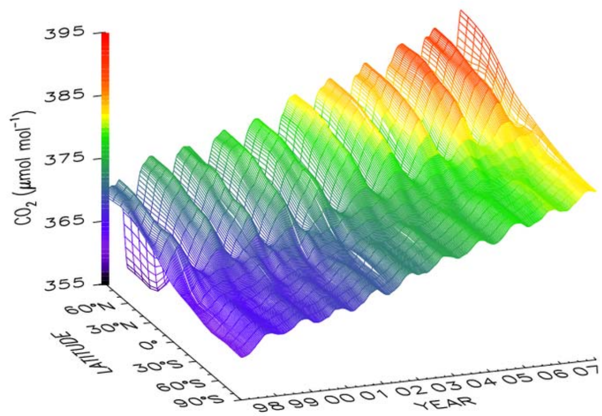
CARBON DIOXIDE, METHANE, AND CLIMATE FORCING

I. INTRODUCTION

Owing primarily to the burning of fossil fuels and secondarily to changes in land-use, the amount of CO_2 in the atmosphere has been increasing globally since the onset of the industrial revolution. Based on 50 years of direct observations of the atmosphere, it is clear that this trend continues and is accelerating. NOAA/ESRL is responsible for acquiring and maintaining the global, regional, and local record of CO_2 and other greenhouse gases. From observatories and cooperative sampling sites around the world, we measure greenhouse gases and work with partners to improve the comparability of these measurements. They are used to quantify and improve our understanding of the sources, sinks, and trends of these gases. This continuing record is critical to the diagnosis of current global climate trends and to help project the potential evolution of climate. Atmospheric data also provide the bottom line for (inter)national emissions management strategies.

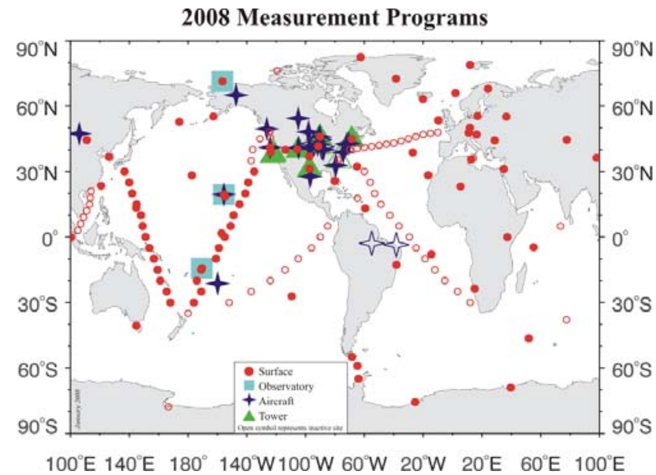


NOAA ESRL's carbon cycle research efforts are conducted under national and international authorities and embedded firmly in the NOAA mission. Carbon cycle monitoring for years has been an integral component of its Climate Forcing Program. Under a recent reorganization of NOAA's Climate Goal (one of NOAA's four mission goals), the carbon cycle measurements now reside in its program for Climate Observations and Monitoring, reflecting the value of, and need for, maintaining a long-term, global effort. Our measurements and products are an important NOAA contribution to the US Climate Change Science Program (CCSP). They also contribute to the North American Carbon Program, an interagency collaboration to quantify sources and sinks of CO_2 in North America. Internationally we are linked to GEOSS through the WMO Global Atmospheric Watch Programme, its activities (including our participation on key committees), and its linkages to the Global Climate Observation System.

II. KEY ACHIEVEMENTS (last 4 years)

Key achievements in 2004-2007 relate to sampling, analysis, cooperative quality control, maintenance of data products, introduction of new products, and contributions to major climate assessments.

