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 2014

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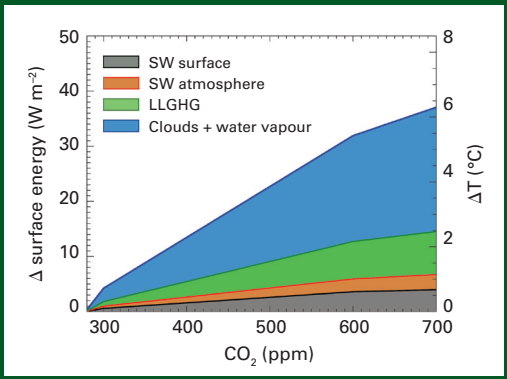

Water vapour and carbon dioxide (CO_2) are the major greenhouse gases (GHGs), with CO_2 the main driver of climate change. Water vapour changes largely happen as a response to the change in CO_2.

Some atmospheric gases, such as water vapour and CO_2, absorb and re-emit infrared energy from the atmosphere down to the surface. This process, the greenhouse effect, leads to a mean surface temperature that is about 33 K greater than it would be in their absence. However, it is the presence of non-condensable greenhouse gases (mainly CO_2, but also methane (CH_4), nitrous oxide (N_2O) and chlorofluorocarbons (CFCs)), that serve as the forcing agents. Water vapour and clouds act as fast feedbacks. Water vapour responds rapidly to changes in temperature, through evaporation, condensation and precipitation. Observations by the Global Atmosphere Watch (GAW) Programme help to investigate this in some detail.

Earth's incoming short-wave (SW) solar radiation provides approximately 340 W m^{-2} at the top of the atmosphere; 30% of it is reflected back to space, mostly by clouds, 20% is absorbed by the atmosphere and 50% is absorbed by the Earth's surface. At equilibrium, the incoming short-wave and outgoing long-wave (LW) energy fluxes at the top of the atmosphere are in balance. Under preindustrial conditions, the energy flux was 160 W m^{-2} larger at the surface than at the top of the atmosphere due to the greenhouse effect. The figure shows changes in global surface energy balance relative to pre-industrial conditions with increasing CO_2 concentration. The vertical axis on the right indicates the increase in surface temperature necessary to reach the balance between incoming (SW + LW) and outgoing (LW) radiation.

The green section in the figure represents the thermal energy contributed by the long-lived, well-mixed greenhouse gases, mostly CO_2. The blue section depicts the feedback contributions by water in the atmosphere as the CO_2 concentration increases. The strong water vapour feedback means that for a scenario considering doubling of CO_2 concentration from pre-industrial conditions (from about 280 to 560 ppm[1]), water vapour and clouds globally lead to an increase in thermal energy that is about three times that of long-lived greenhouse gases (LLGHGs). (The figure is based on Lacis et al., 2013.)

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 2014, with CO_2 at 397.7±0.1 ppm, CH_4 at 1833±1 ppb[2] and N_2O at 327.1±0.1 ppb. These values constitute, respectively, 143%, 254% and 121% of pre-industrial (1750) levels. The atmospheric increase of CO_2 from 2013 to 2014 was close to that averaged over the past 10 years. For both CH_4 and N_2O the increases from 2013 to 2014 were larger than that observed from 2012 to 2013 and the mean rates over the past 10 years. The National Oceanic and Atmospheric Administration (NOAA) Annual Greenhouse Gas Index shows that from 1990 to 2014 radiative forcing by long-lived greenhouse gases (LLGHGs) increased by 36%, with CO_2 accounting for about 80% of this increase.

Overview

This eleventh WMO/GAW Annual GHG Bulletin reports atmospheric abundances and rates of change of the most important LLGHGs – carbon dioxide, methane and 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%[3] 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. 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 2014 and changes in their abundances since 2013 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.

