Global Monitoring Division

Theme 1 Networks: Tracking Greenhouse Gases and Understanding Carbon Cycle Feedbacks

2013-2017 Review

May 21-24, 2018

Five Observing Networks Arranged in Three Themes

The NOAA GMD Atmospheric Baseline Observatories at Barrow, Mauna Loa, Samoa and South Pole and observatories at Trinidad Head and Summit are well-known components of the NOAA GMD monitoring facilities. In addition to this north-to-south backbone of observatories through the Pacific Ocean, GMD has additional observing networks to address specific scientific needs.

Measurement programs from five networks (greenhouse gases, solar radiation, aerosols, ozone depleting gases and atmospheric ozone) are grouped into three GMD themes as shown below and discussed in the following sections.

Themes:

1) Tracking Greenhouse Gases and Understanding Carbon Cycle Feedbacks

- Global Greenhouse Gas Reference Network (GGGRN)

2) Monitoring and Understanding Changes in Surface Radiation, Clouds and Aerosol Distributions

- GMD Radiation Networks (G-RAD)
- NOAA Federated Aerosol Network (NFAN)

3) Guiding Recovery of Stratospheric Ozone

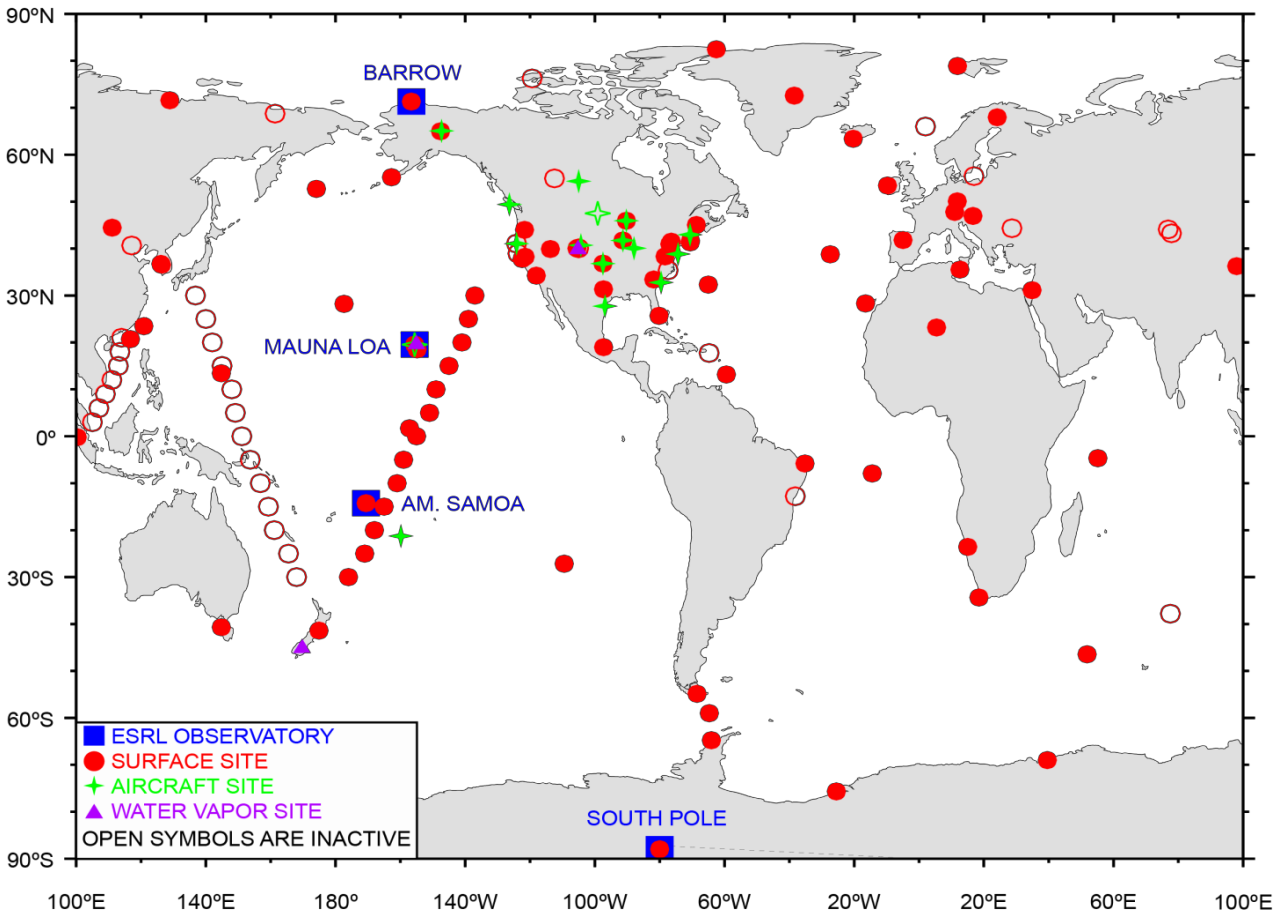
- Ozone and Water Vapor (OZWV) Networks
- Halocarbons (HATS) Network

Theme 1: Global Greenhouse Gas Reference Network (GGGRN)

"Greenhouse gas emissions are currently quantified from statistical data without testing the results against the actual increases of these gases in the atmosphere. This is like dieting without weighing oneself." *Nisbet and Weiss, Science, 238, 1241, 2010.*

GMD makes measurements of the spatial and temporal distributions of greenhouse gases and related tracers from sites in its **Global Greenhouse Gas Reference Network** that provide essential constraints to our understanding of the global carbon cycle and radiative forcing.

