Air Quality Assessment and Forecast System: Near-Term Opportunity Plan

UNITED STATES GROUP ON EARTH OBSERVATIONS

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1. PREFACE

This plan was prepared by the U.S. Group on Earth Observations[1] and is one of six near-term opportunities identified in the *Strategic Plan for the U.S. Integrated Earth Observation System.*[2] Near-term opportunities in this context are identifying observing systems or integration of components that meet high-priority societal needs, and making improvements to update existing systems that can be completed within 5 years and have tangible, measurable results. The near-term opportunities are:

- Improved Observations for Disaster Warnings (published September 2006);
- Global Land Observation System (in development);
- Sea Level Observation System (in development);
- National Integrated Drought Information System (published September 2006);
- Air Quality Assessment and Forecast System (published September 2006); and
- Architecture and Data Management (in development).

2. THE OPPORTUNITY

In spite of substantial progress in air pollution abatement over the last two decades, air quality remains a priority public health concern. To address this issue, the IEOS Strategic Plan proposes an Air Quality Assessment and Forecast System that will improve data collection and provide more accurate and timely forecasts. This system will help the public avoid harmful exposures to air pollution and help decision-makers better manage air quality. These tools will improve environmental resource management by advancing the primary objectives articulated in the U.S. Group on Earth Observations (USGEO) strategic plan:

- Improve the ability to forecast air quality across large parts of the country (and in other parts of the world) for which forecasts are not currently available;
- Provide better information about emissions and transport mechanisms on regional to international scales; and
- Provide important information to help the public avoid harmful exposures and to help air quality management better reduce and respond to air pollution episodes over the short and long terms.

The Global Earth Observation System of Systems (GEOSS) offers the potential to focus the complementary strengths of a variety of observation and modeling platforms toward advancing air quality assessment and forecasting capabilities. This plan integrates existing and planned efforts from a number of agencies and builds on recommendations from multiple sources, including *The Changing Atmosphere: An Integrated Global Atmospheric Chemistry Observation Theme for the IGOS Partnership* and a 2004 joint EPA-NASA-NOAA Air Quality workshop.

Five well-integrated products/services are described below that collectively advance air quality assessment and forecasting:

- **Integrated Observed-Modeled Air Quality Fields** providing enhanced air quality characterizations through the fusion of air observation systems and predictive air quality models for air quality management, forecasting, science, and health effects research;
- **Systems for Utilizing Observations to Improve Air Quality Forecasts** to enable delivery of accurate, high-resolution national forecast guidance for ozone and particulate matter;
- **Assessments of Key Air Quality Processes** at hemispheric, national, regional, and local levels to support the development of well-informed air quality policies, plans, models, and applications;
- **Improved National Emissions Inventories** to serve Federal, State, and local officials for policies, plans, and forecasts; and
- **Improved International Transport Assessments** integrating global observations and models to inform international negotiations and decisions about transnational pollutant flows.

> Particulate matter smaller than 2.5 micrometers in aerodynamic diameter ($PM_{2.5}$) comes from direct (or primary) particle emissions and through reactions (or phase transformations) of nitrogen oxides, sulfur oxides, volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs).
>
> Ozone is a secondarily formed pollutant. Ozone is not directly emitted from a source; it is generated through reactions of precursors, which include VOCs and nitrogen oxides (NO_x), in the presence of sunlight.

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[1] The United States Group on Earth Observations (USGEO) was established in March 2005 as a standing subcommittee of the National Science and Technology Council Committee on Environment and Natural Resources.

[2] http://usgeo.gov/docs/EOCStrategic_Plan.pdf

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This near-term opportunity should focus on ozone and particulate matter smaller than 2.5 micrometers in aerodynamic diameter ($PM_{2.5}$). These two ambient air pollutants are associated with a variety of respiratory and cardiovascular effects at current levels in some areas. Unless stated otherwise, the phrase "air quality" in this plan refers to ozone and $PM_{2.5}$ and their precursors. Outdoor air quality is the primary subject with recognition of its relation to indoor and personal exposures.

This plan leverages existing observing and modeling systems, which are generally more mature for ozone than they are for $PM_{2.5}$. While this near term plan focuses on ozone and $PM_{2.5}$, the steps taken to address these pollutants establish the framework for managing information about hazardous air pollutants (HAPs) and persistent bioaccumulative toxins (PBTs), such as mercury.

Ozone and $PM_{2.5}$ share many common local and regional sources and precursors, including mobile and industrial sources and electric generating units, which emit volatile organic compounds (VOCs) and nitrogen and sulfur oxides, which are precursor gases to secondarily formed $PM_{2.5}$ and ozone. Significant contributions to ozone precursors and PM also come from other source categories, including biogenic emissions from living trees and combustion through wildfires and controlled burns.

2.1 GENERAL BENEFITS

America's air quality has improved substantially over the last few decades. Since 1970, the aggregate total emissions for six pollutants [Carbon Monoxide (CO), Nitrogen Oxides (NO_x), Sulfur Dioxide (SO_2), Particulate Matter (PM), Volatile Organic Compounds (VOCs) and Lead (Pb)] have been cut from 301.5 million tons per year to 138.6 million tons per year, a decrease of 54 percent. Annual emissions statistics for these six pollutants are considered major indicators of the quality of the Nation's air because of their impact on human health and the existence of their long-standing national standards. From 2001-2004, total emissions dropped 21 million tons, a 13.5 percent reduction. Total emissions have continued to decrease even as the U.S. economy has continued to grow.

Despite this progress, reducing exposure to air pollutants remains a national public health priority. More than 158 million U.S. residents live in areas that violate health-based national ambient air quality standards[3]. As an example of the magnitude of the issue, the U.S. EPA estimates that implementation of the Clean Air Interstate Rule designed to reduce $PM_{2.5}$ exposures should result in avoiding 17,000 premature deaths and 22,000 nonfatal heart attacks annually by 2015.[4] Air quality also has a significant economic impact, as illustrated in the sidebar on the right.

An IEOS could provide significant value to efforts to protect public health in the context of an evolving international economic and environmental system. As Figure 1 illustrates, the air quality assessment forecast systems benefit the Nation in two major ways.

