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

Agriculture Societal Benefit Area - Forests

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 Agriculture SBA– Forests

Advisory Group Members & Analysts

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GEO Task US-09-01a
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Summary

The goal of GEO Task US-09-01a is to identify the critical Earth observations for various societal benefit areas (SBAs). This report identifies observation priorities for forests and focuses on three sub-areas of timber, fuel, and fiber management; forest perturbations and protection; and carbon and biomass. Forests include topics relevant to the Ecosystems and Agriculture SBAs; the results of this report will be incorporated into the cross-SBA prioritization in parallel with the results of the Ecosystems and Agriculture SBA reports.

To assist with the forests analysis, the Analyst assembled an *ad hoc* Advisory Group of six members from around the world. Responsibilities of the Advisory Group included selecting the sub-areas of forests for analysis, recommending relevant documents, reviewing prioritization methods, and surveying the results. The total number of potentially relevant documents recommended by the Advisory Group and identified by the Analyst through literature and internet searches was 31. After evaluating these documents for their applicability to this task, the Analyst selected 16 documents that provided information on the observation priorities for the forests sub-areas that were relevant to the analysis.

The Analyst extracted observation parameters from the documents for each of the three forests sub-areas. In order to determine which parameters have the highest priority, the Analyst weighted each parameter based on its applicability across sub-areas considered in this report, emphasis given to the parameter in the documents, and recommendations of the Advisory Group.

Based on the results of the prioritization method, the Analyst generated a list of nine priority observation categories for forests, which are (in approximate order of priority, starting with the most important observation category):

- Land Cover, Land Cover Change
- Forest Area, Forest Area Change
- Degradation
- Afforestation/Reforestation
- Carbon Stocks (soil organic matter, aboveground vegetation, belowground biomass, dead wood, harvested wood, litter)
- Fire Intensity/Burn Intensity/ Fire Radiative Power
- Stand Height
- Biomass (above ground); Stem Volume
- Burned Area.

These priority observation categories represent a broad picture of global Earth observation needs for forests. Forest 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.

1 Introduction

This report articulates Earth observation priorities for forests. Forests include topics relevant to the Ecosystems and Agriculture Societal Benefit Areas (SBAs); the results of this report will be incorporated into the priority setting results of the Ecosystems and Agriculture SBAs, as appropriate. The results of this report are based on an analysis of 16 publicly available documents, including documents produced by the Group on Earth Observations' Member Countries and Participating Organizations.

1.1 GEO and Societal Benefit Areas

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

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

Agriculture	Biodiversity	Climate
Disasters	Ecosystems	Energy
Health	Water	Weather.

1.2 GEO Task US-09-01a

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

This task considers all types of Earth observations, including ground, *in situ*, airborne, and space-based observations. This 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.

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

[1] GEO Website: *http:// www.earthobservations.org*
[2] GEO 10-Year Implementation Plan: *http://www.earthobservations.org/documents.shtml*

Participating Organizations can use the results in determining priority investment opportunities for Earth observations.

1.3 Purpose of the Report

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

The primary audience for this report is the GEO User Interface Committee (UIC), which is managing Task US-09-01a for GEO. The GEO UIC will use the results of this report in combination with reports from the other eight SBAs. 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 forests, the Ecosystems SBA, and Agriculture SBA are additional audiences for this report. Space agencies, natural resource managers, forest services, global change scientists, and the conservation and biodiversity communities may also find the results useful.

1.4 Scope of the Report

This report addresses the Earth observation priorities for forests. In particular, this report focuses on the sub-areas of timber, fuel, and fiber management; forest perturbations and protection; and carbon and biomass.

This report provides some background and contextual information about forests and the associated Ecosystems and Agriculture SBAs. However, this report is not intended as a handbook or primer on these topics. A complete description of the Ecosystems or Agriculture SBAs is beyond the scope of this report. Please consult the GEO website cited above for more information about the Ecosystems and Agriculture SBAs.

This report focuses on the Earth observations relevant to forests, 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 output) 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 to be of higher significance than others for forests, as determined through the methodologies described within. The report uses the terms "user needs" and "parameter needs" to refer to Earth observations that are articulated and desired by the groups and users in the cited documents.

The report discusses the overall approach and methodologies used in this analysis (Section 2). Section 3 describes the forests topic and the specific sub-areas that were part of the analysis. Section 4 articulates the specific Earth observations for each forests sub-area, and Section 5 presents the overall priority observations for forests. Sections 6 and 7 present additional findings from the analysis of the documents and any recommendations. The appendices include a list of the documents cited and consulted, a list of acronyms used throughout the document, and a summary of the input to the Cross-SBA analysis.

2 Methodology and Process

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 nine (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 the 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 forests report had an "Analyst" and an "Advisory Group" working together to identify documents, analyze them, and prioritize the Earth observations. The Analyst served as the main coordinator, and managed the activities of the Task. The Analyst was supported by an Analyst Team.

2.2.1 Analyst

The Analyst for the forests report was Dr. Glynis Lough, an Environmental Research Scientist at Battelle. Dr. Lough has experience in environmental chemistry and environmental policy and planning, and has worked with in situ and remote sensing measurements in a number of projects. Dr. Lough served on the Analyst Team that developed the Ecosystems SBA Report of January 20, 2010. Mr. Adam Carpenter, an environmental researcher at Battelle, assisted the Analyst.

For this task, the forests Analyst and Team served under contract to National Aeronautics and Space Administration (NASA) Earth Science Division Applied Sciences Program.

2.2.2 Advisory Group

The general methodology for GEO Task US-09-01a includes the formation of an expert Advisory Group to help identify appropriate documents, provide feedback on the prioritization methods, and review the preliminary and final reports. For the forests report, the Analyst identified Advisory Group members initially through the recommendations of Michael Brady of Natural Resources Canada. The Analyst identified additional Advisory Group members through recommendations of invitees who were able to participate in the process.

Overall, between January and June 2010, the Analyst invited 17 experts to serve on the Advisory Group. Five experts were unable to participate, but they provided the names of alternate contacts; 3 experts did not respond; 3 experts were unable to participate as the task progressed. For this task, it was important to have representation from both developed and developing nations, to ensure that a global view of forests observation priorities could be captured. The 6 members of the Advisory Group include participants from 5 countries across 3 continents. Table 1 provides a list of the Advisory Group members and their affiliations.

The Analyst sent all interested Advisory Group members a description of the task, including a summary of what their role would be in the Task US-09-01a process. Also, the Analyst asked each expert to supply document references for the analysis of priority observations. The Analyst sent periodic emails to the Advisory Group throughout the course of the project to keep them apprised of the progress of the task. The Advisory Group reviewed possible sub-areas of focus, reviewed the preliminary document, and identified high-priority parameters.

Table 1. Advisory Group for Forests

Name	GEO Country or Organization	Affiliation	Geographic Region	Area of Expertise
Michael BRADY	Canada	Natural Resources Canada	North America	Fire disturbance
Alex HELD	Australia	Commonwealth Scientific and Industrial Research Organisation (CSIRO)	Oceana/ Australia	Forest cover and change monitoring

Name	GEO Country or Organization	Affiliation	Geographic Region	Area of Expertise
Martin HEROLD	Global Observation of Forest and Land Cover Dynamics (GOFC- GOLD)	Wageningen University, Netherlands	Europe/ Global	Remote sensing
Håkan OLSSON	Sweden	Swedish University of Agricultural Sciences	Europe	Forest remote sensing
Kevin RYAN	USA	United States Department of Agriculture (USDA) Forest Service	North America/ Global	Forest fire science, ecophysiology
John TOWNSHEND	USA	University of Maryland	North America/ Global	Land cover dynamics

2.3 Methodology

2.3.1 Documents

In order to identify as many publicly available documents as possible for consideration in the analysis of priority observations for forests, the Analyst sought out documents from various sources. The types of documents included international, regional, and national-level reports, workshop and conference proceedings, summaries and presentations, peer-reviewed journal articles, and other published documents. The Analyst used the following key methods in the document identification process:

- Requested document references for the three sub-areas of forests from the Advisory Group.

- Searched the websites of large national and international working groups and government agencies; for example, the Global Observation of Forest and Land Cover Dynamics (GOFC-GOLD), which is part of the Global Terrestrial Observing System (GTOS) of the Food and Agriculture Organization (FAO) of the United Nations.

