

GEO Task US-09-01a: Critical Earth Observations Priorities

***Health Societal Benefit Area:
Aeroallergens***



**GROUP ON
EARTH OBSERVATIONS**

User Interface Committee

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2010

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Acknowledgements

The Analyst performed this task and prepared this report under subcontract to Eastern Research Group, Inc. (ERG). Funding was provided via ERG's prime contract with the U.S. Environmental Protection Agency (Contract No. GS-10F-0036K, Task Order 1108). ERG provided technical and scientific support in the document review and report preparation.

Group on Earth Observations

GEO Task US09-01a: Earth Observation Priorities for Health SBA- Aeroallergens Sub-Area

Summary

The goal of GEO Task US-09-01a is to identify critical Earth observations for various societal benefit areas (SBAs). This analysis focuses on identifying end user requirements for the Health SBA- Aeroallergens Sub-Area, which addresses airborne substances such as pollen and spores. The task was supported by an Analyst and a 16-member Advisory Group, representing 12 GEO countries and spanning four continents. The team identified documents specifying Earth observation requirements related to aeroallergens.

The document identification process involved extensive online searches of national and international government agencies', workgroups', or organizations' websites; systematic searches of the published scientific literature; direct inquiries via e-mail with a select subset of agencies and organizations; as well as ongoing exchanges with Advisory Group members. The search identified several hundred potentially relevant documents, but the meta-analysis described in this report represents the review of approximately 160 documents. The area of aerobiology and aeroallergens in particular is presently largely using ground Earth observations. This is reflected in the relatively small number of reports (<10%) using remote sensing from satellites for their studies.

The Analyst reviewed documents for relevancy, which was defined as the availability of quantitative or qualitative Earth observations and stated or implied user application(s)/specific endpoint(s). The Analyst systematically extracted pertinent information into a project-specific database. This included Earth observation categories and parameters, end user information, and quantitative detail where possible. The majority of the documents reviewed were papers from the scientific literature, with only a limited number representing larger-scale reports resulting from collaborative projects conducted by national or regional agencies or organizations.

Because of the nature of the documents identified, efforts to prioritize these observations were challenging. The greatest contribution of Earth observations to the area of aeroallergens and allergic disease is the ability to forecast the type and concentration of allergen as much in advance as possible, allowing affected populations and public health officials to act in a timely fashion and prevent disease. Perhaps the second most important contribution stems from the fact that aeroallergens respond to warming and increased carbon dioxide effects, such as in global warming, and are therefore good proxies to provide further evidence for this global effect. The Analyst therefore focused on compiling quantitative data, when available, for the *most common* Earth observations reported among the documents reviewed, and those reported by data users as the *best predictors* of allergic airway disease and which hold the most value in forecasting, risk assessment, and disease prevention.

As illustrated in Figure 1 (Section 3) and detailed in Section 4 of this report, Earth observations from aerobiology and phenology networks as well as those from meteorological and air quality networks are being used in the area of aeroallergens. The emphasis of this SBA report is on the former two, as air quality is a subject of a separate SBA. Air sampling with impaction/volumetric devices is the primary and most critical Earth observation for determining aeroallergen concentrations, with meteorological Earth observations serving as important adjuncts to the concentration data. It needs to be mentioned that not all pollen collected with these devices is allergen. Pollen is the carrier of the allergens, which induces the allergic reaction. The allergen content of pollen can change each year and is dependent on the location of plants, as well as meteorological and other factors. However, although direct measurement of allergens is possible, it is costly and remains a goal rather than the practice (Buters et al., 2009).

The range of Earth observations in the aeroallergen area includes the following:

- **Ground-based samplers** (e.g., impaction devices such as Hirst-type pollen and spore traps) represent the most common and established Earth observation for collecting and measuring pollen and spores.
- **Temperature** is a key factor in the development of aeroallergens in all phenological stages and in later events. Temperature is most frequently quoted as a predictor of aeroallergens, either alone or in conjunction with other parameters. Temperature also proved to be a reliable proxy for global warming trends.
- **Humidity and precipitation** play a key role in affecting aeroallergen levels and their characteristics (positively in the case of some fungal spores, and negatively in the case of pollen).
- **Thunderstorms**, at particular times of the year, have been shown to exacerbate asthma and Earth observations predicting thunderstorms may prevent excess disease.
- **Wind direction, speed, and persistence** have been shown to impact both the concentration and the spatial distribution of pollen. However, the specific effect of wind persistence on pollen transfer has not been studied so far; neither has the interaction effect of the wind components.
- **Air pollution** can have a synergistic effect with meteorological parameters as well as with aeroallergens. Air pollution can also affect the structure, proteins, and allergenicity of pollen. Predicting allergen levels requires integration of aeroallergen data with meteorological and air quality data.
- **Land cover data using remote sensing** is an emerging tool in the area of aeroallergens. Seldom can aeroallergens be seen, but imaging land cover and land cover dynamics can be reliably used to assess land cover as a proxy for aeroallergen sources, release, and abundance. Remote sensing in combination with ground observations is being used to improve the accuracy of forecasting allergen levels and thus reduce asthma incidence.

In sum, ground Earth observations are widely used for predicting aeroallergen levels and providing critical information for allergic individuals, public health authorities, and a wide spectrum of other end users (see Section 3.3). Those methods need to be improved, aiming at more accurate forecasting as well as more advanced forecasting. The contribution of remote sensing in this area has been limited so far but has proven to be valuable, especially in covering large areas and being able to predict spatial trajectories of aeroallergens. Using modeling approaches, satellite data have been successfully integrated with ground observations. There is a definite need for developing further remote sensing data that will improve predictions and human health.

Based on this meta-analysis, no single “priority” Earth observation has been identified for the Health SBA- Aeroallergens Sub-Area. From an aerobiology perspective, counting and characterizing airborne allergens routinely performed utilizing the well-established Hirst-type samplers is undoubtedly the most important Earth observation, especially because of many reports (though not all) suggesting a direct correlation between pollen and spore aeroallergen concentrations and allergic diseases. However, pollen calendars alone cannot predict the severity of the pollen season. More accurate forecasts involve meteorological parameters. Accurate forecasts can improve health by helping physicians develop treatment plans for their allergic patients and enable sensitive populations to avoid exposure to high concentrations of aeroallergens and take advantage of prophylactic treatments. The specific quantitative requirements, however, associated with the Earth observation applications of interest to end users were not specified in most of the documents reviewed.

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GEO Task US-09-01a: Earth Observation Priorities for Health SBA - Aeroallergens Sub-Area

1 Introduction

This report articulates Earth observation priorities for the Health SBA- Aeroallergens Sub-Area based on an initial analysis of more than 600 publicly available documents, including documents produced by Group on Earth Observations Member Countries and Participating Organizations. Most were scientific papers published in peer-reviewed journals. The report's overall findings focus on a representative subset of approximately 160 relevant documents.

1.1 Group on Earth Observations

The Group on Earth Observations (GEO)¹ is an intergovernmental organization working to improve the availability, access, and use of Earth observations to benefit society. GEO is coordinating efforts to build a Global Earth Observation System of Systems (GEOSS).² GEOSS builds on national, regional, and international observation systems to provide coordinated Earth observations from thousands of ground, airborne, and space-based instruments.

GEO is focused on enhancing the development and use of Earth observations in nine Societal Benefit Areas (SBAs):

Agriculture	Biodiversity	Climate
Disasters	Ecosystems	Energy
Health	Water	Weather

1.2 GEO Task US-09-01a

The objective of GEO Task US-09-01a is to establish and conduct a process to identify critical Earth observation priorities within each SBA and those common to the nine SBAs. Many countries and organizations have written reports, held workshops, sponsored projects, conducted surveys, and produced documents that specify Earth observation needs. In addition, researchers and practitioners have also identified and recommended key Earth observation needs in publications and peer-reviewed literature. Task US-09-01a focuses on compiling information on observation parameters from a representative sampling of these existing materials and analyzing across the materials to determine the priority observations.

This task considers all types of Earth observations, including ground, in situ, airborne, and space-based observations. The task includes both direct measurements and derived parameters, as well as model products. This task seeks to identify Earth observation needs across a full spectrum of user types and communities in each SBA, including observation needs from all geographic regions with significant representation from developing countries.

¹ GEO Website: www.earthobservations.org

² GEO 10-Year Implementation Plan: www.earthobservations.org/documents.shtml

GEO will use the Earth observation priorities resulting from this task to determine, prioritize, and communicate gaps in current and future Earth observations. GEO Member Countries and Participating Organizations can use the results in determining priority investment opportunities for Earth observations.

1.3 Purpose of Report

The primary purpose of this report is to articulate the critical Earth observation priorities for the Health SBA- Aeroallergens Sub-Area. The intent of the report is to describe the overall process and specific methodologies used to identify documents, analyze them, and determine a set of Earth observation parameters and characteristics. The report describes the prioritization methodologies used to determine the priority Earth observations for this SBA. It also provides information on key challenges faced, feedback on the process, and recommendations for process improvements.

The primary audience for this report is the GEO User Interface Committee (UIC), which is managing Task US-09-01a for GEO. The GEO UIC will use the results of this report in combination with reports from the other eight SBAs, as well as the other two human health SBA reports. The GEO UIC will perform a meta-analysis across all nine SBA reports to identify critical Earth observation priorities common to many of the SBAs. Based on the nine SBA reports, the GEO UIC will produce an overall Task US-09-01a report, including the common observations and recommendations for GEO processes to determine Earth observation priorities in the future.

The report's authors anticipate that the GEO Secretariat, Committees, Member Countries, Participating Organizations, Observers, Communities of Practice, and the communities associated with the Health SBA are additional audiences for this report.

1.4 Scope of Report

This report addresses the Earth observation priorities for the Health SBA- Aeroallergens Sub-Area. It focuses on the human health area of aeroallergens and allergic airway diseases. Two other sub-tasks within the Health SBA include Air Quality and Infectious Diseases. Earth observations priorities associated with these other two sub-tasks are presented under separate cover.

The report provides some background and contextual information about the Health SBA- Aeroallergens Sub-Area. However, this report is not intended as a handbook or primer on the SBA, and a complete description of the scientific research related to this SBA is beyond the scope of this report. Please consult the GEO website for more information about the Health SBA.

