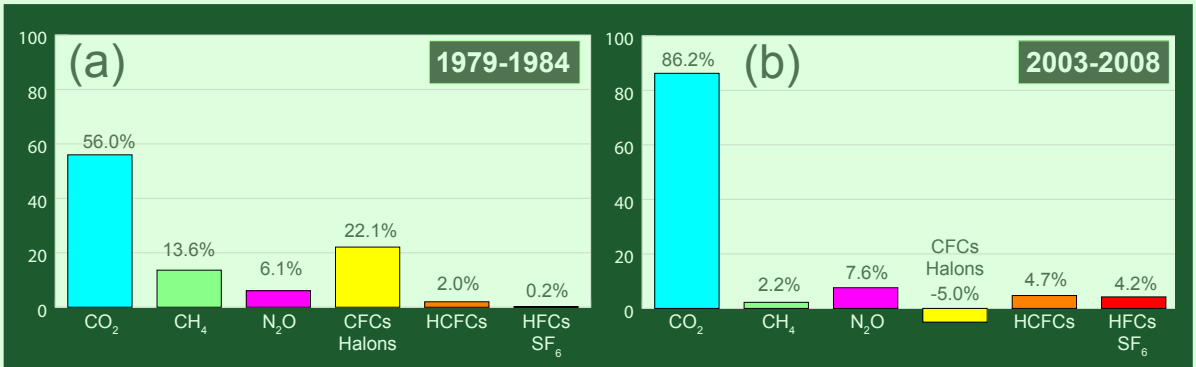
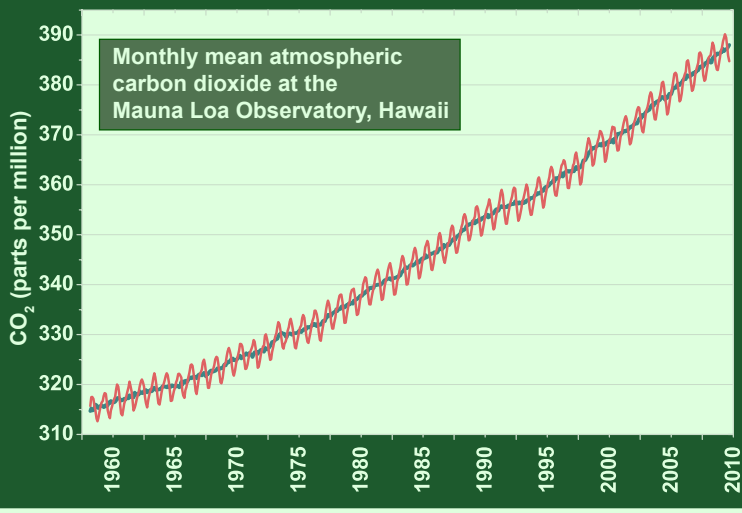
WMO
Greenhouse Gas Bulletin

The State of Greenhouse Gases in the Atmosphere Using Global Observations through 2008



Relative contribution of major greenhouse gases to the overall change in radiative forcing between 1979 and 1984 (a) and from 2003 to 2008 (b). The importance of CO_2 has increased substantially. Whereas the contribution from CFCs and halons has turned around and now is negative, the contributions from HCFCs and HFCs are increasing rapidly. From 2003 to 2008 they were, together with SF_6, responsible for 8.9 % of the increase in the radiative forcing caused by long-lived greenhouse gases.



CO_2 measured on Mauna Loa constitutes the longest record of direct measurements in the atmosphere. The dark curve behind the monthly means represents the seasonally adjusted data. The amount of CO_2 in the atmosphere is increasing exponentially at a rate of about 0.5% per year.

Data courtesy of Scripps Institution of Oceanography, University of California, San Diego and National Oceanic and Atmospheric Administration (NOAA).