1. **Improved information about air quality enables policy-makers and environmental managers to develop and evaluate more effective policies and plans.** Optimization of risk-management strategies improves our tools for assuring public health and well-being, protecting critical ecosystems, and maintaining a vital economy.

> **Examples of Economic Impacts**
>
> Decisions based on air quality information have a significant economic impact on the Nation. For instance, using information provided by the U.S. Environmental Protection Agency (EPA) and several key assumptions, the Office of Management and Budget (OMB) reported that EPA air regulations in the period 1993-2003 produced an estimated annual benefit to the Nation of $35-166 billion, and yet had an estimated annual cost of $16-18 billion[4].
>
> Also, an air quality assessment in Houston in 2000 concluded that unanticipated emissions of highly reactive volatile organic compounds were a key contributor to poor air quality in that region. That information allowed the State of Texas to develop a more focused plan for achieving good air quality, which estimates indicate will save the state more than $9 billion and 64,000 jobs by 2010[4] while still protecting public health.

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[3] U.S. Environmental Protection Agency, "8-Hour Ozone Nonattainment Areas: As of March 2, 2006," http://www.epa.gov/oar/oaqps/greenbk/gntc.html

[4] U.S. Environmental Protection Agency, "Regulatory Impact Analysis for the Final Clean Air Interstate Rule," EPA-452/R-05-002, 2005, http://www.epa.gov/cair/pdfs/finaltech08.pdf

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2. **Enhanced air quality forecasts allow communities and individuals to more effectively mitigate pollution exposures.** Mitigating exposures of all types—outdoors, indoors, and personal—when air quality is poor is especially important for individuals at risk for adverse health effects, including those with asthma, certain allergies, and cardiovascular or pulmonary diseases.

The specific benefits of each product/service are described below. These products/services also provide secondary benefits to most GEOSS societal benefit areas including improvements to weather forecasting and understanding climate change, more effective management of agriculture and energy sectors, and better protection of oceans and ecosystems.
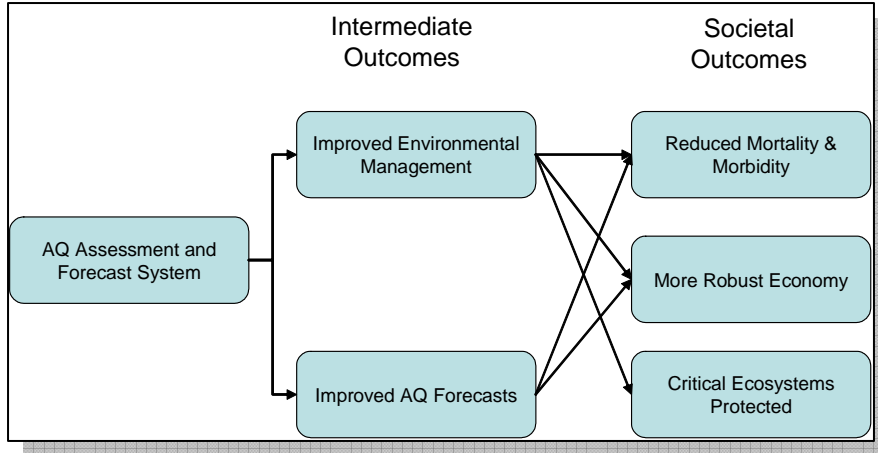

Figure 1: Benefits of the air quality assessment and forecast system

2.2 WHY NOW?

Many of the more straightforward air quality problems have already been addressed through regulation enforcement, including ambient air standards for lead, nitrogen dioxide, sulfur dioxide, and carbon monoxide. However, more complicated issues require sophisticated data collection and integration, such as understanding the toxic components of particulate matter and long-range transport. Fortunately, scientific and technical advancements, including new observing and information technologies, and insights into atmospheric processes, have created opportunities to address these more difficult issues at the applications level. Many of these technologies and processes have been developed for research and applications other than air quality (e.g., status of stratospheric ozone, climate change, weather forecasting). An integrated earth observation system provides an opportunity to leverage these relevant and substantial resources for improving the effectiveness of the Nation's planning and response systems.

2.3 PRODUCTS/SERVICES

Figure 2 illustrates the mutually supporting nature of some of the plan's products/services.

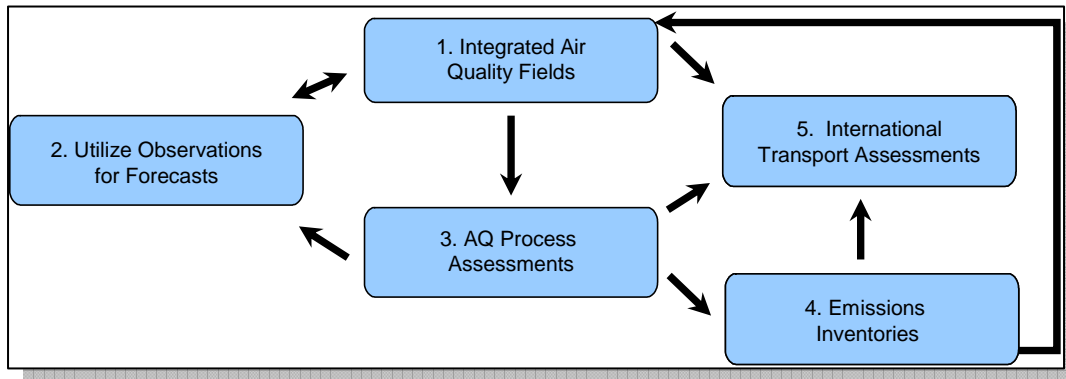Figure 2: Some of this plan's products/services support other of the products/services. In this diagram, the product/service that is the source of an arrow supports the destination of the arrow.

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3. INTEGRATED OBSERVED-MODELED AIR QUALITY FIELDS

3.1 NEED AND RATIONALE

Air quality characterization provides a key infrastructure component underlying virtually any assessment associated with air quality management practices, forecasting, research, and health effects phenomena. Currently, there is an excessive reliance on the Nation's regulatory-based air monitoring networks for forecasting and research. However, the regulatory network typically provides point-based surface measurements, which may not be representative of a wide area.

