World Meteorological Organization
Weather • Climate • Water

GLOBAL ATMOSPHERE WATCH

WMO GREENHOUSE GAS BULLETIN

The State of Greenhouse Gases in the Atmosphere Based on Global Observations through 2012

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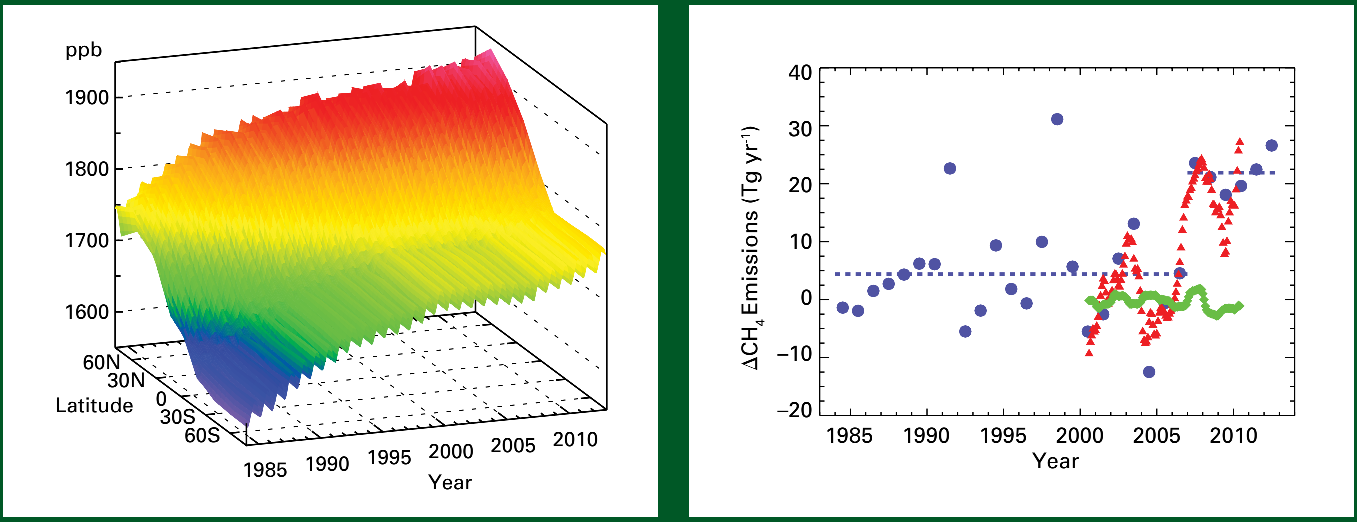

The left-hand figure shows the latitudinal distribution of atmospheric methane (CH_4) interpolated from measurements made at the WMO Global Atmosphere Watch stations. After remaining nearly constant from 1999 to 2006, atmospheric CH_4 began increasing again in 2007. Total global emissions can be calculated from the observed atmospheric CH_4 burden and rate of increase, combined with an estimate of methane's atmospheric lifetime (about 9 years). Differences between these emissions (ΔCH_4) and average emissions for 2003-2005 are plotted as blue circles in the right hand figure; the dashed blue lines show average differences for 1984-2006 and 2007-2012. From 1984 to 2006, emissions were highly variable but persistently lower than for 2007 to 2012, except for 1991 and 1998. Monthly emission differences (in Tg CH_4 yr^{-1}) calculated globally (red) and for the Arctic (green) by a chemical transport model study are also shown (Bergamaschi, et al., 2013). Analysis of the data indicates that tropical and mid-latitude Northern Hemisphere emissions have contributed to increases in atmospheric CH_4 since 2007, and that there has not yet been a measurable increase in Arctic CH_4 emissions.

