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

Ecosystems Societal Benefit Area

GROUP ON EARTH OBSERVATIONS

User Interface Committee

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Group on Earth Observations

GEO Task US-09-01a:
Critical Earth Observation Priorities for Ecosystems SBA

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The following people served as expert panelists for the *ad hoc* Advisory Group for the Ecosystems Societal Benefit Area (SBA) under GEO Task US-09-01a. The Advisory Group supported the Analyst by identifying source materials, reviewing analytic methodologies, assessing findings, and reviewing this report.

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The following people served as the Analyst Team for the Ecosystems SBA under GEO Task US-09-01a, providing overall coordination of the analysis and preparation of this report.

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GEO Task US-09-01a
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Group on Earth Observations

GEO Task US-09-01a:
Critical Earth Observation Priorities for Ecosystems SBA

Summary

The goal of GEO Task US-09-01a is to identify the critical Earth observations for various societal benefit areas (SBAs). This analysis focused on identifying those priorities for the Ecosystems SBA. An Advisory Group of 11 members from around the world helped narrow the focus of the analysis, helped identify documents from both developed and developing nations on Earth observation needs for ecosystems management, and reviewed the methodology and results presented in the preliminary report.

The Analyst Team identified documents that contained information related to the observation needs through literature and internet searches and through Advisory Group recommendations. After evaluating documents for their applicability to this task, the Analyst Team selected 75 documents that provided valuable information for the priority setting analysis. The information pertinent and valuable to this task varied across documents with the publication purpose, geographic scope, and disciplinary focus.

The Analyst Team extracted observation needs from the documents individually for each of three ecosystem sub-areas: forests, coastal and near-shore marine systems, and watersheds. Three factors determined the overall priority of observations: 1) the raw frequency with which observational parameters appeared in documents, 2) the applicability of parameters across multiple ecosystem sub-areas in the report, and 3) Advisory Group recommendations for high-priority parameters. The Analyst Team consulted published consensus documents to confirm that the analysis process produced ecosystem observation priorities that were in agreement with previous efforts.

Two sets of ecosystem observation priorities emerged from this mix of quantitative and qualitative assessments: priority direct parameters, and priority indirect parameters. Direct parameters originate from direct observations or multiple similar, collocated observations. Indirect parameters originate from multiple observation types, relationships, algorithms, and models. Table S-1 lists the priority direct and indirect parameters resulting from the analysis, in descending order. Many of the parameters in the table are broad terms that nonetheless accurately reflect the level of detail the Analyst Team discovered through the analysis.

Table S-1: Priority Direct and Indirect Parameters for Ecosystems SBA

Priority Direct Parameters*	Priority Indirect Parameters*
Vegetation indices (NDVI, SAVI, EVI)	Disturbance
PAR, fPAR, FAPAR	Leaf Area Index (LAI)
Chlorophyll	Hydrology
Soil moisture	Biomass
Topography	Primary productivity
Salinity (ocean and near-shore)	Biodiversity
Precipitation (amount, frequency)	Fuel characteristics
Depth (shallow near-shore)	Impervious surface (extent)
Sea Level	Phenology
Nitrogen (content, flux)	Forest structure
Species composition	Groundwater
Evapotranspiration	Carbon (stores, uptake, flux)
Albedo	Sedimentation rate
Nutrients (load, concentration)	Litter (forest)
Pollutants (load, concentration)	River discharge quantity
Bathymetry	Stand density
Burned area	Woody vegetation cover
Sea Surface Temperature (SST)	
Ocean color	
Attenuation coefficient (clarity)	
Currents	
Waves (height and period)	
Submerged Aquatic Vegetation (extent and composition)	
Soil type	
Stand height	
Snow cover extent	

* Some parameters were listed in the documents only in general terms. The Analyst Team included all details of parameters and observation needs that were identified through the task process.

These observation requirements represent a broad picture of global Earth observation requirements for ecosystems. Ecosystem observation priorities may differ regionally. However, regional, national, and local-level authorities and agencies will be able to use such priority lists in helping develop Earth observation strategies that they can tailor to meet regional management needs. This priority list, along with the available physical characteristics of the observations, will ultimately be incorporated into a cross-SBA synthesis by the GEO User Interface Committee (UIC) to identify critical Earth observations across all nine SBAs.

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1 Introduction

This report articulates Earth observation priorities for the Ecosystems Societal Benefit Area (SBA) based on an analysis of 75 publicly available documents, including documents from Group on Earth Observations' Member Countries and Participating Organizations.

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-based, in situ, airborne, and space-based instruments.

GEO focuses on enhancing the development and use of Earth observations in nine SBAs:

Agriculture	Disasters	Human Health
Biodiversity	Ecosystems	Water
Climate	Energy	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 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 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: *http:// www.earthobservations.org*
[2] GEOSS 10-Year Implementation Plan: *http://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 Ecosystems SBA. The intent of the report is to describe the overall process and specific methodologies that the Analyst Team used to identify documents, analyze them, and determine a set of Earth observation parameters and characteristics. The report describes the methodologies for determining the priority Earth observations for this SBA. The report also provides information on key challenges, 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. 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 Ecosystems SBA are additional audiences for this report.

1.4 Scope of Report

This report addresses the Earth observation priorities for the Ecosystems SBA. In particular, this report addresses the observation of ecosystem health, function, and change in the sub-areas of Forests, Coastal and near-shore marine, and Watersheds within the Ecosystems SBA (see Section 3 for more details).

The report provides some background and contextual information about the Ecosystems SBA. However, this report is not intended as a handbook or primer on the Ecosystems SBA, and a complete description of the Ecosystems SBA is beyond the scope of this report. Please consult the GEO website referenced above for more information about the Ecosystems SBA.

The report focuses on the Earth observations within the Ecosystems SBA, independent of any specific technology or collection method. Thus, the report addresses the "demand" 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 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 the groups and users in the cited documents have indicated are important or desired. The term "requirements" generally reflects users' wants and needs; the 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 Ecosystems SBA and the specific sub-areas that were part of the analysis. Section 4 articulates the specific Earth observations for each Ecosystems sub-area, and Section 5 presents the priority observations across the Ecosystems SBA. Sections 6 and 7 present additional findings from the analysis of the documents and recommendations. The Appendices include abbreviations and the documents cited and consulted.

2 Methodology

This section documents the general process and specific methodologies that the Analyst Team 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 SBA Analysts to follow in order to ensure some consistency across the SBAs. This general process for each SBA involves 9 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* or GEO website. 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 Ecosystems SBA had an "Analyst Team" and an "Advisory Group" working together to conduct the process of identifying documents, analyzing them, and prioritizing the Earth observations. The Analyst Team served as the main coordinator and manager of the activities. The Advisory Group assisted with identification of documents and review of materials, drafts, and methods of analysis.

2.2.1 Analyst Team

For the Ecosystems SBA, the Analyst Team consisted of Glynis Lough, Tom Gulbransen, and Adam Carpenter of Battelle. Dr. Lough is an Environmental Research Scientist with experience in environmental chemistry and environmental policy and planning. Dr. Lough has worked with in situ and remote sensing measurements in a number of projects supporting climate change and environmental studies. Mr. Gulbransen, a Senior Scientist, supports Battelle's ecosystem practice analyzing ecosystem characterization and benefit/cost tradeoff methods. Mr. Gulbransen coordinates involvement in Ocean Observing communities, served as Product Manager and Senior Analyst for Battelle's Environmental Management Information Systems (EMIS), and serves on the IOOS national Meta Data Expert Team and MidAtlantic Coastal Ocean Observing Regional Association committees. Mr. Carpenter is an Environmental Researcher with a Masters' degree in environmental science and policy and experience in ecology, hydrology, risk assessment, and ecotoxicology.

The Ecosystems SBA Analyst Team served under contract to the National Aeronautics and Space Administration (NASA) Earth Science Division Applied Sciences Program.

2.2.2 Advisory Group

The Advisory Group for the Ecosystems SBA consisted of 11 technical experts from the fields of ecosystem research and management. Table 1 shows the Advisory Group members.