Tracking Greenhouse Gases and Understanding Carbon Cycle Feedbacks



Cooperative Global Greenhouse Gas Reference Network

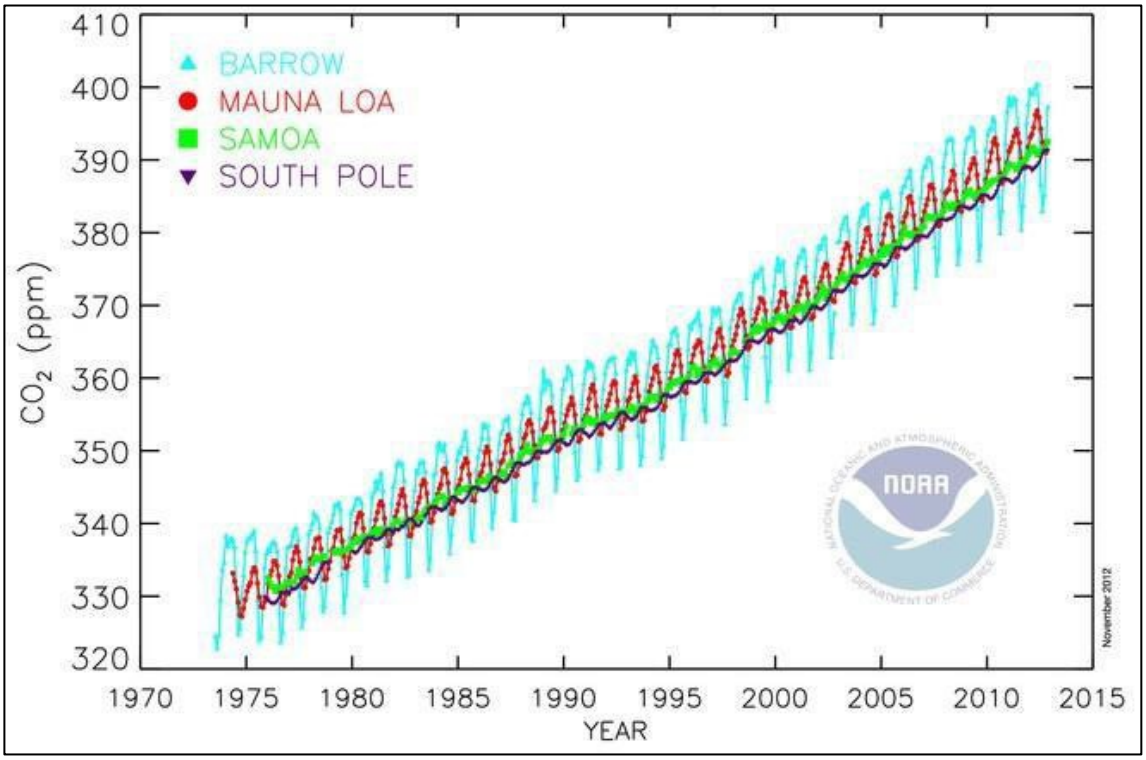
Greenhouse Gas Measurements

The Global Greenhouse Gas Reference Network measures the atmospheric distribution and trends of the main long-lived GHGs, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and sulfur hexafluoride (SF_6), as well as carbon monoxide (CO) which is an important indicator of air pollution. In addition, ~55 other gas species are monitored in air collected weekly in flasks at 60 sites around the globe.

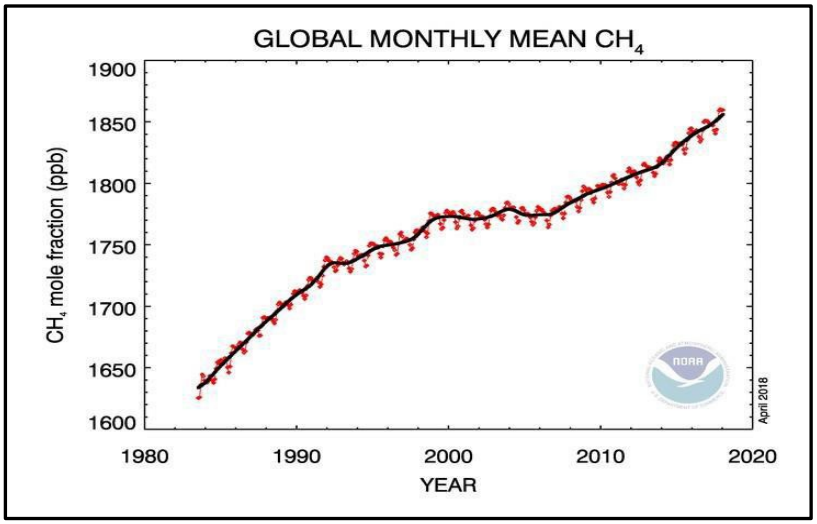
The measurement program includes around the clock measurements at four baseline observatories and 8 tall towers in North America, air samples collected by volunteers at more than 50 sites, and air samples collected regularly from small aircraft mostly above North America. The air samples are returned to the GMD labs in Boulder for analysis.

All measurements are subject to stringent quality control procedures, and are directly traceable to the UN World Meteorological Organization internationally accepted calibration scales where possible. NOAA's Global Greenhouse Gas Reference Network maintains the WMO international calibration scales for CO_2, CH_4, N_2O, SF_6 and CO in air.

WMO has a Mutual Recognition Agreement with the BIPM, which represents the National Metrology Institutes. GMD is party to this agreement.



Monthly average carbon dioxide data for the four NOAA baseline observatories. These data comes from the Global Greenhouse Gas Reference Network (GGGRN) in-situ measurements.



Monthly mean atmospheric methane abundance determined from marine surface sampling sites in the GGGRN from 1983 to 2018.

Global Carbon Dioxide and Methane Growth Rates

The observed increase in CO_2 atmospheric mole fraction is due primarily to emissions from fossil fuel burning and biomass burning and is similar at all four NOAA observatories and uptake by the oceans and the biosphere. It takes centuries to remove CO_2 from the atmosphere and the resulting climate warming persists for millennia.

