Attachment: Satellite Sensors that Detect Air Quality

Aerosols

There are numerous satellite sensors with some type of aerosol detection capability: Each type of satellite system and its sensors have strengths and weaknesses for aerosol detection. The NOAA Polar Operational Environmental Satellite (POES) Advanced Very High Resolution Radiometer (AVHRR) and the NASA Moderate Resolution Imaging Spectroradiometer (MODIS) yield high spatial resolution; NASA Stratospheric Aerosol and Gas Experiment (SAGE) gives vertical resolution; the Total Ozone Mapping Spectrometer (TOMS) detects aerosols over land, but at coarse resolution. An algorithm is under development to retrieve smoke optical thickness and size distribution and derive aerosol mass using the 8 wavelength, 1km resolution Sea-viewing Wide Field-of-view Sensor (SeaWiFS) data. Work is underway to derive aerosol optical thickness using NOAA Geostationary Operational Environmental Satellite (GOES) data in that provides frequent refresh. VIIRS (Visible Infrared Imaging Radiometer Suite), the NPOESS follow sensor for the Defense Meteorological Satellite Program (DMSP) Operational Line Scan (OLS), POES AVHRR, and EOS MODIS will provide MODIS like aerosol products. In addition, the National Polar-orbiting Operational Environment Satellite System (NPOESS) will include an instrument dedicated to aerosol detection, the Aerosol Polarimeter Sensor (APS). APS will first fly on the NASA Glory mission in the 2007 timeframe.

Aerosol Optical Depth and Cloud Optical Thickness are products MODIS sensor aboard both the NASA EOS-Terra and Aqua Satellites. These data, when combined with hourly in-situ PM2.5 mass concentrations from the ground monitoring network, and NOAA National Center for Environmental Prediction (NCEP) model 48 hour forecast data, provide for a synoptic view of aerosol and aerosol transport. Such a depiction is a valuable tool for generating daily air quality forecasts.[1]

Several case studies have been conducted that demonstrate that MODIS data can dramatically improve the manual detection of pollution and enhance the use of the ground based measurements available to the air quality forecaster. This space based view enables monitoring air pollution events over extended periods and geographical areas. A relationship between MODIS Aerosol Optical Thickness (AOT) and ground based hourly fine particulate ($PM_{2.5}$) has been shown that allows MODIS AOT to be used qualitatively and quantitatively to estimate Environmental Protection Agency (EPA) air quality categories.[2] [3]

The Naval Research Laboratory (NRL) has developed a global, multi-component aerosol analysis and modeling capability (called NAAPS: Navy Aerosol Analysis and Prediction System) to combine current and expected satellite-based aerosol retrievals with other available data sources for the analysis and prediction of global and regional aerosols.[4]

Biomass burning CO

The MOPITT (Measurement Of Pollution In The Troposphere) aboard the NASA Earth Observing System (EOS) Terra satellite is a thermal and near IR gas correlation radiometer designed specifically to measure CO profiles and total column CH4. The resolution is 22km horizontal resolution, though the refresh is 3 days. Pinpointing the sources of airborne chemical species is an

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[1] UTILIZING MODIS SATELLITE OBSERVATIONS IN NEAR-REAL-TIME TO IMPROVE AIRNow NEXT DAY FORECAST OF FINE PARTICULATE MATTER, PM2.5 2000). James Szykman*, John White US EPA, Office of Air Quality Planning and Standards

[2] Applications of MODIS satellite data and products for monitoring air quality in the state of Texas, Keith Hutchison, University of Texas, Atmospheric Environment 37 (2003) 2403-2402

[3] Intercomparison between satellite-derived aerosol optical thickness and PM2.5 mass: Implicatins for air quality studies. Jun Wang and Sundar Christopher, University of Alabama. Geophysical Research Letters, Vol 30, No 21, 2095, doi:10.1029/2003GL018174, 2003

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

important role for MOPITT. Although it cannot distinguish between individual industrial sources in the same city, it can map different points of origin that cover a few hundred square miles. This is accurate enough to differentiate air pollution from a major metropolitan area, for example, from a major fire in a national forest. In addition to being a pollutant, CO gas is a useful tracer for other pollutants, such as ozone at or near ground level. CO can also be used to calculate the level of pollutant-cleansing chemicals in the atmosphere, such as the hydroxyl radical. When CO levels are high, the level of the hydroxyl radical is usually lower and fewer pollutants are removed from the atmosphere. A technique has been demonstrated in which radiative transfer modeling is used to determine the amount of CO required to agree with MOPITT observations of elevated CO in conjunction with biomass burning. This technique can also be used to help determine the impact of intense local pollution sources on regional air quality. CO can serve as a pollution tracer because it is produced by incomplete combustion (e.g. electricity generation, petroleum processing, etc.) Combined with Radiative Transfer Modeling, the MOPITT data can be used to improve emission estimates from regional sources. MOPITT measurements are establishing a record of global CO distribution and both regional and global seasonal variations. On a global scale, the impact of biomass burning on global air quality is evident. Assimilating the CO data in MOZART makes it possible to constrain the model's distribution of other chemical species, such as ozone and the hydroxyl radical, that are related to CO through chemical reactions but cannot be directly detected from space. Also, the location and strength of CO sources can be inferred and the data applied to other pollutants, such as nitrogen oxides, produced by the same combustion processes.[5]