The report focuses on the Earth observations within the Health SBA- Aeroallergens Sub-Area, independent of any specific technology or collection method. Thus, the report addresses the "demand" (or user) side of observation needs and priorities. The report does not address the specific source of the observations or the sensor technology involved with producing the observations. Similarly, any discussions of visualization tools, decision support tools, or system

processing characteristics (e.g., data format, data outlet) associated with the direct use of the observations are beyond the scope of this report. In other words, the focus of the report is on *identifying* Earth observation measurements used for public health purposes rather than describing the specific technology or method used to gather identified measurements.

In this report, the term “Earth observation” refers to parameters and variables (e.g., physical, geophysical, chemical, biological) sensed or measured, derived parameters and products, and related parameters from model outputs. The term “Earth observation priorities” refers to the parameters deemed of higher significance than others for the given SBA, as determined through the methodologies described within. The report uses the terms “user needs” and “user requirements” interchangeably to refer to Earth observations that are articulated and desired by the groups and users in the cited documents. The term “requirements” is used generally in the report to reflect users’ wants and needs; its use in this report does not imply technical engineering specifications.

Following this introduction, the report discusses the overall approach and methodologies used in this analysis (Section 2). Section 3 describes the Health SBA- Aeroallergens Sub-Area, the document pool used for the analysis, and the user types for this SBA. Section 4 articulates the specific Earth observations for the Health SBA- Aeroallergens Sub-Area, and Section 5 presents the priority observations across this SBA. Sections 6 and 7 present additional findings from the analysis of the documents and any recommendations. The Appendices include a list of abbreviations and acronyms, the documents cited and consulted, and a summary of the input to the Cross-SBA analysis.

2 Methodology

This section documents the general process followed and specific methodologies used to identify documents, analyze them, determine Earth observation parameters and characteristics, and establish a set of priority Earth observations for this SBA.

2.1 Task Process

The GEO UIC established a general process for each of the SBAs to follow in order to ensure some consistency across the SBAs. This general process for each SBA involves nine steps, as summarized in the following list:

- Step 1: Identify Analyst and Advisory Group for the SBA
- Step 2: Determine scope of topics within the SBA
- Step 3: Identify documents regarding observation priorities for the SBA
- Step 4: Develop analytic methods and priority-setting criteria
- Step 5: Review and analyze documents for priority Earth observations needs
- Step 6: Combine the information and develop a preliminary report
- Step 7: Gather feedback on the preliminary report
- Step 8: Perform any additional analysis
- Step 9: Complete the report on Earth observations for the SBA

A detailed description of the general US-09-01a process is available at the Task website (<http://sbageotask.larc.nasa.gov>) and the GEO website (www.earthobservations.org). Some steps in the process occurred simultaneously or iteratively, such as identifying documents (Step 3) and reviewing documents (Step 5).

2.2 Analyst and Advisory Group

The Health SBA- Aeroallergens Sub-Area had an “Analyst” and an “Advisory Group” to identify documents, analyze them, and prioritize the Earth observations. The Analyst served as the main coordinator to manage the activities.

2.2.1 Analyst

For the Health SBA- Aeroallergens Sub-Area, the Analyst was *Dr. Hillel Koren*. Dr. Koren is an internationally recognized leader in the field of environmental health research and has made significant contributions to our understanding of the immunological mechanisms and environmental factors involved in asthma and other diseases. Dr. Koren served as director of the U.S. Environmental Protection Agency’s (U.S. EPA’s) Human Studies Division and as senior science advisor to the National Health and Environmental Effects Research Laboratory. He was also leader of the Asthma and the Environment Research Program for the U.S. EPA’s Office of Research and Development (2001–2007), where he oversaw comprehensive, multidisciplinary basic and applied research focused on reducing the burden of asthma triggered by environmental factors.

In addition to his positions as Research Professor at the Institute for the Environment at the University of North Carolina at Chapel Hill, Dr. Koren serves on the Board of Trustees of the Fraunhofer Institute of Toxicology and Experimental Medicine (ITEM) in Hannover, Germany, and Chair of the Scientific Advisory Board of the German Research Center for Environmental Health. He has received numerous awards for leadership in environmental health research, including a U.S. EPA Bronze Medal awarded in 1999 for excellence in initiating and implementing an international collaborative arrangement between the U.S. EPA and the National Research Center for Environment and Health in Germany.

Dr. Koren has been active in many national initiatives, including the National Asthma Education and Prevention Program, the Department of Health and Human Services’ “Healthy People 2000” report, the National Research Agenda for Occupational Asthma and Chronic Lung Disease, and the President’s Task Force on Environmental Health Risks and Safety Risks to Children Workgroup on Asthma. He has also been an advisor to various international organizations, such as the World Health Organization (WHO) International Program on Chemical Safety and the International Inhalation Symposia organized by ITEM. Dr. Koren has recently joined the GEO Health and Environment Community of Practice launched at the GEOSS Workshop on Health and the Environment held in Geneva from 7 to 9 July 2009. The new Health and Environment Community of Practice will address the user perspective on issues involving environment and health, with an emphasis on using environmental observations to improve health decision-making at the international, regional, country and district levels. Dr. Koren provided support on this project under subcontract to Eastern Research Group, Inc., under U.S. EPA Contract No. GS-10F-0036K, Task Order 1108.

2.2.2 Advisory Group

The Advisory Group for the Health SBA- Aeroallergens Sub-Area consists of 16 experts and represents a cross-section of experts in the fields of immunology and allergy, botany, aerobiology, phenology, meteorobiology, physical geography, meteorology, and environmental sciences. Overall, the Advisory Group includes members from 13 countries and four continents. Table 1 shows the Advisory Group members.

The Analyst identified a pool of over 40 candidates. Through a series of telephone and e-mail communications, the Analyst contacted 22 candidates who met the project information needs most closely. The Analyst attempted to recruit Advisory Group members from all geographic regions, including developing countries. Of the 22 contacted, 16 expressed interest, three did not respond, and three were unable to participate but provided document references or suggestions for other possible Advisory Group members.

The primary role of the Advisory Group was to assist in:

- Reviewing compiled document inventories and identifying other relevant documents
- Assessing methodologies and analytic techniques
- Assessing prioritization schemes
- Reviewing findings and reports

The primary contact with the Advisory Group was through e-mails (approximately monthly) or one-on-one communications. The wide range of geographic representation necessitated this approach. A single teleconference was held, however, with about half of the Advisory Group (representatives from Europe, North America, and South America) on July 31, 2008, to review key project elements and to further articulate previous requests for documents to support the meta-analysis and to review analysis approaches.

As activities progressed under GEO Task US-09-01a, the Analyst acknowledged that having 16 top-notch scientists from around the world helping with this endeavor was very beneficial, but recognized that communicating with each member across the continents was sometimes a challenging task. In order to improve and accelerate communications, the Analyst established a Core Advisory Group consisting of five members of the Advisory Group (see Table 1). The intent was to have a quick “go to” team for time-sensitive input.

Table 1. Advisory Group Members

Name	GEO Country or Organization	Affiliation	Geographic Region	Area of Expertise/Specialty
Heidrun Behrendt*	Germany	Technical University Munich, Center for Allergy and Environmental Medicine	Europe	Allergotoxicology; allergy; phenology as related to allergy
Kashinath Bhattacharya	India	Visva-Bharati University, Department of Botany	Asia/Middle East	Aerobiology; allergy; palynology
Abdolkarim Chehregani	Iran	Bu-Ali Sina University, Iran	Asia/Middle East	Air pollution and allergy; diesel exhaust particles and pollen allergy
Xiaoqiu Chen	China	College of Urban and Environmental Sciences, Physical Geography	East Asia	Phenology and biometeorology
Bernard Clot*	Switzerland	MeteoSwiss	Europe	Aerobiology; phenology; biometeorology; botany
Simon Hales	Switzerland	WHO	International	Epidemiologist
Stein-Rune Karlsen	Norway	Northern Research Institute Tromsø	Europe	Remote sensing; GIS; phenology
Connie Katelaris*	Australia	University of Western Sydney and Campbelltown Hospital, Immunology and Allergy	Oceania/Australia	Clinical immunology/allergy; aerobiology as it relates to respiratory allergy
Cassim Motala	South Africa	UCT and Red Cross War Memorial Children's Hospital, School of Child and Adolescent Health	Africa	Allergology
Maria Gabriela Murray	Argentina	Universidad Nacional del Sur	South/Central America	Aerobiology; phenology
Hallvard Ramfjord	Norway	Norwegian University of Science and Technology NTNU	Europe	Allergology; aerobiology; remote sensing
Christine Rogers*	United States	University of Massachusetts, School of Public Health and Health Science	North America	Global climate change effects on aeroallergens; forecasting; long-distance transport; health effects
James Scott	Canada	University of Toronto, Dalla Lana School of Public Health	North America	Bioaerosol measurement and characterization; environmental microbiology; fungal ecology
Mikhail Sofiev	Finland	Finnish Meteorological Institute	Europe	Remote sensing; aerobiology modeling
Arnold van Vliet	Netherlands	Wageningen University, Environmental Systems Analysis Group	Europe	Biometeorology; aerobiology; phenology
Richard Weber*	United States	National Jewish Health	North America	Asthma, rhinitis, and sinusitis management; allergen aerobiology; pollen cross-reactivity

*Core Advisory Group members

2.3 Methodology

This section provides a general description of the processes, analytic methods, and approaches the Analyst/Advisory Group used to identify documents, analyze them, and establish a set of priority Earth observations. The approach included a systematic review of the publicly available literature and reports, direct contact with data users, and regular communication with the Advisory Group.

2.3.1 Documents

Document search methodologies included the following:

- Online searches of national and international government agencies', workgroups', or organizations' websites, including review of aeroallergen networks and pollen forecast websites.
- Systematic searches of the published scientific literature using publicly available online databases (i.e., U.S. National Library of Medicine's PubMed and TOXLINE). In addition, a select subset of journals not part of the PubMed/TOXLINE holdings was searched separately (e.g., *International Journal of Climatology*, *Current Allergy and Asthma Reports*).
- Review of reference lists from "key" review documents.
- Direct requests via e-mail to a select subset of national and international government agencies, workgroups, or organizations.
- Input from Advisory Group members, through their critical review of documents identified by the Analyst and suggestions for additional relevant reports.

