WEATHER CLIMATE WATER

WORLD METEOROLOGICAL ORGANIZATION

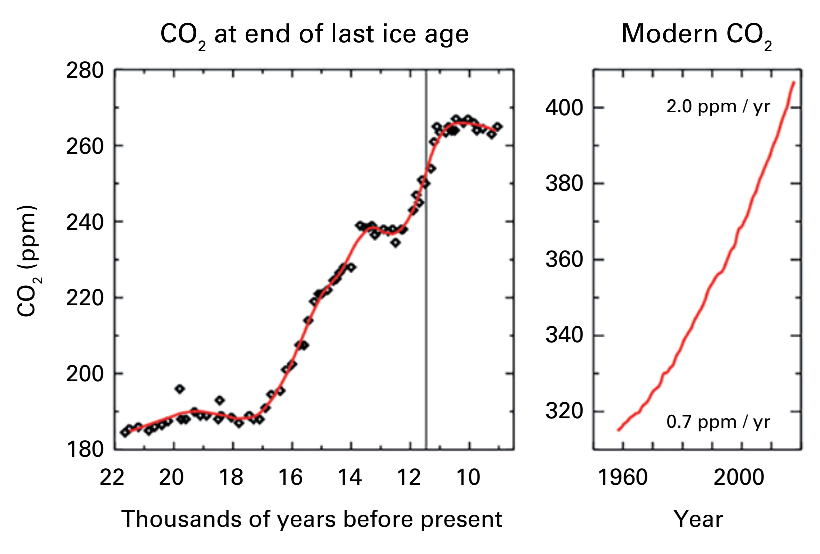
GLOBAL ATMOSPHERE WATCH

WMO GREENHOUSE GAS BULLETIN

The State of Greenhouse Gases in the Atmosphere Based on Global Observations through 2016

No. 13 | 30 October 2017

ISSN 2078-0796



The rate of increase of atmospheric carbon dioxide (CO$_2$) over the past 70 years is nearly 100 times larger than that at the end of the last ice age. As far as direct and proxy observations can tell, such abrupt changes in the atmospheric levels of CO$_2$ have never before been seen. The figure on the left shows the CO$_2$ atmospheric content at the end of the last ice age, and the figure on the right shows recent atmospheric CO$_2$ content [1]. The thin grey area on the left figure, which looks like a vertical line, corresponds to a similar period of 70 years as depicted on the right figure for modern times. Rapidly increasing atmospheric levels of CO$_2$ and other greenhouse gases (GHGs) have the potential to initiate unpredictable changes in the climate system, because of strong positive feedbacks, leading to severe ecological and economic disruptions. The WMO Global Atmosphere Watch (GAW) Programme tracks the changing levels of GHGs and serves as an early warning system by detecting changes in these key atmospheric drivers of climate change.

Growing population, intensified agricultural practices, increases in land use and deforestation, industrialization and associated energy use from fossil fuel sources have all contributed to increases in GHG atmospheric abundances since the industrial era, beginning in 1750. Emissions of CO$_2$ from human activities were again at record levels in 2016, although, according to the most-recent assessment of the Global Carbon Project (http://globalcarbonbudget2016.org/), the year-to-year increase of these emissions has slowed down or even reached a plateau. These emissions, together with the 2015 and 2016 natural emissions related to El Niño, have contributed to the record increase in CO$_2$ concentration in the atmosphere, as detected by the WMO GAW network, thus resulting in a further increase in climate forcing. The steady increase in GHG concentrations in the atmosphere over the observation period from 1970 until present is consistent with the observed increase of global average temperatures in the same period with a record measured in 2016, as reported in the WMO statement on the state of the global climate [2].

As illustrated in the inside story of this bulletin, over the last ~800 000 years, pre-industrial atmospheric CO$_2$ content remained below 280 ppm(1) across glacial and interglacial cycles, but it has risen to the 2016 global average of 403.3 ppm. From the most-recent high-resolution reconstructions from ice cores, it is possible to observe that changes in CO$_2$ have never been as fast as in the past 150 years, and the natural ice-age changes in CO$_2$ have always preceded corresponding temperature changes. Geological records show that the current levels of CO$_2$ correspond to an "equilibrium" climate last observed in the mid-Pliocene (3–5 million years ago), a climate that was 2–3 °C warmer, where the Greenland and West Antarctic ice sheets melted and even some of the East Antarctic ice was lost, leading to sea levels that were 10–20 m higher than those today.

The longer we wait to implement the Paris Agreement, the greater the commitment and the more drastic (and expensive) the required future emission reductions will need to be to keep climate change within critical limits.

