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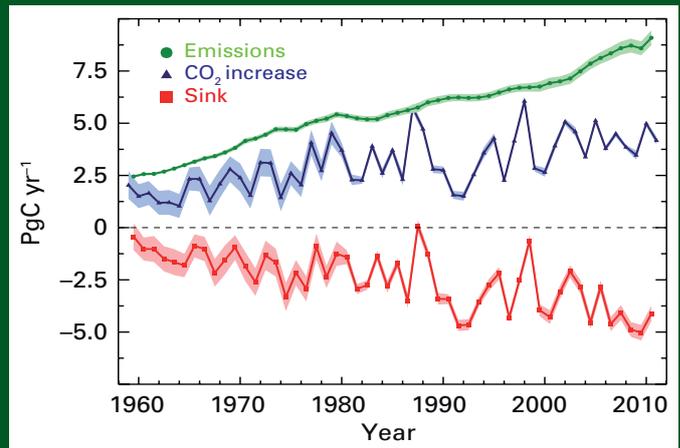
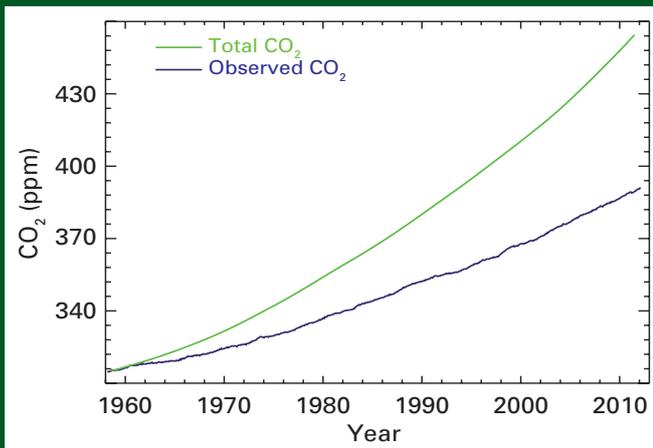
GLOBAL
ATMOSPHERE
WATCH

WMO GREENHOUSE GAS BULLETIN

The State of Greenhouse Gases in the Atmosphere
Based on Global Observations through 2011

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Since the industrial revolution, about 375 billion tonnes of carbon have been emitted by humans into the atmosphere as carbon dioxide (CO₂). Atmospheric measurements show that about half of this CO₂ remains in the atmosphere and that, so far, the ocean and terrestrial sinks have steadily increased. Accurate measurements of atmospheric CO₂ by WMO/GAW partners provide the basis for understanding the fate of CO₂ that has been emitted to the atmosphere. The figure (left) shows globally averaged CO₂ since 1958 inferred from measurements by GAW partners (blue) and as estimated in the absence of oceanic and terrestrial sinks (green). The figure (right) shows the

annual emissions in PgC^[1] from fossil fuel combustion and other industrial processes, the annual atmospheric increase, and the amount of carbon sequestered by sinks each year. These sinks constitute the small net difference between large fluxes (~100 PgC per year) into and out of the atmosphere from the terrestrial biosphere and oceans. This small net difference varies with climate oscillations, such as El Niño and La Niña events. The ocean sink is less susceptible to human interference than the terrestrial biosphere. Net uptake of CO₂ by the ocean makes it more acidic with potentially large impacts on the ocean food chain. (The figures and text are based on Ballantyne et al., 2012 and Levin, 2012.)

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 (CO₂), methane (CH₄) and nitrous oxide (N₂O) reached new highs in 2011, with CO₂ at 390.9±0.1 ppm^[2], CH₄ at 1813±2 ppb^[3] and N₂O at 324.2±0.1 ppb. These values constitute 140%, 259% and 120% of pre-industrial (before 1750) levels, respectively. The atmospheric increase of CO₂ from 2010 to 2011 is similar to the average growth rate over the past 10 years. However, for N₂O the increase from 2010 to 2011 is greater than both the one observed from 2009 to 2010 and

the average growth rate over the past 10 years. Atmospheric CH₄ continued to increase at a similar rate as observed over the last 3 years. The NOAA Annual Greenhouse Gas Index shows that from 1990 to 2011 radiative forcing by long-lived greenhouse gases increased by 30%, with CO₂ accounting for about 80% of this increase.

