SBG User Needs and Valuation Study

Final Report, December 2021
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This final report has been approved by the RTI Innovation Advisors for public dissemination.

Please Note: This report is a good faith effort by RTI to accurately represent information available via secondary and primary sources at the time of the information capture.

Abbreviations

ACCP	Aerosol and cloud, convection and precipitation
Ag	Agriculture
API	Application Programming Interface
AVIRIS	Airborne Visible Infrared Imaging Spectrometer
BMGF	Bill & Melinda Gates Foundation
CARD4L	CEOS Analysis Ready Data for Land
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station
DAACS	Distributed Active Archive Centers
DO	Designated Observable
DS	Decadal Survey
EIA	U.S. Energy Information Administration
EO	Earth observation
EOD	Earth observation data
EPA	U.S. Environmental Protection Agency
ESA	European Space Agency
ESI	Evaporative Stress Index
ET	Evapotranspiration
EU	European Union
FEWS-NET	Famine Early Warning System Network
FSC	Forest Stewardship Council
GeoTIFF	Metadata standard which allows georeferencing information to be embedded within a TIFF
GFW	Global Forest Watch
GHG	Greenhouse gas
HDF	Hierarchical data form
HEA	Household economy model
HIS	Hyperspectral imaging spectroscopy
Landsat	Earth-observing satellite missions jointly run by NASA and the US Geological Survey
LiDAR	Light Detection and Ranging
LSTM	Land Surface Temperature Monitoring
MC	Mass Change
MCC	Millennium Challenge Corporation
Mha	Million hectares
ML	Machine learning
MODIS	Moderate Resolution Imaging Spectroradiometer
MRF	Multispectral raster format
MRV	Monitoring, reporting, and verification
NAFO	National Alliance of Forest Owners
NAIP	National Agricultural Imagery Program
NDVI	Normalized difference vegetation index
NetCDF	Network common data form
NGO	Nongovernmental organization
NIHHIS	National Integrated Heat Health Information System
NIR	Near-infrared
NOAA	National Oceanic and Atmospheric Administration
RS	Remote sensing
SAR	Synthetic aperture radar
SATM	Science Applications Traceability Matrix
SBG	Surface Biology and Geology
SDC	Surface deformation and change
SFI	Sustainable Forestry Initiative
TIFF	Tagged image file format
TIMO	Timber Investment Management Organizations
TIR	Thermal infrared
TNC	The Nature Conservancy
UHI	Urban heat island
UNFCCC	United Nations Framework Convention on Climate Change
USAID	U.S. Agency for International Development
USDA	U.S. Department of Agriculture
USFS	U.S. Forestry Service
USGS	U.S. Geological Survey
VASP	Value-added service provider
VIIRS	Visible infrared imaging radiometer suite
VIS-NIR	Visible to near-infrared
VSWIR/VISWIR /VIS-SWIR	Visible to shortwave infrared
WRI	World Resources Institute

Executive Summary

Study—Background and Objectives

BACKGROUND. This research report is the second in a series of two user needs and valuation studies conducted by RTI International on behalf of NASA for the global imaging spectroscopy Surface Biology and Geology (SBG) Designated Observable (DO) mission. The prospective SBG mission will advance future science on the global atmosphere, cryosphere, and terrestrial and aquatic ecosystems. SBG represents a unique Earth Observation (EO) platform combining hyperspectral visible to short wave infrared (VSWIR) and thermal infrared (TIR) imaging spectroscopy capabilities for unmatched global coverage and coincident spectral resolution. Readers interested in a more detailed explanation of the original project design and integration with the SBG architecture study may reference the original SBG User Needs and Valuation Report, September 2020. RTI and the SBG Applications team began work on this second study in April 2021 and collaborated on application selection, survey development, and expert interviews through the fall of 2021, culminating with delivery of this final report. RTI again used a **user-centered design framework,** as piloted in the first study.

USER-CENTERED DESIGN VARIABLES		
DESIRABILITY	• Users, user archetypes • Use cases, application archetypes	• Users' jobs to be done and needs • Users' perception of benefits
VIABILITY	• Value framework • Value drivers—social, health, economic, environmental • Value measures	
FEASIBILITY	• Performance, operational capabilities, partnerships	

OBJECTIVES. After the inaugural SBG User Needs and Valuation study, the SBG Applications team engaged RTI to research an additional set of five application areas. The primary objective for this follow-on study was consistent with the prior study to identify nontraditional private and public users and to assess their key activities, needs, and perceived value of SBG. Notable differences between the studies include:

- The SBG platform architecture had been set by the start of this second study. As a result, the emphasis shifted from assessing users' prioritization of SBG's capability options to further detailing the extent to which SBG's capabilities and products meet users' needs.

- This study was designed to increase the amount of primary and survey research work to ensure a more detailed and comprehensive assessment of the second set of application areas, which were anticipated to be more involved and challenging than the original set.

Study—Areas of Focus

As in the first study, in collaboration with the SBG Applications team, we used a review and selection process to determine the most suitable application areas to study. The SBG application areas of focus for this follow-on study are **Urban Heat and Health, Forest Management, Coral Reef Ecosystems, and Global Food Security.** Approximately midway through the engagement, and at the direction of the SBG Applications team, a fifth application area, **Conservation and Biodiversity**, was added. These five application areas are rooted in the Decadal Survey science objectives and SBG Science Applications Traceability Matrix (SATM), and strategically span the full range of SBG science objectives. Consistent with the prior report, additional insights on value-added service providers (VASPs) are provided. This follow-on study also highlights insights on user-desired aspects of information quality and accessibility and notes opportunities for effective engagement with specific user groups or communities. These insights are presented in the Findings and General Survey sections.

Primary Application and Other Communities Studied

September 2020	December 2021
Fire Ecology and Risk	Urban Heat and Health
Agriculture and Water Resources	Forest Management
Algal Bloom and Water Quality Mapping	Coral Reef Ecosystems
Mineral Resource Mapping	Global Food Security
VASPs	Conservation and Biodiversity
	VASPs

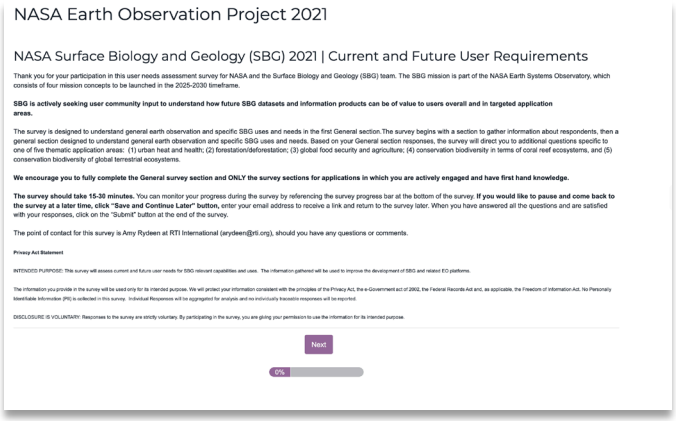
Study—Research Methodology

The study planning, research methods, and tools of this follow-on research study were carried over from the prior engagement with a few noted exceptions. The user-centered research and valuation methods are explained in greater detail in the final report of the first study.

APPLICATION AREA SELECTION. Focus application areas were selected in the same way as the September 2020 study. Interviews with SBG technical experts in each candidate application area were used to complete a rating system that considered the strength of the SBG value proposition, the feasibility of communicating and assessing that value, and the ease with which target users and user communities could be engaged.

	Value Proposition	Rate (1-3)	Feasibility of Communicating Value	Rate (1-3)	Experts	Rate (1-3)	User Community	Rate (1-3)	Research Depth Required	Rate (1-3)	Feasibility of Assessing Value	Rate (1-3)
Evaluation Criteria	Assumed SBG differentiator		Case studies mentioned		Additional known experts posited		1-2 User communities identified		Limited research required for baseline understanding		Clear incremental value of SBG	
	Multiple specific points of differentiation		Known literature with artifacts to demonstrate SBG differentiator		Reference to leads for experts for valuation or use cases		User communities have established lists or databases		Specific leads provided and no additional lead finding required		Possible approach but will require multiple points of validation	
	Solidly confirmed value proposition by expert		Easily gather from first round experts		Direct contact with experts for valuation and use cases		User community has sophisticated users		Direct point of contact in user community and to relevant experts		Body of literature/data on existing valuation approach	
Score	*Summation*		*Summation*		*Summation*		*Summation*		*Summation*		*Summation*	

SURVEY. The September 2020 study survey was a model for the second 2021 user needs survey. Extra time was committed to iterating with the SBG Applications team and NASA leadership to ensure refinements and new lines of enquiry. We added new demographic, EO use, information and computing, algorithm product, and specialized support questions for this second online survey.



NASA Earth Observation Project 2021

NASA Surface Biology and Geology (SBG) 2021 | Current and Future User Requirements

Thank you for your participation in this user needs assessment survey for NASA and the Surface Biology and Geology (SBG) team. The SBG mission is part of the NASA Earth Systems Observatory, which consists of four mission concepts to be launched in the 2025-2030 timeframe.

SBG is actively seeking user community input to understand how future SBG datasets and information products can be of value to users overall and in targeted application areas.

The survey is designed to understand general earth observation and specific SBG uses and needs in the first General section.The survey begins with a section to gather information about respondents, then a general section designed to understand general earth observation and specific SBG uses and needs. Based on your General section responses, the survey will direct you to additional questions specific to one of five thematic application areas: (1) urban heat and health; (2) forestation/deforestation; (3) global food security and agriculture; (4) conservation biodiversity in terms of coral reef ecosystems, and (5) conservation biodiversity of global terrestrial ecosystems.

We encourage you to fully complete the General survey section and ONLY the survey sections for applications in which you are actively engaged and have first hand knowledge.

The survey should take 15-30 minutes. You can monitor your progress during the survey by referencing the survey progress bar at the bottom of the survey. **If you would like to pause and come back to the survey at a later time, click "Save and Continue Later" button,** enter your email address to receive a link and return to the survey later. When you have answered all the questions and are satisfied with your responses, click on the "Submit" button at the end of the survey.

The point of contact for this survey is Amy Rydeen at RTI International (arydeen@rti.org), should you have any questions or comments.

Privacy Act Statement

INTENDED PURPOSE: This survey will assess current and future user needs for SBG-relevant capabilities and uses. The information gathered will be used to improve the development of SBG and related EO platforms.

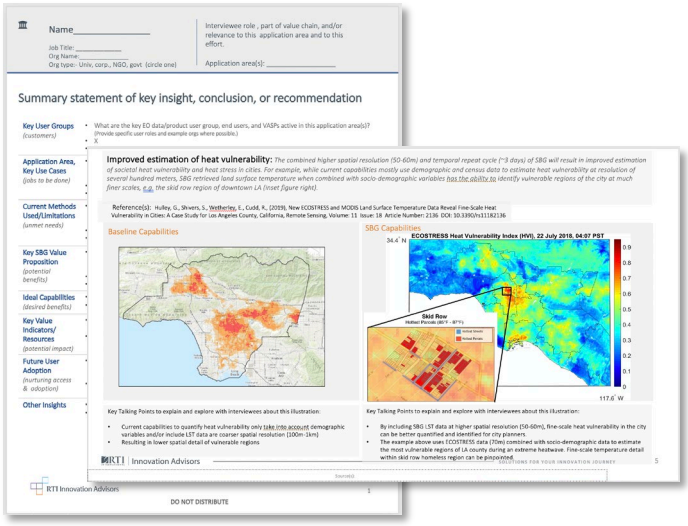
The information you provide in the survey will be used only for its intended purpose. We will protect your information consistent with the principles of the Privacy Act, the e-Government act of 2002, the Federal Records Act and, as applicable, the Freedom of Information Act. No Personally Identifiable Information (PII) is collected in this survey. Individual Responses will be aggregated for analysis and no individually traceable responses will be reported.

DISCLOSURE IS VOLUNTARY: Responses to the survey are strictly voluntary. By participating in the survey, you are giving your permission to use the information for its intended purpose.

Next

0%

END-USER EXPERT INTERVIEWS. The previous interview guide was used with minor changes to facilitate and capture consistent insights on key user communities, use cases, currently used remote sensing (RS) data and products, SBG value, valuation indicators and resources, and insights for future user adoption. Visuals were used where possible to better demonstrate and convey SBG capabilities to nontechnical interviewees. We provided the **Interview Notes** to the SBG Applications team as a separate file.



Name_____

Job Title: _____
Org Name: _____
Org type:- Univ, corp., NGO, govt (circle one)

Interviewee role , part of value chain, and/or relevance to this application area and to this effort.

Application area(s): _____

Summary statement of key insight, conclusion, or recommendation

Key User Groups (customers)
Application Area, Key Use Cases (jobs to be done)
Current Methods Used/Limitations (unmet needs)
Key SBG Value Proposition (potential benefits)
Ideal Capabilities (desired benefits)
Key Value Indicators/ Resources (potential impact)
Future User Adoption (nurturing access & adoption)
Other Insights

- What are the key EO data/product user group, end users, and VASPs active in this application area(s)? (Provide specific user roles and example orgs where possible.)
- X

Improved estimation of heat vulnerability: *The combined higher spatial resolution (50-60m) and temporal repeat cycle (~3 days) of SBG will result in improved estimation of societal heat vulnerability and heat stress in cities. For example, while current capabilities mostly use demographic and census data to estimate heat vulnerability at resolution of several hundred meters, SBG-retrieved land surface temperature when combined with socio-demographic variables has the ability to identify vulnerable regions of the city at much finer scales, e.g. the skid row region of downtown LA (inset figure right).*

Reference(s): Hulley, G., Shivers, S., Wetherley, E., Cudd, R., (2019), New ECOSTRESS and MODIS Land Surface Temperature Data Reveal Fine-Scale Heat Vulnerability in Cities: A Case Study for Los Angeles County, California, Remote Sensing, Volume: 11 Issue: 18 Article Number: 2136 DOI: 10.3390/rs11182136

Baseline Capabilities

SBG Capabilities

ECOSTRESS Heat Vulnerability Index (HVI), 22 July 2018, 04:07 PST

Skid Row

Key Talking Points to explain and explore with interviewees about this illustration:

- Current capabilities to quantify heat vulnerability only take into account demographic variables and/or include LST data are coarser spatial resolution (100m-1km)
- Resulting in lower spatial detail of vulnerable regions

Key Talking Points to explain and explore with interviewees about this illustration:

- By including SBG LST data at higher spatial resolution (50-60m), fine-scale heat vulnerability in the city can be better quantified and identified for city planners.
- The example above uses ECOSTRESS data (70m) combined with socio-demographic data to estimate the most vulnerable regions of LA county during an extreme heatwave. Fine-scale temperature detail within skid row homeless region can be pinpointed.

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Study—Valuation Methodology

The valuation methods are the same as those used in the original SBG valuation research. These methods are based on a simple and proven counterfactual valuation methodology.

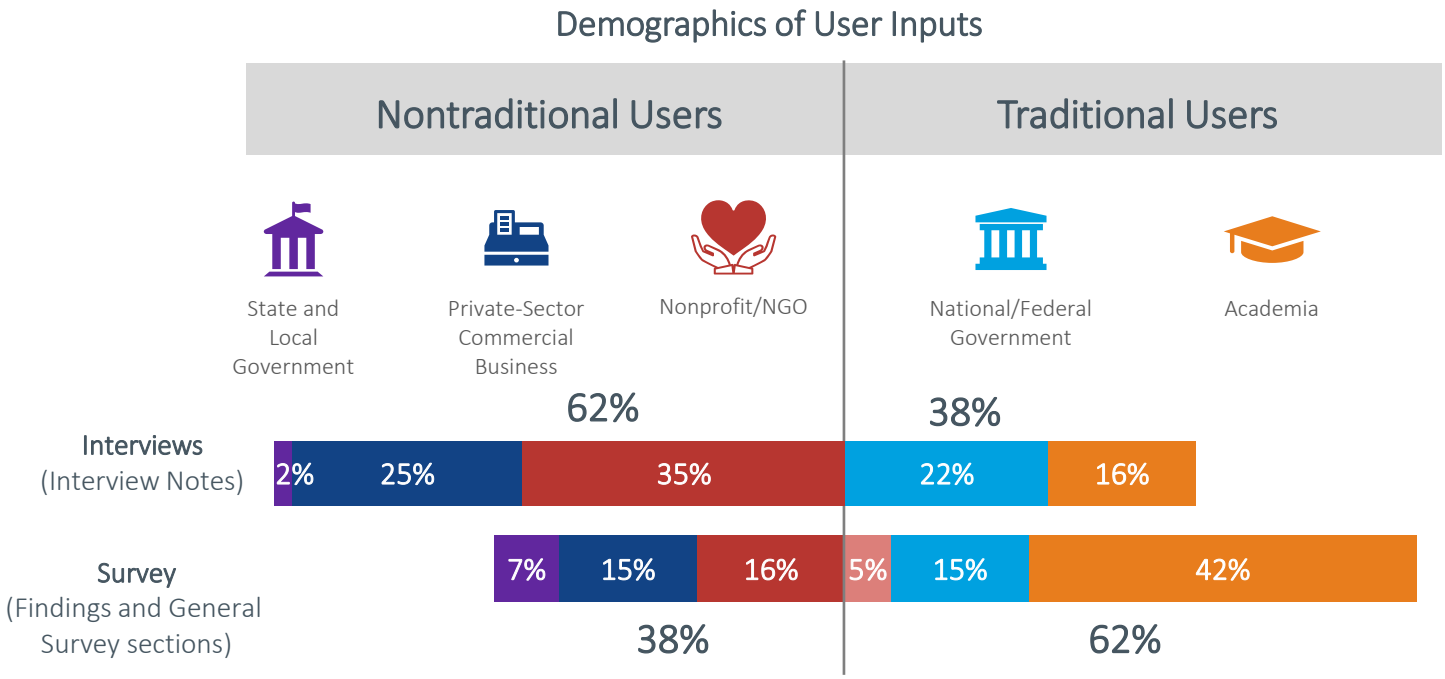
For each primary application area, RTI interviewed specifically targeted user experts. A six-step process was used to understand context, define the SBG benefit, and assess value.

1. Define the most important activities, or "jobs to be done," in the primary application area.
2. Characterize current observation methods used for the most important activities.
   - Current methods set a "baseline" (a counterfactual) against which comparison can be made.
   - When possible, RTI always explored current RS imaging, not ground-based direct methods, as the baseline. In many applications, Landsat 8 and Sentinel 2 are used to support current observations (these are treated as the "baseline" observation methods).
   - To facilitate this discussion, specific visuals provided by NASA application experts and a simple baseline and SBG capability set communication tool (see Appendix) were used.
3. Pose the experts a value proposition hypothesis about SBG benefits.
   - Each activity expert was then queried about how the SBG capability features might provide benefits to users in their primary application area. Technical experts can generally answer these questions.
   - For nontechnical experts less knowledgeable about RS, SBG functionalities were suggested (e.g., assume SBG can distinguish natural versus plantation forests). RTI also posed questions in terms of the utility SBG might bring in key activities (e.g., species mapping for conservation, plant moisture for crop monitoring).
   - Experts were then asked to compare existing baseline observation methods with the potential incremental improvements of SBG capabilities and determine the nature and scale of the benefit.
4. Characterize the value that identified SBG benefits provide.
   - Then the expert interviewees were encouraged to focus on where they saw the greatest potential for SBG to provide value to the most important activities and for their respective user community.
   - After homing in on the high-value activities, RTI asked experts to ascribe any quantitative estimates of the impact of SBG or characterize the nature (economic or noneconomic) and scale of SBG benefits.
   - In cases where experts were less comfortable making explicit hypothetical projections of benefits, we asked them to give optimistic and pessimistic scenarios.
5. Validate and estimate the value scale of key activities and SBG's incremental benefit value.
   - When possible, RTI validated expert estimates with other expert valuation insights and/or existing literature to provide supporting data and to check for and reduce bias.
   - RTI considered possible value economic, market-based value benefits via improved production, products, or both. Nonmarket value benefits include social, health, and environmental benefits.
6. Create SBG valuation case studies and vignettes to illustrate the potential value of SBG.
   - For each application area, we chose the "highest-value" use case as our principal case study but included additional SBG valuation "vignettes" for different activities and user communities.
   - RTI validated case studies with multiple methods and experts, but these case studies and vignettes should be considered very rough estimates and hypothetical values based on a small number of interviews and a review of the published literature. Some SBG valuations are not possible because expert estimates were lacking or the incremental benefits of SBG capabilities could not be quantified in isolation from other variables.

The valuation of targeted SBG applications warrants substantive additional research.

Study—User Input Demographics

A fundamental aspect of the user study was to engage private-sector, nongovernmental organizations (NGOs), and local municipal EO users not traditionally engaged by NASA for science mission planning. Categorically identifying and engaging this type of nontraditional user was paramount to successfully studying their respective needs and perceptions of SBG. The engagement process can be especially challenging and time intensive when seeking "nontraditional" users who neither identify themselves as such nor understand the technical capabilities of SBG. For this second study, RTI and the SBG Applications team used the previous study's work on developing and testing useful categories such as direct vs. research users of EOD, operational or commercial users vs. scientific or academic developers of EOD products, and technical vs. nontechnical. Ultimately nontraditional users and traditional users proved to be the most useful categorization and was used to guide the primary and survey research efforts. With this understanding, we targeted a diverse and representative set of user types across the value chain for each of the five primary application areas.



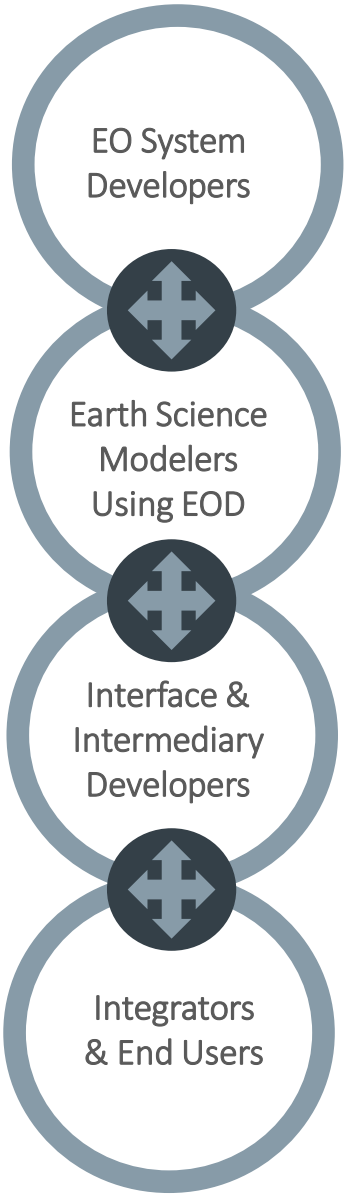
On average, more interviews per application area were done in this second study, and the total interview count was higher due to an additional application area. The percentage of federal experts interviewed was lower in this study, whereas the percentage of NGO expert interviews was higher. In this second survey, a redesign of the demographic questions improved the clarity of traditional versus nontraditional user cohorts. In this survey, the percentage of nontraditional and international respondents is higher, whereas the percentage of federal respondents is lower. Collectively, the research in this study reached a more diverse and intended audience.

Source:

Study—Value Chain

Assessing user needs and valuation for a future SBG mission involves considering the entire value chain for EOD. The target subjects of this user-centered study, end users, are typically several steps removed from application scientists and NASA. RTI prepared a comprehensive and broadly inclusive SBG assessment by engaging with and soliciting insights from the value chain and communities of varied EO and hyperspectral imaging spectroscopy (HIS) adoption maturity. RTI's research targeted end users and intermediary product developers, VASPs, and boundary organizations with specific technical insights and deep knowledge of their respective application domains.

EOD Value Chain[1]



GENERATE EOD
Planning and using instruments for collecting data and making the data available at various degrees of "human readability."

MODEL & ASSIMILATE EOD
Combining disparate observations into a single coherent picture or model to advance earth science objectives.

DISCOVER & VISUALIZE EOD
Developing applications and providing an interface to find and explore data.

TRANSFORM EOD
Creating a data interface based on user needs.

GENERATE KNOWLEDGE
Combining physical, social, economic and other data.

SUPPORT DECISIONS
Providing recommendations for action.

SBG Research Subjects

NASA plays a critical role along the EO value chain as developers of missions, applications, and research data.
Numerous SBG and NASA experts were consulted throughout this effort to understand SBG's capabilities and proposed data/algorithms

Intermediary VASPs and other boundary organizations provide a critical link between the research data and applications developers and private-sector end users.
Over a dozen VASPs were interviewed and many more surveyed, bringing a strong commercial perspective to the findings.

End users ultimately want EO-based tools and services that help them make better decisions for preparation, planning, and policy.
Over 40 end users were interviewed, and a significant number were surveyed.

1 – This graphic is based on other conceptions of EO value chains with RTI research as annotation: Earth science value chain highlighting the functions required to provide insight that can support better decisions [from NASA/TM–2018-219026, 2018], and Virapongse, A., Pearlman, F., Pearlman, J., Murambadoro, M. D., Kuwayama, Y., & Glasscoe, M. T. (2020). Ten rules to increase the societal value of earth observations. Earth Science Informatics, 13, 233–247. https://doi.org/10.1007/s12145-020-00453-w

Insights—SBG-Relevant Use Cases

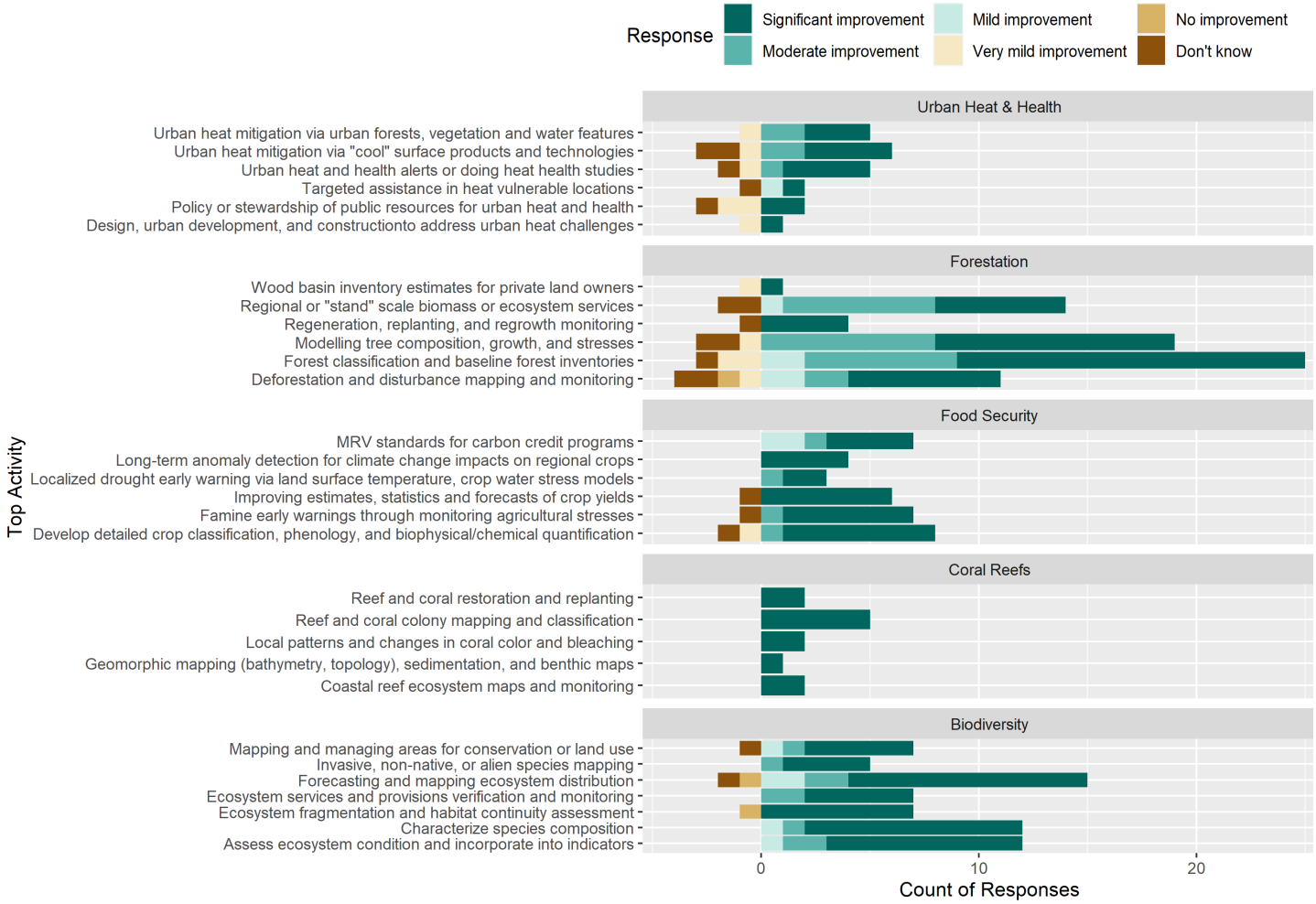
The central research objective of this study was to identify nontraditional user communities within each application area and characterize each community's specific and important activities, or "jobs to be done." To elucidate specific activities, RTI used a jobs-to-be-done methodology that informed the primary research and survey design. Potential users across application areas were considered, as were their needs, and how those needs might be met with RS data. The most cited needs and jobs to be done, as use cases, are summarized below.

Application Area	Key Potential Users of SBG Data/Products	Key Potential Use Cases of SBG Data/Products
Urban Heat and Health 	**Cities**—Large city governments **NGOs**—Urban forestry, heat health, cool surfaces **Companies**—Building cool-roof and reflective surface providers **Planners**—Urban development, consultants **Utilities**—Electric, water companies **Healthcare systems**—Public health agencies, insurance providers, hospitals	**Heat alerts and maps,** high-resolution urban maps for heat alerts and policy making **Targeting heat mitigations,** siting cool buildings, cool roads, urban vegetation **Mapping programs,** heat health and mitigation management, policy, impacts, monitoring, reporting, and verification (MRV) for programs **Albedo/reflectivity/emissivity studies,** urban infrastructure/surface surveys
Forest Management 	**Landowners** (Large/Private)—Vertically integrated corporations, timber investment management organizations (TIMOs) **Managers** (Private)—Consulting foresters, land management companies **Manufacturers** (Private)—Forest products **Consortia** (Academia)—Industry research **Managers** (Government)—State foresters **Corporations** (Large/Private)—Corps with no-deforestation or lower greenhouse gas (GHG) commitments **NGOs**—Forest, watershed conservation **Landowners** (Small/Private)	**Forest inventories,** land/wood baselines and supply assessments **Species classification,** substand classification and invasive or understory composition **Forest health,** tree canopy height, phenology/leaf out timing, insects/disease **Carbon market/offsets,** MRV for owners/NGOs **Disturbance and regeneration,** deforestation, disease, storm/fire; replanting, regrowth **Functional diversity,** functional properties across time and ecosystems/habitats
Coral Reef Ecosystems 	**Governments**—National and state **NGOs**—Relocation, restoration, conservation, economic development, tourism **Universities** **Companies**—Relocation, insurance, reinsurance, tourism	**Marine spatial planning,** location and condition of reefs **Restoration and replanting,** site and monitor **Capture bleaching events** **Condition and composition,** health, resiliency across time **Disturbance,** nutrient and pollution influx, wave action, temperature, acidification
Global Food Security 	**Humanitarian Aid Agencies** (Gov't/NGO)—Major international food aid organizations **Nations** (Government)—Agriculture (Ag) statistic bureaus **Corporations** (Large/Private)—Multinational agriculture products companies **Companies** (Small/Private)—VASPs, crop consultants, digital agriculture tool developers **NGOs**—Food security and aid nonprofits **Food Security Researchers** (Academic/Gov't)—Experts in hyperspectral/RS Ag, hazards **Finance** (Private/NGO)—Forecast-based financing, crop insurance groups	**Global/regional agriculture statistics,** estimates of crop yield and productivity **Land and field assessments,** cropland, crop type classification, monitoring **Hazard events/trend monitoring,** onset, extent, and prediction of drought, floods, and anomaly detection **Land quality surveys,** for suitable land, soil maps, for conversion, regenerative Ag **Carbon markets,** improved indicators and models for soil carbon, certification, MRV **Food insecurity interventions,** regional models for improved interventions
Biodiversity and Conservation 	**Conservation NGOs** (Large)—Global conservation nonprofits **Conservation Agencies** (Gov't/NGO)—Major international sustainable development organizations **Nations** (Gov't)—Conservation agencies **Corporations** (Large/Private)—Multinational consumer products companies **Companies** (Small/Private)—VASPs, environmental services, consultancies **Biodiversity Researchers** (Academic/NGO)—Experts in ecology/biology	**Deforestation and degraded land,** monitoring major crop plantations and natural forests **National surveys,** mapping baselines and establishing high-value conservation areas **Species classification,** plant/crop classification, baselines, invasive/understory composition **Agroforestry and carbon offsets,** MRV of suppliers and smallholders to support sustainable practices **Habitat management,** conservation land management and geo-accounting

Insights—Perceived Benefits of SBG

As noted, an objective of this research study was to characterize in greater detail the extent to which SBG's capabilities and products meet users' needs in specific and high-priority use cases. The ways in which experts perceived SBG's potential benefits for their application areas and user communities varied based on their unique use cases. These expert insights are detailed in the Findings section and application overviews starting on page 22 in the executive summary. However, survey data allow for analysis across application areas, because the survey used a variety of means to assess SBG capabilities, and respondents provided their perceptions of SBG's overall benefits to them. Respondents were asked to consider SBG's capabilities and indicate the extent to which these capabilities provide benefits for their top 2 most important activities. The survey findings (below) highlight that over 80% of respondents believed that SBG will improve sensitivity and fidelity moderately to significantly compared with their current observation methods, which will result in higher quality data and data products.

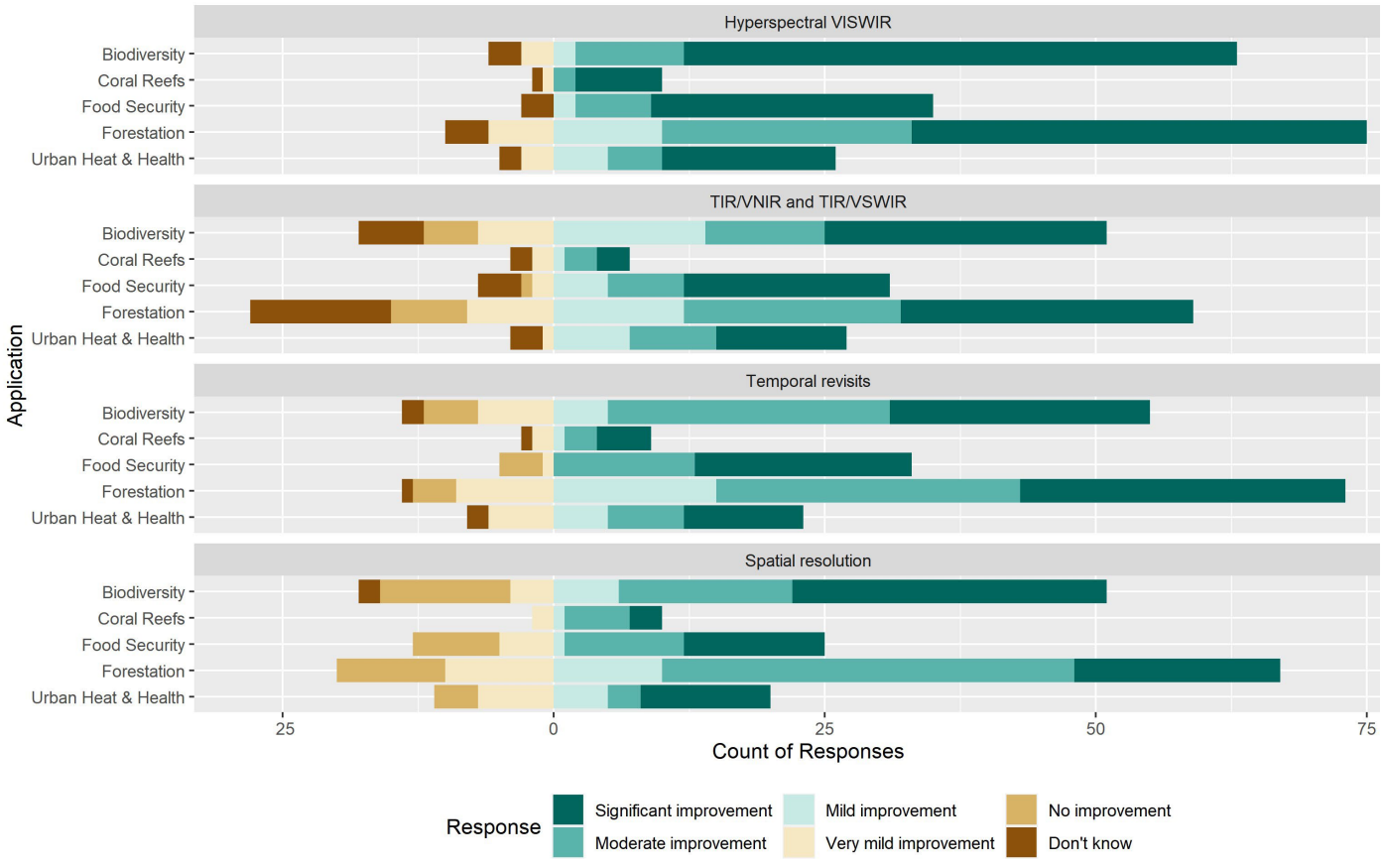
Consider SBG's overall Increased Sensitivity and Fidelity *and indicate the extent to which these will provide benefit for your top 2 activities (by application)?*



Insights—Perceived Benefits of SBG

Both users and VASP experts see great potential for SBG, but they also have very practical and operational use requirements. SBG offers highly desired spectral capabilities but has functional limitations in terms of spatial resolution and revisit rates, especially, for example, in dynamic and complex monitoring applications. Collectively, experts said that SBG's two greatest and newly enabling potential benefits will come from HIS for spectral classification of terrestrial and aquatic species and by filling current observation gaps with better spatial and time-resolved thermal data. Results compiled from all respondents show the improvement potential of each SBG capability for each primary application area. The VSWIR (81%), TIR (58%), spatial (63%), and temporal (70%) capabilities were rated as "moderate" or "significant" improvements, and VSWIR was the highest rated overall at 61% "significant" across applications. Note that "don't know" responses reflect application-specific pockets of uncertainty about certain SBG capabilities. Several nonresearch end-user interviewees also lacked the technical or operational background to assess the importance or value of specific SBG capabilities. These results should be considered as indicative and not definitive given the limited response rates. Further targeted assessments with knowledgeable users will be necessary as specific communities are engaged to prepare for development and adoption.

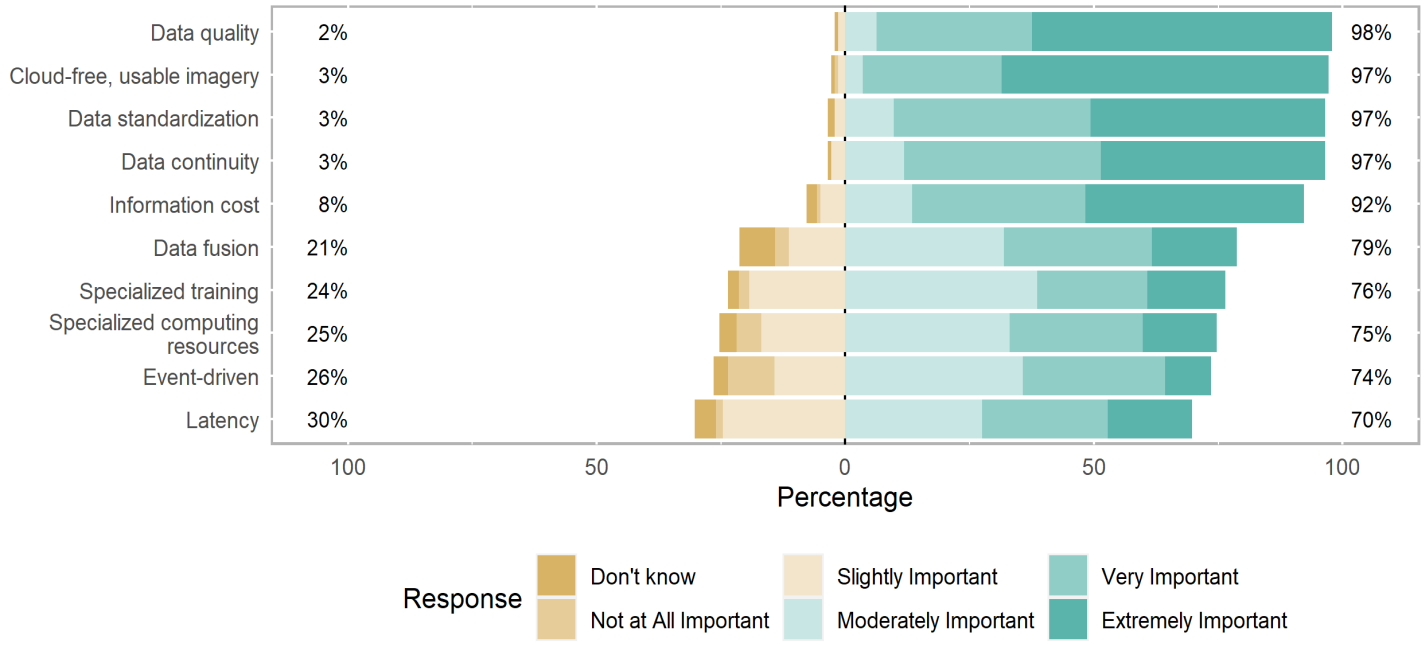
Consider these SBG capabilities and indicate the extent to which each of them provides benefits for the top 2 activities in this application area?



Insights—Perceived Benefits of SBG

According to expert interviews and survey feedback, a fundamental part of NASA SBG's value proposition is that experts trust NASA's credibility and capabilities to ensure high-fidelity data, transparent data processes, verification, and accessibility. Innovators and VASPs, in particular, noted the great value NASA could provide by advancing HIS applied and data sciences and by taking a leadership role in developing and ensuring information quality. Survey responses showed the high importance users, across all applications, place on information quality factors. Multiple experts also noted the necessity for NASA to provide capacity building and training support for new applications and data products like those SBG will generate. Still, survey results show training, while important, is not the top priority.

For the use of EOD/product in your primary application area, how important are the following information quality and accessibility issues? (Definitions for each option were given.)



Across application areas, over 90% of respondents indicated that data-centric issues are most important, whereas specialized training and computing resources were less important to them. Overall, having the ability to receive event-driven updates and latency performance had lower priority for respondents. Additional findings about preferred algorithm products, software and data formats, and latency requirements can be found in the General Survey section of the report.

Study—User Readiness

"Absorptive capacity" is a useful innovation construct to use when assessing an end user's or user community's ability to understand and adopt an innovative EO platform like SBG. Absorptive capacity is defined as "a firm's ability to recognize the value of new information, assimilate it, and apply it to commercial ends."[1] Absorptive capacity characterizes a user's or user community's capacity for awareness, absorption, assimilation, and adoption of a new innovation or capability like SBG. Related to SBG, skilled practitioners, innovators, and lead users working with RS and EOD will tend to have high absorptive capacity; a high tolerance for risk and complexity working with developmental capabilities, like SBG; and the ability to see opportunities based on SBG's new capabilities. Those with little to no awareness and limited technical knowledge to understand a new innovation, like SBG, or its capabilities are considered to have relatively lower absorptive capacity.

Communities with practitioners and innovators already actively working with RS and EOD and currently using multispectral platforms like Landsat and Sentinel have a high absorptive capacity, directly relevant to SBG, and can be considered target communities. For these target communities RTI sought to assess the maturity of EOD use, specifically HIS and combined TIR imaging, used by end users and intermediaries. Early-stage innovators and lead users in established "communities of practice" were identified for potential collaboration. Pathways to further engage and support users and communities that are less developed, but are promising "communities of potential" have also been noted for each primary application area.

In each application area and for each community, RTI assessed their absorptive capacity and determined their "readiness" for NASA SBG to engage them productively. RTI defined and characterized two important aspects of "readiness"—technical and community—as proxies for a community's capacity and suitability to productively engage with SBG and vice versa. The technical and community readiness for each primary application area is summarized in the subsequent charts and detailed in the overview and detailed findings for each application.

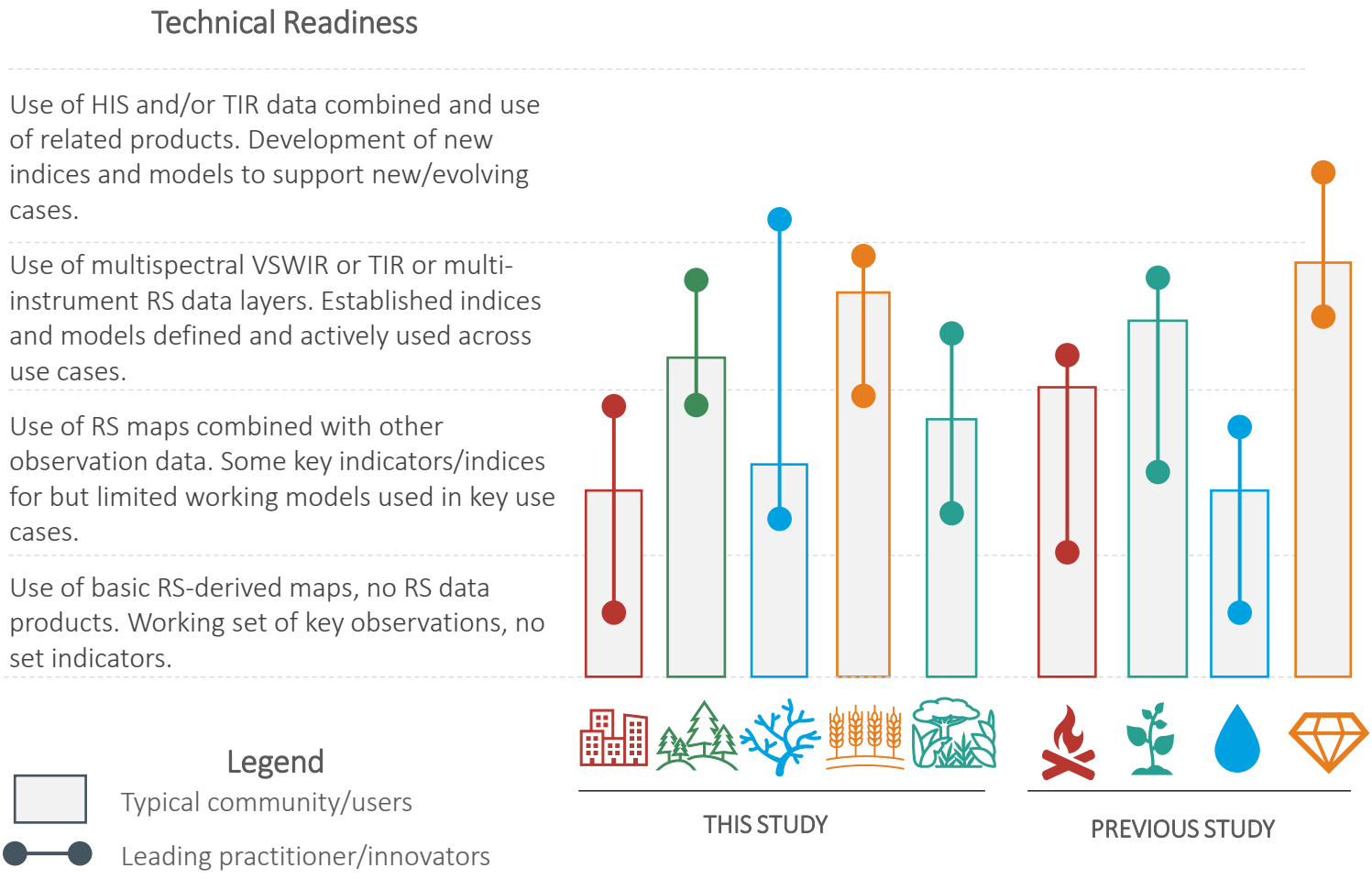
Source: 1- Cohen and Levinthal (1990), "Absorptive capacity: A new perspective on learning and innovation", Administrative Science Quarterly, Volume 35, Issue 1 pg. 128-152. Rogers, Everett M. (1983). Diffusion of innovations (3rd ed.). New York: Free Press of Glencoe. ISBN 9780029266502. .

Insights—Technical Readiness

The future adoption and use of SBG data hinge on the "readiness" of each potential user community. RTI applied the concept of technical readiness to assess:

- A community's maturation toward defining and using a set of key observations and indicators, in which EOD can be or already are being used.
- The technical literacy and sophistication of a community in its current use of EOD.

The chart below details technical readiness using four basic criteria that scale from low "readiness" to high "readiness." The colored bars indicate the technical readiness level of the "typical" community/users within each primary application. The colored line indicates the range of technical readiness of the leading practitioners and innovators within those communities. It is important to note that this chart assesses technical readiness for the nonresearch communities of end users and VASPs, not for the scientific research community.