Per GEO Task US-09-01a charge, primarily post-2000 documents were targeted. For Internet-wide searches and searches of organization websites, journal-specific websites, or online databases of the published literature, key words were used singly and/or in combination with other words to identify potentially relevant documents. For example:

- | | |
|------------------------------------|--------------------|
| • Aeroallergen | • Pollen |
| • Air pollution | • Pollen transport |
| • Allergen | • Predict |
| • Allergic disease/allergies | • Remote sensing |
| • Asthma | • Respiratory |
| • Climate change | • Rhinitis |
| • Earth observations | • Satellite |
| • Forecast/forecasting | • Spore |
| • Fungal/us | • Thunderstorm |
| • Meteorological factors/variables | |

The overarching goal was to identify documents that contained Earth observation parameters associated with aeroallergens and specified public health applications. It became evident relatively early in the document search process that online searches were not yielding larger-scale reports resulting from collaborative projects conducted by agencies or organizations. On

the other hand, numerous potentially relevant journal citations and abstracts were identified that described various Earth observation parameters being used directly or indirectly in a public health context.

At that point, efforts were made to contact organizations directly to help identify any relevant reports issued on an international, national, or regional scale. We identified a subset of national and international organizations with potential interest in aeroallergens, including GEO Participating Organizations. We sent each organization a personalized letter with a brief background on the GEO Task US-09-01a and a request for publicly available reports (post-2000) that describe user needs for Earth observation data pertinent to aeroallergens and airway diseases. Table 2 lists the organizations contacted and those from which responses have been received. In some cases, contacts indicated that they were not aware of documents meeting the specified criteria. Most of those who responded provided listings from the scientific literature, in some cases including comprehensive bibliographies or reference to existing databases. These listings were compared with papers already identified in our document search effort.

Advisory Group members were encouraged throughout the research phase of this task to identify documents to supplement those identified by the Analyst; communication occurred via e-mails and/or one-on-one communication between the Analyst and individual Advisory Group members. Again, in most cases, Advisory Group members pointed to the published scientific literature.

2.3.2 Analytic Methods

EndNote[®] reference management software was used to manage, track, and sort identified documents. The project EndNote library, therefore, contains a complete listing of citations identified via PubMed and TOXLINE searches, as well as potentially relevant reports identified through our search mechanisms and Advisory Group input (n=>600). As a first step, citations and abstracts were screened to identify the most potentially relevant papers—generally, those that appeared to contain both Earth observation measurement or parameter information (quantitative or qualitative) and a specified public health use of the Earth observation parameter.

For those documents meeting the above-stated criteria (n=245), the Analyst reviewed the full papers for “relevancy.” Relevancy was defined as follows, and definitions are based on task goals and discussions with the Advisory Group:

- **Very relevant:** Earth observations are quantitative. User application(s)/specific endpoint(s) are stated.
- **Relevant:** Earth observations are quantitative or qualitative. User application(s)/specific endpoint(s) are stated or implied.
- **Marginally relevant:** Earth observations are quantitative or qualitative. User application(s)/specific endpoint(s) are not stated.
- **Not relevant:** No quantitative or qualitative Earth observations. User applications(s)/specific endpoint(s) are not stated.

Table 2. Organizations Contacted

Organization	Section(s)	Region	Response
American Academy of Allergy, Asthma, and Immunology (AAAAI)	Education and Outreach National Allergy Bureau	North America	X Provided no documents
British Aerobiology Federation		Europe	
Centers for Disease Control and Prevention (CDC)/National Center for Environmental Health	Asthma and Air Pollution	North America	X Provided no documents
California State University, Fresno	Department of Earth and Environmental Scientists	North America	
Committee on Earth Observation Satellites (CEOS)		International	
U.S. Environmental Protection Agency, National Center for Environmental Assessment	Global Change Research Program	North America	
European Meteorological Network (EUMETNET)	UK Met Office Health Team	Europe	X Provided documents
European Centre for Medium-Range Weather Forecasts (ECMWF)		Europe	
Health Climate Foundation			
International Association for Aerobiology		International	X Provided documents
International Panel on Climate Change (IPCC) Working Group II (Climate Change Impacts, Adaptation, and Vulnerability)	Department of Global Ecology, Carnegie Institution for Science	International	X Provided documents
National Jewish Health	Allergy and Immunology	North America	X Provided documents
National Heart, Lung and Blood Institute (NHLBI)	Airway Biology and Disease Branch; Chronic Obstructive Pulmonary Disease/Environment	North America	
National Institute of Allergy and Infectious Diseases (NIAID)	Division of Allergy, Immunology, and Transplantation	North America	
Pan American Health Organization (PAHO)		South/Central America	
Spanish Aerobiology Network		Europe	X Referred to www.uco.es/rea
UK National Pollen and Aerobiology Research Unit		International	X Referred to EU COST action
University of Tulsa Aerobiology Laboratory		North America	
USDA/Agricultural Research Service		North America	
World Allergy Organization	Committee on the Impact of Climate Change on Allergy	International	
World Meteorological Organization		International	X Provided documents

The Analyst then extracted data into a customized Microsoft Access database designed and developed to house citation data for the most relevant papers and reports. This entailed reading documents to identify Earth observation data and recording Earth observation parameters and associated characteristics. As this data mining exercise continued, the Analyst observed certain trends in document types and the degree of relevance for GEO Task US-09-01a. For example, many documents lacked detail about Earth observation parameters, or only implied or inferred end user applications (see also Sections 4 through 7 for results). The Analyst, therefore, focused on a relatively small but representative subset of documents (n=160) that clearly identified Earth observation parameters in a public health end-user context (i.e., “very relevant” or “relevant” documents). The results presented in this report, therefore, reflect Earth observation data from a selected subset of documents.

2.3.3 Prioritization Methods

A combination of quantitative and qualitative approaches was employed to prioritize the Earth observations. Using the data entered into the Health: Aeroallergens database, a series of simple queries and data sorts was conducted. The purpose of this exercise was to evaluate the types of Earth observation categories documented by various end users and the relative frequency of specific Earth observation parameters being used.

The nature of the documents identified for the Health SBA- Aeroallergens Sub-Area and the relatively limited amount of quantitative data reported within these documents did not warrant developing very complex priority-setting criteria. Instead, the Analyst focused on compiling quantitative data, when available, for the *most common* Earth observations reported among the documents acquired in addition to those reported by data users as the *best predictors* of allergic airway disease, and which hold the most value in forecasting, risk assessment, and disease prevention.

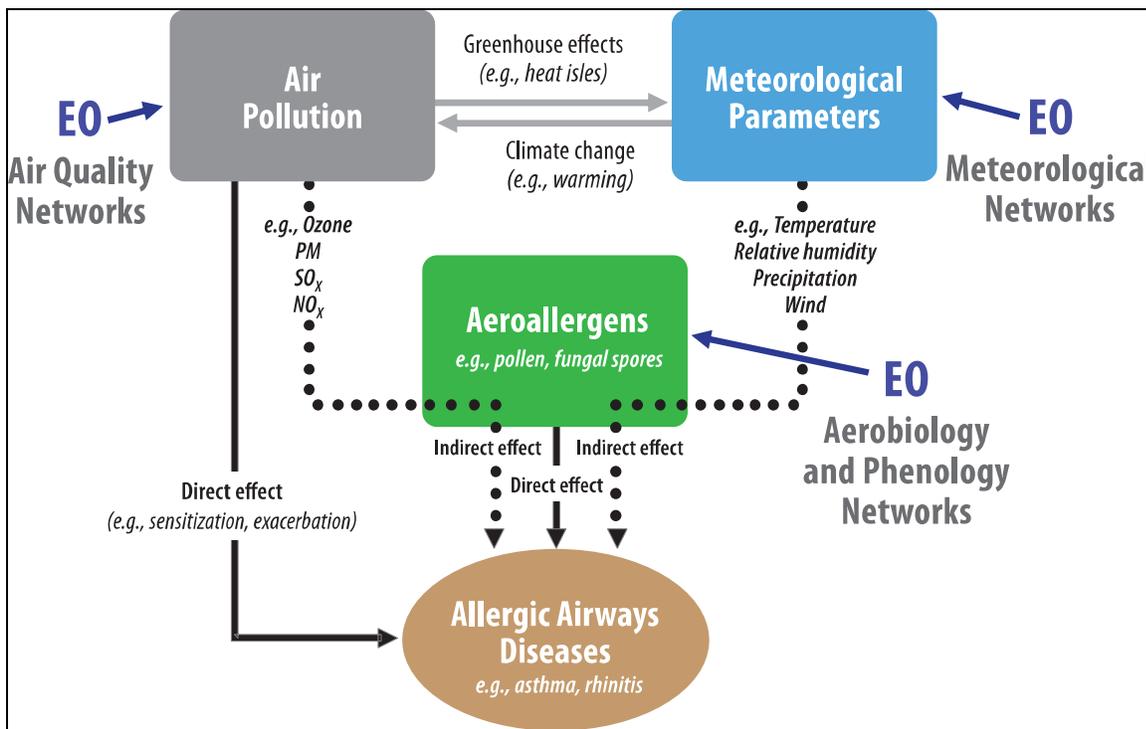
3 Health SBA: Aeroallergens Sub-Area

3.1 Aeroallergens Sub-Area Description

The Health SBA- Aeroallergens Sub-Area focuses on outdoor airborne aeroallergen carriers such as pollen or spores. These aeroallergens represent an important component of air quality that can affect human health (See Figure 1) (Burge and Rogers, 2000). Changes in the environment (e.g., climate change) have been shown to affect the timing of pollen dispersion, duration of a pollen season, severity of allergen production, and the abundance/distribution of allergen sources (U.S. EPA, 2008; Beggs, 2004; WHO, 2003a).

