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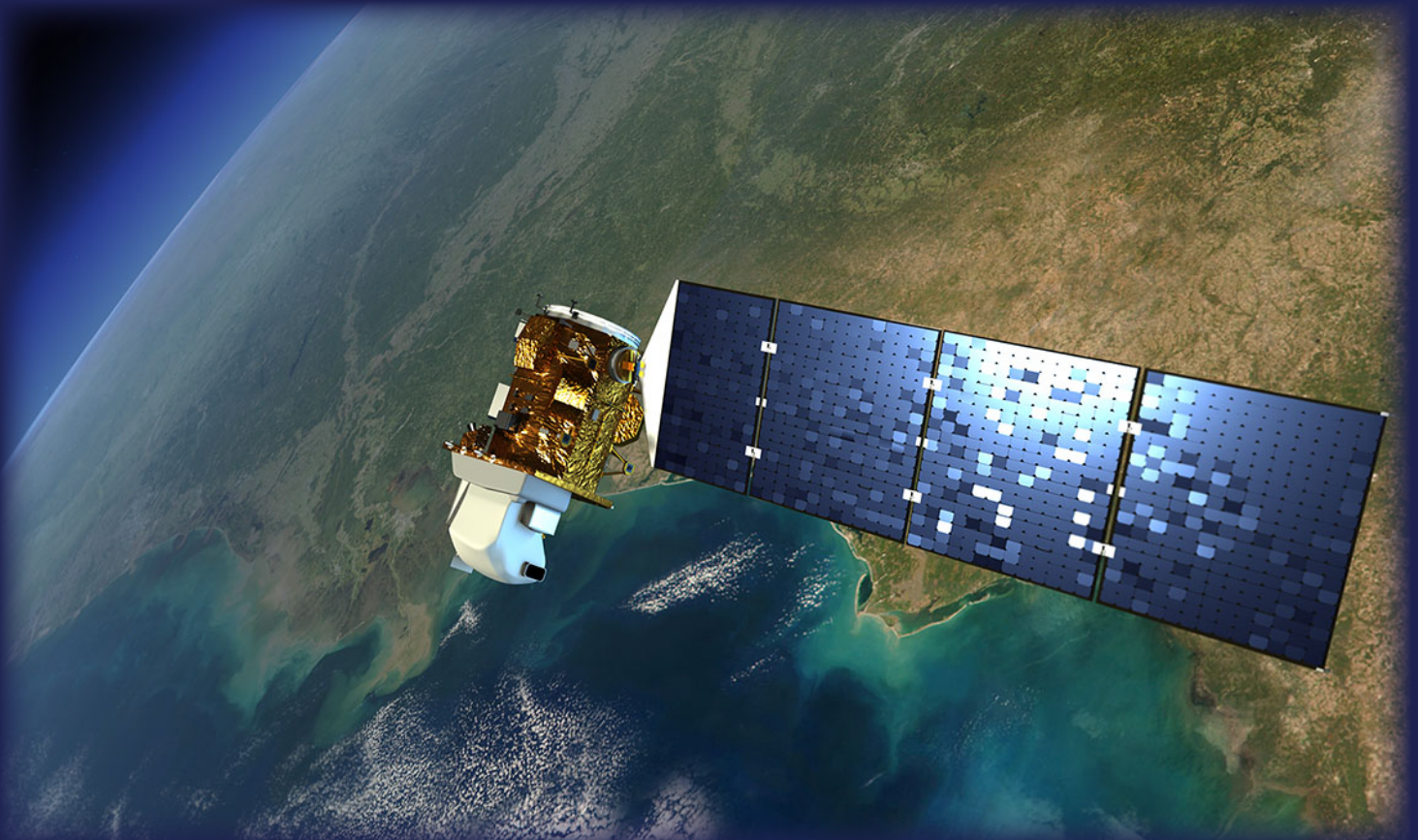
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# 2019 Forest Service–NASA Joint Applications Workshop: Satellite Data to Support Natural Resource Management: A Framework for Aligning NASA Products with Land Management Agency Needs

Matthew C. Reeves, E. Natasha Stavros, Nancy F. Glenn, Andy Hudak, Birgit Peterson, Amanda Armstrong, Everett Hinkley, Elizabeth Hoy, Jeff W. Atkins



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## Abstract

In 2019, about 103 participants from the U.S. Department of Agriculture’s Forest Service (Forest Service), the National Aeronautics and Space Administration (NASA) and other federal, private, and academic entities attended the Forest Service–NASA Joint Applications Workshop. The objective of this workshop was to increase awareness and understanding of the capabilities of NASA data products, and strengthen partnerships between NASA and the Forest Service. In this vein, the workshop sought to identify opportunities for collaboration between the Forest Service and NASA on the topics of (1) soil moisture and hydrology, (2) carbon emissions and flux, and (3) vegetation structure and function. Four key high-level opportunities for increased coordination and collaboration were identified including: (1) develop a strategic framework for collaboration and coordination; (2) establish working groups and engage in early adopter programs; (3) distill needs requirements and conduct feasibility studies; and (4) integrate tools and data. Although the workshop was conducted 4 years ago, the information is still highly relevant, since GTAC (Appendix B) and the SMAP, NISAR, ICESAT-2, CMS Programs are all still very active and numerous points of collaboration between the Forest Service and NASA have occurred.

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**Keywords:** collaboration, NASA, remote sensing, partnership

**Cover:** An artist’s rendition of the next Landsat satellite, the Landsat Data continuity Mission (LDCM), launched in 2013. NASA image by Goddard Space Flight Center.

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## EXECUTIVE SUMMARY

In 2019, approximately 103 participants from the U.S. Department of Agriculture's Forest Service (Forest Service), the National Aeronautics and Space Administration (NASA) (including representatives from SMAP<sup>1</sup>, NISAR<sup>2</sup>, ICESat-2<sup>3</sup>, GEDI<sup>4</sup>, and CMS<sup>5</sup>), and other federal, private, and academic entities attended the Forest Service–NASA Joint Applications Workshop. The objective of this workshop was to increase awareness and understanding of the capabilities of NASA data products, as well as to develop connections and strengthen partnerships between NASA and the Forest Service. In this vein, the workshop sought to identify opportunities for collaboration between the Forest Service and NASA on the topics of (1) soil moisture and hydrology, (2) carbon emissions and flux, and (3) vegetation structure and function. During breakout sessions, participants discussed key opportunities and challenges of utilizing NASA technology by land management agencies. The list below represents key high-level opportunities for increased Forest Service–NASA coordination and collaboration to support sustainable natural resource management.

- 1. Develop a Strategic Framework for Collaboration and Coordination.** A coordinated approach to prioritizing work between the agencies will result in a more efficient use of resources. Describing connections and assigning contacts for activities such as sharing data, transferring technology, or conducting research will streamline efforts and allow for a better understanding and integration of program needs.
- 2. Establish Working Groups and Engage in Early Adopter Programs.** Involving land management agencies in the development of requirements for future missions will help meet science and management objectives. Piloting NASA technology with land management scenarios and working together iteratively will yield tools highly applicable to the needs of land managers.
- 3. Distill Needs Requirements and Conduct Feasibility Studies.** Additional work refining stakeholder needs and clearly outlining barriers to adoption will help determine where to focus resources. Considering stakeholder needs as they pertain to decision support and science from a multi-mission perspective will improve outcomes by shifting from a technology push to a user-need focus. Additional workshops and webinars may be needed before the level of technical details are sufficiently translated and understood by both communities.
- 4. Integrate Tools and Data.** Once technical requirements are clearly defined, understood, and tested, tools for ingesting NASA data into Forest Service models, systems, and workflows will need to be developed. For example, developing methods to integrate multi-sensor data as inputs into fuel models are needed before the technology can be operationalized.

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<sup>1</sup>Soil Moisture Active Passive

<sup>2</sup>National Aeronautics and Space Administration–Indian Space Research Organisation Synthetic Aperture Radar

<sup>3</sup>Ice, Cloud, and Land Elevation Satellite-2

<sup>4</sup>Global Ecosystem Dynamics Investigation

<sup>5</sup>Carbon Monitoring System

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## CHAPTER 1.0 IMPETUS FOR THE WORKSHOP

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From April 29 through May 2, 2019, a collaborative workshop included participants of the Forest Service, multiple NASA missions/projects, multiple NASA data centers, other federal, state, and tribal land managers, and users of Earth observation data as well as academia. This workshop was held to increase awareness of data application in support of land and natural resource management goals. A primary goal of the workshop was to prepare a framework for aligning NASA missions and products with the broad scope of land management agency needs for data-informed management strategies under a changing climate. A coherent framework is critical since the Forest Service faces many natural resource management challenges exacerbated by climate change, human development pressure, and forest disturbance (e.g., fire, plant pests, and pathogens). Continuing shifts in climate and increasing weather variability affect ecological processes (Bradford and others 2018). Such changes challenge natural resource managers to ensure that landscape resilience and planning for desired conditions are developed considering climate adaptive policies and strategies.

In addition to the affected ecological processes driven by climate change, the Forest Service's limited financial resources further challenge agency capabilities to effectively manage natural resources. For example, the area burned by wildfires in the United States has more than doubled since 2000 compared to the prior two decades, driven mainly by declines in summer precipitation and increases in temperature in the western United States (Jolly and others 2015). California has recently experienced an exceptional drought (2011–2017), resulting in record-breaking wildfires and causing severe economic losses—including \$5.5 billion in agricultural losses from 2014 through 2016 (Kam and others 2019), followed by another extreme drought and fire season in 2018. From 1995 to 2015, the portion of the Forest Service's annual appropriated budget devoted to fire increased from 16 percent to over 50 percent (USDA FS 2015a). As the agency directs increasing resources to provide for firefighters, aircraft, and other assets necessary to protect lives, property, and natural resources from wildfires, fewer funds and resources are available to support other agency work. In addition to wildfire impacts, hundreds of millions of trees have died in the 21st century in the United States from droughts and insect outbreaks (USDA FS 2020), and recently, the U.S. Department of Agriculture (USDA) designated rangelands in 25 counties in New Mexico and Arizona as primary natural disaster areas from persistent drought.

With limited resources and expanding need, remote sensing is an increasingly appealing option for gathering the key information needed to inform land management decisions. Remote sensing and GIS technologies provide Forest Service natural resource managers with a more cost-effective approach to monitoring natural resources on National Forest lands, helping to inform management decisions and delivering benefits to the public. Forest Service land managers can leverage up-to-date science available from NASA Earth-observing capabilities to support improved decision-making to improve and sustain our nation's forests' and grasslands' health, diversity, and productivity. NASA Applied Sciences Applications programs promote the use of



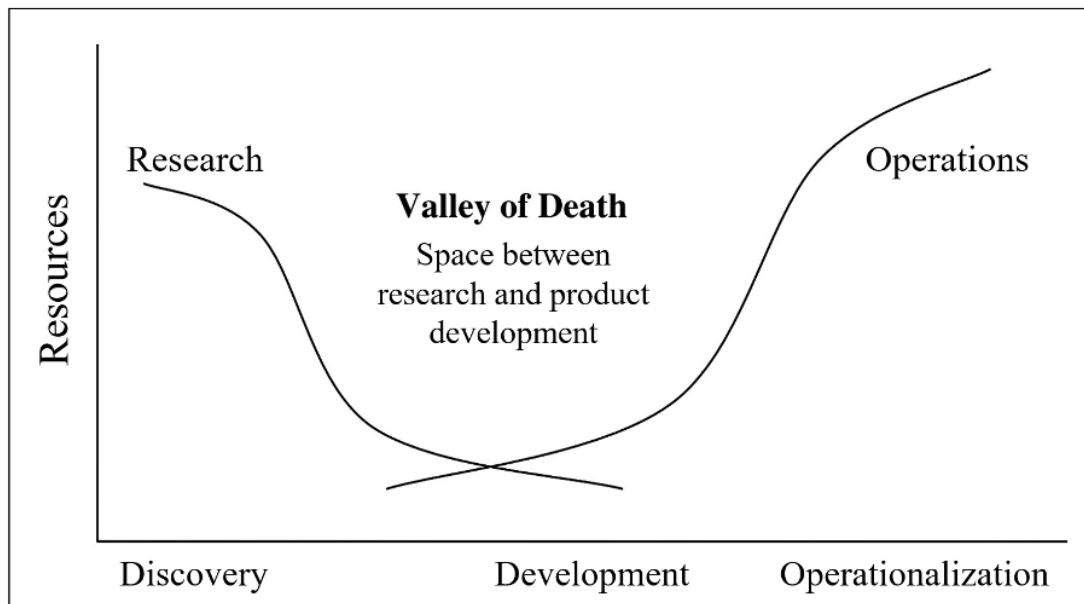
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NASA Earth Observation (EO) information through applied research and engagement activities with end-users. Included in the NASA program goals are to increase awareness of NASA capabilities, understand end-users' data needs, and provide technical support to enable the implementation of NASA observation data into users' decision-support systems. While there are significant opportunities for NASA and the Forest Service to collaborate more effectively, these agencies have a long history of working together. In 1964, USDA and NASA signed an agreement designating the Forest Service as the lead agency for remote sensing applications in forestry and range sciences. In 1971, NASA and the Forest Service initiated the Nationwide Forestry Applications Program as a joint effort. Since then, the two agencies have partnered on many initiatives and projects, including the Tactical Fire Remote Sensing Advisory Committee (TFRSAC), which supports the development, evaluation, and integration of remote sensing technology in support of all phases of wildland fire. The TFRSAC has since grown to include other agencies. These past collaborations and the desire by both agencies to improve land management efficiency and efficacy gave rise to this significant workshop detailed in these proceedings. Furthermore, while the emphasis at this workshop was on past, current, and continued partnership between the Forest Service and NASA, the inclusion of other federal, state, tribal and academic representatives from both the land management and geospatial production perspectives allowed for a more comprehensive and cohesive assessment of EO data needs, applications, and challenges.

A central theme of this workshop was to address the gap between new and emerging NASA technologies and the tools needed by people managing resources on the ground. This gap, often referred to as “the Valley of Death”<sup>1</sup> (fig. 1) was discussed extensively at the workshop. Attendees agreed that bridging this “research-to-operations” gap would ensure better collaboration, and ultimately, the operational use of needed management tools and capabilities. The needs of the Forest Service identified in the workshop included soil moisture and hydrology, vegetation structure and function, emissions, and flux especially relating to monitoring, reporting, and verification (MRV).

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<sup>1</sup> E.g., <https://www.nap.edu/read/10658/chapter/4>



**Figure 1**—Illustration of the reduction in resources between research and operations (Valley of Death).

## 1.1 Workshop Goals and Objectives

The 3-day Forest Service–NASA Joint Applications Workshop, held April 29 through May 2, 2019, at the Forest Service Geospatial Technology and Applications Center (GTAC) in Salt Lake City, Utah, served as a forum to share and demonstrate the capabilities of NASA data products, as well as to foster connections and strengthen partnerships between the two agencies and other partners. In support of these goals, the meeting objectives were to:

1. Share and prioritize Forest Service operational needs with NASA ([Chapter 3.0 Forest Service Operational Needs](#));
2. Provide an overview of NASA missions and projects, data, and tools supporting natural resource management ([Chapter 4.0 NASA Programs](#));
3. Identify opportunities for collaboration; and
4. Expand Forest Service awareness of NASA data sources and tools and mutually explore ways to advance information delivery.

