

Atmospheric Concentrations of Greenhouse Gases

This indicator describes how the levels of major greenhouse gases in the atmosphere have changed over time.

Background

Since the Industrial Revolution began in the late 1700s, people have added a significant amount of greenhouse gases into the atmosphere by burning fossil fuels, cutting down forests, and conducting other activities (see the [U.S.](#) and [Global](#) Greenhouse Gas Emissions indicators). When greenhouse gases are emitted into the atmosphere, many remain there for long time periods ranging from a decade to many millennia. Over time, these gases are removed from the atmosphere by emissions sinks, such as oceans, vegetation, or chemical reactions. Emissions sinks are the opposite of emissions sources, and they absorb and store emissions or cause the gases to break down. However, if these gases enter the atmosphere more quickly than they can be removed, their concentrations increase.

Many greenhouse gases remain in the atmosphere for decades or longer. The greenhouse gases being reported here become well mixed throughout the entire global atmosphere because of their long lifetimes and because of transport by winds. Concentrations of other greenhouse gases such as tropospheric ozone, which has an atmospheric lifetime of hours to days, often vary regionally and are not included in this indicator.

Concentrations of greenhouse gases are measured in parts per million (ppm), parts per billion (ppb), or parts per trillion (ppt) by volume. In other words, a concentration of 1 ppb for a given gas means there is one part of that gas in 1 billion parts of a given amount of air. For some greenhouse gases, even changes as small as a few parts per trillion can make a difference in global climate.

About the Indicator

This indicator describes concentrations of greenhouse gases in the atmosphere. It focuses on the major greenhouse gases that result from human activities. These include carbon dioxide, methane, nitrous oxide, and certain manufactured gases known as halogenated gases. This indicator shows concentrations of greenhouse gases over thousands of years. Recent measurements come from monitoring stations around the world, while older measurements come from air bubbles trapped in layers of ice from Antarctica and Greenland. By determining the age of the ice layers and the concentrations of gases trapped inside, scientists can learn what the atmosphere was like thousands of years ago.

Key Points

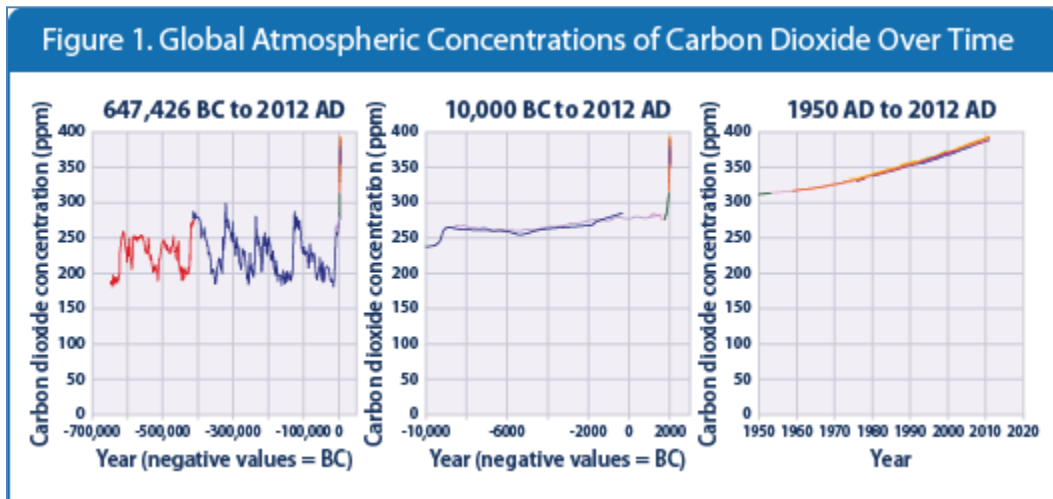
- Global atmospheric concentrations of carbon dioxide, methane, nitrous oxide, and certain manufactured greenhouse gases have all risen over the last few hundred years (see Figures 1, 2, 3, and 4).
- Before the industrial era began in the late 1700s, carbon dioxide concentrations measured approximately 280 ppm. Concentrations have risen steadily since then, reaching an annual

average of 394 ppm in 2012—a 41 percent increase. Almost all of this increase is due to human activities.¹

