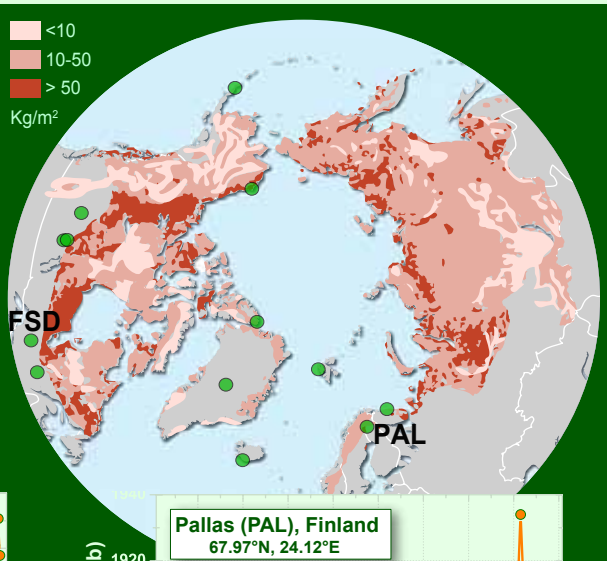
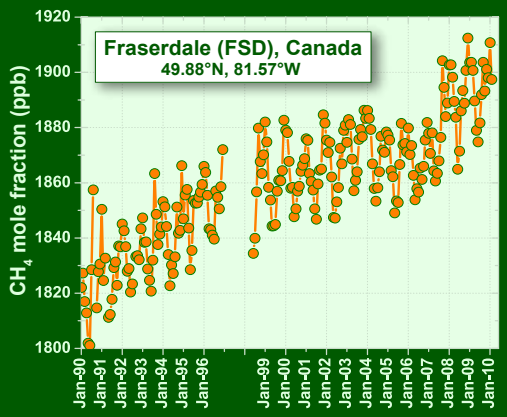
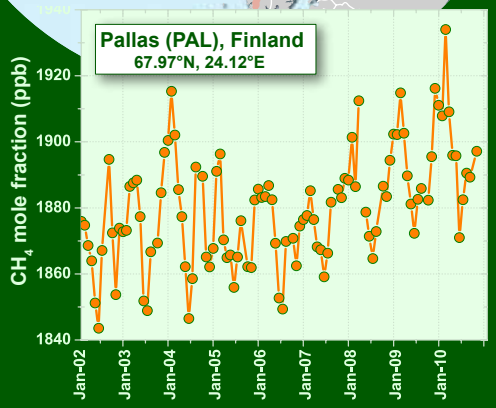
WMO
Greenhouse Gas Bulletin

The State of Greenhouse Gases in the Atmosphere Based on Global Observations through 2009

Permafrost, which contains organic carbon, and methane (CH_4) clathrates are two large northern reservoirs of carbon that are susceptible to the effects of climate change. A rapidly warming high-latitude region has the potential to release large quantities of CH_4 into the atmosphere from these carbon reservoirs, which would provide a strong positive feedback on climate. The map shows Arctic soil organic carbon content (http://maps.grida.no/go/graphic/arctic-soil-organic-carbon-content, Riccardo Pravettoni, UNEP/GRID-Arendal).







Measurements from the Global Atmosphere Watch (GAW) network show increased global CH_4 from 2007 to 2009 after nearly a decade of no growth. The GAW stations in the Arctic region that perform methane measurements and submit their data to the GAW World Data Centre for Greenhouse Gases are shown as dots on the map above. Data from two stations are shown in the graphs. Each reflects regional and larger-scale influences of emissions. The sharp increase in 2007 on the left is linked to the site's proximity to large wetlands and local meteorological effects, while the increase shown on the right is more gradual. Nations contributing to the GAW Programme are expanding CH_4 measurements globally to help scientists understand the processes governing CH_4 emissions.

Executive summary

The latest analysis of observations from the WMO Global Atmosphere Watch Programme shows that the globally averaged mixing ratios of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) reached new highs in 2009, with CO_2 at 386.8 ppm, CH_4 at 1803 ppb and N_2O at 322.5 ppb. These values are greater than those in pre-industrial times (before 1750) by 38%, 158% and 19%, respectively. Atmospheric growth rates of CO_2 and N_2O in 2009 are consistent with recent years, but are lower than in 2008. After nearly a decade of no growth, atmospheric CH_4 has increased during the past three years. The reasons for renewed growth of atmospheric methane are not fully understood, but emissions from natural sources (from northern latitudes and the tropics) are considered potential causes. The NOAA Annual Greenhouse Gas Index shows that from 1990 to 2009, radiative forcing by all long-lived greenhouse gases increased by 27.5%, with CO_2 accounting for nearly 80% of this increase. The combined radiative forcing by halocarbons is nearly double that of N_2O.