To address these objectives, the meeting agenda<sup>2</sup> included a mix of informative sessions punctuated by breakout sessions, hands-on data tutorials, and a poster session. The three breakout session topics included: soil moisture and hydrology; vegetation structure and function; and carbon emissions and flux. The workshop focused on five key discipline areas that are relevant for Forest Service management needs which can

<sup>2</sup> Full workshop agenda and presenter slides available on the workshop website (<https://pikesmeetings.wixsite.com/aeoip/2019-joint-usfs-nasa-workshop>)

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feasibly be addressed with a suite of EO data products and tools:

1. Soil moisture and hydrology—soil moisture dynamics, soil productivity and erosion, inventory and condition of wetland, riparian areas, and groundwater dependent ecosystems, aquatic habitat suitability, land cover and hydrological change and vulnerability;
2. Vegetation condition—vegetation structure and function, silviculture, rangeland management, fire and fuels, wildlife habitat, forest health, and carbon monitoring;
3. Emissions and flux—including air, aerosols, greenhouse gasses (GHGs) and carbon flux;
4. Detecting, assessing, and monitoring ecosystem vulnerabilities due to changing environmental conditions (climate change, and other biotic and abiotic stressors);
5. Data and tools for knowledge synthesis including things such as supported data formats, cloud computing (big-data handling), integration (mission, tools), and technology transfer.

To address each of these key discipline areas, the NASA Carbon Monitoring System (CMS) Program and four NASA Earth Science Missions were represented at the workshop, including Soil Moisture Active Passive (SMAP); NASA-ISRO, Synthetic Aperture Radar (NISAR); Ice, Cloud, and Land Elevation Satellite-2 (ICESat-2); and Global Ecosystem Dynamics Investigation (GEDI).

## **1.2 Workshop Attendees**

With the primary aim of streamlining coordination and strengthening partnerships between NASA and the Forest Service, in-person participation at the workshop was mainly from Forest Service (51 percent) and NASA (21 percent), but also included in-person participation from other U.S. government agencies (5 percent), academia (16 percent), Distributed Active Archive Centers (DAACs) (5 percent), and private firms (2 percent) (table 1). Overall, the workshop brought together 103 participants—78 in-person and 25 via remote access. The diversity of organizations and agencies participating in the workshop is shown below.

**Table 1**—In-person workshop attendance.

Organization	People (no.)
<b>USDA Forest Service</b>	
Forest Service Region	5
Forest Service Washington Office	5
Forest Service Washington Office GTAC	3
Forest Service Research & Development	11
Forest Service State & Private Forestry	6
Forest Service Other	1
<b>NASA</b>	
NASA HQ	1
Langley Research Center	1
Jet Propulsion Laboratory	3
Goddard Space Flight Center	12
Goddard Institute of Space Studies	1
Ames Research Center	2
NASA Other	2
<b>Academia and Other Government</b>	<b>25</b>
Total	78

In-person participants besides the Forest Service or NASA were from the National Oceanic and Atmospheric Administration (NOAA), USDA Natural Resources Conservation Service, and United States Geological Survey (USGS). In-person participants from academia were from the University of Maryland, Massachusetts Institute of Technology, Colorado State University, Boise State University, Michigan Technological University, Clark University, Virginia Tech, University of Utah, Texas A&M University, and University of Texas at Austin. The workshop also counted with representation from three DAACs: the NASA DAAC at the National Snow and Ice Data Center (NSIDC); the United States Department of Energy (DOE) Oak Ridge National Laboratory; and the University of Alaska Fairbanks' Alaska Satellite Facility. In addition, 2 percent of the in-person participants were from private firms that support government clients: Creare, LLC and Global Science & Technology, Inc.

In-person participants representing the USDA Forest Service included people from the Geospatial Technology and Applications Center—host center for the workshop—as well as from other centers, offices, research stations, and divisions. These included the Eastern Forest Environmental Threat Assessment Center, Forest Inventory and Analysis, Forest Service Pacific Southwest Region Remote Sensing Laboratory, Office

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of Sustainability and Climate, Southwestern Regional Office, Intermountain Region, Alaska Region, Pacific Northwest Research Station, Rocky Mountain Research Station, Allegheny National Forest, Northern Research Station, and Redcastle Resources, Inc.

### 1.3 Workshop Planning Committee

Key representation from Forest Service, NASA Mission Applications leads for SMAP, ICESat-2, CMS, and NISAR, as well as ICESat-2 researchers who focus on biomass, came together to create a workshop planning committee. This committee, led by Erik Johnson (Forest Service) and Chalita Forgotson (NASA, SMAP) and described in detail below, facilitated planning of the workshop and ensured a stakeholder-led initiative. Forest Service representatives guided development of the workshop making sure that the planned presentations, breakout panels, and tutorials would all advance information relevant to Forest Service operational needs. The Applications leads for the NASA missions and CMS program supported the development of the workshop, providing guidance on its structure and content, as well as facilitating involvement of key mission representatives and the NASA DAACs. As part of the committee, the ICESat-2 researchers were given the opportunity to provide feedback on overall organization of the workshop agenda and were actively involved in development of the Vegetation Structure and Function breakout panel (Day 2) and with the tutorial for leveraging sampling observations for regional vegetation structure assessments (Day 3).

#### Workshop planning committee members and their affiliations.

Name and position	Organization
<b>Everett Hinkley</b> (National Remote Sensing Program Manager/Satellite Needs Working Group member)	Forest Service/Engineering, Technology, & Geospatial Services
<b>Erik Johnson</b> (Program Analyst)	Forest Service/Office of Sustainability & Climate
<b>Carlos Ramirez</b> (Program Manager—USDA Forest Service, Pacific Southwest Region, Remote Sensing Lab)	Forest Service/Pacific Southwest Region Remote Sensing Laboratory
<b>Jess Clark</b> (Remote Sensing Analyst and Assistant Program Leader at GTAC)	Forest Service/GTAC
<b>Justin Epting</b> (Remote Sensing and GIS Specialist and Assistant Program Leader at GTAC)	Forest Service/GTAC
<b>Matt Reeves</b> (Research Ecologist)	Forest Service—Rocky Mountain Research Station, Human Dimensions Program
<b>Raha Hakimdavar</b> (Hydrologist)	Forest Service/Watershed, Fish, Wildlife, Air, and Rare Plants
<b>Stacie Bender</b> (Geospatial Specialist and Assistant Program Leader at GTAC)	Forest Service/GTAC
<b>Birgit Peterson</b> (ICESAT-2 Early Adopter)	USGS/Earth Resources Observation and Science Center

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Table continued.

Name and position	Organization
<b>Nancy Glenn</b> (ICESAT-2 Early Adopter)	Boise State University
<b>Amy Neuenschwander</b> (GEDI)	University of Texas
<b>Andreas Colliander</b> (SMAP)	NASA JPL
<b>Narendra Das</b> (SMAP)	NASA JPL
<b>Chalita Forgotson</b> (SMAP Applications Lead)	SSAI/NASA Goddard
<b>Sabrina Delgado Arias</b> (ICESat-2 Applications Lead)	SSAI/NASA Goddard
<b>Natasha Stavros</b> (NISAR Applications Lead for Ecosystems)	NASA JPL
<b>Edil Sepulveda Carlo</b> (CMS Applications Lead)	SSAI/NASA Goddard

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## CHAPTER 2.0 MEETING OUTCOMES AND BREAKOUT SESSION FINDINGS

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The workshop accomplished the key objectives of increasing land management agency awareness and understanding of the capabilities of NASA data products, as well as the development of connections and strengthening the partnership between NASA and the Forest Service. Identification of opportunities for further collaboration between Forest Service and NASA included the topics of soil moisture and hydrology, carbon emissions and flux, and vegetation structure and function. The workshop breakout sessions discussed key opportunities and challenges around utilizing NASA technology by land management agencies. In support of increased Forest Service–NASA coordination and collaboration, four key high-level opportunities were identified:

- 1. Develop a Strategic Framework for Collaboration and Coordination.** A coordinated approach to prioritize work between the agencies will result in a more efficient use of NASA earth observation data. Describing connections and assigning contacts for activities such as sharing data, transferring technology, or conducting research will streamline efforts and allow for a better understanding and integration of program needs.
- 2. Establish Working Groups and Engage in Early Adopter Programs.** Involving land management agencies in the development of requirements for future missions will help meet science and management objectives. Piloting NASA technology with land management scenarios and working together iteratively will yield tools highly applicable to the needs of land managers.
- 3. Distill Needs Requirements and Conduct Feasibility Studies.** Additional work refining stakeholder needs and clearly outlining barriers to adoption will help determine where to focus resources. Considering stakeholder needs as it pertains to decision support and science from a multi-mission perspective will improve outcomes by shifting from a technology push to a user-need focus. Additional workshops and webinars may be needed before the level of technical details are sufficiently translated and understood by both communities.
- 4. Integrate Tools and Data.** Once technical requirements are clearly defined, understood, and tested, tools for ingesting NASA data into Forest Service models, systems, and workflows will need to be developed. For example, developing methods to integrate multi-sensor data as inputs into fuel models are needed before the technology can be operationalized.

The objectives of the workshop’s breakout sessions were to: (1) provide an overview of NASA missions and projects, data, and tools supporting natural resource management; and (2) share and prioritize Forest Service operational needs with NASA. In addition to the tutorials and collaboration during the breakout periods, a main product of this process was to enumerate key points for each main topic. Breakout sessions emphasized: (1) soil moisture and hydrology; (2) emissions and flux; and (3) vegetation structure and function. The soil moisture and hydrology breakout discussed the general paucity of consistent soil moisture data collected on federal lands and how it limits Forest Service managers’ capabilities to monitor and detect changes to guide

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management decisions. The vegetation structure and function panel discussion highlighted the needs for post-disturbance recovery, species-specific density and canopy cover, characterization of understory vegetation, and phenology. The emissions and flux panel discussion emphasized that despite a number of maps produced, the products might not be compatible with the country's institutional needs and readiness.

Breakout sessions discussed key opportunities and challenges around NASA technology utilization by land management agencies. All three panels agreed that there are gaps in science and applications of EO data products, along with challenges in translation of agency language and needs, preventing managers from holistically using EO data in their decision-support systems.

## **2.1 Soil Moisture and Hydrology Breakout Panel**

The Soil Moisture and Hydrology breakout panel provided a forum for all participants to discuss technology, management needs, and existing gaps together; and document individual and group recommendations on ways to close gaps and prioritize next steps. The breakout session provided a single forum for managers and scientists from various disciplines to meet and discuss technology opportunities and needs around soil moisture and hydrology. The 2.5-hour session began with three panel presentations followed by discussion and questions from the audience. Twenty-five attendees from science, management, and leadership backgrounds participated in the breakout session.

Following presentations and discussion, the organizers posted the following questions on individual poster boards and asked attendees to answer each question on a sticky note and place their answers on corresponding poster boards:

1. What Forest Service information needs do NASA's existing products address?
2. What are the remaining data/knowledge gaps?
3. What are the biggest technical challenges around this topic that data and tools could fill?
4. What level of error/uncertainty is acceptable?
5. What scale and resolution are needed?
6. How can we best fill the gaps?
7. What recent discoveries have you made on the topic that could help fill data and knowledge gaps?
8. How would you prioritize what needs to be done next?

A common theme voiced by breakout session participants was for Forest Service and NASA to develop a strategic framework for collaboration and coordination to enable uses of NASA data products to support Forest Service management needs. One challenge presented by this exercise was the difference between NASA scientists' and Forest Service managers' understanding of spatial scales needed for informing management decisions. Forest managers are typically concerned with resources at site-specific scales (e.g., stream reaches, forest stands, and so on) whereas SMAP data,

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for example, provides information at synoptic scales. The apparent mismatch between data availability (scale) and management capability was identified as a barrier to using NASA technology for some management applications.

The group identified both short- and long-term actions to increase collaboration and reduce barriers as follows:

- Develop a strategic framework for collaboration and coordination, including updating or entering into new agreements between NASA and the Forest Service.
- Create a platform for collaboration and coordination.
- Identify stakeholders and develop a “Water and Vegetation” working group.
- Collaborate on integration of in situ observations (Forest Service) and satellite observations (NASA SMAP) to improve forest soil moisture and vegetation water content data.
- Develop matrix for Forest Service management requirements. In addition, conduct additional meetings, workshops, and webinars to refine the metrics.
- Provide support for Forest Service managers in terms of capacity building and leveraging existing tools to enable the use of NASA data products for decision-support systems.

These concepts are summarized in the joint Breakout Session Report found in appendix A.

## **2.2 Vegetation Structure and Function Breakout Panel**

Vegetation structure and function information is needed to assess current resource conditions and risks, to develop land management objectives, to implement projects designed to meet those management objectives, and for the monitoring of progress in meeting those objectives. The Forest Service has the Forest Health Protection and Forest Health Monitoring programs to monitor forest health impacts related to climate change, extended drought, and insects and disease. Attributes of interest include tree status (live, dead, or stressed), tree mortality, and canopy cover loss. In addition, the Forest Service Planning Rule of 2012 requires a baseline assessment of carbon stocks, defined as the total ecosystem carbon stored in living biomass, dead wood, litter, and soil.

The 2.5-hour session began with presentations followed by discussion and questions from the audience. Twenty-five attendees from science, management, and leadership backgrounds participated in the breakout session. During the vegetation structure and function breakout, common threads were identified regarding the goals of the Forest Service and the relevant information needs. Among the themes frequently mentioned in need of more data for informed management were: change detection and recovery (with wildland fire being a leading agent of change); long-term, continuous

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and consistent monitoring and recording of landscape conditions; forecasting future conditions; data integration (remote sensing data as well as other data sources) and modeling; and assessment of vulnerability and resilience of landscapes to disturbance and change. Remote sensing data from existing, new, and future missions were identified as key sources to address these management needs. Next, Forest Service concerns regarding the meaningful use of these data were reviewed, again looking at common themes that had evolved through previous discussions. Among the leading concerns were:

1. There is difficulty in integrating new technology and data streams, especially when integrating into current established and operational decision-support mechanisms.
2. Application of remote sensing observations at appropriate scales must be considered, e.g., project-, watershed-, regional-, or national-level. Of considerable concern was how to integrate data published at 500 m, 1 km, or greater scales to local management needs. Researchers and managers working at regional or national scales or with more coarse spatial resolution felt potentially left out of the discussion.
3. Reluctance to rely or depend on a data stream that is not operational. This was a key issue brought up throughout the course of the workshop.
4. Recognition of value added to decision-support systems by adding new EO System, or EOS data. However, potential trade-offs need to be understood and appreciated; e.g., is integration of new data worth the additional cost?
5. Data latency, that is, when are the data available for ingestion into researchers' analyses and/or managers' decision-making processes?

Suggested pathways were reviewed for NASA missions to promote the integration of new data into Forest Service management needs. Foremost was continued and structured communication with end-users to define product development and specifications for utility. Second, a desire for a focus on data streams for observing and understanding climate, disturbance/recovery, and vegetation dynamics was highlighted. Third, there was an expressed need for data and products applicable at different scales and resolutions. While the value of synoptic assessments was appreciated, the consistent mention of "global" products raised considerable concern for those working in smaller areas (see point 2 in list above). Fourth, there is a need for continued dedicated outreach on behalf of NASA to work with the potential applications community to ensure the integration into operational decision-making. Finally, effort needs to be placed into ensuring easy access to data and products, limiting roadblocks where at all possible. Making data easy to locate, easy to download, and easy to work with was paramount. From a NASA mission perspective, it was stressed that feedback from the management/decision-making perspective is extremely valuable. It helps inform data gaps and promote appropriate data use. It also helps define future missions.

