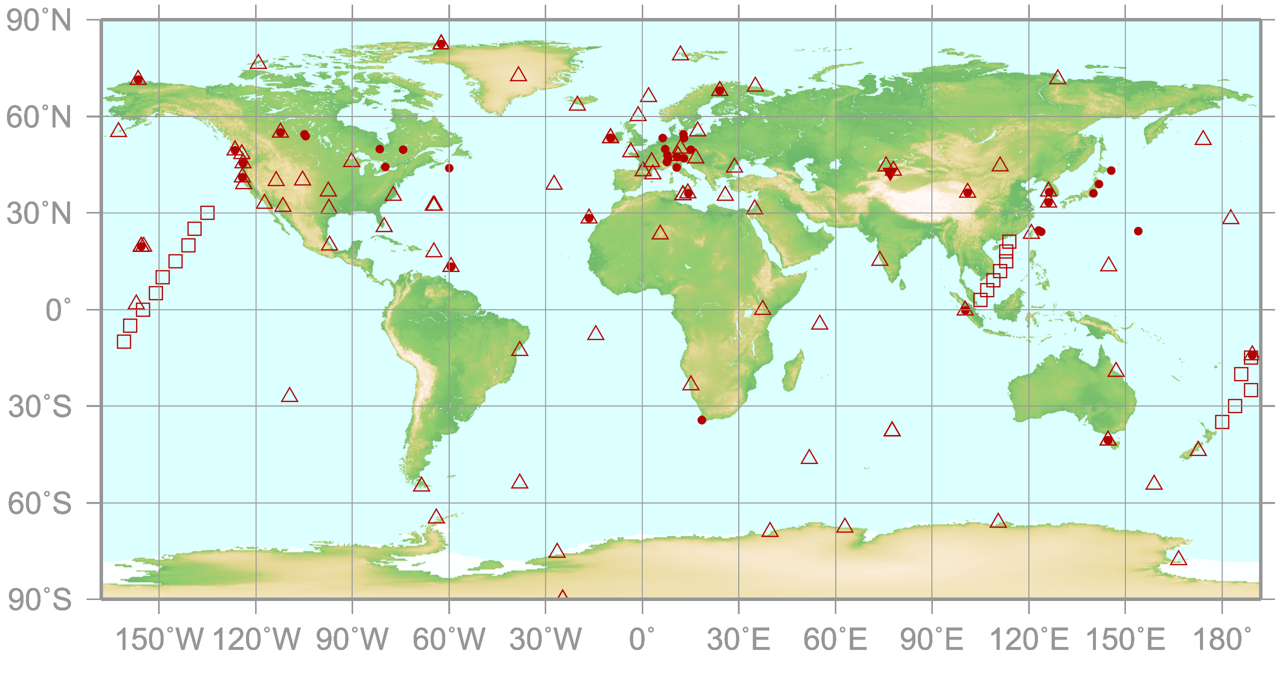
(CH_4)

● : CONTINUOUS STATION

△ : FLASK STATION

□ : FLASK MOBILE (SHIP)

▼ : REMOTE SENSING STATION



This map shows locations of the stations that have submitted data for monthly mean mole fraction.

CH_4 Monthly Data

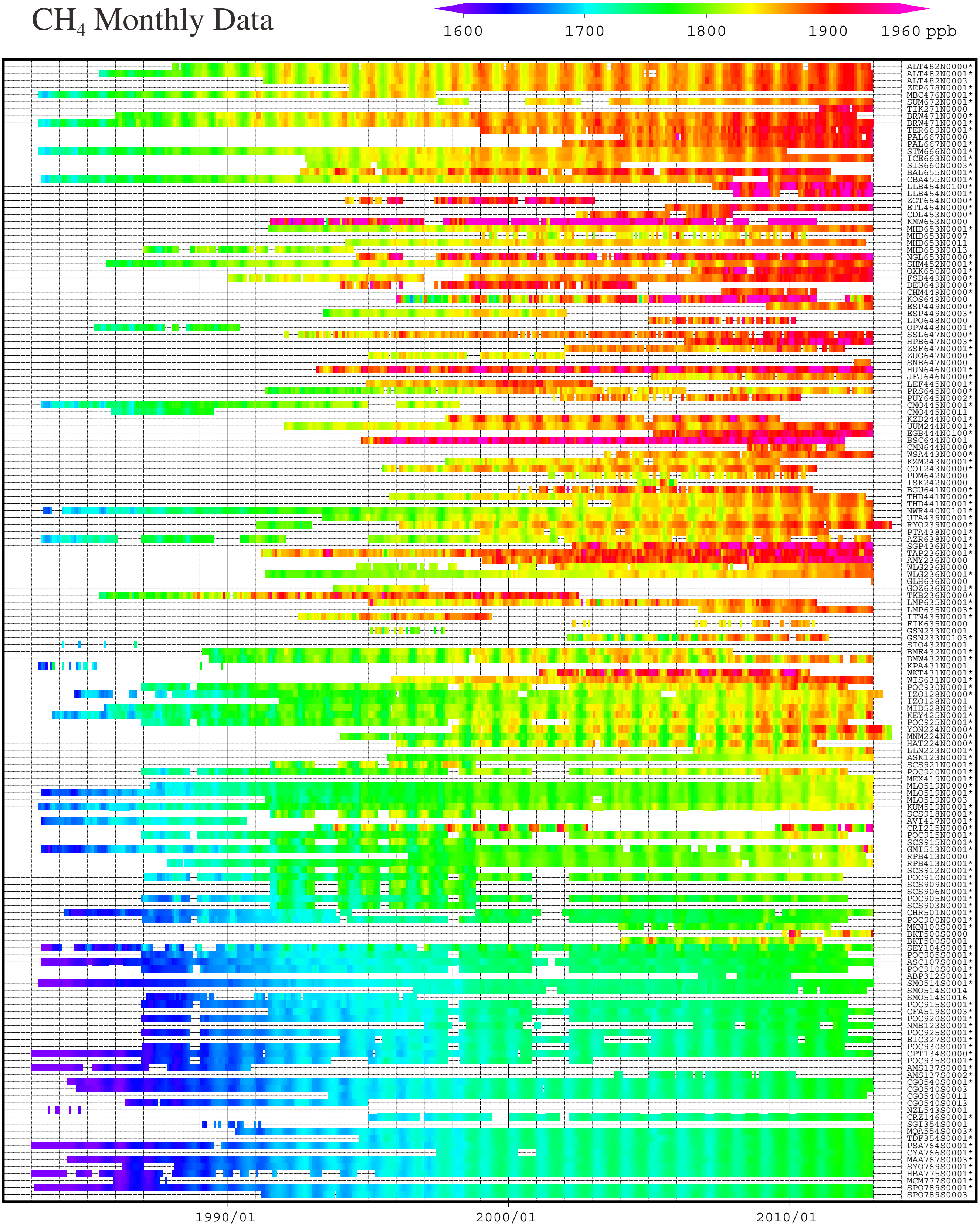
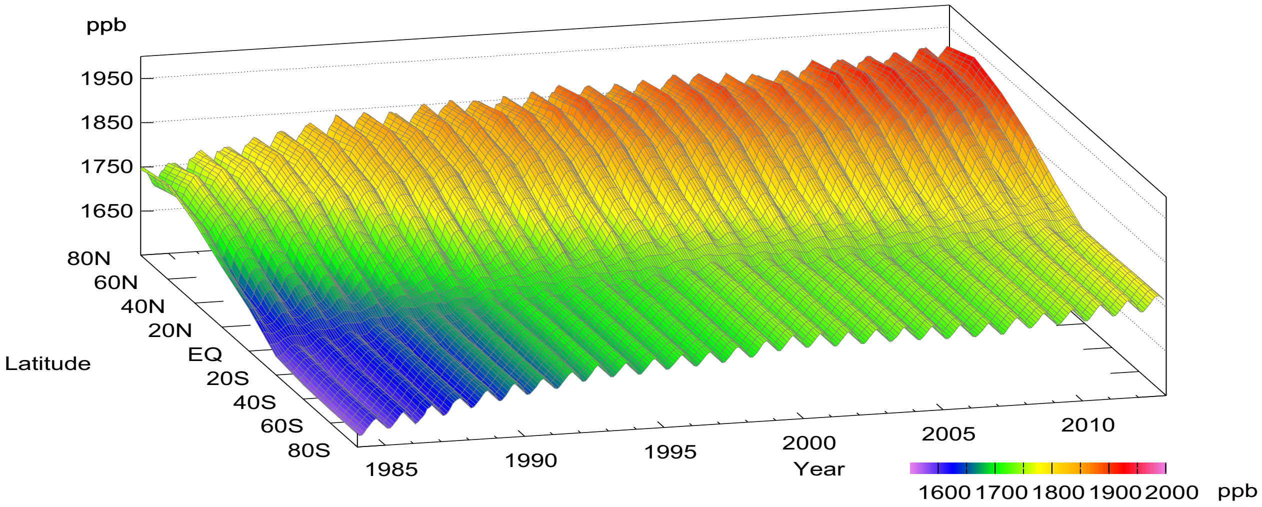
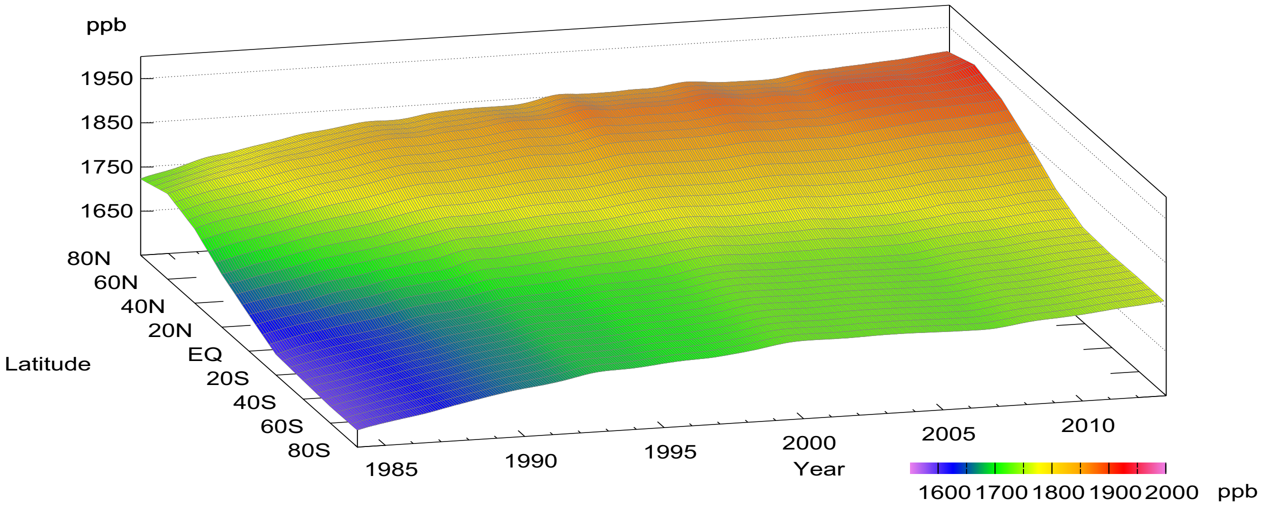


Plate 4.1 Monthly mean CH_4 mole fractions that have been reported to the WDCGG. The mole fractions are illustrated in different colours. The sites are listed in order from north to south. In the case where data are reported for two or three different altitudes, only the data at the highest altitudes are illustrated. In the case where monthly means are not reported, the WDCGG calculates them from hourly or other mole fractions reported to the WDCGG by simple arithmetic mean. The data from the sites with an asterisk at the end of the station index are used for the analysis shown in Plate 4.2. (see Chapter 2)

CH_4 mole fraction



CH_4 deseasonalized mole fraction



CH_4 growth rate

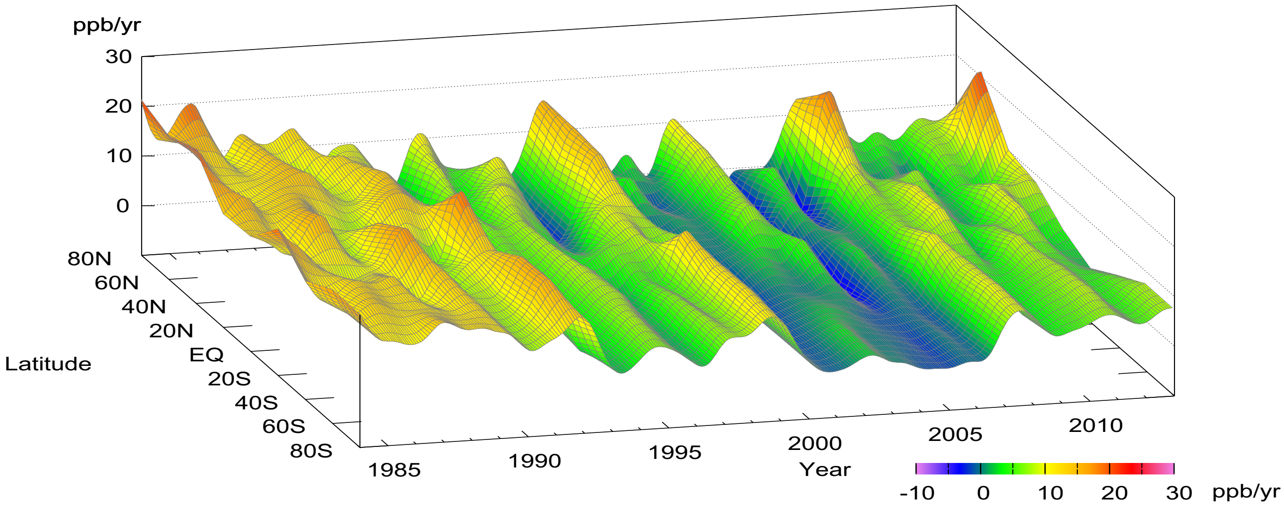


Plate 4.2 Variation of zonally averaged monthly mean CH_4 mole fractions (top), deseasonalized long-term trends (middle), and growth rates (bottom). The zonally averaged mole fractions are calculated for each 20° zone. The deseasonalized trends and growth rates are derived as described in Chapter 2.

4. METHANE (CH_4)

Basic information on CH_4 with regard to environmental issues

Methane (CH_4) is the second most important anthropogenic greenhouse gas, with an estimated global warming potential per molecule 25 times greater over a 100 year horizon and 72 times greater over a 20 years horizon than CO_2. Between 1750 and 2012, CH_4 accounted for about 18% of the total increase in radiative forcing due to long-lived greenhouse gases in the atmosphere (WMO, 2013).

Analyses of air trapped in ice cores from Antarctica and the Arctic revealed that the current atmospheric CH_4 mole fraction is the highest over the last 650,000 years (Solomon *et al.*, 2007). The mole fraction of CH_4 remained at about 700 ppb from 1000 A.D. until the start of the industrial era when it started increasing. Measurements in ice cores have shown that interpolar differences in CH_4 mole fractions between Greenland and Antarctica ranged from 24 to 58 ppb between 1000 and 1800 A.D. (Etheridge *et al.*, 1998). However, the inter-hemispheric difference of the mole fractions (see Fig 4.3) averaged over the years 1984 to 2012 reached the value of 135 ppb. Increase in the interpolar gradient reflects the dominant impact of the emissions from the Northern Hemisphere, where major anthropogenic and natural sources are situated.

CH_4 is emitted by both natural and anthropogenic sources, including natural wetlands, oceans, landfills, rice paddies, enteric fermentation, fossil fuel production and consumption and biomass burning. The global emission of CH_4 was 548 teragrams (Tg) CH_4 per year, with more than 60% related to anthropogenic activities (http://www.globalcarbonproject.org/methanebudget/13/hl-compact.htm). CH_4 is removed from the atmosphere by reaction with hydroxyl radicals (OH) in both the troposphere and stratosphere, and by reaction with chlorine atoms and $O(^1D)$, an excited state of oxygen, in the stratosphere. CH_4 is one of the most important sources of water vapor in the stratosphere and has an atmospheric lifetime of about 10 years. More information regarding sources and sinks of CH_4 must be collected to better understand the budget of atmospheric CH_4.

Mole fractions of CH_4 are analyzed using data submitted to the WDCGG from fixed stations and some ships. These observational sites are shown on the map at the beginning of this chapter.

Annual variation of CH_4 mole fraction in the atmosphere

The monthly mean dry mole fractions of CH_4 used in this analysis are shown in Plate 4.1, with the mole fraction levels illustrated in different colours. Global, hemispheric and zonal mean mole fractions have been calculated based on data from selected stations under unpolluted conditions (see the caption for Plate 4.1). Zonally averaged atmospheric CH_4 mole fractions, together with their deseasonalized components and growth rates, are shown as three-dimensional representations in Plate 4.2. These plots show that the seasonal variations in CH_4 mole fraction are larger in the Northern than in the Southern Hemisphere and that the increase in the Northern Hemisphere propagates to the Southern Hemisphere. The growth rates vary on a global scale with the patterns similar to those for CO_2 (see Section 3). There is a large latitudinal gradient in CH_4 mole fraction from the northern mid-latitudes to the tropics, suggesting major sinks in the tropics, where the mole fraction of OH radicals is higher.

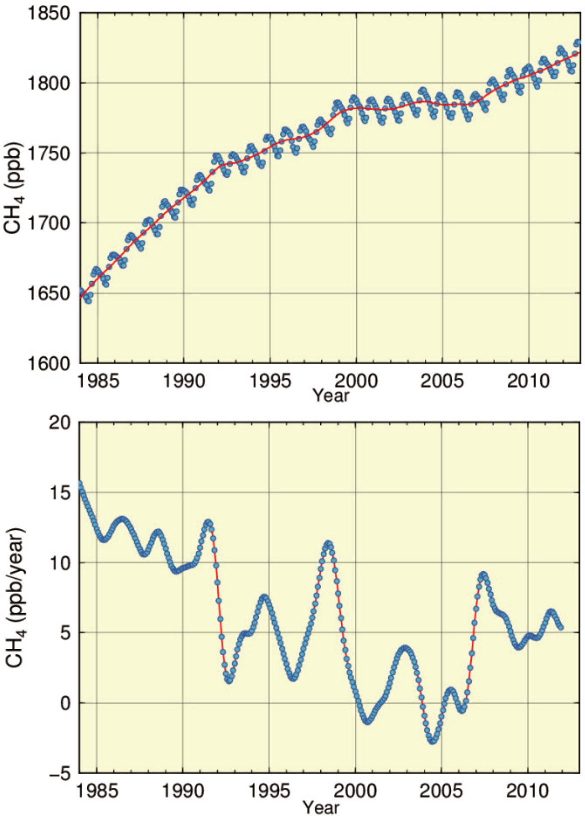


Fig. 4.1 Global monthly mean mole fraction of CH_4 from 1984 to 2012, including deseasonalized long-term trend in red line (top) and annual growth rate (bottom).

Figure 4.1 shows globally averaged monthly mean mole fractions and the growth rates for CH_4 from 1984 to 2012. The global average mole fraction was 1819±1 ppb in 2012, an increase of 6 ppb from 2011. The mole fraction did not change much between 1999 and 2006. The mean annual absolute increase during last 10 years was 3.7 ppb/year. The current mole fraction is 260% of its pre-industrial level of 700 ppb.

Figure 4.2 shows monthly mean mole fractions from 1984 to 2012 for each 30° latitudinal zone. The smallest magnitude of the seasonal variations is observed in the latitudinal zone between the equator and 30°S.

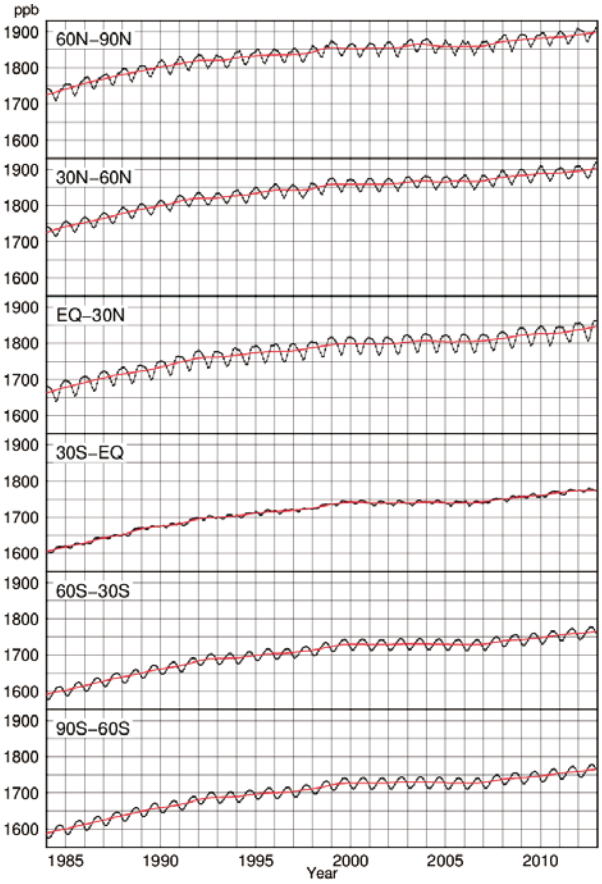


Fig. 4.2 Monthly mean mole fractions of CH_4 from 1984 to 2012 for each 30° latitudinal zone (dots) and their deseasonalized long-term trends (red lines).

Figure 4.3 summarizes deseasonalized long-term trends for each 30° latitudinal zone and their growth rates. A latitudinal gradient between the northern high and mid-latitudes with higher mole fractions and the southern latitudes with lower mole fractions is clearly seen in Fig. 4.3, while mole fractions in most latitudinal belts have similar tendencies. In the 1990s, the growth rates clearly decreased in all latitudinal zones, but remained positive. The declined growth rate was especially evident during the second half of 1992, in 1996, and almost even in 1999 and in 2004/2005, when growth rates were less than 5 ppb/year in all latitudes. During the year 1998, the maximum global growth rate reached about 11 ppb/year (Fig. 4.1). Maximum increases occurred in northern high and mid-latitudes, where the growth rates were over 15 ppb/year. In 2000 and 2001, the global growth rate decreased to around –1 ppb/year. Around 2002/2003, the growth rates increased in the Northern Hemisphere, especially in northern high and mid-latitudes where they reached about 10 ppb/year. The global growth rate was –3 ppb/year in 2004 and 1 ppb/year in 2005. Despite the large growth rates in 1998 and 2002/2003, during El Niño events, the global mean mole fraction was relatively stable between 1999 and 2006. However, the global mean mole fraction increased by a total of 35 ppb in the five years since 2007.

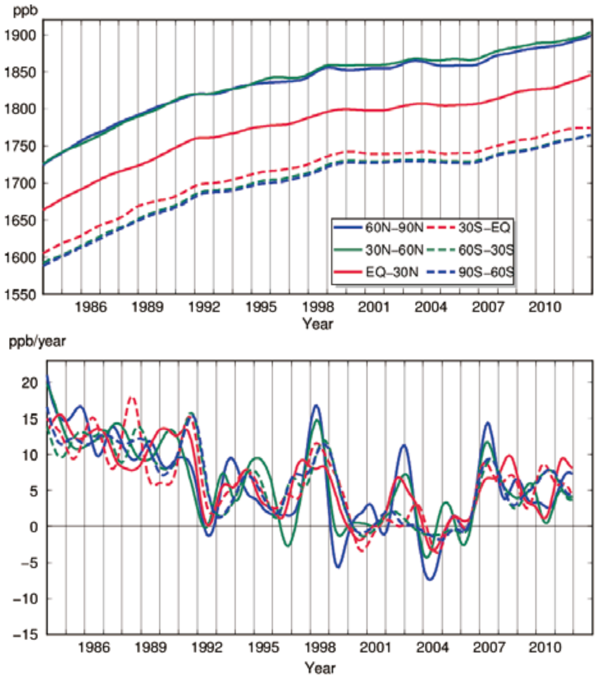


Fig. 4.3 Long-term trends in the mole fraction of CH_4 for each 30° latitudinal zone (top) and their growth rates (bottom).

The large increase in CH_4 growth rate in 1991 may have been caused by decreased levels of OH radicals in the atmosphere due to reduced UV radiation resulting from the eruption of Mount Pinatubo in 1991 (Dlugokencky *et al.*, 1996), and the subsequent decrease in 1992 may have been due to an increase in OH radicals resulting from the depletion of stratospheric ozone following this eruption (Bekki *et al.*, 1994).

In 1998, the growth rates were high in all latitudes, which may have been due to increased emissions in northern high latitudes and tropical wetlands caused by high temperatures and increased precipitation, as well as by biomass burning in boreal forests, mainly in Siberia (Dlugokencky *et al.*, 2001). In contrast, Morimoto *et al*. (2006) estimated from isotope observations that the contribution of biomass burning to the increase in 1998 was about half that of wetlands. The growth rates were low from 1999 to 2006, with an exception during the El Niño event of 2002/2003. The causes of these decreases and increases in CH_4 growth rates are not yet determined.

Since 2007, atmospheric CH_4 has increased significantly throughout the entire monitoring network (Rigby *et al*., 2008; Dlugokencky *et al.,* 2009). This is due to increased emissions in the tropical and mid-latitude Northern Hemisphere. The attribution of this increase to anthropogenic and natural sources is difficult because the current network is insufficient to characterize emissions by region and source process (Bergamaschi *et al.,* 2013).

The WMO/GAW observational network includes the observations of carbon stable isotopes in methane, with 20 datasets submitted to the WDCGG. Such observations can be useful for the identification of primary methane sources.

Seasonal cycle of CH_4 mole fraction in the atmosphere

Figure 4.4 shows seasonal cycles in the mole fraction of CH_4 for each 30° latitudinal zone. The seasonal cycles are driven mainly by reaction with OH radicals, a major CH_4 sink in the atmosphere. Seasonal cycles are also affected by the magnitude and timing of CH_4 emissions from sources such as wetlands and biomass burning as well as by its atmospheric transport. The seasonal cycles are large in amplitude in the Northern Hemisphere. Unlike CO_2, amplitudes were also large in southern high and mid-latitudes. Seasonally, the Northern Hemisphere shows minima in summer and maxima in winter, while the Southern Hemisphere shows a seasonal cycle lagging two-thirds to three-quarter years behind. The seasonal variations in the mole fraction of CH_4 were almost consistent with those of the OH radical that reacts with CH_4. Southern low latitudes have a distinct antiphase annual component with that of the seasonal cycle arising from southern mid-latitudes. The maximum in the former component occurs in boreal winter due to the interhemisphere transport of CH_4 from the Northern Hemisphere.

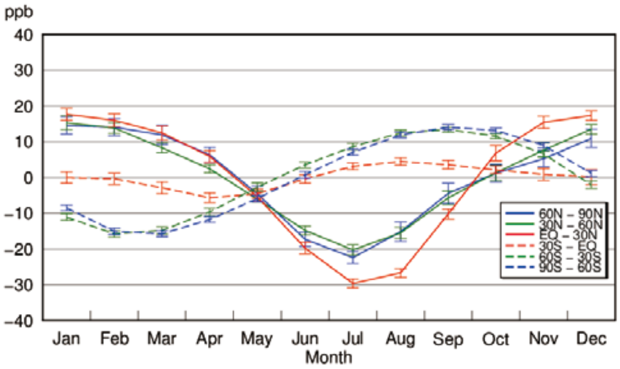


Fig. 4.4 Average seasonal cycles of CH_4 mole fraction for each 30° latitudinal zone obtained by subtracting long-term trends from the zonal mean time series. Vertical error bars represent the range of ±1σ calculated for each month. (Average from 1984 to 2012)

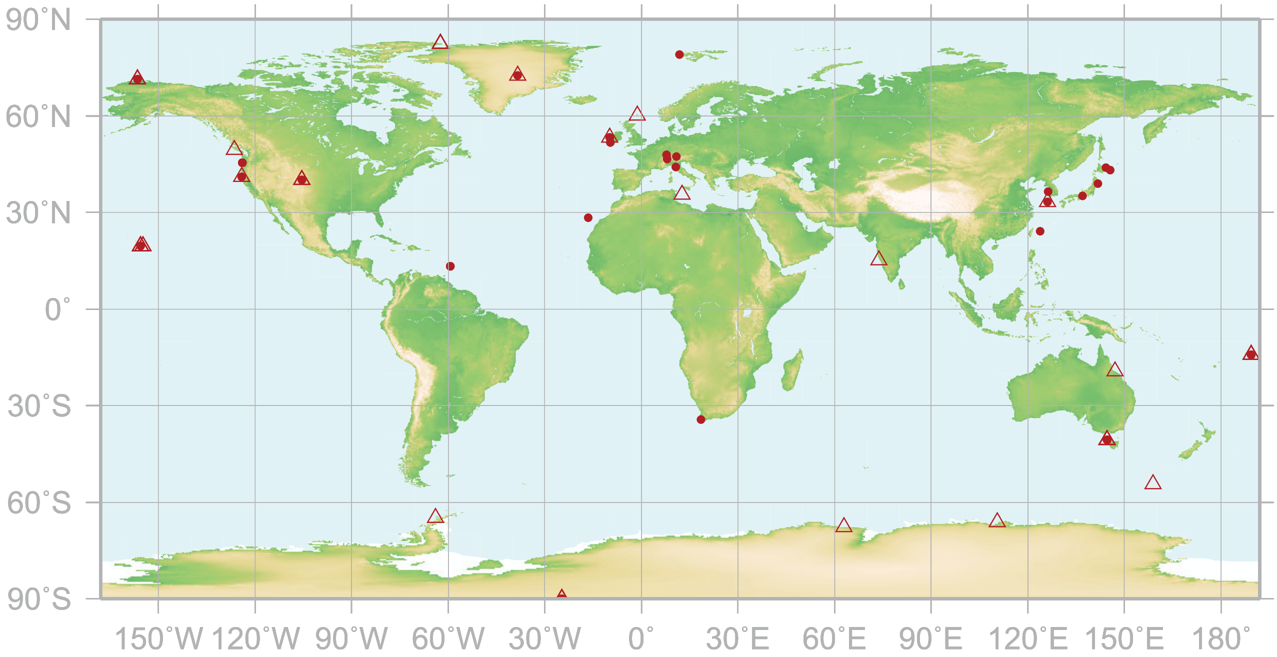
5.

NITROUS OXIDE

(N_2O)

● : CONTINUOUS STATION

△ : FLASK STATION



This map shows locations of the stations that have submitted data for monthly mean mole fraction.

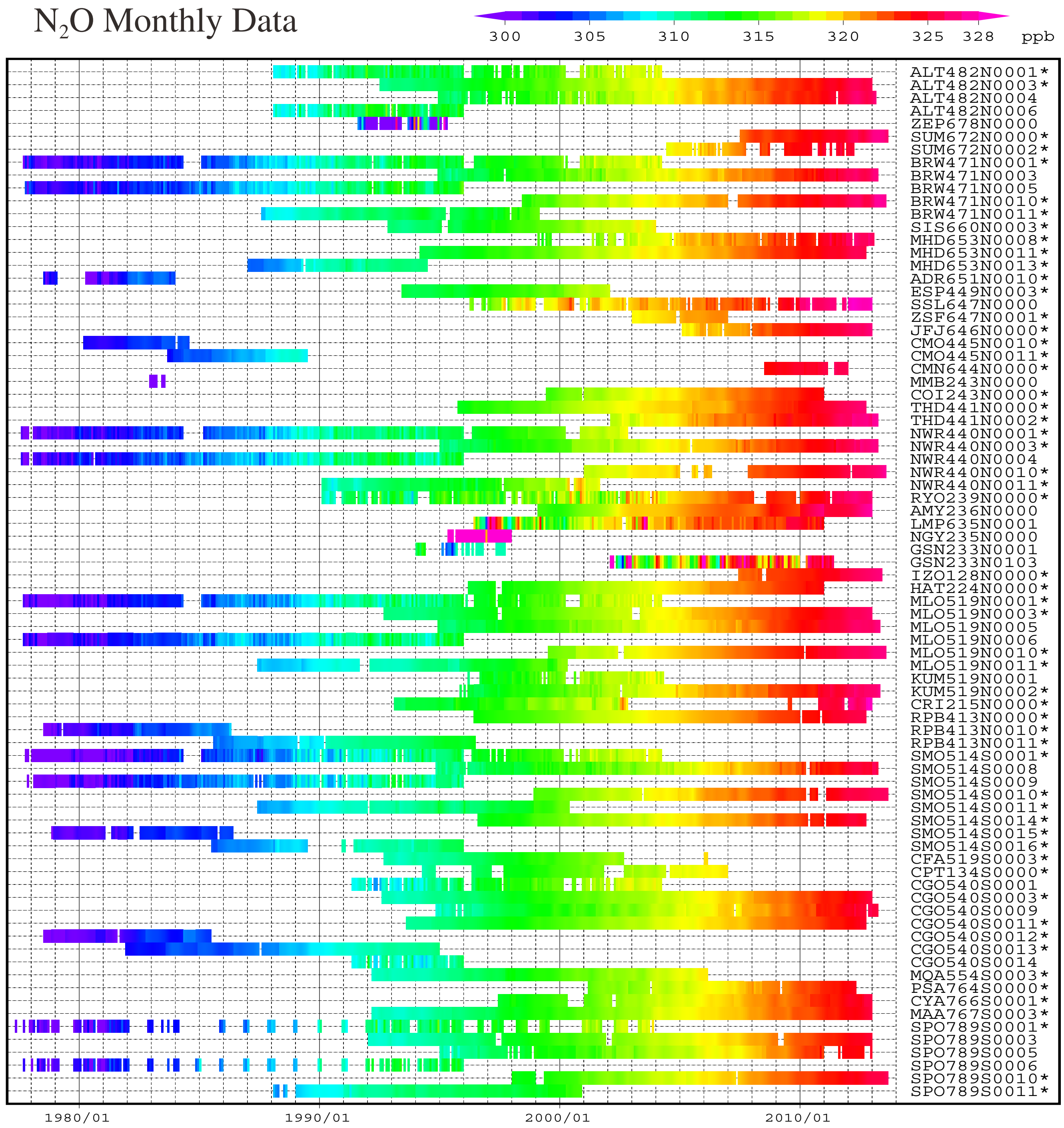
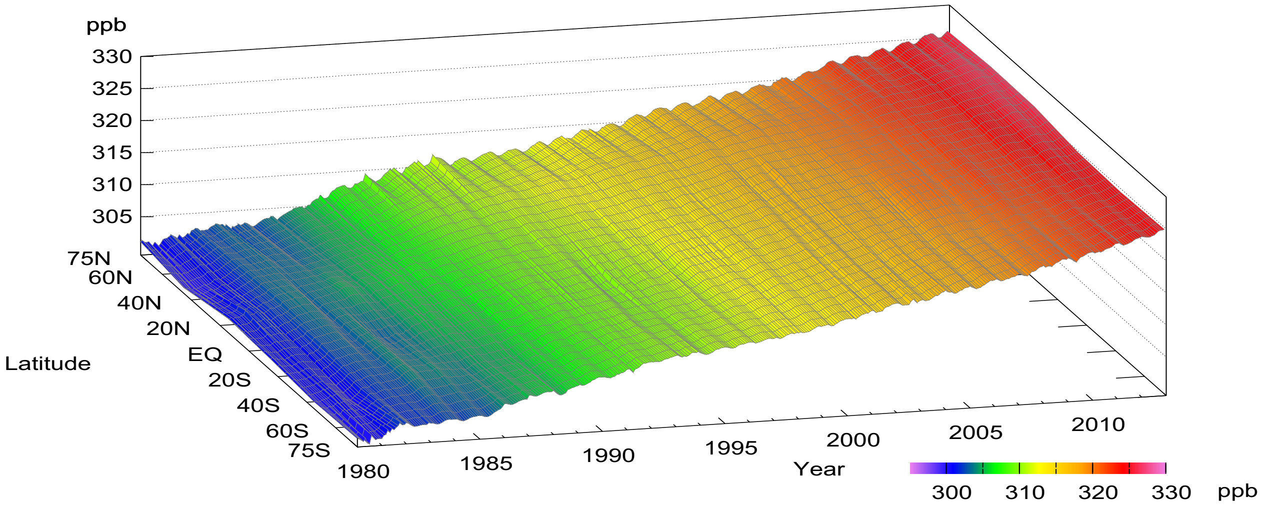
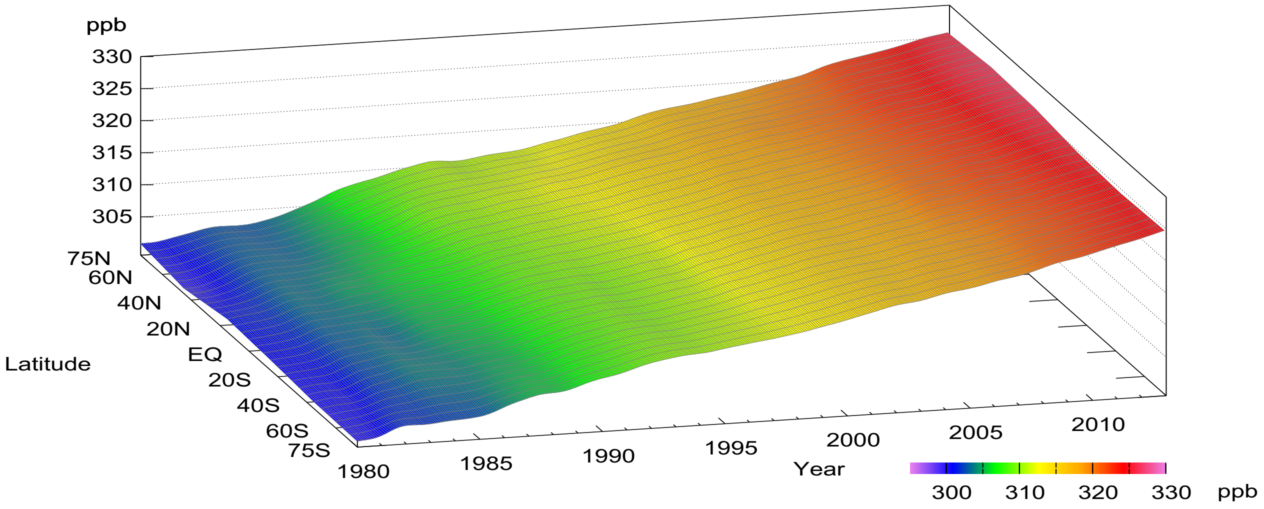


Plate 5.1 Monthly mean N_2O mole fractions that have been reported to the WDCGG. The mole fractions are illustrated in different colours.The sites are listed in order from north to south. The data from the sites with an asterisk at the end of the station index are used for the analysis shown in Plate 5.2. (see Chapter 2)

N_2O mole fraction



N_2O deseasonalized mole fraction



N_2O growth rate

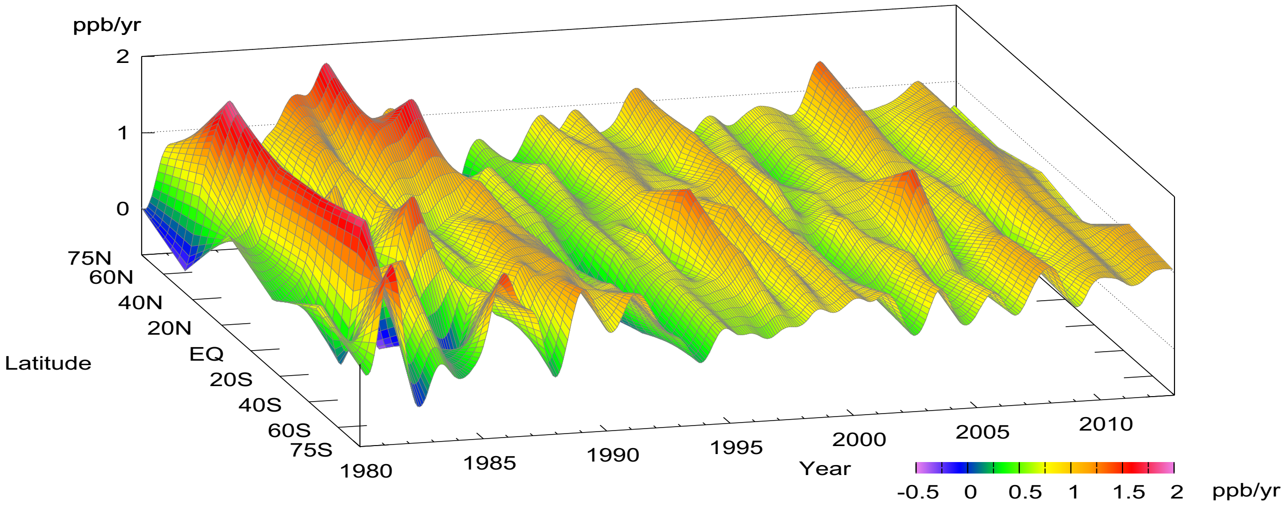


Plate 5.2 Variation of zonally averaged monthly mean N_2O mole fractions (top), deseasonalized long-term trends (middle), and growth rates (bottom). The zonally averaged mole fractions are calculated for each 30° zone. The deseasonalized trends and growth rates are derived as described in Chapter 2.