A more sound, scientifically-rigorous approach would maximize the spatial and temporal resolution of air quality characterizations by using all observational and modeling resources to fill in important gaps (space, time, and composition) that land-based monitors cannot adequately cover alone. Otherwise, analyses based on air quality data, such as judging the effects of regulations or investigating air quality-health relationships, are based on limited characterization fields, which cannot adequately account for vast populations and geographic areas, and are hampered by limited temporal and compositional (i.e., chemistry and physical properties) structure. Moreover, surface observations provide no information about pollutants aloft, which can have a significant impact on surface concentrations.

Through the fusion of land-based systems, overhead measurements (e.g., satellite total column measurements of ozone and aerosols), and results from retrospective simulations, air quality managers can perform more robust assessments across broad spaces and timeframes covering realistic representations of populations and their exposures to air pollution. An integrated observation-modeling platform offers the possibility of advancing air quality characterizations across needed spatial, temporal and compositional dimensions. In addition to supporting air quality assessments, an integrated data infrastructure would support all of the other components of this plan.

3.2 GENERAL DESCRIPTION

The integrated system will be capable of producing gridded and point estimates of concentrations of ozone, $PM_{2.5}$, and precursor species at one-hour time resolution with accompanying information about uncertainties in the estimates. The capability will include prospective air quality fields as well as retrospective archived maps contingent on historical data availability. Air quality maps will be produced by integrating multiple sources of information. Results will be available in multiple forms, including binary fields and contour maps.

3.3 BENEFITS

The integrated data infrastructure will:

Support all phases of air quality management. A robust, integrated information base will strengthen the development of emission reduction strategies and air program policy. Continued availability of the information will drive air quality trends and deposition analyses, which support accountability reviews of existing policies and regulations. In turn, those analyses enable policy modifications and facilitate adjustments for unanticipated changes in atmospheric conditions. An integrated infrastructure with routine air quality information will allow decision-makers to assess air quality across a wide range of geographic areas and determine if mitigation strategies and regulations are accomplishing their intended air quality goals. As new policies and regulations are required, the infrastructure will provide baseline information. Air quality modeling science will reinforce the ability to adjust to unforeseen events and new scientific findings.

Support population-based studies that explore the relationship between health outcomes and ambient air pollution exposures and support national air quality standards development. Such associations in turn will allow for a meaningful accountability of our Nation's air pollution mitigation efforts based on real outcomes and provide a basis for continued assessment and revision of our national air quality standards.

Identify gaps in data and observing systems to maximize information utilization.

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3.4 PRIMARY EXISTING COMPONENTS

Land-Based Ambient Point Measurements. Existing land-based ambient air quality point measurement networks managed by EPA, the Department of the Interior, states, and local air agencies.

Deposition Measurements. Deposition of pollutants to land and watersheds is measured by the National Atmospheric Deposition Program (NADP) and the Mercury Deposition Network, which are supported by multiple organizations to understand long-term trends and to monitor primarily precipitation inputs to ecosystems.

Air Quality Models. The Community Multiscale Air Quality (CMAQ) Model (EPA-NOAA and non-Federal partners) and the chemistry version of the Weather Research and Forecasting model (WRF/CHEM) (NOAA and non-Federal partners) provide state-of-the-art air quality simulation capabilities, which could be applied retrospectively to integrate observations.

Tropospheric and Total Column Observations. Satellite systems operated by NASA (Aqua, Terra, Aura), NOAA (ozone from polar orbiting satellites and aerosols from geostationary satellites), and foreign entities (ENVISAT) provide total column depth observations of ozone, aerosols and other key gaseous species, including CO, CH_4, NO_2, H_2CO, SO_2, and CHOCHO (glyoxal).

Vertical Gradient Systems. The measurement of ozone and water vapor by Airbus in-service aircraft observations from European airliners. Ozonesondes are launched weekly from several locations in the continental United States (NOAA, NASA). NASA, DOE, NOAA, and universities support LiDAR systems that profile aerosols using a vertically pointed laser and, at limited locations, ozone. NASA's Cloud-Aerosol LiDAR and Infrared Pathfinder Satellite Observation (CALIPSO) satellite measures vertical profiles of PM around the world.

Approaches for Integrating Observations. Collaborations between atmospheric scientists and health researchers are underway to test the utility of fused, more geographically broad measurements of ambient air quality for analyses of morbidity and mortality than is provided by point-based air quality measurements. EPA and the Centers for Disease Control and Prevention (CDC) are collaborating to integrate local point data with continuous spatial coverage and gradients provided by models. The National Institute of Environmental Health Sciences (NIEHS), NOAA, and EPA are exploring the benefits of combining surface and satellite air quality observations for health studies.

Data Management. Many separate data management systems are used for the observations described above. For example, routine surface observations of ozone and PM are available through EPA's Air Quality System (AQS) and AIRNOW, and specialized measurement data from some large field studies are available through NARSTO's Quality Systems Science Center. Current research efforts are beginning to demonstrate service-oriented architecture approaches that show promise to allow interoperability between systems with different data formats and access protocols.

3.5 PRIMARY PLANNED COMPONENTS

National Core (NCore) is a new ambient air-land-based monitoring structure that ties together several existing air monitoring networks and adds nearly 75 new colocated multiple pollutant measurement stations in major cities and key background and rural locations. Managed by the EPA, NCore will be phased in from 2006 through 2009 and will facilitate the integration of land-based observations with satellite observations and air quality models.

Following up on successful prototype efforts to compare integrated air quality measures with public health tracking data, EPA and CDC are collaborating on an accessible system for state public health agencies.

Satellite systems coming on line over the next 5 years (see Appendix A):
- MetOp (2006) will provide ozone profiles;
- NPP (2008) will provide aerosol column optical thickness measurements; and
- Glory (2009) will collect data on the chemical, microphysical, and optical properties, and spatial and temporal distributions of aerosols.

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3.6 GAPS

Several core elements are required to create an integrated air quality data system and realize its benefits. These include the following:

- Data management support for accessing, assimilating, archiving, and distributing diverse information sources across Federal agencies. This will include the use of common data protocols and linkages to data analysis and visualization packages. To build upon existing systems, the integrated data management infrastructure should provide a virtual repository where data are actually stored in distributed servers in diverse formats. Data publishing, discovery, assistance in access, and services will be provided via a Web-based portal that exploits open, standards-based approaches to provide interoperability. This is consistent with the vision of the IEOS Architecture and Data Management Working Group whose guidance supports an integrated air quality data infrastructure. (EPA).
- Routine air quality modeling, data interpolation, and observation-model integration that incorporates historical data, (EPA). Also, models should be capable of dynamically assimilating previous data.
- Outreach/capacity building with the air quality and health communities, including regional planning organizations, state/local governments, academia, and the private sector.

