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**HEARING ON
MONITORING, MEASUREMENT AND VERIFICATION OF GREENHOUSE GAS
EMISSIONS II: THE ROLE OF FEDERAL AND ACADEMIC RESEARCH AND
MONITORING PROGRAMS**

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

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INTRODUCTION

Good morning Chairman Gordon, Ranking Member Hall, and other Members of the Committee. I am Alexander MacDonalD, Deputy Assistant Administrator for Laboratories and Cooperative Institutes in the Office of Oceanic and Atmospheric Research at the National Oceanic and Atmospheric Administration (NOAA), in the Department of Commerce. Thank you for inviting me to discuss NOAA's research and monitoring programs that support our understanding of greenhouse gases in the atmosphere, as well as the country's needs with respect to monitoring of greenhouse gases and aerosols in light of potential future mitigation policy and overall advancement of climate science and research.

NOAA's mission is to understand and predict changes in Earth's environment and conserve and manage coastal and marine resources to meet our nation's economic, social, and environmental needs. In support of its mission, NOAA has developed a long-standing capability to monitor and understand climate and climate change. From observatories and cooperative sampling sites and satellites around the world, NOAA measures virtually all greenhouse gases, ozone-depleting gases, and aerosols to understand their trends, distributions, and fluxes. NOAA, in cooperation with other agencies, conducts intensive research campaigns to understand the impacts of regional emissions on climate and air quality. Oceanic distributions and exchange of carbon dioxide (CO₂) and other gases with the atmosphere are monitored intensively by NOAA scientists. From these measurements and models to support them, NOAA scientists quantify and improve our understanding of the sources, sinks, and trends of a host of related greenhouse gases (including CO₂, methane, and nitrous oxide), aerosols, and atmospheric tracers. These continuing data records, maintained by NOAA and its interagency partners (e.g., National Aeronautics and Space Administration (NASA), Department of Energy (DOE), U.S. Department of Agriculture (USDA), et al.), reflect the U.S. scientific leadership in this area, and are essential to diagnose current global climate trends and project future climate impacts, including effects on global

weather extremes. NOAA's field missions and global networks for long-term monitoring of greenhouse gases, ozone, ozone precursors, ozone-depleting compounds, aerosols, aerosol precursors and surface radiation produce the highest quality atmospheric data. These data provide a reference for accurate climate model initialization and validation necessary to develop credible scenarios for the future, and for developing national and international emission management strategies.

In this testimony, I will briefly describe the issues related to reducing greenhouse gas emissions, identify some of the needs and collaborative efforts underway for science-based support of emission reduction efforts, summarize NOAA's capabilities and expertise in providing information on greenhouse gases and aerosols, and address what NOAA can do to provide the information society will need for reducing emissions in this century.

WHAT ARE THE ISSUES?

The carbon cycle and influences of greenhouse gases are complex and dynamic. An efficient emissions policy requires a robust bottom-up and top-down monitoring approach. Identifying and quantifying human and natural emissions of these climate forcing agents, such as CO₂, methane, nitrous oxide, several halocarbons, and certain aerosol and ozone-forming agents is necessary for informing emission reduction strategies. We must understand where the emissions are coming from in order to reduce their quantity. We also must be able to identify which areas act as carbon "sinks", removing CO₂ from the atmosphere and possibly offsetting CO₂ emissions, and which areas act as "sources", adding CO₂ to the atmosphere, e.g., areas of oceanic upwelling. To answer these questions and ensure effective, efficient policy requires monitoring and validation of emissions from specific sources and projects. In addition, monitoring the concentrations of gases in the atmosphere for verification with reported emissions is critical to understand whether policies are having the desired result.

According to the IPCC Assessments, the increase of CO₂ in the atmosphere is the single largest contributor to observed climate change. Increasing atmospheric CO₂, mainly from burning of fossil fuels, has not only substantially altered global climate, but has also increased the acidity of the oceans. This trend will continue as long as humans continue to increase atmospheric CO₂. It is well understood that CO₂, once emitted, remains in the atmosphere and oceans for a very long time — many thousands of years. Thus, the changes induced today will have a long-term impact on climate and ocean acidity. For these reasons, reduction of CO₂ emissions is often the primary focus in discussions about mitigating climate change; urgency in doing so is well understood throughout the scientific community.