Executive summary

The latest analysis of observations from the WMO Global Atmosphere Watch (GAW) Programme shows that the globally averaged mole fractions of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) reached new highs in 2012, with CO_2 at 393.1±0.1 ppm[2], CH_4 at 1819±1 ppb[3] and N_2O at 325.1±0.1 ppb. These values constitute, respectively, 141%, 260% and 120% of pre-industrial (before 1750) levels. The atmospheric increase of CO_2 from 2011 to 2012 is higher than the average growth rate over the past 10 years. For N_2O the increase from 2011 to 2012 is smaller than the one observed from 2010 to 2011 but larger than the average growth rate over the past 10 years. Atmospheric CH_4 continued to increase at a rate similar to the one observed over the past 4 years. The National Oceanic and Atmospheric Administration (NOAA) Annual Greenhouse Gas Index shows that from 1990 to 2012 radiative forcing by long-lived greenhouse gases increased by 32%, with CO_2 accounting for about 80% of this increase.

Overview

This ninth WMO/GAW Annual GHG Bulletin reports atmospheric abundances and rates of change of the most important long-lived greenhouse gases (LLGHGs) – carbon dioxide, methane, nitrous oxide – and provides a summary of the contributions of the other gases. These three together with CFC-12 and CFC-11 account for approximately 96%[4] of radiative forcing due to LLGHGs (Figure 1).

The WMO Global Atmosphere Watch Programme (http://www.wmo.int/gaw) coordinates systematic observations and analysis of greenhouse gases and other trace species. Sites where greenhouse gases are monitored in the last decade are shown in Figure 2. During 2012, the number of observational stations declined. 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.

Table 1 provides globally averaged atmospheric abundances of the three major LLGHGs in 2012 and changes in their abundances since 2011 and 1750. The results are obtained from an analysis of datasets (WMO, 2009) that are traceable to WMO World Reference Standards. Data from mobile stations, with the exception of NOAA sampling in the Pacific (blue triangles in Figure 2), are not used for this global analysis.

The three greenhouse gases shown in the Table 1 are closely linked to anthropogenic activities and they also interact strongly with the biosphere and the oceans. Predicting the evolution of the atmospheric content of greenhouse gases requires an understanding of their many sources, sinks and chemical transformations in the atmosphere.

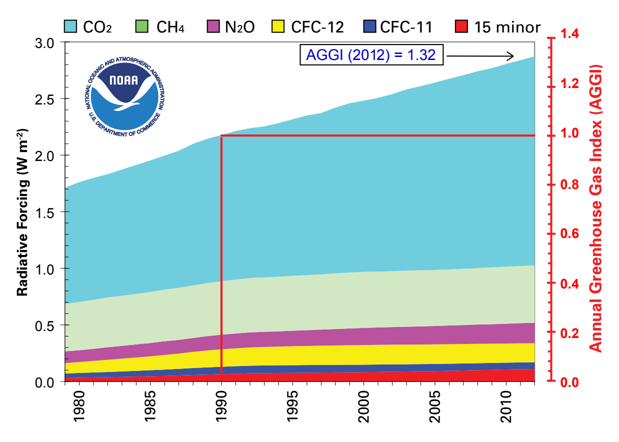

Figure 1. Atmospheric radiative forcing, relative to 1750, of LLGHGs and the 2012 update of the NOAA Annual Greenhouse Gas Index (AGGI).

Table 1. Global annual mean abundances (2012) and trends of key greenhouse gases from the WMO/GAW global greenhouse gas monitoring network. Units are dry-air mole fractions, and uncertainties are 68% confidence limits.

	CO_2	CH_4	N_2O
Global abundance in 2012	393.1± 0.1[5] ppm	1819± 1[5] ppb	325.1± 0.1[5] ppb
2012 abundance relative to year 1750*	141%	260%	120%
2011–12 absolute increase	2.2 ppm	6 ppb	0.9 ppb
2011–12 relative increase	0.56%	0.33%	0.28%
Mean annual absolute increase during last 10 years	2.02 ppm/yr	3.7 ppb/yr	0.80 ppb/yr

* Assuming a pre-industrial mole fraction of 278 ppm for CO_2, 700 ppb for CH_4 and 270 ppb for N_2O.

