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Integrated Earth Observations: Application to Air Quality and Human Health

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Integrated Earth Observations: Application to Air Quality and Human Health

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Integrated Earth Observations: Application to Air Quality and Human Health

On 1-2 August 2005, the National Institute of Environmental Health Sciences and the Environmental Protection Agency sponsored a workshop, "Integrated Earth Observations: Application to Air Quality and Human Health". The goal of the workshop was to identify the data user requirements and products that would enable air quality and climatological data derived from the international Global Earth Observation System of Systems (GEOSS) and from the U.S. Integrated Earth Observation System (IEOS) to be used effectively in public health research, planning, policy, and management of disease. The workshop brought together data producers, data organizers, and data users in a multi-disciplinary, interactive format to identify user requirements and research gaps and needs in the respiratory, cardiovascular and developmental abnormalities/birth defects fields. The workshop was limited to forty experts in data production, organization, and health applications.

The enthusiasm generated by discussions between data producers and data users, as well as the identification of available remotely sensed data sets and potential demonstration projects fulfilled the goals of the workshop. The organizing committee thanks the sponsors, speakers, and participants and looks forward to the success of their research projects emanating from this workshop. Additionally, we thank Charles W. Schmidt for preparing the draft workshop report and the workshop participants who reviewed the final draft.

Sincerely,

Organizing Committee

NIEHS: Sally Tinkle
Mary Gant
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ABSTRACT

In February 2005, ministers from 60 countries and the European Commission met in Brussels, Belgium to endorse the 10-year plan for a Global Earth Observation System of Systems (GEOSS) prepared by the Group on Earth Observations (GEO), a partnership of nations and international organizations. This multinational project integrates surface-based, airborne, and space-based remote sensing and in-situ networks to improve knowledge of the environmental factors that affect human health and well-being. Shortly thereafter, in April 2005, the US Government released its Strategic Plan for the US Integrated Earth Observation System (IEOS), which provides a framework for US contributions to the GEOSS, and also strives to meet requirements for high-quality data on the state of the Earth as a basis for policy and decision-making and to provide more accurate exposure assessments for the health and environment research communities. The plan was drafted by the US Group on Earth Observations (USGEO), an interagency subcommittee that reports to the National Science and Technology Council's Committee on Environment and Natural Resources.

Both the GEOSS and the IEOS emphasize consideration of user needs in the development of Earth observation data architectures. Toward this end, the National Institute of Environmental Health Sciences (NIEHS) and the Environmental Protection Agency (EPA) co-sponsored a workshop that united 40 health and Earth observation scientists in a dialogue over data-user requirements. The results of the workshop titled *Integrated Earth Observations: Application to Air Quality and Human Health*, which was held at NIEHS on 1-2 August 2005, are described in this report. Experts in meteorology, atmospheric chemistry, satellite engineering, and ground-based air measurements represented the Earth observation sciences. Health scientists provided expertise in epidemiology, exposure assessment, biostatistics, spatial statistics, clinical research, toxicology, informatics, and modeling.

Participants were tasked with two key objectives: 1) To determine whether integrated Earth observations could provide useful public health tools for research, policy decisions, and environmental and health planning; and 2) To identify opportunities for improving user access to Earth observation data generated by producers, including the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), and the Environmental Protection Agency (EPA).

The focus on air quality derives from substantial evidence that ozone and respirable particulates produce a spectrum of health effects. Long implicated as respiratory toxicants, these pollutants have more recently been linked to cardiovascular disease, in addition to developmental problems and birth defects. Remote sensing will augment ground-based air quality sampling and help fill pervasive data gaps that impede efforts to study air pollution and protect public health. Expanded Earth observations could support detailed inquiry into environment-disease interactions, and help create predictive exposure models that support science-based environmental and health decision-making.

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OPENING REMARKS

Gary Foley, Director, National Exposure Research Laboratory, EPA
Welcome and Overview of the GEOSS

In his opening remarks, Dr. Foley underscored the challenge of transforming Earth observation data into useful information. The motivating goal, he said, is to use the data to enhance interconnected decision-making that promotes health and environmental sustainability. But to achieve this goal, better ways are needed to deliver the data to users in research, management, and environmental forecasting.

Foley emphasized that the GEO started with a vision to improve sustainability and then went on to identify nine areas that could benefit from expanded Earth observation technologies: Weather forecasting, disaster reduction, ocean resources, climate, sustainable agriculture, human health and well-being, ecological forecasting, water resources, and energy.

Now, the GEO is exploring the needs of the user community, Foley said. The current workshop, he said, provides an opportunity for health scientists to describe what they do, and in this way, contribute to data architectures that suit their requirements and efforts to create better decision tools. The challenge, Foley concluded is for specialists to learn each other’s language, jargon, and research requirements. Foley pointed to existing relationships in this area among the Centers for Disease Control and Prevention (CDC), EPA, NASA, NOAA, and the National Weather Service, adding that multidisciplinary partnerships are essential to the overall effort.

PLENARY SESSION I: Data Production (What can be measured)

The first plenary session featured data producers from NOAA, EPA, and NASA. The goal was to provide a summary of remote sensing platforms for analysis and prediction of regional air quality.

S.T Rao, Director, Atmospheric Sciences Modeling Division, EPA/NOAA
Integrating Air Quality Data to Inform Human Health Decisions

Dr. Rao addressed data production by NOAA’s Atmospheric Sciences Modeling Division (ASMD), which develops modeling and decision support systems for air quality forecasting and management. Ground-based monitors deployed by states and federal agencies are limited with respect to spatial coverage, Dr. Rao said. Monitoring stations are rare in rural areas and temporal air quality estimates for ozone and particulates can vary on an hourly to weekly basis. Meanwhile, public health concerns compel efforts to broaden spatial coverage and measures of pollutant characteristics and concentrations.