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Key findings and recommendations from participant responses for four selected management topics have been condensed in the joint Breakout Session Report found in appendix A below to summarize how well current NASA products match current Forest Service needs, to identify the barriers and gaps, and to propose ways that these might be overcome. The four selected topics are:

1. Silviculture: National Environmental Protection Act and management planning including harvest areas.
2. Fire and fuels: Modeling fire behavior and effects, fuel treatments.
3. Range management: Change over time including biomass and pinyon/juniper encroachment.
4. Wildlife habitat: Habitat modeling with vegetation lifeform (forest/woodland, shrubland, herbaceous) and multi-layer cover.

A specific Forest Service management need that was identified is an improved ability to quantify understory vegetation, which contributes to complexity of vertical and horizontal vegetation structure and is relevant to all four selected management topics. Most satellite-based remote sensing naturally lends itself to better overstory than understory characterization.

There was consensus that the Forest Service should be involved at an early stage of NASA mission planning, such that NASA products are responsive to Forest Service management needs. Differences in terminology between NASA and the Forest Service are a barrier. For example, a NASA biomass product might be highly relevant and useful as an indicator of fuel loads, yet not be used by fuel managers. Attention to translation of NASA products to Forest Service managers would help overcome this cultural gap. Forest Service scientists who are familiar with both cultures are well positioned to serve as bridge builders to managers and planners, and to increase awareness of available NASA data products, such that they are adopted and used more for informing decisions.

In summary, the breakout session identified a number of opportunities to overcome the current gaps between NASA products and Forest Service needs with regard to vegetation structure and function. Simple but proven strategies to engage all participants (small group discussions, integrating across areas of expertise, flip charts) resulted in a richer set of findings than would have likely resulted had we tried to extract information from all 25 participants as a whole and at the same time. This procedure is recommended for future workshops, particularly with regard to future NASA mission planning.



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## 2.3 Emissions and Flux Breakout Panel Breakout Panel

The session began with panel presentations followed by discussion and questions from the audience. Thirteen attendees from science, management, and leadership backgrounds participated in the breakout session. The emission and flux breakout panel made numerous references to the international nature of carbon accounting with respect to emissions and flux. There was general agreement that we have made significant progress towards more accurate carbon accounting with systems such as CMS. However, it was also agreed that the progress over the last decade should be used as a catalyst for further improvements in how we account for emissions and especially how they are communicated across different disciplines. Cross-cutting themes that emerged from the scientist and stakeholder case studies in the breakout session were a need for: (1) greater spatial and temporal resolution in data products; (2) attribution of emissions and fluxes to human activities and natural phenomena; (3) availability of reference data and geolocation accuracy for data harmonization; (4) modeling to support base reporting and scenario analysis for the past, present, and future; and (5) better characterization of uncertainty. The Forest Service and NASA each bring unique assets and expertise in support of emissions and flux estimates and collectively, through collaboration and co-production with internal and external stakeholders, can begin to address these themes and others. The joint Breakout Session Report found in appendix A represents case studies presented by stakeholders and scientists highlighting collaborations and opportunities to close important science and reporting gaps associated with emissions and flux estimation domestically and abroad.

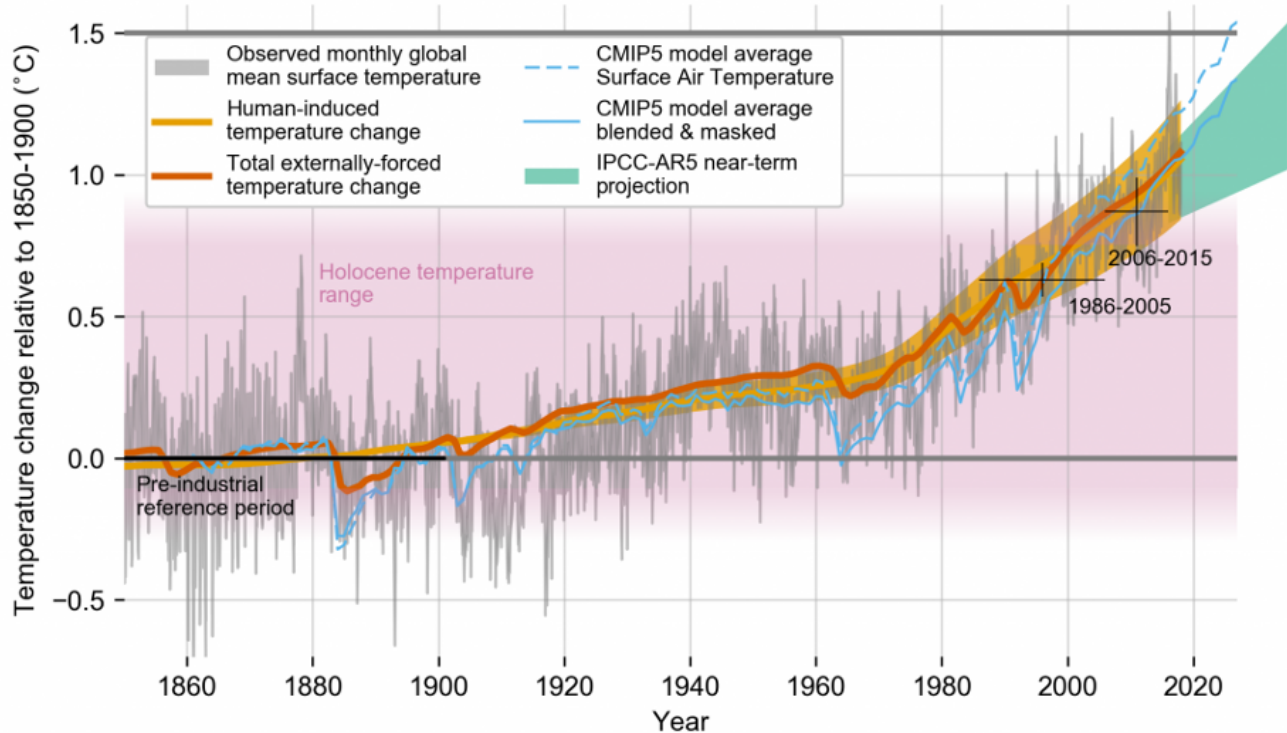
## 2.4 Data and Tool Tutorials

Tutorials were used to provide an overview of NASA missions and projects, data, and tools supporting natural resource management. These hands-on data tutorials to build Forest Service capacity to use NASA data products to support their management needs are summarized in appendix A.

## CHAPTER 3.0 FOREST SERVICE OPERATIONAL NEEDS

The Forest Service manages 193 million acres of public lands and provides assistance for another 500 million acres of state and private lands through state forestry agencies. These lands provide public access through 57,000 miles of trails and 4,300 campgrounds, generating more than \$18 billion per year in recreation-based revenue to small communities across the country. The largest concentration of Forest Service lands is in the western United States, and while Forest Service lands comprise a smaller footprint in the east, they were acquired early in the 20th century, in part to protect critical watersheds.

The 2018 IPCC report on change states, “The planet has warmed 1.9 °F / 1.0 °C (average across land and sea) since the latter half of the 19th century, and four of the last five years were the hottest ever recorded” [see figure 2 from *IPCC Special Report: Global Warming of 1.5 °C* <https://www.ipcc.ch/sr15/chapter/chapter-1/>]. Greater natural disturbances such as more intense storms and larger, more intense fires are being observed. Science provides an understanding of the change that is happening and forecasts future impacts as noted in reports like the *Fourth National Climate Assessment* [<https://nca2018.globalchange.gov/>]. Prolonged droughts across the landscape, particularly in the West but also in the South, are a major concern, as are flash droughts in the West, Southwest, and upper Midwest.



**Figure 2**—Evolution of global mean surface temperature (GMST) over the period of instrumental observations. Source: IPCC 2018: Global Warming of 1.5 °C, Chapter 1, Figure 1.2. (Allen et al. 2018).

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Drought over prolonged periods causes forest decline and tree mortality due to plant stress and lowered resistance to insects and diseases, which can lead to drier forests and dead trees, and can contribute to larger and more intense fires and limit tree ingrowth. The fire behavior in California and other western states shows the risks and impacts of prolonged drought. More than 129 million trees have died in the past 20 years, increasing the fire risk. These dead and dying trees, coupled with fire, also put the Central Valley's irrigation water resources at risk.

Past studies have focused on understanding fire behavior and burned areas across ecosystems in the western United States; however, it is equally important to map and quantify early warning signs of stress in these vulnerable ecosystems. For example, remote sensing methods to detect when forest systems are at risk of fire would be particularly valuable to the land management community. Such early warning signaling would help prioritize management activities on the ground. A fundamental question discussed in the workshop asks: How do we bridge the gap between science and new technology and how do we package that information into tools and clear, defensible information that managers can use? The following list provides examples of environmental information needed by land managers to address bridging this new technology applications gap:

- More timely change detection in forest cover to guide changes in policies and practices.
- Forest soil moisture detection to guide restoration decisions.
- Early warning systems for drought stress to prioritize treatments.
- Changes in snowpack to guide annual water management and adaptation practices.
- Better weather and streamflow information at mid- and high-level elevations to guide water management.
- Changes in range productivity to guide herd and range allotment.

The workshop participants also discussed a need to leverage investments in Smart Forests for the 21<sup>st</sup> Century (<https://www.smartforests.org/>). These sites, located across National Forest lands, contain digital environmental sensors and wireless communications that have the ability to connect with NASA technology to improve instrument calibration and validation. The Forest Service also manages long-term datasets collected at Experimental Forests and Ranges, particularly on water flow that could be used to inform emerging NASA technology and provide better tools for managers.

### **3.1 Soil Moisture and Hydrology**

The Forest Service requires consistent and effective forest soil moisture monitoring to support management decisions to ensure natural resources meet or move toward

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desirable conditions. Forest soil moisture monitoring helps the Forest Service monitor and predict droughts in forests and rangelands; predict wildfires and other disturbances; plan for reforestation and promote predisturbance resilience and resistance; and improve hydrologic and snowpack modeling for sustainable watershed management. While the SMAP mission provides timely and frequent global soil moisture data for near surface and plant root-zones, accuracy of soil moisture estimates in forested areas is limited. Currently, the SMAP program is conducting a field experiment to calibrate and validate forest soil moisture estimates. However, the existing sparse forest soil moisture network limits SMAP's capability to improve forest soil moisture estimates.

There are many opportunities for use of soil moisture information at multiple scales of forest and grassland management. Balancing the needs for soil moisture information with the capacity to utilize the information requires an understanding of management decision risk. All land management decisions incur some level of risk. At some point additional information to inform a decision will not have a substantial reduction of risk. The level of acceptable risk needs to be part of the determination on how much information is required. Soil moisture information is readily available at coarse scales for use in forest and grassland management. Some of the current information fits well for National Forest-wide or multi-state planning and assessments. However, at a project scale the cost to obtain the specificity needed for soil moisture information and the level of risk that is reduced may not justify the pursuit of the information. Individual soil moisture data needs are variable by project type as much as they are by scale. Some common needs include reforestation/seedling, rangeland readiness for grazing use, predicting resilience and resistance of plant communities to disturbance to aid adaptation to climate change, determining management intervention needs following fire, and forest and grassland management planning. Workshop participants discussed the need to match opportunities and needs to capacity, and they considered the importance of identifying common applications of soil moisture data, simplifying an already filled tool box, and acknowledging that we must adapt the use of soil moisture information to changes in land management priorities. Future prioritization for soil moisture information may need to focus less on data availability and more on the understanding of management applications to utilize the information. A strong connection between the type of information needed to make a land management decision and the tools to interpret soil moisture information may be the priority.

The average annual area burned by wildfires in the United States has increased since the mid-1980s. This increase is primarily attributable to a decline in summer precipitation events with some additional influence from increasing atmospheric aridity, a result of warming air (Holden and others 2018). In addition, increases in severe and extended droughts in the southern and western United States over the past decade has led to unprecedented tree deaths. Droughts kill trees directly or predispose trees to attacks by bark beetles and other insects. Ready access to forest

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soil information is critical to understanding thresholds of change for reduced growth as well as predicting tree mortality events. Efforts are underway to develop a National Soil Moisture Network by integrating individual networks into a single database. Since 2013, soil moisture researchers have come together at annual National Soil Moisture Workshops to further this goal.

A central challenge to achieving this goal in the forest sector is the shortage of in situ soil moisture sensors (stations) located in forested locations. Of the 1,902 known stations belonging to soil networks situated around forested regions of the country, only 450 stations (24 percent) are actually in or adjacent to forests; and due to difficulties situating equipment directly under forest canopies, many of the 450 stations are not representative of actual forest soil conditions. The 2018 Farm Bill, which requires the Secretary of Agriculture to conduct a review of the geographic coverage and density of existing data collected by USDA and other governmental and nongovernmental entities, provides an opportunity to incorporate more monitoring stations in forest and grassland ecosystems. Additional datasets exist such as Forest Service Experimental Forests and Ranges (EFRs), the National Science Foundation's Long-Term Ecological Research programs (LTERs), and the National Ecological Observatory Network (NEON). However, an accounting for integrating unique forested sites with ongoing soil moisture measurements within EFRs, LTERs, NEON, and related efforts (e.g., AmeriFlux and SmartForests) is needed to fill current data gaps including providing important information for calibrating and validating NASA technology. Increasing the use of remotely sensed soil moisture monitoring information together with station data will play a critical role in fulfilling current data needs.

### **3.2 Vegetation Structure and Function**

Information about the condition and status of vegetation structure and function is necessary for achieving the Forest Service mission to sustain the health, diversity, and productivity of the nation's forests and grasslands. The Forest Service is responsible for managing 154 National Forests and 20 National Grasslands comprising about 8 percent of the total land area across the nation (USDA FS 2018). The Forest Service has the Forest Health Protection and Forest Health Monitoring programs to monitor forest health impacts related to climate change, extended drought, and insects and disease. Attributes of interest include tree status (live, dead, or stressed), tree mortality, and canopy cover loss. Forest Service business requirements for vegetation information primarily originate from laws and regulations such as the Organic Administration Act of 1897, the Forest and Rangeland Renewable Resources Planning Act of 1974, the National Forest Management Act of 1978, and the Forest Service Planning Rule of 2012. The Forest Service Planning Rule of 2012 aims to improve and protect the condition of forested areas, secure favorable watershed conditions, and ensure the future supply of forest resources while maintaining and restoring the integrity, diversity, and resilience of ecosystem components and processes. In addition, the Planning Rule of 2012 identifies three different levels of management planning at the national



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strategic level, National Forest unit level, and project or activity level and requires a baseline assessment of carbon stocks, defined as the total ecosystem carbon stored in living biomass, dead wood, litter, and soil. Vegetation maps used for planning at the national, regional, mid-scale, and base (project) levels have set expectations for content, consistency, and accuracy. Accordingly, vegetation classification, mapping, and inventory information and data products are needed at various functional scales depicting ecologically relevant and technically feasible levels of spatial and thematic detail to meet information requirements at all management levels of the agency (Lister and others 2020; Nelson and others 2015). Multiple scales of data are needed to identify and support national and regional goals and policies, for developing landscape goals and priorities, and for informing local project needs.

From a National Forest land and ecosystem management perspective, vegetation structure and function information serve as a foundation for (1) the assessment of current resource conditions and risks; (2) planning to develop conservation strategies and land management objectives; (3) conducting site-specific projects and activities to meet those objectives; and (4) monitoring to evaluate progress (USDA FS 2009). The assessment of forest and watershed conditions helps to inform inquiries related to sustainability, productivity and resilience, historic range of variation, wildland fuel loads, and habitat relationships. Planning involves developing conservation strategies and management objectives, and evaluating various project alternatives and projected outcomes. Individual projects generally consist of resource restoration activities such as fuel reduction treatments, reforestation, timber harvests, and rangeland improvements. Monitoring is conducted to assess change in resource condition and evaluate effects against desired management objectives.