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Overview

This is the sixth in a series of WMO-GAW Annual Greenhouse Gas Bulletins. Each year, this publication reports the global consensus on the latest changes in and atmospheric burdens of the most important long-lived greenhouse gases (carbon dioxide, methane, nitrous oxide, CFC-12 and CFC-11), and provides a summary of the contributions of the lesser gases. These five major gases account for approximately 96% (Figure 1) of the increase in radiative forcing due to long-lived greenhouse gases that has occurred since 1750.

The WMO Global Atmosphere Watch Programme coordinates systematic observations and analysis of atmospheric composition, including greenhouse gases and other trace species. The GAW CO_2 and CH_4 networks are comprehensive networks of the Global Climate Observing System (GCOS). Sites where greenhouse gases are monitored are shown in Figure 2. The measurement data are reported by participating countries and archived and distributed by the World Data Centre for Greenhouse Gases (WDCGG) at the Japan Meteorological Agency.

Statistics on present global atmospheric abundances of and changes in the three major greenhouse gases are given in Table 1. These results are obtained from a global analysis method (GAW Report No. 184, see http://www.wmo.int/gaw) using datasets that are traceable to the WMO World Reference Standard. Data from mobile stations, with the exception of NOAA flask sampling in the Pacific (blue triangles in Figure 2), are not used for global analysis.

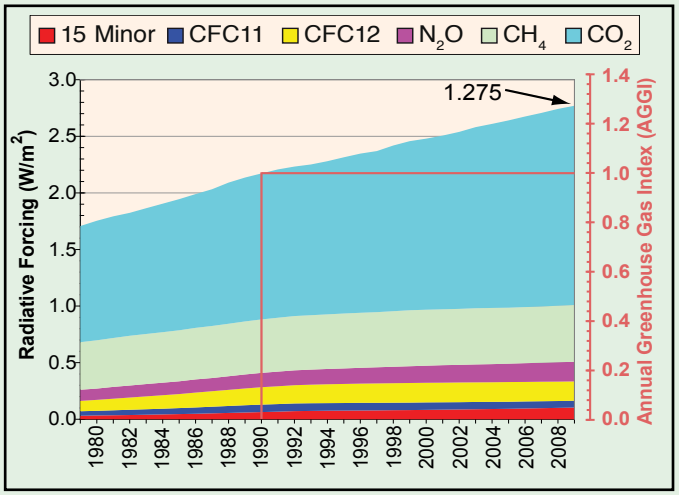

Figure 1. Atmospheric radiative forcing, relative to 1750, of all long-lived greenhouse gases and the 2009 update of the NOAA Annual Greenhouse Gas Index (AGGI). The reference year for the index is 1990 (AGGI = 1).

Table 1. Global abundances of and changes in key greenhouse gases from the GAW global greenhouse gas monitoring network. Global abundances for 2009 are calculated as an average over twelve months.

	CO_2 (ppm)	CH_4 (ppb)	N_2O (ppb)
Global abundance in 2009	386.8	1803	322.5
Increase since 1750[1]	38 %	158 %	19 %
2008–09 absolute increase	1.6	5	0.6
2008–09 relative increase	0.42 %	0.28 %	0.19 %
Mean annual absolute increase during last 10 years	1.88	2.2	0.77

[1] Assuming a pre-industrial mixing ratio of 280 ppm for CO_2, 700 ppb for CH_4 and 270 ppb for N_2O.

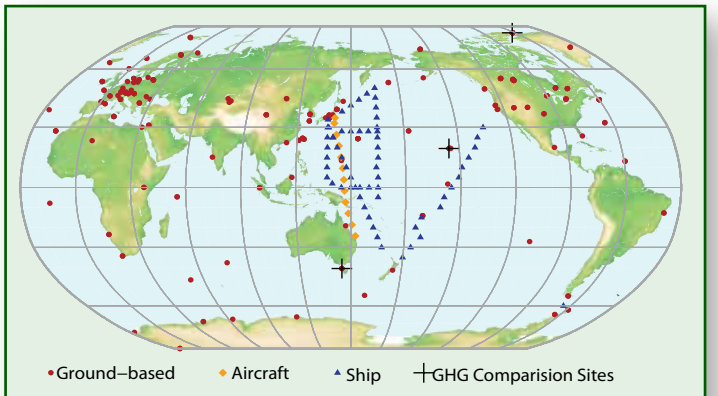

Figure 2. The GAW global network for carbon dioxide. There is a similar network for methane.

