

A REPORT OF THE CSIS  
TECHNOLOGY AND PUBLIC  
POLICY PROGRAM

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ACCOMPLISHMENTS AND FUTURE CHALLENGES

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**CSIS** | CENTER FOR STRATEGIC &  
INTERNATIONAL STUDIES

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# CONTENTS

<b>1. How Earth Observations Can Benefit Public Health</b>	<b>1</b>
Air Quality	1
Water	2
Infectious Disease and Disease Vectors	3
Temperature	3
<b>2. Current Applications of Earth Observations to Health</b>	<b>5</b>
Setting the Context: Earth Observing Systems Organized around Societal Benefits	5
Intergovernmental Group on Earth Observations	5
U.S. Group on Earth Observations	6
Earth Observation Providers and the Public Health Community	6
National Aeronautics and Space Administration	7
National Oceanic and Atmospheric Administration	9
United States Geological Survey	9
Centers for Disease Control and Prevention	10
Environmental Protection Agency	13
National Institutes of Health	15
Department of Defense/Armed Forces Health Surveillance Center	15
U.S. Agency for International Development	16
<b>3. The Task Ahead for Improving the Benefits of Earth Observations for Health</b>	<b>17</b>
Effective Use of Earth Observations from Space	17
Continuity of Data/Research to Operations	19
Integration of Data	20
Interoperability	21
Models and Decision-Support Tools	21
Earth Observation Provider/Public Health Community Dialogue and Interaction	22
Private Sector	24
<b>4. Future Challenges</b>	<b>25</b>
<b>About the Author</b>	<b>27</b>



# 1

## HOW EARTH OBSERVATIONS CAN BENEFIT PUBLIC HEALTH

Public health officials have increasingly recognized links between the environment and health. The World Health Organization (WHO) states that “environmental hazards are responsible for as much as a quarter of the total burden of disease world-wide . . . . The disease burden is much higher in the developing world, although in the case of certain non-communicable diseases, such as cardiovascular diseases and cancers, the per capita disease burden is larger in developed countries.”<sup>1</sup>

Earth observations from space, with validation from *in situ* observations, provide a greater understanding of the environment and enable us to monitor and predict key environmental phenomena and events that can affect our livelihoods and health. Earth observation data can be incorporated into models to help detect, monitor, or predict disease, providing policymakers with the opportunity to control an epidemic, respond more quickly to disease outbreaks, and act to prevent or mitigate the occurrence of disease. The areas in which Earth observations can most readily benefit public health are air quality, water quantity and quality, infectious disease, waterborne and insect disease vectors, and temperature.

### Air Quality

According to WHO, air pollution from both natural and anthropogenic causes is a major environmental health risk estimated to cause approximately 2 million premature deaths worldwide per year. Particulate matter in the lower troposphere can cause or exacerbate cardiovascular and respiratory disease such as heart attacks, decreased lung functioning, and asthma. The American Lung Association reported in 2010 that a National Health Interview Survey conducted by the Centers for Disease Control and Prevention estimated that more than 38 million Americans had been diagnosed with asthma within their lifetime, with the highest prevalence rates occurring since 1999 in children 5 to 17 years of age.<sup>2</sup> WHO reports that currently 235 million people suffer from asthma.<sup>3</sup> In addition to emissions from industrial processes and motor vehicles, particulate matter in the air we breathe includes sand, dust, volcanic and noxious gases, and smoke and soot from fires.

Earth observations measure air masses as they move across the United States. Environmental Protection Agency (EPA) measurements from National Air Monitoring Stations and State and

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1. World Health Organization (WHO) website, “Public Health and Environment” section, <http://www.who.int/phe/en/>.

2. American Lung Association, “Trends in Asthma Morbidity and Mortality,” February 2010, <http://www.lungusa.org/finding-cures/our-research/trend-reports/asthma-trend-report.pdf>.

3. WHO website, Asthma Fact Sheet No. 307, May 2011, <http://www.who.int/mediacentre/factsheets/fs307/en/index.html>.

Local Air Monitoring Stations combined with space-based measurements help local and national policymakers make better decisions about controlling emissions and determine if the source of the emissions is coming from within or outside their communities. They can track the health impact of wildfires and dust that may be carrying meningitis and other diseases that can be transported globally by wind. EPA has revised its standard procedures for monitoring air quality to include the use of space-based measurements from the Moderate Resolution Imaging Spectroradiometer (MODIS) instruments of the National Aeronautics and Space Administration (NASA) Earth Observing System (EOS). Other instruments have demonstrated the ability to monitor some trace species in the air including carbon monoxide and ozone.

## Water

Drought, floods, and water contamination pose significant health risks. Droughts and subsequent drinking water shortages are an increasingly serious problem. Droughts affect the supply of fresh water and can result in famine and life-threatening forest fires. Floods are also increasing in frequency and intensity and are affecting people's livelihoods and health. Flooding causes the spread of disease, either directly or because mosquitoes and other disease carriers, fuel, and toxic pollutants are dispersed along with people. Waterborne pollutants affect the quality of the water available for human consumption. Contaminated water from chemicals, toxins, or sewage can cause or spread disease. The National Integrated Drought Information System of the National Oceanic and Atmospheric Administration (NOAA) provides "nowcasts" of current drought conditions on a regional basis and uses space-based remote sensing information from its Polar Operational and Environmental Satellite (POES) and Geostationary Operational Environmental Satellite (GOES) spacecraft, along with data from NASA's flotilla of spacecraft and sensors and airborne remote sensing systems.

For more than a decade, Earth observations from space have provided a measurement record of tropical and subtropical rainfall using the NASA and Japan Aerospace Exploration Agency (JAXA) Tropical Rainfall Measuring Mission (TRMM) that affects weather in locations thousands of miles away. Remote sensing of water (oceans, lakes, reservoirs, aquifers) has been possible for some time, using a variety of satellite platforms including the joint NASA–French Centre National d'Etudes Spatiale (CNES) TOPEX/Poseidon and Jason and the joint NASA–Deutsche Forschungsanstalt für Luft und Raumfahrt (DLR) Gravity Recovery and Climate Experiment (GRACE) spacecraft and sensors. Continued Earth observations on precipitation and the availability of water in aquifers, lakes, and reservoirs are critical for decisionmakers to plan and adapt to changes in rainfall patterns that are causing imbalances in the availability of water. Soil moisture is a key indicator for heat stress, and global soil moisture measurements can provide early warning and decision support for droughts and improved flood forecasts. Surface soil moisture is also useful in assessing whether precipitation will be absorbed into the ground or pool on the surface.

The health of the oceans is also critically important. However, ocean acidification has contributed to the degradation of coral reefs, stresses to the metabolic rates of many species, and the decline of reproductive health of oceanic organisms. The loss of coral reefs limits their pharmaceutical promise for medicines for cancer, heart disease, HIV, arthritis, and other serious diseases. Waterborne pathogens, toxic algae, and other toxins in the oceans expose humans to health risks. Observations from space from the NASA MODIS instruments on EOS Aqua and Terra measure phytoplankton levels and their locations using ocean color data that provides timely and accurate

measurements of these phenomena. These instruments also measure and monitor coastal and habitat changes and climate impact. Radar altimeters and scatterometers flown by multiple agencies provide measurements of the upper ocean currents that transport algae, sewage, other pelagic organisms, and pathogens (e.g., cholera bacteria).

## Infectious Disease and Disease Vectors

Environmental factors such as water and land surface temperatures, rainfall, water depth, and marine organisms all contribute to disease outbreaks. Changes in weather and climatic conditions can affect the spread of infectious diseases such as cholera, Chikungunya fever, and Rift Valley fever. Changes in temperature, humidity, and habitat affect the life cycle and infectivity of disease vectors as well as their interaction with humans. Changes in climate and weather can affect the distribution of some mosquito and rodent habitats that carry these infectious diseases. Earth observation data from space have been used in developing models that predict areas at risk for disease outbreaks.