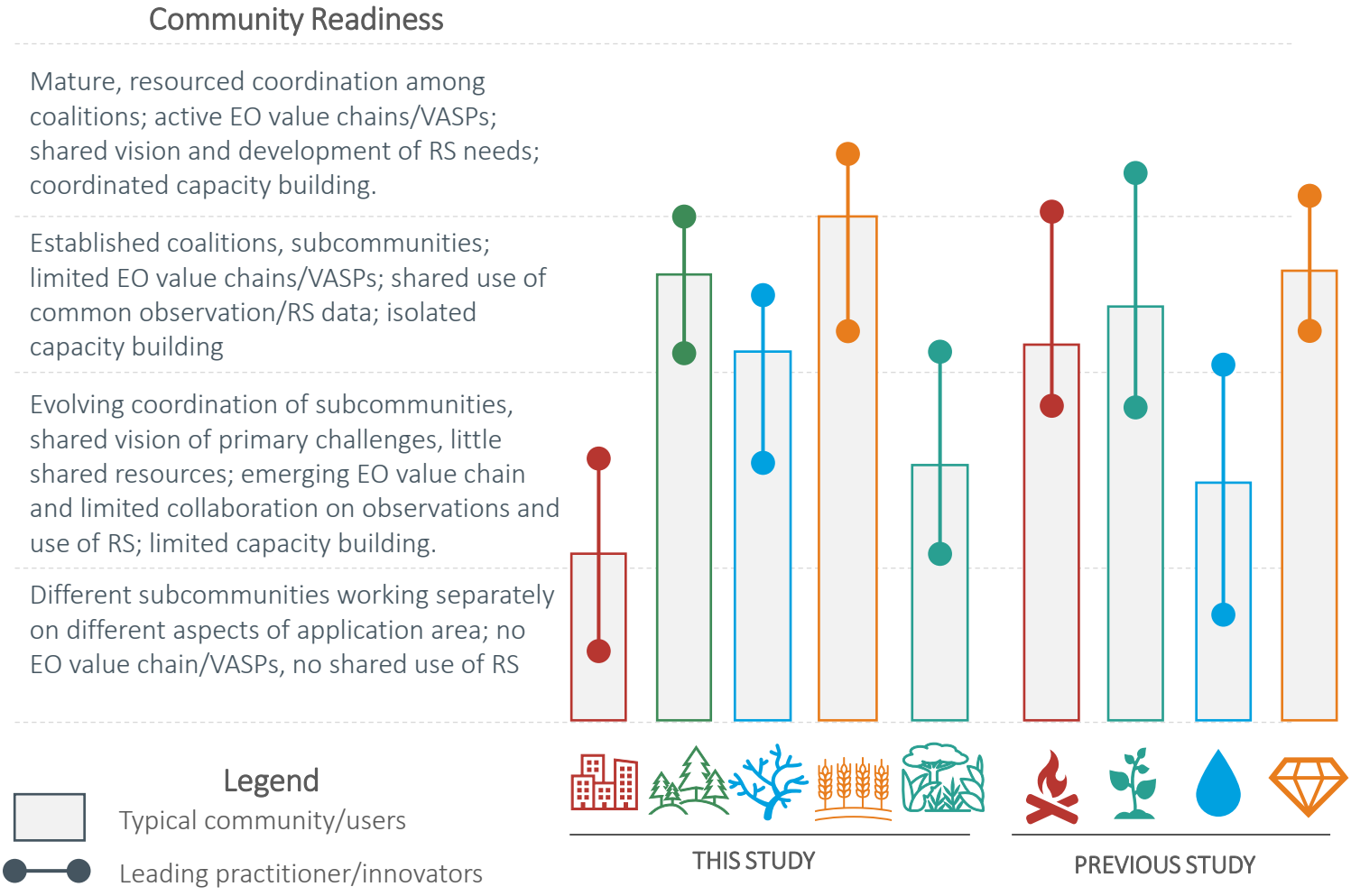


Insights—Community Readiness

The future adoption and use of SBG data hinge on the "readiness" of each potential user community. RTI applied the concept of community readiness to assess:

- The current maturity of the EO value chain, and extent to which RS and EOD resources and services are currently leveraged by the community
- The extent of coordination and collaboration among subcommunities to address primary challenges and advance the use of RS and EOD to solve them

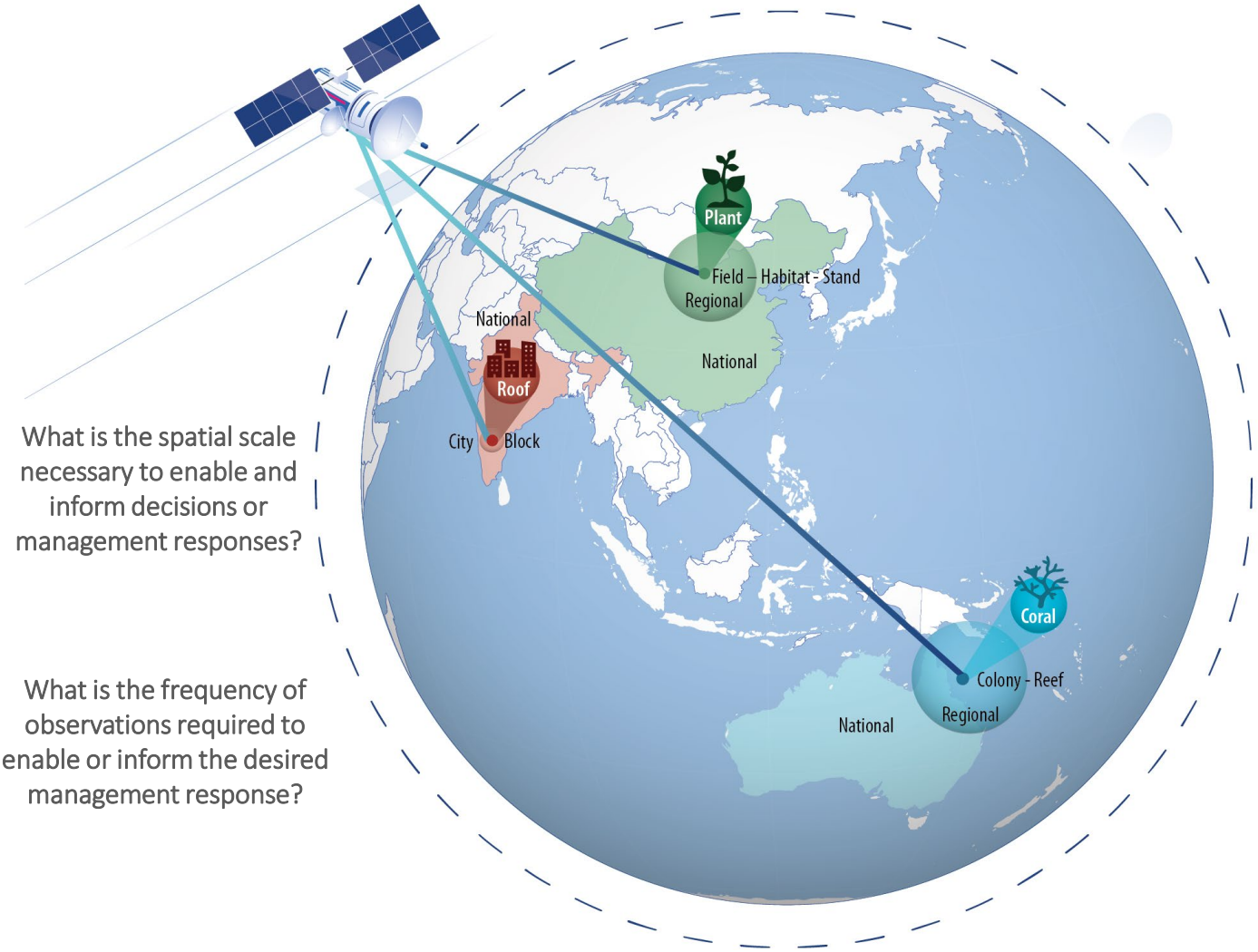
The chart below details community readiness using four basic criteria that scale from low "readiness" to high "readiness." The colored bars indicate the community readiness level of the "typical" community/users within each primary application. The colored line indicates the range of community readiness of the practitioners and innovators at the forefront of those communities. It is important to note that this chart assesses community readiness for the nonresearch communities of end users and VASPs, not for the scientific research community.



Insights—Management Response Needs

Private-sector and nongovernmental end users look to RS and EO products to uniquely inform the management of responses they can make "on the ground." Multiple commercial and NGO experts referenced planning their "management response" in certain locations (scale) and over specific periods (time). Whether it is a corporate sustainability officer managing their response to seasonal deforestation in regional supply chains or a city health official managing daily heat alerts in an urban neighborhood, the management response needs of users dictate their observation needs. Nonresearch managers and decision-makers look to proven and operationalized observations and high-quality information products to provide verified "sources of truth" to guide their management responses. By considering the spatial scales and time frames necessary to make decisions, it is possible to characterize the management response needs of varied user communities. The management scale and response time needs of specific application areas are detailed on the next two pages.

END-USER MANAGEMENT RESPONSE NEEDS



Insights—Management Scale Needs

"Jobs to be done" are operationalized or managed at different spatial scales from 1000s of kilometers to a few meters. The table below summarizes the primary research findings into the desired management scales for SBG-relevant activities within the primary application areas, including the most important or highest impact* activities.

URBAN HEAT AND HEALTH	National	Large City	Block	Roof
Mapping programs,* heat health and mitigation management, policy, MRV				
Heat alerts,* high-resolution urban maps for heat alerts and policy making				
Albedo/reflectivity/emissivity studies, urban infrastructure/surface surveys				
Targeted heat mitigations,* siting cool buildings, cool roads, urban vegetation				
FOREST MANAGEMENT	**National**	**Regional**	**Stand**	**Tree**
Forest inventories/certifications,* land/wood baselines and supply assessments				
Forest health,* tree canopy height, phenology/leaf out timing, insects/disease				
Carbon market/offsets, MRV for owners/NGOs				
Disturbance and regeneration, deforestation, disease, storm/fire; replanting, regrowth				
Functional diversity, functional properties across time and ecosystems/habitats				
Species classification,* substand classification and invasive/understory composition				
CORAL REEFS	**National**	**Reef**	**Colony**	**Coral**
Marine spatial planning,* to sustain reefs and tourism				
Coastal resilience planning,* mapping and reef management				
Capture/predict bleaching events, monitor temperature and coral condition				
Disturbance monitoring, nutrient/pollution influx, wave action, temperature, etc.				
Restoration and replanting,* site and monitor				
Condition and composition, health, resiliency across time				
GLOBAL FOOD SECURITY	**National**	**Regional**	**Field**	**Plant**
Global/regional agriculture statistics,* estimates of crop yield and productivity				
Hazard events/trend monitoring,* onset, extent, and prediction of drought and floods; anomaly detection				
Land quality surveys, for suitable land, soil maps, conversion, regenerative Ag				
Food insecurity interventions,* regional models for improved interventions				
Land and field assessments, cropland, crop type classification, monitoring				
Carbon markets,* improved indicators/models for soil carbon, certification, MRV				
CONSERVATION AND BIODIVERSITY	**National**	**Ecosystem**	**Habitat**	**Plant**
National surveys,* mapping baselines and establishing high-value conservation areas				
Deforestation and degraded land,* monitoring major plantations/natural forests				
Biodiversity compensatory mitigations,* mapping, compliance				
Species classification, plant/crop classification, baselines, invasive/understory				
Agroforestry and carbon offsets, MRV of suppliers/smallholders to support sustainable practices				
Habitat management, conservation land management and geo-accounting				

Insights—Response Time Needs

"Jobs to be done" are operationalized or managed at different response times from years down to a day. The table below summarizes the findings of our primary research into the desired response times for SBG-relevant activities within the primary application areas, including the most important or highest impact* activities.

URBAN HEAT AND HEALTH	Annual Seasonal	Monthly	Weekly	Daily
Albedo/reflectivity/emissivity studies, urban infrastructure/surface surveys				
Mapping programs,* heat health and mitigation management, policy, MRV				
Targeted heat mitigations,* siting cool buildings, cool roads, urban vegetation				
Heat alerts,* high-resolution urban maps for heat alerts and policy making				

FOREST MANAGEMENT	Annual Seasonal	Monthly	Weekly	Daily
Forest inventories/certifications,* land/wood baselines and supply assessments				
Species classification,* substand classification and invasive/understory composition				
Forest health,* tree canopy height, phenology/leaf out timing, insects/disease				
Carbon market/offsets, MRV for owners/NGOs				
Functional diversity, functional properties across time and ecosystems/habitats				
Disturbance and regeneration, deforestation, disease, storm/fire; replanting, regrowth				

CORAL REEFS	Annual Seasonal	Monthly	Weekly	Daily
Marine spatial planning,* to sustain reefs and tourism				
Coastal resilience planning,* mapping and reef management				
Condition and composition, health, resiliency across time				
Restoration and replanting,* site and monitor				
Capture/predict bleaching events, monitor temperature and coral condition				
Disturbance monitoring, nutrient/pollution influx, wave action, temperature, etc.				

GLOBAL FOOD SECURITY	Annual Seasonal	Monthly	Weekly	Daily
Global/regional agriculture statistics,* estimates of crop yield and productivity				
Carbon markets,* improved indicators/models for soil carbon, certification, MRV				
Food insecurity interventions,* regional models for improved interventions				
Land quality surveys, for suitable land, soil maps, conversion, regenerative Ag				
Land and field assessments, cropland, crop type classification, monitoring				
Hazard events/trend monitoring,* onset, extent, and prediction of drought, floods, and anomaly detection				

CONSERVATION AND BIODIVERSITY	Annual Seasonal	Monthly	Weekly	Daily
National surveys,* mapping baselines, establish high value conservation areas				
Habitat management, conservation land management and geo-accounting				
Biodiversity compensatory mitigations,* mapping, compliance				
Species classification, plant/crop classification, baselines, invasive/understory				
Deforestation and degraded land,* monitoring major plantations/natural forests				
Agroforestry and carbon offsets, MRV of suppliers/small holders to support sustainable practices				

Insights—Urban Heat and Health

Community Overview: The use of RS data to address urban heat health issues is of increasing interest to this disparate community of city governments, health officials, urban planners, "cool-surface" product companies, and NGOs driving mitigation programs. The user community and EO value chain are unorganized and nascent; there are few RS decision-support tools available or used. The capacity to use RS is low and lies almost exclusively with researchers (e.g., universities) who serve governments and other stakeholders. The National Integrated Heat Health Information System (NIHHIS) is an evolving multiagency group spearheading the use of EOD.

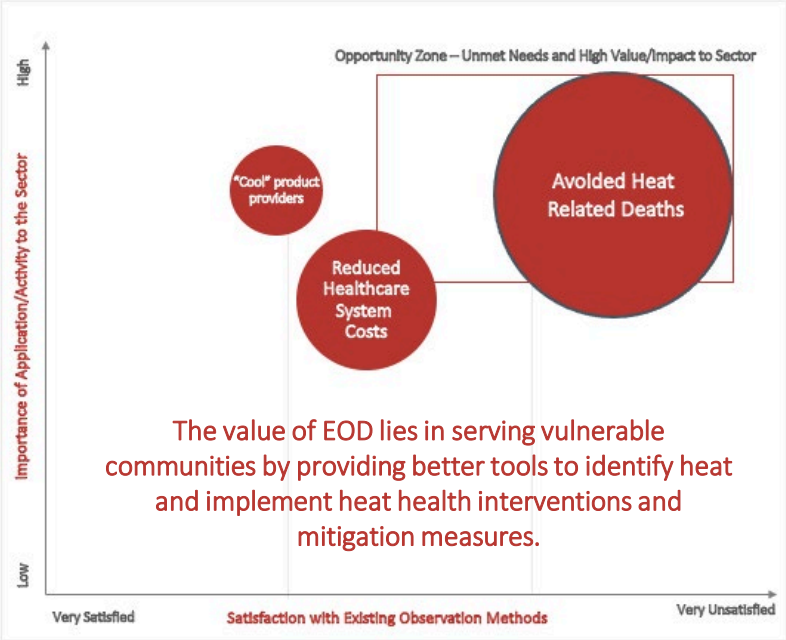
SBG Capability Significant Benefits:

- **Day/Night Pairing:** TIR/NIR day/night pairs, calibrated to the same locations
- **Near-Daily TIR Revisits:** To augment weather/ground data to better characterize extreme heat events and enable heat alerts
- **Global Coverage:** For large cities and countries without thermal RS data to target health interventions and plan/monitor mitigations

Needs: Urban planners in large cities and aid workers can benefit from combined RS and ground-based thermal maps with less resolution (> 30 m) and less than weekly revisits to see urban hot zones and target and assess neighborhood heat mitigation measures. Users working at the building scale, like cool-surface companies, also value surface temperature data but require 10 m or better resolution. NGOs in urban forestry and water management want to combine thermal and VSWIR data to study the impacts of vegetation and water features. There is a need for improved surface-air temperature models because air temperature most affects health. Heat health observations could benefit from better large-area temperature monitoring throughout the day and night to build regional and local models that can predict, not just measure, urban temperatures. Operational users want high-level products, simple heat maps, or dashboards with simple alert ratings to drive decision-making. Survey data indicate heat alerts and mitigation work are top activities and SBG's HIS and TIR promise significant improvements. But urban heat respondents, more than other groups, rated current RS and EOD as "completely adequate" and see cloud-free and low-cost imagery as top priorities.

For Readiness and Management Response details, see pages 16-21.

SBG OPPORTUNITY ZONE



The value of EOD lies in serving vulnerable communities by providing better tools to identify heat and implement heat health interventions and mitigation measures.

The NASA/SBG Opportunity: Urban heat, once considered an infrastructure and energy usage challenge, is now a growing public health issue focused on vulnerable populations and social equity. SBG holds potential to improve urban heat mapping and alerts. Globally, the impact of urban heart increases in the face of climate change. At a societal level, SBG has the potential to reduce heat-related deaths and reduce healthcare system costs. There is also economic value via companies that produce products like cool roofs and pavement. The economic value of reducing energy demand through targeted mitigation efforts is very high. NASA can develop and contribute urban heat data and products (especially priority surface temperature, vegetation, and VISWR reflectance algorithm products) to existing heat mapping and decision-support tools like those developed by NIHHIS.

Insights—Forest Management

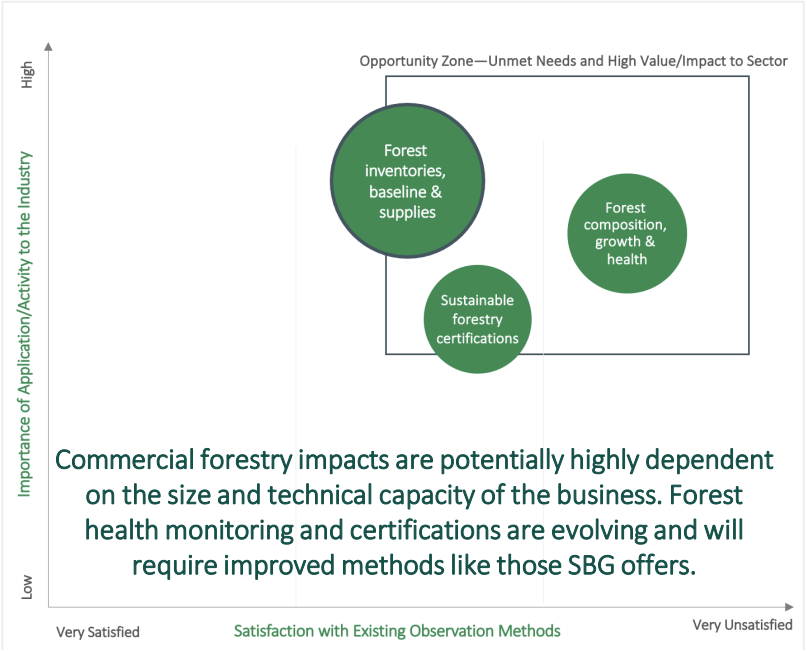
Community Overview: The forestry sector has a well-established commercial and EO value chain and an RS community of practice. Today, only a handful of forest product companies have RS expertise. As a result, university-industry research coalitions and industry associations have established alliances that support RS use and development. U.S. Forest Service (USFS)-supported maps and VASP-provided products are commonly used in North America and the European Union (EU). RS and ground surveys are still used and are primarily driven by the need for efficient, profitable forest inventory/supply management. Outside of meeting sustainability certifications, deforestation monitoring is largely seen as an issue for developing regions. Looming climate change impacts and the need for better MRV are creating interest in new RS methods.

SBG Capability Significant Benefits:

- **Spectral Resolution (VISWIR):** Free, large-area HIS for tree-species classification and composition studies is seen as the highest confirmed value that SBG could address. Using global HIS to provide more accurate and quantified biomass and carbon stock measurements and, hence, low-cost third-party validated MRV, are key to carbon markets.
- Spatial and temporal capabilities are seen as adequate for leading use cases.
- Thermal is seen as a research, not an operational, capability.

Needs: The National Agriculture Imagery Program (NAIP) and Sentinel are popular resources, but users want less than 2-week revisits to monitor phenology and harvest activity, especially in small plots with frequent turnover cycles. More frequent monitoring like MODIS is too coarse. The largest and most sophisticated players want to monitor fluxes in forest health, drought, and degradation at a finer scale than GEDI and Landsat can provide. For targeted management by experts and researchers, classification of trees species is not possible with current satellite datasets, and HIS presents great potential to address this need. SBG could create value with models of "ecosystem fluxes," functional properties and diversity, and photosynthetic efficiency that are readily usable by a broader range of users. Thermal monitoring is not used in the industry but is of interest to researchers for drought and disease detection. SBG's vegetation and cover algorithm products are of highest importance to deforestation and forestation respondents, and latency of 2 or more days is adequate for most.

For Readiness and Management Response details, see pages 16-21.



Commercial forestry impacts are potentially highly dependent on the size and technical capacity of the business. Forest health monitoring and certifications are evolving and will require improved methods like those SBG offers.

The NASA/SBG Opportunity: The forestry sector provides a targeted and established community with strong commercial interests in improved observations, especially forest vegetation species classification, for both commercial and conservation use. If NASA and SBG could develop proven operational, large-scale tree classification and composition products, they would be highly valued. Collaborative research with university/industry consortia could provide cofunded opportunities to develop HIS for a set of forest applications and demonstrate the value to large companies. To target underserved forest owners, NASA can engage the smallholder user community through key organizations such as National Alliance of Forest Owners (NAFO) and U.S. Department of Agriculture (USDA). Partnering with the USDA to augment current forest inventory products is the most viable pathway to engage the broader forestry community using proven data products.

Insights—Coral Reef Ecosystems

Community Overview: Aligned around a common goal of coral conservation, this highly connected and relatively small community of potential is led by researchers and supported by NGOs focused on ocean health. Restoration decisions and processes are driven by field-based time- and resource-intensive processes involving scuba divers. This community recognizes the power of RS for advancing both mapping and restoration, but the limited applied use hinders an articulation of the needs and value. VASPs may enter as restoration economic incentives strengthen.

Needs: Assessing coral composition and health is the greatest unmet need in coral conservation. Applied science and research, relevant to HIS, are needed to further advance the study and conservation of coral. Challenges related to water depth and turbidity translate to limited reef geomorphology and benthic cover information. High-resolution remote imaging of coral is a presumed requirement, and it has yet to be determined if HIS, especially at 30 m, can enable the most needed new observations. Current multispectral RS data delineate basic reef composition (coral vs. algae vs. seaweed) but do not provide insight at the coral colony level. The new Allen Atlas maps (location of global shallow coral reefs) are driving expectations for more detailed and frequently updated maps on the size, condition, and composition of reefs. Not surprisingly survey respondents cited SBG's proposed aquatic and water algorithm products as most important.

For Readiness and Management Response details, see pages 16-21.

Coral reefs bring tremendous tourism and coastal protection value. A restoration and relocation market is emerging to conserve reefs, and SBG can improve composition and condition monitoring to support these efforts.

SBG Capability Significant Benefits:

- **Spatial Resolution:** TIR (at 60 m) provides surface temperatures for discriminating thermal stress and reef condition and will improve resolution of near-shore water temperature measurements to guide preservation and restoration efforts.
- **SBG's Global Coverage:** Enables remote monitoring and relocation away from anthropogenic activity.
- **Spectral Resolution:** VSWIR will improve bathymetry (determinant of composition and key factor for restoration site suitability mapping), rugosity, and water quality measurement.
- **Temporal Resolution:** Frequent TIR will identify persistent cold and hot spots. If spatial resolution is proven sufficient, VSWIR revisit may determine success of projects without the need for launching diver expeditions.

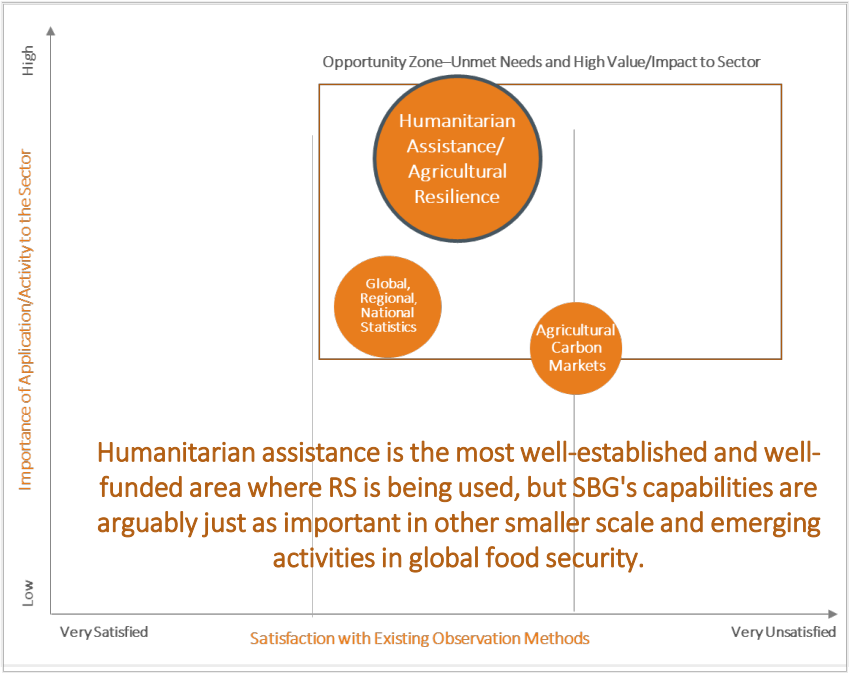
The NASA/SBG Opportunity: The market and nonmarket values of coral reefs globally are enormous. Governments, with NGO support, are active in reef conservation, and a new business ecosystem is emerging around protecting reefs: insurance/reinsurance and suppliers of relocation and restoration services. Companies (e.g., oil and gas, telecommunication, dredging) need to comply with new policies that hold them accountable for relocating corals, which is also driving restoration efforts. All of these activities require enhanced coral health and restoration mapping. Recently completed global coral maps with multiple data layers now exist, and experts indicated that adding SBG data as another layer to these existing maps versus creating new maps is the best pathway to enable global end users. Experts noted that coral species identification is an attractive use case to first demonstrate the utility and enabling potential of SBG. There is an opportunity for NASA to leverage its own HIS efforts and tie directly into Asner/Allen Atlas/Esri/NOAA efforts to improve on existing datasets, maps, and tools. This may be the most efficient entry point to work with this community of potential.

Insights—Global Food Security

Community Overview: Well-funded, well-organized, global humanitarian aid agencies with geospatial expertise and an ever-growing number of mission-driven NGOs and digital Ag startups make this a mature community of practice. Users employ and develop advanced EO tools in high-stakes efforts to assess regional famine early warning, food production statistics, and improved food security planning.

Needs: Broadly, the ability to use RS and other scalable tools with greater frequency to reliably predict regional and local yields and productivity outputs remains an elusive goal. Improved tools and models aim to assess dynamic agricultural environments, anticipate and monitor hazards, and put evidence-based knowledge in the hands of key decision-makers and smallholders alike. Experts felt that SBG has the greatest potential to improve condition monitoring using 3-day TIR for better LSTM and ET/ESI models for rapid hazard events and HIS for cropland (not plant-scale) stress monitoring. Experts speculated that once satellite HIS for spectral agronomy was more advanced, SBG may enhance spectral crop classification. Regardless of whether SBG's 30-m+ spatial resolution will be limited to cropland/forest-scale monitoring, the potential for HIS vegetation species classification was by far the most compelling potential SBG capability. Data continuity/standardization and ET and vegetation/cover products are top priorities, as are latency baselines of 24 to 72 hours. The better the speed and resolution of SBG products, the closer users can get to assessing the dynamic regional and smallholder agriculture practices and production outputs.

For Readiness and Management Response details, see pages 16-21.



Humanitarian assistance is the most well-established and well-funded area where RS is being used, but SBG's capabilities are arguably just as important in other smaller scale and emerging activities in global food security.

SBG Capability Significant Benefits:

- **Temporal Resolution:** For hazard early warning and "flash" droughts/floods, frequent TIR is a key SBG capability.
- **Spectral Resolution for *Assistance*:** New HIS-derived plant spectral libraries to improve vegetative growth indices to get at better yield or faster drought predictions for key crops; combining TIR with VISWIR to identify acute water stress in specific geographies and crops to better target aid, or improve weather-based crop insurance schemes.
- **Spectral Resolution *for Statistics*:** If HIS can improve crop classification on agricultural lands, it may provide enough accuracy to reduce reliance on infrequent field surveys.

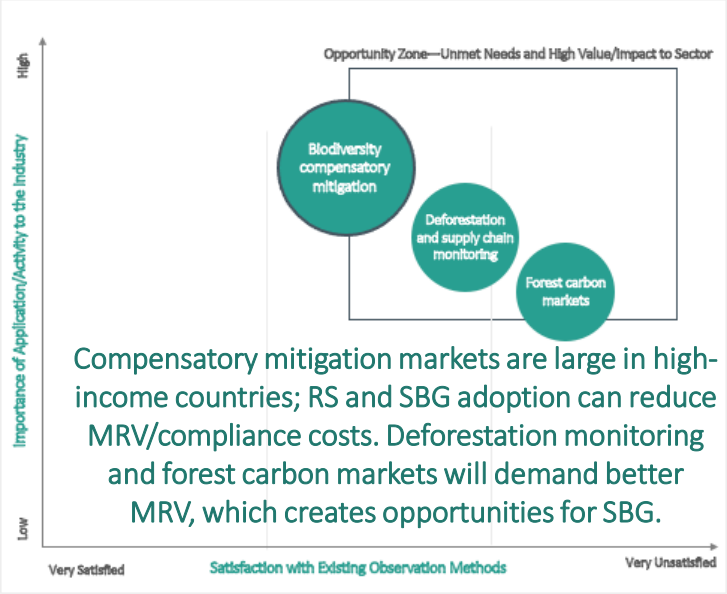
The NASA/SBG Opportunity: The humanitarian and aid investment impacts are enormous, leaving much at stake. In addition to improving specific regional estimates and monitoring (e.g., new crop health indices), important agricultural resilience and smart farming programs will benefit through forecast-based financing, insurance programs, and carbon offsets. The sophisticated geospatial experts in the food security community want open standards and free data to democratize the use of RS data and products for food security applications. There is a strong consensus that NASA must ensure interoperability and continuity of SBG data with other satellite products with a historical record. Experts emphasized that SBG must be in a cloud-native format and well integrated with Sentinel, Landsat, MODIS, and CHIRPS. To ensure effective translation of SBG products to end users. Experts felt that NASA should first develop the applied science and indices, then provide region-specific tutorials on using HIS-integrated products. Experts routinely expressed the desire that NASA play a key role in being a convening force and objective scientific voice to guide and drive consensus on emerging topics, such as carbon market MRV and effects of climate change on agriculture.

Insights—Conservation and Biodiversity

Community Overview: The conservation and biodiversity field is a large fragmented ecosystem of many research groups, large national agencies, and thousands of NGOs, all focused on protecting species. Preventing deforestation due to agriculture and logging drives many conservation efforts, and large corporations have made commitments to improve sourcing practices, which they then extend to their suppliers through third-party (often NGO) sustainable certifications. NGOs are interested in monitoring compliance. Regulatory agencies in high-income countries are well established and drive conservation activities and biodiversity compensatory markets but with little RS. RS in conservation is active, but expertise is very limited and isolated to a few players. This is a community of potential needing NASA's support.

Needs: HIS at 30 m would allow researchers to "bootstrap" better studies. National, meter-scale field observations are good but limited. HIS at 30 m might increase the accuracy from 60% to 90% for natural-standing vegetation surveys. HIS also has high potential for vegetation classification and distribution maps, which can be used to improve species mapping via improved ecosystem/ecological modeling. Experts indicated that there are no effective RS methods to track invasive species. Nonresearch users desire free, frequent, and interoperable data products with intuitive interfaces. Temporal/spectral continuity with Landsat and Sentinel datasets is important, and all of SBG's algorithm products were deemed highly important to respondents.

For Readiness and Management Response details, see pages 16-21.



Compensatory mitigation markets are large in high-income countries; RS and SBG adoption can reduce MRV/compliance costs. Deforestation monitoring and forest carbon markets will demand better MRV, which creates opportunities for SBG.

SBG Capability Significant Benefits:

- **Spectral Resolution:** VSWIR/HIS is needed improve baseline inventory measurements and to enable more accurate ecosystem and species monitoring. Free, large-scale HIS data to automate the ability to distinguish between natural and commercial forests and characterize species diversity and invasive species are highly desired. Also, the ability for global HIS to provide more accurate biomass and carbon stock measurements and reduce the need for expensive on-the-ground surveys could be the key to reducing MRV costs and scaling up carbon markets.
- SBG resolution and temporal revisit were considered sufficient for most purposes.

The NASA/SBG Opportunity: There is a premium placed on trusted, high-resolution, and verifiable data, which NASA can provide. A commonly expressed desire among corporate end users was the need for NASA to help develop useful spectral indices and build consensus around them. NASA already champions efforts like GEOBON. SBG can also engage leading conservation and biodiversity RS experts and partners, particularly those working with airborne HIS, to develop vegetation classification and demonstrate the value of these models and methods for conservation. EnMap is a possible HIS pathfinder mission and has an active focus on conservation and biodiversity applications. NASA should also continue to engage and support the capacity building of NGOs and corporations to advance their efforts to move beyond basic imagery to more sophisticated uses of EOD and products to monitor commodity supply chains. Carbon markets were also discussed as a potential emerging application, particularly if carbon standards move to update their protocols to reduce the costly burden of on-the-ground measurements. NASA could also engage with the national mitigation and ecosystem banking community (e.g., National Mitigation and Ecosystem Banking Conference) to demonstrate how HIS can support monitoring of high value ecosystems and key species prioritized by regulatory markets.

Insights—Value Chain Players

Community Overview: VASPs and boundary organizations worldwide serve as a key part of the EO value chain integrating RS data into products for the commercial, NGO, and government end users working in these application areas. They are an important community of practitioners typically skilled in RS and spectral data applications. They have their commercial interests and those of their many customers at stake when using EOD and when developing products and services from those data sources. As such, these organizations are essential and economically motivated partners for NASA and SBG because they are actively involved in advancing the applied use of enhanced EOD and products like SBG's. NASA's free, open-source, and high-quality data and algorithms have tremendous value to VASPs because their business models, or an NGO's donor funding, often cannot afford to pay for EOD. With the exception of urban heat and coral reefs, many specialist and startup VASPs are working in each of the primary application areas.

Technical Needs: Based on their practitioner experience, VASPs prioritize operationally useful capabilities like <10-m spatial resolution and <2-day revisits and find these more important than having all 200 bands of hyperspectral data. In practice, they see diminishing returns with overly narrow, potentially redundant spectral bands and would prefer fewer selected bands turned into essential classification or health indices. The use of airborne HIS and TIR from various sources has demonstrated SBG's potential. Practitioners are excited about the prospects of satellite HIS and TIR, but they want to see the applied science developed and application-specific demonstrations to prove the utility of SBG. Further, there was an emphatic consensus view that SBG must go cloud-native format and "cannot go the old DAAC FTP/HTTP/PO route." VASPs use common software tools (e.g., ArcGIS, ENVI) and languages (e.g., Python, R) and only a few data formats* (GeoTIFF, netCDF, HDF) and do no want to adapt atypical, unsupported, or developmental data types.

The NASA/SBG Opportunity: Expert practitioners within the VASP community are highly sophisticated users of the kind of observation data that SBG could produce, and they represent an important community of practice for SBG to engage, support, and nurture. The community acknowledges that no major EO platform VASP companies (e.g., Esri, Descartes) or specialists (e.g., IndigoAg, CAPA) are using HIS, let alone coincident with TIR datasets. Although in theory they can handle complex datasets, as a practical matter, such use has not been established. It is not clear how HIS or TIR will fit into their plans. They cannot drive these data and application advances by themselves, so VASPs are looking to NASA to take a leadership role in developing application areas but are willing to partner with NASA to evolve the field.

Another key part of NASA SBG's value proposition is that VASPs trust NASA's credibility and capabilities compared with other satellite HIS developers to ensure high-fidelity data, transparent data processes, corrections, verification, and accessibility. These information quality factors are a huge priority to VASPs. Being a responsive partner is another need. Like NASA, VASPs see the opportunity for applied science, fused datasets, and analytical tools to mature significantly over the coming years. They recognize the urgency by which NASA should begin to develop the skilled professionals and practitioner partnerships necessary to mature SBG application areas and products. There is a workforce need for trained GIS staff, specifically hyperspectral and thermal EOD specialists, and VASP/practitioners are looking for NASA's help. VASPs look to NASA as a partner for capacity building and outreach support to help develop a viable ecosystem of users to begin and sustain use of new platforms like SBG.

* A TIFF, or tagged image file format. GeoTIFF is a metadata standard which allows georeferencing information to be embedded within a TIFF. NetCDF—Network Common Data Form; HDF—Hierarchical Data Format

Insights—Lessons from Study Efforts

Lessons learned from this project will help NASA with user-centered and private-sector engagement activities going forward for the Earth System Observatory missions. RTI has conducted two user needs studies for SBG (this being the second) and completed extensive user needs research for each designated observable mission team—SDC, ACCP, and MC. These efforts included collaboration with dozens of NASA experts and engagement with hundreds of EO service providers, practitioners, experts, and end users. This user-centered research over the last 2 years brings to NASA extensive insights and some lessons to help with future endeavors, including:

- **Collaboration between NASA SBG Applications team leads and the RTI research team was essential.** The SBG Applications team brings significant expertise and knowledge of NASA and the external research community, which makes these kinds of studies possible. The SBG team's deep understanding of the technical and application feasibility was essential to framing and supporting the direction throughout. NASA expert networks enable RTI to engage users at different points along the value chain, which connected RTI to the unique intermediary and end-user perspectives on a range of central topics. RTI, for its part, brings the user-centered and valuation methods, tools, and focused research, including interviews. The combined RTI and NASA team enabled the necessary translation of varied complexities related to SBG, its potential applications, and enabling benefits to a distinct and unique set of communities and dozens of end users. Many of these current or potential users are unfamiliar with RS, let alone HIS, TIR imaging, or any EOD/algorithm products. The RTI/NASA research efforts highlight the need for a strong pairing of NASA's deep technical experts with the needed level of support required for end-user targeting, engagement, assessment, and documentation.
- **Valuation resources are limited, nascent communities are not well positioned to assess hypothetical prospective value, and alternative valuation approaches are warranted.** There are few studies to leverage to understand the value of EOD and even fewer that could inform the valuation of SBG specific applications. Relying on industry and boundary organizations for their speculative estimates proved challenging, especially in the selected application areas and user communities where technical and community readiness were low. It is a rare expert who has the technical competency to assess the benefits of HIS and TIR observations *and* understand the specific market and economic impacts derived from having these SBG capabilities. RTI recommends that future valuation studies consider exploring alternative valuation approaches, including setting an agenda for priority valuations for high-level EO product suites (vs. missions), targeting one specific application or community (vs. many), using "willingness to pay" valuation methods for specific EOD/products (e.g., follow a similar methodology to prior studies done on willingness to pay for Landsat), and studying targeted parts of the EOD value chain or the marketplace, such as VASPs and the value they derive.
- **The research methods were effective but could be more efficient.** RTI has continued to find that reaching "not traditionally engaged users" on behalf of NASA requires extensive networking and outreach. Working across application areas to understand specific individual or organizational contexts within the value chain, their motivations for using EO platforms, and their awareness (or not) requires intentional and time-intensive outreach. Developing a sense of the user personas, needs, and valuations follows. To do this in-depth primary research work one expert at a time, as was done in the SBG studies, is effective; however, it is not the most efficient approach. Through RTI's user needs research with other DOs, the use of expert roundtables demonstrated an equally effective approach. The focus groups are created after some expert interviews and then offer a more engaging and direct way for NASA and RTI to learn about and assess the needs and motivations of nontraditional private-sector users. Convening experts, product developers, and motivated end users in an EOD value chain and targeted communities allows NASA to directly engage with an established ecosystem. These communities could be pre-assessed for their high technical and community readiness, which would better enable such events to lead to actionable EOD development and adoption plans.

Insights—Recommendation for NASA

These SBG user-centered research efforts bring NASA insights into private- and public-sector users, their needs, and prioritized interests in SBG capabilities spanning nine distinct and representative application areas. This kind of user engagement should continue with a broader set of user types and user communities to inform ongoing SBG data product and application developments. To go beyond meeting SBG's science objectives and genuinely have a broader socioeconomic impact, NASA will need to actively nurture, build, and support a wide range of these user communities to ensure those communities are willing and able to convert SBG data products into socioeconomic value. To achieve these desired outcomes, RTI offers the following recommendations, some of which are specific to SBG, while others are more high level and applicable to all of the DO missions:

- For SBG to yield value beyond the science, NASA must commit to extensive development work. It is apparent from this study, and the preceding SBG study, that NASA will have to actively lay the groundwork and develop the application science for SBG. NASA will also have to build the capacity of communities within targeted application domains so that they may fully leverage SBG's capabilities. A lack of awareness and literacy with HIS will be a significant barrier to SBG adoption and socioeconomic value creation. NASA should carefully target and choose value chain partners and communities with high technical readiness and a clear motivation for developing applied uses of HIS and TIR and related products (e.g., mining, Ag, coral). Many applications and communities of potential for SBG exist, and they extend well beyond what these first studies explored.
- Beyond SBG, NASA needs to provide, or continue to provide, high-level data products to users to ease the burden of keeping up with the science embedded within the products and to make EOD more user friendly. By working with the EOD community (e.g., European Space Agency, commercial providers) to converge on standards for high-level products, NASA can ease adoption for private-sector and nonscience end users. By working with users and the EOD community, NASA can participate in the ecosystem, which will inform the types of decisions/products/access needed and will also build awareness. As discussed with NASA, a 1:many model is ideal for leveraging NASA's limited resources and experts' time. SBG should identify partners to work with that have a proven ability to connect to many users (e.g., application-specific paths to multiple end users) and the motivation and willingness to build awareness for SBG (e.g., co-branding strategy where NASA is acknowledged on websites of partners that provide data products with "NASA inside").
- Numerous private-sector communities could gain value from data associated with multiple DO missions, illustrating the importance of an Earth System Observatory. Several data-driven domains such as agriculture and forestry, geohazard risk analysis, mineral exploration and mining, and water management can benefit from SBG and other data sets. For example, drivers that influence the value of EOD related to water include the need for multiple datasets to characterize the water cycle, incorporate ET and weather data, and monitor water levels. One of the most critical needs for agriculture and deforestation monitoring is cloud-free imagery, which requires synthetic aperture radar (SAR) data in addition to optical data. NASA could work with innovative and skilled practitioner partners to develop high-level products that fuse these necessary datasets in key application areas. These same kinds of partners can delineate science-focused and commercially relevant use cases and prioritize real financial or social value.
- The SBG mission has significant potential for both scientific and socioeconomic impact. To successfully ensure these impacts, NASA will have to develop and prove the application science and develop the high-level products and fused data layers of interest to nontraditional, nonresearch users. NASA should work with the noted communities of practice, those with high readiness, and skilled HIS and TIR practitioners to do this. Then with these value chain partners, NASA can better address the practical needs of private-sector end users who want ease of use, clarity, and certainty in the EO tools they employ to de-risk decision-making and create value.

FINDINGS

SBG User Needs and Valuation

Insights from interviews and survey data

Findings

Expert interviews and survey results were distilled to highlight insights, priorities, and value for application areas.

The primary application areas for this study were selected in close consultation and collaboration with the NASA SBG Applications team. This section provides synthesized and analyzed research findings organized by the selected primary application area. The insights were distilled from both value chain and community expert interviews and the user needs survey results. RTI was directed by the SBG team to scale the number of interviews in Coral Reef Ecosystems and Forest Management. Conservation and Biodiversity was added as a topic mid-study. RTI strived to ensure the study was balanced across all areas.

	Findings Sections	Interviews	Survey Respondents	Findings Pages
	Urban Heat and Health	13 individuals 11 organizations	49 respondents	33–53
	Forest Management	12 individuals 11 organizations	104 respondents	54–70
	Coral Reef Ecosystems	9 individuals 7 organizations	24 respondents	71–89
	Global Food Security	16 individuals 13 organizations	55 respondents	90–108
	Conservation and Biodiversity	12 individuals 10 organizations	117 respondents	109–129
	Value-added Service Providers	12 individuals 8 organizations	14 respondents	130–135
			31 other respondents	In General Survey Section 136–151

For each area, this section offers findings related to:

- User community overview with a) potential user types and use cases, b) high-level community EO drivers, and c) application and information needs
- User persona profiles for key value chain participants
- Benefits of SBG capabilities to the community and associated opportunities for NASA
- Valuation analysis, including context, application-specific value, case studies and vignettes, and impact projections
- Basis for the findings, including citations, interviewees, and survey data

Findings

The community profiles and valuations are based on limited input, and the communities are not homogenous.

When considering the findings, including the valuation analysis, it is important to remember that, although the analysis is based on user input, the following should be kept in mind.

- **Research is based on a limited set of individuals representing a small set of organizations.** Although the interviewees and survey respondents represent varied perspectives, the insights do not and cannot represent the opinions of the entire geospatial community.
- **Findings highlight typical needs and opinions on the value of SBG.** No community is homogenous, and perspectives vary based on an individual's familiarity with/awareness of both technical and market realities. The insights provided are directionally representative of the subcommunities and overall application community in terms of typical users, needs, and opportunities (not all users and needs).
- **Survey insights gathered include satisfaction with current EO methods and prioritization of key activities and the perceived benefits of SBG in those activities.** The SBG User Needs survey included five detailed primary application sections from which respondents could select and complete. The survey was designed to semi-quantitatively assess specific topics about SBG relevant to each of the primary application areas. Data on priority EO activities, perceived importance and benefits of SBG capabilities, information quality and access, and latency needs are provided. Not all survey findings are provided in this report, and additional analyses and respondent comments have been provided separately to the NASA SBG Applications team.
- **Survey results are illustrative of the types of responses within a user community, not a conclusive representation of the entire community.** Response rates were limited, and the specific expertise of the respondents varied widely. Data were analyzed for total response rates and rank order scoring was used to determine ratings of relative importance or perceived improvement. Total rank scores are not shown but are reflected in the analyses. When possible, relative comparisons among application areas are highlighted, as are similarities and differences compared with the expert interview findings.
- **These insights are intended to help shape an understanding of current and emerging EO opportunities and the potential for SBG to provide benefits to users in those areas.** The expert interviews (provided in a separate confidential file to NASA) are an important additional source of insights that have been carefully synthesized to ensure a comprehensive and more nuanced understanding of SBG needs and priorities.

Urban Heat and Health

Urban Heat—Community Overview

Diverse stakeholders are coalescing to address urban heat and its impacts on vulnerable communities.

KEY POTENTIAL USERS

- Cities (Gov't): Large city governments
- NGOs: Urban forestry, heat health, cool surfaces
- Companies (Small/Private): Cool-roof and reflective surface product providers
- Planners (Govt/Private): Urban development, consultants
- Corporations (Large/Private): Electric and water utility
- Healthcare systems (Public): Public health agencies, insurance providers, hospitals

KEY USE CASES

- Heat alerts and maps, high-resolution urban maps for heat alerts and policy making
- Targeted heat mitigations, siting cool buildings, cool roads, urban vegetation
- Mapping programs, heat health and mitigation management, policy, impacts, MRV for programs
- Albedo/reflectivity/emissivity studies, urban infrastructure/surface surveys

DRIVERS—Urban heat is a well-known and studied phenomenon. The convergence of climate change and mass urbanization is driving awareness and urgency to address heat challenges in a more data-driven and equitable manner. By 2050, cities are expected to see up to 3 times as many extreme heat days as they experience now, placing large cities (those with the most complex infrastructures and largest populations) at greatest risk. Urban heat is of increasing interest to municipal governments, health officials, urban planners, companies developing cooling technologies, and NGOs advocating for urban vegetation programs. What was once considered an infrastructure and energy usage challenge has now become a public health issue focused on vulnerable populations and the social equity impacts of urban heat. In major cities across the globe, local, diverse, and increasingly active coalitions of stakeholders are working on different aspects of urban heat challenges. Unlike other SBG application areas, the urban heat user community is not a well-established or organized ecosystem; it is a nascent community with potential. The urban heat community is constrained by limited commercial financial incentives, municipal resources, and political advocacy. In this context, it is important for advocates to have tools to help build awareness and gain support. Because "seeing the heat is believing the heat," urban heat maps can aid in decision-making and help stakeholders plan heat mitigation and health intervention strategies. The NIHHIS was established in 2015 and is the central multiagency effort to develop a portal for heat health information. Outside of federal agency and academic research efforts, most municipal heat mapping has been done by occasional ground-based air temperature surveys using fixed and mobile sensors. The use of RS has not been established in the private sector. Very few mitigation companies, nonresearch NGO experts, or VASPs are working to develop the RS tools needed for urban heat monitoring efforts.

Urban Heat—Community Overview

Using SBG thermal and day/night data to improve air temperature measurements and health studies is a key need of urban users.

APPLICATION NEEDS—The complex urban heat ecosystem includes many distinct user communities, each with its own application needs. However, the consensus priority is to serve the most vulnerable people and locations in urban environments. Better heat maps are part of urban heat modeling, which includes a complex set of economic, transportation, and energy considerations used to identify communities that are in most need of interventions. City planners, aid workers, and others working at the regional, municipality, or neighborhood scale can benefit from combined RS and ground-based thermal maps at larger (>30 m) scale and revisits that are more frequent than weekly, which helps them see urban hot zones and target and assess heat mitigation measures. Users working at the building scale, like cool-surface companies, also value surface temperature data but require 10 m or better resolution. NGOs in urban forestry and water management want to combine thermal and VSWIR data to study the impacts of vegetation and water features. Albedo and reflectivity measurements are of interest, but users are generally satisfied with current RS solutions. For heat health alerts and targeted healthcare interventions, understanding air temperatures—not surface temperatures—is critical. Currently, LSTM data are used to infer air temperature. There is a need for improved surface-air temperature models. Heat health observations could benefit from better large-area temperature monitoring throughout the day and night to build models that can predict, not just measure, urban temperatures. Same-day/-night and time-indexed studies are highly valued, because these will provide better models to understand the human health impacts of localized urban heat over daily or weekly cycles. Based on expert interview and survey data, there is a desire for thermal products at more frequent time intervals with finer spatial resolution, combined with field data to provide more local resolution for alerts and mitigation strategies.

INFORMATION NEEDS—Expert insights and survey data indicated cloud-free imagery and low information cost are top priorities. Several information and data needs were expressed by the few sophisticated users at leading NGOs. Seasoned data analysts commented that NASA web portals present large learning curves and offered the Copernicus Climate Change Service as a good model to emulate, due to its efficiency. Currently, researchers download data only to put it back in the "cloud bucket"; therefore, accessing data natively in the cloud would eliminate redundant work, and lead to expanded access and use in the community. Additionally, data services have seen a dramatic increase in use, leading to bandwidth challenges. Dataset discovery and data queries for urban heat applications was described as difficult. Some ECOSTRESS users at NGOs prefer data that are processed and packaged as index layers that represent persistent conditions rather single points in time. Operational users want high-level products, simple heat maps, or dashboards with simple alert ratings to drive decision-making.

Urban Heat—User Personas

This nascent community needs expertise and tools to advance the use of RS to help vulnerable communities.

Municipal/Regional Government

West Coast City Government Official

"Our city uses lots of climate-related maps and visualizations tool, like Cal-Adapt, CCHVIz, CHAT, and CalEnviroScreen, but these don't use satellite data. I've attended presentations about ECOSTRESS and find the data interesting but wouldn't know how to use it. We are lucky to have NASA experts provide us with images that unequivocally show how successful our cool-pavement project has been. A single image of skid row landed us $8M in funding to expand our heat mitigation initiatives."

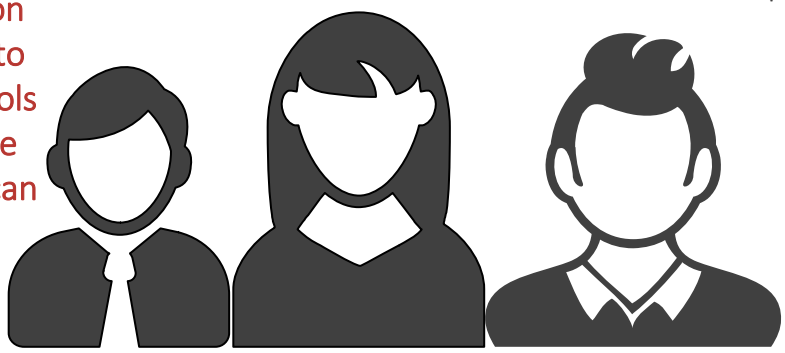
"I think ECOSTRESS is a great resource, but we need more orientation and training on how to access and use the tools that are available. We don't have staff who can manipulate remote sensing data."

NGO

International Aid Workers and City/Government Advisor

"As a health and international aid worker, I am seeing a real crisis with urban heat and heat-related mortality. Urbanization, poverty, and climate change are making urban heat worse in cities across the country. We need better and simpler maps to help us see where the heat is the worst so we can send help there, and we need to do it cheaply across the whole country. Such maps can save lives."

"The greatest benefits of SBG may be to developing countries where conditions make a large percentage of the urban population vulnerable to heatstroke and death."



Value-Added Service Provider

Urban Heat Mapping Specialist

"While there are lots of NGOs and cities worried about urban heat, there are so few of us working to use satellite data to target health alerts and mitigations. NASA and NIHHIS could really help us by being a convening force with key cities and partners because its more complex than just heat maps—it is social, medical, and political, too. If SBG can augment Landsat with better day/night thermal data at neighborhood resolution that would be a really interesting new part of our models, especially if we can tie surface and air temps together for better local 'ZIP code' predictions."

"If NASA could pilot a replicable daily heat product set for about 6 key cities—we could use it anywhere to improve heat health measures."

Urban Heat—Benefits of SBG Capabilities

If SBG can augment field and regional surveys, it will be valuable, especially for day/night global urban heat studies.

CURRENT RS CAPABILITIES *(Consolidated from Interviews)*—For mapping urban heat, the research community overwhelmingly uses Landsat Thematic Mapper/Enhance Thematic Mapper and Terra/Aqua MODIS platforms. Very few VASPs generate decision-support tools using RS data, notably CAPA Strategies in the United States (Landsat, Sentinel) and Project Extrema, led by the National Observatory of Athens. Gramener is piloting a tool to track, predict, and visualize heat islands in Canada. Typical end users do not create or have access to RS-based urban heat maps and must rely on researchers and VASPs to provide them. NGOs working on mitigation projects use roof-scale albedo measurements from high-resolution RS data (NAIP, Planet, Maxar, Airbus). Current albedo estimates use four-band RGBI imagery, and the many available albedo datasets are perceived to be "good enough." The spatial resolution of Landsat is too coarse for building-scale work, and NGOs are downscaling Sentinel data to try and get 0.5-m resolution. Spectral data are used primarily for vegetation studies, but some experts have speculated that the NIR/SWIR portions are useful in better quality heat maps. Ultimately, most nonresearch end users are simply interested in visual demonstrations of the effectiveness of mitigation measures or the ability to target hot zones. Thermal day/night pairs are not currently available and could be key for human health studies are not available. Survey data is consistent with the gathered expert capability priorities and perception of SBG benefits.