5. NITROUS OXIDE (N_2O)

Basic information on N_2O with regard to environmental issues

Nitrous oxide (N_2O) is a relatively stable greenhouse gas in the troposphere with a lifetime of 121 years (IPCC, 2013). Between 1750 and 2012, N_2O accounted for about 6 % of the total increase in radiative forcing due to long-lived greenhouse gases (WMO, 2013). N_2O is the third most important anthropogenic greenhouse gas in the atmosphere. The mole fraction of N_2O in the atmosphere has increased steadily from about 270 ppb during pre-industrial time to its current value, which is 20% higher. N_2O is emitted into the atmosphere from natural and anthropogenic sources, including the ocean, soil, combustion of fuels, biomass burning, use of fertilizer and various industrial processes. The amount of N_2O emitted into the atmosphere by human activities is approximately equal to that derived from natural systems (oceans, chemical oxidation of ammonia in the atmosphere, and soils). Most of the anthropogenic N_2O comes to the atmosphere from the transformation of fertilizer nitrogen into N_2O and its subsequent emission from agricultural soils. N_2O breaks down mainly by photo-dissociation in the stratosphere, forming nitrogen oxides that trigger ozone depleting reactions, so it may play important role in ozone depletion in the future when other ozone depleting substances are depleted or removed from the atmosphere (Ravishankara *et al.*, 2009). However, the complete cycling of N_2O in the global nitrogen cycle remains unclear.

Long-term trend of N_2O mole fraction in the atmosphere

Dry mole fractions of N_2O are analyzed using the data submitted to the WDCGG from fixed stations and some ships. The observational sites that supplied data used for this analysis are shown on the map at the beginning of this chapter. The monthly mean mole fractions of N_2O, including the ones used in the global analysis, are shown in Plate 5.1, with the various mole fraction levels illustrated in different colours. The data submitted to the WDCGG show that N_2O mole fractions have increased at almost all stations. Zonally averaged atmospheric N_2O mole fractions, together with their deseasonalized components and growth rates, are shown as three-dimensional representations from 1980 to 2012 in Plate 5.2. Figure 5.1 shows globally averaged monthly mean N_2O mole fraction from 1980 to 2012 and its long-term trend. The global average mole fraction reached a new high of 325.1±0.1ppb in 2012, an increase of 0.9 ppb over the previous year. The mean annual absolute increase during last 10 years was 0.80 ppb/year. Atmospheric growth rate showed substantial variability (from 0.6 to 1.0 ppb/year) from the beginning of observations. The interhemispheric gradient in the yearly averaged mole fraction of N_2O changed from 0.2 ppb in 1980 to 1.4 ppb in 2012 (Figure 5.2 upper panel), indicating that the majority of N_2O sources are situated in the Northern Hemisphere (mostly agriculture).

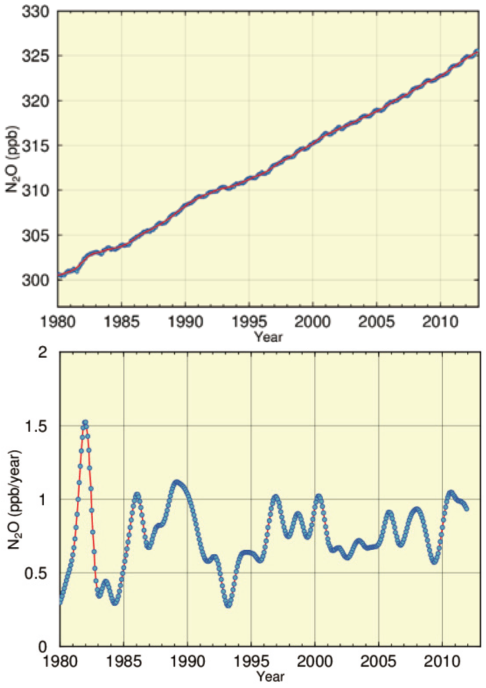


Fig. 5.1 Globally averaged monthly mean mole fraction of N_2O from 1980 to 2012, including deseasonalized long-term trend shown as a red line (top) and annual growth rate (bottom).

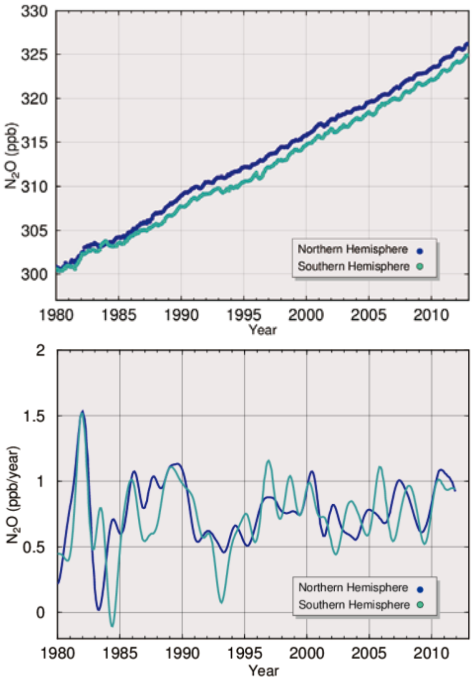


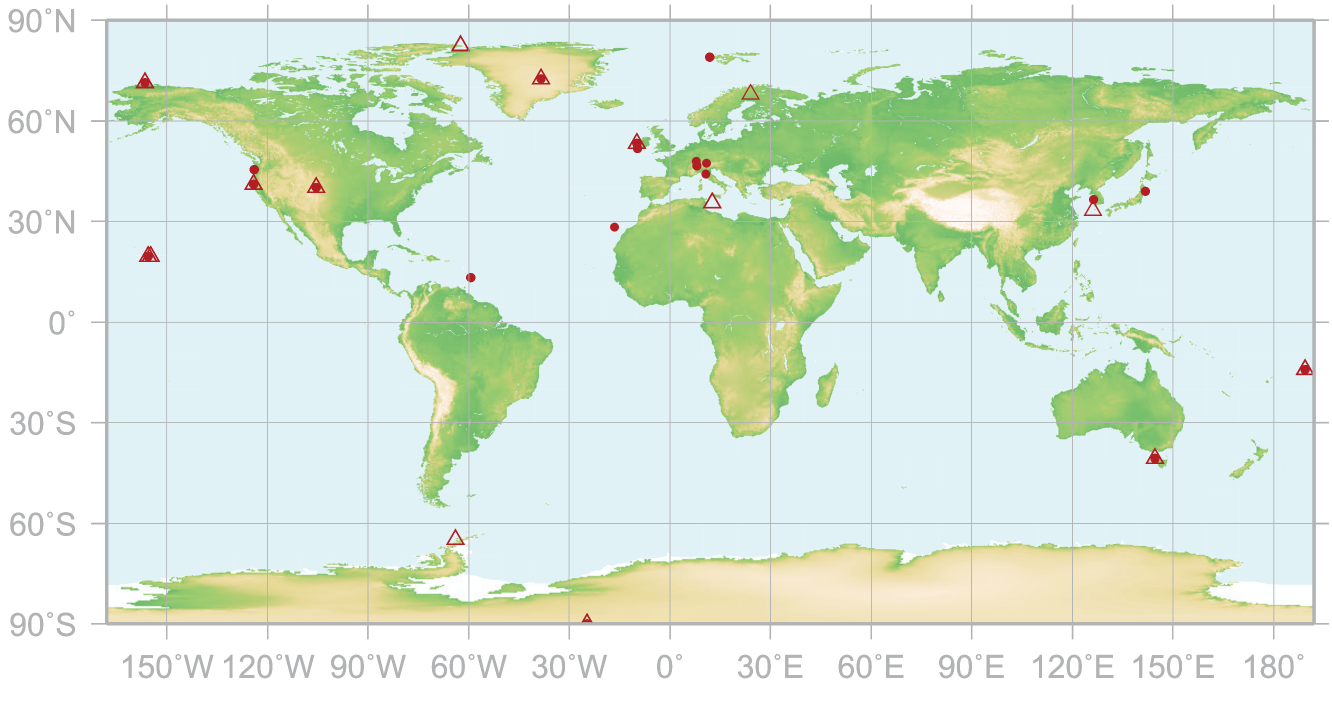
Fig. 5.2 Monthly mean mole fraction of N_2O from 1980 to 2012 (top) and annual growth rates (bottom), averaged over the Northern and Southern Hemispheres.

6.

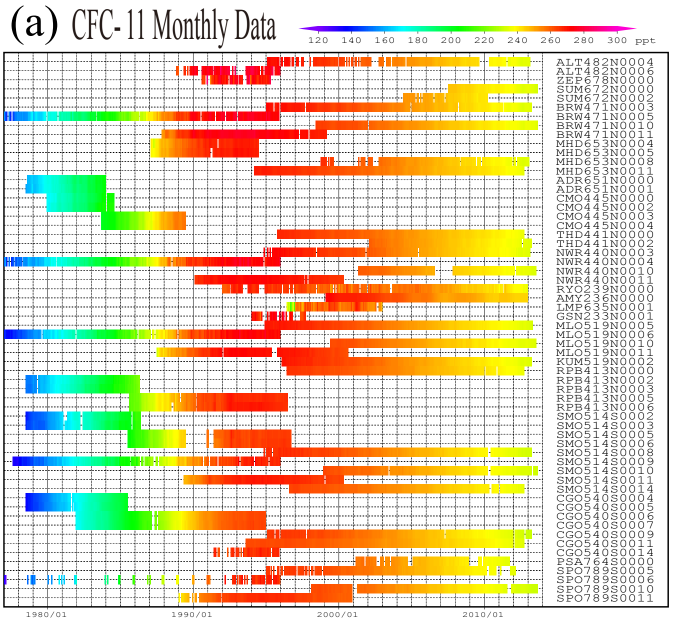
HALOCARBONS
AND
OTHER HALOGENATED SPECIES

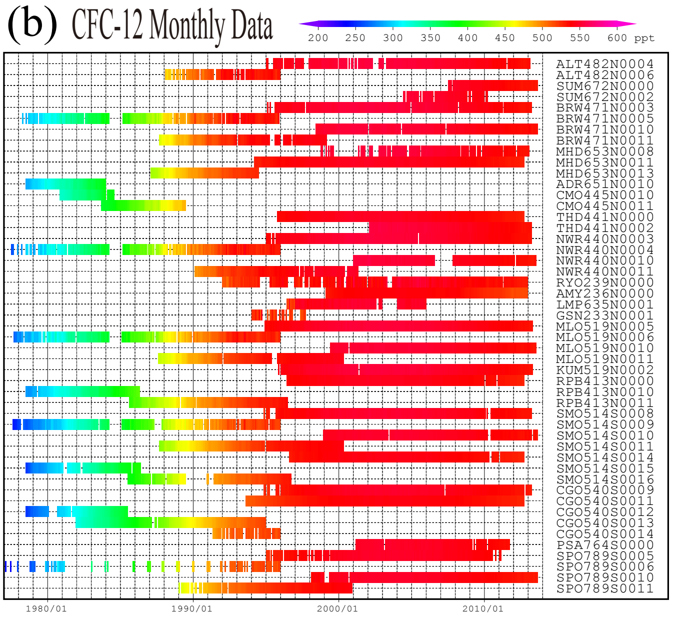
● : CONTINUOUS STATION

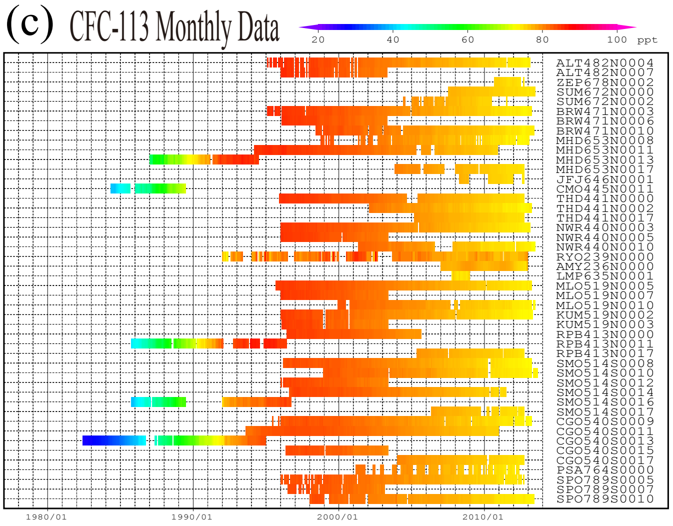
△ : FLASK STATION

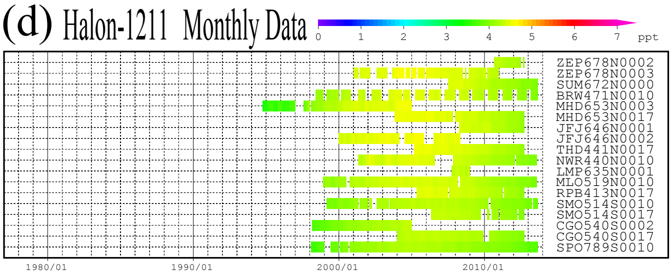


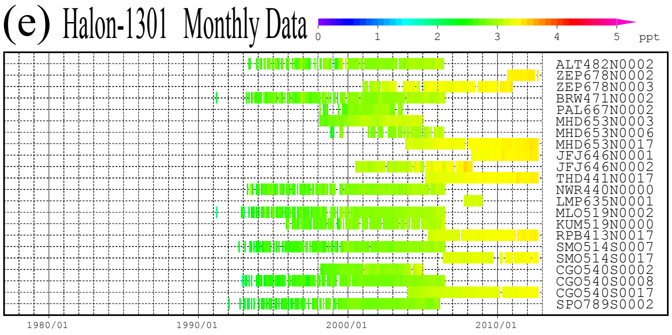
This map shows locations of the stations that have submitted data for monthly mean mole fraction.

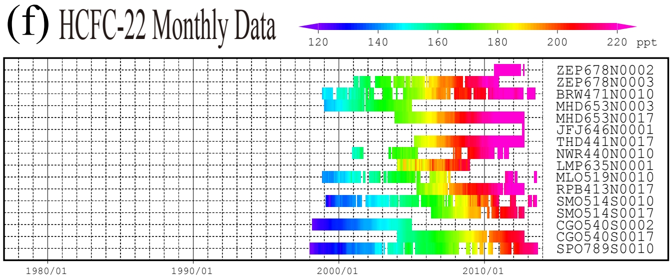


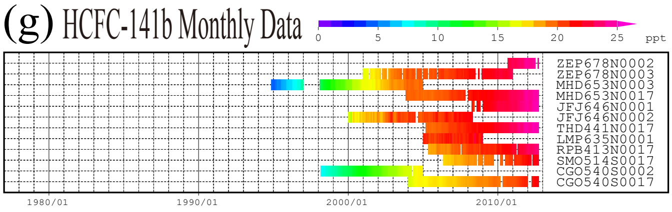












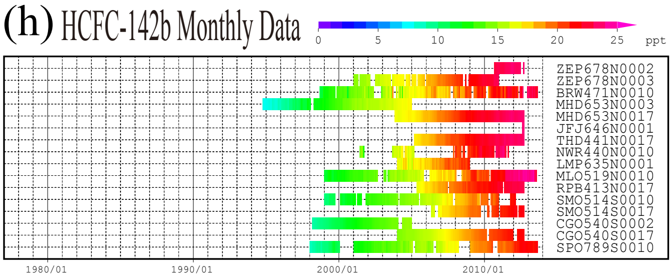


Plate 6.1 Monthly mean (a) CFC-11, (b) CFC-12, (c) CFC-113, (d) Halon-1211, (e) Halon-1301, (f) HCFC-22, (g) HCFC-141b, (h) HCFC-142b mole fractions that have been reported to the WDCGG. The mole fractions are illustrated in different colours. The sites are listed in order from north to south.

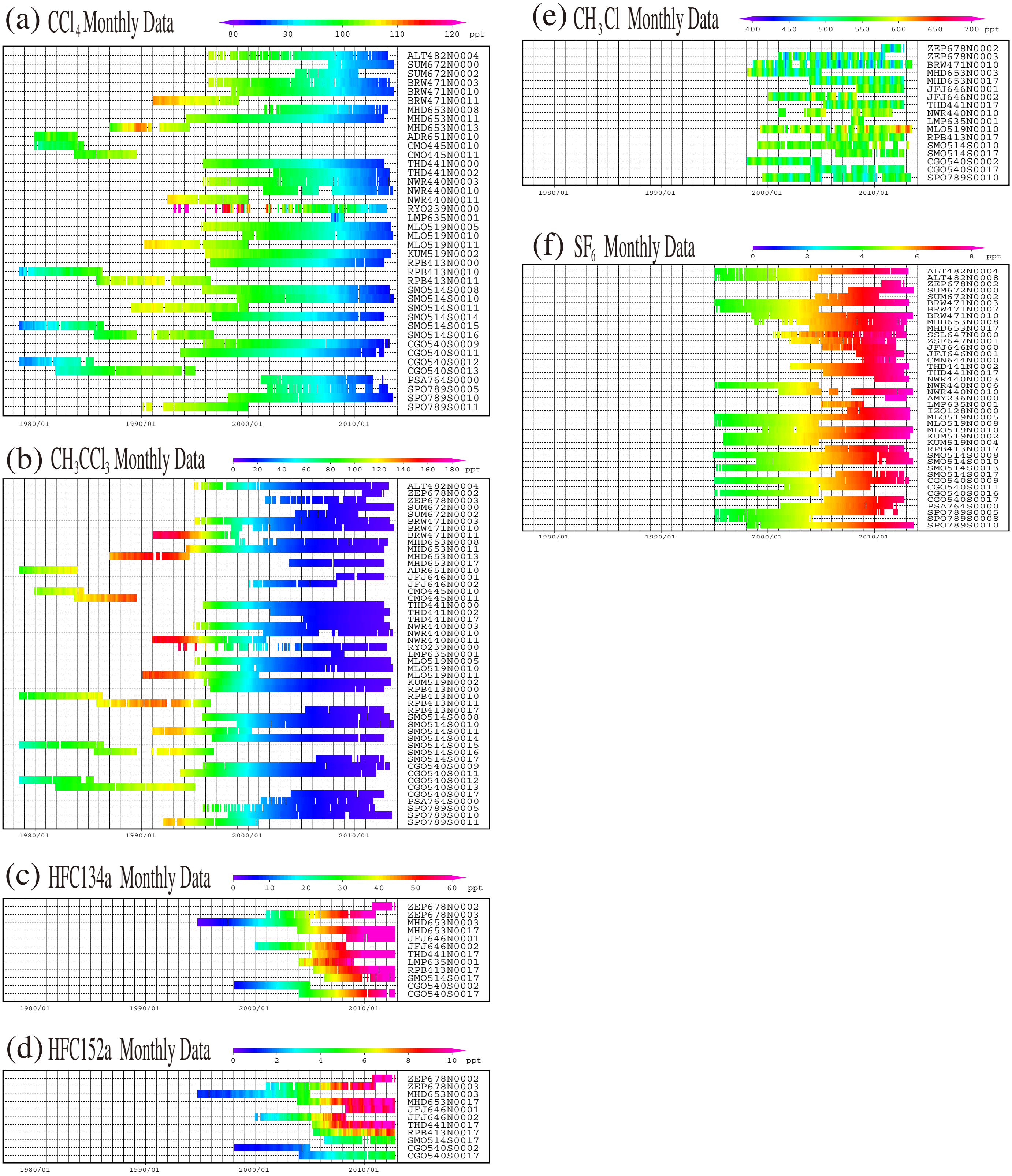


Plate 6.2 Monthly mean (a) CCl$_4$, (b) CH$_3$CCl$_3$, (c) HFC134a, (d) HFC152a, (e) CH$_3$Cl, (f) SF$_6$ mole fractions that have been reported to the WDCGG. The mole fractions are illustrated in different colours. The sites are listed in order from north to south.

6. HALOCARBONS AND OTHER HALOGENATED SPECIES

Basic information on halocarbons with regard to environmental issues

Halocarbons are carbon compounds containing one or more halogens, *i.e.*, fluorine, chlorine, bromine or iodine, with most being industrial products. Halocarbons are classified into chlorofluorocarbons (CFCs), which contain fluorine and chlorine; the hydrochlorofluorocarbons (HCFCs), which contain hydrogen in addition to fluorine and chlorine; and the halons, which contain bromine and other halogens. Perfluorocarbons (PFCs) are carbon compounds in which all hydrogen atoms are replaced by fluorine atoms, and hydrofluorocarbons (HFCs) are halocarbons that contain hydrogen and fluorine but no chlorine. Sulphur hexafluoride (SF_6), although not a halocarbon, behaves similarly to halocarbons and is a potent long-lived greenhouse gas. Carbon tetrachloride (CCl_4) and methyl chloroform (CH_3CCl_3) are produced industrially, whereas methyl chloride (CH_3Cl) has natural sources. Although the mole fractions of the halocarbons are relatively low in the atmosphere, they have high global warming potentials. The halocarbons have been shown to account for about 12% of the total increase in radiative forcing due to long-lived greenhouse gases from 1750 to 2012 (WMO, 2013).

The halocarbons are colourless, odourless and innocuous substances that can be readily gasified and liquefied and have low surface tension. Thus, they were commonly used as refrigerants, propellants and detergents for semiconductors, resulting in a rapid increase in their mole fractions in the atmosphere until the mid-1980s. Halocarbons containing chlorine and bromine led to the depletion of the ozone layer. Since the mid-1990s, the Montreal Protocol on Substances that Deplete the Ozone Layer and its subsequent Adjustments and Amendments have progressively tightened the regulations for the production, consumption and trade of ozone-depleting substances.

The CFCs are destroyed mainly by ultraviolet radiation in the stratosphere, and their lifetimes are generally long (*e.g.*, about 50 years for CFC-11). However, the HCFCs and CH_3CCl_3, which contain hydrogen, react with hydroxyl radicals (OH) in the troposphere and have relatively short lifetimes (*e.g.*, about 5 years for CH_3CCl_3). As the reaction with OH in the troposphere is a major sink for CH_3CCl_3, global measurements of CH_3CCl_3 provide an accurate estimate of the global mole fraction of OH (Prinn *et al.*, 2001). However, due to a substantial decrease of CH_3CCl_3 in the atmosphere, reconstruction of OH levels using this molecule is becoming increasingly difficult and other compounds are now used as reference tracers for OH mole fraction determination.

The Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC), which came into force on 16 February 2005, specifies HFCs, PFCs and SF_6 as targets for quantified emission limitation and reduction commitments.

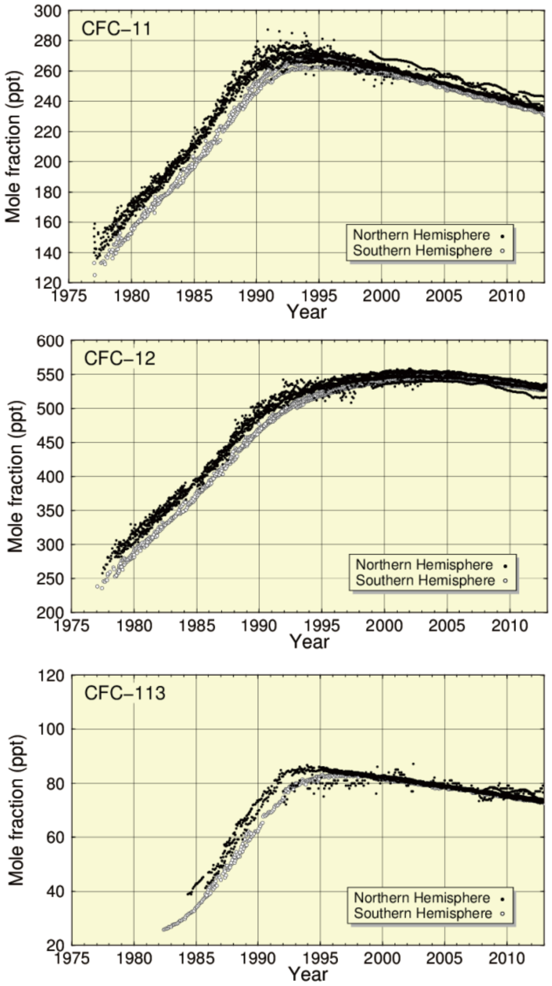


Fig. 6.1 Time series of the monthly mean mole fractions of CFC-11, CFC-12 and CFC-113 at individual stations. Solid circles show mole fractions measured in the Northern Hemisphere and open circles show mole fractions measured in the Southern Hemisphere.

Annual changes in the levels of halocarbons in the atmosphere

The cover map of this chapter shows observational sites that have submitted data on halocarbons and other halogenated species to the WDCGG. Although the number of stations measuring these species is rather limited, halocarbons are generally well mixed in the atmosphere and the data may be sufficient to reflect their global tendencies. Plates 6.1 and 6.2 show all the monthly mean mole fractions of these gases submitted to the WDCGG. The figures (6.1 – 6.7) in this chapter show the monthly mean data reported to the WDCGG without spatial averaging. Some discrepancies in the absolute mole fractions were observed for several stations, suggesting that these stations may have adopted different standard scales. Observational data based on identical standard scales revealed that the differences in the mole fractions between the two hemispheres were large in the 1980s for CFCs, CCl_4 and CH_3CCl_3 but have since narrowed as the emissions have been suppressed and the existing constituents have been mixed across the hemispheres.

Figure 6.1 shows monthly mean mole fractions of CFC-11 (CCl_3F), CFC-12 (CCl_2F_2) and CFC-113 (CCl_2FCClF_2) over time. The mole fractions of CFC-11 were maximal around 1992 in the Northern Hemisphere, followed by a maximum about one year later in the Southern Hemisphere. The mole fractions of CFC-113 were maximal around 1992 in the Northern Hemisphere and around 1997 in the Southern Hemisphere. The mole fractions of these gases have since been decreasing slowly in both hemispheres. The mole fraction of CFC-12 increased until around 2005 and then started decreasing gradually.

Figure 6.2 shows time series of the monthly mean mole fractions of Halon-1211 ($CBrClF_2$) and Halon-1301 ($CBrF_3$). The mole fraction of Halon-1211 has not increased since 2005, whereas the mole fraction of Halon-1301 is increasing.

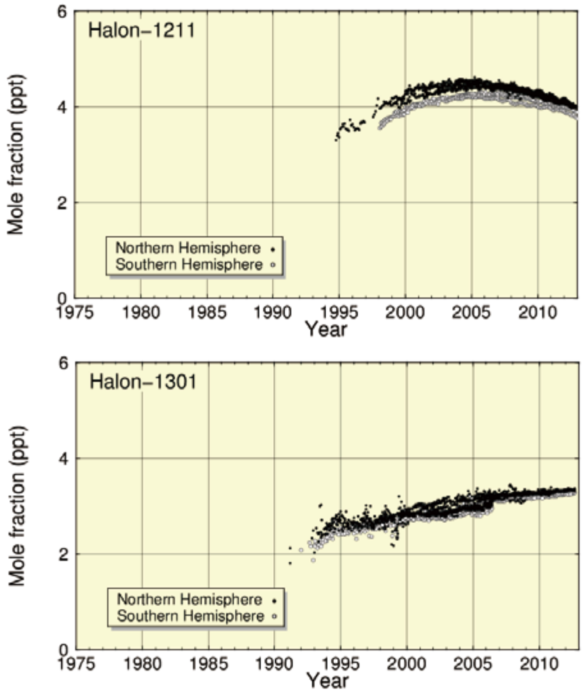


Fig. 6.2 Time series of the monthly mean mole fractions of Halon-1211 and Halon-1301 at individual stations. Solid circles show mole fractions measured in the Northern Hemisphere and open circles show mole fractions measured in the Southern Hemisphere.

Figure 6.3 shows time series of the mole fractions of HCFC-22 ($CHClF_2$), HCFC-141b (CH_3CCl_2F) and HCFC-142b (CH_3CClF_2). The mole fractions of these gases increased significantly during the last decade as a result of their continued use as substitutes for CFCs. However, the growth of HCFC-141b decelerated rapidly in the last decade.

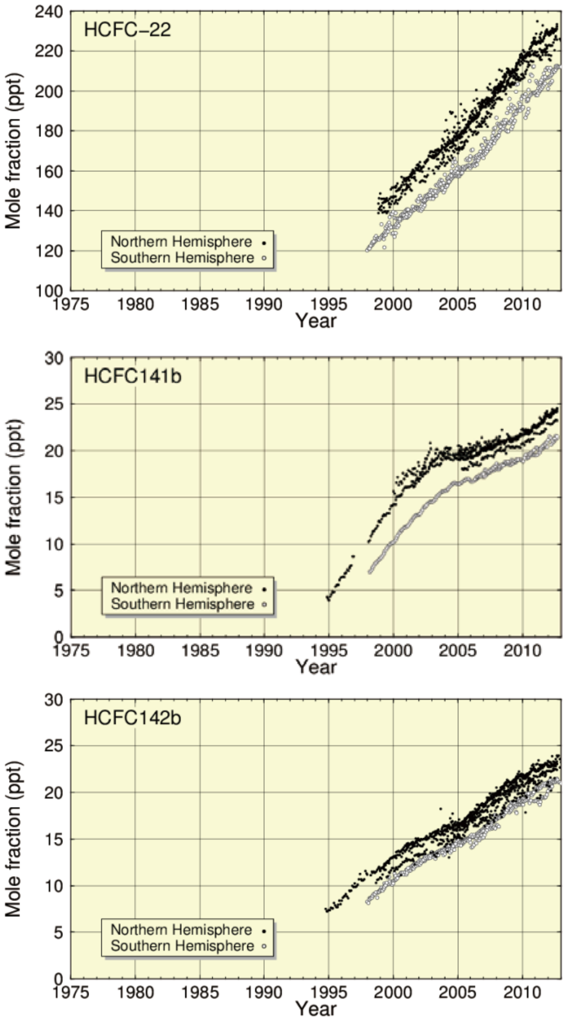


Fig. 6.3 Time series of the monthly mean mole fractions of HCFC-22, HCFC-141b, and HCFC-142b at individual stations. Solid circles show mole fractions measured in the Northern Hemisphere and open circles show mole fractions measured in the Southern Hemisphere.

Figure 6.4 shows time series of the mole fractions of CCl_4 and CH_3CCl_3. The mole fractions of CCl_4 in both hemispheres were at a maximum around 1991. The mole fractions of CH_3CCl_3 were at a maximum around 1992 in the Northern Hemisphere and around 1993 in the Southern Hemisphere. The mole fractions of these gases have since been decreasing.

Figure 6.5 shows time series of the monthly mean mole fractions of HFC-134a (CH_2FCF_3) and HFC-152a (CH_3CHF_2). The mole fractions of HFC-134a and HFC-152a have increased by 4 to

5-fold over the last 10 years. These increases have been larger in the Northern than in the Southern Hemisphere, suggesting that predominant sources of this compound are located in the Northern Hemisphere.

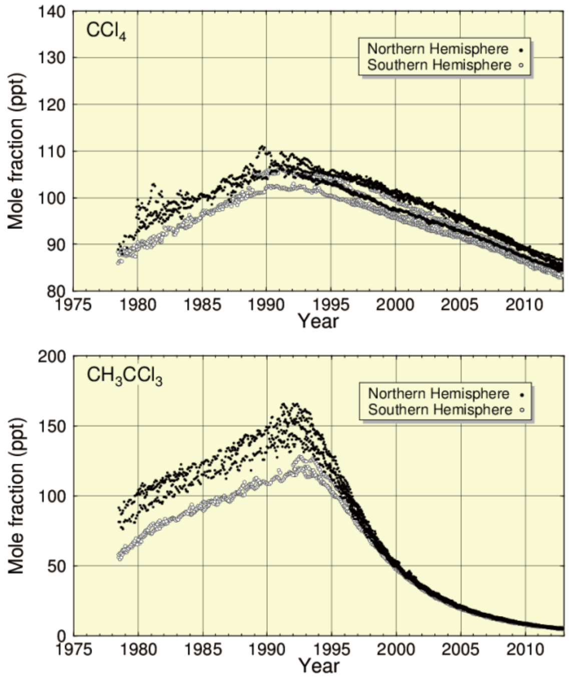


Fig. 6.4 Time series of the monthly mean mole fractions of CCl_4 and CH_3CCl_3 at individual stations. Solid circles show mole fractions measured in the Northern Hemisphere and open circles show mole fractions measured in the Southern Hemisphere.

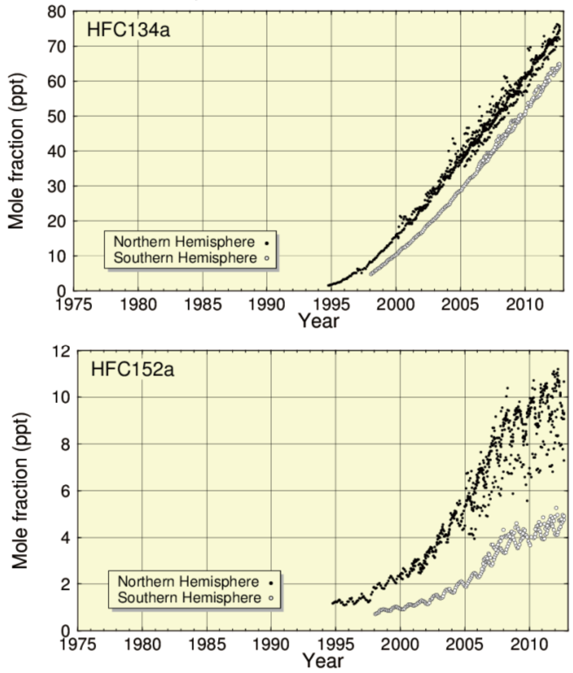


Fig. 6.5 Time series of the monthly mean mole fractions of HFC-134a and HFC-152a at individual stations. Solid circles show mole fractions measured in the Northern Hemisphere and open circles show mole fractions measured in the Southern Hemisphere.

Figure 6.6 shows time series of the monthly mean mole fractions of methyl chloride (CH_3Cl). The mole fraction of CH_3Cl does not show any particular long-term tendency although clear seasonal cycle can be seen in the dataset.

Figure 6.7 shows a time series of the monthly mean mole fractions of SF_6. The mole fraction of SF_6 in 2012 was about twice of the level observed in the mid-1990s increasing nearly linearly at a rate of 0.24 ppt/year (WMO, 2013).

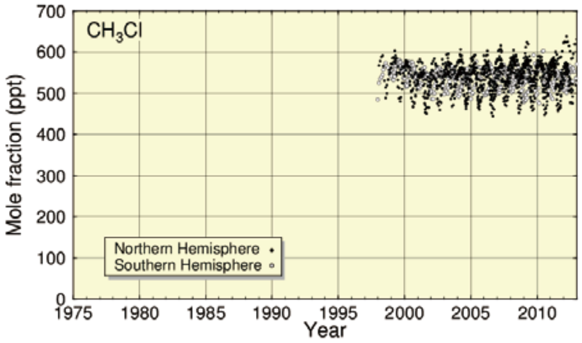


Fig. 6.6 Time series of the monthly mean mole fractions of CH_3Cl at individual stations. Solid circles show mole fractions measured in the Northern Hemisphere and open circles show mole fractions measured in the Southern Hemisphere.

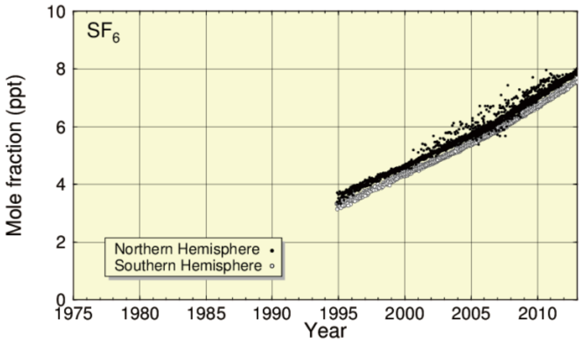
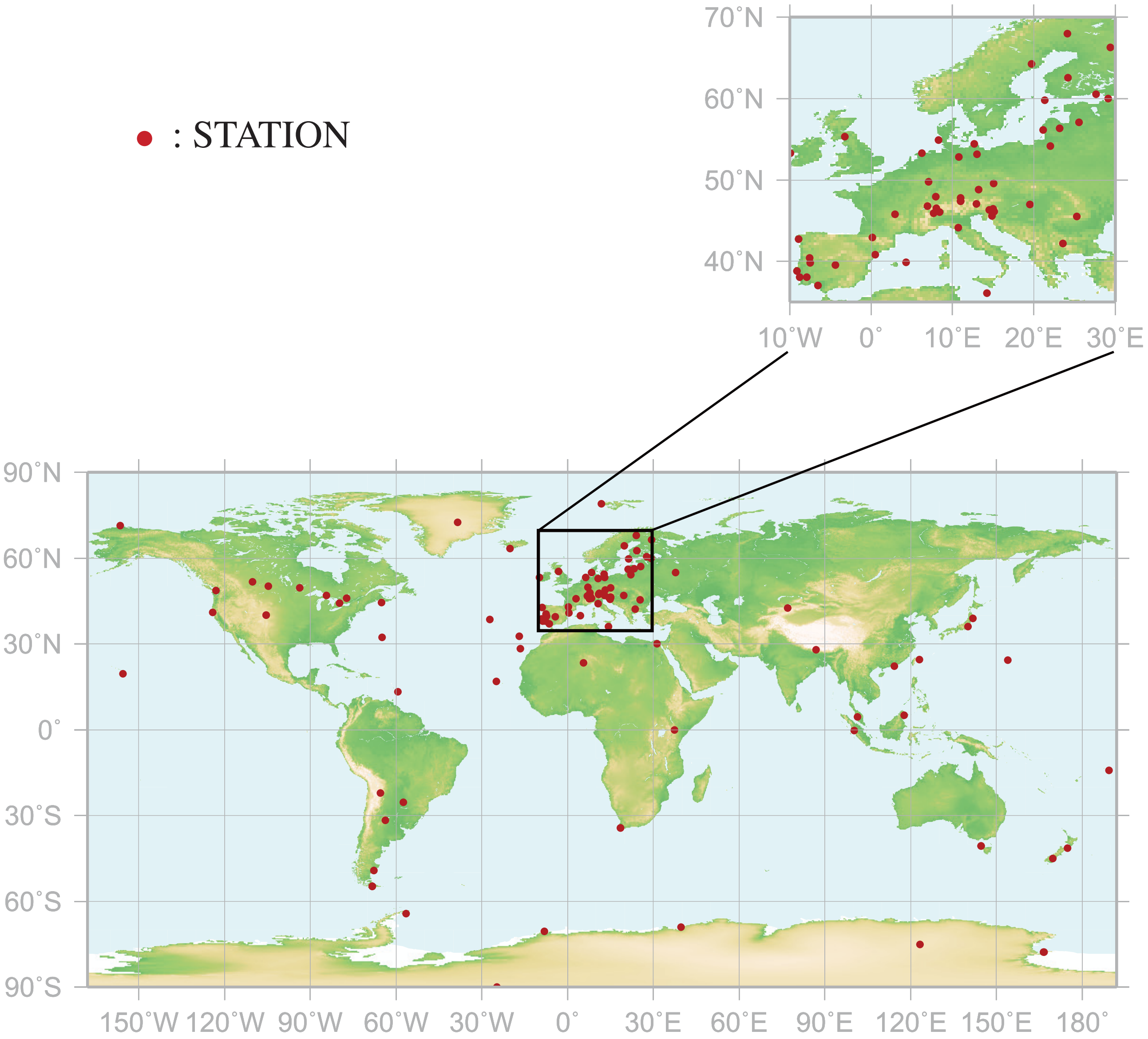


Fig. 6.7 Time series of the monthly mean mole fractions of SF_6 at individual stations. Solid circles show mole fractions measured in the Northern Hemisphere and open circles show mole fractions measured in the Southern Hemisphere.