Executive summary

The latest analysis of observations from WMO's Global Atmosphere Watch (GAW) Programme shows that the globally averaged mixing ratios of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) have reached new highs in 2008 with CO_2 at 385.2 ppm, CH_4 at 1797 ppb and N_2O at 321.8 ppb: higher than those in pre-industrial times (before 1750) by 38%, 157% and 19%, respectively. Atmospheric growth rates of CO_2 and N_2O in 2008 are consistent with recent years. The increase in atmospheric CH_4 was 7 ppb from 2007 to 2008, similar to the increase of the year before. These are the largest increases since 1998. The NOAA Annual Greenhouse Gas Index (AGGI) shows that from 1990 to 2008 the radiative forcing by all long-lived greenhouse gases has increased by 26.2%. The combined radiative forcing by halocarbons is nearly double that of N_2O. Some halocarbons are decreasing slowly as a result of emission reductions under the Montreal Protocol on Substances That Deplete the Ozone Layer, whereas others are increasing rapidly.

World Meteorological Organization
Weather • Climate • Water

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Global Atmosphere Watch

Overview

This is the fifth in a series of WMO-GAW Annual Greenhouse Gas Bulletins. Each year, they report the global consensus on the latest changes and atmospheric burdens of the most important, long-lived greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), CFC-12 and CFC-11, as well as a summary of the contributions of the lesser gases (Figure 1). These five major gases contribute about 96% of the increase in radiative forcing due to long-lived greenhouse gases that has occurred since 1750.

The Global Atmosphere Watch (GAW) Programme of the World Meteorological Organization (WMO) 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 (JMA) (http://gaw.kishou.go.jp/wdcgg).

Statistics on the present global atmospheric abundances and changes of the three major greenhouse gases are given in Table 1. These results are obtained from a global analysis method (GAW report no. 184, http://www.wmo.int/pages/prog/arep/gaw/documents/TD_1473_GAW184_web.pdf) using a data set which is traceable to the WMO World Reference Standard. Data from mobile stations, with the exception of NOAA flask sampling, are not used for global analysis.

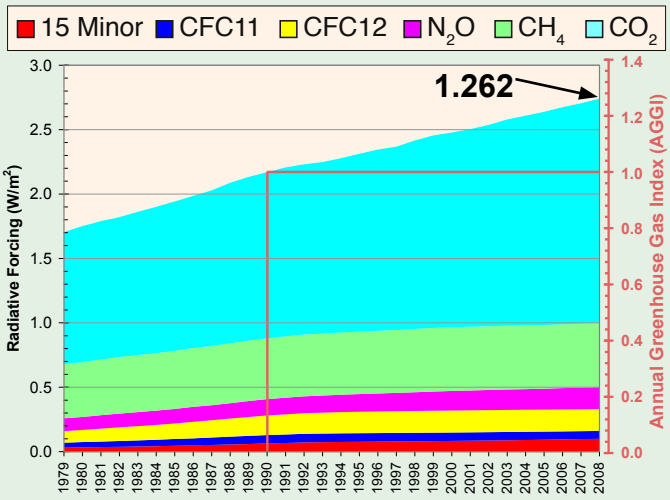

Figure 1. Atmospheric radiative forcing by long-lived greenhouse gases (after 1750) and the 2008 update of the NOAA Annual Greenhouse Gas Index (AGGI). 1990 has been chosen as the year of reference (AGGI = 1) for the Index.

Table 1. Global abundances and changes of key greenhouse gases from the WMO-GAW global greenhouse gas monitoring network. Global abundances for 2008 are calculated as an average over twelve months.