Other greenhouse gases and aerosol influences must be considered in any emission reduction strategy. Although gases such as methane and nitrous oxide are not rising as fast as CO₂, they still contribute substantially to climate change, and their future growth rates are uncertain. Anticipated changes in climate are likely to affect the emission from land and water surfaces. Some aerosols, such as black carbon, have a warming effect and others, which are mostly associated with poor air quality, have a cooling effect. Aerosols, for the most part, are partly offsetting the warming caused by greenhouse gases. Therefore, it is important to know how changes in emissions will alter atmospheric concentrations of greenhouse gases and aerosol.

There is a definite urgency to reduce greenhouse gas emissions, but we cannot expect to see the effects of reduced emissions immediately on the rate of climate change. There are various reasons as to why this is the case: (1) many greenhouse gases, especially CO₂, persist in the atmosphere long after emissions are reduced or halted; (2) even though the emissions are local, the climate change they bring about is global and takes time to realize; (3) links between trends in greenhouse gas concentration and North American weather extremes, including hurricanes, tornadoes, damaging winds, floods, droughts, cold waves, and heat waves have not been fully established; (4) there are natural variations in climate and it will take time before we have the necessary data to show that changes in climate have grown larger than the natural variation (i.e., to establish statistical significance between what we are experiencing and what is part of natural variation); and (5) since climate change is a global problem, the actions of other nations also have an effect on climate. In the short term, then, we must rely on reporting and measurement of human-caused emissions and observations of the greenhouse gas and aerosol abundances in the atmosphere to provide the sole basis for evaluating the effectiveness of actions to mitigate climate change.

Greenhouse gas emissions are generated by practically all economic sectors, including energy, agriculture, manufacturing, transportation, housing and urban planning, and public health.

A NEED FOR SCIENTIFIC INFORMATION

NOAA maintains a widespread global monitoring network, including a dense observation system in North America, and an ability to measure many atmospheric tracers to characterize the origins of greenhouse gases. NOAA works in partnership with many federal agencies and international organizations, and has been providing greenhouse gas information on global, hemispheric, and continental scales for a long time. NOAA's observation systems and partnerships have evolved over several decades around the goal to resolve scientific questions about the global carbon cycle and climate change. But today the question has become, "How can we provide scientific information to support and enhance emission reduction efforts?" An observation and analysis system developed to effectively support and enhance emission reduction efforts would have significant economic and environmental value, and would support the efforts of decision-makers at all levels of government. At regional levels, verification that reported emission reductions are consistent with what is observed in the atmosphere will require many more observations of greenhouse gases and tracers (including those from satellites like those currently being built or planned at NASA), improved and higher resolution modeling, and an enhanced understanding of biospheric responses to climate change. It will require the expertise contained in several federal agencies, especially DOE, NASA, USDA, the Environmental Protection Agency (EPA), and the National Institute of Standards and Technology (NIST).

The need for sound scientific information regarding climate change mitigation will accelerate. The Committee has identified several questions with respect to greenhouse gas emissions, climate change, and the research endeavors and capabilities currently underway in our nation. Chosen courses of action will require a firm grounding in science and a reasonable expectation of success. Taking action to mitigate climate change is followed by the need to answer questions of accountability – Are the actions working as intended? Do we need to do something different?

Do we need to accelerate or can we relax emission reduction efforts? How do these reduction efforts affect other air pollutants and solid and liquid effluents? The lead-up to actions, and the follow-through of determining the effectiveness of those actions, are both rooted in science.

Science-based information is needed to support greenhouse gas emission reduction policy and includes knowledge of the current emissions and atmospheric composition of greenhouse gases, on-going verification that emission reduction efforts are having their intended effect, and an understanding of how natural greenhouse gas emissions and uptake are impacted by climate change.

History shows that emission measurements are most reliable when there is a robust verification process. Reported emissions (i.e., emissions inventories) are necessary for regulation and initiating emission models, but we will have to verify that reported emissions are consistent with what is observed in the atmosphere. No large-scale emission reduction effort has succeeded without independent verification of its progress, whether it is ozone depletion, air quality, acid rain, or wastewater management. For example, such efforts by NOAA and NASA, required by the *Clean Air Act Amendments of 1990*, has been critical to verifying the success of emission reductions related to stratospheric ozone depletion. This and other efforts, however, are simple compared to what lies ahead with climate change forcing agents. The complexity and variability of the carbon cycle alone present a challenging task of verifying that reported emission reductions are consistent with what we observe in the atmosphere. In the end, the atmosphere tells the story — do observed changes in the atmospheric levels reflect calculated emissions?