Table 1. Advisory Group Members for Ecosystems SBA

GEO TASK US-09-01a: Advisory Group for Ecosystems SBA				
NAME	COUNTRY OR ORG.	AFFILIATION	GEOGRAPHIC REGION	AREA OF EXPERTISE/ SPECIALTY
Ana Laura Lara DOMINGUEZ	Mexico	Instituto de Ecologia A.C.	North America	Coastal/Estuarine ecology and management
Hussam HUSEIN	Syria	General Commission for Scientific Agricultural Research	Asia/Middle East	Soils and GIS
Sevda IBRAHIMOVA	Azerbaijan	National Aerospace Agency	Europe	Land use and GIS
Anna KOZLOVA	Ukraine	Scientific Centre for Aerospace Research of the Earth	Europe	GIS and Remote Sensing, forest ecosystems
Jorge LÓPEZ-PORTILLO	Mexico	Instituto de Ecologia A.C.	North America	Coastal/Estuarine ecology and management
Stuart PHINN	Australia	University of Queensland	Oceania/Australia	Biophysical remote sensing
Mukund RAO	ESRI	ESRI India	Asia/Middle East	Remote sensing and GIS
Roger SAYRE	United States	U.S. Geological Survey	North America	Biogeography and remote sensing
Gray TAPPAN	United States	U.S. Geological Survey	North America	Biogeography, remote sensing, and monitoring specializing in Africa
Mphethe TONGWANE	Lesotho	Lesotho Meteorological Services	Africa	Applied Meteorology, Land Use, Climate Change
Andrea Ferraz YOUNG	Brazil	Population Studies Centre	South America	Land use, population issues

The Analyst Team identified the Advisory Group members through professional associations and publications. Several members were identified based upon their authorship of papers identified during the document search, particularly papers that directly addressed Earth observation needs. The Analyst attempted to recruit Advisory Group members from all geographic regions and multiple developing countries. The Analyst contacted 17 people to participate on the Advisory Group. Eleven expressed interest; 5 did not respond; and 1 was unable to participate but provided document references or suggestions for other possible Advisory Group members. Overall, the Advisory Group includes members from nine countries and six continents, including eight from developing countries.

The primary roles of the Advisory Group were to assist in identifying documents, assess prioritization schemes, review findings, and review reports. The primary contact with the Advisory Group was through email and electronic document exchange.

2.3 Methodology for Prioritization

Under GEO Task US-09-01a, this report addresses critical Earth observation priorities for the Ecosystems SBA. The Analyst Team used a combination of literature searches and expert consultations to identify the observational parameters that are of greatest need and will provide greatest environmental, humanitarian, and socioeconomic benefits by improving knowledge about the condition of ecosystems. This section provides a general description of the processes, analytic methods, and approaches the Analyst Team and Advisory Group used to identify documents, analyze them, and establish a set of priority Earth observations.

2.3.1 Documents

Task US-09-01a methodology required examining a wide range of sources for potentially relevant documents, including:

- International, regional, and national consensus documents focused on data sources, applications, or research priorities
- Reports from major regional or national projects
- Workshop and conference summaries
- Peer-reviewed journal articles.

All selected documents were publicly available. The Analyst Team made efforts to represent the major geographic regions, including studies conducted in a region and/or reports from authors in the region. Both developed and developing countries were represented in the document list.

The Analyst Team built the document list largely through literature searches and online searches. Searches applied a range of keywords to identify documents related to different types of studies, such as discovery of new information, establishment of baseline values, investigation of trends, and application to decisions. Table 2 gives examples of the types of search terms. The Advisory Group reviewed the document list and provided additional documents to represent specific ecosystem types and to address observational needs.

Table 2. Example Search Terms Used in Document Identification

Types of studies	Ecosystem terms	Observation terms
Assessment	Forest	Satellite
Monitoring	Ocean	Remote
Modeling	Coastal	Ground
Data Needs	Desert	In situ
Simulation	Wetland	Record
Forecasting	Grassland	Observation
Management	Polar	Measure
Restoration	Lake	Sample

The parameter characteristics desired in documents included coverage/extent, temporal resolution, spatial resolution, timeliness (availability of observation), and accuracy/precision. The Analyst Team specifically sought documents that addressed observational needs, either explicitly or through discussion of present shortcomings.

2.3.2 Analytic Methods

The document search effort yielded hundreds of documents that contained Earth observations of ecosystems. The Analyst Team performed a preliminary review of all documents to identify discussion of Earth observation needs for ecosystems. For the final list, the Analyst Team selected 75 documents (including 11 consensus documents) that included discussion or application of Earth observation parameters for ecosystems and reference to the current adequacy of the parameters.

The Analyst Team extracted information from the documents on ecosystems parameters in each of the three ecosystem sub-areas discussed in this report, and within the nine regions of interest established by Task US-09-01a [Global, Africa, Europe, Oceania, Asia and the Middle East, East Asia, North America, and South and Central America]. Where characteristics of the required observation were available, the Analyst Team recorded them, including frequency, spatial resolution, timeliness, accuracy/precision, and adequacy.

During the analysis, the Analyst Team determined that there are important distinctions between direct observations and indirect, synthetic, synoptic ecosystem parameters. Direct parameters are defined as phenomena that can be observed directly, or that are derived directly from similar observations. Indirect parameters require multiple types of observations, time series of measurements, models, or other methods of derivation and calculation. Indirect parameters are not discrete observations, but are important parameters in the documents. Both direct and indirect parameters are widely used in the documents to understand the health and function of ecosystems and to track changes locally and globally. The Analyst Team did not distinguish between direct and indirect parameters throughout the analysis and prioritization. Many indirect parameters ranked highly in the final prioritization, while the direct parameters they rely on were not ranked as highly. Therefore, in consultation with the Advisory Group, the Analyst Team determined that direct and indirect parameters should be separately listed in the final prioritization to ensure that the priority parameters of both types were clearly represented.

2.3.3 Prioritization Methods

The basic method of setting the collected observations into priority order was to combine and assess the following three factors: 1) frequency of mention, 2) applicability across ecosystem sub-areas considered in this report (discussed below), and 3) recommendations of Advisory Group members. The focus of the Analyst Team and Advisory Group was on parameters necessary for monitoring and evaluation of ecosystem health, function, and change.

The Analyst Team first considered the frequency with which the parameter was discussed or applied across the documents selected for analysis. When the same parameter appeared in multiple parts of a document, it counted only once. The Analyst Team counted parameters with similar names but different purposes (e.g., surface temperature and sea surface temperature) separately. Conversely, for clarity, the Analyst Team combined several parameters with the same purpose but different names (e.g., stand height and canopy height; colored dissolved organic matter and chromophoric dissolved organic matter).

Next, the Analyst Team considered applicability of the parameter to multiple sub-areas in the report. Parameters that were applicable to more than one sub-area received a greater weight as a multiplier on the frequency, which increased the range of prioritization scores. Some parameters used frequently in the documents increased in score to be very clearly at the top of the initial prioritization list (e.g., carbon, biodiversity), and some less frequently used but widely applicable parameters moved higher on the list (e.g., PAR/fPAR/FAPAR).

After the second step, the Analyst Team combined parameters derived from the same observations. For example, the Analyst Team considered three vegetation indices that are derived from the same wavelengths of light from satellite observations as one. The Analyst Team also combined types of ecosystem disturbance derived from the same observations to create one parameter of disturbance, including rates of urbanization, cultivation, and desertification. The frequency rankings for combined parameters were summed.

Third, the Analyst Team considered specific recommendations of the Advisory Group to weight parameters. The Advisory Group recommended prioritization of several parameters within each ecosystem sub-area in this report, but noted that the priority of observations changes with the monitoring need, research question, or application. Parameters the Advisory Group recommended for prioritization in any ecosystem sub-area received a greater weight as a multiplier on the ranking.

Following the third step, the Analyst Team consulted the recommendations of consensus documents to ensure that this process captured the appropriate parameters. In the first step, the Analyst Team included the parameters in the consensus documents in the parameter list and frequency ranking, but did not use the recommendations of the consensus documents to weight or adjust the rankings. Instead, the Analyst Team consulted the consensus documents as a final assurance that the process of frequency rankings, weighting for sub-areas, and weighting Advisory Group recommendations resulted in a prioritization that was compatible with previous efforts.

Finally, the Analyst Team separated the parameters that were direct observations and those that were indirect, derived from multiple types of observations, models, and algorithms. Indirect parameters, such as biodiversity and biomass, appeared frequently in the documents, but not often in a quantitative context. The Analyst Team treated all parameters the same way throughout the prioritization process, and many indirect parameters were ranked higher than the individual direct parameters they are obtained from. In consultation with the Advisory Group, the Analyst Team determined that a clear final prioritization required separate lists of direct and indirect parameters to ensure that the priority parameters of both types were clearly represented.

3 Ecosystems SBA

The term “ecosystems” refers to the many interconnected functions of plants and animals with water, land, and air. As such, ecosystems include both pristine natural environments and human-

impacted environments, on scales ranging from global to highly local. An ecosystem is a sphere of interaction and balance for populations and habitat. Major ecosystem types include forests, deserts, tundra, grassland, shrubland, freshwater systems, ocean and coastal regions, and oceanic islands. The world's ecosystems are the source of much of our natural resources, and house the numerous processes that provide clean water, clean air, and food. Human activities and climate change put stress on ecosystems around the world, threatening their ability to thrive and to recover from damage.

3.1 Ecosystems SBA Description

The following is the brief statement of topics covered and key outcomes in the Ecosystems SBA from the GEOSS 10-Year Implementation Plan:

> "Observations are needed on the area, condition, and natural resource stock levels in ecosystems such as forests, rangelands, and oceans. GEOSS implementation will seek to ensure methodologies and observations are available on a global basis to detect and predict changes in ecosystem condition and to define resource potentials and limits. Ecosystem observations will be better harmonized and shared, spatial and topical gaps will be filled, and in situ data will be better integrated with space-based observations. Continuity of observations for monitoring wild fisheries, the carbon and nitrogen cycles, canopy properties, ocean color, and temperature will be set in place."