For instance, a combination of Earth observation data along with other indicators has shown that the El Niño warm water cycle facilitates stronger cholera outbreaks. This provides a better understanding of how to better predict and prevent, or at least mitigate, cholera outbreaks. El Niño also affects the incidence of malaria and West Nile virus. By altering the range and amount of rainfall and related changes in ecosystems, El Niño impacts the range of mosquitos. Satellite images from Landsat, MODIS, and similar land-imaging instruments can show where vegetation density is higher and where the risk of malaria and West Nile virus may also be higher due to the potential for standing water. Analyzing data from satellite and ground measurements, such as rainfall, can help precisely time crop planting and growth and harvesting cycles that aid in predicting malaria and West Nile outbreaks. Similar methods can also be used to predict Rift Valley fever outbreaks. Rift Valley fever can occur when mosquito eggs, which can be dormant for up to 10 years if they stay dry, suddenly hatch as a result of heavy rainfall. In addition, measuring soil moisture, which can also provide an indication of the presence of surface water, may provide early warning for waterborne diseases and help predict disease vectors.

Lyme disease is also linked to the environment. Changes in habitat—because of climate and weather, urban development, or natural ecosystem progression—affect the distribution and transmission of Lyme disease. Earth scientists use real-time observations to study land cover features related to animal and vector populations and diversity. Changes in land use and the degree of forest fragmentation can affect the local biodiversity of mammalian host species and potentially alter the rates of tick and human infection. Changes in rainfall can alter the dynamics of the system. Earth observations can be critical in more effectively targeting intervention strategies, helping to understand both the connections between the environment and risk of Lyme disease, and in anticipating changes in both short- and long-term risk.

## Temperature

Extreme temperatures have increasingly led to weather-related deaths over the past decade. Heat waves primarily affect the elderly, children, and other immune-compromised populations. Heat exposure can also aggravate several chronic diseases such as cardiovascular and respiratory disease resulting in both increased illness and death. Forecasting the magnitude and occurrence

of extreme temperatures will be very important in saving lives. Understanding heat island effects in built-up urban areas that are hotter than rural areas is also very important to public health officials. Currently, remote sensing resources for weather and climate information from NOAA, U.S. Air Force, and NASA satellite platforms are available to urban and rural planners and other decisionmakers for addressing these environment-related health issues.

Earth observations of air quality, water quantity and quality, infectious disease, waterborne and insect disease vectors, and temperature serve a valuable purpose for the public health community. Linking information on natural phenomena to human health enables a greater understanding and a more informed decisionmaking process. Many organizations have realized the necessity of these links and are working toward strengthening cooperation between the public health and Earth observation communities.

# 2

## CURRENT APPLICATIONS OF EARTH OBSERVATIONS TO HEALTH

### Setting the Context: Earth Observing Systems Organized around Societal Benefits

Several organizations seek to optimize Earth observations by using them to design useful outputs for public health. Two main forums coordinate the efforts of these institutions—the intergovernmental Group of Earth Observations (GEO) and the U.S. Group on Earth Observations (USGEO). GEO and USGEO have focused their efforts on the acquisition and use of Earth observation data to achieve concrete societal benefits, including the improvement of human health.

#### Intergovernmental Group on Earth Observations

In 2003, the United States launched an international effort to develop a Global Earth Observation System of Systems (GEOSS) that would link Earth observation capabilities with plans of nations around the world to improve and sustain the capability to monitor and forecast changes in the global environment. They established the intergovernmental Group on Earth Observations, or GEO, as the implementing body for GEOSS. In 2004, GEO identified nine broad societal areas that would benefit from Earth observation products: disasters, health, energy, climate, water, weather, ecosystems, agriculture, and biodiversity. In 2005, GEO adopted the GEOSS 10-Year Implementation Plan<sup>4</sup> that would “provide the overall conceptual and organizational framework to build toward integrated global Earth observations to meet user needs.” Concerning health, GEOSS would improve the flow of appropriate environmental data and health statistics to the health community, promote a focus on disease prevention, and contribute to the continued improvements in human health worldwide.

Today, 86 nations and the European Commission are members of GEO, and the World Federation of Public Health Associations is a participating GEO organization. WHO is involved in the GEO Health and the Environment Community of Practice, a community of stakeholders ranging from providers to the final beneficiaries of Earth observation data and information. Among GEO’s health goals are supporting the further development of a global public health information network database to improve health decisionmaking at the international, regional, country, and district levels and to advance the application of observation, monitoring, and forecasting systems to health decisionmaking processes. GEO has initiated several health tasks to develop and support operational health-related applications and decision-support tools and to connect Earth observation systems to health monitoring and prediction systems.

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4. See <http://www.earthobservations.org/documents/10-Year Implementation Plan.pdf>.

In addition to organizing the development of GEOSS around societal benefits, a second major contribution of GEO is promoting data sharing. GEOSS data sharing principles were adopted in 2005 in the Ten-Year Implementation Plan. Implementation guidelines for data sharing were agreed to in 2009, and a data sharing action plan was adopted in 2010. While much work remains to be done to achieve full and open exchange of data, metadata, and products within GEOSS as envisioned in the Ten-Year Implementation Plan, GEO members increasingly recognize the benefits of sharing data—for example, the observations about air pollution data that are needed to track the origin and path of diseases—and agree that such data should be shared.

## U.S. Group on Earth Observations

In 2005, the U.S. Group on Earth Observations (USGEO), which includes representatives from 17 federal agencies and the Executive Office of the President, was established under the White House Office of Science and Technology Policy’s Committee on Environmental and Natural Resources to lead federal efforts to achieve a national Integrated Earth Observation System (IEOS) and support efforts to build GEOSS.

USGEO developed a strategic plan for IEOS, focusing its development on “specific and achievable societal benefits” and linking U.S. efforts to the international GEOSS activities. Prior to this, with the exception of weather, U.S. Earth observations were organized around science themes. USGEO identified nine societal benefit areas, eight of which are the same as the GEO areas, but USGEO added oceans and did not include biodiversity.

The IEOS plan described an overall system across the nine societal benefit areas. It highlighted that all of the components of the IEOS contribute to improving human health and well-being and foresaw a future where the development and application of predictive models for diseases influenced by environmental factors could predict occurrence and possibly control or prevent these diseases.

USGEO actively reached out to the public health community, including the World Federation of Public Health Associations and the American Public Health Association, to engage them in the design of GEOSS. In 2010, USGEO developed a preliminary plan for achieving and sustaining Earth observations necessary for U.S. policy and decisionmaking related to the changes affecting the planet. The plan contains recommendations for national Earth observation priorities. Seventeen of these were specific recommendations relevant to health.

## Earth Observation Providers and the Public Health Community

A number of U.S. government Earth observation and public health organizations are engaged in research and applications of remote sensing data to address health issues. These organizations conduct such activities in accordance with their individual charters but also cooperate in science and operational coalitions to address issues with a common purpose. Organizations include the National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, United States Geological Survey (USGS), Centers for Disease Control and Prevention (CDC), Environmental Protection Agency, National Institutes of Health, the Department of Defense, and the U.S. Agency for International Development (USAID). Some of these government agencies are also active participants in the intergovernmental GEO health tasks.

The current U.S. federal agencies responsible for initiating and collecting Earth observations—NASA, NOAA, and the USGS—have to some extent engaged the public health community in the collection of Earth observation data and development of Earth observation application projects, and the benefits of using Earth observations from space have been receiving wider acceptance by the public health community over the past decade.

## National Aeronautics and Space Administration

NASA undertakes activities focusing on Earth science applications to public health and safety regarding infectious disease, emergency preparedness and response, and environmental health issues. NASA is exploring toxic and pathogenic exposure as well as natural and manmade hazards and their effects for risk characterization/mitigation and improvements to health and safety.

In 2001, NASA created the Applied Sciences Program to fund applied research that would translate basic NASA Earth science research into knowledge for societal benefits. NASA initially targeted 12 societal benefit areas, including public health, based on a series of workshops it conducted with user communities in the United States and in response to the establishment of the intergovernmental GEO in 2003. While budget reductions forced the space agency to reduce this to eight societal benefit areas, NASA maintained its strong focus on public health.