Objective, credible, and specific information about the effectiveness of mitigation efforts undertaken, and about the response of the natural carbon cycle to climate change itself, will be necessary to guide policies. Given the sustained investments required to meet this challenge, it is critical that efforts to reduce emissions be verifiable at local, regional and national levels and consistent with evidence in the atmosphere. It is also possible that potential feedbacks in the climate system could exacerbate the problem. For example, there is a real possibility that the melting of Arctic permafrost soils in response to global warming will liberate enormous amounts of methane and CO₂, and would be at that time out of our control. Aerosols also need to be watched, as they can have both warming and cooling effects and are linked to some potential greenhouse gas emission reduction strategies. Thus, in addition to verification of the efficacy of emission reduction programs and offsets, based on observed atmospheric conditions, we must focus on climate information at regional and local levels to confirm the effectiveness of any efforts or policies to mitigate climate change, and understand distributions, trends, and earth-system impacts of increasing CO₂ and other greenhouse gases in the atmosphere. For management to be effective, society will require the best information that research can deliver.

It is also important to clarify the limits to what monitoring (and efforts to verify that reported emissions are consistent with what is observed in the atmosphere) at the local and regional level can accomplish. A comprehensive climate policy will require compliance at the individual source level and a “bottom-up” reporting approach. NOAA’s capabilities will not verify emissions at individual sources, this will be the responsibility of the EPA through compliance assistance efforts. However, at the aggregated level, the information NOAA can provide will serve to inform EPA’s efforts.

WHAT ARE NOAA'S CAPABILITIES?

NOAA's capabilities span a range of activities relevant to climate science, including observations, analysis, modeling, prediction and assessment. NOAA maintains global observational networks and numerous field programs, and works closely with partnering agencies, institutes, and universities across the nation and around the world. NOAA is well-poised to work with key federal agencies and other partners to determine the effectiveness of mitigation efforts, and to integrate new information into its natural resource management efforts.

Measurements and products of NOAA's research contribute significantly to the US Global Change Research Program. NOAA is active with 12 other agencies in the Carbon Cycle Science Program (now part of the U.S. Climate Change Science Program, CCSP). This is coordinated through the NASA/USDA-led Carbon Cycle Interagency Working Group (CCIWG), which meets tri-weekly and sponsors the North American Carbon Program and Ocean Carbon Biogeochemistry Program. Research in these programs, involving both agency and university scientists, is coordinated through separate CCIWG-sponsored Scientific Steering Groups that meet twice yearly. The CCIWG also sponsors biennial all-investigators meetings, workshops at national conferences, and the development of the First State of the Carbon Cycle Report, 2007 (CCSP Synthesis Report 2.2) for North America. This report summarized our current understanding of the sources and sinks of carbon in North America, based primarily upon bottom up (i.e., ecosystem measurements and calculations) approaches which are compared to top down (i.e., atmospheric measurement and analysis) approaches, driven mainly by NOAA's measurements and CarbonTracker. Currently the CCIWG agencies are working with carbon cycle scientists across the nation to develop a new Carbon Cycle Science Program for the coming decade. Efforts coordinated through the CCIWG have been extraordinarily successful in bringing the diverse research capabilities of scientists and organizations across the country to understand how human and natural systems contribute to CO₂ and related greenhouse gases in the atmosphere. NOAA is proud of its on-going role at all levels in this effort.

On a global basis, NOAA's observations of greenhouse gases and aerosols form the backbone of the World Meteorological Organization's (WMO) Global Atmosphere Watch Programme. NOAA's carbon cycle monitoring network currently constitutes 2/3 of the atmospheric monitoring sites reporting to the WMO Greenhouse Gas Data Centre (WDCGG). Data from the WDCGG are a primary component of the Global Climate Observation System. Updated and displayed daily, NOAA's high-quality measurements of carbon cycle and other greenhouse gases from all of its sites are available worldwide to all interested parties. Because of this strong global role, NOAA has leadership positions on the GEO (Group on Earth Observations) Task Team for Carbon and the WMO Scientific Advisory Groups for greenhouse gases, aerosols, and ozone.