The ASMD works with the National Weather Service to forecast air quality in areas where ground-based monitors are inadequate or absent. Forecasts are derived with the community multi-scale air quality (CMAQ) model, which was developed by EPA’S Office of Research and Development in partnership with NOAA. The CMAQ model links meteorological information to pollutant emissions data derived from local traffic patterns and industrial inventories. By simulating chemical reactions and pollution transport and removal processes, the model generates air quality forecasts for local advisories.

Dr. Rao said the ASMD currently investigates methods to merge ground-based air quality monitoring data with CMAQ model outputs. The goal is to produce spatial maps that describe air quality at a specified grid resolution, for instance, every 12 kilometers. Two methods are applied to these efforts: One of these—Bayesian statistics—provides spatial descriptions of predicted air quality along with defined levels of uncertainty. Another method known as Bayesian kriging also produces statistically unbiased estimates of spatial variation, but this method is much more computationally intensive.

Additional research efforts, Dr. Rao said, will link satellite data with CMAQ model outputs. Rao emphasized a strong correlation between a satellite parameter known as aerosol optical depth (AOD), which describes the mass of aerosols in an atmospheric column, and $PM_{2.5}$ concentrations at the ground, particularly in summer when vertical columns in the atmosphere are more integrated. The incorporation of satellite data into CMAQ modeling will allow ASMD researchers to better characterize the spatial and temporal variability of ground-level pollutants.

Richard Kleidman, NASA/Goddard Space Flight Center (GSFC) and Science Systems and Applications, Inc.
Viewing Atmospheric Aerosols from the MODIS Satellite Sensor

The Moderate Resolution Imaging Spectroradiometer (MODIS) resides aboard NASA's Terra and Aqua satellites. Dr. Kleidman's talk addressed two MODIS data products: Aerosol Optical Depth (AOD) and Fine-Mode Fraction.

As noted previously, AOD is a quantitative measure of total column aerosol, which is the mass of aerosols within a measured column extending from Earth to the top of the atmosphere. The fine-mode fraction corresponds to particles within the AOD with a radius of 0.6 micrometers or less. Dr. Kleidman stated that the fine-mode fraction correlates best with anthropogenic emissions while AOD is more representative of natural aerosols, such as dusts and sea salts. Both values are provided daily and also as monthly averages in a MODIS data product known as Level 3. MODIS products are validated by AERONET (Aerosol Robotic Network), which is a global system of approximately 100 ground-based sun-photometers.

MODIS uses different algorithms to turn land- and sea-based measurements into data products. Ocean measurements of AOD and fine-mode fraction—in part because they are made over the homogenous surface of the sea—have less associated uncertainty. Ocean fine-mode fraction measurements are used quantitatively, while land-based measures of the same parameter can only be used as a qualitative indicator of whether AOD values are dominated by natural or anthropogenic emissions.

Today, AOD data products are used in conjunction with EPA ground-based measurements for operational $PM_{2.5}$ air quality forecasting. AOD generally correlates well with $PM_{2.5}$ measurements. However, AOD does not specify the location of aerosols within a column, and likely overestimates actual concentrations at the ground level, Dr. Kleidman said. Ground and spaced-based Light Detection and Ranging instruments (LIDARs) that use lasers to augment sunbased photonic measurements in addition to space-based instruments that measure polarized light should dramatically enhance the capacity of remote sensors to forecast $PM_{2.5}$ over land.

Dr. Kleidman concluded with a description of four pipelines that deliver MODIS data to the user:

- The Goddard Distributed Active Archive Center provides MODIS data in Hierarchical Data Format (HDF) within 24 hours.
- Direct broadcast systems operated collaboratively by NOAA, NASA, and the University of Wisconsin provide MODIS data as it comes over the horizon, typically within several hours.
- MODIS Aerosol and Associated Parameters Subset Statistics produce monthly or daily data. Frequently associated with co-located AERONET sites. Data can be downloaded and used in spreadsheets. See http://modis-atmos.gsfc.nasa.gov/MAPSS
- The MODIS Online Visualization and Access System (MOVAS) offers an interactive tool to graph and plot monthly mean data delivered in American Standard Code for Information Interchange (ASCII) format. See http://g0dup05u.ecs.nasa.gov/Giovanni/

Shobha Kondragunta, Research Physical Scientist and Air Quality Team Lead, NOAA/NESDIS Office of Research and Applications
Availability and Uses of Operational Satellite Data

The NOAA/NESDIS Office of Research and Applications (ORA) develops algorithms for retrieving geophysical parameters from satellite data. Dr. Kondragunta described NOAA’s satellite program and its application to studies of infectious disease and predicted assessments of air quality.

NOAA's Earth observations program encompasses both polar-orbiting satellites (which travel over both poles on a daily basis) and geostationary satellites (which remain in a fixed position in sync with the Earth's rotation, allowing them to make continuous measurements over a particular location). Combined, these satellites generate atmospheric and land-based measures of cloud cover, aerosols, ozone, ocean surface temperature, ice and snow cover, wind, and other parameters.

Dr. Kondragunta described a NOAA study showing that malaria epidemics correlate with a parameter called the vegetation health index (VHI); a unitless value derived from satellite measurements of surface temperature and precipitation. The VHI is derived with the Advanced Very High Resolution Radiometer (AVHRR), a remote sensor developed by NOAA to characterize surface temperatures and cloud cover.

The ORA also collaborates with the National Weather Service to improve air quality forecasting, which is limited by source data for pollutant emissions. To illustrate, Dr. Kondragunta described an occasion during which CMAQ predictions had underestimated pollution levels in the continental US by failing to incorporate long-range transport of smoke from Canadian and Alaskan forest fires. In this particular case, the fires were located beyond the CMAQ model's geographic domain. NOAA's geostationary satellites measured particle emissions from these sources and thus provided more accurate assessments of air quality than those predicted by the CMAQ model. Dr. Kondragunta said she is currently developing algorithms that will incorporate real-time emissions from burning biomass into CMAQ models to improve forecast accuracy.