Priority Application	Capability Priorities	SBG Benefit
Targeting and Monitoring Mitigation Efforts (Measuring LST and Albedo)	**Spatial Resolution (TIR)** is a top priority. City block scale (~80 m) LST is desired. Street scale (30 m) is desired for tree planting. Roof scale (<10 m) resolution is critical for albedo and cool-roof projects.	TIR ● VSWIR ✗
	Temporal Resolution is not a concern in mitigation efforts for structures (roofs, roads).	●
	Spectral Resolution (VISWIR) is useful for albedo/reflectivity and in vegetation mapping, but improving on current methods is not a priority.	●
Managing Heat Health	**Day/Night Pairing** of datasets is unique and highly valued. TIR/NIR day/night pairs, calibrated to the same locations, are not currently available from other constellations.	✓
	Temporal Resolution is a benefit for characterizing extreme heat events, and for example, enabling heat health alerts and cooling center deployments. Near daily TIR revisits are much better than the current LSTM or infrequent ground studies.	✓
	Global Coverage can advance mitigation efforts in countries where thermal RS data are not available. Regional climatic zone heat mapping can augment weather data and ground-based monitoring.	✓
	Spatial Resolution (TIR) of current heat maps is often 10 m, enabled by on-the-ground data measurements collected from citizen science campaigns.	✗

✓ Significant benefit addressing unmet need(s). ● Adequate benefit that meets need(s). ✗ No benefit or does not meet need(s).

Urban Heat—Opportunities for NASA

NASA and SBG can add key capabilities to NIHHIS and other leading cool-city efforts.

COMMUNITY READINESS FOR SBG—Large cities, the NIHHIS, and global entities are the primary focal points of urban heat studies and efforts. In leading cool cities, efforts are led by resilience/adaption offices; sustainability and emergency management functions; public health departments; or, in some cases, science museums and universities. Regardless, governments do not have the capacity to use RS data nor is that capacity expected in the future, even in cutting-edge cities such as Los Angeles, CA. Expert interview and survey data suggest users see high potential for SBG to improve existing applications. Many decision-support tools were mentioned by government officials, none of which integrate thermal RS data. Across the board, the urban heat mitigation community is accustomed to applying proxies of heat, including meteorological data. The capacity to use RS data lies almost exclusively in the not-for-profits that operate in service of governments and other stakeholders such as universities that partner with local city planners. Perhaps a handful of commercial cool-solution providers use RS data to build marketing collateral and do targeted marketing, but this community is also not sophisticated in using RS. This is a nascent community with limited absorptive capacity for RS, let alone SBG products.

OPPORTUNITIES FOR NASA—NASA should look to develop and integrate urban heat data and products (especially priority surface temperature, vegetation, and VISWR reflectance algorithm products) into other more comprehensive and existing heat mapping and decision-support tools like those developed by NIHHIS. NIHHIS is the primary interagency effort related to heat health and is developing heat layers for multifaceted urban heat health mapping efforts, including the use of satellite data. ECOSTRESS Academy was well received and effective for driving adoption. Local and municipal users are intrigued by ECOSTRESS data but require training and orientation on the available data and tools. No interviewee mentioned NASA's Extreme Heat Data Toolkit. A common critique of satellite data is that it measures surface, not air temperature. To drive adoption by the public health community, air temperature must be measured or inferred using models. Developing better real-time air temperature indices, and even predictive models, is highly desired. A suggestion that "NASA partner with cloud providers (Google, Amazon)" was mentioned but underscores the need for NASA to build awareness of existing partners and better inform this nascent "community of potential". The community will need substantial support and capacity-building efforts, and NASA should look to existing interagency efforts and partnerships to evolve these efforts. Globally, a community of users is emerging who are seeking to integrate urban heat into their national action plans, particularly in South Africa, India, Bangladesh, Indonesia, and Thailand. Like cool cities and the NIHHIS, these countries and GHHIN are the best entry point for NASA.

Urban Heat—Valuation

SBG can provide important free, open heat data as part of global UHI mapping, mitigation efforts, and impact studies.

City managers and urban planners do not have the staff or expertise to work with EOD as it is currently available to them. Many larger cities will partner with local universities to help them develop heat maps for their urban areas. However, these types of partnerships are limited, and the lack of readily available, low-cost, and replicable heat maps over time is a major barrier to implementation of mitigation and intervention measures in the United States. This barrier is only magnified when looking at global applications.

All experts interviewed stressed that detailed heat maps alone are not enough to generate the necessary insights about urban heat islands (UHIs) or the impact of urban heat on human health. As such, heat maps alone, like those augmented by SBG, will provide limited value. Thermal information must be integrated with socioeconomic, age, and racial information to help identify the most vulnerable populations and develop and implement appropriate mitigation and intervention strategies.

How can SBG satellite data help?

While thermal data alone are not enough, SBG data can play an important role in supporting the development of cost-effective, high-resolution heat maps with nighttime thermal and more frequent flyovers. SBG's global coverage will support improved remote heat studies of large urban areas in countries and cities where heat mapping has not previously been economically feasible. These studies will provide much needed insights into urban heat health for developing countries, where large shares of the urban population are at risk. The primary expected benefits of improved heat maps are reduction of UHIs through improved heat mitigation efforts and enhanced capabilities for targeted heat alerts and other health interventions.

In addition to identifying vulnerable populations and designing efficient mitigation strategies, SBG data will be important for directly measuring and documenting impacts. Virtually all UHI benefit and valuation estimates and forecasts are based solely on simulation and modeling. Only for select targeted studies have the impacts of tree planting or reflective surveys been verified with pre-post data analysis. SBG could provide the direct observation data necessary to directly verify and quantify the effectiveness of mitigation activities, which, in turn, will build confidence and create improvements in mitigation and intervention measures. This ability demonstrates that the reliability and utility of RS heat data, with tools like SBG, are expected to increase and accelerate adoption of such methods.

Urban Heat—Valuation

There is high societal and economic value in mitigating UHIs, and improved heat mapping is essential to all of these efforts.

Key SBG Applications

SBG's potential to improve the development of better, cheaper, faster high-resolution urban city heat maps is central to almost all identified urban heat health activities listed in the table below. These maps will improve the design, implementation, and evaluation of UHI mitigation and intervention activities and lead to improved health outcomes and cost reductions.

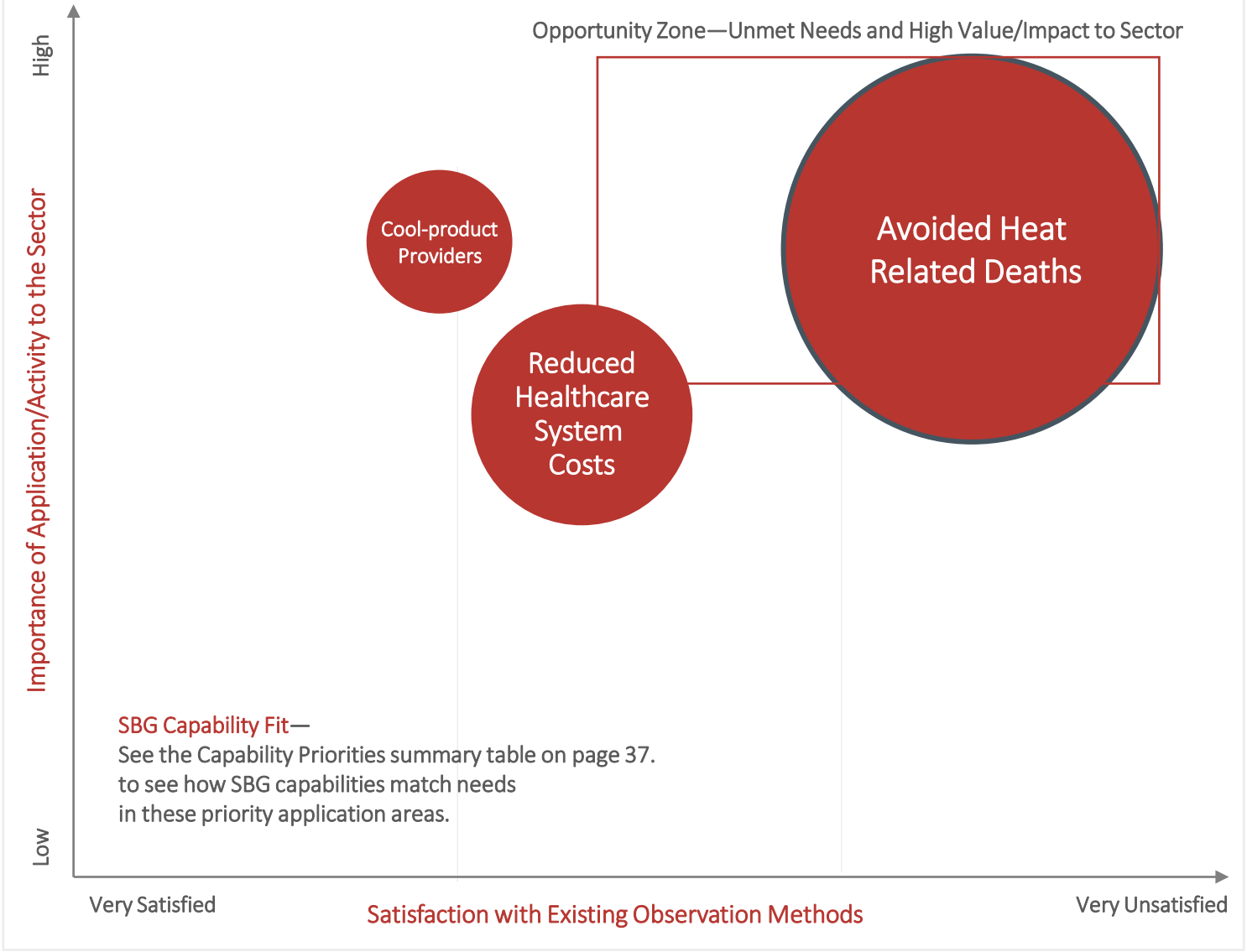
A range of users will either support, develop, enhance, or use maps to generate improved health outcomes in UHI areas. In all instances, the value is directly or indirectly linked to changes in heat-related health incidents and deaths.

In non-health-related activities, the greatest impact is expected to arise from electricity system cost reductions that result from mitigation efforts. Electricity cost savings largely come from peak demand reductions and better electrical system planning.

End-User Community	Activity	Technical Impact with New Capabilities	Economic Value	Potential Magnitude of Impacts
City Governments	Mitigation planning Better response to events	Expanded adoption to additional cities, U.S. and globally More efficient and effective adoption of mitigation activities	Increased health benefits Lower mitigation costs	High Modest
Not-for-Profits (urban forestry, heat health, cool surfaces)	Mitigation planning Better response to events	Expanded adoption to additional cities, U.S. and globally	Social health benefits	High
Cool-Roof and Reflective Surface Providers	Planning and marketing	Expanded adoption to additional cities, U.S. and globally	Company revenue/profits Social health benefits	Low High
Urban Development, Consulting Firms	Improved analysis capabilities	More efficient and effective adoption of mitigation activities	Lower mitigation costs	Low
Electric Utilities	Improved analysis, modeling and planning	Peak demand reduction Efficient generation dispatch	Avoided new generation and transmission capacity Reduced generation costs	Modest Low
Healthcare System (public health agencies, insurance/hospitals)	Contribute to mitigation planning and incentives	Expanded adoption to additional cities, U.S. and globally	Social health benefits Reduced healthcare system costs	High Modest

Urban Heat—SBG Opportunity Zone

Reducing heat-related deaths and health effects is the highest value impact, and SBG can improve heat mitigation methods.



Circle size indicates relative value of application.

The value impact of improved urban heat mapping and the resulting health benefits in the United States are enormous, and SBG holds a lot of potential to improve these methods. Globally, the value increases exponentially in the face of climate change.

Urban Heat—Valuation Case Study

SBG's contribution to targeting UHI mitigation efforts may reduce the socioeconomic costs of heat-related deaths in the United States.

Reducing Heat-related Deaths in the United States

Heat is one of the leading causes of weather-related deaths throughout the world. Studies have estimated over 5,000 heat-related deaths annually in the United States alone (Weinberger et al., 2020).[UH1] This number is likely conservative, although estimates vary greatly. For example, a sole heat wave in July 1995 resulted in approximately 700 deaths in Chicago, IL, alone (Kaiser et al., 2007).[UH2] Adults aged 65 years and older are most vulnerable to heat-related health illness, as are individuals from low-income households, who are less likely to have air- conditioning and more likely to be living in urban areas with little tree cover and high levels of impervious, heat-trapping surface coverings.

Mitigation activities, such as increased vegetation cover and reflective coatings for roads and roofs, have been shown to reduce surface and air temperatures in UHIs. However, an array of factors affect the effectiveness of different mitigation measures. For example, tree cover is much more effective than vegetation ground cover, and city-specific weather patterns can lead to significant differences in the temperature change achieved. Because mitigation programs have limited resources, targeting their deployment is critical.

Most valuation studies of UHI mitigation options to date have been simulations of potential interventions. For example, Sinha et al. (2021)[UH3] estimated that increasing current tree cover by 10% in Baltimore, MD, could reduce annual mortality from 597 deaths down to 416 deaths. The corresponding economic value of these avoided deaths ranges from $1.5B to $3.4B. Estimated impacts for other U.S. cities are similarly significant. (See table below.)

SBG data, along with other socioeconomic and social demographic data layers, will help improve the effectiveness of UHI mitigation efforts. The 5,000 heat-related deaths that occur annually in the United States, at a value of $8.22M per death,* yields an economic cost of $41B per year. Although experts could not provide an incremental improvement estimate, if SBG could help reduce a fraction of these deaths, the economic value would be significant.

U.S. City	Reduced Deaths from Increased Tree Cover	Economic Value ($2011, B)*
Phoenix	1514	$12.5
Miami	306	$2.5
Houston	1130	$9.3
Atlanta	122	$1.0
New York	3834	$31.5
Albuquerque	342	$2.8
Chicago	835	$6.9
Los Angeles	869	$7.2
Minneapolis	58	$0.5
Salt Lake City	56	$0.5

* Based on the value of a statistical life of $8.22M from U.S. EPA (2018).[UH4]

Urban Heat—Valuation Vignettes

Developing countries are most susceptible to UHIs, and the potential for SBG to address unmet needs is of high value.

Impact of Urban Heat Islands

There have been over 100 studies of UHIs for individual cities. However, the overwhelming majority have been for large cities in wealthy developed countries. In contrast, developing countries will likely be most significantly affected by UHIs as global temperatures rise. It is estimated that by 2025 almost 80% of the world's population will live in cities (Luvall et al., 2015),[UH5] and a significant share of this population will live below the poverty level in densely packed, treeless urban areas.

Research suggests that globally, millions of people die of heat-related causes each year with most deaths occurring in developing countries. Some initiatives have studied UHIs globally but not at the spatial resolution needed. A recent National Academy of Sciences study found that, globally, urban heat exposure increased by nearly 200% from 1983 through to 2016. The report stated that "[r]educing the impacts of extreme heat exposure to urban populations requires globally consistent, accurate, and high-resolution measurement of both climate and demographic conditions that drive exposure … spatially heterogeneous exposure patterns highlight an urgent need for locally tailored adaptations and early warning systems to reduce harm from urban extreme heat exposure across the planet's diverse urban settlements" (Tuholske et al., 2021).[UH6]

Climate change will only increase the number of heat-related deaths as global temperatures rise. Gasparrini et al. (2017)[UH7] estimated that under the highest emission scenarios warmer global regions, such as the central and southern America; southern Europe; and southeast Asia, will see a significant increase in heat-related deaths by the end of the century. Estimates include a 3.0% increase in deaths in Central America and a 12.7% increase in southeast Asia.

Detailed heat maps of global cities are an unmet need. SBG will provide the high-resolution thermal data necessary to improve global city heat maps that currently do not exist. SBG's free, open-access data, and algorithm products offer the potential for advanced maps that many cities would not otherwise have the resources to acquire. Filling this unmet need is the highest qualitative value experts see for SBG. Experts could not provide a quantitative estimate of SBG's incremental improvement over existing methods, so direct valuation estimates are not possible. Although SBG data will not solve the problems that magnify UHIs, the data will help assess, document, and effectively communicate the issues to better inform policy decisions and enable funding for mitigation and intervention activities.

Urban Heat—Valuation Vignettes

The economic value of reducing energy demand through targeted mitigation efforts is very high, and SBG may enable those efforts.

Electric Utilities and Peak Demand

In addition to health effects, UHIs have a significant impact on increasing demand for air-conditioning and, therefore, electricity consumption. UHIs directly and indirectly impact peak demand for most cities, occurring at the costliest times of generation and when the least efficient peaking units are dispatched. In addition, peak energy demand drives the need for greater system capacity investments in generation, transmission, and distribution. Climate change and the increasing frequency of heat events mean that mitigation efforts in UHIs will continue to be a focus area for electric utilities.

Increased temperature also reduces the efficiency of air-conditioning systems. For example, studies have found that for every increase of 4°C in outdoor temperature, the cooling capacity of air-conditioning systems at full charge can decrease 2.5% to 4.5% (Yusof, 2018).[UH8] As shown in the table below, a 2.5% reduction in cooling electricity efficiency could lead to tens of millions of dollars of increased electricity bills for residential and commercial customers.

Electric utilities have sponsored tree planting initiatives for decades as part of their demand-side management programs. Electric utilities have long recognized the benefits of tree planting to reduce cooling needs and electricity demand during peak periods. Targeted tree planting and other mitigation efforts to reduce the cooling needs in UHIs are high-value RS needs. The availability of highly accurate, low-cost heat maps will enhance these targeting efforts and provide the ability to monitor the effectiveness of mitigation efforts over time. Experts could not estimate SBG's incremental value but said that SBG would enable mitigation management at a scale and measurement fidelity that are currently not possible. More effective mitigation targeting will make the most of limited resources.

Customer Type	Annual U.S. Cooling Electricity Use (GWh)	Annual Electricity Expenditures ($ Millions)	Potential Savings @ 2.5% Reduction ($ Millions)
Residential (Urban)[UH9]	183,200	$23,650	$591
Commercial (All)[UH10]	185,000	$18,130	$453

Urban Heat—Valuation Vignettes

The provision of "cool pavement" to reduce the impact of UHIs is expected to be a rapidly growing industry that SBG can support.

Cool Pavement Projects

In addition to traditional tree planting initiatives, cool-pavement pilot projects have been gaining momentum as a viable approach to mitigating UHIs. Projects such as the Phoenix Cool Pavement Pilot Program have demonstrated the impact of applying a reflective coating to asphalt roads. The treated pavement had an average surface temperature 10.5°F to 12.0°F lower than traditional asphalt at noon and during the afternoon hours; the human experience of heat exposure was 5.5°F lower as a result of the reduced surface reflectivity. The study used a combination of on-the-ground monitoring and flyovers to document the benefits of the reflective surface coating (ASU, 2021).[UH11] As cool-pavement products demonstrate their ability to reduce urban surface temperatures and reduce the human health effects of heat events, the challenge then becomes demonstrating and targeting these products for urban environments.

Being able to demonstrate and document the impact of cool-pavement projects is essential to their expanded adoption. To date, the cool-products industry has been slow to take off, in part because most cities or cool-product companies do not have the resources or university partners to conduct extensive pre- and post-installation studies. Both industry and city experts working on cool-pavement projects noted that spatially detailed visual pre- and post-heat maps were the most effective tool for convincing city planners to invest in mitigation activities. Early examples of heat maps using ECOTRESS thermal map data have been very effective, leading to over $8 million in investment for mitigation efforts in the City of Los Angeles.

Experts could not speculate on the incremental performance benefits that SBG's capabilities might provide. But experts did suggest that having better and free heat maps, like those SBG will provide, will lower the cost of producing such pre-post impact evidence, which, in turn, is expected to help grow the emerging cool-pavement industry sector. With more than 250,000 lane miles of asphalt road in U.S. cities (FHWA, 2021),[UH12] the market potential is huge if large-scale adoption can be achieved.

1- Email correspondence with Jeffrey Moore, USDA Forest service, 6/24/2020.

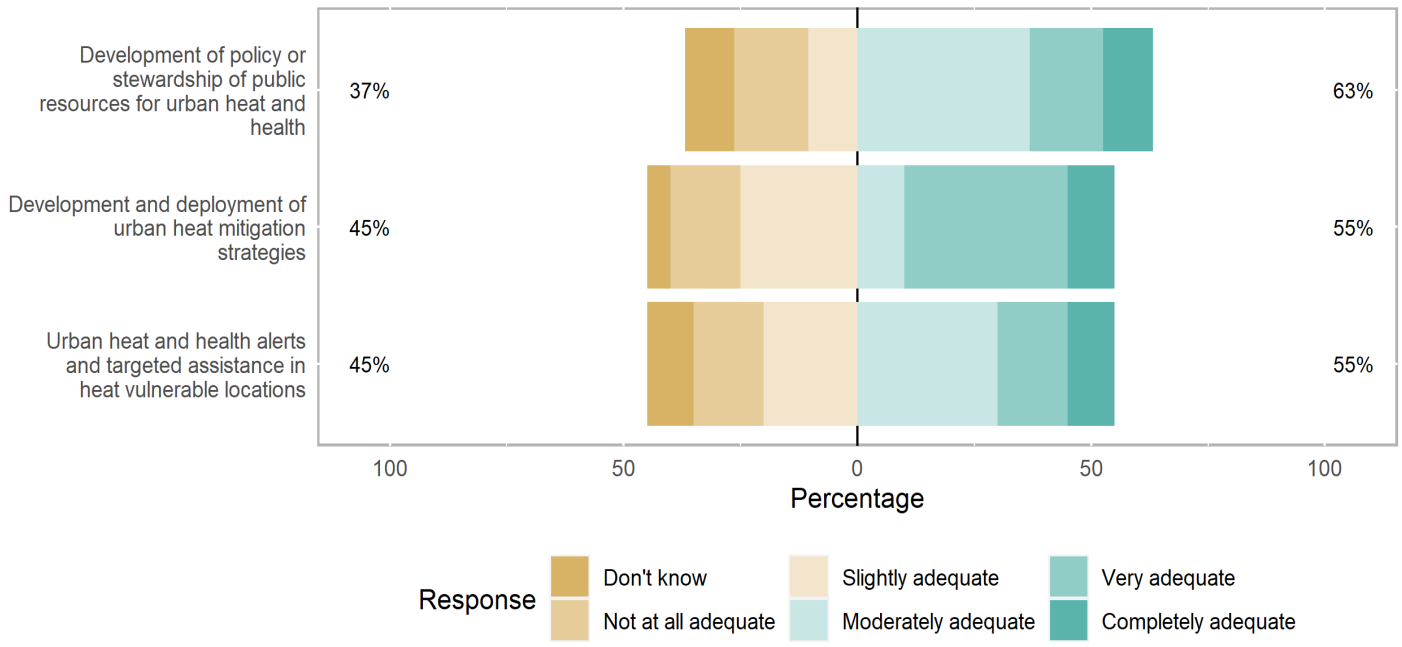
Urban Heat—Users Interviewed

Key Informant	Perspectives
 Kurt Shickman, *Global Cool Cities Alliance*	
   Jonathan Parfrey, Bryn Lindblad, and Kristopher Eclarino, *Climate Resolve*	
 Eric Mackres, *World Resource Institute*	
 Jeff Steuben, *Cool Roofs Rating Council*	
 Hunter Jones, *NIHHIS*	
 Michel Gelobter and Brian Smoliak, *Reflective Earth*	
 Greg Spotts, *Streets LA, City of Los Angeles*	
 Vivek Shandas, *CAPA Strategies*	
 Robert Cudd, *University of California, Los Angeles* *(No interview summary provided)*	
 Glynn Hulley, *NASA JPL* *(No interview summary provided.)*	
 Kalen Davison, *Smart Surfaces Coalition* *(No interview summary provided.)*	

Urban Heat and Health—Survey Results

Current observation methods are generally adequate for the main applications within the urban heat and health area.

To what extent is the current remote sensing and earth observation data you use today adequate for the following urban heat and health applications? (~20 responses)

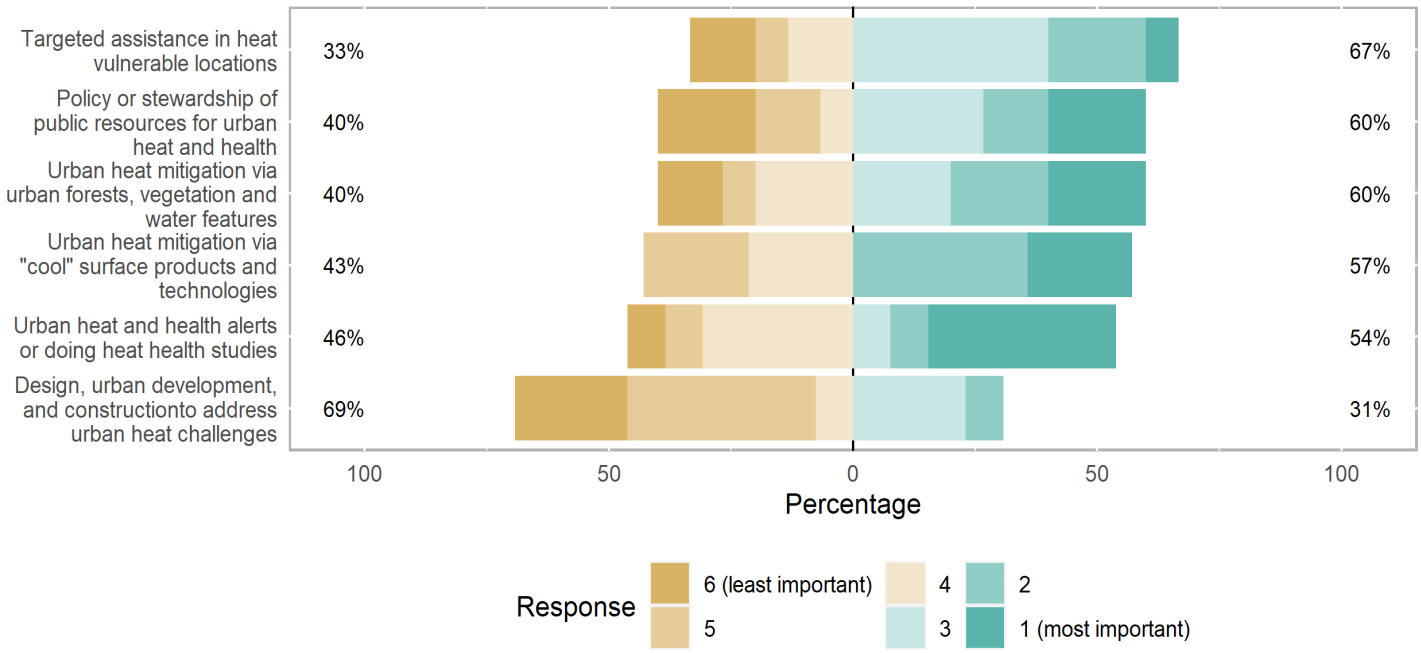


Just over half of respondents rated current methods as "moderately adequate" or higher, and relative to other application areas, the ratio of respondents rating "completely adequate" was high. Just under half of the respondents rated current methods "sightly" or "not at all adequate," and this was fairly even across all applications, which is unique to the urban heat and heath respondents. Experts indicated that currently the use of RS and EO data is limited, and ground-based observations are predominantly used in urban heat studies.

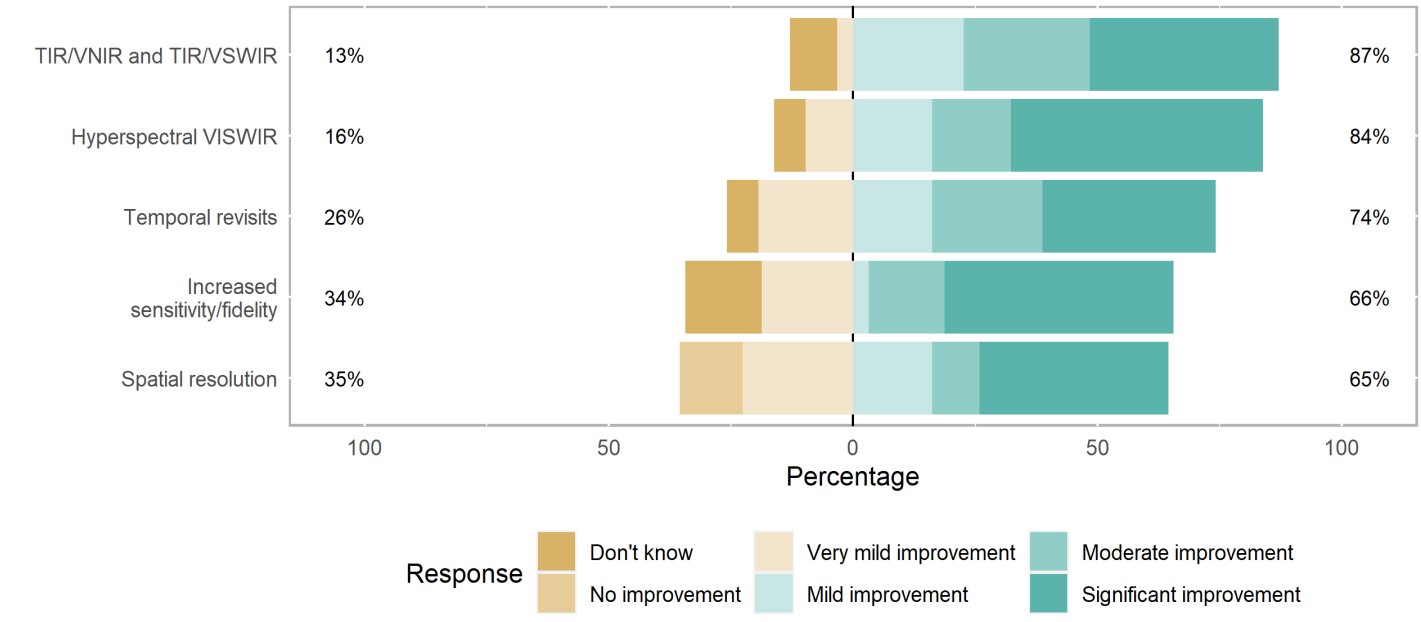
Urban Heat and Health—Survey Results

Heat alerts and mitigation efforts are top priorities, and multiple SBG capabilities provide significant benefits for these activities.

When working on urban heat and health efforts, which of the following are the most important "activities" that your organization is trying to accomplish? (~15 responses)*



Consider these SBG capabilities and indicate the extent to which each of them provides benefits for the top 2 activities you indicated previously. (~30 responses)

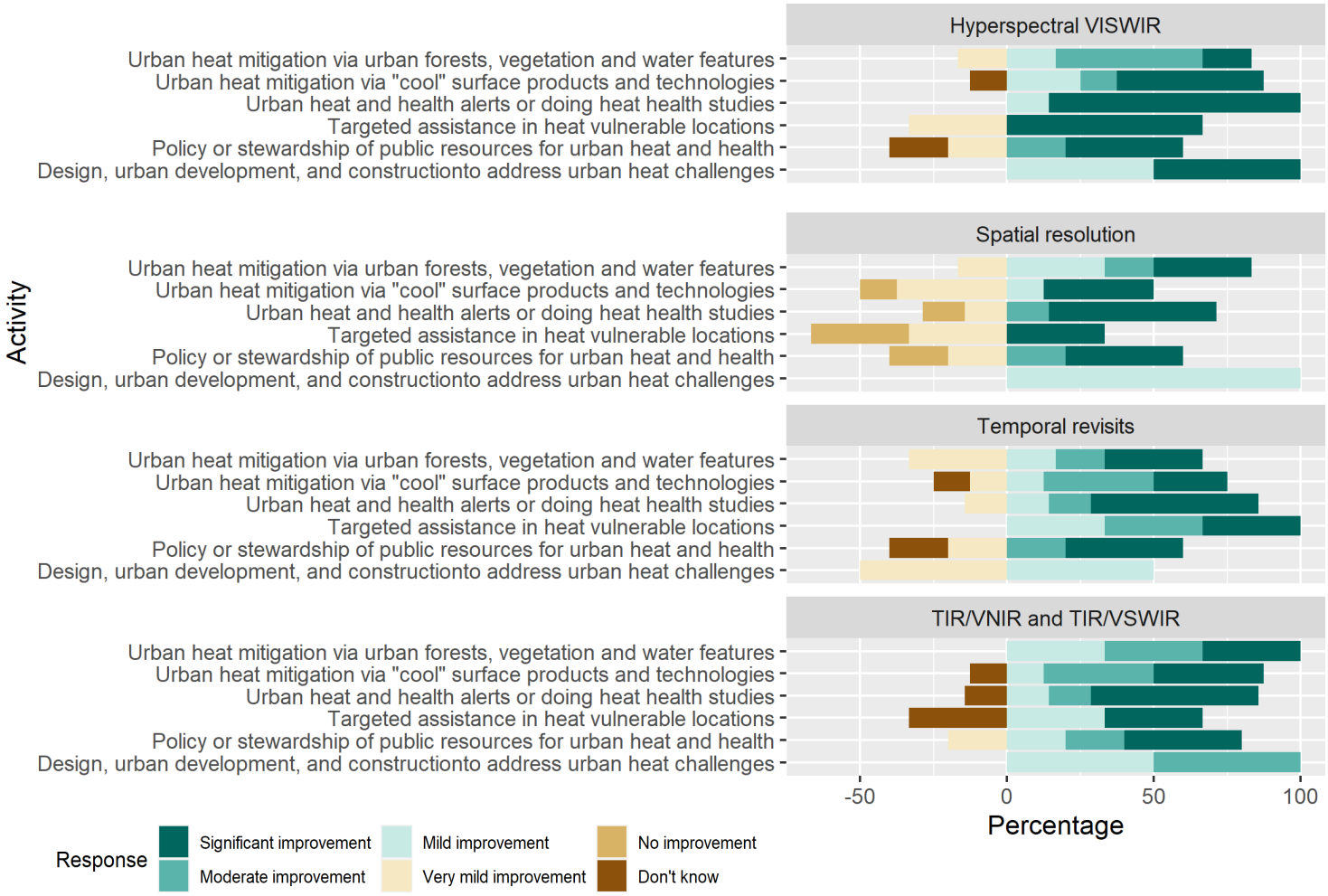


* For all priority rating questions a weighted importance/improvement score was calculated to determine the highest rated choices. Scoring is not shown but is reflected in the analyses.

Urban Heat—Survey Results

SBG's HIS and TIR capabilities promise significant improvements across most high-priority urban heat and health activities.

Consider these SBG capabilities and indicate the extent to which each of them provides benefits for the top 2 activities you indicated previously. (~15 responses)

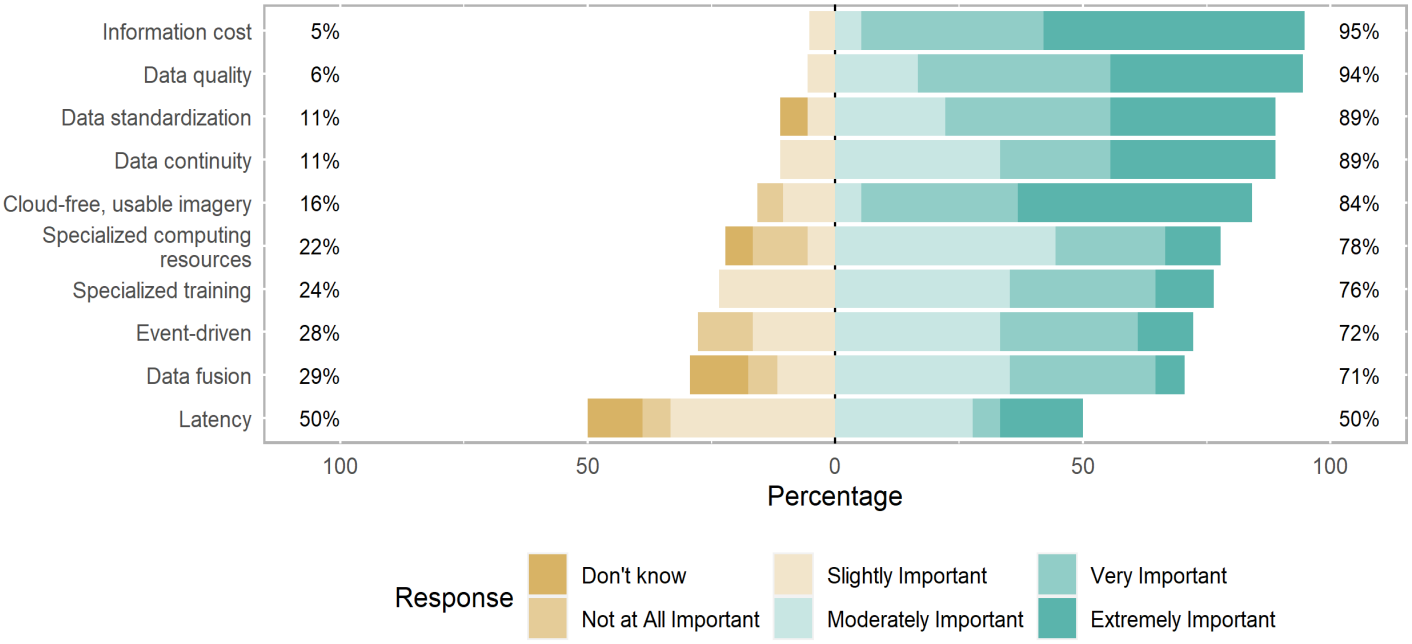


Although 15 respondents answered this question, the response rates by priority activities are low and may not be statistically significant. Response rates varied from eight responses for "mitigation via cool products" to only two responses for "design, urban development, and construction." SBG's enhanced VISWIR and thermal spectral capabilities were rated as offering the most improvement. SBG's spatial resolution is deemed to offer the least improvement. These responses are consistent with expert feedback that day/night pairing of TIR data will be highly enabling and in situations where a spatial resolution of 10 m is desired.

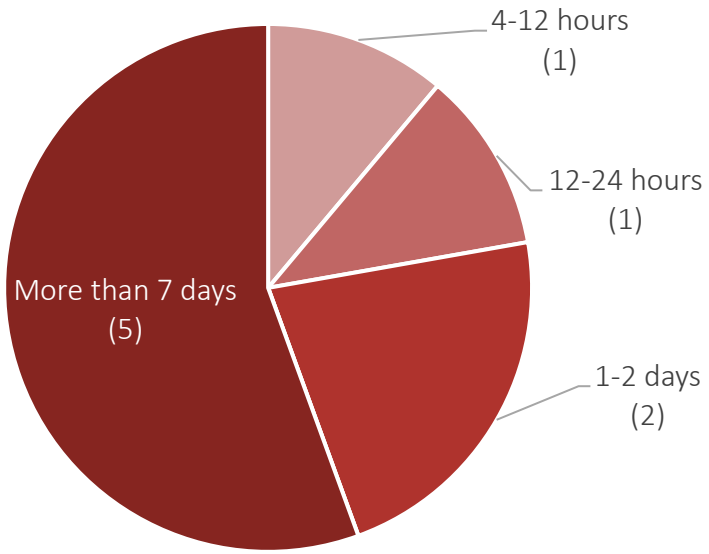
Urban Heat—Survey Results

Information quality issues and cost are a high priority. Latency needs vary, but a majority will accept multiple days.

For the use of Earth observation data in urban heat and health, how important are the following information quality and accessibility issues? (~18 responses)



For those indicating latency as being of moderate to extreme importance: What latency is required in your application?

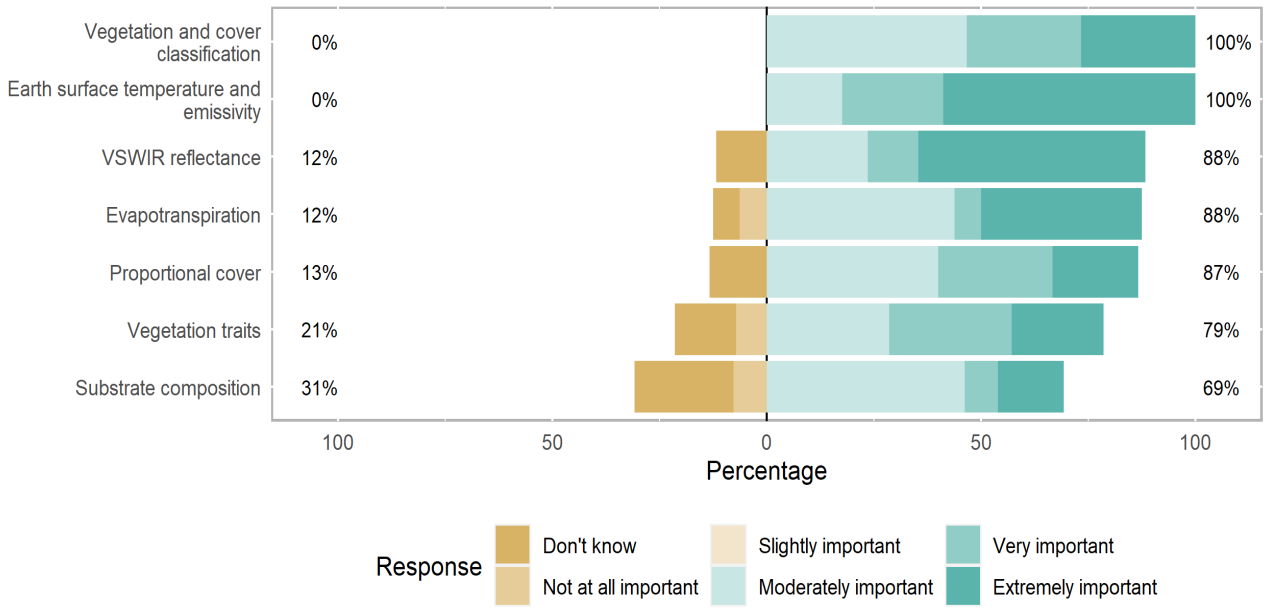


For respondents who desire lower latency, only two out of seven respondents would accept data that are less than fully validated, except for during specific cases such as extreme heat events. In these cases, more timely imagery would be useful and preferred over validated data.

Urban Heat—Survey Results

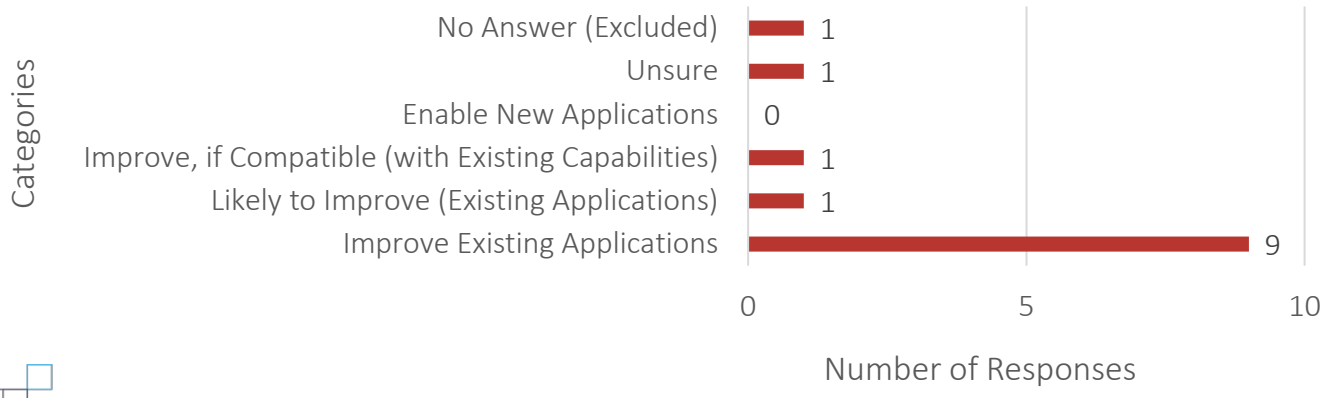
SBG's algorithm products are rated highly important for urban heat and health applications.

For the use of SBG in urban heat and health efforts, how important are the following proposed SBG algorithm products? (~18 responses)



SBG's proposed vegetation/cover, surface temperature and emissivity data products are the most important. VSWIR reflectance was the next highest and was more highly rated by urban heat application respondents than respondents in any other application area. ET, proportional cover and vegetation traits were next in importance. This ranking correlates well with the top priority SBG capabilities and is very consistent with findings from the expert interviews. Although only 13 respondents answered the final set of open-ended questions, a summary of comments shows that a majority believed that SBG will improve existing applications.

Will the proposed SBG capabilities have a strong likelihood of advancing your work? Or might SBG enable entirely new activities or applications? (13 responses)



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Forest Management

Forest Management—Community Overview

New RS offerings are of interest to this established community, which includes both entrenched and isolated RS expertise.

KEY POTENTIAL USERS

- Landowners (Large/Private): Vertically integrated corporations, TIMOs
- Managers (Private): Consulting foresters, land management companies
- Manufacturers (Private): Forest products
- Consortia (Academia): Industry research
- Managers (Government): State foresters
- Corporations (Large/Private): Corps with no-deforestation or lower GHG commitments
- NGOs: Forest, watershed conservation
- Landowners (Small/Private)

KEY USE CASES

- Forest inventories, land/wood baselines, and supply assessments
- Species classification, substand classification, and invasive or understory composition
- Forest health, tree canopy height, phenology/leaf-out timing, insects/disease
- Carbon market/offsets, MRV for owners/NGO
- Disturbance and regeneration, deforestation, disease, storm/fire, replanting, regrowth
- Functional diversity, functional properties across time and ecosystem/habitat

DRIVERS—The 1990s-era market shift to TIMO land ownership gutted the R&D departments of large forest products companies. Today, only a handful of the largest companies have RS expertise. As a result, university–industry research coalitions and industry associations have established alliances that support RS use and development. The forestry industry has a well-established commercial value chain. USFS-supported maps and VASP-provided products are commonly used in the mature North America/E.U. commercial forestry sectors. RS and ground surveys are still used and are primarily driven by the need for efficient, profitable forest inventory/supply management. Industry has become more comfortable with platforms beyond aerial surveys, but only a few top-tier companies and consulting firms are looking to enhance the use of RS-fused datasets. Small private land/forest owners, accounting for up to 40% of forested land in the U.S, are now more interested in making better informed but basic "harvest or conserve" decisions. Outside of meeting Sustainable Forestry Initiative (SFI)[FM1]/FSC certifications, deforestation monitoring is largely seen as a conservation and equity issue for developing regions. Timber and pulp companies in developing regions are monitored by NGOs and consumer products companies; RS-based monitoring is typically provided by forest monitoring specialists like WRI. (*See Conservation and Biodiversity.*) Looming climate change impacts and responses are creating interest in new methods. The SFI have announced that its certified members must "ensure forest management activities address climate change adaptation and mitigation measures," and there is increasing interest in studying forest "degradation" and climate change effects. Nascent carbon markets present new potential revenue sources for landowners, but there is a need for consensus on MRV and functioning markets. These trends are a paradigm shift for the industry – getting paid for carbon (wood) that stays in the forest.

Forest Management—Community Overview

The need for more targeted management, new carbon offsets, and climate change studies creates opportunities for NASA.

APPLICATION NEEDS—For the forestry industry, RS is most valuable when combined with field data. The industry also relies on ground surveys and site-based assessment tools. RS data are viewed to enhance forest inventory, not replace ground sampling methods, which have been used for over a century. This community is accustomed to using RS data to drive business and land management decisions and largely has the mapping and monitoring resources they need for inventory management and disturbance mapping. NAIP and Sentinel are popular resources, but users want less than 2-week revisits to monitor phenology and harvest activity, especially in small plots with frequent turnover cycles. More frequent monitoring like MODIS is too coarse. The largest and most sophisticated players want to monitor fluxes in forest health, drought, and degradation at a finer scale than GEDI and Landsat can provide. For targeted management by experts and researchers, classification of trees species is not possible with current satellite datasets, and HIS presents great potential to address this need. SBG could create value with models of "ecosystem fluxes," functional properties and diversity, and photosynthetic efficiency that are readily usable by a broader range of users. Thermal monitoring is not used in the industry but is of interest to researchers for drought and disease detection. Science-based, trusted measures and MRV methods, backed by large-area, no-fee RS monitoring, will be needed for carbon markets to gain a greater foothold in the forestry sector. If NASA could develop better ways to conduct MRV, it could enable U.S. forest carbon offsets, which experts estimate to have the potential to be equivalent to 10% to 15% of the total forest economy.

INFORMATION NEEDS—Only the most sophisticated users have the process and ability to directly download data in a variety of formats from NASA servers and work in the Python language, and they prefer to work "in the cloud" and analyze data on their own. Less skilled or poorly resourced industry users rely on university support and university–industry research consortia to drive the use of RS data and modeling. Researchers will want to collaborate with NASA to improve classification models, provide APIs, automate tools, and analyze data for complex climate effect models and to leverage HIS in forestry applications. Small landowners and even TIMOs do not have the capacity to process RS data, so simple centralized sources for basic mapping products and consulting will be important. However, the industry can pivot once new tools are proven and become cost-effective. Wood supply analysis software tools using RS datasets, once developed and made user friendly, saw rapid adoption by users across the forestry industry supply chain. This is what it will likely take for SBG-derived tools to gain adoption.

Forest Management—User Personas

With substantial support, this community can gain value from SBG once they see proof of its utility.

University Consortium

RS Research and Forestry Industry Liaison

"Our forestry research collaborative, like a few others, has filled a void in industry R&D. We are trying to help owners and sustainable foresters get the most out of RS, but beyond basic forest stock inventories they need better RS products, access, and help. If it is not a 'one-off' science effort, SBG could really help users understand ecosystem fluxes—what is changing in forest ecosystems, like stresses from drought, pests, climate change effects, etc.—through better tree health indices. If we could get NASA's help with the significant work it will take to bring this to the sector, it could be a big part of the next step in sustainable forestry and conservation."

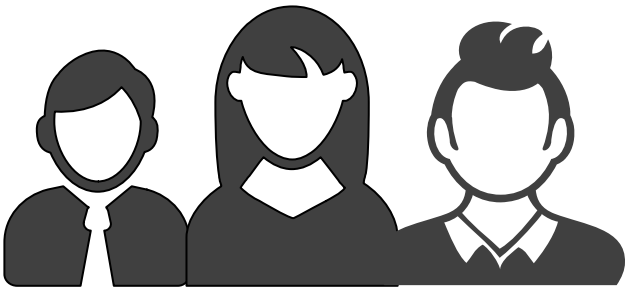
"In forestry practices, there really is no analog for SBG; it will be hard to adopt in a sector that has not used hyperspectral."

Forest Products Company

R&D Head—Pulp/Paper Commodity Manufacturer

"Before we sold off our land, we had a large R&D program with people dedicated to GIS and RS data and integration. The team has been dissolved, and little work is done internally. We now work with university collaboratives. NAIP is too infrequent and other RS methods too coarse to help us accurately model the supply we will have near our mills—this creates a lot of business uncertainty for us and for the market. As a large company, demonstrating that we have sustainable supply chains and are tracking deforestation presents big challenges, and we need help from others to show that we are doing these things."

"If NASA could improve USFS products with better annual RS products that would be great!"



Large Landowner Company

Senior R&D and GIS Group Lead

"We are one of the few remaining companies with a big R&D department that looks beyond entrenched NAIP imagery and uses a variety of RS tools to do forest stand inventories, growth models, and silviculture. RS is the baseline for many of the business decisions we make. SBG will augment much of the work we already do.
Where SBG could really change practices for us is with consistent seasonal data on species identification and growth cycles for regional growth models. Pretty soon we will need to include climate change effects in our sustainable forest growth models—this is where NASA could really help industry!"

"The future of RS in forestry and forest conservation will be hyperspectral."

Forest Mgmt.—Benefits of SBG Capabilities

SBG is a "nice add" to current practices but has the potential to address currently unmet needs for species classification.

CURRENT RS CAPABILITIES *(Consolidated from interviews)*—Traditionally, photogrammetry was the most common form of RS; now USDA's Forest Inventory Analysis and NAIP have become go-to resources in the forestry industry. NAIP aerial imagery (simple RGB and near infrared) is a key resource for industry because of its less than 10-m resolution and height modeling data. Landsat is used for the USFS Health and Monitoring products and leaf area index models, and some forest managers use it for multiyear monitoring. Sentinel and Planet data are frequently used to track harvest activity, but purchased data are less common. MODIS with to its daily revisit capability is used to monitor phenological changes. Canopy structure data are highly valued; LiDAR and SAR are increasingly used to measure overstory height, crown diameter, leaf area index, and understory competition.

