2023 EARTH OBSERVATIONS ASSESSMENT REPORT: AGRICULTURE & FORESTRY

Product of the

SUBCOMMITTEE ON U.S. EARTH OBSERVATION

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About the Subcommittee on the United States Group on Earth Observations

The United States Group on Earth Observations (USGEO) is chartered as a Subcommittee of the NSTC Committee on Environment. The Subcommittee's purpose is to plan, assess, and coordinate Federal Earth observations, research, and activities; foster improved Earth system data management and interoperability; identify high-priority user needs for Earth observations data; and engage international stakeholders by formulating the United States' position for, and coordinating U.S. participation in, the intergovernmental Group on Earth Observations (GEO).

About this Document

In Agriculture & Forestry, societal benefits accrue from Earth observations measurements that can inform both short- and long-term decisions made by farmers, ranchers, foresters, research scientists, as well as watershed, natural resource, and land managers. Earth observations measurements of renewable resources and ecosystem conditions also support evidence-based decision-making by commodity markets, communities, and all levels of government. This report represents a summary of the societal benefit area elicitation results and associated findings. USGEO is making readily available, either through this report or through the online visualization services (https://usgeo.gov/eoa), those elements that are most valuable for agency and public analysis.

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Introduction

In Agriculture & Forestry, societal benefits accrue from Earth observations measurements that can inform both short- and long-term decisions made by farmers, ranchers, foresters, research scientists, as well as watershed, natural resource, and land managers (Figure 1). Land management decisions are complicated by dynamic and ongoing sources of disturbance, such as diseases, pests, climate extremes, as well as climate change and the conversion of natural land to other uses. Earth observations measurements of renewable resources and ecosystem conditions also support evidence-based decision-making within commodity markets, communities, and all levels of government. Accurate and timely (e.g., low latency) information derived from Earth-observing systems can help enhance food supplies, advance the productivity of renewable resources, improve ecosystem condition, and maximize our resilience to disasters and disturbance events. Measurements in this societal benefit area (SBA) improve the ability of farmers and foresters to meet the needs for human food, animal feed, fiber, biofuels, and forest products; support production decisions; and advance forecasting and risk analysis. Measurements in this SBA lead to reduced damages and inform risk from human and natural sources of disturbance including climate change, such as ecosystem degradation, wildfire, drought, flood, and storm events, as well as pests and invasive species. Research and improved data in this SBA can contribute to early warning systems for crop yield shortfalls and pest outbreaks; quantify the potential impact of climate change on the supply of renewable Agricultural & Forestry products; improve data to support the management of and response to disturbance and disaster events; and limit ecosystem degradation associated with agricultural, forestry, and grazing practices.

Summary of Key Takeaways

1. Support continuation of high-priority ecological measurements.
2. Strengthen international partnerships to facilitate and sustain data-sharing in the global land management community.
3. Improve access to and cost feasibility of processing Earth observations in commercial cloud- computing platforms.
4. Reduce data latency and improve data transfer from data providers to users to better support disaster risk and response.
5. Maintain and, as appropriate, expand contracts and agreements to provide access to commercial imagery.
6. Continue to improve terrestrial data quality masks and data documentation to enhance utilization of Earth observing data.
7. Sustain and expand field and in situ measurement networks in forest and agricultural systems.
8. Provide opportunities to facilitate the development of new technologies, products, and partnerships to better inform land management decision-making.

The sustained delivery of long-term Earth observations is critical to monitoring conditions over time and identifying changes and trends in ecosystem condition as is emphasized in the National Plan for Civil Earth Observations. Additionally, the development and support of new technologies is essential to address current data limitations. For example, developing sensors that can better characterize forest structure from ground to treetop at broad geographic extents will improve efforts to track forest attributes such as aboveground biomass, wildfire fuel loads, fuel moisture, and forested water resources. Enhancing the temporal, spatial, and spectral resolution of data sources will improve the accuracy and utility of data products. Further, reducing data latency will support the development of near real-time tools and data products improving preparedness for wildfires, floods, droughts, and risks and reductions in food supply.

Figure 1. ***Illustrating Sub-areas under the Agriculture & Forestry SBA.***

Follow-on Analysis

This report represents a summary of the SBA elicitation results and associated findings. The United States Group on Earth Observations (USGEO) is making readily available either through this report or through the online visualization services (https://usgeo.gov/eoa) those elements that are most valuable for agency and public analysis.

USGEO and the Earth Observations Assessment Working Group (EOA-AWG) will continue to mine the elicited data to derive additional insights, particularly to identify dependencies and chokepoints and obtain unique insights. Such information can further inform investment decisions at both agency and enterprise levels. Also, as additional SBA elicitations are completed over the coming years, USGEO and the AWG will be able to expand analyses beyond individual SBAs and assess across the entire network.

Assessment Results

Within the Agriculture & Forestry SBA, four sub-areas were identified representing the major thematic components. Table 1 shows example data sources including the 3D Elevation Program (3DEP), Land Change Monitoring, Assessment, and Projection (LCMAP), the National Land Cover Dataset (NLCD), the

National Cropland Data Layer (CDL), Landsat, and airborne lidar. Table 2 lists the included sub-areas and key objectives in this SBA.