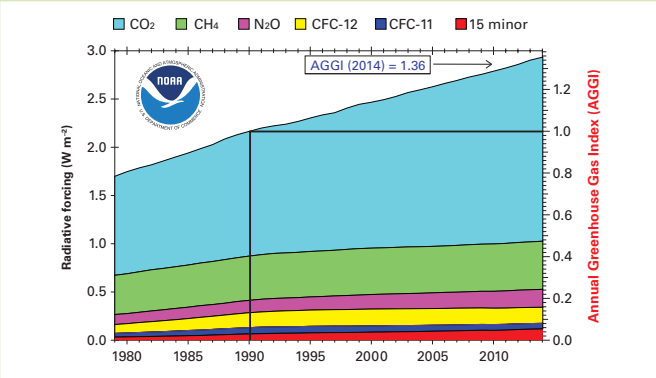

Figure 1. Atmospheric radiative forcing, relative to 1750, of LLGHGs and the 2014 update of the NOAA Annual Greenhouse Gas Index (AGGI)

Table 1. Global annual mean abundances (2014) 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 2014[4]	397.7±0.1 ppm	1833±1 ppb	327.1±0.1 ppb
2014 abundance relative to year 1750[a]	143%	254%	121%
2013–2014 absolute increase	1.9 ppm	9 ppb	1.1 ppb
2013–2014 relative increase	0.48%	0.49%	0.34%
Mean annual absolute increase during last 10 years	2.06 ppm yr^{-1}	4.7 ppb yr^{-1}	0.87 ppb yr^{-1}

* Assuming a pre-industrial mole fraction of 278 ppm for CO_2, 722 ppb for CH_4 and 270 ppb for N_2O. Stations used for the analyses numbered 122 for CO_2, 123 for CH_4 and 33 for N_2O.

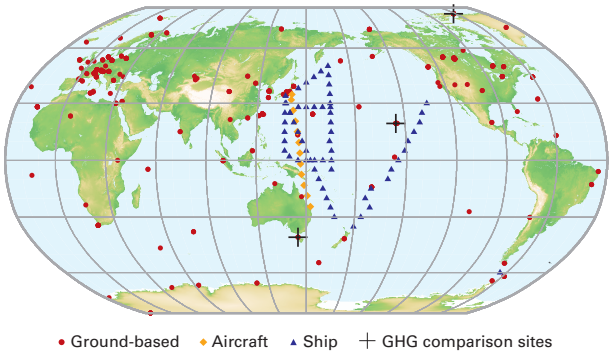

Figure 2. The GAW global network for carbon dioxide in the last decade. The network for methane is similar.

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. Observations from GAW provide invaluable constraints on the budgets of these and other LLGHGs, and they are used to verify emission inventories and evaluate satellite retrievals of LLGHG column averages.

The NOAA Annual Greenhouse Gas Index in 2014 was 1.36, representing a 36% increase in total radiative forcing by all LLGHGs since 1990 and a 1.2% increase from 2013 to 2014 (Figure 1). The total radiative forcing by all LLGHGs in 2014 corresponds to a CO_2-equivalent mole fraction of 481 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 ~65%[3] to radiative forcing by LLGHGs. It is responsible for ~83% 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 143% of the pre-industrial level in 2014, primarily because of emissions from combustion of fossil fuels and cement production (the sum of CO_2 emissions was 9.9±0.5 PgC[5] in 2013, according to http://www.globalcarbonproject.org), deforestation and other land-use change (0.9±0.5 PgC[5] in 2013). The average increase in atmospheric CO_2 during the last decade corresponds to ~44% of the CO_2 emitted by human activity with the remaining ~56% removed by the oceans and 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 without a confirmed global trend. The globally averaged CO_2 mole fraction in 2014 was 397.7±0.1 ppm (Figure 3). The mean annual increase from 2013 to 2014, 1.9 ppm, is smaller than the increase from 2012 to 2013 and the average growth rate for the past decade (~2.06 ppm yr^{-1}) but larger than the average growth rate for the 1990s (~1.5 ppm yr^{-1}). The smaller growth rate in 2014 in comparison with the previous years is most likely related to the larger annual uptake of CO_2 by the terrestrial biosphere in tropical and subtropical regions.