- The concentration of methane in the atmosphere has more than doubled since preindustrial times, reaching about 1,826 ppb in 2012. It is very likely that this increase is predominantly due to agriculture and fossil fuel use.²
- Historical measurements show that the current global atmospheric concentrations of carbon dioxide and methane are unprecedented compared with the past 650,000 years (see Figures 1 and 2).
- Over the past 100,000 years, concentrations of nitrous oxide in the atmosphere have rarely exceeded 280 ppb. Levels have risen since the 1920s, however, reaching a new high of 325 ppb in 2012 (see Figure 3). This increase is primarily due to agriculture.³
- Concentrations of many of the halogenated gases shown in Figure 4 (gases that contain chlorine, fluorine, or bromine) were essentially zero a few decades ago but have increased rapidly as they have been incorporated into industrial products and processes. Some of these chemicals are now being phased out of use because they are ozone-depleting substances, meaning they also cause harm to the Earth's ozone layer. As a result, concentrations of some ozone-depleting gases have begun to stabilize or decline (see Figure 4, left panel). Concentrations of other halogenated gases have continued to rise, however, especially where the gases have emerged as substitutes for ozone-depleting chemicals (see Figure 4, right panel). Some of these halogenated gases are considered major greenhouse gases due to their very high global warming potentials and long atmospheric lifetimes ([see table](#)).

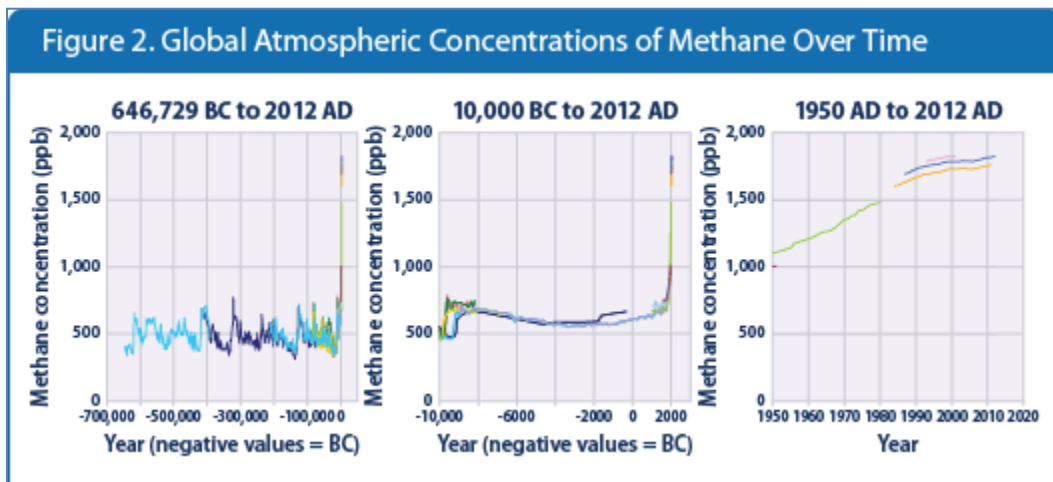
Water Vapor as a Greenhouse Gas

Water vapor is the most abundant greenhouse gas in the atmosphere. Human activities have only a small direct influence on atmospheric concentrations of water vapor, primarily through irrigation and deforestation, so it is not included in this indicator. However, the surface warming caused by human production of other greenhouse gases leads to an increase in atmospheric water vapor, because a warmer climate increases evaporation. This creates a positive “feedback loop” where warming leads to more warming.