Certain strategic investments will yield dramatic increases in the efficiency of leveraging integrated observation systems. In priority order:

- Land-based LiDAR network for characterizing vertical gradients of PM and ozone. Satellite data typically provide total column depth measurements that lack the necessary detail to determine, for instance, if a PM plume actually reaches the ground. Vertical profiling provides the binding ingredient that allows for the most effective integration of remote satellite observations with land-based point measurements. In addition, vertical profile information provides key insights into physical process understanding and supports evaluation of air quality models. A logical starting point for such a network is the Regional East Atmospheric LiDAR Mesonet (REALM). REALM is designed to monitor air quality in the vertical direction from multiple locations on the East Coast, but remains unfunded at this point. Initial proof-of-concept studies integrating LiDAR, land-based point measurements, and satellite-based observations have yielded successful results.
- Based on lessons learned and benefits demonstrated by NASA research satellites, operational NO_2 column measurements could be provided by GOME-2 on the European MetOp satellite. NO_2 is an indicator of combustion and is an important precursor to ozone and particulate matter. To take advantage of this opportunity, development of a retrieval algorithm (based on prior work) and operational products would be required (NOAA).

4. SYSTEMS FOR UTILIZING OBSERVATIONS TO IMPROVE AIR QUALITY FORECASTS

4.1 NEED AND RATIONALE

A number of state and local governments issue air quality forecasts and alerts to try to reduce the severity of poor air quality episodes (e.g., by urging residents to decrease driving) and to help the public protect themselves (e.g., by staying indoors or reducing physical activity). Air quality forecasters routinely use surface air quality observations to inform their forecasts; however, this approach does not adequately incorporate transport and other processes affecting air quality. NOAA's operational air quality forecast guidance provides prognostic information for forecasters, but the current operational model does not incorporate air quality observations. The air quality forecast system uses an emissions inventory and the chemical state of the atmosphere predicted by the last simulation as the chemical basis for predictions, which might not accurately represent the actual state of the atmosphere. Errors in one day's forecasts of the chemical state of the atmosphere may be propagated to a second day's forecasts.

4.2 GENERAL DESCRIPTION

New systems that rely on observations to improve air quality forecasts would improve accuracy and better enable individuals to avoid exposures when air quality is poor. Three paths are envisioned to improve state and local air quality forecasts. The first path is to fuse real-time observations with surface data. The second path is to develop an operational data assimilation capability for air quality models (note: meteorological models routinely assimilate data, which significantly improves accuracy). The third path is to determine what enhancements to the air quality observing system would best enhance forecast accuracy.

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4.3 BENEFITS

This work will improve the information available to air quality forecasters and their ability to utilize that information, leading to better air quality forecasts, more targeted mitigation efforts, and reduced exposures to poor air quality.

4.4 PRIMARY COMPONENTS

Data Fusion and Visualization to Support Forecasting

While an integrated air quality data infrastructure will provide access to diverse observations, the fusion of selected data sets is required to provide effective support for forecasters, who must make decisions in a very limited time.

Primary Existing Systems include:

- **Hazard Mapping System (HMS) (NOAA).** The HMS provides subjectively integrated information about fire locations from multiple sources, including Geostationary Operational Environmental Satellite (GOES), Polar Orbiting Environmental Satellites (POES), Terra and Aqua, and the Defense Meteorological Satellite Program. The HMS also uses images from GOES to identify smoke plumes.
- **Infusing satellite Data into Environmental Applications (IDEA) (NASA, EPA, and NOAA).** The IDEA project provides a prototype integrated view of fire locations derived from: GOES; aerosol optical depth (AOD) and cloud optical thickness from NASA's Terra satellite; surface $PM_{2.5}$ observations from the EPA's AIRNOW system (which collects observations from international, Federal, state, and local partners); and 850mb winds from NOAA's North American Model.
- **BlueSky/RAINS (USDA and EPA).** The locations of forest fire smoke plumes are predicted and displayed on a GIS-like Web site.

Additional Planned Systems include:

- The integrated IDEA prototype will become operational at NOAA.

Utilization of Real-Time Air Quality Observations in Regional Air Quality Models

Observations offer great potential for improving air quality forecasts by enabling air quality models to more accurately represent actual conditions. Observations can be used in several ways. Information about episodic and unpredictable emissions sources, such as biomass burning, can fill gaps in emissions inputs into air quality models. Observations of ambient conditions along a model's boundary can be used to improve information about pollutants such as intercontinental dust clouds flowing into the model's domain. Finally, air quality observations within the model's domain can be dynamically assimilated into the model to guide the initial state of a forecast to more closely match reality. In the future, improvements such as these will be incorporated into operational ozone and particulate matter forecast models.

Primary Existing Systems include:

- **HYbrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) Smoke Forecast Guidance Demo Project (NOAA).** Using biomass burning locations identified by the Hazard Mapping System, this prototype uses the USDA BlueSky fire emissions model and NOAA's HYSPLIT transport model to predict smoke plume locations.
- **IDEA AOD Trajectories (NASA, EPA, and NOAA).** The IDEA project also includes a prototype product that forecasts where areas of high PM may be transported.
- **Regional Air Quality Modeling System (RAQMS) (NASA).** This research system assimilates global satellite observations of ozone into a global model to provide improved boundary conditions for regional air quality models.
- **STEM-II Model (NSF and others).** This research air quality model assimilates surface air quality observations and has demonstrated that such assimilation can improve air quality forecasts, but this work is at an early stage.

Gaps include:

- **Prototype Air Quality Data Assimilation System (NOAA in consultation with EPA).** This will demonstrate the capabilities required to dynamically assimilate real-time air quality observations into operational regional air quality models. This will include enhanced observational data quality control, characterizing errors in observations and models, eliminating biases, and developing data assimilation algorithms and analysis software.