- Performed web-based literature searches using standard search tools and databases. The Analyst used combinations of specific forest terms (e.g., forest, timber, carbon) and Earth observation keywords (e.g., observation, priority, monitoring) to perform the searches.

- Used to the references listed in the documents identified through other methods to provide potential new sources of information.

2.3.2 Meta-Analysis Methods

The Analyst evaluated each document for its usefulness based on the inclusion of specific observation priorities related to the three forest sub-areas of analysis. In order for a document to be included in the analysis, it had to explicitly identify required forests-related Earth observations, and it had to contain information regarding desired characteristics of the observations. The characteristics include the temporal resolution (frequency), spatial resolution, timeliness/latency (how quickly the observation is available), accuracy/precision, and coverage or extent of the observation. The analysis did not include information on the technical infrastructure required to collect and process critical Earth observations, even though information on the technical infrastructure is an important aspect of Earth observations for forest applications.

The Analyst extracted detailed data from the documents that met the criteria for inclusion in the analysis. For each observation, the extracted information included the applicable forests sub-area(s) (of timber, fuel, and fire management; forest perturbations and protection; and/or carbon and biomass), the region of interest of the observation (Global, Africa, Europe, Oceania/Australia, Asia/Middle East, East Asia, North America, or Central/South America), the type of document (e.g., international working group report, peer-reviewed journal article, meeting report), and the desired physical characteristics of the observation, when available.

2.3.3 Prioritization Method

As the basic method of setting the collected observations into priority order, the Analyst combined and assessed the following three factors: 1) applicability across forests sub-areas considered in this report, 2) priorities recommended by consensus documents, and 3) recommendations of Advisory Group members.

Before prioritizing parameters, the Analyst combined parameters derived from the same observations. For example, the Analyst considered three vegetation indices that are derived from the same wavelengths of light from satellite observations as one (Normalized Difference Vegetation Index [NDVI], Soil-Adjusted Vegetation Index [SAVI], and Enhanced Vegetation Index [EVI)]. For clarity, the Analyst also combined several parameters with the same purpose but different names (e.g., forest heterogeneity, local forest variation).

Table 2 summarizes the prioritization process. As the first step in the prioritization, the Analyst considered applicability of the parameter to multiple sub-areas in this report. Parameters that were applicable to more than one sub-area received a score of 1, 2, or 3, according to the number of relevant sub-areas. This step resulted in a ranked list with possible scores of 1-3 for each parameter.

Table 2. Summary of Prioritization Process

Step 1: Cross-Cutting Applicability	
Weight	**Definition**
1	1 Sub-Area
2	2 Sub-Areas
3	3 Sub-Areas
Step 2: Recommendation of Consensus or Review Document	
Multiplier	**Definition**
1	Not explicitly recommended by any of the consensus or review documents considered in this task
2	Recommended for prioritization by 1 or more of the consensus or review documents considered in this task
Step 3: Recommendation of Advisory Group	
Multiplier	**Definition**
0.25	Noted as low priority by two Advisory Group members
0.5	Noted as low priority by one Advisory Group members
1.0	Not recommended by any Advisory Group members
1.5	Recommended by one Advisory Group member
1.75	Recommended by two Advisory Group members
2.0	Recommended by three or more Advisory Group members

The Analyst based the second step of the prioritization on specific recommendations or needs stated in the consensus and review documents. Compared to other reports in Task US-GEO-0901a, this forests report included a relatively small final number of documents (16), of which the majority was consensus and review documents. Because of the relatively small number of documents, the Analyst determined that a ranking based on frequency of mention in the documents might not be representative of overall priorities. Therefore, the Analyst multiplied the ranking (1-3) of a parameter stated as a recommendation or need by 2, whether one document or 10 documents stated the recommendation. The Analyst determined that a multiplier of 2 was sufficient to elevate parameters recommended by the consensus documents in the ranking, but that a multiplier of 2 did not increase the spread of scores too widely. The second step in the prioritization resulted in an intermediate range of possible scores from 1-6 for each parameter.

Finally, the Analyst considered specific recommendations of the Advisory Group to weight parameters. The Advisory Group recommended prioritization of several parameters within each forest sub-area in this report. Parameters the Advisory Group recommended for prioritization in any forest sub-area received a multiplier on the ranking score that emerged from the second step. To determine the multipliers for parameters, the Analyst considered that several Advisory Group members recommended parameters generally for prioritization, and several recommended

numeric changes to the scores that emerged from step 2. The Analyst used the recommended scores to develop a method to weight the step 2 scores to elevate the recommended parameters and to match the recommended scores. The Analyst tested several systems of weighting and determined that the weights listed in Table 2 (1.5 for parameters recommended by one Advisory Group member, 1.75 for parameters recommended by two Advisory Group Members, and 2.0 for parameters recommended by three or more) would both elevate the recommended parameters in the ranking and would closely match the recommended numeric rankings. For example, carbon stocks was scored as a 4 following step 2, but one Advisory Group member recommended that carbon stocks should be ranked as 6, the top of the step 2 list, and one other Advisory Group member recommended general prioritization of carbon stocks. Therefore, the Analyst multiplied the carbon stocks score by 1.75 (recommended by 2 Advisory Group members), resulting in a final score of 7, which is very close to the top of the ranked list. Advisory Group members also noted that several parameters were low priority, and the Analyst multiplied those scores by 0.5 (one Advisory Group member noted low priority) or 0.25 (two Advisory Group members noted low priority).

It is important to note that some listed parameters are direct observations, while others are indirect, derived from multiple types of observations, models, and algorithms. The Analyst treated direct and indirect parameters the same way throughout the prioritization process.

3 Forests – Part of the Ecosystems and Agriculture SBAs

3.1 Forests Description

Forests are considered as part of both the Ecosystems and Agriculture SBAs. Globally, forests include a wide range of distinct ecosystems, from alpine tundra to tropical coastal mangroves. Many agriculture topics such as silviculture, agroforestry, and land change are also very closely linked to forest observation. The results of this forests analysis will be incorporated in cross-SBA analysis in the future as a contribution to either or both of the Ecosystems and Agriculture SBAs.

The general category of forests includes a large number of biomes, 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 experienced many harvests and harvest methods to supply the majority of forest products in the northern regions, but there are also large areas of boreal forests, especially in remote parts of Russia and Canada, which are still unexploited to industrial forestry. 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.

3.2 Forests Sub-Areas

Step 2 of the Task US-09-01a process calls for the determination of the scope for the analysis. The Analyst suggested five possible forest sub-areas to the Advisory Group for comment and feedback. The five possible sub-areas were focused on user applications and were adapted from a GOFC-GOLD paper written by Michael Brady, titled "Identifying Critical Earth Observations for Forest Monitoring: A Role for GEO." Based on input from the Advisory Group, the Analyst selected the following three sub-areas for analysis:

Sub-area 1: Timber, Fuel, and Fiber Management. Forests are harvested and/or managed for timber products, including timber (e.g., wood and wood products), fuel (e.g., biofuel for energy or heating), and fiber (e.g., paper products). Users include commercial landowners, state and national authorities, researchers, fuel-wood gatherers, and natural resource planners. Users can benefit from observations to support planning and management of the economic and environmental forest assets. Land use change, forest density, and species composition are examples of relevant parameters. Many observations are required infrequently, on seasonal to annual temporal scales.

Sub-area 2: Forest Perturbations and Protection. Major threats to forest health include fire, insects, and disease. In many regions, climate change is expected to influence the severity and/or range of these threats. Potential users include forest preserve managers, natural resource managers, state or national authorities, researchers, and landowners of small to large tracts. Users can benefit from both long-term records and near real-time information.

Sub-area 3: Carbon and Biomass. Users from landowners to international policymakers will need tracking of forest carbon to support carbon credit systems (e.g., afforestation, reforestation, reducing emissions from deforestation and forest degradation [REDD]). GEO has launched a Forest Carbon Tracking Portal (Task CL-09-03b), in association with CEOS, to

> "support countries wanting to establish national forest-change, carbon estimation and reporting systems. It will facilitate access to long-term satellite, airborne and in situ data, provide the associated analysis and prediction tools, and create the appropriate framework and technical standards for a global network of national forest carbon tracking systems." (www.geo-fct.org)

The Advisory Group indicated that including this subtopic for GEO US-09-01a would be complementary to, rather than duplicative of, ongoing GEO efforts. This subtopic includes forest mapping and carbon/biomass quantification. Users include policy makers, landowners, carbon traders, national authorities, and data providing agencies.