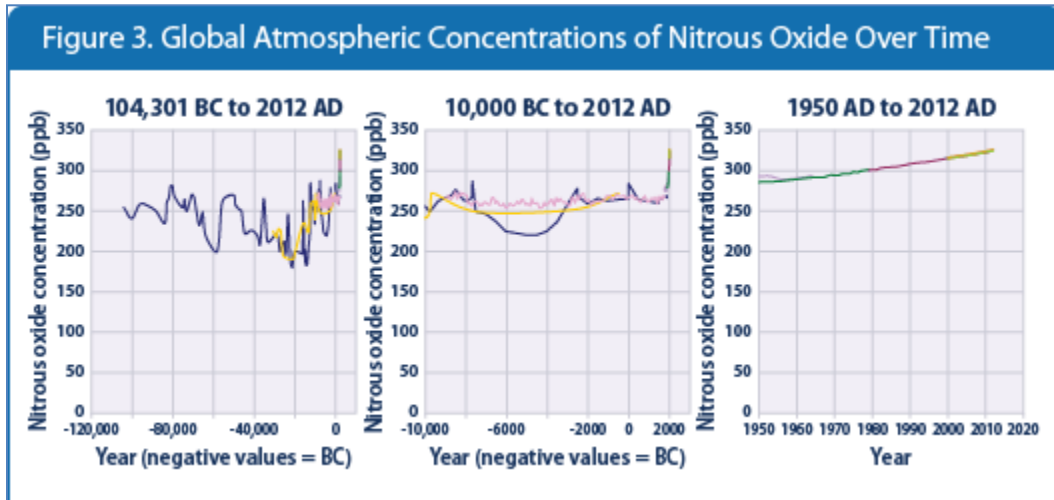
This figure shows concentrations of carbon dioxide in the atmosphere from hundreds of thousands of years ago through 2012. The data come from a variety of historical ice core studies and recent air monitoring sites around the world. Each line represents a different data source.

Data source: Various studies⁴



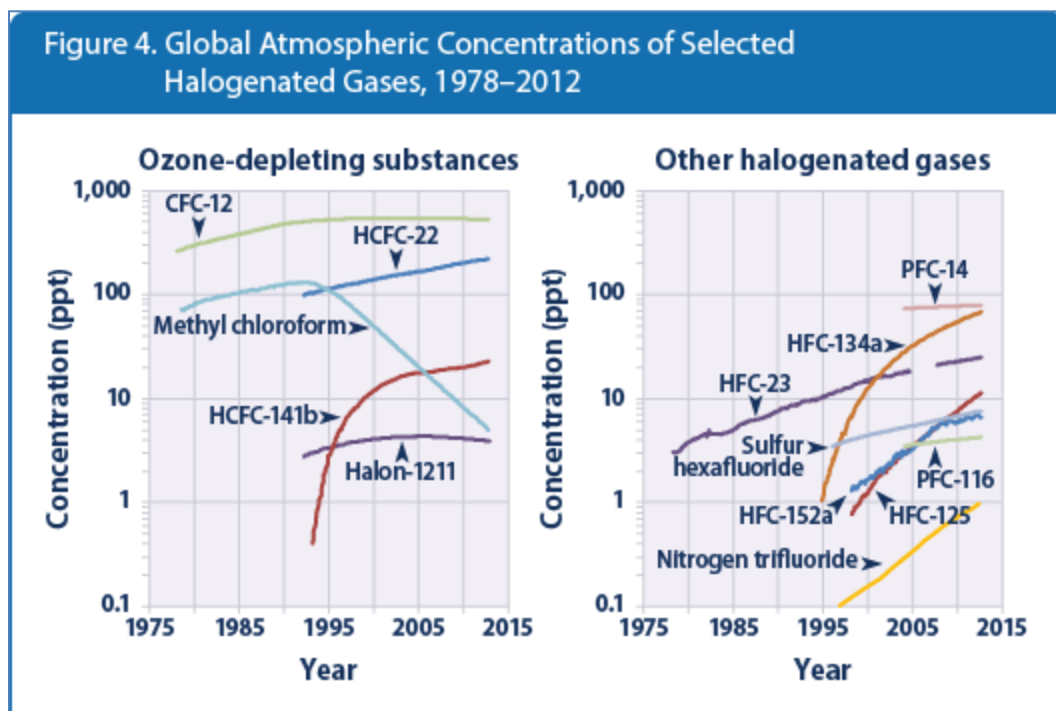
This figure shows concentrations of methane in the atmosphere from hundreds of thousands of years ago through 2012. The data come from a variety of historical ice core studies and recent air monitoring sites around the world. Each line represents a different data source.