Priority Application	Capability Priorities	SBG Benefit
Forest Inventory—Baseline and Supply	**Spatial Resolution** is a top priority. Industry is accustomed to high-resolution imagery and expects 10 m or better resolution. Substand, transition zones, and even tree-scale resolution are required for local monitoring. For some use cases, 30 m is adequate, especially when the management scale is regional, and is "fine to measure change, and a good place to start." However, 30-m VISWIR does not provide a clear benefit.	✗ ●
	Temporal Resolution is important because of the dynamics of the forest, but time series and annual surveys are very common, and biweekly revisits are more than adequate. Commercial foresters desiring detailed phenology, health, and other studies would prefer subweekly but can fuse with other data.	●
	Spectral Resolution (VISWIR)—HIS is expected to improve but not replace current baseline inventory measurements. HIS has more potential it improve health indices. SWIR is valuable for water/drought and climate change effects.	●
	Spectral Resolution (TIR)—Potential for having improved TIR data for fire and fuel load modeling is of most interest to researchers, but not to industry users.	✗
Forest Composition, Growth, and Health	**Spectral Resolution (VISWIR)**—Free, large-area HIS would provide a new capability and address an unmet need for tree-species classification and composition studies. This was seen as perhaps the highest confirmed value area that SBG could address.	✓
	Spatial Resolution—Classification at the stand scale still provides value, but sub-10-m tree-scale resolution is highly preferred, especially for natural forests.	●
	Temporal Resolution of every 16 days is viewed as good enough for this application.	●
Carbon Stock and Climate Change Measurements	**Spectral Resolution (VISWIR)**—Species classification and quantification using global HIS is expected to provide more accurate biomass and carbon stock measurements and, hence, low-cost third-party validated MRV, which are key to carbon markets MRV.	✓

✓ Significant benefit addressing unmet need(s). ● Adequate benefit that meets need(s). ✗ No benefit or does not meet need(s).

Forest Management—Opportunities for NASA

NASA can leverage partnerships with established research players.

COMMUNITY READINESS FOR SBG—Only a handful of the largest vertically integrated landowner companies and land management consultants can work with RS datasets and products. Much of the forestry value chain looks to the USFS and other agency mapping and monitoring platforms, and many work closely with university-led industry research consortia to develop new capabilities. These university–industry consortia and U.S./Canadian agency partner communities are well established and organized and are the most likely to seek and develop innovative RS methods. They represent the best pathway for NASA to engage this sector. The private smallholders are completely underserved and unprepared in terms of using RS. Small private land/forest owners have small associations and NGOs engaging them, but they are not expected to have the capacity to engage in anything beyond basic mapping and simple decision-support tools.

HIS and TIR data are used by researchers, but demonstrations of HIS in forestry will be needed to gain the interest of nonresearch communities. Industry experts have noted that the forestry industry is RS "data-hungry" (large quantities) but has been oversold on RS capabilities and is skeptical. Proving the operational value of HIS at scale in the field will be important to the established forest management RS community of practice. The airborne HIS products produced by the National Ecological Observatory Network and the planned EnMAP mission could be good early adoption proxies for SBG and to develop this community of potential users of HIS. Precision forestry is not yet where precision Ag is at, and it will take a lot of development. NASA should engage and leverage established and central players in the value chain to develop this community's capacity.

OPPORTUNITIES FOR NASA—The forestry sector provides a targeted and established community with a strong interest in improved observations, especially forest vegetation species classification, for both commercial and conservation use. If NASA and SBG could develop proven operational, large-scale tree classification and composition products, they would be highly valued. Collaborative research with university–industry consortia could provide co-funded opportunities to develop HIS for a set of forest applications and demonstrate the value to large companies. To target underserved forest owners, NASA can engage the smallholder user community through key organizations such as the NAFO, National Association of State Foresters, and American Forest Foundation, and established agencies like the USDA. Partnering with the USDA to augment current forest inventory products is the most viable pathway to engage the broader forest management community. As forest carbon markets become more established, there is both an increasing interest and unmet need for improved MRV methods and measures. It would be of high value if SBG could play a role in developing and establishing science-based metrics.

Forest Management—Valuation

RS plays a limited role in the forest sector, but SBG's HIS can expand the value with species classification.

Productive forestry companies and landowners have an appetite for better information that would allow them to plan for forestry activities—this is not academic, but rather highly tied to their financial bottom lines. The forestry inventories are one of their key management information tools. Inventories help them know exactly what is on their land, which is highly important for quantifying supply and planning harvesting schedules. Even marginal improvements in these inventories represent significant value for commercial forest managers, because it means they can sell more timber and reduce costs from overplanting (and needing to invest in thinning later) or underplanting (and losing out on potential revenues later).

Additionally, forest managers trail behind the precision Ag sector in site-specific management applications (e.g., applying fertilizer or precommercial thinning) because of the lack of sophisticated tools for monitoring vegetation stress and quickly identifying where damage has occurred. Some experts felt that an additional nudge was needed for the precision forestry sector to take off. A transition to more site-specific management could mean increasing the net benefits by matching inputs with plant needs more precisely, which, in turn, means reducing input costs and maximizing yields to timberland managers.

How can satellite data help?

Many of the EO tools that are available now are useful but only leveraged by the most sophisticated users. For the companies that have already successfully and actively integrated satellite data into their forest management tools, SBG represents an exciting proposition because they can leverage the new data to create more value. For less sophisticated users who rely primarily on existing USFS products like NAIP, the value of SBG is more tied to improvements made to those specific and limited products. For users who are less technically skilled and have fewer resources, value will only be realized with more investment by service providers.

Challenges with current EO data products?

Current EO products provide a complement to on-the-ground monitoring and help fill the gaps for forest inventories. They also contain useful inputs to physiological processing models that project yields into the future. Experts and practitioners called the current products "adequate" and "a good place to start," but there is room for improvement in distinguishing between different species at the stand level (for plots not already inventoried with high confidence). Although high-resolution USFS and NAIP products are used currently, they are only provided in multiyear cycles, so there is a strong desire for more frequent RS surveys. More frequent surveys means more investment in tools, but the investment would be worth it if these tools could inform more frequent investment decisions.

Forest Management—Valuation

SBG can help improve activities that have impact across the sector, with adoption likely led by a few big timberland companies.

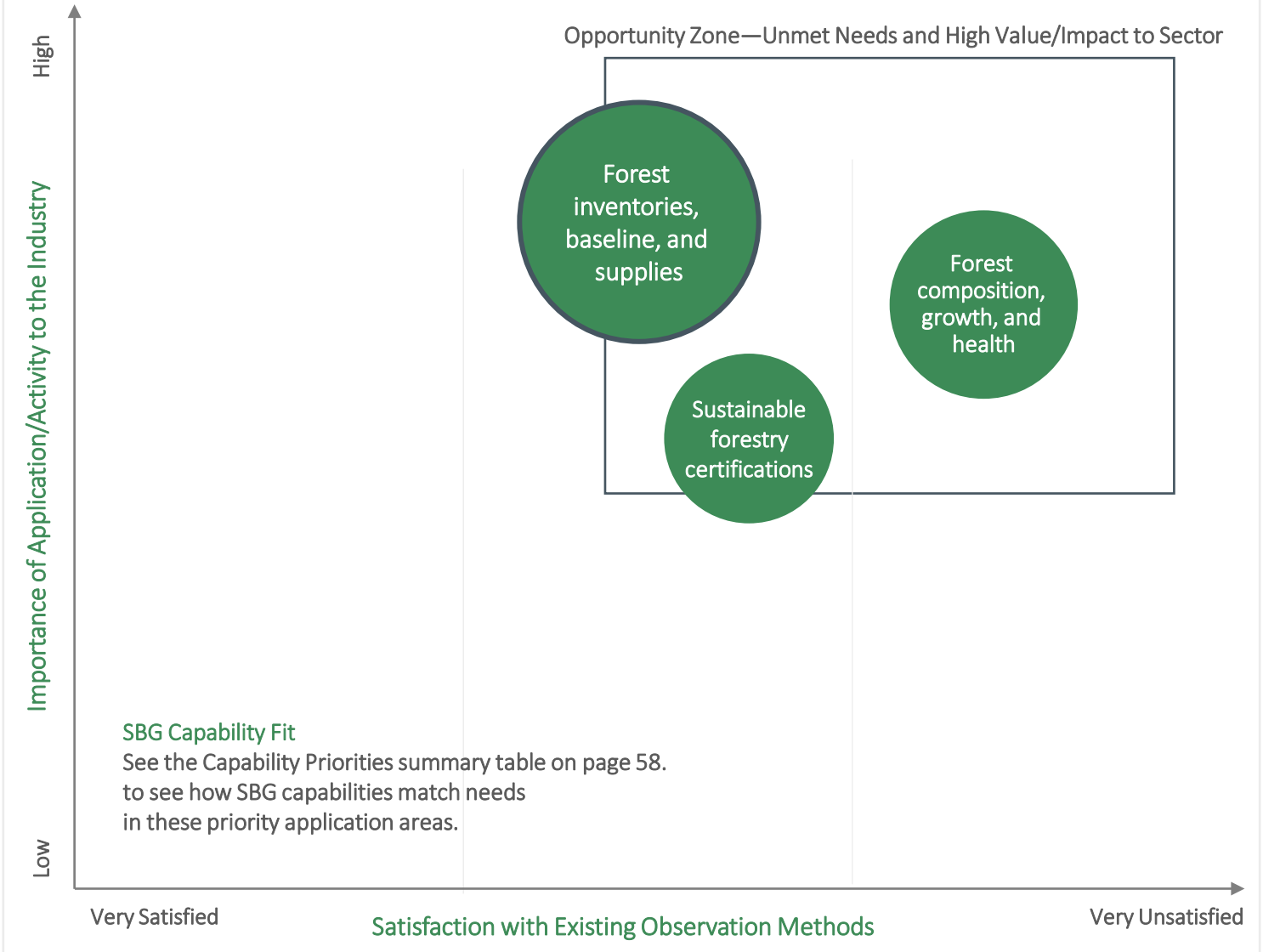
How can SBG help?

For the commercial forestry sector, and particularly for those companies that have in-house RS expertise, SBG holds a lot of promise. These companies see the potential for SBG to help them make better and more frequent planting, harvesting, and management decisions to increase their net revenues over long time horizons. Other small forestry enterprises will be more reliant on technical service providers or public entities and publicly developed tools to help them make sense of the capabilities that SBG has to offer. Lastly, forest certification schemes like FSC and Rainforest Alliance, as well as carbon market certifiers, could use SBG to reduce the burden of compliance costs and enable wider adoption.

End-User Community	Activity	Technical Impact with New Capabilities	Economic Value	Potential Magnitude of Impacts
Large Commercial Forestry Companies and Sophisticated Consultants	Long-term planning: • Develop a more accurate forest inventory • Improve models of physiological processing (e.g., primary productivity, impacts of climate change) • Enable better probability models to do more sophisticated risk analysis Medium-term/short-term planning: • Enable site-specific management: specifically, enable development of tools that can better correlate signs of vegetation stress with needs (e.g., nitrogen deficiency that requires fertilizer or invasive species that require attention)	Long-term planning: • Allows better forest management planning (e.g., improved estimation of the "sustainable allowed cut" over the 10- to 100-year time frame) • Optimized planting and harvesting patterns Medium-term/short-term planning: • More accurate fertilizer application at early and middle stand establishment • Change planting decisions • Help forest managers make decisions on site (e.g., candidates for precommercial thinning)	Long-term planning: • Reduce on-the-ground costs for forest inventory • Optimized growth models mean better decisions about when to plant and harvest, leading to higher net revenues and return on investment over long time horizons Medium-term/short-term planning: • Lower silviculture costs • Lower forest management costs	High
Public Sector (e.g., USFS) and Cooperatives	Improvement of publicly available data with useful information for the forestry and NGO community, such as: • Large-scale speciation mapping • Forest health assessments • Improved forest health and productivity indices (e.g., nitrogen, chlorophyll) • Incorporation of climate change into growth models	With publicly available maps and enhanced tools for tracking species, productivity, and forest health, forest managers without the appropriate technical know-how or capital could make better forest management decisions	Same as listed above, but the economic value would accrue to the users of these publicly available tools and datasets Additionally, public-sector foresters, such as those from USFS, could more effectively manage public lands	Medium
Certification Organizations (e.g., Sustainable Forestry)	Develop better RS methods to monitor climate change effects, sustainable management Measure biomass and carbon over time and integrate those methods into certification schemes	Facilitate updated certification/ sustainability schemes to make them more affordable, scalable, impactful Reduce MRV costs and lower uncertainty related to carbon measurement and models	Lower compliance costs for sustainability schemes and higher market value for sustainable timber for forest landowners—but depends on market size and development	Low/ medium

Forest Management—SBG Opportunity Zone

SBG enables improvements and new capabilities for a set of inter-related applications and players in this sector.



SBG Capability Fit

See the Capability Priorities summary table on page 58.
to see how SBG capabilities match needs in these priority application areas.

Circle size indicates relative value of application.

Example

Case Study Example

Commercial forestry impacts are potentially highly dependent on the size and technical capacity of the business. Forest health monitoring and certifications are evolving and will require improved methods like SBG offers.

Forest Management—Valuation Case Study

If SBG can improve commercial timberland management, it can lead to annual benefits between $52M and $105M per year.

According to an expert who works for a large-scale forestry company and has expertise in RS, SBG holds promise to increase the value of their company in multiple ways. This expert thought that it was realistic to assume the following benefits from SBG:

- **Forest growth models:** Improvements in physiological growth processing (e.g., primary productivity + impacts of climate change) enable the company to define the "sustainable allowed cut"—the primary method used to define the inventory, growth, and harvest schedule over a 10- to 100-year time frame. Right now, the best models can only explain 70% of the variability. If SBG could improve on these growth models by a modest 10% (explaining 80% of variability), the increased net asset value for the company could be in the hundred of millions of dollars over a 100-year time period.
- **Precision fertilizer applications:** Forest management has not caught up to agriculture in precision management. If they can correlate SBG's hyperspectral bands with nutrient deficiency, then they could start implementing more precise fertilizer application at early and middle stand establishment, with an expectation that they could improve fertilizer efficiency by 10%.
- **Silviculture efficiency:** SBG could potentially detect early seedling stress. For example, if a site is covered in grass, it can change the survival rate of the seedlings. Consider that 400+ trees are typically planted to an acre, but 450 are needed in a given year because of high mortality. If SBG can detect the grass, it can improve planting decisions.
- **Thematic maps:** Similarly, if SBG's thermal or hyperspectral capabilities signal an issue that something is wrong, maps can be developed that help forest managers make decisions on site (e.g., candidates for precommercial thinning). These improved maps could save 10% of a forest manager's time.

These benefits were described by a large company with in-house RS capacity. If we assume that the top 5 commercial timberland companies are able to reduce their forest management costs by 10% as a result of using SBG, that could mean savings of more than $100M a year.

Technical metric	Quantity	Source
Total land represented by top 5 timberland owners in the United States and Canada	20.4M	Statista[FM2]
Estimated timberland management costs (annual)	1,045M* ($USD 2020)	Derived from Bair (2006)[FM3]
Assumed impact from SBG (5–10% improvement)	$52M–$105M per year	Calculation

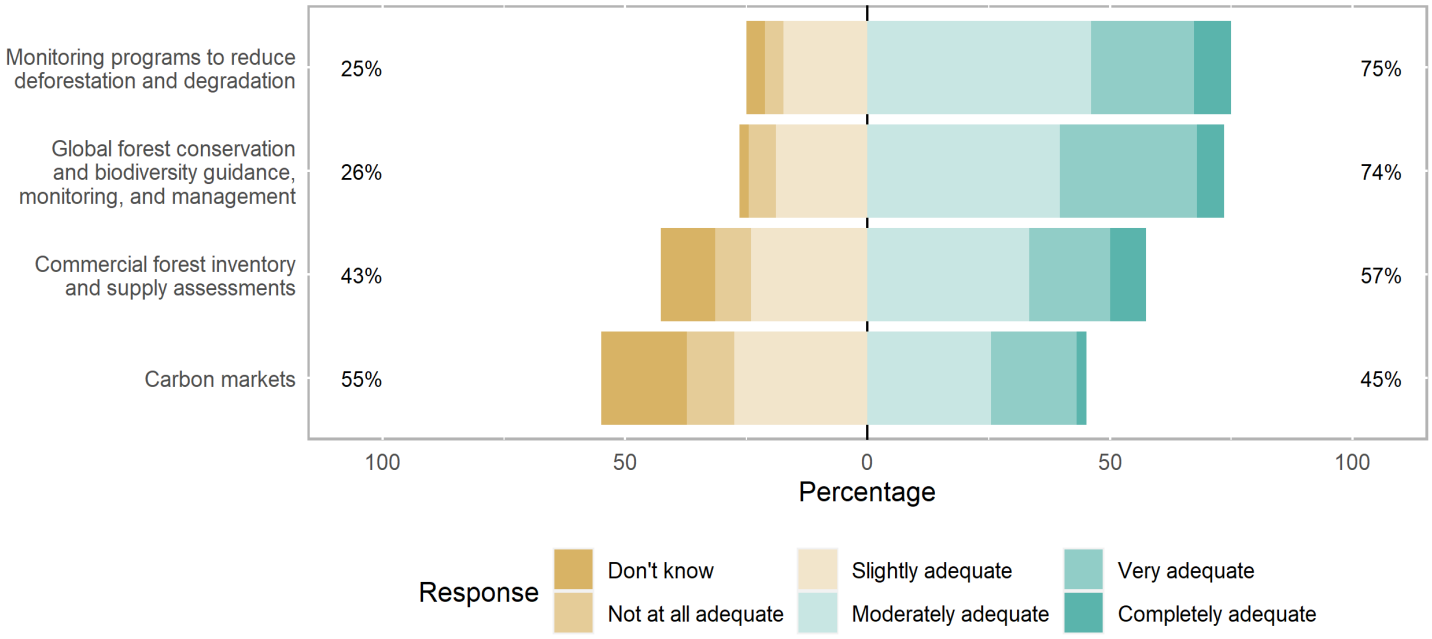
* Timberland management costs, including decadal management, precommercial thinning, and fertilizer and herbicide applications from Bair and Alig (2006), were applied to the total acreage from the top 5 timberland owners.

Commercial Forestry—Users Interviewed

	Key Informant	Perspectives
 	Aaron Weiskittel, Daniel Hayes, *University of Maine*	
	Jim Ellenwood, *USDA Forest Service*	
	Jim Rakestraw, *International Paper*	
	Randy Wynne, *Virginia Tech University*	
	Valerie Thomas, *Virginia Tech University*	
	Steve Prisley, *NCASI*	
	Nate Osborne, *Rayonier*	
	Jose Alvarez, *Weyerhaeuser*	
	Dale Hogg, *Green Diamond Resource Company*	
	Everett Hinkley, *U.S. Forest Service* *(no interview summary provided)*	
	Fred Stolle, *World Resources Institute* *(interview summary in biodiversity section)*	

Forest Management—Survey Results
(Conservation—Forestation/Deforestation)*
Current methods are generally adequate for the main deforestation and forestation applications.

To what extent is the current remote sensing and earth observation data you use today adequate for the following conservation – forest management applications? (~53 responses)



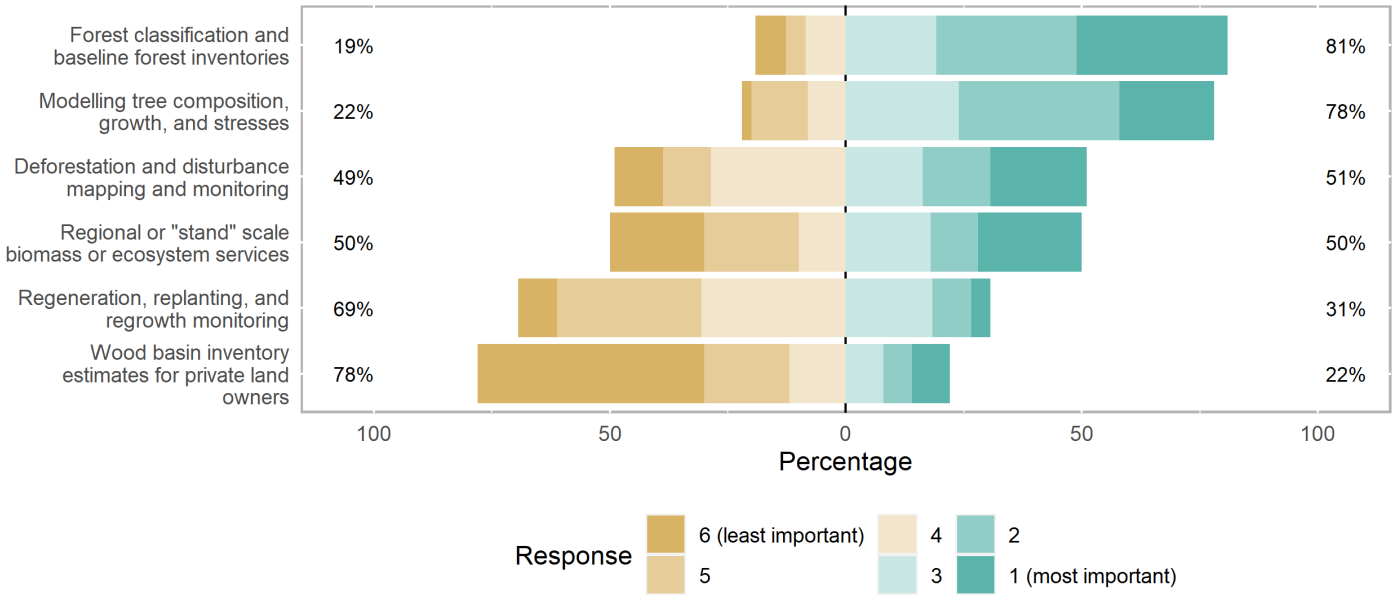
A strong consensus shows that current methods are quite adequate for both deforestation and forest conservation monitoring, which is consistent with industry. However, biodiversity expert feedback indicated that current methods are less than adequate. Mixed satisfaction with current methods for commercial forestry inventory and supply assessments suggests an opportunity area for improved methods, and as shown in subsequent findings, this is a top priority activity for the industry. The highest uncertainty about adequate methods relates to carbon markets, which mirrors experts' sentiment about this new and emerging forestry activity. The survey also asked about what is difficult or not possible to do with existing modes of observation, and a few key themes emerged about unmet needs related to tree classification and composition, plant functional traits and stress indicators, and the ability to assess the understory and biomass. These themes are also consistent with experts' feedback.

* - The survey questions and results for this section more generally deal with conservation forestation and deforestation inclusive of commercial forestry applications, and commercial user communities were engaged to complete the survey.

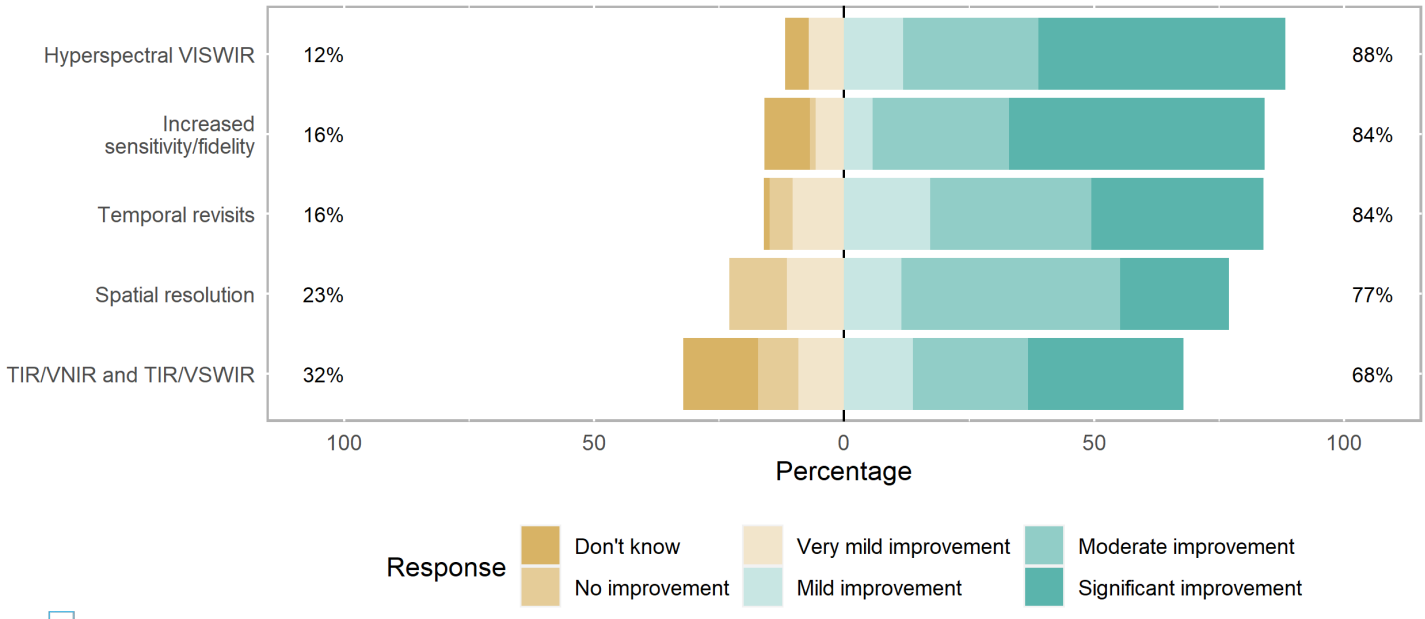
Forest Management—Survey Results

Forest classification/inventories and tree composition/health are top priorities, and multiple SBG capabilities provide benefits.

When working on conservation – forest management efforts, which of the following are the most important "activities" that your organization is trying to accomplish? (~50 responses)



Consider these SBG capabilities and indicate the extent to which each of them provides benefits for the top 2 activities you indicated previously. (~87 responses)

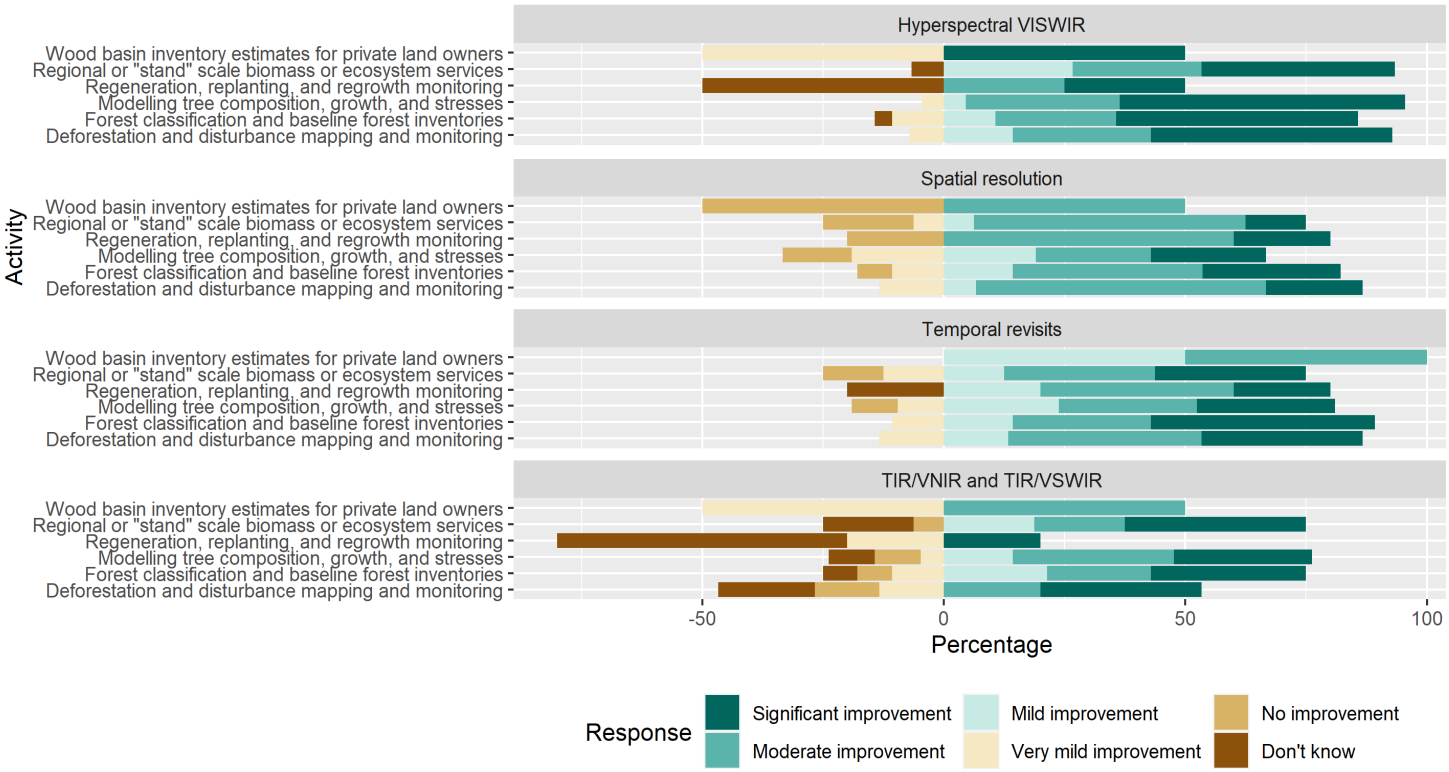


* For all priority rating questions a weighted importance/improvement score was calculated to determine the highest rated choices. Scoring is not shown but is reflected in the analyses.

Forest Management—Survey Results

SBG's capability set provides strong improvements for most priority forestation and deforestation activities.

Consider these SBG capabilities and indicate the extent to which each of them provides benefits for the top 2 activities you indicated previously.

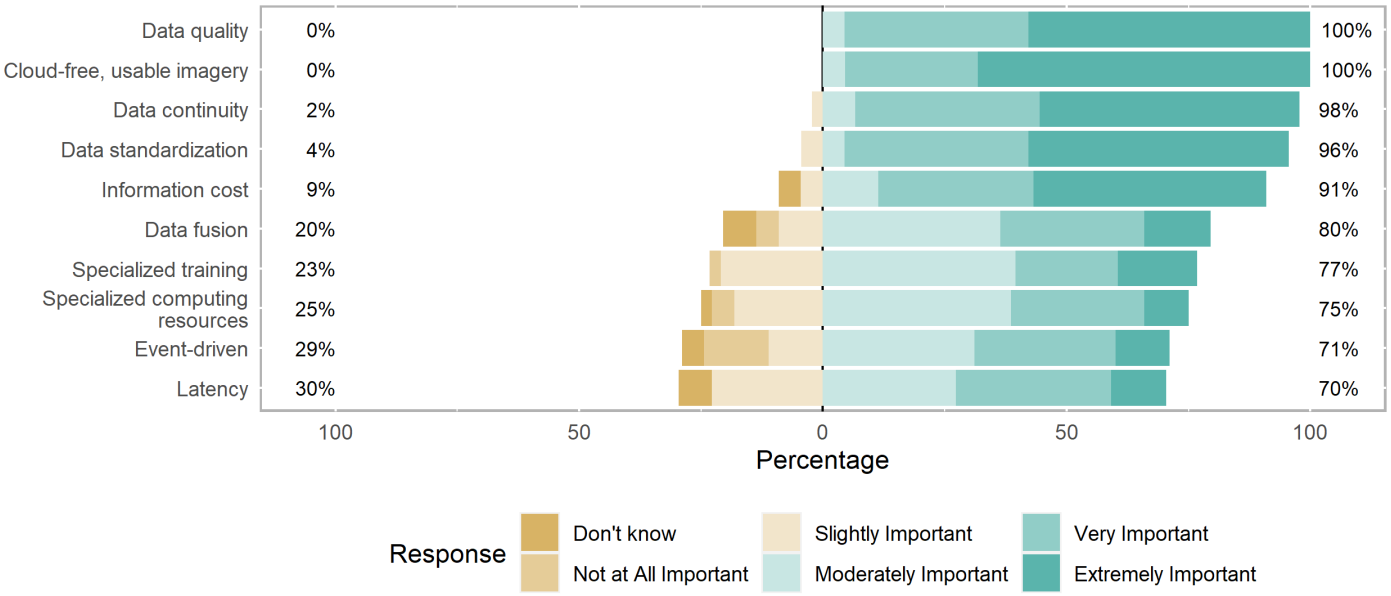


The 86 responses in this section of the survey provided the highest number of SBG capability ratings compared with all other sections. However, the two least selected priority applications—wood basin inventory estimates (2) and regeneration, replanting, regrowth (5)—have so few responses that the results are unreliable. SBG's hyperspectral VISWIR spectral capabilities were top rated for the remaining priority activities, offering moderate to significant benefits across almost all activity areas. This result is consistent with experts' feedback. Respondents had mixed but generally favorable perceptions of SBG's spatial resolution and temporal capabilities. As with other application areas, there tends to be the most uncertainty about the TIR improvement potential.

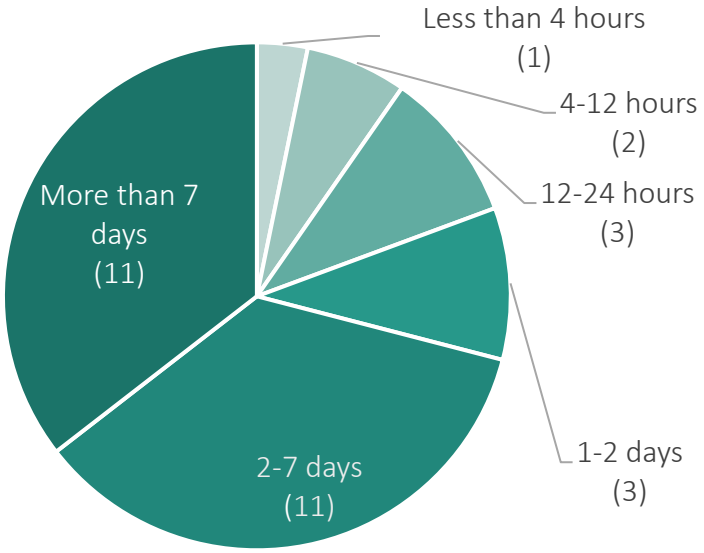
Forest Management—Survey Results

Cloud-free imagery and data quality, standardization, continuity, and cost are top issues. Latency of ≥2 days is good for most.

For the use of Earth observation data in conservation – forest management efforts, how important are the following information quality and accessibility issues? (~44 responses)



For those indicating latency as being of moderate to extreme importance: What latency is required in your application?

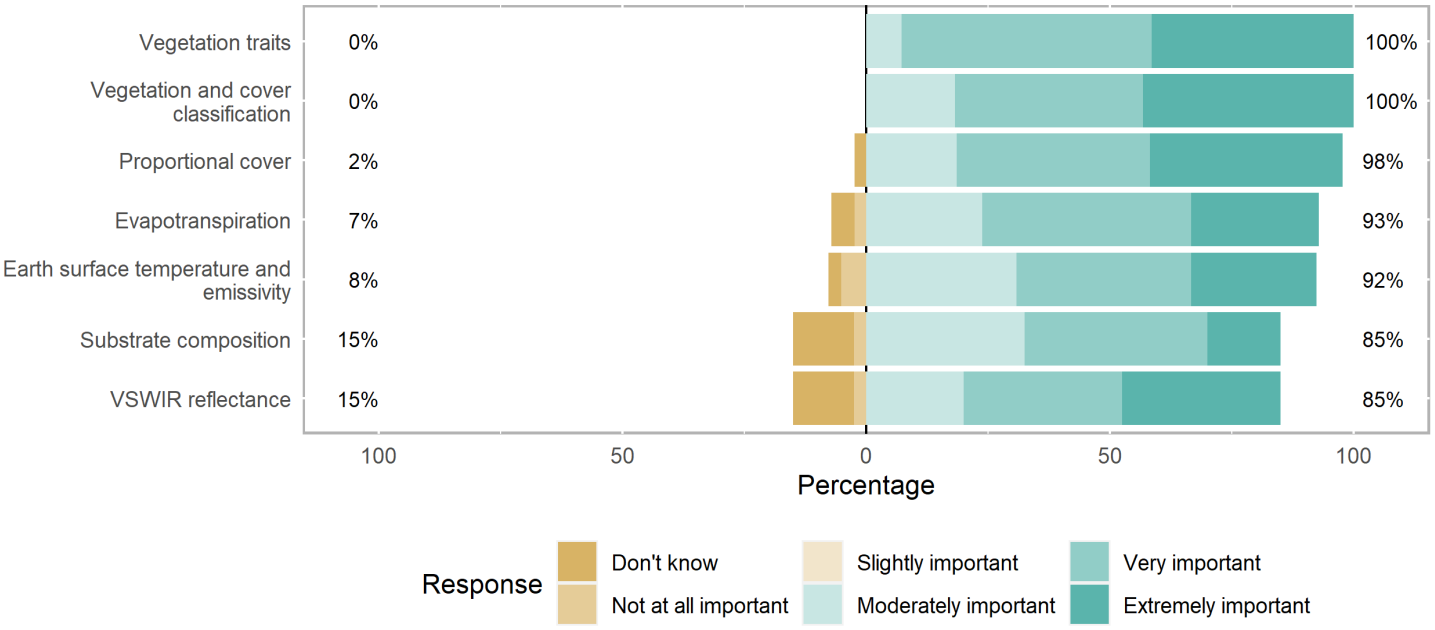


For respondents desiring lower latency, 16 out of 24 would be willing to accept less than fully validated data, but these needs are application dependent. Reponses indicate that some monitoring applications are not time critical, and data are only useful if they are fully validated.

Forest Management—Survey Results

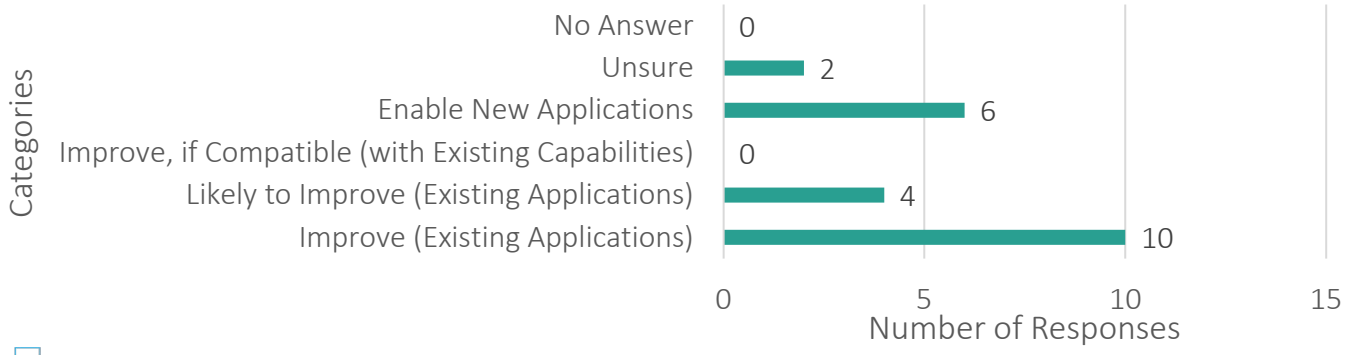
SBG's vegetation and cover algorithm products are of highest importance to forest management respondents.

For the use of SBG in conservation—forest management efforts, how important are the following proposed SBG algorithm products? (~44 responses)



SBG's proposed vegetation and cover products have nearly equally high importance, followed closely by evapotranspiration and temperature products. Twenty-two respondents answered the open-ended questions, and a large majority indicated SBG will improve existing applications, while several mentioned new potential applications. The anticipated impacts of SBG varied widely across conservation efforts, planning and policy decisions, biodiversity monitoring, and stress and disease responses.

Will the proposed SBG capabilities have a strong likelihood of advancing your work? Or might SBG enable entirely new activities or applications? (21 responses)



Forest Management: Citations and Sources

FM1. Sustainable Forestry Initiative. (2021, September 2). SFI forest certification standards advance key global sustainability and conservation priorities. https://www.globenewswire.com/news-release/2021/09/02/2290935/0/en/SFI-Forest-Certification-Standards-Advance-Key-Global-Sustainability-and-Conservation-Priorities.html

FM2. Source for concentrated timberland ownership in valuation case study: Statista. (2021). Leading timberland owners in the United States and Canada in 2021, by land ownership. https://www.statista.com/statistics/623363/leading-timberland-owners-in-the-united-states-by-land-ownership/

FM3. Bair, L. S., & Alig, R. J. (2006). Regional cost information for private timberland conversion and management (Vol. 684). U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Additional Information Sources:

1. GEDI (https://gedi.umd.edu/)
2. National Ecological Observatory Network (https://www.neonscience.org/)
3. NAFO (https://nafoalliance.org/)

Coral Reef Ecosystems

Coral Reef Ecosystems—Community Overview

Constrained by manual fieldwork, this nascent community needs RS to help scale conservation efforts.

KEY POTENTIAL USERS

- Conservation NGOs (Large): Global conservation nonprofits
- Conservation Agencies (Gov't/NGO): Major sustainable development organizations
- Nations (Gov't): Conservation, tourism, fishing bureaus
- Companies (Small/Private): Relocation, re/insurance, environmental consultants
- Coral Researchers (Academic/NGO): Experts in coral and marine ecosystems

KEY USE CASES

- Marine spatial planning, mapping and monitoring of subreef scale coral colonies
- Restoration, relocation and replanting, siting and monitoring, regulatory compliance
- Condition and composition, bleaching events, health and resiliency time series
- Disturbance, nutrient and pollution influx, wave action, temperature, acidification

DRIVERS—Aligned around a common goal of coral conservation, this highly connected and relatively small community is led by researchers and supported by several NGOs focused on ocean health. The world's coral reefs are in rapid decline, and today's systems and approaches to protecting the reefs are limited in scope and scale. Restoration decisions and processes are mostly driven by field-based time- and resource-intensive processes involving scuba divers. This community clearly recognizes the power of RS for advancing two critical objectives: mapping and restoration. The use of RS has led to the recently released Allen Atlas, which maps the location of global shallow coral reefs and is the first of its kind. With basic maps in place, RS is now expected to provide more detailed and frequently updated maps on the size, condition, and composition of existing and relocated reefs. The convergence of proven RS platforms and the urgency of the conservation need suggest that the currently nascent nonresearch, private-sector user community will likely grow and become active users of RS data.

Coral reefs provide many ecosystem services that bring tremendous economic and environmental value. Therefore, governments worldwide, with close support from NGOs, are taking an active role in reef conservation. A business ecosystem is just beginning to emerge around the protection of coral reefs, including insurance/reinsurance companies and suppliers of relocation and restoration services. An international market for coral relocation has sprung up because of new policies that hold for-profit companies (oil and gas, telecommunications, dredging, etc.) accountable for relocating corals that may be damaged as a result of their activities. This private-sector community, separate from the research community focused on mapping, is motivated to use RS information to comply with regulation, better protect valuable assets (tourism, shoreline protection, etc.), and improve relocation services.

Coral Reef Ecosystems—Community Overview

RS is now a priority for characterizing reef health to aid conservation and restoration.

APPLICATION NEEDS—The coral reef mapping community requires more effective and efficient means to understand the composition and condition of existing coral reefs and the impacts of current and future environmental disturbances. RS technology has long been used in this regard, but as a result of challenges with water depth and turbidity, it provides limited reef geomorphology and benthic cover information, necessitating supplementation with diver-collected data. High-resolution remote imaging of coral is a presumed requirement, and it has yet to be determined if HIS, especially at 30 m, can address this requirement and enable the most needed new observations. Current multispectral RS data delineate basic reef composition (coral vs. algae vs. seaweed) but do not provide insight at the coral colony level.

The most important application needs include coral discrimination without field studies: living vs. dead, healthy vs. diseased, resilient vs. nonresilient. A collaboration among leading governmental agencies and conservation NGOs has determined the most critical data layers needed for coral and coral ecosystem conservation: live coral maps, patterns of bleaching, bathymetry/depth, macro-agal cover, changes in color, process/extent of change in colonies, sedimentation, sewage/nutrient influx, and habitat complexity or diversity. Other specific application needs mentioned by leading researchers include presence of diseased corals or coral predators and data to determine reproductive output of outplants to inform success of larval seeding and reef connectivity. Additionally, there is a gap in information at greater water depths and in turbid waters. These needs indicate the extensive amount of applied science and research, relevant to HIS, required to further advance the study and conservation of coral. Additionally, companies involved in relocation or out-planting projects indicated that improved RS data could reduce costs and increase the success of their activities. Choosing an out-planting site is expensive and time consuming: site suitability requires manual investigation. Also improved methods to determine which corals (most vulnerable or resilient), where to relocate them, and success of relocation are needed.

INFORMATION NEEDS—Current global coral maps are being developed with multiple data layers, and experts indicated that adding SBG layers to these existing platforms would be ideal. Even though the Allen Atlas uses high-resolution Planet data, the data are not well calibrated, so there is a desire for higher quality datasets. Experts noted that "raw data scares a lot of people off, particularly in this area, they are divers, they are not data people." VASPs noted their use of netCDF and FTP threads. Given the expected large HIS and TIR datasets, experts recommended compiling data into "physical oceanography characteristics" monthly.

Coral Reef Ecosystems—User Personas

Users need NASA to help with the applied use and capacity building to ensure SBG can add value to coral conservation.

VASP

Hyperspectral Expert

"It's nascent, but there is an industry emerging at the intersection of RS and coral reefs. Coral reef customers are the major clientele of the global Airborne Observatory I direct. We have a VSWIR imaging spectrometer aboard and have proven HIS can provide a more nuanced understanding of coral physiology and better water depth mapping than multispectral data. SBG is the next step in using HIS, but now at a global scale, we just need to do the applied work and we need more skilled folks to advance this work. Let's find ways to build these capabilities now so we can use them when SBG is ready!"

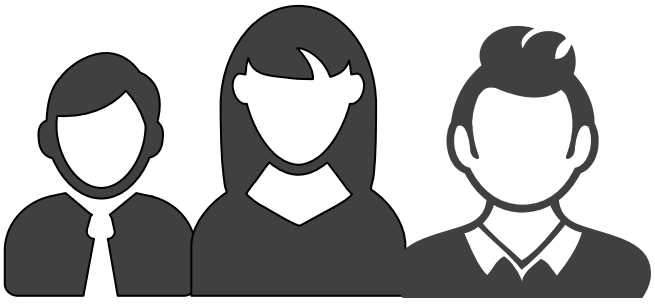
"What I really need is more students to support RS work. There are few master's- and PhD-level talent to handle data/analytics of SBG."

Global Conservation NGO

Senior Coral Reef Researcher

"We already have good global maps that give us a "yes or no" if coral is present and they offer some information on reef composition. Now we need global-scale monitoring of those reefs at the actual unit of change, coral colonies, which is around 1 meter resolution. I would be really hesitant to think that at 30 meters you can get good information on live versus dead coral. The biggest add that SBG will provide is the thermal. Having frequent TIR revisits at 60-meter resolution will really help us understand thermal stress, especially near shore where NOAA data are too coarse to capture dynamic coastal situations. But we will take any better data to help local conservation efforts."

"SBG must get HIS translated, usable, and into the hands of end users."



Environmental Consultant

Reef Restoration, Relocation, and Monitoring Specialist

"Finding the right location to plant or relocate coral is not easy. There are so many factors that go into making the decision and I really think SBG data could help us make better and faster decisions. Although our coral restoration projects are very successful, around 95% or so, and our group does most of the restoration work for commercial companies. Plus, at 30-meter resolution, that won't help us monitor a 20-m by 20-m plot that we put down to satisfy a regulation. I think a another great and totally unaddressed use of this data would be for mapping and monitoring sea grasses or macroalgae."

"Coral restoration works pretty well, we've created habitats in many new locations. This is certainly not the case for sea grass and mangroves."

Coral Reefs—Benefits of SBG Capabilities

SBG's TIR is viewed as a large improvement. The value of hyperspectral will become clear as research progresses.

CURRENT REMOTE SENSING CAPABILITIES *(Consolidated from Interviews)*—Multispectral RS data (Landsat, Sentinel, Planet) has long been used to estimate bathymetry at fine (<10 m) to moderate (10 to 30 m) spatial resolution. The Allen Atlas, powered by multispectral data, provides the first daily global map of shallow reefs at 3.7-m resolution. However, the spectral resolution of these datasets limits estimations of benthic habitats, which can be used to provide basics on composition (coral, algae, sand). Satellite data have not yet been able to resolve benthic surfaces at the resolution of coral colonies or provide information on living versus dead corals. (Foo et al., 2019)[CR1] Airborne hyperspectral imaging (AVIRIS and the Global Airborne Observatory instrument) has demonstrated the value of additional spectral resolution by providing the most detailed classifications in benthic maps to date. (Asner et al., 2020)[CR2] Sea surface temperature observations are also critical. National Oceanic and Atmospheric Administration's (NOAA) Coral Reef Watch provides global daily temperature data at coarse spatial resolution, 5 km. These data are used to trigger bleaching alerts but have not been otherwise integrated. ASTER and GOES are other satellite-based coarse resolution (>1 km) sources of thermal data.

Priority Application	Capability Priorities	SBG Benefit
Composition and Condition of Coral Reefs	**Spatial Resolution** for VSWIR may provide reef-scale data but not coral composition and health. Some experts speculated that HIS at <5-m resolution may be needed. TIR resolution will be a big improvement toward discriminating thermal stress.	VSWIR ✗ TIR ✓
	Temporal Resolution of the TIR and VSWIR will be useful for monitoring reef health, identifying disturbances, and characterizing impacts. Thermal observation may locate persistent hot spots; however, thermal data are currently provided daily.	●
	Spectral Resolution for VSWIR may provide more detailed benthic composition and condition analyses (photosynthetic and calcification rates, live vs. dead, large stand species identification, bleaching events), but 30-m resolution may not suffice.	●
	Global Coverage will enable the monitoring of reefs located in remote areas.	✓
Restoration (site selection, monitoring success)	**Spectral Resolution** of VSWIR will enable more accurate bathymetry (primary determinant of composition and key factor for suitability mapping), rugosity, and water quality measurement.	✓
	Spatial Resolution may not be useful for site selection or monitoring success of plots relocated by out-planting organizations. Thermal will provide better resolution of near-shore water temperatures.	VSWIR ✗ TIR ✓
	Temporal Resolution of thermal is a benefit for identifying persistent cold and hot spots. If spatial resolution is proven sufficient, VSWIR revisits may determine the success of projects without launching diver expeditions.	✓
	Global Coverage will enable relocation efforts away from anthropogenic activity.	✓

✓ Significant benefit addressing unmet need(s). ● Adequate benefit that meets need(s). ✗ No benefit or does not meet need(s).

Coral Reef Ecosystems—Opportunities for NASA

This small motivated community is well positioned to support HIS applied science, and SBG holds potential across marine ecosystems.

COMMUNITY READINESS FOR SBG—In the realm of operational coral reef applications, divers are the go-to experts; few are data scientists, but those who are have a reputation for being innovative. The few leading environmental consultants who conduct most of the reef relocation projects on behalf of commercial companies do have in-house RS data analysis capabilities. There are "progressive" governments that are actively using RS data for coral management, including Fiji, Sri Lanka, Hawaii, and the Dominican Republic, but largely, RS for coral reef studies relies on the academic and research communities. Few integrated decision-support tools or maps exist because there is not yet a compelling incentive for VASP to enter this space. The growth of the insurance/reinsurance industry may shift these dynamics. Until then, this community will look to federal, local, and university-funded researchers to leverage RS data and produce maps and provide consulting. Conservationists expressed a strong desire to get "all of this HIS data translated into usable maps and get them into the hands of end users," but these end users will rely on NASA and others to create these products and make them readily usable.

OPPORTUNITIES FOR NASA—The community is beginning to translate RS data into user-friendly maps and decision-making tools. The Allen Atlas may be engaged with Esri in discussions about incorporating their data into the Living Atlas platform. The fact that HIS experts (Asner/Allen Atlas) are positioned at the nexus of this community may accelerate SBG's adoption considerably compared with other application areas where HIS is virtually unheard of. Esri may also work to bring in NOAA Coral Reef Watch data going back to the 1980s to show how the temperature is changing over time. This momentum signals an opportunity for NASA to leverage its own HIS efforts and tie directly into efforts by Asner/Allen Atlas/Esri/NOAA to improve on existing datasets, maps, and tools.

Many emerging startup companies are developing underwater hyperspectral sensors. This technology, coupled with the hyperspectral data generated from aerial platforms like PRISM, provides fertile ground for developing the application science needed to create a clear and compelling use case for SBG. Experts noted that species identification is an attractive use case. Regulators overseeing coral restoration prioritize conservation of endangered species. Given the importance of biodiversity, they require reporting on the number of those species, a critical index of reef health. Sea grass and kelp are another compelling use case for SBG. Sea grass is considered an essential fish habitat, is a soil stabilizer, is important for fish and fisheries, and supports biodiversity. Sea grasses live in a narrower bathymetric range than coral, and the success of relocation efforts is much lower than coral.

Coral Reef Ecosystems—Valuation

The health of coral reefs is essential for coastal tourism-based economies throughout the world.

