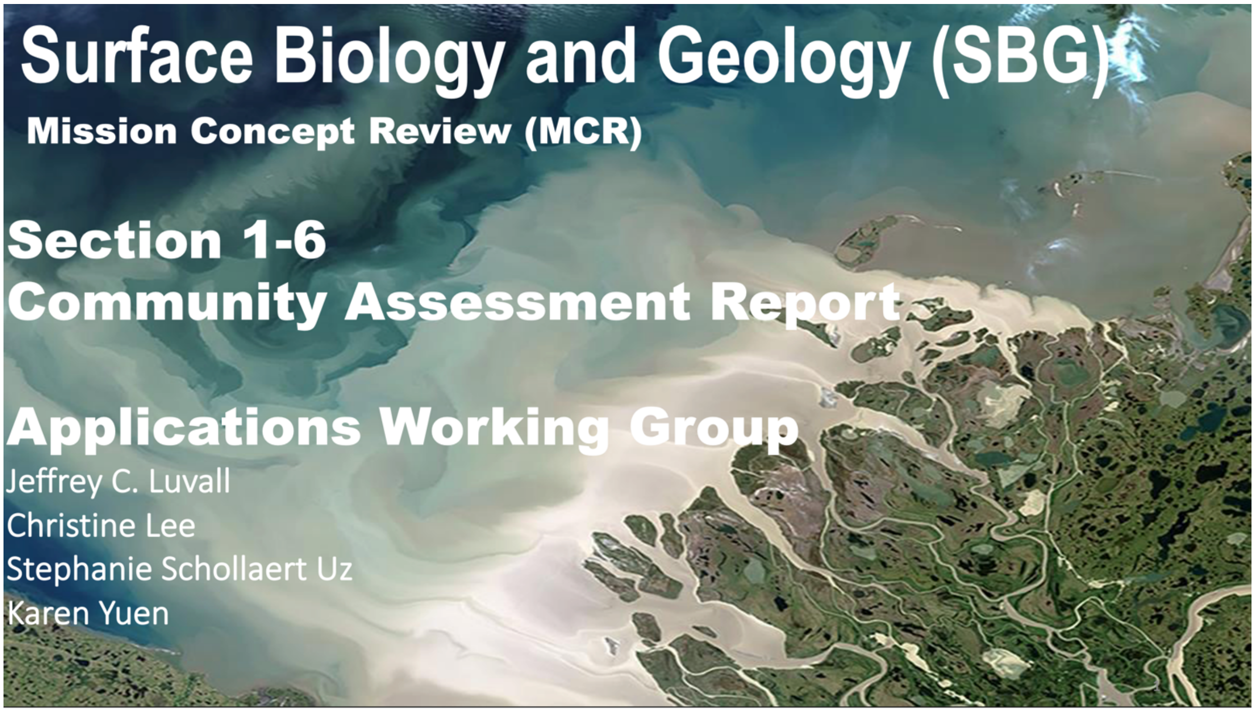

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EXECUTIVE SUMMARY

The Surface Biology and Geology concept is the first NASA Earth mission to develop and implement systematic integration of application needs at the pre-formulation stage as part of Dr. Michael Freilich, director of the Earth Science Division in the Science Mission Directorate 2016 memo "Directive on Project Application Program. Prior NASA mission pre-formulation activities presumed that science measurement needs would encompass application measurement needs so did not explicitly evaluate and include these at this stage; however, this effort identified, documented and integrated application needs that would not have been included by considering science needs only. Furthermore, NASA Earth Science seeks to increase the public use of its research and technology investments by enhancing the applications value and overall societal benefits of Earth observing satellite missions. The *Directive on Project Application Program* urges new NASA Projects to engage a community of users to work with the project throughout the mission life cycle – from input to initial design considerations, to feedback and advocacy in formulation and development, to communication of uses and societal benefits from the mission.

The Community Assessment Report (CAR) serves as the ongoing record for tracking the preparation, assessment, studies and analyses during this novel integrated process, and represents the progressive culmination of the Applications Working Group activities, along with the user communities, to benefit the development of a new NASA project. A key motivation of the assessment and CAR is to expand the breadth and types of non-research uses and users beyond traditional, known, or assumed ones. The assessment spans both technical aspects and organizational characteristics of the user communities. The CAR captures information on applications opportunities, and it is intended to help the flight project become aware of the mission's potential applications value and key "desirements" (NASA term coined by the late Michael Freilich meaning unfunded requirements) of user communities needed to realize that value. The CAR's information is intended to inform system architecture options, design considerations, trade-off decisions, and the overall mission concept.

The CAR will serve as an on-going reference document, and information resource for the project team, Program Executive (PE), Program Scientist (PS), Program Applications Lead (PAL), and others throughout the mission lifecycle. For example, information in the CAR supports a substantive Project Applications Plan (PAP), recruitment of prominent Early Adopters, and creation of illustrative use cases to attract users. Thus, a high-quality CAR supports the flight project and optimizes the potential societal benefits (beyond research) of a mission. As new information emerges during the lifecycle, updates to the CAR will be made.

The applications community was energized and played an active role with SBG by participating in a wide range of SBG Applications Working Group (AppsWG) activities - webinars, RTI user need's surveys and interviews, and in the development of the Applications Traceability Matrix (ATM). To date, the SBG applications community is large, and includes stakeholders ranging from Non-Govermental Organizations (NGO's), private companies, consultants, state, and local governments to more traditional users in universities and federal government. The interest and the importance of SBG applications are reflected in user statements from among the 94+ potential user interviews conducted by RTI as part of the two User Needs and Valuation Studies:

Fire Ecology and Risk

"*SBG would be most effective at the pre-fire stage, providing key data to improve fire risk modeling.*" Technosylva, Inc.

Agriculture and Water Resources

"*SBG would enable variable-rate fertilizer applications to be more dynamic. Farmers could improve profits with mid-season adjustments*." Cloud Agronomics CEO

Mineral Resource Mapping

"*SBG could be a game changer, enabling mining discoveries and uses at reduced cost. NASA should enable data access and usability.*" Principal Spectral Geologist Anglo American

Conservation and Biodiversity

"*Using HIS (VSWIR) for direct measures of species and composition is a game changer*!"

Biodiversity, Ecosystem Knowledge and Services CSIRO

Integration of Applications into SBG Mission Planning

The direct inclusion of the applications team as one of four co-equal groups in the Surface Biology and Geology Research & Analysis (SBG R&A) construct allowed for continuous feedback and integration of the end-user community perspective and needs into the architecture study process. There were four main activities over the course of the architecture study that resulted in the integration of applications considerations into SBG architectures. These activities were coordinated via the SBG Applications Working Group (AppsWG) and include:

1. An Applications Traceability Matrix (ATM) that documented SBG-enabled applications, along with their associated measurement needs, independent of Decadal Survey (National Academies of Sciences and Medicine, 2018) driving science objectives.
2. Expansion of the Science Traceability Matrix (STM), a tool used by mission study teams to show traceability from Decadal Survey priorities, the requisite geophysical parameters needed to address those priorities, and the capabilities necessary to produce those geophysical parameters (Weiss et al., 2005), to include applications. This resulted in forming the first Science Applications Traceability Matrix (SATM) that identifies feasible applications within the context of science objectives and demonstrates traceability from the Decadal Survey to applications.
3. The AppsWG analyzed trades across disciplines and application domains for different capabilities and needs to assess impacts of different mission architecture design decisions.
4. Finally, the AppsWG assessed the applications value as an intrinsically important context that can help improve partnerships with the external community.

Impacts of Applications on Mission Architecture

Latency and Temporal Analysis based on the SATM

The latency analysis based on the SATM was used as part of a guiding document informing the architecture engineering design sessions that evaluated candidate architectures for SBG. Latency is defined in the SBG study as the time between data acquisition and data access by users. Each applications entry includes a maximum latency for enabling decision-support (Fig 1.). The assessment of 10 candidate architectures for applications value showed that the engineering design sessions accounted for low latency targets consistently across the architectures, for all visible-shortwave-infrared (VSWIR) and thermal infrared (TIR) configurations, demonstrating that the integration of the applications perspective within the architecture study was useful at propagating an applications-specific design target through to the architectures.

Key Application Driver: *A 24 hour latency (acquisition to L2+) would enable* ***78%*** *of applications possible with the current capability set (Stavros et al., 2022.), which is the maximum possible in the current configuration.*

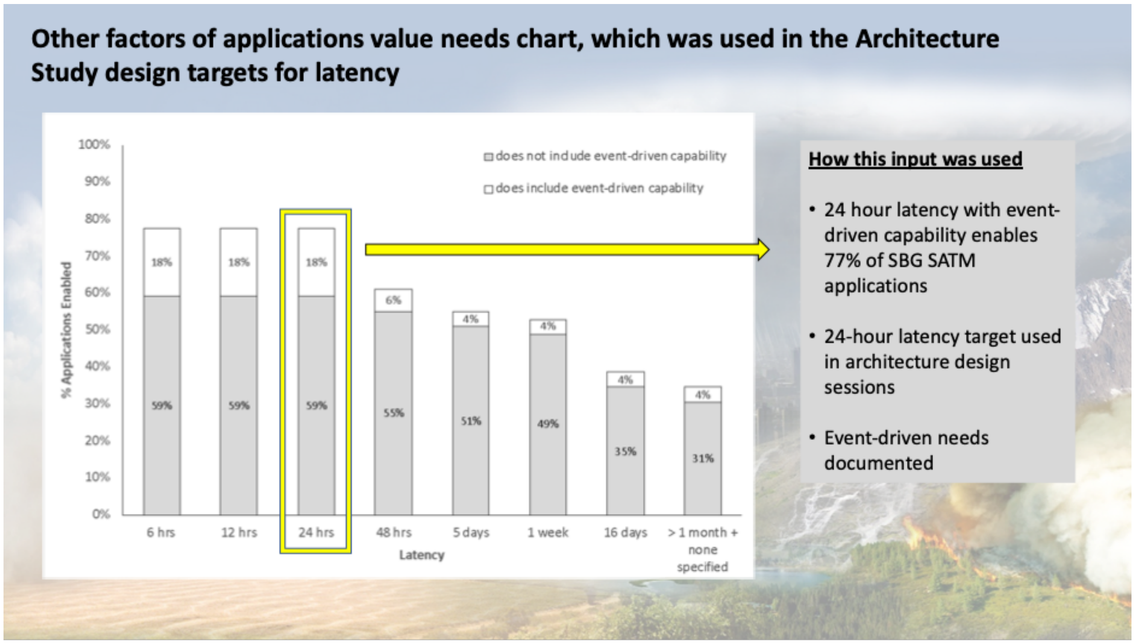

Figure 1*. A 24 hour latency (acquisition to L2+) would enable 78% of applications possible with the current capability set ((Stavros et al., n.d.)), which is the maximum possible in the current configuration*

The combined need for frequent revisit and sensor combinations that included coincident TIR and visible-near-infrared (VNIR) observations for evapotranspiration and cloud filtering were important in determining revisit frequency (Cawse-Nicholson et al. 2021) (Fig. 2). TIR and coincident VNIR measurements enable critical applications that involve supporting active wildfire situational awareness, water resources management, and weather forecasting. Geologic and solid earth applications tended to have greater flexibility with temporal revisit. (Particularly for mineralogy and resource mining); most of the applications for solid earth captured at this stage in the study were related to hazard response, such as active volcanoes and landslides in part because there would likely not be additional temporal revisit targets required for those applications. Mineralogy and resource mining applications, while not featured in this figure, were central to the SBG (Schollaert Uz et al., n.d.).

Key Application Driver: *A 1 day revisit of both VSWIR with TIR/VNIR satisfied the greatest number (78%) of the 49 enabled applications' temporal needs.*

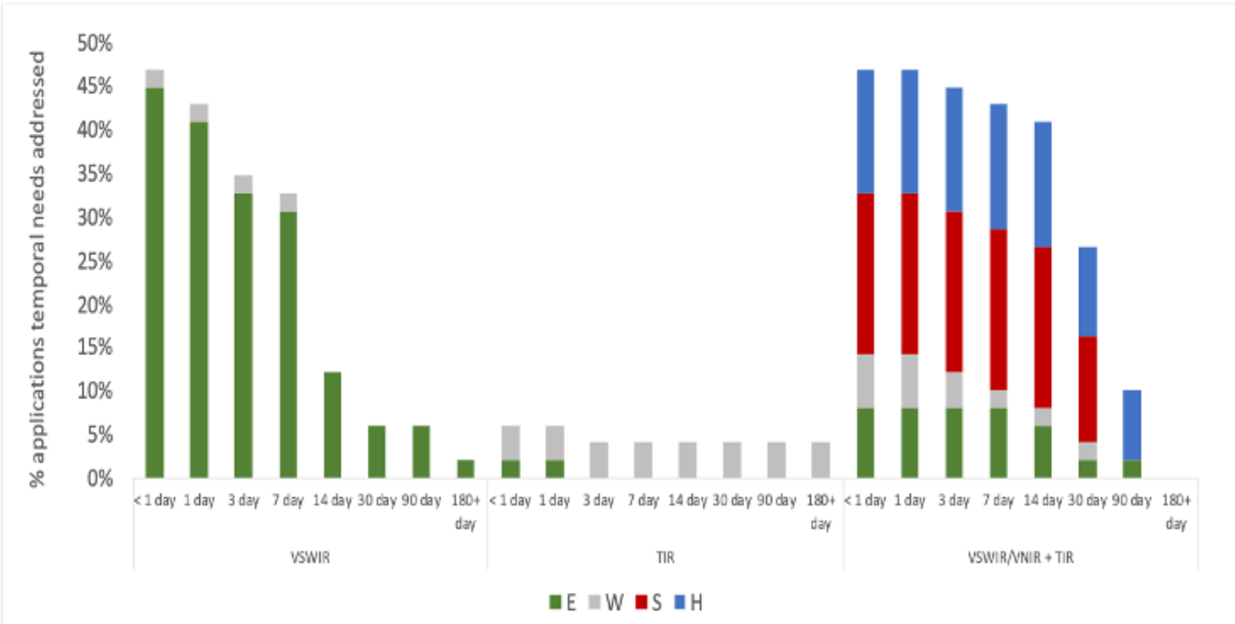

Figure 2. *This figure shows the combined needs for applications around VSWIR and TIR/VNIR sensor targets along with more frequent revisit. The four column (VSWIR, TIR/VNIR) is intended to show the combination of sensor / temporal revisit targets that would enable the maximum number of applications. Steep drop-off in revisit is driven by terrestrial and coast seasonal cycles given cloud cover for VSWIR and rapid changes to LST for TIR as well as need to monitor rapidly evolving events – e.g., natural hazards, oil spills, agriculture.*

Key Application Driver: *Inclusion of a Visible Near InfraRed camera (VNIR) with the TIR platform for coincident NDVI, cloud screening and thermal measurements – largely to improve evapotranspiration estimates.*

With the planned SBG mission configuration, the Thermal infrared (TIR) sensor is not co-located on the same platform as the VSWIR instrument. Algorithms used to estimate evapotranspiration require co-acquisition of VSWIR or VNIR for albedo or Normalized Vegetation Difference Index (NVDI) determination in combination with TIR. Anderson el, al 2021 determined that the time separation between acquisition of TIR and VSWIR inputs used in DisALEXI to calculate evapotranspiration have significant impact on the surface energy balance algorithms that require land surface measurements of temperature, surface albedo, and vegetation cover amount.

Key Application Driver: *The addition of a 4um channe (MWIR) to support the high temperature characterization of fires and volcanoes.*

Documented in the *HyspIRI Hight-Temperature Saturation Study* (Realmuto et al., 2011), the optimum wavelength for measuring high temperature targets is the 4um channel within the Mid wave-infrared (MWIR). The addition of a 4um channel within the MWIR spectral range, would allow the measurement of "hot target" measurements at 1200 Kelvin and would allow the calculation of Fire Radiative Power (FRP) or Volcanic Radiative Power (VRP) for the characterization of fires and volcanoes. FRP is a standard product for MODIS, VIIRS, Sentinel-3 and geostationary satellites. SBG would produce more spatial detail producing high-quality fire intensity measurements that will allow optimized relationships between environmental factors and fire behavior, ultimately providing better predictions of fire behavior and aiding active fire management (K. Cawse-Nicholson et al. 2021). Volcanoes are a growing hazard to large populations. The 4um channel is critical for measuring noticeable changes in volcano temperatures that precede and occur during eruptions. These measurements are key inputs as part of the decision support system providing the disaster managers the ability to make decisions about preparation and evacuation.

Range of communities involved and engaged

A fundamental aspect of the CAR was to engage the private-sector, nongovernmental organizations (NGOs), and local municipal Earth Observation (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. Ultimately both nontraditional and traditional users proved to be the most useful categorization and were used to guide the primary and survey research efforts.

Both (SBG User Needs and Valuation Study; 2020, 2021) targeted a diverse and representative set of nontraditional and traditional user types across the value chain for nine primary application areas (Fig.3). In the first survey more traditional users responded to the survey along with being interviewed. On average, more interviews per application area were done in a second study, and the total interview count was higher due to the inclusion of 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.

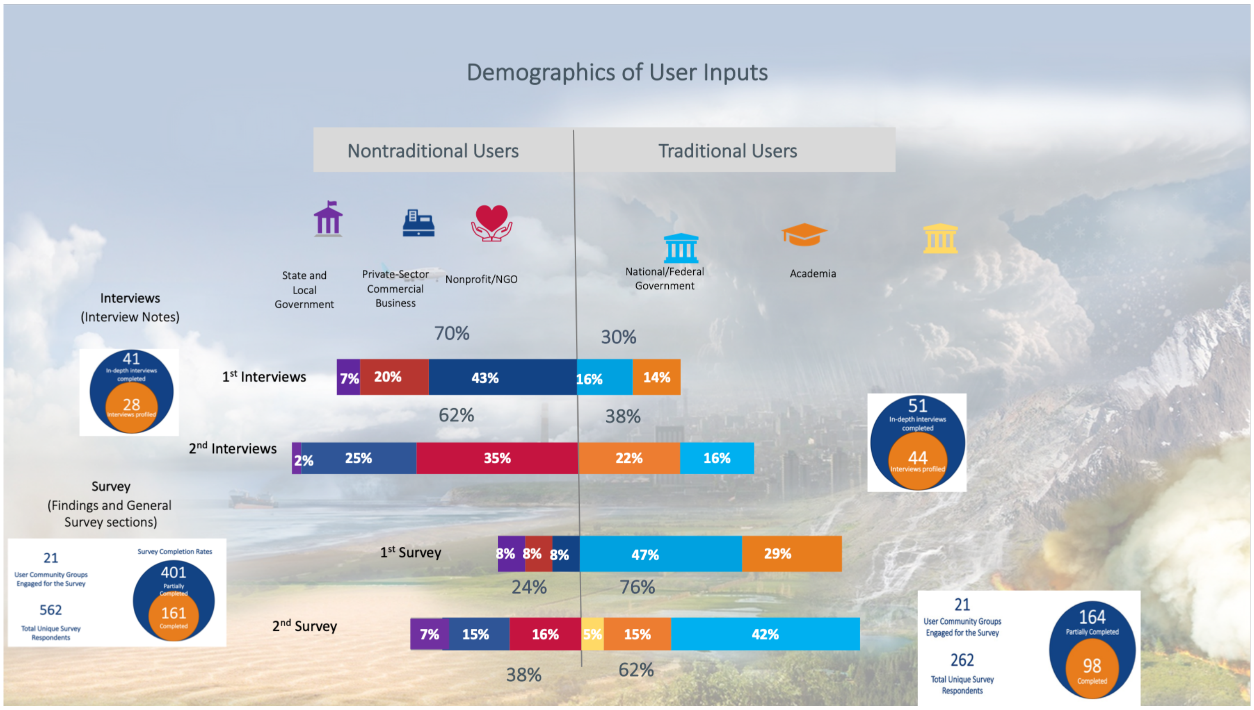

Figure 3. *Both studies included a diverse and representative set of user types across the value chain for each of the nine primary focus application areas studied.*

Assessment & Characterization

The central research objective of these studies 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 (RTI Innovation Advisors) 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 remote sensing data. The most cited needs and jobs to be done, as use cases, are summarized below (Fig. 4).