Greenhouse Gas and Aerosol Monitoring. NOAA has monitored all of the major greenhouse gases, along with aerosols, for nearly 40 years at its baseline observatories and its cooperative sampling sites. This long-term commitment to monitoring these substances has required detailed, accurate measurements, high quality research, and technological advancement over the decades. NOAA's skills and commitment in this effort are unsurpassed. For example, the measurement of CO₂ in the atmosphere and oceans has flourished under NOAA since its work

began several decades ago. This science-based effort requires sustained, comparable measurements at an accuracy level of 0.05 percent or better. NOAA's capabilities and commitment is acknowledged by the scientific community throughout universities, federal agencies, and international organizations. Scientists researching the carbon cycle or conducting climate research depend upon NOAA to provide the world calibration scale and to deliver consistent, accurate field measurements of CO₂ and other climate-relevant gases. The significance of NOAA's capabilities is exemplified by the agency's high level of quality control and assurance (e.g., ongoing, long-term comparisons of field measurements), its involvement in national and international planning and execution, and its leadership role in the world community — via the WMO — for calibration.

Oceanic Measurements. The largest, active reservoir of CO₂ is the ocean, which accumulates 40-50 percent of the CO₂ emitted into the atmosphere. Processes in the ocean constitute the ultimate sink for atmospheric CO₂, though those removal processes take thousands of years. Understanding the cycling of carbon in the ocean has been at the core of NOAA's mission for decades. NOAA scientists provide about half of the nation's measurements of CO₂ in both deep and surface waters globally and are leaders in understanding the processes that drive gas exchange between the ocean and atmosphere. NOAA scientists also are leaders in understanding ocean acidification, which is driven by increasing CO₂ in the atmosphere, and they are major players in the international effort to monitor, understand, and assess the trends of carbon in the ocean and its impacts on ocean habitat and living resources.

Satellite Observations. NOAA retrieves data on CO₂ and other greenhouse gases and aerosols from NASA satellites. NASA and international satellites complement NOAA's global in situ observing system for greenhouse gases by providing global coverage, high-spatial resolution and vertically integrated measurements. To ensure data comparability, it is critical that the satellite retrievals be consistent in form with long-standing, high quality, accurate measurements made on the ground or from aircraft and with reanalysis output such as that of NOAA's CarbonTracker. Data comparability requires a coherent, on-going research effort among groups involved in both ground-based and remote measurements and traceability to international standards such as provided by NIST; these efforts provide NOAA with an opportunity to work closely with national and international partners in this endeavor.

Intensive Field Campaigns. NOAA has a demonstrated capability of carrying out intensive observational campaigns using NOAA aircraft as a "flying chemistry laboratory" to measure all the major greenhouse gases, tracers that help ascertain the origin of the gases, tropospheric ozone and its precursors, and aerosols and their precursors (Figure 1). This capability can be deployed anywhere in the U.S. and in most places in the world to "spot check" emissions of climate forcing agents from specific regions and establish internal relationships among emissions of different gases. Suitably planned observational campaigns can help quantify emissions of climate-forcing agents and identify their locations and emission sectors. NOAA's capability can help establish a reasonably useful baseline of emissions from various parts of the country.

Process Understanding. NOAA has a demonstrated capability in carrying out research to understand and quantify the transformation of chemicals to climate relevant agents such as ozone and aerosols. NOAA also is a leader in seeking to understand and quantify the transport of

chemicals. These capabilities enable NOAA to translate observations into information that can be used in models to predict what actually happens in the Earth system.