The societal and economic value of coral reefs is enormous because coral reefs provide a wide variety of valuable goods and services. Both direct-use economic values and nonuse values are associated with coral reefs. The direct-use economic (market) value of coral reefs includes economic benefits that are mostly derived from tourism activities such as snorkeling, scuba diving, glass boat tours, and recreational fishing. Coral reefs attract visitors and, as such, can be the backbone of a region's entire tourism industry, providing direct and indirect local jobs, business profits, and tax revenue. Approximately 30% of the world's reefs are accessible from nearby land and support local tourism in some form. The global annual economic value of coral reef–related tourism is estimated to be close to $40B (Spalding et al., 2016).[CR3]

Coral reefs also generate nonuse value, which is also referred to as nonmarket value. Nonuse, or nonmarket value, stems from generated benefits that are not traded in an economic market with prices and do not contribute to gross domestic product. Examples range from ecosystem services such as flood/surge protection to overall welfare gains from the basic existence of their beauty and diverse natural marine systems (NOAA, 2013).[CR4] In addition, coral reefs are the "nursery of sea life"; hence, benefits spill over to the entire ocean ecosystem. Studies often find that these nonuse values exceed the market-based economic value associated with coral reefs.

How can satellite data help?

Satellite data play an essential role in managing and conserving coral reefs globally. The monitoring of coral reefs and their ecosystems by divers using specialized instruments is expensive, labor intensive, and time consuming. It is simply not globally scalable or financially feasible. Satellite data have the potential to provide increased frequency of observation, cost efficiency, and global coverage to support the coral reef research, conservation, and tourism communities.

Are there challenges with current EO data products?

Currently, EO data have helped map where coral reefs exist. However, these mapping datasets are not sufficient to support the needed management planning and conservation activities. Coral reef mapping needs to be updated more frequently to plan and monitor conservation, mitigation, and restoration activities. The current EO thermal resolution of 5 km is too coarse to detail dynamic near-shore conditions to analyze or predict coastal impacts of rivers and man-made activities related to water temperature and pollution.

Coral Reef Ecosystems—Valuation

Coral reefs have significant global value, and improved marine spatial planning via RS is critical to all end-user communities.

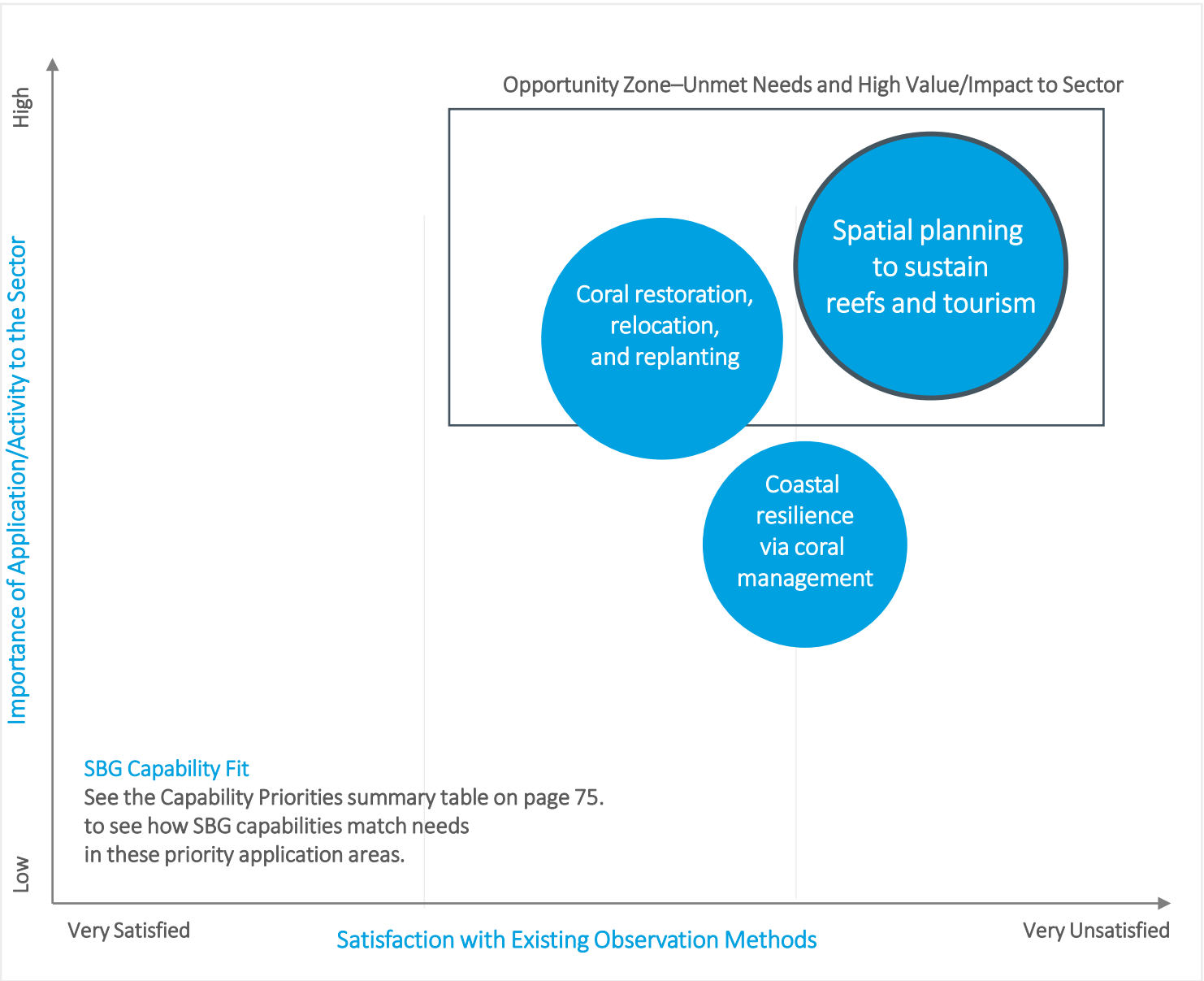
Marine spatial mapping is central to the conservation, protection, and restoration of coral reefs. These mapping efforts can benefit from SBG's improved RS capabilities. SBG would also lower the cost of spatial mapping and make it more scalable. The table below identifies the new technical capabilities that SBG would support and the resulting economic value that would be generated. These are identified for the most likely end-user community activities.

Key SBG Applications

End-User Community	Activity	Technical Impact with New Capabilities	Economic Value	Potential Magnitude of Impacts
National and State Governments	Coastal resilience assessment planning to reduce storm surge and wave disturbance, for example Reef mapping, management, and protections	Enhanced water surface temperature monitoring at higher spatial resolution Enhanced monitoring of coral reefs and coastal factors, such as storm, wave, pollutions	Sustains and maintains tourism economies Shoreline protection	High
Regional Economic Development and Tourism Organizations	Mapping and monitoring to inform marine spatial planning and decision-making to enhance and protect tourism	Enhanced monitoring of coral colonies and reef health, reef diversity, coral classification Live vs. dead classification	Sustains and maintains tourism economies	High
NGOs (most in service of government decision-making)	Monitoring of impacts of disturbances (nutrient/ pollution influx, wave action, temperature, acidification) Capture bleaching events	Enhanced water surface temperature monitoring at higher spatial resolution Enhanced monitoring of coastal area and the interaction of rivers/land with shallow, close-to-shore coral reefs	Sustains and maintains tourism economies Restoration, relocation	High
Universities	Understanding of composition, health, and resiliency	Enhanced thermal monitoring at higher spatial resolution	Sustains and maintains tourism economies Shoreline protection	High
Reef Insurance, Reinsurance	Provide insurance for restoration in case of damage to reefs from laying oil pipelines and dredging, for example	Supports and lowers costs of documentation of coral reef damage and restorations	Facilitates the functioning of the insurance market and provides funds for restoration	Currently low but could grow
Reef Protection and Relocation Organizations	Target and monitor restoration and replanting projects Regulatory compliance	Ability to screen a much larger area for suitable site selection/avoidance and then send divers to high-probability potential sites	Reduced costs of site selection and increased survival rate of coral and sea grass Avoided fines	Low/medium Currently low but could grow

Coral Reef Ecosystems—SBG Opportunity Zone

Spatial planning and site selection for reef restorations represent the most important, and highest, value applications.



Circle size indicates relative value of application.

Example

Case Study Example

Coral reefs bring tremendous value, and although nascent, a business ecosystem is emerging surrounding the management, restoration, and relocation of coral reefs. SBG can foster growth via global, free data that can improve the monitoring of reef composition and condition and increase the success of conservation projects.

Coral Reef Ecosystems—Valuation Case Study

SBG's contributions to the preservation of coral reefs will help sustain key segments of the U.S. tourism economy.

Spatial planning to sustain reefs and tourism

The total value of coral reefs for the United States (direct economic and nonuse) is estimated to be approximately $3.4B per year (NOAA, 2013).[CR4] Direct-use market value includes both direct and indirect economic benefits. Direct economic value accrues primarily through tourism and its related activities. Indirect economic value is also generated by the diverse sectors that support a tourism-based economy, including travel and accommodations.

The table below provides the annual coral reef value for select U.S. states and territories. Many studies have valued the different components of coral reef services, and most studies have found that nonuse value is the largest component of the overall value of coral reefs. For example, the estimated total annual value for Hawaii is approximately $1.7B, a likely conservative value, and nonuse services make up the largest share of this value.

Annual Coral Reef Values for Selected U.S. States and Territories (Millions, $2007)

Select U.S States and Territories	Value
Hawaii*	$1,747
Recreation and tourism[CR6]	$356
Amenity[CR8]	$47
Research[CR6]	$20
Commercial Fishery[CR6]	$3
Non-use value[CR7]	$1,322
Puerto Rico	$1,093
U.S. Virgin Islands	$187
Florida	$174
Guam	$139

*Valuation data for Hawaii were compiled from numerous references, each using a different valuation method. The $1.7B for Hawaii's annual value is conservative because none of the studies captured all ecosystem services. [CR4, CR5, CR6, CR7, CR8]

Experts were not able to quantify the impact that using SBG to inform marine spatial planning would have on the health and survival of coral reefs; thus, attribution of the economic benefits of SBG is not possible. However, if only a fraction of the annual $40.0B global and $3.4B U.S. coral reef–related tourism industry can be saved by using SBG data, this represents a potentially significant economic impact.

Coral Reef Ecosystems—Valuation Vignettes

Advanced EOD, like SBG, could improve the effectiveness and economics of coral restoration.

Coral restoration, relocation, and replanting

Some researchers estimate that 70 to 90% of the world's corals could disappear by the mid-21st century because of increased ocean temperatures, pollution, and dredging and shipping (United Nations Framework Convention on Climate Change [UNFCCC], 2015),[CR9] which places an imperative on better coral management. As the ocean environment evolves, some current coral reef locations will become less suitable, while new locations become more suitable for reef habitat. To this end, reef restoration, including coral relocation/replanting, is becoming increasingly important. Enhanced methods to cost-effectively identify suitable relocation sites increase the effectiveness and success of coral restoration activities.

Currently, most coral reef relocation projects are associated with dredging for maritime/port infrastructure or shallow water oil and gas pipeline development. In these instances, companies are either striving or required to offset reefs that are damaged by their activities by relocating coral. Examples include:

- In 2008, a man-made island property developer in Dubai funded a $9.8M coral relocation project. The project relocated coral to create 24,000 square feet of coral that was about 11 miles long. (Dubai Developer Relocates Coral Reef that Thrives in New Home - Green Prophet)
- Cayman's Verdant Isle has developed a $10M plan to relocate coral affected by planned cruise and cargo port development. (Verdant Isle outlines coral relocation plan - Cayman Compass)
- Abu Dhabi's Khalifa Port's Coral Relocation Plan will relocate coral from Khalifa Port's northern revetment to its environmental breakwater to protect the Ras Ghanada coral reef. (Abu Dhabi Ports Unveils Khalifa Port Coral Relocation Plan | Abu Dhabi Ports, adports.ae)

Data on the size of the coral relocation industry are not available, but tens of millions of dollars of projects are announced globally each year. Relocation and replanting are expensive, ranging from $2,000 to $3M per hectare (Bayraktarov et al., 2015),[CR10] and success rates are less than optimal. One coral reef conservation expert noted, "Coral planting is expensive. A meta-analysis of multiple studies indicated that if you could improve the 1- to 2-year survival of (re)planted coral it would save $100 to $200/coral." Temperature is a fundamental characteristic of site selection that dictates survival of replanted/restored corals, and SBG's thermal resolution is a huge improvement over current EOD. As relocation activities move from mitigating commercial activities to large-scale replanting to restore coral reef habitats in response to global climate change, the industry will likely expand rapidly with SBG data becoming increasingly valuable.

Coral Reef Ecosystems—Valuation Vignettes

Coral reefs can dampen storm surge, protecting valuable property.

Coastal resilience via coral management

Coral reefs offer a natural submerged breakwaters function that provides flood protection by breaking waves and attenuating their energy. This highly valuable ecosystem service is increasingly important given population migration to coastal areas, coastal development, and climate change. Reguero et al. (2021)[CR11] estimated that the upper 1 m of coral reefs prevents the 100-year flood from growing by 23%, mitigating losses of $2.7 B in direct building damage and $2.6 B in indirect economic impacts. They estimated the total hazard risk reduction of U.S. coral reefs to be approximately $1.8 B annually; some highly developed coastlines in Florida and Hawaii realize annual benefits of U.S. $10M/km (Reguero et al., 2021).[CR11]

Climate change is projected to result in sea-level rise and to increase flooding globally. (Beyer et al., 2018) Coral reef loss would magnify the economic impact of such future flooding. Many countries with significant coastal coral reefs, such as Indonesia, Philippines, Malaysia, Mexico, and Cuba, would benefit greatly from improved coral reef management. It is estimated that the annual flood savings from coral reefs is approximately $400 M for each of these nations (Beck et al., 2018).[CR12] SBG could provide cost-effective data to support the development, implementation, and monitoring of coral reef management policies.

Subject matter experts were not able to provide a specific quantifiable impact that SBG could have on the health of coral reefs in terms of increased coral area height preserved. However, they indicated that SBG data could make a significant contribution to preservation activities.

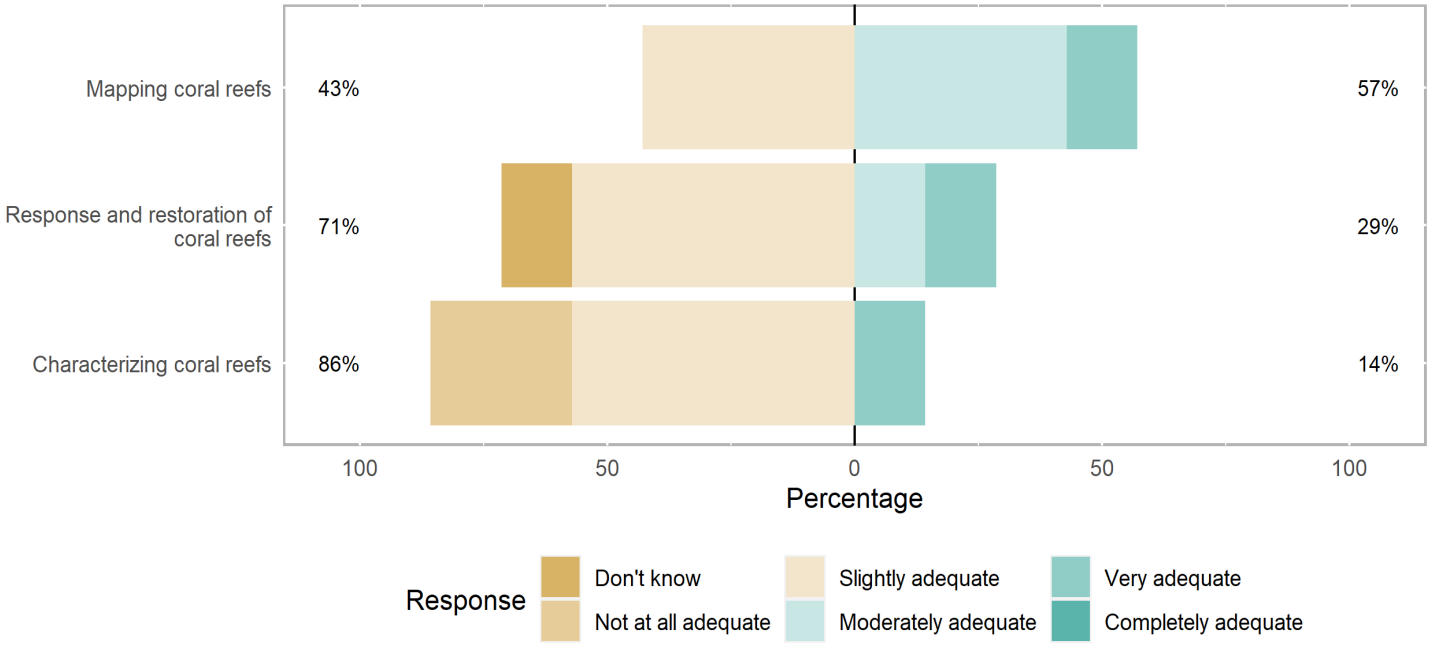
Coral Reef—Users Interviewed

Key Informants	Perspectives
 Liane Guild, *NASA ARC*	
 Greg Asner, *ASU, Allen Coral Atlas*	
 Joseph Pollock, *The Nature Conservancy*	
 Curt Hammill and Keith VanGraafeiland, *Esri*	
 Bruce Graham and Steve Viada, *CSA Ocean Sciences*	
 Alan Li, *NASA Ames* *(No interview summary provided.)*	
 Michelle Gierach, *NASA JPL* *(No interview summary provided.)*	

Coral Reef Ecosystems—Survey Results

For each of the main coral reef application areas, there is the potential to substantially improve on current methods.

To what extent is the current RS and earth observation data you use today adequate for the following coral reef applications? (7 responses)

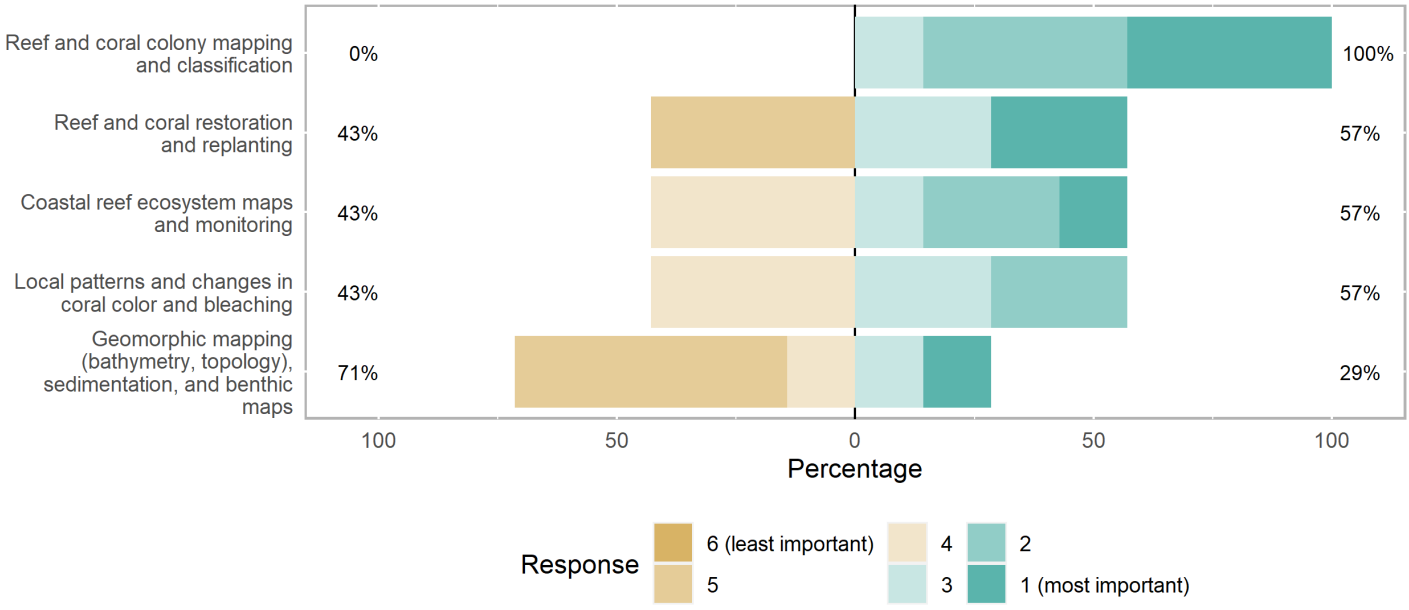


Coral reef respondents see lots of room for improvement in EO data's adequacy for their activities. No respondents said available data were completely adequate for any activity, and few called available data very adequate. More than half of respondents called current data moderately or very adequate for mapping coral reefs, but most respondents found current data not at all or only slightly adequate for other activities. When asked what is difficult or not possible with current methods, respondents cited the need for higher resolution observations, over larger areas, and at greater water depths. This finding is consistent with expert feedback. Beyond the coral mapping available today, there is a stated need for enhanced characterization of coral and reef ecosystems.

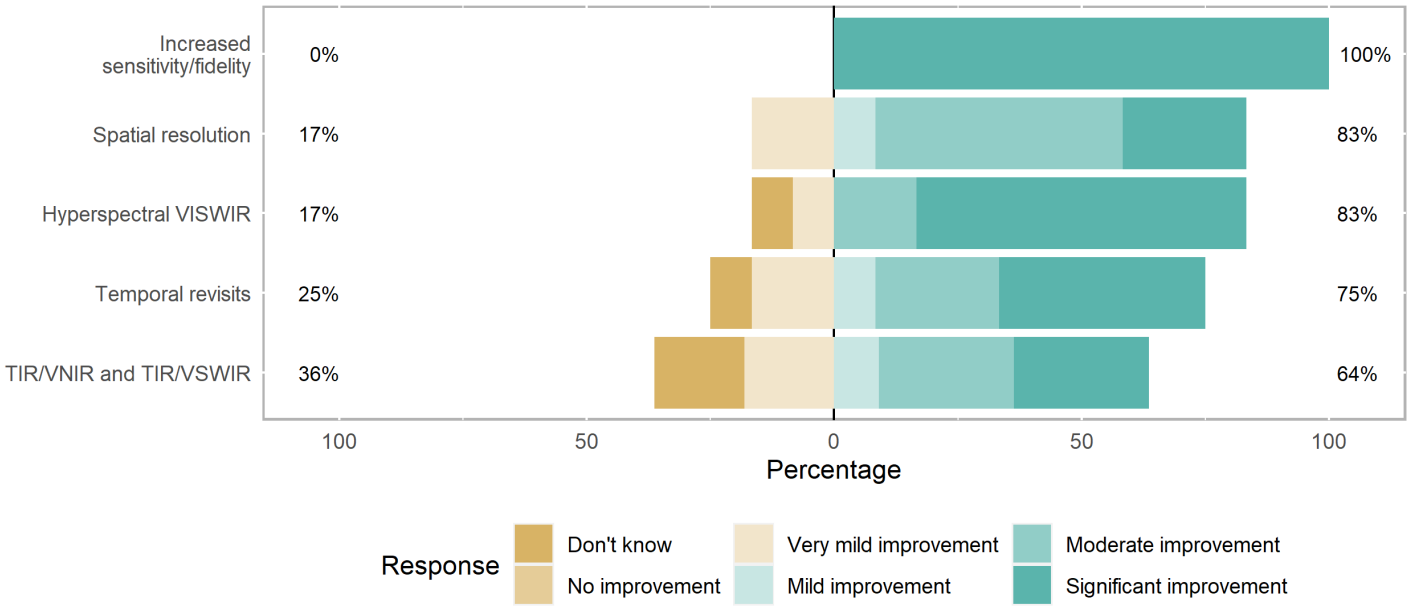
Coral Reef Ecosystems—Survey Results

Coral colony mapping and classification is a top priority, and multiple SBG capabilities offer significant benefit.

When working on coral reef efforts, which of the following are the most important "activities" that your organization is trying to accomplish? (7 responses)



Consider these SBG capabilities and indicate the extent to which each of them provides benefits for the top 2 activities you indicated previously. (~12 responses)

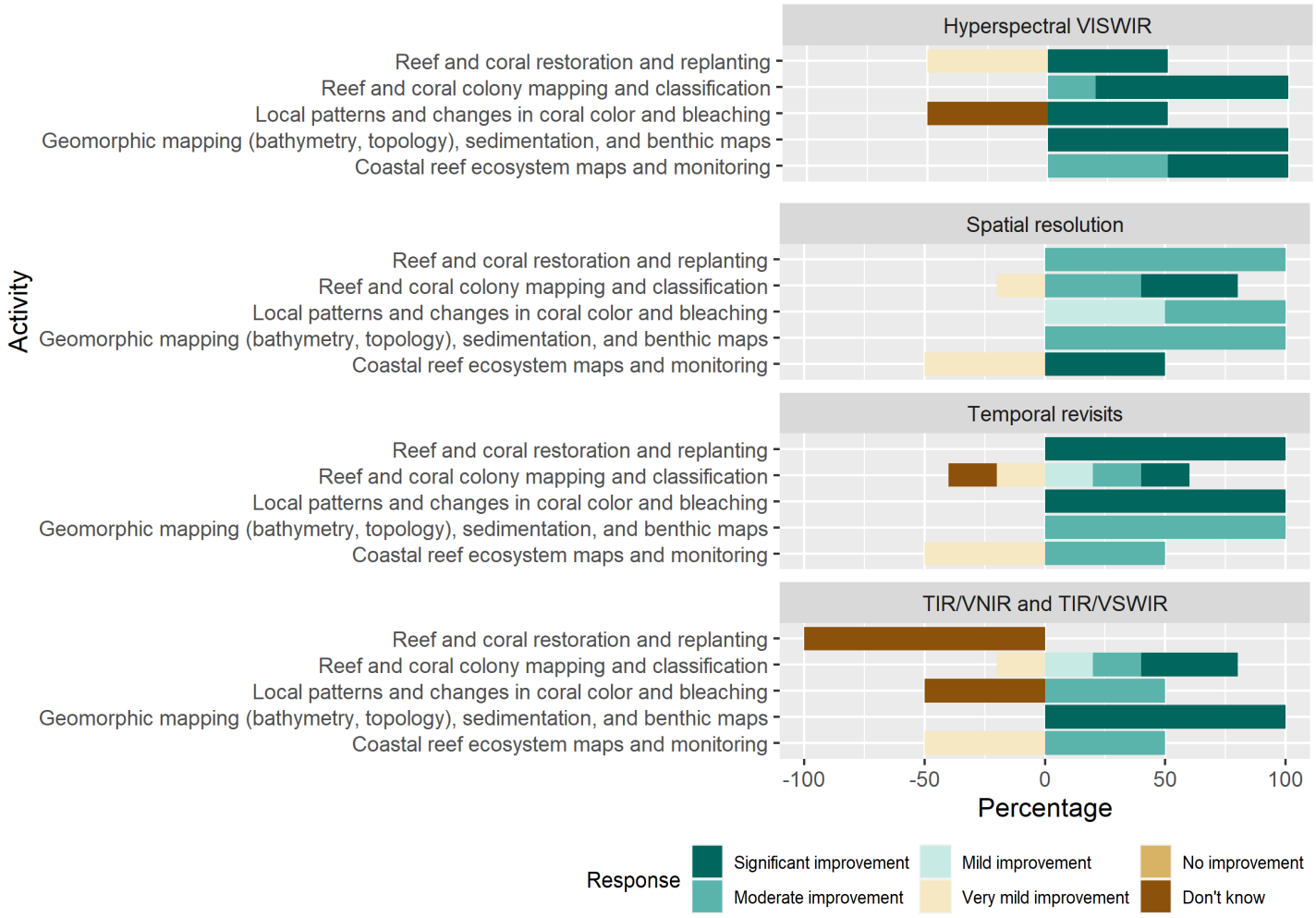


* For all priority rating questions a weighted importance/improvement score was calculated to determine the highest rated choices. Scoring is not shown but is reflected in the analyses.

Coral Reef Ecosystems—Survey Results

SBG's hyperspectral VSWIR and revisit capabilities offer moderate to significant improvements for coral reef conservation activities.

Consider these SBG capabilities and indicate the extent to which each of them provides benefits for the top 2 activities you indicated previously. (7 responses)

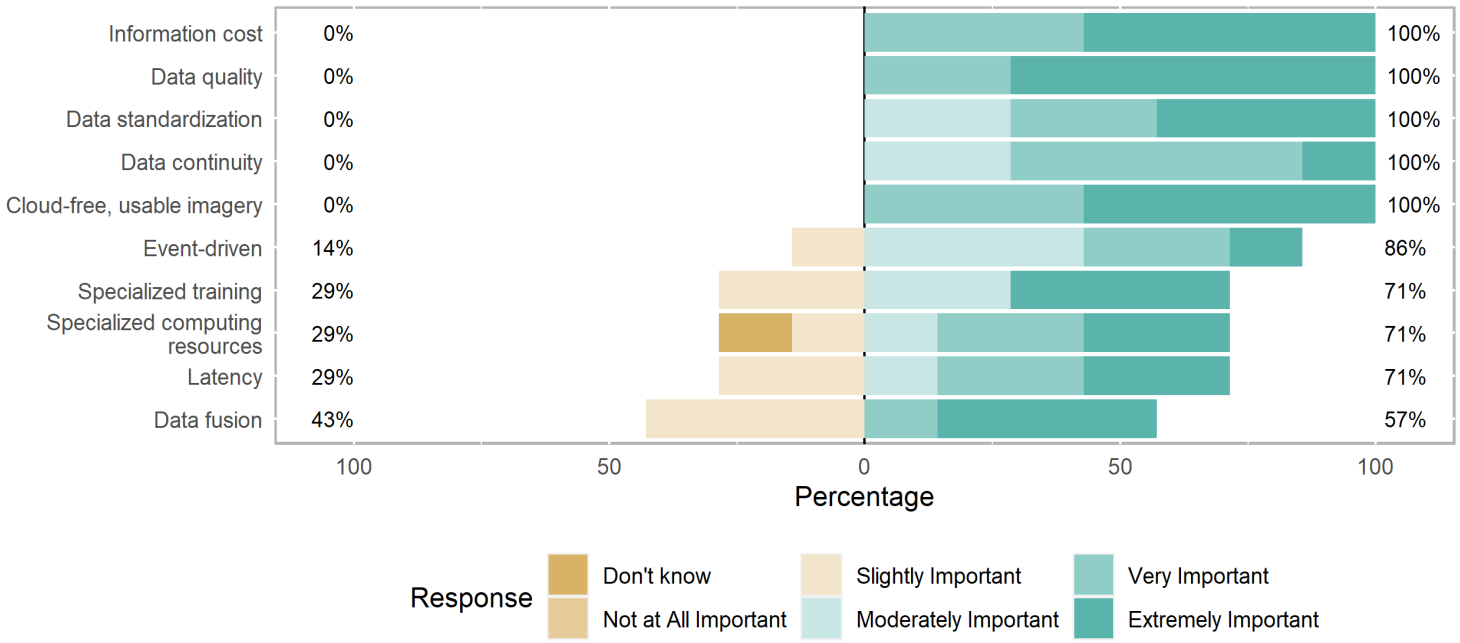


With only seven respondents answering this question, the response rates by priority activities are meager and are not statistically significant. Response rates varied from five responses for "reef and coral colony mapping and classification" to only one response for "geomorphic mapping." SBG's enhanced VSWIR spectral and revisit capabilities were rated as offering the most improvement. SBG's spatial resolution is deemed to offer the least improvement. These findings are consistent with the opinions of experts who desire HIS at a spatial resolution of less than 10 m. Survey respondents were uncertain about the utility of TIR data for restoration, whereas experts indicated that SBG's thermal capabilities (spectral, spatial, and revisit) will be highly enabling for targeting the location of restoration activities.

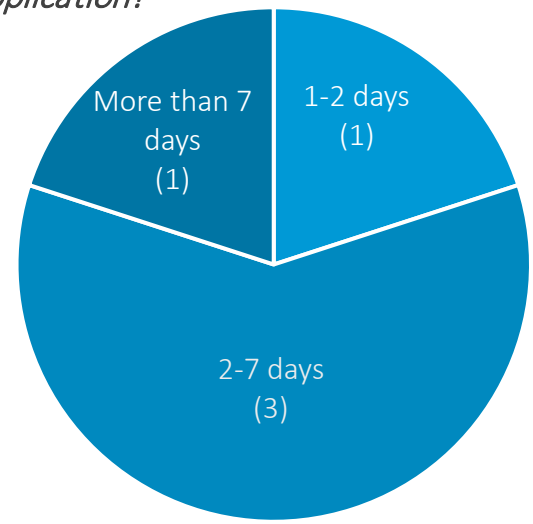
Coral Reef Ecosystems—Survey Results

Data quality, cloud-free imagery, and cost are top scoring priorities. Latency was of varied importance; most will accept multiple days.

For the use of Earth observation data in coral reefs, how important are the following information quality and accessibility issues? (7 responses)



For those indicating latency as being of moderate to extreme importance: What latency is required in your application?

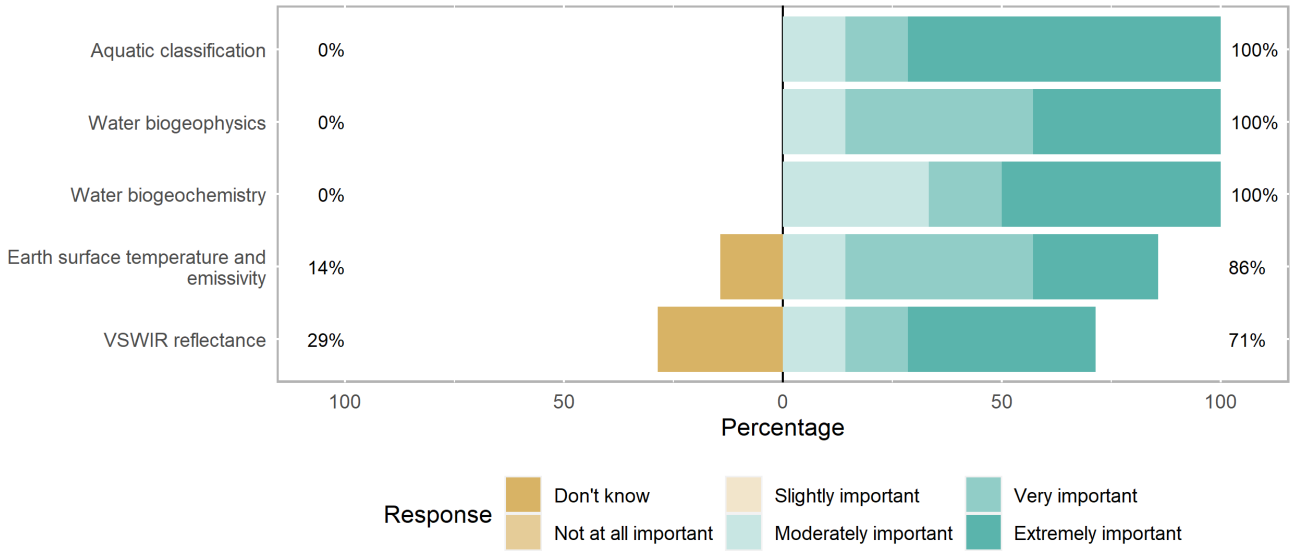


For respondents desiring lower latency, 5 out of 6 would accept data that are less than fully validated.

Coral Reef Ecosystems—Survey Results

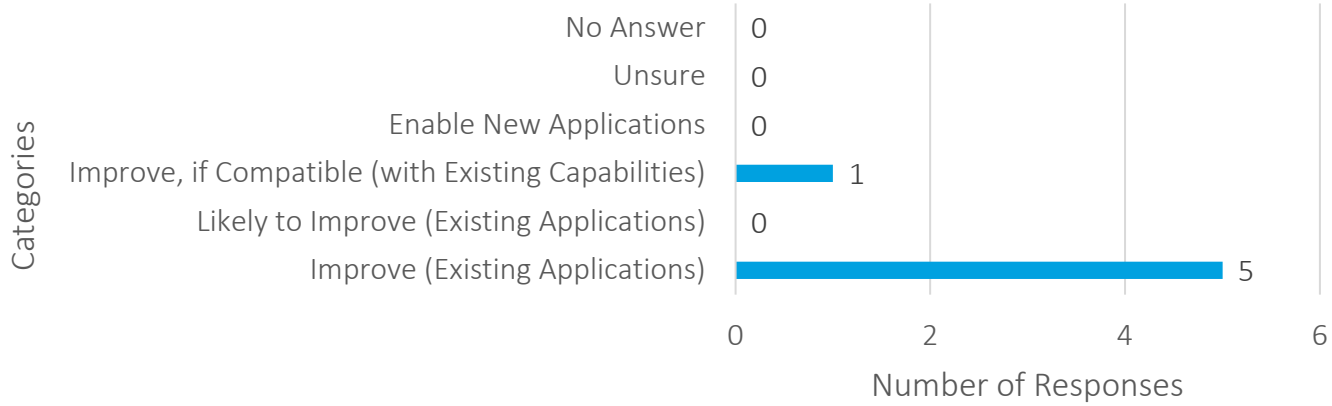
Unsurprisingly, SBG's aquatic and water products are of highest importance to coral reef ecosystem respondents.

For the use of SBG in coral reef efforts, how important are the following proposed SBG algorithm products? (7 responses)



SBG's proposed aquatic and water algorithm products are the most important. The other product options were deemed of slightly lesser but equal importance. Six respondents answered the final set of open-ended questions. They unanimously indicated that SBG capabilities would advance the speed and quality of their work and cited the potential to improve and empower management and policy decision-making.

Will the proposed SBG capabilities have a strong likelihood of advancing your work? Or might SBG enable entirely new activities or applications? (6 responses)



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Global Food Security

Global Food Security—Community Overview

Food security and RS specialists are interested in ways SBG products can improve decision-making and support small holders.

KEY POTENTIAL USERS

- Humanitarian Aid Agencies (Gov't/NGO): Major international food aid organizations
- Nations (Gov't): Ag statistic bureaus
- Corporations (Large/Private): Multinational agriculture product companies
- Companies (Small/Private): VASPs, crop consultants, digital Ag tool developers
- NGOs: Food security and aid nonprofits
- Food Security Researchers (Academic/Gov't): Experts in hyperspectral/RS Ag, hazards
- Finance (Private/NGO): Forecast-based financing, crop insurance groups

KEY USE CASES

- Global/regional Ag statistics, estimates of crop yield and productivity
- Land and field assessments, cropland, crop type classification, monitoring
- Hazard events/trend monitoring, onset; extent; and prediction of drought, floods, and anomaly detection
- Land quality surveys for suitable land, soil maps for conversion, regenerative ag
- Carbon markets, improved indicators and models for soil carbon, certification, MRV
- Food insecurity interventions, regional models for improved interventions

DRIVERS—There are generally well-funded, well-established, and skilled geospatial and RS experts in the global food security application area. These sophisticated RS users and an ever-growing number of mission-driven NGOs and digital Ag startups are developing new and powerful tools for Ag intelligence to help developing countries and smallholders improve agricultural practices and production. Despite these coordinated and technically sophisticated players and toolsets, developing nations still rely heavily on ground-based observations and often, at best, annual estimates. The ability to use RS and other scalable tools with greater frequency to reliably predict regional and local yield and productivity outputs remains an elusive goal. In this context, the global food security complex continues to strive for better tools and models to assess dynamic agricultural environments; anticipate and monitor hazards; and put, simply, evidence-based trusted knowledge in the hands of key decision-makers and smallholders alike. The humanitarian and aid investment impacts of these decisions are enormous, leaving much at stake. With this investment comes a responsibility and mission in this community to "do great work." In addition to improving specific regional estimates and monitoring, important agricultural resilience and smart farming programs will increasingly rely on improved RS products. Forecast-based financing, smallholder insurance programs, and carbon offsets will play an increasingly significant role in ensuring the resilience of farms and providing aid to vulnerable regions. All of this requires better monitoring and models to de-risk and drive investment triggers and develop cost-effective MRV tools. In this context, SBG is seen as one more important platform that should be developed to augment this hard work.

Global Food Security—Community Overview

Global food security and digital Ag specialists see the potential for SBG to improve a key set of context-specific jobs.

APPLICATION NEEDS—For global food security, the unmet RS observation needs include subfield resolution, cloud-free imaging to provide subweekly updates, and enhancements to existing multispectral methods that can be operationalized. SBG's global coverage and HIS/TIR capabilities can improve on existing RS platforms, but potential benefits will come in specific use cases. The most important jobs in this application area are improving early- and mid-season estimates of crop yield and early warning of food security issues in specific regions, near real-time direct observation of conditions on the land surface for fast-moving hazards (e.g., drought, flood, crop abandonment), anomaly detection and retrospective historical baselines/trends to improve current-season estimates, and better MRV for carbon and other programs. Experts felt that SBG has the greatest potential to do these critical jobs: improve condition monitoring using 3-day TIR for better LSTM and ET/ESI models for rapid hazard events; and HIS for cropland (not plant scale) stress monitoring. Experts speculated that once satellite HIS for spectral agronomy was more advanced, SBG may also have great potential for enhanced spectral crop classification. Whether SBG's 30-m+ spatial resolution will be limited to cropland/forest scale monitoring or not, the potential for HIS vegetation species classification was by far the most compelling potential SBG capability. This capability would substantially enable new crop health indices, enhanced models, and better national/regional (not field scale) estimates for all the critical jobs shared by experts. A recurring priority need was a latency baseline of 24 to 72 hours. The better the speed and resolution of SBG products, the closer users can get to assessing the dynamic regional and smallholder agriculture practices and production required for food security decision-making.

INFORMATION NEEDS—The sophisticated geospatial experts in the food security community want open standards and free data to help democratize the use of RS data and products for food security applications. There is a strong consensus that NASA must ensure interoperability and continuity of SBG data with other satellite products with a historical record. Experts emphasized that SBG must be well integrated with Sentinel, Landsat, MODIS, and CHIRPS. Fusion of datasets would be even better. Additionally, ground data and metadata should be in place when SBG is launched. With the volume of current EO and potential HIS data, experts worried about processing capacity and accessibility. Hence, SBG data must be in cloud-native format, the SBG program must not go down the old and slow DAAC FTP/HTTP/PO path. LANCE and NISAR are good respective program models for the SBG program to emulate. To ensure effective translation of SBG products to end users, experts felt that NASA should provide tutorials on the cloud and in native languages. Here too, NASA can look to the Cal/Val campaigns and early adopter programs of SMAP as good models for local engagement. Experts suggested building access to and use of HIS data by using synthetic data to start.

Global Food Security—Benefits of SBG

HIS and TIR are SBG's key enabling capabilities in priority global food security applications. Spatial resolution is just adequate.

CURRENT RS CAPABILITIES *(Consolidated from Interviews)*—A variety of RS platforms are used and have become well established for global agricultural monitoring. Experts cited combinations of platforms to enable monitoring of agriculture in developing regions. Historically, MODIS and VIIRS have been used (now with AVIRIS) to develop global crop monitoring and drought monitoring datasets, which "get the job done." There is increasing use of Landsat, and now Sentinel 1 and 2 (10-m data), for NDVI and similar indices. These, along with IMERG's and CHIRPS' deep period of record, together form a baseline of RS datasets. SAR data are used as needed to provide cloud-free viewing. For commercial missions, near-daily revisits and high-resolution near-real-time products are becoming standard. RS datasets are typically combined with field surveys and ground data to provide quality control.

Priority Application	Capability Priorities	SBG Benefit
Humanitarian Assistance/ Resilience Interventions	**Spatial Resolution**—VSWIR at 30 m is generally not useful for small-scale producer Ag. 30 m is adequate for large-scale Ag contexts in developed countries (where humanitarian assistance/resilience activities are a lower priority).	✗ ●
	Temporal Resolution—Frequent revisits to account for cloud cover is a priority. Users rely on Landsat, so temporal resolution will be sufficient but not ideal. TIR revisit rates are seen as a key part of SBG's thermal capabilities.	VSWIR ● TIR ✓
	Spectral Resolution (VISWIR)—The VISWIR will have more bands than will be needed for humanitarian assistance activities/resilience interventions, but there is great hope that the spectral libraries will improve vegetative growth indices to get at better yield or drought predictions for key crops.	✓
	Spectral Resolution (TIR)—There could be important advances in combining/pairing TIR with VISWIR to identify/model acute water stress, identifying more specific geographies and crops where assistance is needed, or improving metrics for weather-based parametric insurance schemes for crops.	✓
Global, Regional, National Statistics	**Spectral Resolution (VISWIR)**—RS is generally not well incorporated into most government statistical estimates, but if VISWIR can improve crop classification or increase the accuracy of identifying agricultural land, it may tip the scales enough (in terms of acceptable accuracy) to reduce the heavy reliance on field surveys.	✓
	Spatial Resolution—Similar to above, the spatial resolution of SBG will meet needs but does not add a significant benefit.	●
	Temporal Resolution of every 16 days is seen as good enough for this application.	●
Agricultural Carbon Markets	**Spectral Resolution (VISWIR)**—Better identification of crop and livestock management practices could reduce the cost of MRV, but carbon estimation will still be limited to areas of bare soils (which will still be helpful for some applications).	●
	Temporal Resolution—VSWIR <10 days is highly preferred for crop-scale monitoring.	✗

✓ Significant benefit addressing unmet need(s). ● Adequate benefit that meets need(s). ✗ No benefit or does not meet need(s).

Global Food Security—Opportunities for NASA

SBG should leverage existing NASA partnerships now to develop and show the potential for TIR and HIS in regional Ag applications.

COMMUNITY READINESS FOR SBG—The Harvest program and close partnership with GEO, FEWSNET, the USDA and others show that NASA is already well connected to the global food security domain and technically mature but still evolving RS community. This community will look to integrate SBG alongside established RS platforms and into existing analytical practices. Although expected to be willing and able, this community is also very savvy and demanding. One expert speculated that *if* SBG can augment existing platforms to improve hazard detection and crop classification and *if* SBG can improve the accuracy of local "crop census" work by 20%, then it will provide enough value to make the effort and investment to adopt and use SBG routinely worthwhile. If, however, the SBG improvement in these critical jobs is < 5%, then it is not clear if SBG is worth it. Even though this community has deep RS expertise, the SBG program will have to bring experience working with HIS datasets and algorithms and establish the applied science, models, and products with existing partners. Developing countries will not do the R&D and do not have the capacity to trust or leverage new RS products if they do not come through established channels. The digital Ag and VASPs will look for established operational tools before investing time integrating SBG. Free and open data and working with the community to create analysis-ready data products that can be consumed by key user processes will be critical. CEOS Analysis Ready Data for Land (CARD4L), user needs report, and NASA Harvest are key efforts to engage in. SBG must also ensure effective translation of the resulting products to end users. Once such products are established, one expert suggested that SERVIR could create something like HYDRAFloods for SBG and provide training on useable tools from SBG. These kinds of efforts will be necessary to drive adoption of proven SBG products. A common theme was a desire for NASA to help the global food security community build consensus on accepted models that people can use easily and trust.

OPPORTUNITIES FOR NASA—As noted, NASA should leverage existing relationships and begin laying the groundwork for SBG product development and adoption specific to food security application needs. Demonstrating the utility of SBG with central and large players will set the stage to demonstrate its value to others in the global food security community. Experts also pointed to emerging opportunity areas that NASA could consider and explore their synergies with SBG. For example, UN has a task force led by Mark Carney that is working on voluntary carbon targets and standards. Experts routinely expressed the desire that NASA play a key role in being a convening force and objective scientific voice in helping guide and drive consensus on emerging areas and topics, such as carbon monitoring and effects of climate change on agriculture, which are shaping the future of global food security applications.

Global Food Security—User Personas

RS experts in global food security are interested in what SBG can add to their established and emerging applications.

University Consortium

Spectral Agronomy Researcher

"I think SBG has great potential, but there is still a lot to do to use HIS and TIR in global food applications. The HIS benefits will be highly situational. SBG won't give the resolution and quick revisits we would like for more dynamic plant stress studies. But if we can nail down the NIR water bands and get the right spectral libraries for crops we could really take the science to the next step for seeing cropland trends, and even plant health.

The TIR revisits are a huge plus and TIR will get us a much better chance to see plant stress due to flash droughts and heat events."

"The promise of SBG is a global set of hyperspectral plant 'signatures' vs. limited multispectral data points."

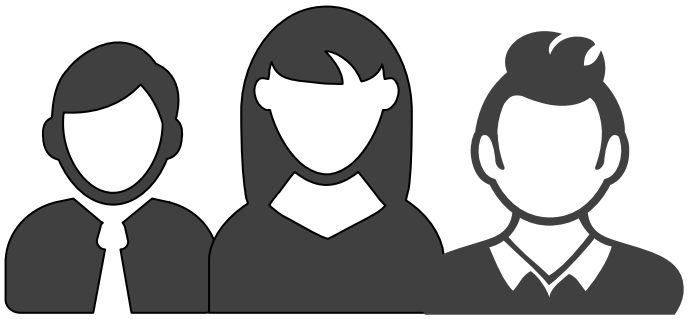
Global Aid Agency

Director, Geospatial Unit

"We have expertise, but we are swamped. We can get most of what we need from Sentinel/Landsat, but we always need better data and help to improve our estimates and target better interventions.

SBG TIR would help with both drought and flood assessments with great revisits, and HIS can help with better crop classification and seasonal indicators. But the SBG resolutions will likely help us with croplands and mono-culture, not small plots. This could be useful for national estimates and forecast-based financing."

"SBG at 30 m and 60 m will be helpful, but it depends on where."



Value-added Service Provider

Digital Ag startup, R&D Lead

"We are working on digital Ag for global smallholders, and we can use any data we can get from the cloud for our new apps. There are a lot of efforts around getting better resolution and revisits, but it will cost us a lot to use those. What is a game changer about SBG is the thermal 3-day and global scale; it would unlock our ability to map some parts of the world. HIS might help us with more data-driven MRV for soil carbon offsets.

For our business model it has to be free data. It should also be interoperable and have continuity to historical datasets. It can augment our current RS products."

"The TIR data could be huge for irrigation studies. and new carbon offset MRV."

Global Food Security—Valuation Context

The role of EOD is well established, and SBG enhancements can support critical global food security efforts.

RS informs many aspects of global food security, ranging from drought/famine early warning and climate change resilience to improving national and global agricultural statistics and measuring soil carbon. In recent decades, enormous strides have been made in integrating RS into global food security tools and products. Many interviewees were excited about the potential for SBG to improve models to identify droughts, forecast yields, and distinguish between crop types at scale. These capabilities, if realized, could have large impacts on end users, including the ability to respond more effectively to food insecurity, design more effective interventions, and develop better policies for the future.

How can satellite data help?

Experts felt that SBG could have a significant impact for several use cases related to the broad categories of (1) responding to food insecurity (e.g., including more specific projections but also better schemes to reduce losses); (2) improving agricultural statistics, especially in developing countries (what crops more specifically grow where and production estimates); (3) evaluating the impact of large-scale interventions in agriculture, citing specific use cases related to expanding improved seeds and expanding irrigation; and (4) playing a role in bringing down MRV compliance costs for agricultural carbon markets or voluntary commitments.

Challenges with current EO data products?

The free global EO products that are used to address food security challenges do a fairly good job at capturing vegetation and where there are concerning deviances. They can also be used to distinguish cropland from noncropland, but with variable accuracy. However, cloud cover is the single most important barrier cited by experts for EO products to address food security in tropical countries. Additionally, Landsat and Sentinel do not have frequent enough flyovers to capture the growing season, and thus far SAR has only been of limited use. Multispectral data are used but inadequate for classification.

The United States currently invests more than **$9B** annually in humanitarian assistance, including food aid (www.foreignassistance.gov). Even small improvements provided by SBG could improve the monitoring and targeting of food security programs. Better food and agriculture aid interventions could have significant downstream impacts on mortality, morbidity, and income for populations living in food-insecure areas.

Global Food Security—Valuation

Experts see multiple applications where SBG can provide benefit.

By incorporating SBG data into current early warning systems, more targeted humanitarian assistance could be provided. SBG's capabilities can lead to better vegetation and water stress indices, reducing the uncertainty in identifying cropland vs. noncropland and distinguishing crops, including production estimates. Additionally, SBG's thermal capabilities could more quickly identify areas of plant stress caused by flash drought or flooding. This enables more precise identification of areas at imminent risk of crop failure and allow the humanitarian response community to plan for more appropriate interventions and outreach.

SBG could improve the efficacy of efforts that support farmer resilience, including index-based insurance. Index-based insurance, forecast-based financing, and more targeted agricultural extension, in general, are examples of schemes intended to enhance farmer resilience. If SBG provides the expected improvements in identifying cropland, identifying pests and diseases, and forecasting yields, these technical schemes can be designed to more precisely design payout triggers to the right households or integrate alerts into digital farmer services. Farmers most in need could avoid losses more effectively from weather-related impacts.