	CO_2 (ppm)	CH_4 (ppb)	N_2O (ppb)
Global abundance in 2008	385.2	1797	321.8
Increase since 1750[1]	38 %	157 %	19 %
2007-08 absolute increase	2.0	7	0.9
2007-08 relative increase	0.52 %	0.39 %	0.28 %
Mean annual absolute increase during last 10 years	1.93	2.5	0.78

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

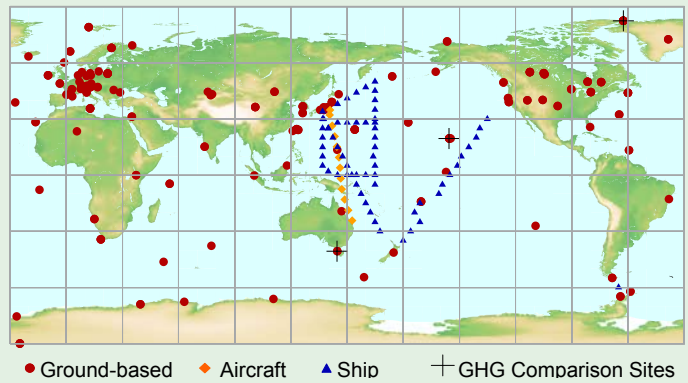

Figure 2. The WMO-GAW global network for carbon dioxide. The network for methane is similar to this.

The three greenhouse gases in Table 1 have been increasing in the atmosphere since the beginning of the industrial age. Water vapour is the most important greenhouse gas, but it is connected to human activities only through climate feedbacks. This Bulletin focuses on those greenhouse gases that are directly influenced by humans and that 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 (AGGI), the total radiative forcing by all long-lived greenhouse gases has increased by 26.2% since 1990 and by 1.3% from 2007 to 2008 (see Figure 1 and http://www.esrl.noaa.gov/gmd/aggi).

Carbon Dioxide (CO_2)

CO_2 is the single most important human-emitted greenhouse gas in the atmosphere, contributing 63.5 %[2] to the overall global radiative forcing. However, it is responsible for 85% of the increase in radiative forcing over the past decade and 86% 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 abundance represented a balance between 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 (8.62 Gt carbon in 2007) and deforestation and land use change (0.5-2.5 Gt carbon per year over

[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).

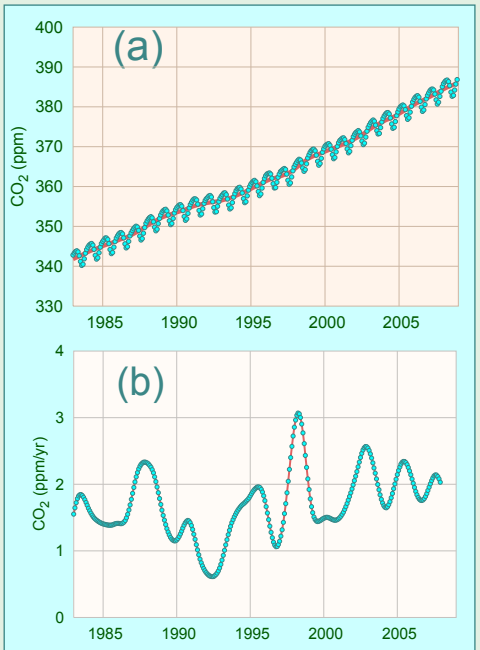

Figure 3. Globally averaged CO_2 (a) and its growth rate (b) from 1983 to 2008.

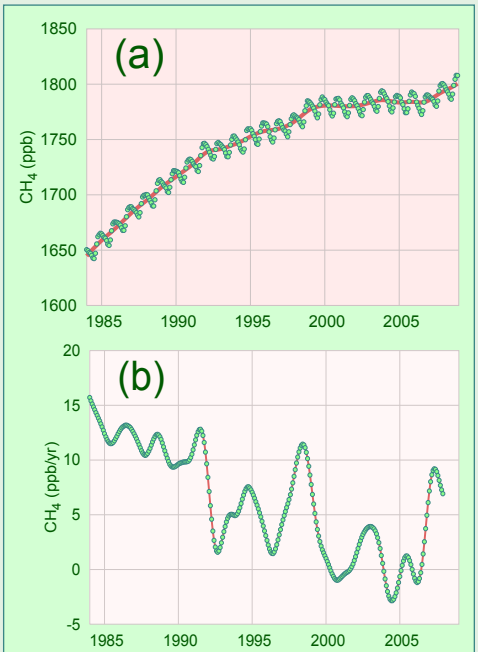

Figure 4. Globally averaged CH_4 (a) and its growth rate (b) from 1984 to 2008.