Integration of Observations through CarbonTracker. NOAA's CarbonTracker tool is widely acknowledged as the most open and effective reanalysis approach to date for estimating CO₂ emissions and uptake (Figure 2.), particularly at large spatial scales. When fully developed, CarbonTracker will make it possible to track regional emissions of CO₂ over long periods of time and to determine which areas are absorbing CO₂ from the atmosphere. CarbonTracker uses an existing land model, recognized as the best for this work. The land model is informed in part by measurements carried out in the DOE's Ameriflux network, which provides information on ecosystem function on kilometer scales. (Augmenting Ameriflux sites in the future would allow for incorporation of additional atmospheric measurements into CarbonTracker and help improve its resolution, particularly near Ameriflux sites.) The land model also is informed by NASA and NOAA satellite observations of land surface and biosphere characteristics. CarbonTracker uses a transport model with satellite-supported meteorological fields that can exploit the current distribution of observing sites. Finally, CarbonTracker incorporates global fossil emission estimates (DOE), fires (NASA MODIS instruments on NASA Aqua and Terra satellites) and a modification of NOAA's world-class ocean circulation model. Because CarbonTracker constrains the model results with atmospheric observations, it was able to identify the impact of the 2002 drought on North American absorption of CO₂. This suggests that, under its current configuration, CarbonTracker is effective in capturing large-scale, North American phenomena. There is not, however, a current greenhouse gas monitoring network large enough for CarbonTracker to provide fine scale resolution with low uncertainty.

An important role that a "top down" system like CarbonTracker plays is to independently validate the combined fluxes calculated from "bottom up" efforts such as estimated fossil fuel emissions and biological sources. If estimates of sources and sinks do not agree with measured atmospheric concentrations, the "top down" approach provides the information needed to continually improve our understanding of the carbon cycle.

Analysis of data to predict climate change and its impacts. NOAA has a demonstrated capability in climate and chemistry modeling. Such modeling is essential for providing information about why past changes occurred, knowing what the "climate baseline" is now, and identifying what can be expected when emissions are altered. These models can quantify consequences of changes in emissions on both climate and air quality. They also are useful in predicting what will happen in the future and how ecosystems and human systems will respond, with and without emission regulations — information that will be important for decision makers.

WHAT NOAA CAN DO TO HELP VERIFY EMISSION REDUCTIONS

Based on the capabilities described above, NOAA will play a central role providing in scientific information that will be necessary to verify whether reported greenhouse gas emission reductions are consistent with what is observed in the atmosphere. NOAA can help, along with other agencies, in characterizing a baseline for atmospheric composition, supporting EPA's development of greenhouse gas emission inventories, and setting up a greenhouse gas information system for the 21st century. NOAA, along with other agencies, can provide timely

analyses on the impacts of the proposed regulatory action by verifying reported emissions at the aggregated level, assessing the effectiveness of offsets, and characterizing the impacts of emission reduction efforts across sectors and regions of the nation and world.

Upgrade the Greenhouse Gas and Aerosol Monitoring System. The current greenhouse gas monitoring systems implemented by the Federal science agencies are designed to support research to understand the role of gases and aerosols in climate forcing. The growing need to provide scientific verification and support to efforts to *mitigate* climate change through changes in human-caused emissions requires a more comprehensive monitoring system. Such a system will need to be developed over the next decade with cooperation among federal agencies, particularly NOAA, NASA, National Science Foundation (NSF), Environmental Protection Agency (EPA), Department of Transportation (DOT), and DOE, and with our international partners. Global measurements of CO₂, such as those NASA's Orbiting Carbon Observatory (recently lost on launch), would have made is one example of the new capabilities that will be needed. NASA's and NOAA's roles in verifying NASA satellite data through comparisons with CarbonTracker profiles and with direct measurements by aircraft and ground-based facilities will be critical for demonstrating the potential for incorporating satellite measurements into a comprehensive system of observations. NOAA and NASA have recently developed a method to measure mid-troposphere CO₂ from the NASA Atmospheric Infrared Sounder instrument on NASA's Aqua satellite. NOAA is investigating other new technologies, including use of manned and unmanned aircraft, commercial aircraft, and tall towers to sample air above the surface. We are also working on exciting new possibilities, such as the Air Core, a method of bringing air from all altitudes (a chemical sounding) back to the laboratory for analysis. Air Core was invented by Dr. Pieter Tans of NOAA's Earth System Research Laboratory. A major advantage of retrieving air samples is that it allows the measurement of many tracers which can be used to attribute sources and sinks of CO₂.

Establish a Greenhouse Gas Information System for the 21st Century. The ability of the United States and other nations to effectively implement policies for limiting atmospheric greenhouse gas concentrations would benefit considerably by ensuring that reported emission reductions and offsets are consistent with atmospheric observations at regional and national scales. A U.S. program to reduce human-caused concentrations of CO₂ that incorporates such a system would help guarantee an efficient, effective, and economic approach to emission reduction. It would have considerable value for improving our approach to reducing emissions and verifying treaty agreements.