Application Area	Key Potential Users of SBG Data/Products	Key Potential Use Cases of SBG Data/Products
Fire	• State and local fire authorities/responders • Commercial utility companies • Fire risk map/model developers/providers • Prescribed burn companies and regulators • Insurance companies	• Pre-/post-fire fuel mapping of vegetation type, live/dead, moisture for risk severity • Fire risk model via better fuel/moisture data • Utility vegetation management, risk mitigation, and operations/planning changes
Agriculture	• Ag input and equipment companies • Crop consultants, large-farm managers, commodities traders, and insurers • Ecosystem market communities • Ag/water resource/policy managers	• Ag and water resource, drought monitoring • Crop type/composition/health monitoring (for ag policies, supply chain, input optimization) • Crop residue/monitoring (e.g., for credits, monitoring, reporting, and verification [MRV]) • National food security/yield forecasting
Algal Blooms	• Local health/environ./water agencies • Aquaculture (fish/shellfish) companies • Drinking water utilities/engineering firms • Forestry/lake management companies/orgs	• Regional-scale water body quality monitoring • Early warning of harmful algal blooms (HABs) • Shellfish site water chemistry for growth/health • Watershed/source pollution/nutrient monitors
Mining	• "Spectral geologists" and exploration consultants for large mining companies • Regulatory/compliance organizations • VASPs serving the energy and mineral resources sectors	• Greenfield/brownfield large-area explorations • Geologic process, mineral/vegetation surveys • Mine opening/operations baseline/monitoring • Environmental/health/regulatory monitoring on-site and in surrounding environs
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,** sub-stand 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

Figure 4. *Potential users across application areas were considered, as were their needs, and how those needs might be met with SBG data.*

The survey findings from the second survey highlight that over 80% of respondents believed that SBG's higher quality data and data products will improve sensitivity and fidelity ranging from moderate to significant compared with their current observation methods (Fig 5).

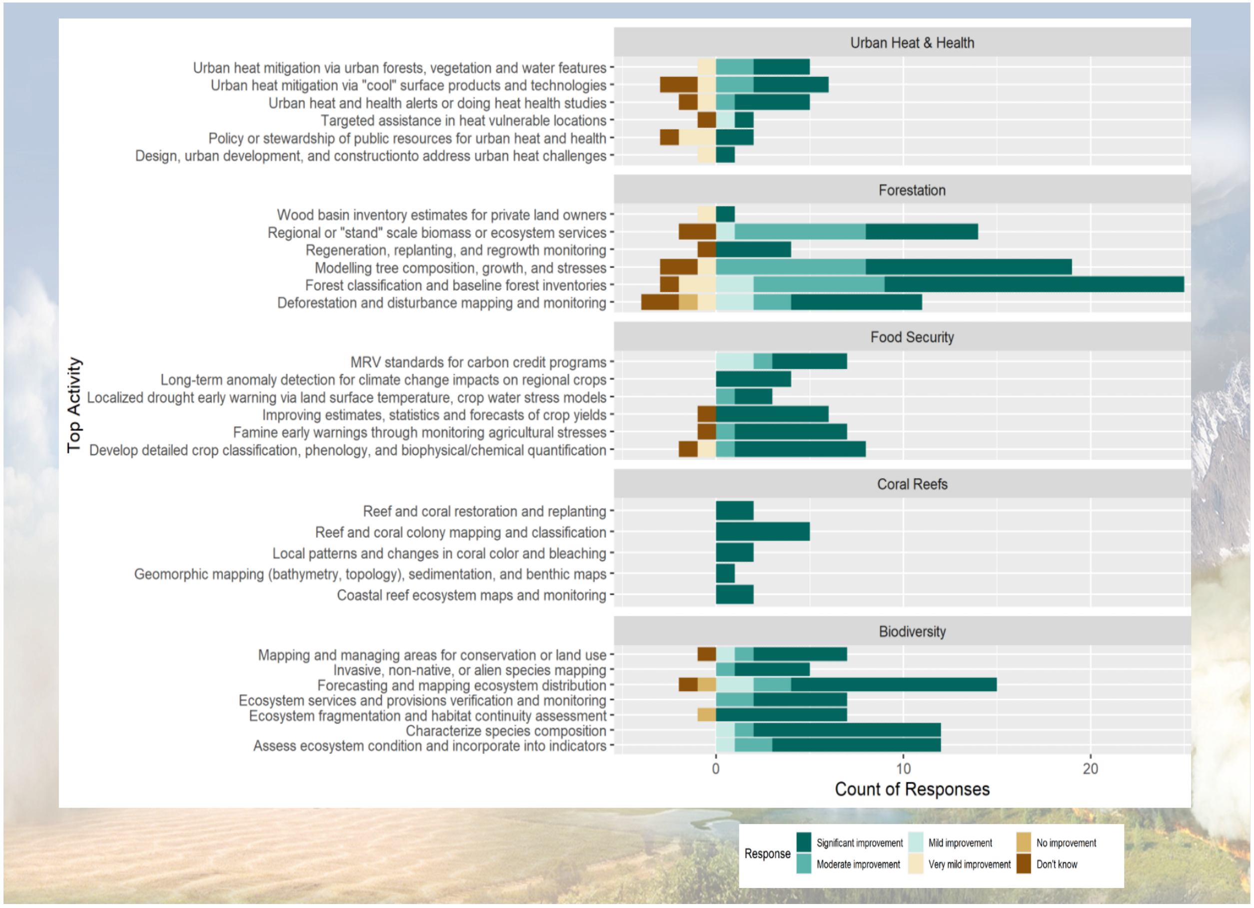

Figure 5*. The extent to which SBG's overall increased sensitivity and fidelity will provide benefit for your top 2 activities by application.*

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 VSWIR for spectral classification of terrestrial and aquatic species and by filling current observation gaps with better spatial and time- resolved thermal data (Fig 6). 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. Several non-research end-user interviewees also lacked the technical or operational background to assess the importance or value of specific SBG capabilities.

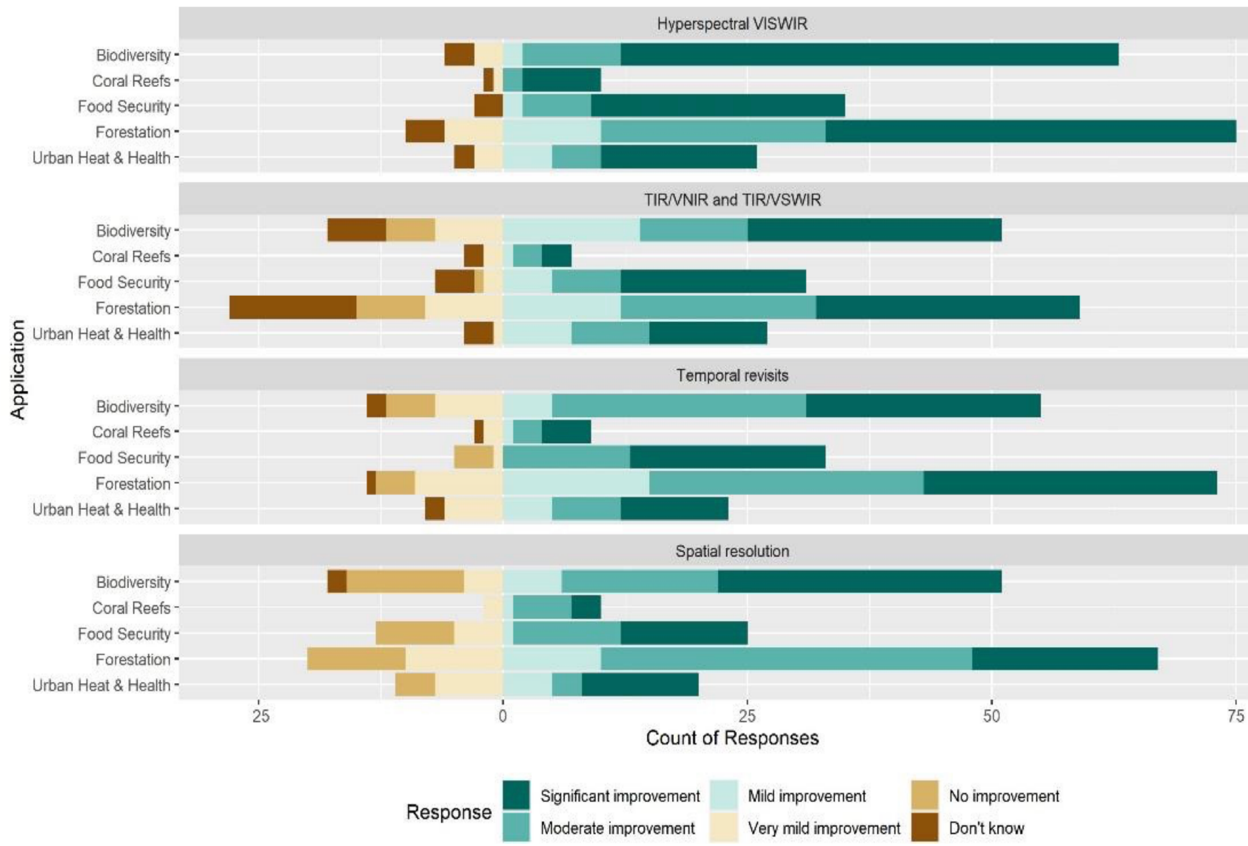

Figure 6. *The extent of specific SBG capabilities that provides benefits for the top 2 activities by application areas.*

Management Needs- Spatial and Temporal Scales

Private-sector and nongovernmental end users look to remote sensing 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. Non-research 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 (Figs. 7 & 8).

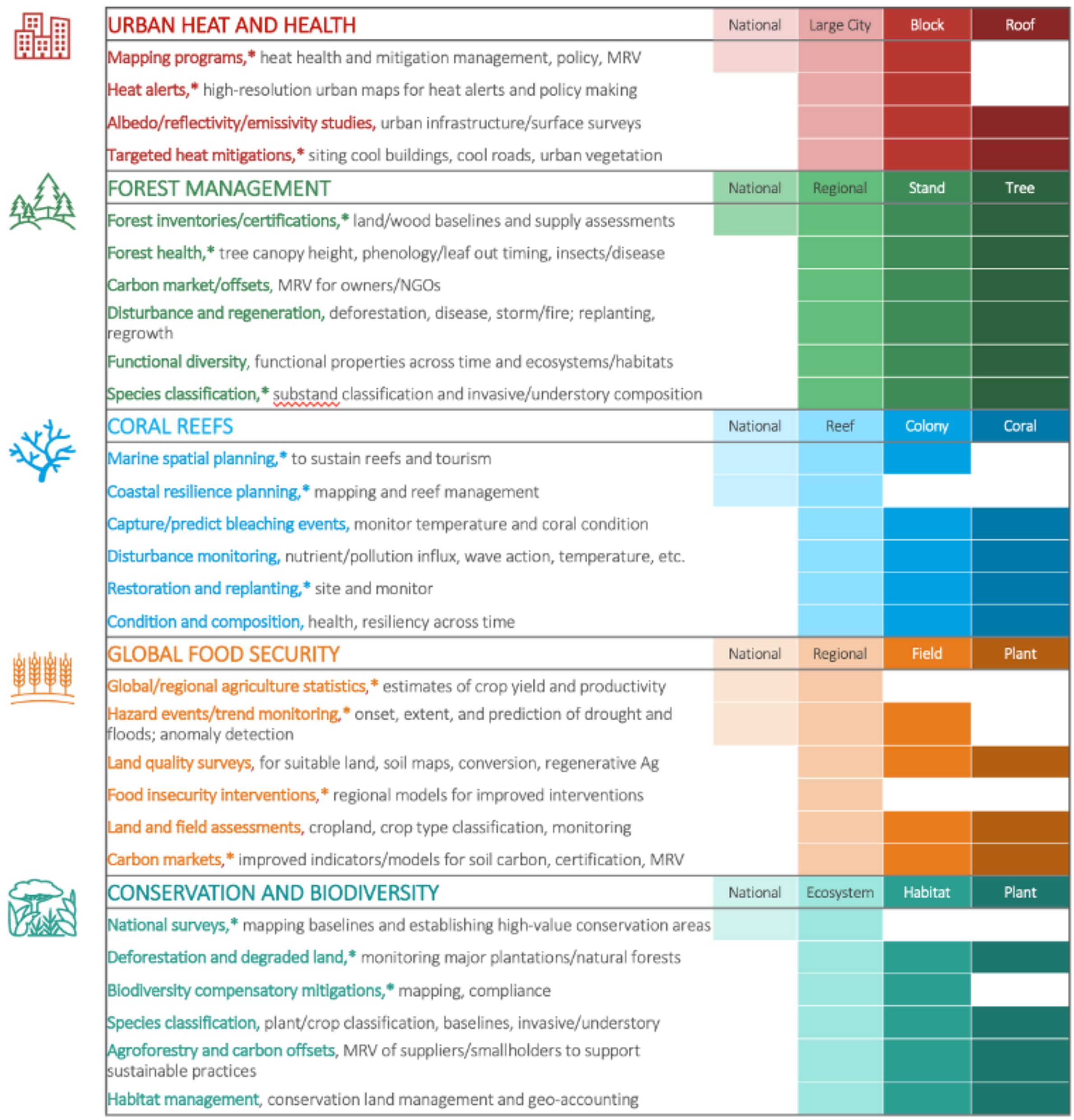

Figure 7. *Management scale needs.*

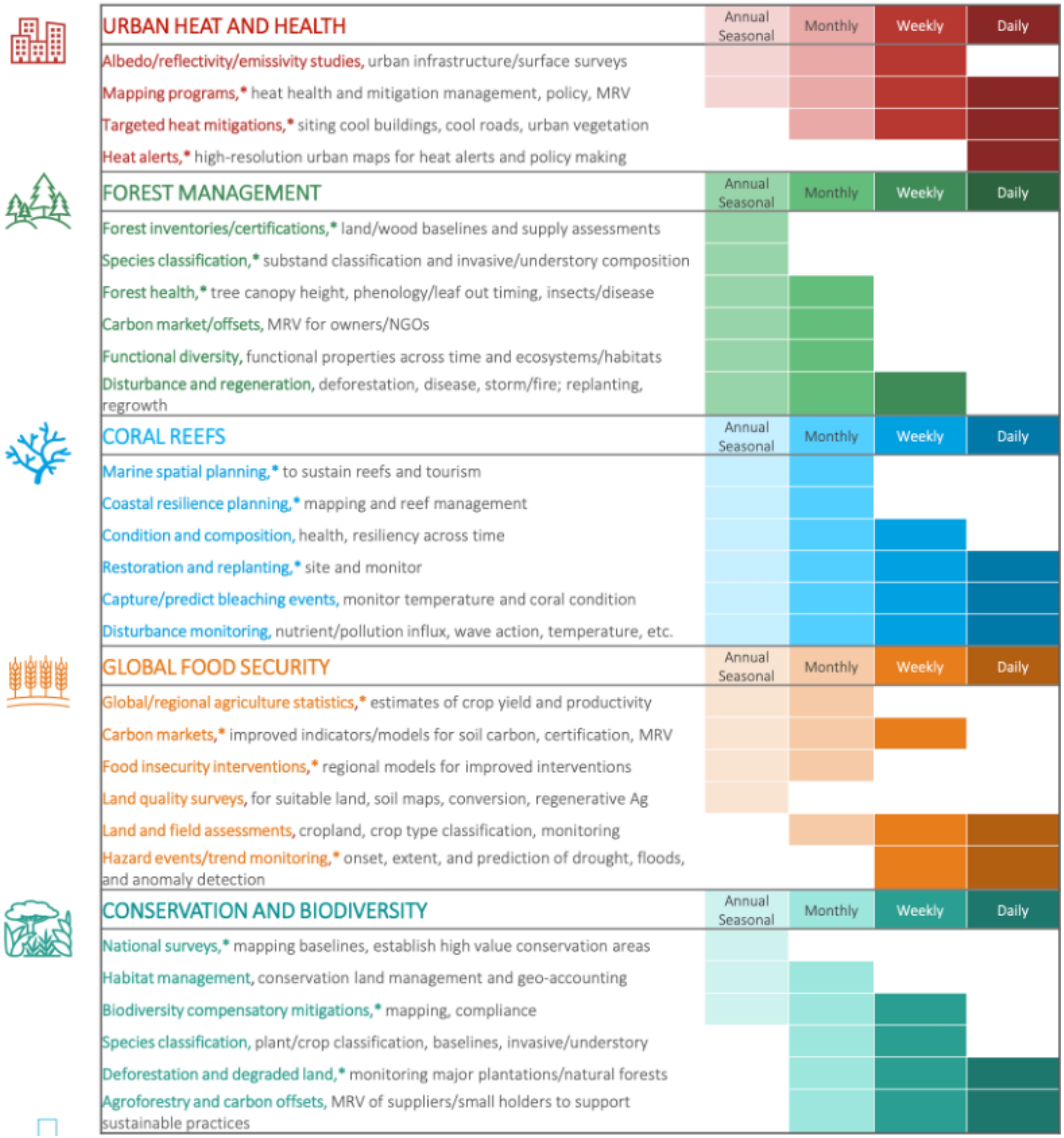

Figure 8. *Management time response needs.*

Findings and Implications

User Readiness

Communities with practitioners and innovators already actively working with remote sensing and Earth observation data (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. The future adoption and use of SBG data hinge on the "readiness" of each potential user community. The technical readiness to assess was defined:

1. 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.
2. The technical literacy and sophistication of a community in its current use of EOD.

The 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 non-research communities of end users and Value Added Service Providers (VASP)s, not for the scientific research community (Fig 9).

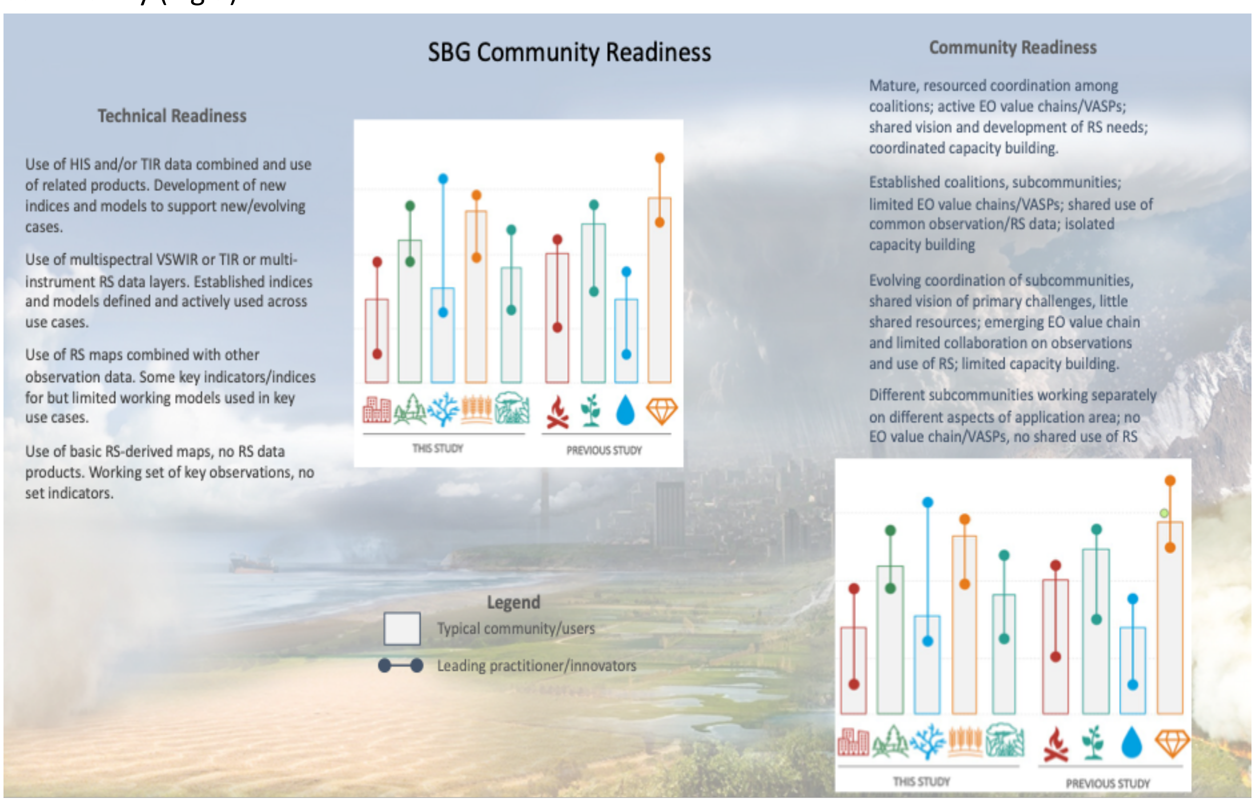

Figure 9. *SBG technical and community readiness to utilize SBG data sets.*

Value Chain

Community Overview

Value Added Service Providers (VASPs) and boundary organizations worldwide serve as a key part of the Earth observation (EO) value chain integrating remotely sensed data into products for the commercial, non-governmental organizations (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 specialists 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 VSWIR and TIR from various sources has demonstrated SBG's potential. Practitioners are excited about the prospects of satellite VSWIR 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 not want to adapt atypical, unsupported, or developmental data types.