Allergic airway diseases represent a growing public health problem, with rhinitis and asthma being those most closely associated with pollen and spores. The most common allergic illness associated with exposure to aeroallergens is allergic rhinitis (hay fever). Since the beginning of the 20th century, the frequency of hay fever has increased considerably, from about 1 percent to the current overall prevalence of about 15 to 20 percent. According to WHO estimates, 300 million people worldwide suffer from asthma, and 255,000 died of asthma in 2005 (www.who.int/respiratory/asthma/en/). Asthma is the most common chronic disease among

Figure 1. Earth Observations Related to Allergic Airways Diseases



children. Asthma is not just a public health problem for high-income countries; it occurs in all countries regardless of level of development. Over 80 percent of asthma deaths occur in low- and lower-middle-income countries. About 80 percent of asthmatics also have rhinitis.

In the United States, allergic rhinitis annually affects approximately 20 to 40 million people, including 10 to 30 percent of adults and up to 40 percent of children (U.S. EPA, 2008). Second to allergic rhinitis, asthma is one of the primary allergic diseases associated with exposure to aeroallergens. According to the Centers for Disease Control and Prevention (CDC), approximately 7.7 percent of the U.S. population reports that it has asthma (NCHS, 2009). Asthma accounts for one-quarter of all emergency room visits in the United States each year and approximately 5,000 deaths per year (AAAAI 1996–2006).

The overarching goal of the Health SBA is to strengthen our understanding of environmental factors affecting human health and well-being. The following is a brief overview of topics covered and key outcomes for the overall Health SBA from the GEOSS 10-Year Implementation Plan:

“GEOSS will contribute significantly to human health for prevention, early warning, and rapid problem-solving by facilitating better data on environmental factors such as exposure factors like air and water contaminants, pathogens, and ultraviolet radiation; nutritional factors such as price and availability of food; extreme weather events and noise; and indicators of the stresses of

overpopulation. Health service providers, researchers, policy makers, and the public in developed and developing countries as well as indigenous communities need such data products for providing the services, science, and decisions that affect human health and well-being. For example, data on population distributions, production and transport of chemicals [and other stressors], as well as hurricanes and floods are factored into emergency management decisions that save lives and property...Data on the transport of air pollution are factored into early warnings for cardiovascular and respiratory responses as well as remediation efforts.”

Coordinated, comprehensive, and sustained Earth observations for the Health SBA-Aeroallergens Sub-Area could contribute to systems and strategies that a variety of users (e.g., public health officials, susceptible individuals and their health care providers) can apply to reduce exposure and associated symptoms in individuals at risk for asthma and other airway diseases. These include, for example, daily air quality indices and pollen counts, as well as improved public health tracking and forecasting of asthma and allergic disease so that public health officials can understand how these illnesses are changing and develop appropriate responses.

Current pollen and spore counts available in the media typically provide information that is 24 to 48 hours old. Aerobiology, in conjunction with meteorology, is beginning to make the transition from descriptive predictions to more quantitative and accurate predictions. With the greater availability of meteorological data, including remote sensing, aerobiologists now are studying the meteorological conditions correlated with the onset of a pollen or spore season and the timing of pollen and spore release, as well as variables associated with peak atmospheric concentrations (e.g., Levetin and Van de Water, 2003). Daily reports of the counts may encourage community efforts to reduce exposure to certain types of pollen. The main benefits of pollen and spore counts are the public’s enhanced awareness of the importance of allergic diseases and familiarity with the aeroallergens that trigger them. This awareness increases the likelihood that allergy sufferers will seek medical help when they need it and that physicians will be familiar with the health effects of the counts and be more prepared to care for allergic patients. Ultimately, pollen and spore counts benefit patients, physicians, and their communities.

3.2 Documents

As described above, 160 documents were identified by the Analyst and the Advisory Group as being potentially relevant to Earth observation priorities in the area of aeroallergens and health. Table 3 summarizes the distribution of documents by geographic region. Of the 160, eight were government or scientific organization reports, three were meeting summaries, and 149 were journal articles. The task goal was to identify documents where user needs were clearly articulated. The Analyst found, however, that user needs were often more implied than explicitly stated.

Table 3. Document Sources for Health: Aeroallergens SBA

Geographic Region	Number of Documents
International	7
Africa	0
Asia/Middle East	9
East Asia	3
Europe	90
North America	29
Oceania/Australia	13
Polar Regions	1
South Central/America	8

Table 4 highlights the general percentage of agent types and associated disease outcomes addressed in the subset of relevant documents reviewed.

Table 4. Summary of Agent and Disease Types in Documents Reviewed

Data Type	Estimated Percent
<i>Agent types</i>	
Pollen	60%
Spore	12%
Pollen and spore	7%
Pollen and air pollution	15%
Spore and air pollution	0%
Pollen and spore and air pollution	6%
<i>Disease</i>	
Allergic asthma	46%
Allergic rhinitis	5%
Allergic asthma and rhinitis	12%
Rhinoconjunctivitis and asthma	1%
No specific allergic disease reported (implied allergic disease)	36%

3.3 User Types

A wide range of user types has been identified for the Health SBA- Aeroallergens Sub-Area. For the purpose of this meta-analysis, data users are defined as those involved directly or indirectly in the protection of public health. Individuals or groups may use Earth observations to:

- Promote prevention and health protection.
- Develop and populate integrative systems, analytical tools, and models.
- Assess and forecast air quality (direct measurements or outcome of integrative systems/tools/models) with respect to allergenic conditions and disease incidence/trends data.

User types may include, but are not limited to:

- Air quality model and systems developers/providers
- Air quality scientists
- Health care providers
- Health outreach and education professionals
- Health risk analysts
- Interested/aware/concerned members of the public, including sensitive populations
- Public health organizations
- Public health policy organizations
- Public health managers and decision-makers
- Public health policy makers
- Non-governmental organizations (NGOs) and advocacy groups
- Health scientists (e.g., epidemiologists, immunologists)
- Weathercasters

Some, but not all, documents identified potential data users and their needs. In many (approximately 40 percent) of those documents, “interested/aware/concerned members of the public” represented the primary end user of reported Earth observations (e.g., beneficiaries of forecast, tools for prevention). Approximately 10 to 12 percent of the documents analyzed did not include any description of potential or current Earth observation end user(s). Further, because of the research-oriented nature of many of the documents reviewed, end users were not always explicitly identified. This is also true of the documents produced by organizations such as WHO (2003a,b), WMO (2004), and U.S. EPA (2008). The Analyst determined that a gap analysis was not possible or appropriate.

The Analyst observed, however, that the majority of the documents included either implicit or explicit statements about the potential use of the Earth observation of interest by end users. The Analyst, therefore, combined those statements as described in the following paragraph.

Pollen forecasts are currently used by physicians (allergists), health professionals, those with allergies, pharmaceutical industry, researchers, and environmental health authorities, and for a wide variety of purposes—for example, avoidance, preventive medication, management of therapy (e.g., pre-seasonal hyposensitization), planning of holidays or travels, planning of medicine production, and distribution and start of short-term forecast models. For instance, numerous national networks exist in Europe that measure pollen concentrations, which demonstrates a well-established cooperation between allergologists and aerobiologists (see Table 9, Section 6.1). The notification of days when pollen levels are above the agreed-upon threshold level (of aeroallergen above which it may trigger an allergic response) is important for some groups in the community, such as asthmatics and rhinitics, as well as the medical services (e.g., hospital emergency wards) that are likely to receive these patients. Pollen counts are already being broadcasted in television weather reports and printed in newspapers during the pollen season.

4 Earth Observations for Health SBA - Aeroallergens Sub-Area

Aeroallergens are classified into three major categories: pollen, mold (or fungi), and indoor allergens. The former two are considered to be primarily outdoor allergens. For the purpose of this report, we focus on outdoor allergens.

Table 5 provides a snapshot of pollen and spore counts across the United States.

Table 5. Pollen and Spore Counts by Percentile Category for 51 Stations in the United States (in Grains or Spores per Cubic Meter)

Particle type	Low (<50th)	Moderate (50th–75th)	High (75th–99th)	Very high (>99th)
Trees	0–15	16–90	91–1,500	>1,500
Grasses	0–5	6–20	21–200	>200
Weeds	0–10	11–50	51–500	>500
Spores	0–6,500	6,501–13,000	13,001–50,000	50,000

Source: 2000 AAAAI pollen and spore report. Milwaukee (OH): American Academy of Allergy, Asthma and Immunology, 2001.

A substantial body of literature demonstrates a correlation between the concentration of aeroallergens, air pollution, meteorological parameters, and the prevalence of allergic diseases (e.g., Frei and Gassner, 2008a; U.S. EPA, 2008; Dopazo et al., 2002; Frenz, 2001; Jager 2000; and Bass et al., 2000). As illustrated in Figure 1, the three major variables have distinct Earth observation methodologies. In the context of aeroallergen and allergic diseases, the main purpose of these methodologies is to assess aeroallergen levels, to predict aeroallergens as far as possible in advance, and to be used as diagnostic tools by allergists.

The objective of using Earth observations is to provide data regarding the concentration of aeroallergens and phenological characteristics, such as start of a flowering season, timing of aeroallergen release, and predicting trajectories of aeroallergens in a region or continent. Most importantly, the data are needed to forecast aeroallergen conditions for a broad group of end users, including patients, physicians, regulators, and public health and public policy organizations (see complete list of end users in Section 3.3). The clinical usefulness of Earth observations is reflected in the number of regional or continental networks and their websites (see Table 9, Section 6.1). Relevant Earth observation parameters for the Health: Aeroallergens SBA are described in more detail below.

Aeroallergens

Aeroallergens are monitored by established methodologies, such as volumetric samplers. Pollen and spores can carry different allergens that induce the allergic reaction. The allergen content of pollen can change each year and is dependent on the location of plants, as well as meteorological and other factors. The most common Earth observation equipment used to collect pollen and spores is the Hirst-type volumetric spore trap device, first developed in 1952 (Hirst, 1952, Portnoy and Barnes, 2003; WHO 2003a). Many of the pollen monitoring sites around Europe, in North America, and in many other places around the world rely on Hirst-type volumetric spore traps. Typically, these traps

have a seven-day recording period, and some traps can be powered by solar energy for field observations. The finest possible time resolution is hourly intervals, although in most cases a simple average daily count is obtained. A daily concentration is obtained by summing the counts for each species, and these figures are then converted to grains per cubic meter of air.