Such a system would combine ground-based, air-based, ocean-based, and space-based measurements with facility and site-specific measurements, carbon-cycle modeling, fossil-fuel emission inventories, land-use data, and an extensive distribution system for information about sources and sinks of greenhouse gases at policy-relevant temporal and spatial scales. A greenhouse gas information system would need to be linked to enhanced capabilities for seamless weather-climate modeling and prediction across timescales.

A global greenhouse gas information system would build from existing capabilities and require collaboration to expand and develop improved ground, sea, and air-based measurements; sustained space-based observations; and measurements of non-CO₂ short-lived gases for fossil-

fuel combustion attribution. Ground-based observations must be focused on accuracy as well as long-term continuity to be of value to the climate record. Deriving actionable information from these observation sources further requires coordinated efforts in carbon-cycle modeling, data assimilation, and data analysis — spanning several networks, spatial scales, disciplines, and agencies. The specific requirements of such a system would be dictated by policy objectives and by the degree of international cooperation.

This information system could build on NOAA's current global leadership, observation, modeling, prediction, and analysis capabilities and would involve coordination with other federal agencies, national and international partners, and the private sector. This information system also would be a structural, operational, and research backbone in a global effort to verify reduction of CO₂ and other greenhouse gas and certain aerosol emissions and quantify changes in emissions or uptake by natural systems. Such a system would have lasting value for national and international assessments and would serve as the ultimate tool for guiding these efforts globally. To successfully simulate the atmospheric CO₂ record, a reanalysis tool like CarbonTracker must work with the most advanced models of the coupled oceanic and terrestrial carbon cycle, which would require collaborations with federal and state agencies, universities, and international partners. A dense observing network and targeted field campaigns combined with a data assimilation capability would provide an objective check on efforts to track emissions and the contributions of fossil fuel use.

Deliver early information to establish a baseline characterizing the influence of current and past emissions on atmospheric composition. There are near-term opportunities for helping establish a baseline of current emissions and providing process information in support of model development. Verification of emissions from some individual sources can be started almost immediately. Climate change forcing agents, their precursors, and related tracers can be measured with existing instruments placed on NOAA's aircraft, ships, and ground-based stations. This early information would aid in evaluating overall emission reduction strategies. Such measurements can be coordinated with those from other agencies (e.g., NASA, DOE, NSF, DOT, and EPA) to provide a more comprehensive coverage of sources, geographic regions, and temporal characteristics for providing baseline information on emissions as quickly as possible.

Support development of robust emission inventory of climate forcing agents for the country. A systematic, up-to-date inventory of emissions, their distributions, and their variations will help decision-makers base their decisions on accurate information, climate scientists more accurately model future climate and its impacts, and stakeholders feel confident of the consequences of the emission changes. A robust, accurate, updated, emissions inventory can be developed, refined, and maintained through close interaction with other agencies, most notably by supporting EPA, DOE's Energy Information Administration, and others maintaining accounting registries. Development of an improved inventory would go hand-in-hand with development of a greenhouse gas information system for the 21st century, as improvements in emission estimates inform model development and vice-versa.

Model, predict and analyze the impacts of proposed mitigation actions on climate change. NOAA has the capability to make climate predictions, and this capability is being continually improved. NOAA's capabilities will be critical for predicting the consequences of any actions

taken to reduce emissions. Such information will be essential to support the best possible decisions.

CONCLUDING REMARKS

In conclusion, I have described the issues involved in dealing with reduction of emissions for the benefit of climate, the science-based information needs for dealing with reductions, the expertise NOAA currently has to address some of the issues, and what more NOAA – in conjunction and coordination with other federal agencies – can do to provide science-based information for emission reductions.

NOAA — with its broad mission responsibilities for physical and life sciences, and its stewardship responsibilities — and its national and international partners have the technological prowess to implement the comprehensive and highly sophisticated global information systems needed to measure the effectiveness of greenhouse gas mitigation strategies. Such a system should include new satellite sensors, an improved monitoring network in the atmosphere and oceans, and powerful new techniques to analyze the data in support of policy. We look forward to the role NOAA will play in providing the information society will need for reducing emissions in this century.