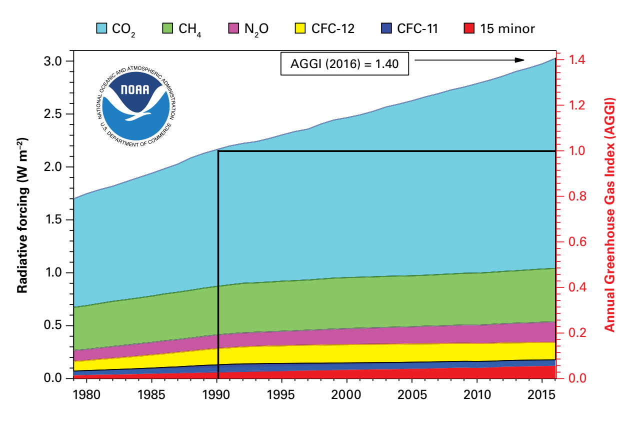


Figure 1. Atmospheric radiative forcing, relative to 1750, of LLGHGs and the 2016 update of the NOAA AGGI [3, 4]

Table 1. Global annual surface mean abundances (2016) and trends of key GHGs from the WMO GAW global GHG observational network. Units are dry-air mole fractions, and uncertainties are 68% confidence limits [7]; the averaging method is described in GAW Report No. 184 [6].

	CO_2	CH_4	N_2O
Global abundance in 2016	403.3±0.1 ppm	1853±2 ppb	328.9±0.1 ppb
2016 abundance relative to year 1750[a]	145%	257%	122%
2015–2016 absolute increase	3.3 ppm	9 ppb	0.8 ppb
2015–2016 relative increase	0.83%	0.49%	0.24%
Mean annual absolute increase during last 10 years	2.21 ppm yr^{-1}	6.8 ppb yr^{-1}	0.90 ppb yr^{-1}

[a] Assuming pre-industrial mole fractions of 278 ppm for CO_2, 722 ppb for CH_4 and 270 ppb for N_2O. Stations used for the analyses numbered 123 for CO_2, 125 for CH_4 and 33 for N_2O.

Executive summary

The latest analysis of observations from the WMO GAW Programme shows that globally averaged surface mole fractions(2) calculated from this in situ network for CO_2, methane (CH_4) and nitrous oxide (N_2O) reached new highs in 2016, with CO_2 at 403.3 ± 0.1 ppm, CH_4 at 1 853 ± 2 ppb(3) and N_2O at 328.9 ± 0.1 ppb. These values constitute, respectively, 145%, 257% and 122% of pre-industrial (before 1750) levels. The record increase of 3.3 ppm in CO_2 from 2015 to 2016 was larger than the previous record increase, observed from 2012 to 2013, and the average growth rate over the last decade. The El Niño event in 2015/2016 contributed to the increased growth rate through complex two-way interactions between climate change and the carbon cycle. The increase of CH_4 from 2015 to 2016 was slightly smaller than that observed from 2014 to 2015, but larger than the average over the last decade. The increase of N_2O from 2015 to 2016 was also slightly smaller than that observed from 2014 to 2015 and the average growth rate over the past 10 years. The National Oceanic and Atmospheric Administration (NOAA) Annual Greenhouse Gas Index (AGGI) [3, 4] shows that from 1990 to 2016, radiative forcing by long-lived greenhouse gases (LLGHGs) increased by 40%, with CO_2 accounting for about 80% of this increase.

Overview of the Global Atmosphere Watch in situ network observations for 2016

This WMO GAW annual GHG bulletin reports atmospheric abundances and rates of change of the most-important LLGHGs – CO_2, CH_4 and N_2O – and provides a summary of the contributions of the other GHGs. These three LLGHGs, together with CFC-12 and CFC-11, account for approximately 96%(4) [5] of radiative forcing due to LLGHGs (Figure 1).

The WMO GAW Programme (http://www.wmo.int/gaw) coordinates systematic observations and analysis of GHGs and other trace species in the atmosphere. Sites where GHGs have been measured in the last decade are shown in Figure 2. Measurement data are reported by participating countries and archived and distributed by the World Data