The goal of the NASA Public Health Program is to generate knowledge to support planning, management, and policy decisionmaking for the public health, medical, and environmental health sectors. When NASA began this initiative, the public health community had little experience using Earth observation data, relying instead on ground-based data. NASA was introducing a whole new field and soon came to realize that the space community and the public health community did not speak the same language. NASA began educating the public health community on remote sensing and on Earth science information through training modules for the CDC and presentations at public health conferences and workshops. Through this process, NASA began to learn the needs of the public health community.

As the benefits of Earth observations were recognized in the public health community, partnerships developed between NASA and a variety of public and private organizations such as EPA, CDC, the U.S. Department of Agriculture (USDA), the National Institutes of Health (NIH), the Association of State and Territorial Health Officials, the National Association of County and City Health Officials, the Association of Schools of Public Health, and WHO.

The NASA Public Health Program supports a range of projects, including feasibility or prototype projects, in the use of Earth science research (including satellite observations) for public health. The projects address epidemiological surveillance in areas of infectious disease, environmental health, and emergency response and preparedness. In fiscal year 2010, there were 18 ongoing projects, and an additional nine projects were selected in January 2011. To ensure that the projects are responsive to the needs of the public health community, feasibility project proposals must have the endorsement of the end user (such as the CDC or a state or local department of public health). End-to-end project proposals must include the end user as a full partner in the project and a plan for transitioning the project to operational use.

For example, the USDA Animal and Plant Health Inspection Service (APHIS) and the U.S. Department of Defense (DoD) Global Emerging Infection Surveillance and Response System have partnered with NASA to use remote sensing data products and models to enhance capabilities for

assessing Avian Influenza risks for poultry farms and humans and for early detection of pandemic influenza. NASA worked with the California Department of Public Health, the Mosquito and Vector Control Association of California, and the University of California, Davis, on a project called Tracking and Predicting the Spread of Mosquito-borne Encephalitis Using NASA Data. This project used remote sensing data and models to determine risks of mosquito outbreaks and improved California's ability to align intervention and public health response strategies with risk, allowing public health officials to initiate mosquito population control methods when necessary. The project developed a Web-based data management system called the Surveillance Gateway, and future plans include production of a revised version of the Surveillance Gateway exportable to other state or federal agencies. NASA is partnered with the University of Alabama at Birmingham, the USGS, and the Universities Space Research Association to use land cover data to track public health in urban areas as part of a large study funded by NIH.

Since 2003, the NASA-funded Environmental Public Health Application System project has been working with the New Mexico Department of Health to use remote sensing data and models to improve forecasts of atmospheric ozone, fine particulates, and other aerosols that trigger asthmatic responses or myocardial infarction. Results have shown that the timing of dust storms in the Southwest U.S. desert can be accurately forecast with 48 hours' notice 67 percent of the time. Daily dust forecasts are now available on the New Mexico Department of Health website and are transmitted to local officials. These forecasts enable hospitals to adjust staffing levels to cope with episodic increases of patients, schools to keep students indoors at recess, and parents to ensure their children use medications. The project is also integrating Earth observation outputs into the New Mexico public health tracking network. These system enhancements are providing epidemiologists with Web-enabled statistical and analytical tools for tracking human exposure to contaminants and air quality episodes and for assessing health outcomes on a daily, monthly, annual, or extended time frame.

NASA conducts an annual review of its public health projects, where partners from the public health community join the project's principal investigators in a broad discussion with NASA on topics for future investigation as well as on current progress. NASA uses these discussions to inform the content of future solicitations. As a barometer of the growing interest of the public health community in the use of Earth Science research, public health partners of projects expiring in 2010 plan to attend future annual review meetings. NASA is also exploring issuing joint solicitations with other organizations such as CDC, NIH, and NOAA. The first opportunity for a joint solicitation would be in 2012 when NASA issues its next public health solicitation.

The NASA Public Health Program also supports national and international activities to improve skills, share data and applications, and broaden the range of users who apply satellite data and Earth science in public health decisions. NASA funds training workshops for the public health community on the application of Earth science data and products to public health and promotes its benefits at venues where the public health community is present. NASA recently organized a session on Earth observations and health at the American Meteorological Society Conference on January 25, 2011, and the American Meteorological Society is considering establishing a standing committee on this topic. Internationally, NASA supports the efforts of GEO to improve the flow of user-friendly environmental data to the global public health community.

## National Oceanic and Atmospheric Administration

There is a loose network within NOAA that is doing work related to health—specifically research activities that help inform environmental links to health, observations that aid response, and predictions that provide warnings. However, only one program within NOAA—the Oceans and Human Health Initiative (OHHI)—is funded specifically to conduct health work. Established by Congress in 2003 and codified through the Oceans and Human Health Act passed in December 2004, OHHI is designed to bring together oceans and health expertise across NOAA in partnership with the academic and private sector communities and in collaboration with other federal, state, and local agencies. More recently, the NOAA Advisory Board created an Ocean Health Working Group to examine what NOAA should be doing in this area. The working group concluded that the health of the “one ocean” is essential to the “one health” of all life on Earth and recommended that NOAA should establish health protection, preservation, and enhancement as an agency-wide goal. It also recommended some near-term priorities including forecasts of impending threats; surveillance systems for emerging pathogens, contaminants, and toxins that affect health; and climate change effects on ocean-related health outcomes.

These recommendations have not turned into programmatic dollars and significant resources yet but have elevated health’s importance in the agency. Other health activities within NOAA flow from its long-standing role in climate and health, ocean and health, and marine animal health and its engagement in weather and climate data acquisition, modeling, forecasting, and scenarios. The National Weather Service (NWS) provides weather forecasts to CDC staff involved in research on the effects of heat waves and is working with state and local officials to prevent heat-related morbidity and mortality. Health is included in the NWS Strategic Plan. NOAA develops products for air quality, drought, natural hazards, heat, disease, and contaminants and collaborates with EPA on forecasts of air pollution and air quality that have direct health outcomes.

NOAA is currently funding forecasting tool studies, such as forecasting algae blooms in the U.S. Great Lakes, by incorporating a climate element; the development of a pathogen model as a tool for managers of drinking water treatment plants and beaches; a sea surface temperature tool for early warning of cholera and other bacteria; a tool to manage razor clam fisheries for public health; and tools for forecasting impacts of coastal development on the ecosystem and public health. In this context, through the GEO Health and Environment Community of Practice, NOAA OHHI is leading an interagency and international effort, including WHO and CNES, to establish early warning systems for cholera or similar bacteria. NOAA is also working with CNES and the GEO-Informatics and Space Technology Development Agency of Thailand to coordinate their efforts in using satellite observations to predict malaria outbreaks and identify areas of increased risk for disease transmission. The project combines remote sensing observations with ground-based data from health practitioners to develop better prediction and risk maps for areas most affected by malaria. The three agencies are also working with GEO to coordinate observations and projects under way in different regions in the world to create a holistic project for malaria detection, monitoring, and prevention.

## United States Geological Survey

USGS decided more than four years ago to expand research in human and wildlife health. Its role is to synthesize the scientific information on natural and living resources that influence human health and bring this knowledge to the public health community in a useful format. For example,

USGS scientists conducted a study on West Nile Virus prevalence and land cover variation derived from Landsat imagery. Although land cover change had often been tied to spatial variation in disease occurrence, the underlying factors were often unknown, limiting the applicability of the results for disease prevention and control. They investigated three potential processes accounting for observed patterns and said their results suggested that preserving large wetland areas and, by extension, intact wetland bird communities may represent a valuable ecosystem-based approach for controlling West Nile Virus outbreaks. USGS scientists work with the public health community to examine the connections between natural science and public health and considers coordination with public health agencies at all levels essential to ensure that resources are focused on the highest priority issues, information is provided in a usable and timely manner, and practical solutions to health problems are achieved.

