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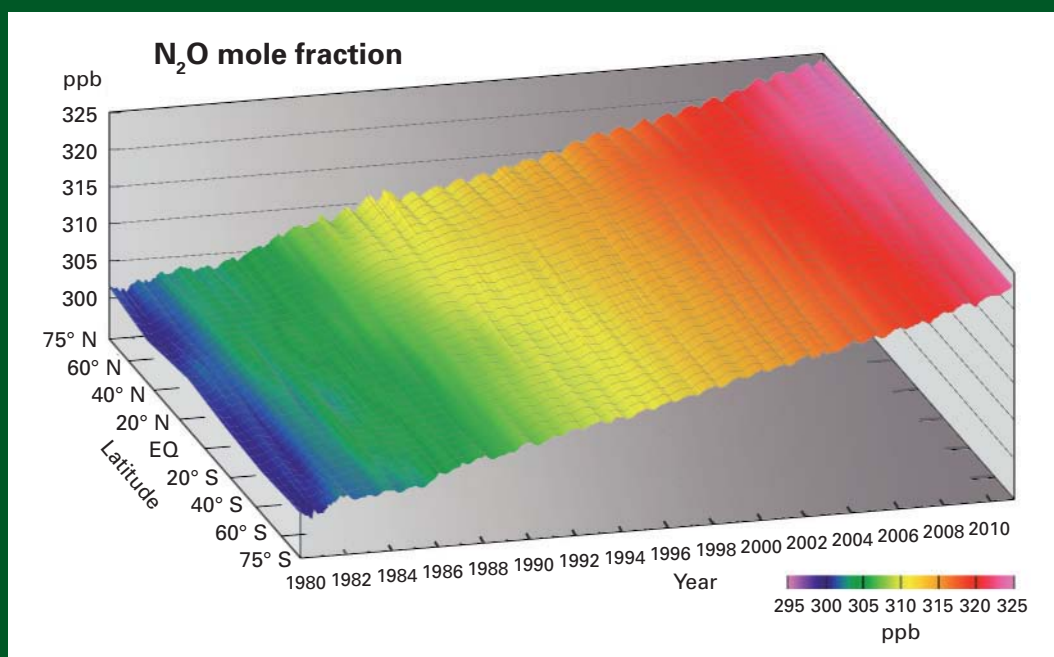


GLOBAL
ATMOSPHERE
WATCH

WMO GREENHOUSE GAS BULLETIN

The State of Greenhouse Gases in the Atmosphere
Based on Global Observations through 2010

No. 7 | 21 November 2011



In the figure above, zonally averaged nitrous oxide (N_2O) abundance from WMO/GAW air sampling sites is plotted as a function of latitude from 1980 to 2010. Nitrous oxide is now the third most important contributor to radiative forcing of long-lived greenhouse gases, recently surpassing CFC-12, and its impact on climate integrated over 100 years is 298 times greater than equal emissions of carbon dioxide (CO_2). It plays an important role in stratospheric ozone (O_3) destruction. The major anthropogenic source of N_2O to the

atmosphere is the use of nitrogen containing fertilizers (including manure), which have profoundly affected the global nitrogen cycle. Reductions in the amounts of fertilizer applied to agricultural fields to better match the nitrogen needs of crops can reduce N_2O emissions. Such changes must be made carefully to avoid lower crop yields, which would raise concerns about global food security. The predominant use of fertilizers in the mid-latitudes of the northern hemisphere is responsible for the small north-to-south gradient of ~ 1.2 ppb.^[1]

Executive summary

The latest analysis of observations from the WMO 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) reached new highs in 2010, with CO_2 at 389.0 ppm,^[2] CH_4 at 1808 ppb and N_2O at 323.2 ppb. These values are greater than those in pre-industrial times (before 1750) by 39%, 158% and 20%, respectively. Atmospheric increases of CO_2 and N_2O from

2009 to 2010 are consistent with recent years, but they are higher than both those observed from 2008 to 2009 and those averaged over the past 10 years. Atmospheric CH_4 continues to increase, consistent with the past three years. The NOAA Annual Greenhouse Gas Index shows that from 1990 to 2010 radiative forcing by long-lived greenhouse gases increased by 29%, with CO_2 accounting for nearly 80% of this increase. Radiative forcing of N_2O exceeded that of CFC-12, making N_2O the third most important long-lived greenhouse gas.

Overview

This is the seventh in a series of WMO/GAW Annual Greenhouse Gas Bulletins. Each year, this bulletin reports the atmospheric burdens and rates of change of the most important long-lived greenhouse gases (LLGHGs) – 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% of radiative forcing due to LLGHGs (Figure 1).