OVERALL FINDINGS & IMPLICATIONS

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. User engagement and feedback should continue with a broader set of user types and 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, the CAR offers the following recommendations, some of which are specific to SBG, while others are applicable to all of the DO missions:

1. For SBG to yield value beyond the science, NASA must commit to extensive development work. It is apparent from the RTI surveys, and the information synthesized for the CAR, that NASA will need 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 hyperspectral data 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 hyperspectral and TIR and related products. Based on the preliminary surveys and reports conducted by RTI and the AppsWG, many applications and communities of potential for SBG exist, and they will extend well beyond what these first studies explored.
2. 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. 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").

3. 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, non-research users. NASA should work with the noted communities of practice, those with high readiness, and skilled hyperspectral 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.

INTRODUCTION

Surface Biology and Geology (SBG) Designated Observable

The National Research Council (NRC) 2017 Earth Decadal Survey (ESAS 2017) recommended a new NASA "Designated" program element to address a set of five high value Designated Observables (DOs) during the next decade. The Surface Biology and Geology (SBG) Designated Observable will enable improved measurements of Earth's surface and atmospheric characteristics that provide valuable information on a wide range of Earth System processes. The specific SBG observations include surface biology and geology, functional traits of terrestrial vegetation and inland and near-coastal aquatic ecosystems, active geologic processes, ground and water temperature, gross primary production (GPP), and snow spectral albedo.

SBG APPLICATIONS WORKING GROUP OVERVIEW

The Surface Biology and Geology concept is the first NASA Earth mission [1] to develop and implement systematic integration of application needs at the pre-formulation stage as part of Freilich's 2016 "Directive on Project Application Program". Prior NASA mission pre-formulation activities presumed that science measurement needs would encompass application measurement needs so did not explicitly evaluate and include these at this stage; however, this effort identified, documented and integrated application needs that would not have been included by considering science needs only. As a result, an Application Working Group Committee (AppsWG) was established in September 2018 with Jeff Luvall (MSFC), Christine Lee (JPL), Natasha Stavros (JPL), and Nancy Glenn (Boise State). Christopher Hain (MSFC) joined in March 2019, Stephanie Schollaert-Uz (GSFC) joined in October 2019 and Karen Yuen (JPL) joined in July 2020. The overall goals are to recruit, coordinate and integrate input on applications needs, data product requirements and training/education and other needs.

The primary goal was to maximize the benefit of the NASA's Earth Science Division (ESD) investment by enhancing the applications value and overall societal benefits of projects through:

1. Scoping and developing applied research and applications as part of the overall observing system concept
2. Demonstrating the system's benefit to and impact on society
3. Identifying specific product applications and Communities of Practice to better understand the impacts and benefit from using products and models derived from the observing system's measurements and associated analyses
4. Increasing the utility of data products; and
5. Fostering a Community of Practice that can work with the designers and implementers of the observing system throughout the system's life cycle.

Charter

The SBG Applications Working Group Committee established a charter for broader community participation in the public SBG Applications Working group (AppsWG) with the goals:

• Identify key applications of the Decadal Survey science questions, including capability needs, latency, and data products. This information is developed into an Applications Traceability Matrix that directly supports the creation of the Science and Applications Traceability Matrix (SATM).
• Characterize SBG communities of practice/potential and understand value-added SBG data products. This information can then be used to assist with the development of the Value Framework.
• Engage SBG community via joint activities, workshops, and design/dissemination of tailored SBG data. The HyspIRI precursor study engaged a large and active imaging spectroscopy community. We aim to continue these efforts in order to provide a dynamic discussion and information to be ready to implement earth observation spectroscopy data.

The Applications Working Group (AppsWG) has over 225 members, including those from the public and private sector, universities, non-profit, non-governmental and governmental organizations (US/non-US, federal, state, regional and local (Figure 1). The membership is open and active. The representation is heavily weighted by US Federal agencies (44%) and University (40%). We are actively seeking participation from sectors under-represented, which will be supported by the Community Engagement efforts. An additional area of growth will be in international partnerships with future planned NASA agreements with CHIME, LSTM, and Trishna. The AppsWG leads maintain an open process for participation and membership upon request through the opt-in email subscription (http://tinyurl.com/SBGApplicationsWG). Through this sign-up we ask for voluntary information of participant organizational affiliation, application areas of interest, current partnerships and prospective partnerships.

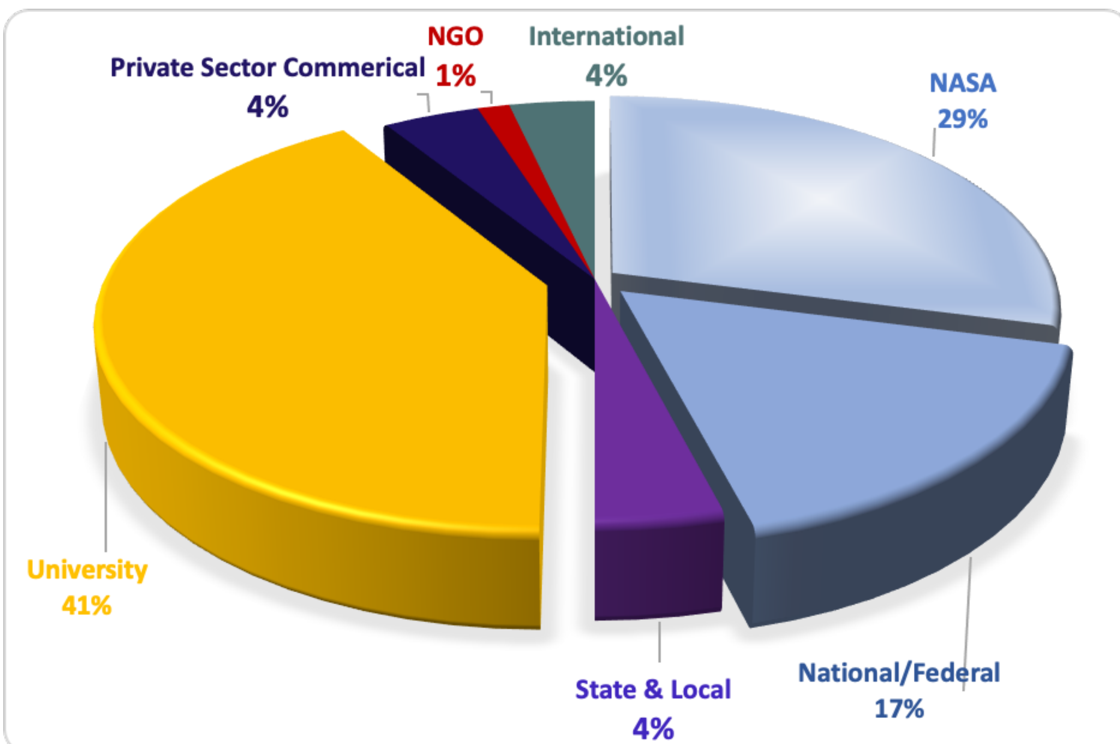

Figure. 10. *Sector participation in the SBG Applications Working Group. As of May 2022, there are approximately 225 participants.*

Community Engagement

The AppsWG leads engaged with members in several key-ways: (1) announcements and news updates by email; (2) a public working group repository for sharing documentation available on a Google shared drive by signing up to participate in the APP-WG (3) monthly AppsWG calls with the community, including community presentations (4) personal (one-on-one or small group) communications and (5) engagement through community conferences (e.g. AGU) and the SBG community workshops. Through these engagements and interactions, the AppsWG provided direct input and the first joint deliverable for the SBG Study – the Science Application Traceability Matrix.

The Kick off AppsWG webinar was held December 6, 2018 with approximately 25 individuals representing a broad segment of the applied science community. The SBG study scope, observations and product priorities were explained. Over months, the study leads, and the broader community co-developed the Application Traceability Matrix (ATM; Section 3.2) as well as presentations and posters for the SBG Community Workshop in June 2019. The AppsWG prepared six core focused application areas posters (Figure 2) - *Natural Geologic Hazards, Surface Composition and Mineralogy; Terrestrial Ecosystems Management- Carbon and Conservation, Wildfires and Restoration; Public Health and Urban Planning; and Water Resources and Agriculture.* These posters were designed to foster an understanding and exchange of ideas on the process used to develop the SBG ATM as well as solicit feedback from the community. The applications community provided an additional 12 posters.

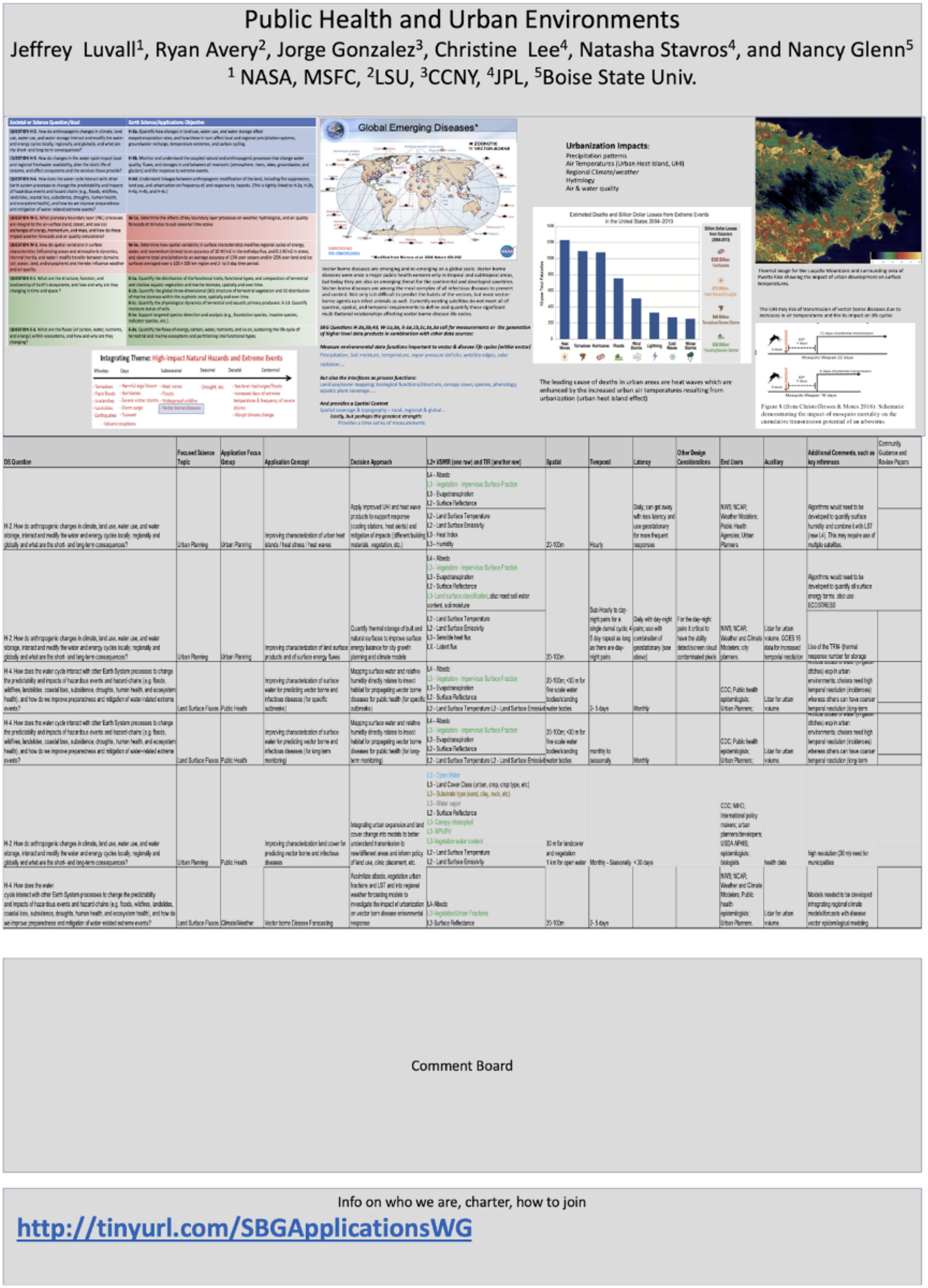

***Figure 11**. Example Poster that showed the discipline-specific Application Traceability Matrix presented at the June 2019 SBG Public Meeting.*

Through May 2022, 36 webinars were held (Appendix, Table 1). Presentations covered a wide range of topics directly linked to the Decadal Survey Science questions. "Deep-dive" webinars provided focused presentations from applications scientists that were actively working on applications aligned with the Decadal Survey Questions and were using various combinations of modeling, aircraft and satellite-based measurements that would be significantly enhanced through the use of SBG datasets. Additional presentations: "Global Hyperspectral Imaging Spectral-library of Agricultural-crops (GHISA)) in Support of NASA's SBG", "USGS National Land Imaging (NLI) Program", "NASA SpoRT A Research-to-Operations Paradigm and Opportunities with SBG Applications", and "NASA's Land, Atmosphere Near real-time Capability for EOS (LANCE) Supports Users in SBG Application Areas" provided information on programs that provide significant support to the current applications community and would be an important resource to the future SGB applications community.

OVERVIEW OF APPLICATIONS INPUT TO SBG

There were four main activities that provided applications input to mission planning over the course of the pre-formulation study. First, the AppsWG developed an Application Traceability Matrix to document all SBG data applications, independent of Decadal Survey (NRC 2017) driving science objectives. Application priorities can then be documented and continue to be populated as new use cases are identified while the mission is being developed or even after launch. Second, the AppsWG expanded the Science Traceability Matrix (Weiss et al. 2005) to include applications, forming the first Science Applications Traceability Matrix (SATM) that identifies practical uses of science objectives and highlights the research to applications process. Third, the AppsWG analyzed trades across disciplines and applications domains for different capabilities needed to assess impacts of different mission architecture design decisions. Finally, the Apps WG assessed the applications' value proposition of SBG (Schollaert Uz et al., in review) to seek external partnerships within the U.S. research and practitioner community as well as internationally for mission planning.

Applications Traceability Matrix (ATM)

The Application Traceability Matrix was co-developed with the SBG AppsWG [2] , and configured to maintain traceability from the Decadal Survey (NRC 2017) priorities to science and application priorities, geophysical parameters with data levels, and measurement capabilities needed to address those parameters. The Application Traceability Matrix expands upon the format of the traditional Science Traceability Matrix (Weiss et al., 2005) to show traceability to applications of NASA data within the decision context. Table 1 summarizes the categories of information collected for the Application Traceability Matrix. The columns highlighted in blue correspond with categories in a traditional Science Traceability matrix; those highlighted in yellow correspond with categories added to the ATM.

SBG Applications Traceability Matrix Categories												
SATM		New Category, ATM Specific			SATM			New Category, ATM Specific				
Decadal Survey Question	Focused Science Topic	Apps Focus Group	Apps Concept	Decision Context	L2+ VSWIR L2+ TIR geophysical parameters	Spatial	Temporal	Latency*	Other Design Factors	End Users	Ancillary Data	Notes

***Table 1**. The SBG Applications Traceability Matrix was formatted to show traceability from Decadal Survey Questions through Applications Concept and Decision Context. Latency information was also documented.*

AppsWG initially cross-referenced 46 applications into the SBG SATM across the Decadal Survey categories (Fig 12). Of the 46 applications included in the SBG SATM, Terrestrial Ecosystems represented 42% of the identified applications, Aquatic Ecosystems (15%), Solid Earth (15%), Hydrology and Cryosphere (15%) and Weather and Climate (13%). The full breadth of applications continue to be documented in the Applications Traceability Matrix; a living document that evolves as new use cases are identified.

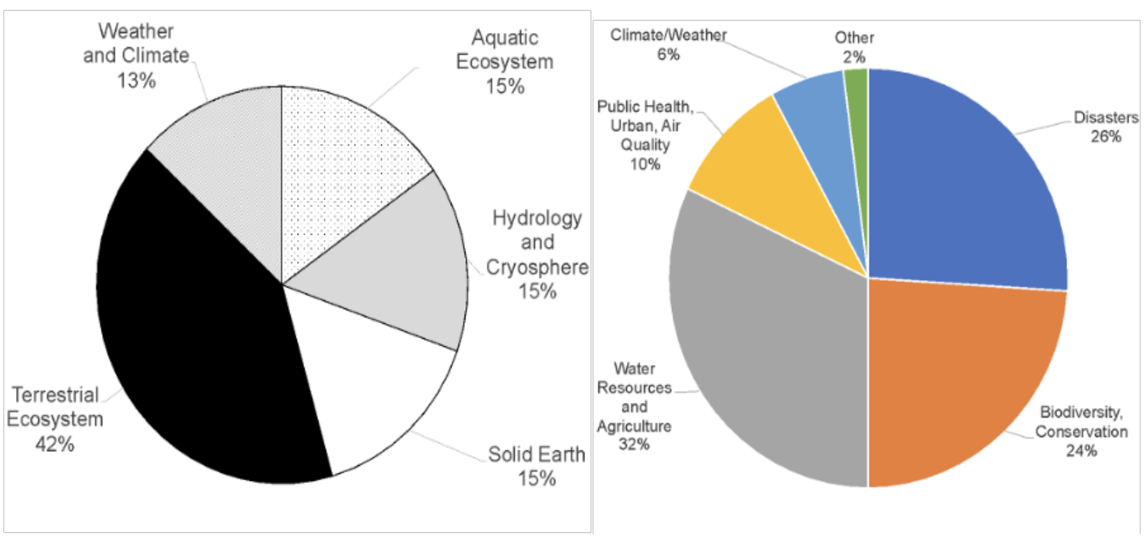

***Figure 12**. A) 46 applications were included in the SATM, relevant to the Decadal Survey priorities identified for SBG, and B) were varied in their application sector.*

RTI User Needs and Valuation Studies

The SBG Study team partnered with an independent nonprofit research institute, RTI, to survey user community needs and estimate socioeconomic value of information as the result of a potential SBG mission. The first study period was from January through June of 2020, with the analysis results summarized below. The second study period was from April through November of 2021 (Culver et al., 2020; Culver et al., 2022).

Applications are defined as data products that are scaled and integrated into policy, business, and management activities to inform decisions. The teams designed the research to assess the societal value of applications that could result from proposed SBG architectures and to contribute to a larger community assessment. Additionally, the teams sought new operational and private sector user communities, beyond the traditional academic and federal partners, to help prioritize the architecture trade studies. In scoping out new sectors, the teams considered communities who had general awareness of the applicability and information available from satellite remote sensing observations, the likelihood of that community assimilating new information, and how it could improve their outcomes. A comprehensive report of the first study was developed with a complete set of insights and findings from our extensive survey and primary research with end users and is available online (RTI Final Report, 2020). The teams synthesized the research and key findings from the report with a focus on how they interpreted and prioritized needs, estimated economic value of the improved information to each sector, and gained new insights through this study as well as the plans for future work.

HOW APPLICATIONS IMPACT SBG

Application Traceability Matrix integration into the SATM

To integrate applications into the SATM, Application Traceability matrix entries were mapped to Decadal Survey priority objectives. This enabled a crosswalk between the two matrices (ATM, SATM). Applications with an associated Decadal Survey objective, were summarized, labeled "Enabled Applications," and captured through unique identifiers tagged to each Decadal Survey objective in the SATM as an extra column in the matrix. An asterisk (*) was used to label Enabled Applications that expressed a low latency need in initial reviews, defined notionally as 48 hours, and which was later investigated in more detail to support engineering design sessions. At this stage "low latency" applications generally included those that were often responding to a natural or anthropogenic hazard or event, which would also benefit from higher revisit or acquisition soon after event occurrence. Applications associated with hazards were still included in the SATM, as long as the geophysical parameters measurement needs were also met.