In addition, USGS makes all of the Landsat scenes in its archive available for download at no charge. Landsat satellites have continuously acquired space-based moderate-resolution land remote sensing for almost 40 years, and the archive holds data from Landsat satellites starting with Landsat 1 in 1972. In May 2011, the U.S. Department of the Interior, USGS's parent agency, announced that a new geospatial website called "ChangeMatters" was making Landsat imagery more easily accessible to the public and would enable scientists and the public to more quickly and easily see how landscapes have changed over time as a result of forest harvesting, urban growth, wildfires, floods, pest outbreaks, and drought. The website was developed by the geographic information system (GIS) company Esri and leverages the 40-year U.S. government investment in the collection and archiving of continuous worldwide Landsat imagery for Earth observations.

The multiple activities involving the use of Earth observations that are being undertaken by the public health community give Earth observation providers greater understanding of the public health community's needs, concerns, and decisionmaking processes. The current U.S. government organizations involved are the CDC, EPA, NIH, the Department of Defense/Armed Forces Health Surveillance Center, and USAID.

## Centers for Disease Control and Prevention

The Centers for Disease Control and Prevention, or CDC, has had a partnership with NASA since 2004 when the National Center for Environmental Health/Agency for Toxic Substances and Disease Registry entered into a memorandum of understanding (MOU) with the NASA Earth Science Division/Applied Sciences Program. The goal of the partnership is to look at public health applications of Earth observations in order to better understand environmental conditions that affect health. The focus has been primarily on noninfectious disease data; infectious diseases may be included later.

The two agencies began by looking at what can be done with the data. They initiated a collaborative study, "Health and Environment Linked for Information Exchange,"<sup>5</sup> to better understand what NASA Earth science can do and to address the following questions: How do we link health and environmental data to take public health actions, and how do we incorporate the data into program planning and evaluation? Most of the work of the study, which is a three-phase project, is being done at the state and local level. The goal of the first phase was to determine how ground data on environmental conditions could be supplemented and whether remote sensing data could

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5. See [http://weather.msfc.nasa.gov/applied\\_science/breakout36.pdf](http://weather.msfc.nasa.gov/applied_science/breakout36.pdf).

fill in the gaps in data. The largest effort undertaken attempted to use remote sensing data to fill in some of the data gaps related to ground water and particulate matter. The agencies specifically studied how to model the data so that it could fill in the gaps with ground data to understand the incidence of asthma.

Following completion of this project, the agencies initiated the second phase for further evaluation of the utility of remote sensing data. This project is examining how to employ Earth science data to provide an accurate daily assessment of the environment. The study, still ongoing, is linking environmental data to cardiovascular data. CDC said that, to date, these activities have shown that remote sensing data can fill gaps in environmental data collected on the ground. However, the data's full utility will not be known until the completion of the full three-phase project. Ultimately, the goal is to make these remote sensing data available to states. CDC is also working jointly with NASA to analyze, organize, and display remote sensing data.

In 2009, CDC established a climate change program to lead efforts to identify the health effects of climate change, anticipate future trends, demonstrate that systems are in place to detect and respond to emerging health threats, and take steps to ensure that these health risks can be managed currently and in the future. A key effort is the development of decision-support tools. CDC is collaborating with NASA on a project using Earth observation data and models to improve heat watch warning systems for decision support, using meteorological, mortality, remotely sensed, and socio-demographic data from 1995 through 2005. Land surface temperature, which was estimated using Earth observations from space, is displayed using geographic information systems, or GIS.

CDC is initiating a similar project on flash flooding. Remote sensing data can provide a good sense of spatial differentiation as well as a strong register of certain stable phenomena like heat islands and coastal flooding. These studies are being undertaken to improve the identification of particularly vulnerable locations and the ability to mitigate the health-related impacts. CDC believes that the spatial distribution provided by remote sensing is the best way to meet its goal of scaling up these projects. Health departments have indicated that incorporating remote sensing data enables them to show the spatial differentiation of health risks at city planning meetings. Epidemiological techniques are more sophisticated than can be done spatially, so using remote sensing and mapping tools can enable the public health community to better inform planning decisionmakers about health impacts of development decisions, configuration of utilities, installation of impervious surfaces, etc.

The climate change program has established a postdoctoral program with the National Center for Atmospheric Research (NCAR) to develop a capability for public health researchers to engage in climate science, learning the latest in climate modeling and ways of working with climate data, including remote sensing.

The climate change program is also working with NASA to develop a climate model. CDC and NASA are integrating observed ground weather station data with modeled data taking into consideration land surface data. Remote sensing data are filling in the gaps from the ground weather stations. The model has full coverage data for eight years, which will form a platform for integrating a host of epidemiological data. In fall 2011, CDC is prepared to include this model in its Environmental Public Health Tracking Network (EPHTN), which it is developing to identify and track incidences of environmentally caused health problems in the United States.

The EPHTN, which became operational in 2009 and now involves more than 20 states, grew out of a September 2000 report by the Pew Environmental Health Commission. The report said that the nation's environmental public health system remained fragmented and too often ineffective at reducing chronic and disabling diseases and conditions. The commission recommended establishing a national environmental public health tracking network that would link information about environmentally related diseases, human exposure, and environmental hazards, and provide the basis for strategies to prevent and control many diseases and disabilities. In 2002, CDC established the National Environmental Public Health Tracking Program, which led some years later to the EPHTN tracking network.

CDC defines environmental public health tracking as the ongoing collection, integration, analysis, interpretation, and dissemination of data from environmental hazard monitoring and from human exposure and health effects surveillance. EPHTN integrates data from these three components into a network of standardized electronic data that provides valid scientific information on environmental exposures and adverse health conditions as well as the possible spatial and temporal relations between them. Developing a sustainable standards-based national network is an iterative process to enable direct electronic data reporting and linkage within and across health effects, exposure, and hazard data and will interoperate with other environmental public health systems.

Because public health is a local responsibility, the CDC spent the last decade promoting the benefits of a national public health tracking network to state and local governments and established partnerships with NASA and EPA to make Earth science/environmental data available to and usable by their public health agencies. CDC provides funds to health departments in 23 states and New York City for building and implementing local tracking networks that contribute data and information to the national network. These state and local data systems feed into the national tracking network. Previous projects by these grantees have improved information technology through better infrastructure, expanded environmental health tracking capacity, and trained public health workers. Grantees have also developed better ways to make information accessible on the tracking network to those who need it to take action, such as policymakers and public health officials.

The EPHTN identifies the NASA Public Health applications team as a primary partner, and the team has provided remotely sensed observations and products as part of the information being distributed to the public. NASA plans to continue to integrate NASA research into the network, including continued work with the CDC on the climate change model to the EPHTN. CDC said the grantees have found the network (which includes aggregated remote sensing, EPA, and state water data) valuable. While some states are already using remote sensing data, such as New Mexico in the NASA-funded Environmental Public Health Application System Project, the NASA/CDC climate change model will make available to all of the states in the EPHTN actual measurements from the counties, including subsets of the underlying data such as remote sensing data.

NOAA works with CDC to support the integration of ocean, climate, and public health information. It cochairs the Climate Change Team in EPHTN. NOAA and CDC are currently developing a memorandum of understanding (MOU) to strengthen the science and services to understand, communicate, and reduce environmental and public health and safety impacts; and enhance the accuracy, timeliness, and integrated application of climate, water, weather, oceanographic, ocean-related marine animal and human health, and ecosystem and resource data to address public health issues. The MOU will cover science research; services; communication and

dissemination of data; integrated data and surveillance; training, education, and capacity building; workshops and meetings; global health and capacity development; and pilot projects and joint field projects. For example, a NWS Pilot Project will incorporate locally relevant CDC health messages into the NWS dissemination system so that they can reach a broader audience.

In 2002, the EPA signed an MOU with the U.S. Department of Health and Human Services to link the EPA National Environmental Information Exchange Network (NEIEN) and EPHTN. The linkage of these two systems has utilized and enhanced information technology tools to advance the analysis and dissemination of information. The two agencies share environmental and public health data to ensure informed decisionmaking and appropriate response to emergency situations.