Table 1. ***Table of value tree structure, descriptions, and example.***

Value Tree	Elements	Description	Example
Top	SBA	Societal Benefit Area	Agriculture & Forestry
	SBA Sub-Area	Natural thematic subdivisions of the parent SBA	Enhance Food Supply
	Key Objective (KO)	An activity within a sub-area that is clearly supported by and can be linked to Earth-observing systems, data, and products	Support forage assessment and management for animal production
	Key Product, Service, or Outcome (KPSO) Group	A group of KPSOs that belong to the same category or class of information products or research outcomes	Indicators of grazing conditions
Bottom	KPSO	A primary or important information product, service, or outcome required to make progress toward or meet a Key Objective	Rangeland Condition Monitoring Assessment and Projection (RCMAP)
	Data Source (Surveyed Product and/or Earth Observations Input)	The data, information, and Earth-observing systems needed to produce KPSOs	3DEP, LCMAP, NLCD, CDL, Landsat
	Earth Observations Input	An observing system or database that is the lowest level of disaggregation in the value tree	Airborne lidar

Key objectives (3–7 per sub-area, 22 total) were established that represent critical components and goals within each sub-area. Within the scope of the effort and in support of the Agriculture & Forestry key objectives, a total of 208 KPSOs were identified, with 1,039 total products surveyed from input from 647 corresponding Subject Matter Experts (SMEs). In turn, 1,172 unique Earth observations inputs (e.g., airborne lidar from Table 1) were identified as supporting the production of the KPSOs. The U.S. Forest Service (USFS), U.S. Geological Survey (USGS), National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA), Natural Resources Conservation Service (NRCS), and National Agricultural Statistics Service (NASS) provide many of the Agriculture & Forestry KPSOs identified in this assessment. The moderate resolution imaging spectroradiometer (MODIS) Aqua and Terra, Landsat Operational Land Imager (OLI), Visible Infrared Imaging Radiometer Suite (VIIRS) Suomi National Polar-Orbiting Partnership (SNPP), NOAA-20 and NOAA-21, and Sentinel-2 multi-spectral imagery (MSI), systems (in that order; Figure 2), were found to be the most impactful remote sensing observing systems providing sustained observations to support objectives across the SBA. A list of the top 20 Earth observations inputs is shown in Table 3.

Table 2. ***Table of Agriculture & Forestry Sub-areas and Key Objectives.***

Sub-area	Key Objectives
Enhance Food Supply	• Understand current agricultural production, production trends, and risks • Improve soil health, increase carbon uptake and storage, and reduce trace gas emissions from soil by promoting soil conservation practices • Improve resilience of agricultural productivity to empower climate smart agriculture • Increase the efficiency of irrigation, fertilizers, and pesticides by encouraging sustainable and precision agriculture • Manage environmental and human health risks associated with fertilizers and pesticides • Support forage assessment and management for animal production • Improve ecosystem condition to diverse support agricultural pollinators
Maximize productivity and conservation of ecosystem condition	• Promote sustainable multi-use management of forests, grasslands, and shrublands that acknowledges Indigenous land management practices • Utilize and advance existing scientific, technical, and traditional ecological knowledge to better manage and use agricultural lands, forests, grasslands, shrublands, and pasture and rangelands • Promote climate resilience by advocating for management practices that adapt to climate change to optimize productivity and improve condition • Minimize adverse effects of human activities on ecosystem condition • Collaboratively promote the conservation of high-value areas and minimally managed forests, grasslands, and shrublands • Collaboratively engage and support geospatial needs in rural and Indigenous communities
Improve resilience to disasters and disturbance events	• Allow natural disturbance (e.g., fire) where appropriate and manage disturbance risk that affect populations (e.g., wildland-urban interface and coastal zones) • Predict and manage fire risk, tactical fire support, and post-fire remediation • Minimize soil erosion from water, wind, active management, and post-fire in agricultural and forest ecosystems • Support risk and impact modeling for drought, flood, pest/disease infestation, fire, and storm-prone areas • Maintain resilience of water supplies and facilitate post-disturbance restoration and rehabilitation • Improve resistance of agriculture, rangelands, grasslands, shrublands, and forests to disease and pests including invasive species
Support regulatory requirements and evidence-based decision-making	• Provide geospatial support to firefighters, aviators, law enforcement, farmers, communities, and agencies • Monitor and promote compliance with Federal laws (farm, insurance, conservation, and leases) and programs • For carbon storage and greenhouse gas emissions, support analysis and evidence-based decision-making

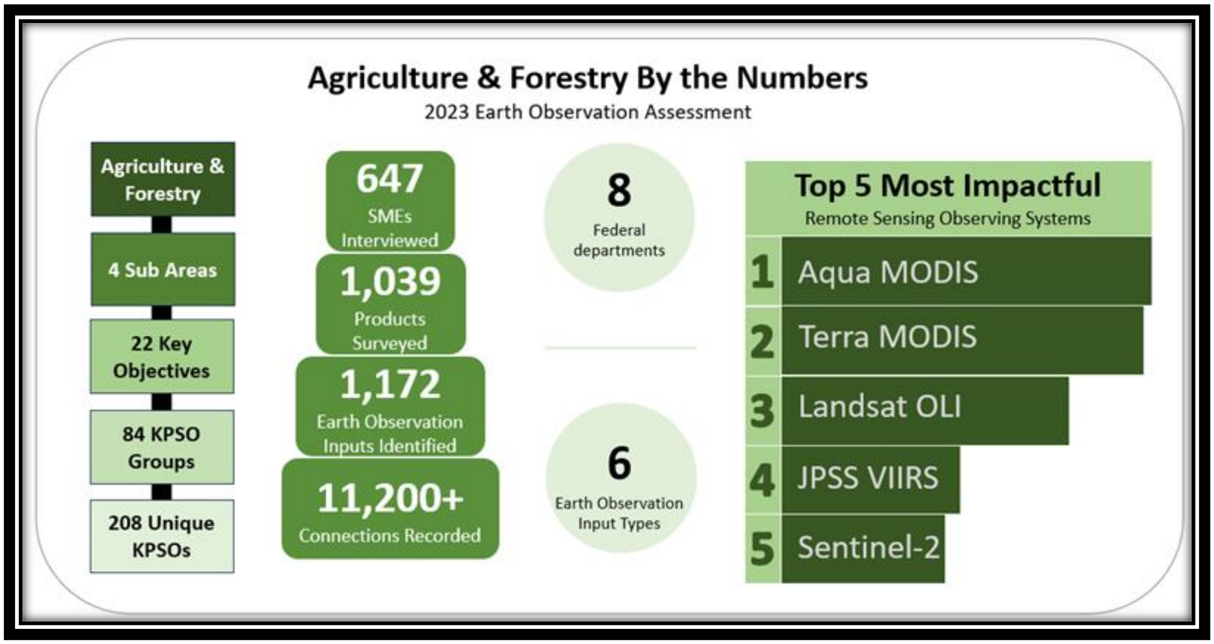

Figure 2. ***Overview of Agriculture & Forestry Assessment Statistics.*** *Bar chart of Top 5 Most Impactful Remote Sensing Observing Systems is representative of the percent impact on the SBA.*