Overview

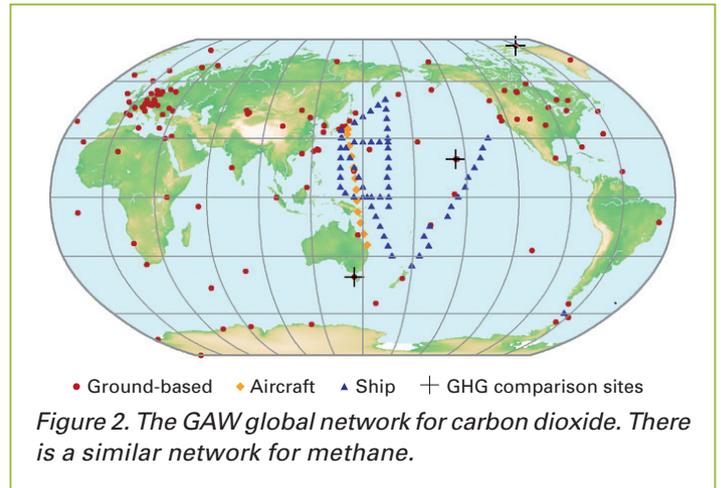
This eighth WMO/GAW Annual Bulletin reports on the atmospheric burdens and rates of change of the most important long-lived greenhouse gases (LLGHGs) – carbon dioxide, methane, nitrous oxide, CFC-12 and CFC-11 – and

provides a summary of the contributions of the other gases. These five major gases 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 the systematic observations and analysis of greenhouse gases and other trace species. 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.

The table provides globally averaged atmospheric abundances of the three major LLGHGs in 2011 and changes in these abundances since 2010 and 1750. The results are obtained from a global analysis of datasets (WMO, 2009) that are traceable to the WMO World Reference Standards. 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 shown in the table are closely linked to anthropogenic activities, and 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.

The NOAA Annual Greenhouse Gas Index in 2011 was 1.30, representing an increase in total radiative forcing by all LLGHGs of 30% since 1990 and of 1.2% from 2010 to 2011 (Figure 1). The total radiative forcing by all LLGHGs in 2011 corresponded to a CO₂-equivalent mole fraction of 473 ppm (<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%^[4] to radiative forcing by LLGHGs. It is responsible for 85% of the increase in radiative forcing over the past decade and 81% over the past five years. The pre-industrial level of ~280 ppm represented a balance of fluxes between the atmosphere, the oceans and the biosphere. Atmospheric CO₂ reached 140% of the pre-industrial level in 2011, primarily because of emissions from combustion of fossil fuels (fossil fuel CO₂ emissions were 9.1±0.5 PgC^[1] in 2010 according to <http://www.globalcarbonproject.org>) and land-use change (0.9±0.7 PgC in 2010, mostly due to tropical deforestation). The average increase in atmospheric CO₂ from pre-industrial time corresponds to ~55% of the CO₂ emitted by fossil fuel combustion, with the remaining ~45% removed by the oceans and the terrestrial biosphere. The portion of CO₂ emitted by fossil fuel combustion that remains in the atmosphere (airborne fraction) varies interannually without a confirmed global trend. The globally averaged CO₂ mole fraction in 2011 was 390.9±0.1 ppm (Figure 3). The annual increase of 2.0 ppm is higher than the average growth rate for the 1990s (~1.5 ppm/yr) and is the same as the average growth rate for the past decade (~2.0 ppm/yr).

Methane (CH₄)

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). In 2011, atmospheric CH₄ reached 259% of the pre-industrial level (~700 ppb) due to increased emissions from anthropogenic sources. Globally averaged CH₄ mole fraction reached a new high of 1813±2 ppb in

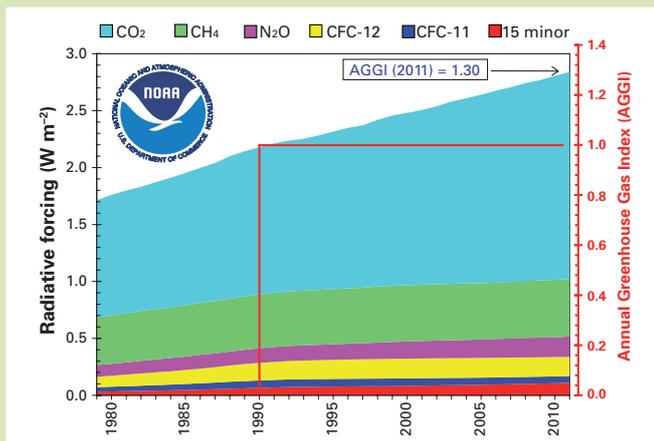


Figure 1. Atmospheric radiative forcing, relative to 1750, of LLGHGs and the 2011 update of the NOAA Annual Greenhouse Gas Index (AGGI)