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Data to Determine Requirements for Additional Observations to Support Air Quality Forecasting

The existing air quality observation system has been designed to support air quality decision-making, compliance monitoring, and climate studies—not air quality forecasting. It is likely that new types of routine air quality monitoring would improve the accuracy of air quality forecast guidance, which can be translated into longer forecast lead times. A combination of field measurements to collect additional observations for a limited period over a wide region and modeling studies that evaluate the benefits of those measurements would provide the information required to guide additional observation investments for air quality forecasting.

Gaps include:

- **Modeling Studies for Observing System Design (NOAA).** Conduct modeling studies to determine which observations might most effectively contribute to improved forecasts.
- **Collect Sample Observations (NOAA).** Guided by the modeling studies, collect enhanced air quality data over a limited geographic and temporal period to simulate what an enhanced operational network might provide. This work could be conducted in conjunction with one or more field studies. This data will be used to confirm the results from the modeling studies and/or contribute to a more comprehensive understanding of how observations could support air quality forecast models.

5. ASSESSMENTS OF KEY AIR QUALITY PROCESSES

5.1 NEED AND RATIONALE

Air pollution sources and atmospheric processes that form, transport, and remove ozone, $PM_{2.5}$, and precursor species determine when and where air quality problems will occur. In many cases, uncertainties in the understanding of such scientific issues can lead to continued threats to public health or approaches that impose unnecessary burdens on the Nation (e.g., the Houston example).

5.2 GENERAL DESCRIPTION

Through intensive field observations and follow-up analysis, agencies characterize the key processes that drive air quality problems. These scientific assessments enable air quality decision-makers to make well-informed decisions that protect public health while also maintaining a vital economy. To address different agency missions, studies are conducted at hemispheric, national, regional, and local scales. These studies lead to policy-relevant summaries of the factors that drive air quality problems. Typical scientific issues addressed by air quality assessments include key chemical processes, factors affecting radiation balance, long-range transport of pollutants, top-down emissions inventory verification, and model evaluation.

While air quality and climate are often considered separately, they are different perspectives on one atmosphere—often with significant areas of overlap. As appropriate, multi-agency studies combine unique capabilities and mission-driven perspectives to provide a more holistic understanding of the atmosphere at less cost than would be possible with independent studies. For instance, NASA, NOAA, DOE, NSF, and a number of U.S. and international partners conducted the International Consortium for Atmospheric Research on Transport and Transformation (ICARTT) in 2004. ICARTT studied air quality and climate issues across the U.S., with a focus on New England and the Atlantic. The insight into atmospheric processes developed during ICARTT will inform policy development and planning for international, national and regional air quality and climate issues.

The observing systems deployed during regional assessments are typically state-of-the-science, providing much more information than permanent monitoring installations. However, these systems also require more hands-on intervention and specialized resources. Often, this work requires new instruments to measure parameters with higher sensitivity or frequency, which can lead to new techniques and equipment for routine monitoring. Field studies deploy observing systems in carefully planned suites that study processes from different perspectives. Integrated analysis of the data from those suites provides the information required to characterize and prioritize the importance of various physical and chemical processes, such as transport and emissions of pollutants and chemical reactions.

5.3 BENEFITS

These assessments provide information that drives improvements in all aspects of air quality management and modeling. These air quality assessments enable air quality policy-makers and environmental managers to more effectively develop approaches to reduce ambient air pollution while also maintaining a vital economy. The scientific information from assessments of key air quality processes also provides critical information for improving air quality models used for forecasting and management assessments.

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5.4 PRIMARY EXISTING SYSTEMS
- WP-3 Orion aircraft for *in situ* air quality measurements of the lower part of the atmosphere (NOAA);
- LiDAR aircraft for measurements in the lower troposphere (NOAA);
- Light aircraft for *in situ* measurements of surface fluxes (NOAA);
- Research Vessel Ronald H. Brown configured for studying air quality processes in marine and coastal environments (NOAA);
- DC-8 aircraft for *in situ* and LiDAR measurements in the mid- and upper-troposphere (NASA);
- WB-57 aircraft for *in situ* measurements in the mid- and upper-troposphere (NASA);
- J-31 aircraft for incoming and outgoing radiation measurements (NASA);
- G-1 aircraft for *in situ* measurements related to PM formation and effects (DOE);
- Ozonesondes (NOAA, NASA);
- Research wind profiler network for frequent characterizations of 3-D wind fields (NOAA); and
- Surface flux network for measuring transfer of pollutants from the atmosphere to the surface (NOAA).

5.5 PRIMARY ADDITIONAL PLANNED SYSTEMS
- Enhanced measurements of PM-related processes (NOAA)

5.6 GAPS
- Extending the spatial extent and duration of regional assessments to better characterize regional transport and to characterize more types of meteorological conditions that drive poor air quality, with the goal of providing the comprehensive information required by air quality decision-makers (NOAA).

6. IMPROVED EMISSIONS INVENTORIES

The National Emission Inventory (NEI) is a national database of air emission information that is compiled by EPA and used for a number of critical environmental management and policy activities. Emissions inventories catalog the amounts of pollutants emitted into the atmosphere. Inventories typically include emissions from several sources, including biogenic (e.g., biomass burning, VOCs released from forests), industrial, and transportation. Considerable uncertainties exist in these inventories, which affect the accuracy and reliability of simulations for air quality forecasting and air quality management assessments.

Observations support two general approaches to improve emissions estimates. The "bottom-up" approach uses observations to assess activities that cause emissions, such as identifying how much of a geographic area has been developed. The "top-down" approach uses observations of a primary (directly emitted) or secondary (formed by reactions in the atmosphere) pollutant to infer emissions. NARSTO has described a number of ways these approaches can be advanced and listed high priority inventories needing improvement, including biogenic emissions.[5]

6.1 NEED AND RATIONALE
Within the NEI, there is a critical need to improve the estimate of biogenic emissions, which include those from wildfires and other biomass burning. In particular, there is a need for a systematic framework within NEI to gather and calculate emissions from prescribed and wildland fires to produce an accurate and automated fire emissions inventory, including routine updating and reporting. In addition, measurements are required to better estimate other classes of emissions, such as mobile, that currently have large uncertainties.