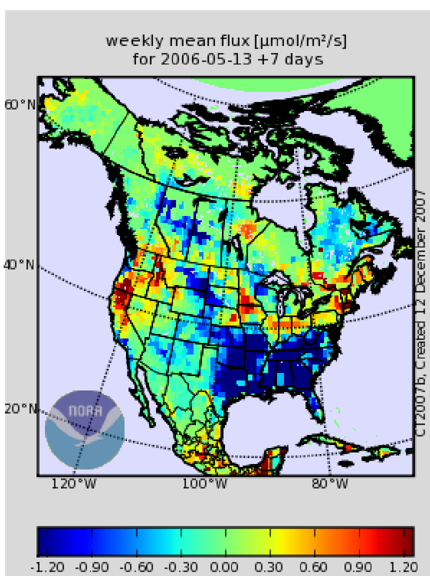
- New sampling sites were added mainly to further our understanding of regional sources and sinks of carbon dioxide, methane, and other climatically important gases. These additions include four continuously operating tall tower sites in North America, thirteen weekly aircraft sampling sites in North America (but with five temporarily discontinued for a net increase of eight sites), and eight new weekly flask sampling sites, distributed globally.



- The analytical capacity was doubled by building a second system that is always closely compared with the original system. A second major analytical improvement was the initiation of GCMS measurements of as many as 54 additional gases on aircraft flask packages to obtain information regarding source attribution and place additional constraints on flux estimates. In 2007, a new instrument to support these increased measurements was built, tested, and placed into operation.
- Ongoing flask sample comparisons, after having started with Australia (Cape Grim), were expanded to the Canadian (Alert), New Zealand (Baring Head), French (Mace Head) and German (Ochsenkopf) networks between 2004 and 2006. New efforts to compare NOAA flask samples with continuous analyzers run by our partners include NCAR (Niwot Ridge, CO), Spain (Tenerife), and Italy (Lampedusa).

Several new data products were introduced since the beginning of 2004, substantially expanding our effort to inform key sectors of society and increase the value of the data we produce.

- NOAA Annual Greenhouse Gas Index (2005, updated annually) – provides an easily understood comparison for tracking annual changes in levels of atmospheric greenhouse gases.



- CarbonTracker (2007, updated annually) – a reanalysis tool that provides validated flux estimates from our entire observing system, including measurements of vetted data from key partners. It has value to scientists, teachers, and, potentially, policy makers.
- Current Trends (2006, updated monthly) – plotted monthly averages of CO_2 at Mauna Loa, Hawaii. Monthly updates of global averages are available at the same website.
- Globalview – (updated annually) smoothed trends and distributions of CO_2 and CH_4 based upon vetted data from investigators around the world.
- Interactive Data Visualization (IADV) – a unique, publicly available, data viewing and sharing system working directly from our operational (up-to-date) database.

- Examples of contributions since 2004 to major national and international assessments and to other information products are:
  - WMO Greenhouse Gas Bulletin (begun 2005, updated annually, available on WMO website)
  - IPCC 4th Assessment Report (2007, available on IPCC website)
  - CCSP Synthesis and Assessment Products, (e.g., SAP 2.2, 2007, available on CCSP website)

III. PAYOFFS

- We are producing a record of measurements that is unchallenged and unequivocal, and which supports much of the science and policy regarding the carbon cycle.
- National and international assessments are strengthened with this unparalleled record of measurements.
- We have made a fundamental contribution to the enhancement of international GHG measurement networks.
- We have reduced uncertainty in estimates of the North American carbon sink.
- We have observed that the rate of increase of CO_2 has accelerated over the last decade, but that "sinks" have not decreased, as has been claimed by some. Although strong CH_4 emissions have been documented in Northeast Siberia, we have not observed an increase of CH_4 emissions in the high Arctic, based on our observing sites.
- Our web products contribute to increasing scientific literacy of the public.

FUTURE PLANS

Our traditional role of monitoring trends of natural components of the carbon cycle, and contributing to the understanding of their response to unfolding climate change and human management will continue. Increased emphasis will need to be given to the potential effect of thawing permafrost, expected to result from Arctic warming, on emissions of methane and carbon dioxide.