Data source: Various studies⁵



This figure shows concentrations of nitrous oxide in the atmosphere from 100,000 years ago through 2012. The data come from a variety of historical ice core studies and recent air monitoring sites around the world. Each line represents a different data source.

Data source: Various studies⁶



This figure shows concentrations of several halogenated gases (which contain fluorine, chlorine, or bromine) in the atmosphere. The data come from monitoring sites around the world. Note that the scale is logarithmic, which means it increases by powers of 10. This is because the concentrations of different halogenated gases can vary by a few orders of magnitude. The numbers following the name of each gas (e.g., HCFC-22) are used to denote specific types of those particular gases.

Data sources: AGAGE, 2013;⁷ Arnold, 2013;⁸ NOAA, 2013⁹

Indicator Notes

This indicator includes several of the most important halogenated gases, but some others are not shown. Many other halogenated gases are also greenhouse gases, but Figure 4 is limited to a set of common examples that represent most of the major types of these gases. The indicator also does not address certain other pollutants that can affect climate by either reflecting or absorbing energy. For example, sulfate particles can reflect sunlight away from the Earth, while black carbon aerosols (soot) absorb energy. Data for nitrogen trifluoride (Figure 4) reflect modeled averages based on measurements made in the Northern Hemisphere and some locations in the Southern Hemisphere, to represent global average concentrations over time.

Data Sources

Global atmospheric concentration measurements for carbon dioxide (Figure 1), methane (Figure 2), and nitrous oxide (Figure 3) come from a variety of monitoring programs and studies published in peer-reviewed literature. References for the underlying data are included in the corresponding exhibits. Global atmospheric concentration data for selected halogenated gases (Figure 4) were compiled by the Advanced Global Atmospheric Gases Experiment,¹⁰ the National Oceanic and Atmospheric

Administration,¹¹ and a peer-reviewed study on nitrogen trifluoride.¹² An older figure with many of these gases appeared in the Intergovernmental Panel on Climate Change's Fourth Assessment Report.¹³

¹ IPCC (Intergovernmental Panel on Climate Change). 2007. Climate change 2007: The physical science basis (Fourth Assessment Report). Cambridge, United Kingdom: Cambridge University Press.

² IPCC (Intergovernmental Panel on Climate Change). 2007. Climate change 2007: Synthesis report (Fourth Assessment Report). Cambridge, United Kingdom: Cambridge University Press.

³ IPCC (Intergovernmental Panel on Climate Change). 2007. Climate change 2007: Synthesis report (Fourth Assessment Report). Cambridge, United Kingdom: Cambridge University Press.

⁴ [see full list provided on next page]

⁵ [see full list provided on next page]

⁶ [see full list provided on next page]

⁷ AGAGE (Advanced Global Atmospheric Gases Experiment). 2013. ALE/GAGE/AGAGE data base. Accessed July 2013. <http://agage.eas.gatech.edu/data.htm>.

⁸ Arnold, T. 2013 update to data originally published in: Arnold, T., C.M. Harth, J. Mühle, A.J. Manning, P.K. Salameh, J. Kim, D.J. Ivy, L.P. Steele, V.V. Petrenko, J.P. Severinghaus, D. Baggenstos, and R.F. Weiss. 2013. Nitrogen trifluoride global emissions estimated from updated atmospheric measurements. PNAS 110(6):2029-2034. Data updated May 2013.

⁹ NOAA (National Oceanic and Atmospheric Administration). 2013. Halocarbons and other atmospheric trace species. Accessed July 2013. www.esrl.noaa.gov/gmd/hats.

¹⁰ AGAGE (Advanced Global Atmospheric Gases Experiment). 2013. ALE/GAGE/AGAGE data base. Accessed July 2013. <http://agage.eas.gatech.edu/data.htm>.

¹¹ NOAA (National Oceanic and Atmospheric Administration). 2013. Halocarbons and other atmospheric trace species. Accessed July 2013. www.esrl.noaa.gov/gmd/hats.