Summary of Key Findings

The 2023 Earth Observations Assessments (EOA) documented the dependence of the Agriculture & Forestry SBA on Landsat, MODIS, National Agriculture Imagery Program (NAIP), elevation datasets, Global Positioning System (GPS), as well as State and local parcel data to support the SBA's objectives. Topographic and elevation data were high impact, attributable to their role in the pre-processing of imagery collections. Since 2016, new data sources such as the Global Ecosystem Dynamics Investigation (GEDI) lidar, depicted in Figure 3, the National Ecological Observatory Network (NEON) network's imaging products, and Sentinel-2 have emerged and increased in importance, along with Airborne lidar and SAR, which have also increased in importance. The imminent loss of MODIS Aqua and Terra has led to an increase in reliance on VIIRS, but the pending loss can still be expected to impact the delivery of KPSOs that currently depend on MODIS. Potential concerns for Agriculture & Forestry include the challenges in maintaining measurements to continue longstanding data records. Meeting the breadth of the Agriculture & Forestry objectives requires a high diversity of Earth observations, as well as sustained observations collected with high frequency and fine to moderate spatial resolution.

Table 3. ***Top 20 Earth Observations Inputs from the Agriculture & Forestry SBA Ordered by Percent Impact on the SBA.***

Rank	Earth Observation Input	Observation Type
1	Aqua MODIS	Satellite sensor/data
2	Terra MODIS	Satellite sensor/data
3	Field Work - Visual Surveys/Lab Samples Collection	Field work
4	Landsat OLI (Landsat 8/9)	Satellite sensor/data
5	JPSS VIIRS	Satellite sensor/data
6	DEM Output – SRTM	Elevation data
7	Sentinel-2 MSI	Satellite sensor/data
8	NAIP	Airborne data
9	Landsat TIRS (Landsat 8/9)	Satellite sensor/data
10	GPS	In situ data
11	National Elevation Dataset (NED)	Elevation data
12	Field Work - Ground Surveys, Field Measurements	Field work
13	State/Local Parcel Data	Other reference data
14	Landsat archives	Satellite sensor/data
15	Commercial Airborne Lidar	Airborne data
16	Global Land Survey DEM (GLSDEM)	Elevation data
17	Citizen Reporting – Phenology	Other reference data
18	USGS Topographic Maps	Elevation data
19	SNOTEL	In situ data
20	GOS Basic Surface Synoptic Network	In situ data

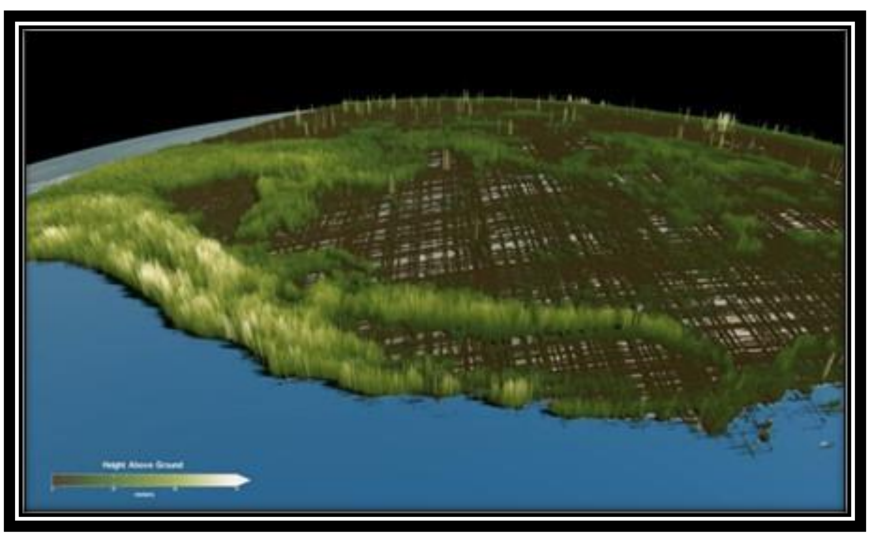

Figure 3. ***Still Image Depicting GEDI Forest Height Data Zoomed in on the Western U.S.***

MODIS and VIIRS Missions

As shown in Figure 4, MODIS (Aqua, Terra) supports all 22 (100%) key objectives and 165 (79%) of the 208 KPSOs, with a total of 27 MODIS products in use within the SBA tree that have the highest impacts of any individual Earth observations input in the assessment. MODIS products—such as active fires, evapotranspiration, leaf area index, and gross primary productivity—actively support the ability to monitor ecosystem condition and the impacts of disturbance and disaster events. Aqua and Terra will be deorbited in 2026 (September) and 2027 (September) respectively, necessitating consideration of product continuation through the use of VIIRS or alternative sensor products. Of the currently produced MODIS products, most now have VIIRS equivalent products established or in progress. VIIRS, which launched in 2011, showed the largest increase in impact from 2016 to 2023 and now supports 125 (60%) of the 208 KPSOs. Figure 5 depicts the individual sensor impacts, but statistics may represent a logical grouping of sensors to represent a system, shown in Figure 4. Despite the increasing use of VIIRS, differences in band-specific spatial resolution and spectral ranges, compared to MODIS, may necessitate evaluation of how the replacement of MODIS with VIIRS products impacts KPSOs. For the surveyed products that directly use a MODIS product, some SMEs reported having transition plans to accommodate for the anticipated loss of MODIS, while more than half either had no plans or did not mention a plan in their elicitation.