Remote sensing capabilities and in situ platforms provide numerous possibilities for observing ecosystems. GEO is working to improve ecosystem information through the GEOSS, an integrated and coordinated network of global monitoring systems. GEO goals include improving spatial information on ecosystem conditions and trends, generating and integrating a wide variety of ecosystem data, and creating high-resolution maps for monitoring of ecosystem services.

3.2 Sub-areas

Because of the enormous variety of ecosystems, their global geographic distribution, and the number of observations that are relevant to their condition, the Analyst Team found it necessary to further define the scope of this report. In reviewing documents, the Analyst Team observed that three areas of ecosystem research dominate the literature: forests, coastal areas, and watersheds, defined below. The Advisory Group agreed to focus on these categories, though one member commented that most ecosystem designations include more than three classes. In consultation with the Advisory Group, the Analyst Team defined the ecosystem sub-areas for this report as:

- Forests: All types and latitudes; function, structure, composition, and productivity
- Coastal and near-shore marine: Oceans, estuaries, wetlands, and bottom types
- Watersheds: Land cover, extent and location of ecosystem elements, and seasonal and interannual dynamics.

Forests cover much of the Earth's surface at many latitudes and conditions, and include northern boreal forests, temperate forests, and tropical forests. For assessing the health, function, and

change of forest ecosystems, the principal focuses are physical structure, plant composition and biodiversity, and function and productivity. Coastal regions and near-shore marine ecosystems include mangrove swamps, wetlands, estuaries, and coral reefs. Assessing health, function, and change of coastal and near-shore marine ecosystems requires information related to the chemical and physical properties of the water, physical structure of the land or seabed, and biological function.

The literature frequently considers forests and coastal areas as ecosystem types, but the third focus of this report is a category of ecosystem observation rather than a particular ecosystem type. Observation of the changes of land-based ecosystems due to disturbance and seasonal and interannual cycles includes the large body of work on what the Heinz Center (2006), in a report on data gaps related to ecosystems observations, called "Extent and Location of Ecosystem/Landscape Elements":

> The area of key ecosystem elements, such as wetlands, coral reefs, impervious surfaces, biological communities, and lands highly affected by non-native species provides fundamental information about the composition of the nation's ecosystems and can provide important clues to its condition. Knowing how individual components are intermingled can provide important information about the functioning of specific ecosystem types. For example, contiguous forest and forests with housing or farmlands intermingled may offer habitat to different species, and farmland areas with higher levels of suburban development may not support a robust agricultural economy.

Identifying and mapping the elements of ecosystems is frequently cited in the documents as necessary for understanding change, protecting habitats, and predicting vulnerabilities. The Analyst Team used the term "Watersheds" for this major area of ecosystems research to reflect its focus on land-based ecosystems in this report. Watersheds, by definition, include uplands to lowlands, and a range of ecosystems and groundcover including snowpack, forests, riparian zones, grasslands, wetlands, and urban areas. This report is concerned with the dynamics and assessment of these land-based systems, consistent with major foci in the literature.

To reduce the duplication of effort and to ensure that the results under Task US-09-01a are as complete as possible, the Ecosystems Analyst Team and Advisory Group did not focus on topics that are also central to other SBAs. For example, the health of ecosystems is closely related to carbon uptake and release, forest agriculture/agricultural practices, biodiversity, water quantity, and water quality, which are frequent focuses of ecosystem research in the literature. However, these topics are central to other GEO SBAs (Climate, Agriculture, Biodiversity, Water, and Human Health, respectively) and thus central to other reports under Task US-09-01a. Therefore, the Analyst Team and Advisory Group focused on identification and prioritization of observational parameters for ecosystem health, function, and change.

3.3 Documents

The Analyst Team and Advisory Group identified hundreds of documents relevant to prioritization of Ecosystem observation parameters. The Analyst Team chose a subset of 75 documents based on the documents' identification of observation needs, application of parameters to ecosystem observation needs, representation of the ecosystem sub-areas (Forests, Coastal and near-shore marine, and Watersheds), and geographic region of the world. Table 3 lists the number of the documents on the final list pertinent to geographic regions and ecosystem observation categories used in this report. Many of the documents were relevant to more than one geographic region or ecosystem sub-area.

Table 3. Representation in final document list for Ecosystems

GEO Task US-09-01a: Document Sources for Ecosystems SBA				
Geographic Region	Number of Documents		SBA Sub-Area	Number of Documents
Global	26		General	15
Africa	6		Forests	40
Asia/Middle East	4		Coastal/Near-Shore Marine	46
East Asia	4		Watersheds	30
Europe	9			
North America	15			
Oceania/Australia	7			
Polar Regions	5			
South/Central America	10			

Of the hundreds of documents investigated through this process, very few provided the level of specific detail the Analyst Team hoped to find on parameter characteristics. In compiling the final list of 75 documents, the Analyst Team therefore included many documents that discussed parameters and observational needs indirectly, in terms of gaps in existing efforts, or very generally, such as needs for more in situ measurements or better algorithms for satellite data interpretation. The Analyst Team recorded the needs that the documents stated generally or indirectly, though specific details were not available.

Among the final list of 75 documents were 11 consensus documents that address ecosystem parameters and observational needs. The consensus documents, which are marked with an asterisk (*) in the reference list in Appendix B, were:

- IGOS-P Land Theme report (Townshend et al., 2008),
- Millennium Ecosystem Assessment reports of the Word Research Institute (Millennium, 2005a, 2005b, 2005c),
- GTOS report on essential terrestrial climate variables (Sessa et al., 2008),
- NASA report on priorities for ocean biology and biochemistry research (NASA, 2006),
- U.S. National Academies report on priorities for Earth observations from space (National Research Council, 2007),
- GOFC-GOLD report on global land cover validation (Strahler et al., 2006),

- GEOSS 10-Year Implementation Plan Reference Document (GEOSS, 2005),
- Heinz Center report on priority data needs for assessment of ecosystem condition (Heinz Center, 2006), and
- Australian Academy of Sciences report on priorities for Earth observation from space (Australian Academy of Sciences, 2009).

4 Earth Observations for Ecosystems SBA

Many useful ecosystem parameters are derived or modeled with input from observations. For example, modeled and derived parameters include the dimensionless indices that are used for vegetation and water content (e.g., Normalized Difference Vegetation Index [NDVI], Water Band Index [WBI], and Leaf Area Index [LAI]). Additionally, many ecosystem observations become useful only in conjunction with other key observations made at the same time (e.g., salinity and river discharge for estuaries). These synoptic dependencies are very important to consider in tracking parameters. Therefore, many of the parameters here, taken from the literature, come from multiple observations (e.g., LAI can be modeled from NDVI and ground-based correlations, or can be measured in situ), or are aggregates for large groups of observations or modeled parameters that may be observed or modeled separately but are generally considered as a unit (e.g., groundwater or phenology).

Many of the listed parameters may be assessed via different methods, using different types of in situ and remote sensing Earth observations. The Advisory Group noted that many parameters have different degrees of usefulness depending on where, when, and how they are measured. For example, WBI may be most useful in some instances to evaluate the minimum evapotranspiration in the dry season, using only remotely sensed data. In other cases, WBI may be more useful to evaluate the responses of specific vegetation species to wet and dry periods, using remotely sensed data and surface measurements. Often, the utility of these parameters is directly related to the research or management question that is being asked.

The Analyst Team listed the parameters in the same way that the documents applied them for monitoring and observation of ecosystem health, function, and change. The documents and the Advisory Group addressed many parameters in broad terms, without providing specific details on requirements. Hydrology is one example of such a broad parameter: the documents stated a need for better information on hydrology, but no specific details on what aspects or specific measurements are needed. Based on the documents and feedback from the Advisory Group, the Analyst Team determined that hydrology and other broad parameters such as pollutants, currents, and biodiversity are important for observation of ecosystem health, function, and change. Therefore, the Analyst Team included these broad parameters, many of which are referenced in the documents as in need of improved observation, though details of observational requirements were not available.

Required spatial and temporal resolutions of parameters relevant to ecosystem assessment and monitoring vary greatly. The consideration of what is high, moderate, or low resolution differs

between applications and between ground-based and remote sensing data. For example, in situ sensors spaced at 30-km intervals are considered high resolution for coastal ocean monitoring, but satellite data products for forest monitoring at 30 km are considered coarse (high resolution is less than 15 m). In situ platforms can collect real-time data in some applications, while remote sensing data on the scale of days is considered frequent for others.