the 2000-2005 time period). High-precision measurements of atmospheric CO_2 beginning in 1958 show that the average increase of CO_2 in the atmosphere corresponds to ~55% of the CO_2 emitted by fossil fuel combustion. The remaining fossil fuel-CO_2 has been removed from the atmosphere by the oceans and the terrestrial biosphere. Globally averaged CO_2 in 2008 was 385.2 ppm and the increase from the year before was 2.0 ppm (Figure 3). This growth rate is larger than the average for the 1990s (~1.5 ppm/yr), mainly because of increasing emissions of CO_2 from fossil fuel combustion.

Methane (CH_4)

Methane contributes 18.2 %[(2)] to the overall global radiative forcing. Methane is emitted to the atmosphere by natural (~40%, e.g., wetlands and termites) and anthropogenic sources (~60%, e.g., ruminants, rice agriculture, fossil fuel exploitation, landfills and biomass burning). It 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 157% increase in CH_4. Globally averaged CH_4 in 2008 was 1797 ppb, which means an increase of 7 ppb from the year before. It exceeds the highest annual mean abundance recorded so far, which was in 2007 (Figure 4). Methane was increasing by up to 13 ppb per year during the late 1980s, while the growth rate decreased during the past decade. The 7 ppb rise from 2007 to 2008 follows the 7 ppb rise the previous year and they represent the highest annual increases since 1998. From the existing data it is not clear if this 14 ppb increase over two years represents the beginning of a new upward trend in CH_4. In order to improve our understanding of the processes that affect CH_4 emissions more in situ measurements would be needed close to the source regions.

Nitrous Oxide (N_2O)

Nitrous oxide (N_2O) contributes 6.2%[(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, fertiliser use, and various industrial processes. Anthropogenic sources may account for about 40% of total N_2O emissions. It is removed from the atmosphere by photochemical processes in the stratosphere. Globally averaged N_2O during 2008 was 321.8 ppb, up 0.9 ppb from the year before (Figure 5) and 19% above the preindustrial level. The mean growth rate has been 0.78 ppb per year over the past 10 years.

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

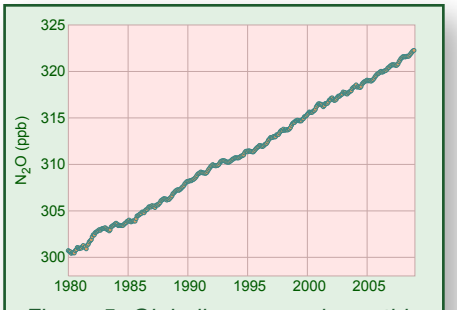

Figure 5. Globally averaged monthly mean mixing ratios of N_2O from 1980 to 2008.

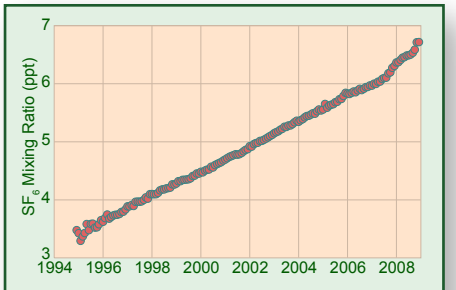

Figure 6. Monthly mean mixing ratios of sulphur hexafluoride (SF_6) from 1995 to 2008 averaged over 24 stations.