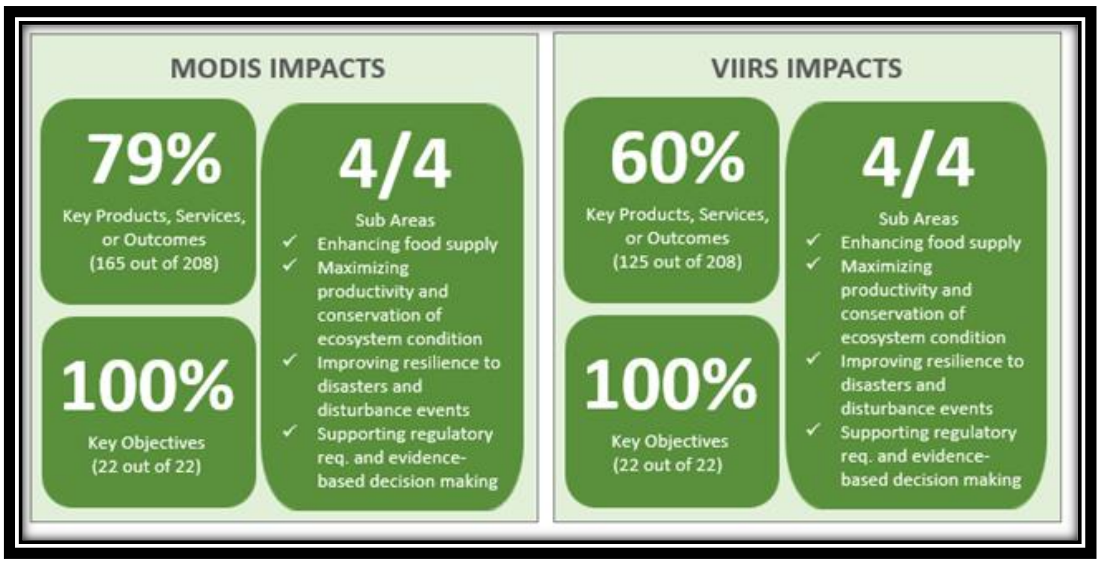

Figure 4. ***Overview of MODIS and VIIRS Observing System Impacts on the Agriculture & Forestry Value Tree.***

Figure 5. ***Graph of Earth Observations Inputs' Impact on the Agriculture & Forestry SBA by the Number of KPSOs (out of 208) Impacted by 0.01% or Greater.*** *Earth observations inputs that impact more than 50 KPSOs can be found in Annex B. Data points in the table are disaggregated by their rank in the list of Earth observations impacts in Annex C. Data points towards the top right have the most impact and broadest applicability in the SBA. Those in towards the bottom left have more niche value.*

Landsat and Sentinel 2 Missions

Landsat-series missions also support all 22 (100%) Agriculture & Forestry key objectives, as noted in Figure 6. Landsat supports 159 (76%) of the 208 KPSOs, most heavily impacting sub-area 2, Maximize productivity and conservation of ecosystem condition, and sub-area 3, Improve resilience to disasters and disturbance events. Examples of KPSOs that depend on Landsat include the Rangeland Condition Monitoring Assessment and Projection (RCMAP); Land Change Monitoring, Assessment, and Projection (LCMAP); Rapid Assessment of Vegetation Condition after Wildfire (RAVG); and Global Forest Change (GFC). Most of Landsat's impact comes from the direct use of Landsat imagery in KPSOs and surveyed products, while the Landsat science products[1] and Harmonized Landsat Sentinel-2 (HLS) Analysis Ready Data (ARD) show increasing value. The Sentinel-2 series, which launched its first satellite in 2015 and second in 2017, was highly impactful for the SBA, most heavily for sub-area 3, Improve resilience to disasters and disturbance events. Although Sentinel-2 lacks a thermal infrared sensor, the overlap in spectral bands between Landsat 8 and 9 and Sentinel-2 reduces the single points of failure or chokepoint for moderate resolution (10–30 m), multispectral data, and is an example of how partner data can be leveraged to increase the value of U.S. data.

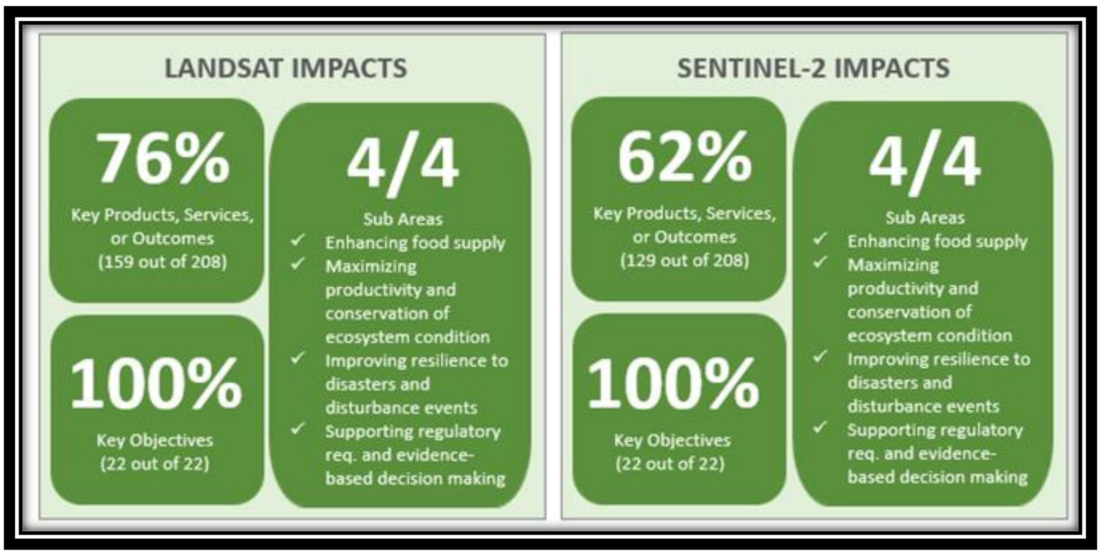

Figure 6. ***Overview of Landsat and Sentinel-2 Observing System Impacts on the Agriculture & Forestry Value Tree.***