In the tables of parameters in the sections below, the Analyst Team listed parameter characteristics available in the documents. Blank spaces indicate that the documents stated no quantitative or qualitative information about parameter requirements. Where the documents included information about parameter requirements, the Analyst Team recorded coverage/extent, spatial resolution, temporal resolution, latency of data availability, and accuracy. Coverage/extent refers to the area of observation, and was recorded as global, regional, or local. The Analyst Team recorded spatial resolution as specific numbers if available in the documents. If only qualitative descriptions were listed, the Analyst Team applied standardized definitions of high (<15 m), moderate (15 to 100 m), or coarse (>100 m), similar to descriptions generally used in the documents for spatial resolution of remote sensing measurements. The Analyst Team recorded temporal resolution as a number if the documents listed numbers, but more frequently this parameter was recorded as hourly, daily, weekly, or monthly. If the sources described a parameter being used at different resolutions for multiple applications, the Analyst Team recorded the finer spatial resolution or the more frequent temporal observation requirement.

The majority of ecosystem observations focus on long-term change and impacts, on the scale of weeks to years. As such, the documents do not mention latency of data availability as a common concern. Observations of quickly evolving events such as fires, storms, or algae blooms are the exception; in such cases, data users may require near real-time data. Therefore, the parameter Tables 4-6 show latency of data availability in the “other” column, only when it was identified as a concern.

The documents rarely mention accuracy of parameters or needs for future improvements in accuracy. Discussion of accuracy typically occurs in the documents in the context of modeling or mapping efforts based on a set of parameters. For example, in a typical source document, the accuracy of a vegetation index based on remote sensing measurements is not discussed, but the ability of a model to create ground-truthed sub-pixel vegetation maps from the index may be discussed. Therefore, the tables below list needs for parameter accuracy in the “other” column, only when the documents list accuracy as a specific concern.

4.1 Earth Observations for Forests

The general category of forests includes a large number of ecosystems, at many latitudes and conditions worldwide, including northern boreal forests, temperate forests, and tropical forests. Forests cover a large portion of the Earth’s surface and account for vast amounts of the planet’s living mass and carbon stores. The boreal forests covering vast swaths of northern Eurasia and North America, predominately composed of coniferous trees, have been subjected to many harvests and harvest methods to supply the majority of forest products in the northern regions. Temperate and tropical forest regions are home to much of the human population, and are under

increasing human pressure as they are cleared for development and for agriculture. With climate change, forests at all latitudes are expected to come under increasing pressure from changing patterns of precipitation and drought, increased fires, and changes in the ranges of pests.

The documents identify observation parameters across a range of spatial and temporal scales. The majority of the documents identify the spatial resolution of observations applied as simply "high," "moderate," or "coarse," which the Analyst Team standardized to <15 m, 15 m to 100 m, and >100 m, respectively. The spatial scales for parameters such as indices (e.g., NDVI and LAI) frequently depend on models containing established relationships between remote-sensing data and ground-based observations. In the case of modeled parameters, remote sensing data that are relatively coarse (spatial scale of kilometers) are refined with models and ground-based information to develop sub-pixel parameters.

The majority of the documents identify longer-term monitoring needs for forest ecosystem function. Temporal resolution of days to months is a common requirement. Two documents identified active fires as a parameter that requires observations at least daily, and preferably multiple times per day.

Table 4 lists the parameters the Analyst Team identified in the documents that are relevant to forests, by observation category, with no priority order. In general, the observation parameters that are useful for forest ecosystems are similar across forest types and latitudes. The parameters pertain to the categories of canopy type/structure and health, canopy chemistry, soil qualities, amount of water, biological function and diversity, and impacts of major events. The table lists all of the information about the parameters that the documents or Advisory Group specified.

The Analyst Team identified three atmospheric observations (atmospheric aerosols, cloud fraction, and water vapor) used in validation and refinement of some remote sensing products. The documents identified atmospheric parameters as necessary for correction of observations from satellite platforms, rather than for assessment of ecosystem health, function, or change. The atmospheric parameters are used to improve the accuracy of some remote sensing products, but the ecosystem observations can be obtained with other methods. Because the priority ecosystem parameters can be obtained through methods that are not dependent on atmospheric correction, the Analyst Team excluded the three atmospheric parameters from the prioritization process.

The Advisory Group agreed with the initial categorization from the literature search and recommended additional parameters, including stand density, stand height, canopy closure, canopy gaps, red-edge position (REP), dominant canopy species, common understory species, net primary productivity, actual evapotranspiration, forest drought index, carbon/nitrogen ratio, and enhanced vegetation index (EVI). Advisory Group members stressed that observational parameters for forests are useful to varying degrees in different applications and under different conditions. In total, the Analyst Team and Advisory Group identified 34 parameters as observational needs for forest ecosystems.

Table 4. Observational Parameters for Forests.

GEO Task US-09-01a: Earth Observations for Ecosystems - Forests					
Observation Category	Parameter*	Characteristics of the Observation Parameters			
		Coverage/ Extent	Spatial	Temporal	Other
Canopy Type and Structure	Normalized Difference Vegetation Index (NDVI)	Regional	15m to 100m	7 to 16 days	
	Soil-Adjusted Vegetation Index (SAVI)	Regional	15m to 100m	7 to 16 days	
	Leaf Area Index (LAI)	Regional	<15m		
	Photosynthetically Active Radiation (PAR), fraction of PAR (fPAR)		<15m		
	Photochemical Reflectance Index (PRI)				
	Forest Structure		<15m		
	Enhanced Vegetation Index (EVI)		15m to 100m		
	Drought Index (DI)		15m to 100m		
	Stand Density		<15m -100m		
	Stand Height		<15m -100m		Accuracy 1m
	Canopy Closure and Gaps		<15m -100m		
Canopy Chemistry	Chlorophyll		15m to 100m		
	Nitrogen (content, flux)	Global	15m to 100m		
	Carbon (content, uptake, storage)	Global	15m to 100m		
	Carbon/Nitrogen Ratio	Global	15m to 100m		
	Red-Edge Position (REP)		<15m		
Soil	Soil Moisture	Global	<15m	3-5 days	
	Soil Type		<15m		
	Forest Litter				
Water	Water Band Index				
	Precipitation (amount, frequency)	Global		Hourly-Daily	
	Evapotranspiration				
	Forest Drought Index (FDI)				
Impacts	Deforestation Rate	Global		Monthly	
	Reforestation Rate	Global		Monthly	
	Burned Area			Monthly	
	Fuel Characteristics			Daily	
	Active Fires	Regional		Hourly-daily	
Biology	Phenology	Global			
	Biodiversity		<15m		
	Primary Productivity		15m to 100m		
	Dominant Canopy Species		<15m		
	Common Understory Species		<15m		
	Biomass				

* The Analyst Team included all details of parameters and observation needs that were identified through the task process. Some parameters were described in the documents only in general terms. Blanks indicate that the documents stated no quantitative or qualitative information about parameter characteristics.

4.2 Earth Observations for Coastal and Near Shore Marine Ecosystems

Observing and tracking changes in coastal and near-shore marine ecosystems is vital to understanding these complex ecosystems and protecting them from growing natural and anthropogenic stressors. Ecosystems such as wetlands, estuaries, coral reefs, and mangrove swamps are complex juxtapositions of geologic setting, hydrologic flows, biologic assemblages, and physical forces. Coastal and near-shore marine ecosystem sectors are important both ecologically and socioeconomically, on scales from global to local.

Coastal ecosystem observational needs include both parameters that describe ecosystem health and function and those that capture external controlling factors, such as pollutants or meteorology. Many of the documents addressed ecosystem observations related to the impacts of climate change in coastal and near-shore marine ecosystems, such as sea level rise and coral bleaching. As stated previously, the Analyst Team focused on observations that are useful to monitor and evaluate the health, function, and change of ecosystems. The Analyst Team included all parameters from the documents, but did not give emphasis to observations that were intended to definitively prove cause-effect relationships of climate change impacts.

The structures and controlling factors in coastal and near-shore marine ecosystems vary greatly in time and space. Temporally, variations in seasonal temperature patterns, weekly changes in precipitation, and daily tidal oscillations are vital to understanding a coastal ecosystem. Likewise, spatial variations in controlling factors and biologic responses can create unique conditions within short distances, such as salinity gradients across hundreds of meters, pockets of dense populations within several kilometers, or hydrodynamic fronts separating distinct bodies of water. Therefore, the spatial and temporal scales of required observational parameters vary greatly. The documents and Advisory Group noted that the required spatial and temporal scales depend on the question to be addressed. Data users require observations of many parameters several times a day to capture some dynamics of coastal ecosystems, but they may need long time series of the same parameters on a monthly basis to address overall ecosystem health and gradual change. The use and priority of any given ecosystem observation may change with the scale of the observation, the scale of the ecosystem, and the relationships between ecosystem elements.

Table 5 lists the parameters that the Analyst Team identified relevant to monitoring and assessment of Coastal and near-shore marine ecosystems by observation category, with no priority order. The parameter categories are: chemistry of the water, physical motion of the water, biological assemblages, geomorphology, and stressors from major events. The table lists all of the information about the parameters that the documents or Advisory Group specified.

