

**COMMITTEE ON SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES**

HEARING CHARTER

*Monitoring, Measurement and Verification of Greenhouse Gas Emissions II: The
Role of Federal and Academic Research and Monitoring Programs*

Tuesday, April 22, 2009
10:00 a.m. to 12:00 p.m.
2318 Rayburn House Office Building

Purpose

On April 22, 2009, the House Committee on Science and Technology will hold a hearing entitled ***“Monitoring, Measurement and Verification of Greenhouse Gas Emissions II: The Role of Federal and Academic Research and Monitoring Programs.”*** The purpose of the hearing is to examine existing and planned federal programs focused on monitoring, measuring, and verifying sources and sinks of greenhouse gases, their atmospheric chemistry and their impacts on Earth’s climate. The Committee will examine both top-down and bottom-up methods for tracking greenhouse gases including: ground-based, tropospheric, and space-based monitoring systems as well as facility-based monitoring systems and inventory and reporting methods.

The Committee seeks to understand how the existing and planned federal measurement and monitoring systems can be utilized to gain greater understanding of sources and sinks of greenhouse gases and to support research on greenhouse gases, evaluation of national and international greenhouse gas mitigation policies, and development of projections of regional climate impacts to inform development and implementation of mitigation and adaptation strategies. The Committee also seeks to identify the key requirements that need to be addressed in developing a scientifically and operationally robust system for verifying compliance with potential climate agreements.

Witnesses

- **Dr. Alexander “Sandy” MacDonald**, *Director, Earth Systems Research Laboratory, National Oceanic and Atmospheric Administration (NOAA)*
- **Dr. Beverly Law**, *Professor, Global Change Forest Science, Oregon State University, and Science Chair, AmeriFlux Network*
- **Dr. Richard Birdsey**, *Project Leader, Climate, Fire, and Carbon Cycle Science, USDA Forest Service, and Chair, Carbon Cycle Scientific Steering Group*
- **Dr. Michael Freilich**, *Director, Earth Science Division, National Aeronautics and Space Administration (NASA)*
- **Ms. Dina Kruger**, *Director, Climate Change Division, Office of Atmospheric Programs, Environmental Protection Agency (EPA)*

- **Dr. Patrick D. Gallagher**, *Deputy Director, National Institute of Standards and Technology (NIST)*
- **Dr. Albert J. Heber**, *Professor of Agricultural and Biological Engineering, Director, Purdue Agricultural Air Quality Laboratory, Purdue University, and Science Advisor, National Air Emission Monitoring Study*

Background

The federal government has a number of programs that gather observations on greenhouse gases, climate, ecosystem function, land use change, and primary production on land and in the oceans using ground-based, aircraft-based, and space-based measurement techniques. These monitoring and measurement programs are integral parts of research and observation programs designed to gain greater understanding of the Earth's carbon cycle, global nutrient budgets, atmospheric chemistry, the fate and transport of air pollutants, and ecosystem health and function.

There are also several monitoring, measurement and reporting activities that are tied to voluntary reporting, regulatory programs, or international treaty obligations. The voluntary emissions reporting program at the Department of Energy (DOE) tracks the emissions of entities that volunteer to provide information about the greenhouse gas emissions associated with their activities. Under the Clean Air Act, the Environmental Protection Agency manages cap-and-trade programs to control the emissions of air pollutants from the power generating sector. The U.S. has ratified two international treaties – the U.N. Framework Convention on Climate Change and the Montreal Protocol. Both of these treaties require monitoring and reporting of greenhouse and ozone depleting gases, respectively to ensure compliance and effectiveness of these treaties.

Research efforts are also underway to quantify greenhouse gas emissions from previously unmonitored sources. For example, the National Air Emission Monitoring Study (NAEMS) is continuously monitoring levels of hydrogen sulfide, particulate matter, ammonia, nitrous oxide, volatile organic compounds and greenhouse gases released from lagoons and animal barns at 20 animal feeding operations in the United States. Led by researchers at Purdue University, the 2.5 year study was established in 2006 by a voluntary Air Compliance Agreement between EPA and the pork, dairy, egg, and broiler industries. The study is currently in its second year of monitoring, and once complete will be used to develop protocols for measuring and quantifying air pollutants emitted by animal feeding operations

Several proposals are under consideration to develop mandatory programs to report and to control the emissions of greenhouse gases associated with the burning of fossil fuels here in the U.S. At the same time, 192 countries are preparing to meet in Copenhagen, Denmark in December of this year to negotiate an agreement on an international framework to control emissions of greenhouse gases.