Latency Analysis

While the SATM flags applications with low latency needs, notionally defined as within 48 hours, the optimal latency period was not identified until the more focused Latency Analysis. Latency is defined in the SBG study as the time between data acquisition and data access by users. Each Applications entry defines a maximum latency for enabling decision-support. These values were qualitatively defined and reviewed by the AppsWG community and using existing studies for additional reference. For the 49 applications associated with the Decadal Survey, information from the latency category was aggregated and visualized in a cumulative probability plot, with latency categories ranging from no latency requirement to 6 hours within acquisition. Latency categories include 6-hours, 12-hours, 24-hours, 48-hours, 5-days, 7-days, 16-days, and >1 month or none.

This latency analysis was then used as a part of a guiding document informing the architecture engineering design sessions that evaluated candidate architectures for SBG. Some core architecture considerations affected by latency include the number of ground stations needed, temporal revisit and subsequently, the number of platforms, ability to point a maneuver, and on-board processing and storage capabilities. The Latency Analysis also included a separate assessment of whether the capability set being proposed for SBG would meet needs for a given application. It is important to note that the target temporal resolution for the VSWIR instrument *was changed from weekly to biweekly* during the architecture study. This change altered the maximum number of applications that could be classified as enabled.

While 46 enabled applications were in the SATM, we discovered an additional three applications that were relevant to the Decadal Survey, and used 49 for all further analysis. When the initial SBG capability set downgraded VSWIR temporal revisit from approximately weekly to biweekly, several application products no longer demonstrated traceability to the proposed capability set (Figure 13). While "enabling" an application is likely not always binary, that is how the team opted to assess latency to ensure consistency in how enabled applications were determined. As a result, 11 applications were not able to be traced to the new capability set. Based on the remaining 38, the latency analysis indicated that **24 hour latency was a minimum threshold** needed to enable the maximum number of possible applications (or 78% of the 49 enabled applications) without adding more constraints on future space and ground data systems.

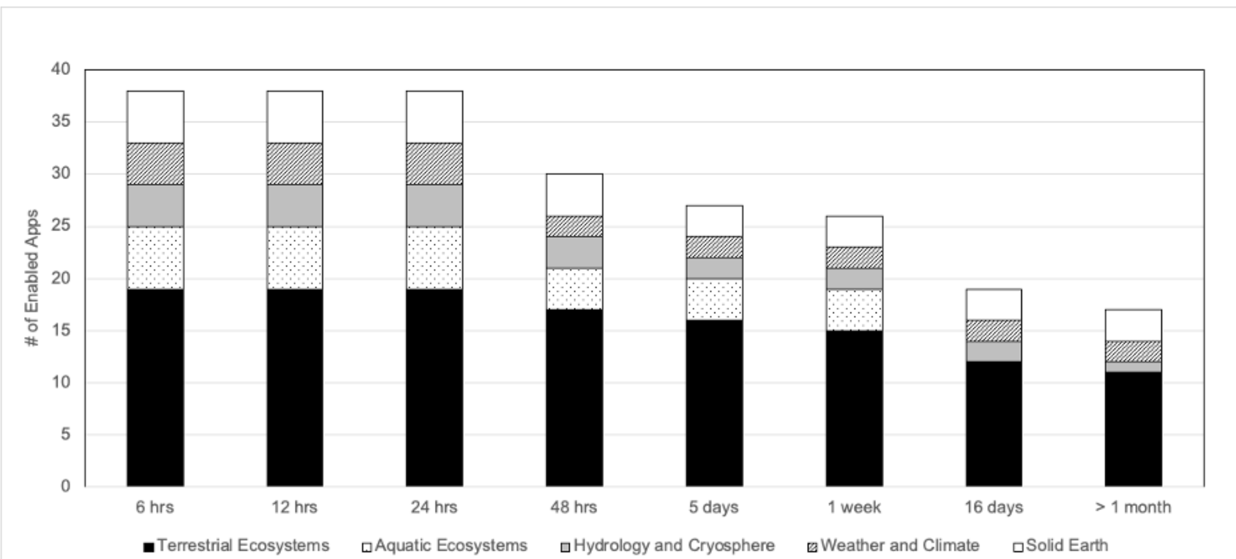

Figure 13 *. 24 hour latency (acquisition to L2+) would enable 78% of applications possible with the current capability set, which is the maximum possible in the current configuration.*

Temporal Analysis

For this analysis, temporal resolution dependencies were considered in conjunction with sensor needs for the 49 applications that were relevant to the Decadal Survey. The team examined applications by their stated sensor needs, combined with temporal needs. First, applications were aggregated into categories based on sensor needs; this was done by reviewing the geophysical products needed to support a particular application, and what combination of sensors would be needed to generate that collection of products. Thus, each application was categorized into sensor combinations: (1) VSWIR only; (2) VSWIR and TIR; (3) TIR only and TIR with a VNIR camera; and (4) VSWIR and TIR/VNIR. The fourth category was considered the most inclusive sensor set. Within each of these four categories, we then reviewed the temporal revisit needs for each application, and binned them into the following categories: <1-day, 1-day, 3-day, 7-day, 14-day, 30-day, 90-day, 180+day. The associated Decadal Survey category was also preserved in this analysis, which was ultimately represented as another cumulative probability plot for each sensor combination.

A < 1 day revisit of both VSWIR with TIR+VNIR satisfied the greatest number (78%) of the 49 enabled applications' temporal needs (Figure 13). This was largely driven by the combined need for frequent revisit and sensor combinations that included coincident TIR and VNIR observations for evapotranspiration and cloud filtering (Cawse-Nicholson et al. 2021). TIR and coincident VNIR measurements enable critical applications that involve supporting active wildfire situational awareness and weather forecasting. Geologic and solid earth applications tended to have greater flexibility with temporal revisit (particularly for mineralogy and resource mining); most of the applications for solid earth captured at this stage in the study were related to hazard response, such as active volcanoes and landslides in part, because there would likely not be additional temporal revisit targets required for those applications. Mineralogy and resource mining applications, while not featured in this figure, were central to the SBG Value of Applications Study (Schollaert Uz et al., n.d.).

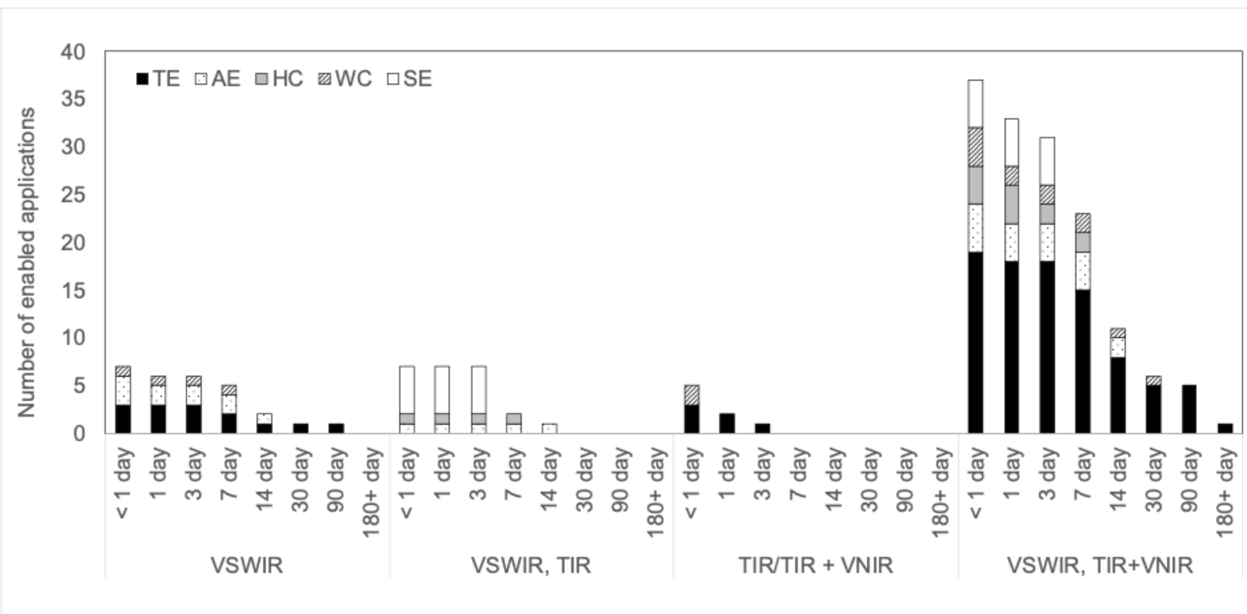

***Figure 14**. This figure shows the combined needs for applications around VSWIR and TIR/VNIR sensor targets along with more frequent revisit. The four column (VSWIR, TIR/VNIR) is intended to show the combination of sensor / temporal revisit targets that would enable the maximum number of applications.*

Application Value Metrics for SBG Candidate Architecture

As with all SBG working groups, the AppsWG provided design targets that were considered in the engineering design sessions, which assessed potential architectures and weighed their technical feasibility to meet SATM measurement and cost targets. Each of the candidate architectures were evaluated against three application value metrics to confirm the integration of the community needs and maximize value of data for applications:

1) Low latency: candidates were scored "A" if they met the <24 hour latency target and "B" if they did not
2) Data downlink: candidate scored an "A" if they costed data priority downlink capabilities and "B" if they did not
3) Hazard response: candidates scored an "A" if they were able to be responsive to hazard applications that required even lower latency than 24 hours, "B" if they did not.

The third metric, "hazard responsiveness," did not explicitly define how an architecture would be responsive to hazard applications but could be notionally envisioned as being able to acquire data upon request, separately from the routine acquisition, and could involve spaceborne, airborne, or other types of solutions. VSWIR and TIR platforms were scored separately as well.

Evaluating SBG candidate architectures for applications value

The capability codes assigned to permutations of the modeled mission architectures allowed us to determine whether or not a given architecture would enable specific application target requirements across each of the DO science questions. As an example, the Baseline AAAA/AAAA enabled 100% of the applications vs the S12 (small satellite) design providing the AAAA/BBAA (78%) or the C5 (medium satellite) BAAB/CACA only 17 % enabled (Table 2).

Apps Enabled	Hydrology	Weather	Ecosystems	Solid Earth	% enabled
Baseline-AAAA/AAAA (100% enabled)	13	4	26	16	100%
Threshold-AAAA/ABBA (95% enabled)	10	4	26	16	95%
S12-AAAA/BBAA (78% enabled)	13		26	7	78%
C5-BAAB/CACA (17% enabled)	3		7		17%

***Table 2**. A subset of architectures are shown here and their relative scoring for applications value.*

SBG VALUE OF INFORMATION

Communities of Practice and Potential

Early and customized engagement with user groups is critical to exploit a global imaging spectroscopy mission combined with thermal remote sensing to enhance capabilities, stimulate innovation, improve decisions, and create socioeconomic value. Communities that we targeted for routine engagement include a range of expertise across scientific research and operations from public and private-sector industry. Focusing on the performance and functional needs of both the research and operational communities, we initially studied four representative applications or first study: fire ecology and risk, algal blooms and water quality, agriculture and water resources, and mineral resources.

We later expanded the user community study, which became the second study, to also focus on biodiversity and conservation, coral reefs, forestation/deforestation, urban heat island impact on human health, global food security and emergency aid. In-depth interviews and an open survey of representative communities provided insights about unmet needs and priorities for capabilities in each application area.

Through these discussions the importance of value-added service providers became clear for better reaching communities of potential. Also called intermediate users or boundary organizations, these are groups that have the technical and organizational capability to take lower level satellite data and apply it to a decision-support tool with which a stakeholder can inform their decision.

We also guided RTI in researching high-level valuation studies and estimated ranges of prospective cost savings or improved productivity to U.S. sectors from an SBG mission, e.g. $33-million in annual savings for electric utilities in fire-prone western states with improved pre-fire risk mapping and modeling; $25-million annual increase in farm revenue through more precise crop health monitoring; $650-million annual increase in productivity for the shellfish industry through wide area water quality monitoring of coastal and inland waters; and a $600-million reduction in exploration costs for the mining industry. Our goal is to understand the potential return on the public investment by SBG, and broaden its impactful benefits through engagement with various sectors. The RTI Final Report (2020) contains the full details from the expert interviews and broad community survey, here we highlight key insights, challenges, and recommendations for future studies assessing potential societal value from proposed missions.

CHARACTERIZATION AND IN DEPTH ANALYSIS

Below is a characterization of the communities of practice and potential from the two "SBG User Needs and Valuation Study" (2020, 2021) including in depth analysis and highlights from interviews of 94 practitioners and the survey that collected over 784 responses from over 42 user communities. Here we assess each community by its needs, current use of Earth observation information, and the value proposition of SBG data to benefit their work flow.

Fire Ecology and Fire-Risk Mapping, and Response

Assessment & Characterization

Remote sensing is currently used for a number of fire-related applications, and many of these applications such as fire risk modeling and mapping are coordinated and led by government agencies. There is not a large commercial sector, yet utilities and prescribed burning and mitigation groups are keen to use the best fire risk mapping data and tools available. In addition, the increase in fire frequency and intensity, and the pressures of drought and population growth in fire-prone areas are driving the need for extended use of remote sensing. Fire ecology, risk, mitigation planning, and operational procedures all have the potential to be informed by new remote sensing observations. There is a strong fire research community and this community is well connected to NASA. Taken together with the above, hyperspectral VSWIR and TIR data are likely to be an asset to this community with a high probability of adoption.

Assessment of Needs - Spatial, Temporal, Spectral Resolution, Latency

Pre-fire fuel loads and risk, post-fire severity assessments, fire ecology and impacts from prescribed burns, and fire models and simulations all benefit from hyperspectral VNIR, SWIR, and TIR. Fire models and simulations require accurate fuel moisture data. The information below provides information on spatial, temporal and latency preferences. Of note is that global coverage of hyperspectral will enable better regional and targeted fire mitigation and operational responses, especially as climate change continues to drive changes in fire behavior and impact across larger spatial and temporal extents. The temporal revisits presented in this study are inadequate for active fire monitoring, so pre- and post-fire are the best application areas. Coincident measures of VNIR, SWIR (4 micron), and TIR can improve fire models via updated fuel load and moisture data.

		Priority Applications		
		Pre-fire fuel load, risk mapping	Active-fire monitoring	Post-fire severity assessment
Spectral	VIS-NIR	✓	✓	✓
	SWIR	✓	✓	●
	TIR	✓	✓	✓
Spatial	VSWIR (≤ 30 m)	●	●	●
	TIR (100 m)	●	●	●
Temporal	VSWIR (16 d)	✗	✗	●
	TIR (3 d)	●	✗	●
		Priority – High (H), Med (M), Low (L), Unknown		
Other	Coincidence	H	H	L
	Sensitivity	M	H	L
	Latency	M	H	L
	Global/Large-Area Coverage	H	M	H

Legend:
✓ Is a significant benefit addressing unmet need(s)
● Is an adequate benefit that meets need(s)
✗ Does not provide benefit or does not meet need(s)

Users' Capability Priorities
(Listed in rough order of importance)

Spectral:
- NIS-VIR are highest priority for vegetation type, live/dead and moisture, ET, surface temperature
    - SWIR important for active fire
    - TIR lower priority

Temporal:
- Pre-fire 16/3 day is marginal, need 3–5 day as moisture/humidity changes
    - Latency should match revisit
- Post-fire 16 day is adequate
- For active fire 16/3 day is inadequate

Spatial:
- Spatial resolution is probably adequate
    - Could use <30 for better mapping/modeling of vegetation/urban boundaries

Coincidence:
- Nice to have for pre/post-fire but not critical at 16/3-day revisits. Would matter more in active fire if < daily revisits.

Sensitivity:
- Expect sensitivity is more than adequate for pre-fire and post-fire

***Figure 15**. Pre-fire, active-fire and post-fire applications relative to SBG parameters (left) and relative to user's priorities (right).*

Findings & Implications

The existing community is sophisticated in using remote sensing but the data and maps they use could be enhanced. In addition, with extended data and products, the community could be extended to include the following sectors: utilities, policymakers, and conservation NGOs. Utilities are faced with rapidly changing conditions, and repeat measurements could provide this updated information. Policy makers could use the data to track, monitor, and make decisions in regards to compliance and regulations around prescribed fires. Land managers, including conservation NGOs could utilize these enhanced products to develop conservation plans and other ecosystem health decisions.

In addition, NASA could augment data and tools for established groups, for example both government and fire agencies. Because NASA has a strong relationship with fire researchers, there is potential for active partnering and preparation in advance of mission launch and for adoption as data become available. In particular, there is an opportunity for NASA to engage with existing mapping programs and platforms managed by other agencies.

Insights on User Needs & Perceptions

Most of the pre-fire risk mapping and post-fire assessment applications can be improved with SBG data at ≤ 30 m VNIR, SWIR, and ≤ 100 m TIR, and the 16/3-day revisit. There is an urgency to the need for better fuel models, though the 16-day temporal resolution of SBG may limit the efficacy due to rapid changes in moisture and humidity. While active fire applications also need improvement, based on the temporal resolution, SBG is unlikely to assist. Overall perceptions are that there is great socioeconomic value for fire mitigation, primarily in pre-fire preparation.

Value Chain

Due to the sheer scale and cost of fires, even small improvements in fire risk mapping can have significant economic and social benefits. There is the potential to reduce liability, reduce property damage, and reduce labor costs around pre-fire risk mapping. Likewise, improvements in post-fire assessments could have significant economic benefit due to reduced labor costs and improved ecosystem and water resources.

End-User Community	Application/Activity	Technical Impact with New Capabilities	Economic Value	Potential Magnitude of Impacts
Electric Utility Companies	Hyperspectral data allow for more detailed fuel mapping that can, in turn, improve risk severity maps Improved thermal sensing and better fuel maps lead to more accurate simulation modeling	Reduced risk of fire outbreaks (due to more precise risk avoidance measures) Reduced fire damage/severity of impacts	Reduced liability costs associated with fire damages Reduced labor costs for on-the-ground inspections or pre-fire mitigation efforts	High
Policymakers State, Local Health Authorities	Hyperspectral capabilities allow policymakers to better prioritize geographies and take actions to prevent wildfires and pre-position resources for wildfire suppression Thermal data allow better tracking of where prescribed fire is happening to enable: • Tracking compliance with EPA NAICS standards (e.g., PM 2.5) • Clarifying relationships between prescribed burns and wildfire incidence and severity	Reduce on-the-ground work to prepare for fires More precise prescribed fire interventions lead to fewer fires Reduce burn severity Improved air quality from compliance with air emissions standards	Reduced labor costs for on-the-ground inspections or pre-fire mitigation efforts Avoided costs of suppression and emergency response Reduced social costs for mortality and morbidity Avoided economic and property losses	Medium
Land Managers	Hyperspectral and thermal capabilities can lead to better underlying data sets behind such tools as LANDFIRE (http://maps.tnc.org/landfire/) used to improve water resource management, more precise prescribed burns, and wildlife protection	More precise prescribed fire interventions lead to fewer fires Improved land and water management decisions at landscape and watershed scales	Improved biodiversity conservation (from economically viable restoration activities) More abundant water resources	Low

Figure 16*. End-user community relative to the fire application, technical impact, and economic value.*

Drought Monitoring/ Mapping in Agriculture

Assessment & Characterization

One of the key areas that has exploded over the last two decades is precision agriculture, or the ability for farmers to manage their land in a site-specific way. Precision agriculture has led to multibillion-dollar benefits for farmers and provides numerous additional environmental benefits that are more difficult to quantify. There is potential for further increases in the benefits of precision agriculture by large-scale incorporation of remote sensing data.

Currently, the agricultural sector uses satellites to support precision agriculture in a limited way and for many other non-precision agricultural uses such as land use mapping, drought identification, and water resource management. The spectral data currently available from freely available satellites enable one to know whether something is growing (e.g., normalized difference vegetation index—NDVI) and can be combined with other data to sometimes distinguish crops, but the data are limited in the ability to provide information on the vegetative composition and water content—both key inputs for making near-term management decisions and doing the predictive yield modeling that is key for medium and longer term planning.