¹² Arnold, T. 2013 update to data originally published in: Arnold, T., C.M. Harth, J. Mühle, A.J. Manning, P.K. Salameh, J. Kim, D.J. Ivy, L.P. Steele, V.V. Petrenko, J.P. Severinghaus, D. Baggenstos, and R.F. Weiss. 2013. Nitrogen trifluoride global emissions estimated from updated atmospheric measurements. PNAS 110(6):2029-2034. Data updated May 2013.

¹³ IPCC (Intergovernmental Panel on Climate Change). 2007. Climate change 2007: Synthesis report (Fourth Assessment Report). Cambridge, United Kingdom: Cambridge University Press.

Atmospheric Concentrations of Greenhouse Gases: Citations for Figures 1, 2, and 3

Figure 1

EPICA Dome C, Antarctica: approximately 647,426 BC to 411,548 BC

Siegenthaler, U., T. F. Stocker, E. Monnin, D. Lüthi, J. Schwander, B. Stauffer, D. Raynaud, J.M. Barnola, H. Fischer, V. Masson-Delmotte, and J. Jouzel. 2005. Stable carbon cycle-climate relationship during the late Pleistocene. *Science* 310(5752):1313–1317. Accessed May 15, 2007.

ftp://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/antarctica/epica_domec/edc-co2-650k-390k.txt.

Vostok Station, Antarctica: approximately 415,157 BC to 339 BC

Barnola, J.M., D. Raynaud, C. Lorius, and N.I. Barkov. 2003. Historical CO₂ record from the Vostok ice core. In: *Trends: A compendium of data on global change*. Oak Ridge, TN: U.S. Department of Energy. Accessed September 14, 2005. <http://cdiac.ornl.gov/trends/co2/vostok.html>.

EPICA Dome C, Antarctica: approximately 9002 BC to 1515 AD

Flückiger, J., E. Monnin, B. Stauffer, J. Schwander, T.F. Stocker, J. Chappellaz, D. Raynaud, and J.M. Barnola. 2002. High resolution Holocene N₂O ice core record and its relationship with CH₄ and CO₂. *Global Biogeochem. Cycles* 16(1):10–11. Accessed April 30, 2007.

ftp://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/antarctica/epica_domec/readme_flueckiger2002.txt.

Law Dome, Antarctica, 75-year smoothed: approximately 1010 AD to 1975 AD

Etheridge, D.M., L.P. Steele, R.L. Langenfelds, R.J. Francey, J.M. Barnola, and V.I. Morgan. 1998. Historical CO₂ records from the Law Dome DE08, DE08-2, and DSS ice cores. In: *Trends: A compendium of data on global change*. Oak Ridge, TN: U.S. Department of Energy. Accessed September 14, 2005.

<http://cdiac.ornl.gov/trends/co2/lawdome.html>.

Siple Station, Antarctica: approximately 1744 AD to 1953 AD

Neftel, A., H. Friedli, E. Moor, H. Lötscher, H. Oeschger, U. Siegenthaler, and B. Stauffer. 1994. Historical CO₂ record from the Siple Station ice core. In: *Trends: A compendium of data on global change*. Oak

Ridge, TN: U.S. Department of Energy. Accessed September 14, 2005.
<http://cdiac.ornl.gov/trends/co2/siple.html>.

Mauna Loa, Hawaii: 1959 AD to 2012 AD

NOAA (National Oceanic and Atmospheric Administration). 2013. Annual mean CO₂ concentrations for Mauna Loa, Hawaii. Accessed May 24, 2013.
ftp://ftp.cmdl.noaa.gov/ccg/co2/trends/co2_annmean_mlo.txt.

Barrow, Alaska: 1974 AD to 2011 AD

Cape Matatula, American Samoa: 1976 AD to 2011 AD

South Pole, Antarctica: 1976 AD to 2011 AD

NOAA (National Oceanic and Atmospheric Administration). 2012. Monthly mean CO₂ concentrations for Barrow, Alaska; Cape Matatula, American Samoa; and the South Pole. Accessed May 10, 2012.
<ftp://ftp.cmdl.noaa.gov/ccg/co2/in-situ>.