The Analyst expected that many of the Earth observation parameters would be somewhat similar across the sub-areas, but also expected that these user-application defined sub-areas would have unique parameters (or parameter properties: accuracy, resolution, etc.), thereby supporting the choice of these sub-topics for the priority setting analysis.

3.3 Documents

The document search effort, including website, database, and online literature searches, as well as recommendations from Advisory Group members, yielded 31 documents that potentially

contained Earth observation priorities for one or more of the forest sub-areas. The Analyst performed a preliminary review of all of the documents to determine if the information provided specific forests-related Earth observation priorities. If such observation priorities were present, the Analyst Team thoroughly reviewed the document and extracted the appropriate data.

Of the 31 documents identified by the Analyst and Advisory Group, 16 (51%) of them contained information on end user needs for Earth observation parameters, meriting further analysis. References for all of the documents are listed in Appendix B as "Documents Cited" and "Documents Consulted." The Analyst identified the primary geographic focus of the 16 documents based upon the region of focus in the work, or the region in which the author(s) and/or sponsoring institution are located. The Analyst assigned a global focus to those documents that came from international working groups or other organizations which, by nature, cross many geographic regions. Of the 16 relevant documents, the Analyst identified 15 as having a global focus. Two of the documents also included end user parameter needs that are specific to forests in Africa (one document included both global and regional parameter needs).

Most of the 16 documents were consensus and review documents that address forest parameters and recommendations. Three of the documents appeared in the peer-reviewed literature. Because of the large number of relevant consensus and review documents identified for forests, relative to other topics under this task, the Analyst Team did not seek out further primary research literature.

3.4 User Types

Throughout the analysis, the Analyst considered the applications for Earth observations related to forests, and conducted an informal gap analysis to ensure all user types were represented in the documents. The types of users for forest observations and information range from researchers of individual topics to international regulatory groups and user agreement bodies. Two of the documents included in the analysis were guides for users, aimed at helping governments or other groups to quantify existing forest area and carbon stocks and identify change (GOFC-GOLD, 2009; IPCC, 2003). Representative user types for the three sub-areas are similar based on the type of application, as listed in Table 3.

Table 3.Representative User Types for Forest Earth Observations

Application Area	User Type
Research	Ecologists
	Climate Scientists
	Atmospheric Scientists
	Remote Sensing Researchers
Forest Management	Forest Product Companies
	Land Use Planners
	Landowners
	Forest/Natural Resource Managers
National Policies and International Agreements	Environmental Ministry Policy Leaders
	Clean Development Mechanism Program Analysts
	Carbon Traders

4 Earth Observations for Forests Sub-Areas

The Analyst Team identified a broad range of forest parameters in the documents for inclusion in this report. The parameters identified for sub-areas in this report can be obtained through a range of observations methods and models. The results of the prioritization of parameters are discussed following the description of the individual sub-area results.

The identified parameters are similar across the forest sub-areas, although the documents discuss certain parameters in greater detail for individual sub-areas. For example, documents in all three sub-areas included the parameter of fuel type, though the use of fuel type as a parameter for fire risk modeling varies by region. Documents addressing Timber, Fuel, and Fiber or Carbon and Biomass included fuel type for understanding fire risk, while documents addressing Forest Perturbations and Protection addressed detailed modeling of fire risk and prediction of fire behavior, and described detailed distinctions of woody, grass, and litter fuel types.

The two reports completed for the Ecosystems SBA under GEO Task US-09-01a also include parameters and sub-areas relevant to forests (e.g., Forests sub-area in the first Ecosystems SBA report, and Tundra sub-area in the second Ecosystems SBA report). Parameters identified for forest and tundra ecosystems are generally used for understanding of ecosystem health, function, and response to stressors on fairly short temporal and small spatial scales, and users of ecosystem observations are likely to be concerned with specific research questions in a local ecosystem. Through the user-defined applications, documents, and sub-areas considered in this analysis, the Analyst identified lists of parameters that are significantly different from those that emerged from the ecosystems analysis. The parameters identified in the three forests sub-areas in this report are focused on forest management, forest protection, and forest change on relatively long temporal and large spatial scales.

Tables 4-6 list the parameters that the Analyst identified in the documents which are relevant to the three forests sub-areas, by observation category, with no priority order. In general, the observation parameters are similar across forest types and latitudes. The parameters pertain to the categories of land cover, forest status, fire, disturbance, biomass, environment (such as meteorological factors and surroundings), and calculations (e.g., parameters used for validation and calibration of remote sensing observations). The tables are comprehensive in capturing the needs identified, explicitly or implicitly, in the documents or by the Advisory Group members. The Analyst did not constrain the parameter needs by concerns about available technology or data management issues. The tables list all of the information about the parameters that the documents or Advisory Group specified.

In the tables (4-6) of parameters, the Analyst listed parameter characteristics available in the documents. Where the documents included information about parameter needs, the Analyst 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 recorded spatial resolution as specific numbers if available in the documents. If only qualitative descriptions were listed, the Analyst 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 recorded temporal resolution quantitatively, if specified, but more frequently this

parameter characteristic was recorded as hourly, daily, weekly, or monthly. If the documents described a parameter being used at different resolutions for multiple applications, the Analyst recorded the finer spatial resolution or the more frequent temporal observation requirement.

The documents rarely mentioned accuracy of parameters or needs for future improvements in accuracy. Discussion of accuracy typically appeared in the documents in the context of modeling or mapping efforts based on a set of parameters. For example, a typical source document did not describe the accuracy needs for land cover observations, but might have discussed the need for ground-truthed sub-pixel land cover classifications for validation. Therefore, the Tables 4-6 list needs for parameter accuracy in the "other" column only when the documents list accuracy as a specific concern.

The spatial scales for some derived parameters, such as carbon stocks, 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 *in situ* information to develop sub-pixel parameters. The Advisory Group noted that resolution as fine as 2 m is needed to obtain a "many pixels per tree" model, where, for example, the fine resolution observations are useful to understand texture. With spatial resolution of 2-30 m, models can represent "many trees per pixel and many pixels per stand," and different pixel sizes within the range will provide similar results. With pixels larger than about 30 m, forest models are more suited to "many stands per pixel," which are less suited to identifying stand level differences in managed forests.

The majority of the documents identify longer-term monitoring needs for forests; annual temporal resolution is common. As such, the documents do not mention latency of data availability as a common concern. Observations of quickly evolving events such as fires and insect outbreaks are the exception for which data users require near real-time data. Therefore, Tables 4-6 show latency of data availability in the "other" column only when it was identified as a concern.

4.1 Earth Observations for Timber, Fuel, and Fiber Management

The parameters that the Analyst identified in the documents for Timber, Fuel, and Fiber Management include many parameters in the categories of land cover, forest status, and disturbance. For this sub-area, many of the documents are focused on understanding of forest change on large and small scales. Common topics in the documents were prediction of anthropogenic impacts, natural impacts, and recovery and response. Human factors such as land use practices (e.g., managed logging, cultivation patterns, fire management plans) were often mentioned in the documents for forest management. Such human factors can be partly understood through Earth observations, but also require socioeconomic and policy information. For example, remote sensing observations can be used to detect patterns in the canopy indicating trees planted in rows, or gaps that indicate selective logging. Additional information would be required to understand the extent of practices detected by remote sensing, whether they are sanctioned or illegal, and whether they are likely to change. The list of parameter needs for Timber, Fuel, and Fiber Management is given in Table 4.