Topographic and Geographic Positioning Datasets

Earth observations inputs providing elevation, topography, and geographic positioning—including the Shuttle Radar Topography Mission (SRTM), GPS, National Elevation Dataset (NED), and Global Land Survey Digital Elevation Model (GLSDEM)—provide key inputs to support image pre-processing as well as the production of secondary products. Elevation, topographic and geographic positioning datasets comprise 5 of the top 10 Earth Observations Inputs impacting Agriculture & Forestry. Global and national topographic and elevation products are a key input to the pre-processing of widely used satellite and airborne image collections such as MODIS, VIIRS, Landsat, and NAIP. The accuracy of elevation, topography, and geographic positioning currently limits the positional accuracy of emerging commercial

[11] Landsat science products include Landsat Surface Reflectance Analysis Ready Data [ARD], surface temperature, burned area, dynamic surface water extent, fire and thermal anomalies, actual ET.

high-resolution datasets, particularly in mountainous regions. High geolocation accuracy is a necessary precursor for time series analysis, where individual image pixels are tracked over time. Examples of specific applications include the support of disaster risk and response, such as predicting flood risk and tracking flood depth, as well as predicting post-fire soil stability and areas at risk for debris flows.

Field Collected and In Situ Measurements [Key Takeaway 7]

Field collected and in situ measurements, including visual surveys, lab samples, ground surveys, and field measurements showed high impact across the SBA, particularly in supporting sub-area 2, Maximize productivity and conservation of ecosystem condition. Field work, including visual surveys and lab sample collections represented the third most impactful data source for Agriculture & Forestry (Table 3). Field collected and in situ measurements often provide data that cannot be obtained from remote sensing but support efforts to parameterize, train, calibrate, and validate analyses and products produced from remotely sensed data. In this way, in situ data builds stakeholder confidence in remotely sensed data products. The Forest Service's Forest Inventory and Analysis (FIA) program, for instance, provides key on-the-ground measurements needed to assess America's forests through repeated plot analysis over time. Estimates of forest carbon continue to be constrained by limited field data, and the need for data to supplement the FIA data.

Figure 7. ***USGS Scientists Collect Water Samples for Chemical Analysis from an Excavated Pond in the New Jersey Pinelands.***

Field data is also essential for water-related applications. The U.S. Department of Agriculture (USDA) NRCS Snowpack Telemetry (SNOTEL) Network, which impacts 118 (57%) of KPSOs in Agriculture & Forestry, is an example of in situ measurement, comprising over 900 automated data collection sites monitoring snowpack and meteorological conditions in remote, high-elevation mountain watersheds across the Western United States. In addition, the USGS's Stream gage network, which supports 72 (35%) of KPSOs, provides data for more than 10,000 stream and river locations across the Nation. SNOTEL data and the USGS Stream gage network inform projections of river discharge and the risk of downstream floods and droughts. Networks of sites, such as those supported by NEON, Long-Term Ecological Research

(LTER), Long-Term Agroecosystem Research (LTAR), Bureau of Land Management's (BLM) Assessment, Inventory and Monitoring (AIM), and NRCS's National Resource Inventory (NRI) provide a high diversity of sustained field collected and in situ data that are valuable to support the development, training, and validation of remotely sensed research and products related to vegetation condition, soil type, soil moisture, and surface water dynamics.

High Spatial Resolution Data

High impact, high spatial resolution systems for the Agriculture & Forestry SBA include NAIP, commercial airborne lidar, airborne synthetic aperture radar (SAR), and commercial satellite data from MAXAR's WorldView-2 and WorldView-3, and Planet Dove. Of these sources, NAIP showed the greatest relative impact, supporting regulatory requirements and evidence-based decision-making (sub-area 4; Figure 8). NAIP directly supports 34 KPSOs, including Food Security Act (FSA) compliance activities and farm programs, the Emergency Conservation Program (ECP), Forest Stewardship Plans, National Wildlife Refuge System, and Landscape Change Monitoring System (LCMS). The reliance on NAIP is likely attributable to free and open access, as well as NAIP's long data collection record. Airborne SAR and commercial airborne lidar, both within the top 25 impactful Earth observations sources, support the USGS's 3D Elevation Program (3DEP) in Alaska and the conterminous United States. They have shown notable increases in impact in recent years and have enabled improvements in the quality of digital elevation models across much of the United States. The 3DEP products are used in KPSOs such as flood inundation mapping, consumptive water use and loss reporting, and actuarial rate maps. Commercial imagery—such as WorldView-2, 3, and Planet's Dove—have become key inputs for product training, calibration, and validation, and support KPSOs including insect and disease detection surveys, hazard and disaster support on national forest system lands, and tribal land vegetation and watershed modeling.

Figure 8. ***Sample of NAIP Data Near Waitsburg, Washington.***

Role of Niche KPSOs Critical to Specific Objectives

In addition to widely used satellite missions like MODIS and Landsat, specific objectives commonly rely heavily on more niche Earth observations inputs. For example, in active fire management short data latency and high temporal frequency are key—which has led to a reliance on missions such as FireFly/FireGuard, and the Geostationary Operational Environmental Satellite - R Series (GOES-R) Advanced Baseline Imager to detect active fires and track fire spread. Meteorological and air-quality-related datasets are important to inform wildfire risk/spread, as well as to characterize wildfire emissions and air quality. Additionally, accurate and complete data on building and structure footprints are needed for estimating and managing wildfire risk in the wildland-urban interface (WUI). Alternatively, supporting the enhancement of food supplies and field work (including visual surveys and lab samples) were the most heavily weighted Earth observations inputs, especially to support forage assessment, to manage animal production, and to improve soil health and promote soil conservation practices. The key objective to improve soil health also depends heavily on commercial airborne lidar, airborne SAR, and the NEON network's airborne imagery. Further, the key objective to understand current agricultural production, trends, and risks is disproportionately impacted by NAIP and precipitation datasets. Differences in the importance of Earth observations inputs by objective demonstrates the importance of maintaining and developing diverse sources of Earth observations to support objectives across the Agriculture & Forestry SBA.