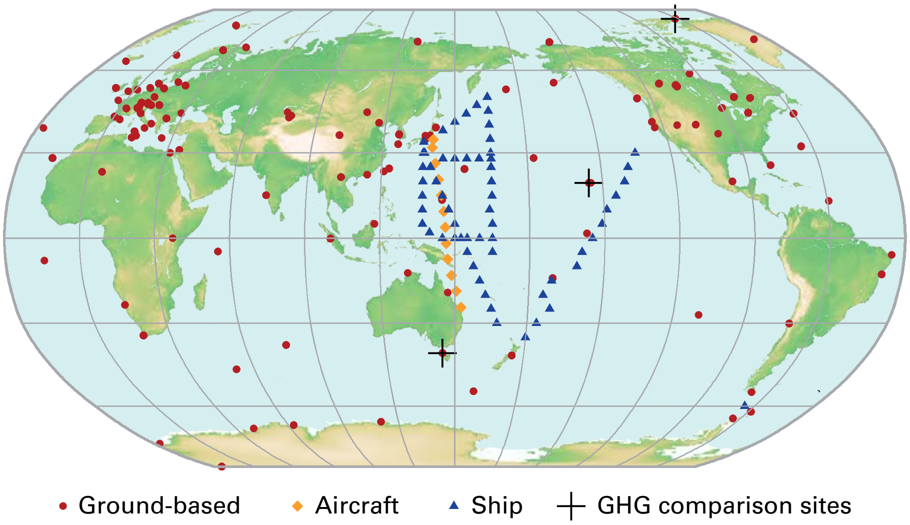


Figure 2. The GAW global network for CO_2 in the last decade (the network for CH_4 is similar)

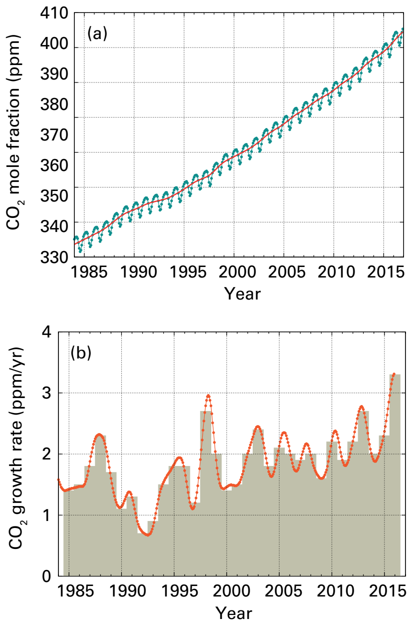


Figure 3. Globally averaged CO_2 mole fraction (a) and its growth rate (b) from 1984 to 2016. Increases in successive annual means are shown as the shaded columns in (b). The red line in (a) is the monthly mean mole fraction with the seasonal variations removed; the blue dots and line depict the monthly averages. Observations from 123 stations have been used for this analysis.

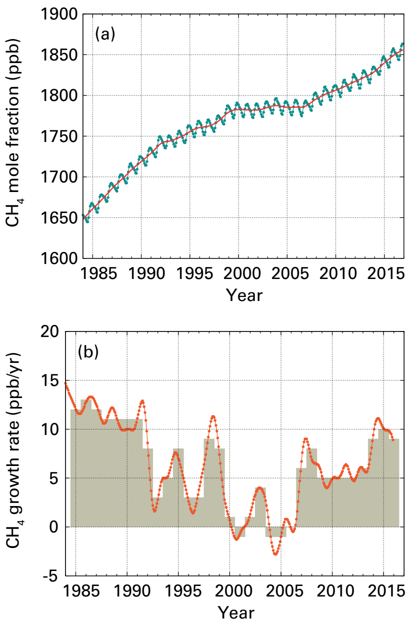


Figure 4. Globally averaged CH_4 mole fraction (a) and its growth rate (b) from 1984 to 2016. Increases in successive annual means are shown as the shaded columns in (b). The red line in (a) is the monthly mean mole fraction with the seasonal variations removed; the blue dots and line depict the monthly averages. Observations from 125 stations have been used for this analysis.

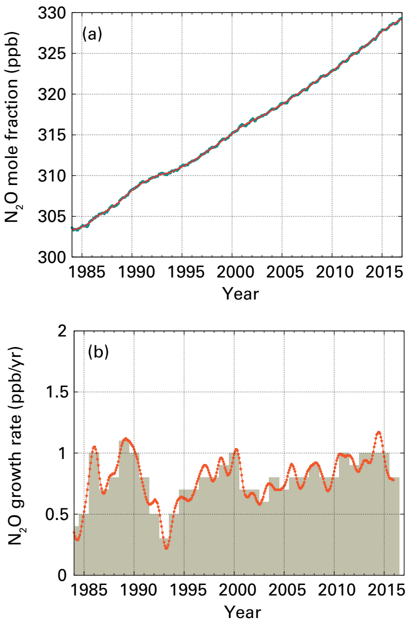


Figure 5. Globally averaged N_2O mole fraction (a) and its growth rate (b) from 1984 to 2016. Increases in successive annual means are shown as the shaded columns in (b). The red line in (a) is the monthly mean mole fraction with the seasonal variations removed; in this plot, it overlaps with the blue dots and line that depict the monthly averages. Observations from 33 stations have been used for this analysis.

Centre for Greenhouse Gases (WDCGG) at the Japan Meteorological Agency.

The results reported here by WMO WDCGG for the global average and growth rate are slightly different from the results reported by NOAA for the same years [1], due to differences in the stations used, differences in the averaging procedure and a slightly different time period for which the numbers are representative. WMO WDCGG follows the procedure described in GAW Report No. 184 [6].