Global abundances (as mole fractions) of key greenhouse gases averaged over the 12 months of 2011 as well as changes relative to 2010 and 1750 from the WMO/GAW global greenhouse gas monitoring network

	CO ₂	CH ₄	N ₂ O
Global abundance in 2011	390.9±0.1 ^[5] ppm	1813±2 ^[5] ppb	324.2±0.1 ^[5] ppb
2011 abundance relative to year 1750*	140%	259%	120%
2010–2011 absolute increase	2.0 ppm	5 ppb	1.0 ppb
2010–2011 relative increase	0.51%	0.28%	0.31%
Mean annual absolute increase during last 10 years	2.0 ppm/yr	3.2 ppb/yr	0.78 ppb/yr

* Assuming a pre-industrial mole fraction of 280 ppm for CO₂, 700 ppb for CH₄ and 270 ppb for N₂O.

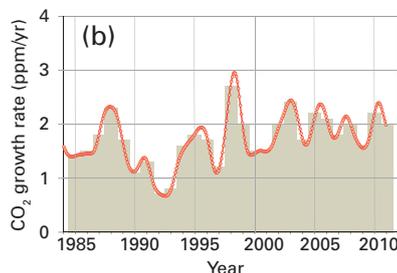
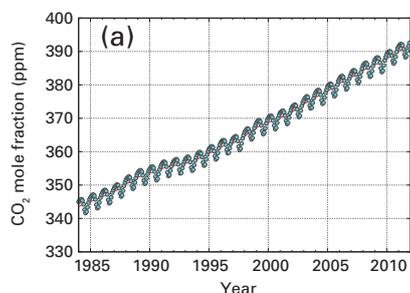


Figure 3. Globally averaged CO_2 mole fraction (a) and its growth rate (b) from 1984 to 2011. Annually averaged growth rate is shown by columns at (b).

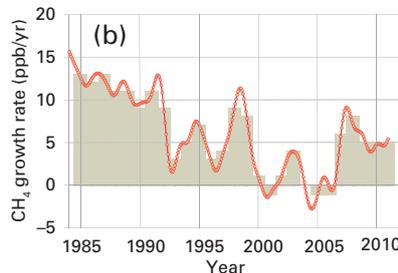
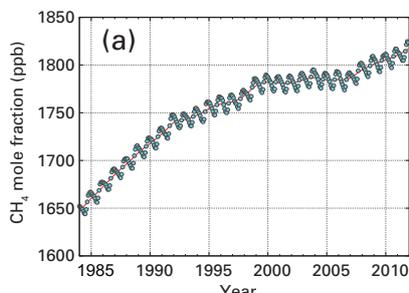


Figure 4. Globally averaged CH_4 mole fraction (a) and its growth rate (b) from 1984 to 2011. Annually averaged growth rate is shown by columns at (b).

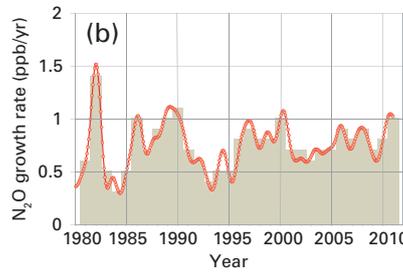
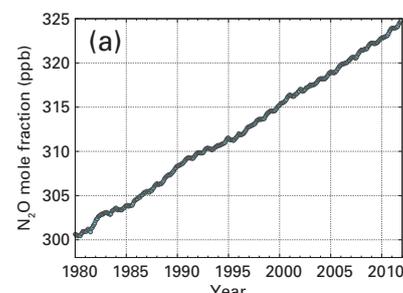


Figure 5. Globally averaged N_2O mole fraction (a) and its growth rate (b) from 1980 to 2011. Annually averaged growth rate is shown by columns at (b).

2011, an increase of 5 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, with a nearly constant rate during the last 3 years. The distribution of useful observations is too sparse, especially in the tropics, to fully understand the renewed increase in CH_4 abundance.