Dr. Kondragunta also described a collaborative effort with the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) to develop algorithms for use in next-generation Global Ozone Monitoring Experiment 2 (GOME 2) instrument, which will be launched on the MetOP satellite in 2006. These algorithms will produce near real-time troposphere measurements of many air pollutants, including nitrogen dioxide, sulfur dioxide, carbon monoxide and ozone, among others.

Richard Scheffe, Office of Air Quality Planning and Standards, USEPA

Ambient Air Observation Systems: Infrastructure for Air Pollution and Health Effects Associations

Ground-based air quality monitoring networks deployed throughout the United States routinely measure pollutants that include $PM_{2.5}$, PM_{10}, ozone, NO_x, NO_2, CO, lead, ozone precursors, sulfur, and nitrogen. Most of these data are generated by states and local air quality monitoring stations. The EPA's primary role is to apply the data towards program goals in a number of areas, such as identifying non-attainment areas under the Clean Air Act, developing emission control strategies, tracking progress on pollution control, and supporting basic research, among others.

The most robust air quality networks are devoted to ozone and $PM_{2.5}$, the latter accounting for up to 70% of the nation's regulatory air quality monitoring budget. $PM_{2.5}$ sampling occurs at roughly 1,000 sites throughout the country. Routine speciation, whereby the levels of sulfate, nitrogen, and carbon in $PM_{2.5}$ aerosols are quantified, occurs at approximately 400 sites nationally.

Dr. Scheffe raised a number of concerns with the current monitoring system. Spatial coverage for $PM_{2.5}$ and ozone are adequate, however sampling for multiple pollutants is rare, and monitoring locations are designated by convenience rather than design. Critics of the current approach recommend a more integrated, multi-pollutant strategy with real time reporting capability.

In response to these recommendations, EPA will soon propose the National Core Network (NCore), which revises current sampling strategies in a number of ways. The overall goal is to de-emphasize regulatory compliance in favor of a suite of broader objectives, including better assessment of human pollutant exposures and health effects.

NCore measurements comprise three levels: Level 1 measurements will take place at 3- 10 master sites. The goal is to generate multi-pollutant data that advance method development and technology transfer.

Level 2 measurements will generate core data at 75 sites for numerous pollutants including NO, NO_x, SO_2, CO, $PM_{2.5}$, PM_{10}, ozone, and ozone precursors. Level 3 measurements will be made for single pollutants—mainly $PM_{2.5}$ and ozone) at roughly 500 sites. Ideally, the NCore data infrastructure will accommodate data from additional sources, including space-based remote sensing.

PLENARY SESSION II. Data Integration (Translating data to information)

Brenda Smith, Geospatial Information Officer, USEPA

Integrating and Accessing Spatial Data: Challenges and Successes

Ms. Smith began her presentation by defining terms used in Earth observations. Two such terms are Geographic Information Systems (GIS), which refer to technologies that organize and display geo-referenced data for solving complex resource planning and management problems; and remote sensing, which refers to technologies that monitor atmospheric and ground-based features from a distance. Smith pointed out that remote sensing can detect features from far-space, near-space, airborne, and terrestrial vantage points.

Ms. Smith then described several GIS data formats. One of these, known as vector data, connects X, Y, and Z coordinates in ways that form points, lines, and polygons. This format is best suited to data structures that represent features, such as well locations, rivers, and lakes. Another format, known as raster data, places data values within squares distributed on an evenly spaced grid. Raster formats are well suited to pictures and images of land cover, elevation and slope. In addition, metadata allows users to inquire about the origins, history, and quality of a particular dataset used in GIS modeling.

Ms. Smith emphasized that GIS systems allow many questions to be answered simultaneously. However, implementation challenges remain, she said, particularly with regards to identifying and fulfilling user needs. A key problem, Smith stated, emerges when new technologies are developed without sufficient, up-front evaluation of user requirements. In these cases, the technologies are adapted to purposes for which they may not be well suited.

Ray Hoff, Professor, Department of Physics, University of Maryland, Baltimore County (UMBC) and Director, Joint Center for Earth Systems Technology
Integrating Spatial Data to Address Air Quality

Dr. Hoff contrasted the strengths and weaknesses of ground-based and satellite approaches for measuring air quality. Ground measures, he explained, provide continuous pollutant measures at discrete locations. Thus, they offer optimal temporal resolution but their spatial coverage is poor. Satellites, on the other hand, offer tremendous spatial coverage, but have drawbacks that limit their use for health research. This is in part due to the distances and atmospheric changes through which photons must travel before reaching remote sensors in space, Hoff said. With few exceptions, satellite-based spatial resolution ranges from one to 10 square kilometers, which may be inadequate for health studies. In addition, most satellites quantify column airborne aerosol levels without specific reference to concentrations on the ground. The best air quality assessments, Dr. Hoff concluded, emerge from integrated datasets that include both satellite and ground-based measures.

Dr. Hoff went on to discuss LIDAR systems, which deploy lasers from space or Earth to augment passive solar detectors found on most satellites today. LIDAR systems allow scientists to add a vertical component to column measurements. Thus, they offer three-dimensional views of atmospheric columns (that also include two horizontal planes: north and east) that allow for assessments of ground level air quality.

NASA's new CALIPSO satellite, for instance—developed cooperatively with the French government and launched on October 26, 2005—uses LIDAR to measure discrete vertical columns at a resolution of 37 meters. NASA's GLAS (Geoscience Laser Altimeter System) satellite, launched in 2003, achieves a vertical resolution of 75 meters.