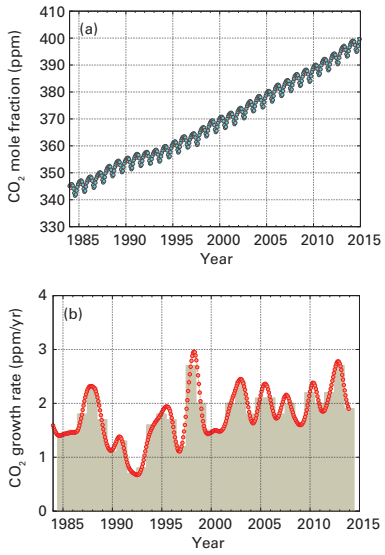

Figure 3. Globally averaged CO_2 mole fraction (a) and its growth rate (b) from 1984 to 2014. Annually averaged growth rates are shown as columns in (b).

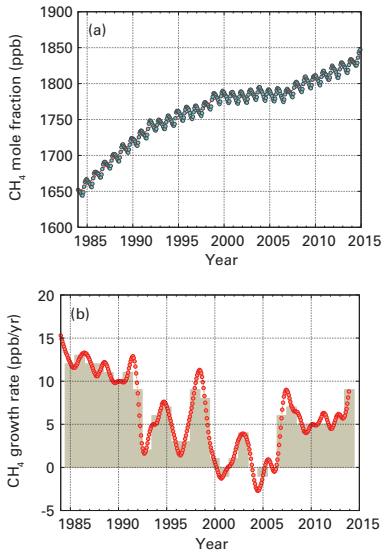

Figure 4. Globally averaged CH_4 mole fraction (a) and its growth rate (b) from 1984 to 2014. Annually averaged growth rates are shown as columns in (b).

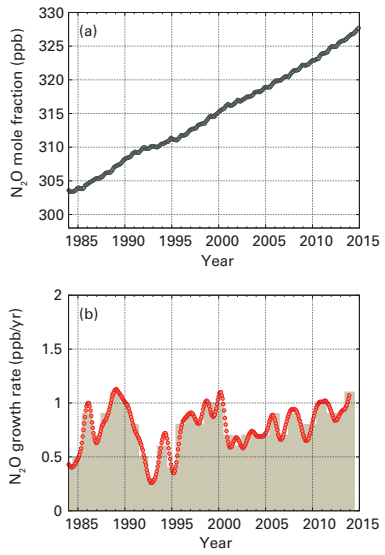

Figure 5. Globally averaged N_2O mole fraction (a) and its growth rate (b) from 1984 to 2014. Annually averaged growth rate is shown as columns in (b).

Methane (CH_4)

Methane contributes ~17%[3] 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 254% of its pre-industrial level (~722 ppb) due to increased emissions from anthropogenic sources. Globally averaged CH_4 reached a new high of 1833±1 ppb in 2014, an increase of 9 ppb with respect to the previous year (Figure 4). The growth rate of CH_4 decreased from ~13 ppb yr^{-1} 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. Studies using GAW CH_4 measurements indicate that increased CH_4 emissions from wetlands in the tropics and from anthropogenic sources at mid-latitudes of the northern hemisphere are likely causes.

Nitrous oxide (N_2O)

Nitrous oxide contributes ~6%[3] to radiative forcing by LLGHGs. It is the third most important individual contributor to the combined forcing. It is emitted into the atmosphere from both natural (about 60%) and anthropogenic sources (approximately 40%), including oceans, soils, biomass burning, fertilizer use and various industrial processes. The globally averaged N_2O mole fraction in 2014 reached 327.1±0.1 ppb, which is 1.1 ppb above the previous year (Figure 5) and 121% of the pre-industrial level (270 ppb). The annual increase from 2013 to 2014 is greater than the mean growth rate over the past 10 years (0.87 ppb yr^{-1}).

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 (a)). The stratospheric 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 relatively rapid rates, although they are still low in abundance (at ppt[6] levels, Figure 6 (a) and (b)).

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 (CO), 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 observed within the GAW Programme, with support from WMO Member countries and contributing networks.