Table 1 provides globally averaged atmospheric abundances of the three major LLGHGs in 2016 and changes in their abundances since 2015 and 1750. Data from mobile stations (blue triangles and orange diamonds in Figure 2), with the exception of NOAA sampling in the eastern Pacific, are not used for this global analysis.

The three GHGs shown in Table 1 are closely linked to anthropogenic activities and interact strongly with the biosphere and the oceans. Predicting the evolution of the atmospheric content of GHGs requires quantitative understanding of their many sources, sinks and chemical transformations in the atmosphere. Observations from the GAW Programme provide invaluable constraints on the budgets of these and other LLGHGs, and are used to assist the improvement of emissions inventories and evaluate satellite retrievals of LLGHG column averages. The Integrated Global Greenhouse Gas Information System, promoted by WMO, provides further insights into the sources of GHGs at national and subnational levels.

The NOAA AGGI [4] in 2016 was 1.40, representing a 40%$^{(4)}$ increase in total radiative forcing by all LLGHGs since 1990 and a 2.5% increase from 2015 to 2016 (Figure 1). The total radiative forcing by all LLGHGs in 2016 corresponds to a CO_2-equivalent mole fraction of 489 ppm [4].

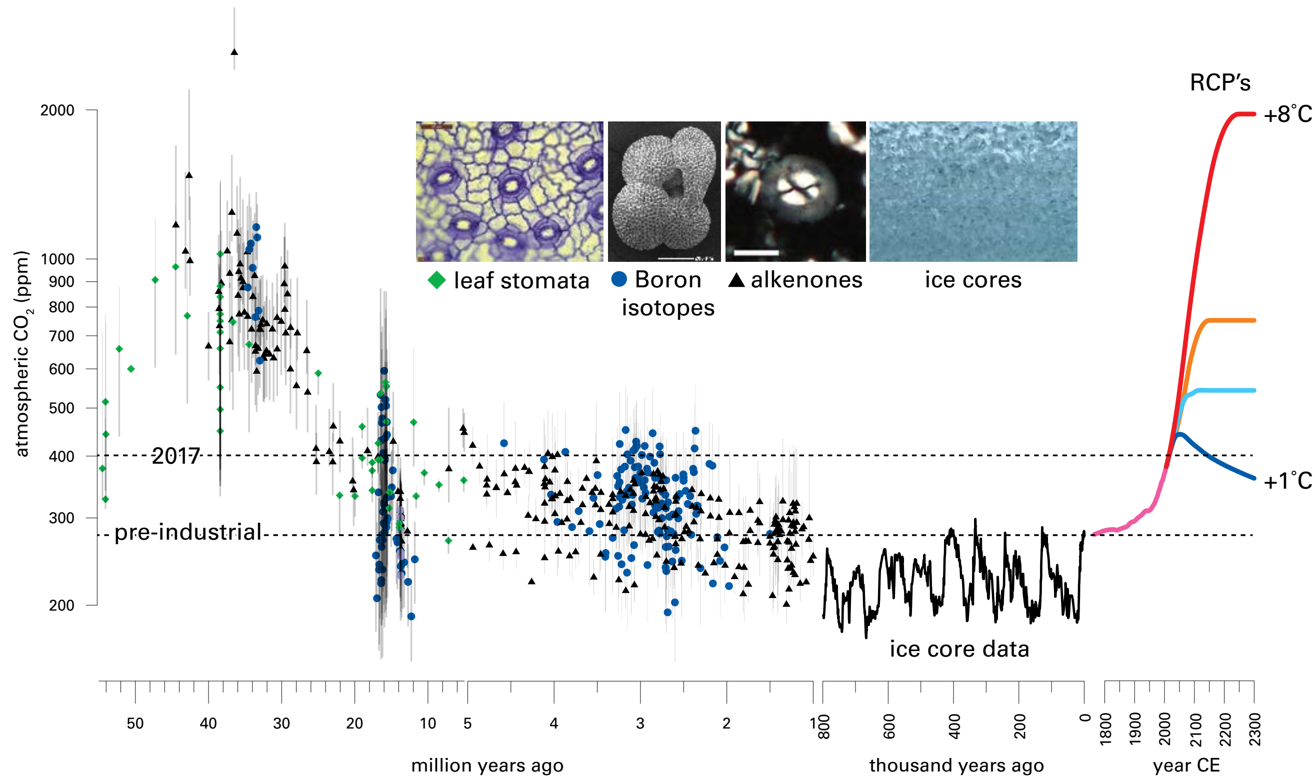
Carbon dioxide

Carbon dioxide is the single most-important anthropogenic GHG in the atmosphere, contributing ~65%$^{(4)}$ of the radiative forcing by LLGHGs. It is responsible for ~82% of the increase in radiative forcing over the past decade and ~83% over the past 5 years. The pre-industrial level of 278 ppm represented a balance of fluxes among the atmosphere, the oceans and the land biosphere. Atmospheric CO_2 reached 145% of the pre-industrial level in 2016, primarily because of emissions from combustion of fossil fuels and from cement production (the total sum of CO_2 emissions was 9.9 ± 0.5 PgC$^{(5)}$ in 2015 [8]), deforestation and other land-use change (1.0 ± 0.5 PgC average for 2006–2015). Of the total emissions from human activities during the period 2006–2015, about 44% accumulated in the atmosphere, 26% in the ocean and 30% on land [8]. The portion of CO_2 emitted by fossil fuel combustion that remains in the atmosphere (airborne fraction) varies inter-annually due to the high natural variability of CO_2 sinks without a confirmed global trend.

(Continued on page 6)

DISCOVERY OF ANCIENT ATMOSPHERES IN ANTARCTIC ICE

Nancy Bertler (GNS Science and Victoria University of Wellington), Richard Levy (GNS Science) and
Jocelyn Turnbull (GNS Science, New Zealand)



Reconstructions of atmospheric CO_2 over the past 55 million years are generated from proxy data that include boron isotopes (blue circles), alkenones (black triangles) and leaf stomata (green diamonds). Direct measurements from the past 800 000 years are acquired from Antarctic ice cores and modern instruments (pink). Future estimates include representative concentration pathways (RCPs) 8.5 (red), 6 (orange), 4.5 (light blue) and 2.6 (blue). References for all data shown in this plot are listed in the extended version online (http://www.wmo.int/pages/prog/arep/gaw/ghg/ghg-bulletin13.html). CE = Common Era.