Table 4. Earth Observation Parameters for Timber, Fuel, and Fiber Management

GEO Task US-09-01a: Earth Observations for Forests: Timber, Fuel and Fiber Management					
Observation Category	**Parameter**	**Characteristics of the Observation Parameters**			
		Coverage/ Extent	**Spatial**	**Temporal**	**Other**
Land cover	Forest Area, Forest Area Change	Local to Global	<5m for validation, 10-60m for monitoring, 250-1000m for large-scale monitoring	Seasonal to Annual	Need multiple observations/ year, specific to location (e.g., wet/dry season, spring/summer
	Infrastructure (human settlements, roads, logging infrastructure)	Local	5-250m	Seasonal to Annual	
	Land Cover, Land Cover Change	Local to Global	<1m for validation, 10-60m for monitoring, 250-1000m for large-scale monitoring	Seasonal to Multi-Year	Need long term datasets as well as near real-time for some applications
	Land Cover Type or Classification (Forest, Other Wooded, Grass/Herbaceous, Wetlands, Agricultural, Developed, Bare Land, Water, Other Land)	Local to Global	250m	Annual	Need 90% accuracy
	Afforestation/Reforestation	Local to Regional	<30m	Annual	
	Vegetation (cover, type)	Local to Global	Not indicated	Seasonal to Annual	
Forest Status	Canopy cover, Canopy Density	Local to Regional	5m to 250m	Annual	Need 5% accuracy
	Forest Type (heterogeneity, local variation)	Local to Regional	250m	Multi-Year	
	Forest Use (forest management practices)	Local to Regional	1000m	Annual	
	Photosynthetically active radiation (PAR, fPAR)	Local	Not indicated	Daily to Weekly	
	Growing season (length)	Local	1000m	Annual	
	Leaf Area Index (LAI)	Local	30m	Weekly	
	Leaf longevity, duration, vegetation seasonality	Local	250m	Multi-Year	
	Leaf Type	Local	Not indicated	Multi-Year	
	Net Primary	Local	Not indicated	Annual	

GEO Task US-09-01a: Earth Observations for Forests: Timber, Fuel and Fiber Management					
Observation Category	**Parameter**	**Characteristics of the Observation Parameters**			
		Coverage/ Extent	**Spatial**	**Temporal**	**Other**
	Nutrients (content, fluxes, distribution)	Local to Regional	Not indicated	Seasonal	
	Phenology	Local to Regional	Not indicated	Seasonal to Multi-Year	
	Soil Moisture	Local to Regional	250m	Not indicated	
	Species Composition	Local to Regional	30m	Not indicated	
	Stand Density	Local	30m	Not indicated	
	Vegetation Indices (NDVI, SAVI, EVI)	Not indicated	Not indicated	Not indicated	
Fire	Burned Area	Local to Regional	30m or finer	Monthly-Annual	
	Fire Frequency	Not indicated	Not indicated	Annual	
	Fuel Types	Not indicated	Not indicated	Multi-Year	
	Active Fires	Local to Regional	Not indicated	Daily	
Disturbance	Deforestation	Local, National, Regional	<5m for validation, 10-60m for monitoring, 250m for monitoring	Seasonal	
	Degradation	Local	<5m for validation, 10-60m for monitoring	Annual	
	Fragmentation	Local to Regional	250-1000m	Seasonal to Multi-Year	
	Canopy Damage	Local	30-60m	Seasonal	
	Harvest Rate	Local	Not indicated	Annual	
	Flood (extent, duration)	Local to Regional	Not indicated	Daily to Weekly	
	Drought (extent, duration)	Local to Regional	Not indicated	Daily to Weekly	
	Insects (presence, extent, infestation)	Local to Regional	Not indicated	Daily to Multi-Year	
	Disease (presence, extent)	Local to Regional	Not indicated	Weekly to Multi-Year	
Biomass	Biomass (above ground); Stem Volume	Local-regional	<30m	Annual	

GEO Task US-09-01a: Earth Observations for Forests: Timber, Fuel and Fiber Management					
Observation Category	**Parameter**	**Characteristics of the Observation Parameters**			
		Coverage/ Extent	**Spatial**	**Temporal**	**Other**
Calculation	Atmospheric Correction	Local to Global	Parallel to land cover observation	Parallel to land cover observation	
	Cloud Cover	Parallel to land cover observation	Parallel to land cover observation	Parallel to land cover observation	
	Elevation	Local	Not indicated	Multi-Year	
Environment	Precipitation	Local to Regional	Not indicated	Daily to Annual	
	Temperature	Local to Regional	Not indicated	Daily to Annual	
	Water (Soils)	Local	Not indicated	Not indicated	

4.2 Earth Observations for Forest Perturbations and Protection

The parameters that the Analyst identified in the documents for Forest Perturbations and Protection include many parameters in the categories of land cover, forest status, fire, disturbance, biomass, environment, and calculation. The documents in this sub-area were related to fire threats; insect and disease impacts; climate and long-term change; and monitoring of protected areas. Parameters are relevant to both ground-based monitoring (e.g., observations of insect range and of forest use management practices) and to remote-sensing observations to extend ground-based information (e.g., vegetation indices to monitor changes in insect range, and land cover observations to extend monitoring of changes in forest management status). The list of parameter needs for Forest Perturbations and Protection is given in Table 5.

Table 5. Earth Observation Parameters for Forest Perturbations and Protection

GEO Task US-09-01a: Earth Observations for Forests: Forest Perturbations and Protection					
Observation Category	**Parameter**	**Characteristics of the Observation Parameters**			
		Coverage/ Extent	**Spatial**	**Temporal**	**Other**
Land cover	Forest Area, Forest Area Change	Local to Global	<5m for validation, 10-60m for monitoring, 250-1000m for large-scale monitoring	Seasonal to Annual	Need wet/dry season over multiple years
	Infrastructure (human settlements, roads, logging infrastructure)	Local	Not indicated	Seasonal to Annual	
	Land Cover, Land Cover Change	Local to Global	<1m for validation, 10-60m for monitoring, 250-1000m for large-scale monitoring	Seasonal to Multi-Year	Need long term datasets as well as near real-time for some applications
	Land Cover Type or Land Cover Use Classification, including Human Dimensions (Forest, Other Wooded, Grass/Herbaceous,	Local to Global	250m	Annual	
	Afforestation/Reforestation	Local to Regional	<30m	Annual	
	Vegetation (cover, type)	Local to Global	Not indicated	Seasonal to Annual	
	Snow and Ice	Local	Not indicated	Seasonal	
Forest Status	Canopy Cover, Canopy Density	Local to Regional	5m to 250m	Annual	Need 5% accuracy

GEO Task US-09-01a: Earth Observations for Forests: Forest Perturbations and Protection					
Observation Category	**Parameter**	**Characteristics of the Observation Parameters**			
		Coverage/ Extent	**Spatial**	**Temporal**	**Other**
	Forest Type (heterogeneity, local variation)	Local to Regional	250m	Multi-Year	
	Forest Use (forest management practices)	Local to Regional	1000m	Annual	
	Photosynthetically active radiation (PAR, fPAR)	Local	Not indicated	Daily to Weekly	
	Growing season (length)	Local to Regional	1000m	Annual	
	Habitat Status, Trends	Local to Regional	<50m	Not indicated	
	Invasive Species	Local to Regional	Not indicated	Seasonal to Multi-Year	
	Leaf Area Index (LAI)	Local	5m	Weekly	
	Leaf longevity, duration, vegetation seasonality	Local	250m	Multi-Year	
	Leaf Type	Local	Not indicated	Multi-Year	
	Net Primary Productivity	Local	Not indicated	Annual	
	Nutrients (content, fluxes, distribution)	Local to Regional	Not indicated	Seasonal	
	Phenology	Local to Regional	250m-1000m	Seasonal to Multi-Year	
	Soil Moisture	Local to Regional	250m	Not indicated	Need near real-time
	Species Composition, Biodiversity	Local to Regional	30m	Not indicated	
	Stand Density	Local to Regional	30m	Not indicated	
	Stand Height	Local	Not indicated	Not indicated	
	Vegetation Indices (NDVI, SAVI, EVI)	Local	Not indicated	Not indicated	
	Vegetation Structure	Not indicated	Not indicated	Not indicated	
Fire	Burned Area	Local to Regional	30m or finer, 250m-1000m for large-scale monitoring	Monthly-Annual	
	Fire Frequency	Local to Regional	Not indicated	Annual	
	Fuel Types, Fuel Composition (woody, grass, litter)	Local	Not indicated	Multi-Year	