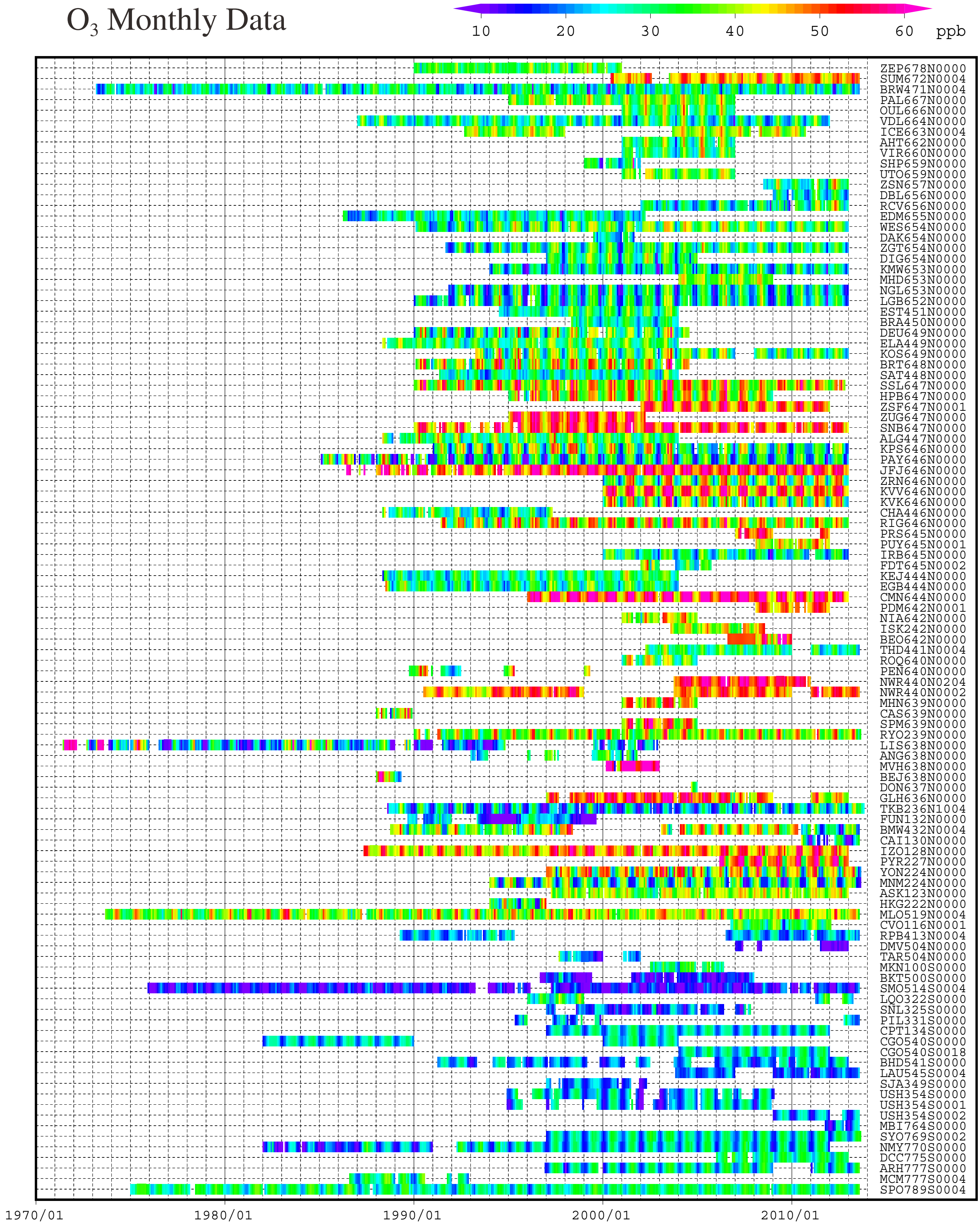
7.

SURFACE OZONE

(O_3)



This map shows locations of the stations that have submitted data for monthly mean mole fraction.



O$_3$ Monthly Data

Plate 7.1 Monthly mean O$_3$ mole fractions that have been reported to the WDCGG. The mole fractions are illustrated in different colours. The sites are listed in order from north to south.

7. SURFACE OZONE (O_3)

Basic information on surface ozone (O_3) with regard to environmental issues

Ozone (O_3) in the atmosphere exists mostly in the stratosphere, with less than 10% in the troposphere. However, O_3 in the troposphere plays an important role in the atmospheric environment through its impact on radiative forcing and its involvement in the chemical processes. O_3 absorbs UV radiation in the stratosphere, thus influencing the vertical profile of temperature and circulation in the stratosphere. Moreover, as a greenhouse gas in the troposphere, O_3 absorbs IR radiation. The latter effect is more significant in the upper toposphere. Tropospheric O_3 in the northern extra tropics was the greatest contributor to global warming during the 20th century, and increases in tropospheric O_3 related to industrialization in developing countries was found to contribute to accelerated warming in the tropics during the latter half of the century (Shindell *et al.*, 2006). Furthermore, by reacting with water vapor in the presence of UV radiation, O_3 produces OH radicals, which control atmospheric mole fractions of many greenhouse gases, such as CH_4, through chemical reactions.

The observational results at high altitudes around 1990, compared with those from the end of the 19th century to the first half of the 20th century, show increases in tropospheric O_3, especially in urban areas (Staehelin *et al.*, 1994). However, ozonesonde measurements in the troposphere show stable or decreasing trends in northern mid-latitudes after 1980 (Oltmans *et al.*, 2006). There is as yet no consensus on the global trend of tropospheric O_3. Recently however, an attempt has been made to systematically review the observed trends. It was found that in most regions of the world — excluding East Asia — surface and free tropospheric ozone concentrations have not risen significantly since year 2000. Prior to the 1990s almost all records indicate a strong rise, while during the 1990s the picture is very diverse (http://www.igacproject.org/sites/all/themes/bluemasters/images/NewsletterArchives/Issue_45_Oct_2011.pdf).

Tropospheric O_3 originates from flux/mixing from the stratosphere and in-situ photochemical production. O_3 is destroyed in various processes, including chemical reactions with NO, the hydroperoxyl radical (HO_2) and OH, and deposition at different surfaces. The lifetime of tropospheric ozone varies from one or a few days in the boundary layer to a few tens of days or even a few months in the free troposphere.

In the troposphere, the mole fractions of O_3 are high in high and mid-latitudes in both hemispheres, and low in the tropics over the Atlantic (Marenco and Said, 1989) and Pacific (Tsutsumi *et al.,* 2003) oceans. The localised sources of ozone precursors and the generally short lifetime of surface O_3 make its distribution spatially non-uniform and time-variant.

Annual variation of surface O_3 mole fraction

The observational sites that have submitted data for surface O_3 to the WDCGG are shown on the map at the beginning of this chapter. The monthly mean wet mole fractions of O_3 that have been reported from these observational sites are shown in Plate 7.1, with different mole fraction levels illustrated in different colours. Data for the mole fractions of surface O_3 are reported in two different units, *i.e.*, mixing ratio (ppb) and concentration (μg/m^3) at 25°C. The latter is converted to the former using the formula:

$$X_p\,[\mathrm{ppb}] = (R \times T / M / P_0) \times 10 \times X_g\,[\mu\mathrm{g/m^3}]$$

where R is the molar gas constant (8.31451 [J/K/mol]),
T is the absolute temperature reported from each station,
M is the molecular weight of O_3 (47.9982), and
P_0 is the standard pressure (1013.25 [hPa]).

If temperature is not reported by a station, T is taken to be 298K (25 °C).

The mole fraction of surface O_3 was found to vary from station to station, though many of these stations are located in Europe. Moreover, the seasonal and interannual variations were found to be relatively large at most stations, making it difficult to identify a global long-term trend in the mole fraction of surface O_3.

The seasonal cycles of monthly mean mole fraction of surface O_3 averaged for each 30° latitudinal zone for all available periods are shown in Figure 7.1. The latitudinal mean mole fractions were found to be elevated in spring in most latitudinal zones. However, several patterns of seasonal-diurnal cycles were observed at different locations, including a pronounced spring maximum, a spring maximum at night and a summer maximum during the day, a wide spring-summer maximum, and a pronounced winter maximum (Tarasova *et al.*, 2007).

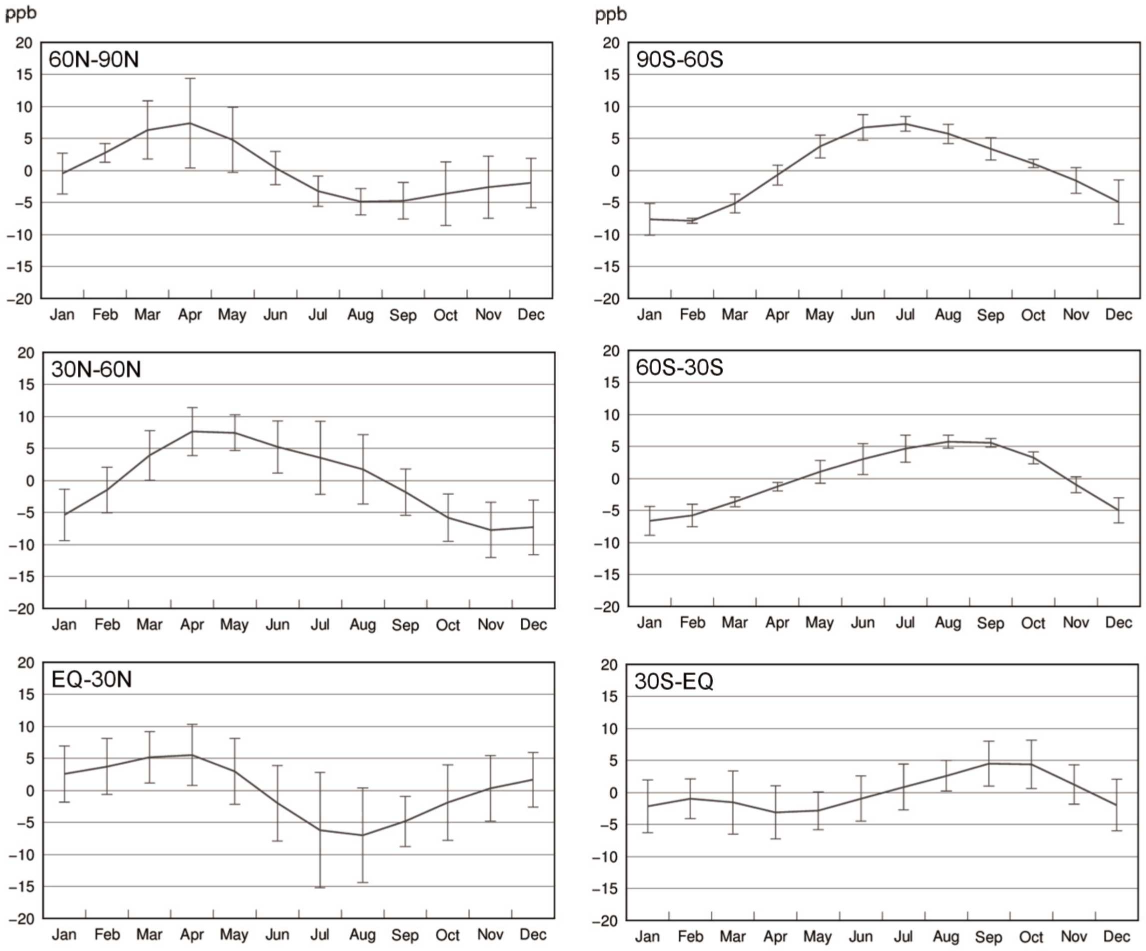


Fig. 7.1 Average seasonal cycles in the mole fraction of O_3 for each 30° latitudinal zone obtained from the seasonal cycle of each station for all available periods. Vertical error bars represent the range of ±1σ calculated for each month.

8.

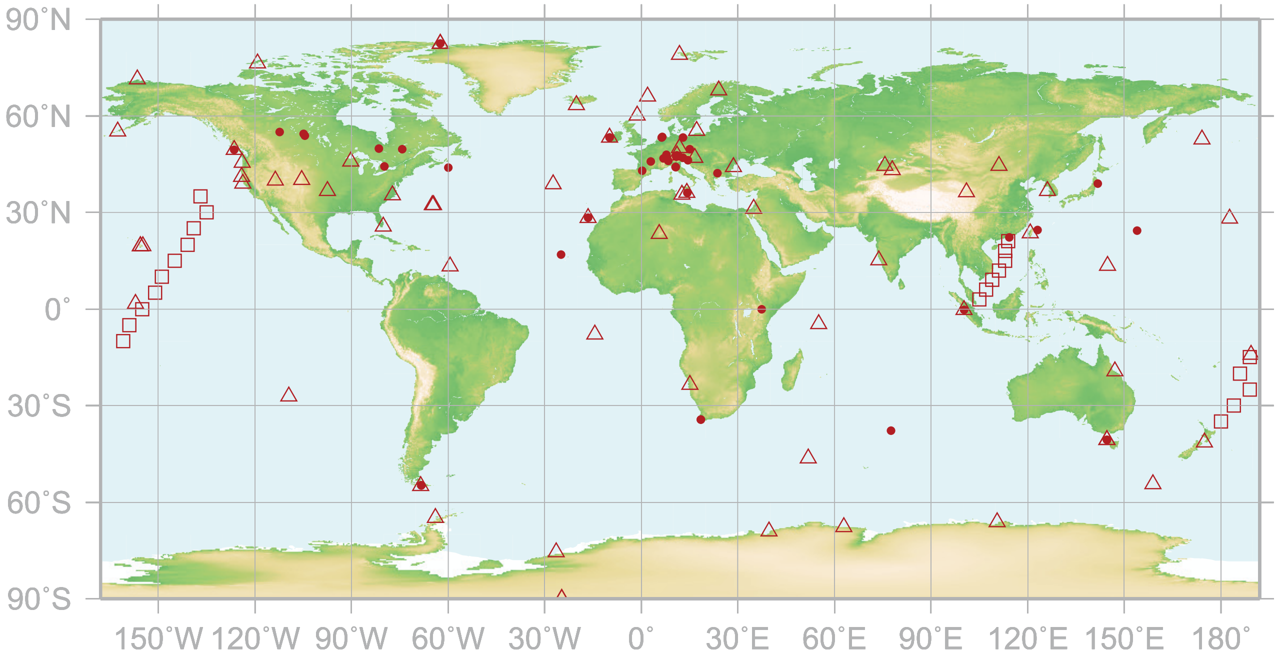
CARBON MONOXIDE

(CO)

● : CONTINUOUS STATION

△ : FLASK STATION

□ : FLASK MOBILE (SHIP)



This map shows locations of the stations that have submitted data for monthly mean mole fraction.

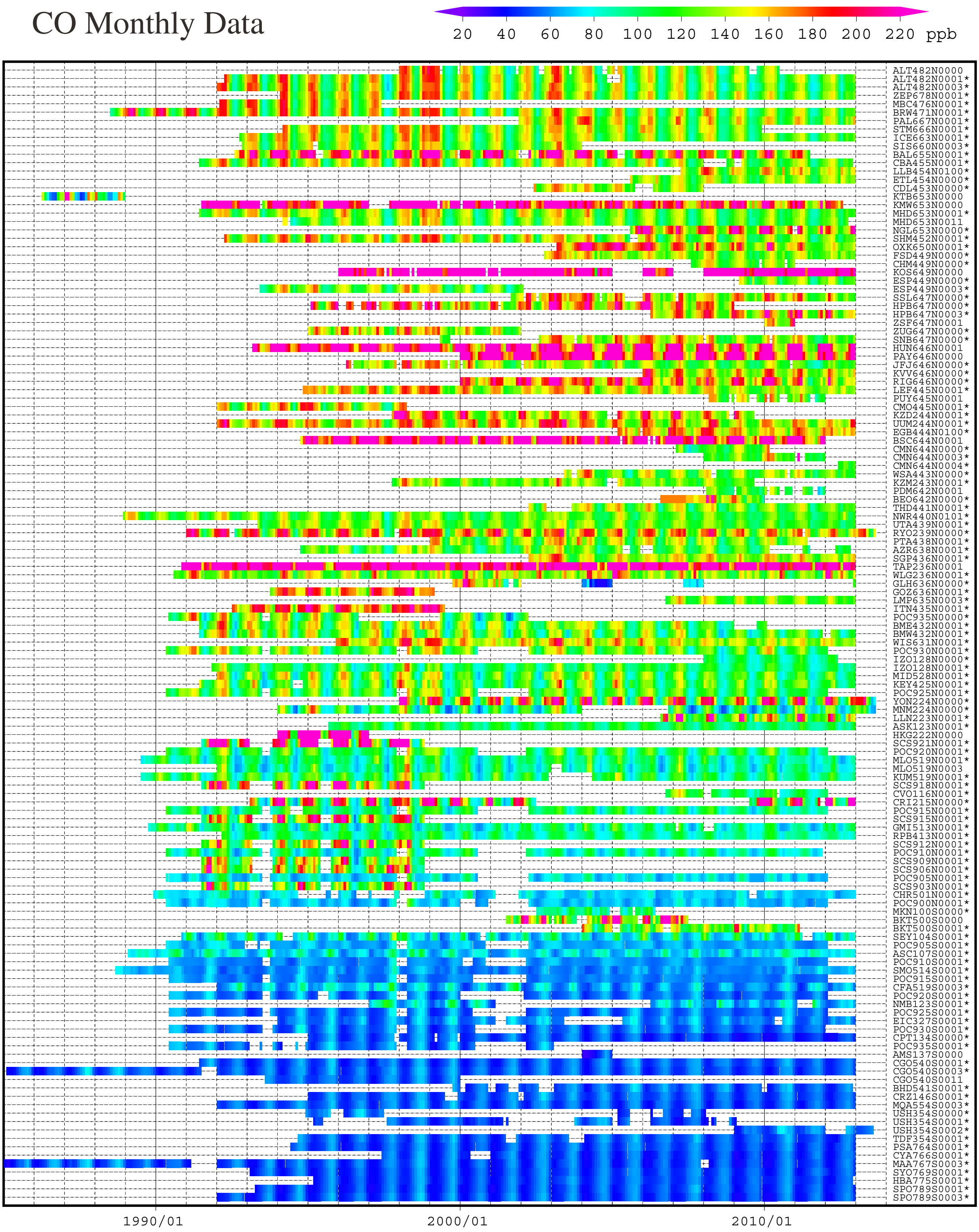
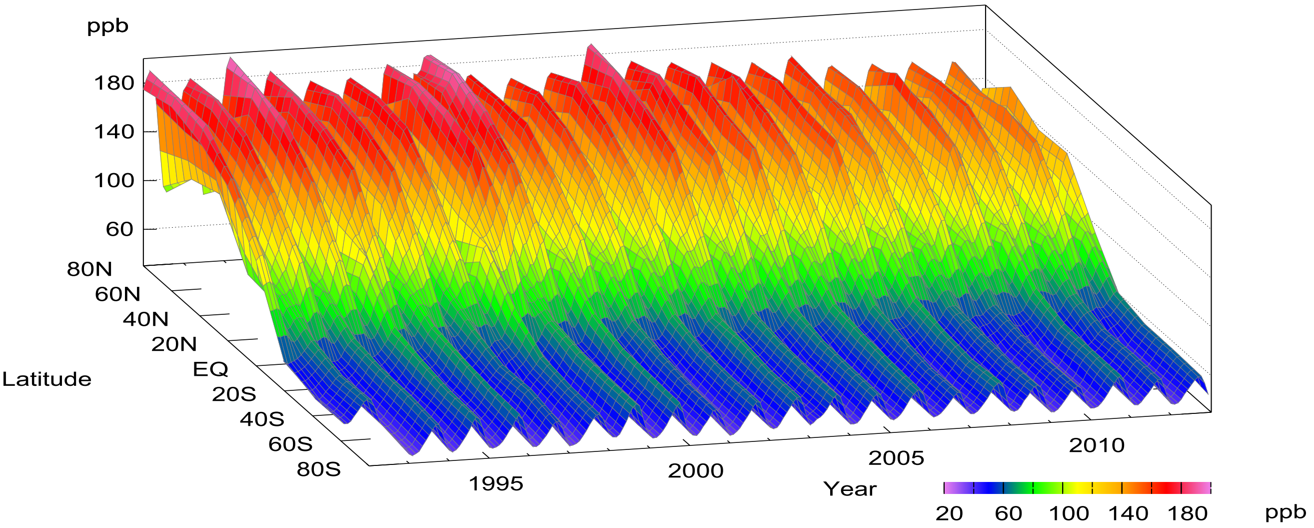
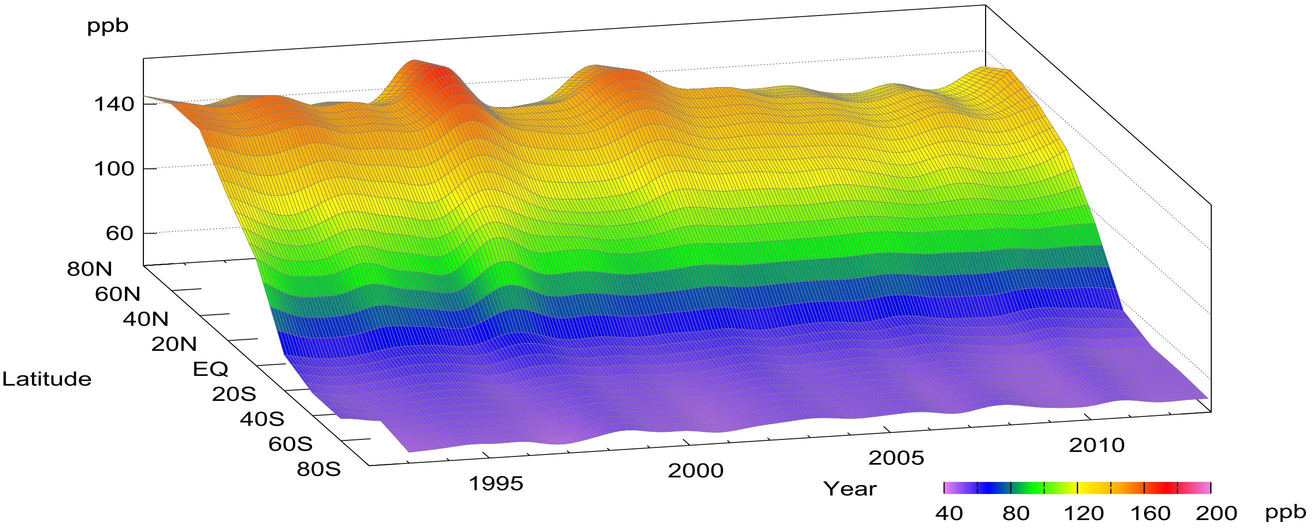


Plate 8.1 Monthly mean CO mole fractions that have been reported to the WDCGG. The mole fractions are illustrated in different colours.The sites are listed in order from north to south. The data from the sites with an asterisk at the end of the station index are used for the analysis shown in Plate 8.2. (see Chapter 2)

CO mole fraction



CO deseasonalized mole fraction



CO growth rate

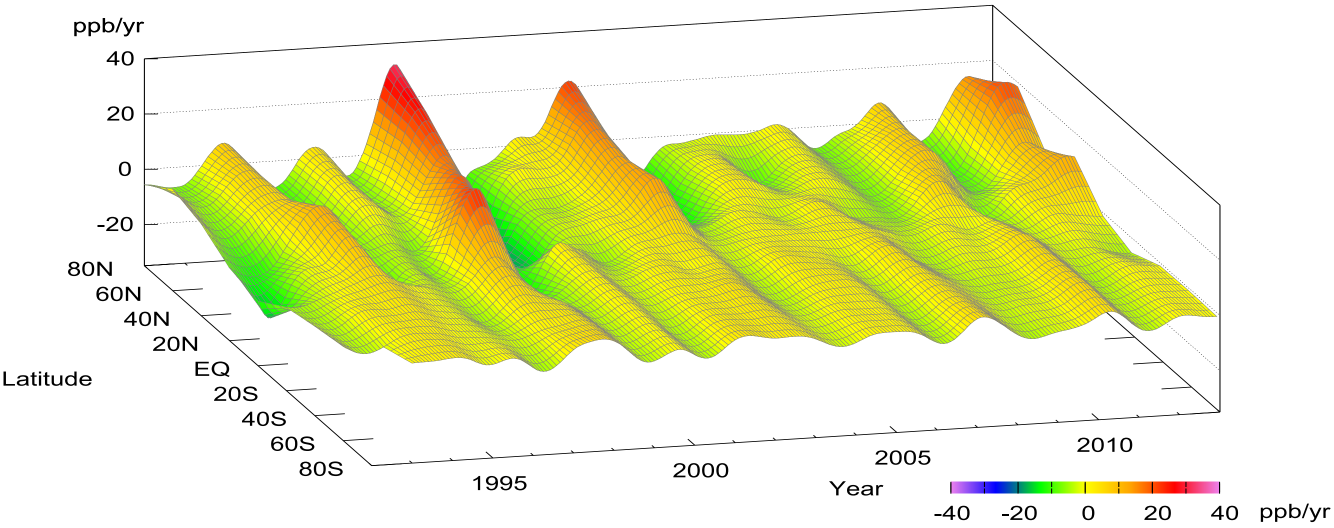


Plate 8.2 Variation of zonally averaged monthly mean CO mole fractions (top), deseasonalized long-term trends (middle), and growth rates (bottom). The zonally averaged mole fractions are calculated for each 20° zone. The deseasonalized trends and growth rates are derived as described in Chapter 2.

8. CARBON MONOXIDE (CO)

Basic information on CO with regard to environmental issues

Carbon monoxide (CO) is not a greenhouse gas; it absorbs hardly any infrared radiation from the Earth. However, CO influences the oxidation capacity of the atmosphere through its reaction with hydroxyl radicals (OH), which control the lifetimes of methane, halocarbons and tropospheric ozone. CO has been monitored due to its indirect influence on greenhouse gases through such reactions.

Sources of atmospheric CO include fossil fuel combustion and biomass burning, along with the oxidation of methane and non-methane hydrocarbons (NMHCs). Major sinks include reaction with OH and surface deposition; the reaction of CO and OH accounts for all of the chemical loss of CO in the troposphere (Seinfeld and Pandis, 1998). CO has a relatively long atmospheric lifetime, ranging from 10 days in summer in the tropics to more than a year over the polar regions in winter. Thus anthropogenic CO emissions do not lead to CO accumulation in the atmosphere. Furthermore, the uneven distribution of sources causes large spatial and temporal variations in CO mole fraction.

Measurements of trapped air in ice cores have shown that the pre-industrial CO mole fraction over central Antarctica during the last two millennia was about 50 ppb and the CO level increased to 110 ppb by 1950 in Greenland (Haan and Raynaud, 1998). Beginning in 1950, the global average CO mole fraction increased at a rate of 1% per year but started to decrease in the late 1980s (WMO, 1999). Between 1991 and 2001, the global average mole fraction of CO decreased at an annual rate of about 0.5 ppb, excluding temporal enhancements from large biomass burning events (Novelli *et al*., 2003). Since 2001 global averaged CO mole fraction does not show any confirmed tendency.

Annual variation of CO mole fraction in the atmosphere

The monthly mean mole fractions of CO that have been reported from fixed stations and some ships to the WDCGG are shown in Plate 8.1, in which different mole fraction levels are plotted in different colours. The observational sites that provide data for global analysis are shown on the map at the beginning of this chapter.

Zonally averaged mole fractions of CO in the atmosphere, together with their deseasonalized mole fractions and growth rates, are shown in Plate 8.2 as three-dimensional representations.

Data for the mole fractions of CO are reported in various units, *i.e.*, ppb, μg/m^3-25°C, μg/m^3-20°C and mg/m^3-25°C. Units other than ppb were converted to ppb using the formulas:

$$X_p\ [\mathrm{ppb}] = (R \times T / M / P_0) \times 10 \times X_g\ [\mu\mathrm{g/m^3}]$$
$$X_p\ [\mathrm{ppb}] = (R \times T / M / P_0) \times 10^4 \times X_g\ [\mathrm{mg/m^3}]$$

where R is the molar gas constant (8.31451 [J/K/mol]),
T is the absolute temperature reported from each station,
M is the molecular weight of CO (28.0101), and
P_0 is the standard pressure (1013.25 [hPa]).

If temperature is not reported by a station, T is taken to be 298K(25 °C).

Plate 8.2 shows that the seasonal variations of CO were larger in the Northern Hemisphere and smaller in the Southern Hemisphere, and that the deseasonalized mole fractions were the highest in northern mid-latitudes and the lowest in the Southern Hemisphere, having a large latitudinal gradient from northern mid- to southern low latitudes. This is likely due to the presence of numerous anthropogenic sources of CO in the northern mid-latitudes, combined with the destruction of CO in the tropics, where OH radicals are abundant.

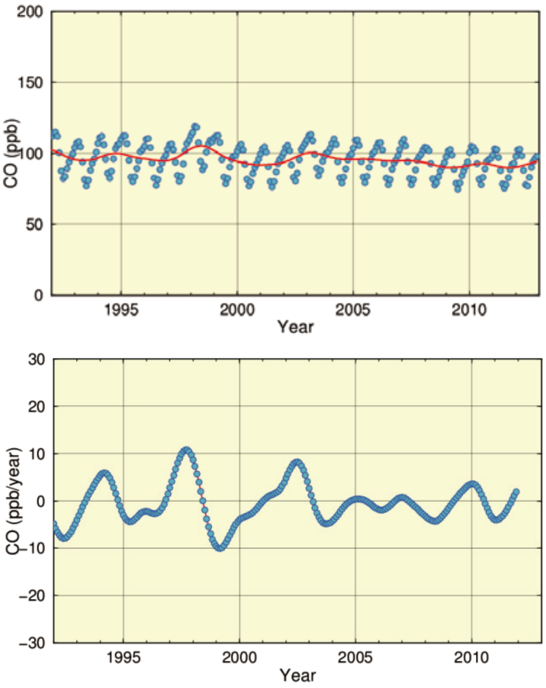


Fig. 8.1 Globally averaged monthly mean mole fraction of CO from 1992 to 2012, including deseasonalized long-term trend in red line (top) and annual growth rate (bottom).

Figure 8.1 shows globally averaged monthly mean CO mole fractions and their growth rates. Growth rates were high in 1993/1994, 1997/1998 and 2002, and low in 1992 and 1998/1999. The global annual mean mole fraction was about 92±2 ppb in 2012, which was calculated irrespective of the difference in observation scales.

Figure 8.2 shows monthly mean mole fractions of CO for each 30° latitudinal zone. Seasonal variations were observed in both hemispheres, with mole fractions being higher in winter. Amplitudes of the seasonal cycle were larger in the Northern Hemisphere than in the Southern Hemisphere.

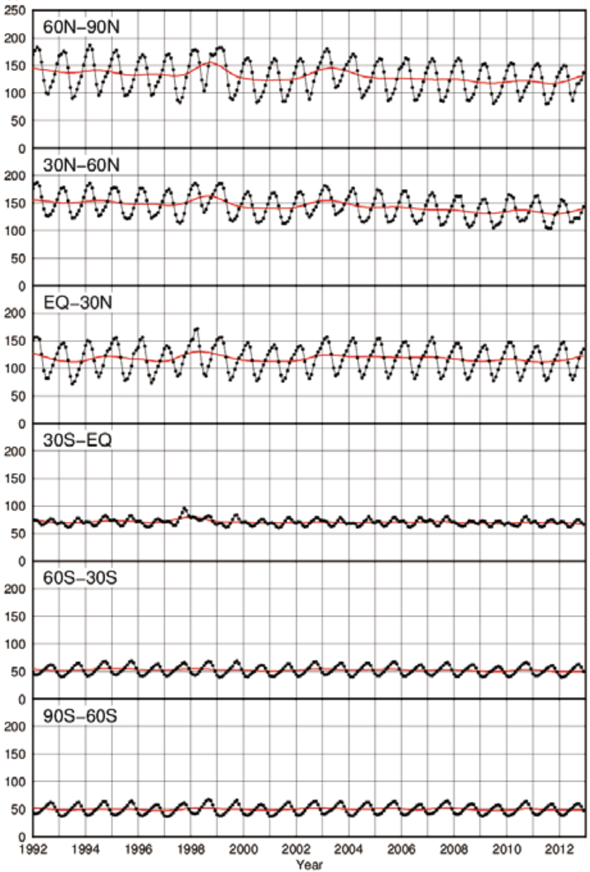


Fig. 8.2 Monthly mean mole fractions of CO from 1992 to 2012 for each 30° latitudinal zone (dots) and their deseasonalized long-term trends (red lines).

Figure 8.3 summarizes deseasonalized long-term trends for each 30° latitudinal zone and their growth rates. The CO mole fractions were the highest in northern mid-latitudes. There was a decline in CO mole fractions around 1992, almost coinciding with the decrease in the growth rate of CH_4 mole fractions, most likely due to variations in their common sink (reaction with OH). The enhanced stratospheric ozone depletion due to increased volcanic aerosols following the eruption of Mount Pinatubo in 1991 may have increased atmospheric OH radicals, which react with both CO and CH_4 (Dlugokencky *et al.*, 1996).

Increases in CO mole fractions were observed from 1997 to 1998 in northern latitudes and in southern low latitudes. These increases were attributed to large biomass burning events in Indonesia in late 1997 and in Siberia in the summer and autumn of 1998 (Novelli *et al.*, 1998).

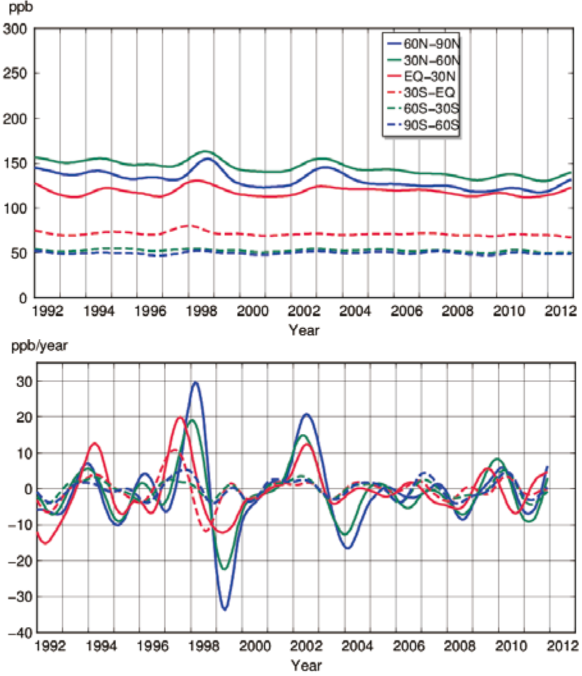


Fig. 8.3 Deseasonalized long-term trends of CO for each 30° latitudinal zone (top) and their growth rates (bottom).

The CO mole fractions returned to normal after 1999, but the growth rates in the Northern Hemisphere increased substantially again in 2002. The latter may have been due to large biomass burning. Large-scale boreal forest fires occurred in Siberia and North America from 2002 to 2003. Large forest fires also occurred in Russia in summer 2010 which is reflected in the data in the bottom panel of Figure 8.3.

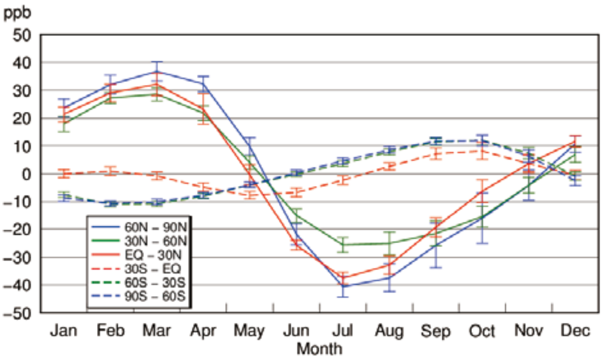


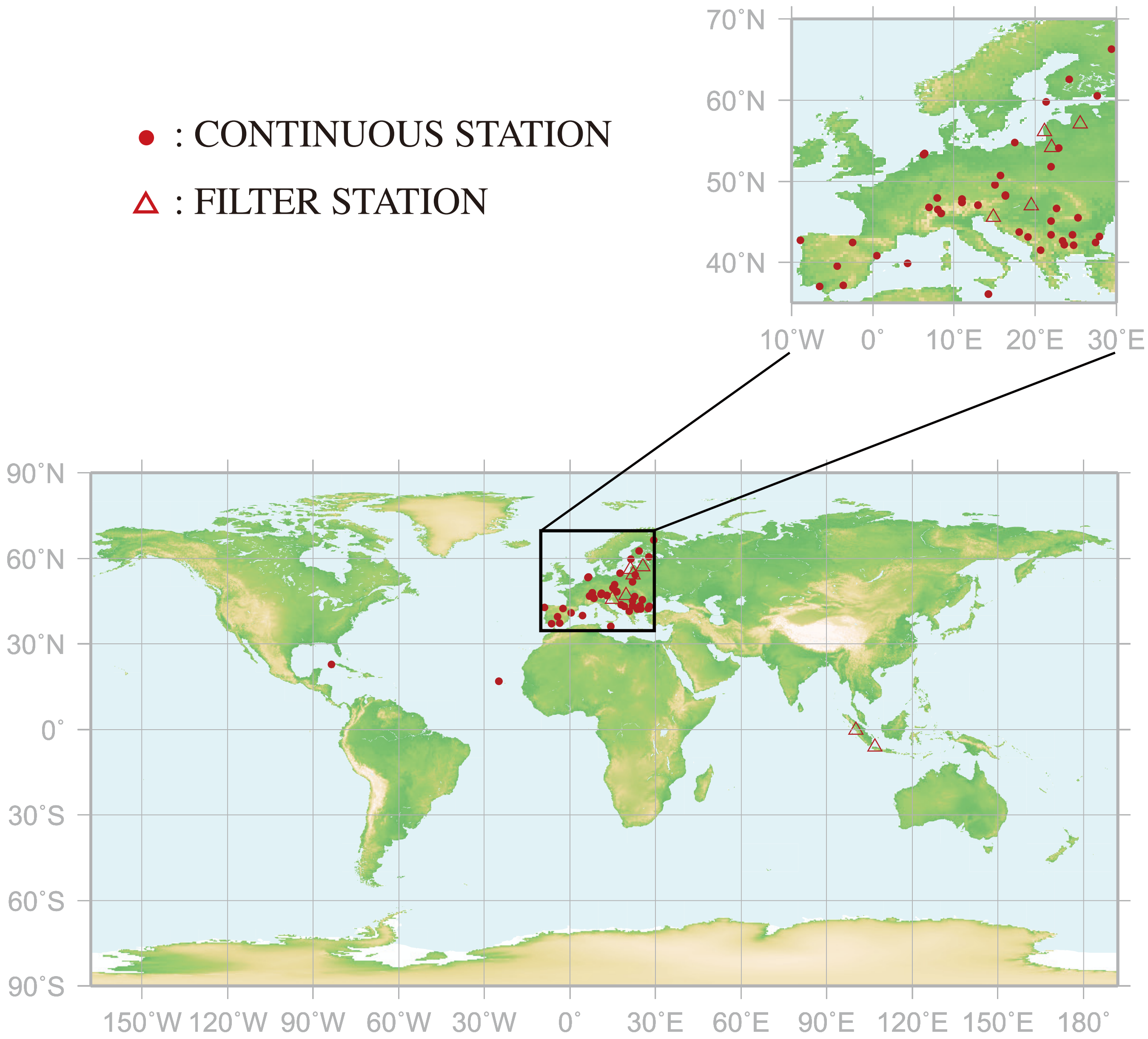
Fig. 8.4 Average seasonal cycles of CO mole fraction for each 30° latitudinal zone obtained by subtracting long-term trends from the zonal mean time series. Error bars represent the range of ±1σ calculated for each month. (Average from 1992 to 2012)

Seasonal cycle of CO mole fraction in the atmosphere

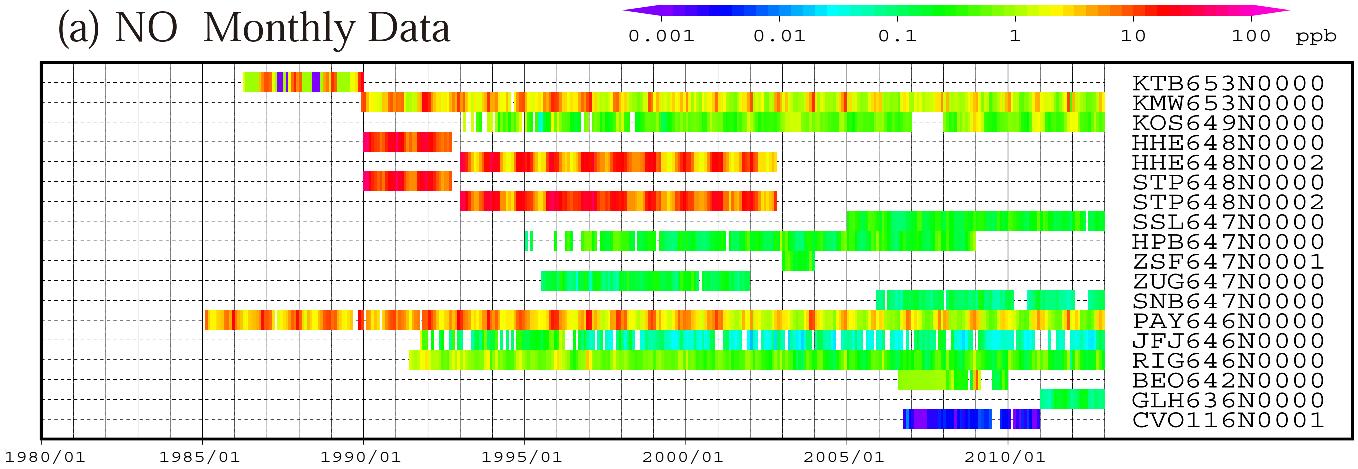
Figure 8.4 shows average seasonal cycles in the mole fraction of CO for each 30° latitudinal zone. The seasonal cycle is driven mainly by seasonal variations in OH abundance as a CO sink. This seasonality and a short lifetime of about a few months resulted in a sharp decrease in early summer followed by a relatively slow increase in autumn. The levelling-off in the beginning of the year observed in the southern low latitudes may be attributed to the transport of CO from the Northern Hemisphere.