Over the past 30 years, techniques have been developed to coax tiny air bubbles in Antarctic ice cores to reveal an intricate record of atmospheric GHG concentrations, in particular CO_2, CH_4 and N_2O. Unlike most paleoclimate reconstructions, the GHG record is not a proxy but rather a measurement of past atmospheres obtained from minute parcels of ancient air captured in the ice as new snow accumulating at the top solidifies into ice. The first record was developed by the French scientist Claude Lorius at Dome C and Vostok Station in the 1970s during the height of the cold war, in collaboration with Soviet and American scientists. Since then, many more records have been measured including the longest yet recovered during the European Project for Ice Coring in Antarctica Dome C, which spans the past 740 000 years. These records provide proof that over the past eight swings between ice ages (glacials) and warm periods similar to today (interglacials), atmospheric CO_2 varied between 180 and 280 ppm, demonstrating that today's CO_2 concentration of ~400 ppm exceeds the natural variability seen over hundreds of thousands of years.

Over the past decade, new high-resolution ice core records have been used to investigate how quickly CO_2 changed in the past. These records come from inland West Antarctica (West Antarctic Ice Sheet Divide Ice Core) and coastal Antarctica, where snow accumulates quickly and therefore records have a fine time resolution (for example, Law Dome, Talos Dome and Roosevelt Island), and are used for direct comparison with the Mauna Loa record and with globally averaged mole fractions. Horizontal ice cores, where very old ice lies exposed near the surface (for example, Taylor Dome and Allan Hills) are also being used to expand the records back in time and to permit large volumes of ice to

Ice core segment extracted in southeast Greenland by the team of Lora Koenig, a glaciologist with the NASA Goddard Space Flight Center in Greenbelt.

NASA's Goddard Space Flight Center/Ludovic Brucker

be sampled for additional measurements, including stable isotopes in CO_2, to investigate what sources and sinks caused the changes in CO_2 concentration.

Pacing and mechanisms of past carbon dioxide changes

Some 23 000 years ago, Earth emerged from the last ice age as atmospheric CO_2 concentrations and temperature began to rise. Between 23 000 and 9 000 years ago, the amount of CO_2 in the atmosphere increased by 80 ppm, rising from 180 to 260 ppm. State-of-the-art measurements and analytical techniques show that the increases in CO_2 occurred several centuries **before** the associated temperature changes. The West Antarctica ice core record reveals three distinct types of CO_2 variability during this time period:

- *Slow CO_2 increases*. CO_2 increased slowly at about 10 ppm per 1 000 years between 18 000 and 13 000 years ago. This slow change is thought to be due to the enhanced release and reduced uptake of carbon stored in the deep ocean, caused by changes in ocean temperature and salinity, a reduction in sea ice and biological activity in the Southern Ocean.