Assessment of Needs - Spatial, Temporal, Spectral Resolution, Latency

By providing improved hyperspectral VSWIR and thermal data at better spatial resolution and temporal frequency, there are numerous ways that different users in the agricultural sector may be able to benefit. Within precision agriculture, some of the greatest potential for benefits are through the improvement of Variable Rate & Timing (VRTs) and those that match agricultural inputs to crop needs. Technical experts also believe that SBG would be a game changer for improved mapping of cover crops and soil residue badly needed for unlocking ecosystem services, but these benefits are more difficult to quantify. Experts also believe that SBG could improve water resource management, but challenges include the temporal frequency of the data and would only represent one improved input into complex evaporative stress models.

Users Capability Priorities
(Listed in rough order of importance)

Temporal:
- High priority. 16 day is inadequate, need <2 days to see growth/stress events in time.
  - Temporal is as important as spectral to monitor crop health, but weekly is adequate for NPK, damage
  - Latency should match need for near-daily monitoring

Spatial:
- Spatial resolution is inadequate for most crop monitoring.
  - 30 m is only adequate for intra-field/boundary, water rights.
  - Require <5 m for crop-/plant-scale monitoring

Spectral:
- NIS-VIR and TIR resolution are high priority for composition and stress.
  - SWIR bands nice for soil/disease, but more than needed

Coincidence:
- Is important for soil moisture and ET data products and complex boundary area mapping.

Sensitivity:
- Expect sensitivity is more than adequate.

		Priority Applications		
		Crop type, composition, health monitoring	Agricultural water use monitoring	Crop residue, cover crop monitoring
Spectral	VIS-NIR	✓	✓	✓
	SWIR	✓	●	●
	TIR	✓	✓	✓
Spatial	VSWIR (≤30 m)	✗	✗	●
	TIR (100 m)	✗	✗	●
Temporal	VSWIR (16 d)	✗	✗	●
	TIR (3 d)	●	●	●
		Priority – High (H), Med (M), Low (L), Unknown		
Other	Coincidence	H	H	H
	Sensitivity	H	M	M
	Latency	H	H	M
	Global/Large-Area Coverage	M	M	M

Legend:
- ✓ Is a significant benefit addressing unmet need(s)
- ● Is an adequate benefit that meets need(s)
- ✗ Does not provide benefit or does not meet need(s)

Figure 17. *Capability Priorities and Applications aligned with Temporal and Spatial specifications*

Findings & Implications

There is a growing need for better models. The diversity of users and applications across the agriculture and water nexus make common drivers hard to identify, but one trend prevails, which is the need for more advanced monitoring and models. Agriculture is shifting to precision farming and improved "right practice at the right place" to increase yields, conserve soil, and develop new ecosystem service offerings. These highly localized practices demand better crop, soil, moisture, and data to enable these new pursuits. Those trying to manage scarce water resources need better models and monitoring to improve forecasting, usage management, and decision-making. However, the typical end user is not an expert in geospatial data sets or advanced models. They look to algorithm and model developers and digital agronomists to make advanced observations usable and actionable.

Users need precise and timely data. Current remote sensing and field-level monitoring are often seen as adequate but meeting the future needs of this diverse sector will require not just more advanced tools but advances in science, modeling, and data-driven practices that can be applied locally and scaled broadly. But the data and models must meet practical temporal and spatial resolution requirements of dynamic systems.

NASA must build communities of potential and practice. Ag and water users deal with large dynamic ecosystems, complex variables, and numerous stakeholders, so they want practical and applied tools. NASA likely will have to expand support for the evolution of HIS/VSWIR applied science and ongoing model development to an even wider range of agriculture, conservation, and water management demonstration projects. Like other diverse user communities this will require continued and expanded partnering across the many different types of user communities to ensure SBG creates high value.

Insights on User Needs & Perceptions

SBG may enable precise crop monitoring but not at the desired scale. Large commercial agriculture companies and model developers see strong potential for SBG's HIS/VSWIR and coincident TIR resolution and view it as a significant improvement over current methods. The high fidelity could substantially improve ET models and the precision monitoring of seasonal trends, crop cover, and ecosystem services. SBG could improve growth and yields by monitoring water, nutrient, and disease stress and enabling growers to do mid-season corrections. The field scale monitoring can support a variety of MRV programs and improved farm, business, and national-scale food supply management. Yet the temporal revisits cannot observe most crop growth/moisture dynamics, and <3 days revisits are needed for better ET models. Also 30-m/100-m spatial resolution limits the ability to support industry shifts toward site-specific management and precision and plant-scale farming.

Value Chain

Farmers regularly face uncertainty and risk from unpredictable rainfall patterns, highly variable field conditions, and commodity price volatility. To mitigate this risk, farmers often overapply inputs (e.g., seeds, agrochemicals, water) that negatively affect their bottom line and lead to environmental impacts. These impacts include increased greenhouse gas emissions, groundwater contamination, surface water runoff, and downstream water pollution. Because they lack resources, smallholder farmers are less likely to overapply inputs and to contribute to these environmental impacts, but they are even more susceptible to food insecurity.

KEY SBG USE CASES – BY VALUE IMPACT				
End-User Community	Application/Activity	Technical Impact with New Capabilities	Economic Value	Potential Magnitude of Impacts
Commercial/ Technology-oriented Farmers	HIS data that identify plant composition will improve precision agriculture in the form of: • More precise and dynamic input applications TIR data enable more precise estimates of • Data products for water/irrigation management	Increased net benefits to farmers due to improvements and expansions of precision agriculture adoption and, in particular, variable-rate applications	Increased yields (higher revenues) and reduced input costs due to the ability to more precisely apply inputs and maximize yields throughout the growing season	High
Public Sector and NGOs Promoting Climate Change Mitigation/ Ecosystem Services	HIS data enable improvements in mapping cover crop type and residue mapping to better target and incentivize conservation practices with multiple ecosystem service benefits.	Federal and local governments can better target conservation incentive programs to areas of higher risk Scaled MRV for conservation programs Removed barriers to scaling ecosystem services in agriculture	Reduced cost or removed barriers to developing verified emission reductions Value of increasing carbon offsets Reduced nitrogen and agrochemical pollution	Medium/ High
Commercial Agricultural Companies and Crop Consultants	Hyperspectral data would allow agricultural input companies to: • Optimize their supply chains to farmers' needs • Improve precision agricultural technology offerings to farmers	Input provision companies can pre-position their representatives to provide advice and sell inputs.. Agriculture equipment manufacturers can improve their technological tools and offerings	Reduced supply chain costs (e.g., labor) Increased sales of agricultural inputs and technology	Medium

Figure 18. *Value Impact Summary*

Algal Blooms and Water Quality

Assessment & Characterization

The water quality community we engaged in this study included academic researchers, federal, state, and local resource managers, and private sector, e.g., aquaculture, commercial fishing, water utilities and engineering, tourism, real estate. We held pre-survey discussions with the various sectors and RTI to help RTI develop survey questions and to identify existing valuation studies and other resources to help quantify the value of future SBG data. In-depth interviews were conducted with the same sectors, with an emphasis on environmental and public health managers and policymakers, shellfish and finfish aquaculture companies, water utilities, and university scientists whose applied research supports these activities.

Assessment of Needs - Spatial, Temporal, Spectral Resolution, Latency

Global hyperspectral and TIR coverage are key benefits of SBG for wide area monitoring of surface water quality features. The spatial resolution needed by coastal managers and mariculture sites is generally greater while inland water bodies and aquaculture site require a spatial resolution of 30-m or better. Data fusion with high resolution commercial satellites or in situ sensors is of great interest to this community. Spectral resolution in the VNIR and TIR are top priorities, but only a few SWIR bands are needed for atmospheric correction and basic monitoring. High SNR in the VNIR and SWIR is critical for the differentiation of aquatic constituents. The aquatic environment is dynamic, thus daily monitoring of harmful blooms or features impacting water quality is desired; 16-day revisit is inadequate except for long-term studies, e.g., aquaculture siting. Latency of less than 24 hours is desired by the water quality community, but frequent revisit is a higher priority. Coincidence between VNIR and TIR would be helpful, but more frequent revisit would be even more helpful.

Findings & Implications

A representative sampling of key findings and impacts in which SBG could improve water quality applications is outlined in Figure 19. Early-warning of algal blooms, polluted runoff, oil spills, and other water quality impairments would help resource managers protect public health by ensuring water is swimmable, fishable, drinkable. Additionally, using SBG data to optimize coastal aquaculture farm siting could improve long-term health outcomes, productivity and profitability. In addition to aquatic applications, water quality indicators have land use applications such as forestry and agriculture impacts on downstream waterbodies, e.g., nutrient reductions, upstream phosphorus, and pollutants to help differentiate sources for regulatory, compliance, and liability management. SBG also has the potential to provide large-scale monitoring of the health of nutrient buffer zones such as coastal marshes and riparian buffers, including vegetation extent, health, shading, run-off, and temperature.

End-User Community	Application/Activity	Technical Impact with New Capabilities	Economic Value	Potential Magnitude of Impacts
Local Municipalities and State/Local Health Authorities	Better forecasting and early detection of blooms Improved identification of HAB species/colonies	Reduced time to public notification Fewer illnesses and death	Reduced health care costs Social value of morbidity	High
Shellfish Farms	Better detection of water temperature and food sources for optimal siting of farms	Increased productivity/yield of farms	Increased production Increased financing for industry growth	Modest
Salmon Farms	Better detection of water temperature for siting in areas with lowest probability of a super chill event	Reduced fish loss from a super chill event	Increased production Increased financing for industry growth	Modest
Water Utilities	Managing intake and treatment systems when blooms approach	Optimal timing of switching between multiple water intake sources	Reduced operating costs and need for chemicals	Low
Policymakers and Land-Use Monitoring Organizations	Development, monitoring, and enforcement of land-use policies to reduce nutrient run off into streams and lakes • Monitoring of vegetation and riparian buffers • Monitoring agricultural and livestock activities adjacent to water resources	Reduced nutrient runoff into streams and lakes Reduced algal blooms in streams and lakes Reduced algal blooms in coastal areas fed by these streams/rivers	Less economic loss due to fewer HABs • Tourism • Property values • Aquaculture productivity • Human health impacts	High

Figure 19. *Representative algal bloom and water quality communities and the potential impact that information from SBG would have on their activities.*

Insights on User Needs & Perceptions

Overall, this sector places the highest priority on improved early warning of harmful algal blooms or other impairments to water quality. Having 30-m resolution HIS/VSWIR could improve coverage of coastal areas and smaller water bodies, including tributaries, lakes, and reservoirs. Harmful algal blooms cause costly closures of aquaculture sites, water utility intake, and livestock deaths. Many stakeholders express a desire for readily accessible, user-friendly platforms and data products for large-area water quality monitoring, like CyAN but with better spatial resolution. Such platforms or apps would help advance and widen the application of remote sensing observations in this community.

Value Chain

Tracking algal blooms is of interest to fishers and aquaculture, but there is no immediate solution to them except to close the aquaculture sites and wait for the bloom to clear and the toxins to flush out of the shellfish or finfish. Better sighting could enable the aquaculture industry to transition from large near-shore farms that compete with many stakeholders to more farms located off-shore and smaller estuary sites with optimal water quality and dynamics. Location impacts the time it takes shellfish to mature—ranging from 1–6 years depending on quality and characteristics of the site. SBG products could help take the guesswork out of siting. For example, a 15-acre farm could yield a million pounds of mussels, if optimally sited, thus 12–15 of these farms could produce higher yields at optimized sites and reach the market in 1.5 years versus 6 years for very large farms. A $1M investment now could eventually yield $10M of business; moving the industry toward industrial farming (Culver et al., 2020).

Mineral/Energy Composition Mapping

Assessment & Characterization

The mining sector is a well-funded community of practice that could use SBG now (Table x). Mining companies are well resourced and have a lot invested in remote sensing already and will continue to invest in exploration technologies. This sector has strong trade associations and is part of a global community actively using ASTER and EnMAP data. The mining sector can be engaged now to use the SBG early adopter data sets such as SISTER (**S**pace-based **I**maging **S**pectroscopy and **T**hermal pathfinder**)** and for future adoption of SBG products.

The mining sector is an early adopter of HIS/VSWIR but has struggled to promote its widespread adoption, seeing remote sensing research efforts come and go. Mineral exploration typically focuses on new discovery “greenfield” and additional exploration around known areas, called “brownfield” exploration. Current spectral imaging solutions are “good enough” for the mining applications of today. However, the industry is now experiencing a shift in focus, as exploration of “greenfield” opportunities diminish, and “brownfield” deposits require better remote exploration techniques. Also, geo-botany, “rare earth” exploration, and operations are emerging HIS/VSWIR uses for “extractive” companies. These applications require satellite imaging solutions using hyperspectral and multispectral thermal remote sensing. At the same time, a new generation of spectral geologists skilled in advanced digital tools is looking for the next generation of observation platforms. The industry will seek step changes in capabilities, and SBG could bring this kind of step change with HIS/VSWIR and high SNR capabilities that will enable broader use or new applications in this sector if priority exploration needs are met.

Key Potential SBG Users

- Large mining companies with "spectral geologists"
- Exploration consultants serving "junior" mining companies
- Regulatory and compliance monitoring organizations
- Hyperspectral researchers advancing applications for the energy and mineral resources sector
- VASPs serving the energy and mineral resources sectors

Key Use Cases of SBG Data/Products

- Studying large geologic processes
- "Greenfield" surveys of large areas
- Revisiting greenfield areas for alterations and previously hard-to-discern minerals
- "Brownfield" discovery of subtle deposits, alterations, and coincident vegetation
- Geobotany—Mineral/vegetation surveys
- Mine site opening baseline mapping
- Operational ore pile and tailing studies
- Environmental/health monitoring on-site and in surrounding environs

Figure 20*. Key Mining Sector Potential SBG Users and Use Cases*

Assessment of Needs - Spatial, Temporal, Spectral Resolution, Latency

Remote sensing experts in the mining sector understand the complexity of HIS/VSWIR data sets, however they require "operational" platforms. Among seasoned spectral geologists, there is some concern about the complexity of huge SBG data sets and "spectral mixing" at such narrow VSWIR bands. They are also concerned that SBG may be seen as "just another research platform" that did not live up to expectations. It is critical that NASA supports the evolution of HIS/VSWIR-applied science, data processing, well calibrated data products, large data access, analytics platforms, and visualizations to help build usability and ease of adoption of SBG HIS/VSWIR and TIR data products.

For the deep domain experts in this sector, the potential for highly sensitive, high SNR HIS/VSWIR in the VIS-NIR and especially in the SWIR is considered a game changer. If realized, SBG will enable subtle mineral deposits (e.g., rare earth elements and battery metals) exploration and operational monitoring that requires higher fidelity than currently available. The additional TIR bands also enable enhanced applications (Table 3).

However, the current 30-m spatial resolution is not adequate for the mining industry's top priority exploration needs. Users indicate that VSWIR resolution of 10 m or better is necessary for brownfield and emerging applications. SBG's full potential will not be realized for this sector without better spatial resolution. Experts would trade spectral for spatial resolution.

SBG Capability User Assessment—Mineral Resource Mapping

		Priority Applications		Emerging Applications	
		Regional Exploration	Local/Site Exploration	Geobotany Mineral/Veg	Site Monitoring, Environmental
Spectral	VIS-NIR	✓	✓	✓	✓
	SWIR	✓	✓	✓	✓
	TIR	✓	✓	✓	✓
Spatial	VSWIR (30 m)	●	✗	✗	✗
	TIR (100 m)	●	✗	✗	✗
Temporal	VSWIR (16 d)	●	●	●	●
	TIR (3 d)	●	●	●	●
		Priority – High (H), Med (M), Low (L), Unknown			
Other	Coincidence	M	M	H	H
	Sensitivity	H	H	H	H
	Latency	L	L	L	M
	Global/Large-Area Coverage	H	M	M	H

Legend:
- ✓ Is a significant benefit addressing unmet need(s)
- ● Is an adequate benefit that meets need(s)
- ✗ Does not provide benefit or does not meet need(s)

Users Capability Priorities
(Listed in rough order of importance)

Spectral:
- VIS-NIR and SWIR spectral range and hyperspectral resolution are the highest priority.
  - Particularly adding the SWIR bands, which are a primary unmet need

Sensitivity:
- High (>100) SNR in VIS-NIR and SWIR bands is critical and essential.
  - >400 VIS-NIR, >250 SWIR is much more than adequate

Spatial:
- Global hyperspectral and TIR coverage is key benefit of SBG.
- But spatial resolution of 30 m is inadequate. Require <10 m for key brownfield and emerging applications.
  - 30 m is adequate only for very large regional/nation-scale surveys

Coincidence:
- Nice to have for exploration, but important for emerging applications

Temporal:
- Revisit of VSWIR and TIR are both more than adequate and are lowest priority. As such, latency is also not a priority.

***Table 3**. Mining Sector Users Capability Priorities and Emerging Applications*

Findings & Implications

Remote sensing has valuable applications across all stages of mining operations. Mining companies already have a good sense of the relative value that multispectral brings through use of ASTER and hyperspectral aerial flyovers for targeted applications. But most interviewees said the availability of global hyperspectral would be a game changer. The use of SBG for mapping and monitoring will reduce costs and increase effectiveness throughout exploration, opening and ongoing mining operations, and closing and remediation. The largest benefit of SBG is likely to be in the exploration/discovery stage of mining operations. Greenfield and brownfield exploration/discovery would greatly benefit from SBG satellite capabilities. Exploration using remote sensing is evolving to be more than looking for "rocks" but finding more subtle, mineral, vegetation, and alteration signatures. Today most of the large global deposits of value have been "found." So future greenfield reconnaissance work is about finding small-scale or difficult-to-image deposits.

The use of SBG hyperspectral could potentially reduce initial exploration time and expenses significantly, potentially reducing from 3 years to 3 months the time needed for large tracks of land. This use has the potential to reduce exploration costs by 60% to 70%. The use of SBG hyperspectral also has the potential to increase discovery from a given track of land, locating deposits that might otherwise have been missed. This use could potentially increase productivity of leases by at least 30%.

Insights on User Needs & Perceptions

Current data and products do not support efficient and frequent large-area surveys. Vegetation mapping in association with soil/mineral deposits for exploration and environmental impact monitoring will be expanded if SBG capabilities are available. Exploration is typically regional (large scale 100s km2) or local-typical mine site (10–15 km2), and these scales and the kind of exploration and monitoring that occur dictate specific use cases and different desired spatial resolutions. SBG would afford more efficient larger area surveys compared with airborne fly-over surveys that are mostly one-off studies.

After years of unfulfilled promise, spectral geology is having a “rebirth." Yet, besides a small community of spectral experts, and the limited availability of regionally collected aircraft based hyperspectral data sets, very few people understand the potential for satellite imaging spectroscopy and what it can do for the mining industry. SBG would provide the required data sets with the following caveats expressed by the user community:

- A new (second) generation of spectral geologists and data scientists will need better tools and training to leverage SBG data sets. The small community of spectral geologists has been waiting for reliable hyperspectral satellite data for a long time: “if there were finally one up there it would be huge!”

- SGB data sets need to be freely available and easily accessible. Commercially available satellite data such as WorldView can cost $800/km2, which can quickly become expensive for large areas. Contractually, companies cannot own the data they pay for and often require consultants to process the data.

- Descartes, Esri, Envi, and a few others are key service providers, but none currently work with hyperspectral data. Descartes has a great mosaic of ASTER data, essentially a Google Earth for mineral maps. These mineral maps are a good example of how ASTER data is broadly accessible for remote imaging spectroscopy.

- Spectral continuity: Commercial missions are aligning spectral bands with legacy missions to provide better spectral continuity. Spectral continuity with ASTER and for mineral deposits exploration is key.

- Coverage continuity: Data and global coverage continuity with current and soon to be ASTER legacy mission would also be good, but not critical. Most good platforms can overlay and even fill gaps of archive data. (ASTER data collection is tasked and thus limited in extent. SBG is a global mission and will by default provide coverage for ASTER imaged areas)

• Most software platforms and skilled analysts can handle different data types/formats, so this is not as much of a problem as it has been in the past.