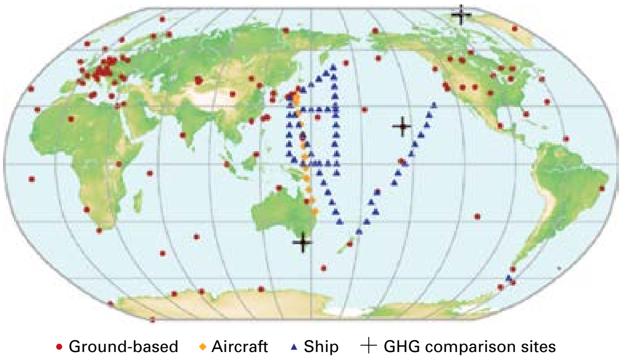

Figure 2. The GAW global network for carbon dioxide in the last decade. The network for methane is similar.

The NOAA Annual Greenhouse Gas Index (AGGI) in 2012 was 1.32, representing a 32% increase in total radiative forcing (relative to 1750) by all LLGHGs since 1990 and a 1.2% increase from 2011 to 2012 (Figure 1). The total radiative forcing by all LLGHGs in 2012 corresponds to a CO_2-equivalent mole fraction of 475.6 ppm (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 ~64%[4] to radiative forcing by LLGHGs. It is responsible for ~84% of the increase in radiative forcing over the past decade and ~82% over the past five years. The pre-industrial level of ~278 ppm represented a balance of fluxes between the atmosphere, the oceans and the biosphere. Atmospheric CO_2 reached 141% of the pre-industrial level in 2012, primarily because of emissions from combustion of fossil fuels (fossil fuel CO_2 emissions 9.5±0.5 PgC[1] in 2011, according to http://www.globalcarbonproject.org), deforestation and other land-use change (0.9±0.5 PgC[1] in 2011). The average increase in atmospheric CO_2 from pre-industrial time corresponds to ~55% of the CO_2 emitted by fossil fuel combustion with the remaining ~45% removed by the oceans and the terrestrial biosphere. The portion of CO_2 emitted by fossil fuel combustion that remains in the atmosphere (airborne fraction), varies inter-annually due to high natural variability of CO_2 sinks (Levin, 2012) without a confirmed global trend. The globally averaged CO_2 mole fraction in 2012 was 393.1±0.1 ppm (Figure 3). The mean annual increase from 2011 to 2012, 2.2 ppm, is greater than the increase from 2010 to 2011, the average growth rate for the 1990s (~1.5 ppm/yr) and the average growth rate for the past decade (~2.0 ppm/yr).

Methane (CH_4)

Methane contributes ~18%[4] to radiative forcing by LLGHGs. Approximately 40% of methane is emitted into the atmosphere by natural sources (e.g., wetlands and termites), and about 60% comes from anthropogenic sources (e.g., ruminants, rice agriculture, fossil fuel exploitation, landfills and biomass burning). Atmospheric CH_4 reached 260% of the pre-industrial level (~700 ppb) due to increased

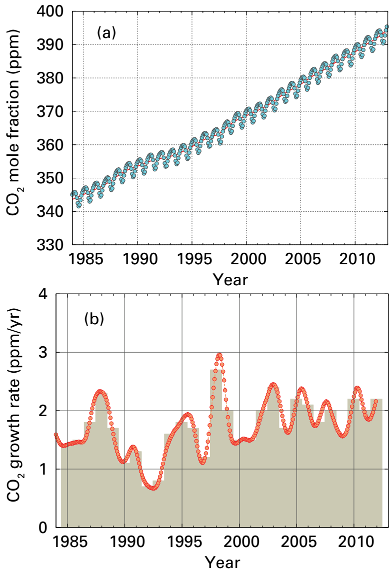

Figure 3. Globally averaged CO_2 mole fraction (a) and its growth rate (b) from 1984 to 2012. Annually averaged growth rates are shown as columns in (b).