- *Abrupt CO_2 increases*. Fast CO_2 increases of 10–15 ppm over 100–200 years have been seen at three time periods: 16 000, 15 000 and 12 000 years ago. These three periods of rapid change account for almost half of the total CO_2 increase during the deglaciation and are linked to sudden changes in ocean circulation patterns, a "see-saw tug of war" between the North Atlantic and Southern Ocean deep ocean currents, causing a rapid release of carbon to the atmosphere. In comparison, fossil fuel combustion caused CO_2 to increase by 120 ppm in the last 150 years.

- *Stable CO_2 plateaux*. Curiously, each of the rapid events was followed by stable CO_2 conditions that lasted about 1 000–1 500 years. While the explanation for these stable conditions is still under debate, plausible causes are further changes in ocean circulation from the melting ice sheets, slow changes in growth of land plants and ocean–atmosphere exchange following the rapid CO_2 increases.

Past examples for future commitments

Geological records that predate ice core archives provide an opportunity to learn how the Earth system responded when atmospheric CO_2 concentrations were last similar to those recorded today and those expected in the coming decades. Information derived from alkenones, boron isotopes and fossil leaf stomata preserved in layers of rock and sediment provides estimates of CO_2 concentrations over the past millions of years. These data help to estimate the sensitivity of the Earth's environmental systems to CO_2 concentrations that were higher than pre-industrial levels and thus help to test and improve climate, ice sheet and Earth system models. Time periods of interest include the mid-Pliocene, 3–5 million years ago, in which was the last time Earth's atmosphere contained 400 ppm CO_2. During that period, global mean surface temperatures were 2–3 °C warmer than today, ice sheets in Greenland and West Antarctica melted and even parts of East Antarctica's ice retreated, causing the sea level to rise 10–20 m higher than that today. During the mid-Miocene, some 15 to 17 million years ago, atmospheric CO_2 reached 400–650 ppm and global mean surface temperatures were 3–4 °C warmer than those today. During the warmest intervals, East Antarctica's ice sheets retreated to the continent's interior, causing the sea level to rise to 40 m. Prior to 34 million years ago, atmospheric CO_2 levels were typically greater than 1 000 ppm. Temperatures were so warm that ice sheets were unable to grow in Antarctica.

These precious data on windows into the past provide useful examples to assess the environmental and ecosystem responses to high CO_2 concentrations and thus provide invaluable constraints to model projections of the impact of future GHG emission scenarios.

References for this article can be accessed in the extended version online at http://www.wmo.int/pages/prog/arep/gaw/ghg/ghg-bulletin13.html.

The globally averaged CO_2 mole fraction in 2016 was 403.3 ± 0.1 ppm (Figure 3). The record increase in the annual mean from 2015 to 2016 (3.3 ppm) is larger than the previous record increase from 2012 to 2013 and 50% above the average growth rate for the past decade (~2.2 ppm yr^{-1}). The higher growth rate in 2016 and 2015, in comparison with previous years, is due, in part, to the increased natural emissions of CO_2 related to the most-recent El Niño event, as explained in the previous (twelfth) edition of this GHG bulletin.

Methane

Methane contributes ~17%(4) of the radiative forcing by LLGHGs. Approximately 40% of CH_4 is emitted into the atmosphere by natural sources (for example, wetlands and termites), and ~60% comes from anthropogenic sources (for example, ruminants, rice agriculture, fossil fuel exploitation, landfills and biomass burning). Atmospheric CH_4 reached 257% of the pre-industrial level (~722 ppb) in 2016 due to increased emissions from anthropogenic sources. Globally averaged CH_4 calculated from in situ observations reached a new high of 1 853 ± 2 ppb in 2016, an increase of 9 ppb with respect to the previous year (Figure 4). The mean annual increase of CH_4 decreased from ~13 ppb yr^{-1} during the early 1980s to near zero during the period 1999–2006. Since 2007, atmospheric CH_4 has been increasing again. 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

Nitrous oxide contributes ~6%(4) of the 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 (~60%) and anthropogenic sources (~40%), including oceans, soils, biomass burning, fertilizer use and various industrial processes. The globally averaged N_2O mole fraction in 2016 reached 328.9 ± 0.1 ppb, which