Nitrous oxide (N_2O)

Nitrous oxide contributes ~6%^[4] to radiative forcing by LLGHGs. It is the third most important contributor to this total. 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 average global N_2O mole fraction in 2011 reached 324.2 ± 0.1 ppb, which is 1.0 ppb above the previous year (Figure 5) and 120% of the pre-industrial level (270 ppb). The annual increase from 2010 to 2011 is greater than the mean growth rate over the past 10 years (0.78 ppb/yr).

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). The 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 rapid rates, although they are still low in abundance (ppt^[6] levels, Figure 7).

This bulletin mostly 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 the 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 Research Laboratory (ESRL). The bulletins are available through the GAW Programme or the WDCGG Web page.

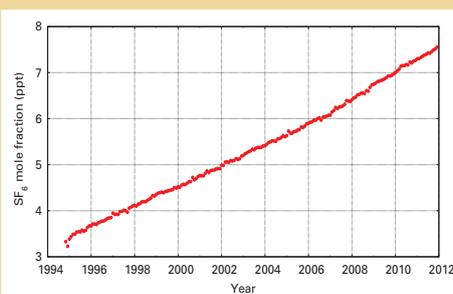


Figure 6. Monthly mean mole fraction of sulphur hexafluoride (SF_6) from 1995 to 2011 averaged over 20 stations

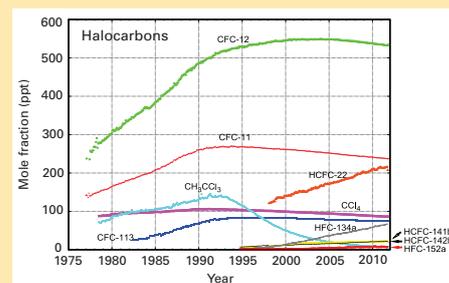


Figure 7. Monthly mean mole fractions of the most important halocarbons from 1977 to 2011 averaged over the network (between 7 and 19 stations)

Acknowledgements and links

Fifty WMO member countries have contributed CO₂ 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>), operated by EMPA, Switzerland.

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Website: <http://ds.data.jma.go.jp/gmd/wdcgg>

[1] 1 PgC = 1 billion (10⁹) 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 (10⁹) 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.

[6] ppt = number of molecules of the gas per trillion (10¹²) molecules of dry air.

Selected greenhouse gas observatories



J. HATTAKA

The Pallas–Sodankylä GAW station is located in northern Europe in the transport route of trace gases to the Arctic. The station has two main nodes, Pallas (67.93°N, 24.12°E, 565 m a.s.l.) and Sodankylä (67.36°N, 26.63°E, 179 m a.s.l.), which are 150 km apart. Greenhouse gases,

reactive gases and a wide suite of aerosol parameters, which are reported to the GAW database, are monitored on an arctic mountaintop in a clean national park environment at Pallas. Micrometeorological eddy-covariance fluxes of CO₂ and CH₄ are measured at representative ecosystems at both nodes (<http://en.ilmatieteenlaitos.fi/greenhouse-gases>, <http://fmiarc.fmi.fi/>).

The Air Chemistry Observatory of the German Antarctic station Neumayer

is situated 1.5 km south of the main building, located on the Ekström Ice Shelf, about 8 km from Atka Bay (70.666°S, 8.266°W, 42 m a.s.l., http://www.awi.de/en/infrastructure/stations/neumayer_station/).

During summer, Atka Bay and the nearby coastline are mainly free of sea ice. The isolated location of Neumayer makes it a valuable reference site for conducting measurements under extremely pure atmospheric conditions. The Observatory is operated in a collaboration between the Alfred Wegener Institute for Polar and Marine Research and the Institute of Environmental Physics at the University of Heidelberg. A number of greenhouse gases and their isotopic composition are measured there simultaneously.



R. WELLER



A. RESHTNIKOV

The Arctic Hydrometeorological Observatory at Tiksi (71.59°N, 128.92°E, 5 m a.s.l.) is located near the mouth of the Lena River at the Laptev Sea. Measurements are performed to address issues related to the

variability of atmospheric chemical composition. The region surrounding the station is reasonably homogeneous and is characterized by a mixture of regionally typical wet and dry tundra vegetation, seasonal streams, rocky shale areas and permafrost. Since 2010, both continuous and flask measurements of CO₂ and CH₄ are performed at the station. Several research groups are making observations at Tiksi, including Roshydro, the Russian Academy of Sciences, NOAA and the Finnish Meteorological Institute.