Forest Service management needs in vegetation structure and function stem from program areas and activities related to silviculture, wildland fire and fuels, rangelands, wildlife habitat, forest health, and carbon monitoring, among others. Specific vegetation information needed for characterizing ecosystem condition and informing the management and decision-making process includes forest attributes such as forest species composition, tree height and diameter, basal area, timber volume, and total biomass for silviculture activities; additional attributes such as canopy base height and canopy bulk density for wildland fire behavior modeling and fuels risk assessment; plant community distributions, ground cover, and biomass for rangeland management; multi-layer understory cover, snag density, and down woody debris for wildlife habitat management; the status of tree condition in terms of live, moisture stressed, dead, and canopy cover loss for monitoring forest health; and the amount of carbon stored in the ecosystem, living biomass, soil, dead wood, and litter for baseline assessments and monitoring of carbon stocks.

There are numerous examples of Forest Service units using data produced by NASA to develop indicators of vegetation structure and function. At the workshop, the Forest Health Early Warning System (EWS) was presented as a remote-sensing based EWS



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to provide a regular, consistent, and all-lands approach to forest health monitoring. An EWS is more than forest monitoring though, as it presumes the expectation that monitoring will be used for some proactive purpose that is made possible due to early recognition of a problem and the systematic tracking of its progression. Forest managers are well aware of the challenges they face on the ground, but they are less aware of the locations and spatial extent of where they occur. Systematic monitoring through remote sensing that targets tree mortality, stress, fragmentation, recovery, and other forest health concerns can provide that missing information. The ability to deliver meaningful information varies according to need in addition to the different remote sensing platforms available, the techniques used to process data, and then communication with end-users.

For many intraseasonal forest health problems that manifest at coarse spatial resolution, 250m MODIS is well-adapted. With twice-daily fly-over frequency, clouds are less of a problem for multi-week compositing efforts, and this provides analysts with a reliable means of separating seasonal phenological change and ephemeral disturbances from change that is more substantial. This has been used by the Forest Service's ForWarn II system (<https://forwarn.forestthreats.org/>; Hargrove and others 2009) that generates a range of weekly change products for the entire conterminous United States using twice-daily MODIS imagery. By contrast, satellite platforms that have less frequent revisit intervals are more likely to provide irregular snapshots due to cloud cover, and the higher spatial resolution of these products greatly increases the big-data computational requirements that are needed.

For certain forest monitoring needs such as the effects of changing disturbance regimes on vegetation structure and composition that only manifest across years or decades, high resolution (10s of meters spatial resolution) maps annually or a few times per year are available (LCMAP, LCMS, Global Forest Watch). The 10m Sentinel 2 imagery provides managers with finer resolution products as needed, and given the 5-day temporal resolution of Sentinel 2, change products can be delivered less than a week after disturbance, clouds permitting. The HiForm project provides this on a project-by-project basis (<https://hiform.org>). A landscape perspective on long-term resilience is more appropriately addressed using MODIS by the LandAT tool (<https://landat.org/>) and targeted higher resolution efforts that use the Landsat archive (Vogelmann and others 2012, 2017). Such higher resolution monitoring efforts typically have expectations for a smaller footprint and lower frequency of image acquisition.

For forest disturbances that require near-real-time monitoring, coarse products from MODIS are useful for general disturbances, such as drought monitoring (Brown and others 2008) and large insect and disease outbreaks (Chastain and others 2015). Used in an awareness/operational strategic sense, MODIS change products provide a way to detect landscape change activity that can then be investigated through either higher resolution remote sensing, aerial flights, or site visits (Chastain and others 2015; Hargrove and others 2009). This approach has real limits in mixed forests that

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experience the loss of minor constituent species, as with the scattered mortality of ash from the emerald ash borer.

Remote sensing data has proven useful for recognizing and tracking intraseasonal forest disturbances for a range of early warning applications, yet these, like any technologies, are only effective when they are applied. As forest managers often wait to adopt new technology until its utility has been proven, it is important that developers understand managers' needs and constraints so that future challenges of forest monitoring can be met effectively.

### **3.3 Emissions and Flux**

Consistent information regarding emissions and flux is critical for both greenhouse gas accounting, especially through monitoring, reporting, and verification, and air resources management.

#### ***3.3.1 Monitoring, reporting, and verification***

There is a clear and growing need for accurate, transparent, and reproducible greenhouse gas emission and removal estimates for the land sector in the United States as national (e.g., Paris Climate Agreement, global stocktake), state (U.S. Climate Alliance), and entity-level (e.g., regulatory and voluntary carbon offset markets) needs expand and evolve. Governments around the world have embraced remote sensing as one of the key components of their monitoring systems. Critical to supporting these needs are monitoring, reporting, and verification (MRV).

To this end, there are many drivers of progress in MRV using remote sensing including cost reductions in Earth-observing systems, improvements in radiometric and spatial resolution of imagery, new data collection approaches such as air- and space-borne LiDAR and drone systems, and the ability to interact with imagery, build models, and distribution of results using cloud-based technologies. However, in the midst of this abundance of resources, there is a fundamental problem: there exists such a diversity of similar products, each with its own enthusiastic proponents, that countries are left feeling overwhelmed with so many choices. Often, well-meaning development agencies and others seeking to assist these countries will transfer a single technology with which they have experience, or the one with the most charismatic supporters. As noted by participants in the workshop, the problem with this approach is that there are key questions that need to be asked before a technology is endorsed. The questions discussed included the following:

1. Does the complexity of the technology align with the country's ability to institutionalize it? With institutionalization, the ability to use the technique remains even after the current staff or contractors move on, and external support is not required. If the technology being transferred is too complex, or relies on components that must be furnished by an external donor, it is unlikely to be institutionalized.

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2. Does the technology rely upon components that will become unavailable or obsolete as the science advances? Sometimes a rigid workflow that relies on a specific software platform or image source provided by an external entity is vulnerable to disruption. It is often better to rely on a set of modular process components drawn from a library of institutional knowledge the country has developed. In that way, processes can be assembled strategically, fully understood, and adapted with new tools from within the country.
  3. Are we being stewards of the whole by advocating holistic thinking, rather than focusing on individual products? Often, technical staff become insular and do not recognize how their process relates to the big picture. It is best to promote the construction of a strategic and logical vision for how individual pieces contribute to the overall monitoring system, how to explain or eliminate redundancies, and how to see each component as input to a larger process that addresses a larger goal. This holistic thinking attitude helps break down barriers, because stakeholders are more likely to cooperate when they see themselves as all working toward a common goal.

By carefully considering these three questions, government agencies, academia, and private consultants can more effectively address the need that originally motivated the monitoring work, making the best use of limited financial and human resources. Likewise, these questions can also be applied to air resources management in the Forest Service.

### **3.3.2 Air resource management**

Air resources management is a growing concern as wildfires get larger and wildfire seasons get longer. In addition, federal law and agency policies dictate Forest Service responsibilities to monitor, assess, and prevent air pollution on National Forests and Grasslands. Primary air resource management duties are managing smoke from prescribed and wildland fires; monitoring air quality, establishing air quality related values, and assessing air pollution effects in 88 Clean Air Act Class I Wilderness Areas; preparing air quality analyses for forest planning and projects; reviewing new federal air quality regulations; and reviewing permit applications for new stationary sources of emissions under the Clean Air Act Prevention of Significant Deterioration program and state implementation plans under the Regional Haze Rule. The Forest Service also contributes to state documentation of exceptional events due to wildfires.

The Forest Service manager needs include: easily accessible ambient air concentrations of the criteria pollutants (nitrogen and sulfur oxides, ozone, carbon monoxide, 2.5 and 10  $\mu\text{m}$  diameter fine particulates), ammonia, greenhouse gasses, hazardous air pollutants, and/or fine particulate composition (sulfates, nitrates, ammonium, carbon) on a spatial resolution of 10–100 m grid cells horizontally, 100 m–1 km vertical resolution, measured as hourly to daily measurements of 1 to 10 years duration. Other data needs include total deposition of sulfur and nitrogen containing compounds ( $\text{kg ha}^{-1} \text{y}^{-1}$ ) and measures of algal concentrations in lakes. Such data would be used

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to conduct source apportionment; interpret haze events intercepted by IMPROVE monitors; document heterogeneity of haze causing pollution in Class I areas; track point sources of nitrogen and sulfur oxides to determine how well permitted pollution controls are working or support modeling results; check emissions inventories; verify modeling results for deposition and document exceedance of critical loads for multiple ecosystem components; track down sources of nutrient nitrogen causing algal blooms in lakes; provide early warning of lake eutrophication; and look for methane leaks and determine compliance with lease conditions and the National Ambient Air Quality Standards (NAAQS).

Ongoing NASA–Forest Service air management collaborations revolve primarily around NASA HAQAST (Health and Air Quality Applied Sciences Team) activities with the air quality Regional Partnership Organizations (of which the Forest Service is a charter member) to (1) develop guidance documents for using NASA formaldehyde and nitrogen dioxide satellite data to indicate ambient concentrations of ozone and nitrogen oxide levels in support of wildfire exceptional event demonstrations; (2) improve emissions inventories of nitrogen oxides; and (3) investigate the human health burden of recent wildfires. In addition, Forest Service smoke scientists already collaborate with NASA to improve smoke modeling tools. Lastly, satellite-based EO data play a critical role for managers serving as Air Resource Advisors during wildfires. Air Resource Advisors use visible satellite imagery to “eyeball” plume tracks and compare with BlueSky model predictions; infer plume heights from the satellite imagery to estimate plume heights; and understand transport patterns as smoke is advected aloft by winds. Air specialists also use thermals or burn scar detects for fire modeling to pinpoint the location and size of fires. Within meteorological models, initialization products incorporate cloud drift winds detected from satellites to help with the initial numerical solution of models.



## CHAPTER 4.0 CONCLUSION AND FUTURE ENGAGEMENT

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The inaugural joint applications workshop led to an improved understanding of the information needs of the Forest Service to aid in land management decisions and operational NASA satellite missions and data products. In summary, three key outcomes resulted from this inaugural meeting. First, both the Forest Service and NASA cited a lack of consistent communication at appropriate management levels within the agencies as a barrier towards adoption of NASA data products into Forest Service workflows. This was highlighted by the consistent theme that the current models of data portals are intimidating or time consuming to use for most managers, and more emphasis is needed on converting the data to information in key areas of opportunities, as is indicated in appendix A, the workshop summary document. Second, workshop participants recognized the need to advocate for better dissemination of the various sensor missions into science information so that it is ready to use and simple to navigate and understand. Third, the workshop led to a series of deliverables that are ongoing and are in direct response to action items and logical next steps identified at the workshop.

These three action items include the formation of a partnership (formalized in 2021 as the “**Applied Earth Observation Innovation Partnership**”), a virtual “Pitch Fest,” a post workshop publication (McAndrew and others 2019), a detailed questionnaire, and a virtual “Ideas Forum.” The **Applied Earth Observation Innovation Partnership (AEOIP)** website (AEOIP; <https://www.aeoip.com/>) provides information on the partnership, previous and upcoming events, publications and media, and NASA resources supporting natural resources management. For the Pitch Fest, a subgroup of the original workshop’s planning committee devised a virtual platform to share ideas and spark new collaborations around using NASA data products and tools to meet pressing land management needs. An outcome of the Pitch Fest was the selection of a group of projects where collaborators agreed to codevelop science products to meet specific needs of managers. Twelve out of 55 pitches were chosen to move forward with and are ongoing at this time. The goals of the Ideas Forum were to:

1. Provide specific feedback to pitch teams and awareness of data, tools, and expertise to help the ideas reach their potential.
2. Create a collaborative environment where teams have access to people and tools needed to codevelop a path forward.

A detailed questionnaire given in the months following the Ideas Forum helped participants and organizers understand the experiences of each other and also the types of activities they engage in regarding remotely sensed and other spatially explicit information. This questionnaire provided valuable information for creating mutually beneficial activities and collaborations in the future.

This initial workshop was a successful engagement that serves as a roadmap for improved collaboration between NASA and the Forest Service as well as other federal, state, tribal, and academic partners. Furthermore, the outcomes of this workshop have



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established a general forum in which representatives from the resource management, remote sensing science, and data analysis communities can collaborate, innovate, and share new products, tools, and applications. The workshop paved the way for several workshops and webinars and the AEOIP continues the work of improving collaboration and data sharing between NASA and the land management agencies and other data providers. The USDA–NASA memorandum of understanding signed in November of 2020 will help to strengthen this partnership, and it provides an agreement to cover more focused engagements in the future.

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## ACRONYMS

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ARSET: Applied Remote Sensing Training

ATLAS: Advanced Topographic Laser Altimeter System

AWS: Amazon Web Services

CMS: NASA Carbon Monitoring System

DAAC: Distributed Active Archive Center

DEVELOP: Digital Earth Virtual Environment and Learning Outreach Project

EO: Earth Observation

EFR: Experimental Forests and Ranges (Forest Service)

EOS: Earth Observation System

ESA: European Space Agency

EWS: Early Warning System

FGDC: Federal Geographic Data Committee

FIA: Forest Inventory Analysis

FORCaMF: Forest Carbon Management Framework

GEDI: Global Ecosystem Dynamics Investigation

GEE: Google Earth Engine

GTAC: Geospatial Technology and Applications Center (Forest Service)

HAQAST: Health and Air Quality Applied Sciences Team

HiForm: High Resolution Forest Monitoring

ICESat-2: Ice, Cloud and Land Elevation Satellite

InSAR: Interferometric Synthetic Aperture Radar

ISRO: Indian Space Research Organisation

JPL: Jet Propulsion Laboratory

LanDAT: Landscape Dynamics Assessment Tool

LCMS: Landscape Change Monitoring System

LiDAR: Light Detection and Ranging



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LTER: Long-Term Ecological Research  
MODIS: Moderate Resolution Imaging Spectroradiometer  
MRLC: Multi-Resolution Land Characteristics Consortium  
MRV: Monitoring, Reporting, and Verification  
NAAQS: National Ambient Air Quality Standards  
NASA: National Aeronautics and Space Administration  
NEON: National Ecological Observatory Network  
NISAR: NASA-ISRO Synthetic Aperture Radar  
NRCS: National Resources Conservation Service  
PolSAR: Polarimetric Synthetic Aperture Radar  
RGT: Reference Ground Tracks  
SAR: Synthetic Aperture Radar  
SMAP: Soil Moisture Active Passive  
SSURGO: Soil Survey Geographic Database  
TEUI: Terrestrial Ecological Unit Inventory  
TFRSAC: Tactical Fire Remote Sensing Advisory Committee  
UAVSAR: Uninhabited Aerial Vehicle Synthetic Aperture Radar  
USDA: United States Department of Agriculture

## APPENDIX A

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### Breakout Sessions Reports

#### USFS-NASA Joint Applications Workshop

(April 30–May 2, 2019, GTAC, Salt Lake City, UT)

##### ***Key Opportunity Areas for NASA-Forest Service Collaboration***

**Executive Summary:** In 2019, 107 (82 in-person, 25 remote) U.S. Forest Service, NASA (SMAP, ICESat-2, NISAR, CMS, GEDI), and participants from other entities attended the workshop to increase awareness and understanding of the capabilities of NASA data products, as well as to develop connections and strengthen partnerships between NASA and the Forest Service. One of the workshop objectives was to identify opportunities for collaboration between USFS and NASA. During breakout sessions on (1) soil moisture and hydrology, (2) emissions and flux, and (3) vegetation structure and function, participants discussed key opportunities and challenges around utilizing NASA technology by land management agencies. The bullets below represent high-level key opportunity areas for increased NASA–Forest Service coordination and collaboration to support sustainable natural resource management.