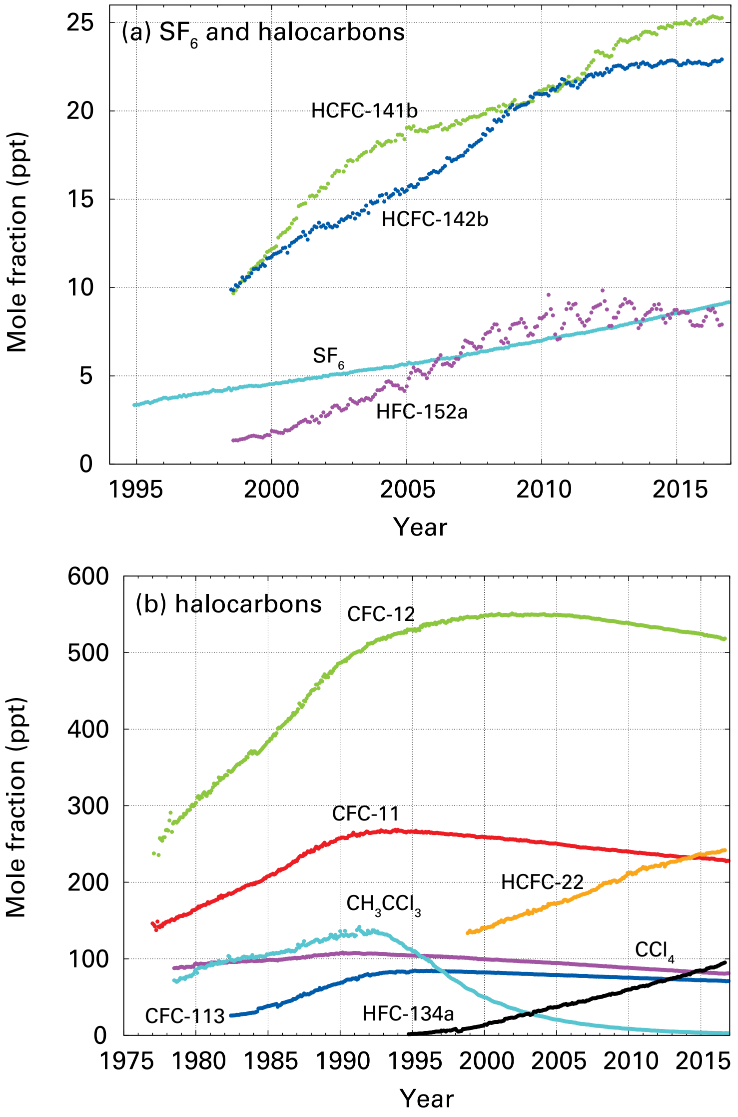


Figure 6. Monthly mean mole fractions of sulphur hexafluoride (SF_6) and the most important halocarbons: SF_6 and lower mole fractions of halocarbons (a) and higher ones of halocarbons (b). The numbers of stations used for the analyses are as follows: SF_6 (24), CFC-11 (23), CFC-12 (24), CFC-113 (20), CCl_4 (21), CH_3CCl_3 (24), HCFC-141b (10), HCFC-142b (14), HCFC-22 (14), HFC-134a (10) and HFC-152a (9).

is 0.8 ppb above the previous year (Figure 5) and 122% of the pre-industrial level (270 ppb). The annual increase from 2015 to 2016 is slightly lower than the mean growth rate over the past 10 years (0.9 ppb yr^{-1}). The likely causes of N_2O increase in the atmosphere are an increased use of fertilizers in agriculture and an increased release of N_2O from soils due to an excess of atmospheric nitrogen deposition related to air pollution.

Other greenhouse gases

Sulphur 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)). Stratospheric ozone-depleting chlorofluorocarbons (CFCs), together with minor halogenated gases, contribute ~11%(4) of the radiative forcing by LLGHGs. While CFCs and most halons are decreasing, some hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs), which are also potent GHGs, are increasing at relatively rapid rates, although they are still low in abundance (at ppt(6) levels).

This bulletin primarily addresses LLGHGs. Relatively short-lived tropospheric ozone has a radiative forcing comparable to that of halocarbons. Many other pollutants, such as carbon monoxide, nitrogen oxides and volatile organic compounds (VOCs), although not referred to as GHGs, have small direct or indirect effects on radiative forcing. Aerosols (suspended particulate matter) are short-lived substances that alter the radiation budget. All gases mentioned herein, as well as aerosols, are included in the observational programme of GAW, with support from WMO Members and contributing networks.

Acknowledgements and links

Fifty-one WMO Members have contributed CO_2 and other GHG data to GAW WDCGG. Approximately 46% of the measurement records submitted to WDCGG were obtained at sites of the NOAA Earth System Research Laboratory cooperative air-sampling network. For other networks and stations, see GAW Report No. 229. The Advanced Global Atmospheric Gases Experiment also contributed observations to this bulletin. Furthermore, the GAW observational stations that contributed data to this bulletin, shown in Figure 2, are included in the list of contributors on the WDCGG website (http://ds.data.jma.go.jp/gmd/wdcgg/). They are also described in the GAW Station Information System (http://gawsis.meteoswiss.ch) supported by MeteoSwiss, Switzerland.

References

[1] National Oceanic and Atmospheric Administration Earth System Research Laboratory, 2016: Trends in atmospheric carbon dioxide, http://www.esrl.noaa.gov/gmd/ccgg/trends/.