The monitoring system now in place serves important ongoing functions in the support of research on the Earth's climate and carbon cycling systems. The current observation system also provides us with information about the likely direction and magnitude of changes in climate and

other phenomena, such as ocean acidification, that we are likely to experience as concentrations of greenhouse gases in the atmosphere continue to increase.

A different configuration and level of investment may be required if we are to adapt the current monitoring and observation systems to address specific questions about the efficacy and level of compliance we are achieving as a result of a control program for greenhouse gases. This hearing will explore the following three issues:

- Is our current monitoring system being maintained to support research and general information needs to track the Earth's climate and anticipate future impacts?
- What changes need to be made to the current monitoring systems to support the need for verification and compliance with a greenhouse gas control program domestically?
- What is the status of the international effort to monitor greenhouse gases and will the international monitoring effort be able to support compliance with an international greenhouse gas control program?

The specific type of monitoring system needed is dependent upon the nature of the reporting or control program that is ultimately selected. The current observing and monitoring networks include both "top-down" and "bottom-up" measurements in addition to utilizing modeling, accounting, and other estimation methods.

Top-down measures include satellite-based monitoring or ground-based monitoring focused on measurement of aggregate emissions over large areas or global averages such as the concentration of carbon dioxide in the atmosphere. Bottom-up measures include monitoring or reporting of emissions from specific facilities or geographic locations. Both general categories of measurements and observations will be needed. However, the extent and mix of top-down and bottom-up approaches will be different depending upon the design of the control program.

In both cases, key parameters that need to be determined are the baselines from which changes in emissions will be measured. In some instances, these baselines will be relatively easy to determine. For example, the measurement of carbon dioxide (CO₂) emissions associated with fossil fuel based electric generation has been directly measured using continuous emission monitors for some years. The determination of baseline emissions for a forest or an agricultural area is much more challenging.

While CO₂ is the most prevalent greenhouse gas of concern, there are five other greenhouse gases that are included in reporting programs and are likely to be included in a greenhouse gas control program. These are methane (CH₄), nitrous oxide (N₂O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF₆). These gases, the dynamics of their sources and sinks, and the monitoring and measurement of them is less well-developed than the systems for CO₂.

The witnesses will discuss the specific types of monitoring programs, how these are being used, and how they may need to be altered to provide information to verify compliance and effectiveness of a greenhouse gas control program.

In addition to his role at the U.S. Forest Service, Dr. Richard Birdsey serves as chair of the Carbon Cycle Scientific Steering Group which provides scientific advice to the North American Carbon Program and the Carbon Cycle Science Program. Interagency coordination of the research, observation, and monitoring efforts is done through the U.S. Global Change Research Program and is essential to this effort.

The information in the Appendix that follows provides a brief overview of key programs supported by the federal government. They include programs of the National Oceanic and Atmospheric Administration (NOAA), the Environmental Protection Agency (EPA), the National Institute of Technology and Standards (NIST), the US Department of Agriculture Forest Service, and the National Aeronautics and Space Administration (NASA). In addition, two monitoring efforts managed by the academic community are also included. These programs are supported with federal funds provided by multiple agencies.

APPENDIX

INTERAGENCY RESEARCH AND MONITORING COORDINATION

Climate Change Science Program (CCSP)

The major goal of the CCSP initiatives is to study and understand key aspects of the climate system, including the global carbon cycle. According to *Our Changing Planet: The U.S. Climate Change Science Program for Fiscal Year 2009*, the strategic research questions for the global carbon cycle are:

- *What are the magnitudes and distributions of North American carbon sources and sinks on seasonal to centennial time scales, and what are the processes controlling their dynamics?*
- *What are the magnitudes and distributions of ocean carbon sources and sinks on seasonal to centennial time scales, and what are the processes controlling their dynamics?*
- *What are the effects on carbon sources and sinks of past, present, and future land-use change and resource management practices at local, regional, and global scales?*
- *How do global terrestrial, oceanic, and atmospheric carbon sources and sinks change on seasonal to centennial time scales, and how can this knowledge be integrated to quantify and explain annual global carbon budgets?*
- *What will be the future atmospheric concentrations of carbon dioxide, methane, and other carbon-containing greenhouse gases, and how will terrestrial and marine carbon sources and sinks change in the future?*
- *How will the Earth system, and its different components, respond to various options for managing carbon in the environment, and what scientific information is needed for evaluating these options?*

To address these questions, Federal agencies, including the Department of Energy, NASA, the National Institute of Standards and Technology, the National Oceanic and Atmospheric Administration, the National Science Foundation, the US Department of Agriculture's Agricultural Research Service, Cooperative State Research, Education, and Extension Service, Forest Service, and Natural Resources Conservation Service, and the US Geological Survey contribute to and coordinate carbon cycle research.