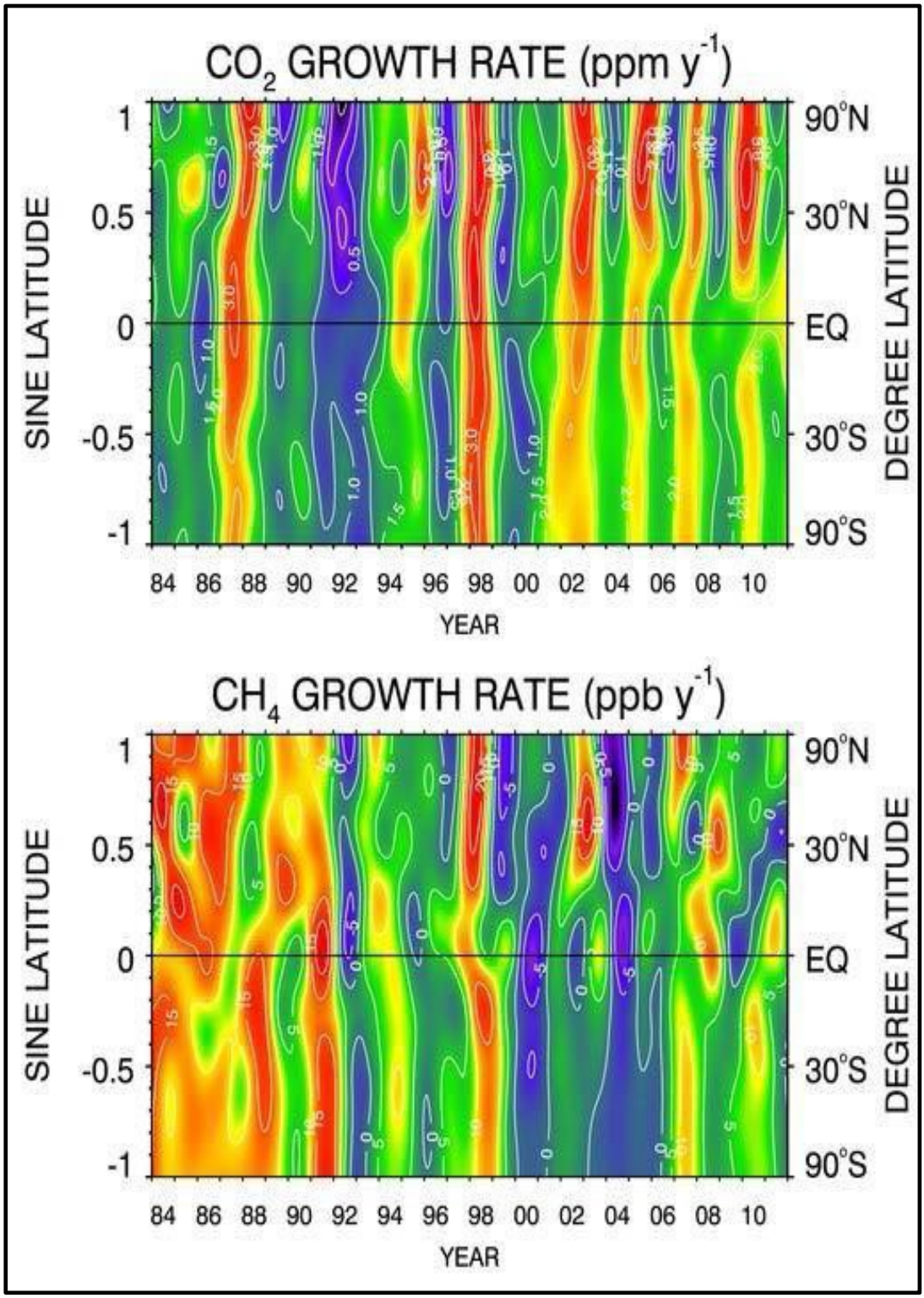
Emissions of long-lived gases from any location mix throughout the atmosphere in about one year (https://www2.cgd.ucar.edu/sites/default/files/asp-colloquium/files/Solomon-Daniel-etal-2010.pdf)

The annual oscillations at the two northern hemisphere sites (Barrow, Alaska and Mauna Loa, Hawaii) are due to the seasonal imbalance between the photosynthesis and respiration of plants on land. During the summer photosynthesis exceeds respiration and CO_2 is removed from the atmosphere, whereas outside the growing season respiration exceeds photosynthesis and CO_2 is returned to the atmosphere.

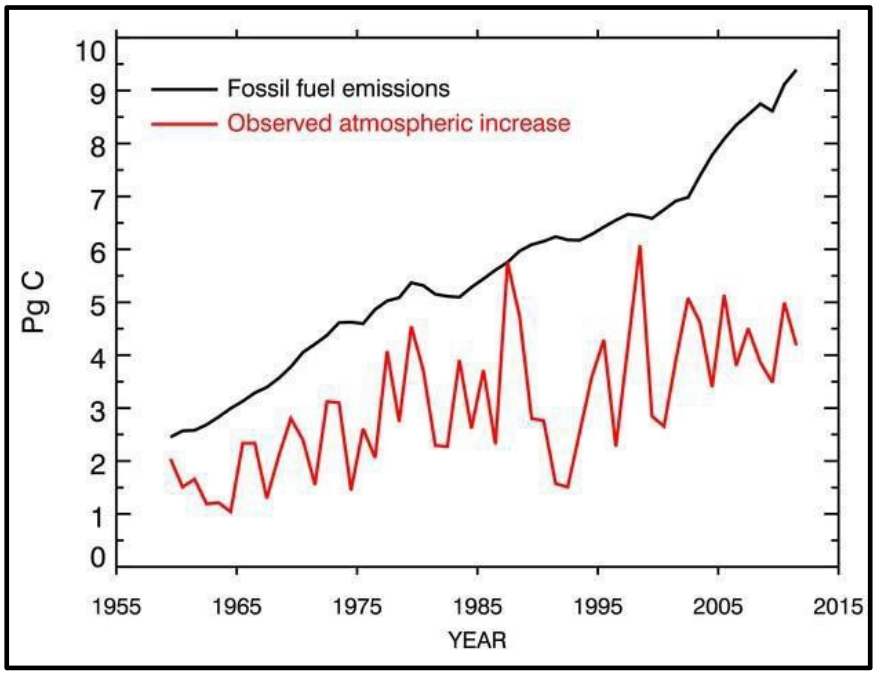
The seasonal cycle is strongest in the northern hemisphere because of the presence of the continents. The difference between Mauna Loa and the South Pole has increased over time as the global rate of fossil fuel burning, most of which takes place in the northern hemisphere, has accelerated.