Cape Grim, Australia: 1992 AD to 2006 AD

Shetland Islands, Scotland: 1993 AD to 2002 AD

Steele, L.P., P.B. Krummel, and R.L. Langenfelds. 2007. Atmospheric CO₂ concentrations (ppmv) derived from flask air samples collected at Cape Grim, Australia, and Shetland Islands, Scotland. Commonwealth Scientific and Industrial Research Organisation. Accessed January 20, 2009.
<http://cdiac.esd.ornl.gov/ftp/trends/co2/csiro>.

Lampedusa Island, Italy: 1993 AD to 2000 AD

Chamard, P., L. Ciattaglia, A. di Sarra, and F. Monteleone. 2001. Atmospheric CO₂ record from flask measurements at Lampedusa Island. In: Trends: A compendium of data on global change. Oak Ridge, TN: U.S. Department of Energy. Accessed September 14, 2005.
<http://cdiac.ornl.gov/trends/co2/lampis.html>.

Figure 2

EPICA Dome C, Antarctica: approximately 646,729 BC to 1888 AD

Spahni, R., J. Chappellaz, T.F. Stocker, L. Loulergue, G. Hausammann, K. Kawamura, J. Flückiger, J. Schwander, D. Raynaud, V. Masson-Delmotte, and J. Jouzel. 2005. Atmospheric methane and nitrous oxide of the late Pleistocene from Antarctic ice cores. *Science* 310(5752):1317–1321. Accessed May 15, 2007. [ftp://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/antarctica/epica_domec/edc-ch4-2005-650k.txt](http://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/antarctica/epica_domec/edc-ch4-2005-650k.txt).

Vostok Station, Antarctica: approximately 415,172 BC to 346 BC

Petit, J.R., J. Jouzel, D. Raynaud, N.I. Barkov, J.M. Barnola, I. Basile, M. Bender, J. Chappellaz, M. Davis, G. Delaygue, M. Delmotte, V.M. Kotlyakov, M. Legrand, V. Lipenkov, C. Lorius, L. Pépin, C. Ritz, E. Saltzman, and M. Stievenard. 1999. Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica. *Nature* 399:429–436. Accessed April 24, 2007. [ftp://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/antarctica/vostok/ch4nat.txt](http://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/antarctica/vostok/ch4nat.txt).

Greenland GISP2 ice core: approximately 87,798 BC to 8187 BC

Byrd Station, Antarctica: approximately 85,929 BC to 6748 BC

Greenland GRIP ice core: approximately 46,933 BC to 8129 BC

Blunier, T., and E.J. Brook. 2001. Timing of millennial-scale climate change in Antarctica and Greenland during the last glacial period. *Science* 291:109–112. Accessed September 13, 2005. [ftp://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/greenland/summit/grip/synchronization/readme_blunier2001.txt](http://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/greenland/summit/grip/synchronization/readme_blunier2001.txt).

EPICA Dome C, Antarctica: approximately 8945 BC to 1760 AD

Flückiger, J., E. Monnin, B. Stauffer, J. Schwander, T.F. Stocker, J. Chappellaz, D. Raynaud, and J.M. Barnola. 2002. High resolution Holocene N₂O ice core record and its relationship with CH₄ and CO₂. *Global Biogeochem. Cycles* 16(1):10–11. Accessed April 24, 2007. [ftp://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/antarctica/epica_domec/readme_flueckiger2002.txt](http://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/antarctica/epica_domec/readme_flueckiger2002.txt).

Law Dome, Antarctica: approximately 1008 AD to 1980 AD

Various Greenland locations: approximately 1075 AD to 1885 AD

Etheridge, D.M., L.P. Steele, R.J. Francey, and R.L. Langenfelds. 2002. Historical CH₄ records since about 1000 AD from ice core data. In: *Trends: A compendium of data on global change*. Oak Ridge, TN: U.S.

Department of Energy. Accessed September 13, 2005.
http://cdiac.ornl.gov/trends/atm_meth/lawdome_meth.html.

Greenland Site J: approximately 1598 AD to 1951 AD

WDCGG (World Data Centre for Greenhouse Gases). 2006. Atmospheric CH₄ concentrations for Greenland Site J. Accessed May 30, 2013. <http://ds.data.jma.go.jp/gmd/wdcgg/cgi-bin/wdcgg/catalogue.cgi>.

