Satellite Data for the Air Quality Forecaster

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ABSTRACT
Satellite data have traditionally been underexploited by the air quality community. The Environmental Protection Agency (EPA), together with state and regional air quality agencies, rely instead on an extensive ground-based measurement network to monitor and predict urban air quality. Recent and planned technological advancements in remote sensing are demonstrating that space-based measurements can be an invaluable tool for air quality forecasting. Satellite data can aid in the detection, tracking and understanding of pollutant transport by providing observations over large spatial domains, and vertical information not available from traditional monitoring stations. Satellites can be the only data source in rural and remote areas where there are no ground-based measurements. Satellite data are being used qualitatively to provide the air quality forecaster a regional view of pollutants and to help assess the impact of events such as biomass burning or dust transport from remote sources. Space-based data can also be used quantitatively to initialize and validate air quality models. Just as new satellite data assimilation techniques are at the forefront of weather prediction science, satellite data assimilation should become an integral part of air quality forecasting. The amount of satellite data available is going to increase by five orders of magnitude over the next ten years including an abundance of information about pollutant concentrations not well-measured previously. It is essential to plan now to procure the capability to acquire, display, and assimilate these valuable sources of data into air quality assessment and prediction processes. This paper discusses how The Aerospace Corporation (hereafter referred to as "Aerospace") can help the air quality community in exploiting satellite data resources, provides examples of current systems that can provide air quality information and some the related research (which is expanded in the attached "Satellites that Detect Air Quality), and provides a view of the future generation National Polar-orbiting Operational Environment Satellite System (NPOESS).

The Aerospace Commitment
The use of satellite data for air quality applications has been hindered by an historical lack of collaboration between air quality and satellite scientists[1]. Aerospace, as a Federally Funded Research and Development Center (FFRDC) that provides research, development, and advisory services for the development and acquisition of satellite systems, can help bridge the gap between the satellite and air-quality communities. Aerospace has a long history of support to a wide variety of satellite programs including meteorological satellite programs, such as the Defense Meteorological Satellite Program (DMSP), NOAA Polar-orbiting Operational Environment Satellites (POES) and Geostationary Operational Environment Satellites (GOES) and, more recently, with environmental satellite systems such as the NASA Earth Observing System (EOS). Aerospace assists the Air Force in the transition of remote sensing, data assimilation, and numerical weather prediction technologies into operations at the Air Force Weather Agency. Aerospace is also supporting NASA in developing prototyping systems that demonstrate operational use of Earth Observing System (EOS) Aqua and Terra data. Aerospace is heavily involved in the future National Polar-orbiting Operational Environmental Satellite System

[1] AWMA ACE03 by J Engel-Cox/Battelle Memorial Inst, A Haymet/Dept Chem, U. Houston, R Hoff/Joint Center for Earth Systems Technology, U MD

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(NPOESS) that evolves the DMSP and POES operational "weather" satellites into an integrated operational environmental observing system that provides higher resolution and more timely data. Because NPOESS is a joint NOAA/NASA/DOD program, managed by NOAA, Aerospace involvement in environmental data exploitation has broadened beyond military weather applications to include air quality. This is particularly true now that NOAA has teamed with EPA to provide national real time air quality forecasts. Aerospace is well positioned to provide air quality agencies insight to the development and acquisition of environmental satellite systems such as NPOESS, and to assist with transitioning satellite data applications into prototype capabilities for the air quality mission.

Background

Global scale climate and weather prediction related concerns have driven the design for many weather and environmental satellite sensors that have been flown to date, though research is advancing that demonstrates that these data are directly applicable to regulatory and operational air quality missions. While EPA models for regulatory air quality modeling are quite sophisticated, neither ground or space-based measurements of either weather nor air quality data are routinely used for regulatory (non-real time) air quality modeling. In addition to regulatory air quality modeling, there is a need to issue real time operational air quality forecasts. Meteorological satellite (METSAT) data are used to generate the weather forecasts that support operational air quality predictions, but no space based pollution data are used in forecasting air quality. Data are available today that can be used to generate imagery and graphical displays to assist the air quality forecaster. Techniques can be developed to quantitatively assimilate these satellite data sets into the air quality forecast models for either regulatory or real time air quality prediction. The recent agreement between NOAA and EPA to provide national forecasts of ozone and fine particulates represents a new era in air quality forecasting in which satellite data will become essential for establishing the background and boundary conditions necessary to model air quality on a national scale.