9.

NITROGEN MONOXIDE (NO) AND NITROGEN DIOXIDE (NO_2)



This map shows locations of the stations that have submitted data for monthly mean mole fraction.


(a) NO Monthly Data

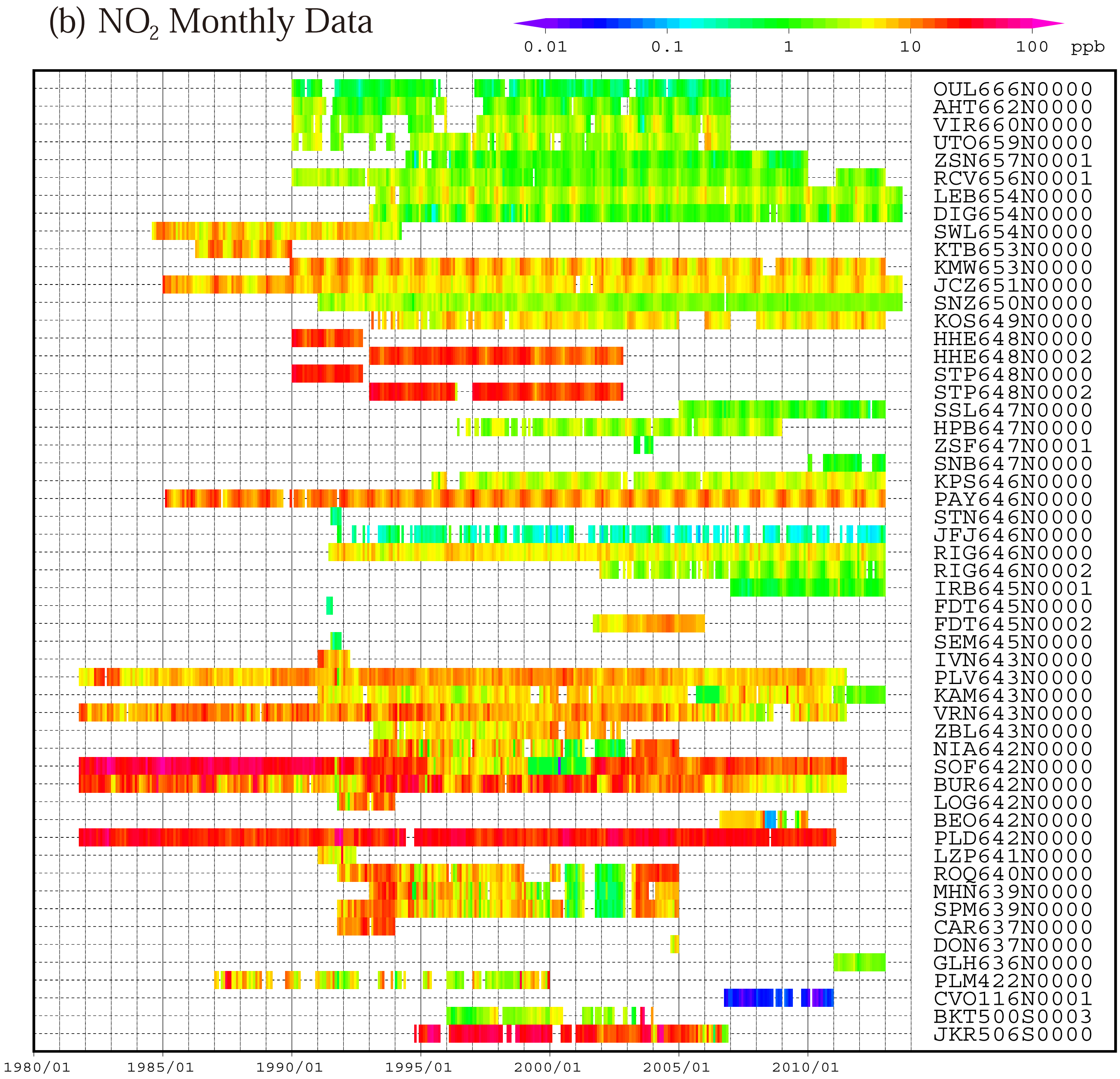

(b) NO_2 Monthly Data

Plate 9.1 Monthly mean (a) NO and (b) NO_2 mole fractions that have been reported to the WDCGG. The mole fractions are illustrated in different colours. The sites are listed in order from north to south.

9. NITROGEN MONOXIDE (NO) AND NITROGEN DIOXIDE (NO_2)

Basic information on NO and NO_2 with regard to environmental issues

Nitrogen oxides (NO_x, *i.e.*, NO and NO_2) are not greenhouse gases. Nevertheless, these compounds have a central regulatory role in the free radical and oxidising chemistry of the troposphere. These chemical cycles regulate the lifetime of methane and the production of tropospheric O_3 and secondary aerosols, all of which have important roles in the natural and anthropogenic greenhouse effect. The O_3 produced in the atmosphere as a result of the availability of nitrogen oxides in the atmosphere can affect vegetation growth and human health.

Sources of NO_x include energy production, transport, lightning, soils and biomass burning (Reis *et al.*, 2009). They constitute major causes of acid rain and deposition. The dominant sink of NO_x in the atmosphere is its conversion into nitric acid (HNO_3) and peroxyacetyl nitrate (PAN), which are eventually removed by dry or wet deposition. In some cases, NO_x is removed from the atmosphere directly by dry deposition. NO_x abundance varies in both space and time because of their short lifetimes and uneven source distribution. Some regional assessments are done based on satellite information to clarify such variations and trends.

Annual variation of NO and NO_2 mole fractions in the atmosphere

The observational stations that have submitted data for NO and NO_2 to the WDCGG are shown on the map at the beginning of this chapter. Most of these stations are located in Europe.

The monthly mean mole fractions of NO and NO_2 reported to the WDCGG are shown in Plate 9.1, in which different mole fraction levels are plotted in different colours. Data for NO_x are reported in various units, *i.e.*, ppb, $\mu g/m^3$-25°C, $\mu g/m^3$-20°C, $\mu gN/m^3$-25°C and mg/m^3-25°C. Units other than ppb were converted to ppb using the formulas:

$$X_p\,[\text{ppb}] = (R \times T / M / P_0) \times 10 \times X_g\,[\mu g/m^3]$$
$$X_p\,[\text{ppb}] = (R \times T / M / P_0) \times 10^4 \times X_g\,[mg/m^3]$$
$$X_p\,[\text{ppb}] = (R \times T / M_N / P_0) \times 10 \times X_g\,[\mu gN/m^3]$$

where R is the molar gas constant (8.31451 [J/K/mol]),
T is the absolute temperature reported from each station,
M is the molecular weight of NO (30.00614) or NO_2 (46.00554),
M_N is the atomic weight of N (14.00674), and
P_0 is the standard pressure (1013.25 [hPa]).

If temperature is not reported by a station, T is taken to be 298K (25 °C).

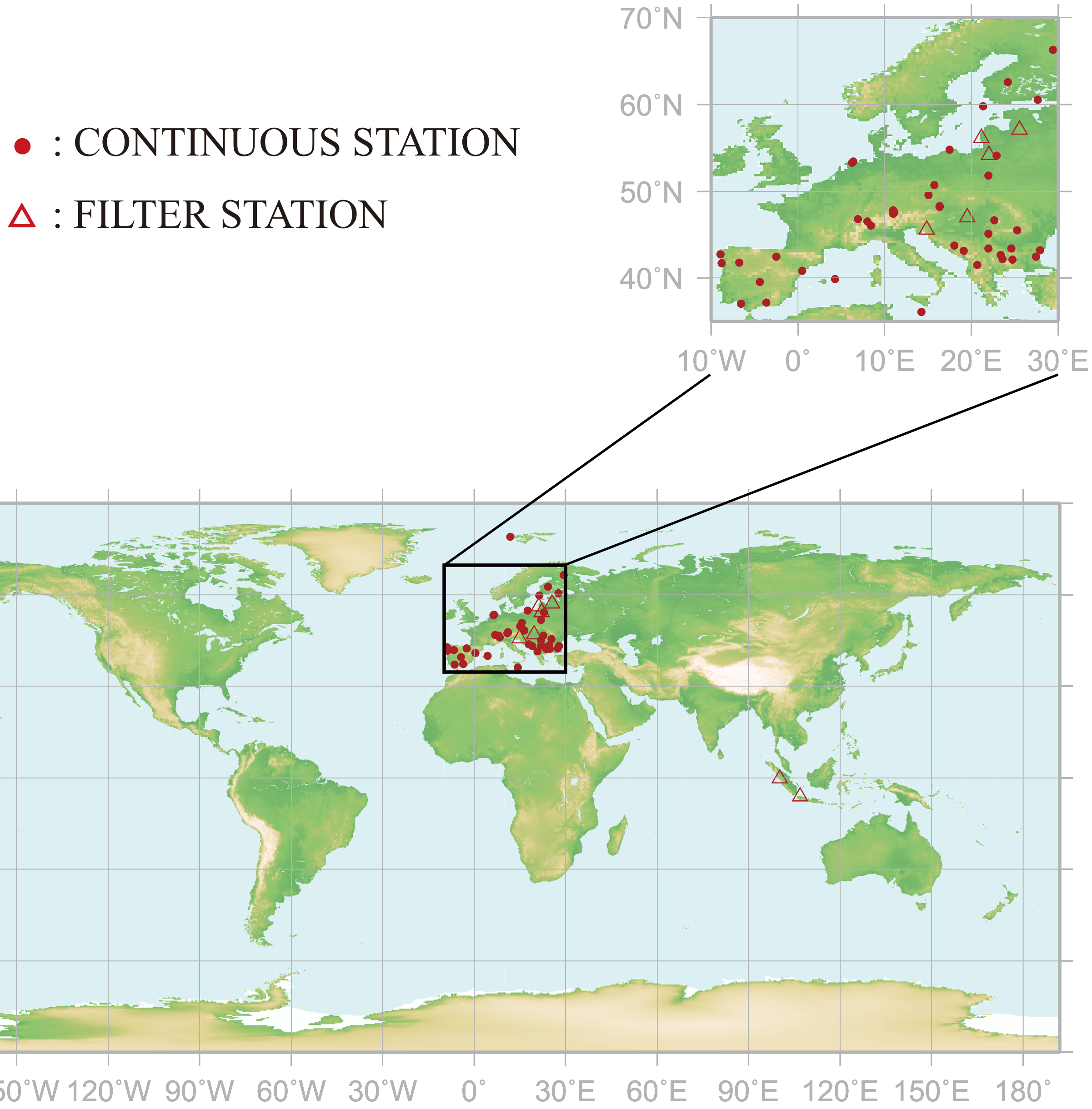
The distributions of NO and NO_2 are spatially non-uniform and variable over time. Due to the high temporal variability in the mole fraction of NO_2 at each observational site, it was difficult to identify a long-term trend. A number of stations located in southern Europe showed higher mole fractions, and some stations reported increased NO_2 in winter.

As there are few observational sites for NO, it was difficult to identify whether the global average NO mole fraction increases or decreases.

10.

SULPHUR DIOXIDE

(SO$_2$)



This map shows locations of the stations that have submitted data for monthly mean mole fraction.

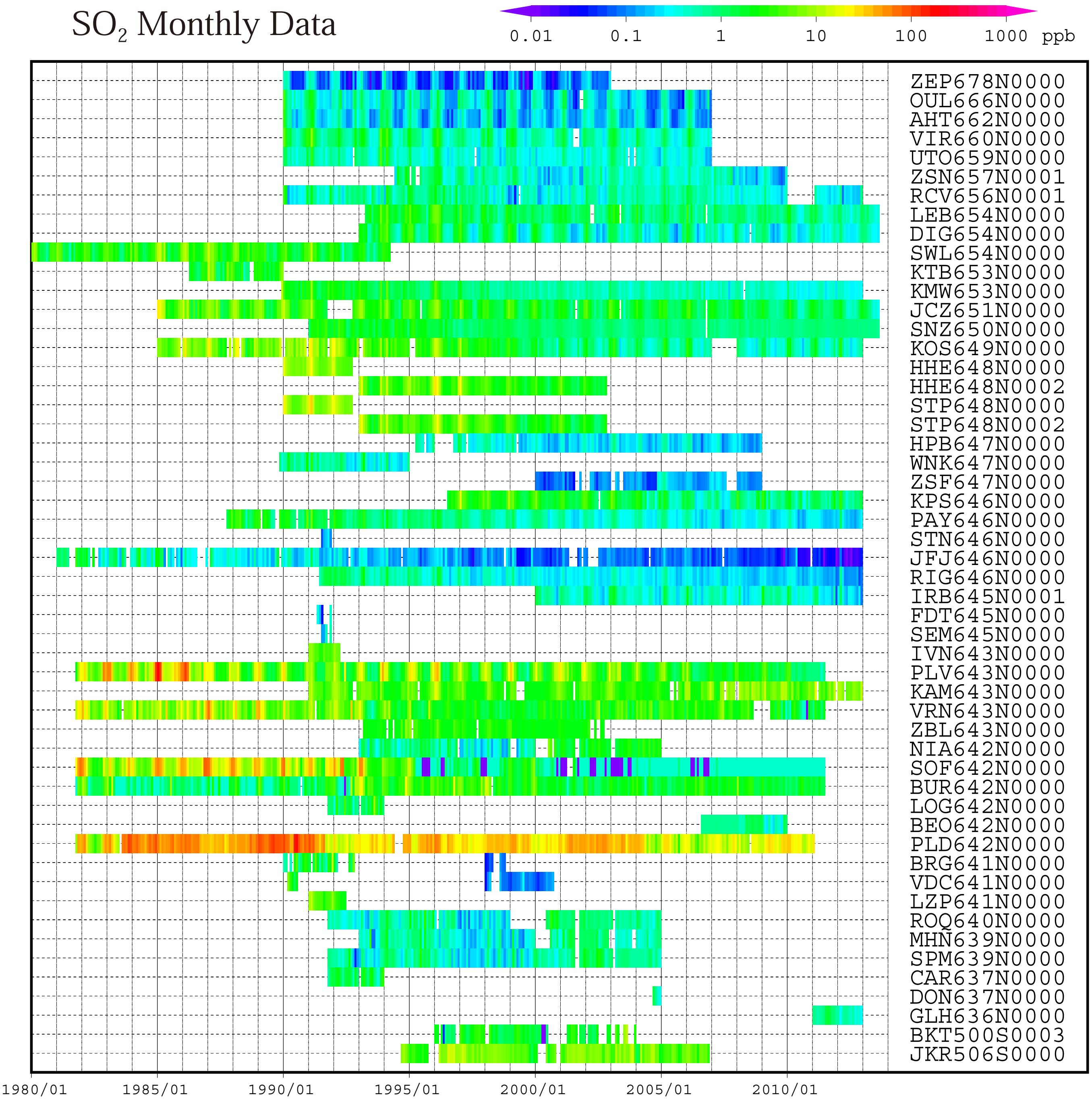


Plate 10.1 Monthly mean SO$_2$ mole fractions that have been reported to the WDCGG. The mole fractions are illustrated in different colours. The sites are listed in order from north to south.

10. SULPHUR DIOXIDE (SO_2)

Basic information on SO_2 with regard to environmental issues

Sulphur dioxide (SO_2) is not a greenhouse gas, but it is a precursor of atmospheric sulphuric acid (H_2SO_4) and sulphate aerosol. SO_2 is oxidized by hydroxyl radicals (OH) to form sulphuric acid, which then becomes aerosols through photochemical gas-to-particle conversion. While SO_2 reacts much more slowly with OH than does NO_2, SO_2 dissolves readily in suspended liquid droplets in the atmosphere. The global sulphur cycle affects atmospheric chemistry, including tropospheric ozone (Berglen *et al.*, 2004).

Sources of SO_2 include fossil fuel combustion by industry, biomass burning, volcanic release and the oxidation of dimethylsulphide (DMS) from the oceans (IPCC, 2007). Major SO_2 sinks are oxidation by OH and deposition onto wet surfaces. Anthropogenic SO_2 has caused acid rain and deposition throughout the industrial era. The mole fractions of SO_2 have shown large variations in both space and time because of the short lifetime and uneven anthropogenic source distribution of SO_2.

Annual variation of SO_2 mole fraction in the atmosphere

The observational sites that have submitted data for SO_2 to the WDCGG are shown on the map at the beginning of this chapter. Most of these stations are located in Europe.

The monthly mean mole fractions of SO_2 that have been reported to the WDCGG are shown in Plate 10.1, with different mole fraction levels illustrated in different colours. Data for SO_2 are reported in various units, *i.e.*, ppb, $\mu g/m^3$, mg/m^3 and $\mu gS/m^3$. Units other than ppb were converted to ppb using the formulas:

$$X_p\,[\text{ppb}] = (R \times T / M / P_0) \times 10 \times X_g\,[\mu g/m^3]$$
$$X_p\,[\text{ppb}] = (R \times T / M / P_0) \times 10^4 \times X_g\,[mg/m^3]$$
$$X_p\,[\text{ppb}] = (R \times T / M_S / P_0) \times 10 \times X_g\,[\mu gS/m^3]$$

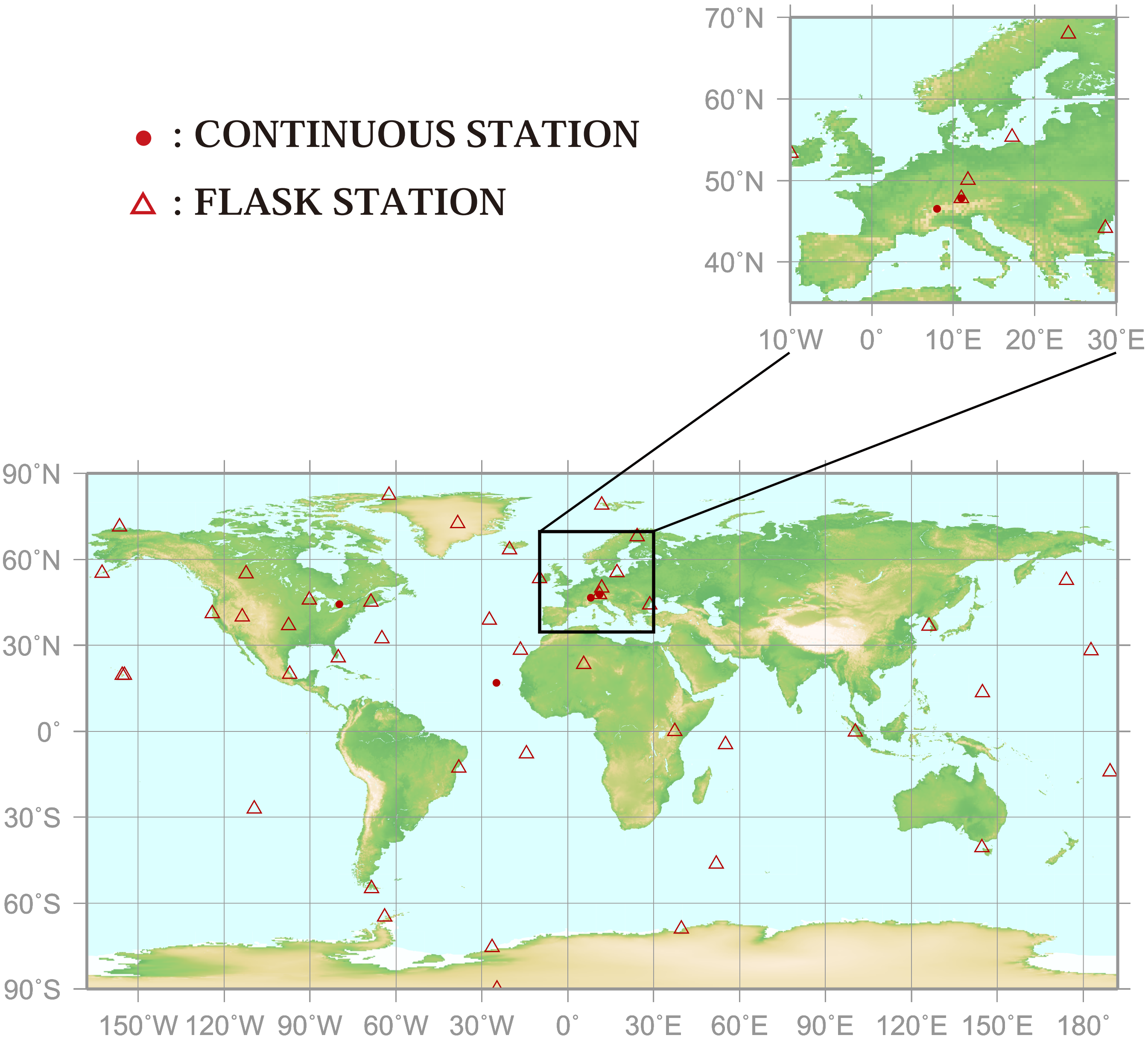
where R is the molar gas constant (8.31451 [J/K/mol]),
T is the absolute temperature reported from each station,
M is the molecular weight of SO_2 (64.0648),
M_S is the atomic weight of S (32.066), and
P_0 is the standard pressure (1013.25 [hPa]).

If temperature is not reported by a station, T is taken to be 298K (25 °C).

Although some stations in southern Europe have reported higher mole fractions, it has been difficult to identify the magnitude and direction of the trend for SO_2.

11.

VOLATILE ORGANIC COMPOUNDS (VOCs)



The map shows locations of the stations that have submitted data for mole fraction of VOCs (ethane and propane).

Ethane Data

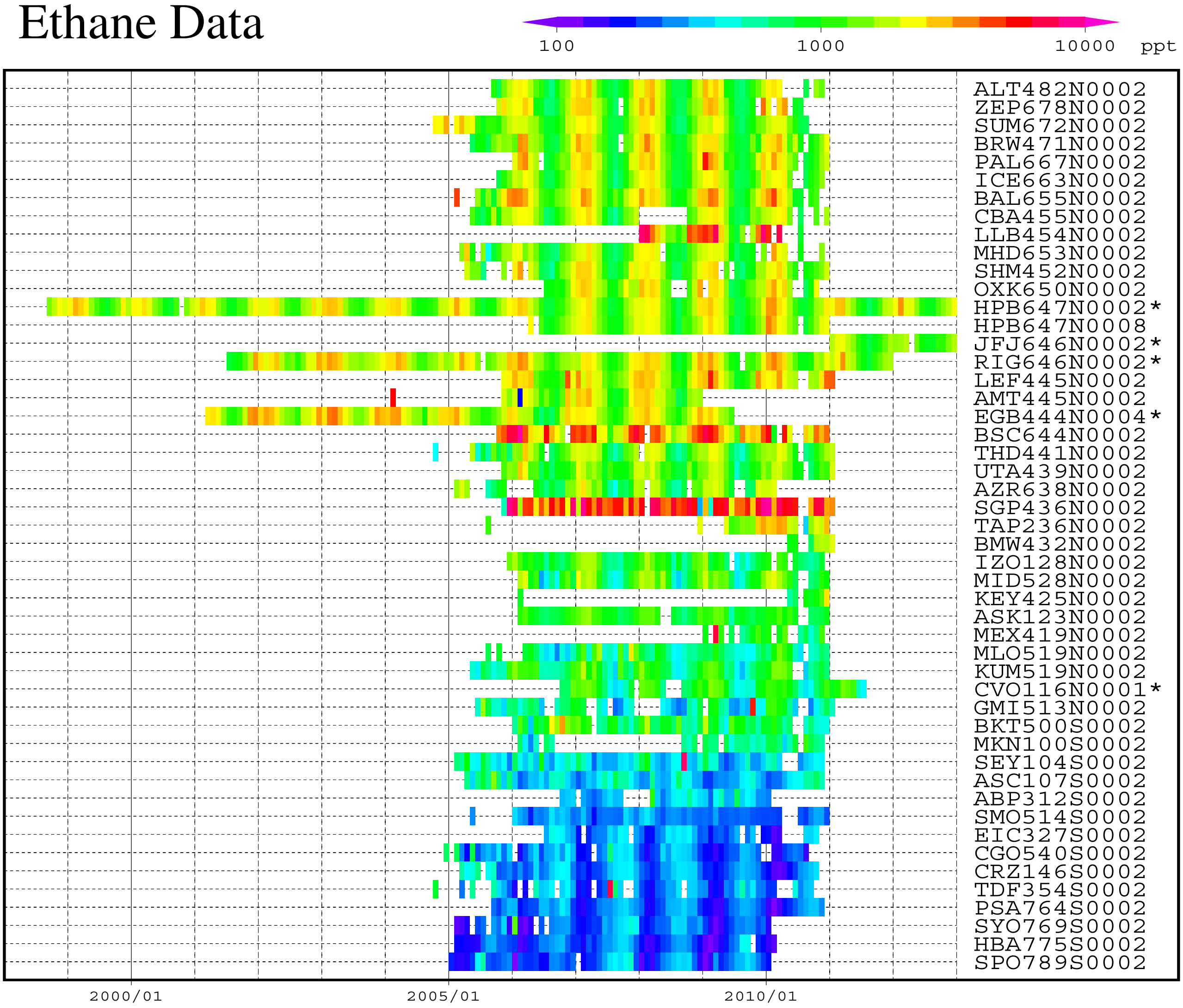


Plate 11.1 Monthly mean ethane mole fractions that have been reported to the WDCGG. The mole fractions are illustrated in different colours. The sites are listed in order from north to south. The data from the sites with an asterisk at the end of the station index are derived from continuous data.

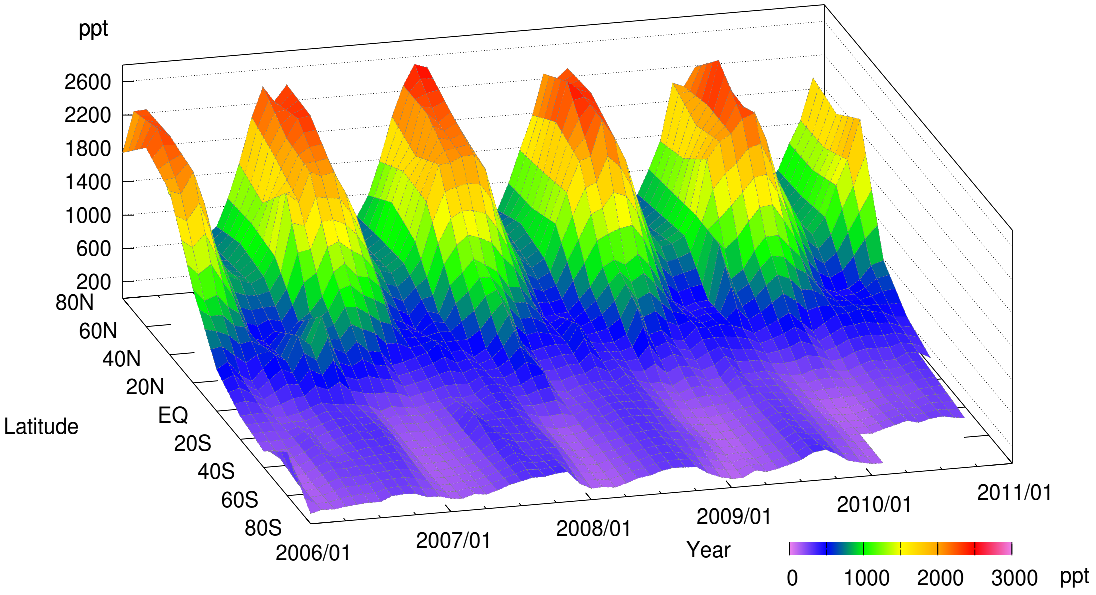


Plate 11.2 Variation of zonally averaged monthly mean ethane mole fractions. The zonally averaged mole fractions are calculated for each 20° zone.

Propane Data

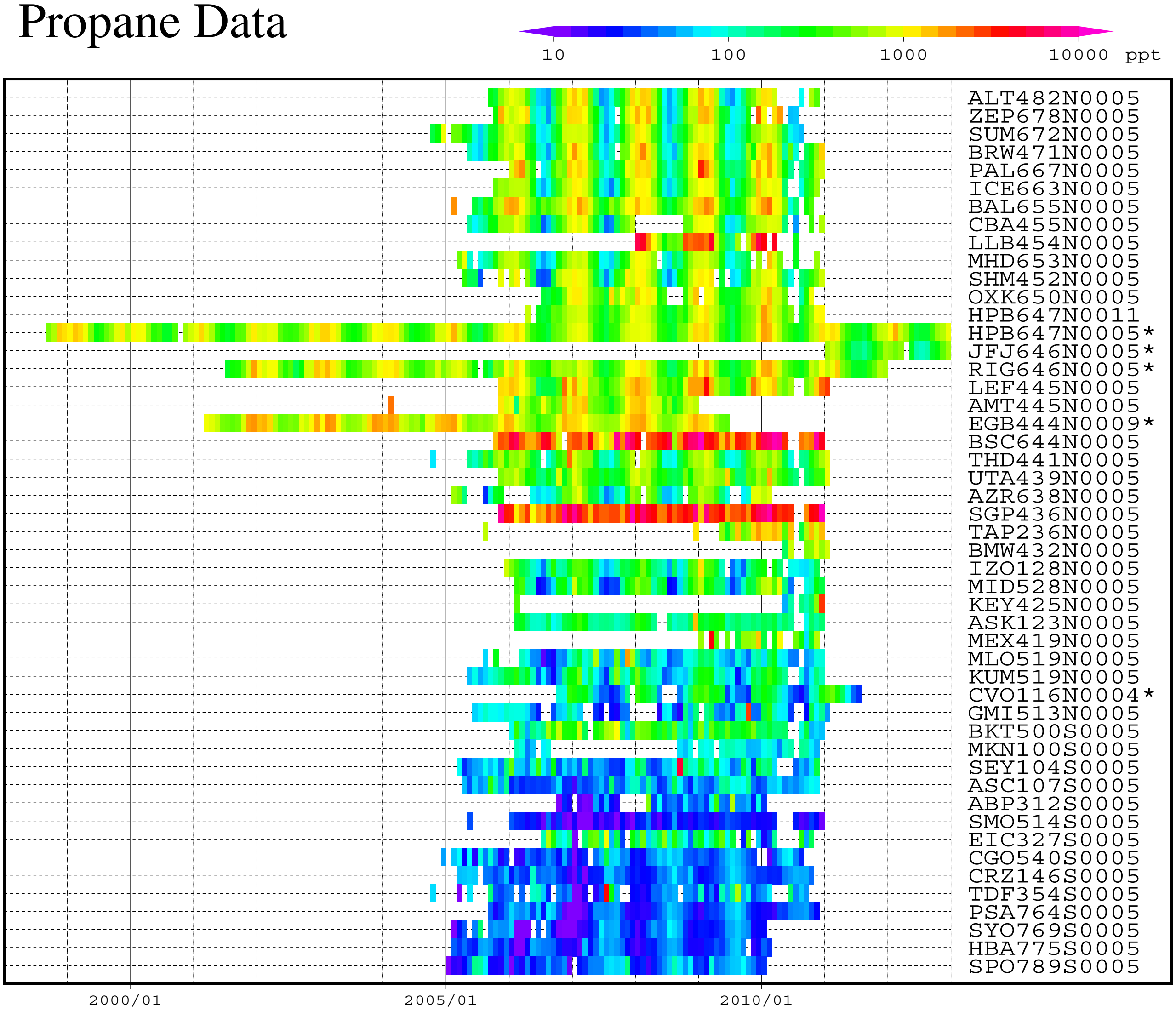


Plate 11.3 Monthly mean propane mole fractions that have been reported to the WDCGG. The mole fractions are illustrated in different colours. The sites are listed in order from north to south. The data from the sites with an asterisk at the end of the station index are derived from continuous data.

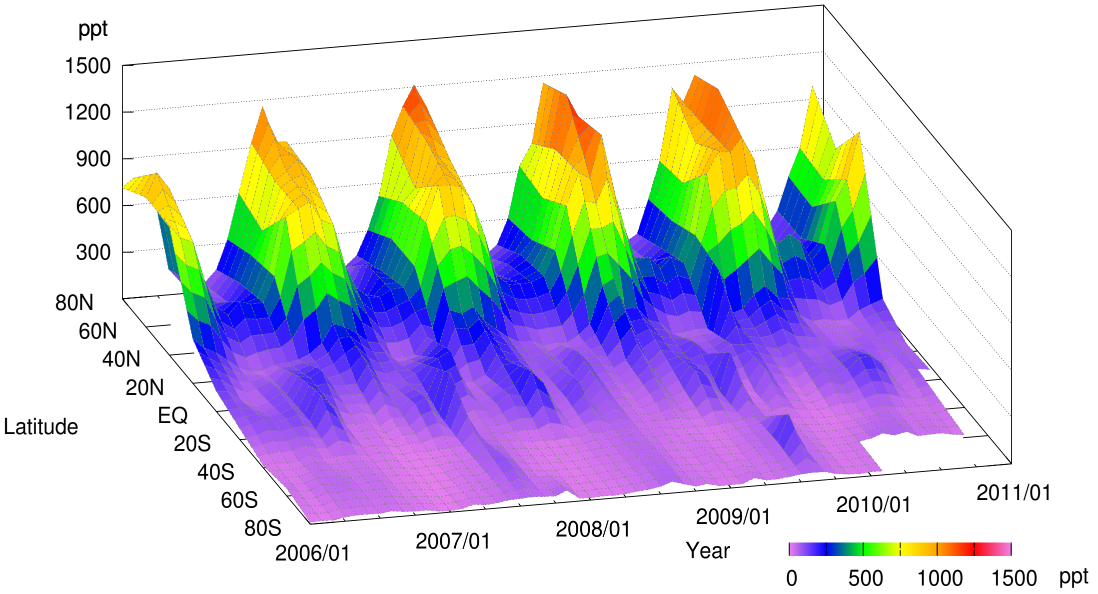


Plate 11.4 Variation of zonally averaged monthly mean propane mole fractions. The zonally averaged mole fractions are calculated for each 20° zone.

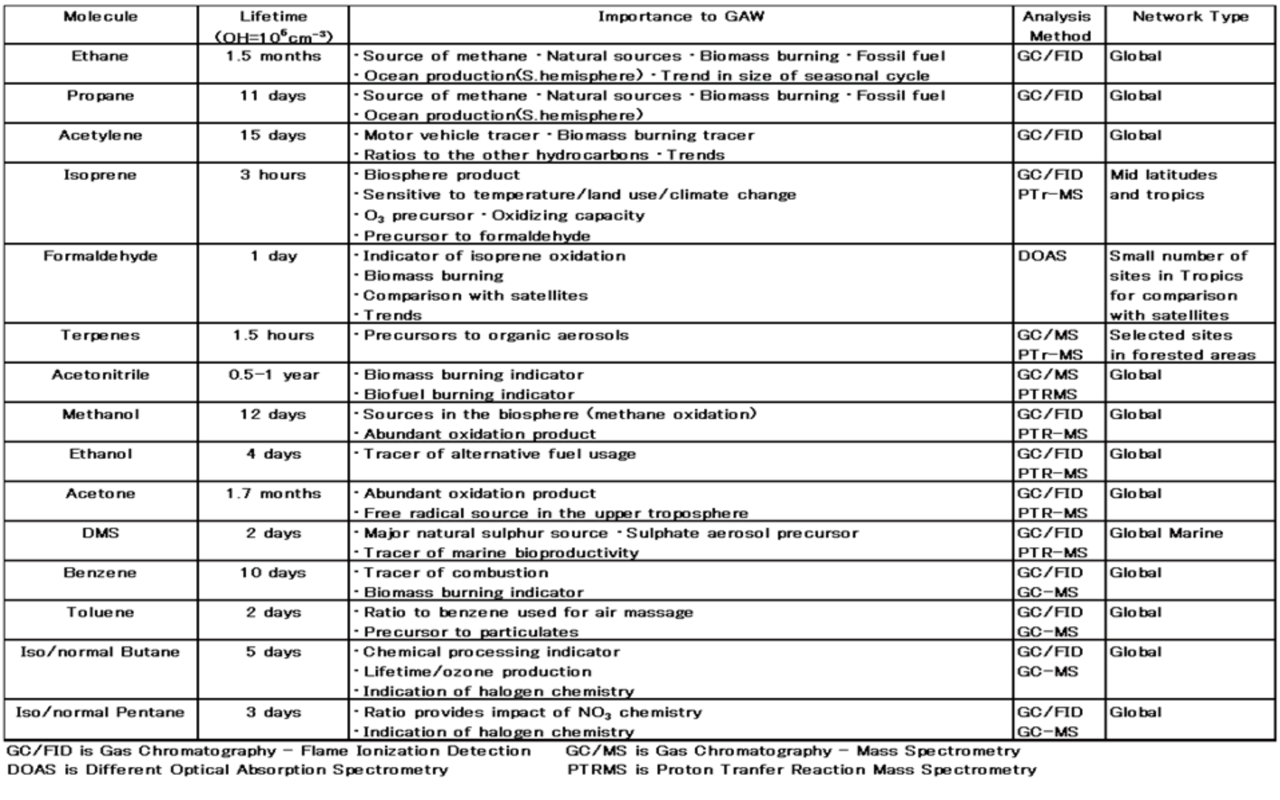
11. VOLATILE ORGANIC COMPOUNDS(VOCs)

Basic information on VOCs with regard to environmental issues

Volatile organic compounds (VOCs) have a variety of roles in atmospheric chemistry. They are major contributors to photochemical air pollution on both urban and regional scales and together with NO_x also impact ozone in the background troposphere. Some VOCs are injurious to human health at modest concentrations; they are also precursors to aerosols at quite low concentrations. VOCs can serve as tracers of many atmospheric processes and emission sources. VOC molecules occur in many forms and have both natural and anthropogenic sources. The GAW Programme has sought to focus measurements on species which help to provide understanding of a wide range of atmospheric properties, and which can mostly be measured using currently approved techniques. Table 11.1 shows the molecules selected for measurements within GAW, with reasons for their selection (WMO, 2007c). The main reasons for measurements within GAW are associated with their use as tracers of the source types of greenhouse gases such as methane, to provide quantitative information on the extent of atmospheric processing by hydroxyl radicals (OH) and other oxidants, and as precursors to organic acids and aerosols, particularly organic aerosols and sulphate aerosols. In addition, VOC measurements provide valuable information for air mass characterisation at some stations to identify local sources of pollution. All of this information is of value to atmospheric modellers both in terms of input parameters and as constraints to model results.

Some GAW stations have the analytical capability to produce high quality measurements of an extended range of VOCs. Where appropriate calibration and quality assurance can be provided, these data should wherever possible be provided to WMO databases for wider scientific dissemination (WMO, 1996). The current global network of VOC measurements is shown on the front page of this chapter. In many respects it is identical to that set up by NOAA to measure stable greenhouse gases and carbon monoxide with flask samples collected every 1 or 2 weeks, but it does include a number of sites where selected gases are measured at a higher frequency. These include three sites in Europe, one in Greenland (Summit) and one on the Island of Cape Verde. Unfortunately, Egbert, a Canadian site which provided valuable information on the VOC composition over North America discontinued high frequency VOC measurements in 2010. It is anticipated, however, that the number of sites with high frequency measurements will increase significantly in the next few years in the European region and the adjacent Arctic.