The Analyst Team and Advisory Group focused this list on water properties and underwater vegetation. However, the parameters vital to mangrove assessment are a combination of the coastal water properties and forest canopy properties. The Analyst Team divided the observational needs for mangrove swamps into the canopy observations (listed in Table 4 with forest parameters) and the water observations (listed in Table 5 with coastal parameters). The Analyst Team consulted with the Advisory Group, including two members who are experts in

mangrove ecosystems, to ensure that dividing mangrove parameters between the two lists resulted in an appropriate prioritization of parameters.

The Advisory Group agreed with the overall classification from the literature, and recommended additional parameters, including suspended sediment, attenuation coefficients, bathymetry, and extent and composition of submerged aquatic vegetation. In total, the Analyst Team and Advisory Group identified 32 parameters as observational needs for coastal and near-shore marine ecosystems.

Table 5. Observational Parameters for Coastal and Near-Shore Marine Ecosystems.

GEO Task US-09-01a: Earth Observations for Ecosystems – Coastal and Near-Shore Marine					
Observation Category	Parameter*	Characteristics of the Observation Parameters			
		Coverage/ Extent	Spatial	Temporal	Other
Water Chemistry	Ocean Color	Global to Local	<250m Global, <10m Local		Near-Real Time, Spectral Coverage 350 to 1050nm
	Salinity (ocean and near-shore)	Regional			
	Dissolved Oxygen (DO)	Regional	15m to 100m		
	Suspended Sediment		15m to 100m		
	Nutrients		15m to 100m		
	Air-Sea Flux of Gases and Particles	Regional			
	Pollutants		15m to 100m		
	Organic Carbon		15m to 100m		
Water Physics	River Discharge Quantity	Local	<15m		
	Currents				
	Tides (height, variation)			Hourly to Daily	
	Waves (height, period)		<15m	Hourly	
	Depth (shallow areas)	Global to Local	<10km Global	Hourly to Daily (Local)	
	Sea Surface Temperature (SST)		15m to 100m	Daily	
	Sedimentation rate				
	Sea Surface Roughness		<100m		
	Attenuation Coefficient, Clarity	Regional	15m to 100m		
	Air-Sea Flux of Heat	Regional			

GEO Task US-09-01a: Earth Observations for Ecosystems – Coastal and Near-Shore Marine					
Observation Category	Parameter*	Characteristics of the Observation Parameters			
		Coverage/ Extent	Spatial	Temporal	Other
Biology	Chlorophyll		<15m	Daily	
	Chromophoric Dissolved Organic Matter (CDOM)		15m to 100m		
	Photosynthetically Active Radiation (PAR)				
	Submerged Aquatic Vegetation (Extent and Composition)		<15m	Weekly	
	Primary Productivity				
	Species Composition	Local	<15m	Yearly	
Structure	Seabed Class/Type	Local	15m to 100m	Yearly	
	Bathymetry		<15m		Vertical Accuracy <1m in shallows
Impacts	Sea Level	Global	15m to 100m		
	Soil Moisture/Inundation	Regional	<15m	3-5 days	
	Population density (human)				
	Impervious surface (extent)				
	River Discharge Pattern	Local	<15m		Near-Real Time

* The Analyst Team included all details of parameters and observation needs that were identified through the task process. Some parameters were described in the documents only in general terms. Blanks indicate that the documents stated no quantitative or qualitative information about parameter characteristics.

4.3 Earth Observations for Watersheds

The Watersheds sub-area of ecosystems observations is concerned with dynamics of land-based ecosystems and interaction and location of ecosystem elements. Understanding and tracking land changes due to natural and anthropogenic activities is a major focus of ecosystem observation in the documents, because changes in one region can have far-reaching impacts. For example, clearing of a relatively small area can lead to natural expansion of boundary zone vegetation, impacting a radius far beyond the initial change. Such alterations to the inputs and boundaries of an ecosystem can have significant impacts on its form and function in the future, causing changes in everything from biodiversity to hydrology.

Table 6 lists the observational parameters the Analyst Team identified in the documents that are relevant for Watersheds by observation category, with no priority order. In most of the documents, these parameters are applied with models (or derived from models) to support ecosystem assessment or management. The categories of watershed parameters pertain to the vegetation present, the characteristics of the surface itself, the soil in the area, the amount of water present and its flow, the amount and movement of snow and ice, and parameters that are specific to quantifying impacts. The table lists all of the information about the parameters that the documents or Advisory Group specified.

Many of the parameters are related to identification of land cover because of its value in assessment of the location and function of key ecosystem elements. As the IGOS-P Land Theme (Townshend 2008) noted, "Land cover is not only important in its own right, but is also vital in the estimation of many other terrestrial characteristics, such as land use, and properties relating to biodiversity, conservation and many other ecosystem services." Many Watersheds parameters are also similar to those used for forests, but the questions being asked are often different. While forest assessments may require LAI to assess the health of the canopy, questions of watershed dynamics may apply LAI to understand large shifts and changes in type or quantity of vegetation.

The Advisory Group noted that, when used for ecosystem studies, these Watersheds parameters are very useful for describing ecosystem function, processes, and condition. To understand the distributions of ecosystem components, one member of the Advisory Group noted that these parameters must be used to create mappable categories, including physiognomically-defined vegetation assemblages, isobioclimate regions based on ombrotype (wet/dry regime) and thermotype (hot/cold regime), surficial materials lithology, landforms, and surface moisture index. The parameters listed can support development of these classifications and allow generalizations among regions.

The Analyst Team identified three atmospheric observations (atmospheric aerosols, cloud fraction, and water vapor) applicable to Watersheds and useful in validation and refinement of parameters derived from remote and satellite observations, particularly vegetation indices and surface properties. As discussed under Section 4.1, the Analyst Team did not include the atmospheric parameters because the priority ecosystem parameters can be obtained through methods that are not dependent on atmospheric correction.

The Advisory Group agreed with the Analyst Team's categorization of parameters. Several Advisory Group members recommended additional parameters, including snow cover duration, desertification rate, urbanization rate, cultivation rate, and Enhanced Vegetation Index (EVI), bringing the total list for Watersheds to 35 parameters.

Table 6. Observational Parameters for Watersheds.

GEO Task US-09-01a: Earth Observations for Ecosystems - Watersheds					
Observation Category	Parameter*	Characteristics of the Observation Parameters			
		Coverage/ Extent	Spatial	Temporal	Other
Vegetation	Normalized Difference Vegetation Index (NDVI)	Regional	<15m -100m	Daily-Weekly	
	Soil-Adjusted Vegetation Index (SAVI)	Regional	<15m -100m	Daily-Weekly	
	Enhanced Vegetation Index (EVI)	Regional	<15m -100m	Daily-Weekly	
	Leaf Area Index (LAI)	Regional	<15m	Weekly	
	Photosynthetically Active Radiation (PAR, fPAR, FAPAR)		<15m	Weekly	
	Primary Productivity				
	Photochemical Reflectance Index (PRI)				
Surface	Albedo		<15m	Daily	
	Impervious Surface (extent)		<15m	Yearly	
	Topography		<15m	Yearly	
	Temperature	Global	<15m	Daily	
	Woody Vegetation Cover		15m to 100m	Weekly	
	Non-Woody Vegetation Cover		15m to 100m	Weekly	
	Bare Ground		15m to 100m	Weekly	
Soil	Soil Moisture	Regional	<15m	Weekly	
	Soil Type		15m to 100m		
	Soil Chemistry		15m to 100m		
Water	Water Band Index (WBI)		15m to 100m	Weekly	
	Precipitation (amount, frequency)		<15m	Daily	
	Hydrology		<15m	Weekly	
	Lake and Reservoir Levels		15m to 100m	Weekly	
	Groundwater Level		15m to 100m	Weekly	
Snow and Ice	Snow Depth			Daily	
	Snow Cover Extent			Weekly	
	Snow Cover Duration			Weekly	
	Ice Thickness			Weekly	
	Ice Velocity			Weekly	
Impacts	Deforestation Rate			Monthly	
	Reforestation Rate			Monthly	
	Active Fires	Regional	<15m	Daily	
	Burned Area			Weekly	
	Fuel Characteristics			Daily	
	Desertification Rate	Regional		Monthly	
	Urbanization Rate	Regional		Monthly	
	Cultivation Rate	Regional		Monthly	

* The Analyst Team included all details of parameters and observation needs that were identified through the task process. Some parameters were described in the documents only in general terms. Blanks indicate that the documents stated no quantitative or qualitative information about parameter characteristics.