6.2 GENERAL DESCRIPTION
A systematic framework within or supported by NEI regarding biomass burning emissions must include detection of fire events, estimates of fire fuel type, the amount of fuel consumed, and ambient air quality observations. Satellite-based fire detection products need to be evaluated and improved to advance their application to improving inventories. Also, more frequent updates to land cover and fuel maps could reflect changing fuel conditions. A highly automated framework could reduce biomass burning emissions inventory updates from a 2-year time lag to near-real-time. This activity would span organizational and state boundaries.

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[5] "Improving Emission Inventories for Effective Air Quality Management Across North America," NARSTO, http://www.narsto.org/section.src?SID=8.

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Much of the data, knowledge, and techniques are underutilized because tools to integrate the data are not readily available. GEOSS provides the opportunity for both bottom-up and top-down improvements in the inventory. As noted, the availability of specific fire information is a rich source of 'bottom-up" information on activity levels that with, modest direct chemical measurements of fire composition, will add significant contributions. From a "top-down" perspective, components of the integrated observation and modeling system will support an effective "inverse modeling" inventory enhancement by identifying key disparities (spatially and temporally) between predictions and observations. This product/service will make significant use of information generated as part of the integrated air quality data and air quality processes assessment products/services. Appendix B provides an example of how these sources of information can be integrated to improve emissions estimates (in this case with application to international transport assessments).

6.3 BENEFITS
Emission modeling utilizing all available data sources (including expanded observations) will help in lowering the uncertainty in retrospective and forecast models. This will improve air quality planning, regulatory decisions, and forecasts. The benefits also include timely allocation and fulfillment of requests for prescribed burning permits.

6.4 EXISTING COMPONENTS
- Monitoring and source characterization studies of all major categories of sources, including agricultural, landfill, and hazardous air pollutant emissions (EPA);
- Vegetation and landcover change datasets, including leaf-area and vegetation indices (NASA).
- Landfire data set providing high-resolution fuel information (USDA);
- Fuels Characteristics Class derived in part from NASA data used to estimate fire emissions (EPA);
- Analysis of emissions of nitrogen oxides and volatile organic compounds based on satellite observations (NASA);
- Identify locations of large fires from satellite observations (includes use of GOES Imager and Moderate Resolution Imaging Spectroradiometer [MODIS]) (USDA, NOAA, NASA);
- Identify burn scars (USDA);
- Collect emission factors and radiant energy information for planned and actual fires (USDA, EPA);
- Models to compute emissions from forest fires, such as BlueSky (USDA, EPA, NOAA);
- Field monitoring and reporting of wildfires and agricultural burns (USDA, States);
- Satellite-based monitoring of burn plumes and locations using MODIS instruments on Aqua and Terra, and GOES satellites (NASA, NOAA);
- Monitoring of lower tropospheric gases (NO_x, selected VOCs) and particulates from NASA and European satellites;
- Inverse modeling, where observations are compared to model predictions based on varying emissions estimates to identify and/or address issues with inventories - for instance, CMAQ and surface PM observations are used to estimate seasonal ammonia emissions (EPA/NOAA); and
- Space-borne LiDAR observations of PM from CALIPSO (NASA).

6.5 PLANNED COMPONENTS
- Advanced fire/burn-area detection from satellite (USDA, NASA);
- Routine gridded estimates of emissions from biomass burning (EPA, USDA); and
- Characterization of particulate matter emissions and hazardous air pollutants from aircraft engines that power commercial transport aircraft (FAA, EPA, NASA).

6.6 GAPS
Source oriented measurements of the chemical constituents from wildfires, and controlled burning efforts, including open agricultural burning operations. These measurements are necessary to produce emission factor estimates that vary across the type of burning operation (e.g., fuel/vegetation composition). The relative activity data (frequency, extent, duration, and location) provided by satellites is combined with emission factors to yield emission estimates.

Additional size-segregated and speciated emission measurements of pollutants and their precursors from additional major source categories, including: forests and crops, large-scale petrochemical and industrial facilities, animal feed lots, off-road mobile sources like farm and construction equipment, and air and marine transport, and paved and unpaved roadways.

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Inverse modeling assessment and improvement of emission inventories. The availability of the fused observation and air quality modeling datasets described in Section 1 can support emissions inventory improvement. What is lacking is a dedicated data analysis effort that specifically diagnoses the underlying causes leading to disparities between emissions and observations.

7. IMPROVED INTERNATIONAL TRANSPORT ASSESSMENTS

7.1 NEED AND RATIONALE

Air quality assessment and forecasting are linked and dependent on transport of pollutants across various scales (urban, regional, continental, and global). Ozone, PM, precursor species, and mercury all have potential for significant long-range transport both into and out of the United States. Such transport can be episodic, driven for instance by dust storms in Siberia and Africa, biomass burning in the Americas, or industrial/combustion emissions in Asia. In addition, recent observational and modeling studies indicate that intercontinental transport of air pollutants may persist over time and can have significant impact on air quality and climate. Assessment needs addressing long-range transport and climate-air quality interactions are founded on a set of common analytical tools (e.g., global scale modeling and emission inventories). Consequently, other efforts such as the International Polar Year 2007-2008 would realize peripheral benefits associated with GEOSS support for transport.

While components of transport characterization are included in all previous products (Sections 1-4), international transport characterization by itself stands as a seminal (and logical) product emerging from the GEOSS framework, particularly from hemispherical-and global-scale perspectives. The ability to bring together a diversity of physical and chemical data sets across a variety of scales in combination with predictive models in the aggregate forms the basis for sound transport analyses. For instance, The Long Range Transboundary Air Pollution Convention was enacted in 1979 and currently has 49 signatures. Eight protocols have been negotiated under the Convention, establishing a monitoring and modeling program and national obligations for emission reductions of SO_2, NO_x, VOC, NH_3, metals, and Persistent Organic Pollutants (POPs). Work is currently in progress to provide information and the scientific basis for hemispheric transport of air pollutants, and the United States and European Commission are the task force leads.

Imported transport of PM, ozone, and persistent bioaccumulative toxins such as mercury have the potential to become an increasingly important contributor to adverse U.S. air quality over the next two decades, given the growth projections of Asia and Central/South America. The relative influence also will grow as the United States continues to implement air quality regulations impacting emissions. In addition, EPA is reviewing the National Ambient Air Quality Standards for both ozone and particulate matter.