The major elements of the U.S. Carbon Cycle Science Program are:

- The North American Carbon Program (NACP). The NACP addresses some of the strategic questions on the global carbon cycle noted above. The goal is to better characterize and understand the factors that influence changes in the concentrations of carbon dioxide and methane in the atmosphere and the amount of carbon, including the fraction of fossil fuel carbon, being taken up by North America's ecosystems and adjacent coastal oceans.
- The Ocean Carbon and Climate Change (OCCC) Program. The OCCO addresses specific aspects of the global carbon cycle associated with ocean processes. The OCCC and the NACP are complementary programs with a focus on understanding the exchanges of carbon between terrestrial and coastal ocean systems.

There are several interagency working groups with the larger interagency effort that are focused on the carbon cycle and on the coordination of climate observations. These include the Carbon Cycle Interagency Working Group and the Observations Working Group of the U.S. Climate Change Science Program.

U.S. observation and research efforts are linked to the broader international scientific community through our participation in international organizations associated with the World Meteorological Organization (WMO) including the Global Climate Observing System (GCOS) and the Intergovernmental Panel on Climate Change (IPCC).

MONITORING NETWORKS AND PROGRAMS

The AmeriFlux Network

The AmeriFlux network is a ground-based, terrestrial carbon observing system that measures the exchange of carbon dioxide, water vapor and energy between the atmosphere and terrestrial ecosystems. The 90 sites are located in different ecosystems throughout North, Central, and South America and consist of towers equipped with instruments at various heights above ground level. These sites adhere to common protocols across the network to produce continuous, long-term measurements of temperature, wind, water, energy, and carbon dioxide. Using these measurements, researchers estimate terrestrial carbon sources and sinks, the responses of these sources and sinks to climate and land use change, and test models of the carbon cycle and the climate system. Data from ground-based sensors is also needed to calibrate remote sensing and space-based monitoring systems.

The AmeriFlux Network is supported by a number of federal agencies. The Department of Energy's Office of Biological and Environmental Research supports approximately 20 of the sites, measurement and data quality assurance, and data archiving activities for the network. The network's science office is funded by the National Science Foundation and the remaining sites are funded individually by other agencies such as the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration, the United States Geological Service, the Forest Service, the Agricultural Research Service, and the National Science Foundation.

The AmeriFlux Network's carbon dioxide flux observations and carbon cycle modeling are important contributions to other national and international observation networks. The Network's information is linked to other federal agencies' observing systems (i.e. NASA, NOAA, NSF, USDA Forest Service) through the North American Carbon Program's (NACP) research plan. The NACP plan for research on the carbon cycle is focused on measuring and understanding the permanence of North American carbon sinks, and the AmeriFlux network is an integral component of this effort.

The AmeriFlux network is linked to international carbon flux measurement networks (i.e. CarboEuroFlux, Fluxnet-Canada, AsiaFlux and OzFlux) through the National Science Foundation's global carbon flux network known as FLUXNET. FLUXNET provides infrastructure for managing, archiving and distributing data collected at FLUXNET sites to the science community. FLUXNET also supports efforts to calibrate observations collected at different sites and to ensure data from these sites are intercomparable. FLUXNET also provides forums for exchange of research findings and facilitates communication among scientists working in related fields. The goal is to build an integrated global network of information from the regional networks in place on each continent to better understand the carbon, energy and water balance of ecosystems and how they fluctuate seasonally and in response to changes in climate.

Monitoring Networks Managed by the National Oceanic and Atmospheric Administration (NOAA)

NOAA's climate observations are extensive and support a number of atmospheric measurement platforms. The majority of atmospheric measurements are conducted by NOAA's Earth System Research Laboratory (ESRL), located in Boulder, Colorado. ESRL's Global Monitoring Division (GMD) conducts long-term continuous measurements on atmospheric gases, aerosols, and solar radiation to inform research on source and sink strengths, global climate forcing, stratospheric ozone depletion, and baseline air quality. The Division has a number of measurement capabilities. However, the global baseline observations and the carbon cycle observations are most likely to have a role in verifying the effectiveness of emission reduction strategies. The programs which support these observations will be examined briefly below.