The WMO Global Atmosphere Watch Programme coordinates systematic observations and analysis of atmospheric composition, including greenhouse gases and other trace species. The GAW CO₂, CH₄ and N₂O networks are comprehensive and baseline networks of the Global Climate Observing System (GCOS). Sites where greenhouse gases are monitored are shown in Figure 2. 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 global atmospheric abundances in 2010 and changes in abundance since 2009 and 1750 for the three major greenhouse gases are given in the table. These results are obtained from a global analysis (GAW Report No. 184, available at <http://www.wmo.int/gaw>) of datasets

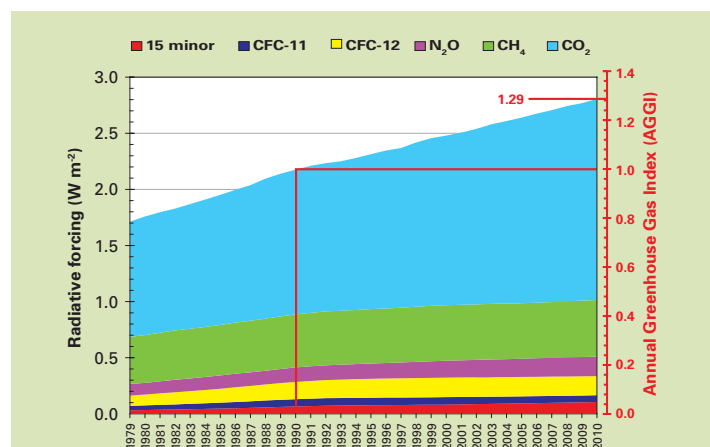


Figure 1. Atmospheric radiative forcing, relative to 1750, of all long-lived greenhouse gases and the 2010 update of the NOAA Annual Greenhouse Gas Index (AGGI). The reference year for the index is 1990 (AGGI = 1).

Global abundances of and increases in key greenhouse gases from the GAW global greenhouse gas monitoring network. Global abundances for 2010 are calculated as an average over 12 months.

	CO ₂ (ppm)	CH ₄ (ppb)	N ₂ O (ppb)
Global abundance in 2010	389.0	1808	323.2
2010 abundance relative to year 1750 ^a	139%	258%	120%
2009–2010 absolute increase	2.3	5	0.8
2009–2010 relative increase	0.59%	0.28%	0.25%
Mean annual absolute increase during last 10 years	1.97	2.6	0.75

^a Assuming a pre-industrial mixing ratio of 280 ppm for CO₂, 700 ppb for CH₄ and 270 ppb for N₂O.

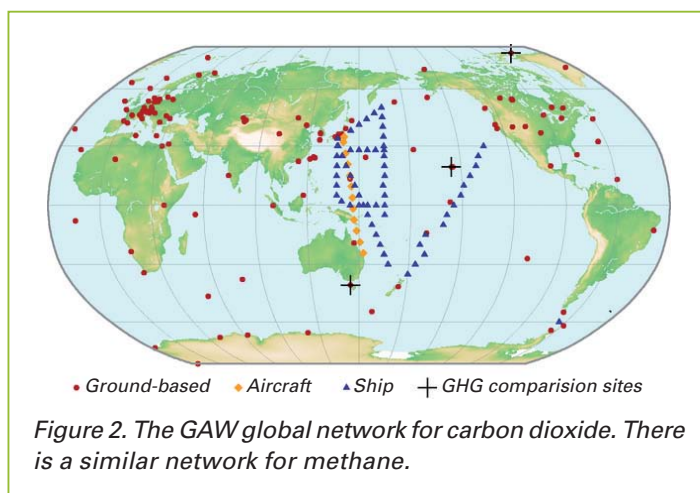


Figure 2. The GAW global network for carbon dioxide. There is a similar network for methane.

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 this global analysis.

The three greenhouse gases summarized in the table have been increasing in the atmosphere since the beginning of the industrial era. Their atmospheric abundances are directly connected with human activity, unlike water vapour, which is the most important greenhouse gas but whose abundance is controlled by fast climate feedbacks. They 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 they 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 LLGHGs increased by 29% from 1990 to 2010 and by 1.4% from 2009 to 2010 (see Figure 1 and <http://www.esrl.noaa.gov/gmd/aggi>).