Table 11.1 Molecules selected for measurements within the GAW VOC Programme with reasons for their selection



Molecule	Lifetime ($OH=10^6cm^{-3}$)	Importance to GAW	Analysis Method	Network Type
Ethane	1.5 months	・Source of methane ・Natural sources ・Biomass burning ・Fossil fuel ・Ocean production(S.hemisphere) ・Trend in size of seasonal cycle	GC/FID	Global
Propane	11 days	・Source of methane ・Natural sources ・Biomass burning ・Fossil fuel ・Ocean production(S.hemisphere)	GC/FID	Global
Acetylene	15 days	・Motor vehicle tracer ・Biomass burning tracer ・Ratios to the other hydrocarbons ・Trends	GC/FID	Global
Isoprene	3 hours	・Biosphere product ・Sensitive to temperature/land use/climate change ・O_3 precursor ・Oxidizing capacity ・Precursor to formaldehyde	GC/FID PTr-MS	Mid latitudes and tropics
Formaldehyde	1 day	・Indicator of isoprene oxidation ・Biomass burning ・Comparison with satellites ・Trends	DOAS	Small number of sites in Tropics for comparison with satellites
Terpenes	1.5 hours	・Precursors to organic aerosols	GC/MS PTr-MS	Selected sites in forested areas
Acetonitrile	0.5-1 year	・Biomass burning indicator ・Biofuel burning indicator	GC/MS PTRMS	Global
Methanol	12 days	・Sources in the biosphere (methane oxidation) ・Abundant oxidation product	GC/FID PTR-MS	Global
Ethanol	4 days	・Tracer of alternative fuel usage	GC/FID PTR-MS	Global
Acetone	1.7 months	・Abundant oxidation product ・Free radical source in the upper troposphere	GC/FID PTR-MS	Global
DMS	2 days	・Major natural sulphur source ・Sulphate aerosol precursor ・Tracer of marine bioproductivity	GC/FID PTR-MS	Global Marine
Benzene	10 days	・Tracer of combustion ・Biomass burning indicator	GC/FID GC-MS	Global
Toluene	2 days	・Ratio to benzene used for air massage ・Precursor to particulates	GC/FID GC-MS	Global
Iso/normal Butane	5 days	・Chemical processing indicator ・Lifetime/ozone production ・Indication of halogen chemistry	GC/FID GC-MS	Global
Iso/normal Pentane	3 days	・Ratio provides impact of NO_3 chemistry ・Indication of halogen chemistry	GC/FID GC-MS	Global

GC/FID is Gas Chromatography − Flame Ionization Detection　GC/MS is Gas Chromatography − Mass Spectrometry
DOAS is Different Optical Absorption Spectrometry　PTRMS is Proton Tranfer Reaction Mass Spectrometry

Seasonal Variation of VOCs and trends

As with all other measurements within GAW which are designed to study atmospheric composition, an important use of the data is to evaluate trends over time. Sufficient data are available for many individual molecules, particularly the non-methane hydrocarbons (NMHCs) both from the American and the European continents. The current database also contains much information on the seasonal variation of both natural and anthropogenic hydrocarbons. The map on the front page of this chapter shows the network currently reporting VOC data, differentiating between sites where flask samples are collected for a limited set of NMHC measurements, and sites with measurements of a wider range of VOCs collected in a semi-continuous manner.

The review of the data record from the different sites reveals some interesting and important features, both concerning the characteristics of the measurement sites and the global and seasonal atmospheric behavior of VOCs. The data from many of the sites illustrate a regular seasonal behavior, with concentration maxima being observed in the winter and minima in the summer. Sites in Plate 11.1 and 11.3 are sorted by the station latitude, with the northern most site at the top, and South Pole at the bottom. NMHCs show a latitudinal concentration gradient, with concentrations decreasing from the poles to the equator, most notable during the winter. A number of stations, however, deviate from this behavior, showing higher VOC levels than other sites at similar latitude, with these deviations being more pronounced during the winter. Examples for this behavior are the stations: Lac La Biche (LLB), Constanta, Black Sea (BSC), and the Southern Great Plains (SGP). These elevated NMHC data are clear evidence of these sites being influenced by nearby local sources of these gases, elevating atmospheric NMHC mole fractions significantly above their latitudinal background. Consequently, while these data are of value for assessing the burden and long-term change of VOCs in these regions, they are not suitable for consideration in the reconstruction of the latitudinal background of these gases.

Focusing on ethane and propane, which have rather longer lifetimes amongst VOCs, Plate 11.1 and 11.3 show monthly mean mole fractions of ethane and propane, respectively, from 1998 to 2012 at each of the stations reporting to the database at WDCGG; and Plate 11.2 and 11.4 show the global ethane and propane distribution, respectively, from the flask network between 2006 to 2010 projected on to a continuous surface, with vertical and horizontal coordinates, respectively, of the mole fraction in ppt and latitude in degrees.

The ethane mole fraction shows a large seasonal variation which is mostly associated with its removal from the atmosphere by hydroxyl radical chemistry, leading to lower values in the summer months. The stronger latitudinal gradients in winter in the Northern Hemisphere compared to summer are also associated to corresponding larger OH gradients in winter. Absolute mole fractions are much larger in the Northern Hemisphere reflecting the preponderance of sources, mostly from oil and gas extraction in this region; Southern Hemisphere sources are dominated by emissions from biomass burning with a much smaller contribution associated with fossil fuel usage. A consideration of the budget of ethane in the atmosphere and its relevance to understanding the sources of methane was published by Simpson *et al.* (2012). This study concluded that the slow-down in the growth of atmospheric methane observed in 1999 to 2006 was predominantly associated with improved containment of methane emissions from processes such as flaring during oil and gas extraction. This result is a good example of how VOCs can be used as tracers to understand the behavior of important greenhouse gases.

The 38th edition of the *Data Summary* includes results for the global distribution of propane. Mole fractions of propane are generally lower than for ethane owing to shorter lifetimes of propane by about a factor of 5 and roughly 50% lower sources for propane (mole-base). The propane distribution shows similar general features as for ethane, however, stronger seasonality and more pronounced latitudinal gradients in the Northern Hemisphere (NH) during winter. Due to its shorter atmospheric lifetime compared to ethane, the NH seasonal cycle shows a maximum close to mid-winter, whereas the ethane maximum is shifted by about 2 months towards spring owing to ethane reacting slower to the changes in OH. The seasonal cycle for propane is more pronounced than for ethane mainly due to its higher reactivity. The higher rate decay of propane in summertime during transport of the air masses to remote observation sites compared to ethane contributes to the relatively lower summer minima seen in the representation of the network data.

REFERENCES

References

Angert, A., S. Biraud, C. Bonfils, W. Buermann, and I. Fung, CO_2 seasonality indicates origins of post-Pinatubo sink, *Geophys. Res. Lett.*, **31**, L11103, doi:10.1029/2004GL019760, 2004.

Bekki, S., K. S. Law, and J. A. Pyle, Effects of ozone depletion on atmospheric CH_4 and CO concentrations, *Nature*, **371**, 595–597, 1994.

Bergamaschi, P., et al., Atmospheric CH_4 in the first decade of the 21st century: Inverse modeling analysis using SCIAMACHY satellite retrievals and NOAA surface measurements, *J. Geophys. Res. Atmos.,* **118**, 7350–7369, doi:10.1002/jgrd.50480, 2013.

Berglen, T. F., T. K. Berntsen, I. S. A. Isaksen, and J. K. Sundet, A global model of the coupled sulfur/oxidant chemistry in the troposphere: The sulfur cycle, *J. Geophys. Res.*, **109**, D19310, doi:10.1029/2003JD003948, 2004.

Boden, T. A., G. Marland, and R. J. Andres, Global, Regional, and National Fossil-Fuel CO_2 Emissions. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., USA, doi: 10.3334/CDIAC/00001_V2013, 2013.

Cleveland, W. S., and S. J. Devlin, Locally weighted regression: an approach to regression analysis by local fitting, *J. Amer. Statist. Assn.*, **83**, 596–610, 1988.

Conway, T. J., P. P. Tans, L. S. Waterman, K. W. Thoning, D. R. Kitzis, K. A. Masarie, and N. Zhang, Evidence for interannual variability of the carbon cycle from the National Oceanic and Atmospheric Administration/Climate Monitoring and Diagnostics Laboratory global air sampling network, *J. Geophys. Res.*, **99**, 22831–22855, doi:10.1029/94JD01951, 1994.

Denman, K. L., G. Brasseur, A. Chidthaisong, P. Ciais, P. M. Cox, R. E. Dickinson, D. Hauglustaine, C. Heinze, E. Holland, D. Jacob, U. Lohmann, S. Ramachandran, P. L. da Silva Dias, S. C. Wofsy and X. Zhang, Couplings Between Changes in the Climate System and Biogeochemistry. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor and H. L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2007.

Dlugokencky, E. J., L. P. Steele, P. M. Lang, and K. A. Masarie, The growth rate and distribution of atmospheric methane, *J. Geophys. Res.*, **99**, 17021–17043, 1994.

Dlugokencky, E. J., E. G. Dutton, P. C. Novelli, P. P. Tans, K. A. Masarie, K. O. Lantz, and S. Mardronich, Changes in CH_4 and CO growth rates after the eruption of Mt. Pinatubo and their link with changes in tropical tropospheric UV flux, *Geophys. Res. Lett.*, **23**, 2761–2764, 1996.

Dlugokencky, E. J., B. P. Walter, K. A. Masarie, P. M. Lang and E. S. Kasischke, Measurements of an anomalous global methane increase during 1998, *Geophys. Res. Lett.*, **28**, 499–502, 2001.

Dlugokencky, E. J., L. Bruhwiler, J. W. C. White, L. K. Emmons, P. C. Novelli, S. A. Montzka, K. A. Masarie, P. M. Lang, A. M. Crotwell, J. B. Miller, and L. V. Gatti, Observational constraints on recent increases in the atmospheric CH_4 burden, *Geophys. Res. Lett.*, **36**, L18803, 2009.

Duchon, C. E., Lanczos filtering in one and two dimensions, *J. Appl. Meteor.*, **18**, 1016-1022, 1979.

Etheridge, D. M., L. P. Steele, R. J. Francey, and R. L. Langenfelds, Atmospheric methane between 1000 A.D. and present: Evidence of anthropogenic emissions and climatic variability, *J. Geophys. Res.*, **103**, 15979–15993, 1998.

Francey, R. J., P. P. Tans, C. E. Allison, I. G. Enting, J. W. C. White, and M. Trolier, Changes in oceanic and terrestrial carbon uptake since 1982, *Nature*, **373**, 326–330, 1995.

Gu, L., D. D. Baldocchi, S. C. Wofsy, J. W. Munger, J. J. Michalsky, S. P. Urbanski, and T. A. Bonden, Response of a deciduous forest to the Mount Pinatubo eruption enhanced photosynthesis, *Science*, **299**, 2035–2038, 2003.

Haan, D. and D. Raynaud, Ice core record of CO variations during the last two millennia: atmospheric implications and chemical interactions within the Greenland ice, *Tellus*, **50B**, 253–262, 1998.

Hansen, J., A. Lacis, R. Ruedy, and M. Sato, Potential Clim. Impact of Mount-Pinatubo Eruption, *Geophys. Res. Lett.,* **19(2)**, 215–218, 1992.

Heimann, M. and M. Reichstein, Terrestrial ecosystem carbon dynamics and climate feedbacks, *Nature,* **451**, 289–292, 2008.

IPCC, Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M.Manning, Z.Chen, M.Marquis, K.B.Averyt, M.Tignor and H.L.Miller(eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2007.

IPCC, Climate Change 2013: The Physical Science Basis. Working Group I Contribution to the IPCC Fifth Assessment Report [Thomas Stocker, Qin

Dahe, and Gian-Kasper Plattner]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2013.

Keeling, C. D., R. B. Bacastow, A. F. Carter, S. C. Piper, T. P. Whorf, M. Heimann, W. G. Mook, and H. Roeloffzen, A three-dimensional model of atmospheric CO_2 transport based on observed winds: 1. Analysis of observational data, in aspects of climate variability in the Pacific and the Western Americas, edited by D. H. Peterson, *Geophysical Monograph* **55**, 165–236, American Geophysical Union, Washington, D.C., 1989.

Keeling, C. D., T. P. Whorf, M. Wahlen, and J. van der Plicht, Interannual extremes in the rate of rise of atmospheric carbon dioxide since 1980, *Nature*, **375**, 666–670, 1995.

Lambert, G., P. Monfray, B. Ardouin, G. Bonsang, A.Gaudry, V. Kazan and G. Polian, Year-to-year changes in atmospheric CO_2, *Tellus*, **47B**, 35–55, 1995.

Levin, I., Earth science: The balance of the carbon budget, Nature, **488**, 35–36, doi:10.1038/488035a, 2012.

Manning, A. C., and R. F. Keeling, Global oceanic and land biotic carbon sinks from the Scripps atmospheric oxygen flask sampling network, *Tellus*, **58B**, 95–116, 2006.

Marenco, A., and F. Said, Meridional and vertical ozone distribution in the background troposphere from Scientific aircraft measurements during the STRATOZ III experiment, *Atmos. Env.,* **23**, 201–214, 1989.

Matsueda, H., S. Taguchi, H. Y. Inoue, and M. Ishii, A large impact of tropical biomass burning on CO and CO_2 in the upper troposphere, *Science in China (Series C)*, **45**, 116–125, 2002.

Morimoto, S., S. Aoki, T. Nakazawa, and T. Yamanouchi, Temporal variations of the carbon isotopic ratio of atmospheric methane observed at Ny Alesund, Svalbard from 1996 to 2004, *Geophys. Res. Lett*., **33**, L01807, doi:10.1029/2005GL024648, 2006.

Nakazawa, T., K. Miyashita, S. Aoki, and M. Tanaka, Temporal and spatial variations of upper tropospheric and lower stratospheric carbon dioxide, *Tellus*, **43B**, 106–117, 1991.

Nakazawa, T., S. Morimoto, S. Aoki and M. Tanaka, Time and space variations of the carbon isotopic ratio of tropospheric carbon dioxide over Japan, *Tellus*, **45B**, 258–274, 1993.

Nakazawa, T., S. Morimoto, S. Aoki and M. Tanaka, Temporal and spatial variations of the carbon isotopic ratio of atmospheric carbon dioxide in the western Pacific region, *J. Geophys. Res.*, **102**, 1271–1285, 1997.

Nevison, C. D., N. M. Mahowald, S. C. Doney, I. D. Lima, G. R. van der Werf, J. T. Randerson, D. F. Baker, P. Kasibhatla, and G. A. McKinley, Contribution of ocean, fossil fuel, land biosphere, and biomass burning carbon fluxes to seasonal and interannual variability in atmospheric CO_2, *J. Geophys. Res.*, **113**, doi:10.1029/2007JG000408, 2008.

Novelli, P. C., K. A. Masarie, and P. M. Lang, Distributions and recent changes of carbon monoxide in the lower troposphere, *J. Geophys. Res.*, **103**, 19015–19033, 1998.

Novelli, P. C., K. A. Masarie, P. M. Lang, B. D. Hall, R. C. Myers, and J. W. Elkins, Reanalysis of tropospheric CO trends: Effects of the 1997–1998 wildfires, *J. Geophys. Res.,* **108(D15)**, 4464, doi:10.1029/2002JD003031, 2003.

Oltmans *et al.*, Long-term changes in tropospheric ozone, *Atmos. Env*., **40**, 3156–3173, 2006.

Prinn, R. G., J. Huang, R. F. Weiss, D. M. Cunnold, P. J. Fraser, P. G. Simmonds, A. McCulloch, C. Harth, P. Salameh, S. O'Doherty, R. H. J. Wang, L. Porter and B. R. Miller, Evidence for substantial variations of atmospheric hydroxyl radicals in the past two decades, *Science*, **292**, 1882–1888, 2001.

Rayner, P. J., I. G. Enting, R. J. Francey and R. Langenfelds, Reconstructing the recent carbon cycle from atmospheric CO_2, $\delta^{13}C$ and O_2/N_2 observations, *Tellus*, **51B**, 213–232, 1999.

Ravishankara, A. R., J. S. Daniel, and R. W. Portmann, Nitrous Oxide (N_2O): the dominant ozone-depleting substance emitted in the 21st century, *Science*, **326**, 123-125, 2009.

Reis, S., R. W. Pinder, M. Zhang, G. Lijie, and M. A. Sutton, Reactive nitrogen in atmospheric emission inventories, *Atmos. Chem. Phys.*, **9,** 7657–7677, 2009.

Rigby, M., R. G. Prinn, P. J. Fraser, P. G. Simmonds, R. L. Langenfelds, J. Huang, D. M. Cunnold, L. P. Steele, P. B. Krummel, R. F. Weiss, S. O'Doherty, P. K. Salameh, H. J. Wang, C. M. Harth, J. Mühle, and L. W. Porter, Renewed growth of atmospheric methane, *Geophys. Res. Lett.*, **35**, L22805, doi:10.1029/2008GL036037, 2008.

Seinfeld, J. H., and S. N. Pandis, Atmospheric Chemistry and Physics: From Air Pollution to Climate Change, *John Wiley & Sons, Inc., New York*, 1326 pp., 1998.

Shindell, D., G. Faluvegi, A. Lacis, J. Hansen, R. Ruedy, and E. Aguilar, Role of tropospheric ozone increases in 20th-century climate change, *J. Geophys. Res.,* **111**, D08302, doi:10.1029/2005JD006348, 2006.

Simpson, I. J., M. P. S. Anderson, S. Meinardi, L. Bruhwiler, N. J. Blake, D. Helmig, F. S. Rowland, and D. R. Blake, Long-term decline of global atmospheric ethane concentrations and implications for methane, *Nature*, **488**, 490-494, 2012.

Solomon, S., D. Qin, M. Manning, R. B. Alley, T.

Berntsen, N. L. Bindoff, Z. Chen, A. Chidthaisong, J. M. Gregory, G. C. Hegerl, M. Heimann, B. Hewitson, B. J. Hoskins, F. Joos, J. Jouzel, V. Kattsov, U. Lohmann, T. Matsuno, M. Molina, N. Nicholls, J. Overpeck, G. Raga, V. Ramaswamy, J. Ren, M. Rusticucci, R. Somerville, T. F. Stocker, P. Whetton, R. A. Wood and D. Wratt, Technical Summary. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2007.

Solomon, S., G-K. Plattner, R. Knutti and P. Friedlingstein, Irreversible climate change due to carbon dioxide emissions, *Proc. Natl. Acad. Sci. USA*, **106**, 1704-1709, doi:10.1073/pnas.0812721106, 2009.

Staehelin, J., J. Thudium, R. Buehler, A. Voltz-Thomas, and W. Graber, Trends in surface ozone concentrations at Arosa (Switzerland), *Atmos. Env.*, **28**, 75–87, 1994.

Stenchikov, G., A. Robock, V. Ramaswamy, M. D. Schwarzkopf, K. Hamilton, and S. Ramachandran, Arctic Oscillation response to the 1991 Mount Pinatubo eruption: Effects of volcanic aerosols and ozone depletion, *J. Geophys. Res.*, **107(D24)**, 4803, doi:10.1029/2002JD002090., 2002.

Tans, P., An accounting of the observed increase in oceanic and atmospheric CO_2 and an outlook for the fiture, *Oceanography*, **22(4)**, 26-35, http://dx.doi.org/10.5670/oceanog.2009.94, 2009.

Tarasova, O. A., C. A. M. Brenninkmeijer, P. Jöckel, A. M. Zvyagintsev, and G.I. Kuznetsov: A climatology of surface ozone in the extra tropics: cluster analysis of observations and model resolts, *Atmos. Chem. Phys.*, **7**, 6099-6117, 2007.

Tsutsumi, Y, Y. Makino, and J. B. Jensen, Vertical and latitudinal distributions of tropospheric ozone over the western Pacific: Case studies from the PACE aircraft missions, *J. Geophys. Res.*, **108(D8)**, 4251, doi:10.1029/2001JD001374, 2003.

Thoning, K. W., P. P. Tans, and W. D. Komhyr, Atmospheric carbon dioxide at Mauna Loa observatory, 2. Analysis of the NOAA GMCC data, 1974-1985, *J. Geophys. Res.*, **94**, 8549–8565, 1989.

WMO, WMO-BMBF Workshop on VOC – Establishment of a “World Calibration/Instrument Intercomparison Facility for VOC” to Serve the WMO Global Atmosphere Watch (GAW) Programme, GAW Report No. 111, WMO TD No. 756, 1996.

WMO, Scientific assessment of ozone depletion: 1998. WMO global ozone research and monitoring project—Report No. 44, 2-43, World Meteorological Organization, Geneva, 1999.

WMO, World Data Centre for Greenhouse Gases (WDCGG) Data Summary, WDCGG No. 22, 84pp, 2000.

WMO, Global Atmospheric Watch (GAW) Strategic Plan: 2008–2015, GAW Report No. 172, WMO TD No. 1384, 2007a.

WMO, World Data Centre for Greenhouse Gases Data Submission and Dissemination Guide, GAW Report No. 174, WMO TD No. 1416, 2007b.

WMO, A WMO/GAW Expert Workshop on Global Long-Term Measurements of Volatile Organic Compounds (VOCs), GAW Report No. 171, WMO TD No. 1373, 2007c.

WMO, Technical Report of Global Analysis Method for Major Greenhouse Gases by the World Data Center for Greenhouse Gases, GAW Report No. 184, WMO TD No. 1473, 2009a.

WMO, Revision of the World Data Centre for Greenhouse Gases Data Submission and Dissemination Guide, GAW Report No. 188, WMO TD No. 1507, 2009b. (http://www.wmo.int/pages/prog/arep/gaw/documents/GAW_188_web_20100128.pdf, accessed on 27 Jan. 2014)

WMO, Addendum for the Period 2012-2015 to the WMO Global Atmosphere Watch (GAW) Strategic Plan 2008-2015, GAW Report No. 197, 2011a.

WMO, Second Tropospheric Ozone Workshop - Tropospheric Ozone Changes: observations, state of understanding and model performances, GAW Report No.199, 2011b.

WMO, 16th WMO/IAEA Meeting on Carbon Dioxide, Other Greenhouse Gases and Related Measurement Techniques (GGMT-2011), ed. Gordon Brailsford, WMO/GAW Report No.206, 2012.

WMO, WMO Greenhouse Gas Bulletin No.9, 2013. (http://www.wmo.int/pages/prog/arep/gaw/ghg/GHGbulletin.html, accessed on 27 Jan. 2014)

APPENDICES

CALIBRATION AND STANDARD SCALES

1. Calibration System in the GAW Programme

Under the Global Atmosphere Watch (GAW) Programme, the Central Calibration Laboratories (CCLs) are assigned to host a Primary (Reference) Standard/scale, while the World Calibration Centres (WCCs) are responsible for the scale propagation to the stations via distribution of calibration standards for certain compounds, conducting instrument calibrations, comparison campaigns, station audits and providing training to the station personnel. A Reference Standard/scale is designated for each variable to be used for all GAW measurements of that variable. Table 1 lists the organizations that serve as WCCs and CCLs for GAW (WMO, 2011). For CFCs and SO_2, no central facilities or quality control systems have so far been established within the GAW Programme.

Table 1. Overview of the GAW Central Calibration Laboratories (GAW-CCL, Reference Standard) and World Calibration Centres for greenhouse and other related gases. The World Calibration Centres have assumed global responsibilities, except where indicated (Am, Americas; E/A, Europe and Africa; A/O, Asia and the South-West Pacific)

Compounds	Central Calibration Laboratory (Host of Primary Standard)	World Calibration Centre
Carbon Dioxide (CO_2)	NOAA/ESRL	NOAA/ESRL (round robin) Empa (audits)
carbon isotopes	MPI-BGC	
Methane (CH_4)	NOAA/ESRL	Empa (Am, E/A) JMA (A/O)
Nitrous Oxide (N_2O)	NOAA/ESRL	IMK-IFU
Chlorofluorocarbons (CFCs)		
Sulphur Hexafluoride (SF_6)	NOAA/ESRL	KMA
Molecular Hydrogen (H_2)	MPI-BGC	
Surface Ozone (O_3)	NIST	Empa
Carbon Monoxide (CO)	NOAA/ESRL	Empa
Volatile Organic Compounds (VOCs)	NPL (8 components)	KIT/IMK-IFU
Sulphur Dioxide (SO_2)		
Nitrogen Oxides (NO_x)		FZ-Jurich

2. Carbon Dioxide (CO_2)

In 1995, the National Oceanic and Atmospheric Administration's Earth System Research Laboratory (NOAA/ESRL, formerly CMDL; Climate Monitoring and Diagnostics Laboratory) in Boulder, Colorado, USA, took over the role of the Central Calibration Laboratory (CCL) from the Scripps Institution of Oceanography (SIO) in San Diego, California, USA. Since then, NOAA/ESRL has served as the CCL responsible for the maintenance of the GAW Primary Standard for CO_2. As CCL for CO_2, NOAA/ESRL maintains a high-precision manometric system for absolute calibration of CO_2 as the reference for GAW measurements throughout the world (Zhao *et al.*, 1997), as well as carrying out Round-Robin in the function of WCC. It has been recommended that the standards of the GAW measurement laboratories be calibrated at least every three years at the CCL (WMO, 2012).

Under the WMO calibration system, there have been several calibration scales for CO_2, *e.g.*, SIO-based X74, X85, X87, X93 and X2002 scales and the NOAA/ESRL-based WMO Mole Fraction Scale partially based on previous SIO scales. The CCL adopted the WMO X2005 scale, reflecting historical manometric calibrations of the CCL's set of cylinders and the possible small differences between SIO and NOAA/ESRL calibrations. The most current WMO Mole Fraction Scale is the WMO-X2007 scale.

To assess the differences in standard scales among measuring laboratories, NOAA/ESRL organizes intercomparisons or Round Robin experiments endorsed by WMO. It is recommended that round-robins are repeated at least once every three years. Many laboratories participated in the experiments organized in 1991–1992, 1995–1997, 1999–2000, 2002–2006, and 2009-2012. Table 2 shows the results of the experiments performed in 2009–2012, in which the mole fractions measured by various laboratories are compared with the mole fractions measured by NOAA/ESRL (http://www.esrl.noaa.gov/gmd/ccgg/wmorr/results.php). In addition, many laboratories compare their standards bilaterally or multilaterally.

Table 3 lists laboratories and sites that contributed to the present issue of the *Data Summary* with standard scales of reported data and history of participation in WMO intercomparison experiments.

Table 2. Round robin results for the mole fraction of carbon dioxide. Differences between the mole fractions measured by various laboratories and the mole fractions measured by NOAA (Laboratory minus NOAA, ppm).

Laboratory	Measurement Date	Mole fraction Difference (ppm)		
		Low 365-375 ppm	Medium 380-390 ppm	High 395-405 ppm
JMA	Jun-09	–0.00	–0.06	–0.04
MRI	Jul-09	–0.13	–0.05	–0.05
AIST	Sep-09	0.08	0.13	0.16
NIES	Oct-09	–0.03	–0.01	0.03
TU	Jan-10	0.15	0.21	0.28
CMA	Apr-10	–0.21	–0.14	–0.04
KMA/KGAWO	Jul-10	–0.54	0.01	0.05
KRISS	Jul-10	0.14	0.20	0.24
SNU	Nov-10	0.01	0.03	0.14
IPEN	Jul/Aug-11	–0.09	–0.03	–0.02
AEMET	Sep-12	0.03	–0.03	0.02
EC	Apr-09	–0.02	–0.02	–0.03
SIO	May-09	–0.20	–0.14	–0.11
AMERIFLUX	May-09	–0.02	0.03	0.02
SAWS	Aug-09	0.04	0.06	–0.04
NIWA	Nov-09	0.02	–0.02	–0.07
CSIRO	Jan-10	0.00	0.00	–0.10
PSU	Sep-10	0.06	0.08	–0.01
HU	Nov-10	–0.04	–0.07	–0.09
NCAR	Apr-11	–0.02	0.01	–0.02
OSU	Aug-11	0.02	0.08	0.00
ITM	May-09	–0.86	–0.73	–0.20
FMI	Jun-09	0.02	0.03	0.03
UBA/SCH	Aug-09	–0.00	0.01	0.04
UHEI-IUP	Aug-09	–0.04	–0.04	–0.08
MRI-BGC	Sep/Oct-09	–0.02	0.00	–0.00
UBA/ZUG	Dec-09	–0.07	–0.24	–0.48
HMS	Mar-10	0.07	–0.02	–0.03
CESI/RICERCA	Apr-10	–0.01	0.06	0.08
ENEA	Jun-10	–0.18	–0.30	–0.37
JRC	Oct-10	–0.04	0.02	0.00
WCC-EMPA	Nov-10	0.07	0.11	0.13

EMPA	Dec-10	–0.02	0.04	0.06
UEA	Dec-10	–0.26	–0.17	–0.12
KUP	Jan-11	–0.15	–0.11	–0.04
ECN	Mar-11	0.01	0.03	0.04
LSCE	Apr-11	0.06	0.01	0.12
RHUL	Jun-11	–0.08	–0.07	–0.11

Table 3. Status of standard scales and calibration/intercomparison for CO_2 at laboratories.

Laboratory	WDCGG Filename Code	Calibration Scale	WMO Inter-comparison
AEMET	IZO128N0000	WMO	91/92, 96/97, 99/00, 09/12
Aichi	MKW234N0000	WMO	
AIST	TKY236N0000	AIST	96/97, 99/00, 02/06, 09/12
BMKG & Empa	BKT500S0000	WMO	
BoM & CSIRO	CGO540S0000, CGO540S0010	WMO	
CMA	WLG236N0000	WMO	96/97, 99/00, 02/06, 09/12
CNR-ICES & DNA-IAA	JBN762S0000	WMO	
CSIRO	ALT482N0003, CFA519S0003, CGO540S0003, CRI215N0000, CYA766S0001, ESP449N0003, MAA767S0003, MLO519N0003, MQA554S0003, SIS660N0003, SPO789S0003	WMO	91/92, 96/97, 99/00, 02/06, 09/12
EC	ALT482N0000, ALT482N0005, CDL453N0000,CHM449N0000, CSJ451N0000, EGB444N0100 , ESP449N0000, ETL454N0000 , FSD449N0000, LLB454N0100, WSA443N0000, WSA443N0001	WMO	91/92, 96/97, 99/00, 02/06, 09/12
EMA	CAI130N0000		
Empa	JFJ646N0000	WMO	09/12
ENEA	LMP635N0001	WMO	91/92, 96/97, 99/00, 02/06, 09/12
FMI	PAL667N0000	WMO	02/06, 09/12
HKO	HKG222N0001, HKO222N0001	WMO	
	HKO222N0000	NIST	
HMS	HUN646N0000, KPS646N0000	WMO	91/92, 96/97, 99/00, 02/06, 09/12
IAFMS	CMN644N0001, CMN644N0002	WMO	91/92, 96/97, 02/06
IGP	HUA312S0000	WMO	
IMK-IFU	WNK647N0000, ZUG647N0014	WMO	99/00
INRNE	BEO642N0000	WMO	
IOEP	DIG654N0000	IOEP	
ITM	ZEP678N0000	WMO	96/97, 99/00, 09/12

JMA	MNM224N0000, RYO239N0000, YON224N0000	WMO	91/92, 96/97, 99/00, 02/06, 09/12
KMA	AMY236N0000, KSG762S0000	KRISS	02/06, 09/12
KSNU	ISK242N0000		
KUP	JFJ646N0003	WMO	
LSCE	AMS137S0000, BGU641N0000, LPO648N0000, MHD653N0002, PDM642N0000, PUY645N0000	WMO	91/92, 96/97, 99/00, 02/06, 09/12
	FIK635N0000		
MGO	BER255N0001, KOT276N0001, KYZ240N0001, STC652N0001, TER669N0001, TIK271N0000	WMO	
MMD	DMV504N0000	WMO	
MRI	TKB236N0002		91/92, 96/97, 99/00, 02/06, 09/12
NIER	GSN233N0103	WMO	
NIES	COI243N0000, HAT224N0000	NIES 95**	96/97, 99/00, 02/06, 09/12
NIMR	GSN233N0001	WMO	96/97
NIPR & Tohoku Univ.	SYO769S0000		Tohoku Univ.: 91/92, 96/97, 99/00, 02/06, 09/12
NIWA	BHD541S0000	WMO	91/92, 96/97, 99/00, 02/06, 09/12
NMA	FDT645N0002		
NOAA/ESRL	BRW471N0000, MLO519N0000, SMO514S0000, SPO789S0000, NOAA/ESRL flask network*	WMO	91/92, 96/97, 99/00, 02/06, 09/12
Osaka Univ.	SUI234N0000		
RIVM	KMW653N0000	NIST	
RSE	PRS645N0000	WMO	99/00, 02/06
Saitama	DDR236N0000, KIS236N0000, URW235N0000	WMO	
SAWS	CPT134S0000	WMO	99/00, 02/06, 09/12
Shizuoka Univ.	HMM234N0000		
UBA	BRT648N0000, DEU649N0000, LGB652N0000, NGL653N0000, SNB647N0000, SSL647N0000, SSL647N0002, WES654N0000, ZGT654N0000, ZSF647N0010, ZUG647N0000	WMO	91/92, 96/97, 99/00, 02/06, 09/12
Univ. Malta	GLH636N0000		

[*] NOAA/ESRL flask network:
ABP312S0001,ALT482N0001,AMS137S0001,ASC107S0001,ASK123N0001,AVI417N0001,AZR638N0001,BAL655N0001,BHD541S0001 , BKT500S0001,BME432N0001,BMW432N0001,BRW471N0001,BSC644N0001,CBA455N0001,CGO540S0001,CHR501N0001,CMO445N0001, CRZ146S0001,EIC327S0001,GMI513N0001,GOZ636N0001,HBA775S0001,HPB647N0003,HUN646N0001,ICE663N0001,ITN435N0001, IZO128N0001,KCO204N0001,KEY425N0001,KUM519N0001,KZD244N0001,KZM243N0001,LEF445N0001,LLB454N0001,LLN223N0001, LMP635N0003,MBC476N0001,MEX419N0001,MHD653N0001,MID528N0001,MKN100S0001,MLO519N0001,NMB123S0001,NWR440N0101, OPW448N0001,PAL667N0001,POC900N0001,POC905N0001,POC905S0001,POC910N0001,POC910S0001,POC915N0001,POC915S0001, POC920N0001,POC920S0001,POC925N0001,POC925S0001,POC930N0001,POC930S0001,POC935S0001,PSA764S0001,PTA438N0001, RPB413N0001,SCS903N0001,SCS906N0001,SCS909N0001,SCS912N0001,SCS915N0001,SCS918N0001,SCS921N0001,SEY104S0001, SGP436N0001,SHM452N0001,SMO514S0001,SPO789S0001,STC654N0001,STM666N0001,SUM672N0001,SYO769S0001,TAP236N0001, TDF354S0001,THD441N0001,UTA439N0001,UUM244N0001,WIS631N0001,WLG236N0001,ZEP678N0001

[**] NIES 95 CO_2 scale is 0.10 to 0.14 ppm lower than WMO in a range between 355 to 385 ppm.
(Machida *et al*., WMO/GAW Report No. 186, 26-29, 2009.)

3. Methane (CH_4)

The GAW Programme has established two WCCs for CH_4, the Swiss Federal Laboratory for Materials Testing and Research (Empa), Dübendorf, Switzerland; and the Japan Meteorological Agency (JMA), Tokyo, Japan (WMO, 2007). In addition, the Central Calibration Laboratory for CH_4 has been established at NOAA/ESRL (Dlugokencky *et al.*, 2005; WMO, 2007).

The NOAA04 scale has been designated as the Primary scale of the GAW Programme. This scale results in CH_4 mole fractions that are a factor of 1.0124 higher than the previous NOAA scale (Dlugokencky *et al.*, 2005).

Table 4 summarizes the CH_4 standard scales used by laboratories contributing to the WDCGG and lists tentative multiplying conversion factors applied for analysis in this issue of the *Data Summary*. The standard is the NOAA04 scale, and conversion factors were calculated from the results of comparisons with other laboratories performed bilaterally or multilaterally before the establishment of the GAW Standard.

The former CMDL scale is lower than an absolute gravimetric scale (Aoki *et al.*, 1992) by ~1.5% (Dlugokencky *et al.*, 1994) and lower than the AES (Atmospheric Environment Service, currently EC) scale by a factor of 1.0151 (Worthy *et al.*, 1998). The former CMDL scale can be converted to the Tohoku University standard by multiplying by 1.0121 (Dlugokencky *et al.*, 2005). The conversion factors 1.0124 / 1.0151 = 0.9973 and 1.0124 / 1.0121 = 1.0003 have been adopted for comparisons with the NOAA04 scale.

Table 4. Status of the standard scales of CH_4 at laboratories with conversion factors.

Laboratory	WDCGG Filename Code	Calibration Scale	Conversion Factor
AEMET	IZO128N0000	NOAA04	1
AGAGE	CGO540S0011, CGO540S0013, CMO445N0011, MHD653N0011, MHD653N0013, RPB413N0000, RPB413N0011, SMO514S0014, SMO514S0016, THD441N0000	Tohoku Univ.	1.0003
BMKG & Empa	BKT500S0000	NOAA04	1
CHMI	KOS649N0000	CHMI	
CMA	WLG236N0000	NOAA04	1
CSIRO	ALT482N0003, CFA519S0003, CGO540S0003, CRI215N0000, CYA766S0001, ESP449N0003, MAA767S0003, MLO519N0003, MQA554S0003, SIS660N0003, SPO789S0003	NOAA04	1
EC	ALT482N0000, CDL453N0000, CHM449N0000, EGB444N0100, ESP449N0000, ETL454N0000, FSD449N0000, LLB454N0100, WSA443N0000	NOAA04	1
Empa	JFJ646N0000	NOAA04	1
ENEA	LMP635N0001	NOAA04	1
FMI	PAL667N0000	NOAA04	1
ISAC	CMN644N0000	NOAA04	1
JMA	MNM224N0000, RYO239N0000, YON224N0000	NOAA04	1
KMA	AMY236N0000	KRISS	
KSNU	ISK242N0000		
LSCE	AMS137S0002, BGU641N0000, LPO648N0000, PDM642N0000, PUY645N0002	NOAA83	1.0124
	FIK635N0000, MHD653N0007		
MGO	TER669N0001, TIK271N0000	NOAA04	1
MRI	TKB236N0000		0.9973
NIER	GSN233N0103	NOAA04	1
NIES	COI243N0000, HAT224N0000	NIES	0.9973

NIMR	GSN233N0001	SIO X97	
NOAA/ESRL	BRW471N0000, MLO519N0000, NOAA/ESRL flask network*	NOAA04	1
	KPA431N0001, LEF445N0001, MCM777S0001, NZL543S0001, POC935S0001, SGI354S0001, SIO432N0001	NOAA/CMDL	1.0124
RIVM	KMW653N0000	NIST	0.9973
RSE	PRS645N0000	NOAA04	1
SAWS	CPT134S0000	NOAA04	1
UBA	DEU649N0000, NGL653N0000, SSL647N0000, ZGT654N0000, ZSF647N0010, ZUG647N0000	NOAA04	1
	SNB647N0000		
Univ. Malta	GLH636N0000		

[*] NOAA/ESRL flask network:
ABP312S0001,ALT482N0001,AMS137S0001,ASC107S0001,ASK123N0001,AVI417N0001,AZR638N0001,BAL655N0001,BKT500S0001,BME432N0001,BMW432N0001,BRW471N0001,BSC644N0001,CBA455N0001,CGO540S0001,CHR501N0001,CMO445N0001,CRZ146S0001,EIC327S0001,GMI513N0001,GOZ636N0001,HBA775S0001,HPB647N0003,HUN646N0001,ICE663N0001,ITN435N0001,IZO128N0001,KEY425N0001,KUM519N0001,KZD244N0001,KZM243N0001,LLB454N0001,LLN223N0001,LMP635N0003,MBC476N0001,MEX419N0001,MHD653N0001,MID528N0001,MKN100S0001,MLO519N0001,NMB123S0001,NWR440N0101,OPW448N0001,OXK650N0001,PAL667N0001,POC900N0001,POC905N0001,POC905S0001,POC910N0001,POC910S0001,POC915N0001,POC915S0001,POC920N0001,POC920S0001,POC925N0001,POC925S0001,POC930N0001,POC930S0001,PSA764S0001,PTA438N0001,RPB413N0001,SCS903N0001,SCS906N0001,SCS909N0001,SCS912N0001,SCS915N0001,SCS918N0001,SCS921N0001,SEY104S0001,SGP436N0001,SHM452N0001,SMO514S0001,SPO789S0001,STM666N0001,SUM672N0001,SYO769S0001,TAP236N0001,TDF354S0001,THD441N0001,UTA439N0001,UUM244N0001,WIS631N0001,WKT431N0001,WLG236N0001,ZEP678N0001

4. Nitrous Oxide (N_2O)

The Halocarbons and other Atmospheric Trace Species (HATS) Group of NOAA/ESRL maintains a set of standards for N_2O (Hall *et al.*, 2001) and serves as a CCL for N_2O. The NOAA-2006 N_2O scale (Hall *et al.*, 2007), revised and updated to NOAA-2006A in 2011 to deal with drifting in secondary standards, has been designated as the Primary scale for the GAW Programme. CCL compares its standards with the ones of other laboratories, including those of Environment Canada (EC) and the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO). Karlsruhe Institute of Technology, Institute for Meteorology and Climate Research, Germany, serves as the GAW WCC for N_2O.