Although direct measurement of allergens is possible, it is costly and remains a goal rather than the practice (Buters et al., 2009). New technologies taking advantage of the growing use of molecular genetic and gene chip methods have recently started being used in the field of aerobiology (Brodie et al., 2007). Ongoing efforts are directed at quantifying the allergen content carried by the pollen rather than counting pollen grain alone. Future forecasting will therefore be based on actual concentration of allergen not pollen (Buters et al., 2009).

Traps typically are located on the roof of a suitably accessible building about two or three stories high. Traps are located at this height so that they can sample ambient airflow, which contains a mix of local and more distant aeroallergen sources. Predictions of aeroallergen counts can be made locally by a single station or regionally by a network of stations. Numerous papers (e.g., Emberlin et al., 1999) have shown the advantage of a network in extrapolating results, as one monitoring site is valid only within a biogeographical and land-use area. Recently, techniques such as laser optics have been introduced to this area to promote automation and objectivity in collecting pollen and spore data. Unfortunately, significant hurdles remain using this technology (Delaunay et al., 2007; Weber, 2007).

The most extensive survey of pollen and spore counts in the United States has been performed by the National Allergy Bureau (NAB) of the American Academy of Allergy, Asthma and Immunology (AAAAI). NAB consists of a network of stations that are located in various parts of the United States and report spore and pollen concentrations on a regular schedule. The European Aeroallergen Network centralizes data and provides information on airborne pollen and allergy risk in Europe (www.polleninfo.org). The European Phenology Network (EPN), the National Phenology Network (NPN), and other similar networks provide information for a variety of end users, describing network information and the relation between climate and natural systems. The information these national networks deliver is of phenological nature and pertains to the development stage of plants.

Meteorological Parameters

Meteorological parameters such as relative humidity, temperature, wind, and precipitation are important parameters for phenological characteristics such as flowering, and for aerobiological processes such as emission and dispersion of pollen, long- and short-range transports of aeroallergens, and daily patterns of aeroallergens (Clot, 2001). Warming, for instance, can increase productivity, allergen counts, and allergen characteristics (U.S. EPA, 2008), all of which will indirectly affect the allergic responses.

Extreme weather conditions like thunderstorms have also been associated with asthma episodes (Marks et al., 2001; Marks and Bush, 2007; D’Amato et al., 2005; Dales et al., 2003; Newson et al., 1998). At present, the main limitation on predicting these events is the low specificity of meteorological prediction of thunderstorms producing outflows. Clearly, Earth observations of meteorological parameters provide critical data for models that integrate meteorological and aeroallergen data for forecasting purposes. Meteorological parameters are usually obtained by regional or national networks of stations based on ground measurement as well as remote sensing. In Europe, EUMETNET provides a framework to organize cooperative programmes between the members in the various fields of basic meteorological activities, such as observing systems, data processing, basic forecasting products, research and development, and training (www.eumetnet.eu/). Weather forecast models developed by meteorological services are extremely useful to forecast pollen or spore concentrations. When they include dispersion modules (as for pollution dispersion), they allow accurate forecasting of emission and dispersion of pollen and spores for every grid point.

Air pollution

Air pollution can have direct effects on allergic individuals by causing an inflammatory response in their airways, making them more susceptible to exposure to aeroallergens. In addition, air pollution can have indirect effects by combining with aeroallergens, which is a phenomenon well-studied with particles such as diesel exhaust particles (Diaz-Sanchez et al., 1997; Chehregani and Kouhkan, 2008)—and can modify their characteristics (D’Amato et al., 2007a; Behrendt and Becker, 2001; Behrendt et al., 1999; Traidl-Hoffman et al., 2003, Chehregani et al., 2004, and Majd et al., 2004). A large proportion (up to a third) of the carbon mass of particulate matter with a diameter of <2.5 microns—known as PM_{2.5}—consists of whole and comminuted biological particles such as pollen grains and fungal spores (Womiloju et al., 2003; Winiwarter et al., 2009). This fraction, somewhat counter-intuitively, is greater in urban than in rural settings.

Air pollution is monitored in most countries by using a network of monitoring stations or by regional monitors. The direct effect of air pollution on human health (including allergic diseases) is a topic of intensive investigation (Dockery et al., 1993) and is beyond the scope of the Health: Aeroallergens SBA; instead, it is addressed under the Health: Air Quality SBA.

Table 6 presents a summary of the ground-based Earth observation systems used for aeroallergens and examples of representative documents in which these systems are described. The table includes Earth observation parameters and methodologies for predicting pollen concentrations and demonstrating the relationship between allergen concentration and disease. To simplify the complexity in this field, the Analyst divided the table into the following categories: 1) aeroallergen counts, 2) the relationship between aerobiological and meteorological observations, and 3) areas where aerobiological, meteorological, and air pollution observations are combined relative to allergic disease. Because of the multiple factors affecting aeroallergen concentrations and their allergenic characteristics, many investigators commonly use

mathematical approaches and statistics in forming various models that can integrate data from different Earth observation sources. Representative examples are shown in Table 7.

In general, in the field of aerobiology, forecasting models can be short-term (1 to 3 days), medium-term (3 to 7 days), and long-term (>7 days) (Stach et al., 2008a). The short-term forecasts provide information on pollen concentration, and the accuracy depends on the weather forecast. The accuracy of the medium-range forecast models is also linked to the accuracy of the weather forecast (Smith and Emberlin, 2005). A long-term 30-day model for London, for example, has been described by Smith and Emberlin (2006). In fact, three models were used for each 30-day forecast. The models achieved 62.5 percent accuracy. The models took in account winter averages of the North Atlantic Oscillation to forecast 10-day means of allergenic pollen counts. Long-term forecasts are useful in predicting the main season parameters, such as peak and end dates of particular grasses and pollen season. The ability to predict allergenic pollen counts for a 30-day period and beyond is of great assistance to the medical profession, including allergists planning treatment and physicians scheduling clinical trials.

Table 6. Earth Observation Parameters for the Health SBA: Aeroallergens Sub-Area

Observation Category	Earth Observation Parameter	Earth Observation Method Used	Documents (Examples)	Comments
Aerobiological	<ul style="list-style-type: none"> Pollen Spores 	Hirst Rotorod Laser optics Image analysis Satellite (see Table 7)	Belmonte and Canela, 2002 Katelaris et al., 2004 Kawashima et al., 2007 Lierl and Hornung, 2003 Madeja et al., 2005 Menezes et al., 2004 Portnoy and Barnes, 2003	<ul style="list-style-type: none"> Examples of method application Most end users relying on Hirst-type samplers Use of laser optics is in experimental stage
Aerobiological + Phenological	<ul style="list-style-type: none"> Phenophases, including onset of pollen season 	Remote sensing from satellites	Karlsen et al., 2009 (see more remote sensing data in Table 8)	<ul style="list-style-type: none"> Normalized Difference Vegetation Index (NDVI) from remote sensing correlated with birch pollen data from pollen traps
Aerobiological + Meteorological	<ul style="list-style-type: none"> Relative humidity Temperature Wind speed Wind direction Precipitation 	Meteorological stations as stand-alone or connected as networks covering cities or larger regions	Altinatas et al., 2004 (pollen and allergies ; no meteorological parameter correlation) Barnes et al., 2001 (pollen, temperature, rain) Burch and Levetin, 2002 (spore and increased temperature, humidity, air pressure)	<ul style="list-style-type: none"> Parameters studied included parenthetically Correlations between aeroallergen concentration and meteorological parameters and/or disease highlighted in bold

Observation Category	Earth Observation Parameter	Earth Observation Method Used	Documents (Examples)	Comments
	Continued— <ul style="list-style-type: none"> • Relative humidity • Temperature • Wind speed • Wind direction • Precipitation 		<p>Cecchi et al., 2006 (pollen and prevailing wind promote long range transport)</p> <p>Dales et al., 2008 (pollen and hospital admission for asthma)</p> <p>D'Amato and Cecchi, 2008 (pollen, temperature, wind speed, and respiratory allergies)</p> <p>Das and Gupta-Bhattacharya, 2008 (spores and respiratory allergies, min/max temperature, rainfall)</p> <p>Diaz de la Guardia et al., 2006 (pollen, temperature, humidity and respiratory allergies)</p> <p>Galan et al., 2001 (pollen, temperature, season onset)</p> <p>Green et al., 2004a, 2004b (pollen, temp, season onset)</p> <p>Laaidi, 2001a (pollen dispersion and allergies, correlate with wind, humidity, precipitation)</p> <p>Latorre and Caccavari, 2009 (pollen, temp, wind speed)</p> <p>Molina et al., 2001 (pollen, temp, wind direction/speed)</p> <p>Peternel et al., 2004 (spore and allergies)</p> <p>Puc, 2004 (pollen, wind speed, humidity, and long-distance transportation)</p> <p>Rasmussen, 2002 (pollen, temperature, season onset)</p> <p>Ribiero et al., 2003 (pollen, temperature, wind direction)</p>	

Observation Category	Earth Observation Parameter	Earth Observation Method Used	Documents (Examples)	Comments
	Continued— <ul style="list-style-type: none"> • Relative humidity • Temperature • Wind speed • Wind direction • Precipitation 		Ribiero et al., 2009 (pollen and ER visits) Riera et al., 2002 (pollen, neg correlation rain; pos correlation wind speed, allergies) Rizzi-Longo et al., 2009 (spores, temperature) Troutt and Levetin, 2001 (spores, temperature, humidity) Weber, 2003 (pollen, temp, wind, precipitation; spore, temperature, drafts) Zanolin et al., 2004 (pollen/spores, temperature—best correlation)	
	<ul style="list-style-type: none"> • Thunderstorms 	Ground-based Earth observation as single or multiple stations forming networks	Anderson et al., 2001 (asthma admission correlates with thunder; no association with spore/pollen concentration or rainfall) Burch and Levetin, 2002 (thunder and spore plumes) Dales et al., 2003 (thunder and asthma attacks) D'Amato et al., 2007b (thunder and pollen and increased asthma episodes) Lewis et al., 2000 (thunder and pollen and asthma attacks) Marks et al., 2001 (thunder and pollen and increased asthma episodes) Marks and Bush, 2007 (thunder triggers <i>Alternaria</i> , exacerbates asthma) Newson et al., 1998 (thunder and pollen and increased asthma episodes; thunder does not act alone)	Representative papers demonstrating how Earth observations (e.g., forecasting thunderstorms) can help prevent asthma outbreaks