5 Priority Earth Observations for Ecosystems SBA

5.1 General Description

To determine the priority observation parameters for Ecosystems, the Analyst Team first considered the relative frequency with which the parameter was discussed or applied in the 75 documents selected for analysis. Table 7 lists the parameters in order of frequency. The table lists all parameters referenced at least five times in the documents. Of the parameters listed in Tables 4 through 6, 25 were referenced four or fewer times in the documents and are therefore not listed here. Table 7 also lists: (a) the number of the three ecosystem sub-areas discussed in this report to which the parameter applies, (b) the ecosystem sub-areas for which the Advisory Group recommended the parameter as a priority, and (c) the number of consensus documents consulted that list the parameter as a necessary observation.

Table 7. Parameters Most Frequently Referenced and Applied in the Documents

Parameter	Documents (#)	Ecosystem Sub-areas (#)	Advisory Group Priority	Consensus Document (#)
Biomass	42	1		2
Biodiversity	35	1		
NDVI	30	2	F	1
Precipitation (amount, frequency)	29	2		1
Hydrology	29	1	C	
Temperature (surface, air)	28	1		1
Topography	26	1	W	1
Chlorophyll	23	2	C	1
Leaf Area Index (LAI)	22	2	F,W	1
Phenology	22	1		
Salinity (ocean and near-shore)	22	1	C	2
Species composition	22	2		2
Evapotranspiration	21	1		1
Primary productivity	21	3		2
Attenuation coeff. (clarity)	21	1		
Albedo	21	1	W	
Nutrients (load, concentration)	20	1		2
Pollutants (load, concentration)	20	1		3
Soil moisture	19	2	W	2
Fuel characteristics	18	2		
Urbanization rate	17	1	W	2
Sea level	16	1	C	1
Depth (shallow coastal)	16	1		2
Sea Surface Temperature	15	1		1
Groundwater	15	1		2
Nitrogen (concentration)	14	1		3

Parameter	Documents (#)	Ecosystem Sub-areas (#)	Advisory Group Priority	Consensus Document (#)
PAR, fPAR, FAPAR	14	3	F,W	1
Desertification rate	14	1	W	
SAVI	14	2		
Currents	14	1		
Waves (height, period)	13	1		
Carbon (content, uptake, flux)	12	1		3
Cultivation rate	12	1	W	
Forest structure	12	1	F	
Soil type	11	1		
Litter (forest, leaf)	10	1		
Stand height (canopy height)	10	1		
Bathymetry	9	1	C	1
Impervious surface (extent)	9	2	W	
Deforestation rate	8	2	F,W	
Burned area	8	2		2
Tides (height, variation)	8	1		
Snow cover extent	8	1		
Snow cover duration	8	1		
Ocean color	7	1	C	2
Suspended sediment	7	1		
Dissolved oxygen	6	1		
Stand density	5	1		
Organic carbon	5	1		1
River discharge quantity	5	1		3
Submerged aquatic vegetation extent	5	1	C	3
Submerged aquatic vegetation composition	5	1	C	1
Woody vegetation cover	5	1		
Chromophoric Dissolved Organic Matter (CDOM)	5	1		

The ecosystem sub-areas for which the Advisory Group recommended priority parameters are F=Forests, C=Coastal and near-shore marine, and W=Watersheds. Consensus document priority is the number of the 11 consensus documents that recommended a parameter as a priority. See text for further description.

As described in previous sections, the Analyst Team listed parameters as they were referenced in the documents. If the documents or Advisory Group did not provide specific details on parameter requirements, the Analyst Team listed the broad parameters. As described in Section 4, hydrology is one example of such a broad parameter: the documents stated a general need for better information on hydrology, but included no details on what aspects or specific measurements might be needed.

After the frequency ranking, the Analyst Team considered applicability of the parameter to multiple sub-areas in the report. The frequency counts for parameters that were applicable to more than one sub-area were given a higher weight as a multiplier. Each additional sub-area gave a parameter an additional 50% weight, so that the frequency scores of parameters applicable to two sub-areas were multiplied by 1.5, and the frequency scores of the few parameters that appear on the parameter lists for all three sub-areas were multiplied by 2. The use of these factors increased the range of frequency scores, while ensuring that parameters applicable to a single sub-area were not excluded. Some parameters used frequently in the documents increased in score to be very clearly at the top of the initial prioritization list (e.g., NDVI, precipitation), and some parameters that were less frequently mentioned in the documents but widely applicable across sub-areas moved higher on the ranked list (e.g., PAR/fPAR/FAPAR).

Third, the Analyst Team screened the list of parameters for redundancy and combined multiple individual parameters that require the same set of observations. The three vegetation indices listed [NDVI, EVI, and Soil-Adjusted Vegetation Index (SAVI)] are created from the same observations of surface reflection at red and near-infrared wavelengths, but SAVI includes an extra constant to correct for vegetation sparseness, and EVI also applies additional blue wavelengths. All three were combined in the parameter list as one group of vegetation indices. Similarly, rate/area of disturbance is a parameter listed in the documents as vital to assessing ecosystem health, and the individual disturbance types (rates of urbanization, cultivation, desertification, and deforestation) are evaluated in the same way, with land cover products derived from remote and in situ measurements. Combined, these disturbance types appear frequently in the documents. For combined parameters, the frequencies of mention in the documents for individual parameters were summed.

Fourth, the Analyst Team considered the recommendations of the Advisory Group for prioritization of several parameters within each ecosystem sub-area in this report. The Advisory Group also noted that the priority of observations changes with the particular question to be answered. For Forests, the Advisory Group identified coarse to moderate resolution observations of NDVI and soil moisture and high-resolution observations for LAI, primary productivity, stand density, and plant species composition. For Coastal and near-shore marine, the Advisory Group recommended that ocean color, depth, salinity, and turbidity be monitored twice daily at moderate to high spatial resolution, and that attenuation, sea surface temperature, and PAR be observed daily at moderate to high resolution. For Watersheds, the Advisory Group recommended that albedo, topography, soil moisture, LAI, PAR, hydrology, disturbance, and burned area be monitored at high spatial resolution. Frequency counts of parameters specifically recommended by the Advisory Group were multiplied by 2, regardless of the number of ecosystem sub-areas for which they were recommended (i.e., because the parameters were already weighted by number of applicable sub-areas earlier in the prioritization process, parameters recommended by the Advisory Group were multiplied by 2 at this step whether the Advisory Group recommended them for one, two, or three sub-areas).

The Analyst Team noted that many of the parameters near the top of the priority list are obtained indirectly, meaning that they require multiple types of observations, time series of measurements, models, or other methods of derivation and calculation. As examples of indirect parameters, biomass, biodiversity, and primary productivity were very frequently mentioned in

the documents as proxies for mass of total living matter and ecosystem health, but were rarely applied functionally. All three are meaningful in ecosystem assessment, and can be assessed with a variety of methods. Primary productivity (or production) is an indirect parameter identified by the documents as in need of improvement, and is estimated from a combination of field measurements, models, and remote observations including vegetation indices (terrestrial) and chlorophyll (ocean). Biomass and biodiversity of plant and animal species (biodiversity is also a separate GEO SBA) can be assessed directly, through field measurements, or indirectly, through remote observations and models. Total biomass is estimated primarily to assess carbon sequestration or carbon emissions from fires. As an indicator for ecosystem health, biomass is sometimes used as a parameter in coastal observations to assess the quantities of phytoplankton and aquatic vegetation present.

The documents consulted in this analysis were primarily concerned with developing large-scale methods to track biomass and biodiversity, including developing new algorithms for interpretation of remote sensing data and improvement of correlations between field observations and remote observation methods. These parameters involve field observations of plant and animal species as well as Earth observations of primary production, ecosystem disturbance, land cover, topography, bathymetry, chlorophyll, and submerged aquatic vegetation. Observations with high spatial resolution are required on a weekly to monthly basis to develop baselines and monitor changes. The Analyst Team listed biomass and biodiversity as individual, indirect parameters, as the documents listed them, but noted that global biomass and biodiversity products would be derived from a wide range of models, observations, and other listed parameters. Though the documents did not quantify biomass and biodiversity, they cited amounts of biomass and biodiversity and rates of change as observational needs. As with all the indirect parameters, the Analyst Team treated biomass and biodiversity in the same way as all other parameters throughout the prioritization process.

Another indirect parameter, carbon, is considered in the documents for carbon content, uptake, and flux, which are used in estimates of primary productivity and assessment of carbon stores. The documents in this analysis rarely quantified carbon stores, uptake, or flux, but frequently mentioned the need for improved understanding of these parameters.

Because of the variety of observations and methods that are applied to derive indirect parameters in different ecosystems, and due to the lack of consensus on a preferred method for evaluating many of them, the Analyst Team did not divide indirect parameters into the required direct observations. Prioritization of the individual direct parameters required to develop the indirect parameters would skew the importance of direct observations relative to the importance of synoptic observations, models, and algorithms. To capture the importance of both direct observational parameters and indirect, derived parameters, the Analyst Team separately listed direct and indirect parameters in the order obtained from the overall prioritization.