The SIO-98 scale is essentially equivalent to the NOAA-2006 scale, with an average difference of 0.01% over the range of 299–319 ppb; the NOAA-2000 scale can be converted to the 2006 scale by using the factor 0.999402 (Hall *et al.*, 2007). A constant ratio of 1.0017 between CSIRO and AGAGE data was used by Huang *et al.* (2008), and a factor of 1 / 1.0017 = 0.9983 has been used in this report to convert CSIRO scale to the NOAA-2006 scale.

Table 5. Status of the standard scales of N_2O at laboratories.

Laboratory	WDCGG Filename Code	Calibration Scale	Conversion Factor
AEMET	IZO128N0000	NOAA-2006	1
AGAGE	ADR651N0010, CGO540S0011, CGO540S0012, CGO540S0013, CMO445N0010, CMO445N0011, MHD653N0011, MHD653N0013, RPB413N0000, RPB413N0010, RPB413N0011, SMO514S0014, SMO514S0015, SMO514S0016, THD441N0000	SIO 1998	1
CSIRO	ALT482N0003, CFA519S0003, CGO540S0003, CRI215N0000, CYA766S0001, ESP449N0003, MAA767S0003, MLO519N0003, MQA554S0003, SIS660N0003, SPO789S0003	NOAA-2006A	1
Empa	JFJ646N0000	SIO 1998	1
ENEA	LMP635N0001	NOAA-2006	1

ISAC	CMN644N0000	NOAA-2006	1
JMA	RYO239N0000	NOAA-2006A	1
KMA	AMY236N0000	KRISS	
MRI	MMB243N0000		
Nagoya Univ.	NGY235N0000		
NIER	GSN233N0103	NOAA-2006	1
NIES	COI243N0000, HAT224N0000	NIES 96*	1
NILU	ZEP678N0000		
NIMR	GSN233N0001	WMO X97	
NOAA/ESRL	ALT482N0001, BRW471N0001, CGO540S0001, KUM519N0001, MLO519N0001, NWR440N0001, SMO514S0001, SPO789S0001	NOAA/CMDL	0.999402
	ALT482N0004, ALT482N0006, BRW471N0003, BRW471N0005, BRW471N0011, CGO540S0009, CGO540S0014, KUM519N0002, MHD653N0008, MLO519N0005, MLO519N0006, MLO519N0011, NWR440N0003,NWR440N0004, NWR440N0011, PSA764S0000, SMO514S0008, SMO514S0009, SMO514S0011, SPO789S0005, SPO789S0006, SPO789S0011, SUM672N0002, THD441N0002	NOAA-2006	1
	BRW471N0010, MLO519N0010,NWR440N0010, SMO514S0010, SPO789S0010, SUM672N0000	NOAA-2006A	1
SAWS	CPT134S0000	NOAA/CMDL	0.999402
UBA	SSL647N0000, ZSF647N0010	SIO 1998	1

*NIES 96 N_2O scale is approximately 0.6 ppb lower than NOAA-2006 in a range between 317 to 321 ppb. (http://www.esrl.noaa.gov/gmd/ccgg/wmorr/results.php?rr=rr5&param=n2o)

5. Surface Ozone (O_3)

The National Institute of Standards and Technology (NIST) has developed and deployed Standard Reference Photometers (SRPs) in the USA and other countries. The GAW has designated SRP #2 maintained by NIST as the Primary Standard for the GAW Programme, making NIST the CCL for O_3. The Swiss Federal Laboratory for Materials Testing and Research (Empa) maintains NIST SRP #15 as the reference and is the GAW WCC for surface ozone (Hofer *et al.*, 1998). The traceability and uncertainty of O_3 within the GAW network were reported by Klausen *et al.,* (2003). Regional Calibration Centre has been established at Observatorio Central Buenos Aires, Argentina (WMO, 2007).

Table 6. Status of surface ozone standard scales at laboratories

Laboratory	WDCGG Filename Code	Calibration Scale	Audit Empa-WCC
AEMET	IZO128N0000	WMO (NIST & Empa)	96, 98, 00, 04, 09
	DON637N0000, MHN639N0000, NIA642N0000, ROQ640N0000, SPM639N0000	NPL (U. K.)	
AQRB	ALG447N0000, BRA450N0000, CHA446N0000, EGB444N0000, ELA449N0000, EST451N0000, KEJ444N0000, SAT448N0000		
ARSO	IRB645N0000, KVK646N0000, KVV646N0000, ZRN646N0000	WMO (NIST & Empa)	
AWI	NMY770S0000		

BMKG & Empa	BKT500S0000	WMO (NIST & Empa)	99, 01, 04, 07, 08, 11
BoM & CSIRO	CGO540S0000		
	CGO540S0018	WMO (NIST & Empa)	02
CHMI	KOS649N0000	WMO (NIST & Empa)	
DEFRA	EDM655N0000		
DWD	HPB647N0000	WMO (NIST & Empa)	97, 06, 11
EMA	CAI130N0000		
Empa	JFJ646N0000, PAY646N0000, RIG646N0000	WMO (NIST & Empa)	Jungfraujoch: 99, 06
Empa & KMD	MKN100S0000	WMO (NIST & Empa)	00, 02, 05, 06, 08, 10
FMI	AHT662N0000, OUL666N0000, PAL667N0000, UTO659N0000, VIR660N0000		Pallas-Sammaltunturi: 97, 03, 07, 12
HMS	KPS646N0000	WMO (NIST & Empa)	
IM	ANG638N0000, BEJ638N0000, CAS639N0000, FUN132N0000, LIS638N0000, MVH638N0000, PEN640N0000		
INRNE	BEO642N0000	WMO (NIST & Empa)	
IOEP	DIG654N0000	WMO (NIST & Empa)	
ISAC	CMN644N0000, DCC775S0000, PYR227N0000	WMO (NIST & Empa)	Monte Cimone: 12
IVL	VDL664N0000	WMO (NIST & Empa)	
JMA	MNM224N0000, RYO239N0000, SYO769S0002, TKB236N1004, YON224N0000	WMO (NIST & Empa)	Ryori: 05
KSNU	ISK242N0000		
LA	PDM642N0001	EMD (France)	
LAMP	PUY645N0001	EMD (France)	
LVGMC	DBL656N0000, RCV656N0000, ZSN657N0000	WMO (NIST & Empa)	
MMD	DMV504N0000, TAR504N0000	WMO (NIST & Empa)	Datum Valley GAW Baseline Station: 08
NILU	ZEP678N0000	WMO (NIST & Empa)	97, 01, 05, 12
NIWA	BHD541S0000	WMO (NIST & Empa)	

NMA	FDT645N0002		
NOAA/ESRL	ARH777S0000, BMW432N0004, BRW471N0004, ICE663N0004, LAU545S0004, MLO519N0004, NWR440N0002, NWR440N0204, RPB413N0004, SMO514S0004, SPO789S0004, SUM672N0004, THD441N0004	WMO (NIST & Empa)	Mauna Loa: 03 Barrow: 08 Lauder: 10
	MCM777S0004		
NUI	MHD653N0000	NPL (U. K.)	96, 98, 02, 05, 09
ONM	ASK123N0000	WMO (NIST & Empa)	03, 07
PolyU	HKG222N0000		
RIVM	KMW653N0000		
Roshydromet	DAK654N0000, SHP659N0000		
RSE	PRS645N0000	INRIM (Itary)	
SAWS	CPT134S0000	WMO (NIST & Empa)	97, 98, 02, 06, 11
SMN	USH354S0000, USH354S0001	WMO (NIST & Empa)	98, 03, 08
SMNA	LQO322S0000, MBI764S0000, PIL331S0000, SJA349S0000 , USH354S0002	WMO (NIST & Empa)	
UBA	BRT648N0000, DEU649N0000, LGB652N0000, NGL653N0000, SNB647N0000, SSL647N0000, WES654N0000, ZGT654N0000, ZSF647N0010, ZUG647N0000	WMO (NIST & Empa)	Zugspitze: 96, 97, 01 Sonnblick: 98 Zugspitze/Schneefernerhaus: 06, 11
UNA	SNL325S0000		
Univ. Malta	GLH636N0000	Tohoku Univ.	
Univ. York	CVO116N0001	NPL (U. K.)	

6. Carbon Monoxide (CO)

The Swiss Federal Laboratory for Materials Testing and Research (Empa) serves as the WCC under GAW based on its secondary standards calibrated against the standard at NOAA/ESRL designated as the Primary Standard for GAW. The most recent scale is WMO CO X2004.

Table 7. Status of CO standard scales at laboratories

Laboratory	WDCGG Filename Code	Calibration Scale	Audit Empa-WCC
AEMET	IZO128N0000	WMO 2004 (NOAA/ESRL & Empa)	00, 04, 09
AGAGE	CGO540S0011, MHD653N0011	CSIRO	
ARSO	KVV646N0000	CHMI	
BMKG & Empa	BKT500S0000	WMO 2000 (NOAA/ESRL & Empa)	04, 07, 08, 11
CHMI	KOS649N0000	CHMI	

CSIRO	ALT482N0003, CFA519S0003, CGO540S0003, CRI215N0000, CYA766S0001, ESP449N0003, MAA767S0003, MLO519N0003, MQA554S0003, SIS660N0003, SPO789S0003	CSIRO	Cape Grim: 02
DWD	HPB647N0000	WMO (NOAA/ESRL & Empa)	97, 06, 11
EC	ALT482N0000, CDL453N0000, CHM449N0000, EGB444N0100, ESP449N0000, ETL454N0000, FSD449N0000, LLB454N0100, WSA443N0000	WMO (NOAA/ESRL & Empa)	Alert: 04
Empa	JFJ646N0000, PAY646N0000, RIG646N0000	WMO 2000 (NOAA/ESRL & Empa)	Jungfraujoch: 99,06
Empa &KMD	MKN100S0000	WMO 2000 (NOAA/ESRL & Empa)	05, 06, 08, 10
INRNE	BEO642N0000	WMO (NOAA/ESRL & Empa)	
ISAC	CMN644N0000, CMN644N0003, CMN644N0004	WMO 2004 (NOAA/ESRL & Empa)	12
JMA	MNM224N0000, RYO239N0000, YON224N0000	WMO 2000 （NOAA/ESRL）	Ryori:　05
LA	PDM642N0001	EMD (France)	
LAMP	PUY645N0001	EMD (France)	
LSCE	AMS137S0000	WMO 2004 (NOAA/ESRL & Empa)	08
NOAA/ESRL	NOAA/ESRL flask network*	WMO (NOAA/ESRL & Empa)	Mauna Loa: 03 Barrow: 08 Mt. Waliguan: 00, 04, 09
PolyU	HKG222N0000		
RIVM	KMW653N0000, KTB653N0000	NMI	
SAWS	CPT134S0000	WMO (NOAA/CMDL)	98, 02, 06, 11
SMN	USH354S0000, USH354S0001	WMO (NOAA/ESRL & Empa)	98, 03, 08
SMNA	USH354S0002	WMO (NOAA/ESRL & Empa)	
UBA	NGL653N0000, SSL647N0000, ZSF647N0001, ZUG647N0000	WMO (NOAA/CMDL)	Zugspitze: 01 Sonnblick: 98 Zugspitze/Schneefernerhaus: 06, 11
	SNB647N0000		
Univ. Malta	GLH636N0000		
Univ. York	CVO116N0001	WMO 2000 (NOAA/ESRL & Empa)	

*NOAA/ESRL flask network:
ALT482N0001,ASC107S0001,ASK123N0001,AZR638N0001,BAL655N0001,BHD541S0001,BKT500S0001,BME432N0001,BMW432N0001, BRW471N0001,BSC644N0001,CBA455N0001,CGO540S0001,CHR501N0001,CMO445N0001,CRZ146S0001,EIC327S0001,GMI513N0001, GOZ636N0001,HBA775S0001,HPB647N0003,HUN646N0001,ICE663N0001,ITN435N0001,IZO128N0001,KEY425N0001,KUM519N0001, KZD244N0001,KZM243N0001,LEF445N0001,LLN223N0001,LMP635N0003,MBC476N0001,MHD653N0001,MID528N0001,MLO519N0001, NMB123S0001,NWR440N0101,OXK650N0001,PAL667N0001,POC900N0001,POC905N0001,POC905S0001,POC910N0001,POC910S0001, POC915N0001,POC915S0001,POC920N0001,POC920S0001,POC925N0001,POC925S0001,POC930N0001,POC930S0001,POC935N0000, POC935S0001,PSA764S0001,PTA438N0001,RPB413N0001,SCS903N0001,SCS906N0001,SCS909N0001,SCS912N0001,SCS915N0001, SCS918N0001,SCS921N0001,SEY104S0001,SGP436N0001,SHM452N0001,SMO514S0001,SPO789S0001,STM666N0001,SYO769S0001, TAP236N0001,TDF354S0001,THD441N0001,UTA439N0001,UUM244N0001,WIS631N0001,WLG236N0001,ZEP678N0001

References

Aoki, S., T. Nakazawa, S. Murayama and S. Kawaguchi, Measurements of atmospheric methane at the Japanese Antarctic station, Syowa, *Tellus, Ser. B,* **44**, 273–281, 1992.

Dlugokencky, E. J., L. P. Steele, P. M. Lang, and K. A. Masarie, The growth rate and distribution of atmospheric methane, *J. Geophys. Res.,* **99**, 17021-17043, 1994.

Dlugokencky, E. J., R. C. Myers, P. M. Lang, K. A. Masarie, A. M. Crotwell, K. W. Thoning, B. D. Hall, J. W. Elkins, and L. P. Steele, Conversion of NOAA atmospheric dry air CH_4 mole fractions to a gravimetrically prepared standard scale, *J. Geophys. Res.,* **110**, D18306, doi: 10.1029/2005JD006035, 2005.

Hall, B. D. (ed.), J. W. Elkins, J. H. Butler, S. A. Montzka, T. M. Thompson, L. Del Negro, G. S. Dutton, D. F. Hurst, D. B. King, E. S. Kline, L. Lock, D. Mactaggart, D. Mondeel, F. L. Moore, J. D. Nance, E. A. Ray, and P. A. Romashkin, Halocarbons and Other Atmospheric Gases, Section 5 in Climate Monitoring and Diagnostics Laboratory, Summary Report N. 25, 1998–1999, R. S. Schnell, D. B. King, R. M. Rosson (eds.), NOAA-CMDL, Boulder, CO., USA, 2001.

Hall, B. D., G. S. Dutton, and J. W. Elkins, The NOAA nitrous oxide standard scale for atmospheric observations, *J. Geophys. Res.*, **112**, D09305, doi:10.1029/2006JD007954, 2007.

Hofer, P., B. Buchmann and A. Herzog, Traceability, Uncertainty and Assessment Criteria of Surface Ozone Measurements, *EMPA-WCC Report 98/5*, 20 pp, 1998.

Huang, J., A. Golombek, R. Prinn, R. Weiss, P. Fraser, P. Simmonds, E J. Dlugokencky, B. Hall, J. Elkins, P. Steele, R. Langenfelds, P. Krummel, G. Dutton, and L. Porter, Estimation of regional emissions of nitrous oxide from 1997 to 2005 using multinetwork measurements, a chemical transport model, and an inverse method, *J. Geophys. Res.*, **113**, D17313, doi:10.1029/2007JD009381, 2008.

Klausen, J., C. Zellweger, B. Buchmann, and P. Hofer, Uncertainty and bias of surface ozone measurements at selected Global Atmosphere Watch sites, *J. Geophys. Res.,* **108(D19)**, 4622, doi:10.1029/2003JD003710, 2003.

WMO, WMO Global Atmosphere Watch (GAW) Strategic Plan: 2008–2015, WMO/GAW Report No. 172, 108pp, 2007.

WMO, Addendum for the Period 2012 – 2015 to the WMO Global Atmosphere Watch (GAW) Strategic Plan 2008 – 2015, WMO/GAW Report No. 197, 57pp, 2011.

WMO, 16th WMO/IAEA Meeting on Carbon Dioxide, Other Greenhouse Gases and Related Measurement Techniques (GGMT-2011), ed. Gordon Brailsford, WMO/GAW Report No.206, 67pp, 2012.

Worthy, D. E. J., I. Levin, N. B. A. Trivett, A. J. Kuhlmann, J. F. Hopper and M. K. Ernst, Seven years of continuous methane observations at a remote boreal site in Ontario, Canada, *J. Geophys. Res.,* **103***,* 15995–16007, 1998.

Zhao, C. L., P. P. Tans, and K. W. Thoning, A high precision manometric system for absolute calibrations of CO_2 in dry air, *J. Geophys. Res.,* **102**, 5885–5894, 1997.

LIST OF ABBREVIATIONS IN THE CALIBRATION AND STANDARD SCALES

AEMET	Agencia Estatal de Meteorología (Spain)
AGAGE	Advanced Global Atmospheric Gases Experiment
Aichi	Aichi Prefecture (Japan)
AIST	National Institute of Advanced Industrial Science and Technology (Japan)
AQRB	Air Quality Research Branch, Meteorological Service of Canada (Canada)
ARSO	Agencija Republike Slovenije za Okolje (Slovenia)
AWI	Alfred Wegener Institute for Polar and Marine Research (Germany)
BMKG	Agency for Meteorology, Climatology and Geophysics (Indonesia)
BoM	Commonwealth Bureau of Meteorology (Australia)
CHMI	Czech Hydrometeorological Institute (Czech Republic)
CMA	China Meteorological Administration (China)
CNR-ICES	International Centre for Earth Sciences, Consiglio Nazionale delle Ricerche (Italy)
CSIRO	Commonwealth Scientific and Industrial Research Organisation (Australia)
DEFRA	Department for Environment, Food and Rural Affairs (United Kingdom)
DNA-IAA	Direccion Nacional del Antartico-Instituto Antartico Argentino (Argentina)
DWD	Deutscher Wetterdienst (German Meteorological Service, Germany)
EARS	Environmental Agency of the Republic of Slovenia
EC	Environment Canada (Canada)
EMA	Egyptian Meteorological Authority (Egypt)
EMD	Ecole des Mines de Douai (France)
Empa	Swiss Federal Laboratories for Material Testing and Research (Switzerland)
ENEA	Italian National Agency for New Technology, Energy and the Environment (Italy)
FMI	Finnish Meteorological Institute
GAGE	Global Atmospheric Gases Experiment
GAW	Global Atmosphere Watch (WMO)
HATS	Halocarbons and other Atmospheric Trace Species Group, NOAA/ESRL
HKO	Hong Kong Observatory (Hong Kong, China)
HMS	Hungarian Meteorological Service (Hungary)
IAFMS	Italian Air Force Meteorological Service (Italy)
IEK-8	Institute for Energy and Climate Research: Troposphere (IEK-8), Research Center Juelich GmbH (Germany)
IGP	Instituto Geofísico del Perú (Peru)
IM	Instituto de Meteorologia (Portugal)
IMK-IFU	Institut für Meteorologie und Klimatologie, Atmosphärische Umweltforschung, Forschungszentrum Karlsruhe (Germany)
INRIM	Istituto Nazionale di Ricerca Metrologica (Italy)
INRNE	Institute for Nuclear Research and Nuclear Energy (Bulgaria)
IOEP	Institute of Environmental Protection (Poland)
ISAC	Istituto di Scienze dell'Atmosfera e del Clima, Consiglio Nazionale delle Ricerche (Italy)
ITM	Department of Applied Environmental Science, Stockholm University, (Sweden)
IVL	Swedish Environmental Research Institute, Göteborg (Sweden)
JMA	Japan Meteorological Agency (Japan)
KMA	Korea Meteorological Administration (Republic of Korea)
KMD	Kenya Meteorological Department (Kenya)

KRISS	Korea Research Institute of Standards and Science (Republic of Korea)
KSNU	Kyrgyz State National University (Kyrgyzstan)
KUP	Physics Institute, Climate and Environmental Physics, University of Bern (Switzerland)
LA	Laboratoire d'Aérologie (France)
LAMP	Laboratoire de Météorologie Physique (France)
LEGMA	Latvian Environment, Geology and Meteorology Agency (Latvia)
LSCE	Laboratoire des Sciences du Climat et de l'Environnement (France)
LVGMC	Latvian Environment, Geology and Meteorology Centre (Latvia)
MGO	Main Geophysical Observatory, Roshydromet (Russian Federation)
MPI-BGC	Max-Planck Institute (MPI) for Biogeochemistry in Jena (Germany)
MMD	Malaysian Meteorological Department
MRI	Meteorological Research Institute, JMA (Japan)
Nagoya Univ.	Nagoya University (Japan)
NIER	National Institute of Environmental Research (Republic of Korea)
NIES	National Institute for Environmental Studies (Japan)
NILU	Norwegian Institute for Air Research (Norway)
NIMR	National Institute of Meteorological Reserch, KMA (Republic of Korea)
NIPR	National Institute of Polar Research (Japan)
NIST	National Institute of Standards and Technology (USA)
NIWA	National Institute of Water & Atmospheric Research (New Zealand)
NMA	National Meteorological Administration (Romania)
NMI	Nederlands Meetinstituut
NOAA/ESRL	Earth System Research Laboratory, NOAA (USA)
NPL	National Physical Laboratory (United Kingdom)
NUI	National University of Ireland, Galway (Ireland)
ONM	Office National de la Météorologie (Algeria)
Osaka Univ.	Osaka University (Japan)
PolyU	Hong Kong Polytechnic University (Hong Kong,China)
RIVM	National Institute for Health and Environment (Netherlands)
Roshydromet	Federal Service for Hydrometeorology and Environmental Monitoring (Russian Federation)
RSE	Ricerca sul Sistema Elettrico (Italy)
Saitama	Saitama Prefecture (Japan)
SAWS	South African Weather Service (South Africa)
Shizuoka Univ.	Shizuoka University (Japan)
SMN(SMNA)	Servicio Meteorológico Nacional (Argentina)
Tohoku Univ.	Tohoku University (Japan)
UBA	Umweltbundesamt (Germany)
UNA	Universidad Nacional de Asuncion (Paraguay)
Univ. Malta	University of Malta (Malta)
Univ. York	University of York (United Kingdom of Great Britain and Northern Ireland)
WDCGG	World Data Centre for Greenhouse Gases, operated by JMA, Japan (WMO)
WMO	World Meteorological Organization

LIST OF OBSERVATIONAL STATIONS

Station	Country/Territory	Index Number	Latitude (° ')	Location Longitude (° ')	Altitude (m)	Parameter
REGION I (Africa)						
Amsterdam Island	France	AMS137S00	37 47 S	77 31 E	55	CH_4, CO_2
Amsterdam Island	France	AMS137S00	37 47 S	77 31 E	55	CH_4, CO, CO_2, O_3, VOCs
Ascension Island	United Kingdom of Great Britain and Northern Ireland	ASC107S00	7 55 S	14 25 W	54	$^{13}CH_4$, $^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2, VOCs
Assekrem	Algeria	ASK123N00	23 16 N	5 37 E	2710	O_3
Assekrem	Algeria	ASK123N00	23 16 N	5 37 E	2710	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2, VOCs
Cairo	Egypt	CAI130N00	30 04 N	31 16 E	35	CO_2, O_3
Cape Point	South Africa	CPT134S00	34 21 S	18 28 E	230	CH_4, CO_2
Cape Point	South Africa	CPT134S00	34 21 S	18 28 E	230	CH_4, CO, CO_2, N_2O, O_3
Cape Verde Observatory	Cape Verde	CVO116N00	16 50 N	24 52 W	10	CO, NO, NO_2, NOx, NOy, O_3, VOCs
Crozet	France	CRZ146S00	46 27 S	51 51 E	120	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2, VOCs
Funchal	Portugal	FUN132N00	32 38 N	16 52 W	58	O_3
Gobabeb	Namibia	NMB123S00	23 34 S	15 01 E	461	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2
Izaña (Tenerife)	Spain	IZO128N00	28 18 N	16 30 W	2367	CH_4, CO, CO_2, N_2O, O_3, SF_6
Izaña (Tenerife)	Spain	IZO128N00	28 18 N	16 30 W	2367	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2, VOCs
Mahe Island	Seychelles	SEY104S00	4 40 S	55 10 E	7	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2, VOCs
Mt. Kenya	Kenya	MKN100S00	0 03 S	37 17 E	3678	CO, O_3
Mt. Kenya	Kenya	MKN100S00	0 03 S	37 17 E	3678	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO_2, VOCs
REGION II (Asia)						
Anmyeon-do	Republic of Korea	AMY236N00	36 31 N	126 19 E	47	CFCs, CH_4, CO_2, N_2O, SF_6
Bering Island	Russian Federation	BER255N00	55 12 N	165 58 E	13	CO_2
Cape Ochi-ishi	Japan	COI243N00	43 09 N	145 29 E	42.5	CH_4, CO_2, HCFCs, HFCs, N_2O
Cape Rama	India	CRI215N00	15 04 N	73 49 E	60	$^{13}CO_2$, CH_4, CO, CO_2, H_2, N_2O
Everest - Pyramid	Nepal	PYR227N00	27 57 N	86 48 E	5079	O_3
Gosan	Republic of Korea	GSN233N00	33 16 N	126 10 E	72	CFCs, CH_4, CO_2, N_2O
Gosan	Republic of Korea	GSN233N01	33 10 N	126 05 E	72	CFCs, CH_4, CO_2, N_2O
Hamamatsu	Japan	HMM234N00	34 43 N	137 43 E	35	CO_2
Hateruma	Japan	HAT224N00	24 03 N	123 48 E	10.8	CH_4, CO_2, HCFCs, HFCs, N_2O
Hok Tsui	Hong Kong, China	HKG222N00	22 12 N	114 15 E	60	CO_2
Hok Tsui	Hong Kong, China	HKG222N00	22 12 N	114 15 E	60	CO, O_3
Issyk-Kul	Kyrgyzstan	ISK242N00	42 37 N	76 58 E	1640	CH_4, CO_2, O_3
Kaashidhoo	Maldives	KCO204N00	4 58 N	73 28 E	1	$^{13}CO_2$, CH_4, CO_2
King's Park	Hong Kong, China	HKO222N00	22 18 N	114 10 E	65	CO_2
Kisai	Japan	KIS236N00	36 04 N	139 33 E	13	CO_2
Kotelny Island	Russian Federation	KOT276N00	76 00 N	137 52 E	5	CO_2
Kyzylcha	Uzbekistan	KYZ240N00	40 52 N	66 09 E	340	CO_2
Lulin	China	LLN223N00	23 28 N	120 52 E	2867	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2
Memanbetsu	Japan	MMB243N00	43 55 N	144 11 E	32.9	N_2O
Mikawa-Ichinomiya	Japan	MKW234N00	34 51 N	137 25 E	50	CO_2
Minamitorishima	Japan	MNM224N00	24 16 N	153 58 E	8	CH_4, CO, CO_2, O_3
Mt. Dodaira	Japan	DDR236N00	36 00 N	139 10 E	840	CO_2
Mt. Waliguan	China	WLG236N00	36 16 N	100 54 E	3810	CH_4, CO_2
Mt. Waliguan	China	WLG236N00	36 16 N	100 54 E	3810	$^{13}CH_4$, $^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2

LIST OF OBSERVATIONAL STATIONS (continued)

Station	Country/Territory	Index Number	Location Latitude (° ')	Longitude (° ')	Altitude (m)	Parameter
Nagoya	Japan	NGY235N00	35 08 N	136 58 E	35	N_2O
Plateau Assy	Kazakhstan	KZM243N00	43 15 N	77 52 E	2519	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2
Ryori	Japan	RYO239N00	39 01 N	141 49 E	260	CCl_4, CFCs, CH_3CCl_3, CH_4, CO, CO_2, N_2O, O_3
Sary Taukum	Kazakhstan	KZD244N00	44 27 N	75 34 E	412	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2
Shangdianzi	China	SDZ240N00	40 38 N	117 06 E	287	CH_4, CO_2
Ship between Ishigaki Island and Hateruma Island	Japan	SIH224N00	24 07 N	123 49 E	5	CO_2
South China Sea (03N)	N/A	SCS903N00	3 00 N	105 00 E	15	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2
South China Sea (06N)	N/A	SCS906N00	6 00 N	107 00 E	15	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2
South China Sea (09N)	N/A	SCS909N00	9 00 N	109 00 E	15	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2
South China Sea (12N)	N/A	SCS912N00	12 00 N	111 00 E	15	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2
South China Sea (15N)	N/A	SCS915N00	15 00 N	113 00 E	15	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2
South China Sea (18N)	N/A	SCS918N00	18 00 N	113 00 E	15	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2
South China Sea (21N)	N/A	SCS921N00	21 00 N	114 00 E	15	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2
Suita	Japan	SUI234N00	34 49 N	135 31 E	63	CO_2
Tae-ahn Peninsula	Republic of Korea	TAP236N00	36 43 N	126 07 E	20	$^{13}CH_4$, $^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2, VOCs
Takayama	Japan	TKY236N00	36 08 N	137 25 E	1420	CO_2
Tiksi	Russian Federation	TIK271N00	71 35 N	128 55 E	8	CH_4, CO_2
Tsukuba	Japan	TKB236N00	36 02 N	140 07 E	26	CH_4, CO_2
Tsukuba	Japan	TKB236N10	36 02 N	140 07 E	25	O_3
Ulaan Uul	Mongolia	UUM244N00	44 27 N	111 04 E	914	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2
Urawa	Japan	URW235N00	35 52 N	139 35 E	10	CO_2
Yonagunijima	Japan	YON224N00	24 28 N	123 01 E	30	CH_4, CO, CO_2, O_3
REGION III (South America)						
Arembepe	Brazil	ABP312S00	12 46 S	38 10 W	0	CH_4, CO, CO_2, N_2O
Arembepe	Brazil	ABP312S00	12 46 S	38 10 W	0	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO_2, VOCs
Bird Island	United Kingdom of Great Britain and Northern Ireland	SGI354S00	54 00 S	38 02 W	30	CH_4, CO_2
Easter Island	Chile	EIC327S00	27 07 S	109 27 W	50	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2, VOCs
Huancayo	Peru	HUA312S00	12 04 S	75 31 W	3313	CO_2
La Quiaca Observatorio	Argentina	LQO322S00	22 06 S	65 35 W	3459	O_3
Pilar Observatorio	Argentina	PIL331S00	31 40 S	63 53 W	338	O_3
San Julian Aero	Argentina	SJA349S00	49 18 S	67 49 W	58	O_3
San Lorenzo	Paraguay	SNL325S00	25 22 S	57 32 W	133	O_3
Tierra del Fuego	Argentina	TDF354S00	54 52 S	68 28 W	20	$^{13}CO_2$, $C^{18}O_2$, C_2Cl_4, $CBrClF_2$, CFCs, CH_2Cl_2, CH_3Br, CH_3CCl_3, CH_3Cl, CH_4, CO, CO_2, H_2, HCFCs, HFCs, VOCs
Ushuaia	Argentina	USH354S00	54 49 S	68 17 W	18	CO, O_3
Ushuaia	Argentina	USH354S00	54 49 S	68 17 W	18	CO, O_3
REGION IV (North and Central America)						
Alert	Canada	ALT482N00	82 27 N	62 31 W	210	$^{13}CO_2$, CH_4, CO, CO_2, H_2, N_2O
Alert	Canada	ALT482N00	82 27 N	62 31 W	210	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, N_2O, SF_6

LIST OF OBSERVATIONAL STATIONS (continued)

Station	Country/Territory	Index Number	Location		Altitude (m)	Parameter
			Latitude (° ')	Longitude (° ')		
Alert	Canada	ALT482N00	82 27 N	62 31 W	210	$^{13}CH_4$, $^{13}CO_2$, $C^{18}O_2$, C_2Cl_4, $CBrClF_2$, $CBrF_3$, CCl_4, CFCs, CH_2Cl_2, CH_3Br, CH_3CCl_3, CH_3Cl, CH_4, CO, CO_2, H_2, HCFCs, HFCs, N_2O, SF_6, VOCs
Algoma	Canada	ALG447N00	47 01 N	84 22 W	411	O_3
Argyle	United States of America	AMT445N00	45 01 N	68 40 W	50	$^{13}CO_2$, $C^{18}O_2$, CH_4, VOCs
Barrow	United States of America	BRW471N00	71 19 N	156 35 W	11	$^{13}CH_4$, $^{13}CO_2$, $C^{18}O_2$, C_2Cl_4, $CBrClF_2$, $CBrF_3$, CCl_4, CFCs, CH_2Cl_2, CH_3Br, CH_3CCl_3, CH_3Cl, CH_4, CO, CO_2, H_2, HCFCs, HFCs, N_2O, O_3, SF_6, VOCs
Bratt's Lake	Canada	BRA450N00	50 12 N	104 42 W	595	O_3
Candle Lake	Canada	CDL453N00	53 52 N	104 39 W	489	CH_4, CO, CO_2
Cape Meares	United States of America	CMO445N00	45 28 N	123 58 W	30	CCl_4, CFCs, CH_3CCl_3, CH_4, N_2O
Cape Meares	United States of America	CMO445N00	45 28 N	123 58 W	30	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2
Cape St. James	Canada	CSJ451N00	51 55 N	131 01 W	89	CO_2
Chalk River	Canada	CHA446N00	46 04 N	77 24 W	184	O_3
Chibougamau	Canada	CHM449N00	49 40 N	74 20 W	393	CH_4, CO, CO_2
Churchill	Canada	CHL458N00	58 45 N	94 04 W	35	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO_2, N_2O
Cold Bay	United States of America	CBA455N00	55 12 N	162 43 W	25	$^{13}CH_4$, $^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2, VOCs
East Trout Lake	Canada	ETL454N00	54 21 N	104 59 W	492	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2
Egbert	Canada	EGB444N00	44 13 N	79 46 W	253	O_3
Egbert	Canada	EGB444N01	44 13 N	79 46 W	253	CH_4, CO, CO_2, VOCs
Estevan Point	Canada	ESP449N00	49 22 N	126 32 W	39	$^{13}CO_2$, CH_4, CO, CO_2, H_2, N_2O
Estevan Point	Canada	ESP449N00	49 22 N	126 32 W	39	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, N_2O, SF_6
Esther	Canada	EST451N00	51 40 N	110 12 W	707	O_3
Experimental Lakes Area	Canada	ELA449N00	49 40 N	93 43 W	369	O_3
Fraserdale	Canada	FSD449N00	49 52 N	81 34 W	210	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2
Grifton	United States of America	ITN435N00	35 21 N	77 22 W	505	$^{13}CO_2$, $C^{18}O_2$, CCl_4, CFCs, CH_4, CO, CO_2, H_2, N_2O, SF_6
Harvard Forest	United States of America	HFM442N00	42 53 N	72 17 W	340	C_2Cl_4, $CBrClF_2$, CCl_4, CFCs, CH_2Cl_2, CH_3Br, CH_3CCl_3, CH_3Cl, HCFCs, HFCs, N_2O, SF_6
Kejimkujik	Canada	KEJ444N00	44 25 N	65 12 W	127	O_3
Key Biscayne	United States of America	KEY425N00	25 40 N	80 12 W	3	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2, VOCs
Kitt Peak	United States of America	KPA431N00	31 58 N	111 35 W	2083	CH_4
La Jolla	United States of America	SIO432N00	32 49 N	117 16 W	14	CH_4
La Palma	Cuba	PLM422N00	22 45 N	83 31 W	47	NO_2
Lac La Biche	Canada	LLB454N00	54 57 N	112 27 W	540	CH_4, CO_2, VOCs
Lac La Biche (Alberta)	Canada	LLB454N01	54 57 N	112 27 W	540	CH_4, CO, CO_2

LIST OF OBSERVATIONAL STATIONS (continued)

Station	Country/Territory	Index Number	Location		Altitude (m)	Parameter
			Latitude (° ')	Longitude (° ')		
Mex High Altitude Global Climate Observation Center, Mexico	Mexico	MEX419N00	19 58 N	97 10 W	4560	CH_4, CO_2, VOCs
Moody	United States of America	WKT431N00	31 19 N	97 19 W	708	$^{13}CO_2$, $C^{18}O_2$, CH_4
Mould Bay	Canada	MBC476N00	76 15 N	119 19 W	58	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2
Niwot Ridge (C-1)	United States of America	NWR440N00	40 02 N	105 32 W	3021	C_2Cl_4, $CBrClF_2$, $CBrF_3$, CCl_4, CFCs, CH_2Cl_2, CH_3Br, CH_3CCl_3, CH_3Cl, HCFCs, HFCs, N_2O, O_3, SF_6
Niwot Ridge (Saddle)	United States of America	NWR440N02	40 03 N	105 35 W	3528	O_3
Niwot Ridge (T-van)	United States of America	NWR440N01	40 03 N	105 35 W	3523	$^{13}CH_4$, $^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2, N_2O
Olympic Peninsula	United States of America	OPW448N00	48 15 N	124 25 W	488	CH_4, CO_2, H_2
Pacific Ocean (15N)	N/A	POC915N00	15 00 N	145 00 W	10	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2
Pacific Ocean (20N)	N/A	POC920N00	20 00 N	141 00 W	10	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2
Pacific Ocean (25N)	N/A	POC925N00	25 00 N	139 00 W	10	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2
Pacific Ocean (30N)	N/A	POC930N00	30 00 N	135 00 W	10	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2
Pacific Ocean (35N)	N/A	POC935N00	35 00 N	137 00 W	10	$^{13}CO_2$, $C^{18}O_2$, CO, H_2
Pacific Ocean (40N)	N/A	POC940N00	40 00 N	136 00 W	10	$^{13}CO_2$, H_2
Pacific Ocean (45N)	N/A	POC945N00	45 00 N	131 00 W	10	$^{13}CO_2$, H_2
Park Falls	United States of America	LEF445N00	45 55 N	90 16 W	868	$^{13}CO_2$, $C^{18}O_2$, C_2Cl_4, $CBrClF_2$, CCl_4, CFCs, CH_2Cl_2, CH_3Br, CH_3CCl_3, CH_3Cl, CH_4, CO, CO_2, H_2, HCFCs, HFCs, N_2O, SF_6, VOCs
Point Arena	United States of America	PTA438N00	38 57 N	123 43 W	17	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2
Ragged Point	Barbados	RPB413N00	13 10 N	59 25 W	45	C_2Cl_4, C_2HCl_3, $CBrClF_2$, $CBrF_3$, CCl_4, CFCs, CH_2Cl_2, CH_3Br, CH_3CCl_3, CH_3Cl, CH_4, $CHCl_3$, HCFCs, HFCs, N_2O, PFCs, SF_6, SO_2F_2
Ragged Point	Barbados	RPB413N00	13 10 N	59 25 W	45	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2, O_3
Sable Island	Canada	WSA443N00	43 55 N	60 01 W	5	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, N_2O, SF_6
Saturna	Canada	SAT448N00	48 46 N	123 07 W	178	O_3
Shemya Island	United States of America	SHM452N00	52 43 N	174 04 E	40	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2, VOCs
Southern Great Plains	United States of America	SGP436N00	36 46 N	97 30 W	314	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2, N_2O, SF_6, VOCs
St. Croix	United States of America	AVI417N00	17 45 N	64 45 W	3	CH_4, CO_2
St. David's Head	United Kingdom of Great Britain and Northern Ireland	BME432N00	32 22 N	64 39 W	30	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2

LIST OF OBSERVATIONAL STATIONS (continued)