Global Atmospheric Baseline Observatories

ESRL/GMD supports the Global Atmospheric Baseline Observatories in five locations around the world: Barrow, Alaska; Mauna Loa, Hawaii; Cape Matatula, American Samoa; the South Pole, Antarctica, and Trinidad Head, California. Up to 250 different atmospheric parameters relevant to the study of climate change and ozone depletion are measured at each of these locations. Measurements are made to determine baseline greenhouse gas levels and are critical to the collection and continuity of the world's atmospheric measurements. The first continuous carbon dioxide measurements, for example, were taken in 1958 by Dr. Charles David Keeling at the Mauna Loa Observatory in Hawaii. The Mauna Loa observations are now the longest record of continuous monthly mean carbon dioxide measurements in the world and were the basis for the now-famous Keeling Curve. The Keeling Curve showed the first significant evidence of increasing carbon dioxide levels in the atmosphere and was instrumental in showing that human activity is changing the composition of the atmosphere through the combustion of fossil fuels.

Carbon Tracker and Related Observations

ESRL/GMD also conducts a number of greenhouse gas measurements through its observation networks. The Division's Carbon Cycle Greenhouse Gases Group conducts measurements that document the spatial and temporal distributions of carbon-cycle gases and provide essential constraints to our understanding of the global carbon cycle. The Group conducts in-situ and flask sampling of CO₂ and other atmospheric trace gases using platforms such as: tall towers and existing television, radio and cell phone towers; ships; cooperative fixed sampling sites; and aircraft.

These observations are linked with other agencies' and international observation networks to support the ESRL's research and visualization projects. One of ESRL/GMD's programs that could have a role in verifying the effectiveness of emission reduction strategies is its CarbonTracker program. Launched in 2007, the Carbon Tracker a visualization tool for biological carbon flux on a regional and global basis. Carbon tracker uses the aforementioned measurement networks, other NOAA and DOE sampling sites, and sampling sites operated by Australia and Canada. The measurements are fed into a model with 135 ecosystems and 11 ocean basins worldwide. The model then calculates carbon release or uptake by oceans, wildfires, fossil fuel combustion, and the biosphere and transforms the data into a color-coded map of sources and sinks.

ESRL is also planning to support a future project known as CALNEX. CALNEX 2010 is a joint NOAA, California Air Resources Board, and California Energy Commission field study of atmospheric processes over California and the eastern Pacific coastal region set to begin in 2010. Direct emissions of a wide range of species will be studied, including aerosol, gas-phase ozone, aerosol precursors (e.g., VOCs, NO_x, SO₂, CO, etc.) and greenhouse gases (CO₂, CH₄, etc.). The top-down approach that that will be used is expected to provide an independent assessment of existing inventories.

Carbon Inventory, Management, Monitoring and Reporting by the USDA Forest Service

The Forest Inventory and Analysis (FIA) Program is one of the longest running and oldest research programs of the US Forest Service. The U.S. program was modeled on inventory programs established in Scandinavian countries in the 1920s. The first comprehensive inventory of forests in the U.S. began in the early 1930s but was not completed until the 1960s. The need for more current information led to direction in the 1998 Farm Bill to the Forest Service to adopt a continuous annual inventory system. The information in the inventory is used to estimate the greenhouse gas emissions associated with U.S. forest lands. These estimates are incorporated into the National Inventory of Emissions for the U.S. reported to the U.N. Framework Convention on Climate Change.

In addition, the Forest Service has an active research program on carbon cycling in forests that includes more specific direct measurements of the flux of greenhouse gases from forest vegetation and soils and change in these in response to changes in ecosystem conditions or management practices.

Compilation of the National Emissions Inventory and Monitoring by the Environmental Protection Agency (EPA)

EPA is the lead agency charged with compiling the U.S. National Greenhouse Gas Emissions Inventory. Data from DOE, USDA, and other federal agencies are compiled to provide an annual accounting of U.S. greenhouse gas emissions. This Inventory is submitted to the U.N. Framework Convention on Climate Change in accordance with our obligations under this treaty.

EPA receives data on carbon dioxide emissions from electric power generation facilities from continuous emission monitors at these facilities. These data are collected as part of the cap-and-trade systems for controlling emissions of sulfur dioxide and nitrogen oxides in accordance with the Clean Air Act. The carbon emissions are monitored as a means of verifying individual facility emissions and ensuring compliance with the cap-and-trade program.