Meteorological Satellite (METSAT) data is currently used operationally in numerical weather prediction (NWP) models. Examples include DMSP microwave moisture and temperature profiles, and sea surface winds, GOES cloud drift winds, and infrared (IR) temperature and moisture soundings, POES IR and microwave radiances, and NASA EOS ocean surface wind speed and direction. Chemical data assimilation is in its infancy for both ground and space based measurements of air pollutants. Research is needed to adapt the techniques, used to initialize NWP models with METSAT data, to the assimilation of remotely sensed pollutant data into air quality models. Initial research has begun to explore the impact of chemical data assimilation on air quality model prediction skill and which methods, such as 4-dimensional variational analysis, are most suitable for chemical data assimilation.[2] Such investigations are a critical first step and should be expanded upon to include the assimilation of space based air quality data.

Space-based air pollution data sources

The combination of measurements from current and planned environmental satellite sensors that measure the troposphere will play an increasingly important role in explaining chemistry and transport processes in the lower atmosphere. NASA and EPA are sponsoring a joint project, IDEA (Infusing satellite Data into Environmental Air quality applications), to investigate the use of NASA satellite measurements to improve air quality assessment, management, and prediction. The IDEA project has evaluated existing satellite based measurements of the criteria pollutants O3, SO2, NO2, CO, and aerosols (PM2.5), in comparison with EPA ground based data, to

[2] Chemical Data Assimilation in Support of Air Quality Forecasting Gregory R Carmichael, University of Iowa, Iowa City, IA; and A. Sandu, D. Daescu, T. Chai, J. Seinfeld, P. Hess, and T. Anderson

demonstrate the great potential benefit of these satellite data sources to the detection of emissions and their transport. [3] The European Computational Assessment via Remote Observation Systems, ICAROS, project has demonstrated the use of Landsat and SPOT data to provide a relative quantitative scale of urban air pollution, specifically fine particulates and SO2.[4] The third in a series of NASA Earth observing satellites is designed to study the Earth's ozone, air quality and climate, with one of the sensors designed specifically to measure tropospheric trace gases. There are numerous satellite sensors with some type of aerosol-detection capability, including the detection of smoke plumes from fires, from which emissions estimates can be derived. Satellite imagery has traditionally been used to characterize land cover to estimate biogenic emissions and is now being used more directly to perform inverse analysis of biogenic emissions. There are several satellite missions designed to detect stratospheric ozone that can also provide information on tropospheric ozone levels. [5]

Operational Use of Satellite Data

Much, though not all, of the research to date to detect pollutants from space has focused on science-mission sensors, in which the satellite-overpass times and or swath widths limit the data-refresh times, or the data processing and distribution times limit the data timeliness. This is changing rapidly however. While science-satellite missions may not have been designed to meet operational timelines, many initiatives are underway to use the data operationally. NASA is sponsoring extensive research to facilitate the operational use of Earth Observing System (EOS), particularly for the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor aboard both the Terra and Aqua satellites. These data are now being routed to the Air Force Weather Agency (AFWA) and to Fleet Numeric Meteorology and Oceanography Center (FNMOC) in near-real-time for direct support to operational weather forecasting. Both Terra and Aqua platforms have a direct broadcast X-band downlink that allows MODIS data to be received in real time by sites having the proper reception hardware. In order to facilitate use of the data, science production software is being freely distributed through the International MODIS/AIRS processing package (IMAPP). The Texas Commission on Environmental Quality (TCEQ) recently purchased an EOS ground station to obtain real-time MODIS products to assist in monitoring the transport of aerosol borne pollutants. The Naval Research Laboratory (NRL) enhanced the MODIS aerosol detection algorithms for operational applications and developed a global, multi-component aerosol analysis and modeling capability to combine satellite-based aerosol retrievals with other available data sources for the analysis and prediction of global and regional aerosols.[6] NASA, NOAA and the DoD are sponsoring the Joint Center for Satellite Data Assimilation to fully exploit the assimilation of satellite data for both operational and research purposes.

NPOESS

NPOESS marks a new era in advanced environmental monitoring from space. Science environmental satellites and operational weather satellites and will be merged into an integrated operational environmental observing system. NPOESS satellites will fly in three orbital planes providing frequent data-refresh and rapid-downlink, and processing that delivers the products in

[3] Utilization of NASA Data and Information to Support Emission Inventory Development, Doreen Neil and Jack Fishman NASA, Jim Szykman EPA

[4] http://mara.jrc.it/orstommay.html, http://mara.jrc.it/icaros.htm
http://www-ceneg.cma.fr/Public/themes_de_recherche/teledetection/title_tele_air/mapping_of_urban_air/view

[5] Global distribution of tropospheric ozone from satellite measurements using the empirically corrected tropospheric ozone residual technique: Identification of the regional aspects of air pollution J. Fishman , A. E. Wozniak, and J. K. Creilson, Atmos. Chem. Phys., 3, 893–907, 2003, www.atmos-chem-phys.org/acp/3/893/

[6] http://www.nrlmry.navy.mil/aerosol/Docs/nrlmryonrprop.html

less than a half hour. The system will also have direct broadcast for immediate receipt. The increased data quality, refresh, timeliness, and volume have tremendous potential to improve both numerical weather and air quality prediction in the next decade.