Dr. Hoff also discussed a new 3D air quality system (3D-AQS) being developed by UMBC with assistance from NOAA, NASA, Battelle Memorial Institute, and other organizations. The 3D-AQS will use LIDAR to integrate vertical dimensions at a scale of 7.5 meters into the EPA's air quality forecasting efforts.

Finally, Dr. Hoff described new research from his students showing that AOD measurements made in eastern regions of the United States correlate highly with hourly $PM_{2.5}$ measurements.

PLENARY SESSION III. DATA USE (Application of information to human health)

Doug Dockery, Harvard School of Public Health (HSPH)

Spatial-Temporal Analysis in Air Pollution Epidemiology

Dr. Dockery began with a discussion of the NIEHS-funded “Harvard Six-Cities Study,” which ranks among the most influential, long-running investigations of air pollution and human health. Launched in 1973, the Six Cities Study—conducted in Watertown, Massachusetts; Portage, Wisconsin; Topeka, Kansas; Kingston/Harriman, Tennessee; St. Louis, Missouri; and Steubenville, Ohio—showed that increased mortality correlates with elevated levels of airborne particulates. Additional Harvard investigations using data from the American Cancer Society’s Cancer (ACS) Prevention Study found similar associations, Dockery said.

More recent investigations show that air pollution variability within cities correlates with differential health outcomes. For example, reanalysis of the ACS data show mortality rates within Los Angeles vary among high and low air pollution areas designated by zip code. Based in part on these findings, Dr. Dockery emphasized the need for air pollution monitoring data that resolves spatially on a scale of city blocks. This need, he said, offers a clear opportunity for satellite data. (At this point, Dr. Hoff mentioned that ground-based LIDAR systems now used for national security could enable finer-scale spatial resolution for health research).

Dr. Dockery described new Harvard research that suggests a need for greater temporal satellite resolution. These investigations study the relationship between air pollution and cardiac events measured by implanted defibrillators. Preliminary data show increased risk of ventricular arrhythmia with increasing particle levels. These findings, Dockery said, point to the need for air pollution monitoring at extremely fine time scales, on the order of minutes to hours. Ideally, technology enhancements will drive improvements in both spatial and temporal resolution that facilitate in-depth assessments of air pollution and human health.

Marie Lynn Miranda, Professor, Children's Environmental Health Initiative (CEHI), Nicholas School of Environment and Earth Sciences, Duke University
Spatial Analysis of Mercury Policy Options

The CEHI is a research, education, and outreach program committed to fostering environments where children can prosper. Dr. Miranda described a CEHI effort to compare mercury emissions reductions in North Carolina resulting from two distinct policy options: 1) Maximum Achievable Control Technology with 90% reduction standard (MACT90); and 2) a national cap and trade program with caps set at 26 and 15 tons in 2010 and 2018 respectively (NCT2615). Mercury emissions data were obtained from the EPA's Toxics Release Inventory for 2002 and also from the North Carolina Department of Environment and Natural Resources' Division of Air Quality. The CALPUFF, a multi-layer, multi-species non-steady-state puff dispersion model that simulates the effects of time- and space-varying meteorological conditions on pollution transport, transformation and removal, was used to predict air concentrations, in addition to wet and dry deposition rates, among 5200+ census block groups located in North Carolina.

The key findings are:

- Preliminary analyses suggest that MACT90 achieves greater reductions than NCT2615; however, North Carolina's mercury emissions reporting programs leave out important sources. Moreover, new cap designations proposed under the EPA's new Clean Air Mercury Rule were higher than those used in the analysis.
- Both programs produce the greatest benefits in areas of the state where the population is more affluent and more likely to be Caucasian.

Dr. Miranda proposed a variety of additional data that could improve modeling efforts: These include: 1) comprehensive inventory of mercury emissions across space and time; 2) emissions fingerprints off stacks; 3) event-based wet deposition sampling; and 4) high-altitude sampling. The characterization of these parameters provides an opportunity for remote sensing.

Judith Qualters, Chief, Environmental Tracking Branch, National Center for Environmental Health, Centers for Disease Control and Prevention (CDC)
Integrating Earth Observations and Health Data for Public Health Surveillance

The Environmental Tracking Branch bears responsibility for implementing the CDC's National Environmental Public Health Tracking (EPHT) Program, which was initiated at the request of Congress in 2002. The EHPT Program goals are twofold: to integrate information about environmental hazards, human exposures, and disease; and to deliver this information to state and local agencies working to protect public health.

Two specific EPHT projects were discussed in detail. The first, known as the Public Health Air Surveillance Evaluation Project (PHASE), critiques methods to generate surrogate measures of ozone and $PM_{2.5}$ that can be linked to health effects data corresponding to asthma and acute cardiac events. This effort is a collaboration of CDC, EPA, and scientists from health departments in three states: Maine, New York, and Wisconsin. Four methods for characterizing air quality are currently being investigated: 1) proximity-based assessments derived with local ground monitoring stations; 2) statistical interpolation of ambient air monitoring data using kriging techniques that extrapolate continuous surface estimates from a known set of sample points; 3) CMAQ modeling; and 4) Bayesian methods that combine monitoring and CMAQ data. Results of this comparison are ongoing and conclusive results are not yet available.

Dr. Qualters then described another multi-agency EPHT project called Health and Environment Linked for Information Exchange, Atlanta (HELIX-Atlanta). This project seeks to build an EPHT network in five Atlanta counties: Clayton, Cobb, DeKalb, Fulton, and Gwinnett. As part of these efforts, EPHT scientists combine MODIS AOD measures generated by the Terra and Aqua satellites with ground-based $PM_{2.5}$ monitoring to estimate population exposure. The goal is to enhance spatial and temporal coverage with remote sensing data. Qualters stated that AOD measures correlate best with ground-based monitoring in the summer, likely because of stronger boundary layer mixing during the warmer months. Thus, as it currently stands, the Helix-Atlanta respiratory health and birth defects projects will add AOD simulations into exposure assessments only in summer until technical details are resolved.