[2] World Meteorological Organization, 2016: WMO statement on the state of the global climate, https://library.wmo.int/opac/index.php?lvl=notice_display&id=97#.Wdon81uCzlV.

[3] Butler, J.H. and S.A. Montzka, 2016: The NOAA annual greenhouse gas index (AGGI), http://www.esrl.noaa.gov/gmd/aggi/aggi.html.

[4] National Oceanic and Atmospheric Administration Earth System Research Laboratory, 2016: NOAA's annual greenhouse gas index, http://www.esrl.noaa.gov/gmd/aggi/.

[5] Intergovernmental Panel on Climate Change, 2014: *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (R.K. Pachauri and L.A. Meyer, eds.). Geneva.

[6] World Meteorological Organization, 2009: *Technical Report of Global Analysis Method for Major Greenhouse Gases by the World Data Center for Greenhouse Gases* (Y. Tsutsumi, K. Mori, T. Hirahara, M. Ikegami and T.J. Conway). GAW Report No. 184 (WMO/TD-No. 1473), Geneva, https://www.wmo.int/pages/prog/arep/gaw/documents/TD_1473_GAW184_web.pdf.

[7] Conway, T.J., P.P. Tans, L.S. Waterman, K.W. Thoning, D.R. Kitzis, K.A. Masarie and N. Zhang, 1994: Evidence for interannual variability of the carbon cycle from the National Oceanic and Atmospheric Administration/Climate Monitoring and Diagnostics Laboratory Global Air Sampling Network. *Journal of Geophysical Research*, 99:22831–22855.

[8] Le Quéré, C., et al., 2016: Global carbon budget 2016. *Earth System Science Data* 8:605–649, doi:10.5194/essd-8-605-2016.

Contacts

World Meteorological Organization

Atmospheric Environment Research Division,
Research Department, Geneva
Email: gaw@wmo.int
Website: http://www.wmo.int/gaw

World Data Centre for Greenhouse Gases

Japan Meteorological Agency, Tokyo
Email: wdcgg@met.kishou.go.jp
Website: http://ds.data.jma.go.jp/gmd/wdcgg/

---

(1) ppm = number of molecules of the gas per million (10^6) molecules of dry air.

(2) Mole fraction = the preferred expression for abundance (concentration) of a mixture of gases or fluids. In atmospheric chemistry, it is used to express the concentration as the number of moles of a compound per mole 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 LLGHGs since 1750.

(5) 1 PgC = 1 petagram (10^{15} grams) of carbon.

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

Selected greenhouse gas observatories

Cape Point station is located in a nature reserve at the southern tip of the Cape Peninsula, South Africa (34°21′S, 18°29′E), about 60 km south of Cape Town. The station is situated atop a cliff of 230 m above sea level (a.s.l.), surrounded by ocean on three sides. It is predominantly exposed to well-mixed marine air from the South Atlantic, as the dominant wind direction is south-east to south-south-west. On occasion, continental air masses reach the sampling site, providing the opportunity to study contrasting air-flow regimes. The Cape Peninsula has a Mediterranean-type climate where the summers are generally dry and windy, and the winters are cold and wet.

Now in its fortieth year of existence, the primary focus of the station is continuous monitoring of long-lived GHGs, namely CO_2, CH_4 and N_2O, and trace gases such as carbon monoxide, surface ozone, gaseous elemental mercury, halocarbons and aerosols. Since 1995, the station has been one of the WMO GAW global stations and regularly participates in Empa audits and WMO intercomparison studies. The station also hosts a full suite of meteorological parameters and solar radiation measurements.

The Greenland Environmental Observatory at Summit (GEOSummit) station is a year-round Arctic sampling station funded by the National Science Foundation. GEOSummit is located at the top of the Greenland Ice Sheet (72.58°N, 38.48°W, 3 202 m a.s.l.) and provides unique opportunities for investigation of atmospheric processes. A baseline measurement programme was established in 2003 to provide year-round measurements of key site-specific variables. Currently, the suite of baseline measurements available to researchers includes station meteorology, accumulation measurements from a 100-stake array and a 12 km transect, weekly surface snow chemistry, monthly snow pit chemistry and stratigraphy, and filter-sampled radionuclides. Also available are aerosol data from continuous measurements with an eight-drum impactor sampler. Instrumentation from the NOAA Global Monitoring Division is on site to provide continuous ozone and black carbon observations. In addition, GHGs are monitored from weekly flask sampling. In the same samples, VOCs have been analysed by the University of Colorado Institute of Arctic and Alpine Research (INSTAAR) since 2006. A second set of samples has been collected in stainless steel flasks every two weeks for halocarbon measurements. Continuous measurements of CH_4 (hourly resolution) and VOCs (4 hourly resolution) have been conducted at the site with a remotely controlled gas chromatography instrument by INSTAAR since 2008.