## Environmental Protection Agency

In support of EPA's mission to protect human health, the EPA Group on Earth Observations (EPA GEO) serves as a forum to facilitate the agency's response and contribution to the development of GEOSS, including EPA's Advanced Monitoring Initiative (AMI) to bring environmental information—both remote sensing and *in situ*—to decisionmakers. Under this initiative, EPA has provided seed money for more than 100 projects, many of which relate to air quality forecasting/assessment and decisionmaking for human health. Many other EPA offices and other federal agencies including NASA and NOAA are collaborators on AMI projects, bringing funding and/or in-kind resources. While some of these projects were begun prior to GEO, GEO offered the opportunity to expand their scope.

AMI has integrated remotely sensed data and *in situ* data to form new models for air quality forecasting, nitrogen deposition, harmful algal blooms (HABs), and Lyme disease risk maps. User-friendly tools have been developed that allow imagery to be semiautomatically georectified so it can be used in a geographic information system. AMI has also contributed to the development of several communities of practice. All AMI projects strive to involve the final stakeholders in the project early on, so that the products designed are relevant and useful. Some project participants have indicated that in the absence of AMI, public health and environmental protection would not have reached today's level as projects might have been slower to develop without AMI support.

The AIRNow Program provides local air quality conditions and forecasts in the United States. It partnered with NOAA, NASA, the National Park Service, and state and local environmental and health agencies to develop the AIRNow website to provide daily air quality index (AQI) forecasts and real time AQI conditions. AQI, an index for reporting daily air quality and associated health concerns, is calculated for four major air pollutants regulated by the Clean Air Act—ground level ozone, particle pollution, carbon monoxide, and sulfur dioxide. When EPA began adding small atmospheric particles also known as particulate matter into the AQI, it contacted NASA for assistance in finding a way to forecast particulate matter that can cause serious health problems, including respiratory difficulties and even premature death. The index at that time did not take particulate matter into consideration, only tropospheric ozone. NASA developed a tool to make particulate matter forecasts by bringing in NASA satellite data such as the Moderate Resolution Imaging Spectroradiometer (MODIS) aerosol optical depth, EPA ground sites, and trajectory forecast capabilities, and the tool was adopted by EPA in its AIRNow real-time air quality forecasts.

AIRNow is registered with GEOSS and has been redesigned to provide multiple language support and worldwide mapping capability, using open components that can be adopted by any country or locality. Called AIRNow International, GEO states that it is improving global access to

air quality information through more advanced mapping and data distribution techniques. It envisions using GEOSS models and observations such as satellite air quality data and in turn providing GEOSS with observations from ambient air monitors around the globe. Worldwide sharing of air quality forecasts and observations can help researchers better understand the transmission pathways of respiratory diseases and help decisionmakers intervene to reduce air pollution-related disease.

Continuing to leverage GEO as an effective coordination platform, EPA and NOAA through its Integrated Ocean Observing System (IOOS) Program, have recently developed a proposal named Real Time Dissemination of Air and Coastal Beach Water Quality through a Global Geospatial System. The proposal aims to integrate the real-time data on air quality and beach water quality being collected by various GEO members from their cities and coastal area into an operational system consisting of one or more data dissemination platforms on a global map.

Remote sensing data was used in another AMI project to develop a tool to evaluate *in situ* data on nitrogen emissions. The tool detected a discrepancy in the numbers recorded in the National Emission Inventory (NEI) and the predicted emissions based on the NO<sub>2</sub> column. EPA's investigation found a transcription error between the numbers reported by the states and entry into the NEI and corrected the error. EPA is also applying this tool to quantify emissions from sources difficult to measure, such as cars and regions where a monitoring infrastructure does not exist.

AMI projects have advanced forecasting technology for beach and coastal hazards by developing detection and warning systems for harmful algal blooms, bacteria outbreaks, and coastal flooding that aid decisionmaking for human health. Remotely sensed ocean color data was integrated into hydrodynamic models that are being used by EPA's Gulf of Mexico Program to advance the accuracy of harmful algal bloom predictions.

A remotely sensed landscape-based Lyme disease prediction model was developed to make Lyme disease management decisions, and it is anticipated that it soon will be used by public health officials in two states. EPA is also working with GEO to integrate Earth observation and field data in the study of disease systems potentially influenced by changes in biodiversity, such as Lyme disease and West Nile encephalitis. Earth observation data on land cover features related to animal and vector populations and diversity will be combined with environmental factors affecting hosts and vectors of disease, knowledge of disease life cycles and transmission, identification of human behavior that affects biodiversity and human health, and an assessment of the monetary value of biodiversity as it relates to disease reduction, to create tools to help environmental decisionmakers and public health practitioners develop environmentally based and behavioral strategies to prevent risk of human disease and loss of biodiversity. This effort involves the end users who will use the scientific knowledge to inform decisions on regulations and on environmental and pest management.

Through AMI, EPA is creating and testing ways to deliver environmental information to users. One project was a pilot research effort to develop and test an automated, ortho-rectification process that would enable the timely and cost-efficient geo-registration of analog and/or raw aerial photography and other remote sensing data and the automated development of digital metadata that would in turn facilitate Internet service-based distribution of these data. The pilot's objective was to significantly increase the base of remotely sensed information and efficiently provide that information through GIS/Internet services to decisionmakers.

## National Institutes of Health

The National Institute of Environmental Health Sciences (NIEHS) is engaged in multiple activities with other federal agencies, international research and policy organizations, academia, and non-governmental organizations to identify gaps in knowledge of the links between climate change and adverse human health impacts, develop a research agenda to address them, communicate findings, and work with decisionmakers to incorporate this information into health policy and actions. Its focus is on understanding how climate changes will impact human health and on the health consequences of strategies to adapt to and mitigate climate change (such as transportation, energy, etc.) in order to ensure that public health is considered in decisionmaking processes related to climate change adaptation and mitigation.

The Human Health Impacts of Climate Change (HHICC) Program is the first program dedicated to the health impacts of climate change within NIH and supports a variety of NIEHS-sponsored research- and mission-related activities. It has already funded research related to heat morbidity and mortality; respiratory effects of wildfires; modeling asthma, skin cancer, and salmonellosis; cholera-climate prediction; and population displacement disease. It is currently soliciting proposals for small research projects focusing on assessing population vulnerability to climate change and hopes to fund 10 to 12 grants and solicit additional proposals this year.

The HHICC program also coordinates research initiatives across NIH and with other federal agencies. NIEHS cochairs (with CDC and NOAA) the Interagency Working Group on Climate Change and Health established to look at the health implications of climate change and identify research needed to address direct health effects. Members include NASA, EPA, and a number of other federal agencies. The working group is charged with prioritizing research with the goal of increasing interagency cooperation to fill in data gaps. In the category of monitoring, early warning, data integration, and surveillance, the group is developing an inventory of relevant databases and what is needed to enhance their capability.

NIEHS is a member of USGEO and has begun raising awareness within NIH of the availability of remote sensing data. In September 2010, NIH launched a multi-year study to look at the potential health effects from the oil spill in the Gulf Region and used remote sensing data to assist in some of its exposure scenarios and exposure modeling in planning the study. The researchers plan to use remote sensing data more extensively as more data for the Gulf study become available. NIEHS also participates in the U.S. Global Change Research Program (USGCRP) which coordinates and integrates federal research on changes in the global environment and their implications for society and supports research and observational activities in collaboration with several other national and international science programs.

## Department of Defense/Armed Forces Health Surveillance Center

The Armed Forces Health Surveillance Center collects and interprets data that impact the health of U.S. military (and military-associated) populations in order to address obstacles to military readiness. Space-related data are key to determining emerging health threats to U.S. military populations worldwide. For example, the Department of Defense, using Earth observation data from NASA, tracks malaria conditions in areas of Southeast Asia where U.S. troops are deployed in or-

der to determine appropriate chemo-prophylaxis regimens. One of their key projects is the Global Emerging Infections Surveillance and Response System (GEIS), which focuses on both national and international preparedness for infectious disease outbreaks. NASA, using near-real-time satellite vegetation measurements and climate data to generate predictions of epidemics, provides monthly reports and risk maps to GEIS that support GEIS efforts toward improving worldwide surveillance systems and improving local epidemiological capabilities. This model successfully predicted an outbreak of rift valley fever in 2006–2007 and again in 2010, providing warnings two to six weeks in advance that enabled local health authorities to implement programs for informing the public, controlling mosquitoes, and providing livestock vaccinations.