PLENARY SESSION IV

Guy Duchossois, Work Plan Manager, GEO Secretariat, Geneva Switzerland

Overview of the GEO Work Plan

Dr. Duchossois first listed numerous European initiatives in Earth observations by entities that include the European Union, the European Space Agency (ESA), and the European Center for Medium-Range weather forecasts. He then shifted his talk to a discussion of the GEO and its development of a ten-year plan for a Global Earth Observation System of Systems (GEOSS). [N.B. At the time of the workshop GEO membership included 58 member nations, the European Commission, and 43 international organizations; an additional eight nations joined by October 2006.]

The GEO Work Plan is divided among two, six, and 10 year targets. The initial focus is on 107 two-year targets, of which 14 focus specifically on health. Among these, three were highlighted: 1) advocate new high-resolution Earth observations relevant to health needs; 2) facilitate mechanisms to translate data user needs into requirements that data generators can address; 3) facilitate development of data products and systems that integrate Earth science databases with health and epidemiological information.

To advance these aims, the GEO is now strengthening links with the World Health Organization and participating in workshops planned by the European Commission, the US EPA, and the ESA. In addition, GEO is sponsoring with WHO a workshop on human health, the environment and Earth observations. The draft GEO 2006 Work Plan is being prepared for submission to the GEO Executive Committee, with comments expected back in late October. It will be submitted with a report on 2005 achievements for approval by the GEO at its meeting in December 2005.

Dr. Duchossois emphasized that health is a top GEO priority in its plan for the GEOSS and that Earth observations— despite gaps in coverage—have the capacity to advance health studies in many parts of the world, including developing nations. He reported that representatives of the G8 nations expressed strong political support for the GEO at their Summit in Gleneagles, Scotland in July 2005. They welcomed the adoption of the ten-year plan for the development of the GEOSS and made a commitment to move forward in implementing it in their member states and to support efforts to help developing countries obtain full benefit from GEOSS.

Meredith Golden, Center for International Earth Science Information Network, The Earth Institute, Columbia University

Confidentiality Issues and Policies Related to the Use of Geospatial Data

Ms. Golden pointed out that data gaps in Earth observations derive from sampling shortages and also from confidentiality mechanisms that restrict data access. To define confidentiality, Golden quoted Mark Rothstein, Professor of Law at the University of Louisville: "The right of an individual to prevent the redisclosure of certain sensitive information that was disclosed originally in the confines of a confidential relationship."

Ms. Golden cited three reasons to protect confidentiality: 1) Confidentiality preservation is regarded as an ethical statistical practice; 2) confidentiality preservation may be required by law or regulation or by organization policy; 3) it is believed that respondents would not divulge confidential information truthfully or completely without assurance of confidentiality preservation.

Spatial data pose unique threats to confidentiality, Golden stressed, because they are often publicly available and displayed as maps. Relational databases could conceivably link a subjects' personal information with visual imagery of their residential locations. Ms. Golden pointed out that the QuickBird satellite's fine spatial resolution is sufficient to visualize and identify individual households. Thus, researchers must consider how data gathered during Earth observations research are used, to ensure that privacy and confidentiality are protected.

WORKING GROUP REPORTS

Working groups were organized and asked to consider: (1) Types of data collected versus needed; (2) Areas of application for remotely sensed measurements; (3) Strategies for data integration and application; (4) Knowledge Gaps; and (5) Impediments of remote sensing data to cardiovascular health.

1. Cardiovascular Working Group

Types of data collected versus data needed

Existing sources of remote sensing data were listed for ground-level particulates and ground-level gases (namely, carbon monoxide and ozone).

Particulate data sources include ground-based monitors, MODIS, NOAA's Geostationary Environmental Satellites (GOES), NOAA's Advanced Resolution Very High Radiometer (AVHRR), and the Automated Weather Observing System (ASOS), which is a suite of ground-based meteorology sensors deployed jointly by the National Weather Service, the Federal Aviation Administration, and the Department of Defense. For gases, the key source was said to be Differential Optical Absorption Spectroscopy (DOAS), which is an emerging technique for trace gases measurement. Emerging and future sources of remote sensing data cited by working group participants include LIDAR spatial maps and the CALIPSO satellite, which will be launched in 2006 to provide the next generation of climate observations, including an advanced study of clouds and aerosols, drastically improving our ability to predict climate change and to study air pollution and transport.

In terms of data needs, the working group identified greater quality assurance and data documentation mechanisms, historical GIS information, and spatially distributed data for cardiac risk factors, such as housing characteristics, traffic emissions, point-source pollution emissions, and residential locations for susceptible populations, such as the elderly and under-served minorities.

Areas of Application within cardiovascular research for remotely sensed data

Application areas that might be served by remote sensing data were classified as clinical and sub-clinical cardiovascular outcomes that might be linked to acute or chronic exposures on individual or population-based levels. Among the clinical outcomes are myocardial infarction, arrhythmias, heart failure, hypertension and stroke. Hospital admissions or emergency room visits for these outcomes could be evaluated in population-level as well as individual-based studies. Sub-clinical outcomes include heart rate variability, blood pressure, changes in the ST-segment that represents the period of ventricular muscle contraction before repolarization, brachial artery diameter, flow-mediated dilation, systemic inflammation, and measures of atherosclerosis.