- 1. Develop a Strategic Framework for Collaboration and Coordination.** A coordinated approach to prioritizing work between the agencies will result in a more efficient use of resources. Describing connections and assigning contacts for activities such as sharing data, transferring technology, or conducting research will streamline efforts and allow for a better understanding and integration of program needs.
- 2. Stand-up Working Groups and Engage in Early Adopter Programs.** Involving land management agencies in the development of requirements for future missions will help meet science and management objectives. Piloting NASA technology on actual land management scenarios and working together iteratively will increase yield tools highly applicable to the needs of land managers.
- 3. Develop Needs Requirements, Study Feasibility.** Additional work refining stakeholder needs and clearly outlining barriers to adoption will help determine where to focus resources. Considering stakeholder and science needs from a multi mission perspective will improve outcomes by integrating not only technology, but also ideas and perspectives into the process. Additional workshops and webinars may be needed before the level of technical details are sufficiently translated and understood by both communities.
- 4. Tools & Data Integration.** Once technical requirements are clearly defined, understood, and tested, tools for ingesting NASA data into Forest Service models, systems, and workflows will need to be developed. For example, developing methods to integrate multi-sensor data as inputs into fuel models are needed before the technology can be operationalized.

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### ***Panel Discussion Report Out of the Soil Moisture and Hydrology Breakout Panel***

**Summary:** U.S. Forest Service needs consistent and effective forest soil moisture monitoring to support its management decisions that ensure natural resources meet or moving toward desirable conditions. Forest soil moisture monitoring helps USFS monitor and predict droughts in forests and rangelands, predict wildfires, plan for reforestation and promote pre-disturbance resilience and resistance, and improve hydrologic and snowpack modeling for sustainable watershed managements. While NASA Soil Moisture Active Passive (SMAP) provides timely, frequent and high-resolution global soil moisture both for near surface and root-zone, accuracy of soil moisture estimates in forested areas is limited. Currently, the SMAP program is conducting a field experiment to calibrate and validate (cal/val) forest soil moisture estimates. However, the existing sparse forest soil moisture network limits SMAP's capability to improve forest soil moisture estimates. In addition, there are gaps in science and applications of NASA data products preventing the translation of NASA data into USFSs' management tools. It is recommended that USFS and NASA develop a strategic framework for collaboration and coordination to enable uses of NASA data products to support USFS management needs. For example, collaborations between USFS and SMAP to utilize existing forest soil moisture and vegetation water content data and identify where to place additional *in-situ* sensors could help improve satellite-based forest soil moisture observations. Table 1 provides detailed information regarding USFS decision-support needs, relevant NASA products and tools to support the needs, gaps, and ways to close the gaps.

Summary of soil moisture and hydrology information opportunities and challenges resulting from the breakout panel discussion at the 2019 USFS-NASA Joint Applications workshop. An asterisk (\*) indicates short-term achievable priorities.

### **USFS decision-support need and how is USFS meeting this need now?**

#### **1. General themes**

- a. What are relevant NASA product(s) and tool(s) to address the need?
  - SMAP
  - NISAR
  - Soil moisture visualizer
  - MODIS
  - Landsat
  - ECOSTRESS
  - GOES
  - VIIRS
  - LIS
- b. How could these NASA product(s) and tool(s) improve USFS decision-making?
  - More efficient decision making
  - Appropriate information reduces the level of risk

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- Improve ability to better predict and plan for medium (3–5 yrs) to long term (10–20 yrs) change (i.e. improving parametrization in existing or future models)
  - Improve landscape level data consistency across all forests and for “all lands approach”
  - Improve data sources and tools for broad level climate change indicators (e.g., USGCRP indicators, Forest Service Broader-Scale Monitoring Strategies)
- c. What are barrier(s) and gap(s) for NASA product/tool integration? (e.g., resolution, errors)
- Lack of in-situ measurements (cal/val data)
  - Differing perspectives on uncertainty and what are acceptable levels of risk
  - Translating NASA data into FS management tools:
    - ◆ Gap between science and applications
    - ◆ “Pixels scare people” (FS GIS community more experienced working with vector data; majority of FS GIS data is vector)
    - ◆ Tool box is already “stuffed”
  - Communication:
    - ◆ Managers understanding of data availability, uses, limitations, scale, and uncertainty.
    - ◆ Data producer's understanding of management capabilities and limitations for user of remote sensed soil moisture information.
  - Spatial resolution of NASA data:
    - ◆ NASA makes measurements from a difficult vantage point (mostly space) so that it is a synoptic context picture; and cannot replace the project or plot scale observers. Instead, show added-value of synoptic information to site-specific applications (in both NASA & USFS).
    - ◆ Contrast the above with the way Forest Service managers generally thinks of scale requirements: project level: 1m–30m; mid-scale: 30m–100m; Broad-scale: >100 m
    - ◆ NASA data can address the temporal and temporal change issues, but are limited to spatial scales in the km range.
- d. What are way(s) to close the gap(s)? (please rank by priority)
- Develop a Strategic Framework for Collaboration and Coordination\*:
    - ◆ Use an all-lands approach and include all land management agencies in the strategic framework. Bring land use managers across agencies together to identify common priorities.
    - ◆ Develop a list of FS–NASA joint efforts already underway.
    - ◆ Describe connections between R&D and NASA. The R&D branch is the most appropriate place to engage NASA at the tactical level.
    - ◆ Internally, do more to connect R&D staff with NFS managers (e.g., the Be Smart program).
    - ◆ Develop strategy for USFS Earth Observation (EO) integration and outlook.

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- Develop Needs Requirements, Study Feasibility\*:
    - ◆ Broadly synthesize needs, requirements, gaps, and barriers to adoption within the USFS that are clearly defined, accepted, and stated.
    - ◆ Identify and prioritize issues of common interest and capability between USFS and NASA. Continue to engage in ongoing discussions about what is needed versus what is possible.
  - Stand-up Working Groups and engage in Early Adopter Programs\*:
    - ◆ Ensure FS requirements are captured in Traceability Matrices and participate on Decadal Survey Workgroups (application community requirements for future missions). Work with NASA iteratively on workgroups and early adopter programs
    - ◆ Form focused Working Groups that have the correct expertise and current working knowledge of existing tools. Meet on telecons regularly.
    - ◆ Designate a Working Group Liaison for every FS-NASA priority.
  - Tools & Data Integration:
    - ◆ Build tools for ingesting NASA data into USFS models, systems, and workflows where feasible.
    - ◆ Invest in open technologies that are interoperable with existing data and methods.
    - ◆ Provide incentives to citizen scientists to participate in data collection (via schools, towns, states).
    - ◆ Develop tools and use-cases for synoptic information.
  - Launch Pilots and Case Studies:
    - ◆ Ensure inputs from regions and forests (in addition to R&D and WO) are included when designing case studies/ proof of concept studies.
    - ◆ Prioritize pilot studies/management applications where the risk to management is high and there is a need across land ownerships.
    - ◆ Show a success-story or two (case study). Take a regional or specific example, pair NASA & USFS enthusiastic individuals, and show it can be done. Both members of pair need to do the technical work.

## **2. Forest soil moisture monitoring:**

- Soil inventories
  - Soil probes (somewhat cost prohibitive)
  - Some (not many) forest soil monitoring networks
  - Remote sensors (e.g., experimental use in R5 for ‘data driven’ opening and closing of ATV trails)
- a. What are relevant NASA product(s) and tool(s) to address the need?
- Large-scale frequent mapping of soil moisture at various spatial scales is available from various NASA soil moisture products:
    - ◆ Satellite-based: SMAP (current); AMSRE (historical)
    - ◆ Model-based: NLDAS, MERRA2, etc.

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- ◆ Vegetation water content can also be inferred indirectly through SMAP's vegetation opacity parameter
  - b. How could these NASA product(s) and tool(s) improve USFS decision-making?
    - Improve plant stress early warning
    - Improve modelling surface soil moisture to predict soil moisture at deeper layers
    - Improve consistency of soil moisture information across scales (reconciling project/plot/sub-watershed scale with watershed (>HUC 12) and Region)
  - c. What are barrier(s) and gap(s) for NASA product/tool integration? (e.g., resolution, errors)
    - Lack of forest soil moisture in situ sensors
    - SMAP performance in complex terrain
  - d. What are way(s) to close the gap(s)? (please rank by priority)
    - Sharing validation resources for forest soil moisture and vegetation water content (e.g., share data collected at USFS experimental forests for cal/val)
    - Need a national survey and assessment of where forest soil moisture in situ sensors are available in order to better define gaps and needs.
    - Explore how modeling /stats can show us where to place additional sensors.
    - Tap into the wealth of underutilized georeferenced soil information (e.g., NASA's data set includes over 50,000 soil pedon samples that are to protocol; soil moisture, soil temperature, soil carbon, texture etc. are available for validation. Another 30,000 points probably exist that are not in the database.
    - Provide funding to an adequate number of forest soil moisture in situ sensors.
    - Equip RAWs stations with soil moisture sensors.
    - Develop forested validation sites for soil moisture (more than a dozen or 50 in situ stations within 40 km so that the replicability of SMAP data to USFS applications is quantitatively known).

### **3. Soil mapping/ inventory:**

- Resource photography interpretation
  - Field data collection
  - NRM database
  - NRCS maps
- a. What are relevant NASA product(s) and tool(s) to address the need?
    - SMAP
  - b. How could these NASA product(s) and tool(s) improve USFS decision-making?
    - Additional parameters and data to integrate into mapping workflows

### **4. Soil carbon:**

- a. What are relevant NASA product(s) and tool(s) to address the need?
  - SMAP



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- b. What are barrier(s) and gap(s) for NASA product/tool integration? (e.g., resolution, errors)

- Lack of soil carbon and carbon flux info in different environments/land use categories

## **5. Wildfire prediction:**

- a. What are relevant NASA product(s) and tool(s) to address the need?

- SMAP
- NISAR

- b. How could these NASA product(s) and tool(s) improve USFS decision-making?

- Inform spatial variability in fire behavior modeling
- NASA data can provide reliable estimates of fuel load and wetness conditions.

- c. What are way(s) to close the gap(s)? (please rank by priority)

- Pursue value case study with fire and reverse engineering exercise to improve risk scenario analysis
- USFS does not use SMAP or any remote soil moisture product in fire danger rating. Could be an easy feasibility study to set up to test added value of SMAP data for this application

## **6. Pre-disturbance resilience and resistance:**

- Forest level expertise
- National Insect and Disease Risk Map
- Hazardous Fuel Models (FAM)
- Existing Vegetation maps
- Climate Change Vulnerability Assessments
- NRM database

- a. What are relevant NASA product(s) and tool(s) to address the need?

- SMAP
- NISAR
- MODIS
- Landsat
- ECOSTRESS
- GOES
- VIIRS
- LIS

- b. How could these NASA product(s) and tool(s) improve USFS decision-making?

- Early stress detection
- Additional information on tree canopy water content and change to aid models
- Utility of microwave VOD from SMAP as a new indicator of vegetation water relations, phenology, and health

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- c. What are way(s) to close the gap(s)? (please rank by priority)
- “SMAP is working on an algorithm to retrieve vegetation water content in physical unit (kg/m<sup>2</sup>) using passive microwave observations. The resulting parameter will be a direct indicator of vegetation/forest health and vitality.”

## **7. Rangeland monitoring:**

- Drought indicators
  - Local expertise
  - Productivity data
- a. What are relevant NASA product(s) and tool(s) to address the need?
- SMAP
  - MODIS
  - Landsat
  - ECOSTRES
  - GOES
  - VIIRS
- b. How could these NASA product(s) and tool(s) improve USFS decision-making?
- Better early warning indicators

## **8. Hydrologic and Snowpack modeling:**

- Fine scale DEMs (e.g., topographic wetness index)
  - SNOTEL network
  - vegetation maps
  - USGS stream gauges
  - NHD
  - VIC
  - WaSSI
  - NRM database
- a. What are relevant NASA product(s) and tool(s) to address the need?
- SMAP
  - NISAR
  - MODIS
  - Landsat
  - ECOSTRESS
  - GOES
  - VIIRS
  - LIS

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- b. How could these NASA product(s) and tool(s) improve USFS decision-making?
    - Improve water supply maximization strategies
    - Better infiltration capacity information to improve understanding of watershed runoff
    - Contribution of improved LAI models: temporally specific; overstory vs understory
    - Operationalized production of a periodically updated overstory LAI map at high resolution
  - c. What are way(s) to close the gap(s)? (please rank by priority)
    - Model LAI using FIA plot data combined with LiDAR and Landsat data (then used in distributed hydrological models)

### ***Panel Discussion Report Out of the Emissions and Flux Breakout Panel***

Summary of emissions and flux information opportunities and challenges resulting from the breakout panel discussion at the 2019 USFS-NASA Joint Applications workshop.

### **USFS Decision-Support Needs**

#### **1. Reporting a Map (which forest monitoring map is better for a country)—under USFS International Programs (SilvaCarbon).**

- a. How is USFS meeting this need now?
  - Using Guidance (in a Box) that Grant mentioned; they follow the IPCC good practice guidelines and REDD+ requirements.
- b. What are relevant NASA product(s) and tool(s) to address the need?
  - ICESat-2, GEDI, Airborne LiDAR, and data sets that are consistent, institutionalized, and at the country-scale.
- c. How could these NASA product(s) and tool(s) improve USFS decision-making?
  - They can help countries decide which map to use; they are helpful because the data is consistent and institutionalize.
- d. What are barrier(s) and gap(s) for NASA product/tool integration? (e.g. resolution, errors)
  - Too many maps out there, which one to choose? Andrew Lister mentioned that we should not push a science product that is not compatible with the country's institutional readiness. Sassan brought up the issue of limited funding for a just a couple of years, which leaves no room to interact with potential users for a long time, thus affecting the integration of products.
- e. What are way(s) to close the gap(s)? (please rank by priority)
  - Develop workshops and roadmaps to understand what stakeholders really need/want; and make sure that they understand the science and uncertainty metrics.

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2. **The USFS Air Resource and Management (ARM) Program identified several data needs, among those, monitoring for Regional Haze, and criteria pollutants or aerosol fine particulates.** They needed in 10–100m grid cells horizontally; 100 m–1 km vertical resolution; they need to know where the pollutants are coming from?; hourly to daily measurements; 1 to 10 years of data; aerosol size and composition; and the data should be easy to access.
- How is USFS meeting this need now?
    - By other means besides remote sensing. They use little remote sensing data.
  - What are relevant NASA product(s) and tool(s) to address the need?
    - Engagement with the Air Quality & Health Working Group from Goddard Applied Sciences, and connect with Stephanie Uz, who should provide guidance on relevant NASA air quality products (e.g. MODIS instrument onboard NASA's Terra and Aqua satellites provides near daily observations of aerosols over global land and ocean surfaces with moderate spatial resolution; others that can help include MISR, OMI, VIIRS, POLDER, and CALIPSO)
  - How could these NASA product(s) and tool(s) improve USFS decision-making?
    - They can help in source apportionment, and to interpret events intercepted by IMPROVE monitors, among other uses.
  - What are barrier(s) and gap(s) for NASA product/tool integration? (e.g. resolution, errors)
    - Lack of engagement between USFS and NASA personnel
  - What are way(s) to close the gap(s)? (please rank by priority)
    - More engagement between USFS and NASA scientists and program managers
3. **Does NASA have data to track algal blooms in lakes that we could use as an early warning for lake eutrophication?**
- How is USFS meeting this need now?
    - By other means besides remote sensing. They use little remote sensing data.
  - What are relevant NASA product(s) and tool(s) to address the need?
    - MODIS. For more information contact Stephanie Uz at NASA GSFC, or Rick Stumpf from NOAA.
  - What are barrier(s) and gap(s) for NASA product/tool integration? (e.g. resolution, errors)
    - Lack of engagement between USFS and NASA personnel
  - What are way(s) to close the gap(s)? (please rank by priority)
    - More engagement between USFS and NASA scientists and program managers

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**4. Does NASA have a means to monitor deposition of nitrogen and/or sulfur containing pollutants?**

- a. What are relevant NASA product(s) and tool(s) to address the need?
  - Yes, the Aura Ozone monitoring Instrument and NO<sub>2</sub>

**5. Data Needs for NEPA AQ Analyses for Energy and Minerals Projects: criteria pollutants, methane, CO<sub>2</sub> at project level**

- a. How is USFS meeting this need now?
  - By other means besides remote sensing. They use little remote sensing data.
- b. What are relevant NASA product(s) and tool(s) to address the need?
  - See Riley Duren's (NASA JPL) CMS Project: Prototype Methane Monitoring System for California. A dataset has been archived: "Sources of Methane Emissions (Vista-LA), South Coast Air Basin, California, USA." See also Daniel Jacob's (Harvard University) CMS Projects, and engagement with EDF.
- c. How could these NASA product(s) and tool(s) improve USFS decision-making?
  - Could use remote sensing to look for methane leaks and determine compliance with lease conditions
- d. What are barrier(s) and gap(s) for NASA product/tool integration? (e.g. resolution, errors)
  - Resolution. Most of the products from Daniel Jacob are not for project level analysis.
- e. What are way(s) to close the gap(s)? (please rank by priority)
  - Higher-resolution products, collaborations with organizations like Environmental Defense Fund (EDF), who are working on launching MethaneSAT.