Value Chain

The economic value and impact of hyperspectral and SBG benefits will be hard to assess. Companies consider this proprietary, and there is little to no systematic and publicly available research on this. Remote sensing expedites and focuses exploration efforts, reducing cost and investment risk. For example, exploration costs for gold are about $0.55/oz, and HIS/VSWIR over larger areas would certainly reduce this cost by reducing time, invested resources, and risk to field staff.

Greenfield exploration typically requires surveying large, often difficult to access tracts of land, it is estimated that costs could be cut by 60–70%. The costs for routine monitoring for regulatory compliance of waste piles, water issues, hazardous air emissions, and other environmental concerns would be reduced with SBG.

KEY SBG USE CASES – BY VALUE IMPACT				
Use Cases	Application/Activity	Technical Impact with New Capabilities	Economic Value	Potential Magnitude of Impacts
Exploration and Discovery	Regional surveys of greenfield areas and targeted local site brownfield exploration Combined mineral and vegetation exploration (geobotany) mapping	Hyperspectral and TIR at scale: Large-area and local hyperspectral data on target mineral and alteration signatures	Reduced time and cost of large-area and target area exploration	High
Mine Opening and Operations	Vegetation monitoring for operational impacts Monitoring hazardous fugitive dust during operations	More comprehensive coverage and greater precision of monitoring activities	Lower operating costs and avoided environmental and health incidents	Modest
Mine Closing, Reclamation, and Monitoring	Monitoring acid water leakage from mines Monitoring structural integrity of mining dams and tailing stacks	More comprehensive coverage and greater precision of monitoring activities	Avoidance of environmental penalties and poor public relations Reduced risk of catastrophic events	Modest

Table 4. *Value Impact of Key SBG Use Cases for the Mining Sector.*

Urban Heat and Health

Assessment and Characterization

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). 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 Urban Heat Islands (UHI). 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.

Assessment of Needs

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.

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 (Fig. 21). 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/SWIR 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.

Spatial Scales

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				

Temporal Scales

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				

Figure 21. *Management spatial and temporal scales.*

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 heat 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 (Fig. 21). 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 the National Integrated Heat Health Information System(NIHHIS). Information quality issues and cost are a high priority. Latency needs vary, but a majority will accept multiple days.

Findings and Implications

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.

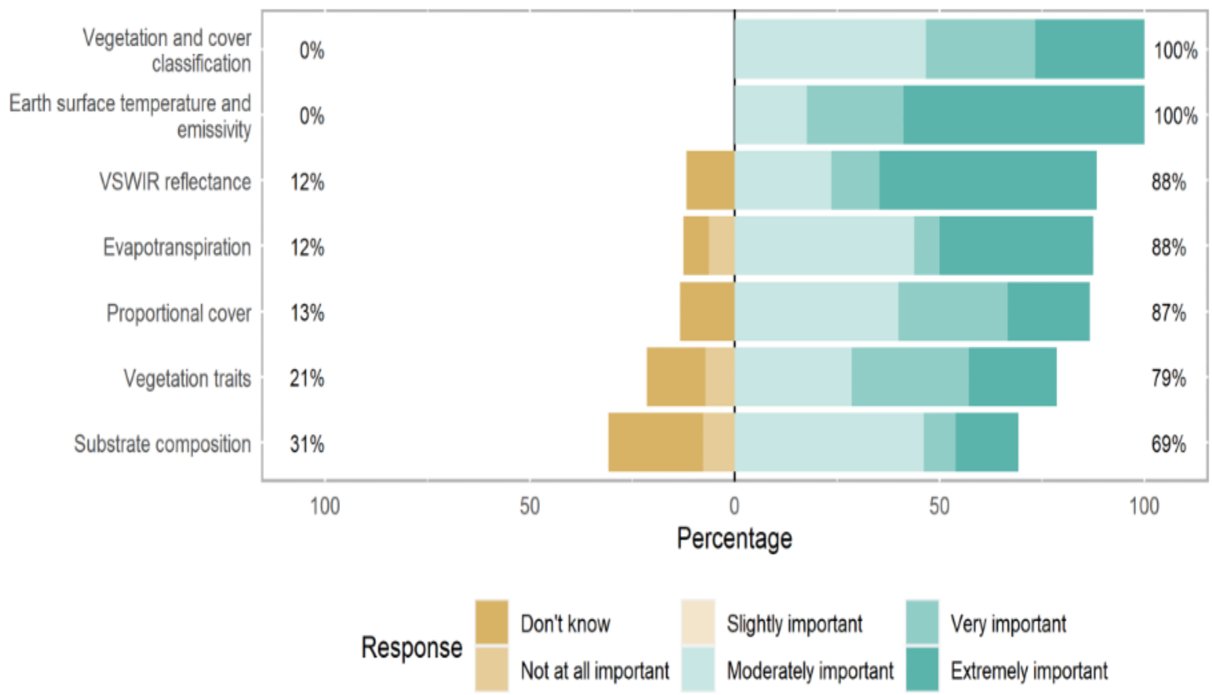

Figure 22. *For the use of SBG in urban heat and health efforts, how important are the following proposed SBG algorithm products? (~18 responses)*

Insights on User Needs and Perceptions

In absence of top-down implementation, urban heat efforts are organized and led by different stakeholders in every city. Each city has its own coalition of organizations with different types of leading organizations (e.g., museums, academics, resilience or sustainability functions within the municipal agency). The result is there is no vertical integration across stakeholders. Surface and roof providers are transactional with little incentive to move toward cooler products. Tree planting efforts and other "greening" efforts are oftentimes done through various types of tree NGO's. Many countries/cities do not have the in situ boots on the ground to generate heat maps. Some have a few stationary sensors. SBG would be an advance providing a low-cost heat map option to support mitigation investments.

Additional insights and perceptions are captured by value added service providers, interagency organizations, NGOs, and consultants:

The National Integrated Heat Health Information System (NIHHIS) is an interagency organization that helps coordinate national UHI mitigation efforts. "SBG data would not be directly useful in early warning systems and identifying where to dispatch resources in advance of a heat event. However, historical heat map data could be used to help calibrate the models that are providing the forecasts".

"The UHI is a very nascent community and application area. There are a lot of disparate but interested parties, but it will take coordination and help to mature this area—science, applied use, and user adoption".

"SBG's day/night thermal mapping has the most value in targeting global cities with highest and most rapid night-time heat gains for better decision-making tools—to drive policy, heath alerts, energy loading and infrastructure vulnerabilities. These are the areas where the valuation and impact of SBG would be best determined."

Value Chain

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) 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 (Fig. 23).

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***

Figure 23*. The potential impact of SBG data sets in reducing heat related deaths and economic value when utilized in UHI mitigation activities.*

Coral Reef Conservation

Assessment and Characterization

The coral reef community is highly connected and a relatively small community that is spearheaded by research scientists and NGOs (Figure 24). The primary focus of the coral reef applications community is monitoring and protecting ocean health, through restoration efforts, marine spatial planning, and disturbance monitoring. End user communities in this group are comprised of conservation NGOs, conservation agencies (government level), national governments, companies (small / private) and coral researchers. The community recognizes the benefits of remote sensing, particularly in the areas of mapping and restoration, as they have traditionally relied upon field-based and resource-intensive surveys conducted by scuba divers.

Figure 24*. Key Potential Users and Use Cases for Coral Reef Preservation.*

Coral reefs are critical to both economic and environmental well-being, underpinning ecosystem services and touristic/economic benefits. Organizations and nations worldwide have taken an active role in reef conservation. While still emerging, a business sector is forming around protection of coral reefs, including insurance/reinsurance companies and suppliers of relocation and restoration services.

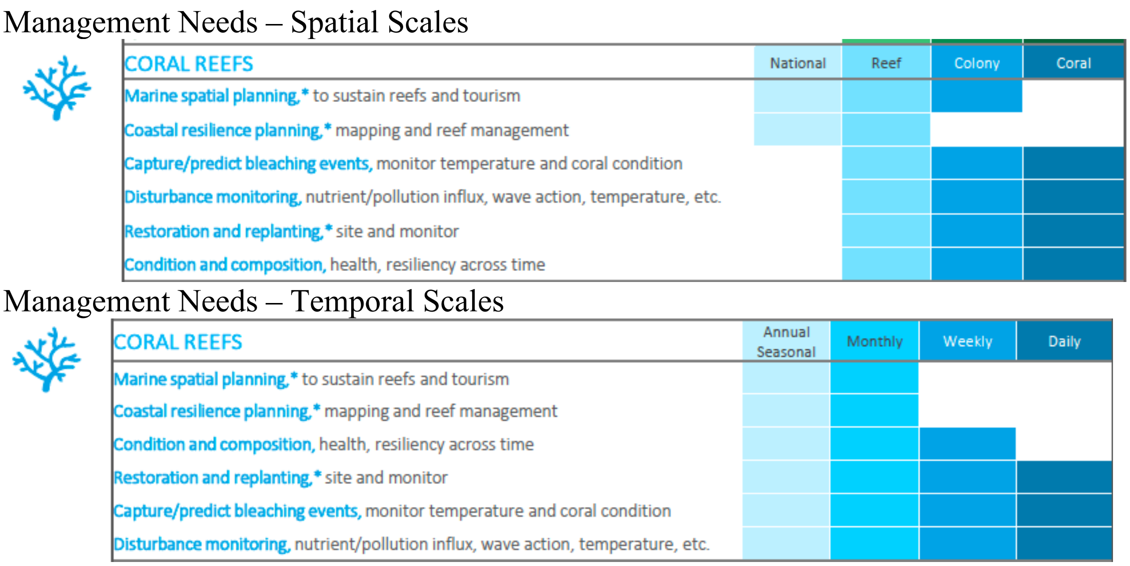

***Figure 25**. Management Needs defined by Spatial and Temporal Scales*

Assessment of Needs

The greatest unmet need for this community is the ability to assess coral composition and health. One of the largest barriers to meeting this need is accounting for benthic reflectance and water depths.

The coral reef mapping communities, as noted, tend to rely on field and labor-intensive methods for acquiring the data needed to inform improved conservation, restoration, and planning efforts for coral ecosystems. Water quality disturbances can interfere with mapping of coral conditions and cover, which necessitate diver acquired data. Coral reef community needs are likely to require better spatial resolution in VSWIR, for mapping benthic cover and condition, than what will be possible with SBG (better than 30-m) (Figure 25).

Coral reef applications communities are seeking information about the condition of corals, in addition to coral stressors. Regarding coral conditions, this includes classification of corals as live/dead, healthy/diseased and resilient/non-resilient. Stressors include water temperature anomalies and increases, nutrients, and sediments that could cause coral bleaching and degradation of corals.

Current available remote sensing products of coral, based on multispectral optical remote sensing, do not have sufficient quality for use in applications. This community also prefers that future coral-relevant SBG products have customization functions that would minimize challenges with handling large data volumes.

SBG capabilities have some likely benefits, including thermal products at 60-m resolution with 3-day revisit, which will allow this community to study thermal stress and its impact on reef condition. There will be some opportunities for the VSWIR to improve mapping of water quality stressors in coral ecosystems as well the potential to support mapping of shallow water bathymetry and larger spatial scale benthic conditions.

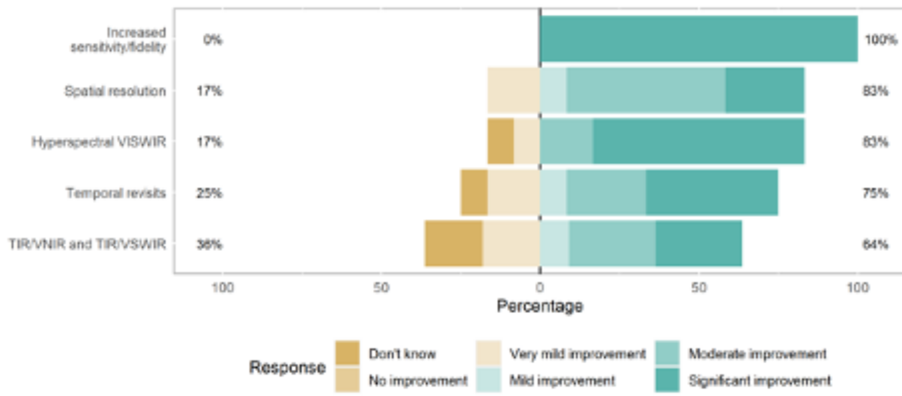

Figure 26. *Survey potential impact results*

The survey respondents indicated that sensitivity and spatial resolution were critical. Some experts indicated that thermal was the key SBG benefit, given that SBG VSWIR may be too spatially coarse to monitor coral conditions.

While the sample size was small, latency of SBG products to support the coral community was generally sufficient at >2 days. The product needs were prioritized as follows: aquatic classification, water biogeophysics, and water biogeochemistry. Temperature and reflectance were still important and ranked slightly lower.

Findings and Implications

There may be some limited utility for meeting this community's primary need around mapping coral conditions due to the spatial resolution of SBG's VSWIR instrument. However, if this limitation can be addressed, there are potential opportunities for a global mission like SBG to provide substantial benefit to the coral applications community, allowing regions to be studied and monitored that would not be possible due to resource constraints.

Insights on User Needs and Perceptions

The perception of this community is that the go-to science domain expertise and guidance come from divers, not data scientists or remote sensing scientists. The few leading consultants who provide consultation for reef restoration and relocation efforts often have remote sensing experts in house. Furthermore, there are some conservation-leaning governments who have begun to use remote sensing for coral reef studies by partnering with academics. There are few integrated decision-support tools for this community. There is some potential for the insurance/reinsurance industry to shift these dynamics. There is also a growing community of experts that will use imaging spectroscopy data that is collected locally and in-water.

Additional insights and perceptions are captured by value added service providers, NGOs, and consultants:

"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 company I direct. We have a VSWIR imaging spectrometer aboard and have proven HIS/VSWIR can provide a more nuanced understanding of coral physiology and better water depth mapping than multispectral data."

"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."

"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."

Value Chain

Indeed, there is traceability of SBG products and provision of value to the coral reef community, particularly for governments, NGOs supporting conservation efforts, and tourism organizations. Areas where there is likely benefit from SBG include marine spatial planning, which is core to conservation, protection, and restoration. Furthermore, there are longer term benefits via coral management as healthy coral reefs and ecosystem services will provide resilience to flooding. It is estimated that 1 mile of coral reefs prevents a 100-year flood from growing by 23%, mitigating losses of 2.7B in direct building damage and 2.6B in indirect economic impacts. For the US this translates to 5.3B annually.

Conservation/Biodiversity

Assessment and Characterization

Among all the sectors that were surveyed for the two RTI studies, Conservation and Biodiversity was the sector that was the most diverse and fragmented, because each user or group was bound by their focus on vegetative or animal species, economic/reputational impact(s) by country or corporation and the very limited practice of using remote sensing data (Figure 27).

Figure 27. *Key Potential Users and Key Cases for Conservation and Biodiversity*

The desire and need for SBG or other RS data was indicated; however, the current dominating practice is to rely on ground data, even with the awareness of the limitations and scalability issues. Individual NGO or agencies would fund their own ground survey or use what they accept as a trusted source of data for analysis and decision support. Any existing use of RS data would be among the academic and research communities. SBG could provide new capabilities and insights welcomed among the users, but the products will have to be in formats that are in current use or can be easily applied to existing systems or platforms.

Since NASA supports current programs such as GEOBON, SBG may have an opportunity to pull together the diverse but fragmented community in using RS data for conservation and biodiversity practices, especially to develop vegetative classification and demonstrating the value of these models and methods for conservation, as well as encourage development of other applications beyond employing basic imagery.

Management Needs- Spatial Scale

Management Needs- Temporal Scale

Figure 28*. Assessed Management Needs for Conservation and Biodiversity*

Assessment of Needs

The needs among the Conservation and Biodiversity groups are as varied as the many members but can be lumped into broad categories: Deforestation in agricultural supply chains, niche conservation applications, and biodiversity monitoring (Figure 28). Since RS data is not used outside of research, there is potential for adaptation, with caveats, as long as SBG will provide custom products and support. NASA is perceived as a trusted and unbiased source for data, which is one of the most important points stated among the surveyed.

In research, HIS/VSWIR at 30m would allow researchers to "bootstrap" better studies. Current practice is limited to national, meter-scale field observations which are considered good but limited. HIS/VSWIR at 30m may increase the accuracy from 60% to 90% for natural standing vegetation surveys (Figure 29). Of particular note is the high potential for HIS/VSWIR to be used for vegetative classification and distribution maps, where RS data are not widely employed. Improved maps can improve species mapped via improved ecosystem/ecological modeling. This would be a novel step because there currently does not exist an effective RS method to track invasive species.

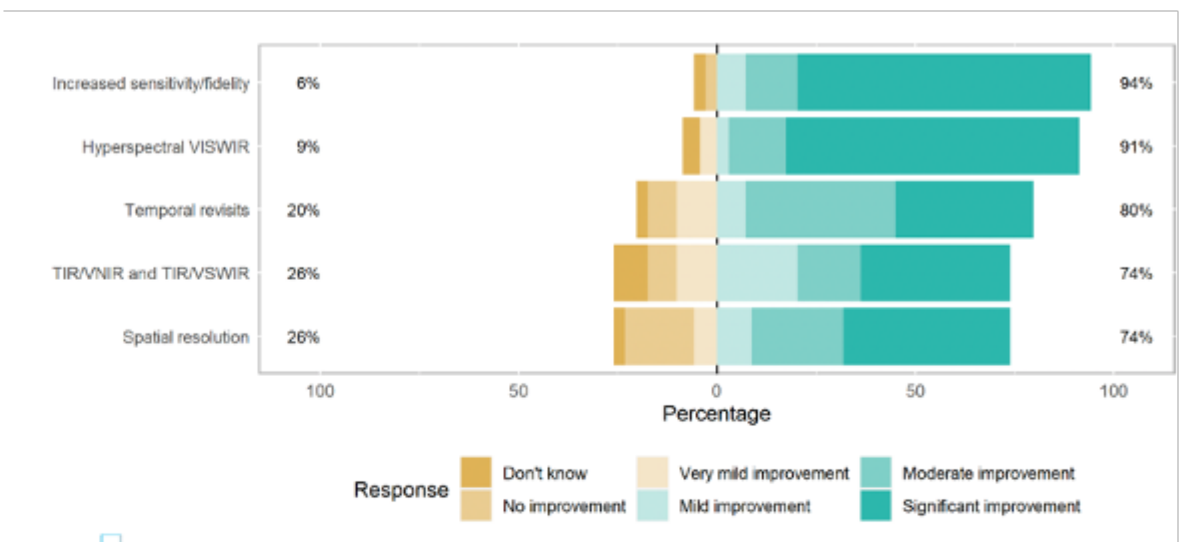

Figure 29*. Survey potential impact results by sensitivity and resolution*

Among the non-research users which included remote sensing practitioners, commercial and NGO end users in the conservation space, the priority need is for free, frequent and interoperable data products with intuitive interfaces. The current business of satellite companies serving large private companies that do not transparently share their datasets and maps means an alternate open source option would be valuable for all users, especially NGOs. Temporal/spectral continuity with Landsat and Sentinel datasets is deemed important, and all of SBG's algorithm products were deemed highly important among the survey respondents, especially if they can create new science validated and community accepted indices that would meet critical information for all users.

Findings and Implications

Despite the limited current use of RS data among community members, SBG hyperspectral VISWIR spectral capabilities ratings were very high among those surveyed and potentially offer significant benefits if adopted (Figure 30). This is a reflection of the perceived trust of NASA as an unbiased source of information that would be freely available for any user. However, SBG spatial resolution is not perceived to be of significant improvement, due to the meter scale ground surveys being employed.