Opportunities for data integration and application

The working group participants identified opportunities for pilot studies evaluating the potential for data integration and application. Ground level central site and personal measurements might be supplemented by data from remote sources: (1) to estimate exposure during times and days when there were no ground level measurements; and (2) to get better spatial resolution of certain pollutants measured only at central ground sites. However, a more specific understanding is needed of the temporal and spatial resolution of exposure measurements that could be specifically linked to past or ongoing measurements of health outcomes, and the comparability of exposures estimated from global Earth observations to ground level observations. If feasible, a combination of MODIS measures and ground-level $PM_{2.5}$ might be incorporated into several ongoing studies, including the Harvard's Nurses Health Study and the American Cancer Society's Cancer Prevention Study, to assess chronic cardiac effects of ambient pollutants. Moreover, MODIS measures of aerosol optical depth could be applied to acute health studies, such as the Harvard investigation of air pollution and its effect on ventricular arrhythmias or paroxysmal atrial tachycardia detected by cardiac defibrillators. However, pollution data applied to these acute studies must be resolved at a scale of 24-hours or less to be useful.

Opportunities and challenges for data integration and application

Remote sensors used for particulates and gases were said to have a number of drawbacks. Those used for particle detection, for instance, were described as limited with respect to both spatial resolution and their capacity to identify chemical composition. Moreover, remote sensors are unable to measure ultra-fine particles with a diameter of less than 2.5 micrometers that are now implicated in a range of cardiac health effects. The detection of ground-level ozone gas was also said to be problematic, chiefly because of the need to subtract out stratospheric ozone, which filters ultra-violet solar rays. Efforts to improve spatial resolution may be complicated by higher noise-to-signal ratios, which could limit precision. Participants also speculated that privacy and national security concerns could limit the availability of remote sensing data and thus its application to human health research.

Knowledge gaps: data measurement

Quality assurance mechanisms are potentially not as robust for remote sensing data as they are for conventional regulatory measurements. In addition, cloud cover, snow reflectivity, and diminished vertical mixing all reduce the accuracy of ground-level pollutant levels measured in winter.

Knowledge gaps: data application

Participants noted that polar orbiting satellites have higher spatial resolution but less temporal detail owing to Earth's rotation beneath them. Geostationary satellites, on the other hand, have greater temporal resolution (on the order of four measurements per hour) but lower spatial resolution. U.S. investigators need to become more familiar with measurements being conducted by colleagues from Europe, Asia and other areas outside of North America, participants said.

Impediments to application of remotely sensed data to cardiovascular health

Privacy concerns articulated by the Health Insurance Portability and Accountability Act (HIPAA) must be considered in studies that link addresses and geocodes to exposure measurements. HIPAA regulations designed to protect patient privacy could limit access to hospital data. Homeland security concerns may also limit access to satellite data.

Challenges of and barriers to multidisciplinary problem solving between biological and physical scientists

Limited knowledge of data availability and the lack of resources to translate raw data into useable formats were cited as barriers to multidisciplinary research in this area. In addition, the use of technical jargon and the lack of avenues for effective communication can inhibit collaborations necessary for multidisciplinary research.

Demonstration Project

Several demonstration projects were proposed. Researchers could compare cardiovascular associations with particle exposures estimated from ground versus satellite measurements. A combination of MODIS measurements with ground-level measurements for $PM_{2.5}$ might be incorporated into both the Harvard's Nurses Health Study and the American Cancer Society's (ACS) Cancer Prevention Study to assess chronic cardiac effects of ambient pollutants. Moreover, MODIS measurements of aerosol optical depth could be applied to acute health studies, such as the Harvard investigation of air pollution and its effect on ventricular arrhythmias or paroxysmal atrial tachycardia detected by cardiac defibrillators. Participants emphasized repeatedly that remote sensing data must be matched appropriately with the applications under investigation. Along these lines, spatial and temporal limits may not impede research on chronic applications. However, acute studies--for instance those that address myocardial infarction, stroke, or pollution-related factors that trigger implanted defibrillators--do require highly resolved temporal data.

2. Respiratory Working Group

Types of data collected versus data needed

The respiratory working group identified several data needs that apply to remote sensing and studies of respiratory health. These include additional mechanisms for data quality assurance and control, and access to long-term data for retrospective research. Participants suggested remote sensing could help fill gaps in existing data, and singled out inadequate air quality assessments downwind of urban areas as a key opportunity, but greater use of remote sensing must be accompanied by validation studies to confirm that remote sensing and ground-based measurements are comparable.

Areas of application within respiratory research for remotely sensed data

Participants proposed that remote sensing might differentiate anthropogenic and natural sources of dust, particularly pollen grains, which can—in the opinion of some health scientists—pose health risks equal to or greater than those posed by criteria pollutants. EPA does not currently measure pollen levels, so this presents an opportunity for remote sensing, the participants concluded. Remote sensors can detect bioaerosols from space, but the associated methods have not yet been standardized. Thus, an alternate approach was proposed—namely to construct predictive models for pollen release based on seasonal information and geophysical parameters such as temperature, sunlight, humidity, and vegetation health.

Participants also suggested that remote sensing could advance knowledge of large-scale respiratory health events, such as the dramatic rise in asthma cases typically observed in Baltimore, MD, during the month of September.

Strategies for data integration and application

Remote sensing could be integrated with data from the EPA's Supersites program, which uses ambient monitoring to address the scientific uncertainties associated with fine particulates. However, in order for remote sensing to function in this context, methods for data reduction and uncertainty analysis must also be developed.

Knowledge gaps: data measurement and application

Knowledge gaps were categorized by relevance to either Earth or health sciences. In terms of the latter, knowledge gaps include inadequate measures of coarse versus fine particles; inability to distinguish chemical species; and insufficient vertical modeling for ground-level contaminants. Health science knowledge gaps include limited population-based surveillance systems; insufficient sample sizes; poor characterization of residential and activity-based mobility patterns; and inadequate awareness of individual susceptibilities and risk factors.

Knowledge gaps: data integration

Scientists should confirm temporal and spatial concordance of remote sensing data, focusing in particular on optimal data resolution for specific health outcomes and affected populations. International collaboration and data exchange was suggested as a mechanism for enhancing data integration.

Challenges of and barriers to multidisciplinary problem solving between biological and physical scientists.

