2. Carbon Cycle

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2.1. OVERVIEW

It is the goal of the CMDL Carbon Cycle Greenhouse Gases (CCGG) group to improve the understanding of the factors that determine the atmospheric burdens of major trace gases influencing the earth's climate, in particular CO_2, CH_4, and CO. The anthropogenic impact on each of these species is large, but natural cycles are involved as well. The international climate change negotiations during December 1997 in Kyoto, Japan, highlighted the fact that the world has tentatively started to take steps to try to control the steadily increasing climate forcing by anthropogenic greenhouse gases. One of the factors required for effective policies is a quantitative understanding of what controls the atmospheric concentrations.

Our main tool for studying the global budgets of the trace gases is the measurement of atmospheric spatial concentration patterns and their changes over time. Two experimental methods have been employed from the start of the Geophysical Monitoring for Climatic Change program, the forerunner of CMDL: continuous measurements in remote clean air locations, namely the four CMDL observatories, and weekly pairs of discrete flask samples, also at remote clean air locations. Initially the samples were analyzed only for CO_2, but gradually more species have been added (Table 2.1). The isotopic ratio measurements are being carried out at the Institute for Arctic and Alpine Research (INSTAAR) of the University of Colorado in close cooperation with the CCGG group. Anomalous ^{17}O enrichments are measured in a small subset of the flasks by a group at the University of California, San Diego. The global air samples provide a unique resource for narrowing uncertainties of greenhouse gas budgets as well as other atmospheric problems. The feasibility of adding additional measurements continues to be investigated.

Information on sources and sinks of the trace gases is obtained from their rates of change and from their spatial distributions. Numerical models of atmospheric transport, operating in both two and three dimensions, provide the quantitative link. Since this is working "backwards" from observed concentrations to the sources causing them, this problem is in the class of so-called inverse problems. The greatest limitation is sparseness of data, especially in regions close to important sources and sinks. Therefore, the spatial coverage of the global cooperative air sampling network has gradually expanded. Isotopic analyses were added because different sources/sinks may be characterized by different isotopic "signatures."

TABLE 2.1. Species Analyzed in Samples of the Global Air Sampling Network

Species	Start Date	Method	Precision (One Sigma)	Collaborators
CO_2	1976	NDIR	0.05 ppm (0.02%)	
CH_4	1983	GC/FID	<1 ppb (0.07%)	
CO	1988	GC/HgO	0.5 ppb (0.5-1%)	
H_2	1988	GC/HgO	2 ppb (0.4%)	
$CO_2{}^{13}C$	1990	IRMS	0.01‰	CU/INSTAAR
$CO_2{}^{18}O$	1990	IRMS	0.03‰	CU/INSTAAR
N_2O	1996	GC/ECD	0.2 ppb (0.07%)	HATS Group
SF_6	1996	GC/ECD	0.03 ppb (1%)	HATS Group
$CO_2{}^{17}O$	1997	IRMS	0.03‰	UC San Diego
$CH_4{}^{13}C$	1998	GC/IRMS	0.06‰	CU/INSTAAR

CU, University of Colorado

INSTAAR, Institute for Arctic and Alpine Research, University of Colorado, Boulder

UC, University of California

To overcome the limitation of having only measurements from the remote marine boundary layer, two new approaches were initiated. One is to continuously measure a number of chemical species and atmospheric physical parameters at different heights on very tall towers. Mixing ratios (also called mole fractions) in the continental boundary layer are highly variable, making them more difficult to interpret and require much more auxiliary data than the traditional marine air samples. The second new approach is to obtain discrete air samples from low-cost airplanes in automated fashion from the boundary layer up to about 8-km altitude. These samples are then sent back to the laboratory in Boulder for analysis. In order to provide significant regional-scale constraints on the budgets of the gases measured, it is hoped that this method will be greatly expanded, especially over North America.

Since the global coverage of the sampling network is unmatched, CMDL plays an active role in bringing together the measurements from many different laboratories around the world. Toward this end, measurements of standard reference gases, as well as actual field samples, are being intercompared. The CMDL link with the Commonwealth Scientific and Industrial Research Organization (CSIRO, Australia) is particularly strong in this regard. For CO_2 and CO, CMDL provides calibrated reference gas mixtures under the auspices of the World Meteorological Organization (WMO).

A common global database for CO_2, named Globalview-CO_2, is continually assembled, updated, and is currently based on the measurements from laboratories in 14 countries, hopefully without significant calibration or methodological discrepancies. Its intended use is for three-dimensional (inverse) modeling. The first data base release was in 1996 and has been updated once a year since then (http://www.cmdl.noaa.gov/ccgg/globalview/co2/default.html). Plans are to maintain and enlarge this database, as well as assemble similar ones for isotopic ratios, CH_4, CO, etc.

Full individual data records and monthly means can be obtained for each species for each sampling site from the CMDL World Wide Web page (http://www.cmdl.noaa.gov), the ftp file server's "pub" directory (ftp.cmdl.noaa.gov), from the WMO World Data Center for Greenhouse Gases in Tokyo and from the Carbon Dioxide Information Analysis Center in Oak Ridge, Tennessee.

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