GEO Task US-09-01a: Earth Observations for Forests: Forest Perturbations and Protection					
Observation Category	**Parameter**	**Characteristics of the Observation Parameters**			
		Coverage/ Extent	**Spatial**	**Temporal**	**Other**
	Fuel Moisture Content	Local	Not indicated	Daily to Weekly	Need near real-time
	Fuel Loading (g/m2)	Local	Not indicated	Seasonal to Multi-Year	
	Active Fires	Local to Regional	Not indicated	Multiple observations per day	
	Fire Intensity/Burn Intensity/ Fire Radiative	Local	1km or finer	Daily	
	Combustion Factor (g/g, biomass consumed)	Local to Regional	Not indicated	Multi-Year	
	Emission Factor (g/g, emissions per burned	Local to Regional	Not indicated	Multi-Year	
Disturbance	Deforestation	Local, National, Regional	<5m for validation, 10-60m for monitoring, 250m for monitoring	Seasonal	Need data within <3 months to restrict illegal activities
	Degradation	Local	<5m for validation, 10-60m for monitoring	Annual	
	Fragmentation, Clearings	Local to Regional	10-30m	Seasonal to Multi-Year	
	Canopy Damage	Local	30-60m	Seasonal	
	Harvest Rate	Local to Regional	Not indicated	Annual	
	Flood (extent, duration), Flooded Forest	Local to Regional	250m	Daily to Weekly	
	Drought (extent, duration)	Local to Regional	Not indicated	Daily to Weekly	
	Insects (presence, extent)	Local to Regional	Not indicated	Daily to Multi-Year	
	Disease (presence, extent)	Local to Regional	Not indicated	Weekly to Multi-Year	
	Urbanization	Local to Regional	Not indicated	5-10 years	
Biomass	Biomass (above ground); Stem volume	Local-regional	<30m	Annual	
	Carbon Emissions (net)	Not	Not indicated	Not	

GEO Task US-09-01a: Earth Observations for Forests: Forest Perturbations and Protection					
Observation Category	**Parameter**	**Characteristics of the Observation Parameters**			
		Coverage/ Extent	**Spatial**	**Temporal**	**Other**
	Carbon Stocks (soil, vegetation)	Not indicated	Not indicated	Not indicated	
	Carbon Stocks (change)	Not indicated	Not indicated	Not indicated	
Calculation	Atmospheric Correction	Local to Global	Parallel to land cover observation	Parallel to land cover observation	
	Cloud Cover	Local to Global	Parallel to land cover observation	Parallel to land cover observation	
	Elevation	Local	Not indicated	Multi-Year	
	Water (Soils)	Local to Global	Parallel to land cover observation	Parallel to land cover observation	
Environment	Precipitation	Local to Regional	Not indicated	Not indicated	
	Temperature	Local to Regional	Not indicated	Not indicated	
	Relative Humidity	Not indicated	Not indicated	Not indicated	
	Water (Surface water presence and extent)	Local	Not indicated	Not indicated	
	Wind	Local	Not indicated	Not indicated	

4.3 Earth Observations for Carbon and Biomass

The parameters that the Analyst identified in the documents for Carbon and Biomass include many parameters in the categories of land cover, fire, forest status, biomass, and disturbance. In recent years, researchers, land managers, and policy makers have increased efforts to quantify and monitor the carbon and biomass in forests. The Analyst noticed two main foci of parameters in the documents in this sub-area: quantification of forest cover and forest cover change, and quantification of carbon stocks and cycles. Many of the parameters that appeared in the documents in this sub-area are related to fires and the need to quantify emissions to understand carbon cycles. The parameters for this sub-area are listed in Table 6.

Table 6. Earth Observation Parameters for Carbon and Biomass

GEO Task US-09-01a: Earth Observations for Forests: Carbon and Biomass					
Observation Category	**Parameter**	**Characteristics of the Observation Parameters**			
		Coverage/ Extent	**Spatial**	**Temporal**	**Other**
Land cover	Forest Area, Forest Area Change	Local to Global	<5m for validation, 10-60m for monitoring, 250-1000m for large-scale monitoring	Seasonal to Annual	Need wet/dry season over multiple years
	Infrastructure (human settlements, roads, logging infrastructure)	Local	Not indicated	Seasonal to Annual	
	Land Cover, Land Cover Change	Local to Global	<1m for validation, 10-60m for monitoring, 250-1000m for large-scale monitoring	Seasonal to Multi-Year	Need long term datasets as well as near real-time for some applications
	Land Cover Type or Land Cover Use Classification, including Human Dimensions (Forest, Other Wooded, Grass/Herbaceous,	Local to Global	250m	Annual	
	Afforestation/Reforestation	Local to Regional	<30m	Annual	
	Vegetation (cover, type)	Local to Global	Not indicated	Seasonal to Annual	
	Snow and Ice	Local	Not indicated	Seasonal	
Forest Status	Canopy Cover, Canopy Density	Local to Regional	5m to 250m	Annual	Need 5% accuracy
	Forest Type (heterogeneity, local variation)	Local to Regional	250m	Multi-Year	
	Forest Use (forest management practices)	Local to Regional	1000m	Annual	
	Photosynthetically active radiation (PAR, fPAR)	Local	Not indicated	Daily to Weekly	
	Growing season (length)	Local to Regional	1000m	Annual	
	Leaf Area Index (LAI)	Local	5m	Weekly	
	Leaf longevity, duration, vegetation seasonality	Local	250m	Multi-Year	

GEO Task US-09-01a: Earth Observations for Forests: Carbon and Biomass					
Observation Category	**Parameter**	**Characteristics of the Observation Parameters**			
		Coverage/ Extent	**Spatial**	**Temporal**	**Other**
	Leaf Type	Local	Not indicated	Multi-Year	
	Net Primary Productivity	Local	Not indicated	Annual	
	Nutrients (content, fluxes, distribution)	Local to Regional	Not indicated	Seasonal	
	Soil Moisture	Local to Regional	250m	Not indicated	
	Species Composition, Biodiversity	Local to Regional	30m	Not indicated	
	Stand Density	Local to Regional	30m	Not indicated	
	Stand Height	Local	Not indicated	Not indicated	
	Vegetation Indices (NDVI, SAVI, EVI)	Local	Not indicated	Not indicated	
	Vegetation Structure		Not indicated	Not indicated	
Fire	Burned Area	Local to Regional	30m or finer, 250m-1000m for large-scale monitoring	Monthly-Annual	
	Fire Frequency	Local to Regional	Not indicated	Annual	
	Fuel Types, Fuel Composition (woody, grass, litter)	Local	Not indicated	Multi-Year	
	Fuel Moisture Content	Local	Not indicated	Daily to Weekly	
	Fuel Loading (g/m2)	Local	Not indicated	Seasonal to Multi-Year	
	Active Fires	Local to Regional	Not indicated	Daily	
	Fire Intensity/Burn Intensity/ Fire Radiative	Local	1km	Daily	
	Combustion Factor (g/g, biomass consumed)	Local to Regional	Not indicated	Multi-Year	
	Emission Factor (g/g, emissions per burned	Local to Regional	Not indicated	Multi-Year	
	Emissions (gas, aerosol)	Local	Not indicated	Daily	
Disturbance	Deforestation	Local, National, Regional	<5m for validation, 10-60m for monitoring, 250m for monitoring	Seasonal	Need data within <3 months to restrict illegal activities

GEO Task US-09-01a: Earth Observations for Forests: Carbon and Biomass					
Observation Category	**Parameter**	**Characteristics of the Observation Parameters**			
		Coverage/ Extent	**Spatial**	**Temporal**	**Other**
	Degradation	Local	<5m for validation, 10-60m for monitoring	Annual	
	Fragmentation, Clearings, Land Disturbance	Local to Regional	250-1000m	Seasonal to Multi-Year	
	Canopy Damage	Local	30-60m	Seasonal	
	Harvest Rate	Local to Regional	Not indicated	Annual	
	Flood (extent, duration), Flooded Forest	Local to Regional	250m	Daily to Weekly	
Biomass	Biomass (above ground); Stem volume	Local	<30m	Annual	
	Carbon Emissions (net)	Local to Regional	Not indicated	Annual	
	Carbon Stocks (soil organic matter, aboveground vegetation, belowground biomass, dead wood, harvested wood, litter)	Local to Regional	Not indicated	5 Years	Need soil carbon to 30cm depth
	Carbon Stocks (change)	Local to Regional	Not indicated	5 Years	Need 2% accuracy
Calculation	Atmospheric Correction	Local to Global	Parallel to land cover observation	Parallel to land cover observation	
	Cloud Cover	Local to Global	Parallel to land cover observation	Parallel to land cover observation	
	Water (Soils)	Local to Global	Parallel to land cover observation	Parallel to land cover observation	
Environment	Precipitation	Local to Regional	Not indicated	Not indicated	
	Temperature	Local to Regional	Not indicated	Not indicated	
	Topography	Local	Not indicated	Multi-Year	

5 Priority Earth Observations for Forests

Following the initial weighting procedure (Steps 1 and 2 of the method described in Section 2.3.3), the results were reviewed by the Advisory Group to identify any important gaps in parameters of high priority. Consensus was reached by the Advisory Group on the high priority parameters to include in this report. The overall weighting and ranking of parameters is included in Appendix C.