Current international transport assessments build on strengths provided by large-scale meteorological and physical transport models and access to a limited set of observations amenable to large scale air quality assessment and prediction. Important information gaps remain in:

- Air quality observations appropriate for characterizing transport across key import and export trajectories, and that separate pollutants aloft from those diffused down to ground level;
- More effective linking between global- and regional-scale meteorological and air quality models that enable impacts of transport to be quantified over short and long time periods; and
- Emission releases from emerging growth areas such as East and Southeast Asia, Africa, and Central/South America.

Clearly, GEOSS presents an opportunity to address directly some of the important information gaps attendant with international transport assessments.

7.2 GENERAL DESCRIPTION

The product envisioned is an improved integrated assessment capability that brings together observational sources and air quality models throughout the Northern Hemisphere and Equatorial regions.

Integrated observational datasets combining, on a hemispherical scale, remote satellite observations, aircraft, and land-based systems. This may include both routine observations and the more comprehensive and detailed datasets produced by air quality assessments. This component differs from the major data integration product (Section 1) by having a global scope but limited temporal period (e.g., selected episodes or years) without the automated data management infrastructure to support continuous updates and distribution (which could be added later).

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Improved model linkage that allows for the systematic and dynamic coupling across global-regional spatial scales and climate-air quality temporal scales. Currently, such coupling is usually unidirectional and difficult to implement, but the interactions between those scales are bidirectional and common.

Dedicated inflow and outflow sentinel observation platforms characterizing the amount and types of pollutants that cross continental U.S. boundaries and that are brought down to ground level.

International emissions inventory enhancements in those pollutant categories and geographical regions of greatest uncertainty and magnitude. Without such improvements, the contributions of tasks 1-3 by themselves will be insufficient to adequately evaluate model performance and future growth and related emission strategy scenarios.

7.3 BENEFITS
- Stronger analytical framework and scientifically sound tools for assessing the impact of international transport on air quality;
- Improved assessment framework for developing U.S. air program policy, (any analysis of internal policies will be contingent on an accurate understanding of long-range transport); and
- Scientific knowledge base for future international agreements on hemispheric transport of air pollutants.

7.4 PRIMARY EXISTING COMPONENTS
- Global scale air quality model platforms (e.g., GEOS-CHEM, Model for OZone And Related chemical Tracers-2, and RAQMS) by multiple agencies;
- Regional Scale air quality model platforms (e.g., CMAQ, WRF/CHEM) (EPA, NOAA);
- Observation platforms listed in Section 1 (satellite, land-based and vertical profiling systems) supported by multiple agencies;
- Global emissions inventories (EPA); and
- Observations of selected long-lived species from light aircraft (NOAA).

7.5 PRIMARY PLANNED COMPONENTS
- Improved linking and comparison of GEOS-CHEM and CMAQ (EPA)
- Model performance evaluation against satellite, aircraft intensive, and surface-based observations (EPA).

7.6 GAPS
- Sentinel land-based observation platforms dedicated to characterizing long range transport and mixing to the ground. Six monitoring stations capable of detecting Asian and African inflow to the United States and North American outflow to Europe. Parameters include CO, NO_2, NO_y, O_3, SO_2, $PM_{2.5}$ aethalometer (black carbon), continuous sulfate, and organic carbon (EPA);
- Mercury monitoring to supplement measurements for PM and ozone issues (EPA);
- Vertically resolved measurements of key species (EPA);
- An integrated data set composed from *in situ* and remotely sensed observations (EPA);
- Improved global emissions inventory and future projections, especially for rapidly growing countries such as China and India (EPA);
- Dynamic linking of global and regional models and model intercomparisons (EPA)
- Assessment of current and future transport based on the integrated data set and improved emissions inventory and models (EPA); and
- Vertically resolved NO and NO_2 measurements (NOAA).

8. RELATED ISSUE
Transport and diffusion modeling for emergency response is related to traditional air quality issues in that the people are exposed to harmful material in the air, but the sources are often much more localized than for air quality issues, and events can be very irregular—typically involving an unusual or accidental release of material. Examples include an accidental release of industrial materials. Risk mitigation includes collection and distribution of observational data, incorporation of the data in predictive/diagnostic tools, and interpretation of the results for those who take mitigating action. There appear to be significant near-term opportunities for the IEOS to improve the Nation's ability to deal with emergencies. For instance, see the Federal Research and Development Needs and Priorities for Atmospheric Transport and Diffusion Modeling (Office of the Federal Coordinator for Meteorological Services and Supporting Research, FCM-R23-2004, September 2004).

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9. PROJECT EXTENSIONS AND LONGER-TERM CONSIDERATIONS

Most air pollution assessments share a common need for an underlying characterization of physical and chemical processes that drive pollutant movement and reactions. Consequently, the work discussed in this plan can lead to additional future benefits. Example applications include:

Cross-media environmental assessments. Deposition of pollutants from the atmosphere to land and water surfaces is a major contributor to high mercury levels in fish (and people) and excess nutrients in estuaries and coastal regions. Improved understanding and modeling of air quality is a key component to assessments of such cross-media issues.

Bio-aerosol transport. Pollens and spores can be transported long distances in the air. Improvements in characterizing and modeling transport of particulate matter can contribute to assessments of bio-aerosol issues, such as the spread of soybean rust.

Redesigned air quality compliance system. The current point-based system of monitoring compliance with air quality regulations could be extended to use synthesized air quality surfaces harmonized with the physical/chemical environment to yield more realistic attainment and non-attainment boundaries.

Improved observing systems. The near-term opportunities will improve our understanding of requirements and opportunities for air quality observations. This may lead to observing systems such as advanced satellites with broader coverage of chemical compounds; higher horizontal, vertical, and temporal resolution; and/or greater temporal continuity.

Multi-scale exposure and health assessments. Integrating the work and results of air quality process assessments typically done at hemispheric to large urban scales with that of air quality composition and concentration studies done at regional to neighborhood scales can contribute to health effects studies.

Ongoing research is required to develop the advanced capabilities required to prevent and respond to such air quality issues. The Air Quality Research Subcommittee of the Committee on Environment and Natural Resources and its member agencies work to enhance the effectiveness and productivity of U. S. air quality research and to improve the information interface between research and public policy on these issues.