Consideration for Meeting Key Objectives

Opportunities for Improvement in Meeting Objectives

SMEs scored KPSO Earth observations inputs and provided an evaluation of each input ranging from "provided no value" to "met all requirements and exceeded some." Across the SBA, improving our understanding of current agricultural production, trends, and risks is needed, as is improved support to monitor agricultural pollinators and empower climate smart agriculture. Specific challenges highlighted by SMEs included inadequate accuracy of evapotranspiration, soil moisture, and crop type data products, as well as challenges in data latency. Improvements are also needed to facilitate natural disturbance while managing disturbance risks that affect human populations. Associated objectives, including our capacity to predict and manage fire risk, provide geospatial support for tactical active fire management, and prioritize post-fire remediation were also identified as needing improvement. Specific challenges included that MODIS was typically too coarse in spatial resolution for tactical fire management, and requests for infrared imagery collected from aircraft can go unfilled due to adverse weather conditions, priority conflicts, mechanical issues (aircraft/sensor) and/or pilot duty day restrictions. Limitations in the field-based accuracy of remotely sensed burn severity was also identified. The most common limitations identified by all SMEs across KPSOs included temporal or spatial resolution, latency both in data and data products, as well as gaps in field data availability.

Meeting Stakeholder Needs

Enabling improved and efficient decision-making with Earth observations requires consideration of the format in which data are delivered. While raw imagery and analysis-ready data are key inputs for research, including methods and new product development, data in this format can be difficult for end-users to ingest directly. Consequently, the production and support of Earth observations variables such as forest cover, leaf area index, burned area, surface water, and crop cover—which were commonly used as inputs to produce other KPSOs—are also important. Therefore, guided by stakeholder engagement, the SBA will greatly benefit from the continued and expanded production of Earth observations products that can be directly used to inform key objectives and guide decision-making, such as near real-time products on crop health, crop yields, drought indicators, water availability, forest health, carbon sequestration, wildfire risk, as well as projected impacts of climate change. Ongoing stakeholder engagement and co-production is central to understanding the desired end-user information needs, current capabilities, and gaps. Structured engagement also helps to inform end-users on the "Art of the Possible" in terms of new capabilities and data streams of which the users may not be aware.

Barriers to Commercial Cloud-Computing Platforms [Key Takeaway 3]

Cloud-computing platforms provide users rapid access to a catalog of satellite imagery and geospatial datasets and enable scientists to increase their computing power by processing large amounts of Earth observations data without storing it locally. As cloud-computing platforms can vastly improve the time efficiency of efforts, particularly efforts over large spatial or temporal scales, these platforms are now a necessary component of both research as well as producing regional, national, and global forest and agriculture-related products. Much of the sensor-specific data processing and production performed by agencies including NASA, USGS, and NOAA, for example, have been moved to commercial cloud space. However, access and use of commercial platforms for projects, scientists, and users has quickly escalated in cost, which is currently limiting its use and serving as a barrier for new users and new projects. Additionally, this challenge can make it more difficult to operationalize products as workflows can become reliant on a platform with uncertain access or prohibitive costs. Public sector cloud-computing platforms could potentially help bypass some of these challenges.

Production of FAIR (Findability, Accessibility, Interoperability, and Reusability) Data

The acronym "FAIR" defines the responsibility of data managers to make data findable, accessible, interoperable and reusable. The concept is focused on principles "emphasizing machine-actionability, or the capacity of computational systems to find, access, interoperate, and reuse data with no or minimal human intervention." With rapid increases in the volume and complexity of remotely sensed and geospatial data, the ability to efficiently find, access, integrate, interpret, and analyze datasets using machine learning (ML), deep learning, and artificial intelligence (AI) is increasingly indispensable. The need for data that meet FAIR standards will continue to grow with an ever-expanding array of sensors and associated derivative products. With the FAIR principles firmly in mind, the Federal geospatial community is working collaboratively to adopt standards for metadata, data formats, and file formats for all geospatial data.

Commercial Data Utilization [Key Takeaway 5]

Increases in the popularity of SmallSats and other commercial satellites have led to rapid growth in the commercial Earth observations sector. This source of data provides exciting opportunities for improved spatial and temporal resolution of Earth observations, for example to map narrow streams, or track daily crop condition or fire spread. Access to commercial imagery by researchers and users, however, is dependent on the establishment and maintenance of contracts or partnerships, such as NASA's Commercial SmallSat Data Acquisition (CSDA) Program, and the Electro-Optical Commercial Layer (EOCL) provided by the National Reconnaissance Office (NRO), both of which provide avenues for civil agencies to access and use commercial imagery. The use of commercial data is governed by the End-User Licensing Agreements (EULAs) which are associated with each data purchase. Licensing restrictions on commercial imagery also has implications for sharing and publishing those data. For commercial remote sensing data collected on-demand, tasking requirements, inconsistent coverage, and cost are challenges. Data quality (specifically data consistency for long term analysis) is particularly important. For example, variability in sensor calibration, quality, and georeferencing accuracy can hinder the feasibility of time series applications. Algorithm Theoretical Basis Documents (ATBDs) from commercial vendors help characterize data uncertainty and provide the community with a level of transparency in data pre-processing which is essential to ensure data can be used and processed appropriately. High-resolution, open access or broadly licensed unclassified imagery that is routinely collected, if costs are not prohibitive, facilitates data sharing and supports mission-critical situational awareness, disaster response, and humanitarian assistance.