**6. Predictors or imputation modeling at continental scales, and repeated height products to incorporate into these models**

- a. How is USFS meeting this need now?
  - Model-assisted and model-based inference may use data in "stages" across spatial and temporal resolutions
- b. How could these NASA product(s) and tool(s) improve USFS decision-making?
  - Could help with their customers' needs for wall-to-wall products over time
- c. What are way(s) to close the gap(s)? (please rank by priority)
  - Bridge the gaps between the sensed landscape and the full raster mesh used for mapping

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7. **Shrub Biomass.** Shrub species represent a significant component of aboveground carbon stocks in interior AK, but FIA is not funded to establish field plots in “non-forest” conditions, such as shrubs.
- How is USFS meeting this need now?
    - It is not currently, and Alaska was included in the U.S. National Forest Inventory just recently.
  - What are relevant NASA product(s) and tool(s) to address the need?
    - G-LiHT: Goddard’s LiDAR, Hyperspectral, & Thermal Imager
    - NASA CMS-funded project proposes to measure shrub biomass on a representative set of plots, develop G-LiHT-field relationships, and then estimate shrub biomass over entire inventory unit.
  - How could these NASA product(s) and tool(s) improve USFS decision-making?
    - It could help in acquiring high-resolution airborne remote sensing data for highly-complex and remote areas, where otherwise it would be too costly. Including large shrubs as tree tally species would likely add several million acres to FIA inventory.
8. **Other data needs identified by Hans Andersen from USFS are: forest type/ species-level & mortality information, and uncertainties in carbon emissions from wildfire in boreal forests.**
- What are relevant NASA product(s) and tool(s) to address the need?
    - Readily-available frequent radar imaging (NISAR), and accessible satellite LiDAR (ICESat-2) for forest monitoring
  - What are way(s) to close the gap(s)? (please rank by priority)
    - Frequently collected, and easily-available L-band radar from NISAR will likely be a game changer; continued development of methods to integrate multi-sensor data (ICESat-2, NISAR, G-LiHT, etc. & field data)
9. **In general, George Hurtt indicated that there is a need to move from considering stakeholder and science needs separately to consider them jointly, moving to co-production. There is a need for more data and models, with very high resolution, accurate, transparent, easy to use, and repeatable.**
- What are relevant NASA product(s) and tool(s) to address the need?
    - Huge potential in new missions, such as GEDI
  - What are barrier(s) and gap(s) for NASA product/tool integration? (e.g. resolution, errors)
    - Considering science needs and capabilities separately.
  - What are way(s) to close the gap(s)? (please rank by priority)
    - Move to co-production, into considering the stakeholder and science needs jointly



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### ***Panel Discussion Report Out of the Vegetation Structure and Function Breakout Panel***

**Summary:** During this session, we broke into four groups and rotated amongst topics such that each group discussed the following four topics:

USFS management issues

1. Silviculture: NEPA and management planning including harvest areas
2. Fire & fuels: Modeling fire behavior and effects, fuel treatments
3. Range management: Change over time including biomass, pinyon/juniper encroachment
4. Wildlife habitat: Habitat modeling with vegetation lifeform (forest/woodland, shrubland, herbaceous) and multi-layer cover

The following questions were used for prompts

1. What Forest Service information needs do NASA's existing products address?
2. What are the remaining data/knowledge gaps?
3. What are the biggest technical challenges around this topic that data and tools could fill?
4. How can we best fill the gaps?
5. What recent discoveries have you made on the topic that could help fill data and knowledge gaps?
6. How would you prioritize what needs to be done next?
7. What level of error/uncertainty is acceptable?

Each group then reported out on one of four topics. Two recurring USFS needs that were discussed amongst all four topics was the ability to quantify the vegetation understory, and the ability to quantify the vertical and horizontal complexity of the vegetation. There was also ensuing conversation about the need for translation between USFS and NASA and in particular a sensitivity to NASA vs USFS terminology; and secondly tech transfer and specifically that NASA products needs to be ready to go into USFS models (i.e. fuel models) as inputs. The group also felt that more Involvement by USFS before NASA missions will help with adoption and use of NASA data.

**Table 3a**—Silviculture: NEPA and management planning including harvest areas. Summary of vegetation structure and function information opportunities and challenges resulting from the breakout panel discussion at the 2019 USFS–NASA Joint Applications workshop.

USDA Forest Service Needs	NASA product(s) and tool(s) to address the need	Example(s) of where the product(s)/tool(s) match the need	Barrier(s) and gap(s) e.g., resolution, errors	Way(s) to close the gap(s)—please rank by priority
Disturbance + Recovery	SMAP, ICESat-2	Disturbance products are available but not recovery	Need a time sequence, spectral information	
Tree species, stocking, crown bulk density	Future hyperspectral (SBG)	Forest density / canopy cover needs to be tied to specific species (e.g. stocking normalizes density to species); need phenology	Legacy of Landsat under delivering is an issue; species is very important, separating trees from shrubs	Sentinel (10 m large improvement over 30 m but need additional R&D for applicability), time series; SBG
Height	Airborne LiDAR, GEDI, ICESat-2	Airborne LiDAR already used but not regularly repeated	Could learn to accept GEDI as a sampling mission	SAR? Probably skills needed make this difficult to adopt; complexity also difficult to explain to managers
Separating trees from shrubs	Airborne LiDAR	Understory estimates	Availability of data	

**Table 3b**—Fire & fuels: Modeling fire behavior and effects, fuel treatments. Summary of vegetation structure and function information opportunities and challenges resulting from the breakout panel discussion at the 2019 USFS–NASA Joint Applications workshop.

USDA Forest Service Needs	NASA product(s) and tool(s) to address the need	Example(s) of where the product(s)/tool(s) match the need	Barrier(s) and gap(s) e.g., resolution, errors
Improved estimates of where the fuels are	Mid-regional level land cover mapping		Need model ready products
Utility in LandFIRE but needs to be updated more regularly	30 km to 1 km	LandFIRE, mid-level data already available	Increased temporal resolution
Crown Bulk density CBH Understory fuels across landscapes		Need model level inputs that are easily ingested	

**Table 3c**— Range management: Change over time including biomass, pinyon/juniper encroachment Summary of vegetation structure and function information opportunities and challenges resulting from the breakout panel discussion at the 2019 USFS–NASA Joint Applications workshop.

USDA Forest Service Needs	NASA product(s) and tool(s) to address the need	Example(s) of where the product(s)/tool(s) match the need	Barrier(s) and gap(s) e.g., resolution, errors	Way(s) to close the gap(s)—please rank by priority
Invasive species mapping	MODIS at very coarse scales	MODIS at very coarse scales—phenology	Need project level data at finer spatial scales	ICESat-2 & GEDI might not have height resolution needed; future SBG

**Table 3d—** Wildlife habitat: Habitat modeling with vegetation lifeform (forest/woodland, shrubland, herbaceous) and multi-layer cover. Summary of vegetation structure and function information opportunities and challenges resulting from the breakout panel discussion at the 2019 USFS–NASA Joint Applications workshop.

USDA Forest Service Needs	NASA product(s) and tool(s) to address the need	Example(s) of where the product(s)/tool(s) match the need	Barrier(s) and gap(s) e.g., resolution, errors	Way(s) to close the gap(s)—please rank by priority
Strata and layers (horizontal and vertical), including snags, understory		Structural mapping has happened in forests but not shrublands	60% accuracy acceptable; 80% outstanding	Improve with LiDAR data
Mesic/ephemeral areas	Significant gaps now	Not many examples	Need high temporal resolution	Could use SMAP plus a high resolution product?
Landcover change, tracking change near real time (this is prioritization)	Currently have Landsat but need higher temporal resolution in some ecosystems where phenology is driver			
Tracking snow cover under forested canopy	Have MODIS and Landsat snow covered pixels	LiDAR	Need higher resolution for snow cover extent but also snow depth from LiDAR	
Climate and topographic information, adaptation to climate change	NLCD	Rates of change	Need more frequent products for assessing rates of change	

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### ***Annex: List of Acronyms***

CALIPSO: Cloud-Aerosol LiDAR and Infrared Pathfinder Satellite Observation  
CBH: Canopy Base Height  
CMS: Carbon Monitoring System  
DEM: Digital Elevation Model  
ICESat-2: Ice, Cloud, and land Elevation Satellite-2  
EDF: Environmental Defense Fund  
FAM: USFS Fire and Aviation Management (staff area)  
FIA: USFS Forest Inventory and Analysis (program)  
GEDI: Global Ecosystem Dynamics Investigation  
G-LIGHT: Goddard LiDAR, Hyperspectral, & Thermal Imager  
GOES: Geostationary Operational Environmental Satellite  
LAI: Leaf Area Index  
LandFIRE: Landscape Fire and Resource Management Planning Tools  
LiDAR: Light Detection and Ranging  
LIS: Land Information System  
MDZ: Moisture Difference Z-Score (dataset)  
MERRA2: Modern-Era Retrospective analysis for Research and Applications, Version 2  
MISR: Multi-angle Imaging SpectroRadiometer  
MODIS: Moderate Resolution Imaging Spectroradiometer  
NASA: National Aeronautics and Space Administration  
NEPA: National Environmental Policy Act  
NISAR: NASA-ISRO SAR Mission  
NLCD: National Land Cover Database  
NLDAS: North American Land Data Assimilation System  
NOAA: National Oceanic and Atmospheric Administration  
NRCS OMI: Natural Resources Conservation Service Ozone Monitoring Instrument  
PDSI: Palmer Drought Severity Index  
POLDER: Polarization and Directionality of Earth's Reflectances  
RAWS: Remote Automated Weather Stations  
R&D: Research and Development  
REDD+: Reducing Emissions from Deforestation and Forest Degradation  
SAR: Synthetic-aperture radar  
SBG: Surface Biology and Geology  
SMAP: Soil Moisture Active Passive  
SNOTEL: Snow Telemetry  
SPI: Standardized Precipitation Index  
USFS: U.S. Forest Service  
VIIRS: Visible Infrared Imaging Radiometer Suite

## APPENDIX B

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### **The Forest Service Geospatial Technology and Applications Center (GTAC): Helping Translate Geospatial Data to Information for Forest Service Managers**

The future of geospatial data products for the Forest Service relies on numerous factors. Five are identified and were discussed by workshop participants. First, the Forest Service should identify clear and concise business needs which, in turn, direct appropriate leveraging of Earth observations to support those needs. Second, more recognition should be given to improving the ability within the Forest Service to engage, develop, and provide access to required or helpful EO data and information. Third, investments in hardware and software are needed that enable geospatial personnel to engage, analyze, and develop geospatial data as well as to provide land managers access to needed geospatial data. Fourth, improved science/management partnerships should be a priority. Finally, training opportunities need to be more readily available to maintain a comprehensive workforce capable of harnessing the best available data and science for supporting land management activities. To this end, the [Geospatial Technology and Applications Center \(GTAC\) Forest Service](#) continues to play a significant role in moving towards this goal. The GTAC is a Forest Service geospatial business center supporting and working in cooperation with all Forest Service Deputy Areas and other business areas: National Forest System, Chief Information Office, State and Private Forestry, and Research and Development, as well as Forest Service International Programs, Forest Service Office of Sustainability and Climate, and other government agencies.

At the time of this workshop, the Center was a detached unit of the Forest Service Washington Office and was aligned under the National Forest Systems Engineering, Technology, and Geospatial Services staff area (the layout has since changed). GTAC provides geospatial knowledge, data, tools, and services to all levels of the Forest Service to help effectively communicate resource opportunities to stakeholders, partners, and the public. The Center specializes in the advancement of emerging geospatial science and the development of cost-effective methods for collecting and integrating resource data into land management operations. There are eight geospatial support program areas at GTAC. These programs have unique, yet cross-cutting, focus areas functionally striving for delivery of geospatial products and services including: supporting geospatial workflows, strengthening employee capacity, improving authoritative data, and engaging stakeholder communities through the use of geospatial technologies and best practices.

GTAC's support services are guided and directly requested by multiple sources. The work accomplished at GTAC directly supports strategic actions identified in multiple federal laws including, but not limited to, the USDA Farm Bill and the Federal Geospatial Data Act (Agriculture Improvement Act of 2018; FAA Reauthorization Act of 2018). These laws influence national committee efforts and are influences on the work being accomplished. One example of an important effort is the implementation of



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the National Vegetation Classification accomplished by the Federal Geographic Data Committee (FGDC 2008). This work provides clarity and guidance to ensure all existing vegetation data developed by land management agencies supports national goals. The nation's laws provide focus points for the Forest Service to align strategies such as the Forest Service Strategic Plan (USDA FS 2015b). Agency strategies give focus to ensuring the work accomplished is aligned with the underlying principles and outcomes are supporting the national focus points. The Forest Service uses strategy documents to clarify its land management principles and speak to the nation's leaders and public concerning the objectives and goals to care for the land and serve the people.

Products and workflows developed and used by all of GTAC are in part defined by multiple effects including the available enterprise tools (hardware and software), supported methods, data requirements and standards, and vehicles for accomplishing the work (contracts, agreements, etc.). Data quality is influenced by multiple inputs including national standards, defined "best available science/data," technical guides, and best practices.

A very important component of the work accomplished at GTAC comes from the partners and cooperators. These are the land managers or support networks for active management decisions requiring or requesting geospatial data. It is their data needs that give focus to comprehend the outcomes supported. These outcomes and needs are defined through multiple pathways internal to the Forest Service, including steering committees, advisory groups, Forest Service staff, and field unit sponsors. The GTAC provides valued geospatial products, through using available technology, clearly defining the data uses and goals of the partners and cooperators, and meeting Forest Service business needs.

GTAC delivers work in support of multiple organizations in the Forest Service as well as partnering with and supporting other agencies and departments and supports the provisioning of geospatial data for the public. This work encompasses a number of focus areas:

- Innovation Development and Evaluation Projects: Subject matter experts evaluate field needs and investigate the use of geospatial data and develop innovative solutions for supporting land management.
- Geospatial Technical Training: Geospatial specialists promote best practices and build capacity at home and abroad. They develop briefings, self-led tutorials, instructor-led training materials, technical webinars, and help-desk services.
- Web Mapping and Geospatial Applications: GTAC customizes geospatial workflows that leverage enterprise architecture and exploit image services and web mapping capabilities to streamline data collection, analysis, and information sharing.