5.1 Summary of Results

Table 7 lists the ranking of parameters that emerged from the first two steps of prioritization.

Table 7. Ranking of parameters by number of relevant sub-areas and consensus document recommendation

Parameter*	Step 2 Rank
Active Fires	6
Afforestation/Reforestation	6
Canopy Damage	6
Deforestation	6
Degradation	6
Flood (extent, duration), Flooded Forest	6
Forest Area, Forest Area Change	6
Forest Type (heterogeneity, local variation)	6
Forest Use (forest management practices)	6
Fragmentation, Clearings, Land Disturbance	6
Infrastructure (human settlements, roads, logging infrastructure)	6
Land Cover Type or Land Cover Use Classification, including Human Dimensions (Forest, Other Wooded, Grass/Herbaceous, Wetlands, Agricultural, Developed, Bare Land, Water, Other Land)	6
Land Cover, Land Cover Change	6
Species Composition, Biodiversity	6
Topography	6
Vegetation (cover, type)	6
Carbon Emissions (net)	4
Carbon Stocks (change)	4
Carbon Stocks (soil organic matter, aboveground vegetation, belowground biomass, dead wood, harvested wood, litter)	4
Combustion Factor (g/g, biomass consumed)	4
Disease (presence, extent)	4
Emission Factor (g/g, emissions per burned mass)	4
Fire Intensity/Burn Intensity/ Fire Radiative Power	4
Fuel Loading (g/m2)	4
Insects (presence, extent)	4
Atmospheric Correction	3
Biomass (above ground); Stem volume	3

Parameter*	Step 2 Rank
Burned Area	3
Canopy Cover, Canopy Density	3
Cloud Cover	3
Fire Frequency	3
Fuel Types, Fuel Composition (woody, grass, litter)	3
Growing season (length)	3
Harvest Rate	3
Leaf Area Index (LAI)	3
Leaf longevity, duration, vegetation seasonality	3
Leaf Type	3
Net Primary Productivity (NPP)	3
Nutrients (content, fluxes, distribution)	3
Photosynthetically active radiation (PAR, fPAR)	3
Precipitation	3
Soil Moisture	3
Stand Density	3
Temperature	3
Vegetation Indices (NDVI, SAVI, EVI)	3
Water (Soil water table)	3
Drought (extent, duration)	2
Emissions (gas, aerosol)	2
Fuel Moisture Content	2
Habitat Status, Trends	2
Invasive Species	2
Phenology	2
Snow and Ice	2
Stand Height	2
Urbanization	2
Vegetation Structure	2
Relative Humidity	1
Water (Surface water presence and extent)	1
Wind	1

* Parameters are listed alphabetically within tied ranks.

Based on the prioritization process outlined in Section 2.3.3 and Table 2, the Analyst ranked the forest parameters across all three sub-topics. The parameters with a final score greater than 3 are listed in Table 8, together with their rank scores. The Analyst determined that priority parameters were those with scores greater than 3, because all but one of the parameters suggested for prioritization by the Advisory Group had a score greater than 3. The exception is noted below. The full prioritized list is given in Appendix C.

One parameter identified as a priority by the Advisory Group was not included in Table 8. Wind was identified by one Advisory Group member as a very high priority parameter for fire monitoring and prediction. (Wildfires were addressed as a sub-area of disasters in the second Disasters SBA report for GEO Task US-09-01a). Because wind was applicable to only one sub-

area considered in this report (score 1), not explicitly recommended by the consensus documents considered in this review (weight 1), and explicitly recommended by only one Advisory Group member (weight 1.5), its final score in the parameterization was 1.5. Therefore, the Analyst did not consider it to be a critical observation priority for forests.

Table 8. Results of Prioritization of Forest Parameters

Prioritized List of Forest Parameters	
Afforestation/Reforestation	9
Degradation	9
Forest Area, Forest Area Change	9
Land Cover, Land Cover Change	9
Carbon Stocks (soil organic matter, aboveground vegetation, below ground biomass, dead wood, harvested wood, litter)	7
Fire Intensity/Burn Intensity/ Fire Radiative Power	7
Biomass (above ground); Stem volume	7
Active Fires	6
Canopy Damage	6
Carbon Emissions (net)	6
Carbon Stocks (change)	6
Deforestation	6
Flood (extent, duration), Flooded Forest	6
Forest Type (heterogeneity, local variation)	6
Forest Use (forest management practices)	6
Fragmentation, Clearings, Land Disturbance	6
Fuel Loading (g/m2)	6
Infrastructure (human settlements, roads, logging infrastructure)	6
Land Cover Type or Land Cover Use Classification	6
Species Composition, Biodiversity	6
Vegetation (cover, type)	6
Burned Area	5.25
Canopy Cover, Canopy Density	4.5
Fire Frequency	4.5
Soil Moisture	4.5
Combustion Factor (g/g, biomass consumed)	4
Disease (presence, extent)	4
Emission Factor (g/g, emissions per burned mass)	4
Insects (presence, extent)	4
Forest structure, Vegetation structure	4
Stand Height	3.5

5.2 Final List of Priority Observations and Advisory Group Feedback

The Analyst gathered feedback from the Advisory Group on the analytical methods used to determine the priority observations for forests. The Analyst used the feedback from the Advisory Group to develop a shorter list of recommended priority parameters as verification of the prioritization process. The parameters that received the strongest recommendations from Advisory Group members, and are therefore considered the most critical Earth observation needs for forests, are shown in Table 9.

Table 9. Most Critical Earth Observation Needs for Forests

Priority Needs (Approximate Priority Order, Most Important First)
Land Cover, Land Cover Change
Forest Area, Forest Area Change
Degradation
Afforestation/Reforestation
Carbon Stocks (soil organic matter, aboveground vegetation, belowground biomass, dead wood, harvested wood, litter)
Fire Intensity/Burn Intensity/Fire Radiative Power
Stand Height
Biomass (above ground); Stem Volume
Burned Area

All of these parameters were strongly recommended by multiple Advisory Group members. With the exception of burned area (final rank score of 5.25), this brief list represents the parameters with a final rank score of 7 or greater.

In addition to the parameters the Analyst identified in the documents, the Advisory Group members recommended several additional parameters. Stem volume was recommended as a new parameter by one Advisory Group member, and the Analyst added stem volume to biomass (above ground). Biomass (below ground) was recommended by another Advisory Group member, but the Analyst considered that parameter to be part of carbon stocks (soil organic matter, aboveground vegetation, belowground biomass, dead wood, harvested wood, litter), and made no changes to the final list of priority observations.

A number of these priority parameters are highly interrelated. For example, Land cover/Land cover change and Forest area/Forest area change are very similar in purpose and method of observation. The Analyst maintained separate listings for these parameters to capture end user language, and also because the parameters are often used in different contexts in the documents.

One of the Advisory Group members recommended that the parameters be prioritized according to their applicability for national-scale and global-scale uses (including national use in international environmental agreements). The Analyst determined that the parameters applicable

on a global scale were well-represented in the final list of priority parameters, and thus, the Analyst did not further weight the parameters as recommended.