## **U.S. Agency for International Development**

Since 2003, USAID has worked with NASA to establish centers to enable people in developing regions to use Earth observations to address challenges in agriculture, biodiversity conservation, climate change, disaster response, weather forecasting, and energy and health issues. The SERVIR initiative integrates satellite observations, ground-based data, and forecast models to monitor and forecast environmental changes to enable improved decisionmaking on these issues. It provides public access to information products in a variety of formats, tailored to a range of decisionmakers from scientists to the general public. Regional SERVIR hubs are located in Panama, Kenya, and Nepal.

# 3

## THE TASK AHEAD FOR IMPROVING THE BENEFITS OF EARTH OBSERVATIONS FOR HEALTH

What information is actually needed for effective and efficient decisionmaking by the public health community? How much awareness exists that such information might be provided by processing and analyzing Earth observation data? What are the existing gaps between the Earth observation providers and the public health community? Understanding these factors can clarify how to improve the benefits of Earth observations for health.

Although efforts have been made to actualize the benefits of Earth observations for health, improvements are possible. These include increases of and enhancements in remote sensing capabilities; continuity of Earth observation data and research; integration and interoperability of satellite, *in situ*, health and socioeconomic data; and models and decision-support tools to analyze and apply these data. Furthermore, enhanced dialogue between the Earth observation and public health communities is needed to increase understanding of current and potential uses of Earth observation data for health and to involve broader segments of the public health community in this dialogue.

Since the release of the National Research Council's report "Transforming Remote Sensing Data into Information and Applications" ten years ago, stronger emphasis has been placed on strengthening the practical applications of remote sensing for societal benefits. As a result, the interactions between Earth observation data producers and users have significantly increased, fostering a greater understanding of what users need in order to fully realize the benefits of the Earth science data collected. The use of Earth observation information in public health decisions is a relatively new application area compared to its use in other areas—for example, agricultural efficiency, air quality, water management and energy management. Nonetheless, several activities undertaken over the past decade have identified some specific Earth observation needs of the public health community. In addition, lessons can be learned from the federal agencies currently engaged in the application of Earth observations to health and from the Intergovernmental GEO's efforts to establish the Health and the Environment Community of Practice. Finally, elements of the public health community who have interacted with or been engaged by Earth observation providers have offered some important perspectives on what they believe they need in order to effectively use these data in their activities as well as what is needed to expand its use more broadly by the public health community.

### Effective Use of Earth Observations from Space

Appropriate spatial, temporal, and spectral resolution measurements are needed to support public health decisionmaking, but as the National Research Council (NRC) points out, there are currently limits on temporal (frequency of observations) and spatial resolution. The 2007 NRC Decadal Survey, *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond*, stated that "effective incorporation of remote sensing data into public-health and risk management practices requires measurements that are at spatial and temporal resolutions appro-

appropriate to the scale of the problems at hand. This often means that data are needed at more finely detailed spatial and temporal resolutions than current technology allows.”<sup>6</sup> Fine-spatial resolution data are required to target forecasts and warnings to specific geographical locations that have been shown to be more effective than blanket warnings over entire regions. The report examined six broad categories of health effects mitigation that have been enhanced by the application of remote sensing data (ultraviolet radiation and cancer; heat stress and drought; acute toxic pollution releases; air pollution and respiratory/cardiovascular disease; algal blooms and water-borne infectious diseases; and vector-borne and zoonotic disease) and identified new sensors that have finer spatial or spectral resolution. It prioritized remote sensing measurements associated with the six categories (stratospheric ozone, water vapor, precipitation, soil moisture, vegetation state, temperature, ocean color, aerosol composition and size, tropospheric ozone, sea surface temperature, and wind speed) and identified associated space-based missions.

Building on the NRC recommendations, in 2010, USGEO made recommendations on Earth observations from space that would benefit public health in its report *Achieving and Sustaining Earth Observations: A Preliminary Plan Based on a Strategic Assessment by the U.S. Group on Earth Observations*. These recommendations are related to air quality, greenhouse gases, ocean color, precipitation, soil moisture, and water quality and quantity, and include specific recommendations on satellites and sensors funded by the United States or in cooperation with international partners. USGEO said the top operational and research need for air quality measurements from space is more frequent and finer spatial resolution data. This need could be met in coordination with other geostationary and low Earth orbit observations developed and deployed with international partners. In addition, NASA should proceed with the Geostationary Coastal and Air Pollution Events Mission and launch a replacement for the Orbiting Carbon Observatory (OCO) and build a spare OCO instrument. USGEO further recommended that NOAA and NASA should continue to pursue international partnerships with the European Space Agency (ESA), JAXA, and the Indian Space Research Organization (ISRO) to provide risk mitigation strategies for ocean color measurements while proceeding with ocean color sensors on several U.S. missions. It stated that NASA should launch the joint NASA/JAXA Global Precipitation Measurement Mission and proceed with the Soil Moisture Active-Passive Mission. NASA should also continue its observations of gravity fields from the Gravity Recovery and Climate Experiment Mission and follow-on gravity missions for ground water storage and ice sheet mass variations. In addition, NOAA and NASA should seek international partnerships such as with JAXA on its Global Change Observation Mission.

The public health community has indicated some areas where remote sensing data could be helpful, including:

- Climate change parameters and health
- Heat island effects on urban areas
- Precipitation (water, drought)
- Data on at risk populations
- Detection of algae blooms that are harmful to health
- Pesticides and crop prediction.

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6. National Research Council, *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond* (Washington, D.C.: National Academies Press, 2007).

## Continuity of Data/Research to Operations

A critical need is a commitment to the continuous acquisition of Earth observations from space applicable to public health decisionmaking. There are strong concerns about the continuity of systems that provide data to health-related programs and research. The existing base of health community users of space-based observations has experience with such sensor systems as Landsat, Advanced Very High Resolution Radiometer (AVHRR) and MODIS, and the availability of these data products are necessary to ensure that the users have access to the data they understand. Because some sensors are beginning to fail, while others are beyond their design life, plans are needed to maintain these sensors (or their equivalents) so that long-term, time-series research linking environmental processes to health risks or disease patterns can be continued. This will also be critical for early warning of when and where risk mitigation efforts are warranted.

Furthermore, a shift toward operational systems is necessary to realize the potential benefits of space-based operations for improving human health. The NRC noted that the confidence with which most diseases and other effects can be forecast is still very low. Continued availability of space-based observations of land use and land cover, oceans, weather and climate, and atmospheric pollutants is critical to further enhancing the understanding of links to diseases and to expanding capacity for early warning where risk is elevated. There is an absence of continuous temporal and spatial data sets required for the study of specific diseases or disorders, including human activity patterns. Making the data collection operational requires that the data be used to address prediction of occurrence of disease or disease outbreaks; rapid detection and tracking of events; construction of risk maps; targeting interventions; and enhancing knowledge of human health-environment interaction.

In its 2010 report *Achieving and Sustaining Earth Observations: A Preliminary Plan Based on a Strategic Assessment by the U.S. Group on Earth Observations*, USGEO identified three elements needed to achieve the maximum benefits from Earth observations: a sustainable observation system of systems that enables useful products for decisionmakers; data systems that are compatible and produce clear, timely information; and accurate, long-term data records.