A quantity of keen interest for each trace gas is the global-average rate of increase ("growth rates") for CO_2 and CH_4 as shown on the following page as a function of time and latitude.

The warmer colors (yellow, orange) indicate periods of higher-than average growth rate and the cooler colors (blue, purple) indicate periods of lower growth rate. The CO_2 growth rate varies from year to year with a higher growth rates since 2000. The CH_4 growth rate slowed during the 1990s. Global CH_4 was relatively stable in the early 2000s, but growth is back since 2007.



CO_2 and CH_4 growth rates as a function of time and latitude.



Annual atmospheric increase of CO_2 and reported annual fossil fuel emissions.

The annual variations of the CO_2 growth rate are not due to variations in fossil fuel emissions. The ups and downs in the atmospheric increase are due to variations in the exchange of CO_2 between the atmosphere, oceans, and land ecosystems. They are primarily due to small annual fluctuations of temperature and precipitation affecting photosynthesis and respiration on land.

It is very important to know that the added CO_2 does not disappear, but, as long as atmospheric CO_2 keeps rising, a portion of it transfers each year from the atmosphere to the oceans and to the biosphere on land. Since CO_2 is an acid, the transfer to the oceans causes the surface oceans to acidify.

The variations in the CH_4 growth rate are also related to climate anomalies. Analysis of the GMD and CU INSTAAR data suggests that the recent increase is related to greater-than-average precipitation in tropical regions resulting in above average emissions from tropical wetlands.

Understanding the processes that cause the CO_2 and CH_4 growth rate variations and long-term trends is crucial to enable governments and society in general to make informed decisions on energy policy and on mitigating climate change. Long-term projections of CO_2, CH_4, and N_2O depend on future emissions trajectories, which include fossil fuel and land use, and on climate feedbacks as they are incorporated into climate-ecosystem models.

An example of the latter would be Arctic warming releasing CH_4 and CO_2 emissions from melting permafrost. For emission models to be credible, it is necessary (but not sufficient) that they reproduce the recent past.

Where and How the Greenhouse Gas Data are Collected

With reference to the map presented on the introduction page, the mole fractions of greenhouse gases and other species of interest are obtained from the:

- Cooperative Global Air Sampling Network (flask-air measurements from the background atmosphere):

  - Weekly sample pair collected in 2.5 L glass flasks at 60 active air sampling sites shown by red dots on the map at the beginning of this section.

- Observatories (quasi-continuous measurements)

  -In situ CO_2 analyzers at 4 NOAA observatories.

  -In situ CH_4 and CO analyzers at BRW and MLO, N_2O at BRW also.

- Tall Tower (flask-air and quasi-continuous measurements)

  -9 active North American sampling and measurement sites.

- Aircraft (weekly or biweekly) vertical profiles of flask-air samples

  -17 active North American sampling sites.

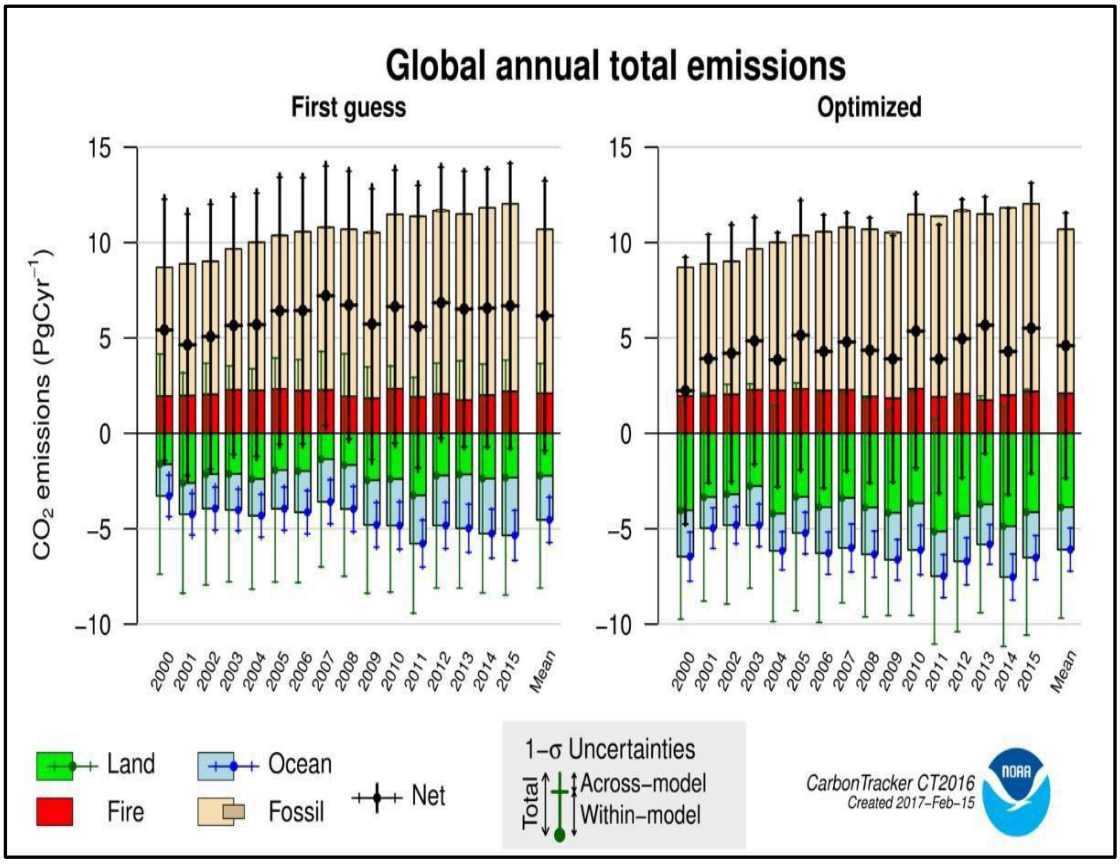
The main gases of interest measured from the networks:

Gas	**Repeatability**
CO_2	0.07 μmol mol^{-1}
CH_4	0.7 nmol mol^{-1}
CO	1.0 nmol mol^{-1}
N_2O	0.15 nmol mol^{-1}
SF_6	0.03 pmol mol^{-1}
$\delta^{13}CO_2$	0.01‰
$\delta^{13}CH_4$	0.07‰
NMHC	

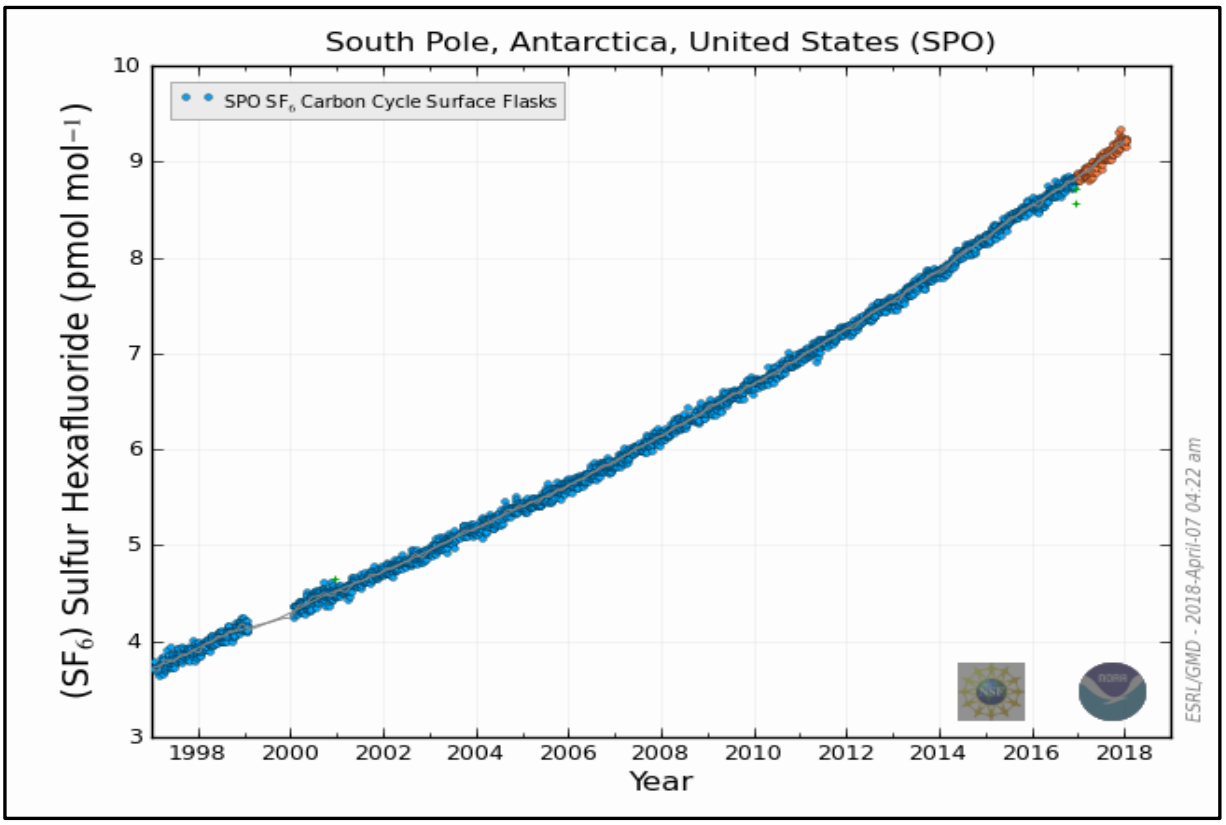
Tower and aircraft flasks are analyzed for 65 additional species, including ozone depleting substances (ODS), hydrocarbons (HCs), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur containing compounds (S-containing).

Some Important Scientific Results from the CC

From CarbonTracker (CO_2), using a data assimilation system to determine emissions and sinks of GHGs, GMD has developed a new global annual emissions data set for CO_2 as shown below.



Annual total emissions. The bars in this figure represent carbon dioxide emissions for each year in PgC yr^{-1} from the specified region. The final bar, labeled 'Mean', represents the 2001-2015 average. CarbonTracker models four types of surface-to-atmosphere exchange of CO_2, each of which is shown in a different color: fossil fuel emissions (tan), terrestrial biosphere flux (excluding fires) (green), direct emissions from fires (red), and air-sea gas exchange (blue). Negative emissions indicate that the flux removes CO_2 from the atmosphere, and such sinks have bars that extend below zero. The net surface exchange, computed as the sum of these four components, is shown as a **thick black** symbols.