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- Geographic Base Data and Vegetation Maps: Cartographers develop topographic maps, National Forest visitor maps, and custom thematic maps for Forest Service and public use. Geospatial specialists follow national standards and guidelines to steward Forest Service base data and produce existing vegetation maps, land use, and land cover change products at multiple scales and across all lands.
  - Operational Support Services: GTAC supports the detection, mapping, and monitoring of many disturbances at landscape and continental scales. Examples include active fire detection and monitoring, postfire burn severity mapping and assessment, early detection and monitoring of insect and disease outbreaks, monitoring of land use/land cover and agent of change inventory and monitoring, and enterprise delivery of remote sensing and GIS data products as mapping and data services.
  - Geospatial Project Support: GTAC offers consultation and support services to inform cooperators about their options to address business needs by implementing geospatial solutions. It also advises on the use of geospatial contracts for securing additional expertise and surge capacity as needed. GTAC maintains a skilled and knowledgeable staff and utilizes numerous contract staff support. GTAC staff engage with Forest Service business areas to support their geospatial information needs. The boundaries of geospatial technology (hardware and software) are ever evolving, and being flexible and adaptable to change while retaining a focus on delivering products and services is paramount to meeting and supporting the geospatial needs of the agency. Examples of work and geospatial data supported at GTAC include: existing vegetation data and maps, terrestrial unit inventory and support for digital soil mapping, and monitoring land use and land cover changes. Key information about each of these areas is as follows:
    - ◆ Existing vegetation data support the knowledge of where specific resources are located. This is key information towards ensuring land managers are aware of where resources exist on the landscape, comprehension of current conditions, and development of awareness of existing conditions for discerning how much a resource is available. Information about existing vegetation processes and data are available in Nelson and others 2015. An example of existing vegetation data includes the Forest Service tree canopy cover contribution to the Multi-Resolution Land Characteristics Consortium (MRLC 2019).
    - ◆ Terrestrial Ecological Unit Inventory (TEUI), available soils data, and other ecological framework data are vital to support ecological based land management decisions. These datasets support the land being mapped to different and appropriate scales to distinguish land areas based on ecologically important factors (i.e., geology, soils, climate, hydrology, and

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vegetation). They are also vital to support applied landscape planning. Information about TEUI and related work accomplished in the Forest Service is found in Winthers and others 2005. An example of geospatial data and remote sensing supporting Forest Service business needs in novel ways is applying them to the development of digital soil products (USDA Natural Resources Conservation Service 2017). In this effort the Forest Service worked alongside USDA National Resources Conservation Service (NRCS) personnel to accomplish a NRCS–SSURGO publication of digital soils data.

Estimation of natural resources is a key component to land management—how much of a resource (e.g., average tree diameter, animal unit month) is a key requirement for land managers. The Forest Service is very active and has many programs ensuring “best available data” is available to land managers for supporting decisions related to land management activities. These programs support analysis of timber, mill resources, enabled grazing, water quality, and many more. One example of using geospatial data for supporting the measurement of land use and land cover resources on the landscape is work accomplished by Forest Service researchers found in Frescino and others 2009, and Patterson 2012. This work shows methods for estimating land characteristics for the State of Nevada using remote sensing.

The Forest Service manages an ever-changing landscape for multiple uses. The Forest Service Landscape Change Monitoring System (LCMS) project is focused on providing consistent land cover change data from 1984 to the present. This geospatial data product utilizes a relatively new component of available data (Landsat archive being freely available), available large capacity computing/processing power (Gorelick 2017) such as Google Earth Engine (GEE) and Amazon Web Services (AWS), and the capacity to operationally produce and provide national data (Cohen and others 2017; LCMS 2019). The Forest Service LCMS product ([LCMS Data Explorer \(usda.gov\)](https://dataexplorer.usda.gov/)) supports geospatial data to land managers and the public alike to better understand annual changes of cover and use through time.

## APPENDIX C

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### Relevant NASA Programs

NASA is responsible for unique scientific and technological achievements in human spaceflight, aeronautics, Earth and space science, and space applications that have had widespread impacts on our nation and the world. NASA's Earth Science Research Program supports research activities that address the Earth system to characterize its properties on a broad range of spatial and temporal scales, to understand the naturally occurring and human-induced processes that drive them, and to improve our capability for predicting its future evolution. The focus of the Earth Science Research Program is the use of space-based measurements to provide information not available by other means. NASA's program is an end-to-end one that starts with the development of observational techniques and the instrument technology needed to implement them; tests them in the laboratory and from an appropriate set of in situ, surface-, ship-, balloon-, aircraft-, and/or space-based platforms; uses the results to increase basic process knowledge; incorporates results into complex computational models that can be used to more fully characterize the present state and future evolution of the Earth system; and develops partnerships with other national and international organizations that can use the generated information in environmental forecasting and in policy, business, and management decisions.

In the workshop, the NASA Carbon Monitoring System (CMS) Program and four NASA Earth Science Missions were represented including Soil Moisture Active Passive (SMAP), NASA-ISRO Synthetic Aperture Radar (NISAR), Ice, Cloud, and Land Elevation Satellite-2 (ICESat-2), and Global Ecosystem Dynamics Investigation (GEDI, which was in planning phases at the time of the workshop).

#### C.1 Overview of SMAP, Data Products and Applications

SMAP has been operating since April 2015. The SMAP instrument includes a rotating reflector antenna spinning at 14.6 revolutions per minute with a 6-meter aperture that scans a wide 1,000 km swath as the observatory orbits the Earth, allowing global coverage every 3 days. The antenna is shared by a radar and a radiometer, operating at L-band frequencies. The radar ceased operation in July 2015, while the radiometer has continued to operate. The NASA Earth Science Division reviewed and approved SMAP's reconfiguration plan in March 2016 with the baseline re-established as a radiometer-only mission. The 3-year prime mission was concluded in June 2018 and the mission operation has continued through the first extension phase, leading to a five-year dataset,<sup>1</sup> which has resulted in new insights into Earth System science and has been used in several applications such as flood, drought, and agriculture decision-support systems. The SMAP radiometer is currently operational, and science data products are delivered to the National Snow and Ice Data Center (NSIDC) DAAC with public access (<https://nsidc.org/data/smap/smap-data.html>).

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<sup>1</sup> At the time of the 2019 workshop, a 5-year dataset existed. More information can be found here: <https://smap.jpl.nasa.gov/data/>.

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Current baseline products include: (1) radiometer data products in 36 km grids as well as a 9 km gridded product by employing an optimal interpolation technique to take advantage of the oversampling characteristics of the radiometer; (2) high-resolution soil moisture products at 3 km resolution by utilizing a combination of SMAP radiometer data with radar data from the European Union Copernicus Sentinel-1 mission as a surrogate for SMAP radar data; (3) radiometer-based freeze/thaw products; and (4) Level 4 model-derived, data-assimilated root-zone soil moisture and land surface carbon flux products. Assessment of the data quality has been performed for annual data release based on the in situ data acquired at core SMAP calibration/validation sites and sparse networks.

The SMAP radiometer has been calibrated to meet the required accuracy and stability with ample margins. The built-in spectral and time-domain filtering is designed to mitigate radio-frequency interference (RFI) and has been effective in reducing data loss and measurement errors due to RFI. The RFI detection and mitigation capabilities of the SMAP radiometer make it unique among past and current global L-band radiometry missions (e.g., NASA's Aquarius and the European Space Agency's Soil Moisture and Ocean Salinity [SMOS] missions). SMAP radiometer data have been used to produce high quality soil moisture and freeze/thaw products. The products have been calibrated and validated using well-instrumented in situ networks. All products have met science requirements. The SMAP soil moisture product performance, in terms of validation against in situ ground-truth measurements, exceeds those from other past and current sources including SMOS and other microwave missions. Assessment reports of each of the SMAP science products have been published in peer-reviewed journals and are included as part of the background documentation at the DAACs. Detailed information about SMAP data products can be found on the SMAP landing page at the National Snow & Ice Data Center: <https://nsidc.org/data/smap/smap-data.html> and <https://smap.jpl.nasa.gov/data/>.

The original SMAP L-band radar and radiometer configuration was designed to produce an active-passive combined soil moisture product in addition to the baseline radiometer-only product that is currently operational. The relatively more sensitive but coarser resolution radiometer-derived brightness temperature was to be combined with the coincident higher resolution but less sensitive (to soil moisture variations) radar backscatter to produce an intermediate-resolution (9 km) soil moisture product. Since the end of the SMAP radar operation, the SMAP Project undertook activities to leverage high-resolution data from other radar platforms to partially recover the capability to produce a high-resolution active-passive surface soil moisture product. The SMAP Project has actively engaged the Copernicus Sentinel-1 Project on the synergistic use of SMAP L-band radiometer and Sentinel-1A/1B C-band (~5 GHz) synthetic aperture radar (SAR) data to develop research soil moisture products at a spatial resolution of 3 km or better.

The quality of SMAP/Sentinel-1A/1B soil moisture products are assessed against in situ



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calibration and validation network data and airborne field campaign measurements. The combined SMAP-Sentinel-1A/1B high-resolution active-passive product is operationally produced by the SMAP Project and distributed through the NSIDC DAAC. The SMAP-Sentinel-1A/1B temporal refresh rate is constrained by the data acquisition from the Sentinel-1 platforms. The utility of C-band Synthetic Aperture Radar (SAR) data in forming an active-passive product is limited to regions with light vegetation canopy cover (up to about 3 kg/m<sup>3</sup> vegetation water content) than would be the case with an L-band active system (up to about 5 kg/m<sup>3</sup> that excludes only dense forests). The SMAP Science Team and application users have produced scientific results from the available data (about 4 years and 11 months) to address SMAP's overarching scientific goals for understanding water, energy and carbon cycles, and various applications with significant impact on society. Diverse Earth system science research communities have also found new applications of the SMAP Level 1 radiometer science data products for ocean, cryosphere, and global ecology research and applications.

## **C.2 NISAR Mission Overview, Products and Applications**

The NASA–Indian Space Research Organisation (ISRO) Synthetic Aperture Radar (NISAR) mission is a partnership between NASA and ISRO with a scheduled launch in January 2024. The satellite will carry an L-band SAR provided by NASA and an S-band SAR provided by ISRO. The L-band SAR will collect data over nearly all land globally, and the S-band SAR will focus collections over India. The L-band SAR is designed to have a minimum mission lifetime of 3 years while carrying consumables for 15 years of operation.

The NISAR mission is optimized to study hazards and global environmental change, specifically in support of ecosystem, cryosphere, and solid earth science. The satellite is designed to provide a detailed view of the Earth to observe and measure some of the planet's most complex processes, including ecosystem disturbances, ice-sheet collapse, and natural hazards. The mission's tasking and processing systems are designed to support disaster response by providing reduced latency product generation after acquisition. No changes to satellite pointing or imaging mode will be made for emergency response, as the satellite will be collecting imagery over almost all land surfaces at every observation opportunity.

NISAR will provide imaging data for mapping and monitoring of the United States' and international forest resources. The upcoming NISAR mission can provide relevant information for sustainably managing forests and their numerous ecosystem services including below-canopy inundation from natural and catastrophic flooding events, structural changes from disturbances like large forest fires (at low latency), and biomass. SAR images from satellites such as NISAR are known for their ability to penetrate through clouds and their day/night imaging capability. Hence even under near-perpetual dense tropical or frequent temperate cloud cover or smoke, SAR imagery will provide biweekly observations that complement the fleet of optical (e.g.,

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Landsat, Sentinel-2) and shorter wavelength SAR missions (e.g., Sentinel-1).

NISAR's L-band radar instrument will provide all-weather, day/night imaging of nearly the entire land and ice masses of the Earth repeated 4–6 times per month considering both ascending and descending orbits, and the S-band instrument will provide additional coverage of India and parts of the polar regions. Depending on the operating mode, NISAR's orbiting radar can image at resolutions of 3–50 meters to identify and track subtle movement of the Earth's land, sea-ice, and subsurface processes that result in surface deformation. Regular and consistent repeat imagery can be used to detect small-scale changes before they are visible to the naked eye and to track dynamic changes as conditions evolve.

The NISAR acquisition modes for the L-band and S-band instruments, along with parameters specific to each mode and the observation plan, can be found in the NISAR Science User's Handbook ([https://nisar.jpl.nasa.gov/documents/26/NISAR\\_FINAL\\_9-6-19.pdf](https://nisar.jpl.nasa.gov/documents/26/NISAR_FINAL_9-6-19.pdf)). The ground resolution in the cross-track direction is set by the pulse bandwidth (BW), and can be 3, 6, 12, or 50 m for 80, 40, 20, or 5 MHz bandwidths respectively. The ground resolution in the along-track direction is 8 m for all modes. The instruments can operate in single-polarization (SP) HH or VV (the first letter indicates the transmit polarization and the second indicates the receive polarization, either H for horizontal or V for vertical); dual-polarization (DP) HH/HV or VV/VH; co-polarization (QD) HH/VV; quad-polarization (QP) HH/HV/VV/VH; or quasi-quad polarization (QQ) (HH/HV/VV/VH with slightly different frequency H and V transmit). The selected mode depends upon the science target for a given location (see section 3.3). The L-band instrument can also operate in Compact Polarimetry (CP) mode transmitting right circular polarization (R), but there are no plans for using that mode operationally. The near-final observing plan will be dominated by L-band SAR HH/HV observations with a 12 m x 8 m spatial resolution and a 12-day repeat interval across most of the land area outside of the polar regions and Greenland. A funding augmentation currently underway will provide 6 m x 8 m spatial resolution data over North America lands.

All NISAR data will be processed into a set of standard polarimetric (PolSAR) image and interferometric SAR (InSAR) data products by the NISAR project team. These data products are expected to be available 24–48 hours after observation. The standard products include polarization-dependent images, interferograms, and interferometric coherence. The latter two can be used for change detection and for measurement of surface displacement. In addition to the standard acquisition and processing stream, an urgent response capability will be available through which lower latency products can be made available. The project's goal is to deliver with <6-hour latency following acquisition when urgent response acquisitions are initiated. The time between when an event occurs and when the next NISAR image of the area can be made depends upon when the next pass of the satellite over the event location (within the maximum 6-day period on either ascending or descending orbits). At continental U.S. latitudes, there is a 77 percent probability of imaging any location within 4 days of a disaster.