The three greenhouse gases in Table 1 have been increasing in the atmosphere since the beginning of the industrial age. Unlike water vapour, which is the most important greenhouse gas, their atmospheric abundances are directly connected with human activity and are generally much longer lived in the atmosphere than water vapour. The three primary greenhouse gases are not only closely linked to anthropogenic activities, but also have strong interactions with the biosphere and the oceans. Chemical reactions in the atmosphere affect their abundances as well. Prediction of the evolution of greenhouse gases in the atmosphere requires an understanding of their many sources and sinks.

According to the NOAA Annual Greenhouse Gas Index, the total radiative forcing by all long-lived greenhouse gases increased by 27.5% from 1990 to 2009 and by 1.0% from 2008 to 2009 (see Figure 1 and http://www.esrl.noaa.gov/gmd/aggi).

Carbon Dioxide (CO_2)

Carbon dioxide is the single most important anthropogenic greenhouse gas in the atmosphere, contributing 63.54 %[2] to the overall global radiative forcing. It is responsible for 85% of the increase in radiative forcing over the past decade and 83% over the last five years. For about 10 000 years before the industrial revolution, the atmospheric abundance of CO_2 was nearly constant at ~ 280 ppm (ppm = number of molecules of the gas per million molecules of dry air). This level represented a balance among the atmosphere, the oceans and the biosphere. Since 1750, atmospheric CO_2 has increased by 38%, primarily because of emissions from combustion of fossil fuels (8.7 Gt carbon in 2008, http://www.globalcarbonproject.org/), deforestation and land-use change. High-precision measurements of atmospheric CO_2 beginning in 1958 show that the average increase in CO_2 in the atmosphere (airborne fraction) corresponds to ~ 55% of the CO_2 emitted by fossil fuel combustion. The

[2] This percentage is calculated as the relative contribution of the mentioned gas to the increase in global radiative forcing caused by all long-lived greenhouse gases since 1750 (http://www.esrl.noaa.gov/gmd/aggi).

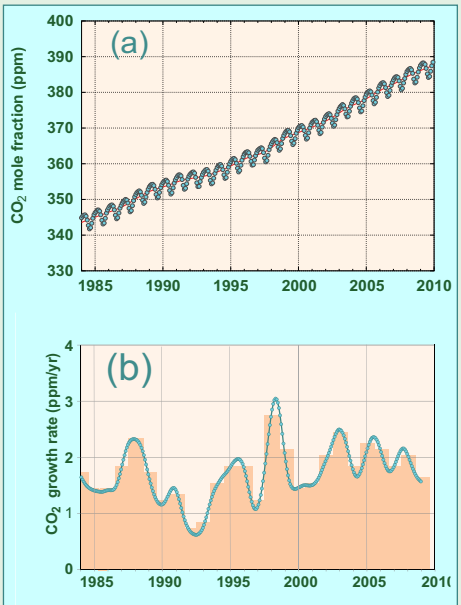

Figure 3. Globally averaged CO_2 mole fraction (a) and its growth rate (b) from 1984 to 2009. Annually averaged growth rate is shown by columns at (b).

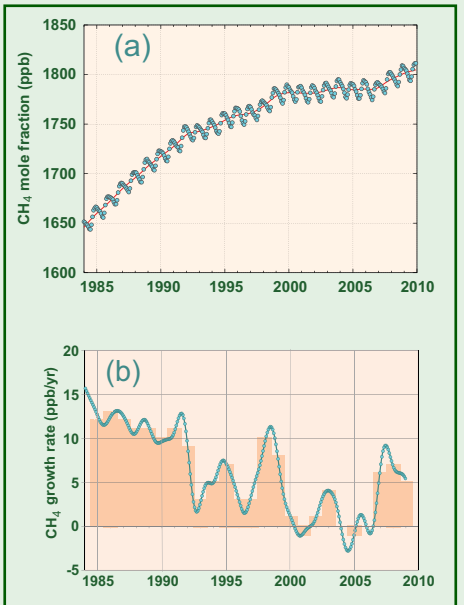

Figure 4. Globally averaged CH_4 mole fraction (a) and its growth rate (b) from 1984 to 2009. Annually averaged growth rate is shown by columns at (b).