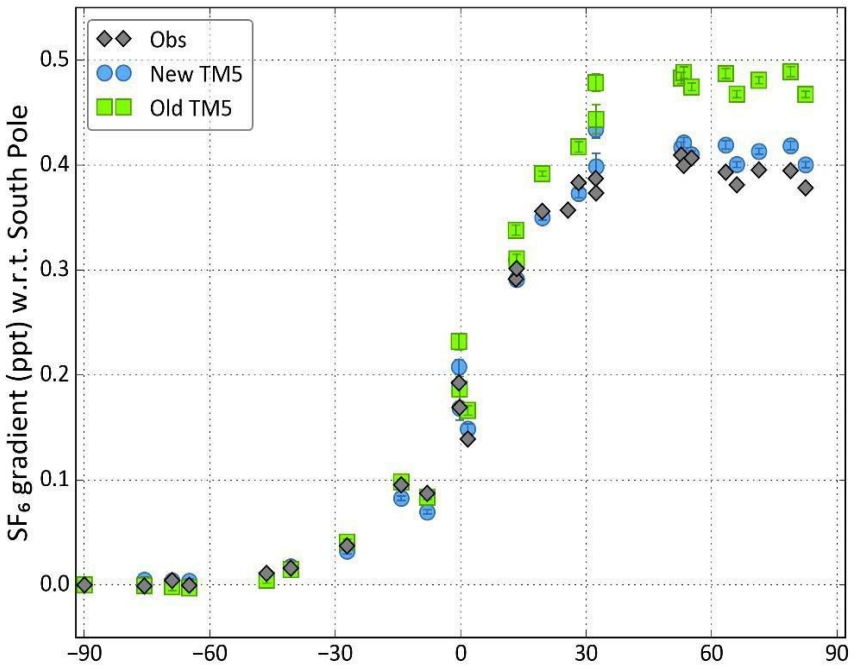


Interactive data visualization software open to the public on the GMD web site allows plotting of all gas data sets for any site and any period from the global networks. A plot of SF_6 concentrations from January 1, 1998 to December 31, 2017 shown above. <https://www.esrl.noaa.gov/gmd/dv/iadv/graph.php?code=SPO&program=hats&type=ts>

SF_6 Used to Constrain Models

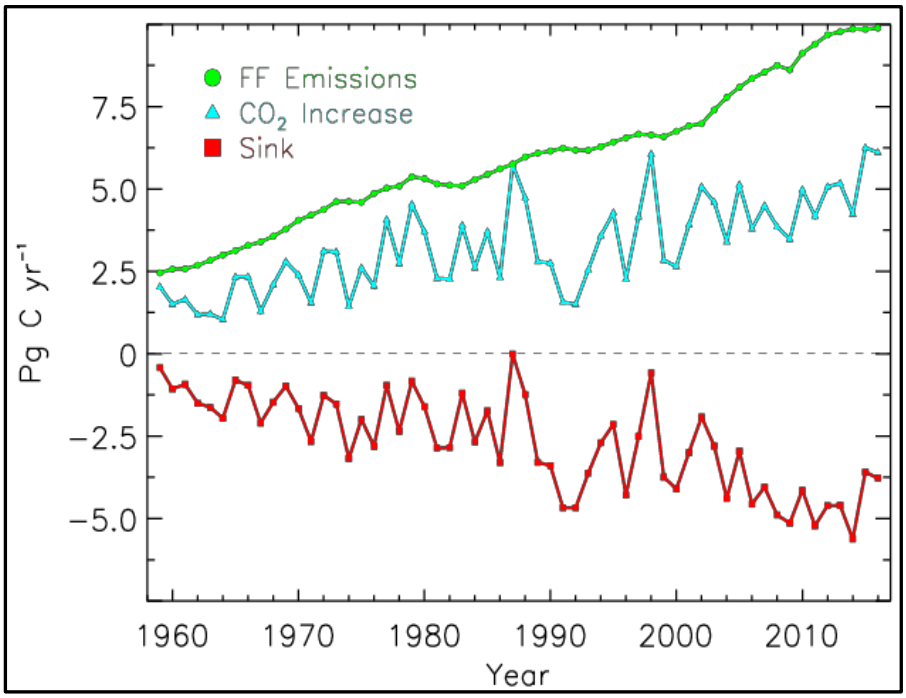
Measurements from the GGGRN are used to constrain nearly every large scale study of CO_2, CH_4, N_2O, SF_6, and CO on the globe. Measurements from tall towers and aircraft vertical profiles are used in many continental to regional scale studies. Examples include using SF_6, a long lifetime gas, as a test for atmospheric transport models.

SF_6, with relatively well-known emission rates and distribution and an atmospheric lifetime of ~700 years, can provide a good test of atmospheric transport models. When measurements of SF_6 from GGGRN air sampling sites were compared with output from an early version of “TM5”, an atmospheric transport model used for global forward and inverse modeling (for ex. CarbonTracker), transport to the free troposphere was not vigorous enough, resulting in over-estimate of the latitudinal gradient. For CH_4 and N_2O, this resulted in under-estimate of emissions at mid-northern latitudes. As the figure below shows, agreement between model and observations improved after the model’s vertical transport parameterization was modified, especially in the northern hemisphere.



Improvement in the widely used TM5 transport model by adding SF_6 atmospheric concentration data (*Basu et al., Atmos. Chem Phys., 2016).*