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NISAR mission applications are outlined in the Utilization Plan, which documents how the NISAR team will engage with the broader user community to increase the utility of the data from now through launch. Early engagement with the NISAR mission prior to launch in January 2024 can occur in any of five ways:

1. The lowest barrier to entry is to sign up for the email subscription of the semi-annual *NISAR Newsletters* (<https://tinyurl.com/NISARapplicationsUpdates>).
2. NISAR organizes several *Application Workshops* annually. In 2014 and 2015 these were in the form of an omnibus workshop with all potential applications of NISAR data represented at a single venue. From 2016–2020, workshops were conducted multiple times a year with specific application areas to enable more in-depth discussion about the needs of each community for using NISAR data. These workshops are organized to identify high impact applications for development in preparation for launch based on a community information needs assessment and identify a roadmap to go beyond NISAR data to actionable information. Reports are posted on the NISAR Applications Webpage (<https://nisar.jpl.nasa.gov/applications/>); three [workshops](#) of particular interest to the Forest Service are: (1) Ecosystems: Forest and Disturbance; (2) Ecosystems: Agriculture and Soil Moisture; and (3) Ecosystems: Wetlands.
3. In the workshops, actions are identified by the community to facilitate use and integration of NISAR data into existing decision-support tools. To respond to these activities, volunteers from the community work with the project, science team, and NISAR Applications Team through *Ad-Hoc Applications Working Groups*. These working groups have discrete objectives, deliverables, plan for completion, and a list of members with their role towards meeting the objectives.
4. Invited community members who present information about the NISAR mission at community meetings and workshops as *NISAR Envoys*. Envoys will be listed on the [NISAR Applications Webpage](https://nisar.jpl.nasa.gov/applications/) (<https://nisar.jpl.nasa.gov/applications/>) and receive updates in biannual telecoms and up-to-date slides about the mission for their presentations. These slides are based on a series of *Applications White Papers* that are also available for distribution from the [NISAR Applications Webpage](#).
5. The final opportunity to engage with the NISAR mission prior to launch is to become an *Early Adopter of NISAR-like data* (<https://nisar.jpl.nasa.gov/engagement/early-adopters/>). Anyone interested in working with NISAR(-like) data is eligible to become an Early Adopter subject to acceptance of the terms and conditions. Early Adopters will have access to NISAR-like data produced from existing radar datasets (e.g., NISAR-format using Sentinel C-band and NISAR-simulated from Uninhabited Aerial Vehicle Synthetic Aperture Radar, UAVSAR).

Meanwhile, there are many ways that the NISAR mission is working with NASA Applied Sciences Program Capacity Building to develop resources for using (NI-)SAR data. Links to resources for using SAR can be found on the SAR education resource

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webpage (<https://nisar.jpl.nasa.gov/resources/sar-education-resources/>). The first program of interest is Digital Earth Virtual Environment and Learning Outreach Project (DEVELOP). DEVELOP is a capacity building program to help conduct feasibility studies for integrating Earth observations into resource management agency decision-support systems. If you have an idea for a feasibility study related to the utility of NISAR for your agency, please email the corresponding author to find out how you can propose to NASA DEVELOP. The second program is the NASA Applied Remote SEnsing Training (ARSET). [ARSET](#) has conducted three relevant archived webinar series:

1. Introduction to Synthetic Aperture Radar: five-part webinar series recorded in Spanish and English using open-source resources and data.
2. Advanced Webinar: Radar Remote Sensing for Land, Water and Disaster Applications: four-part webinar series recorded in Spanish and English.
3. Advanced Webinar: SAR for Landcover Applications.

The final capacity building program that NISAR is working with is the NASA *SERVIR* program, which has produced a SAR Handbook including Comprehensive Methodologies for Forest Monitoring and Biomass Estimation.

### **C.3 ICESat-2 Mission Overview, Products and Applications**

Ice, Cloud, and Land Elevation Satellite-2 (ICESat-2) may be useful for inferring information relevant to a variety of applications including biomass mapping, habitat/biodiversity mapping, wildfire behavior modeling, fire fuel mapping, long-term land management, forest inventories, snow cover mapping, and parameterization of land-climate models. Continued engagement with the Forest Service and ecosystem community will help to identify key opportunities for effective use of ICESat-2 to help improve operations for characterizing, monitoring, and forecasting changing conditions of natural resources. The following were some of the key takeaways from the ICESat-2 presentations shown at the workshop:

- ICESat-2 is a space-based, profiling-LiDAR mission that does not provide the same resolution as airborne LiDAR mapping data, but does provide near global coverage.
- ICESat-2's strong beams represent a good option for vegetation studies.
- Night acquisitions have less background noise than day acquisitions.
- Data quality should improve over time.
- More calibration of the laser ranges.
- Improved modeling of orbital variations.
- Continuous improvements to software.
- Data will be reprocessed periodically.

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The NASA ICESat-2 Mission launched on September 15, 2018, to measure changes in land ice elevation and sea-ice freeboard and enable determination of vegetation canopy height globally (Markus and others 2017). ICESat-2 builds upon the measurements from the first generation ICESat mission (Schutz and others 2008; Zwally and others 2002) and uses a photon counting LiDAR to make its altimetry measurements. The science objectives for ICESat-2 are to: (1) quantify polar ice-sheet contributions to current and recent sea-level change and the linkages to climate conditions; (2) quantify regional signatures of ice-sheet changes to assess mechanisms driving those changes and improve predictive ice-sheet models (this includes quantifying the regional evolution of ice-sheet change, such as how changes at outlet glacier termini propagate inward); (3) estimate sea-ice thickness to examine ice/ocean/atmosphere exchanges of energy, mass, and moisture; and (4) measure vegetation canopy height as a basis for estimating large-scale biomass and biomass change.

The land- and sea-ice objectives are the primary drivers for ICESat-2's mission design, as well as its vertical and horizontal accuracy and precision requirements, as detailed in Markus and others (2017). The sole instrument on the ICESat-2 observatory is the Advanced Topographic Laser Altimeter System (ATLAS). ATLAS has multiple beams of 532 nanometer (nm) laser light—six beams arranged in three pairs—that allow for measurement of surface slope in both the along- and across-track directions with a single pass and provide a dense coverage of the Earth's surface. ATLAS transmits energy through three strong beams and three weak beams each illuminating an area of approximately 14 m diameter on the ground. A combined spacecraft velocity of  $\approx 7$  km/s and a 10 kHz pulse repetition frequency produce footprints on the ground spaced  $\approx 0.7$  m along-track, resulting in substantial overlap between shots. The reflectance of the surface at 532 nm drives the number of returned photons detected by ICESat-2.

Over the polar regions, the ICESat-2 observatory is pointed toward the same track every 91 days to allow for determination of seasonal height changes. ICESat-2 samples 1387 such tracks (reference ground tracks or RGTs) over the course of 91 days. In mid-latitudes, the observatory will systematically off-point over the first 2 years of the mission to create a dense map of canopy and ground-heights as shown in Markus and others (2017). Controlled pointing to the RGTs began in early April 2019 and the first off-pointing cycle on August 1, 2019.

The ICESat-2 mission provides 20 data products ranging from a telemetry product, which includes individual times of flight (identified as ATL02; Martino and others 2018), to several surface-specific geophysical products such as the vegetation canopy height data (ATL08; Neuenschwander and Pitts 2019a). The latency of the surface-specific geophysical products—defined as the approximate time it takes from data acquisition until data product release—will ultimately be about 49 days once data processing reaches nominal status. The Global Geolocated Photon data product (identified as ATL03; Neumann et al. 2018) is used as the foundation for the surface-specific geophysical data products and provides the latitude, longitude, and ellipsoidal height of

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photons detected by the ATLAS instrument.

All ICESat-2 data products are in the Hierarchical Data Format (version 5 HDF-5 format) and generate along-track histograms of photon ellipsoidal heights. These histograms distinguish signal photons from background photons based on surface-specific signal thresholds. Depending on the signal-to-noise ratio, photons classifications range from *high-confidence signal*, *medium-confidence signal*, *low confidence signal*, to *likely background*. All heights derived from the ATLAS instrument are the absolute height above the WGS84 ellipsoid.

Both the strong and weak beams provide sufficient signal-to-noise ratios for altimetry measurements over bright surfaces such as sea ice and ice sheets. Over relatively flat reflective surfaces, such as the interior of the Antarctic ice sheet,  $\approx 7$  signal photons per shot for the strong beams and  $\approx 1.75$  signal photons per shot for the weak beams can be expected on average. Since vegetation and ground are not as bright of reflectors as snow and ice, the expectation per shot average is approximately one photon from the ground and one photon from vegetation. The mission requirement for single photon horizontal geolocation is 6.5 m one sigma. The current (October 2019) geolocation accuracy (bias) is  $<10$  m horizontal,  $<30$  cm vertical.

While the land- and sea-ice objectives are the primary drivers for ICESat-2's mission design, as a global mission ICESat-2 takes height measurements over non-cryospheric surfaces. Besides geophysical data products to determine glacier and ice-sheet height, as well as sea-ice freeboard, there are data products available for vegetation canopy height, ocean surface topography, and inland water body height. For the Forest Service and others in the ecosystem community, the ICESat-2 data acquisition strategy allows for estimates of terrain and canopy heights, as well as canopy cover, across large areas scalable to the global level.

One of the primary motivations for obtaining global vegetation height from ICESat-2 is to improve the understanding of global forest biomass using the ATL08 data product, which reports terrain and canopy heights—among other parameters—suitable for stand level or regional assessments. The ATL08 along-track data product classifies photons as either terrain or canopy, which allows for computation of additional parameters described in the ATL08 Algorithm Theoretical Basis Document (Neuenschwander and Pitts 2019b). The data product calculates the terrain and canopy height parameters using a fixed 100 m distance (resolution) over vegetated surfaces to capture fine-scale geomorphology, as well as to provide the user community continuity of data parameters and consistency of the metrics in the along-track direction. The ICESat-2 strong beams are the best option for detecting ground and canopy photons, particularly during daytime acquisitions, while the weak beams cannot see through clouds and limited usage during night acquisitions. After a few years of data collection, the ICESat-2 mission will generate a gridded data product (identified as ATL18), which will provide a coarse resolution (1 km resolution tiles) canopy height and ground elevation time

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series. A higher resolution grid (e.g., 100 m to 500 m, TBD) will be available at the end of the mission.

The ICESat-2 scientific data sets are available through the NASA DAAC: NSIDC, <https://nsidc.org/data/icesat-2>. The NSIDC distributes and archives the ICESat-2 data, as well as provides subsetting, reprojection, reformatting, and visualization services to facilitate its discovery and access. To receive updates about ICESat-2 data releases, sign up to the NSIDC website mailing list by sending an email to [nsidc@nsidc.org](mailto:nsidc@nsidc.org) (subject: ICESat-2 mailing list signup).

## C.4 CMS Program Overview, Products and Applications

NASA's Carbon Monitoring System (CMS) program was started in 2010 from U.S. Congressional direction. The goal of CMS is to prototype the development of capabilities necessary to support stakeholder needs for MRV of carbon stocks and fluxes. Using a range of NASA satellite observations, modeling and analysis capabilities, and commercial off-the-shelf technologies, this program aims to establish the accuracy, quantitative uncertainties, and utility of products for supporting national and international policy, regulatory, and management activities. In its second phase<sup>2</sup>, CMS funded over 80 projects in a broad range of topics including land biomass, atmospheric flux, ocean biomass, and stakeholder engagement. Several of these projects involve important collaborations with the Forest Service on land biomass. NASA has recognized the urgent need for the development of MRV through its initiation of the CMS program.

The University of Maryland, working with NASA centers, the Forest Service, and commercial entities has led research efforts in Phase 1 and Phase 2 prototype developments that have laid the basic groundwork of the approach to high-resolution and precise MRV. The overall goal of this work is the continuing development of a framework for estimating high-resolution forest carbon stocks and dynamics and future carbon sequestration potential using remote sensing and ecosystem modeling, linked with existing field observation systems such as the Forest Service Forest Inventory and Analysis (FIA) network. In particular, the CMS program seeks to demonstrate an approach at the county/state-scale to cover a multi-state region encompassing the Regional Greenhouse Gas Initiative (RGGI) domain and the coterminous United States. The intent is to drive the model at 1 km resolution over the lower 48 states using the first year of canopy height observations from GEDI. This will address the following objectives: (1) build upon, extend, and improve our existing methodology for carbon stock estimation and uncertainty based on lessons learned from our Phase 2 studies; (2) provide wall-to-wall, high-resolution, estimates of carbon stocks, carbon sequestration potential, and their uncertainties for multi-state RGGI domain; (3) validate and enhance national biomass maps using FIA data and high-resolution biomass maps over an expanded domain; (4) demonstrate MRV efficacy to meet stakeholder needs at

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<sup>2</sup> A third phase of CMS began in 2022 but was not available at the time of the 2019 workshop. Find the most up-to-date information on CMS here: <https://carbon.nasa.gov/cms/>.



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a regional scale, and a vision for future national-scale deployment; and (5) prototype national-scale forest carbon products for CONUS using GEDI data. The research directly responds to the research topics identified for the second phase of CMS.

The CMS Applications Program Framework depicts most of the activities that the CMS applications team conduct on a regular basis. One of the most successful activities is the monthly Policy Speaker Series, which brings together developers and users of carbon related products in an effort to expand the knowledge of how CMS products can be used by decision makers, data user groups, the broader CMS community, and those in the public policy realm. At the time of the 2019 workshop, 48 seminar talks had taken place at Goddard Space Flight Center, by stakeholders from federal, state, and local government, non-profit organizations, international organizations, and private companies. The talks are archived in the [CMS website](#), and they have helped identify data needs, knowledge gaps, and specific interests from the stakeholder community.

The CMS applications efforts also organize an annual CMS Applications Workshop, during the CMS Science Team Meeting, where users of the data products present applications, challenges, lessons learned, and impacts of CMS data products for their organization's goals. A [Data Products Fact Sheet](#) has also been created as part of CMS applications that contains a collection of CMS metadata for each product being developed, and which is integrated into the CMS website. Application Readiness Levels (ARLs) are also collected as part of the Data Products Fact Sheet, which provides transparency to the user community on the maturity of each CMS product. The ARLs are used as a communication tool for stakeholders to assess the maturity of the product. Finally, the CMS applications team also develops surveys and community assessments to understand the challenges and assess the impact of CMS data products for end user organizations; as well as develop socio-economic case studies that provide a better understanding of the impact of CMS data products for the end user organizations, and a better understanding of societal benefits of select CMS data products.

The CMS funds multiple projects that address diverse natural resource issues around the world that are developing diverse data products, methodologies, and tools to better measure carbon stocks and fluxes, and understand the carbon cycle, using existing NASA satellite data, or other remote sensing data, such as LiDAR. At the time of the workshop (2019), there were 96 CMS-funded projects and more than 170 data products available or in development throughout the world (search them online here: <https://carbon.nasa.gov/cms/data.html>). Some of these data products are scaled for international-level resource management, and others are scaled for national and local-resource management, which can be of interest for the Forest Service.

An example of the NASA–Forest Service collaboration within the CMS program, Forest Carbon Management Framework (ForCaMF) is a system for identifying the landscape-specific role of different kinds of management and disturbance on carbon storage. It uses remotely sensed maps of forest disturbance and forest structure, and it is tightly

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constrained by estimates from FIA. ForCaMF addresses congressionally mandated assessments of the National Forest System (36 CFR Part 219), and its results have formally supported the forest planning process of more than 20 National Forests (a number expected to grow to over 100 as Plan revision comes due for more units). The Forest Service has conducted workshops and developed videos and a visualization tool to help managers understand ForCaMF's methods and implications. NASA technology and support was crucial in the development of ForCaMF. Future Forest Service /NASA partnerships may benefit from reviewing how ForCaMF went from a remote sensing research idea to a key operational monitoring system.

Lessons from this experience that were highlighted during the 2019 Workshop that may be of use in future interagency collaboration include:

1. Foresight—ForCaMF started with a NASA investment in applied science, targeting new (at the time) mapping techniques and a part of the Forest Service (FIA) that has a mandate for operational forest monitoring.
2. Patience—NASA's involvement lasted more than one 3-year research cycle.
3. Build with the end in mind—The application was codeveloped with the client (National Forest System managers).
4. Consistency with the existing monitoring framework—ForCaMF carbon reports were constrained by FIA data, which are used by the National Forest System in most other fields, frames carbon assessment coherently with the rest of the reporting strategy.
5. Consider decision support that is actionable at a local level—Systems calibrated with a sparse system of tower data or field plots may yield useful fundamental information about carbon dynamics at regional or national scales, but management happens much more locally. ForCaMF's use of both FIA's extensive inventory and Landsat-resolution maps met demands for local interpretability.



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