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APPENDIX A: SATELLITE SENSORS

Sensor	Name	Vertical extent of measurement	Horizontal resolution, domain	Target Constituent/ Property for air quality	Platform (launch)
Current and past instruments					
GOME	Global Ozone Monitoring Experiment	TR and ST	40 x 40 km², 40 x 320 km² swath	Tropospheric columns for O_3, NO_2, HCHO, clouds and aerosols	ESA ERS-2 (1995)
MODIS	Moderate Resolution Imaging Spectroradiometer	Surface to space	0.25 - 1 km, 2330 km wide swath	Aerosol column optical thickness, aerosol type (sulfate, biomass burning) over land	NASA Terra (1999) NASA Aqua (2002)
AVHRR	Advanced Very High Resolution Radiometer	Surface to space	0.5-1km, ~3km	Fire locations, aerosol column thickness	NOAA POES
MISR	Multi-angle Imaging SpectroRadiometer	Surface to space	275 m, 360km wide swath	Aerosol properties (angular radiance dependence)	NASA Terra (1999)
SCHIAMACHY	Scanning Imaging Absorption SpectroMeter for Atmospheric CHartographY	ST & TR	30x60 km, 960 km swath	O_3, NO_2, SO_2, aerosols	ESA ENVISAT (2002)
OMI	Ozone Monitoring Instrument	ST profiles, TR columns	48 x 48 km²	Tropospheric columns for O_3, SO_2, HCHO, NO_2, and aerosol	NASA Aura (2004)
TES	Total Emission Spectrometer	ST profiles, TR layers	26 x 42 km²	Tropospheric columns for O_3, NO_y, CO, SO_2, CH_4	NASA Aura (2004)
CALIOP	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations	ST profiles, TR profiles	0.3 x 0.3 km²	Aerosol density and radiative properties	CALIPSO (2006)
Future instruments scheduled to be launched					
VIIRS	Visible/Infrared Imager/Radiometer Suite	Surface to space	400m, ~3km swath	Aerosol column optical thickness, aerosol type	NPP (2008)
APS	Aerosol Polarimetric Sensor	Surface to space	1-4 km, 10km swath	Aerosols – optical depth, size	Glory (2009; formulation)
GOME-2	Global Ozone Monitoring Experiment	TR and ST	40km x 40km	Ozone profiles	MetOp (also does temp, humidity, and winds

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APPENDIX B: EXAMPLE OF INTEGRATED USE OF FIELD STUDY DATA AND MODELS TO ESTIMATE EMISSIONS
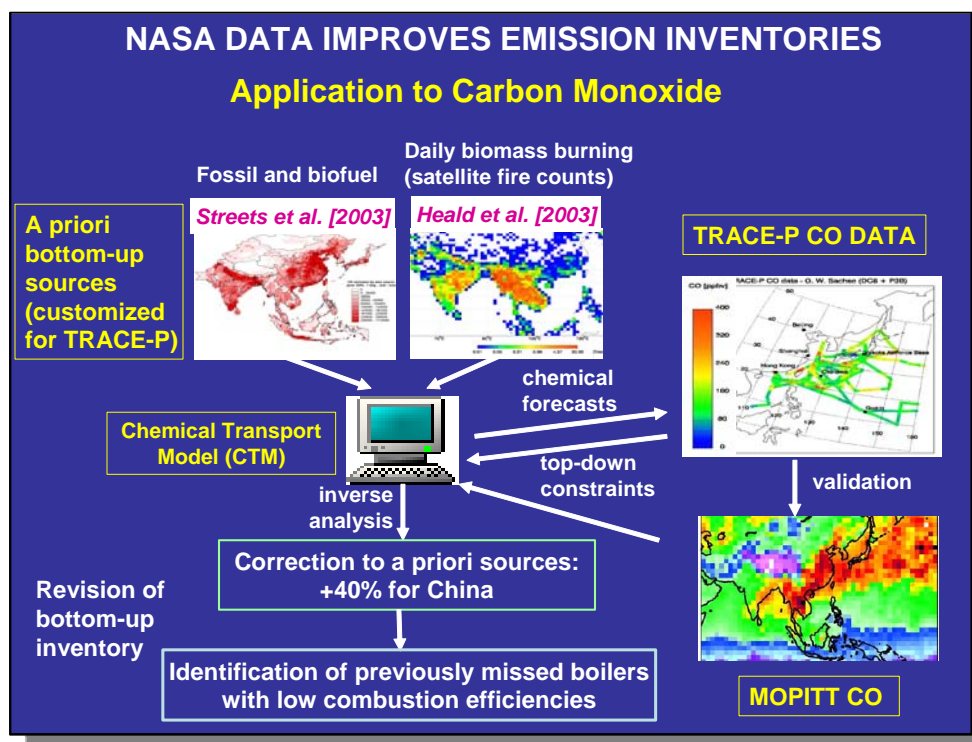
This figure summarizes the experimental design of the Transport and Chemical Evolution over the Pacific (TRACE-P) as an integrated chemical-transport model (CTM)-aircraft-satellite mission with application to analysis of Asian carbon monoxide (CO) sources. (CO is a byproduct of combustion.) A central objective of TRACE-P was to facilitate improved knowledge of Asian sources through combining top-down constraints from observations of Asian outflow together with the bottom-up inventories. *A priori* Asian emissions for the TRACE-P period, based on the best bottom-up understanding of processes, were generated prior to the mission by Streets (anthropogenic emissions) and Logan (biomass burning emissions). These were used in chemical forecasts by five different CTMs during execution of the mission to guide the aircraft towards Asian outflow and therefore optimize the testing of the models. Validation of the Measurements of Pollution in the Troposphere (MOPITT) CO observations was conducted during the mission to provide a seamless aircraft-satellite CO data set. The top-down CO data from the satellite and aircraft mission were then used in an inverse model analysis to improve the *a priori* emission estimates. Major conclusions were that anthropogenic emissions from China are 50 percent too low (indicating sources that were not included in the emissions inventory), biomass burning emissions from Southeast Asia are 60 percent too high, and Japanese and Korean emissions are roughly correct.

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