Underutilized Earth Observations

Certain types of Earth observations were notably limited or absent from the KPSOs and their Earth observations inputs. For instance, SAR data were limited in use. SAR data have important potential applications for characterizing forest structure, leaf area index, below canopy surface water, as well as snow and ice. Its limited use in the Agriculture & Forestry KPSOs may be attributed to previous international missions (e.g., RADARSAT-2, ALOS-2/4) collecting data on-demand. Sentinel-1 (C-Band) hosted by Copernicus is the first regularly collected and freely accessible SAR satellite, but the end of Sentinel-1B's mission in December 2021 has reduced its return interval. However, with the recent launch of the Surface Water and Ocean Topography (SWOT; Ka-band) by NASA in December 2022, the upcoming launch of the NASA-ISRO SAR mission (NISAR; L- & S-band), and the inclusion of commercial SAR vendors in NASA's CSDA program, opportunities for KPSOs with SAR inputs are rapidly increasing. Similarly, hyperspectral data have shown limited use in the KPSOs or their Earth observations inputs. Much of the hyperspectral data to date (e.g., NASA's Airborne Visible/Infrared Imaging Spectrometer [AVIRIS] or NASA's Hyperion [decommissioned in 2017)] have collected data on-demand resulting in limited coverage. PRecursore IperSpettrale della Missione Applicativa (PRISMA), launched in 2019 by the Italian Space Agency, as well as two German hyperspectral satellite missions—the DLR Earth Sensing Imaging Spectrometer (DESIS, launched in 2018) and the Environmental Mapping and Analysis Program (EnMAP, launched in 2022)—provide additional sources of hyperspectral data.

Planning for Product Continuity

A significant caveat in the use of remotely sensed imagery is the need for measurement and product continuity. Once uptake of sensor data is embedded in analyses, products, and services, reliance on a sensor's data becomes high. When a heavily used sensor, approaches end-of-life, there is not always a new system to transition to, and even when there are other sensors the transition is not always (or often) smooth. Just as training and engagement with the user community is key at the start of a mission to maximize data use and adoption, engagement and communication with the user community at the end of a mission is just as important to develop and implement transition plans to ensure the continuity of products, when possible, and minimize the impact the loss of these systems will have in supporting Agriculture & Forestry KPSOs.

Recommendations

Support and Expand Sustained Observing Systems to Maintain and Improve Our Ability to Monitor Landscape Change [Key Takeaway 1]

The 2015 effort, "Continuity of NASA Earth Observations from Space: A Value Framework," recognized that many resource management and climate applications require near real-time, accurate measurements, driven by science and application objectives, and obtained through long, stable, uninterrupted time-series. Long-term, sustained observations of the Earth and its condition are critical to detect patterns, trends, and changes in ecosystem condition, as well as measure the impacts of disturbances, disasters, and management and restoration activities. For example, Landsat 4, 5, 7, 8, 9 and the planned Landsat Next provide the longest, continuous source of data to track ecosystem condition and support Agriculture & Forestry objectives. The NAIP program, although more limited in geographic extent, also continues to show high importance in the production of agricultural data. Coordination of data and product availability for sustained missions in the case of decommissioning is also important. For instance, supporting the transition of MODIS products to VIIRS, Sentinel-3 Ocean and Land Colour Instrument (OLCI), or other product equivalents and supporting the ingestion of these new products by end-users will help minimize the impact of decommissioning Terra and Aqua.

Facilitate Diverse Earth Observations, Collaborations, and Partnerships [Key Takeaway 2, 3, 5]

Supporting the Agriculture & Forestry objectives in a comprehensive and resilient manner requires a large and growing number of diverse Earth observations inputs, as well as the creation and maintenance of domestic and international collaborations and partnerships. Supporting stakeholder-scientist partnerships, for example, will facilitate increased awareness of Earth observations data sources, improved product generation, and improved use of Earth observations in decision-making. The Applied Earth Observations Innovation Partnership, for instance, supports collaboration between NASA, USFS, USGS and other Federal civil agencies, while the USGS's National Innovation Center (NIC) supports collaboration between public, private, and nonprofit partners in Silicon Valley, facilitating the efficient utilization of Earth observations data for decision-making. Such partnerships encourage operations-oriented activities, such as promoting sustainable multi-use land management, encouraging climate resilience within agricultural and silviculture activities, and minimizing the adverse effects of human activities on ecosystem condition. Sustainable and reliable partnerships with commercial partners are also essential to avoid major disruptions in the production of KPSOs and to ensure that the continued and growing access and use of commercial imagery. As the number of Earth observations produced by international entities, such as Copernicus and Japan Aerospace Exploration Agency (JAXA), continue to increase, international partnerships to share data are also increasingly important to improve observation types, frequency, as well as to reduce chokepoints or single points of failure.

Enhance Data and Tools to Better Manage Fire and Other Disaster Risk, Response, and Recovery [Key Takeaway 4]

There has been a long running effort to better leverage remote sensing data and tools to improve the timely flow of remotely sensed information to wildland fire managers before, during, and after a fire event. Managing fire risk requires information on fuel conditions, drought indicators, and the probability of Red Flag Warning conditions, specifically, temperature, low humidity, high winds, and dry lightning. Earth-observing capabilities are an important component in understanding where fire may occur on the landscape, tracking fire ignitions, and predicting fire behavior once a fire has started, such as the location of active fronts, rate and direction of spread, and spread mechanisms. The key to effectively utilizing Earth-observing capabilities in wildland fire management is to minimize the latency in delivering information on current fire conditions. Toward this end, fire fighters have benefited from a number of remote sensing technologies, including new thermal sensors, uncrewed aircraft systems (UAS) and spaceborne observing systems. Continued improvement in disaster support is critical, including reducing data latency, improved communication between data providers and data users, and improved data products and models.