Observation Category	Earth Observation Parameter	Earth Observation Method Used	Documents (Examples)	Comments
			Pulimood et al., 2007 (thunder followed by high <i>Alternaria</i> spores and increase asthma hospital admissions)	
Aerobiological + Meteorological + Air Pollution		Aerobiological, meteorological, and air quality databases	<p>Atkinson et al., 2006 (spore and asthma ER visits; pollen did not add to observed effect based only on meteorological parameters)</p> <p>Bartra et al., 2007 (air pollution impact on allergens; exacerbates allergies)</p> <p>Chehregani et al., 2004 (air pollution and pollen allergenicity)</p> <p>Chehregani and Kouhkan, 2008 (diesel exhaust particles and pollen allergenicity)</p> <p>Dales et al., 2004 (ozone and aeroallergens show synergistic effects on asthma)</p> <p>D'Amato et al., 2002 (air pollution [diesel exhaust] and pollen allergenicity)</p> <p>Lewis et al., 2000 (air pollution not adding to effects of aeroallergens; rain and thunder assoc)</p> <p>Newhouse and Levetin, 2004 (pollen interacts with pollutants [e.g., ozone]; correlated with asthma and rhinitis)</p> <p>Shea et al., 2008 (CO₂ and warming and pollution assoc with increase in all allergic diseases)</p> <p>Tobias et al., 2004 (air pollution and meteorological variables not affecting aeroallergen mediated asthma)</p>	Representative papers demonstrating explicitly or implicitly how Earth observation (meteorological, aerobiological, and air pollution) can help predict aeroallergen levels and some of their characteristics, leading to prevention of allergic diseases

Note: Documents cited are provided for illustration purposes; a more complete list of citations is presented in Appendix B. Highlighted words indicate an association between an Earth observation and disease.

Table 7. Examples of Integrative Models Used to Improve Forecasting and Health

Citation	Highlights
Moreno-Grau et al., 2000	Multiple regression models; correlation in distribution of pollen and temperature
Cotos-Yanez et al., 2004	Additive regression model and partially linear model to predict pollen concentration, temperature, and wind, corresponding to real time recording
Erbas et al., 2007	Semi-parametric regression-type model estimating effects of temperature, humidity, wind speed, rain, and asthma admission
Laaidi et al., 2003	Regression model allows predictions 3–5 weeks in advance
Newhouse and Levetin, 2004	Linear regression analysis, integrating aeroallergen concentration and meteorological data
Rodriguez-Rajo et al., 2009	Statistical model for long-term prediction, <i>neural network</i> , improves predictions
Sanchez-Mesa et al., 2002	Based on <i>neural network</i> , high accuracy prediction
Smith and Emberlin, 2005	Use of several regression models allowing prediction of pollen 5–7 days in advance
Smith and Emberlin, 2006	Use of multiple regression models 30 days in advance with 63% accuracy
Skjoth et al., 2007	Long-range atmospheric transportation model showing Germany and Poland to be sources for birch pollen in Europe
Prosbjorg et al., 2003	Models to estimate starting date based on growing degree hours; predicted birch and grass pollen accurately; correlation with temperature.
Stennett and Beggs, 2004	Multiple regression model: pollen concentration, temperature, wind speed, dew point
Adams-Groom et al., 2002	Multiple regression model most accurate with meteorological stations depended on the city and distance of meteorological station from pollen counting stations

Phenological parameters and remote sensing

Remote sensing from satellites has started to be applied to the aeroallergen area using indicators such as vegetation development states and flowering times (land cover). Phenology has achieved new importance as an integral bioindicator for changing environmental conditions, as phenological phases are mainly triggered by environmental conditions and are easy to observe (WHO, 2003a). The general survey of phenological trends in Europe and North America, along with results from CO₂ records, NDVI (Normalized Difference Vegetation Index) satellite data, and duration of ice cover, gives a relatively consistent image of the changes on the northern hemisphere with a clear lengthening of the growing season, mainly due to the advance of spring (WHO, 2003a; Defila and Clot, 2001). The utility of phenological data in conjunction with remote sensing can be seen in Table 8.

Though this area is promising, it is not very widespread in the aerobiological community and may need further research and confirmation. Studies by Sofiev et al. (2006) and Karlsen et al. (2009) utilized satellite data to map several European forest regions and characterize the onset of various pollen seasons, revealing regional differences not easily detected by ground Earth observations alone. Table 8 focuses on the types of Earth observations identified in a relatively small subset of the documents reviewed—documents aimed at assessing the burden of aeroallergen and accurately predicting the level of aeroallergen early enough to prevent suffering of sensitive populations.

Table 8. Remote Sensing Observations Providing Data to Support Aeroallergen Forecasting

Observation Category ^a	Purpose	Parameter	Characteristics of Observation Parameters					
			Coverage/Extent	Spatial	Temporal	Accuracy	Spatial Resolution	Source
Direct	Map the average date of onset of birch flowering, correlated with data from Burkard traps; shows large regional differences	Land cover, MODIS-NDVI	Global	Europe	16 days	Data NA	250 m	Karlsen et al., 2009
Direct	Find correlation with birch phenology data—moderately high	Land cover, MODIS-NDVI	Global	Europe	16 days	Data NA	250 m	Karlsen et al., 2008
Derived	Map the onset of bud burst of birch and of birch pollen season to improve pollen forecast models	GIMMS, vegetation, land cover	Global	Europe	15 days	1 pixel or <	8 km	Hogda et al., 2002
Derived	Develop forecasting for long-range air transport of birch pollen	Land use, NOAA-AVHRR	Global	Europe	15 days	1 pixel or <	8 km	Sofiev et al., 2006
Derived	Develop forecasting for long-range air transport of birch pollen	Land cover, CORINE derived from LANDSAT	—	Europe	Data NA	25 m or 1 pixel or <	25 m	Sofiev et al., 2006 (same paper)
Direct	Allow characterization of ecosystems to atmospheric models to forecast aeroallergens	Land cover AVHRR-NDVI	2399 km	North America	Daily	Data NA	1 km	Gage et al., 1999
Direct	Allow characterization of ecosystems to atmospheric models to forecast aeroallergens	Land cover, LANDSAT TM-NDVI	185 km	North America	16 days	Data NA	30 m	Gage et al., 1999 (same paper)
Direct	Enable study of longer-term variations and land cover and site specific variability in pollen data	Land cover AVHRR-NDVI	Global	North America	1–30 days	1 pixel or <	1 km	Williams and Jackson, 2003

Observation Category ^a	Purpose	Parameter	Characteristics of Observation Parameters					
			Coverage/ Extent	Spatial	Temporal	Accuracy	Spatial Resolution	Source
Direct	Develop adaptable approach ascribing a sequence of ground conditions (e.g., vegetative growth, pollen production) to remotely sensed land surface phenology observations	Land cover AVHRR-NDVI	Continental	North America	15 days	Data NA	8 km	White and Nemani, 2006
Derived	Develop adaptable approach ascribing a sequence of ground conditions (e.g., vegetative growth, pollen production) to remotely sensed land surface phenology observations	Land cover GIMMS-NDVI	Global	North America	15 days	Data NA	8 km	White and Nemani, 2006 (same paper)

^a In the context of this document, a “direct” observation category is interpreted to be the base version of the data that is generally available to end users. If the data values are simple measures of reflectance intensity, they are considered “direct.” The “derived” category represents cases where multiple data sources are combined or some algorithm is applied to the data.

5 Priority Earth Observations for Health SBA- Aeroallergens Sub-Area

5.1 General Description

Most Earth observations for aeroallergens are ground-based, involving the Hirst-type sampler. New emerging technologies such as laser optics (Kawashima et al., 2007), automated pollen monitoring using microscope image analysis techniques, and/or nonautomated airborne allergen monitoring (Buters et al., 2009) are useful and will presumably become more mainstream methodologies. In the future, it seems most likely that a combination of different Earth observation systems (including integrative modeling) will deliver a more accurate and quantitative assessment of the distribution of allergen carriers and allergens in space and time. However, explicit needs and priorities in this area have not been formally identified. (See Section 3.3 and Section 6 for additional perspective on implied user needs for this SBA.)

Meteorological observations correlate in many cases with aeroallergen concentrations (and therefore with symptoms). However, the aerobiological data are frequently obtained daily; this sometimes makes it difficult to correlate them with meteorological data because some parameters (such as precipitation) may have their effects on aeroallergens a few days after the event. This is particularly true for fungi. A wide variety of meteorological parameters have been analyzed, though temperature was by far the most often quoted parameter in successful prediction of aeroallergen concentration and disease. Thunderstorms, as a weather extreme, are associated with increased asthma episodes. A close association also exists between the concentration of spores/pollen and the prevalence of asthma attack or admission rate to hospitals associated with this event. Epidemiological studies done in conjunction with extensive Earth observations will need to be done to strengthen this association. Added air pollution (see Figure 1) also can increase the prevalence of allergic disease. Statistical evaluation and mathematical modeling of the different parameters can increase the accuracy of aeroallergen prediction and provide longer-range forecasting.

5.2 Priority Observations

In line with the prioritization methodology described in Section 2.3.3, this section highlights the parameters that end users most commonly report as making the greatest contribution to forecasting and prevention of allergic disease. The choice of parameters in this section is based on those citations that were most relevant to the issue addressed, many of which are highlighted in Tables 6 and 7 in Section 4.

Ground Earth observations are widely used for predicting aeroallergen levels and providing critical information for allergic individuals, public health authorities, and a wide spectrum of other end users (see Section 3.3). Based on this meta-analysis, it was difficult to single out a “priority” Earth observation. From a purely aerobiology perspective, there is no doubt that counting and characterizing airborne pollen and spores, as is routinely performed with the well-established Hirst-type samplers, is the most important Earth observation, especially because many reports suggest a direct correlation between pollen and spore concentrations and allergic diseases, and because in most cases, data are obtained in real-time; however, more accurate forecasts involve meteorological parameters. Remote sensing has made a limited contribution in

this area so far, but it has proven to be valuable—especially when integrated into statistical models as a means of covering large areas and predicting trajectories of aeroallergens moving in space. Accurate forecasts can improve health by helping physicians develop treatment strategies and enable sensitive populations to avoid exposure to high concentrations of aeroallergen and take advantage of preventive measures.