The main barriers to multidisciplinary collaboration were said to be the lack of effective communication among data users and producers and support for multidisciplinary, multiproject research. Continued dialogue among specialists and cross-disciplinary education were proposed as solutions.

Demonstration Project

Participants suggested a study of asthma. Such a study would layer remote sensing data for meteorology, fine particulates, and bioallergens over geo-referenced datasets for asthma prevalence and exacerbation. Geo-referenced data would be obtained from health maintenance organizations, hospitals, and large-scale surveys such as the CDC's National Health and

Nutrition Examination Survey (NHANES). The effort would build on existing studies and use remote sensing to fill gaps in exposure data.

3. Reproductive Working Group

Types of data collected versus data needed

Participants emphasized that studies linking remote sensing to reproductive health effects must delineate specific outcomes, such as fetal death, stillbirth, post-infant mortality, and subclinical events such as neurological and immune dysfunction. Integration of satellite-based exposure data must consider windows of reproductive vulnerability (for instance, early pregnancy), which remain poorly understood. Database needs were cited in the area of reproductive outcomes and residential history for study subjects.

Areas of application within reproductive health research for remotely sensed data

Participants questioned whether remote sensing could provide better air quality data than that provided by EPA's current monitoring programs in metropolitan areas. Niche applications might be found in areas where current ground-based networks do not currently exist. Several application areas for these locations were identified. Among them is the need to identify windows of vulnerability before, during, and following parturition; the need to identify acute versus chronic pollutant exposures and their differential reproductive effects; and efforts to assess pollutant interactions with maternal and fetal genetic susceptibilities. Participants focused their discussions on low-birth-weight and pre-term birth, which are currently the best-understood outcomes.

Strategies for data integration and application

Existing and on-going birth outcome and child development studies that allow for incorporation of air pollution data should be identified and compiled. The CDC's National Birth Defects Prevention Study, which is among the largest case-control studies ever on the causes of birth defects, was proposed as a possible candidate. Participants emphasized that if remote sensing is to comprise the source of air pollution data, then it must be resolved appropriately, with a minimum sampling frequency of once per day, and a minimum spatial resolution of one square mile.

Knowledge gaps: data measurement

Measurement gaps were identified in three key areas: time-activity data for pregnant women and children that overlay with pollutant exposure and outcome data; uncertainty estimates for measures of air pollution derived with remote sensing, and data corresponding to non-criteria pollutants, such as ultrafine particles.

Knowledge gaps: data integration and application

Participants recommended the creation of lists that correlate health outcomes with exposure to criteria and/or toxic air pollutants. Similarly, participants suggested that air pollutants that can be monitored with remote sensing be listed, with accompanying assessments of how remote sensing measures of these pollutants compares with ground- based measurements in under-sampled areas, such as rural locations.

Impediments to application of remote sensing data to reproductive health outcomes

Several key impediments to the use of remote sensing in reproductive health studies were identified. These include inconsistent temporal and spatial matching with health outcomes of interest; problems extrapolating ground-level concentrations from column AOD measurements; insufficient spatial resolution; and remote sensing's inability to identify air toxics, such as metals and ultrafine particles.

Challenges of and barriers to multidisciplinary problem solving between biological and physical scientists

The main barriers to multidisciplinary collaborations were said to be the absence of personal relationships among biological and physical scientists; and difficulties with integrating data needs for population-based human studies with those of in-depth, cellular and molecular studies of individuals. The first study type requires long-term, population-level exposure data and additional measures that account for confounding and risk modification. The second type of study incorporates biomarkers and other in-depth exposure characterizations that are not feasible in population studies.

Demonstration project

Projects were proposed on both neighborhood and regional scales. On a neighborhood scale, reproductive outcomes data could be linked with remote sensing data archives, such as those produced by Canada's Measurements of Pollution in the Troposphere (MOPITT) instrument which measures atmospheric carbon monoxide. On a regional scale, existing satellite data could be linked to epidemiological data, in an effort to match pollutant levels with adverse reproductive outcomes. Participants emphasized the need for preliminary studies that compare results obtained with remote sensing-based exposures with results obtained from ground-level monitoring-based exposures. Should remote sensing provide comparable results then greater use of the technology for reproductive and developmental effects studies is warranted.

CONCLUSIONS

The workshop successfully fostered a vigorous exchange of information between scientists from the Earth observation and health research communities. It established additional communication links between the producers of air quality measurements and health researchers and practitioners who use those data to understand the effects of air pollution on human health and make decisions regarding public health. The workshop has launched what will ideally become far more robust and sustainable collaborations between these data producers and data users than exists at the present time.

In addition to a discussion on data architecture (the way data are organized, stored, and made available to users), health scientists raised feasibility issues. These issues focused on several key areas, including quality assurance and control for remote sensing data; correlations with ground-based measurements; limits on temporal and spatial resolution; the capacity to assess chemical speciation from space; extrapolation of ground-level pollutant levels from measures of aerosol optical depth (AOD); and data limitations imposed by national security concerns. On the other hand, health scientists were also optimistic that technology issues can be resolved and that remote sensing will increasingly complement ground-based measures in studies of air pollution and health. Emerging LIDAR systems, for instance, which provide vertical resolution for AOD, can be used to quantify pollutant levels on the ground. Moreover, studies increasingly show that column AOD measures correlate with $PM_{2.5}$. Health scientists from CDC, EPA, and other federal and state agencies described growing uses for remote sensing, which provides a valuable supplement to ground-based air measures and opportunities for predictive modeling.

THE SECRETARY OF HEALTH AND HUMAN SERVICES
WASHINGTON, D.C. 20201

Dear Participants:

Welcome to the "Integrated Earth Observations: Application to Air Quality and Human Health," workshop co-sponsored by the Environmental Protection Agency and the National Institute of Environmental Health Sciences.