Strengthen Delivery of Earth Observations Products to Better Support the Sustainable use of Natural Resources [Key Takeaway 6]

The delivery of research quality data should continue to be a priority. Thorough data pre-processing and provision of supporting data and documentation—such as cloud, cloud-shadow masks, QA/QC masks, snow and water masks, high-quality metadata, user guides, and example code—improve the condition and reliability of the delivered data, which in turn enables improved efficiency of research efforts and improved quality of end products ingested by decision-makers. Earth observations and their metadata need to be machine readable, cloud accessible, and meet the FAIR data standards. Examples of data portals that compile and deliver diverse Earth observations include NASA's Open Data Portal, the Environmental Protection Agency's (EPA) Remote Sensing Information Gateway, USGS's Earth Explorer and National Map, and USDA's Geospatial Data Gateway. In addition, support of new technologies and new product development is necessary to more directly inform decision-making by farmers, land managers, foresters, and fire managers.

Coordinate with Complementary Efforts [Key Takeaway 7]

Coordination between related efforts, including other national planning efforts, such as the USGEO National Plan and climate change action and adaptation plans, can create more mutually beneficial situations and minimize the duplication of efforts. Coordination with data creation programs and efforts can also help support Agriculture & Forestry objectives. For example, the Satellite Needs Working Group (SNWG) has enabled access to DESIS data, provided broader access to commercial imagery, and supported the production of the HLS dataset and ArcticDEM, all activities that support Agriculture & Forestry KPSOs. Additionally, the USGS's 3DEP program is helping to improve the quality of elevation data across the United States. As elevation data derived from the program is extensively used across the SBA and highly beneficial for fire and disaster applications, complete and repeat airborne lidar data collection will increasingly benefit the Agriculture & Forestry SBA. In addition, support and coordination with field-based networks, such as NEON, LTER, LTAR, USFS FIA, SNOTEL, and the Streamgage network, is key to guide the development, calibration, training, and validation of airborne and satellite-based products.

Support Research Development and Evaluation of New Data Sources [Key Takeaway 8]

Research is an essential activity to evaluate the utility of new data systems as well as develop new data processing, integration, and analysis approaches. Research continues to be needed to further our understanding of the science supporting Agriculture & Forestry objectives, and our ability to detect patterns, trends, risks, and impacts of climate change and human activities on ecosystem condition and productivity. Additionally, continued support of field and in situ measurements is crucial to calibrate and validate remotely sensed products. Supporting both research-oriented and operations-oriented activities, as well as the transition from research to operational products and further to decision-making tools, are important activities that will benefit from additional support.

Abbreviations and Acronyms

3DEP	3D Elevation Program
AI	artificial intelligence
AIM	Assessment, Inventory, and Monitoring
ARD	Analysis Ready Data
AVIRIS	Airborne Visible/Infrared Imaging Spectrometer
AWG	Assessment Working Group
BLM	Bureau of Land Management
CDL	Cropland Data Layer
CSDA	Commercial SmallSat Data Acquisition
DEM	Digital Elevation Model
DESIS	DLR Earth Sensing Imaging Spectrometer [DLR — German Aerospace Center]
ECP	Emergency Conservation Program
EnMAP	Environmental Mapping and Analysis Program
EOCL	Electro-Optical Commercial Layer
EOP	Executive Office of the President
EPA	Environmental Protection Agency
FAIR	findable, accessible, interoperable, and reusable
FIA	Forest Inventory and Analysis
GEDI	Global Ecosystem Dynamics Investigation
GEO	Group on Earth Observations
GFC	Global Forest Change
GLSDEM	Global Land Survey DEM
GOES-R	Geostationary Operational Environmental Satellite-R Series
GOS	Global Observing System
GPS	Global Positioning System
HLS	Harmonized Landsat Sentinel
JAXA	Japan Aerospace Exploration Agency
JPSS	Joint Polar Satellite System
KPSO	key product, service, or outcome
LCMAP	Land Change Monitoring, Assessment, and Projection
LCMS	Landscape Change Monitoring System
LiDAR	light detection and ranging
LTAR	Long-Term Agroecosystem Research

LTER	Long-Term Ecological Research
ML	machine learning
MODIS	moderate resolution imaging spectroradiometer
MSI	multi-spectral imagery
NAIP	National Agriculture Imagery Program
NASA	National Aeronautics and Space Administration
NASS	National Agricultural Statistics Service
NED	National Elevation Dataset
NEON	National Ecological Observatory Network
NIC	National Innovation Center
NISAR	NASA-ISRO SAR Mission [ISRO — Indian Space Research Organization]
NOAA	National Oceanic and Atmospheric Administration
NLCD	National Land Cover Dataset
NRCS	National Resources Conservation Service
NRI	National Resource Inventory
NRO	National Reconnaissance Office
NSTC	National Science and Technology Council
OLCI	Ocean and Land Colour Instrument
OLI	Operational Land Imager
OSTP	Office of Science and Technology Policy
PRISMA	PRecursore IperSpettrale della Missione Applicativa
QA/QC	quality assurance/quality control
RADAR	radio detection and ranging
RAVG	Rapid Assessment of Vegetation Condition after Wildfire
RCMAP	Rangeland Condition Monitoring Assessment and Projection
SAR	synthetic aperture radar
SBA	societal benefit area
SME	subject matter expert
SNOTEL	Snowpack Telemetry
SNPP	Suomi National Polar-Orbiting Partnership
SNWG	Satellite Needs Working Group
SRTM	Shuttle Radar Topography Mission
SWOT	Surface Water and Ocean Topography
TEK	Traditional Ecological Knowledge
TIRS	Thermal Infrared Sensor

UAS	uncrewed aircraft systems
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
USGEO	U.S. Group on Earth Observations
VIIRS	Visible Infrared Imaging Radiometer Suite
WUI	wildland-urban interface