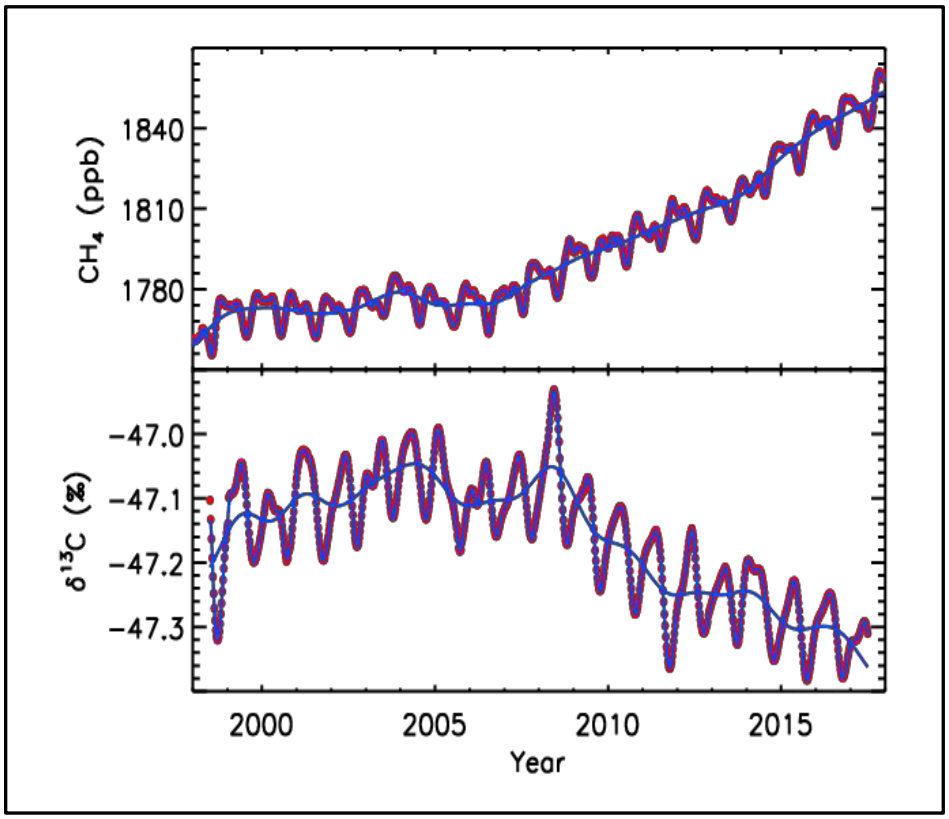
Plants and the Oceans are taking up increasing amounts of Fossil Fuel Combustion CO_2



Fossil fuel emissions, atmospheric CO_2 and the increasing CO_2 sinks *(updated from Ballantyne et al., Nature, 2012).*

When measurements of atmospheric CO_2 are combined with CO_2 emissions from fossil fuel combustion and cement production it is observed that ~45% of the emissions remain in the atmosphere (with no change in this airborne fraction over many years). The remainder is taken up by sinks in the terrestrial biosphere and ocean.

Increasing Atmospheric Methane is not from the Arctic

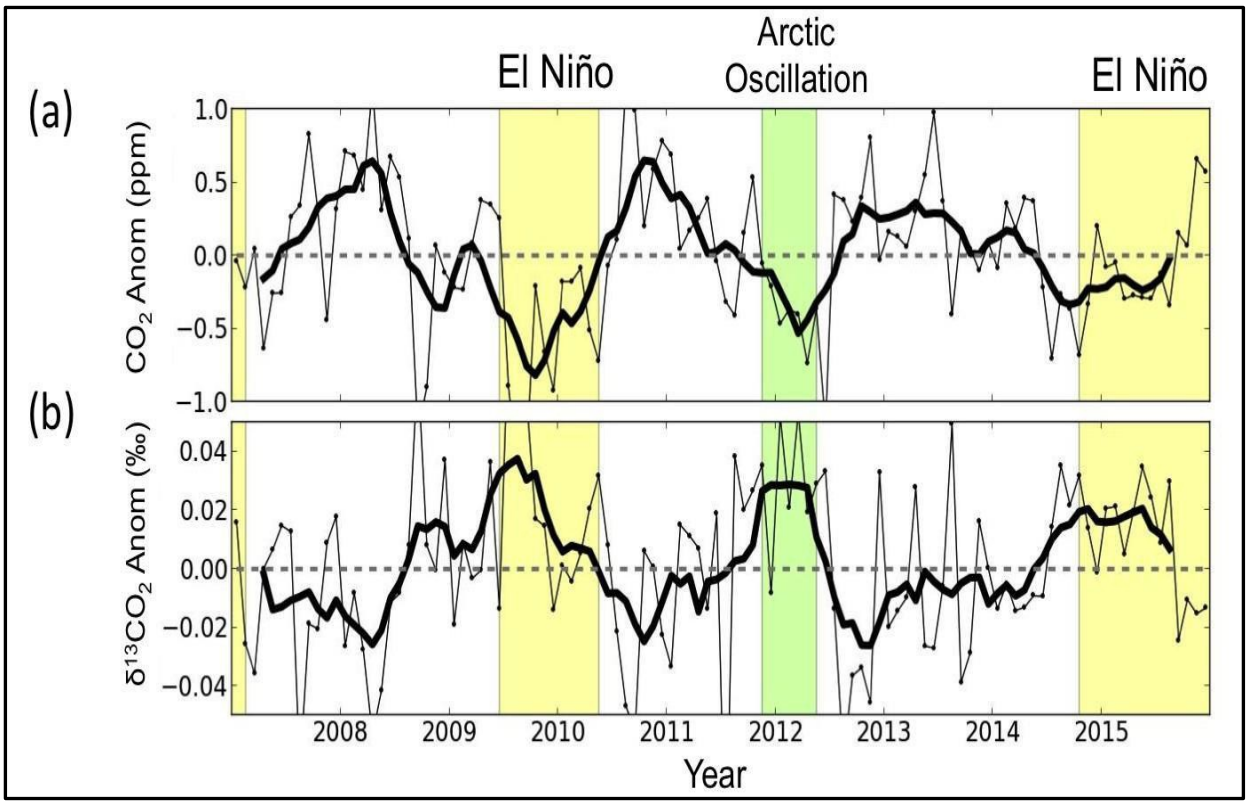


Global average CH_4, 1998-2017 showing an increase since 2007 and $\delta^{13}C$ exhibiting a corresponding decrease.