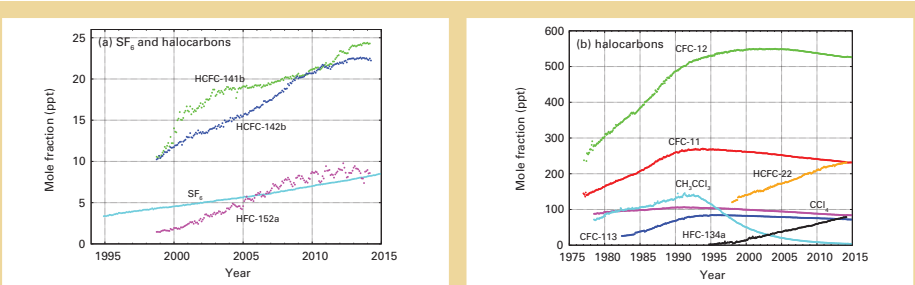

Figure 6. Monthly mean mole fractions of sulfur hexafluoride (SF_6) and the most important halocarbons: SF_6 and lower mole fractions of halocarbons (a) and higher ones of halocarbons (b). The numbers of stations used for the analyses are as follows: SF_6 (23), CFC-11 (24), CFC-12 (24), CFC-113 (23), CCl_4 (21), CH_3CCl_3 (23), HCFC-141b (9), HCFC-142b (13), HCFC-22 (13), HFC-134a (9), HFC-152a (8).

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 on Greenhouse Gases, with the assistance of the NOAA Earth System 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 46% 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 the *16th WMO/IAEA Meeting on Carbon Dioxide, Other Greenhouse Gases, and Related Measurement Techniques (GGMT-2011)* (GAW Report No. 206, available at http://www.wmo.int/gaw). The Advanced Global Atmospheric Gases Experiment (AGAGE) contributes 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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[1] ppm = number of molecules of the gas per million (10^6) molecules of dry air.

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

[3] 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.

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

[5] 1 PgC = 1 billion (10^9) tonnes or 10^{15} g of carbon.

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

Selected GAW greenhouse gas observatories

Izaña (28.31°N, 16.50°W, 2 373 m a.s.l., http://izana.aemet.es) is located on the top of Tenerife (Canary Islands, Spain), well above a strong subtropical temperature inversion layer. It is run by the Izaña Atmospheric Research Center (IARC) of the State Meteorological Agency of Spain (AEMET). In situ measurements of greenhouse gases began at Izaña in 1984 (CO_2 and CH_4) and subsequently in 2007 (N_2O and SF_6). More details about the station's measurement programme are provided in the *Izaña Atmospheric Research Center Activity Report 2012–2014* (GAW Report No. 219, 2015).

Anmyeondo (AMY) station (36.54°N, 126.33°E, 46 m a.s.l.), operated by the Korea Meteorological Administration, is located on the west coast of the Korean Peninsula. The station experiences continental air masses from winter to spring, and maritime air masses from the North Pacific in the summer. Since 1999, the measurements of CO_2 and CH_4 are carried out at the station by cavity ring-down spectrometer, while the measurements of N_2O, CFCs and SF_6 are done with a gas chromatography coupled with an electron capture detector. As part of its cooperation within the NOAA flask-sampling network, the AMY station collects data of the isotopic composition of CO_2.

The Puy de Dôme (PUY) station in France (45.77°N, 2.97°E, 1 465 m a.s.l.) is operated by the National Center for Scientific Research and the Blaise Pascal University (www.opgc.fr/SO/mesures/index.php). The air is representative of the synoptic-scale atmospheric composition of the regional atmospheric background. Atmospheric CO_2 mole fractions have been continuously measured at PUY since 2000. A non-dispersive infrared gas analyser, used from 2000, was replaced in 2011 by a cavity ring-down spectrometer that measures both CO_2 and CH_4 (https://icos-atc.lsce.ipsl.fr/PUY). From 2010 to the present, CO_2, CH_4, N_2O and SF_6 have also been measured with a gas chromatograph. Greenhouse gases will continue to be monitored at the top of Puy de Dôme as part of the European research infrastructure – the Integrated Carbon Observation System (ICOS) – and both WMO and ICOS audits of those measurements are scheduled for 2016.

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