One Advisory Group member noted that all the SBAs are interrelated, with multiple complex feedbacks. To meet critical Earth observation needs for forest end users, there is a need for strong linkages with climate and weather priorities, particularly in order to give managers and policy makers early warning of impending events, such as fires. With respect to forest fire, the Advisory Group member noted that early warning might be of little use in countries unable to manage future forest fire planning, but in the long term it would be good to have monitoring systems and infrastructure/protocols in place to minimize the crisis management aspect of fire management.

One Advisory Group member commented on measurement technology, which is beyond the scope of GEO Task US-09-01a. Their comments are summarized as follows, for completeness sake. The Advisory Group member noted that there are only a few dimensions of information in optical satellite data (information related to tree size, species composition, and various types of changes, when multitemporal data are compared). This Advisory Group member noted that the most important variable for the forestry sector is stem volume, and that spatially explicit maps of national forest resource are needed (with total stem volume being the most important variable in the maps). Such applications require:

- A secure, long-term supply of optical satellite data,
- Large scenes (ideally 200 ×200 km or more),
- Inclusion of the mid-infrared band, which in the boreal region is best correlated with biomass and stem volume, and
- Pixel sizes in the order of 1-30 m, depending on the application.

The Advisory Group member summarized that there is a need for world-wide cooperation to obtain continuity of 1-30 m resolution of scenes on the order of 200 km square, including the mid-infrared band. In addition, the Advisory Group member noted that techniques should be developed to obtain better biomass estimates, possibly from promising 3-D techniques.

6 Additional Findings

This section discusses additional findings and general comments from Advisory Group members. 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. Forest 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 forests on a larger scale, tracking of global changes, and identification of impacts.

Across regions, forest 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 internally consistent products, and consistency of data availability
- Finer temporal and spatial resolution
- Model integration.

Each of these needs is detailed below.

Improved correlations between remote sensing and ground-based data sets:
The documents noted that links between Earth observation data and field measurements must be established or improved in order for the forest 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 users to apply remotely sensed data. In other regions, correlation between in-situ observation and remote sensing data is in the research phase.

In some countries, such Finland and Sweden and parts of the United States, national forest inventory field sample plots are use to train remote sensing data to obtain large area forest estimates. For such applications, it is especially important that the satellite scenes used are large enough (unspecified quantitatively) to obtain many reference points per satellite scene.

There was a frequently expressed need in the documents for detailed ground-based measurements (location-specific case studies) to enable development of improved 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 forest 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, in order 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 documents and Advisory Group members agreed that validated, standardized maps are needed at high to moderate resolutions (see Table 4-6 for specifics) to monitor forests.

Long time series of data and consistency of data availability:

Several Advisory Group members and documents stressed the importance of long time series of internally-consistent data and consistent availability of data for forest 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 forest 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 are generally used for specific studies or specific questions, while long time series of moderate resolution data are used for observing larger-scale trends.

Finer temporal and spatial resolution:
The need for new observations with finer spatial and temporal resolution was stated in the documents, often without quantification or mention of specific parameters. The documents noted that certain dynamic phenomena, such as fires and flooding, require monitoring on timescales more frequent than daily to fully capture event evolution and understand forest impacts.

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 forest status and change. 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 forest changes on fine scales.

7 Analysts' Comments and Recommendations

As a whole, the Analyst found that the 9-step process worked very well for this topic area. A relatively large number of international and national organizations have addressed forest planning and the needs for forest observations. The Analyst found that the focus provided by the existing consensus documents from those organizations was essential to prioritizing the forest parameters in this report. In addition, the input of the Advisory Group members, most of whom have been involved with national and international forest planning activities, was invaluable. Often, the Analyst disregarded references in the documents to needs for specific technologies. Advisory Group members also had a number of recommendations for specific technologies which the Analyst did not include.

Throughout the process, the Analyst and team was required to start and stop work several times due to inconsistent funding for the Analyst. Such interruptions made it difficult to make steady progress and to maintain engagement of the Advisory Group. Despite this challenge, the Advisory Group was quite engaged.

Appendix A: Abbreviations/Acronyms

EVI: Enhanced Vegetation Index

FAO: Food and Agriculture Organization of the UN

GEO: Group on Earth Observations

GEOSS: Global Earth Observation System of Systems

GOFC-GOLD: Global Observation of Forest and Land Cover Dynamics

IPCC: Intergovernmental Panel on Climate Change

LAI: Leaf Area Index

NDVI: Normalized Difference Vegetation Index

PAR, fPAR: Photosynthetically Active Radiation, fraction of PAR

SAVI: Soil Adjusted Vegetation Index

SBA: Societal Benefit Area

UIC: User Interface Committee

UN: United Nations

UNFCCC: United Nations Framework Convention on Climate Change

Appendix B: References

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Appendix C: Parameter Prioritization

Table C-1: Parameters across all three sub-areas, ranked scores emerging from prioritization step 2, number of Advisory Group members recommending prioritization of the parameter, multiplier on the score, and final ranked score

Parameter	Step 2 Rank	# of AG recs*	Multiplier	Final score
Active Fires	6		1	6
Afforestation/Reforestation	6	1	1.5	9
Canopy Damage	6		1	6
Deforestation	6		1	6
Degradation	6	1	1.5	9
Flood (extent, duration), Flooded Forest	6		1	6
Forest Area, Forest Area Change	6	1	1.5	9
Forest Type (heterogeneity, local variation)	6		1	6
Forest Use (forest management practices)	6		1	6
Fragmentation, Clearings, Land Disturbance	6		1	6
Infrastructure (human settlements, roads, logging infrastructure)	6		1	6
Land Cover Type or Land Cover Use Classification, including Human Dimensions (Forest, Other Wooded, Grass/Herbaceous, Wetlands, Agricultural, Developed, Bare Land, Water, Other Land)	6		1	6
Land Cover, Land Cover Change	6	1	1.5	9
Species Composition, Biodiversity	6		1	6
Topography	6		0.25	1.5
Vegetation (cover, type)	6		1	6
Carbon Emissions (net)	4	1	1.5	6
Carbon Stocks (change)	4	1	1.5	6
Carbon Stocks (soil organic matter, aboveground vegetation, belowground biomass, dead wood, harvested wood, litter)	4	2	1.75	7
Combustion Factor (g/g, biomass consumed)	4		1	4
Disease (presence, extent)	4		1	4
Emission Factor (g/g, emissions per burned mass)	4		1	4
Fire Intensity/Burn Intensity/ Fire	4	2	1.75	7

Parameter	Step 2 Rank	# of AG recs*	Multiplier	Final score
Radiative Power				
Fuel Loading (g/m2)	4	1	1.5	6
Insects (presence, extent)	4		1	4
Atmospheric Correction	3		1	3
Biomass (above ground); Stem volume	3	3	2	6
Burned Area	3	2	1.75	5.25
Canopy Cover, Canopy Density	3	1	1.5	4.5
Cloud Cover	3		1	3
Fire Frequency	3	1	1.5	4.5
Fuel Types, Fuel Composition (woody, grass, litter)	3		1	3
Growing season (length)	3		1	3
Harvest Rate	3		1	3
Leaf Area Index (LAI)	3		0.5	1.5
Leaf longevity, duration, vegetation seasonality	3		1	3
Leaf Type	3		1	3
Net Primary Productivity (NPP)	3		1	3
Nutrients (content, fluxes, distribution)	3		1	3
Photosynthetically active radiation (PAR, fPAR)	3		1	3
Precipitation	3		1	3
Soil Moisture	3	1	1.5	4.5
Stand Density	3		1	3
Temperature	3		1	3
Vegetation Indices (NDVI, SAVI, EVI)	3		1	3
Water (Soil water table)	3		1	3
Drought (extent, duration)	2		1	2
Emissions (gas, aerosol)	2		1	2
Fuel Moisture Content	2	1	1.5	3
Habitat Status, Trends	2		1	2
Invasive Species	2		1	2
Phenology	2		1	2
Snow and Ice	2		1	2
Stand Height	2	2	1.75	3.5
Urbanization	2		1	2
Vegetation Structure	2	3	2	4
Relative Humidity	1	1	1.5	1.5
Water (Surface water presence and extent)	1		1	1
Wind	1	1	1.5	1.5