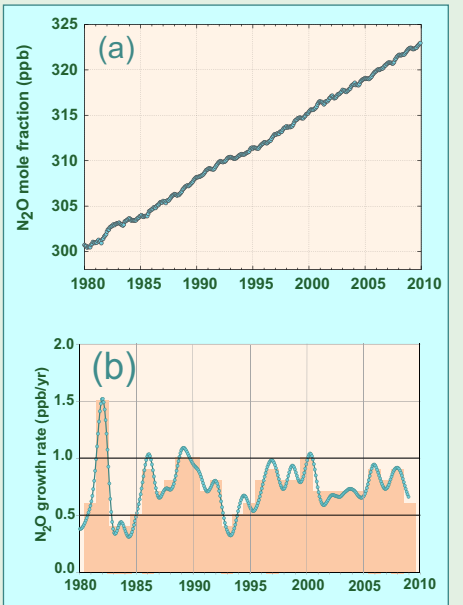

Figure 5. Globally averaged N_2O mole fraction (a) and its growth rate (b) from 1980 to 2009. Annually averaged growth rate is shown by columns at (b).

remaining ~45% has been removed from the atmosphere by the oceans and the terrestrial biosphere. The airborne fraction of CO_2 varies interannually, without a confirmed global trend. Globally averaged CO_2 in 2009 was 386.8 ppm and the increase from the year before was 1.6 ppm (Figure 3). This growth rate is higher than the average for the 1990s (~1.5 ppm/yr), but lower than the average for the past decade.

Methane (CH_4)

Methane contributes 18.1 %[2] to the overall global radiative forcing. Approximately 40% of the methane emitted into the atmosphere comes from natural sources, such as wetlands and termites, while anthropogenic sources, such as ruminants, rice agriculture, fossil fuel exploitation, landfills and biomass burning, account for around 60%. Methane is removed from the atmosphere primarily by reaction with the hydroxyl radical (OH). Before the industrial era, atmospheric methane was at ~700 ppb (ppb = number of molecules of the gas per billion (10^9) molecules of dry air). Increasing emissions from anthropogenic sources are responsible for the 158% increase in CH_4. Globally averaged CH_4 in 2009 was 1803 ppb, an increase of 5 ppb from the previous year. It exceeds the highest annual mean abundance so far, which was recorded in 2008 (Figure 4). The growth rate of CH_4 decreased from ~13 ppb/yr during the early 1980s to near zero from 1999 to 2006. Since 2007, atmospheric CH_4 has been increasing again. The 13 ppb rise from 2006 to 2008 was followed by a 5 ppb rise in 2009. Studies based on GAW network data found that the likely drivers of these increases are: a) greater than average wetland CH_4 emissions at high northern latitudes during 2007 owing to exceptionally warm temperatures; and b) tropical emissions during 2007 and 2008 related to greater than normal precipitation in wetland regions during a La Niña episode. The reasons for the recent increase in CH_4 are not fully understood, and it is uncertain if growth at the same rate will continue. In order to improve our understanding of the processes that affect CH_4 emissions, more in situ measurements are needed close to the source regions, supported by measurements of column CH_4 abundances from satellites.

Nitrous Oxide (N_2O)

Nitrous oxide contributes 6.24%[2] to the overall global radiative forcing. Its atmospheric abundance prior to industrialization was 270 ppb. N_2O is emitted into the atmosphere from natural and anthropogenic sources, including the oceans, soil, biomass burning, fertilizer use, and various industrial processes. Anthropogenic sources may account for approximately 40% of total N_2O emissions. It is removed from the atmosphere by photochemical processes in the stratosphere. Globally averaged N_2O during 2009 was 322.5 ppb, up 0.6 ppb from the year before (Figure 5) and 19% above the pre-industrial level. The mean growth rate has been 0.77 ppb/yr over the past 10 years.

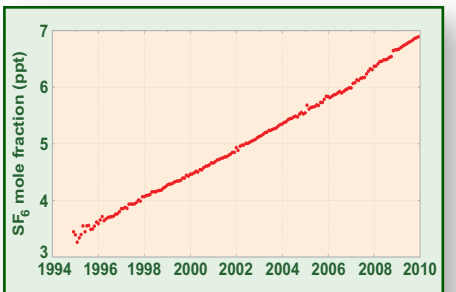

Figure 6. Monthly mean mole fraction of sulphur hexafluoride (SF_6) from 1995 to 2009 averaged over 15 stations.

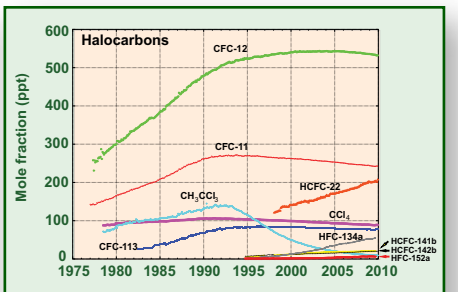

Figure 7. Monthly mean mole fraction of the most important halocarbons from 1977 to 2009 averaged over the network (between 5 and 18 stations).