National Institute of Technology and Standards (NIST)

NIST's role is to develop standard reference materials and assist with calibration and characterization of the instruments used to observe and monitor greenhouse gases. Because these measurements are made over long period of time and from many sources and by many different groups and individuals, NIST's role of ensuring comparability and accuracy of these measurements is very important. NIST works with federal agencies to ensure the quality of the data gathered through our monitoring and observation networks. In addition, NIST serves as the official U.S. representative in international efforts to ensure quality and comparability of data contributed by different nations to global data repositories.

Observations and Monitoring Programs of the National Aeronautics and Space Administration (NASA)

The Advanced Global Atmospheric Gases Experiment (AGAGE)

The Advanced Global Atmospheric Gases Experiment (AGAGE) network is sponsored by NASA's Atmospheric Composition Focus Area in Earth Science. AGAGE and previous experiments that measure the composition of the global atmosphere have been in place since 1978. The ground-based network supports high frequency measurements of gases specific to the Montreal Protocol—chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons—and non-CO₂ gases specific to the Kyoto Protocol (hydrochlorofluorocarbons, methane, and nitrous oxide). AGAGE includes stations in non-U.S. countries and is part of a collaboration with the System for Observation of Halogenated Greenhouse Gases in Europe (SOGEE).

NASA Space-Based Greenhouse Gas Sensors

NASA satellite and airborne data has in the past had an influence on environmental policy, specifically in the case of the Montreal Protocol. NASA Earth observing data helped develop the scientific basis that led to the Montreal Protocol and contributes to the subsequent ozone monitoring program to support the Protocol.

Data from existing NASA sensors on orbit are already being used to study GHGs. Planned satellites are expected to have a greater contribution. Satellites are expected to be a critical component in obtaining the measurements needed to support potential climate policies.

- Tropospheric Emission Spectrometer (TES) on NASA's Aura spacecraft. TES is a high-resolution infrared spectrometer that makes direct measurements of the ozone globally and of other gases, including carbon monoxide and methane. TES takes a global survey on a 16-day repeat cycle. TES' measurements of ozone at different altitudes are used to create an ozone profile.
- Atmospheric Infrared Sounder (AIRS) on NASA's Earth observing Aqua satellite. AIRS measures temperatures, humidities and other properties to help researchers understand the climate system and to improve weather forecasting. Included in its measurements are global data on CO₂ in the mid-troposphere (about 5 miles above Earth). Researchers also use AIRS data to measure ozone, carbon monoxide, carbon dioxide, methane, sulfur dioxide, and dust particles. AIRS, however, does not measure CO₂ near the surface where it is emitted and absorbed into the land and ocean. To detect the sources of emissions and the absorption of CO₂ near the surface, a different type of sensor was required; that requirement led to the development of the Orbiting Carbon Observatory.
- The Ozone Monitoring Instrument (OMI) on NASA's Aura spacecraft continues the record of ozone measurements collected by the Total Ozone Mapping Spectrometer (TOMS) instrument and other ozone measurements collected from previous NASA satellites in support of the Montreal Protocol. OMI also measures nitrogen dioxide (NO₂), sulfur dioxide (SO₂), bromine monoxide (BrO), and OCIO among other aspects of air quality.

Orbiting Carbon Observatory (OCO)

The Orbiting Carbon Observatory (OCO), which was launched on February 24, 2009 and failed to reach orbit, “*is the first spacecraft dedicated to studying atmospheric carbon dioxide*”, according to a December 2008 NASA publication entitled, “Orbiting Carbon Observatory: Science Writer’s Guide”. OCO carried three spectrometers and would have detected CO₂ at the level of 1 to 2 parts per million—an increase of three times the precision of any earlier satellites that had trace gas sensors. “*The surface footprint of each measurement is [was to have been] about 1 square mile....*” OCO was to have collected 8 million measurements of CO₂ atmospheric concentration every 16 days. The small size of the footprint and the number of measurements are important for achieving the quality and accuracy of OCO measurements, which are “*accurate to 0.3 to 0.5 percent on regional to continental scales,*” according to the OCO Science Writers Guide. The Guide also notes that the level of precision at which OCO’s instrument was designed was necessary, “*because atmospheric carbon dioxide concentrations rarely vary by more than two percent from one pole to the other.*”

Better understanding of the absorption and emission of carbon and the variation of those changes over time, would have provided researchers with new knowledge about how carbon dioxide emissions contribute to climate change, the efficiency of carbon sinks, and helped researchers forecast changes in atmospheric carbon dioxide. This fundamental knowledge will be important for designing strategies to manage carbon emissions, according to researchers involved in the OCO project.