The requirements for the NPOESS system are developed through a Joint (NASA, NOAA, DoD) Agency Requirements Group (JARG). Though air-quality agencies did not play a role defining requirements for the baseline system, many of the eleven baseline sensors aboard NPOESS will provide data directly applicable to monitoring air pollutants. The Visible Infrared Imaging Radiometer Suite, VIIRS (a follow-on sensor for DMSP OLS and POES AVHRR, and EOS MODIS) will provide MODIS-like aerosol products. In addition, the NPOESS mission will include an instrument dedicated to aerosol detection, the Aerosol Polarimeter Sensor (APS). APS will first fly on a NASA mission in the 2007 timeframe. High-spatial-resolution thermodynamic soundings will be provided by the Crosstrack Infrared Sounder (CrIS) and can contribute to the detection of trace gas concentrations. The Ozone Mapping and Profiler Suite (OMPS) consists of a nadir system for both total column ozone and profile ozone observations, as well as a limb system for high vertical resolution profile ozone observations. NPOESS is not required to deliver lower tropospheric ozone concentrations, but studies with data from heritage sensors indicate this information can be derived. The CrIS, VIIRS, and OMPS sensors will first fly in 2006 on the NPOESS Preparatory Project (NPP) satellite, an NPOESS risk reduction mission that will also provide a bridge between NASA's EOS Aqua and Terra and the first NPOESS satellite in 2009.

The historic lack of collaboration between satellite and air quality agencies has prevented air quality agencies from taking steps to ensure they are prepared to make maximum use of the vast NPOESS satellite data resources. However, numerous avenues exist to stay abreast of and even affect the NPOESS program. The NPOESS acquisition process is designed to allow the science and user community to be involved: the NPOESS IPO sponsors scientists to participate in Operational Algorithms Teams (OATs) and to perform Internal Government Studies (IGS); NASA sponsors experts to advise and perform related analyses through the NASA NPP Science Teams (N^2ST); the system contractor, Northrop Grumman Space Technology (NGST) sponsors an external Science Advisory Team and special topic studies.

NPOESS requirements include Pre-planned Product Improvements (P^3I), mission needs that could not be met based on Concept Design studies and thus were not included in the program baseline. DOC and DoD maintain a need for these observations, however, and the NPOESS acquisition process allows for continued examination of possible solutions. For example, three trace gases are included in the NPOESS P^3I: CH4, CO and CO2. Discussion is underway on whether NPOESS should pursue further study into measuring trace gases with CrIS. Recommendations are also being considered to enhance the VIIRS fire detection algorithm to provide assessments of fire area, temperature, and emitted power that will lead to improved estimates of fire emissions.

Potential improvements also include active LIDAR systems for wind profile measurements and enhanced vertical resolution water vapor, temperature, and ozone profiles.[7] These are examples of numerous system trades ongoing in which air quality needs, if properly communicated, could potentially affect NPOESS design. It is essential that the EPA take an active interest in the development of this next generation operational environmental observing system.

Under contract with NOAA, Aerospace plays a major role supporting the NPOESS Integrated Program Office (IPO) in program oversight, performing analyses to verify design, and conducting data exploitation research. Aerospace serves as the government's technical lead on many of the NPOESS sensors and participates in all the NGST core Integrated Product Teams (IPTs) as well as supporting NPOESS Customer Forum (NCF), the OATS, and N^2ST. Aerospace

[7] 84th Annual AMS Conference, Improved Sounding Capability, William L. Smith, LaRC, NASA

supports requirements definition and evolution helps ensure these user requirements are accurately interpreted. Aerospace also directly supports the AWFA user in defining the NPOESS interface and in preparation for operational implementation of NPOESS products. The Aerospace centrality to the NPOESS program can be leveraged by the Air Quality community to make maximum use of this valuable satellite resource to the benefit the air quality forecasting mission.

About The Aerospace Corporation

Aerospace is a nonprofit corporation that operates a Federally Funded Research and Development Center (FFRDC) to provide research, development, and advisory services for the development and acquisition of satellite systems, from on-orbit hardware to ground-based processing systems and data exploitation. Our primary customer is the DoD Space and Missile Systems Center (SMC) in Los Angeles, although Aerospace also supports NOAA, NASA and other government agencies. Aerospace has around 3000 employees, with 2000 in the Los Angeles offices, 500 in the DC area, and the rest in smaller offices around the country (Cape Canaveral, Houston, Albuquerque, Colorado Springs, Denver, Omaha, Vandenburg, and Sunnyvale). The corporate website www.aero.org provides organizational information about Aerospace. Crosslink magazine http://www.aero.org/publications/crosslink/headlines.html provides an interesting glance at the variety activities at Aerospace.

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