# Summary

This issue of *Data Summary* covers the results of basic analyses on greenhouse gas concentrations reported to the WMO World Data Centre for Greenhouse Gases (WDCGG). The data reached the WDCGG by September 2002 were used for analysis and the periods of observation ranged from 1968 to 2001. This *Data Summary* includes analyses of the monthly mean concentrations in global, hemispheric and zonal averages for greenhouse gases and related gases. The produced analyses should provide useful information on the change in concentrations of greenhouse gases and related gases.

For the analyses in this publication, only monthly mean concentrations are used. The WDCGG considers it even better to adopt monthly mean data so that the analysis can incorporate more observation sites including a large number of stations in the NOAA flask-sampling network. Of course, it is also appreciated that some stations submit daily and hourly mean concentrations, which may be more appropriate for analyzing the variations in various time-scales. All the submitted data are available on the WDCGG web site (http://gaw.kishou.go.jp/wdcgg.html).

A time series of greenhouse gas concentrations, which is often produced by removing local effects with very-short-term variations, is an integration of the variation on different time scales. The two major components of variations in $CO_2$ concentration are a seasonal variation and a long-term trend. Annual growth rates are derived from the deseasonalized long-term trend.

Plates 1 and 3 show the variation in zonal mean concentrations, as well as deseasonalized concentrations and growth rates for $CO_2$ and $CH_4$, respectively. For both $CO_2$ and $CH_4$, the concentrations are clearly dependent on latitude and have a long-term increasing trend and a seasonal variation. The amplitude and phase of the seasonal variation also depend on latitude. The growth rate is also uneven in latitude and time. These differences in time and space are attributed to variations in the emission/production and removal/dissociation of $CO_2$, $CH_4$ and other related gases.

The analytical results are summarized for each of greenhouse and related gases below:

## 1. Carbon Dioxide ($CO_2$)

The level of $CO_2$, which of all the greenhouse gases contributes most to global warming, has been increasing since the pre-industrial period. Global mean concentrations reflect an annual increase, and the annual mean concentration was 371 ppm in 2001. Concentrations peak in northern high and mid-latitudes, suggesting strong net sources in these areas.

The global growth rate is 1.6 ppm/year on average for the period 1983-2001. However, growth rates vary significantly interannually. The high growth rates in 1983, 1987/1988, 1994/1995 and 1997/1998 are associated with the warm events of El Niño-Southern Oscillation (ENSO). The anomalously strong El Niño event in 1997/1998 brought about worldwide high increases in 1998. The exceptionally low growth rates in 1992, including negative values for northern high and mid-latitudes, were caused by low global temperatures following the eruption of Mt. Pinatubo in 1991.

Amplitudes of the seasonal cycle are clearly large in northern high and mid-latitudes and small in the Southern Hemisphere. The northern seasonal cycle mainly reflects the seasonal variation in the absorption/emission in the biosphere there, while the southern cycle reflects oceanic variations and biomass burning in addition to the influence of the biosphere. In southern low latitudes, an annual cycle cannot be seen clearly but a semiannual cycle can. This is probably due to two opposing factors, *i.e.*, the direct influence of sources and sinks there and the propagation of the out-of-phase seasonal variation from the Northern Hemisphere.

## 2. Methane ($CH_4$)

$CH_4$ is the second most significant greenhouse gas, and its level has been increasing since the beginning of the 19th century. Global mean concentrations reflect an annual increase, and the annual averaged concentration was 1782 ppb in 2001. The annual concentrations produce a peak in the northernmost latitudes and decrease toward the southernmost latitudes, suggesting significant net sources in northern latitudes.

The global growth rate is 8 ppb/year on average for the period 1984-2001, but the rates show a distinct decrease from the 1980s to 1990s. Growth rates decreased significantly in some years, including 1992, when negative values were recorded in northern high latitudes, and 1996, when growth almost stopped in many regions. However, both hemispheres experienced high growth rates in 1998, caused by an exceptionally high global mean temperature. And the global growth rates decreased again largely to record negative values in 2000 for the first time during the analysis period.

Monthly mean concentrations have a seasonal variation with high concentrations in winter and low ones in summer. Unlike $CO_2$, amplitudes of the seasonal cycle are large for $CH_4$ not only in the Northern Hemisphere but also in southern high and mid-latitudes. In southern low latitudes, a distinct semi-annual component with a secondary maximum in boreal winter overlays the annual component. This is attributed to the large-scale transportation of $CH_4$ from the Northern Hemisphere.