Carbon dioxide (CO₂)

Carbon dioxide is the single most important anthropogenic greenhouse gas in the atmosphere, contributing ~64%^[3] to radiative forcing by LLGHGs. It is responsible for 85% of the increase in radiative forcing over the past decade and 81% over the last five years. For about 10 000 years before the industrial revolution, the atmospheric abundance of CO₂ was nearly constant at ~280 ppm. This level represented a balance among the atmosphere, the oceans and the biosphere. Since 1750, atmospheric CO₂ has increased by 39%, primarily because of emissions from combustion of fossil fuels (total of 8.4±0.5 PgC^[4] in 2009; <http://www.globalcarbonproject.org>), deforestation and land-use change. High-precision measurements of atmospheric CO₂ beginning in 1958 show that the average increase in CO₂ in the atmosphere corresponds to ~55% of the CO₂ emitted by fossil fuel combustion. The remaining ~45% has been removed from the atmosphere by the oceans and the terrestrial biosphere. The airborne fraction, the portion of CO₂ emitted by fossil fuel combustion that remains in the atmosphere, varies interannually without a confirmed global trend. Globally averaged CO₂ in 2010 was 389.0 ppm and the increase from the previous year

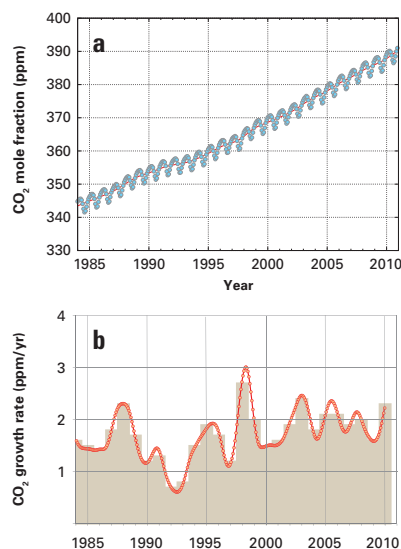


Figure 3. Globally averaged CO_2 mole fraction (a) and its growth rate (b) from 1984 to 2010. Annually averaged growth rate is shown by columns at (b).

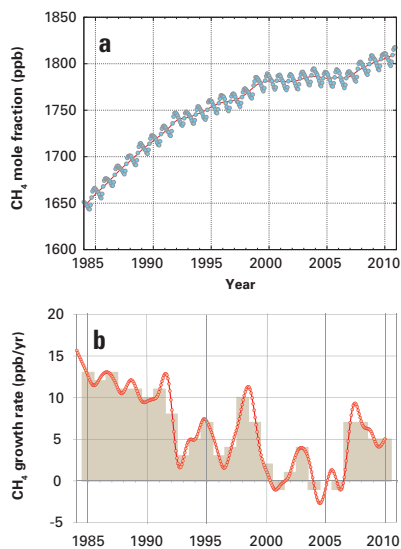


Figure 4. Globally averaged CH_4 mole fraction (a) and its growth rate (b) from 1984 to 2010. Annually averaged growth rate is shown by columns at (b).

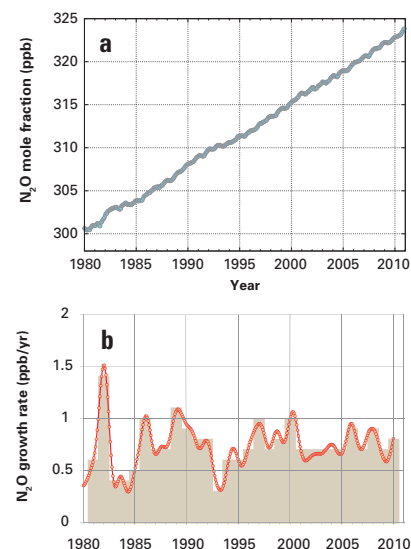


Figure 5. Globally averaged N_2O mole fraction (a) and its growth rate (b) from 1980 to 2010. Annually averaged growth rate is shown by columns at (b).

was 2.3 ppm (Figure 3). This growth rate is higher than the average for the 1990s (~1.5 ppm/yr) and the average for the past decade (~2.0 ppm/yr).

Methane (CH_4)

Methane contributes ~18%^[3] to radiative forcing by LLGHGs. Approximately 40% of 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 about 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. Increasing emissions from anthropogenic sources are responsible for the 158% increase in CH_4 . Globally averaged CH_4 in 2010 was 1808 ppb, an increase of 5 ppb from the previous year. It exceeds the highest annual mean abundance so far, which was recorded in 2009 (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 19 ppb rise from 2006 to 2009 was followed by a 5 ppb rise in 2010. The reasons for the renewed increase in CH_4 are not fully understood and several factors, mostly biogenic, were reported to contribute to this increase. To improve our understanding of the processes that affect CH_4 emissions, more in situ measurements are needed close to the source regions.

Nitrous oxide (N_2O)

Nitrous oxide contributes ~6%^[3] to radiative forcing by LLGHGs. It is now the third most important contributor to this total. Its atmospheric abundance prior to industrialization was 270 ppb. It is emitted into the atmosphere from natural and

anthropogenic sources, including oceans, soil, biomass burning, fertilizer use, and various industrial processes. Anthropogenic sources may account for approximately 40% of the total N_2O emissions. It is removed from the atmosphere by photochemical processes in the stratosphere. Globally averaged N_2O during 2010 was 323.2 ppb, up 0.8 ppb from the previous year (Figure 5) and 20% above the pre-industrial level. The mean growth rate has been 0.75 ppb/yr over the past 10 years.