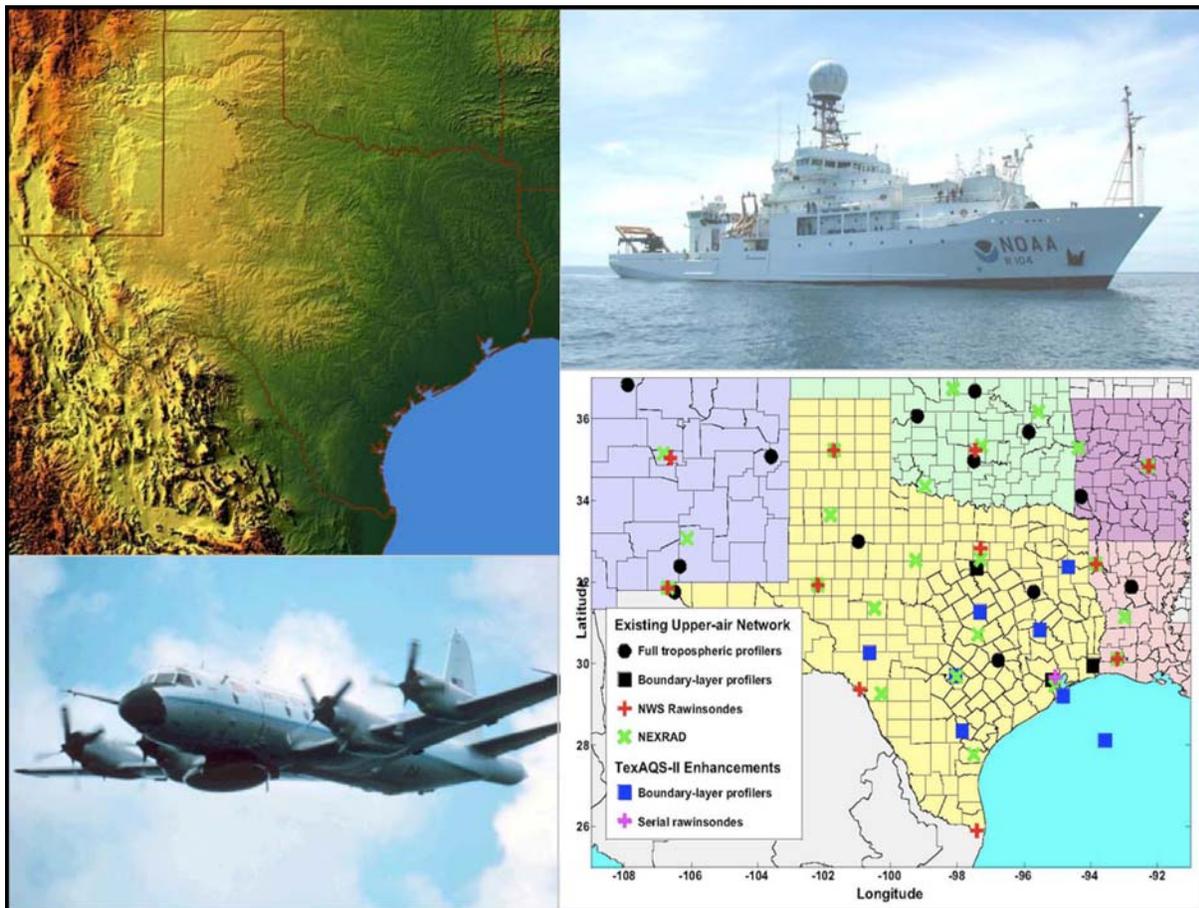


Figure 1. Measurements of various chemicals such as greenhouse gases, precursors of ozone (a potent greenhouse gas), reactive chemicals, tracer chemicals, and aerosols (including black carbon) were carried out using a flying “chemical laboratory” (a NOAA WP-3 aircraft) and a “floating chemical laboratory” (a NOAA ship) over and around Texas in 2000 and 2006. Such measurements combined with meteorological data allowed quantification of emissions of various chemicals from different locations in Texas. It was shown from these studies that emissions of olefins- highly reactive chemicals that produce ozone- from petrochemicals were major sources of ozone over Houston.