The Ice, Cloud and land Elevation Satellite (ICESat)

ICESat is the satellite used to measure the mass balance of ice sheets, cloud and aerosol heights and variations in land elevation and vegetation cover. This satellite provides global coverage of topography and vegetation. This satellite also provides specific observations of the major polar ice sheets in Greenland and Antarctica. A follow-on mission is planned to provide continuity for the study of the major ice sheets.

Other Federal Agency Satellite and Airborne Measurement Projects

The Landsat 5 and Landsat 7 satellites were developed by NASA and launched in 1985 and 1999 respectively. The satellites continue the space-based Landsat observations of the Earth’s land cover, which began in 1972. The Landsat satellites are currently operated by the Department of Interior’s U.S. Geological Survey. NASA is developing the Landsat Data Continuity Mission (LDCM)—the follow-on to Landsat 7—for the USGS. A proposed 2007 plan for a National Land Imaging Program, which would sustain U.S. long-term space observations of the land has thus far not been implemented.

A 2006 report, *Reducing Greenhouse Gas Emissions from Deforestation in Developing Countries: Considerations for Monitoring and Measuring*, noted that Landsat and other remote sensing data can be used to identify deforestation. Landsat data have also been used in studies to identify selective logging in the Brazilian Amazon. (Selective logging affects the carbon storage

of tropical forests.) In addition, Landsat data have been applied to research on the use of satellite images for monitoring and verifying agricultural practices related to soil carbon sequestration.

NASA was one of several agencies including the U.S. Department of Energy's Lawrence Berkeley National Laboratory, the National Oceanic and Atmospheric Administration, the University of California, and the California Air Resources Board that participated in an airborne research campaign to measure GHGs over California. According to a June 2008 news release from the Berkeley Lab, the goal was to gain knowledge about how much California's greenhouse gas emissions are contributing to the overall GHG total worldwide.

The flight was linked to the NASA ARCTAS (Arctic Research in the Composition of the Troposphere from Aircraft and Satellites) program. ARCTAS connects to the broader International Polar Year effort known as Polar Study using Aircraft, Remote Sensing, Surface Measurements and Models (POLARCAT), which is an international initiative to employ aircraft and remote sensing platforms to investigate climate change, air pollution, and atmospheric chemistry.

In addition, the High Performance Instrumented Airborne Platform for Environmental Research (HIAPER) Pole-to-Pole Observations (HIPPO) project is an example of an airborne carbon measuring project that involved other research institutions and facilities. With funding support from NSF and NOAA, researchers from the National Center for Atmospheric Research (NCAR), Scripps, and Harvard teamed-up to develop a project that would investigate whether northern forests were absorbing less carbon than had been estimated and tropical forests were absorbing more than estimated.

The project used an NSF/NCAR Gulfstream V jet, which has long-range and high-flying capabilities that suited the project. Repairs and spare parts were easily obtained because Gulfstream is a commercial aircraft that is used around the world. In addition to carbon dioxide, HIPPO measured other greenhouse gases at 1-10 second intervals.

Key Non-U.S. Satellites and Sensors

Europe's key greenhouse gas monitoring sensor is known as SCIAMACHY on the European Space Agency's Envisat satellite. The SCIAMACHY instrument measures trace gases, including carbon dioxide, methane, and carbon monoxide in the troposphere and the stratosphere.

Japan's Greenhouse Gas Observing Satellite (GOSAT), named "Ibuki," was developed to detect atmospheric carbon dioxide and methane to support compliance monitoring of the Kyoto Protocol. The Protocol is an international and binding agreement under the United Nations Framework Convention on Climate Change and establishes targets for reducing greenhouse gas emissions during the 2008-2012 period.

Ibuki, which was launched on a Japanese H2-A rocket on January 23, 2009, includes an infrared spectrometer to detect carbon dioxide (CO₂) and methane (CH₄) concentrations and a cloud/aerosol sensor.

Japan also operates the Advanced Land Observing Satellite (ALOS) and its Phased Array L-Band Synthetic Aperture Radar (PALSAR) is an advanced imaging radar which is particularly suited for forest and wetland observations. PALSAR measurements are strengthening the satellite capabilities for mapping tropical forests for initiatives such as Reduced Emissions from Deforestation and Degradation (REDD).

Finally, University of Toronto's Canadian Advanced Nanospace eXperiment (CanX) program is a technology demonstration project. The CanX-2 microsatellite includes an Argus spectrometer which was designed to record greenhouse gas constituents in the near infrared band at a surface resolution of 1 kilometer.