Budgetary and structural factors impede the U.S. government's ability to transition Earth observation research into operational or sustained capabilities. The Obama administration proposed a significant increase in funding for Earth science in its fiscal year 2011 budget requests for NASA and NOAA that went a long way toward implementing many of the 2007 Earth Science Decadal Survey's recommendations. However, the proposed budget was not enacted. Instead, a year-long continuing resolution provided significantly reduced levels of funding for NOAA in particular. In the fiscal year 2012 budget request, due to increasing concerns about the U.S. budget deficit, the administration scaled back its Earth science plans as part of its overall decision to freeze discretionary spending. Two of the Earth science decadal study missions at NASA that were to be accelerated by two years will not see their launch dates advanced.

While the budget request will continue on schedule with the development and launch of several key NASA Earth science missions, it will only continue pre-formulation studies of three other missions. Although the administration proposed increases in NOAA's fiscal years 2011 and 2012 budget requests to initiate the Joint Polar Satellite System (JPSS), the follow-on program to NPOESS (National Polar-orbiting Operational Environmental Satellite System), Congress did not provide the fiscal year 2011 funding increase for JPSS, which threatens to result in a data gap for civilian meteorological and climate data. Congress also prohibited funding for a new Climate

Service Office that NOAA said would have enabled the agency to provide a reliable and authoritative source for climate data, information, and decision-support services at no additional cost and to more effectively coordinate with other agencies and public and private sector partners.

For the past several years, the U.S. government has been attempting to address how to turn research capabilities needed by users into operational systems. NASA and NOAA have been focusing their efforts on transitioning climate and ocean sensors from NASA research missions to NOAA operational satellites. The readiness of several sensors for this transition has been evident since 1990, but these sensors were included by NASA in the Earth Observing System (EOS) to ensure that their data would be available for research. The radar altimetry measurement has now been transitioned from NASA to NOAA, but efforts to transition radar scatterometry have not yet been successful.

The Landsat series was developed to provide 30-meter resolution imaging in at least five spectral bands for scenes covering roughly 185 km on a side. Despite several failed attempts to commercialize these observations, responsibility has continued to be at NASA. The National Land Imaging program was established in 2007 to provide a focal point in the U.S. government for understanding land imaging requirements and planning and budgeting for missions to meet those requirements. Responsibility for Landsat operations and data systems have been transitioned from NASA to USGS, but the Obama administration's fiscal year 2012 budget request marks the first time that USGS requested funding for the development of Landsat satellites.

The outcome of these efforts, however, will be contingent on the final fiscal year 2012 budgets for NASA, NOAA, and USGS as efforts are made to reduce the federal deficit. Further pressure on these budgets can be expected in the future. Furthermore, satellite missions have often experienced significant cost overruns, and the smaller budgets of NOAA and USGS have difficulty handling these costs without compromising other essential agency functions. Finally, while these efforts are important steps in transforming research capabilities into operational capabilities, current budgetary and structural factors prevent concrete plans for a comprehensive, coordinated, and sustained national Earth observation system to gather data over the long term.

## Integration of Data

Earth science and health science data often must be collected in the same time and space. Temporally and spatially compatible data sets are key elements to developing health early warning systems and producing useful Earth science tools for the health community. Integration of Earth observation data will increase understanding of the connections between environment and health and improve the ability to make sound decisions to protect human health and the environment. Earth observations are a major component, but factors affecting health outcomes, including population demography and underlying health and nutritional status, are key to addressing public health issues.

Space-based observations are most effective as inputs to public health decisionmaking when they are used in concert with other data such as ground-based observations of environmental and epidemiological conditions, data collected from aircraft, demographic data, and outputs from numerical models. Ground-based measurements are needed to calibrate space-based observations and to gain confidence in the accuracy of space-based data. For example, remote sensing will increasingly complement ground-based measurements in studies of air pollution and health. Instead of extrapolating ground-level pollutant levels from aerosol optical depth (AOD) mea-

measurements, emerging LIDAR systems, which provide vertical resolution for AOD, can be used to quantify pollutant levels on the ground. In addition, studies increasingly show that column AOD measurements correlate with fine particulates. Given the complexity of infectious disease systems, satellite-based models that predict areas at risk for disease outbreaks must be validated with *in situ* observations and health outcomes before becoming a viable tool for public health management. Research efforts to monitor ecosystem and environmental conditions from the depth of the root zone in soil to the top of the atmospheric boundary layer have begun through National Science Foundation funding of the National Ecological Observatory Network (NEON), and these observations may prove to be important for health considerations as well.

An interdisciplinary approach is needed for the public health community to better realize the benefits of Earth science products. In particular, the use of socioeconomic data can result in better predictions of health outcomes. Integrated data systems should incorporate a breadth of environmental parameters, as well as socio-demographic parameters such as population, income and education. Ensuring health data privacy is an important issue. While there is great interest in making data more usable at the local level, maintaining appropriate data privacy is an important priority for the public health community, both in the United States and globally.

There are complexities associated with health and environment relationships due to the diversity and number of variables. Research is needed on integrating climate science with health science; integrating environmental, public health, and marine and wildlife surveillance; applying climate and meteorological observations to real-time public health issues; and down-scaling long-term climate models to estimate human exposure risks and burden of disease.

## Interoperability

Data systems associated with different types of data and data acquisition (e.g., satellite remote sensing, aerial surveys, ground-based monitoring systems, and socioeconomic data) often do not work together, resulting in excess difficulty in using these data together, limited assessments, and major gaps in scientific understanding. Differences in format, resolution, projection, and computer systems as well as the lack of an integrated system with generally accepted standards for unified studies make access to data and value-added products difficult. Comprehensive, integrated data systems and standards, including those for health and disease surveillance, are needed to ease the process of making meaningful assessments.

The future needs of the CDC EPHTN include improving current data and adding new data. Current data challenges for the network include availability, resolution, standards, translation, cause/effect relationships, and dissemination.

## Models and Decision-Support Tools

The challenge is to translate Earth observation data into actionable information for health decisionmaking. To be able to use Earth observations, the public health community needs user-friendly tools, indicators, models, and decision-support systems based on the ready availability of massive amounts of data to yield a wide array of products. Tools such as predictive models are needed to improve forecasting and prevention, evaluations of the vulnerability of health care and public health systems, and infrastructure and health impact assessments. For example, the combination

of *in situ* measurements and remote sensing data using GIS and the Global Positioning System (GPS), models, indicators, and other information are fundamental tools for the planning, analysis, surveillance and intervention in the control and management of infectious diseases outbreaks and preventative public health measures (e.g., nutrition, safe drinking water).

Research is needed to develop decisionmaking frameworks, tools to analyze space-based observations, and tools of efficacy in the context of real-world health interventions. Multidisciplinary development would help to ensure that tools, such as improved baseline monitoring, will be more widely applicable and thus more efficient and cost effective than those currently available.

Public health community users are interested in

- Areas of high intrinsic variability or high trend (rapid change)
- Integrated Earth observation climate models for health impacts that address novel ways of using high spatial resolution observations
- Indicators to monitor climate change–related health outcomes within surveillance systems
- Development of early warning systems
- Improved decision support for vulnerability and adaptation assessment; operational predictions; and understanding of the decisionmaking process.

NASA, NOAA, and EPA need to work together to incorporate and/or combine more remote sensing and ground-based measurements on environmental parameters into existing or new models that would greatly enhance the ability to understand the link between exposure and health outcomes.

In 2008, the CSIS report *Earth Observations and Global Change* found insufficient funding for the development of models and decision-support tools to turn Earth observation data into knowledge in all of the societal benefit areas.<sup>7</sup> It was estimated that approximately \$100 million to \$200 million annually is needed to improve and enhance weather, climate, and hazard forecast models, and a similar level of funding is needed to configure the decision-support process and tools, a relatively small but still significant investment compared to federal funding for Earth observation satellites and research.