MODIS data are also used to predict and monitor emissions from forest fires nationwide. The Fire Lab receives the MODIS Direct Broadcast (DB) in real time as the satellites pass overhead. This data are used to monitor area recently burned using two methods: a preliminary near-IR spectral test being developed at NASA and the convex hull of the cumulative active fire pixel centers (hot spots) when thick smoke obscures the burn scar. Emission factors from previous studies are used to estimate fire emissions from the MODIS observations. The emission estimates are used by a NOAA model to predict the dispersion of the emissions at three-hour intervals over several days.[6] The NPOESS is developing VIIRS fire detection algorithms that may produce products such as the fire area, temperature, and emitted power that will lead to improved estimates of fire emissions.

A new instrument in orbit aboard NASA's ICESat satellite—the Geoscience Laser Altimeter System (GLAS)—reveals another dimension of the California wildfires. By transmitting a green beam of laser light downward at the Earth and then precisely measuring how much of that light is backscattered back up into space, GLAS can determine the vertical structure of clouds, pollution, or smoke plumes in the atmosphere.

PM and Toxic Pollutants

Satellite imagery has been used to develop refined spatial surrogates for use in emissions modeling. LANDSAT 15-meter panchromatic and the higher resolution IKONOS 1-meter panchromatic and 4-meter color imagery can be used in the development of emission inventories for particulate matter less than 10 microns (PM10) and in the development of border area inventories for toxic and criteria air pollutants. This type of satellite imagery has been used in the development of temporal distributions in crop cover and related emissions.[7] IKONOS, SPOT HRV, and the Landsat Thematic Mapper (TM) sensors provide low refresh, but high-resolution information at the regional to local levels. Strong correlation has been found between satellite observations in the thermal infrared and measurements of

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[5] Carbon Monoxide Measurements From Terra/MOPITT: Improving Emissions, D.P. Edwards, NCAR

[6] Development of A Forest Fire Smoke Emission and Dispersion Model Using Real-time MODIS Data Wei Min Hao, J. Meghan Salmon, and Bryce Nordgren USFS Rocky Mountain Research Station, Missoula Fire Sciences Laboratory

[7] Use of Remotely-Sensed Data in the Development and Improvement of Emission Inventories Stephen M. Roe, Joel Hearne E.H. Pechan & Associates, Inc., Shingle Springs, CA 95682 Tom Summers, Randy Sedlacek, Darlene Jenkins Arizona Department of Environmental Quality, Phoenix, AZ 85007

air quality, such as black particulate, sulphur dioxide and nitrogen dioxide. Such correlations can be used to develop models to convert satellite imagery into a pollutant quantity that can be applied periodically over the same urban area to provide a detailed mapping of the air quality. The European Computational Assessment via Remote Observation Systems (ICAROS) project has demonstrated the use of Landsat and SPOT data to determine air quality at the urban level, by quantitatively subtracting a clear day image from images of polluted days. This provides a relative quantitative scale of air pollution, specifically fine particulates (0.1-3um) and SO_2.[8]

Trace Gas Missions

The NASA Aura mission, to be launched later this year, will measure atmospheric chemistry, following up on measurements which began with NASA's Upper Atmospheric Research Satellite (UARS) and continuing the record of satellite ozone data collected from the TOMS missions. The Aura Tropospheric Emission Spectrometer (TES) is designed specifically to measure numerous trace gases. It will provide simultaneous measurements of NOy, CO, O3, and H2O and measurements of SO2 and NOy. The remaining Aura sensors, Microwave Limb Sounder (MLS), Ozone Monitoring Instrument (OMI), and the High Resolution Dynamics Limb Sounder (HIRDLS) are primarily designed to retrieve temperatures and concentrations of data in the stratosphere, but yield atmospheric chemistry data in the upper troposphere.