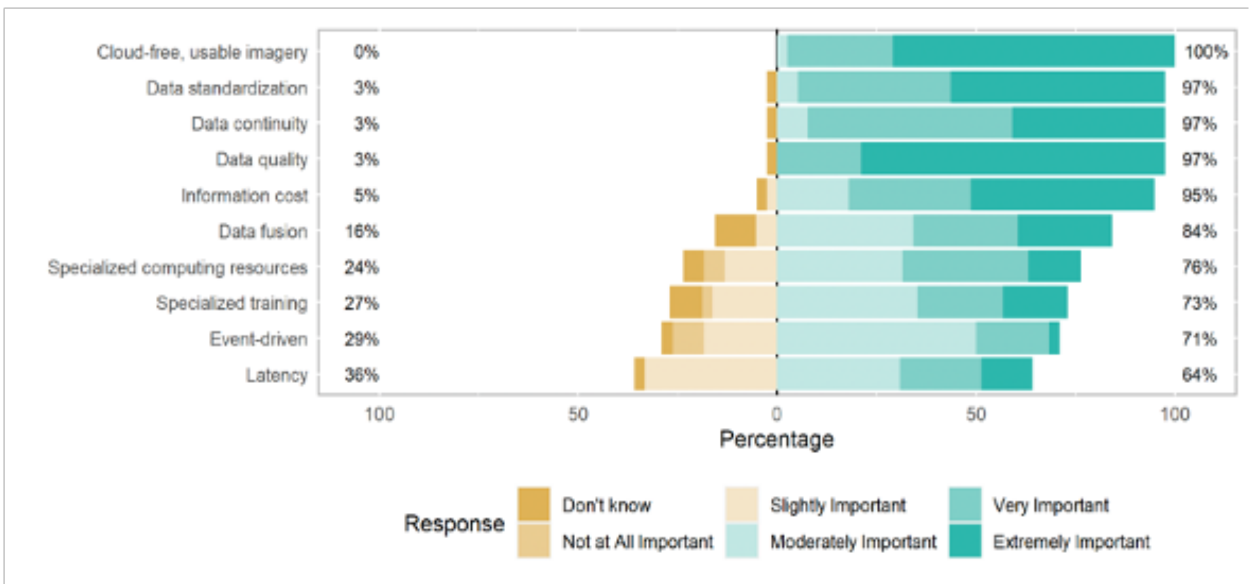

Figure 30. *Prioritized Survey User Needs*

Survey potential impact results

SBG's proposed vegetation, cover and surface temperature products have the highest importance (Figure 31). The anticipated impacts of SBG are better technical understanding, forecasting, and precision to guide conservation and biodiversity management and planning.

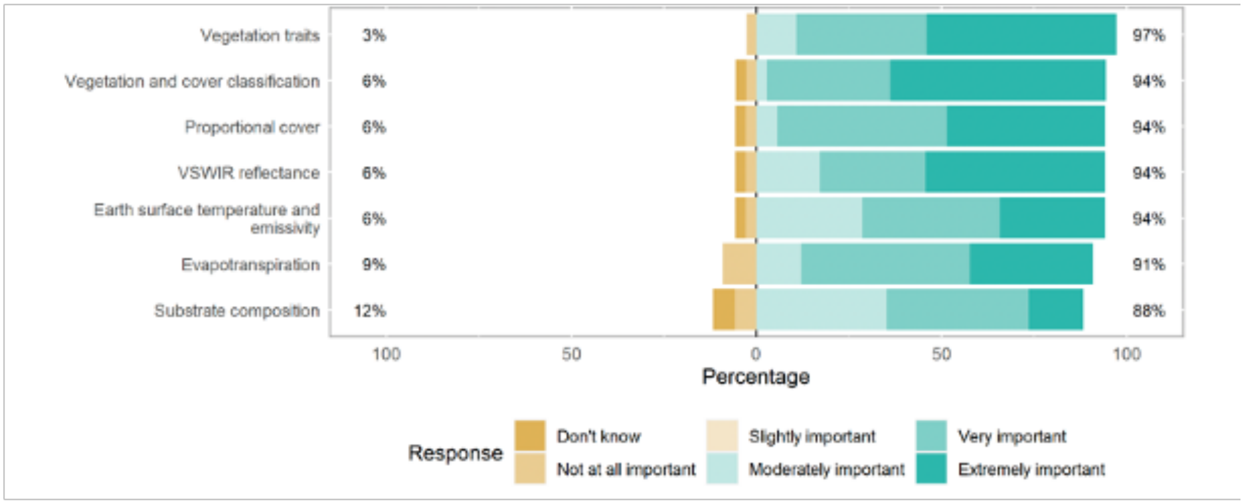

***Figure 31**. Prioritized Survey User specified Impacts*

Insights on User Needs and Perceptions

The management practices of this diverse community are still rooted in trusting what they "see" with their eyes through ground surveys. The use of RS data is largely basic imagery and noting or confirming regional changes to support ground results. Very few users in the community actually employ RS data because they are not trained for to use remote sensing observations. There will be work needed to convince broader adoption of RS data, let alone SBG data.

Additional insights and perceptions are captured by value added service providers, NGOs, and consultants:

"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 with HIS/VSWIR 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."

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

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

Value Chain

Free, large scale HIS/VSWIR data from SBG are highly desired for multiple applications from distinguishing between natural and commercial forests, characterizing species diversity and invasive species, to more accurate biomass and carbon stock measurements. The ability to reduce the need for expensive ground surveys and greater data transparency would be of tremendous value to the Conservation and Biodiversity community at large because they are key to reducing Monitoring Reporting and Verification (MRV) costs. In one case study (under the Clean Water Act and Endangered Species Act relating to compensatory mitigation policies), it is estimated that approximately 20% of costs are for technical surveys or analytics where SBG could play an important role. They postulated that the SBG hyperspectral capability could reduce the cost in this case by $120M per year.

Community engagement could have far-reaching especially beyond the research community because the data would be desired and used by NGOs, private corporations, and carbon and regulatory markets.

Forest Management

Assessment & Characterization

Forest management in this study spans forest inventories, species classification, forest health, carbon markets, disturbance and regeneration, and functional diversity. Many of these areas within the sector already use remote sensing data, and there is significant potential for growth. For example, photogrammetry was the most common form of remote sensing though 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 the industry because of the spatial resolution (< 10-m). In addition, Landsat is used for the USFS Health and Monitoring products and leaf area index models, and some forest managers use it for time-series monitoring. Sentinel and Planet data are frequently used to track harvest activity, but purchased data are less common. MODIS with its daily revisit capability is used to monitor phenological changes. Canopy structure data are highly valued such as lidar and SAR are increasingly used to measure overstory height, crown diameter, leaf area index, and understory competition.

User sectors include landowners, managers (private and government), manufacturers, researchers (academia and government), corporations, and NGOs.

Assessment of Needs - (Spatial, Temporal, Spectral Resolution, Latency, Data Format)

The availability of spectral resolution that SBG may provide has wide potential in forest management. The spatial resolution is a top priority and because users in the U.S. have become readily accustomed to NAIP, SBG's 30-m spatial resolution is considered a challenge. It is noted that the 30-m resolution is still useful at the stand scale for management. Almost all forest management application areas indicated tree to regional scales are most important. National scale inventories and certifications are also important. The temporal resolution of 16-days is considered adequate, especially because all forest management application areas identified annual to seasonal as needs. Monthly resolution is needed for forest health, carbon markets, functional diversity, and disturbance. In cases where finer temporal scale (weekly) may be needed, for example with disturbance such as fire or storm situations, there is an option to fuse with other available data. The potential for improved TIR data for fire and fuel load modeling (see above Section on Fire ecology and fire-risk mapping) is seen as a benefit to the forest management research community.

The spectral resolution of SBG has significant potential to improve monitoring for drought and water stress, and for tree-species classifications. The latter will provide more accurate biomass and carbon stock measurements, key for quantifying deforestation as well as carbon market needs. Ultimately SBG would provide new capabilities and unmet needs in these areas.

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).

Figure 32*. Forest management applications and assessment of spatial, temporal, and spectral needs.*

Findings & Implications

Significant opportunity exists for SBG to improve forest inventories, inform sustainable forestry certifications, and to quantify forest composition, growth, and health. Free, large area hyperspectral classifications of tree-species is seen as the highest confirmed value that SBG could provide. This information can be coupled with other data to provide more accurate estimates of biomass and carbon stock measurements. While thermal is of interest, it is perceived as research, not operational, capability.

The societal benefit of SBG to the forest management community is multifold. Improved monitoring for climate change, deforestation, and overall forest health has high societal benefit.

From the private sector, improved forest growth models will allow for sustainability. There is also a perceived benefit similar to precision agriculture, with fertilizer applications and silviculture efficiency.

Insights on User needs & Perceptions

The forest management community is diverse, from less technically skilled users to researchers who have been using hyperspectral data for species classification, health indices, and deforestation. There is excitement in the community overall for improved spectral resolutions that will enable more sophisticated uses of remote sensing for forest inventories and management, specifically due to impacts from climate change.

Because the forest management community has diverse user sectors, the need for products varies. For example, there is a need for proven operational, large-scale tree classification and species composition data. This could be tackled by NASA, USFS, and other government and university researchers to demonstrate the value to the large management sectors. However, there is also a need to help smaller forest owners and NGOs that would like to utilize the data for improved management, and thus an opportunity for NASA and other organizations to partner.

Value Chain

Developing more accurate and more frequent forest inventories will have positive economic impacts, whether for NGOs, commercial sector, or public sector. These forest inventories will reduce the number and intensity of on-the-ground surveys and enable better decision making on forest health and restoration. Note that in the case of less technically skilled users, this value may only be realized if service providers can deliver products. NASA will also need to provide training to enable the use of hyperspectral for these improved inventories.

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

***Figure 33**. Valuation study of several forest management end-user communities. Note that forest inventories and vegetation stress are areas that if improved will have high economic impact/value. Species mapping and biomass are noted to have medium and low, respectively, economic impact/value, though high societal benefit.*

Global Food Security

Assessment & Characterization

The use of remote sensing to inform global food security and humanitarian aid decisions is the most well-established and well-funded satellite application area with a 50-year legacy by Landsat through the Sustainable Land Imaging Program that was initiated as a research program by NASA in the late 1960s. The U.S. Department of Agriculture (USDA) Foreign Agricultural Service (FAS) has a long-standing partnership with NASA Goddard Space Flight Center for the use of its satellite data to monitor global crop supplies and stocks to forecast shortfalls or gluts of various crops on the market. USDA and insurance companies also use NASA satellite data to assess and quantify flood damage to crops and determine crop-insurance payouts to farmers (NASEM 2018; Goward et al., 2017). Around the world, an ever-growing number of governments, NGOs, and digital agriculture 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.

Assessment of Needs (Spatial, Temporal, Spectral Resolution, Latency, Format)

Experts speculate that once satellite spectral agronomy is more advanced, SBG may enhance spectral crop classification. The potential for hyperspectral vegetation species classification is the most compelling potential SBG capability, regardless of whether SBG's 30-m spatial resolution will be limited to cropland monitoring (i.e., not plant scale). The 3-day TIR will enable better land surface temperature monitoring and evapotranspiration (ET)/evaporative stress index (ESI) models for rapid hazard events and hyperspectral for cropland (not plant-scale) stress monitoring. Data continuity, 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.

Findings & Implications

Operational humanitarian aid decisions by governments and NGOs span spatial scales ranging from large scale flood and drought impacts on crop timing and yield to pest infestations at the plant level (Figure 34). Additionally, a nascent area for potential future development is with carbon markets.

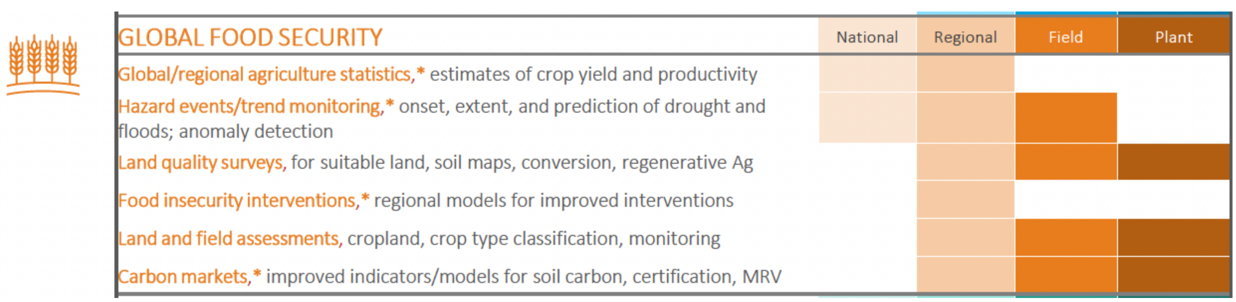

***Figure 34**. Spatial scales of the most important uses of satellite remote sensing for global food security management applications range from country-level down to plant health with the highest impact (denoted by*).*

Operational global food security decisions span temporal scales ranging from annual to daily (Figure 35). Specific opportunities for SBG from frequent TIR sensing are for hazard early warning of flash droughts and floods. SBG hyperspectral resolution will enable spectral libraries to improve vegetative growth indices for better crop yield predictions. The combination of TIR with VSWIR will improve ET/ESI estimates to identify water stress to better target humanitarian aid or improve crop insurance payouts or crop rotations. Once spectral agronomy advances, SBG hyperspectral could improve crop classifications and reduce reliance on infrequent field surveys.

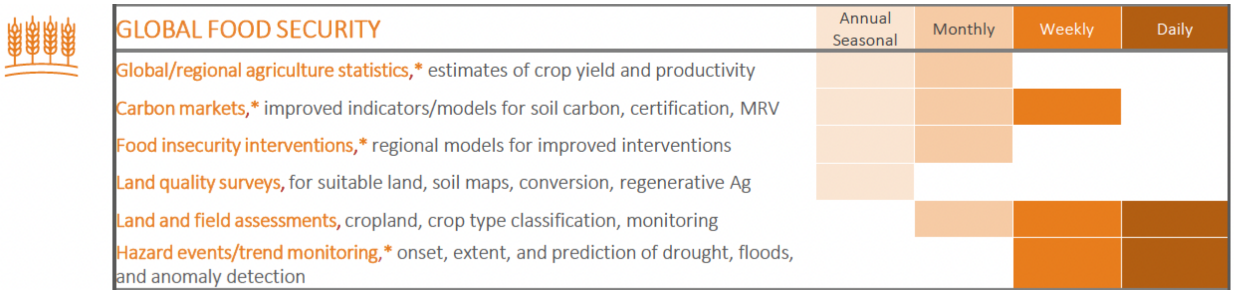

***Figure 35**. Temporal scales of the most important uses of satellite remote sensing for global food security management responses range from annual or seasonal down to daily with the highest impact*.*

Insights on User Needs & Perceptions

Experts cited combinations of platforms to enable monitoring of agriculture in developing regions. Historically, Landsat, MODIS and VIIRS have been used for global crop monitoring. There is increasing use of Copernicus Sentinel 1 and 2 (10-m data), for NDVI and similar indices. These form a baseline record, along with assimilated precipitation products, e.g., IMERG, CHIRPS. SAR data from Sentinel 1 provide cloud-free viewing. Commercial satellite missions, such as Planet and Maxar, provide near-daily revisits at high spatial resolution in near-real-time. RS datasets are typically combined with field surveys and ground data to provide quality control.

NASA is already well-established in the global food security domain through its long-term partnership with USDA as well as the more recent international Group on Earth Observation (GEO) collaborations by the NASA Harvest Program. Even though this community has long-standing and deep satellite applications expertise, hyperspectral remote sensing is an unproven research domain that will require significant development of algorithms, models, and products before it will be adopted by existing partners. Developing countries do not have the capacity to trust or leverage new satellite products if they do not come through established channels.

Value Chain

The humanitarian and aid investment impacts are enormous. 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. Developing detailed crop classification, phenology, and biophysical quantification is the largest area that SBG offers the potential for significant improvement over current imaging platforms. Another area of potential improvement over current capabilities is in developing monitoring, reporting, and verification (MRV) standards and indicators for carbon credit programs. 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 current assimilated products. To ensure effective translation of SBG products to end users. Experts routinely expressed the desire that NASA play a key role as 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.

OVERALL FINDINGS & IMPLICATIONS

One clear distinction between prior Early Adopter and mission application programs and the presented work is that the SBG Applications Working Group began the systematic integration of applications **at pre-formulation**, at the stage of the architecture study, as well as its co-equal status within the SBG Project Research and Applications Team (an analog to the Project Science Team). By further building on the vision of the Early Adopters Program, SBG Applications has demonstrated that integration of applications into the full mission life cycle can start at pre-formulation and that the Applications Community confers unique technical needs and perspectives relative to architecture and engineering (Figure 1). Furthermore, SBG Applications and Science are fully integrated, in a way that shows co-reinforcement of key needs, including new needs that emerge. Two key examples of this are the:

- Inclusion of a 4 micron band for improved quantification of active fire states
- Inclusion of a Visible Near InfaRed camera (VNIR) with the TIR platform for coincident albedo/thermal measurements – largely to improve evapotranspiration estimates

The other area for high return for systematic integration for applications is international partnership to maximize, in particular, frequent temporal revisit. While the SBG Applications Working Group efforts were able to secure a low latency target for VSWIR and TIR architectures, more frequent temporal revisit was not possible under the cost / budget boundaries put forward in the Decadal Survey. For many applications, a combination of frequent temporal revisit and low latency would add tremendous value to natural hazards and
disaster response applications (Schollaert Uz et al., submitted).

The AppsWG efforts identified, documented and integrated application needs that would not have been included by considering science needs only. First, a low latency of 24 hours was identified as the optimal target to enable the maximum number of applications, and was then carried through into <u>all</u> SBG candidate architectures. Second, many applications expressed needs around improved spatial and temporal resolution. While increased spatial resolution would not be possible under current cost and technology considerations, the need for improved resolution for temporal sampling helped drive and bolster discussions with international partners such as the European Space Agency and the Italian Space Agency.

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APPENDIX

Table 1. SBG Applications Working Group Webinar Series

Date	Topic	Presenters
12/6/18	Introduction to SBG & Applications Working Group SBG Integrated Schedule Discuss the SBG Applications Table and request input **Relevant to all Decadal Survey Topics TO-**	[1]Jeff Luvall (MSFC), Christine Lee (JPL), Nancy Glenn (Boise State), Natasha Stavros (JPL)
1/10/19	Mode of operating during shutdown Make good progress where we can, expect some adjustments in our work schedule and work plans to make sure we are including colleagues affected by shutdown Community wide meeting end of April or beginning of May Review / discuss draft SBG applications table Walk through how to provide your feedback Please submit first round by next Friday - this will help us adapt the process and see if we can effectively integrate your inputs into one table Questions or comments from AWG? **Relevant to all Decadal Survey Topics TO-**	Christine Lee (JPL), Nancy Glenn (Boise State), Natasha Stavros (JPL)
2/7/19	**SBG updates** Discuss the SBG Applications table and incorporate initial inputs/feedback. **Relevant to all Decadal Survey Topics TO-**	Applications Working Group Co-Leads[1]
3/7/19	**SBG updates** Discuss the SBG Applications table and incorporate initial inputs/feedback. Transition to Applications Traceability Matrix (ATM) and starting integration with the Science Traceability Matrix (STM) to produce Science & Applications traceability Matrix (SATM) Review of areas requested for input from SATM Community Assessment Report (CAR) **Relevant to all Decadal Survey Topics TO-**	Applications Working Group Co-Leads[1]
4/4/19	**SBG updates** Discuss the SBG Applications table (ATM & SATM) and continued incorporating inputs/feedback. Other SBG Working group updates **Relevant to all Decadal Survey Topics TO-**	Applications Working Group Co-Leads[1]
4/16/19	**NASA's Land, Atmosphere Near real-time Capability for EOS (LANCE) Supports Users in SBG Application Areas.** • Most LANCE near real-time (NRT) data products are available within 3 hours from satellite observation. • LANCE NRT imagery is generally available within 3-5 hours after observation from GIBS and Worldview. • LANCE provides NRT data and imagery from 10 instruments much quicker than routine processing allows: AIRS, AMSR2, LIS, MISR, MLS, MODIS, MOPITT, OMI, OMPS, and VIIRS. • LANCE Provides access to 87 products. **Relevant to all Decadal Survey Topics TO-**	**Diane Davies (NASA GSFC/SSAI, LANCE Operations manager)** **Tian Yao (NASA GSFC/SSAI, Disasters-LANCE coordinator)**
5/2/19	**Geological Hazards-SATM deep-dive exercise** *QUESTION S-1* How can large-scale geological hazards be accurately **forecast** in a socially relevant timeframe?	**Florian Schwandner (AMS)** florian.m.schwandner@nasa.gov **Dalia Kirschbaum (GSFC)** dalia.b.kirschbaum@nasa.gov