## 3. Nitrous Oxide ($N_2O$)

Nitrous oxide is an important greenhouse gas, and its level is increasing on a global scale. Data for $N_2O$ reported to the WDCGG show that concentrations are increasing in both hemispheres.

## 4. Halocarbons

Halocarbons, most of which are anthropogenic, are effective greenhouse gases and some also act as ozone-depleting compounds. Levels of some of the halocarbons (CFCs, etc.) increased in the 1970s and 1980s, but have now almost ceased increasing due to the regulation of production and emission under the Montreal Protocol on Substances that Deplete the Ozone Layer and its Adjustments and Amendments.

The following descriptions are about long-term trends for CFC-11, CFC-12, CFC-113, HCFC-141b, HCFC-142b, $CCl_4$ and $CH_3CCl_3$ since around 1990 based on data reported to the WDCGG:

Concentrations of CFC-11 were at a maximum around 1992 and then started decreasing. CFC-12 increased slowly, but growth has almost stopped in recent times. CFC-113 increased slightly, but growth has almost stopped at this point. Concentrations of HCFC-141b and HCFC-142b are linearly increasing. Concentrations of $CCl_4$ are decreasing slowly. Concentrations of $CH_3CCl_3$ were at a maximum around 1992 and then started to clearly decrease.

## 5. Surface Ozone ($O_3$)

Ozone plays important role in the atmospheric environment through radiative and chemical processes. Ozone absorbs UV radiation in the stratosphere making temperature profile and circulation there with its absorbed energy. As well, ozone absorbs IR radiation in the troposphere, thus is one of greenhouse gases.

A variation in ozone near the surface (so-called surface ozone) reflects various processes there. While a part of tropospheric ozone is transported from the stratosphere, the rest is chemically produced in the troposphere through oxidation of CO or hydrocarbons in the presence of rich $NO_x$.

The concentration of surface $O_3$ is variable from station to station. As the seasonal and interannual variation is relatively large, it is difficult to identify a general long-term trend for surface $O_3$ concentrations.

## 6. Carbon Monoxide (CO)

CO is not a significant greenhouse gas, but brings about changes in the concentrations of greenhouse gases by interacting with hydroxyl radicals (OH). Concentrations of CO have increased in northern high latitudes since the mid-19th century, but have not changed significantly over Antarctica during the previous two millennia. The annual averaged concentration was about 93 ppb in 2001. The annual mean concentration is high in the Northern Hemisphere and low in the Southern Hemisphere, suggesting substantial anthropogenic emissions in the Northern Hemisphere.

Though the level of CO was increasing before the mid-1980s, the averaged global growth rate was –0.8 ppb/year for the period from 1992 to 2001. The variability of the growth rates is large. High positive growth rates and subsequent high negative growth rates were observed in northern latitudes and southern low latitudes from 1997 to 1999.

Monthly mean concentrations show a seasonal variation with large amplitudes in the Northern Hemisphere and small ones in the Southern Hemisphere. This seasonal cycle is driven by variations in OH concentration as a sink, emission by industries and biomass burning, and transportation on a large scale.

## 7. Nitrogen Monoxide (NO) and Nitrogen Dioxide ($NO_2$)

Nitrogen oxides ($NO_x$, i.e., NO and $NO_2$) are not greenhouse gases, but bring about changes in the concentrations of other important greenhouse gases by interacting with hydroxyl radicals (OH). 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 reporting $NO_x$ data to the WDCGG are located in Europe. $NO_x$ has large variability in time and space, and it is difficult to identify a long-term trend. In Europe, $NO_2$ concentrations are generally higher in southern regions than in northern regions.

## 8. Sulfur Dioxide ($SO_2$)

$SO_2$ is not a greenhouse gas but a precursor of atmospheric sulfuric acid ($H_2SO_4$) aerosol. Sulfuric acid aerosol is produced by $SO_2$ oxidation through photochemical gas-to-particle conversion. $SO_2$ has been a major source of acid rain and deposition throughout industrial times.

Most of the stations reporting $SO_2$ data to the WDCGG are located in Europe. Generally, in Europe, $SO_2$ concentrations are higher in the southern regions than in northern regions.