Three trace gases are included in the NPOESS Pre-planned Product Improvements (P^3I): CH4, CO and CO2. NPOESS P^3I are 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. These gases can be measured by virtue of their IR absorption features. The NPOESS Crosstrack Infrared Sounder (CrIS) records a high-resolution spectrum of the atmosphere; the full spectral resolution is not needed to meet the baseline sounding product requirements, but could perhaps be exploited to measure trace gases. A study on the feasibility of trace gas measurements with the European METOP Infrared Atmospheric Sounding Interferometer (IASI), a sensor very similar to CrIS showed predicted detectability appears to meet trace gas goals. There has also been investigation of trace gases in to determine the impact on CrIS H20 retrievals. Discussion is underway on whether NPOESS should pursue further study into measuring trace gases with CrIS. This is an excellent example of an area in which the air quality community could potentially affect the design of an NPOESS sensor, but is essential that the EPA take an active interest in the development of this next generation operational environmental observing system.

Formaldehyde/Isoprene

GOES imagery can be used to improve spatial and temporal estimates of photosynthetically active radiation (PAR) needed to determine isoprene emission. MODIS-derived products offer the potential to provide more finely resolved vegetation classes.[9] Satellite imagery is being used more directly to perform inverse analysis of biogenic emissions. For example, GOME data are being used to derive formaldehyde as a check against estimated isoprene emission distributions. [10]

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

[9] Improving Biogenic Emission Estimates with Satellite Imagery
Thomas E. Pierce Atmospheric Sciences Modeling Division/ARL National Oceanic and Atmospheric Administration, Research Triangle Park, North Carolina

[10] Palmer, P. I. D. J. Jacob, A. M. Fiore, R. V. Martin, K. Chance, and T. Kurosu,Mapping isoprene emissions over North America using formaldehyde column observations from space, J. Geophys. Res. , 108, 4180, doi: 10.1029/ 2002JD002153, 2003.

Landuse Categorization

Satellite imagery has traditionally been used to characterize land cover used in estimation of biogenic emissions. AVHRR derived landscape characterization and forest cover datasets significantly enhances the Biogenic Emission Landuse Database (BELD). Vegetation data in the current version of the Biogenic Emissions Inventory System (BEIS) are largely based on the USGS National Land Cover Characteristics (NLCC) dataset, which is derived from AVHRR imagery. The NLCC data have been further augmented with a forest fraction database available at 1 km resolution from the U.S. Forest Service and based on analysis of AVHRR, LANDSAT, and ground-truth measurements. LANDSAT 15-meter and the higher resolution IKONOS 1-meter and 4-meter images have been used to develop detailed land use data to support the development of bottom-up emission estimates for windblown dust and agricultural sources.[11] AVHRR data has also been used to more directly drive biogenic emission calculations.[12]

Ozone

Both science and operational ozone missions, such as the current NASA Total Ozone Mapping Spectrometer (TOMS) and Stratospheric Aerosol and Gas Experiment (SAGE), the NOAA SBUV and the planned OMI and OMPS sensors, are designed to monitor stratospheric ozone. However, a technique has been developed to derive tropospheric ozone by using coincident observations of total ozone from the TOMS instrument and stratospheric ozone profiles from the SAGE or the Solar Backscattered Ultraviolet (SBUV) instrument. OMI, scheduled to fly in the spring of 2004 will provide a smaller footprint, enhancing the applicability of tropospheric ozone retrievals to urban air quality. The NPOESS Ozone Mapping and Profiler Suite (OMPS) includes a nadir system that has two focal planes: one operating from 300 to 380 nm for total column ozone observations; the other operating at 250 to 310 nm for profile ozone observations. The limb system has one focal plane operating from 290 to 1000 nm for high vertical resolution profile ozone observations. The UV Nadir Total Column Ozone Algorithm is adapted from the heritage TOMS algorithm with enhancements to meet NPOESS requirements and to provide for graceful degradation for less than optimal conditions. The UV Nadir Profile Ozone Algorithm is adopted from the heritage SBUV/2 operational algorithm. The ozone profile from this algorithm not only provides an initialization for the UV/VIS Limb Profile Algorithm but also provides a link to the heritage twenty-year ozone profile data set. The UV/VIS limb profile ozone algorithm is adapted from the heritage SOLSE/LORE algorithm enhancements. In addition, data from the NPOESS Crosstrack Infrared Sounder (CrIS) sensor could be used to generate ozone total column data products for very high solar zenith angles (>80 degrees). In order to improve the performance of the ozone retrieval, auxiliary parameters such as temperature and moisture profiles, surface emissivity, and surface skin temperature are retrieved simultaneously with the ozone column amount.

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[11] Improving Biogenic Emission Estimates with Satellite Imagery, Thomas E. Pierce Atmospheric Sciences Modeling Division/ARL National Oceanic and Atmospheric Administration, Research Triangle Park, North Carolina

[12] Estimates of biogenic emissions using satellite observation, Xu et al. Atmospheric Environment, vol. 36, 2002)