The Analyst Team eliminated two parameters from the prioritization list because none of the documents or Advisory Group members identified a need for their prioritization: (a) surface temperature and surface air temperature, and (b) active fires. The temperature parameters were cited frequently in the documents in general discussions of ecosystem responses to long-term temperature trends, but none of the documents or Advisory Group members identified surface

temperature as a need for observation or prioritization. Only two of the documents mentioned active fires, and neither indicated a need for observation of active fires. Rather, a number of the documents listed fuel characteristics and burned area as fire-related observational needs that are compatible with the focus, in this analysis, on ecosystem health, function, and change. Therefore, the Analyst Team removed active fires from the prioritization and included fuel characteristics and burned area.

Finally, the Analyst Team considered the parameter prioritization in relation to the conclusions of published consensus reports. The consensus documents were focused on the broad application and integration of Earth observation data sets and on general requirements to improve assessment of indirect parameters. The consensus documents expressed great needs to create standardized products for land cover and ecosystem components, improve spatial resolution of global remote sensing products, and increase the interoperability of diverse datasets. The consensus documents did not make strong recommendations for prioritization of individual parameters over others, but all of the parameters listed in Table 7 were referenced in the consensus documents consulted in this analysis. The Analyst Team did not adjust the priority rankings based on the recommendations of the consensus documents, but used the consensus documents as a confirmation that the appropriate parameters were included.

5.2 Priority Observations

Considering the relative frequency with which parameters were applied in the documents and the recommendations of the Advisory Group, the Analyst Team identified the parameters in Tables 8 and 9 as priorities for observation. Table 8 lists the priority indirect ecosystems parameters, and Table 9 lists the priority direct parameters. As described above, direct parameters are directly observed, or obtained from the same type of observations, while indirect parameters are obtained from multiple measurements, multiple types of measurements, time series, or models. Tables 8 and 9 list the parameters in descending order of their final prioritization, based on the process described in Section 5.1.

As in Section 4, Tables 8 and 9 list the categories for observational parameters. Many parameters in these tables have two categories listed, reflecting their categorization for ecosystem sub-areas in Tables 4, 5, and 6.

Table 8. Priority Indirect Observational Parameters for Ecosystems.

GEO Task US-09-01a: Priority Earth Observations for Ecosystems: Indirect Observations					
Observation Category	Parameter*	Aggregated Characteristics of Priority Observation Parameters			
		Coverage/ Extent	Spatial	Temporal	Other
Impacts	Disturbance (Urbanization, Desertification, Cultivation, Deforestation)		<15m	Monthly	
Vegetation	Leaf Area Index (LAI)		<15m	Weekly	
Water	Hydrology	Regional	<15m	Weekly	
Biology	Biomass				
Biology	Primary productivity		<15m		
Biology	Biodiversity	Regional	<15m		
Impacts	Fuel characteristics			Daily	
Impacts	Impervious surface (extent)		<15m	Monthly-Yearly	
Biology	Phenology	Global-Local			
Vegetation	Forest structure	Regional	<15m		
Water Physics	Groundwater		15m to 100m	Weekly	
Vegetation/Biology	Carbon (stores, uptake, flux)				
Water Physics	Sedimentation rate				
Soil	Litter (forest)				
Water Physics	River discharge quantity	Local	<15m		Near-Real Time
Vegetation	Stand density		<15m -100m		
Surface	Woody vegetation cover		15m to 100m	Weekly	

* The Analyst Team included all details of parameters and observation needs that were identified through the task process. Some parameters were described in the documents only in general terms. Blanks indicate that the documents stated no quantitative or qualitative information about parameter characteristics.

Table 9. Priority Direct Observational Parameters for Ecosystems.

GEO Task US-09-01a: Priority Earth Observations for Ecosystems: Direct Observations					
Observation Category	Parameter*	Aggregated Characteristics of Priority Observation Parameters			
		Coverage/ Extent	Spatial	Temporal	Other
Vegetation	Vegetation indices (NDVI, SAVI, EVI)	Global-Regional	<15m -100m	Daily - Weekly	
Vegetation	PAR, fPAR, FAPAR		<15m -100m	Daily	
Vegetation/Biology	Chlorophyll		<15m	Daily	
Soil	Soil moisture	Global-Regional	<15m	3-5 days	
Surface	Topography		<15m	Yearly	
Water Chemistry	Salinity (ocean and near-shore)	Regional	<15m -100m	Twice Daily	
Water Physics	Precipitation (amount, frequency)		15m to 100m	Daily	
Water Physics	Depth (shallow near-shore)	Regional-Global	<15m -100m	Twice Daily	
Impacts	Sea Level	Global	15m to 100m		
Vegetation/Biology	Nitrogen (content, flux)	Global	15m to 100m		
Biology	Species composition		<15m		
Vegetation	Evapotranspiration				
Surface	Albedo		<15m	Daily	
Water Chemistry/Canopy Chemistry	Nutrients (load, concentration)		15m to 100m		
Water Chemistry	Pollutants (load, concentration)		15m to 100m		
Structure	Bathymetry		<15m		Accuracy <1m in shallows
Impacts	Burned area		<15m	Monthly	
Water Physics	Sea Surface Temperature (SST)		<15m -100m	Daily	
Water Chemistry	Ocean color	Global-Local	<15m	Twice daily	Near-Real Time, 350-1050nm
Water Physics	Attenuation coefficient (clarity)		15m to 100m	Daily	
Water Physics	Currents				
Water Physics	Waves (height, period)		<15m	Hourly	
Biology	Submerged Aquatic Vegetation (extent and composition)		<15m	Weekly	
Soil	Soil type				
Vegetation	Stand height				
Snow/Ice	Snow cover extent				

* The Analyst Team included all details of parameters and observation needs that were identified through the task process. Some parameters were described in the documents only in general terms. Blanks indicate that the documents stated no quantitative or qualitative information about parameter characteristics.

6 Additional Findings

During the US-09-01a analysis, the Analyst identified some common themes and additional findings. This section discusses the additional findings, as well as information related to ecosystem observation parameters that is not directly represented in the prioritizations above.

Throughout the documents, the most frequently stated needs were not for specific observational parameters, but rather for improvements in the ability to apply the parameters. Ecosystem observation has historically been conducted in the field, on relatively small scales, and at relatively large expense of cost and manpower. Many of the documents indicated a great need to relate field measurements to methods, such as remote sensing, that allow understanding of ecosystem function on a larger scale, tracking of global changes, identification of impacts, and description of the functional relationships between various ecosystems and components.

Across regions, ecosystem types, and parameters, several general needs appeared repeatedly:

- Improved correlation between remote sensing observations and ground-based observations
- Better algorithms to interpret and correct remote sensing data
- Validation and standardization of land cover maps
- Long time series of data and consistency of data availability
- Synoptic observations
- Finer temporal and spatial resolution
- Model integration.

Improved correlations between remote sensing and ground-based data sets:
Advisory Group members and the documents noted that links between Earth observation imagery and field measurements must be established or improved in order for the ecosystem management community to use many Earth science data sets. In some areas, such as vegetation cover on regional scales, correlation is far enough advanced to allow managers to use remotely sensed data. In other ecosystems, including coastal and near-shore marine regions, correlation between in situ observation and remote sensing data is in the research phase.

There was a frequently expressed need in the documents for detailed ground-based measurements (case studies specific to ecosystem or location) to enable development of correlation between remote observations and ground-based measurements. The documents and members of the Advisory Group noted that, for additional Earth observations to be of the most use to ecosystems researchers and managers, remote observations must be sufficiently validated with in situ and intensive field data. Also, documents recommended that comparison of ground-based and remote sensing data should be used to understand the accuracy of satellite data.

To support improved correlation between remote and in situ data sets, many of the documents noted a need for integration of multiple data sets, including in situ and remote sensing, coarse and fine spatial and temporal resolutions, traditional and emerging methods, and observations of diverse parameters.

Improved algorithms
Many of the documents stated a need for improved algorithms for detailed interpretation of remote sensing data to make products more accessible and reliable for end users. The documents identified needs for improved algorithms for all types of remote sensing parameters, including improved methods to account for interferences such as mixed pixels and atmospheric aerosols.

Validation and standardization
Several consensus documents (GEOSS 2005, Heinz 2006, Townshend 2008, Australian Academy of Sciences 2009) identified the need for global, validated, standardized maps of land cover and ecosystem components and parameters. Advisory Group members agreed that validated, standardized maps are needed at the high to moderate resolutions required to evaluate ecosystem processes.

Long time series of data and consistency of data availability
Several Advisory Group members and documents stressed the importance of long time series of data and consistent availability of data for ecosystem research and management. To ensure the continuity of data sets, the documents noted that new observations added to the time series must be related to existing data sets, that data must be continuous both spatially and temporally, and that new, finer-resolution data must be related to previous, coarser data.