Through your participation in this workshop, you join a growing list of national and international experts who are focusing their research efforts on linking remote sensing and ground-based earth observations techniques designed to improve the management of our environment and improve human health. Geographical and climatological data obtained through the Integrated Earth Observation System (IEOS) will support more complex and detailed inquiries into environment-health interactions and lead to the development of more comprehensive predictive exposure-health models. These models will support the development of disease management plans specific to an individual's exposure environment and provide indicators for disease prevention in large populations. The use of geospatial data in IEOS will help us improve the urban environment, preserve the rural environment, plan for city growth, and create healthy cities. The vision for IEOS is one integrated, interoperable system that spans the globe and protects the health of the planet and of humankind.

The task before you in this workshop may seem daunting, however, you may be assured that your colleagues who are serving within the U.S. Global Earth Observations committee have proposed a comprehensive IEOS initiative that recognizes the importance of data users in the development of an architecture that will translate data to information. You are being challenged to continue the dialogue that will result in a better understanding of the types of remote sensing and ground-based data that are being acquired, or that are needed, and to ask the important questions about how these data would apply to human health research, clinical management, policy decisions, and environmental and health planning. Your conclusions will help shape that architecture and provide significant insights into the challenges facing the research community.

Again, welcome to the workshop and thank you for your time, energy and talent.

Sincerely,

Michael O. Leavitt

Michael O. Leavitt

Integrated Earth Observations: Application to Air Quality and Human Health

National Institute of Environmental Health Sciences
Research Triangle Park, NC

MONDAY, AUGUST 1, 2005

8:00 – 8:30 AM	*Registration*
8:30 – 8:40 AM	Welcome and Introductions **Dr. Sally Tinkle**, Meeting Organizer, NIEHS **Dr. Anne Sassaman**, Director, Division of Extramural Research and Training, NIEHS
8:40 – 9:00 AM	Welcome and Overview of the Global Earth Observation System of Systems (GEOSS) **Dr. Gary Foley**, Director, National Exposure Research Laboratory, EPA

Plenary Sessions

DATA PRODUCTION (what can be measured)
Chair: Ms. Valerie Garcia, EPA

9:00 – 9:20 AM	Setting the Stage: Strengths and Limitations of Spatial Data **Dr. S T Rao**, NOAA
9:20 – 9:40 AM	New Discoveries and Future Directions of Satellite Research **Dr. Richard Kleidman**, NASA
9:40 – 10:10 AM	Availability and Uses of Operational Satellite Data **Dr. Shobha Kondragunta**, NOAA
10:10 – 10:30 AM	Land-Based Networks **Dr. Richard Scheffe**, EPA
10:30 – 10:45 AM	*Break*

<u>DATA INTEGRATION (translating data to information)</u>
Chair: Ms. Valerie Garcia, EPA

10:45 – 11:05 AM Integrating and Accessing Spatial Data: Challenges and Successes
Ms. Brenda Smith, EPA

11:05 – 11:25 AM Integrating Spatial Data to Address Air Quality
Dr. Ray Hoff, UMBC

<u>DATA USE (application of information to human health)</u>
Chair: Ms. Mary Gant, NIEHS

11:25 – 11:45 AM Spatial-Temporal Analyses in Air Pollution Epidemiology
Dr. Doug Dockery, Harvard School of Public Health

11:45 – 12:05 AM Spatial analysis of mercury policy options
Dr. Marie Lynn Miranda, Duke University

12:05 – 12:25 PM Integrating Earth Observation and Health Data for Public Health Surveillance
Dr. Judy Qualters, Centers for Disease Control and Prevention

12:25 – 12:30 PM **<u>CHARGE TO WORKING GROUPS</u>**
Dr. Sally Tinkle, NIEHS

12:30 – 1:30 PM *Lunch*

Working Group Sessions

1:30 – 2:45 PM **<u>WORKING GROUPS</u>**
Conference Room A: Respiratory
Conference Room B: Cardiovascular
Conference Room C: Developmental/Birth Defects

2:45 – 3:00 PM *Break*

3:00 – 5:00 PM **<u>WORKING GROUPS</u>** (continued)

5:00 PM *Shuttles back to hotel*

6:00 – 7:30 PM **DINNER**
Radisson

8:00 PM **WORKING GROUP LEADER AND RAPPORTEUR MEETING**
Radisson
Chair: Dr. Sally Tinkle, NIEHS

TUESDAY, AUGUST 2, 2005

8:30 – 8:40 AM	**Announcements and introduction to plenary session** **Chair: Ms. Mary Gant**, NIEHS Professor and Chair

Plenary Sessions

8:40 – 9:00 AM	Overview of the GEOSS Work Plan **Dr. Guy Duchossois**, GEOSS Work Plan Manager
9:00 – 9:20 AM	Confidentiality Issues and Policies Related to the Use of Geospatial Data **Ms. Meredith Golden**, Columbia University

Working Group Sessions

	WORKING GROUP REPORTS **Co-Chairs: Dr. Sally Tinkle**, NIEHS **Ms. Valerie Garcia**, EPA
9:20 – 9:50 AM	Respiratory Working Group **Dr. Peggy Reynolds**, California Dept. of Health Services
9:50 – 10:20 AM	Cardiovascular Working Group **Dr. Diane Gold**, Harvard School of Public Health
10:20 – 10:35 AM	*Break*
10:35 – 11:05 AM	Developmental/Birth Defects Working Group **Dr. Beate Ritz**, UCLA
11:05 – 11:45 AM	**SUMMARY OF FINDINGS AND NEXT STEPS** **Dr. Sally Tinkle**, NIEHS
11:45 – 12:00 AM	**CLOSING REMARKS** **Dr. Gary Foley**, EPA
12:00 – 1:00 PM	*Lunch and/or departure for airport*

Global Earth Observations: Application to Air Quality and Human Health
August 1-2, 2005

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