NOAA Measurements of atmospheric CH_4 combined with CU INSTAAR measurements of methane stable carbon isotopic composition ($\delta^{13}C$) offer clues to the increase in CH_4 burden that renewed in 2007. At about the same time, $\delta^{13}C$-CH_4 began decreasing after ~200 years of increase. Lighter $\delta^{13}C$-CH_4 comes from recent biological activity, not from fossil CH_4. While the exact causes of the increase remain under discussion, increasing emissions from isotopically light biogenic sources are a likely contributor probably from plant decay in tropical wetlands.

El Niño and Arctic Oscillation Effects on Atmospheric CO_2

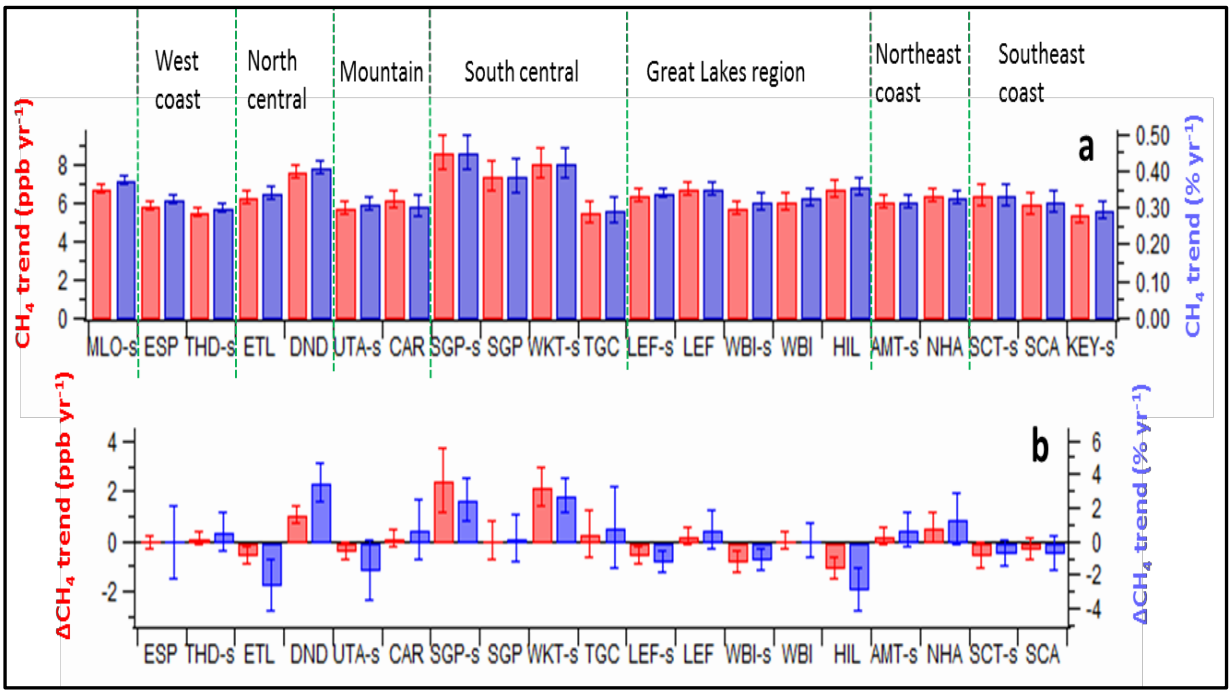
On global scales, observed CO_2 growth rate during El Niño conditions is larger than during La Niña or neutral conditions as a response to drying in the tropics and net increase in respiration and biomass burning returning carbon to the atmosphere. But for North America, as shown in the following figure of CO_2 and $\delta^{13}CO_2$ anomalies for North America (Hu et al., in preparation), CO_2 uptake by terrestrial ecosystems is enhanced during El Niño and Arctic Oscillation years. The changes in CO_2 correlate with North American hydrological parameters, suggesting increased precipitation results in larger net carbon uptake.



Net CO_2 and corresponding $\delta^{13}CO_2$ anomalies observed recently over North America through two El Niños and one Arctic Oscillation.

Increased Oil and Natural Gas Extraction in the U.S.

Rapid expansion of oil and natural gas extraction in the U.S. has been suggested as being a contributor to the increasing global atmospheric burden of CH_4 since 2007. Two studies based on NOAA GMD and University of Colorado INSTAAR measurements of GMD flask-air samples run somewhat counter to this. Schwietzke et al. (Nature, 2016) used isotope mass balance to show that, while CH_4 emissions from geologic sources are much larger than suggested by inventories, there has been no increase over the past 30 years. A group of scientist (Lan et al. in preparation) finds that trends in atmospheric CH_4 and its vertical gradient are consistent with localized increases in emissions near increased oil and gas production sites, but indicate small increases in total U.S. emissions.



Trends in CH_4 time series by NA regions (upper panel) for 2006-2015 from both aircraft and surface data. Trends in the vertical gradient, a sensitive indicator of changes in emissions (lower panel). The only locations where the trends are significantly different than background are located in regions with increasing oil and natural gas production operations, specifically OK and TX (Lan et al., GMD, in preparation).

Applications for the Global Greenhouse Gas Reference Network Data

The carefully calibrated and documented measurements of the Global Greenhouse Gas Reference Network are freely available on the NOAA GMD website (https://www.esrl.noaa.gov/gmd/). They serve as a comparison with measurements made by other international laboratories, and add a global or NA context to more focused regional studies. They are widely used in studies inferring space-time patterns of emissions and removals of greenhouse gases that are optimally consistent with the atmospheric observations. They serve as an early warning for climate feedbacks.

The calibrated observations are also indispensable for the ongoing evaluation of remote sensing technologies: Greenhouse gas abundances derived from optical absorption measurements from space can never be calibrated because one cannot control the abundance of the gases being estimated, nor can we control potential interfering factors in the optical path. Given the requirement that for remote sensing data to be useful any systematic biases need to be kept to an extremely low level, ongoing comparisons with calibrated measurements are a must.