Other greenhouse gases

Sulphur hexafluoride (SF_6) is a potent LLGHG controlled by the Kyoto Protocol to the United Nations Framework Convention on Climate Change. It is produced artificially and used as an electrical insulator in power distribution equipment. Its mixing ratio has increased to double that observed in the mid-1990s (Figure 6). The ozone-depleting chlorofluorocarbons (CFCs), together with minor halogenated gases, contribute ~12%^[3] to radiative forcing by LLGHGs. 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).

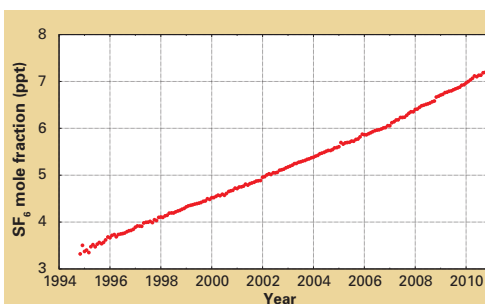


Figure 6. Monthly mean mole fraction of sulphur hexafluoride (SF_6) from 1995 to 2010 averaged over 18 stations

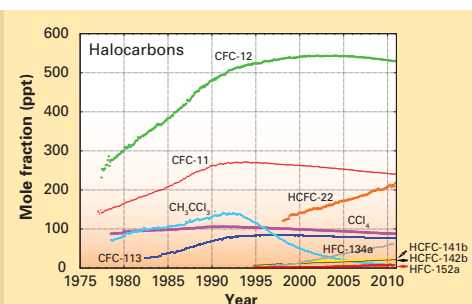


Figure 7. Monthly mean mole fraction of the most important halocarbons from 1977 to 2010 averaged over the network (between 7 and 19 stations)

Tropospheric ozone has a relatively short lifetime. Its radiative forcing, 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 insignificant as greenhouse gases, have an indirect effect on the radiative forcing through their impact on the tropospheric ozone abundance. Aerosols (suspended particulate matter) are also short-lived substances that influence radiative forcing.

All gases mentioned herein as well as aerosols are monitored by the GAW Programme, with support from WMO 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 GAW Programme Web page and on the home page of WDCGG.

Acknowledgements and links

Fifty WMO Member countries have contributed CO₂ 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 data to this bulletin, shown in Figure 2, are 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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Selected greenhouse gas observatories



The Samoa Observatory (14.23°S, 170.56°W) was established in 1974, and is one of six NOAA ESRL Global Monitoring Division (GMD) Baseline Observatories. It is located on the north-eastern tip of Tutuila Island, American Samoa, on a ridge over-

looking the South Pacific Ocean. Since its construction, the Observatory has survived two major hurricanes with only minor damage. It has the distinction of obtaining 30% of its daytime power from solar panels. Flask collection for measurements of N₂O started in January 1977 and continuous measurements have been carried out since July 1978.

Barrow Observatory

(71.32°N, 156.61°W), established in 1973 in Alaska, United States of America, is staffed year-round by two engineers/scientists who often commute to work in winter on snowmobiles. The Observatory is host to numerous cooperative



research projects from around the world owing to its unique location, dedicated and highly trained staff, excellent power and communications infrastructure. It is located so that it receives minimal influence from local pollution. Flask collection for measurements of N₂O started in January 1977 and continuous measurements have been carried out since January 1987.



Niwot Ridge (40.05°N, 105.59°W) is located approximately 35 km west of Boulder, Colorado, United States, with the entire study site lying above 3000 m elevation. Niwot Ridge, including the main alpine

study site, is part of the Roosevelt National Forest and has been designated a Biosphere Reserve by UNESCO, and an Experimental Ecology Reserve by the United States Department of Agriculture Forest Service. Air samples have been taken here, in flasks, for NOAA ESRL GMD since 1963. These flasks have been analysed for N₂O since January 1977 and continuous N₂O observations have been carried out since January 1987.

There are a number of other stations with long-term observations of N₂O mole fractions: Cape Grim, Australia (N₂O observations have been carried out since 1978), Adrigole, Ireland (started in 1978) then moved to Mace Head, Ireland (records from 1987 onward), Ragged Point, Barbados (since 1978) and, in the United States, Cape Meares, Oregon (beginning in 1979) then moved to Trinidad Head, California (1995), and Mauna Loa, Hawaii (started in 1978).

^[1] ppb = number of molecules of the gas per billion (10⁹) molecules of dry air.

^[2] ppm = number of molecules of the gas per million molecules of dry air.

^[3] 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>).

^[4] 1 PgC = 1 billion tons or 1 000 x million tons of carbon.