	QUESTION S-2 How do geological disasters directly **impact** the Earth system and society **following an event**? *QUESTION S-4* What processes and interactions determine the rates of landscape change? *QUESTION S-7* How do we improve discovery and management of energy, mineral, and soil resources? **Focused science topic:** Understanding and predicting geological natural hazards**,** active surface geological processes (deformation, eruptions, landslides and evolving landscapes). **SBG updates** Gap-Fill Application Traceability Matrix Jun 12-14, 2019 SBG Community Meeting in Washington, DC Draft SATM update **Relevant to Decadal Survey S-1a, 1c, 2b, 4b, 4c, 7a**	Applications Working Group Co-Leads[1]
5/10/19	**Terrestrial Ecosystems / Natural Hazards - Wildfires, Restoration- deep-dive exercise** E1c: Quantify the physiological dynamics of terrestrial primary producers. Pre-fire Fuels (Loads, Condition, Types) and Moisture content (Also E1a) E-2a. Quantify the fluxes of CO2 and CH4 globally at spatial scales of 100 to 500 km Fuel Loads and Condition, Active Fire Products E-3a. Quantify the flows of energy, carbon, water, nutrients - sustaining the life cycle of terrestrial ecosystems and partitioning into functional types Active Fire Products, Post-fire Severity, Post-fire Recovery E-5b. Discover cascading perturbations in ecosystems related to carbon storage. Pre-fire Fuels, Drought, Biotic Attack (Bark Beetles) H-4d. Understand linkages between anthropogenic modification of the land, including fire suppression, land use, and urbanization, on frequency of and response to hazards. Burned Area, Fire Severity, Post-fire Recovery **Focused science topic:** Ecosystem response to fire – severity, recovery, gas emissions, and biomass storage. **SBG updates** Gap-Fill Application Traceability Matrix Architecture study update **Relevant to Decadal Survey**	**Dar Roberts (UCSB)** dar@geog.ucsb.edu Applications Working Group Co-Leads[1]
5/16/19	**Terrestrial Ecosystems Carbon and Conservation-- deep-dive exercise** *DS Question: E-1*. What are the structure, function, and biodiversity of Earth's ecosystems, and how and why are they changing in time and space? **Focused science topic:** Ecosystem traits and biodiversity – terrestrial **SBG updates** Gap-Fill Application Traceability Matrix **Relevant to Decadal Survey**	**Konrad Wessels (GMU)** kwessel4@gmu.edu Applications Working Group Co-Leads[1]
5/23/19	**Terrestrial Ecosystems: Public Health and Urban Environment-dive exercise** DS Question: Prediction of Changes, Hazards. How do anthropogenic changes in climate, land use, water use, and water storage interact and modify the water and energy cycles locally, regionally, and globally, and what are the short- and long-term consequences? **Focused Science Topic**: Impact of urbanization along with climate variables, local environmental factors, such as the type of housing, housing density, and peri-urban and peri-domestic areas can provide favorable conditions for the breeding of dengue mosquitoes. **SBG updates** Gap-Fill Application Traceability Matrix	**Ryan Avery Louisiana State University** ravery3@lsu.edu Applications Working Group Co-Leads[1]

5/30/19	**Water Resources and Agriculture- deep-dive exercise** How is the water cycle changing? Are changes in ET and precip accelerating, with greater rates of ET and precip, and how are these changes expressed in the space-time distribution of rainfall, snowfall, ET, frequency of extremes, such as floods and droughts? H-2: How do anthropogenic changes in climate, land use, water use, and water storage interact and modify the water and energy cycles locally, regionally, globally, and what are the short and long term consequences? H-3: How do changes in the water cycle impact local and regional freshwater availability, alter biotic life of streams, and affect ecosystems and the services these provide? H-4: How does the water cycle interact with other Earth system processes to change the predictability and impacts of hazardous events and hazard chains (eg, floods, wildfires, landslides, coastal loss, subsidence, droughts, human health, ecosystem health) and how do we improve preparedness and mitigation of water-related extreme events? **SBG updates** Gap-Fill Application Traceability Matrix	**Forrest Melton (ARC-CREST)** forrest.s.melton@nasa.gov **Christopher Hain (MSFC)** christopher.hain@nasa.gov Applications Working Group Co-Leads[1]
6/7/19	**Aquatic Ecosystems** **Corals, Harmful Algal Blooms (HABS), Water Quality, Restoration-deep-dive exercise** **I**mproved identification and quantification of specific phytoplankton groups. **Focused Science Topic**: Hyperspectral observations would allow us to identify HABs and track their evolution and variability over seasonal to interannual time scales. High spatial resolution measurements (better than 100 m) would allow to capture intense small patches of HABs in estuaries and inland waters-30m). **SBG updates** Jun 12-14, 2019 SBG Community Meeting in Washington, DC Gap-Fill Application Traceability Matrix	**Maria Tzortziou (CCNY/CUNY & NASA/GSFC)** mtzortziou@ccny.cuny.edu **Stephanie Uz (NASA/GSFC)** stephanie.uz@nasa.gov Applications Working Group Co-Leads[1]
7/25/19	**SBG updates** Links for access to Apps Working Group Google Public Drive June 12-14, 2019 SBG Community Meeting in Washington, DC - Public Notes[3] Workshop on International Cooperation in Spaceborne Imaging Spectroscopy 2019, 9-11 July 2019, ESRIN, Frascati, Italy Applications specific topics covered Schedule of SBG activities Community Assessment Report RFI Feedback & suggestions **Architecture**	Applications Working Group Co-Leads[1] **Shannon Zareh(JPL)** Shannon.Kian.G.Zareh@jpl.nasa.gov
8/8/19	**SGB updates** Schedule of SBG activities Community Assessment Report RFI Co-Leads Meeting August 20-21 where prototype process for testing value framework. New SATM (v20) out but likely to change	Applications Working Group Co-Leads[1]
8/19/19	**An Overview of Spectral and Thermal Satellite Instruments Relevant to the Surface Biology and Geology Mission** SBG Observables Classes Snow ET Coastal	**Betsy Middleton (GSFC)** elizabeth.m.middleton@nasa.gov Fred Huemmrich(GSFC) karl.f.huemmrich@nasa.gov Kevin Turpie(GSFC) kevin.r.turpie@nasa.gov Ben Poulter(GSFC)

	Land Cover/Land Use Terrestrial productivity/plant stress Volcanoes Landslides Mineralogy	benjamin.poulter@nasa.gov Applications Working Group Co-Leads[1]
9/25/19	**NASA SPoRT** **A Research-to-Operations Paradigm and Opportunities with SBG Applications** Bridge the "Valley of Death" through interactive partnership with end users. Maintain interactive partnerships with help of specific advocates Integrate into user decision support tools. Create product training Perform targeted product assessments. Concept has been used to successfully transition more than 40 satellite datasets to operational users for nearly 15 years. **SBG updates** Review of Architecture Classes and Candidates Walk through of process for mapping capabilities to addressing science priorities Presentation of SBG SATM v 23, which includes Applications addressing Most Important and Very Important DS Priorities and includes a code to show dependency of Applications on low latency Community Assessment Report (CAR) will be used to character SBG user communities, relative to SBG architecture capabilities, and integrated into the science and applications value framework	**Christopher Hain(MSFC)** christopher.hain@nasa.gov Applications Working Group Co-Leads[1]
11/14/19	**The Application of Satellite Data for Chesapeake Bay Water Quality** Interagency group of satellite data providers connecting with end users around the Bay that is focused on the remote sensing of environmental variables required to perform resource management tasks. What can we observe or derive using satellites? What are your observing priorities for future missions? **SBG updates**	**Stephanie Schollaert-Uz (GSFC)** stephanie.uz@nasa.gov Applications Working Group Co-Leads[1]
12/19/19	**The Application of Satellite Data for Monitoring and Managing Oak Wilt Disease** Oak wilt (*Bretziella fagacearum*) is a lethal fungal pathogen and one of the most destructive threats to oak trees in the US. Use satellite hyperspectral data to help distinguish Two-Lined Chestnut Borer from Oak Wilt at an early stage of pocket formation based on the physiological differences between wilt disease and other types of tree mortality. **SBG updates** Next SBG community meeting late April-May timeframe- Goddard. CAR Australian Space Agency - a) cal/val activities; b) applications in urban heat island, precision ag, veg health/SIF, water quality /coastal aquatics, and mineral resources a good example of getting folks to think about potential opportunities for global case studies / precursor activities (Nancy Glenn) Focus on students/early career scientists CDC/NASA use of ECOSTRESS/DESIS data for public health applications TVA interested –Fall 2019 DEVELOP project using ECOSTRESS for water temperature patterns in the Tennessee River AGU Sessions –Nancy's Glenn's SBG	**Jeannine Cavender-Bares(Univ of MN)** cavender@umn.edu **Minnesota Invasive Terrestrial Plants and Pathogens Center (MITPPC)** Applications Working Group Co-Leads[1]

2/13/20	**NASA's Western Water Applications Office activities** Strategic engagement with Western States Water Council (WSWC) and California Department of Water Resources (CaDWR), Key Federal Agencies and other strategic partners **SBG updates** RTI study on the Value of Information selecting 4-5 archetypes and user groups May 27-29, SBG community meeting (2) at the Beckman Auditorium, CalTech, Pasadena, CA, Assessment of SBG Architecture Recommendations and VSWOR/TIR Science Advances	**Indrani Graczyk(JPL)** Indrani.Graczyk@jpl.nasa.gov Applications Working Group Co-Leads[1]
3/12/20	**Harmful algal bloom monitoring and constituent differentiation in optically complex waters** KSU VPCA decomposition method has be applied successfully to hyperspectral and multispectral lab samples, field-based spectroradiometers, HICO, NASA Glenn HSI2, MODIS A/T, Landsat 4-8, Sentinel-3A/B. VPCA is well suited for application to current and the upcoming hyperspectral PACE & SBG **SBG updates** Architecture study status May 27-29, SBG community meeting (2) at the Beckman Auditorium, CalTech, Pasadena, CA Special issue of Remote Sensing, entitled "Hyperspectral-Multispectral Data Fusion in Coastal and Inland Aquatic Habitats" seeking letters, research articles, or reviews. Tom Bell, Guest Editor, offering a 30% discount on article processing charges. Manuscript submission deadline is June 30, 2020, but write to Tom now if you'd like to submit: tbell@ucsb.edu	**Joe Ortiz (Kent State)** jortiz@kent.edu Applications Working Group Co-Leads[1]
4/16/20	**Global Hyperspectral Imaging Spectral-library of Agricultural-crops (GHISA)) in Support of NASA's SBG** A comprehensive and systematic collection, collation, synthesis, standardization, and characterization of global agricultural crop hyperspectral signatures obtained from spaceborne, airborne (e.g., aircrafts, drones), platform-mounted, and ground-based hand-held spectroradiometers or imaging spectroscopy. **SBG updates** Architecture design study status	**USGS-Prasad Thenkabail,** pthenkabail@usgs.gov **Itiya Aneece, Adam Oliphant,** Applications Working Group Co-Leads[1]
5/14/20	**USGS National Land Imaging (NLI) Program** ***User needs and requirements process*** User needs are geophysical parameters (NASA Global Change Master Directory) such as vegetation structure, surface temperature, snow cover extent, and observation attributes. It focuses on spatial resolution, cloud-free observation frequency and spectral characteristics. Other attributes include data latency, accuracy, geographic coverage, sampling condition, and other comments. **SBG updates** Special issue of Frontiers in Marine Science, entitled "Remote Sensing for Applied Coral Reef Science and Management". Optional abstract submission: 20 June 2020. Manuscript deadline: 20 October 2020. Guest editors Eric Hochberg, Michelle Gierach, and Sam Purkis. Contact Eric with questions: eric.hochberg@bios.edu SBG Architecture Study May 2020 Update	**Greg Snyder(USGS)** gsnyder@usgs.gov **Zhuoting Wu (USGS)** zwu@usgs.gov Applications Working Group Co-Leads[1]
6/25/20	**Multi-platform, multi-sensor snow surface properties for energy balance and model validation** Better understand uncertainty in existing products from multispectral sensors with longer temporal record (Landsat/Sentinel;MODIS/VIIRS) Hyperspectral from SBG should significantly improve our albedo validation globally Improved estimates of SWE from Energy balance models or at least better uncertainty.	**Karl Rittger-Univ Colorado, Boulder NCAR** Karl.Rittger@colorado.edu **Snow surface properties:** **Kat Bormann, William Kleiber, Mary Brodzik, Balaji Rajagopalan, Keith Musselman, Thomas Painter** **Modeling contributions:**

	With SBG better ability to forecast as we calibrate and validate large scale models land surface models **SBG updates**	**Ned Bair, Veronica Chan, Aubrey Dugger, Bill Doan**
9/17/20	**SBG User Needs and Valuation Study** A fundamental aspect of the user study was to engage private-sector, nongovernmental organization (NGO), 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 needs. 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. **SBG updates** The July Community Webinar slides and Q&A are on the SBG website: https://sbg.jpl.nasa.gov/doc_links/2020-07-15-sbg-community-webinar-3	**Tom Culver, RTI Innovation Advisors** tculver@rti.org
1/28/21	**PRISMA spaceborne imaging spectrometry** **Early results for aquatic applications** ● Open free data for all (apart for commercial uses) ● PRISMA archive already counts thousands of images (capacity of 200 per day) ● Tasking on pre-defined target is working fine ● L1 and L2 are systematically produced on-demand The link for registration is: https://prismauserregistration.asi.it/ After registration, the PRISMA documentation (e.g., PRISMA Product Specifications) is also available in the same portal for data search and download at: https://prisma.asi.it The PRISMA web page can be found here: http://www.prisma-i.it/index.php/en/ **SBG updates** **4th SBG Community Webinar 2/18/21** **1:00 pm to 2:30pm Eastern Standard Time** **register** **https://sbg.jpl.nasa.gov/news-events/4th-sbg-community-webinar**	**Vittorio E. Brando** vittorio.brando@cnr.it Claudia Giardino, Mariano Bresciani, Alice Fabbretto, Gary Free, Monica Pinardi (CNR-IREA, Milan, Italy) Simone Colella, Federica Braga, Gian Luigi Liberti (CNR-ISMAR, Rome, Venice, Italy)
2/18/21	**SBG Community Webinar**	
2/25/21	**Global Lake Observatory Network (GLEON)** Creates a framework for collaboration through community policy, process, and structure • Holds annual working meetings – all hands, in person (meeting #22, Poland, 2022) • Innovates science through working groups • Facilitates “bubble up” science through ad hoc groups • Empowers members through leadership and training opportunities	Paul C. Hanson1 and Kathleen C. Weathers2 1University of Wisconsin-Madison 2Cary Institute of Ecosystem Studies, Millbrook, NY http://gleon.org
4/28/21	**IrriWatch Guiding Farmers with TIR Information** SEBAL4.0 is core model IrriWatch Who is purchasing the IrriWatchservice ? •Commercial farmers •Smallholders	Wim Bastiaanssen Wim.bastiaanssen@irriwatch.com www.irriwatch.com

	•Farmer cooperatives •Commodity processors and exporters (potatoes & sugarcane) •Local agri & irrigation consultants •Sensors providers (soil moisture, weather stations) •Equipment providers (drip, pivots, machinery) •Irrigation Districts (direct, donor) •Insurance company •International water consultants	
6/1/21	**Land Surface Temperature Monitoring LSTM Mission: *User Requirements*** *LSTM – Mission Objectives* Primary objective: to enable monitoring evapotranspiration (ET) rate at European field scale by capturing the variability of Land Surface Temperature (LST) (and hence ET) allowing more robust estimates of field-scale water productivity. ET goal: accuracy 15% [mm/day], precision 5%, field scale MFU [0.5 ha], daily ET threshold: accuracy 20% [mm/day], precision 10%, field scale MFU [1 ha], 3 days Complementary objective: to support a range of additional services benefitting from TIR observations – in particular soil composition, urban heat islands, coastal zone management, High-Temperature Events	Benjamin Koetz Benjamin.Koetz@esa.int https://directory.eoportal.org/web/eoportal/satellite-missions/l/lstm
6/15/21	**SBG Community Webinar**	NASA has authorized SBG to proceed to Pre-Phase A
7/9/21	How hyperspectral imagery informs ecosystem management: The potential for SBG	Shruti Khanna CA Dept. Fish and Wildlife shruti.khanna@wildlife.ca.gov
09/21	CHIME	
10/12/21	**SBG Community Webinar**	
1/20/22	SBG User Needs and Valuation Stud**y (2nd)** *Video presentation link:*	Tom Culver, RTI
2/16/22	**SBG Community Webinar**	
3/24/22	Forest Restoration	Jonas Hamberg, University of Toronto, on
5/16/22	**SBG Community Webinar**	
5/26/22	Tall Timbers Fire Ecology	Tall Timbers-Fire

A series of deep dives for ATM development along with other areas of interest.

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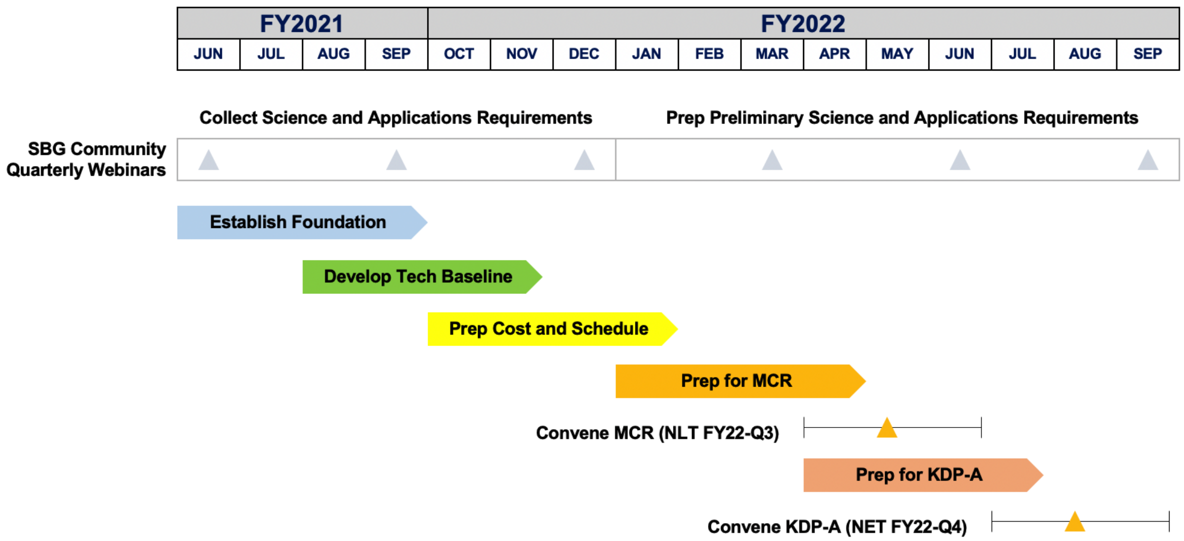
http://tinyurl.com/SBGApplicationsWG

SBG TIMELINE

Pre-Phase A Top-Level Schedule



Notional Phase A Top-Level Schedule

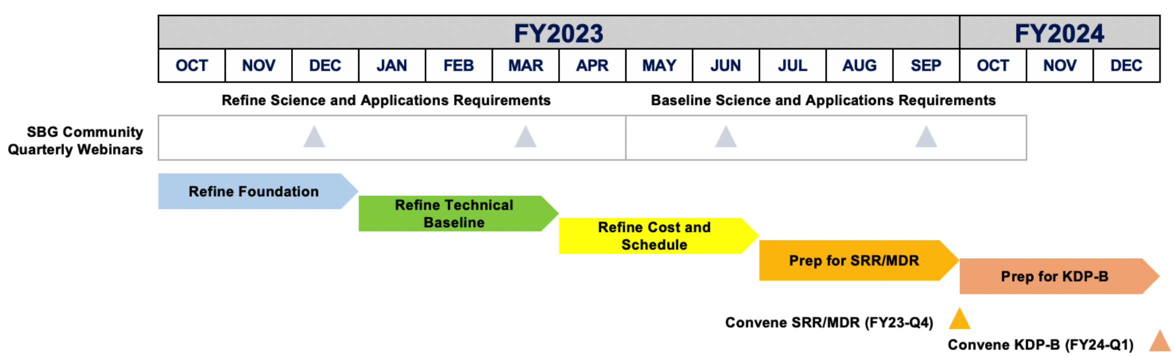


Figure A1. SBG pre Phase A and Phase A schedule.

Document repository on SBG webpage/urls