Global, regional, and national agricultural statistics are critical. Reliable agricultural statistics are critical for agricultural research, policy making, and reduction of commodity price volatility. RS is currently underused as a tool that can reduce the cost and increase the frequency of agricultural statistics, particularly in low-income countries where data are scarce. One of the barriers is the ability to distinguish between crops and estimate yields. These capabilities could help improve and reduce the cost of national and regional production estimates. Just as Landsat has helped refine estimates of yields and enormously reduce damaging price volatility/uncertainty in agriculture, SBG can continue these trends into the future.

Evaluating the effectiveness of interventions. There is limited information about the effectiveness of agricultural interventions in terms of adoption or raising of yields. Donors, including the Bill & Melinda Gates Foundation (BMGF) and the Millennium Challenge Corporation (MCC), make huge investments in interventions such as the development of new seed varieties (BMGF) and irrigation infrastructure projects (MCC). If SBG can effectively distinguish between different crop varieties or the presence of irrigation, then these organizations could better evaluate, course correct, or scale up interventions that are working and discontinue those that are not.

SBG could lower MRV costs, supporting agricultural carbon markets to scale. Carbon markets for agriculture have been around for decades but have struggled to gain their footing. One of the biggest barriers has been MRV costs. Farming margins tend to be small and highly volatile. As a result, farmers tend to be risk averse. If SBG can better identify management practices that mitigate carbon, such as different types of tillage, cover crops, and sustainable grazing at scale, it could be a game changer. Soil carbon measurements are another possibility, but advances may be limited to bare soil, which limits the use for monitoring carbon over time.

Global Food Security—Valuation

Improvements to key applications will yield substantial impacts.

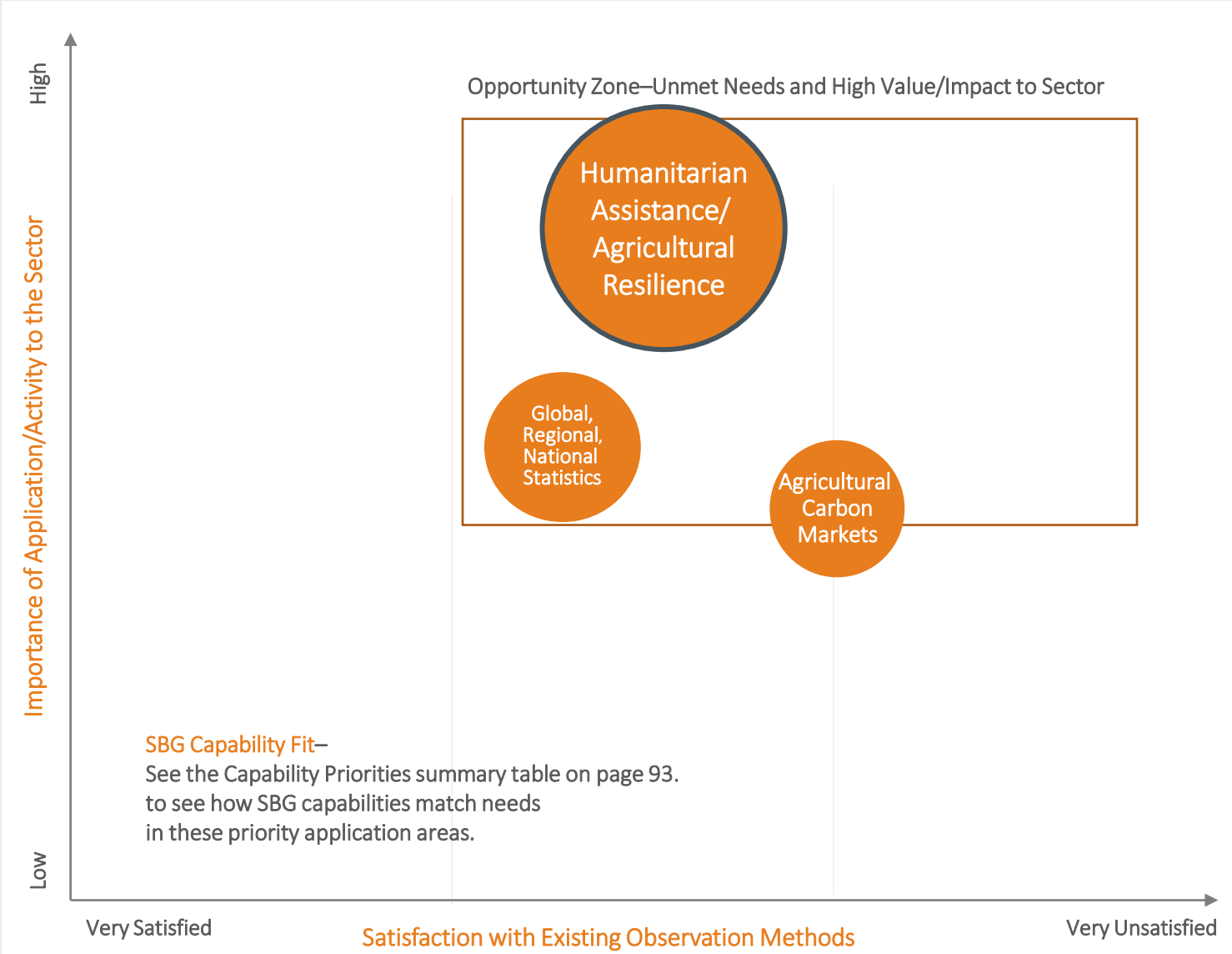
Key SBG Applications

End-User Community	Activity	Technical Impact with New Capabilities	Economic Value	Potential Magnitude of Impacts
Humanitarian aid Organizations Involved in Early Warning Response	Estimates: Earlier and more accurate estimates of crop losses, including geographic specificity Identifying hazard events: Capturing flash drought/flood or fields abandoned due to conflict	Early warnings could more specifically target places and communities in need and quantify food deficits more accurately, enabling more targeted interventions	More targeted humanitarian response could reduce mortality/morbidity and mitigate food price volatility during emergencies	High
Humanitarian Aid Organizations Involved in Food Security Planning	Refinement of schemes that reduce food insecurity, such as more targeted agricultural extension, index-based crop insurance, and forecast-based financing	Better targeting of event-driven or chronically insecure areas ensures farmers are more likely to receive products and services that allow them to bounce back from shocks more effectively	More targeted interventions could reduce mortality/morbidity and economic losses caused by prolonged shocks	High/ Medium
Global, Regional, and National Statistical Agencies	Provide frequent and accurate agricultural information, including production statistics, land use maps, and global irrigation coverage	Better data allow for better agricultural policy planning, more targeted research, and reduction in the burden on expensive field-based surveys	Reduces the cost of expensive field-based surveys; longer term, policy makers can design policies that increase net benefits to farmers	Modest
Donors or Aid Organization Conducting Monitoring, Evaluation, and Learning	Monitor, evaluate, and learn from large-scale investments in activities such as improved seeds, wider coverage of agrochemical inputs, and infrastructure (e.g., irrigation)	Better data and insights for adaptive management enables scale-up of activities that are working well and discontinuation of those that are not	Reduces the cost of field-based monitoring and scaling up over wider areas; in the longer term, it increases net benefits to farmers	Medium/ Low
Developers of Agricultural Carbon Markets	Improve identification where carbon mitigation activities have taken place Development of compliance markets	Better indices and MRV practices can help scale up carbon markets in the agricultural sector Better measurement of soil carbon over bare soils	Reduces MRV costs, thereby facilitating wider adoption and increasing carbon market financial flows to farmers	Low

The economic value of these key applications is highly dependent on the geography in question and on having the right experts to translate the data into usable tools. Additionally, SBG datasets and products will have to be integrated into existing monitoring programs. With so much data available, these constraints are not trivial and will ultimately determine the realization of economic benefits.

Global Food Security—SBG Opportunity Zone

Areas with High Unmet Needs and Potential Value



Circle size indicates relative value of application.

Example

Case Study Example

Humanitarian assistance is the most well- established and well-funded area where RS is being used, but SBG is arguably just as important in other smaller scale and emerging activities in global food security.

Global Food Security—Valuation Case Study

If SBG is used to inform humanitarian response, it could provide up to an additional $43M per year in the Horn of Africa.

Modeled Value of Improved Humanitarian Response

A study conducted by the U.S. Agency for International Development (USAID) in 2018 (Venton, 2018)[FS1] found that an earlier, more proactive humanitarian response could have led to $4.3B in net savings over a 15-year period (2001–2015) and affected 15 million people in Kenya, Ethiopia, and Somalia. The study used the Household Economy Model (HEA) with detailed data from these countries to model the potential impact of different scenarios.

The $4.3B in net savings reflected interventions that build people's resilience, including direct cost savings to donors and governments through reduced liabilities (38%), reduced safety net transfers (30%), and avoidance of livestock and income losses to households (32%) (Venton, 2018).

Many experts thought that SBG could make a material difference in improving early warning specificity (by at least 10%) and accuracy. Assuming these SBG improved early warning models could be incorporated into the resilience-building activities modeled by Venton et al., it would imply additional savings of ~$14M to $43M, depending on whether an optimistic (15% improvement) or pessimistic (5% improvement) scenario was used.

Considering that the three countries above represent only 11.7% of total humanitarian costs over the same period and assuming avoided losses were similar in other countries over the same period, then total implied losses could be anywhere from $120M to $368M per year.

Savings from Humanitarian Response	Value (Millions, $2016)	Source
Building resilience in affected communities	$287	USAID
Optimistic scenario (15% improvement via SBG)	$43	Interviews
Pessimistic (5% improvement via SBG)	$14	Interviews
Annual value for Horn of Africa	$14–$43 per year	USAID/interviews
Proportion of global humanitarian aid in Horn of Africa	11.7%	foreignassistance.gov
Scaled-up potential value to rest of world	$120–$368 per year	Simple valuation calculation

Global Food Security—Valuation Vignettes

SBG has the potential to improve the accuracy and lower the costs of crop production estimates and MRV for carbon markets.

Global, Regional, and National Statistics

For decades, ground-based and EO data have played an important role in improving agricultural statistics and production estimates. The USDA Foreign Agricultural Service uses RS as an input into their global production and supply estimates that are known to affect global commodity prices and markets (Adjemian, 2012).[FS2] National agricultural censuses and multicountry surveys that contain agricultural information, such as the World Bank's Living Standards and Measurement Surveys, also use RS to complement survey data (Lobell et al., 2020).[FS3] The data from these surveys are combined with field data and provide a critical basis of knowledge for countries to shape agricultural policy, track important trends, and target interventions.

SBG has the potential to build on the relatively limited role that RS has already played in complementing and refining estimates from these surveys at the national, regional, and global scales, particularly by providing more reliable and verifiable estimates of crop production. Experts discussed various ways that SBG could provide value to these surveys:

- Lowering the cost and burden for on-the-ground data collection.
- Producing more accurate data that ultimately lead to more targeted policies and interventions in the agricultural space; in particular, there is a growing body of literature commissioned by the World Bank that indicates RS methods were just as effective—if not better—than farmer recall at estimating yields (Lobell et al., 2020).
- Lowering the volatility of global commodity markets for highly traded global agricultural commodities (thus improving the efficiency and raising producer and consumer welfare gains).

Agricultural Carbon Markets

An oft-cited key barrier to scaling up of agricultural carbon markets are MRV costs (Proville et al., 2020).[FS4] These costs vary wildly depending on activity but are often too high to allow agricultural carbon markets to scale up. Also, these markets are primarily voluntary, so there are limited permanent drivers (Proville et al., 2020). However, experts in the carbon markets space thought that the promise of SBG to develop more spatially explicit and accurate estimates of cover crops, various tillage types, improvement of nutrient management, and the presence of crop residue could relieve the burden on farmers and crop developers to do this using on-the-ground survey methods. One expert estimated that SBG might optimistically provide cover crop accuracy that is 20% to 30% better than Landsat. Another said, "If you can get the MRV costs down to less than $2/acre it might start to get viable." If SBG could contribute to improving accuracy and alleviating some of these cost constraints, it would provide a huge benefit.

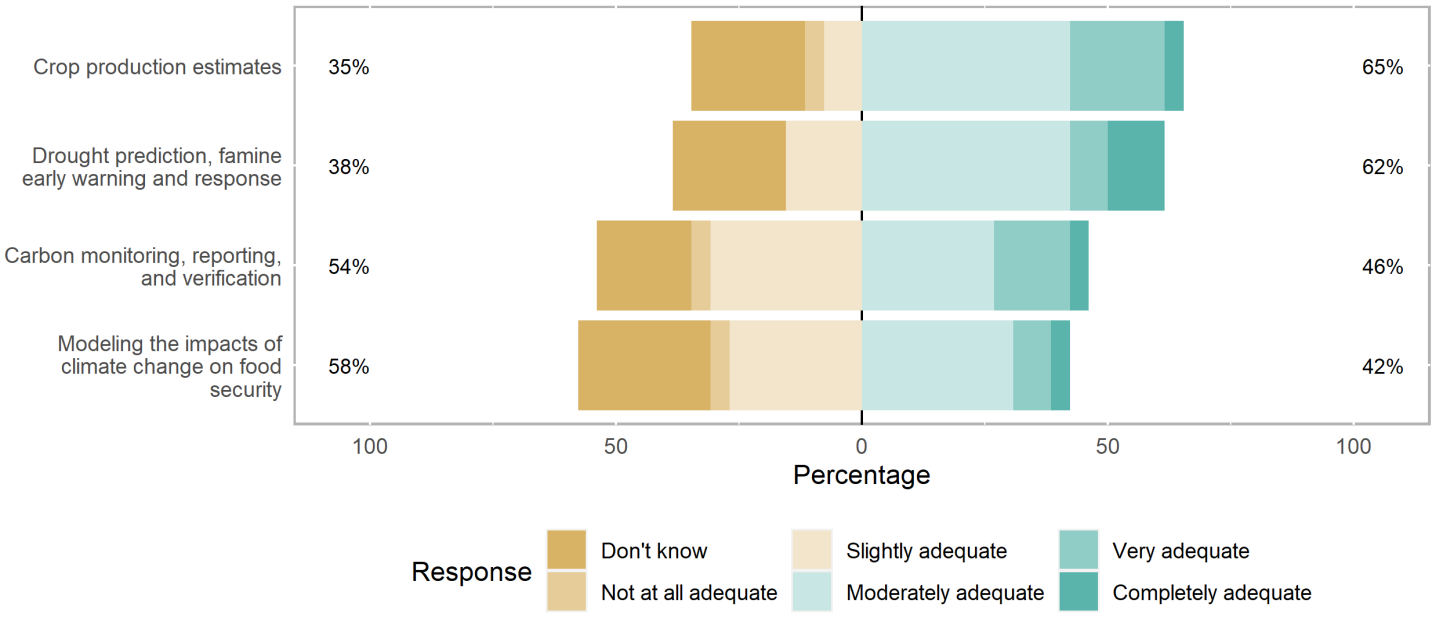
Food Security—Users Interviewed

	Key Informant	Perspectives
	Martha Anderson, *USDA*	
	Prasad Thenkabail, *USGS*	
	Christopher Neale, *Water for Food Global Institute at University of Nebraska*	
	Jim Verdin, *USAID FEWS NET*	
	Chris Funk, *Climate Hazards Center at UC Santa Barbara*	
	Ian Jarvis, *GEOGLAM*	
	Jeff Seale, *Bayer Crop Science*	
	A.J. Kumar, Kat Jensen, Ignacio Zuleta, Christopher Holden, *Indigo Ag*	
	Hamed Alemohammad, *Radiant Earth Foundation*	
	Jawoo Koo, *CGIAR*	
	Rogerio Bonafacio, *World Food Program*	
	Frank Riely, *Food Security Analyst/Economist*	
	Chris Justice, *University of Maryland, NASA Harvest* *(No summary interview provided.)*	

Global Food Security—Survey Results

Current observation methods are generally adequate for the four main applications within the global food security area.

To what extent is the current remote sensing and earth observation data you use today adequate for the following global food security applications? (26 responses)

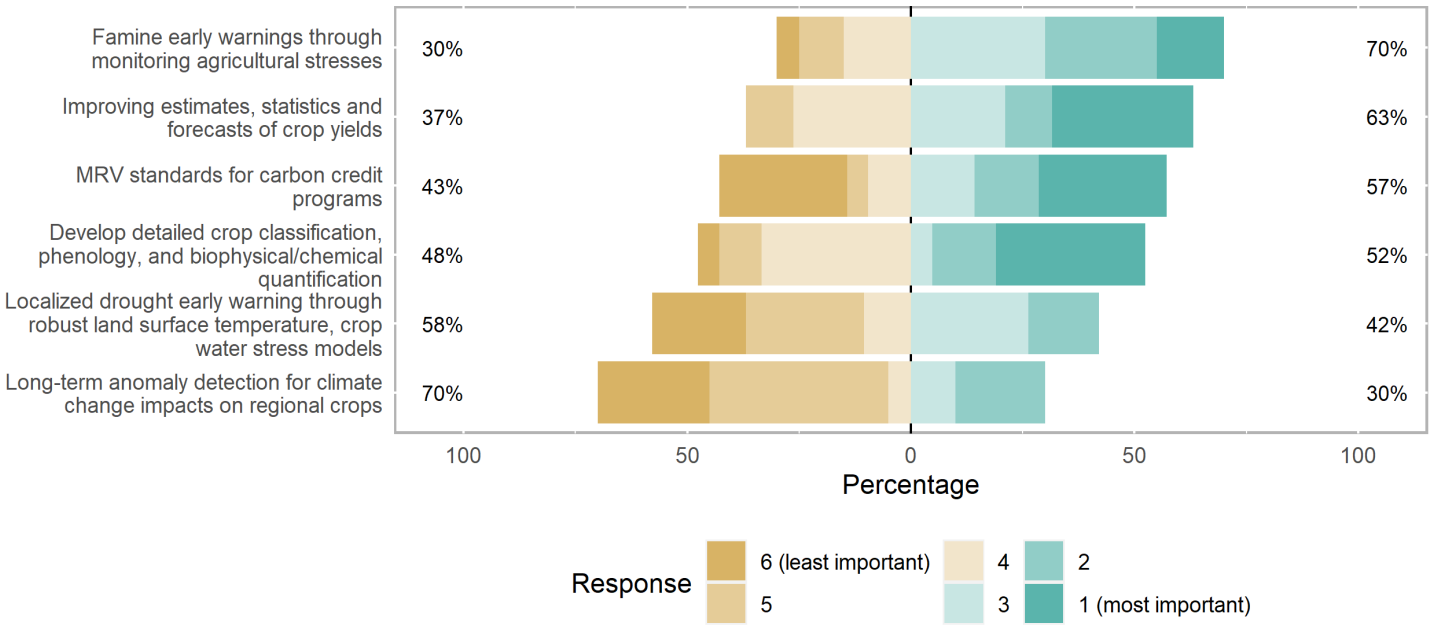


A relatively large number of food security respondents are uncertain about the adequacy of current data for each activity, with about a quarter answering "don't know" for each activity. Aside from those responses, the level of adequacy of current methods is relatively high compared with other application areas, and this is consistent with expert feedback. More than 60% of respondents rated data as at least moderately adequate for crop production estimates and drought prediction/famine early warning, while adequacy for carbon monitoring and modeling the impacts of climate change were more mixed. Experts were more inclined to find current methods inadequate for carbon MRV and for modeling the impacts of climate change on food security. When asked what is difficult or not possible with current methods, cloud-free and high spatial resolution for small crop and boundary monitoring, low latency and frequent revisits, and TIR and HIS data for higher fidelity monitoring and estimates were all mentioned.

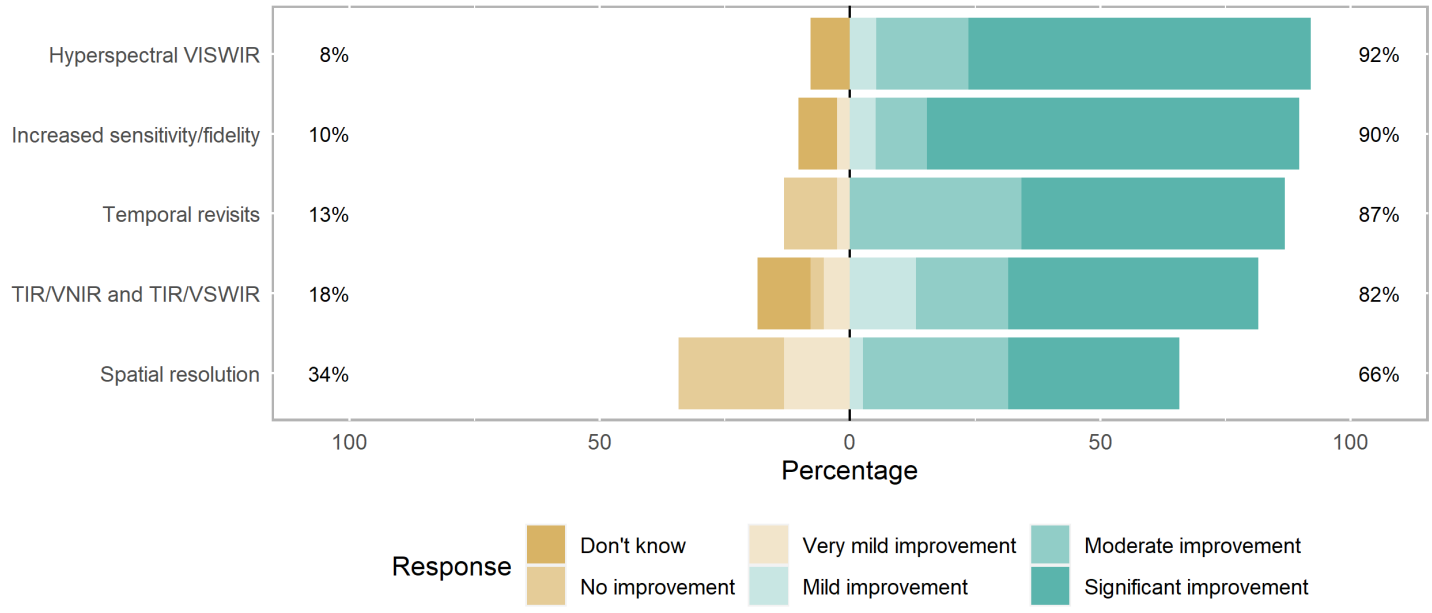
Global Food Security—Survey Results

Crop classification, forecasts, and famine early warning are top priorities, and SBG's HIS and sensitivity offer top improvements.

When working on global food security efforts, which of the following are the most important "activities" that your organization is trying to accomplish? (~20 responses)



Consider these SBG capabilities and indicate the extent to which each of them provides benefits for the top 2 activities you indicated previously. (~38 responses)



* For all priority rating questions a weighted importance/improvement score was calculated to determine the highest rated choices. Scoring is not shown but is reflected in the analyses.

Global Food Security—Survey Results

SBG's HIS and TIR capabilities promise significant improvements across all priority global food security activities.

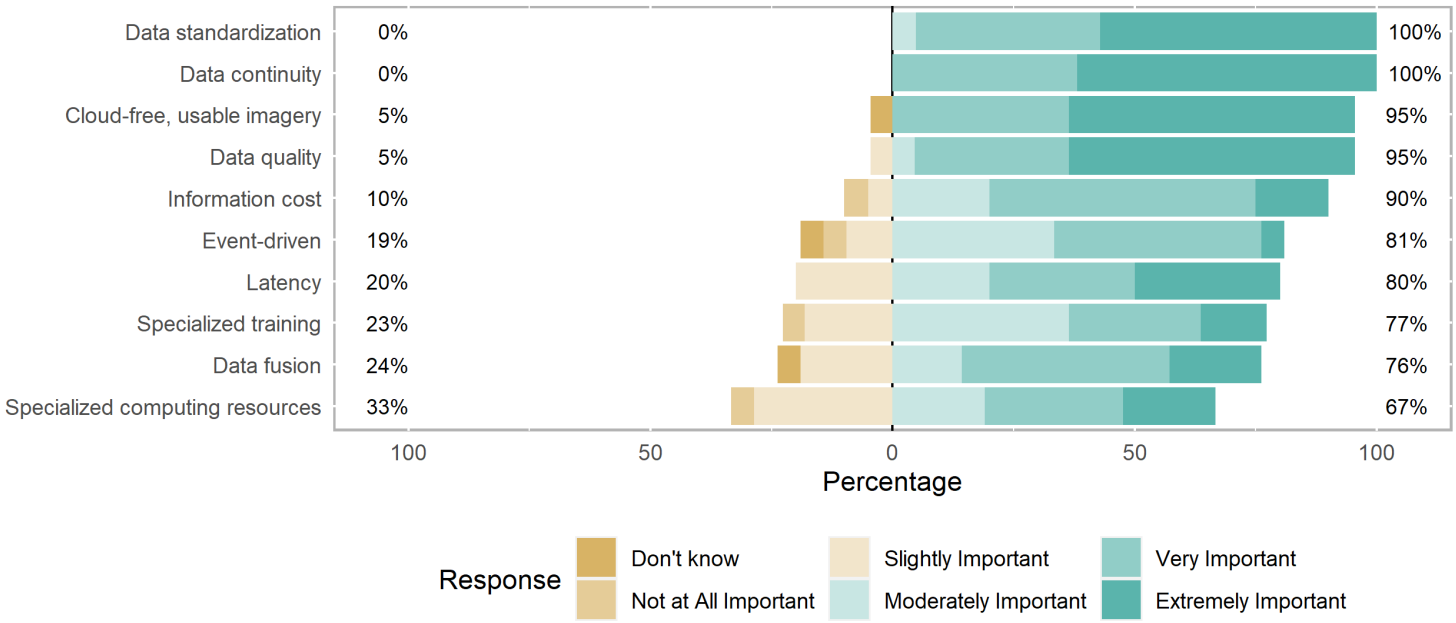
Consider these SBG capabilities and indicate the extent to which each of them provides benefits for the top 2 activities you indicated previously. (~38 responses)

Each of the top four priority food security activities received between seven and nine responses, whereas the lowest priority activities only received three or four. SBG's hyperspectral VSWIR spectral and TIR capabilities were top-rated, offering significant benefits across all activity areas. This result is consistent with expert feedback. Among all respondents, the food security respondents rated SBG's spectral capabilities the highest. However, there is shared uncertainty ("don't know") about the benefits of HIS and TIR for three specific activities. Survey results showed once again that SBG's spatial resolution offers the least overall perceived improvement. This finding is consistent with expert feedback that noted that the higher resolution of current methods used, such as Sentinel at 10 m, is preferred.

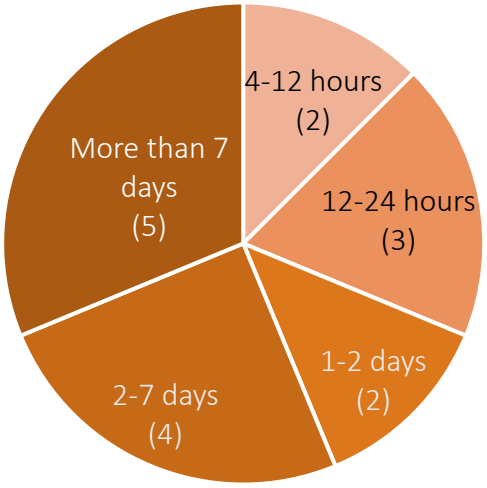
Global Food Security—Survey Results

Information quality and cloud-free imagery are top priorities. Latency is of relatively greater importance to food security users.

For the use of Earth observation data in global food security, how important are the following information quality and accessibility issues? (~21 responses)



For those indicating latency as being of moderate to extreme importance: What latency is required in your application?



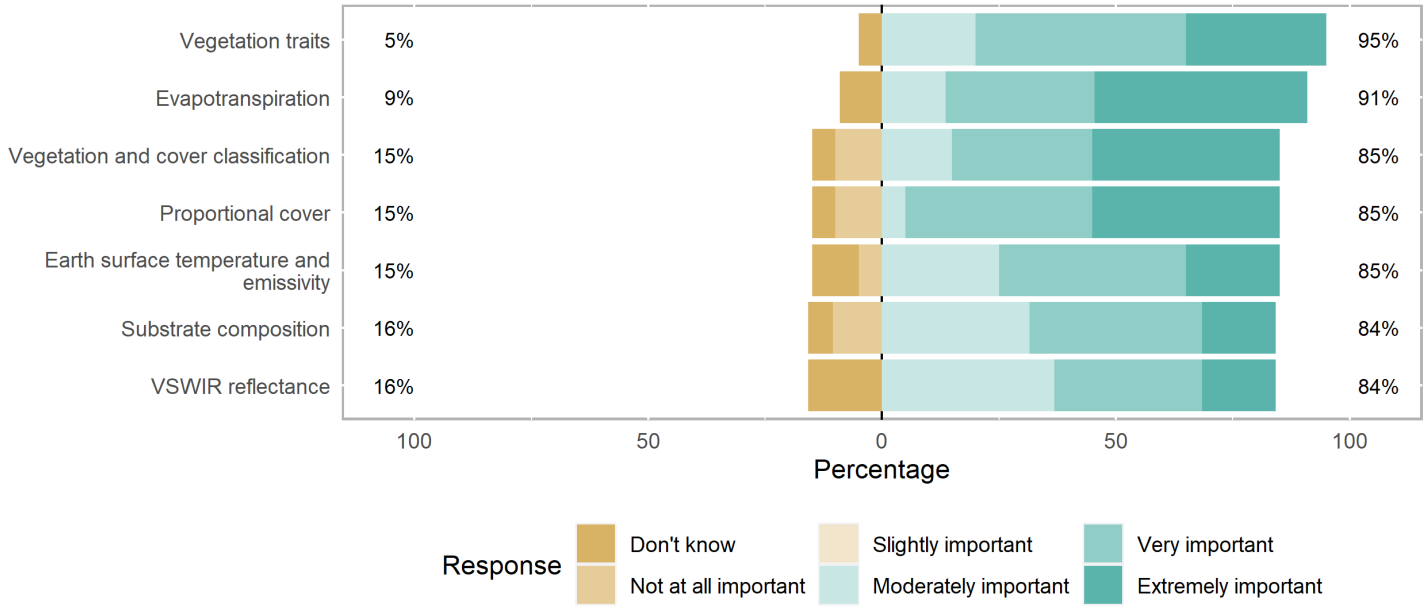
Compared with other application areas, food security respondents placed more importance on latency. This finding is consistent with expert feedback.

For those seeking lower latency, 6 out of 11 respondents would accept less than fully validated data, with the caveat that local validation methods are available, and the data could be corrected or processed once received.

Global Food Security—Survey Results

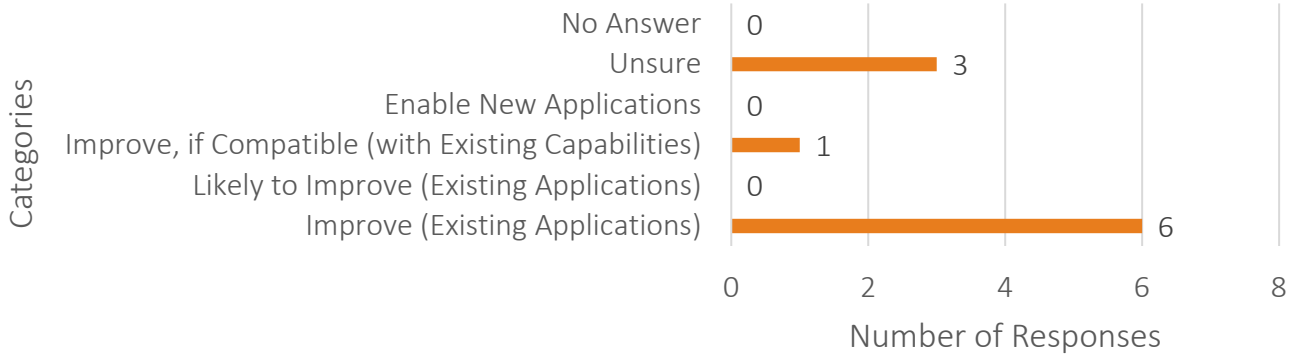
SBG's ET, vegetation, and cover algorithm products are of highest importance to global food security respondents.

For the use of SBG in global food security efforts, how important are the following proposed SBG algorithm products? (~21 responses)



SBG's proposed evapotranspiration, vegetation, and cover products are rated to have the highest importance. Ten respondents answered the open-ended questions, and a majority indicated SBG will improve existing applications, but 40% were more unsure or conditional in their assessment of SBG's benefits. These findings are consistent with experts' sentiments. Responses about the anticipated impacts of SBG were limited (five) and evenly divided between more positive and more skeptical views about the potential for SBG to improve food security outcomes.

Will the proposed SBG capabilities have a strong likelihood of advancing your work? Or might SBG enable entirely new activities or applications? (10 responses)



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FS1. Venton, C. C. (2018). The economics of resilience to drought. USAID: Washington, DC. https://www.usaid.gov/resilience/economics-resilience-drought

FS2. Adjemian, M. K. (2012). Quantifying the WASDE announcement effect. American Journal of Agricultural Economics, 94(1), 238-256.

FS3. Lobell, D. B., Azzari, G., Burke, M., Gourlay, S., Jin, Z., Kilic, T., & Murray, S. (2020). Eyes in the sky, boots on the ground: Assessing satellite-and ground-based approaches to crop yield measurement and analysis. American Journal of Agricultural Economics, 102(1), 202-219.

FS4. Proville, J., Parkhurst, R., Koller, S., Kroopf, S., Baker, J., & Salas, W. (2020, September 25). Agricultural offset potential in the United States: Economic and Geospatial Insights Environmental Defense Fund Economics Discussion Paper Series, EDF EDP 20-01. http://dx.doi.org/10.2139/ssrn.3699751

Additional Information Sources:

1. CEOS (https://ceos.org/ard/)
2. User needs report (https://earthobservations.org/geoglam.php?t=eo_data_coordination&s1=eodc_eo_requirements_wg)
3. HYDRAFloods (http://hydrafloods-servir.adpc.net/)
4. UN task force led by Mark Carney (https://www.iif.com/tsvcm)

Conservation and Biodiversity

Conservation/Biodiversity—Overview

This is a diverse and fragmented community of players with varied motivations related to monitoring.

KEY POTENTIAL USERS

- Conservation NGOs (Large): Global conservation nonprofits
- Conservation Agencies (Gov't/NGO): Major international sustainable development orgs
- Nations (Gov't): Conservation bureaus
- Corporations (Large/Private): Multinational consumer product companies
- Companies (Small/Private): VASPs, environmental services, consultancies
- Biodiversity Researchers (Academic/NGO): Experts in ecology/biology

KEY USE CASES

- Deforestation and degraded land, monitoring major crop plantations, and natural forests
- National surveys, mapping baselines and establishing high-value conservation areas
- Species classification, plant/crop classification, baselines, invasive/understory composition
- Agroforestry and carbon offsets, MRV of suppliers and smallholders to support sustainable practices
- Habitat management, conservation land management, and geo-accounting

DRIVERS

- A focus on species—The conservation and biodiversity field is a large and traditionally fragmented community of many research groups, large national agencies, and literally thousands of NGOs focused on all manner of causes. For conservation efforts, a central rallying point for society, and hence for advocates, is the preservation of endangered species, including both flora and fauna. As a result, species detection and protection is a primary objective for industry and NGO end users. Customers and constituents place high importance on protecting endangered species, so this is a primary focus of conservation and related biodiversity efforts. The impact is measured by showing "key" species that are under threat (e.g., from deforestation) and need to be protected.
- Economic and reputational impacts— Nations receive funds and external NGO and agency support to help determine what land to set aside as conservation areas and what concessions to allow (e.g., logging). These decisions have large economic and aid impacts. Deforestation due to industrial agriculture (for crops like palm oil, sugar, soy, cocoa, rubber, and vanillas), logging for timber, or infrastructure expansion are the major focus of conservation efforts. Large consumer brands do not like supply chain risk, uncertainty, or bad public perception, so they have made commitments to improve sourcing practices, which they then extend to their suppliers through third-party (often NGO) sustainability certifications. NGOs are interested in monitoring to ensure companies and nations are complying and to hold them publicly accountable for meeting conservation commitments. Fines and reputational risk drive the behaviors of large companies and small suppliers alike.

Conservation/Biodiversity—Overview

RS is used more often in conservation than in biodiversity, but the level of RS expertise is very limited and isolated to a few players.

DRIVERS *(continued)*

- Limited use of RS—Experts indicated that most conservation and biodiversity work is still based on ground-based observations, and the level of sophistication and expertise for RS observations is very limited. Even in established compensatory biodiversity markets in developed countries, RS is not widely used. The private-sector agricultural community that has made zero-deforestation commitments is mostly driven by mapping and monitoring of their supply chains and has a different set of expectations for observation than the research-driven biodiversity community. Conservation MRV is still often a ground-based practice, and to the extent that RS data are used, it is primarily simple mapping. Even multinational corporations rely on Google maps as a primary source of information. Only the largest corporations and NGOs appear to have the internal expertise to work with RS, and they often use free, operationalized disturbance maps for deforestation monitoring. Most conservationists and biodiversity specialists do not even use multispectral data, and only a handful of the largest global NGOs have the capacity to use RS maps and datasets. A few large NGOs and some developing countries have developed their own RS monitoring programs and deforestation alerts using satellite imagery and other platforms like SAR. Compliance monitoring for other sectors, like transportation infrastructure and oil and gas, is all about "boots on the ground." Ground-based compliance monitoring in these sectors is an entrenched practice, with very limited use of even basic imagery.
- Growing corporate/brand interest—There is a strong expectation and hope for the use of RS to become a new and enabling capability for large corporations and VASPs working on conservation. REDD+,* declarations,[CB1] and NGO certifications are driving corporate monitoring practices. In addition, the largest global consumer brands are increasingly interested in going beyond basic tropical forest protections and are thinking more holistically about sourcing and sustainable methods. These emerging methods include agroforestry** and regenerative agriculture practices, protection and restoration of ecosystems with targeted afforestation,+ and net-zero GHG emissions. These new methods will require much more advanced monitoring capabilities than are currently used, which in turn will demand an increase in the quality of remote observation methods that can meet these emerging application needs.

*- REDD+ is a framework to guide developing country activities to reduce emissions from deforestation and forest degradation, sustainable management of forests, and the conservation and enhancement of forest carbon stocks.

**- "Agroforestry is an alternative to intensive agriculture, which uses forest-based products and has the added benefits of "carbon sequestration, soil structure and fertility, shade, tree products and other ecosystem services." [CB2]

+ – "Afforestation, or planting trees on lands that have not historically had trees (e.g., savannas or moorlands), can actually release carbon from the ground and be destructive to the ecosystem, therefore selecting the appropriate areas and species for reforestation is critical."[CB2]

Conservation/Biodiversity—Overview

Nonresearch end users need higher confidence in conservation monitoring and species classification, and SBG may provide that.

APPLICATION NEEDS

- Deforestation in agricultural supply chains—For private sector–related conservation, the priority RS observation needs are frequent, trusted, and third party–verifiable change mapping products. Cloud-free, subweekly maps and alerts for large and targeted areas are highly desired; currently, these needs can be adequately if not fully met. However, corporate and NGO users noted that the World Resources Institute (WRI) Global Forest Watch (GFW) provides useful alerts, but they are not fully adequate and require additional disturbance and vegetation classification. Legal palm oil harvesting can show up as natural forest loss, which triggers false alerts, and supplier "plantation maps" are not accurate enough and must be verified using ground studies. Thus, a premium is placed on trusted, high-resolution, and verifiable data.
- Niche conservation applications—Beyond deforestation mapping, degraded land mapping and agroforestry monitoring are more difficult and much less common. Supporting degradation mapping and agroforestry will require species mapping and classification, which is an unmet need that SBG's HIS might fill. Research experts noted that applied sciences will have to be further developed for species identification, ecosystem composition, and carbon market MRV, all of which are of high interest to the nonresearch community. Another commonly expressed desire among corporate end users was the need for NASA to help standardize MRV indices and build consensus around them, so all supply chain players are using the same measures, which will build confidence and reduce the risk of making conservation commitments.
- Biodiversity monitoring—Currently, almost all biodiversity work is done with field data, but this is a big bottleneck when trying to scale up and capture recurring and large-area data. Most of the observation work is about ground surveys and some basic accounting of "what is there" in an ecosystem, rather than detailed classification or information on ecosystem condition (function). Outside of researchers, "the field [of biodiversity] is just not there yet" when it comes to RS. HIS at 30 m would allow researchers to "bootstrap" better studies. National field studies and ground-observations can provide "good" 1- to 2-m resolution but are limited and unscalable. Experts suggest that HIS at 30 m could increase the accuracy from 60% to 90% for natural standing vegetation surveys. HIS also has high potential for vegetation classification and distribution maps, which can be used to get better resolution species mapping via improved ecosystem/ecological modeling. Additionally, experts indicated that there are really no effective methods to track invasive species. If SBG could do that, it would be a significant new capability and provide substantial benefits to biodiversity efforts.

Conservation/Biodiversity—Overview

Nonresearch users desire free, frequent, and interoperable data products available in intuitive formats.

INFORMATION NEEDS

RS practitioners and commercial and NGO end users working in the conservation space suggested the following information priorities:

- Access to higher fidelity, free, validated, and transparent datasets would provide a lot of value to the deforestation, conservation, and biodiversity NGO ecosystem. There is a whole business of satellite companies serving large private companies, and they do not transparently share these datasets and maps. NGOs do not have access, so having an alternative open-source option would provide a lot of value to those ensuring conservation happens.
- Continuity of datasets (e.g., spectral bands) with Landsat and Sentinel is important (e.g., historical trends). Experts expected that SBG might fill in the gaps with new bands, but also at different times of day or week.
- Combining HIS with GEDI,* for example, was requested to improve modeling.
- Derived, higher level end products provided in simple intuitive visual formats will need to be available if SBG is going to make much headway into the conservation community, especially for organizations that are not leading global NGOs like The Nature Conservancy (TNC).
- Science-validated and community-accepted indices are valued by sophisticated large corporations and conservation agencies for crop/forest, soil, and water cycle monitoring. If SBG algorithm products can enable these desired new indices, that would meet a critical information need for this community. Users in this community do not generally have the technical expertise to opine about specific computing requirements but will look to NASA and leading VASPs to ensure readily accessible data platforms and formats.

It is worth noting that few explicitly called for HIS information. Additionally, thermal data was considered useful to researchers but not for current use by forest management professionals and practitioners.

*- Global Ecosystem Dynamics Investigation is a NASA LiDAR based mission to measure how deforestation has contributed to atmospheric CO_2 concentrations.

Conservation/Biodiversity—Current RS Capabilities

A small set of RS experts uses commonly available mapping and trend datasets, but HIS and TIR are not used.

CURRENT RS CAPABILITIES *(Consolidated from interviews)*—

- Conservation—For today's terrestrial conservation, the most common and globally active private-sector conservation work using RS data is in deforestation monitoring. For deforestation monitoring, Google Earth Engine, cloud EO, and Landsat and Sentinel data (at 30 m+), USDA crop maps, and European Space Agency (ESA) land cover maps at 10 m are the most used EO data products. For looking at trends in an ecosystem landscape, Sentinel and Landsat at 10 m to 30 m is adequate; MODIS is used for specific data layers. VASPs are leveraging multispectral data for vegetation monitoring, but only the biggest global conservation NGOs are using it. End users are typically only using derivatives of multispectral data, like IBAT dashboards, which provide multiple datasets via subscription. Spatial resolution is important; end users and nonpractitioners will always desire 10-m or better resolution—because it "looks right" (not pixelated). When needed, VASPs and larger corporations report using 1-m or 3-m data from Planet or Maxar. They are also now looking to new platforms like NISAR, ESA-Bio, and SAR to see what new datasets can be enabled for regeneration, agroforestry, and carbon markets.
- Biodiversity—The use of RS in biodiversity work is almost entirely in the scientific research realm, and much of the observations for biodiversity studies are still done in the field. Some experts reported using GlobeLand data at 30-m resolution and typically to support multiyear studies. MODIS, Landsat/Sentinel, and Planet data are all used to create national ecosystem maps and indirectly infer changes in condition. NGO researchers use Level 3 or 4 products (like industry) but rely on WRI and TNC for RS expertise and data scientists or collaborate with partners like the U.S. Geological Survey (USGS) for their mapping efforts. Leading NGOs provide RS-based mapping, but only a few provide good resources for biodiversity work. In general, experts noted that the biodiversity community has limited experience with, and expertise for, the use RS data and products.

Conservation/Biodiversity—Benefits of SBG Capabilities

HIS for use in species classification will provide great benefits in multiple priority conservation and biodiversity applications.

Priority Application	Composite EO Capability Priorities	SBG Benefit
Ecosystem and Biodiversity Monitoring and Policy	**Spatial Resolution** is important, but resolution depends on application. For large-landscape or national-level conservation analyses or large-scale ecosystem monitoring, 30 m is sufficient and if harmonized with historical Landsat. For other needs, such as tracking invasive or endangered species, identifying unique tree species, or monitoring degradation, even 10 m may not be sufficient.	● ✗
	Temporal Resolution is less critical for most ecosystem and biodiversity applications, which often occur on an annual basis to ensure compliance with regulations or are intended to track year-on-year changes, which can happen over long time scales and over wide geographic spaces.	●
	Spectral Resolution (VISWIR)—HIS is expected to not only improve but also create new opportunities to replace baseline inventory measurements with RS data (which is currently uncommon). VISWIR HIS should enable specific classification, which is of high value and enable ecosystems and invasive/endangered species monitoring.	✓
	Spectral Resolution (TIR)—Potential for having TIR data is of most interest to researchers but is of less immediate interest to practitioners.	✗
Monitoring Deforestation Caused by Supply Chains in Tropical Forests	**Spectral Resolution (VISWIR)**—The most important benefit of free, large-area HIS is to automate the ability to distinguish between natural and commercial forests. Further characterizing carbon stocks and species diversity was highly desired.	✓
	Spatial Resolution—Classification at the forest stand level is considered adequate for most deforestation monitoring purposes. For degraded land mapping and agroforestry, 10 m or better resolution is needed.	● ✗
	Temporal Resolution of every 16 days is seen as good enough for most uses in this application. More frequent revisits would mainly be helpful for tropical cloud cover or for quickly (<1-2 days) identifying active areas of deforestation for enforcement purposes.	● ✗
Forest Carbon Markets and Offsets	**Spectral Resolution (VISWIR)**—Species classification and quantification via global HIS is expected to provide more accurate biomass and carbon stock measurements and, hence, low cost, third party–validated MRV, which are key to carbon markets' MRV.	✓
	Spatial Resolution—For forest carbon markets, 30 m is adequate. For smallholder carbon offset programs, less than 10 m is desired.	● ✗

✓ Significant benefit addressing unmet need(s). ● Adequate benefit that meets need(s). ✗ No benefit or does not meet need(s).

Conservation/Biodiversity—User Personas

Few in the sector are ready for HIS, but all need proof of HIS to see the potential utility and lots of help to gain value from SBG.

Research Institutes

Chief Research Scientist

"I am an ecologist, and most people in conservation and biodiversity come from similar backgrounds. There are very few like me that use RS data to do modeling of ecosystems. We have to separate the science to be done from what NGOs are trying to do. To use SBG, we will need to develop the applied science of what we can do with HIS to create species maps; this can't be done today. Then we can help conservation NGOs and companies do species classification, which is what they really want. Measuring functional traits, and defining ecosystem extent, those are things biodiversity researchers care about. We need capacity building to help the nonresearchers."

"Biodiversity is one of the least resourced and RS-skilled areas; datasets are poor, and there are very few RS practitioners, let alone experts."

Global Consumer Brand Company

Director, Sustainable Supply Chains

"We are just building a GIS group and I am the only one with an RS background. So we rely on Google Maps or WRI to provide us deforestation alerts; we are good with those. I think we use Landsat and Sentinel, and we may use Planet; for us it is about the information, not the money. We have made big public commitments to protect species, which is what consumers care about. This means we must use RS to make sure our supply chains and suppliers are not deforesting to source our materials. We need everyone to agree on MRV indices, if NASA can provide certainty and consensus on the metrics that reduce our risk."

"Between climate change and tech, the moment is now for us to realize the potential of EO data!"

Value-Added Service Provider

Director of Geospatial Tech

"Landowners must see why their land should be conserved versus their neighbors, so we had to map an entire coastline at 1-m resolution to help them see. People want to see 10-m or better resolution; it just looks right to them. Without great data and product insights, you are using averages to make decisions, so you do the easiest, not the best, conservation projects. Up to now, conservation accounting has been based on coarse and decades-old maps, it is "static," forcing averages. We need to move to "dynamic accounting" and biweekly and 30 m is good enough for ecosystems, but not habitats. Environmental users want insights, they don't do data."

"It is not 'if you build it (SBG) they will come'; that is not how it works in conservation. But SBG is a game changer for species detection."

Conservation/Biodiversity—Opportunities

NASA should work with established conservation and biodiversity entities to build the capacity for RS data use and eventual HIS use.

COMMUNITY READINESS FOR SBG—The global conservation and biodiversity community is quite large, with thousands of NGOs and many multinational groups focused on key species and ecosystems, often in specific regions. The use of ground-based surveys and basic imagery is typical. The level of adoption of advanced EO platforms is functionally limited to VASPs and some leading global nonprofits like WRI, TNC, NatureServe, and Conservation International. Even among the more sophisticated large NGOs, there is limited advanced use of RS. A TNC report with survey data from over 350 global members suggests that the vast majority (83%) use GIS for basic mapping and cartography, and only (53%) do any type of RS data management. Other experts noted that even multispectral EO data are seldom used in conservation and biodiversity. Conservation focused on deforestation prevention drives most of the global use of satellite imagery, but there is an increasingly active community of ocean conservationists leveraging RS for basic global mapping. Experts indicated that the biodiversity community is one of the least resourced and skilled application areas with inadequate datasets and very few RS practitioners, let alone deep RS expertise. Even though they are so large and diverse, the conservation and biodiversity communities have a relatively small and concentrated set of players with the capacity to work with and develop RS capabilities and products. However, the use of HIS is not at all well established outside of the research community. Additionally, researchers noted that substantial applied science will have to be developed for species identification, ecosystem composition, and carbon monitoring MRV, which are of great interest to the nonresearch community.

OPPORTUNITIES FOR NASA—NASA already champions efforts like GEOBON. SBG can also engage leading conservation and biodiversity RS experts and partners, particularly those working with airborne HIS, to develop vegetation classification and demonstrate the value of these models and methods for conservation. EnMap is a possible HIS pathfinder mission and has an active focus on conservation and biodiversity applications. NASA should also continue to engage and support the capacity building of larger corporations and their NGO partners to advance their efforts to move beyond basic imagery to more sophisticated uses of EO data and products. To engage the private sector, this would best be organized by commodity geography (e.g., soy in South America), then by topic (e.g., soil management, carbon markets). Once HIS is further developed, demonstrating the potential utility of SBG will allow NASA to engage larger corporations and countries that have significant financial and public relations interests in more sustainable practices and conservation efforts. These corporations will also likely look to NASA to build common indices and a "single source of truth" for more challenging, but important, efforts such as agroforestry and carbon markets for smallholders.

Conservation/Biodiversity—Valuation

RS plays a high-value role in global deforestation monitoring, and SBG's HIS could create value via better species classification.

Conservation efforts everywhere rely heavily on boots-on-the-ground to establish baselines and effectively monitor endangered or invasive flora and fauna species. In high-income countries, biodiversity compensatory markets are well established but highly reliant on expensive on-the-ground surveys rather than RS. Commercial commodity supply chains (e.g., palm oil, soy, cattle) are a major cause of deforestation and land clearing in carbon- and biodiversity-rich tropical forests (Pendrill et al., 2019).[CB3]

Forest carbon projects have been active for more than two decades, transacting $160M worth of forestry and land use voluntary carbon offsets in 2019 alone (Forest Trends, 2020).[CB4] Market demand continues to grow, but supply is projected to be a constraint in future years.

How can satellite data help?

RS has played a crucial role in shining the light on most tropical deforestation caused by supply chain actors, but current RS is not an efficient way to distinguish between commodity plantations and natural forest. With the global coverage and hyperspectral data provided by SBG, there is an opportunity to automate the tools and process for exposing the biggest threats in a more timely and standard way. Other big thematic areas where satellite data have played a limited role and where SBG holds promise is in developing better ecosystem and species biodiversity maps, tracking forest degradation versus simple disturbance, and modeling the impacts of climate change on forests.

Challenges with current EO data products?

There are many well-known EO-derived data products, including the University of Maryland's Global Forest Change dataset, WRI's Global Forest Watch, and Conservation International's Trends Earth platform. Many experts pointed to the utility of these datasets for different purposes, but almost all thought improvements could be made in distinguishing vegetation types, tracking invasive species, and identifying distinct ecosystems. SBG resolution and temporal revisit were considered sufficient for most purposes, but revisit rates may present a challenge in the tropics because of cloud-cover interruptions.