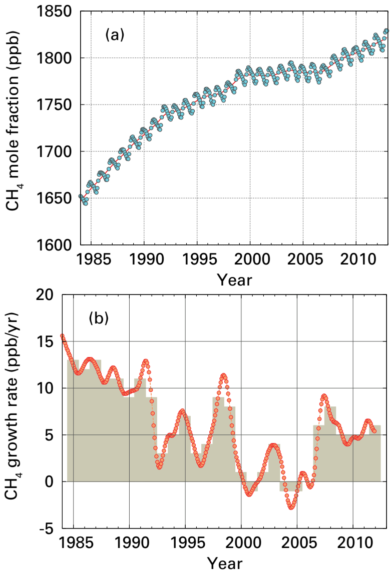

Figure 4. Globally averaged CH_4 mole fraction (a) and its growth rate (b) from 1984 to 2012. Annually averaged growth rates are shown as columns in (b).

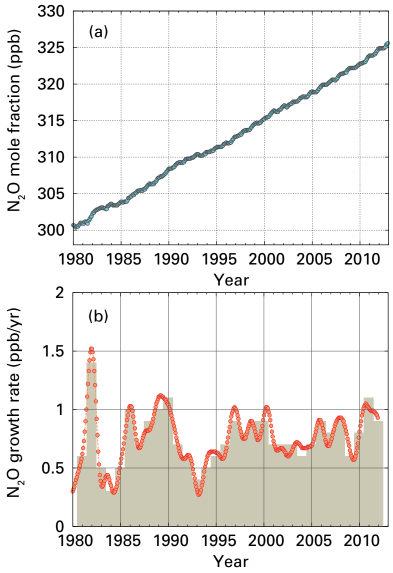

Figure 5. Globally averaged N_2O mole fraction (a) and its growth rate (b) from 1980 to 2012. Annually averaged growth rates are shown as columns in (b).

emissions from anthropogenic sources. Globally averaged CH_4 reached a new high of 1819 ± 1 ppb in 2012, an increase of 6 ppb with respect to the previous year (Figure 4). The growth rate of CH_4 decreased from ~13 ppb/yr during the early 1980s to near zero during 1999-2006. Since 2007, atmospheric CH_4 has been increasing again 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.

Nitrous oxide (N_2O)

Nitrous oxide contributes ~6%[4] to radiative forcing by LLGHGs. It is the third most important contributor to the combined forcing. N_2O is emitted into the atmosphere from both natural (about 60%) and anthropogenic sources (approximately 40%), including oceans, soil, biomass burning, fertilizer use, and various industrial processes. The globally averaged N_2O mole fraction in 2012 reached 325.1 ±0.1 ppb, which is 0.9 ppb above the previous year (Figure 5) and 120% of the pre-industrial level (270 ppb). The annual increase from 2011 to 2012 is greater than the mean growth rate over the past 10 years (0.80 ppb/yr).

Other greenhouse gases

Sulfur hexafluoride (SF_6) is a potent LLGHG. It is produced by the chemical industry, mainly as an electrical insulator in power distribution equipment. Its current mole fraction is about twice the level observed in the mid-1990s (Figure 6). The stratospheric ozone-depleting chlorofluorocarbons (CFCs), together with minor halogenated gases, contribute ~12%[4] 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 relatively rapid rates, although they are still low in abundance (at ppt[6] levels, Figure 7).