Cape Grim, Australia: 1984 AD to 2011 AD

NOAA (National Oceanic and Atmospheric Administration). 2013. Monthly mean CH₄ concentrations for Cape Grim, Australia. Accessed May 30, 2013.
ftp://ftp.cmdl.noaa.gov/ccg/ch4/flask/month/ch4_cgo_surface-flask_1_ccgg_month.txt.

Mauna Loa, Hawaii: 1987 AD to 2012 AD

NOAA (National Oceanic and Atmospheric Administration). 2013. Monthly mean CH₄ concentrations for Mauna Loa, Hawaii. Accessed May 30, 2013. ftp://ftp.cmdl.noaa.gov/ccg/ch4/in-situ/mlo/ch4_mlo_surface-insitu_1_ccgg_month.txt.

Shetland Islands, Scotland: 1993 AD to 2001 AD

Steele, L.P., P.B. Krummel, and R.L. Langenfelds. 2002. Atmospheric CH₄ concentrations from sites in the CSIRO Atmospheric Research GASLAB air sampling network (October 2002 version). In: Trends: A compendium of data on global change. Oak Ridge, TN: U.S. Department of Energy. Accessed September 13, 2005. http://cdiac.esd.ornl.gov/trends/atm_meth/csiro/csiro-shetlandch4.html.

Figure 3

Greenland GISP2 ice core: approximately 104,301 BC to 1871 AD

Taylor Dome, Antarctica: approximately 30,697 BC to 497 BC

Sowers, T., R.B. Alley, and J. Jubenville. 2003. Ice core records of atmospheric N₂O covering the last 106,000 years. *Science* 301(5635):945–948. Accessed September 14, 2005.
www.ncdc.noaa.gov/pub/data/paleo/icecore/antarctica/taylor/taylor_n2o.txt.

EPICA Dome C, Antarctica: approximately 9000 BC to 1780 AD

Flückiger, J., E. Monnin, B. Stauffer, J. Schwander, T.F. Stocker, J. Chappellaz, D. Raynaud, and J.M. Barnola. 2002. High resolution Holocene N₂O ice core record and its relationship with CH₄ and CO₂. *Global Biogeochem. Cycles* 16(1):10–11. Accessed September 14, 2005.
ftp://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/antarctica/epica_domec/readme_flueckiger2002.txt.

Antarctica: approximately 1756 AD to 1964 AD

Machida, T., T. Nakazawa, Y. Fujii, S. Aoki, and O. Watanabe. 1995. Increase in the atmospheric nitrous oxide concentration during the last 250 years. *Geophys. Res. Lett.* 22(21):2921–2924. Accessed September 8, 2005.
ftp://daac.ornl.gov/data/global_climate/global_N_cycle/data/global_N_perturbations.txt.

Antarctica: approximately 1903 AD to 1976 AD

Battle, M., M. Bender, T. Sowers, P. Tans, J. Butler, J. Elkins, J. Ellis, T. Conway, N. Zhang, P. Lang, and A. Clarke. 1996. Atmospheric gas concentrations over the past century measured in air from firn at the South Pole. *Nature* 383:231–235. Accessed September 8, 2005.
ftp://daac.ornl.gov/data/global_climate/global_N_cycle/data/global_N_perturbations.txt.

Cape Grim, Australia: 1979 AD to 2011 AD

AGAGE (Advanced Global Atmospheric Gases Experiment). 2012. Monthly mean N₂O concentrations for Cape Grim, Australia. Accessed May 31, 2013. <http://ds.data.jma.go.jp/gmd/wdcgg/cgi-bin/wdcgg/catalogue.cgi>.

South Pole, Antarctica: 1998 AD to 2012 AD

Barrow, Alaska: 1999 AD to 2012 AD

Mauna Loa, Hawaii: 2000 AD to 2012 AD

NOAA (National Oceanic and Atmospheric Administration). 2013. Monthly mean N₂O concentrations for Barrow, Alaska; Mauna Loa, Hawaii; and the South Pole. Accessed May 31, 2013.
www.esrl.noaa.gov/gmd/hats/insitu/cats/cats_conc.html.