Conservation/Biodiversity—Valuation

The global social and economic impacts of conservation efforts are high, and SBG could enable several key application areas.

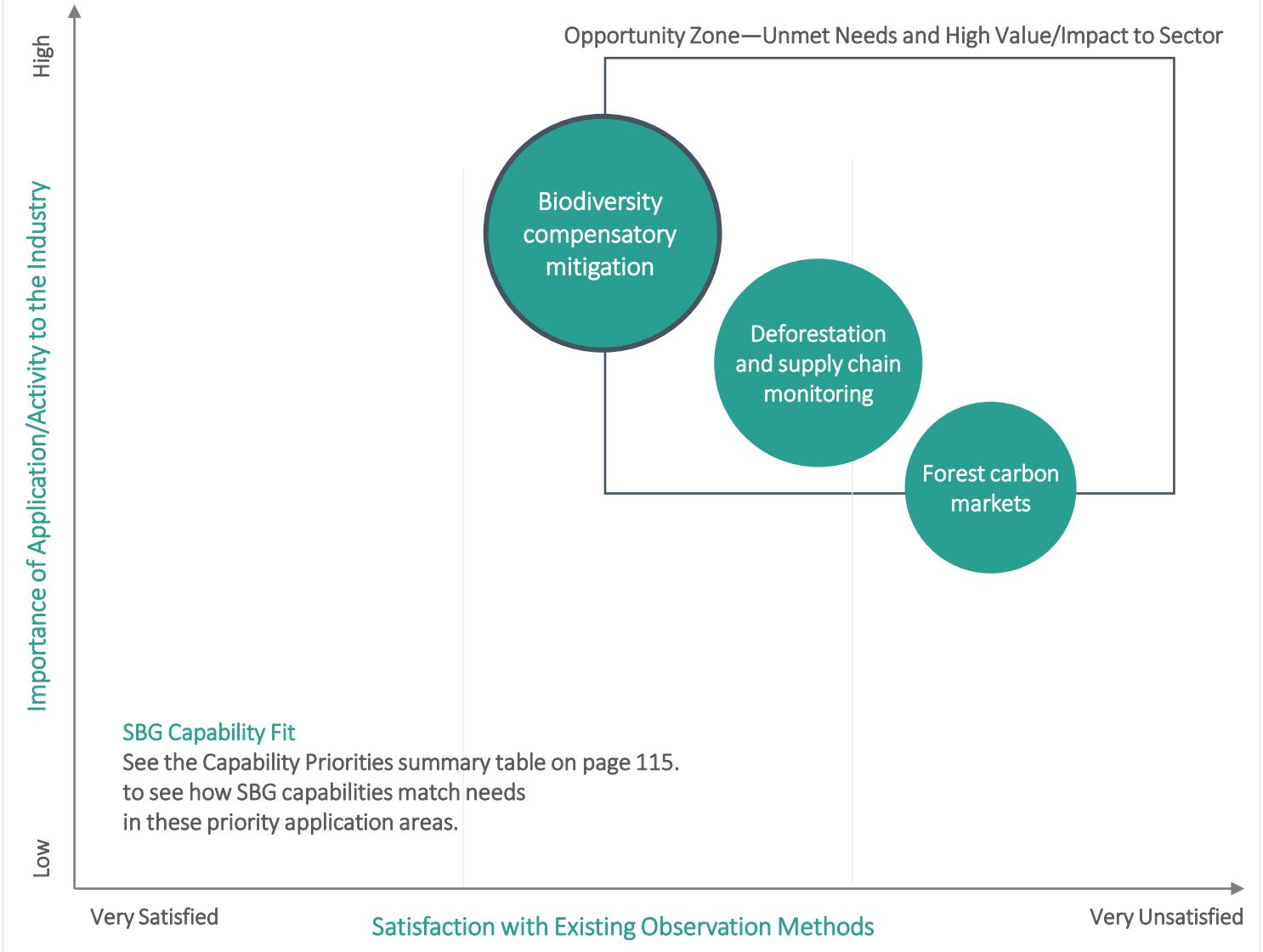
How can SBG help?

Experts in this sector were more interested in SBG's hyperspectral capabilities than its thermal capabilities. Most pointed to the utility of having classification indices that they could use to better distinguish between vegetation types, both for monitoring and predictive modeling. The technical and economic value of the activities are highly dependent on the application (see table below). The highest potential magnitude of impacts was expressed for applications that could monitor biodiversity, especially as they relate to established compensatory mitigation markets in developed countries. Another area highlighted involves monitoring the impact of global commodity supply chains so that companies and NGOs could hold themselves and others accountable in the wake of the many "zero deforestation" commitments that have taken place in recent years. Carbon markets were also discussed as a potential emerging application, particularly if carbon standards groups move to update their protocols to reduce the costly burden of on-the-ground measurements.

End-User Community	Activity	Technical Impact with New Capabilities	Economic Value	Potential Magnitude of Impacts
Government or Market Actors Involved in Ecosystem/Biodiversity Monitoring and Biodiversity Compensatory Mitigation	Ecosystem mapping and prediction of the presence of species or ecosystems (e.g., wetlands) based on ecosystem characteristics; also holds promise for improved degradation tracking MRV for the large compensatory mitigation market in the United States (see valuation case study)	Hyperspectral bands may allow for better mapping and MRV. Federal and local governments can better target conservation efforts (including protecting species and habitat corridors), compensatory markets, and incentive programs to areas of higher risk	Reduced cost of mitigation efforts (e.g., controlling invasive species, restoring ecosystems) and increased value of having more biodiversity and ecosystem services provided by diverse habitats	Medium/high
NGOs and Companies Monitoring Deforestation Caused by Supply Chains in Tropical Countries	Large-scale, regional, and site-specific deforestation and degraded land identification in and around natural forests and commercial plantations NGOs using MRV to hold corporations accountable and for corporations to more easily monitor their own suppliers and activities	Hyperspectral bands would enable better abilities to distinguish disturbances, distinguish degraded land, and classify natural forests Avoided deforestation and biodiversity in tropical countries caused by global commodity supply chains and illegal actors	Ecosystem services provided by natural forests in tropical countries, including biodiversity, carbon, and water, as well as direct economic benefits, such as ecotourism and nontimber forest products	Medium
Developers of Forest Carbon Markets and Offsets	Better distinction between different types of forests and correlation with aboveground biomass could lead to less burden from on-the-ground surveys and lower MRV costs for global carbon projects	HIS may improve biomass, soil, and carbon indices. If carbon protocols adopt new methods based on SBG, MRV can be scaled for forest carbon projects	Reduced cost for carbon market developers; greater revenues for owners of forest carbon credits	Medium/low

Conservation/Biodiversity—SBG Opportunity

SBG can address important unmet needs and bring value in large, diverse conservation and biodiversity applications.



SBG Capability Fit

See the Capability Priorities summary table on page 115. to see how SBG capabilities match needs in these priority application areas.

Circle size indicates relative value of application.

Example

Case Study Example

Compensatory mitigation markets are large in high-income countries; if RS and SBG are adopted, it could help reduce MRV and compliance costs. Deforestation monitoring and forest carbon markets rely on RS, and new market and compliance drivers will demand better MRV, which create opportunities for SBG.

Conservation/Biodiversity—Case Study

SBG could expand the biodiversity compensatory mitigation market in the U.S. by anywhere from $10M to $120M annually.

Biodiversity Compensatory Markets

In the United States, under the Clean Water Act and Endangered Species Act, compensatory mitigation policies require that environmental harm caused by the use of public lands be completely offset by environmentally protective actions, such as payments for land restoration in other areas.

One expert estimated the total market for these projects is about $3B per year under the Clean Water Act and $300M under the Endangered Species Act (adjusted to $3B total based on historical data).* The expert assumed approximately 20% of these costs are for technical surveys or analytics related to (1) site selection/prioritization; (2) baseline field survey analysis; (3) interim monitoring (years 0–10); and (4) long-term stewardship, where RS could play a more important role. Another expert postulated that, with the hyperspectral capabilities of SBG, it might be possible to reduce the cost of these analytics by another 20%: $3.0B x 20% x 20% = **$120M** per year (see table).

A project developer gave a specific example of a state highway administration developing a bridge and disturbing wetlands in the process. Under compensatory restoration, the entity must monitor wetland restoration annually and demonstrate that it is still thriving 10 years after establishment. Assuming it costs $50,000 a year to monitor compliance, SBG could save this individual project $10,000 per year. The expert estimated that there were "hundreds or perhaps thousands" of projects like this every year. Assuming there are 1,000 similar projects, this amounts to **$10M** in savings per year, or ($10,000 x 1,000 = $10M) see bottom-up approach in the table).

Compensatory Mitigation Savings/Efficiency	Value (Millions)	Source
Value of compensatory mitigation market for biodiversity in the United States	$3,000	Interviews, verified by Madsen et al. (2010)[CB5]
Costs related to activities where RS could play a bigger role ($3,000 x 20% x 20%)	$120	Interviews applied to market value
Example of wetland restoration project	$0.01	Interviews
Scaled up to larger market ($0.01 x 1,000)	$10	Interviews
Range of annual benefits to compensatory markets	**$10–$120**	N/A

* - Madsen et al. (2010) estimated this market to be between $1.5B and $2.5B in 2010. Adjusted for inflation, this is $1.9B to $3.2B in 2021 USD. We chose to assume $3B, because it is within this range and aligns with stakeholder estimates.

Conservation/Biodiversity—Valuation

Monitoring and verification for deforestation and emerging carbon markets have significant value but need better EOD.

Monitoring Deforestation in Indonesia

Commodity supply chains are a major contributor to deforestation in tropical countries. NGOs regularly use RS products such as Global Forest Watch to monitor deforestation and report when a supply chain is contributing to the clearing of primary forest. In Indonesia, these efforts have contributed to a major reduction in deforestation in recent years, peaking from approximately 2.26 million hectares (Mha) in tree cover loss in 2016 to 1.07Mha in 2019 (47% decline). This is equivalent to a 749 $MtCO_2$ reduction, which, even at a low carbon value of $5 per ton, is still equal to ~$3.7B in carbon value over that time period* (data from www.globalforestwatch.org > Dashboard > Indonesia, accessed on 12/7/2021).[CB6]

An important reason for this decline in deforestation is the efforts of NGOs and companies in monitoring deforestation in commodity supply chains and tracking compliance with zero-deforestation commitments. According to experts, it can be labor- and time-intensive to monitor, track, and verify where deforestation has occurred in biodiversity-rich and high-carbon stock forests compared with legal commodity plantations, and there are often "false alerts." One NGO relies on grants to purchase $200,000 in Planet imagery annually, as well as pay for labor and consultants needed to monitor these events. In addition to the benefits that SBG offers to reduce deforestation in tropical countries, an added benefit is the opportunity to reduce these NGO costs and automate and standardize these monitoring activities. While more difficult to value these potential SBG benefits, they could play an important role in preserving highly valued ecosystems and the local communities that rely on them.

Forest Carbon Markets

An organization that manages commercial forest carbon project spends approximately $120,000 to $200,000 to validate each carbon project and an average of $40,000 annually to monitor the carbon. The organization believes that with SBG's hyperspectral benefits they could reduce these costs by 25%. To realize these benefits, the carbon standards would have to change and allow RS to play a bigger role. Given the large and growing forest carbon market ($160M of global voluntary credits transacted in 2019 alone), including global REDD+ efforts, there is a big opportunity for SBG to provide more robust and validated certifications, which will be necessary to allow these markets to expand in the future.

*According to Global Forest Watch, in 2019 commodity-driven deforestation led to 2.26 Mha in tree cover loss representing 1.40 Gt CO_2e in GHG emissions, and in 2016 this dropped to 1.07 Mha representing 0.651 Gt CO_2e in GHG emissions.

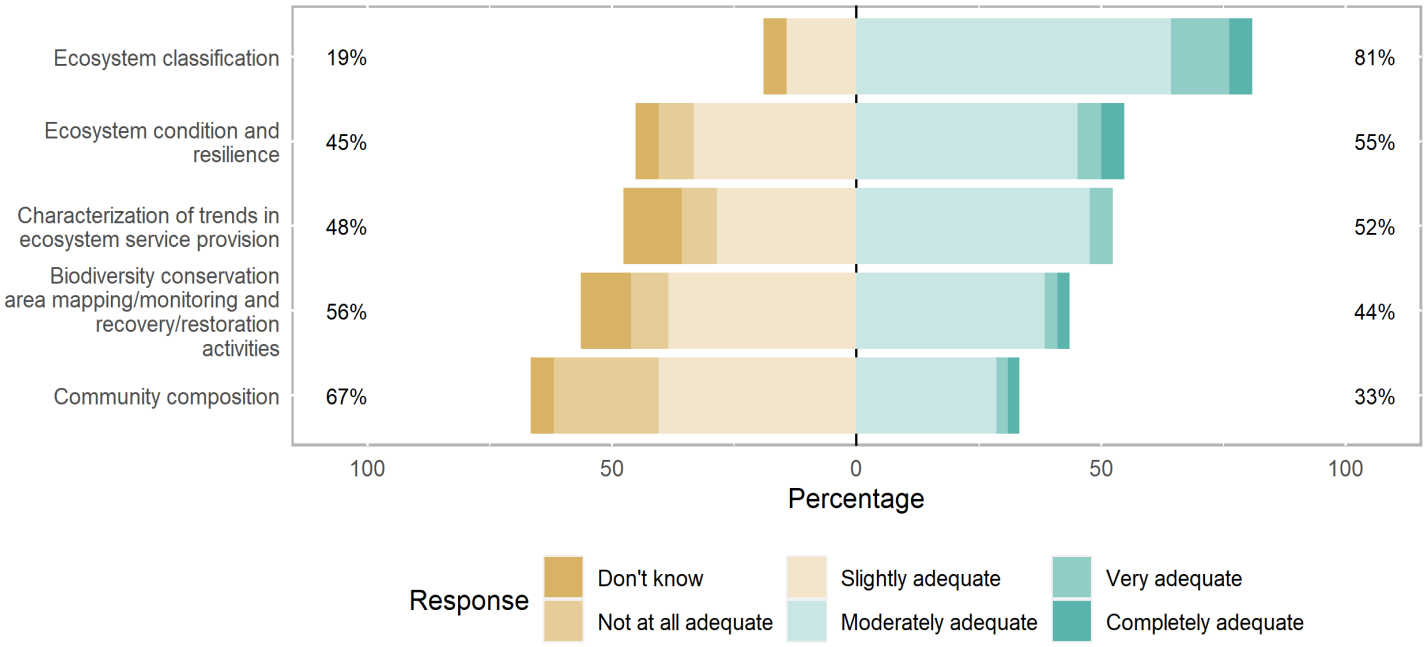
Biodiversity—Users Interviewed

	Key Informants	Perspective
	Fred Stolle, *World Resources Institute*	
	Simon Ferrier, *CSIRO*	
	Florence Landsberg, *Mars, Inc.*	
	Pat Comer, Healy Hamilton, *NatureServe*	
	Deborah Lapidus, *Mighty Earth*	
	David Gadsden, Adam Jenkins, *Esri*	
	Jeff Allenby, *Lincoln Institute of Land Policy*	
	Andrew Wilcox, *Unilever*	
	George Kelly, *Bespoke Mitigation Partners*	
	Rob Wilson, *The Nature Conservancy – Canada*	

Conservation/Biodiversity—Survey Results

Conservation and biodiversity respondents generally find current methods slightly to moderately adequate.

To what extent is the current remote sensing and earth observation data you use today adequate for the following conservation and biodiversity applications? (~42 responses)

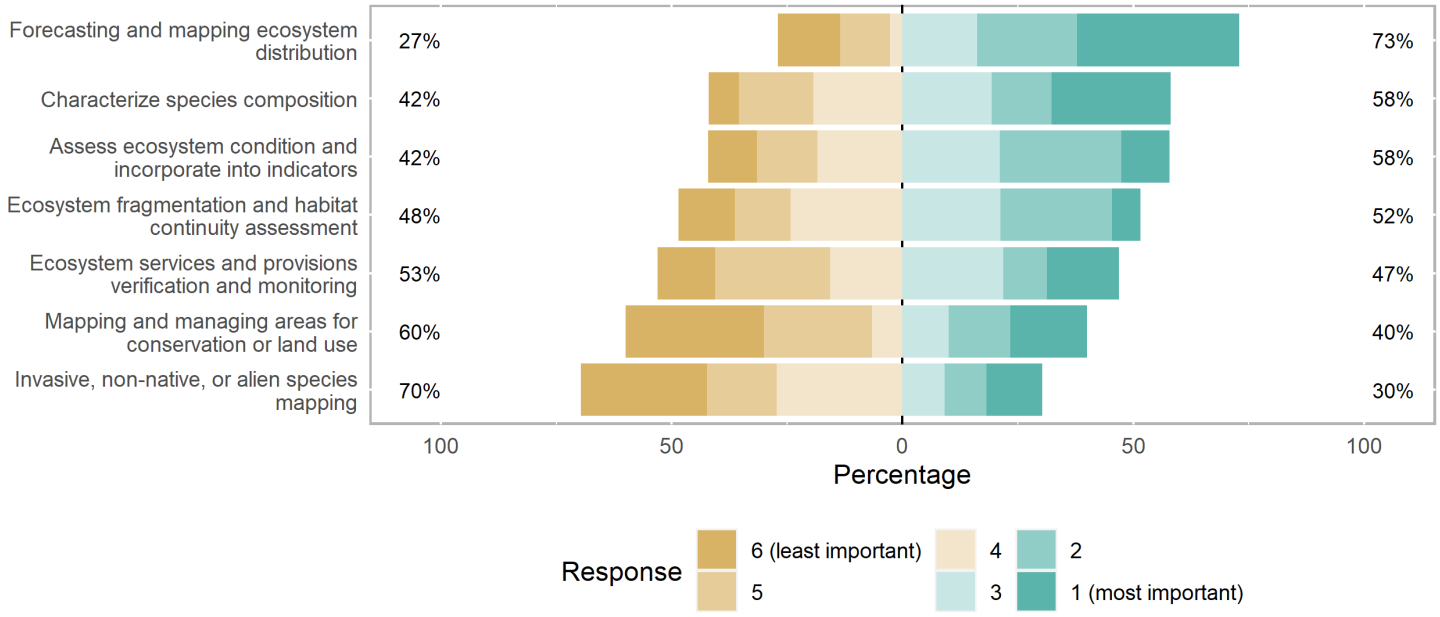


With over 40 responses for this application area, the survey data basic analyses are more reliable. For most respondents working on conservation and biodiversity, available data are only slightly or moderately adequate for each activity. Only a few respondents thought data were very or completely adequate or not at all adequate. The adequacy of methods for ecosystem classification was rated the highest. Methods for community composition were rated least adequate. When asked what is difficult or not possible with current methods, detailed classification of habitats and species was a predominant theme. These results are consistent with most expert feedback, but experts emphasized that field observations dominate, especially biodiversity work, and RS and EOD are not widely used.

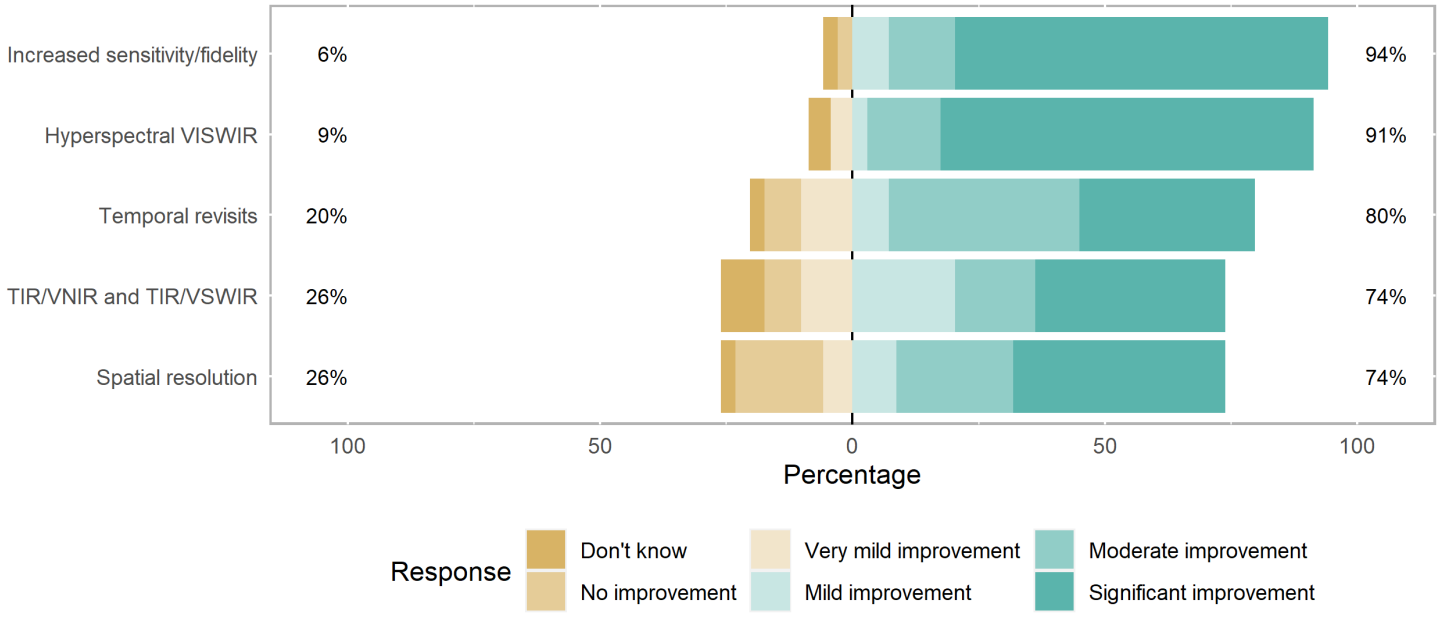
Conservation/Biodiversity—Survey Results

Ecosystem distribution/condition and species composition are top jobs for which SBG's high-fidelity HIS will bring great benefit.

When working on conservation/biodiversity efforts, which of the following are the most important "activities" that your organization is trying to accomplish? (~35 responses)



Consider these SBG capabilities and indicate the extent to which each of them provides benefits for the top 2 activities you indicated previously. (~69 responses)

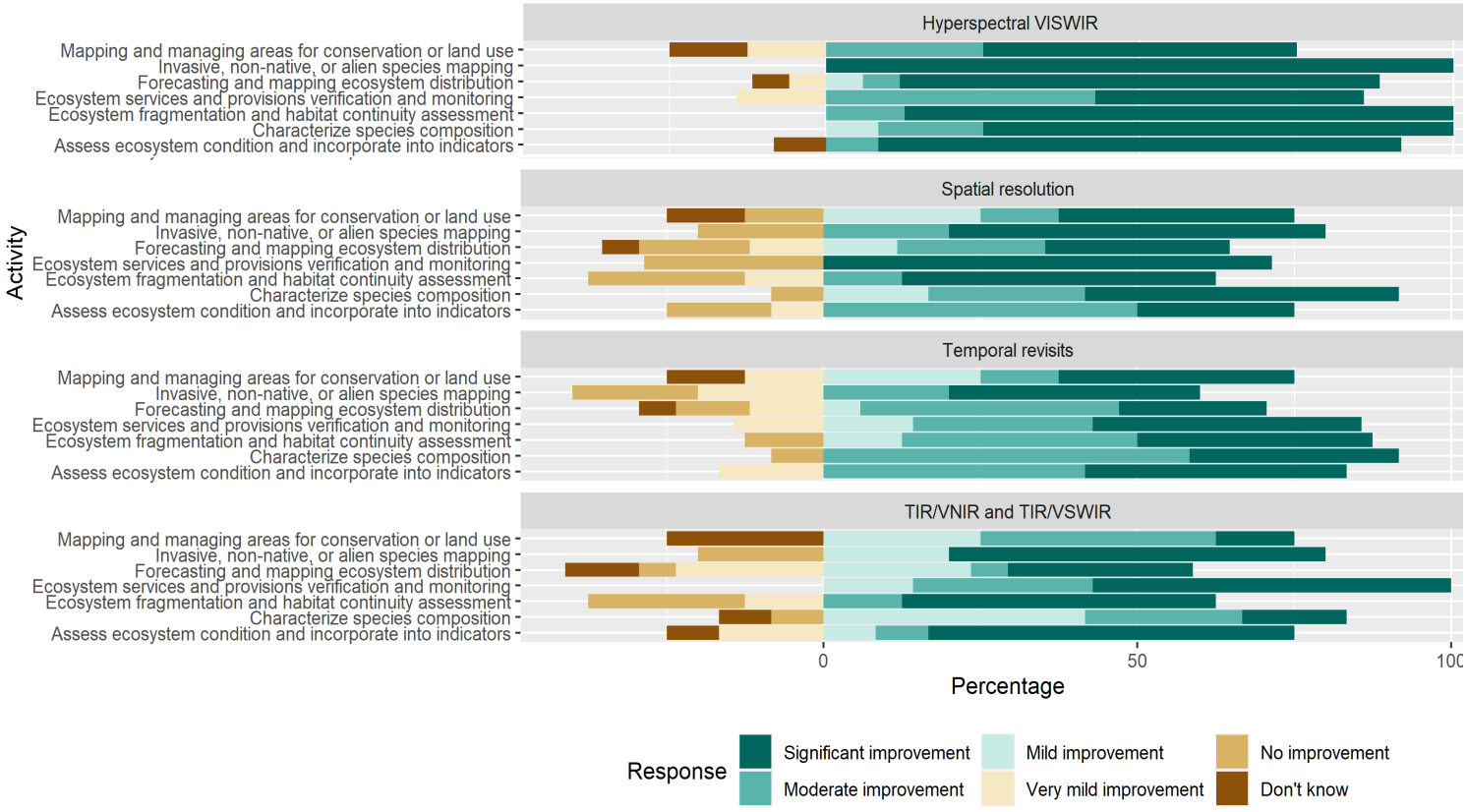


* For all priority rating questions a weighted importance/improvement score was calculated to determine the highest rated choices. Scoring is not shown but is reflected in the analyses.

Conservation/Biodiversity—Survey Results

SBG's HIS is expected to provide the greatest benefit across the most conservation and biodiversity applications.

Consider these SBG capabilities and indicate the extent to which each of them provides benefits for the top 2 activities you indicated previously. (~69 responses)

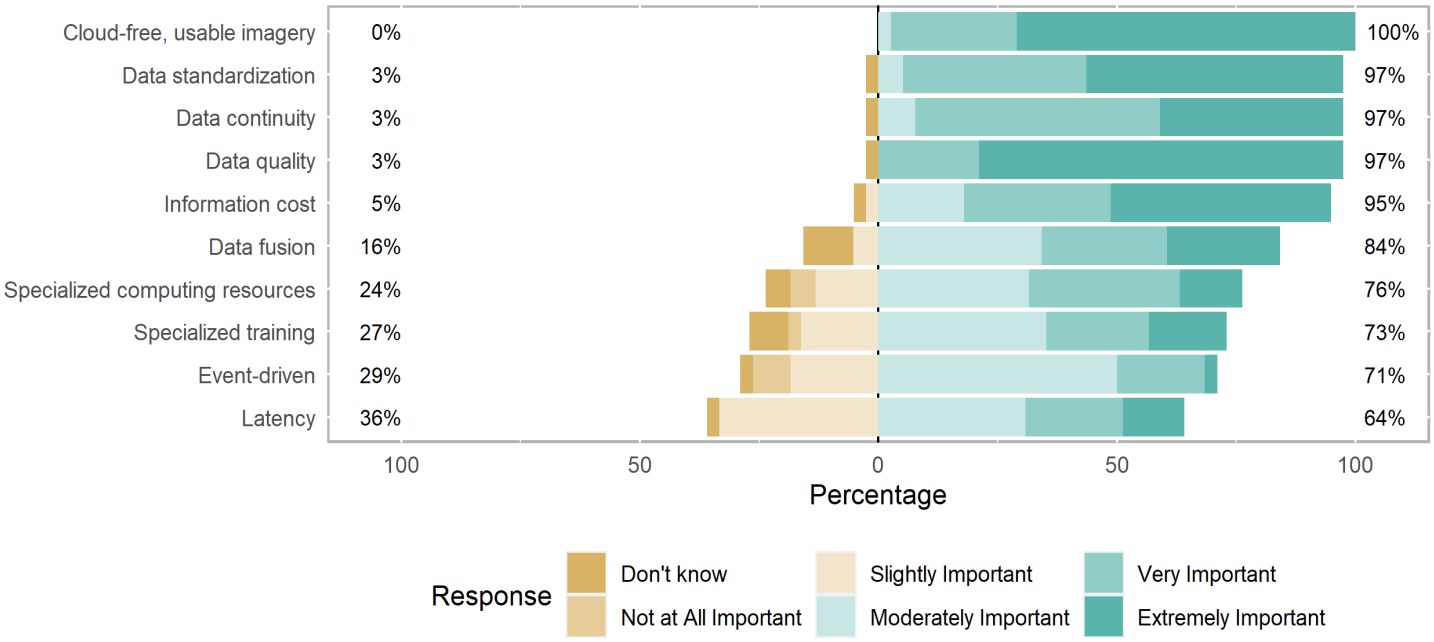


The 69 responses in this section of the survey provided the second highest number of SBG capability ratings. SBG's hyperspectral VISWIR spectral capabilities were top rated, offering significant benefits across almost all activity areas. This result is consistent with expert feedback. Survey results show that SBG's spatial resolution offers the least overall improvement. Multiple "no improvement" and "significant improvement" ratings for the same SBG capabilities demonstrate a wider distribution of ratings and opinions within this set of respondents. But this may be a result of higher response counts not seen in other sections. As with other application areas, there tends to be more uncertainty about the benefits of TIR capabilities.

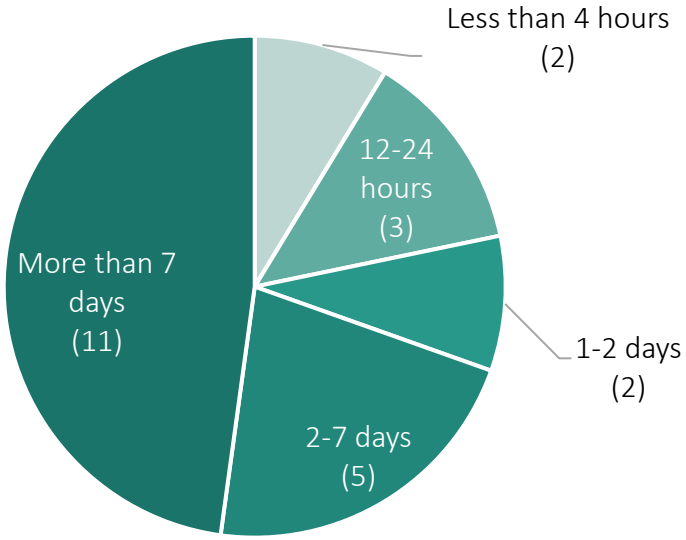
Conservation/Biodiversity—Survey Results

Cloud-free imagery and data quality, standardization, continuity, and cost are top issues. There are a wide range of latency needs.

For the use of Earth observation data in biodiversity, how important are the following information quality and accessibility issues? (~38 responses)



For those indicating latency as being of moderate to extreme importance: What latency is required in your application?

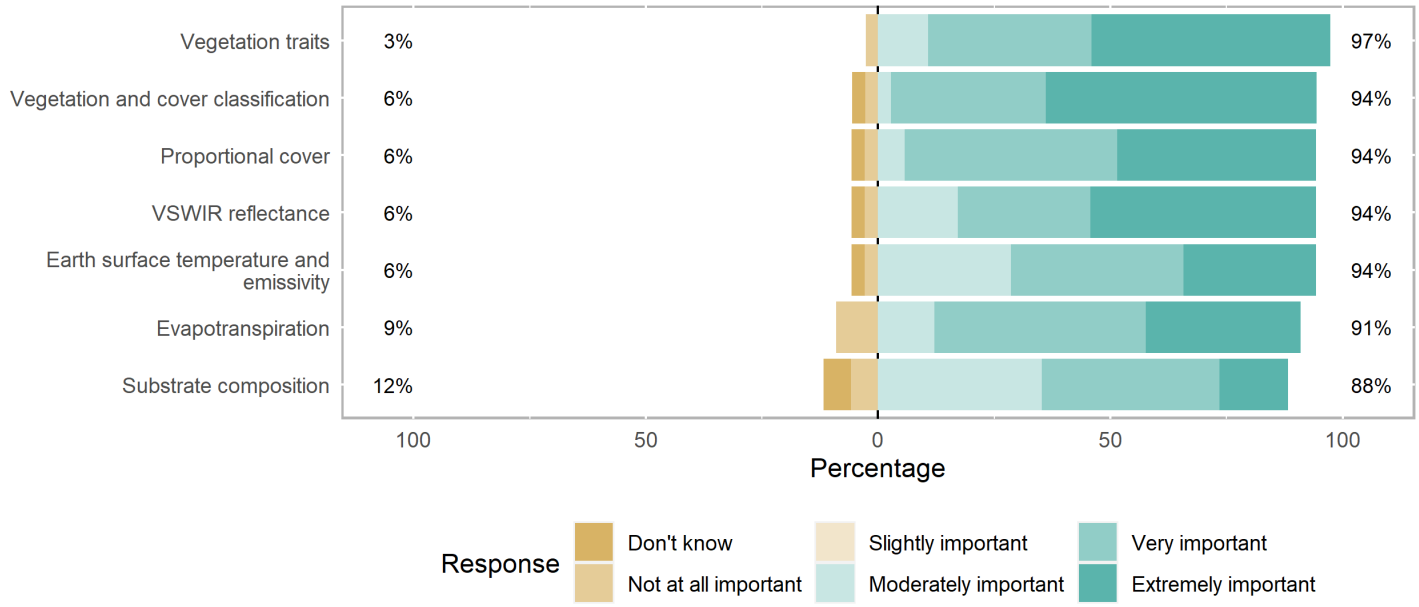


For those that desire lower latency, 6 out of 13 respondents would accept data that are less than fully validated.

Conservation/Biodiversity—Survey Results

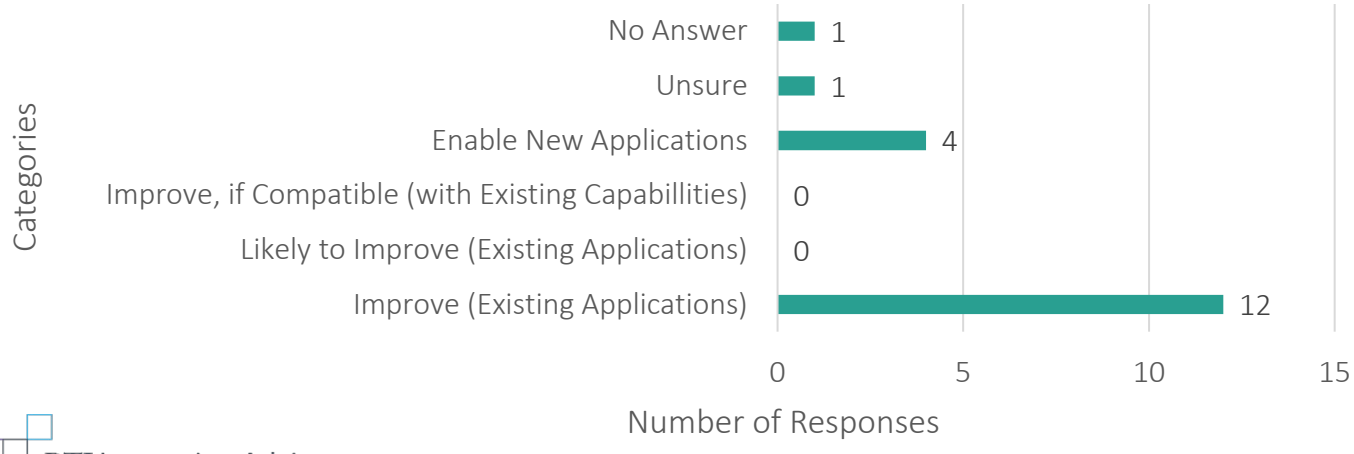
Almost all SBG algorithm products are at least very important to conservation and biodiversity users.

For the use of SBG in conservation/biodiversity efforts, how important are the following proposed SBG algorithm products? (~38 responses)



SBG's proposed vegetation, cover, and surface temperature products have nearly equally high importance, followed closely by the remaining two products. Eighteen respondents answered the open-ended questions, and a majority indicated SBG will improve existing applications, and a subset indicated the potential for entirely new applications. The anticipated impacts of SBG are better technical understanding, forecasting, and precision to guide conservation and biodiversity management and planning.

Will the proposed SBG capabilities have a strong likelihood of advancing your work? Or might SBG enable entirely new activities or applications? (~18 responses)



Conservation/Biodiversity: Citations and Sources

CB1. Kimbrough, L. (2021, October 13). "Kew Declaration" unites experts on reforestation, aims at policymakers ahead of COP26. Mongabay. https://news.mongabay.com/2021/10/kew-declaration-offers-guidance-on-reforestation-aims-to-reach-policymakers-ahead-of-cop26

CB2. Di Sacco, A., Hardwick, K. A., Blakesley, D., Brancalion, P. H. S., Breman, E., Rebola, L. C., Chomba, S., Dixon, K., Elliott, S., Ruyonga, G., Shaw, K., Smith, P., J. Smith, R. J., Antonelli, A. (2021). Ten golden rules for reforestation to optimize carbon sequestration, biodiversity recovery and livelihood benefits. Global Change Biology.

CB3. Pendrill, F., Persson, U. M., Godar, J., Kastner, T., Moran, D., Schmidt, S., & Wood, R. (2019). Agricultural and forestry trade drives large share of tropical deforestation emissions. Global Environmental Change, 56, 1-10.

CB4. Forest Trends' Ecosystem Marketplace. (2020, September 21). voluntary carbon and the post-pandemic recovery. State of voluntary carbon markets report, Special Climate Week NYC 2020 Installment. Washington, DC: Forest Trends Association.

CB5. Madsen, B., Carroll, N., Moore Brands, K. (2010). State of biodiversity markets report: Offset and compensation programs worldwide. http://www.ecosystemmarketplace.com/documents/acrobat/sbdmr.pdf

CB6. Data from www.globalforestwatch.org, > Dashboard > Indonesia, accessed on 12/7/2021.

Additional Information Sources:

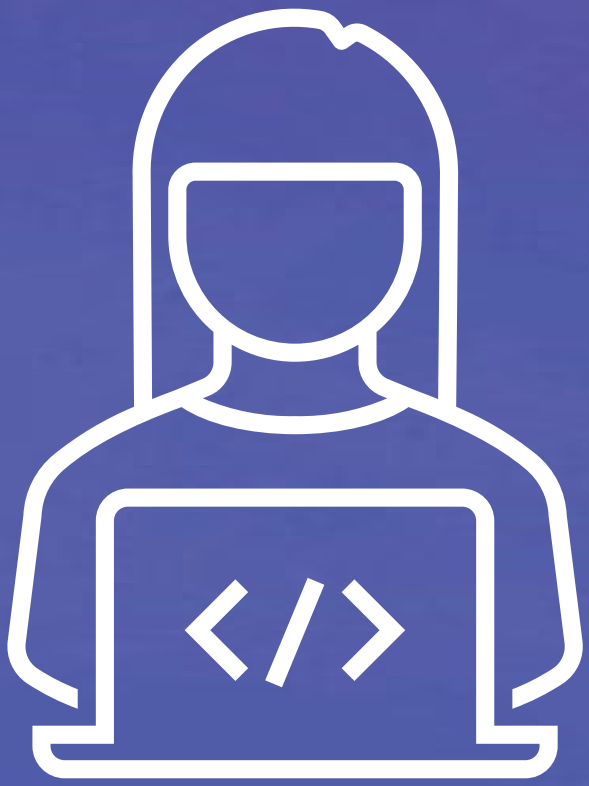
1) IBAT Dashboard (http://datazone.birdlife.org/sowb/casestudy/birdlife-has-developed-a-decision-support-tool-(ibat)-for-business-government-and-conservation)

2) GlobeLand (https://www.un-spider.org/links-and-resources/data-sources/land-cover-map-globeland-30-ngcc)

3) TNC Report (https://www.nature.org/content/dam/tnc/nature/en/documents/TNC_Geospatial_Annual_Report_2019.pdf)

Key Value Chain Players

Value-Added Service Providers



VASPs—Community Overview*

SBG could be a game changer, but service providers need NASA to develop the science and ensure data and data product quality.

VASPs comprise the most willing and able community of practice for NASA to engage. Many VASPs are already actively working in the SBG primary application areas and are well known to NASA. Globally, these VASPs serve as a key part of the EO value chain integrating RS data into products for the commercial, NGO, and government end users working in these application areas. As such, these organizations are essential partners for SBG because they are actively involved in, and motivated about, advancing the science and applied use of satellite spectral and thermal data, which aligns very well with NASA SBG's interests. Yet also, very importantly, they have their own commercial interests and those of their many customers at stake when using EO data and developing data products and services from those data sources. **VASPs expressed universal interest in the potential of SBG, and they are a critical link to the kind of private- and public-sector end users that NASA would like to engage with and serve.** Expert practitioners within the VASPs are highly sophisticated users of the kind of observation data that SBG could produce, and they represent an important community of practice for SBG to engage, support, and nurture.

These sophisticated users are looking to specific NASA leadership. Many VASPs see the future of RS as being driven by data science and modeling, which will require enhanced datasets, better analytical tools, and accessible cloud-computing platforms. The potential of SBG to provide complex hyperspectral datasets will only drive the need for better applied data science solutions. They also acknowledge that major EO platform VASP companies (e.g., Esri, Descartes) and specialists (e.g., IndigoAg, CAPA Strategies) are *not* using HIS, let alone coincident with TIR datasets. Although in theory they can handle complex datasets, as a practical matter such use has not been established. It is not clear how HIS or TIR will fit into their plans. They cannot drive these data and application advances by themselves, so **VASPs will look to NASA to take a leadership role in developing these areas but are willing to partner with NASA to evolve the field.** Another key part of NASA SBG's value proposition is that VASPs trust NASA's credibility and capabilities compared with other satellite HIS developers to ensure high-fidelity data, transparent data processes, corrections, verification, and accessibility. These information quality factors are a huge priority for VASPs. NGOs, boundary organizations, university–industry research consortia, and application specialist VASPs all expressed a desire for NASA to be a responsive partner. As NASA missions and data details change, it can create both opportunities and challenges for these groups, and they want to be engaged, notified, and consulted where possible because it affects their operations.

"The biweekly hyperspectral data would be huge for mapping ecosystems."

"The thermal 3-day repeat would be a game-changer for irrigation methods and monitoring of water usage."

* VASP user community insights were drawn from the interviews, which can be found in the primary application area Interview Notes, a separate file.

VASPs—Community Overview

Skilled practitioners have learned to be cautiously optimistic but see work to be done before SBG is feasible for commercial use.

Practitioners are hopeful but not convinced that SBG can meet operational needs. Many VASPs are skilled spectral data imaging and analysis practitioners. Based on this experience, they would prioritize operationally useful capabilities like <10-m spatial resolution and <2-day revisits over SBG's 200-band hyperspectral capabilities. In practice, they see diminishing returns with overly narrow, potentially redundant spectral bands that could lead to counterproductive spectral mixing. The use of HIS from airborne platforms has demonstrated the potential, but practitioners wondered if the global coverage advantages of a satellite platform might in practice be offset by practical matters. For example, in applications like food security and deforestation monitoring, the more pressing need is for routine cloud-free imaging to enable up-to-date maps that decision-makers rely on.

Data product and model developers see the need for more applied science and operational viability. Practitioners and VASPs also noted that there is still a lot of applied science work to do before their end-user clients have the commercially usable decision-making and modeling tools they desire. For example, VASPs working closely on imaging spectroscopy applications recognize that HIS compositional analysis of vegetation still needs more hyperspectral ground-truthing and scientific validation. Developers of tree classification, plant functional traits, and urban surface/air temperature models and algorithms are uncertain how much SBG's capabilities will specifically improve these models, and they know a lot more work is needed before these models can be integrated with other existing data sources. Because combined HIS and TIR imaging data are not widely used, the true value of these datasets is not well understood even in these sophisticated circles. VASPs also are wary of "just another research mission," and if they are to build services around NASA data, they want it to be "operationally viable." Like NASA, VASPs see the opportunity for applied science, fused datasets, and tools to mature significantly over the coming years. They recognize the urgency with which NASA should begin to develop the skilled professionals and practitioner partnerships necessary to support commercial maturation beyond science objectives. There is a workforce need for trained GIS, specifically hyperspectral and thermal EOD, specialists, and VASP/practitioners are looking for NASA's help.

"We don't need all 200 bands, but the 20-30 that will enable crop indices. This will take more work."

"NASA and others need to be growing professionals trained in using airborne HIS data now."

"We need missions that will be around for 10 years or more so we can leverage them operationally."

VASPs—Community Overview

VASPs and skilled practitioners have clear and generally consistent information quality and accessibility preferences.

These skilled practitioners working actively with EOD can provide valuable insights about desired information quality and preferred computing resources. Many experts and VASPs commented on the technical capacity of different user groups. They indicated that nonresearch users and typical end-user decision-makers do not have the technical background or interest to engage with EOD directly but instead look to VASPs and partners. This feedback is consistent with findings from a TNC survey* that found in their geospatial community "… programming does not seem to be a widespread skill among survey respondents (only 25% answered this question)." Nonresearch experts, even at large corporations with GIS groups, explained that they rely on VASPs and research consortia partners to provide the expertise necessary to gain EOD-derived insights. If NASA SBG wants to further understand the specific information needs of the private sector, it should talk directly to the VASP community and similar boundary organizations.

SBG should consider a common set of GIS and EOD tools and user needs. While most sophisticated research and VASP users can work with data directly, they all rely on common platforms and data formats to engage their communities and customers. Leading VASP developers like Esri say they are focused on multispectral raster format (MRF), and SBG data would have to be in MRF, or cloud-optimized GeoTIFF. Esri also works with cloud-optimized Zarr (an open-source Python library) and has its own cloud raster formats. TNC notes that Python and R were selected as the most common programming languages used by their GIS community. Many Esri partners, and other groups interviewed, use ArcGIS imaging combined with SaaS Image raster programs, deep machine learning (ML) for national-level mapping, and advanced analytics and algorithms. There are, of course, other platforms, but SBG can look to VASPs and the SBG survey data to get an additional sense of the most common tools in use. These commonly used cloud-native platforms and data formats are the ones SBG will be expected to be compatible with. Startups and even a large global agency noted that they could not afford to adapt atypical, unsupported, or R&D data types.

"NASA can provide the data transparency and low cost we need."

"NASA puts datasets up on DAACs but this is for super users … and biodiversity users 'fall through the cracks'."

"VASPs and startup companies that interpret data and make it easy for farmers will be the near future of EO for food security uses."

* – The Nature Conservancy. (n.d.). Geospatial conservation at The Nature Conservancy: 2019 annual report and map book. https://www.nature.org/content/dam/tnc/nature/en/documents/TNC_Geospatial_Annual_Report_2019.pdf

VASPs—Community Overview*

VASPs and skilled practitioners see free, open, and interoperable datasets and high-level derived products as essential to SBG adoption.

SBG will have to invest to ensure the data is free, open, and cloud accessible. Free, open-source data and algorithms have tremendous value to VASPs because their business models, or an NGO's donor funding, often cannot afford to pay for the data. One VASP startup serving the deforestation monitoring community noted that their free data workflow allows them to have viable client pricing of $200k per year. If they had to buy data, that price would increase to $2M per year, and their business model would fail. Free, transparent, open-source data are a major prerequisite for SBG across multiple applications like emerging carbon markets or in nascent communities that are just beginning to adopt RS. Additionally, multiple experts noted the need for cloud-based access and portals like LANCE. There was an emphatic consensus view that SBG must go cloud-native format and "cannot go the old DAAC FTP/HTTP/PO route."

Easily usable interoperable data for high-level products are a priority. Beyond the need for free, open data, VASPs and users want derived, higher level end products. Fully developed high-level products must be developed if SBG is going to make headway into most of the VASP and practitioner user communities. NASA must ensure interoperability and continuity of SBG data with other mission sensors and data, especially those with historical trend data like Landsat and Sentinel. Continuity will significantly improve the utility of SBG and likelihood of use. Fusion of datasets would add even higher value to VASPs. VASPs pointed to multiple opportunities to combine HIS data with various other datasets, like those from GEDI (for better conservation modeling), optical/SAR and optical/LiDAR (for forestry classification), and SMAP (global Ag monitoring). VASPs have a vested interest in partnering with NASA to develop these combined datasets into products for their customers. Given the relatively low technical readiness of the nonresearch communities across the primary application areas, NASA will need to make concerted efforts to provide capacity building. As one expert said, "There should be a platform to help the user community access information products and decision tools, not just data. We can't dump data in their laps and expect them to use it." Early adopter programs targeting specific user communities are considered a good model for helping to build access to and use of new data products. VASPs look to NASA as a partner for capacity building and outreach support to help develop a viable ecosystem of users to begin and sustain use of new platforms like SBG.

"We had huge switching costs going from Landsat to Sentinel data. ... If there's a way to avoid this [for NASA data] it would be a huge advantage."

"We need mature, stable data, and communication about APIs and changes. Each time a NASA researcher experiments with data we are liable."

VASPs—Users Interviewed

	Key Informants	Perspective
 	David Gadsden, Adam Jenkins, *Esri*	
 	Curt Hammill, Keith Van Graafeiland, *Esri*	
  	A.J. Kumar, Kat Jensen, Ignacio Zuleta, Christopher Holden, *Indigo Ag*	
	Greg Asner, *ASU/Allen Atlas*	
	Hamed Alemohammad, *Radiant Earth Foundation*	
	Vivek Shandas, *CAPA Strategies*	
	Jawoo Koo, *CGIAR*	
	Fred Stolle, *World Resources Institute*	

* Interview notes for many of the VASPs can be found in the primary application area interview section in Interview Notes, a separate file.

General Survey

Methodology and Broad Findings

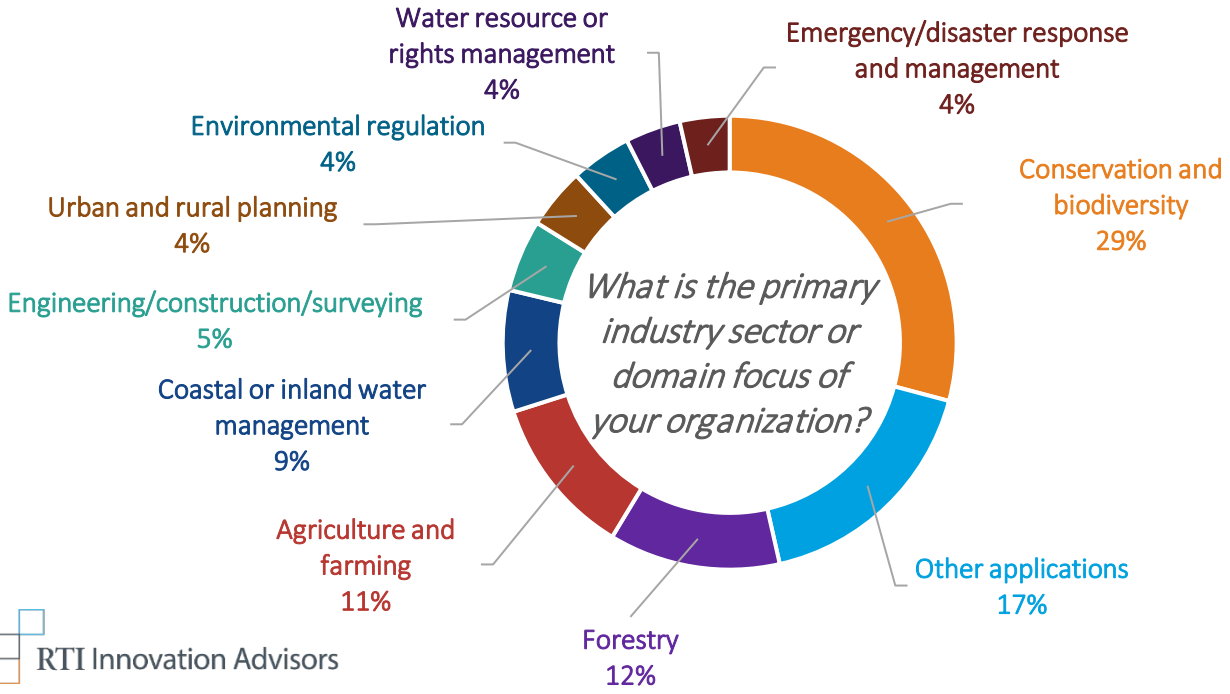
Survey Methodology

An online survey, targeting primary application user communities, provided quantitative findings from diverse application areas.