## Earth Observation Provider/Public Health Community Dialogue and Interaction

Good communication and understanding are needed between the data producer community and users in the health and environment research fields in order to optimize the benefits of Earth observations for public health. However, on many Earth science initiatives, scientists do not consider how their research can be applied to health community problems. There is also little feedback from the public health community on what it needs from Earth observation providers. While some in the public health community are using or have been involved in projects that use remote sensing data and have found it useful in predicting, monitoring, and taking actions related to pub-

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7. Lyn Wigbels, G. Ryan Faith, and Vincent Sabathier, *Earth Observations and Global Change* (Washington, D.C.: Center for Strategic and International Studies, 2008), [http://csis.org/files/media/csis/pubs/080725\\_wigbels\\_earthobservation\\_web.pdf](http://csis.org/files/media/csis/pubs/080725_wigbels_earthobservation_web.pdf).

lic health, many others have not used remote sensing or been involved in these projects, resulting in some communication gaps.

Research and applications such as support for capture, synthesis, and analysis of remote sensing data aimed at understanding health problems are critical. Ongoing federal efforts to develop models and decision-support tools have produced good results and should be expanded. In addition, there is a need to identify support for the continuation of some of these efforts in order to integrate the results into decisionmaking. It would be helpful to have consortia of federal agencies (Earth observation producers and public health) that would collaboratively fund projects that have progressed from research and application development but still require funding to initiate and operate the application and/or require the integration of long-term remote sensing and epidemiological data to relate exposures with health outcomes.

Identifying lessons from agencies' work with the public health community would be beneficial. One lesson is that the initial and continuous involvement of the public health community in application projects is very important. Involving the end user as part of the research design process from the very beginning helps to better and more quickly translate new scientific knowledge into better decisions to help protect both the environment and health. Interdisciplinary collaboration and partnerships with federal agencies and state and local authorities are also important.

While these efforts have been a useful first step, the engagement of the public health community needs to be broadened. There is a need for more dialogue and interaction with public health end user groups that reach a broader segment of the health community than what has previously occurred, focusing on how Earth scientists can interpret Earth observation data for the public health community and how these data can be used for health. Health end users need to know what Earth observation data are available and their capabilities and limitations. With this understanding, they will be able to determine how they can use the data and engage in a discussion on what is possible. Long-term pilot studies where interactions with the users are developed would be helpful. These studies should be driven by user needs and should demonstrate collaboration with decisionmakers.

More information on how to link Earth observation data to health is needed. Public health agencies do not have the expertise to do this. Scientists and specialist groups need to help with translating the data. Public health practitioners, risk managers, emergency responders, and the public need accurate information products in a timely manner. The data have to be analyzed so that they are understandable in the context of the problems and timelines faced by decisionmakers and must be deemed reliable.

The role of NASA, NOAA, USGS, and other agencies is critical in funding environment and health scientists for the use of remote sensing data. It is also important to provide training for the public health community, risk managers, and emergency responders to make the best use of new remote sensing systems when they are brought online. It would be beneficial for epidemiologists to partner with experts in geographical systems and visualization tools in order to graphically display the connections between environment and health.

While the GEO Health and Environment Community of Practice has been a good step globally, it needs to be strengthened. A mid-term evaluation of GEOSS conducted in 2010 found that GEO should put more effort into incorporating user needs into the development of GEOSS. It recommended that GEO acquire a better understanding of its current users and increase opportu-

nities for dialogue with the user community to match what the existing Earth observation architecture provides with what the users need.

## Private Sector

Limited access to and the high cost of commercial high resolution satellite remote sensing data are impediments to realizing the full benefits of using remote sensing data for public health. The private sector needs to work with the public sector to share information. There is also a need for the Earth observation and public health communities to engage the private sector as a partner in the development of decision-support tools.

# 4

## FUTURE CHALLENGES

We have identified some future near-term needs, but efforts must also be focused on identifying other potential needs. What are the near-term challenges? What are the long-term challenges? What needs to be done so that the full potential benefits of Earth observations for health can be realized?

Recognition of the benefits of remote-sensing data for public health has grown rapidly over the past decade. Organizing Earth observations around societal benefits such as health have helped raise the importance of providing decisionmakers and end users with Earth observation data and the tools to use it. Several U.S. government agencies are now involved in using these data in pursuit of their goals and objectives and are cooperating with each other to leverage their activities. In addition, efforts have been made over the past decade to provide the public health community with Earth observation data and to work with public health officials to apply the data to their objectives and needs. The decision by the NASA Public Health Program to require the involvement of the public health community in all projects it funds is an important step towards improved understanding and meeting of the public health community's needs. Also important is NASA's and EPA's partnership with CDC to analyze, organize and display Earth observation data for the EPHTN in ways that the public health community can use, and NOAA's growing partnership with CDC and the EPHTN will enhance this activity.

However, funding for the NASA Public Health Program has stayed at a very low level over the past several years due to other competing NASA programs. Similarly, NOAA's climate variability and health program is no longer funded, and its Ocean and Human Health program budget is also at very low levels. There is the potential to greatly scale up these benefits by engaging a broader segment of the public health community. Furthermore, while these application activities have been important steps in translating Earth observation data and research into knowledge that the public health community can use, in general, Earth science is not optimized for health use. Underpinning the success of all these efforts is the continued availability of Earth observations, and there are no plans to specifically sustain the Earth observation capabilities now in place. The current uncertainty in the budget outlook for the next several years complicates the prospects for addressing these challenges.

To fully deliver on the potential of Earth observations for public health requires that we follow these steps:

- The United States should increase its investment in, and pursue opportunities for, international cooperation to enhance and sustain Earth observations from space and *in situ* that would benefit public health that have been identified by the NRC and USGEO.

- Support should be increased for Earth observation health application activities that engage the public health community in the development and/or improvement of models and decision-support tools. Agencies should summarize “lessons learned” and identify best practices from these activities to inform future application activities.
- Priority and support should be provided for consortia of producer and public health agencies to pursue the issuance of collaborative solicitations to further mature application activities, initiate new ones, and make mature applications operational. This includes research that requires the integration of Earth observations from space, *in situ*, epidemiological and social data to relate exposures with health outcomes; and projects that have progressed from research and application development but will require funding to initiate and operate the application.
- Workshops focused on specific health topics should engage Earth observation providers and the U.S. public health community in an interactive dialogue on what Earth observation data are available; how they can contribute to the detection, monitoring and prediction of disease; and what models and decision-support tools are needed to translate Earth observation data into information that the public health community can use. Private sector entities that provide advice on public health issues at the state and local levels should also be included. Consideration should be given to scheduling these workshops in conjunction with NASA’s annual meetings on its health applications projects to increase awareness of how Earth observations have been used for public health. NOAA and other Earth science agencies should consider hosting annual health applications project meetings in conjunction with public health communities specifically to identify public health needs (or requirements) and discuss current use of Earth observations for public health.
- U.S. government support of the Intergovernmental GEO and federal agencies’ participation in GEO health tasks should be continued. The GEO Health and Environment Community of Practice should be strengthened, and participating GEO nations should be encouraged to share public health data. The U.S. Department of Health and Human Service’s Community Health Data Initiative provides a model for how public health authorities can become comfortable with providing these data while protecting privacy.
- The private sector should be engaged as an active participant in the application of Earth observations to public health. Innovative public-private partnerships at the federal, state, and local levels, such as the Department of Interior’s partnership with Esri on a new geospatial website, should be promoted.



## ABOUT THE AUTHOR

Lyn D. Wigbels, a senior associate for space initiatives in the CSIS Technology and Public Policy Program, focuses her research on space policy and programs with particular emphasis on Earth observations and space education. She coauthored the CSIS report *Earth Observations and Global Change* and two CSIS papers, “Earth Observation, Risk Assessment, and Global Change: Implications for the Insurance and Aerospace Sectors” and “Human Space Exploration Education.” Wigbels also serves as a senior fellow at the Center for Aerospace Policy Research, School of Public Policy, George Mason University, and is president of RWI International Consulting Services. She has more 15 years experience as a senior government executive at NASA in policy and programmatic areas and more than 25 years experience in developing and managing international programs. She is executive vice president of the American Astronautical Society (AAS) and was elected as a fellow of AAS. Wigbels is vice president for youth and workforce development activities for the International Astronautical Federation and chairs its Space Education and Outreach Committee. She received a B.A. in political science from Dickinson College and an M.A. in political science from George Washington University.



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