Data continuity (spatial and temporal) is cited in the documents as a key issue for effectively identifying ecosystem change. A need for more consistent collection and availability of moderate resolution remote sensing data, in particular, was noted repeatedly. In the documents, high resolution data is generally used for specific studies or specific questions, while long time series of moderate resolution data are used for observing larger-scale trends.

Synoptic observations
During this analysis, the Analyst Team recognized the importance of conducting observations in a way that enables a complete understanding of the system. The large number of indirect parameters prioritized through this activity indicated to the Analyst Team that individual, discrete, observable parameters are not sufficient for ecosystem assessment. The availability of synoptic observations would improve the ability to compare across datasets. From the documents and discussion with the Advisory Group, the Analyst Team observed the need for synoptic observations relevant to the spatial and temporal resolution of the phenomena being observed (e.g., collecting data within the same month, ensuring that the in situ sample is taken at the same hour as the satellite overpass, or aligning sampling grids). The Analyst Team inferred that spatial and temporal alignment across data sets could be more important than improved resolution, and that the focus in ecosystem assessment should be on observation of multiple complementary parameters within relevant spatial and temporal scales.

Finer temporal and spatial resolution
The need for new observations with finer spatial and temporal resolution was stated in the documents, often without specific mention of parameters. Documents and Advisory Group members noted that certain dynamic phenomena, such as fires and runoff events, require monitoring on timescales more frequent than daily to fully capture event evolution and

understand ecosystem impacts. Advisory Group members also mentioned that dynamic ecosystems, such as dryland regions with dynamic seasonal vegetation patterns, require land cover observations with finer spatial and temporal resolution than the common observation points in summer and winter. As the Advisory Group noted repeatedly, the temporal and spatial scales required are specific to a given issue, and the ecosystem question to be answered must be considered in each case.

Related to the need stated above for longer time series, the documents also noted that newer, finer-resolution optical data should be integrated with older data sets to estimate changes over time. For example, new high-resolution products can be used with older lower-resolution forest observations to understand long-term change in the structure of forests.

Model Integration
Users apply a wide range of models in evaluation of ecosystem function and health. Integrating different types of models is frequently cited in the documents as necessary to understand the relationships between stressors and impacts. The documents discussed the need for integration of global, regional, and local climate and impacts models to describe ecosystem vulnerabilities on fine scales. Likewise, a number of documents recommended that atmospheric, coastal, and land change models be integrated with hydrologic, biodiversity, socioeconomic, and ecosystem process models to create comprehensive models of ecosystem change and impacts.

7 Analyst's Comments and Recommendations

While conducting the nine-step analytical process that the UIC outlined for Task US-09-01a, the Analyst Team found the steps to be generally effective and adequate. This section describes the experience of the Analyst Team with the process and includes the Team's recommendations for future iterations of the task for other SBAs.

7.1 Process and Methodology

The Analyst Team recognized throughout this process that among the SBAs, the background literature and the maturity of GEOSS differ widely. The 9-step process was flexible enough to accommodate the variety of SBAs. Here, the Analyst Team reflects on the process as implemented for the Ecosystems SBA and suggests refinements that may be useful for other SBAs or future iterations.

More narrowly define the scope of the report. In this report, the Analyst Team focused on observational needs to assess ecosystem health, function, and change, rather than needs for specific ecosystem management applications, such as municipal wasteload allocations, sustainable fisheries management, or wetlands restoration. The Analyst Team concluded from an initial literature review that the observational requirements for ecosystem management applications require location-specific data and data collection methods that are tailored to individual decision making needs. Therefore, to ensure that the prioritization would be broadly and globally applicable, the Analyst Team did not address specific ecosystem management questions.

Following the decision to make the prioritization as applicable as possible to a wide range of users, the Analyst Team selected broad, physically defined sub-areas with similar observation requirements. The top-down approach, beginning with similarity of observation needs, allowed good examination and prioritization of a wide range of parameters. A bottom-up approach, starting with very specific ecosystem management questions for particular locations, might have resulted in a much narrower prioritization. The Analyst Team recommends that future iterations of a task like US-09-01a should narrow the focus by either: 1) prioritizing the observation needs for a combined group of related ecosystem management needs, or 2) focusing on a more specific set of physical sub-areas (e.g., mangrove forests or coniferous taiga rather than the broad sub-area of forests). Either of these two recommended approaches would necessarily result in a narrower prioritization of parameters, while requiring multiple iterations to achieve broad coverage of the Ecosystems SBA.

Determine the scope of the report before selecting advisory group members. The Analyst Team recruited the Advisory Group members before narrowing the scope of the report. Though the Analyst Team narrowed the scope of the report with the input of the Advisory Group, the final selection of topics did not include direct interests of many members, which may have contributed to the low levels of participation of some members of the Advisory Group. The members of the Advisory Group whose interests were best aligned with the chosen sub-areas were the most active throughout the analysis.

The Analyst Team recommends that Analysts for future iterations consult with a few experts in various ecosystem disciplines to determine the scope of the analysis. Once the scope is determined, the Analyst can seek out experts from GEO member countries and participating organizations with expertise in the chosen sub-areas. Selecting Advisory Group members with specific, relevant expertise and interests might promote increased participation in the process.

Document identification and analysis. As described previously, the Analyst Team and Advisory Group reviewed a broad range of documents and selected a final list of 75 documents, including 11 consensus documents. Several of the consensus documents had a broad view of ecosystem observation requirements across regions and ecosystems, though others were more narrowly focused on a particular region, ecosystem type, or observation category. To avoid the possibility of skewing the prioritization based on these few documents of varied specialization, the Analyst Team did not weight parameters that were listed as priorities by the consensus documents. Instead, the Analyst Team included the parameters from consensus documents in the frequency count, and later compared the final prioritized list with the findings of the consensus documents to ensure that the prioritization was compatible with previous findings. The Analyst Team found this to be a very effective strategy, and would recommend it to other SBAs, particularly those with a limited number of focused consensus documents.

7.2 Challenges

Throughout the analysis, the Analyst Team was struck by apparent differences between ecosystems and other SBAs. In particular, the Analyst Team found ecosystems to be broader than other SBAs. The variety of potential observations in ecosystems is extremely vast, and closely interrelated with other SBAs – biodiversity, climate, health, disasters, water, and agriculture. Conversely, SBAs such as disasters and energy are fairly self-defining in scope in that they are readily associated with specific Earth observation applications, such as earthquakes or solar energy. To avoid duplication of the work on US-09-01a for other SBAs, the Analyst Team focused on prioritization of parameters necessary to observe the health, function, and change of ecosystem sub-areas. Though the focus on health, function, and change was effective, a greater body of literature is devoted to observation needs for ecosystem services (e.g., clean water, timber, food, carbon sequestration, disease control, and hydropower, among many others) that are integral to other SBAs. The Analyst Team therefore recommends that the scope of a future effort might consider ecosystem services to a greater degree, recognizing that extra care will be required to avoid duplication of the work for other SBAs.

When ecosystems documents included discussion of observation needs, they tended to focus on the general need for more data, rather than identification of an ideal set of observations. The application of existing observations was discussed in the literature far more than the needs for ideal observations. Additionally, many of the documents that discussed ecosystem observation needs focused on the general need for new observation platforms or networks, which were outside the scope of this analysis. The Analyst Team found that identification of general inadequacies of current observations was not sufficient to make any conclusions regarding necessary parameter characteristics. Historically, the focus of most ecosystem observation has been on site-based studies, in part because the factors affecting health, function, and change in one ecosystem may be very different from those in similar ecosystems nearby. Moreover, remote sensing data has not always been available at resolutions adequate for ecosystem observation. In recent years, integration of observation networks and improved resolution of remote sensing products has led to a rapid expansion in applications to understand ecosystem health, function, and change on larger, more interconnected scales. As ecosystems monitoring and research advances in the application of GEOSS and GEO goals, the Analyst Team anticipates that the results of Task US-09-01a will be useful to the ecosystem community as it becomes increasingly interested in identifying and obtaining ideal parameter characteristics.

Appendix A: Abbreviations

CDOM	Chromophoric (or Colored) Dissolved Organic Matter
DI	Drought Index
DO	Dissolved Oxygen
EMIS	Environmental Management Information System
EVI	Enhanced Vegetation Index
FAPAR	Fraction of Absorbed Photosynthetically Active Radiation
FDI	Forest Drought Index
fPAR	Fraction of Photosynthetically Active Radiation
GEO	Group on Earth Observation
GEOSS	Global Earth Observation System of Systems
IGOS	Integrated Global Observing Strategy
IOOS	Integrated Ocean Observing System
LAI	Leaf Area Index
NASA	U.S. National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
PAR	Photosynthetically Active Radiation
PRI	Photochemical Reflectance Index
REP	Red-Edge Position
SAVI	Soil-Adjusted Vegetation Index
SBA	Societal Benefit Area
SST	Sea Surface Temperature
UIC	User Interface Committee
WBI	Water Band Index

Appendix B: Bibliography and References

*Consensus documents, as listed in Section 3.3, are indicated with an asterisk.

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