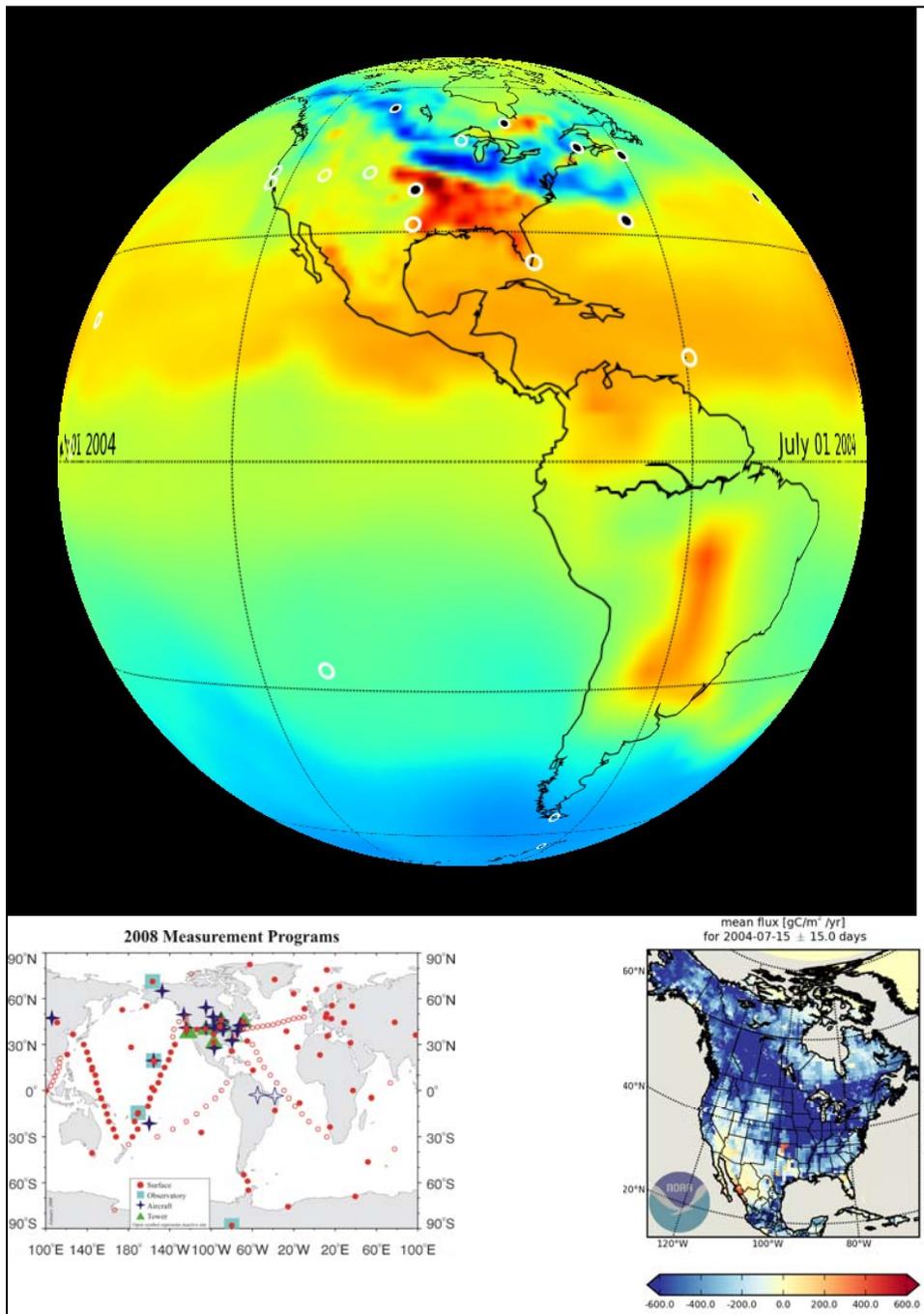


Figure 2. NOAA's CarbonTracker is a system to keep track of carbon dioxide (CO₂) uptake and release at Earth's surface over time. It is constrained by NOAA's highly accurate observation system (lower left), produces maps of biosphere emission and uptake of CO₂ (lower right), and provides vertical profiles of CO₂ everywhere all the time (upper figure). Blue indicates net uptake by the biosphere (lower right) or a CO₂ deficit in the air (upper figure), red indicates net emission or excess. Data are for July 2004.