5.2.1 Most Common Parameters Used in Association with Aeroallergen Concentration

Aeroallergen-carrying particle (pollen, spores) counts represent by far the most critical Earth observation in this field. Methodologies are well established and provide direct information on aeroallergen levels, though without the meteorological Earth observations it is insufficient to provide accurate and advance forecasting.

Temperature—a key factor in the development of aeroallergens in all phenological stages—was most frequently quoted as a predictor of aeroallergens either alone or in conjunction with other parameters. Temperature can cause early season onset, a warning sign for allergic subjects. A warming trend also can result in a longer flowering period, increased concentration of aeroallergens, and introduction of new allergens (in an area), and is therefore also used as a parameter to associate global warming and aeroallergen concentrations (e.g., Rogers et al., 2006; Ziska and Caulfield, 2000; Yli-Panula et al., 2009).

Humidity and precipitation play an important role in affecting aeroallergen count and were measured parameters in multiple aeroallergen documents. The documents reviewed showed that the correlation is sometimes negative due to the scrubbing effect of rain, but not always.

- **Thunderstorms** represent a particular meteorological event used in evaluating potential health impacts. Studies have shown a relationship between thunderstorm occurrence and increased asthma episodes, though clearly not every thunderstorm is followed by an increase in allergic disease. It is therefore important to be able to forecast thunderstorms as much in advance and as accurately as possible.

5.2.2 Air Pollution and Meteorological Parameters' Effect on Allergic Disease

Air pollution is known to have its own effects on human health, but it has also been demonstrated to have a synergistic effect when combined with aeroallergen, in the sense that it exacerbates the effects of allergen alone. Our analysis shows that the two pollutants that contribute most to the synergistic effects with aeroallergens are ozone and particulate matter (in particular, diesel exhaust). Some studies have not been able to show an additive or synergistic effect (e.g., Lewis et al., 2000; Atkinson et al., 2006). Earth observations and modeling for air quality purposes are widely used by various agencies and governments, and their specific needs are discussed in detail in the Health SBA- Air Quality Sub-Area

Wind direction, speed, and persistence have an impact on both the concentration and the spatial distribution of pollen. However, the specific effect of wind persistence on pollen transfer has not been studied so far; neither has the interaction effect of the wind components (Damialis

et al., 2005). The three wind components are measured by some of the aeroallergen investigators, though this is not a very widespread practice. Nevertheless, predictive models of local airborne pollen circulation should take wind parameters more into consideration (e.g., Chamecki et al., 2009; Martin et al., 2009).

5.2.3 The Role of Remote Sensing in Forecasting

Our meta-analysis revealed a relatively small but important subset of documents identifying use of remote sensing by satellites relative to aeroallergen forecasting (see Table 8). The parameter used most often in the process of forecasting is land use or land cover. Data obtained by satellites are usually proxies for phenological or aerobiological events and can be very useful in predicting pollen season onset, regional differences by covering large areas, and forecasting long-range air transport of aeroallergens.

Earth observations and modeling for particle dispersal purposes are widely used by various agencies and governments also in the air pollution domain. Remote sensing of weather parameters is necessary for dispersion modeling, which is the most promising forecasting system, with the particular advantage of spatial coverage and integration of weather data and forecasts. These integrated models require precise mapping of the sources and precise knowledge of the phenological stage of the sources (e.g., start of flowering, full flowering).

Remote sensing as it relates to the Health SBA - Aeroallergens Sub-Area clearly has advantages and limitations. For example, the type of birch pollen cloud that occurred over Europe in 2006 is rare

(www.eumetsat.int/Home/Main/News/CorporateNews/005954?l=en). This pollen cloud was detected by satellite imaging and later modeled, showing a very good correlation between NDVI data and birch pollen data (Sofiev et al., 2006). Considering the very low concentrations of aeroallergens that are needed to provoke symptoms (daily average between 5 and 200 pollen grains per cubic meter of air, depending on the personal sensitivity of the allergic person and the pollen type/allergen and the very high level of specificity of the allergic reaction), there is ordinarily little chance to directly measure the allergens by remote sensing. On the other hand, as shown in Table 8, remote sensing is being used for some indirect measurements, particularly land cover measurements (e.g., satellite images in determining the distribution and abundance of plants, and their phenological stage). Using these types of indirect measurements makes it possible to assess where, how much, and when flowering takes place; provides information for modeling pollen emission and transport; and could be used for integrative modeling. From an economic and public health perspective, forecasting aeroallergen type, timing, and concentration greatly benefits the medical community, allergic individuals, and others. Methodologies that provide accurate and advance forecasts by combining ground and satellite observations can prevent or at least ameliorate allergic airways diseases.

The potential importance of remote sensing is of particular relevance in areas with complex topography, such as the Scandinavian Peninsula and the Alps in Europe, where “atmospheric models” are less reliable. In the future, there will be an increasing number of satellites with a range of scales in spatial resolution suitable to be used for near real-time phenological

monitoring. Hence, satellite-based monitoring of phenology is rapidly developing, and observations will be assimilated into phenological models. For instance, the new generation of satellite sensors, with both daily data and high resolution (as Formosat-2, Komsat-2, and RapidEye), provide an opportunity to monitor the onset of the pollen season at a local scale. Due to the high data costs, it is only realistic to use this data for relatively small areas (< ~1,000 km²) and only for some years. However, this new scale of observation creates a link between Earth observation of phenology/data from pollen traps and medium resolution sensors such as MODIS. This would increase our understanding of the seasonal dynamics of the vegetation and improve the up-scaling of data from pollen traps to large regions—for instance, by using MODIS-NDVI data (personal communication, Stein Rune Karlsen).

6 Additional Findings

6.1 Additional Resources Identified

In addition to the documents identified, the Analyst accessed and reviewed a number of websites related to aerobiology, phenology, and aeroallergen Earth observations. Along with weather forecast sites, these included aerobiology organizations, allergen forecast networks, and associated pollen network sites. Most are based in Europe. These sites provide insights on aeroallergen research programs, established and evolving aerobiology and phenology networks, and forecast tools, among others. Table 9 presents a sampling of these websites.

Table 9. Online Resources Relevant to the Health SBA - Aeroallergens Sub-Area

Website link	Region	Description
www.enviport.com	Europe	Allergy Forecast Information Service
http://pollen.fmi.fi/	Europe	Evaluation and Forecasting of Atmospheric Concentrations of Allergenic Pollen in Europe
http://pollenuk.worc.ac.uk/	Europe	National Pollen and Aerobiology Research
https://ean.polleninfo.eu/Ean/	Europe	European Aeroallergen Network (EAN) Pollen Database, used by scientists to create dispersion and forecast models; represents a unit of the European Pollen Information (EPI)
www.polleninfo.org/	Europe	Graphical displays with EAN data for public use; represents the public web portal for EPI
www.hialine.com/en/about.php	Europe	A clearinghouse of asthma information, along with descriptions of work projects such as development of forecast models and methods to incorporate allergen release capacity from pollen into allergen forecasts
http://aerobiologia.utu.fi/	Europe	Finnish Pollen Network

Website link	Region	Description
www.pollens.fr/accueil.php	Europe	French Network of Aerobiological Monitoring (RNSA)
www.uco.es/investiga/grupos/rea/	Europe	Spanish Aerobiology Network (REA)
www.meteoswiss.admin.ch/web/en/weather/health/pollen.html	Europe	National pollen monitoring network of Switzerland (MeteoSwiss)
www.lumc.nl/home/0001/	Europe	Pollen Information Service, Leiden University Medical Centre, The Netherlands
www.worldallergy.org/pollen/	International	World Allergy Organization Pollen Network, including links to activities in multiple regions, including emerging society program < http://www.worldallergy.org/esp/ >
www.aaaai.org/nab/index.cfm	North America	AAAAI National Allergy Bureau; responsible for reporting current pollen and mold spore levels to the public
www.pollen.com/allergy-weather-forecast.asp	North America	Presents daily local and national allergy levels
www.polenes.cl/paginas/alergiometro.asp	South America	Niveles de Pólenes (Chile) (in Spanish)

In addition, MeteoSwiss (which is part of the Swiss Federal Department of Home Affairs and Federal Office of Meteorology and Climatology) continues to assess needs in the areas of measuring and forecasting airborne biological particles. MeteoSwiss' National Pollen Network (NAPOL), which has been operating since 1983, informs physicians, persons concerned by allergy, and the public about current pollen conditions. Efforts are in progress to further demonstrate how and why additional or better pollen collection and forecasting data can benefit end users. The link to MeteoSwiss can be found above in Table 9.

6.2 Data Gaps

The meta-analysis for this task revealed several important information gaps relative to the Health SBA - Aeroallergens Sub-Area, as highlighted below.

- While both rhinitis and asthma have increased in prevalence in recent years, limited observational data on aeroallergen trends across the continents present some difficulty in making an association with the observed increases in these allergic diseases. While some regional examples exist that show increasing trends in mold and pollen, the observational studies of U.S. pollen levels, for example, do not appear to have sufficient data to conduct trend analyses. More systematic and quantitative data need to be collected regionally, and networks need to be established to cover as much ground or land as possible.
- Several studies have shown that allergen concentrations in pollen grains can increase in warmer climates, areas with higher carbon dioxide concentrations, and in polluted areas.

Direct measurements of aeroallergen concentrations are limited and are needed to more fully assess the long-term trend in allergies.