This bulletin primarily addresses LLGHGs. Relatively short-lived tropospheric ozone has a radiative forcing comparable to that of the halocarbons. Many other pollutants, such as carbon monoxide, nitrogen oxides and volatile organic compounds, although not referred to as greenhouse gases, have small direct or indirect effects on radiative forcing. Aerosols (suspended particulate matter), too, are short-lived substances that alter the radiation budget. 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 these 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

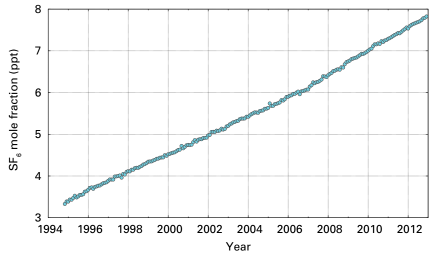

Figure 6. Monthly mean mole fraction of sulfur hexafluoride (SF_6) from 1995 to 2012 (based on the measurements at 20 stations).

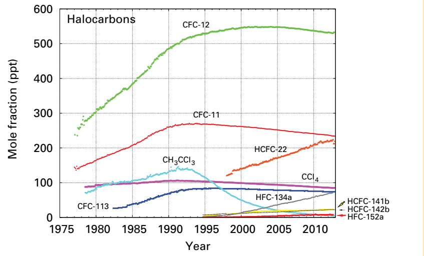

Figure 7. Monthly mean mole fractions of the most important halocarbons from 1977 to 2012 averaged over the network (based on the measurements between 7 and 19 stations).

Research Laboratory (ESRL). The bulletins are available through the GAW Programme or the WDCGG web page.

Acknowledgements and links

Fifty WMO member countries have contributed CO_2 data to the GAW WDCGG. Approximately 47% of the measurement records submitted to WDCGG are obtained at sites of the NOAA ESRL cooperative air-sampling network. For other networks and stations see, GAW Report No. 206 (available at http://www.wmo.int/gaw). The Advanced Global Atmospheric Gases Experiment (AGAGE) is contributing observations to this bulletin. Furthermore, 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://ds.data.jma.go.jp/gmd/wdcgg/). They are also described in the GAW Station Information System, GAWSIS (http://gaw.empa.ch/gawsis) supported by MeteoSwiss, Switzerland.

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Selected greenhouse gas observatories

The Plateau Rosa (45.93°N, 7.71°E, 3480 m a.s.l.) is one of the highest GAW Regional stations in Europe. It is located near the Matterhorn, on the Italian side of the Alps (operated by the Turin section of the National Institute for Astrophysics). Its position in the free troposphere upon a large snowfield located over a bare mountain plateau and far from urban and polluted zones makes it appropriate for background measurements of greenhouse gases. The measurements of the main greenhouse gases (CO_2 and CH_4) and tropospheric ozone have been regularly carried out by the Research on Energy Systems (RSE). The longest time series is for CO_2, currently covering more than 20 years (discrete sample measurements from 1989 to 1997, and continuous measurements from 1993 to present).

The Lauder Atmospheric Research Laboratory, New Zealand (45.038°S, 169.684°E, 370m a.s.l.) is a GAW Global station. It belongs to the National Institute of Water and Atmospheric Research (NIWA). The laboratory provides high-quality measurements in the data-sparse, clean environment of the high southern latitudes. Lauder operates an FTIR, dedicated to measurements of trace gases associated with ozone chemistry, and high-precision column CO_2. In-situ greenhouse gas measurements are performed continuously, using flask sampling and remote sensing techniques. Greenhouse gas observations have been performed at the station since 1990 (http://www.niwa.co.nz/our-science/atmosphere/lauder).

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[1] 1 PgC = 1 billion (10^9) tonnes of carbon.

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

[3] ppb = number of molecules of the gas per billion (10^9) molecules of dry air.

[4] This percentage is calculated as the relative contribution of the mentioned gas(es) to the increase in global radiative forcing caused by all long-lived greenhouse gases since 1750.

[5] Indicated error ranges are calculated by a bootstrap method following Conway et al., 1994. This uncertainty is calculated with a confidence interval of 68% (one sigma).

[6] ppt = number of molecules of the gas per trillion (10^{12}) molecules of dry air.