Based on the successful survey design used in the first SBG user needs study, RTI worked closely with the SBG Applications team to refine and update an online survey tool. The survey design was reviewed with the SBG team and NASA application specialists for accuracy and intent before it was launched. As in the previous study, the survey executed for this report and application areas had both demographic and general sections that all respondents were guided to complete. The survey also included five detailed primary application sections from which respondents could select and complete based on their community.

The survey was designed to assess specific topics: (1) respondent demographics and characterization, (2) general EO user needs, (3) insights about the SBG-relevant primary application areas, (4) perceived benefits of SBG capabilities, and (5) information quality and access needs. In parallel to survey development, the RTI/SBG team identified and engaged community sponsors in each application area, as an avenue to connect to survey participants. The final custom online survey was distributed via email, social media posts, and sponsor websites and remained open from September 22, 2021, through October 27, 2021.

Survey insights and summary charts for specific application areas are in the application-specific sections in this report. General survey findings are presented in this section. Survey respondents represented a diverse but targeted set of SBG-relevant industry and domain areas, indicating that the survey reached the intended application areas and audiences. "Other" includes respondents from climate and weather, education, and Earth science domains.



Survey Demographics

More than 250 respondents from over 20 user communities provided responses.

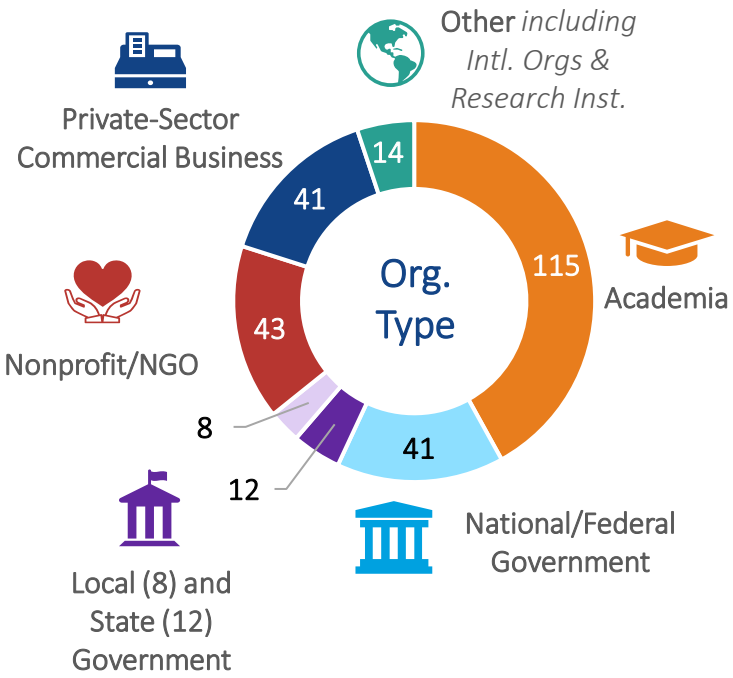
Many respondents came from research organizations that NASA might traditionally engage for scientific and applied research efforts. However, almost one-third of respondents were private and NGO organizations not typically engaged by NASA.

21

User Community Groups Engaged for the Survey

262

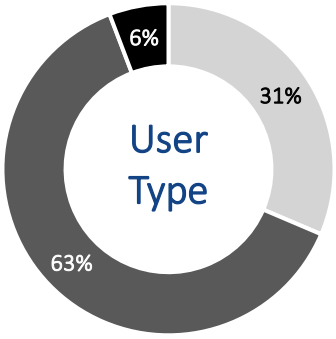
Total Unique Survey Respondents



Respondents by Organization Type

6% Value-Added Service Providers

Produce and distribute EO data/data products or software platforms



31% Nonresearch

Use of EO data interfaces and/or EO products to support ongoing operations, decision-making, advocacy or recommendations, competitive advantage, or compliance (e.g., commercial, NGO, municipal/regional response, planning, management policy)

63% Research

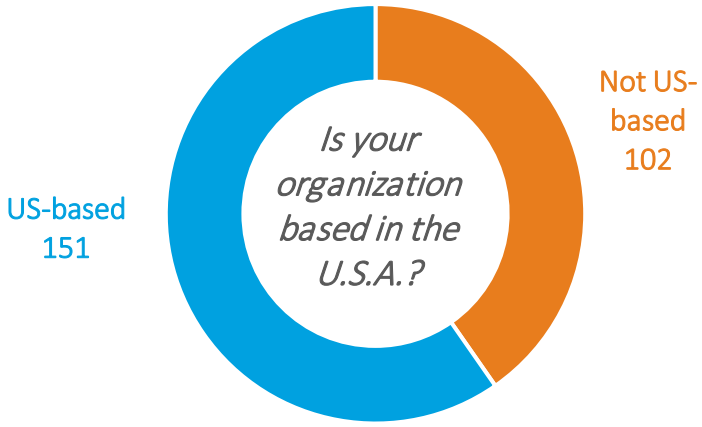
Research or development of EO system, data, modeling, and applications to advance state of the science/art or to produce publicly available EO products (e.g., scientific and academic research or government, operational EO efforts)

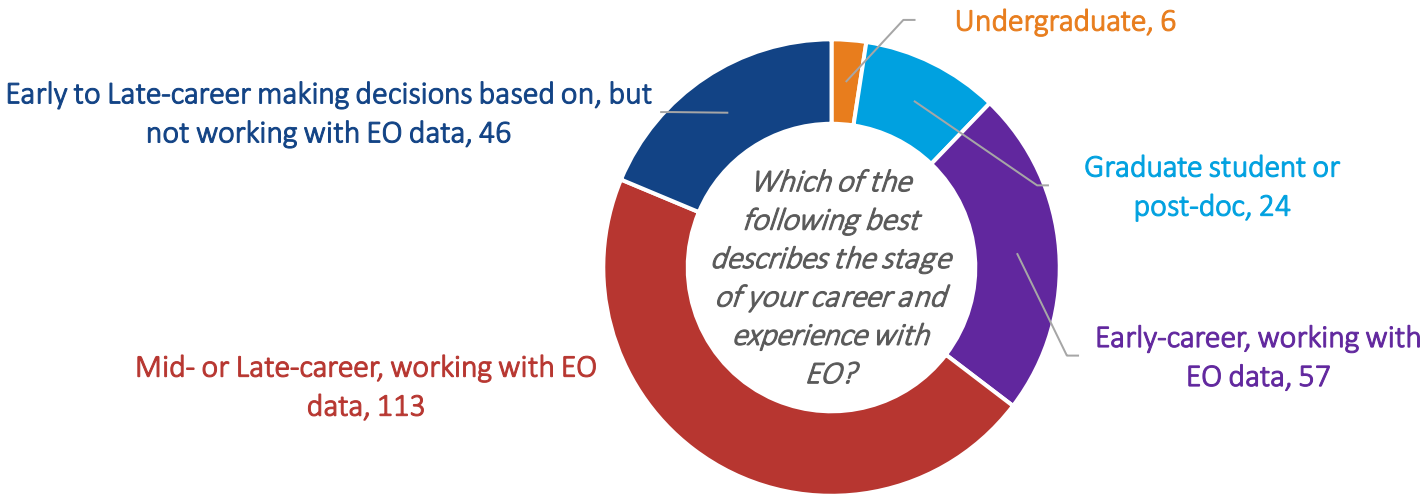
Respondents by Engagement Segment

Survey Demographics

Survey respondents were global and predominantly mid- and later-career professionals, including academics, who work with EO data.

In addition to the diversity of application domains and organization types, the survey reached an international audience. Although more than half of respondents worked in organizations based in the United States, international organizations were also well represented in the survey data.



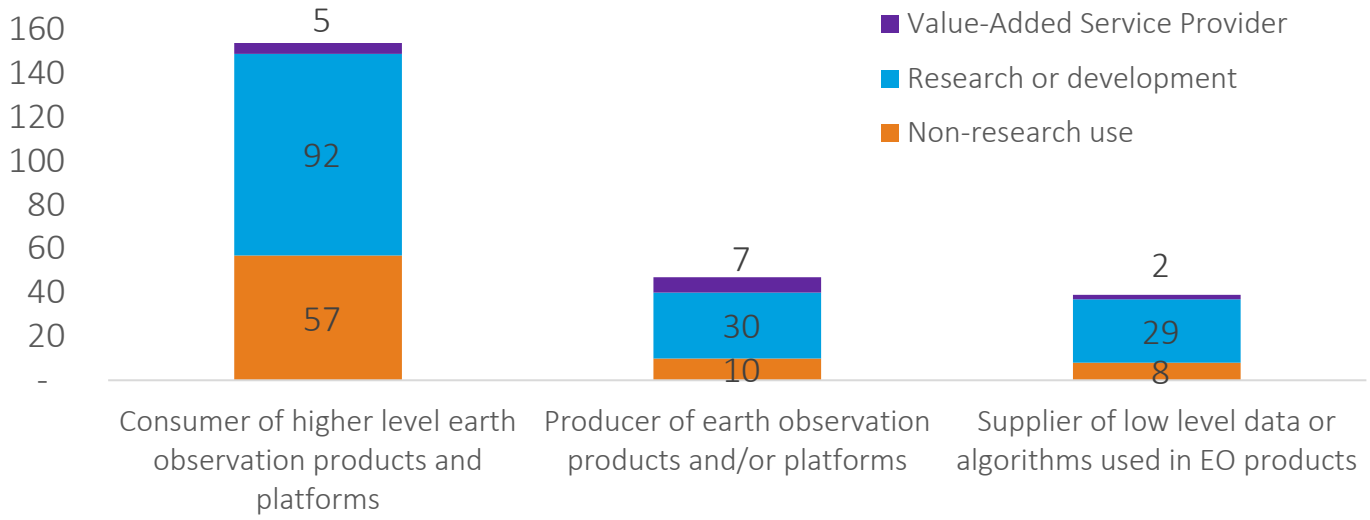


Almost 70% of respondents were early-, mid-, or late-career professionals working directly with EO data. Interestingly, ~19% of respondents make decisions based on EO data without directly working with it. This finding suggests that end users and decision-makers are reasonably represented in the survey results. The career level and use of EO data indicate an informed and knowledgeable set of respondents.

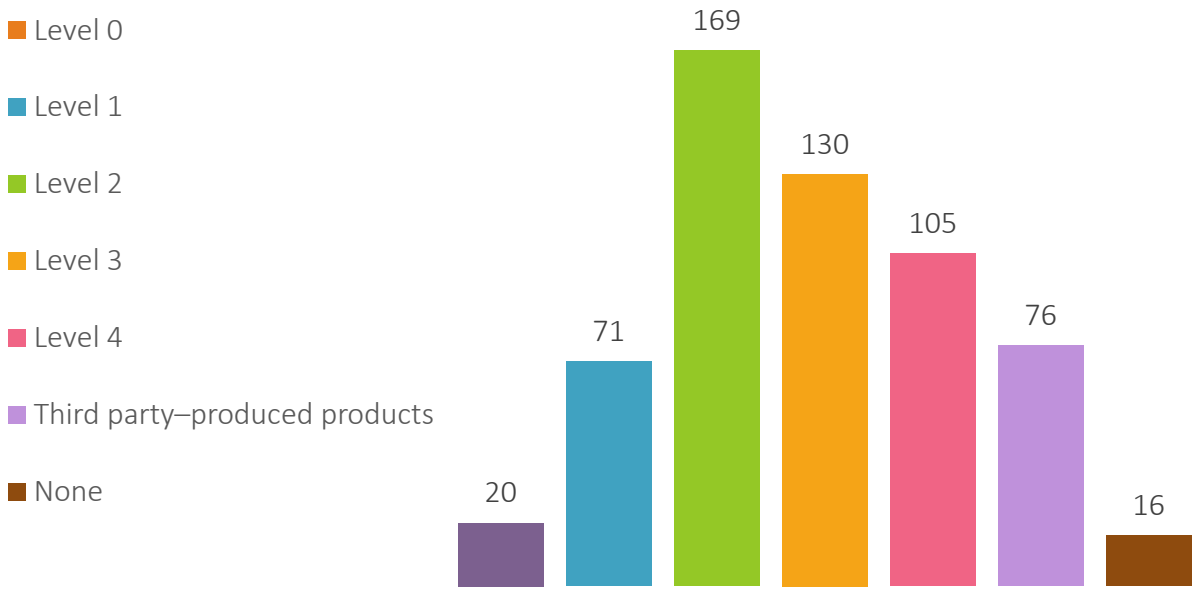
General—Use of EO Data and Products

Respondents were predominantly users of high-level EO data products, but producers and suppliers were well represented.

Which of the following best describes the kind of work that you do with Earth observation data and data products?



Please tell us about the kind of Earth observation data and data products you typically access or use. (Definitions for each level were given)



General—Modes of Observation

Users rely on a mix of RS observation methods, but low- to moderate-resolution modes are predominantly used.

For your primary application, which of the following methods does your organization use on an ongoing basis?

	Number of respondents who use **frequently**	Number of respondents who use **occasionally**	Total
Low-resolution, multispectral satellite imagery, such as MODIS or VIIRS and GOES	75	48	123
Moderate-resolution, multispectral satellite imagery, such as Landsat, Sentinel, and ASTER	104	44	148
High-resolution, multispectral satellite imagery, such as Planet or WorldView	44	43	87
Visible to shortwave infrared (VIS-SWIR) spectral data	45	28	73
Low-resolution thermal imagery, such as AVHRR	13	20	33
Moderate- to high-resolution thermal, such as ECOSTRESS	15	21	36
TIR spectral data	20	19	39
Airborne multispectral imagery	12	27	39
Airborne hyperspectral imagery, such as AVIRIS	24	16	40
Unmanned aerial vehicle (UAV)/drone multispectral imagery	31	25	56
UAV/drone hyperspectral imagery	11	14	25
Moderate- or high-resolution LiDAR	32	43	75
Moderate- or high-resolution radar	14	18	32
Other	2	4	6

Across respondent types, moderate- and low-resolution multispectral imagery are used most commonly. High-resolution imagery, VIS-SWIR spectral data, and LiDAR were also top choices. Some modes, like airborne multispectral imagery, thermal imagery, and LiDAR, are more likely to be used on an occasional basis. Relative to multispectral observations, thermal imagery and data and radar have much lower use rates. It is worth noting that these findings on the use of remote observation modes are consistent with the expert interview findings.

General—Modes of Observation Not Used

Many modes of observation are not applicable to users' work.

You indicated your organization does not use these methods. Which of the following reasons best match why your organization does not use these methods?

	Too complicated	Too expensive	Not applicable	Don't know	Total checks
Low-resolution, multispectral satellite imagery, such as MODIS or VIIRS and GOES	1	3	51	24	79
Moderate-resolution, multispectral satellite imagery, such as Landsat, Sentinel, and ASTER	5	2	24	23	54
High-resolution, multispectral satellite imagery, such as Planet or WorldView	8	36	32	38	114
VIS-SWIR spectral data	6	4	54	57	121
Low-resolution thermal imagery, such as AVHRR	5	4	100	52	161
Moderate- to high-resolution thermal such as ECOSTRESS	9	4	71	76	160
TIR spectral data	5	2	78	65	150
Airborne multispectral imagery	13	42	57	43	155
Airborne hyperspectral imagery, such as AVIRIS	19	42	48	50	159
UAV/drone multispectral imagery	17	26	54	41	138
UAV/drone hyperspectral imagery	22	41	61	45	169
Moderate- or high-resolution LiDAR	16	25	53	31	125
Moderate- or high-resolution radar	27	16	69	50	162
Total checks	153	247	752	595	

"Not applicable" was the most common reason specific methods were not used, and "don't know" was second. These responses indicate that many methods are not relevant or are unfamiliar to respondents and suggest users choose very specific modes to support their applications and work. Few indicated complexity was a primary deterrent, but it is a notable factor for nonsatellite methods. Cost can be a relatively important barrier for some modes, particularly for high-resolution satellite imagery, airborne, and UAV/drone imagery.

General—Nonresearch vs. Research Users

Nonresearch and research user respondents generally use the same mix of RS and imaging platforms.

When you use remote sensing (RS) and imaging, which specific platforms do you typically use?

		Number of respondents who use **frequently**	Number of respondents who use **occasionally**	Total
Non-research users & value-added service providers	Low-resolution, multispectral satellite imagery, such as MODIS or VIIRS and GOES	17	14	31
	Moderate-resolution, multispectral satellite imagery, such as Landsat, Sentinel, and ASTER	31	15	46
	High-resolution, multispectral satellite imagery, such as Planet or WorldView	18	12	30
	VIS-SWIR spectral data	12	5	17
	Low-resolution thermal imagery, such as AVHRR	2	5	7
	Moderate- to high-resolution thermal such as ECOSTRESS	5	8	13
	TIR spectral data	6	6	12
	Airborne multispectral imagery	6	7	13
	Airborne hyperspectral imagery, such as AVIRIS	4	3	7
	UAV/drone multispectral imagery	11	6	17
	UAV/drone hyperspectral imagery	3	7	10
	Moderate- or high-resolution LiDAR	10	19	29
	Moderate- or high-resolution radar	3	6	9
Research users	Low-resolution, multispectral satellite imagery, such as MODIS or VIIRS and GOES	56	35	91
	Moderate-resolution, multispectral satellite imagery, such as Landsat, Sentinel, and ASTER	74	29	103
	High-resolution, multispectral satellite imagery, such as Planet or WorldView	25	32	57
	VIS-SWIR spectral data	32	23	55
	Low-resolution thermal imagery, such as AVHRR	12	14	26
	Moderate- to high-resolution thermal such as ECOSTRESS	11	13	24
	TIR spectral data	14	13	27
	Airborne multispectral imagery	6	20	26
	Airborne hyperspectral imagery, such as AVIRIS	20	13	33
	UAV/drone multispectral imagery	20	19	39
	UAV/drone hyperspectral imagery	8	7	15
	Moderate- or high-resolution LiDAR	22	24	46
	Moderate- or high-resolution radar	10	12	22

Collectively researchers across applications were more likely than nonresearch respondents to report "frequently" using almost all RS platforms and "occasionally" using most platforms. Nonresearch users and VASPs were more likely to report occasional use of some platforms, like LiDAR and UAV/drone hyperspectral imagery.

General—Nonresearch vs. Research Users

Both nonresearch and research respondents are moderately satisfied with the ability of current RS/EOD to meet their needs.

To what extent is the current remote sensing and earth observation data you use today adequate in your primary application area?

	Don't know	Not at all adequate	Slightly adequate	Moderately adequate	Very adequate	Completely adequate
Nonresearch users and VASPs	23	17	43	77	42	9
Research users	40	29	111	148	42	21

Based on the RS observation modes and EO data selected in the previous question, respondents across user types and across many application areas had generally similar perceptions about the adequacy of current methods. There was a consensus and average view that current methods and data are "moderately adequate" at meeting their needs. About 10% of respondents in both groups selected "don't know," which further indicates a degree of unfamiliarity with the specific and relevant capabilities of RS observation methods and data. This same question was asked in the primary application survey sections, and results are reported in the Findings section. The general survey findings for this question are consistent with the expert interview findings. Experts reported being generally satisfied with current methods, but they were able to easily identify opportunities to improve on current methods.

General—Nonresearch vs. Research Users

Both nonresearch and research respondents indicated that SBG will provide a substantial improvement.

Please indicate the extent to which each SBG capability listed could provide benefit in your primary application area.

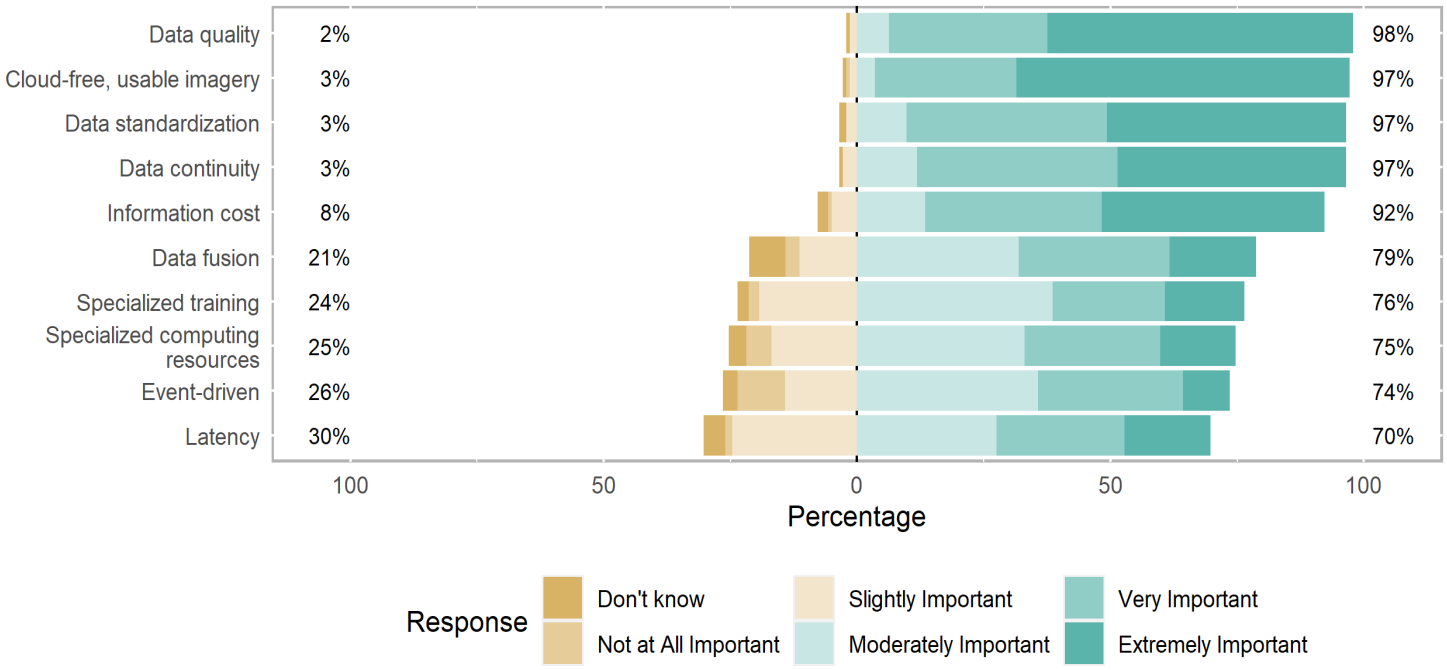
		Hyperspectral VISWIR	Increased sensitivity/fidelity	Spatial resolution	Temporal revisits	TIR/VNIR and TIR/VSWIR
Nonresearch users and VASPs	Don't know	10	14	3	3	24
	Very mild improvement	10	8	18	13	9
	Mild improvement	10	5	14	10	19
	Moderate improvement	13	11	17	24	14
	Significant improvement	43	49	16	30	13
	No improvement	0	0	17	5	5
Research users	Don't know	5	7	2	4	7
	Very mild improvement	5	5	11	9	12
	Mild improvement	10	6	9	18	19
	Moderate improvement	32	31	56	53	34
	Significant improvement	97	101	57	60	72
	No improvement	0	3	17	8	8

Both groups of respondents indicated that the hyperspectral VIS-SWIR and increased sensitivity and fidelity capabilities of SBG would provide significant improvements to their work in their primary application areas. Both groups also were likely to rate temporal revisits as providing moderate or significant improvements. Research users saw moderate to significantly improved potential benefits from spatial resolution, TIR/VNIR, and TIR/VISWIR, while nonresearch users and VASPs had more mixed views. SBG's spatial resolution was seen as offering the least perceived benefit, and both groups had mixed opinions but tended toward mild to no improved benefit. Nonresearch users were more likely to respond that they "don't know" what benefits each SBG capability would provide. These general survey findings differed from the application-specific survey findings, which asked about the benefit of SBG in reference to specific activities in each primary application area. Expert feedback was consistent with the general survey VISWIR and TIR findings above, but experts thought SBG's spatial and temporal capabilities offered more mild improvements.

General—Information Quality and Access

Cloud-free, usable imagery; data issues; and information costs are extremely important to all groups and applications.

For your primary application area, how important are the following information quality and accessibility issues? (Definitions for each option were given.)



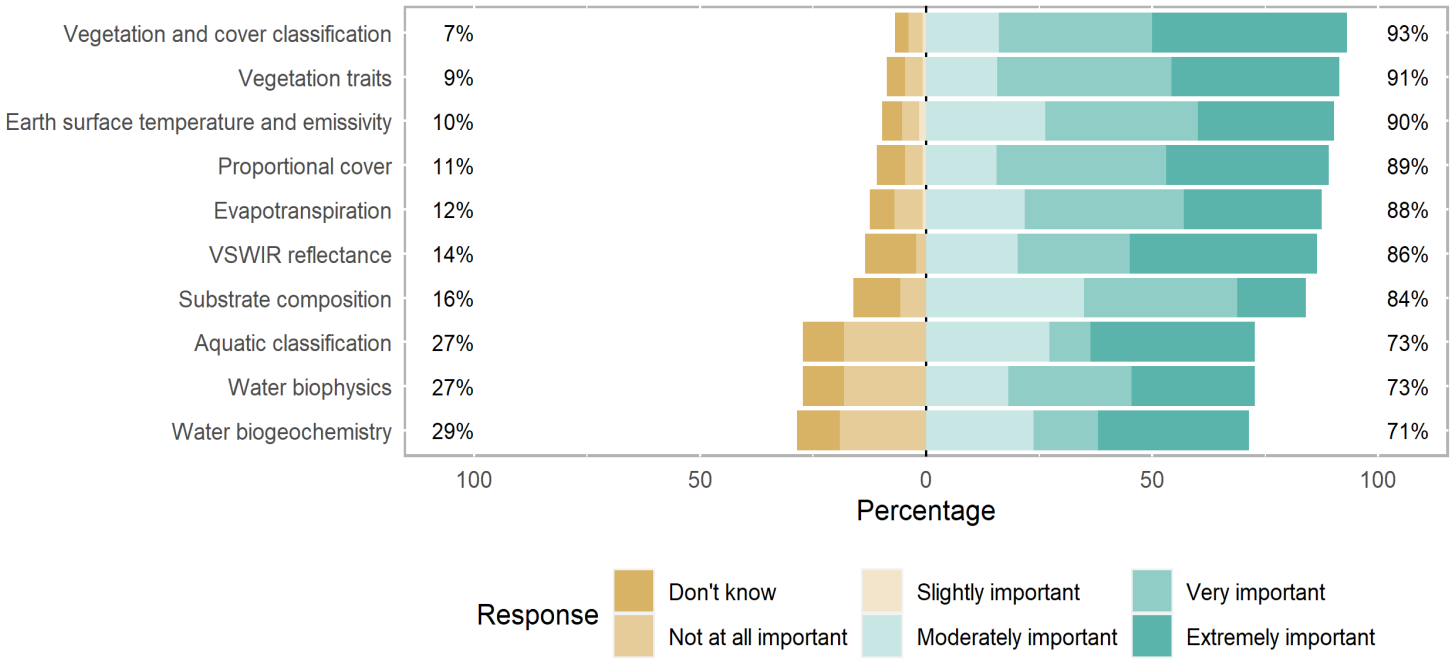
Approximately 143 respondents answered this question, and across different user groups, the information quality and accessibility priorities showed little variation. Cloud-free, usable imagery and "data quality" (accuracy, provenance, calibration/validation ensured by NASA) were both the most highly rated as extremely or very important to both nonresearch and research users. Data standardization and continuity were also highly rated, followed closely by information cost. The high importance ratings of these top EO information issues were very consistent in both the general and application-specific sections of the survey and were confirmed by experts. This finding underscores the overall importance of these top information quality issues to all user communities across all applications.

Respondents indicated a wider range of opinions and more uncertainty ("don't know") about the importance of data fusion, specialized training, specialized computing, and latency necessary to support the use of EO data products. Event-driven information access (the ability to acquire data on demand in response to an event) had the lowest overall importance score. These lower rated issues have more application-to-application variation but, on average, are consistent with the general section findings.

General—Algorithm Products

Vegetation and surface temperature algorithm products are most important across all respondents.

For the use of EOD/product in your primary application area, how important are the following proposed SBG algorithm products? (~143 responses)



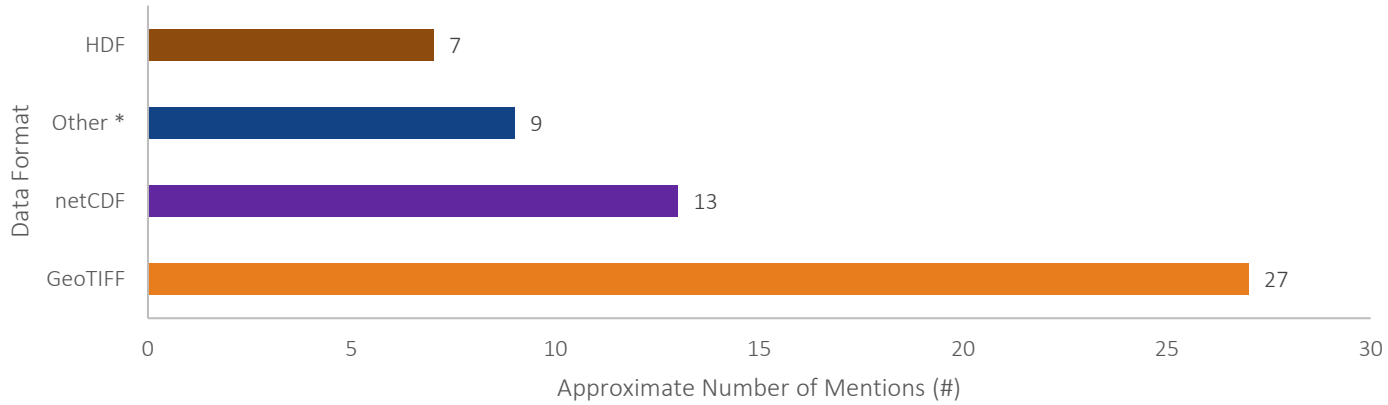
Across all user groups, vegetation traits and vegetation and cover classification emerged as particularly important algorithm products. These two products, along with Earth surface temperature and emissivity, were rated as moderately, very, or extremely important by more than 90% of respondents.

Note that respondents were shown only products particularly relevant to their application areas. Presenting selective algorithms ensured only application-relevant options but may have limited total response counts. The water and aquatic classification algorithms were only provided as options to respondents working in the coral reefs application section and the general section (note that coral reefs application respondents scored these products as very important; lower responses may have been provided by "general" section respondents working in areas not related to water). Evapotranspiration, proportional cover, and vegetation traits were shown to all groups except coral reefs respondents. Substrate composition was shown to all users except coral reefs respondents and general respondents.

General—Software and Data Formats

Most respondents use a common set of EOD tools and formats.

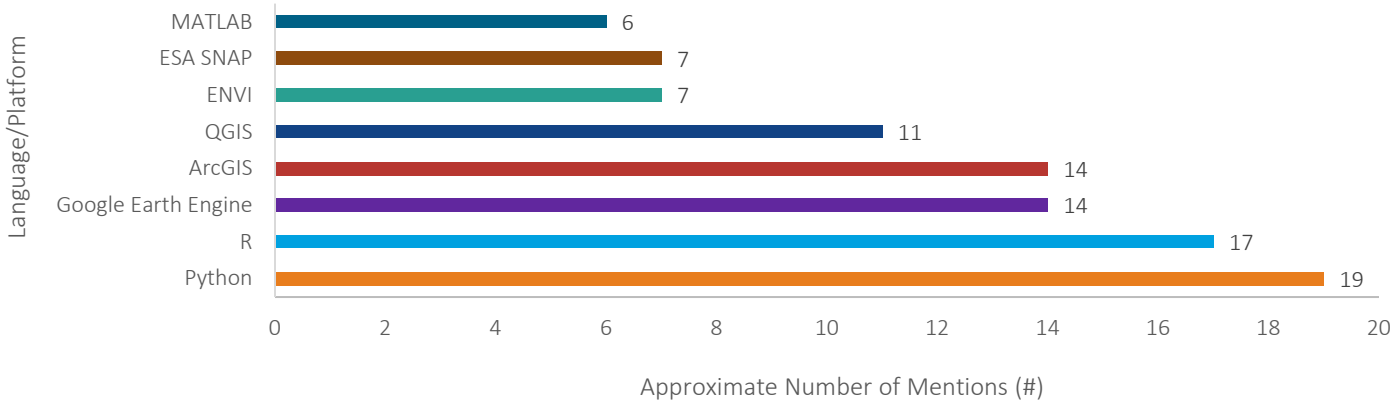
What are the EO data formats you typically use and/or data format preferences?



*Other formats mentioned only once or twice include csv, h5, SAVE, L2/L3, LAZ, SID, ASCII, BIP, TIFF, and shp.

In answer to an open-ended question about preferred data formats, 51 respondents listed 12 different format types, but three formats were the most popular: GeoTIFF,[1] netCDF, and HDF, each mentioned three or more times. Some respondents noted the importance of compatibility with formats used within a specific community; however, data and expert feedback suggest the use of the top three most popular formats will meet most user needs.

What are the primary software, tools, or APIs you routinely use for EO data analysis?



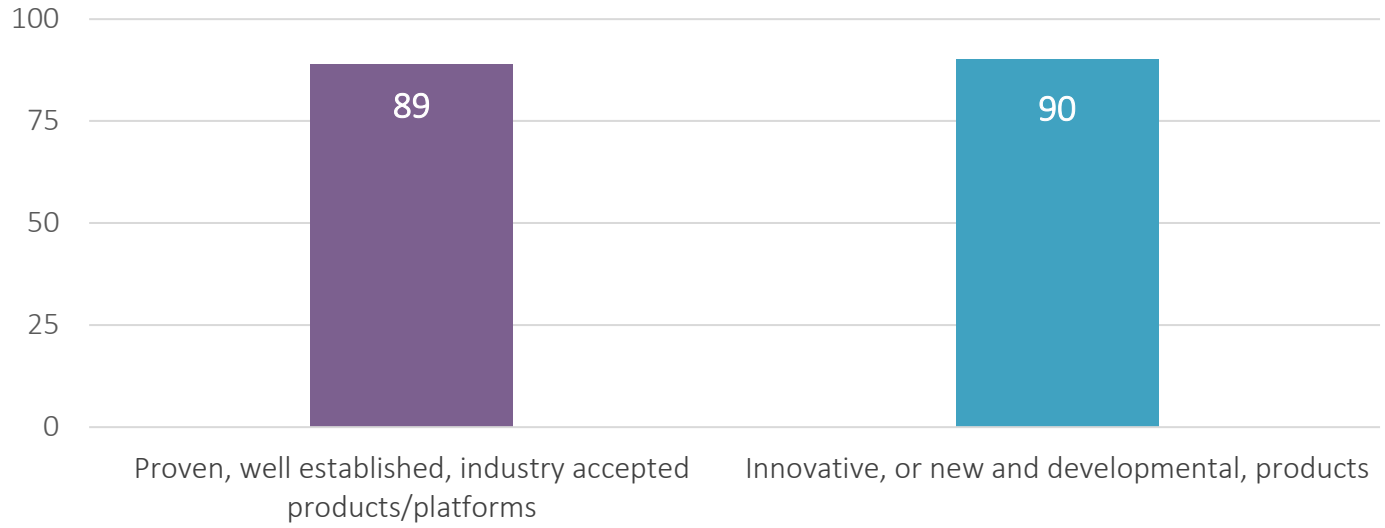
For software preferences, 54 respondents listed several dozen languages or platforms, and of these, 8 were mentioned 6 or more times. Many other software, languages, or platforms were mentioned once or twice, which shows that a wide range of these tools are used routinely.

1. Although not specified, it is assumed the respondents consider GeoTIFF to be The Open Geospatial Consortium OGC GeoTIFF Standard in September 2019.

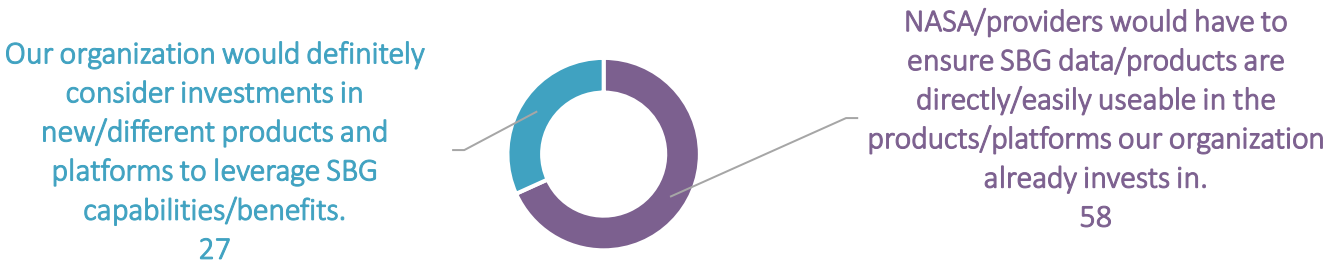
General—User Willingness to Invest

Users are willing to invest in innovative EO products, but a majority want SBG products to be usable on existing platforms.

Which type of earth observation data products or platforms is your organization willing to substantially invest in? (Select all that apply.)



For your organization to use new NASA data/products like SBG (Select one.)



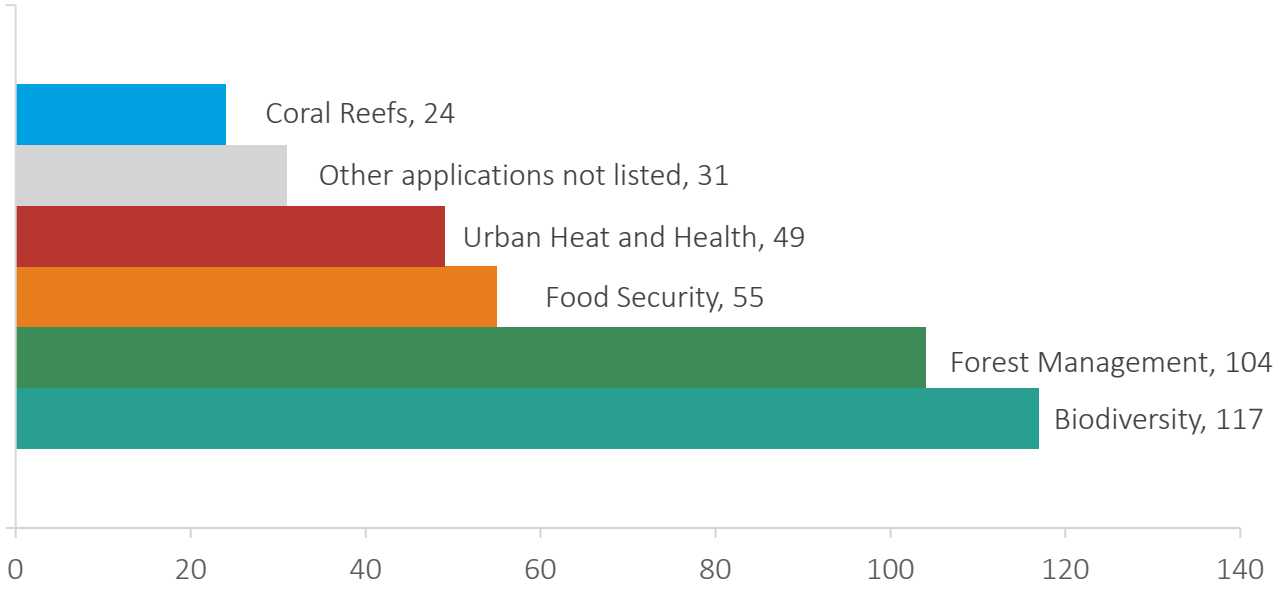
Both research and nonresearch responses were consistent and show an equally high willingness to invest in both proven and innovative development EO products. However, interestingly, a much smaller percentage of respondents are willing to invest in new products and platforms to be able to leverage SBG. By a large margin, they prefer SBG products that easily and directly work on their existing platforms. This finding seems consistent with experts' feedback that indicated NASA will have to demonstrate the utility of SBG and make it easily usable before additional investments in SBG would be made. When asked what NASA could do to de-risk the use of innovative SBG products, these common themes emerged: open access, training, calibrated/validated and documented data, and easily accessible/usable high-level products. Notably, funding (for science) was mentioned only once in all of the survey results.

Primary Application Survey—Distribution

In addition to general questions, respondents chose a primary application survey section.

As noted, the SBG User Needs survey was designed with two main user needs sections—a general section and a primary application section. Respondents could choose to answer questions in one or more of the primary application areas (listed below), which were targeted by the SBG Applications team for this focused user assessment effort.

Which of the following application areas are you and your organization actively involved in, and have first-hand knowledge of?



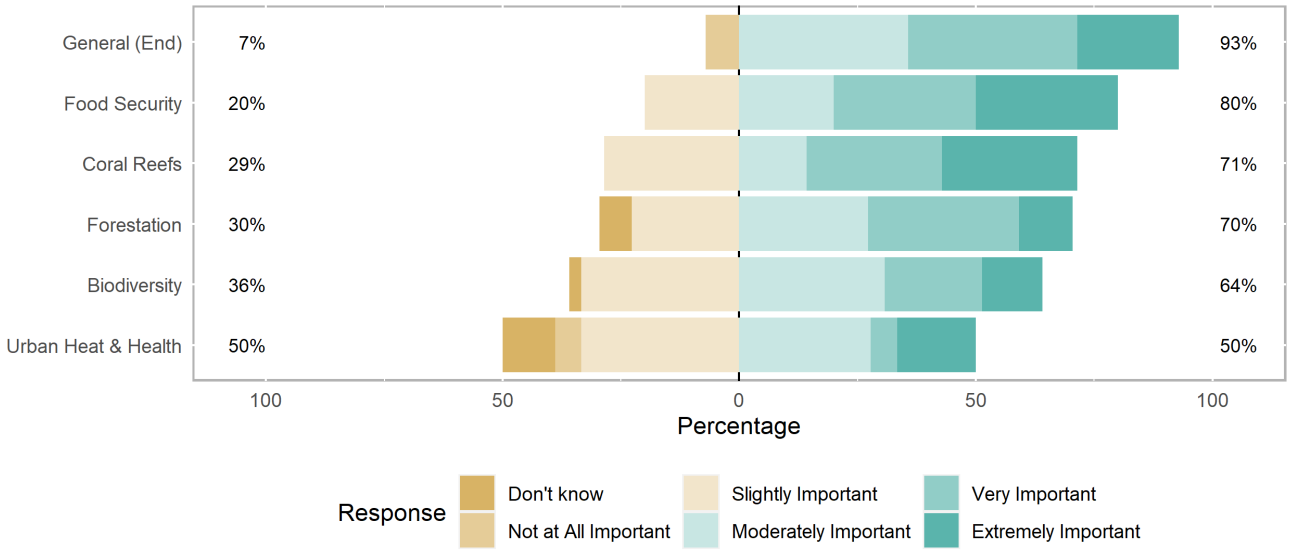
The response counts show the distribution of respondents who then went on to answer a more detailed set of questions about their needs and priorities specific to their chosen application areas. As noted previously, respondents' primary industry or domains were highly aligned with the targeted primary application area questions they chose to answer. This and the response rate per survey section indicate that the survey reached the intended application areas and audiences.

Respondents answering "other purposes not listed here" were directed to the general section, the results of which have been presented in the preceding pages. Summary survey results by primary application area are provided in the Findings section of this report.

Primary Application Survey—Latency

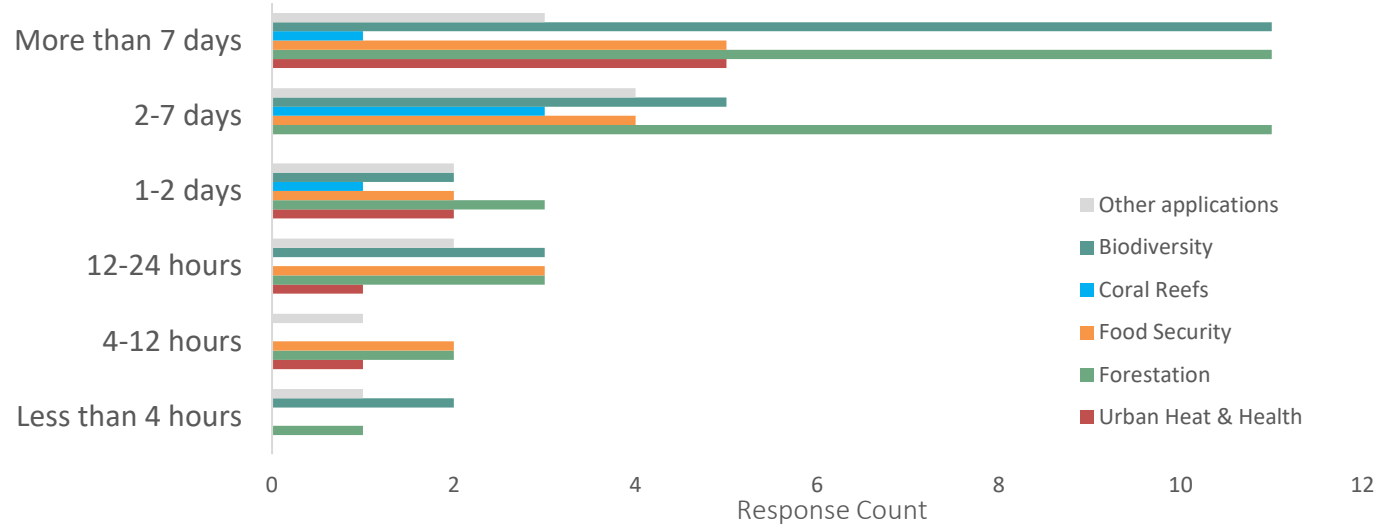
Users in each primary application area value latency differently, and the latency needs vary greatly even within an application area.

How important is latency for the use of earth observation data and products in your primary application area?



Among those who selected that latency was "moderately important" or higher importance:

What latency do you currently require for your application? (Select one only)



The total response rates for the required latency are relatively low and may not be statistically adequate to deduce insights for a single application area. But the response trends for all application areas indicate a majority think that latency of 2 or more days is adequate. Less than 2 days, the stated need for shorter latency periods declines within each application area. More complete application-specific data are provided in the Findings section.

Appendix

SBG Capability Set

Application Area Selection Matrix

Capability sets for the prospective SBG and a baseline "counterfactual" were determined.

RTI worked with the SBG Applications team to determine relevant programs of record and settled on Landsat 8 and Sentinel 2 as valid satellite spectral imaging capabilities to use as existing and "baseline" capability sets. The prospective SBG platform capability sets were communicated with and without capabilities enabled by international constellation. The capability sets were critical to subsequent interview and survey methods and allowed us to connect user needs and valuation research insights back to specific SBG capabilities.

Prospective SBG Capability Set

Capability Set	VSWIR Spatial	VSWIR Revisit	VSWIR Spectral Range	VSWIR Sensitivity	VSWIR Orbit	TIR+VNIR Spatial	TIR + VNIR Revisit	TIR + VNIR Spectral Range	TIR Sensitivity	TIR Overpass Time	VSWIR/ TIR Coincidence
NASA SBG	30 m	16 days	400-2500 nm @ 10nm sampling, 200+ bands	VNIR SNR 400 SWIR SNR 250 5% uncertainty	sun sync orbit 10:45 local time	60 m	3 days	4 TIR + 1 MIR (+2 VNIR channels)	0.2 NEdT or 1K for LST	Sun sync orbit 13:30 local time	Same day (AM VSWIR; PM TIR with NDVI camera)
NASA SBG Plus International Constellation: CHIME, LSTM, TRISHNA	30 m	8 days	400-2500 nm @ 10nm sampling, 200+ bands	VNIR SNR 400 SWIR SNR 250 5% uncertainty	sun sync orbit 10:45 local time	<60 m LSTM 30-50m TRISHNA 50m	1-1.5 day	1.6-12um 8 bands Trishna-4IR, 6 VSWIR LSTM- 3-5 IR, 2 VSWIR, 2MIR	0.2 NEdT or 1K for LST	Sun sync orbit 13:30 local time	With additional VSWIR bands from LSTM & Trishna and VNIR coincidence

"Baseline" Capability Set

Capability Set	VSWIR Spatial	VSWIR Revisit	VSWIR Spectral Range	VSWIR Sensitivity	VSWIR Orbit	TIR	TIR Revisit	TIR Spectral Range	TIR Sensitivity	TIR Overpass Time
"Baseline" Existing Observing System Platforms*	30 m	16 days	430-900 nm VNIR – 5 bands, 2 SWIR bands at 1570 - 1650 nm and 2110 - 2290 nm	SNR ~200	sun sync orbit 10:45 local time	100 m	16 days	2 bands in 10.6 – 12.51 um	0.4 NEdT for 300K for LST	Coincident with VSWIR

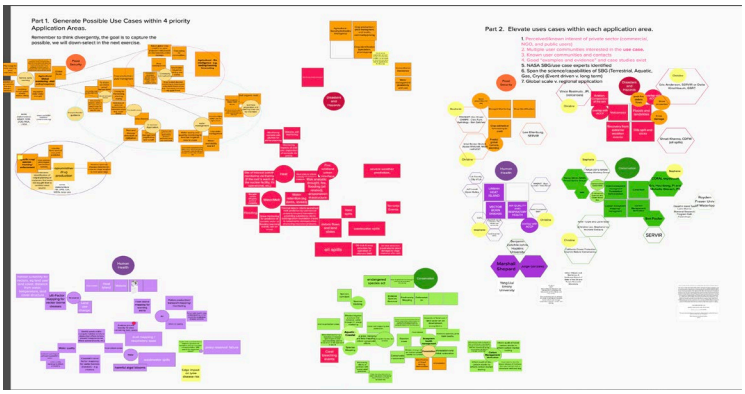
*Based on Landsat 8 and Sentinel 2 capabilities

RTI facilitated a virtual white boarding session to generate a preliminary list of applications.

Mural Session with SBG Applications Team

Generate a comprehensive set of possible applications four priority domain areas, not covered in the previous study:

1. Food security
2. Disasters and Hazards
3. Human Health
4. Conservation



Possible Applications within Four Domain Areas

Human Health	Disasters and Hazards
• Urban Heat Islands • Vector-borne Disease • Air Quality and Respiratory Health	• Volcanic Ash – monitoring • Flood, landslides (including snow properties) • Oil Spill • Recovery from extreme weather events
Conservation	**Food Security**
• Inland Ecosystem Management – Forestation/Deforestation focus • Coral Reef • Coastal Ecosystem Mapping/management • Carbon Stock Management/Verification	• Agricultural Global/Regional Response • Agricultural Business Intelligence- supply forecasting • Specific Crop/Species Surveillances – Identification/tracking/enforcement

SBG interviews and secondary research informed a down selection evaluation matrix.

Extensive research expert interviews in conjunction with the SBG Application Team leads, enabled key applications to be assessed and down-selected. All promising applications were scored using an evaluation matrix. Numerical scoring criteria were constructed to enable a semi-quantitative analysis of the applications. Highest scoring applications were chosen for detailed investigation in the next phase of the RTI process. The scoring criteria considered the value SBG might uniquely provide to an application area, the feasibility of RTI's assessment of that value, and the level of effort necessary to reach private- and public-sector users and user communities "not traditionally engaged" by NASA.

Application Evaluation Matrix

	Value Proposition	Rate (1-3)	Feasibility of Communicating Value	Rate (1-3)	Experts	Rate (1-3)	User Community	Rate (1-3)	Research Depth Required	Rate (1-3)	Feasibility of Assessing Value	Rate (1-3)
Evaluation Criteria	Assumed SBG differentiator		Case studies mentioned		Additional known experts posited		1-2 User communities identified		Limited research required for baseline understanding		Clear incremental value of SBG	
	Multiple specific points of differentiation		Known literature with artifacts to demonstrate SBG differentiator		Reference to leads for experts for valuation or use cases		User communities have established lists or databases		Specific leads provided and no additional lead finding required		Possible approach but will require multiple points of validation	
	Solidly confirmed value proposition by expert		Easily gather from first round experts		Direct contact with experts for valuation and use cases		User community has sophisticated users		Direct point of contact in user community and to relevant experts		Body of literature/data on existing valuation approach	
Score	*Summation*		*Summation*		*Summation*		*Summation*		*Summation*		*Summation*	

The selected application areas align with SBG SATM and accessible user communities

Application Evaluation Matrix Results

	Urban Heat Island	Volcanic Ash	Inland Ecosystem Management	Coral Reef	Agricultural Global/Regional Response
Value Proposition	7	3	6	6	6
Feasibility of Communicating Value	8	4	8	8	8
Known Experts	7	3	6	4	8
Known User Community	7	3	9	4	7
Research Level of Effort	7	4	6	3	6
Feasibility of Assessing Value	8	3	8	4	7
Score	44	20	43	29	42

Highest ranking application areas were selected for investigation after confirmation with the SBG applications team.

Primary Applications Selected by SBG Applications Team

Inland Ecosystem Management

- Urban Heat & Health
- Forest Management
- Coral Reef Ecosystems
- Global Food Security
- Conservation & Biodiversity