- Pollen/spore sampling is fairly labor intensive, and man-power resources are frequently inadequate to collect and characterize pollen/spore data. Because of its importance for many health and regulatory aspects, as well as a fairly sensitive measure for monitoring climate change, more automated systems are needed. Additional funding would likely promote and accelerate the progress needed in the building of data sets.
- The relationships between local flowering (phenology) and pollen concentrations needs to be better studied using ground and remote sensing techniques. Phenological programs (which rely on data obtained by remote sensing) need to be adapted to meet the needs of pollen forecasting. A specific example of this sort of information is the need to identify and map areas invaded by invasive species such as ragweed (*Ambrosia*) in Europe. The next step would be to assess the success of eradication of those invasive species.
- While day-to-day forecasts are issued, longer-term forecasting capabilities are still evolving. As discussed in Sections 4 and 5, this can be achieved by developing models that combine remote sensing and ground-based technologies. Ideally, real-time forecasting of large-scale distribution of long-distance dispersal events can be achieved.
- Several geographical regions such as Europe, the Americas, and Great Britain have established and published protocols, but many other countries are lacking such protocols. Standardized methods recommended by international bodies such as WHO and WMO would be useful for improving forecasting of aeroallergen globally.

7 Analyst Comments and Recommendations

7.1 Process and Methodology

The nine-step process developed by the GEO UIC provided a practical and workable framework for the Health SBA - Aeroallergens Sub-Area meta-analysis. The document identification process proved somewhat challenging for this SBA, in that searches and requests did not yield the primary sought-after national- or regional-scale reports. It is assumed that these findings are the result of the limited number of larger scale reports on end-user needs related to aeroallergen Earth observations and not a function of the search process.

The provision of templates for the report and requested summary tables greatly facilitated report preparation by setting clear expectations and tools to guide data compilation efforts. However, because limited quantitative data were identified in the documents for the Health SBA - Aeroallergens Sub-Area, prioritizing and aggregating data became largely a qualitative exercise, as articulated in Sections 2 and 5.

7.2 Challenges

The field of aeroallergens and aerobiology has so far applied primarily ground-based Earth observations and very few remote sensing methodologies. The requirements for this report stressed the importance of quantitative data. Ground-based data can also be quantitative, but the templates and structure of this report seemed to have preferred remote sensing data.

The other challenge in writing this report was the fact that when Earth observations and aeroallergens are discussed, it becomes clear that one has to take a multi-pronged approach that will take into consideration three Earth observation systems (air pollution, meteorological parameters, and aerobiology parameters) in order to address key issues. The interaction among atmospheric pollutant, aeroallergens, and meteorological variables adds a further complicating dimension to this analysis.

The Analyst was aware of the need to obtain and reference as many “official reports” as possible and be less than exhaustive on peer-reviewed publications. In the process of the meta-analysis, it became clear that official documents on this topic were scarce. For example, out of the 21 national and international organizations the Analyst contacted regarding official documents, only six provided relevant information (see Table 2). This finding may reflect the early stage of the application of Earth observation in the field of allergy.

Lastly, as noted earlier, most of the documents reviewed lacked specific quantitative data for the Earth observation parameters of interest to this SBA. For example, specifications on the coverage, spatial/temporal resolution, and accuracy of Earth observation parameters of interest were simply not presented in many of the documents analyzed.

7.3 Recommendations

The Analyst felt that in general, the steps outlined in the Task US-09-01a process were sufficient to accomplish the goal of identifying priority Earth observations for each SBA. Areas that can possibly be considered to refine the process are as follows:

- Providing more guidance on and specific examples of what should be considered an observation with respect to directly observed, derived, modeled, and other types of parameters.
- Having GEO leaders invite Advisory Group members to participate in the project. The Analyst observed that not all members were fully engaged in the review process. Given that the experts in the Advisory Group are likely to have many demands on their time, sending the invitation to participate in the Advisory Group directly from GEO, early in the process, may help to keep the Advisory Group engaged and active.
- Considering a process to enable the remuneration of the Advisory Group members (e.g., a modest honorarium). Doing so may enhance Advisory Group member involvement

throughout the process. This may be especially helpful in obtaining increased involvement from experts in developing countries.

- Having one face-to-face meeting with the Advisory Group members (or at least with the majority of them) at the onset of the project to ensure a better understanding of what is needed to achieve the goals of the project.
- In the case of the SBA for Health, which was subdivided into three groups (air quality, infectious diseases, and aeroallergen), having a face-to-face meeting of the three Analysts at the beginning of the project would have been helpful to agree on the boundaries of these areas. This type of active communication would help prevent overlap and facilitate possible cross-referencing across the three documents.

Appendix A: Acronyms

AAAAI	American Academy of Allergy, Asthma, and Immunology
AG	Advisory Group
CDC	Centers for Disease Control and Prevention (U.S.)
CEOS	Committee on Earth Observation Satellites
ECMWF	European Centre for Medium-Range Weather Forecasts
EPA	Environmental Protection Agency (U.S.)
EPN	European Phenology Network
EUMETNET	European Meteorological Network
GEO	Group on Earth Observation
GEOS	Global Earth Observation System of Systems
IPCC	International Panel on Climate Change
ITEM	Institute of Toxicology and Experimental Medicine
NAB	National Allergy Bureau (U.S.)
NGO	Non-governmental organization
NHLBI	National Heart Lung and Blood Institute (U.S.)
NIAID	National Institute of Allergies and Infectious Diseases (U.S.)
NDVI	Normalized Difference Vegetation Index
NPN	National Phenology Network
PAHO	Pan American Health Organization
SBA	Societal Benefit Area
UIC	User Interface Committee
WHO	World Health Organization
WMO	World Meteorological Organization

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Appendix C: Input to the Cross-SBA Analysis

At the conclusion of the individual SBA priority-setting analysis, the Health SBA-Aeroallergens Analyst provided input on the overall critical Earth observation parameters for the Aeroallergens sub-area for inclusion in the Cross-SBA meta-analysis.³ Upon receiving input from the SBA Analysts, the Cross-SBA Analyst reviewed the priorities in order to harmonize the terminology employed across SBAs. The Cross-SBA Analyst aggregated observation parameters that are the same or very similar but have different names (e.g., precipitation intensity and precipitation duration). In some cases, the Cross-SBA Analyst also disaggregated observation parameters from observation categories that were identified as priorities by individual SBAs. As a result, the number of observation priorities identified by individual SBAs may vary from the number of observations that were included in the Cross-SBA analysis. To the extent possible, the Cross-SBA Analyst focused on retaining the observation parameter terminology employed by the majority of the SBAs.

Three separate sub-reports (Air Quality, Infectious Diseases, and Aeroallergens) were prepared by separate Analysts for the Health SBA. The results of these sub-reports were merged and treated as a single SBA report for the purposes of the Cross-SBA analysis. The Health SBA-Aeroallergens Analyst determined the overall critical Earth observation priorities for the Aeroallergens sub-area by using a combination of quantitative and qualitative approaches, as described in Sections 2.3.3 and 5.2. Based on the results of the prioritization analysis, the 19 observations listed below have the highest rankings and thus are considered to be the observation priorities for the Health SBA-Aeroallergens sub-area. The Health SBA-Aeroallergens Analyst divided the 19 observations into the three tiers representing “High,” “Medium,” and “Low” priority observations for numerical weighing in Cross-SBA Methods 2 and 3. (Italicized observations were also included in Method 4, as explained below). The below-listed 19 observations were included as part of the single integrated list of Health SBA priorities for Methods 1-3 of the Cross-SBA Analysis.

High

Aeroallergen

Temperature

Relative Ambient Humidity

Medium

Precipitation

Thunderstorms

Air Pollution (e.g., ozone, PM_{2.5})

Low

Land Cover

Ice Cover

³ For full description of methods and results, refer to: Group on Earth Observations. Task US-09-01a. Critical Earth Observation Priorities. Final Report. October 2010. Available on GEO Task US-09-01a website: <http://sbageotask.larc.nasa.gov/>.

Wind Direction
Wind Speed
Wind Persistence
Population Density
 NDVI
 Leaf Area Index
 Photosynthetically Active Radiation
 Gross Primary Productivity
 Continuous Field Tree Cover
 Field Cover (continuous)
 Land Cover Dynamics

The list of 49 observations, provided below, is the union of the three Health SBA sub-reports' priority lists. This list was used for Method 1 (unweighted tally of observations) and Methods 2 and 3 (weighted tally of observations) in the Cross-SBA analysis. For Methods 2 and 3, the rankings of "High," "Medium," and "Low" were determined based on the highest ranking assigned to an observation parameter across the 3 Health SBA Analysts.

Ambient Nitrogen Dioxide Concentration	Health Care Access
Ambient Ozone Concentration	Land Cover
Ambient Particulate Matter (fine) Composition	Land Use
Ambient Particulate Matter Composition (coarse)	Leaf Area Index
Ambient Particulate Matter Concentration (coarse)	NDVI
Ambient Particulate Matter Concentration (fine)	Ocean Topography
Ambient Sulfur Dioxide Concentration	Pathogen Population Dynamic
Ambient Volatile Organic Compounds	Phenology
Biodiversity	Photosynthetically Active Radiation (PAR)
Column Nitrogen Dioxide Concentration	Population
Column Ozone Concentration	Precipitation
Column Particulate Matter Concentration (coarse)	Sea Level
Column Particulate Matter Concentration (fine)	Sea Surface Temperature (SST)
Column Sulfur Dioxide Concentration	Soil Moisture
Deforestation	Soil Type
Density of animal hosts	Source of Drinking Water
Elevation	Surface Air Temperature
Field Cover (Continuous)	Surface Humidity
Forest Cover	Surface Wind Direction
Glacier/Ice Sheet Extent	Surface Wind Speed
Global Horizontal Irradiation (GHI)	Urbanization
Gross Primary Productivity	Vector Population
	Vegetation Cover
	Vegetation Type
	Water Algal blooms
	Water Bodies (location)
	Water Quality & Composition, pH and salinity, Dissolved Oxygen Content

For Method 4, the “15 Most Critical” observation list for the Health SBA was prepared collectively by the Health Analysts and Cross-SBA Analyst based on the commonality across the 3 sub-reports’ “Most Critical” observation lists. The “15 Most Critical” observations for the Health SBA are listed below. The Health SBA-Aeroallergens sub-report contributed the italicized priority observations (listed previously) to this list.

1. Population Density
2. Precipitation
3. Air temperature
4. Humidity
5. Land Use/Land Cover
6. Vegetation
7. Water Bodies
8. Sea Surface Temperature
9. Wind
10. Sea Surface Height
11. Topography
12. Vector population
13. Atmospheric Particulates
14. Biodiversity
15. Atmospheric trace gases