Station	Country/Territory	Index Number	Location Latitude (° ')	Location Longitude (° ')	Altitude (m)	Parameter
Trinidad Head	United States of America	THD441N00	41 02 N	124 09 W	120	C_2Cl_4, C_2HCl_3, $CBrClF_2$, $CBrF_3$, CCl_4, CFCs, CH_2Cl_2, CH_3Br, CH_3CCl_3, CH_3Cl, CH_4, $CHCl_3$, HCFCs, HFCs, N_2O, PFCs, SF_6, SO_2F_2
Trinidad Head	United States of America	THD441N00	41 02 N	124 09 W	120	$^{13}CO_2$, $C^{18}O_2$, C_2Cl_4, $CBrClF_2$, CCl_4, CFCs, CH_2Cl_2, CH_3Br, CH_3CCl_3, CH_3Cl, CH_4, CO, CO_2, HCFCs, HFCs, N_2O, O_3, SF_6, VOCs
Tudor Hill	United Kingdom of Great Britain and Northern Ireland	BMW432N00	32 16 N	64 52 W	30	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2, O_3, VOCs
Wendover	United States of America	UTA439N00	39 52 N	113 43 W	1320	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2, VOCs
West Branch	United States of America	WBI441N00	41 43 N	91 21 W	241.7	$^{13}CO_2$, $C^{18}O_2$
REGION V (South-West Pacific)						
Baring Head	New Zealand	BHD541S00	41 24 S	174 52 E	85	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2
Baring Head	New Zealand	BHD541S00	41 24 S	174 52 E	85	$^{13}CH_4$, $^{14}CO_2$, CH_4, CO, CO_2, N_2O, O_3, VOCs
Bukit Koto Tabang	Indonesia	BKT500S00	0 12 S	100 19 E	864.5	NO_2, SO_2
Bukit Koto Tabang	Indonesia	BKT500S00	0 12 S	100 19 E	864.5	CH_4, CO, CO_2, O_3
Bukit Koto Tabang	Indonesia	BKT500S00	0 12 S	100 19 E	864.5	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2, N_2O, SF_6, VOCs
Cape Ferguson	Australia	CFA519S00	19 16 S	147 03 E	2	$^{13}CO_2$, CH_4, CO, CO_2, H_2, N_2O
Cape Grim	Australia	CGO540S00	40 40 S	144 40 E	94	CO_2, O_3
Cape Grim	Australia	CGO540S00	40 40 S	144 40 E	94	C_2Cl_4, C_2HCl_3, $CBrClF_2$, $CBrF_3$, CCl_4, CFCs, CH_2Cl_2, CH_3Br, CH_3CCl_3, CH_3Cl, CH_4, $CHCl_3$, CO, H_2, HCFCs, HFCs, N_2O, PFCs, SF_6, SO_2F_2
Cape Grim	Australia	CGO540S00	40 40 S	144 40 E	94	$^{13}CO_2$, CH_4, CO, CO_2, H_2, N_2O
Cape Grim	Australia	CGO540S00	40 40 S	144 40 E	94	$^{13}CH_4$, $^{13}CO_2$, $C^{18}O_2$, C_2Cl_4, $CBrClF_2$, $CBrF_3$, CCl_4, CFCs, CH_2Cl_2, CH_3Br, CH_3CCl_3, CH_3Cl, CH_4, CO, CO_2, H_2, HCFCs, HFCs, N_2O, SF_6, VOCs
Cape Kumukahi	United States of America	KUM519N00	19 31 N	154 49 W	3	$^{13}CH_4$, $^{13}CO_2$, $C^{18}O_2$, C_2Cl_4, $CBrClF_2$, $CBrF_3$, CCl_4, CFCs, CH_2Cl_2, CH_3Br, CH_3CCl_3, CH_3Cl, CH_4, CO, CO_2, H_2, HCFCs, HFCs, N_2O, SF_6, VOCs
Christmas Island	Kiribati	CHR501N00	1 42 N	157 10 W	3	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2
Danum Valley GAW Baseline Station	Malaysia	DMV504N00	4 58 N	117 49 E	426	CO_2, O_3
Guam	United States of America	GMI513N00	13 25 N	144 46 E	2	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2, VOCs
Gunn Point	Australia	GPA512S00	12 14 S	131 02 E	25	$^{13}CO_2$, CH_4, CO, CO_2, H_2, N_2O
Jakarta	Indonesia	JKR506S00	6 10 S	106 49 E	7	NO_2, SO_2
Kaitorete Spit	New Zealand	NZL543S00	43 49 S	172 37 E	3	CH_4
Lauder	New Zealand	LAU545S00	45 01 S	169 40 E	370	O_3

LIST OF OBSERVATIONAL STATIONS (continued)

			Location			
Station	Country/Territory	Index Number	Latitude (° ')	Longitude (° ')	Altitude (m)	Parameter
Macquarie Island	Australia	MQA554S00	54 28 S	158 58 E	12	$^{13}CO_2$, CH_4, CO, CO_2, H_2, N_2O
Mauna Loa	United States of America	MLO519N00	19 32 N	155 34 W	3397	$^{13}CO_2$, CH_4, CO, CO_2, H_2, N_2O
Mauna Loa	United States of America	MLO519N00	19 32 N	155 34 W	3397	$^{13}CH_4$, $^{13}CO_2$, $C^{18}O_2$, C_2Cl_4, $CBrClF_2$, $CBrF_3$, CCl_4, CFCs, CH_2Cl_2, CH_3Br, CH_3CCl_3, CH_3Cl, CH_4, CO, CO_2, H_2, HCFCs, HFCs, N_2O, O_3, SF_6, VOCs
Pacific Ocean (00N)	N/A	POC900N00	0 00 N	155 00 W	10	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2
Pacific Ocean (05N)	N/A	POC905N00	5 00 N	151 00 W	10	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2
Pacific Ocean (05S)	N/A	POC905S00	5 00 S	159 00 W	10	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2
Pacific Ocean (10N)	N/A	POC910N00	10 00 N	149 00 W	10	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2
Pacific Ocean (10S)	N/A	POC910S00	10 00 S	161 00 W	10	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2
Pacific Ocean (15S)	N/A	POC915S00	15 00 S	171 00 W	10	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2
Pacific Ocean (20S)	N/A	POC920S00	20 00 S	174 00 W	10	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2
Pacific Ocean (25S)	N/A	POC925S00	25 00 S	171 00 W	10	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2
Pacific Ocean (30S)	N/A	POC930S00	30 00 S	176 00 W	10	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2
Pacific Ocean (35S)	N/A	POC935S00	35 00 S	180 00 E	10	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2
Sand Island	United States of America	MID528N00	28 11 N	177 22 W	7.7	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2, VOCs
Tanah Rata	Malaysia	TAR504N00	4 28 N	101 22 E	1545	O_3
Tutuila (Cape Matatula)	United States of America	SMO514S00	14 14 S	170 34 W	42	C_2Cl_4, C_2HCl_3, $CBrClF_2$, $CBrF_3$, CCl_4, CFCs, CH_2Cl_2, CH_3Br, CH_3CCl_3, CH_3Cl, CH_4, $CHCl_3$, HCFCs, HFCs, N_2O, PFCs, SF_6, SO_2F_2
Tutuila (Cape Matatula)	United States of America	SMO514S00	14 14 S	170 34 W	42	$^{13}CH_4$, $^{13}CO_2$, $C^{18}O_2$, C_2Cl_4, $CBrClF_2$, $CBrF_3$, CCl_4, CFCs, CH_2Cl_2, CH_3Br, CH_3CCl_3, CH_3Cl, CH_4, CO, CO_2, H_2, HCFCs, HFCs, N_2O, O_3, SF_6, VOCs
REGION VI (Europe)						
Adrigole	Ireland	ADR651N00	51 40 N	9 43 W	50	CCl_4, CFCs, CH_3CCl_3, N_2O
Angra do Heroismo	Portugal	ANG638N00	38 40 N	27 13 W	74	O_3
BEO Moussala	Bulgaria	BEO642N00	42 10 N	23 35 E	2925	CO, CO_2, NO, NO_2, NOx, O_3, SO_2
Baltic Sea	Poland	BAL655N00	55 21 N	17 13 E	28	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2, VOCs
Begur	Spain	BGU641N00	41 58 N	3 13 E	13	CH_4, CO_2
Beja	Portugal	BEJ638N00	38 01 N	7 52 W	246	O_3
Black Sea	Romania	BSC644N00	44 10 N	28 40 E	3	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2, VOCs
Bragança	Portugal	BRG641N00	41 47 N	6 43 W	690	SO_2
Brotjacklriegel	Germany	BRT648N00	48 49 N	13 13 E	1016	CO_2, O_3
Burgas	Bulgaria	BUR642N00	42 28 N	27 28 E	16	NO_2, SO_2
Castelo Branco	Portugal	CAS639N00	39 49 N	7 28 W	386	O_3
Danki	Russian Federation	DAK654N00	54 53 N	37 47 E	140	O_3
Deuselbach	Germany	DEU649N00	49 46 N	7 02 E	480	CH_4, CO_2, O_3
Dobele	Latvia	DBL656N00	56 22 N	23 11 E	42	O_3
Doñana	Spain	DON637N00	37 02 N	6 32 W	5	NO_2, O_3, SO_2

LIST OF OBSERVATIONAL STATIONS (continued)

Station	Country/Territory	Index Number	Location		Altitude (m)	Parameter
			Latitude (° ')	Longitude (° ')		
Dwejra Point	Malta	GOZ636N00	36 02 N	14 10 E	30	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2
Eskdalemuir	United Kingdom of Great Britain and Northern Ireland	EDM655N00	55 19 N	3 12 W	242	O_3
Finokalia	Greece	FIK635N00	35 20 N	25 40 E	150	CH_4, CO_2
Fundata	Romania	FDT645N00	45 28 N	25 18 E	1383.5	NO_2, SO_2
Fundata	Romania	FDT645N00	45 28 N	25 18 E	1383.5	CO_2, NO_2, O_3
Giordan Lighthouse	Malta	GLH636N00	36 04 N	14 13 E	160	^{222}Rn, CH_4, CO, CO_2, NO, NO_2, NOx, O_3, SO_2
Hegyhatsal	Hungary	HUN646N00	46 57 N	16 38 E	248	CO_2
Hegyhatsal	Hungary	HUN646N00	46 57 N	16 38 E	248	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2, N_2O, SF_6
Heimaey	Iceland	ICE663N00	63 23 N	20 16 W	100	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2, O_3, VOCs
Hohe Warte	Austria	HHE648N00	48 15 N	16 22 E	202	NO, NO_2, SO_2
Hohe Warte	Austria	HHE648N00	48 15 N	16 22 E	202	NO, NO_2, SO_2
Hohenpeissenberg	Germany	HPB647N00	47 47 N	11 01 E	985	^{222}Rn, CO, H_2O_2, NO, NO_2, NOx, NOy, O_3, PAN, ROOH, SO_2, VOCs
Hohenpeissenberg	Germany	HPB647N00	47 47 N	11 01 E	985	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, VOCs
Ile Grande	France	LPO648N00	48 48 N	3 35 W	10	CH_4, CO_2
Iskrba	Slovenia	IRB645N00	45 34 N	14 52 E	520	NO_2, O_3, SO_2
Ivan Sedlo	Bosnia and Herzegovina	IVN643N00	43 46 N	18 01 E	970	NO_2, SO_2
Jarczew	Poland	JCZ651N00	51 49 N	21 58 E	180	NO_2, SO_2
Jungfraujoch	Switzerland	JFJ646N00	46 32 N	7 59 E	3580	CO_2
Jungfraujoch	Switzerland	JFJ646N00	46 32 N	7 59 E	3580	CH_4, CO, CO_2, H_2, N_2O, NO, NO_2, NOx, NOy, O_3, PAN, SF_6, SO_2, VOCs
Jungfraujoch	Switzerland	JFJ646N00	46 32 N	7 59 E	3580	C_2Cl_4, C_2HCl_3, $CBrClF_2$, $CBrF_3$, CFCs, CH_2Cl_2, CH_3Br, CH_3CCl_3, CH_3Cl, $CHCl_3$, HCFCs, HFCs, PFCs, SF_6, SO_2F_2
K-puszta	Hungary	KPS646N00	46 58 N	19 33 E	125	CO_2, NO_2, O_3, SO_2
Kamenicki Vis	Serbia	KAM643N00	43 23 N	21 56 E	813	NO_2, SO_2
Kloosterburen	Netherlands (the)	KTB653N00	53 23 N	6 25 E	0	CO, NO, NO_2, NOx, SO_2
Kollumerwaard	Netherlands (the)	KMW653N00	53 19 N	6 16 E	0	CH_4, CO, CO_2, NO, NO_2, NOx, O_3, SO_2
Kosetice	Czech Republic	KOS649N00	49 34 N	15 04 E	534	CH_4, CO, NO, NO_2, O_3, SO_2
Kovk	Slovenia	KVK646N00	46 07 N	15 05 E	600	O_3
Krvavec	Slovenia	KVV646N00	46 17 N	14 31 E	1720	CO, O_3
La Cartuja	Spain	CAR637N00	37 12 N	3 36 W	720	NO_2, SO_2
Lampedusa	Italy	LMP635N00	35 31 N	12 37 E	45	$CBrClF_2$, $CBrF_3$, CCl_4, CFCs, CH_2Br_2, CH_2Cl_2, CH_3Br, CH_3CCl_3, CH_3Cl, CH_3I, CH_4, $CHCl_3$, CO_2, HCFCs, HFCs, N_2O, SF_6
Lampedusa	Italy	LMP635N00	35 31 N	12 37 E	45	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2
Lazaropole	The former Yugoslav Republic of Macedonia	LZP641N00	41 31 N	20 41 E	1320	NO_2, SO_2
Leba	Poland	LEB654N00	54 45 N	17 31 E	2	NO_2, SO_2
Lisboa / Gago Coutinho	Portugal	LIS638N00	38 46 N	9 07 W	105	O_3
Logroño	Spain	LOG642N00	42 27 N	2 30 W	370	NO_2, SO_2
Mace Head	Ireland	MHD653N00	53 19 N	9 54 W	8	O_3

LIST OF OBSERVATIONAL STATIONS (continued)

Station	Country/Territory	Index Number	Location Latitude (° ')	Location Longitude (° ')	Altitude (m)	Parameter
Mace Head	Ireland	MHD653N00	53 19 N	9 54 W	8	CH_4, CO_2
Mace Head	Ireland	MHD653N00	53 19 N	9 54 W	8	C_2Cl_4, C_2HCl_3, $CBrClF_2$, $CBrF_3$, CCl_4, CFCs, CH_2Cl_2, CH_3Br, CH_3CCl_3, CH_3Cl, CH_4, $CHCl_3$, CO, H_2, HCFCs, HFCs, N_2O, PFCs, SF_6, SO_2F_2
Mace Head	Ireland	MHD653N00	53 19 N	9 54 W	8	$^{13}CH_4$, $^{13}CO_2$, $C^{18}O_2$, C_2Cl_4, $CBrClF_2$, $CBrF_3$, CCl_4, CFCs, CH_2Cl_2, CH_3Br, CH_3CCl_3, CH_3Cl, CH_4, CO, CO_2, H_2, HCFCs, HFCs, N_2O, SF_6, VOCs
Mahón	Spain	MHN639N00	39 52 N	4 19 E	78	NO_2, O_3, SO_2
Monte Cimone	Italy	CMN644N00	44 10 N	10 41 E	2165	CO_2
Monte Cimone	Italy	CMN644N00	44 10 N	10 41 E	2165	CH_4, CO, H_2, N_2O, O_3, SF_6
Monte Velho	Portugal	MVH638N00	38 04 N	8 48 W	43	O_3
Neuglobsow	Germany	NGL653N00	53 10 N	13 01 E	65	CH_4, CO, CO_2, O_3
Noia	Spain	NIA642N00	42 43 N	8 55 W	685	NO_2, O_3, SO_2
Ocean Station "M"	Norway	STM666N00	66 00 N	2 00 E	5	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2
Ocean Station Charlie	Russian Federation	STC652N00	52 45 N	35 30 W	5	CO_2
Ocean Station Charlie	United States of America	STC654N00	54 00 N	35 00 W	6	CO_2
Ochsenkopf	Germany	OXK650N00	50 01 N	11 48 E	1185	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, VOCs
Oulanka	Finland	OUL666N00	66 19 N	29 23 E	310	NO_2, O_3, SO_2
Pallas-Sammaltunturi	Finland	PAL667N00	67 58 N	24 07 E	560	CH_4, CO_2, O_3
Pallas-Sammaltunturi	Finland	PAL667N00	67 58 N	24 07 E	560	$^{13}CO_2$, $C^{18}O_2$, $CBrF_3$, CH_4, CO, CO_2, VOCs
Payerne	Switzerland	PAY646N00	46 49 N	6 57 E	490	CO, NO, NO_2, NOx, O_3, SO_2, VOCs
Penhas Douradas	Portugal	PEN640N00	40 25 N	7 32 W	1380	O_3
Pic du Midi	France	PDM642N00	42 56 N	0 08 E	2877	CO, O_3
Pic du Midi	France	PDM642N00	42 56 N	0 08 E	2877	CH_4, CO_2
Plateau Rosa	Italy	PRS645N00	45 55 N	7 42 E	3480	CH_4, CO_2, O_3
Pleven	Bulgaria	PLV643N00	43 25 N	24 36 E	64	NO_2, SO_2
Plovdiv	Bulgaria	PLD642N00	42 07 N	24 45 E	179	NO_2, SO_2
Puszcza Borecka/Diabla Gora	Poland	DIG654N00	54 08 N	22 04 E	157	CO_2, NO_2, O_3, SO_2
Puy de Dome	France	PUY645N00	45 46 N	2 57 E	1465	CO, O_3
Puy de Dome	France	PUY645N00	45 46 N	2 57 E	1465	CH_4, CO_2
Ridge Hill	United Kingdom of Great Britain and Northern Ireland	RGL651N00	51 59 N	2 32 W	204	CH_4, CO_2, N_2O, SF_6
Rigi	Switzerland	RIG646N00	46 04 N	8 26 E	1031	CO, NO, NO_2, NOx, O_3, SO_2, VOCs
Roquetes	Spain	ROQ640N00	40 49 N	0 28 E	50	NO_2, O_3, SO_2
Rucava	Latvia	RCV656N00	56 09 N	21 10 E	18	NO_2, O_3, SO_2
San Pablo de los Montes	Spain	SPM639N00	39 32 N	4 20 W	917	NO_2, O_3, SO_2
Schauinsland	Germany	SSL647N00	47 55 N	7 55 E	1205	CH_4, CO, CO_2, N_2O, NO, NO_2, O_3, PAN, SF_6
Sede Boker	Israel	WIS631N00	31 07 N	34 52 E	400	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2
Semenic	Romania	SEM645N00	45 07 N	21 58 E	1432	NO_2, SO_2
Shepelevo	Russian Federation	SHP659N00	59 58 N	29 07 E	4	O_3

LIST OF OBSERVATIONAL STATIONS (continued)

			Location			
Station	Country/Territory	Index Number	Latitude (° ')	Longitude (° ')	Altitude (m)	Parameter
Shetland	United Kingdom of Great Britain and Northern Ireland	SIS660N00	60 04 N	1 15 W	30	$^{13}CO_2$, CH_4, CO, CO_2, H_2, N_2O
Site J	Denmark	GRL666N00	66 30 N	46 12 W	2030	CH_4
Sniezka	Poland	SNZ650N00	50 43 N	15 43 E	1603	NO_2, SO_2
Sofia	Bulgaria	SOF642N00	42 38 N	23 22 E	586	NO_2, SO_2
Sonnblick	Austria	SNB647N00	47 02 N	12 56 E	3106	CH_4, CO, CO_2, NO, NO_2, NOy, O_3
Stephansplatz	Austria	STP648N00	48 13 N	16 22 E	171	NO, NO_2, SO_2
Stephansplatz	Austria	STP648N00	48 13 N	16 22 E	171	NO, NO_2, SO_2
Stîna de Vale	Romania	STN646N00	46 40 N	22 37 E	1116	NO_2, SO_2
Summit	Denmark	SUM672N00	72 34 N	38 28 W	3238	$^{13}CO_2$, $C^{18}O_2$, $CBrClF_2$, CCl_4, CFCs, CH_2Cl_2, CH_3Br, CH_3CCl_3, CH_3Cl, CH_4, CO_2, HCFCs, HFCs, N_2O, O_3, SF_6, VOCs
Suwalki	Poland	SWL654N00	54 07 N	22 56 E	184	NO_2, SO_2
Tacolneston Tall Tower	United Kingdom of Great Britain and Northern Ireland	TAC652N00	52 31 N	1 08 E	56	C_2Cl_4, C_2HCl_3, $CBrClF_2$, $CBrF_3$, CFCs, CH_2Cl_2, CH_3Br, CH_3CCl_3, CH_3Cl, CH_4, $CHCl_3$, CO, CO_2, H_2, HCFCs, HFCs, N_2O, PFCs, SF_6, SO_2F_2
Terceira Island	Portugal	AZR638N00	38 46 N	27 22 W	40	$^{13}CH_4$, $^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2, VOCs
Teriberka	Russian Federation	TER669N00	69 12 N	35 06 E	40	CH_4, CO_2
Utö	Finland	UTO659N00	59 46 N	21 22 E	7	NO_2, O_3, SO_2
Varna	Bulgaria	VRN643N00	43 12 N	27 55 E	41	NO_2, SO_2
Viana do Castelo	Portugal	VDC641N00	41 42 N	8 48 W	16	SO_2
Vindeln	Sweden	VDL664N00	64 15 N	19 46 E	271	O_3
Virolahti	Finland	VIR660N00	60 31 N	27 40 E	4	NO_2, O_3, SO_2
Waldhof	Germany	LGB652N00	52 47 N	10 46 E	74	CO_2, O_3
Wank Peak	Germany	WNK647N00	47 31 N	11 09 E	1780	CO_2, NOx, SO_2
Westerland	Germany	WES654N00	54 55 N	8 19 E	12	CO_2, O_3
Zabljak	Montenegro	ZBL643N00	43 08 N	19 07 E	1450	NO_2, SO_2
Zavodnje	Slovenia	ZRN646N00	46 25 N	15 00 E	770	O_3
Zeppelinfjellet (Ny-Alesund)	Norway	ZEP678N00	78 54 N	11 52 E	475	CO_2
Zeppelinfjellet (Ny-Alesund)	Norway	ZEP678N00	78 54 N	11 52 E	475	CCl_4, CFCs, CH_3CCl_3, N_2O, O_3, SO_2
Zeppelinfjellet (Ny-Alesund)	Norway	ZEP678N00	78 54 N	11 52 E	475	C_2Cl_4, C_2HCl_3, $CBrClF_2$, $CBrF_3$, CFCs, CH_2Cl_2, CH_3Br, CH_3CCl_3, CH_3Cl, $CHCl_3$, HCFCs, HFCs, PFCs, SF_6, SO_2F_2
Zeppelinfjellet (Ny-Alesund)	Norway	ZEP678N00	78 54 N	11 52 E	475	$^{13}CH_4$, $^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2, VOCs
Zingst	Germany	ZGT654N00	54 25 N	12 43 E	1	CH_4, CO_2, O_3
Zoseni	Latvia	ZSN657N00	57 04 N	25 32 E	182	NO_2, O_3, SO_2
Zugspitze	Germany	ZUG647N00	47 25 N	10 58 E	2960	CO_2
Zugspitze	Germany	ZUG647N00	47 25 N	10 58 E	2960	CH_4, CO, CO_2, NO, NOx, NOy, O_3
Zugspitze / Schneefernerhaus	Germany	ZSF647N00	47 25 N	10 58 E	2656	SO_2
Zugspitze / Schneefernerhaus	Germany	ZSF647N00	47 25 N	10 58 E	2656	CH_4, CO, CO_2, N_2O, NO, NO_2, NOy, O_3, PAN, SF_6
Ähtäri	Finland	AHT662N00	62 34 N	24 11 E	180	NO_2, O_3, SO_2

LIST OF OBSERVATIONAL STATIONS (continued)

Station	Country/Territory	Index Number	Location			Parameter
			Latitude (° ')	Longitude (° ')	Altitude (m)	
ANTARCTICA						
Arrival Heights	New Zealand	ARH777S00	77 47 S	166 40 E	184	O_3
Arrival Heights	New Zealand	ARH777S00	77 47 S	166 40 E	184	$^{13}CH_4$, CH_4, CO, N_2O
Casey Station	Australia	CYA766S00	66 16 S	110 31 E	60	$^{13}CO_2$, CH_4, CO, CO_2, H_2, N_2O
Concordia, Dôme C	France	DCC775S00	75 05 S	123 20 E	3233	O_3
Halley Bay	United Kingdom of Great Britain and Northern Ireland	HBA775S00	75 34 S	26 30 W	33	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2, VOCs
Jubany	Argentina	JBN762S00	62 13 S	58 40 W	15	CO_2
King Sejong	Republic of Korea	KSG762S00	62 12 S	58 46 W	0	CO_2
Marambio	Argentina	MBI764S00	64 14 S	56 37 W	198	O_3
Mawson	Australia	MAA767S00	67 37 S	62 52 E	32	$^{13}CO_2$, CH_4, CO, CO_2, H_2, N_2O
McMurdo Station	United States of America	MCM777S00	77 49 S	166 34 E	11	CH_4, O_3
Mizuho	Japan	MZH770S00	70 42 S	44 17 E	2230	CH_4
Neumayer	Germany	NMY770S00	70 39 S	8 15 W	42	O_3
Palmer Station	United States of America	PSA764S00	64 55 S	64 00 W	10	$^{13}CO_2$, $C^{18}O_2$, C_2Cl_4, $CBrClF_2$, CCl_4, CFCs, CH_2Cl_2, CH_3Br, CH_3CCl_3, CH_3Cl, CH_4, CO, CO_2, H_2, HCFCs, HFCs, N_2O, SF_6, VOCs
South Pole	United States of America	SPO789S00	89 58 S	24 48 W	2810	$^{13}CO_2$, CH_4, CO, CO_2, H_2, N_2O
South Pole	United States of America	SPO789S00	89 58 S	24 48 W	2810	$^{13}CH_4$, $^{13}CO_2$, $C^{18}O_2$, C_2Cl_4, $CBrClF_2$, $CBrF_3$, CCl_4, CFCs, CH_2Cl_2, CH_3Br, CH_3CCl_3, CH_3Cl, CH_4, CO, CO_2, H_2, HCFCs, HFCs, N_2O, O_3, SF_6, VOCs
Syowa Station	Japan	SYO769S00	69 00 S	39 34 E	16	O_3
Syowa Station	Japan	SYO769S00	69 00 S	39 34 E	16	CO_2
Syowa Station	Japan	SYO769S00	69 00 S	39 34 E	16	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2, VOCs
MOBILE STATION						
Aircraft (over Bass Strait and Cape Grim)	Australia	AIA999900				$^{13}CO_2$, CH_4, CO, CO_2, H_2, N_2O
Aircraft Observation of Atmospheric trace gases by JMA	Japan	AOA999900				CH_4, CO, CO_2, N_2O
Aircraft: Orleans	France	ORL999900			150	CH_4, CO_2
Akademik Korolev, R/V	United States of America	AKD999900				CH_4
Alligator liberty, M/V	Japan	ALG999900				CO_2
Atlantic Ocean	United States of America	AOC9XXX00			10	CH_4, CO_2
Comprehensive Observation Network for TRace gases by AIrLiner (CONTRAIL)	Japan	EOM999900				CH_4, CO_2

LIST OF OBSERVATIONAL STATIONS (continued)

			Location			
Station	Country/Territory	Index Number	Latitude (° ')	Longitude (° ')	Altitude (m)	Parameter
Comprehensive Observation Network for TRace gases by AIrLiner (CONTRAIL)	Japan	EOM999900				$^{13}CH_4$, CH_3D
Discoverer 1983 & 1984, R/V	United States of America	DIS999900				CH_4
Discoverer 1985, R/V	United States of America	DSC999900				CH_4
Drake Passage	United States of America	DRP999900				$^{13}CO_2$, $C^{18}O_2$, CH_4, CO_2
HATS Ocean Projects	United States of America	HOP999900				HFCs
INSTAC-I (International Strato/Tropospheric Air Chemistry Project)	Japan	INS999900				$^{13}CO_2$, CH_4, CO_2
John Biscoe, R/V	United States of America	JBS999900				CH_4
Keifu Maru, R/V	Japan	KEF999900				CO_2
Kofu Maru, R/V	Japan	KOF999900				CO_2
Korolev, R/V	United States of America	KOR999900				CH_4
Long Lines Expedition, R/V	United States of America	LLE999900				CH_4
MRI Research, 1978-1986, R/V	Japan	MRI999900				CH_4
MRI Research, Hakuho Maru, R/V	Japan	HKH999900				CO_2
MRI Research, Kaiyo Maru, R/V	Japan	KIY999900				CO_2
MRI Research, Mirai, R/V	Japan	MMR999900				CO_2
MRI Research, Natushima, R/V	Japan	NTU999900				CO_2
MRI Research, Ryofu Maru, R/V	Japan	RFM999900				CO_2
MRI Research, Wellington Maru, R/V	Japan	WLT999900				CO_2
Mexico Naval H-02, R/V	United States of America	MXN999900				CH_4
NOPACCS - Hakurei Maru -	Japan	HAK999900				TIC
Observation of Atmospheric Chemistry Over Japan	Japan	OAJ999900				CFCs, N_2O
Oceanographer, R/V	United States of America	OCE999900				CH_4
Pacific Ocean	New Zealand	BSL999900				$^{13}CH_4$, CH_4, VOCs
Pacific Ocean	United States of America	POC9XXX00			10	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2
Pacific-Atlantic Ocean	United States of America	PAO999900				CH_4
Polar Star, R/V	United States of America	PLS999900				CH_4
Ryofu Maru, R/V	Japan	RYF999900				CFCs, CH_4, CO_2, N_2O, TIC

LIST OF OBSERVATIONAL STATIONS (continued)

Station	Country/Territory	Index Number	Location Latitude (° ')	Longitude (° ')	Altitude (m)	Parameter
Santarem	Brazil	SAN999900				CH_4, CO, CO_2, N_2O, SF_6
South China Sea	United States of America	SCS9XXX00			15	$^{13}CO_2$, $C^{18}O_2$, CH_4, CO, CO_2, H_2
Soyo Maru, R/V	Japan	SOY999900				CO_2
Surveyor, R/V	United States of America	SUR999900				CH_4
The Observation of Atmospheric Methane Over Japan	Japan	OAM999900				CH_4
The Observation of Atmospheric Sulfur Hexafluoride Over Japan	Japan	OAS999900				SF_6
WEST COSMIC - Hakurei Maru No.2 -	Japan	HAK999901				TIC
Wakataka-Maru	Japan	WAK999900				CO_2
Western Pacific	United States of America	WPC9XXX00			10	$^{13}CH_4$, $^{13}CO_2$, $C^{18}O_2$, CH_4, CO_2
northern and western Pacific	Japan	NWP999900				N_2O

LIST OF CONTRIBUTORS

Station Country/Territory	Name	Address
REGION I (Africa)		
Cairo (Egypt)	AbdElhamid Gouda Elawadi	Egyptian Meteorological Authority Department of Air Pollution Study Egyptian Meteorological Authority P.O.Box:11784 - Cairo, Egypt
Izaña (Tenerife) (Spain)	Angel J. Gomez-Pelaez	Izana Atmospheric Research Center, Meteorological State Agency of Spain (AEMET) C/ La Marina, 20, Planta 6. Apartado 880. 38071 Santa Cruz de Tenerife, Spain
	Carlos Marrero	Izana Atmospheric Research Center, Meteorological State Agency of Spain (AEMET) C/ La Marina, 20 - Planta 6. Apartado 880. 38071 Santa Cruz de Tenerife, Spain
Funchal (Portugal)	Diamantino Henriques	Instituto de Meteorologia,I.P. Observatorio Afonso Chaves, Rua Mae de Deus - Relvao, 9500-321 Ponta Delgada, S. Miguel, Portugal
Cape Point (South Africa)	Ernst Günther Brunke	South African Weather Service (Climate Division) SAWS, c/o CSIR (Environmentek), P.O. Box 320,Stellenbosch 7599, South Africa
Amsterdam Island (France)	Jean Sciare	LSCE (Laboratoire des Sciences du Climat et de l'Environnement) UMR CEA-CNRS LSCE - CEA Saclay - Orme des Merisiers - Bat.701 91191 Gif-sur-Yvette, France
	Michel Ramonet	LSCE (Laboratoire des Sciences du Climat et de l'Environnement) UMR CEA-CNRS LSCE - CEA Saclay - Orme des Merisiers - Bat.701 91191 Gif-sur-Yvette, France
Mt. Kenya (Kenya)	Josiah Kariuki Murageh	KMD, Kenyan Meteorological Department Kenya Meteorological Department Dagoretti Corner P.O. Box 30259 00100 Nairobi, Kenya
	Jörg Klausen	Federal Office of Meteorology and Climatology MeteoSwiss Krähbühlstrasse 58 P.O. Box 514 CH-8044 Zürich, Switzerland
	Stephan Henne	Empa, Swiss Federal Laboratories for Materials Testing and Research Ueberlandstrasse 129 8600 Duebendorf, Switzerland

LIST OF CONTRIBUTORS (continued)

Station Country/Territory	Name	Address
Cape Verde Observatory (Cape Verde)	Katie Read	Department of Chemistry, University of York Department of Chemistry, University of York, Heslington, York, Y010 5DD, United Kingdom
	Zoë Fleming	National Centre for Atmospheric Science (NCAS) Department of Chemistry University of Leicester National Centre for Atmospheric Science (NCAS) Department of Chemistry University of Leicester Leicester LE1 7RH, UK
Assekrem (Algeria)	Mimouni Mohamed	Office National de la Meteorologie POBox 31 Tamanrasset 11000, Algeria
REGION II (Asia)		
Nagoya (Japan)	A. Matsunami	Research Center for Advanced Energy Conversion, Nagoya University Furo-cho, Chikusaku, Nagoya 464-8603, Japan
Anmyeon-do (Republic of Korea)	Haeyoung Lee	Korea Global Atmosphere Watch Center, Korea Meteorology Administration 1764-6, Seungen-Ri, Anmyeon-Eup, Taean-Kun, ChungNam, 357-961, Republic of Korea
	Sang-Hoon Kim	Korea Global Atmosphere Watch Center, Korea Meteorology Administration 1764-6, Seungen-Ri, Anmyeon-Eup, Taean-Kun, ChungNam, 357-961, Republic of Korea
Cape Ochi-ishi Hateruma (Japan)	Hitoshi MUKAI	Center for Global Environmental Research, National Institute for Environmental Studies 16-2, Onogawa, Tsukuba-shi, Ibaraki 305-8506, Japan
	Yasunori TOHJIMA	Center for Global Environmental Research, National Institute for Environmental Studies 16-2, Onogawa, Tsukuba-shi, Ibaraki 305-8506, Japan
Gosan (Republic of Korea)	Jeong-Ah Yu	National Institute of Environmental Research Environmental Research Complex, Gyeongseo-dong, Seo-gu, Incheon, 404-708, Republic of Korea
	Seung-Yeon Kim	National Institute of Environmental Research Environmental Research Complex, Gyeongseo-dong, Seo-gu, Incheon, 404-708, Republic of Korea

LIST OF CONTRIBUTORS (continued)

Station Country/Territory	Name	Address
Hok Tsui (Hong Kong, China)	Ka Se Lam	Department of Civil and Structural Engineering,Hong Kong Polytechnic University Hung Hom, Kowloon, Hong Kong, China
Tsukuba (Japan)	Koji Miyagawa	Lower Aerological Observations Division, Aerological Observatory, Japan Meteorological Agency (JMA) Lower Aerological Observations Division, Aerological Observatory1-2 Nagamine, Tsukuba, Ibaraki, 305-0052, Japan
Mikawa-Ichinomiya (Japan)	Koji Ohno	Aichi Air Environment Division 1-2 Sannomaru-3chome, Naka-ku, Nagoya, Aichi 460-8501, Japan
Mt. Waliguan (China)	Lingxi ZHOU	Professor, PI for Greenhouse Gases & Related Tracers Chinese Academy of Meteorological Sciences (CAMS) China Meteorological Administration (CMA) 46 Zhongguancun Nandajie Beijing 100081, China
Memanbetsu (Japan)	Michio Hirota	Geochemical Research Department, Meteorological Research Institute 1-1, Nagamine, Tsukuba, Ibaraki 305-0052, Japan
Tsukuba (Japan)	Michio Hirota	Geochemical Research Department, Meteorological Research Institute 1-1, Nagamine, Tsukuba, Ibaraki 305-0052, Japan
	Yousuke Sawa	Geochemical Research Department, Meteorological Research Institute 1-1, Nagamine, Tsukuba, Ibaraki 305-0052, Japan
Hamamatsu (Japan)	Mitsuo TODA	Shizuoka University 3-5-1 Jyohoku, Hamamatsu 432-8561, Japan
Bering Island Kotelny Island Tiksi (Russian Federation)	Nina Paramonova	Main Geophysical Observatory (MGO) Karbyshev Street 7, St. Petersburg, 194021, Russian Federation
Kyzylcha (Uzbekistan)		
Hok Tsui King’s Park (Hong Kong, China)	Olivia S.M. Lee	Hong Kong Observatory 134A, Nathan Road, Kowloon, Hong Kong
	David H.Y. Lam	Hong Kong Observatory 134A, Nathan Road, Kowloon, Hong Kong
Everest - Pyramid (Nepal)	Paolo Cristofanelli	ISAC-CNR ISAC-CNR, VIa Gobetti 101 - 40129 Bologna -Italy

LIST OF CONTRIBUTORS (continued)

Station Country/Territory	Name	Address
	Paolo Bonasoni	ISAC-CNR ISAC-CNR, VIa Gobetti 101 - 40129 Bologna -Italy
Takayama (Japan)	Shohei Murayama	Research Institute for Environmental Management Technology, National Institute of Advanced Industrial Science and Technology (AIST) AIST Tsukuba West, 16-1 Onogawa, Tsukuba, Ibaraki 305-8569, Japan
Gosan (Republic of Korea)	So-young Bang	Applied Meteorology Research Laboratory,Meteorological Research Institute (METRI),Korea Meteorological Administration (KMA) 460-18, Shindaebang-dong, Dongjak-gu, Seoul 156-720, Rep. of Korea
Ship between Ishigaki Island and Hateruma Island (Japan)	Takakiyo Nakazawa	Center for Atmospheric and Oceanic Studies, Graduate School of Science, Tohoku University Aoba, Sendai 980-8578, Japan
	Shuji Aoki	Center for Atmospheric and Oceanic Studies, Graduate School of Science, Tohoku University Aoba, Sendai 980-8578, Japan
Suita (Japan)	Tomohiro Oda	Division of Sustainable Energy and Environmental Engineering, Graduate School of Engineering, Osaka Universiy, Japan Green Engieering Lab Division of Sustainable Energy and Environmental Engineering 2-1 Yamadaoka, Suita, Osaka 565-0871 Japan
Issyk-Kul (Kyrgyzstan)	V. Sinyakov	Laboratory of Geophysics, Institute of Fundamental sciences at the Kyrgyz National University Manas Street 101, Bishkek, 720033, Kyrgyz Republic
Mt. Dodaira Kisai Urawa (Japan)	Yosuke MUTO	Center for Environmental Science in Saitama 914 Kamitanadare, Kisai-machi, Kita-Saitama-gun, Saitama 347-0115, Japan
Minamitorishima Ryori Yonagunijima (Japan)	Yukio Fukuyama	Atmospheric Environment Division, Global Environment and Marine Department,Japan Meteorological Agency (JMA) 1-3-4 Otemachi, Chiyoda-ku, Tokyo 100-8122, Japan

REGION III (South America)

LIST OF CONTRIBUTORS (continued)