In addition, we anticipate a need for a greatly expanded GHG monitoring network that will be able to quantify emissions from fossil fuel burning and other anthropogenic sources on national to regional and metropolitan scales. Nations, states or provinces, and cities are setting goals for emissions reductions and the success or lack thereof in these efforts will require independent verification. We anticipate and encourage participation by many organizations, including those with closer links to policy making entities.

The demanding and continuing accuracy (comparability) requirements of GHG measurements make this an enormous challenge. We have several decades of experience in assuring measurement comparability among international laboratories. It takes careful use of reference gas standards as well as a significant amount of duplication of actual measurements by independent methods, a very well developed data management system, automated frequent exchange of data, automated algorithms to carry out comparisons, and above all, determination of all participants to get it right. We have used our multi-laboratory data product, Globalview, to foster the above by demonstrating the value of ongoing comparisons. We intend to use CarbonTracker in a similar way – before data can be incorporated, certain quality requirements have to be fulfilled. A crucial feature of a GHG observing system (which includes CarbonTracker) is complete and prompt disclosure of all data (including rejected data) and methods if we are to foster understanding and accuracy.

From a more technical angle, the measurement of multiple species provides diagnostic power for interpreting GHG variance. Carbon-14 in CO_2 deserves special mention as a unique tracer for recent fossil fuel additions to an air mass. The desirability of measuring multiple species suggests a mutually beneficial relationship with the air quality community. We plan to expand CarbonTracker by including more atmospheric data from partner organizations, including new types of data such as total-column CO_2 measured from solar absorption spectra, satellite CO_2 data, as well as other species. Increasing the resolution of CarbonTracker is crucial for the ability to provide policy-relevant feedback on small spatial scales. We are pursuing the possibility of using commercial airlines to add frequent vertical profiles at low cost, as is currently being done by Japanese and European colleagues.

Selected, Relevant Publications

Peters, W., et al. (2007), An atmospheric perspective on North American carbon dioxide exchange: CarbonTracker, **Proc. Nat. Acad. Sciences 104**, 18925-18930, doi: 10.1073/pnas.0708986104.

Stephens, B., et al. (2007), Weak northern and strong tropical land carbon uptake from vertical profiles of atmospheric CO_2, **Science 316**, 1732-1735

Bender, M., et al. (2005), Atmospheric O_2/N_2 changes, 1993-2002: Implications for the partitioning of fossil fuel CO_2 sequestration, **Global Biogeochem. Cycles, 19**, GB4017, doi:10.1029/2004GB002410

Michalak, A., et al. (2004), A geostatistical approach to surface flux estimation of atmospheric trace gases, **J. Geophys. Res. 109**, D14109, doi: 10.1029/2003JD004422

Turnbull, J. et al. (2006), Comparison of $^{14}CO_2$, CO, and SF_6 as tracers for recently added fossil fuel CO_2 in the atmosphere and implications for biological CO_2 exchange, **Geophys. Research Lett. 33**, L01817, doi: 10.1029/2005GL024213

Montzka, S., et al. (2007), On the global distribution, seasonality, and budget of atmospheric carbonyl sulfide (COS) and some similarities to CO_2, **J. Geophys. Res 112,** D09302 doi: 10.1029/2006JD007665

Miller, J., et al. (2007), Airborne measurements indicate large methane enissions from the eastern Amazon basin, **Geophys. Res. Lett. 34**, L10809, doi: 10.1029/2006GL029213

Yang, Z., et al. (2007), New constraints on Northern Hemisphere growing season net flux, **Geophys. Res. Lett. 34**, L12807, doi: 10.1029/2007GL029742

LeQuéré, C., et al. (2007), Saturation of the Southern Ocean CO_2 sink due to recent climate change, Science 316, 1735. doi: 10.1126/science.1136188

Canadell, J. et al. (2007), Contributions to accelerating atmospheric CO_2 growth from economic activity, carbon intensity and efficiency of natural sinks, Proc. Nat. Acad. Sciences 104, 18866-18870. doi: 10.1073/pnas.0702737104.