*number of Advisory Group members recommending the parameter

Table C-2: Parameters across all three sub-areas, most to least important

Parameter	Final score
Afforestation/Reforestation	9
Degradation	9
Forest Area, Forest Area Change	9
Land Cover, Land Cover Change	9
Carbon Stocks (soil organic matter, aboveground vegetation, belowground biomass, dead wood, harvested wood, litter)	7
Fire Intensity/Burn Intensity/ Fire Radiative Power	7
Active Fires	6
Canopy Damage	6
Deforestation	6
Flood (extent, duration), Flooded Forest	6
Forest Type (heterogeneity, local variation)	6
Forest Use (forest management practices)	6
Fragmentation, Clearings, Land Disturbance	6
Infrastructure (human settlements, roads, logging infrastructure)	6
Land Cover Type or Land Cover Use Classification, including Human Dimensions (Forest, Other Wooded, Grass/Herbaceous, Wetlands, Agricultural, Developed, Bare Land, Water, Other Land)	6
Species Composition, Biodiversity	6
Vegetation (cover, type)	6
Carbon Emissions (net)	6
Carbon Stocks (change)	6
Fuel Loading (g/m2)	6
Biomass (above ground); Stem volume	6
Burned Area	5.25
Canopy Cover, Canopy Density	4.5
Fire Frequency	4.5
Soil Moisture	4.5
Combustion Factor (g/g, biomass consumed)	4
Disease (presence, extent)	4
Emission Factor (g/g, emissions per burned mass)	4
Insects (presence, extent)	4
Vegetation Structure	4
Stand Height	3.5
Atmospheric Correction	3
Cloud Cover	3
Fuel Types, Fuel Composition (woody, grass, litter)	3
Growing season (length)	3

Parameter	Final score
Harvest Rate	3
Leaf longevity, duration, vegetation seasonality	3
Leaf Type	3
Net Primary Productivity (NPP)	3
Nutrients (content, fluxes, distribution)	3
Photosynthetically active radiation (PAR, fPAR)	3
Precipitation	3
Stand Density	3
Temperature	3
Vegetation Indices (NDVI, SAVI, EVI)	3
Water (Soil water table)	3
Fuel Moisture Content	3
Drought (extent, duration)	2
Emissions (gas, aerosol)	2
Habitat Status, Trends	2
Invasive Species	2
Phenology	2
Snow and Ice	2
Urbanization	2
Topography	1.5
Leaf Area Index (LAI)	1.5
Relative Humidity	1.5
Wind	1.5
Water (Surface water presence and extent)	1

Appendix D: Input to the Cross-SBA Analysis

At the conclusion of the individual SBA priority-setting analysis, the Agriculture Analyst provided input on the overall critical Earth observation parameters for the Agriculture SBA for inclusion in the Cross-SBA meta-analysis.[3] As a subset of the Agriculture SBA, a separate Analyst conducted an analysis of the critical Earth observation parameters for forests. The results of the Agriculture SBA - Forests sub-report were merged with the results of the Agriculture SBA analysis for the purposes of the Cross-SBA meta-analysis. The Agriculture SBA - Forests Analyst also specified a subset of priority observations from the Forests sub-analysis that were incorporated in the results of the Ecosystems SBA analysis.

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

The Agriculture SBA- Forests Analyst determined the overall critical Earth observation priorities for the Forests sub-area by using a weighted indexing method to rank the observations, as described in Section 2.3.3 and Chapter 5. Based on the results of the prioritization analysis, the 31 observations listed below have the highest rankings and thus are considered to be the observation priorities for the Agriculture SBA- Forests sub-area. The Agriculture SBA- Forests Analyst divided the 31 observations into three tiers representing “High,” “Medium,” and “Low” priority observations and designated the italicized “High” and “Medium” priority observations as the “15 Most Critical” observations for the Agriculture SBA-Forests sub-area. (Italicized observations were also included in Method 4, as explained below).

High
Afforestation/Reforestation
Degradation
Forest Area, Forest Area Change
Land Cover, Land Cover Change
Carbon Stocks (soil organic matter, aboveground vegetation, belowground biomass, dead wood, harvested wood, litter)
Fire Intensity/Burn Intensity/Fire Radiative Power
Active Fires
Biomass (above ground)
Canopy Damage

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

Carbon Emissions (net)

Medium
Carbon Stocks (change)
Deforestation
Flood (extent, duration), Flooded Forest
Forest Type (heterogeneity, local variation)
Forest Use (forest management practices)
Fragmentation, Clearings, Land Disturbance
Fuel Loading (g/m^2)
Infrastructure (human settlements, roads, logging infrastructure)
Land Cover Type or Land Cover Use Classification
Species Composition, Biodiversity

Low
Vegetation (cover, type)
Burned Area
Canopy Cover, Canopy Density
Fire Frequency
Soil Moisture
Combustion Factor (g/g, biomass consumed)
Disease (presence, extent)
Emission Factor (g/g, emissions per burned mass)
Insects (presence, extent)
Forest structure, Vegetation structure
Stand Height

The Agriculture SBA Analyst took the union of the 31 priority observations for the Agriculture SBA-Forests sub-area with the other Earth observation priorities for the Agriculture SBA, creating a single integrated list of observation priorities for the Cross-SBA analysis. Accounting for differences in observation terminology across the SBAs, the Agriculture SBA effectively contributed 61 observation parameters, listed below, to Methods 1-3 of the Cross-SBA analysis. The "High," "Medium," and "Low" priority designations for the observation parameters on the single combined list were based on the higher of the two individual rankings by the Agriculture SBA and Agriculture SBA-Forests Analysts.

Ambient Particulate Matter Concentration (fine)
Bathymetry
Biodiversity
Biomass
Burned Area/Fires
Carbon (stores, uptake, flux)
Carbon Dioxide Concentration
Column Nitrogen Dioxide Concentration
Column Particulate Matter Concentration (fine)
Crop Emergence
Crop Residue
Crop Yield
Cultivation Area
Deforestation
Desertification
Direct Normal Irradiation (DNI)
Ecosystem Function/Dynamics
Evaporation
Evapotranspiration
EVI
Floods
Forest Cover

Forest Litter
Forest management practices
Forest Structure
Fraction of Photosynthetically Active Radiation (fPAR)
Fraction of Absorbed Photosynthetically Active Radiation (FAPAR)
Fuel Load/Characteristics
Global Horizontal Irradiation (GHI)
Gross Primary Productivity
Hydrology
Impervious Surface Extent
Land Cover
Land Surface Temperature
Land Use
Leaf Area Index
NDVI
Net Primary Productivity (NPP)
Non-native species
Photosynthetically Active Radiation (PAR)
Population
Precipitation
SAVI
Soil Carbon
Soil Composition
Soil Moisture
Soil Thickness
Soil Type
Species Composition
Stand Density/Height/Volume
Surface Air Temperature
Surface Atmospheric Pressure
Surface Humidity
Surface Wind Direction
Surface Wind Speed
Upper Level Humidity
Upper Level Temperature
Upper Level Winds
Urbanization
Vegetation Cover
Vegetation Type

For Method 4 of the Cross-SBA analysis, the Agriculture, Forests, and Cross-SBA Analysts collectively prepared a combined list of the "15 Most Critical" observations based on the commonality across the "15 Most Critical" observation lists for the Agriculture SBA analysis and Agriculture SBA-Forests sub-analysis. Accounting for differences in observation terminology across the SBAs, the Agriculture SBA effectively contributed 35 observation parameters to Method 4 of the Cross-SBA analysis (similar to the number of observations contributed to Method 4 from other SBAs). The Agriculture SBA-Forests sub-report contributed the italicized "High" and "Medium" priority observations (listed previously) to the Agriculture SBA "15 Most Critical" observations.

The Cross-SBA Analyst also incorporated a subset of the priority observations from the Agriculture SBA-Forests sub-analysis, listed below, into the results of the Ecosystems SBA analysis. The Task Team included this step to reflect the overlap between the Agriculture and Ecosystems SBAs in the area of forests. The Agriculture SBA-Forests/ Ecosystems Analyst (the same person) selected the specific priority observations that were incorporated into the Ecosystems SBA results.

Forest Use (forest management practices)
Forest Structure
Forest Cover (listed as Forest Area/Forests Area Change in the Agriculture SBA-Forests list)
Urbanization (a sub-category of the observation parameter Degradation, in the Agriculture SBA-Forests list)
Vegetation (type)