Other Greenhouse Gases

Sulphur hexafluoride (SF_6) is a potent long-lived greenhouse gas controlled by the Kyoto Protocol. It is produced artificially and used as an electrical insulator in power distribution equipment. Its mixing ratio has increased to double that in the mid-1990s (Figure 6).

The ozone-depleting chlorofluorocarbons (CFCs), together with minor halogenated gases, contribute 12%[2] to the overall global radiative forcing. While CFCs and most halons are decreasing, hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs), which are also potent greenhouse gases, are increasing at rapid rates, although they are still low in abundance (Figure 7).

Ozone in the troposphere does not have a long lifetime. The greenhouse effect of the tropospheric ozone increase over the last century due to human activities, however, appears to be comparable to that of the halocarbons, although much less certain. It is difficult to estimate the global distribution and trend of tropospheric ozone because of its uneven geographical distribution and high temporal variability.

Many other pollutants (such as carbon monoxide, nitrogen oxides and volatile organic compounds), although they are insignificant as greenhouse gases, have an indirect effect on the radiative forcing through their impact on tropospheric ozone, CO_2 and methane. Aerosols (suspended particulate matter), including black carbon, are also short-lived substances that influence radiative forcing.

All the gases mentioned here and aerosols are monitored by the GAW Programme, with support from member countries and contributing networks.

Distribution of the bulletins

The WMO Secretariat prepares and distributes bulletins in cooperation with the World Data Centre for Greenhouse Gases at the Japan Meteorological Agency and the GAW Scientific Advisory Group for Greenhouse Gases, with the assistance of the NOAA Earth System Research Laboratory (ESRL). The bulletins are available through the Global Atmosphere Watch Programme Web page and on the home pages of WDCGG and the NOAA Carbon Cycle Greenhouse Gases Group (http://www.esrl.noaa.gov/gmd/ccgg).

Acknowledgements and links

Forty-eight WMO member countries have contributed CO_2 data to the GAW WDCGG. Approximately 49% of the measurement records submitted to WDCGG are obtained at sites in the NOAA ESRL cooperative air sampling network. The rest of the network is maintained by Australia, Canada, China, Japan and many European countries (see the national reports in GAW Report No. 186, available at http://www.wmo.int/gaw). The Advanced Global Atmospheric Gases Experiment (AGAGE) is also a GAW-affiliated network contributing observations to this bulletin. The GAW monitoring stations contributing to the data used in this bulletin are shown on the map (Figure 2) and included in the List of Contributors on the WDCGG Web page (http://gaw.kishou.go.jp/wdcgg/). They are also described in the GAW Station Information System (http://gaw.empa.ch/gawsis/) operated by EMPA, Switzerland.

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   Website: http://gaw.kishou.go.jp/wdcgg/

Selected greenhouse gas observatories

The Mount Chacaltaya Station, GAW Regional Station since 2010, is located at 5 320 m a.s.l., 16.2º S and 68.1º W in the East Andes in Bolivia. Chacaltaya is operated by the Atmospheric Physics Laboratory (Universidad Mayor de San Andrés, also part of the Physics Research Institute) and supported by Servicio Nacional de Meteorologia e Hidrologia of Bolivia. Some equipment and facilities are in intermittent operation at this site. It is also a well-known Cosmic Ray Laboratory, where the pion was found in emulsion plates exposed to cosmic rays in 1948. An international team from Bolivia, France, Italy and Switzerland is working on the implementation of the world´s highest atmospheric monitoring station for aerosols and reactive and greenhouse gases. For more information, visit http://www.chacaltaya.edu.bo/

The Nepal Climate Observatory - Pyramid (PYR, 27.95º N, 86.82º E) is located at 5 079 m a.s.l. in the eastern Nepal Himalaya, near the Mt Everest base camp area in the high Khumbu valley. PYR was set up during January and February 2006, and the observation programme was launched at the end of February 2006. It became a GAW Global Station in September 2010 with high-quality continuous measurements of aerosol physical properties, surface ozone, solar radiation, meteorological parameters, AOD measurements within the AERONET programme and offline samples of halogenated compounds and aerosol chemistry, carried out using renewable energy. PYR is operated by the Italian National Research Council, the Centre National de la Recherche Scientifique, Urbino University, the Italian National Agency for New Technologies and the Nepal Academy of Sciences and Technology. PYR is also part of the Atmospheric Brown Cloud project. For further information, visit http://evk2.isac.cnr.it/.