Station Country/Territory	Name	Address
Arembepe (Brazil)	LuanaăS. Basso	IPEN Atmospheric Chemistry Laboratory Av. Prof. Lineu Prestes, 2242, Cidade Universitaria, Sao Paulo, SP- BRAZIL CEP 05508-900
	Luciana Vanni Gatti	IPEN Atmospheric Chemistry Laboratory Av. Prof. Lineu Prestes, 2242, Cidade Universitaria, Sao Paulo, SP- BRAZIL CEP 05508-900
Ushuaia (Argentina)	Maria Elena Barlasina	National Weather Service Observatorio Central Villa Ortuzar División Radiación Av. de Los Constituyentes 3454 Cp 1427, Argentina
	Manuel Cupeiro	National Weather Service 245 Viviendas Tira 8A, Dpto 10. Ushuaia, Tierra del Fuego, Argentina
	Ricardo Sanchez	National Weather Service Observatorio Central Villa Ortuzar División Radiación Av. de Los Constituyentes 3454 Cp 1427, Argentina
La Quiaca Observatorio Pilar Observatorio San Julian Aero (Argentina)	Maria Elena Barlasina	National Weather Service Observatorio Central Villa Ortuzar División Radiación Av. de Los Constituyentes 3454 Cp 1427, Argentina
	Ricardo Sanchez	National Weather Service Observatorio Central Villa Ortuzar División Radiación Av. de Los Constituyentes 3454 Cp 1427, Argentina
Huancayo (Peru)	Mutsumi Ishitsuka	Observatorio de Huancayo, Instituto Geofisico del Peru Apartado 46, Huancayo, Peru
Ushuaia (Argentina)	Sergio Luppo	Servicio Meteorológico Nacional - Gobierno de Tierra del Fuego Estación VAG Ushuaia Subsecretaria de Ciencia y Tecnología, Ministerio de Educación, Cultura, Ciencia y Tecnología Gobierno de Tierra del Fuego 9410 Ushuaia, Tierra del Fuego, Argentina
San Lorenzo (Paraguay)	Victor Ayala	Universidad Nacional de Asuncion, Facultad de Ciencias Exactas y Naturales, Laboratorio de Investigacion Atmosferica y Problemas Ambientales

LIST OF CONTRIBUTORS (continued)

Station Country/Territory	Name	Address
	Carlos Quevedo	
REGION IV (North and Central America)		
Candle Lake Chibougamau Cape St. James Lac La Biche (Alberta) (Canada)	Doug Worthy	Environment Canada (EC) 4905 Dufferin Street, Toronto, Ontario, Canada, M3H 5T4
Alert Churchill Estevan Point East Trout Lake Fraserdale Sable Island (Canada)	Doug Worthy	Environment Canada (EC) 4905 Dufferin Street, Toronto, Ontario, Canada, M3H 5T4
	Lin Huang	Environment Canada 4905 Dufferin Street, Toronto, Ontario, Canada, M3H 5T4
Egbert (Canada)	Doug Worthy	Environment Canada (EC) 4905 Dufferin Street, Toronto, Ontario, Canada, M3H 5T4
	Peter C. Brickell	Environment Canada (EC) 4905 Dufferin Street, Toronto, Ontario, Canada, M5T 1V7
Algoma Bratt's Lake Chalk River Egbert Experimental Lakes Area Esther Kejimkujik Saturna (Canada)	Mike Shaw	Environment CanadaMeteorological Service of CanadaAir Quality Research Branch 4905 Dufferin StreetToronto, Ontario CANADA M3H 5T4
La Palma (Cuba)	Osvaldo Cuesta Santos	Institute of Meteorology, Atmospheric Environment Research Center Aptdo. 17032, Postal Code 11700, Havana 17, Cuba
REGION V (South-West Pacific)		
Cape Grim (Australia)	Bruce Forgan	Commonwealth Bureau of Meteorology 700 Collins St, Docklands GPO Box 1289K, Melbourne, Victoria 3001, Australia

LIST OF CONTRIBUTORS (continued)

Station Country/Territory	Name	Address
	Ian Galbally	CSIRO Marine and Atmospheric Research CSIRO Marine and Atmospheric Research Private Bag 1, Aspendale Victoria 3195 Australia
Bukit Koto Tabang (Indonesia)	Ilahi, Asep Firman	Global GAW Bukit Kototabang Jl. Raya Bukittinggi-Medan Km. 17 Palupuh, District Agam, West Sumatera, Indonesia PO BOX 11 Bukittinggi 26100
	Mangasa Naibaho	The Indonesia Agency for Meteorology Climatology and Geophysics (BMKG) Jl.Angkasa 1,No.2,Kemayoran Jakarta 10720,Indonesia
	Jörg Klausen	Federal Office of Meteorology and Climatology MeteoSwiss Krähbühlstrasse 58 P.O. Box 514 CH-8044 Zürich, Switzerland
	Nahas, Alberth Christian	The Indonesia Agency for Meteorology Climatology and Geophysics (BMKG) Jl. Raya Bukittinggi-Medan Km. 17 Palupuh, District Agam, West Sumatera, Indonesia PO BOX 11 Bukittinggi 26100
	Dr Martin Steinbacher	Empa - Swiss Federal Laboratories for Materials Science and Technology Ueberlandstrasse 129 8600 Duebendorf Switzerland
Tanah Rata (Malaysia)	Lim Sze Fook	Environmental Studies Division Malaysian Meteorological Department Jalan Sultan, 46667 Petaling Jaya, Selangor, Malaysia
Danum Valley GAW Baseline Station (Malaysia)	Lim Sze Fook	Environmental Studies Division Malaysian Meteorological Department Jalan Sultan, 46667 Petaling Jaya, Selangor, Malaysia
	Maznorizan Mohamad	Environmental Studies Division Malaysian Meteorological Department
Bukit Koto Tabang Jakarta (Indonesia)	Mangasa Naibaho	The Indonesia Agency for Meteorology Climatology and Geophysics (BMKG) Jl.Angkasa 1,No.2,Kemayoran Jakarta 10720,Indonesia

LIST OF CONTRIBUTORS (continued)

Station Country/Territory	Name	Address
Baring Head (New Zealand)	Sylvia Nichol	National Institute of Water & Atmospheric Research Ltd. 301 Evans Bay Parade, Greta Point, Private Bag 14-901, Kilbirnie, Wellington, New Zealand
	Gordon Brailsford	National Institute of Water & Atmospheric Research Ltd. 301 Evans Bay Parade, Greta Point,Private Bag 14-901, Kilbirnie, Wellington, New Zealand
	Ross Martin	National Institute of Water & Atmospheric Research Ltd. 301 Evans Bay Parade, Greta Point, Private Bag 14-901, Kilbirnie, Wellington, New Zealand
REGION VI (Europe)		
Puszcza Borecka/Diabla Gora (Poland)	Anna Degorska	Institute of Environmental Protection Kolektorska 4 01-692 Warsaw, Poland
Monte Cimone (Italy)	Attilio Di Diodato	Italian Air Force Meteorological Service C.A.M.M. Mt. CIMONE,Via delle Ville 40, 41029-Sestola (MO), Italy
Hohe Warte Stephansplatz (Austria)	August Kaiser	Department for Environmental MeteorologyCentral Institute for Meteorology and Geodynamics Postfach 342, Hohe Warte 38, A-1191 Wien, Austria
Zeppelinfjellet (Ny-Alesund) (Norway)	Birgitta Noone	Department of Applied Environmental Science (ITM) Stockholm University SE-10691 Stockholm
	Hans-Christen Hansson	Department of Applied Environmental Science (ITM) Stockholm University SE-10691 Stockholm
Jungfraujoch (Switzerland)	Brigitte Buchmann	Empa, Swiss Federal Laboratories for Materials Testing and Research, Air Pollution / Environmental Technology Überlandstrasse 129, CH-8600 Dübendorf, Switzerland
	Hoerger Corinne	Swiss Federal Laboratories for Materials Science and Technologyh, EMPA, Air Pollution/Environmental Technology
	Dr Martin Steinbacher	Ueberlandstrasse 129, CH-8600, Duebendorf, Switzerland

LIST OF CONTRIBUTORS (continued)

Station Country/Territory	Name	Address
	Stefan Reimann	Empa - Swiss Federal Laboratories for Materials Science and Technology Ueberlandstrasse 129 8600 Duebendorf Switzerland
	Thomas Seitz	Swiss Federal Laboratories for Materials Science and Technologyh, EMPA, Air Pollution/Environmental Technology Ueberlandstrasse 129, CH-8600, Duebendorf, Switzerland
Payerne Rigi (Switzerland)	Brigitte Buchmann	Empa, Swiss Federal Laboratories for Materials Testing and Research, Air Pollution / Environmental Technology Überlandstrasse 129, CH-8600 Dübendorf, Switzerland
	Thomas Seitz	Empa, Swiss Federal Laboratories for Materials Testing and Research, Air Pollution / Environmental Technology Überlandstrasse 129, CH-8600 Dübendorf, Switzerland
Hohenpeissenberg (Germany)	Christian Plass-Duelmer	Deutscher Wetterdienst (DWD, German Meteorological Service)Meteorologisches Observatorium Hohenpeissenberg Albin-Schwaiger-Weg 10D-82383 Hohenpeissenberg, Germany
	Stefan Gilge	Deutscher Wetterdienst (DWD, German Meteorological Service)Meteorologisches Observatorium Hohenpeissenberg Albin-Schwaiger-Weg 10D-82383 Hohenpeissenberg, Germany
Fundata Semenic Stîna de Vale (Romania)	Daniela ZISU	National Research and Development Institute for Environmental Protection Splaiul Independentei nr. 294, sector 6, 77703 Bucuresti , Romania
Angra do Heroismo Beja Bragança Castelo Branco Lisboa / Gago Coutinho Monte Velho Penhas Douradas Viana do Castelo (Portugal)	Diamantino Henriques	Instituto de Meteorologia,I.P. Observatorio Afonso Chaves, Rua Mae de Deus - Relvao, 9500-321 Ponta Delgada, S. Miguel, Portugal
Kamenicki Vis (Serbia)	Dragan Djordjevic	Republic Hydrometeorological Service, Environmental Control Department Kneza Viseslava 66, 11030 Belgrade, Serbia

LIST OF CONTRIBUTORS (continued)

Station Country/Territory	Name	Address
Burgas Plovdiv Pleven Sofia Varna (Bulgaria)	Ekaterina Batchvarova	National Institute of Meteorology and Hydrology 66 Tzarigradsko chaussee, 1784 Sofia, Bulgaria
Jarczew Leba Suwalki (Poland)	Eugeniusz Brejnak	Institute of Meteorology and Water Management;Laboratory for Research and Monitoring of Air Pollution 61 Podlesna Street, 01-673 Warszawa, Poland
Fundata (Romania)	Florin Nicodim	National Meteorological Administration Sos. Bucuresti-Ploiesti nr. 97, 71552 Bucharest, Romania
Giordan Lighthouse (Malta)	Francelle Azzopardi	
	Raymond Ellul	Atmospheric Research Unit / Physics Department /University of Malta Msida MSD 06, Malta
	Martin Saliba	
Plateau Rosa (Italy)	Francesco Apadula	Ricerca sul Sistema Energetico - RSE S.p.A. via Rubattino 54, 20134 Milano, Italy
	Daniela Heltai	Ricerca sul Sistema Energetico - RSE S.p.A. via Rubattino 54, 20134 Milano, Italy
	Andrea Lanza	Ricerca sul Sistema Energetico - RSE S.p.A. via Rubattino 54, 20134 Milano, Italy
Site J (Denmark)	Gen Hashida	National Institute of Polar Research Kaga 1-9-10, Itabashi-ku, Tokyo 173-8515, Japan
	Shinji Morimoto	National Institute of Polar Research Kaga 1-9-10, Itabashi-ku, Tokyo 173-8515, Japan
	Shuji Aoki	Center for Atmospheric and Oceanic Studies, Graduate School of Science, Tohoku University Aoba, Sendai 980-8578, Japan
Mace Head (Ireland)	Gerard Spain	National University of Ireland, Galway (NUI) Mace Head Research Station Carna, Co. Galway, Ireland
Hohe Warte Stephansplatz (Austria)	Guenther Schermann	Municipal Department 22 - Environmental ProtectionAir quality subdepartment, City of Vienna Ebendorferstrasse 4, A-1082 Vienna, Austria

LIST OF CONTRIBUTORS (continued)

Station Country/Territory	Name	Address
Vindeln (Sweden)	Hakan Blomgren	IVL Swedish Environmental Research Institute P.O.Box 5302S-400 14 Goteborg, Sweden
Kloosterburen (Netherlands (the))	Hans Berkhout	RIVM - Centre for Environmental Monitoring (MIL) PO Box 1 3720 BA Bilthoven the Netherlands
Kollumerwaard (Netherlands (the))	Hans Berkhout	RIVM - Centre for Environmental Monitoring (MIL) PO Box 1 3720 BA Bilthoven the Netherlands
	Ronald Spoor	RIVM - Centre for Environmental Monitoring (MIL) PO Box 1 3720 BA Bilthoven the Netherlands
Wank Peak Zugspitze (Germany)	Hans-Eckhart Scheel	Karlsruhe Institute of Technology (KIT), IMK-IFU 82467 Garmisch-Partenkirchen, Germany
Danki Shepelevo (Russian Federation)	Irina Brouskina	
BEO Moussala (Bulgaria)	Ivo Kalapov	INRNE Institute for Nuclear Research and Nuclear Energy Tsarigradsko shose Blvd. 1784 Sofia Bulgaria
	Todor Arsov	
La Cartuja Doñana Logroño Mahón Noia Roquetes San Pablo de los Montes (Spain)	J.M. Saenz	Servicio de Desarrollos Medioambientales, Instituto Nacional de Meteorologia,Ministerio de Medio Ambiente Leonardo Prieto Castro, 8, 28071 Madrid, Spain
Monte Cimone (Italy)	Jgor Arduini	Università degli Studi di Urbino Istituto di Scienze Chimiche, piazza Rinascimento 6, 61029 Urbino - Italy
	Paolo Bonasoni	ISAC-CNR ISAC-CNR, VIa Gobetti 101 - 40129 Bologna -Italy
	Paolo Cristofanelli	ISAC-CNR ISAC-CNR, VIa Gobetti 101 - 40129 Bologna -Italy

LIST OF CONTRIBUTORS (continued)

Station Country/Territory	Name	Address
	Rocco Duchi	
Pallas-Sammaltunturi (Finland)	Juha Hatakka	Finnish Meteorological Institute P.O.Box 503,FI-00101 Helsinki, Finland
	Timo Salmi	Finnish Meteorological Institute Erik Palmenin aukio 1, P.O.Box 503, FIN-00101 Helsinki, Finland
Brotjacklriegel Deuselbach Waldhof Neuglobsow Schauinsland Westerland Zingst Zugspitze / Schneefernerhaus Zugspitze (Germany)	Karin Uhse	Umweltbundesamt (UBA, Federal Environmental Agency) Air Monitoring Network Paul-Ehrlich-Strasse 29 D-63225 Langen, Germany
Sniezka (Poland)	Krzaczkowski Piotr, MSc	Institute of Meteorology and Water Management - Wroclaw Branch, Meteorological Observatory on Sniezka Mountain
Hegyhatsal K-puszta (Hungary)	Laszlo Haszpra	Hungarian Meteorological Service P.O. Box 39, H-1675 Budapest, Hungary
Iskrba Kovk Krvavec Zavodnje (Slovenia)	Marijana Murovec	Slovenian Environment Agency Agencija RS za okolje / Slovenian Environment Agency Urad za hidrologijo in stanje okolja / Hidrology and State of the Environment Office Sektor za kakovost zraka / Air Quality Division Vojkova 1b, 1001 Ljubljana, p.p. 2608, Slovenia
Dobele Rucava Zoseni (Latvia)	Marina Frolova	Observation Network Department, Latvian Environment, Geology and Meteorology Centre, Ministry of Environmental 165 Maskavas str. LV-1019, Riga, Latvia
Sonnblick (Austria)	Marina Fröhlich	Federal Environment Agency Austria Spittelauer Lände 5, A-1090 Wien, Austria
	Wolfgang Spangl	Federal Environment Agency Austria Spittelauer Lände 5, A-1090 Wien, Austria
	Elisabeth Friedbacher	Federal Environment Agency Austria Spittelauer Lände 5, A-1090 Wien, Austria

LIST OF CONTRIBUTORS (continued)

Station Country/Territory	Name	Address
Jungfraujoch (Switzerland)	Markus Leunberger	University of Bern University of Bern Physics Institute Sidlerstrasse 5 CH-3012 Bern
Ivan Sedlo (Bosnia and Herzegovina)	Martin Tais	Meteoroloski zavod Bosne i Hercegovine Bardakcije 12, 71000 Sarajevo, Bosnia and Herzegovina
Pic du Midi (France)	Meyerfeld Yves	Laboratoire d'Aérologie
	Gheusi Francois	
Ile Grande Pic du Midi Puy de Dome (France)	Michel Ramonet	LSCE (Laboratoire des Sciences du Climat et de l'Environnement) UMR CEA-CNRS LSCE - CEA Saclay - Orme des Merisiers - Bat.701 91191 Gif-sur-Yvette, France
Finokalia (Greece)		
Mace Head (Ireland)		
Begur (Spain)		
Kosetice (Czech Republic)	Milan Vana	Czech Hydrometeorological Institute, Kosetice Observatory Na Sabatce 17, 143 06 Praha 4 - Komorany, Czech Republic
Ocean Station Charlie Teriberka (Russian Federation)	Nina Paramonova	Main Geophysical Observatory (MGO) Karbyshev Street 7, St. Petersburg, 194021, Russian Federation
Zeppelinfjellet (Ny-Alesund) (Norway)	Ove Hermansen	Norwegian Institute for Air Research (NILU) P. O. Box 100 Instituttveien 18, N-2027 Kjeller, Norway
Eskdalemuir (United Kingdom of Great Britain and Northern Ireland)	Peter Kuria	Air and Environment Quality Division, DEFRA 4/F15, Ashdown House123 Victoria StreetLondon, SW1E 3DE, United Kingdom
Puy de Dome (France)	Pichon Jean-Marc	Laboratoire de Météorologie Physique
	Meyerfeld Yves	Laboratoire d'Aérologie

LIST OF CONTRIBUTORS (continued)

Station Country/Territory	Name	Address
Lampedusa (Italy)	Salvatore Chiavarini	Italian National Agency for New Technology, Energy, and Sustainable Economic Development (ENEA) ENEA-UTPRA Via Anguillarese, 301 00123 Rome, Italy
	Salvatore Piacentino	Italian National Agency for New Technology, Energy, and Sustainable Economic Development (ENEA) Laboratory for Earth Observations and Analyses (UTMEA-TER) ENEA ACS-CLIMOSS, Via Catania 2, 90141 Palrmo, Italy.
	Damiano Sferlazzo	Italian National Agency for New Technology, Energy, and Sustainable Economic Development (ENEA) Laboratory for Earth Observations and Analyses (UTMEA-TER) Station for Climate Observations Contrada Capo Grecale 92010 Lampedusa Italy
	Alcide di Sarra	Italian National Agency for New Technology, Energy, and Sustainable Economic Development (ENEA) Laboratory for Earth Observations and Analyses (UTMEA-TER) Via Anguillarese, 301 00123 Rome, Italy.
Ridge Hill Tacolneston Tall Tower (United Kingdom of Great Britain and Northern Ireland)	Simon O'Doherty	Atmospheric Chemistry Research Group School of Chemistry University of Bristol Atmospheric Chemistry Research Group School of Chemistry University of Bristol Cantocks Close BS8 1TS Bristol United Kingdom
	Aoife Grant	Atmospheric Chemistry Research Group School of Chemistry University of Bristol Atmospheric Chemistry Research Group School of Chemistry University of Bristol Cantocks Close BS8 1TS Bristol United Kingdom
Zugspitze / Schneefernerhaus (Germany)	Stefan Gilge	Deutscher Wetterdienst (DWD, German Meteorological Service)Meteorologisches Observatorium Hohenpeissenberg Albin-Schwaiger-Weg 10D-82383 Hohenpeissenberg, Germany

LIST OF CONTRIBUTORS (continued)

Station Country/Territory	Name	Address
	Christian Plass-Duelmer	Deutscher Wetterdienst (DWD, German Meteorological Service)Meteorologisches Observatorium Hohenpeissenberg Albin-Schwaiger-Weg 10D-82383 Hohenpeissenberg, Germany
Lazaropole (The Former Yugoslav Republic of Macedonia)	Suzana Alcinova Monevska	Hydrometeorological Service Skupi bb, 1000 Skopie,The former Yugoslav Republic of Macedonia
Ähtäri Oulanka Utö Virolahti (Finland)	Timo Salmi	Finnish Meteorological Institute Erik Palmenin aukio 1, P.O.Box 503, FIN-00101 Helsinki, Finland
ANTARCTICA		
Jubany (Italy)	Claudio Rafanelli	ICES (Int.l Center for Earth Sciences) c/o CNR-Istituto di Acustica- Area della Ricerca di Roma Tor Vergata,via Fosso del Cavaliere 100, 00133 Rome, Italy
Marambio (Argentina)	Maria Elena Barlasina	National Weather Service Observatorio Central Villa Ortuzar División Radiación Av. de Los Constituyentes 3454 Cp 1427, Argentina
	Ricardo Sanchez	National Weather Service Observatorio Central Villa Ortuzar División Radiación Av. de Los Constituyentes 3454 Cp 1427, Argentina
Syowa Station (Japan)	Masato Fukuda	Office of Antarctic Observations,Japan Meteorological Agency (JMA) 1-3-4 Otemachi, Chiyoda-ku, Tokyo 100-8122, Japan
Concordia, Dôme C (Italy)	Paolo Cristofanelli	ISAC-CNR ISAC-CNR, VIa Gobetti 101 - 40129 Bologna -Italy
	Paolo Bonasoni	ISAC-CNR ISAC-CNR, VIa Gobetti 101 - 40129 Bologna -Italy
Neumayer (Germany)	Rolf Weller	Alfred Wegener Institute Am Handelshafen 12,27570 Bremerhaven, Germany
King Sejong (Republic of Korea)	Sang-Hoon Kim	Korea Global Atmosphere Watch Center, Korea Meteorology Administration 1764-6, Seungen-Ri, Anmyeon-Eup, Taean-Kun, ChungNam, 357-961, Republic of Korea

LIST OF CONTRIBUTORS (continued)

Station Country/Territory	Name	Address
	Haeyoung Lee	Korea Global Atmosphere Watch Center, Korea Meteorology Administration 1764-6, Seungen-Ri, Anmyeon-Eup, Taean-Kun, ChungNam, 357-961, Republic of Korea
	Taejin Choi	Division of Polar Climate Research, KOPRI Get-Pearl Tower, 12 Gaetbeol-ro, Yeonsu-gu, Incheon, 406-840, Republic of Korea
Arrival Heights (New Zealand)	Sylvia Nichol	National Institute of Water & Atmospheric Research Ltd. 301 Evans Bay Parade, Greta Point, Private Bag 14-901, Kilbirnie, Wellington, New Zealand
	Gordon Brailsford	National Institute of Water & Atmospheric Research Ltd. 301 Evans Bay Parade, Greta Point,Private Bag 14-901, Kilbirnie, Wellington, New Zealand
	Ross Martin	National Institute of Water & Atmospheric Research Ltd. 301 Evans Bay Parade, Greta Point, Private Bag 14-901, Kilbirnie, Wellington, New Zealand
Mizuho (Japan)	Takakiyo Nakazawa	Center for Atmospheric and Oceanic Studies, Graduate School of Science, Tohoku University Aoba, Sendai 980-8578, Japan
Syowa Station (Japan)	Takakiyo Nakazawa	Center for Atmospheric and Oceanic Studies, Graduate School of Science, Tohoku University Aoba, Sendai 980-8578, Japan
	Gen Hashida	National Institute of Polar Research Kaga 1-9-10, Itabashi-ku, Tokyo 173-8515, Japan
	Shinji Morimoto	National Institute of Polar Research Kaga 1-9-10, Itabashi-ku, Tokyo 173-8515, Japan

MOBILE STATION

NOPACCS - Hakurei Maru - WEST COSMIC - Hakurei Maru No.2 - (Japan)	General Environmental Texhnos	The General Environmental Technos Co., Ltd. (Old:Kansai Environmental Engineering Center, Co., Ltd.) 1-3-5, Azuchi machi, Chuo-ku, Osaka 541-0052, Japan
INSTAC-I (International Strato/Tropospheric Air Chemistry Project) (Japan)	Hidekazu Matsueda	Geochemical Research Department, Meteorological Research Institute Nagamine 1-1, Tsukuba, Ibaraki 305-0052, Japan

LIST OF CONTRIBUTORS (continued)

Station Country/Territory	Name	Address
Comprehensive Observation Network for TRace gases by AIrLiner (CONTRAIL) (Japan)	Hidekazu Matsueda	Geochemical Research Department, Meteorological Research Institute Nagamine 1-1, Tsukuba, Ibaraki 305-0052, Japan
	Toshinobu Machida	National Institute for Environmental Studies 16-2 Onogawa, Tsukuba 305-8506, Japan
MRI Research, Mirai, R/V (Japan)	Hisayuki Yoshikawa-Inoue	Laboratory of Marine and Atmospheric GeochemistryGraduate School of Environmental Earth ScienceHokkaido University N10W5, Kita-ku, Sapporo 060-0810, Japan
northern and western Pacific (Japan)	Kentaro Ishijima	Japan Agency for Marine-earth Science and Technology (JAMSTEC) 3173-25 Showamachi, Kanazawa-ku, Yokohama, 236-0001, Japan
	Shuji Aoki	Center for Atmospheric and Oceanic Studies, Graduate School of Science, Tohoku University Aoba, Sendai 980-8578, Japan
	Takakiyo Nakazawa	Center for Atmospheric and Oceanic Studies, Graduate School of Science, Tohoku University Aoba, Sendai 980-8578, Japan
Santarem (Brazil)	Luciana Vanni Gatti	IPEN Atmospheric Chemistry Laboratory Av. Prof. Lineu Prestes, 2242, Cidade Universitaria, Sao Paulo, SP- BRAZIL CEP 05508-900
	LuanaăS. Basso	IPEN Atmospheric Chemistry Laboratory Av. Prof. Lineu Prestes, 2242, Cidade Universitaria, Sao Paulo, SP- BRAZIL CEP 05508-900
	Alexandre Martinewski	

LIST OF CONTRIBUTORS (continued)

Station Country/Territory	Name	Address
MRI Research, Hakuho Maru, R/V MRI Research, Kaiyo Maru, R/V MRI Research, 1978-1986, R/V MRI Research, Natushima, R/V MRI Research, Ryofu Maru, R/V MRI Research, Wellington Maru, R/V (Japan)	Masao Ishii	Geochemical Research Department, Meteorological Research Institute Nagamine 1-1, Tsukuba, Ibaraki 305-0052, Japan
Aircraft: Orleans (France)	Michel Ramonet	LSCE (Laboratoire des Sciences du Climat et de l'Environnement) UMR CEA-CNRS LSCE - CEA Saclay - Orme des Merisiers - Bat.701 91191 Gif-sur-Yvette, France
Observation of Atmospheric Chemistry Over Japan The Observation of Atmospheric Methane Over Japan The Observation of Atmospheric Sulfur Hexafluoride Over Japan (Japan)	Michio Hirota	Geochemical Research Department, Meteorological Research Institute 1-1, Nagamine, Tsukuba, Ibaraki 305-0052, Japan
Alligator liberty, M/V Keifu Maru, R/V Kofu Maru, R/V Ryofu Maru, R/V (Japan)	Shu Saito	Marine Division, Global Environment and Marine Department, Japan Meteorological Agency (JMA) 1-3-4 Otemachi, Chiyoda-ku, Tokyo 100-8122, Japan
Pacific Ocean (New Zealand)	Sylvia Nichol	National Institute of Water & Atmospheric Research Ltd. 301 Evans Bay Parade, Greta Point, Private Bag 14-901, Kilbirnie, Wellington, New Zealand
	Gordon Brailsford	National Institute of Water & Atmospheric Research Ltd. 301 Evans Bay Parade, Greta Point,Private Bag 14-901, Kilbirnie, Wellington, New Zealand
Comprehensive Observation Network for TRace gases by AIrLiner (CONTRAIL) (Japan)	Taku Umezawa	Max Planck Institute for Chemistry Atmospheric Chemistry Department
	Shuji Aoki	Center for Atmospheric and Oceanic Studies, Graduate School of Science, Tohoku University

LIST OF CONTRIBUTORS (continued)

Station Country/Territory	Name	Address
Soyo Maru, R/V Wakataka-Maru (Japan)	Tsuneo Ono	Hokkaido National Fisheries Research Institute 116 Katsurakoi, Kushiro 085-0802, Japan
Aircraft Observation of Atmospheric trace gases by JMA (Japan)	Yukio Fukuyama	Atmospheric Environment Division, Global Environment and Marine Department,Japan Meteorological Agency (JMA) 1-3-4 Otemachi, Chiyoda-ku, Tokyo 100-8122, Japan

LIST OF CONTRIBUTORS (continued)

Station Country/Territory	Name	Address
NOAA/ESRL Flask Network		
Assekrem (Algeria) Tierra del Fuego (Argentina) Cape Grim (Australia) Ragged Point (Barbados) Arembepe (Brazil) Alert Lac La Biche Mould Bay (Canada) Easter Island (Chile) Lulin Shangdianzi Mt. Waliguan (China) Summit (Denmark) Pallas-Sammaltunturi (Finland) Amsterdam Island Crozet (France) Hohenpeissenberg Ochsenkopf (Germany) Hegyhatsal (Hungary) Heimaey (Iceland) Bukit Koto Tabang (Indonesia)	Bruce Vaughn** James White** ($^{13}CH_4$, $^{13}CO_2$ and $C^{18}O_2$) Edward J.Dlugokencky* (CH_4) Paul C. Novelli* (CO and H_2) Thomas J. Conway* (CO_2) Bruce Vaughn** (N_2O and SF_6) Detlev Helmig** Jacques Hueber** (VOCs)	(*)NOAA/ESRL Global Monitoring Division 325 Broadway R/GMD1 Boulder, CO 80305-3328, U.S.A. (**)Institute of Arctic and Alpine Research (INSTAAR) INSTAAR, Univ. of Colorado 1560, 30th Street UCB 450 Boulder, CO 80309 U.S.A.

LIST OF CONTRIBUTORS (continued)

Station Country/Territory	Name	Address
Mace Head (Ireland)		
Sede Boker (Israel)		
Lampedusa (Italy)		
Syowa Station (Japan)		
Sary Taukum Plateau Assy (Kazakhstan)		
Mt. Kenya (Kenya)		
Christmas Island (Kiribati)		
Kaashidhoo (Maldives)		
Dwejra Point (Malta)		
Mex High Altitude Global Climate Observation Center, Mexico (Mexico)		
Ulaan Uul (Mongolia)		
Gobabeb (Namibia)		
Arrival Heights Baring Head Lauder Kaitorete Spit (New Zealand)		
Ocean Station "M" Zeppelinfjellet (Ny-Alesund) (Norway)		
Baltic Sea (Poland)		

LIST OF CONTRIBUTORS (continued)

Station Country/Territory	Name	Address
Terceira Island (Portugal)		
Tae-ahn Peninsula (Republic of Korea)		
Black Sea (Romania)		
Mahe Island (Seychelles)		
Cape Point (South Africa)		
Izaña (Tenerife) (Spain)		
Ascension Island St. David's Head Tudor Hill Halley Bay Bird Island (United Kingdom of Great Britain and Northern Ireland)		
Akademik Korolev, R/V		
Argyle		
Atlantic Ocean		
St. Croix		
Barrow		
Cold Bay		
Cape Meares		
Discoverer 1983 & 1984, R/V		
Drake Passage		
Discoverer 1985, R/V		
Guam		
Grifton		
John Biscoe, R/V		

LIST OF CONTRIBUTORS (continued)

Station Country/Territory	Name	Address
Key Biscayne		
Korolev, R/V		
Kitt Peak		
Cape Kumukahi		
Park Falls		
Long Lines Expedition, R/V		
McMurdo Station		
Sand Island		
Mauna Loa		
Mexico Naval H-02, R/V		
Niwot Ridge (T-van)		
Niwot Ridge (Saddle)		
Oceanographer, R/V		
Olympic Peninsula		
Pacific-Atlantic Ocean		
Polar Star, R/V		
Pacific Ocean		
Palmer Station		
Point Arena		
South China Sea		
Southern Great Plains		
Shemya Island		
La Jolla		
Tutuila (Cape Matatula)		
South Pole		
Ocean Station Charlie		

LIST OF CONTRIBUTORS (continued)

Station Country/Territory	Name	Address
Surveyor, R/V		
Trinidad Head		
Wendover		
West Branch		
Moody		
Western Pacific		
(United States of America)		
NOAA/ESRL/HATS Network		
Tierra del Fuego (Argentina)	Geoffrey S. Dutton James W. Elkins Stephen A. Montzka	Halocarbons and Other Atmosphere Trace Species Group (HATS)/NOAA/ESRL Global Monitoring Division 325 Broadway R/GMD1 Boulder, CO 80305-3328, U.S.A.
Cape Grim (Australia)		
Alert (Canada)		
Summit (Denmark)		
Mace Head (Ireland)		
BACPAC 99		
BLAST1		
BLAST2		
BLAST3		
Barrow		
CLIVAR 01		
Gas Change Experiment		
Harvard Forest		
HATS Ocean Projects		
Grifton		

LIST OF CONTRIBUTORS (continued)

Station Country/Territory	Name	Address
Cape Kumukahi		
Park Falls		
Mauna Loa		
Niwot Ridge (C-1)		
PHASE I-04		
Palmer Station		
Tutuila (Cape Matatula)		
South Pole		
Trinidad Head		
(United States of America)		
NOAA/ESRL Surface Ozone Network		
Ragged Point (Barbados)	Audra McClure-Begley Irina Petropavlovskikh	NOAA/ESRL Global Monitoring Division 325 Broadway, R/GMD1, Boulder, CO 80305, U.S.A
Summit (Denmark)		
Heimaey (Iceland)		
Arrival Heights Lauder (New Zealand)		
Tudor Hill (United Kingdom of Great Britain and Northern Ireland)		
Barrow McMurdo Station Mauna Loa Niwot Ridge (C-1) Niwot Ridge (Saddle) Tutuila (Cape Matatula) South Pole Trinidad Head (United States of America)		

LIST OF CONTRIBUTORS (continued)

Station Country/Territory	Name	Address
CSIRO Flask Network		
Aircraft (over Bass Strait and Cape Grim) Cape Ferguson Cape Grim Casey Station Gunn Point Mawson Macquarie Island (Australia)	Ray Langenfelds Paul Krummel Marcel van der Schoot Paul Steele Colin Allison	Commonwealth Scientific and Industrial Research Organisation (CSIRO) CSIRO Marine and Atmospheric Research Private Bag 1 Aspendale, Vic, Australia 3195
Alert Estevan Point (Canada)		
Cape Rama (India)		
Shetland (United Kingdom of Great Britain and Northern Ireland)		
Mauna Loa South Pole (United States of America)		
ALE/GAGE/AGAGE Network		
Cape Grim (Australia)	Ray Wang Stefan Reimann Simon O'Doherty Paul Krummel Paul Steele Ray F. Weiss Chris Harth Chris Lunder Dickon Young Jens Muhle Martin Vollmer	School of Earth and Atmospheric Sciences, Georgia Institute of Technology 311 Ferst Drive School of Earth and Atmospheric Sciences Georgia Institute of Technology Atlanta, GA 30332-0340
Ragged Point (Barbados)		
Adrigole Mace Head (Ireland)		
Zeppelinfjellet (Ny-Alesund) (Norway)		
Jungfraujoch (Switzerland)		
Cape Meares Tutuila (Cape Matatula) Trinidad Head (United States of America)		

GLOSSARY

ATMOSPHERIC SPECIES:

CCl_4	tetrachloromethane (carbon tetrachloride)
CFC-11	chlorofluorocarbon-11 (trichlorofluoromethane, CCl_3F)
CFC-12	chlorofluorocarbon-12 (dichlorodifluoromethane, CCl_2F_2)
CFC-113	chlorofluorocarbon-113 (1,1,2-trichlorotrifluoroethane, CCl_2FCClF_2)
CFCs	chlorofluorocarbons
CH_3Cl	chloromethane (methyl chloride)
Halon-1211	chlorodifluorobromomethane ($CBrClF_2$)
Halon-1301	bromotrifluoromethane ($CBrF_3$)
HCFC-141b	hydrochlorofluorocarbon-141b (1,1-dichloro-1-fluoroethane, CH_3CCl_2F)
HCFC-142b	hydrochlorofluorocarbon-142b (1,1-difluoro-1-chloroethane, CH_3CClF_2)
HCFC-22	hydrochlorofluorocarbon-22 (chlorodifluoromethane, $CHClF_2$)
HCFCs	hydrochlorofluorocarbons
HFC-134a	hydrofluorocarbon-134a (1,1,1,2-tetrafluoroethane, CH_2FCF_3)
HFC-152a	hydrofluorocarbon-152a (1,1-difluoroethane, CHF_2CH_3)
HFCs	hydrofluorocarbons
CH_4	methane
CH_3CCl_3	trichloroethane (methyl chloroform)
CO	carbon monoxide
CO_2	carbon dioxide
N_2O	nitrous oxide
NO	nitrogen monoxide
NO_2	nitrogen dioxide
NO_X	nitrogen oxides
O_3	ozone
SF_6	sulphur hexafluoride
SO_2	sulphur dioxide
VOCs	volatile organic compounds

UNITS:

ppm	parts per million
ppb	parts per billion
ppt	parts per trillion

Others:

ENSO	El Niño-Southern Oscillation
M/V	merchant vessel
R/V	research vessel

LIST OF WMO/WDCGG PUBLICATIONS

DATA REPORTING MANUAL:

WDCGG No. 1	January	1991

WMO WDCGG DATA REPORT:

			(period of data accepted)				
WDCGG No. 2 Part A	October	1992	October	1990	~	August	1992
WDCGG No. 2 Part B	October	1992	October	1990	~	August	1992
WDCGG No. 3	October	1993	September	1992	~	March	1993
WDCGG No. 5	March	1994	April	1993	~	September	1993
WDCGG No. 6	September	1994	September	1993	~	March	1994
WDCGG No. 7	March	1995	April	1994	~	December	1994
WDCGG No. 9	September	1995	January	1995	~	June	1995
WDCGG No.10	March	1996	July	1995	~	December	1995
WDCGG No.11	September	1996	January	1996	~	June	1996
WDCGG No.12	March	1997	July	1996	~	November	1996
WDCGG No.14	September	1997	December	1996	~	June	1997
WDCGG No.16	March	1998	July	1997	~	December	1997
WDCGG No.17	September	1998	January	1998	~	June	1998
WDCGG No.18	March	1999	July	1998	~	December	1998
WDCGG No.20	September	1999	January	1999	~	June	1999
WDCGG No.21	March	2000	July	1999	~	December	1999
WDCGG No.23	September	2000	January	2000	~	June	2000
WDCGG No.25	March	2001	July	2000	~	December	2000

WMO WDCGG DATA CATALOGUE:

WDCGG No. 4	December	1993
WDCGG No.13	March	1997
WDCGG No.19	March	1999
WDCGG No.24	March	2001

WMO WDCGG DATA SUMMARY:

WDCGG No. 8	October	1995
WDCGG No.15	March	1998
WDCGG No.22	March	2000
WDCGG No.26	March	2002
WDCGG No.27	March	2003
WDCGG No.28	March	2004
WDCGG No.29	March	2005
WDCGG No.30	March	2006
WDCGG No.31	March	2007
WDCGG No.32	March	2008
WDCGG No.33	March	2009
WDCGG No.34	March	2010
WDCGG No.35	March	2011
WDCGG No.36	March	2012
WDCGG No.37	March	2013

WMO WDCGG CD-ROM:

			(period of data accepted)				
CD-ROM No. 1	March	1995	October	1990	~	December	1994
CD-ROM No. 2	March	1996	October	1990	~	June	1995
CD-ROM No. 3	March	1997	October	1990	~	June	1996
CD-ROM No. 4	March	1998	October	1990	~	December	1997
CD-ROM No. 5	March	1999	October	1990	~	December	1998

CD-ROM No. 6	March	2000	October	1990	~	December	1999
CD-ROM No. 7	March	2001	October	1990	~	December	2000
CD-ROM No. 8	March	2002	October	1990	~	January	2002
CD-ROM No. 9	March	2003	October	1990	~	December	2002
CD-ROM No.10	March	2004	October	1990	~	December	2003
CD-ROM No.11	March	2005	October	1990	~	December	2004
CD-ROM No.12	March	2006	October	1990	~	December	2005
CD-ROM No.13	March	2007	October	1990	~	November	2006
CD-ROM No.14	March	2008	October	1990	~	November	2007

WMO WDCGG DVD: (period of data accepted)

DVD No. 1	March	2009	October	1990	~	November	2008
DVD No. 2	March	2010	October	1990	~	November	2009
DVD No. 3	March	2011	October	1990	~	November	2010
DVD No. 4	March	2012	October	1990	~	November	2011
DVD No. 5	March	2013	October	1990	~	November	2012
DVD No. 6	March	2014	October	1990	~	November	2013