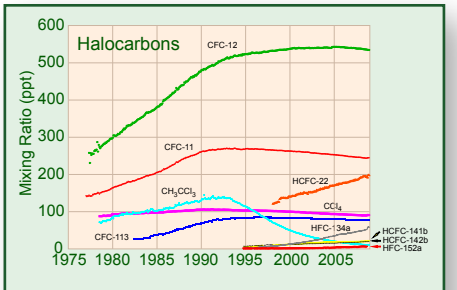

Figure 7. Monthly mean mixing ratios of the most important halocarbons from 1977 to 2008 averaged over the network (between 7 and 56 stations).

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 still low in abundance (Figure 7).

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

Many other pollutants (e.g. 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 WMO-GAW Programme, supported by member countries, and contributing networks.

Distribution of the bulletins

The Secretariat of the World Meteorological Organization (WMO) 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. The Bulletins are available through the Global Atmosphere Watch Programme web page at http://www.wmo.int/gaw/, and on the home pages of WDCGG (http://gaw.kishou.go.jp/wdcgg/) and the NOAA Carbon Cycle Greenhouse Gases Group (http://www.esrl.noaa.gov/gmd/ccgg).

Acknowledgements and links

Forty-five WMO member countries have contributed CO_2 data to the GAW WDCGG. Approximately 50% 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 #186 available at http://www.wmo.int/pages/prog/arep/gaw/documents/revised_SEPT_2009_GAW_186_TD_No_1487_web.pdf). The Advanced Global Atmospheric Gases Experiment (AGAGE) is also a GAW affiliated network contributing observations to this Bulletin. The WMO-GAW monitoring stations contributing to the data used in this Bulletin are shown on the map (Figure 2) and listed in the List of Contributors on the WDCGG web page at (http://gaw.kishou.go.jp/wdcgg/). They are also described in the GAW Station Information System (GAWSIS) (http://gaw.empa.ch/gawsis/) operated by EMPA, Switzerland.

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   Web site: http://gaw.kishou.go.jp/wdcgg/

Selected greenhouse gas observatories

The TCCON observatory in Darwin, Australia. The Total Carbon Column Observing Network (TCCON) is a ground-based network of high resolution Fourier transform spectrometers (FTSs) which retrieve high-quality column-average mixing ratios of CO_2, CH_4, N_2O and several other gases. Total column measurements of CO_2 are tied to the WMO calibration scale through comparisons of FTS data with integrated aircraft profiles measured over TCCON stations with in situ instruments themselves calibrated to the WMO scale. TCCON data are insensitive to vertical transport processes and can be used for verification of forward and inverse models. Furthermore, they serve to validate total column CO_2 and CH_4 satellite measurements from for example GOSAT and SCIAMACHY. TCCON was established in 2004 and joined GAW as a contributing network in 2009. Many of the current measurement sites are also part of the GAW-affiliated Network for Detection of Atmospheric Composition Change (NDACC). TCCON currently has 13 observation stations from Spitsbergen in the high Arctic to Lauder, New Zealand. For further information see the TCCON web site (http://www.tccon.caltech.edu). *Photo: David Griffith, University of Wollongong, Australia.*

The Cape Verde Atmospheric Observatory (CVAO, "Observatorio Atmosferico de Cabo Verde: Humberto Duarte Fonseca") located near Calhau on São Vicente island. It became a Global GAW station in 2009. It is operated jointly by the Instituto Nacional de Meteorologia e Geofisica de Cabo Verde, the University of York, UK (atmospheric chemistry, http://www.york.ac.uk/capeverde), the Max-Planck-Institute for Biogeochemistry, Jena, Germany (greenhouse gases, http://www.bgc-jena.mpg.de/projects/cape_verde) and the Leibniz Institute for Tropospheric Research, Leipzig, Germany (aerosols). *Photo: René Schwalbe, MPI BG, Jena, Germany.*

The atmospheric chemistry observatory at Trinidad Head, California, USA. It became a global GAW station in 2009. *Photo: Michael Ives, Humboldt State University, USA.*